TORNADO OUTBREAK *of* 2011

IN ALABAMA, GEORGIA, MISSISSIPPI, TENNESSEE, AND MISSOURI

11 Recommendations of the 2011 Tornado MAT

The tornadoes of April 25–28, 2011 and May 22, 2011 were devastating in their intensity, severity, and loss of life and property.

While the events of April and May 2011 cannot be undone, the affected communities can commit to planning for future tornadoes through promoting sustainable and tornado-resistant construction. The recommendations in this report are based solely on the MAT's observations, assessments, analysis, and conclusions. These recommendations are intended to assist individuals, communities, and businesses through the reconstruction process and to help reduce future damage and impacts from other tornadic wind events.

At a minimum, as communities begin to rebuild homes, businesses, and critical facilities, there are several ways they can reduce the effects of future tornadoes, including:

- Design buildings to the most current building codes and engineering standards to improve building performance and reduce damage

- Construct residential and community safe rooms to provide safe refuge in the event of a strong or violent wind storm or tornado

Specific recommendations are included in the following subsections. Mitigating future losses, however, will not be accomplished by simply reading this report; mitigation is achieved when a community actively seeks and applies methods and approaches that will lessen the DOD, injuries, and loss of life in future tornadoes. For example, the Tornado Recovery Action Council of Alabama is encouraging the adoption of a statewide building code to mitigate future losses (2012). These recommendations can be used across the United States and for other disasters, as applicable, to prepare, plan, and design for mitigating deaths and damages in similar hazard events.

11.1 Codes and Standards

This section provides MAT recommendations related to codes and standards intended to improve building performance of residential, commercial, industrial, and critical facilities. In addition to property protection, the MAT provides recommendations for requirements related to personal protection.

11.1.1 Residential Buildings

Recommendation #1 – Adopt and enforce current model building codes: State and local officials should adopt and enforce a current edition of a model building code (current codes at the time of publication of this report are the 2012 or 2009 IRC, Figure 11-1) for all new residential construction. The minimum requirements of the code should be kept intact, including the criteria set forth in ASCE 7, the ICC 500, and Chapter 3 of the IRC. Where the State is deficient in model code adoption, the local jurisdictions should adopt and enforce the latest model building codes. Some jurisdictions may qualify for HUD Community Development Block Grants and FEMA HMGP opportunities to establish inspection departments.

Figure 11-1: IBC/IRC

As an interim step to code adoption, engineers should design and builders should build to the latest model building codes. Designers, builders, and owners should consider voluntary implementation of these codes in jurisdictions where they are not adopted by government authorities.

Recommendation #2 – Increase emphasis on code compliance: Where codes are in place, more emphasis should be placed on code compliance. Homebuilders and code enforcement agencies should consider developing an active education and outreach program with contractors to emphasize the importance of code compliance for wind resistance.

Recommendation #3 – Maintain and rigorously enforce the adopted model building code since amendments or lax enforcement practices may weaken the continuous load path of the building: Minimum requirements of the IRC and IBC that specify prescriptive connections along the critical load path from roof, through walls, into floor systems, and into the foundation should not be weakened through local amendments or enforcement practices. Weakening the critical load path threatens the integrity of buildings and endangers their occupants unnecessarily.

11.1.2 Commercial and Industrial Buildings

Recommendation #4 – Include failure states and survivability in building codes and standards: For a coherent design approach, structural loads need to be addressed and presented in a clear, consistent philosophy of design. Failure states and building survivability also need to be addressed in the codes. Wind design provisions important for building resistance to high-wind events such as tornadoes should be discussed in ASCE 7, and wind design methodologies should be developed for use by practitioners.

Recommendation #5 – Change risk category for large-footprint commercial structures with long-span roofs to Risk Category III in ASCE 7-10: Classify one- and two-story, large-footprint commercial structures with long-span roofs as Risk Category III under ASCE 7-10 to protect the large number of people that may occupy these structures at any given time.

Recommendation #6 – Improve design approach in ASCE 7 and IBC to address risk consistently across hazards: The codes and standards need a coherent approach to risks, threats, and hazards. The ASCE 7 standard does not have a clearly articulated design approach as part of the document. If clear and consistent designs with predictable and acceptable performance are to be achieved our codes and standards must clearly state the basis for their development and implementation. Therefore, the MAT recommends that ASCE 7 and IBC undertake the task of capturing a better design approach that treats risk consistently across hazards. Part of the code and standard performance objective must be to prevent building collapse even in extreme events. A building may be rendered a complete functional and economic loss, but it should not collapse. This area of code improvement implies a more sophisticated approach that is partially captured by the development of performance-based design methods. Performance-based design methods should be expanded to more areas of ASCE 7 and the IBC, particularly as they relate to the wind hazard.

Recommendation #7 – ASCE 7 should improve the commentary on code limitations: The current codes and standards that govern building design do not clearly express how they handle tornado loads. The narrative that explains the limitations does not clearly state what elements of tornado risk or exposure are covered. ASCE 7 should make clear, unambiguous statements in the commentary about code limitations. These statements should clarify whether tornadoes are dealt with in the process, and if not, why. The commentary discussion needs to objectively explain the rationale for the decision.

Recommendation #8 – Clarify risk tolerance in ASCE 7 and IBC: ASCE 7 and the IBC should begin the discussion of risk tolerance so that probability-based design of building performance can be better understood, communicated and implemented.

Recommendation #9 – Include best practices for wind design in IBC: The IBC should develop a best practices section for wind design similar to the seismic portion of the code. This section can incorporate details and systems that enhance building performance in extreme wind events. Expansion of this discussion may incorporate concepts that are familiar to seismic designers and also address progressive collapse. Best practices for extreme wind design include redundancy of the

MWFRS, ductility of connections, alternate load paths, design for load reversal, robust perimeter element design, continuity of boundary elements, good connectivity, and inclusion of discrete MWFRS components.

11.1.3 Critical Facilities

Recommendation #10 – Propose IBC code change: The MAT recommends submitting the following IBC code change proposal regarding schools:

> "In areas where the shelter design wind speed for tornadoes per Figure 304.2(1) of ICC 500 (2008) is 250 mph, all new kindergarten through 12th grade schools with 50 or more occupants in total, per school, shall have a FEMA 361-compliant safe room or an ICC 500-compliant storm shelter."

Recommendation #11 – Propose IBC code change: Submit the following IBC code change proposal regarding fire and police stations, 911 call centers, and EOCs:

> "In areas where the shelter design wind speed for tornadoes per Figure 304.2(1) of ICC 500 (2008) is 250 mph, all new 911 call stations, emergency operation centers, and fire, rescue, ambulance, and police stations shall have a FEMA 361-compliant safe room or an ICC 500-compliant storm shelter."

11.1.4 Tornado Refuge Areas, Hardened Areas, and Safe Rooms

Recommendation #12 – Continue to coordinate standards and guidance for storm shelters and safe room design: The ICC and FEMA should continue to work together to establish standards and guidance that are complementary. There are design elements based on emergency management considerations in the FEMA guidance related to the operations and maintenance of storm shelters or safe rooms that are not appropriate for inclusion in the ICC 500, as it is an engineering standard. As FEMA programs continue to fund the design and construction of safe rooms, there are valuable lessons in engineering and construction, in addition to the operational aspects of its safe room program, that could be incorporated into the ICC standard.

The primary reason to keep the FEMA guidance and ICC 500 documents separate is to ensure that emergency management considerations receive appropriate attention during design and construction. While most technical elements in the documents are the same, some remain different. These few differences, less notable in the tornado hazard areas as compared to the hurricane hazard areas, need to be understood and explained to designers, emergency management officials, property owners and managers, and people in communities seeking protection from tornadoes. This outreach is necessary to minimize potential confusion that may exist. As the ICC enters its next cycle of standards development, it should develop a commentary for the ICC 500 ICC 500 that discusses assumptions and limitations of the standard. Further, as FEMA continues to provide guidance in its publications and policies, ICC and FEMA should continue to work together to develop a common message on life-safety protection from tornadoes.

Recommendation #13 – Improve performance of safe rooms and storm shelters through code adoption and enforcement: The 2009 and newer versions of both the IBC and IRC require compliance with the ICC 500 for any plan-designated storm shelter. The ICC 500 includes testing standards for storm shelter and safe room components. Components for newly constructed storm shelters and safe rooms, including elements such as doors, door hardware, ventilation, and anchorage, should be verified as compliant with ICC 500 as part of enforcing the aforementioned model building codes.

Recommendation #14 – Submit proposed IBC code change: The MAT recommends submitting the following IBC code change proposal regarding identification of best available refuge areas:

> "For new buildings that do not incorporate a FEMA 361-compliant safe room or an ICC 500-compliant shelter, the floor plan shall indicate the best available refuge area(s).
>
> - "The best available refuge area(s) shall be capable of accommodating the building's occupant load based on the allowable square footage per occupant prescribed in ICC 500.
> - "When signage is provided to identify the refuge area, the terminology should read: "Best Available Refuge Area.
> - "Exception: If building occupants have access to a community FEMA 361-compliant safe room or an ICC 500-compliant shelter, this provision is not applicable."

11.2 Residential Construction

Recommendation #15 – Implement voluntary best practices to mitigate damage to one- and two-family residential buildings: The MAT recommends implementing the voluntary best practices for one- and two-family residential construction listed in this section and described further in Appendix G; these best practices will greatly reduce tornado damage to new and rebuilt one- and two-family residential buildings that are exposed to wind loads associated with weaker (i.e., EF0, 1, and 2) tornadoes. Since the decision to implement best practices for enhanced building performance is cost-based, and therefore ultimately lies with the consumer (prospective homeowner), the MAT recommends that designers and builders offer enhanced performance option packages for new residential buildings. These options should be clearly presented so that the potential homeowner understands that improved wind resistance does not equate to "windproof."

The guidance for improved building performance presented in Appendix G is intended solely for enhanced property protection and should not be construed in any way as an alternative to sheltering. Consequently, occupants of residential buildings in tornado-prone regions should have a tornado emergency operations plan in place, and whenever possible, have practiced this plan through drills to quickly access their safe room, storm shelter, or best available storm refuge.

Prescriptive guidance is provided in Appendix G, per specific sections referenced below, to enhance performance of components, cladding, and critical load path connections observed to have failed during the spring 2011 tornado events. The prescriptive guidance in Appendix G is intended to:

- Improve roof and wall coverings per Section G.3.1
- Increase awareness of glazing damage and strengthen garage doors per Section G.3.1
- Strengthen roof decking (sheathing) attachment per Section G.3.2
- Strengthen roof-to-wall connections per Section G.3.2
- Improve wall performance through sheathing attachment, hold-down installation, and better top plate splicing per Section G.3.3
- Improve wall-to-floor connections and bottom plate attachment per Section G.3.3

11.3 Commercial and Industrial Construction

For new commercial and industrial buildings, the MAT recommends that architects and engineers consider the following approaches to improve building performance related to communications and operations, and to detailing and connections.

11.3.1 Occupant Notification and Operations

Recommendation #16 – Install a storm shelter or safe room or identify best available refuge areas in large-footprint buildings: In buildings where there can be a significant number of people, there should be a designated area that has been evaluated for its vulnerability to damage from tornadic winds and wind-borne debris where occupants can take refuge during a high-wind event. This space could be a break room, an office, or any other space with sufficient floor space for the occupants. Because best available refuge areas do not guarantee safety, the space should be designed to FEMA 361 or ICC 500 criteria.[1]

Recommendation #17 – For all public buildings, install signage in a conspicuous place at building entrances (similar to maximum occupancy signs from the fire department): The resulting information may lead to the decision to abandon a structure and find more suitable refuge in certain situations. Signs should:

- Include relevant building design parameters such as importance factor, design wind speed, ground snow load, seismic criteria, rain fall intensity criteria, and if the building is constructed from URM.
- Prominently display “Best Available Storm Refuge Area – Maximum Occupancy of” with the maximum occupancy on the sign.

1 This chapter references the 2008 versions of FEMA 320 and 361, as well as ICC 500, unless another date is specified.

- Be of similar size and placement as the occupancy limitation signs currently used and placed in all buildings.

Recommendation #18 – Place decision-making check lists or flip charts in prominent locations: Such check lists or flip charts help people make critical decisions in times of high stress and are a preferred method of ensuring that consistent and good decisions are made in high-stress situations. Checklists or flip charts should be located where building occupants can easily find them. An example of a flip chart is shown in Figure 9-15.

11.3.2 Detailing and Connections

Recommendation #19 – Do not use URM in primary or critical support areas of a building: All masonry used in a building as a support wall or shear wall should be reinforced and tied into the adjacent structural elements to ensure ductile and robust performance in overload conditions, as URM has been known to fail in extreme events. URM is not allowed in parts of the country that are subject to increased seismic performance requirements due to its poor behavior in extreme events and insufficient ductility (FEMA 2009). The MAT recommends that all masonry for retail and commercial buildings be reinforced. This will ensure positive connections and a clear load path that is not dependent on gravity alone for the integrity of the building during an extreme wind event. Critical areas of buildings lacking reinforcement should be upgraded to include reinforcement and a continuous load path.

Recommendation #20 – Use screws in deck-to-joist connections instead of puddle welds: Several past MAT studies and damage assessments from FEMA, as well as other FEMA guidance documents, recommend the use of screws instead of puddle welds in the deck-to-joist connection. (See FEMA 342; FEMA P-424; FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings* [2007]; and FEMA 577, *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and Buildings* [2007], for more context.) The screws provide a more reliable and consistent connection than puddle welds and have been shown to perform better in high-wind events. The MAT recommends the use of screws in accordance with observed failures during spring 2011 deployment and past FEMA reports and assessments.

Recommendation #21 – Include enhancements to building connections beyond the code requirements: Design improvements can be achieved in new construction by incorporating enhancements that go beyond code requirements. Improving the performance of building connections is a low-cost improvement that can increase design strength and ductility. Until better criteria are established by a rational means, design non-residential buildings as Risk Category III structures under ASCE 7-10.

Recommendation #22 – Incorporate redundancy in the MWFRS: To reduce high-wind damage to buildings with long-span roofs and tall walls and limit the progression of a failure, building designers should incorporate redundancy in the MWFRS. Specifically:

- Design redundant features to limit the area supported by each element to a relatively uniform shape (aspect ratio no greater than 2).

- Limit the maximum area supported by a bracing system to 40,000 square feet. The area should be large enough that it does not severely affect building operations and flow.
- Design redundant support, or minimize deflections, such that a column or wall could be damaged and the structural system would not collapse.
- Provide lateral load resistance in tall walls with more than one means of support at both the top and bottom of the walls.
- Account for the break in continuity at the expansion/contraction joint when designing the MWFRS wall system.

Recommendation #23 – Incorporate more redundancy in the design of large-footprint buildings: To limit the extent of a progressive collapse from failure of a small element or from a non-redundant system, more redundant systems should be incorporated into the design of large-footprint buildings. The limiting area should be large enough to permit use of the space without substantially affecting the operations and flexibility of the facility. Single-purpose structural stability systems should also be considered. Additional ductility and continuity measures at the perimeter of the structure would allow load distribution to other elements in the event of massive overloads (see Figure 5-48).

Recommendation #24 – Use discrete structural systems in large, long-span buildings: To improve building performance, designers should consider solutions that provide for discrete service of components. For example, a building can be designed so that it could lose the roof and not lose stability from the loss of the diaphragm critical to the MWFRS. Although such solutions may add construction cost by removing efficiency of design, they will result in a more robust, redundant system. The greater construction costs may be regained in lower risk and loss profiles.

An example of such a design would be installing a roof deck that provides weather protection, but is separated from the MWFRS and not used as the shear diaphragm. Another example would be including a wall system that does not provide vertical support and shear resistance, but acts solely as an environmental barrier. Such a wall could be lost, and the MWFRS would not be compromised.

11.4 Critical Facilities

Design enhancements can be made to both existing critical facilities and those in the planning stage that can be incorporated into the construction documents. Design enhancements beyond IBC requirements are necessary to minimize damage from tornadoes. Design enhancements (including provisions pertaining to electrical power and communications) are also necessary to ensure COOP after a tornado strike.

The MAT prepared several Tornado Recovery Advisories in the wake of the April 25–28, 2011 and May 22, 2011 tornado events. FEMA Recovery Advisory No. 5, *Critical Facilities Located in Tornado-Prone Regions: Recommendations for Facility Owners* (Appendix F), provides recommendations for owners of critical facilities. FEMA Recovery Advisory No. 6, *Critical Facilities Located in Tornado-Prone Regions: Recommendations for Architects and Engineers* (Appendix F), provides recommendations for architects and engineers. These recommendations pertain to both existing and new critical facilities. The recommendations address best available refuge areas, safe rooms, strengthening new facilities to minimize tornado damage, and enhancements to avoid interrupted operations.

The MAT's key recommendations for improving the performance and operation of existing and new critical facilities during and after a tornado are described below (refer also to the Recovery Advisories in Appendix F).

11.4.1 Existing Critical Facilities

Recommendation #25 – Perform a vulnerability assessment: A team of architects and engineers should perform a high-wind vulnerability assessment of existing facilities. Findings from such an assessment can lay the groundwork for planning and budgeting capital improvement projects and for developing contingency plans that address facility disruptions that result from a tornado or other natural hazard event, as illustrated in Figure 11-2. Figure 11-2 shows a collapsed CMU/brick veneer wall and collapsed roof structure at Joplin High School (see also Section 6.1.5).

Figure 11-2:
Collapse of exterior CMU/brick veneer wall and roof collapse at the Joplin High School (Joplin, MO). The wall debris fell into the corridor.

Recommendation #26 – Identify best available refuge areas: Best available refuge areas should be identified in all critical facilities that do not have areas designed and constructed as safe rooms or storm shelters. Best available refuge areas do not guarantee safety; they are, however, the safest areas available for building occupants. A design professional familiar with tornado risk should assess existing buildings and identify the best available refuge areas. Once identified, the locations of the best available refuge areas should be clearly marked with a permanent sign that reads "*Best Available Refuge Area*."

11.4.2 New Critical Facilities

Recommendation #27 – Include safe rooms in design of new facilities: One or more safe rooms should be incorporated into new designs to provide occupant protection. FEMA 361 provides comprehensive guidance for the design of safe rooms. If a safe room is not incorporated, the architect or engineer should identify the best available refuge area(s), and specify that those area(s) should have a permanent sign that reads "*Best Available Refuge Area*."

Recommendation #28 – Enhance building design to better withstand tornadoes: By using design strategies and building materials that are used in hurricane-prone regions, critical facilities can be built to be more wind resistant to most tornadoes (i.e., EF0–EF3). Detailed recommendations for three levels of enhancement to minimize building damage are given in FEMA Recovery Advisory No. 6.

Recommendation #29 – Strengthen facilities to remain operational: For critical facilities that should remain operational if struck by a violent tornado (i.e., EF4 and EF5), designers should follow the detailed recommendations related to the MWFRS, the building envelope, HVAC, water, sewer, and emergency power provided in FEMA Recovery Advisory No. 6.

If, because of the additional expense, the owner determines that a critical facility does not need to be operational if struck by a violent tornado, then this reduced building performance should be clearly considered and addressed in emergency operations plans. Other critical facilities (that are not expected to be impacted by the same tornado) should be identified from which to continue critical operations. Appropriate planning, emergency plans, and cooperative agreements, typically referred to as COOP Plans, should be put in place. For facilities such as EOCs that are determined to be critical in providing effective emergency response, owners should budget facility enhancements to avoid interrupted operations even if struck by violent tornadoes.

11.5 Infrastructure Facilities

The MAT assessed the performance of water treatment facilities, water distribution facilities, wastewater treatment facilities, and communications towers. It is important that these facilities stay operational after a disaster to provide clean water, sanitation, and communications for the people and emergency responders of the community. The following are recommendations for enhancing infrastructure performance based on the MAT's observations.

Recommendation #30 – Work collaboratively to better understand the risks of wind-displaced materials on communications towers: The authors of ANSI/TIA-222, *Structural Standard for Antenna Supporting Structures and Antennas* (2005), should investigate the risks that wind-displaced materials pose to communications towers and develop methods in that standard to address those risks.

Recommendation #31 – Work collaboratively to better understand the effects of wind-displaced materials on latticed structures: The ASCE should provide commentary in Chapter 29 of ASCE 7 on the effects of wind-displaced materials clinging to latticed structures so that designers can consider the possible increases in wind loads on those structures.

Recommendation #32 – Provide an alternate electrical source: For water distribution systems that are fed only from utility power systems and that rely on electrically driven pumps to fill storage tanks or boost system pressures, alternate power supplies should be provided. Alternate power supplies may be from on-site standby generators or from temporary portable generators brought to the site after an event. If temporary portable generators are used, provisions should be installed to allow operators to quickly and safely connect the generators to the pump stations before tanks drain or system pressures significantly affect operations.

Recommendation #33 – Work collaboratively to better understand communications tower performance: Stakeholders should collaborate to better understand tower performance.

11.6 Tornado Refuge Areas, Hardened Areas, and Safe Rooms

Safe rooms are the best means of providing near-absolute protection for individuals who are attempting to take refuge during a tornado. Whether a safe room is constructed by a homeowner for protection of his or her family or is constructed as a group or community safe room, all safe rooms should be designed and constructed in accordance with either FEMA 320 or FEMA 361.

Safe rooms and storm shelters constructed in compliance with FEMA guidance and ICC 500 provide **life-safety protection** to building occupants. Refer to Sections 11.3 (Commercial and Industrial) and 11.4 (Critical Facilities) for specific sheltering recommendations related to those building types. Also, refer to Recovery Advisory Nos. 2, 3, and 4 in Appendix F.

The following are recommendations for personal protection based on the MAT's observations and conclusions.

Recommendation #34 – Research travel time to, and use of, safe rooms and storm shelters: Travel time and safe room use research should be sponsored by FEMA, NIST, NSF, NWS, or other Federal entities who have the resources to investigate both the technical and social science issues that are part of the decision-making process of where and how to take shelter from a tornado. How far individuals will travel to find a safe place or shelter from tornadoes is a topic that is not well documented, and as a result, people may be making decisions to find shelter during an event in which there is no time (due to a short warning time period). This complex issue requires further study to better answer the question of how to provide safe rooms, storm shelters, and safe places of refuge at the community level and how to most effectively communicate needed tornado response activities to their community.

Recommendation #35 – Locate safe rooms or storm shelters close to people who will use them: Safe rooms and storm shelters should be provided as close to the specific population being protected as possible. This reduces the risk to occupants who have to walk, run, drive, or otherwise travel to the safe room or storm shelter. Safe rooms within the actual building where the occupants are located provide life-safety protection while minimizing the risk to individuals who are attempting to access the space.

Recommendation #36 – Identify best available refuge areas: Best available refuge areas should be identified in all non-residential buildings that do not have safe rooms. Best available refuge areas do not guarantee safety; they are, however, the safest areas available within the existing space for building occupants.

A design professional familiar with tornado risk analysis should assess existing buildings and identify the best available refuge areas. Once identified, the location(s) of the best available refuge area(s) should be clearly marked with a permanent sign. This sign should not use the term “shelter” or “safe room” since those terms should be used only for areas that meet the criteria set forth in FEMA 320, FEMA 361, or ICC 500. If a design professional is not used to identify the space, the area should be referred to only as a tornado refuge area. Tornado refuge areas offer the least amount of protect from a tornado and may not offer any better protection than typical construction.

Recommendation #37 – Perform vulnerability assessments: For existing, non-residential buildings, a team of architects and engineers should perform a vulnerability assessment. Findings from such an assessment can lay the groundwork for planning and budgeting capital improvements and for developing contingency plans that address facility disruptions that result from a natural hazard event.

Recommendation #38 – Register safe rooms: All safe rooms, storm shelters, and refuge areas within a community should be registered or noted on a list with local emergency management and first responders. The coordinates for the primary entrance to the safe room, storm shelter, or best available refuge area should be provided to help responders locate the structures in the event debris has hidden them or buildings, street signs, etc. have been destroyed. This applies to FEMA-funded safe rooms as well.

Recommendation #39 – Equip safe rooms, storm shelters, and best available refuge areas with tools to assist occupants when doors and egress routes become damaged, inoperable, or blocked by debris: All safe rooms, storm shelters, and best available refuge areas should be equipped with whatever tools are necessary for occupants to open or dismantle the door from inside in the event that egress is blocked or the door is damaged.

Recommendation #40 – Equip safe rooms, storm shelters, and best available refuge areas with an alternate means of communication: Safe room and storm shelter owners and operators should plan for potential disruptions to both wired and wireless communications systems. Community safe rooms and storm shelters in particular may require backup power to operate alternate communication systems.

Recommendation #41 – Provide training: Training on tornado safe rooms, storm shelters, and refuge areas needs to be expanded for professional organizations and should continue for public officials, emergency managers, building owners/operators, and the public. This training should include both technical issues, such as how to perform a vulnerability assessment and identify the best available area for storm refuge in an existing building, as well as non-technical issues, such as travel time and decision-making during tornado warnings as discussed in this report.

11.7 EF Scale

Based on the MAT's observations and conclusions about the current EF scale provided in *A Recommendation for an Enhanced Fujita Scale* (TTU 2006), the MAT recommends that the EF scale guidance be modified as follows:

Recommendation #42 – Add DIs: While the current 28 DIs encompass most buildings, some common building types, such as fire stations and churches, are not included. The MAT recommends that guidance on the EF scale be updated by adding DIs for common building types that are not currently included

Recommendation #43 – Increase the number of DOD categories for specific DIs: The MAT recommends that the DODs for all DIs be reevaluated for consistency and expanded upon where appropriate. Specifically, the number of DODs for communications towers needs to be increased. Any updates should be reflected in published guidance on the EF scale.

Recommendation #44 – Provide additional guidance for DOD assessment when only a portion of a large building is struck: For large buildings where only a portion of the building is struck, guidance should be provided that instructs users on the appropriate DOD selection. Any updates should be reflected published guidance on the EF scale.

Recommendation #45 – Modify EF scale DI 2 (One- and Two-family Residences): Based on the MAT's observations for DI 2 (One- and Two-family Residences), DOD 5 ("entire house shifts off foundation") was rarely witnessed, unlike DODs 4 and 6, and should be eliminated from the list of DODs.

Recommendation #46 – Provide photographs with DOD descriptions in EF rating guidance: The MAT recommends that photographs be added to published guidance on the EF scale to illustrate each DOD in each DI.

11.8 Post-Tornado Imagery

Based on the MAT's observations and conclusions about the current methods for capturing post-tornado imagery and using graphics to display tornado intensity, the MAT recommends that the process be modified as follows:

Recommendation #47: NOAA should capture post-tornado aerial photographs: When tornado damage is potentially greater than EF3, the MAT recommends that NOAA shoot aerial photographs soon after the event. Opportunities to coordinate post-tornado aerial photograph missions between FEMA and NOAA to better capture perishable forensic evidence should be explored.

Recommendation #48 – NWS should develop EF contours: The MAT recommends that the NWS develop EF contours for all tracks that are rated.

Recommendation #49 – NWS should enhance the determination of EF ratings at individual structures by including a design professional as part of the QRTs: QRTs were deployed to many of the sites visited by the MAT in spring 2011, but only the Birmingham, AL area QRT included an engineer. The MAT recommends that a design professional be included in NWS QRTs to improve damage analysis of individual structures after a tornado and to support the documentation of NWS tornado ratings.