National Institute of Standards and Technology
National Construction Safety Team Act
Annual Report
Fiscal Year (FY) 2021

Summary

This annual report to Congress for Fiscal Year (FY) 2021 is required by the National Construction Safety Team (NCST) Act (Public Law 107-231). The National Institute of Standards and Technology (NIST) continues to evaluate Hurricane Maria's 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 2021, NIST deployed a preliminary reconnaissance team to gather observations and information on the partial collapse of the Champlain Towers South Condominium in Surfside, FL, on June 24, 2021. The recommendations of the preliminary reconnaissance team and evaluation of the criteria set forth in the NCST Act and its implementing regulations resulted in a new NCST technical investigation launched by the NIST Acting Director on June 30, 2021. The goal of this investigation is to determine the factors that contributed to the initiation and sequence of the partial building collapse.

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

Highlights of FY 2021 activities include:

- NIST published a report in January 2021, *Learning from Hurricane Maria's Impacts on Puerto Rico*,[3] which summarizes the significant progress of the Hurricane Maria NCST Investigation.
- NIST exercised contract options to enhance ongoing data collection efforts in support of the Hurricane Maria NCST Investigation, including a contract option with the George Washington University to retrieve and review additional data to help determine the causes of hurricane-related deaths, contract options with Stantec Consulting Services for additional tasks to evaluate the performance of critical buildings, a contract option with University of Florida (UF) for a second year of wind measurements on instrumented towers in the Yabucoa region of Puerto Rico, and a contract option with Applied Research Associates (ARA) to evaluate wind load histories on buildings through integration of wind tunnel measurements with the final wind-field model for Hurricane Maria.

[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.

[3] English version: https://doi.org/10.6028/NIST.SP.1262; Spanish version: https://doi.org/10.6028/NIST.SP.1262es.

- NIST established a National Construction Safety Team to investigate the partial collapse of the Champlain Towers South (CTS) Condominium in Surfside, FL, on June 24, 2021. The CTS Team includes eight members from NIST and six outside members, working on six specific projects.
- NIST staff led the effort to develop a new chapter on tornado loads for ASCE/SEI 7-22 Minimum Design Loads and Associated Criteria for Building and Other Structures, the national loading standard. This chapter, which incorporates the NIST tornado hazard maps and methodology for computing tornado design loads on buildings and other structures, was incorporated in the ASCE 7-22 Draft for Public Comment, published in June 2021. This addresses Recommendations #3, #5, and #6 from the NCST Joplin Tornado Investigation.
- NIST continued to work with the American Society of Civil Engineers (ASCE) Structural Engineering Institute (SEI) Standards Committee that is developing the new Tornado Wind Speed Estimation Standard, which directly addresses Recommendation #4 from the NCST Joplin Tornado Investigation.
- NIST supported the development of the next edition of the International Code Council (ICC) 500 Standard for Design and Construction of Storm Shelters, which was published in December 2020 and includes a large number of improvements for tornado shelter standards, and which directly addresses Recommendation #7a from the NCST Joplin Tornado Investigation.
- NIST contributed to the draft consensus ASCE/SEI standard for disproportionate collapse mitigation of building structures, which will be released for public comment soon, and which addresses Recommendation #1 from the WTC Investigation.

NIST presented the FY 2021 activities to the NCST Advisory Committee (NCSTAC or Committee) via web conference on June 10 - 11, 2021, and November 8, 2021. NIST briefed the NCSTAC on:

- NIST's response to the Committee's FY 2020 report to Congress;
- Progress of the NCST Investigation of Hurricane Maria's impacts on Puerto Rico, including completion of required reviews and approvals for data collection instruments and methods, completion of pilot testing for survey and interview instruments, establishment of data use agreements to support attribution of hurricane-related deaths, collection and review of documents to evaluate critical building performance, completion of wind tunnel tests of topographic models and building models to evaluate the effects of Puerto Rico's mountainous topography on wind loads, and completion of interviews with information providers to evaluate the role of emergency communications in the public's response to the hurricane;
- Related studies of Hurricane Maria under the National Windstorm Impact Reduction Program (NWIRP);
- The establishment of the CTS Team to investigate the partial collapse of the Champlain Towers South Condominium in Surfside, FL, including naming of CTS Team members, and announcement of projects focused on the building history, evidence preservation, remote-sensing and data visualization, materials science, geotechnical engineering, and structural engineering;
- 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; and
- Other NIST efforts, under the Disaster and Failure Studies Program, that enhance the readiness of National Construction Safety Teams .

The NCSTAC:

- complimented NIST on assembling a diverse team of highly qualified researchers in a range of critical areas including both engineering and social sciences, and for including local professionals in the Hurricane Maria NCST investigation;
- complimented NIST for their approach in securing and managing disaster-related data;
- suggested the consideration of alternative means for systematic data collection that can be implemented in a timely fashion that are not reliant upon face-to-face, in-person research methods;
- urged that NCST data collection efforts be coordinated with NWIRP researchers who are focused on the physical performance of wireless communication systems, as these systems are critical infrastructure for both response and recovery;
- suggested that NIST should be prepared for counterproposals to the current NIST proposal for tornado resistant design, which prescribes tornado wind speeds that are proportional to building size (due to the increased tornado strike probability for buildings with larger plan areas), in case this new approach is not accepted;
- encouraged NIST to continue to explore alternative strategies for the protection of life during tornadoes, especially the improvement of tornado shelter standards and public tornado sheltering strategies;
- recommended continued perseverance with obtaining and analyzing social media data for future research endeavors;
- emphasized the need to quickly collect and document time-sensitive data with future NCST activities, and suggested capitalizing on the current efforts by institutionalizing the procedures and capabilities deployed for the Hurricane Maria investigation, and looking to other entities (e.g., the National Transportation Safety Board) that may have developed protocols for quick response activities; and
- recommended to Congress that the NCST Act be revised to emphasize the important role NIST should play in investigations of failures of nonbuilding structures.

A summary of these meetings may be found on the NIST NCST website[4] and in the FY 2020 Annual Report of the NCSTAC to Congress.[5]

[4] 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.

[5] FY 2020 NCSTAC Report to Congress available at: https://www.nist.gov/topics/disaster-failure-studies/national-construction-safety-team-ncst/advisory-committee.

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:

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 2021 as required by Section 10 of the Act.

1. Investigations Conducted Under the NCST Act during FY 2021

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 related to the investigation, 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 2021, improvements to the hurricane modeling approach were completed to better adapt the model to strongly asymmetric wind fields and incomplete data, and procedures for automation and optimization of model fitting were demonstrated using observed data from several previous hurricanes, including Hurricanes Irma, Michael, and Dorian. The improved methodologies will enhance the final version of the wind field model for Hurricane Maria, which will also incorporate refined modeling of topographic effects based on wind tunnel and numerical results. In FY 2021, an optional task on the ARA contract was exercised for integration of the final wind field model with wind tunnel measurements from building models to evaluate time histories of wind loads on buildings during Hurricane Maria.

The wind tunnel testing and field measurement of winds is supported by a contract with UF, awarded in May 2019. In FY 2021, NIST and UF made significant progress in evaluating the effects of Puerto Rico's mountainous topography on winds. Model fabrication and wind tunnel testing was completed for 1:3100 scale topographic models of the Mayagüez and Yabucoa regions in Puerto Rico, and detailed flow field measurements were obtained using a Particle Image Velocimetry (PIV) measurement system. Improvements to the PIV system in FY 2021 enabled measurements of wind flow much closer to the model surface than was possible in initial testing (within 10 m above ground at full scale), providing important information on topographic speedup factors of relevance to building design. PIV flow measurements from the Mayagüez model were used to obtain required information on approach flow velocity profiles for wind tunnel testing of a selected hospital facility, as discussed below for the project on Performance of Critical Buildings. Wind tunnel testing was also completed for generic ridge and plateau models with both smooth and terraced surfaces, to provide data for validation of computational models and for evaluation of current standard provisions. PIV flow measurements were obtained for both the smooth and terraced models, and surface pressure measurements were also obtained for the smooth model.

Field measurements of topographic speedup effects are supported by WeatherFlow, a UF subcontractor. In FY 2021, meteorological measurement stations were installed on three cell towers in the Yabucoa region, incorporating upgraded data acquisition systems to enable recording of continuous, high-resolution wind velocity histories for both vertical and horizontal anemometers with a consistent sampling interval of three seconds. A contract option was also exercised to continue data collection for a second

year, and a new task was funded for onsite measurements of anemometer orientation to improve the accuracy and quantify the uncertainty in the wind direction measurements. A real-time feed of the measured data from these instrumented towers is now 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 2021, the HM Team developed a verification and validation procedure for estimating uncertainties in CFD simulation results and completed an uncertainty quantification analysis for CFD simulations of flow over the generic ridge and plateau models. The HM Team also developed and implemented a canopy model to capture the effect of tree cover on flow profiles, using satellite data to obtain required model parameters with their spatial variation, as well as a procedure for using Digital Elevation Model (DEM) data to generate CFD meshes for simulation of wind flow. Using this approach, a CFD model of the Mayagüez region was developed, and simulations of wind flow were performed, including initial comparisons with PIV measurements from wind tunnel testing.

To support documentation of other hazards associated with Hurricane Maria, the HM Team performed analysis of rainfall and flood data, including sub-daily comparisons of space-based and ground-based precipitation data for Hurricanes Irma and Maria and analysis of USGS stream gauge data. The HM Team also initiated a collaboration with Bristol University for flood modeling of Puerto Rico using rainfall observation inputs for Hurricane Maria based on NIST analyses.

(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 2021, NIST exercised contract options for additional tasks to support the facility evaluation work, and Stantec established a subcontract with the University of Puerto Rico at Mayagüez to support this work. The HM Team developed relational databases for linking various sources of information for hospitals, schools, and storm shelters in Puerto Rico, including hazard exposure at facility sites, building characteristics, reported damage, and shelter population over time. Using this information, a sampling methodology was developed for selection of storm shelters for detailed evaluation. Many of the storm shelters in Puerto Rico are schools, and as a prerequisite for evaluation of public school facilities, project plans were reviewed and approved by the Puerto Rico Department of Education. The first selected shelter facility was a non-school shelter, and the first phase of detailed evaluation for this facility was initiated with Stantec, including collection and review of documents such as architectural drawings and damage assessment reports. For the five previously selected hospital facilities, Stantec

completed the first phase of evaluation work, including quality control review and updates to data collection forms in preparation for upcoming interviews. An interview guide for the upcoming second phase of facility evaluations was developed and translated into Spanish.

For one of the five selected hospitals, located in a region where the topography results in significant speed-up of winds, a 1:100 scale model of the facility was designed, fabricated, and tested in the wind tunnel through the UF contract, incorporating tubulation for pressure tap measurements and base force balance for resultant force measurements. For the wind tunnel testing of this facility, UF successfully achieved target inflow profiles at 1:100 scale based on PIV measurements from a 1:3100 scale topographic model, using machine-learning to iteratively adjust the wind tunnel control parameters. Wind tunnel testing was performed over a 180° range of wind angles in 10° increments, for cases with and without the local topography and surrounding buildings. A second hospital facility was also selected for wind tunnel testing, and Stantec conducted drone photography of that hospital site to provide detailed information on the dimensions of the buildings on site and the surrounding area. This information is being used to support the design and fabrication of a scale model of the second hospital facility for wind tunnel testing planned in FY 2022.

(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 examine 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 Puerto Rico.

Albizu University is supporting the Public Response to Emergency Communications project by conducting surveys and interviews of households to better understand factors that influenced decisions to evacuate or not to evacuate, including the role of emergency communications in those decisions. In FY 2021, the household surveys were launched, with a planned sample of 1,500 households within four study regions selected by NIST, following a stratified sampling plan that ensures representative responses across demographic characteristics as well as risk exposure to flooding and landslide conditions. Paperwork Reduction Act (PRA) approval for the final survey instrument has been granted by the Office of Management and Budget (OMB),[6] including revisions to the instrument to streamline and clarify questions following a pilot study. In adaptation to the COVID-19 pandemic, online and telephone-based response modes have been provided and strict safety protocols have been developed for in-person responses, along with additional training that has been completed by Albizu University. The household interviews were also launched in FY

[6] OMB approved the household survey instrument under the NIST Generic Clearance for Community Resilience Data Collections, OMB Control #0693-0078, Expiration Date: 07/31/2022. The pilot study was approved in December 2020 and the full data collection was approved in April 2021.

2021, after PRA approval for the interview instrument was granted by OMB.[7] Household interviews are in progress with a planned sample of 100 individuals who have also completed the household survey. Interviews are planned for 60 minutes in length, with a focus on barriers to taking protective action, as well as unmet information needs before and during the hurricane.

Horsley Witten has also supported NIST by completing semi-structured interviews with expert information providers in Puerto Rico to help characterize message dissemination, organizational interactions and constraints, and areas to facilitate communication effectiveness. Following PRA approval of the interview instrument,[8] interviews have been completed for the full planned sample of 35 information providers, including mayors, emergency managers, meteorologists, forecasters, journalists, and government agency representatives. The interviews have been transcribed and translated from Spanish to English, and data analysis is currently in progress.

Complementary to these efforts, NIST is also conducting qualitative content analysis (QCA) of emergency communications and messages to assess their distribution and effectiveness. As part of this effort, more than 1,500 long- and short-form messages have been extracted, organized, and translated, and a tailored methodological approach for QCA has been defined, based on deductive coding and inductive analysis of fallout data. The QCA incorporates theory-driven metrics for evaluating message effectiveness with a special emphasis on social media data.

(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).[9] In FY 2021, NIST exercised an option on the GW contract to

[7] OMB approved the household interview instrument in June 2021 under the NIST Generic Clearance for Community Resilience Data Collections, OMB Control #0693-0078, Expiration Date: 07/31/2022.

[8] OMB approved the information provider interview instrument in December 2020 under the NIST Generic Clearance for Community Resilience Data Collections, OMB Control #0693-0078, Expiration Date: 07/31/2022.

[9] 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

retrieve and review additional data from hospitals to help determine the causes of hurricane-related deaths. The HM Team also established Data Use Agreements with the Demographic Registry at the Puerto Rico Department of Health and the Institute for Forensic Sciences to obtain updated information on deaths following Hurricane Maria in support of the NCST Investigation. The GW Biostatistics Center statisticians have designed an integrated database structure to link data from various data sources on the deaths that occurred up to six months after Hurricane Maria made landfall in Puerto Rico, and the GW geospatial analysis group has finalized the geocoding of places of residence and death from the death certificate data. A preliminary analysis of cause-specific excess mortality has been completed for periods of 14 days and 6 months following landfall, with grouping of death categories using International Classification of Diseases (ICD), and layers of information for geospatial analysis have been created from these analysis results.

Informed by the integrated database, UPR has begun surveying 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. PRA approval for the final VA+S'E instrument has been granted by OMB,[10] including revisions to the instrument following a pilot study that included 50 people interviewed by phone. Extensive training has been conducted for interviewers, and additional data collectors have been added to support the full data collection effort, which is now underway. GW-UPR has also completed a mortality and injury literature review and has compiled a digital library of over 240 resources using a citation management tool shared across the HM Team.

In the context of the COVID-19 pandemic, the HM Team adapted through the addition of online and/or telephone-based response modes for surveys and interviews. Extensive training was conducted to familiarize the contractors with these modes of data collection, along with safety protocols and training for in-person recruitment and data collection activities. Virtual meetings were conducted with hospital staff in support of critical building evaluations by Stantec, with some local travel by PR-based contractors to collect documents shared by hospitals.

In January 2021, NIST published a progress report, *Learning from Hurricane Maria's Impacts on Puerto Rico*[3] (*Aprendiendo del impacto del huracán María en Puerto Rico*), which explains in detail the rationale for launching this effort, the specific regions of focus selected by the HM Team, and the approach that NIST is using, which includes building upon information gathered by others, but also conducting extensive original data collection and analyses. The report also summarizes progress to date. The HM Team continues to provide regular updates of progress through the NIST website.[11]

b. Champlain Towers South Condominium Collapse

aspects of evacuation and emergency response procedures, including multiple-occupant behavior or evacuation (egress or access) system, emergency response system, and emergency communication system."

[10] OMB approved the VA+S'E instrument under the NIST Generic Clearance for Community Resilience Data Collections, OMB Control #0693-0078, Expiration Date: 07/31/2022. The pilot study was approved in March 2021 and the full data collection was approved in September 2021.

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

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-July 2, 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.

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 under the NCST Act 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."

The criteria considered and associated analysis of the event against each criterion are set forth below.

Criterion 1:
The event was any of the following:
(i) A major failure of one or more buildings or types of buildings due to an extreme natural event (earthquake, hurricane, tornado, flood, etc.);
(ii) A fire that resulted in a building failure of the building of origin and/or spread beyond the building of origin;
(iii) A major building failure at significantly less than its design basis, during construction, or while in active use; or
(iv) An act of terrorism or other event resulting in a Presidential declaration of disaster and activation of the National Response Plan.

Analysis: The Champlain Towers South Condominium collapse falls within category (iii). Nearly half of the 136-unit, 12-story condominium collapsed, and resulted in 98 fatalities.

Criterion 2:
A fact-finding investigation of the building performance and emergency response and evacuation procedures will likely result in significant and new knowledge or building code revision recommendations needed to reduce or mitigate public risk and economic losses from future building failures.

Analysis: There are more 4.5 million high-rise condominium units in Florida alone,[12] with many others throughout the U.S., many of which are oceanside, and/or aging. While an investigation of the collapse of the engineered building could help identify the cause specifically for Champlain Towers South, it could also uncover potential issues that could be exhibited by other similar buildings nearby and throughout the nation. It is expected that an investigation of the causal issues

[12] https://www.miamiherald.com/news/business/real-estate-news/article252366973.html.

of the collapse will result in novel insights that will lead to important recommendations for codes, standards, and practices for existing and new buildings.

In performing the analyses set forth above, the following factors listed in 15 CFR 270.102(b) were also considered; in these instances, "Team" refers to the CTS Team:

(a) Whether sufficient financial and personnel resources are available to conduct an investigation — The estimated costs of the recommended investigation were within the NIST's fiscal year (FY) 2021 budget and NIST's requested (but not yet appropriated) FY 2022 budget. The NIST Acting Director recommended that the Team be comprised of NIST employees and one or more individuals from outside NIST to serve as a non-NIST member of the Team. The NIST funding level in FY 2021 and the FY 2022 budget request support the NIST Team members, as well as one non-NIST Team member if required. In addition, NIST received $22M in supplemental funds from Congress in 2021 (PL 117-43) that will fund additional team members and service contracts. The NIST employees were selected based on their expertise and availability to conduct the investigation and several individuals from outside NIST were also identified to serve on the Team.

(b) Whether an investigation of the building failure warrants the advanced capabilities and experiences of a Team — The investigation of the building collapse warranted the advanced capabilities and experiences of the members of the Team to determine the factors that contributed to the initiation and sequence of the collapse. The investigation objectives above could not be accomplished without the unique combined expertise in structural engineering and reinforced concrete design, material properties, and geotechnical engineering of NIST and non-NIST Team members.

(c) If the technical cause of the failure is readily apparent, whether an investigation is likely to result in relevant knowledge other than reaffirmation of the technical cause — The cause of the building collapse was and is still unknown, and the investigation is likely to result in knowledge that could be applicable to other reinforced concrete buildings, with potential for new recommendations for changes to codes, standards, and practices.

(d) Whether deployment of a Team will substantially duplicate local or state resources equal in investigatory and analytical capability and quality to a Team — There were no known local or state resources equal to NIST in investigatory and analytical capability nor current or planned investigations addressing the specific scope of the recommended NIST investigation of the building collapse. Local authorities communicated a preference for an unbiased, third-party investigation by NIST.

(e) Recommendations resulting from a preliminary reconnaissance of the site of the building failure — Based on the assessment of the preliminary reconnaissance team of the site of the building failure, the NIST Acting Director recommended the additional study of the

event to determine the factors that contributed to the initiation and sequence of the collapse.

The NIST Acting Director, therefore, appointed the following individuals to the NCST for conducting a technical investigation of the partial collapse of the Champlain Towers South Condominium:

Dr. Judith Mitrani-Reiser, Lead Technical Investigator
Affiliation: Associate Chief, Materials and Structural Systems Division, EL, NIST
Relevant Areas of Expertise: building failure investigations, performance-based design, Federal interagency coordination

Mr. Glenn Bell, (outside) Associate Lead Technical Investigator
Affiliation: Glenn R. Bell Consulting
Relevant Areas of Expertise: structural design and rehabilitation, structural failures, forensic engineering

Dr. David Goodwin, Team Member
Affiliation: Research Chemist, Infrastructure Materials Group, EL, NIST
Relevant Areas of Expertise: forensic chemistry, durability of infrastructure materials, field investigations of material performance, spectroscopic and microscopic characterization of materials

Dr. James Harris, (outside) Team Member
Affiliation: J.R. Harris & Company
Relevant Areas of Expertise: structural design and evaluation, loading and response of structures, improving the formulation and use of engineering standards

Dr. Youssef Hashash, (outside) Team Member
Affiliation: William J. and Elaine F. Hall Endowed Professor of
Civil & Environmental Engineering, University of Illinois Urbana-Champaign
Relevant Areas of Expertise: geotechnical engineering, geomechanics, soil-structure interaction, modeling of granular material, soil constitutive modeling, deep learning, geo-forensic engineering

Dr. Georgette Hlepas, (outside) Team Member
Affiliation: National Geotechnical Policy Advisor, US Army Corps of Engineers, Headquarters
Relevant Areas of Expertise: geotechnical engineering, instrumentation, design and evaluation of subsurface explorations, foundation remediation

Dr. Kenneth Hover, (outside) Team Member
Affiliation: Professor, Civil and Environmental Engineering, Cornell University
Relevant Areas of Expertise: concrete materials, structural design and construction, analysis and rehabilitation of deteriorated concrete, specifications for structural concrete

Dr. Scott Jones, Team Member
Affiliation: Mechanical Engineer, Infrastructure Materials Group, EL, NIST

Relevant Areas of Expertise: mechanical behavior of materials, durability of steel reinforced concrete structures, service life prediction, transport properties

Dr. Jack Moehle, (outside) Team Member
Affiliation: Ed and Diane Wilson Presidential Professor of Structural Engineering, University of California-Berkeley
Relevant Areas of Expertise: design and analysis of structural systems, reinforced concrete construction, development of professional design guidance

Dr. Aspasia Nikolaou, Team Member
Affiliation: Leader, Earthquake Engineering Group, EL, NIST
Relevant Areas of Expertise: soil-structure interaction, geo-hazard analysis, multi-hazard risk assessments, foundation design, development of codes and guidelines

Dr. Fahim Sadek, Team Member
Affiliation: Research Structural Engineer, Structures Group, EL, NIST
Relevant Areas of Expertise: finite element modeling and computer simulation, static and dynamic structural response, extreme loadings, structural testing, reinforced concrete structures, progressive collapse, mitigation of progressive structural collapse, degradation and aging of infrastructure, reliability-based design, 9/11 World Trade Center investigation

Dr. Christopher Segura, Team Member
Affiliation: Research Structural Engineer, Earthquake Engineering Group, EL, NIST
Relevant Areas of Expertise: risk assessment and mitigation, performance-based design, dynamic loading, nonlinear modeling of reinforced concrete structures, large-scale structural testing

Dr. Kamel Saidi, Team Member
Affiliation: Leader, Sensing and Perception Systems Group, EL, NIST
Relevant Areas of Expertise: development of metrics and methods for performance of ground and aerial robots, remote-sensing applications in construction and emergency response

Dr. Jonathan Weigand, Team Member
Affiliation: Research Structural Engineer, Structures Group, EL, NIST
Relevant Areas of Expertise: structural analysis under extreme loads, disproportionate collapse, and experimental, computational, and analytical research of steel and reinforced concrete structural systems

The appointed CTS Team members are working on six projects 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.

(2) Evidence 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 will also include interviews of residents, first responders, family members or others with knowledge of the building condition and collapse events.

(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 from before the collapse. The analyzed 2D and 3D surface and subsurface data will be compiled, organized, georeferenced, visualized and communicated as part of a geospatial data management system that will be designed to support the other investigation projects.

(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 will compare these to the characteristics specified in the building design and the data will be used in the partial collapse analyses and simulations.

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

(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 that will simulate the failure initiation and progression.

Updates on the NCST Champlain Towers South Condominium Investigation are posted on the NIST website.[13]

2. Summary of Recommendations Made in Reports Issued Under Section 8 of the NCST Act during FY 2021.

During FY 2021, 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 2021 in Response to Reports Issued Under Section 8 of the NCST Act.

During FY 2021, 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 2021 to implement recommendations in the NCST World Trade Center Investigation final report[14] to improve building safety and structural integrity:

- In FY 2012, based on a proposal from NIST, a new ASCE/SEI Standards Committee (named Disproportionate Collapse Mitigation Standard Committee) was established to

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

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

develop a consensus standard for disproportionate collapse mitigation of building structures, which addresses Recommendation #1 from the WTC Investigation. This 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 2021, the committee completed balloting of the draft standard and it is being prepared for release for public comment.

- A revision of the ASCE 49 Wind Tunnel Testing for Buildings and Other Structures Standard - with contributions by NIST staff in characterization of approach flow, aerodynamic loads, wind climate analysis and modeling, and quality assurance areas - was approved and published as ASCE 49-20. This addresses Recommendation #2 from the WTC Investigation.

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

The following actions were taken in FY 2021 to implement recommendations in the NCST Joplin Tornado Investigation final report[15] to improve building safety and structural integrity:

- NIST staff led the Tornado Task Committee (TTC) within the ASCE 7-22 Wind Load Subcommittee (ASCE 7: Minimum Design Loads and Associated Criteria for Buildings and Other Structures) and developed a new chapter on Tornado Loads for the ASCE 7-22 draft standard. This chapter, which incorporates the NIST tornado hazard maps and prescribes methodology for computing tornado design loads for ASCE 7 Standard Risk Category III and IV buildings and other structures, was approved by the ASCE 7 Main Committee in April 2021. The ASCE 7-22 draft standard was released for public comment in June 2021. The TTC then developed responses to public comments, which were in ballot by the ASCE 7 Main Committee through the end of FY21. These efforts directly address NIST Recommendations #3, #5, and #6 (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report[2]).
- 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 2021, the committee completed drafts of a partial chapter of the new standard on remote-sensing methods and began balloting those chapters through the ASCE SEI Standards Committee. A draft of an engineering-based "Smart" Damage Indicator for residences using the EF-Scale was circulated and is in beta-testing with the National Weather Service. Work on additional chapters for other wind speed estimation methods continued. This standards development activity directly 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[2]).
- NIST staff chairs the standards committee for the ICC 500 Standard for Design and Construction of Storm Shelters. In FY 2021, ICC 500-2020 was published, with the Commentary currently in press. These efforts directly address NIST Recommendation #7a (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report[2]).

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

- FEMA published updates to FEMA P-320, *Taking Shelter from the Storm: Building or Installing a Safe Room for Your Home* (March 2021, 5th ed.) and FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms* (April 2021, 4th ed.), incorporating improvements made in the ICC 500-2020 standard. These efforts directly address NIST Recommendation #7b and #8 (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report[2]).
- 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 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). Fourteen domestic and international events were scored in FY 2021, including seven windstorms, three earthquakes, two structural failures, and two wildland-urban interface fires. These events occurred in Alabama, California, Georgia, Florida, Illinois, Louisiana, New Jersey, New York, Texas, Greece, Haiti, Indonesia, Mexico, and Turkey. Only one of the events scored in FY 2021, the partial collapse of the Champlain Towers South Condominium, met the NIST preliminary deployment criteria. The others did not meet the criteria 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. As a result, NIST only deployed a single team in FY 2021 to collect preliminary reconnaissance data.

As was the case in FY 2020 due to the COVID-19 pandemic, NIST relied more heavily in FY 2021 on virtual reconnaissance activities, as well as partners located in areas where events took place, to minimize travel.

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 2021, NIST assessed 14 events (fires, earthquakes, hurricanes, tornadoes, winter storms, 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 14 events, NIST completed one preliminary reconnaissance mission, which resulted in the establishment of a new National Construction Safety Team for the Champlain Towers South Condominium partial collapse. NIST has begun the new investigation, 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. As part of the Hurricane Maria investigation, NIST exercised several contract options to support the Hazard Characteristics project, Performance of Critical Buildings project, and the Characterization of Morbidity and Mortality project in FY 2021. NIST presented these FY 2021 activities to the NCST Advisory Committee during web-conference meetings on June 10 - 11, 2021, and November 8, 2021.