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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• Chap 6 – Tsunami Loads and Effects
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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 will also be publishing a companion design guide in late 2017 with numerous design examples.
Tsunami-Resilient Engineering Subject Matter Incorporated in ASCE 7

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

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

Performance by Risk Category

Consequences (Life and economic losses)

Warning and Evacuation Capability

Tsunami Inundation Modeling to Define Tsunami Design Zones

Loads and Effects incorporating Coastal, Hydraulic, Structural, and Geotechnical Engineering

Consensus on Seismic Source Assessment by USGS

Maps based on Probabilistic Tsunami Hazard Analysis (PTHA)

Scope of ASCE/SEI 7 Chapter 6

Societal Impact Assessment for the Five Western States by USGS

Structural Reliability Validated
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
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- 6.15 Designated Nonstructural Systems
- 6.16 Non-Building Structures
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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

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

1. **SOURCE**
   - Moment Magnitude and Slip, Source Locations, and Recurrence based on Seismology

2. **PROPAGATION**
   - Propagation per long wave equations in deep ocean to determine amplitude and period at offshore locations

3. **SITE ANALYSIS of DESIGN**
   - Inundation limit and Runup determined by nonlinear wave propagation models

4. **DESIGN MAPS**
   - Probabilistic Maps of Offshore Amplitude, Inundation Limit and Runup for 5 states
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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 $k_s \rho_{sw} gh$)
  – 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 $\frac{1}{2} k_s \rho_{sw} (hu^2)$)
  – 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 $\sqrt{k \text{ m}}$)
  – 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

![Diagram of Tsunami Vertical Evacuation Refuge Structures]

6.14-1. Minimum Refuge Elevation

The minimum elevation of the lowest occupiable Refuge Level is one story higher, but not less than 10 ft. above the Refuge Design Inundation Depth.

Refuge Design Inundation Elevation coincides with 130% of inundation elevation.

Grade Plane of Structure

Reference Datum NAVD 88

Site-Specific Max. Considered Tsunami inundation elevation at the structure
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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.
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

Questions?