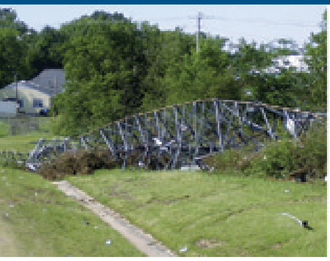
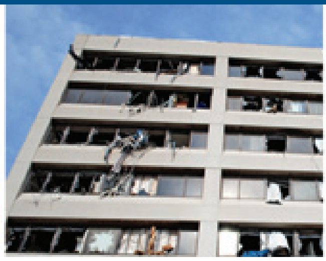

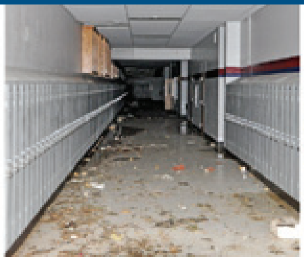
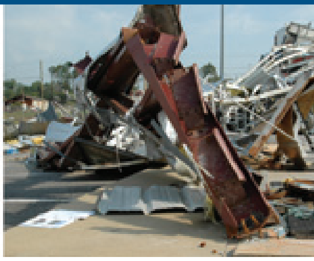

TORNADO OUTBREAK *of* 2011

IN ALABAMA, GEORGIA, MISSISSIPPI, TENNESSEE, AND MISSOURI

1 Introduction

In the spring of 2011, a historic number of powerful and destructive tornadoes struck portions of the United States, causing widespread damage and loss of life. In response to these events, the Federal Insurance and Mitigation Administration (FIMA) of the U.S. Department of Homeland Security's (DHS) Federal Emergency Management Agency (FEMA) deployed building science experts to assess the damage.

On May 6, 2011 FEMA deployed a Mitigation Assessment Team (MAT) to the States of Alabama, Georgia, Mississippi, and Tennessee to assess the damage caused by an outbreak of tornadoes occurring April 25 through April 28, 2011. A second MAT was deployed on June 1, 2011 to Missouri following the tornado on May 22 in Joplin. This report presents the observations, conclusions, and recommendations in response to those field assessments. The objective of this report is to provide information to communities, businesses, design professionals, and individuals so that they can rebuild safer, more robust structures and minimize loss of life, injuries, and property damage in future tornadoes and high-wind events.

1.1 FEMA Mitigation Assessment Teams

Along with responding to disasters and providing assistance to people and communities affected by disasters, FEMA conducts building performance studies after disasters in order to better understand how natural and manmade events affect the built environment. Following a Presidentially declared disaster, FEMA determines the potential need to deploy one or more MATs to observe and assess damage to buildings and structures caused by wind, rain, and/or flooding associated with the storm. FEMA bases this need on estimates from preliminary information of the potential type and severity of damage in the affected area(s) and the magnitude of the expected hazards.

The intent of the building performance studies is to reduce the number of lives lost to future events and minimize the economic impact on the communities where these events occur. The MAT studies the adequacy of current building codes, other construction requirements, and building practices and materials in light of the damage observed after a disaster. MATs are deployed only when FEMA believes the findings and recommendations derived from field observations will provide design and construction guidance that will not only improve the disaster resistance of the built environment in the impacted State or region, but will also be of national significance to all disaster-prone regions. Lessons learned from the MAT's observations are provided in a comprehensive report available to communities to aid their rebuilding effort and enhance the disaster-resistance of building improvements and new construction.

1.1.1 Purpose of the 2011 Tornado Mitigation Assessment Team

The outbreak of tornadoes on April 25 through April 28, 2011 and on May 22, 2011 in the Southeastern and Midwestern regions of the country has been cited as the deadliest and most destructive group of tornadoes of its kind according to National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) data[1] in over 50 years. In accordance with its mission of *"supporting our citizens and first responders to ensure that as a nation we work together to build, sustain, and improve our capability to prepare for, protect against, respond to, recover from, and mitigate all hazards...,"* [2] FEMA responded to the April tornado outbreak in the Southeastern states of Alabama, Mississippi, Tennessee, and Georgia, and the Joplin, MO, tornado on May 22, 2011 by deploying a MAT composed of national and regional experts to each of the affected areas. Figures 1-1 and 1-2

> The National Weather Service (NWS) is one of the six scientific agencies that make up the National Oceanic and Atmospheric Administration (NOAA). It is tasked with providing "weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy."
>
> The Storm Prediction Center (SPC) is part of the National Centers for Environmental Prediction (NCEP), which operates under NWS. The SPC is tasked with forecasting the risk of severe thunderstorms and tornadoes in the contiguous United States.

1 NOAA NWS, 2011 Tornado Information, www.noaanews.noaa.gov/2011_tornado_information.html

2 FEMA Web site, www.fema.gov/about/

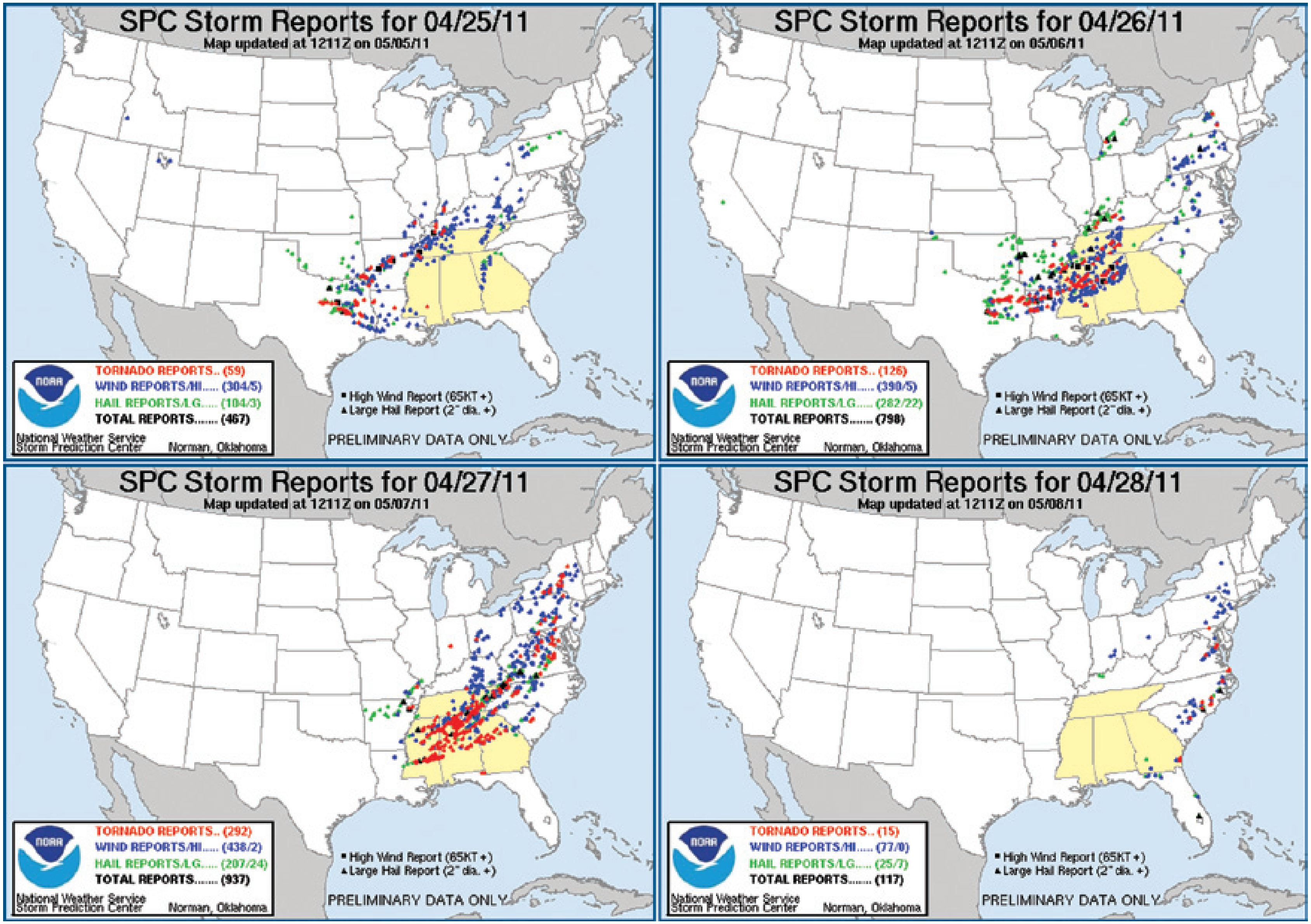

Figure 1-1:
NOAA SPC Storm Reports for April 25-28, 2011 tornado outbreak
SOURCE: HTTP://WWW.SPC.NOAA.GOV

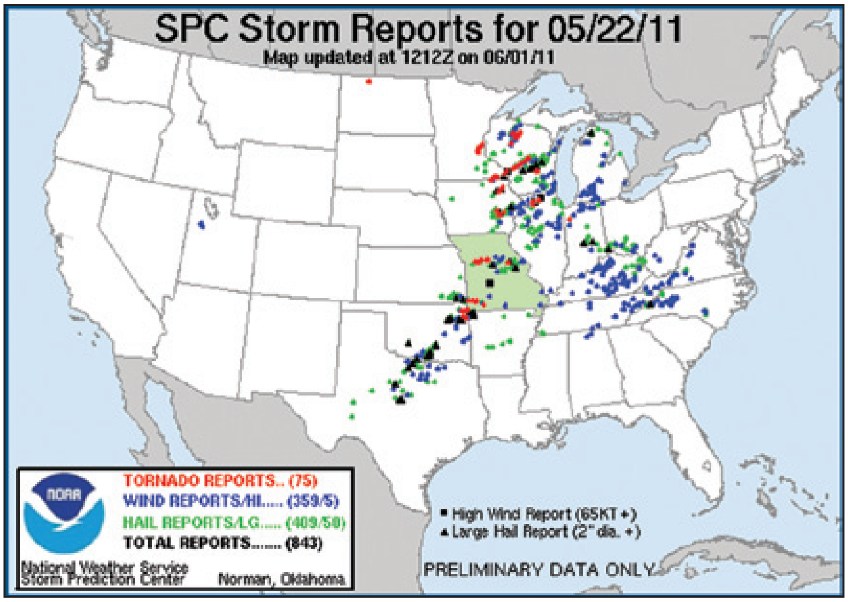

Figure 1-2:
NOAA SPC Storm Report for the May 22, 2011 tornado outbreak
SOURCE: HTTP://WWW.SPC.NOAA.GOV

show NOAA's Storm Prediction Center (SPC) storm reports for each day of the two outbreaks. The reports shown on these maps come from NWS Weather Forecast Offices.

The mission of the MAT was to assess the performance of structures affected by the tornadoes, review safe room and shelter performance in the affected area (in particular the performance of safe rooms and storm shelters that received FEMA mitigation funding for construction), and describe the lessons learned to help future efforts more successfully mitigate damage from tornado events.

1.1.2 Team Composition

The MAT included FEMA Headquarters and Regional Office engineers and experts, technical consultants, and construction industry experts. Team members included structural engineers, architects, planners, wind engineers, civil engineers, meteorologists, electrical engineers and communications specialists. The MAT members are listed on the front pages of this document.

The MAT received invaluable support from home and business owners and guides in Alabama, Georgia, Missouri, Mississippi, and Tennessee who assisted the MAT during its deployment. These individuals accompanied the MAT through many of the affected areas, providing valuable insights regarding local communities and their experiences before, during, and after the tornadoes.

1.1.3 Methodology

FEMA deployed a MAT to Alabama, Mississippi, Georgia, and Tennessee on May 6, 2011 and to Joplin, MO, on June 1, 2011. The FEMA Region IV Regional Response Coordination Center, joint field offices (JFOs), and State and local government agencies informed the MAT of the tornado paths and preliminary damage data. This information guided the site selection for the field assessments. The members of the MAT visited several sites as a complete team to calibrate findings, after which they split into three teams to traverse the widespread affected areas across Alabama, Mississippi, Georgia, and Tennessee. This MAT report expands upon the content in previous MAT reports, and focuses on three additional areas: 1) how engineering and construction practices can be changed to reduce the loss of life in tornado events, 2) how damage affected the operation of critical facilities, particularly those involved in first response, and 3) how storm shelters and safe rooms performed in the events.

Field Assessments: Field assessments for the April 25–28 tornado events began on May 6 and were conducted through May 13. In Alabama, assessments were made in the communities of Athens, Birmingham, Cordova, Cullman, Hackleburg, Harvest, Huntsville, Phil Campbell, Pleasant Grove, and Tuscaloosa. In Mississippi, assessments were made in the communities of Philadelphia, Raleigh and Smithville. In Tennessee, assessments were made in the communities of Chattanooga, Cleveland, and Dunlap. In Georgia, assessments were made in the community of Ringgold. Field assessments for the May 22 tornado event in Missouri began on June 1 and were conducted through June 4. Assessments were made in the cities of Joplin and Seneca. Figure 1-3 shows all of the communities visited by the MAT.

Figure 1-3:
Communities in Alabama, Georgia, Mississippi, Tennessee, and Missouri visited by the MAT in 2011

The MAT spent over 12 days in the field conducting site assessments and inspecting damage. All findings were documented through geotagged photographs and field notes, which were then condensed and organized to make the data easier to reference in the final analysis and report. The MAT took thousands of photographs, and compiled extensive field notes of observations made at numerous sites.

Wind Speed Ratings: One of the MAT's goals was to determine if building damage observed was preventable, particularly for buildings subjected to the lower wind speeds located at the periphery of the tornado. To accomplish this goal, the MAT related observed building damage to the wind conditions experienced at that site using the Enhanced Fujita (EF) scale. The EF scale is used to classify the intensity of a tornado based on damage observed along its entire track; the scale ranges from EF0 (weakest) to EF5 (most violent). The EF scale is used both to classify the entire tornado track as well as to assess wind speeds experienced by an individual structure based on observed damage to the structure (refer to Sections 2.2, 2.3, and Appendix E for additional information). The MAT assigned structure-specific ratings in order to exercise engineering judgment about whether damage could have been avoided.

EF scale ratings of tornado tracks are developed and published by the NWS. The NWS developed EF contours for the Joplin, MO, tornado and for some of the April 25–28, 2011 tornado outbreak tracks. For the other tracks, the NWS provided a rating for the center of tornado circulation along the track. The MAT report includes figures showing NWS EF contour ratings (when available) superimposed on a NOAA aerial photograph or a pre-tornado photograph. For locations where the NWS did not develop EF contours, the building discussion includes the NWS rating of the track at the center of its circulation in the vicinity of the building. The building discussion also includes the MAT-determined EF rating for the individual sites visited. Besides the MAT, other agencies and groups performed their own determinations on buildings throughout the affected area.

Aerial Photographs: Soon after the April 25–28, 2011 tornado outbreak, NOAA shot aerial photographs of portions of many of the tornado tracks. NOAA also shot aerial photographs of the area damaged by the May 22, 2011 Joplin, MO, tornado. Relevant NOAA aerial photographs are included in this report to show the location of buildings visited by the MAT relative to the tornado track and to show other damage in its vicinity. For buildings in locations where NOAA did not obtain aerial photographs, pre-tornado aerial photographs of the building are included for reference.

1.1.4 Types of Buildings and Structures Assessed by the MAT

The MAT assessed the overall structural performance and the performance of building envelope elements during its field investigations. If possible, building or facility owners were interviewed to gain insight into how the building occupants reacted during the tornado. The MAT spent considerable time assessing damaged buildings and only minimal time assessing buildings that were totally destroyed. Studying partially destroyed buildings provided the MAT the opportunity to determine why some buildings survived the tornadoes and why some failed. In many cases, the inspection of the damaged buildings revealed weaknesses in building design or construction. As part of their building investigations, the MAT assessed the effects of wind-borne debris (missile) impact on structural performance, as missile impact plays a key role in the success or failure of a building under tornadic wind loads.

The MAT did not look specifically for examples of construction techniques that, though not required by current building codes for this area of the country, are proven to minimize damage in other wind-prone areas (e.g., hurricane areas). These types of practices are often referred to as code-enhanced or ***best practices***. The MAT did, however, take note of such practices if observed in the field.

As described below, the structures selected by the MAT for damage assessment included the following five categories: residential building, commercial and industrial building, critical facilities, infrastructure, and personal protection and sheltering structures.

Residential Buildings: Although residential construction was not its focus, the MAT visited many residential homes with a variety of construction types. The majority of one- and two-family residential buildings visited were older construction (pre-1970), but some newer homes less than 10 years old were also visited. Many of the single- and multi-family residences visited were unreinforced masonry or wood frame stick-built ***non-engineered construction*** on slab-on-grade foundations. The MAT attempted to observe residential buildings of all ages, particularly in areas where buildings would have been built under the International Residential Code (IRC), first published in 2000.

Commercial and Industrial Buildings: The MAT assessed commercial and industrial buildings of ***engineered construction***, including shopping plazas and large footprint stores, throughout the area damaged by tornadoes. The types of commercial and industrial buildings the MAT visited are normally designed by a design professional and included the following:

- Tilt-up pre-cast concrete walls with steel joists
- Load-bearing masonry with steel joist
- Light steel frame
- Reinforced concrete frame with concrete masonry unit (CMU) infill walls

Critical Facilities: The MAT assessed critical facilities including schools, hospitals and healthcare facilities, and facilities used by first responders (police and fire departments and Emergency Operations Centers [EOCs] / Emergency Management Agencies [EMAs]). The MAT report presents the results categorized by use: schools are described in Chapter 6, while other critical facilities are described in Chapter 7. In addition to building performance, the MAT recorded whether the facility was equipped with a safe room or place of refuge and the functional loss resulting from the tornado damage.

Infrastructure: The MAT assessed various infrastructure systems in Alabama, Mississippi, and Missouri. The infrastructure systems are categorized in this report by their use: water treatment and distribution facilities, waste water treatment facilities, and towers (both communications and antennae). Both free-standing towers and guyed towers were assessed.

Personal Protection and Sheltering Structures: The MAT examined personal protection and sheltering in areas directly in the path of the strong and violent (EF ranking of 2 or greater) tornado vortices and in areas on the periphery of tornadoes. The MAT visited three types of spaces: tornado refuge areas (residential and non-residential), hardened areas, and safe rooms and storm shelters.

Both small individual and larger community safe rooms were observed. Refer to Section 1.2 for definitions of personal protection and sheltering structures.

The residential and non-residential safe rooms and storm shelters observed by the MAT were installed or constructed as above-ground in-residence shelters, above-ground exterior shelters, below-ground in-residence shelters, and below-ground exterior shelters. The MAT visited safe rooms that had been constructed using FEMA Hazard Mitigation Grant Program (HMGP) funds, including underground in-residence safe rooms, above-ground residential safe rooms (such as the safe room shown in Figure 1-4), and community safe rooms. In addition to safe rooms constructed using HMGP funds, the MAT observed more than 16 other tornado refuge areas, hardened structures, storm shelters, and safe rooms of various levels of construction, including underground in-residence shelters, above-ground in-residence shelters, and community shelters.

Figure 1-4: HMGP-funded residential safe room in Smithville, MS, that was occupied during the storm, but was not in the tornado path

1.1.5 Involvement of State and Local Agencies

FEMA encouraged the participation of State, county and local government officials, and locally based experts in the assessment process. Their involvement was critical and resulted in:

- Improving the MAT's understanding of local construction practices
- Encouraging the MAT to develop recommendations that were both economically and technically feasible for the communities involved
- Facilitating communication among Federal, State, and local governments and the private sector

The MAT met with local emergency management and government officials in many of the cities and towns they visited. The officials were able to give an overview of the damage in their area and identify key sites to visit. The MAT also coordinated with the FEMA JFOs that had been set up in the area shortly after the tornadoes, and these offices provided invaluable information and resources for the MAT's field activities. The MAT also met with several other groups that had been deployed immediately after the tornadoes and had gathered preliminary data on the damage, including:

1) A team assessing the Tuscaloosa damage. The team was funded by the National Science Foundation (NSF) and included representatives from the University of Florida (UF), University of Alabama (UA), Texas Tech University (TTU), Iowa State University, Oregon State University (OSU), South Dakota State University (SDSU), Simpson Strong Tie, and the Applied Technology Council (ATC).

2) A team assessing the Joplin damage. The team was funded by the American Society of Civil Engineers (ASCE) and included representatives from UF, UA, OSU, SDSU, and ATC.

Meeting with these teams provided the MAT with valuable information, allowing it to establish a more efficient and effective plan to assess the impacted area. Appendix A lists these and other individuals who assisted the MAT in its field operations and report development.

1.1.6 Past Tornado MAT Deployments

Prior to the 2011 MAT deployment, FEMA had deployed two other tornado MATs: one after the April 23–24, 2010 tornado outbreak in Mississippi and one after the May 1999 tornado outbreak in Kansas and Oklahoma. In addition, FEMA deployed a building sciences field team after each of two tornado outbreaks in 2007, one of which occurred in the Southeast and the other in Kansas. Although no MAT report was published after the 2007 tornadoes, Recovery Advisories were published shortly after each event to assist communities in rebuilding efforts.

Mississippi Tornado Outbreak, April 23–24, 2010: Beginning the afternoon of Friday, April 23, and continuing through the evening of April 24, 2010 the Arkansas, Louisiana, and Mississippi region experienced severe weather, including multiple tornadoes, from a strong storm system. The most devastating tornado from this event developed in northern Louisiana and caused damage from Tallulah, LA, through eight counties in Mississippi. In response to this tornado outbreak, FEMA deployed a Pre-Mitigation Assessment Team (PMAT) to survey the general building damage and the performance of the residential and community safe rooms located along the path of the tornado. The PMAT performed site visits and assessments to gather information on the tornado classification, building damage, building performance, and safe rooms. The PMAT's observations, lessons learned, and recommendations regarding the performance of FEMA-funded residential and community safe rooms are presented in their report, *Pre-Mitigation Assessment Team Report – Mississippi Tornado Outbreak, April 23rd – 24th: Damage and Safe Room Performance Observations, Recommendations, and Conclusions* (FEMA 2010b).

Kansas and Oklahoma Tornado Outbreak, May 3, 1999: 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, FEMA deployed a MAT to Oklahoma and Kansas to assess damage caused by the tornadoes. The MAT report written following the field assessments, titled FEMA 342, *Building Performance Assessment Report – Oklahoma and Kansas, Midwest Tornadoes of May 3, 1999: Observations, Recommendations and Technical Guidance* (1999a), presents observations, conclusions, and recommendations 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. This 1999 MAT investigation led to the development of the First Edition of FEMA 361, *Design and Construction Guidance for Community Safe Rooms* (2000).

Tornado Outbreaks of 2007: In the early morning hours of February 2, 2007, a small but devastating outbreak of three tornadoes struck central Florida, impacting the area between Lady Lake and New Smyrna Beach. Two of the tornadoes were rated by the NWS as EF3 and the other was rated EF1. Less than 1 month later, on March 1, 2007, tornadoes hit Alabama and Georgia, causing damage and loss of life. Enterprise, AL, experienced one of the top 10 deadliest tornadoes to impact a school when, in the early afternoon hours, a tornado ripped through a high school, killing eight students. Later that day, a tornado severely damaged a hospital in Americus, GA.

A few months later, on the evening of May 4, 2007, supercell thunderstorms formed across portions of the Midwestern United States, spawning tornadoes in several States. An intense supercell developed southwest of Greensburg, KS, that evening, resulting in the formation of 12 tornadoes. One of these tornadoes formed in northwest Comanche County and within an hour had reached Greensburg, KS, a small community of approximately 1,400 people, and traveled from the town's southern edge to its northwest border. The tornado was rated an EF5 and destroyed or severely damaged the majority of the buildings in Greensburg.

FEMA deployed a building sciences team to the field following each of these tornado outbreaks to assess the damage. In order to provide the most immediate direct feedback to those in the affected areas during the early stages of reconstruction, FEMA published eight tornado Recovery Advisories to provide technical guidance. These can be found on the FEMA Library Web site, under *2007 Tornadoes in Florida Recovery Advisories* and *2007 Tornadoes in Kansas Recovery Advisories.*

1.2 Terminology and Background for Tornado Protection Alternatives

As evidenced by this and previous MAT assessments, it is critical to take precautions and seek the best possible protection available to minimize the risk for injury or death in the event of a tornado. A basic understanding of the tornado hazard, as well as an understanding of relevant building codes and construction techniques, is helpful for individuals and communities to better mitigate against tornadoes. This section presents a background of tornado protection terminology and a history of FEMA's role in developing technical guidance.

FEMA has developed specific terminology to differentiate types of tornado refuge areas from other types of "shelters." An understanding of these specific terms and the historic guidance is important since the terms FEMA uses to describe sheltering options are often similar, such as "safe room" and "storm shelter," but have slightly different meanings (see text box on next page). Furthermore, the term "shelter" is used in different ways by different agencies and entities. For instance, the American Red Cross uses the term "shelter" to refer to temporary recovery areas. Similarly, homeless housing is often called "shelters."

Most homes and buildings are typically designed only to the design wind speed prescribed in the codes, and are not designed to withstand tornado-force winds and impact from wind-borne debris. Even homes and buildings constructed in hurricane-prone regions would not survive a direct hit from a violent tornado because they are not designed to resist extreme wind speeds of 200–250 miles per hour (mph), but are only typically designed to resist speeds up to 150 mph. Furthermore, aside from wind-borne debris regions within hurricane-prone regions, design codes do not address impacts from wind-borne debris. Wind-borne debris can cause failure of a critical structural system in a building, which may then cause global failure and endanger its occupants.

FEMA has provided technical guidance on tornado protection since 1980 when it released FEMA TR-83A, *Interim Guidelines for Building Occupant Protection from Tornadoes and Extreme Winds* (1980). Ten years later, FEMA issued additional guidance in FEMA TR-83B, *Tornado Protection: Selecting and Designing Safe Areas in Buildings* (1990). Then, in 1998, FEMA refined their approach to tornado protection and provided technical guidance on how to design and construct a "safe room" that provides near-absolute protection from the wind and wind-borne debris associated with tornadoes. This guidance is presented in the First Edition of FEMA 320, *Taking Shelter from the Storm: Building a Safe Room Inside Your House* (1998).[3]

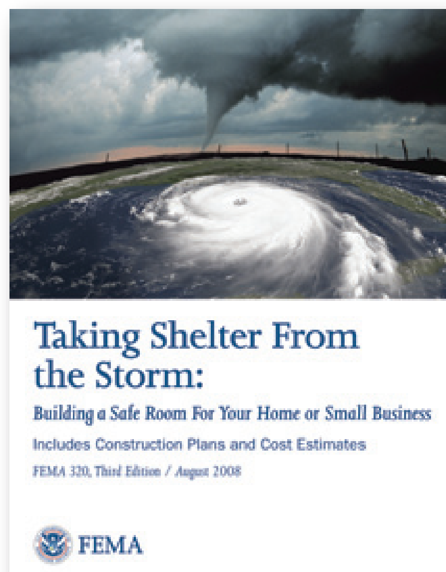

Figure 1-5: Cover of FEMA 320 (FEMA 2008, Third Edition)

Most recently updated in 2008, FEMA 320 (Figure 1-5) prescribes safe room designs that homeowners, builders, and

3 The Third Edition of FEMA 320 (released in 2008) is titled *Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business*. However, readers should be aware that the First and Second Editions of FEMA 320 (released in 1998 and 1999, respectively) were titled *Taking Shelter from the Storm: Building a Safe Room Inside Your House*.

TERMINOLOGY

Tornado refuge area is a general term used to describe any location where people go to seek cover during a tornado. Tornado refuge areas may have been constructed to comply with basic building code requirements (that do not consider tornado hazards). These areas may also have continuous load paths, bracing, or other features that increase resistance to wind loads. It is important for people to know that such an area may not be a safe place to be when a tornado strikes and they still may be injured or killed during a tornado event.

Best available refuge areas are areas in an existing building that have been deemed by a qualified architect or engineer to likely offer the greatest safety for building occupants during a tornado. It is important to note that, because these areas were not specifically designed as tornado safe rooms, their occupants may be injured or killed during a tornado. However, people in best available refuge areas are less likely to be injured or killed than people in other areas of a building (FEMA P-431, *Tornado Protection: Selecting Refuge Areas in Buildings* [October 2009]).

Hardened areas are designed and constructed to provide some level of protection, but do not necessarily meet International Code Council (ICC) / National Storm Shelter Association (NSSA) *Standard for the Design and Construction of Storm Shelters* (ICC 500) criteria or FEMA guidelines. These areas are commonly referred to by builders and homeowners as ***shelters*.**

Storm shelters provide life-safety protection; they are designed and constructed to meet ICC 500 criteria.

Safe rooms provide near-absolute protection; they are designed and constructed to meet the guidelines provided in FEMA 361, *Design and Construction Guidance for Community Safe Rooms* (2008a) or FEMA 320, *Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business* (2008c).

	Tornado Refuge Area	Best Available Refuge Area	Hardened Area or Room	Storm Shelter	Safe Room
Designed to minimum building code requirements	✔	✔	✔	✔	✔
Evaluated by a design professional and identified as least vulnerable area/room in building		✔		✔	✔
Designed to consider wind speeds or wind-borne debris impacts at some level between code and ICC 500/FEMA criteria			✔		
Designed specifically to provide life-safety protection per ICC 500 or FEMA Criteria				✔	✔
Designed specifically to provide near-absolute protection per FEMA criteria (including operational and emergency planning criteria)					✔

contractors can use to construct safe rooms in homes or small businesses. Design options include safe rooms located in basements or garages, or in an interior room of a new home or small business. Other guidance includes how to modify an existing home or small business to add a safe room in one of these areas. These safe rooms are designed to provide near-absolute protection for their occupants from the extreme winds expected during tornadoes and hurricanes and from flying debris, such as wood studs, that tornadoes and hurricanes usually generate.

In 2000, FEMA released the First Edition of FEMA 361 (Figure 1-6). Updated in 2008,[4] this publication contains guidance for architects, engineers, building officials, local officials and emergency managers, and prospective safe room owners and operators about the design, construction, and operation of safe rooms and storm shelters for extreme-wind events. It presents important information about designing and constructing community safe rooms, including design criteria for wind, wind-borne debris, and flood hazards. The 2008 update to FEMA 361 also includes the technical design criteria used for the prescriptive safe room designs presented in FEMA 320. It includes guidance on shelter management and operations and has checklists to help designers, owners, and emergency management officials ensure safe rooms are correctly designed and constructed. FEMA 361 also has checklists that can be used to evaluate existing buildings that may be used as refuge areas if a FEMA 361-compliant safe room is not available in a community or jurisdiction. The refuge area checklists can help identify how vulnerable different areas of a building are to the effects of wind and wind-borne debris associated with tornadoes or hurricanes.

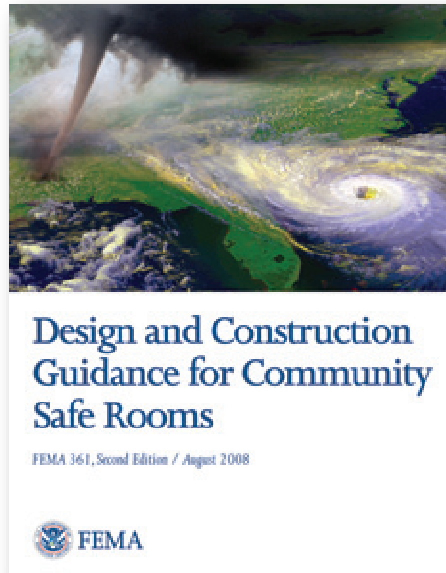

Figure 1-6: Cover of FEMA 361 (FEMA 2008, Second Edition)

It is important to remember that the building codes and standards used in the United States prior to 2008 did not address life-safety protection from tornadoes or hurricanes. Although the guidance from FEMA and others has existed since the late 1990s, it was not until the release of ICC 500 in 2008 that such criteria were introduced into building standards. Following the release of the ICC 500, the 2009 International Building Code (IBC) and IRC incorporated the standard by reference. This means that if a building is constructed to the 2009 IBC and IRC and there is a portion of the building designated to be a shelter, it must be designed to the criteria of the ICC 500, which has specific provisions on how to provide protection from extreme wind events and wind-borne debris associated with those events (Figure 1-7).

> Building codes aim to reduce the level of damage to structures during design wind events but do not address life-safety protection for building occupants in design or extreme wind events.

4 The Second Edition of FEMA 361 (2008) is titled *Design and Construction Guidance for Community Safe Rooms*.

However, at this time, neither the ICC 500 nor the International Codes (I-Codes) require shelters to be designed or constructed within buildings. ASCE 7, *Minimum Design Loads for Buildings and Other Structures,* also does not address tornadoes as part of the wind design considerations and requirements for buildings or other structures. Therefore, it is imperative that the design community, emergency management officials, and the general public develop a better understanding of the vulnerabilities of existing buildings to tornadoes and other high-wind events.

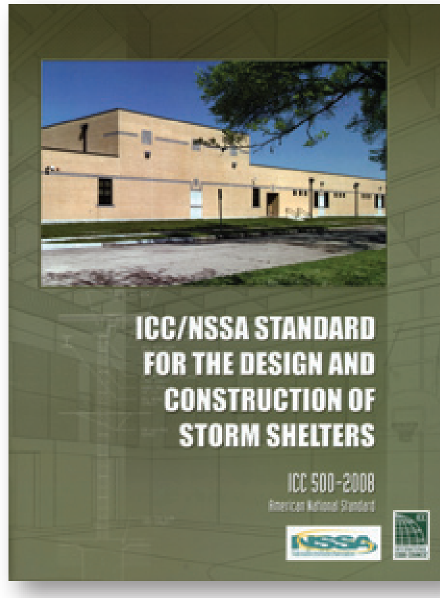

Figure 1-7:
Cover of ICC 500 (ICC/NSSA 2008)

1.3 2011 Tornado Recovery Advisories

Through investigation and observation of the performance of both residential and non-residential buildings, the MAT developed eight new recovery advisories to provide guidance for post-tornado reconstruction; these recovery advisories were published soon after the events and are available online through the FEMA Library Web site[5] and in Appendix F. The set of recovery advisories includes:

- Recovery Advisory 1: *Tornado Risks and Hazards in the Southeastern United States*
- Recovery Advisory 2: *Safe Rooms: Selecting Design Criteria*
- Recovery Advisory 3: *Residential Sheltering: In-Residence and Stand-Alone Safe Rooms*
- Recovery Advisory 4: *Safe Rooms and Refuge Areas in the Home*
- Recovery Advisory 5: *Critical Facilities Located in Tornado-Prone Regions: Recommendations for Facility Owners*
- Recovery Advisory 6: *Critical Facilities Located in Tornado-Prone Regions: Recommendations for Architects and Engineers*
- Recovery Advisory 7: *Rebuilding and Repairing Your Home After a Tornado*
- Recovery Advisory 8: *Reconstructing Non-Residential Buildings After a Tornado*

These guidance documents are directed not only toward architects, engineers, and contractors, but also to building owners, homeowners, and State and local government officials. This MAT report supplements the information provided in the recovery advisories and provides more detailed analysis and recommendations.

5 FEMA Library, Tornado Recovery Advisories, www.fema.gov/library/viewRecord.do?id=4723

1.4 Organization of Report

This report is organized in the following manner:

Chapter 1: Provides an overview of the purpose and methodology behind the MAT's activities.

Chapter 2: Provides a general background on tornadoes and a detailed discussion of the meteorological events that led up to the April 25–28, 2011 tornado outbreak in the mid-south area of the United States and the May 22, 2011 Joplin, MO, tornado.

Chapter 3: Presents a discussion of the general causes of observed failures, the regulations that govern construction, and recommended construction practices resulting from the MAT's field investigations.

Chapter 4: Presents the MAT's observations on the performance of residential buildings. The MAT assessed one- and two-family residences and multi-family residences.

Chapter 5: Presents the MAT's observations on the performance of commercial buildings.

Chapter 6: Presents the MAT's observations on the performance of schools.

Chapter 7: Presents the MAT's observations on the performance of healthcare and first responder facilities and EOCs.

Chapter 8: Presents the MAT's observations on the performance of two infrastructure categories: water treatment and distribution facilities and towers (communications and antennae).

Chapter 9: Presents general information and the MAT's observations related to refuge areas, shelters, and safe rooms/storm shelters.

Chapter 10: Provides conclusions based on the MAT's observations; this information is intended to assist States, communities, businesses, and individuals who are recovering and rebuilding from the tornadoes.

Chapter 11: Provides recommendations intended to assist individual, communities, and businesses through the reconstruction process and to help reduce future damage and impacts from similar tornadic wind events.

Appendix A: Lists contributors to the MAT including those who supported preparatory efforts, supported the MAT in the field, and contributed to writing and reviewing the MAT report.

Appendix B: Provides the references cited in the report.

Appendix C: Provides a list of acronyms and their definitions.

Appendix D: Provides a glossary of terms.

Appendix E: Provides a background on the development and use of the EF scale, as well as a summary of the EF scale ratings determined by the MAT for structures it accessed.

Appendix F: Includes the Recovery Advisories created for the April 25–28, 2011 tornado outbreak in the mid-south area of the United States and the May 22, 2011 Joplin tornado.

Appendix G: Provides prescriptive guidance to enhance wood-frame residential building performance when impacted by tornadoes rated EF2 or less or inflow winds associated with tornadoes rated EF3 or greater.