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National Institute of Standards and Technology (NIST)
Technical Investigation of the Joplin, Missouri, Tornado of May 22, 2011

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Background:
Following the May 22, 2011, tornado that devastated the city of Joplin, Missouri (MO), NIST sent four engineers to the area on May 24 through May 28 to conduct a preliminary reconnaissance[1]. Based on analysis of the data collected and other criteria required by law and regulation, NIST Director Patrick Gallagher established a Team under the National Construction Safety Team (NCST) Act on June 29, 2011, to proceed with a more comprehensive study of the impacts of the disaster. This document describes NIST's plan for conducting the technical investigation.

Goals:
- To investigate the wind environment and technical conditions that caused fatalities and injuries in the May 22, 2011, Joplin, MO, tornado, the performance of emergency communications systems and public response, and the performance of residential, commercial, and critical buildings; designated safe areas in buildings; and lifelines.
- To serve as the basis for:
    - Potential improvements to requirements for design and construction of buildings, designated safe areas, and lifeline facilities in tornado-prone regions;
    - Potential improvements to guidance for tornado warning systems and emergency response procedures;
    - Potential revisions to building, fire, and emergency communications codes, standards, and practices; and
    - Potential improvements to public safety.

Objectives:
The primary objectives of the NIST technical investigation of the Joplin tornado are to:
1. Determine the tornado hazard characteristics and associated wind fields in the context of historical data;
2. Determine the pattern, location, and cause of fatalities and injuries, and associated performance of emergency communications systems and public response;
3. Determine the response of residential, commercial, and critical buildings, including the performance of designated safe areas;
4. Determine the performance of lifelines as it relates to the continuity of operations of residential, commercial, and critical buildings; and

[1] See http://www.nist.gov/el/disasterstudies/upload/Joplin_Reconnaissance_Presentation061511-2.pdf for more information about the preliminary reconnaissance of the Joplin MO tornado.

5. Identify, as specifically as possible, areas in current building, fire, and emergency communications codes, standards, and practices that warrant revision.

Guiding Principles:

- Active, comprehensive, independent, and objective technical investigation that is fully informed by the scientific and engineering facts and phenomena, within the limits of available resources.
- Open and inclusive process in planning and conducting the investigation, and in publishing and disseminating findings and recommendations.
- Contribute to improving standards, codes, and practices to reduce future risks by focusing on:
    - Fact-finding and analysis of the facts, and
    - Validating and verifying existing knowledge.
- Non-technical issues are outside scope of investigation: no findings of fault of any individual or organization.
- Maintain ongoing liaison with professional community, public, and local authorities.
- Project Team includes world-class technical experts from both within and outside NIST.

Sources of Information for Plan Development:

The NIST technical investigation plan draws upon many sources of data and information from within and outside NIST, including external experts and organizations (i.e., federal, state, and local governments; industry; and academia), NIST experts in building and fire safety, and the public at large. NIST deployed a four-member reconnaissance team on May 24, 2011, two days after the tornado struck the City of Joplin. The NIST team conducted a four-day preliminary reconnaissance to collect data on the wind environment, fatalities and injuries, building performance and emergency communications during the tornado, and fires following the tornado. This plan is based on findings from the NIST preliminary reconnaissance and data and information from the sources identified above.

Rationale for the Technical Investigation:

The EF-5 tornado that struck Joplin on May 22, 2011, was the deadliest single tornado in the United States (U.S.) since the beginning of official record keeping in 1950 and the 7th deadliest in U.S. history.[2] The death toll currently stands at 162.[3] The loss of life occurred despite a warning time of 24-26 minutes, which is nearly double the National Weather Service (NWS) national average warning lead time of approximately 14 minutes[4]. On the order of 8,000 buildings in Joplin were damaged or destroyed[5], including a wide range of building types and construction types. Insured loss for the Joplin tornado alone has been estimated to be between $1 billion and $3 billion.[6] For context, in 2011 there were an estimated total of 550 tornado

[2] NOAA (http://www.noaanews.noaa.gov/2011_tornado_information.html)
[3] National Weather Service (http://www.crh.noaa.gov/sgf/?n=event_2011may22_survey)
[4] National Weather Service average for 2008 (http://www.nws.noaa.gov/cfo/program_planning/doc/FY-2009%20NOAA's%20NWS%20National%20Performance%20Measures%20-%20Graph%20Update.pdf)
[5] U.S. Army Corps of Engineers and Jasper County Geographic Information Services
[6] Eqecat, Inc (http://www.eqecat.com/catWatchREV/secureSite/report.cfm?id=321)

deaths[2], the most since official record keeping began in 1950[7] and the 4th deadliest year in U.S. history[2]. There were an estimated 1,691 tornadoes in 2011, the second most active tornado season on record.[2] Thunderstorms and tornadoes caused $25.8 billion of insured catastrophe losses during 2011, accounting for 72.1 percent of the total insured catastrophe losses from all U.S. natural hazards for the year (2.5 times above the 30-year average).[8] The Joplin tornado was a record tornado in a year of record U.S tornado activity and impacts. It is therefore significant and thus presents a unique learning opportunity.

The results of this investigation could stimulate major changes in U.S. building codes, standards, and in engineering practice to improve life safety and decrease property damage from tornadoes. It also could lead to significant changes to codes and standards for emergency communications systems. Therefore, the eventual impact of this investigation is expected to be the improvement of the resilience of buildings, infrastructure, and communities subjected to tornadoes.

Context and Scope of the Technical Investigation:
The large number of fatalities and buildings destroyed in the Joplin, MO, tornado is not necessarily surprising, as current national standards, codes, and practices do not require buildings and other structures to be built to withstand tornadoes. Although there are standards, codes, and guidelines which address the design and construction of tornado shelters and tornado safe rooms, their use is not mandatory, and furthermore, they only address life safety issues. There is little guidance currently available on the topic of reducing property damage in tornadoes.

The plan described in this document is to perform an investigation of the wind environment and technical conditions contributing to the fatalities and injuries, performance of emergency communications systems and public response, and performance of buildings and lifelines in the May 22, 2011, Joplin, MO, tornado. The primary outcomes of the NIST technical investigation are expected to provide the technical basis for improved codes, standards, and practices related to tornado hazard characterization and tornado-resilient design and construction, emergency communications systems, and emergency response. The intent is for the findings and recommendations to be introduced into the voluntary consensus process that is used to develop U.S. codes and standards.

Technical Approach:
The technical approach of the NIST investigation includes the following major tasks:

- **Identification of Issues Requiring Technical Investigation:** Review data and information collected from the NIST preliminary reconnaissance related to the performance of both the building envelope and the main wind force resistance system, of residential (e.g. single-family and multi-family wood frame construction), commercial (e.g. professional office, big box retail), and critical or high occupancy (e.g. hospital, schools) buildings;

[7] NOAA (http://www.norman.noaa.gov/2009/03/us-annual-tornado-death-tolls-1875-present/)
[8] Insurance Information Institute (http://www.iii.org/assets/docs/pdf/IFNY-012012.pdf)

review of the wind conditions based on observed damage and available measurements; review of performance of designated safe areas and lifeline facilities; review of the tornado warning systems, emergency procedures, and patterns, locations and causes of fatalities and injuries; review of locations and causes of post-tornado fires.

- **Data Collection:** Types of data to be obtained include: building design documents, records, plans, and specifications; construction, maintenance, and operations records; video and photographic data; field data; interviews and other oral and written accounts from building occupants, families of victims, emergency responders, building operators, and other witnesses; emergency response records, including audio communications; physical evidence; and other records. Obtain data and information from: building officials, fire and emergency response officials; local, state, and federal authorities; and the public. To the extent permitted by law, collected data will be stored in NIST's Disaster and Failure Studies Events Data Repository.
- **Analysis and Comparison of Designs, Codes and Practices for Buildings and Emergency Communications Systems:** Conduct analysis of and comparisons among various codes, standards, and specifications used in the past for the City of Joplin; comparison of as-designed conditions with model code requirements and with as-built conditions as observed in the NIST preliminary reconnaissance; review and analysis of practices used for design, construction, and operation.
- **Technical Findings and Recommendations:** Preparation of final reports; peer review by established NIST Editorial Review Board; augmented NIST review to include senior management, legal, and public affairs; review of key reports by NCST Advisory Committee; review of key reports by individual outside experts as necessary.
- **Identification of Needs for Revisions to Codes, Standards, and Practices:** Identify specific areas of codes, standards, and practices in need of revision based on findings of the investigation.

Descriptions of the investigation plan related to the five objectives are outlined in Attachment 1.

Technical Expertise:
The NIST technical investigation will include world-class technical experts from both within and outside NIST. Team experts will be drawn from the NIST Engineering Laboratory and from NOAA's National Severe Storm Laboratory. Expert consultants from academia, practice, and government may be contracted on an as-needed basis.

Federal Advisory Committee:
Since the investigation is being conducted under the authority of the NCST Act, the NCST Advisory Committee (Advisory Committee) will be available to provide advice to the NIST Director on all aspects of the investigation, including scope, approach, work plan, schedule, results, findings, recommendations, and interim and final technical reports. The Advisory Committee may provide advice on the objectivity, thoroughness, and integrity of the investigation. Committee meetings will be announced in the Federal Register. The NIST Director has appointed individuals to the committee who are recognized for distinguished professional

service, possess broad technical expertise and experience, and have a reputation for independence, objectivity, and impartiality. Members represent a balance of the diverse disciplines relevant to the investigation.

Liaison with the Professional Community, the Public, and Local Authorities:
NIST will maintain ongoing liaison with the professional community and local stakeholders over the course of the investigation through briefings, presentations, and news announcement from the NIST Public Affairs Office. NIST has established a website to communicate information related to the investigation, *http://www.nist.gov/el/disasterstudies/weather/joplin_tornado_2011.cfm*.

Impact and Outcomes:
The NIST technical investigation aims to establish an understanding of the wind environment and technical conditions that caused fatalities and injuries, the performance of emergency communications systems and public response, and performance of residential, commercial, and critical buildings, including designated safe areas within buildings, and lifelines associated with the Joplin, MO, tornado.

The expected outcomes of this investigation will include findings and recommendations that provide the technical basis for:

- Assessing tornado hazard probabilities at the local, regional, and national levels;
- Potentially improving emergency communications systems and public response to those communications; and
- Potentially improving requirements for tornado-resilient design and construction of buildings and structures, including residential buildings, designated safe areas within buildings, and lifeline facilities as related to maintaining building operations.

The anticipated impacts of the NIST technical investigation include improved resilience of buildings, infrastructure, and communities to tornadoes. These improvements are specifically focused on life safety objectives and enhanced performance of buildings during tornadoes to better protect building occupants and property. In addition, the investigation may lead to enhanced emergency communications systems and lifeline performance in future disasters. Finally, the results of this investigation will inform future research for the development and dissemination of guidance and tools for assessing and reducing vulnerabilities related to tornadoes, and producing the technical basis for cost-effective changes in national codes, standards, and practices.

Attachment 1
Description of Investigation Project

Objective #1: Determine the Tornado Hazard Characteristics and Associated Wind Fields in the Context of Historical Data.

Purpose: To obtain, review and analyze information and documents relating to the specific characteristics of the May 22, 2011, Joplin, MO, tornado and how those characteristics compare to similar tornado events in an historical context at the local, regional, and national levels.

Technical Approach: This objective focuses on collection and analysis of information relevant to understanding the tornado hazard. The sources of information will include data on the meteorological conditions leading to and during the event, along with historical tornado data at the local, regional, and national levels. This information will be supplemented with measured wind speeds and estimated wind speeds, coupled with a tornadic wind field model. In addition, hazard, vulnerability, and consequences associated with the Joplin, MO, tornado compared to other events will be assessed using accumulated information for tornado characteristics, buildings and associated damage, and human, economic, and property losses. Lastly, the current process of rating tornadoes based on damage will be assessed. This objective is divided into eight tasks as follows:

Task 1 – Collect data on: meteorological conditions leading to and during the Joplin, MO, tornado; pre-storm natural and built environment conditions; post-storm conditions and damage; and historical and climatological information on tornadoes and impacts in the Joplin area.

Task 2 - Assess the meteorological conditions leading to and during the tornado, including the upper level and synoptic setup, analysis of WSR-88D radar characteristics, as well as a timeline and history of the tornado itself.

Task 3 – Develop wind speed estimates from anemometry data and indirect wind speed estimates inferred from the local tornadic environment. These estimates will then be compared with tornadic wind field models to create a map documenting the overall best estimates of maximum surface wind speeds in the tornado.

Task 4 – Assess the Joplin, MO, tornado in a climatological context. Probabilistic approaches to assess the tornado hazard at the local, regional, and national levels will be studied.

Task 5 – Analysis of the spatial characteristics and consequences of the Joplin, MO, tornado, including historical context. This analysis will include a detailed characterization of the total affected area, including damage states and a comprehensive estimate of the human, economic, and property losses by location. Comparisons with other tornado events of similar magnitude and consideration of historical changes in vulnerability due to changes in land use patterns, urbanization, and building design and construction will also be conducted.

Task 6 – Assess the practice of rating tornadoes based on observed damage, using the Enhanced Fujita (EF) scale. This task will address implementation and usage of the current EF scale and appropriateness and sufficiency of the existing damage indicators and degrees of damage used to rate the most intense tornadoes, including its use after the Joplin, MO, tornado.

Task 7 - Develop findings and issues pertaining to Objective #1.

Task 8 – Develop draft chapter of final report for Objective #1.

Objective #2: Determine the Pattern, Location, and Cause of Fatalities and Injuries and Associated Emergency Communications and Public Response.

Purpose: To determine the behavior and fate of individuals - both those who survived and those who did not - by collecting and analyzing information on injuries and fatalities, human behavior, situation awareness, and emergency communications before and during the Joplin, MO, tornado.

Technical Approach: This objective focuses on the collection and analysis of information relevant to the behavior and fate of individuals affected by the tornado. The major sources of data for this objective will include information on the location and causes of injuries and fatalities and the response of individuals to the tornado, including emergency communications, gathered via direct accounts from first responders, survivors and families and friends of victims. In addition, archival data on previous tornado events, and national and local codes, standards, and practices related to U.S.-based tornado warnings will be studied. Finally, pre-event data for Joplin, MO, in relation to tornadoes and the tornado warning system will be collected to establish a baseline for studying the performance of the emergency communications systems on May 22, 2011. This objective is divided into seven tasks as follows:

Task 1—Gather baseline information on the response of individuals to the Joplin, MO, tornado through a comprehensive and interdisciplinary data collection effort, focused on public response behavior, situation awareness, emergency communications (including warnings provided, interpretation of the warnings, and response to warnings) and pre-tornado perceptions and preparation activities. This task will involve the collection of new data from people affected by the tornado via direct accounts from survivors and families and friends of victims. Interviews will be conducted via telephone and face-to-face to collect this information. Official records will also be obtained regarding the causes and locations of injuries and fatalities resulting from the tornado disaster. Additionally, written accounts, transcripts of (emergency) communications, published accounts, and other sources of communications-related information will be obtained, in coordination with other data collection efforts for the investigation.

Task 2—Collect archival records from prior tornado incidents and community response, including oral history data from people who experienced these events. Additionally, national codes, standards, and practices for U.S.-based tornado warnings will be documented as will local practices in communities surrounding the Joplin, MO, area.

Task 3—Document pre-event archival records for Joplin, MO, in relation to tornadoes and the tornado warning system. This information includes, but is not limited to, emergency plans, type and frequency of practice (weekly) warnings, community-wide training and education, the pre-tornado emergency communications system and dissemination practices, and census-based demographic data for Joplin, MO. This information will provide a baseline for studying the performance of the emergency communications systems.

Task 4—Information from third-party sources, such as television interviews and newspaper articles, as well as other relevant published material will be analyzed, examined, and assembled in a database.

Task 5—Analyze the data to study the public response to the tornado and/or the emergency communications system, documenting how situation awareness, decision-making, and the environment influenced the performance of protective action (e.g., sheltering in place) and survival (including coordination with Tasks 3 and 5 of Objective 3). A timeline of the incident will be developed using the results of these analyses together with other data sources. The characteristics of the community-level emergency communications and planning will be studied, and the design and use of these systems will also be compared with codes, standards, and practices for other communities in the U.S. The observed public response data will be compared with previous tornado incidents in this community as well as others in the U.S. The results of the analyses will be reviewed in the context of public protection in the event of a tornado.

Task 6 - Develop findings and issues pertaining to Objective #2.

Task 7—Develop draft chapter of final report for Objective #2.

Objective #3: Determine the Response of Residential, Commercial, and Critical Buildings, Including the Performance of Designated Safe Areas.

Purpose: To obtain, review, and analyze information and documents relating to the design, construction, and performance of single and multi-family residential, commercial, and critical buildings, including designated safe areas, affected by the Joplin, MO, tornado, and identify technical issues for development and/or revisions of codes, standards, and practices pertaining to designing for tornadoes.

Technical Approach: This objective focuses on acquiring, reviewing, and analyzing information relevant to the design, construction, and performance of buildings that did and did not sustain damage during the Joplin, MO, tornado, including both the building envelopes and the structural systems. The representative buildings evaluated in this investigation include reinforced concrete frame construction, steel frame construction, precast concrete wall, and concrete masonry wall constructions, as well as single- and multi-family wood frame constructions. By use, the buildings include hospital, fire station, police station, school, medical and commercial office, large retail, nursing home, single family home, and lifelines. The performance of these buildings is characterized by the observed damage they sustained from the environmental conditions they were exposed to during the tornado. The building design and actual construction are compared with model code requirements to assess the design, construction practice, and expected performance, and to identify areas in the current model building codes, standards, and practices that might warrant revisions. This objective is divided into seven tasks as follows:

Task 1 – Collect, review, and summarize field data on the performance of critical, commercial, and residential buildings that were surveyed by the NIST team in the affected areas in Joplin, MO, during the preliminary reconnaissance and follow up deployment. Based on field data and observations, and in coordination with objective #1, establish the environmental conditions that affected these buildings and develop failure hypothesis for each of the buildings.

Task 2 – Obtain and review design drawings (architectural and structural) of select buildings. Compare designs with field observations to assess consistency between design and actual construction practice. Combine design information with field observations to refine the failure hypothesis for select buildings.

Task 3 – Review the performance of designated safe areas within buildings, including shelters, safe rooms, and areas of buildings used for refuge from the tornado, in coordination with Task 5 of Objective 2.

Task 4 – Obtain, review, and evaluate appropriate model building code and standards requirements for design of building envelopes and main wind force resistance systems of the select buildings.

Task 5 – Assess building performance based on estimated wind field (from Objective 1 Task 3) and observed damage, relative to model code requirements.

Task 6 – Develop findings and issues pertaining to Objective #3.

Task 7 – Develop draft chapter of final report for Objective #3.

Objective #4: Determine the Performance of Lifelines as it Relates to the Continuity of Operations of Residential, Commercial, and Critical Buildings.

Purpose: To obtain, review, and analyze information and documents relating to the performance of lifelines that support continuity of operations for select buildings and facilities in the Joplin, MO, tornado.

Technical Approach: This objective focuses on gathering and analyzing information relevant to lifeline performance. The major sources of information will include data on the timelines associated with disruption and resumption of power, water, sewer, and gas systems over the course of the event. This information will be supplemented with information regarding the building type and performance to study system robustness. In addition, assessment of back-up systems (e.g., generators) that support continuous operation of buildings, if applicable, will be carried out. The impacts of fires following the tornado will also be studied. This objective is divided into six tasks as follows:

Task 1 – Gather information on lifeline systems and facilities that support building operations in their pre-storm condition.

Task 2 – Study the performance and timelines from disruption to restoration of service of lifelines, including power, water, sewer, and gas systems. Using the timeline information in addition to building classification (i.e., critical, commercial, residential) and associated damage, assess the robustness of the systems during the Joplin, MO, tornado event.

Task 3 –Study the performance of back-up power systems and protective enclosures.

Task 4 – Collect data on and assess the causes and extent of building fires resulting from the tornado within the tornado damage path.

Task 5 - Develop findings and issues pertaining to Objective #4.

Task 6 – Develop draft chapter of final report for Objective #4.

Objective #5: Identify, as Specifically as Possible, Areas in Current Model Building, Fire, and Emergency Communications Codes, Standards, and Practices that Warrant Revision.

Purpose: To make recommendations for potential improvements to model codes, standards, and practices, and/or further research based on findings from this investigation of the Joplin, MO, tornado.

Technical Approach: Based on the results of Objectives 1-4, make recommendations for potential changes to existing model codes, standards, and practices, and, if appropriate,

recommendations for new codes and/or standards, including use of performance-based approaches. This objective is divided into two tasks as follows:

Task 1 – Evaluate the results of Objectives 1-4 with regard to potential improvements needed in model building, fire, and emergency communications codes, standards, and practices, and/or further research. Make recommendations for potential changes to these codes, standards, and practices to increase tornado resilience of buildings, lifelines, and communities.

Task 2 – Develop draft chapter of final report for Objective #5.