Update to FEMA P-646 and SESI Tsunami Subcommittee

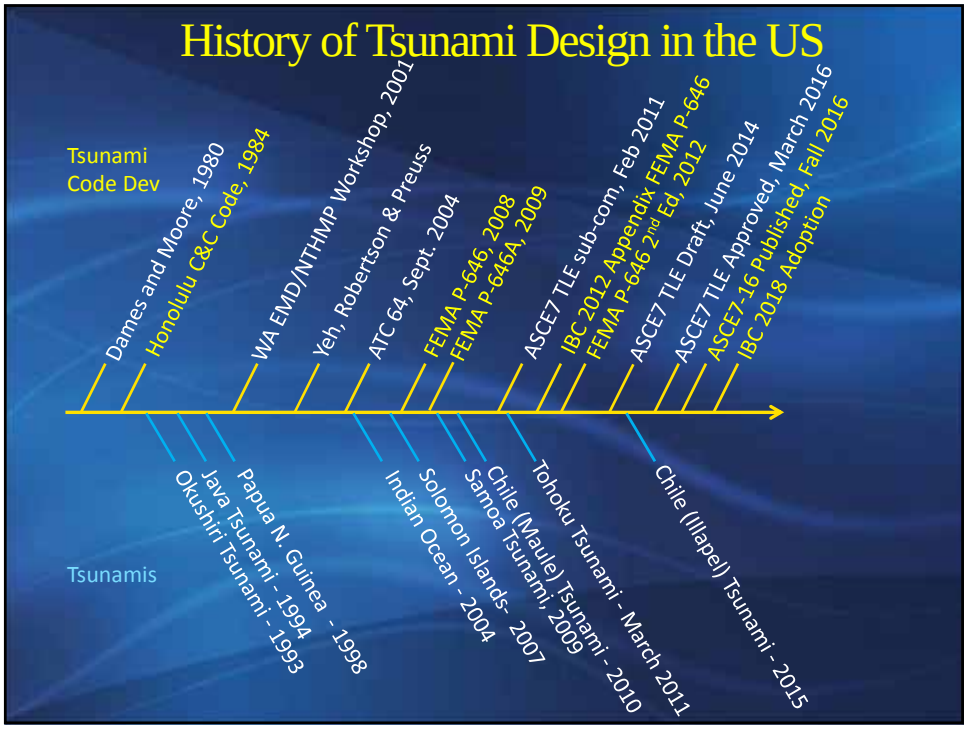
Ian N. Robertson, S.E., Ph.D.
Professor of Structural Engineering
University of Hawaii at Manoa

School Earthquake Safety Initiative

NTHMP Summer Meeting, July 27, 2016

Outline

- History of Tsunami Design in US
- Update to FEMA P-646 and P-646A
- Relevant lessons learned from Tohoku Tsunami
- Development of ASCE 7-16 Chapter 6, Tsunami Loads and Effects
- SESI Tsunami Subcommittee
- Identify schools with tsunami hazard



Outline

- History of Tsunami Design in US
- **Update to FEMA P-646 and P-646A**
- **Relevant lessons learned from Tohoku Tsunami**
- **Development of ASCE 7-16 Chapter 6, Tsunami Loads and Effects**
- **SESI Tsunami Sub-committee**
- **Identify schools with tsunami hazard**

FEMA P-646

- Design Guide – non-mandatory language
- Hazard assessment
- Siting and planning
- Tsunami Loads
- Design procedures
- Sample vertical evacuation options

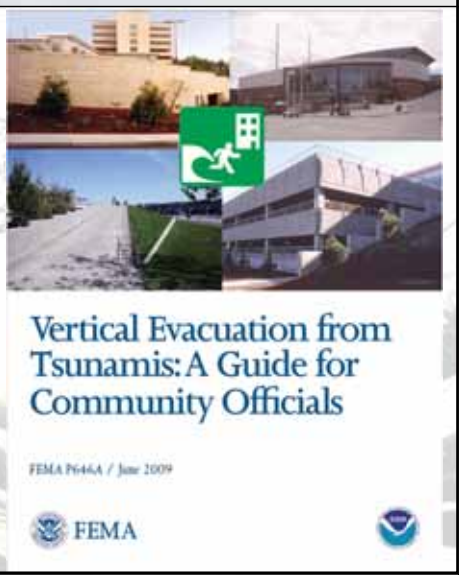
FEMA P-646

- Design Guide – non-mandatory language
- **Hazard assessment**
- Siting and planning
- **Tsunami Loads**
- **Design procedures**
- Sample vertical evacuation options

Portions of these chapters are superceded by ASCE 7-16 Chap 6, Tsunami Loads and Effects

FEMA P-646A

- Community Planning Guide
- Companion to P-646
- Duplicates some material but does not include any design provisions



Third Edition of FEMA P-646

- FEMA has funded an ATC project to revise FEMA P-646 and P-646A
- Avoid duplication of hazard, loading and design information with ASCE 7-16
- Merge P-646 and P-646A as a more comprehensive community planning guide
- Provide more detailed examples of vertical evacuation options including alternatives for financing construction
- Publish FEMA P-646 Third Edition early in 2017.

Outline

- History of Tsunami Design in US
- Update to FEMA P-646 and P-646A
- **Relevant lessons learned from Tohoku Tsunami**
- **Development of ASCE 7-16 Chapter 6, Tsunami Loads and Effects**
- **SESI Tsunami Sub-committee**
- **Identify schools with tsunami hazard**

Relevance of Tohoku Lessons to the USA

- Cascadia Subduction Zone is larger than the zone that ruptured in Tohoku
- Cascadia Subduction Zone governs both the MCE and MCT
- 1700 Cascadia Earthquake M9 is only the most recent occurrence of numerous great earthquakes and tsunamis throughout the past 10,000 years.

Evacuation to high ground

- Evacuation areas readily available and signposted
- However, many not easily accessible for disabled

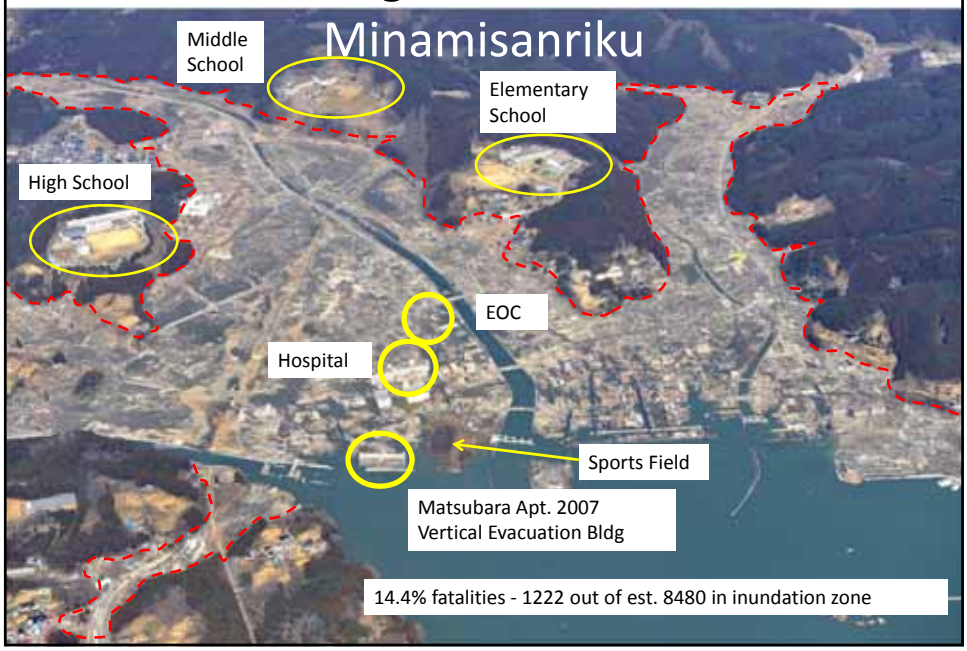
Designated evacuation building: Kamaishi

Designated evacuation building

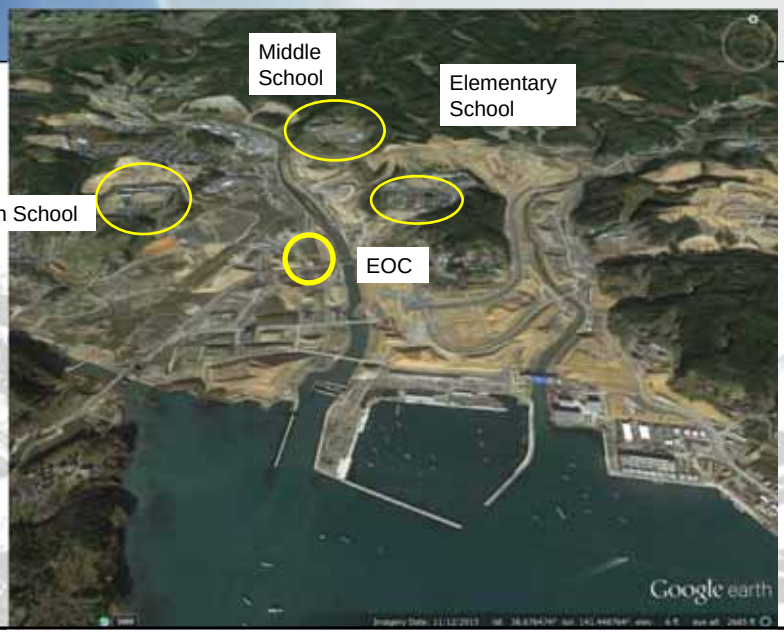
Tsunami Video 1

Tsunami Video 2

Warning and Evacuation

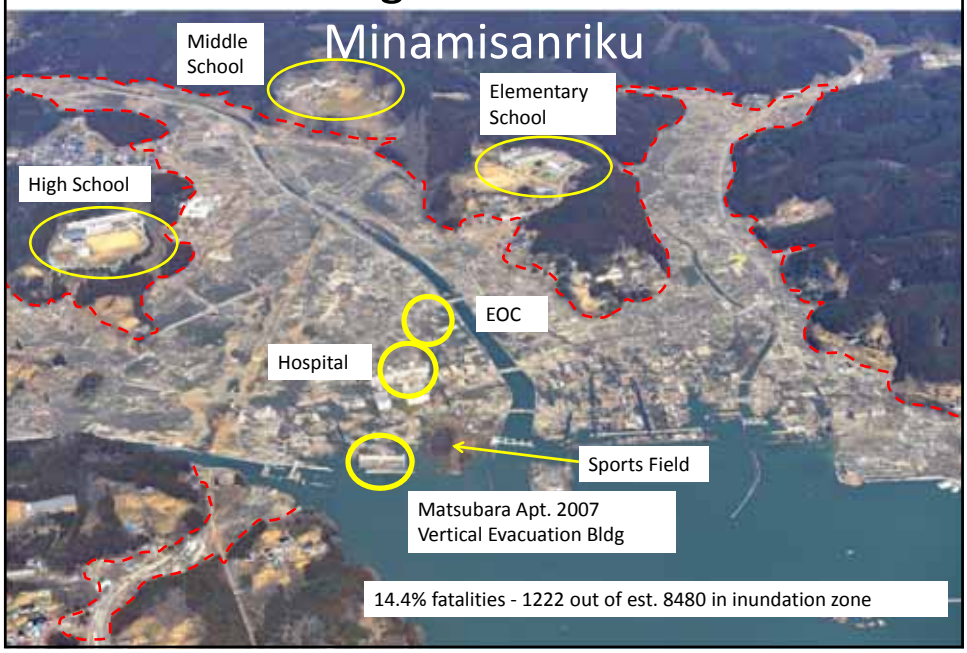


Minamisanriku – Feb 2016



Warning and Evacuation

Minamisanriku



Effective Vertical Evacuation

Matsubara Community Apt. Bldg. - 2007

- High-rise tsunami evacuation buildings can be effective refuges, but must be high enough!
- New 4-story reinforced concrete coastal residential structure with public access roof for tsunami evacuation

Effective Vertical Evacuation

Matsubara Community Apt. Bldg. - 2007

- Significant scour around corners of building
- Collapse prevented by deep foundations

Japan Failures: Minamisanriku Emergency Center

- Mayor Jin Sato, and 29 workers remained at center to provide live warnings during inundation
- 24 made it to the roof

Japan Failures: Minamisanriku Emergency Center

- Mayor Jin Sato, and 29 workers remained at center to provide live warnings during inundation
- 24 made it to the roof
- Sato and 8 others survived

Alternate high ground

- Earth mounds can act as effective evacuation sites
- Must be high and large enough

Inadequate Evacuation Sites

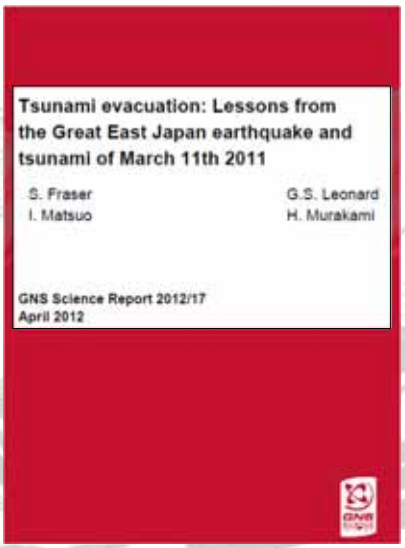
- Elementary school in Rikuzentakata designated as evacuation building.
- Principal decided to evacuate students to nearby high ground

Inadequate Evacuation Sites

- Rikuzentakata City Hall Community Center and Gym that served as an official tsunami evacuation center was completely inundated leading to loss of life of almost all evacuees.

Report on Performance of Evacuation Structures in Japan

- By Fraser, Leonard, Matsuo and Murakami
- GNS Science Report 2012/17, April 2012
- This follow-up report of evacuation sites provided additional survivor details for many sites visited by Chock and others of the ASCE Tsunami Reconnaissance Team



Tsunami evacuation: Lessons from the Great East Japan earthquake and tsunami of March 11th 2011

S. Fraser G.S. Leonard
I. Matsuo H. Murakami

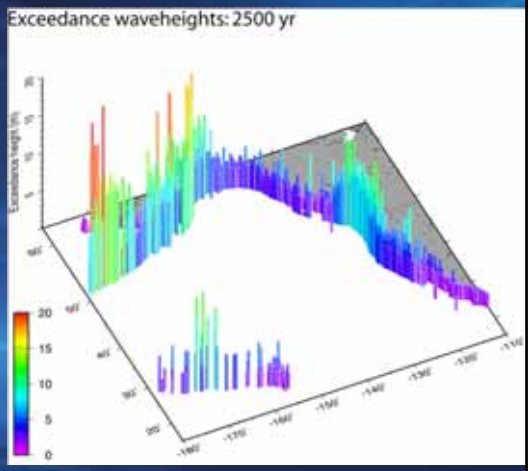
GNS Science Report 2012/17
April 2012

Outline

- History of Tsunami Design in US
- Update to FEMA P-646 and P-646A
- Relevant lessons learned from Tohoku Tsunami
- **Development of ASCE 7-16 Chapter 6, Tsunami Loads and Effects**
- **SESI Tsunami Sub-committee**
- **Identify schools with tsunami hazard**

Tsunami Design Zone: Lessons from the Tohoku, Chile, and Sumatra Tsunamis

- Recorded history may not provide a sufficient measure of the potential heights of great tsunamis.
- Design must consider the occurrence of events greater than in the historical record
- Therefore, probabilistic physics-based Tsunami Hazard Analysis should be performed in addition to historical event scenarios
- This is consistent with the probabilistic seismic hazard analysis



ASCE 7 – Chapter 6: Tsunami Loads and Effects

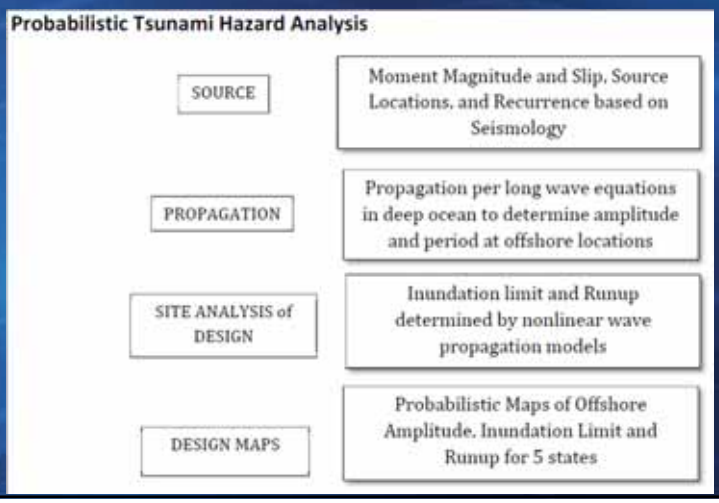
- ASCE 7 is the loading standard used for all building design in the US (earthquake, wind, snow, etc.)
- ASCE 7 is referenced by the International Building Code, adopted by most US jurisdictions.
- The 2016 edition of ASCE 7 will, for the first time, include a chapter on Tsunami Loads and Effects
- The TLE Sub-committee of 30 members and associate members was formed in Feb. 2011 and spent 3.5 years drafting the chapter.
- Chapter 6, Tsunami Loads and Effects was officially approved by ASCE 7 main committee on March 11, 2016, exactly 5 years after the Tohoku Tsunami.

ASCE 7 – Chapter 6: Tsunami Loads and Effects

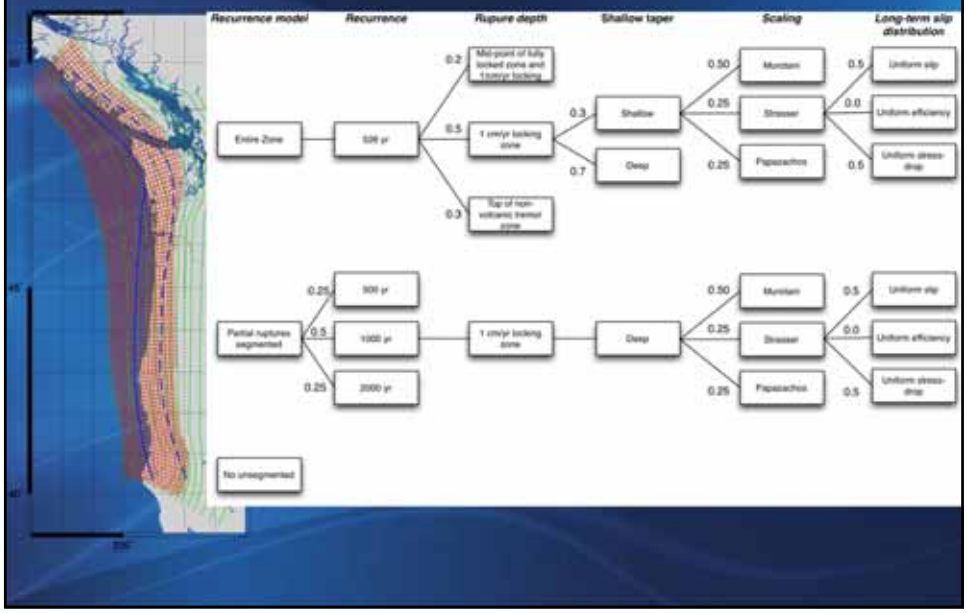
- Based on 2500-year Maximum Considered Tsunami
- Only applies to the five US Western States – Washington, Oregon, California, Alaska and Hawaii
- Only applies to Risk Category IV (Essential facilities) and III (Large occupancy buildings).
- Will only apply to Risk Category II (General Building Stock) if adopted by the local jurisdiction, and then only for buildings over a particular height.
- Will not apply to light framed residential or commercial buildings.

PTHA determines the Max. Considered Tsunami

- The ASCE PTHA procedure was peer reviewed by a broad stakeholder group convened by the NOAA National Tsunami Hazard Mitigation Program, and included independent comparative pilot studies.
- Subduction Zone Earthquake Sources are consistent with USGS Probabilistic Seismic Hazard model.



USGS Logic Tree for Cascadia adapted for Tsunamis

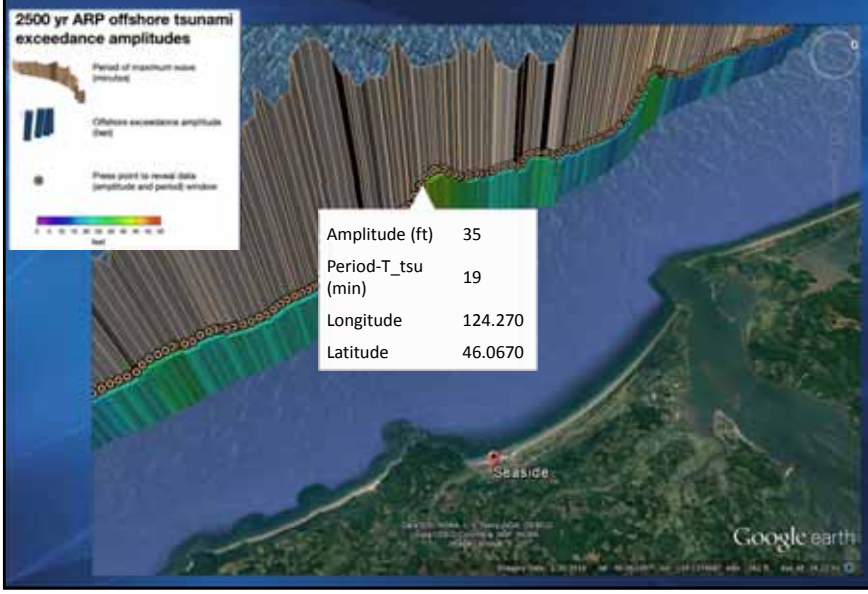


PTHA to develop Offshore Wave Heights and Periods

- Developed by Hong Kie Thio of AECOM (was URS) based on approved USGS Logic Tree approach.
- Includes Aleatory and Epistemic Uncertainty of source mechanism, wave propagation and inundation.
- Results stored as database and as Google Earth kml files of wave amplitudes and periods at 100m off-shore bathymetric depth.

Database of PTHA Offshore Tsunami Amplitudes

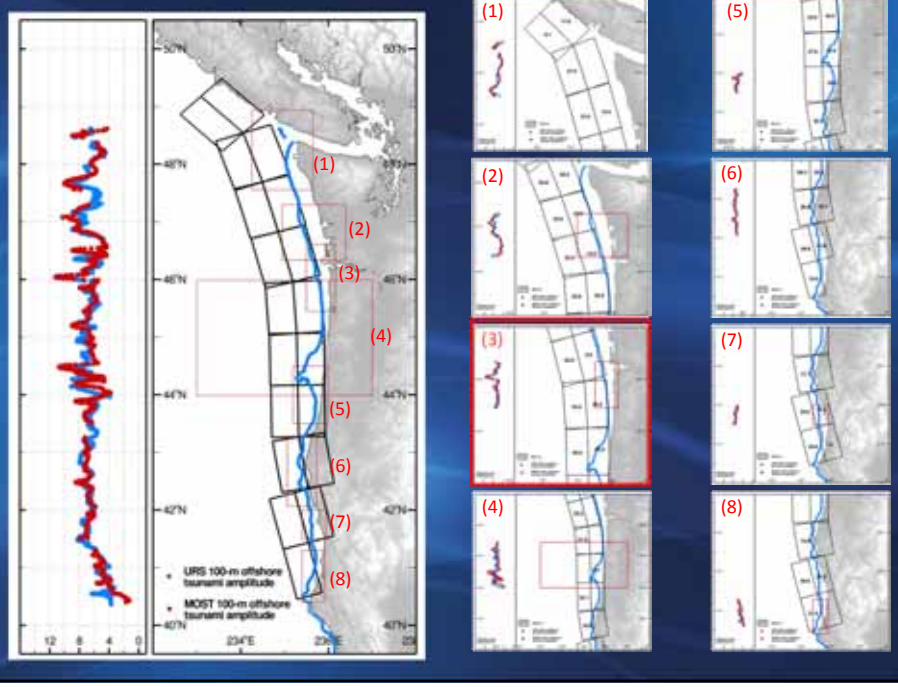
Offshore Tsunami Amplitude and Period for the Maximum Considered Tsunami at Seaside, Oregon

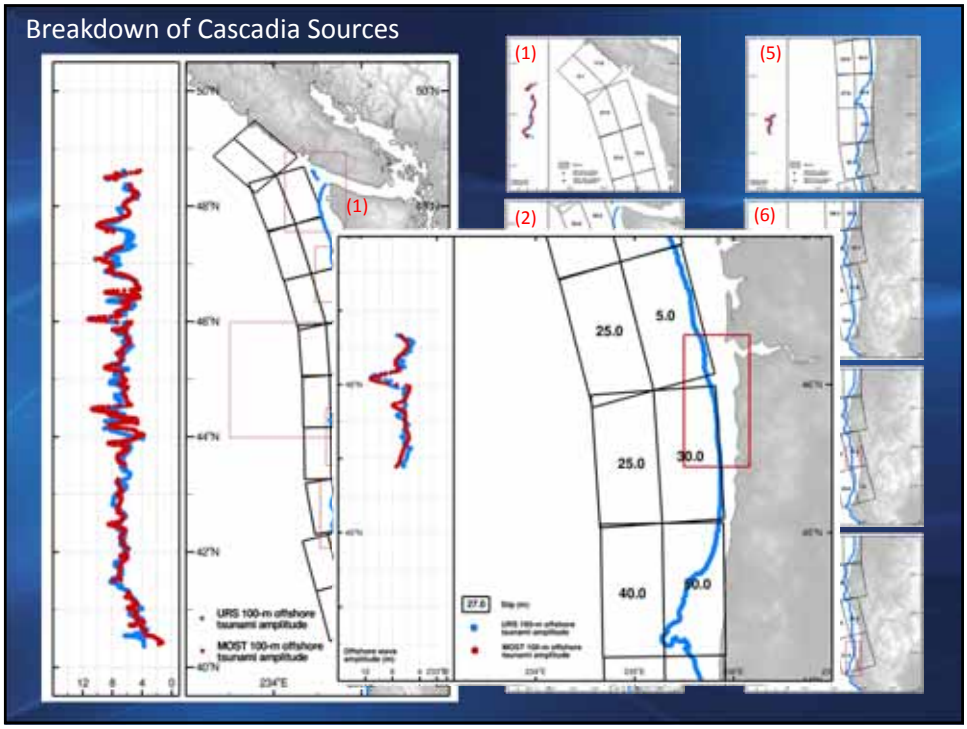


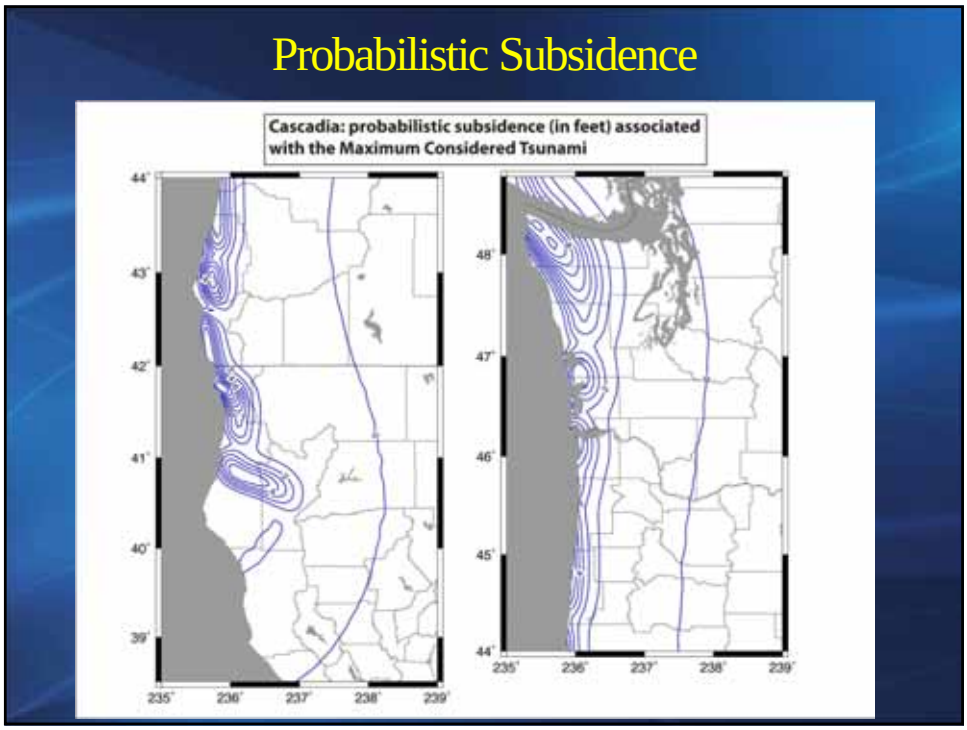
Inundation Modeling to develop Tsunami Design Zone Maps

- Performed by Yong Wei and Vasily Titov of the NOAA funded Pacific Marine Env. Lab, PMEL, Seattle, WA.
- The PTHA is used to generate disaggregated sources for each location of interest
- Disaggregated sources are used to generate tsunamis and propagate them towards the location of interest
- The resulting offshore wave at 100m depth must not be less than 80% of the PTHA 2500 year wave amplitudes
- The tsunami is then propagated onland using 60m grid resolution to determine the inundation limit
- All land seaward of the inundation limit is in the Tsunami Design Zone, TDZ.

Breakdown of Cascadia Sources




Breakdown of Cascadia Sources
(1)
(2)
(5)
(6)
URS 100-m offshore tsunami amplitude
MOST 100-m offshore tsunami amplitude
25.0
5.0
25.0
30.0
40.0
50.0


Probabilistic Subsidence
Cascadia: probabilistic subsidence (in feet) associated with the Maximum Considered Tsunami

Tsunami Design Zone - Seaside

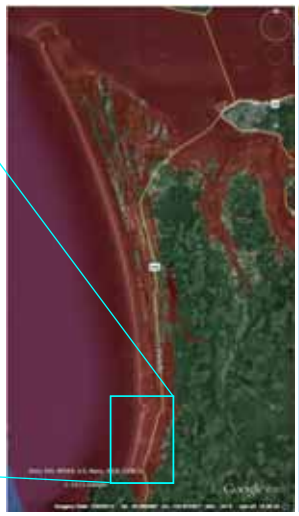
Comparison of the ASCE TDZ Maps with the Existing Tsunami Evacuation Maps and Probabilistic Tsunami Inundation Zones

- Oregon: The tsunami inundation zones indicated by the ASCE TDZ maps are between the zones of L1 and XXL1.
- Hawaii: the tsunami design zones are mostly consistent with Hawaii's Extreme Tsunami Evacuation Zone
- California: the tsunami design zones are being compared with California's existing tsunami inundation maps, and AECOM's 2,475-year probabilistic tsunami inundation zones based on DEMs of 10-m grid resolution.

Oregon: The tsunami inundation zones indicated by the ASCE TDZ maps are between the zones of L1 and XXL1.

Warrenton-Astoria-Gearhart-Seaside, OR

500-year tsunami inundation (Gonzalez et al., 2009)



ASCE TDZ

OR Evacuation map (defined by XXL1)

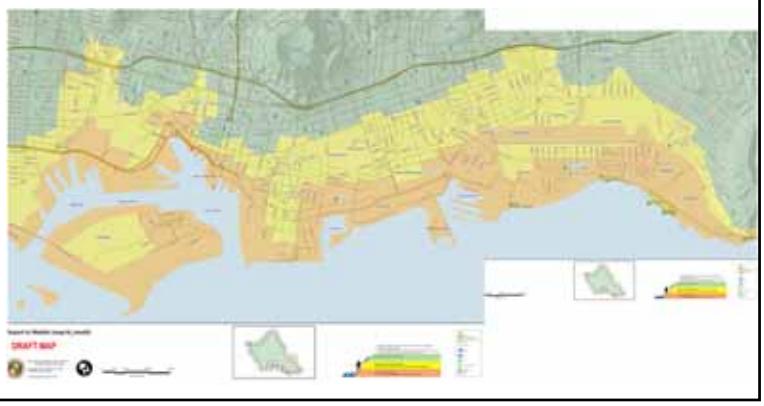
http://nvs.nanoos.org/TsunamiEvac

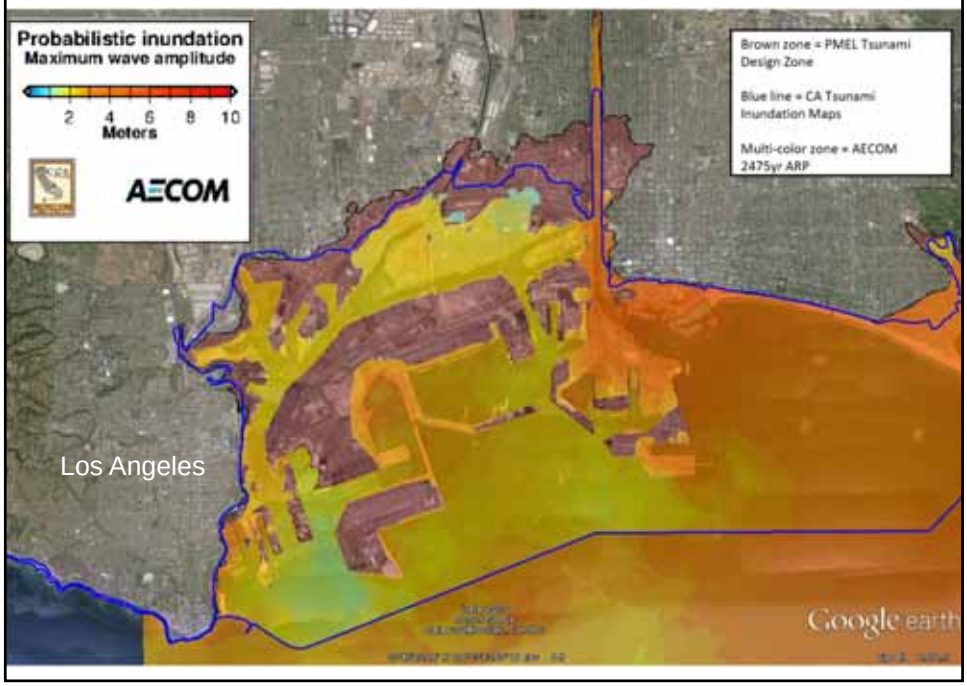
TDZ based on PTHA 2,475-yr offshore amplitude

Extreme Tsunami Evacuation Zone (Courtesy of City and County of Honolulu)

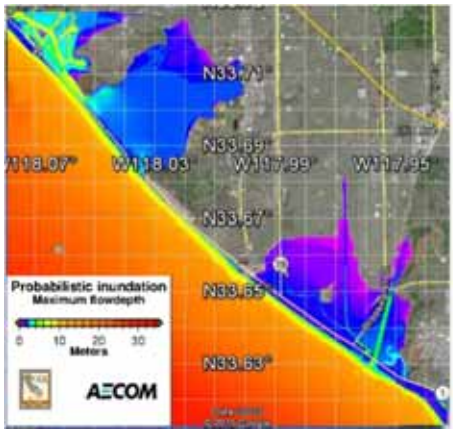
Extreme Tsunami Evacuation Zone

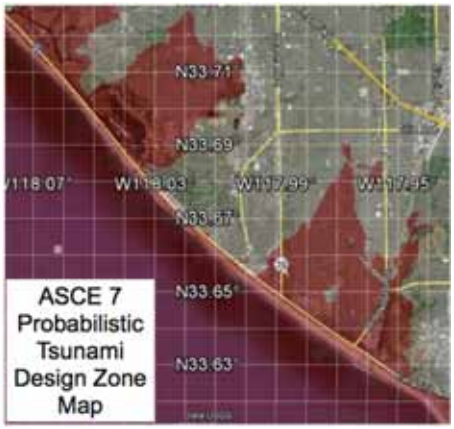
Tsunami Evacuation Zone





Huntington Beach, California





Outline

- History of Tsunami Design in US
- Update to FEMA P-646 and P-646A
- Relevant lessons learned from Tohoku Tsunami
- Development of ASCE 7-16 Chapter 6, Tsunami Loads and Effects
- **SESI Tsunami Sub-committee**
- **Identify schools with tsunami hazard**

SESI
School Earthquake Safety Initiative

promoting safe buildings for school children
eeri.org/schools

Ian N. Robertson, S.E., Ph.D. - NTHMP Summer Meeting, July 27, 2016




School Earthquake Safety Initiative • Earthquake Engineering Research Institute

About EERI

- Global earthquake engineering institute
- Nonprofit, technical membership society
- Dedicated to reducing earthquake (and associated) risk

SESI Mission, Vision & Goals

What is SESI?

- School Earthquake Safety Initiative is a global and collaborative network of diverse, expert, and passionate professionals who are committed to creating and sharing knowledge and tools that enable progressive, informed decision making around school earthquake safety.

Our Goal:

- Leverage our extensive expertise and reputation to conduct regionally appropriate actions that make a tangible and positive difference in communities around the world, by protecting the lives of all who inhabit school buildings.

Our Vision:

- Serving the world as a leader in the science, public policy, and advocacy of school earthquake safety.

SESI Subcommittees

- **Safety Screening, Inventory, and Evaluation**
  Chair: *Ken Goettel*
  Charge: Promote use of screening methodologies to efficiently identify school buildings with seismic risk.

- **Code Updating and Improvements**
  Chair: *Rob Jackson*
  Charge: Advocate for code improvements and implementation practices that will enhance school safety.

New Havens Elementary School, Piedmont, California was retrofitted in 2012

Portland, Oregon's Franklin High School will be rebuilt using school bonds approved in 2012.

SESI Subcommittees

- **Classroom Education & Outreach**
  Chairs: *Lelli Van Den Einde & Thalia Anagnos*
  Charge: Use classroom education to develop advocates for earthquake school safety.

- **Tsunami Mitigation for Schools**
  Interim Chair: *Yumei Wang*
  Charge: Support schools with tsunami hazard by providing them access to experts and sharing best practices for tsunami risk mitigation.

SESI Members teach 4th grade students about earthquake engineering design

SESI Subcommittees: Tsunami Mitigation for Schools Subcommittee

YUMEI WANG (CHAIR)

OCOSTA ELEMENTARY SCHOOL

SESI Tsunami Sub-committee Overview & Goals

- Support schools with tsunami hazard by providing them access to experts and sharing best practices for tsunami risk mitigation.
- Funding provided by the Coastal Zone Foundation
- Phase 1: Identifying Schools with Tsunami Risk has been completed. 196 at-risk schools identified in Washington, Oregon, California, Alaska and Hawaii using ASCE Tsunami Design Zones and local state evacuation maps.
- 2016 Goal: Collaborate with State Tsunami Program managers on outreach and mitigation for identified schools at risk.

Outline

- History of Tsunami Design in US
- Update to FEMA P-646 and P-646A
- Relevant lessons learned from Tohoku Tsunami
- Development of ASCE 7-16 Chapter 6, Tsunami Loads and Effects
- SESI Tsunami Sub-committee
- **Identify schools with tsunami hazard**

Identifying Schools exposed to tsunami hazard

- Initial list of schools in tsunami hazard zone was developed using the ASCE 7 Tsunami Design Zone
- List compared with existing state tsunami evacuation maps
  - Washington: Combination of Scenario 1A (Walsh et al 2000) and L1 scenario from WDNR.
  - Oregon: Evacuation Zone (XXL Line) from DOGAMI.
  - California: The state maximum hazard zone from CGS.
  - Hawaii: The new Extreme Tsunami Evacuation Zone
- Resulted in a reduction in the number of schools on the list.

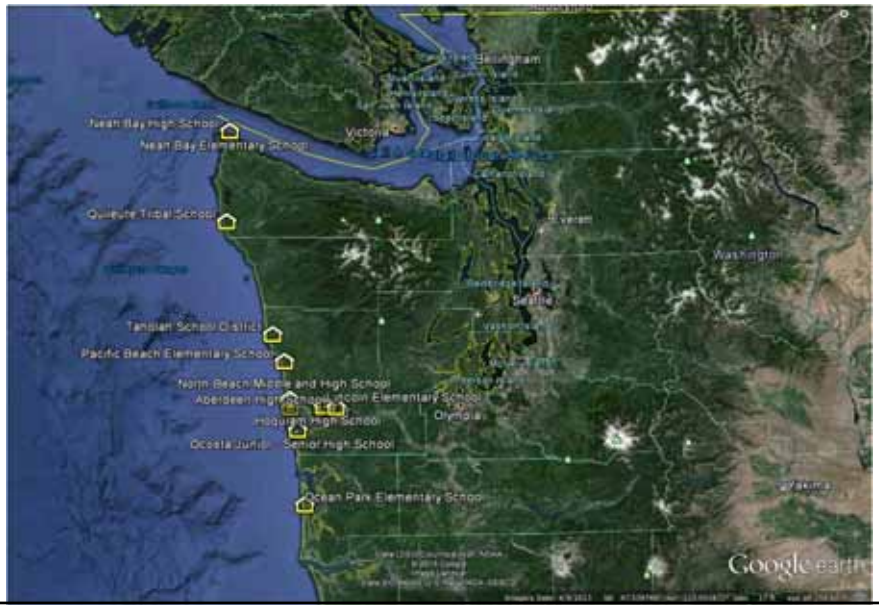
196 Schools exposed to tsunami hazard

State	Public Schools	Private Schools
Washington	18	1
Oregon	14	2
California	52	4
Alaska	4	0
Hawaii	69	32

- We have spreadsheet lists of these schools for each state. Anyone interested in reviewing the lists is welcome to email me at ianrob@hawaii.edu
- We would particularly like help with locating any missing charter and private schools, and
- Estimating the number of students in each school.

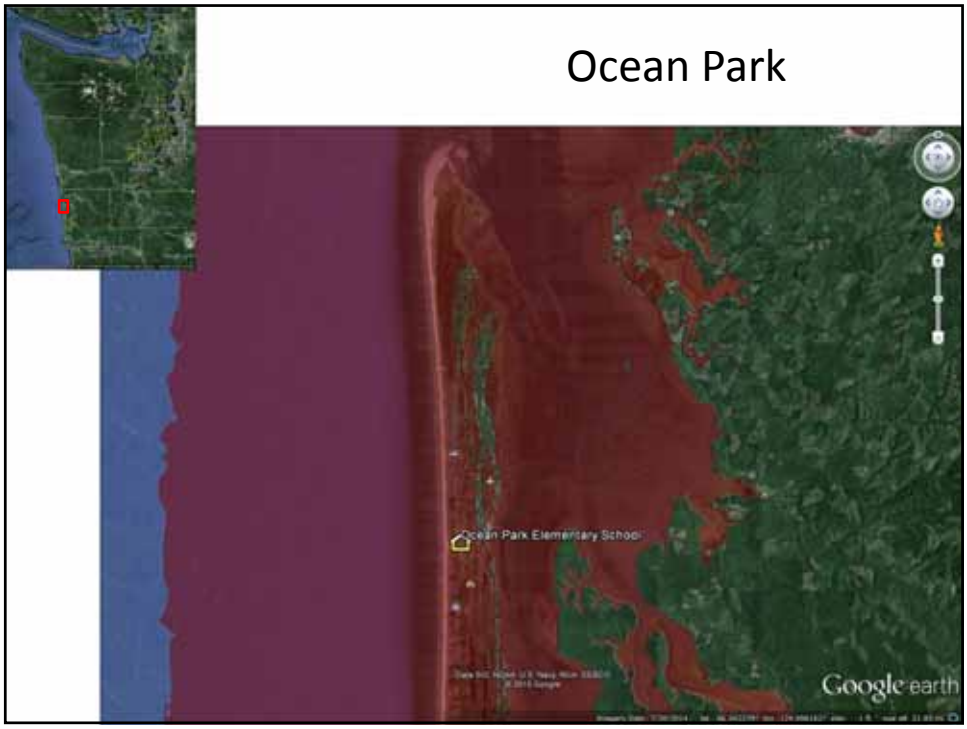
Washington

Public Schools – 18: Private Schools - 1




Ocean Shores
North Beach Middle and High School
Ocean Shores Elementary School
Ocean Shores
Google earth


Ocosta
Ocosta Junior - Senior High School
Ocosta Elementary School
Google earth

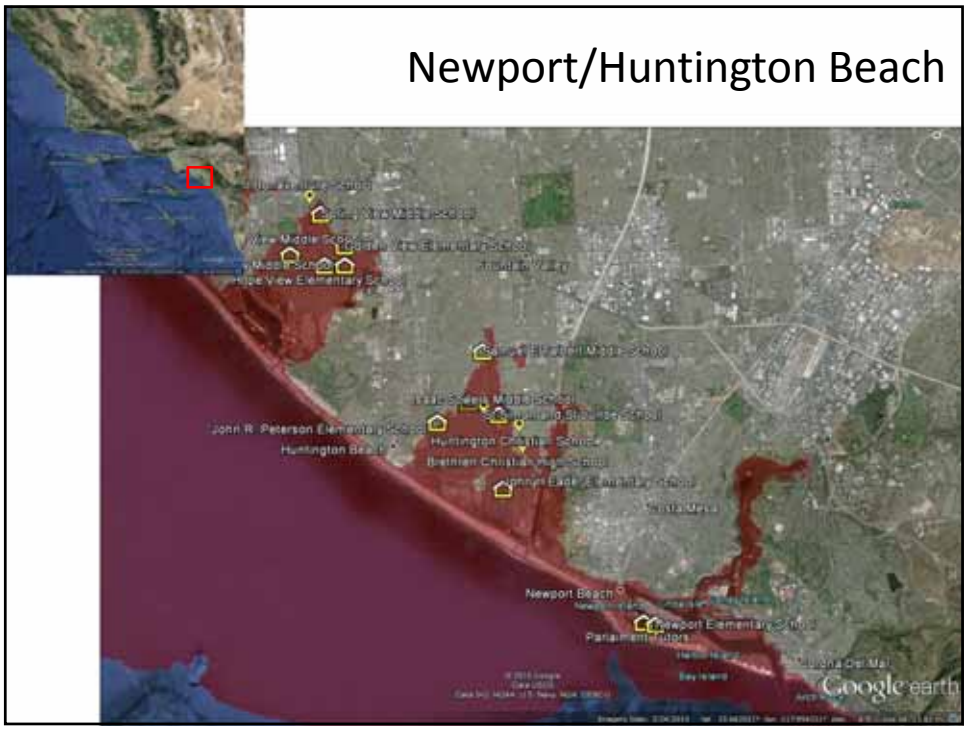

Ocean Park
Ocean Park Elementary School
Google earth


Oregon
Public Schools - 14: Private Schools - 2
Portland
Salem
Google earth

California

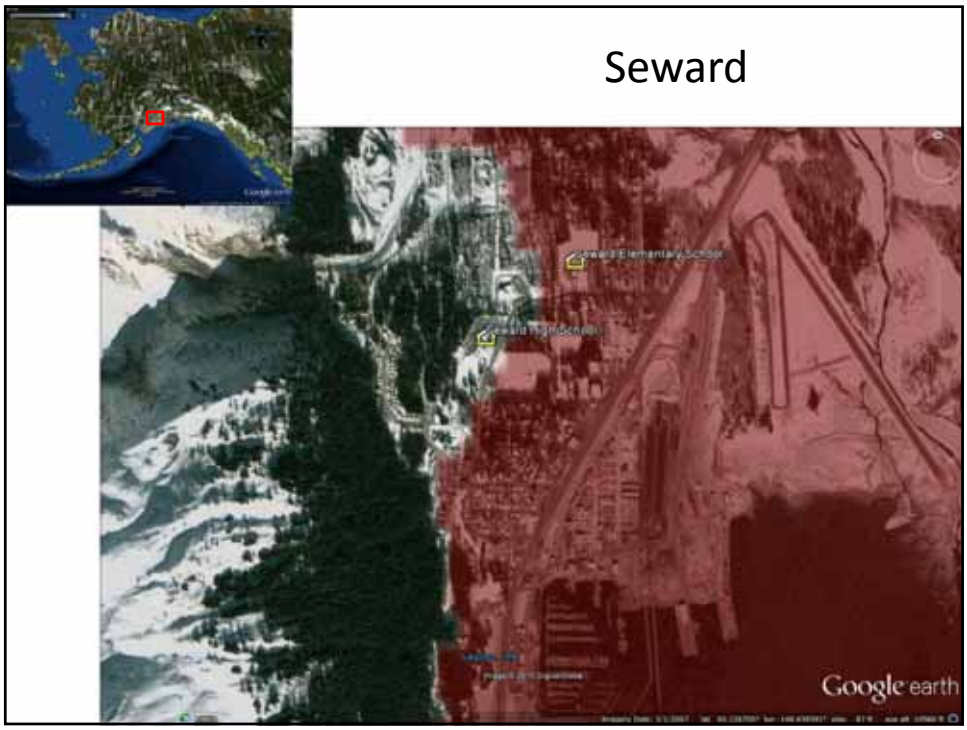
Public Schools – 52 : Private Schools - 4


Cayucos Elementary School
Del Mar Elementary
Pierpont Elementary School
Coeur d'Alene Elementary School
Will Rogers Middle School
Edison Elementary School
Mission Bay High School
Silver Strand Elementary School
Google earth

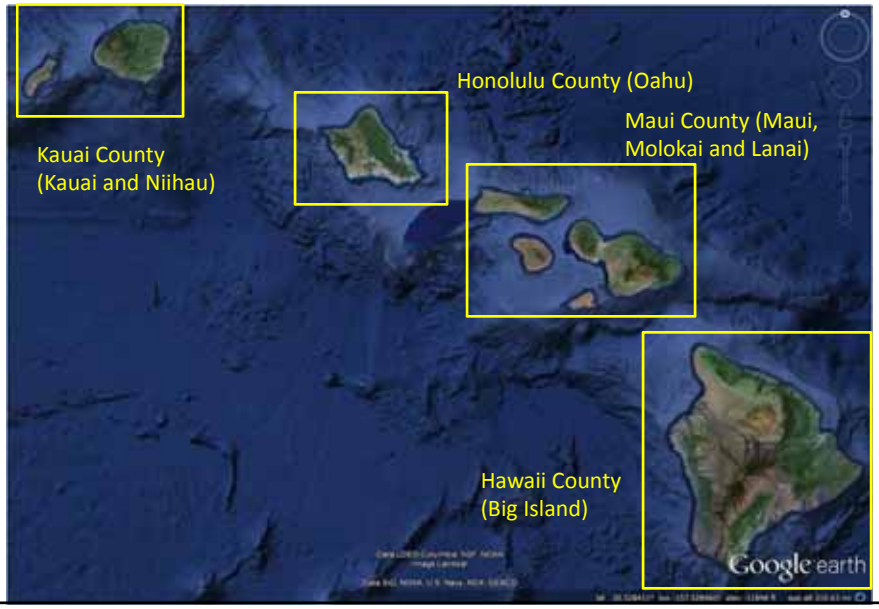

Newport/Huntington Beach
Hope View Elementary School
John R. Peterson Elementary School
Huntington Beach
Newport Beach
Newport Elementary School
Google earth

Alaska

Public Schools - 4



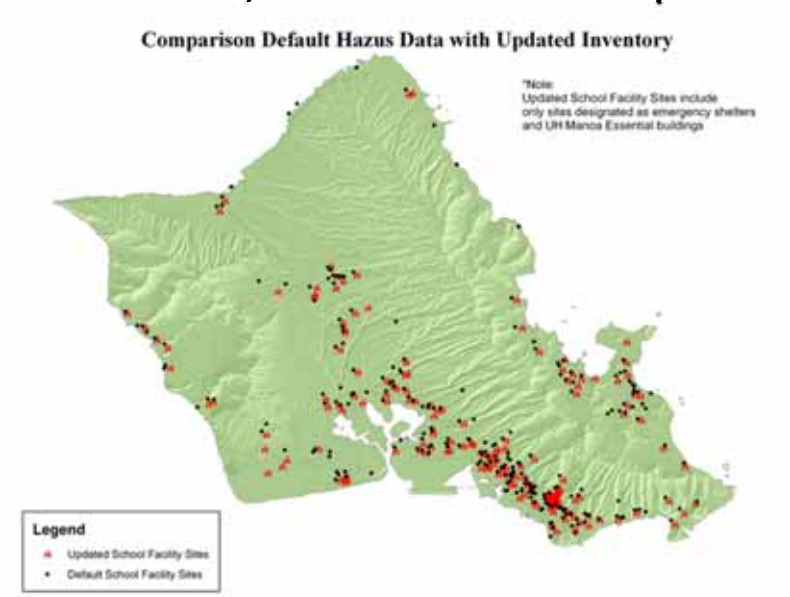
Hawaii Islands



Hawaii Counties

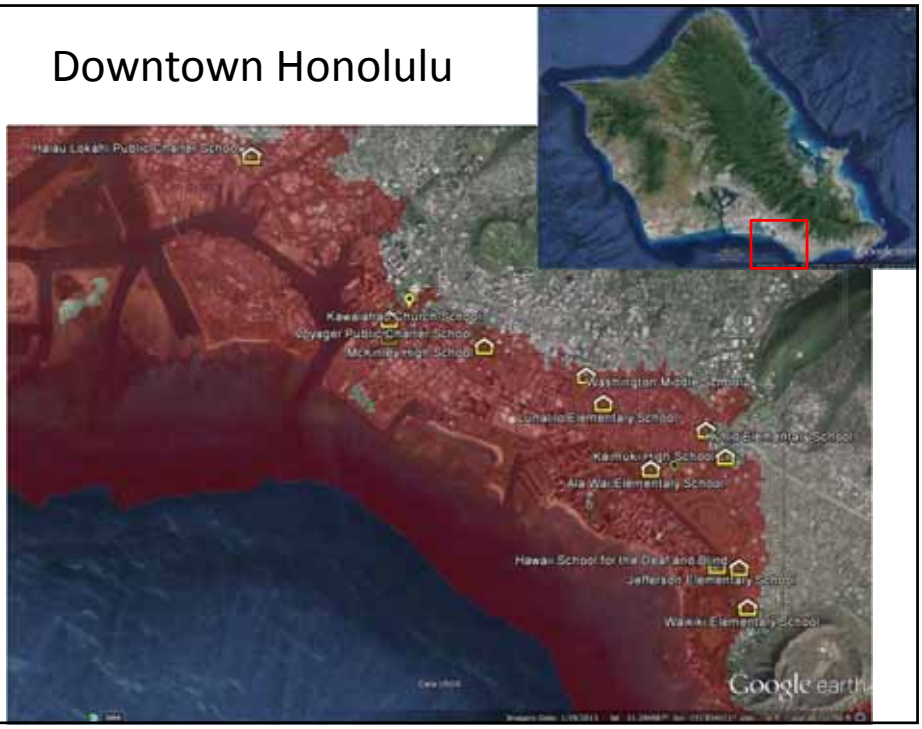
County	Public Schools	Private Schools	Total Students
Honolulu	50	18	39,000
Maui	6	9	6,330
Hawaii	6	4	2,034
Kauai	7	1	2,021
Totals	69	32	49,385

Oahu, Honolulu County



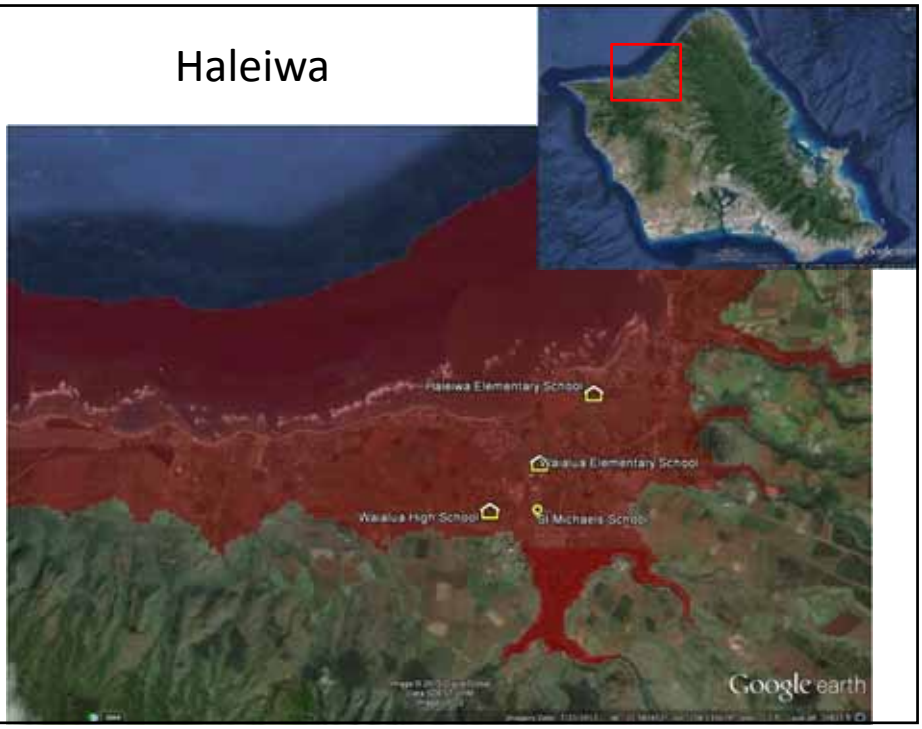
Oahu, Honolulu County

Downtown Honolulu

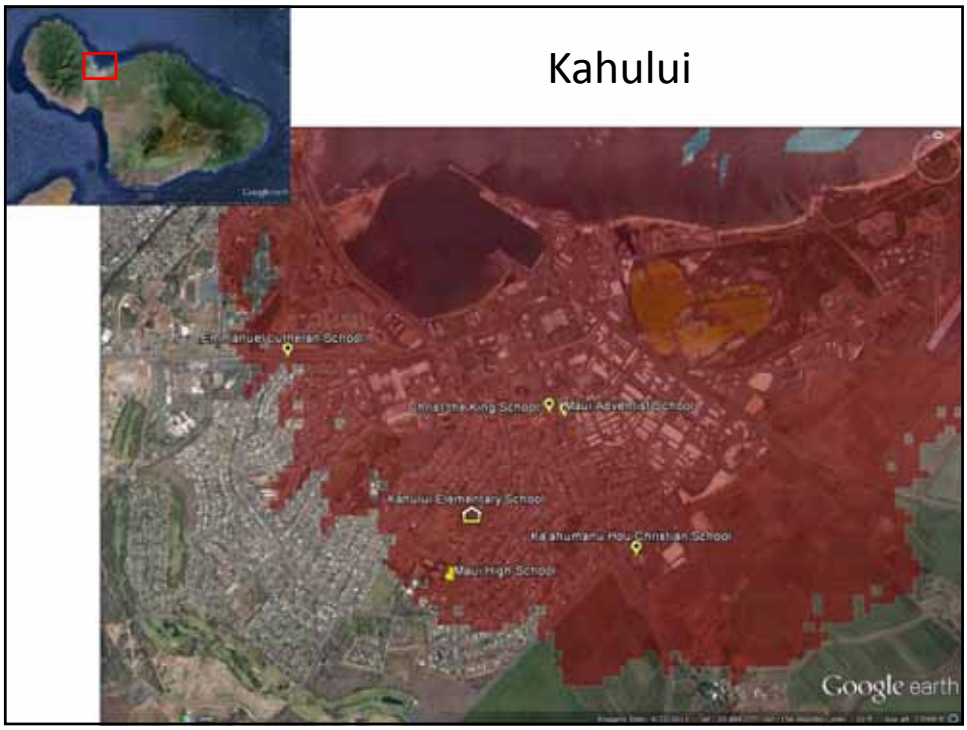


Kailua

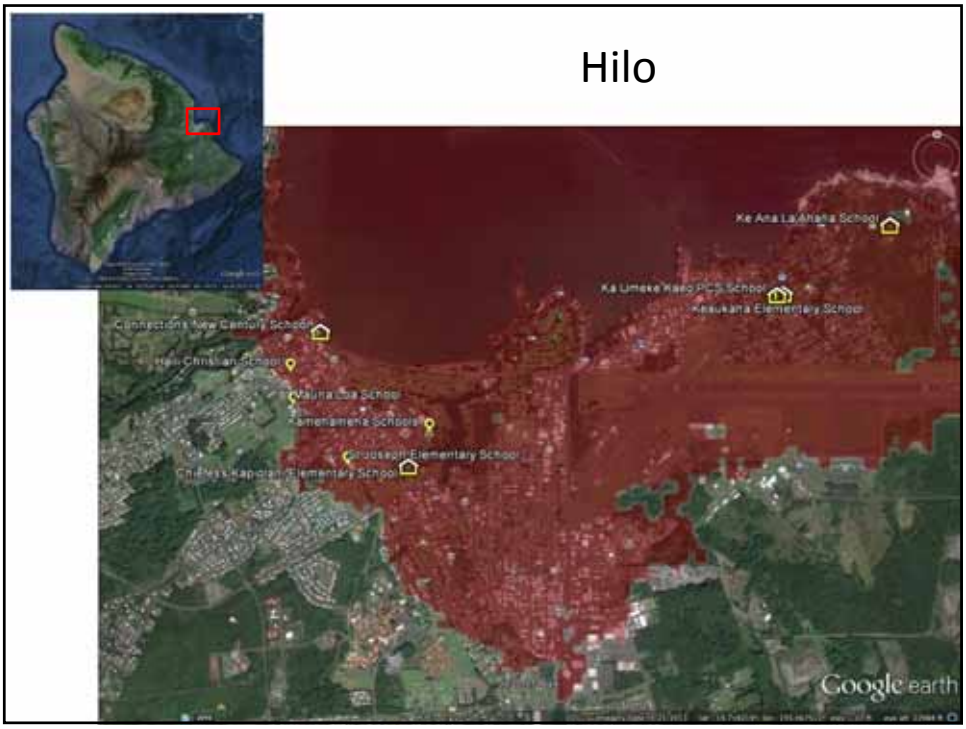
Haleiwa



Kahului



Hilo



SESI Tsunami Subcommittee Outreach

- The subcommittee members will work with each state's tsunami program manager to provide information to schools in the tsunami zone
- We do not want to duplicate or contradict efforts already underway at the local level, but hope to augment those efforts wherever possible.
- If you are a tsunami mitigation professional in any of the US West Coast states, and would like to be involved, please contact Shizza Fatima at shizza@eeri.org.

Acknowledgements

- Funding for the SESI Tsunami Subcommittee provided by Coastal Zone Foundation
- Assistance from a number of state mitigation personnel: Kevin Miller, Rick Wilson, Ian Madin, Maximilian Dixon, Kevin Richards, and many others
- Other members of the SESI Tsunami Subcommittee
- EERI Interns assisting with SESI, Shizza Fatima and Heidi Tremayne

Thank - You

Any questions?

School Earthquake Safety Initiative • Earthquake Engineering Research Institute