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List of Acronyms

ADA	Americans with Disabilities Act
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BOCA	Building Officials and Code Administrators, International
BPAT	Building Performance Assessment Team
CABO	Council of American Building Officials
COHBA	Central Oklahoma Home Builders Association
CMU	Concrete Masonry Unit
EIFS	Exterior Insulating Finishing System
EPDM	Ethylene Propylene Diene Monomer
EPS	Expanded Polystrene System
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
HUD	Department of Urban Development
HVAC	Heating, Ventilation, and Air Conditioning
ICBO	International Conference of Building Officials
MCHSS	Manufactured Home Construction and Safety Standards
NBC	National Building Code
NCSBCS	National Conference of States on Building Codes and Standards
NFIP	National Flood Insurance Program
NFPA	National Fire Protection Association
NOAA	National Oceanic Atmospheric Administration
NSSL	National Severe Storms Laboratory
OSB	Oriented Strand Board
SBCCI	Southern Building Code Congress International
UBC	Uniform Building Code
URM	Un-reinforced Masonry

Executive Summary

On the evening of May 3, 1999, an outbreak of tornadoes tore through parts of Oklahoma and Kansas, in areas that are considered part of "Tornado Alley", leveling entire neighborhoods and killing 49 people. The storms that spawned the tornadoes moved slowly, contributing to the development and redevelopment of individual tornadoes over an extended period of time.

On May 10, the Federal Emergency Management Agency's (FEMA's) Mitgation Directorate deployed a Building Performance Assessment Team (BPAT) to Oklahoma and Kansas to assess damage caused by the tornadoes. The team was composed of national experts including FEMA Headquarters and Regional Office engineers and staff; a meteorologist; architects; planners; wind engineers; structural engineers; and forensic engineers. The mission of the BPAT was to assess the performance of buildings affected by the tornadoes, investigate losses, and describe the lessons learned. This report presents the BPAT's observations, conclusions, and recommendations, which are intended to help communities, businesses, and individuals reduce future injuries and the loss of life and property resulting from tornadoes and other high-wind events. It is not the intent of this report to reclassify the strength of the May 3 tornadoes or the ratings of the damage observed, or to debate the magnitude of the wind speeds associated with those tornadoes. Rather, the intent is to clearly define some basic concepts associated with tornadoes and tornado damage that will be referred to throughout this report.

The observations, conclusions, and recommendations in this report are grouped to address issues concerning (1) residential property protection, (2) non-residential property protection, and (3) personal protection and sheltering. The BPAT's findings are correlated with the Fujita damage scale, which ranks tornadoes according to the damage they cause, and general tornado intensity (Table 1-1).

Tornadoes are extremely complex wind events that cause damage ranging from minimal or minor to absolute devastation. For the purposes of this report, tornado intensity is simplified and referred to by three categories: moderate, severe, and violent. In a violent tornado, the most severe damage occurs. Typically, all buildings are destroyed and trees are uprooted, debarked, and splintered. In a severe tornado, buildings may also be destroyed, but others may suffer less severe damage, such as the loss of exterior walls, the roof structure, or both. Even when buildings in this area lose their exterior walls and roofs, interior rooms may survive. In moderate tornadoes, damage to buildings primarily affects roofs and windows. Roof damage ranges from loss of the entire roof structure to the loss of all or part of the roof sheathing or roof coverings. Typically, many of the windows in buildings will be broken by wind-borne debris.

During the field investigation, the BPAT investigated buildings to identify successes and failures that occurred during the tornadoes. Building failures were identified as being directly struck by the vortex or core of the tornado, affected by winds outside the vortex of the tornado, or out on the extreme edge or periphery of the tornado path. Considerable damage to all types of structures throughout Oklahoma and Kansas was observed. Failures occurred when extreme winds produced forces on the buildings that they were not designed to withstand. Failures also occurred when wind-borne debris penetrated the building envelope, allowing wind inside the building that again produced forces on the buildings that they were not designed to withstand. Additional failures observed were attributed to improper construction techniques and poor selection of construction materials. It was a goal of the BPAT to determine if any of the damage observed to both residential and non-residential buildings was preventable.

Most residential construction in Oklahoma and Kansas is currently required to be designed per the 1995 Council of American Building Officials (CABO) One and Two Family Dwelling Code. Although some amendments have been adopted by local municipalities, this code does not incorporate wind speed design parameters used by the newer 1997 Uniform Building Code (UBC) and 1996 National Building Code (NBC). Furthermore, engineering standards such as the American Society of Civil Engineers (ASCE) 7-95 and 7-98 design standard provide better structural and non-structural design guidance for wind loads than these newer codes. Although designing for tornadoes is not specifically addressed in any of these newer codes or standards, constructing residential homes to these codes and standards would improve the strength of the built environment. The BPAT concluded that building to these codes and standards would have led to reduced or minimized damage in areas that were affected by the inflow winds of all tornadoes and reduced the damage observed where moderate tornadoes impacted residential construction.

The BPAT concluded that the best means to reduce loss of life and minimize personal injury during any tornadic event is to take refuge in specifically designed tornado shelters. Although improved construction may reduce damage to buildings and provide for safer buildings, an engineered shelter is the best means of providing individuals near absolute protection.

The BPAT developed recommendations for reducing future tornado damage to property and providing personal protection. Broad recommendations include the following:

- Proper construction techniques and materials must be incorporated into the construction of residential buildings to reduce their vulnerability to damage during extreme wind events. Existing construction techniques proven to minimize damage in wind-prone areas are not always being utilized in areas that are subject to tornadoes.

- Construction should be regulated and inspected to ensure that residential buildings meet the most current building code requirements, including those regarding structural seismic issues.

- For engineered buildings, the engineer should review connections to ensure adequate capacity for moderate to severe uplift and lateral loads that may be in excess of loads based on the building codes currently in effect.

  - Cities and appropriate local governments should adopt the 1997 UBC or 1996 NBC as the model building codes.

  - Cities and appropriate local governments not already using the 1995 CABO One- and Two-Family Dwelling Code should do so immediately.

  - The International Building Code (IBC) and the International Residential Code (IRC) should be adopted upon their release in 2000.

  - Shelters are the best means of providing near absolute protection for individuals who are attempting to take refuge during a tornado.

  - All shelters should be designed and constructed in accordance with either FEMA 320 or The National Performance Criteria for Tornado Shelters