

ASCE 7-16 Chapter 6, Tsunami Loads and Effects

Gary Chock, S.E., F.SEI, Dist. M. ASCE, D.CE
Structural Engineer
ASCE Structural Engineering Institute Fellow
Distinguished Member ASCE
Diplomate, Coastal Engineer, of the Academy of
Coastal, Ocean, Port and Navigation Engineers
ASCE 7 Tsunami Loads and Effects Subcommittee Chair
gchock@martinchock.com

Tohoku Tsunami photograph at Minami Soma by Sadatsugu Tomizawa

USA CODES AND STANDARDS

- International Building Code (IBC)
- ASCE 7 Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE 7) is developed in an ANSI-accredited consensus process
- ▶ Other Standards:
 - ▶ Material specific design specifications
 - ▶ Non-structural installation standards
 - ▶ Testing and qualification standards



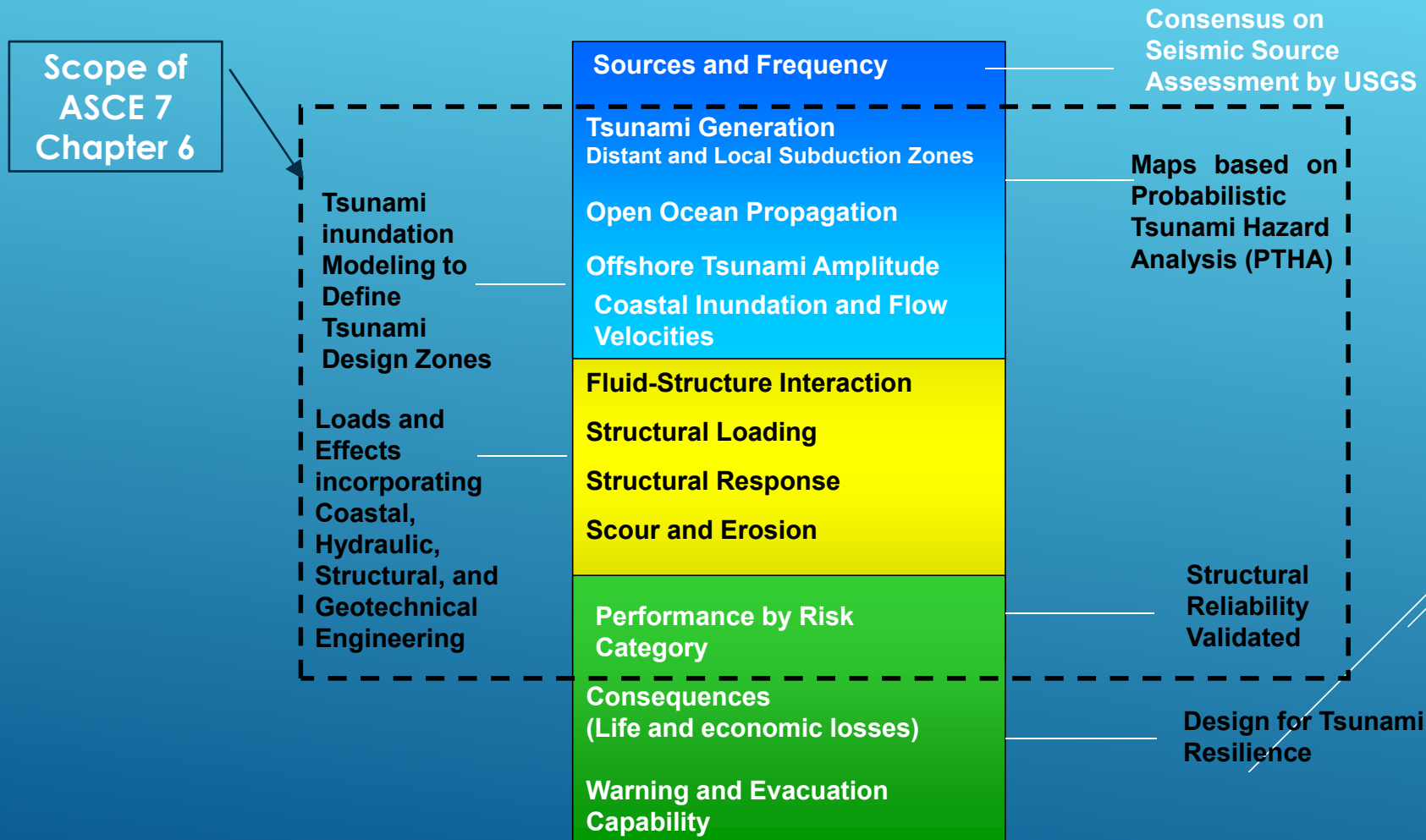
ASCE 7-16 TSUNAMI LOADS & EFFECTS

The ASCE 7-16 Chapter 6– Tsunami Loads and Effects is applicable to the five western states of the USA. (Alaska, Washington, Oregon, California, Hawaii)

It will improve resilience of communities for the tsunamis risk in the areas of:

- **Planning and Siting**
- **Structural Design**
- **Post-disaster reconstruction to Build Back Better**
- **ASCE Tsunami Design Geodatabase**
 - Maps, parameters, and criteria in the ASCE 7 design standard are based on engineering risk analysis and reliability targets, rather than deterministic scenarios.
 - Tsunami Design Zone (TDZ) Maps based on 2500+ -yr Maximum Considered Tsunami (MCT) from probabilistically aggregated sources

TSUNAMI-RESILIENT ENGINEERING SUBJECT MATTER INCORPORATED IN ASCE 7



ASCE 7 CHAPTER 6- TSUNAMI LOADS AND EFFECTS

6.1 General Requirements

6.2-6.3 Definitions, Symbols and Notation

6.4 Tsunami Risk Categories



GENERAL INFORMATION –
WHAT BUILDINGS ARE
SUBJECT TO CHAPTER 6

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

6.8 Structural Design Procedures for Tsunami Effects

6.9 Hydrostatic Loads

6.10 Hydrodynamic Loads

6.11 Debris Impact Loads

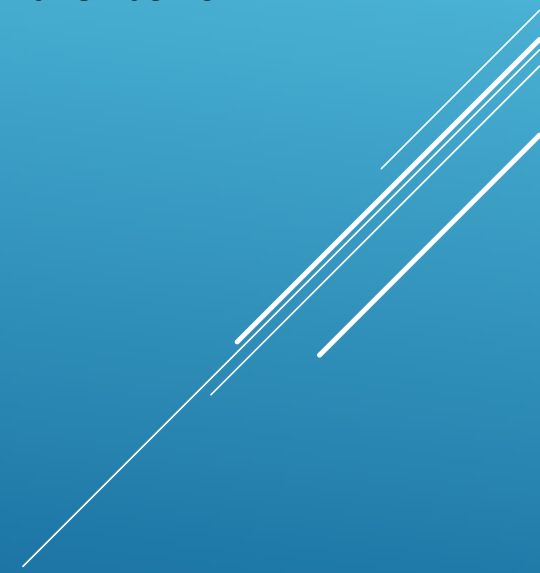
6.12 Foundation Design

6.13 Structural Countermeasures for Tsunami Loading

6.14 Tsunami Vertical Evacuation Refuge Structures

6.15 Designated Nonstructural Systems

6.16 Non-Building Structures



ASCE 7 CHAPTER 6- TSUNAMI LOADS AND EFFECTS

6.1 General Requirements

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

6.8 Structural Design Procedures for Tsunami Effects

6.9 Hydrostatic Loads

6.10 Hydrodynamic Loads

6.11 Debris Impact Loads

6.12 Foundation Design

6.13 Structural Countermeasures for Tsunami Loading

6.14 Tsunami Vertical Evacuation Refuge Structures

6.15 Designated Nonstructural Systems

6.16 Non-Building Structures

HAZARD
DETERMINATION
AT BUILDING SITE
(I.E. DEPTH &
VELOCITY)



ASCE 7 CHAPTER 6- TSUNAMI LOADS AND EFFECTS

6.1 General Requirements

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

6.8 Structural Design Procedures for Tsunami Effects

6.9 Hydrostatic Loads

6.10 Hydrodynamic Loads

6.11 Debris Impact Loads

6.12 Foundation Design

6.13 Structural Countermeasures for Tsunami Loading

6.14 Tsunami Vertical Evacuation Refuge Structures

6.15 Designated Nonstructural Systems

6.16 Non-Building Structures

BUILDING DESIGN
FORCES &
REQUIREMENTS



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 strength within the inundation height to resist hydrostatic and hydrodynamic forces
- ▶ Check resistance of lower elements for hydrodynamic pressures and debris impacts to avoid progressive collapse
- ▶ Design foundations to resist scour and potential uplift
- ▶ Elevate critical equipment as necessary

SCOPE AND GENERAL REQUIREMENTS

Application in accordance with Risk Categories

RISK CATEGORIES OF BUILDINGS AND OTHER STRUCTURES PER ASCE 7

Risk Category I	Buildings and other structures that represent a low risk to humans
Risk Category II	All buildings and other structures except those listed in Risk Categories I, III, IV
Risk Category III	<p>Buildings and other structures, the failure of which could pose a substantial risk to human life.</p> <p>Buildings and other structures with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure.</p>
Risk Category IV	<p>Buildings and other structures designated as essential facilities</p> <p>Buildings and other structures, the failure of which could pose a substantial hazard to the community.</p>

- *The tsunami provisions target the performance of Risk Category III and IV (and taller Risk Category II structures)*

SCOPE OF CHAPTER 6

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

- 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.

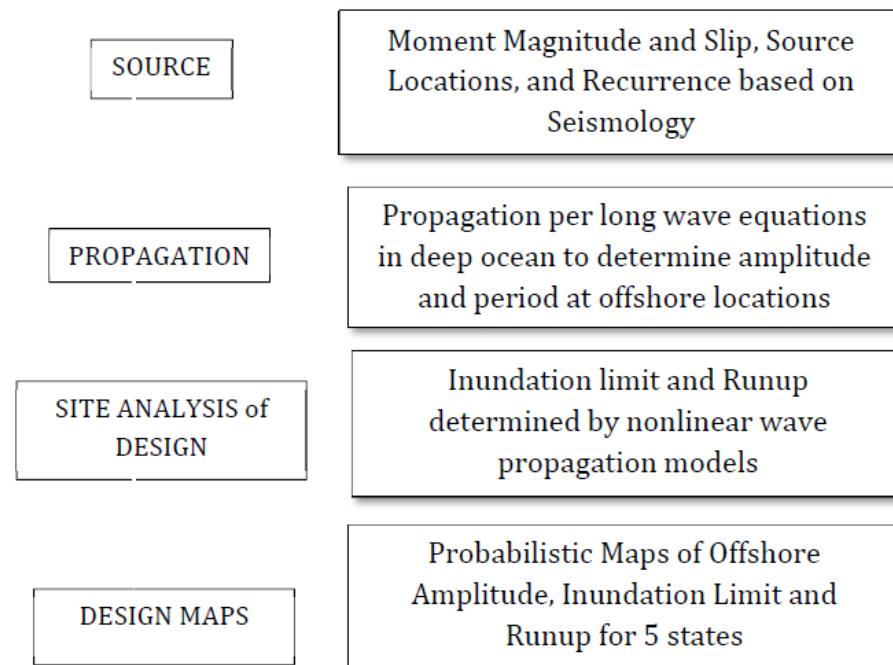
HOW PTHA AND TDZ BASIS OF DESIGN ARE INTEGRATED INTO THE ASCE STRUCTURAL DESIGN PROCESS

- ▶ 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
- ▶ Probabilistic Offshore Tsunami Amplitude maps and Tsunami Design Zone inundation maps
- ▶ Tsunami inundation mapping is based on using these probabilistic values of Offshore Tsunami Amplitude
- ▶ Hydraulic analysis or site-specific inundation analysis to determine site design flow conditions
- ▶ Physics-based fluid loads, debris loads, foundation demands

PTHA DERIVED 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.

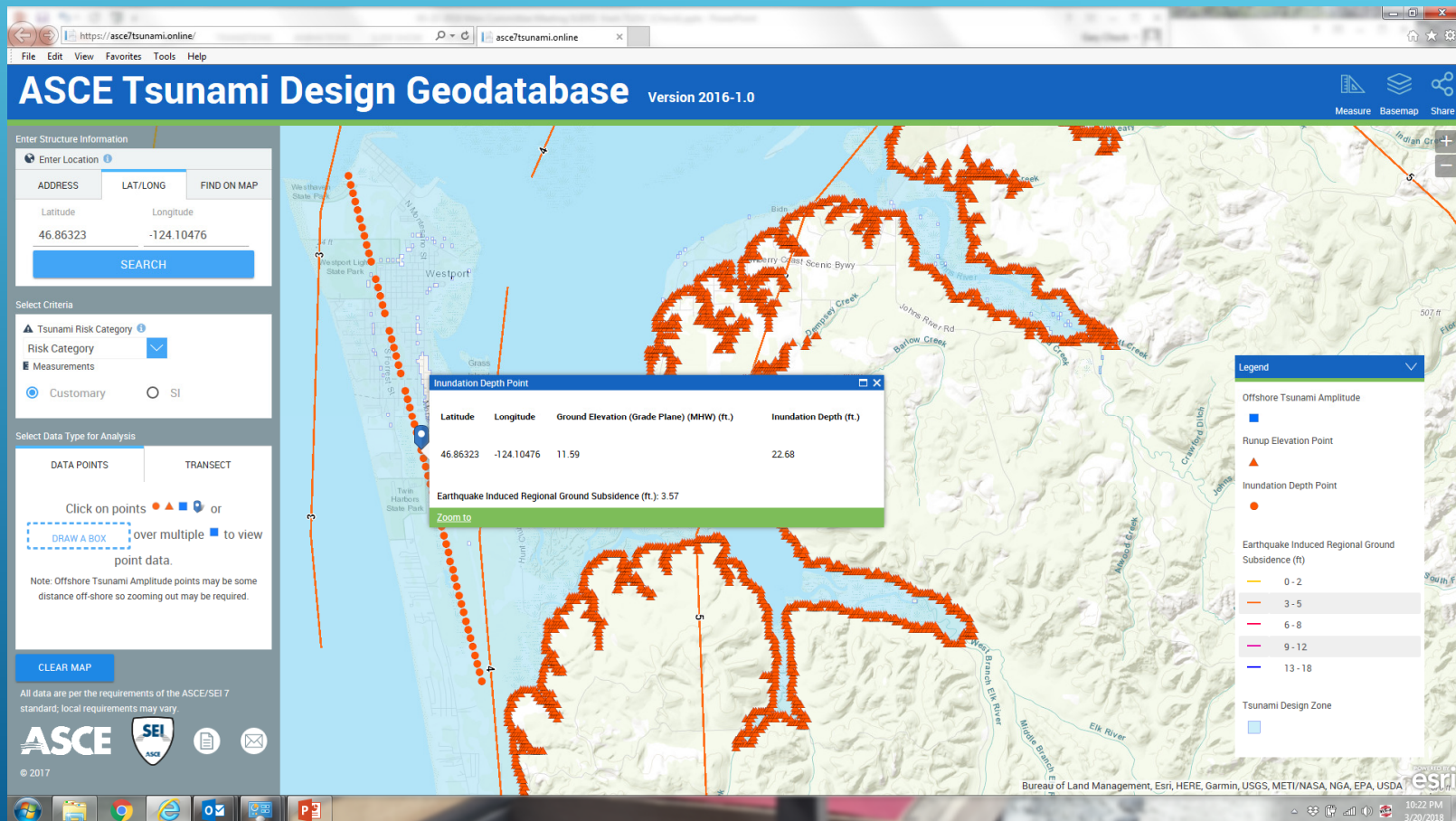
Probabilistic Tsunami Hazard Analysis



TSUNAMI DESIGN GEODATABASE IS HOSTED BY ASCE ON AN ELECTRONIC DATABASE

- ▶ 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

ASCE TSUNAMI DESIGN GEODATABASE AS IMPLEMENTED [HTTPS://ASCE7TSUNAMI.ONLINE/](https://asce7tsunami.online/)



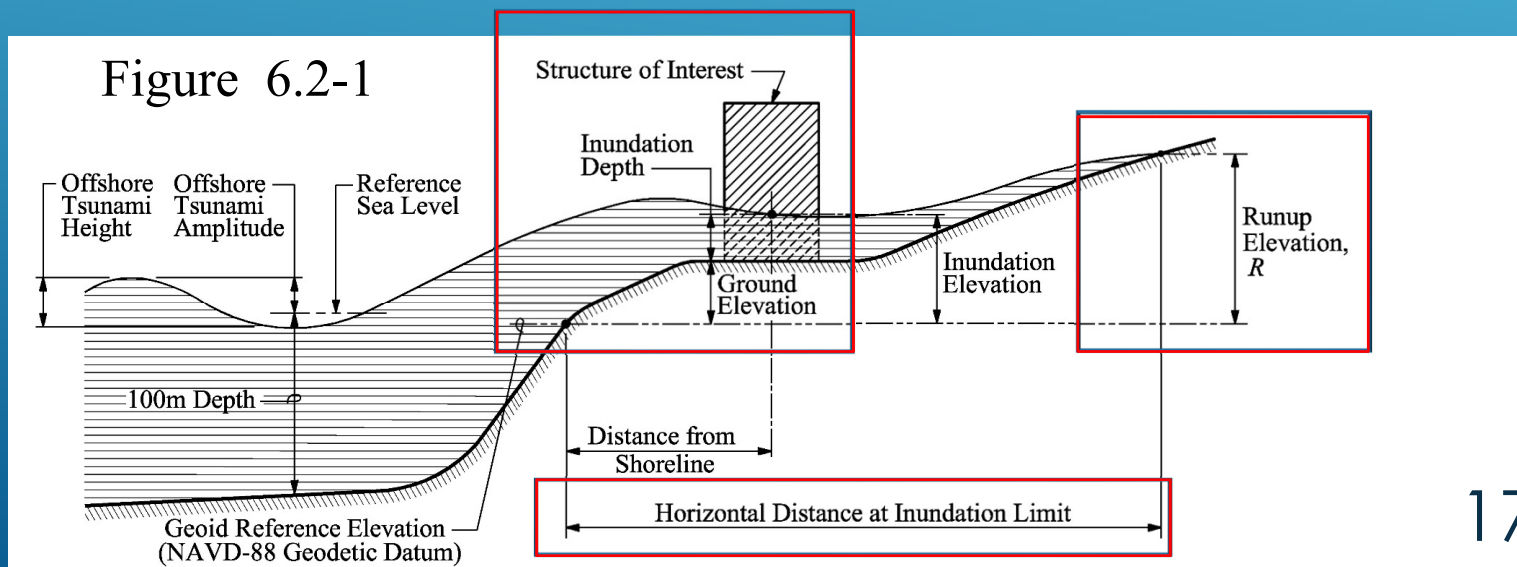
CHARACTERIZING THE DESIGN INUNDATION DEPTH AND FLOW VELOCITIES AT A SITE IN THE TDZ

Energy Grade Line Analysis

Site-Specific Tsunami Inundation Analysis

Terminology

- ▶ **RUNUP ELEVATION:** Difference between the elevation of maximum tsunami inundation limit and the 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



TSUNAMI FLOW CHARACTERISTICS

Two approaches to determine flow depth and velocity

▶ **Energy Grade Line Analysis method, EGLA**

- ▶ Developed by members of ASCE 7 Tsunami Loads and Effects Committee
- ▶ Based on pre-calculated runup from the Tsunami Design Zone maps
- ▶ Accumulation of energy lost through friction and altitude gain
- ▶ Biased to provide slightly conservative hydrodynamic forces

▶ **Site-Specific Probabilistic Hazard Analysis**

- ▶ Required for TRC IV
- ▶ Optional for other TRCs
- ▶ Velocity lower limit of 75-90% EGLA method

TSUNAMI LOADS

▶ 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
- ▶ Hydrodynamic Pressurization by Stagnated Flow
- ▶ 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

FOUNDATION DESIGN

- ▶ General Site Erosion
- ▶ Local Scour
- ▶ Plunging Scour (i.e., overtopping a wall)
- ▶ Under-seepage Forces
- ▶ Loss of Strength due to pore pressure softening during drawdown

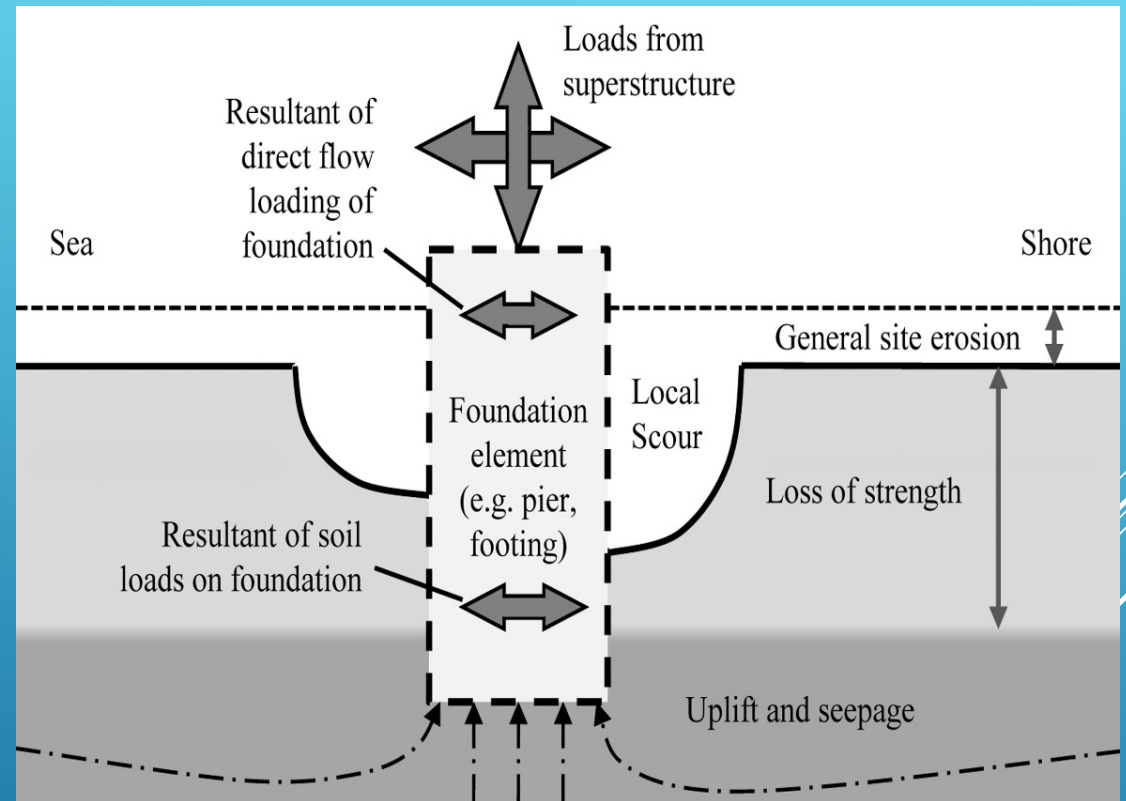


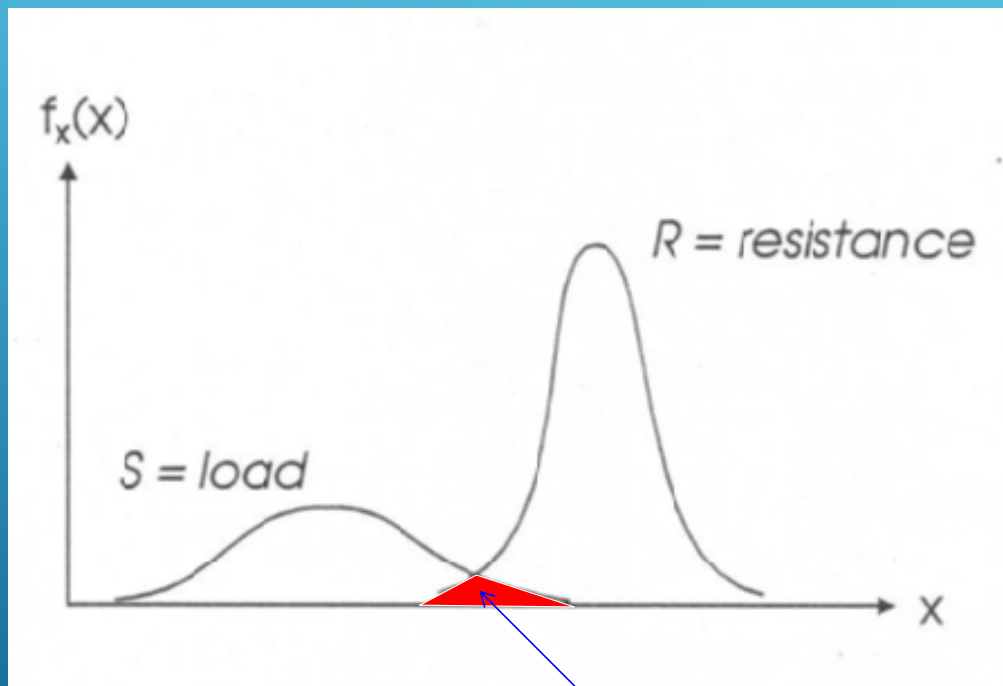
Figure C6.12-1. Schematic of tsunami loading condition for a foundation element

STRUCTURAL RELIABILITY

Chock, G., Yu, G., Thio, H.K., Lynett, P. (2016). Target Structural Reliability Analysis for Tsunami Hydrodynamic Loads of the ASCE 7 Standard. Journal of Structural Engineering, ASCE. 10.1061/(ASCE)ST.1943-541X.0001499 , 04016092.

BASICS OF RELIABILITY ANALYSIS

- Limit State (LS) equation for $Z = R - S < 0$



GOAL: LIMIT THE OVERLAP, I.E.,
PROBABILITY OF FAILURE

ANTICIPATED RELIABILITIES (MAX. PROBABILITY OF A FAILURE) FOR EARTHQUAKE AND TSUNAMI

Risk Category	Probability of failure* in 50-ys		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

- ▶ The ASCE 7 provisions constitute a comprehensive method for reliable tsunami structural resilience, making tsunamis a required consideration in planning, siting, and design of coastal structures in the five western states of the USA.
- ▶ Probabilistic Tsunami Hazard Analysis is the basis for the 2475-yr MRI Tsunami Design Zone maps.
- ▶ Specified design procedures are provided for all possible loading conditions to achieve target reliabilities based on Risk Categories.
- ▶ Coastal communities and cities are also encouraged to require tsunami design for taller Risk Category II buildings, in order to provide a greater number of taller buildings that will be life-safe and disaster-resilient, especially where horizontal egress inland to safe ground takes longer than the travel time of the tsunami.

gchock@martinchock.com