Consideration of Multi-Hazard Conditions as Applied to Infrastructures

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History

- The recent devastating effects of hazards..
  - Earthquakes (Loma Prieta and North Ridge)
  - Hurricanes (Atlantic and Gulf Coasts)
  - Terrorism (Blast/PC mitigation needs)

- .. prompted the search for methods to limit
  - Social, and
  - Economic effects..

- This led to Multihazards consideration ideas.
Potential for an economic design and construction.
A more accurate estimation of inherent resiliency of the system.
A more accurate treatment/estimation of life cycle cost of the system.
A more accurate analysis of the system.
Optimization of the Structural Health Monitoring (SHM) to increase experimental efficiency.
The multihazard design philosophy of a particular infrastructure project may affect the entire network on infrastructure systems.

For example, multihazard design of an important highway bridge may improve the reliability of the entire transportation network of the region that the highway bridge serves.
Multihazards: Disadvantages

- Lack of a concise set of tools that can accommodate multihazards considerations.
- This results in spotty applications to an otherwise increasingly important subject.
- Thus, even though the infrastructures community realizes this value, there are no objective roadmaps to tap on the immense potential of the multihazards philosophy.
- This Presentation shows potential ways of quantifying multihazards
Theory of Multihazards

- For a given system that is exposed to multihazards, there exists an inherent multihazards resiliency within the system. This multihazards resiliency implies an interrelationship between the manners that the system responds to different hazards.
Different hazards can result in conflicting demands

- **Blast**: inversely proportional to mass
- **Seismic**: Directly proportional to mass
- **Wind**: Independent of mass

Note lack of ductile detailing at center, where plastic hinges will form during blast events
Hazards can have similar demands from systems.

- Blast: Inelastic behavior
- Seismic: Inelastic behavior
- Wind: Elastic behavior
Optimization is The Ultimate Goal

- To account for all those conflicting and consistent demands, an optimization of design is needed
  - Not necessarily formal optimization
## Multihazards Table (Bridges)

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H – High inter-dependence  
M – Medium Inter-dependence  
L – Low Inter-dependence  
N.A.- Not Applicable
Analysis needs vary immensely for different hazards.

Degree of F.E. resolution depends on:
- Geometry,
- Time, and
- Amplitude

Characteristics of different hazards

Failure to accommodate such needs would produce an inaccurate results
Analysis of Hazards

- Definition of hazards include three parameters:
  - Space
  - Time
  - Amplitude
Frequency-Amplitude Hazards Spectrum

Qualitative Frequency-Amplitude distribution for different Hazards:
- Wind
- Seismic
- Blast
- Machine Vibration
- Acoustic

Amplitude Scale:
- Very Low
- Low
- Medium
- High
- Very High

Frequency Scale:
- Very Low
- Low
- Medium
- High
- Very High
Extent of Hazards

Different Popular Hazards

- Blast Pressure
- Impact
- Corrosion
- Machine Vibrations
- Acoustic
- Gravity Loads
- Wind
- Earthquakes
- Progressive Collapse

Local (affects few sub-components)
Intermediate (affects several components, sub-global effects)
Global (affects most components, global effect)
Design: Conventional

- Ensure safety by

\[ CD_{ij} \geq AC_{ij} \]

- Ensure economy by

\[ \text{Minimize} \left( CD_{ij} - AC_{ij} \right) \]
Design: Multihazards

- Ensure safety by

\[ CD_{ij} \geq AC_{ij} \]

- Ensure economy by

\[ \text{Minimize} \left( CD_{ij} - AC_{ij} \right) \]

- While satisfying the Multihazard capacity function

\[ CP_{ij} = f\left( CP_{i1}, CP_{i2}, \ldots CP_{i(j-i)}, CP_{i(j+1)}, \ldots CP_{iNH} \right) \]
Wind drift requirements affect the lateral stiffness capacity of the building.

The seismic design of the same building will also be affected by the same lateral stiffness capacity (in the form of vibration characteristics).

Thus the interrelationship between seismic and wind designs is obvious:

A change in the wind capacity will have a direct effect on seismic capacity, and the reverse is true.
Example of Capacities Interrelationships – Floor Vibrations

- The floor beams in an office building are designed for a given gravity weight *capacity*.
- The same beams would offer certain *capacity* (again, in the form of vibration characteristics) for perceived floor vibration.

- The two capacities are interrelated through the flexural properties of the floor beam:
  - Any change in the floor beam characteristics would affect both capacities.
Example of Capacities Interrelationships – Blast vs. Seismic Retrofits

- Blast and seismic designs of columns in framed buildings (or bridges):
- Good seismic design practice requires that there are no abrupt changes in properties of columns to avoid the phenomenon of soft stories.
- Blast design of columns might result in an abrupt change in column properties (due to fast attenuation of blast pressures).
- But, such an abrupt change would create the undesired seismic soft story behavior. Care must be taken to balance these opposing requirements of the two hazards.
Seismic vs. Blast

Spatial differences in loads will result in several differences in response, hence analysis and design steps.

- Seismic loads are applied only at the ends of columns and beams. Plastic hinges occur only at ends of structural members.
- Blast pressures are applied directly to the whole length of columns and beams. Plastic hinges occur at the center as well as at the ends of structural members.
Life Cycle Costs

- Perhaps the easiest manner to quantify Multihazard considerations
- This is due to the fact that it accounts for ALL parameters of the facility, and relate them in a single denominator: cost vs. longevity

- LCC is another emerging topic. Mostly in Bridges.
- Building owners/developers are resisting the concept, so far!!
Life Cycle Cost: Conventional

- LCC is computed for single hazard as
  \[ C_j = \int h_j(x)c_{aj}(x)dx \]

- Total LCC is computed for multiple hazards as
  \[ C_T = \sum_{j=1}^{j=NH} C_j \]
Life Cycle Cost: Multihazards

- LCC is computed for single hazard, accounting for other hazards as

\[ C_j = \sum_{k=1}^{k=NH} \int h_k(x) c_{ajk}(x) \, dx \]

- Total LCC is computed for multiple hazards as

\[ C_T = \sum_{j=1}^{j=NH} C_j \]
Life Cycle Cost: Multihazards

- the sign of $C_{obj}$ controls how different hazards at different intensities can affect the total cost.

- If the sign is positive, then the $i^{th}$ and $j^{th}$ hazards have conflicting demands on the system, thus increasing the total cost.

- If the sign is negative, then mitigating the hazards, which have consistent demands, can end up reducing the total cost.
Relative Risk

- **Conventional Relative Risk for Single Hazard**
  \[ R_j = \sum_{i=1}^{i=NS} M_i V_i I_i \]

- **Multihazard Relative Risk for Single Hazard**
  \[ R_j = \sum_{k=1}^{k=NH} \sum_{i=1}^{i=NS} M_{ik} V_{ikj} I_{ik} \]

- **Total relative Risk**
  \[ R = \sum_{j=1}^{j=NH} R_j \]
Structural Health Monitoring (SHM)

- Multihazards considerations manifest itself in many SHM applications
  - Optimal Sensor Locations
  - Value of Experimentation
  - “Serendipity” Principle

- In addition, it plays a major role in Decision-Making Techniques
  - Out of our current scope
Instrumentation of a Bridge

Notes:
All dimensions are in Feet
First natural period = 2.57 Sec.

Figure 4. Bridge Structure for Optimum Sensor Locations
Figure 5. OSL with a threshold of 0.5
Value of Experimentation

- Can maximize value of any SHM experimentation if it is designed to accommodate more than single hazard
  - A seismic monitoring experiment (waiting for earthquake event) can have more value if combined with wind or live load monitoring
  - Can be accomplished with minimal extra cost!
Serendipity Principle in SHM

Hazard #1 (Target Hazard)

SHM Experiment designed only for hazard #1

SHM Experiment designed mainly for hazard #1, with additional considerations to other hazard possibilities

If targeting Hazard #1 for SHM experimenting was erroneous, the experiment would fail, since it was designed to monitor Hazard #1 only.

If targeting Hazard #1 for SHM experimenting was erroneous, the experiment would succeed, since it still can monitor Hazard #2
Why Multihazards now?
- Impress the client
- Have an advantage over competitor
- Better understand the profession
- Prepare for the future