The New Chapter 6 on Tsunami Loads and Effects in ASCE 7-16

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The New Chapter 6 on Tsunami Loads and Effects in ASCE 7-16

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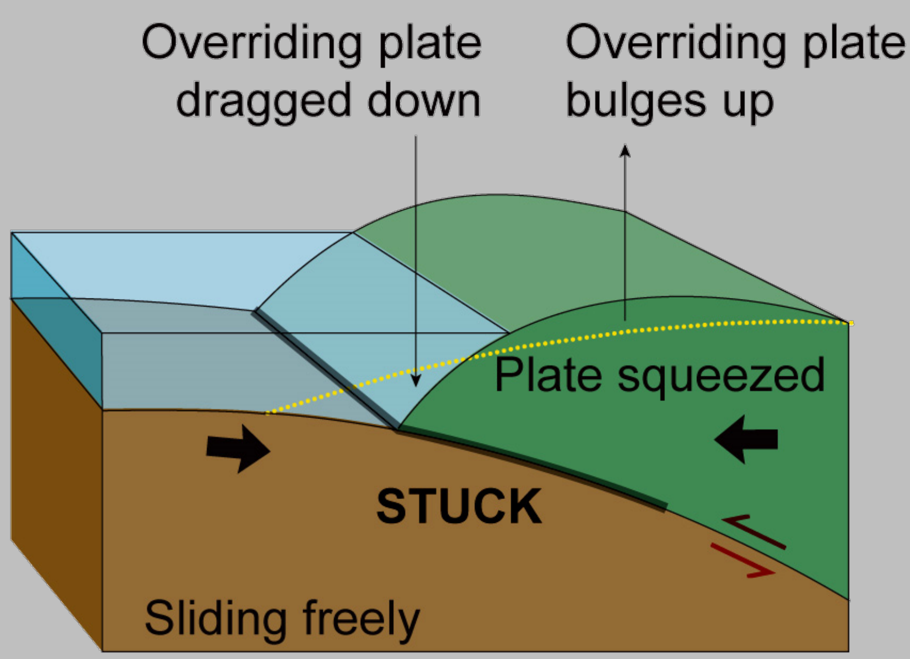
Tsunami Loads and Effects Subcommittee Chair

October 1, 2015

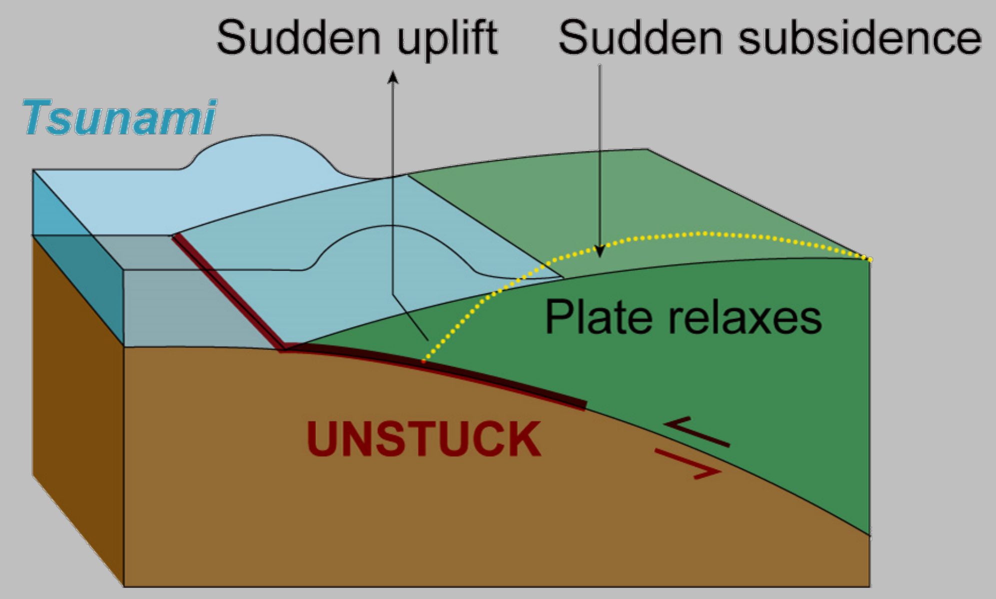
Subduction Zone Tsunami Generation



BETWEEN EARTHQUAKES the plates slide freely at great depth, where hot and ductile. But at shallow depth, where cool and brittle, they stick together. Slowly squeezed, the overriding plate thickens.

After Atwater et al. (2005)

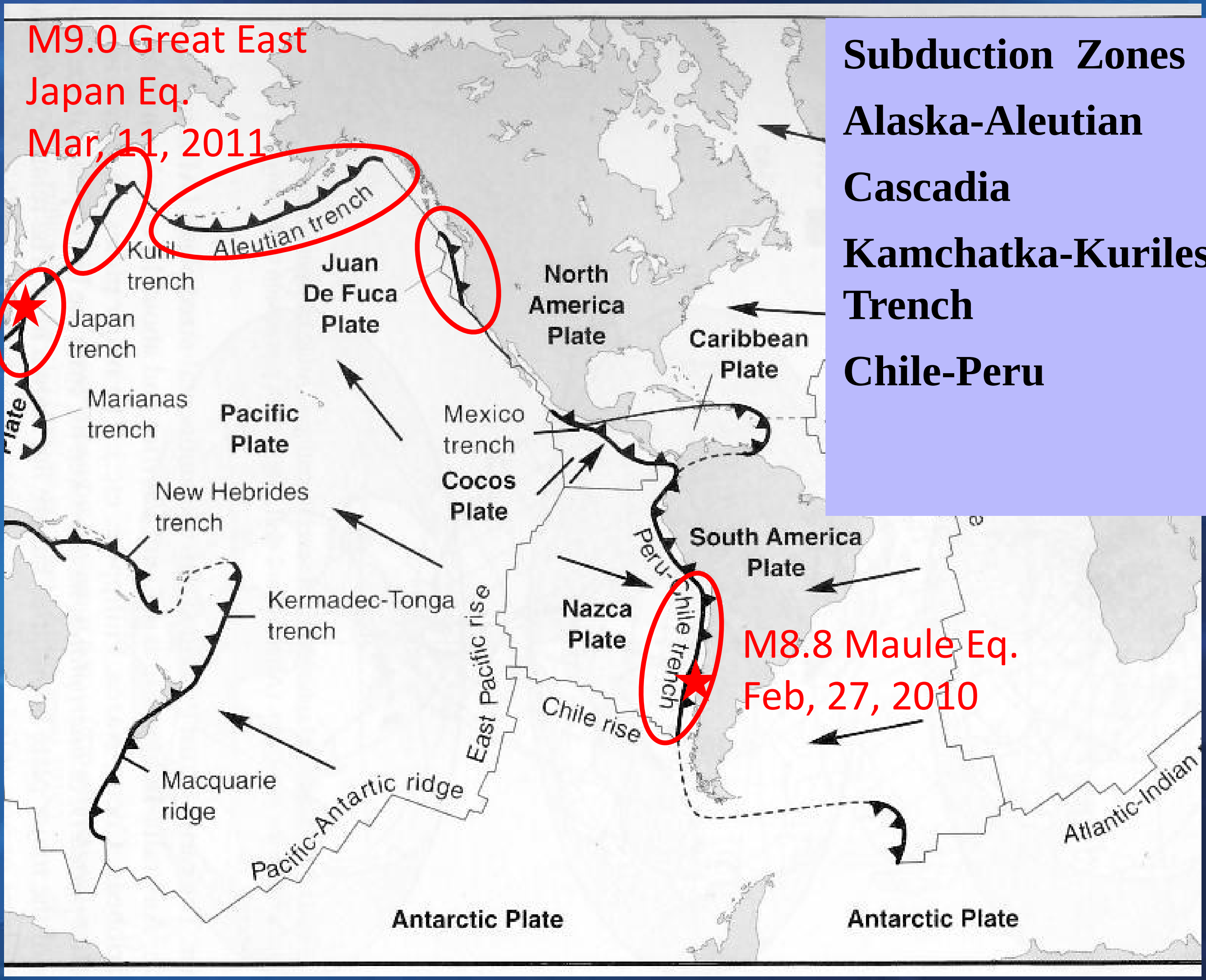
Subduction Zone Tsunami Generation



DURING AN EARTHQUAKE the leading edge of the overriding plate breaks free, springing seaward and upward. Behind, the plate stretches; its surface fails. The vertical displacements set off a tsunami.

After Atwater et al. (2005)

Tsunami-genic Seismic Sources of Principal Relevance to the USA



Subduction Zones

Alaska-Aleutian

Cascadia

Kamchatka-Kuriles & Japan Trench

Chile-Peru

Exposure to Tsunami Hazard

State	Population at Direct Risk [1, 2]	Profile of Economic Assets and Critical Infrastructure
California	275,000 residents plus another 400,000 to 2,000,000 tourists; 840 miles of coastline	>$200 Billion plus 3 major airports (SFO, OAK, SAN) and 1 military port, 5 very large ports, 1 large port, 5 medium ports
	Total resident population of area at immediate risk to post-tsunami impacts[3]: 1,950,000	
Oregon	25,000 residents plus another 55,000 tourists; 300 miles of coastline	$8.5 Billion plus essential facilities, 2 medium ports,1 fuel depot hub
	Total resident population of area at immediate risk to post-tsunami impacts[3]: 100,000	
Washington	45,000 residents plus another 20,000 tourists; 160 miles of coastline	$4.5 Billion plus essential facilities, 1 military port, 2 very large ports, 1 large port, 3 medium ports
	Total resident population of area at immediate risk to post-tsunami impacts[3]: 900,000	
Hawaii	~200,000[4] residents plus another 175,000 or more tourists and approximately 1,000[4] buildings directly relating to the tourism industry; 750 miles of coastline	$40 Billion, plus 3 international airports, and 1 military port, 1 medium port, 4 other container ports, and 1 fuel refinery intake port, 3 regional power plants; 100 government buildings
	Total resident population of area at immediate risk to post-tsunami impacts: 400,000[4]	
Alaska	105,000 residents, plus highly seasonal visitor count; 6,600 miles of coastline	>$10 Billion plus International Airport's fuel depot, 3 medium ports plus 9 other container ports; 55 ports in total
	Total resident population of area at immediate risk to post-tsunami impacts[5]: 125,000	

[1]USGS Scientific Investigations Reports 2007-5208 (HI), 2007-5283 (OR), 2008-5004 (WA), 2012-5222 (CA)

[2] Estimates based on evacuation zones

[3] National Research Council, 2011,Tsunami Warning and Preparedness, An Assessment of the U.S. Tsunami Program and the Nation's Preparedness Efforts. The total population at immediate risk includes those in the same census tract whose livelihood or utility and other services would be interrupted by a major tsunami with this inundation.

[4] Updated for exposure to great Aleutian tsunamis (University of Hawaii and Hawaii State Civil Defense)

[5]Primarily Ketchikan, Sitka, Juneau, Yakutat, Skagway, Valdez, Seward, Homer, Anchorage, Kodiak, Sand Point, Unalaska, and Adak

Implementation of Tsunami-Resilient Engineering Design

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Scope of work
ASCE 7 TLESC

Sources and Frequency — Consensus Assessment by USGS

Tsunami Modeling:

- Tsunami Generation
  Distant and Local Subduction Zones
- Open Ocean Propagation
- Offshore Tsunami Amplitude
- Coastal Inundation and Flow Velocities

Probabilistic Tsunami Hazard Analysis

Coastal, Hydraulic, Structural, and Geotechnical Engineering:

- Fluid-Structure Interaction
- Structural Loading
- Structural Response
- Scour and Erosion

Performance by Risk Category — Structural Reliability

Consequences
(Life and economic losses)

Warning and Evacuation Capability

Societal Impact Assessment for the Five Western States by USGS

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The Tsunami Resilient Provisions of ASCE 7-16

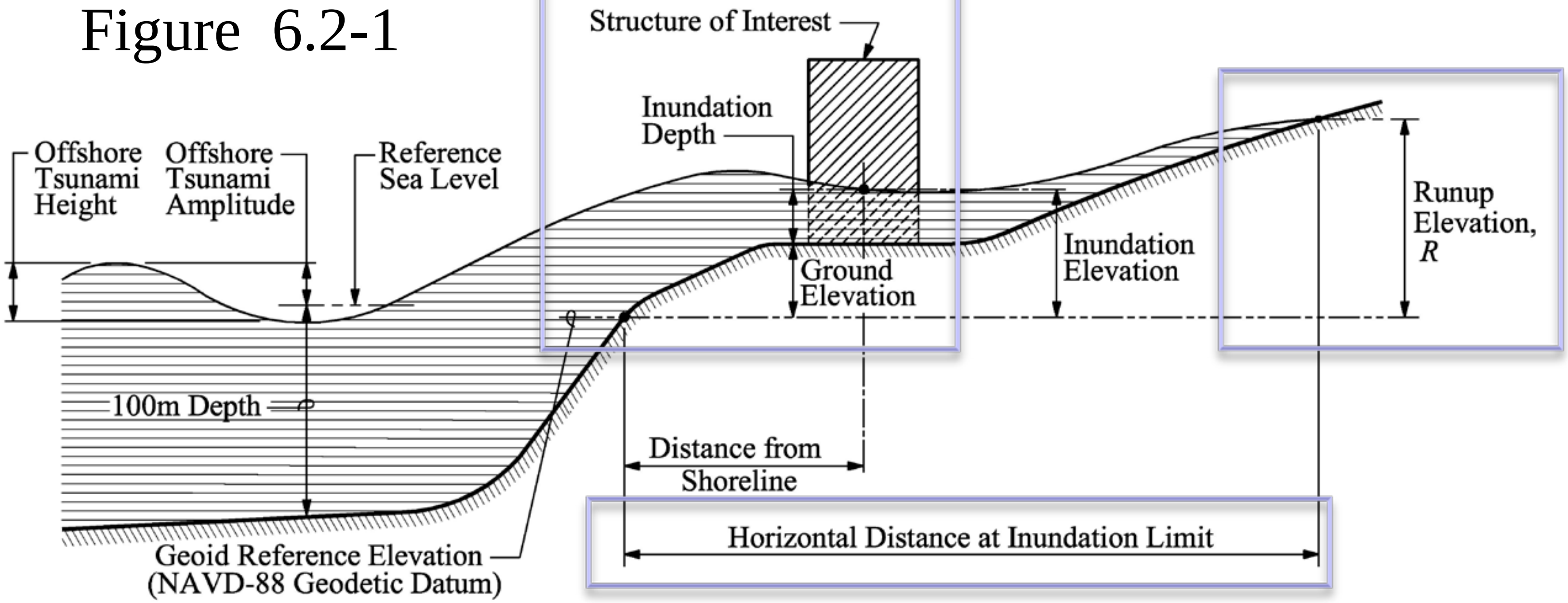
- The Tsunami Loads and Effects Subcommittee of the ASCE/SEI 7 Standards Committee has developed a new Chapter 6 - Tsunami Loads and Effects for the ASCE 7-16 Standard, which has been approved.
- ASCE 7-16 to be published by March 2016
- Tsunami Provisions would then be referenced in IBC 2018
- State Building Codes of AK, WA, OR, CA, and HI ~ 2020
- ASCE will be publishing two design guides in 2016 with design examples.

TLESC chair: Gary Chock <gchock@martinchock.com>

Terminology

- RUNUP ELEVATION: Difference between the elevation of maximum tsunami inundation limit and the (NAVD-88) reference datum
- INUNDATION DEPTH: The depth of design tsunami water level with respect to the grade plane at the structure
- INUNDATION LIMIT: The horizontal inland distance from the shoreline inundated by the tsunami
- Froude number: F_r A dimensionless number defined by $u/\sqrt{(gh)}$, where u is the flow velocity and h is the inundation depth

Figure 6.2-1



Fundamental Basis of Design per ASCE 7

- PTHA-based design criteria - The method of Probabilistic Tsunami Hazard Analysis is consistent with probabilistic seismic hazard analysis in the treatment of seismicity.
- Maximum Considered Tsunami – 2500-year MRI
- The tsunami design provisions utilize probabilistic Offshore Tsunami Amplitude maps and Tsunami Design Zone inundation maps
- Procedures for tsunami inundation mapping are based on using these probabilistic values of Offshore Tsunami Amplitude
- Hydraulic analysis or site-specific inundation analysis to determine site design flow conditions: depth and velocity
- Fluid loads, debris loads, foundation demands

6.1.1 Scope

The following buildings and other structures located within the Tsunami Design Zone shall be designed for the effects of Maximum Considered Tsunami including hydrostatic and hydrodynamic forces, waterborne debris accumulation and impact loads, subsidence, and scour effects in accordance with this Chapter:

a. **Tsunami Risk Category IV buildings and structures;**

b. **Tsunami Risk Category III buildings and structures with inundation depth at any point greater than 3 feet, and**

c. Where required by a state or locally adopted building code statute to include design for tsunami effects, Tsunami Risk Category II buildings with mean height above grade plane greater than the height designated in the statute, and having inundation depth at any point greater than 3 feet.

Exception: Tsunami Risk Category II single-story buildings of any height without mezzanines or any occupiable roof level, and not having any critical equipment or systems need not be designed for the tsunami loads and effects specified in this Chapter.

Report on Performance of Taller Structures in Japan used by Evacuees – (whether Designated or Not)

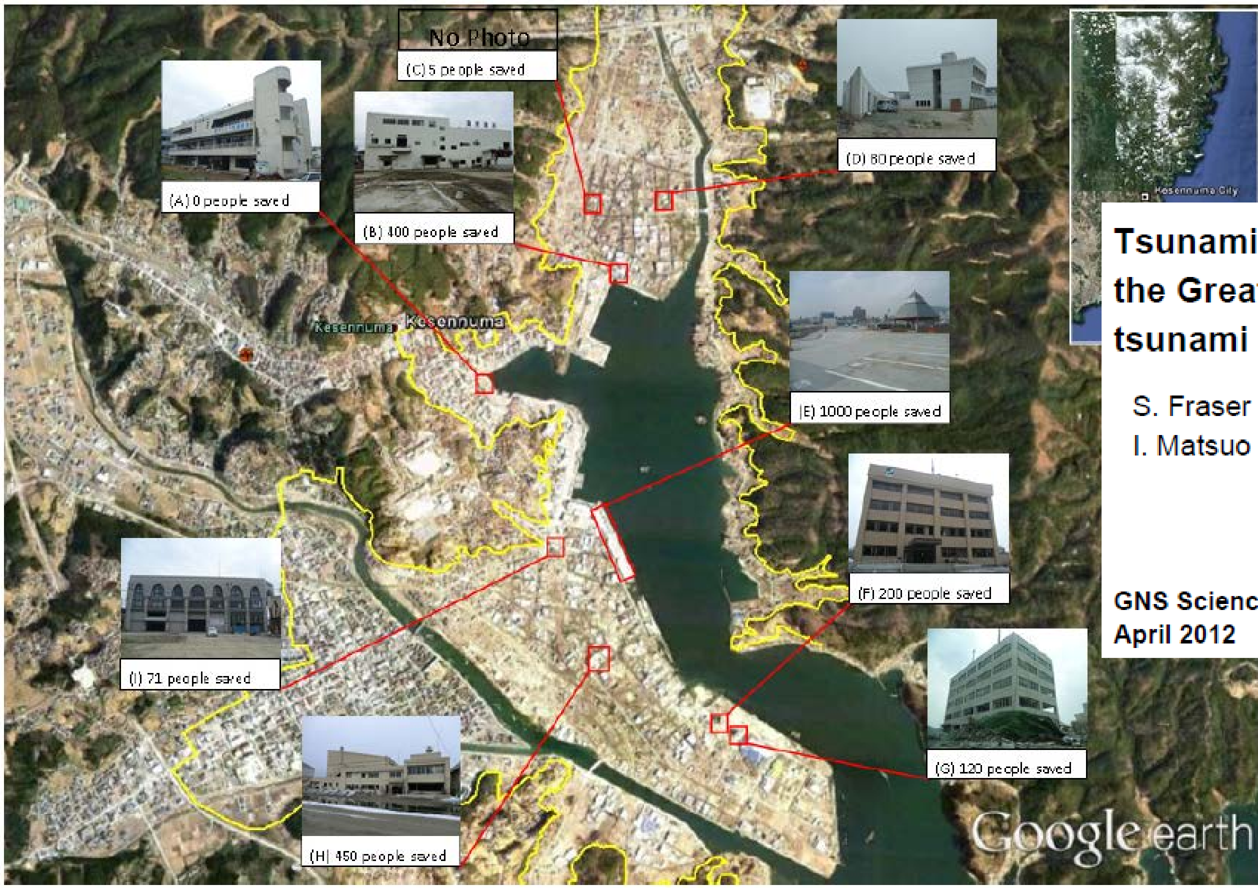


Fig. 2. Map and images of nine vertical evacuation buildings in Kesennuma City, including numbers of people saved and tsunami inundation marked in yellow [29]. These comprise office buildings (A, F, G, I); a cannery (B), a retail building (C), welfare centre (D), a car parking deck (E) and a community centre (H).

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

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

GNS Science Report 2012/17
April 2012

Tsunami Safety in Multi-Story Buildings

- *Tsunami Evacuation: Lessons from the Great East Japan Earthquake and Tsunami of March 11th 2011 (State of Washington sponsored investigation)*
- An example from the City of Ishinomaki (low-lying area similar to coastal communities at risk in the US) near Sendai
- "There was widespread use of buildings for informal (unplanned) vertical evacuation in Ishinomaki on March 11th, 2011. In addition to these three designated buildings, almost any building that is higher than a 2-storey residential structure was used for vertical evacuation in this event. About 260 official and unofficial evacuation places were used in total, providing refuge to around *50,000* people. These included schools, temples, shopping centres and housing." (emphasis added)

Section 6.4 Tsunami Risk Categories

For the purposes of this chapter, Tsunami Risk Categories for buildings and other structures shall be the Risk Categories given in **Section 1.5** with the following modifications:

1. State, local, or tribal governments shall be permitted to include Critical Facilities in Tsunami Risk Category III, such as power-generating stations, water treatment facilities for potable water, waste water treatment facilities and other public utility facilities not included in Risk Category IV.
2. The following structures need not be included in Tsunami Risk Category IV and state, local, or tribal governments shall be permitted to designate them as Tsunami Risk Category II or III:
   a. Fire stations and ambulance facilities, emergency vehicle garages
   b. Earthquake or hurricane shelters
   c. Emergency aircraft hangars
   d. Police stations that do not have holding cells and that are not uniquely required for post-disaster emergency response as a Critical Facility.
3. Tsunami Vertical Evacuation Refuge Structures shall be included in Tsunami Risk Category IV.

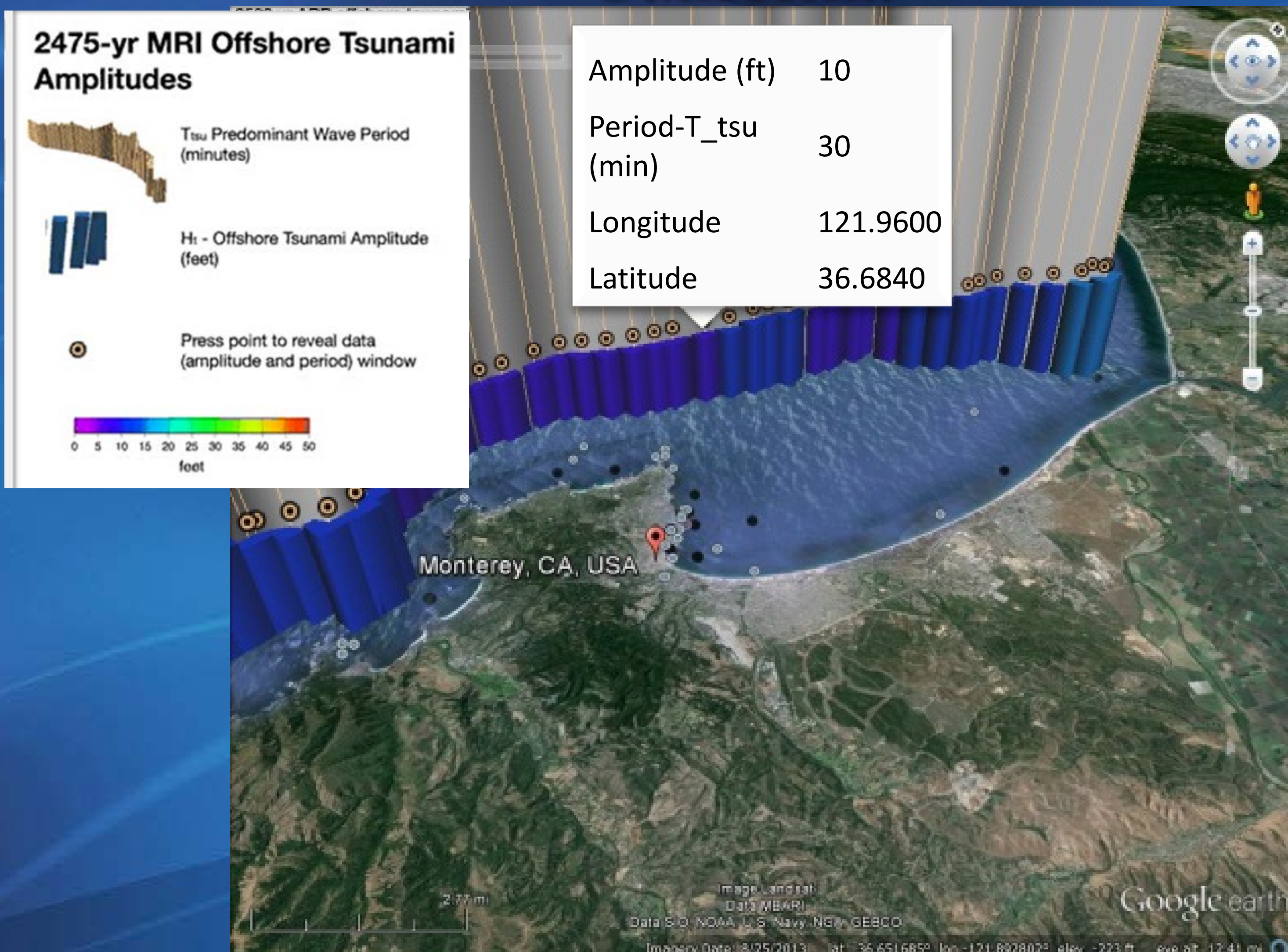
MCT and Tsunami Design Zone

- The Maximum Considered Tsunami (MCT) has a 2% probability of being exceeded in a 50-year period, or a ~2500 year average return period.
- The Maximum Considered Tsunami is the design basis event, characterized by the inundation depths and flow velocities at the stages of in-flow and outflow most critical to the structure.
- The Tsunami Design Zone is the area vulnerable to being flooded or inundated by the Maximum Considered Tsunami. The runup for this hazard probability is used to define a Tsunami Design Zone map.

Tsunami Design Information Products to be hosted on an electronic database:

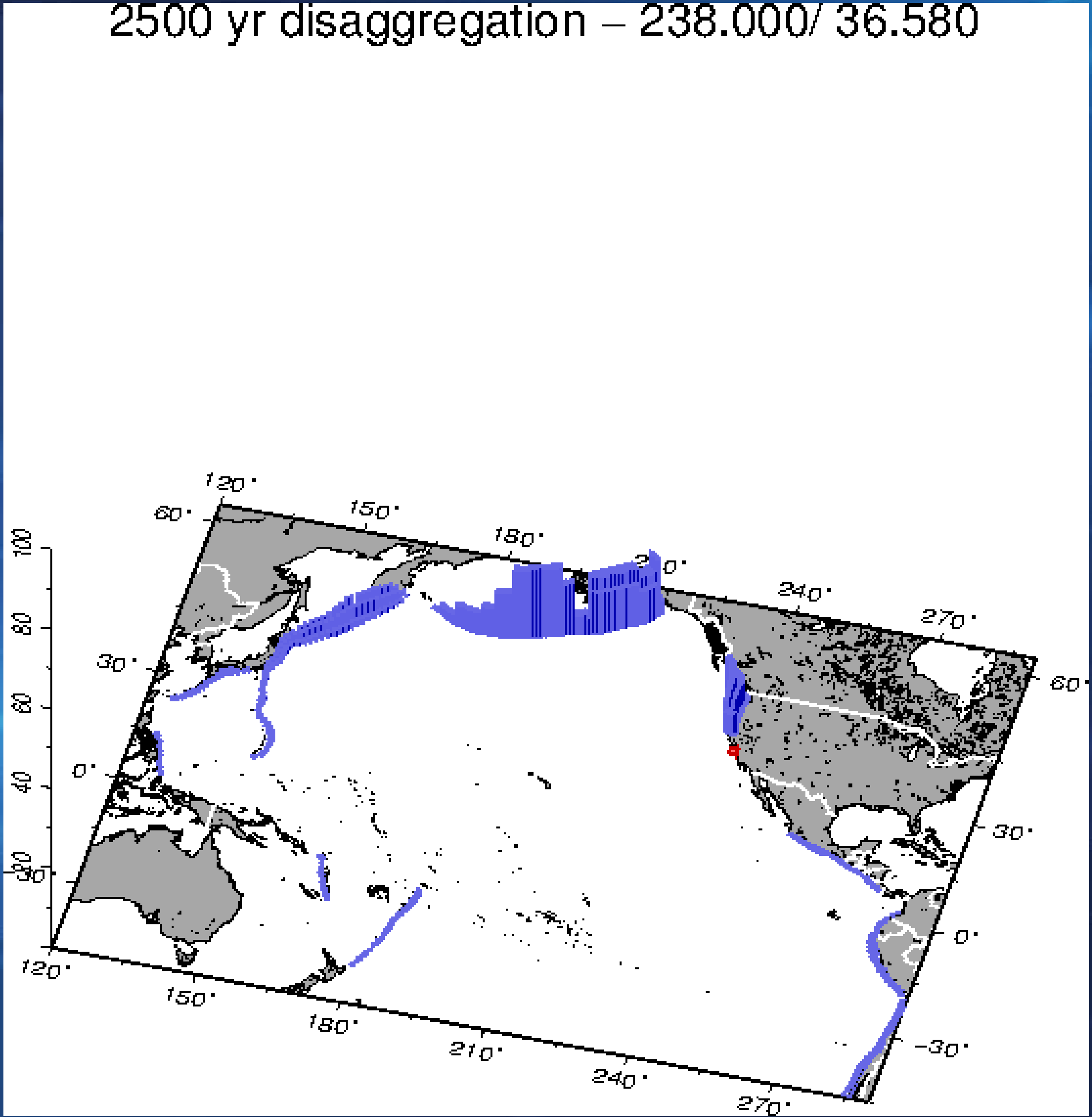
- PTHA Offshore Tsunami Amplitude and Predominant Period in kmz format and GIS point data format Disaggregated source figures
- 62 nondigital Tsunami Design Zone pdf maps that are equivalent to digital maps produced from the following digital geodatabase:
- GIS layers from the subsidence maps
- Runup in kmz format, and GIS point data format
- Inundation depth points for overwashed peninsulas and/or islands
- Tsunami Design Zone in kmz format, and GIS polygon format
- Metadata documentation, suitable as an accompanying user manual
- Notes:
  - Alaska TDZ also include seismically induced submarine landslide scenarios modeled by UAF per the state geologist
  - The Tsunami Design Zones in the Puget Sound considers both CSZ and local sources. The local inundation events comes from three potential thrust faults: the Seattle Fault, the Tacoma Fault, and the Rosedale Fault. The TDZ is the envelope of inundation hazards produced by all four scenarios; the inundation hazards in Puget Sound are mostly dominated by the local faults.

PTHA Offshore Tsunami Amplitude and Period for the Maximum Considered Tsunami at Monterey California

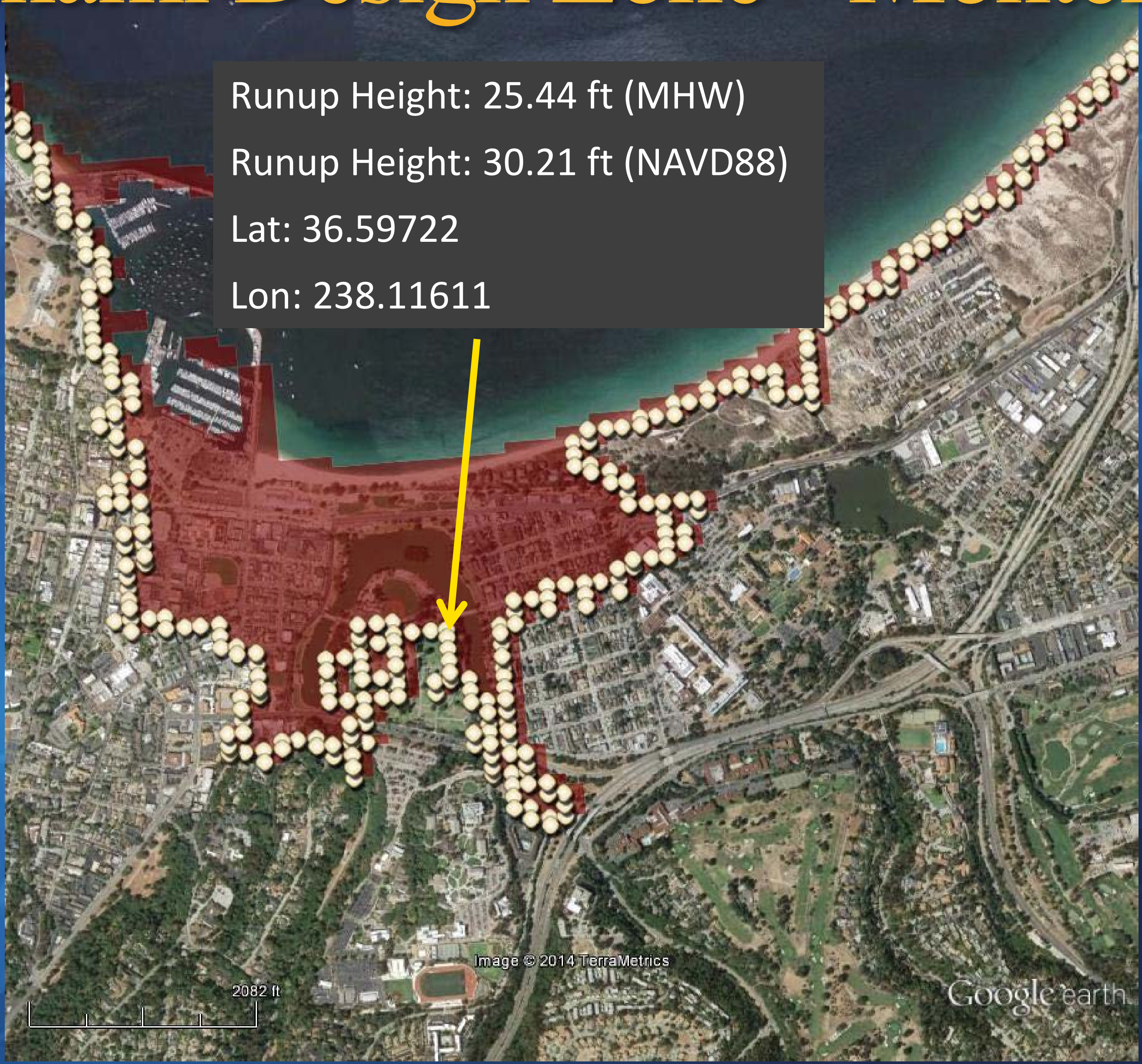


Disaggreagated Predominant Probabilistic Sources for Monterey, CA

- sources are primarily Alaska, East Aleutian, and Kuriles



Tsunami Design Zone - Monterey



Tsunami Flow Characteristics

- Near constant velocity over land, top to bottom, with very rapidly rising depth; Unlike a storm surge; there is no stillwater
- Wave period ranges between 30 minutes to 45 minutes for *each* wave in a series; shoaling leads to nearshore amplitude typically being amplified to several times the offshore amplitude; fluid forces must be considered force-sustained actions
- Flow reversal
- Two approaches to determine depth and flow velocity
  - **Flow parameters based on pre-calculated runup from the maps (the Energy Grade Line Analysis)**
  - **Flow parameters based on a Site-Specific Probabilistic Hazard Analysis**

Inundation Depth and Flow Velocity Analysis Procedures where Runup is mapped

Analysis Procedure using the Tsunami Design Zone Map	Tsunami Risk Category (TRC) Structure Classification			
	TRC II	TRC III	TRC IV (excluding TVERS)	TRC IV - Tsunami Vertical Evacuation Refuge Shelter (TVERS)
Energy Grade Line Analysis	✔	✔	✔	✔
Site-Specific Analysis	Permitted;	Permitted;	✔ Required if EGLA inundation depth ≥ 12 ft (3.7 m)*	✔

✔ indicates a required procedure

* MCT inundation depth including sea level rise component

- **A "floor value" of either 90% or 75% of the Energy Grade Line calculated from the runup is maintained based on terrain roughness (urban - 90%, other roughnesses – 75%)**
-

Tsunami-Specific Conditions

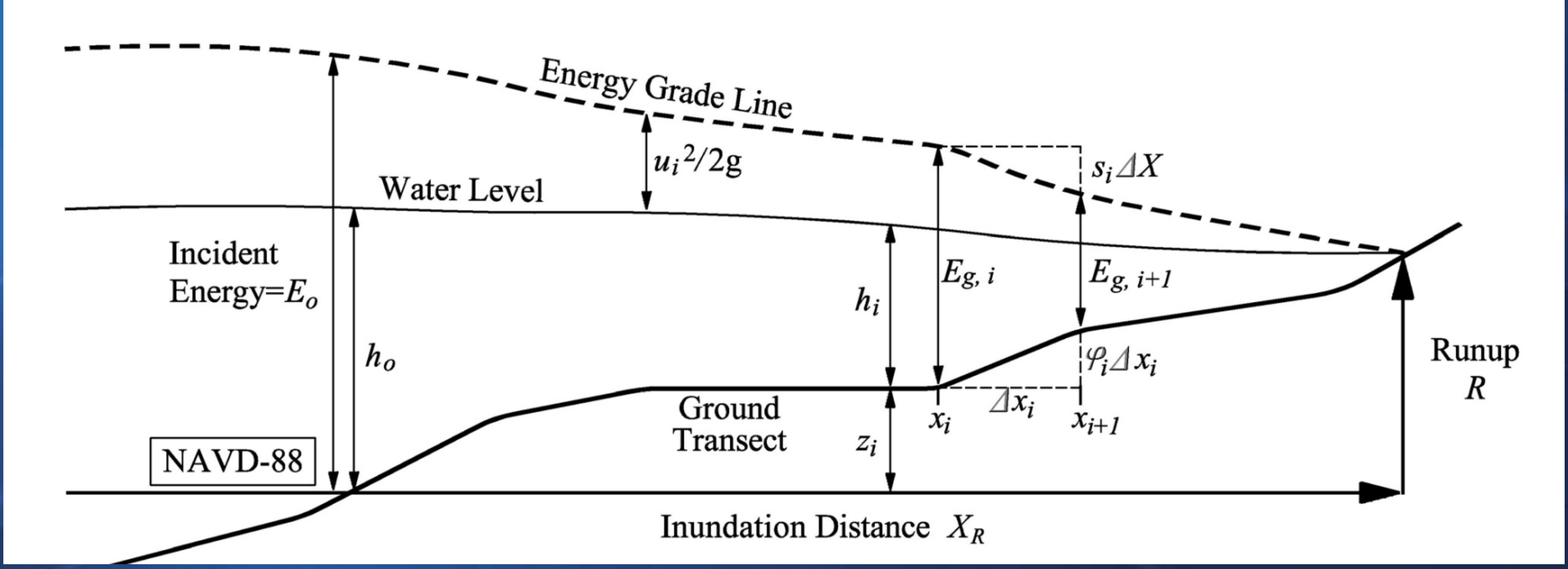
- Minimum Fluid Density – prescribed with 10% increase accounting for debris-laden seawater
- Directionality of Flow – variation of flow shall be considered +-22.5 degrees off the principal transect
- Minimum Closure Ratio – accounts for the “piling-on” effect of copious tsunami debris to create more obstruction to flow than just the bare structure

Inundation Depth and Flow Velocity Based on Runup

- Energy Grade Line Analysis
  - Calculation based on simple hydraulics using Manning's roughness coefficients

$$E_{g,i+1} = E_{g,i} - \left(\phi_i + s_i\right)\Delta X_i$$

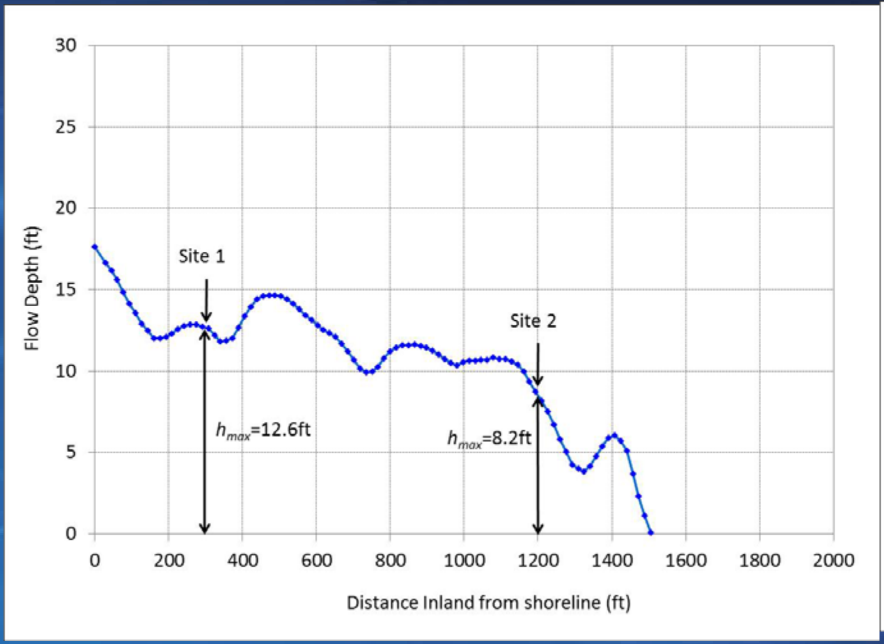
  - Straightforward site hydraulic analysis technique by an Energy Method to give expected flow depths and current velocities from topographic transect properties and (Manning's) surface roughness



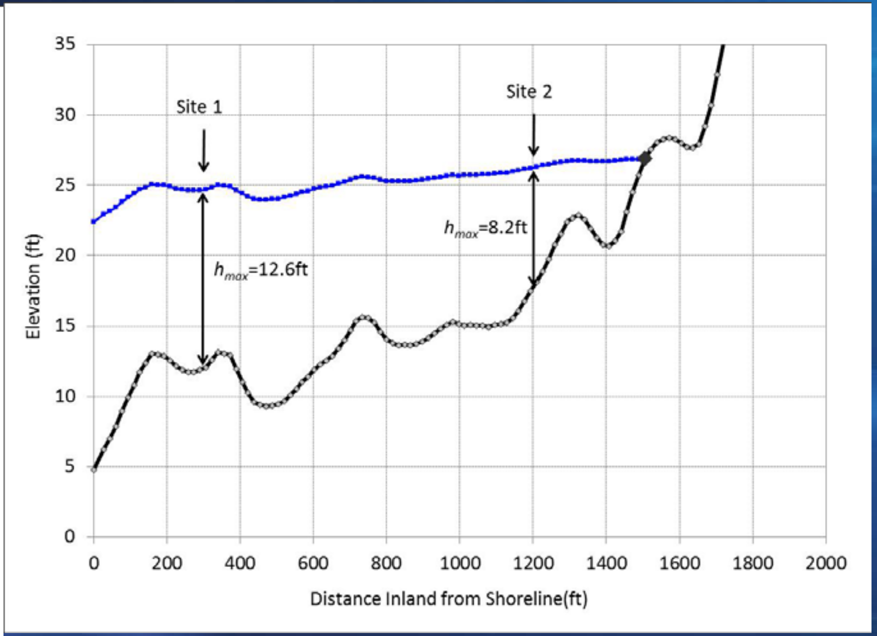
Monterey, California

EGLA results

Inundation depth (h_i) profile from Energy Grade Line analysis

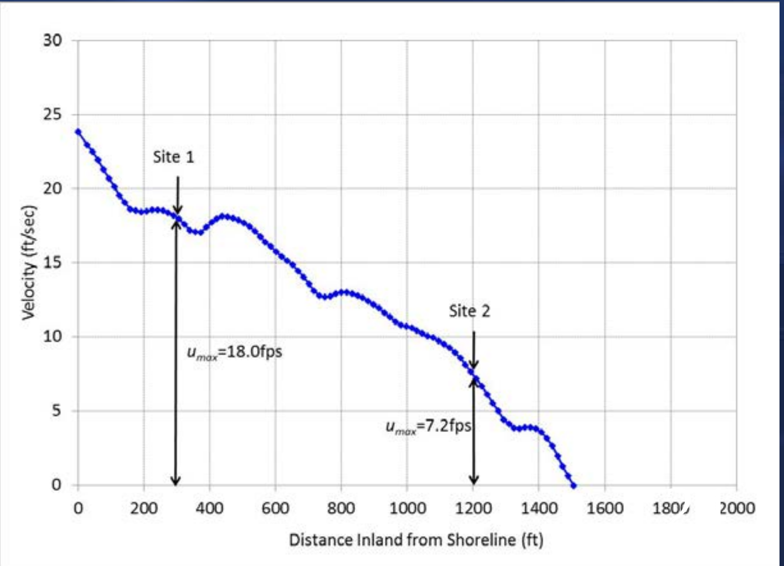


Inundation elevation ($h_i + z_i$) profile from Energy Grade Line analysis



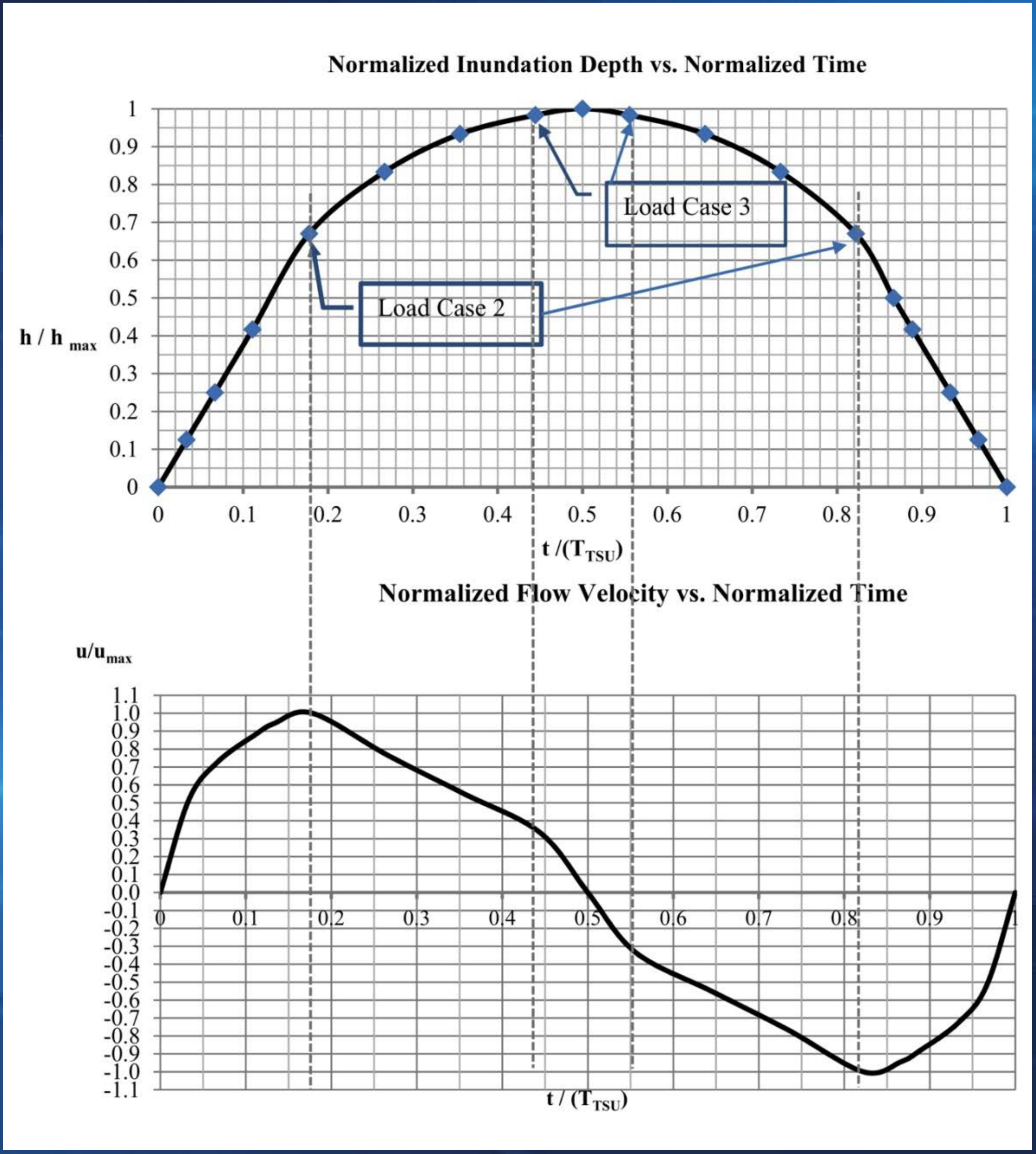
- Also see Robertson,I.N. (2016) *Tsunami Loads and Effects: Guide to the Tsunami Design Provisions of ASCE 7-16*, ASCE Publications
- This publication will have several completely worked structural design examples

Flow velocity (u_i) profile from Energy Grade Line analysis

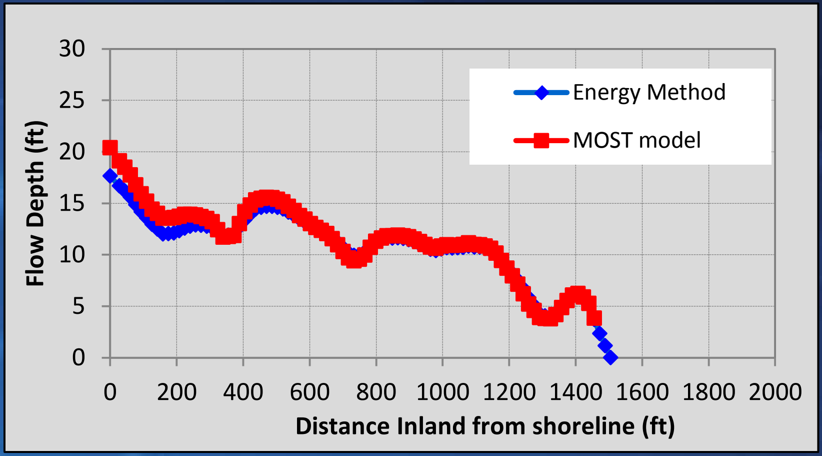


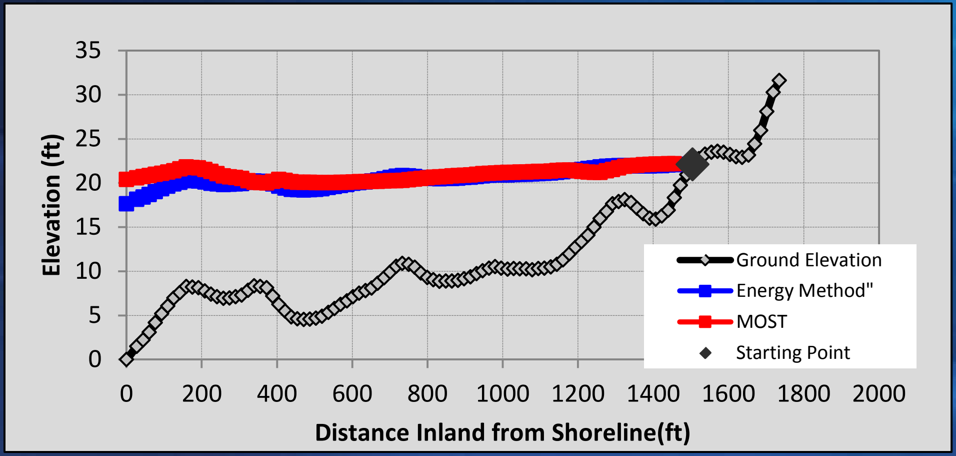
Load Cases

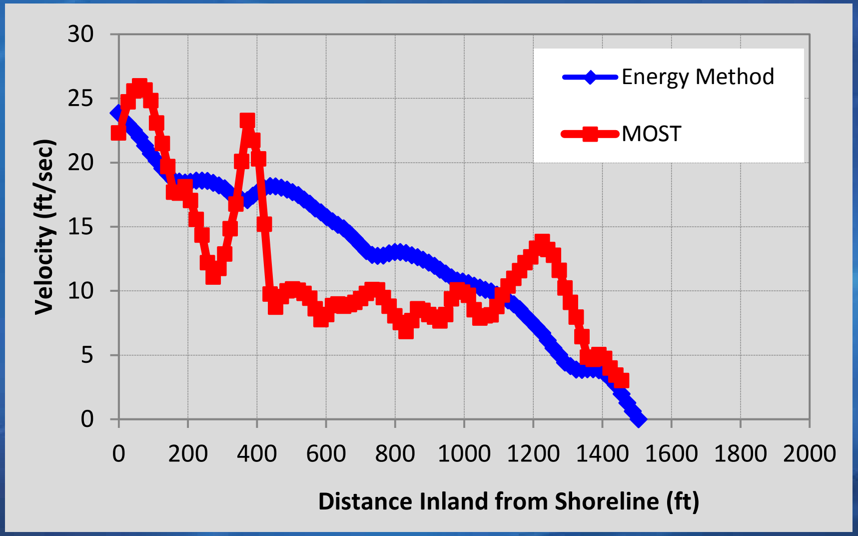
- Based on a prototypical time history of depth and flow velocity as a function of the maximum values determined from the Energy Grade Line Analysis
- Check 3 discrete governing stages of flow
- Load Case 1 is a maximum buoyancy check during initial flow

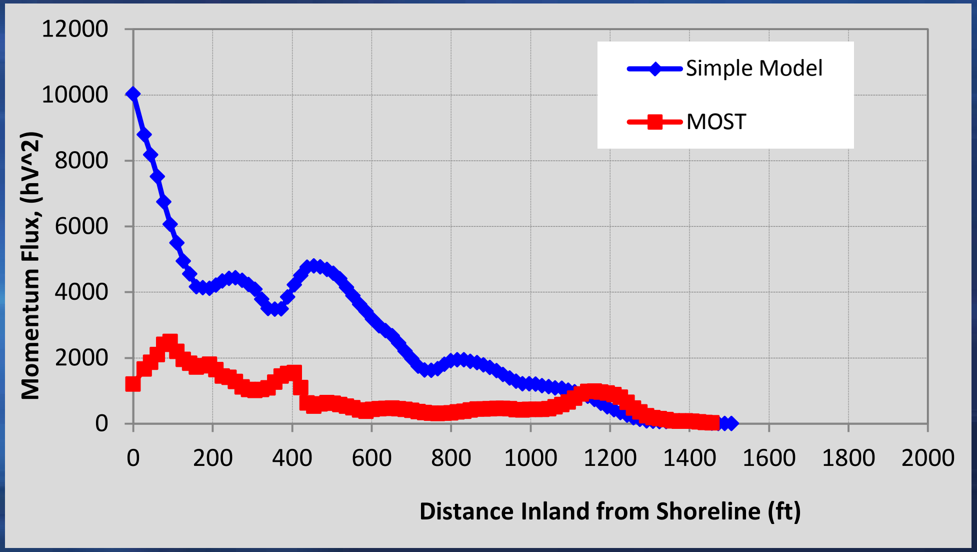


Energy Grade Line Analysis comparisons

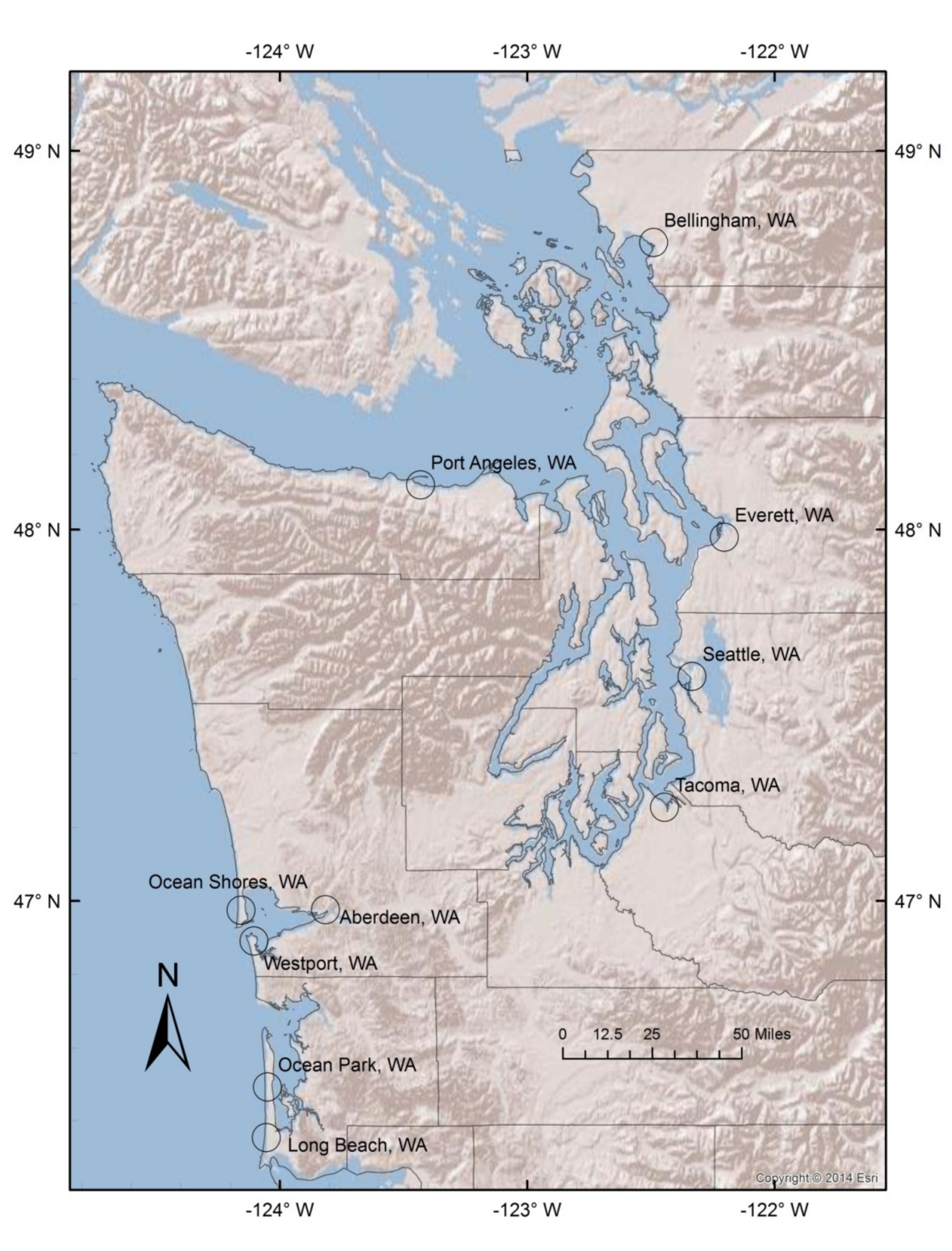


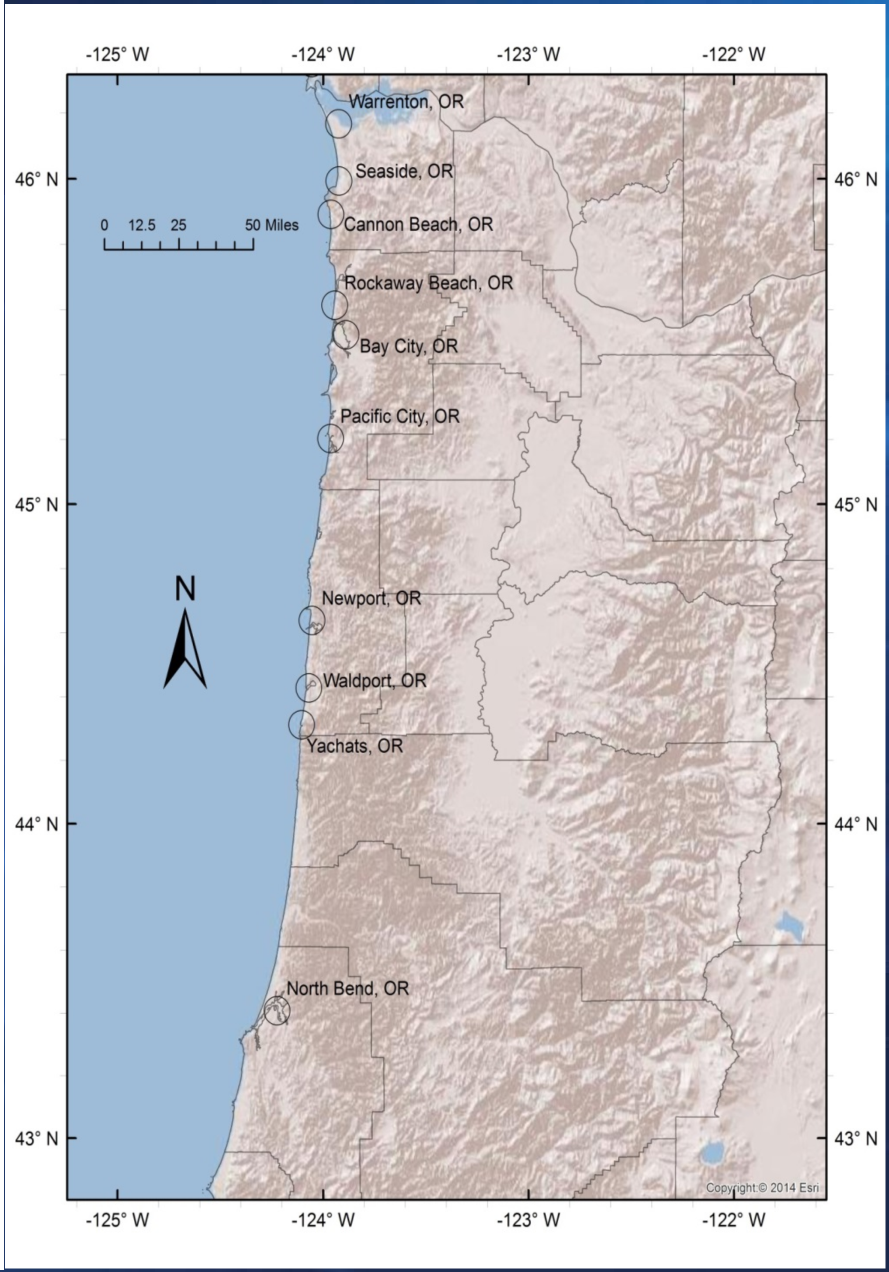




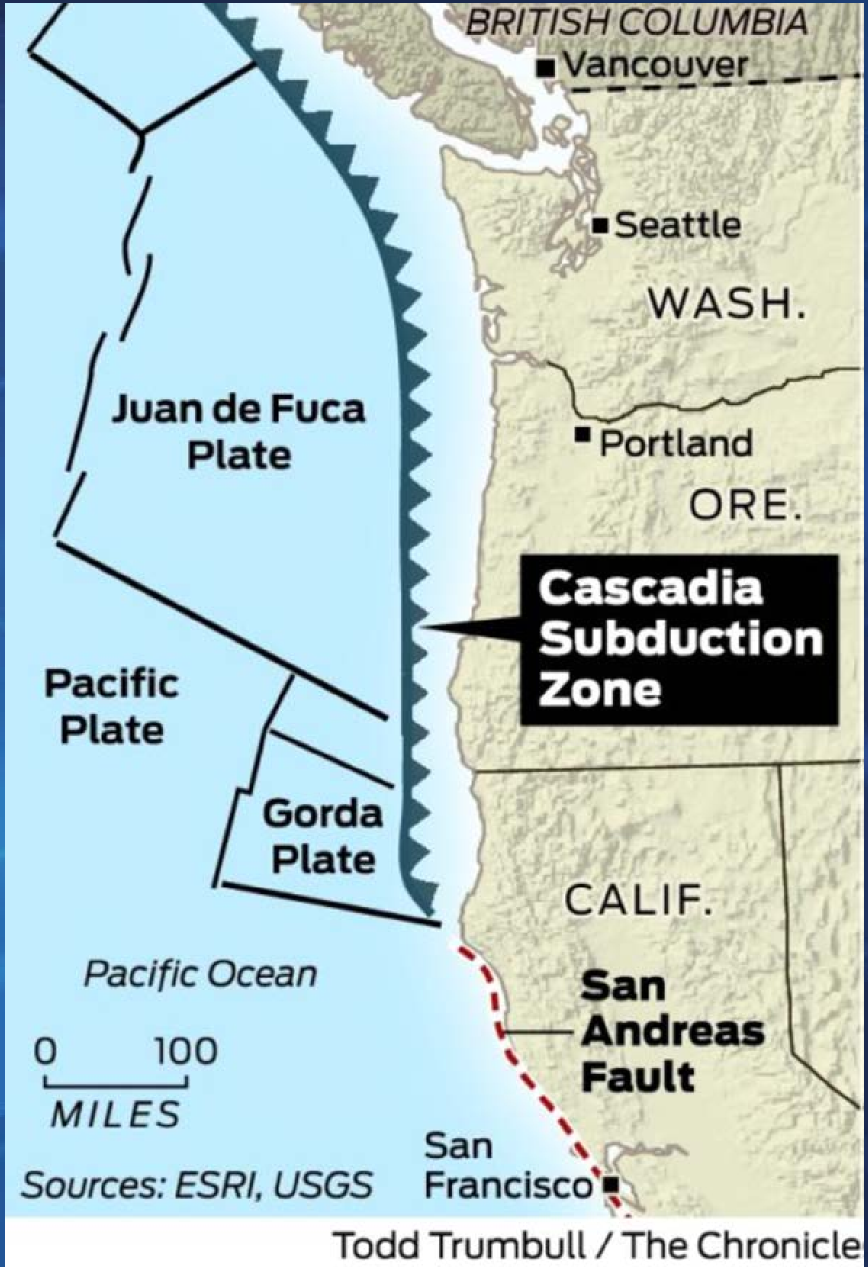


Pacific Northwest Communities



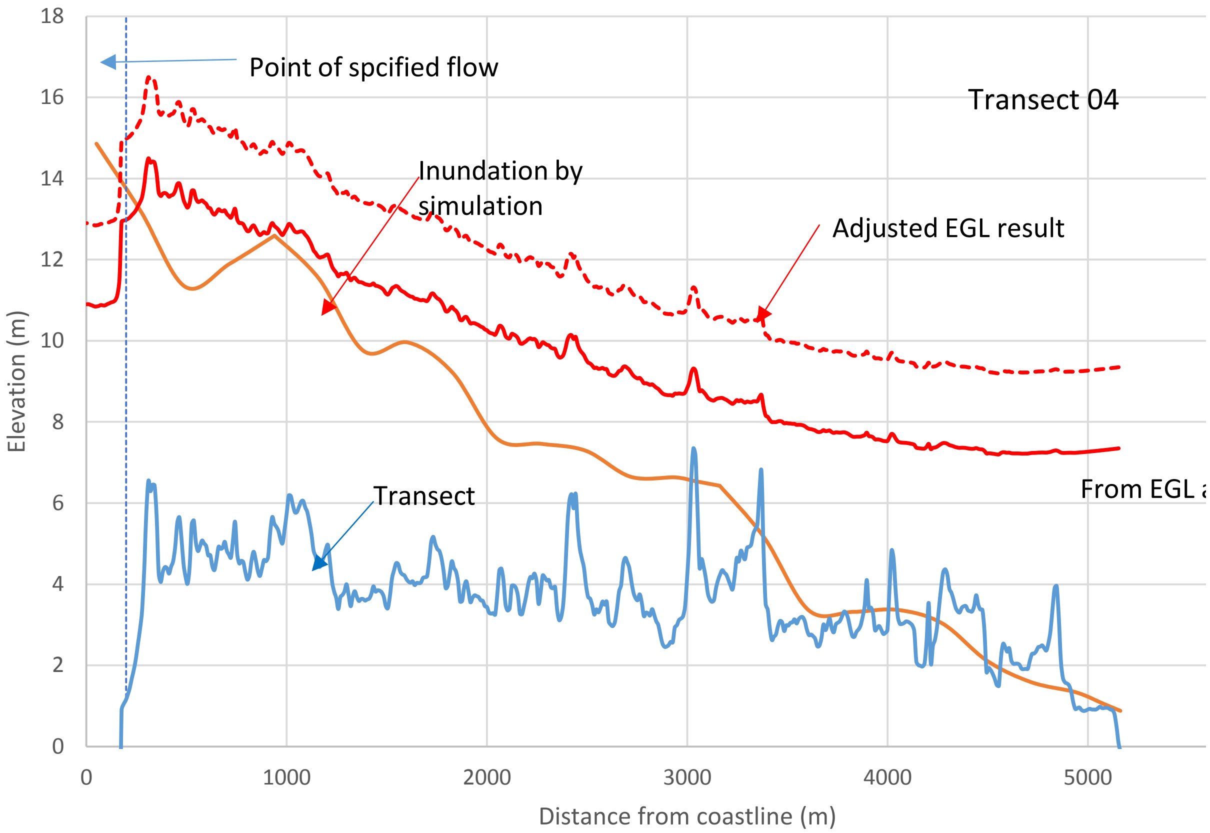


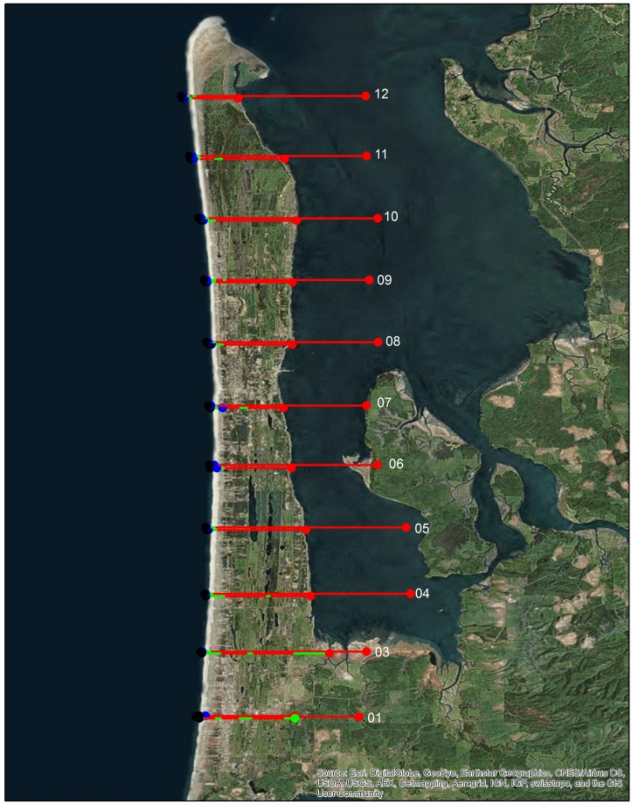
Cascadia Subduction Zone



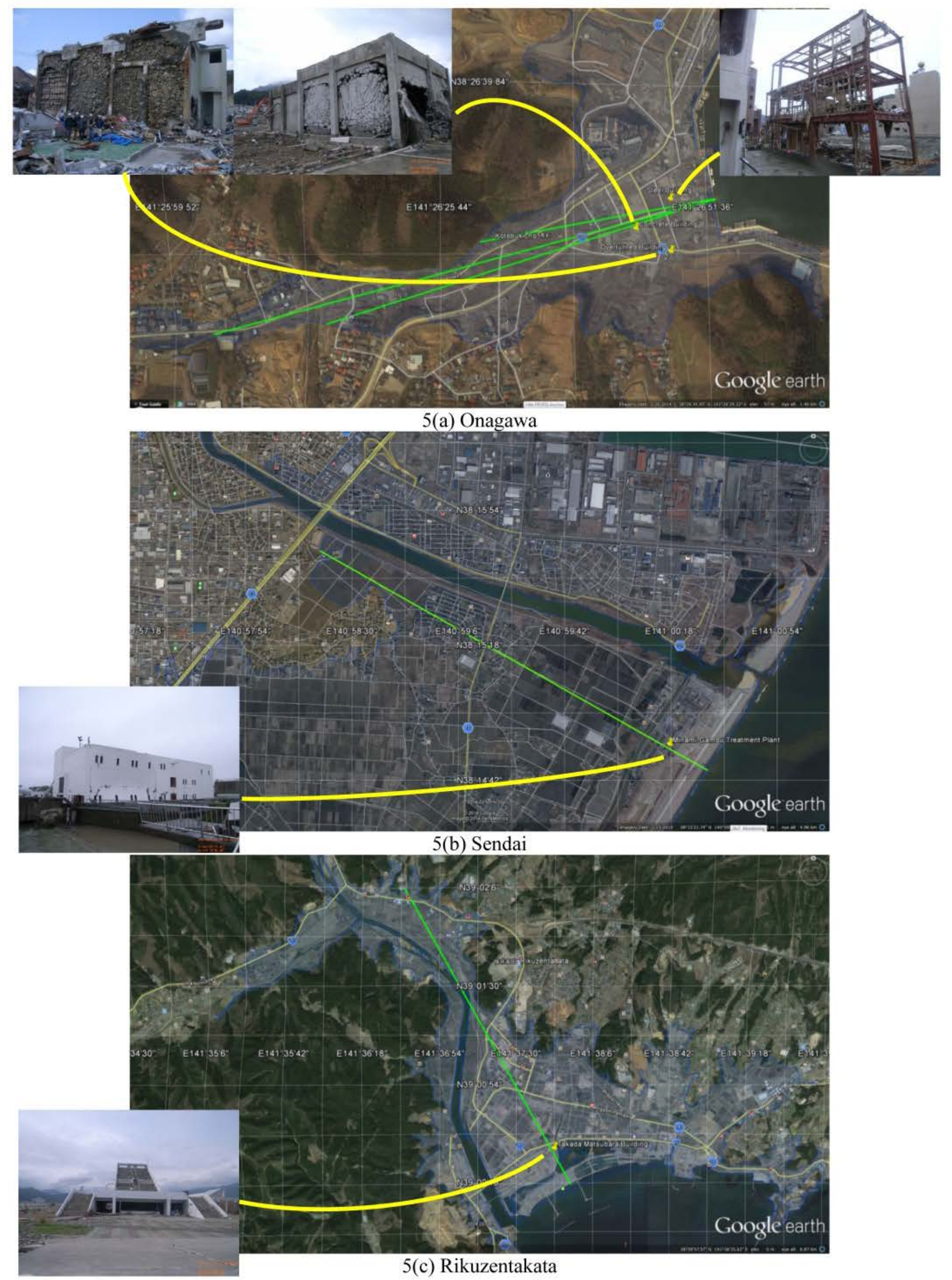
Pacific Northwest – Coastal Peninsulas

- Example of Energy Grade Line Analysis: Long Beach – Ocean Park, WA





Applying the Energy Grade Line Analysis to structures in Japan: Inundation zones, EGL transects, and coastal structures of interest at a) Onagawa, b) Sendai, c) Rikuzentakata



5(a) Onagawa

5(b) Sendai

5(c) Rikuzentakata

Summary of Flow Depths and Velocities from Energy Grade Lines

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Site	Distance from shoreline (m)	Calculated EGL		Estimated from Survey[1]	
		Flow Depth (m)	Flow Velocity (m/s)	Flow Depth (m)	Flow Velocity (m/s)
Onagawa					
Site 1 – Overturned Concrete Bldg.	150	16.2	11.8	19	7.4-8.2
Site 2 – Steel Residential Bldg.	120	16.2	12.0		
Site 3 – Concrete Warehouse	210	16.1	11.5		
Sendai					
Minami-Gamou Wastewater Treatment Bldg.	330	8.2	11.1	6.0	6.5 (bore)
Rikuzentakata					
Takada Matsubara building	420	15.6	11.7	10.5	7.25-7.75

Notes: 1. Derived from field observations, video and other analysis (Chock, 2013b)

Inundation Depth and Flow Velocity Based on Site-Specific Probabilistic Tsunami Hazard Analysis

- Can be run as a nonlinear time history inundation model analysis using Hazard Consistent Tsunami matching the defined probabilistic waveform
  - Offshore Tsunami Amplitude & effective Wave Period Relative amplitudes of crest and trough for each region
- Can be run as a complete probabilistic simulation from the seismic source slip event, calibrated to match the defined probabilistic Offshore Tsunami Amplitude
- In either case, time histories of site-specific flow parameters are generated.

Section 6.8.3.3 Load Combinations [Strength Design]

Principal Tsunami Forces and Effects shall be combined with other specified loads in accordance with the load combinations of Eq. 6.8.3.3-1:

$0.9D + \mathbf{F_{TSU}} + 1.0\ H_{TSU}$ (Eq. 6.8.3.3-1a)

$1.2D + \mathbf{F_{TSU}} + 0.5L + 0.2S + 1.0\ H_{TSU}$ (Eq. 6.3.3.3-1b)

where,

F_{TSU} =tsunami load effect for incoming and receding directions of flow

H_{TSU} = load due to tsunami-induced lateral foundation pressures developed under submerged conditions. Where the net effect of H_{TSU} counteracts the principal load effect, the load factor for H_{TSU} shall be 0.9.

Tsunami Loads and Effects

- Hydrostatic Forces (equations of the form $k_s \rho_{sw} gh$)
  - Unbalanced Lateral Forces at initial flooding
  - Buoyant Uplift based on displaced volume
  - Residual Water Surcharge Loads on Elevated Floors
- Hydrodynamc Forces (equations of the form $\frac{1}{2} k_s \rho_{sw} (hu^2)$)
  - Drag Forces – per drag coefficient C_d based on size and element
  - Lateral Impulsive Forces of Tsunami Bores or Broad Walls: Factor of 1.5
  - Hydrodynamic Pressurization by Stagnated Flow – per Benoulli
  - Shock pressure effect of entrapped bore – (this is a special case)
- Waterborne Debris Impact Forces (flow speed and √mass)
  - Poles, passenger vehicles, medium boulders always applied
  - Shipping containers, boats if structure is in proximity to hazard zone
  - Extraordinary impacts of ships only where in proximity to Risk Category III & IV structures
- Scour Effects (mostly prescriptive based on flow depth)

Hydrodynamic Loads

- Formulations for detailed calculations on the building and for loads on components
  - Typically of the standard form drag (h- inundation depth and u – flow velocity for each load case)
  - Adjustments for perforated and angled walls

$$f_{dx} = \frac{1}{2}\rho_s C_d C_{cx} B\left(hu^2\right)$$

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Types of Floating Debris
Logs and Shipping Containers

Boats,
Ferries,
Ships

Power poles and tree trunks become floating logs

Shipping containers float even when fully loaded

Debris Impact Loads

- Waterborne Debris Loads
  - Utility poles/logs
  - Passenger vehicles
  - Tumbling boulders and concrete masses
  - Shipping containers only where near ports and harbors
  - Large vessels considered for Critical Facilities and Risk Category IV only where near such ports and harbors
- Can be considered a DUCTILITY-GOVERNED ACTION: Any action on a structural component characterized by post-elastic force versus deformation curve that has 1) sufficient ductility and 2) results from an impulsive short-term force that is not sustained

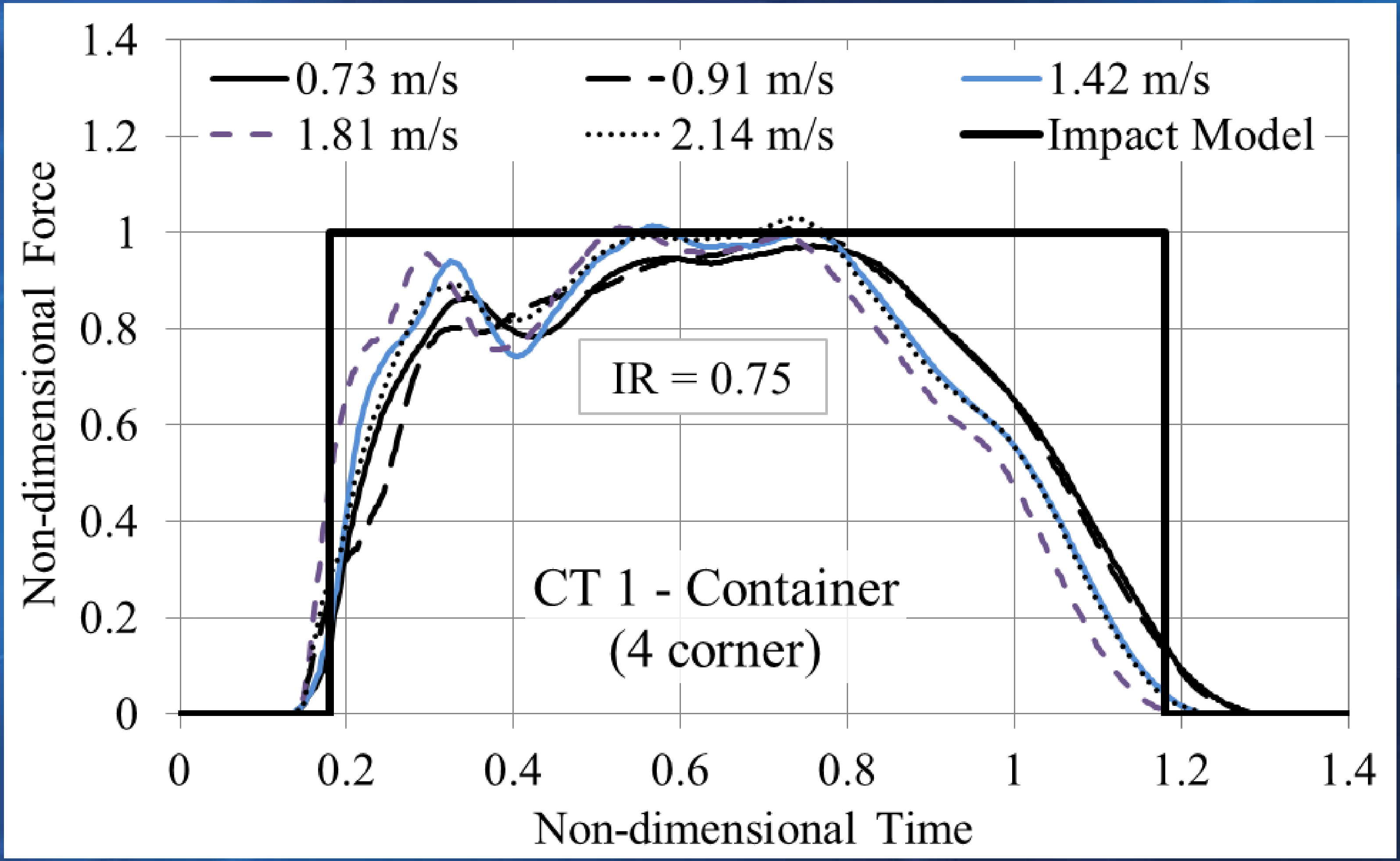
Conditions for which Design for Debris Impact are Evaluated

Debris	Buildings and Other Structures	Threshold Inundation depth
Poles, logs, passenger vehicles	All	3 ft (0.91 m)
Boulders and Concrete Debris	All	6 ft (1.8 m)
Shipping Containers	All	3 ft (0.91 m)
Ships and/or barges	Tsunami Risk Category III Critical Facilities and Category IV	12 ft (3.6 m)

Shipping Container Impact

Video

Impact Force Time History
(think about using SBEDS for impulsive load analysis)



Debris Impact Force

- Nominal maximum impact force

$$F_{ni} = u_{\max}\sqrt{km_d}$$

- Design force based on the importance factor and an orientation factor

$$\boldsymbol{F_i = I_{TSU} C_o F_{ni}}$$

- Impact duration

$$t_d = \frac{2m_d u_{\max}}{F_{ni}}$$

  - Typical durations are about 5 milli-sec
- Dynamic force capped based on yielding or crushing strength of debris (about 140k for shipping containers, 110 kips for logs and poles)

Site Hazard Assessment for Shipping Containers and Boats or Ships

- Point source of debris
  - Shipping container yards
  - Ports with barges/ships

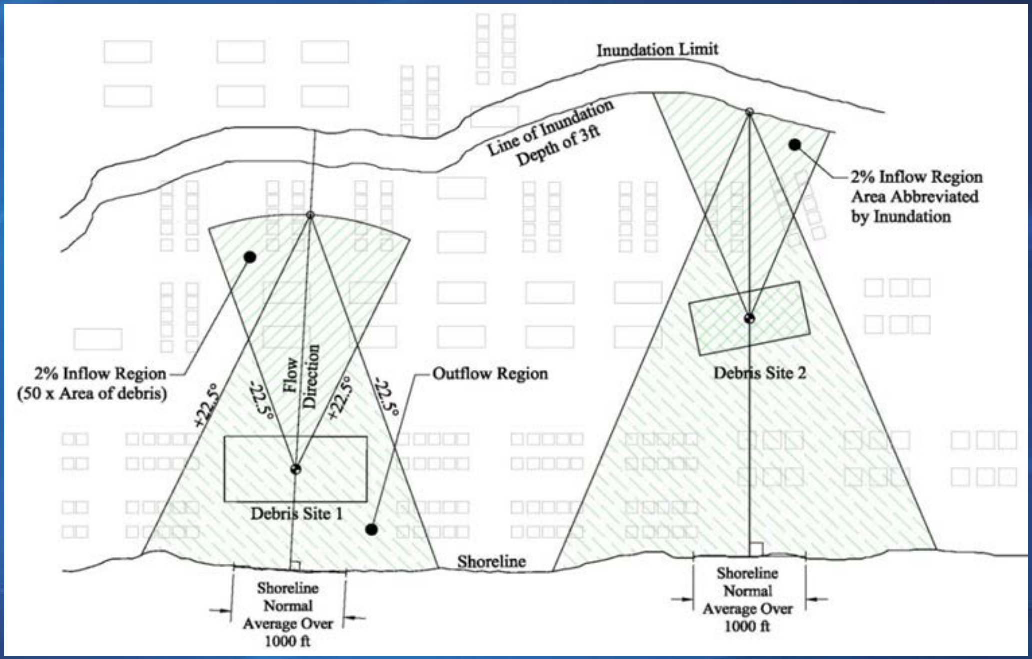
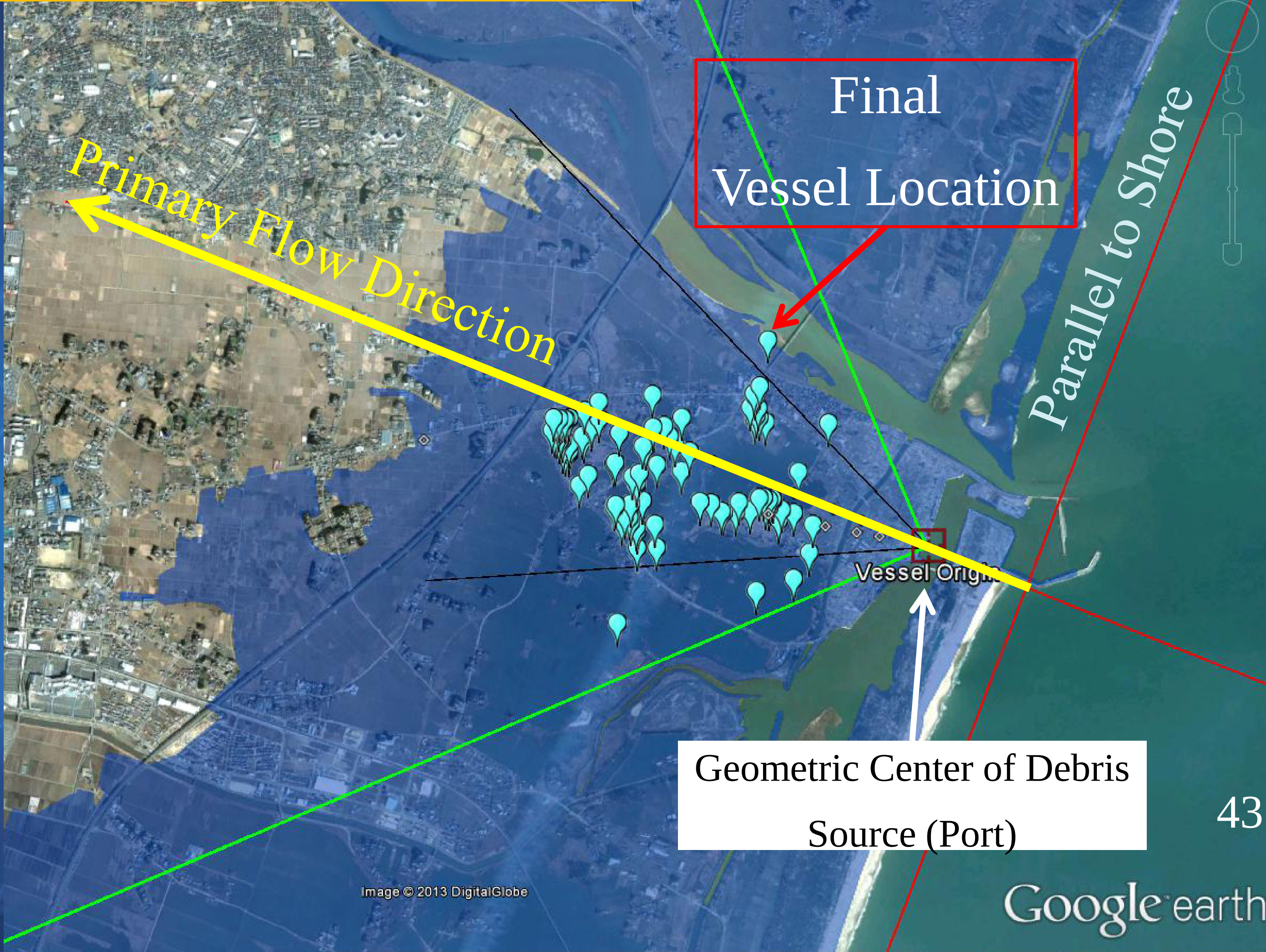


Figure 6.11-1

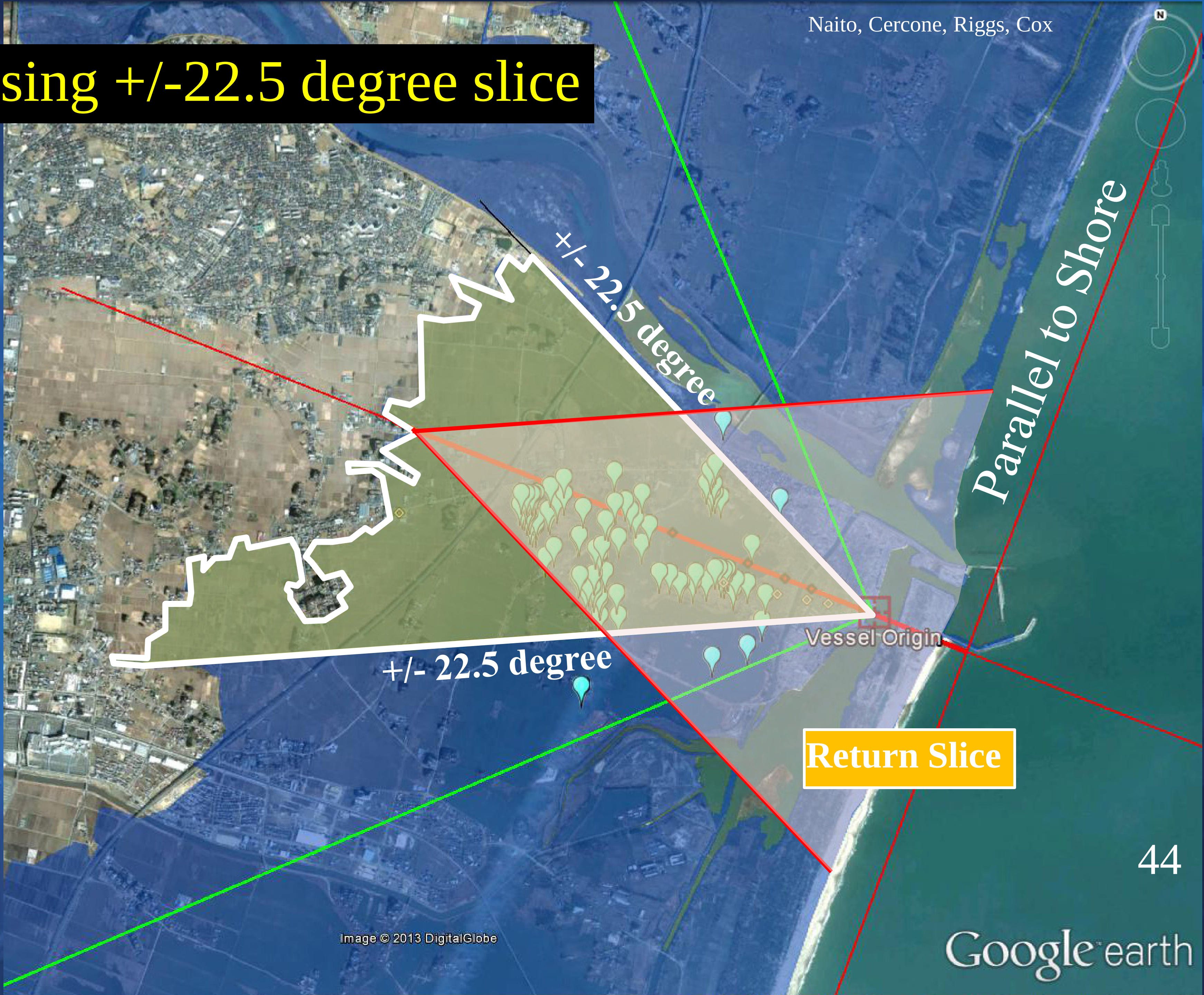
- Approximate probabilistic site assessment procedure based on proximity and amount of potential floating objects
  - Determine potential debris plan area
    - Number of containers * area of a container
  - Determine concentration: area of debris/land area
  - 2% concentration defines debris dispersion zone

Natori, Japan (Vessels)

Naito, Cercone, Riggs, Cox, 2013



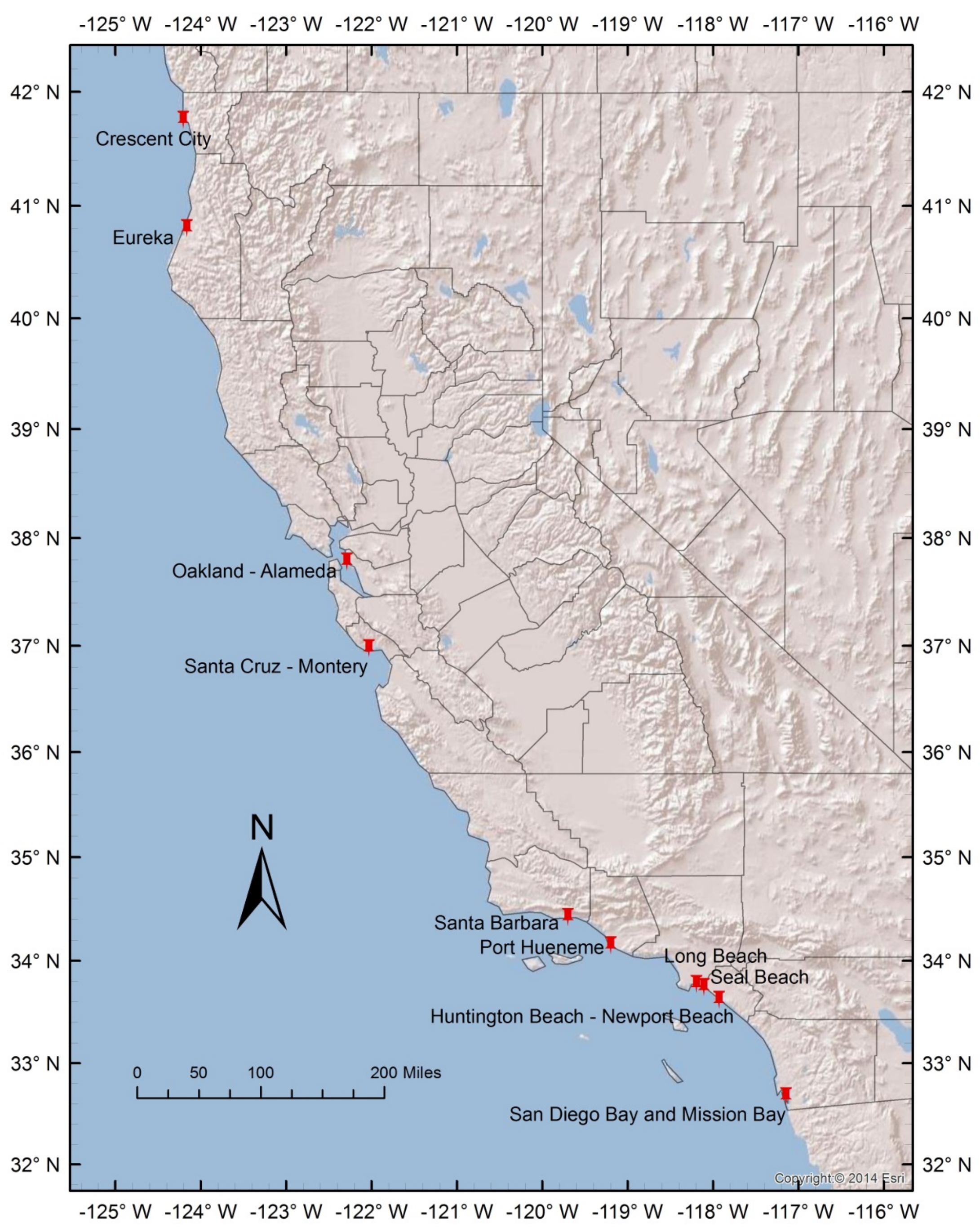
Using +/-22.5 degree slice



Tsunami Design

- Overall Lateral Force Resisting System
  - Drag on entire structure
  - Closure coefficient based on projected area of all structural elements below flow level, but not less than 0.7
  - For SDC D, if $V_{Tsu} \leq 0.75\Omega_o E_h$, then system okay

Region-California	Typical Offshore Tsunami Amplitude	Typical Inundation Depth in the coastal shoreline area	Seismic Hazard Ss (g)	Typical min. threshold height* for RC II Bldg's
Crescent City	22-25 ft	**19 ft**	1.42	**35 ft**
Eureka	13-18 ft	**14 ft.**	3.12	**30 ft**
Oakland-Alameda (within SF Bay)	10-12 ft. (offshore of bay mouth)	**Less than 3 ft.**	1.68	**Exempt from tsunami design**
Santa Cruz-Monterrey	9-12 ft.	**14 ft.**	1.50	**30 ft.**
Port Hueneme - Santa Barbara	7 – 9 ft.	**5 ft**	2.0	**25 ft**
Long Beach - Seal Beach	6 ft.	**8 ft.**	1.61	**25 ft**
Huntington Beach – Newport Beach	6 ft.	**8 ft.**	1.61	**25 ft**
San Diego Bay and Mission Bay	6 ft	**Less than 3 ft.**	1.23	**Exempt from tsunami design**



Buoyancy

- At an exterior inundation depth not exceeding the maximum inundation depth nor the lesser of one-story or the height of the top of the first story windows, evaluate uplift conditions.
- Buoyancy shall also include the effect of air trapped below floors. All windows, except those designed for large missile wind-borne debris impact or blast loading, shall be permitted to be considered openings when the inundation depth reaches the top of the windows or the expected strength of the glazing, whichever is less.
  - Exception: **Load Case 1 need not be applied to Open Structures nor to structures where the soil properties or foundation and structural design prevents detrimental hydrostatic pressurization on the underside of the foundation and lowest structural slab.**

Hydrodynamic Loads

- Formulations for detailed calculations on the building and for loads on components
  - Typically of the standard form drag (h- inundation depth and u – flow velocity for each load case)

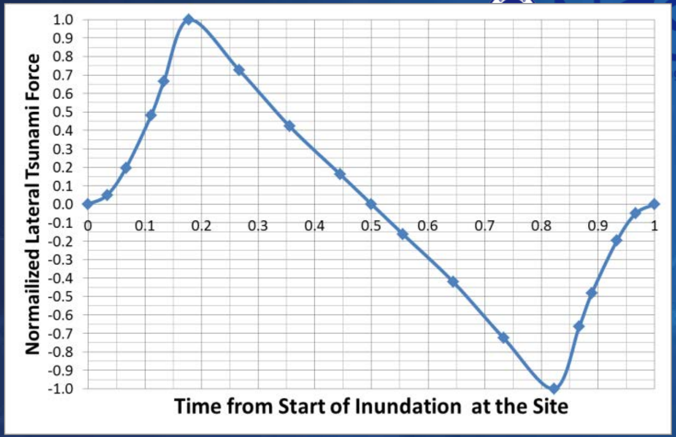
$$f_{dx} = \frac{1}{2}\rho_s C_d C_{cx} B\left(hu^2\right)$$

  - Adjustments for perforated and angled walls

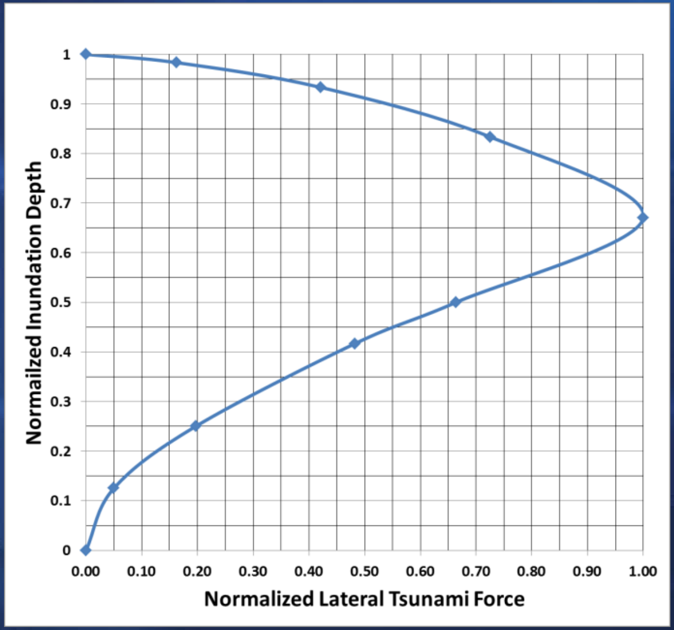
Tsunami Loading Curves

- Maximum lateral tsunami hydrodynamic force on the structures occurring when the inundation depth is 2/3 of the maximum inundation depth.

- The tsunami inundation depth vs. tsunami force curve is useful for comparisons with seismic sustainable inelastic strength of the lateral-force-resisting system, which also varies with the height of the structure.

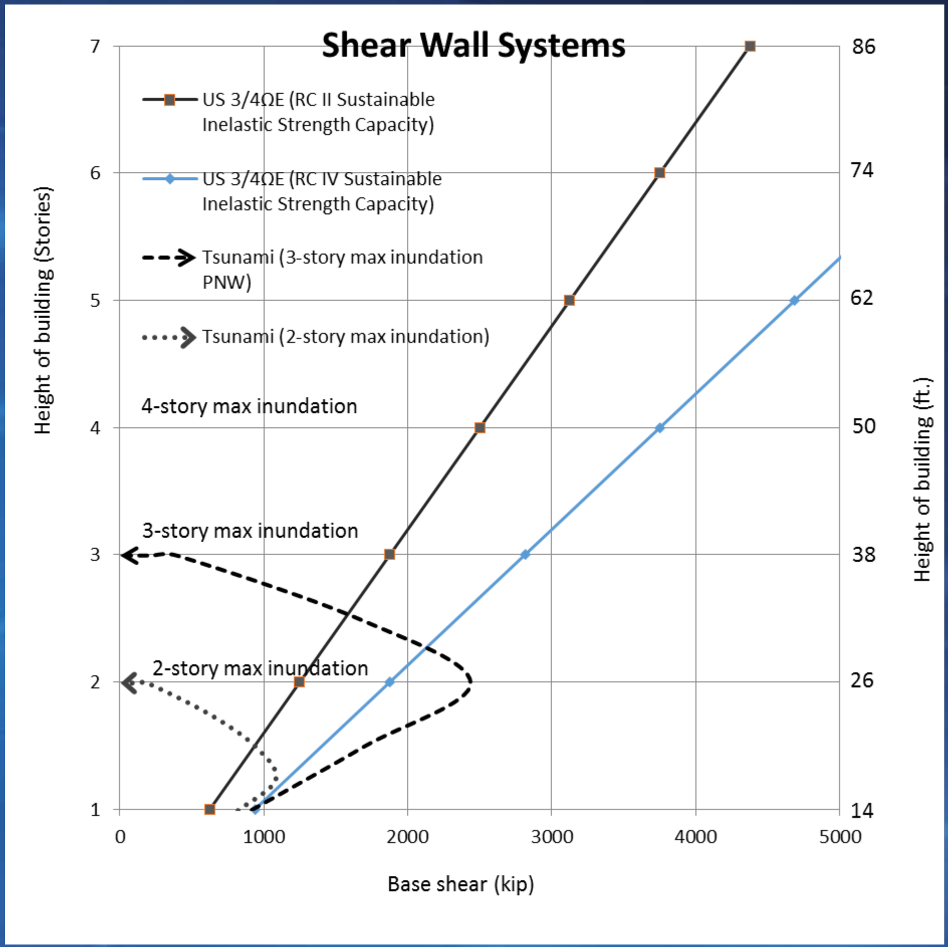


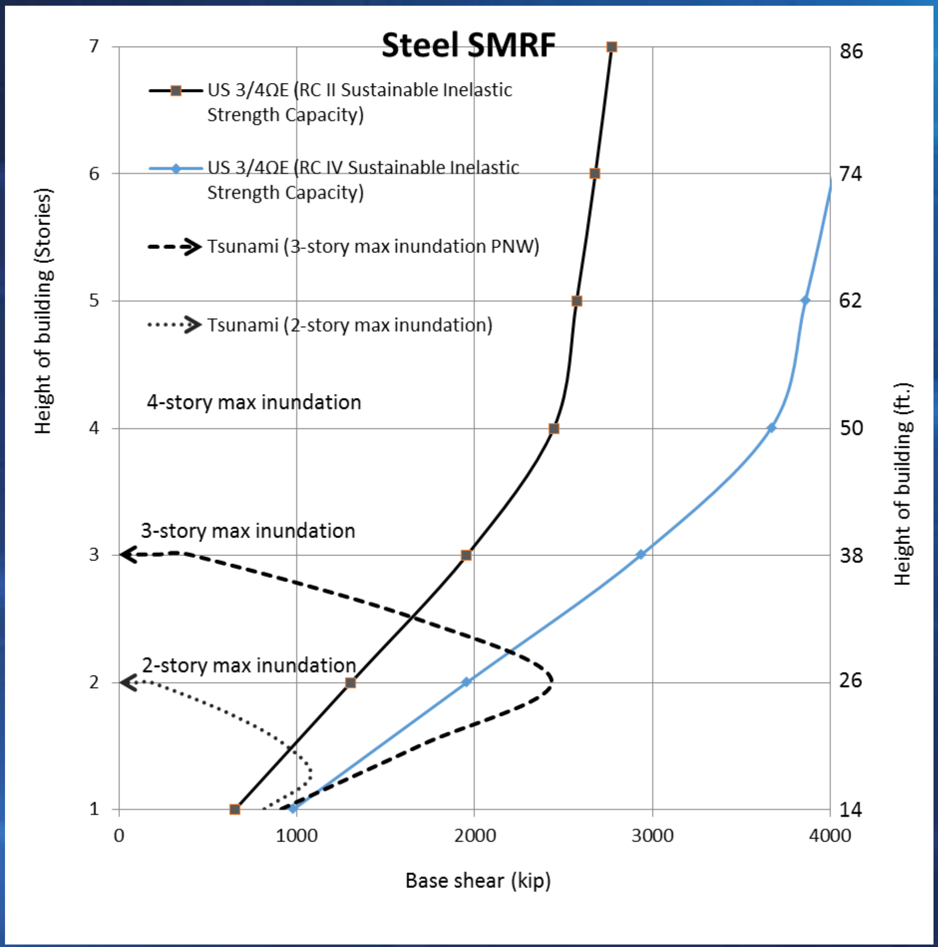
Tsunami Force vs. Time



Inundation Depth vs. Tsunami Force

Example of Comparing Lateral Resistance of a Minimum High-Seismic RC II Designed System @ 0.75Ω Overstrength to Maximum Tsunami Loading





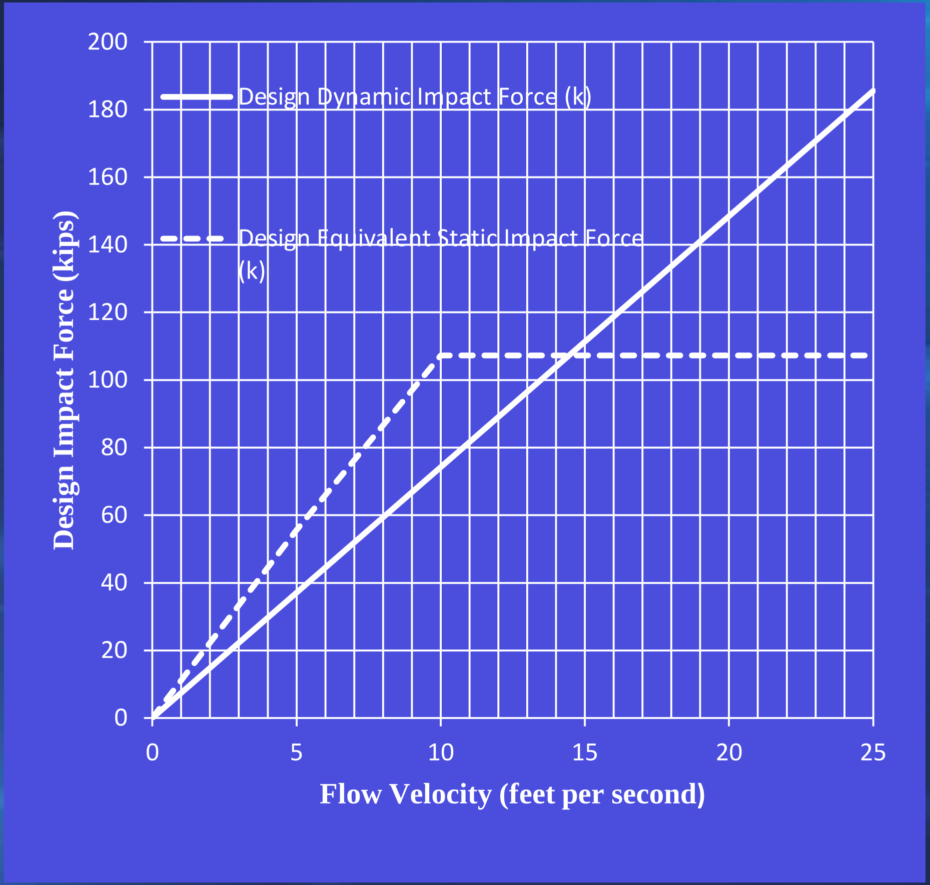
- The conditions shown above are for the more severe inundation cases in the Pacific Northwest (Up to 3 story deep inundation - Pacific coast only).

Tsunami Design

- Component Design
  - Exterior Columns and Shear Walls
    - Hydrodynamic drag including effects of debris damming ($C_{cx} = 0.7$)
    - Debris Impact including orientation factor ($C_o = 0.65$)
  - Interior Columns and Shear Walls
    - Hydrodynamic drag *without* debris damming (therefore, interior shear walls are favorable)
    - No debris impact loads

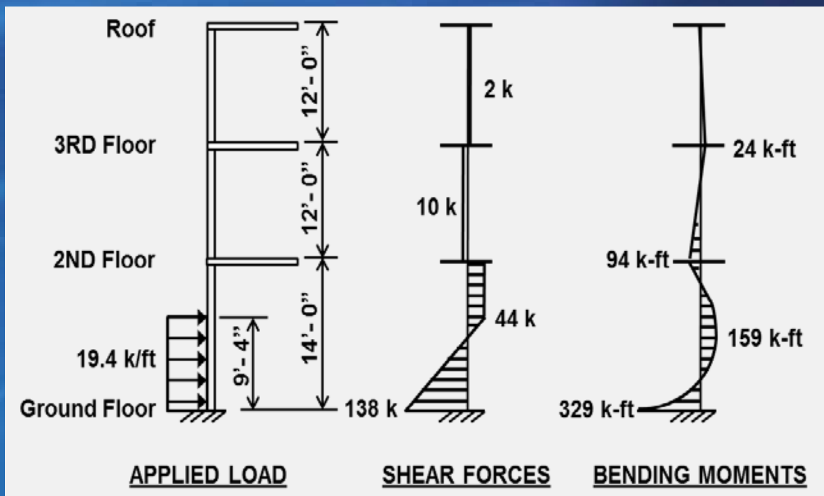
Tsunami Design of Components

- Vertical Component Design
  - Exterior Columns and Shear Walls
    - Hydrodynamic drag including effects of debris damming
    - Debris Impact including orientation factor
  - Interior Columns and Shear Walls
    - Hydrodynamic drag *without* debris damming (therefore, interior shear walls are favorable)
    - No debris impact loads

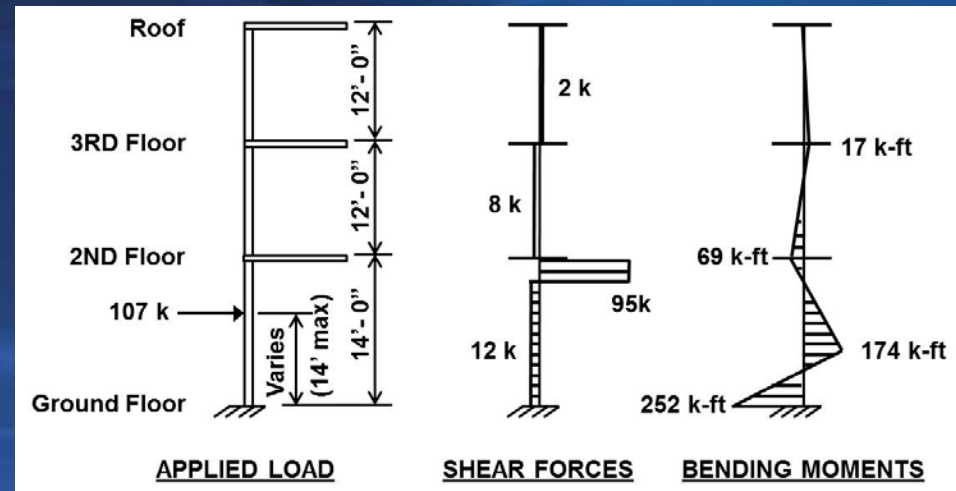


Monterey: Typical Exterior Column Design (3-stories)

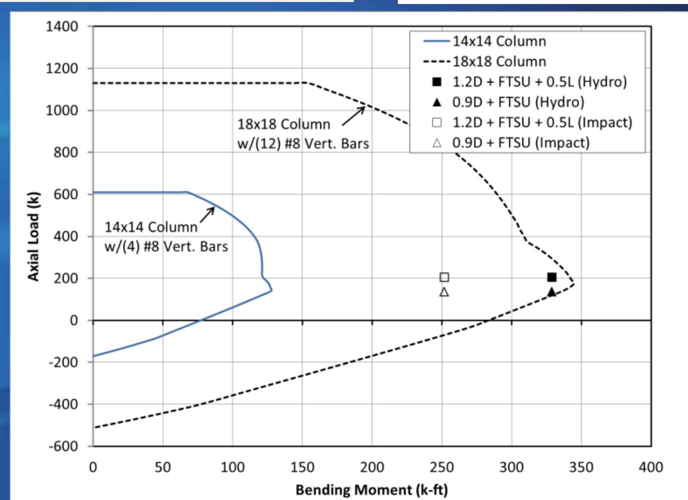
- Hydrodynamic Pressure



- Debris Impact (simplified)



Reinforced Concrete Minimum Gravity-Load Column increases from 14" Sq. to 18" Sq.



Structural Steel Minimum Gravity Load Column W14 x 61 section is upgraded to a W14 x 68 section

Monterey – Reinforced Concrete Buildings

Building	LFRS	Site Class	Conc. Vol. Increase (%)	Reinf. Wt. Increase (%)
Office	SMRF (Exterior)	D	0	0
Office	SMRF (Exterior)	B	0	0
Residential	Sp. Shear Wall	D	0.1	~5
Residential	Sp. Shear Wall	B	0.1	~7

Monterey – Structural Steel Buildings

Building	LFRS	Site Class	Str. Steel Material Increase (%)
Office	SMRF (Exterior)	D	0
Office	EBF	D	<0.5%
Residential	EBF	D	<1%

Foundation Design

- Under-seepage Forces
- Loss of Strength
- Erosion
- Local Scour
- Plunging Scour (i.e., overtopping a wall)

- Design solutions involve scour protection or perimeter deep foundations

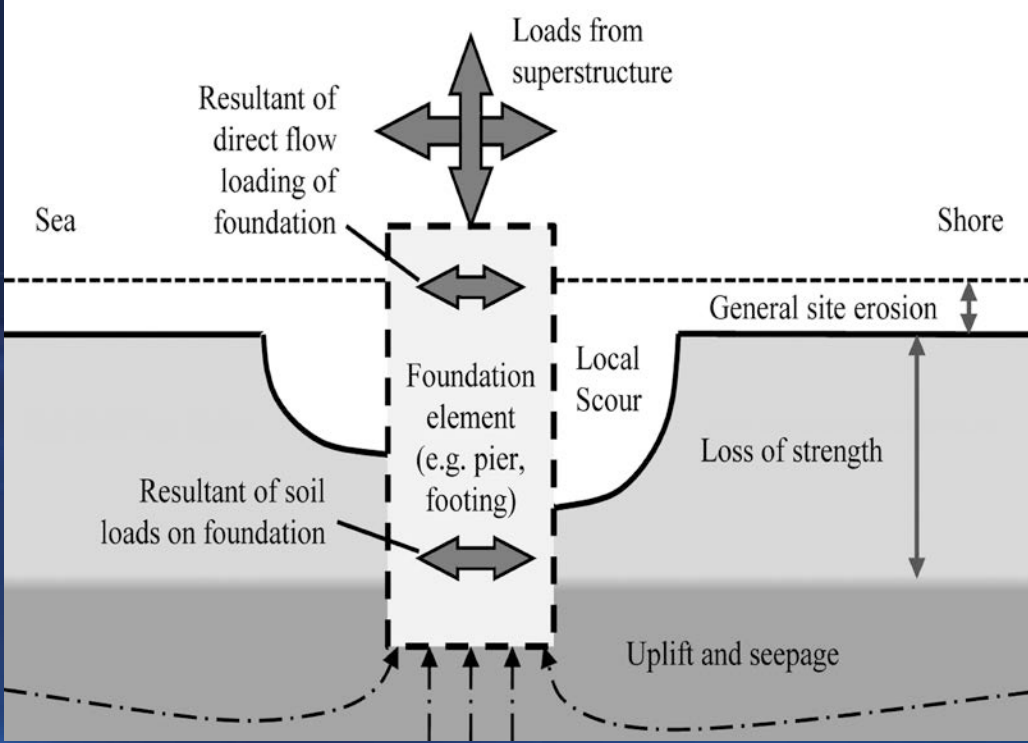


Figure C6.12-1. Schematic of tsunami loading condition for a foundation element

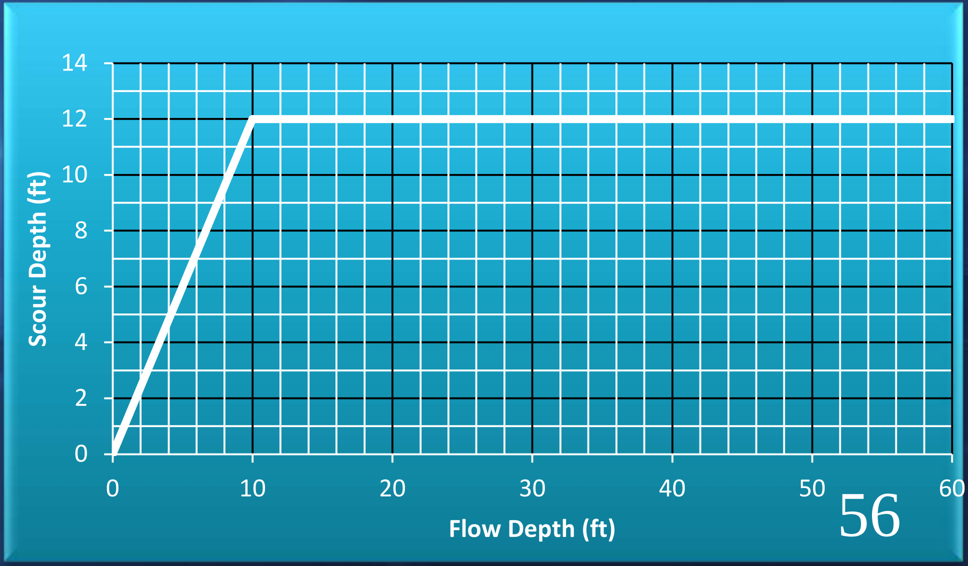
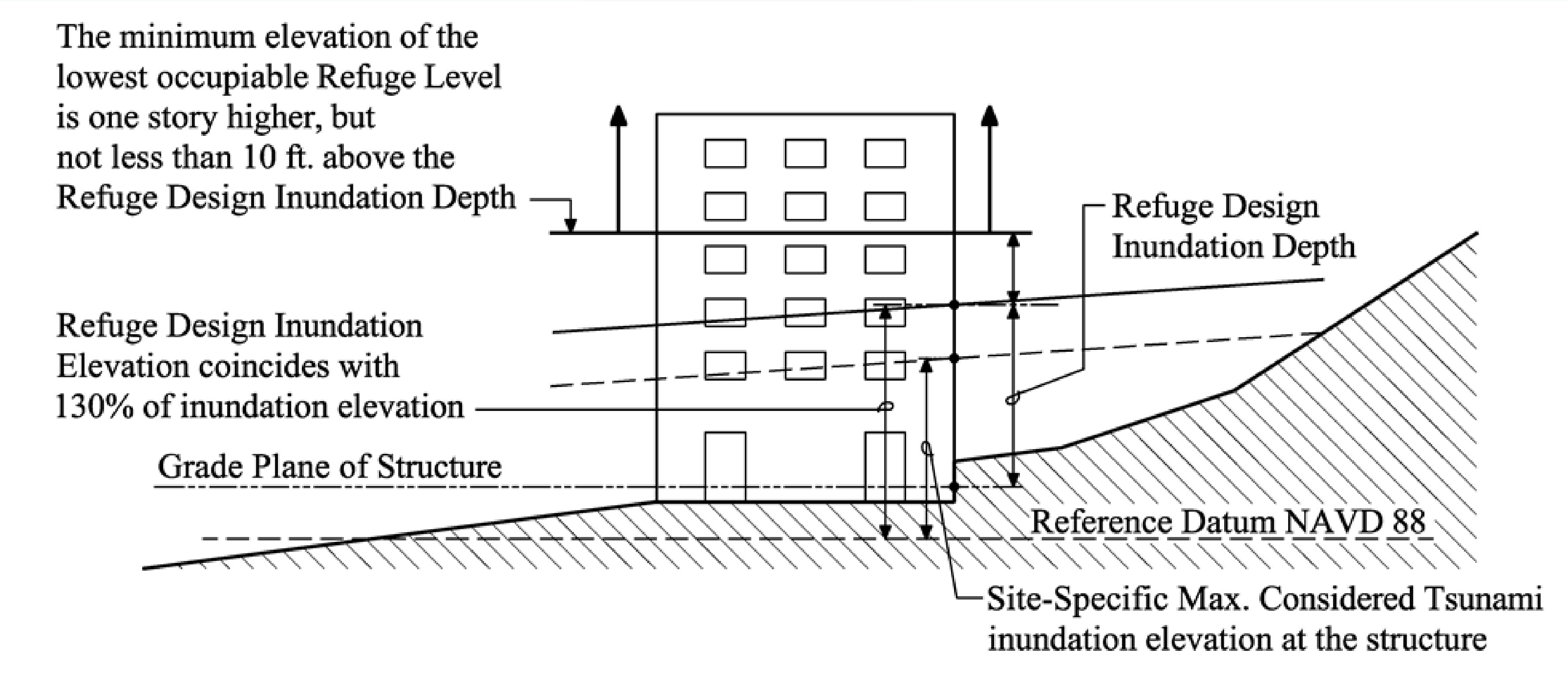


Figure 6.12-1 Local Scour Depth due to Sustained Flow and Pore Pressure Softening

Tsunami Vertical Evacuation Refuge Structures

- Tsunami Vertical Evacuation Refuge Structures - ASCE 7 Chapter 6 is intended to supersede both FEMA P646 structural guidelines and IBC Appendix M

Figure 6.14-1. Minimum Refuge Elevation



Sections 6.15 and 6.16

- Section 6.15 Designated Nonstructural Systems
  - *These are defined in the seismic provisions for high importance systems in high importance structures*
  - Options are
    - Protection
    - Position
- Section 6.16 Non-Building Structures
  - Risk Category III and IV
  - Options are
    - Protection
    - Position
    - Strength

DESIGNATED NONSTRUCTURAL COMPONENTS AND SYSTEMS: Nonstructural components and systems per Section 13.1.3 of this Standard [Risk Category IV structures, those containing or conveying hazardous materials].

CRITICAL EQUIPMENT AND SYSTEMS: Nonstructural components designated essential for the functionality of the critical facility or essential facility, or are necessary to maintain safe containment of hazardous materials.

Reliability Analysis of Structures Designed in Accordance with ASCE 7 Tsunami Chapter Hydrodynamic Forces

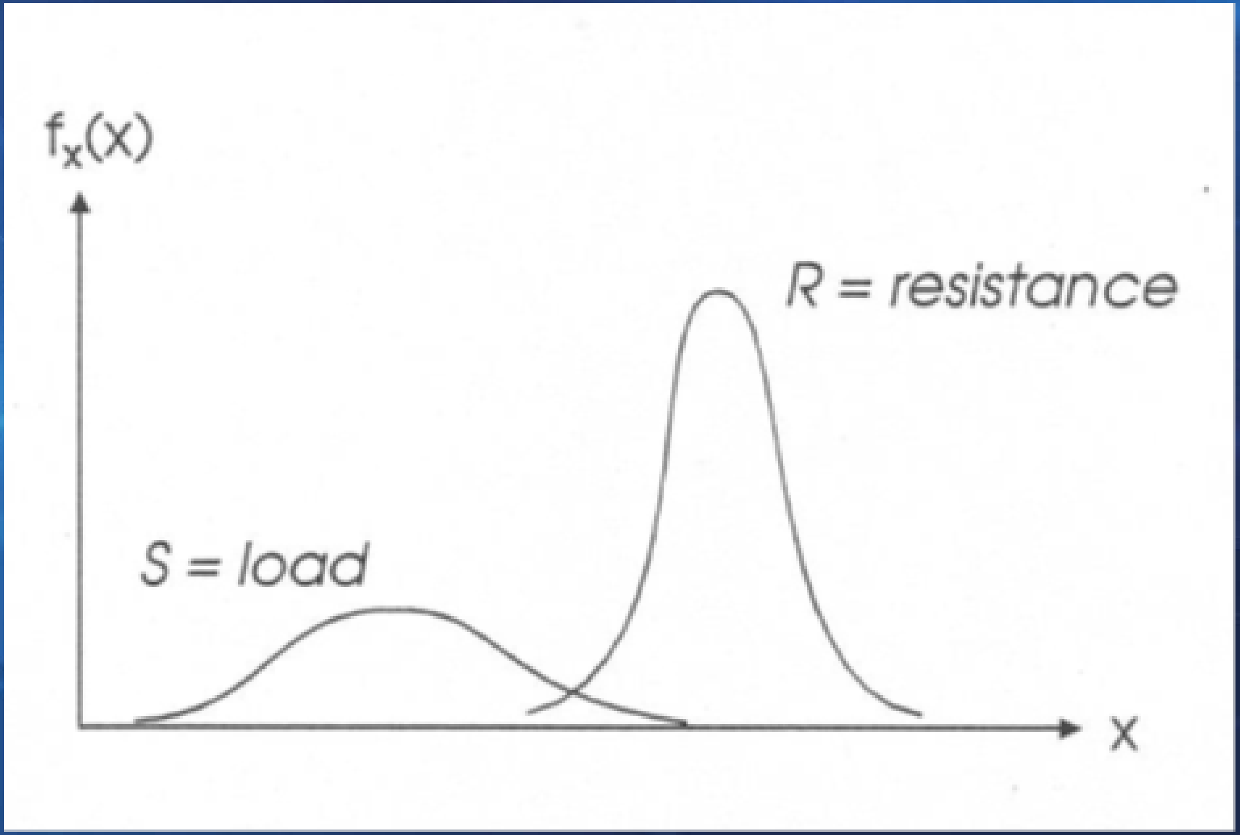
- Probabilistic limit state reliabilities have been computed for representative structural components carrying gravity and tsunami loads, utilizing statistical information on the key hydrodynamic loading parameters and resistance models with specified tsunami load combination factors.
- Through a parametric analysis performed using Monte Carlo simulation, anticipated reliabilities for tsunami hydrodynamic loads meet the general intent of the ASCE 7 Standard.
- Factors for tsunami design were verified for consistency with the target reliabilities for extraordinary loads (such as earthquakes).

Basics of Reliability Analysis

NCSEA
National Council of Structural Engineers Associations

- **Limit State (LS) equation for $Z = R - S < 0$**
- **$P[LS] = P[R - S < 0] = Pf \leftrightarrow \mu_{R\text{-}S} - \beta\, \sigma_{R\text{-}S} \geq 0$**
- μ, σ = mean, standard deviation of [Resistance (design requirements)-S (load)]
- β = reliability index ~ $\Phi^{-1}(1 - P_F)$

Chock, G., Yu, G., Thio, H.K., and Lynett, P. (2016 in publication). "Target Structural Reliability Analysis for Tsunami Hydrodynamic Loads of the ASCE 7 Standard", *Journal of Structural Engineering*, ASCE, Reston, VA.



Summary of Target Reliabilities of the ASCE 7 Tsunami Design Provisions

NCSEA
National Council of Structural Engineers Associations

		Tsunami Risk Category II I = 1.0	Tsunami Risk Category III I = 1.25	Tsunami Risk Category IV I = 1.25	Tsunami Vertical Evacuation Refuge RC IV I = 1.25 & 1.3h_n
Average Reliabilities	Reliability index, β	2.74	2.87	3.03	3.68
	$P_{f\ 50\text{-year}}$	0.31%	0.21%	0.13%	0.05%
Component Failure, conditional given the MCT	Reliability index, β	1.44	1.65	1.92	2.43
	Probability of failure	7.5%	5%	3%	<1%

- The conditional vertical load-carrying <u>component</u> reliabilities for the Maximum Considered Tsunami (MCT) are nearly equivalent to those expected for seismic systemic pushover (MCE) effects. The long-term 50-year reliabilities for RC II structure components are better for tsunami.

Anticipated reliabilities (maximum probability of failure*) for earthquake and tsunami

Risk Category	Probability of failure* in 50-yrs		Failure* probability conditioned on Maximum Considered event	
	Earthquake	Tsunami	Earthquake (MCE)	Tsunami (MCT)
II	1%	0.3%	10%	7%
III	0.5%	0.2%	5-6%	4-5%
IV	0.3%	0.1%	2.5-3%	2.5-3%
Vertical Evacuation Refuge Structures	0.3%	<0.1%	2.5-3%	0.5 - 1%

Tsunami probabilities are based on exceeding an exterior structural component's capacity that does not necessarily lead to widespread progression of damage, but the seismic probabilities are for the more severe occurrence of partial or total systemic collapse.

Summary of ASCE 7 Tsunami

- PTHA-based design criteria - The method of Probabilistic Tsunami Hazard Analysis is consistent with probabilistic seismic hazard analysis in the treatment of uncertainty.
- Maximum Considered Tsunami – 2500-year MRI
- The tsunami design provisions utilize probabilistic Offshore Tsunami Amplitude maps and Tsunami Design Zone inundation maps
- Procedures for tsunami inundation mapping are based on using these probabilistic values of Offshore Tsunami Amplitude
- Hydraulic analysis or site-specific inundation analysis to determine site design flow conditions: velocity, depth for at least three critical loading stages
- Fluid loads, debris loads, foundation demands

Summary (1 of 3)

- The primary structural risk to tsunami hazard is for the gravity-load-carrying exterior structural members that are not a part of the lateral-force-resisting system.
- Enhanced resistance of these exterior gravity-load-carrying structural members such as columns and walls within the inundation depth may be required

Summary (2 of 3)

NCSEA
National Council of Structural Engineers Associations

- Coastal communities and cities are encouraged to require tsunami design for RC II buildings and structures exceeding an appropriate mean height, in order to provide a greater number of taller buildings that will be life-safe and disaster-resilient.
- This is especially true for areas where horizontal egress inland to safe ground takes longer than the travel time of the Maximum Considered Tsunami. There is great uncertainty in predicting the actual evacuation clearing time.

Summary (3 of 3)

- Structural engineering expertise is necessary to evaluate several important technical factors relevant to the jurisdiction’s decision to establish a threshold height of applicability for Risk Category II buildings and structures.
- The criteria could also be a combination of threshold height and occupancy classification.

Questions?

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