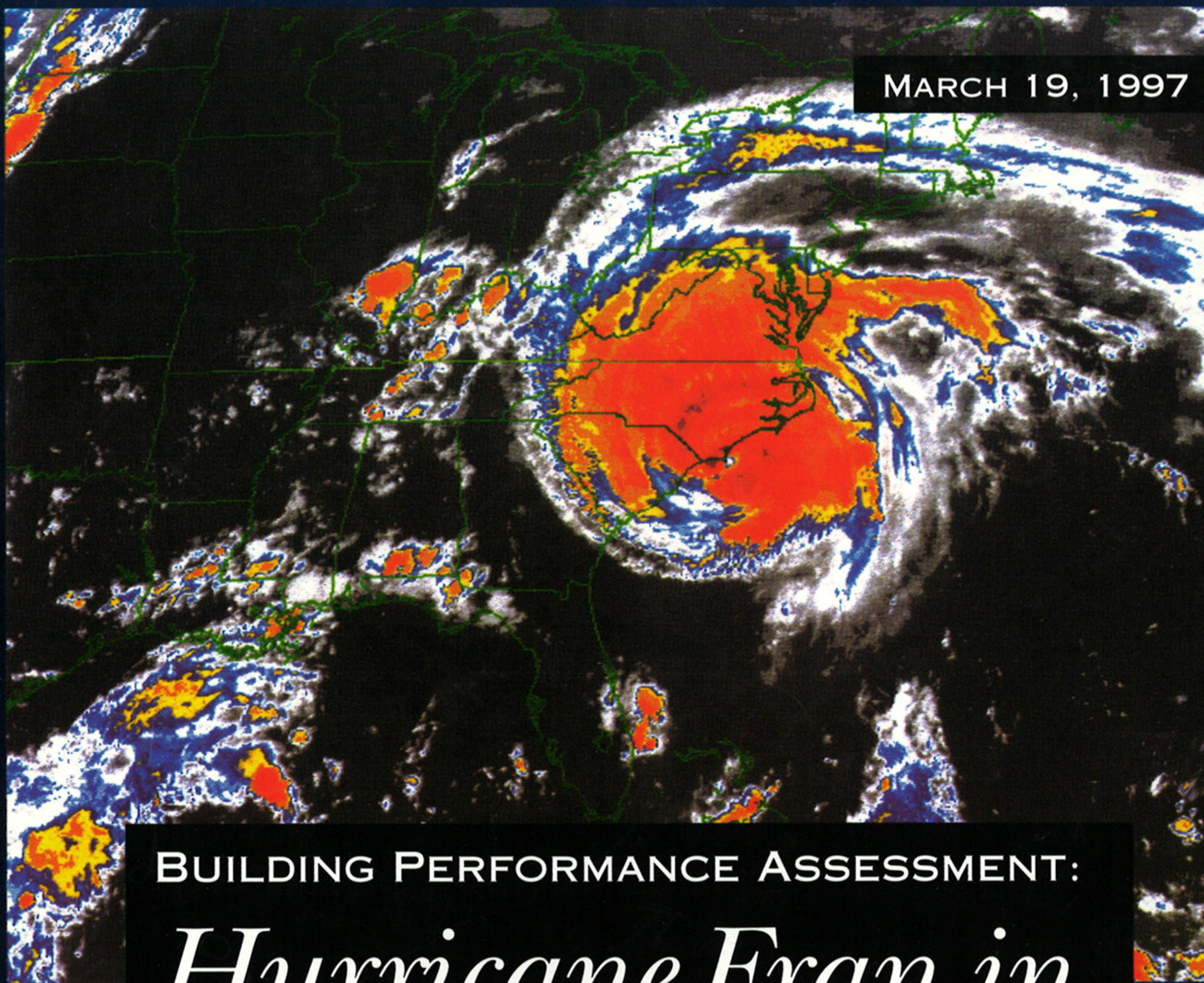
MARCH 19, 1997



BUILDING PERFORMANCE ASSESSMENT:

Hurricane Fran in North Carolina

OBSERVATIONS, RECOMMENDATIONS, AND TECHNICAL GUIDANCE

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE

WASHINGTON, DC
AND
REGION IV
ATLANTA, GEORGIA

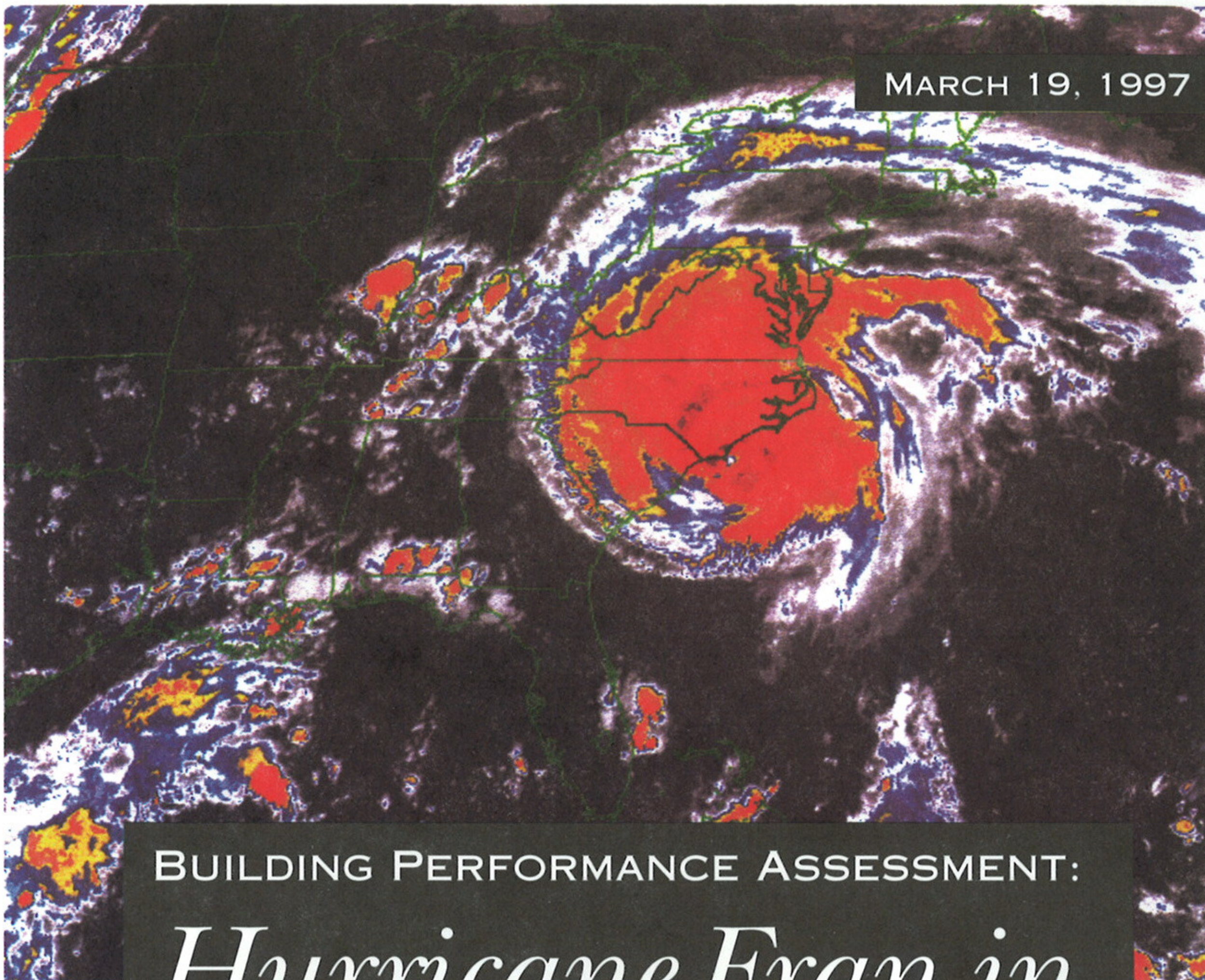
FEMA 290/*March 1997*

The Building Performance Assessment Team Process

In response to hurricanes, floods, earthquakes, and other disasters, the Federal Emergency Management Agency (FEMA) often deploys Building Performance Assessment Teams (BPATs) to conduct field investigations at disaster sites. The members of a BPAT include representatives of public sector and private sector entities who are experts in specific technical fields such as structural and civil engineering, building design and construction, and building code development and enforcement. BPATs inspect disaster-induced damages incurred by residential and commercial buildings and other manmade structures; evaluate local design practices, construction methods and materials, building codes, and building inspection and code enforcement processes; and make recommendations regarding design, construction, and code issues. With the goal of reducing the damage caused by future disasters, the BPAT process is an important part of FEMA's hazard mitigation activities.

Cover Photograph:

Hurricane Fran at landfall, September 5, 1996, 7:45 p.m., e.d.t. National Oceanic and Atmospheric Administration GOES-8 Color Enhanced IR photograph.



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Preface

The Federal Emergency Management Agency (FEMA) Mitigation Directorate administers the floodplain management provisions of the National Flood Insurance Program (NFIP). The Federal Insurance Administration (FIA), also part of FEMA, administers the insurance provisions of the NFIP. Together, the Mitigation Directorate and FIA have been involved in assessing the performance of buildings affected by flooding. To date, FEMA has prepared over 25 building performance assessment, damage assessment, and flood hazard mitigation reports. A list of these reports is provided in Appendix A of this report. Over ten thousand copies of FEMA's report on Hurricane Andrew have been distributed, and the report has been cited by the national media and used by State and local governments and model building code organizations as the basis for changes to building codes and standards. The findings and recommendations of these reports have been used by all levels of government to enhance the performance of buildings subject to natural hazards.

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Executive Summary

On September 5, 1996, Hurricane Fran made landfall near Cape Fear, North Carolina (see Figure 1-1 in Section 1), and generated considerable rainfall, moderately high winds, and storm surge and waves along the coast. The National Oceanic and Atmospheric Administration estimated that Hurricane Fran generated 1-minute sustained winds of 115 miles per hour. Storm surge elevations approached or exceeded National Flood Insurance Program (NFIP) base flood elevations from Kure Beach North, Carolina, to North Topsail Beach, North Carolina, along approximately 50 miles of coastline. The recorded maximum high water, assumed to include wave effects, was 15.4 feet above mean sea level (m.s.l.) at Kure Beach. Although the storm generated high winds along the coast and well inland, severe damage to buildings was concentrated in those areas also impacted by the flood surge and waves. This report focuses on the damages along the North Carolina coast that resulted from flood surge, wave action, erosion, and scour.

On September 12, 1996, the Mitigation Directorate of the Federal Emergency Management Agency (FEMA) deployed a Building Performance Assessment Team (BPAT) to coastal North Carolina to assess damage caused by Hurricane Fran. The team was composed of FEMA Headquarters and regional engineers, a State representative, a consulting structural engineer, a consulting specialist in coastal construction and shoreline erosion, a consulting coastal engineer, the Chief Underwriter of the NFIP, and an engineer from the Insurance Institute for Property Loss Reduction. (See Appendix B for a list of team members.) Some members of the BPAT also represented the American Society of Civil Engineers (ASCE) Committee on Flood-Resistant Design and Construction.

The mission of the BPAT was to assess the performance of buildings on the barrier islands most directly affected by Hurricane Fran and to make recommendations for improving building performance in future events. Better performance of building systems can be expected when the causes of observed failures are determined and repair and reconstruction are undertaken in accordance with recognized standards of design and construction. The immediate goal of the BPAT process is to provide guidance to State and local governments for post-hurricane reconstruction. In addition, the BPAT's findings can enhance future coastal design and construction.

The BPAT made its assessments by conducting site investigations to observe the condition of buildings in selected areas affected by the storm. The scope of the BPAT process did not include recording the numbers of buildings damaged by the hurricane, determining the frequency of specific types of damage, or collecting other data that could serve as the basis of statistical analyses. Collectively, the team invested over 600 hours of effort conducting site investigations, inspecting damages, and preparing documentation. Documentation of observations made during ground-level and aerial surveys included field notes and photographs.

The BPAT assessed the performance of primary structural systems of buildings, i.e., systems that support the building against lateral and vertical loads experienced during a hurricane; building extensions, such as decks, porches, and roof overhangs; nonstructural building components such as breakaway walls and below-building concrete slabs; and on-site building support utilities such as electrical, water, and sewage services. The team focused its efforts on primary structural systems. It is extremely important to note, however, that damage to other portions of buildings often contributed to the damage incurred by the primary structural systems.

The building types observed were primarily one- and two-family, one- to three-story, wood-frame structures elevated on wood pilings. Other types of construction observed included one- and two-family wood-frame slab-on-grade houses, manufactured homes and permanently installed recreational vehicles (RVs) on dry-stack masonry foundations, and a small number of wood-frame structures elevated on solid-perimeter masonry walls. In general, wood-frame structures elevated on piling foundations outperformed structures on all other types of foundations (e.g., masonry pier, continuous masonry wall [crawl space], slab-on-grade) in resisting flood effects, including velocity flow from storm surge, wave action, debris impact, erosion, and scour. The team also observed two commercial structures: a hotel in which dry floodproofing measures helped protect the building from flood damage and a large oceanfront engineered concrete structure that performed well.

Coastal areas from Cape Fear to Cape Lookout experienced significant erosion and scour. Erosion caused by Hurricane Fran was exacerbated by the previous dune erosion caused by Hurricane Bertha, which made landfall in the same area only 2 months earlier. In many locations, especially from Topsail Beach to North Topsail Beach, localized frontal dunes were eroded and the beach profile was lowered 2 to 3 feet. Erosion of up to 4 to 6 vertical feet beneath oceanfront homes was measured in many locations. In addition, localized scour measured at vertical foundation members generally reached one to 1 to 1.5 times the diameter or width of the member. Measurements of combined erosion and scour commonly totaled 5 to 7 vertical feet at oceanfront homes in the area from Topsail Beach to North Topsail Beach. This erosion and scour, added to the average long-term erosion rate of 1 to 2 feet a year, left many oceanfront homes unable to withstand the loads experienced.

The combined effects of erosion and scour resulted in the collapse of well over 100 oceanfront homes with shallow piling foundation systems in the area from Topsail Beach to North Topsail Beach. Several similar oceanfront homes were lost in the Kure Beach-Carolina Beach area. The loss of supporting sand left many short pilings either completely exposed or embedded less than 2 feet. In either case, some pilings gave way. As a result, the remaining foundation pilings were overloaded and the elevated building collapsed. In those rare instances where oceanfront homes were constructed on slabs-on-grade, the loss of supporting sand coupled with the impact of velocity flow and breaking waves on the walls of the structures caused the structures to collapse.

The team observed very little damage in some areas, even oceanfront areas where velocity flows, wave action, and severe erosion occurred. The successful performance of buildings in these areas demonstrates the value of compliance with NFIP requirements regarding the elevation of buildings in coastal flood hazard areas and current State of North Carolina requirements regarding setback and piling embedment depth for oceanfront structures. The observations of the team and the findings of a separate study of piling embedment depth conducted for FEMA on Topsail Island (see Appendix C) suggest that the more stringent embedment depth requirements incorporated into the North Carolina State Building Code in 1986 helped reduce damage. The use of flood-resistant construction materials and techniques, such as in engineered concrete buildings was also effective. In addition, breakaway walls, although generally not installed properly, usually broke away as intended under the impact of flood forces and helped prevent structural damage.

Although the BPAT noted that breakaway walls generally performed as intended, three design and construction errors were observed that are worth noting:

- Breakaway wall panels were often installed immediately adjacent to and seaward of cross-bracing. When the panels broke away, they were pushed against the cross-bracing by flood waters. The resulting force on the vertical surface generated loads far in excess of the design strength of the cross-bracing. As a result, cross-bracing was broken or torn away.

- Utilities were installed on, through, or adjacent to breakaway wall panels. As a result, the panels were often prevented from breaking away cleanly under flood loads, and when they did break away, the utilities were damaged. Much of the utility damage observed was a direct result of improper installation.

- Sheathing was installed on the exterior of breakaway wall panels, continuously over the outside face of vertical foundation members. Sheathing installed in this way inhibits the ability of the breakaway wall panels to break away cleanly.

Most slabs-on-grade below elevated buildings broke apart under the hydrodynamic and impact loads imposed by flood waters and therefore did not transfer those loads to the foundation system. Also, the resulting slab fragments were usually small enough that when they became waterborne debris, they did not damage foundation system components. However, the BPAT observed some design and construction errors worth noting:

- In some instances, slabs were attached to vertical foundation members with steel dowels placed in the piling and cast into the slab. This practice resulted in the transfer of unanticipated loads to the foundation system and may have caused the failure of some foundations systems.

- The slabs observed generally did not have a sufficient number of contraction joints to promote the slab's breaking into small pieces. In one instance, a large section of a slab was observed to have been lifted by flood forces and to have come to rest against vertical foundation members. Although evidence of a cause and effect relationship was not directly observed, slabs that reacted in this way may have led to the failure of some buildings as well.

- The use of wire mesh cast into slabs further complicated matters by holding pieces of the slabs together after the slabs had fractured.

- Concrete collars were occasionally placed around pilings during the construction of slabs. Although the collars were intended to provide stability, they increased wave loads and scour by presenting larger obstructions to flow. Also, once the underlying sand was removed by erosion, the collars increased the dead weight of the pilings to which they were attached.

Utilities that were not installed in a manner that afforded the greatest extent of flood protection possible were damaged. Although portions of most utility services must extend below the flood level, many simple techniques are available to minimize or eliminate damages. Observed damage to water, sewage, electrical, telephone, and cable TV services could have been avoided. Septic tanks were routinely left exposed by storm-induced erosion and scour, and their connections to buildings were severed. The tanks were then filled with flood water and debris.

On oceanfront homes, many porches, decks, and roof overhangs supported on vertical foundation members collapsed or became structurally unsound. Similar failures occurred in the porches, decks, and roof overhangs attached to some inland homes. These failures were observed in both new and old structures. The vast majority of the vertical foundation members were found to have been embedded only 4 to 5 feet below existing grade without any regard for erosion or scour. In a few situations, undersized vertical support members, usually measuring 4 inches by 4 inches or 6 inches by 6 inches, were shattered, probably by the impact of waterborne debris.

Many manufactured homes and permanently installed RVs were installed on dry-stack masonry block foundations with metal tiedown straps attached to ground anchors. This method of installation performed very poorly. The failure of these foundations resulted in the loss of approximately 50 percent of the manufactured homes and RVs observed in the Surf City and North Topsail Beach areas. The causes of failure observed by the BPAT were undermining of the dry-stack block by scour resulting from relatively shallow velocity flow, failure of the tiedown straps due to corrosion from salt spray, and pullout of the ground anchors. Pullout of ground anchors occurred when the pullout resistance of the soil was exceeded because of improper anchor selection and/or saturation of the restraining sandy soil when the site flooded.

The BPAT developed recommendations for reducing future hurricane damage. The recommendations address areas of concern such as building materials (including corrosion protection for metal structural components, e.g., hurricane clips, straps, and fasteners), design practices, construction techniques, and quality of construction. The recommendations presented in this report are applicable in other communities that experience similar coastal flooding.

This report presents the BPAT's observations of the successes and failures of buildings that experienced the flood effects of Hurricane Fran, comments on building failure modes, and provides recommendations intended to enhance the performance of buildings in future hurricanes.