ASCE 7-16 Tsunami: The new resiliency approach and design provisions

kpff Engineering Opportunities

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About the Speaker

- Structural Engineer at KPFF
- Licensed Professional & Structural Engineer
- Member of ASCE 7 Tsunami, Flood, Seismic and Main committees
- Member of ASCE 41 Committee
- Current Past President of SEAO
- Current SEAO Delegate to NCSEA

How to Design for Tsunami: The New ASCE 7-16 Tsunami Provisions and Project Examples *2019 SEA-NW Conference, Salishan Resort*

Outline

- Tsunami Background
- Tohoku Tsunami Lessons
- ASCE 7-16 Tsunami Loads and Effects
  - Scope of Chapter 6
  - Probabilistic Tsunami Design Maps
  - ASCE 7-16 Tsunami Geodatabase
  - Site flow parameters
  - Design Load Cases
  - Structural Loading
- Project Examples

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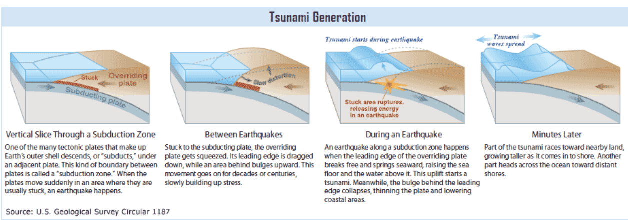
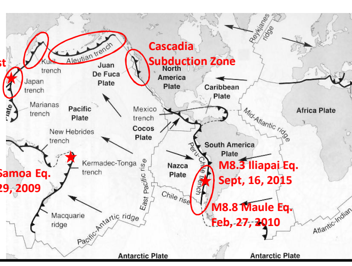
Tsunami Generation



Tsunami-genic Seismic Sources of Relevance to the USA



Subduction Zones
Cascadia
Alaska-Aleutian
Kamchatka-Kuril Trench
Japan Trench
Peru-Chile

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.

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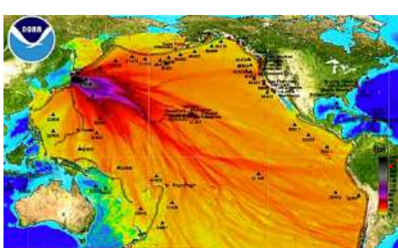
Tohoku Tsunami – March 11, 2011



OFFSHORE WAVE HEIGHTS

240cm (~7.9ft)

GRAPHIC GENERATED BY NOAA

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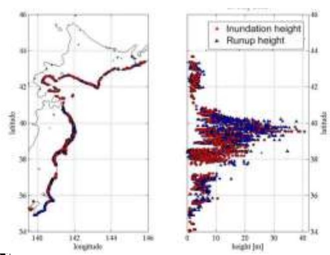
Peak Water Level Measurements



- Tsunami Inundation and Runup
- Typical inundation depth from 10m to 20m (~30-65ft)
- Maximum runup of 38m and 40m

From: The 2011 Tohoku Earthquake Tsunami Joint Survey Group http://www.coastal.jp/ttjt/

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Evacuation to high ground: Kamaishi Example

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Designated evacuation building: Kamaishi

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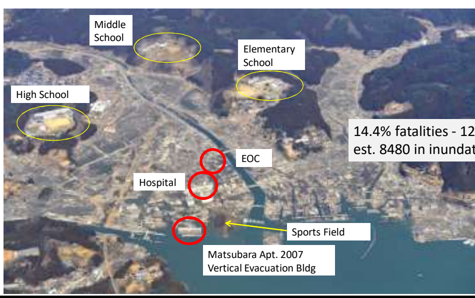
Warning and Evacuation: Minamisanriku



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Effective Vertical Evacuation Matsubara Community Apt. Bldg. – (Built 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

Concrete building survived tsunami, but roof evacuation area inundated by 0.7m water

44 refugees, including several children, survived on roof evacuation area

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Effective Vertical Evacuation - Matsubara Community Apt. Bldg. – (Built 2007)

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





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Varied Performance of Reinforced Concrete Buildings

Varied performance of neighboring concrete buildings in Minamisanriku

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Essential and Emergency Response Facilities in Harm's Way

Minamisanriku Emergency Operations Center

- Over 300 disaster responders killed
- Mayor Jin Sato, and 29 workers remained at center to provide live warnings during inundation

- 24 made it to the roof
- But only Sato and 8 others survived
- Tragic loss of lives at adjacent hospital


EOC and Hospital in Background at Minamisanriku

Hospital: RC building with seismic retrofit

- Hospital was occupied during the tsunami
- Some patients were moved to evacuation zone on roof
- Three full stories of patient drowning fatalities

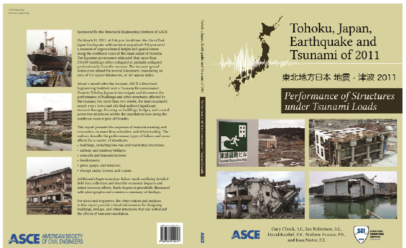
Inundation level

Many Evacuation Sites Inundated

- Over 120 Tsunami Evacuation Buildings/Sites Overtopped with High Fatality Rates

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.

東北地方津波 Tohoku Tsunami ASCE Report



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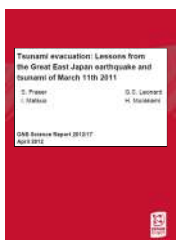
Report on Performance of Taller Structures in Japan used by Evacuees (whether Designated Refuges or Not)

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

Tsunami Safety provided by 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 centers and housing."

Tsunami Resilient Engineering Philosophy

- The lesson of recent devastating tsunami is that **historical records alone do not provide a sufficient measure of the potential heights of future tsunamis**. Engineering design must consider the occurrence of events greater than scenarios in the historical record.
- A Probabilistic physics-based Tsunami Hazard Analysis methodology was used for ASCE 7-16
- The ASCE 7-16 national tsunami design provisions utilizes a consistent reliability-based standard of structural performance for disaster resilience of essential facilities and critical infrastructure.

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ASCE 7-16 and Commentary

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ASCE 7-16 Format

Minimum Design Loads for Buildings and Other Structures

- Chap 1 & 2 – General and load combinations
- Chap 3 - Dead, soil and hydrostatic loads
- Chap 4 - Live loads
- Chap 5 - Flood loads (riverine and storm surge)
- Chap 6 – Tsunami Loads and Effects
- Chap 7 - Snow loads
- Chap 8 - Rain loads
- Chap 10 - Ice loads
- Chap 11 – 23 - Seismic Design
- Chap 26 – 31 - Wind Loads

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2018 IBC

- References ASCE 7-16 for structural loads.
- Tsunami Design will be required for all TRC III and TRC IV buildings in the Tsunami Design Zone.
- Local jurisdictions are strongly encouraged to require tsunami design for taller RC II buildings. This will provide additional locations as “refuge of last resort”.

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ASCE 7 Chapter 6: Tsunami Loads and Effects

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6.2-6.3 Definitions, Symbols and Notation
6.4 Tsunami Risk Categories
6.5 Analysis of Design Inundation Depth and Velocity
6.6 Inundation Depth and Flow Velocity Based on Runup
6.7 Inundation Depth and Flow Velocity Based on Site-Specific Probabilistic Tsunami Hazard Analysis
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MCT and Tsunami Design Zone

- The ASCE 7 Tsunami Loads and Effects Chapter is applicable only to the states of Alaska, Washington, Oregon, California, and Hawaii, which are tsunami-prone regions that have quantifiable hazards.
- 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.

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

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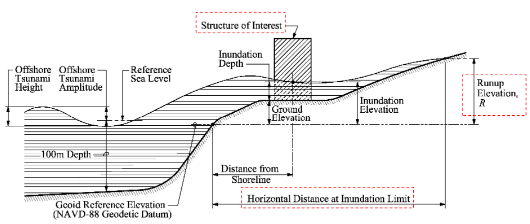
Terminology



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ASCE Tsunami-Resilient Design Process

- Select a site appropriate and necessary for the structure
- Select an appropriate structural system mindful of configuration and perform seismic and wind design first
- Determine the maximum flow depth and velocities at the site based on mapped Runup based on probabilistic tsunami hazard analysis.
- Check robustness of expected overall structural system strength within the inundation height to resist hydrostatic and hydrodynamic forces
- Check resistance of lower level elements for hydrodynamic pressures and debris impacts to avoid progressive collapse
- Design foundations to resist scour and potential uplift
- Elevate critical equipment as necessary

Consequence Guidance on RC of Buildings Per ASCE 7

Risk Category I	**Up to 2 persons affected** (e.g., agricultural and minor storage facilities, etc.)
Risk Category II (Tsunami Design Optional)	**Approximately 3 to 300 persons affected** (e.g., Office buildings, condominiums, hotels, etc.)
Risk Category III (Tsunami Design Required)	**Approximately 300 to 5,000+ affected** (e.g., Public assembly halls, arenas, high occupancy educational facilities, public utility facilities, etc.)
Risk Category IV (Tsunami Design Required)	**Over 5,000 persons affected** (e.g., hospitals and emergency shelters, emergency operations centers, first responder facilities, air traffic control, toxic material storage, etc.)

Scope of Chapter 6

The following buildings and other structures located within the Tsunami Design Zone shall be designed for the effects of the Maximum Considered Tsunami …. :

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

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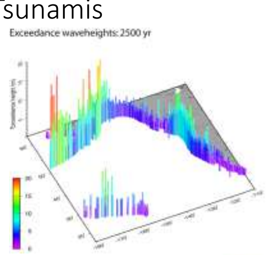
Definition of Tsunami Design Zone

- ASCE's Definition of the Tsunami Design Zone Maps:
  - The maps designating the potential horizontal inundation limit of the Maximum Considered Tsunami, or a state or local jurisdiction's probabilistic map produced in accordance with Section 6.7 of ASCE7-16 provisions.
- ASCE's Definition of Maximum Considered Tsunami:
  - A probabilistic tsunami given a 2% probability of being exceeded in a 50-year period or a 2,475-year mean recurrence interval.

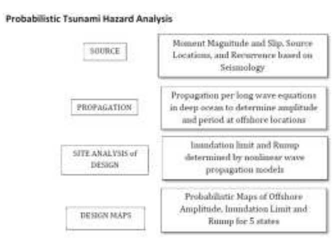
Tsunami Design Zone: Lessons from the Tohoku, Chile, and Sumatra Tsunamis

- 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



PTHA derived Max. Considered Tsunami

- The ASCE PTHA was performed by Hong Kie Thio of AECOM.
- Subduction Zone Earthquake Sources are consistent with USGS Probabilistic Seismic Hazard model.



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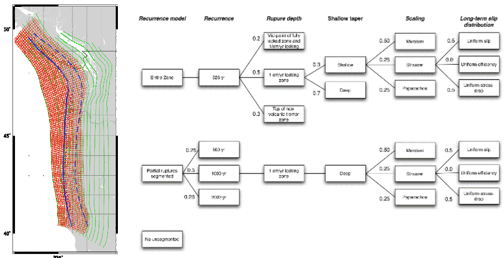
USGS Logic Tree for Cascadia adapted for Tsunamis



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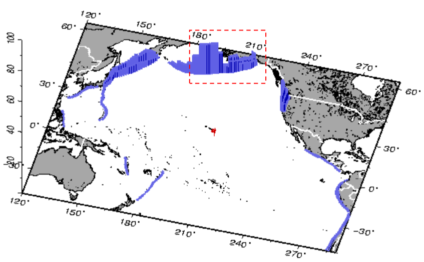
Disaggregated Tsunami Hazard for Hilo, HI



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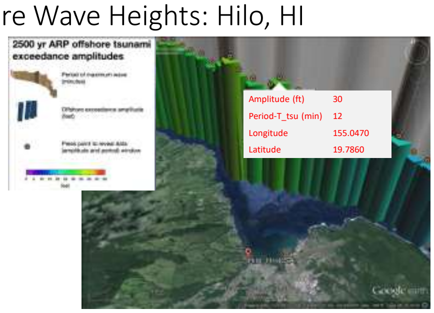
Offshore Wave Heights: Hilo, HI



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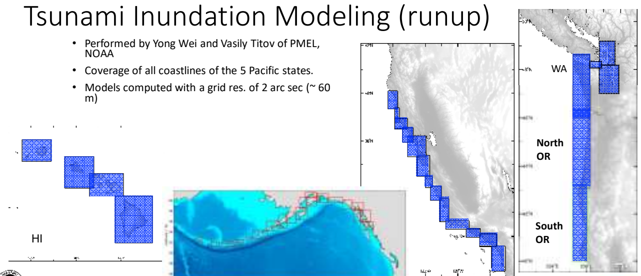
Tsunami Inundation Modeling (runup)

- Performed by Yong Wei and Vasily Titov of PMEL, NOAA
- Coverage of all coastlines of the 5 Pacific states.
- Models computed with a grid res. of 2 arc sec (~ 60 m)



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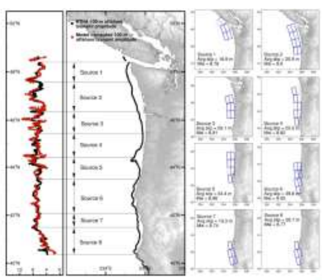
Reconstruction of Probabilistic Tsunami Sources in the Cascadia for WA, OR & Northern CA



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Tsunami Design Zone - Hilo, HI

Runup (ft)	90
Longitude	155.470
Latitude	19.60

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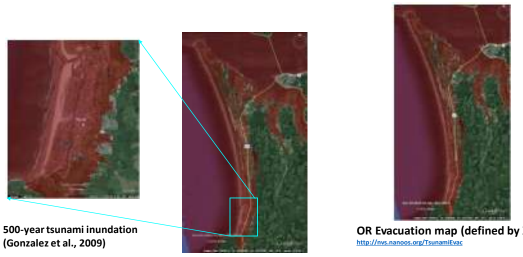
Oregon

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



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

OR Evacuation map (defined by XXL1)
http://nvs.nanoos.org/TsunamiEvac

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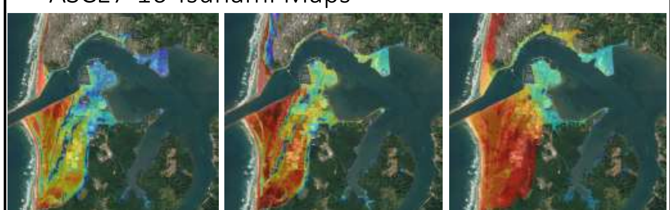
ASCE7-16 Tsunami Maps



DOGAMI L1 | **ASCE 2500YR** | **DOGAMI XXL1**

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- 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

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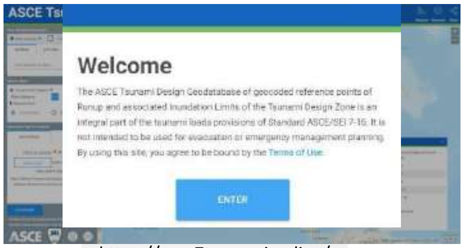
Tsunami Design Geodatabase being hosted by ASCE

- Probabilistic Subsidence Maps
- PTHA Offshore Tsunami Amplitude and Predominant Period
- Disaggregated source figures
- Runup, or Inundation depth reference points for overwashed peninsulas and/or islands to be presented in an electronic map
- Tsunami Design Zones organized by state (all applicable areas in the five western states)
- 62 nondigital Tsunami Design Zone pdf maps for specific areas that are equivalent to the digital maps

ASCE7-16 Tsunami Geodatabase

https://asce7tsunami.online/

ASCE7-16 Tsunami Geodatabase



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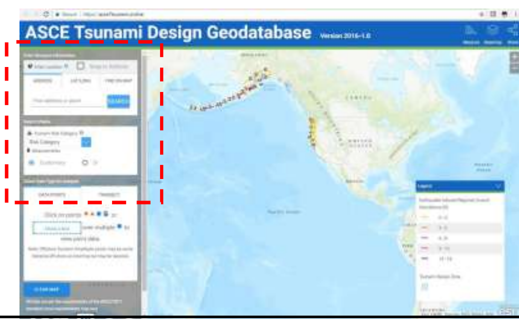

ASCE7-16 Tsunami Geodatabase

- Enter Project Site:
  - Address or
  - Latitude/Longitude or
  - Find on Map
- Select Risk Category
  - TRC I, II, III or IV
- Select Units
  - US or Metric

ASCE7-16 Tsunami Geodatabase Example

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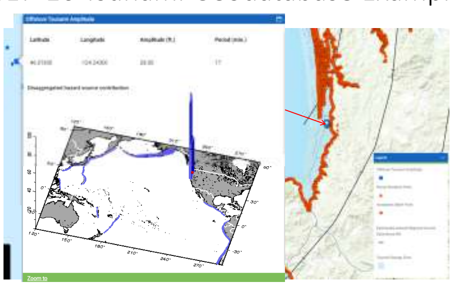

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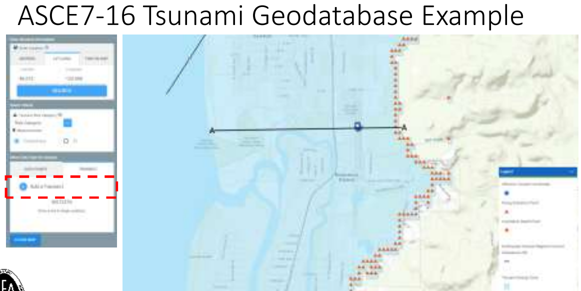

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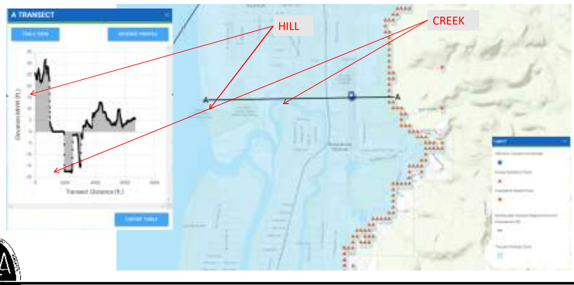

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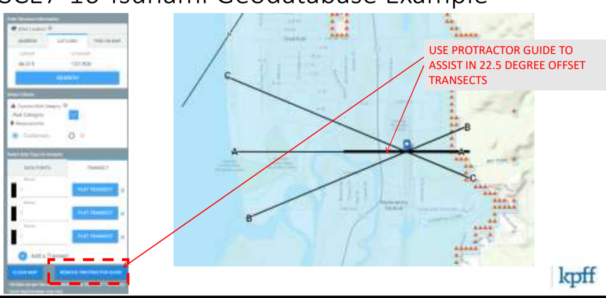

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Tsunami Flow Characteristics

- Two approaches to determine flow depth and velocity
- Energy Grade Line Analysis method based on pre-calculated runup from the Tsunami Design Zone maps
- Site-Specific Probabilistic Hazard Analysis
  - Required for tsunami risk category IV
  - Optional for other risk category II and III
  - Velocity lower limit of 75-90% EGLA method

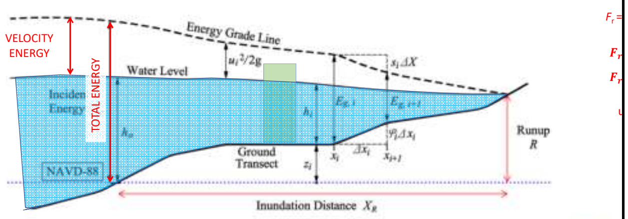
Method 1: Energy Grade Line Analysis

- Re-accumulate the hydraulic head required to reach the inundation limit and runup elevation
- Sum the energy lost to altitude ($\varphi_i \Delta X_i$) and friction ($s_i \Delta X_i$) during inflow
- Total energy at any location along the transect is then:

$$E_{g,i} = E_{g,i+1} + (\varphi_i + s_i)\Delta X_i$$

- Validated to be conservative through field data & 36,000 numerical simulations yielding 700,000 data points

Method 1: Energy Grade Line Analysis



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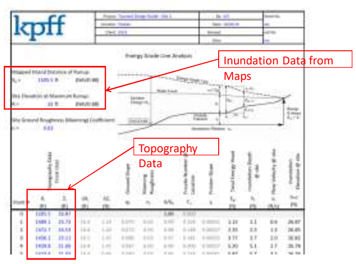
Method 1: Energy Grade Line Analysis



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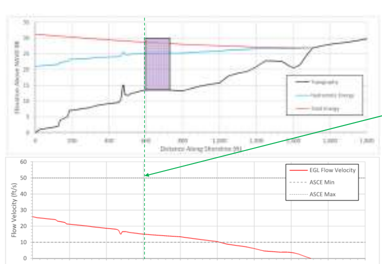

X_{site} = 610ft
Z_{site} = 13.5ft
h_{site} = 11.7ft
u_{site} = 15ft/s

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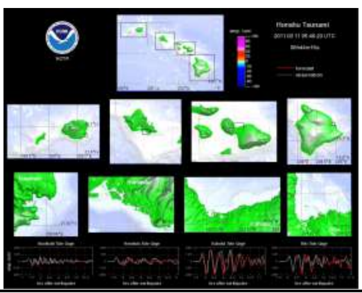
Method 2: Site Specific Study

- Site specific analysis will give time-step by time-step data for all points of interest
- Allows use of better topographic data and higher resolution modeling
- Allowed to go below mapped modeling with an 80% cap (similar to seismic)

Method 2: Site Specific Study



Inundation analysis for Tohoku tsunami (2011) [NOAA]

Outline

- Tsunami Background
- Tohoku Tsunami Lessons
- ASCE 7-16 Tsunami Loads and Effects
  - Scope of Chapter 6
  - Probabilistic Tsunami Design Maps
  - ASCE 7-16 Tsunami Geodatabase
  - Site flow parameters
  - Design Load Cases
  - Structural Loading
- Project Examples

ASCE 7 Chapter 6: Tsunami Loads and Effects

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Design Cases for Tsunami Loads (Section 6.8)

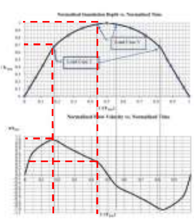
- Load cases developed from normalized flow time-histories

KJ4

LC #3: h = 0.66*h_{max}
v = 0.33*v_{max}

Normalized Depth

Normalized Velocity



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Structural Design for Tsunami Loads (Section 6.8)

- Reliability analysis was performed based on ASCE 7 target reliabilities discussed in chapter 2
- From this importance factors were calibrated.
  - RC II = 1.0
  - RC III = 1.25
  - RC IV = 1.25

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Structural Loads (Section 6.9 – 6.11)

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Tsunami Loads and Effects

- Hydrostatic Forces
  - Unbalanced Lateral Forces
  - Buoyant Uplift based on displaced volume
  - Residual Water Surcharge Loads on Elevated Floors
- Hydrodynamic Forces
  - Drag Forces – per drag coefficient C_d based on size and element
  - Lateral Impulsive Forces of Tsunami Bores on Broad Walls: Factor of 1.5
  - Hydrodynamic Pressurization by Stagnated Flow – per Benoulli
  - Shock pressure effect of entrapped bore
- Waterborne Debris Impact Forces
  - 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 and Remedial Measures

Tsunami Loads and Effects

- Hydrostatic Forces
  - Unbalanced Lateral Forces
  - **Buoyant Uplift based on displaced volume**
  - Residual Water Surcharge Loads on Elevated Floors
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  - **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 and Remedial Measures

Effective Fluid Density, ρ_s

- Seawater plus sediment and small debris is more dense than regular seawater.
- ASCE 7-16 specifies $\rho_s = k_s \times \rho_{sw}$
  - Where $k_s = 1.1$ (represents 7% sediment)
- US lb-in units: $\rho_s = 1.1 \times 2 = 2.2$ slugs/ft^3

  and $\gamma_s = 1.1 \times 64 = 70.4$ pcf

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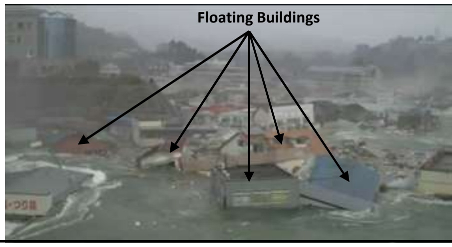
Floating Buildings (Onagawa Japan)

- Floating buildings and debris cause measurable difference I effective density for hydrodynamic calculations



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Buoyancy induced overturning

- Onagawa overturned concrete fish storage building
- Buoyancy and lateral load

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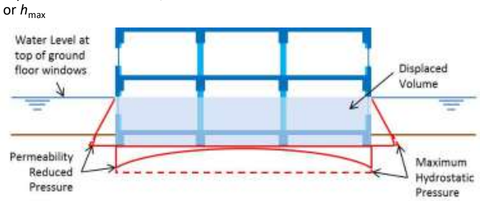
Hydrostatic Loads – Section 6.9

- Load case 1 from Section 6.8 is a hydrostatic check
- Designer to consider buoyancy up to
  - One story,
  - top of first floor windows,
  - or h_{max}



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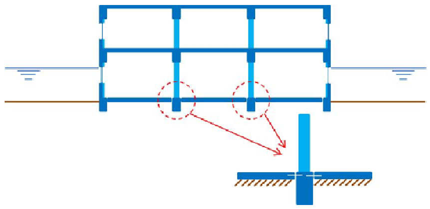
Hydrostatic Loads – Section 6.9

- Possible Solution: Avoid uplift by separating the slab-on-grade from structural columns and walls



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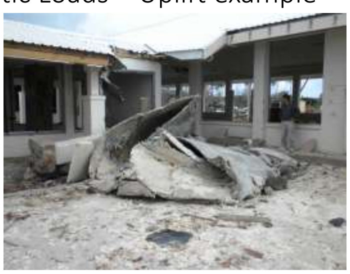
Hydrostatic Loads – Uplift example



Samoa - Uplifted Slab-on-Grade

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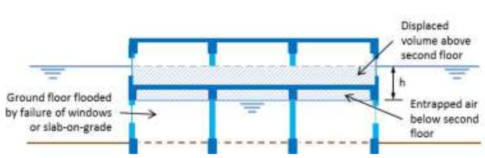
Hydrostatic Loads – Section 6.9

- After failure of non-structural walls at lower levels, trapped air below floor and dry space on elevated floor will result in uplift due to buoyancy.



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Hydrostatic Loads – Uplift example

- Collapse of prestressed double tee sections at second floor of parking garages in Biloxi, Mississippi during Hurricane Katrina due to buoyancy induced uplift

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Hydrostatic Loads – Boyancy on Tanks

- Storage Tankers will float unless relatively full or well restrained.
- The thin walls rupture easily during impact leading to fuel spills and fires

Storage tankers in Kesennuma

Storage tankers in Onagawa

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Hydrodynamic Loads – Drag Force (Section 6.10)

- Tsunami Base Shear – hydrodynamic drag forces on entire structure

$$V_{tsu} = \frac{1}{2}\rho_s I_{tsu} C_d C_{cx} B(hu^2)$$

- V_{tsu} = tsunami base shear
- ρ_s = fluid design of seawater.
- I_{tsu} = Importance Factor (1.0 for TRC II, 1.25 for TRC III & IV)
- C_d = Drag coefficient, varies between 1.25 and 2.0, depending on B/h.
- C_{cx} = Closure coefficient, based on projected area of structural elements below flow level.
- B = building width perpendicular to flow.
- h = inundation depth for load case considered
- u = flow velocity for load case considered

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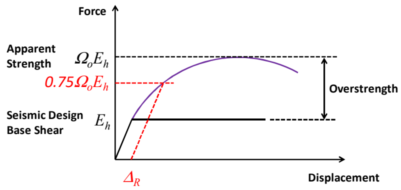
Hydrodynamic Loads – Lateral System Check

- Alternative analysis for SDC D, E and F
  - Compare tsunami base shear, V_{Tsu}, with seismic non-linear capacity
  - If $V_{Tsu} \leq 0.75\Omega_o E_h$, then system is adequate
- Not adequate for higher performance design



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Hydrodynamic Loads – Drag Force (Section 6.10)

- Individual Component Evaluation
  - Apply hydrodynamic drag to individual members
    - Columns: 6.10.2.2
    - Walls 6.10.2.3
    - Perforated Walls: 6.10.2.4
    - Non-Perpindicular Elements: 6.10.2.5
    - Flow Stagnation on Walls & Slabs: 6.10.3
    - 50% Increase for bore effects where $F_r > 1.0$
  - Evaluate members using conventional strength design
    - Load considered as sustained static load
    - Include appropriate load combinations and factors
    - Include material strength reduction factors (ϕ)

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Hydrodynamic Loads – Debris Damming (6.10.2.4)

Three-Story Steel MRF collapsed and pushed into concrete building

Three-Story Steel MRF with 5 meters of debris load accumulation wrapping

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Debris Impact Loads – Section 6.11

- 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

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Debris Impact Loads – Section 6.11

- Shipping containers float even if fully loaded
- Medium to large boulders can be moved in moderate flow conditions

Medium Bolder

Power poles / tree trunks

Shipping Containers

Seawall Debris

Debris Impact Loads – Section 6.11

Base Design Option: Elastic Impact force Equation (EQ 6.11-2)

- Nominal maximum impact force
  $$F_{ni} = u_{max}\sqrt{km_d}$$
- Factored design force based on importance factor
  $$F_i = I_{TSU}F_{ni}$$
- Impact duration
  $$t_d = \frac{2m_d u_{max}}{F_{ni}}$$
- Force capped based on strength of debris
  - Shipping Container: $F_i = 330C_oI_{TSU}$
  - Wooden Log: $F_i = 165C_oI_{TSU}$
  - Where: C_o=0.65, Impact orientation factor
- Contents increase impact duration but not force\

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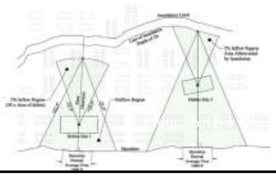
Debris Impact Loads – Assessment for Containers and Ships

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



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
- 2% concentration defines debris dispersion zone

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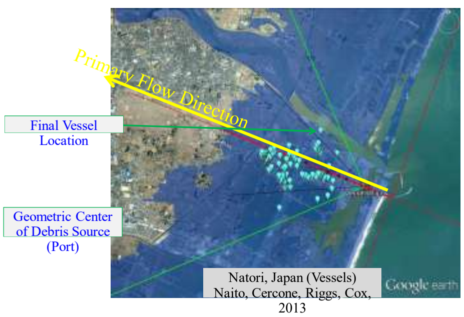

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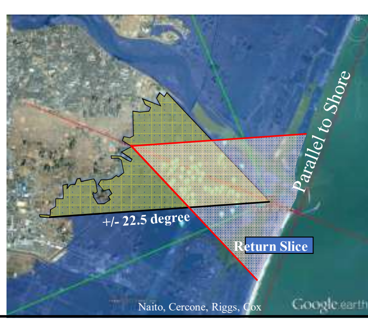

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Ship Impact – Sendai Port

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Foundation Design – Scour Examples

8-ft. Scour by inflow at Dormitory Bldg corner

Scour by return flow around Minamisanriku Vert. Evacuation Apt. building

Onagawa scour during return flow from valleys

Miyako Bridge Abutment Scour

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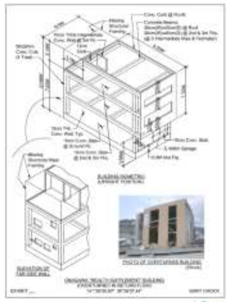
Building Overturning

Three-Story Concrete Retail Building (2050 kN deadweight) on mat foundation overturned during return flow when submerged in 8 m/s flow; would have toppled at only 3 m/s



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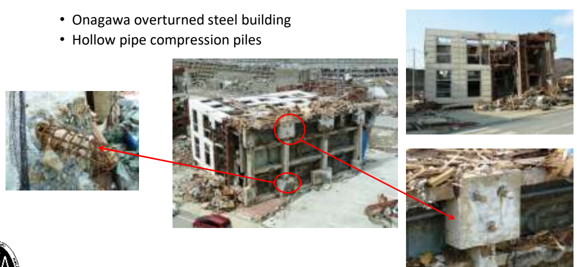
Piled Foundation Failure

- Onagawa overturned steel building
- Hollow pipe compression piles



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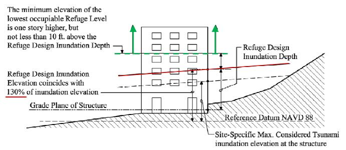
Tsunami Vertical Evacuation Refuge Structures (6.14)

- Tsunami Vertical Evacuation Refuge Structures - ASCE 7 Chapter 6 is intended to supersede both FEMA P646 structural guidelines and IBC Appendix M
- Additional reliability (99%) is achieved through site-specific inundation analysis and an increase in the design inundation elevation



6.14-1. Minimum Refuge Elevation

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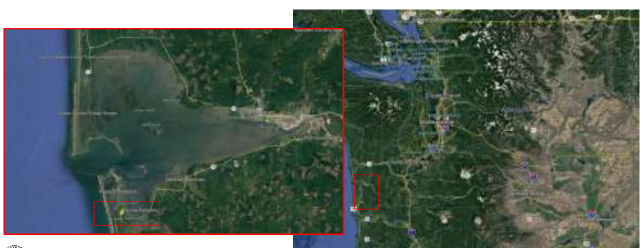
Vertical Evacuation Projects In The United States

Vertical Evacuation Project #1 : Ocosta Elementary School

Ocosta, WA

Ocosta Elementary School



Ocosta Elementary School

Ocosta School –Project Team

Owner:	Ocosta School District
Architect:	TCF Architecture
Structural Engineer:	Degenkolb Engineers
Tsunami Modeler:	Frank Gonzalez (University of Washington)
Contractor:	Integrity Structures

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Ocosta Elementary School - Requirements

- Project Requirements
  - New classrooms (23)
    - Ideal to be one level for elementary students
  - Office, kitchen, music room, cafeteria, and gym
  - Evacuation Space for ~1,000 people set above DOGAMI L_1 event
    - ASCE 7 draft provisions used (before mapping complete)
- Solution was to use tall volume spaces (Gym, cafeteria & music room) to create evacuation area
  - Minimized the impact of having tall roof area

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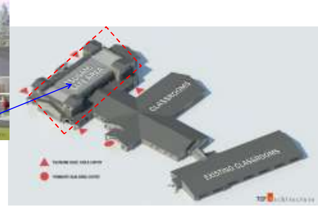
Ocosta Elementary School - Building

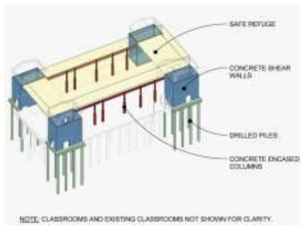


REFUGE AREA

Images courtesy of TCF Architecture

Ocosta Elementary School – Structural System

- Gym building (Evacuation Space)
  - 4 concrete cores in each corner (stairs)
  - Pile foundation under cores
  - Steel truss w/ steel columns
  - Structural steel & composite deck roof



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Ocosta Elementary School

School opened in 2016

Images courtesy of TCF Architecture

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Vertical Evacuation Projects #2 : Oregon State University Marine Sciences Initiative Building

Newport, OR

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OSU Marine Sciences Building –Project Team

Owner:	Oregon State University
Architect:	Yost Grube Hall Architects
Structural Engineer:	KPFF Consulting Engineers
Geotechnical Engineer:	GRI
Tsunami Modeler:	Yong Wei (NOAA/University of Washington)
Contractor:	Anderson Construction

OSU Marine Sciences Building

OSU Marine Sciences Building – Design Criteria

- Design Criteria set by presidents message announcing the project
- Guiding principles
  - Demonstration Project
  - Intuitive Evacuation
  - Promote Collaboration
  - Iconic Building
- Building program/space requirements
  - Natural Light
  - Auditorium
  - Educational lab space
  - Research lab space w/ faculty office
  - Enclosed MEP space to combat environmental conditions

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OSU Marine Sciences Building – Design Criteria

- Performance Based Design Requirements
  - Structural Requirements
    - Seismic – Immediate Occupancy at MCE_R
    - Tsunami – Immediate Occupancy for ASCE 7 MCT and DOGAMI XXL_1
    - Debris – Life Safety for "extraordinary" debris strikes
  - Full Building
    - Repairable for MCE_R EQ & DOGAMI L_1
- Vertical Evacuation Design Requirements
  - Evacuation area for 900 people
  - Easy/intuitive access to evacuation area
  - Elevation set by maximum of
    - ASCE 7-16 requirements
    - DOGAMI XXL + 2ft

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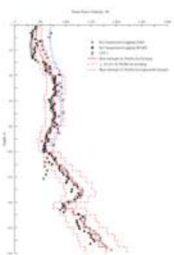
OSU Marine Sciences Building - Hazards

- Seismic hazard
  - Site located on liquefiable soil at multiple layers to 95ft
    - Considered cyclic degradation below 100ft
  - High water table
  - Close proximity to Cascadia subduction zone leads to high site specific spectra
  - Considered near source effects from local fault (<1km)



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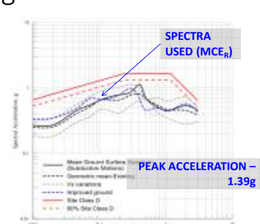
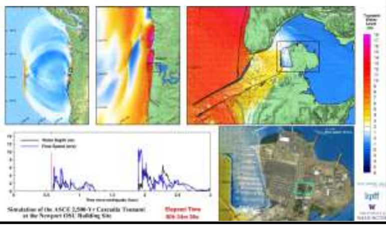
OSU Marine Sciences Building - Hazards

- MCER site spectra developed based on site response modeling
  - Considered variations in Vs30 data
- Ground improvement (Deep soil mixing) moved site to site class D
  - 80% of site class D code limit controlled spectra



OSU Marine Sciences Building - Hazards

- Site Specific Tsunami Modeling done by Dr. Yong Wei (NOAA/UW)
  - 3 scenarios
  - Hi-RES DEM
- Results:
  - DOGAMI L_1
    - D = 12.4ft
    - V = 29.3ft/s
  - DOGAMI XXL_1
    - D = 30.5ft
    - V = 40.4ft/s
  - ASCE 7 MCT (2,500yr)
    - D = 20.7ft
    - V = 31.7ft/s



OSU Marine Sciences Building – Inundation Modeling

Inundation Video

OSU Marine Sciences Building – Debris

- Per ASCE 7 debris analysis is required
  - Logs
  - Cars/trucks
  - Boulders
  - Ships (if required)
  - Shipping containers (if required)

OSU Marine Sciences Building – Debris

- Numerical modeling done to establish if large debris could make it to project site
  - NOAA research ship
  - OSU research ship
  - Commercial fishing fleet
  - Cargo vessel
  - Personal vessels (marina)

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OSU Marine Sciences Building – Debris

- ASCE 7-16 Code debris cone check performed for each debris source
- Only marina to west impacted site

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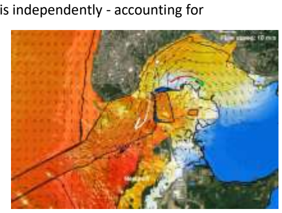
OSU Marine Sciences Building – Debris

- Numerical modeling considered each debris independently - accounting for
  - Debris mass
  - Debris orientation (relative to flow)
  - Changing flow direction/velocity
  - Grounding/flow depth
- Numerical modeling confirmed only marina to west impacted the site



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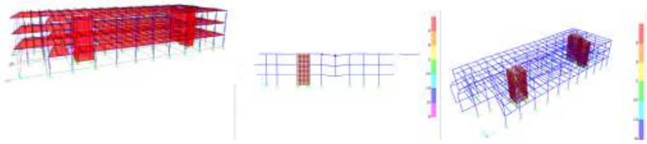
OSU Marine Sciences Building – Progressive Collapse

- Progressive Collapse design required due to large debris
  - Roof framing designed to pick up lower floors for lost column
  - Non-linear dynamic model used to remove columns and check framing



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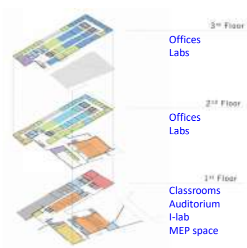
OSU Marine Sciences Building - Site



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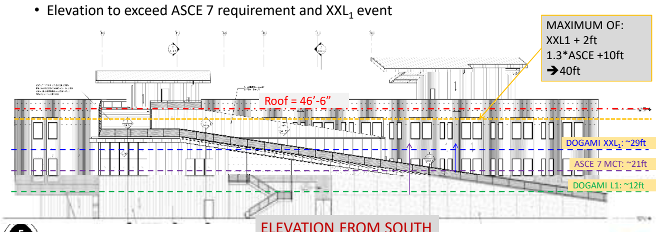
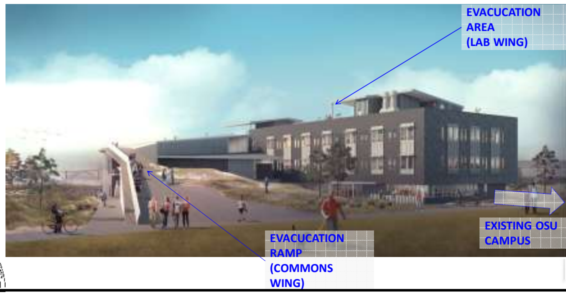
- Lab roof serves as evacuation space
  - Min 1,000 occupants
- Elevation to exceed ASCE 7 requirement and XXL_1 event

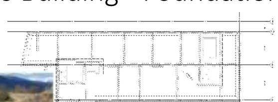


OSU Marine Sciences Building



OSU Marine Sciences Building - Foundation

- Deep Soil Mixing columns
  - 30" Diameter
  - 100ft depth



OSU Marine Sciences Building - Structure

- Spread footings & Mat Foundations
  - Uplift Anchors into DSM
- Concrete Shear wall Lateral System
- Steel Framed Gravity System
  - Concrete on Metal Deck Diaphragm
- Metal Stud Exterior

OSU Marine Sciences Building - Construction

- Deep Soil Mixing Operation

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OSU Marine Sciences Building - Construction

- Mat Foundations

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- Concrete Cores

OSU Marine Sciences Building - Construction

- Steel Framing

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- Structural Slabs being poured

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OSU Marine Sciences Building - Construction

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OSU Marine Sciences Building - Construction

- Exterior Skin

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OSU Marine Sciences Building - Construction

Questions?