A Need for Risk-Consistent Approach to Multi-Hazard Engineering

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Hazards Considered

- Natural Hazards only
  - Earthquakes
  - Hurricanes
  - Floods
  - Fires
  - Other natural Hazards e.g. landslides should be considered on a local condition basis

- Occurrence determined Probabilistically
- Probability for each hazard event is different
Interdependency of Hazards

- Some Primary causative Hazards lead to cascading effects resulting in other hazards:
  - Fires following earthquakes
  - Floods following hurricanes or tornados
  - Tsunamis following earthquakes

Probabilities for independent events are different than for interdependent events.
Systems Approach to Hazard-based Hierarchy

Acceptable Solution

Decision Variables

Capacity Measure

Demand Requirements

Damage Potential

Hazard Characterization
Interdependency of **Response**

Even at the Technical level – non-structural systems ignored, e.g.

- **Window-wall systems & internal partitions** may substantially impact the overall behavior of a structural system
- **Design-behavior of structural system does not always minimize damage to non-structural systems**

Interdependency is usually ignored
Interdependency of Response

- At the **Economic and Societal level** the issues are more complex
- **Geographic Interdependency**
- **Physical Interdependency**
- **Societal Interdependency**
Global Interdependence

Osaka Port - 1995
25% of Japanese export through port. Disrupted worldwide shipments

Chi Chi EQ. – Taiwan ‘99
Electronic Products shipments disrupted worldwide

New Madrid Fault --?
Major transportation hub for US – impact?
Physical interdependence of various utilities
Building Stock
Transportation Systems
Infrastructure Systems
Critical Facilities

Hazard
Impact
Physical Damage
Societal Impact

1. Emergency Response
   a. Basic necessities
   b. Business disruptions
2. Critical Infrastructure
   a. Transport. disruptions
   b. Healthcare
   c. Lifelines
3. Regional Impact
4. Long-term health issues

1. Recovery
   a. Reconstruction
   b. Business closures & relocation
2. Critical Infrastructure
   a. Restoration, rerouting, alternates
   b. Restore & retrofit
   c. Restore & retrofit
3. Economic recovery
4. Long-term health issues
Thresholds of Acceptable Hazards

- **Earthquakes**
  10% probability of exceedence in 50 years

- **Hurricanes**
  5% probability of exceedence in 50 years

- **Floods**
  100 year flood level

- **Fires**
  1, 2, 3, 4 hour fire protection of elements
Thresholds of Acceptable Hazards

- The inconsistency in standards of “Hazard Risk Acceptance” is evident

- Based on:
  - Some historical data
  - Macro-scale mapping
  - Derived from economic viability
  - Social acceptability
  - Not in our control generally

*Not All hazards are low - probability-high consequence type*
Current codes & Standards

- Define “code level” Hazards criteria
- No discussion of vulnerability
- Define specific performance requirements
- Define acceptable materials
- Define expected standards of quality
- Define structural systems
- Other criteria

*Codes generally address individual facilities not networks*
Total Multi-Hazard Risk

- **Total Risk** = \{ Expected lives lost, Persons Injured, Property damage, Disruption of economic activity, Societal services disruption \}

- Total Risk = \( f ( \text{hazard, exposure, vulnerability}) \)

- Total Multi-hazard Risk comprises of ranking values of exposures and their contribution to vulnerability
Hazard Exposure

- For a specific location, exposure to a given hazard is same, however, the vulnerabilities are different.

- Community exposure vs. Single facility exposure

- Some exposures can be reduced, e.g. floods, fires
Vulnerability

- Vulnerability of a system to a hazard can be defined as a resulting aggregate outcome of degree of exposure, system sensitivity, and system resiliency.

- Vulnerability of coupled Human-Environment System exposed to natural hazards depends on the dynamics of the system (Turner et al – May 2006, Sustainability Science)
Vulnerability is contextual

- Given a degree of exposure, vulnerability depends on system sensitivity, and system resiliency.
- System sensitivity, and system resiliency depends on each subsystem and links between subsystems.
Contextual Nature of Vulnerability

- **1994 Northridge, CA Earthquake (6.9 mag.)**
  65 fatalities, $40b economic loss, limited interruption

- **1995 Kobe Earthquake (6.9 mag.)**
  5500 fatalities, $150b economic loss, major interruption

- **1999 Turkey Earthquake, magnitude (7.6 mag.)**
  17,000 fatalities, $13b economic loss, major interruption

_Economic losses must be viewed as a % of total GDP of a nation_
Vulnerability here is considered only in physical infrastructure, in two contexts:

1. Individual facility level

2. Network level

Vulnerability Redefined:
Vulnerability is defined as likelihood in future, at a given point in time, a level of performance lower than an established benchmark.
Vulnerability

1. **Single Facility** Vulnerability

2. **Network** Vulnerability

- Measures and dimensions for each are different
Vulnerability Assessment

1. Single Facility Vulnerability

A. Structural Vulnerability

i. Age of facility
ii. Construction material
iii. Foundation system
iv. Height of facility
v. Type of structural system
vi. Capacity of lateral load system
vii. Plan and vertical irregularity
Building System

- MEP Systems
- Architectural Systems
- Special Systems
- Structural Systems
- Foundation System

Building System
Vulnerability Assessment

B. Operational Vulnerability

i. Non-Structural systems

ii. Exit ways

iii. Essential equipment and other tools necessary for operation
Capacity Measure

- Capacity determination of a structure or a system (pre damage or post damage) is not easy. Techniques involve: analytical models, computer simulation, physical model simulation in the laboratory, non-destructive on-site tests etc.

- Advances in hybrid simulation, visualization, large computer systems with fast speed help in accuracy of capacity determination
Retrofitting built environment is extremely important:

1. In North America, only 1% gets replaced each year

2. Will take 100 years to completely replace existing built environment
Parking garage – Northridge 1994

Inadequate capacity of non participating elements

Soft story

Apt. Bldg.- Loma Prieta - 1989

Excessive Drift

Kobe Earthquake - 1995
Multi-Span Bridge

Computer Model

Test Columns

Actuator

Site 1

Site 2

Site 3

Geographically Distributed Tests

Real-time testing on simulated basis
Model of the Entire bridge including abutments

Soil-Foundation- Structure Interaction

Courtesy PEER
Vulnerability Assessment

2. Network vulnerability

i. Most vulnerable component determines vulnerability of a series type network

ii. Vulnerability of weakest link determines network vulnerability

iii. Hard linkages vs. flexible linkages

iv. Alternate network routes
Highway Network System

Network Solution
- Links connected -

Parallel Type

Isolated structure Solution

Courtesy MAE
Vulnerability Assessment

Networks

- Is the network *series* type or *parallel* type?
- Determine the *weakest link* in series type
- Determine its *contribution* in the overall performance of the network
- Determine the *capacity* of the weakest link based on demand imposed
- Other *weaker links with strategic locations* may have larger impact on the overall network performance

- **Determine vulnerability score for the network**
# Vulnerability Scores

## Single Facility

<table>
<thead>
<tr>
<th>Facility</th>
<th>Earthquakes</th>
<th>Hurricanes</th>
<th>Floods</th>
<th>Fires</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A BC Co.-Office HQ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hazard</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Exposure</td>
<td>50</td>
<td>100</td>
<td>25</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Structural Vulnerability</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Operational Vulnerability</td>
<td>8</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Total Risk</td>
<td>161</td>
<td>156</td>
<td>52</td>
<td>28</td>
<td>397</td>
</tr>
</tbody>
</table>
Hazard Scores

Earthquakes:

- Very High exposure = 100
- High Exposure = 75
- Medium Exposure = 50
- Low exposure = 25

Similar scores can be assigned to other hazards
Total Risk Scores

Typical Risk Score = Hazard x Exposure x Vulnerability

- Earthquake **Structural** Risk = $100 \times 50 \times 3 = 1500$
- Earthquake **Operational** Risk = $100 \times 50 \times 8 = 4000$
- Hurricane **Structural** Risk = $50 \times 100 \times 2 = 1000$
- Fire **Structural** Risk = $20 \times 5 \times 1 = 100$
- Flood **Operational** Risk = $25 \times 25 \times 1 = 625$

Various risks can be compared and facilities can be appropriately designed for performance
Combined quantitative and Bayesian Decision Framework is required
to
Develop a risk-consistent approach to multi-hazard engineering
THANK YOU