Aug 30, 2018
NCST Advisory
Committee Meeting

NCST Technical Investigation of Hurricane Maria's Impacts on Puerto Rico:

Preliminary Project Plan for Evaluation of Critical Building Performance

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Goal 2: The Performance of Representative Critical Buildings, and Designated Safe Areas in those Buildings, Including their Dependence on Lifelines

Project: Performance of Critical Buildings

Objective: To characterize the performance of critical buildings in Hurricane Maria by (1) documenting failures of structural systems, building envelopes, and rooftop equipment, along with the resulting intrusion of wind-driven rain, interior damage, and loss of function for a representative sample of hospitals and schools, (2) identifying dependencies in loss of function on lifelines, (3) characterizing wind loads on building envelopes and rooftop equipment through wind tunnel testing for a subset of these hospitals and schools to correlate with observed damage, and (4) evaluating the adequacy of existing selection criteria and design requirements for storm shelters.

Background

Observations from preliminary reconnaissance of engineered buildings:

- Limited ***structural*** damage to reinforced concrete and concrete-block buildings with concrete roofs
- Some failures of non-concrete roofs (wood or steel frame) on reinforced concrete and concrete-block buildings
- Wind-induced damage to and failure of metal building systems, potentially due to corrosion

Background

Even for engineered buildings with good structural performance, extensive ***nonstructural damage*** and ***loss of function*** was observed as a result of water intrusion through building envelopes via:

- Failures of rooftop equipment
- Damage to roof coverings
- Rainfall ponding on the roof
- Damage to windows and doors
- Wind-driven rain penetration, even through undamaged cladding

Preliminary Project Plan (1/3)

Documenting Performance of Critical Buildings:

- Identify available data on characteristics and performance of hospitals and schools in Hurricane Maria in coordination with federal partners (through National Disaster Recovery Framework)
- Select a representative sample of hospitals, schools, and emergency shelters for detailed study, with consideration of available information on the buildings, the hazards, and social factors
- Perform detailed on-site evaluations of the selected sample of critical buildings:
  - Building characteristics; design criteria; construction, inspection, and maintenance practices
  - Structural and non-structural damage, loss of functionality, dependence on lifelines
- Select a subset of the critical buildings for forensic wind-tunnel testing
- Evaluate the performance of the critical buildings with consideration of:
  - Wind loads and other hazard levels encountered during Hurricane Maria
  - Code and standard requirements, including consideration of seismic hazards

Preliminary Project Plan (2/3)

Forensic Wind Tunnel Testing of Selected Critical Buildings:

- Wind tunnel testing is planned for a subset of the sample of critical buildings, where detailed characterization of the wind loads would be warranted for evaluation of building performance
- Buildings models will be extensively instrumented:
  - Pressure taps to measure pressures on the building envelope (e.g., roof, walls, windows, doors)
  - Pressure taps or force balances to measure wind loads on rooftop equipment
- Surrounding buildings and terrain will be included in area models
- Selected tests may be repeated with varying conditions:
  - With and without surrounding buildings, to quantify their effect on the resultant wind loads
  - With different configurations of rooftop equipment
- Directional pressure and force coefficients from wind tunnel testing will be combined with the time-dependent hurricane wind-field model to estimate wind load histories during Hurricane Maria, which will be used in evaluating building performance

Preliminary Project Plan (3/3)

Evaluation of Storm Shelter Section Criteria and Design Requirements:

- Collect relevant data on the hurricane shelter program in Puerto Rico:
  - Shelter selection criteria and process
  - Shelter facilities used during Hurricane Maria
  - Storm impact on these facilities, including damage and any injuries or fatalities
- Determine the hazard levels experienced at shelter site locations
- Evaluate shelter performance and selection criteria in consideration of:
  - Hazard levels experienced during Hurricane Maria
  - Code and standard requirements
- Develop findings and recommendations based on these results

FY18 Planning Tasks

(Presented at NCST Advisory Committee Meeting on May 16, 2018)

1. Other agencies with information on the performance of schools and hospitals will be identified, and plans will be made on best ways to reach out
2. A sampling strategy will be developed, and a representative sample of critical buildings will be selected for detailed study
3. Buildings will be identified where wind tunnel testing would be warranted for evaluating building performance
4. Staff with GIS expertise may be hired or detailed to assist the Team
5. Contract specifications will be developed:
   - Local engineering support for evaluation of building performance
   - Forensic wind tunnel testing of selected critical building models

FY18 Planning Tasks – PROGRESS (1/3)

1. Other agencies with information on the performance of schools and hospitals will be identified, and plans will be made on best ways to reach out

   - The following potential sources of information on building performance have been identified:
     - Results of USACE School Assessments under FEMA Mission Assignment (Fall 2017)
     - Public Assistance Project Worksheets for hospitals, schools, and storm shelters
     - Results of FEMA School Evaluations (Summer 2018)
   - We are currently coordinating with FEMA in evaluating the potential need for updates to our existing Memorandum of Understanding, including an Information Sharing Agreement to facilitate sharing of data

FY18 Planning Tasks – PROGRESS (2/3)

2. A sampling strategy will be developed, and a representative sample of critical buildings will be selected for detailed study
   - To support the selection of buildings for detailed study, a complete list of hospitals and official emergency shelters (most of which are schools) in Puerto Rico has been compiled, along with GPS coordinates, and has been organized in GIS format to facilitate mapping
   - NIST will host a public meeting to discuss the state-of-the-practice in post-disaster field data collection methods, including sampling methodologies across multiple disciplines

3. Buildings will be identified where wind tunnel testing would be warranted for evaluating building performance
   - Factors of potential interest for wind tunnel testing are being noted as information is collected (e.g., surrounding topography, structural failures, failures of rooftop equipment), and final selection will occur after baseline and detailed building evaluations are performed

FY18 Planning Tasks – PROGRESS (3/3)

4. Staff with GIS expertise may be hired or detailed to assist the Team
   - An announcement for a detail opportunity was shared with partnering federal agencies through the NWIRP and NEHRP working groups, and other hiring mechanisms are also being considered
   - Applicants are currently being interviewed

5. Contract specifications will be developed
   - Local engineering support for evaluation of building performance
   - Forensic wind tunnel testing of selected critical building models

   - Specifications for these contracts have been developed and are working their way through the NIST approval and procurement process
   - Anticipated contract awards/start dates in Fall 2018
   - Planned wind tunnel testing approach was described previously
   - Planned approach for evaluation of building performance is described in the following slides

Planned Approach: Evaluation of Building Performance (1/3)

- The principal goal is for the Contractor to document the performance of selected hospitals, schools, and storm shelters during Hurricane Maria
- The main tasks for the Contractor will be the completion of baseline building evaluations for at least 20 buildings, with further detailed evaluation for at least 10 buildings
- The Contractor will also be responsible for organization of information collected during the evaluations in a suitable format to facilitate analysis by the NIST Team
- The information gathered by the Contractor will be analyzed by NIST to determine candidate buildings for wind tunnel testing or other detailed analysis

Planned Approach: Evaluation of Building Performance (2/3)

Baseline building evaluations will include the following tasks:

- Conduct technical discussions with relevant building personnel and obtain photographs (with associated permissions), inspection reports, and other information to provide evidence of direct and indirect damages
- Perform inspections of the building and surrounding area and take photographs to provide evidence of direct and indirect damages
- Document significant sources of water intrusion that contributed to interior damage
- Document damages to building-located communication towers, other wireless communication equipment, and infrastructure connections, including electrical and water connections
- Document any loss of function for the building along with the associated factors that contributed to the loss of function
- Document operational conditions of the building if it was occupied during the storm, and any fatalities or injuries

Planned Approach: Evaluation of Building Performance (3/3)

Detailed building evaluations may include tasks such as the following:

- Document the applicable building code and standards used in the design of the building
- Obtain design documents, including design drawings and calculations
- Document the functional intent of the building
- Document as-built conditions of the building or a portion thereof
- Obtain construction-related records such as building permits and building inspection reports
- Document relevant pre-storm building maintenance, repair, and operational activities that may have affected the building performance during Hurricane Maria
- Obtain aerial photographs of the building using an aerial drone, and assemble a three-dimensional model of the building

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NWIRP Study of Hurricane Maria's Impacts on Puerto Rico:

Preliminary Project Plan for Evaluating Infrastructure Support of Critical Buildings

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NWIRP Project: Infrastructure Support of Critical Buildings

Project Objective:

- As they relate to critical buildings, investigate power, water, and transportation infrastructure dependencies in
  - Impacts
  - Recovery
- Make recommendations for increasing resilience through changes to codes, standards and practice

Areas of Study

Impacts

- Damage to components
- Cascade of 'Loss of function'
- Mitigating factors (e.g., backup capacity, redundancy)

Recovery

- Time to recover functionality
- Time/resource dependencies
- Temporary measures (e.g., generators)
- Critical path – set of activities, any of which if shortened, would have shortened recovery

Planning:

- Where in the system to
  - Increase hazard resistance?
  - Add backup capacity?
  - Employ new technologies?
- Which changes to codes, standards and practice would be supportive?

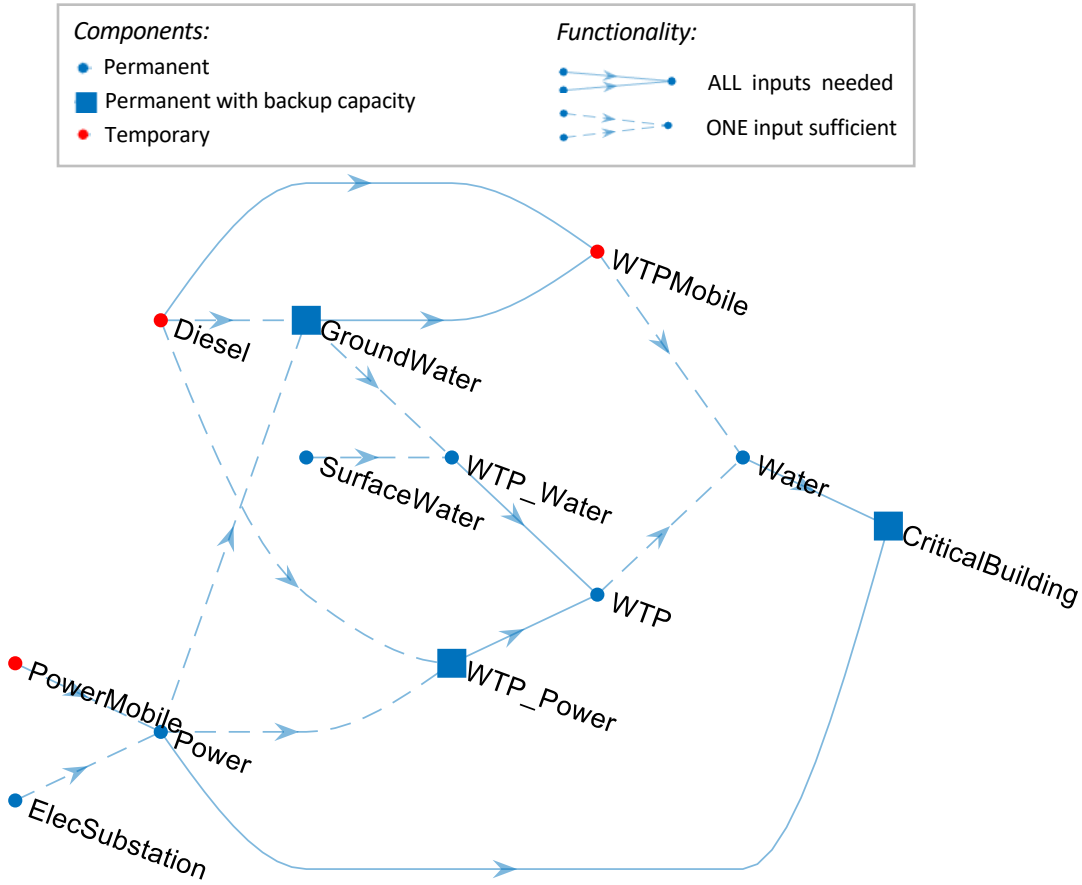


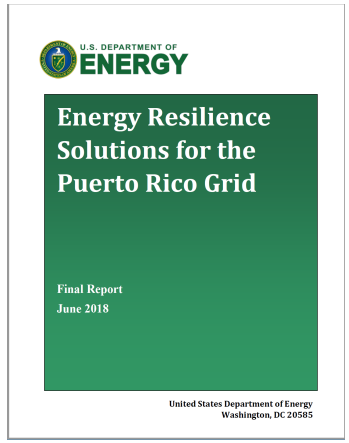
Figure: A highly simplified network showing critical building functional dependencies on infrastructure (and other components/services), based on NIST field deployments/studies, including 2016 Hurricane Matthew and 2017 Hurricane Harvey. Such networks are needed input to the systems models developed within the NIST Community Resilience Group

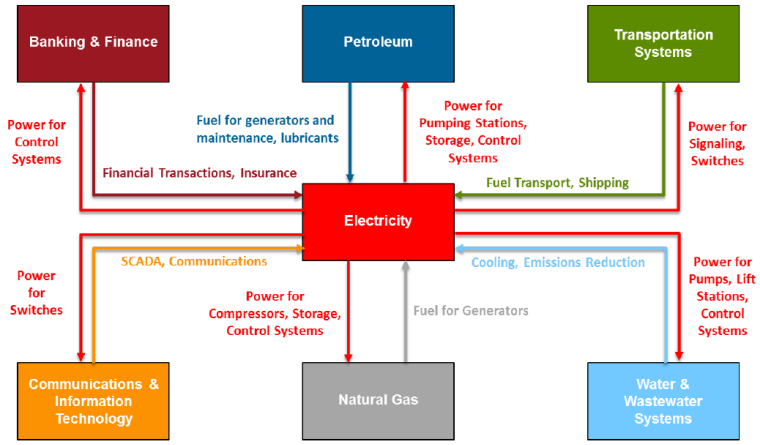
NWIRP Project's Preliminary Study Plan

1. Establish partnerships and official collaborations
2. Gather information at the community level on cascade, recovery, and considered resilience-improving actions
   - 200 semi-structured interviews with Power, Water, and Transportation officials at local and regional levels and Municipal officials
3. Extend and test NIST community resilience planning systems models
4. Apply model in a Puerto Rico based resilience planning case study

NWIRP Project updates

1. Establish partnerships and official collaborations
   - Argonne National Laboratory (ANL) (Resilience Assessment, Decision and Infrastructure Sciences)
     - Contributor to DOE Energy Resilience report
     - Potential contribution: Puerto Rico - wide network dependency modeling complementary to NIST modeling
     - Webinar planned for September
   - NIST Smart Grid Program
     - Microgrid potential interactions with building design





Electric Power Interdependency Examples (Source: DOE)

https://www.energy.gov/sites/prod/files/2018/06/f53/DOE%20Report_Energy%20Resilience%20Solutions%20for%20the%20PR%20Grid%20Final%20June%202018.pdf

NWIRP Project updates

2. Gather information at the community level on cascade, recovery, and considered resilience-improving actions
   - 200 semi-structured interviews with Power, Water, and Transportation officials at local and regional levels and Municipal officials

   - Data collection related to infrastructure to support sampling of buildings
     - Infrastructure: GIS shapefiles
     - Maps: Precipitation, Peak Wind gusts
     - Recovery data: Power (regional-level)

   - Contract for interview research services has been written and submitted to NIST's Acquisition Management Division

Next Steps

1. Establish partnerships and official collaborations
2. Gather information at the community level on cascade, recovery, and considered resilience-improving actions
   - 200 semi-structured interviews with Power, Water, and Transportation officials at local and regional levels and Municipal officials
     - Continue infrastructure-related data collection
     - Application of the infrastructure –related data to support sampling critical buildings and other NCST and NWIRP projects
     - Develop interview instrument questions, drawing from prior field studies
3. Extend and test NIST community resilience planning systems models
     - Equations representing reserve capacity (e.g., diesel generators) within NIST systems modeling framework (mixed-integer linear programming)
4. Apply model in a Puerto Rico based resilience planning case study