Regional Seismic Damage Assessment and Interdependencies of Critical Infrastructures during Earthquakes

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Workshop on Seismic Hazard and Microzonation
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Seismic Risk Studies in BC

- **Seismic risk in south-western BC**
  - Deals with damage, monetary losses and casualties

- **Critical Infrastructure Interdependencies**
  - Development of technology and tools to better understand the interdependency between critical infrastructure during natural and man-made disasters

- **Real-time monitoring of infrastructure in BC**
  - Development of Internet-based technology for monitoring earthquakes and their effects in BC.

*The methodology of each of these projects will be presented briefly.*
Elements of Seismic Risk

Select Probability Level

PGA / MMI

Building Type

Damage Table

% Damage and $ Loss
Structural Damage in Vancouver

Average MDF (%) by Block for MMI VIII
Main geological units and the corresponding amplification factors are:

- R2  1.0
- C1  1.5
- F   1.5
- C2  2.0
- O1  2.5

These amplification factors are for strong shaking and long-period ground motion.
Structural Damage in Victoria

*with and without* Site Amplification
Monetary Losses

- Economic losses estimated based on building use, replacement value and damage
- FEMA Facility Dependent monetary loss estimation

![Cost Distribution in Buildings](chart.png)

After Prof. E. Miranda
Non-structural Damage

Average MDF for NSCs on UBC Campus

MDF (%) vs. Instrumental Intensity

- Contents
- Displacement
- Acceleration

Contents: 0, 5, 10, 15, 20, 25, 30, 35

Displacement: VI, VII, VIII, IX, X, XI, XII

Acceleration: VI, VII, VIII, IX, X, XI, XII
Building Functionality

UBC Campus

![Bar chart showing the number of buildings by Instrumental Intensity across different buildings (VI, VII, VIII, IX, X, XI, XII). The categories of Instrumental Intensity are represented by different colors: A, B, C, D, E. The chart illustrates the distribution of buildings across the spectrum of Instrumental Intensity.]
Collaborative work in BC to adapt HAZUS Methodology to CANADA
Recent collaborative work in BC

A Framework for Collaborative for Earthquake Risk Assessment in Western Canada

- Earthquake Hazard Assessment
  - ground shaking
  - site amplification
  - ground deformation

- Asset Inventory Database
  - building stock
  - people
  - essential facilities
  - infrastructure

- Vulnerability Assessment Methods
  - NRCan Hazus
  - UBC EERF
  - UBC SCARP

- Probabilistic Scenarios
- Deterministic Scenarios

- Level 1 Stats Canada
- Level 2 BC Assessment
- Level 3 Site Survey

- Earthquake Risk Loss Estimation
  - Physical Damage
  - Economic Loss
  - Injuries
  - Social Disruption
  - System Functionality

Institutions involved:
- UBC - EERF
- UBC - SCARP
- SFU - CNHR
- NRCan - PSGP
Example of Earthquake Damage Scenarios
Developed by NRCan as part of this Collaborative Work

The following slides were kindly provided by Dr. M. Journeay of NRCan
Disclaimer:

The results presented here are of very preliminary nature and should only be used to better understand the concepts described in this presentation and to get a general idea of the comparative impact of various types of earthquakes that may affect the BC region.
Hazard Threat - Earthquake Ground Shaking

Cascadia Subduction Zone Event

Magnitude probability of occurrence: 10% in 50 years.
Ground motions used, probability of exceedance: 1.6% ~ 2% in 50 years.
Reference NEHRP soil type “C”
Hazard Threat - Earthquake Ground Shaking

Georgia Strait Fault Zone Event

Probabilities are unknown for this scenario.
Reference NEHRP soil type “C”
Hazard Threat - Earthquake Ground Shaking

Kendall Fault Zone Event

Magnitude, event, probability of occurrence: 3% in 50 years. Ground motions used, probability of exceedance: 0.5% in 50 years. Reference NEHRP soil type “C”
Hazard Threat - Site Amplification of Seismic Energy
Hazard Threat - Liquefaction Susceptibility
Physical Damage & Loss - Building Stock

- HAZUS estimates that about **68,973** buildings will be at least moderately damaged. This is over 14% of the total number of buildings in the region.
- There are an estimated **2,291** buildings that will be damaged beyond repair.
- The total building-related losses are ~ **$10B dollars**; 25% of the estimated losses were related to the business interruption of the region.
- By far, the largest loss was sustained by the residential occupancies which made up over 62% of the total loss.
Physical Damage & Loss - Building Stock

- HAZUS estimates that about 129,034 buildings will be at least moderately damaged. This is over 27% of the total number of buildings in the region.
- There are an estimated 8,093 buildings that will be damaged beyond repair.
- The total building-related losses are ~ $21B dollars; 21% of the estimated losses were related to the business interruption of the region.
- By far, the largest loss was sustained by the residential occupancies which made up over 68% of the total loss.
HAZUS estimates that about 8,847 buildings will be at least moderately damaged. This is over 2% of the total number of buildings in the region.

- There are an estimated 16 buildings that will be damaged beyond repair.
- The total building-related losses are ~ $1.5B dollars; 13% of the estimated losses were related to the business interruption of the region.
- By far, the largest loss was sustained by the residential occupancies which made up over 72% of the total loss.
Physical Damage – Social Disruption

- Hazus estimates **25,424 households** to be displaced due to the earthquake.
- Of these, **14,229 people** (out of a total population of 2,095,210) will seek temporary shelter in public shelters.
Physical Damage – Social Disruption

- Hazus estimates **41,015 households** to be displaced due to the earthquake.
- Of these, **21,825 people** (out of a total population of 2,095,210) will seek temporary shelter in public shelters.
Social Disruption – Social Disruption

- Hazus estimates **703 households** to be displaced due to the earthquake.
- Of these, **394 people** (out of a total population of 2,095,210) will seek temporary shelter in public shelters.

**Legend**

<table>
<thead>
<tr>
<th>Displaced Households # Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1</td>
</tr>
<tr>
<td>2 - 3</td>
</tr>
<tr>
<td>4 - 8</td>
</tr>
<tr>
<td>9 - 15</td>
</tr>
<tr>
<td>16 - 31</td>
</tr>
</tbody>
</table>

Kendall Fault Event
Induced Damage - Debris Generation

- Hazus estimates that a total of 5.32 million tons of debris will be generated.
- Of the total amount, Brick/Wood comprises 22% of the total, with the remainder being Reinforced Concrete/Steel.
- If the debris tonnage is converted to an estimated number of truckloads, it will require 212,680 truckloads (@25 tons/truck) to remove the debris generated by the earthquake.
Hazus estimates that a total of **9.38 million tons** of debris will be generated.

- Of the total amount, **Brick/Wood comprises 26%** of the total, with the remainder being **Reinforced Concrete/Steel**.
- If the debris tonnage is converted to an estimated number of truckloads, it will require **375,080 truckloads (@25 tons/truck)** to remove the debris generated by the earthquake.
Induced Damage - Debris Generation

- Hazud estimates that a total of 0.33 million tons of debris will be generated.
- Of the total amount, Brick/Wood comprises 39% of the total, with the remainder being Reinforced Concrete/Steel.
- If the debris tonnage is converted to an estimated number of truckloads, it will require 13,040 truckloads (@25 tons/truck) to remove the debris generated by the earthquake.
UNDERSTANDING INTERDEPENDENCIES AMONG CRITICAL INFRASTRUCTURES
Many critical infrastructure Networks rely on one another in order to function.

In the event of a disaster, Critical Infrastructures can sustain significant damage which could render them inoperable.

Important to identify infrastructure interdependencies in order to mitigate the effects of a disaster.
How do we do it?

- First, there are interdependencies within and in between infrastructures networks
- Second, we need to recognize that interdependencies are time dependent and have very complex relationships
- Third, we have to recognize that this is a difficult problem to solve because it is highly nonlinear and time dependent

The problem can be made more manageable by linearizing the interdependencies in segments of time, using Seismic Risk Assessment techniques for individual infrastructures and implementing a rational approach to combine the information available to determine the effect of these interdependencies.
I2Sim is a tool that we have developed to determine the consequences of the failure of one or more of the infrastructures.

www.i2sim.ca
Superimposed Layers

ICT Layer

Decisions Layer

Damage Layer

Production Layer

Production Cell

Distributor
Cell’s State

Physical Operability 100% (green)

- PM01
  - Sensory Information 0%
  - Effective Operability 50% because of lack of water

Physical Operability 50% (yellow)

- PM03
  - Sensory information 100%
  - Effective Operability 0% because of lack of electricity
i2Sim Model

Structure + NSCs + Lifelines

PM, RM
Cell 1
Channel $i$

Distributor
Control points
Aggregator

Cell 2
Interdependencies

Can be represented by the following equation:

\[
[T][X] = [W]
\]

[T]: Transportation matrix
[X]: Received Goods
[W]: Sent Goods

\[\begin{bmatrix}
p1 & p2 & p3 & w1 & w2 & w3 & r1 & r2 & r3 \\
p1 & x & x & x & y & y & y \\
p2 & x & x & x & y & y & y \\
p3 & x & x & x & y & y & y \\
w1 & y & x & x & Water & x & x & x \\
w2 & y & x & x & Water & x & x & x \\
w3 & y & y & y & y & x & x & x \\
r1 & y & y & y & y & x & x & x \\
r2 & y & y & y & y & x & x & x \\
r3 & y & y & y & y & x & x & x \\
x = internal transmission link \\
y = interdependency link \\
p1 = power token value node 1 \\
p2 = power token value node 2 \\
... \\
w1 = water token value node 1 \\
... \\
\end{bmatrix} = \begin{bmatrix}
p1 & p2 & p3 \\
w1 & w2 & w3 \\
r1 & r2 & r3 \\
Sp1 & Sp2 & Sp3 \\
Sw1 & Sw2 & Sw3 \\
Sr1 & Sr2 & Sr3 \\
\end{bmatrix}\]
Real-Time Responsiveness

- Closed solution much faster than open iterative solutions (e.g., agent-based modelling) by two or three orders of magnitude

- As an example, a system of 3,000 cells with 15 inputs/outputs per cell (45,000 state variables) for a 10 hr scenario with $\Delta t = 5$ minutes can be analyzed in a few seconds of computer time

- Interactive scenario playing is basically instantaneous
Cells Outputs

Water (%)

Doctors (%)

Medicines (%)

Beds (%)

TIME (h)

20080116
Decision Making Scenario

A, B = decision points
Decision A
- Take Action A2
Decision B
- Take Action B1

Screens at A
- Real World
- No Action (Sim)
- Action A1 (Sim)
- Action A2 (Sim)

A, B = decision points
Decision A
- Take Action A2
Decision B
- Take Action B1

Screens at A
- Real World
- No Action (Sim)
- Action A1 (Sim)
- Action A2 (Sim)

A, B = decision points
Decision A
- Take Action A2
Decision B
- Take Action B1

Screens at A
- Real World
- No Action (Sim)
- Action A1 (Sim)
- Action A2 (Sim)
UBC Campus Case Study
Why modeling UBC campus?

- The UBC campus shares many attributes of a small city
  - 47000 daily transitory occupants
  - 10000 full time residents
  - own utilities providers
- Information

After an earthquake, you will have losses in the services (electricity, water, etc.)

**What will be the overall functionality of UBC?**

**Where to put the available resources?**
Campus Networks: GIS

JIIRP - I2C
UBC campus case

JIIRP - I2C
UBC campus case
Campus Fiber Network
Earthquake Damage Assessment

BC31 Mean Damage Factors with Modifiers
Intensity VIII - UBC Campus

BC31 Mean Damage Factors with Modifiers
Intensity IX - UBC Campus

BC31 Mean Damage Factors with Modifiers
Intensity X - UBC Campus
GIS: Decision Makers Risk Mapping
Water system
Buildings & Water System
Overlayed Damage Assessments
Intensity IX

WATER SYSTEM
Water Loss
- 0.5%
- 2.5%
- 5%
- 8%
- 12%

BUILDINGS
Functionality
- 100%
- 80%
- 50%
- 0%

0 135 270 540 Meters
Buildings & Water System
Interdependency Assessments
Intensity IX

WATER SYSTEM
Loss of water
- 0 %
- 0.5 %
- 10 %
- 8 %
- 15 %

BUILDINGS
Functionality
- 100 %
- 95 %
- 50 %
- 0 %
Global Interdependency of the Hospital

Global Interdependency between hospital water and electricity systems

Functionality Conditions

Instrumental Intensity

- H interdependency
- Electricity to H
- Water Zone A12
- Hospital
Collaborative effort between BCMOT-UBC-GSC (and BCMOE)

Internet-based tools for:

- Instant notification of levels of ground shaking (main shock and aftershocks)
- Real-time shake maps
- Performance of infrastructure
- Emergency response planning
- Real-time maps of damage distribution
- Earthquake warning system

www.bcsims.ca
Remarks

- When interdependencies are taken into account, they can help develop more realistic risk reduction programs and emergency response plans.

- Methodologies being developed are useful for the identification of regions of high seismic risk and the interdependencies among critical infrastructures.

- Real-time information tools, such as the BCSIMS project, and simulators, such as I2SIM, are powerful tools that allow the investigation of risk levels and interdependencies among Critical Infrastructure, so that consequences can be minimized.

- Improving response to infrastructure failures is a necessary condition for disaster resilience.

- First priority during disaster situations is, and should be, human survival.