ASCE 7 DEVELOPMENT OF TSUNAMI STRUCTURAL DESIGN PROVISIONS FOR THE U.S.

Gary Chock

August 2013

Status & Need for Design Maps

Tohoku Tsunami photograph at Minami Soma by Sadatsugu Tomizawa

ASCE is Developing a Tsunami-Resilient Design Code

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- **The Tsunami Loads and Effects Subcommittee of the ASCE/SEI 7 Standards Committee is developing a new Chapter 6 - Tsunami Loads and Effects for the ASCE 7-16 Standard.**
- **ASCE 7-16 to be published by March 2016**
- **Tsunami Provisions would then be referenced in IBC 2018**
- **Application by engineers to design for community resilience before a tsunami event.**
- **After a tsunami, it will have even more significance as means to plan and evaluate what is appropriate in reconstruction and to enable Building Back Better.**

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 Categories
6.5 Hazard Level of the Maximum Considered Tsunami
6.6 Flow Parameters Based on Runup
6.7 Site-Specific Probabilistic Tsunami Hazard Analysis
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

The Code Development Process

Experience from Design Practice and Post-Disaster Surveys – Evaluation of Performance

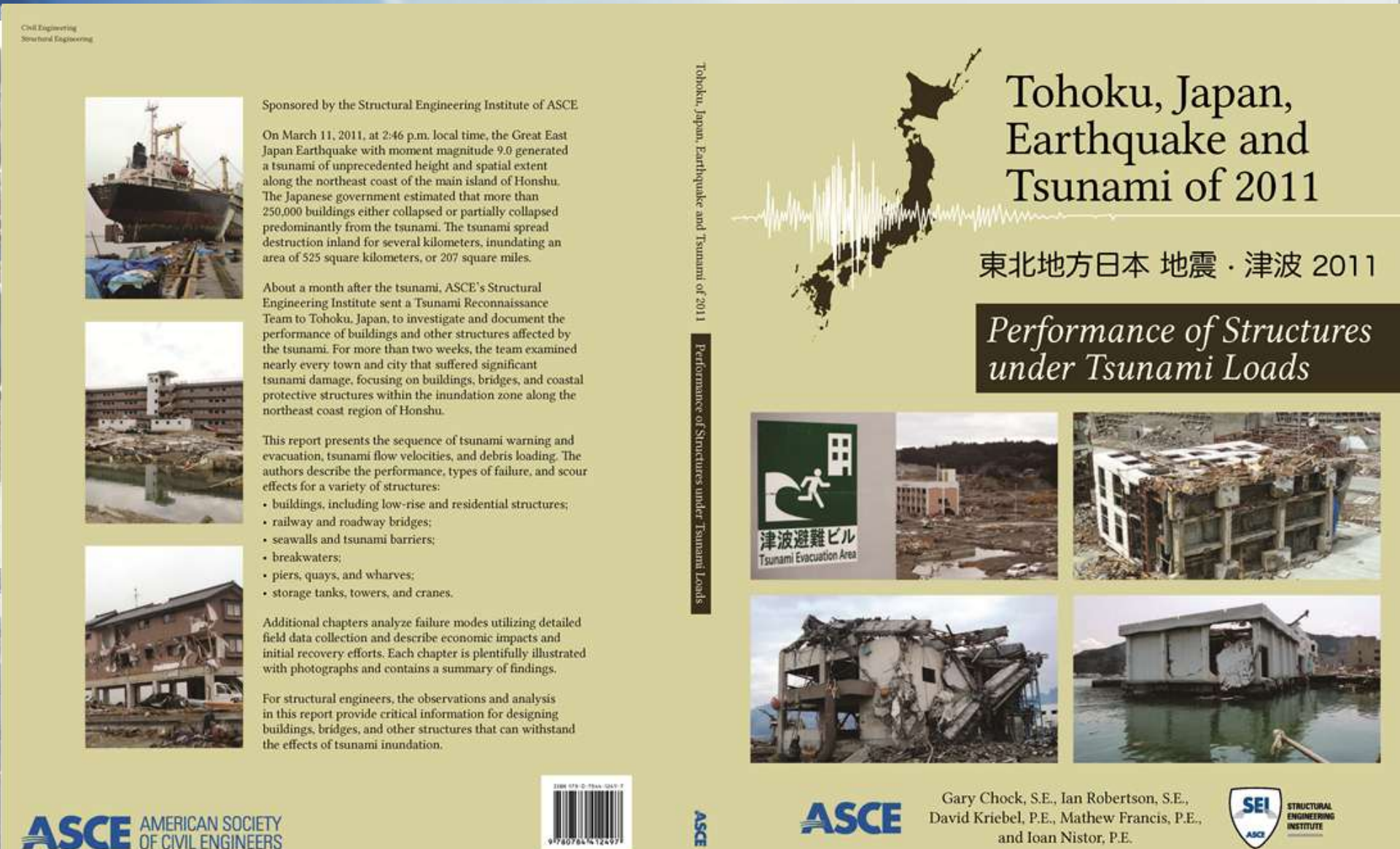
Research & Development

Codes and Standards

<u>Stakeholders</u>
Users
Producers
General Interest

Building Officials

東北地方津波 Tohoku Tsunami



Civil Engineering
Structural Engineering

Sponsored by the Structural Engineering Institute of ASCE

On March 11, 2011, at 2:46 p.m. local time, the Great East Japan Earthquake with moment magnitude 9.0 generated a tsunami of unprecedented height and spatial extent along the northeast coast of the main island of Honshu. The Japanese government estimated that more than 250,000 buildings either collapsed or partially collapsed predominantly from the tsunami. The tsunami spread destruction inland for several kilometers, inundating an area of 525 square kilometers, or 207 square miles.

About a month after the tsunami, ASCE's Structural Engineering Institute sent a Tsunami Reconnaissance Team to Tohoku, Japan, to investigate and document the performance of buildings and other structures affected by the tsunami. For more than two weeks, the team examined nearly every town and city that suffered significant tsunami damage, focusing on buildings, bridges, and coastal protective structures within the inundation zone along the northeast coast region of Honshu.

This report presents the sequence of tsunami warning and evacuation, tsunami flow velocities, and debris loading. The authors describe the performance, types of failure, and scour effects for a variety of structures:

- buildings, including low-rise and residential structures;
- railway and roadway bridges;
- seawalls and tsunami barriers;
- breakwaters;
- piers, quays, and wharves;
- storage tanks, towers, and cranes.

Additional chapters analyze failure modes utilizing detailed field data collection and describe economic impacts and initial recovery efforts. Each chapter is plentifully illustrated with photographs and contains a summary of findings.

For structural engineers, the observations and analysis in this report provide critical information for designing buildings, bridges, and other structures that can withstand the effects of tsunami inundation.

ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS

Tohoku, Japan, Earthquake and Tsunami of 2011

Performance of Structures under Tsunami Loads

ASCE

Tohoku, Japan, Earthquake and Tsunami of 2011

東北地方日本 地震・津波 2011

Performance of Structures under Tsunami Loads

津波避難ビル
Tsunami Evacuation Area

ASCE

Gary Chock, S.E., Ian Robertson, S.E., David Kriebel, P.E., Mathew Francis, P.E., and Ioan Nistor, P.E.

SEI STRUCTURAL ENGINEERING INSTITUTE

Report on Performance of Evacuation Structures in Japan

Tsunami Vertical Evacuation Buildings – Lessons for International Preparedness Following the 2011 Great East Japan Tsunami

Fig. 2. Map and images of nine vertical evacuation buildings in Kesennuma City, including numbers of people saved and tsunami inundation marked in yellow [29]. These comprise office buildings (A, F, G, I); a cannery (B), a retail building (C), welfare centre (D), a car parking deck (E) and a community centre (H).

Tsunami evacuation: Lessons from the Great East Japan earthquake and tsunami of March 11th 2011

S. Fraser
I. Matsuo
G.S. Leonard
H. Murakami

GNS Science Report 2012/17
April 2012

Basic Lessons for Design of Buildings from Past Tsunami

- Structures of all material types can be subject to general and progressive collapse during tsunami, but it is feasible to design buildings to withstand tsunami events
- Mid-rise and larger buildings with robust structural systems survive.
- Seismic Design has significant benefits to tsunami resistance.
- Local structural components may need local “enhanced resistance
- Hydrodynamic loading of high intensity and debris impacts
- Foundation system should consider uplift and scour effects particularly at corners.

Lessons from the Tohoku, Chile, and Sumatra Tsunamis

- **Recorded history has not provided a sufficient measure of the potential heights of great tsunamis.**
- **Engineering design must always consider the occurrence of possible events greater than in the historical record**
- **Therefore, Probabilistic Tsunami Hazard Analysis should be performed in addition to historical event scenarios, so that the uncertainty of scientific estimation is explicitly considered**
- **This is consistent with the ASCE approach for probabilistic seismic hazard analysis**
- **This approach is inherently more precautionary with lives and property than deterministic scenario assumptions based on historical records.**

Tsunami-Resilient Design Strategy

- Select a site appropriate and necessary for the building
- Select an appropriate structural system and perform seismic design first
- Determine flow depth and velocities at the site based on a probabilistic tsunami hazard analysis
- Check robustness of expected strength within the inundation height to resist hydrodynamic forces
- Check resistance of lower elements for hydrodynamic pressures and debris impacts to avoid progressive collapse
- Foundations to resist scour at the perimeter of the building
- Elevate critical equipment as necessary

Visual 20.9

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**

- Tsunami provisions have some amended itemization of the above

Consequence Guidance on Risk Categories of Buildings Per ASCE 7

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

Visual 20.11

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 only Risk Category II buildings greater than ~65 ft height
- Economic impact is anticipated to be very nominal to western states since most buildings subject to these requirements will be designed to Seismic Design Category D or greater (design for inelastic ductility).

Tsunami Performance Levels

Hazard	Tsunami Performance Level			
Tsunami Frequency	Operational	Immediate Occupancy	Life Safe	Collapse Prevention
Maximum Considered (2500 yrs)		Vertical Evacuation Refuge Buildings	Risk Category IV	Risk Category III and Risk Category II > 65-ft.-high

Critical Facilities and Lifelines are essential for Community Resilience

- **Critical Facilities**
  - Maintain the public's health and safety
  - e.g., hospitals, police, fire, and emergency medical services buildings, essential government buildings, ports, airports, water supply, wastewater treatment plants, power generating stations
- **Lifelines**
  - Power, transportation systems, and storage, treatment, and distribution systems of water and fuel, IT services and communications, and sewage systems

Structural Performance Levels

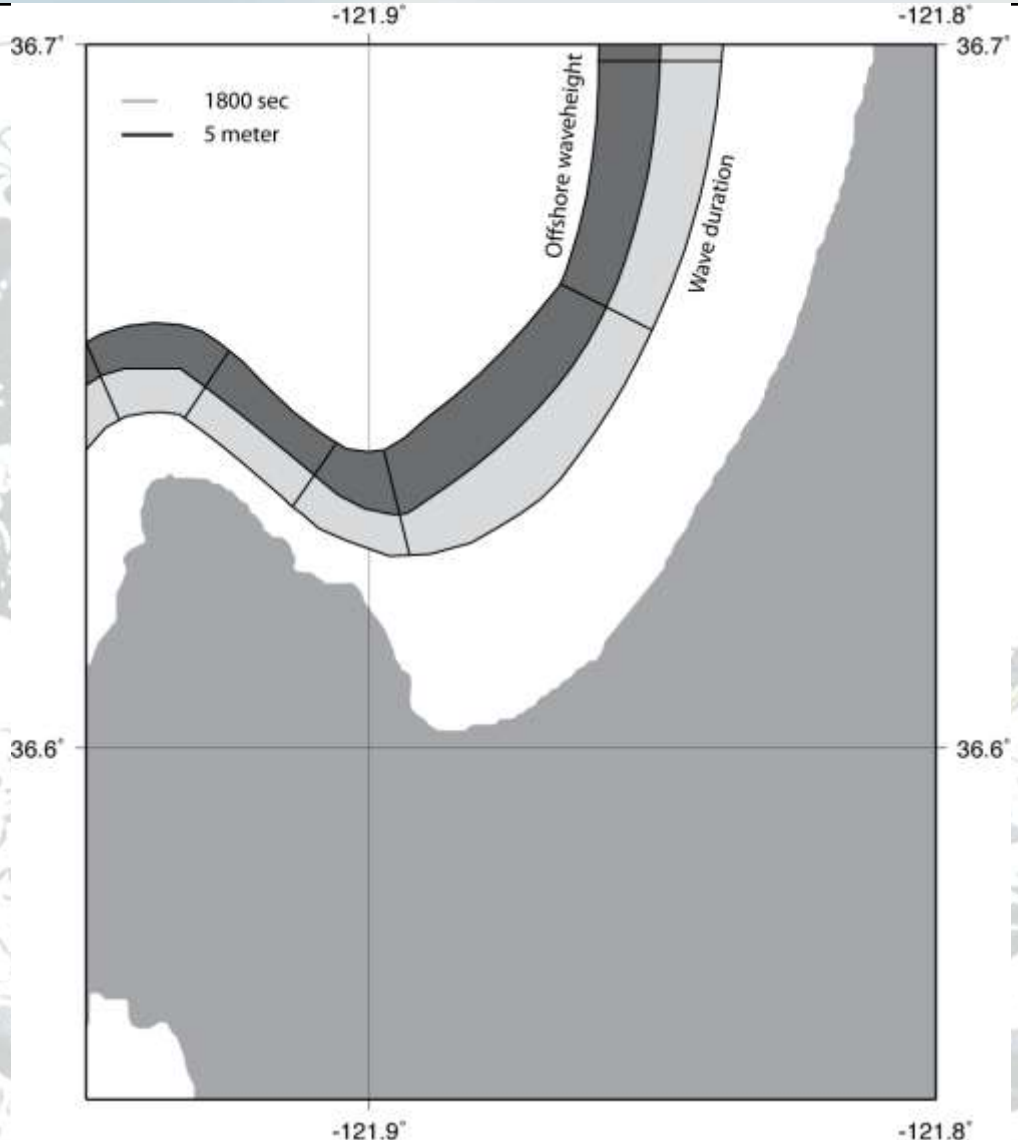
- IMMEDIATE OCCUPANCY STRUCTURAL PERFORMANCE: The post-event damage state in which a structure remains safe to occupy
- LIFE SAFE STRUCTURAL PERFORMANCE: The post-event damage state is that in which a structure has damaged components but retains a margin against onset of partial or total collapse.
- 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.

Procedure

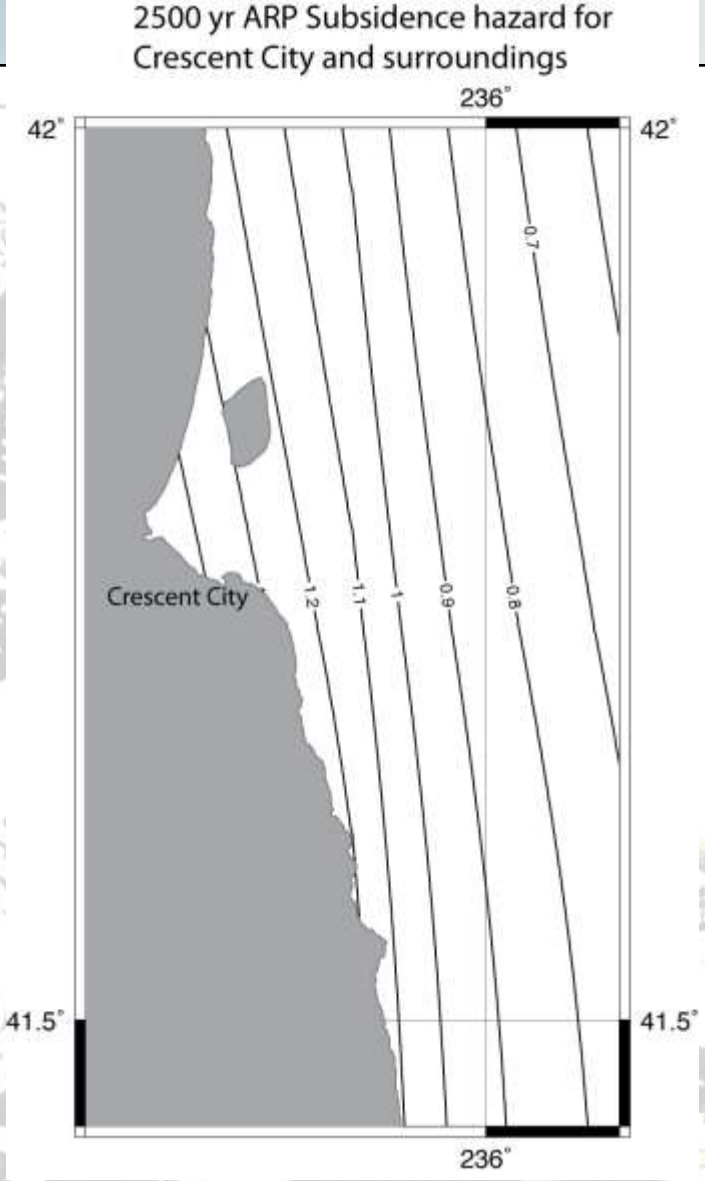
- Performance criteria to be based on 2,500-year hazard level Maximum Considered Tsunami
- Consistency with ASCE 7 seismic hazard criteria.
- Probabilistic hazard map of offshore tsunami height and waveform
- The tsunami hazard inland inundation limiting zone affected at the 2,500-year hazard level by Monte Carlo simulation or Hazard-Consistent Tsunami scenarios with allowance for aleatory uncertainty
- Water depth and current velocity at a site to be determined by energy principles with a method calibrated to tsunami observations
- Criteria for regions where ground shaking and subsidence from a preceding local offshore Maximum Considered Earthquake
- Extraordinary Load Combinations of forces in consideration of rarity

Example of an Offshore 2500-yr. Tsunami Amplitude Map

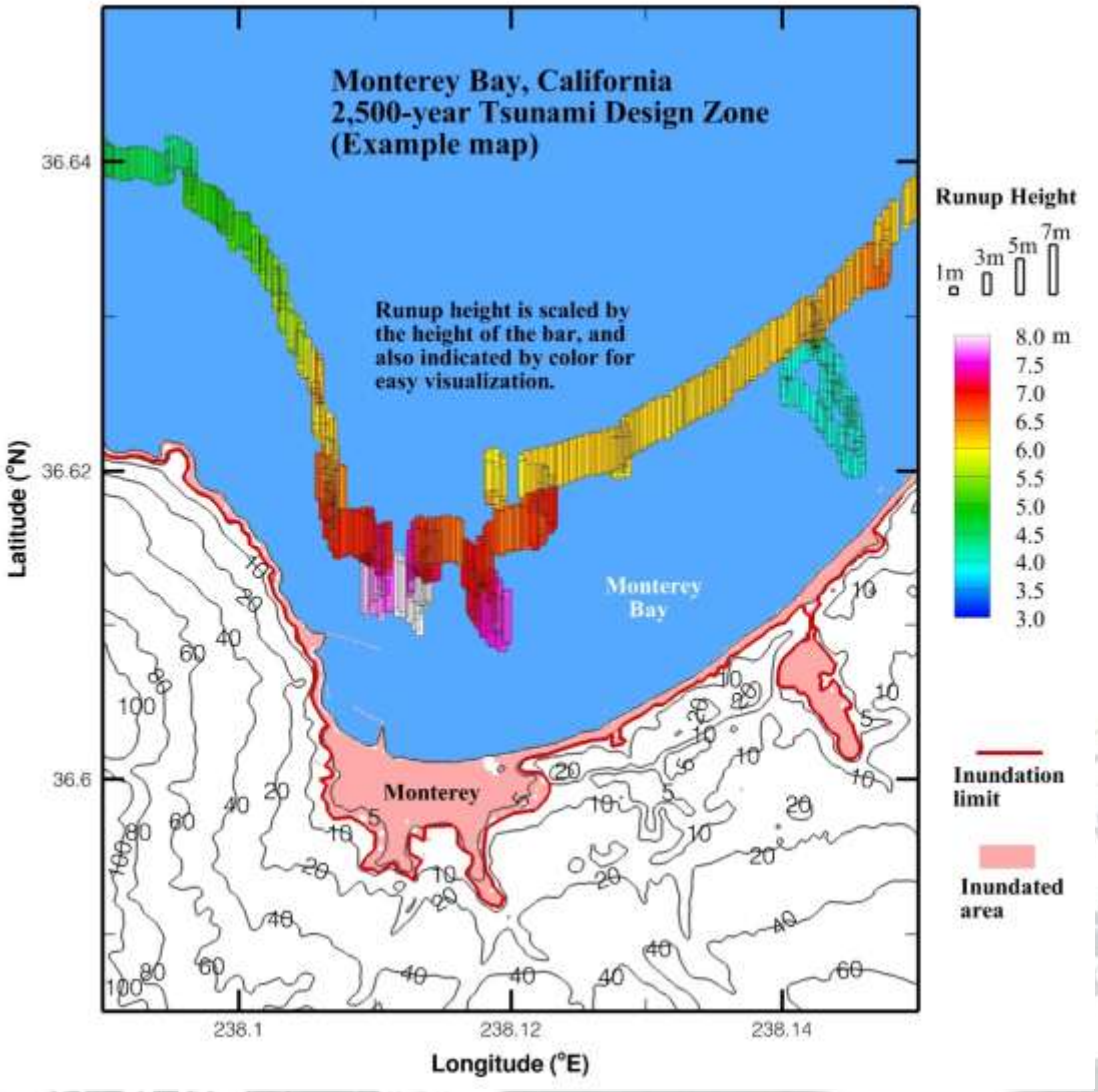
- Monterey CA
  - Amplitude
  - Predominant Period
  - (Plus Regional Wave Form Parameters)

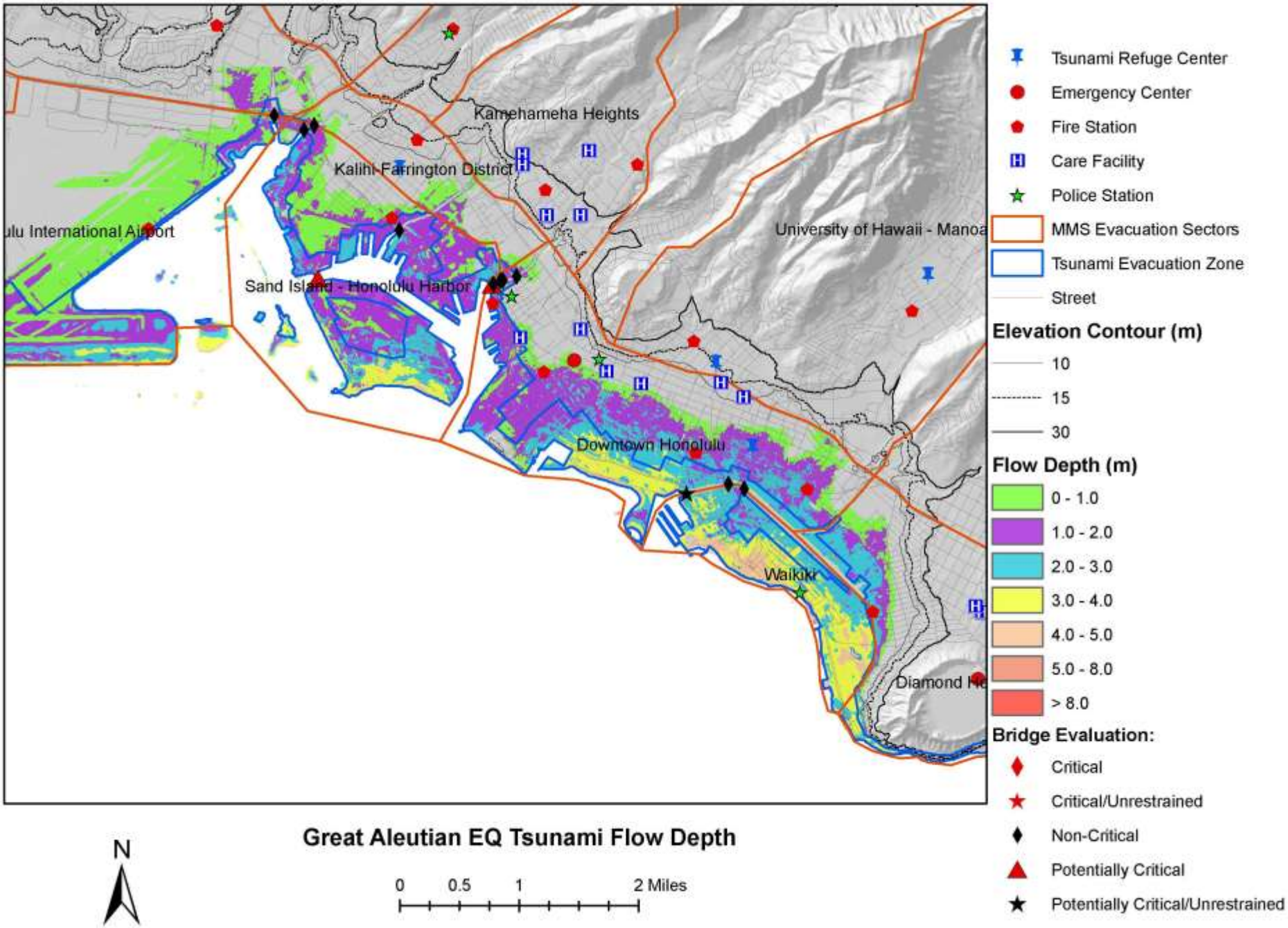


Subsidence Hazard Map to be provided where regions are predominated by local seismic source



Example Illustration of a Design Map at a Reference Site





Example of a more detailed locally-produced inundation map (GAT event ~ 3,000 ARP?)

Strategy for Two-Stages of Mapping Implementation

- **ASCE role in rectifying consistency with criteria for other extreme loading, and establishing the probabilistic inundation hazard maps (and standardization of map style and format).**

  [1 year ending in 2014]

- **Later development of consistent local probabilistic inundation maps by the states under the federal National Tsunami Hazard Mitigation Program (NTHMP) or other programs**

  [Five years leading up to 2019]

The ASCE Tsunami Loads and Effects Subcommittee

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