BUILDING RESILIENCE AS A DESIGN OBJECTIVE

Mehrdad Sasani
Department of Civil and Environmental Engineering
Northeastern University, Boston, MA

ACI Spring Convention
Hot Topic: Building Resiliency
Kansas City, MO, 4/12/2015
Resilience

• Resilience is a measure of persistence of systems and of their ability to absorb change and disturbance and still maintain same relationships between populations (In Ecology; Holling, 1973).

• Three important characteristics are ability to
  1) absorb disturbances
  2) self organize
  3) learn and adapt
Community Resilience

- Resilience is the ability to **prepare** and **plan** for, **absorb** impacts of, and **recover** from, or **adapt** to adverse hazards and threats.

- A community’s resilience reflects ability to absorb impact of a hazard and to **continue to operate**.

- In 2005 Hyogo Framework for Action (HFA) by 168 members of United Nations, it was used in: Building Resilience of Nations and Communities To Disasters.
Community Resilience

• Evaluating and enhancing resilience of a community to natural and man-made hazards should be conducted for a **system of systems**, which includes whole community composed of **various systems**, such as **transportation, water supply, communication**, etc., and the local, **socioeconomic context** within which they operate.
Community Resilience

- Community or system-of-systems resilience to adverse events should be evaluated and enhanced before, during or shortly after (emergency response), and longer term (recovery).
Risk

• Possibility that something unpleasant or unwelcome will happen (Oxford Dictionary).

• A probability or threat of damage, injury, liability, loss, or any other negative occurrence that is caused by external or internal vulnerabilities, and that may be avoided through preemptive action (Business Dictionary).
Risk

• Risk associated with a hazard is a function of probability that hazard occurs, and consequences or damages.

• Consequences are typically measured in terms of property damages and lives lost, evacuation and recovery costs, lost profits and tax revenues (UNDP, 1994).

• Effects that are more difficult to measure include disruptions of people’s everyday life and impacts on social capital.
Risk

• There is a continuing effort to use risk-based (as opposed to uniform hazard-based) approaches in building codes (e.g. ASCE 7-10, 2010).

• For instance, in seismic design, a uniform risk of collapse is now used as basis of new risk-targeted ground motion maps, which is an effort to account for uncertainty in structural capacity (e.g. fragility) and region dependent shapes of seismic hazard curves.
Risk

• While this is a step forward in achieving uniform risk (of collapse), it applies only to one hazard and one design level, i.e. design for extreme seismic ground motions.

• An extension of this effort is to account explicitly for resilience under multiple hazards.
Risk vs Resilience

• Risk = Hazard + Vulnerability + Consequence

• Resilience has to do with restoring (Critical) Functionality in a reasonable period of time.
Risk vs Resilience

Functionality

Realization of Risk (Hazard + Vulnerability)

Time

N.T.S
Risk vs Resilience

Functionality vs Time

Prepare & Plan
Absorb
Recover
Realization of Risk (Hazard + Vulnerability)
Adapt 1

N.T.S
Building Resilience

- Resilience is better suited for systems, therefore, in building resilience we look at building as a system, which includes: foundation, structure, envelope, and other non-structural components.

- Resilience of a building for multiple hazards can be defined as its capacity to absorb impact of adverse events, provide a minimum level of functionality after event, and to permit rapid rehabilitation to a level of performance close to or even greater than its initial performance state.
Building Resilience

• Resilience Metrics may include time to recovery, percent functional, casualties (collapse resistance), cost, and social and environmental impacts.

• There is a need to consider resilience in context of multiple hazards.
Multiple Hazards (Charleston, min. practice; Wood-frame residential)

Preliminary Hazard-Damage Matrix

Future variation (nonstationarity) of wind and flood hazards as a result of climate change and urbanization should be accounted for.
Relating Damage to Time to Recovery & Percent Functional

• Calculate damage levels using fragility functions.

• Identify damage to individual building components and systems and determine what percentage of building area is still useable for its intended function.

• Partial damage may result in partial occupancy, which is measured as a **percentage of functional area**, a primary resilience metric.
Relating Damage to Time to Recovery & Percent Functional

• Building Information Modeling (BIM) allows us to track these relationships. The total elapsed time—including lead-times—yields: time to recovery.
Collapse Resistance (Uncertainties)

• Develop new or use existing performance models in which the model error is accounted for

\[ y_i = h_i(x_i + \theta_i) + \varepsilon_i \]

• Describe different types of damage functions, e.g. \( j^{th} \) limit state

\[ g_j(x, \Theta, \varepsilon, IM) \leq 0 \]
Collapse Resistance (Uncertainties)

- Fragility function for a hazard is calculated

\[
F(IM) = P(\bigcup g_j \leq 0 \mid IM) \\
= \int_{\bigcup g_j \leq 0} f(x) f(\Theta) \Phi(\varepsilon) \, dx \, d\Theta \, d\varepsilon
\]
Collapse Resistance (Casualties)

• To minimize likelihood of mass casualties, collapse resistance is an important measure of resilience.

• For collapse analysis due to seismic ground motions, both lateral instability and loss of gravity load carrying capacity need to be considered.

• It is important to recognize that element failure does not necessarily constitute partial or total building collapse.
20-story Baptist Hospital, Memphis, TN
Plan of a Wing
20-story Baptist Hospital, Memphis, TN
20-story Baptist Hospital, Memphis, TN
Linear Transformers (Displacement Measurement)
Displacement of 2\textsuperscript{nd} Floor

Vertical Displacement (in)

Vertical Displacement=0.34 in
20-story Baptist Hospital, Memphis, TN
10-story RC Structure in Little Rock, AR
10-story RC Structure in Little Rock, AR
10-story RC Structure in Little Rock, AR
Plan of Building

[Diagram showing a building plan with dimensions and labels such as 20" x 20" (TYP.), 10'-2" (3.10 m), 22' (6.71 m), and 15' (4.57 m).]
Reinforcement Details

Beam #11
Bent bars

Slab #4
Top bars

Slab #4
Bottom bars

4 in (0.1 m)
Building Resilience

• Buildings should be designed to limit maximum probability of exceeding each level of resilience criteria across multiple hazards.

• e.g. design criterion: Probability of requiring more than 15 days of time to recover 80% of normal functionality should be less than 50% over the lifespan of building for multiple hazards.
Building Resilience

• Develop a design framework that provides uniform resilience across different hazards, so buildings designed for sites prone to different hazards will have roughly equivalent times to recovery and roughly equal loss of functionality over a given building lifespan.

• **Goal:** Design buildings for uniform resilience across multiple hazards with different levels of severity.
Acknowledgements

• This presentation was in based upon research supported by NSF Award Nos. CMMI-0547503 & 1455450, which are appreciated.

• Support provided by Douglas and Mark Loizeaux (Controlled Demolition Inc.) is greatly appreciated.

• I would like to thank my former students, Drs. Marlon Bazan and Serkan Sagiroglu for their significant effort in conducting field experiments.
Acknowledgements

• Thanks also to my colleagues Professors Matthias Ruth, David Fannon, Laurie Gaskins Baise, Matt Eckelman, Dennis Bernal and Mr. William Coulbourne for their inputs and productive discussions.
Final Request

- Looking for 2 knowledgeable and motivated Structural Engineering PhD student to work on this topic.

- Email: sasani@neu.edu

Thank you.