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Seismic Risk Assessment in UAE by the Large-Magnitude Offshore Shallow Crustal Earthquake

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Magnitude
Seismic Wave Energy

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Magnitude is a number that characterizes the relative size of an earthquake. Each whole number increase represents a tenfold increase in the measured amplitude, and 32 times more energy release.

Examples of major earthquakes and their magnitudes:

- **Alaska** 1964 M 9.2
- **San Francisco** 1989 M 6.9
- **Haiti** 2010 M 7.0
- **Christchurch** 2011 M 6.2
- **Kashmir** 2005 M 7.6
- **Sumatra** 2004 M 9.1
- **Sichuan** 2008 M 7.9
- **Tōhoku** 2011 M 9.1
- **Kobe** 1995 M 6.9

3 of the 5 largest earthquakes in the 21st century have occurred in the Sumatra region of Indonesia.

Here are some factors that determine how destructive an earthquake can be:

- Location
- Magnitude
- Depth
- Distance from epicenter
- Geologic conditions
- Secondary effects
- Architecture

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Loss of life, $1 billion+ in damage

Energy release of Mount St. Helens eruption

3

Energy release equivalent to the Hiroshima atomic bomb

Moderate shaking, property damage

150

Energy release of an average tornado

1,500

Light shaking, some property damage

10,000

Felt by humans

100,000

Energy release of a large lightning bolt

1,000,000

Number of earthquakes per year, globally

Source: U.S. Geological Survey

Image: www.visualcapitalist.com
Earthquake visuals

Haiti

5th century earthquake Rome

Alaska 2021

Japan

Indonesia

Taiwan
Earthquake Induced Hazards

• Landslides

• Tsunami

• Volcanoes

• Adds more to the disaster

• Way out: Science is needed!!
Risk

Uncertainty

Likelihood

Probability of Hazard

Undesirability

Severity

Number of Injuries

Exposure and vulnerability

End up with two numbers!!

Risk = f(Hazard, Exposure, Vulnerability)

Reduce Risk (R → 0)

Hazard → 0 (Impossible as hazard cannot be controlled)

Exposure → 0 (Impossible if exposed object is a requirement)

Vulnerability → 0 (needs to be worked on!!)

We with our decision, increase or reduce the Risk

Hazard may NOT cause disaster if there is no construction or construction with better planning.
Composition of Loss

Physical damage/loss of lives

Socio-Economic Impact

Functioning Disruption

Risk Analysis

- Determine potential undesirable consequences associated with the Hazard.
- Identify Scenarios that such consequence could shape up.
- Estimate the Loss associated with such events.
- Provide inputs to decision makers on effective plan of action to reduce the loss.
- It is an exercise in expressing preferences with the knowledge of Science, History and Computation.
- It is the only way to integrate our understanding of Complex Systems!!
Overview of our Strategy:

Earthquake Risk-Modeling Workflow

Seismic CAT Tool – RsRL (2020)

1. Global Models for Seismic Risk Analysis

2. Temporal Regional Input Variables and Geographic Information

3. Regionalized Time-Dependent Risk Analysis

Automated Time-Dependent Regionalization by AI
Regional tectonic setting of the Arabian Peninsula for the UAE (Lippard et al. 1982)
(a) Seismicity (658–2019) of the UAE and its surroundings. (b) Spatial distribution of used focal-mechanism solutions in and around UAE (Sawires, et al. 2019)
Abu Dhabi International Building Code (ADIBC) is public available (building codes (abudhabi.ae)). ADIBC provides seismic design guideline for structural design.
• These maps are only for Maximum Considered Earthquake (MCE)
• The ground motion level of PSA(0.2s) = 0.55g at Abu Dhabi (0.65g) at Rock Site
• The ground motion level of PSA(1.0s) = 0.165g at Abu Dhabi (0.20g) at Rock Site
Abu Dhabi International Building Code

• Rock motions are amplified through soil deposits depending on “Site Class”
• Site class is categorized based on average shear wave velocity of top 30 m ($V_{s30}$).
• For seismic risk assessment, surface soil conditions in the UAE need to be understood.

<table>
<thead>
<tr>
<th>Site Class</th>
<th>Profile</th>
<th>$V_{s30}$ (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Hard Rock</td>
<td>&gt; 1,500</td>
</tr>
<tr>
<td>B</td>
<td>Rock</td>
<td>760 &lt; $V_{s30}$ &lt; 1,500</td>
</tr>
<tr>
<td>C</td>
<td>Very dense soil/Soft rock</td>
<td>365 &lt; $V_{s30}$ &lt; 760</td>
</tr>
<tr>
<td>D</td>
<td>Stiff soil</td>
<td>185 &lt; $V_{s30}$ &lt; 365</td>
</tr>
<tr>
<td>E</td>
<td>Soft soil</td>
<td>&lt; 185</td>
</tr>
<tr>
<td>F</td>
<td>Liquefiable</td>
<td></td>
</tr>
</tbody>
</table>
Data Used

- First near-global topographical map of Earth, collecting data on nearly 80 percent of Earth's land surfaces.
- U.S. Geological Survey has the STRM database
- We use STRM 1 Arc-second Digital elevation Model Data Set
Site Class Estimation based on Remote Data and Geology

- Digital elevation model (DEM) will be utilized to estimate Vs30.
- Terrain categories are computed from DEM

Digital Elevation Model (DEM) from Shuttle Radar Topographic Mission (SRTM) data in USGS

Terrain categories from DEM
Surface Geology Map in the UAE

Geological map of UAE (modified from British Geological Survey and Ministry of Energy 2006)
Vs30 Prediction from Surface Geology

<table>
<thead>
<tr>
<th>Geologic category</th>
<th>Mean $V_{S30}$ (m/s)</th>
<th>Standard Deviation ($\sigma_{inV}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeolian sand dunes</td>
<td>662</td>
<td>0.22</td>
</tr>
<tr>
<td>Coastal sabkha</td>
<td>568</td>
<td>0.29</td>
</tr>
<tr>
<td>Delta or shoal deposits</td>
<td>557</td>
<td>0.14</td>
</tr>
<tr>
<td>Fluvial deposits</td>
<td>511</td>
<td>NA</td>
</tr>
</tbody>
</table>
## Vs30 Prediction from Terrain Category (DEM)

<table>
<thead>
<tr>
<th>Terrain Category</th>
<th>Description</th>
<th>Mean $V_{S30}$ (m/s)</th>
<th>Standard Deviation ($\sigma_{InV}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Well eroded plain of weak rocks</td>
<td>689</td>
<td>0.22</td>
</tr>
<tr>
<td>13</td>
<td>Incised terrace</td>
<td>623</td>
<td>0.24</td>
</tr>
<tr>
<td>15</td>
<td>Dune, Incised terrace</td>
<td>656</td>
<td>0.19</td>
</tr>
<tr>
<td>16</td>
<td>Fluvial plain, alluvial fan, low lying flat plains</td>
<td>561</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Development of $V_{s30}$ Map in the UAE

- Kriging Method (conditional probability) is used to develop Vs30 Map in the UAE. It requires:
  - Measured Vs30
    \[
    \mu_{Y_1|Y_2} = \mu_{Y_1} + \rho_{Y_1,Y_2} \sigma_{Y_1} \frac{1}{\sigma_{Y_2}^2 + \tau^2 + \sigma_{30|Z}^2} (y_2 - \mu_{Y_2})
    \]
    \[
    \sigma_{Y_1|Y_2}^2 = \sigma_{Y_1}^2 + \tau^2 - \frac{\left(\rho_{Y_1,Y_2} \sigma_{Y_1} \sigma_{Y_2}\right)^2}{\sigma_{Y_2}^2 + \tau^2 + \sigma_{30|Z}^2}
    \]
  - Prediction and uncertainty models of $V_{s30}$ (DEM, Surface geology models)
  - Spatial correlation model.

\[
\rho(h) = e^{-\frac{h}{a}}
\]
Drafting $V_{s30}$ Map in the UAE
Given the earthquake scenario, peak ground acceleration maps can be computed by connecting:

- Earthquake Ground Motion Prediction Equations
  - e.g. NGA-West2 Studies (Abrahamson et al. 2014)
- Site amplification models using $V_{S30}$ maps in the UAE
Peak Ground Acceleration Map in the UAE

PGA shaking distributions are computed quickly for any locations and earthquakes in the UAE.

Earthquake scenario is inland Arabian Peninsula (M4.0)  
Coastal Iran Earthquake
Dynamic Financial Analysis (DFA)
Components of a end-end DFA solution:

1. Underwriting Risk module
2. Reserve Risk module
3. **Catastrophe risk module**
4. Credit and Market risk module
5. Operational risk module
6. Dependencies module
7. Reinsurance module
8. Balance Sheet/Risk metrics module

The basic requirements of a DFA software for (re)insurance. Each module (except 6, 7 and 8) models a specific risk to the (re)insurance company.
Catastrophe risk (CAT Risk)

- Simulate or take as input, catastrophe losses (on existing and new business) and apportion them to respective lines of business
- Ensure losses from all perils are accounted for (even if they are not directly modelled by nat-cat models) by appropriate adjustments
What is Acceptable Risk?

Reff: m-dimensional independence problem
(arXiv paper June 2022 by Delbaen, Majumdar)
Conclusions

Seismic hazard is presented in Abu Dhabi International Building Code.

To compute seismic risk, regional shaking levels need to be obtained for any scenarios.

Machine Learning bias reduced DFA to minimize losses.

What is acceptable risk?

For questions & comments, please email: info@rsrldigital.com