Vertical Evacuation from Tsunamis: A Guide for Community Officials

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Vertical Evacuation from Tsunamis: A Guide for Community Officials

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FEDERAL EMERGENCY MANAGEMENT AGENCY
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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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Foreword

This publication was equally funded by the National Oceanic and Atmospheric Administration (NOAA), which leads the National Tsunami Hazard Mitigation Program (NTHMP) and by the Federal Emergency Management Agency (FEMA), which is responsible for the implementation portion of the National Earthquake Hazard Reduction Program (NEHRP).

This project was originally undertaken to address the need for guidance on how to build a structure that would be capable of resisting the extreme forces of both a tsunami and an earthquake. This question was driven by the fact that there are many communities along our nation's west coast that are vulnerable to a tsunami triggered by an earthquake on the Cascadia subduction zone, which could potentially generate a tsunami of 20 feet in elevation or more within 20 minutes. Given their location, it would be impossible to evacuate these communities in time, which could result in a significant loss of life.

This issue came into sharp relief with the December 26, 2004 Sumatra earthquake and Indian Ocean tsunami. While this event resulted in a tremendous loss of life, this would have been even worse had not many people been able to take shelter in multi-story reinforced concrete buildings. Without realizing it, these survivors were among the first to demonstrate the concept of vertical evacuation from a tsunami.

Many coastal communities subject to tsunami located in other parts of the country also have the same issue. In these cases, the only feasible alternative is vertical evacuation, using specially designed, constructed and designated structures built to resist both tsunami and earthquake loads. The design of such structures was the focus of the earlier work on this project, which resulted in the FEMA publication, *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis* (FEMA P646).

This is a companion publication intended to present information on how vertical evacuation design guidance can be used and encouraged at the state and local level. It is meant to help state and local government officials and interested citizens by providing them with the information they would need to address the tsunami hazard in their community, to help determine if vertical evacuation is an option they should consider, and if so, how to fund, design and build such a refuge.

FEMA is grateful to all who worked on this publication. They are listed at the end of the document. We also wish to acknowledge the staff and consultants of the Applied Technology Council. Their hard work has provided the citizens of our nation with guidance on how they would be able to survive a tsunami.

– Federal Emergency Management Agency

Preface

This document was prepared under a "Seismic and Multi-Hazard Technical Guidance Development and Support" contract (HSFEHQ-04-D-0641), which was awarded to the Applied Technology Council (ATC) in 2004 by the Federal Emergency Management Agency (FEMA) to conduct a variety of tasks, including development of the companion FEMA P646 Report, *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis* (ATC-64 Project). The effort was co-funded by FEMA and the National Oceanic and Atmospheric Administration (NOAA).

The guidance for community officials contained in this document is based on the information provided in the companion FEMA P646 Report, which covers a broad range of technical topics, including characterization of the tsunami hazard, choosing between various options for vertical evacuation structures, locating and sizing vertical evacuation structures, estimation of tsunami load effects, structural design criteria, and design concepts and other considerations. The FEMA P646 Report also includes examples of vertical evacuation structures from Japan, and illustrates the concepts of designing and configuring a series of evacuation structures for a hypothetical community.

In contrast to the technical engineering information provided in FEMA P646, this document contains information and guidance specifically designed for community officials written in layman's terms. Included are background information on tsunami types and historic tsunami activity, in-depth discussions of issues to be considered when planning the design and construction of a structure for vertical evacuation from tsunamis, discussions on funding issues, and information on operation and maintenance of vertical evacuation structures.

ATC is indebted to the members of the ATC-64 Project Team who participated in the development of this document. J. L. Clark served as Lead Report Preparation Consultant, and George Crawford served as Assistant Report Preparation Consultant. Review and guidance were provided by the Project Review Panel, consisting of Lesley Ewing, James Goltz, William Holmes, Ervin Petty, George Priest, Althea Turner, and Timothy Walsh. Ayse Hortacsu served as ATC project manager for this work and Peter N. Mork provided ATC report production services. The affiliations of these individuals are provided in the list of Project Participants.

ATC also gratefully acknowledges the input and guidance provided by Michael Mahoney (FEMA Project Officer), Chris Jonientz-Trisler (FEMA Program Specialist), and Michael Hornick (FEMA Program Specialist).

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Chapter 1

Introduction

1.1 Objectives and Scope

Strategies for mitigating tsunami risk have generally involved evacuating to areas of naturally occurring high ground outside of the tsunami inundation zone. In some locations, high ground may not exist, or tsunamis triggered by local events may not allow sufficient warning time for communities to evacuate to high ground. A potential solution is vertical evacuation into the upper levels of structures designed to resist the effects of a tsunami.

A Vertical Evacuation Refuge from Tsunamis is a building or earthen mound that has sufficient height to elevate evacuees above the level of tsunami inundation, and is designed and constructed with the strength and resiliency needed to resist the effects of tsunami waves.

The focus of this document is on a vertical evacuation strategy that includes structures intended to provide short-term protection during a high-risk tsunami event. A *vertical evacuation refuge from tsunamis* is a building or earthen mound that has sufficient height to elevate evacuees above the level of tsunami inundation, and is designed and constructed with the strength and resiliency needed to resist the effects of tsunami waves.

This document is intended to be a resource for elected officials, agency and department managers and staff, tribal officials, engineers, architects, emergency managers, park managers, building officials, community planners, Chambers of Commerce, building owners, and tsunami planning activists who are considering the design, construction, and operation of a vertical evacuation structure. It is intended for use in areas of the United States that are exposed to tsunami hazard, but that should not preclude the use of this guidance for facilities located in other areas exposed to similar hazards.

1.2 Limitations

This document is a compilation of the best information available at the time of publication. It provides guidance for the planning, design, and construction of vertical evacuation structures that is currently not available in other documents. It is not intended to supersede or replace current codes and standards, but rather to supplement them with guidance where none is otherwise provided. In addition, this document is focused on the tsunami hazard, and specific considerations for other hazards are beyond the scope of this document.

1.3 Organization

This document is a companion to FEMA P646, *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis.* Specific design criteria and other technical information provided in that document are not repeated here.

Information contained in this document is organized as follows:

Chapter 1 defines the scope and limitations for the guidance contained in this document. Chapter 2 provides background information on tsunami effects and their potential impacts on buildings in coastal communities. Chapter 3 includes a number of topics such as tsunami hazard, siting considerations, and liability that must be considered in planning for a vertical evacuation structure. Chapter 4 outlines design and building considerations, including specific types of vertical evacuation structures. Chapter 5 discusses potential funding strategies. Chapter 6 outlines issues in the operation and maintenance of a vertical evacuation refuge structure.

References identifying resources for additional information are provided at the end of this document.

Chapter 2
Background

A tsunami is a naturally occurring series of waves that can result when there is a rapid, large-scale disturbance in a body of water. The most common triggering events are earthquakes below or near the ocean floor, but a tsunami can also be created by volcanic activity, landslides, undersea slumps, and impacts of extra-terrestrial objects. The waves created by this disturbance propagate away from the source. Since these are pressure waves within the water, as opposed to wind-generated surface waves, they can travel at hundreds of miles per hour. In deep water, the waves are gentle sea-surface slopes that can be unnoticeable. As the waves approach the shallower waters of the coast, however, the velocity decreases while the height increases. Upon reaching the shoreline the waves can reach hazardous height and force, penetrating inland, damaging structures, and flooding normally dry areas.

A Tsunami is a naturally occurring series of ocean waves resulting from a rapid, large-scale disturbance in a body of water, caused by earthquakes, landslides, volcanic eruptions, and meteorite impacts.

Historically, tsunamis are rare events but the damage they cause can be great. Thus, proper planning for their consequences is important.

2.1 Categorization of Tsunamis

In this document, tsunamis are categorized by the distance to the location of the triggering event and the time it takes the waves to reach a given site.

A far-source-generated tsunami is one that originates from a source that is far away from the site of interest, and takes 2 hours or longer after the triggering event to arrive.

A mid-source-generated tsunami is one in which the source is somewhat close to the site of interest, and would be expected to arrive between 30 minutes and 2 hours after the triggering event.

A near-source-generated tsunami is one that originates from a source that is close to the site of interest, and arrives within 30 minutes. The site of interest might also experience the effects of the triggering event.

A far-source-generated tsunami is one that originates from a source that is far away from the site of interest and takes 2 hours or longer after the triggering event to arrive. The originating earthquake or landslide will likely not be felt before the first wave arrives, thus the warning will come from the tsunami warning center. The warning will generally give a population time to evacuate to safe, high ground but the tsunami can still cause significant damage. In the December 2004 Indian Ocean Tsunami, Sri Lanka suffered major damage despite being located 1,000 miles from the earthquake that triggered the tsunami.

A mid-source-generated tsunami is one in which the source is somewhat closer to the site of interest, but not close enough for the effects of the triggering event to be felt at the site. Mid-source-generated tsunamis would be expected to arrive between 30 minutes and 2 hours after the triggering event. The tsunami warning center can give a timely warning that needs to be responded to almost immediately in order to provide enough time for evacuation. In general, a community at risk from mid-source-generated tsunamis should use the same considerations as those at risk from a near-source-generated tsunami.

A near-source-generated tsunami is one that originates from a source that is close to the site of interest, and can arrive within 30 minutes or less. The 1993 tsunami that hit Okushiri, Hokkaido, Japan, for example, reached the shoreline within 5 minutes after the earthquake, and resulted in 202 fatalities. Figure 2-1 shows bare concrete foundations typically observed as remnants of wood-frame residential construction after the tsunami in the village of Aonae. Sites experiencing near-source-generated tsunamis will generally feel the effects of the triggering event (e.g., shaking caused by a near-source magnitude-7 or larger earthquake). The December 2004 Indian Ocean tsunami, which killed more than 230,000 people, was preceded by a magnitude-9.3 earthquake. Figure 2-2 shows the destruction from this tsunami.

Figure 2-1 Total destruction of a group of wood-frame houses in Aonae Village, Okushiri Island, Japan in the 1993 Okushiri Tsunami.

Figure 2-2 Destruction caused by the 2004 Indian Ocean tsunami in Indonesia (Photo by Evan Schneider, United Nations).

2.2 Historic Tsunami Activity

Although considered rare events, tsunamis occur on a regular basis around the world. Communities on any coastline may be at risk from a tsunami. As of 2003, 153 million people resided in more than 500 U.S. county jurisdictions, each with one or more coastal communities (Crosset et al., 2004).

Relative tsunami hazard can be characterized by the distribution and frequency of recorded runups. Table 2-1 provides a qualitative assessment of tsunami hazard for regions of the United States that are threatened by tsunamis, as it has been characterized by the National Oceanic & Atmospheric Administration (NOAA) using data on recorded runups over the last 200 years.

Table 2-1 Qualitative Tsunami Hazard Assessment for U.S. Locations (Dunbar et al., 2008)

Region	*Hazard Based on Recorded Runups*	*Hazard Based on Frequency of Runups*
Atlantic Coast	Very low to low	Very low
Gulf Coast	None to very low	None to very low
Caribbean	High	High
West Coast	High	High
Alaska	Very high or severe	Very high
Hawaii	Very high or severe	Very high
Western Pacific	Moderate	High

Alaska's tsunami hazard comes largely from seismicity along the Alaska subduction zone. Hawaii is hit most frequently by far-source-generated tsunamis because of its location in the middle of the Pacific Ocean. Prehistoric data based on paleoseismic studies and tsunami modeling indicate that the West Coast of North America from Cape Mendocino in California to Vancouver Island in British Columbia is subject to tsunamis that may approach the destructive power of the 2004 Indian Ocean tsunami (Priest et al., 2008). The last event of this kind was caused by a magnitude-9 earthquake on the Cascadia subduction zone on January 26, 1700. The resulting tsunami left an historic record of widespread destruction in Japan (Satake et al., 2003).

In 1946, a magnitude-8.6 earthquake with an epicenter in Alaska's Aleutian Islands generated a tsunami that caused the complete destruction of the Scotch Cap Lighthouse on Unimak Island. Figure 2-3 shows the lighthouse structure before and after the tsunami. The 1946 Aleutian tsunami also swept across the Pacific Ocean and caused damage in Hawaii, killing 159 people in Hilo and causing property damage estimated to be over $26 million in 1946 dollars. A 1960 earthquake in Chile of magnitude 9.5 generated another tsunami that hit Hilo. Sixty-one people died and damage was estimated at $24 million in 1960 dollars (Pararas-Carayannis, 1968). In 1975, the tsunami following a magnitude-7.2 earthquake off the southeast coast of the island of Hawaii resulted in two deaths and more than $1 million in property damage.

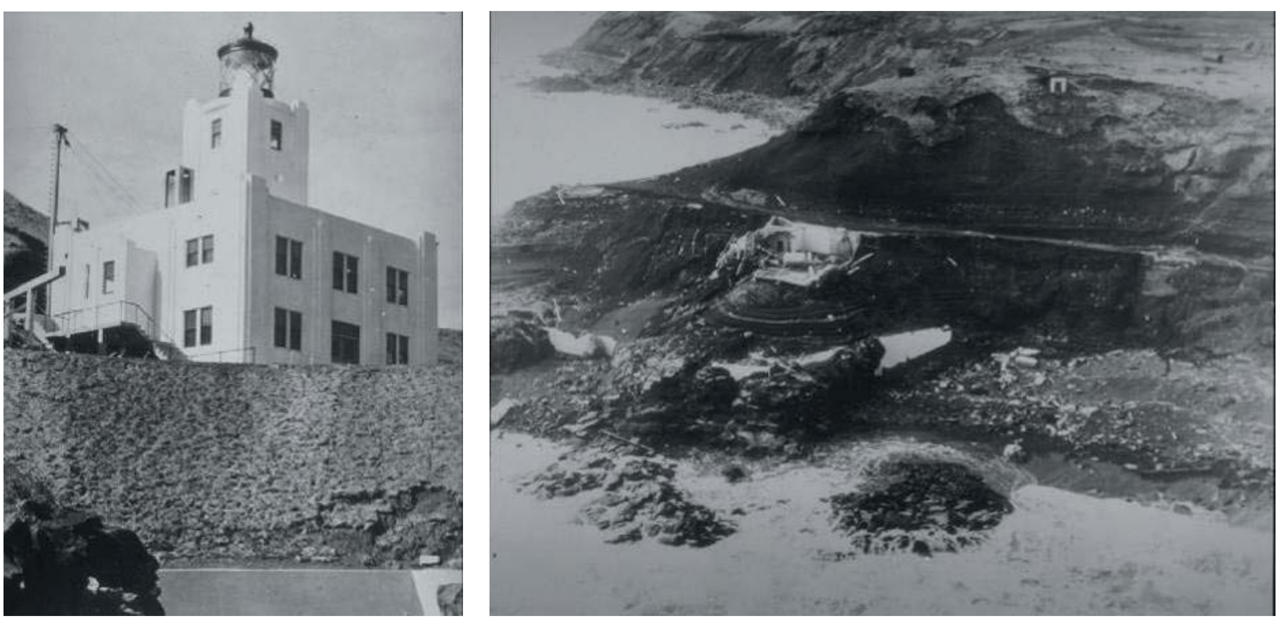

Figure 2-3 Scotch Cap Lighthouse destroyed by the 1946 Aleutian Tsunami.

In 1964, a magnitude-9.2 earthquake in Alaska's Prince William Sound resulted in 122 fatalities, including 12 in California and 4 in Oregon. About 90% of the Alaskan deaths, and all those outside the state, were due to the tsunami. In 1994, a landslide-generated tsunami in Skagway Harbor resulted in one death and $21 million in property damage.

The Cascadia subduction zone, off the coast of Washington, Oregon, and northern California, produces about one magnitude-9 earthquake and large tsunami on average, every 500 years. In southern Oregon and northernmost California, somewhat smaller earthquakes and tsunamis occur between these magnitude-9 events, so on average tsunamis happen about every 300 years in this part of the subduction zone.

> Although the Atlantic and Gulf Coast Regions of the United States are perceived to be at less risk, there are examples of deadly tsunamis that have occurred in the Atlantic Ocean.

Although the Atlantic and Gulf Coast Regions of the United States are perceived to be at less risk, there are examples of deadly tsunamis that have occurred in the Atlantic Ocean. Since 1600, more than 40 tsunamis and tsunami-like waves have been cataloged in the eastern United States. In 1929, a tsunami generated in the Grand Banks region of Canada hit Nova Scotia, killing 51 people (Lockridge et al., 2002).

> Puerto Rico and the U.S. Virgin Islands are at risk from earthquakes and underwater landslides that occur in the Puerto Rico Trench subduction zone.

Puerto Rico and the U.S. Virgin Islands are at risk from earthquakes and underwater landslides that occur in the Puerto Rico Trench subduction zone. More than 50 tsunamis of varying intensity have occurred in the Caribbean since 1530. In 1918, an earthquake in this zone generated a tsunami that caused an estimated 40 deaths in Puerto Rico. In 1867, an earthquake-generated tsunami caused 12 deaths on the islands of Saint Thomas and Saint Croix (Lander, 1999).

Chapter 3

Planning

Many factors influence a community's decision to construct a vertical evacuation structure, including:

- the likelihood of a region being affected by a tsunami event,
- the potential consequences of a tsunami event (e.g., damage, injury, and loss of life),
- the elements of a local emergency response plan, including available evacuation time, routes, and alternatives,
- the availability of high ground that could be reached in time,
- the planned and potential uses for a refuge facility, and
- the cost of constructing and maintaining a tsunami-resistant structure.

A flowchart outlining the decision-making process for vertical evacuation structures is shown in Figure 3-1.

Given a known or perceived tsunami threat in a region, the first step is to determine the severity of the tsunami hazard. Given the tsunami hazard and extent of inundation, the potential risk of damage, injury, and loss of life in the region must then be evaluated.

Given a known or perceived tsunami threat in a region, the first step is to determine the severity of the tsunami hazard. Given the tsunami hazard and extent of inundation, the potential risk of damage, injury, and loss of life in the region must then be evaluated.

The feasibility of evacuation to existing areas of refuge, as well as the tsunami resistance of these areas, must be considered. Vertical evacuation structures will be most useful when there is not enough time between the tsunami warning and tsunami inundation to allow a community to evacuate out of the inundation zone or to existing areas of high ground.

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Design and construction of a network of designated vertical evacuation structures, securing funding, performing maintenance, operating, and periodically re-evaluating these structures will require long-term commitments by all stakeholders.

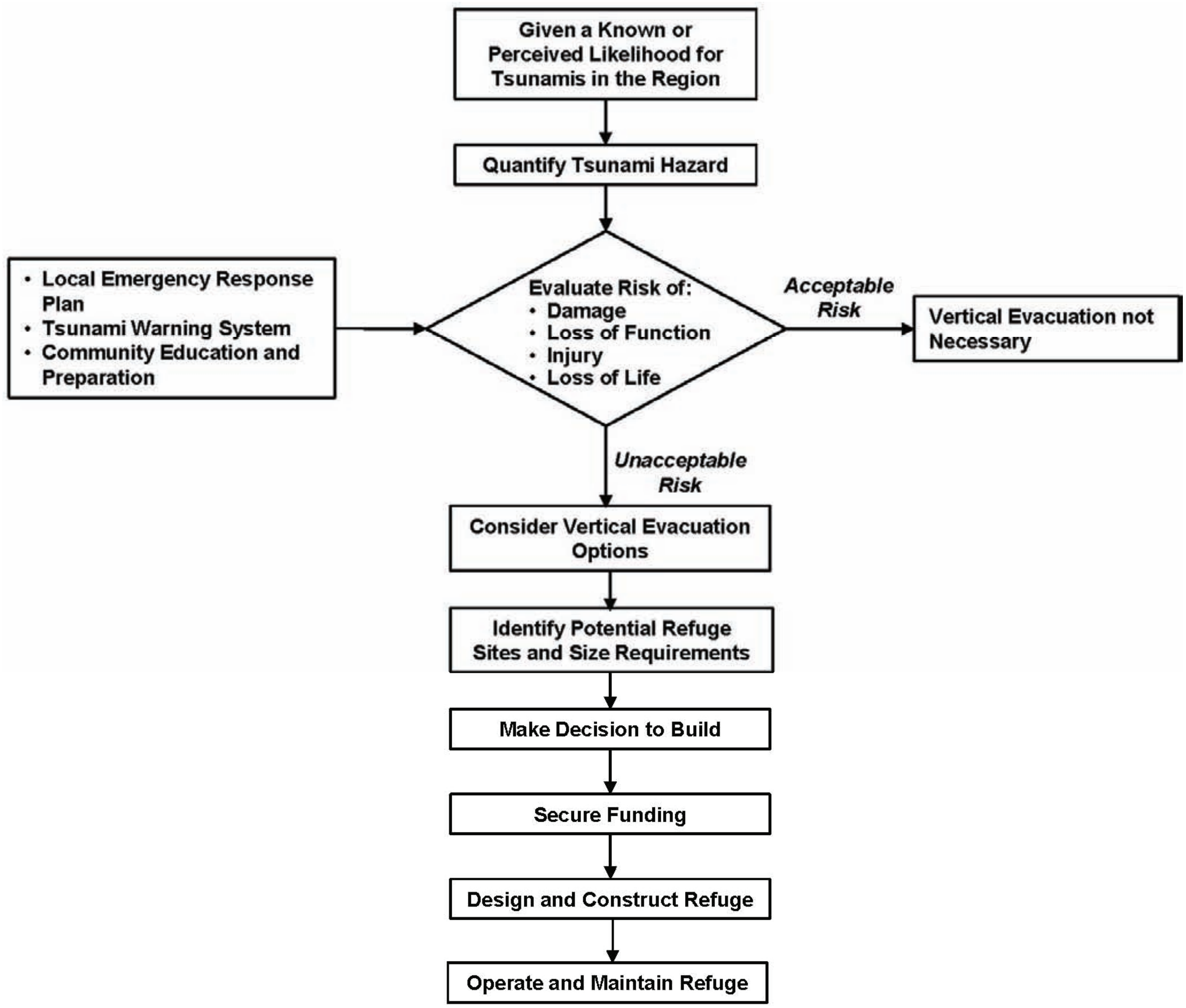

Figure 3-1 Decision-making process for vertical evacuation structures.

3.1 Decision-making Process

The process of considering a vertical evacuation strategy could be initiated by one concerned person or by a grass-roots advocacy group asking the local government to consider building a vertical evacuation structure. It could begin with a state or local government body wanting to protect its population.

In either case, a group that involves a wide variety of stakeholders will be an asset. This group could include neighborhood organizations, land-use planners, emergency managers, engineers, geologists, continuity planners, Chambers of Commerce, other business interests, other government agencies such as the state emergency management agency, or individuals or groups interested in the long-term health of the community. One advantage of having a wide variety of stakeholders is their ability to efficiently disseminate information about the tsunami risk and the potential value of vertical evacuation structures. Another advantage is that the group may be able to help fund or build support for funding the project.

After assessing an area's vulnerability and potential resources, a decision must be made as to whether or not vertical evacuation is needed, what capacity for evacuation is needed, where it should be sited, and what type of structure should be built or designated as refuge. These decisions must be made based on the conditions of each specific area, with the need for vertical evacuation from tsunamis prioritized against other needs in the area.

Local governments have a variety of mechanisms they can employ to help drive the decision process. One mechanism is to encourage development of vertical evacuation structures by offering tax incentives. Another mechanism could involve requiring new coastal construction projects to include vertical evacuation facilities. Strategies will differ from community to community.

A successful effort will probably involve a variety of stakeholders, including public, private, and not-for-profit representatives. Public-private partnerships are one model that can be pursued. A cross-section of interests will generate more support for the project, allow access to a greater number of funding possibilities, and increase the chances of a successful program for vertical evacuation and tsunami planning in general. This is especially important in planning for tsunami response, since it is a long-term process to address a hazard that will continue to threaten future generations.

A successful effort will involve a variety of stakeholders, including public, private, and not-for-profit representatives.

3.2 Making Tough Choices

Developing and implementing a vertical evacuation strategy involves serious decisions that often have no clear-cut answer. Resources are often limited, and a community might not be able to achieve the ideal solution in terms of number and location of vertical evacuation structures. If there is not enough funding to build the requisite number of vertical evacuation facilities necessary to shelter the entire vulnerable population, questions about where the structures should be built, or whether a structure should be built in a less than ideal location must be thoroughly discussed. Some communities may question whether or not an existing building that is not built to specific tsunami design criteria should be included in an evacuation plan because there are no better options.

Conditions and resources in specific communities will drive the answers to these and other questions that arise in the planning process. These tradeoffs are not easy, and will require discussion by the affected community. In practice, a community may only be able to afford one vertical evacuation structure. By analyzing the above factors, it can be placed at the most advantageous site.

3.3 Determining the Tsunami Hazard

In order to determine the need for a vertical evacuation structure, the tsunami hazard should first be determined. The tsunami hazard assessment of a site involves determining a combination of the presence of a geophysical tsunami source, exposure to tsunamis generated by that source, and the extent of inundation that can be expected as a result of a tsunami reaching the site.

An essential component of tsunami hazard assessment is modeling of tsunami inundation. These detailed computer models produce inundation estimates that guide the development of evacuation maps, public education and training materials, and tsunami risk reduction plans. By 2004, the National Tsunami Hazard Mitigation Program Hazard Assessment component, in cooperation with local state governments and local universities, had completed 22 inundation mapping efforts and 23 evacuation maps covering 113 communities and an estimated 1.2 million residents at risk (González, et al., 2005a). Figures 3-2 and 3-3 show three types of hazard maps for Seattle, Washington that can be used as a basis for creating evacuation routes, siting vertical evacuation structures, and public education materials.

> A state or local emergency manager or state geology department will have information on the tsunami hazard in an area.

A state or local emergency manager or state geology department will have information on the tsunami hazard in an area. Unfortunately, estimating tsunami inundation comes with inherent uncertainty. Damaging tsunamis are rare events, and data for tsunami models must be extrapolated from the past using best available information. The need for a vertical evacuation structure must take science into account, but is ultimately a decision that must be made for each area based on a combination of local tolerance for risk and available resources.

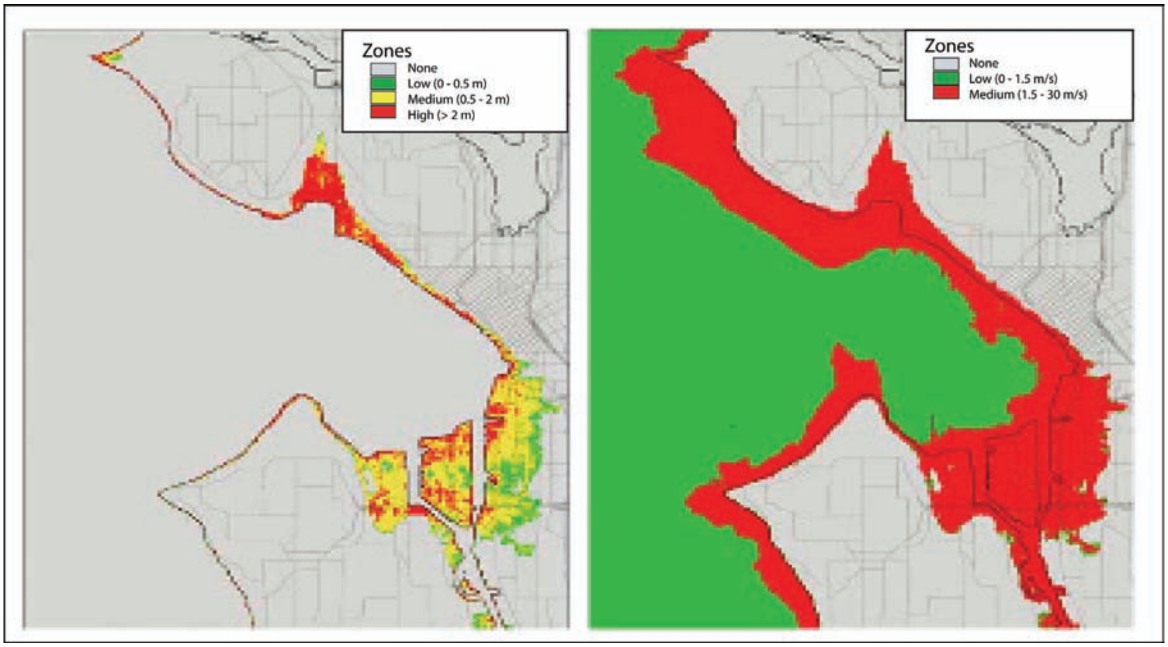

Figure 3-2 Zoned estimates of maximum inundation depth (left) and zoned estimates of maximum current (right) for Seattle, Washington (Titov, et al., 2003).

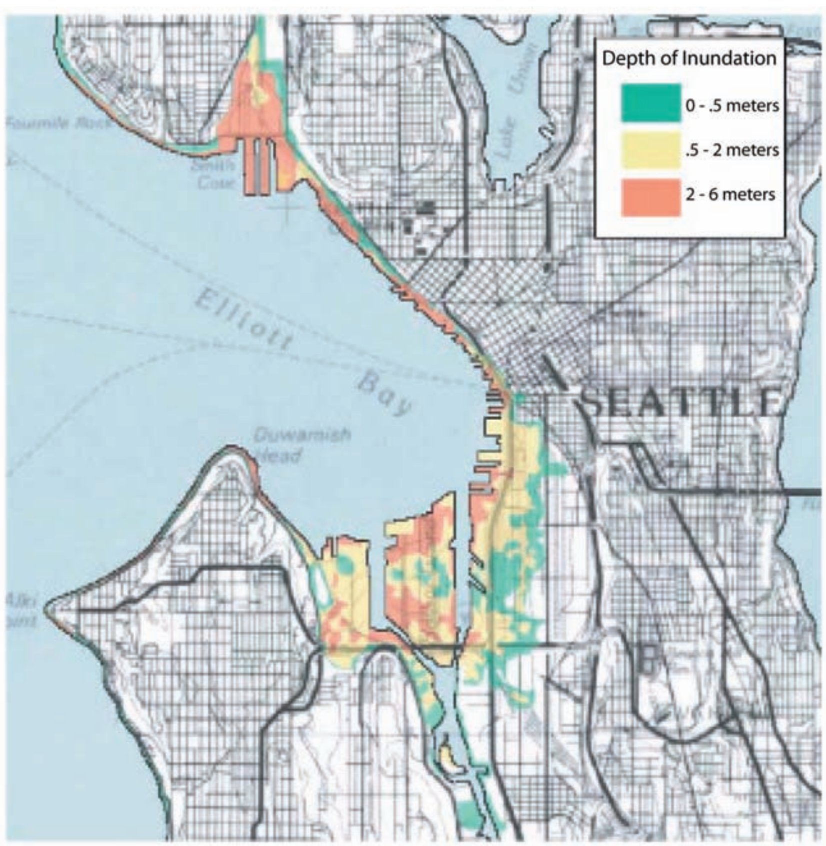

Figure 3-3 Tsunami inundation map for Seattle, Washington (Walsh, et al., 2003).

3.4 Consideration of Concurrent Hazards

When deciding on a vertical evacuation strategy, it is important to keep in mind that tsunami events are commonly preceded or followed by other natural hazards.

When deciding on a vertical evacuation strategy, it is important to keep in mind that tsunami events are commonly preceded or followed by other natural hazards. The consequences of these events should also be considered in the decision-making process:

- *Earthquakes.* Most tsunamis are generated by earthquakes. In a near-source-generated event, the triggering earthquake may be larger than a magnitude 7 and can cause enormous destruction before the first tsunami wave hits. A designated tsunami vertical evacuation structure must be able to first withstand this earthquake and remain functional. A large earthquake may disorient people because of the length of shaking, destroy roads and bridges, and create debris that can make tsunami waves even more destructive. A strong education program will need to be developed to educate the public that a tsunami vertical evacuation refuge is safe to enter after a major earthquake and can withstand the tsunami forces.
- *Landslides.* An earthquake that generates a near-source-generated tsunami can also trigger landslides onshore. Also, some tsunamis are generated by underwater landslides, even without an earthquake. Additionally, the tsunami waves themselves can scour hillsides, producing more landslides. These potential hazards should also be considered when planning evacuation routes and assembly areas, including vertical evacuation facilities.
- *Floods.* One does not need to be in sight of the ocean to be inundated by a tsunami. Tsunami waves can cover not just open coastlines and harbors, but can travel upstream and cause damage along rivers and waterways. Although tsunamis rapidly lose energy and elevation as they proceed up coastal rivers and estuaries, low-lying areas near the coast may be vulnerable to tsunamis. These low-lying areas may also be subject to riverine flooding.

3.5 Tsunami Preparation

Tsunami preparation can fit into the emergency management and planning processes that may already be in place in a community to address other hazards such as earthquakes, floods, wind, and man-made events.

Tsunami preparation can fit into the emergency management and planning processes that may already be in place in a community to address other hazards such as earthquakes, floods, wind, and man-made events. The similarities and differences between planning for a tsunami or an earthquake or other hazard must be considered.

Some coastal states and island territories have tsunami programs funded by NOAA. These programs work with local emergency managers and coastal communities to map inundation areas, develop evacuation routes and assembly areas, conduct workshops to assist in the development of plans, facilitate exercises to test planning assumptions, and help develop public education programs and materials to support community planning. States may also provide funding for local planning efforts and coordinate planning on a regional basis. U.S. coastal states and island territories that are members of the National Tsunami Hazard Mitigation Program receive funding annually to help support policy and programs.

Most preparedness efforts to date have focused on developing effective warning systems, creating and improving inundation and evacuation maps, placing signs for tsunami evacuation routes and assembly areas, and developing educational programs to make evacuation more effective when it becomes necessary. Figure 3-4 shows the tsunami evacuation sign in use in the five states along the Pacific Ocean. These and other signs can be posted in English or Spanish, depending on the needs of the local population and tourists. Figure 3-5 shows the sign designating an assembly area in use in Puerto Rico.

Figure 3-4 Example tsunami evacuation sign, as typically used in Hawaii, Alaska, Washington, Oregon, and California. Tsunami evacuation routes have been mapped and signs posted in many areas within these states (Photo by J. L. Clark).

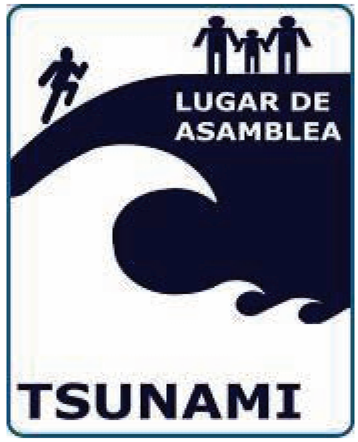

Figure 3-5 Spanish sign for a designated assembly area (Graphic, Puerto Rico Seismic Network, University of Puerto Rico at Mayaguez).

3.5.1 Pre-tsunami Public Education

Pre-tsunami education is critical to prepare the population to act quickly and appropriately in the event of a tsunami. Residents and tourists must understand the importance of the tsunami threat. They also need to know how to get more information about tsunamis and what warning systems are available. Whether a tsunami source is near or far, people must respond immediately when a warning is issued, or when strong ground shaking from a coastal earthquake is felt.

According to research, **door-to-door outreach** and **evacuation drills** were the most effective pre-tsunami public education techniques.

A systematic study of what educational strategies work the best was carried out by the National Tsunami Hazard Mitigation Program in a pilot study of Seaside, Oregon, as documented in Oregon Department of Geology and Mineral Industries Open File Report O-05-10 (Connor, 2005). According to polls conducted for this study, door-to-door outreach and evacuation drills were the most effective techniques (see Figure 3-6).

As demonstrated in the Seaside outreach experiment, tsunami evacuation drills are an important part of the education process. They help people respond quickly and efficiently to a tsunami warning and generate local media attention to the issue. This is particularly important if a major earthquake is expected to trigger a near-source-generated tsunami. The waves may arrive within just a few minutes, so it is imperative for people to instinctively know where to evacuate immediately after the shaking stops. Having a Community Emergency Response Team (CERT) could help with public education and drills. Information on organizing and funding a CERT is available at www.citizencorps.gov/cert. CERT training is also available from FEMA's Emergency Management Institute.

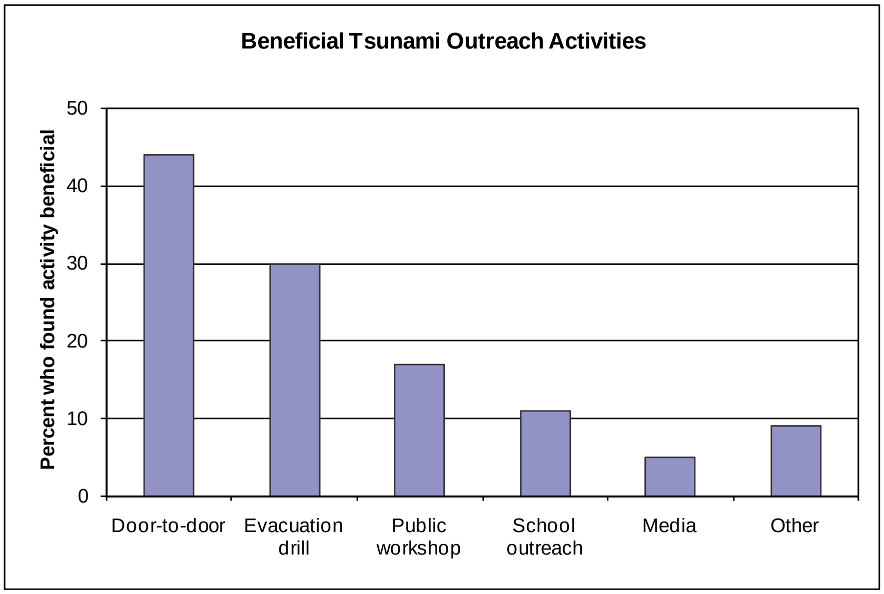

Figure 3-6 Results of Seaside, Oregon outreach experiment showing perceived effectiveness of various outreach activities. The total is more than 100%, because an option to choose more than one answer was provided (Data from Connor, 2005).

3.5.2 TsunamiReady Program

The TsunamiReady Program, developed by the National Weather Service in coordination with the National Tsunami Hazard Mitigation Program, is designed to help cities, towns, counties, universities and other large sites in coastal areas reduce the potential for disastrous tsunami-related consequences. The program's goal is to save lives through better planning, education, and awareness. More information about the program is available online at http://www.tsunamiready.noaa.gov. Figure 3-7 shows the entrance to Rockaway Beach, Oregon, which has met the conditions to become a TsunamiReady city. In addition, local and state emergency management agencies can provide guidance with both planning and acquisition of resources to aid planning efforts.

3.6 Vertical Evacuation Structures

If evacuating to natural high ground is not possible or practical, vertical evacuation is a potential solution. A vertical evacuation structure is a more expensive option than going to natural high ground and should be targeted to individuals who cannot remain at their location at the time of the event yet cannot evacuate to high ground.

It is important to note that a vertical evacuation refuge is not the same as a shelter. A refuge is meant to serve for a few hours until the danger of

Figure 3-7 Signage indicating that a community is designated TsunamiReady after completing steps that reduce their tsunami risk (Photo by J. L. Clark).

tsunami waves has passed. In most areas, damaging waves will occur within the first 12 hours after the triggering event origin time, though the potential for abnormally high tides and coastal flooding can last as long as 24 hours. On the other hand, a shelter is a longer-term facility, such as a Red Cross shelter, which will typically include a place to sleep along with food and water supplies. A vertical evacuation refuge can be built to serve as a shelter, or a shelter may serve as a vertical evacuation refuge if it meets the necessary tsunami design criteria.

3.6.1 Analyzing the Need for a Vertical Evacuation Structure

An analysis including but not limited to the following information will help decide the need for a vertical evacuation structure:
(1) the topography of the area,
(2) age and construction type of the building stock,
(3) total number of residents and visitors in an area,
(4) variations in population due to seasonal or other fluctuations,
(5) number of vulnerable populations and their sizes,
(6) preparedness of population, and
(7) preparedness of emergency management and response operations.

A vertical evacuation plan is not needed for every area in a community. Even if it is needed, it may not need to include everyone in a given area. An analysis including but not limited to the following information will help decide the need for a vertical evacuation structure: (1) the topography of the area; (2) age and construction type of the building stock; (3) total number of residents and visitors in an area; (4) variations in population due to seasonal or other fluctuations; (5) number of vulnerable populations and their sizes; (6) preparedness of resident and visiting populations; and (7) preparedness of emergency management and response operations. Much of this information may already be collected in emergency management and land-use plans. Figure 3-8 shows an example tsunami evacuation map from Oregon showing expected inundation areas, evacuation routes, and assembly areas created as a result of such an analysis.

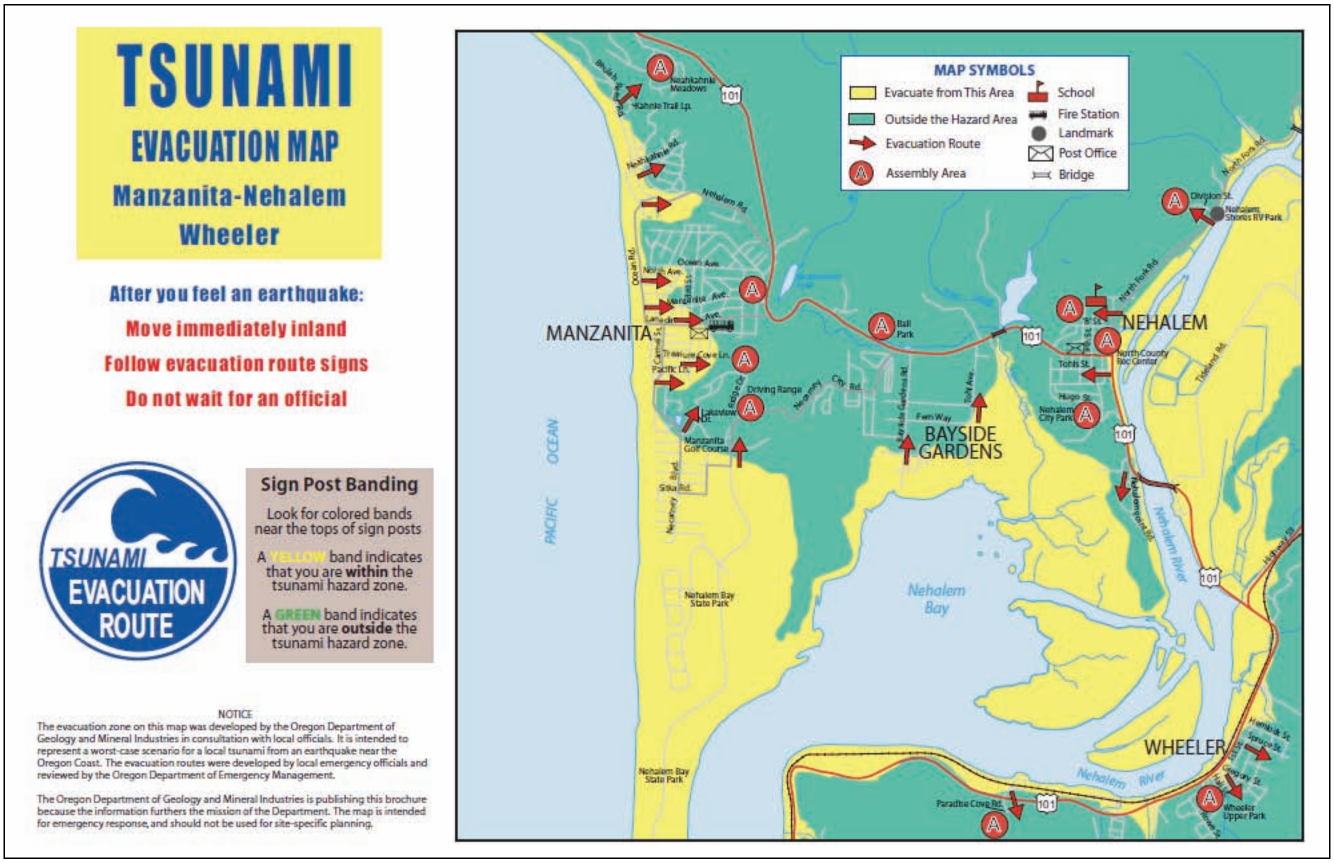

Figure 3-8 Tsunami evacuation map of Manzanita, Nehalem, and Wheeler, Oregon (Source, http://www.oregongeology.com/sub/earthquakes/Coastal/Tsubrochures.htm).

3.6.2 *Vulnerability Assessment*

A vulnerability assessment calculates what percentage of the population is at-risk to tsunami inundation, and needs a vertical evacuation structure. It estimates the size of the vulnerable population, where they are, how far they can travel, and what options are available for evacuation or refuge. The vulnerable population consists of those with limited mobility, often seniors or young children, and those who are in areas where high ground is not easily accessible. This population may vary considerably from day to night or season to season, depending on the residential population and number of seasonal tourists in the community.

Increasing the preparedness of a population can reduce their risk. People are less vulnerable if they know what to expect and how to react. Activities such as an ongoing public education program, developing inundation maps, marking evacuation routes and assembly areas, and local tsunami warning dissemination protocols can make the community less vulnerable.

Building stock is another critical asset to consider. Compared to older building stock, buildings that meet current seismic codes may better withstand the intense ground shaking that precedes a near-source-generated tsunami and create a lower risk of collapsing and trapping people trying to evacuate. However, tsunami forces are different from earthquake forces. Many buildings still standing after an earthquake may be swept away by the force of the subsequent tsunami.

FEMA's Hazards U.S. Multi-Hazard (HAZUS-MH) is a useful tool for a vulnerability assessment.

Loss estimation software, such as FEMA's Hazards U.S. Multi-Hazard (HAZUS-MH) (FEMA, 2007), are useful tools for a vulnerability assessment. Although there currently is no tsunami module in HAZUS-MH, its earthquake module could be particularly useful for determining earthquake damage for near-source-generated tsunamis, and the hurricane module may also be useful in some areas. Both modules include standardized methodology and quantitative information that can be used in a vulnerability assessment, such as population, building numbers and types, and sites of emergency facilities.

3.7 Siting Considerations

Vertical evacuation structures must be easy to walk to and distributed throughout the inundation zone. The location of the sites will depend on how much time it will take for the population to reach the structure and various environmental conditions.

3.7.1 Travel Time to Safety

In the case of a near-source-generated tsunami, the first wave can arrive within minutes. Travel time to a vertical evacuation structure is a primary concern. A systematic study of evacuation time from each part of the inundation zone should precede site selection. Such studies can either utilize sophisticated computer programs or can simply assume walking speeds or ask volunteers from each neighborhood to walk to potential sites. A map depicting lines of equal travel time to candidate sites is a useful product from these types of simple studies.

In this document and the companion design guide, FEMA P646, *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis*, an average, healthy person is assumed to walk approximately 4 miles per hour (mph). However, portions of the population with limited mobility due to age, health, or disability, are assumed to walk approximately 2 mph. Spacing of vertical evacuation structures must take into account the time it will take for people to reach an area of refuge. The travel time to safety should include the following three components:

- *Leaving their original location and traveling to the vertical evacuation site.* Most coastal communities have educated their populations to "go to high ground" in the event of a tsunami warning. Also, a natural tendency for evacuees will be to move away from the coastline. To take advantage of this behavior, vertical evacuation structures should be located on the inland side of evacuation zones that people can comfortably walk to. Travel time must account for the maximum distance people will be expected to travel in the evacuation zone.
- *Accessing the structure.* An engineered high ground may provide the easiest access to the appropriate height above the inundation zone. The sides can be built so they slope enough for water drainage, but are also easy to walk up. Disabled users may need to travel along a special ramp that accommodates wheelchairs, and those with special needs may require assistance from others to move within the structure. Travel time must include time to gain entrance to the structure or berm.
- *Navigating to the appropriate level of the structure.* Inside a building, stairs or elevators are traditional methods of vertical circulation but have limited capacity by design. In addition, elevators may not be operational after a major earthquake. Ramps, such as the ones used in sporting venues or parking structures, are more effective for moving large numbers of people up to appropriate levels in a vertical evacuation structure. Travel time must include time for mobility impaired populations to move vertically to levels above the inundation elevation.

Travel time to safety should include:
(1) traveling from original location to the vertical evacuation site;
(2) accessing the structure; and
(3) navigating to the appropriate level of the structure;

3.7.2 Considerations in Site Selection

If the vertical evacuation structure is located near other buildings that are damaged during the earthquake, debris may block the entrance. Also, if a vertical evacuation structure serves another purpose, such as community center or school, the building contents for those uses could impede access for those coming to use the facility.

Each potential site will have benefits and drawbacks. Potential site hazards include sources of large waterborne debris, sources of waterborne hazardous materials, and unstable land. The professional opinion of a geologist or engineer is needed to assess these hazards. If possible, vertical evacuation structures should be located away from potential hazards that could result in additional damage to the structure and reduced safety for the occupants. Due to limited availability of possible sites, and limitations on travel and mobility of the population in a community, some vertical evacuation structures may need to be located at sites that would be considered less than ideal. A more

If possible, vertical evacuation structures should be located away from potential hazards that could result in additional damage to the structure and reduced safety for the occupants.

detailed discussion about site hazards to consider can be found in FEMA P646.

3.7.3 Number of Sites

For complete coverage of the population, the following questions must be considered:

- How many people need vertical evacuation?
- What is the capacity of the vertical evacuation structures?
- What is the topography of the community?
- How far apart will the vertical evacuation structures be?
- How much space is needed for each occupant within the refuge?

FEMA P646 provides guidance on spacing and sizing of vertical evacuation structures. By combining answers to the above questions, the ultimate number of vertical evacuation structures can be determined. Figure 3-9 illustrates one example of an arrangement of vertical evacuation structures in a coastal community.

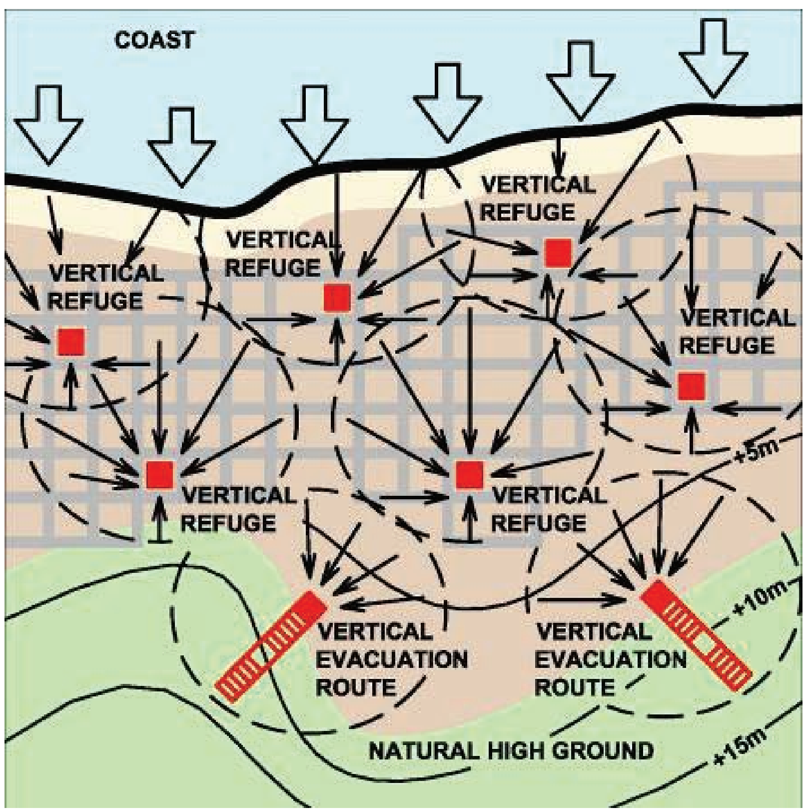

Figure 3-9 Vertical evacuation refuge locations considering travel distance, evacuation behavior, and naturally occurring high ground. Arrows show anticipated vertical evacuation routes.

If more than one vertical evacuation structure is planned, the distance between them depends on the available tsunami warning time and the estimated travel time to safety of potential users. For example, for a near-source-generated tsunami with a 30-minute warning time, assuming people walk at 2 mph, a vertical evacuation structure should be located a maximum of 1 mile from any given starting point. This would mean planning for 2 miles between vertical evacuation structures.

3.8 Land Use Planning

Comprehensive planning and zoning ordinances may not include vertical evacuation structures as a permitted use. In some cases, height limitations may need to be waived. A variance or conditional use permit, or change in the underlying zoning for the site, may be required. This step may add to the cost of the structure.

Some communities do not allow new critical facilities, such as fire stations and hospitals, to be built within an inundation zone. Even though a vertical evacuation structure is different than a critical facility, the rules may require special permission to build a vertical evacuation structure within an inundation zone. Research must be done in each area to determine if these or other restrictions apply.

Building a vertical evacuation structure within an inundation zone may require a special permission.

3.9 Cost Considerations

Design standards that allow a structure to withstand seismic and tsunami forces will add a premium to the cost of construction. Information on cost differentials is provided in FEMA P646. A tsunami-resistant structure, including seismic-resistant and progressive collapse-resistant design features, can be expected to add about a 10% to 20% increase in total construction costs over that required for normal-use buildings.

A tsunami-resistant structure, including seismic-resistant and progressive collapse-resistant design features, can be expected to add about a **10% to 20% increase in total construction costs** over that required for normal-use buildings.

3.10 Liability

Creating a vertical evacuation structure is a process. The vertical evacuation structure must be planned, built, maintained, and be ready for immediate use to protect people from a tsunami. Questions of liability may arise at each of those steps and answering them is an important part of the planning process. In general, as long as a community makes a best faith effort to address a hazard, they are not liable for damages. Each community should, however, seek legal counsel for its exact situation.

3.11 Long-term Planning

Even if the community cannot afford to build a vertical evacuation structure in the near-term, the planning process can be started by researching building options and possible sites, and preparing the public through community education efforts. As resources become available, intermediate steps can be taken.

It is important to make identification or construction of vertical evacuation structures a priority, and to move forward with a plan. In the event of a large, near-source-generated tsunami, anything done to decrease the number of fatalities is a good use of resources.

Chapter 4

Design and Construction

4.1 Design Considerations

A vertical evacuation structure must not only withstand the tsunami waves and waterborne debris, it must also withstand the preceding earthquake and remain functional. The structure should not show appreciable damage following the earthquake since people will be reluctant to enter a building if there are, for example, large cracks in walls or other signs of damage.

A vertical evacuation structure must not only withstand the tsunami waves and waterborne debris, it must also withstand the preceding earthquake and remain functional.

4.1.1 Use of Existing Structures

If there is no naturally occurring high ground inside the inundation zone, exploring existing structures as potential vertical evacuation facilities should be a first step. An assessment of both the functional needs and potential structural vulnerabilities would be required to determine if an existing building can serve as a vertical evacuation structure. Multistory buildings, such as larger concrete frame structures like hotels or condos that meet seismic standards could be appropriate choices for vertical evacuation structures with some strengthening. However, it will generally be more difficult to strengthen an existing structure than to build a new tsunami-resistant structure using the criteria in FEMA P646. If appropriate strengthening is not possible, the use of an existing building would still provide some level of protection, which is better than none. Concrete and steel framed buildings at levels higher than six stories can be considered to provide increased level of protection.

If there is no naturally occurring high ground inside the inundation zone, exploring existing structures as potential vertical evacuation facilities should be a first step.

4.1.2 Designing New Structures

A new vertical evacuation structure would need to comply with all applicable state and local building codes. These codes provide minimum prescriptive requirements necessary to protect the safety of building occupants for natural and man-made hazards. This does not necessarily mean that the building will not suffer any damage in a design event. A vertical evacuation structure could also be used to provide refuge from other hazards, such as hurricanes. Each hazard will have specific design criteria and operational needs, such as allowances for different occupancy durations and different post-event rescue and recovery activities.

A new vertical evacuation structure would need to comply with all applicable state and local building codes.

Performance-based design provides a systematic methodology for assessing the performance capability of a building, system, or component and allows engineering solutions to be tailored to the exact needs of a site and potential hazard.

State and local building codes provide requirements for structural loading, however, in most cases these codes do not address tsunami loading. To calculate tsunami loads, the guidance provided in FEMA P646 should be used with the permission of the local building code official.

In contrast to such prescriptive design approaches contained in building codes, performance-based design provides a systematic methodology for assessing the performance capability of a building, system, or component. It can be used to verify the equivalent performance of alternatives, deliver standard performance at a reduced cost, or confirm higher performance needed for critical facilities. It also facilitates meaningful discussion between stakeholders and design professionals on the development and selection of design options. It provides a framework for determining what level of safety and property protection, at what cost, are acceptable to the stakeholders based upon the specific needs of the project.

Tsunamis are infrequent events and there is a relatively small database of how newer types of construction would respond to tsunami loading. Performance-based designs allow engineering solutions to be tailored to the exact needs of a site and potential hazard. It is a means of providing higher standards as needed for specific projects. A vertical evacuation structure lends itself well to performance-based design.

Researchers at the University of Hawaii were awarded a National Science Foundation grant in 2005 to conduct research on Performance Based Tsunami Engineering (PBTE) issues. The project is being modeled after the FEMA-funded efforts now underway by the Applied Technology Council (ATC) to develop next-generation guidelines for performance based seismic design of new and existing buildings (ATC, 2009). The focus of the four-year Performance Based Tsunami Engineering project will be on the development of methodology and validated simulation tools for use in the analysis, evaluation, design and retrofit of coastal structures and facilities, as well as the development of code-compatible provisions for tsunami-resistant structural design (Riggs et al., 2008).

In addition, communities should rconsider Americans with Disabilities Act (ADA) requirements when designing a vertical evacuation structure.

4.2 Use of Vertical Evacuation Structures

The simplest and least expensive type of new vertical evacuation structure that can be built may be a single-purpose, stand-alone structure, as shown in Figure 4-1. If a coastal community does not have sufficient resources to develop a single-purpose structure, possible solutions to justify funding for a new structure include co-location with other community-based or commercial-based functions, and offering economic or other incentives for private developers to provide tsunami-resistant areas of refuge within their developments. The ability to use a facility for more than one purpose may provide immediate possibility for a return on investment through daily business or commercial use when the structure is not needed as a refuge. Communities exposed to other hazards, such as earthquakes and hurricanes, may also consider the possible sheltering needs associated with these other hazards.

The simplest and least expensive type of new vertical evacuation structure that can be built may be a single-purpose, stand-alone structure.

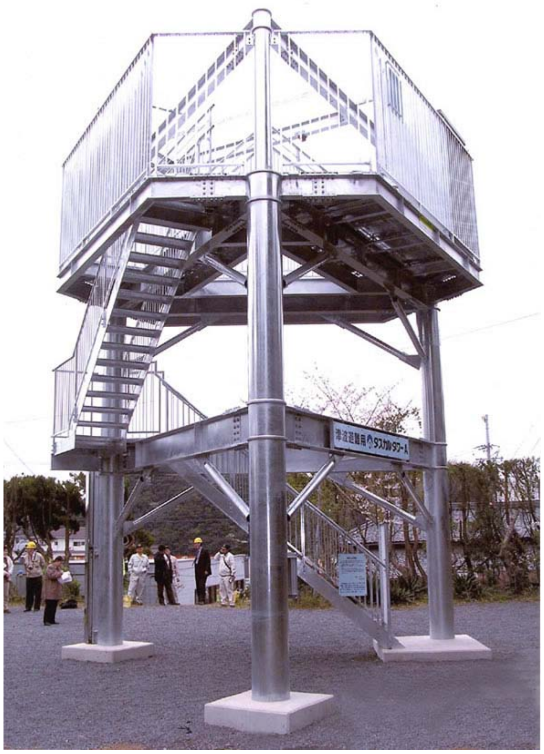

Figure 4-1 Photo of a vertical evacuation structure in Japan that was developed as a simple and economical vertical evacuation option.

4.3 Types of Vertical Evacuation Structures

A vertical evacuation structure can be as simple as natural or man-made high ground or as complex as a facility co-located with a building that is primarily used for another purpose.

Vertical evacuation structures can be high ground, parking garages, community facilities, commercial buildings, or schools.

Several types of vertical evacuation structures are outlined below, along with advantages and disadvantages of each.

4.3.1 Existing or Engineered High Ground

Areas of existing high ground can be used for vertical evacuation. Some modifications may need to be made to ensure that the high ground is completely above the inundation zone and can withstand potential damage from wave runup or erosion. If natural high ground does not exist, a soil berm can be constructed, as shown in Figure 4-2, where open space allows raising the ground level above the inundation height. In either case, the slope of the sides must allow for efficient ingress and water drainage and yet be protected against scour and ramping from the inundation flow.

Figure 4-2 Photo of an engineered high ground that is combined with a community open space.

The advantages of using high ground areas are as follows:

- High ground areas provide easy access for large numbers of people.
- High ground areas allow people to follow natural instinct or trained response to go to high ground in the event of a tsunami.
- After a major earthquake many people are reluctant to enter a structure for fear of collapse to seek safety from a tsunami.
- High ground areas can be used as open space or park.
- Sloped sides provide easy access for members of the community with limited mobility.

The disadvantages of using high ground areas are as follows:

- High ground areas lack protection from the elements, such as wind and rain.

- People using the high ground area as a vertical evacuation structure may not feel safe or remain calm if they can see the waves approaching.
- The slopes of the high ground area would need to be armored or otherwise designed and protected to prevent scour and ramping caused by fast moving inundation flow.

4.3.2 Parking Garages

A parking garage, as shown in Figure 4-3, is a candidate for use as a vertical evacuation structure. However, existing parking garages are often not individually engineered and generally not designed to withstand the forces of a tsunami. If a new structure is designed with higher performance objectives in mind, and subjected to additional code review and construction inspection by local jurisdictions, parking garages could be designated vertical evacuation structures with the following advantages:

- The lower levels of parking garages are open spaces that allow water to flow through with minimal resistance.
- Interior ramps allow easy circulation to higher levels within the structure.
- Additional community amenities can be provided on the top level, including parks and observation decks.
- The top level of a parking garage can provide a helicopter landing site if rescue personnel, food, and shelter need to be brought in after the tsunami.
- When not in use as an evacuation structure, a parking garage can generate revenue.

A disadvantage of using a parking garage is that cars within the garage can become debris that hinder public access during a tsunami event.

4.3.3 Community Facilities

Vertical evacuation structures could be developed as part of other community-based needs such as community centers, recreational facilities, sports complexes, libraries, museums, and police or fire stations (see Figure 4-4). Advantages include it being much easier to justify a facility that would often be used by the community as opposed to one that would almost always be vacant. Another would be the ability to generate revenue. Also, an indoor community facility would provide protection against the elements and potentially room for first aid and water storage.

Figure 4-3	A typical parking structure. The design of a parking garage offers some advantages as a vertical evacuation structure.

Figure 4-4	Photo of an example sports complex. Facilities of this type, which hold large numbers of people, can serve as a vertical evacuation structure from tsunamis.

A disadvantage to using a community facility as a refuge is that the community activity can hamper the vertical evacuation. For example, if the vertical evacuation structure is co-located with a library, fallen books and shelves after an earthquake can impede movement inside the building.

4.3.4 Commercial Buildings

Vertical evacuation structures could be developed as part of business or other commercial facilities including multi-level hotels, condominiums, restaurants, or retail establishments (see Figure 4-5). For example, if the vertical evacuation regufe area is part of a hotel complex, then meeting rooms, ballrooms, and exhibit spaces that are located above the estimated tsunami inundation height could be used to provide refuge when the tsunami occurs.

Advantages to using commercial buildings as vertical evacuation structures include:

- Financing can be done through private-sector funding and can be supplemented by tax incentives, if desired.
- The location of large beach-front hotels puts them in an ideal spot for a vertical evacuation structure. The upper floors of a hotel would be a short distance from the beach and already the temporary home of many visitors who may not know other options that might exist. (Many videos of the 2004 Indian Ocean tsunami were taken by survivors in upper floors of tourist hotels.)

Figure 4-5 Example beach-front hotel. With proper planning and agreements ahead of time, a hotel could provide a vertical evacuation refuge from tsunamis.

Disadvantages to using commercial buildings include:

- Space available for refuge would exclude private rooms that are locked.
- With ownership in the hands of the private-sector, their willingness to provide refuge might change in the future.

- A private owner might not be willing to accept liability for protecting people from a tsunami. This concern might be addressed by proper legislation.

4.3.5 School Facilities

School facilities are another opportunity for consideration as vertical evacuation structures. By building a new school, or by upgrading an existing school to act as a vertical evacuation facility, the population of children attending the school is also made safer from tsunami risk. An example from Japan is shown in Figure 4-6. As in the case of other existing buildings, existing school buildings would likely need significant strengthening or replacement, in order to meet tsunami design criteria. Clear advantages to using schools as vertical evacuation facilities include:

- Many people are already familiar with the neighborhood schools, and their locations are well marked.
- Ongoing construction of schools provides an opportunity and potential funding mechanism for co-located tsunami vertical evacuation structures.

A disadvantage to using a school facility is that the daily needs of the school can interfere with the vertical evacuation process. For example, after a major earthquake, keeping a school full of children contained so others can enter the school is a potential problem. School security will also be an issue.

Figure 4-6 School building in Aonae, Japan, in which the upper floors are intended to be used as tsunami refuge space.

4.3.6 Existing Buildings

Historic damage patterns suggest that many structures not specifically designed for tsunami loading can survive tsunami inundation and provide areas of refuge. Where some existing buildings may require significant strengthening and replacement to meet tsunami design criteria, it is possible that some existing structures could serve as vertical evacuation structures or could be made more tsunami-resistant with only minor modifications. An assessment of both the functional needs and potential structural vulnerabilities would be required to determine if an existing building can serve as a vertical evacuation structure.

4.4 Quality Assurance

Because of the high design criteria that a vertical evacuation structure must meet, a number of design specialties need to be involved. Architects can help design the layout and ingress/egress patterns within the building, engineers can ensure that the structure can withstand expected forces, and an engineering geologist can analyze the site in the larger context of the geology and report whether there are additional hazards such as potential landslides or liquefiable soils.

4.4.1 Peer Review

Professional peer review is an important tool for quality assurance. Architectural, engineering, and geologic peer review should be considered before plans are submitted.

4.4.2 Plan Checks

The special design criteria employed in the design of a tsunami vertical evacuation structure may warrant the need for special approvals. In some communities, the local building authority may not be familiar with tsunami design criteria, or with performance-based design concepts, and should seek assistance from other sources to check the plans.

4.4.3 Construction Quality Assurance and Quality Control

High performance structures such as vertical evacuation structures require extra care to make sure that the designs are properly implemented during the construction phase. An effective Quality Assurance and Quality Control Plan is critical to ensuring the structure will perform as expected.

Chapter 5

Funding

5.1 Potential Funding

As of 2009, there is no dedicated funding for vertical evacuation structures in the United States. Although vertical evacuation has been successfully implemented in Japan and other countries, the concept is relatively new in the United States. Figure 5-1 shows a tower in Japan that was specifically built to serve as a vertical evacuation structure, but serves other community purposes the rest of the time.

As of 2009, there is no dedicated funding for vertical evacuation structures in the United States. Creative use of other types of available funding sources can help a community build a new structure or strengthen an existing one for this use.

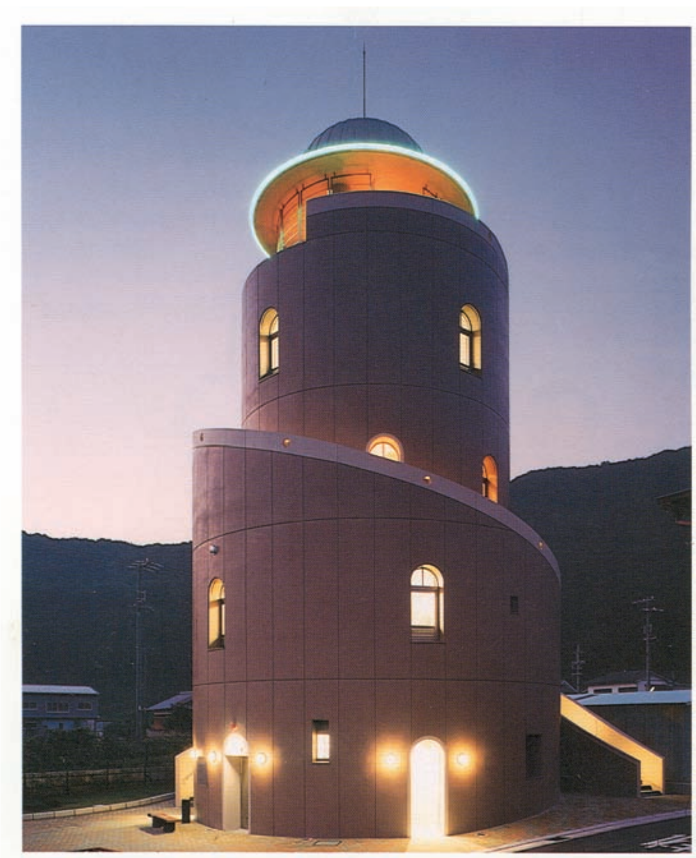

Figure 5-1 Tsunami evacuation structure in Kise, Japan, that includes an archival library on a lower level. A structure such as this can also be used as a community center and may bring in revenue that can be used to repay costs or maintain it.

5.1.1 Federal Funds

Possible sources of federal funding include the Department of Commerce, Department of Homeland Security, Department of Housing and Urban Development, Department of the Interior, the Federal Emergency Management Agency, the Small Business Administration, and the Veterans Administration.

State and local governments receive grants from many different departments and agencies of the federal government for a wide array of services. Possible sources of federal funding include the Department of Commerce, Department of Homeland Security, Department of Housing and Urban Development, Department of the Interior, the Federal Emergency Management Agency, the Small Business Administration, and the Veterans Administration. Just one example of such a grant program would be Community Development Block Grants from the Department of Housing and Urban Development, which could be used to help build a vertical evacuation structure if it is co-located with a qualifying asset like a community center. In general, however, as this is a relatively new concept addressing a hazard not normally covered by these programs, it may take some time for agencies to be able to modify the federal regulations governing their programs to qualify these types of projects. Each community should work with the applicable state and federal offices to explore the options available for its specific needs.

5.1.2 Public-private Partnership

The community might develop a public-private partnership to build a vertical evacuation structure if there is a new private-sector or tribal development being planned in the community that could support vertical evacuation. For example, if a new hotel is being considered, a city might be able to partner with the developer to build it to a higher standard, allowing the public to use it as a vertical evacuation structure in case of a tsunami.

If such a partnership is forged, there should be a clear understanding in advance that the public will have free access to all entrances in the facility in the event of a tsunami evacuation. Many facilities routinely lock all but one central door, limiting free access. If using a privately-funded facility, explicit legal agreements need to be negotiated. Ownership and liability issues must be agreed to before a tsunami warning is issued or a large earthquake strikes.

5.1.3 Self-funding

It will be difficult to wholly self-fund a vertical evacuation structure, but there might be an opportunity to generate revenue by co-locating a vertical evacuation facility with a different primary use such as a parking garage or community center. The vertical evacuation structure would be available for emergencies, but the primary use could generate money that could be used to repay initial bonds or investment. Alternatively, revenue from the primary use could be dedicated and reserved until a sufficient amount is available to modify the structure to include a vertical evacuation component.

5.1.4 State and Local Revenue

State and local governments are funded by a variety of tax and fee mechanisms. Each of these should be investigated to see if they could provide partial or total funding for a vertical evacuation strategy.

State and local governments also have the ability to raise money for dedicated projects. For example, a project like building engineered high ground that could also be used as a park or open space might be paid for by a local improvement district. A special bond assessment could also be used for funding.

Another alternative is to provide tax incentives to add a refuge capability to private development. The state or local government would not have to raise cash to contribute to a project but would reduce tax assessments instead.

Chapter 6
Operation and Maintenance

6.1 Facility Operations Plan

A Facility Operations Plan should be in place before a tsunami occurs. Such a plan includes instructions on how the vertical evacuation structure will open after a warning, how it will operate, what supplies will be stocked, and how people will leave the structure when the threat is over. Answers to these questions will depend on the type of vertical evacuation structure chosen. Logistics for engineered high ground will be different than those for a vertical evacuation structure co-located with a community center.

The **Facility Operations Plan** should include instructions on:
(1) how the vertical evacuation structure will open after a warning,
(2) how it will operate,
(3) what supplies will be stocked, and
(4) how people will leave the structure when the threat is over.

In the case of a near-source-generated tsunami, it may be necessary to assume that few or no public staff will be immediately available for facility operation. A Facility Management Team that oversees regular maintenance and is responsible for operations may be necessary. Members of the local public works, parks, and emergency management staff would be candidates for this team. Additionally, a Community Emergency Response Team (CERT), if constituted, can play an important role in a tsunami response plan. CERTs could help with maintenance of the vertical evacuation structure, and in the case of an actual tsunami, CERT members could operate the vertical evacuation structure.

A **Facility Management Team** can be formed to oversee regular maintenance and operations at the facility.

The Facility Operations Plan should cover the needs of a community from the first issue of a tsunami watch or tsunami warning until an "all clear" announcement is issued.

6.2 Tsunami Warnings

The only warning available for an impending near-source-generated tsunami will likely be the severe ground shaking of the triggering earthquake. In this case, the earthquake should serve as the tsunami warning, and the Facility Operations Plan should be activated when strong ground shaking is felt.

In the case of a mid- or far-source-generated tsunami, the ground shaking may not be felt, but a tsunami warning will be issued by the National Weather Service if a tsunami threat is imminent. As water level data are collected, the warning will be cancelled, restricted, or expanded incrementally. The warning will give adequate time for immediate response activities to be initiated in accordance with the Facility Operations Plan.

When the Facility Operations Plan is activated, responsible personnel, such as the Facility Management Team, should begin performing tasks such as:

- disseminating a public warning to the community,
- alerting the public to evacuate potential inundation areas and head to vertical evacuation structures or high ground,
- distributing supplies, administering first aid, and
- communicating with emergency managers, and monitoring the tsunami from within the facility.

6.3 Opening the Vertical Evacuation Structure

Ideally, the facility should be configured so that it is always accessible or can be entered without emergency personnel. Figure 6-1 shows a simple concrete building used as a vertical evacuation structure in Japan. Especially in a near-source-generated event, emergency responders may not be able to get to the vertical evacuation structure immediately. If people arrive at a facility but cannot enter, they will be confused, angry, or frightened. The responsibility of opening the shelter must be clearly assigned in the Facility Operations Plan and should include backup personnel.

Figure 6-1 A concrete structure in Kaifu, Japan, that is used as a vertical evacuation structure. Structures like this are easy to reach, easy to navigate within, and still provide protection from the destructive forces of tsunamis.

Every vertical evacuation structure will have a maximum recommended occupancy. This number should be clearly posted. Lack of clarity about the capacity of the structure may cause potential conflicts and disturbances. A community may have to educate their able-bodied population to pass by a crowded vertical evacuation structure and continue on to an adjacent structure, the closest high ground, or further inland.

Policies regarding maximum occupancy, accommodation for pets and vehicles should be clearly posted at the vertical evacuation structure and included in the public education materials to avoid misunderstandings.

Planning and operation of a vertical evacuation structure should include consideration of pets. Many people will not want to leave their pets behind during a disaster. The policy regarding pets should be carefully considered and clearly stated in the Facility Operations Plan. Information about accommodation of pets (or not) should be clearly posted to avoid misunderstandings and hostility when users arrive at the facility. It should also be included in public education materials.

It is important to discourage people from using cars to evacuate after a tsunami warning, especially in a near-source-generated event. Figure 6-2 shows severe road damage after the 1964 Alaska earthquake, demonstrating that driving to vertical evacuation structures after a near-source-generated tsunami may not be feasible. Also, parking at vertical evacuation structures can create problems, such as blocking or constricting access to the site and thus preventing users from getting to the structure before the tsunami strikes. Parked vehicles may also become water-borne debris that can cause damage to the structure. Policies about parking need to be developed for every facility and included in public education materials.

Figure 6-2 Roadway damage from the 1964 Alaska earthquake (Photo from United States Geological Survey).

6.4 Operating the Vertical Evacuation Structure

The primary purpose of a vertical evacuation structure is to escape tsunami inundation. In most areas, damaging waves will occur within the first 12 hours, though the potential for abnormally high tides and coastal flooding can last as long as 24 hours.

Ideally, a vertical evacuation structure would be stocked with necessary supplies. However, it is better to have a facility with no supplies than to have no facility at all. Figure 6-3 shows a vertical evacuation structure in Japan that holds few supplies, but will keep people at a safe level above tsunami inundation.

Figure 6-3 Vertical evacuation structure at Shirahama Beach Resort in Japan that is designed as a simple platform to keep people safe during a tsunami.

> If supplies are stored onsite, someone must be responsible for making sure they are stocked, accessible during emergencies, and rotated at regular intervals.

Nevertheless, provisions for supplies should be considered if possible. When supplies are provided, storage areas will need to be included in the design. If supplies are stored onsite, someone must be responsible for making sure they are stocked, accessible during emergencies, and rotated at regular intervals. Security measures to protect them when the vertical evacuation structure is not in use should also be in place.

If possible, a vertical evacuation structure would contain, as a minimum, the following supplies:

- water and food sufficient for the capacity and planned duration of the use of the refuge,
- flashlights with continuously charging batteries (one flashlight per 10 shelter occupants); flashlights with hand crank charging are an option,
- fire extinguishers (number required based on occupancy type) appropriate for use in a closed environment with human occupancy,
- first-aid kits rated for the shelter occupancy,
- NOAA weather radio with continuously charging batteries,
- radio with continuously charging batteries (solar or mechanical charging) for receiving commercial radio broadcasts,
- supply of extra batteries to operate radios and flashlights, and
- audible sounding device that continuously charges or operates without a power source (e.g., canned air horn) to signal rescue workers if shelter egress is blocked.

In a near-source-generated tsunami event, in particular, major destruction of surrounding structures due to the earthquake ground shaking should be expected. To facilitate communication and public sanitation in such instances, the following utilities and equipment should also be considered for inclusion at the vertical evacuation facility:

To facilitate communication and public sanitation the following utilities and equipment should be considered for inclusion at the vertical evacuation facility:
(1) on-site sanitation facilities,
(2) backup communication to telephone,
(3) battery-powered radio transmitter or signal-emitting device, and
(4) emergency power to meet lighting and ventilation needs.

- *On-site sanitation facilities that function without power, water supply, and possibly waste disposal.* Although sanitation facilities may be damaged during a tsunami, locating a vertical evacuation structure above a pump station would allow the system to have some capacity during the event.
- *At least one means of backup to telephone communication.* Since telephone service is likely to be disrupted, backup communication equipment such as satellite phones, ham radios, cellular telephones, citizen band radios, or emergency radios capable of reaching police, fire, or other emergency personnel should be available. If cell phones are relied upon for communications, a signal amplifier should be provided to boost cellular signals from within the vertical evacuation structure. It should be noted that cellular systems might be completely saturated in the hours immediately after an event if regular telephone service has been interrupted.
- *A battery-powered radio transmitter or signal-emitting device that can be used to signal the location of the facility to local emergency personnel.* In case the occupants become trapped inside the vertical

The Facilities Operation Plan should designate who has the authority to issue an "all clear" announcement and release people from the structure after a tsunami warning is canceled.

evacuation structure, community vertical evacuation sites should be communicated to police, fire, and rescue organizations before an event occurs.

- *Emergency power to meet lighting and possibly ventilation needs.* In case of a disruption in the electricity service, a battery-powered system is recommended as a power backup source because it can be located and fully protected within the vertical evacuation structure. If the backup power supply for the lighting system is not contained within the structure itself, it should be located in a structure designed to the same criteria as the vertical evacuation structure.

6.5 Leaving the Vertical Evacuation Structure

It is important for people to stay in a vertical evacuation structure until local officials declare it safe to leave. After the tsunami waves have subsided, other hazards, such as chemical spills or fire, may still exist in the surrounding area. Public education programs should stress the importance of staying at the structure, and should warn people of the danger of successive waves.

The Facilities Operation Plan should designate who has the authority to issue an "all clear" announcement and release people from the structure after a tsunami warning is canceled. It should also include backup designees with this authority. If there is no communication with the outside world or no qualified officials at the facility, someone on site may have to be provided with information needed to make that determination.

After local officials have determined that evacuees can leave a vertical evacuation structure, the evacuees should be instructed on whether they can return to their homes, go to a long-term shelter, or be evacuated to another area.

6.6 Maintenance

The Facility Operations Plan should include a **maintenance plan** designating at least one person or team to coordinate and schedule regular maintenance of the facility, including keeping a regular inventory checklist of emergency supplies and a plan for rotation of provisions.

The Facility Operations Plan should include a maintenance plan designating at least one person or team to coordinate and schedule regular maintenance of the facility, including keeping a regular inventory checklist of emergency supplies and a plan for rotation of provisions. In addition, signage needs to be kept current. It is not uncommon for tsunami evacuation signs to be stolen, and they need to be replaced as soon as possible. After a tsunami event, the facility will need to be assessed for damage, evaluated for feasibility of continued use, repaired, cleaned and re-stocked.

6.7 Long-term Issues

The community's needs should be periodically reassessed because the population may increase or decrease, new hazards may be discovered, or new vertical evacuation structures may be developed. Every few years, the community should reassess its hazard, response plans, and need for vertical evacuation structures.

References

ARC, 2002, *Standards for Hurricane Evacuation Shelter Selection*, Publication No. 4496, http://www.floridadisaster.org/Response/engineers/documents/newarc4496.pdf, American Red Cross, Tallahassee Florida.

ATC, 2009, *Guidelines for the Seismic Performance Assessment of Buildings,* ATC-58 Report – 35% Draft, prepared by the Applied Technology Council for the Federal Emergency Management Agency, Redwood City, California.

Connor, D., 2005, *The City of Seaside's Tsunami Awareness Program: Outreach Assessment — How to Implement an Effective Tsunami Preparedness Outreach Program*, Open-File Report O-05-10, Oregon Department of Geology and Mineral Industries.

Crossett, K.M., T.J. Culliton, P.C. Wiley, and T.R. Goodspeed, 2004: *Population Trends Along the Coastal United States: 1980-2008.* National Oceanic and Atmospheric Administration, National Ocean Service. Management and Budget Office, Silver Spring, MD.

Dunbar, P., Weaver, C., Bernard, E., and Dominey-Howes, D., 2008, *U.S. States and Territories National Tsunami Hazard Assessment, 2006 Historical Record and Sources for Waves*, National Oceanic and Atmospheric Administration, Washington, D.C. (draft report).

FEMA, 2000, *Design and Construction Guidance for Community Shelters*, FEMA 361 Report, Federal Emergency Management Agency, Washington, D.C.

FEMA, 2007, *Hazards U.S. Multi-Hazard*, http://www.fema.gov/plan/prevent/hazus/index.shtm

González, F.I., Titov, V.V., Mofjeld, H.O., Venturato, A., Simmons, S., Hansen, R., Combellick, R., Eisner, R., Hoirup, D., Yanagi, B., Yong, S., Darienzo, M., Priest, G., Crawford, G., and Walsh, T., 2005, "Progress in NTHMP Hazard Assessment," *Natural Hazards*, Special Issue: U.S. National Tsunami Hazard Mitigation Program, Vol. 35, No. 1, pp. 89-110.

ICC/NSSA, 2007, *Standard on the Design and Construction of Storm Shelters*, ICC 500, International Code Council and National Storm

Shelter Association, Country Club Hills, Illinois (Third Public Comments Draft).

Lander, J.F., 1999, *Caribbean Tsunamis: An Initial History*, http://www.mona.uwi.edu/uds/Tsunami_Lander.html.

Lockridge, P.A., Whiteside, L.S., Lander, J.F., 2002, "Tsunamis and Tsunami-Like Waves of the Eastern United States," *Science of Tsunami Hazards*, Vol. 20, No. 3.

Pararas-Carayannis, G., 1968, *Catalog of Tsunamis in Hawaiian Islands*, http://www.drgeorgepc.com/TsunamiCatalogHawaii.html.

Priest, G.R., Goldfinger, C., Wang, K., Witter, R.C., Zhang, Y., and Baptista, A.M., 2008 submitted, "Tsunami Hazard Assessment of the Northern Oregon Coast: A Multi-deterministic Approach Tested at Cannon Beach, Oregon", *Special Paper 41,*Oregon Department of Geology and Mineral Industries.

Satake, K., Wang, K., and Atwater, B.F., 2003, "Fault Slip and Seismic Moment of the 1700 Cascadia Earthquake Inferred from Japanese Tsunami Descriptions", *Journal of Geophysical Research* Vol. 108, pp. ESE 7-1-17.

Riggs, H. R. et al., 2008, "Project Abstract", *Tsunami Engineering Research Initiative*, http://teri.hawaii.edu/abstract.htm.

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