Developing Tsunami Damage Estimation and Mitigation Technologies

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Tsunami Research Group (G2)

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Objectives and Goals

• To assess the **potential tsunami disaster** and its **impact** to the Peruvian coast
• To develop **practical technologies** to mitigate tsunami risks in Peru
• Implementation to the **strategic plans** for disaster mitigation of Peruvian government
• Contributions to **Pacific** tsunami disaster mitigation strategies

Tsunami modeling technology

• Tsunami Modeling techniques (Tsunami-code to simulate tsunami generation, off-shore/near-shore propagation and coastal inundation)
Research Plan (Scientific phase)

• Assessing historical tsunami events and its impact in Peru
  – Tsunami sources
  – Tsunami hazard (Tsunami generation, near-shore propagation and coastal inundation)
  – Damage (Casualties, Structural damage)
• Identifying potential tsunamis and the worst case scenarios
  – Tectonic settings and tsunami source scenarios
  – Potential tsunami exposure (Exposed population)
  – Potential impact
• Mapping tsunami hazard and its impact
  – Inundation modeling
  – Damage estimation (Casualties, Structural damage)
  – Hazard maps, Cartography
Research Plan (Implementation Phase)

• Developing a fundamental procedure for mapping tsunami hazard
  – Training program (Tsunami modeling and mapping)
  – Warning, guidance and public education
• Strategic planning to mitigate tsunami risks and damage
  – Tsunami disaster mitigation program for Peruvian government
  – Tsunami countermeasures
  – Design for tsunami evacuation facilities
  – Tsunami evacuation strategies
What we have done so far ...

- Post-tsunami field survey in Chile
- Tsunami field survey in Camana
- Validation of tsunami numerical model and tsunami source study (2001 Camana tsunami)
- Tsunami risk assessment using PTE (Potential Tsunami Exposure)
- Tsunami risk perception in Callao, Lima

<table>
<thead>
<tr>
<th>Casualty</th>
<th>House damage</th>
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<tbody>
<tr>
<td>Dead</td>
<td>Missing</td>
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<tr>
<td>24</td>
<td>62</td>
</tr>
</tbody>
</table>
Field survey of the 2001 tsunami

- Survey area: Camana
- Measurement: Flow depth, Run-up/inundation height

Field survey of the 2001 tsunami

Elevation (m)
- 1m
- 2m
- 3m
- 4m
- 5m-6m

Damage class
- Destroyed
- Major
- Middle-Minor
- Houses for survey

Flow depth [m]
- Tensile failure of wall
- Shear failure of wall

Weaker
Stronger
Preparing bathymetry/topography grid

<table>
<thead>
<tr>
<th>#</th>
<th>Longitude 1°</th>
<th>Longitude Max</th>
<th>Latitude 1°</th>
<th>Latitude Max</th>
<th>Resolution arc-second</th>
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<tbody>
<tr>
<td>1</td>
<td>-78.00</td>
<td>-70.00</td>
<td>-19.00</td>
<td>-11.00</td>
<td>27</td>
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<tr>
<td>2</td>
<td>-74.00</td>
<td>-72.00</td>
<td>-18.00</td>
<td>-16.00</td>
<td>9</td>
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<tr>
<td>3</td>
<td>-73.15</td>
<td>-72.40</td>
<td>-17.00</td>
<td>-16.25</td>
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<tr>
<td>4</td>
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<td>-72.58</td>
<td>-16.75</td>
<td>-16.50</td>
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<table>
<thead>
<tr>
<th>Domain</th>
<th>Bathymetry</th>
<th>Topography</th>
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<tbody>
<tr>
<td>1</td>
<td>GEBCO 30</td>
<td>GEBCO 30</td>
</tr>
<tr>
<td>2</td>
<td>GEBCO 30</td>
<td>GEBCO 30</td>
</tr>
<tr>
<td>3</td>
<td>GEBCO 30</td>
<td>STRM</td>
</tr>
<tr>
<td>4</td>
<td>DHN</td>
<td>ASTER GDEM</td>
</tr>
</tbody>
</table>

GEBCO: http://www.gebco.net/
STRM: http://srtm.csi.cgiar.org/
ASTER: http://www.gdem.aster.ersdac.or.jp/index.jsp/

Tide gauge stations for tsunami waveform inversion

NOAA/PMEL/Center for Tsunami Research

<table>
<thead>
<tr>
<th>No.</th>
<th>Code</th>
<th>Station name, Country</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>antf</td>
<td>Antofagasta, Chile</td>
<td>23.65° S</td>
<td>70.42° W</td>
</tr>
<tr>
<td>2</td>
<td>aric</td>
<td>Arica, Chile</td>
<td>18.47° S</td>
<td>70.34° W</td>
</tr>
<tr>
<td>3</td>
<td>cald</td>
<td>Caldera, Chile</td>
<td>27.06° S</td>
<td>70.83° W</td>
</tr>
<tr>
<td>4</td>
<td>call</td>
<td>Callao, Peru</td>
<td>12.07° S</td>
<td>77.17° W</td>
</tr>
<tr>
<td>5</td>
<td>coqu</td>
<td>Coquimbo, Chile</td>
<td>29.93° S</td>
<td>71.35° W</td>
</tr>
<tr>
<td>6</td>
<td>iqui</td>
<td>Iquique, Chile</td>
<td>20.22° S</td>
<td>70.17° W</td>
</tr>
<tr>
<td>7</td>
<td>juan</td>
<td>Juan Fernandez, Chile</td>
<td>33.62° S</td>
<td>78.83° W</td>
</tr>
<tr>
<td>8</td>
<td>lobo</td>
<td>Lobos de Afuera, Peru</td>
<td>6.94° S</td>
<td>80.72° W</td>
</tr>
<tr>
<td>9</td>
<td>matni</td>
<td>Matarani, Peru</td>
<td>16.99° S</td>
<td>72.10° W</td>
</tr>
<tr>
<td>10</td>
<td>anto</td>
<td>San Antonio, Chile</td>
<td>33.58° S</td>
<td>71.63° W</td>
</tr>
<tr>
<td>11</td>
<td>valp</td>
<td>Valparaiso, Chile</td>
<td>33.03° S</td>
<td>71.62° W</td>
</tr>
</tbody>
</table>
Tsunami waveform inversion (Satake, 1987)

- Slip (asperity) distribution on fault
- j-th subfault
- Finite difference computation on actual bathymetry
- Green's functions
- Observation at station i

Uniform slip
Heterogeneous slip (Kikuchi & Yamanaka, 2001)
Tsunami waveform inversion
Tsunami run-up height
Tsunami vulnerability assessment

**Earthquake scenarios**
- \( Mw \) 8.0, 8.2, 8.4, 8.6, 8.8 along the plate boundary
- Source parameters similar with the 2001 event

**Tsunami propagation model**
- Maximum tsunami height

**Tsunami fragility curve**
- Death ratio
- Population data
- Potential tsunami exposure

Potential tsunami exposure

Tsunami fragility curves from the 2004 event

![Graphs showing structural damage probability and death ratio over inundation height](image-url)
Potential tsunami exposure (PTE)
LandScan 2008

Where is at-risk area?
How people perceive tsunami risks?
Questionnaire survey in Callao, Lima

I. General Information
II. Tsunami Evacuation Experience and Knowledge
III. Risk Perception and Start Evacuation Decision
IV. Tsunami Warning and Evacuation Decision
V. Earthquake Scenarios and Decision-making
VI. Where and how to evacuate

Multi Agent Simulation
So far so good …
Moving on to the next phase

Next phase; Callao, Lima

- Tsunami source scenario: 1746 earthquake (M8.8)
- High-resolution merged bathymetry/topography data
- Building inventory (Shape, Structural type)
### Tsunami Evacuation Experience and Knowledge

**KNOWLEDGE**

- Regular: 49%
- Most: 46%
- High: 30%

**HAZARD MAP?**

- Yes: 65%
- Do not know: 4%
- No: 31%

**SAFE AREAS?**

- Yes: 84%
- No, but I would like to know: 14%
- No, it is not necessary: 2%

**EVACUATION EXPERIENCE?**

- Yes: 52%
- No: 48%

Most stated evacuation experiences were for tsunamis of: Pisco (2007), Camana (2001), Chile (2010), Lima (1974).

### Tsunami Warning and Evacuation Decision

**EXPECTED SOURCE OF WARNING**

- Friends: 41%
- Neighbors: 24%
- Print: 5%
- Radio: 4%
- Other: 14%
- Television: 5%
- Internet: 3%

**SOURCE RELIABILITY**

- Radio: 18%
- Internet: 4%
- Television: 11%
- Officials: 7%
- Neighbors: 4%
- Schools: 54%

**EXPECTED TIMES**

<table>
<thead>
<tr>
<th></th>
<th>Warning</th>
<th>Preparation</th>
<th>Evacuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5 min</td>
<td>47.0%</td>
<td>16.4%</td>
<td>19.9%</td>
</tr>
<tr>
<td>5-15 min</td>
<td>31.1%</td>
<td>30.5%</td>
<td>39.7%</td>
</tr>
<tr>
<td>15-30 min</td>
<td>19.7%</td>
<td>27.3%</td>
<td>32.8%</td>
</tr>
<tr>
<td>30-45 min</td>
<td>1.5%</td>
<td>17.2%</td>
<td>4.6%</td>
</tr>
<tr>
<td>45 min-1h</td>
<td>0.0%</td>
<td>6.3%</td>
<td>1.5%</td>
</tr>
<tr>
<td>more than 1 hr</td>
<td>0.8%</td>
<td>2.3%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Total (N=132)</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Total time:** 32.6 min

Warning time: 9.8 min
Preparation time: 7.5 min
Evacuation time: 15.3 min
Where and how to evacuate

Where?
- Any high building in district: 3%
- Evacuation building in the district: 30%
- Anywhere out of district: 15%
- Shallow out of district: 25%
- Relative house out of district: 10%
- Not sure: 5%
- Other: 4%

N = 129

How?
- Walk: 42%
- Bus: 10%
- Car: 5%
- Other: 1%
- Not sure: 36%

N = 131

ROUTE PREFERENCE
- Away from the sea: 24%
- Not crowded: 21%
- Low slope: 0%
- Few obstacles: 2%
- Short: 10%

N = 127

Bathymetry measuring points at Callao by DHN
The 2nd Workshop at Chiba University (10 March, 2011)

**Gender**
- Female: 51%
- Male: 49%

**Occupation**
- Employee: 35%
- Independent: 31%
- Retired: 12%
- Student: 4%
- Unemployed: 2%

**Resident?**
- Yes: 73%
- No: 27%

**Workplace**
- In the city: 72%
- Out of the city: 28%

**Home Distance**
- Less than 100m: 17%
- 100m - 200m: 35%
- 200m - 300m: 15%
- 300m +: 17%

**Knowledge**
- Regular: 69%
- High: 30%
- Poor: 11%
- None: 4%

**Hazard Map?**
- Yes: 65%
- No: 31%
- Do not know: 4%

**Evacuation Experience?**
- Yes: 54%
- No, but I would like to know: 14%
- No, it is not necessary: 2%

**Safe Areas?**
- Yes: 53%
- No: 47%

*Most stated evacuation experiences were for tsunamis of:*
- Piscon (2007)
- Camana (2001)
- Chile (2010)