Tsunami – General Issues

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Tsunami Hazard Reduction

- Because mega tsunamis are rare and because forewarning of these events is possible (although the lead time can be very short), the primary mitigation tactic to date has been **EVACUATION** – distinct difference from earthquake hazard.

Time and loading scales of various coastal hazards

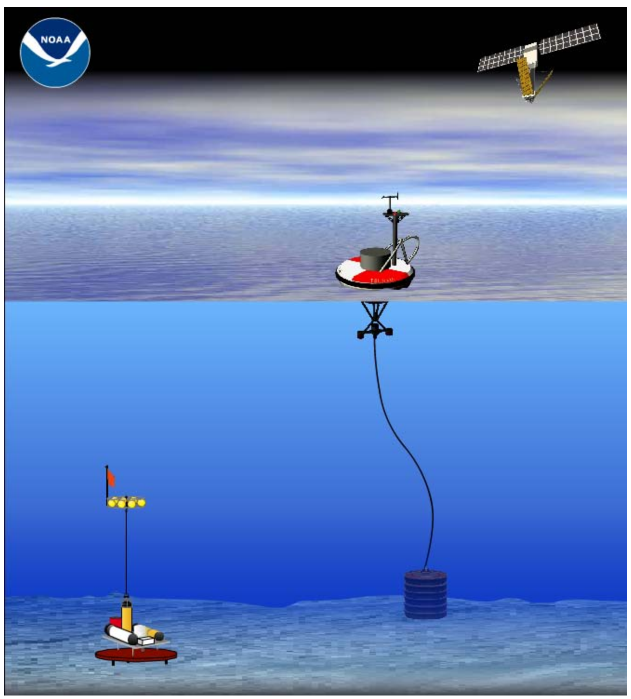
Phenomenon	Time Scale	Pressure Head	Forewarning Time
River Flood	days	< 3 meters	**a few days**
Hurricane/Storm Surge	hours	< 5 meters	**several days**
Storm-Generated Wave	seconds	< 10 meters	**several days**
Tsunami	minutes	< 10 meters	**minutes to hours**
Earthquake	seconds	N/A	**none to seconds**

- High-consequence low-frequency hazard: saving human lives is the priority.

- The tactic for tsunami hazard reduction is distinct from that of earthquake hazard.

Tsunami Hazard Reduction by Evacuation

- Effective Evacuation.
  - Development of an effective warning system
  - Inundation and evacuation mapping
  - Education for tsunami awareness



Tsunami Detection by DART Buoys (NOAA)

All Hazard Alert Broadcasting, Long Beach, Washington

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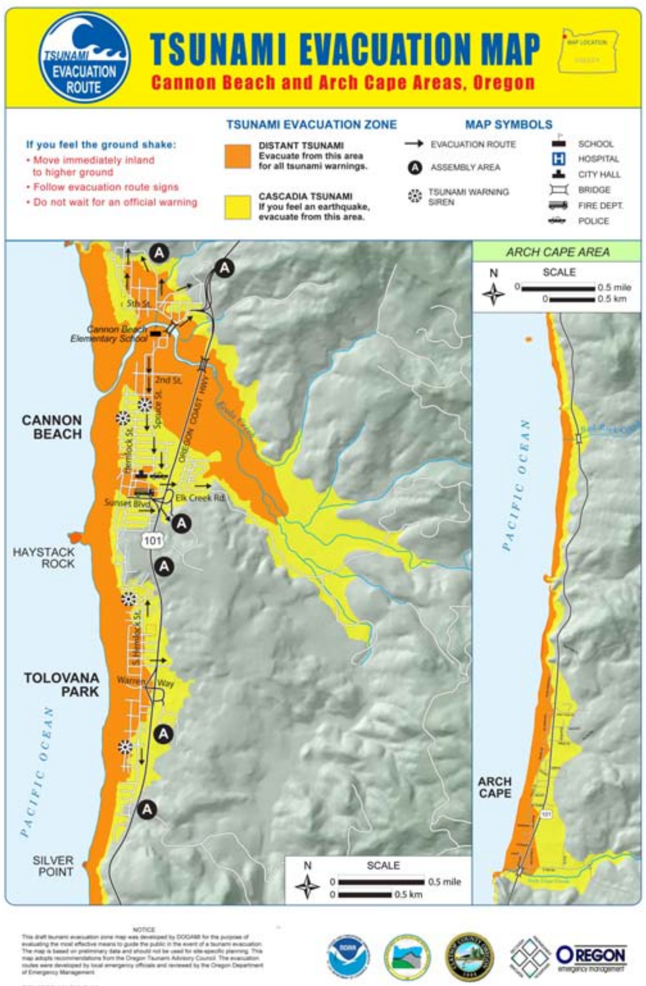

Tsunami Hazard Reduction by Evacuation

- Development of an effective warning system
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- Education for tsunami awareness

Education is not straightforward.

Knowledge alone is not enough, and potentially causes an adverse effect.

How can we convince and <u>lead</u> people to evacuate from the tsunami threat zone in a short time?

Tsunami Hazard Reduction by Protection

- Coastal structures for tsunami mitigation.
  - Tsunami Seawalls; Breakwaters.
  - Tsunami Evacuation Structures.
  - Tsunami Berms.

10 m tall tsunami seawall in Okushiri, Japan

Tsunami Evacuation Tower in Nishiki, Japan

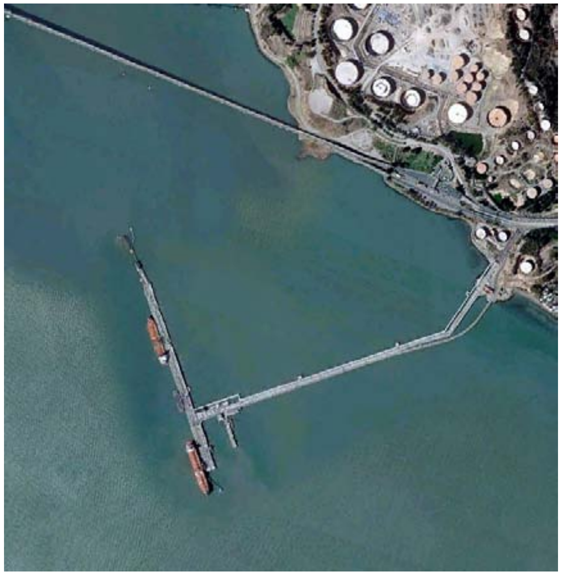
Tsunami Evacuation Berm in Okushiri, Japan

Tsunami Hazard Reduction by Protection

- It is unrealistic in the US to construct large tsunami seawall and breakwater to protect every coastal community.
- Yet, we still need to consider tsunami resistant design and construction for **critical coastal structures**.

Diablo Canyon

San Diego



Point Richmond

Critical Coastal Infrastructures and Facilities

Tsunami Induced Fires

Scenes of the Japan Tsunami one day after

Photos by Satake: March 12, 2011

The March 2011 East Japan Tsunami: Onagawa

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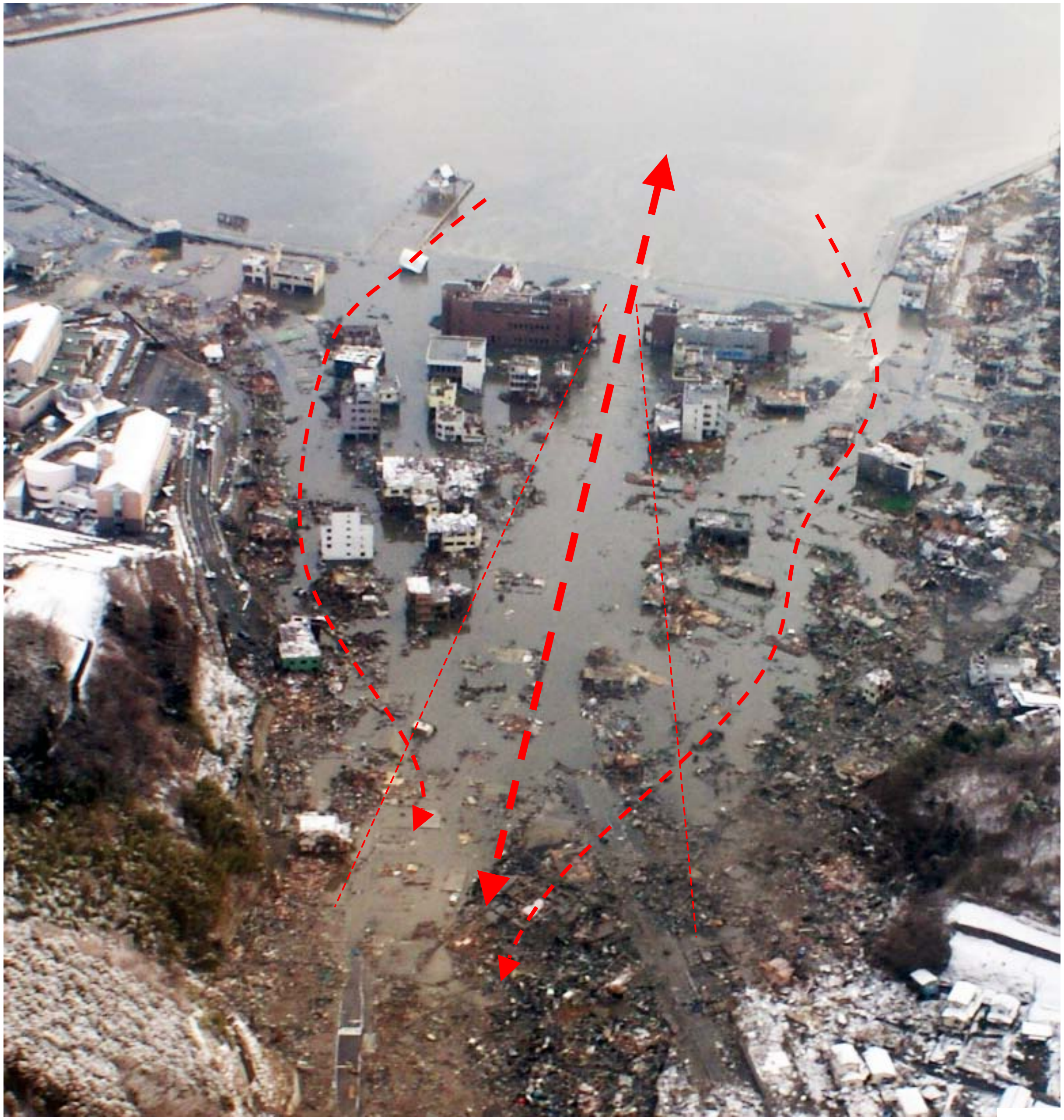

Photo by Satake: March 12, 2011

Tsunami impacts are substantially affected by the surroundings

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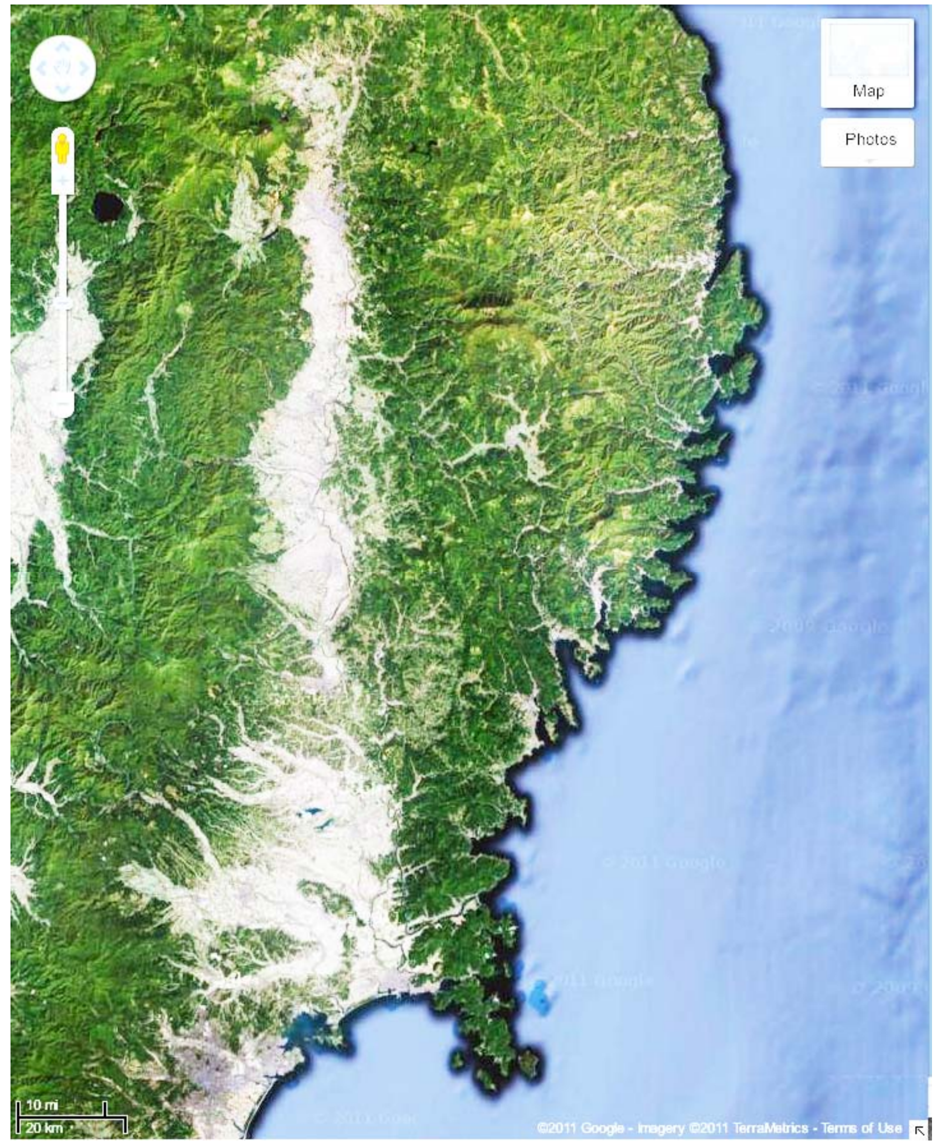
This resembles engineering considerations of wind loadings on high-rise buildings

Rapid Response and Relief Mission are Critical

The March 11 2011 East Japan Tsunami

No water, no food, and no heat and blankets for more than one week!

- Rugged mountain geography.
- Lack of gasoline for automobiles.
- Lack of communication means.
- Japanese top-down system.



The post-tsunami rapid response and relief mission are critical.

Performance-Based Earthquake Engineering (PBEE)

(adapted from G.C. Deierlein)

1. Seismic Hazard Analysis
   Site → Intensity Measure (*IM*)
2. Structural Analysis
   IM → Engineering Demand Parameter (*EDP*)
3. Damage Assessment
   EDP → Damage Measure (*DM*)
4. Loss & Risk Analysis
   DM → Decision Variable (*DV*)

$$\lambda(\overrightarrow{DV}) = \iiint G\left\langle \overrightarrow{DV} \middle| \overrightarrow{DM} \right\rangle \left| dG\left\langle \overrightarrow{DM} \middle| \overrightarrow{EDP} \right\rangle \right| dG\left\langle \overrightarrow{EDP} \middle| \overrightarrow{IM} \right\rangle \left| d\lambda(\overrightarrow{IM}) \right.$$

$\lambda(\overrightarrow{IM})$: exceedence frequency for $\overrightarrow{IM}$

$\lambda(\overrightarrow{DV})$: probabilistic description of the performance metrics

$G\langle A|B\rangle$: conditional probabilities for the methodology components

Tsunami Version

1. Tsunami Hazard Analysis
   Area → Tsunami Inundation Measure (*TM*)
2. Damage Assessment
   TM → Damage Measure (*DM*)
3. Loss & Risk Analysis
   DM → Decision Variable (*DV*)

$$\lambda(\overrightarrow{DV}) = \iint G\left\langle \overrightarrow{DV} \middle| \overrightarrow{DM} \right\rangle \Big| \, dG\left\langle \overrightarrow{DM} \middle| \overrightarrow{TM} \right\rangle \Big| \, d\lambda(\overrightarrow{TM})$$

$\lambda(\overrightarrow{TM})$: design exceedence for $\overrightarrow{TM}$

$\lambda(\overrightarrow{DV})$: description of the damage metrics

$G\langle A|B\rangle$: conditional probabilities for the methodology components

TM – Tsunami Inundation Measure

- Inundation Depth
  - Maximum
  - Time history: how quick and how long
- Flow Velocity
  - Maximum
  - Time history: how quick and how long
- Position of Interest
  - Elevation & distance from the shore
  - Terrain & surrounding buildings and infrastructures
  - Debris & fire sources

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Unlike earthquakes (USGS Seismic Hazard Maps), tsunami hazard maps are still under development and complex to determine.

DM – Damage Assessment

- Quasi-Steady Lateral Forces and the Line of Action
  - Hydrostatic forces
  - Hydrodynamic forces including potential damming effects due to debris accumulation.
- Water-Surge Impulsive Lateral Forces
- Debris Impact Forces and the Line of Action
- Buoyant Forces
- Moments induced by the Foregoing Forces
- Vertical Forces on Floor Elements
  - Uplift and excess weights due to flooding the floor.
- Scour, Lateral Spreading, and Soil Liquefaction

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But these *DM*s are more or less for structures.
What about the elements for evacuation ?

DV – Loss & Risk Analysis

- Number of Casualties
- Effectiveness of Rapid Relief Missions
  - Improvement of critical supply lines, e.g. roads and bridges
  - Provision for helicopter landing pads
- Evacuation Routes and Safe Havens
- Time and Costs of the Community Recovery
- Economic Loss
- Buildings
  - Fully Operational – Immediate Occupancy – Life Safety – Near Collapse; % Replacement
- Service Downtime
- Repair Costs

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Proposition: Design for a Tsunami Resilient Community or Facility (but not individual buildings)

- Distant Tsunami Case ($R_{max} < 2$ m): a few hours of warning.
  - No casualty; limited but mandatory evacuation; minor flooding for a few hours; prevent small boats from tsunami damage; minimum economical impacts.
- Intermediate Tsunami Case ($R_{max} < 5$ m): 1 ~ 2 hours warning.
  - No casualty; full mandatory evacuation; flood to x m from the shoreline; some economical impacts with a few days for recovery.
- Major Local Tsunami Case ($R_{max} < 10$ m): 30 min warning.
  - Some casualty; full mandatory evacuation; damage some infrastructures and lifelines; flood to xx m from the shoreline; major but local economical impact with a few weeks for recovery.
- Catastrophic Tsunami Case ($R_{max} > 10$ m): 30 min warning.
  - Many casualty; full mandatory evacuation; total destruction up to xxx m from the shoreline; fire potential, critical tactic for this event is response and relief; need to secure lifelines.

Summary

- Primary mitigation tactic for tsunami is evacuation.
- Tsunami protection structures are needed for critical coastal infrastructures and buildings.
- PBTE must be centered around the objective of evacuation, in addition to buildings.
- Comprehensive analysis for the interaction with the surroundings is crucial.
- Engineering contributions for the rapid response and effective relief missions are important.
- Methodology development for PBTE for a resilient community and/or a critical coastal facility, instead of an individual building.