ASCE 7 AND THE DEVELOPMENT OF A TSUNAMI BUILDING CODE FOR THE U.S.

Tohoku Tsunami photograph at Minami Soma by Sadatsugu Tomizawa

Background Information on the Objective of the ASCE TLESC

- A national standard for engineering design for tsunami effects written in mandatory language does not exist. As a result, tsunami risk to coastal zone construction is not explicitly and comprehensively addressed in design.
- The Tsunami Loads and Effects Subcommittee of the ASCE/SEI 7 Standards Committee is developing a proposed new Chapter 6 - Tsunami Loads and Effects for the ASCE 7-16 Standard.
- Anticipated completion by TLESC in November 2013
- Review by ASCE 7 Main Committee in 2014
- ASCE 7-16 to be published by March 2016
- ASCE 7 Tsunami Provisions will then be referenced in IBC 2018
- Local jurisdiction codes could decide to adopt Chapter 6 earlier.

ASCE 7-16

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

USA Codes and Standards

- **International Building Code (IBC)**
- **ASCE 7 Minimum Design Loads for Buildings and Other Structures (ASCE 7) developed in an ANSI-accredited consensus process**

- **Other Standards:**
  - **Material specific design specifications**
  - **Non-structural installation standards**
  - **Testing and qualification standards**

The Code Development Process

Special Considerations for Tsunami Design

- For Pacific NW regions governed by nearby offshore earthquakes, structure will need to resist earthquake prior to onset of tsunami.
- Need for local tsunami inundation mapping of hydrodynamic loading parameters, based on probabilistic regional offshore tsunami heights
- Tsunami wave height not proportional to EQ magnitude
- Include possible earthquake-induced subsidence affecting tsunami inundation
- Flow acceleration in urban landscapes
- Analyze the key loading phases of depth and velocity in momentum flux pairs
- Tsunami forces not proportional to building mass
- Inflow and outflow characteristics will be different
- Debris accumulation and low-speed debris impacts
- Scour depth at the perimeter of the building can be equal to the flow depth

Proposed Scope of the ASCE Tsunami Design Provisions
2016 edition of the ASCE 7 Standard, Minimum Design Loads for Buildings and Other Structures

6.1	**General Requirements**
6.2	**Definitions**
6.3	**Symbols and Notation**
6.4	**Tsunami Risk Category Design Criteria**
6.5	**Procedures for Determination of Offshore Tsunami Wave Height**
6.6	**Procedures for Determining Tsunami Inundation**
6.7	**Design Parameters for Tsunami Flow over Land**
6.8	**Structural Design Procedure 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 reduced loading on buildings***
6.14	**Special Occupancy Structures**
6.15	***Designated Nonstructural Systems (Stairs, Life Safety MEP)***
6.16	***Non-building critical facility structures***
C6	**Commentary and References**

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	**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.**
Risk Category IV	**Buildings and other structures designated as essential facilities**

- Evacuation procedures for emergency response are still necessary.
- In most communities, it will not be economically practical or justified to prohibit construction in a tsunami hazard zone based on a long return period. Therefore, the tsunami maps of ASCE are <u>not</u> for land use zoning

Tsunami Risk Category Design Criteria

- Not applicable to any buildings within the scope of the International Residential Code; Not applicable to light-frame residential construction
- Not applicable to any Risk Category I buildings
- Not applicable to any Risk Category II structures up to ~65 feet in height
- Applicable to all Risk Category III and IV buildings and structures, and Risk Category II buildings greater than 65 ft height for reliable life safety and reasonable economy
- Economic impact in high seismic regions is anticipated to be nominal since most buildings subject to these requirements will be designed to Seismic Design Category D or greater (design for inelastic ductility).

Structural Performance Levels

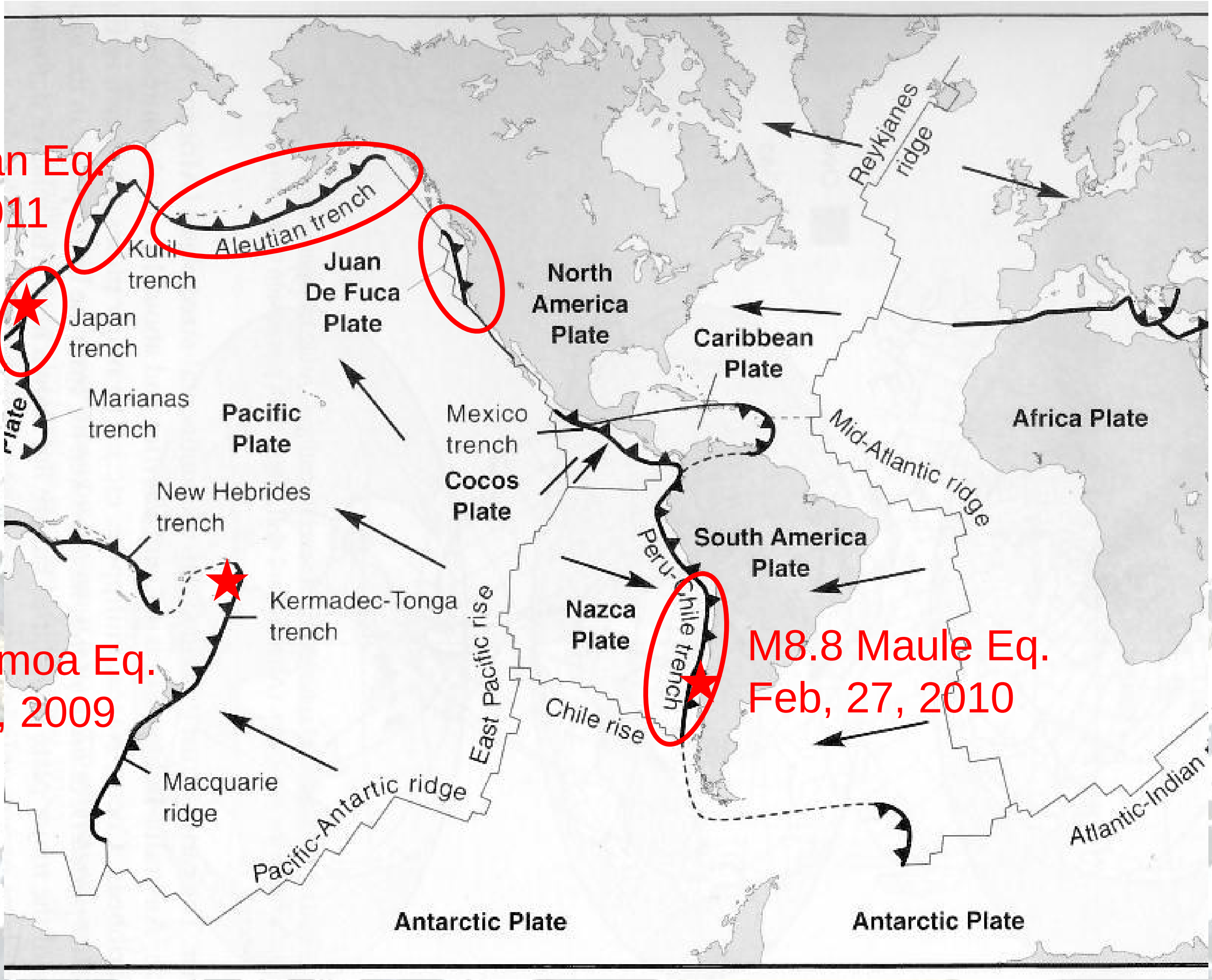
- IMMEDIATE OCCUPANCY STRUCTURAL PERFORMANCE: The post-event damage state in which a structure remains safe to occupy
- LIFE SAFE STRUCTURAL PERFORMANCE: The post-event damage state is that in which a structure has damaged components but retains a margin against onset of partial or total collapse.
- COLLAPSE PREVENTION STRUCTURAL PERFORMANCE: The post-event damage state is which a structure has damaged components and continues to support gravity loads but retains little or no margin against collapse.

Design based on Risk Category

		Tsunami Design Performance Level		
Tsunami Frequency	Operational	Immediate (Repairable) Occupancy	Life Safe	Collapse Prevented
Occasional (100 years)	Risk Category IV	Risk Category III	Risk Category II	
Max Considered (2500 yrs)			Risk Category IV	Risk Category III and > 65-ft. high Risk Category II

This is not a table of Performances for Seismic Ground Shaking

Tsunami-genic Seismic Sources of Principal Relevance to the USA



Lexicon Hierarchy of Hazard Definition from an Engineering (and Code Development) Perspective

- Hypothetical Hazards
- Historical and Paleo Hazards
- Hazard Assessment – (not necessarily quantified)

- **Probabilistic Hazard Analysis**
- Vulnerability and Exposure Assessment
- Vulnerability Analysis
- Engineering Risk Analysis

ASCE Tsunami Provisions to be applicable only to states and territories with quantifiable probabilistic hazard: Alaska, Washington, Oregon, California, Hawaii, and Guam, American Samoa, and Puerto Rico

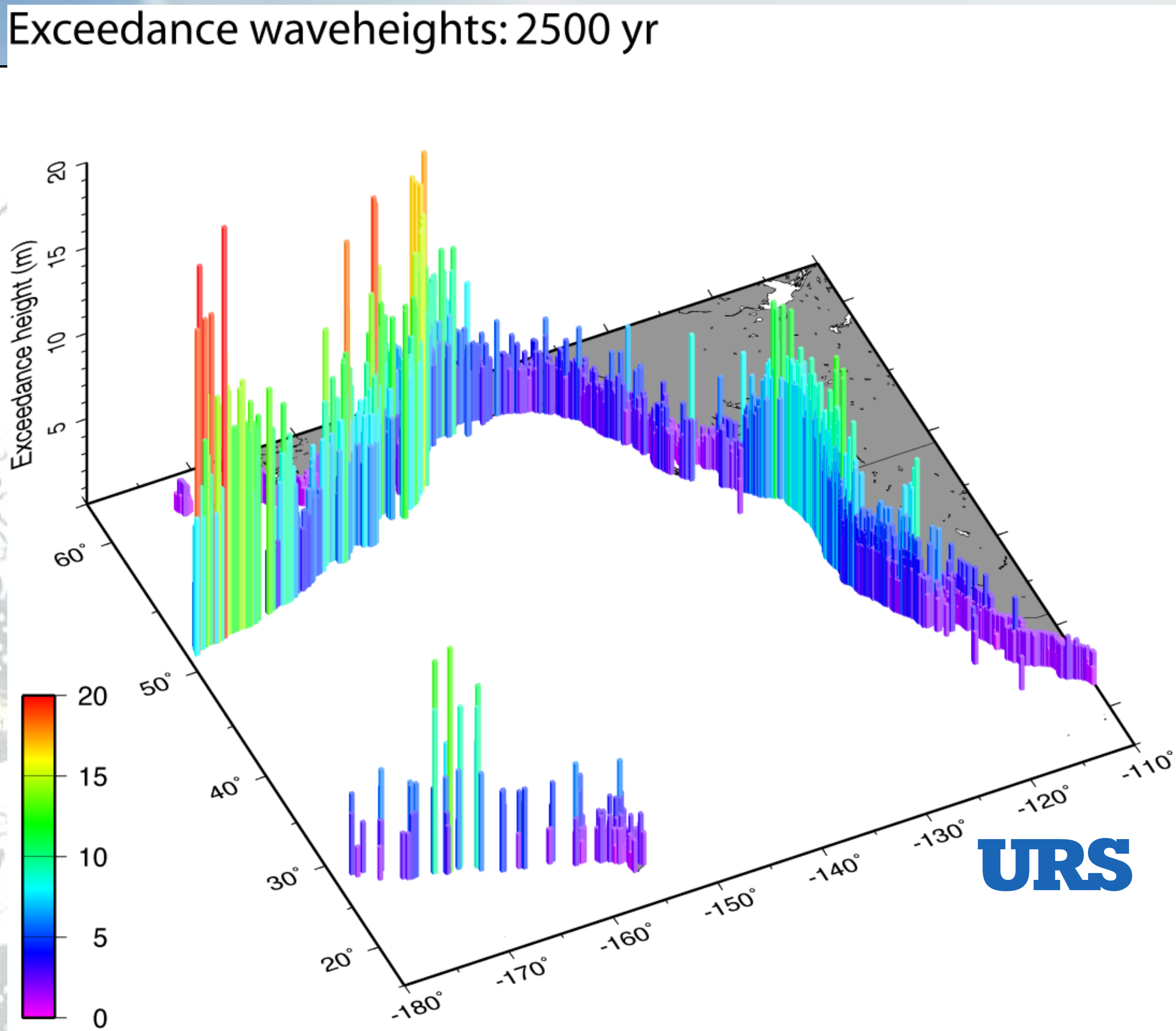
Procedures for Determination of Offshore Tsunami Wave Height

- **Performance criteria to be based on 2,500-year hazard level Maximum Considered Tsunami for consistency with ASCE 7 seismic hazard criteria with tsunami as a coseismic effect.**
- **A probabilistic Hazard Map of offshore tsunami height is being developed and will be incorporated in the Standard.**
- **The tsunami hazard inland inundation limiting zone affected at the 2,500-year level would be identified.**
- **Criteria will identify where ground shaking and subsidence from a preceding local offshore Maximum Considered Earthquake needs to be considered prior to tsunami arrival (for Alaska and the regions directly affected by the Cascadia Subduction Zone).**

Lessons from the Tohoku, Chile, and Sumatra Tsunamis

- <u>**Recorded history may not provide a good measure of the potential heights of great tsunamis**</u>**.**
- **Planning 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**

Example of Probabilistic Offshore Wave Heights



Probabilistic Tsunami Hazard Analysis

- The 2,500-year tsunami offshore wave height to used as the initial condition benchmark for local inundation maps or prescriptive inundation calculation
- The specified offshore wave height is attributed to the disaggregated predominant seismic sources for that region.

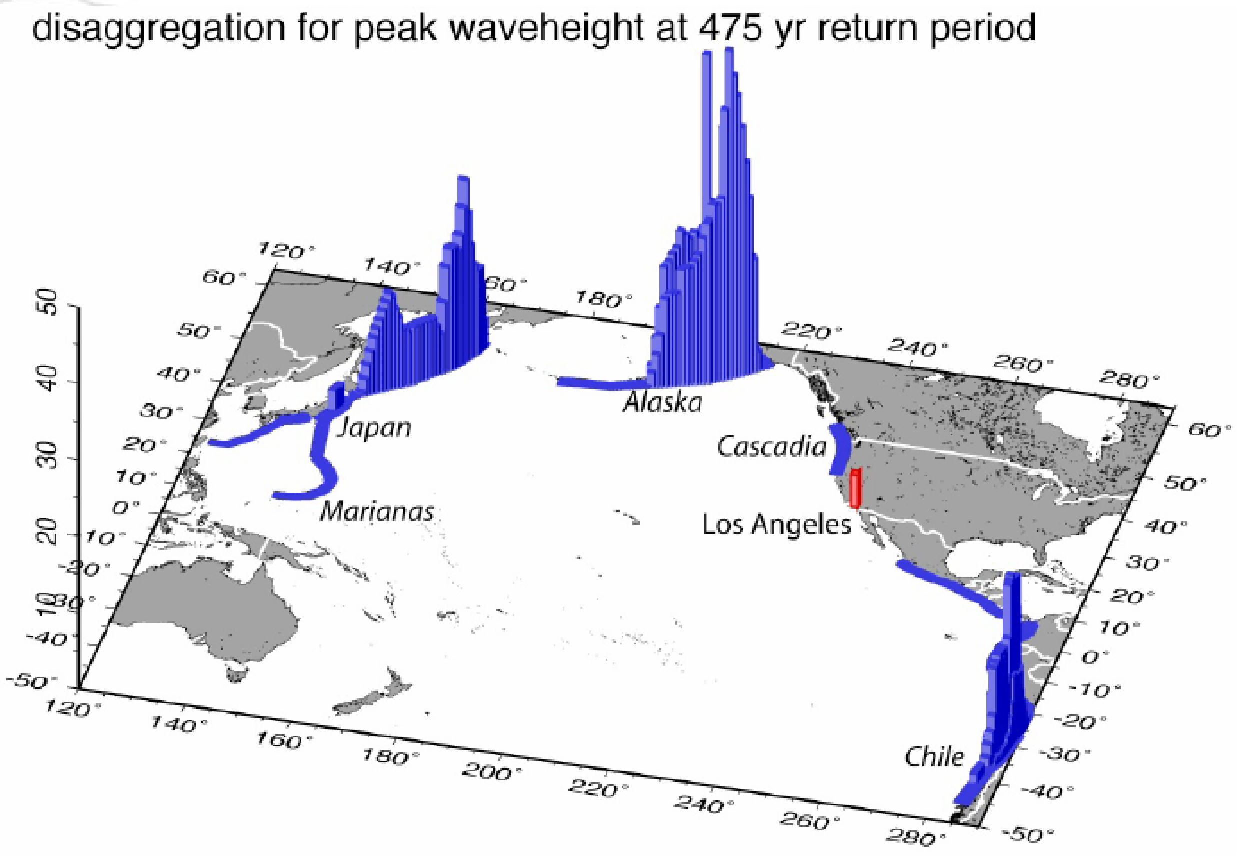
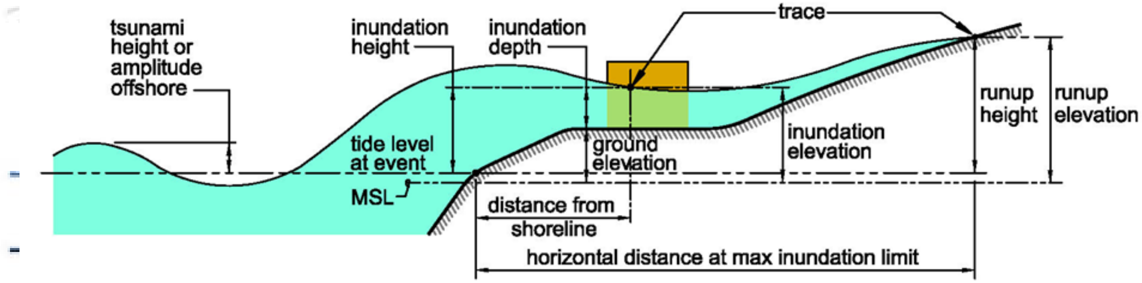


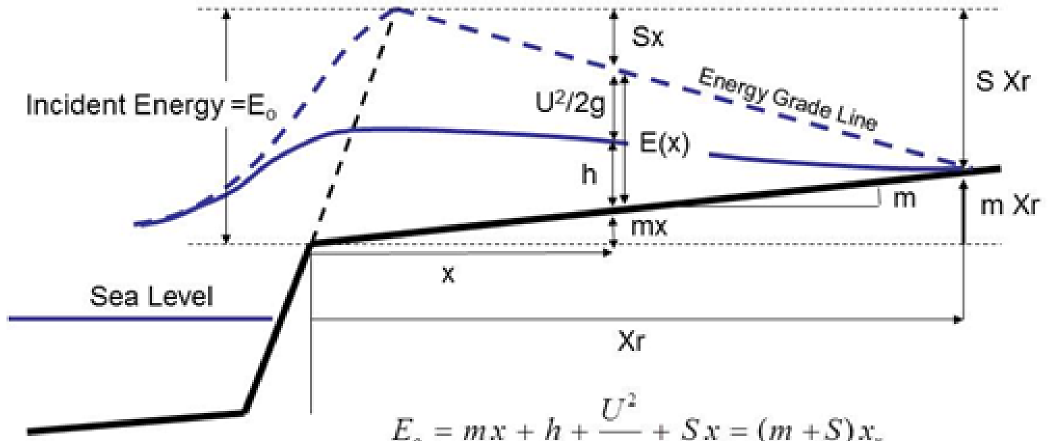
Figure 3 Source disaggregation for the tsunami hazard in the Los Angeles area for peak waveheight. The blue bars represent the relative contribution of each element towards the tsunami hazard (red bar) in the target area

Procedures for Determining Tsunami Inundation and Design Parameters

- **Site-specific modeling by an Energy Method to give expected flow depths, velocities, and horizontal inundation limits**



Idealized Geometry



$$E_o = mx + h + \frac{U^2}{2g} + Sx = (m+S)x_r$$

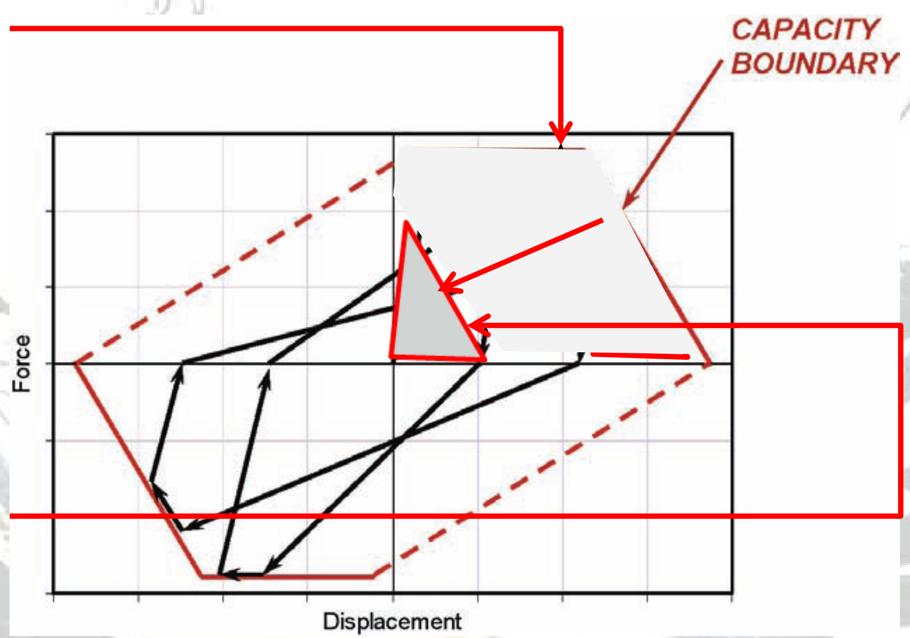
$$E(x) = h + \frac{U^2}{2g} \qquad E_o = h_o + \frac{U_o^2}{2g}$$

Structural Design Procedures for Tsunami Effects

- **Design as an extraordinary event (with no load factor on the tsunami effect)**
- **Consider critical stages of inundation**
- **Consider preceding earthquake if a local subduction zone**

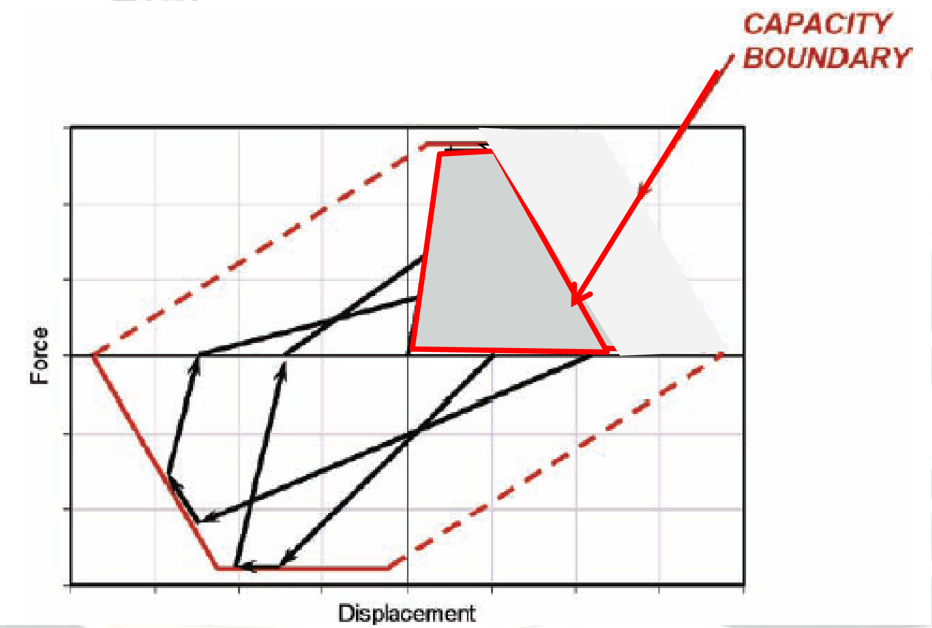
Conceptual Illustration: In the limit, if earthquake demand exhausts ductility to the Collapse Prevention point , the available tsunami capacity would be found to the right of the seismic end state, up to the strength degraded capacity boundary

Frame of Reference for capacity space for post-earthquake tsunami resistance then becomes severely force-controlled if seismic exhausts pre-degradation cyclic load path



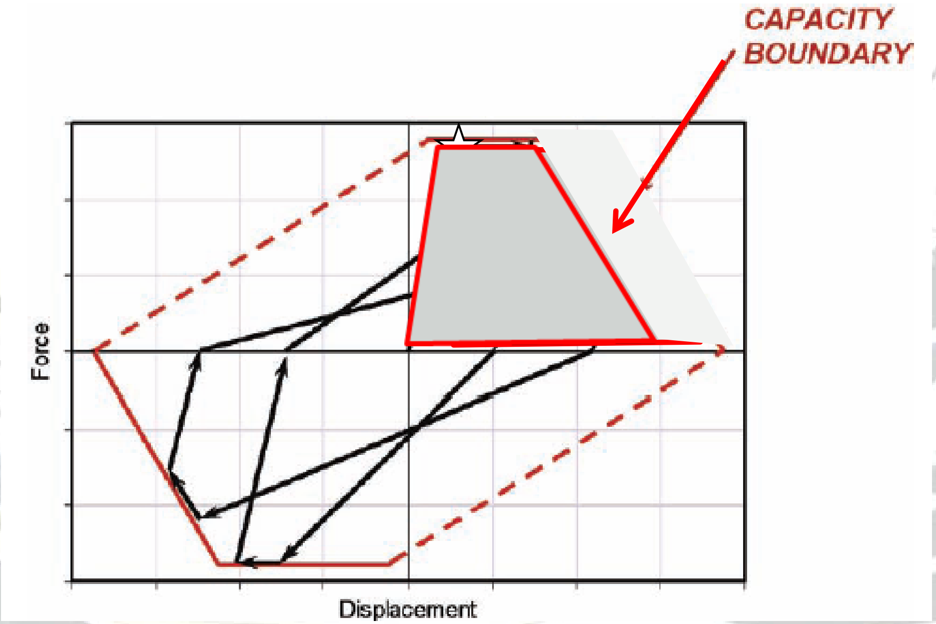
Structural Design Procedures for Tsunami Effects

- **Post-Life Safety Seismic Performance and resulting available response region for Tsunami Performance**
- **This may also define a force-controlled response space if available post-yield deformation becomes insufficient (per ASCE 41)**



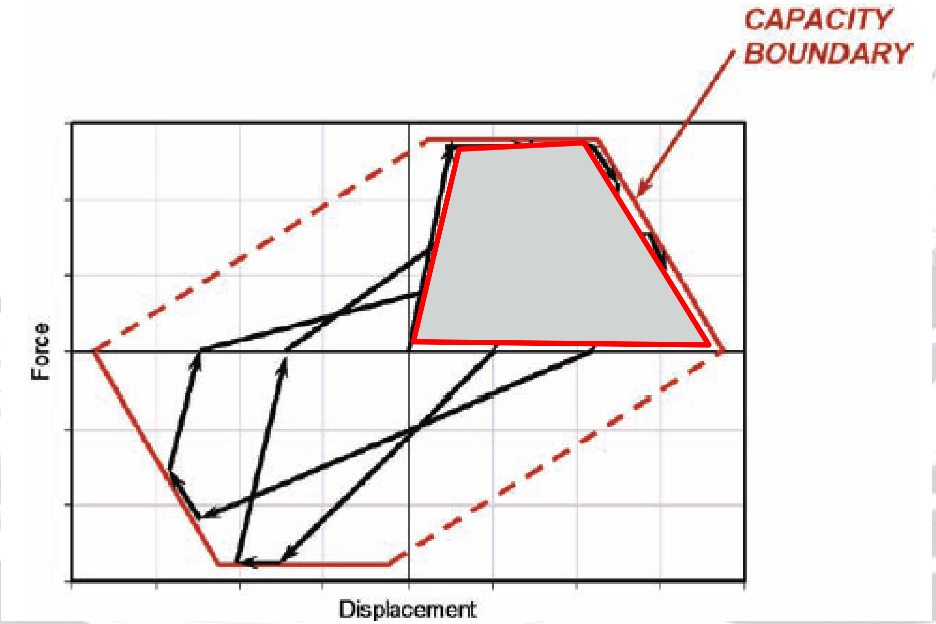
Structural Design Procedures for Tsunami Effects

- **Post –Immediate Occupancy Seismic Performance and available response region for Tsunami Performance**



Structural Design Procedures for Tsunami Effects

- **Available response region for Tele-Tsunami Performance**



Tsunami Loads and Effects

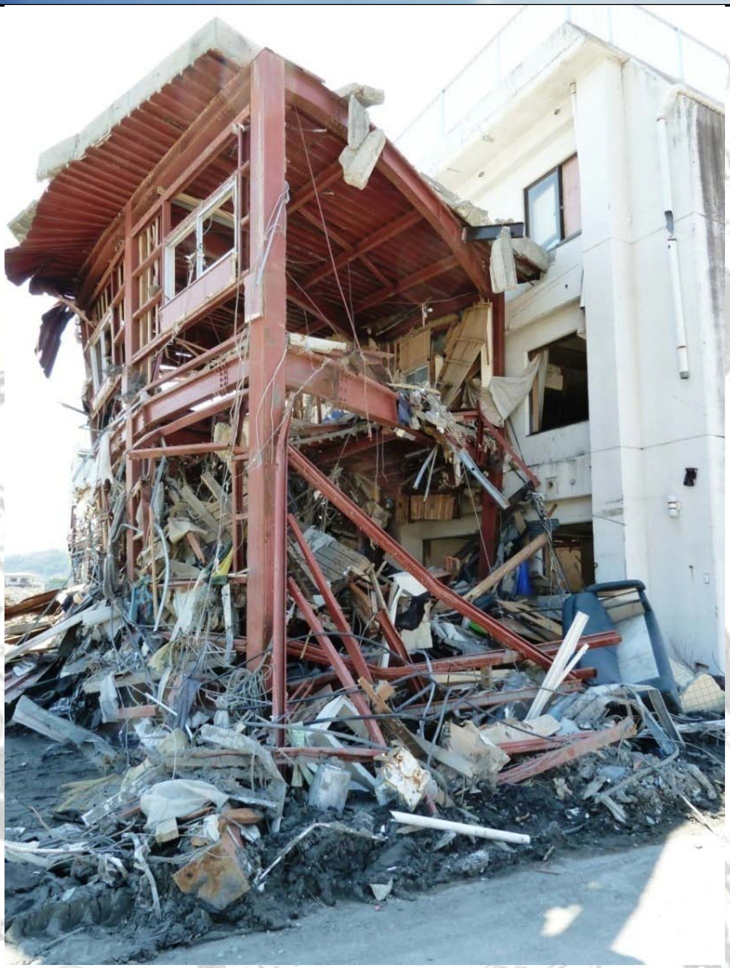
- Hydrostatic Forces:
  - Unbalanced Lateral Forces
  - Buoyant Uplift
  - Residual Water Surcharge Loads on Elevated Floors
- Hydrodynamic Forces:
  - Lateral Impulsive Forces of Tsunami Bores
  - Hydrodynamic Pressurization
  - Surge Forces
  - Damming by Waterborne Debris
- Waterborne Debris Impact Forces
- Scour Effects:
  - Shear of cyclic inflow and outflow
  - Transient liquefaction during rapid drawdown

Hydrodynamic Lateral Loading on Walls - Japan

Onagawa reinforced concrete fish storage building

Rikuzentakata Takada Matsubara Building Shear Wall Blowout

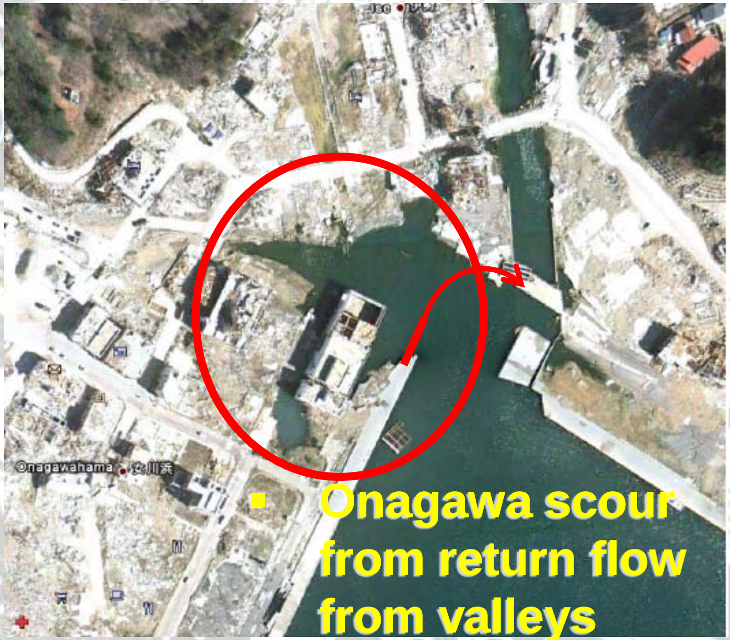
Building Performance - Debris Loading



Three-Story SMRF collapsed and pushed into concrete building

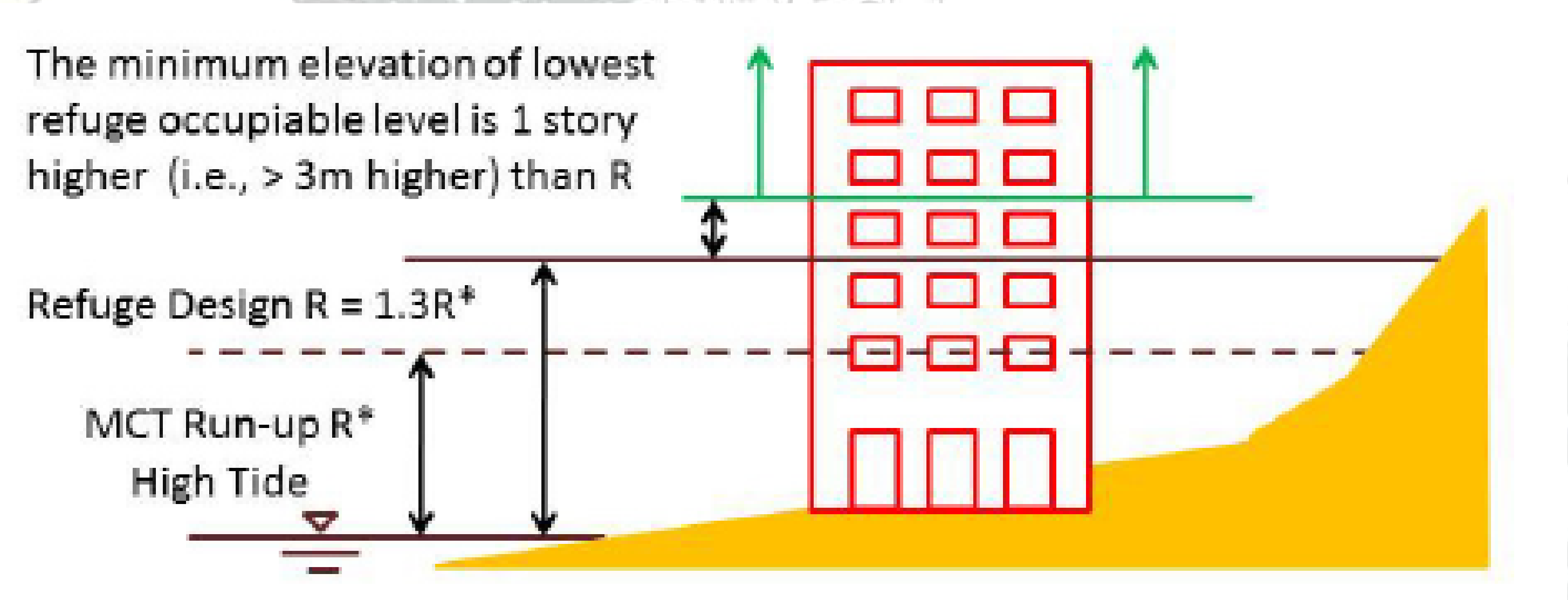
Three-Story SMRF with 5 meters of debris load accumulation wrapping

Scour/Erosion – Plentiful Examples



Special Occupancy Requirements

- **Vertical Evacuation Refuge Structures**



Summary of information

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- A method of probabilistic tsunami hazard analysis has been established.
- Methodologies for 2D tsunami inundation modeling have been further developed.
- Structural loading and analysis techniques for determining building performance have been developed.
- Analysis procedures for regions governed by local subduction earthquakes involves a multi-hazard performance-based approach
- The proposed ASCE 7 provisions for Tsunami Loads and Effects enables a set of analysis and design methodologies that are consistent with tsunami physics and performance based engineering.