FEMA P646 and P646A
Guidelines for Design of Structures for Vertical Evacuation from Tsunamis

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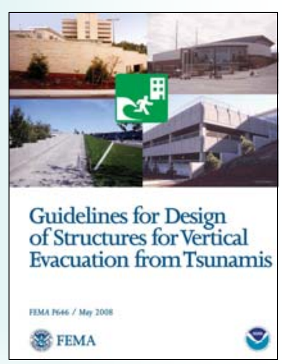
Tsunami Evacuation Building Workshop
September 28 & 29, 2009
Cannon Beach, Seaside, Portland

Outline

- Discuss feasibility of tsunami-resistant construction
- Introduce FEMA P646
- Highlight major concepts:
  - ✓ Vertical evacuation options
  - ✓ Siting, spacing, sizing, and elevation considerations
  - ✓ Load determination and structural design criteria
- Introduce FEMA P646A



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Feasibility

Photographer
Jean Guichard

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Feasibility

Figure 2-11 Beach houses with varying levels of damage in El Popoyo, Nicaragua (1992 Nicaragua Tsunami).

All three houses are in the same vicinity.

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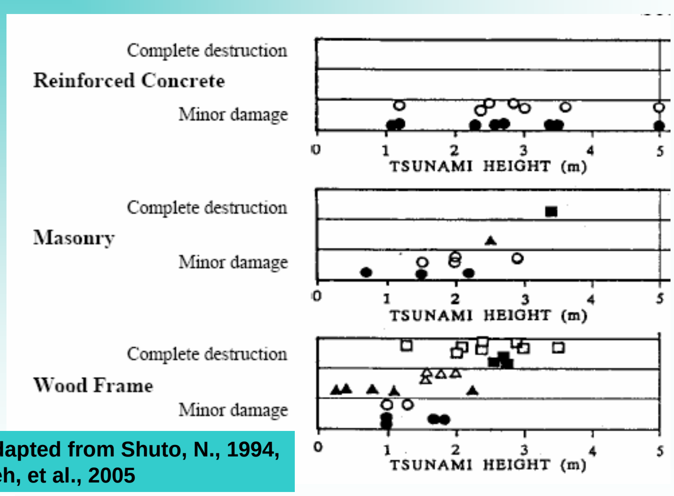
Feasibility

Figure 2-13 Examples of reinforced concrete structures that survived the 1993 Okushiri Tsunami: vista house at Cape Inaho (left); and fish market in Aonae (right).

Photos courtesy of N. Shuto

Historic Building Performance



Adapted from Shuto, N., 1994, Yeh, et al., 2005

ATC-64 Project Participants

Project Management Committee

- Steve Baldridge
- John Hooper — **code/design**
- Ian Robertson — **feasibility**
- Tim Walsh — **hazard**
- Harry Yeh — **theory/forces**

FEMA/ATC

- Mike Mahoney
- Bob Hanson
- Chris Rojahn
- William Holmes — **code/design**
- Jon Heintz

Project Review Panel

- Chris Jones
- John Aho
- George Crawford
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- Leslie Ewing
- Michael Hornick
- Chris Jonientz-Trisler
- Marc Levitan
- George Priest — **hazard**
- Charles Roeder
- Jay Wilson

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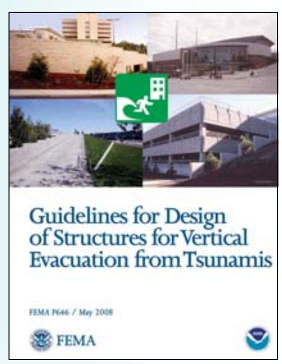
FEMA P646 Contents

- Tsunami behavior, characteristics, and historic data
- Tsunami hazard assessment
- Vertical evacuation options
- Siting, spacing, sizing, and elevation considerations
- Load determination and structural design criteria
- Structural design concepts and additional considerations
- Appendices (examples and additional information)



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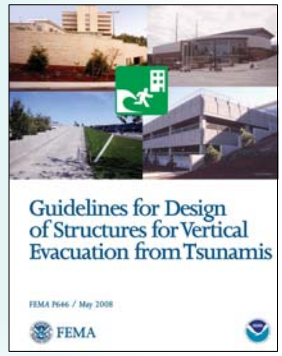
Objectives, Scope, and Limitations

- Engineering design guidance manual
- Tsunami-resistant design
- Supplement to existing U.S. codes/standards
- Best present knowledge
- Intended for Refuge Structures
- Not a mandate for all structures in tsunami hazard areas



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Tsunami Hazard Assessment

- Tsunami hazard is a combination of
  - ✓ the presence of a geophysical tsunami source,
  - ✓ exposure to tsunamis generated by that source, and
  - ✓ extent of inundation that can be expected as a result of a tsunami reaching the site.

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The National Tsunami Hazard Mitigation Program: "Credible Worst-Case Scenarios"

- State mapping efforts are based on credible worst-case scenarios
- Credible worst-case scenarios are based on:
  - ✓ a geophysical tsunami source that can be scientifically defended as a worst-case scenario for a particular region or community, and
  - ✓ a tsunami inundation model for that scenario.
- Maps typically display maximum inundation depth and maximum velocity

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Recommended Tsunami Hazard Level

- Maximum Considered Tsunami (MCT):
  - ✓ Recommended design tsunami
  - ✓ Based on the Deterministic Maximum Considered Earthquake (MCE)
  - ✓ Consistent with the 2500-yr return period associated with the MCE

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Vertical Evacuation Concepts

- Characteristics of vertical evacuation solutions:
  - ✓ Ability to receive a large numbers of people in a short time frame
  - ✓ Ability to efficiently transport occupants vertically to areas of refuge located above the level of flooding
  - ✓ Ability to withstand loss of lower level walls, nonstructural systems, and contents

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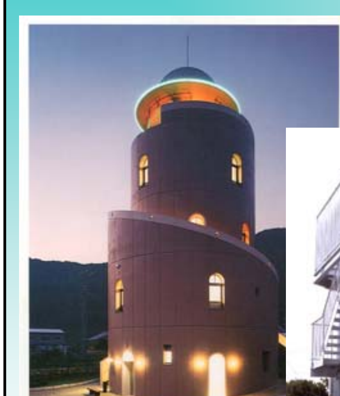
Vertical Evacuation Concepts



Nishiki Tower, Mie Prefecture

Tasukaru Tower (Fujiwara Industries CO., LTD)

Shirahama Resort, Tokushima Prefecture

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Vertical Evacuation Concepts

- ***Soil Berms***
  - ✓Easy to design and construct
  - ✓Easy ingress
  - ✓Alleviates apprehension about entering buildings following earthquakes
  - ✓Natural tendency to "go to high ground"

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Vertical Evacuation Concepts

- ***Parking Garages***
  - ✓Revenue generating facilities
  - ✓Open structure
  - ✓Ramps provide easy ingress and vertical circulation

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Vertical Evacuation Concepts

- ***Community Facilities***
  - ✓Fills community-based needs
  - ✓Enhances quality of life in a community
  - ✓Assembly uses can accommodate circulation and service needs for large numbers of people

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Vertical Evacuation Concepts

- ***Commercial Facilities***
  - ✓Revenue generating facilities
  - ✓Commercial financing options
  - ✓Substantial construction that is more likely to be tsunami-resistant

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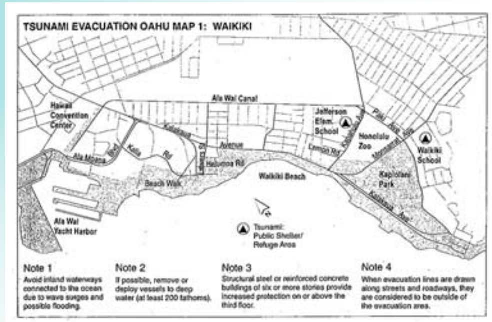
Vertical Evacuation Concepts

- ***Existing Buildings***
  - ✓Utilizes existing construction
  - ✓Avoids the need to procure or develop vacant land
  - ✓Minimizes impacts on community



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Siting Spacing and Sizing Considerations

- Factors influencing the design of a vertical evacuation refuge:
  - ✓The time it takes a tsunami to propagate to the site
  - ✓Ability to evacuate to areas of refuge
  - ✓Integrity of the built environment
  - ✓Population
  - ✓The duration of occupancy
  - ✓Maximum flood depth and velocity

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Siting, Spacing, and Sizing Considerations

Location of Source	*Warning time*
Far-source-generated tsunami	> 2 hrs
Mid-source-generated tsunami	30 min < *t* < 2 hrs
Near-source-generated tsunami	< 30 min

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Siting, Spacing, and Sizing Considerations

Warning time	*Ambulatory Speed**	*Travel Distance***	*Required Spacing*
> 2 hrs	2 mph (3 kph)	4 miles (6 km)	8 miles (12 km)
30 min	2 mph (3 kph)	1 mile (1.5 km)	2 miles (3 km)

* Assumed average speed of mobility-impaired population
** Must allow time for vertical circulation within refuge

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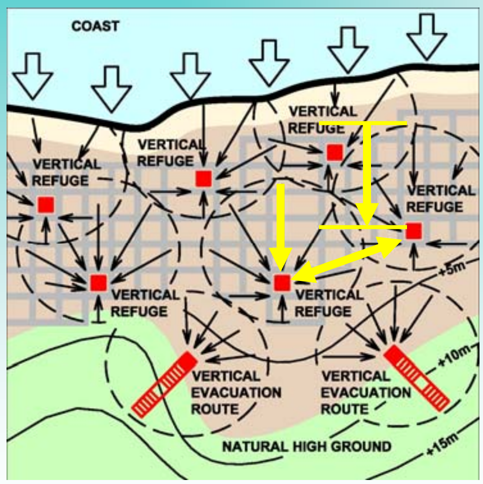
Siting Spacing and Sizing Considerations



- Maximum travel distance from any evacuation point ($d = t * 2$mph)
- Maximum spacing between refuges ($s = 2 * d$)
- Locations skewed away from the coast

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Siting, Spacing, and Sizing Considerations

- Short-Term Refuge Area = 10 ft^2 * population *(1 m^2 * population)*
- Freeboard = 30% plus one story height (10 ft) *(3 m)*

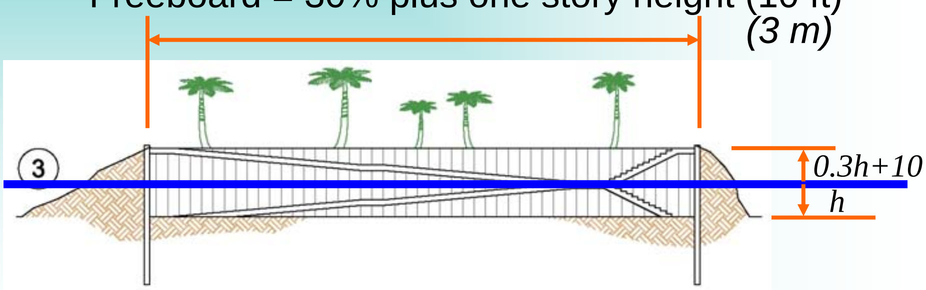

Figure C-7 Example Escape Berm Rear Elevation

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Section 6.2 Performance Objectives

- Tsunami Performance Objective
  - ✓Very large, very rare events
  - ✓Structures expected to allow for safe refuge, but may ***not*** be economically feasible to repair
- Seismic Performance Objectives
  - ✓Immediate Occupancy for the DBE
  - ✓Life Safety for the MCE

Tsunami Force Effects

Type of Force	***Tsunami Consideration***
Hydrostatic	Local effect on elements when one side is dry.
Bouyant	Controlled by inundation depth and rate of water level increase
Hydrodynamic	Drag forces controlled by the product of the inundation depth and the square of flow velocity
Impulse	Impulsive force controlled by the flow velocity of the leading edge of the runup
Debris Impact	Controlled by the maximum flow velocity, debris mass, debris stiffness, and added mass of water behind debris
Retained Water	Gravity load surcharge controlled by weight of water retained in the structure
Breaking Wave	Not considered. Tsunami waves tend to break offshore

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Debris Impact Force

$$F_i = C_m u_{\max} \sqrt{km}$$

- Based on linear dynamic model by Haehnel and Daly (2002)
- C_m = 2.0, the added mass coefficient
- *k* is the stiffness of the debris object
- *m* is the mass of the debris object

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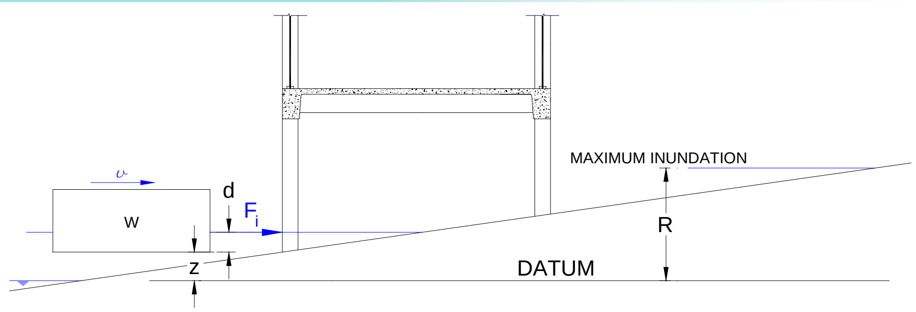
Application of Impact Force

- Consider flow depth sufficient to float shipping container



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Section 6.6 Combination of Tsunami Forces

- Not all of the load effects occur simultaneously
- Refer to the report for guidance on combining tsunami force effects

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Section 6.7 – Load Combinations

- Follow ASCE/SEI 7-05
- Tsunami effect on entire building or on individual member designated as T_s

Combination 1: $1.2D + 1.0T_S + 1.0L_{REF} + .25L$

Combination 2: $0.9D + 1.0T_S$

2500 yr hazard
30% higher runup
elastic design

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Section 6.8 – Member Design

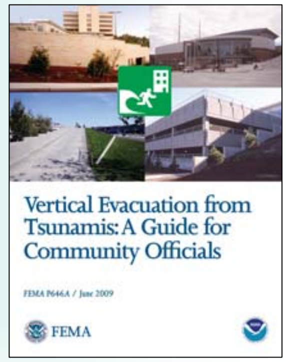
- Apply LRFD strength reduction factors and member capacity calculations per U.S. Model Building Code provisions in same manner as currently applied to Seismic and Wind design.
- Use collapse prevention methods to guard against unusual loading conditions that may cause severe local damage

Structural Design Concepts

- Structural attributes that have demonstrated good behavior in past tsunamis include:
  - ✓ strong systems with reserve capacity to resist extreme forces;
  - ✓ open systems that allow water to flow through with minimal resistance;
  - ✓ ductile systems that resist extreme forces without failure; and
  - ✓ redundant systems that can experience partial failure without progressive collapse.

FEMA P646A Contents

- Guidance for policy-makers and planners
- Contents
  - ✓Introduction/Background
  - ✓Planning
  - ✓Design and Construction
  - ✓Funding
  - ✓Operation and Maintenance



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Conclusion

Thank you!

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