NIST Technical Note 1795

Developing Guidelines and Standards for Disaster Resilience of the Built Environment: A Research Needs Assessment

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Executive Summary

The term 'resilience' has a number of definitions. With regards to hazard events, it has been defined as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events". The term resilience is applied to a range of topics that include physical security against terrorism, security screening of people at public venues, continuity in business operations, emergency planning and response for essential services, hazard mitigation, and the capability of the built environment (e.g., facilities, transportation, utilities) to physically resist and rapidly recover from disruptive events. This report addresses the role of the built environment in community resilience. The basic premise is that critical facilities and infrastructure systems (e.g., hospitals, emergency response, power, and transportation) need to be operational and functional during and after a hazard event to support other aspects of community resilience. Additionally, the remaining buildings and infrastructure systems need to be restored within a specified period of time, if damage does occur, to minimize disruption to the community, expenditures for repair and rebuilding, and economic impacts. Resilience of the built environment depends upon the capacity of each facility and infrastructure system, when considered in the context of the community, to maintain acceptable levels of functionality during and after disruptive events and to recover full functionality within a specified period of time.

Despite progress in science and technology towards improved performance of the built environment during disasters, natural and man-made hazards in the United States are responsible for significant losses and damage. To improve the resilience of the built environment to hazard events, each community or region needs a comprehensive plan that specifies performance levels and timeframes for recovery from damage that are consistent across building and infrastructure systems. Community resilience objectives and policies should be developed for local and regional hazards and resilience needs, and should include goals and performance criteria, based on the role of each facility or infrastructure system in the community. However, guidance for developing resilience in the built environment, including quantitative metrics and tools for assessing component and community resilience, is not available.

The NIST Engineering Laboratory conducts research on resilience of the built environment, structural robustness, and structural performance during hazard events. NIST research aims to develop metrics and tools for assessing the resilience of building and infrastructure systems, such as predicting structural performance up to failure, assessing and evaluating the ability of existing structures to withstand seismic, fire, and other extreme loads, and predicting disaster resilience at the community scale.

To assist with identifying critical gaps and needs in tools and metrics for assessing the resilience of the built environment, two national workshops were convened by NIST in 2011, which were sponsored by the Department of Homeland Security (DHS), and supported by the American National Standards Institute's Homeland Security Standards Panel (ANSI-HSSP). The Resilience Roundtable convened invited leaders from engineering practice and research communities and the standards development community to identify gaps in current practice, standards, and codes and the assessment

and design of resilient buildings and infrastructure systems. The Standards for Disaster Resilience Workshop further developed technical input and guidance from participants for identifying critical gaps and needs in tools and metrics for resilient communities. The Standards for Disaster Resilience Workshop was open to all interested participants. Panel sessions addressed the following topics: need for resilience in buildings and infrastructure systems, community planning for resilience, insurance perspective on building and infrastructure resilience, and standards for building, electric power, transportation, and water and wastewater systems.

This report provides an assessment of technical gaps and research needs for developing guidelines and standards supporting community resilience based on the workshops and NIST research. The gaps and needs are grouped as short term (less than 3 to 5 years) and long term (greater than 3 to 5 years) activities, based on funding and staffing levels. The short term activities address resilience planning at the community level, where the role of facilities or systems in a community's physical resilience is defined. The long term activities address identification and development of tools and metrics that determine the expected level of performance during and after a hazard event, and include recovery of functional performance.

Short term activities

- Identify technical gaps and research needs from reviews of past disaster events and existing model codes and standards
- Define resilience terminology for the built environment to help communicate new concepts
- Develop guidance for community resilience planning

Long term activities

- Develop risk-based performance goals for resilient communities
- Develop tools and metrics to support quantitative technical assessment, policy development, and decision making
- Develop guidelines on risk-based performance goals and criteria for inclusion in standards for voluntary reference.

Acknowledgements

This report has benefitted from a number of individuals and sources. Two workshops were held by NIST in 2011 to discuss research needs for developing more resilient buildings and infrastructure systems, which provided a valuable source of data and ideas. Chris Poland and Steve Cauffman, Co-Chairs of both workshops, provided invaluable assistance in organizing the topics, scope, and technical experts. The American National Standards Institute's Homeland Security Standards Panel (ANSI-HSSP) coordinated the arrangements for the two events and provided valuable support. The following individuals provided insightful views on the state of resilience at the workshops:

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Steve Ernst, Federal Highway Administration

Ron Hamburger, Simpson Gumpertz & Heger

Jim Harris, JR Harris Company

Dan Howell, FM Global

Chris Poland, Degenkolb Engineers

Woody Savage, University of Nevada Las Vegas

Alex Tang, L&T Consultants

Participants at the 2011 workshops included professionals knowledgeable about many aspects of the built environment, and their input greatly assisted in identifying technical gaps and research needs in the present codes, standards, and practices. They are grouped by organization to illustrate the breadth of the participants.

Government Agencies

Bonneville Power Administration - Leon Kempner

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University at Buffalo - Michael Bruneau

University of Florida - David Prevatt

University of Waterloo - Elizabeth English

Private Firms

Applied Technology Council - Bill Coulbourne

Catalyst Partners - David McWhorter

CIP Consulting - Paul Domich

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Steve Cauffman, Program Manager of Disaster Resilient Structures and Communities Research, NIST, MD

Anthony Hamins, Program Manager of Fire, NIST, MD

Fahim Sadek, Program Manager of Structural Performance Under Multi-Hazards Research, NIST, MD

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release.

Contents

Appendices

1. Introduction

Hazards[1] pose continuing and significant threats to U.S. buildings and infrastructure systems. Hazard types and intensities vary by location, making resilience of the built environment a community or regional issue. Buildings[2] and infrastructure systems[3], also referred to as the built environment, play critical roles in community resilience. Resilience of the built environment depends upon the capacity of each facility and infrastructure system to maintain acceptable levels of functionality during and after a disruptive event and to recover full functionality within a specified period of time. Despite substantial progress in science and technology towards improved performance of the built environment during disasters, natural and man-made hazards in the United States are responsible for loss of life, disruption of commerce and financial networks, damaged property, and loss of business continuity and essential services.

The term 'resilience' has a number of definitions. With regards to hazard events, and responding to hazard events, it has been defined as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (NAC 2012) or, similarly, "the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions" (PPD-21 2013). Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents. The term resilience is applied to a range of topics that include physical security against terrorism, security screening of people at public venues, continuity in business operations and employment, emergency planning and response for essential services, hazard mitigation, and the capability of the built environment (e.g., facilities, transportation, utilities) to physically resist and rapidly recover from disruptive events. This report addresses the role of the built environment in community resilience. The basic premise is that critical facilities and infrastructure systems (e.g., power, emergency response, hospitals, and transportation) need to be operational and functional during and after a hazard event to support other aspects of community resilience. Additionally, the remaining buildings and infrastructure systems need to be restored within a specified period of time, if damage does occur, to minimize disruption to the community. Resilience of the built environment depends upon the capacity of each facility and infrastructure system, when considered in the context of the community, to maintain acceptable levels of functionality during and after disruptive events and to recover full functionality within a specified period of time.

This document addresses resilience issues related to the performance of the built environment during and after hazards and disruptive events. In particular, the technical

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[1] Hazards include earthquakes, wind-related hazards (hurricanes, tornadoes, windstorms), fire-related hazards (community-scale fires in the wildland-urban interface, building fires), water-related hazards (storm surge, flood, tsunami) and human-made hazards (accidental, criminal, or terrorist in nature).

[2] The term building includes all the systems necessary for its functional operation, including architectural, structural, life safety, mechanical, electrical, plumbing, security, communication and IT systems.

[3] The terms infrastructure and lifelines are used interchangeably in this paper, and include the physical plants, transmission, and distribution networks for transportation facilities (e.g., roads, bridges, airports, tunnels, ports, rail) and utilities (e.g., electric power, water and wastewater, fuels, and communication).

gaps for achieving resilience in the built environment are identified and research needs are identified. The other aspects of a resilient community—security, protection, emergency response, business continuity, and social issues related to human health, safety, and general welfare—are not addressed. However, these broader issues drive requirements for the performance of the built environment. The objective of this effort is to establish the needs for improving the performance of the built environment.

The built environment needs improved performance during and after a disruptive hazard event. For example, critical facilities, such as emergency response stations and hospitals, and their supporting power, communication, and transportation systems, should be designed to the same performance levels for a design hazard event. Presently, this is not occurring in many communities for several reasons. A number of communities have not adopted current building codes and standards, or have exempted critical sections such as seismic requirements, or do not enforce compliance with adopted codes. Many state transportation codes lag the current national transportation codes and standards. Electric power, communication, and water systems rely on industry standards, but these standards often focus on reliability of service rather than system performance during or after hazard events. Additionally, the built environment in each community has buildings and infrastructure systems that may range from historic to modern, and were constructed under codes and standards of the time. Many facilities do not meet current design standards, or may have degraded performance due to aging effects or inadequate maintenance.

However, resilience is more than adopting and enforcing the current codes and standards. In communities that adopt and enforce the latest codes, there is still uncertainty about the expected performance of the built environment when subjected to hazard events. This is because codes, standards, and current practices for the built environment emphasize life safety issues and reliable service but not issues associated with community resilience, such as expected performance during a design-level hazard event or rapid repair and recovery afterwards. Hazard events across the country and around the world repeatedly demonstrate that buildings and infrastructure systems do not perform in a manner that supports community resilience.

Recent disaster events are first reviewed to illustrate the types and extent of damage that occur across the nation. Then, a short history of the evolution of resilience concepts in the framework of national disaster events is provided. Parallel with the disaster events, the resilience activities of the federal government are described, including key documents such as the Grand Challenges for Disaster Reduction (OSTP 2008), the National Infrastructure Protection Plan (DHS 2009) which was developed in response to Homeland Security Presidential Directive 7 (HSPD-7 2003), and the National Preparedness Goal (DHS 2011) which was developed in response to Presidential Policy Directive 8 (PPD-8 2011). Presidential Policy Directive (PPD) 21, Critical Infrastructure Security and Resilience, was released in February 2013 with the goal of advancing national unity of effort to strengthen and maintain secure, functioning, and resilient critical infrastructure for all hazards (PPD-21 2013). Private sector resilience activities are also summarized. These summaries set the background for recommendations for research needs, which are based on the collected data and the workshops described below.

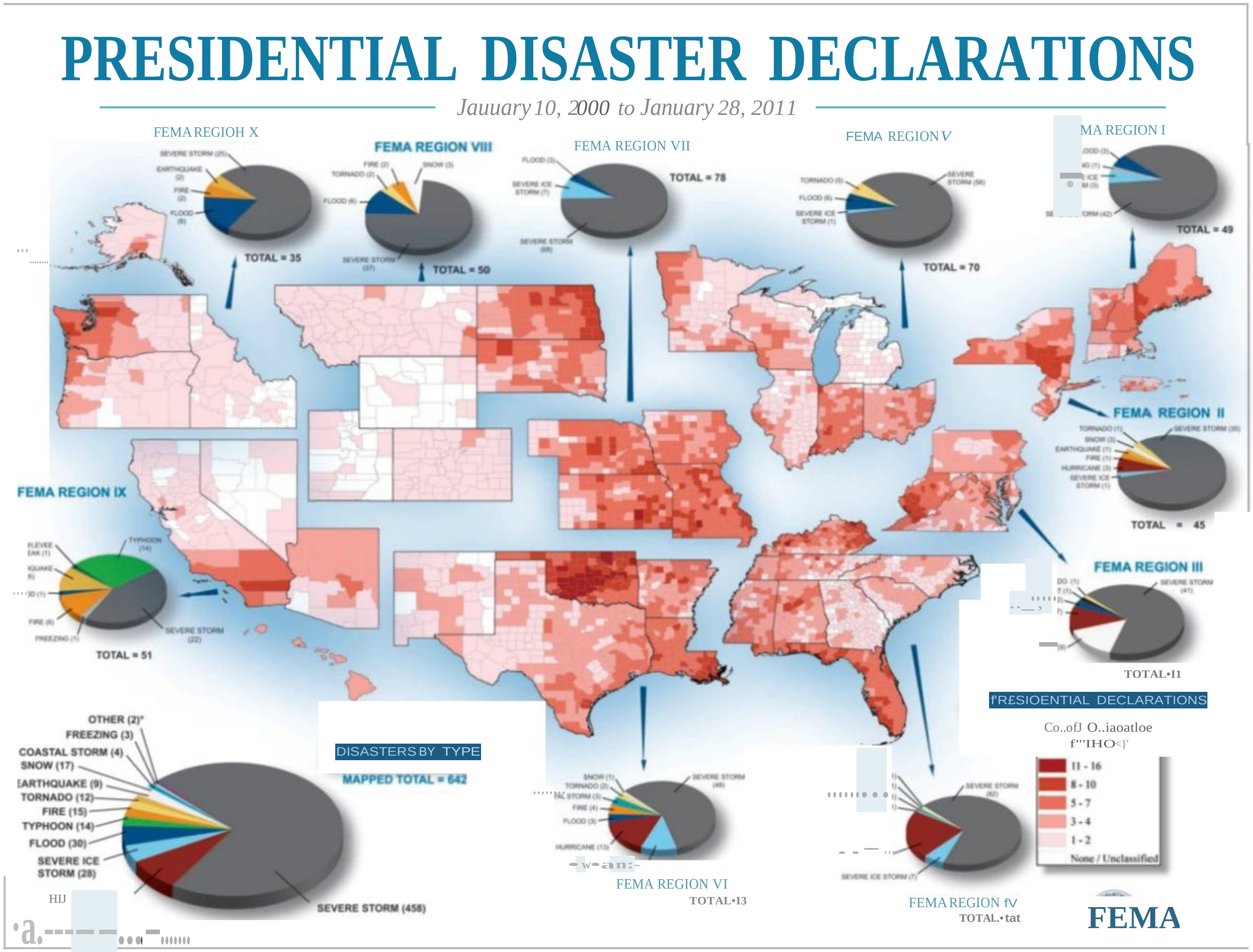
Two national workshops were held with experts from the building and infrastructure communities to discuss the needs and gaps for achieving resilience in the built environment. Introductory and background information are presented first to provide context for the concept of resilience in the built environment and to review activities related to community resilience by government and private sectors. Then, a summary of the recommendations from each workshop are presented, based on the detailed comments provided in the Appendices. Last, a consolidated set of short and long term research needs are also presented, based on input from the workshops and NIST research, for developing tools and standards for resilient communities.

2. Recent Disaster Events

The risk across the Nation for substantial damage due to hazard events continues to increase, due to the combined effects of urban development and population growth (NOAA 2005, NRC 2006). Much of the Nation's physical infrastructure is susceptible to natural hazards (e.g., along coastlines, in the wildland-urban interface, in tornado alley, and in earthquake-prone regions). Additionally, much of the Nation's infrastructure is vulnerable due to aging effects resulting in a diminishing capacity to resist hazards.

The American Society of Civil Engineers has issued report cards for America's Infrastructure since 1998. The 2009 report (ASCE 2009) evaluated aviation, bridges, dams, drinking water, energy, hazardous waste, inland waterways, levees, public parks and recreation, rail, roads, schools, solid waste, transit, and wastewater systems at a national level. The highest grade was a C+ for solid waste and 5 systems received the lowest grade of D-. More recent reports have evaluated the infrastructure status by state. ASCE released 'A Failure to Act' (2013) which evaluates the economic consequences of continued underinvestment in the national infrastructure. The report addresses the economic opportunity associated with infrastructure investment and the cost of failing to fill the investment gap.

Risk is commonly thought of as a product of a threat or hazard, the vulnerability of a community or facility to a threat or hazard, and the resulting consequences that may impact the community or facility (DHS 2012). As an indicator of the risk of the existing built environment experiencing damage from hazard events, Figure 1 shows Presidential disaster declarations for the period from January 2000 to January 2011. Between 45 and 81 declarations were made every year for floods, hurricanes, tornadoes, earthquakes, fire events, and severe storms. The 2001 World Trade Center (WTC) terrorist attack, a man-made disaster, also was declared as a Presidential disaster. The Robert T. Stafford Disaster Relief and Emergency Assistance Act authorizes the President to issue a major disaster declaration for federal aid to states determined to be overwhelmed by natural hazards or other catastrophes. The Stafford Act authorizes temporary housing, grants for immediate needs of families and individuals, and the repair of public infrastructure and emergency communication systems. For instance, Congress appropriated over $10 billion to the Disaster Relief Fund in FY2005, largely in response to the four hurricanes that struck Florida in the fall of 2004. However, many disaster declarations are based on economic recovery costs, and the hazard intensity experienced during the events fall below current design thresholds.


PRESIDENTIAL DISASTER DECLARATIONS
Jauuary 10, 2000 to January 28, 2011
FEMA REGIOH X
TOTAL = 35
FEMA REGION VIII
TOTAL = 50
FEMA REGION VII
TOTAL = 78
FEMA REGION V
TOTAL = 70
MA REGION I
TOTAL = 49
FEMA REGION II
TOTAL = 45
FEMA REGION III
FEMA REGION IX
TOTAL = 51
OTHER (2)
FREEZING (3)
COASTAL STORM (4)
SNOW (17)
EARTHQUAKE (9)
TORNADO (12)
FIRE (15)
TYPHOON (14)
FLOOD (30)
SEVERE ICE STORM (28)
SEVERE STORM (458)
DISASTERS BY TYPE
MAPPED TOTAL = 642
FEMA REGION VI
FEMA REGION IV
PRESIDENTIAL DECLARATIONS
11 - 16
8 - 10
5 - 7
3 - 4
1 - 2
None / Unclassified
FEMA

The International Standards Organization (ISO) defines a catastrophe as an event that causes $25 million or more in insured property losses and affects a substantial number of property/casualty policyholders. The ten most costly catastrophes in the United States, normalized by insured property losses in 2010 dollars, are shown in Table 1 (Insurance Information Institute, 2012). These catastrophes affected large regions or multiple states, damaging buildings and infrastructure systems to an extent that full recovery took years. The role of the top three catastrophes in defining resilience of the built environment is discussed in the next section.

Total losses can exceed $100 billion in large disaster events. The wind and storm surge during Hurricane Katrina in 2005 caused extensive damage across several states (NIST 2006). Beyond the storm surge, the winds damaged industrial facilities, oil storage tanks, and the power distribution system. Insured losses for Hurricane Katrina in 2005 were $44 billion, and total economic (non-insured) damages were thought to exceed $200 billion (King 2005, 2008). More recently, Japan had a triple disaster of earthquake, tsunami, and nuclear power plant crises. The World Bank estimated that the reconstruction costs for this disaster will range between $122 and $235 billion (Nakamura 2011).

Table 1. Ten most costly catastrophes in the United States.[(1)]

Rank	Date	Peril	Insured property loss in 2010 dollars [(2)] ($ millions)
1	2005	Hurricane Katrina	$45 481
2	2001	World Trade Center and Pentagon terrorist attacks	$22 924
3	1992	Hurricane Andrew	$11 412
4	1994	Northridge, CA Earthquake	$17 318
5	2008	Hurricane Ike	$12 735
6	2005	Hurricane Wilma	$11 398
7	2004	Hurricane Charley	$8 548
8	2004	Hurricane Ivan	$8 130
9	1989	Hurricane Hugo	$6 678
10	2005	Hurricane Rita	$6 227

(1) Property coverage only. Does not include flood damage covered by the federally administered National Flood Insurance Program.
(2) Adjusted for inflation through 2010 by ISO using the gross domestic product (GDP) implicit price deflator.

Model codes and standards for building and infrastructure systems tend to be developed independently through different public or private processes. Their independent development can lead to varying hazard and performance criteria for buildings, transportation systems, utilities, and other infrastructure systems within a community. The codes and standards are developed to ensure life safety of buildings and reliability of service for utilities, but do not address resilience issues. The uneven level of damage that occurs across building and infrastructure systems during hazard events indicates that the present codes, standards, and practices are not compatible in their scope or requirements for performance. Additionally, many of the existing building and infrastructure systems were built to earlier codes and standards. The following examples from 2011 hazard events in the U.S. demonstrate how the built environment is often excessively damaged in hazard events.

Hurricane Irene was a Category I hurricane when it made first landfall on the Outer Banks, North Carolina on 27 August 2011. It made a second landfall at Little Egg, New Jersey, and a third landfall at Brooklyn, NY, after which it was downgraded to a tropical storm. Hurricane Irene primarily caused extensive flood damage. Over 40 million people were affected by the storm, and over 6 million homes and businesses lost power from downed power lines and flooded or damaged substations. Many roads and bridges in New Jersey and Vermont were impassable, isolating communities. Hurricane Irene caused insured losses of $2 billion to $4.5 billion, according to Risk Management Solutions Inc. The worst of the damage resulted from flooding, a hazard which is not covered under standard homeowners' policies and is largely excluded from the RMS estimate (Holm 2011). If flood damage losses were included, the total loss estimate increased to between $7 billion and $10 billion (Cooper 2011).

On May 22nd, 2011, a tornado occurred in Joplin, MO. While portions of the 22 mile damage swath were rated as EF3 to EF5, much of the tornado damage was rated between EF0 and EF2 (National Weather Service 2011a). Approximately 7500 houses, 18000 cars, and 450 businesses were damaged or destroyed. Communication and power were lost in many areas of the city. It is likely to be the costliest tornado in U.S. history, reaching $3 billion (EQECAT 2011). St. John's Regional Medical Center is an example an engineered structure's response to direct impact by tornadic winds and debris. Nearly all the low-rise buildings surrounding St. John's were destroyed. In the main hospital structure, there was extensive damage to the glazing, interior walls, and furnishings, and sections of the roof were missing, but there was no observed damage to main wind force resisting system of the 1965 reinforced concrete frame or the 1983 steel frame (Phan 2011). However, ancillary buildings for the generator and chiller plants were substantially damaged or collapsed. Due to mold and other contaminants (Bollin 2011) which were too costly to remediate, the St. John's medical facility was demolished and is being rebuilt at a new location[4]. The damage to St John's Regional Medical Center demonstrates the need to consider the functionality of a facility after a hazard event, in addition to structural integrity.

On 11 July, 2011, a severe thunderstorm struck central eastern Iowa. The National Weather Service (NWS) storm survey teams estimated wind speeds in the 110 to 130 mph range based on observed damage. The NWS stated that this was the largest and most damaging wind event since 1998. No tornadoes were detected; the straight line winds were due to a derecho[5]. However, the strongest winds were similar to those found in an

[4] Personal communication, St John's Medical Research Center and NIST personnel
[5] The National Weather Service defines derechos as windstorms that are able to last for several hours with gust fronts that produce high levels of damage. In order for these storms to last so long, they need both instability and wind shear.

EF1 tornado (National Weather Service 2011b). Damage included widespread power outages and downed power lines, partial or total removal of many roofs, and collapsed walls of some buildings.

There was an increased rate of water pipe failures across the U.S. during the 2011 drought in the Midwest and South. Older pipes are more susceptible to bursting. Beginning in August 2011, Oklahoma City had 685 water main breaks over a six-week period, four times the normal rate. On August 23, 2011, Houston had 847 water leaks, more than three times the normal rate. The American Water Works Association (AWWA) report, "Dawn of the Replacement Era, Reinvesting in Drinking Water Infrastructure" (May 2001) points out that many of the water systems are 80 to 100 years old and approaching the end of their useful lives.

Deteriorating infrastructure increases the severity and rate of failure during hazard events or extreme conditions. The ASCE (2009) report card rate the national infrastructure between a C+ and D-. The United States has fallen sharply in the World Economic Forum's ranking of national infrastructure systems. In the 2007-2008 report, American infrastructure was ranked No.6 in the world. In the 2009-2010 report, the U.S. was ranked at No.14. The U.S. spends roughly 2 percent of its gross domestic product on infrastructure systems, about half of that spent 50 years ago. Europe spends around 5 percent, and China 9 percent. Deteriorating infrastructure impacts business continuity and increases costs to taxpayers and businesses.

As projected losses from hazard events continue to rise, there is increasing recognition that minimizing the need for emergency response and post-event rebuilding and recovery depends on proactive measures to identify and mitigate risks posed by hazards and to plan for rapid recovery for all infrastructure systems in the built environment.

3. Historical Basis of Resilience Concepts

Three disaster events significantly influenced the development of resilience concepts in the United States: Hurricane Andrew in 1992, the World Trade Center (WTC) and Pentagon terrorist attacks in 2001, and Hurricane Katrina in 2005.

3.1. 1992 Hurricane Andrew

3.1.1. Event

Andrew stuck Dade County on August 24th as a Category 5 hurricane, with the center first reaching the coast at the northern tip of Elliott Key. The storm devastated Dade County where it caused an estimated $25 billion in damage, especially over the Homestead area. The number of homes destroyed was approximately 49 000, with an additional estimated 108000 damaged (National Weather Service 2012).

The widespread structural damage from Hurricane Andrew in 1992 resulted in improved building codes and practices in South Florida (Florida Building Commission 2004). Some of the important changes included adopting wind provisions from a national standard[6], developing requirements for impact resistant glazing through testing, and requiring positive ties at all connections to resist uplift forces (Tsikoudakis 2012).

3.1.2. Federal Government Activities

After Hurricane Andrew, FEMA was reorganized with an emphasis on preparedness and mitigation for natural hazards. Response and recovery efforts primarily focused on providing financial and housing aid to communities immediately after a disaster. Today, FEMA public assistance ranges from training to flood insurance to personal and community disaster relief. Their activities have improved community planning for shelters and communication during hazard events and provided assistance when damage exceeded local and state resources. FEMA reports on building performance during disasters and support of seismic design practices have resulted in changes to building practices (e.g., continuous load paths for wind resistance, elevation above flood levels, and improved seismic design guidelines, including performance based design). Most recently, FEMA issued Comprehensive Preparedness Guidance (CPG) 201 (DHS 2012) to help communities conduct a threat and hazard identification and risk assessment process. The process has the user identify hazards, vulnerabilities, and consequences to provide a basis for examining existing plans and capabilities for preparedness, mitigation, response, and recovery. The findings are used to identify needed capabilities and set new targets for performance during a hazard. The process supports informed decision making by communities for managing risk and developing capabilities.

3.2. 2001 WTC and Pentagon Terrorist Attacks

3.2.1. Event

On September 11, 2001, large aircraft were flown into the World Trade Center (WTC) 1 and 2 buildings and the Pentagon by terrorists. The fires following the aircraft impact caused WTC 1 and WTC 2 to collapse within approximately 1 to 1.5 h. When the towers collapsed, fire spread to the WTC 7 building, which also collapsed due to uncontrolled fires. The Pentagon damage was limited to the area of aircraft impact, largely due to the redundant framing designed for large floor loads and reinforcement continuity at supports (Mlakar et. al. 2003). Buildings for use by the general population are not designed in this manner, so they will not withstand attacks of such severity. The collapse of the WTC buildings led to major damage to surrounding buildings and loss of power, communication, and water in lower Manhattan, as well as interruption to financial markets. The loss of life by occupants and emergency responders, and the damage to the surrounding buildings and infrastructure systems in lower Manhattan, raised issues about how building collapse can affect the entire built community (NIST 2005, NIST 2008).

The NIST (2005, 2008) reports made recommendations to improve safety for tall buildings and their occupants and for emergency responders. The recommendations

[6] American Society of Civil Engineers (ASCE) Standard 7, Minimum Design Loads for Buildings and Other Structures, provides minimum load requirements for the design of buildings and other structures that are subject to building code requirements. Loads and appropriate load combinations, which have been developed to be used together, are set forth for strength design and allowable stress design.

addressed structural integrity, fire resistance of structures, building evacuation, emergency response, and improved procedures and practices for design and construction. Many of these recommendations have been adopted by codes and standards (WTC Disaster Study 2008).

3.2.2. Federal Government Activities

Following the WTC and Pentagon disasters in 2001, efforts focused on enhancing security against terrorism for critical infrastructure. National policy for deterrence of terrorist attacks was addressed in The USA Patriot Act (2001), which defined critical infrastructure as "systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact" on national economic security, public health, or safety. The Homeland Security Presidential Directive-7 (HSPD-7 2003), Critical Infrastructure Identification, Prioritization, and Protection, established a national policy for federal agencies to identify and prioritize critical[7] infrastructure and key resources (CIKR) and to protect them from terrorist attacks. Table 2 lists the Critical Infrastructure Sectors, which were originally identified by DHS (2009). The performance of the built environment is not explicitly addressed in the critical infrastructure sectors, but each sector relies on the built environment and the interrelation of the sectors is critical to resilience.

Table 2. Eighteen Critical Infrastructure Sectors Identified by DHS (2009).

Food & Agriculture	Banking and Finance	Chemical
Commercial Facilities	Communications	Critical Manufacturing
Dams	Defense Industrial Base	Emergency Services
Energy	Government Facilities	Information Technology
Healthcare & Public Health	National Monuments & Icons	Nuclear Reactors, Materials & Waste
Postal & Shipping	Transportation Systems	Water

3.3. 2005 Hurricane Katrina

3.3.1. Event

Hurricane Katrina struck the Gulf Coast region as a Category 3 hurricane on the Saffir-Simpson hurricane scale. The accompanying storm surge was observed to be as high as

[7] The terms critical and essential are often used interchangeably to indicate facilities and infrastructure that are necessary for public safety, health, and welfare and are intended to remain operational during and after hazard events.

8.5 m (28 ft) at some locations along the Mississippi Gulf Coast. Hurricane Katrina reached Category 5 intensity while in the Gulf of Mexico, with maximum sustained winds of 78 m/s (175 mph). The storm began weakening about 18 hours before making landfall as a Category 3 hurricane with maximum sustained winds of 56 m/s (125 mph) (NIST 2006).

At the time of the hurricanes, there was no statewide building code in Louisiana, Mississippi, or Alabama, although some local jurisdictions had adopted model building codes. The City of New Orleans had adopted the 2000 edition of the model building and residential codes issued by the International Code Council in January 2004 (NIST 2006).

In coastal areas and in New Orleans, storm surge was the dominant cause of damage. Storm surge heights, in general, exceeded the levels defined by existing flood hazard maps as well as historical records. Storm surge and associated wave action led to breaches in the flood protection system in New Orleans, resulting in substantial structural damage to residences in the immediate vicinity of breaches and flooding in approximately 75 percent of the city. Bridges in the coastal areas were damaged due to the uplift and lateral loads imparted by storm surge and associated wave action. Industrial facilities, such as seaports, petrochemical facilities, and utilities also sustained damage due to storm surge and flooding (NIST 2006).

Away from the immediate coastal areas, wind and wind-borne debris were the dominant causes of damage to structures. Substantial damage occurred in many instances where the winds were lower than those levels cited in codes and standards—suggesting that the structures did not perform as expected. Buildings suffered wind-induced damage to glazing (window glass) as a result of debris impact from aggregate surface roofs on adjacent buildings, debris from damaged equipment screens on top of buildings, and debris from the damaged façade or structure of adjacent buildings. Wind damaged roofing and rooftop equipment, providing paths for water ingress into buildings. Wind-driven rain through walls and around intact windows also was responsible for water damage to the interiors of buildings. As many as one million timber electric power distribution poles were lost in the two hurricanes, as well as a number of high voltage transmission towers (NIST 2006).

The extensive, multi-state damage from Hurricane Katrina in 2005 reminded the U.S. that natural disasters continue to be a significant threat to our communities. The unprecedented level of destruction by storm surge in Mississippi and Louisiana brought renewed focus on the need to address natural disasters, in addition to protection from manmade hazards.

3.3.2. Federal Government Activities

A broadened definition of disaster resilience was reflected in the Grand Challenges for Disaster Reduction and the National Infrastructure Protection Plan developed by The President's Office of Science and Technology Policy in 2005, and updated 2008 (OSTP 2008). The Grand Challenges identify technical problems due to lack of adequate scientific understanding of natural hazards and availability of information, predictive technologies, and mitigation strategies to improve the performance of buildings and infrastructure, and standard methods to predict and assess the disaster resilience of buildings and infrastructure.

The Department of Homeland Security (DHS) released a National Infrastructure Protection Plan (DHS 2009) in response to HSPD-7. Eighteen CIKR sectors were identified (see Table 2), as well as high priority technology needs, including analytical tools to quantify interdependencies and cascading consequences across critical infrastructure sectors; effective and affordable blast analysis and protection for critical infrastructure; decision support systems to prevent disruption, mitigate results, and build resiliency; rapid mitigation and recovery technologies; and critical utility components that are affordable and highly transportable.

The DHS Science and Technology Directorate sponsored a 2010 workshop that focused on the resilience of buildings and related infrastructure, and discerning possible strategies for the Federal departments and agencies to pursue. The resilience of U.S. buildings and infrastructure systems for hazard events was considered for four design-related approaches: high performance, codes and standards, continuity of operations, and integrated design. The Summit was attended by 82 experts from the building industry, federal agencies, state and local governments, universities, and professional and trade organizations. The workshop was documented in a report, "Designing for a Resilient America" (DHS 2010), in which recommendations were made for increasing resiliency in six areas: role of government, public/private partnerships, codes and standards, research and development, design practice and performance outcomes, and education and outreach.

Presidential Policy Directive 8 (PPD-8 2011) called for strengthening the security and resilience of the United States through an integrated, capabilities-based approach to national preparedness and resiliency and directed DHS to develop a national preparedness goal and plan. DHS issued a report, National Preparedness Goal (DHS 2011), describing how the nation would strive to develop "a secure and resilient Nation with the capabilities required across the whole community to prevent, protect against, mitigate, respond to, and recover from the threats and hazards that pose the greatest risk". The goal addresses natural disasters, disease pandemics, chemical spills and other manmade hazards, terrorist attacks and cyber system attacks. The approach includes development of 31 core capabilities and the mission areas of prevention, protection, mitigation, response and recovery. The 31 core capabilities are intended to encompass possible requirements for any given community, allowing flexibility in planning and responding to risks.

3.4. 2012 Hurricane Sandy

3.4.1. Event

Hurricane Sandy was a Category 2 storm at its peak intensity. While off the coast of the northeastern United States, the winds spanned approximately 1100 miles (1800 km) and the storm become the largest tropical system on record. Prior to landfall, Hurricane Sandy was downgraded to a post-tropical storm. The storm system came ashore near Atlantic City, New Jersey, at 8 p.m. on October 29, 2012. A wind gust of 79 mph was reported at

John F. Kennedy International Airport in New York, and 90 mph was reported at Islip, New York (Sullivan and Doan 2012).

The path and width of Sandy created a storm surge that flooded coastal areas from North Carolina to Massachusetts. The total water level rise during Hurricane Sandy was caused by a combination of astronomical tides, storm surge, and a full moon which increased the high tide level. The large area affected by onshore winds north of Sandy's center near Atlantic City caused the highest storm surge levels to occur in New Jersey and New York. The peak water level rise of 13.9 ft (4.2 m) occurred in the Battery Park area of Manhattan shortly after 9:00 p.m., with 9.2 ft (2.9 m) of storm surge and a 4.7 ft (1.4 m) tide (Cox 2012).

Sandy damaged or destroyed 305 000 housing units and disrupted more than 265 000 businesses in New York. In New Jersey, 346 000 housing units were destroyed or damaged, and 190000 businesses affected (AP 2013). Engineered structures suffered little if any structural damage, as pile foundations to bedrock were not affected by the flood event. There was significant damage to infrastructure systems in the communities, including power, transportation, communication, waste water treatment, and gasoline stations. Many of the flooded engineered structures were built prior to the establishment of flood zones by FEMA in the early 1970s and used basement levels to house building electric power, heating and ventilation, communication, and fire safety systems as well as fuel tanks and pumps for emergency power. A number of critical facilities, including hospitals and emergency service centers, lost all of these systems during the storm surge flooding[8].

In Jan 2013, insurance company Munich Re Ag estimated insured losses at $25 billion and total losses at $50 billion. In December, state governments reported a total of $62 billion in damage and other losses (AP 2013).

3.4.2. Federal Government Activities

Congress passed a $50.5 billion emergency package of relief and recovery aid and $9.7 billion for the National Flood Insurance Program (AP 2013). On January 29, 2013, the Disaster Relief Appropriations Act of 2013 was signed into law, which provided $10.9 billion in funding for an Emergency Relief Program by the Federal Transit Administration to support repairs to seriously damaged transit systems and facilities in New York, New Jersey, Connecticut and elsewhere (US DOT 2013).

Prior to the occurrence of Hurricane Sandy, an update to PPD-7 was being prepared for release in early 2013. Presidential Policy Directive (PPD) 21, Critical Infrastructure Security and Resilience, was released in February 2013 with the goal of advancing national unity of effort to strengthen and maintain secure, functioning, and resilient critical infrastructure for all hazards (PPD-21 2013). PPD-21 updated the list of Critical Infrastructure Sectors, as shown in Table 3, and addresses the resilience of the built environment by focusing on the following issues:

- Identify and prioritize critical infrastructure, considering physical and cyber threats,

[8] Based on personal inspections of damage to critical buildings and infrastructure systems in the New Jersey and New York areas.

vulnerabilities, and consequences.

- Provide analysis, expertise, and other technical assistance to critical infrastructure owners and operators and facilitate access to and exchange of information and intelligence necessary to strengthen the security and resilience of critical infrastructure.
- Conduct comprehensive assessments of the vulnerabilities of the Nation's critical infrastructure.

Table 3. Sixteen National Critical Infrastructure Sectors (PPD-21 2013).

Chemical	Commercial Facilities	Communications	Critical Manufacturing
Dams	Defense Industrial Base	Emergency Services	Energy
Financial Services	Food and Agriculture	Government Facilities	Healthcare and Public Health
Information Technology	Nuclear Reactors, Materials, and Waste	Transportation Systems	Water and Wastewater Systems

3.5. Private Sector Activities

Private sector organizations also responded to disaster events, and the technical needs outlined in the Grand Challenges and by governmental agencies. The following activities provide examples how the private sector has addressed resilience issues for the built environment.

ASCE formed the Technical Council for Lifeline Earthquake Engineering (TCLEE), which has held international conferences approximately every four years since 1977. The 2009 conference addressed regional disruptions that often have had national impacts that were strongly dependent on the performance of lifelines. ASCE (2009) released "Guiding Principles for the Nation's Critical Infrastructure," which promoted four guiding principles:

- Make risk analysis, management, and communication the standard basis on which infrastructure projects are developed and implemented,
- Properly maintain, operate, and modify systems to perform effectively under changing conditions,
- Provide technical oversight, coordination with related projects, appropriate control and change management, and effective communication with project stakeholders, and
- Adapt critical infrastructure in response to dynamic conditions and practice throughout their life cycle.

In 2001, The Infrastructure Security Partnership (TISP) was formed as a non-profit partnership of private and federal organizations to advance infrastructure security and resiliency. A White Paper on Infrastructure Resilience and Interdependencies (TISP 2010) made three recommendations for improving the resilience of the built environment: develop a unified national resilience goal, develop consistent methods identifying core functions and interdependencies for risk and resilience management, and adopt consistent methods for prioritizing infrastructure investments. TISP also publishes a Regional Disaster Resilience Guide (TISP 2011), which has a step-by-step process for communities and organizations to develop a strategy and action plan to improve their capabilities and resilience to deal with major incidents or disasters. The document addresses many aspects of community resiliency in developing an action plan, such as characterizing all hazards, infrastructure dependencies and interdependencies, risk assessment and management, business and operations continuity, communication during hazards, recovery, and training and exercises.

The American Society of Mechanical Engineers (ASME) Innovative Technologies Institute (ITI) and the American Water Works Association's (AWWA) developed a consensus-based standard to support utilities in becoming more resilient through risk management (Morley 2010). The standard, ANSI/ASME-ITI/AWWA (2010) J-100-10: Risk Analysis and Management for Critical Asset Protection (RAMCAP) Standard for Risk and Resilience Management of Water and Wastewater Systems, provides a process for evaluating threats, vulnerabilities, and consequences to improve risk management of water and wastewater utility systems. The standard outlines a general process that requires use of hydraulic models to evaluate scenarios of a particular water system. Risk can be evaluated either qualitatively (high, medium, low) or quantitatively for economic risks (monetary damage) or safety (fatalities) risks. AWWA (2009) also released the "All Hazards Consequence Management Plan" to help drinking water and wastewater utilities incorporate all-hazard consequence management concepts into their existing emergency preparedness, response, and recovery planning.

The risk assessment process developed for RAMCAP, was incorporated into a model that evaluates a 'system of systems' for a community or region. The dependencies and interdependencies among the systems within a regional system are simulated to identify how potential failures in one infrastructure system may cause failures in other systems. ASME-ITI (2011), A Regional Resilience/Security Analysis Process (RR/SAP) for the Nation's Critical Infrastructure Systems, documents the modeling concept.

The Pacific Earthquake Engineering Research Center (PEER) released "Guidelines for Performance Based Seismic Design of Tall Buildings" (PEER 2010). The guidelines present a recommended alternative to the prescriptive procedures for seismic design of buildings contained in standards such as ASCE 7 and the International Building Code (IBC). They are intended primarily for use by structural engineers and building officials engaged in the seismic design and review of individual tall buildings.

The National Earthquake Hazard Reduction Program (NEHRP) commissioned the National Research Council (NRC) to develop a roadmap for earthquake hazard and risk reduction in the United States based on goals and objectives for achieving national earthquake resilience as described in the NEHRP Strategic Plan (2008). The NRC committee was directed to assess the activities and costs that would be required for the

Nation to achieve earthquake resilience in 20 years, and published its findings in "National Earthquake Resilience: Research, Implementation, and Outreach" (NRC 2011).

The National Academies published "Disaster Resilience, a National Imperative" (NAS 2012) was asked to examine ways to increase disaster resilience in the United States by eight federal agencies and a community resilience group that were concerned about the nation's increasing vulnerability to disasters. The report reviews the many challenges for achieving disaster resilience and a plan of action for the nation. Recommendations included: community coalitions that address infrastructure resilience, land-use planning, and adoption and enforcement of building codes and standards; a risk management strategy that includes complementary structural and nonstructural risk-reduction measures developed and adopted by the public and private sectors; and a national resource of disaster-related data that documents injuries, loss of life, property loss, and impacts on economic activity.

3.6. NIST Research Activities

The Engineering Laboratory (EL) of the National Institute of Standards and Technology (NIST) conducts research on resilience of the built environment, structural robustness, and structural performance during hazard events. Metrics and tools are being developed to predict structural performance under multi-hazard conditions, measure disaster resilience of the built environment, assess the ability of existing structures to withstand extreme loads, design buildings using performance-based methods, and derive lessons learned from disasters and failures involving structures.

NIST has a long history of conducting research on the performance of the built environment during hazard events. NIST[9] has a number of statutory responsibilities related to natural and manmade hazards on the built environment, including:

- Basic and applied research that enables protection of life and property from fire under the Federal Fire Prevention and Control Act of 1974.
- Structural failure investigations through the National Construction Safety Team Act of 2002.
- Lead Agency for the National Earthquake Hazards Reduction Program (NEHRP) to promote earthquake hazard reduction measures for buildings and lifelines, support the development of performance-based seismic engineering tools, and promote the commercial application of those tools under the NEHRP Reauthorization of 2004.
- Wind research and development to improve building codes and standards and practices for design and construction of buildings, structures, and lifelines under the National Windstorm Impact Reduction Act of 2004.

9 NIST is a non-regulatory agency of the Department of Commerce. NIST's Engineering Laboratory (EL) supports U.S. industry and public safety by providing critical tools –metrics, models, and knowledge – and the technical basis for standards, codes, and practices.

3.7. Looking Forward

By 2012, a national need for the protection of critical infrastructure had been identified in PPD-21 and PPD-8, and a National Infrastructure Protection Plan for Critical Infrastructure and Key Resources (CIKR) and a National Preparedness Goal had been developed by DHS. Most of the research to date on critical infrastructure has focused on anti-terrorism security measures for facilities and emergency response efforts. The Grand Challenges report (OSTP 2008) broadened the definition of disaster resiliency for building and infrastructure systems to include natural and manmade hazard events, system interdependencies, and rapid recovery.

Standards and codes for resilient communities, based on meaningful metrics, are needed for communities to progress to a more resilient state. Two workshops were sponsored to support the development of resilience standards by NIST, DHS, and the American National Standards Institute's Homeland Security Standards Panel (ANSI-HSSP). The first, Resilience Roundtable on Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems, was an invitational workshop held September 26, 2011 in Arlington, Virginia. The second, Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems, was an open workshop held November 10, 2011 in Arlington, Virginia.

An assessment of gaps and needs for developing standards for resilience of the built environment, based on the two national workshops and NIST research, is presented in the next section.

4. Codes and Standards

When essential building or infrastructure systems are damaged, a ripple effect spreads through the community and disrupts its ability to function. Essential facilities and systems may include hospitals, emergency response centers, chemical or processing plants, roads and bridges, electric power, fuel systems, communications, water and wastewater, airports, rail systems, ports and harbors. Damage in the built environment leads to loss of essential services, such as the critical infrastructure sectors listed in Table 2, and impedes response and recovery. Damage to other buildings and infrastructure systems (not deemed essential, including residential buildings) also affects community functionality and rate of recovery. When a hazard event damages multiple infrastructure systems, a community may experience significant loss of functionality and business interruption; in severe cases, it can lead to permanent relocation of businesses and residents.

The performance of the built environment depends on the codes and standards that are adopted and enforced. Codes and standards adopted by cities, counties, or states often lag the current model codes and standards. However, even if a community adopts and enforces all current codes and standards, there will be inconsistencies between the codes and standards for the same hazard event. Model codes and standards tend to be 'stovepiped' for building and infrastructure systems, as they are independently developed through different public or private processes and are based on varying performance criteria. The codes and standards used in the built environment can be broadly categorized as follows:

- Codes and standards for buildings and other structures provide minimum performance criteria for design-level hazard events, with some variation in performance criteria between hazards. For wind (non-tornadic) and snow events, buildings are not expected to experience structural damage during a design hazard event. During seismic or fire events, some structural damage may occur during a design hazard event (requiring major repair or replacement), but structural stability must be maintained to meet minimum life safety requirements and allow safe evacuation of occupants. Building or facility functionality is only explicitly addressed for essential facilities designed for seismic hazards, with anchorage and support requirements for stability of specified equipment, such mechanical, electrical, and fire pump equipment. However, their continued operation is not assured if components within the anchored housing fail under seismic accelerations.
- Codes and standards for roads and bridges provide minimum life safety performance criteria for design-level hazard events, similar to that for buildings and other structures, but must also account for degradation and aging effects (such as steel fatigue and corrosion and concrete cracking) for exposed facilities.
- Electric power, water, wastewater, and communication systems have standards that emphasize reliability (no interruptions to customer service) and single point failures for normal service conditions, but generally do not consider hazard events and potential multi-point failures.

Many codes and standards are based on prescriptive requirements, where satisfactory performance is assumed if the requirements are met, also referred to as ‘deemed to comply’ requirements. These prescriptive requirements generally focus on life safety goals and do not address functionality of building and infrastructure systems.

There are several provisions for performance goals and criteria in current building codes and standards (see Appendix B). The building codes recognize the relative importance of buildings and facilities in a community through Occupancy Categories, and more recently, Risk Categories. The most recent version of the ASCE 7-10 Minimum Design Loads Standard (ASCE 2010) defines Risk Categories as an alternative to the Occupancy Categories in the building codes. The Occupancy Categories are based on construction and occupancy types, whereas Risk Categories are based on the number of persons at risk in a facility. Buildings are assigned to one of four Risk Categories, based on construction features and occupancy, with tiered performance expectations for each category. Design loads are modified with importance factors to reflect the change in the expected probability of failure between Risk Categories. This approach to risk categorization recognizes that not all facilities with common function are equally important. The primary reasons for assigning Risk Categories is to reduce the “lives at risk” due to structural failure and to enhance the probability that important and essential facilities remain fit for use.

Another approach is performance-based design where the desired performance is directly addressed through a process that explicitly considers performance goals and risk in the design process. Such methods are included in codes as an acceptable alternative means provisions for design. Resilient communities can be achieved with facilities and systems that are designed to common, specific performance targets. Performance-based design permits owners to specify performance goals that are more stringent than the minimum standards required in model codes and standards.

4.1. Resilience in the Built Environment

Community and national resilience depends upon the capacity of the built environment to maintain acceptable levels of functionality during and after disruptive events and to recover full functionality within a specified period of time. Figure 2 illustrates the concept of resilience for the built environment. There is uncertainty in the condition of the built system prior to the event, the degree of lost functionality after the event, and the time to full recovery. If proactive modifications are made that improve the performance of the built environment prior to disruptive events, the time to full recovery of functionality can be shortened considerably. Repairs after a disruptive event have a larger uncertainty, depending on the degree of interdependency among building and infrastructure systems. However, at present, communities do not plan for recovery of their physical infrastructure following disruptive events, and both the time to full recovery and the accompanying costs, are highly uncertain.

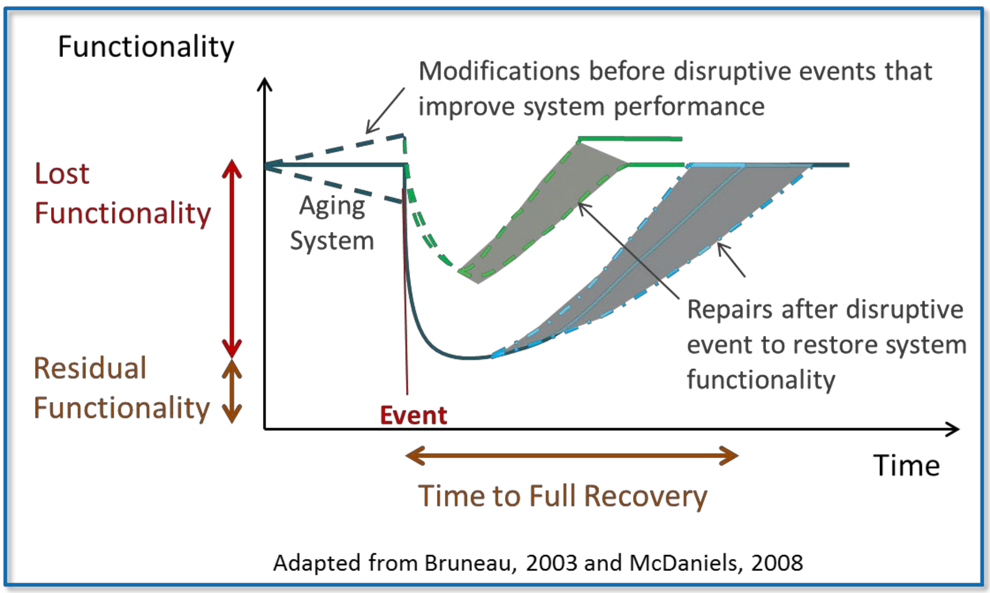


Figure 2. Resilience concept of functionality versus recovery time for the performance of the built environment during a disruptive event.

A plan for developing resilience in the built environment should be based on performance goals, such as:

- Identify systems by resilience performance categories, such as critical or essential facilities that should not experience significant damage, facilities critical to recovery, or systems with a specified recovery time.
- Establish performance goals for design, functionality, and recovery of building and infrastructure systems.
- Identify resilience levels (e.g., routine, expected, and extreme) for performance goals and appropriate hazard intensities.

- Establish metrics for resilience at the community and system levels.

San Francisco is conducting such a performance-based community planning process through the San Francisco Planning and Urban Research (SPUR) Association (see Appendix B). Performance goals are established for the physical infrastructure for various earthquake intensities, which are assigned categories of routine (likely to occur routinely), expected (reasonably expected to occur once during the system lifetime), and extreme (reasonably expected to occur near a seismic fault). Performance measures are defined to help determine if the performance goals are attained. While SPUR activities provide an example of resilience planning, more general guidelines and criteria need to be developed for use by all communities, because different communities will have different needs.

If resilience concepts in terms of performance of the built environment are adopted, then communities, owners, and stakeholders can prioritize which systems should function during and after a disruptive event (e.g., hospitals, emergency response, primary infrastructure systems), and which systems should sustain only minor damage (e.g., businesses, schools, secondary infrastructure systems) so that they can operate while minor repairs are made. Improved resilience will reduce vulnerabilities in today's constructed systems, lower economic losses, and improve community stability and productivity. However, before such improvements can be incorporated, methods to determine compliance or estimate expected performance are needed. Quantitative metrics and validated tools for evaluating performance of the built environment at component and system levels need to be developed.

4.2. Technical Gaps and Research Needs for Resilience in the Built Environment

Based on the review of historical events, the performance of the built environment, and the codes and standards used to design and construct the built environment, the following guidance and metrics are needed to promote the development of a resilient built environment.

4.2.1. Consistent performance goals across codes and standards

Consistent performance goals for all buildings and infrastructure system across the codes and standards that govern their design are a key component for achieving a resilient community. More specifically, consistent reliability-based criteria for system or component performance are needed as part of the performance goals, including definitions of hazards and failure modes.

Model codes and standards for building and infrastructure systems tend to be stovepiped, or developed independently. Codes and standards for seismic performance of structural systems are being pushed toward performance-based methods with consideration of nonstructural building systems. Codes and standards for building envelope systems and building utilities (e.g., fuel lines, water lines, and power and communication systems) tend to be more prescriptive. Electric power, water, wastewater, and communication systems have standards that emphasize reliability (no interruptions to customer service) and single point failures, but generally do not consider hazard events and potential multi-point failures. Most transportation systems are designed and maintained by cities or states, which may not adopt current model codes and standards, or may exempt significant requirements. While parallel development may still be the most productive and efficient method of code and standard development, a consistent set of hazard definitions and performance goals would minimize such inconsistencies.

Codes and standards are likely to continue to provide criteria for minimum life safety performance, but a consistent set of reliability-based performance criteria would improve the overall performance and expectations of performance across a community. However, to achieve resilience in the built environment, communities will need to develop additional performance criteria to achieve the desired level of performance.

4.2.2. Comprehensive community resilience plans and guidance

Comprehensive plans and guidance for community resilience that can be tailored to individual community performance goals for its built environment are needed to help communities plan for hazard-specific performance, as well as restoring building and infrastructure systems in a cost effective and timely manner. Such planning needs to consider infrastructure dependencies and interdependencies, priorities for constrained resources in planning, mitigation, and recovery modes, and performance goals and measures for critical/essential systems, while accounting for uncertainties.

Resilience planning will improve risk management and decision making by the community and its businesses. Additionally, a resilient community will attract businesses looking to locate within a resilient environment. Such planning also better prepares and protects communities against unexpected extreme events (sometimes referred to as black swan events), though such events are not easily addressed in planning stages due to their unexpected nature. An example of a black swan event includes the 2012 Japanese disaster with earthquake, tsunami, and nuclear power plant or the 2001 WTC disaster.

The following standards and guidance for developing community resilience plans provide an initial basis for evaluating community resilience of the built environment:

- The SPUR community planning process establishes performance goals and measures for the built environment for a range of hazard intensities.
- The RAMCAP standard (ANSI/ASME-ITT/AWWA 2010) provides a risk-based process for evaluating threats, vulnerabilities, and consequences, with either qualitative or quantitative measures.
- The RR/SAP (ASME-ITI 2011) process uses a ‘system of systems’ approach, based on RAMCAP, to evaluate infrastructure dependencies and interdependencies within a regional system.
- The Regional Disaster Resilience Guide (TISP 2011) helps develop an action plan to improve community or organizational capabilities and resilience for hazard events.
- FEMA CPG 201 (DHS 2012) supports risk-informed decision making with a process where hazards, vulnerabilities, and consequences provide a basis for evaluating and improving existing plans and capabilities.

The risk-based procedures outlined in these documents contribute toward the development of community resilience, but significant gaps remain in reliable, quantitative assessment of damage and risk, based on the available tools, metrics, and standards.

4.2.3. Performance goals including recovery

Performance goals for building and infrastructure systems should consider a system's role in the community (e.g., essential facilities, facilities of a major employer, etc.), the performance that is required (alternatively, the level of damage that is acceptable) during and after a hazard event, as well as system recovery. Performance issues may include identifying hazards and risk-based performance criteria for essential systems to continuously operate during hazard events, systems that need to meet other levels of performance based on their role in the community or on owner needs, and specified recovery times.

4.2.4. Multiple resilience levels with risk-based performance criteria and a given hazard

The development of multiple resilience levels with associated risk-based performance criteria for a given hazard would allow communities to develop resilience in stages, depending on their resources. As an example, SPUR is considering three hazard intensities for earthquake, which is the primary hazard for the San Francisco area. The community resilience planning (see Appendix B) identified an "expected" earthquake, an extreme earthquake, and routine seismic event. The expected earthquake may occur during the useful life of the structure or system and is the basis for design and evaluation of facility resilience. The extreme earthquake is the largest earthquake that could reasonably be expected to occur on a nearby fault and is used for emergency response planning. The routine earthquake will likely occur during the life of a facility and is intended to verify service-level performance of a facility, where minimal damage or interruption is expected. Such hazard levels should be tied to risk-based performance criteria, as described below.

For hazards not addressed by codes and standards, design criteria need to be developed with a rational technical basis. Loading events considered by ASCE 7-10 include the structure's own weight, live loads associated with the structure's occupancy, rain loads, atmospheric ice loads, earthquake, flooding, snow, and winds. ASCE 7-10 does not address either tsunami flooding or tornadic winds. For all loads in ASCE 7-10 except earthquake, consistent failure rates are sought for typical construction addressed by material standards (on the order of 10^{-4}/yr for ductile, local failures to 10^{-7}/yr for sudden, widespread damage). However, failure rates are lower for earthquake events than other events (on the order of 10^{-3}/yr to 10^{-4}/yr partial or total collapse), primarily because it is perceived that for the severity of earthquake loading, it is not economically practical to obtain failure rates consistent with other loads. Annualized failure rates in ASCE 7-10 are based on concurrent consideration of the target reliability, hazard load factors, and structural resistance factors listed in material standards (e.g., steel, concrete, wood, etc.). Adjustments to the target reliability, load factors, or resistance factors without corresponding adjustments to the other factors will lead to an unpredictable change in structural performance and reliability. ASCE 7 does not address loss of functionality in buildings or other structures due to load effects, with the exception of seismic design requirements.

4.2.5. Existing building and infrastructure systems

Community resilience planning must consider existing buildings and infrastructure systems as well as new construction. Depending on when existing facilities were constructed, they may lack design features that would be required in a new building or infrastructure system, and may vary considerably in expected performance from new construction.

Construction standards do not require existing building to meet current codes and standards, only the codes and standards that were adopted when they were built. In many cases, existing buildings cannot be sufficiently modified to meet all of the requirements of newer codes and standards. While there are a handful of mandatory retrofit programs for existing buildings in communities, most work is done on a voluntary basis when there is a change of occupancy.

Beginning in the early 1980s, FEMA funded an extensive program to develop performance based techniques for evaluating and retrofitting existing buildings to achieve designated performance levels for seismic hazards. The performance levels provide owners and operators a metric for determining a suitable level of performance. Historically, hazard and/or performance levels have been modified to account for the fact that existing facilities either cannot fully meet criteria for new facilities or to minimize the need to strengthen facilities that would otherwise only have modest deficiencies (Pekelnicky and Poland 2012). For instance, ASCE Standard 31-03, Seismic Evaluation of Existing Buildings, and ASCE Standard 41-06, Seismic Rehabilitation of Existing Buildings, focused on standardizing the seismic performance criteria for existing buildings.

5. Resilience Roundtable on Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems

The Resilience Roundtable convened leaders from engineering practice and research communities for buildings and infrastructure systems, and leaders of the standards development community. The purpose of the Roundtable was to identify gaps in current practice, standards, and codes for the assessment and design of resilient buildings and infrastructure systems.

Roundtable participants (see Appendix A) were selected for their technical knowledge of building and infrastructure systems, codes and standards, resilience, and performance-based design methods. Attendees included potential adopters of resilience standards, such as standards developing organizations (SDOs) and model building codes, and end users of resilient codes and standards, including designers, insurers, and owners.

Presentations based on invited white papers (see Appendix B) addressed resilience of the built environment, community resilience planning and performance goals, provisions in U.S. building codes and standards that support resilience, and resilience in lifeline standards. The white papers were intended to succinctly present the state-of-the-art and to foster discussion on the required scope of community resilience guidance, codes, and standards.

Following the presentations, Roundtable participants responded to the following questions in breakout sessions:

1. How should hazard definitions be modified for multiple performance levels?
2. What performance objectives, in addition to life safety and usability, are needed to promote community resilience?
3. What metrics and vocabulary are needed to describe building and infrastructure performance in terms of response and recovery?

4. Building Systems
    a. What can be done in the short-term (3 yrs) to improve codes and standards for buildings to implement concepts of resilience?
    b. What long term improvements are needed?
    c. What technical basis is required to support long-term improvements?

5. Infrastructure Systems
    a. What can be done in the short-term to improve codes and standards for infrastructure systems to implement concepts of resilience?
    b. What long term improvements are needed?
    c. What technical basis is required to support long-term improvements?

Each breakout session recorded the key points of the discussions following the presentations, which are provided in Appendix C. The following sections summarize the technical gaps and research needs identified for resilience in the built environment during breakout sessions.

5.1. Terminology and Metrics

Define terminology for resilience objectives.

New terminology and/or metrics may need to be defined, such as functionality and recovery definitions, levels to support risk-based performance goals, or levels of adoption and enforcement of codes and standards. Clear communication between technical and nontechnical participants, stakeholders, policy makers, and code and standard bodies will be enhanced if resilience objectives are understood.

Develop resilience metrics.

Resilience metrics for buildings and infrastructure systems are needed that:

- Support policy development, decision making, and quantitative technical assessment. Objective, quantitative metrics of community resilience could be used by communities to encourage business development, and could eventually become a required aspect of business planning.

- Measure functionality and the time and cost of recovery before and after hazard events for building and infrastructure systems. Individual system (component) measures would provide input to community and regional (composite) resilience measures.
- Estimate design and recovery costs that include varying levels of functionality and costs. Such metrics would allow comparisons between proposed methods or designs to ensure that any incremental improvement for resilience is consistent with the incremental cost.

5.2. Multiple Resilience Levels

Identify multiple resilience levels to support risk-based performance goals.

Communities may benefit from examining multiple resilience levels with associated risk-based performance criteria for hazards of interest. Resilience levels need associated risk-based performance goals and reliability-based hazard and failure criteria. For instance, performance criteria could be developed for routine, expected, and extreme resilience levels. Each resilience level would need distinct performance and acceptance criteria. Risk-based performance criteria and hazard definitions for resilience levels need to be developed by experts for use by communities.

Develop methods to characterize hazard levels for undefined hazards.

ASCE 7 defines minimum design load requirements for natural hazards through reliability targets that account for both structural resistance and design loads. Building codes reference ASCE 7 for building design loads, or adopt the load criteria from ASCE 7. Hazards that do not have defined design load requirements, such as fire (building fire, wildfires, fire following earthquakes), storm surge, tsunamis, tornadoes, and blast and impact events, need to be developed.

5.3. Performance Goals and Metrics

Establish performance goals and metrics.

Performance goals and metrics are needed that:

- Compare options for mitigation and recovery planning, such as strengthening structural systems or relocating infrastructure systems versus post-event system repair or replacement.
- Measure the effect of system redundancy on system resilience, such as multiple load paths within a structure, multiple transportation options, or multiple communication networks. The concept of 'system redundancy' has different implications depending on the context.
- Determine the relative contribution by all subsystems to system functionality (e.g., if the structure survives and the envelope fails – the building is nonfunctional).
- Address hazard-specific performance objectives, such as burnout without collapse for

fire hazards.

- Specify recovery goals and metrics for systems (e.g., utilities develop objectives for system performance during hazard events to minimize multipoint or system-wide failures).
- Establish performance goals and metrics for different functions within a community system (e.g., essential facilities and infrastructure systems vs commercial facilities).

Establish performance goals and metrics for existing building and infrastructure systems.

Community resilience levels and associated performance goals and metrics for existing systems should account for deterioration and aging effects on infrastructure resilience and the increased likelihood of disruption to community functionality. However, whether or not existing buildings and infrastructure systems should have different performance criteria than that of recently constructed systems should be carefully considered in terms of the expected and desired performance of a given facility or system within the community.

Additionally, the role and relative importance of facilities and infrastructure systems to community resilience, system interdependence and co-location impacts on community resilience (e.g., a bridge carrying utility lines), and urban versus rural issues need to be considered. For instance, urban areas may need to address building adjacency issues so that damage does not spread beyond an individual building and a rural issue may address the importance of a major employer that is critical to community resilience.

Establish performance goals and metrics for regional infrastructure systems.

Regional performance may need to be considered to adequately address the resilience of power, communication, and transportation systems. For example, the transfer of risk from one community to another may occur when changes are made to the built environment (e.g., levee systems may affect floor hazards of adjacent communities).

5.4. Codes and Standards

Develop guidance that supports adoption of model codes and standards

Communities need guidance on adopting model codes and standards to achieve life safety and on identifying situations when the minimum codes and standards requirements should be exceed to promote resilience. Many states and communities do not adopt current model codes and standards, or may exempt important requirements, further increasing their lack of resilience in the built environment. Adoption of current model building codes and standards is necessary but may not be sufficient for achieving resilience. Resilience may require exceeding the minimum level of construction required by codes and standards. The SPUR activities by San Francisco illustrate the gap between implementation of the codes and standards and achieving resilience. San Francisco actively adopts and enforces current building codes, but recognized that the community was not prepared for a design-level earthquake event, and initiated planning for resilience of their community.

6. Standards for Disaster Resilient Buildings and Infrastructure Systems

The Disaster Resilience Workshop (see Appendix D) included participants from a range of communities, including buildings, transportation, power, water, research, insurance, codes and standards, and state and federal agencies interested in disaster resilience.

Three panel sessions were conducted with invited presentations to summarize present practice and to support discussion on resilience issues (Appendix E), followed by discussion with the workshop participants. The first panel session addressed resilience concepts for buildings and infrastructure systems and for community resilience planning, with the San Francisco Urban Renewal (SPUR) project as an example. The second panel session focused on standards for building systems and included an insurance perspective on building and infrastructure resilience. The third panel session addressed standards for electric power systems, transportation systems, and water and wastewater systems.

Following the panel sessions, participants were requested to identify technical gaps that inhibited the development of resilience standards for: community resilience, water and wastewater, transportation, electric power, and building systems (see Appendix F). The following sections summarize the technical gaps and research needs identified. Technical gaps and research needs similar to those identified during the Roundtable in Section 5.0 were not repeated here.

6.1. Community Resilience

Develop guidance for community resilience planning

Guidance documents for communities that want to develop resilience in their built environment beyond that provided by adopting current codes and standards is needed. Example cases should be provided, such as San Francisco seismic resilience planning and South Florida hurricane resistance efforts. Performance goals should include mitigation, robustness, functionality, and recovery criteria, particularly for essential facilities and infrastructure systems.

The impact on resilience of infrastructure systems that extend beyond a community, such as transportation, communication, or power systems, may need to be considered separately, depending on their regulatory environment. For instance, utility performance may be enhanced by requirements to stockpile supplies and components for recovery after a disaster event, or agreements for mutual aid and borrowed components between power companies at different locations. Infrastructure interdependence also needs to be considered, where failure of one system will impact recovery of other building and infrastructure systems.

The guidance should help communities understand the long-term benefits of adopting and enforcing current codes and standards as a minimum, with particular consideration given for small to large communities and available resources. Community guidance needs to address methods to ensure the quality of the built environment, and motivators such as incentives and cost savings. For a community to achieve a desired resilience level, it will likely need to establish performance goals beyond those that can be achieved with current building codes.

Develop metrics for changes in resilience

Resilience metrics should include the ability to measure changes in resilience due to system additions, aging, damage and repairs. Qualitative metrics, such as high, medium, and low, will not be useful for such comparisons. For instance, the impact of adding a new bridge, or the failure one of two existing bridges, on community resilience for an island or river bound area can be better managed with quantifiable measures that include interdependencies.

6.2. Performance of the Built Environment for Disaster Events

Conduct case studies of selected disaster events

Case studies of selected disaster events should be conducted to identify issues for community resilience, including performance goals and criteria, functionality, and recovery. Documented disaster events should be selected to cover a broad range of hazard and performance issues, such as the Northridge earthquake (1994), Hurricanes Andrew (1992) and Katrina (2005), Oklahoma City (1999) and Joplin (2011) tornadoes, Northeast flood event of 2011, the Northeast blackout of 2003, and the WTC disaster (2001). The studies should document damage to the built environment and with a standardized format to support future use and accessibility. The case studies should identify low-cost, high-impact solutions that have worked in the past, such as hurricane shutters or structural bracing. The studies should identify combinations of component or system failures that led to substantial failures or disasters in a community.

6.3. Building Systems

Develop performance goals and resilience metrics for all building systems

To fulfill its role in a resilient community, a building needs all of its systems to achieve the same level of performance. Building systems include architectural, structural, life safety, mechanical, electrical, plumbing, security, communication, and information technology systems. Most buildings are privately owned and developed according to adopted local or state-wide codes and standards. All building systems need to be reviewed to determine gaps in performance, particularly between performance criteria for structural and nonstructural systems. Performance goals and criteria necessary for resilient performance should be identified, which may exceed that presently in the codes and standards.

6.4. Transportation Systems

Transportation systems include roads, bridges, tunnels, ports, and rail systems. They may be owned and/or funded by federal, state, or local governments. Financial and/or technical assistance for transportation facilities is provided by:

- Federal Highway Administration (FHWA) and state Department of Transportation (DOTs) for highways, bridges and tunnels.

- Federal Transit Administration (FTA) for transit (subway and rail) systems
- Federal Aviation Administration (FAA) for aviation facilities

Design guidance and standards are provided by:

- American Association of State Highway and Transportation Officials (AASHTO) for highways, air, rail, water, and public transportation systems.
- Department of Defense (DOD) Military Handbooks (previously NAVFAC design manuals) for piers, wharves, seawalls, bulkheads, ferry terminals, berthing facilities, and waterfront construction.

In 2012, the Moving Ahead for Progress in the 21st Century Act (MAP-21) was signed into law (FHWA 2012). FHWA administers the program that funds surface transportation programs and provides a programmatic framework for investments in the transportation infrastructure. MAP-21 is a performance-based program that addresses challenges that include improvements in safety, infrastructure condition, and efficiency of freight movement. Performance measures and targets are identified by the system operators for evaluation of short and long term progress, but many of the criteria are qualitative in nature.

Develop metrics to evaluate the impact of damage or failure on the resilience of transportation systems and the community.

Codes and standards for transportation systems need to be reviewed to determine gaps in performance, particularly between risk-based performance criteria for all transportation systems. Additionally, metrics to support risk management decisions and to evaluate the impact of damage on the resilience of transportation systems and the community are needed. Intermodal transportation dependencies, such as ship to rail or ship to truck transport of goods, also need to be considered.

6.5. Water and Wastewater Systems

Water and wastewater systems are comprised of a series of facilities and distribution systems, including treatment facilities (filtration, disinfection, aeration, sedimentation), transmission systems (pump stations and pipelines), storage tanks, and administrative buildings.

There are thousands of water and wastewater systems across the nation and most water and wastewater systems are owned and operated by local governments or municipalities. The design of water and wastewater systems is governed by the American Water Works Association (AWWA) standards, American Society of Civil Engineers (ASCE) standards, and the International Building Code (IBC).

As noted previously, the RAMCAP Standard for Risk and Resilience Management of Water and Wastewater Systems (ANSI/ASME-ITI/AWWA 2010) provides a process for evaluating threats, vulnerabilities, and consequences. Risk can be evaluated either qualitatively (high, medium, low) or quantitatively for economic risks (monetary damage) or safety (fatalities) risks. AWWA (2009) also released the "All Hazards Consequence Management Plan" to help incorporate all-hazard consequence management concepts into existing emergency preparedness, response, and recovery plans.

Develop water and wastewater system performance goals and metrics

Codes and standards for water and wastewater systems need to be reviewed to determine gaps in performance, particularly for risk-based performance criteria for natural hazards. Additionally, quantitative metrics to support risk management decisions and to evaluate the impact of damage on the resilience of water and wastewater systems and the community are needed.

Community resilience performance goals that consider interdependencies with other utilities are needed. Performance goals could consider a “smart grid” for the water sector or a planned replacement program for aging water systems that considers integrating other utilities with newly buried pipelines. Performance goals for water systems should consider requirements by the Environmental Protection Agency (EPA).

Develop seismic standards for pipelines and sewer systems

Seismic standards for pipelines and sewer systems are needed in the U.S. Practices for pipelines and sewer systems in other countries, such as Japan and Australia, should be reviewed for improvements to U.S. design and recovery practices.

6.6. Electric Power Systems

Electric power systems include generation, transmission, and distribution systems, which may be part of an integrated system within a single company or owned by separate entities. Power systems may be managed by major utilities, electric cooperatives, or municipal utilities. In addition, electric power systems are subject to regulations by the Federal Energy Regulatory Commission (FERC) and the North American Electric Reliability Corporation (NERC) on reliability of service, as well as cost structures imposed by state and local regulatory bodies. The Nuclear Regulatory Commission (NRC) oversees commercial nuclear power reactors. The varying types of ownership and regulation significantly impact the flexibility of electric utilities to address system maintenance and improvements for hazards, and makes coordinated management and upgrade efforts among utilities difficult to implement.

Distribution systems experience the most frequent outages with only local effects. Transmission systems and substations have less frequent failures, which are often addressed by redistribution of power; occasionally, hazard events cause failures that result in loss of power (NRC 2012). Utilities plan for events such as tree falls, vehicle impacts, and lightning strikes, as well as hazard events, such wind and ice on distribution and transmission lines or seismic events on generation facilities and transmission towers. In general, earthquakes can damage all types of power system equipment. Hurricanes primarily affect transmission and distribution systems, and flooding can damage substations and generating equipment. Tornadoes and severe thunderstorms may affect transmission and distribution lines by wind-induced damage and downed trees (OTA 1990).

Develop performance goals and metrics for electric power systems

Triggers for potential cascading events that lead to loss of power, and its consequences, need be identified. Performance criteria that are consistent with community resilience goals need to be developed. Alternative energy and power sources, such as solar panels and wind farms, may be considered as possible sources for distributed backup power for community resilience. However, there may be disadvantages from a resilience perspective based on more complex systems and their interactions. Performance criteria could be used to prioritize investments and system improvements, which are often subject to regulatory approval.

Community recovery after significant hazard events is strongly dependent on the availability of power. Electric power systems could also be deemed as critical infrastructure and have design guidance developed consistent with Risk Category IV used in ASCE Standard 7 (2010).

6.7. Communication Systems

A communication system is a collection of networks, transmission systems, relay stations, tributary stations, and data terminal equipment (DTE) that form an integrated system based on optical, radio, or electronic signals. Communication systems include fiber optic and copper cable systems, cellular radio towers, satellite systems, and microwave systems which are used for phone, television, internet, and radio communications.

Communication systems are largely privately held, constructed according to adopted building codes, and regulated by federal, state, and local regulations for reliability of service. With regards to community resilience and the built environment, the facilities and transmission systems are of interest.

Develop performance goals and metrics for communication systems

Triggers for potential cascading events due to hazards that lead to wide spread or long term loss of communication systems, and their consequences, need to be identified. Risk-based performance criteria for given hazards that are consistent with community resilience goals need to be developed.

6.8. Codes and Standards

Identify current hazard criteria and performance goals in U.S. codes and standards

To understand the present basis for the built environment, criteria for hazards and performance goals in U.S. codes and standards need to be identified, as well as technical gaps for resilient systems. Several perspectives need to be considered: government facilities that use a mix of federal guidance and public codes and standards; building, transportation, and water systems that are governed by public consensus codes and standards; and power and communication utilities that are governed by privately developed standards and regulatory bodies.

Technical gaps within a system could include differing risk or reliability bases for hazards and performance levels within the built environment. For instance, are design-level wind criteria consistent for building structures and cladding systems, or for power generation, transmission, and distribution systems? Gaps in performance criteria between systems might include differences among building and infrastructure systems. For example, for a hospital to remain functional, supporting transportation and utility systems essential to hospital functionality should be designed to the same performance criteria, which may need to exceed criteria provided by current codes and standards. Common and conflicting practices among systems should be identified.

To be successful, broad participation by all sectors and systems is needed. Existing codes and standards, public-private roles, agency and industry involvement, and available guidance documents for building and infrastructure systems must be considered.

Several mechanisms for developing standards offer possible models for developing resilience standards: the Smart Grid model for electric power systems, the Building Seismic Safety Council[10] model for seismic resistance of buildings and other structures, and the DOE Energy Star model for rating energy consumption of consumer products.

The following code and standard bodies are adopted or followed by communities and should be considered when establishing resilience goals, criteria, and metrics for the built environment. The listed codes and standards are not comprehensive, but are provided as a representative set for the built environment.

- American Association of State Highway Transportation Officials (AASHTO) – state highways and transportation systems
- American Society of Civil Engineers (ASCE) – Architectural engineering; coasts, oceans, ports, and rivers; construction engineering; engineering mechanics; environmental and water resources; geotechnical engineering; structural engineering; and transportation
- American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) – energy, HVAC
- American Water Works Association (AWWA) – water and wastewater
- Federal Energy Regulatory Commission (FERC) – fuels and power
- International Association of Plumbing and Mechanical Officials (IAPMO) – plumbing and mechanical
- International Code Council (ICC) - buildings, plumbing, mechanical, fire
- National Fire Protection Association (NFPA) – fire, electrical
- North American Electric Reliability Corporation (NERC) – reliability of bulk power

The following documents provide an initial listing of available guidance for performance goals, criteria, and metrics for the built environment.

Buildings

- Building Owners and Managers Association (BOMA), 360 Program, http://www.boma.org/getinvolved/boma360/

[10] The Building Seismic Safety Council (BSSC) was established by the National Institute of Building Sciences (NIBS) to develop and promote earthquake risk mitigation regulatory provisions for buildings.

- Department of Homeland Security (DHS), http://www.dhs.gov/xabout/2011-dhs-accomplishments-ensuring-resilience-to-disasters.shtm
- National Institute of Building Science (NIBS), http://www.nibs.org/index.php/newsevents/BuildingResilience
- Applied Technology Council (ATC), ATC 58, Development of Next Generation Performance-Based Seismic Design Procedures for New and Existing Buildings, https://www.atcouncil.org/Projects/atc-58-project.html
- American Society of Civil Engineers, ASCE 41-06, Seismic Rehabilitation of Existing Buildings, http://www.asce.org/Product.aspx?id=2147485435

Water, power, communication

- American Lifelines Alliance (ALA), http://www.americanlifelinesalliance.com/
- ASCE Technical Committee for Lifeline Earthquake Engineering (TCLEE), http://content.asce.org/conferences/tclee2009/

Resilience of the built environment

- Grand Challenges in Earthquake Engineering Research 2011, http://www.nap.edu/catalog.php?record_id=13167
- National Academies, Disaster Management and Homeland Security, http://dels.nas.edu/Disaster/Reports-Academies-Findings
- United Nations International Strategy for Disaster Reduction (UNISDR), http://www.unisdr.org

7. Research Needs Assessment for Developing Resilience Standards

The technical gaps and research needs identified in Sections 5 and 6 are summarized in this section and grouped as short term (less than 3 to 5 years) and long term (greater than 3 to 5 years) activities, depending on funding and participation levels across sectors for the built environment. Short term activities address resilience planning at the community level, where the role of facilities or systems in a community's physical resilience is defined. Long term activities address identification and development of tools and metrics that determine the expected level of performance during and after a hazard event, and include recovery of functional performance.

7.1. Short Term Activities - Community Resilience Planning

7.1.1. Determine technical gaps and research needs from reviews of past disaster events and existing model codes and standards

- Develop collaborative mechanism, such as a resilience council with representatives for building and infrastructure systems, to identify performance goals and hazard definitions for use by all codes and standards for the built environment. Such a body would be an umbrella organization outside stovepiped codes and standards that would allow dissemination of information, methodologies, and consistent metrics between standard bodies.

- Identify successes and failures in case studies of selected disaster events. Identify technical gaps and research needs for performance goals, hazards, and system functionality and recovery for new and existing buildings and infrastructure systems. Include interdependencies among infrastructure systems for hazard events that affected community functionality and recovery.
- Review and compare U.S. and international model codes and standards to identify performance goals, hazards, and recovery requirements for new and existing buildings and infrastructure systems. Identify technical gaps and research needs for construction materials (e.g., steel, concrete, wood, etc.), and system type (e.g., building types, bridge types, power systems, etc.), as needed.
- Review and identify U.S. and international best practices for ensuring business continuity and community resilience. Best practices may vary according to business size and geographic distribution.

7.1.2. Define terminology for resilience objectives in the built environment.

- Define terminology for resilience concepts, such as hazard, functionality, and recovery definitions or levels to support risk-based performance goals, or levels of adoption and enforcement of codes and standards.

7.1.3. Develop guidance for community resilience planning

- Develop risk-based performance goals for resilient communities. The performance goals should include the role of individual building and infrastructure systems in the community functionality and recovery, system interdependencies, and new and existing construction. Infrastructure systems may need to consider influences on a regional or national scale that are outside of the community sphere of control, particularly for power and communication systems.
- Develop guidelines and case studies to assist community resilience planning and development of performance goals and acceptance criteria. The guidelines should develop guidance tailored for small/rural and large/urban communities and identify the types of expertise needed for resilience planning. The case studies should provide examples of community performance goals, the development process and sequence of events, and the benefit and value of adopting model codes and standards, conducting inspections, and code enforcement as well as situations that require exceeding the minimum requirements of the model codes and standards.
- Develop guidance on how to develop community resilience performance goals and criteria for inclusion in standards for voluntary reference. Such materials would be developed in a consensus process with experts in the appropriate fields and representation for owners, users, and codes and standards.

7.2. Long Term Activities - Metrics and Standards

7.2.1. Develop multiple resilience levels to support risk-based performance goals

- Develop guidance for identifying multiple resilience levels with associated risk-based performance criteria. For example, three resilience levels could be defined, such as a routine level for serviceability, an expected level for design, and an extreme level for emergency response planning. Each resilience level needs distinct performance and acceptance criteria.
- Develop methods to define hazard criteria where there is a current lack of data or hazard definition, such as tornado, storm surge, tsunami, and fire hazard events.

7.2.2. Develop consistent performance goals and metrics for building and infrastructure systems

- Develop performance goals for building and infrastructure systems, consistent with community performance goals. Performance goals should account for risk categories, system functionality and recovery, and new and existing systems. Existing systems may also require consideration of degradation effects, repairs, and/or rehabilitation. Infrastructure systems may require performance goals for consistent performance across segmented industries (e.g., electric power generation, transmission, distribution). Hazards without a probabilistic basis, such as tornadoes, storm surge, tsunami, or fire events, may require additional performance goals and scenario-based criteria for conditional hazard probabilities.
- Develop a technical basis to support risk-based performance assessment, including interaction of building and infrastructure systems, during and after hazard events. Technical capabilities that would support improved performance assessment include simplified methods of analysis that include failure mechanisms, tools that evaluate the impact of damage to distributed infrastructure systems across a community or region, and a risk assessment tool (e.g., water pipelines and sewer systems performance during seismic events).

7.2.3. Develop metrics for community and component resilience

- Develop metrics for measuring the resilience of communities and of their components (building and infrastructure systems) to support risk management, technical assessment, policy development, and decision making:
    - An overall resilience level for a community or system.
    - The effect of system interdependencies and damage to such systems on community or system resilience.
    - Changes in resilience due to system additions, damage and repairs, and changes in functionality before and after hazard events.
- Develop economic measures, such as cost-benefit valuations of design or recovery options on community resilience that support risk assessment and decision making. Economic metrics and tools should compare design, maintenance, and recovery costs

in a rational approach.

7.2.4. Develop guidelines and standards for achieving resilient communities with adoption of codes and standards

- Develop guidance for communities on adopting model codes and standards to achieve life safety and on identifying situations when the minimum codes and standards requirements should be exceed to promote resilience.
- Develop or modify standards on design loads that address risk-based hazards for multiple resilience levels.
- Develop or modify standards to address risk-based building and infrastructure system performance.
- Develop or modify standards for risk-based total building performance that address structural and non-structural building systems.
- Develop or modify standards for risk-based infrastructure system performance, including multi-point failures, interdependencies of infrastructure systems, and consistent performance goals for segmented systems (e.g., power generation, distribution, and transmission).

8. Summary

The resilience of the built environment strongly depends on the building standards, codes, and practices used when they were built. As construction and rebuilding costs continue to rise, there is increasing recognition of the need for communities to develop consistent performance goals across the built environment for the hazards that pose the greatest threats to its operations and functionality. A resilient built environment considers the role of buildings and infrastructure systems on the community, desired levels of functionality before, during, and after disruptive hazard events, and prioritization of steps needed to achieve such performance.

Resilience standards for the built environment, and supporting metrics, tools, and guidelines, will provide a unified and rational basis for transforming the current set of stovepiped standards for the built environment to a coordinated, holistic approach to achieving community resilience. Research needs for a resilient built environment include the following activities:

Short term activities

- Identify technical gaps and research needs from reviews of past disaster events and existing model codes and standards
- Define resilience terminology for the built environment to help communicate new concepts
- Develop guidance for community resilience planning

Long term activities

- Develop risk-based performance goals for resilient communities

- Develop tools and metrics to support quantitative technical assessment, policy development, and decision making
- Develop guidelines on risk-based performance goals and criteria for inclusion in standards for voluntary reference.

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APPENDICES

A. Resilience Roundtable Participants

Co-Chairs

Steve Cauffman	National Institute of Standards and Technology (NIST)
Chris Poland	Degenkolb Engineers

Participants

William Anderson	The Infrastructure Security Partnership (TISP)
Katie Appenrodt	U.S. Department of Homeland Security (DHS)
Don Ballantyne	Degenkolb Engineers
Michael Bruneau	University at Buffalo
Bob Chapman	National Institute of Standards and Technology (NIST)
Jasper Cooke	U.S. Department of Homeland Security (DHS)
Bill Coulbourne	Applied Technology Council (ATC)
Bert Coursey	U.S. Department of Homeland Security (DHS)
Michelle Deane	American National Standards Institute (ANSI)
Paul Domich	CIP Consulting
Christian Dubay	National Fire Protection Association (NFPA)
Leonardo Duenas-Osorio	Rice University
Elizabeth English	University of Waterloo, Architecture
Ian Friedland	Federal Highway Administration (FHWA), Office of Bridge Technology
Jennifer Goupil	Structural Engineering Institute (SEI), ASCE
Doug Ham	U.S. Department of Homeland Security (DHS)
Ron Hamburger	Simpson, Gumpertz, & Heger (SGH)
Jack Hayes	National Institute of Standards and Technology (NIST)
John Hooper	Magnusson Klemencic Associates
Dan Howell	FM Global Insurance
Morgan Hurley	Society of Fire Protection Engineers (SFPE)
Mike Kangior	U.S. Department of Homeland Security (DHS)
David Karmol	International Code Council (ICC)
Leon Kempner	Bonneville Power Administration
Marc Levitan	National Institute of Standards and Technology (NIST)
Lacy Love	American Association of State Highway and Transportation Officials (AASHTO)
Therese McAllister	National Institute of Standards and Technology (NIST)
David Prevatt	University of Florida
Tim Reinhold	Institute for Business & Home Safety (IBHS)
James Rossberg	American Society of Civil Engineers (ASCE)
Fahim Sadek	National Institute of Standards and Technology (NIST)

Dennis Schroder	URS Corporation
Fran Schrotter	American National Standards Institute (ANSI)
Don Scott	PCS Structural Solutions
Peter Shebell	U.S. Department of Homeland Security (DHS)
Steve Skalko	Portland Cement Association
Douglas Smith	U.S. Department of Homeland Security (DHS)
Robert Solomon	National Fire Protection Association (NFPA)
Alex Tang	L&T Consultants

B. White Papers

1. Resilience of the Built Environment, Therese McAllister, Ph.D., PE., Research Structural Engineer, National Institute of Standards and Technology (NIST)

2. SPUR Resilient City Goals, Chris D. Poland, Chairman & Senior Principal, Degenkolb Engineers

3. Provisions in Present U.S. Building Codes and Standards for Resilience, Ron Hamburger, Senior Principal and Head of Structural Engineering, Simpson Gumpertz & Heger

4. Lifeline Resilience Standards – Approach to Instill Consistent Post Disaster Performance, Alex Tang, President, L&T Consultants

Resilience of the Built Environment

Therese McAllister[1], P.E., Ph.D.

Introduction

A resilient built environment—the collection of building[2] and infrastructure systems[3] within a defined boundary—should perform in a predictable manner during and after a hazard event or disaster. Presently, this is not occurring in many communities for several reasons. Many communities are not performing well during hazard events as they either have not adopted current building codes and standards, have adopted the current building code but exempted critical sections such as seismic requirements, or do not enforce compliance with adopted codes. Additionally, states adopt codes and standards for transportation systems, but many state transportation codes lag the current national transportation codes and standards. Electric power, communication, and water systems rely on industry standards, but these standards often focus on reliability of service rather than system performance during hazard events. However, resilience is more than adopting and enforcing the current codes and standards. In communities that adopt and enforce the latest codes, there is still uncertainty about the expected performance of the built environment when subjected to a hazard event. Recent events across the country and around the world have repeatedly demonstrated that the building and infrastructure systems in our communities are not resilient to hazard events.

The concept of a resilient community is one that is prepared to respond and recover following a hazard event. Community resilience requires an understanding of the various hazards likely to impact the community and the performance that is required (alternatively, the level of damage that is acceptable) during a hazard event. The required level of performance will vary depending on the function of a building or infrastructure system and its importance to the recovery of the community following a hazard event or disaster.

The current minimum performance level of life safety in building codes and standards does not guarantee functional buildings after a hazard event. Similarly, current standards for infrastructure systems do not necessarily ensure functionality or rapid recovery following a hazard event. Resilient codes and standards need a risk-consistent, performance-based framework that can address desired performance levels for community hazard events. Resilience codes and standards should seek input from standards developing organizations (SDOs), model building codes, and communities as well as from the end users of resilience standards—practicing engineers for building structures and infrastructure systems.

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[1] Research Structural Engineer, National Institute of Standards and Technology, Gaithersburg, MD

[2] The term building includes all the systems necessary for its functional operation – architectural, structural, life safety, mechanical, electrical, plumbing, security, communication and IT systems.

[3] The terms infrastructure and lifelines are considered interchangeable in this paper, and include the physical plants, transmission, and distribution networks for transportation facilities (e.g., roads, bridges, tunnels, ports, rail) and utilities (e.g., electric power, water and wastewater, fuels, and communication).

The Department of Homeland Security (DHS), the National Institute of Standards and Technology (NIST), and American National Standards Institute's Homeland Security Standards Panel (ANSI-HSSP) are supporting the development of resilience standards. In particular, DHS Science and Technology Directorate's Office of Standards and NIST are supporting the development of measurement science and tools to assess the disaster resilience of engineered buildings and other structures, both individually and at a community level, through the use of risk-based assessment and performance-based methods for design and retrofit. ANSI-HSSP facilitates the development and enhancement of homeland security design standards for all man-made and natural hazards by supporting private/public sector partnerships for standards issues and facilitating dialogue and networking on key issues for homeland security standards developers and stakeholders.

This paper, addresses the following topics: examples of recent hazard events and the corresponding performance of the built environment, resilience concepts for the built environment, a brief history of public and private sector resilience efforts, and some thoughts on gaps and needs for codes and standards.

Recent Events and the Performance of the Built Environment

Hazards[4] are a continuing and economically significant threat to U.S. buildings, infrastructure, and lifelines in communities or over a region. A single event such as a major earthquake or hurricane could potentially cause $80 billion to $200 billion in total economic losses. For instance, Hurricane Katrina's (2005) insured losses were $44 billion, and total economic (non-insured) damages are expected to exceed $200 billion[5]. The storm surge and waves damaged homes, buildings, industrial facilities, and bridges in the coastal area[6]. Beyond the storm surge region, the winds damaged industrial facilities, oil storage tanks, and the power distribution system. More recently, Japan has had a triple disaster of earthquake, tsunami, and nuclear power plant crises. The World Bank estimated that the reconstruction costs for this disaster will range between $122 and $235 billion[7].

The risk across large, disaster-prone regions of the Nation is substantially greater now than ever before, due to the combined effects of urban development and population growth.[8, 9] Additionally, much of the Nation's physical infrastructure is located in parts of the country that are susceptible to natural hazards (e.g., along coastlines, in the wildland-

[4] Hazards include earthquakes, wind-related hazards (hurricanes, tornadoes, windstorms), fire-related hazards (community-scale fires in the wildland-urban interface, structural fires), water-related hazards (storm surge, flood, tsunami) and human-made hazards (accidental, criminal, or terrorist in nature).
[5] CRS Report for Congress, Hurricane Katrina: Insurance Losses and National Capacities for Financing Disaster Risks, Updated January 31, 2008, Order Code RL33086
[6] NIST Technical Note 1476, Performance of Physical Structures in Hurricane Katrina and Hurricane Rita: A Reconnaissance Report, Gaithersburg, MD, 20899, June 2006.
[7] http://siteresources.worldbank.org/INTEAPHALFYEARLYUPDATE/Resources/550192-1300567391916/EAP_Update_March2011_japan.pdf
[8] *Improved Seismic Monitoring – Improved Decision Making: Assessing the Value of Reduced Uncertainty*, National Academies Press, 2006.
[9] Economic Statistics for NOAA – May 2005 – Fourth Edition.

urban interface, and in earthquake-prone regions), and much of the infrastructure is vulnerable due to diminishing capacity to resist hazards associated with an aging infrastructure.

In the 10-year period from January 2000 to January 2011, between 45 and 81 Presidential disaster declarations have been made every year for floods, hurricanes, tornadoes, earthquakes, fire events, and severe storms (e.g., high winds). The 2001 World Trade Center (WTC) terrorist attack, a man-made hazard, also has been declared as a Presidential disaster. Figure 1 shows the distribution of disaster declarations across the 10 FEMA regions of the United States. The Robert T. Stafford Disaster Relief and Emergency Assistance Act (hereinafter called the Stafford Act) authorizes the President to issue a major disaster declaration for federal aid to states determined to be overwhelmed by natural hazards or other catastrophes. The Stafford Act authorizes temporary housing, grants for immediate needs of families and individuals, the repair of public infrastructure, and emergency communication systems. Congress appropriated over $10 billion to the Disaster Relief Fund in FY2005, largely in response to the four hurricanes that struck Florida in the fall of 2004.

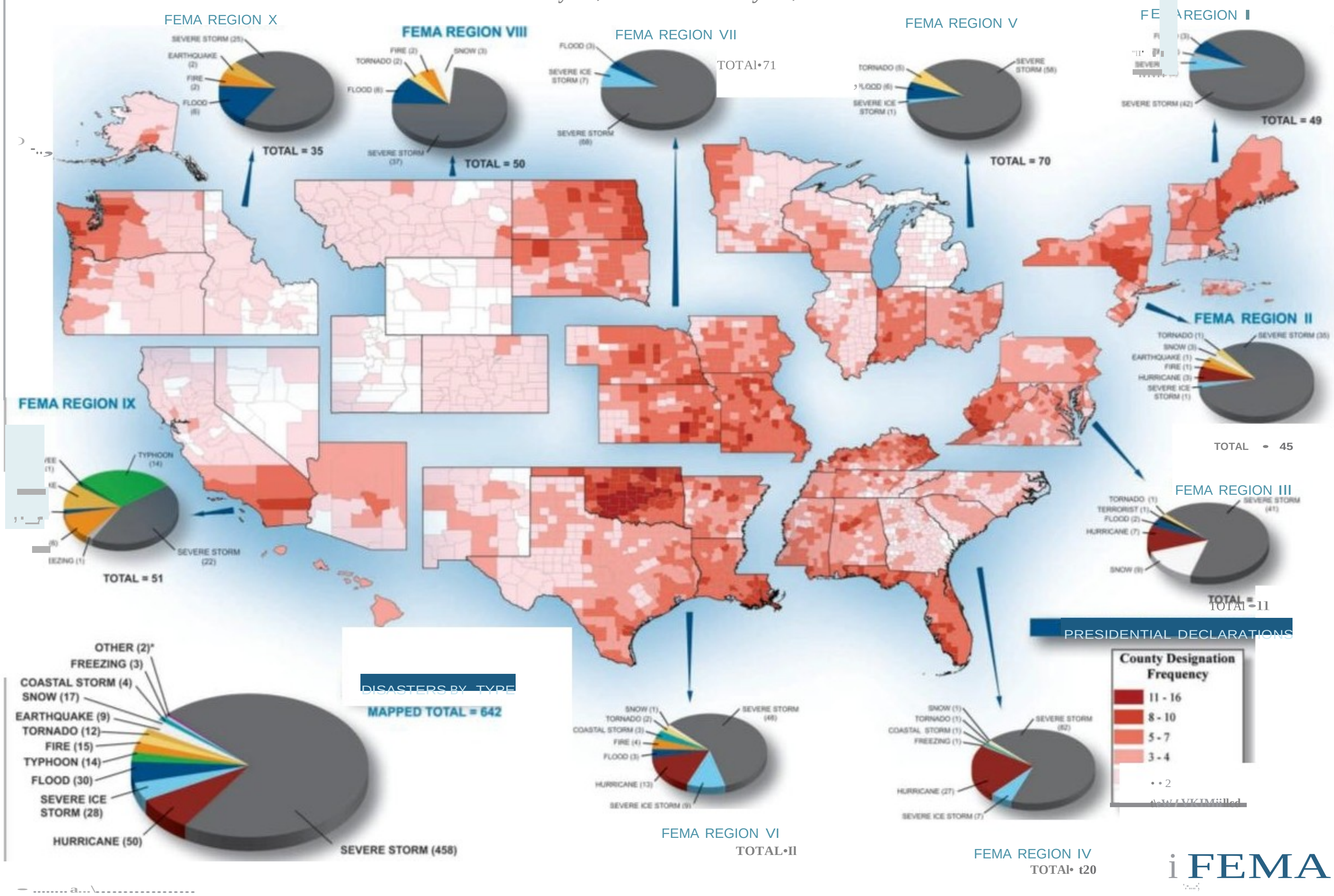
Hurricane Irene was a Category I hurricane when it made first landfall at the Outer Banks, North Carolina on 27 August 2011. It made a second landfall at Little Egg, New Jersey, and a third landfall at Brooklyn, NY, after which it was downgraded to a tropical storm. Hurricane Irene caused some wind damage but primarily caused extensive flood damage. Over 40 million people were affected by the storm, and over 6 million homes and businesses lost power from downed power lines and flooded or damaged substations. The flooding was most severe in New Jersey and Vermont. Many New Jersey roads were impassable, and most of the state train lines were shut down. In Vermont over 260 roads and bridges were damaged, isolating communities. Hurricane Irene caused insured losses of $2 billion to $4.5 billion, according to Risk Management Solutions Inc. (RMS). The worst of the damage resulted from flooding, a hazard which is not covered under standard homeowners' policies and is largely excluded from the RMS estimate[10]. If flood damage losses were included, the total loss estimate would be between $7 billion and $10 billion[11].

On May 22nd, 2011, an EF5 tornado occurred in Joplin, MO. The tornado was about 0.75 to 1 mile (1.2 to 1.6 km) wide when it first touched down on the west side of the city and tracked eastward across the city into rural areas. While portions of the tornado damage were rated as EF3 to EF5, other tornado damage was rated between EF0 and EF2[12]. Approximately 8000 houses, 18000 cars, and 450 businesses were damaged or destroyed. Communication and power were lost in many areas of the city. It is likely to be the costliest tornado in U.S. history, reaching $3 billion[13]. As an example of damage to engineered structures, St. John's Regional Medical Center windows and exterior walls (cladding) were damaged, but there was no significant structural damage. However,

[10] Wall Street Journal, 12 Sep 2011, Hurricane Irene Caused Up to $5.5B in Insured Losses
[11] New York Times, 31 Aug 2011, Hurricane Cost Seen as Ranking Among Top Ten
[12] http://www.crh.noaa.gov/sgf/?n=event_2011may22_survey
[13] ProgramBusiness.com, Insurance News, 24 May 2011, EQECAT: Joplin Tornado Losses Could Reach $3 Billion

PRESIDENTIAL DISASTER DECLARATIONS

Ja11uary 10, 2000 to January 28, 2011



nearly all buildings surrounding St. John's were destroyed. Due to significant water intrusion that led to mold and other contaminants which were too costly to remediate, the St. John's medical facility will be demolished and rebuilt at a new location[14]. The damage to St John's Regional Medical Center, and other engineered structures, shows that a building must be designed and constructed holistically to take into account both its structural and non-structural performance.

On 11 July, 2011, a severe thunderstorm struck central eastern Iowa. The National Weather Service (NWS) storm survey teams estimated wind speeds in the 110 to 130 mph range based on observed damage. The NWS stated that this was the largest and most damaging wind event since 1998. No tornadoes were detected; the straight line winds were due to a derecho[15]. However, the strongest winds were similar to those found in an EF1 tornado[16]. Damage included widespread power outages and downed power lines, partial or total removal of many roofs, and collapsed walls of some buildings. Severe storm events and the resulting damage occur repeatedly across the country every year.

Deteriorating infrastructure increases the severity and rate of failure during hazard events or extreme conditions. The United States has fallen sharply in the World Economic Forum's ranking of its national infrastructure systems. In the 2007-2008 report, American infrastructure was ranked No.6 in the world. In the 2009-2010 report, the U.S. was ranked at No.14. The U.S. spends roughly 2 percent of its gross domestic product on infrastructure, about half of what it did 50 years ago. Europe spends around 5 percent, and China 9 percent. Deteriorating infrastructure impacts business continuity and increases costs to taxpayers and businesses.

One example is the increased rate of water pipe failures across the U.S. during the 2011 drought in the Midwest and South. Older pipes are more susceptible to bursting, due to combined effects of high temperatures and dry soils that shrink away from buried pipes. Increased water usage then raises internal water pressure, which can cause failures in unsupported deteriorated pipes[17]. Thousands of water pipes have burst across the Nation. On August 14, 2011, Oklahoma City had 685 water main breaks over a six-week period, four times the normal rate. On August 23, 2011, Houston had 847 water leaks, more than three times the normal rate. The American Water Works Association (AWWA) report, "Dawn of the Replacement Era, Reinvesting in Drinking Water Infrastructure" (May 2001) points out that many of the water systems are 80 to 100 years old and approaching the end of their useful lives.

When the level of damage that occurs every year to our buildings and infrastructure by hazards and disruptive events is considered with just a few recent examples, it becomes apparent that the present codes, standards, and practices used to build and maintain our

[14] Personal communication, St John's Medical Research Center and NIST personnel

[15] The National Weather Service defines derechos as windstorms that are able to last for several hours with gust fronts that produce high levels of damage. In order for these storms to last so long, they need both instability and wind shear. Instability refers to the storm's ability to tap into the warm moist air near the surface as it develops.

[16] National Weather Service Weather Forecast Office, Des Moines, IA, http://www.crh.noaa.gov/dmx/?n=july2011derecho

[17] CNN, Building Up America, Heat pops pipes nationwide; brace for higher bills, August 14, 2011

communities are not sufficiently comprehensive in their scope or requirements, even when one accounts for communities that do not adopt or enforce building codes and standards. These few examples demonstrate that even though our codes and standards have criteria for hazard events the built environment is not resilient during or after hazard events that occur on an annual or multi-year basis.

Referring again to Figure 1, should society depend on private and public insurance (state and federal disaster aid) to such a large degree for reoccurring events? A resilient community can offer a better way forward, where the present level of annual damage is reduced, and local and national resources can be put to more productive use.

Resilience of the Built Environment

Resilience of the built environment is both a local and a national issue. Just as the damage effects of hazard events can cascade from localized damage to impact a community, they also can cascade across entire regions, and even the Nation. example is the loss of power during Hurricane Katrina. Mississippi Power Company had 402 damaged transmission towers due to falling trees, wind, and, in some cases, cascading tower collapses due to unbalanced line tension. A major problem in restarting one of the generating plants was the lack of electric power needed to start the auxiliary equipment – the entire regional power systems was down (NIST 2006). As projected losses from hazard events continue to rise, there is increasing recognition that minimizing the need for response and recovery depends on proactively identifying hazards that pose threats and acting to mitigate their potential impact. Preventing hazards from becoming disasters depends upon the resilience of our buildings and infrastructure.

Buildings are typically constructed under present codes, standards, and design practice for minimum life safety performance criteria for design events. Life safety allows for safe evacuation of occupants during or after a design event, even though constructed systems may be damaged significantly. If resilience concepts are added to codes and standards, then owners and stakeholders can prioritize which systems should function during and after a disruptive event (e.g., hospitals, emergency response, primary infrastructure systems), and which systems should sustain only minor damage (e.g., businesses, schools, secondary infrastructure systems). Inclusion of resilience will reduce or eliminate significant vulnerabilities present in today's constructed systems, as well as lower economic losses, and will improve community stability and productivity. However, before such changes can be made, performance goals, metrics, and validated tools to evaluate the performance of built systems and associated risks need to be developed. Nevertheless, risk-consistent, performance-based design tools, while necessary, are not sufficient to develop tools for resilience of the built environment.

Resilience depends upon the capacity of the built environment to maintain acceptable levels of functionality during and after disruptive events and to recover full functionality within a specified period of time. Figure 2 illustrates resilience for the built environment. Both the degree of lost functionality after the event and the time to full recovery are random variables. If proactive modifications are made that improve the performance of the built environment prior to disruptive events, the time to full recovery of functionality can be shortened significantly. However, at present, communities do not plan for recovery of their physical infrastructure following disruptive events, and the time to full recovery is uncertain.

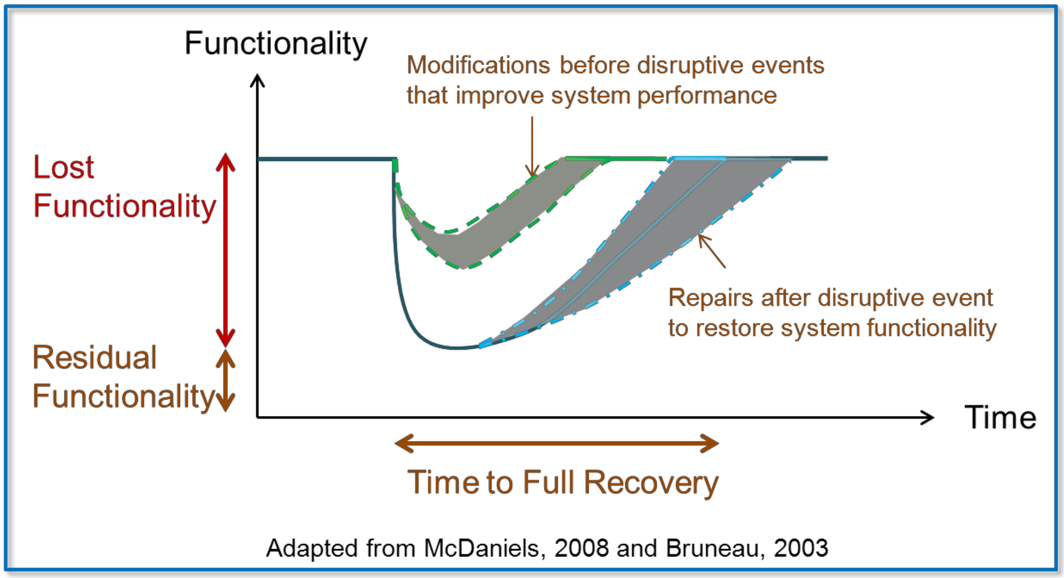


Figure 2. Resilience concept of functionality versus recovery time for the performance of the built environment during a disruptive event.

Community resilience is distinct from FEMA disaster activities. FEMA promotes four activities to reduce the impact of disasters with a focus on community readiness, mitigating damage, and emergency management of public safety and health and property damage:

- Plan - community and individual readiness for events
- Prepare and mitigate - avoiding or minimizing damage and loss of life
- Respond - emergency management of public safety and health and property damage
- Recover and rebuild - federal aid to recover and rebuild

FEMA's public assistance ranges from training to flood insurance to personal and community disaster relief. Their activities have improved community planning for shelters and communication during events and provided assistance when damage exceeded local and state resources. Their reports on building performance during disasters and support of seismic design practices have resulted in changes to building practices (e.g., continuous load paths for wind resistance, elevation above flood levels, and improved seismic design guidelines, including performance based design). FEMA's disaster reduction activities are important for community resilience, but there remain significant gaps in codes and standards for resilient buildings and infrastructure systems.

Formative Events and Government Responses for Community Resilience

Three events have had significant influence on the development of resilience concepts: Hurricane Andrew in 1992, the WTC and Pentagon terrorist attacks in 2001, and Hurricane Katrina in 2005. The federal aid response to Hurricane Andrew was widely criticized as inadequate, insurance claims led to the closure of insurance companies, and the widespread structural damage led to efforts to improve building codes and practices in South Florida. After Hurricane Andrew, FEMA was reorganized with an emphasis on preparedness and mitigation for natural hazards. Response and recovery efforts primarily focused on providing financial and housing aid to communities immediately after a disaster.

Following the WTC and Pentagon disasters in 2001, deterrence of terrorist attacks was addressed in The Patriot Act (2001) and efforts focused on security against terrorism for critical infrastructure. The Patriot Act defined critical infrastructure as "systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact" on national economic security, public health, or safety. The National Strategy for Physical Protection of Critical Infrastructure and Key Assets (2003) identified critical infrastructures and key assets (CIKR), and the Homeland Security Presidential Directive-*7* (HSPD-7, 2003) on Critical Infrastructure Identification, Prioritization, and Protection established a national policy for federal agencies to identify and prioritize critical infrastructure and key assets and to protect them from terrorist attacks.

Hurricane Katrina in 2005 reminded the US that natural disasters continue to be a significant threat to our communities. The unprecedented level of destruction by storm surge in Mississippi and Louisiana brought renewed focus to the need to address natural disasters. The broadened definition of disaster resiliency was reflected in the Grand Challenges for Disaster Reduction and the National Infrastructure Protection Plan developed by The President's Office of Science and Technology Policy in 2005 (updated 2008). The Grand Challenges identify technical problems due to a lack of adequate scientific understanding of natural hazards and availability of information, predictive technologies and mitigation strategies to improve the performance of buildings and infrastructure, and standard methods to predict and assess the disaster resilience of buildings and infrastructure.

The Department of Homeland Security (DHS) released a National Infrastructure Protection Plan (NIPP, 2009) in response to HSPD-7. Eighteen critical infrastructure and key resources (CIKR) sectors were identified, as well as high priority technology needs, including the following:

- Analytical tools to quantify interdependencies and cascading consequences as disruptions occur across critical infrastructure sectors;
- Effective and affordable blast analysis and protection for critical infrastructure and an improved understanding of blast-failure mechanisms and protection measures for the most vital CIKR;

- Advanced, automated, and affordable monitoring and surveillance technologies, specifically, decision support systems to prevent disruption, mitigate results, and build resiliency;
- Rapid mitigation and recovery technologies to quickly reduce the effects of natural and manmade disruptions and cascading effects; and
- Critical utility components that are affordable and highly transportable, and provide robust solutions during manmade and natural disruptions.

The DHS Directorate for National Protection and Programs addresses both physical and virtual threats. Under this directorate, the Office of Infrastructure Protection (IP) leads a national coordinated effort to reduce risk to the infrastructure posed by acts of terrorism through the NIPP and a set of programs and partnerships. An example of a product developed for the Commercial Facilities Sector is a Risk Self-Assessment Tool for Stadiums and Arenas that was designed to assist owners with the identification and management of security vulnerabilities.

The DHS Directorate for Science and Technology is the research and development arm of DHS. The Infrastructure Protection and Disaster Management Division has infrastructure (dams, bridges, tunnels) projects that include (1) tools for protective measures and design guidance to reduce blast effects and (2) protection, rapid mitigation, and recovery following an event.

In December 2010, DHS Science and Technology Directorate held a summit with public and private sector representatives to develop recommendations for resilient buildings and infrastructure. The primary issue under consideration was the lack of guidance available for architects and engineers to design buildings and infrastructure that is resilient and high-performing. The summit confirmed the need to improve the performance of the built environment, emphasized the need to coordinate resiliency efforts, and promoted public-private partnerships.

By 2010, a national need for resilient buildings and infrastructure to natural and manmade hazards had been identified by the President's Office, and national sector plans had been developed by DHS. However, most of the efforts to date have focused primarily on security measures for facilities. Resilience of the built environment needs to be addressed with a similar focused national effort.

<u>Private Sector Responses for Resilience</u>

In response to the Presidential Directives and DHS activities, the private sector also responded to the need for resilience.

In 2001, eleven professional organizations, technical organizations, and federal agencies formed The Infrastructure Security Partnership (TISP), a non-profit partnership to facilitate dialogue on domestic infrastructure security and public policy related to the security of the nation's built environment. TISP works to advance infrastructure security and resiliency. TISP holds annual conferences to engage the public and private sector in resilience topics, with an emphasis on management preparedness and business continuity. In 2010, TISP released the White Paper on Infrastructure Resilience and Interdependencies. Three recommendations were made for improving the resilience of the built environment: (1) develop a unified national resilience goal, (2) develop consistent methods identifying core functions and interdependencies for risk and resilience management, and (3) adopt consistent methods for prioritizing infrastructure investments.

ASCE formed the Technical Council for Lifeline Earthquake Engineering in 1977. TCLEE has held international conferences approximately every four years since 1977. The 2009 conference addressed significant regional disruptions that often have had national impacts that were strongly dependent on the performance of lifelines. In 2009, ASCE released “Guiding Principles for the Nation’s Critical Infrastructure,” which promoted four guiding principles: (1) make risk analysis, management, and communication the standard basis on which infrastructure projects are developed and implemented, (2) properly maintain, operate, and modify systems to perform effectively under changing conditions, (3) provide technical oversight, coordination with related projects, appropriate control and change management, and effective communication with project stakeholders, and (4) adapt critical infrastructure in response to dynamic conditions and practice throughout their life cycle.

The American Society of Mechanical Engineers (ASME) published “Prioritizing Critical Infrastructure Security/Resilience” in 2009. It presents the Risk Analysis and Management for Critical Asset Protection (RAMCAP) method that directly compares risk, resilience, and risk management benefits so that decision-makers can better allocate limited resources. Also in 2009, the American Water Works Association’s (AWWA) “All Hazards Consequence Management Plan” was released to help drinking water and wastewater utilities incorporate all-hazard consequence management concepts into their existing emergency preparedness, response, and recovery planning.

In 2010, the Pacific Earthquake Engineering Research Center (PEER) released “Guidelines for Performance Based Seismic Design of Tall Buildings.” The guidelines present a recommended alternative to the prescriptive procedures for seismic design of buildings contained in standards such as ASCE 7 and the International Building Code (IBC). They are intended primarily for use by structural engineers and building officials engaged in the seismic design and review of individual tall buildings. These guidelines also can be used to achieve higher seismic performance objectives. Performance-based methods allow for performance goals to be directly addressed in the design process.
In 2011, the National Research Council (NRC) published “National Earthquake Resilience: Research, Implementation, and Outreach.” NEHRP commissioned NRC to develop a roadmap for earthquake hazard and risk reduction in the United States based on goals and objectives for achieving national earthquake resilience as described in the 2008 NEHRP Strategic Plan. The NRC committee was directed to assess the activities, and their costs, that would be required for the Nation to achieve earthquake resilience in 20 years.

Standards Supporting Resilience of the Built Environment

The following standard has been developed explicitly to support optimization of resources for security measures for water and wastewater systems:

- ANSI/ASME-ITI/AWWA J100-2010, RAMCAP® Standard for Risk and Resilience Management of Water and Wastewater Systems

The following standards implicitly support resilience of the built environment through risk-consistent, performance-based methodologies:

- ASCE 41-06, Seismic Rehabilitation of Existing Buildings, a performance-based seismic rehabilitation methodology
- ASTM E 2506-06, Standard Guide for Developing a Cost-Effective Risk Mitigation Plan for New and Existing Constructed Facilities
- ASCE 7-10, Minimum Load Requirements for Buildings and Other Structures, performance-based procedures and risk consistency

However, as noted previously, risk-consistent, performance-based methodologies, while necessary components for resilience standards, are not sufficient. There is a significant amount of work that remains to develop comprehensive standards for resilience in the built environment.

What is Needed to Achieve Resilient Communities?

At present, our society is using prescriptive codes and standards for most of the built environment. Individual owners are often reluctant to make investments beyond the minimums required to satisfy codes and standards. However, as shown in the examples of recent hazard events, many buildings and infrastructure systems are failing in natural hazard events.

At the community level, emergency response activities, while good and necessary, often are seen as a sufficient plan for potential disasters. There appears to be an increasing reliance by communities on receiving federal disaster funding for recovery and repairs rather than planning and building for likely scenarios.

However, there is little in place that a forward looking community could use to develop a resilient built environment. The following steps are needed to support resilience in the built environment:

- Clear definitions and vocabulary for resilience concepts
- Performance goals for functionality and recovery
- Metrics to measure levels of resilience
- Tools and methodologies for evaluating and designing resilient buildings and infrastructure

These steps will support development of standards and codes for resilient buildings and infrastructure, leading to reduced emergency response and recovery costs and increased investment return from resilient communities.

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Roundtable on Standards for Disaster Resilience for Buildings and Infrastructure Systems
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SPUR Resilient City Goals

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Design and construction professionals have been working to understand and mitigate the effects of earthquakes for centuries. While the historical record is vague, there is evidence to suggest that local construction techniques changed with each major earthquake and it is reasonable to expect that the goal was always to protect life and property. In the United States, the 1906 San Francisco Earthquake and Fire initiated an understanding in California that has never stopped evolving. The goal for seismic design has consistently focused on limiting damage in moderate earthquakes and preserving life in major events (Geschwind 2001).

Starting in the mid-20th century, building officials with the help of engineers started to codify the style and extent of seismic design that would be required for public safety and lifeline system owners generally followed suit. By the mid 1980s, most agree that the resulting guidelines, codes and standards defined what was needed for earthquake-safe buildings and systems. As new projects were built, the safety of communities began to improve, though they remained plagued by the vast majority of existing buildings, those built prior to the modern codes. While some of those buildings will actually resist earthquakes well, due to the wisdom of their design and construction professionals, most will not. A small subset will be outright dangerous, that is likely to collapse and capable of causing a large number of casualties.

The 1994 Northridge Earthquake brought to new light the consequence of earthquake damage. Engineers were delighted with the life safe performance of their buildings, especially the unreinforced masonry buildings that had recently undergone mandatory rehabilitation. The public, the government, and especially the insurance companies were all startled by the cost of the damage and the disruption to people and business, especially small local businesses. The call for better performance led to the formalization of performance based seismic engineering that has yielded new standards for evaluation, rehabilitation and new building design (SEAOC 1995).

Unfortunately, the traditional silos that separate designers and code writers were not immediately broken down and the resulting efforts for implementing performance based seismic engineering stalled. New buildings continued to be designed for prescriptive requirements without clear definition about was being accomplished (ASCE 1995). Existing buildings continued to be evaluated and rated for a wide variety of performance

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goals with no direct relationship to those being used for new buildings (ASCE 2002, 2006). Lifeline systems, the very heartbeat of each community's economy, continued to be designed and rehabilitated by their public and private providers often without a consistent understanding of their independencies and the consequences of their systems failure on the pace of the recovery.

Fortunately, the new century has brought a new perspective. Driven by the experiences in 9/11, the Katrina floods, and most recently the earthquakes in Haiti, Chile, New Zealand and Japan, many earthquake professionals realize the goals for natural hazard reduction need to shift from safety to resilience. Communities need to be able to take the "punch" of an event and depend on their own preparedness and the impromptu response of those affected to recover. Their preparedness needs to focus on saving people, their neighborhoods, their cultural heritage, and the local economy. It requires a clear understanding of the social and physical impacts of the disasters that may occur and determining the best means to mitigate them to acceptable levels. Part of the plan needs to be a new set of performance goals for the built infrastructure and a new set of related design standards and construction guidelines. The built infrastructure needs to provide a place to govern after a disaster, and power, water, and communication networks must begin operating quickly. People need to be able to return almost immediately to their homes, travel to where they need to be, and resume a fairly normal living routine within a few weeks. Communities can then return to a "new" normal, which occurs within a few years after the event (ACEHR 2010).

SPUR STARTS FRESH WITH GOALS RELATED TO RECOVERY

Defining disaster resilience and setting resilience goals is a contemporary issue that has generated a wide range of definitions and expectations. Some define it qualitatively with goals for response and recovery. Others have developed an analytical measurement that scores abilities, declares when advancement is needed, and allows overall progress to be tracked. Some have suggested that large, modern urban cities are already sufficiently resilient because of their considerable assets, small impact ratios, and extensive and available government support. However, the City and County of San Francisco has not taken that position and in fact, has launched a comprehensive recovery planning initiative. Beginning with 75 different projects aimed at improving the City's ability to recover, the San Francisco Citywide Post-Disaster Resilience and Recovery Initiative, called Resilient SF, is setting a new pace for achieving resilience (Chakos 2008).

The San Francisco Planning and Urban Research Association, working in collaboration with the City of San Francisco, is addressing this issue within its Disaster Planning Program. As a public policy think tank, SPUR recommends policies to the City and County of San Francisco on a wide range of topics. Their Disaster Planning Program is focused in three areas: mitigation, response, and recovery. This SPUR program started during the commemoration of the 100th anniversary of the 1906 Earthquake and Fire. SPUR has published a policy paper defining a Resilient San Francisco in terms of performance goals for the cities built environment and a series of recommendations related to the first steps that are needed. (SPUR 2009)

The SPUR goals for resilience are unique in that they are defined in the context of disaster planning by defining what the city needs, in the event of a major expected earthquake, from its buildings and lifelines to support the three phases of response; rescue, recovery and rebuilding. In the first phase, the weeklong response and rescue period, only the emergency response centers are needed. The second phase of recovery focuses on restoring the neighborhoods within 30 to 60 days so that the workforce can be reestablished as people return to a normal lifestyle and are able to get back to work. Special consideration is given to the needs of the economically and physically challenged populations. The third phase of recovery covers the repair and reconstruction of the affected area. Defining the size of the major earthquake that is the basis for resilience is one of the key aspects of the plan.

SPUR DEFINES EXPECTED AND EXTREME EARTHQUAKES

Earthquakes arrive in all sizes and shapes. The intensity of shaking at a particular location depends on the site conditions, the location of the epicenter, the magnitude, and the geologic setting. The earliest definitions of the largest earthquake that could affect a site were based on the strength of the buildings that adequately resisted the ground motion during great earthquakes. In the early 1970s, the “maximum credible earthquake” was defined based on the frequency of occurrence of all sizes of events. In recent decades, that definition has given way to probabilistic estimates of earthquake of various sizes in terms of their probabilities of occurrence. For purposes of design today, ground motion with a 10% probability of exceedence in 50 years (the 10/50 ground motions) and ground motions with a 2% probability of exceedence in 50 years (the 2/50 ground motions) are the basis. These ground motions are also referred to as having a 500 year return period and a 2500 year return period, respectively. The 10/50 ground motions represent the traditional design level used in the western United States and the 2/50 ground motions, referred to as the maximum considered earthquake (MCE), has become the basis for new design.

Setting resilience goals requires the combination of a defined level of shaking and a transparent performance goal. To be effective and understood, today’s probabilistic definitions need to be translated into equivalent scenario events. For that purpose, SPUR defined three scenario events for San Francisco that included an “expected” earthquake – one that could reasonably be expected to occur during the useful life of the structure or system - along with extreme and routine events. The expected earthquake is defined for use in design and evaluation for resiliency. The extreme earthquake - the largest earthquake that could reasonably be expected to occur on a nearby fault - is intended to be used as the basis for response planning. The routine earthquake – the event that will likely occur routinely during the life of a building – is intended to verify the service level performance of buildings. That is the level of earthquake a building or system can endure without damage or interruption in its operational ability.

For buildings in San Francisco, SPUR has defined the following:

Routine	Magnitude 5.5, 70% probability of exceedence in 50 years
Expected	Magnitude 7.2, 10% probability of exceedence in 50 years
Extreme	Magnitude 7.9, 2% probability of exceedence in 50 years

For lifeline systems such as major bridges, levees, or utility systems, the useful life of the systems is much longer. The expected earthquake for lifelines should represent a ground motion with a much lower probability than defined for buildings, perhaps even as low as for the extreme event.

SPUR DEFINES TRANSPARENT INFRASTRUCTURE GOALS

The current move from a safety focus to resilience needs to be supported by a complete set of transparent performance goals that declare what is needed from both lifeline systems and buildings to facilitate recovery. The intent is to identify what elements of the built environment are needed for effective response and rapid recovery. Buildings and systems need to be designed and constructed so they are available just when they are needed.

SPUR chose to define performance goals in terms of the City's three response and recovery phases, using five performance categories for buildings, three performance categories for lifeline systems, and a matrix presentation format as the metric for defining and tracking the state of resilience:

Response and Recovery Phases

Phase	Time Frame	Condition of the built environment
1	*1 to 7 days*	*Initial Response and staging for reconstruction*
	Immediate:	Mayor proclaims a local emergency and opens the Emergency Operations Center. Hospitals, police stations, fire stations, and City Department Operations Centers are operational.
	Within 4 hours:	People can leave or return to the city in order to get home.
	Within 24 hours	Emergency response workers are able to activate and their operations are fully mobilized. Hotels designated to house emergency response workers are safe and usable, and temporary shelters are open. All occupied households are inspected by their occupants and less than 5 percent of all dwelling units are found unsafe to be occupied. Residents

	will shelter in place[1] in damaged buildings even if utility services are not functioning.
Within 72 hours	Ninety percent of the utility systems (power, water. waste water, and communication systems) are operational and serving the facilities supporting emergency operations and neighborhoods. Ninety percent of the major transportation systems routes, including Bay crossings and airports, are open at least for emergency response. The focus of the initial recovery and reconstruction efforts will be focused on repairing neighborhoods to a usable condition including providing the utilities they need. Essential City services are fully restored.
2. 30 to 60 days	*Housing restored – ongoing social needs met*
Within 30 days	All utility systems and transportation routes serving neighborhoods are restored to 95 percent of pre-event service levels, public transportation is running at 90 percent capacity, public schools are open and in session. Ninety percent of the neighborhood businesses are open.
Within 60 days	Airports are open for general use, public transportation is running at 95 percent capacity, minor transportation routes are repaired and reopened.
3 Several Years	*Long Term Reconstruction*
Within 4 months	Temporary shelters are closed. All displaced households have returned home or have permanently relocated. 95 percent of the community retail services are reopened. 50 percent of the non-workforce support businesses are reopened.
Within 3 years	All business operations, including all City services not related to emergency response or reconstruction, are restored to pre-earthquake levels.

Performance Categories for Buildings

SPUR recommends using the following terms in developing the new building design standards and mitigation programs needed to achieve resilience objectives

Category A: *Safe and Operational*. This describes the performance now expected of new essential facilities, such as hospitals and

[1] Shelter in place is used by emergency response professionals to mean the place in a building where people can seek safety during a life threatening incident. SPUR uses "shelter in place" to mean that a building is disaster resilient enough for people to safely remain in their home during both the earthquake itself and subsequent needed repairs, even though the public utility systems may not be working.

emergency operations centers. Buildings will experience only very minor damage and have energy, water, wastewater, and telecommunications systems to back-up any disruption to the normal utility services.

Category B: *Safe and usable during repair*. This describes the performance needed for buildings that will be used to shelter in place and for some emergency operations. Buildings will experience damage and disruption to their utility services, but no significant damage to the structural system. They may be occupied without restriction and are expected to receive a green tag[19].

Category C: *Safe and usable after repair.* This describes the current expectation for new, non-essential buildings. Buildings may experience significant structural damage that will require repairs prior to resuming unrestricted occupancy and therefore are expected to receive a yellow tag[20]. Time required for repair will likely vary from four months to three years or more.

Category D: *Safe but not repairable.* This level of performance represents the low end of acceptability for new, non-essential buildings, and is often used as a performance goal for existing buildings undergoing rehabilitation. Buildings may experience extensive structural damage and may be near collapse. Even if repair is technically feasible, it might not be financially justifiable. Many buildings performing at this level are expected to receive a red tag[21].

Category E: *Unsafe: Partial or complete collapse.* Damage that will likely lead to significant casualties in the event of an "expected" earthquake. These are the "killer" buildings that need to be addressed most urgently by new mitigation policies.

Performance Categories for Lifelines

SPUR defines the expected performance of all utility and transportation systems, or portions of systems, serving the City in terms of the days required to restore service to 90 percent, 95 percent and 100 percent of the defined customer base.

Category I Resume *100 percent of service levels within four hours*

Critical response facilities - including emergency housing centers – need to be supported by utility and transportation systems critical to their success. This level of performance assures that these systems will be available within four hours of the disaster. It requires a combination of well-built buildings and systems, provisions for making immediate repairs as needed, and redundancy within the

[19] Building inspected and deemed safe for occupancy.
[20] Building inspected and found to be damaged enough to warrant restricted access.
[21] Building inspected and found to be unsafe to occupy.

networks that allows troubled spots to be isolated and repaired without system interruption.

Category II *Resume 90 percent service within 72 hours, 95 percent within 30 days, 100 percent within four months*

Housing and residential neighborhoods require that utility and transportation systems are restored quickly so that these areas can return to livable conditions. There is time to make repairs to lightly damaged buildings and replace isolated portions of the networks or create alternate paths for bridging around the damage. There is time for parts and materials needed for repairs to be imported into damaged areas. These systems need to have a higher level of resilience and redundancy than the systems that support the rest of the City.

Category III *Resume 90 percent of service within 72 hours, 95 percent within 30 days, 100 percent within three years*

The balance of the city needs to have its systems restored as buildings are returned to operation. There will be time to repair and replace older vulnerable systems with new. Temporary systems can be installed as needed. Most existing lifeline systems will qualify for Category III performance.

SPUR distilled these goals into the resilience matrix, shown in Figure 1, which indicates both the goals and the estimated current condition of the city's infrastructure.

ACHIEVING RESILIENCE

The concept of moving from safety to resilience is compelling. The reality of how to do it is complex. There is a need to settle on a set of consistent performance goals that are fully incorporated in the design standards and codes for new buildings and lifeline systems and tailored to the needs of each community that uses them. These standards and codes need to be adopted and enforced by knowledgeable building officials and inspectors. Design and construction professionals need to fully embrace the change, learn the new procedures that are needed to achieve the resilience goals and become accustomed to constructing projects to a revised set of standards.

Setting and achieving resilience goals is needed at the local level, but they will not be fully effective if they are not developed and implemented in a consistent manner nationally. A community's ability to recover depends on regionally distributed lifelines and national resources. The federal government should take the lead in establishing the performance goals needed for recovery along with incentives for states, regions and communities to adopt and implement them. These goals need to be set for the full set of natural hazards that the nation faces, including seismic. Continuous research related to how to effectively achieve resilience needs to be funded at the federal level along with continuous funding for the development of national design standards and model building codes. Specific, first order attention needs to be given to the nation's lifeline systems and their interdependencies.

The new generation of design standards and codes that are needed must incorporate transparent performance levels and consistent hazard levels to be effective. The public and their policy makers will make the necessary decisions to change from a safety focus to a resilience focus if given a clear and understandable vocabulary to discuss seismic safety, realistic goals and consistent standards. In the United States, ASCE 7, 31 and 41 and the standards used for lifeline design need to be brought into consistency in terms of vocabulary and transparent performance goals. The SPUR goals are well suited for this purpose.

Finally, the culture of the design and construction industry must change and that is perhaps the toughest challenge. The significant strides that have been made over the past 100 years are evidence that it can be done. It appears that change most often comes after a major disaster when the codes are changed. Those who write standards and codes evaluate the disaster and determine what changes are needed. Those changes are incorporated into the standards and model codes, and when enforced, actually change the way buildings and systems are constructed. It is a slow process, perhaps the only process that effects uniform change.

Figure 1

TARGET STATES OF RECOVERY FOR SAN FRANCISCO'S BUILDING AND INFRASTRUCTURE

INFRASTRUCTURE CLUSTER FACILITIES	Event Occurs	Phase 1 Hours 4	24	72	Phase 2 Days 30	60	Phase 3 Months 4	36	36+
CRITICAL RESPONSE FACILITIES AND SUPPORT SYSTEMS									
Hospitals								X	
Police and fire stations			X						
Emergency operations center	X								
Related utilities						X			
Roads and ports for emergency				X					
CalTrain for emergency traffic					X				
Airport for emergency traffic				X					
EMERGENCY HOUSING AND SUPPORT SYSTEMS									
95% residence shelter-in-place								X	
Emergency Responder Housing				X					
Public shelters							X		
90% Related Utilities								X	
90% roads, port facilities, and public transit							X		
90% Muni and BART Capacity						X			
HOUSING AND NEIGHBORHOOD INFRASTRUCTURE									
Essential city service facilities							X		
Schools							X		
Medical provider offices								X	
90% neighborhood retail services									X
95% of all utilities								X	
90% roads and highways						X			
90% transit						X			
90% railroads							X		
Airport for commercial traffic					X				
95% transit							X		
COMMUNITY RECOVERY									
All residences repaired, replaced or relocated									
95% neighborhood retail businesses open								X	
50% offices and workplaces open									X
Non-emergency city service facilities									
All businesses open									X
100% utilities									X
100% highway and roads									X
100% transit									X

Source: *SPUR Urbanist, February 2009*

Tile "x's" in the chart to tile right indicate SPUR's best educated guesses about current standards for recovery times. The shaded areas represent the goals — targets based on clearly stated performance measures (see next page) — for recovery times for the city's buildings and lifelines. Tile gaps between "x's" and shaded boxes represent how far we are from meeting resiliency targets.

TARGET STATES OF RECOVERY

Performance Measure	Description of usability after expected event: BUILDINGS	LIFELINES
	Category A: Safe and operational	
(lightest shading)	Category B: Safe and usable dunng repairs	100% restored in 4 hours
(medium shading)	e after repairs	4 months
	Category C: Safe and usabl moderate repairs	100% restored in
(darkest shading)	Category D: Safe and usable after major repairs	100% restored in 3 years
X	Expected current status	

CONCLUSION

In many ways, the tools and procedures to create disaster resilient cities exist and are continually being refined. Achieving resiliency nationwide, however, will require a new process and uniform application. Modifications to the current building codes, alignment of the lifeline systems around common performance objectives, and strong community support for adopting and enforcing the new design standards are needed. Deficient buildings and systems need to be mitigated, and new buildings and systems need to be designed, to the minimum performance levels that are needed for community resilience.

Making such a shift to updated codes and generating community support for new policies is not possible without solid, unified support from all levels of government and the private sector. The federal government needs to set performance standards that can be embedded in the design codes and the SPUR Goals are a rational and complete set. Communities need to adopt and enforce these new resilience codes and develop mandatory programs that mitigate their built environment as needed to assure survival. The private sector is expected to respond and cooperate as the reality is defined in clear and compelling terms, and financial incentives are provided to support the community needs.

CONTRIBUTORS

The thinking behind the shift from safety to resilience has been in process for at least 40 years. Triggered by the 1971 San Fernando earthquake, the concept of building better has been developing in the minds of many researchers and practitioners like me. Most recently, my work with the Disaster Planning Program at SPUR and the National Earthquake Hazard Reduction Programs (NEHRP) Advisory Committee on Earthquake Hazard Reduction (ACEHR) has been stimulating, encouraging, and thought-provoking. I am grateful for the interactions I have had over the years with the following people:

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Provisions in Present U.S. Building Codes and Standards for Resilience

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Introduction

State and municipal governments in the United States have traditionally adopted building codes through the duty of government to protect the public safety and the powers granted by the governed that enable governments to adopt and enforce regulations to that effect. In granting government the power to act to protect the public safety, the individuals simultaneously surrender some portion of their right, absent such regulatory authority, to act in the manner deemed most appropriate by the individuals. By granting, recognizing and accepting this authority, the individuals, either knowingly or not, voluntarily or not, agree to sacrifice to some extent, an ability to act in what they may believe is their own best interest, to the betterment of the collective good. In the simplest statement of this compact, individual building developers and owners, by agreeing to abide by building regulation, accept that they will pay more to develop their property then they otherwise might have, and they might not be able to build some types of structures that they might otherwise have, recognizing that in so doing, they are providing themselves and society at large, a building stock which will be both safer and more reliable. The building regulation process therefore inherently involves tradeoffs between the rights of the individual to build in the manner that best suits them and the rights of society at large to have safe places to conduct commerce and reside. While it may be in the power of government to require design of buildings such that they would survive and remain functional following any likely environmental or human-induced event, it would not be practically economical to do so. Thus, building codes represent a compromise between acceptable safety and reliability and economic practicality.

But what constitutes acceptable safety and reliability? Society's notion of this is a function of several things, including: its recent exposure to destructive events, including earthquakes, fires and hurricanes that have adversely affected it; the available technology and the ability this technology brings to control losses resulting from poor performance of construction; society's economic wealth and its ability to devote substantial resources to protect against future potential losses, as opposed to providing for basic survival; and, the existence of other societal demands for the use of these resources. At a given period in time, society will come to a determination, through some means, that either real or perceived losses resulting from the possible or probable response of its built environment to stress, including that resulting from normal occupancy, environmental loading or even terrorist attacks, is unacceptable, that both the economic means and technical capability exist to reduce these possible/probable losses to acceptable levels; and, that the use of the money necessary to do this is the most desirable of several possible applications.

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For this discussion, we define resilience as the measure of society's level of acceptance of the potential for adverse consequences, resulting both from the hazard environment and the minimum acceptable design and construction criteria, as embodied in building practice. It can be defined in terms of several sub-measures including: the potential for large numbers of lost lives owing to building failures of one type or another; the potential for individual life loss resulting from such failure; the need to have to expend additional resources to conduct repairs following a stress event; and the potential that entire communities in some cases, even large cities, will lose viability, due to a simultaneous collective failure of the built environment. Society's tolerance for these poor outcomes of design and construction criteria selection is a function not only of time, and the previously mentioned factors of technical capability, economic welfare and competing needs, but also the individual hazard. Society has apparently been willing to accept one level of risk for earthquake, another for snow, a third for hurricane, a fourth for flood, a fifth for fire, etc. Society's tolerance for lack of resilience to any of these hazards is in turn a function of belief the hazard can occur; fear of the consequences of the hazard; belief that one can practically affect the outcome; and though often not quantified or even stated, an explicit or implicit cost benefit evaluation. This paper explores the levels of resilience society has apparently been willing to accept through the basis for its building regulation as embodied in the building codes and their referenced standards adopted in the United States today.

U.S. Building Regulation

Building regulation in the United States is generally conducted at the most local level of government available within a community, through adoption and enforcement of a building code. Within the incorporated boundaries of a City, building codes are adopted and enforced by City government. Outside the boundaries of incorporated cities, counties are generally responsible for building regulation. In some cases, state government will mandate the minimum acceptable criteria for local building codes, allowing individual county and city governments within the state to make amendment to these criteria on the basis of local conditions, or a desire for improved resilience. The U.S. Constitution, by omitting the assignment of this power to the federal government, prohibits the federal government from adopting and enforcing building codes except as pertains to federal property, e.g. government buildings, military reservations, federal territories, and the like; and within the boundaries of federal territories.

While the federal government is constitutionally prohibited from adopting and enforcing building codes at the local level, it nonetheless can have and has had substantial influence on this process. Major cities, principally in the eastern United States, were the first adopters of building codes, in the latter half of the nineteenth century. These cities principally adopted building codes in response to the large urban conflagrations that would periodically devastate large portions of these cities, which in that era incorporated the unfortunate combination of dense development, substantial wood construction and the use of open flames for cooking, heating and lighting, as well as industrial processes. Baltimore, Chicago, New York and Philadelphia all experienced large conflagrations that devastated entire neighborhoods and in some cases large portions of the cities. These conflagrations resulted in large life loss, substantial economic loss, migration of populations, and also periodic urban renewal. For the most part, cities that experienced these fires, in each case, rebuilt and did so in a manner that was superior, though sometimes equally vulnerable, to the city that pre-existed the event. Urban fires were not new. They had plagued European cities for centuries. Yet by the late 1800s, major U.S. cities decided they had the technical means, the economic resources and the collective will to reduce this risk.

These first U.S. building codes were developed in an informal public and private partnership with the insurance industry, the design professions and City governments working hand in hand to develop the codes. Insurance industries, burdened with shouldering the economic loss associated with these conflagrations began to conduct research, largely through post-disaster investigation, into relative resistance of different construction types to fire spread and loss. The design professions, interested in bettering their practice and communities worked with the insurers to develop appropriate solutions and the Cities imposed the recommendations of these two groups on society at large by adopting the resulting recommendations. Initially, these early codes were intended only to prevent the loss of large portions of communities through the spread of fire from one building to another, resulting in urban conflagrations. The codes imposed bans on exposed wood construction in dense urban neighborhoods, required the use of fire-resistant materials on perimeter building walls in these regions and required parapets at roof lines, all identified as ways to avoid rapid spread of fire from one building to its neighbors. Once these codes proved successful in reducing the risk of conflagration, code developers began to address the potential for large life loss in individual building fires, and started to regulate exiting and ventilation, to enable occupants to escape, as well as require standpipes to facilitate fire department capability to fight fires, once they occurred. Later still, these codes began to address sanitation, structural stability under wind and snow, and a host of other hazards and risks, including in the Western United States, earthquakes.

The performance goals intended by these codes were not uniform for all hazards. By the 1930s, U.S. Building Codes sought not only to prevent urban conflagration but also to increase the probability that individual building fires could be brought under control without life loss, and possibly, with repairable damage to the structure. These same building codes, however, if they addressed earthquake performance at all, sought only to avoid mass loss of life by avoiding earthquake-induced collapse. Through the mid 1970's this remained the primary goal of earthquake design provisions in the building codes. As noted in the SEAOC Blue Book (SEAOC, 1976), the primary goal of the earthquake design provisions was to protect life rather than the survival of individual structures. These codes did not address many hazards such as tsunami or tornado at all.

By the middle of the twentieth century, most major U.S. cities had adopted and enforced building codes, though many smaller communities and many states did not. Building code adoption was most prevalent in regions subject to extreme hazards of one type or another. Larger cities, as noted above, all faced a substantial fire risk, encouraging building code adoption. Communities along the Pacific coast, including those in Alaska, California, Oregon and Washington found themselves at unacceptable risk from earthquake and adopted building codes at the level of states, counties and even smaller cities and townships. Similarly, communities in the hurricane belt of south Florida and the gulf coast, finding themselves at unacceptable risk of loss from hurricane also developed and adopted codes. Development of these codes remained the work of a partnership of the insurance industry, the design professions, and city officials, often acting in a voluntary capacity through professional organizations, with the substantial participation of the building trades, product suppliers and other industry groups.

In the mid twentieth century, three major partnerships formed and gained regional dominance over the building code development and adoption process. In the northeast, the Building Officials and Code Administrators International (BOCA) formed the nexus for this process while in the south east the Standard Building Code Congress International (SBCCI) dominated and in the Western U.S. the Pacific Coast Building Officials, later called the International Conference of Building Officials (ICBO) formed and sponsored the building code development process. Each of these three groups sponsored the development and publication of a model building code, intended to be used by local communities as the basis for building regulation, often with local amendment.

As late as the early 1990s, many communities throughout the central and southern United States had not adopted building codes or had adopted building codes that addressed only some of the hazards these communities actually faced. Although the Federal government could not require adoption of appropriate building codes, it could encourage the adoption of such codes through the threat that disaster assistance funds would be withheld from communities that did not adopt reliable building codes, meeting federally adopted standards. This strategy became particularly effective when the three regional model building code development organizations, BOCA, ICBO, and SBCCI combined to from the International Code Council (ICC) and publish the first nationally applicable building code, the *International Building Code* (ICC, 2000). Today, nearly all U.S. communities adopt and enforce building regulation based on one of the International Building Code editions published on a three year cycle since 2000.

Building resilience is a function not only of the structure but also of the architectural, mechanical, electrical, plumbing and other systems that comprise buildings. The International Building Code primarily regulates the design of architectural and structural aspects of buildings and most structural requirements are adopted through reference to consensus standards published by the American Society of Civil Engineers and other industry organizations. Design of mechanical, electrical and plumbing systems are typically regulated through adoption of companion codes and standards including the *International Mechanical Code* (ICC, 2009a), *International Plumbing Code* (ICC 2009b), *International Fire Code* (ICC 2009c) and the National Electrical Code (NFPA, 2011) published by the National Fire Protection Association. The performance intended by these various codes are rarely quantified and typically can be found only in commentary. In some cases, clues as to the intended performance can also be found in *International Performance Code* (ICC, 2009), a rarely-adopted performance-based design code intended to serve as a companion to the other code documents published by ICC. The balance of this paper cites the principal resiliency goals inherent in the present editions of these codes, primarily with regard to resilience to natural hazards and fire.

Occupancy and Risk Categories

Since publication of the 1976 edition of the *Uniform Building Code* (ICBO, 1976) U.S. building codes have recognized that some buildings and facilities are more important to a community's resiliency than others, and therefore, should be designed and constructed to provide better performance under design events. The *International Building Code* and the primary standard referenced by that code for structural design, *ASCE 7.05* (ASCE, 2005) categories buildings and other structures into four Occupancy Categories with tiered performance expectations for each category. Occupancy Category I comprises buildings that present a low risk to human life including barns, storage buildings and other structures that are not normally occupied by humans, do not support processes important to community welfare, and do not contain materials or substance that could present a hazard to the community if released. Occupancy Category II structures and facilities include most ordinary occupancy buildings including most residential, office, retail and industrial structures. These building may house hundreds of people but are regarded as replaceable without gross impact on the community, should individual structures assigned to this category become uninhabitable or be damaged beyond use. Occupancy Category III structures include those that house large numbers of people in close proximity, such as auditoriums and public assembly halls; that house persons society perceives as important to protect, such as school children; that house people with impaired mobility, including prisons; that house modest quantities of potentially hazardous substances or materials, or that house functions important to the community such as water treatment and power generation facilities. Occupancy Category IV encompasses those structures deemed essential to community response to disasters and resilience including hospitals, police and fire stations, emergency communications facilities, and air traffic control facilities.

The most recent edition of the *ASCE 7* (ASCE, 2010) Minimum Design Loads standard, suggest an alternative definition of Occupancy Category, actually termed Risk Category in the standard, that relates to the number of persons who would be placed at risk should the facility fail. Figure 1 below, reproduced in the commentary to ASCE 7.10 indicates that facilities the failure of which would place only a few persons at risk should be classified as Risk Category I. Risk Category II would encompass structures the failure of which would place up to several hundred people at risk; Risk Category III, several thousand and Risk Category IV, tens of thousands. This approach to risk categorization recognizes that not all facilities with common function are equally important. Thus, a fire station, in a City with many fire stations and significant redundancy in firefighting capability might be placed in a relatively low Risk Category, while one the failure of which could result in urban conflagration would be in the highest category. Similarly, small power generation stations, in power grids with significant redundancy would be assigned low Risk Category, while those that produce large portions of a region's power would be in high Risk Categories.

Neither the Occupancy/Risk Category designations contained in ASCE 7.05 and the IBC, nor those in ASCE 7.10, however, address the effect of regional disasters, such as earthquakes or hurricanes, well. Rather, these categories tend to address the performance of individual buildings and structures rather than the entire community's collection of these structures. Thus, under both systems, individual residences are assigned to low protection categories because failure of a single residence will affect very few people. Neglected however, is the fact that destruction of large numbers of these residences in a single community by a single event, for example by a flood, hurricane or earthquake, could jeopardize the very viability of a community. This was graphically illustrated by the effects of Hurricane Katrina on New Orleans, in 2005.

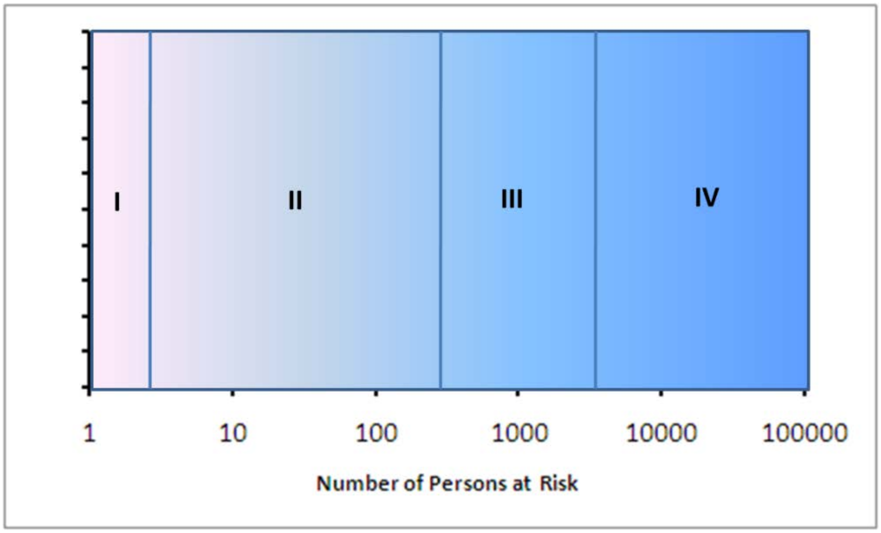

Figure 1 – Definition of Risk Category in ASCE 7.10

Resiliency Goals Inherent in Present Codes

Quantification of the structural resiliency goals for construction inherent in present U.S. building codes is best described in commentary to ASCE 7-10. Loading events considered by this standard include the structure's own weight; live loads associated with the structure's occupancy; rain loads, atmospheric ice loads, earthquake; flooding, other than from tsunami; snow; and winds, other than from tornado. The standard does not presently require or address design either for tsunami flood or tornadic winds. For all of the loads addressed by the standard, except earthquake, ASCE 7-10 seeks to attain failure rates that exceed those shown in Table 1, below. As can be seen, for loads addressed by the code, other than earthquake, the intended reliability is very high, with the potential for load induced collapse ranging from one in several hundred thousand years to one in over a million years. Even when factored by the very large number of buildings present in a major city, this indicates negligible likelihood of structural failure for these loads.

Table 1 – Target Annual Failure Rate for Load other than Earthquake

Risk Category	I	II	III	IV
Individual member or connection	$1.25x10^{-4}$	$3.0x10^{-5}$	$1.25x10^{-5}$	$5.0x10^{-6}$
Progressive failure	$3.0x10^{-5}$	$5.0x10^{-6}$	$2.0x10^{-6}$	$1.0x10^{-7}$

The standard does not seek this same reliability with regard to earthquake resistance primarily because it is perceived that given present day construction technology, and the severity of earthquake loading, it is not presently economically practical to do so. Table 2 summarizes the reliabilities targeted by the standard for earthquake. The probabilities of failure indicated are conditioned on the building experiencing Maximum Considered Earthquake (MCE) effects, having a 2% chance of exceedance in 50 years in most regions of the nation. In regions of very high earthquake activity, however, MCE shaking has exceedance probabilities closer to 5% in 50 years. Thus for ordinary (Category II) structures in most regions of the U.S., the target failure probability is 1% in 50 years, or an annual rate of 2.0×10^{-4}, several orders of magnitude larger than is deemed acceptable for other load types. For communities located in regions of high earthquake risk, like portions of Los Angeles and San Francisco, this annual risk is substantially higher and approaches 1.0×10^{-4}.

Table 2 – Conditional Probability of Failure, given MCE shaking

Risk Category	I	II	III	IV
Failure resulting in individual life loss	25%	25%	15%	10%
Structural Collapse	10%	10%	6%	3%

Not addressed in Tables 1 or 2 are failures that would not result in injury or fatality but which would result in loss of functionality. Such loss of functionality can have extreme impact on a community's resiliency. For Occupancy Category I and II structures, if 10% of the structures affected by MCE shaking can be expected to experience collapse, a far greater number can be expected to experience damage short of collapse, but sufficiently severe that building officials would placard the structures prohibiting their further use until subject to further investigation or repair. Authoritative documentation as to the fraction of Occupancy Category structures that would be declared unsafe following MCE shaking does not exist. This author believes the fraction could be as high as 25%. Clearly the effect on a community's resiliency of the loss of 25% of its residences and businesses would be significant.

A primary reason for the assignment of Occupancy Categories is not only to reduce the risk of structural collapse but also to enhance the probability that important and essential facilities would remain fit for occupancy and use following extreme events such as earthquakes. Commentary to the 2009 *NEHRP Provisions* (BSSC, 2009) suggests that Occupancy Category IV structures, including hospitals and emergency communication centers would be fit for occupancy if not use following Design shaking, having an intensity 2/3 that of Maximum Considered shaking, while they would be fit for actual use in the normal mode only following much less severe shaking. The performance expectation for other Occupancy Categories is less demanding, as illustrated in Figure 2, below, reproduced from *FEMA P750*. Although expressed in qualitative terms in the figure and in the *FEMA P750* commentary, quantification of the probability of attaining these performance goals, either on an event basis or annual basis has never been undertaken.

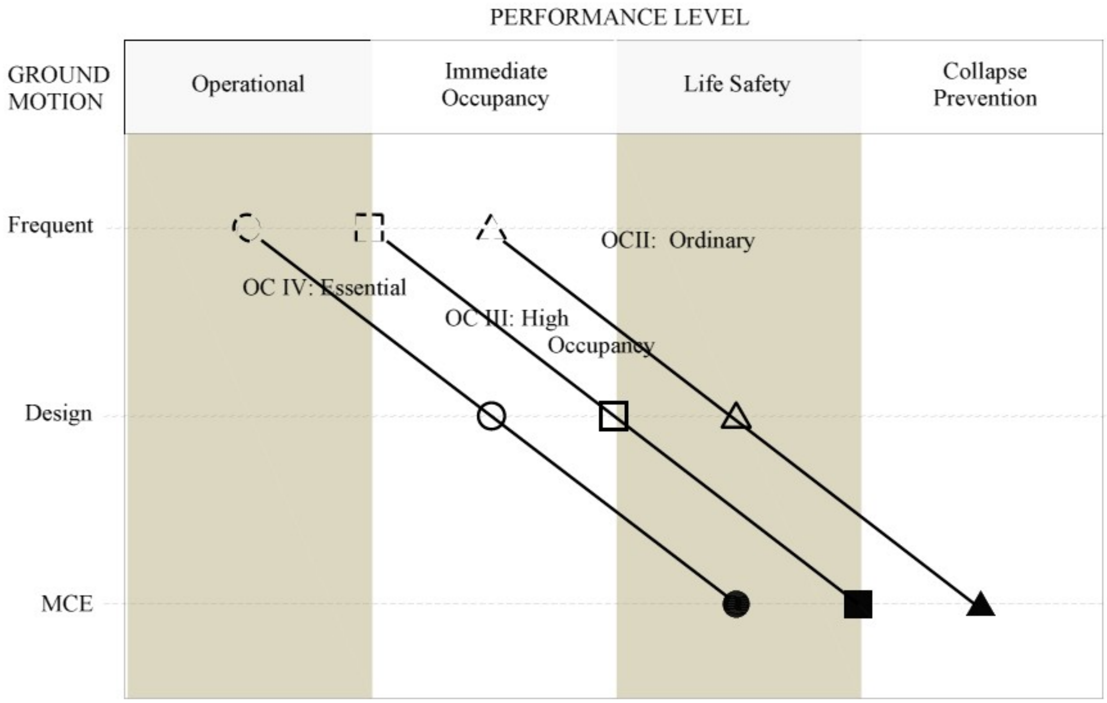

Figure 2 – Seismic performance expectations for buildings of various Occupancy Categories (reproduced from FEMA P750).

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Lifeline Resilience Standards – Approach to Instill Consistent Post Disaster Performance

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Abstract

This white paper is intended to provide a base for open discussion on the need for lifeline performance standards during and after a disaster that impacts a community. The standards establish lifeline performance expectations, which will allow rescue and emergency response groups to plan their activities accordingly. In this paper performance and resilience are used interchangeably.

Lifelines are assumed to be available in any situation by everyone. This is largely a result of the reliable lifeline services in normal times. In North America we are fortunate that normal time happens 99% of the time.

Technology advances render the lifeline systems more complex than a few decades ago. There is not one lifeline system that does not rely on a certain type of computer to function. On top of this, there is lifeline interdependence – operation of one lifeline depending on the operation of another lifeline. For example, a water pump in a water treatment plant requires electric power to operate.

I am sure that there are many approaches to develop a performance standard. The suggestion in this paper is one method or process to achieve the goal of lifeline performance standards. There will be more questions than answers through our discussion.

Lifeline

Lifeline is a collective word of many systems or networks that any society needs to function normally – social, health, law & order, economic, and subsistence.
Lifeline systems or networks are:

1. Telecommunications,
2. Electric Power,
3. Water and Wastewater,
4. Transportation,
5. Ports, and
6. Gas and Liquid Fuel.

Telecommunications includes telephone systems (landline, cellular, and satellite), television systems, and radio systems. Electric power includes power generation, transmission and distribution. Water and Wastewater includes treatment plants, and pipeline and pumping network. Transportation includes roads & highways, bridges, overpasses, railways, metro system, traffic control systems, etc. Ports are seaports and airports. Gas and liquid fuel are storage systems, pipelines (transmission and distribution) and pumping network. The equipment that these systems use to operate is housed in buildings – critical facilities.

All of these complicated systems and networks can be simplified as shown in Figure 1.

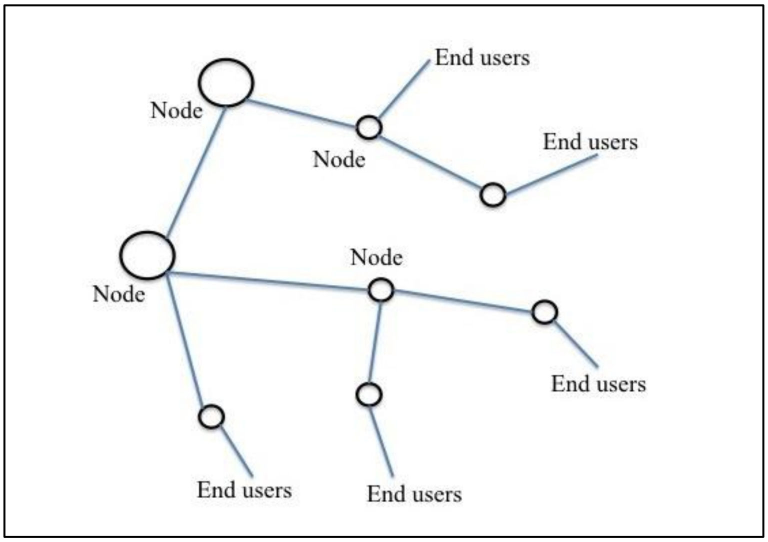

Figure 1 Simplified network diagram

In order to demonstrate the complexity of a lifeline system/network, an electric power system is used as an example. In the electric power system the power generation plant will be a major node. It is connected to a transformer substation by power transmission lines. The substation reduces the voltage to the distribution lines, which connect to individual houses or buildings. There are hundreds of components in this network and each one has to perform within its design parameters (standard) so that the whole system functions properly. Then there is the control system and network that are overlay on top of this network to monitor all nodes and operate the electricity delivery. This control system and network is a telecommunication system. Part of this is privately owned and part of it is outsourced.

The cables that connect the nodes, either transmission or distribution cables, can be either routed underground or aerial via towers or utility poles.

Critical infrastructure is another term of lifeline.

Resilience and Complexity

I have no intention to define the term resilience in this paper. It is just a goal that the lifeline performance standards are heading towards. I am sure that there are many opinions on this subject and resilience will be defined when the boundary of lifeline performance is established. The word resilience means readily recovered from depression without assistance. In lifeline performance terms, we have to define how ‘readily’ is ‘readily’, and what are the intervention(s) of ‘recovered’.

Each lifeline by itself is a complex system and lifeline interdependence creates a higher order of complexity. As a lifeline is spatial, geological factors play another important role in the overall consideration of the system performance. Therefore lifelines in different geological settings may need to have different degree of resilience.

Lifeline Standards Proposed Processes

Within the lifeline community, there exist many standards for the components used in the system/network. These standards are independent of the operation of the system/network. For example, telephone equipment buildings have their own set of requirements.

There are also sub-system standards such as computers, pumps, control systems, etc. With all these are combined, analysis can be performed to identify the weakest link within the system. The weakest link will be the governing factor of the performance of the system. That is the resilience is the weakest link within the lifeline/network.
This is independent of other attributes such as system capacity and dispersed redundancy. The final performance standard must include these attributes.

As the system evolves (either technology changes or additional capacity) the standard must be changed to reflect reality. Therefore a continuous process of reviewing standards and a process of making modification must be put in place.

Approach to Performance Standards

This is one of many ways to achieve the lifeline performance standard. This is based on a number of assumptions. The first assumption is: there is not a common database of standards, guidelines, and practices of each lifeline at the component level. In order to identify ‘what is missing’ is to collect all available standards. Integrating these base standards will help to develop a concept of the performance standard of a particular lifeline. When all these are done for all lifelines, then integrate these concepts within each lifeline to establish a general direction of the performance standard of the lifeline. Then add in the interdependence and geological factors to arrive at the real resilience.
This sounds awfully simple, however the complexity of each lifeline system/network and their inter dependence creates many attributes that govern the final performance standard. In addition, system/network capacity is also part of the equation of the performance standard.

I am going to provide an example in my presentation at the round table based on PSTN[23] network. Hopefully this becomes the base of our discussion to explore how to deal with lifeline performance standard development.

[23] PSTN = Public Switch Telephone Network.

Concerns

Time and effort are the main concerns. The other concern is what and how to guarantee adherence to the standard when a standard is developed.
Finally, shall there be a standard for each hazard?

References

Disaster Resilience: A Guide to the Literature by Stanley W. Gilbert. NIST Special Publication 1117

C. Roundtable Breakout Discussion by Participants

The input from the three breakout sessions was combined and grouped by topic areas. Some items could be grouped under several topic headings, so the groupings are somewhat subjective.

1. How should hazard definitions be modified for multiple performance levels?

- Define all hazards in terms of their frequency of occurrence and magnitude for each performance level.
- Develop consistent hazard definitions for each performance level, with a consistent risk basis for buildings and infrastructure systems.
- Hazard definitions and levels should be developed by experts in hazards and engineering; communities need well-explained guidance and examples.
- Broaden wind event definitions to include tornadoes.
- Develop fire hazard definitions for wildland-urban interface (WUI) and building fires.
- Evaluate the effects of sequential hazard events and accompanying damage (consequences), such as fire following earthquake or flood following hurricane.
- Develop separate hazard definitions and performance levels for new and existing structures.

2. What performance objectives, in addition to life safety and usability (operability), are needed to promote community resilience?

- Develop criteria for issues of adjacency of buildings (damage or failure in a building should not affect adjacent buildings).
- Include floor burnout without collapse for building fire hazards (assumes services not available to fight fire).
- Develop a methodology that will consider deterioration/aging effects on resilience and the increased likelihood of disruption to community functionality.
- Consider differences in performance criteria for urban vs. rural areas due to the population and ‘built’ density.
- Balance the challenge (competing demands) between mitigation and recovery planning.
- Identify practices for preparing structures for the future (different) uses.
- Link resilience to sustainability and its recognized benefits.

- Develop guidelines to help communities determine the relative importance of facilities to the community resilience.
- Adoption and enforcement of current codes and standards would contribute to improved performance as well as routine inspections during construction to ensure compliance.
- Design and evaluate all building systems for meeting criteria for usability (operability) and functionality (e.g., if the structure survives and the envelope fails – the building is nonfunctional).
- Recognize redundancy in building and lifeline systems and its role in resilience.
- Develop comprehensive design standards for buildings that address all building systems.
- Review approach to man-made hazards (e.g., industrial accidents) addressed with fail-safe systems.
- Develop performance and recovery objectives for hazard events that also meet customer service objectives for lifelines.
- Determine the interaction and interdependence of lifelines on a systems level
    - prioritize performance levels for lifeline components for community resilience needs
    - address co-location impacts on community resilience (e.g., a bridge carrying utility lines)
- Evaluate the transfer of risk from one community to another when changes are made to the built environment. For example, consider how flood events interact with engineered controls (urban development, dams and levees) and resulting consequences (e.g., lack of drainage increases flood frequency, constrained flow areas lead to more frequent overtopping).

OBSERVATIONS

- Codes could emphasize: (1) property conservation (reduced damage after hazard events); (2) mission (business) continuity; and (3) better tools to enforce codes.
- TISP Regional Resilience Guide provides a process for considering resilience planning at the regional scale.
- High end resilience standards can be developed for reference as an option by the codes.
- Develop options for flexibility in lifeline standards so communities can adapt them for their needs.
- A series of comprehensive standards needs to be developed to address each type of infrastructure system.
- A community process is needed that guides zoning and planning for resilience.

- Consider recommended principles in the ASCE Guiding Principles: Leadership and Stewardship responsibility of the engineering community.
- Some communities will have to want to become resilient – leaders or drivers of the process are needed to demonstrate the benefits.
- Communities and the private sector need to be persuaded/convinced to spend money in advance for disasters that may be far in the future.
- Challenges and gaps are relatively small for technical issues and big for political issues.
- Retroactive requirements will be difficult for the community to accept.
- The as-built condition often does not match the as-designed condition.

3. What metrics and vocabulary is needed to describe building and infrastructure performance in terms of response and recovery?

VOCABULARY

- Definitions of successful performance levels and recovery times
- Definition of levels for state/community adoption and enforcement of most recent codes and standards
- Rebuilding vocabulary and metrics to measure progress of recovery
- Tend not to talk about risk. DHS risk lexicon. Need to get risk lexicon into our discussions. Safety factors not enough.
- Politics play a significant role in decision-making. Political leaders should set the definition to ensure consideration of existing work in this area and to get community involvement in the process.
- Need to include the word “durability” in discussions of resilience.
- Develop methods to communicate what performance levels mean to the technical and nontechnical communities.
- Educate technical and nontechnical communities on hazard definitions.
- Understand resilience message content vs. how it is conveyed to the affected groups.
- Clearly communicate hazards between code/standard bodies and policy makers.
- Include insurance industry in resilience research as they can play a significant role in communicating importance of resilience and have the data to inform the discussion.

METRICS

- Resilience ‘component’ measures for individual homes, buildings, infrastructure
- Cost-benefit or other economic measure for recovery costs for existing building stock

- Guidelines for communities/regions/states to determine hazards and resilience performance levels for buildings and infrastructure
    - New construction
    - Existing construction
- Overall levels of community resilience – can be used to encourage businesses wanting resilience
- Develop regional analyses with loss estimation tools for all types of disasters.
- From a standards and codes perspective
    - how will the 'stovepiped' standards and codes be integrated to a consistent 'systems' approach to codes and standards (how to avoid ALA problems?)
    - how will changes to one standard be evaluated to avoid adverse impacts to other standards or overall resilience
- Ensure that any incremental improvement for resilience is consistent with the incremental cost.
- Tie disaster relief with requirements for community improvements for resilience
- Include social impact and costs to homes, businesses, and government for consequences.

OBSERVATIONS

- Resilience is an outcome of the design process.
- Has to be a reward for implementing resilience.

4a. What can be done in the short-term to improve codes and standards for buildings to implement concepts of resilience (in the next 3 yrs)?

VOCABULARY

- Develop definitions of multiple performance levels for resilient facilities.
- Resilience should be defined for various levels as communities and hazard events are not all equal. Examples of resilience levels and resilient communities should be developed for communication with communities.

METRICS

- Develop a way to convey resilience value for builders and communities (e.g., an example is the Fortified program for homes by IBHS)
- Develop rigorous performance criteria for non-structural systems in buildings.
- Address the performance of the building envelope as it often fails in wind and rain events (e.g., to hurricane prone regions).
- Develop a building commissioning process where certain features must be present and/or functioning before the building is considered a resilient facility.

- Establish a voluntary building rating system for evaluating resiliency that addresses multiple hazards (this could be a possible basis for the resilience star concept).
- Establish levels of resilience star ratings, where as a minimum the facility or system must meet current codes and standards, such as the International Building Codes (IBC) code requirements for buildings or AASHTO standard requirements for transportation systems.
- Develop a voluntary resilience rating system, such as the resilience star rating, to be useful for marketing facilities and buildings, similar to the LEEDS criteria in place today.

DATABASE

- List the performance criteria in present codes and standards for all hazards and construction types/systems.
- Develop a public database of loads and construction technology for all hazards and construction types to identify gaps in current practice within sectors and between sectors (e.g., build on FEMA's Hazus data).

PERFORMANCE GOALS

- Develop an example of community performance goals for other communities to follow, such as the San Francisco Planning and Urban Research (SPUR) Association initiatives.
- Develop performance goals and objectives for resilient systems that could be published in standard commentaries (e.g., Public Welfare goal in NFPA codes).
- Address subsystem failures (e.g., sprinkler system) when considering the performance of building and infrastructure systems after an event.

STANDARDS

- Develop a commentary or appendix on resilience for inclusion in existing standards for voluntary reference.
- Encourage the adoption and enforcement of building codes and design standards, without amendments that make the local code less stringent than the model code.
- Consider larger load requirements to improve robustness and support re-occupancy after an event.

4b. What long term improvements are needed?

METRICS

- Develop measures of performance for resilience that can be used when upgrading existing buildings.

PERFORMANCE LEVELS

- Develop more accurate procedures for analyzing structures to enable use of defined levels of structural performance for resilience.

STANDARDS

- Develop standards for performance of envelope and building systems that is consistent with structural performance levels.
- Develop standards for total building performance.

PERFORMANCE GOALS

- Establish an improved federal disaster aid program by creating two distinct components: humanitarian and economic. The economic assistance (rebuilding city hall, etc.) should not be available if reasonable efforts to mitigate the damages have not been taken by the community in advance. Why will anyone spend money on mitigation if the risk is shifted to a higher level of government?

4c. What technical basis is required to support long-term improvements?

METRICS

- Develop a methodology for considering community level cost-benefits for resilient features.
- Develop a technical basis for building system standards and interaction of building systems.

5a. What can be done in the short-term to improve codes and standards for infrastructure systems to implement concepts of resilience?

VOCABULARY

- Develop a document to define terms related to resilience for infrastructure systems.

METRICS

- Include resilience in ASCE report card on infrastructure.

DATABASE

- Identify differences between state transportation system standards and national AASHTO standards

PERFORMANCE GOALS

- Hold forums for interactions about resilience among lifelines professionals, public health, public safety, and engineers.
- Establish utility councils to identify interdependencies between infrastructure systems for selected cities.

STANDARDS

- Encourage adoption of current AASHTO standards by states DOTs.

5b. What long term improvements are needed?

PERFORMANCE GOALS

- Develop a system-wide, interdependency approach to all lifeline systems.
- Develop criteria for consistent performance for hazard events within segmented industries (e.g., power generation, transmission, distribution)

PERFORMANCE LEVELS

- Address the existing condition of infrastructure and its continuing decline.
- Address tolerated decline in infrastructure performance over time through performance measures and capital reinvestment approaches.
- Identify gaps and possible solutions for community resilience (recovery) from review of best practices used by supply chains for business continuity.
- Create environment and policies where competitors would cooperate to keep lifeline services available for hazard events.
- Create reliability councils for other lifeline systems, beyond electric power, to support establishment of resilience criteria.

STANDARDS

- Modify current standards to address systems, not just components, and hazard events that can cause multi-point failures.
- Develop national resilience standards for light rail transit, fuel pipelines, and other lifeline systems.

5c. What technical basis is required to support long-term improvements?

METRICS

- Use Presidential Policy Directive 8: National Preparedness and the revised CIKR criteria to help define resilience goals, system definitions, and mitigation and response criteria.

DATABASE

- Develop a database of building and infrastructure systems to collect a body of knowledge for multiple purposes.

PERFORMANCE GOALS

- Promote the creation of resilience metrics, tools, and standards.

PERFORMANCE LEVELS

- Develop a way to link infrastructure resilience documents to address community resilience and infrastructure interdependence issues.
- Develop a list of technical gaps for systems that are not currently being designed for hazards.

D. Standards for Disaster Resilience Workshop Participants

Co-Chairs

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Elizabeth English	University of Waterloo School of Architecture
Steve Ernst	Federal Highway Administration (FHWA)
Gordon Gillerman	National Institute of Standards and Technology (NIST)
Sandra Gogol	U.S. Department of Homeland Security (DHS)
David Goldbloom-Helzner	U.S. Environmental Protection Agency
Pamela Greenlaw	U.S. Department of Homeland Security (DHS)
James Harris	JR Harris Company
Dan Howell	FM Global
Tasha Johnson	AASHTO
David Karmol	International Code Council (ICC)
Kristin Korte	FLIR Systems
John Kulick	Siemens USA
Richard Lake	ASTM International
Hai Lew	National Institute of Standards and Technology (NIST)
Alison Littlepage	U.S. Department of Homeland Security (DHS)

Jennifer Marshall	National Institute of Standards and Technology (NIST)
Jon Martin	National Institute of Standards and Technology (NIST)
Evette Maynard-Noel	U.S. Department of Homeland Security (DHS)
Terri McAllister	National Institute of Standards and Technology (NIST)
Nancy McNabb	National Institute of Standards and Technology (NIST)
David McWhorter	Catalyst Partners
Kalpesh Patel	U.S. Department of Homeland Security (DHS)
Will Peart	William H. Gordon Associates, Inc.
Chris Poland	Degenkolb Engineers
Nancy Pomerleau	U.S. Department of Homeland Security (DHS)
Irmak Renda-Tanali	University of Maryland University College
James Rossberg	American Society of Civil Engineers (ASCE)
Fahim Sadek	National Institute of Standards and Technology (NIST)
Woody Savage	University of Nevada Las Vegas
Fran Schrotter	American National Standards Institute (ANSI)
Everett Sedgwick	Federal Emergency Management Agency (FEMA)
Peter Shebell	U.S. Department of Homeland Security (DHS)
Steve Skalko	Portland Cement Association
Robert Stenner	Pacific Northwest National Laboratory (PNNL)
Kaan Tanali	Weidlinger Associates
William Taylor	Washington Metropolitan Area Transit Authority (WMATA)
Robert Vondrasek	National Fire Protection Association (NFPA)
Randy Wagoner	Federal Emergency Management Agency (FEMA)
Erin Walsh	U.S. Department of Homeland Security (DHS)
Jefferson Welch	Carnegie Mellon Software Engineering Institute
Heiko Werner Federal	Agency for Technical Relief (THW) - Germany
Marcus Williams	Homeland Security Studies and Analysis Institute
Kevin Wong	National Institute of Standards and Technology (NIST)
Robert Zimmerman	Homeland Security Studies and Analysis Institute

E. Presentations for Standards for Disaster Resilience Workshop

Workshop on Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems

November 10, 2011

Panel 1 – Introduction to Resilience of the Built Environment

- **Therese McAllister, NIST:** Introduction to Resilience for Buildings and Infrastructure Systems
- **Chris Poland, Degenkolb Engineers:** Community Planning for Resilience – SPUR

Panel 2 – Focus on Building Systems

- **Jim Harris, JR Harris Company:** Standards for Building Systems
- **Dan Howell, FM Global:** Insurance Perspective on Building and Infrastructure Resilience

Panel 3 – Focus on Lifelines

- **Woody Savage, University of Nevada Las Vegas:** Standards for Electric Power Systems
- **Steve Ernst, FHWA:** Standards for Transportation Systems
- **Don Ballantyne, Degenkolb Engineers:** Standards for Water and Wastewater Systems

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ANSI Homeland Security Standards Panel Workshop on:
Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems

Introduction to Resilience in the Built Environment

Therese McAllister, PE, PhD

10 November 2011

NIST National Institute of Standards and Technology U.S. Department of Commerce

Workshop Goals

- Identify gaps in current practice, standards, and codes that need to be addressed to enable resilient buildings and infrastructure.
- Develop a framework for the development of standards and codes for resilient buildings and infrastructure systems .

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What is the Problem?

- The Built Environment Fails in Disaster Events Repeatedly
  - The Stafford Act authorizes the President to issue a **major disaster declaration** for federal aid to states overwhelmed by natural hazards or other catastrophes.
  - The Stafford Act authorizes temporary housing, grants for immediate needs of families and individuals, the **repair of public infrastructure**, and emergency communication systems
  - Congress appropriated over $10 billion to the Disaster Relief Fund in FY2005, for the four hurricanes that struck Florida in 2004.
- Performance of the built environment is dependent on the codes and standards in place at the time of construction, enforcement, maintenance, and operation
- The built environment is highly interconnected; current codes and standards are generally independent and do not account for this interconnectedness

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Defining the Built Environment

- Buildings (engineered and non-engineered)
  - All systems necessary for intended function
  - Architectural, structural, life safety, mechanical, electrical, plumbing, security, communication and IT systems
- Infrastructure or lifelines
  - Transportation - roads, bridges, tunnels, ports, rail
  - Utility plants and distribution systems - electric power, water and wastewater, fuels, communication

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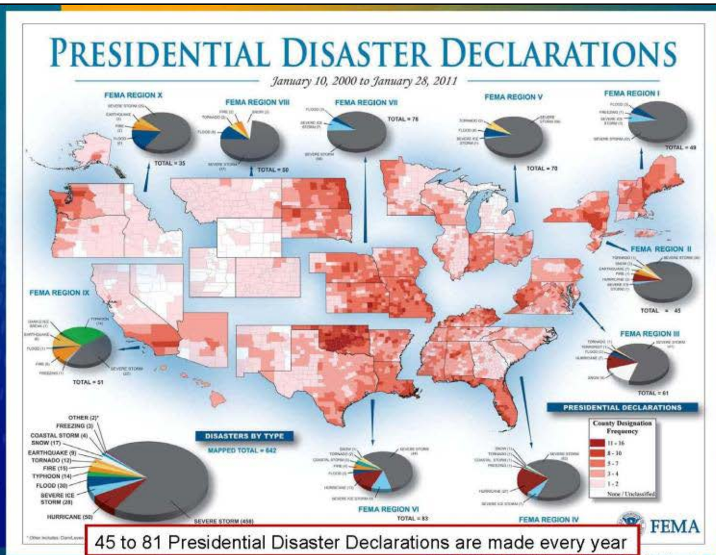
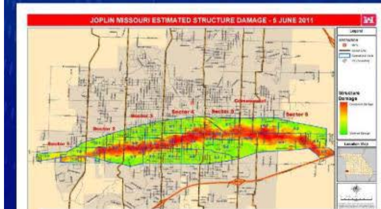


Joplin, MO EF5 Tornado
22 May 2011

- Damage zone was about 0.75 to 1 miles (1.2 to 1.6 km) wide
- About 8000 houses, 18000 cars, and 450 businesses were destroyed
- St. John's Regional Medical Center had exterior damage and water intrusion
  - Facility will be demolished and relocated
  - Surrounding structures nearly all destroyed
- Communications and power were lost to many areas
- Cost to rebuild Joplin could reach $3 billion



USACE Map of Structural Damage

St John's Regional Medial Center

Severe Storm in East Central Iowa
11 July 2011

Wind Event

- NWS storm survey teams assessed damage and estimated wind speeds up to 110 to 130 mph

Damage

- Wide spread power outages and downed power lines
- Many roofs were partially or fully removed
- Walls of some buildings collapsed

2011 Drought and Water System Failures
Summer 2011

Deteriorating Infrastructure

- Older pipes are more susceptible to bursting due to combined effects of
  - Dried soils shrink away from buried pipes
  - Increased usage raises internal water pressure
- Burst rate of water pipes has risen in CA, KS, OK, TX, IN, KY, and NY
  - Aug 14, 2011 - Oklahoma City had 685 water main breaks at ~4 times normal rate.
  - Aug 23, 2011 – Houston had 847 water leaks, more than 3 times the normal.
- American Water Works Association (AWWA) projects that
  - Many water systems are 80 to 100 years old
  - Water utilities nationwide need to be replaced

Category 1 Hurricane Irene 27-28 August 2011

Storm progress

- First landfall at Outer Banks, NC
- Second landfall at Little Egg, NJ
- Third landfall as a tropical storm at Brooklyn, NY

Wind and flood damage

- Over 40 million people were affected
- Over 6 million homes and businesses lost power
- New Jersey flooded roads were impassable and train lines were shut down
- Vermont had over 260 roads and bridges damaged
- Insured losses are ~$2 to 6 billion and total losses are ~$7 to 10 billion

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2011 Northeast Snow Storm 29-30 October 2011

- First October snow fall over 1 inch since record keeping began in 1860
  - Maryland to Maine
  - Up to 32 in. of heavy wet snow
- Over 3,000,000 homes and businesses lost power (NJ, CN, MA)
  - Fallen trees blocked roads and damaged distribution lines
  - 1,000,000 without power 4 days later.
  - 50,000 without power in Connecticut 10 days later.
- Causes for slow rate of restoration are being examined
  - Conn. Governor launched probe of utility response
  - US Senators Lieberman and Blumenthal called for reviews of preparedness and response

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Fire Following Earthquake

2008 Report for USGS and CA Geological Survey

- Ignitions would be 50% electrical , 25% gas, and 25% other causes (1994 Northridge earthquake)
- Refineries can have large fires that burn for days (2003 M8 Tokachi-oki, Japan EQ)
- Lifelines—water supply, electric power, communications, transportation—are needed to fight fire following earthquake
- Economic and business continuity impacts will be high if there are FFE

2003 Tokachi-oki Earthquake

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What is Resilience?

Department of Homeland Security (DHS) Risk Lexicon, 2010

Definition: ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption

Sample Usage: The county was able to recover quickly from the disaster because of the resilience of governmental support systems.

Extended Definition: ability of systems, infrastructures, government, business, communities, and individuals to resist, tolerate, absorb, recover from, prepare for, or adapt to an adverse occurrence that causes harm, destruction, or loss

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Resilience in the Built Environment

- Maintain or restore the functionality of community buildings and infrastructure systems after a hazard event within a prescribed timeframe.
- Includes ability to prepare, mitigate, resist, and recover.

Physical Infrastructure	Social, Environmental, Economic
Critical Facilities Government Businesses Homes	Emergency Management Shelter Food Supplies
Power Transportation Water Communication Fuel	Governance Social services Healthcare Economy Natural resources

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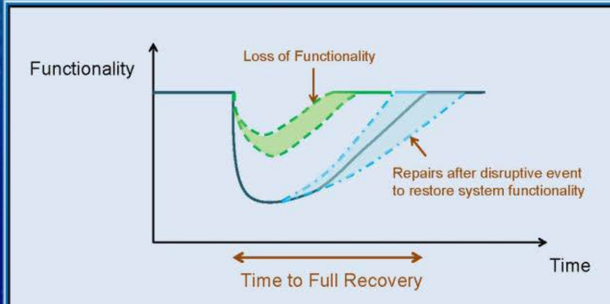
Resilience Concept for the Built Environment

- Maintain acceptable levels of functionality during and after disruptive events
- Recover full functionality within a specified period of time



Adapted from McDaniels, et al 2008 and Bruneau, et al 2003

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Formative Events and Government Responses for Resilience

Hurricane Andrew 1992 — WTC Disaster 2001 — Hurricane Katrina 2005

- 1993: **FEMA** Natural hazards *Prepare, mitigate, respond, recover*
- 2001: **Patriot Act** Security against terrorism
- 2003: **National Strategy for Physical Protection** Security for Critical Infra-structure & Key Resources
- **HSPD-7 Critical Infrastructure Identification, Prioritization, and Protection** Policy for Federal Departments
- 2005/2008: **Grand Challenges for Disaster Reduction** Reduce vulnerability of critical infrastructure *Hazards, vulnerability, risk assessment*
- 2009: **National Infrastructure Protection Plan (NIPP)** All hazards for Critical Infrastructure & Key Resources

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Critical Infrastructure & Key Resources (CIKR)

National Strategy for the Physical Protection of Critical Infrastructures and Key Assets (2003)

Strategic Objectives

- Identify and assure the protection of assets, systems, and functions deemed most critical for national public health and safety, governance, economic and national security, and public confidence.
- Assure the protection of infrastructure and assets that face a specific, imminent threat.
- Pursue collaborative measures and initiatives to assure the protection of other potential targets that may become attractive over time.

Critical Infrastructure Sectors

1. Agriculture and Food
2. Banking and Finance
3. Chemical Industry and Hazardous Materials
4. Communications
5. Critical Manufacturing
6. Defense Industrial Base
7. Emergency Services
8. Energy
9. Healthcare and Public Health
10. Information
11. Postal and Shipping
12. Transportation Systems
13. Water

Key Assets/Resources

1. Commercial Facilities
2. Dams
3. Government Facilities
4. National Monuments and Icons
5. Nuclear Reactors, Materials, Waste

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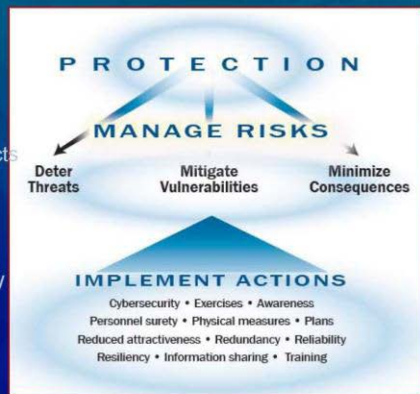
DHS National Infrastructure Protection Plan (NIPP 2009)

Overarching goal:

Build a safer, more secure, and more resilient America

- Prevent or mitigate the effects of terrorist acts
- Strengthen national preparedness, timely response, and rapid recovery of CIKR

in the event of an attack, natural disaster, or other emergency.



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Private Sector Responses for Resilience

2009

American Society of Civil Engineers (ASCE)
Critical Infrastructure Guidelines

American Society of Mechanical Engineers (ASME)
Prioritizing Critical Infrastructure Security/Resilience

American Water Works Association (AWWA)
All Hazards Consequence Management Plan

Technical Council on Lifeline Earthquake Engineering (TCLEE) Conference on Lifeline Earthquake Engineering in a Multi-Hazard Environment

2010

The Infrastructure Security Partnership (TISP)
White Paper on Infrastructure Resilience & Interdependencies

Pacific Earthquake Engineering Research Center (PEER)
Guidelines for Performance Based Seismic Design of Tall Buildings

2011

National Research Council
National Earthquake Resilience

Examples of:
- More than security
- Uniform facility risk
- Plans for recovery from damage
- Systems interdependencies

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Standards Supporting Resilience

2006

ASCE 41-06
Seismic Rehabilitation of Existing Buildings
Performance-based seismic rehabilitation methodology

ASTM E 2506-06
Standard Guide for Developing a Cost-Effective Risk Mitigation Plan for New and Existing Constructed Facilities

2009

ANSI/ASME-ITI/AWWA J100
RAMCAP® Standard for Risk and Resilience Management of Water and Wastewater Systems

2010

ASCE 7-10
Minimum Load Requirements for Buildings and Other Structures
Performance-based procedures and risk consistency

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ASCE 7-10 Risk Category for Buildings and Other Structures

Risk Category	Use or Occupancy
I	Unoccupied or low risk to public
II	All others
III	House large numbers of people (assembly uses, theatres), or those with limited mobility (elementary schools, healthcare), or community utilities (power, water, wastewater, communications) or hazardous materials
IV	Essential community service facilities (hospitals, police and fire stations, emergency communications)

Occupancy category in codes relates to fire and life safety protection issues

Risk category relates structural failure and life safety or welfare

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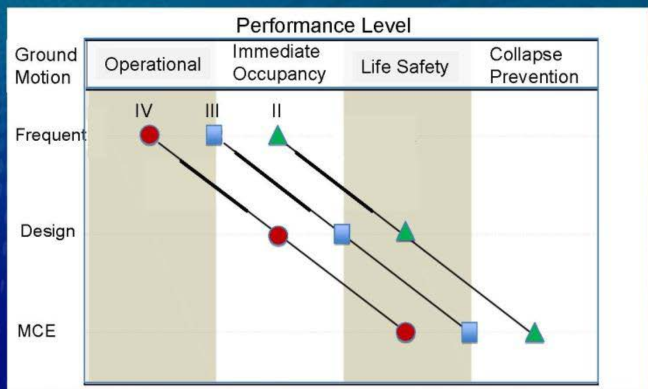
Seismic Performance Levels for Buildings
FEMA P750



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Example of a Risk Consistent, Performance-Based Standard for Structures and Seismic Hazards

Target Structural Performance Levels (ASCE 41-06)

	Collapse Prevention	Life Safety	Immediate Occupancy	Operational
Damage Level	Severe	Moderate	Light	Very Light
General Structural Performance	Little residual stiffness and strength, but load bearing walls and columns function. Large permanent drifts.	Some residual strength and stiffness in all stories. Gravity load bearing elements function. No out of plane failures, some permanent drift.	No permanent drift, most of original strength and stiffness in all stories. Elevators and fire protection functional.	No permanent drift, most of original strength and stiffness in all stories. All systems important for operation are functional.
Nonstructural Component Performance	Extensive	No falling hazards; architectural damage; many utilities damaged	Equipment and contents secure, but may not operate	Negligible damage. May need to use backup systems.

What is Needed to Achieve Resilient Communities?

Status Quo

- Prescriptive codes and standards for life safety
- Poor building and infrastructure resilience performance during hazard events
- Emergency response planning but little community resilience planning
- Reliance upon federal disaster funding for recovery

Moving Forward

- Risk consistent, performance based codes and standards for resilience
- Comprehensive approach to design guidance for built environment
- Proactive planning by communities to achieve resilience
- Reduced emergency response and recovery costs

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San Francisco Planning + Urban Research Association
a member-supported nonprofit organization
SPUR IDEAS AND ACTION FOR A BETTER CITY

Community Performance Goals

SPUR planning for community resilience to a major earthquake

- Establish clear goals and performance objectives for disaster recovery
- Take steps now toward resilience
- Create a culture of preparedness
- Plan for long-term building

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SPUR Target Performance States

TARGET STATES OF RECOVERY

Performance measure	Description of usability after expected event: BUILDINGS	LIFELINES
(lightest shade)	Category A: Safe and operational	
(medium shade)	Category B: Safe and usable during repairs	100% restored in 4 hours
(darkest shade)	Category C: Safe and usable after moderate repairs	100% restored in 4 months
X	Expected current status	

TARGET STATES OF RECOVERY FOR SAN FRANCISCO'S BUILDINGS AND INFRASTRUCTURE

INFRASTRUCTURE CLUSTER FACILITIES	Event occurs	Phase 1 Hours			Phase 2 Days		Phase 3 Months		
		4	24	72	30	60	4	36	36+
CRITICAL RESPONSE FACILITIES AND SUPPORT SYSTEMS									
Hospitals								X	
Police and fire stations			X						
Emergency Operations Center									
Related utilities						X			
Roads and ports for emergency				X					
CalTrain for emergency traffic					X				
Airport for emergency traffic				X					
EMERGENCY HOUSING AND SUPPORT SYSTEMS									
95% residence shelter-in-place								X	
Emergency responder housing				X					
Public shelters							X		
90% related utilities								X	
90% roads, port facilities and public transit							X		
90% Muni and BART capacity						X			
HOUSING AND NEIGBORHOOD INFRASTRUCTURE									
Essential city service facilities							X		
Schools							X		
Medical provider offices								X	
90% neighborhood retail services									X
95% of all utilities								X	
90% roads and highways						X			
90% transit						X			
90% railroads							X		

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What is Needed to Achieve Resilient Communities?

- Community Performance Goals
  - Performance goals with target states of recovery
  - Performance levels
  - Hazard levels
- Codes and Standards
  - Definitions and metrics for resilience
  - Risk consistent, performance based methodologies
  - Guidelines and pre-standards

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Thank You

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Building Standards for Earthquake Resilient Communities

Unified support is required from all Earthquake Professionals

- Design Professionals need to join the conversation about achieving resiliency
- Transparent design codes based on standards for new and existing buildings and all lifeline systems need to be developed
- Research needs an expanded focus

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems. November 10, 2011

Community Planning for Resilience SPUR

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems

November 10, 2011

Chris D. Poland, SE, FSEAOC, NAE
Chairman & Senior Principal
Degenkolb Engineers

SPUR
SAN FRANCISCO PLANNING + URBAN RESEARCH ASSOCIATION

The Resilient City:

Defining what San Francisco needs from its seismic mitigation policies for three phases

Before the Disaster, Response, Recovery

www.spur.org

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Seismic Mitigation Task Force

Urban Planners:	Laurie Johnson, George Williams
City Officials:	Laurence Kornfield, Hanson Tom, Debra Walker
Public Policy Makers:	Sarah Karlinsky, Laura Dwelley-Samant, Tom Tobin
Engineers:	Chris Barkley, David Bonowitz, Joe Maffei, Jack Moehle, Robert Pekelnicky, Chris Poland
Labor:	Michael Theriault
Developers:	John Paxton, Ross Asselstine
Economist:	Jessica Zenk
Contractor:	Jes Penderson
PG&E:	Kent Ferre

A unique gathering of Earthquake professionals and Stakeholders

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems. November 10, 2011

Healthy Cities

Require jobs, heritage, urban planning, progressive governance, sustainability and disaster resilience

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Earthquake Resilient Communities

Requires a Holistic Approach

- Physical Resilience is the foundation
- Environmental sustainability is a parallel goal – eliminate the deconstruct/reconstruct cycle.
- Integrated with urban design
- Supportive of Social issues
- Conscience of Institutional and governance constraints
- Supported by new financial mechanism and incentives

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Earthquake Resilient Communities

Physical Resilience

- A place, ability and procedures to govern
- Building and lifeline design standards that support continuity and recovery
- Repair standards for reconstruction

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How Much Damage Can a City Endure?

Haiti - 2010

Katrina - 2005

Chile - 2010

L'Aquila - 2009

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Approach:

- Define concept of ***resilience*** in the context of disaster planning and recovery, not a measure of the status
- Establish ***performance goals*** for the physical infrastructure for the **"expected"** earthquake that supports the definition of resilience
- Define transparent ***performance measures*** that help reach the performance goals

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Performance Goals for the "Expected" Earthquake

Phase	Time Frame	Condition of the built environment
I	1 to 7 days	Initial response and staging for reconstruction
II	7 to 60 days	Workforce housing restored – ongoing social needs met
III	2 to 36 months	Long term reconstruction

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems. November 10, 2011

Transparent Hazard Definitions

Category	Hazard Level
Routine	Likely to occur routinely
Expected	Reasonably expected to occur once during the useful life of a structure or system
Extreme	Reasonably be expected to occur on a nearby fault

Transparent Performance Measures for Buildings

Category	Performance Standard
Category A	***Safe and operational:*** Essential facilities such as hospitals and emergency operations centers
Category B	***Safe and usable during repair:*** "shelter-in-place" residential buildings and buildings needed for emergency operations
Category C	***Safe and usable after repair:*** current minimum design standard for new, non-essential buildings
Category D	***Safe but not repairable:*** below current standards for new buildings, often used for voluntary retrofit
Category E	***Unsafe – partial or complete collapse:*** damage that will lead to casualties in the event of the "expected" earthquake - the killer buildings

What is Safe?
What is Useable?

Observed Damage
L'Aquila, Italy
May 2009

ATC 20 Tagging

Green tag – May be used for continuous occupancy

Yellow tag – Safe enough to remove contents and do repair work

Red tag – Unsafe for entry during aftershock sequence

Transparent Performance Measures for Lifelines

Category	Performance Standard
Category I	Resume 100% service within 4 hours
Category II	Resume 90% service within 72 hours
	95% within 30 days
	100% within 4 months
Category III	Resume 90% service within 72 hours
	95% within 30 days
	100% within 3 years

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems. November 10, 2011

Target States of Recovery for San Francisco's Building & Infrastructure

Phase	Time Frame	Focus of Attention
I	1 to 7 days	Initial response and staging for reconstruction

EOC's,

City Buildings,

Hospitals,

Police and Fire Stations,

Shelters

San Francisco General Hospital

Building Category A: "Safe and Operational"

Life Line Category I: "Resume essential service in 4 hours"

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems. November 10, 2011

Target States of Recovery for San Francisco's Building & Infrastructure

Phase	Time Frame	Focus of Attention
II	7 to 30 days	Workforce housing restored – ongoing social needs met

Residential structures,

Schools,

Community retail centers,

Doctors offices

Building Category B: "Safe and usable while being repaired"

Life Line Category II: "Resume 100% workforce service within 4 months"

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems. November 10, 2011

Target States of Recovery for San Francisco's Building & Infrastructure

Phase	Time Frame	Focus of Attention
III	2to 36 months	Long term reconstruction

Industrial Buildings

Commercial buildings

Historic buildings

Building Category C: "Safe and usable after repair"

Life Line Category III: "Resume 100% commercial service within 36 months"

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems. November 10, 2011

Target States of Recovery for San Francisco's Building & Infrastructure

Phase I

TARGET STATES OF RECOVERY FOR SAN FRANCISCO'S BUILDINGS AND INFRASTRUCTURE

INFRASTRUCTURE CLUSTER FACILITIES	Event occurs	Phase 1 Hours 4	Phase 1 Hours 24	Phase 1 Hours 72	Phase 2 Days 30	Phase 2 Days 60	Phase 3 Months 4	Phase 3 Months 36	Phase 3 Months 36+
CRITICAL RESPONSE FACILITIES AND SUPPORT SYSTEMS									
Hospitals								X	
Police and fire stations			X						
Emergency Operations Center	X								
Related utilities						X			
Roads and ports for emergency				X					
CalTrain for emergency traffic					X				
Airport for emergency traffic				X					
EMERGENCY HOUSING AND SUPPORT SYSTEMS									
95% residence shelter-in-place								X	
Emergency responder housing				X					
Public shelters							X		
90% related utilities								X	
90% roads, port facilities and public transit							X		
90% Muni and BART capacity						X			

TARGET STATES OF RECOVERY

Performance measure	Description of usability after expected event: BUILDINGS	LIFELINES
	Category A: Safe and operational	
	Category B: Safe and usable during repairs	100% restored in 4 hours
	Category C: Safe and usable after moderate repairs	100% restored in 4 months
	Category D: Safe and usable after major repairs	100% restored in 3 years
X	Expected current status	

Note: Categories A–D are defined on page 10.

Target States of Recovery for San Francisco's Building & Infrastructure

Phase II

TARGET STATES OF RECOVERY FOR SAN FRANCISCO'S BUILDINGS AND INFRASTRUCTURE

INFRASTRUCTURE CLUSTER FACILITIES	Event occurs	Phase 1 Hours 4	Phase 1 Hours 24	Phase 1 Hours 72	Phase 2 Days 30	Phase 2 Days 60	Phase 3 Months 4	Phase 3 Months 36	Phase 3 Months 36+
HOUSING AND NEIGBORHOOD INFRASTRUCTURE									
Essential city service facilities							X		
Schools							X		
Medical provider offices								X	
90% neighborhood retail services									X
95% of all utilities								X	
90% roads and highways						X			
90% transit						X			
90% railroads							X		
Airport for commercial traffic					X				
95% transit							X		

TARGET STATES OF RECOVERY

Performance measure	Description of usability after expected event: BUILDINGS	LIFELINES
	Category A: Safe and operational	
	Category B: Safe and usable during repairs	100% restored in 4 hours
	Category C: Safe and usable after moderate repairs	100% restored in 4 months
	Category D: Safe and usable after major repairs	100% restored in 3 years
X	Expected current status	

Note: Categories A–D are defined on page 10.

Target States of Recovery for San Francisco's Building & Infrastructure

Phase III

TARGET STATES OF RECOVERY FOR SAN FRANCISCO'S BUILDINGS AND INFRASTRUCTURE

INFRASTRUCTURE CLUSTER FACILITIES	Event occurs	Phase 1 Hours 4	Phase 1 Hours 24	Phase 1 Hours 72	Phase 2 Days 30	Phase 2 Days 60	Phase 3 Months 4	Phase 3 Months 36	Phase 3 Months 36+
COMMUNITY RECOVERY									
All residences repaired, replaced or relocated									X
95% neighborhood retail businesses open								X	
50% offices and workplaces open									X
Non-emergency city service facilities									
All businesses open									X
100% utilities									X
100% roads and highways									X
100% travel									X

Source: SPUR analysis

TARGET STATES OF RECOVERY

Performance measure	Description of usability after expected event: BUILDINGS	LIFELINES
	Category A: Safe and operational	
	Category B: Safe and usable during repairs	100% restored in 4 hours
	Category C: Safe and usable after moderate repairs	100% restored in 4 months
	Category D: Safe and usable after major repairs	100% restored in 3 years
X	Expected current status	

Note: Categories A–D are defined on page 10.

Need New Design Codes and Standards

Requires a Transparent Approach

- Next generation hazard definitions
  - Expected earthquake for building resilience
  - Extreme earthquake for lifelines and building safety
- New Vocabulary to describe damage in terms of response and recovery
  - Describe in terms of safety and usability
  - Required for Buildings and lifelines
- Performance Objectives to support resilience
  - Add an intermediate "shelter-in-place" goal
  - Add lifeline system restoration goals

National Earthquake Hazards Reduction Program

Vision :

A nation that is earthquake-resilient in public safety, economic strength, and national security

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems. November 10, 2011

National Earthquake Hazards Reduction Program

Advisory Committee on Earthquake Hazards Reduction

Walter Arabasz	Jim Beavers
Jon Bray	Richard Eisner
Jim Harris	John Hooper
Mike Lindell	Tom O'Rourke
Chris Poland (Chair)	Susan Tubbesing
Anne vonWeller	Yumei Wang
Brent Woodworth	

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems. November 10, 2011

Achieving National Disaster Resilience

Unified support is required from all levels of government

- Federal Government
  - Set performance standards for all construction
  - Insist that states adopt and enforce the codes
  - Provide financial incentives to stimulate mitigation
  - Support research that leads to cost effective mitigation, response, and recovery

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems. November 10, 2011

Achieving National Disaster Resilience

Unified support is required from all levels of government

- State and local governments
  - Identify and mitigate regional lifeline system vulnerabilities
- Local Governments
  - Adopt and enforce appropriate Building codes
  - Current Expand preparedness planning
  - Develop mandatory mitigation programs

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems. November 10, 2011

Building Standards: What about disaster resilience?

Jim Harris
J. R. Harris & Company
Denver, Colorado

Building Standards

- Primary Structure
- Fire
- Mechanical/Electrical/Plumbing
- Secondary Structure
- Communication/Information/…
- Standards v Model Building Codes
- National Voluntary Consensus Standards (ANSI)

Standards for Disaster Resilience:
Workshop November 10,2011

Current Structural Objectives

Safety

- Generally mandatory
- Many structural limit states
  - Yield
  - Fracture
  - Buckling
  - Crushing
  - Fatigue
- Based upon structural reliability
- Influenced by risk

Serviceability

- Generally optional
- Empirical and simplistic (the real sophistication is not standardized)
- Typical limit states
  - Deflections
  - Lateral Drift
  - Durability
  - Vibrations

Standards for Disaster Resilience:
Workshop November 10,2011

Primary Structure (New Buildings): Criteria for Safety

DEMAND < CAPACITY

•ASCE 7 *Minimum Design Loads…*
•ACI 318 *…Structural Concrete*
•AISC 360 & 341 *…Structural Steel Buildings*
•NDS *…Wood Construction*
•TMS 402 *…Masonry Structures*
•AISI *…Cold Formed Steel…*
•AA *…Aluminum Structures*

Standards for Disaster Resilience:
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How Safe?

- For most ordinary hazards
  - Approximately 0.15% chance in 50 years of *benign* failure of a structural component in an *ordinary* risk building
- For earthquakes, except near active faults
  - 1% chance of structural collapse in 50 years
  - Higher (even twice as high) near major faults in California

Standards for Disaster Resilience: Workshop November 10,2011

Current Objectives

Existing criteria related to resilience

•Risk adjustments for importance of structure

I. Relatively unimportant facilities (barns)
II. Ordinary buildings
III. Impaired occupants, moderately hazardous, or truly large facilities
IV. Essential or truly hazardous facilities

•Higher levels of safety / higher levels of functionality

In concept, this is based upon the community as a system, but it is not well measured

Standards for Disaster Resilience: Workshop November 10,2011

ASCE 7-10 Performance Clause

1.3.1.3 Performance-Based Procedures

Structural and nonstructural components and their connections shall be demonstrated by analysis or by a combination of analysis and testing to provide a reliability not less than that expected for similar components designed in accordance with the Strength Procedures of Section 1.3.1.1 when subject to the influence of dead, live, environmental, and other loads. Consideration shall be given to uncertainties in loading and resistance.

Standards for Disaster Resilience: Workshop November 10,2011

Performance Based Design is not efficient design, although it may produce efficiency and effectiveness later

- Analysis
- Testing
- Documentation
- Peer Review

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Secondary Structure in Buildings

- *Enclosure walls (nonstructural)*
- *Roofing*
- *Cladding*
- *Partitions*
- Ceilings
- Vertical transportation
- Equipment
  - Light
  - Ventilation
  - Heating/Cooling
- Distribution Systems
  - Plumbing: waste & supply
  - Power
  - Fuel
  - Fire suppression

Standards for Disaster Resilience:
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Where Does Resilience Fit?

Risk of failure:

•Life safety at 0.15% to 1% in 50 years?

•Serviceability at 50% in 50 years?

•Or in between??

Limit State:

•Component failure?

•System failure?

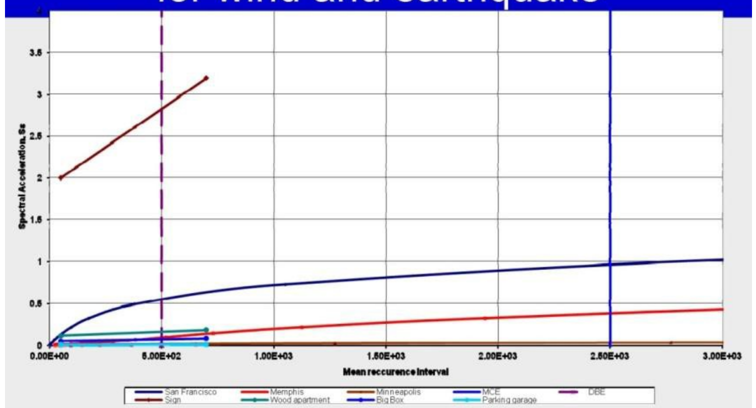
Standards for Disaster Resilience:
Workshop November 10,2011

Impediments to Standards for Resilience in Buildings

- Rational basis for establishing the performance target
  - Improved definition of the hazard
  - Robust economic analysis
- Persuasion for long-term planning and spending
- Inherently complex issue of resource allocation

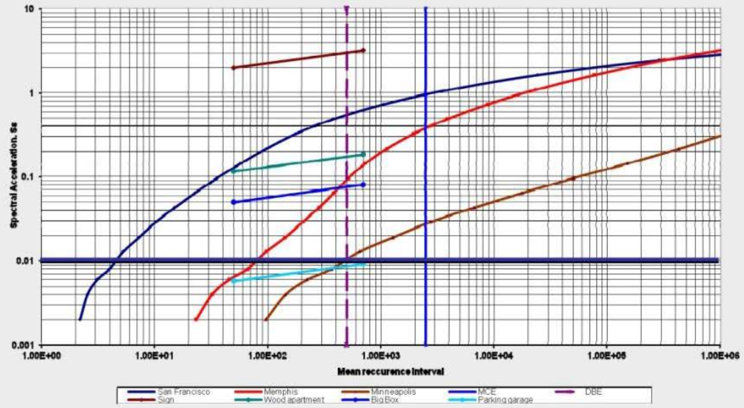
Standards for Disaster Resilience:
Workshop November 10,2011

Selected Hazard Curves for wind and earthquake



6 December 2010 BSSC PUC Issue Team 2

Selected Hazard Curves



6 December 2010 BSSC PUC Issue Team 2

A Possible Opportunity

The Federal disaster assistance, response, and recovery program could have a more effective carrot and stick:

- Separate humanitarian and economic assistance
- Economic assistance is an insurance policy: limit its availability to those who have paid the "premium" – they have taken the steps to mitigate their losses and prepare an resilient community
  - This would be conditioned upon appropriate Federal leadership and technical assistance to define resilience

Standards for Disaster Resilience: Workshop November 10,2011

Resilience is definitely not simple

Standards for Disaster Resilience: Workshop November 10,2011

FM Global

Resiliency – a Property Insurer's View

November 2011

Dan Howell, PE

FM Global

FM Global (Factory Mutual)

- Est. 1835
- Commercial Property Insurance
- Business Model:
  - Research
  - Loss prevention engineering
  - Risk improvement
- 220,000 insured locations
- 1200 field engineers
- 350 Loss Prevention Data Sheets

Losses ($)

Nat Haz / Fire / Other

Risk Improvement

- Physical
- Human Element / Response

FM Global

FM Global Research Campus

FM Global

Building Hazards

- Natural Hazards
  - Flood
  - Wind
  - Earthquake
  - Snow
  - Ice
  - Rain
  - Hail
  - Bush/Wild Fire
- Fire (occupancy)
- Other (blast, impact, terrorism, etc.)

FM Global

Flood

FM Global

Flood (2008 Midwest)

FM Global

Flood (2008 Midwest)

FM Global

Flood: Water Treatment Plant

FM Global

Flood

FM Global

Flood

FM Global

Reducing Flood Damage

FM Global

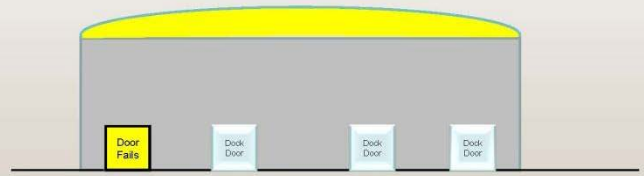
Wind: Roof Flashing

FM Global

Wind : RTU

FM Global

Failure of Dock Door(s) ⇩ Roof Failure?



FM Global

Wind: Building envelope is breached (dock door, windows, louvers,etc.)

- "Enclosed" → "Partially Enclosed"
  Internal pressure: 3x +/-
  External pressure: no change
  Net wind pressure <u>increases</u> (low rise, low slope) by:
  35% / 25% on walls (f/c) +/-
  30% / 20% / 15% on roof (f/p/c) +/-
- Could lose portion of roof → significant PD & BI

FM Global

Dock Door Bracing (int + ext)

FM Global

Miami-Dade NOA – Dock Door

MIAMI-DADE

BUILDING CODE COMPLIANCE OFFICE (BCCO)
PRODUCT CONTROL DIVISION

MIAMI-DADE COUNTY, FLORIDA
METRO-DADE FLAGLER BUILDING
140 WEST FLAGLER STREET, SUITE 1603
MIAMI, FLORIDA 33130-1563
(305) 375-2901 FAX (305) 375-2908

NOTICE OF ACCEPTANCE (NOA)

Cornell Iron Works, Inc.
100 Elmwood Avenue
Mountaintop, PA 18707

SCOPE: This NOA is being issued under the applicable rules and regulations governing the use of construction materials. The documentation submitted has been reviewed by Miami-Dade County Product Control Division and accepted by the Board of Rules and Appeals (BORA) to be used in Miami Dade County and other areas where allowed by the Authority Having Jurisdiction (AHJ).

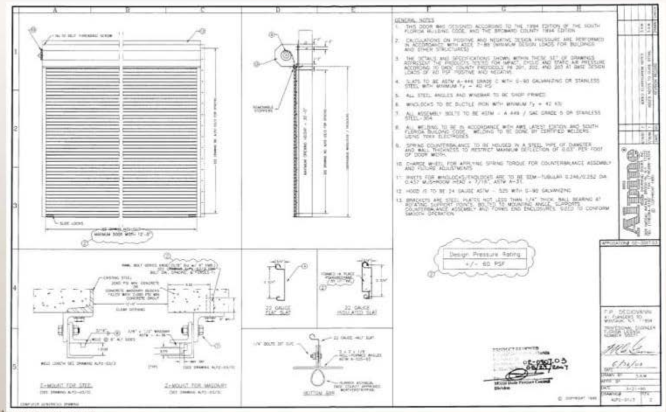
This NOA shall not be valid after the expiration date stated below. The Miami-Dade County Product Control Division (In Miami Dade County) and/or the AHJ (in areas other than Miami Dade County) reserve the right to have this product or material tested for quality assurance purposes. If this product or material fails to perform in the accepted manner, the manufacturer will incur the expense of such testing and the AHJ may immediately revoke, modify, or suspend the use of such product or material within their jurisdiction. BORA reserves the right to revoke this acceptance, if it is determined by Miami-Dade County Product Control Division that this product or material fails to meet the requirements of the applicable building code.

This product is approved as described herein, and has been designed to comply with the High Velocity Hurricane Zone of the Florida Building Code.

DESCRIPTION: 25'- 4"Rolling Steel Door

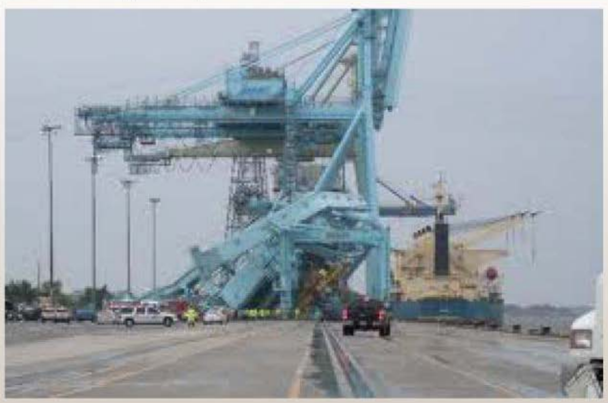
FM Global

Miami-Dade NOA – Dock Door Submittal Drawing (SF = 1.5)



FM Global

Wind damage to port cranes



FM Global

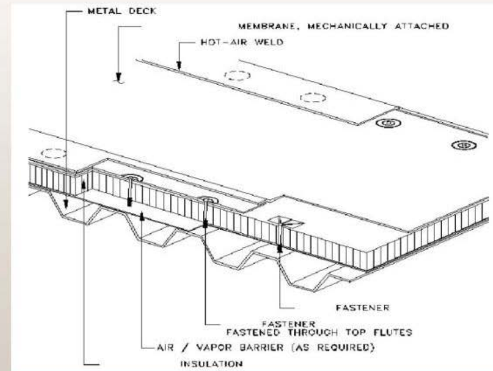
Broadcast tower: Ice + wind

FM Global

Broadcast station roof: ice shedding and debris impact

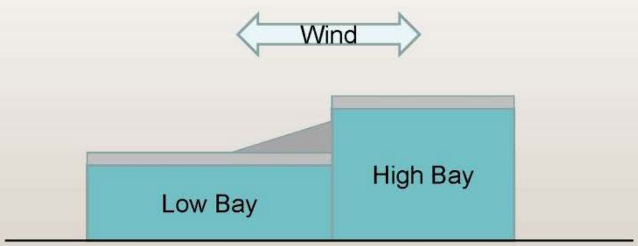
FM Global

Coordination of Design Disciplines (Arch & Struct)
Wind Uplift on deck w/MASP: line load ≠ uniform load



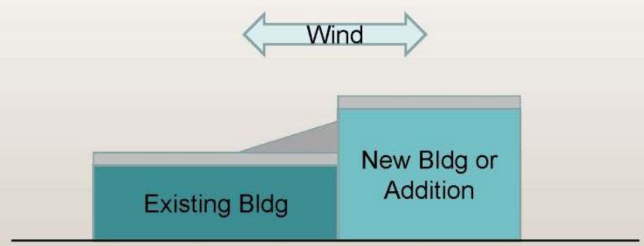
FM Global

Snow collapse at roof step (high/low bay)



FM Global

Snow collapse at roof step (new/exist.)



FM Global

Snow: purlin failure

FM Global

Snow: purlin failure (corrosion)

FM Global

Corrosion: Food processing plant (high int. humidity)

FM Global

Rain/Drainage: roof + wall

FM Global

Rain/drainage: soaked cover boards and ponding

FM Global

Rain/drainage: blocked scupper

FM Global

Partially blocked drains, slope

FM Global

Material deterioration

FM Global

Wave/surge damage to wharf utilities

FM Global

Wave/surge damage to wharf

FM Global

EQ damage: Storage rack (photo courtesy of ABS consulting)

FM Global

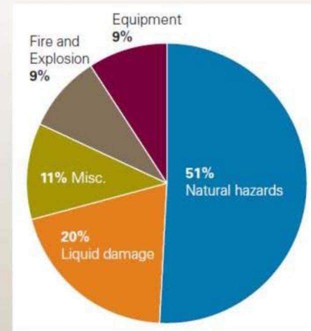
EQ damage: Electrical equipment (photo courtesy of ABS consulting)

FM Global

EQ damage – Non Struct Comp (photo FEMA 74 1994 Northridge)

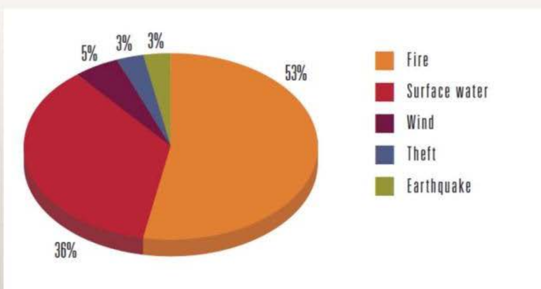
FM Global

Example: Hospital losses (2005-2009)



FM Global

Example: Telecom equipment bldg losses (1980-2000)

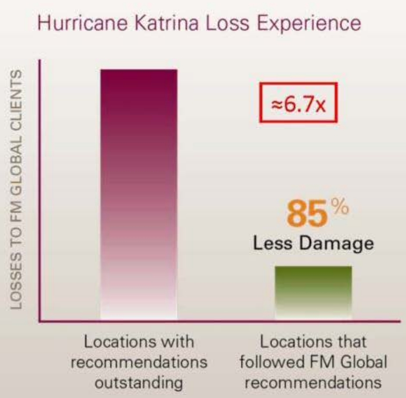


FM Global

520 large multi-national companies (annual revenue >$1 billion): Avg. Loss Severity ($/loss)

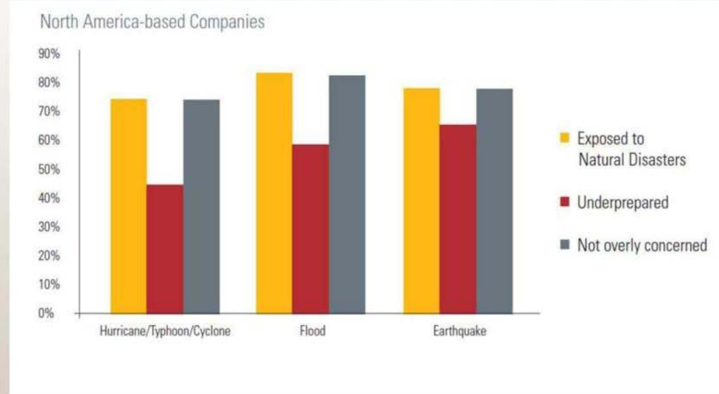
FM Global

Katrina Losses



FM Global

Perception of Risk: Exposure, Concern, and Preparation



FM Global

Perception of Risk: Wind Speeds

"50-year" = 2% annual probability of exceedance (PoE)

"50-year" = 1 failure every 50 years?? No.

We just had a hurricane – I'm good for 50-years?? No.

- "50-year" (64% PoE over 50 years)
- "100-year" (39% PoE over 50 years)
- "500-year" (10% PoE over 50 years)

FM Global

Summary

1) FM supports evolution of code/std/guidelines for improving performance & resiliency of the built environment
2) Exposure-driven risk-based approach (beyond life safety)
3) Whole building approach – e.g., more attention to building envelope (wind) and non-struct comp (EQ)
4) Better assurance that: As-built = As-designed
   - Targeted (exposure) inspection/observation and enforcement
   - Periodic inspection (corrosion/alteration)

   (Risk & resiliency improvement similar to risk improvement with 1200 FM field engineers inspecting insured locations)
5) Nat Haz Response Team (facilities) – feasible/enforceable?
6) Design: Better arch/struct coordination (how?)
7) Risk awareness: countering wishful thinking (e.g. likihood, PoE)

Standards for Electric Power Systems

Woody Savage (USGS and UNLV)

Leon Kempner (BPA)

Stu Nishenko (PG&E)

Homeland Security Standards Panel (ANSI - HSSP)

November 10, 2011

Performance Standards for Electric Power Systems--Framework Issues (1)

- Varying combinations of generation, transmission, and distribution
- Complex network of components within and connecting the built infrastructure
- Lifeline characteristics differ from buildings
  - Large interconnected spatial distribution
  - Large affected population
  - System function not directly related to component damage

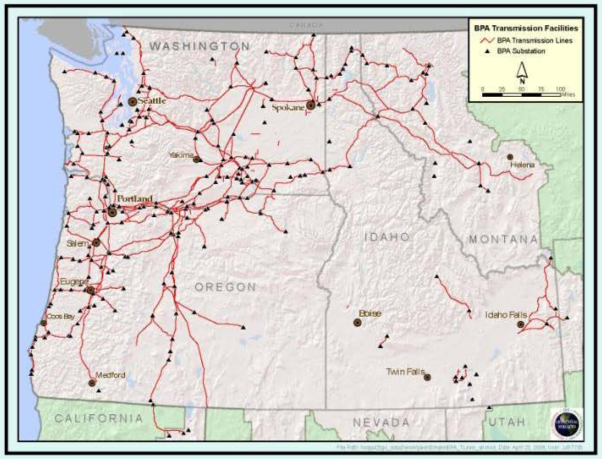
Performance Standards for Electric Power Systems--Framework Issues (2)

- Multiple ownerships and multiple jurisdictions make coordination complicated
- More than a century's development creates a huge legacy inventory and long-standing rights-of-way
- Utilities and regulators are familiar with "routine" hazard events and other reliability disruptions, not rare events
- Owners/operators have knowledge unique to each system

PG&E's Transmission System: 500, 230, 115 kv

- 1890 first generator; PG&E formed in 1905
- Interstate transmission
- Internal municipal utilities
- Serves 14,000,000 people

Bonneville Power Administration
Transmission Facilities Serve Multiple States



Policy on Acceptable Levels of Earthquake Risk for California Gas and Electric Utilities

- Prepared for the California Public Utilities Commission at request of the state's Seismic Safety Commission
- Prepared in 1995 by the ad hoc Inter-Utility Seismic Working Group
- Used experience of 1989 Loma Prieta and 1994 Northridge earthquakes

"Each California gas and electric power utility system shall withstand earthquakes to provide reasonable protection of life, to limit damage to property, and to provide for resumption of utility system functions in a reasonable and timely manner. An acceptable level of earthquake risk is the residual risk that remains when this policy has been fully implemented."

- Policy Implementation Checklist
  - Seismic Safety Program: identify hazards, assess vulnerability, carry out mitigations, practice emergency responses, update seismic criteria
  - Responsible staff
  - Adequate funds
  - Accountability to verify progress
- Goal is to meet societal needs

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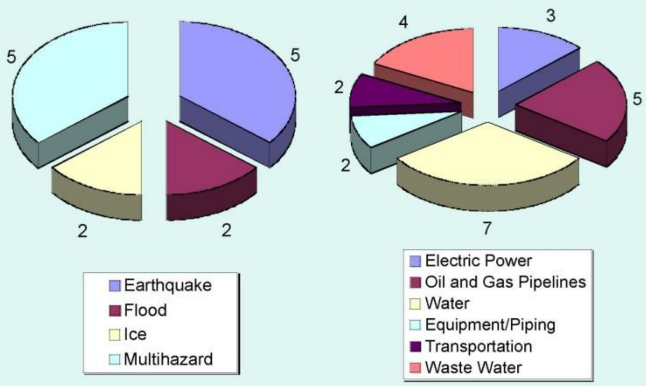
American Lifelines Alliance

- A Public/Private partnership with the objective of reducing risks to utility and transportation systems from natural hazards and human threat events
- American Lifelines Alliance project initiated in 1998 under a cooperative agreement between FEMA and ASCE
- In 2002, ALA operations shifted to a project under the Multihazard Mitigation Council of the National Institute for Building Safety
- Project funding ended in 2006, final products issued in 2008

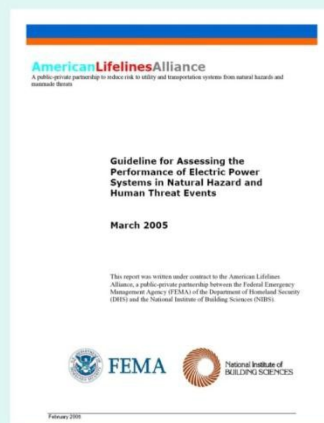
ALA Objective and Approach

- Facilitate the creation, adoption, and implementation of ***national consensus guidelines*** to improve lifeline performance during natural hazards and human threat events
  - Focus on existing practice, not research
  - Maximize use of standards developing organizations
  - Address lifeline systems and their key components (buildings are addressed by other existing guidance)
- Utilize utility industry participants and Corresponding Advisors to identify needed projects
- An updated matrix of lifeline types and available guidance documents served to make visible the breadth and depth of available information.

Distribution of ALA Projects



ALA Guidelines on Conducting Performance Assessments


AmericanLifelinesAlliance

A public-private partnership to reduce risk to utility and transportation systems from natural hazards and manmade threats

Guideline for Assessing the Performance of Electric Power Systems in Natural Hazard and Human Threat Events

March 2005

This report was written under contract to the American Lifelines Alliance, a public-private partnership between the Federal Emergency Management Agency (FEMA) of the Department of Homeland Security (DHS) and the National Institute of Building Sciences (NIBS).

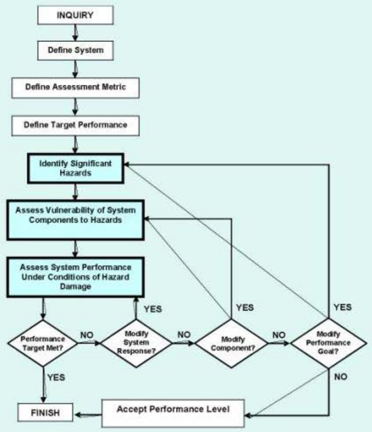
FEMA National Institute of BUILDING SCIENCES

February 2005

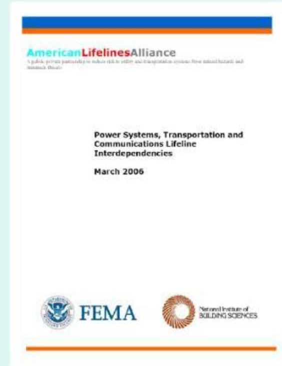
ALA also prepared guidelines for Oil and Natural Gas Pipeline Systems, and Water and Wastewater Systems

Generic Approach to Performance Assessment

- Begins with "Inquiry"
- Requires definition of how performance is measured
- Requires definition of a target level of performance
- Includes analyses of hazard, vulnerability, and system performance



ALA Project on Lifeline Interdependency


AmericanLifelinesAlliance

Power Systems, Transportation and Communications Lifeline Interdependencies

March 2006

FEMA

National Institute of BUILDING SCIENCES

Virginia Polytechnic Institute
Dr. Frederick Krimgold et al.

Tree-caused Damage Last Week in Enfield, Connecticut


LESLLOYD F. ALLEYNE/THE ASSOCIATED PRESS

North Palm Springs 6.2 M_w (1986)


Live Tank Power Circuit Breaker


Current Transformer (CT)

Photos by D. Ostrom

Element	Natural Hazard	Guidance/Oversight
Generation		
Hydro	Earthquakes, Storms	Federal/State Dam Safety
Fossil	Earthquakes, Storms	Federal/State
Substation	Earthquakes, Storms	IEEE, ASCE, NESC
Transmission (HV)		
Substation	Earthquakes, Storms	IEEE, ASCE, NESC
Transmission Lines	Trees, Wildfires	NESC, PUC, FERC
Distribution (LV)		
Overhead lines	Earthquakes, Storms	NESC, PUC
Underground lines	Earthquakes, Storms	NESC, PUC
Substations	Earthquakes, Storms	NESC, PUC
Customer Buildings	Earthquakes, Storms	Building Codes

Electric Power Guidance (Partial List)

- IEEE 693: Recommended Practice for Seismic Design of Substations
- ASCE MOP 113: Substation Structure Design Guide
- National Electric Safety Code (NESC) (2007)
- Expert panels assessed performance for the M7.8 2008 Southern California ShakeOut (Porter and Sherrill, Earthquake Spectra, Vol. 27, no. 2, 2011)
- Numerous electric power research activities: NEHRP, DOE, EPRI, PEER/MCEER/MAE, and utility-sponsored projects (PG&E, BPA, LADWP, and others)

Recommendations

There needs to be a near-term focus on implementation of performance-oriented guidance based on current knowledge of hazards and vulnerabilities. Implementation issues such as investment priorities and confidentiality* could be addressed by utility-public agency partnerships. The time to get this implementation experience is now!

The ALA public-private approach to identifying and developing risk reduction guidance was successful and cost-effective; such activities should be resumed.

**Roadmap to National Earthquake Resilience,* National Research Council, 2011

Highway Bridge and Tunnel Resilience

Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems

Arlington, Virginia

U.S. Department of Transportation
Federal Highway Administration

November 10, 2011
Steven Ernst, P.E.

Bridge Design Standards

- Like some other infrastructure systems, bridge standards do not address all hazards – such as security
- Katrina spotlighted need to look at wave-forces
- Security is another non-traditional hazard under consideration

What We're Trying to Prevent

Bridge Design Standards

- Security is added to the AASHTO Load and Resistant Factor Design Code as **Guidance**
- Comprehensive Guidance is under development
- This guidance is in "code form" and mimics seismic standard language

Design Guideline Format

- Competing needs for owners and operators means that bridges and tunnels must undergo a formal risk assessment before applying design guidance
- Assessment will help determine the level of protection required (analogous to seismic design)

System Risk and Component Risk

- What is important?
  - Vital to the economy
  - Safe enough to prevent deaths or casualties
  - National icons
- Component risk for bridges
  - Apply to a structure that has been determined to be important

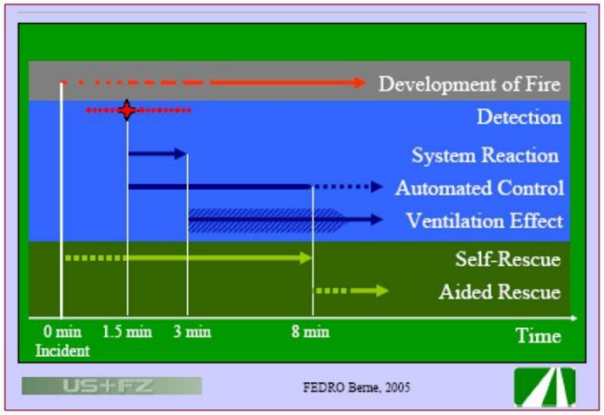
Design Guideline Format for Blast Loading

- Assessment results help determine the level of protection needed (threat level)
- Threat level and scaled standoff (Z) can place a component into a Blast Design Category
- Blast Category (A, B, or C) determines the method of detailing or other design actions that must be taken

Design Guidelines for Tunnels

- Highway Tunnels do not have security standards
- NFPA 502, Standard for Road Tunnels, Bridges, and Other Limited Access Highways is used for fire design
- NFPA 502 also has a section for bridges
- This standard and the guidance have some security application

Fire Mitigation Strategies



LED Lighting for Safety
(Human Factor Engineering)

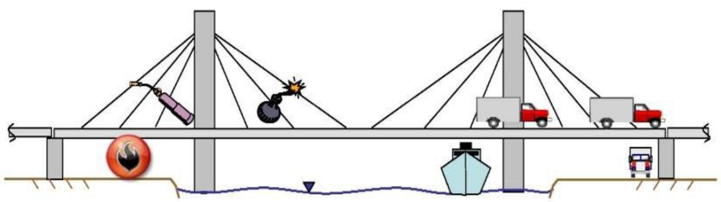
Assessment Goal

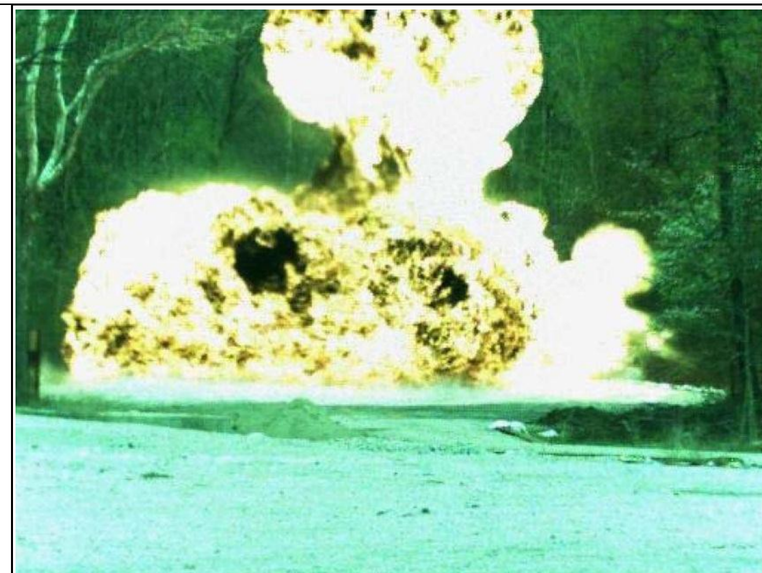
- Develop a cost-effective risk management plan for a critical bridge, using a component level analysis to present to management

Assessment Products

- Describe:
  - What we know
  - What is not known
  - The unknowable
- We are not optimizing solutions, rather, we are informing decisions

Identify Components



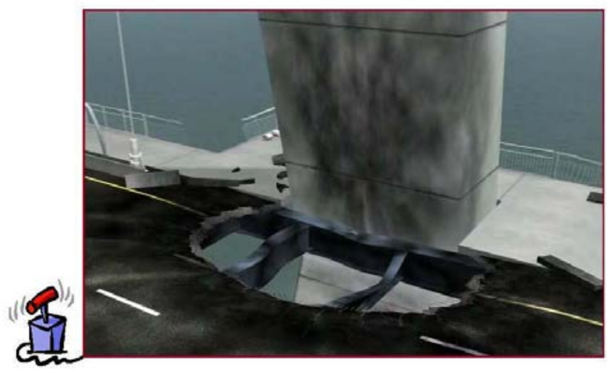


Steel Tower Retrofit
Design Category Requirement

Un-retrofitted

Retrofitted

Successful Retrofit



Questions?

- Steven Ernst, P.E.
- Senior Structural Safety and Security
- FHWA – Office of Bridge Technology
- (202) 366-4619
- Steve.ernst@dot.gov

Standards for Water and Wastewater Systems

ANSI-HSSP Workshop on Standards for Disaster Resilience for Buildings and Physical Infrastructure Systems

Donald Ballantyne PE
Principal, Degenkolb Engineers

November 10, 2011

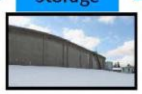
Degenkolb

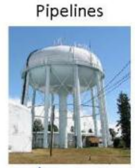
Overview

- What's in a water or wastewater system?
- Level of service
- Standards ownership
- Probabilistic hazards approach
- Damage data
- System metrics
- System and component standards
- Summary and questions

Degenkolb

Water System Elements





Filtration
Disinfection

Impoundments
Large Tanks

Well

Supply → Treatment → Transmission → Terminal Storage → Distribution

Treatment ↓ Sludge Treatment

Surface Supply

Pump Stations, Large Diam. Pipelines

Pump Stations
Tanks
Distribution Pipelines

- Administration building/offices
- Operation and maintenance facilities

Degenkolb

Wastewater System Elements

Manholes, Small Diameter Pipelines, Pump Stations

Sedimentation Tanks, Aeration, Disinfection

Collection → Transmission → Treatment → Outfall

Treatment ↓ Sludge Treatment

Pump Stations
Large Diameter Pipelines

Large Diameter Pipe, Diffusers

- Administration building/offices
- Operation and maintenance facilities

Degenkolb

Water/Wastewater Level of Service

- Impacts and Associated Time Frame for Required Service
  - Water for fire suppression
  - Public health
  - Business interruption end users
  - Environmental Impact
- Compare these drivers and time frame with other infrastructure – Community Resilience
  - Other lifeline systems
  - Transportation systems
  - Building infrastructure use categories

Degenkolb

Example Water Level of Service Goals

Performance Category	Acceptable Adverse Consequences	
	OBE (50% chance in 50 years)	DBE (10% chance in 50 years)
Life Safety	Minimal - Injury or loss of life not acceptable	Minimal - Injury or loss of life not acceptable
Fire Suppression	Minimal - Water for fire suppression should be available for entire service area.	Moderate - Water for fire suppression available for 70% of service area.
Public Health	Low - Water should be available for all but a few isolated areas.	Moderate - Provide service for at least 50% of system. Restore100% service in 1 week.
System Restoration/ Business Operation	Low - Water should be available for all but a few isolated areas.	Moderate – Provide service for at least 50% of system. Restoration to 100% service within one week.
Property Damage	Low - Any damage should not affect facility functionality and should be repairable.	Moderate - 100% loss of nonessential facilities acceptable if not cost-effective to upgrade.

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Water/Wastewater Standards Ownership

- Stovepiped
  - American Water Works Association (AWWA)
  - American Lifelines Alliance (ALA)(No longer active)
  - American Society of Civil Engineers (ASCE)
  - International Building Code (IBC)
- Need to be close to users
  - I.E. - water works people don't look to ASCE for standards
- Public versus Private
  - Different drivers and hurdles

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Probabilistic Hazards Approach (All Infrastructure)

- 50 years used as facility life span
- Earthquake
  - 50% in 50 years – 72 year return or
  - 10% in 50 years – 500 year return
  - 2% in 50 years – 2,500 year return
- Flood
  - 40% in 50 years - 100-year flood plain
  - 10% in 50 years – 500 year flood plain

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Example List of Hazards (All Infrastructure)

Natural
1. Earthquakes/tsunamis
2. Wildland fire
3. Urban Fire
4. Flooding - Heavy rainfall and associated landslides
5. Lightning
6. High winds
7. Tornado
8. Water quality event
9. Microbial contamination

Human/Technological

10. Staff Unavailable
11. Intentional act of vandalism or sabotage
12. Computer disruption
13. Chemical release
14. Mechanical failure

Human/Technologic - continued

15. Operational error
16. Building fire/explosion
17. Building Flood
18. Accidental third-party damage

Transportation Accidents

19. Airplane collision
20. Airplane fuel dump
21. Truck/car collision
22. Rail collision

Lifeline Service Loss

23. Regional electricity outage
24. Wireless communications outage
25. Wire communications outage
26. Liquid fuel service loss
27. Treatment chemical supply and delivery disruption

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Collection and Storage of Damage Data Following Earthquakes (All Infrastructure)

- Damage data used for fragility development
- No system in place to address:
  - Standardization of data
  - Collection of data
  - Storage of data

Water/Wastewater Metrics

- Functionality (Level of Service)
  - Capacity/Probability of achieving
- Planning & Response
  - Emergency planning
  - Emergency response – Near-Real-Time Assessment
  - Restoration planning
- Financial
  - Direct losses
  - Insurance coverage assessment
  - Post-event financial planning
  - Reliability assessment for bond sales
- Social Impacts/Indirect Losses
  - Outage time
  - Capacity during recovery
  - Business interruption – end users
  - Resilient community goals
- Asset Management/Capital Improvements
  - Identification of deficiencies
  - Prioritization of capital improvements
  - Benefit/cost analysis
  - Input to asset management plan (annualized loses)

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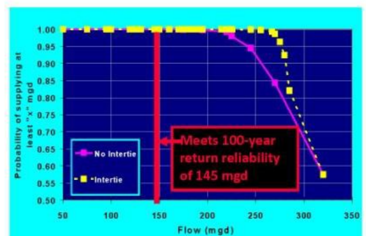
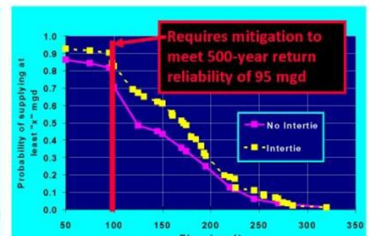
Portland Earthquake Reliability



Supply System Reliability, 100-Year Return Earthquake



Supply System Reliability, 500-Year Return Earthquake

Santa Clara Valley WD Baseline Level of Service Results

Scenario / Time Increment (Days)	Probability of meeting average winter demand for at least one turnout for each retailer										
	0.0	0.2	0.5	1	3	7	14	21	30	45	60
Earthquakes											
San Andreas Fault	0%	0%	0%	0%	0%	0%	5%	34%	96%	100%	100%
Southern Hayward Fault	44%	10%	15%	73%	74%	75%	95%	100%	100%	100%	100%
Central Calaveras Fault	73%	17%	5%	86%	94%	94%	100%	100%	100%	100%	100%
Floods											
100-Year	82%	77%	74%	75%	75%	81%	98%	100%	100%	100%	100%
500-Year	66%	32%	17%	12%	11%	51%	94%	100%	100%	100%	100%
Power Outages											
Regional	100%	100%	100%	98%	100%	100%	100%	100%	100%	100%	100%

Very Low <= 25%	Medium <= 90%
Low <= 50%	High <= 100%

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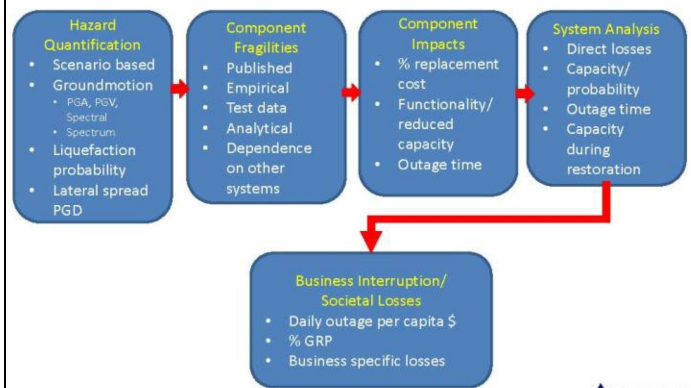
System Risk Assessment



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Water/Wastewater Standards

- System Performance – Existing Systems
  - AWWA J-100 Standard– outcome of 9/11
  - ALA
    - Development of Guidelines to Define Natural Hazards Performance Objectives for Water Systems
    - Wastewater System Performance Guidelines
  - Various proprietary methodologies
- Suggest integrating ALA water document into AWWA J-100 or other similar document
- Suggest developing wastewater system performance document – organization TBD
- Standards should be risk based

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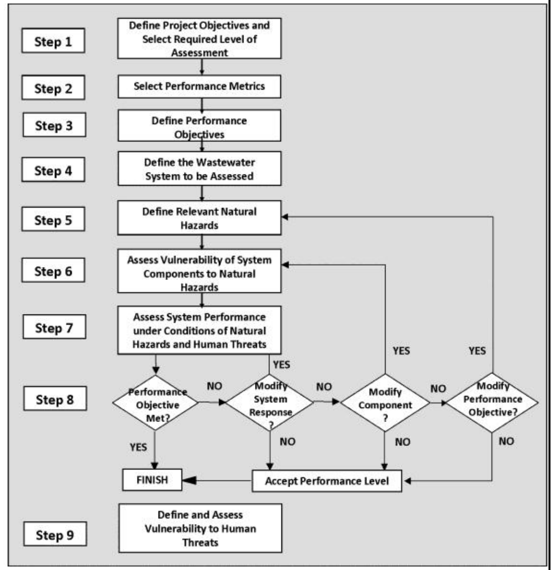
American Lifelines Alliance Wastewater System Assessment Methodology



Water/Wastewater Component Standards

- Facilities/Components – New
  - IBC – buildings and other facilities by reference
  - ASCE 7
  - AWWA – Tank Standards D100-D115
  - ACI – 350 Environmental Engineering Concrete Structures
- Performance Based Design
  - Only addressed by Importance Factor
    - Risk Category 4 (x1.5) – Fire Suppression, Critical Services
    - Risk Category 3 – (x1.25) – all other water/wastewater
  - Gap – need PBD provisions
- Existing Facilities
  - IEBC – buildings
  - Gap – need for tanks

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Water/Wastewater Pipeline Standards

- Existing US Pipeline Standards and Guidelines
  - AWWA Pipeline Standards
  - ASTM Concrete, PVC, Pipe Standards
  - AWWA/WEF/ASCE – Manuals of Practice
  - No seismic provisions (above)
  - ASME B 31.3 – Welded steel pipe
- Japanese Water/Wastewater Standards
  - Seismic Design and Construction Guidelines for Water Supply Facilities - Japan Water Works Association
  - Seismic Planning Guidelines for Water Supply System – Japan Ministry of Health and Welfare
  - Earthquake Disaster Countermeasure Manual, Guidelines and Commentary for Sewage System – Japan Sewage Works Association

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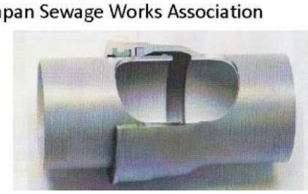
Water/Wastewater Pipeline Standards - Continued

- Suggested AWWA Pipeline Seismic Design Standard for Water
  - ALA – Seismic Guidelines for Water Pipelines
  - JWWA – Seismic Design and Construction Guidelines for Water Supply Facilities
  - Various utility standards – EBMUD, Marin Municipal WD, SFPUC
  - Various published guidelines
- Suggested WEF (or other) Pipeline Seismic Design Standard for Sewers
  - Earthquake Disaster Countermeasure Manual, Guidelines and Commentary for Sewage System – Japan Sewage Works Association
  - Various utility standards
  - Various published guidelines



Summary

- Level of service – what's needed for resiliency
- Establish LOS and hazards umbrella, keep standards within lifeline industry
- Probabilistic hazards approach
- Standardize, collect, and store data
- Establish common metrics useful across the industry
- Develop system assessment standards for water and wastewater
- Develop water and sewer pipeline seismic/multi-hazard standards

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Standards for Water and Wastewater Systems

QUESTIONS ?

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F. Resilience Standards Workshop Discussion

Recommended Research Areas for Resilience

- Synergies with sustainability, green, high performance (EISA)
- Consensus on definition and scope – who is audience, what is purpose
- Support of White House OSTP/NSTC (David Applegate for Natural Hazards)
- Business Incentives – standard practices and supporting data for
    - Builders/owners/leases – only respond to what is valued
    - Protection/security/hardening
    - Energy reliability
- Community planning for mitigation, robustness, and recovery (easily repaired) with supporting standards
- Identify what is implicit in codes and standards, and gaps
- Information to inform decision making – risk management, cost effective for defined scope and duration
- Evaluate combinations of component failures
- Clarify use of importance factors vs PBD risk approach
- Is community measure adequate for systems that are regional (water supply or power) or national (communication)?

Hazards

- Cyber attacks for power
- National criteria for definitions and levels

Recovery

- Stockpile supplies/components for recovery (e.g., borrowed transmission units from other locations and mutual aid agreements between power companies)
- Plans for coordination of crews, equipment materials for water systems in 49/50 states
- Measure impact of asset loss in network system (small bridge, large bridge, effects on business)
- Stockpile only for Risk Cat I systems?
- Shakeout Drills conducted in San Fernando Valley to exercise interoperability of lifelines http://www.firerescuemagazine.com/bonus_content/frm_great_shakeout.html

Standards development process/mechanism

- Smart Grid model
- BSSC model
- DHS Resilience Star

Building Codes based on

- Health (water)
- Safety (conflagrations)
- Welfare (sustainability)

Documents/Orgs

- EISA
- PPD-8
- NIPP 2009
- National Security Strategy – Mar 2011
- National Disaster Recovery Framework – Sep 2011
- CIKR annual strategies
- National Earthquake Resilience NRC 2011
- Grand challenges in Earthquake Engineering Research 2011
- National Academies, Disaster Roundtable, 26 Oct 2011, Report??
- UNISDR – United Nations International Strategy for Disaster Reduction
- BOMA
- FEMA
- NAHB
- ATC 33
- ATC 58
- ASCE 41-06
- ALA
- TCLEE- lifeline interdependencies

Utilities and Networked Systems

- GIS utility locator
- Plan to bury all utilities when restoration occurs for aging water systems

Electric power

- Consider roles of nuclear power and smart grid in resilience of electric power.
- Identify potential cascading events and consequences that lead to 'disaster' situations.

Code/Standard Bodies

- ASHRAE – energy, HVAC
- IAPMO – plumbing
- NFPA – fire, electric
- ICC - buildings and other structures
- ASCE – buildings and other structures (8 institutes – architectural engineering, coasts oceans ports rivers, construction, engineering mechanics, environmental and water, geotech, structural, transportation)
- AWWA - water
- AASHTO – state highways and transportation
- Federal Energy Regulatory Commission (FERC) – fuels and power

- North American Electric Reliability Corporation (NERC) – reliability of bulk power
- Smart Grid – NIST, George Arnold http://collaborate.nist.gov/twiki-sggrid/pub/SmartGrid/IKBFramework/Draft_NIST_Framework_Release_2-0_10-17-2011.pdf

Failures or Lack of Performance Data

- Pre-Engineered systems
- Building envelope
- Dock doors (large areas for wind loads)
- Roofing
- Collect damage data – standardize format, make accessible (TCLEE)
- Natural hazard insurance losses are approx. 30%
    - Flood 35-40% - physical loss plus time for decontamination & cleanup
    - Wind 35-40% - 80% losses in hurricane prone regions
        - 75% roofing
        - 25% walls, fenestrations
        - Enclosed building become non-enclosed with damage
    - Snow 10-15% - roof steps lead to drifting (add-ons to existing structures)
    - Rain/drainage 10% - debris leads to ponding, roof collapse

Community Resilience
Performance goals, system dependencies, integrated hazard and performance levels

- Safe havens – community design
    - Shelter & recreational
- Framework document
    - Example – comparable to SPURs/Project Impact
    - Process guidance & tools
    - From White House - NSTC
- Temporary Housing
    - One design for both ADA & non-ADA
- Determine goals/principles (DHS/public/private)
- Methodologies – consistent across sectors
- Collect other activities & materials, i.e. ALA (Get from FEMA)
-
- National Consensus Guidelines
- Spreadsheet/poster of all standards
-

Water and Wastewater
Supply, treatment, transmission, storage, distribution, collection, transmission, treatment, outfall

- Seismic Standards for pipelines and sewer systems

- General system evaluation for multi hazards (consistent with ALA documents)
- Community based water resiliency (local level interdependencies) (guidance – EPA?)
- “smart grid” for water sector
- Look to other countries (Japan, Australia)
- Replacement of old systems, integration of new with old
- Community planning – replace water lines, bury power
- Mid 90s – AWWA established service goals

Electric Power
Generation, transmission, and distribution systems

- There needs to be a near-term focus on implementation of performance-oriented guidance based on current knowledge of hazards and vulnerabilities. Implementation issues such as investment priorities and confidentiality* could be addressed by utility-public agency partnerships. The time to get this implementation experience is now!
- The ALA public-private approach to identifying and developing risk reduction guidance was successful and cost-effective; such activities should be resumed.
- Smart grid – resilience collaboration
- Solar/Wind farms - Alternative energy power
- ASCE – wind turbines guidance
- Solar as a backup power for community resilience (more distribution of power supply)

Transportation
Roads, bridges, tunnels, ports, rail

- System evaluation
- Intermodal dependencies and efficiencies
- Hazards (non-traditional) into planning process – waves, security
- Inspection and maintenance (asset management)
- Part of the Supply chain
- Public private funding mechanism (creative financing)
- First line interdependency (transportation) – needs to be understood and communicated
- Risk management for our systems

Buildings
Architectural, structural, life safety, mechanical, electrical, plumbing, security, communication, IT

- Standards for primary, secondary building systems
- Public/private partnerships – local/state/federal partnerships as well
- Incentive to adopt codes
- Robustness of buildings (codes are minimums)

- Durability of building envelope to maintain themselves
- Inspection and enforcement
  - Vary from location to location
- Education (re-education) - look to the past - .i.e. shutters – low cost, high impact solutions
- Allocate resources based
- Standardized evaluation procedures
- Provide how to go beyond code if offered and known – owners may choose to do (incentive and costs)
- Look to – National Research Council: Increasing National Resilience to Hazards and Disasters…. (being developed)
- FM Global has public information on costs/savings (other insurance companies)