Roof wind damage mitigation: Lessons from Hugo

Studies on Hurricane Hugo reveal that inadequate attention by designers was the predominate cause of roofing problems in and around Charleston, S.C.

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The following report was presented at a symposium that was sponsored by the American Society of Civil Engineers. The forum, "Hugo One Year Later," was held September 13-14, in Charleston, S.C.

Hurricane Hugo caused extensive roof damage in Charleston, S.C., and surrounding areas. Extensive field investigations have revealed the causes of many of the problems. This paper summarizes the investigative findings and presents recommendations for mitigation of future roof wind damage.

Immediately after Hurricane Hugo came ashore in South Carolina, a research team from Texas Tech University's Institute for Disaster Research (IDR), in cooperation with NRCA, performed a comprehensive field investigation

Disaster response by roofing contractors is critical, yet difficult when a large area is impacted by high winds.

in Charleston and surrounding areas. The IDR report, *Performance of Roofing Systems in Hurricane Hugo,*[3] discusses wind speeds, structural damage and roof damage, and makes a number of recommendations.

Extent of roof damage

In the Charleston area, probably in excess of 75 percent of the roofs had at least minimal roof damage. While several roofs had slight damage, other roofing systems experienced catastrophic failure. Water damage to buildings and their contents, due to roof leakage, often caused greater financial loss than the roof damage itself.

The magnitude of Hurricane Hugo roof damage is not too surprising for two reasons: 1) roof systems experience higher loadings than any other building elements, and 2) roof systems often do not receive the engineering (design) attention that they should.

What Hugo showed

Hurricane Hugo roof investigations confirmed a number of issues that had been experienced in previous wind storms:

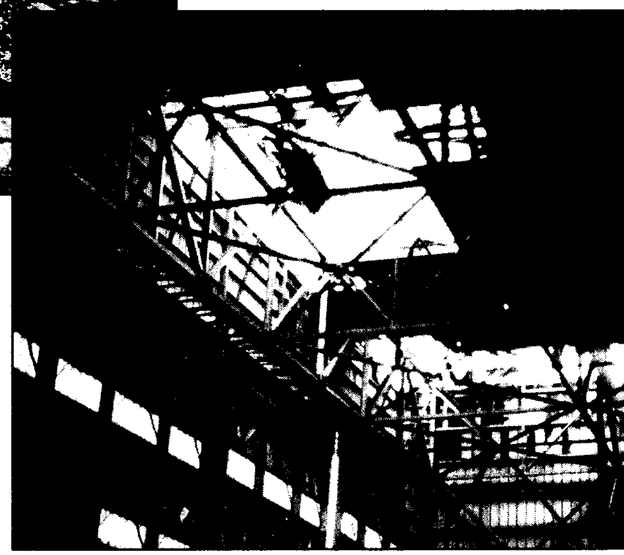
Internal air pressure. The development of high internal air pressure due to window breakag the collapse of large doors and leakage around large doors resul ed in some roof failures. Curren codes and design guides do not adequately address this issue.

Structural roof decks. Roof de or deck support elements occasic ally failed. Common problems w the use of toe-nailed connections and inadequate load capacity of the deck/support fasteners.

Workmanship. Some roof failures were directly related to workmanship deficiencies.

Metal edge flashings. Many failures were initiated by inadequate metal edge flashings. An a cle in the *International Journal of Roofing Technology* titled, "Hurrica Hugo's Effects on Metal Edge Flashings[4]," reviews current code and guidelines regarding metal edge flashings, counterflashings, copings, gutters and nailers. Inch ed are several detailed design recommendations for these elements, which are vital for roof wind resistance.

Built-up membrane roof (BUR aggregate blow-off. The loss of



Built-up roof over a steel deck. Many deck panels blew off during Hurricane Hugo because of an inadequate number of welds (left).
Interior view of left photo. High internal pressure probably contributed to the loss of deck panels (below).

small aggregate has the potential of causing significant injury or damage to adjacent buildings. In one case, aggregate blew more than 245 feet (75 meters) from one two-story building to another and broke nearly all of the outer panes of the double-glazed windows. Several of the inner panes also were broken. Where analysis[2] indicates aggregate blow-off at design wind speeds the aggregate should be fully embedded (using the double-surfacing technique), or sufficiently high parapets should be used to prevent blow-off, or an aggregate surfaced membrane should not be used.

Asphalt shingles. Performance of asphalt shingles was highly variable. To a large extent, this was due to the wind resistance of the shingles, which primarily is governed by the performance of the self-seal adhesive. Mislocated fasteners also commonly were observed. In some cases, this was the probable cause of failure.

Underlayment. Underlayment provided beneficial secondary protection for many roofs that lost their primary roof covering.

Metal roofing clip fasteners. Nails commonly were used to fasten traditional metal roofing (tinplate and terneplate) clips to the structural deck. Some new architectural metal panels also used nails to fasten the clips. Many fastener failures were experienced, due to the low pull-out resistance of the nails and their susceptibility to dynamic loading failure.

Hurricane Hugo also revealed new information or gave additional information that previously had limited reporting:

Single-ply membrane ballast (aggregate) blow-off. Several aggregate ballasted, single-ply membranes that experienced significant ballast blow-off were investigated. These large aggregate (ASTM D448, number 4) have the potential to cause significant injury and building damage.

Either current design guides[1,2] are inadequate or designers are not following the guides. A reevaluation of the current design guides will be presented at the Third International Symposium on Roofing Technology in Montreal in April 1991.

Mechanically attached single-ply membranes. Some of these systems performed well, while others experienced catastrophic failure. Some of the blow-offs were due to fatigue. Current U.S. testing methodology does not evaluate fatigue resistance, which is critical for these systems because they may be prone to flutter-induced failure.

Metal shingles. Several roofs used metal shingles that are vulnerable to moderate and high wind loads.

Manufactured roof components. Some of the manufactured roof components (i.e., some of the architectural metal panels and their connection clips) are inadequate for high wind areas.

Essential facilities

Roofs on essential facilities fared poorly. All 20 fire department buildings and all five police department buildings in Charleston experienced roof damage. Roofs on six of the 25 buildings had to be completely replaced. An accurate record of hospital roof damage was not compiled, but it is known that several hospitals had roof damage that interfered with the functioning of the facility during and after the hurricane.

Public schools, which often are used for evacuation shelters or in post-disaster response operations, also suffered significant roof damage. Forty-nine of 70 school facilities in Charleston had roof damage.

Recommendations

1. Roof systems should be designed to resist wind loads. Inadequate attention by the roof designer was the predominate cause of problems inflicted by Hurricane Hugo.
2. Many designers use Factory Mutual (FM) or Underwriters Laboratory (UL) for design criteria. While FM has several good design aids and FM and UL have a number of testing methods that may be useful, designers should use ANSI A 58.1 (or its replacement, ASCE 7), or a model or local building code. Code loads typically are much larger than loads derived from FM or UL.
3. Greater attention is needed for the design of roofs on essential facilities. These include hospitals, police and fire stations, schools and other buildings used for evacuation shelters or in housing post-disaster response operations.

   In addition to using an increased load factor (as found in building codes), the designer should consider using a higher safety factor. The designer also should consider the roof's resistance to missile impacts, because flying debris often causes substantial damage to some types of roofs. A design guide for roofs on essential facilities needs to be developed.
4. A fundamental and difficult issue to address is the need to better educate designers, manufacturers and contractors. The educational needs are two-fold. First, there is the need to communicate the vast amount of information that currently is known regarding roof wind performance issues. Second, there is the need to communicate information that is developed in the future.
5. Tests for some types of roof systems need to be improved. Other types of systems don't have any recognized test procedures at all. Improved test methods currently are being evaluated for asphalt shingles, for mechanically attached, single-ply membranes, and for metal roofing. This work needs to be expedi ed, and work needs to commence on tests for those syste that currently lack test metho
6. The wind research/engineerin community needs to work clo with the roofing industry to identify problems and solutio that are unique to roofs. Fortunately, positive steps recent have been taken. The Roofin Industry Committee on Wind sues (RICOWI), formed early 1990, provides a forum for th various segments of the roofi industry. The establishment o RICOWI hopefully will bring about increased cooperative work between the wind research/engineering commun and the roofing industry.
7. Code provisions and code enforcement, as they relate to tl wind performance of roof sys tems, need to be re-evaluated and changes need to be made where appropriate.
8. Disaster response by roofing contractors is critical, yet diffi when a large geographical are

Ballasted EPDM system. Much of the ballast was scoured and several stones blew off the roof.

Mechanically attached PVC system. The edge nailer lifted from the brick wall. However, good interlock between the cleat and metal-edge flashing prevented peeling of the membrane.

is impacted by very high winds. In Charleston and surrounding areas that experienced a tremendous amount of roof damage, roofing contractors were unable to make temporary repairs quickly. As a result, many buildings had extensive interior water damage. Local contractors were faced with enormous challenges that they previously had not experienced.

The Roofing Industry Educational Institute, with NRCA funding, responded by offering application training for residential asphalt shingle application. NRCA also provided technical assistance to the Historic Charleston Foundation and to Historic District building owners and others. And as a result of Hurricane Hugo, NRCA recently established a disaster response task force to develop information and strategies that the roofing industry can use in responding to future disasters.

9. Continued field investigations of major wind storms is important. There is the potential to learn new information that can lead to practices that minimize future problems. Also, confirming and enlarging the data base of previously learned information can be important in moving needed changes forward.

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