National Institute of Standards and Technology
National Construction Safety Team Act
Annual Report
Fiscal Year (FY) 2019

Summary

This annual report to Congress for Fiscal Year (FY) 2019 is required by the National Construction Safety Team (NCST) Act (Public Law 107-231). The National Institute of Standards and Technology (NIST) continues to assess Hurricane Maria's impacts on Puerto Rico as part of the NCST investigation launched in FY 2018. The NIST Director established a Team on February 21, 2018, to perform a technical investigation of the 2017 Hurricane Maria and its impacts on Puerto Rico. The goals of this investigation are to characterize: (1) the wind environment and technical conditions associated with deaths and injuries; (2) the performance of representative critical buildings, and designated safe areas in those buildings, including their dependence on local lifelines; and (3) the performance of emergency communications systems and the public's response to such communications.

In FY 2019, NIST deployed preliminary reconnaissance teams to North Carolina, Florida, California, and Alaska, in response to Hurricane Florence, Hurricane Michael, the Camp Fire, and the Cook Inlet Earthquake, respectively. The observations from these preliminary reconnaissance efforts did not result in new NCST technical investigations.

NIST is continuing to implement the recommendations to develop consensus standards and code provisions related to progressive collapse from the Federal Building and Fire Safety Investigation of the World Trade Center Disaster (WTC Investigation)[1] and the Technical Investigation of the May 22, 2011, Tornado in Joplin, Missouri (NCST Joplin Investigation)[2].

Highlights of FY 2019 activities include:

- NIST awarded a contract to conduct the wind field modeling efforts and develop a time-dependent wind-field model of Hurricane Maria's impact on Puerto Rico;
- NIST awarded a contract to conduct wind tunnel testing at the National Science Foundation (NSF) supported University of Florida's (UF) Natural Hazards Engineering Research Infrastructure Experimental Facility (NHERI EF) and to collect full-scale measurements of winds in regions of topographic interest in Puerto Rico;
- NIST awarded several grants under the NIST Disaster Resilience 2018 Notice of Funding Opportunity, supporting the recommendations from the NCST Joplin Investigation;
- NIST and the American Society of Civil Engineers (ASCE) made significant progress on the development of tornado hazards maps and on performance-based design for wind hazards as part of the recommendations from the NCST Joplin Investigation;
- NIST made significant progress on guidance of public alerts and warnings as part of the recommendations from the NCST Joplin Investigation; and
- NIST contributed to the development and committee balloting of a draft consensus standard for disproportionate collapse mitigation of building structures, which addresses Recommendation #1 from the WTC Investigation.

[1] Report available at: http://www.nist.gov/customcf/get_pdf.cfm?pub_id=909017.
[2] Report available at: http://www.nist.gov/customcf/get_pdf.cfm?pub_id=915628.

Additionally, NIST held two meetings[3] of the NCST Advisory Committee (NCSTAC or Committee) during FY 2019. One meeting was held via web conference on November 27, 2018, and one meeting was held in person at NIST in Gaithersburg, Maryland, on September 6, 2019. In these meetings, NIST briefed the NCSTAC on:

- NIST's response to the Committee's FY 2018 report to Congress;
- progress on NIST implementation of the NCST Joplin Investigation recommendations;
- progress on the NCST Investigation of Hurricane Maria's impacts on Puerto Rico, including investigation methods and project management, data security and management, and hazard characterization efforts;
- related studies of Hurricane Maria under the NWIRP authority;
- disaster and failure events scored using the preliminary reconnaissance screening criteria;
- preliminary deployment activities for Hurricanes Florence and Michael, the Camp Fire, and the 2018 Cook Inlet Earthquake (Anchorage, Alaska); and
- other NIST efforts, under the Disaster and Failure Studies Program, that enhance the readiness of National Construction Safety Teams (Teams).

In these meetings, the NCSTAC:

- supported NIST's diverse team of researchers in a range of critical areas, including hazard characterization, performance of buildings and critical infrastructure, risk communication, business and supply chain logistics, and health and medicine;
- emphasized the need to engage and include local scientific and professional talent in Puerto Rico in the investigation;
- reinforced the need for NIST to combine engineering and social sciences across projects to offer new insights that could not be accomplished without collaboration of multiple disciplines;
- encouraged continued collaboration with experts in data-driven science to progress efforts to secure and manage disaster-related data;
- suggested focusing future implementations of the NCST Joplin Investigation's recommendations on wood-frame house construction, which represents the majority of occupied structures in the United States and are designed using less rigorous standards, while recognizing that this may require extensive revisions to traditional practice and may be challenging;
- encouraged improvement of tornado shelter standards and public tornado sheltering strategies;
- suggested that efforts to develop standards for risk communication continue to aid in effective messaging for populations at risk; and
- emphasized the need to quickly collect and document time-sensitive data with future NCST activities, and suggested looking to other entities (e.g., the National Transportation Safety Board) that may have developed protocols for quick response activities.

A summary of these meetings may be found on the NIST NCST website[3] and in the FY 2019 Annual Report of the NCSTAC to Congress.[4]

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[3] NCSTAC meeting agendas, presentations, and summaries are available at: https://www.nist.gov/topics/disaster-failure-studies/national-construction-safety-team-ncst/advisory-committee-meetings.

[4] FY 2019 NCSTAC Report to Congress available at:https://www.nist.gov/system/files/documents/2020/03/13/2019_NCSTAC_ReporttoCongress.pdf.

Introduction

In October 2002, the NCST Act was signed into law by President George W. Bush and authorized the Director of NIST to establish and deploy Teams to investigate events leading to failure of a building or buildings that result in substantial loss of life or that pose significant potential for substantial loss of life.

The purpose of these investigations is to improve the safety and structural integrity of buildings in the United States. A Team shall:

1. Establish the likely technical cause or causes of building failure;
2. Evaluate the technical aspects of evacuation and emergency response procedures;
3. Recommend, as necessary, specific improvements to building standards, codes, and practices based on the findings made pursuant to (1) and (2); and,
4. Recommend any research and other appropriate actions needed to improve the structural safety of buildings, and improve the evacuation and emergency response procedures, based on the findings and recommendations of the investigation.

Under Section 10 of the NCST Act, NIST is to provide an annual report to the House Committee on Science, Space, and Technology and to the Senate Committee on Commerce, Science, and Transportation each year. This report is to include:

1. A summary of the investigations conducted by Teams during the prior fiscal year;
2. A summary of recommendations made by the Teams in reports issued under Section 8 of the NCST Act during the prior fiscal year and a description of the extent to which those recommendations have been implemented; and
3. A description of the actions taken to improve building safety and structural integrity by NIST during the prior fiscal year in response to reports issued under Section 8 of the NCST Act.

This report summarizes NIST's activities under the NCST Act for FY 2019 as required by Section 10 of the Act.

1. Investigations Conducted Under the NCST Act during FY 2019

On September 20, 2017, Hurricane Maria made landfall in Puerto Rico as a strong Category 4 storm, causing fatalities, injuries, and damage to buildings and infrastructure. The NIST Director established a Team under the NCST Act—based on an analysis of the event against the criteria found in the NCST Act and its implementing regulations (15 C.F.R. Part 270)—to conduct a technical investigation of the building performance and emergency response and evacuation during Hurricane Maria. The goals of the NCST Hurricane Maria Investigation are to characterize: (1) the wind environment and technical conditions associated with deaths and injuries; (2) the performance of representative critical buildings, and designated safe areas in those buildings, including their dependence on lifelines; and (3) the performance of emergency communications systems and the public's response to such communications.

The Team members continue to work on four projects related to the investigation:

(1) Hazard Characterization

The objective of this project is to characterize the wind environment associated with Hurricane Maria's impact on Puerto Rico, including topographic effects, and to document other hazards associated with the hurricane, including storm surge, rainfall, flooding, and landslides, in order to understand subsequent building failures. The investigative methods for this project include wind field modeling, wind tunnel testing, field measurements, and numerical simulation.

A contract was awarded on February 8, 2019, to Applied Research Associates to support the wind field modeling efforts and develop a time-dependent wind-field model of Hurricane Maria's impact on Puerto Rico that optimally matches available measured data. The current version of the wind field model incorporates topographic effects. The final version of the wind field model will: include additional surface-level meteorological observations; improve characterization of hurricane asymmetry; optimize the model fitting process; quantify uncertainty in results; and refine the topographic effects model based on wind tunnel and numerical results.

A contract was awarded to UF on May 1, 2019, to conduct the wind tunnel testing and field measurements. Experiments will be conducted at the NSF-supported NHERI EF at the University of Florida (UF), on a large, reconfigurable boundary layer wind tunnel. The purpose of these experiments is to obtain flow-field measurements from wind tunnel testing of topographic features to provide experimental data with quantified uncertainties for characterization of topographic speedup effects and for validation of numerical models. Fabrication and testing of topographic models are currently in progress, with fabrication and testing of building models planned in FY 2020. In addition to the laboratory experiments, a subcontractor to UF will deploy weather stations to obtain full-scale measurements of winds in regions of topographic interest in Puerto Rico, to provide information for validation of wind tunnel test results and numerical models. The Team is currently selecting sites across Puerto Rico to deploy weather stations on existing towers, with anemometers at multiple elevations per tower.

The Team is also developing computational fluid dynamics (CFD) models to characterize topographic effects on winds. The Team plans to verify CFD simulations and validate CFD results against wind tunnel and field measurement data. These validated CFD models will be used to evaluate and characterize topographic speedup effects in Puerto Rico.

(2) Performance of Critical Buildings

The objective of this project is to characterize the performance of critical buildings in Hurricane Maria by: (1) documenting failures of structural systems, building envelopes, and rooftop equipment, along with the resulting intrusion of wind-driven rain, interior damage, and loss of function for a representative sample of hospitals and schools; (2) identifying dependencies on lifelines in loss of function; (3) characterizing wind loads on building envelopes and rooftop equipment through wind tunnel testing for a subset of these hospitals and schools to correlate with

observed damage; and (4) evaluating the adequacy of existing selection criteria and design requirements for storm shelters.

A contract award to support this project is forthcoming in early FY 2020[5]. The principal goal of the award is for a contractor to document the performance of selected critical facilities in Puerto Rico during Hurricane Maria, to include hospitals, schools, and storm shelters. NIST will specify which facilities are to be evaluated, and the Contractor will provide services to gather information and documentation on the following: (1) characteristics of each facility prior to Hurricane Maria, (2) damage to the facility caused by Hurricane Maria, and (3) the function and operation of the facility during and immediately after Hurricane Maria. Recognizing that post-storm repairs have been completed, the evaluations will not be limited to simply documenting the current conditions. It is anticipated that interviews with facility managers and personnel will be required to document the direct and indirect damage caused by Hurricane Maria, as well as the impacts of Hurricane Maria on the operation and function of the facility. The building characteristics that are most relevant prior to Hurricane Maria are those that describe the facilities' structural and nonstructural components (e.g., type and age of roof covering, type of structural system, and type of opening protective systems), describe the age of the structure (e.g., date of construction and building code used for design), document utility redundancies (e.g., capacity of any existing backup generators and emergency water supplies), and summarize mitigation efforts taken before Hurricane Maria's landfall (e.g., sandbagging and anchoring of rooftop equipment). The contractor will be asked to collect damage data (e.g., damage to the envelope, roofing system, structural system, rooftop equipment, etc.) to these facilities to identify any trends in structural performance by occupancy type, construction era, and structural system. Finally, the contractor will be expected to also collect data on the functionality of the facilities immediately following Hurricane Maria's landfall, including relocation of services and/or building occupants, status of availability of lifelines in the days following the storm, and hazardous conditions encountered by building occupants due to identified damage.

(3) Public Response to Emergency Communications

The objective of this project is to investigate the role of emergency communications in public response for those under imminent threat from Hurricane Maria. This project will also investigate the use of communications in disaster response (during and immediately after the hurricane event).

A contract award to support this project is forthcoming in early FY 2020[6]. The principal goal of the award is for a contractor to conduct structured surveys and open-ended, semi-structured interviews with multiple populations in Puerto Rico. The structured surveys shall be conducted with sampled households within four emergency management regions (or zones) within Puerto Rico, identified by NIST.

[5] Although outside the FY 2019 reporting period of this report, NIST can report that a contract was awarded to Stantec Consulting Services, Inc. on March 3, 2020 to support the *Performance of Critical Buildings* project.

[6] Although outside the FY 2019 reporting period of this report, NIST can report that a contract was awarded to Horsley Witten Group, along with subcontractors Eastern Research Group, Issues & Answers, and Albizu University in Puerto Rico, on January 6, 2020 to support the *Public Response and Emergency Communications* project.

The sampling frame will most likely encompass households located in flood-prone regions, based on flood hazard information for Puerto Rico produced by the Federal Emergency Management Agency (FEMA), and landslide-prone regions, based on the landslide hazard map for Puerto Rico produced by the U.S. Geological Survey. The survey will ask households about pre-Hurricane Maria activities and perceptions, including previous experience with hurricanes, pre-event risk perception, and knowledge of risk zones; the types of emergency information sought/received before and during the hurricane; their perceptions of this information as well as other environmental and social cues; protective action decisions; information needs during and after the event; and health or medical care needs after the hurricane. From the survey respondents, NIST will identify a small sample, with input from the contractor, to participate in follow-up open-ended, semi-structured interviews. NIST will also conduct open-ended, semi-structured interviews with Commonwealth, regional and/or local emergency managers; National Weather Service officials, broadcast meteorologists and other members of the media, and others responsible for communication with the public. The goal of these interviews is to better understand pre-hurricane preparation and planning; situational awareness prior to and during the event; decisions made about communicating with the public; and lessons learned that may have led to changes in communication-related policies, procedures and/or guidelines.

(4) Characterization of Morbidity and Mortality

The objective of this project is to complete a quantitative morbidity and mortality assessment of Puerto Rico, to better understand how damaged buildings and supporting infrastructure played a role in the injuries and deaths associated with Hurricane Maria. The study results will provide guidance to improve codes, standards and inform future approaches to accurately attribute and predict life loss due to windstorm building failure(s).

A contract award to support this project is forthcoming in early FY 2020. The principal goal of the award is for a Contractor to identify deaths in Puerto Rico directly and indirectly related to Hurricane Maria, and more specifically identify deaths attributed to building and/or building system failure(s). The contractor will collect and merge data on the deaths that occurred up to six months after Hurricane Maria made landfall in Puerto Rico. They will develop an integrated database from various data sources, which may include the Puerto Rico Vital Registration System, Disaster Mortuary Operational Response Teams E-Cases records, pathology registry records, 911 emergency calls obtained from the Bureau of Police, and funeral and burial assistance data from FEMA and the American Red Cross. The contractor shall geocode the deaths and submit a text searchable database alongside a report documenting the process for merging data sources, as well as the data coverage and quality from each source, highlighting the potential added value of integration of data from specific sources. Subsequently, the contractor will: analyze the integrated database to calculate cause-specific mortality rates adjusted for age and gender and compare these to the prior years; examine each broad cause of death (i.e. ICD-10 chapters) and specific causes of death typically attributed to hurricanes (e.g., drowning, death from a fallen object, etc.) and compare them to previous years; calculate age and gender-adjusted cause specific mortality rates for other

specific causes of death that are identified as being significantly greater following Hurricane Maria (compared to the previous year); identify any significant increases in death rates from particular causes between the period after the storm and years prior and flag all deaths from those causes in the first two weeks after the storm; and identify spatial and temporal clusters of deaths occurring up to six months after the storm in study areas identified by NIST staff.

The contractor will conduct verbal autopsies (and possibly clinical panels) to determine attribution of deaths that occurred immediately after the storm made landfall. The contractor shall develop verbal autopsy (VA) instrument and script (instructions to the respondent and interviewer) to be used to determine if a death was the direct result of a building and/or building system failure(s), secondary to the forces of the hurricane including wind, storm surge, flooding or landslides. The purpose of the VA instrument is to determine if a death was the direct or indirect result of the building and/or building system failure(s). This means that the person died from injury related to the structural failure, damage to the building, or loss function of building systems.

In order to support all of the projects outlined above, Team members traveled to Puerto Rico on July 23-26, 2019. Members of NIST's Hurricane Maria study team met individually with high-level officials from seven Puerto Rico government departments and agencies in San Juan. The sessions were aimed at explaining NIST's multiple projects under the Hurricane Maria program and describing the range of information being requested by NIST. The 5-member team met with: Economic Development and Commerce Secretary Manuel Laboy Rivera, Education Secretary Eligio Hernandez Perez, Health Secretary Rafael Rodriguez-Mercado, Transportation and Public Works Secretary Carlos Contreras Aponte, Telecommunications Regulatory Board President Sandra Torres Lopez, Central Office for Recovery, Reconstruction and Resiliency Deputy Director Karla Fraguada, and Puerto Rico Aqueduct and Sewer Authority Vice President of Strategic and Corporate Planning Ryan Arrieta. The Team also met with FEMA and other U.S. government officials during their visit to San Juan.

Updates on the NCST Hurricane Maria Investigation are posted frequently on the NIST website[7].

2. Summary of Recommendations Made by Teams in Reports Issued Under Section 8 of the NCST Act during FY 2019

During FY 2019, NIST did not issue a report under Section 8 of the NCST Act.

3. Actions Taken to Improve Building Safety and Structural Integrity During FY 2019 in Response to Reports Issued Under Section 8 of the NCST Act

During FY 2019, NIST did not issue a report under Section 8 of the NCST Act.

a. Actions Related to Report on the NIST World Trade Center Investigation:

[7] NIST Hurricane Maria website: https://www.nist.gov/topics/disaster-failure-studies/hurricane-maria.

The following recommendations in the final report of the Collapse of the World Trade Center Towers[1] were addressed in FY 2019 to improve building safety and structural integrity:

- In FY 2012, based on a proposal from NIST, a new American Society of Civil Engineers (ASCE) Structural Engineering Institute (SEI) Standards Committee was established to develop a consensus standard for disproportionate collapse mitigation of building structures, which addresses Recommendation #1 from the NIST World Trade Center Investigation. This voluntary committee has developed a complete draft of the new standard, with substantial contributions from four NIST staff who have informed the standard with the results of NIST research. In FY 2019, the committee completed revisions to the draft standard in response to comments from the second committee ballot. A third committee ballot was also initiated in FY 2019, and a public ballot of the standard is planned after the completion of committee balloting.

b. Actions Related to Report on the NIST Joplin Tornado Investigation:

The following recommendations in the NCST Joplin Investigation final report[2] were addressed in FY 2019 to improve building safety and structural integrity:

- NIST awarded 4 grants totaling $2.24 million under the NIST Disaster Resilience 2018 Notice of Funding Opportunity[8], supporting development of sensors and methods to collect spatiotemporal data on windstorm phenomena, including surface-level winds and near ground velocity profiles in tornadoes, hurricanes, thunderstorms and other high wind events. This effort directly addresses NIST recommendation #1 (of Recommendations Group 1, Tornado Hazard Characteristics and Associated Wind Field) in the final report.
- NIST completed the methodology for development of tornado hazard maps for use in tornado-resistant design of buildings. A workshop for over 100 stakeholders was held on May 14, 2019, where the draft methodology and maps were presented. Valuable feedback was obtained and used to finalize the methodology. This effort directly addresses NIST recommendation #3 (of Recommendations Group 1, Tornado Hazard Characteristics and Associated Wind Field) and provides prerequisite technical underpinning for recommendations #5 and #6 (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report).
- NIST continued to work with the ASCE SEI committee that is developing the new Tornado Wind Speed Estimation Standard. The American Meteorological Society (AMS) is also engaged in this effort, and the standard will be a joint ASCE/SEI/AMS document when completed. The committee, co-chaired by National Oceanic and Atmospheric Administration (NOAA) and NIST staff, is developing standardized methods for estimating the wind speeds in tornadoes and other severe windstorms, including significant improvements to the Enhanced Fujita Scale. During FY 2019, the committee completed drafts of two chapters of the new standard and began balloting those chapters. This standards development activity directly addresses NIST recommendation #4 and supports NIST recommendations #1 and #2 (of Recommendations Group 1, Tornado Hazard Characteristics and Associated Wind Field, in the final report).
- NIST is collaborating with the ASCE 7-22 Wind Load Subcommittee's Task Committee on

[8] Disaster Resilience 2018 Notice Of Funding Opportunity (NOFO), available at https://www.nist.gov/el/disaster-resilience/disaster-resilience-federal-funding-opportunity-ffo.

Performance-Based Design for Wind Hazards, addressing NIST recommendation #5 (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report). The Wind Load Subcommittee is creating a performance-based design framework for wind hazards, intended for inclusion in the ASCE 7-22 Standard, Minimum Design Loads and Associated Criteria for Buildings and Other Structures.

- NIST staff lead the Tornado Task Committee within the ASCE 7 Wind Load Subcommittee. This task committee is developing a tornado wind load design methodology and standards provisions, incorporating the NIST tornado hazard maps and other research to create a new chapter on Tornado Loads for ASCE 7-22. These efforts directly address NIST recommendation #6 (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report).
- NIST staff lead the committee developing the 2020 edition of the ICC 500 Standard for the Design and Construction of Storm Shelters. NIST submitted proposed changes to explicitly address certain unique issues relating to design and installation of storm shelters in existing buildings, provisions for impact loads due to falling debris, and other changes. These efforts directly address NIST recommendation #7a (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report).
- NIST conducted a workshop to identify the opportunities and challenges associated with planning, communications, and operations related to public tornado shelters. The workshop was held on March 4, 2019, in Oklahoma City, in collaboration with NOAA, FEMA, the City of Birmingham (Alabama), and representatives of academia and the private sector. These efforts directly address NIST recommendation #8 (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report) as well as recommendations #13 and #16 (of Recommendations Group 3, Pattern, Location, and Cause of Fatalities and Injuries, and Associated Performance of Emergency Communications Systems and Public Response, in the final report).
- NIST staff collaborated on a publication of guidance on short message alert templates for 280-character Twitter and 360-character Wireless Emergency Alert (WEA) messages[9]. This effort supports NIST recommendation #13 (of Recommendations Group 3, Pattern, Location, and Cause of Fatalities and Injuries, and Associated Performance of Emergency Communications Systems and Public Response, in the final report).
- NIST contributed to an annex (Annex K) on community-wide public alerts and warnings in disaster response that was incorporated into the latest edition of NFPA 1600 Standard on Continuity, Emergency, and Crisis Management (2019). This effort supports NIST recommendations #13, #14, and #15 (of Recommendations Group 3, Pattern, Location, and Cause of Fatalities and Injuries, and Associated Performance of Emergency Communications Systems and Public Response, in the final report).

In addition to the actions described above, NOAA's National Severe Storms Laboratory (NSSL) has continued to make significant progress toward the development of new grid-based watch/warning hazardous weather forecasting capability for communicating probabilistic threats to advance the Forecasting a Continuum of Environmental Threats (FACETs) paradigm. This effort

[9] J. Sutton, E. Kuligowski, Alerts and warnings on short messaging channels: guidance from an expert panel process, Nat. Hazards Rev. 20 (2019). https://doi.org/10.1061/(ASCE)NH.1527-6996.0000324.

supports NIST recommendation #16 (of Recommendations Group 3, Pattern, Location, and Cause of Fatalities and Injuries, and Associated Performance of Emergency Communications Systems and Public Response, in the final report).

4. Preliminary Investigations

NIST uses a screening tool to assess the need for preliminary reconnaissance of disasters and failures that includes the following key decision criteria: event consequences (substantial loss of life or disabling injury, significant potential for loss of life; hazard intensity; consequences to resilience), major challenges in evacuation and/or emergency response, international factors (relevance to the United States), and study impacts (safety of team; new knowledge gains; and potential impact to existing standards, codes, and guidelines). Thirteen domestic and international events were scored in FY 2019, including six windstorms, three earthquakes, two structural failures, one wildland-urban interface fire, and one building fire. Three of the thirteen events scored in FY 2019 and one of the eleven events scored in FY 2018 met the NIST preliminary deployment criteria and resulted in the deployment of teams in FY 2019 to collect preliminary data and inform recommendations for further study. NIST deployed teams to collect preliminary data in response to four events: (1) Hurricane Florence, (2) Hurricane Michael, (3) Camp Fire, and (4) the Cook Inlet Earthquake (Anchorage, AK).

Hurricane Florence made landfall in North Carolina at approximately 7:30 AM EDT on Friday September 14, 2018, as a Category 1 hurricane according to the Saffir Simpson scale with maximum 1-min sustained wind speeds of 92 mph and a minimum central pressure of 956 mb[10]. Preliminary reports indicated a modest amount of direct wind related structural damage with isolated incidents of inland roof failures at some businesses and inundation of private residences[11]. However, state estimates have Hurricane Florence causing $17 billion in damages to homes, businesses, farms and governments in North Carolina; a figure greater than the combined damages from Hurricanes Matthew and Floyd[12]. Some coastal areas of North Carolina experienced significant, but highly localized, structural impacts due to coastal inundation from storm surge levels exceeding 10 feet. Furthermore, record rainfall caused catastrophic flooding across large inland portions of North Carolina and South Carolina[13]. Despite being a Category 1 hurricane, both the storm surge and rainfall amounts were amplified by the anomalously slow forward speed of Florence – a characteristic that historical measurements show is becoming more common over time. Despite significant warnings from government officials and the media, many residents in critical areas did not evacuate[14], potentially due to the reduction in the official classification from a Category 4 to a Category 1 hurricane as Florence approached the coast; this lack of evacuation complicated aspects of emergency operations. At one point, Florence caused more than 900,000 power outages across portions of the Carolinas. NIST sent a preliminary reconnaissance team to collect perishable data on the performance of commercial and residential structures in Lumberton, North Carolina (an area similarly impacted by Hurricane Matthew in 2016). Despite its serious nature, after preliminary investigation, NIST determined that this event did not meet the criteria

[10] NOAA, 2019, National Hurricane Center Tropical Cyclone Report: Hurricane Florence (AL062018).
[11] NWS, 2018. "Hurricane Florence: September 14, 2018". https://www.weather.gov/ilm/HurricaneFlorence.
[12] Stradling, Richard and Abbie Bennett, 2018. "'Historic' Hurricane Florence caused more damage than Matthew and Floyd combined, governor says", The News and Observer, October 31, 2018.
[13] NOAA, 2019, National Hurricane Center Tropical Cyclone Report: Hurricane Florence (AL062018).
[14] Mindock, Clark, 2018. "Hurricane Florence: Residents ignore evacuation orders in North Carolina 'hoping God protects us' as storm hits", Independent, September 13, 2018.

for a NCST investigation. NIST continues to study the recovery of Lumberton, including commercial and residential structures, businesses and households from Hurricanes Matthew and Florence under another authority, and in collaboration with the NIST *Center of Excellence for Risk-Based Community Resilience Planning*, headquartered at Colorado State University.

Hurricane Michael made landfall near Mexico Beach, Florida, around 1:00 PM EDT on Wednesday, October 10, 2018, as a high-end Category 5 storm, with maximum 1-min sustained wind speeds of 161 mph and a minimum central pressure of 919 mb[15]. The storm underwent rapid intensification (increase of at least 35 mph sustained winds in a 24-hour period) as it approached the Florida panhandle coastline due to above average sea-surface temperatures in the Gulf of Mexico. Michael is the most powerful storm to impact the Florida Panhandle in recorded history (by wind speed and central pressure) and is considered the third most-powerful hurricane (by central pressure) to impact the United States behind the Labor Day Hurricane (1935) and Hurricane Camille (1969). The storm remained at Category 3 intensity as it crossed into Georgia and continued to deliver tropical force winds and significant rainfall as it moved into the Carolinas and up the eastern seaboard. The hurricane produced storm surge in the range of 9 to 14 ft in areas from Mexico Beach to Apalachee Bay, Florida[8]. Hurricane Michael caused catastrophic damage from strong winds over a wide swath that stretched across much of the Florida panhandle and into southeastern Georgia and beyond. Estimates of the hurricane wind speeds indicated that design wind speeds were exceeded for a sizable region near Mexico Beach and further inland. The higher wind speed combined with storm surge resulted in significant damage to residential and commercial buildings, critical facilities, and infrastructure. Initially, over 1.1 million people lost power. The storm also caused moderate evacuation challenges and severe emergency response challenges in localized areas. NIST deployed a preliminary reconnaissance team to collect perishable data on: the performance of residential buildings, commercial buildings, and critical facilities, the availability of hazard information and the effectiveness of emergency communications in producing protective actions by citizens and explaining the variance observed, and loss of building functions stratified by occupancy type (e.g., education and healthcare). Despite its serious nature, after preliminary investigation, NIST determined that this event did not meet the criteria for an NCST investigation.

The Camp Fire is the deadliest California fire in history which resulted in 86 civilian fatalities and three firefighter injuries with more than 52,000 residents forced to evacuate their homes. It was also the most destructive fire, destroying or damaging a total of 19,558 structures, equivalent to three times the losses of the 2017 Tubbs Fire (5,636 structures) or six times the losses of the 1991 Oakland Hills Fire (2,900 structures). The Camp Fire started on November 8, 2018, at 6:29 AM and consumed 153,336 acres and destroyed 13,696 single residences. The fire spread quickly and became very active and intense throughout the day. Extreme conditions including very strong winds and very low humidity levels in the area, made containment difficult. The fire was declared 100 percent contained after 18 days on November 25, 2018. Nine agencies, including California Department of Forestry and Fire Protection, Butte County Sheriff Department, Paradise Police Department, and the U.S. Forest Service participated in fire suppression activities. Total personnel involved in firefighting reached 5,471 with 900 pieces of apparatus (620 engines, 101 fire crews, 102 dozers, and 77 water tenders). Preliminary estimates indicate that the Camp Fire will be the

[15] NOAA, 2019, National Hurricane Center Tropical Cyclone Report: Hurricane Michael (AL 142019).

most destructive fire in California history at a cost of $11-13 Billion[16] and $3 Billion for cleaning up debris.[17] The Camp Fire is expected to become the most destructive Wildland-Urban Interface fire in the last century. A considerable regional area and population was exposed to the fires, causing a large number of deaths, and severe physical damage to non-engineered buildings. The fire also caused moderate challenges to evacuations and emergency response. NIST sent a preliminary reconnaissance team to collect perishable data on: (1) physical damage to residential and commercial buildings; (2) the availability of hazard information, decisions made by emergency officials, and the effectiveness of emergency communications in producing protective actions by residents/tourists and explaining the variance observed; (3) first responder fire suppression tactics and operations; (4) the efficacy of recent changes to codes, standards and practices; and (5) refining scope and potential study area(s) for a possible subsequent investigation that aligns with and advances the engineering and science research already underway at NIST. Despite its serious nature, after preliminary investigation, NIST determined that this event did not meet the criteria for an NCST investigation. NIST continues to study the timeline and impacts of the Camp Fire under another authority, and in collaboration with the U.S. Forest Service and CAL FIRE.

The M_w 7.1 Cook Inlet Earthquake struck seven miles north of Anchorage, Alaska, at 8:29 AM on Friday, November 30, 2018[18]. A tsunami warning was issued for the Cook Inlet and Kenai Peninsula but was cancelled shortly afterwards. The earthquake directly affected Anchorage and Matanuska-Susitna Boroughs. There were no earthquake-related deaths and only minor, non-life-threatening injuries reported at the time of evaluating a preliminary deployment to Alaska. The earthquake did not result in significant structural damage to buildings; however, there were a moderate number of homes that exhibited damage and three damaged schools required structural repairs before they can reopen. Damage to nonstructural components (i.e., ceiling assemblies, façade, windows, etc.) was observed across multiple sectors. The main airport terminal and control tower (west of downtown Anchorage) were evacuated on the day of the earthquake, then reopened later that day and flights resumed. The Port of Anchorage was shutdown then reopened after the tsunami warning was cancelled and site inspections were completed. Additionally, the transportation networks within Anchorage did not sustain noticeable damage, but there are discrete locations outside of Anchorage that sustained catastrophic failure and were unusable to motorists. Power and water distribution systems suffered moderate damage, but services resumed quickly. There were no reports of damages to telecommunication networks, and internet service provides were able to maintain services. In early January 2019, NIST sent a preliminary reconnaissance team to collect perishable data on: (1) assessing the performance of buildings instrumented with strong motion accelerographs, since there are several instrumented structures in Anchorage; (2) assessing the performance of buildings that have been retrofitted with fiber reinforced polymers (FRP); (3) assessing how minor/moderate structural and moderate/severe nonstructural damage affected the immediate occupancy (functional recovery) of buildings, including a review of forcible building closures, inspection protocols, and safety tagging mechanisms in place after the

[16] L.A. Biz article on California fire property loss, November 27, 2018: https://www.bizjournals.com/losangeles/news/2018/11/27/calif-wildfires-property-losses-could-reach-19b.html.
[17] U.S. News article on California fire cleanup, December 12, 2018: https://www.usnews.com/news/best-states/california/articles/2018-12-11/california-wildfires-cleanup-to-cost-at-least-3-billion.
[18] USGS Earthquake Hazards Program: https://earthquake.usgs.gov/earthquakes/eventpage/ak20419010/executive.

earthquake; and (4) refining scope and potential study area(s) for a possible subsequent investigation that aligns with and advances the engineering and science research already underway at NIST. Despite its serious nature given the magnitude of the event, after preliminary investigation, NIST determined that this event did not meet the criteria for a formal NCST investigation. NIST continues to study the reliability of fiber reinforced composite systems in resilient infrastructure under another authority.

The remaining events did not meet the criteria for a preliminary deployment for one or more of the following reasons: no clear study objectives that would impact standards, codes, and practices; unsafe conditions for NIST investigators; no primary authority or in-house expertise of hazard type; construction practice and codes for international events are not similar to those used in the U.S.; no new lessons would be gained; or minimal impact to building occupants.

5. Conclusion

The NCST Act authorizes NIST to establish and deploy Teams to investigate building failures that result in a substantial loss of life or pose significant potential for loss of life. In FY 2019, NIST assessed thirteen events (fires, earthquakes, hurricanes, tornadoes, bomb cyclones, and structural failures) using a screening tool that considers: event consequences (substantial loss of life or disabling injury; potential for loss of life; hazard intensity; physical damage) and evacuation and/or emergency response, international factors (relevance to the United States), and study impacts (safety of team; new knowledge gains; and potential impact to existing standards, codes, and guidelines). NIST completed four preliminary deployments in FY 2019, and in analyzing the data from North Carolina, Florida, California, and Alaska, the NIST Director did not establish any new Teams under the NCST Act. NIST continues to further investigate the building performance and emergency response and evacuation during Hurricane Maria in Puerto Rico and continues to pursue actions related to improving building safety and structural integrity that were recommended by previous NCST investigations. NIST has made several awards to support the Hazard Characterization project and expects to make several awards in FY 2020 to support the Performance of Critical Buildings project, the Public Response to Emergency Communications project, and the Characterization of Morbidity and Mortality project. NIST presented these FY 2019 activities to the NCST Advisory Committee during a web-conference meeting November 27, 2018, and one in-person meeting at the Gaithersburg campus on September 6, 2019.