Modeling Interdependent CI Systems for Seismic Resilience Evaluation and Design

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Community:
Geographically bounded entity with shared history and future
Community Resilience

- Not giving up
  - Continuity of community existence thorough the survival of its inhabitants and the continuity of its social and economic functions

- Hypothesis: community resilience depends on the resilience of its built infrastructure

http://science.k12flash.com/naturalhazards.html
Community Functions and Its Civil Infrastructure Systems

- Safety
- Physical infrastructure:
  - Energy
  - Water
  - Communication
  - Transportation
  - Waste
- Health and Economy
- Social:
  - Culture
  - Heritage
  - Education...

While an effective response is essential to a resilient community's ultimate recovery, it alone is not sufficient to achieve the swiftest return to normalcy. In its Capstone Doctrine (as cited in Blanchard 2007), the Department of Homeland Security notes this distinction and defines the recovery mission as the sustained commitment to return an impacted population and geographic area to a sustainable standard of living following an incident. This supports the goal of creating resilient populations and communities. Whereas response is focused primarily on minimizing immediate impacts, minimizing immediate consequences, and setting the conditions for long-term success, recovery is focused on restoring societies. Without a commitment to that restoration, resiliency is not possible.

In effect, recovery means "getting back to normal" functioning along all dimensions of the community. Such resilient recovery has three essential characteristics.

First, resilient communities deliberately plan for recovery with the same attention that is paid to planning for protection or response. "Planning to recover" means that all the functioning dimensions of the community must be restored, recovery goals must be identified and benchmarked, and strengths, weaknesses and interdependence across community functional areas are identified (i.e., infrastructure, economy, and social). For example, workers cannot return to work if there are no roads or bridges to use for commuting, if there are no day care centers and schools for their children, if there is no adequate plan for short-term housing needs, and so on. In turn, businesses cannot get back up and running without both workers and consumers.

Further, data suggest that communities that plan to meet the long-term mental health needs of the citizens avoid unnecessary disruption costs ranging from failed marriages, increased rates of violence, and worker absenteeism. Resilient recovery plans have analyzed and understood these interdependencies and put measures into place to eliminate cascading failures and to prioritize restoration activities (Fig. 2).

Second, resilient communities link recovery to a rapid return to...
Quantification of Community Infrastructure System Resilience

- Measured in terms of loss of community function (MCEER’03)
  - Collapse:
    - Abandoned
  - Ductile:
    - Did not give up
  - Robust:
    - Same as before
  - Adapted:
    - Better than before

![Graph showing community function performance over time](image)

*Event*:
- **Losses**
- **100%**
- **absorb**
- **recover**
- **time (yr)**

(adapted, robust, "ductile", "elastic" threshold, collapsing)

(after Brunearu, 2003, and Heinemann and Kröger, 2012)
Quantification of Community Infrastructure System Resilience

Supply

Transmission

Distribution

Demand

http://ceeesa.es.anl.gov/images/ceeesa_ProjectsWECC_Climat

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Quantification of Community Infrastructure System Resilience

- Infrastructure system supply:
  - Suffers an (instantaneous) drop when the event occurs
  - Recovers over time
  - Recovery depends on the vulnerability and recovery of elements of community infrastructure
Quantification of Community Infrastructure System Resilience

- **Infrastructure system demand:**
  - Suffers an (instantaneous) drop when the event occurs
  - Recovers over time
  - Recovery depends on the vulnerability and recovery of elements of community infrastructure
Supply/Demand Formulation to Quantify Community Infrastructure Resilience

- Lack of Resilience is the unmet demand of the community for the considered resource:
  - Power, water, communication…

\[
LoR_{sys,r} = \int_{t_0}^{t_f} \left(D_{sys,r}(t) - C_{sys,r}(t)\right) dt
\]

Re-CoDeS Framework

supply nodes

supply capacity
\[ S_{C,i}, S_{C,sys} = \sum S_{C,i} \]

system level

network functioning model

considered elements:
- efficiency losses of supply facilities (e.g. due to ageing)
- damages of supply facilities

considered elements:
- transmission losses
- network inefficiencies
- link capacity limitations
- link damages
- allocation strategy

demand
\[ D_i, D_{sys} = \sum D_i \]

available supply (to distribute)
\[ S_{av,i}, S_{av,sys} \neq \sum S_{av,i} \]

consumption
\[ C_i = \min(S_{av,i}, D_i), C_{sys} = \sum C_i \]

considered elements:
- efficiency losses of distribution facilities (e.g. due to ageing)
- damages of distribution facilities

More details in:
https://doi.org/10.1080/23789689.2017.1364560
Re-CoDeS Framework: Formulation and Implementation

- Modeling the community on an component level:
  - Buildings, generators, pumps, cellular network base stations…
  - Modular simulation platform architecture
  - Physics-based (as much as possible)
Lack of Resilience is the unmet demand of the community for the considered resource:
- Power, water, communication...
- Interdependences among civil infrastructure system components play a significant role in community recovery.

Re-CoDeS Framework: Interdependence among Infrastructure Systems

Rinaldi et al., 2001
A Virtual Community

- Area of 10 x 30 km
- 3600 inhabitants

- Three infrastructure systems:
  - Electric Power Supply
  - Cellular Communication
  - Water Supply

- Three types of links:
  - Power lines
  - Water pipes
  - Roads (to transport repair crews, machinery and material)
A Virtual Community: Interdependence among Infrastructure Systems

- Community components are dependent on each other for function

- Interdependencies among infrastructure systems are defined at the component level
A Virtual Community: Interdependence among Infrastructure Systems

- Restoration of component function depends on:
  - Its damage
  - Resources needed for recovery
  - Start and rate of its recovery
  - Availability of resources it needs to function:
    - A generator needs cooling water and communication

Emergency response center
A Virtual Community: Interdependence among Infrastructure Systems

- At each recovery time step, functionality of each component is established in an iteration designed to detect feedback loops.
A Virtual Community: Post-Earthquake Recovery Simulation
A Virtual Community: Post-Earthquake Recovery Simulation
A Virtual Community: Effect of Interdependencies

Interdependencies increase LoR of EPS by 74%
A Virtual Community: Effect of Interdependencies

Interdependency increases community disaster risk exposure
A Virtual Community: Investigation of Community Sensitivity

- Sensitivity analysis:
  - Sobol index approach

- Find which community infrastructure elements contribute the most to changes in community disaster resilience (or lack thereof)
Challenge: Make Communities more Resilient

- Community risk is increasing:
  - Population growth
  - Productivity
  - Innovation

- Engineering resilient communities is a key element of societal risk governance
  - Re-CoDeS framework can be used for community resilience evaluation and design

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Questions

- What
- Who
- Help
- Confusion
- Support
- Network
- Mark
- Solution
- Problems
- Three-dimensional
- White
- Endorsing
- Caught
- Objects
- Decisions
- Nobody
- Mark
- Support
- Lost
- Who
- Exploring
- Strategies
- White
- Logistic
- How
- Supporting
- Image
- Questionnaire
- Asking
- Single
- Text
- Why
- How