Enhancing the resilience of acute care facilities against extreme events

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VISON STATEMENT

The overall goal is to enhance the seismic resiliency of communities through improved engineering and management tools for critical infrastructure systems (water supply, electric power, and hospitals) and emergency management functions. Seismic resilience (technical, organizational, social, and economic) is characterized by reduced probability of system failure, reduced consequences due to failure, and reduced time to system restoration.
Reference:
“A Framework to Quantitatively Assess and Enhance Seismic Resilience”
Earthquake Spectra Journal

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Resilience

- Framework that quantitatively measures
  - The “ends” of robustness and rapidity
  - The “means” of resourcefulness and redundancy

- Dimensions of resilience
  - Technical and Organizational (T & O)
  - Societal and Economic (S & E)
Measure of Seismic Resilience
Conceptual Definition

Quality Of Infrastructure (percent)

Loss of Resilience

Resilience depends on “4Rs”
Robustness, Rapidity, Resourcefulness, Redundancy
Adding Resourcefulness Dimension

- Quality Of Infrastructure (percent)
- Resources
- Time

- $t_0$
- $t_1^-$
- $t_1^+$
Adding Redundancy Dimension

Hospital #1

Hospital #2

Hospital #n

Linkages
1985
Mexico City
9,500  Lives
30,000  Injuries
$4B    Loss

1988
Armenia
25,000  Lives
20,000  Injuries
$16B   Loss

1989
Loma Prieta
62     Lives
3,750  Injuries
$8B    Loss

1994
Northridge
57     Lives
1,500  Injuries
$20B   Loss

1995
Kobe
5,000   Lives
26,000  Injuries
$120B  Loss

1999
Turkey
17,000  Lives
46,000  Injuries
$7.8B  Loss

1999
Taiwan
2,300   Lives
10,000  Injuries
$14B   Loss
Research Strategies

- Observations:
- Seismic rehabilitation of existing, under-designed systems is most urgently needed.
- Well Executed Disaster Management Could Significantly Reduce the Losses
Research Strategies

- Nationwide upgrading of existing inventory is not fiscally prudent.

- However, protecting critical and essential facilities together with efficient response and recovery is a socio-economically viable national strategy for earthquake loss reduction.
Lifelines: Power Systems
Lifelines: Pipeline Systems
Highways
Earthquake Response and Recovery
SPOT Image of the I-5/14 Interchange after the 1994 Northridge Earthquake (1/17/94)

Change Detection Map Overlaid onto USGS Aerial Photo - I-5/14 Interchange
(Changes represented by brown shaded areas)
Loss Estimation Models

Empirical Fragility Functions

Advanced GIS

Experiments/Analyses

DECISION SUPPORT SYSTEMS

for

Preparedness, Emergency Response, and Restoration

To Minimize

- Human Suffering
- Physical Damage
- Restoration Time
- Economic Loss
- Interruption of Societal Activities

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Seismic Retrofit of Hospitals
System Diagram – (Schematic Level of Details)
System Diagram – (Schematic Level of Details)
Knowledge Needed for New Decision Tools

Resilience Assessment and Decision System

Component and System Estimation

Advanced System Modification
- Adv. Response Modification
- Rapid Restoration
- Repair and Retrofit
- Rapid Organizational Response
- Recovery Management

Component and System Evaluation

Monitoring & Sensing

Response / Consequences Information

Facility System and / or Community Information

Earthquake Information

Sensing & Monitoring

System Assessment and Actions

Conventional System

Resilient Community / System

PRE-EVENT CONTROL

Conventional System

System Assessment and Actions

Resilience Assessment and Decision System

Component and System Estimation

Knowledge Needed for New Decision Tools

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Resiliency Targets

- Example: There is a 95% chance that 80% of hospitals can operate at 90% of their capacity within 5 days.
- Communities cannot articulate such resiliency objectives.
  - Tools to support such statements don’t exist.
  - Communities do not operate at this level yet.
- MCEER to develop knowledge needed to create the tools that could provide such formulation (not the numbers themselves).
**Deliverables**

- A methodical framework that can be used to construct decision support system for critical facilities
  - Lifelines and Hospitals as a stand-alones first
  - Integrate into framework for all critical systems
  - Demonstrate how could work using demonstration projects and specific advanced technologies
Decision Support Tools
Structural System Considerations

1. Serviceability – “clean aesthetic”
2. Threshold of collapse
3. Damage states

Advanced Technologies have the potential to reduce some of these uncertainties.

Fragility functions for initial limit state, condition at time $t_i$, and time to recovery also random variables.
Example of Integrated Research Project to Seismic Resilience of Acute Care Facilities
Importance of nonstructural components and contents

Figure 1. Typical investments in building construction (after E. Miranda)
Research Integration Road Map

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MCEER Specific Barrier Ground Motion Model (A. Papageorgiou, UB)
- Stochastic Modeling Approach
- Magnitude-Distance Scenarios
- East and West Coast Ground Motions
- Near-Field Effects
GIS Database of Subsurface and Site Characteristics for California Hospital Facilities (T. O’Rourke, Cornell)
Structural Fragilities

State of Practice

Development of Self-Centering Systems
(A. Filiatrault, UB)
Rehabilitation Decision Analysis Model

D. Von Winterfeldt, USC
W. Petak, USC
D. Alesch, UW

Organizational Dimension

% Operational (Patients/day Capacity)

Physical Dimension

% Infrastructure Operational

Time to Recovery

Services Provided

Acceptable

Resilience Objective Met/failed

Resilience Evaluations

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Fragility Based Rehabilitation Decision Analysis (M. Grigoriu, Cornell, D. von Winterfeldt, USC)

Adaptive Decision Support Model (G. Dargush, UB D. Alesch, UW W. Petak, USC)

Design support Methodology
Research Integration

1) Global Integration

- % Operational (Patient/Day Capacity)
- Organizational Dimension
- Time to Recovery

Acceptable

ES

Resilience Objective Attained

NO

These options not admissible after 2050 in California
Vision

The same approach can be adopted for the development of innovative and integrated solutions to enhance the resilience of infrastructure against extreme events (natural disasters, technological disasters, and acts of terrorism against our society), and is known worldwide for its ability to deliver superior products to its sponsors.
Steps to Enhance Resilience Spectrum of Needs

Pre-Event

- Risk and vulnerability assessment, including the development of risk and vulnerability assessment methodologies, to prioritize the allocation of limited resources;
- System analysis and design, to investigate the ultimate behavior of systems and foster capacity-design principles for fail-safe outcomes;
- Improved materials, devices, or systems, to enhance the ability of infrastructure components and systems to withstand hazards;
- Retrofitting prior to an event.
Steps to Enhance Resilience
Spectrum of Needs

During Event

- Sensing technologies, for structural health monitoring, with possible applications for detection, surveillance and prevention
Steps to Enhance Resilience

Spectrum of Needs

Post-Event

- Post-event assessment, including the use of remote sensing (airborne or satellite-based) to rapidly locate areas impacted by a disaster, the type of damage suffered, and rapid assessment of losses;
- Post-event on-site screening methodologies, to assess safety of structures after an event using simple tools based on expert knowledge;
- Advanced technologies for repair and restoration following an event;
- Evaluation test-beds, to test and validate new technologies proposed to achieve above objectives.
Steps to Enhance Resilience

- In that perspective, much research results from the field of earthquake engineering could be modified to contribute to this objective. Earthquake engineering research has provided practical solutions to address a number of needs that are similar (although not identical) for a number of hazards.
Major Accomplishments

- World Trade Center Research: Comparing and Contrasting Natural and Human-Induced Disasters
  - Data analysis will advance the conceptualization and quantification of a community’s resilience to disasters
  - Engineering and social science knowledge to address the impact of major urban earthquakes
Major Accomplishment

- Hurricane Charley Reconnaissance Report
  - Satellite-Referenced Building Damage Information in the Aftermath of Hurricane Charley
Conclusion

- Definition of resilience allows to frame objectives in a global integrated model that focus on key issues
- On-going research important to develop the models and technologies to deliver such a framework for acute care facilities
- Select advanced technologies and demonstration project will be used to provide quantitative data and benchmark for validation
Thank you!

Questions?