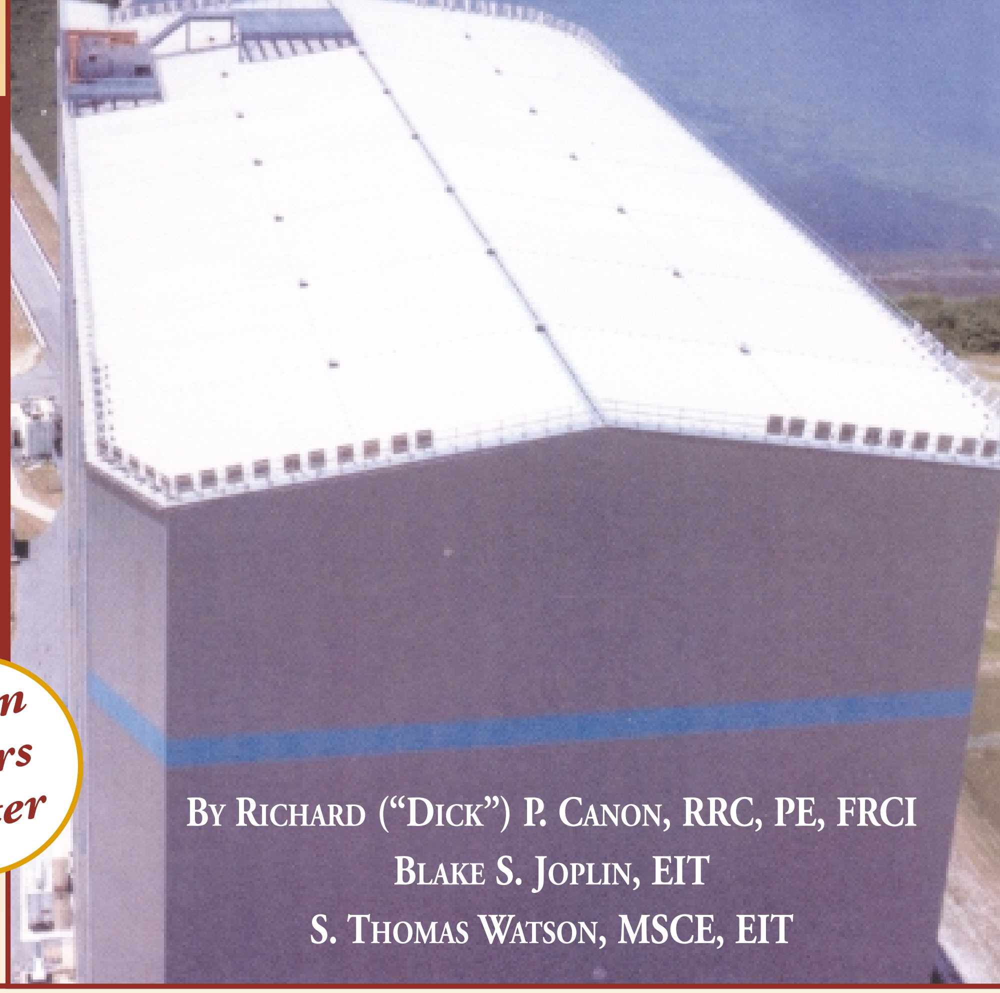


SMARF Building Cape Canaveral Air Force Station, Florida

Seven Years Later

By Richard ("Dick") P. Canon, RRC, PE, FRCI
Blake S. Joplin, EIT
S. Thomas Watson, MSCE, EIT

At the 1994 RCI Convention in San Antonio, Texas, Richard Canon presented a paper regarding the investigation of a roof failure following a wind event on the Solid Motor Assembly and Readiness Facility (SMARF) located at Cape Canaveral Air Force Station, Florida. The topic, "High Rise Roof Investigation Design and Construction," was of particular interest because of the techniques Canon had developed to resist extremely high wind uplift pressures with a peak of up to 300 psf.

This innovative roof has now been in service for seven years. During that time, it has been exposed to a number of significant wind events with no reports of damage. This article, written for a follow-up presentation at the 2002 RCI Convention in Galveston, Texas, will relate both the history of the project and the results of an investigation of the roof's performance after seven years. The investigation includes: uplift testing, fastener pullout testing, a review of the flashing systems, a review of the sheet metal component performance, and the performance of the roof system design.

The article should be beneficial to those interested in the design and performance of roof systems on tall buildings with high exposure to wind events and accompanying high wind pressures.

PROJECT BACKGROUND AND INFORMATION

Historical Data

The Solid Motor Assembly and Readiness Facility (SMARF) Building is a hangar-type structure constructed in or about 1990 (*Photo 1*). The original roof on the facility was a structural standing seam metal roof system installed over a single layer of polyisocyanurate insulation over a metal deck secured to steel beams. The roof has an area of about 60,500 ft^2 and is approximately 245 ft. above grade. On March 13, 1993, this facility was subjected to moderate wind speeds of about 80 MPH

Photo 1: Exterior view of SMARF Building.

during a low-pressure, cyclonic weather system that moved through the Cape Canaveral Air Force Station, Florida, area. After that event, it was reported that the roof had been partially displaced, presumably as a direct result of negative uplift pressures.

Canon Consulting was retained by the Air Force to investigate the cause of the SMARF roof displacement. Canon issued its preliminary report on March 24, 1993, finding that the roof system failed due to a combination of improper design and improper construction. The firm recommended a redesign of the roof and installation of a retrofit roof system.

The Air Force then directed Canon Consulting to design a new roof assembly, retaining only the original steel deck and beams. As part of its design, Canon subcontracted Clemson University in Clemson, SC, to conduct a "Wind Pressure Study" under the direction of Dr. Tim Reinhold, PE, with assistance from Dr. Scott Shiff, PE, also of Clemson. During the study, Canon Consulting did the following:

- Conducted a boundary layer wind tunnel study of a 1:200 scaled model of the SMARF Building.
- Designed an innovative and revolutionary negative pressure suppression wind diverter/spoiler system.
- Simulated the negative pressures to the decking system at design wind loads.
- Simulated the negative pressures to the roof membrane system at design wind loads.
- Designed a technique to enhance the existing roof deck to accommodate the design wind loads.
- Introduced a new roofing assembly that could meet the design wind loads.

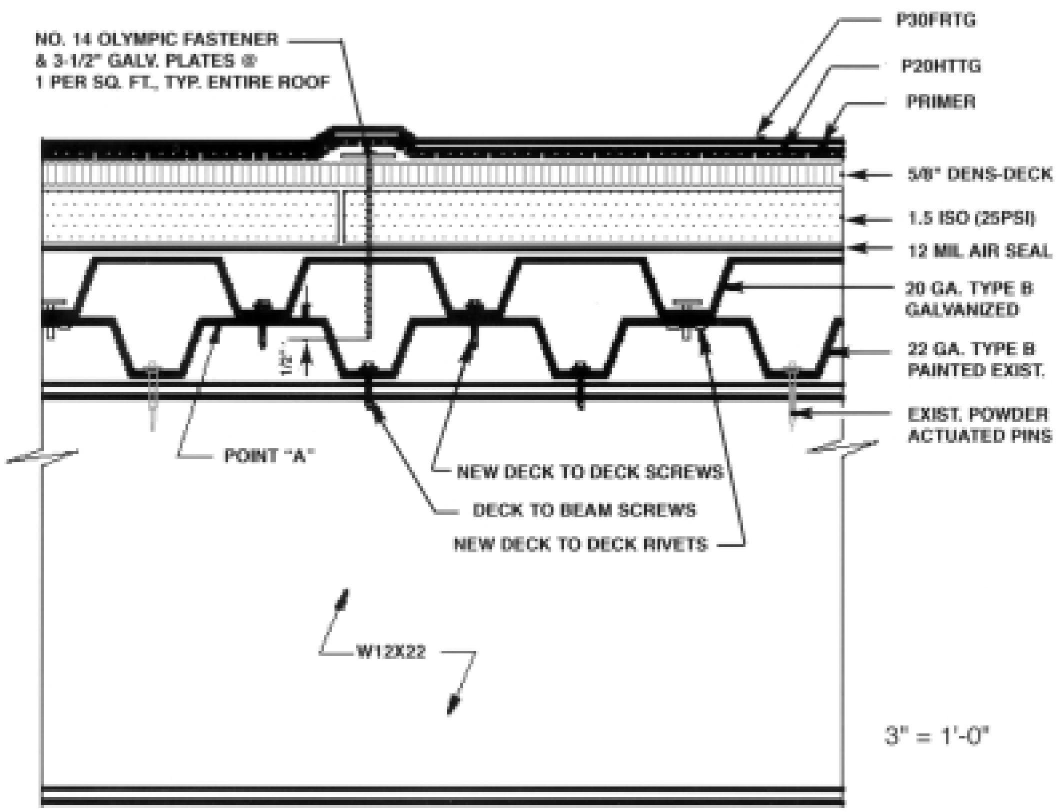


Figure 1: Roof cross-section.

Roof System Installed in 1994

Canon Consulting designed the retrofit roof system to the then current design wind velocity of 100 mph and negative (uplift) pressures of 220 psf. Referring to *Figure 1*, the roof cross-section was as follows, from top to bottom:

- Granular surfaced Siplast modified bitumen cap sheet, torch applied (P30HTFRTG).
- Siplast modified bitumen base sheet, torch applied (P20EGTG).
- 5/8"-thick Georgia Pacific Dens-Deck, primed and mechanically fastened (1/ft^2) to a new retrofit steel deck.
- 1.5" Atlas AC Foam II polyisocyanurate (25 psi), mechanically fastened concurrent with the Dens-Deck.
- 12 mil polyethylene film air seal with sealed seams.
- New, 20-gauge galvanized wide rib steel deck installed with ribs offset (ribs bearing on the flanges of the original steel deck).
- Original, 22-gauge painted wide-rib steel deck with the attachment and side laps enhanced (original).
- Steel beams bolted to steel girders (original).

The contract for the repairs was awarded to GRI of Orlando, Inc., Casselberry, FL. Their work started in January of 1994 and was completed in June of 1994. During the construction, Canon Consulting provided quality assurance construction observation services on a daily basis for the Air Force.

PURPOSE OF THE EVALUATION PROGRAM

The roof on the SMARF building, now over seven years old, has been subjected to several noteworthy wind events since completion with no reports of wind damage. Due to the unique design undertaken on this facility to accommodate high negative wind uplift pressures (± 220 psf), and since the Air Force, Navy, and others (including the private sector) have utilized the system it developed, Canon Consulting envisioned conducting an evaluation of the performance of the roof.

Richard P. Canon, RRC, PE, discussed the concept of such a study with the Chief of Range/Base Civil Engineering Operation for Cape Canaveral, who agreed and requested a proposal, which Canon Consulting provided. On October 4, 2001, Canon was subsequently authorized to do an evaluation of the performance of the roof and to provide a written report.

PROJECT STAFFING

The above-listed scope of work was accomplished by, or under the direction of Richard P. Canon, RRC, PE, a registered structural engineer in several states who is experienced in roof surveys, investigations, and roof design. Some of the work was accomplished by engineering assistants Blake S. Joplin and S. Tom Watson, who are Engineers-in-Training (EITs) and roof consultant interns with Canon Engineering.

PROCEDURES

On January 3 and 4, 2002, Canon, Joplin, and Watson were escorted to the roof of the SMARF Building. Timothy L. Kersey represented Siplast, the manufacturer and warrantor of the roof system, on the building. Employees from the roofing repair contractor were also on site to assist in the testing and to make repairs to test sites. Because of operation inside the facility at the time of evaluation, no testing was done on two areas of the roof.

The project procedures are summarized below.

Visual Inspection of Roof Membrane, Flashings, and Sheet Metal

The authors observed the subject roof area, using general recommendations of the Roof Consultants Institute and other accepted industry procedures. Observed roof condition deficiencies indicating workmanship, material defects, or damages were noted and are presented below. The roof's leak history was also discussed with the building operations manager.

Test Cuts for Analysis

Samples of the membrane were extracted to determine the physical properties of the *in situ* membrane. Due to time constraints with the SMARF building's ongoing mission, Canon was limited in its available site time. To conserve time, test cut samples would be extracted at some of the negative pressure test site locations where cutting of the roof would already be taking place. The original proposal had anticipated taking four random membrane test cuts for laboratory analysis. Test cuts were extracted from test sites U-1, U-2, U-5, U-6, and one near P-7. (See *Drawing R-2* for location.)

Each sample was carefully separated from the Dens-Deck, placed in a self-sealing polyethylene bag, and labeled by project name, location, Canon project number, the name of the sampler, date of extraction, and physical size. Samples were returned to Canon Consulting's office for repackaging and submitted for analysis.

Laboratory Analysis of Roofing Membrane

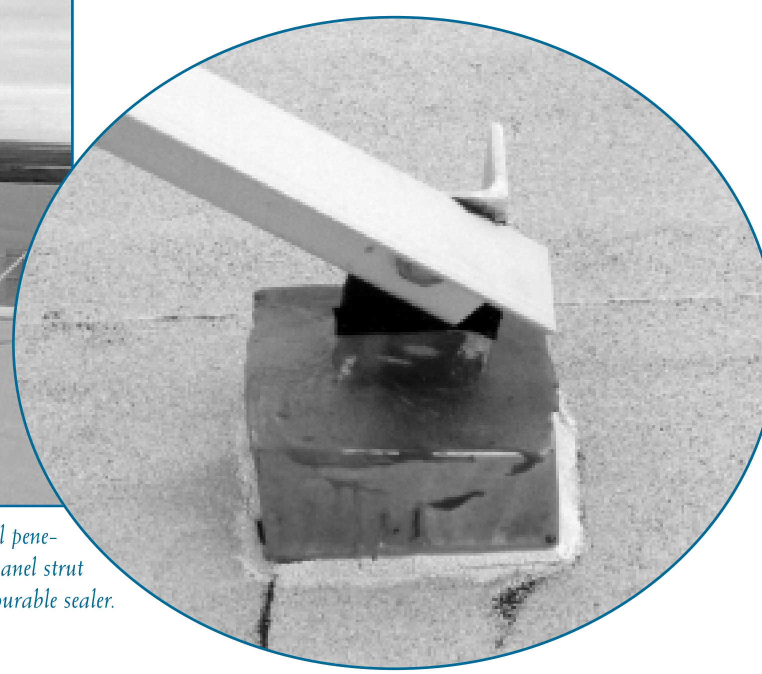
Samples of roofing membrane extracted from four of the negative pressure test sites were subjected to a battery of tests typically utilized to monitor the performance of their products. All tests were conducted according to ASTM D 5147-97, "Standard Test Methods for Sampling and Testing Modified Bituminous Sheet Materials" and ASTM D 6163-00, "Standard Specifications for Styrene Butadiene Styrene (SBS) Modified Bituminous Sheet Materials Using Glass Fiber Reinforcements."

The following tests were run: tensile strength, elongation at maximum load, elongation at 5% of maximum load (also known as ultimate elongation), low temperature flexibility at -4.0°F, -13°F, and -22°F, and high temperature stability at 230°F and 248°F. Tests were also run on the surface sheet's granule embedment.

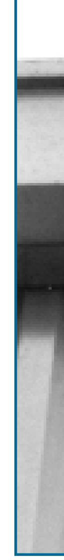
Visual Inspection of Wind Diverter/Spoiler System

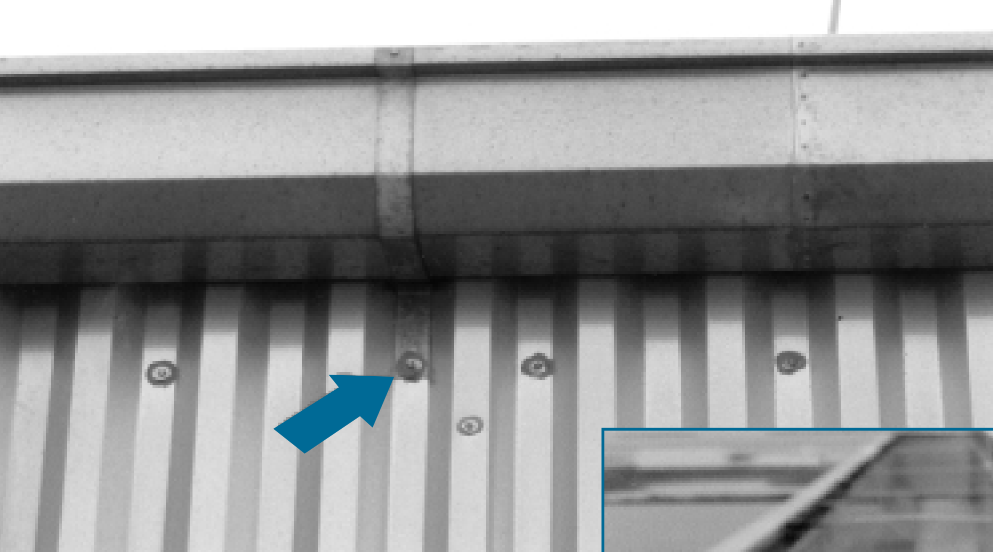
To the best of the authors' knowledge, the wind diverter/spoiler system shown in *Photo 2* is the first such assembly used to reduce the negative (uplift) pressures on a building in the U.S. Canon Consulting, therefore, had to develop its own test protocol to assess its condition. The inspection process the firm developed consisted of randomly choosing numerous panels and looking for any indication of loose U-bolts connecting the aluminum spoiler panels to the handrail assembly. Penetration pockets (pitch pans) for the handrail legs and for the struts bracing the handrail at the spoiler panels (*Photo 3*) were also examined. Finally, the overall assembly was examined for indications of any corrosion, damage, or fatigue to the spoiler assembly.

Above: Photo 2: Wind diverter/spoiler system. Chamber in place at U-3.



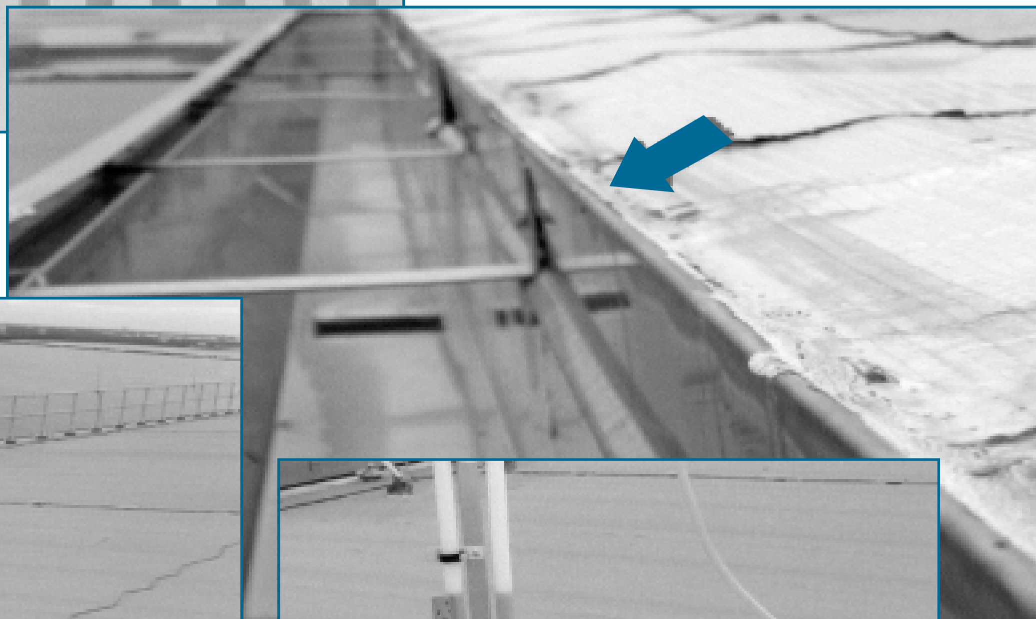
Right: Photo 3: Typical penetration pocket at spoiler panel strut filled with two-part pourable sealer.



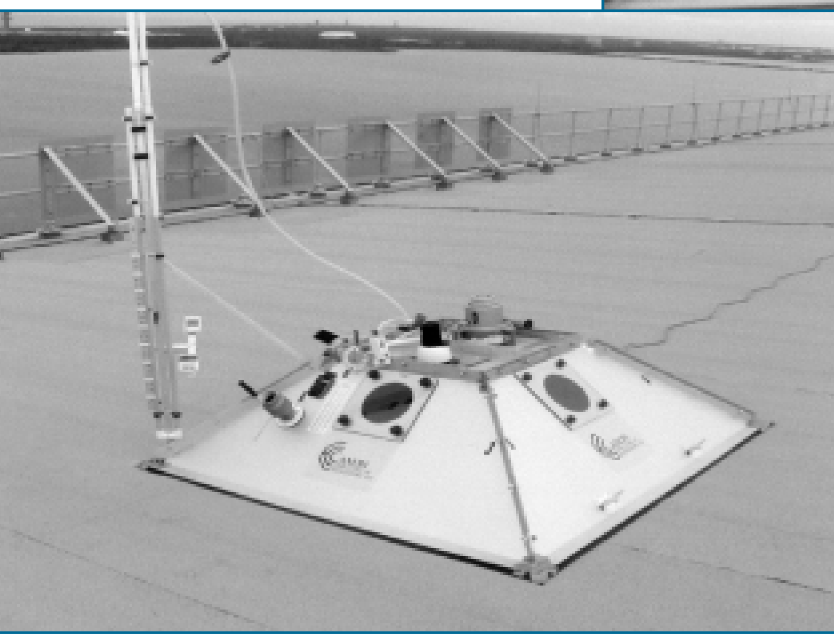


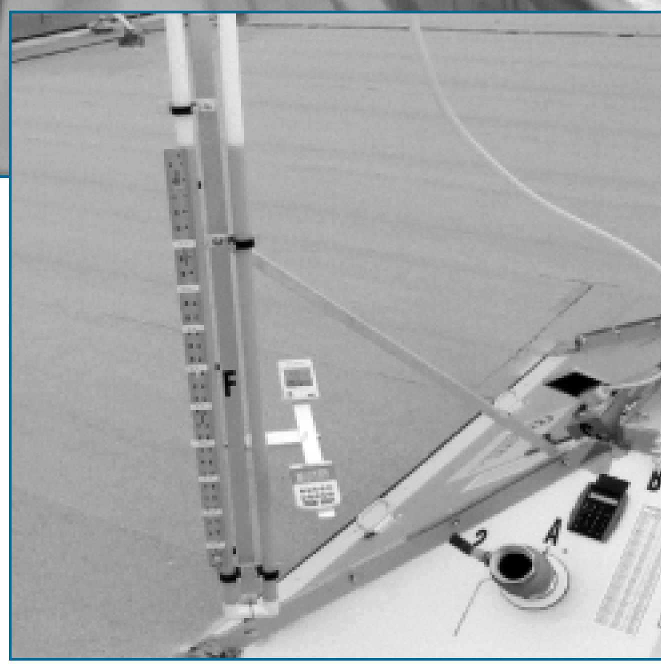
Left: Photo 4: Gutter with wrap-around bracket. Note back of bracket has an extension that is fastened to the wall girt for securement to resist rotation of the gutter in high wind conditions.

Below: Photo 5: View inside gutter. Several loose bolts noted.



Below: Photo 6: Negative pressure chamber in place. Control valve is at "A." Manometer is at "F." Vacuum is at "D."





Above: Photo 7: Manometer ("F"), with timer and thermometer. Control valves at "A" and "B."

Visual Inspection of the Gutter/Fascia System

Taking into consideration the excessive height of the SMARF Building (± 244 feet above grade), inspection of the entire gutter and rake system from the exterior of the building was not feasible without costly scaffolding or crane rental. For this reason, the protocol was to select representative locations along all four edges and inspect the attachment from the roof as shown in *Photos 4* and *5*.

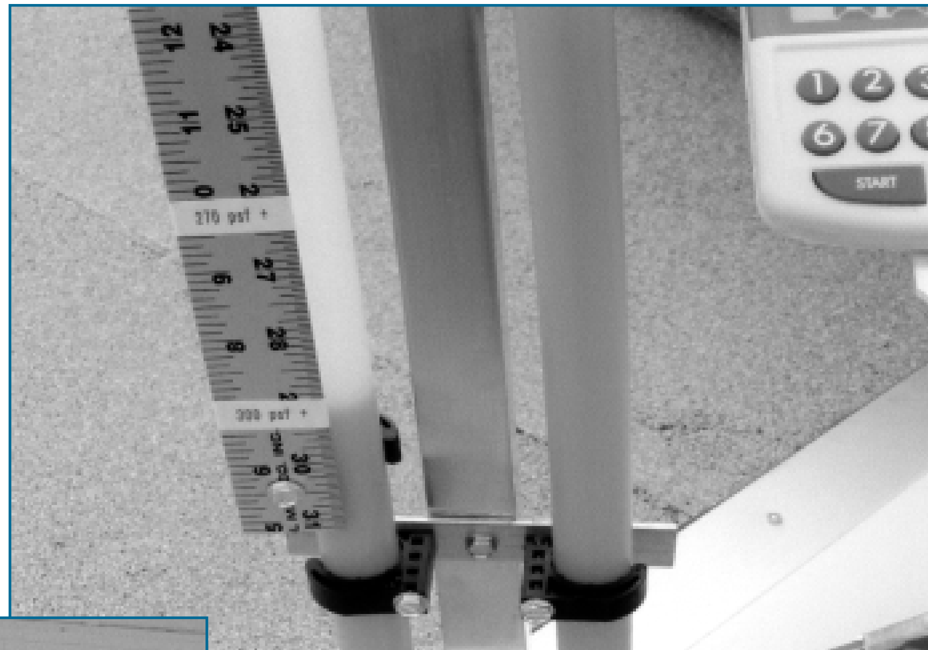
As shown in *Photo 5*, as part of the firm's 1994 design, the gutter is secured with a wraparound cradle, a standoff support bracket, and a hanger bracket secured to the wall girt with a gasketted, self-drilling anchor. The inspection procedure was for the engineer (properly secured in safety harness equipment) to lean over the edge and physically tug or pull on the gutter assembly and check for any excessive movement or displacement.

The rake assembly was inspected in a similar fashion, except the fascia was specifically checked to verify that the metal was still properly engaged to the continuous cleat.

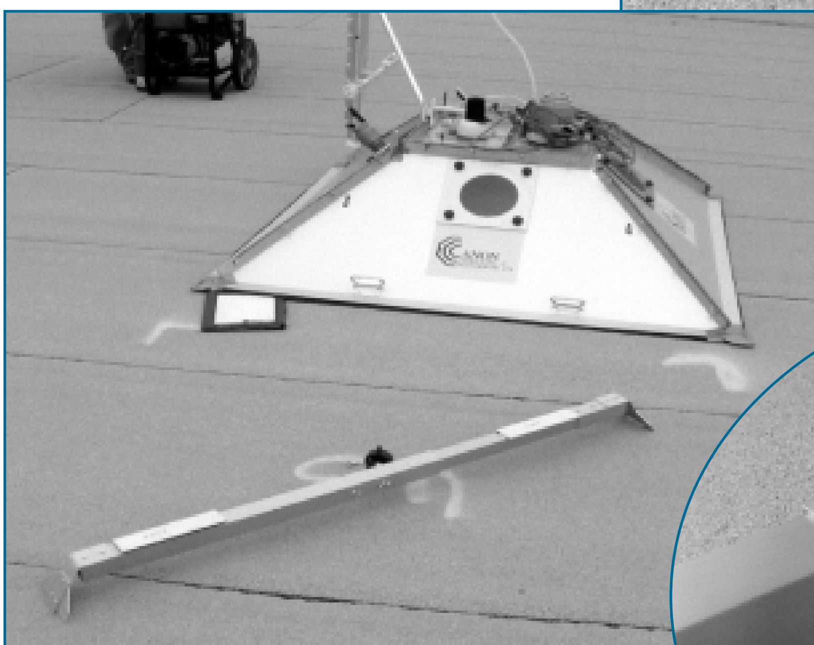
Negative Pressure Testing

On January 3, Canon Consulting performed uplift tests using a negative pressure chamber specially designed and constructed by the firm. All negative pressure uplift tests were performed in accordance with Factory Mutual (FM) Loss Prevention Data Sheet 1-52 and ASTM E 907-96. Both tests are performed with a 5′-0″ x 5′-0″ negative pressure chamber as shown in *Photo 6*. The negative pressure is measured with a water manometer *(Photo 7)* capable of measuring in excess of 300 psf attached to the chamber (*Photo 8*). A rigid metal bar with a foot on each end is placed beneath the chamber resting on the roof surface (*Photo 9*). A digital dial indicator gauge is attached to the bar at the midpoint (*Photo 10*). The tip of the dial gauge is in contact with the roof surface near the center of the test area. As the negative pressure is increased, the primary operator observes the manometer and timer. The assistant monitors the dial gauge for movement of the membrane. Both observe the roof surface for deflection of the roof covering within the chamber through the portals on each face and the top.

The system fails the FM 1-52 if the roof assembly deflects upward more than 0.25 inch. The ASTM E 907-96 test fails if the roof assembly deflects upward more than 1.00 inch. For this project, Canon Consulting considered deflection in excess of 0.50 inch to be a failure. This was consistent with original design assumptions.

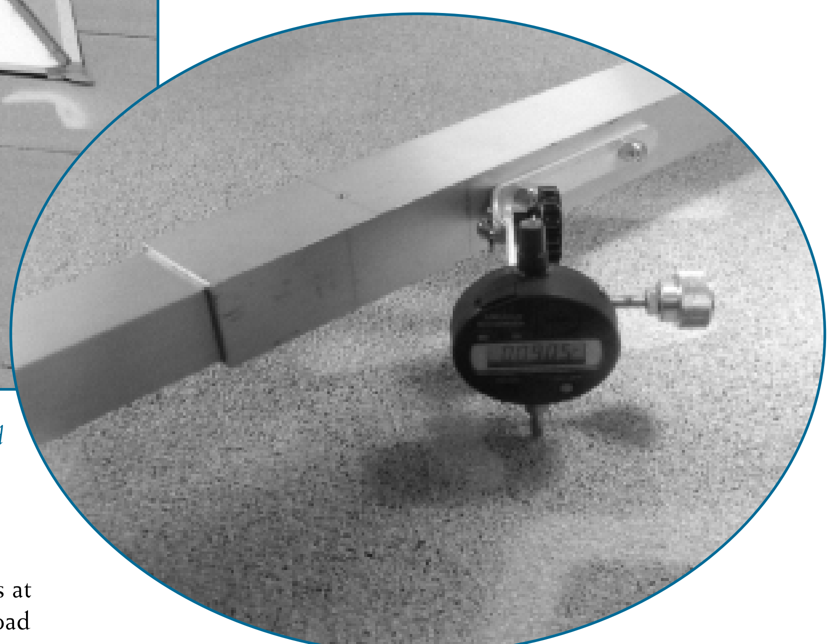


Above: Photo 8: Negative pressure capacity of chamber is in excess of 300 psf. Test pressures ranged from 150 psf to 270 psf.



Above: Photo 9: Chamber placed to the side of the test site to position rigid metal bar with digital dial indicator attached.

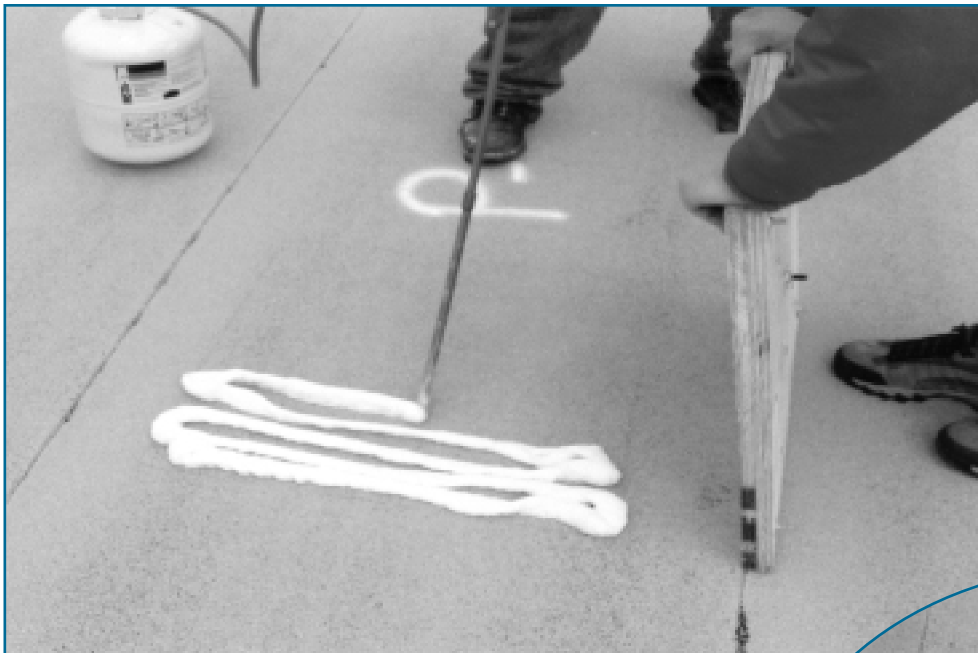
Below: Photo 10: Digital dial indicator in position.



The typical procedure protocol for FM and ASTM begins at 15 pounds per square foot (psf) and is held at this negative load for 60 seconds. If the test passes (less than the specified deflection), the negative load is increased by 7.5 psf and the negative load is again held for 60 seconds. This process continues until the design uplift resistance requirement is met or until maximum deflection in the roof system occurs. This test also fails if the membrane lifts or "balloons" at any location under the chamber. Deflection of the roof assembly was noted at the end of each incremental pressure increase to the nearest ten-thousandth of an inch (0.0001). The values were recorded on Field Data sheets. Notes were made of observed ballooning at the test sites.

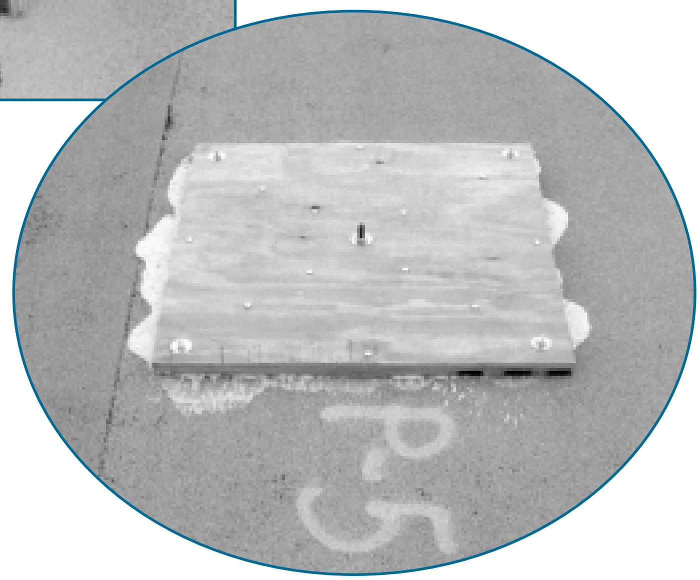
Because the target pressure on this project was significantly higher than usually constructed on buildings, a revised sequence of applying pressure was established. Testing started at 60 psf and tested thereafter in 30 psf increments. According to FM Data Sheet 1-52, "The vertical distance of the water column is the difference between the elevation of the two water columns, and not the distance of one column from the original 0 set point." Therefore, the total head for a 240 psf test is 46.2 inches.

The roof system was designed to meet a minimum negative or uplift pressure of 220 psf. For these tests, however, Canon decided to set the target pressure for all test sites slightly higher, at 240 psf. Three of the seven tests were carried up through 270



Left: Photo 11: Placement of "Insta-Stik" to secure plywood panels for the FM Global Mechanical Pull Test. Application rate was determined to be heavier than needed, resulting in the panel sliding until material cured.

Below: Photo 12: Plywood panel in final position for testing. Insta-Stik cured for approximately 20 hours before testing in relatively cold weather (±35°F to ±50°F).



psf and into the 300 psf range before failure. (See *Table A*).

In the FM protocol, tests are run in the "field" of the roof, the "perimeters," and the "corners." Because of the unique design of the SMARF Building, the entire roof was designed and constructed for a common pressure coefficient of 220 psf with Dens-Deck fasteners securing the system at a rate of one per square foot.

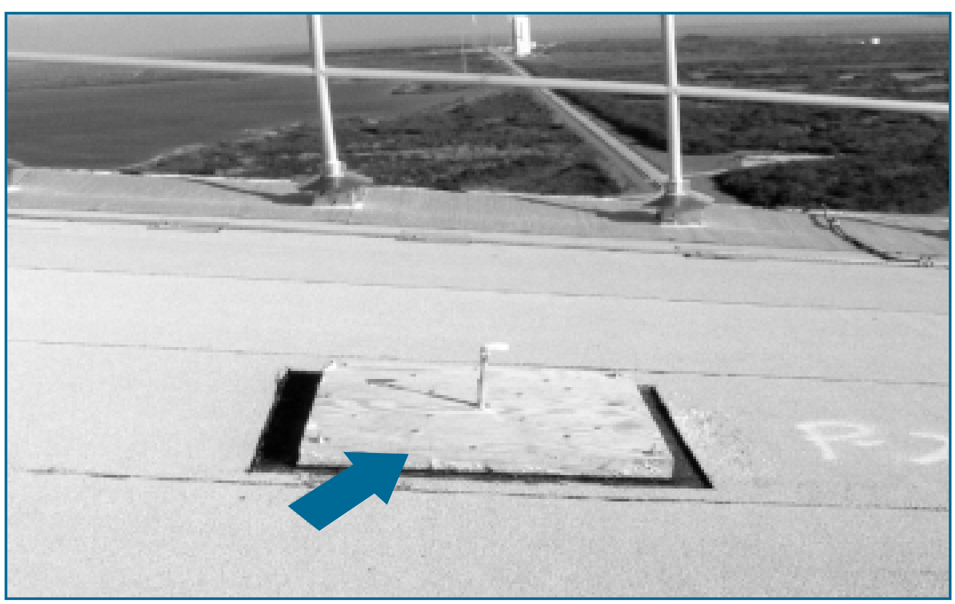
Canon Consulting randomly selected seven test locations throughout the roof area. Four were intentionally located near the corners. The remaining three were in the central portion of the roof. Due to the confinement of such a small roof, no tests were conducted on the penthouse over the elevator for safety reasons. The test sites were given designations of U-1 through U-7 on the roof. Test cuts were extracted at Test Sites U-1, U-2, U-5, and U-6.

FM Global Mechanical Pull Testing

In this procedure, a test panel is adhered to the surface of the membrane and pulled to failure. This is the test protocol Canon used in its 1993 design development as a basis of construction. Those design tests gave a working load of 240 psf in one battery of tests and 255 psf in another independent test done by Trinity Engineering, Inc. From these, the roof was designed with an ultimate load of 220 psf.

Prior to arrival on site, the test panels were pre-assembled by fastening two 24″ x 24″ x 23/32″ plywood panels together with screws and through-bolts. An eyebolt assembly was installed through both plywood sheets. The plywood test panels were fully adhered at seven test sites to the P30 surface sheet of the roof system on January 3 using "Insta-Stik," a single-component, moisture-cured polyurethane adhesive (*Photos 11* and *12*). The adhesive was then allowed to cure overnight, which, although relatively cold, was adequate for a good bond.

Below: Photo 13: Membrane trimmed away from edge of panel down to the top of the Dens-Deck. Eyebolt is in place and ready to attach pull device.



In this field test, the goal was to test for the membrane's adhesion to the Dens-Deck, not the securement of the Dens-Deck to the steel deck. To accomplish this, Canon decided to leave the Dens-Deck intact, as it would be in service (i.e., the Dens-Deck would not be cut). On January 4, Canon Consulting cut a 2-inch wide "channel" in the membrane to the Dens-Deck facer around the perimeter of each test panel (*Photo 13*). They then placed a four-foot square plywood "collar" with a 30-inch square cutout around the test panel (*Photo 14*). This was to support the test stand's four legs and restrain movement adjacent to the test panel. A Com-Ten Industries Model 341, hand operated, digital readout test apparatus was clamped to the top plate of the "quadrapod" test stand. A chain was connected between the eyebolt in the test panel and the test apparatus. Load was applied by slowly rotating the pull test apparatus' handle at a constant rate, thus measuring the weight of the material and the uplift resistance of the membrane (*Photo 15*). The load (lbs.) at which the roofing components yielded was recorded for each test. These are summarized in *Table A*.

Assuming a target uplift pressure of 240 psf on a 2'-0" x 2'-0" (4 sf.) panel, a pull in excess of 978 lbs. was established as a load passing the test. [(4 sf. x 240 psf) + (18 lbs. weight of a test panel) = 978 lbs.].

As with the negative pressure test, the high target value of 240 psf prompted Canon to start testing at an initial higher load. Testing began at 45 psf for one minute. The loading was then increased in 30 psf increments until 195 psf was reached. Loading was then increased in 15 psf increments until the target value of 240 psf was reached or failure, whichever occurred first. (Note: All tests met the 240 psf loading. Five of the seven tests were run to 300 psf.)

Summary of Test Results
SMARF Building Roof Evaluation
Cape Canaveral AFS, Florida

A Test Site	B Test Type	C Test Value Passed	D Design Value[1,2]	E Safety Factor[3]	F Average Safety Factor	
U-1	Negative pressure	270 psf	160 psf	1.69	1.64	1.97
U-2	Negative pressure	210 psf	120 psf	1.75		
U-3	Negative pressure	240 psf	180 psf	1.33		
U-4	Negative pressure	240 psf	120 psf	2.00		
U-5	Negative pressure	270 psf	140 psf	1.93		
U-6	Negative pressure	150 psf	120 psf	1.25		
U-7	Negative pressure	270 psf	180 psf	1.50		
P-1	FM pull test	270 psf	120 psf	2.25	2.30	
P-2	FM pull test	300 psf	140 psf	2.14		
P-3	FM pull test	300 psf	120 psf	2.50		
P-4	FM pull test	300 psf	120 psf	2.50		
P-5	FM pull test	300 psf	120 psf	2.50		
P-6	FM pull test	300 psf	120 psf	2.50		
P-7	FM pull test	240 psf	140 psf	1.72		
F-1	SPRI fastener pull test	550 lbs	485 lbs	1.13	1.64	NA
F-2	SPRI fastener pull test	1274 lbs	485 lbs	2.63		
F-3	SPRI fastener pull test	528 lbs	485 lbs	1.09		
F-4	SPRI fastener pull test	828 lbs	485 lbs	1.70		
F-5	SPRI fastener pull test	939 lbs	485 lbs	1.96		
F-6	SPRI fastener pull test	894 lbs	485 lbs	1.84		
F-7	SPRI fastener pull test	1051 lbs	485 lbs	2.17		
F-8	SPRI fastener pull test	590 lbs	485 lbs	1.22		
F-9	SPRI fastener pull test	1036 lbs	485 lbs	2.14		
F-10	SPRI fastener pull test	528 lbs	485 lbs	1.09		
F-11	SPRI fastener pull test	695 lbs	485 lbs	1.43		
F-12	SPRI fastener pull test	621 lbs	485 lbs	1.28		

[1]See Drawing R - 2, which depicts the uplift pressure zones based on testing by Canon and Reinhold in 1993.
[2]Target value of fastener = 485 lbs.
[3]Safety Factor = Test Value Passed divided by Design Value.

Table A: Summary of test results.

Fastener Pull Out or Withdrawal Testing

Fasteners used to simultaneously secure the Dens-Deck and polyisocyanurate insulation to the new steel deck in the construction were tested for pull out or withdrawal resistance. These tests were performed in general conformance with the American National Standards Institute (ANSI)/Single Ply Roofing Institute (SPRI) joint document, *ANSI/SPRI FX-1-1996*, Section 4.2, "Standard Field Test Procedure for Determining the Withdrawal Resistance of Roofing Fasteners."

This test is typically conducted by driving a new fastener into a deck with a screw gun to determine the design withdrawal resistance in pounds. As the intent was to determine the resistance of the fasteners in place, Canon pulled the fasteners installed in 1994. These were No. 14 Olympic Roof Insulation Fasteners.

The firm had a limited window of opportunity to conduct its test, due to SMARF missions. Canon Consulting decided, therefore, to utilize four locations where the membrane had already been removed at the mechanical pull tests and pull three screws at each location (*Photos 16* and *17*). See *Drawing R-2* for locations. With the membrane removed at the locations, Canon Consulting carefully scored and removed the Dens-Deck, leaving the fastener and 3"-diameter steel plate exposed. Fastener heads were grasped with the foot of the Com-Ten Industries Model 341, hand operated, digital readout test apparatus. In this test, force is applied continuously with a slow, steady application of pressure until failure. The target pull out or withdrawal value was 485 pounds force, the published value from Olympic's testing for the fastener installed. At each site, the reading at failure was recorded and shown on *Table A*.

OBSERVATIONS AND FINDINGS

Visual Inspection of Roof Membrane, Flashings, and Sheet Metal

Roof condition deficiencies were observed. For each, Canon Consulting recommended a course of action and identified the party (owner or membrane manufacturer) it believed was probably responsible for the repairs. "Owner repairs" were those that would generally be excluded from a manufacturer's warranty, such as cuts and tears, physical abuse after acceptance, caulking, and sheet metal. All repairs should be made by a manufacturer approved applicator/contractor using Siplast approved materials to avoid infringing upon the warranty.

Some crazing of the P30 cap sheet was observed sporadically throughout the roof. This was reviewed on site with Tim Kersey of Siplast. He said that crazing is typical for an SBS modified bitumen cap sheet of this age and that such would not affect the sheet's long-term performance. Thus, no repairs were necessary, per Mr. Kersey.

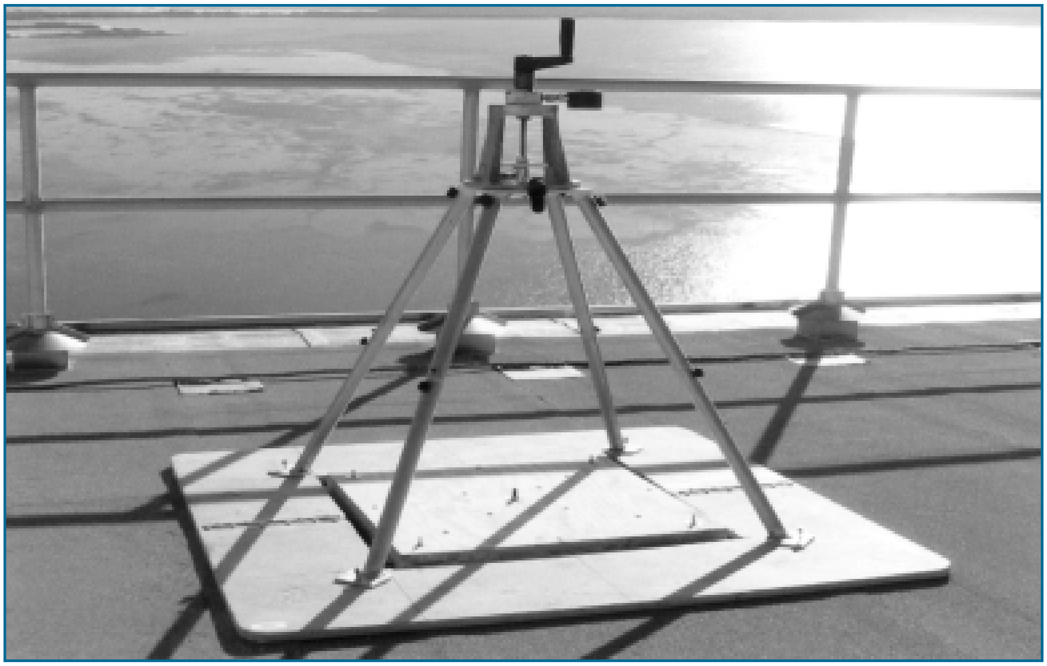


Photo 14: Plywood "collar" under legs of quadrapod test stand to distribute load. Digital readout pull test apparatus in place on top of stand. (Connecting chain and eyebolt are not in place in this photo.)

Laboratory Analysis of Roofing Membrane

The samples of membrane were tested. Quoting from the laboratory report,

> "From the Elongation at 5% Max. Load and Low Temperature Flexibility data, we can conclude that these membranes have performed well and will continue to provide excellent elongation and flexibility.
>
> "The granule embedment test showed that the cap sheet is allowing more granule loss than when [the product] is new. This is expected since it is the first layer of protection that takes the environmental abuse... The base sheet had better results than the cap sheet in all cases. This test is not usually done on aged materials. We do not have enough statistical data for comparison on aged products from Florida. For example, we took samples.... installed in 1992, and the average granule loss was 2.9g. This shows that it is normal to have a small increase in granule loss as the product ages.
>
> "Based on sample observation, field inspection, photos and these results, we can conclude that this membrane has performed as expected."

Visual Inspection of Wind Divert/Spoiler System

Richard Canon personally inspected the spoilers. No deficiencies of any kind were observed. The U-bolt-to-handrail connections observed were tight and double-nutted. There was no vibration of the panels checked when struck with the hand, indicating securement. The brace struts were tight. No unusual corrosion was observed. The penetration pockets need some attention relative to water resistance.

Visual Inspection of the Gutter/Fascia System

Donning a safety harness, Richard Canon inspected several locations on each face of the building to evaluate the attachment of the gutter and rake fascia assembly. Generally, the gutter is well secured with no displacement under heavy pulling on the hanger/strap assembly. At one point of observation on the west side, two adjacent lag screws into the edge nailer at the gutter bracket were not driven snugly. They were, however, tight, indicating they have not been withdrawn or backed out. It is believed that they were simply never snugged up. (For long-term performance, this and all other gutter brackets should be checked and snugged up if found deficient.)

The fascia metal was typically tight to the wall with good engagement between the fascia piece and the continuous cleat. At one location, disengagement from the cleat was observed. Other occurrences of this may be present. (For long-term performance, every linear foot of the rake should be checked. It may be necessary to supplement the attachment with fasteners simultaneously run through the fascia and cleat and into the metal wall panels. This would provide an enhanced securement and prevent displacement.)

Negative Pressure Testing

The results of each of the seven negative pressure tests are summarized in *Table A*. At test sites where the field pressure did not achieve the target pressure of 240 psf, the plane of failure was between the P20 base sheet and the facer of the primed Dens-Deck. This is precisely where it was anticipated the failure plane would be. At test site U-1 (at test cut U-1B), there was separation in a small area between the P20 and the P30. This occurrence is probably an anomaly due to inadequate melt of the P30 to the P20 during application.

Photo 15: Test in progress. Test values ranged from 240 psf to 300 psf.

FM Global Mechanical Pull Testing

As stated above, this is the test protocol used during the original design and was the basis of the construction of the SMARF roof. The results of these tests are summarized on *Table A*. All seven of the tests meet or exceed the target pull of 978 lbs., equivalent to 240 psf. Referring to *Table A*, note that one of the seven passed the 270 psf test, and five of the seven passed the 300 psf test.

Fastener Pull Out or Withdrawal Testing

The results of all twelve fastener tests exceeded the target value of 485 lbs. force as shown on *Table A*. The higher values of over 1,000 lbs. are probably because the screw penetrated both the over-lay deck and the original deck at point "A" on *Figure 1*.

CONCLUSIONS AND RECOMMENDATIONS

Membrane, Flashings, and Sheet Metal Condition

The roof membrane and flashings have several deficiencies to be addressed, but the roof membrane and flashings were determined to be in good condition. The observed deficiencies should be corrected as soon as practical, but ideally no later than the onset of the traditional Atlantic hurricane season, which starts on June 1, 2002. Some crazing observed on the P30 sheet is worthy of note, but no repairs are needed per Siplast.

Wind Diverter/Spoiler System Condition

The system of spoilers mounted on the handrail is in good condition. The connections and bracing are sound and functional. No repairs to the spoiler components are needed, but Canon Consulting suggested that it would be prudent to have these inspected annually or at least on the 10th, 15th and 20th anniversaries of completion (2004, 2009, and 2014).

Gutter and Fascia System Condition

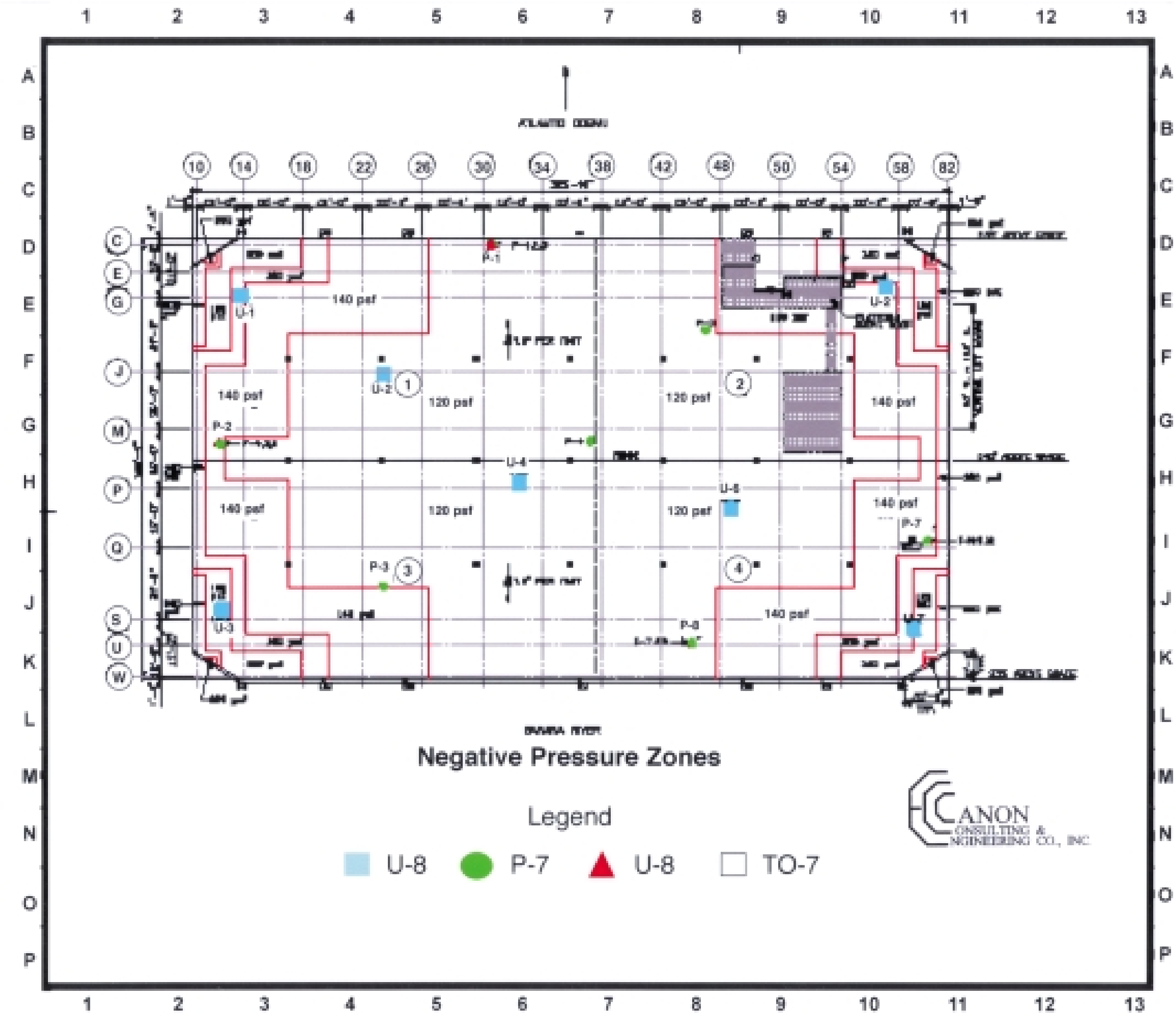
The gutters are believed to be safe as they are, but since a random inspection identified several lag bolts that were never snugly driven, all should be checked and driven snug. The pri-

Left: Photo 16: Fastener Pull Out or Withdrawal Test conducted after removing the membrane and Dens-Deck, leaving the fasteners and 3" plates exposed.

Below: Photo 17: Plywood panels placed on surface to distribute load during testing. Values ranged from 528 pounds to 1,274 pounds. Fasteners are spaced at approximately 1'-0" on centers.

mary concern prior to inspection was rotation of the gutter. It is now believed that securement is adequate for the original design, and no enhancements are needed.

The fascia/cleat system does not have any redundancy as does the gutter (lag screw and bottom clip). Since some disengagement of the fascia and cleat was discovered, more of the same could be present. One option would be to have the entire perimeter checked by a contractor and



Drawing R-2: Negative pressure zones.

repair each disengaged location. Another, more positive system would be to mechanically fasten all of the fascia and cleats to the edge nailers at 36″ o.c., reducing spacing to ±18″ o.c. for a distance of 15′ from the corners. Self-drilling, gasketted, stainless steel screws with a thread suitable for fastening into wood should be used. Although this process may result in some distortion of the fascia, this should not be too visible from the ground.

Uplift Resistance of the Roof

Based on available weather data, the peak gust at 33′ for the area occurred on October 16, 1999, with a value of 71.9 knots or 82.8 MPH. Although the roof has not experienced a "design condition," testing and observations concluded that the SMARF roof is performing as intended after seven years of service.

There are no recommendations for corrective actions, as none are needed.

PROBABLE SAFETY FACTOR OF SMARF BUILDING ROOF

Canon Consulting suggested that its scope be augmented to determine the most probable factor of safety of the roof on the SMARF Building, as this was never determined during the design phase due to time constraints. The suggestion was granted. The firm proposes to do the following:

1. Assemble pressure data from wind tunnel testing conducted as part of Canon's 1993 design of the roof system.
2. Superimpose on the roof plan the pressure zones relative to the field of the roof, the perimeters, and the corners, based upon the installation of the wind spoiler/diverter system.
3. Analyze the test results from Canon's field testing (the original scope of services under this contract) and the pressure zones (Item 2 above) and determine the safety factor for the roof assembly.

To accomplish this, Canon Consulting returned to the data gathered by Dr. Reinhold in the wind tunnel study he performed with the firm in 1993. From that data, Canon Consulting developed a composite load contour plot of the SMARF roof. This is shown on *Drawing R-2*.

Note on *Drawing R-2* that from the wind tunnel study, the field of the roof and the long axis perimeters along the east and west sides have a maximum uplift value of 120 psf. The corner pressures range from 140 psf up to 220 psf with the 220 psf value applicable at only at a very small segment on the beveled corner of the building corners as shown on the drawing.

An added objective in this study was to gather sufficient data to conclude what the most probable safety factor is for the roof, as constructed. To do this, Canon Consulting superimposed the uplift contours on the roof plan to determine what the design uplift pressure was for each test site. Based upon the results of the test, the safety factor was calculated at each test site as shown in column "E" of *Table A*. This information provides data from which conclusions may be drawn regarding the overall safety factor of the roof and to better predict the risks for the building at or near design wind speeds.

To determine the most appropriate safety factor for each test method, the values of the results of each test method were averaged, as shown in column "F" of *Table A*.

- For the Negative Pressure Test, the average Safety Factor is 1.64.
- For the FM Pull Test (the basis of Canon Engineering's original design), the average Safety Factor is 2.30.
- For the Fastener Pull Out Test, the average Safety Factor is 1.64.

The authors believe that the Negative Pressure Test and the FM Pull Test are more representative of a test of the roof's failure mode under uplift. This is because if a single fastener is overloaded, its load will be redistributed to the four adjacent fasteners and thus resist the uplift. In summation, the probable safety factor on the SMARF roof is derived from the average of the Negative Pressure Tests and the FM Pull Tests. This value is 1.97.

SUGGESTION FOR ADDITIONAL STUDY

As a closing comment, it would most likely be of value to the Air Force and others with similar designs if some form of wind recording device were to be installed on the SMARF Building. A recording anemometer could be mounted either at the ridge or on the penthouse. Such equipment may be available at no cost to the government through the Roof Consultant Institute's Foundation. The data gathered and retained over the next 10 to 15 years could add to the assessment and performance of this unique design. ■

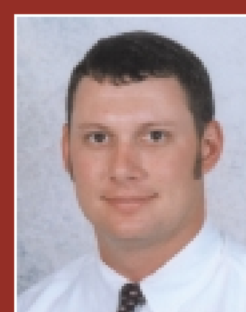
About the Authors


RICHARD "DICK" CANON, RRC, PE

Richard "Dick" Canon, RRC, PE, graduated with an engineering degree from Auburn University and worked for the U.S. Army Corps of Engineers for a few years before working with Milliken & Co., Lockwood Greene Engineers Inc., and Law Engineering Testing Co. In 1983, he formed Canon Consulting & Engineering Co., headquartered in Spartanburg, SC. He is a Past President and founding member of RCI, a member of the RCI Jury of Fellows, and the 1996 recipient of the Herbert W. Busching Memorial Award for his contributions to roof consulting. Dick is a member of the National Society of Professional Engineers, the American Society of Civil Engineers, and the Southern Building Code Congress International.


BLAKE S. JOPLIN, EIT

Blake S. Joplin, EIT, graduated with a Bachelor of Science degree in Civil Engineering from Clemson University. He has worked for Canon Consulting & Engineering Co., Inc., for approximately four years. Blake was active in wind tunnel research while attending Clemson University and is a member of RCI.


S. THOMAS WATSON, MSCE, EIT

S. Tom Watson, EIT, has a Bachelor of Science degree in Civil Engineering from the University of South Carolina, and a Masters of Science in Civil Engineering from Clemson University. He worked with QORE Property Sciences, Inc. for three years before joining Canon Consulting & Engineering Co., Inc., in early 2001. Tom is a member of the Construction Specification Institute and the American Society of Civil Engineers.