

Enhancing Resilience Some Engineering Issues

by

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Resilience (as of 06/2010)John Lennon 1966: "(The Beatles) are more popular than Jesus now; I don't know which will go first — rock and roll or Christianity." Google "Jesus": 192,000,000 results Google "John Lennon":10,800,000 results Google "Resilience": 7,880,000 results Google "Paul McCartney": 7,250,000 results Google "George Harrison": 3,790,000 results Google "Ringo Starr": 2,660,000 results

MILLER EARTHQUAKE ENGINEERING TO EXTREME EVENTS

Resilience (as of 06/2010) Google "Resilience": 7,880,000 results Google "Obama Resilience": 420,000 hits Google "Engineering Resilience": 6,200 hits Google "Quantifying Resilience: 953 results Google "Quantification of Engineering Resilience": 1 result (almost a googlewhack) Resilience = The new Babel Tower? Nood for Pigorous Quantifiable Posiliones **KE ENGINEERING TO EXTREME EVENTS**



Some Key Factors

- 1. Need a resilience framework (What is Resilience; what to measure?)
- 2. Need quantification method (How to quantify?)
- 3. Need strategies to enhance resilience (How to engineer greater resilience?)
- 4. Need multidisciplinary collaborations (How comprehensively to address the problem?)





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General Framework for Quantification: Extent of Disruption and Recovery Time





POPULATION AND DEMOGRAPHICS Composition, Distribution, Socio-Economic Status, etc. **E**NVIRONMENTAL/ECOSYSTEM Air quality, Soil, Biomass, Biodiversity, etc. **O**RGANIZED GOVERNMENTAL SERVICES Legal and security services, Hygiene and health services, etc. **P**HYSICAL INFRASTRUCTURE Facilities, Lifelines, etc. LIFESTYLE AND COMMUNITY COMPETENCE Quality of Life, etc. **E**CONOMIC DEVELOPMENT Financial, Production, Employment distribution, etc. SOCIAL-CULTURAL CAPITAL

Education services, Child and elderly care services, etc.

C.S. Renschler, A.E. Frazier, L.A. Arendt, G.P. Cimellaro, A.M. Reinhorn, and M. Bruneau (2010), "'Developing the 'PEOPLES' Resilience Framework for Defining and Measuring Disaster Resilience at the Community Scale', 9th US NCEE/ 10th CCEE, Toronto July 2010.

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Working Definition of Terms used within the **PEOPLES Resilience Framework**:

Resilience Dimension – one of the seven realms of a community

Resilience Component – components within a dimension of a community; those can have interdependencies to resilience components of other dimensions

Resilience Indicator – quantitative measure of resilience/ systems functionality based on quantitative and/or qualitative data sources





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Resilience: Unique decision variable (DV)





Resilience of Power Grid





Functionality of Health System

(Cimellaro et al, 2009)

 $Q_{H}(t) = Q_{QS}(t) \cdot Q_{LS}(t)$

where Q_{QS} =Qualitative functionality related to the quality of service (QS); Q_{LS} =Quantitative functionality related to losses in healthy population;



Suggested Combination Formula

$$Q(t) = \frac{Q_{EP}(t) \cdot Q_{H}(t)}{Q_{EP}(t) + Q_{H}(t) - Q_{EP}(t) \cdot Q_{H}(t)}$$

The formula has been evaluated considering the functionality of the Electric power system (Q_{EP}) and of the Health system (QH), but it can be extended to more than two functionalities when they are quantified.



ΈP

Combining Functionalities

The functionality of Electric power system (Q_{EP}) and of Health system (Q_H) are dependent. Resilience of the community can be improved by making the two systems independent with redundancies

Oн



H

Spatial-Temporal Scales in PEOPLES





University at Buffalo The State University of New York Spatial-Temporal Resilience Maps

$$Q_{EP}(x_i, y_i, t) = \frac{N_{CP}(x_i, y_i, t)}{N_C(x_i, y_i)}$$
 Time dependent
functionality maps
$$R_{EP}(x_i, y_i) = \int_{t_{OE}}^{t_{OE}+T_{LC}} Q_{EP}(x_i, y_i, t) / T_{LC} dt \underset{\text{lience}}{\text{maps}}$$

$$CR_{EP} = \iint_{t_{OE}} R_{EP}(x_i, y_i) dx dy$$
 Community
Resilience index



PEOPLES Layer Model





PEOPLES Layer Model **'P**'



$$R = \iint_{r_o t_o} U \left[p_i Q_i \left(r, t \right) \right] dt dt$$

Housing - Q_{hou}(r,t)
Transportation - Q_{tra}(r,t)
Electrical/Power - Q_{ele}(r,t)

Water –
$$Q_{H20}(r,t)$$

Sewage $- Q_{sew}(r,t)$

Communication $- Q_{com}(\mathbf{r}, t)$

Wireless $- Q_{com}(\mathbf{r}, t)$

U is a union operator P_i are priority indices for specific dimension

Community Resilience indices are integral of the geospatialtemporal functionality of components, or dimensions, of resilience



Union Operators



 $\sum_{i=1}^{N_i} \sum_{i=1}^{N_j} \sum_{n=1}^{N_n} \left[\pi \left(\mathcal{Q}_i, \mathcal{Q}_j, \dots, \mathcal{Q}_n \right) \right]$

It may include more interactive components (e.g., model for health care facilities and services.

Q are non-dimensional functions of capacity and demands (demand/capacity ratio).

P_i are probability distributions associated with the functionality.





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Key Role of Mitigation

- (Complementary to improvements in response/ recovery) Enhancing the Nation's disaster resilience requires mitigating the disaster vulnerability of critical facilities and lifelines
- A perfect response and recovery plan will not eliminate the massive initial losses
- Mitigation needed to break cycle of destructionreconstruction-destruction-...
- Public expects critical facilities and lifelines to be operational following a disaster



Mitigation and Response



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Mitigation and Response



MCFFR EARTHQUAKE ENGINEERING TO EXTREME EVENTS

Mitigation and Response





Engineering

For example, need new structural engineering concepts that prevent/minimize disruption without higher initial cost, and effective in a multi-hazard perspective.

Example: bridge piers with concrete-filled steel tube columns for seismic, blast, and fire resistance (next slide).





CFST Column Test Results Test 5: Bent 1, C5 (1.3X, W, Z=0.75m)







Seismically Designed **Ductile Column Shear Failure** Seismic Design Alone is not a **Guarantee of Multi-Hazard Performance** Need Optimal Seismic/Blast Design





Multi-Hazard because:

Great design for one Hazard...



ANHTSA crash test



May be useless for other hazards...



...and resilience measures must account for post-disaster "pile-up"







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Possible Research Mechanism

Creative Research Chairs

- 1. Complexity of problem requires flexibility and adaptability as not all issues can be foreseen at the onset (too easy to torpedo topic-specific proposals)
- 2. Type I: Collaborative Chair: Only requirement for yearly renewal is evidence of effective on-going multidisciplinary collaboration among Chair holders (as assessed by NSF Program Director).
- **3.** Type II: Targeted Effort Chair: Single highly productive individual focused on set critical topic (as if a resource).
- 4. Chairs would be fix amount per year for 5 years (amount could vary across disciplines to reflect relative cost of research)
- 5. Works only if multiple Chairs awarded across disciplines

Benchmark Study Collaboration

System Properties

- Structural system (NHMC, UB, Cornell)
- Nonstructural systems
 - Ceiling (UB)
 - HVAC (UB, York Int' I.)
 - Piping (UNR, UB, Cornell)
 - Partition walls (CUREE, UB, Cornell)

Seismic Hazard

- Activity matrix (USGS, Cornell)
- Ground motion model (UB, Cornell)

SYSTEM RESILIENCE

Damage States

- Structural system (FEMA)
- Nonstructural systems
 - Ceiling (UB)
 - HVAC (ASHRAE)
 - Piping (UNR)
 - Partition walls (CUREE)

Capacity/Cost Estimates

- Structural system (NHMC, KPFF, USC, Taylor Dev.)
- Nonstructural systems
 - Ceiling (Terra Firm)
 - HVAC (York Int' I.)
 - Piping (UNR, Terra Firm, Degenkolb, Clark, ISAT)
 - Partition walls (CUREE, NHMC)



Decision-assisting models to improve resilience of hospitals

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Spatial-Temporal Scales in PEOPLES





Conclusions

- 1. Need resilience framework, quantification methods, strategies to enhance resilience, and multidisciplinary collaborations
- 2. Innovative and integrated solutions are key to enhance the resilience of infrastructure against extreme events
- **3.** Need to expand "single-hazard solutions" to satisfactorily address multiple hazards (without incremental costs)
- 4. Multidisciplinary research requires a substantial investment
- 5. Consider "Creative Research Chairs" funding researchers with track record, rather than ideas in a proposal

