Development of Tsunami Design Provisions for the ASCE/SEI 7-16 Standard

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Tohoku Tsunami photograph at Minami Soma by Sadatsugu Tomizawa

ASCE/SEI 7-10

- Minimum Design Loads for Buildings and Other Structures by American Society of Civil Engineers' (ASCE) Structural Engineering Institute (SEI).
- Consensus design standard updated every 5 years using ANSI-approved process.
- ASCE/SEI 7-10 is adopted by reference by the 2012 and 2015 International Building Codes (IBC), and therefore most US jurisdictions.

ASCE/SEI 7-10

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 - Vacant
- 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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ASCE/SEI 7 Tsunami Loads and Effects

- Subcommittee of 16 members and 14 associate members formed in February 2011.
  - One month before Tohoku tsunami.
- Subcommittee met 4-5 times per year for three years.
- Processed 8 consensus ballots through ASCE/SEI 7-16 Main Committee, addressing over 1500 comments.
- Final version issued for public comment in Fall 2015.
- Officially approved for ASCE/SEI 7-16 March 11, 2016.
- ASCE/SEI 7-16 accepted by International Code Council for inclusion in IBC 2018 in December 2017.
- ASCE/SEI will also be publishing a companion design guide in late 2017 with numerous design examples.

Tsunami-Resilient Engineering Subject Matter Incorporated in ASCE 7

Scope of ASCE/SEI 7 Chapter 6

- **Sources and Frequency** — Consensus on Seismic Source Assessment by USGS
- **Tsunami Generation**
  Distant and Local Subduction Zones
- **Open Ocean Propagation**
- **Offshore Tsunami Amplitude**

  (Tsunami Generation through Offshore Tsunami Amplitude) — Maps based on Probabilistic Tsunami Hazard Analysis (PTHA)
- **Coastal Inundation and Flow Velocities**

  (Offshore Tsunami Amplitude, Coastal Inundation and Flow Velocities) — Tsunami Inundation Modeling to Define Tsunami Design Zones
- **Fluid-Structure Interaction**
- **Structural Loading**
- **Structural Response**
- **Scour and Erosion**

  (Fluid-Structure Interaction through Scour and Erosion) — Loads and Effects incorporating Coastal, Hydraulic, Structural, and Geotechnical Engineering
- **Performance by Risk Category** — Structural Reliability Validated
- **Consequences**
  (Life and economic losses) — Societal Impact Assessment for the Five Western States by USGS
- **Warning and Evacuation Capability**

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
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MCT and Tsunami Design Zone

- ASCE 7 Tsunami Loads and Effects Chapter is applicable only to the states of Alaska, Washington, Oregon, California, and Hawaii, which have quantifiable tsunami 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 MCT is the design basis event, characterized by the inundation depths and flow velocities at the stages of in-flow and out-flow most critical to the structure.
- The Tsunami Design Zone is the area vulnerable to being flooded or inundated by the Maximum Considered Tsunami.

Consequence Guidance on Risk Categories of Buildings Per ASCE/SEI 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.)

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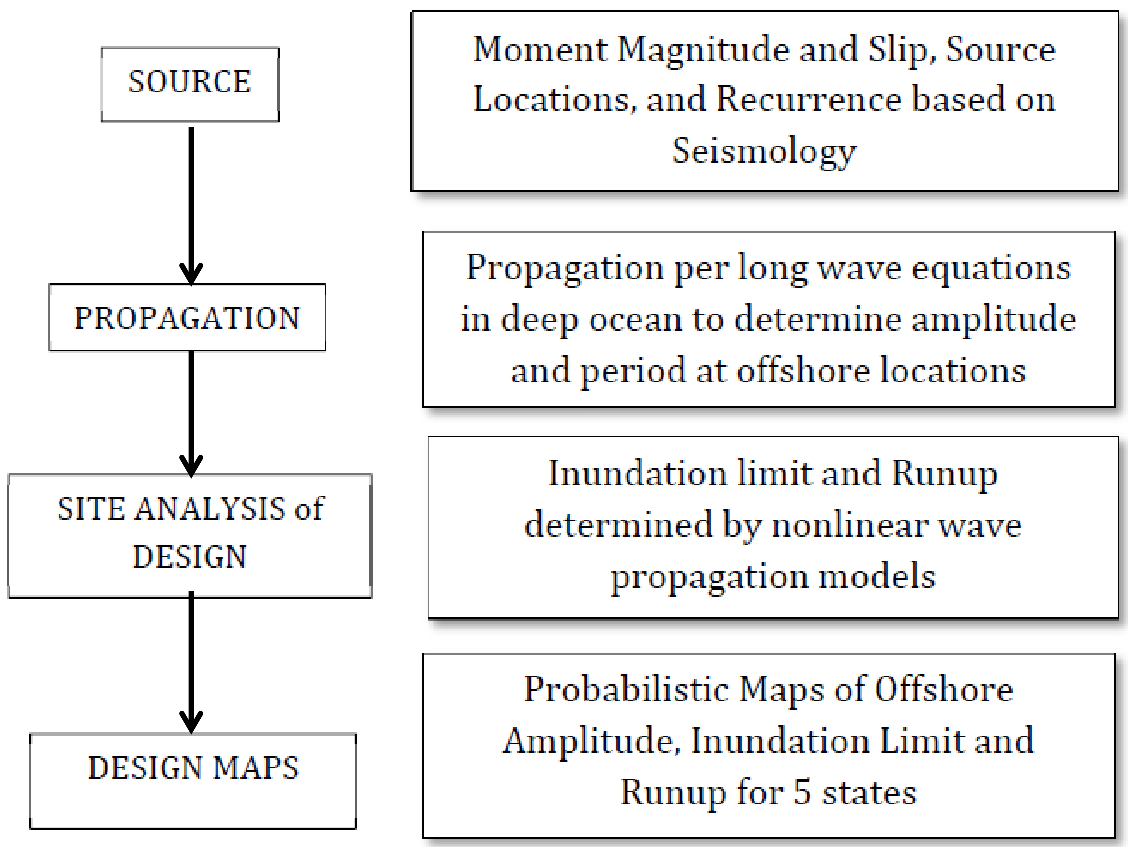
PTHA Derived MCT

- Probabilistic hazard identification required in order to be in the model code.
- The ASCE PTHA procedure was peer reviewed by NTHMP stakeholder group.
- Subduction Zone Earthquake Sources are consistent with USGS Probabilistic Seismic Hazard model.

Probabilistic Tsunami Hazard Analysis



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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
  - Required for all TRC III and IV buildings
- **Site-Specific Probabilistic Hazard Analysis**
  - Required for TRC IV buildings
  - Optional for other TRCs
  - Velocity lower limit of 75-90% EGL method

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Tsunami Load Conditions

- Hydrostatic Forces (equations of the form $k_s \rho_{sw} g h$)
  - Unbalanced Lateral Forces at initial flooding
  - Buoyant Uplift based on displaced volume
  - Residual Water Surcharge Loads on Elevated Floors
- Hydrodynamic Forces (equations of the form $\frac{1}{2} k_s \rho_{sw} (h u^2)$)
  - 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 (flow speed and $\sqrt{k\,m}$)
  - 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

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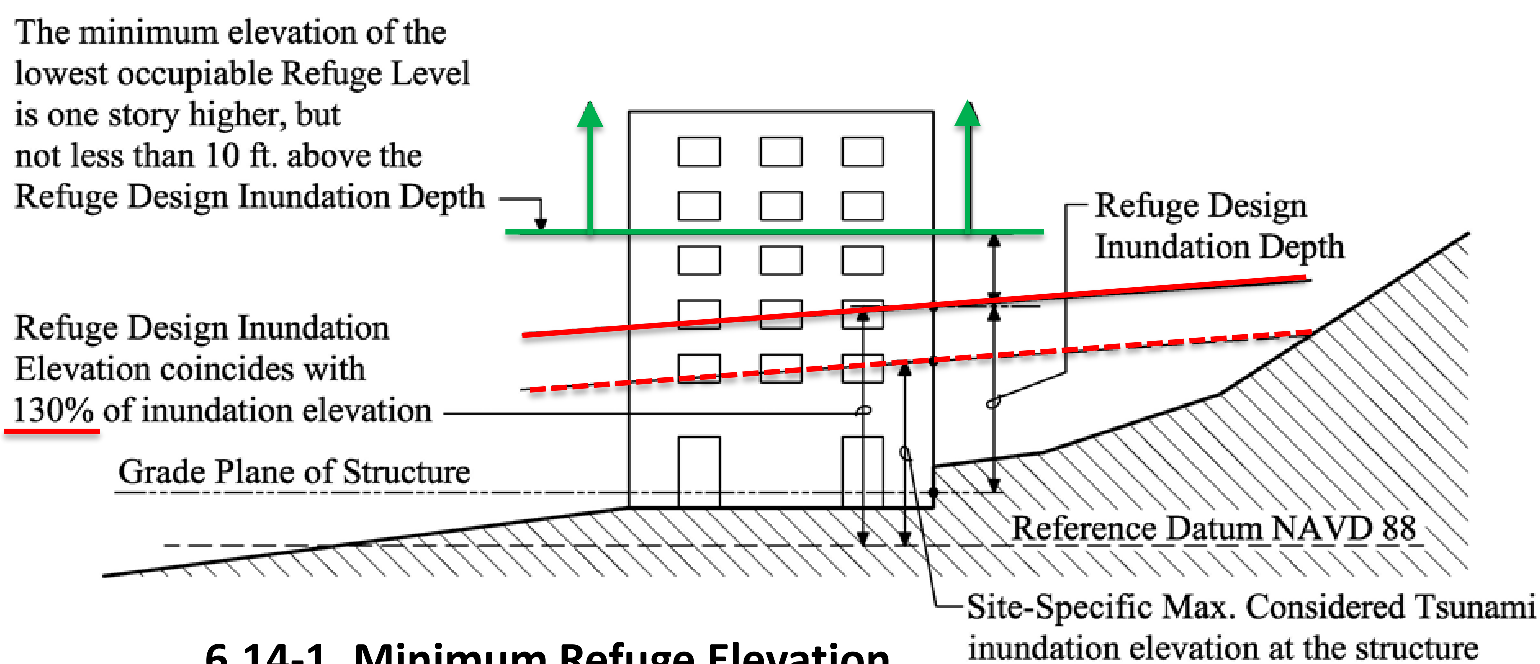
Tsunami Vertical Evacuation Refuge Structures

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

- ASCE/SEI 7 Chapter 6 provides 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.
- Probabilistic Tsunami Hazard Analysis is the basis for the development of 2475-yr MRI Tsunami Design Zone maps.
- Specified design procedures are provided for all possible loading conditions.
- Coastal communities are encouraged to require tsunami design for taller Risk Category II buildings to provide a greater number of buildings that will be disaster-resilient.
- ASCE/SEI 7-16 (and Chapter 6) still need to be adopted by the 5 western States into their State building codes.

IBC Appendix M

- IBC Appendix M, Tsunami Generated Flood Hazard, was originally submitted using the analysis and structural design aspects of FEMA P-646, *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis.*
- However, this much of the technical provisions have been superseded by Chapter 6 of ASCE/SEI 7-2016.
- A proposal to update Appendix M for the 2018 IBC was submitted by FEMA and ASCE so it now only refers to the tsunami evacuation and site planning criteria of FEMA P-646.
- It will now defer to the tsunami hazard mapping and structural design guidelines of ASCE/SEI 7-16 Chapter 6.
- The title of Appendix M was also revised to focus only on tsunami vertical evacuation refuge structures.

APPENDIX M TSUNAMI-GENERATED FLOOD HAZARD SECTION

M101 REFUGE STRUCTURES FOR VERTICAL EVACUATION FROM TSUNAMI-GENERATED FLOOD HAZARD

M101.1 General. The purpose of this appendix is to provide tsunami vertical evacuation planning criteria for those coastal communities that have a tsunami hazard as shown in a Tsunami Design Zone Map.

M101.2 Definitions. The following words and terms shall, for the purposes of this appendix, have the meanings shown herein. Refer to Chapter 2 of this code for general definitions.

> **TSUNAMI HAZARD DESIGN ZONE MAP.**
>
> A map that designates the extent of inundation by a Maximum Considered Tsunami as defined by ASCE 7-16 Standard.

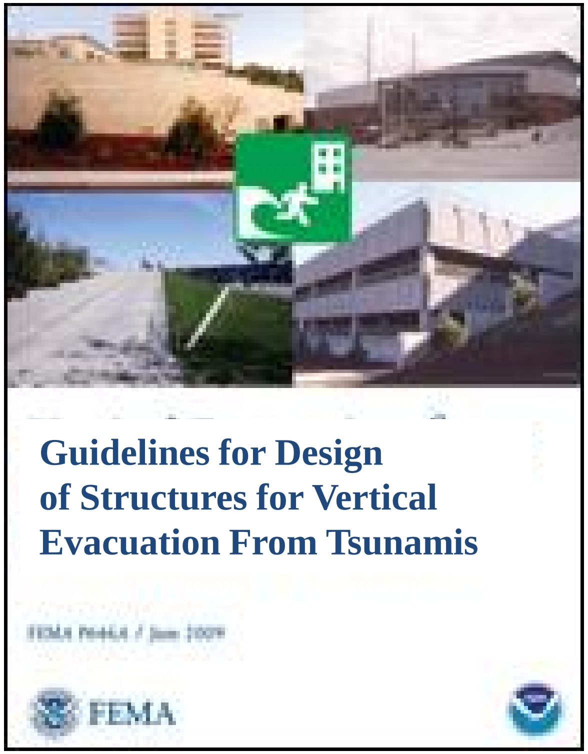
M101.3 Establishment of tsunami design zone. Where applicable, the Tsunami Design Zone Map shall meet or exceed the inundation limit given by the ASCE 7 Tsunami Design Geodatabase.

M101.4 Planning of tsunami vertical evacuation refuge structures within the tsunami design zone. Tsunami Vertical Evacuation Refuge Structures located in a tsunami design zone shall be planned, sited and developed in general accordance with the planning criteria of FEMA P646-12.

> **Exception:** These criteria shall not be considered mandatory for evaluation of existing buildings for evacuation planning purposes.

FEMA P-646 Vertical Refuge Guide

- The April 2012 edition of FEMA P646 contains information now in conflict with ASCE/SEI 7-16 Chapter 6 and must be updated to remove those conflicts.
- Funding for a full update was not available from either NOAA/NTHMP or FEMA/NEHRP.
- A “low cost” update has been added to an existing task order and is currently being performed by Ian Robertson.
- The final draft due this spring and will be sent out for review; including NTHMP MES State and territorial representatives.



Thank-You