2011 Tsunami in Tohoku, Japan: Planning and Design of Vertical Evacuation Buildings

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Content

- $M_w 9.0$ 11th March 2011 Tohoku earthquake and tsunami damage
- Performance of tsunami protection
- Vertical evacuation buildings – a case study for Yamamoto
- Key lessons to be learned
EEFIT-Tohoku Mission

- 9 members
- May 27 to June 3, 2011
- Wide spatial area
- Focus on tsunami affected locations
- Ground shaking damage, landslide, liquefaction, etc.
Earthquake Facts

- Very large earthquake: $M_w 9.0$
- Catastrophic tsunami damage
- 19000+ death/missing
- Direct loss: 300-400 billion U.S. dollars
- Infrastructure damage – levee, road, bridge, railway, water treatment plant, industrial facilities, …

Kesennuma

- Fukushima Daiichi nuclear power plant crisis
General Damage Statistics

- Widespread damage to buildings – concentrated in Iwate/Miyagi/Fukushima. This includes both tsunami-affected and shaking-affected cases.

<table>
<thead>
<tr>
<th>Prefecture</th>
<th>Total collapse</th>
<th>Half collapse</th>
<th>Partial damage</th>
<th>Non-residential damage</th>
<th>Road</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iwate</td>
<td>20998</td>
<td>3174</td>
<td>2668</td>
<td>1538</td>
<td>30</td>
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<tr>
<td>Miyagi</td>
<td>65462</td>
<td>48684</td>
<td>76785</td>
<td>17826</td>
<td>390</td>
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<tr>
<td>Fukushima</td>
<td>15885</td>
<td>29125</td>
<td>92455</td>
<td>1015</td>
<td>19</td>
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<tr>
<td>Ibaraki</td>
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<td>14873</td>
<td>132921</td>
<td>8551</td>
<td>307</td>
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<tr>
<td>Tochigi</td>
<td>257</td>
<td>2074</td>
<td>56799</td>
<td>295</td>
<td>257</td>
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<tr>
<td>Gunma</td>
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<td>6</td>
<td>16145</td>
<td>195</td>
<td>7</td>
</tr>
<tr>
<td>Saitama</td>
<td>0</td>
<td>5</td>
<td>1800</td>
<td>33</td>
<td>160</td>
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<tr>
<td>Chiba</td>
<td>771</td>
<td>8056</td>
<td>27714</td>
<td>708</td>
<td>2343</td>
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<tr>
<td>Tokyo</td>
<td>0</td>
<td>11</td>
<td>257</td>
<td>20</td>
<td>13</td>
</tr>
<tr>
<td>Kanagawa</td>
<td>0</td>
<td>7</td>
<td>279</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Others</td>
<td>343</td>
<td>959</td>
<td>110</td>
<td>1673</td>
<td>33</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>105895</strong></td>
<td><strong>106974</strong></td>
<td><strong>407933</strong></td>
<td><strong>31855</strong></td>
<td><strong>3559</strong></td>
</tr>
</tbody>
</table>

Damage statistics from National Police Agency

- Widespread damage to buildings – concentrated in Iwate/Miyagi/Fukushima. This includes both tsunami-affected and shaking-affected cases.
• $M_w 9.0$ mega-thrust earthquake occurred at 2:46:23 pm.
• It triggered tsunamis more than 10 m high, causing immense tsunami damage
• Significant deformation on land – up to 1 m subsidence

Colour contour: slip
Vector: ground deformation
(Simons et al. 2011)
Was This Tsunami Forecasted?

- The Sanriku coast suffered tsunamis in 1896, 1933, and 1960 earthquakes repeatedly.
- The 2011 event generated much larger tsunami waves. Nobody had expected such high tsunami.
- However, historical records indicate such massive tsunamis did occur in the past – e.g. 1611 Keicho tsunami and 869 Jogan tsunami.
Rikuzen Takata

Only several buildings are standing ...
Sendai
Kamaishi

- Deepest seawall in the world
- 9.0+ m inundation
- One vertical evacuation building performed well – with sacrifice structure & breakable partition wall

North breakwater
Length: 990 m

South breakwater
Length: 670 m
Taro

- 10-m high walls over 2 km – a well-protected town against tsunami – did not protect the town completely – but significantly reduced the damage.
Tsunami Casualty Mitigation

- Lot of discussion on what is the best strategy to reduce the number of fatalities in the future catastrophic tsunami.
- Option 1: As it is; sufficient tsunami protection – Fudai.
- Option 2: Rebuild the protection structures with higher capacity – Taro.
- Option 3: Relocation of an entire town/city to high ground – Noda.
- Option 4: Combination of horizontal and vertical evacuation structures
• 19000+ death - disproportionate risks for elderly (75% of deaths for age 50+).

• Both horizontal and vertical evacuation must be improved.

• Different strategies for different communities (topography, sea defence, tsunami hazard, demography, etc.)
Design of Vertical Evacuation Buildings

- Input information – tsunami height and velocity at a location
- Various forces act on buildings subjected to tsunami: hydrostatic force, hydrodynamic force, debris, buoyant force, etc.
Case Study for Yamamoto (1)

- Coastal plains; Aging society; 676 deaths; only one vertical evacuation building
Case Study for Yamamoto (2)

- Post-tsunami survey was conducted in Natori by Murakami et al. (2012)
- Tsunami warning was heard through: radio, TV, municipalities/police
- Use of cars

Timing of evacuation

- Before shaking ended: 18
- Right after shaking: 33
- Some time after shaking: 14
- In dangerous situations: 31
- Did not evacuate: 4

Travel means for evacuation

- On foot/running: 66
- Bicycle: 31
- Motor bike: 2
- Car: 1
Case Study for Yamamoto (3)

- **Five sites** for vertical evacuation buildings; Anticipated inundation height plus some freeboard; Coverage area - 500 m radius; Occupancy: local needs for services

- **Assume 600 lives saved; 80K GBP/life versus 20-30K GBP/quality year**; Cost-effective!

<table>
<thead>
<tr>
<th>Evacuation building site &amp; occupancy type</th>
<th>Inundation depth (m)</th>
<th>Design tsunami height (m)</th>
<th>Building height (m) [# of storeys]</th>
<th>Covered population [Floor area (m²)]</th>
<th>Cost (million GBP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1: Care home</td>
<td>1.95</td>
<td>5.54</td>
<td>14 &amp; [4]</td>
<td>1320 &amp; [2400]</td>
<td>18.1</td>
</tr>
</tbody>
</table>
500 m radius primary catchment and extended catchment
Open ground space, breakaway walls
Structural design: lateral forces and pile foundation
Key Lessons

• Imagine extreme situations – scenarios!
• Combination of soft and hard measures – resistant structures plus emergency planning/evacuation.
• Multi-layer protection – system robustness & resilience.
• Cooperation among victims, Self-Defence Forces, municipalities, NGOs/NPOs, companies, governments, foreign aids, etc.
• **EPSRC** funded three team members (including KG).

• Many individuals who helped us before, during and after our time in Japan, including: Dr. Eri Gavanski, Dr. Manjae Lee, Dr. Hitomi Murakami, Dr. Maki Koyama, and Prof. Akira Mano (and many others).

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