# *Appendix A*

## Building Performance Assessment, Damage Assessment, and Hazard Mitigation Reports Prepared by the Federal Emergency Management Agency

*The Oklahoma City Bombing: Improving Building Performance Through Multi-Hazard Mitigation*, in conjunction with the American Society of Civil Engineers, August 1996

*Hurricane Opal in Florida, A Building Performance Assessment*, August 1996

*FEMA DR-TX-1041, Flooding in Southeast Texas from the Storm of October 15 - 21, 1994*, August 1995

*FEMA DR-GA-1033, Flooding in Georgia from Tropical Storm Alberto*, January 1995

*Preliminary Field Assessment — Hurricane Emily on the North Carolina Outer Banks*, January 1994

*Building Performance: Hurricane Iniki in Hawaii — Observations, Recommendations, and Technical Guidance*, January 1993

*Building Performance: Hurricane Andrew in Florida — Observations, Recommendations, and Technical Guidance*, December 1992

*Building Performance Assessment Team Report: Noreaster, Delaware and Maryland*, January 1992

*Flood Damage Assessment Report: Hurricane Bob*, August 1991

*Damage Assessment of Flooded Buildings 1985 - 1990*, June 1991

*Flood Damage Assessment Report. Tropical Storm Allison*, June 1990

*Flood Damage Assessment Report: Noreaster of April 1990*, June 1990

*Flood Damage Assessment Report: Riverine Flooding in Central Kentucky*, February 1990

*Flood Damage Assessment Report. Hurricane Hugo*, October 1989

*Flood Damage Assessment Report: Texas*, June 1989

*Flood Damage Assessment Report: Noreaster, Mid-Atlantic Coast*, March 1989

*Flood Damage Assessment Report: Riverine Flooding in Maine,* June 1988

*Flood Damage Assessment Report: Noreaster, Mid-Atlantic Coast,* April 1988

*Flood Damage Assessment Report: Riverine Flooding in Central Michigan,* May 1987

*Flood Damage Assessment Report: Riverine Flooding in Allegheny County, Pennsylvania,* January 1987

*Flood Damage Assessment Report: Riverine Flooding in Clive, Iowa,* September 1986

*Flood Damage Assessment Report: Hurricane Gloria,* February 1986

*Improving Resistance of Buildings to Wind Damage: Hurricane Elena,* September 1985

*Hazard Mitigation Team: Hurricane Diana,* 1984

*Proposed Changes to Building Codes in Response to Hurricane Alicia,* August 1983

*Hazard Mitigation Report: Noreaster, Outer Banks, North Carolina,* October 1982

*Hazard Mitigation Report: Hurricane Frederic,* September 1979

# *Appendix B*

## Members of the Building Performance Assessment Team for Hurricane Fran

CLIFFORD OLIVER
**Senior Engineer / Project Officer and Team Leader**
**Mitigation Directorate**
Federal Emergency Management Agency
Washington, DC

DONALD BEATON
**Chief, Regulations & Underwriting Branch**
**Policy Analysis & Emergency Management Coordination Division**
**Federal Insurance Administration**
Federal Emergency Management Agency
Washington, DC

PAUL TERTELL
**Senior Engineer**
**Mitigation Directorate**
Federal Emergency Management Agency
Washington, DC

MARK VIEIRA, P.E.
**Civil Engineer**
**Hazard Identification and Risk Assessment Branch**
Federal Emergency Management Agency, Region IV
Atlanta, Georgia

CHARLES BORNMAN, P.E.
**Senior Structural Engineer**
**Greenhorne & O'Mara, Inc.**
Greenbelt, Maryland

CHRISTOPHER JONES, P.E.
**Senior Coastal Engineer**
**Earth Tech**
Charlottesville, Virginia

SPENCER ROGERS
**Coastal Construction and Shoreline Erosion Specialist**
**North Carolina Sea Grant**
Kure Beach, North Carolina

GREG CHIU
**Insurance Institute for Property Loss Reduction**
Boston, Massachusetts

DAN DEEGAN
**Senior Coastal Engineer**
**Woodward-Clyde Federal Services**
Atlanta, Georgia

# *Appendix C*

## *Executive Summary from Piling Embedment Study Performed by Woodward-Clyde Federal Services on Topsail Island, North Carolina*

# Executive Summary

## Purpose

As a result of Hurricane Bertha (July 12, 1996) and Hurricane Fran (September 5, 1996), a large number of structures were damaged on Topsail Island, North Carolina. Topsail Island includes the communities of Topsail Beach, Surf City, and North Topsail Beach. An initial review of the structures indicated that shallow embedment depth of their foundation pilings could have been the primary cause of structural failure due to the storms. FEMA contracted with Woodward-Clyde Federal Services (Woodward-Clyde) to perform testing and evaluation of the piling lengths and embedment depths. The purpose of the testing was to determine whether the pilings meet the embedment depth requirements of the current North Carolina State Building Code. The current version of the Code was implemented on January 1, 1986.

## Project Execution

To identify oceanfront structures built after the implementation of the current Code (January 1, 1986), Woodward-Clyde obtained aerial photographs for Topsail Island from the North Carolina Department of Transportation. The photographs represent the periods immediately after January 1, 1986, prior to Hurricane Bertha, after Hurricane Bertha, and after Hurricane Fran. From these photographs, a total of 205 post-1985 oceanfront structures were identified. Duplex or multiplex units (two- to four-family structures) were considered single structures for purposes of this study.

Of the 205 structures, a total of 16 (7.8 percent) were identified as having leaning pilings (11 structures) or were identified as total losses (5 structures). Structures identified as total losses were either completely washed away by the storm or were so severely damaged that the structures were totally destroyed. Many of the 205 structures identified received other damage such as roof, wall, deck, and concrete damage caused by both flooding and high winds. However, the focus of this study was on damage to piling foundations that supported elevated residential one- to four-family structures.

Field inspections of the 205 oceanfront structures were conducted to identify piling damage and general building parameters. A total of 20 damaged and undamaged structures were initially identified for piling testing. However, after homeowner approvals were requested and received, it was determined that only 11 structures would be tested. These 11 structures include 7 structures with leaning pilings and 4 structures with no leaning pilings.

## Testing Procedures

Using a nondestructive test methodology to determine total piling length, Woodward-Clyde tested 5 pilings at each structure, a sampling of approximately 25 percent. For the test, accelerometers were mounted directly to each piling. The piling then was struck on its side with a hammer. The hammer blow created dispersive stress waves that traveled the length of the piling. Data recorded by the accelerometers were then digitally processed and analyzed. Analysis of the data yielded a computation for the total length of the piling. Ground level and top-of-piling elevations were surveyed and used to determine piling embedment depth.

Typical accuracy using this type of testing is ± 10 percent. In three piling test cases, the return signals recorded were not accurate enough to allow for a piling length determination. Therefore, for 3 of the eleven 11 structures, only 4 instead of 5 pilings were tested, yielding a total of 52 tested pilings.

## Piling Test Results

The current North Carolina State Building Code requires that piling tips be at -5 feet m.s.l. or 16 feet below grade, whichever is shallower. The findings of the tests are based on the evaluation of the piling embedment depths in relation to the -5 feet m.s.l. criterion, since this, rather than the 16 feet below grade criterion, is the controlling factor for piling embedment in the test area. This is because pre-storm grade elevations for most oceanfront houses on Topsail Beach were less than 11 feet m.s.l.

Of the 11 structures tested, 4 were one-story above the pilings and 7 were two or more stories above the pilings. The following table summarizes the findings.

| No. | Stories Above Top of Piling | Pilings Leaning | Cross Bracing | Total Pilings per Structure | Piling Not Meeting Code | Average Differential to Meet Code[1] (Feet) |
|---|---|---|---|---|---|---|
| 1 | 1 | yes | yes | 21 | 4 of 5 | 0.9 |
| 2 | 1 | yes | yes | 21 | 4 of 5 | 2.0 |
| 3 | 2 | yes | no | 20 | 4 of 4 | 4.7 |
| 4 | 2 | yes | no | 20 | 4 of 4 | 5.6 |
| 5 | 2 | yes | no | 15 | 5 of 5 | 3.3 |
| 6 | 2 | yes | yes | 15 | 4 of 4 | 4.2 |
| 7 | 2 | yes | yes | 12 | 5 of 5 | 6.1 |
| 8 | 3 | no | no | 30 | 2 of 5 | 3.4 |
| 9 | 2 | no | no | 15 | 1 of 5 | 0.7 |
| 10 | 1 | no | yes | 50 | 5 of 5 | 2.6 |
| 11 | 1 | no | no | 25 | 5 of 5 | 4.7 |

[1]Average differential is the average distance from the tip of piling to -5 feet m.s.l.

*Note:* Information on the effects of erosion and scour is provided in the sections of the report preceding this appendix.

### One-Story Structures (Total of Four)

- Two had leaning pilings.
- Three had some bracing, although none is required by the current Code. The structure that had no cross-bracing was not damaged.
- Ninety percent of the pilings tested for these four one-story structures (both with and without leaning pilings) did not meet the current Code requirement for piling embedment depth.

### Two- and Three-Story Structures (Total of Seven)

- Five had leaning pilings.
- Two of the five structures with leaning pilings had cross-bracing at the time of the storm, but none of the structures had cross-bracing in accordance with the current Code. The two structures that did not have leaning pilings had no cross-bracing. It should be noted that the current Code allows for alternative bracing systems if they are designed and sealed by a Licensed Professional Engineer or Architect.
- Including the pilings within the 10-percent accuracy range, 78 percent of the pilings tested for the seven two-story structures (both with and without leaning pilings) did not meet the current Code requirement for piling embedment depth.

The following table provides a breakdown of the number of pilings by the amount of additional embedment depth necessary for the piling to meet the Code requirement. Of the 52 pilings tested (including those pilings within the 10-percent accuracy range), over 80 percent did not meet the Code requirement.

| Additional Depth (feet) Required to Meet Code | Number of Pilings |
|---|---|
| 0 | 9 |
| 0-1 | 3 |
| 1-2 | 6 |
| 2-3 | 8 |
| 3-4 | 4 |
| > 4 | 22 |

It was observed that all on the identified post-1985 structures that had leaning pilings, the pilings leaned inland in a westerly direction (the direction of the storm surge).

## Conclusions

From the field observations and test results, Woodward-Clyde concludes the following:

- Approximately 92 percent of oceanfront structures built after the implementation of January 1986 Code changes did not sustain significant piling damage.
- All tested post-1985 structures that had leaning pilings did not meet the requirements of the current Code. Of all the pilings tested, both leaning and not leaning, over 80 percent did not meet the Code requirement.
- It appears that the Code requirement for piling embedment depth may be more effective in preventing piling damage than the requirement for cross-bracing. This includes those pilings within the 10-percent accuracy range.

From the test results and the field observations, it appears that a structure should sustain minimal piling damage if it is constructed according to the current Code requirements. However, several factors exist that prevent a complete evaluation of the piling requirements in the Code:

- The study involved testing only 11 of 205 post-1985 oceanfront structures.
- The findings for the piles not meeting Code are limited to structures whose piling embedment depth is controlled by the -5 foot m.s.l. criterion.
- The majority of the structures tested did not meet the embedment depth requirement of the Code, including those that did not have leaning pilings.

## Recommendations

For the reasons cited above, the relative effectiveness of the two embedment criteria, "tip penetration of at least 5.0 below mean sea level or 16 feet below average original grade which ever is least," cannot be made. Therefore, Woodward-Clyde can not recommend a change to the piling embedment depth requirement of the North Carolina State Building Code at this time. Woodward-Clyde does, however, recommend that better construction and inspection practices be implemented to ensure proper installation of the pilings so that they at least meet the current Code requirements.