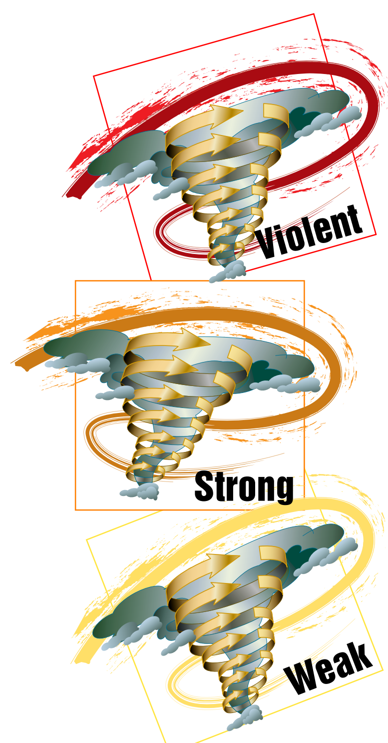
Executive Summary

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, 1999, the Federal Emergency Management Agency's (FEMA's) Mitigation Directorate deployed a Building Performance Assessment Team (BPAT) to Oklahoma and Kansas to assess damage caused by the tornadoes. The BPAT 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. Members of the BPAT are presented in Appendix A. 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. The observations, conclusions, and recommendations in this report are grouped to address issues concerning residential property protection, non-residential property protection, and 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 (Tables 1-1 and 2-1). 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.

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: violent, strong, and weak. The greatest damage occurs in a violent tornado. Typically, all buildings are destroyed and trees are uprooted, debarked, and splintered. In a strong tornado, some buildings may be destroyed, but most suffer less damage, such as the loss of exterior walls, the roof structure, or both. Even when buildings affected by a strong tornado lose their exterior



walls and roofs, interior rooms may survive. In weak 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 windborne debris. Weak tornadoes can often cause significant damage to manufactured housing.

The BPAT investigated buildings to identify successes and failures that occurred during the tornadoes. Buildings were classified as being directly struck by the vortex (i.e., core) of a tornado, affected by winds outside (but near) the vortex of a tornado, or out on the extreme edge (i.e., periphery) of a tornado path. Few successes were observed by the BPAT. Successes consisted of the utilization of engineered shelters within a home or commercial building or voluntary utilization of known construction techniques that strengthened the structural system of a building. Considerable damage occurred to all types of structures throughout the areas observed in Oklahoma and Kansas. Failures occurred when extreme winds produced forces on the buildings that they were not designed to withstand. Failures also occurred when windborne 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 the construction techniques used, the selection of construction materials, the fasteners used, and the design of, or lack of, connections. It was a goal of the BPAT to determine if the damage observed to both residential and non-residential buildings was preventable.

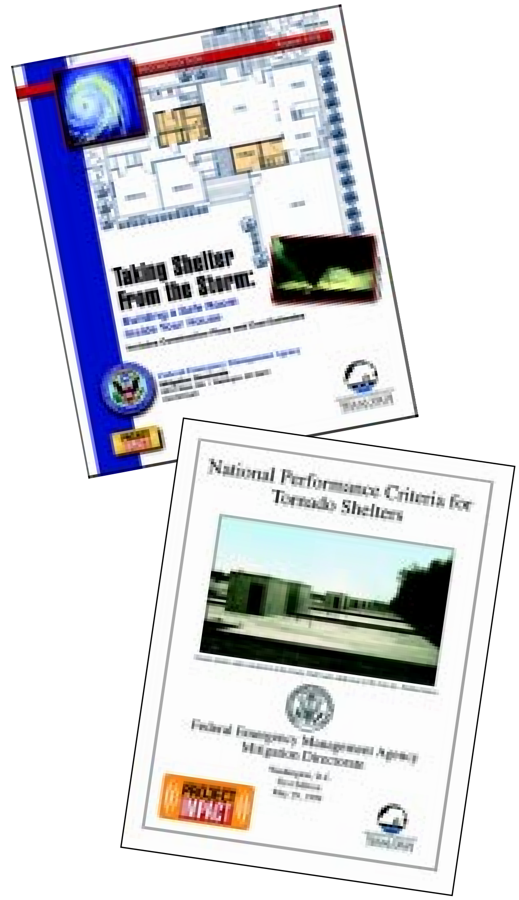
Most residential construction in Oklahoma and Kansas is currently required to be designed per the 1995 Council of American Building Officials (CABO) One- and Two-Family Dwelling Code. Although some amendments have been adopted by local municipalities, this code does not incorporate wind speed design 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) 7-98 design standard provide better guidance for determining design wind loads than these newer codes. Although designing for tornadoes is not specifically addressed in any of these newer codes or standards, constructing homes to these codes and standards would improve the strength of the built environment. The BPAT concluded that buildings constructed to these newer codes and standards would have experienced less damage in areas that were affected by the inflow winds of all tornadoes and reduced the damage where weak tornado vortices directly affected buildings.

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:

- Building Code Recommendations. Neither building codes nor engineering standards explicitly address design for tornadoes. However, designing to the wind loads in ASCE 7-98 can reduce damages from both weak tornadoes and in outlying areas damaged by strong and violent tornadoes. The model building codes consider these latest engineering standards, such as ASCE 7, when model building codes are revised, usually on a 3-year cycle. In order that design and construction practices reflect our improved understanding of high winds, jurisdictions having authority should consider the following alternatives in amending their current building code or in adopting new building codes:
    - Adopt the International Building Code (IBC) and the International Residential Code (IRC) upon their expected release in February 2000.
    - As an interim step to adopting the IBC and IRC, adopt the 1997 UBC, the 1997 Standard Building Code, (SBC), or the 1996 NBC as the building code until the IBC or IRC can be adopted. To further improve the wind resistance of buildings, adopt an amendment that requires the use of ASCE 7-98 to calculate wind loads.
    - As an interim step to adopting the IRC, State and local governments should adopt the 1995 edition of the CABO One- and Two-Family Dwelling Code for jurisdictions using previous editions of this code or having no residential code in place. This will provide some guidance for designing for wind loads.
- Communities should consider the need for adopting ordinances and regulations that promote disaster-resistant communities by incorporating tornado shelters into new construction and communities.
- The Federal Government (HUD) should review its standards and enforcement program in an effort to improve the performance of manufactured homes in moderately high wind events, such as in inflow areas of all tornadoes and the tracks of weak tornadoes. Specifically, the capacity of anchoring and strapping equipment and systems needs to be evaluated to eliminate the discontinuity between the Federal standard and the State and local installation and enforcement process.

- Consideration should be given to permanently connecting the manufactured home unit to its foundation. The BPAT observed newer double-wide manufactured houses on permanent foundations and did not see significant differences in damage between these manufactured homes on permanent foundations and conventionally built houses. Double-wide manufactured housing on permanent foundations performed better than both double-wide and single units on non-permanent foundations.
- Construction techniques and materials to provide a continuous load path for wind loads should be incorporated into the construction of buildings, including houses. This will reduce their vulnerability to damages during extreme wind events. There are existing proven construction practices to minimize damages in other wind-prone areas (hurricane areas) of the country.
- Construction should be regulated and better inspected to ensure that buildings (including residences) meet current building code requirements. A lack of compliance with building codes was observed in many of the damaged buildings.
- Garage doors are an extremely important residential building component. Failure of these doors led to catastrophic progressive failures of primary structural systems that could have been avoided. New garage doors should be installed with improved resistance to high wind loads.
- Where new doors are not installed, retrofits should be made to improve the wind resistance of existing garage doors, particularly double-wide garage doors. These retrofits and new doors will better resist wind forces and should reduce the roof and wall damage that was observed in homes that experienced garage door failures.
- Architectural features should be appropriately designed, manufactured, and installed to resist wind loads and to minimize the creation of windborne debris. To accomplish this, the local community may want to further regulate these features to ensure a reduction in potential debris materials.
- The brick masonry industry should consider re-evaluating attachment criteria of masonry, specifically regarding product usage. Greater emphasis should be given to code compliance for the bond between the mortar and brick tie, the mortar and the brick, and the spacing of brick ties.



- In areas subjected to high winds from either tornadoes or hurricanes, masonry chimneys should have continuous vertical reinforcing steel placed in the corners to provide greater resistance to wind loads. This reinforcing steel should be placed to the requirements set forth in the 1995 CABO One-and Two- Family Dwelling Code (Requirements for Masonry Fireplaces and Chimneys for seismic zones 3 and 4) or the masonry fireplace provisions of the IRC; available in February 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: Taking Shelter From the Storm* or *the National Performance Criteria For Tornado Shelters* (Appendixes C and D). All shelters should provide access to persons with disabilities as necessary and in conformance with the Americans with Disabilities Act (ADA). Local officials should monitor the installation of shelters to ensure that the floors of all shelters are located at or above expected flood levels.
- Manufactured homes typically offer little protection from severe wind storms and tornadoes. In the event of such storms, occupants of manufactured homes should exit their home and seek shelter in storm cellars, basements, or above-ground shelters. If shelters are provided in manufactured home parks, which is recommended, dispersed shelters, which can be accessed in a short time period, are recommended.
- Prospective occupants of community shelters should be acutely alert to storm warnings in order to allow sufficient time for the travel distance to the community shelter. Custodians of the shelter should be similarly alert so that the shelter is unlocked at appropriate times. Community shelters should be ADA compliant and the admission rules permanently posted (i.e. “No Pets Allowed,” etc.).
- Existing essential facilities that offer inadequate protection should have shelters retrofitted or a shelter added. New essential facilities should be designed with shelters. Interested states should form a committee to evaluate the need for tornado plans and shelters in essential facilities and other establishments serving the public (e.g., schools, hospitals, and critical facilities). All facilities for public accommodation should have a National Oceanic and Atmospheric Administration (NOAA) weather radio in continuous operation.

- The installation of laminated glass in essential facilities should be considered because of the substantial protection that it offers from debris missiles. A recommended standard for determining minimum strength of openings with laminated glass is to conduct testing, in accordance with ASTM E 1886, in consideration of the load criteria given in ASTM E 1996.
- Fire departments and emergency services agencies should make a list of addresses with shelters both above ground and below ground. This list will assist post disaster response teams and agencies in checking after a tornado to see if people are trapped inside their shelters.