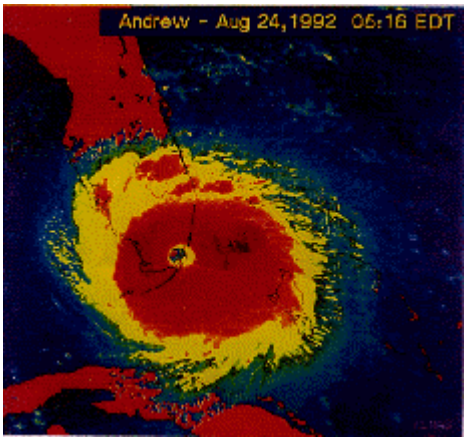
How did PUF/SPF roofs perform during Hurricane Andrew? top of page

Based on observations made during Hurricane Andrew, PUF/SPF roof systems appear to have the potential to be excellent performers during high-wind events.



The October 1992 "Tech Transfer" article presented a preliminary assessment of roof performance during Hurricane Andrew, which struck South Florida on Aug 24, 1992. Following is a detailed assessment of the wind performance of 11 spray-applied polyurethane foam (PUF) roofs, which were inspected on August 29 and 30, and on September 19 and 20.

Contour maps showing estimated wind speeds at 33 feet (10 m) above grade have not yet been finalized. However, from damage observations of surrounding buildings and trees, three of the PUF roofs were in areas of very high winds, one was in an area of high winds and seven were in areas of moderately high winds.

Some areas received extremely high winds, but no PUF roofs were found in those areas. The following descriptions of buildings are grouped in descending order of estimated wind speeds. Unless noted otherwise, the roof slopes were about 1/4 inch per foot (21 mm per m), or less. Also, unless noted otherwise, a metal-edge flashing (gravel stop) was used at the perimeter.

Very high winds

Building 68. This is a two-story residence near Naranja, with roofs on levels one and two. It sits in terrain Exposure C (as defined by ANSI/ASCE 7-88, *1 and is about eight miles from the coast.

The roof system is PUF, reportedly installed over a built-up roof (BUR--mineral surface cap sheet, ply sheet and a nailed base sheet), over wood planks. The PUF roof is approximately 10 years old.

A portion of the PUF roof apparently was blown off on parts of the upper and lower roofs. At the time of inspection, temporary repairs had been made. The entire second-level roof and a portion of the lower roof had been covered with what appeared to be a

two-ply, built-up membrane with an aluminum coating. The nature of the temporary repairs made investigative work difficult. The lower roof consists of several separate sections. About half of the main section occurs over a canopy that is open on three sides. It appeared that the BUR/PUF composite roof over the canopy had blown off, but apparently it did not progressively fail beyond the canopy area (see . Photo 1). The metal-edge hashing had been replaced along the canopy edge.

Beyond the canopy area, a piece of foam was missing at the metal-edge flashing flange. This probably was caused by missile (i.e., windblown debris) impact. The BUR/PUR roof did not progressively peel beyond the impact area.

The other lower roofs are less than 100 square feet (9.3 meters squared) each. These roofs were not damaged, except for some minor missile damage. The building has an overhang of about 4 feet (1,200 mm) along one edge of the upper roof. As with the lower canopy, it appeared that the BUR/PUF roof over the over-hang blew off. But, as on level one, it did not appear to progressively fail beyond the overhang.

Within about 200 feet (60 m) from the house, in different directions, there are three other one-story buildings. One building is framed with wood trusses. It experienced significant gable end wall failure and collapse of several trusses. Several sheathing panels were also blown-off, along with many asphalt shingles.

The second building has a hip roof that had been covered with felt. The type of roof covering and the extent of damage was not determined. The third building has a low-sloped roof. It was reported that its BUR blew off. Although there are few trees nearby, several were significantly damaged.

Building 20.

This is a one-story commercial building near Cutler Ridge, composed of two intersecting domes. It sits in terrain Exposure B and is about three miles, from the coast. The roof system is PUF (self-flashed at the edge), presumably over thin-shell concrete.

No missile damage or peeling of the PUF roof was observed. A television antenna on the side of the domes was blown over, and a cowling on a fan on top of the domes was blown off. A lack of buildings within about 110 feet of the domes may be the reason for the lack of missile damage.

Gable end wall failure of a wood truss-framed apartment building west of the domes was observed. Several asphalt shingles were blown off of these buildings.

Building 14. This is a one-story house near Howard in terrain Exposure B. The coast is about three miles to the east and about two miles to the southeast. The roof system is PUF, reportedly over a BUR. The roof slope is about 2·in·12. The PUF roof is about 10 years old (see Photo 2).

The only apparent damage to the PUF roof was minor missile damage in several areas. One of the missiles was a piece of a tree limb about 3/8 inch (10 mm) in diameter. Also, at the overhang, an electrical conduit penetration for the power feeder had moved back-and-forth, causing a hole. The homeowner reported no leaks. *This roof appeared to be easily repairable.*

A garage roof (with a very low slope) joins the PUF roof. It is covered with a mineral surface cap sheet. A portion of this roof lifted at a corner and peeled. The base sheet was nailed to plywood, but there were few nails. However, the failure appeared to be related to the lack of attachment of the metal-edge flashing. There was extensive tree damage in the area. It also appeared that essentially all of the nearby houses experienced roof covering problems. An aggregate-surfaced BUR (on a house similar to the PUF house) apparently had problems along the rake, because it was temporarily covered with felt. Some houses experienced a loss of asphalt shingles, while others lost tiles.

High winds

Building 56. This is a two-story condominium near Kendale Lakes in terrain Exposure B. It is about 10.5 miles (17 km) from the coast. The roof system-PUF over an existing BUR-has a 14-inch (350-mm) parapet. Rather than having a coping, the parapet was self-flashed with PUF. In the field of the roof, the foam was covered by loose aggregate (similar to the type used for BUR). Because of the aggregate surfacing, only the exposed portions of the foam were coated. The PUF roof is about a year old.

An extensive area of the aggregate was scoured (blown away-see Photo 3). However, because of the parapet, it appeared that little (if any) aggregate had blown off of the roof. The only other damage to the PUF roof was caused by missiles impacting the parapet and equipment curbs. Some of this minor damage was caused by the aggregate, and some was caused by pieces of BUR felt from another building. The homeowner reported no leaks. With this minor damage, the roof was easily repairable, with most of the work related to relocation of the aggregate.

Tree damage in this area was light. Reportedly, some of the other condominiums in this complex experienced problems with their roofs (presumably BUR), but it did not appear that damage was widespread. However, in another nearby condominium complex (of a different design), it appeared that most of the BUR systems were damaged. These buildings had metal-edge flashings, which appeared to be the cause of the problem due to inadequate attachment. Also in this neighborhood, there are several houses and condominiums roofed with asphalt shingles or tiles. Performance of each type of covering was variable; some roofs appeared to have little or no damage, while others had extensive damage. The variability was likely due to design, materials or application, rather than variations in the wind field.

Moderately high winds

Building 66. This is a two-story hotel on the east side of Miami Beach. It sits in terrain Exposure D (only a street and the beach separate the hotel from the ocean). The roof system is PUF over a BUR. The parapet height is about 32 inches (800 mm), and the top is self-flashed with PUF. The PUF roof is about five years old. The only apparent damage to the PUF roof was caused by missiles in several areas, including a portion of the parapet. The damage was caused by the BUR and by wood framing from an adjacent building. Some of the missiles landed on the PUF roof with fairly great force. One caused a large gouge that was 7/8 inches (22 mm) deep. In another location (an area about 17 x 22 inches, or 425 x 550 mm), the latex (acrylic) coating peeled. The building owner reported no leaks. *This roof appeared to be easily repairable.*

There are few trees in this area. Those on the ocean-side of the hotel appeared to have little (if any) damage. Besides the damage to the adjacent building's BUR, other roofing damage in this area appeared to be light. However, most of the buildings have low- slope roofs, so it was difficult to accurately judge surrounding damage. From periodic piles of debris along the streets, occasional BUR damage was surmised.

Building 67. This is a vaulted· shaped church near West Miami. The maximum roof height is about three stories. It sits in terrain Exposure B, and the coast is about nine miles (15 km) to the east and about six miles (10 km) to the southeast. The roof system is PUF (self-flashed at the edge), presumably over concrete. A two-story building, with a smooth-surface BUR, is connected to the back of the vaulted structure. The PUF roof is about one year old. It was not possible to gain access to the top of the vaulted building, but no PUF damage was observed from the second-level roof or from the ground. A recent patch was observed on the BUR; it was about 6 x 10 feet (1.8 x 3 meters). It appeared that a gutter had lifted and peeled the membrane. Tree damage in this area was very light. A few of the houses in the neighborhood had minor asphalt shingle and tile damage.

Building 72. This is a tall, one-story warehouse near Hialeah in terrain Exposure B. It is about eight-and-a-half miles (14 km) from the east coast of Miami Beach. The roof system, a PUF over BUR, is about eight years old. There was no apparent damage to the PUF. Tree damage ill this area was minimal. A BUR on an adjacent building (of slightly lower height) suffered some damage. The extent of damage could not be determined, because the entire roof had been replaced. Near to this building is Building 73 (described below).

Building 73. This warehouse is two buildings away from Building 72. The two buildings are about the same height. The roof system is PUF over BUR. In one area, the PUF is about 3/4 inches (19 mm) thick. The PUF is about 10 years old. At one corner, the metal-edge flashing (including the nailer) and the BUR/PUF composite lifted and peeled. The peeled area was about 20 x 45 feet (6 x 14 m-see Photo 4). The nailer was attached to the concrete wall with cut nails, but it was not possible to determine the spacing. In addition, there were a few minor damaged areas due to missile impact. The peeled area had been temporarily patched with a relatively thin layer of uncoated PUF. *This roof appeared to be easily repairable.*

Adjacent to this building is Building 74. It is an aggregate surfaced BUR, with a base sheet nailed to a lightweight insulating concrete deck (which appeared to have perlite aggregate). It also peeled, near the peel on Building 73 (Photo 4). The peeled area was about 20 x 40 feet (6 x 12 m), plus an additional strip 25 feet (8 m) beyond the 40·foot (12-m) dimension. This strip varied in width from about 2 to 5 feet (600 to 1,500 mm). The peel appeared to be caused by lifting of the nailer to which the gutter and metal edge were attached. It appeared that all of the base sheet fasteners remained in the deck (which is typically the case with peeling with this type of system). The nailer was fastened into the concrete walls with cut nails at about 29 inches on center. At another corner, a portion of the membrane and deck was missing. A 5-foot-long (1,500mm) hole occurred in the deck between bulb tees. It appeared that this was caused by impact of the BUR/PUF composite debris from Building 79. Repair, rather than replacement, of the roof on Building 74 would be possible. However, besides the difficulty of tying in the new work to the existing, the exposed deck also presents problems. At the time of the investigation, it had been exposed for 27 days and subjected to a lot of rain. In addition, there could be undetected damage to the membrane where the nailer/gutter/membrane landed. In the vicinity of Buildings 72, 73 and 74, there are several similar warehouse buildings. It appeared that most of them have aggregate-surfaced BUR, and it appeared that most of them had small membrane peels at corners. which were likely due to inadequate attachment of the metal-edge flashing. The metal-edge flashing on two of these other buildings was not cleated or face-fastened.

Building 75 This is a tall, one-story warehouse a few blocks from Buildings 72, 73 and 74. It also is in terrain Exposure B; the roof system is PUF over BUR. In the field of the roof, the foam is covered by loose aggregate (similar to the type used for BUR). The PUF roof is about one year old. There was no apparent damage, nor was there any significant aggregate scour. Tree damage in this area was minimal. There are two buildings behind this building, one with a single story, and the other with two stories. The one-story building had recently been re-roofed, but it was not possible to determine the original type of roof covering. The two-story building had flashing damage, and perhaps some peeling at a corner. It appeared that it is covered with an aggregate-surfaced BUR. Across the street from Building 75, there are three one-story buildings. One roof had been replaced. On the other two, a portion of each roof was peeled at a corner. These roofs appeared to be aggregate-surfaced BUR. Another building beyond these buildings was temporarily covered with a tarp. On the other side is Building 76, a warehouse of similar height to Building 75. This building has an aggregate-surfaced BUR (membrane, wood fiberboard, nailed ventilated base sheet) over a lightweight insulating concrete deck (which appeared to have perlite aggregate). The metal-edge flashing lifted at the corner and peeled the membrane. It has an uncleated, 6·inch (150·mm) vertical face. A portion of the nailer was rotted and some of the lightweight concrete adjacent to the nailer was in poor condition. There was a hole about 12 x 18 inches (300 x 450 mm) through the membrane and deck several feet from the roof edge. Perhaps this was caused by debris from the peeled area. Around the hole, the deck appeared to be in poor condition.

Building 69. This is a tall, one-story warehouse near Hialeah, a few miles from the warehouses previously described. It sits in terrain Exposure B, and is about 11 miles from

the east coast of Miami Beach. The roof system is PUF over BUR. The PUF is about 10 years old. There was no apparent damage to the PUF. Behind this building is a building of similar height with an aggregate-surfaced BUR. Scour was observed at two corners. Adjacent to Building 69 is Building 70, as described below.

Building 70. This building is about the same height as Building 69. The roof system is PUF over BUR (with a nailed base sheet) over a lightweight insulating concrete deck (which appeared to have perlite aggregate). In one area, the PUF is about 1 inch (25 mm) thick. The PUF is about 11 years old. At one corner, the metal-edge flashing and the BUR/PUF composite lifted and peeled. A gutter occurs along one edge. At the other edge, the nailer lifted with the flashing. The nailer was attached to the concrete wall with cut nails. A portion of the nailer that remained attached was rotted. The metal flashing is attached to the nailer with 1 1/4-inch (31·mm) nails spaced at 5, 6, 7 and 6 1/2 inches (125, 150, 175 and 163 mm). It has an uncleared 4-inch (100-mm) vertical face and a 5·inch (75·mm) horizontal flange. The peeled area was about 20x 30 feet (6 x 9 m--see Photo 5). The peel appeared to be caused by lifting of the nailer along one side, and lifting of the metal-edge flashing on the other side. The deteriorated nailer probably played a key role in the failure. It appeared that all of the base sheet fasteners remained in the deck.

Portions of the deck were deteriorated along some of the bulb tees, and in one area there were holes through the deck along a line perpendicular to the tees (see Photo F,). These deck problems did not appear to be related to the hurricane.

The coating (polyurethane) is in poor condition, with foam exposed over much of the roof (not related to the hurricane). Because the foam has been exposed for an extended time, in several areas much of it has weathered away. However, the foam was dry, except for the cells near the surface. Across the street is a two-story warehouse that has a smooth-surfaced BUR over perlite over an aggregate-surfaced BUR (with a nailed base sheet). It was not possible to get on this roof. However, from debris on the ground, it appeared that a very large area of the roof had peeled.

Discussion

1. It appears that if the substrate to which the PUF roof is applied (e.g., BUR) lifts and peels, PUF plays a role in limiting the size of the peel. Undoubtedly, PUF limited progressive peeling failure on the second-level roof (and perhaps on the first level roof) of Building 68. However, the extent of the peel on Building 73 (PUF) was not greatly smaller than the peel on Building 74 (BUR).

PUF's ability to limit progressive failure is probably proportional to its thickness. Two of the PUF roofs that peeled had thickness' of about 1 inch (25 mm). By increasing the thickness to 2 inches (50 mm), the area of peel could probably have been greatly reduced. With this greater thickness, it is believed that the lifted portion of the composite (e.g., BUR/PUF) would snap off near the roof edge, or the lifted section would just drop down

onto the deck. Of course, if peeling occurs, it is advantageous to limit its size to minimize water infiltration and the generation of missiles.

2. Compared to BUR, modified bitumen or metal, PUF is more easily damaged by missiles. However, the damage is probably easier to visually find and easier to repair. PUF's greatest attribute regarding missile damage is its ability to remain watertight, provided that the missile does not fully penetrate the foam. It appears that a thickness of about 2 inches (50mm) is sufficient to prevent penetration of most missiles. PUF also does not appear to be susceptible to progressive peeling after being struck by large missiles, unlike a few other types of roof coverings.*2

3. Scour of aggregate surfaced PUF (Building 56) does not present a problem to the foam, provided that the aggregate is repositioned within a few months. However, if the aggregate blows off of the roof, it can cause damage to adjacent buildings and cars, and it can cause injury. In high·wind environments, parapets are needed to prevent aggregate blow-off. 4. Damage to many of the warehouse roofs was probably related to the age of these buildings (which could easily be more than 30 years). They were constructed with some practices that are not recommended in high· wind environments, such as using cut nails to attach the nailers to concrete, and the use of uncleated metal-edge flashing. The deteriorated nailers also probably played an important role, and illustrates the wisdom of the recommendation to use preservative treated nailers.

Conclusions

Based upon observations made during Hurricane Andrew, Hurricane Hugo *3 and the 1990 Plainfield (Ill.) tornado, *4 it appears that *PUF roof systems have the potential to be performers during highwind events*. Besides being resistant to the wind loading, PUF's high·wind attribute is in part due to its resistance to progressive peeling failure due to missile impact, deck failure or a lifting and peeling failure at the roof edge. PUF's ability to resist water infiltration after being impacted by missiles is also a great asset, particularly in an area that has been impacted by a powerful hurricane, because emergency repairs may take weeks or months.

Recommendations

1. In high-wind environments, if the designer specifies an aggregate-surfaced PUF roof, it is recommended that the potential for aggregate blow-off be evaluated using the 1976 Kind and Wardlaw guide.)

2. For metal-edge flashings, refer to the recommendations in the 1990 IJORT.*6 <

3. If the designer specifies a PUF roof (or any other type of roof covering) over an existing membrane, the designer should recommend evaluation of the deck by an engineer if deck deterioration is suspected.

4. If the designer specifies a PUF roof over an existing membrane in a highwind environment, a minimum foam thickness of 1.5 to 2 inches (38 to 50 mm), depending upon wind conditions, is recommended to limit the extent of a possible peeling failure of the exiting membrane. The reason for this conservative measure is that the integrity/strength of the existing roof covering system will be unknown to some extent.

5. If the designer specifies a PUF roof over an existing membrane, and if the designer decides to reuse the existing metal-edge flashing, the vertical face should be evaluated by the designer. If it is uncleated, if there is little interlock between the metal and cleat or if the face can be deflected outward far enough to possibly unlock the metal/cleat, then it is recommended that the metal be fastened along its face or replaced. However, it should be realized that if the metal is not replaced, it is very difficult to know if the nailers are adequately attached or still in sound condition.

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