Seismic Microzonation: A key Link in Earthquake Risk Identification and Management in Trinidad and Tobago

Seismic Microzodnation Workshop
Institute of Critical Thinking
The University of the West Indies
St Augustine
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Seismic Research Centre
The University of the West Indies
Once the shaking hazard is determined, it is possible to assess the potential of the secondary hazards that are circled.
Earthquake Site Effects

Seismic energy travels from source in the form of elastic waves.

Waves undergo amplification in specific bands of periods in moving from basement to less dense medium.

Amplification may also be caused by focussing of waves by strata.
Natural Period of Buildings

Height is the main determinant:

Building Period $T(\text{sec}) \approx 0.1N$

where $N = \text{Number of floors}$

But $T$ also depends on Mass and Stiffness
Earthquakes don’t have to be close to be damaging

Considerable damage to I-880 Interstate Highway in the San Francisco Bay Area located 80km N of epicentre

The Loma Prieta quake killed 63 people throughout northern California, injured 3,757 and left some 3,000-12,000 people homeless.

Date: October 17, 1989  
Duration: 15 seconds  
Magnitude: 6.9 $M_w$  
Depth: 11 miles (18 km)  
Epicenter: $37^\circ02'24''N 121^\circ52'37''W$  
Country: United States
Recent Seismic Hazard Map of Trinidad
1692, Jamaica; M 7.5, MMI - IX-X; 3000 Killed 66% of city sank

1842, Northern Haiti; M 8.1, MMI - IX-X; Over 10000 Killed Cap Hatien destroyed. Fatal to other cities.

1867, Virgin Islands MMI – VIII, St Johns; St Thomas, St. Croix Tsunami Damaged V.I., PR & St. Georges

1766, Trinidad; M 7.8, MMI – VII-IX; Changed face of Island. Most masonry buildings destroyed

1843, Guadeloupe; M 7.9, MMI - IX-X; 2000 Killed. Heavy liquefaction. Pointe-a-Pitre ruined

1918, Puerto Rico M 7.3, MMI - IX-X; 118 Killed, Deadly Tsunami US$4M losses

1997, Tobago MMI – VIII; Damaged several buildings; TT$18M in losses

2010, Haiti, P-a-P M7.0(Mw), MMI IX-X 230,000 killed, 300,000 injured 1,000,000 homeless US$12Billion in losses
<table>
<thead>
<tr>
<th>EVENT</th>
<th>MAGNITUDE</th>
<th>DAMAGE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1839 Martinique. Mag. 7.5</td>
<td></td>
<td>4.7 M FF</td>
<td>Est. cost to repair damage to Point-a-Pitre (MMI VIII)</td>
</tr>
<tr>
<td>Fort de France MMI: IX</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1907 Jamaica. Mag. 6.5</td>
<td></td>
<td>£2 M</td>
<td>Est. cost of repairs to fire and earthquake damage. 90K homeless.</td>
</tr>
<tr>
<td>Kingston MMI: IX</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1918 Puerto Rico. Mag. 7.3</td>
<td></td>
<td>US$4 M</td>
<td>Earthquake and tsunami destroyed about 700 homes and buildings.</td>
</tr>
<tr>
<td>Mayaguez MMI: VIII</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1932 Cuba. Mag. 6.8</td>
<td></td>
<td>20 M Pesos</td>
<td>Most buildings were damaged. 500 injured</td>
</tr>
<tr>
<td>Santiago de Cuba MMI: VIII</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1974 Antigua. Mag. 7.4</td>
<td></td>
<td>EC$23 M</td>
<td>Larger and older buildings damaged. Oil refinery and Port also suffered.</td>
</tr>
<tr>
<td>1997 Tobago. Mag. 6.7</td>
<td></td>
<td>TT$18-25M</td>
<td>6 houses destroyed and damage to several public buildings</td>
</tr>
<tr>
<td>SW Tobago MMI: VII-VIII</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Puerto Plata</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007 Martinique. Mag. 7.4</td>
<td></td>
<td>€20-30 M</td>
<td>Deep earthquake. Many larger structures suffered significant damage</td>
</tr>
<tr>
<td>Martinique MMI: VI-VIII</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010 Haiti. Mag. 7.0</td>
<td></td>
<td>US$12 B</td>
<td>Est. Total cost of damage by ECLAC. 216K dead and over 1 million injured</td>
</tr>
<tr>
<td>Port-au-Prince MMI: IX</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cause for Concern

• It is important to recognize that no truly catastrophic earthquake—that is, one that affects production facilities, economic markets, and distribution systems in any significant manner—has occurred in Trinidad and Tobago in the last 200 years.

• Fatalities as well as the social and economic costs of recent earthquakes have increased dramatically. A national concern about potential threat should be raised as scientifically based probabilities of future earthquakes near the country have risen.
Trinidad and Tobago Damaging Earthquakes
Size, Intensity, Chronology and Locations

Seismic Energy

1700 1750 1800 1850 1900 1950 2000

7.8 (IX) 1766
6.6 (VIII) 1825
7 (VII) 1888
7.3 (VIII) 1918
6.3 (VIII) 1954
6.7 (VIII) 1997
7.4 (VI) 2007

Depth (km)  
0 – 15 15 – 35 35 – 70 70 – 100 100 – 150 150 – 300

1800s
1900s
2000s

Seismic Energy: Magnitude levels from IX to 5.3 are depicted, illustrating the intensity of damaging earthquakes in Trinidad and Tobago.
Released Energy vs. Epi-central Distance (Trinidad)
Seismic Records and Earthquake Recurrence Intervals

Recurrence Interval decreases with Magnitude

After Console et al.
Seismic Records and Earthquake Recurrence Intervals
Paleo-seismological information – preserved in geological record
Seismic Records and Earthquake Recurrence Intervals
Historical seismological information – historical catalogues
500 years for the Caribbean
Seismic Records and Earthquake Recurrence Intervals

Instrumental seismological information – Instrumental catalogues
60 years for the E. Caribbean

All events > M4.5 since 1964

All events > M5.5 since 1955

60 Yrs
RISK $F(NH, V)$

Underlying Risk Sources

Uncontrollable

Controllable

Natural Hazards

- Severe Natural Event
- Resilience of Environment

Vulnerability

- Presence of Human Settlement
- Fragility to Natural Hazards

Environmental Degradation
Implementation Strategy for Achieving Seismic Safety
- as Proposed by the Ministry of Works Design Branch

1. **New Construction: Stop Increasing Risk**, all new construction should be earthquake resistant so that there is no increase in risk.

2. **Existing Buildings: Decrease Unacceptable Risk**, existing structures should be either retrofitted or reconstructed to withstand reasonable shaking.

3. **Accept Inevitable Earthquake: Prepare for Consequences**, awareness level should be increased at all levels from policy makers to community to individuals.
### Population Growth and Urbanization

<table>
<thead>
<tr>
<th>Metropolitan</th>
<th>Country</th>
<th>Population</th>
<th>Metro area</th>
<th>Density (/km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santo Domingo</td>
<td>Dom. Rep.</td>
<td>3,813,214</td>
<td>1,400.79 km²</td>
<td>2,722.2/km²</td>
</tr>
<tr>
<td>Puerto Plata</td>
<td>Dom. Rep.</td>
<td>277,981</td>
<td>459.71 km²</td>
<td>604.7/km²</td>
</tr>
<tr>
<td>Port-au-Prince</td>
<td>Haiti</td>
<td>3,000,000</td>
<td>735.78 km²</td>
<td>3,817.89/km²</td>
</tr>
<tr>
<td>Kingston/St. Andrew</td>
<td>Jamaica</td>
<td>651,880</td>
<td>480 km²</td>
<td>1,358.1/km²</td>
</tr>
<tr>
<td><strong>East-West Corridor</strong></td>
<td><strong>Trinidad/Tobago</strong></td>
<td><strong>548,000</strong></td>
<td><strong>899 km²</strong></td>
<td><strong>609.6/km²</strong></td>
</tr>
<tr>
<td>San Juan</td>
<td>Puerto Rico</td>
<td>434,374</td>
<td>199.2 km²</td>
<td>2,180.6/km²</td>
</tr>
<tr>
<td>Santiago de Cuba</td>
<td>Cuba</td>
<td>423,392</td>
<td>1,023.8 km²</td>
<td>413.5/km²</td>
</tr>
</tbody>
</table>

More than 70% of Population of T’nT lives in Urban Settings
Population Growth ~ 0.4%/year
CONSEQUENCE OF UNPLANNED URBANIZATION IN PORT-AU-PRINCE

EAST POS, TRINIDAD - SIMILAR TYPE OF SETTLEMENT UNDER DEVELOPMENT
RC Concrete and Masonry with Hollow Clay Bricks are the leading types of residential construction in Trinidad and Tobago.

<table>
<thead>
<tr>
<th>Municipalities</th>
<th>Brick/Concrete</th>
<th>Wood</th>
<th>Wood/brick/Concrete</th>
<th>Wood/Galvanize</th>
<th>Wattle/Adobe/Tapia</th>
<th>Other</th>
<th>Not Stated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trinidad and Tobago</td>
<td>64.28</td>
<td>12.28</td>
<td>20.23</td>
<td>2.22</td>
<td>0.45</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>Port of Spain</td>
<td>73.92</td>
<td>13.01</td>
<td>9.56</td>
<td>2.36</td>
<td>0.79</td>
<td>0.23</td>
<td>0.13</td>
</tr>
<tr>
<td>San Fernando</td>
<td>72.75</td>
<td>11.94</td>
<td>11.29</td>
<td>2.66</td>
<td>0.61</td>
<td>0.04</td>
<td>0.71</td>
</tr>
<tr>
<td>Arima</td>
<td>77.54</td>
<td>8.78</td>
<td>7.3</td>
<td>1.41</td>
<td>2.72</td>
<td>1.87</td>
<td>0.37</td>
</tr>
<tr>
<td>Chaguanas</td>
<td>80.66</td>
<td>6.68</td>
<td>11.15</td>
<td>1.17</td>
<td>0.02</td>
<td>0.02</td>
<td>0.31</td>
</tr>
<tr>
<td>Point Fortin</td>
<td>49.05</td>
<td>15.52</td>
<td>32.07</td>
<td>2.85</td>
<td>0.04</td>
<td>0.13</td>
<td>0.33</td>
</tr>
<tr>
<td>Diego Martin</td>
<td>82.22</td>
<td>6.93</td>
<td>8.84</td>
<td>1.33</td>
<td>0.16</td>
<td>0.09</td>
<td>0.43</td>
</tr>
<tr>
<td>San Juan/Laventille</td>
<td>77.12</td>
<td>8.81</td>
<td>11.17</td>
<td>1.5</td>
<td>0.66</td>
<td>0.09</td>
<td>0.65</td>
</tr>
<tr>
<td>Tunapuna/Piarco</td>
<td>77.98</td>
<td>7.04</td>
<td>10.68</td>
<td>2.32</td>
<td>1.09</td>
<td>0.4</td>
<td>0.49</td>
</tr>
<tr>
<td>Couva/Tabaquete/Talparo</td>
<td>60.48</td>
<td>11.91</td>
<td>24.35</td>
<td>2.6</td>
<td>0.14</td>
<td>0.31</td>
<td>0.21</td>
</tr>
<tr>
<td>Mayaro/Rio Claro</td>
<td>34.56</td>
<td>17.41</td>
<td>46.03</td>
<td>1.58</td>
<td>0.16</td>
<td>0.03</td>
<td>0.23</td>
</tr>
<tr>
<td>Sangre Grande</td>
<td>56.95</td>
<td>9.35</td>
<td>29.04</td>
<td>3.78</td>
<td>0.58</td>
<td>0.08</td>
<td>0.22</td>
</tr>
<tr>
<td>Princes Town</td>
<td>39.36</td>
<td>20.67</td>
<td>36.59</td>
<td>3.13</td>
<td>0.02</td>
<td>0.04</td>
<td>0.19</td>
</tr>
<tr>
<td>Penal/Debe</td>
<td>48.2</td>
<td>19.09</td>
<td>30.19</td>
<td>2.33</td>
<td>0.03</td>
<td>0.02</td>
<td>0.13</td>
</tr>
<tr>
<td>Siparia</td>
<td>44.34</td>
<td>19.76</td>
<td>32.87</td>
<td>2.53</td>
<td>0.23</td>
<td>0.13</td>
<td>0.14</td>
</tr>
<tr>
<td>Trinidad</td>
<td>64.51</td>
<td>11.96</td>
<td>20.25</td>
<td>2.26</td>
<td>0.47</td>
<td>0.21</td>
<td>0.34</td>
</tr>
<tr>
<td>Tobago</td>
<td>59.18</td>
<td>19.2</td>
<td>19.72</td>
<td>1.29</td>
<td>0.00</td>
<td>0.04</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Source: Population and Housing Census 2000
EVALUATION OF EXISTING BUILDINGS
(Fragility curve courtesy: Richard Clarke)

VULNERABILITY CURVES FOR LOCAL HOUSES (1-STORY)

No Reinforcement
URM Clay Tile house
2 Storey URM Clay Tile

Expected range of shaking (in rock) ≈0.24-0.34g
Design level for residential buildings (500 yr Event) Exceedance Prob. (damage) - 0.45-0.65
Vulnerability in T&T – Cities and Energy Industries

Soft Soils
Exposure Series

Trinidad Schools and Health Facilities
(Only sub-sets are shown in maps)

EW Corridor Health Facilities. Construction of Many Health Facilities pre-dates Seismic codes

2 Schools Collapsed in the 1997 Cariaco Earthquake, NE Venezuela
A M5.9 @ 50km depth below N Trinidad caused serious structural damage in 6 schools in 2006
<table>
<thead>
<tr>
<th>Chronic Deficiencies related to Earthquake Safety in Trinidad and Tobago</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Weak policy on earthquake safety.</td>
</tr>
<tr>
<td>➢ National disaster legislation is outmoded.</td>
</tr>
<tr>
<td>➢ There is no suitable inventory of buildings and infrastructures.</td>
</tr>
<tr>
<td>➢ A large majority of buildings are not insured or underinsured.</td>
</tr>
<tr>
<td>➢ Lack of a consistent data collection programme for risk management.</td>
</tr>
<tr>
<td>➢ Inadequate regulatory system for builders and engineering practice.</td>
</tr>
<tr>
<td>➢ Inadequate system for design approval and monitoring of construction.</td>
</tr>
<tr>
<td>➢ Lack of an adequate network of instruments to measure strong ground motion.</td>
</tr>
<tr>
<td>➢ National disaster institutions are ill-equipped to respond to severe earthquakes.</td>
</tr>
<tr>
<td>➢ Institutions suffer from incapacity; as such it is difficult to discharge their functions.</td>
</tr>
<tr>
<td>➢ Poor coordination between the key institutions responsible for earthquake safety.</td>
</tr>
<tr>
<td>➢ Insufficient awareness earthquake risk and appreciation of risk reduction measures.</td>
</tr>
<tr>
<td>➢ There is no fit-for-purpose public education programme on earthquake risk reduction.</td>
</tr>
</tbody>
</table>
An Earthquake Risk Reduction Programme

Mitigation

- Structures
  - Retrofitting
  - Retrofitting of Lifelines & Critical Infrastructure

Preparedness

- People
  - Human Capital
    - Earthquake Awareness
    - Individual preparedness

- Emergency management systems
  - Resources
    - Coordination
    - Communications
    - Search & Rescue

- Plans
  - Disaster Response
  - Stand alone
  - Supporting plans

- Regulation/Risk Transfer
  - Land Use Management
  - Building Codes
  - Insurance

Microzonation

Information
Dynamics of Earthquake Risk in Trinidad and Tobago: 1750-2010

Seismic Risk can and will expand unchecked in the absence of adequate awareness, commitment and capacity to address it.
Institutional Strengthening

Where institutional capacity is high, development policies and practices are informed by disaster risk, and people are aware and able to manage, society is less vulnerable to disasters.

- Bureau of Standards (Standards and Quality)
- Local Government (Building Regulation)
- Engineering & Construction
- Environmental Management Agency (Environmental Protection)
- Town & Country Planning Division (Development Planning)
- Insurance and Finance (Risk Transfer)
- Central Government (Public Safety)
- Disaster Management (Development Planning)
Constraints and Challenges

• **Inadequate Human Resource Capacity for**
  – Eq. Hazard/Risk/Impact Assessment
  – Planning and development
  – Building regulation
  – Disaster Management (Earthquake risk under-appreciated)

• **Ignorance/Apathy/Indifference/Impotence**
  – Public
  – Civil society
  – Government
  – Professional Associations
  – Institutions

• **Building Resilience**

• **Coordination** of

the many programmes and projects that are already underway or soon to come on stream as well as bringing to bear the useful results of concluded projects that have so far not been incorporated into policy and practice.
Earthquakes don’t have to be “shallow” to be damaging

March 4, 1977 earthquake

\[ M_w = 7.5 ; h = 109 \text{ km} \]

Killed 1,578 people (1424 in Bucharest)
Injured 11,221 people (7598 in Bucharest)

- Destroyed or seriously damaged 33,000 housing units and caused lesser damage to 182,000 other dwellings
- Destroyed 11 hospitals and damaged 448 others hospitals, etc.


- Total losses in Romania : 2.05 billion USD (100%)
- Construction losses : 1.42 (70%)
- Building and housing losses : 1.02 (50%)

Credit: Dan Lungu
High dynamic amplification at high periods. Dangerous for high-rise buildings.

INCERC Stations in Bucharest
March 4, 1977 - NS component
SMAC-B, Japanese instr.

32 tall buildings completely collapsed.

Credit: Dan Lungu
## Corruption Perception Index: Caribbean Rankings

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country/territory</th>
<th>2008 CPI Score</th>
<th>Surveys used</th>
<th>Confidence range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>New Zealand</td>
<td>9.3</td>
<td>6</td>
<td>9.2–9.5</td>
</tr>
<tr>
<td>18</td>
<td>Japan</td>
<td>7.3</td>
<td>8</td>
<td>7.0–7.6</td>
</tr>
<tr>
<td>18</td>
<td>United States</td>
<td>7.3</td>
<td>8</td>
<td>6.7–7.7</td>
</tr>
<tr>
<td>21</td>
<td>Saint Lucia</td>
<td>7.1</td>
<td>3</td>
<td>6.6–7.3</td>
</tr>
<tr>
<td>22</td>
<td>Barbados</td>
<td>7.0</td>
<td>4</td>
<td>6.5–7.3</td>
</tr>
<tr>
<td>23</td>
<td>Chile</td>
<td>6.9</td>
<td>7</td>
<td>6.5–7.2</td>
</tr>
<tr>
<td>28</td>
<td>Saint Vincent</td>
<td>6.5</td>
<td>3</td>
<td>4.7–7.3</td>
</tr>
<tr>
<td>33</td>
<td>Dominica</td>
<td>6.0</td>
<td>3</td>
<td>4.7–6.8</td>
</tr>
<tr>
<td>36</td>
<td>Puerto Rico</td>
<td>5.8</td>
<td>4</td>
<td>5.0–6.6</td>
</tr>
<tr>
<td>65</td>
<td>Cuba</td>
<td>4.3</td>
<td>4</td>
<td>3.6–4.8</td>
</tr>
<tr>
<td>72</td>
<td>T’dad &amp; Tobago</td>
<td>3.6</td>
<td>4</td>
<td>3.1–4.0</td>
</tr>
<tr>
<td>96</td>
<td>Jamaica</td>
<td>3.1</td>
<td>5</td>
<td>2.8–3.3</td>
</tr>
<tr>
<td>102</td>
<td>Dom. Republic</td>
<td>3.0</td>
<td>5</td>
<td>2.7–3.2</td>
</tr>
<tr>
<td>177</td>
<td>Haiti</td>
<td>1.4</td>
<td>4</td>
<td>1.1–1.7</td>
</tr>
</tbody>
</table>

*CPI Score* relates to perceptions of the degree of corruption as seen by businesspeople and country analysts, and ranges between 10 (highly clean) and 0 (highly corrupt).
Key Points

• Given the infrequent nature of natural hazard activity, the maintenance of preparedness over time is essential to sustaining individual and community resilience.

• From a public policy viewpoint, disaster preparedness and prevention must be part of a single, well integrated process and policy.

• Current mechanisms in place are grossly inadequate to finance recovery from a catastrophic earthquake (tens of billions in losses).

• Policy decisions should be based on a sound assessment of risk.

• Disaster Risk Management
  – Establishes priorities so that scarce resources can be allocated wisely.
Thank You