WITHSTANDING HURRICANE IVAN

By S.P. Graveline

Of the four hurricanes that battered Florida between August and September of 2004, Ivan was estimated to have been the most powerful and destructive. Although it had weakened as it approached the Gulf Coast, Ivan was still a Category Three hurricane (winds of 110 to 130 mph) on the Saffir-Simpson scale when it came ashore. Although it first hit land near Mobile, Alabama, the region around Pensacola, Florida, absorbed the full force of the storm. Pensacola was struck by the northeast edge of the hurricane – the front right quadrant. This quadrant is the most damaging, combining the strongest winds with the force of the hurricane's forward motion. This resulted in wind speeds of up to 130 mph, the formation of six tornadoes, and severe flooding. The devastation included uprooted trees, downed power lines, buildings literally blown apart, and bridge spans washed away. Estimates of the damage caused by Ivan range from three to ten billion dollars.

Despite the tremendous forces unleashed by the storm, some buildings (and more specifically, their roofs) weathered the storm remarkably well.

Photo 1: Pensacola Civic Center.

The Pensacola Civic Center (*Photo 1*) was built in 1985. The 10,000-seat arena is a popular venue for major concerts, sporting events, and trade shows. More importantly, the building is one of the region's emergency hurricane shelters. It is counted on to provide a safe haven through the worse possible storms.

A fully-adhered EPDM assembly was originally installed on its 136,000 square-foot roof. Hurricane Erin struck Pensacola in 1995 and did approximately $7 million worth of damage to the building. More than 80% of the roof was destroyed. Over most of the roof's surface, the facer had delaminated from the core of the insulation boards, which allowed the membrane to peel back.

A decision was made to re-roof the facility with a polyvinyl chloride membrane secured by lineal fixation elements.

A mechanically-attached thermoplastic assembly was chosen so that the roof's integrity would no longer be so dependent on the cohesive properties of the insulation panel. In order to achieve maximum performance, a lineal fixation system was selected rather than the more common plate-attached approach.

In a traditional mechanically-attached installation, the fasteners and plates are installed in the sheet overlap. Under wind loading, the membrane (and consequently, the fastening components) are subjected to unbalanced or asymmetrical forces (*Figure 1*). This imposes tremendous stress on the seams, on the membrane where it is penetrated by the fastener, and most importantly causes the fasteners to tilt slightly. Fastener pull-out resistance is reduced as the fastener is acting at an angle to the deck. Additionally, under cyclic wind loads, the fastener and plate assembly "rock" back and forth, potentially elongating the point at which the fastener penetrates the deck, further reducing pull-out resistance. Although these spot-attached assemblies have a good track record on roofs exposed to more modest wind loads, there was concern that such a system would not provide the level of performance required to protect this structure from hurricane-force winds.

In a lineal attachment system, stiff 14-gauge, U-shaped profiles are used to distribute the wind loads. The bars are secured with fasteners through the membrane to the structural deck. The bars are then made watertight with cover strips hot-air welded to the base membrane. Such systems allow for a uniform load distribution on both sides of the fixation element (*Figure 2*).

Figure 1: Inseam spot attachment – unbalanced loading.

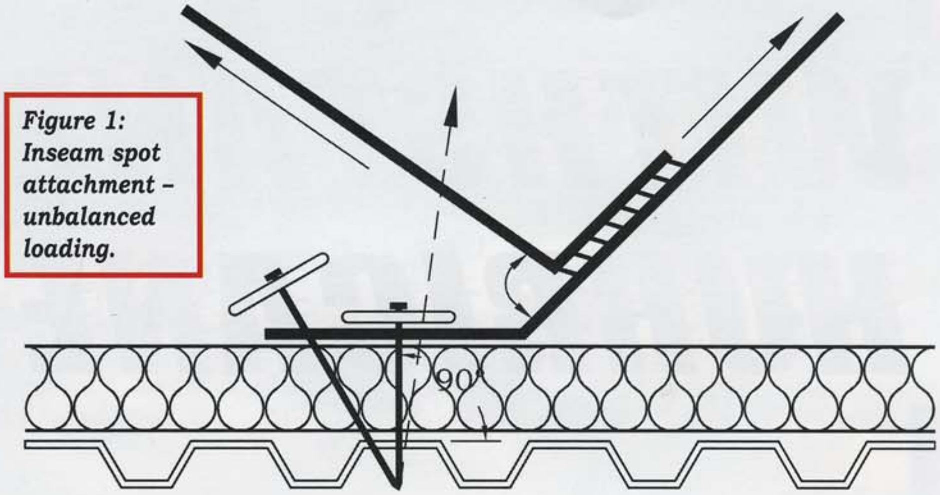
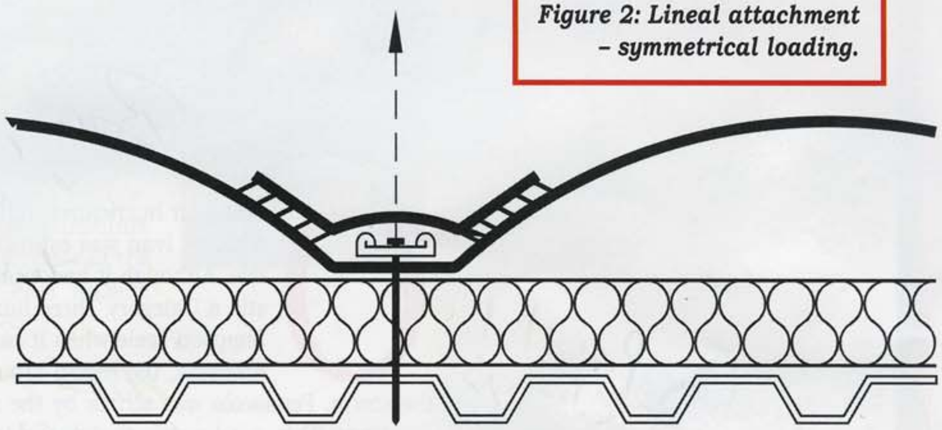


Figure 2: Lineal attachment – symmetrical loading.



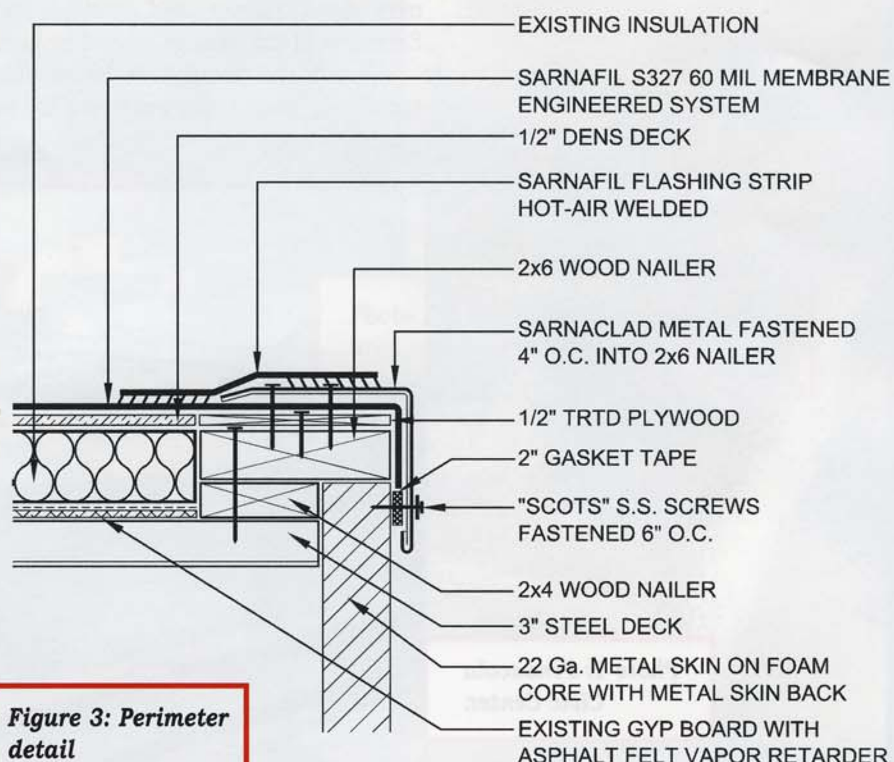


Figure 3: Perimeter detail

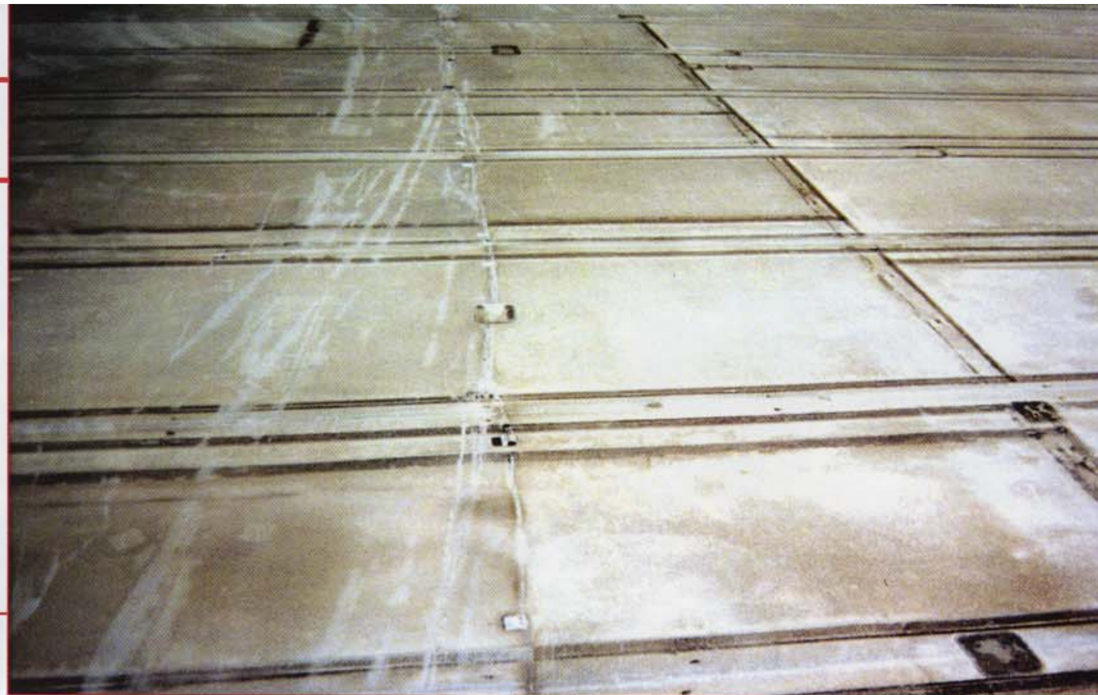


Photo 2: "Track" of one of the wind-blown HVAC units.

Photo 3: Exhaust unit blown off the roof.

This eliminates peel stress on the seams, rocking of the fixation elements, and ensures that fasteners are loaded perpendicular to the deck, ensuring that maximum pull-out resistance is achieved, also reducing fatigue.

The system is specifically engineered for each project. As the fastening components are installed on top of the membrane rather than in the overlap, spacing can be specified according to the anticipated loads for a given project, independent of the sheet's width.

As a result of the blow-off, the owners insisted on a 110-mph wind warranty for the new roof. At that wind speed, with the building located so close to the coast, and a roof height of 102 feet, the design uplift pressure was calculated to be 52 psf for the field of the roof. Applying multipliers in use at that time, the perimeter and corner pressures were evaluated to be 104 and 156 psf respectively.

Photo 4: Membrane cut by an exhaust unit.

Photo 5: Membrane punctured by an exhaust unit.

Photo 6: Membrane slit by a tumbling exhaust unit.

As most of the fixation bars would be installed perpendicular to the direction of the steel deck, the design was based on an 8-inch o.c. fastener spacing, to match the deck profile. The layout was designed within the limitations of two key parameters: the elastic limit of the polyester reinforced sheet, and fastener pull-out values. A safety factor of four was applied to the field measured pull-out values. The bar spacing in each roof area was designed to ensure that, under full tensile load, the membrane would not suffer any permanent deformation.

The 20-gauge steel deck, gypsum board, and the vapor retarder from the original installation were left in place. Much of the original polyisocyanurate insulation was salvaged, with new insulation used over the balance of the roof. A layer of half-inch Dens Deck was fastened over the entire surface. The 60-mil, polyester-reinforced PVC was then installed, seamed, and fastened. In the field of the roof, the fixation bars were installed at 4-foot, 6-inch intervals. In the 34-foot perimeter area, they were installed 2 feet, 3 inches o.c. The bars were installed in a radial pattern in the rounded corner areas.

Photo 7: Partially deformed fixation bar.

The perimeter detail (*Figure 3*) was designed to ensure the critical edge of the roof was airtight. The fascia was face fastened through a gasket tape sealed to the wall panel.

The Civic Center is located less than a half of a mile from the waterfront. At 102 feet in height, and with only much smaller, lower buildings in front of it, the building took the full brunt of Ivan coming in along the Gulf of Mexico. The 130-mph winds dislodged five rooftop exhaust units from their curbs. Each of the units was approximately 6 x 6 feet in size and weighed roughly 300 lbs. The units were literally blown

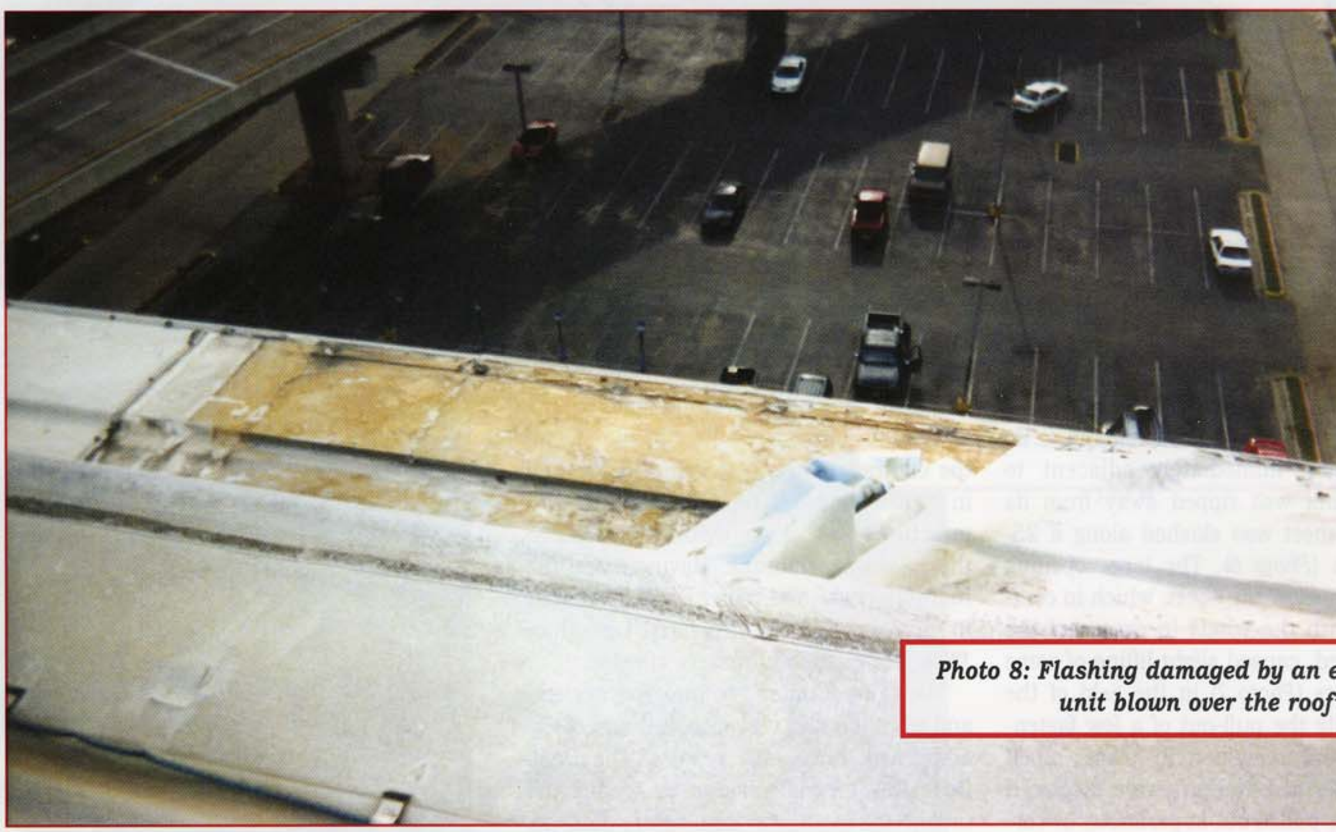


Photo 8: Flashing damaged by an exhaust unit blown over the roof's edge.

Photo 9: Downtown Pensacola in the area around the Civic Center.

across the roof surface, leaving their paths clearly marked on the membrane's surface (*Photo 2*). One of the units actually blew off the roof and landed on a car in the adjacent parking lot (*Photo 3*).

The membrane was cut or punctured in numerous locations (*Photos 4* and *5*). At one location, immediately adjacent to where a unit was ripped away from its base, the sheet was slashed along a 25-foot length (*Photo 6*). The large opening allowed air below the sheet, which in combination with the winds in excess of the design speed, caused slight lifting of some fixation bars (*Photo 7*) in the field of the roof. Despite the pull-out of a few fasteners, the bars remained in place, albeit slightly deformed. No bars were displaced or fasteners pulled out in perimeter or corner zones, where the highest loads are generated.

The flashing was damaged at the location where the unit went over the edge of the roof (*Photo 8*). Otherwise, the flashings remained fully intact and undamaged.

Within a couple of days of the storm, the contractor who had installed the roof in 1995 was able to repair all the cuts and punctures by hot air welding patches to the existing membrane. Having made the roof watertight, the roofer will return later to address the deformed bars. Less than 1% of the fixation bars were affected.

Very little water got into the system, and what did was very localized and easily addressed during the repairs. The Dens Deck was very effective at protecting the underlying insulation from severe damage.

In light of how well the roof performed overall, one could assume that it would not have suffered any damage whatsoever had the mechanical units remained securely fastened to their bases. In fact, Ivan was not the first hurricane the roof experienced. Shortly before the completion of the re-roofing operations in the fall of 1995, Hurricane Opal struck. This was also a Category 3 hurricane. Although not quite 100% complete at that time, the new roof assembly resisted the storm without any damage.

Having survived winds in excess of the design speed for a second time, the system proved itself to be truly hurricane resistant.

Pensacola's downtown core in the area surrounding the Civic Center was absolutely devastated (*Photos 9* and *10*). However, although the noise from the displaced mechanical units rolling around the roof was disconcerting, the thousands of people who weathered the storm inside the Civic Center were kept dry and secure.

Acknowledgement: The author would like to thank the staff of the Edwards Roofing Company, Inc., Pensacola, Florida, for its input on this article.

Stanley P. Graveline

Stanley P. Graveline is vice president, technical services, for Sarnafil Inc., Canton, MA. He has worked in the roofing industry for more than 20 years in various technical, sales, and management capacities in Canada, Switzerland, and the USA. He has participated in numerous technical committees and standard writing bodies in North America and Europe. Graveline is a member of the Roofing Consultants Institute and of Professional Engineers Ontario. He is a director of the Cool Roof Rating Council and of the North East Roofing Contractors Association.

Photo 10: Downtown Pensacola in the area around the Civic Center.