Mitigation Assessment Team Report
Spring 2011 Tornadoes

Building Performance Observations, Recommendations, and Technical Guidance

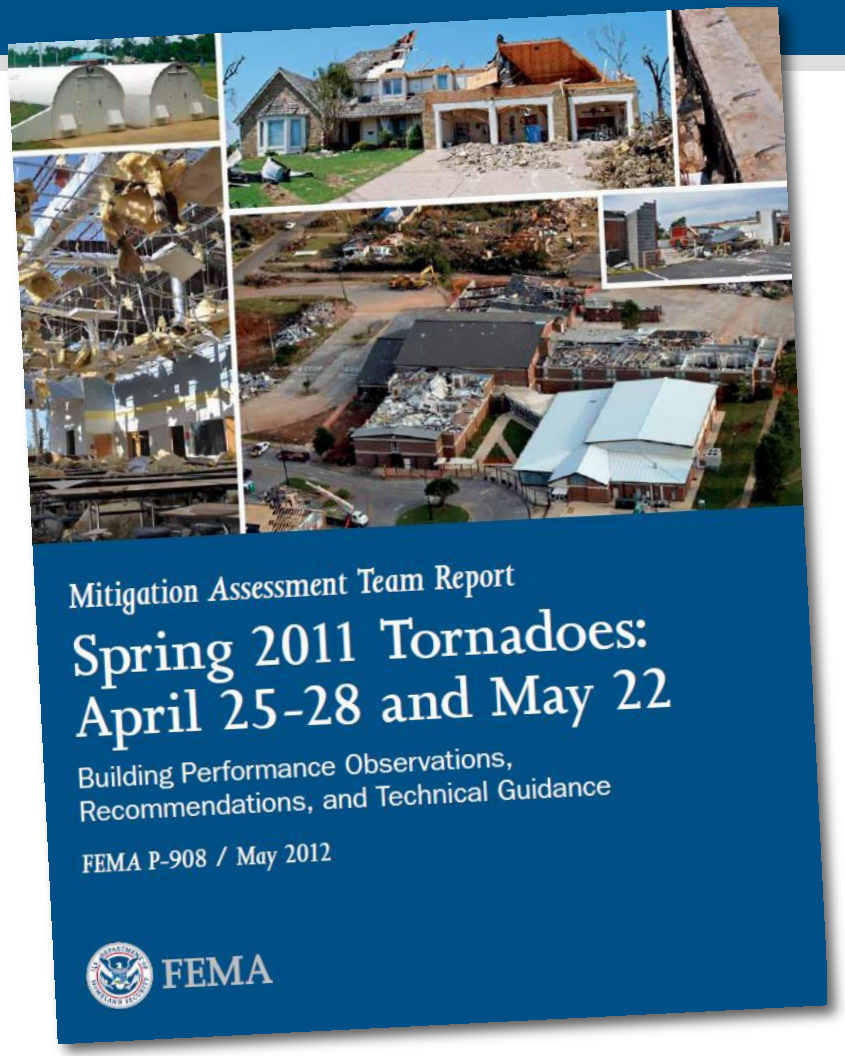
FEMA P-908 / May 2012

FEMA

Building Science Branch

Overview

- MAT program mission
- Spring 2011 Tornado MAT
  - Partners
  - Field activities
  - Findings & recommendations
  - Putting results into action
  - Lasting impacts



MAT Program Mission

- Evaluate post-disaster building performance
- Identify knowledge gaps
- Promote best practices and successes
- Improve codes/standards/materials
- Provide recommendations

MAT Deployment Decision

The 25 MAT studies developed over the past 30 year focusing on hurricanes, floods, tornadoes, and terrorism events.

- New insights for design and construction guidance
- Findings will be of national significance

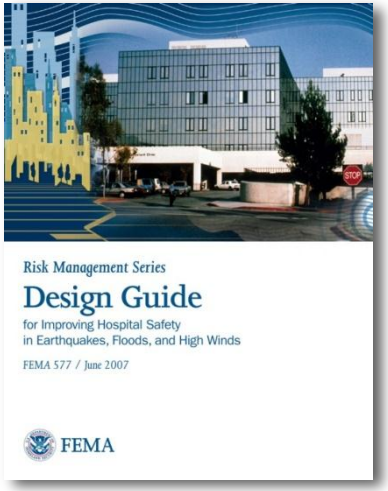
St. John's Regional Medical Center, Joplin, MO

Previous Tornado MATs

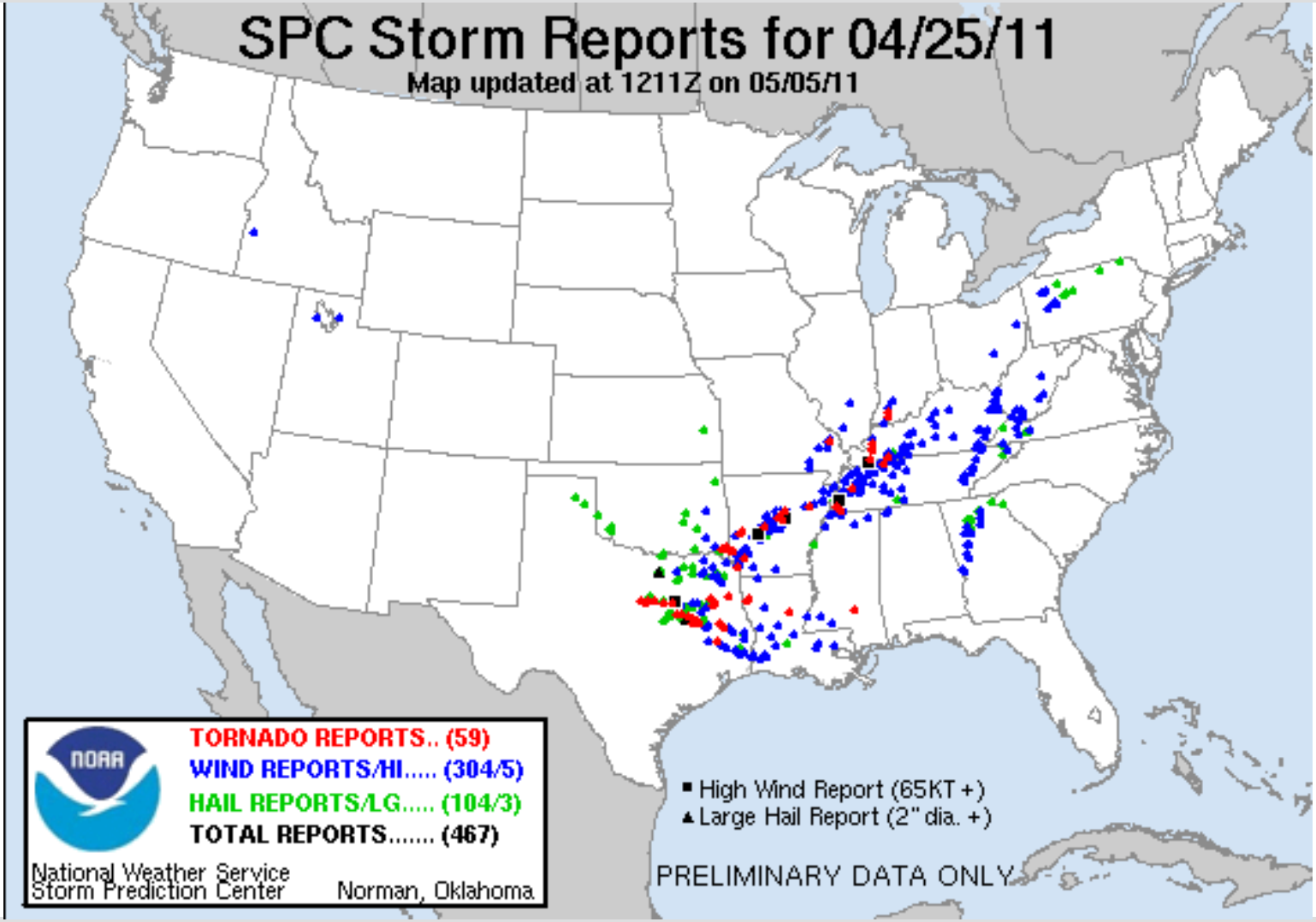
1999 Oklahoma and Kansas (FEMA 342)

2007 Florida (HMTAP)

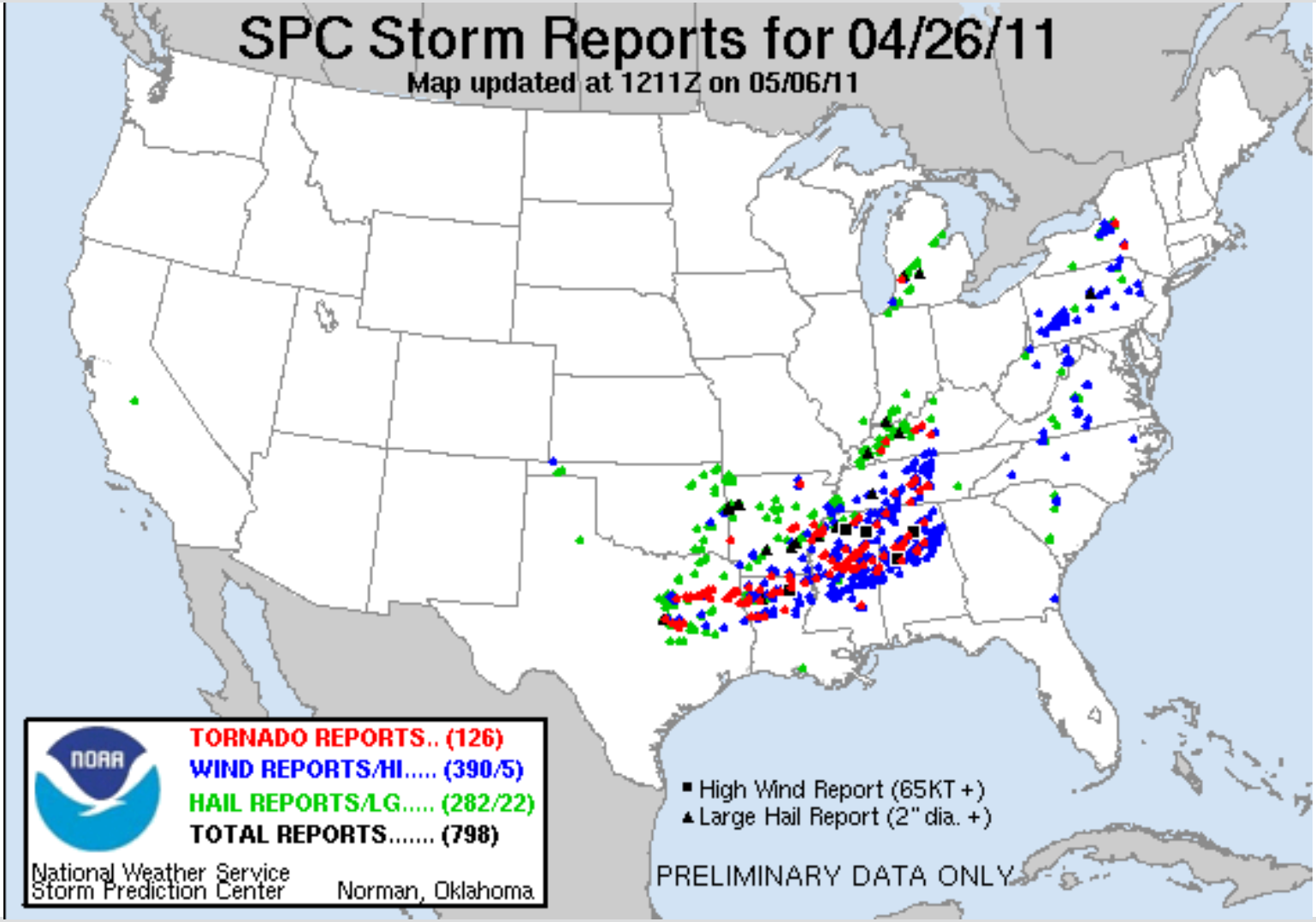
2007 Greensburg, KS (HMTAP)



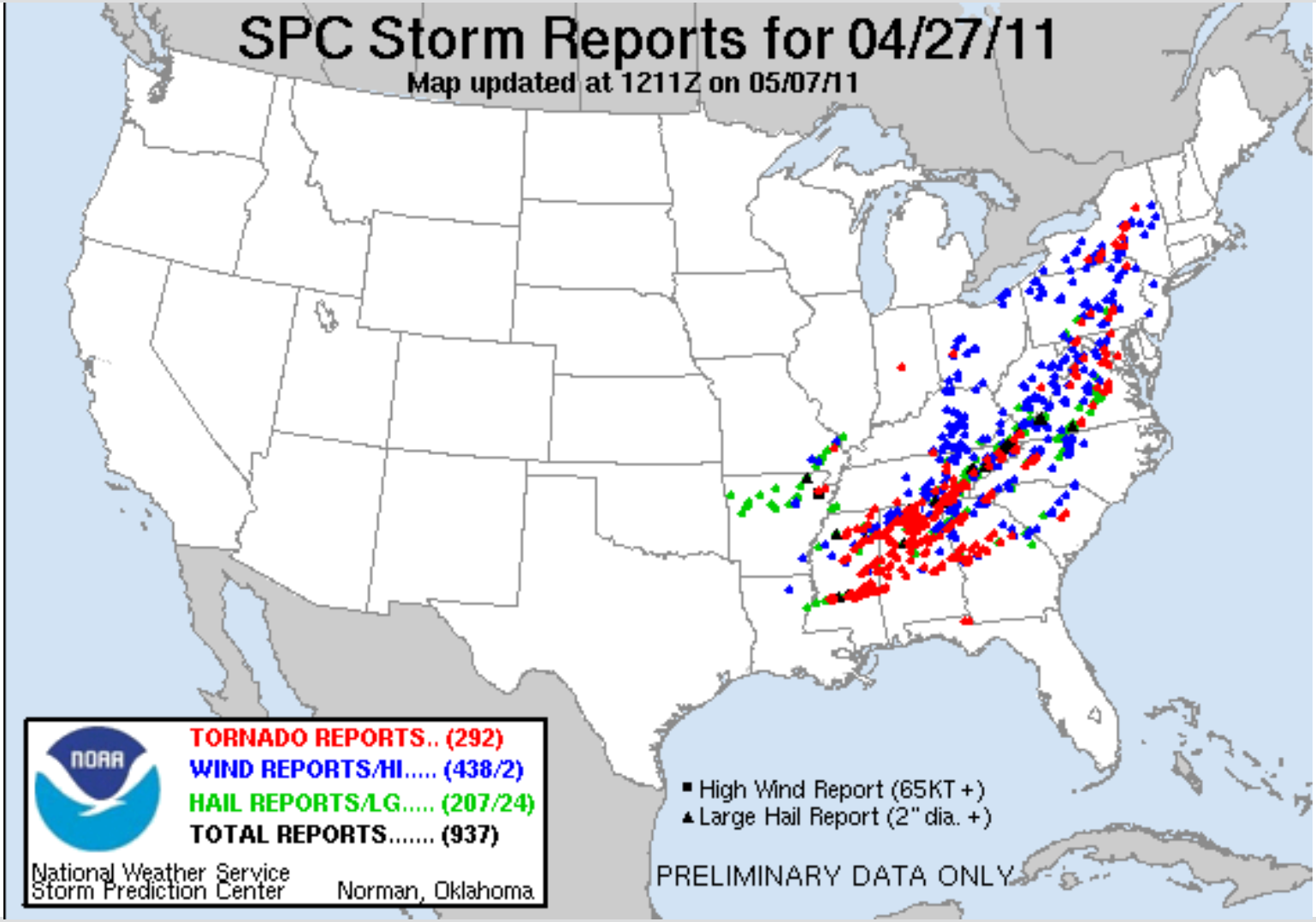
2011 Spring Tornado Outbreak: April



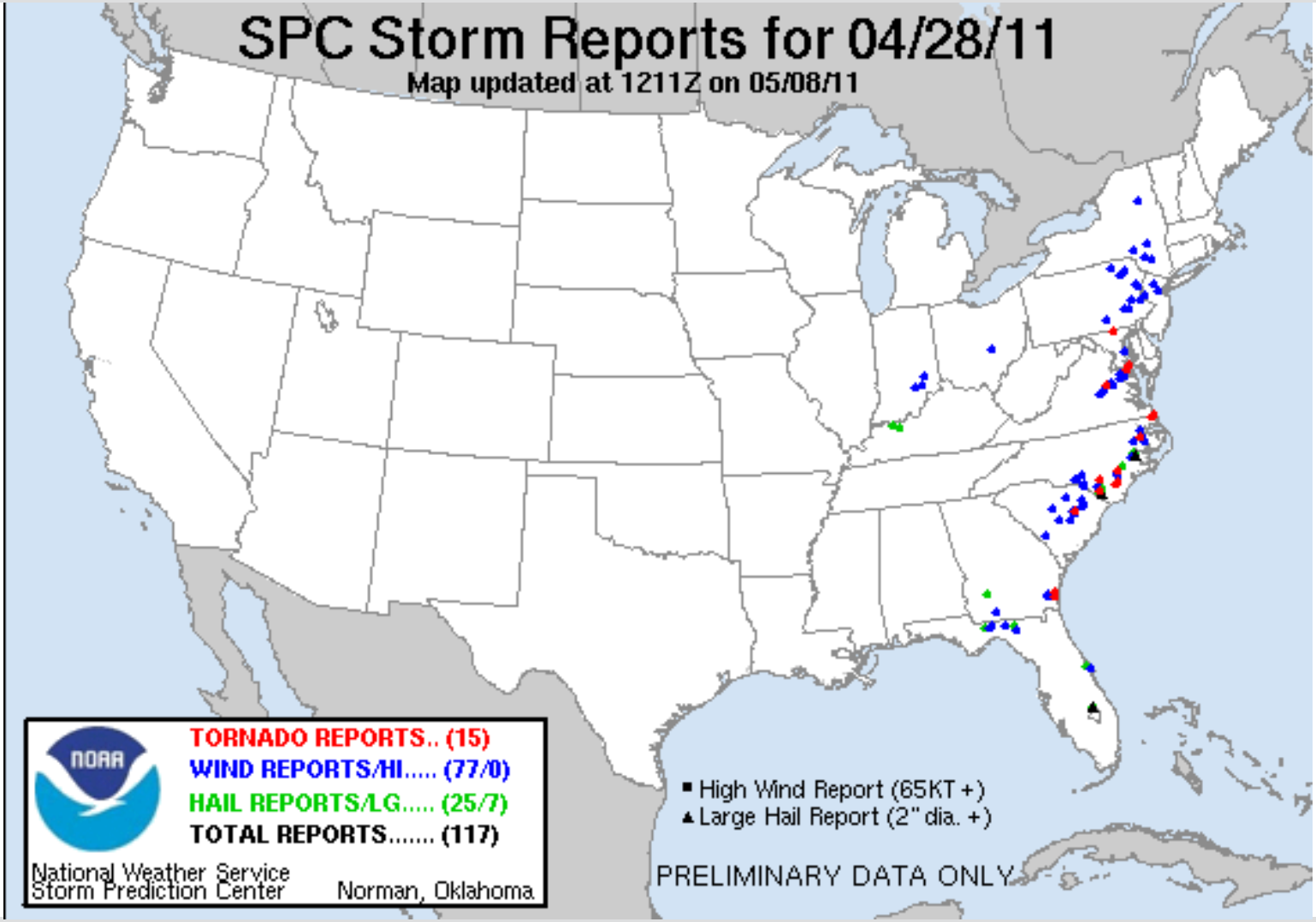
2011 Spring Tornado Outbreak: April



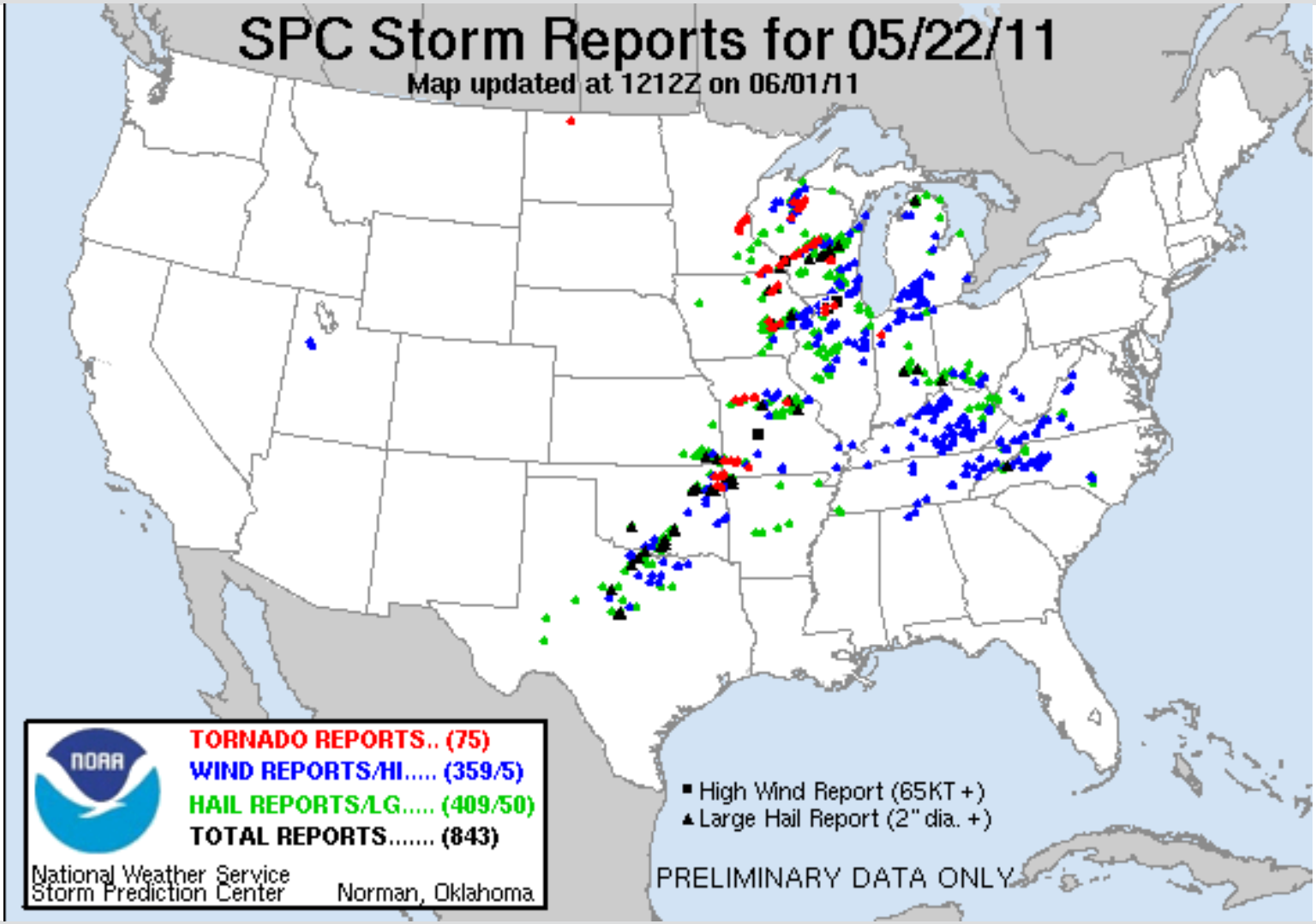
2011 Spring Tornado Outbreak: April



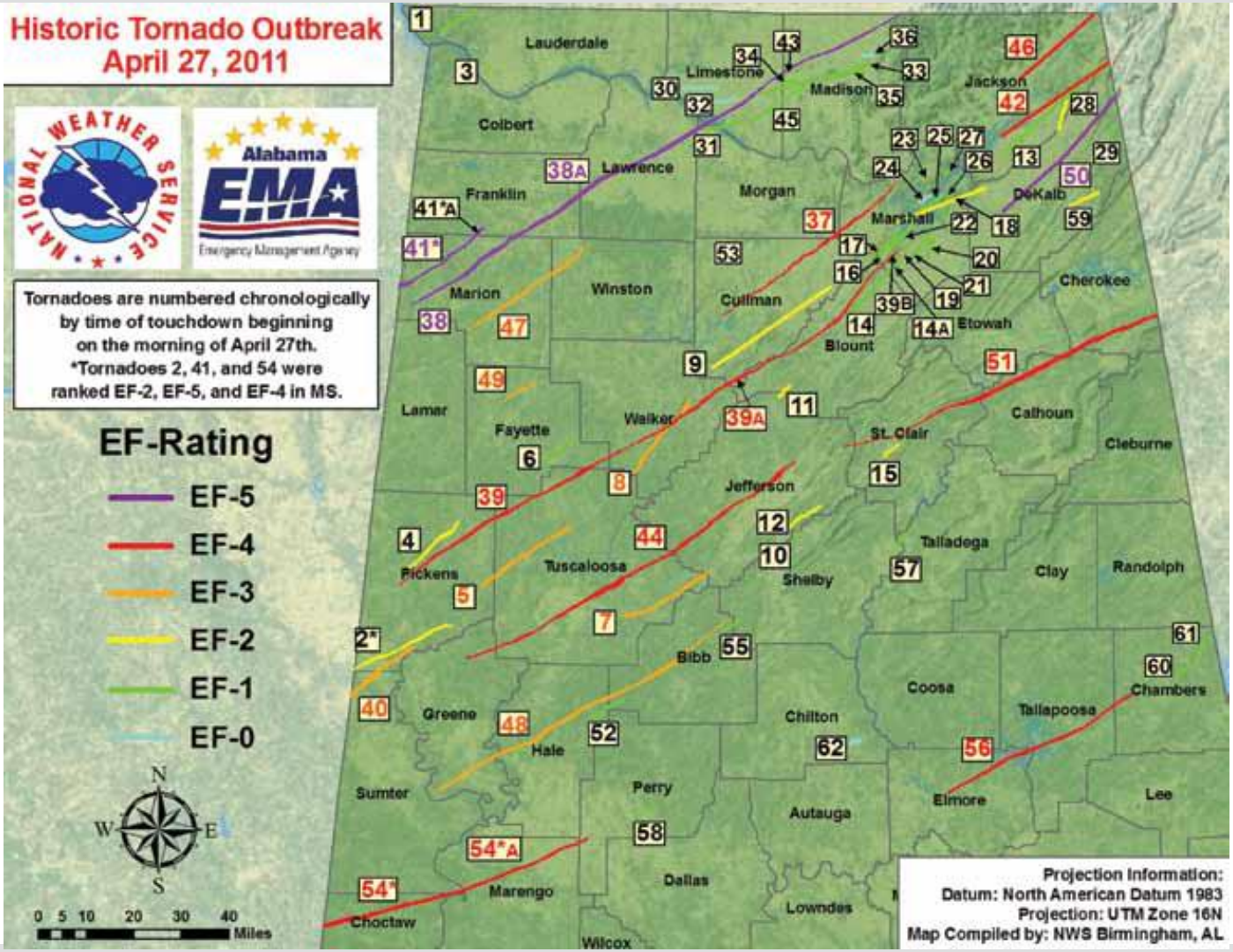
2011 Spring Tornado Outbreak: April



2011 Spring Tornado Outbreak: May



Alabama Swath Map



Source: NWS, FEMA

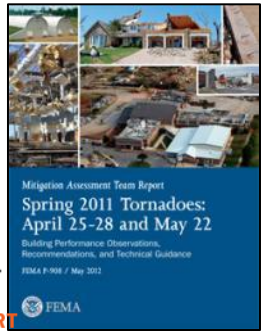
MAT Objectives and Applications

At the invitation of Alabama, Georgia, Missouri, Mississippi & Tennessee:

- Assess building performance
- Investigate safe room and shelter performance
- Provide recommendations to mitigate future tornado damage
- Advocate mitigation during recovery

MAT Timeline

FEMA MAT
MITIGATION ASSESSMENT TEAM



TORNADO DISASTERS April 27 and May 22, 2011

SAFER AL SUMMIT June 2011

RECOVERY ADVISORIES June–August 2011

R&D, RECOMMENDATIONS August 2011–April 2012

JOPLIN TRAININGS April–May 2012

MAT REPORT May 2012

Congressional Briefing / Displays and Animations / Exhibits / Multimedia
National Conferences / Publications / Guidance for Regions

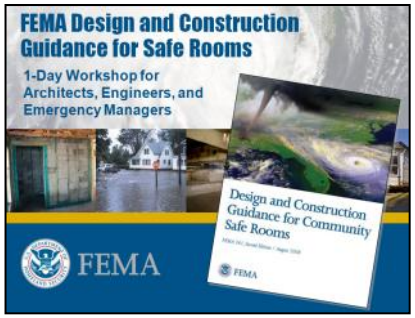
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2011 2012

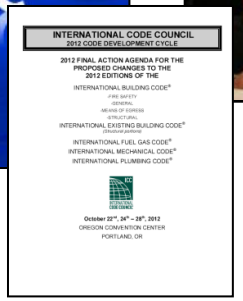
AL AND GA TRAININGS May–Sept 2011

CODE PROPOSALS January 2012

CODE HEARINGS April 2012

eGOV DELIVERY May 18, 2012





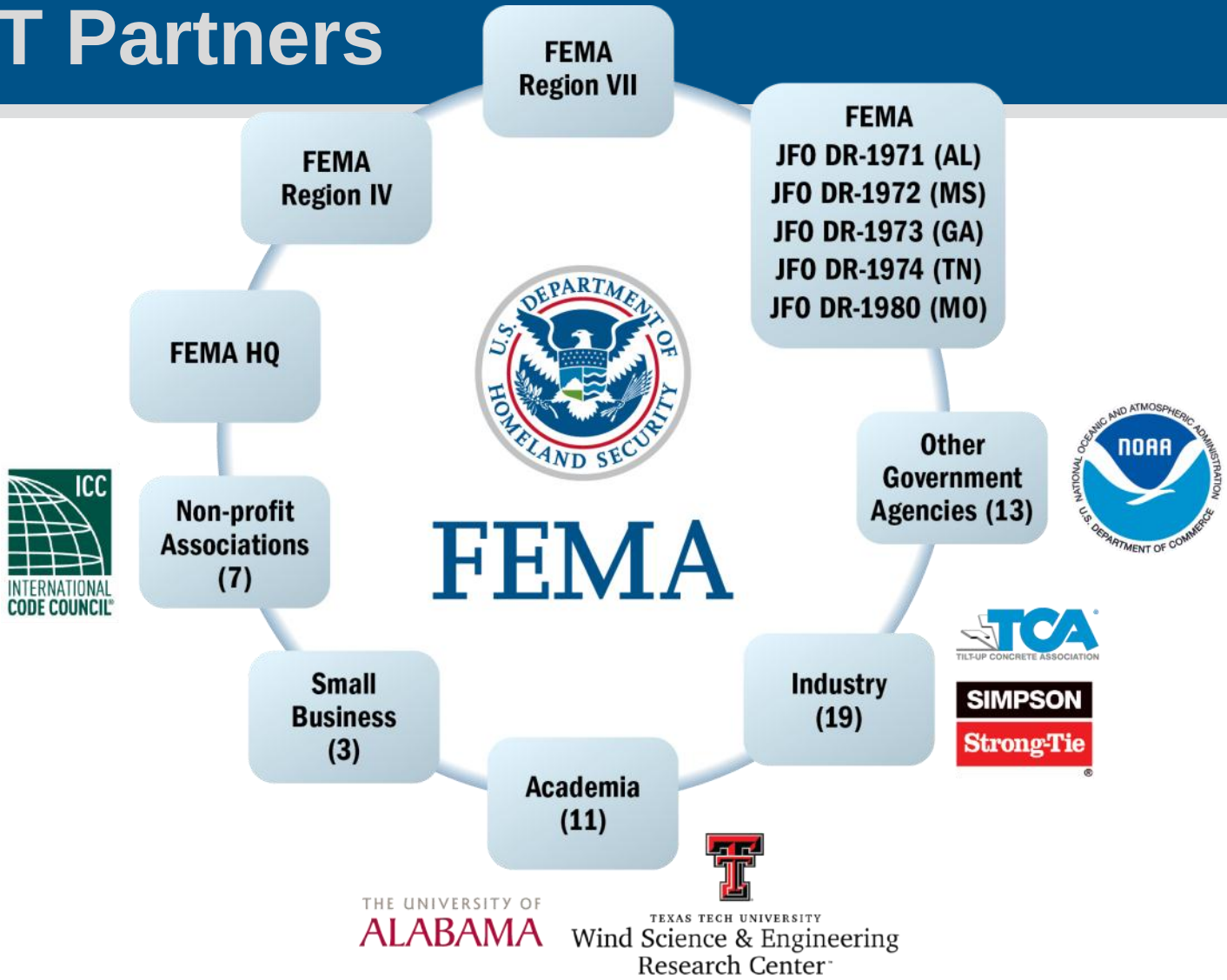
SEI ASCE STRUCTURAL ENGINEERING INSTITUTE

Bring awareness of MAT results to groups for outreach

FEMA 320 CMU with WOOD FRAME and STEEL SHEATHING ROOF SAFE ROOM

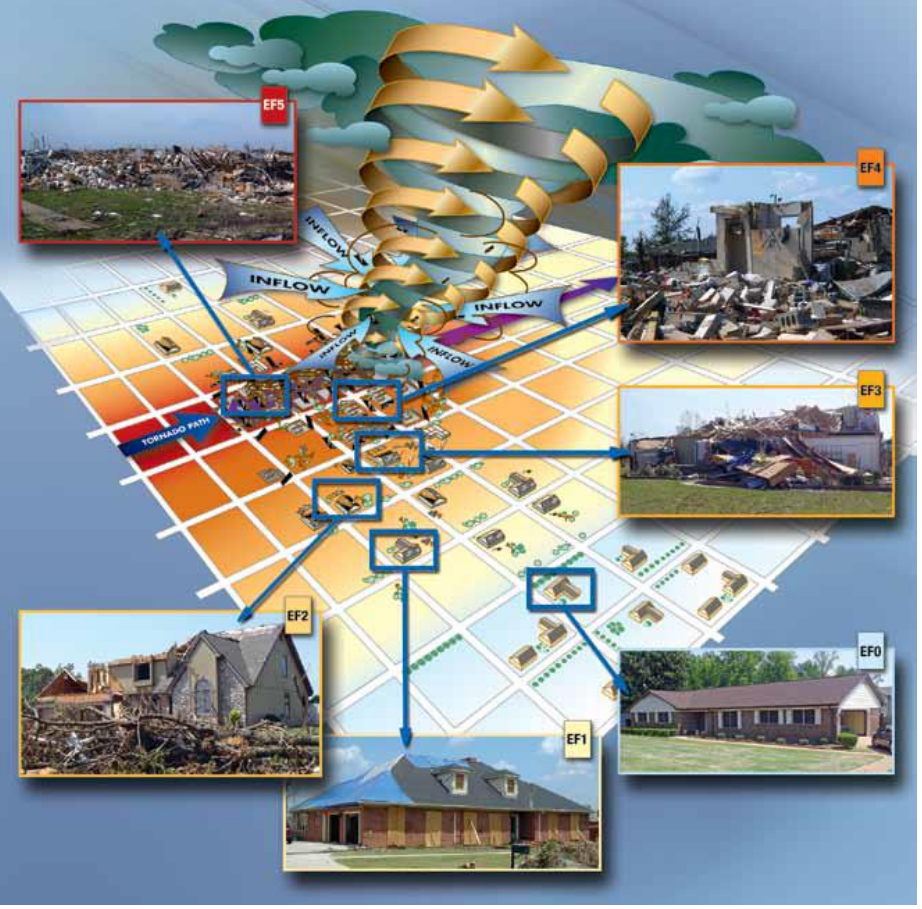
DR -1971 Alabama awarded grants for 2937 private and 109 public saferooms

MAT Partners



Numbers represent organizations or other agencies, including team members, reviewers, and other acknowledged parties

Sites Visited by the MAT



EF 0	EF 1	EF 2	EF 3	EF 4	EF 5

Observations ➡ Conclusions ➡ Recommendations

Observations are vital -- but perishable

Tree-fall

Tuscaloosa, AL **EF2**

Occupied nursing home

New Housing Complex

Tuscaloosa, AL

EF4

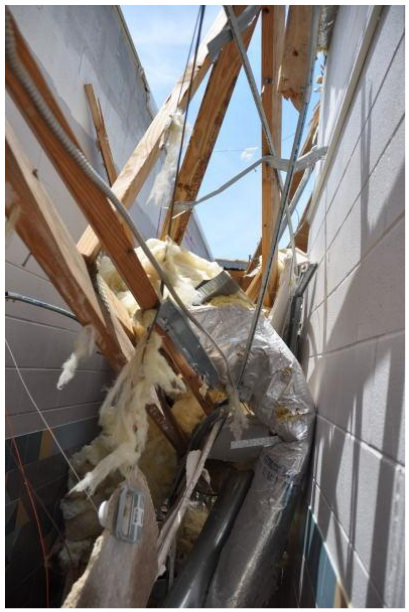
New Housing Complex

Sales Office

EF4

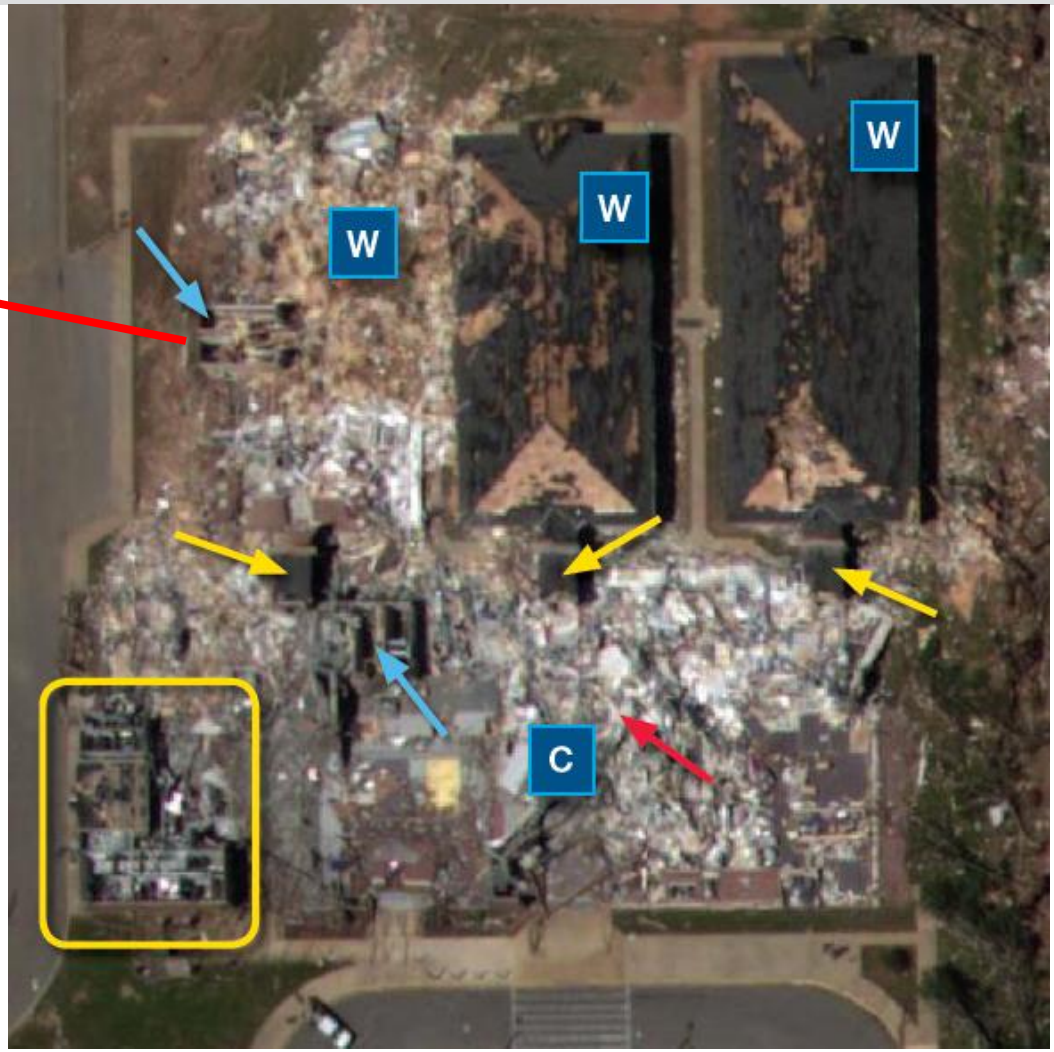
Tuscaloosa, AL

Elementary School

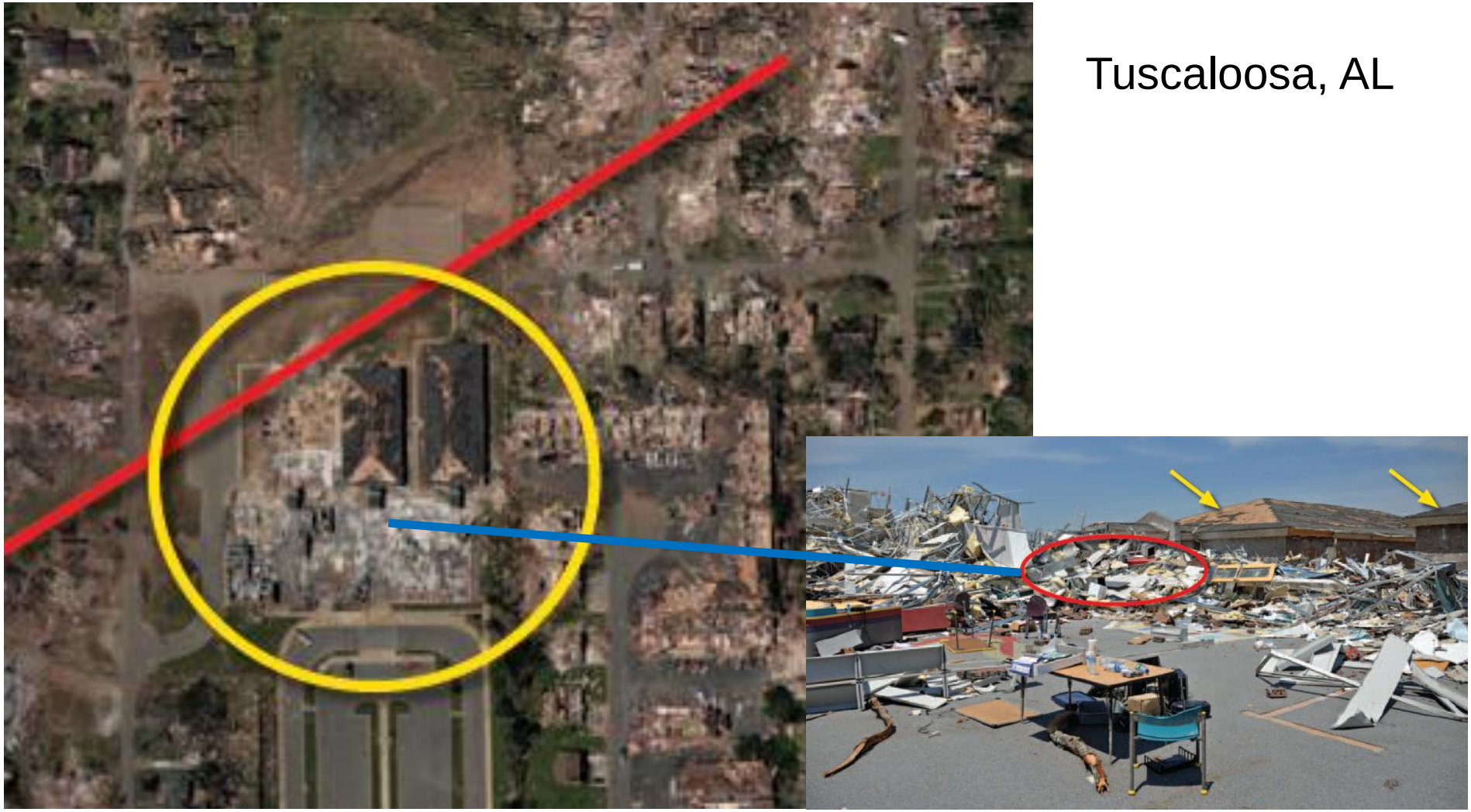


EF4

Tuscaloosa, AL

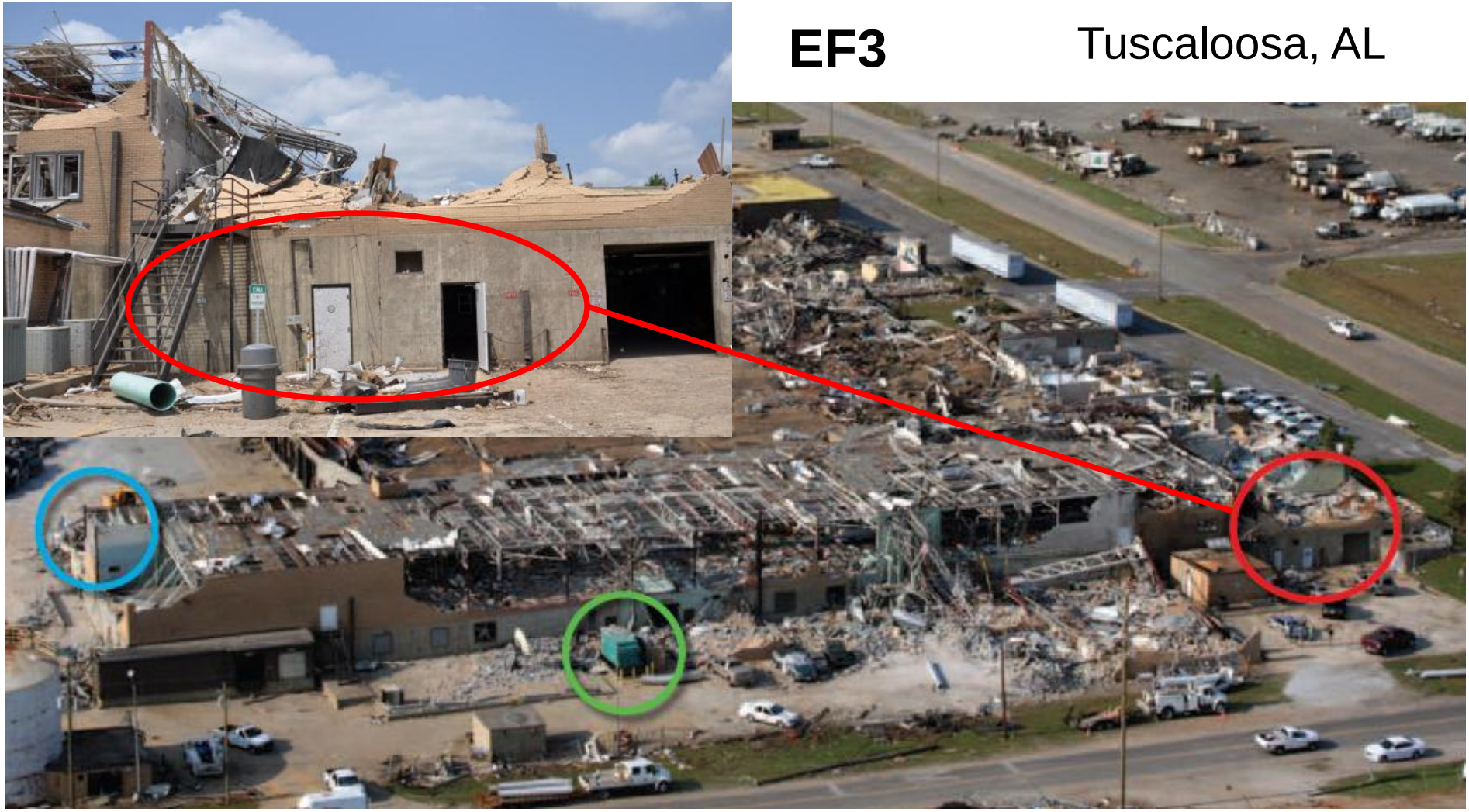


Elementary School



Tuscaloosa, AL

Emergency Operations Center

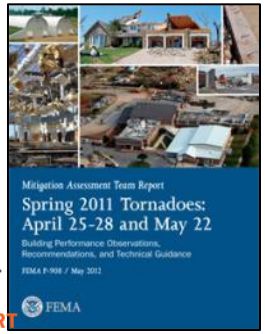


EF3 Tuscaloosa, AL

Public Works Department Refuge Area

MAT Timeline

FEMA MAT
MITIGATION ASSESSMENT TEAM



TORNADO DISASTERS
April 27 and May 22, 2011

SAFER AL SUMMIT
June 2011

RECOVERY ADVISORIES
June–August 2011

R&D, RECOMMENDATIONS
August 2011–April 2012

JOPLIN TRAININGS
April–May 2012

MAT REPORT
May 2012

Congressional Briefing / Displays and Animations / Exhibits / Multimedia
National Conferences / Publications / Guidance for Regions

APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2011 2012

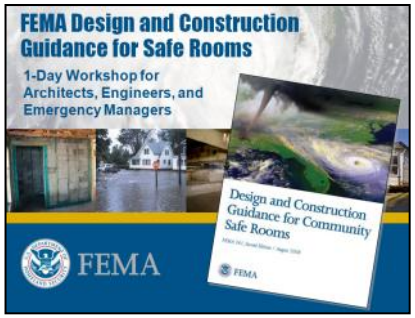
AL AND GA TRAININGS
May–Sept 2011

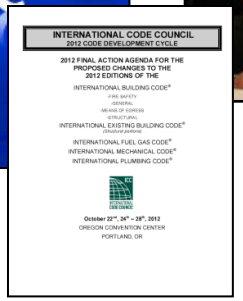
CODE PROPOSALS
January 2012

CODE HEARINGS
April 2012

eGOV DELIVERY
May 18, 2012

Bring awareness of MAT results to groups for outreach



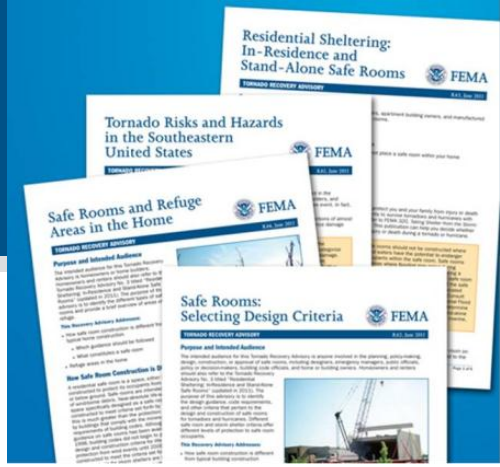


SEI ASCE STRUCTURAL ENGINEERING INSTITUTE

FEMA 320 CMU with WOOD FRAME and STEEL SHEATHING ROOF SAFE ROOM

DR -1971 Alabama awarded grants for 2937 private and 109 public saferooms

Recovery Advisories



- RA 1 – **Tornado Risks and Hazards in the Southeastern United States**
- RA 2 – **Safe Rooms: Selecting Design Criteria**
- RA 3 – **In-Residence and Stand-Alone Safe Rooms**
- RA 4 – **Safe Rooms and Refuge Areas in the Home**
- RA 5 & 6 – **Critical Facilities in Tornado-Prone Regions** (for facility owners and A/E professionals, respectively)
- RA 7 – **Rebuilding and Repairing Your Home After a Tornado**
- RA 8 – **Reconstructing Non-Residential Buildings After a Tornado**

Findings and Recommendations: Critical Facilities

Critical Facilities Located in Tornado-Prone Regions: Recommendations for Architects and Engineers

FEMA

RA6, August 2011

TORNADO RECOVERY ADVISORY

Purpose and Intended Audience

Critical facilities are emergency operations centers (EOCs), fire and police stations, hospitals, nursing homes, schools, and other buildings that are essen... tial for the delivery of vital services or protection of a community. Tornado damage investigations and other research have helped to identify techniques for protecting occupants of critical facilities struck ... tornadoes, as well as maintaining continuity of ope... tions for those facilities. The 2011 tornadoes that struck the southeast United States specifically hig... lighted the importance of properly selecting the be... available refuge areas in existing facilities as well ... the importance of minimizing collapse hazards, su... as tall trees and other nearby objects.

The purpose of this advisory is to inform architects and engineers of design enhancements that can be made to both existing facilities and facilities in the planning stage. With this awareness, desired enhancements can be incorporated into construc... documents.

The interim information in this Recovery Adviso... intended to assist during the recovery and rede... opment of tornado-damaged areas and to mini... future tornado damage and interruption of ope... tions. This information was developed because the lack of design guidance on this topic.

This Recovery Advisory Addresses:

- Existing Buildings
  - Best available refuge areas
  - Tree fall and other collapse hazards
- New Buildings and Additions to Existing Buil...
  - Safe rooms
  - Strengthening new facilities to minimize damage from tornadoes
  - Enhancements to avoid interrupted ope... tions

Critical Facilities Located in Tornado-Prone Regions

Critical Facilities Located in Tornado-Prone Regions: Recommendations for Facility Owners

FEMA

RA5, July 2011

TORNADO RECOVERY ADVISORY

Purpose and Intended Audience

Critical facilities are emergency operations centers (EOCs), fire and police stations, hospitals, nursing homes, schools, and other buildings that are essential for the delivery of vital services or protection of a community. Tornado damage investigations and other research have shown us techniques for protecting occupants of critical facilities struck by tornadoes, as well as maintaining continuity of operations for those facilities. The 2011 tornadoes that struck the southeast United States specifically highlighted the importance of properly selecting the best available refuge area in existing facilities as well as the importance of minimizing collapse hazards, such as tree fall and other nearby objects. The purpose of this advisory is to inform critical facility owners of enhancements that can be made both to existing facilities and those still in the planning stage. With this awareness, facility owners can budget for desired enhancements and request that these enhancements be incorporated into the construction documents.

This Recovery Advisory Addresses:

- Best available refuge areas
- Tree fall and other collapse hazards
- Safe rooms
- Strengthening new facilities to minimize damage from tornadoes
- Enhancements to avoid interrupted operations

Existing Buildings

Critical facility owners should hire the services of a qualified architect or engineer to evaluate their existing building. The evaluation should determine whether the facility adequately protects occupants, operations, and the facility itself from tornadoes and other appropriate hazards. The evaluation should identify the best available refuge areas in the existing facility. Any needed enhancements can be incorporated into capital improvement planning and budgeting. Lack of adequate planning can result in loss of operation and possible loss of life when buildings are inadequately hardened or lack a best available refuge area for occupants (Figure 1).

Best Available Refuge Areas

In regions of the United States subject to tornadoes, identifying the best available refuge areas within buildings is essential for the safety of building occupants. **Safe rooms** specifically designed

Figure 1: An EOC in Tuscaloosa, AL, that saw a loss of operations but remained intact even though the story above it collapsed (Tornado 2011)
PHOTO COURTESY OF THE TUSCALOOSA COUNTY SHERIFF'S OFFICE.

Recommendations for Facility Owners HSFEHQ-11-J-0004, 0005 / July 2011 Page 1 of 6

RA 5 (owners) & RA6 (architects/engineers)

- Existing facilities
- New facilities

Findings and Recommendations: Critical Facilities

Existing facilities

- **Best available refuge area**
- Tree fall and other collapse hazards

Figure 2: Collapsed concrete masonry unit (CMU) walls at a Joplin, MO, school restroom (2011 Tornado)

Findings and Recommendations: Critical Facilities

New facilities

- **Safe rooms**
- Minimize damage
- Ensure continuity of operations

Findings and Recommendations: Critical Facilities

Table 1: Summary of Provisions to Minimize Building Damage by Enhancement Level

Enhancement Levels	Recommendations
Level 1	• Resist test Missile E • Special roof system • Avoid listed roof and wall coverings • Design fire station apparatus bay doors for a basic wind speed of 150 mph
Level 2	• Level 1 enhancement recommendations • Design for basic wind speed of 150 mph
Level 3	• Level 2 enhancement recommendations • Special roof deck and exterior walls

New facilities

- Safe rooms
- **Minimize damage**
- Ensure continuity of operations

Findings and Recommendations: Critical Facilities

New facilities

- Safe rooms
- Minimize damage
- **Ensure continuity of operations**

EF3

St. John's Medical Center, Joplin, MO

MAT Report - FEMA P-908

3. Design and Construction Considerations

4. Residential Buildings

5. Commercial and Industrial Buildings

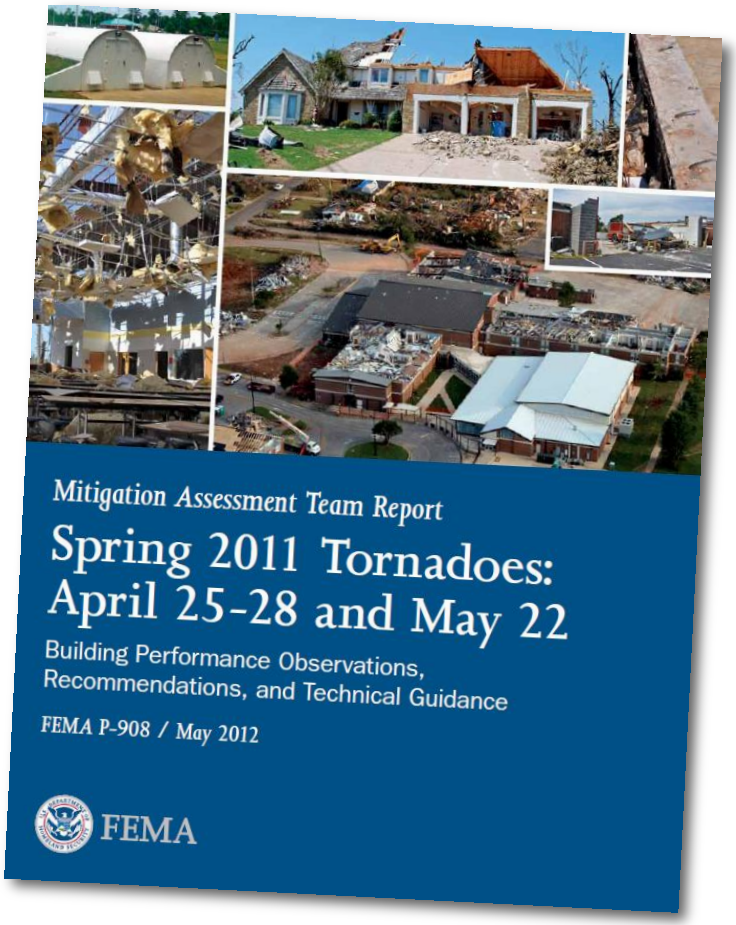
6 & 7. Schools & Critical Facilities

8. Infrastructure

9. Sheltering & Safe Rooms

App F. Recovery Advisories

App G. One- and Two-Family Residences



Recommendation Summary

Topic	49 Total Recommendations
Codes and Standards - Improve risk identification and guidance - Safe rooms / storm shelters required for some occupancies - Continue code adoption	14
Residential Construction	1
Commercial and Industrial Buildings - Design/construction/materials solutions - Perform vulnerability assessments or install safe rooms or storm shelters	9
Critical Facilities	5
Infrastructure Facilities	4
Tornado Refuge Areas, Hardened Areas, and Safe Rooms - Perform vulnerability assessments of refuge areas/hardened areas - Research travel time, more guidance on locating safe rooms for communities	8
EF Scale	5
Post-Tornado Imagery	3

Residential Buildings: Above-Code Best Practices

Conclusion: Voluntary implementation of better design and construction practices could mitigate damage

Recommendation: Implement voluntary best practices to mitigate damage to one- and two-family residential buildings

Reference MAT Report Appendix G

Commercial and Industrial Buildings: Long Spans and Large Footprints

Conclusion:

Current codes and standards are insufficient to manage building performance in wind overload events

Recommendations:

Change risk category for large-footprint commercial structures with long-span roofs to Risk Category III in ASCE 7-10

Install a storm shelter or safe room or identify best available refuge areas in large-footprint buildings

Schools: Code Requirements

Conclusion: IBC-compliant facilities can be susceptible to building damage

Recommendation: Propose IBC code change to require FEMA 361 or ICC 500-compliant safe room/storm shelter in new K-12 schools in areas where shelter design wind speed is 250mph

Schools: Code Requirements

Recommendation: Propose IBC code change to require FEMA 361 or ICC 500-compliant safe room/storm shelter in new K-12 schools in areas where shelter design wind speed is 250mph

SECTION 423
STORM SHELTERS

423.1 General. In addition to other applicable requirements in this code and this section, storm shelters shall be constructed in accordance with ICC-500.

423.1.1 Scope. This section applies to the construction of storm shelters constructed as separate detached buildings or constructed as safe rooms within buildings for the purpose of providing safe refuge from storms that produce high winds, such as tornados and hurricanes. Such structures shall be designated to be hurricane shelters, tornado shelters, or combined hurricane and tornado shelters.

423.2 Definitions. The following terms are defined in Chapter 2:
STORM SHELTER.
Community storm shelter.
Residential storm shelter.

423.3 Group E Occupancies. In areas where the shelter design wind speed for tornadoes is 250 MPH per Figure 304.2(1) of ICC 500, all Group E Occupancies with an aggregate occupant load of 50 or more shall have a storm shelter constructed in accordance with ICC 500. The shelter shall be capable of housing the total occupant load of the Group E occupancy.

Exceptions:
1. Group E day care facilities.
2. Group E occupancies accessory to places of religious worship.
3. Buildings meeting the requirements for shelter design in ICC 500.

PASSED!

Code change proposal will be incorporated into the 2015 IBC

Other Critical Facilities: Code Requirements

Conclusion: IBC-compliant facilities can be susceptible to building damage

Recommendation: Propose IBC code change to require FEMA 361 or ICC 500-compliant safe room/storm shelter in new critical facilities

Other Critical Facilities: Code Requirements

Recommendation:
Propose IBC code change to require FEMA 361 or ICC 500-compliant safe room/storm shelter in new critical facilities

PASSED!

Code change proposal will be incorporated into the 2015 IBC

SECTION 423
STORM SHELTERS

423.1 General. In addition to other applicable requirements in this code and this section, storm shelters shall be constructed in accordance with ICC-500.

423.1.1 Scope. This section applies to the construction of storm shelters constructed as separate detached buildings or constructed as safe rooms within buildings for the purpose of providing safe refuge from storms that produce high winds, such as tornados and hurricanes. Such structures shall be designated to be hurricane shelters, tornado shelters, or combined hurricane and tornado shelters.

423.2 Definitions. The following terms are defined in Chapter 2:

STORM SHELTER.
Community storm shelter.
Residential storm shelter.

423.3 Critical Emergency operations. In areas where the shelter design wind speed for tornadoes per Figure 304.2(1) of ICC 500 is 250 MPH, 911 call stations, emergency operation centers and fire, rescue, ambulance and police stations shall have a storm shelter constructed in accordance with ICC 500.
Exception: Buildings meeting the requirements for shelter design in ICC 500.

Refuge and Safe Rooms: Usage

Conclusions:

People traveled excessive distances to community shelters and safe rooms

Guidance for identifying how to communicate where community-wide protection is lacking

Recommendations:

Research travel time to, and use of, safe rooms and storm shelters

Locate safe rooms or storm shelters close to people who will use them

Refuge and Safe Rooms: Labeling and Signage

Conclusion: There is a lack of proper labeling and signage for areas where people seek refuge from tornadoes

Recommendation: Submit proposal for code change to IBC regarding identification of best available refuge areas

Refuge and Safe Rooms: Vulnerability

Conclusion:

Tornado refuge areas located in large, single-story buildings performed poorly

Recommendations:

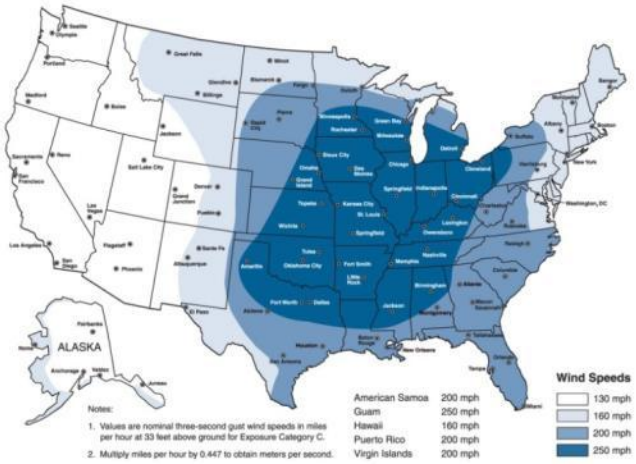
Identify best available refuge areas

Perform vulnerability assessments

Building Codes and Standards Changes

ICC 500 compliant shelters in school facilities with 50 or more occupants and all first-responders facilities

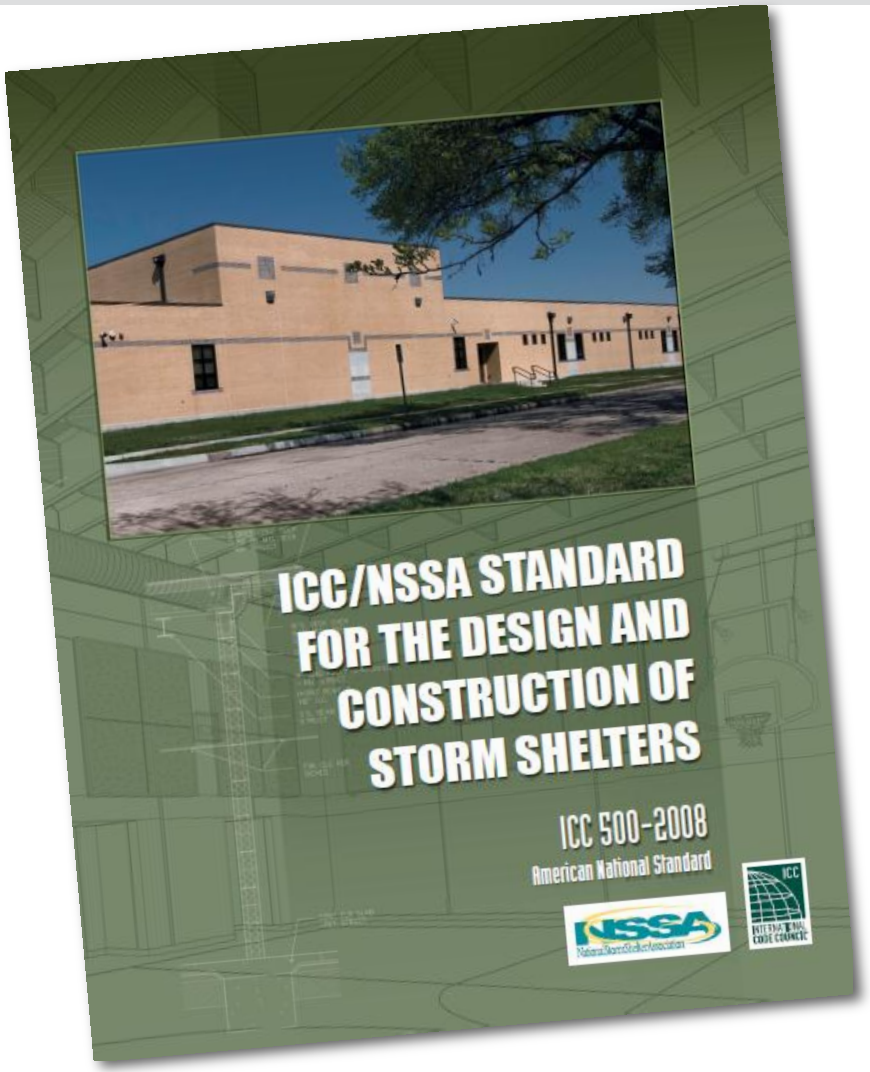
May 2012: passed the 2015 IBC first public I-code hearing



Building Codes and Standards Changes

- Standard does not address tornadoes
- Commentary has 2 paragraphs about tornadoes, and a wind speed map from 1983
- Expanded Commentary and the wind speed map from FEMA 361 is being developed for balloting

Building Codes and Standards Changes



- MAT recommendations considered
- 14 proposals submitted to committee
- MAT observations used for justification of proposed changes

HMA Considerations

Conclusions
Travel Distances (Proximity)
Public action/movement patterns, safe room type selection
Labeling/signage, unregistered safe rooms, access, safe room location.
Anchoring, Ventilation
Non BS Eligible Costs
Recommendations
Visual Aides: Check Lists or Flip Charts
Alternate Electrical Source
Travel Time Research, Safe Room Location/Proximity to users
Register Safe Room

Putting Results into Action

Recovery advisories

Training

Summit

Video

Interviews

Models

Codes advocacy

Structures Congress

Peer reviewed journal articles

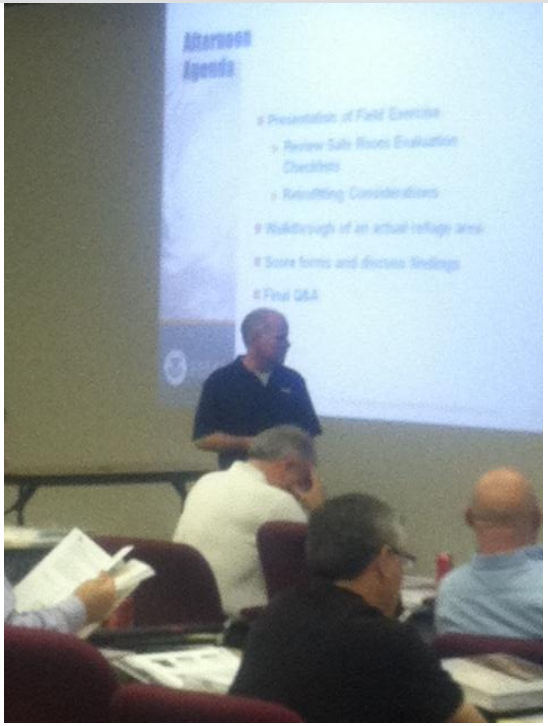
FEMA Administrator's Award

I remember being a little worried about the cost of the MAT but I was confident it was the right thing to do. It is so great to see all the benefit that came from their good work. I won't hesitate to bring them in again in the future, and will share with other FCOs.

Michael Byrne, FCO

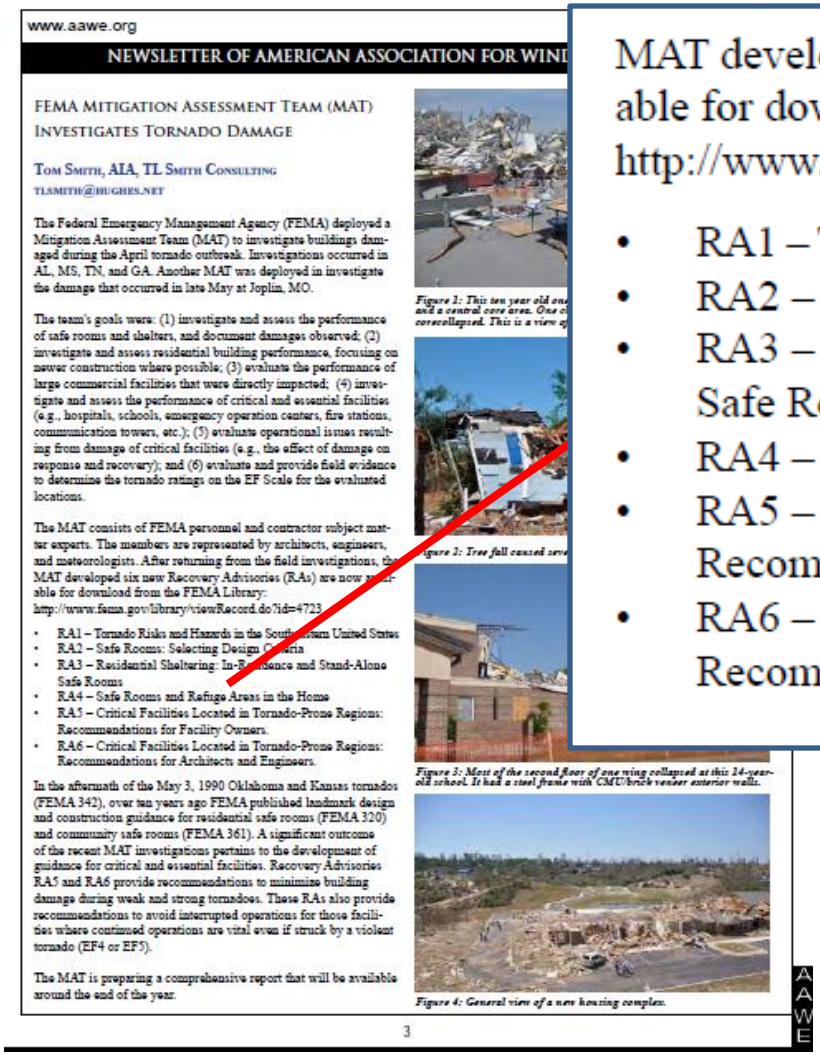
Safe Room Training

- **Preparing a Successful Safe Room Grant Application**
  - Birmingham, AL
  - Kansas City, MO and Springfield, MO
- **Evaluating Buildings for Use as Best Available Refuge**
  - Athens, Dalton, Tifton and Barnesville, GA
  - Kansas City, MO Joplin, MO, Jefferson City, MO
- **Design and Construction for Safe Rooms**
  - Birmingham, AL
  - St. Charles, MO and Jefferson City, MO



Here's what they're saying:
"Hands-on…Practical.. …Lots of Info…Not Watered Down…Great study guide."

Putting Results into Action



www.aawe.org

NEWSLETTER OF AMERICAN ASSOCIATION FOR WIND

FEMA MITIGATION ASSESSMENT TEAM (MAT) INVESTIGATES TORNADO DAMAGE

TOM SMITH, AIA, TL SMITH CONSULTING
TLSMITH@HUGHES.NET

The Federal Emergency Management Agency (FEMA) deployed a Mitigation Assessment Team (MAT) to investigate buildings damaged during the April tornado outbreak. Investigations occurred in AL, MS, TN, and GA. Another MAT was deployed in investigate the damage that occurred in late May at Joplin, MO.

The team's goals were: (1) investigate and assess the performance of safe rooms and shelters, and document damages observed; (2) investigate and assess residential building performance, focusing on newer construction where possible; (3) evaluate the performance of large commercial facilities that were directly impacted; (4) investigate and assess the performance of critical and essential facilities (e.g., hospitals, schools, emergency operation centers, fire stations, communication towers, etc.); (5) evaluate operational issues resulting from damage of critical facilities (e.g., the effect of damage on response and recovery); and (6) evaluate and provide field evidence to determine the tornado ratings on the EF Scale for the evaluated locations.

The MAT consists of FEMA personnel and contractor subject matter experts. The members are represented by architects, engineers, and meteorologists. After returning from the field investigations, the MAT developed six new Recovery Advisories (RAs) are now available for download from the FEMA Library: http://www.fema.gov/library/viewRecord.do?id=4723

- RA1 – Tornado Risks and Hazards in the Southeastern United States
- RA2 – Safe Rooms: Selecting Design Criteria
- RA3 – Residential Sheltering: In-Residence and Stand-Alone Safe Rooms
- RA4 – Safe Rooms and Refuge Areas in the Home
- RA5 – Critical Facilities Located in Tornado-Prone Regions: Recommendations for Facility Owners.
- RA6 – Critical Facilities Located in Tornado-Prone Regions: Recommendations for Architects and Engineers.

In the aftermath of the May 3, 1990 Oklahoma and Kansas tornados (FEMA 342), over ten years ago FEMA published landmark design and construction guidance for residential safe rooms (FEMA 320) and community safe rooms (FEMA 361). A significant outcome of the recent MAT investigations pertains to the development of guidance for critical and essential facilities. Recovery Advisories RA5 and RA6 provide recommendations to minimize building damage during weak and strong tornadoes. These RAs also provide recommendations to avoid interrupted operations for those facilities where continued operations are vital even if struck by a violent tornado (EF4 or EF5).

The MAT is preparing a comprehensive report that will be available around the end of the year.

Figure 3: Most of the second floor of one wing collapsed at this 24-year-old school. It had a steel frame with CMU/brick veneer exterior walls.

Figure 4: General view of a new housing complex.

3

MAT developed six new Recovery Advisories (RAs) are now available for download from the FEMA Library: http://www.fema.gov/library/viewRecord.do?id=4723

- RA1 – Tornado Risks and Hazards in the Southeastern United States
- RA2 – Safe Rooms: Selecting Design Criteria
- RA3 – Residential Sheltering: In-Residence and Stand-Alone Safe Rooms
- RA4 – Safe Rooms and Refuge Areas in the Home
- RA5 – Critical Facilities Located in Tornado-Prone Regions: Recommendations for Facility Owners.
- RA6 – Critical Facilities Located in Tornado-Prone Regions: Recommendations for Architects and Engineers.

American Association for Wind Engineering newsletter, August 2011

Putting Results into Action

ASCE Structures Congress, March 2012, paper and presentation on RA5 and RA6:

- Enhancing Tornado Performance of Critical Facilities: *Findings and Recommendations of FEMA's Mitigation Assessment Team*

Reprinted in May issue of Civil Engineering (90,000 circulation)

PROTECTING CRITICAL FACILITIES

After a series of powerful tornadoes struck several states in April and May of last year, the Federal Emergency Management Agency dispatched a team to assess the performance of residential and commercial buildings and such critical facilities as hospitals and emergency operations centers. The team's observations formed the basis of several publications issued by the agency referred to as tornado recovery advisories.

By Thomas L. Smith, AIA, Manuel Perotin, P.E., CFM, M.ASCE, and Erin Walsh

A SERIES OF TORNADOES in the spring of 2011 were record breaking in their intensity and severity and in the loss of life and property damage they caused. In April a large outbreak of tornadoes struck several states, including Mississippi, Tennessee, Alabama, and portions of Georgia. Approximately 150 tornadoes touched down on April 27 and April 28, killing some 361 persons, injuring hundreds more, and causing at least $6 billion in property damage. On May 22 Joplin, Missouri, was devastated by a large tornado with winds in excess of 200 mph that killed at least 141 persons, injured more than 750, and caused as much as $3 billion in damage. The Joplin storm was "the deadliest single tornado since modern record keeping began in 1950," according to "Tornado Risks and Hazards in the Southeastern United States," a document issued by the Federal Emergency Management Agency (FEMA) in June 2011 and referred to as a tornado recovery advisory.

FEMA dispatched a team to assess building performance in five of the states hit by last year's tornadoes. The team assessed residential and commercial buildings, as well as such critical facilities as hospitals, fire stations, police stations, schools, and emergency operation centers, that had been struck by weak (EF0–EF1), strong (EF2–EF5), or violent tornadoes (EF4–EF5). (See table 1, on page 55, for the wind speeds associated with the EF ratings.) The tornadoes significantly affected many critical facilities, destroying some and severely interrupting operations at others. Some of the observed facilities were damaged by winds that were below current design wind speeds.

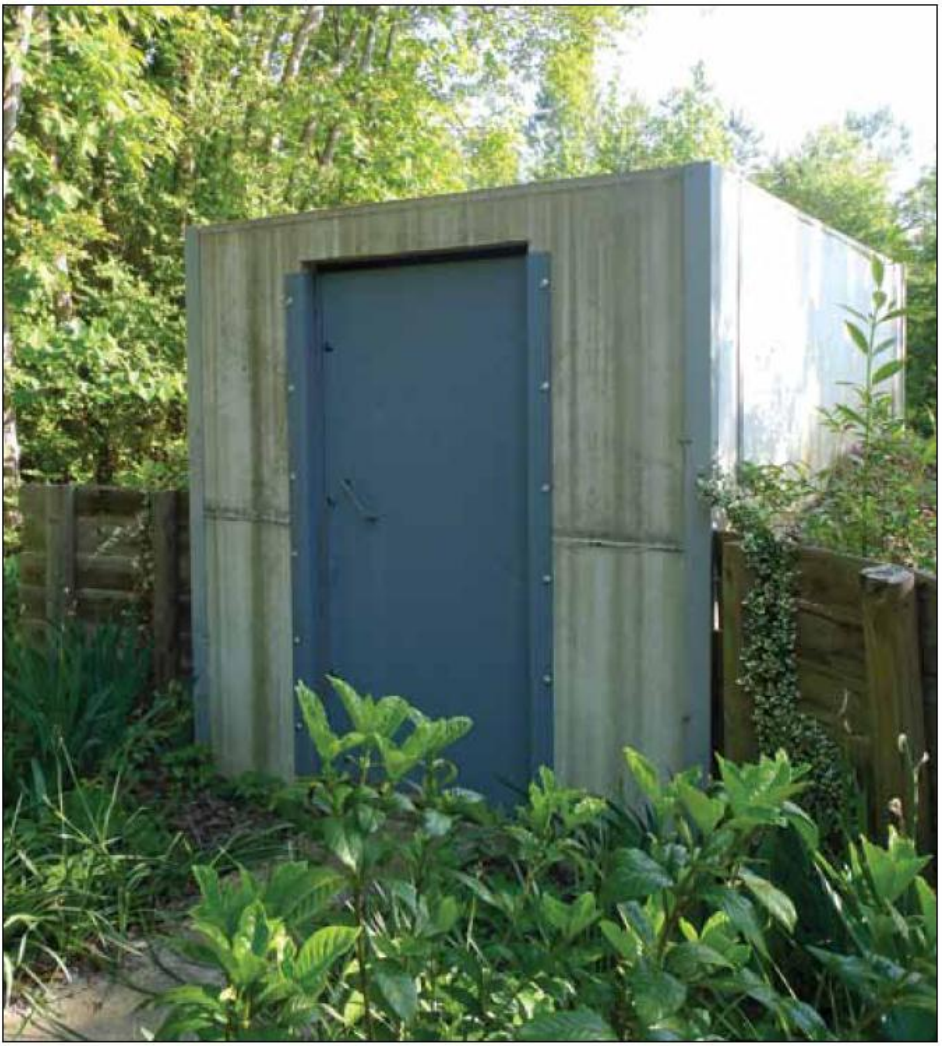
Several of the critical facilities that were observed performed poorly, and most did not perform any better than the commercial buildings. The damage to critical facilities resulted in occupant deaths and injuries and jeopardized many other occupants. Building damage placed additional burdens on response and recovery

A hospital in Joplin, Missouri, lost its emergency power when the building housing the switchgear and emergency generator collapsed following an EF5 tornado in 2011. Most of the exterior glass was broken as well, too.

[52] Civil Engineering MAY 2012

MAY 2012 Civil Engineering [53]

Building Science / Safe Room Helpline



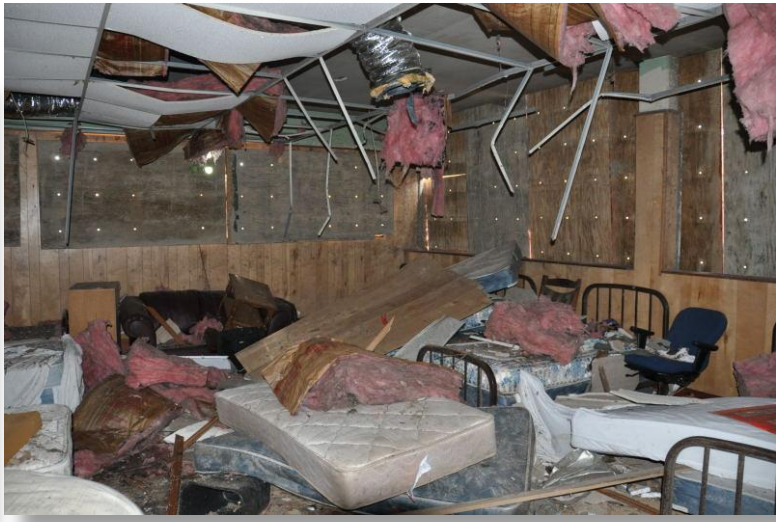
- Building Science Helpline received over 1,800 inquiries related to safe rooms in the past 12 months
- SafeRoom@fema.dhs.gov
- (866) 927-2104

Lasting Impacts

Building Code Changes to Require Safe Rooms for Schools and First-Responder Facilities

IBC 2015 requirement to have an ICC 500 compliant shelter

Tuscaloosa Fire Station 4



Lasting Impacts

Mind-set and guidelines (RA5 and RA6) to:

- Minimize damage from weak and strong tornadoes (EF0-EF3)
- Maintain continuity of operations if struck by violent tornadoes (EF4-EF5)