PAPER

The NIST-NOAA Resilient Communities Cooperative Initiative and Its Contribution to Coastal Community Resilience

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ABSTRACT
Inspired by the development of a collaborative plan on understanding wildland fires, their interaction with weather and the built environment, the National Institute of Standards and Technology (NIST) and the National Oceanic and Atmospheric Administration (NOAA), both within the U.S. Department of Commerce, completed a more comprehensive collaborative plan entitled "Disaster Resilient Communities: A NIST/NOAA Partnership" during the winter of 2006. This plan addresses, in addition to wildland fires, the effects on the built environment of winds (hurricanes, tornadoes, and straight-line thunderstorm-generated winds), storm surge, tsunamis, and earthquakes. Since most of the structural risks appear in coastal areas of the U.S., the plan provides some emphasis on coastal communities. The plan also has two cross-cutting themes: 1) Multi-hazard failure analysis and mitigation and 2) community scale damage forecasting, including loss estimation methodology. This paper provides an overview of the NIST-NOAA plan with a focus on the components of the plan that address issues related to the resiliency of coastal communities.

1. Background

Each year, natural and technological[1] disasters are responsible for many billions of dollars in costs in the United States in terms of lives lost, disruption of commerce, properties destroyed, and the costs of mobilizing emergency response personnel and equipment (Mileti, 1999)—and average annual costs are growing. These costs could be reduced through the development of more resilient infrastructure (buildings, bridges, tunnels and lifelines[2]). Toward that end, the President's National Science and Technology Council's Subcommittee (NSTC) on Disaster Reduction identified six Grand Challenges (NSTC, 2005a). This proposed program is focused directly on providing some of the solutions called for by 5 of the 6 Grand Challenges:

- *Grand Challenge #1—Provide hazard and disaster information where and when it is needed;*
- *Grand Challenge #2—Understand the natural processes that produce hazards;*
- *Grand Challenge #3—Develop hazard mitigation strategies and technologies;*
- *Grand Challenge #5—Assess disaster resilience using standard methods.*
- *Grand Challenge #6—Promote risk-wise behavior.*

Given this background the National Institute of Standards and Technology (NIST) and the National Oceanic and Atmospheric Administration (NOAA) developed a plan of collaboration so as to better meet the mission of each organization. NOAA performs research to understand natural phenomena and measures, models, and predicts the natural phenomena that may, at times, be hazardous to the built environment. NIST, on the other hand, develops and implements computational, theoretical, and experimental methods to reduce the vulnerability of buildings and infrastructure systems to extreme events through cost-effective, reliability-based multi-hazard approaches. Both organizations provide public outreach and education in their respective mission areas. NIST and NOAA are organizations within the U.S. Department of Commerce which focuses on the economic viability of the nation. As Hurricanes Hugo in 1989 and Katrina in 2005 dramatically illustrated, hazards to structures can affect the economy in a major way. One need not go further than the 2004 and 2005 hurricane seasons along the Florida and Gulf of Mexico coasts to see illustrations of this fact.

The NIST-NOAA Resilient Communities collaboration addresses wildland fires, wind (hurricanes, tornadoes, and thunderstorm-generated straight-line winds), storm surge, tsunamis, and earthquakes. In addition, the plan addresses multi-hazard failure analysis and mitigation and community scale damage forecasting, including loss estimation methodology. These are crosscutting themes that focus on aspects of resilience. In this paper, we briefly address only the coastal community structural hazards which are an important part of overall hazard resiliency of coastal communities.

[1] Technological disaster – a disaster that results from a technological hazard event. Technological hazard – a hazard that originates in accidental or intentional human activity (e.g., oil spill, chemical spill, building fires, terrorism). From the National Science and Technology Council, Committee on Environmental and Natural Resources, Subcommittee on Disaster Reduction, Grand Challenges for Disaster Reduction, June 2005, p. 17.

[2] Lifelines include: electric power, water, sewage, communications, financial networks, and others.

2. Coastal Storms

The coastal storms activity in the NIST-NOAA plan is under the program element called "Hurricanes, Extreme Winds, and Storm Surge—Innovative Risk-Based Engineering and Prediction Tools." This program element addresses cooperative work between NOAA and NIST in the following areas: (a) meteorology for hurricanes, tornadoes, and thunderstorms; (b) micrometeorology associated with near surface wind profiles over land and water; (c) risk-based storm surge maps for design in coastal regions; (d) revised Saffir-Simpson hurricane intensity scale; (e) estimating wind effects on structures based on aerodynamics and computational fluid dynamics; and (f) community-scale damage forecasting and loss estimation.

2.1. Meteorology for Hurricanes

Understanding and forecasting the rapid intensification and decay of hurricanes is critical to forecasting and estimating the level of structural risk along coastlines prone to hurricane landfalls. Currently, there is little or no skill in these forecasts, and the forecasts are not accurate enough to be useful. The NIST-NOAA plan addresses the aircraft measurements of the hurricane inner core and eye wall, air-sea energy transports, and hurricane environment required to improve these forecasts. Another critically important issue is the ability to better forecast the decay of hurricanes as they move inland. Some hurricanes, such as Hugo, maintain their strength well inland, creating a long swath of damage. Others, such as Katrina weaken quickly and the damage is limited to the immediate coastal area.

2.2 Micrometeorology: Near Surface Wind Profiles Over Land and Water

Although it is the wind near the surface that causes damage, accurate wind measurements close to the ground and within the atmospheric boundary layer are very difficult to obtain in high wind conditions, particularly with the spatial and temporal resolution needed by structural engineers. In addition to portable towers that are deployed before hurricane landfall, there are some relatively new and innovative wind measurement capabilities that hold promise of providing surface winds and near-ground wind profiles of use to structural engineers.

The extreme turbulence (ET) probe (Figure 1) shows much promise in providing needed high frequency wind measurements for input to structural engineering models. It has been successfully field tested in hurricane force winds and could be placed on or near structures prior to landfall (Eckman et al., 2007).

Small, portable radar devices have been used for more than a decade, but only in recent years have they been deployed on the shore prior to hurricane landfall. A class of radar devices with a high degree of sophistication is the Shared Mobile Atmospheric Research and Teaching Radar (SMARTR) (Figure 2). There are currently two of them in operation and they are housed at the University of Oklahoma and the NOAA facilities nearby. They provide continuous high resolution Doppler winds in the atmospheric boundary layer (Biggerstaff et al., 2006; Knupp et al., 2005) and help explain the gustiness in the surface winds that can cause considerable damage in hurricanes.

An ocean and coastal wind decision support product that has been used experimentally for several years is the H*WIND (Real-time Hurricane Wind Analysis System) surface wind analysis developed by NOAA (Powell et al., 1996, 1998). H*WIND uses all available data sources from a variety of platforms to produce a single surface wind analysis of the storm (Figure 3). Insurance companies, FEMA, and the Army Corps of Engineers use these analyses for damage estimation and as input to models estimating coastal structural risk.

FIGURE 1

The extreme turbulence probe deployed prior to landfall of Hurricane Ivan. The height of the probe is three meters and the battery is in the black box on the ground.

FIGURE 2

Photograph of a Shared Mobile Atmospheric Research and Teaching Radar (SMARTR) which has been deployed near the shore during hurricane landfalls.

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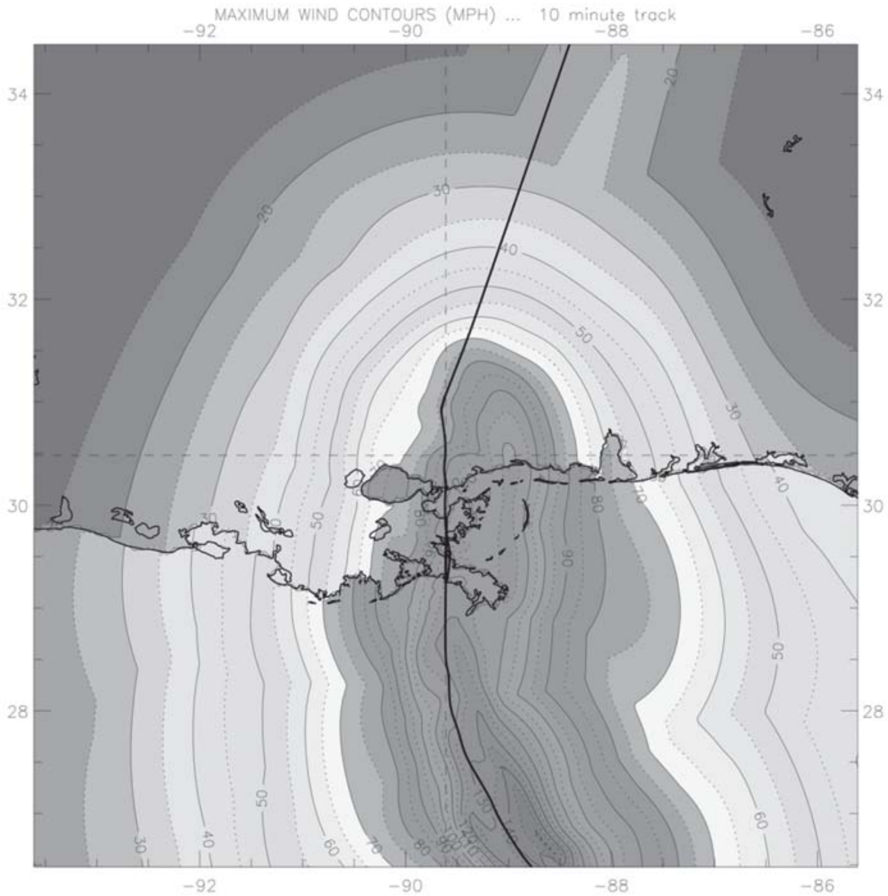
Photograph of a Shared Mobile Atmospheric Research and Teaching Radar (SMARTR) which has been deployed near the shore during hurricane landfalls.



2.3 Storm Surge

NOAA uses the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model for both operational, real time forecasting and to assist emergency managers in hurricane evacuation planning (Jelesnianski, 1992; Massey et al., this volume). SLOSH is run in simulation studies for hypothetical hurricanes with differing intensity, size, and track and provides inundation estimates. Results from the simulation studies are used by emergency managers primarily in planning. Operational SLOSH runs allow emergency managers to make some last-minute evacuation decisions or provide other safety instructions to those at risk as a hurricane threatens. Operational forecasting of surge is still limited by the ability to forecast the hurricane track, intensity, and size—inputs required by any storm surge model. SLOSH and its implementation need to be improved and extended in various ways, including:

1) The methods of defining the bathymetry and topography for input to SLOSH need to be more fully automated to decrease costly labor (cf., Stockdon et al., 2007). As new elevation and bathymetry datasets are developed, they need to be quality controlled and incorporated into national datasets with standardized formats and with adequate metadata.
2) SLOSH needs to be put into a community model framework so it can be tested with other models and improvements accelerated
3) SLOSH should be engineered to run over an entire coastline and not individual basins This is feasible using fine scale grids made possible with today's computing power.
4) The probabilistic storm surge model should be continuously evaluated with future storms to determine its reliability and possible calibration. Useful, easy to understand products need to be developed to aid users in assessing risk due to storm surge.
5) SLOSH needs to be compared to other storm surge models in an operational framework (using actual forecast variables) for its accuracy, timeliness, and expense to implement and run.
6) Depending on the results from 5), a business case may need to be made for changing the model used for producing inundation maps for emergency managers.
7) As land features, land use, and waterways change, the topography and bathymetry needs to be updated on a frequent basis.
8) Interactive, user friendly interfaces need to be developed so users will be better able to view the results of surge model runs remotely and understand the level of un certainty in these forecasts.

Using the SLOSH model as a tool, NIST and NOAA are working together to develop procedures for estimating statistical data on coupled wind-speed and storm-surge events that can improve standards used for structural design. In addition to wind speed, the aim is to estimate design surge heights and velocities and shallow water wave heights and speeds for different regions along the U.S. Atlantic and Gulf Coasts. The design surge and shallow water wave heights and velocities for different regions are to be risk-based, taking into account hurricane-related parameters (forward speed, barometric pressure, track, size, etc.) and geographic features associated with specific areas along the coastline (bathymetry and topography). The estimates are being considered for mean return periods consistent with those currently used for wind speeds in standards for structural design. Estimates would be obtained by using validated models available for hurricane forecasts and storm surge hydrodynamics in shallow water coastal regions.

NIST brings expertise in finite element modeling and probabilistic methods that can be used in collaborative efforts with other federal agencies and private sector entities to achieve the above objectives. Partnerships are being considered with NOAA and other relevant agencies (U.S. Army Corps of Engineers, the Federal Emergency Management Agency, and the Federal Highway Administration), academic experts (e.g., University of South Alabama, Texas Tech University, and other universities as appropriate), and the Applied Technology Council, the American Society of Civil Engineers, and the Institute for Business and Home Safety—an organization which represents the insurance industry. Using simulations and data from NOAA, NIST is developing the conceptual basis of procedures for estimating storm surge effects on structures, which presently are not adequately covered in standards and codes.

2.4 Developing a Hurricane Intensity Scale Reflecting Impacts

The assessment completed by NIST based on a physical reconnaissance in the aftermath of Hurricanes Katrina and Rita indicated that there is a critical need to develop a damage scale similar to the widely used Saffir-Simpson hurricane intensity scale, which is used to provide public warnings and support decision-making on evacuation. Each intensity level in the Saffir-Simpson scale is associated with both a specific range of wind speeds and a specific range of storm-surge heights.

Structures designed in accordance with current building codes based on a widely accepted national standard performed as expected for the wind speeds encountered during Hurricane Katrina (the wind speeds were consistent with a Category 3 storm on the Saffir-Simpson hurricane intensity scale). The unexpectedly high storm-surge heights encountered during Hurricane Katrina, however, exceeded Category 5 on the hurricane intensity scale. Given the inconsistency inherent in the Saffir-Simpson hurricane intensity scale between the observed wind speeds and storm surge heights during hurricane Katrina, this event demonstrated the need for an intensity scale specific to coastal inundation that indicates the potential for damage due to storm surge and flooding, as well as wind.

NIST will work with NOAA to develop a hurricane impact scale based on the newly developed design surge maps and joint probability maps that will be developed for surge storm and extreme wind speed. The latter will provide the basis on which extreme wind/storm surge events corresponding to various mean recurrence intervals can be developed for design purposes. The scale will consider the possible need, if any, for decoupling the estimated wind speeds and surge heights in the current scale into two sub-categories. One sub-category would be related only to wind speeds that would retain the existing classifications. The other would relate only to storm surge heights.

2.5 Wind Effects on Structures Based on Aerodynamics and Computational Fluid Dynamics

NIST will work with NOAA in three interrelated program areas: (1) development of extreme wind databases and innovative methodologies for defining design wind speeds, (2) advanced wind measurement and computational tools for determining realistic wind loads in the built environment, and (3) methodologies for predicting ultimate structural capacities and estimating safety margins (Simiu and Miyata, 2006). This work is particularly important in light of the rebuilding that occurs after recent hurricanes (e.g., Katrina and Rita) and of the requisite improvements of codes and standards.

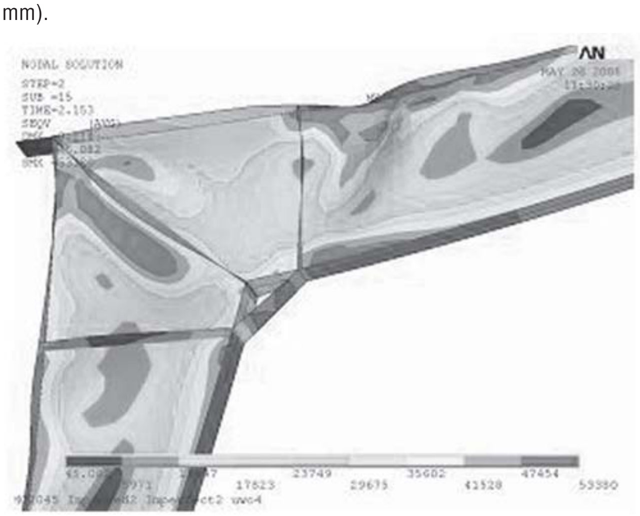
Current codes and standards are based largely on tables which provide over-simplified and often unrealistic design wind loads. NIST will develop advanced wind/structural engineering techniques that allow for the allocation of structural strength with increased effectiveness to enhance the safety of physical structures, and reduce loss of life, in most instances at virtually no increase in construction costs for new buildings or at modest cost for existing buildings. This goal will be achieved through the development of performance-based methods that, unlike prescriptive methods, account explicitly for the physical phenomena governing loading and response and, therefore, better reflect actual behavior in strong winds.

Specifically, NIST will develop realistic wind pressure databases and methodologies that use these databases for predicting ultimate structural capacities and improved safety margins of low-rise buildings. As recommended by the NIST's WTC investigation report (NIST, 2005) attention needs to be given not only to low-rise buildings, but also to significantly improving design practices for tall buildings experiencing dynamic effects. Recent studies have revealed that estimates of wind effects by various wind engineers can differ from each other by almost 50 % for tall buildings such as the World Trade Center twin towers and by even larger amounts for low-height buildings, particularly in suburban terrain.

Advanced wind measurements and computational tools will be used in support of the wind-load database development. Wind load databases consist of records of time histories of pressures induced by winds from a sufficient number of directions on hundreds of points of the external surfaces of a wide variety of building types (e.g., Main and Fritz, 2006). User-friendly design methods that will improve upon current methods by incorporat-

FIGURE 4

Left haunch of initially imperfect portal frame structure subjected to wind loading. Stresses in psi (1 psi = 6895 Pa) at ultimate limit state, obtained by nonlinear finite element analysis. Maximum deflection = 9.11 in (231 mm).



ing advanced aerodynamics, statistics, structural dynamics, structural reliability theory, and nonlinear structural theory (Figure 4). This approach is achievable now due to advances in information technology that allow solution of these highly computer-intensive problems—both on the desktop (for use by practicing engineers) and via high-performance parallel processors (for research in support of code and standard provisions). In addition, NIST will initiate a major effort to promote the development of validated computational fluid dynamics (CFD) modeling tools aimed at producing a "computational wind tunnel", i.e., as set of computational tools for predicting wind effects on structures that will reduce the dependence on or substitute for more expensive and less effective wind tunnel testing.

NIST will continue to work closely with standards committees on wind effects, where it has already initiated ongoing innovations in standard provisions for wind effects through the use of advanced electronic databases in lieu of the current, simplified design graphs originally developed for slide-rule calculations.

3. Tsunami Risk Reduction

Subduction zones similar to the one off of the coast of Indonesia that caused the December 26, 2004 tsunami exist off the coasts of the Pacific Northwest states, Alaska, and the U.S. Territories of Puerto Rico and the U.S. Virgin Islands. A similar tsunami from an earthquake in either the Juan de Fuca Plate or the Puerto Rico trench could have catastrophic effects on heavily populated U.S. cities. Fifty percent of the U.S. population lives on or near the coast. A significant tsunami arriving anywhere along the U.S. coast is likely to threaten life, property, and infrastructure—and disrupt local and regional economies. Tsunamis also impact the natural environment and the many services coastal resources provide—from nurseries for commercial fisheries to the primary attraction for vacation and resort economies. Popular vacation spots such as The Outer Banks, North Carolina and Caribbean nations would also be impacted resulting in significant loss of life and severe impact on their economies and natural environments.

The loss of life from local or distant tsunamis is not a matter of if but when. The advance toward a more disaster resilient America depends on enhanced federal, state and local capabilities to ensure coastal communities better recognize the threat, know when such hazards are imminent, understand the vulnerabilities, are safe, and experience minimum disruption to life and economy. The December 26, 2004 Indian Ocean tsunami was a wake-up call showing that while the frequency of damaging tsunami in the United States is low compared to many other natural hazards, the impacts will be extremely high.

In response to the 2004 Indian Ocean Tsunami, the U.S. Administration called on NOAA to strengthen the existing Tsunami Warning and Mitigation System capacities and capabilities to better protect lives and property along all U.S. coasts (Bernard and Titov, 2007). Lessons learned from the 2004 Indian Ocean Tsunami indicate that an effective and end-to-end tsunami system requires: (1) Tsunami Hazard Assessment; (2) Preparedness (3) Timely and Effective Warnings and Forecasts; (4) Mitigation (5) Public Outreach and Communication; (6) Research; and (7) International Coordination within a multi-hazard approach. The National Tsunami Hazard Mitigation Program (NTHMP) provides the partnerships and organizational framework to address this need in the near-term and develop, coordinate, and sustain an effective and efficient tsunami risk reduction effort in the United States over the long term.

NTHMP was launched over 10 years ago as a partnership between NOAA (lead), U.S. Geological Survey, Federal Emergency Management Agency, National Science Foundation, and state emergency management organizations on the U.S. West Coast, Alaska, and Hawaii in response to known risks. Today, NOAA is the national and global leader, providing technical assistance, research, technology transfer and operational services required to develop credible tsunami hazard and risk assessments, improve sensor data and infrastructure, enhance and deliver real-time monitoring and inundation forecast modeling, develop response plans and mitigation measures, increase community-level outreach and education, and ensure data exchange and interoperability among national, regional and international warning and communication systems. In December 2005, the President's National Science and Technology Council (NSTC) issued the *Tsunami Risk Reduction for the United States: A Framework for Action* (NSTC, 2005b), which called for the expansion of NOAA's NTHMP to serve a total of 28 coastal states, commonwealths, and territories and deliver the expected benefit of more disaster-resilient communities.

Since all United States coastal communities are threatened by tsunamis generated by both local sources and distant sources, there is an urgent need to meet the requirement for a truly comprehensive NTHMP program. Local tsunamis give residents only a few minutes to seek safety. Tsunamis of distant origins give residents more time to evacuate the threatened coastal areas, but require timely and accurate forecasts to avoid false alarms. Of the two, local tsunamis pose a grater threat to life because of the short time between generation and impact. The expanded NTHMP is needed to ensure that all states and local communities develop effective community-based emergency response plans, educate their public so they are aware of the risk, have the necessary inundation mapping so the community can better assess vulnerabilities and identify evacuation routes, and that our 24/7 operational tsunami detection and warning system communicates information in an easy to understand, accurate, effective, and timely manner, while having access to the latest tsunami science and research information.

NOAA and NIST are at the early stages of a partnership concerning co-efforts toward building improved tsunami resiliency. Areas where NIST will assist/partner with NOAA and its other partners are: development of Standardized and coordinated Tsunami Hazard Assessments for all coastal regions of the United States and its territories and commonwealths (including social-science studies) and community based emergency response plans.

4. Multi-Hazard Failure Analysis and Mitigation—Tools for Complex Structural Systems

The collapse of the World Trade Center towers on September 11, 2001, brought to the fore the problem of whether complex structural systems, whose performance depends upon the effective action and interaction of vast numbers of component elements, can be designed to survive severe combinations of extreme events, e.g., significant structural and fire damage. Current wind engineering approaches to this problem are still rudimentary and based on ad-hoc methods. Development of improved mitigation technologies and prediction of performance requires a significantly greater understanding of how complex structural systems fail. While such analysis is routine in some industries (e.g., automotive design), the capability to conduct such analysis is virtually non-existent in other industries (e.g., construction). Improving the ability to perform failure analysis of complex systems is critical to ensuring the security of our nation's physical infrastructure and the overall success of this multifaceted program. At the same time, decision support tools are needed for the economic assessment of multi-hazard mitigation solutions for such complex systems.

NIST is a leader in the failure analysis of complex structural systems and is well positioned to develop the fundamental failure analysis and mitigation tools required to analyze the performance and failure of such systems in response to many types of hazards (e.g., hurricanes, earthquakes, fires, blasts, explosions, progressive collapse, and others). The availability of validated tools to conduct such failure analyses will enable significant changes in structural design, resulting in major safety enhancements at lower life-cycle costs. These tools are also required to implement a key recommendation from NIST's WTC investigation for the adoption of the performance objective of full building burnout without collapse.

NIST will develop the underlying scientific basis that is required to define methodologies for estimating ultimate capacities, residual reserve capacity, and safety margins leading to safer structures at lower life-cycle cost and reduced embodied energy. The underlying science and methodologies for multi-hazard failure analysis developed in this program will be applied to, among others, two important structural safety issues: *progressive collapse*, and *structural performance in the presence of an uncontrolled fire* (structural-fire interactions).

Progressive collapse is the spread of local damage—from an initiating event—from element to element resulting, eventually, in the collapse of an entire structure or a disproportionately large part of it; it is also known as *disproportionate collapse.* Hazards that increase the risk of local structural failures that, in turn, can lead to a partial or complete progressive collapse include design and construction errors, abnormal loads not considered routinely in design (e.g., gas explosion, vehicular collision, the transport and storage of hazardous materials, bomb explosions and other forms of sabotage), extreme fires, extreme values of environmental loads (e.g., earthquakes, hurricanes) that stress the building well beyond the design envelope, and abuse. NIST is studying changes in the way buildings are designed and constructed so that progressive collapse can be mitigated explicitly via provisions in codes and standards (see www.bfrl.nist.gov/861/861pubs/collapse/).

5. Community Scale Damage Forecasting—Loss Estimation Methodology

Policy, operational, and risk management decisions must be based on reasonably accurate predictions of the economic losses induced by various natural and manmade hazardous events, as well as on the anticipated benefits from protection against those events. Such predictions may pertain to statistics of future losses, or to losses to be expected from an ongoing event. Losses consist in part of physical damage to the built environment, including residential, commercial, institutional, industrial, infrastructure construction, and building appurtenances. For hurricanes they are also due to interior, utility, and contents damage caused by penetration of wind and water (rain or flooding) once the envelope is breached. Additional losses stem from increased living expenses, medical expenses, loss of income and other socio-economic consequences of the hurricane event.

Several loss prediction models exist, most of them proprietary "black boxes." However, predictions from current tools can vary widely. For example, it appears that calculations carried out for Florida yielded estimates by various hurricane loss prediction models that differed in some cases several fold. This prompted the State of Florida to support the development of The Florida Public Hurricane Loss Projection Model, aimed at providing an open and more dependable basis for decisions on insurance rates. Regarding the FEMA HAZUS model, the Florida study (Florida, 2005) noted that "HAZUS vulnerability curves are heavily dependent upon roughness of the terrain, while the vulnerability curve of the Florida model is independent of the roughness of the terrain and is a representation of the actual wind speed acting on the structure." The study also noted that: "the HAZUS model drastically over-predicts our vulnerability curve for this model type." The Florida model uses state-of-the-art-methodologies, and is a step forward with respect to other prediction models. However, some of the variables of the Florida model were developed without the benefit of thorough physical and reliability modeling supported by laboratory and field measurements.

NIST and NOAA in collaboration with FEMA and other entities, notably the Institute for Building and Home Safety (IBHS), will conduct research aimed at providing public or private organizations concerned with assessing and managing risks at the community or regional scale an enhanced scientific base that can be used to improve existing loss prediction models and tools (NSTC, 2005b). The proposed research will be focused on: (1) developing or improving requisite models (e.g., hurricane and storm surge) (2) organizing the collection of relevant statistics concerning the exposed building and infrastructure stock, and historical records of losses, (3) producing requisite measurements and statistics of component strengths, (4) identifying and modeling community cost components, and (5) producing draft standards for modeling losses. This research will provide the technical basis necessary for the development of improved tools needed by forecasters, and also by policy makers for planning response, recovery, and rebuilding activities and estimating budget requirements for such activities in the immediate aftermath of disasters. Case studies will be developed for hurricanes, storm surge, and tsunamis.

Key synergies exist between the expertise of NOAA (observing, modeling and forecasting) and NIST (engineering and economics) necessary to address this complex issue. This problem demands a multi-disciplinary approach which will include collaborations with other agencies (FEMA, Federal Highway Administration, Housing and Urban Development, U.S. Army Corps of Engineers), academia, industry, and codes and standards groups. NIST and NOAA have many years of experience establishing these types of successful collaborative partnerships.

The role of NOAA includes the provision of the most accurate, validated, and, if necessary, analyzed field data that can be used as input to decision support and structural engineering models, an example of which, H*WIND, is discussed in Section 2.2 above. H*WIND is currently used as input to FEMA's HAZUS MH. NOAA also provides expert assistance in damage surveys that will be an important component of the NIST-NOAA cooperation.

6. Summary and Conclusions

The tasks described in this paper, yet to be accomplished and most barely begun, represent an important technical underpinning to the societal, behavioral, educational, and outreach components of resiliency. They primarily address the built coastal environment and mostly focus on engineered structures. However, resiliency of the built environment is a cornerstone of coastal community resilience. The NIST and NOAA collaborative effort described here addresses a challenging and complex problem that the coastal environment posses. The complex interface between the ocean, the atmosphere, and the land offers a daunting problem for structural and civil engineers. Yet, this problem must be addressed if our coastal communities are even to approach the claim of resiliency.

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