National Institute of Standards and Technology
National Construction Safety Team Act
Annual Report
Fiscal Year (FY) 2023

Summary

This annual report to Congress for Fiscal Year (FY) 2023 is required by the National Construction Safety Team (NCST) Act (Public Law 107-231).

In FY 2023, the National Institute of Standards and Technology (NIST) continued to evaluate Hurricane Maria's (HM) impacts on Puerto Rico as part of the NCST investigation launched by the NIST Director on February 21, 2018. 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 2023, NIST also continued the NCST investigation launched by the NIST Director on June 30, 2021, to investigate the partial collapse of the Champlain Towers South (CTS) Condominium that occurred in Surfside, FL, on June 24, 2021. The goals of this investigation are (1) to establish the likely cause or causes of the partial collapse, (2) recommend any changes to standards, codes, and practices, and (3) recommend any research or other appropriate actions needed to improve the structural safety of buildings.

The World Trade Center (WTC) NCST Investigation[1] and the Joplin Tornado NCST Investigation[2] resulted in recommendations to develop consensus standards and building code provisions related to progressive collapse and tornado resistant design, respectively, and NIST has made additional progress on implementing those recommendations.

Highlights of FY 2023 activities include:

- NIST completed all data collection activities associated with the four NCST projects in the HM NCST Investigation, including interviews for hospitals and shelters.

- NIST expanded data collection efforts already underway for the HM NCST Investigation by incorporating data collection examining how Hurricane Fiona in 2022 affected recovery efforts from Hurricane Maria.

- The NIST Director appointed Dr. Gina Eosco as a member of the HM NCST Investigation Team, and reappointed Dr. Thomas Kirsch following his federal retirement.

- To support the HM NCST Investigation, NIST awarded contracts to Applied Research Associates, Inc. for wind field modeling and wind load analysis, and WeatherFlow, Inc. for continuation of field measurements of topographic effects on winds in Puerto Rico.

[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.

- The NIST CTS Team released preliminary evaluations of the pool deck structure of the building, including the results of a structural design check, the as-built conditions, modifications made to the structure over its life, and potential degradation effects. The Team also released preliminary evaluations of geotechnical conditions, including the potential for sinkholes and impacts of differential foundation settlement. They continued the next phases of invasive testing of evidence and completed the code checks for the building.

- To support the CTS Investigation, NIST awarded contracts to: TreAltamira Inc. for InSAR Data acquisition, processing, and reporting; the University of Washington for structural testing; Tourney Consulting Group LLC for corrosion and concrete durability expertise and testing; YA Engineering Services LLC for petrographic expertise and examination of hardened concrete elements; and Florida International University for co-leader services and social science, social work, urban history, and psychiatry expertise required for interviews and surveys. NIST executed one task order with Strativia LLC for co-leader services for the Building and Code History project, and two task orders with Applied Research Associates, Inc. (ARA) for historic review of wind loading and invasive testing management. NIST also executed four work orders with the US Army Corps of Engineers to extract and test subsamples from the building evidentiary debris, and to provide co-leader and project support for the remote-sensing and data visualization project.

- NIST led the development of a proposal in collaboration with the American Society of Civil Engineers (ASCE) and the Federal Emergency Management Agency (FEMA) to include the ASCE 7-22 tornado load requirements into the 2024 International Building Code (IBC). The ASCE 7-22 tornado load requirements were also approved for inclusion in the 2024 National Fire Protection Association (NFPA) 5000 Building Construction and Safety Code, as well as the 2023 Florida Building Code. NIST also published a tornado load design guide in collaboration with FEMA. These activities address Recommendation #5 from the Joplin Tornado NCST Investigation.

- NIST collaborated with FEMA to publish interim guidance for tornado resistant design and retrofit of residential structures and supported FEMA in the development of a wind retrofit guide for residential buildings. These activities address Recommendation #6 from the Joplin Tornado NCST Investigation.

- NIST continued to work with the ASCE Structural Engineering Institute (SEI) Standards Committee that is developing the new Tornado Wind Speed Estimation Standard, including main committee ballots on new and revised damage indicators for the Enhanced Fujita Scale, and additional work on the development of a Smart^DI for wood-frame residences, which will result in a more quantitative wind speed estimate based on materials and connections. This work addresses Recommendation #4 from the Joplin Tornado NCST Investigation.

- NIST contributed to the consensus ASCE/SEI Standard for Mitigation of Disproportionate Collapse Potential in Buildings and Other Structures, which was published as ASCE 76-23 in May 2023. This addresses Recommendation #1 from the WTC NCST Investigation.

- NIST contributed to updating ASCE 7-22 wind velocity pressure profiles for a more accurate estimation of wind load on structures as function of height. These were approved for incorporation into the 2024 International Building Code. This addresses Recommendation #2 from the WTC NCST Investigation.

- NIST conducted a preliminary reconnaissance mission in March and April for the Turkey (Türkiye) and Syria earthquakes that occurred in February 2023, in conjunction with the American Concrete Institute. An NCST Investigation will not be undertaken, but there is no decision yet about conducting a research study under another NIST authority or possibly in conjunction with external partners.

- NIST conducted a preliminary reconnaissance mission for the Maui wildfires in August 2023. An NCST Investigation will not be undertaken, but there is no decision yet about conducting a research study under another NIST authority or possibly in conjunction with external partners.

NIST presented the FY 2023 activities to the NCST Advisory Committee (NCSTAC or Committee) via web conference on June 14-15, 2023, and September 7, 2023. NIST briefed the NCSTAC on:

- NIST's response to the Committee's FY 2022 report to Congress;

- Progress of the NCST Investigation of Hurricane Maria's impacts on Puerto Rico, including: stakeholder outreach and agency coordination; onboarding of additional staff members; delivery of processed datasets from wind tunnel tests of buildings and topographic models; completion of household surveys and interviews on emergency communications; delivery of integrated mortality database; cross-project integration and analysis associated with hospitals, sheltering, and infrastructure dependencies; data collection status for each project; contracting status; a projected timeline for publication of a draft report for internal review; and an overview of how NIST is integrating concerns caused by Hurricane Fiona;

- Related studies of Hurricane Maria under the National Windstorm Impact Reduction Program (NWIRP);

- Progress on NCST Investigation into the partial collapse of the Champlain Towers South Condominium in Surfside, FL, including: the reorganization of physical evidence to allow for safe invasive testing; the invasive testing program and associated workflow; efforts to locate security system footage; cross-project integration and analysis associated with (1) evidence collection, measurements, and visualization, (2) materials, geotechnical, and structural analysis and testing, and (3) failure hypotheses development and evaluation; delivery of material that matches that used in the original construction for use in structural testing, as well as details of the testing program; contracting status; public engagement; the as-built conditions of CTS; records located; the 3D site information model; analysis of videos, karstic features, and differential settlements; the integration of evidence and analyses into the collapse model; and a projected timeline for the completion of the investigation.

- Progress of NIST implementation of the NCST World Trade Center and Joplin Tornado Investigation recommendations;

- Disaster and failure events scored using the preliminary reconnaissance screening criteria, including the stand-up of an NWIRP study on Hurricane Ian, and preliminary reconnaissance activities following the February 2023 Turkey (Türkiye) and Syria earthquakes and the August 2023 Maui wildfires; and

- Other NIST efforts under the Disaster and Failure Studies Program that enhance the readiness of National Construction Safety Teams.

The NCSTAC:

- Acknowledged that the changes made to the NCST Act in August 2022 were an important step forward toward timely and just resolution of civil suits that pertain to events the NCST investigates;

- Recommended to Congress that revisions be made to the NCST Act to broaden the scope to include structures other than just buildings;

- Acknowledged that the Interagency Agreement (IAA) with the National Science Foundation (NSF) was an important first step to leverage the studies and capabilities of each agency to minimize the negative consequences of natural hazard events;

- Complimented NIST for their thorough and thoughtful responses to the Committee's recommendations;

- Was impressed with the panel discussion-style of presentations utilized in the June 2023 meeting to show the cohesive and interconnected nature of the investigations;

- Applauded NIST for continued efforts to automate scoring of disaster events;

- Noted the excellent advancements in team readiness;

- Noted the importance of a top-down approach to safety culture;

- Encouraged the incorporation of social scientists into any studies or investigations that include evacuations, and noted the importance of collecting perishable memories;

- Noted the value of the Office of Management and Budget Generic Clearance for Community Resilience Data Collections renewal in making reviews of interview requests timelier for data collection purposes, which is a welcome change compared to the past for several investigations;

- Emphasized the need for performance requirements for buildings, not just codes and standards, and education for engineers;

- Encouraged NIST to be involved and take a leading role in responding to the Maui wildfires in some fashion, even though the decision had previously been made to not conduct an NCST investigation;

- Commended NIST on the thorough work done in the area of hazard characterization for Hurricane Maria, which includes uncertainty analysis;

- Appreciated the methodological rigor being applied in the HM projects, including the use of verbal autopsies for the Morbidity and Mortality project;

- Applauded NIST for tackling the challenging task to evaluate the cause of fatalities in the HM NCST Investigation;

- Complimented NIST for their reformatted approach to data collection for the HM projects due to the pandemic;

- Noted the rich data being produced by the HM projects, and that it could be used by others once published;

- Acknowledged the world-class team assembled for the CTS NCST Investigation, and complemented NIST on the inclusion of social scientists;

- Recommended careful attention to several highly challenging elements of the CTS NCST Investigation;

- Acknowledged the benefit of providing a detailed timeline for all projects in the CTS NCST Investigation;

- Noted that they were highly impressed by NIST's progress and plans to understand the CTS collapse, and urged NIST to expedite the investigation and issue interim summaries of critical lessons learned as the Investigation progresses;

- Congratulated the CTS team on their approach to conduct interviews to tell the story of the CTS collapse, and requested that they publish methodological papers at the end of the investigation;

- Acknowledged the codification of tornado loading requirements as a significant advancement in the resistance of ASCE 7 Category III and IV buildings;

- Was pleased that NIST was continuing efforts to develop recommendations for construction guidelines for tornado effects, and encouraged NIST to broaden these efforts to include building code Risk Category II;

- Noted the comprehensive presentations provided on progress on implementation of recommendations from previous investigations; and

- Noted that the NCST program is highly valuable to the safety and resilience of the U.S. built environment, and commended NIST for diligently administering the program.

Public comments addressed:

- Victim's family member concerns about the collapse site safety and that it will have a new building built prior to NIST completing its investigation;
- Victim's family member concerns that while the civil litigation has been completed, the families still do not know why the collapse occurred;
- Questions about cooperation with other authorities; and
- International Code Council efforts to develop guidelines for a proactive approach to evaluating the safety of existing buildings, and to develop a new standard for inspecting existing properties.

A summary of these meetings may be found on the NIST NCST website[3] and in the FY 2023 Annual Report of the NCSTAC to Congress.[4]

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 resulted in substantial loss of life or that posed 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:

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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 2023 NCSTAC Report to Congress available at: https://www.nist.gov/topics/disaster-failure-studies/national-construction-safety-team-ncst/advisory-committee.

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 2023 as required by Section 10 of the Act.

1. Investigations Conducted Under the NCST Act during FY 2023

a. Hurricane Maria

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 (HM Team) under the NCST Act, based on an analysis of the event against the criteria 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 HM Team members continue to work on four projects that address the investigation goals, as described below:

(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.

The wind field modeling is supported by a contract with ARA, awarded in February 2019, which includes the development of a time-dependent wind field model of Hurricane Maria's impact on Puerto Rico. In FY 2023, comparisons were performed with wind tunnel measurements of flow fields over topographic models to provide validation of the approach used to capture topographic speedup effects in the wind field model. Refinements to the wind field model were also incorporated to account for variations in air density associated with the hurricane's passage over the complex topography of Puerto Rico and to provide quantification of uncertainty in the modeled wind speeds.

The wind tunnel testing and field measurement of winds is supported by a contract with the University of Florida (UF), awarded in May 2019. In FY 2023, NIST and UF completed the post-processing and curation of flow-field measurements from wind tunnel testing of topographic models, including 1:3100 scale models of the Mayagüez and Yabucoa regions in Puerto Rico as well as models of generic ridge and plateau features with various surface conditions. The post-processing of Particle Image Velocimetry (PIV) measurements involved calculation of 3-dimensional velocity fields from over 80 terabytes of imagery from a high-speed stereo camera system. Complementing the PIV measurements, the curated dataset also includes flow profile measurements obtained using discrete velocity probes. Flow measurements over the generic ridge and plateau models provide data for validation of numerical models and for evaluation of current standard provisions, while flow measurements over the Mayagüez and Yabucoa models provide data to characterize the effects of Puerto Rico's mountainous topography on wind fields.

Field measurements of topographic wind speedup effects over terrain commenced in March 2021 and were supported for a period of two years through a UF subcontract to WeatherFlow, Inc. In FY 2023, the second year of data collection was completed, and a new contract for a third year of data collection was awarded directly to WeatherFlow. Through these contracts, long-term measurements of continuous, high-resolution wind velocity histories were continued throughout FY23 using meteorological stations previously installed at multiple heights on three cell towers in the Yabucoa region. Anemometers that had been damaged by Hurricane Fiona were repaired in FY 2023, and the as-installed orientation angle of each propellor-vane anemometer was measured using a high-accuracy laser scanning system to provide reduced uncertainty in the wind direction measurements. A total of 30 months of data were collected by the end of FY 2023, and analysis of the measured data is underway. A real-time feed of the measured data from these instrumented towers continues to be available to NIST and partnering agencies, including the National Weather Service in San Juan.

Complementary to the wind tunnel testing and field measurements, the HM Team has been developing Computational Fluid Dynamics (CFD) models to evaluate topographic effects on winds, including consideration of the effects of terrain surface roughness. In FY 2023, the HM Team evaluated ground roughness treatment approaches, including wall functions and forest canopy modeling in conjunction with various CFD turbulence models, aiming to identify the most effective modeling approach for accurate simulation of topographic effects. The HM Team has developed an uncertainty quantification procedure for the CFD models that uses Gaussian process emulators and accounts for varying model inputs. The HM Team also has collected quantitative information on forest cover in Puerto Rico, including tree height, leaf area index, and leaf density, at several different points in time (e.g., just before and after Hurricane Maria as well as various other times up to the present). The information, sourced from multiple remote-sensing datasets, allows the HM Team to evaluate Hurricane Maria's damaging effects on local forest cover. CFD simulations that account for the forest canopy will then provide insights on how these changes in forest cover influenced the topographic speedup of winds.

To support documentation of other hazards in addition to wind, in FY 2023 the HM Team analyzed hindcast data from an ensemble of 14 high-resolution Weather Research and Forecasting (WRF) models and compared the modeled rainfall results for Hurricane Maria

with rain gauge measurements and with rainfall estimates based on multi-sensor measurements. The HM Team analyzed the available rainfall measurements and developed an uncertainty model to understand the relationship between rainfall estimates from different sources. Through an ongoing collaboration with Bristol University, the HM Team is evaluating the influence of different rainfall estimates on modeling of inland flooding in Puerto Rico during Hurricane Maria.

(2) Performance of Critical Buildings:

The objective of this project is to characterize the performance of critical buildings in Hurricane Maria by evaluating damage and loss of function for representative hospitals, schools, and storm shelters with respect to the hazards they experienced and by evaluating the selection criteria and design requirements for storm shelters.

Support in evaluating the performance of critical buildings is being provided through a contract with Stantec Consulting Services, Inc., awarded in March 2020, with key personnel and engineering experts based in Puerto Rico. In FY 2023, NIST and Stantec completed the second phase of evaluation work for the five hospitals and five shelter facilities previously selected for detailed evaluation. This second phase included site visits and interviews with facility managers to document damage to the buildings and impacts on the function and operation of the facilities. The first phase of evaluation work, completed previously, involved collection and review of documents such as architectural drawings and damage assessment reports. The selected shelter facilities included four public schools and one non-school shelter. Through ongoing coordination with the Puerto Rico Department of Education, the previously granted approval for evaluation of public-school facilities under this project was extended for an additional year to support the completion of these data collection efforts.

Also in FY 2023, NIST and the UF contractor team completed post-processing and curation of measured data from wind tunnel testing of 1:100 scale models of two hospital facilities for detailed evaluation of wind loads sustained during Hurricane Maria. The models incorporated tubing for pressure tap measurements and load cells for resultant force measurements. Post-processing of the data included corrections to account for the frequency response of the tubing system used for pressure measurements, incorporating the effects of the tubing dimensions and the temperature and atmospheric pressure at the time of testing. The corrected pressures were then normalized as nondimensional pressure coefficients using consistent measurements of reference velocity and pressure. The curated dataset includes wind tunnel measurements for cases with and without the local topography and surrounding buildings to enable examination of these effects in the analysis of the data.

(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 also examines the use of communications during response and recovery (during and immediately after the hurricane).

This project is supported by a contract with the Horsley Witten Group, Inc., awarded in December 2019, with subcontractors Eastern Research Group, Inc., Issues & Answers, Inc., and Albizu University in San Juan, Puerto Rico.

On behalf of NIST, Albizu University has conducted surveys and interviews of households to better understand factors that influenced evacuation decision-making, including the role of emergency communications in those decisions. In FY 2023, data from the household surveys were received, with over 1,500 households participating within four study regions selected by NIST. The data collection followed an area probability sampling plan to produce representative responses across urban and rural areas, as well as areas prone to flooding and landslide impacts; the response rate for the data collection was about 26%. Most respondents (about 95%) completed the survey in person, and appreciated interacting with interviewers, who were Puerto Rican students from Albizu University; the remaining responses were collected online after respondents were recruited to participate during a visit of the data collection team to their residence. The majority (about 86%) reported that they did not evacuate for Hurricane Maria, and only about 11% of those that did evacuate went to a public or private emergency shelter. Analysis of survey data is ongoing by the NIST Hurricane Maria Emergency Communications team, including assessment of weighting strategies to correct bias in data representation, such as an over-representation of older and female respondents.

The household interviews, which are an optional follow-on for survey respondents, are also complete. A total of 60 respondents participated in the interviews. These interviews focus on barriers to taking protective action, as well as unmet information needs before and during the hurricane. In FY23, NIST received the translated and transcribed data from these interviews and is using qualitative coding analyses to better understand the experiences of Puerto Ricans before and during the storm, and also to provide more context-specific information that can help characterize quantitative data from survey responses.

In FY23, NIST continued analysis of the data from 35 semi-structured interviews with expert information providers in Puerto Rico to help characterize message dissemination, organizational interactions and constraints, and activities to facilitate communication effectiveness. These anonymous data provide insights from mayors, emergency managers, meteorologists, forecasters, journalists, and government agency representatives. Data analysis of the interview transcripts focuses on the purpose or emphasis of the message, target audience, and partners involved in developing the message. For example, the National Hurricane Center emphasized the seriousness of wind, rain, and flooding and the media distributed messages about shelter locations. Mayors and local government representatives emphasized evacuation for people in deficient structures and with health care needs.

NIST has also completed the qualitative content analysis (QCA) of emergency communications and messages to assess their timing, distribution, and effectiveness. More than 200 long- and short-form messages from newspapers, press releases, and NOAA weather radio, and over 2,500 anonymized social media messages from Twitter were collected, organized, translated, coded and analyzed. Insights gathered help characterize

the risk information environment in which people were assessing and making protective action decisions in advance of and during Hurricane Maria.

(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 and standards as well as to inform future approaches to accurately attribute and predict life loss due to windstorm building failure(s).

This project is supported by a contract with the Milken Institute School of Public Health at the George Washington University (GW), awarded in July 2020, with collaborators at the University of Puerto Rico-Graduate School of Public Health (UPR), and the Institute for Health Metrics and Evaluation (IHME) at the University of Washington. These contractors are supporting the Morbidity and Mortality Project's goal of identifying deaths in Puerto Rico directly and indirectly related to Hurricane Maria and, more specifically, to identify deaths attributed to building and/or building system failure(s).[5] In FY 2023, NIST received several key deliverables of the GW contract.

UPR completed all remaining data collection in FY 2023 including surveying 410 next-of-kin and other key informants using a Verbal Autopsy and Socio-Environmental (VA+S'E) instrument to determine attribution of deaths that occurred within two weeks after the storm made landfall. Of these deaths, 11% occurred the day of the hurricane's landfall and 88% occurred in the 14 days after landfall. Preliminary assessment of the VA+S'E data shows that approximately 66% of individuals sought health care in at least one place, and the more frequently mentioned hospital disruptions were power outages, loss of AC/ventilation, and shortage of staff. The data collection for the hospital functions review (six hospitals) and medical records extraction (five hospitals) was also completed; these components of the project inform an understanding of the deaths that occurred in hospitals.

In FY 2023, data analysis was also completed by the GW contract team. Deliverables include reports on the use of geographic data to better understand Hurricane Maria mortality, the findings from the Verbal Autopsy and Socio-Environmental (VA+S'E) survey, attribution of deaths, and results of the hospital functions review and medical records extraction. Additionally, the integrated mortality database was delivered to NIST. This database, which includes 2,562 variables and data for over 16,000 deaths, links data from various data sources on the deaths that occurred up to six months after Hurricane Maria made landfall in Puerto Rico.

In FY23, NIST's Engineering Laboratory received $40M in additional funding from Congress through a disaster supplemental appropriation "…to support the development of resilience standards with regard to weather and climate disasters, in addition to the underlying research to

[5] Under 15 CFR § 270.100(b), "a building failure may involve one or more of the following: structural system, fire protection (active or passive) system, air-handling system, and building control system. Teams established under the Act and this part will investigate these technical causes of building failures and will also investigate the technical aspects of evacuation and emergency response procedures, including multiple-occupant behavior or evacuation (egress or access) system, emergency response system, and emergency communication system."

support those standards, and for necessary expenses to carry out investigations of building failures pursuant to the National Construction Safety Team Act of 2002". A portion of these funds will support the extension of existing work on Hurricane Maria to consider impacts of Hurricane Fiona, including assessment of the hazard, specifically wind and rainfall; evaluation of Hurricane Fiona's impacts on selected hospitals and shelters being evaluated in the Hurricane Maria NCST Investigation; assessment of impacts on infrastructure systems and their interdependencies (e.g., power, water, transportation); and evaluation of physical and non-physical impacts of Hurricane Fiona as well as effects on recovery from Hurricane Maria. Observations from Hurricane Fiona are expected to provide context to inform recommendations that come from the Hurricane Maria NCST Investigation

The HM Team's efforts in FY 2023 included a focus on data analysis and cross-project integration through a number of activities, including:

- Thematic presentations to the NCST Advisory Committee in June 2023 on hospitals, sheltering, and infrastructure dependencies, in which preliminary analyses were presented alongside relevant data streams and analysis questions from each of the investigation projects;
- Geospatial analysis planning and coordination on topics such as representation of hazard exposure in relation to schools, hospitals, and businesses, and quantification of forest cover in relation to wind hazard exposure and infrastructure impacts; and
- Collaborative work with statisticians to address uncertainty quantification, weighting of survey data, and imputation of missing values in datasets.

The HM Team continues to provide regular updates of progress through the NIST website.[6]

b. Champlain Towers South Condominium Collapse

On June 24, 2021, around 1:30 am, approximately half of the Champlain Towers South Condominium collapsed suddenly in Surfside, FL, causing 98 fatalities. NIST sent a preliminary reconnaissance team on June 25, 2021, to establish relationships and collect information and data to be used to determine whether a further NIST study should be conducted. Based on the recommendations of the preliminary reconnaissance team and evaluation of the criteria listed in the NCST Act and its implementing regulations, on June 30, 2021, the NIST Acting Director established the CTS Team under the NCST Act to conduct a technical investigation of the partial collapse. The goal of this investigation is to uncover factors that contributed to the initiation and sequence of collapse of the building and make recommendations to improve public safety and prevent recurrence of failures like the partial collapse of CTS.

The recommendation to establish the CTS Team was based on analysis of the event against the criteria found in the NCST Act and its implementing regulations (15 C.F.R. Part 270) for establishing a Team and firsthand observations in Surfside made by the NIST preliminary reconnaissance team. The NCST Act and its implementing regulations (15 CFR 270.102) set forth the criteria the Director must use in determining whether to establish and deploy a Team "after an event that caused the failure of a building or buildings that resulted in substantial loss of life or posed significant potential for substantial loss of life."

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

The CTS Team is in custody of more than 3 TB of photos and videos, as well as more than 600 pieces of physical evidence located at two secure primary evidence facilities. The Team extracted more than 350 concrete cores from the evidence for materials characterization and testing. The Team has conducted more than 25 interviews of building residents, staff, and families as well as first responders and others supporting the emergency response effort. They have been reviewing all of this material while actively exploring more than two dozen failure hypotheses. The appointed CTS Team members are working on six technical projects and one management project, related to the investigation:

(1) Building and Code History:

The objective of this project is to assess the entire history of the building from original design through the partial collapse, including relevant codes and standards, design drawings and other documents, construction records, inspections, maintenance, renovations, and loads and environmental conditions.

The Building Code and History project is supported by a contract with Strativia LLC awarded in 2022 and again in 2023 to provide the project co-leader, and by a contract awarded to Applied Research Associates in 2023 for the analysis of historic wind loading of the CTS building.

The Building and Code History project team is focused on describing how the site and the structure came to be, and their conditions at the time of failure. This project team has completed its analysis of the design drawings and original construction permits and has studied the codes and standards of practice relevant at the time of design and construction of CTS. The project team has been reviewing available permits and other documents for repairs and renovations to the structure over its life. The project team has been cataloging relevant public and private records, including recently received records from the civil litigation, that are relevant for the investigation. The project team is also conducting contextual interviews of people with knowledge of prevailing design and construction practices in South Florida at the time of original construction.

The project team has also been working closely with the Evidence Preservation and Structural Engineering project teams in establishing the as-built conditions of CTS by examining and measuring the collapse specimens in the primary evidence facility located in Miami, Florida. Substantial progress has been made in measuring the as-constructed detailing of pool deck slab, other floor slabs, slab-to-column connections, column cross-sections, and column compression splices. The project team has also been analyzing the building's loading history, including superimposed dead loads, live loads, and lateral loads from windstorms, that it experienced over its life.

(2) Evidence Collection and Preservation:

The objective of this project is to use innovative tagging and data collection methods to catalog and organize evidence and ensure the integrity of its origin through proper storage, handling and sampling. This project also focuses on determining the original locations of evidentiary building debris from the CTS building prior to collapse using identification

clues, design drawings and data collected during collapse pile deconstruction. This project leads the effort to extract and document testable subsamples, such as concrete cores and rebar, from evidentiary building debris that are representative from different areas of the building. This project also includes collecting key pieces of evidence by conducting interviews with CTS residents, first responders, family members or others with knowledge of the building condition and collapse events.

The Evidence Collection and Preservation project leveraged the expertise and equipment from the NSF-supported Natural Hazards Engineering Research Infrastructure (NHERI) RAPID Facility at the University of Washington, under a Memorandum of Understanding, who also provided training to NIST staff for the operation of disaster-data collection equipment. This project is currently supported by a contract awarded in 2022 to Miami-Dade County for evidence protection services, a contract awarded in 2023 to Applied Research Associates for invasive testing management, and a contract awarded to Florida International University to conduct additional interviews and focus groups. This project is also supported by a work order under an interagency agreement (IAA) with the Bureau of Reclamation (BurRec) for reinforcing bar testing, by several work orders under an IAA with the US Army Corps of Engineers (USACE) for subsample extractions and materials testing, and by a Memorandum of Understanding with the Federal Bureau of Investigation (FBI) for multimedia analysis.

The Evidence Collection and Preservation project has completed documentation of evidence specimens and cataloged these in a physical evidence database. The team has populated the database with much of the collected information, including specimen dimensions, materials characteristics, photographs, and the determination of the origin of the specimens. The project team continuously adds information to this database, such as origin identification clues, 3D scans, and additional measurements and observations of the specimens. The project team has also developed the workflow and associated documentation to track, in the database, the history of any subsamples extracted from the physical evidence for subsequent invasive testing.

The Evidence Collection and Preservation project leads the investigation-wide invasive testing program and has collected more than 350 subsamples of concrete and steel reinforcing bars for laboratory testing. This effort was preceded by identification of where over 100 specimens were likely located in the building prior to collapse to inform extraction of subsamples from evidence specimens that were representative of different areas in the CTS building. This effort has included developing a statistical sampling approach that collects data relevant to all failure hypotheses and enables quantification of propagation of uncertainties throughout the investigation.

The Evidence Project leads the program of interviews, focus groups, and surveys of people with knowledge of CTS (e.g., eyewitnesses and residents), as well as other stakeholders. The project team has developed instruments and consent forms, collected background materials, and conducted more than 25 structured interviews with several types of key informants and have consulted with all projects on technical inquiries with stakeholders.

In concert with the Building and Code History project, the Evidence Collection and Preservation project has been documenting dimensions, features, and properties of the

physical specimens to determine their as-built conditions.

(3) Remote-Sensing and Data Visualization:

The objective of this project is to analyze data collected from the Champlain Towers South site after the collapse, as well as any available data on the building prior to the collapse. The analyzed 2D and 3D surface, and subsurface data will be compiled, organized, georeferenced, visualized and communicated as part of a geographic information system (GIS) model that will be designed to support the other investigation projects.

The Remote-Sensing and Data Visualization Project is supported by a contract awarded to Tre Altamira, Inc. in 2023 for InSAR data collection and analysis. This project is currently supported by a work order (under an IAA with USACE) that provides project co-leadership and data analysis, and a work order (under an IAA with NSF) for data processing of drone data by Florida State University.

The Remote Sensing and Data Visualization project collected lidar data and drone imagery during the search and rescue, and recovery efforts. The team added satellite-based InSAR data in 2023 as well, which looked at surface deformations from before and after the collapse at the CTS site and its surroundings. The project has nearly completed validation and registration of the lidar data and has conducted multiple analyses in response to measurement requests from other projects. Processing of drone data into 2D and 3D drone maps was also completed in 2023 and the maps were incorporated into the GIS model. The project has also been tagging and finding images and videos in response to search requests from the other investigation projects. The team plans to complete this effort early next fiscal year.

The project team has also continued to develop the 3-D GIS model that serves as an interactive tool that centralizes the investigation's information and is searchable by components or areas of the site and structure. The tool is built and has been deployed to the entire team in a user-friendly web tool. This tool will be continuously populated with information from all the projects as the investigation develops.

This project team also leads the ongoing detailed image and video analysis, such as the forensic analyses that were conducted on surveillance videos and phone videos from eyewitnesses. Additionally, this project leads efforts to recover hard drives from the CTS security camera digital video recorder; several recovered hard drives are undergoing forensic analysis in an attempt to recover data from them.

The project plans to create several realistic animations to convey the investigation's findings on the initiation and sequence of the failure, and to illustrate contributing mechanisms.

(4) Materials Science:

The objective of this project is to evaluate the strength, appropriateness, uniformity, and deterioration of materials used in specific building features and at different floors in the building. This project compares the measured material properties to the characteristics

specified in the building design and the measured data will be used in the partial collapse analyses and simulations.

The Materials Science project is supported by a contract awarded in 2022 to the University of Florida to conduct testing of trial concrete mix designs, a contract awarded in 2023 to Tourney Consulting Group LLC for an evaluation of durability and corrosion, and a contact awarded in 2023 to YA Engineering Services for petrographic examination of concrete materials.

The Materials Science project has conducted petrographic examination of material extracted from specimens to provide contextual information regarding compression strength results. The project has conducted transport property measurements on an initial sample of 30 specimens, to help refine the investigation's invasive testing plan and to provide insight into material performance as it relates to failure hypotheses.

The Materials Science project has used non-destructive testing methods at hundreds of recording points on columns and slab specimens in the primary evidence facility. This helps to understand the range of properties and conditions of the specimens collected at the collapse site and stored in the primary evidence facility. The project team has conducted macro- and micro-examinations of an initial collection of concrete samples using optical and scanning electron microscopes. This non-destructive testing and preliminary invasive testing informed the investigation's invasive testing program, including its sampling approach. The project has used this information to identify locations on the specimens to extract concrete cylinders for material property measurements to provide evidence to assess failure hypotheses. More than 350 concrete cores and steel reinforcing bar samples have been extracted, and many tested so far, for this purpose.

The Materials Science project is also analyzing the mechanisms of corrosion in the reinforcing steel, any possible deterioration mechanisms in the concrete, and the impact of maintenance and repairs over the life of the structure. The project has developed a method to assess the degree of corrosion of rebar from the physical evidence and is working with the Evidence Collection and Preservation project and the Structural Engineering project, to identify and extract rebar samples for subsequent mechanical testing and degree of corrosion measurements.

The project team has developed a methodology to create concrete samples representative of the concrete of Champlain Towers South at the time of collapse for use in the structural laboratory testing program. The project provides continuous support to the structural testing contractors supporting the Structural Engineering project, focused on concrete-mixing and specimen-curing protocols, and is working with contractors to develop a procedure to accelerate corrosion of reinforcing steel.

(5) Geotechnical Engineering:

The objective of this project is to evaluate the foundation's design, as-built construction and current condition. It will also assess geotechnical and soil factors that may have affected the foundation.

The Geotechnical Engineering project is supported by a contract awarded in 2022 to the University of Illinois at Urbana-Champaign to provide the project co-leader. It has also been supported by multiple work orders (under an IAA with the USACE) to conduct testing, a geophysical investigation, and a site survey. This project was also supported by a work order (under an IAA with NSF) for wave propagation testing by the NSF-supported NHERI mobile facility at the University of Texas with Utah State University.

In FY23, the project team identified and met with local practitioners, engineers and contractors who designed and installed the same type of foundations (Franki piles) as in the CTS building in the late 1970's and early 1980's. Local construction practices were identified and copies of a guideline by the company Franki that produced these foundations, were provided to the CTS Team to assist with calculations of load bearing capacity of the CTS foundations.

The Geotechnical project team is also processing the site information collected such as survey data on the as-built elevations and thickness of the basement slab, and the site stratigraphy. The geotechnical analyses and structural analyses need to be closely linked to understand any impact of soil-structure interaction.

(6) Structural Engineering:

The objective of this project is to use evidence collected from the collapse site, the results of the other projects, and structural engineering and reinforced concrete design knowledge to generate computer models to simulate the failure initiation and progression.

The Structural Engineering project is supported by a contract awarded in 2022 to Muttoni et Fernandez Ingenieurs Conseils SA on the role of slab-column failures, a contract awarded in 2022 to Cagley and Associates to conduct building code checks; as well as a contract awarded in 2023 to the University of Washington, with a subaward to the University of Minnesota, to conduct structural testing.

The structural engineering team has created baseline computer models using state-of-the-art software packages, ETABS and ADAPT, for checks of the structural design and to understand the points of vulnerability of the structure. The project team is engaging Cagley and Associates to make detailed analyses of the compliance of the Champlain Tower South's structural design to codes and standards applicable at the time of original construction, as well as to perform an assessment relative to today's standards. These studies support the analysis of any design-related contributions to the failure and also help inform any recommendations that may be made for changes to codes and standards of practice. The code checks were completed in FY 2023 and a final contractor report is currently under review.

The project team has developed a detailed plan for laboratory testing of replicas to failure for components of the structure including columns, slab-column connections, and slab-beam-column connections. These tests will be performed at the Universities of Washington and Minnesota, where the fabrication of the first test specimens is underway.

The Structural Engineering project team has built detailed nonlinear, finite element models

of the first level of the collapsed part of the CTS structure along with the entire building for the purpose of simulating collapse initiation and progression. The team is currently performing test runs of these models and plans to expand and update it with information (i.e., as-built, changed, and aging and deterioration conditions) from the other project teams over the course of the investigation.

(7) Project Management:
The six technical projects described above are managed by the investigation's co-leads, which provides technical and project oversight to meet the objectives of each project and identify the underlying cause(s) of collapse of CTS.

In FY 2023, the Investigation obligated the remaining 51% of the total $22M in funds appropriated by Congress as part of the Extending Government Funding and Delivering Emergency Assistance Act, 2022 (Public Law 117-43). Roughly three-quarters of these funds paid for travel, contracts, work orders under interagency agreements, micro-purchases, and simplified acquisitions. The remaining 28% of the funds spent in FY 2023 paid for more than 40 employees at NIST that contributed directly to the investigation, at various levels of percent effort. The Investigation also spent approximately $1M of the of the funds provided by Congress under the Disaster Relief Supplemental Appropriations Act, 2023, as part of the Consolidated Appropriations Act, 2023 (Public Law 117-328). The majority (97%) of these additional funds were spent on travel, contracts, and micro-purchases. Many additional individuals at NIST, and outside of NIST, generously support the CTS Team's efforts. The Team has cooperated, collaborated, and coordinated with more than 15 Federal and local agencies.

The Champlain Towers South NCST Investigation is highly visible to the public and media. Families and others impacted by the partial collapse need to know how and why the failure occurred. Owners, residents, managers, building officials, and regulators need to know whether the factors that caused the Champlain Towers South partial collapse have implications for other structures. The team continues to communicate with families directly, by email and via virtual meeting platforms, regarding major updates in the investigation. The Investigation works under continual time pressures to provide results and subsequent recommendations for changes to codes, standards, and practice.

The NCST CTS Investigation is one of the most complex and challenging investigations of its type ever undertaken, with dozens of failure hypotheses to pursue and an enormous amount of evidence to analyze. The implications of the findings of the Investigation are far reaching. The Investigation must be thorough.

Investigations like Champlain Towers South have plans, tasks, and needs for resources which evolve as the investigation unfolds. In this regard, the processes imposed by Federal Acquisition Regulations have been a hindrance. With the extraordinary support of NIST's Acquisition Management Division and other NIST operating units, as well as support of NIST management and leadership, the Investigation has used all possible means to procure materials and services at speeds that align with the investigation's timeline, while continuing to meet the Federal Acquisition Regulations requirements. NIST has awarded more than 30 contracts, IDIQ task orders, and IAA work orders in support of the investigation. At the September 7 NCSTAC, the Team announced that they expect the technical work to be completed by Q4 of FY 2024 and the final report to be shared by Q4 of FY 2025.

Updates on the NCST Champlain Towers South Condominium Investigation are posted on the NIST website.[7]

2. Summary of Recommendations Made in Reports Issued Under Section 8 of the NCST Act during FY 2023.

During FY 2023, 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 2023 in Response to Reports Issued Under Section 8 of the NCST Act.

During FY 2023, 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:

The following actions were taken in FY 2023 to implement recommendations in the World Trade Center NCST Investigation final report[8] to improve building safety and structural integrity.

- In FY 2012, based on a proposal from NIST, the ASCE/SEI Disproportionate Collapse Mitigation Standard Committee was established to develop a consensus Standard for Mitigation of Disproportionate Collapse Potential of Buildings and Other Structures. The final standard, with contributions from NIST staff based on results of NIST research, was published in May 2023 as ASCE 76-23. This addresses Recommendation #1 from the WTC NCST Investigation.
- NIST contributed to updating ASCE 7-22 wind velocity pressure profiles for a more accurate estimation of wind load on structures as function of height. These were approved for incorporation into the 2024 International Building Code. This addresses Recommendation #2 from the WTC NCST Investigation.

With these actions, implementation is complete for all recommendations from the World Trade Center NCST Investigation.

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

The following actions were taken in FY 2023 to implement recommendations in the NCST Joplin Tornado Investigation final report[9] to improve building safety and structural integrity:

- NIST led the development of a proposal in collaboration with ASCE and FEMA to include the ASCE 7-22 tornado load requirements into the 2024 International Building Code (IBC). The ASCE 7-22 tornado load requirements were also approved for inclusion in the 2024 NFPA 5000 Building Construction and Safety Code, as well as the 2023 Florida Building Code. NIST also published a tornado load design guide in collaboration with

[7] https://www.nist.gov/disaster-failure-studies/champlain-towers-south-collapse.

[8] https://www.nist.gov/el/final-reports-nist-world-trade-center-disaster-investigation.

[9] https://www.nist.gov/publications/final-report-national-institute-standards-and-technology-nist-technical-investigation

FEMA. These activities address NIST Joplin Recommendation #5 (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report[9]).

- NIST collaborated with FEMA to publish interim guidance for tornado-resistant design and retrofit of residential structures and supported FEMA in the development of a wind retrofit guide for residential buildings. These activities address NIST Joplin Recommendation #6 (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report[9]).
- NIST and National Oceanic and Atmospheric Administration (NOAA) staff continued to lead the ASCE/SEI/AMS Standards Committee that is developing the new Tornado Wind Speed Estimation Standard. During FY 2023, the committee conducted balloting of four draft Damage Indicators in the Enhanced Fujita (EF) Scale. Work on additional chapters for other wind speed estimation methods continued. This standards development activity addresses NIST Joplin Recommendation #4 and supports NIST Joplin Recommendations #1 and #2 (of Recommendations Group 1, Tornado Hazard Characteristics and Associated Wind Field, in the final report[9]).
- NIST conducted analysis on data collected following the December 10-11, 2021, Quad-State Tornado Outbreak, to further support the development of a Smart^DI. This supports NIST Joplin Recommendation #4 (of Recommendations Group 1, Tornado Hazard Characteristics and Associated Wind Field, in the final report[9]).
- NIST staff chair the standards committee for the ICC 500 Standard for Design and Construction of Storm Shelters and the next edition of the standard will be published in 2023. These efforts directly address NIST Recommendation #7a (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report).
- 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 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[2]).

4. Preliminary Investigations

NIST uses a scoring tool to assess the need for preliminary reconnaissance of disasters and failures. The scoring tool utilizes the following key decision criteria: event consequences (substantial loss of life or disabling injury, significant potential for loss of life, hazard intensity, and consequences to resilience); major challenges in evacuation and/or emergency response; international factors (relevance to the United States); feasibility (resources and safety of team); and study impacts (new knowledge gains, and potential impact to existing standards, codes and guidelines). Twenty-two domestic and international events were scored in FY 2023, including seven windstorms, eight earthquakes, six structural failures, and one wildfire. These events occurred in Alabama, Arkansas, California, Colorado, Florida, Georgia, Hawaii, Illinois, Indiana, Iowa, Kentucky, Louisiana, Mississippi, New York, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Texas, Wisconsin, Colombia, Dominican Republic, Greece, Indonesia, Iran, Libya, Syria, and Turkey (Türkiye). Preliminary reconnaissance missions were conducted for the Turkey (Türkiye)-Syria earthquakes and the Maui wildfires. Preliminary reconnaissance missions

were not conducted for any of the other events, due to 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; minimal impact to building occupants; or limited financial and personnel resources.

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 2023, NIST assessed 22 events (earthquakes, hurricanes, tornadoes, wildfires, and structural failures) using a scoring tool that considers: event consequences (substantial loss of life or disabling injury, potential for loss of life, hazard intensity and physical damage) and evacuation and/or emergency response; international factors (relevance to the U.S.); and study impacts (safety of team, new knowledge gains, and potential impact to existing standards, codes and guidelines). After analyzing the data from these 22 events, NIST conducted two preliminary reconnaissance missions, for the Turkey (Türkiye)-Syria earthquakes and the Maui wildfires.

NIST continues to further investigate the building performance and emergency response and evacuation during Hurricane Maria in Puerto Rico, the partial collapse of Champlain Towers South in Surfside, FL, and continues to pursue actions related to improving building safety and structural integrity that were recommended by previous NCST Investigations. As part of the Hurricane Maria Investigation, in FY 2023 NIST processed several contract modifications and exercised contract options to support all seven of the technical projects and awarded new contracts to provide wind field modeling and field measurements of wind to support the Hazard Characterization and Performance of Critical Buildings projects. As part of the Champlain Towers South Investigation, in FY 2023 NIST executed numerous IAA work orders and non-disclosure agreements, processed several contract modifications to exercise contract options and fund additional tasks to support the Geotechnical Engineering and Evidence Preservation projects, and awarded several new contracts to provide project co-leader support and wind loading evaluation for the Building and Code History project, invasive testing management for the Evidence Preservation project, InSAR data collection and analysis for the Remote Sensing and Data Visualization project, corrosion and durability support for the Materials Science project, and structural testing for the Structural Engineering project. NIST presented these FY 2023 activities to the NCST Advisory Committee during web-conference meetings on June 14-15, 2023, and September 7, 2022.