National Institute of Standards and Technology
National Construction Safety Team Act
Annual Report
Fiscal Year (FY) 2022

Summary

This annual report to Congress for Fiscal Year (FY) 2022 is required by the National Construction Safety Team (NCST) Act (Public Law 107-231). In FY 2022, the National Institute of Standards and Technology (NIST) continued 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 2022, NIST has 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 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, respectively, and NIST has made additional progress on implementing those recommendations.

Highlights of FY 2022 activities include:

- NIST completed several important data collection activities as part of its Hurricane Maria NCST Investigation, including wind tunnel testing of building and topographic models to better understand the topographic effects of wind loads on buildings, household surveys about the public's response to emergency communications, hospital interviews and medical record abstraction for the study of hurricane-related deaths, and building administrator interviews as well as collection and review of existing documentation on building design and performance for the study of buildings designated as shelters.
- NIST obtained Office of Management and Budget approval for the renewal of the NIST Generic Clearance for Community Resilience Data Collections OMB #0693-0078 through July 2025. This clearance supports both NCST investigations and other data collection under the Disaster and Failure Studies Program.
- The NIST CTS Team assumed physical custody of the evidentiary building debris from Miami-Dade County and developed a Joint Access Protocol with civil litigants and the Miami-Dade Police Department.

[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.

- For the CTS Investigation, NIST added an outside social scientist to the Team and awarded contracts to the Miami-Dade Police Department for protection of evidence, to Strativia LLC for co-leader services for the Building Code and History Project, to Muttoni et Fernandez Ingenieurs Conseils SA for consulting services on the role of slab-column failures, to the University of Florida (UF) for trial mix testing of concrete, and to the University of Illinois at Urbana-Champaign (UIUC) for co-leader services for the Geotechnical Engineering Project. NIST executed four work orders with the US Army Corps of Engineers, a new interagency agreement and two associated work orders with the National Science Foundation, and a new interagency agreement and one associated work order with the Department of the Interior's Bureau of Reclamation.
- NIST published an economic analysis of the new ASCE 7-22 tornado load provisions showing that while wind loads may increase on some elements of a building by 100% or more, the overall effect on cost is modest, typically not exceeding 0.15% of total construction cost for the several example structures evaluated.
- NIST led the development of a successful proposal to include the first-ever tornado load requirements into the 2024 International Building Code (IBC), based on the new tornado load Chapter in the ASCE 7-22 national load standard whose development was also led by NIST. These activities address Recommendation #5 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, including main committee ballots on two chapters and continued development of new and revised damage indicators for the Enhanced Fujita Scale. This work directly addresses Recommendation #4 from the NCST Joplin Tornado Investigation.
- NIST contributed to the draft consensus ASCE/SEI Standard for Mitigation of Disproportionate Collapse Potential in Buildings and Other Structures, which was released by ASCE for public comment in April 2022. The resolution of public comments was completed as of August 22, 2022. The draft standard is currently in final editorial review by ASCE and will be considered for publication in December 2022 by the ASCE Codes & Standards Activities Division (CSAD) Executive Committee (ExCOM). This addresses Recommendation #1 from the WTC Investigation.
- A revision of ASCE 49 Wind Tunnel Testing for Buildings and Other Structures was approved and published as ASCE 49-21, and a revision to the wind velocity pressure profiles was published in ASCE 7-22, to better reflect the state-of knowledge on atmospheric boundary-layer flows. These address Recommendation #2 from the WTC Investigation.
- NIST conducted a preliminary reconnaissance mission for Hurricane Ian on the Gulf Coast of Florida. No decision about a further study or investigation has been made.

NIST presented the FY 2022 activities to the NCST Advisory Committee (NCSTAC or Committee) via web conference on June 8 - 9, 2022, and October 19, 2022. NIST briefed the NCSTAC on:

- NIST's response to the Committee's FY 2021 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; completion of wind tunnel tests of topographic models and two hospital building

models; completion of additional required reviews and approvals for data collection instruments and methods; completion of interviews, document collection, and data review for selected hospitals and shelters to evaluate building performance; completion of household surveys on public response to emergency communications; completion of hospital interviews and medical records extraction for evaluation of hurricane-related deaths; preliminary assessment of Hurricane Fiona's impacts on Puerto Rico as well as on the Hurricane Maria Investigation; and integration of data and analysis plans across projects;

- 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 investigation's overarching goals; summary of activities undertaken in the investigation to advance investigative goals; the Team's integrated approach for assessing failure hypotheses, using progressive collapse analysis and collapse evidence analysis; progress updates in the six technical projects; planned milestones and an investigation timeline; budget allocation; physical evidence collection, management, and measurements; development and implementation of a 3-D model for evidence visualization; collection and analysis of additional evidence (e.g., interviews, documents, and remotely sensed data); methods and applications of non-destructive testing of physical evidence; sampling and methods for invasive testing of physical evidence; structural testing and analysis; structural design evaluation; collapse modeling and analysis; subsurface wave attenuation testing at the building site; contracting process and awards made to date; interagency agreements executed; transfer of evidence and data from civil litigation; procurement and layout of a second warehouse space; and public communication and stakeholder outreach plans.
- 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 for their thorough and thoughtful responses to the Committee's recommendations, particularly those related to emergency communications during Hurricane Maria and design for tornado hazards;
- complimented NIST for restarting the Disaster Working Group to help streamline processes for future investigations;
- suggested alternative options for assessing severity when scoring disaster events;
- complimented NIST for their approach in the Hurricane Maria Program to develop alternative means for systematic data collection that could be implemented in a timely fashion and that are not reliant upon face-to-face, in-person research methods, and complemented NIST on the significant data collections underway;
- recognized the excellent progress NIST has made with the Hurricane Maria Program in spite of challenges and delays;

- noted the value of developing and obtaining approval for data collection instruments that can be used in future studies and allow research activities to more quickly ramp up, potentially eliminating some of the hurdles faced by previous study teams;
- complimented NIST on the inclusion of social scientists in the Hurricane Maria Program and encouraged their involvement and placement early in the design of research and data collection;
- applauded NIST for disseminating the progress report on the Hurricane Maria Investigation;
- commended NIST for their decision to continue their work with social media data from Hurricane Maria, by completing translation activities and commencing with data coding and analysis;
- commended NIST for their progress on implementing the 16 recommendations in the comprehensive report on the 2011 Joplin tornado, including primary completion of eight of them;
- noted NIST's dedication to follow-through on recommendations developed in their reports;
- expressed concern for the overall building code adoption process in the U.S., where it will take 14 years (the process includes going from the NCST Investigation recommendations and findings, to proposals, ballots, then inclusion in ASCE 7-22, to proposals, ballots, then inclusion in national building codes) for NIST's work on tornado hazard maps to be included in national building codes—and probably one-to-two more years for effective enforcement;
- noted that the improved tornado design process only applies to "important buildings" (Risk Category III and IV), and that the vast majority of buildings, including the housing stock, are Risk Category II and thus will be unaffected by this code change.
- encouraged NIST to continue to explore alternative strategies for the improved tornado design process for houses and other small wood-frame buildings, as well as the improvement of tornado shelter standards and public tornado sheltering strategies;
- noted that NIST had assembled an extremely strong team of experts for the Champlain Towers South Investigation, both within NIST and from the outside;
- noted that the extensive amount of field data collected by NIST and others may provide the opportunity to understand patterns of mortality and morbidity throughout the Champlain Towers South building, which could be of interest for search and rescue guidelines and evacuation patterns in the case of future failures;
- recommended that NIST provide a tentative timeline for the Champlain Towers South Investigation, including milestones, and have a well-developed communication plan to keep the public informed, and expressed appreciation when a detailed timeline was produced;
- expressed gratitude for NIST's outreach to Champlain Towers South's victim's families and suggested it could provide a model for NIST and other agencies going forward;
- expressed enthusiasm at the addition of a social scientist to the CTS Team;
- asked for specific information regarding the non-destructive and destructive testing plans for the Champlain Towers South Investigation, and appreciated the lay-person explanation of non-destructive testing and the correlation between the two as a framework for future investigations;
- asked questions about sensitivities and uncertainty in the Champlain Towers South Investigation;
- asked questions about material properties characterizations, corrosive environments, and replica test programs for Champlain Towers South;

- noted the complexity and sensitivity of the structural model being developed for the Champlain Towers South Investigation;
- stressed the importance of understanding the history of Champlain Towers South, including previous wind loading events and as-built conditions;
- noted that recommendation(s) from the Champlain Towers South Investigation will affect similarly constructed buildings in the US, but will need to consider how design and construction practices differ by locale;
- noted the high value of the NCST program for the safety of community members;
- commended the current NIST administration for their diligence in evaluating events for worthwhile study and the commitment to finding the funding to carry out studies when justified;
- commended NIST staff for initiating updates to the NCST Act which clarify interactions with civil suits and setting priorities for investigations; 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.

Public comments addressed:

- International Code Council efforts to convene a group of experts to create guidelines to prevent future catastrophic collapses;
- Florida passage of SB 4-D which mandates milestone inspections of condominiums when buildings reach either twenty-five or thirty years of age, and includes requirements for inspections every ten years after, along with other new requirements;
- 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; and
- questions about cooperation with other authorities.

A summary of these meetings may be found on the NIST NCST website[3] and in the FY 2021 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.

[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 2021 NCSTAC Report to Congress available at: https://www.nist.gov/topics/disaster-failure-studies/national-construction-safety-team-ncst/advisory-committee.

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 2022 as required by Section 10 of the Act.

1. Investigations Conducted Under the NCST Act during FY 2022

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 2022, an updated hurricane wind field model was developed that incorporates additional surface-level meteorological observations and uses an improved process to optimize the model fit.

The wind tunnel testing and field measurement of winds is supported by a contract with UF, awarded in May 2019. In FY 2022, NIST and UF completed the final wind tunnel tests in a test series intended to evaluate the effects of Puerto Rico's mountainous topography on winds. Wind tunnel testing was completed for models of generic ridge and plateau features with rough surfaces, completing a test series in which corresponding models with both smooth and terraced surfaces were tested previously. These generic model tests provide valuable data for validation of computational models and for evaluation of current standard provisions. Detailed flow field measurements were obtained using a Particle Image Velocimetry (PIV) measurement system in conjunction with flow profile measurements using discrete velocity probes. NIST and UF also made continued progress in processing and analysis of measured flow field data from previous wind tunnel tests, including testing of 1:3100 scale topographic models of the Mayagüez and Yabucoa regions in Puerto Rico.

Field measurements of topographic speedup effects are supported by WeatherFlow, a UF subcontractor. In FY 2022, continued long-term measurements were conducted using meteorological stations that were previously installed on three cell towers in the Yabucoa region to record continuous, high-resolution wind velocity histories at multiple heights on each tower. Data processing and analysis was completed for a total of 18 months of data collected as of the end of FY 2022. 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, and measurements of strong winds were captured during Hurricane Fiona in September 2022.

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 2022, the HM Team performed quantification of uncertainties associated with numerical errors in the CFD simulation results and developed and implemented an optimization procedure to select CFD model parameters to best match the measured approach flow profile from the wind tunnel tests. The HM Team also collected information on tree height and leaf density from various satellite-based datasets and used this information to implement a previously developed canopy model to capture the effect of tree cover on flow profiles in the CFD simulations. Using this approach, CFD models of the Mayagüez and Yabucoa regions were developed, and CFD results were compared with measurements from wind tunnel testing.

To support documentation of other hazards in addition to wind, in FY 2022 the HM Team identified, collected, and analyzed additional ground-based and satellite-based measurements of rainfall associated with Hurricane Maria. The HM Team also continued a

collaboration with Bristol University on modeling of inland flooding for 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 2022, NIST and Stantec completed the first phase of evaluation work for five shelter facilities that were selected for detailed evaluation, including four 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. The first phase of evaluation for the five shelter facilities included collection and review of documents such as architectural drawings and damage assessment reports. Stantec also conducted interviews with facility managers at all five of the selected shelter facilities and at one of the hospitals, using an interview guide that was developed previously.

Also in FY 2022, NIST and the UF contractor team completed wind tunnel testing of two hospital facilities to enable detailed evaluation of the wind loads sustained during Hurricane Maria, including the effect of the surrounding buildings and topography. For these facilities 1:100 scale models were designed and fabricated based on 3D point cloud models of the facilities obtained from drone photography, along with verification of dimensions from architectural drawings. The models incorporated tubing for pressure tap measurements and load cells for resultant force measurements. For the first facility, located in a region where the topography results in significant speedup of winds, 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. For the second facility, wind tunnel testing was performed using a novel nonstationary approach in which the wind direction history for Hurricane Maria was simulated in the wind tunnel by controlling the rotation of a turntable during the testing. Wind tunnel testing was performed for cases with and without the local topography and surrounding buildings to enable isolation of these effects in the analysis of the resulting 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 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 2022, the household surveys were completed, with a total of 1,522 households responding within four study regions selected by NIST. The data collection followed an area probability sampling plan to ensure representative responses across residential and rural areas, as well as areas prone to flooding and landslide risks. In adaptation to the COVID-19 pandemic, online and telephone-based response modes were provided alongside an in-person survey mode and strict safety protocols were developed and applied for data collectors. A large majority of respondents (95%) completed the survey in person. The household interviews, which launched in FY 2021 after PRA approval for the interview instrument was granted by OMB, are approximately 60% complete. The planned sample for the household interviews is 100 individuals who also completed the previous household survey. The interviews focus on barriers to taking protective action, as well as unmet information needs before and during the hurricane.

Horsley Witten is supporting 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. This data collection occurred between March and September of 2021 with interviews completed for the full planned sample of 35 information providers, including mayors, emergency managers, meteorologists, forecasters, journalists, and government agency representatives. Data analysis of the interview transcripts is in progress with coding focused on the emphasis of the message, target audience, and partners involved in developing the message.

Complementary to these efforts, NIST is conducting qualitative content analysis (QCA) of emergency communications and messages to assess their distribution and effectiveness. As part of this effort, more than 200 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 the data. In addition, over 2,500 social media messages have been collected and translated. Long form message analysis is complete, while short form message analysis and social media message analysis are in progress. Message distribution timing and geographic variance are being examined alongside many other factors. 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).[5] In FY 2022, NIST modified the GW contract to explore new methods in finding next-of-kin and key informants for the verbal autopsy surveys. A preliminary analysis of cause-specific excess mortality was completed in FY 2021 for periods of 14 days and 6 months following landfall, with grouping of death categories using International Classification of Diseases (ICD). Layers of information for geospatial analysis were created from these analysis results. In FY 2022, NIST provided the GW Biostatistics Center statisticians with geospatial data on hazards and infrastructure to inform cause-specific mortality assessments using the integrated database structure that links data from various data sources on the deaths that occurred up to six months after Hurricane Maria made landfall in Puerto Rico.

UPR made great progress in 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. As of the end of September 2022, 412 surveys had been completed. Additional outreach using a people finder service proved to be a successful mechanism of identifying key informants. The contract option that was exercised in FY 2021 for medical records and hospital functions review has concluded; the GW contract team completed interviews for a sample of six hospitals and medical records extraction has been done for five hospitals. This work will inform an understanding of the deaths that occurred in hospitals.

In the ongoing context of the COVID-19 pandemic, the HM Team continued to utilize online and/or telephone-based response modes for survey and interview data collection, though COVID-19 case rates allowed for the return to some in-person data collection with safety protocols in place. Virtual meetings were conducted with shelter building staff in support of critical building evaluations by Stantec, with some local travel by PR-based contractors to conduct interviews with hospital and shelter staff and to collect relevant documents shared with NIST. The NIST HM Team continued to conduct outreach virtually, including numerous meetings with government agencies in Puerto Rico and other briefings for stakeholders.

NIST continues to track the readership of the progress report, *Learning from Hurricane Maria's Impacts on Puerto Rico*[3] (*Aprendiendo del impacto del huracán María en Puerto Rico*), published in January 2021. The English version of the progress report had 788 downloads in FY 2022, while the Spanish version had 1275 downloads. The HM Team continues to provide regular updates of progress through the NIST website, including posting a news update on the fifth anniversary of Hurricane Maria's landfall in Puerto Rico.[6] This progress update was accompanied by a social media campaign to share updates on the investigation and research study with a broader audience.

[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."

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

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."

The CTS Team has acquired more than 3 TB of photos and videos, more than 600 pieces of physical evidence located at a primary evidence facility that is soon to be expanded to two facilities. 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 to provide the project co-leader.

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 nearly 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 reviewing relevant public and private records and conducting contextual interviews of people with knowledge of 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. The project team has also developed a plan to conduct a study of the building's loading history, including 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 includes interviews of residents, first responders, family members or others with knowledge of the building condition and collapse events.

The Evidence Preservation project was initially supported by the NSF-supported NHERI RAPID facility under a Memorandum of Understanding to provide training to NIST for operation of data collection equipment. This project is supported by a contract with the Miami-Dade Police Department for evidence protection services. This project is also supported by a work order under an Interagency Agreement (IAA) with the Bureau of Reclamation (BurRec) for reinforcing bar 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 the physical evidence database. The team has populated the database with much of the collected information, including the determination of the origin of the specimens. The project team continuously adds information to this database, such as observations, scans, and measurements of the specimens. The project team has also developed the workflow and associated documentation to track the history of any subsamples extracted during the invasive testing phase.

In concert with the Building and Code History project, the Evidence Project has been documenting dimensions, features, and properties of the physical specimens to determine their as-built conditions and how those conditions changed over the life of the structure.

The Evidence Project leads our 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 for various types of key informants and are conducting interviews.

The Evidence Project has also led the Investigation-wide development of an extensive invasive testing program, wherein hundreds of samples of concrete and steel reinforcing bars will be extracted from the specimens for laboratory testing. This includes developing a statistical sampling approach that collects data relevant to all failure hypotheses and enables quantification of propagation of uncertainties throughout the investigation. This program will commence in FY 2023.

(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 geospatial data management system that will be designed to support the other investigation projects.

The Remote-Sensing and Data Visualization Project is supported by a work order under an IAA with the US Army Corps of Engineers (USACE) to provide the project co-leader and data analysis support. This project is also supported by a work order under an IAA with the National Science Foundation (NSF), which provides a grant to Florida State University to conduct data processing.

The Remote Sensing & Data Visualization project collected lidar data and drone imagery during the search and rescue, and recovery efforts. The team has plans to add satellite imagery as well. The project has nearly completed validation and registration of lidar data, is processing drone data into 2D and 3D drone maps and has developed a database and tagging system for storage and retrieval of images of all types. The team plans to complete this effort early next fiscal year.

The project team has also developed a 3-D geospatial 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 is in the process of being deployed to the entire team in a user-friend web tool. This tool will be continuously populated with information from all the project teams as the investigation develops.

This project team also leads the ongoing detailed image and video analysis, such as the forensic analyses that will be conducted on surveillance videos and phone videos of eyewitnesses.

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 will compare 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 with the UF to conduct trial mix testing of concrete.

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 examination of an initial collection of concrete samples using optical and scanning electron microscopes. This non-destructive testing and preliminary invasive testing informs the investigation's invasive testing program, including its sampling approach.

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 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 laboratory mockup test program expected to be executed in the middle of FY 2023.

(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 with the University of Illinois at Urbana-Champaign to provide the project co-leader. It is also supported by multiple work orders under an IAA with the USACE to conduct testing, a geophysical investigation, and a site survey. This project is also supported by a work order under an IAA with NSF for wave propagation testing.

The geotechnical engineering team completed their subsurface investigation at the collapse site in FY 2021 but continued to visit the site periodically to measure pore water pressure in several selected locations. The subsurface investigation included standard penetration tests to measure the stiffness and strength of different layers of soil and drilling small-diameter boreholes to collect soil samples to determine the general characteristics and type (e.g., sand, clay, rock) of soil deposits, the general soil classification, the size of the grains within the soil mass, and soil strength characteristics. Rock core samples were also collected from these boreholes to assess rock quality and structure.

NIST complemented this testing with cone penetrometers, which are pushed into the soil to measure its type and strength properties without taking samples. Geophysical methods that send very low intensity waves (e.g., impulse echo and ground penetrating radar) into the ground or the foundations were used to obtain information about the condition of the foundation and its surrounding soil with minimal disturbance to the site conditions. Laboratory testing continues of the extracted subsurface soil, rock, and foundation specimens.

The project team also returned to the site in the summer of 2022 to collect data to improve the team's computer models. The team used custom-built vibration sensors and pushed them into the ground to measure wave propagation, or how the waves moved through and were diminished (attenuated) by the soil layers. The project team was able to measure how the waves traveled through the site's subsurface soils over relatively short distances and determine soil characteristics. The data can help investigators determine how the structure may have interacted with the soil and foundations beneath it, which may in turn have affected how it would have responded to various loads or stresses.

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 with Muttoni et Fernandez Ingenieurs Conseils SA on the role of slab-column failures.

The structural engineering team has created baseline computer models using state-of-the-art software packages ETABS and SAFE for checks of the structural design and to understand the points of vulnerability of the structure. The project team is engaging an outside structural engineering company 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 will support the analysis of any design-related contributions to the failure and will also help inform any recommendations that may be made for changes to codes and standards of practice.

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 various outside labs at universities, private companies, and/or other government facilities.

The Structural Engineering project team has built a detailed nonlinear, finite element model of the first level of the collapsed part of the CTS structure. The team is currently performing test runs of this model 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 2022, the Investigation spent 49% of the funds appropriated by Congress. Roughly two-thirds of the funds paid for travel, contracts, work orders under interagency agreements, micro-purchases, and simplified acquisitions. The remaining 37% of the funds spent in FY 2022 paid for more than 40 employees at NIST that contribute directly to the investigation, at various levels of percent effort. 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 Investigation works under continual time pressures.

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 the Federal Acquisition Regulations have been a hindrance. With the 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 acquire some of the necessary materials and services at speeds very unusual for NCST Investigations. In spite of these efforts, the rigidity of the acquisition constraints under which the Investigation operates is impacting the schedule. At the October 19, NCSTAC meeting, the Team announced a six-month delay in completion of the CTS Investigation from its schedule presented in June.

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 2022.

During FY 2022, 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 2022 in Response to Reports Issued Under Section 8 of the NCST Act.

During FY 2022, 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 2022 to implement recommendations in the NCST World Trade Center 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, which addresses Recommendation #1 from the WTC Investigation. This committee has completed a draft standard, with contributions from NIST staff based on results of NIST research. In April 2022, the draft standard was released for public comment by ASCE. Following the public comment period, NIST staff worked with ASCE Disproportionate Collapse Mitigation Standard Committee on resolution of public comments, which was completed on August 22, 2022. The draft standard is in final editorial review and is pending publication by ASCE in December 2022.

[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.

- 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 49-21. A revision to the wind velocity pressure profiles was published in ASCE 7-22 to better reflect the state-of-knowledge on atmospheric boundary-layer flows. These address Recommendation #2 from the WTC Investigation.

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

The following actions were taken in FY 2022 to implement recommendations in the NCST Joplin Tornado Investigation final report[9] to improve building safety and structural integrity:

- NIST published an economic analysis of the new ASCE 7-22 tornado load provisions showing that while wind loads may increase on some elements of a building by 100% or more, the overall effect on cost is modest, typically not exceeding 0.15% of total construction cost for the example elementary school and high school designs evaluated in nine cities across the tornado-prone region. This work directly addresses NIST Recommendation #5 (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report).
- NIST led the development of the proposal to include ASCE 7-22 tornado load requirements into the 2024 International Building Code (IBC), in collaboration with ASCE and FEMA. This proposal passed the IBC Structural Committee at ICC Committee Action Hearings in April (14-0 vote), and received no public comments, meaning tornado loads will be included for the first time in the 2024 IBC. These activities directly address NIST Recommendation #5 (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report).
- 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 2022, the committee conducted balloting of many draft Damage Indicators in the Enhanced Fujita (EF) Scale and a complete draft of the radar and treefall pattern wind speed estimation chapters. 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).
- NIST deployed a team of contractors to collect detailed data on damage to residential structures in four communities following the December 10-11, 2021, Quad-State Tornado Outbreak. NIST hosted a workshop in March 2022 to promote data sharing and research collaboration among the many field research groups that investigated the Quad-State Outbreak. This supports NIST Joplin Recommendation #4 (of Recommendations Group 1, Tornado Hazard Characteristics and Associated Wind Field, in the final report[11]).
- NIST staff chairs the standards committee for the ICC 500 Standard for Design and Construction of Storm Shelters and kicked off a new revision cycle, with the next edition of the standard to be published in 2023. These efforts directly address NIST

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

Recommendation #7a (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report).

- In addition to the actions described above, NOAA's National Severe Storms Laboratory (NSSL) has continued to make significant progress toward the development of new grid-based watch/warning hazardous weather forecasting capability for communicating probabilistic threats to advance the Forecasting a Continuum of Environmental Threats (FACETs) paradigm. This effort 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). Nineteen domestic and international events were scored in FY 2022, including four windstorms, eight earthquakes, one structural failure, one wildland-urban interface fire, and five building fires. These events occurred in Alabama, Arkansas, Colorado, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, Missouri, New York, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Texas, Puerto Rico, Afghanistan, China, Egypt, Haiti, Mexico, Peru, Philippines, and Taiwan. Preliminary reconnaissance missions were not conducted for any events other than Hurricane Ian, because of 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 2022, NIST assessed 19 events (fires, earthquakes, hurricanes, tornadoes, 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 19 events, NIST conducted one preliminary reconnaissance mission for Hurricane Ian. 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, NIST processed several contract modifications to exercise contract options and fund additional tasks to support the Hazard Characteristics project, Performance of Critical Buildings project, and the Characterization of Morbidity and Mortality project in FY 2022.

As part of the Champlain Towers South Investigation, NIST executed numerous IAA work orders, memorandums of understanding, and non-disclosure agreements. Champlain Towers South Investigation contracts were also awarded to provide project co-leader support for the Building and Code History project and the Geotechnical Engineering project, as well as consulting on slab-column failure for the Structural Engineering project, and trial mix testing of concrete for the Materials Science project. NIST presented these FY 2022 activities to the NCST Advisory Committee during web-conference meetings on June 8-9, 2022, and October 19, 2022.