Seven Principles for Planning and Designing for Tsunami Hazards

Designing for Tsunamis

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March 2001

National Tsunami Hazard Mitigation Program

NOAA, USGS, FEMA, NSF, Alaska, California, Hawaii, Oregon, and Washington

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A multi-state mitigation project of the National Tsunami Hazard Mitigation Program (NTHMP)

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Burning petroleum storage tanks along the Seward, Alaska, waterfront after the 1964 tsunami and earthquake. Credit: Anchorage Museum of History and Art

"Seward was…attacked by the main tsunami waves…as the wave traveled along the shore, it spread burning oil…the resulting fires engulfed the downtown…surge forces destroyed homes, docks, canneries, and the small boat harbor…virtually the entire downtown…was destroyed by fire."

Account of the effects of the 1964 Alaska earthquake and resultant tsunami in Seward, Alaska, in *Planning for Risk: Comprehensive Planning in Tsunami Hazard Areas.*

The Threat of Tsunamis to Coastal Communities

Tsunami waves generated by earthquakes, volcanic eruptions, or underwater landslides can reach 50 feet or more in height and devastate coastal communities. In recorded history, tsunamis worldwide have killed hundreds of thousands of people. Since 1946 six tsunamis have killed nearly 500 people and damaged hundreds of millions of dollars of property in Alaska, Hawaii, and along the West Coast of the United States.

Tsunamis are infrequent events but can be extremely destructive. While Hilo, Hawaii, suffered seven significant tsunamis in the last century, and Crescent City, California, experienced two damaging tsunamis in four years (1960 and 1964), many communities at risk in the Pacific region have no recent experience with tsunami damage and, hence, may have a false sense of security regarding the hazard.

An estimated 489 cities within the Pacific states of Alaska, California, Hawaii, Oregon, and Washington are susceptible to tsunamis; as many as 900,000 residents of these cities would be inundated by a 50-foot tsunami.

Beyond preparing for evacuation and emergency response, communities can reduce their tsunami risk by modifying their land use planning and development approval practices. Although planning for tsunamis will not be a top priority for most coastal communities, relatively small efforts to plan for this hazard can significantly increase community safety.

900,000 people in Alaska, California, Hawaii, Oregon, and Washington live in areas in danger of being inundated by a 50-foot tsunami.

Introduction

Purpose and Organization of the Guidelines

The purpose of these guidelines is to help coastal communities in the five Pacific states—Alaska, California, Hawaii, Oregon, and Washington—understand their tsunami hazards, exposure, and vulnerability, and to mitigate the resulting risk through land use planning, site planning, and building design. Emergency response and evacuation are addressed extensively in other publications and are only discussed in these guidelines as they relate to land use, siting, and building design and construction issues (see the references at the end of the guidelines concerning emergency response and evacuation planning for tsunamis).

These guidelines are intended for use by local elected, appointed, and administrative officials involved in planning, zoning, building regulation, community redevelopment, and related land use and development functions in coastal communities. The guidelines should also be helpful to state officials having similar responsibilities.

These guidelines are organized according to seven basic principles:

Principle 1: Know your community's tsunami risk: hazard, vulnerability, and exposure

Principle 2: Avoid new development in tsunami run-up areas to minimize future tsunami losses

Principle 3: Locate and configure new development that occurs in tsunami run-up areas to minimize future tsunami losses

Principle 4: Design and construct new buildings to minimize tsunami damage

Principle 5: Protect existing development from tsunami losses through redevelopment, retrofit, and land reuse plans and projects

Principle 6: Take special precautions in locating and designing infrastructure and critical facilities to minimize tsunami damage

Principle 7: Plan for evacuation

For each principle, the discussion includes background information on the topic, recommended process steps for implementing the principle, and specific how-to strategies. Several case studies in the guidelines illustrate how communities in the Pacific

Damage from the 1964 tsunami in Kodiak, Alaska. Credit: NOAA region are addressing tsunami hazards. The guidelines also contain references and contacts for obtaining further information about planning for tsunami hazards. More detailed information on each of the topics discussed in the guidelines is contained in a companion set of background papers that were compiled during the preparation of these guidelines.

The Regulatory Context

All development in coastal areas is subject to federal, state, and local policies and regulations. Understanding the regulatory context is critical to the successful implementation of a tsunami mitigation program.

State and Local Development Regulations

Every coastal community in the five Pacific states has a land use planning and regulation process that responds to state mandates or guidelines, which vary among the states:

- All five Pacific states require local land use planning, and all except Alaska have statewide planning guidelines. Alaska has statewide planning guidelines for coastal resource districts.
- Oregon and Washington require local plans to be consistent with statewide planning goals. California and Hawaii have statewide planning guidelines that are advisory only. Alaska requires a consistency review of coastal resource district plans with statewide standards and with other districts' plans.
- California, Oregon, and Washington require hazard mitigation as part of their general land use planning process. Alaska requires it for coastal resource district plans only. Hawaii only suggests that this topic be addressed.
- California, Oregon, and Washington require conformance with a state model building code based on the Uniform Building Code (UBC). Alaska only mandates adoption of a fire code, and Hawaii does not have a state-mandated building code. All of the counties in Hawaii and the larger cities in Alaska have adopted a version of the UBC.

A community's comprehensive plan is at the top of the local land use planning/regulatory process hierarchy. The comprehensive plan is implemented day-to-day through project review and permitting.

Local governments typically require formal approvals for land divisions, the establishment of certain new uses ("conditional uses"), and the physical layout of new development.

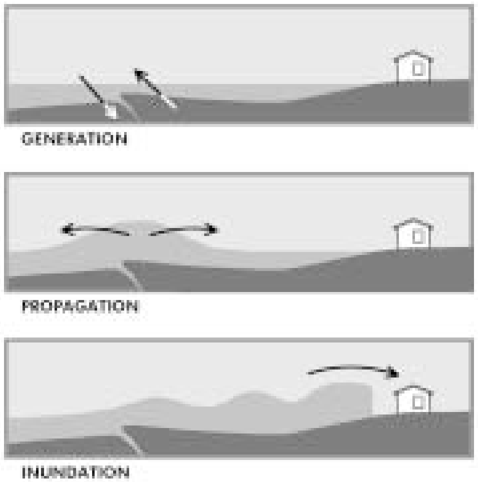
Federal Regulations and Programs

While the federal government has supported state and local planning through numerous programs over the years, there are no federal requirements for statewide or local land use planning. There are, however, two federal programs that are particularly important for land use planning in coastal areas.

The 1972 Coastal Zone Management Act (CZMA) established a voluntary partnership among the federal government, coastal states, and local governments to develop individual state programs for managing coastal resources. The state component consists of federally-approved Coastal Management Programs (CMPs) in 32 coastal states and territories, including the five Pacific states. The purpose of the CZMA is to promote the orderly development and protection of the country's coastal resources.

The National Flood Insurance Program (NFIP), established in 1968, is part of a comprehensive approach to reduce flood damage and to cope with the disastrous effect of floods. The NFIP is administered by the Federal Insurance Administration (FIA), a component of the Federal Emergency Management Agency (FEMA). The NFIP makes federally-backed flood insurance available in communities that adopt and enforce floodplain management ordinances to reduce future flood losses. NFIP requires projects to be located above the 100-year flood or inundation areas.

P•1 Principle 1: Know your community's tsunami risk: hazard, vulnerability, and exposure



A tsunami is a series of long waves generated by a sudden displacement of a large volume of water.

Understanding your community's tsunami hazard, vulnerability, and exposure to damage is the foundation for land use and building strategies that can mitigate tsunami risk. While much remains to be learned about tsunamis, sufficient knowledge, technical information, and expertise already exist to assess the tsunami hazard and risk in all coastal communities.

The Nature of Tsunamis

A tsunami is a series of long waves generated by a sudden displacement of a large volume of water. Tsunamis are triggered by submarine earthquakes, submarine volcanic eruptions, underwater landslides or slumps of large volumes of earth, meteor impacts, and even onshore slope failures that fall into the ocean or a bay.

Most tsunamis originate in the Pacific "Ring of Fire," which is the most active seismic feature on earth. Tsunamis are typically classified as either local or distant. Locally-generated tsunamis have minimal warning times and may be accompanied by damage resulting from the triggering earthquake such as groundshaking, surface faulting, liquefaction, or landslides. Distant tsunamis may travel for hours before striking a coastline.

In the open ocean, a tsunami may be only a few feet high but can travel up to 500 miles per hour. As a tsunami enters the shoaling waters near a coastline, its speed diminishes, its wavelength decreases, and its height increases greatly. However, the first wave usually is not the largest. Several larger and more destructive waves often follow the first one. While tsunami waves slow upon reaching the coastline, they still travel faster than Olympic long-distance runners can run—faster than 15 miles per hour.

The configuration of the coastline, the shape of the ocean floor, and the characteristics of advancing waves play important roles in the destructiveness of the waves. A wave may be small at one point on a coast and much larger at other points. Bays, sounds, inlets, rivers, streams, offshore canyons, islands, and flood control channels may cause various effects that result in greater damage than many people

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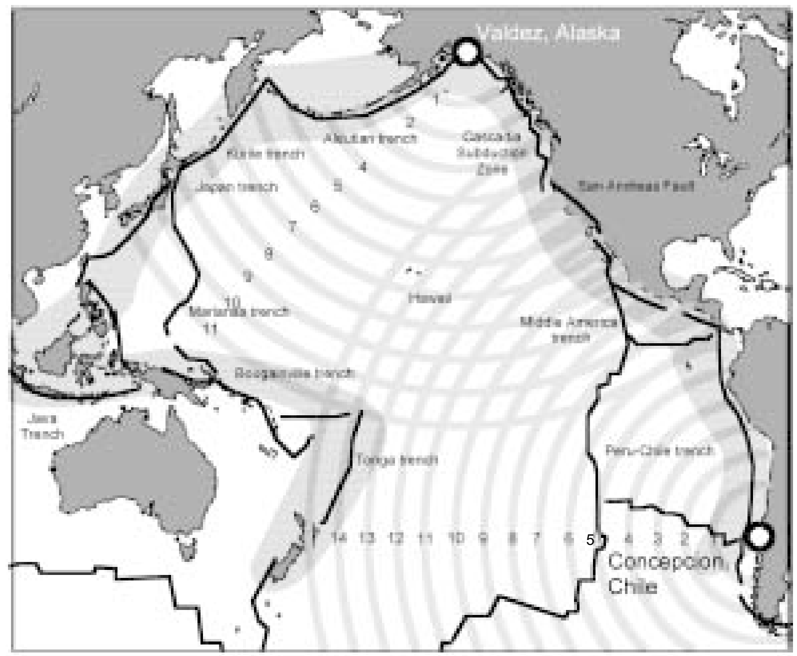
would expect. It has been estimated, for example, that a tsunami wave entering a southern California flood control channel could reach a mile or more inland, especially if it enters at high tide. Offshore canyons can focus tsunami wave energy and islands can filter the energy. The orientation of the coastline determines whether the waves strike head-on or are refracted from other parts of the coastline.

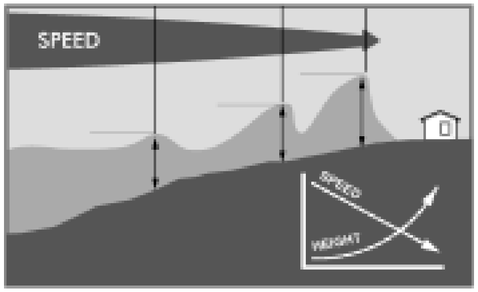
Unlike earthquake shaking that can be damaging over large areas—hundreds of square miles is not unusual—tsunamis impact long, low-lying stretches of linear coastlines, usually extending inland for relatively short distances. Upon striking a coast, the wave reflects back to sea, and then can return to the coastline as a series of waves.

The first visible indication of an approaching tsunami may be recession of water (drawdown) caused by the trough preceding the advancing, large inbound wave crest. Rapid drawdown can create strong currents in harbor inlets and channels that can severely damage coastal structures due to erosive scour around piers and pilings. As the water's surface drops, piers can be damaged by boats or ships straining at or breaking their mooring lines. The vessels can overturn or sink due to strong currents, collisions with other objects, or impact with the harbor bottom.

Conversely, a rise in water level may be the first indication of a tsunami. The advancing tsunami may initially resemble a strong surge increasing the sea level like the rising tide, but the tsunami surge rises faster and does not stop at the shoreline. Even if the wave height appears to be small, three to six feet for example, the strength of the accompanying surge can be deadly. Waist-high surges can cause strong currents that float cars, small structures, and other debris. Boats and debris are often carried inland by the surge and left stranded when the water recedes.



The Pacific "Ring of Fire" is the most active seismic feature on earth. Tsunami waves triggered by seismic activity can travel across the Pacific Ocean at up to 500 miles per hour, striking distant coastal areas in a matter of hours. The figure shows the estimated number of hours for tsunami-generated waves to travel across the Pacific Ocean from Alaska and Chile, respectively.



As a tsunami approaches shore, it slows down and dramatically increases in height.

Outflow following inundation also creates strong currents, which rip at structures and pound them with debris, and erode beaches and coastal structures.

As tsunamis reach the shoreline, they may take the form of a fast-rising tide, a cresting wave, or a bore. The bore phenomenon resembles a step-like change in the water level that advances rapidly (from 10 to 60 miles per hour). Normal tidal bores at the Bay of Fundy, Canada, or the Yellow River, China, provide examples of this phenomenon.

The force and destructive effects of tsunamis should not be underestimated. At some locations, the advancing turbulent wave front will be the most destructive part of the wave. In other situations, the greatest damage will be caused by the outflow of water back to the sea between crests, sweeping all before it and undermining roads, buildings, bulkheads, and other structures. This outflow action can carry enormous amounts of highly damaging debris with it, resulting in further destruction. Ships and boats, unless moved away from shore, may be dashed against breakwaters, wharves, and other craft, or be washed ashore and left grounded after the withdrawal of the seawater.

The Destructiveness of Tsunamis

Though rare, tsunamis are devastating events for humankind. In recorded history, hundreds of thousands of people all over the world have died as a result of tsunamis. Some scholars believe that a tsunami resulting from the eruption of the volcano Thera destroyed the Minoan culture in the Mediterranean in 1628 B.C.

Since 1946, six destructive tsunamis have caused nearly 500 deaths and damaged hundreds of millions of dollars of property in Alaska, Hawaii, and along the U.S. West Coast.

The destructive potential of tsunamis was most dramatically illustrated by the 1960 Chile earthquake and the 1964 Alaska earthquake, two of the largest earthquakes ever measured.

The 1960 earthquake off coastal Chile devastated parts of Chile and almost instantly raised a California-sized piece of land on the ocean floor about 30 feet. Its companion series of tsunami waves resulted in further losses in many other Pacific Rim and island locations, including Hilo, Hawaii, and Japan.

Principle 1: Know your community's tsunami risk: hazard, vulnerability, and exposure

Over 2,000 lives were lost, including 61 in Hawaii and 122 in Japan. The earthquake-generated tsunami waves registered on tide gauges for more than a week around the Pacific Rim.

The tsunamis generated by the 1964 Alaska earthquake also spread destruction around the Pacific Rim. In Alaska alone, waves and the effects of groundshaking and submarine landslides destroyed portions of numerous coastal communities. Whittier suffered losses to docks, oil facilities, and rail facilities with wave run-up noted at an elevation of 104 feet in a narrow passage. Kodiak suffered subsidence due to the groundshaking, followed by multiple tsunami waves that inundated the low-lying areas of town, destroying virtually all docking facilities and driving boats and other debris ashore. Valdez experienced submarine landslides triggering waves as high as 23 feet, destroying much of the town. Seward experienced 30- to 40-foot tsunamis and local submarine landslides, causing extensive damage to the docking areas and fires in petroleum storage facilities.

Exposure to Tsunamis

Coastlines have always been a favored location for human settlements. Because of the attractiveness of coastal locations and the long gaps between devastating tsunami events, coastal communities have continued to develop in recent times with new housing, maritime facilities, and resort developments. As a result, more people and facilities are threatened by the destructive force of tsunamis. According to one recent estimate, 489 cities in Alaska, California, Hawaii, Oregon, and Washington are susceptible to tsunami inundation, with an estimated 900,000 people living or working within areas that could be inundated by a 50-foot tsunami.

Understanding the Risk to Your Community

Understanding the tsunami threat is the first step in reducing potential losses. These guidelines repeatedly stress the importance of compiling and applying good local tsunami hazard information.

Potential destructiveness of tsunamis in the five Pacific states

State	Cities susceptible to tsunamis	Population endangered by a 50-foot tsunami
Alaska	52	47,000
California	152	589,500
Hawaii	123	131,000
Oregon	60	31,500
Washington	102	96,000
Total	489	895,000

Source: Tsuinfo Alert, v.2, no. 2, March-April, 2000. Terry Wallace, University of Arizona, Department of Geosciences.

Principle 1: Know your community's tsunami risk: hazard, vulnerability, and exposure

Damage to Crescent City, California, from the 1964 tsunami. Nearly 900,000 people in the five Pacific states live in the inundation zone for a 50-foot tsunami. Credit: Del Norte Historical Society

Tsunami risk is a function of three factors: 1) the nature and extent of the tsunami hazard; 2) the vulnerability of facilities and people to damage; and 3) the amount of development or number of people exposed to the hazard.

There is no substitute for having a local evaluation of a community's hazard, vulnerability, and exposure. The information will help communities understand the causes and consequences of a tsunami in order to design specific loss-prevention measures and programs.

Process for Obtaining Local Tsunami Hazard Information

1) Prepare Tsunami Inundation Studies

The first step in understanding your risk is to estimate the extent and pattern of your community's potential tsunami inundation, tsunami frequency (recurrence interval), and the reliability of the estimate. In all five Pacific states, state agencies are conducting ongoing tsunami mapping programs. The methodologies used and the geographic coverage of efforts vary from state to state. Generally, the mapping programs involve some combination of computer modeling, historical research, and field confirmation. The current round of tsunami inundation mapping is designed primarily to support evacuation planning, but provides a good starting point for land use planning as well.

Because of the often simplistic assumptions that are made in a statewide study, local land use managers should conduct their own more refined assessments of tsunami inundation potential. Each level in the land use planning, site planning, and building design hierarchy requires a different level of refinement in the information concerning potential inundation and destructive effects. In many cases, it will only be possible to gather adequate information about the potential effects of local tsunamis because distant tsunamis are more difficult to model.

Principle 1: Know your community's tsunami risk: hazard, vulnerability, and exposure

Tsunami studies should include:

- reviewing historic records and describing potential local and distant tsunami sources
- evaluating potential for ground failures and other geologic effects
- estimating number of waves, their heights, arrival times, and inundation depths
- calculating water velocities and debris loads
- estimating probabilities of occurrence and levels of certainty

Preparing these studies will ordinarily require the assistance of consulting specialists. Local governments may also want to create an advisory committee composed of members from nearby colleges and universities, government agencies, consulting organizations, and civic and professional organizations.

2) Prepare Tsunami Loss Scenario Studies

Knowing the extent and pattern of inundation allows communities to assess the potential damage such inundation would do to existing development and infrastructure. Scenario studies based on assumed conditions provide a graphic illustration of what can happen to a community, both during and after a destructive tsunami. These studies should also address other hazards, such as local earthquakes, that may cause concurrent damage. Local tsunamis pose unique problems for emergency planners since the facilities and infrastructure needed for evacuation may be damaged by the earthquake that triggers the tsunami.

Such scenarios typically assess potential losses to important buildings and structures, transportation systems, and utility systems. The resulting tsunami loss scenario study will provide the foundation for reducing potential losses. The most important principle is that the study be accepted as the best that could have been done within the constraints of funding, time, and knowledge. Because of the inherent limitations associated with loss studies, it will be important for all involved to reach consensus on the results. This will help ensure community and political acceptance–a key ingredient for establishing effective loss-reduction measures. However, consensus may be hard to reach in these

Wave generated by the 1946 tsunami in the Keaukaha area of Hilo, Hawaii. Credit: Pacific Tsunami Museum studies, and differing interpretations or conclusions need to be identified and discussed.

The case study on page 14 describes an earthquake and tsunami scenario for the north coast of California, including damage probability and assessments for a variety of facilities, infrastructures, and services. The Federal Emergency Management Agency (FEMA) has developed a geographic information system (GIS)-based natural hazard loss estimation methodology, called HAZUS, that can be adapted to address tsunami hazards in scenario studies.

Release of any loss scenario study should be accompanied by briefings of key community groups and leaders, the media, elected and appointed officials, and others important to adopting and applying loss reduction measures.

Strategies for Applying Hazard Information to Reducing Future Losses

Strategy 1: Incorporate Hazard Information into Short- and Long-Term Planning Processes

One of the best ways to prevent future losses from natural hazards is to ensure the subject is addressed along with all other issues in short- and long-term comprehensive planning programs and project reviews. Some jurisdictions require that public safety considerations or specific hazards be addressed. The resulting information becomes part of the evaluation and decision-making processes. The scope of the hazard information will vary with the breadth or narrowness of the project, such as amending a growth management plan, reviewing a specific development proposal, or modifying a zoning ordinance.

The information should be used to evaluate major development proposals so that risk mitigation is factored into decisions, approvals, and permits.

Moreover, knowing that such information will be needed, owners and developers should be required to supply detailed hazards data and mitigation measures as part of their proposals. Communities should have specific administrative and review procedures to ensure the effectiveness of this process.

Strategy 2: Use Hazard Information to Build Public and Political Support for Mitigation Measures

Hazard information, loss estimates, and planning scenarios are powerful tools to create understanding and commitment to mitigation. They should be used to acquaint the populace with their exposure and vulnerability, empower them to take precautionary measures, build political consensus about acceptable risk-reducing policies and programs, and strengthen emergency preparedness and warning programs.

Moreover, hazard information, or procedures for consulting such information, should be included in other programs and processes affecting current and future development. This will ensure that risk management becomes a regular part of the decision-making processes leading to sustainable and more disaster-resistant communities.

Strategy 3: Estimate Reduced Future Losses by Evaluating the Effectiveness of Loss-Prevention Measures

One of the biggest challenges in preventing losses from natural hazards, especially for rare events such as tsunamis, is to show that mitigation measures would be effective. At the community level, the value of mitigation investments can be estimated by using scenarios and maps to evaluate actions taken to reduce vulnerability and exposure to tsunami hazards. Informed judgments can be made by quantifying the losses that likely would have occurred if such precautions had not been taken.

Strategy 4: Periodically Re-evaluate Community Vulnerability and Exposure

The tsunami hazard is unlikely to change over time, but communities are changing constantly. This dynamic process leads to changes in vulnerability and exposure. Effective long-term tsunami

Damage from the 1960 tsunami in the Waiakea area of Hilo, Hawaii. Parking meters were bent by the force of the debris-filled waves. Credit: U.S. Navy

mitigation means that loss studies should be reviewed and revised periodically—at least every five years—to reflect changes in development patterns and demographics. Regular review and revision will ensure that the most current information is applied, and it could help to demonstrate the effectiveness of loss prevention.

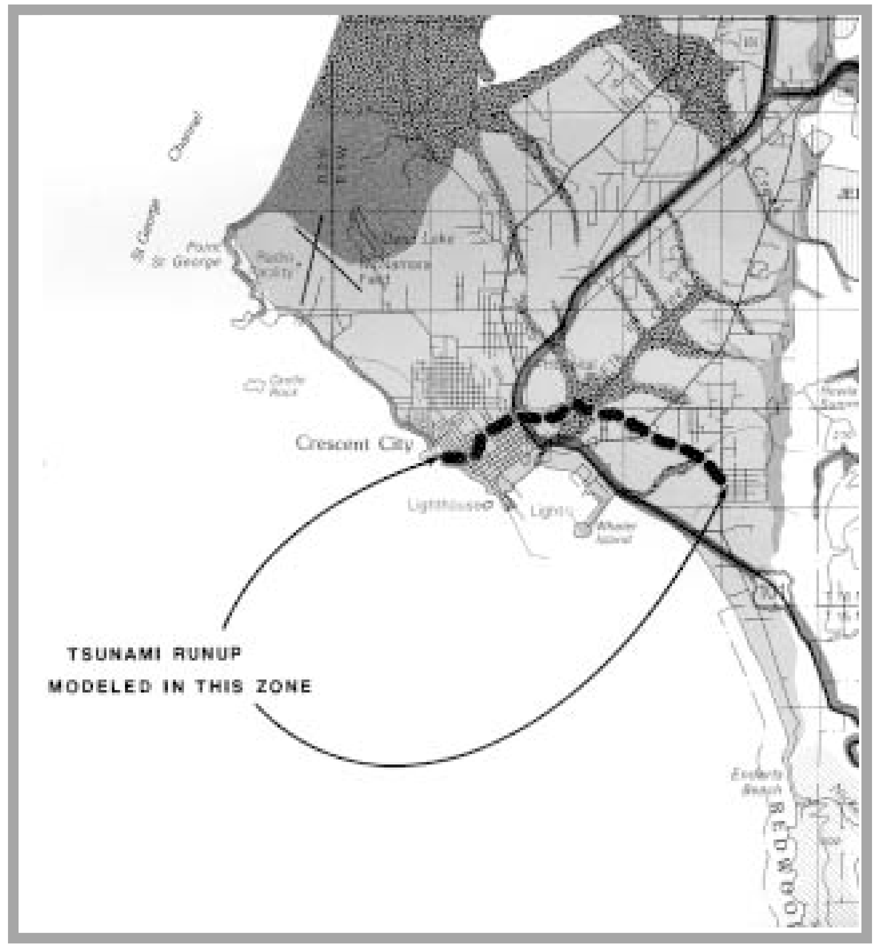
Community vulnerability certainly should be re-evaluated following a disaster or other severe event, perhaps including comparable events in other locations around the world.

Case Study: Planning Scenario for Humboldt and Del Norte Counties

In 1995, the California Division of Mines and Geology published Special Publication 115, entitled *Planning Scenario in Humboldt and Del Norte Counties, California for a Great Earthquake on the Cascadia Subduction Zone.* This report includes a description with supporting maps of the potential effects of a tsunami on the cities of Eureka (Humboldt County) and Crescent City (Del Norte County). This report is an example of local hazard and risk information that can be used to support mitigation efforts.

The scenario earthquake is assumed to generate a local tsunami that would arrive minutes after the earthquake. The maps depict potential structure and infrastructure damage and show locations likely to be flooded by a tsunami caused by a potential great earthquake (magnitude 8.4) occurring offshore on the Gorda segment of the Cascadia Subduction Zone.

The planning scenario includes damage probability and assessments for a variety of facilities, infrastructure, and services including: schools and colleges, hospitals, highways, airports, marine facilities, railroads, and facilities for electric power, natural gas, petroleum products, water supply, and wastewater. These assessments are intended to assist localities in planning for emergency response efforts and pre-disaster retrofitting and other risk mitigation efforts.



Excerpt from Scenario Map for Humboldt and Del Norte Counties

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Principle 2: Avoid new development in tsunami run-up areas to minimize future tsunami losses

Aerial view of tsunami and earthquake damage to Valdez, Alaska, showing the extent of inundation along the coastline from the 1964 Great Alaska Earthquake. Coastal-dependent development can conflict with safety goals. Credit: U.S. Department of the Interior

Tsunami risk can be mitigated most effectively by avoiding or minimizing the exposure of people and property through land use planning. Development should be prevented in high-hazard areas wherever possible. Where development cannot be prevented, land use intensity, building value, and occupancy should be kept to a minimum. Where these strategies are not available and development will occur in possible tsunami inundation areas, planners and designers must look to mitigation through site planning techniques as discussed under Principle 3 or building construction techniques as discussed under Principle 4.

The Role of Land Use Planning in Reducing Tsunami Risks

Land use planning in communities guides the location, type, and intensity of development and can, therefore, be used to reduce the community's exposure to tsunami hazards. Principle 2 focuses on large-scale land use planning issues, such as those that are dealt with in comprehensive plans, zoning ordinances, and subdivision regulations. It focuses on the types, patterns, and densities of uses that could and should be allowed within potential tsunami inundation areas based on consideration of the risk. It is important to remember that the more locational mitigation (Principle 2) is used, the less design mitigation (Principles 3 and 4) is required.

Process for Implementing Land Use Planning Strategies

The following outlines the steps that can be taken when formulating a community land use strategy for tsunami risk mitigation.

1) Understand Locational Context

Opportunities for reducing tsunami risk differ depending on local circumstances, so a one-size-fits-all approach cannot be used. The presence or absence of development within tsunami hazard areas will determine the type of planning approach that is feasible. For example, vacant land conversion, such as expansion of an existing

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community or development of a new community, will require different mitigation strategies than will other forms of development such as infill, redevelopment, reuse, or changes in occupancy (see Principle 5).

2) Understand Trade-Offs

Mitigation often means making trade-offs between or among competing goals when dealing with land use planning issues and tsunami hazards. For example, the public access emphasis in Coastal Zone Management (CZM) programs argues for locating visitor-serving development along the coastline; yet this access can be at direct odds with public safety goals for minimizing new development in tsunami inundation areas.

Coastal-dependent development such as ports and harbors that, by their nature, have to be situated on the coast can also conflict with safety goals. Other planning goals such as compact/dense downtowns can also result in increased risk.

These trade-offs need to be recognized in the planning process. The revision process for a comprehensive plan is a good time to weigh alternatives and to balance competing goals.

3) Review and Update Existing Safety Element

The existing safety or natural hazards element of the comprehensive plan should be reviewed to determine if it adequately recognizes tsunami hazards and how the risk is managed when decisions are made. The following information should be inventoried and updated, as necessary (see Principle 1):

- technical information such as inundation zones
- loss scenario information
- goals and policies

In addition, it should be recognized that tsunami hazards often overlap other hazards and that mitigation for other hazardous conditions can assist in mitigating tsunami risk. Such hazards might include riverine flooding, hurricanes/typhoons, landslides, coastal erosion, and earthquakes.

4) Review and Update Existing Land Use Element and Other Plans

The existing land use element, other comprehensive plan elements, and special plans should be reviewed to determine what changes are needed to address

Erosion along the Oregon coast. Mitigation for other hazardous conditions such as erosion, flooding, hurricanes, and seismic hazards can assist in mitigating tsunami risk. Credit: Oregon Department of Land Conservation and Development the tsunami hazard, and be updated as necessary. Land use policies and programs should address tsunami hazards as part of a comprehensive tsunami mitigation program.

Such an update should focus on the location and vulnerability to damage of existing and planned land uses in the community, including the following:

- residential
- commercial/visitor-serving
- industrial (general)
- industrial (hazardous materials)
- public facilities (transportation and water systems)
- critical facilities and systems (communication, emergency response, electrical power, water supply, and natural gas systems)

5) Review and Update Existing Zoning, Subdivision, and Other Regulations

Existing zoning, subdivision, and other regulations should be reviewed and updated with an eye toward mitigating future tsunami losses. Requirements for consistency between the comprehensive plan and zoning and subdivision regulations vary among the states. In California, for example, the zoning code is considered part of the local coastal program (LCP) for coastal communities and is required to be consistent with the general plan.

6) Planning for Post-Tsunami Reconstruction

Disasters create the opportunity to eliminate nonconforming uses and reshape existing patterns of development to minimize future losses. On the other hand, they can also create enormous pressure to rebuild the community quickly and exactly as it was before the disaster. These rebuilding issues should be addressed through the land use planning process before a disaster strikes so that a community is prepared to deal with rebuilding issues in the event of a disaster.

Principle 2: Avoid new development in tsunami run-up areas to minimize future tsunami losses

Specific Land Use Planning Strategies to Reduce Tsunami Risk

The following are specific recommended land use planning strategies that a community can use to reduce tsunami risk.

Strategy 1: Designate Tsunami Hazard Areas for Open-Space Uses

The designation and zoning of tsunami hazard areas for such open-space uses as agriculture, parks and recreation, or natural hazard areas is recommended as the first land use planning strategy to consider. This strategy is designed to keep development at a minimum in hazard areas. It is particularly effective in areas that have not yet experienced development pressure. It is obviously more difficult in areas that are already partially developed or that have strong development pressures.

Strategy 2: Acquire Tsunami Hazard Areas for Open-Space Uses

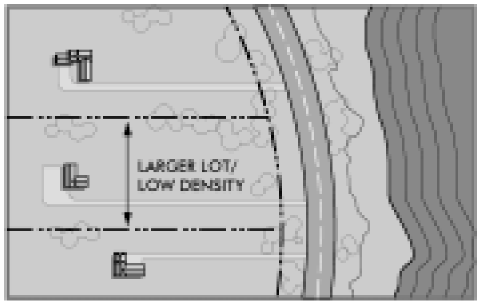
A second strategy is to acquire tsunami hazard areas for open-space uses. Open-space acquisition has several advantages over strictly regulatory approaches such as zoning. Acquisition ensures that the land will be controlled by a public agency or nonprofit entity, and it removes any question about a regulatory taking. The primary disadvantage to acquisition is cost.

There are multiple approaches to acquisition. Since land ownership is in effect a bundle of rights, including the rights to sell, lease, and develop the property, some of these rights, such as the right to develop, can be sold separately from the rest of the property.

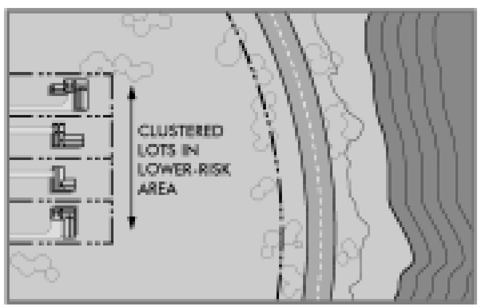
For example, a purchase of development rights (PDR) program is based on purchasing the right to develop land from the bundle of rights associated with the land. A PDR program involves the purchase of the development rights to a property, generally through the granting of a conservation, open-space, or scenic easement that restricts the uses to which the property owner may put the land. A PDR program can also be constructed to purchase a fee-simple interest in a property and then to resell the property with an easement restricting future

Park on the Hilo, Hawaii, waterfront. Open space uses such as parks can keep development at a minimum in hazard areas. Credit: County of Hawaii

Principle 2: Avoid new development in tsunami run-up areas to minimize future tsunami losses



Large-lot zoning can ensure that only very low density residential uses are allowed in hazard areas.



Development can be clustered on site areas where risks are the lowest.

development. A similar result can be obtained through purchasing a fee-simple interest and then leasing the property with restrictions on use. PDR programs are more effective in preserving land from development where development pressure has not yet driven up land prices.

Strategy 3: Restrict Development through Land Use Regulations

In areas where it is not feasible to restrict land to open-space uses, other land use planning measures can be used. These include strategically controlling the type of development and uses allowed in hazard areas, and avoiding high-value and high-occupancy uses to the greatest degree possible.

For example, plan designations and zoning districts can use density restrictions or large-lot zoning (e.g., 10-acre minimum) to ensure that only very low-density residential uses are allowed in hazard areas. Another technique is to require clustering of development on site areas where risks are the lowest.

Strategy 4: Support Land Use Planning through Capital Improvement Planning and Budgeting

The capital improvement planning and budgeting process can be used to reinforce land use planning policies. A major factor in determining future development patterns is where a local jurisdiction chooses to extend sewer and water lines, roads, and other public facilities and services. Decisions can either discourage or encourage development in tsunami and other hazard areas.

Natural hazard risk mitigation should be integrated into infrastructure policy. Infrastructure policies by themselves will not preclude development in certain areas, but they can reinforce land use plans, and they can shape market forces to encourage development in less hazardous areas by not subsidizing infrastructure that serves a higher-risk hazardous area.

Strategy 5: Adapt Other Programs and Requirements

The safety element of a comprehensive plan and the zoning, subdivision, and other programs designed to implement the comprehensive plan may contain regulations that are applicable to tsunami risk mitigation even if tsunami hazards are not mentioned explicitly. Many of these programs and regulations can be adapted relatively easily to address tsunami hazards. For example, existing floodplain restrictions, hillside and landslide controls, and environmental, scenic, recreational, and wildlife-protection requirements can help address tsunami hazards and should be modified for that purpose.

P•3

Principle 3: Locate and configure new development that occurs in tsunami run-up areas to minimize future tsunami losses

The waterfront area of Crescent City, California, flooded by the 1960 tsunami. Credit: USGS

When development is to be sited within a tsunami hazard area, the physical configuration of structures and uses on a site can reduce potential loss of life and property damage. This includes the strategic location of structures and open space areas, interaction of uses and landforms, design of landscaping, and the erection of barriers.

The Role of Site Planning in Reducing Tsunami Risk

Within the broader framework of a comprehensive plan, site planning determines the location, configuration, and density of development on particular sites and is, therefore, an important tool in reducing tsunami risk.

At the site planning level in the planning/regulatory hierarchy, the focus typically is on a single parcel or collection of parcels of land 2 to 200 acres in size, under the control of a single owner. This scale of planning provides limited opportunities for avoiding the tsunami hazard entirely, but can provide a broad range of opportunities to design a project to minimize tsunami damage.

Process for Implementing Site Planning Strategies

The following outlines the steps that can be taken when formulating a site planning strategy for tsunami hazard mitigation.

1) Create a Project Review Process that is Cooperative, Comprehensive, and Integrated

The most effective site planning in coastal areas includes a project review process that reflects the area's vulnerability and exposure to tsunami hazards, considers the broader policy and regulatory context, and is part of a larger mitigation strategy. An interactive and informed site planning and review process can save time for project sponsors and provide better mitigation solutions.

Communities interact with project proponents at various levels in the preparation and review of site plans. The level of review relates to the scale and context of a project. Some projects require site and concept review, while others require a review of fully developed designs. Community-level project review can occur parallel to the design process in an interactive fashion. Alternatively, project site review can be more reactive based on predetermined criteria or plans.

Some communities have adopted comprehensive development policies for waterfront areas to ensure that site planning is part of a review process that implements a larger mitigation plan, economic objectives, and community design concepts. Without this broader framework, community-wide mitigation objectives can be overlooked in a site plan review process that involves different disciplines and multiple departments and decision-making bodies.

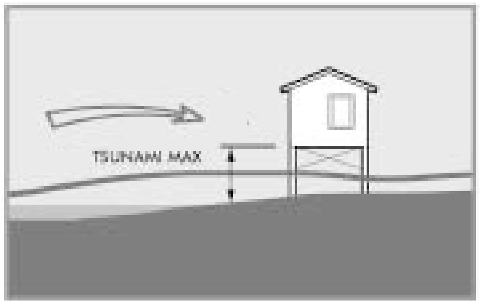
2) Understand Local Site Conditions

Local planning officials and project sponsors must develop mitigation strategies that reflect the character of the site and immediate context. This includes understanding how tsunamis impact different types of site geography, land uses and building types, and development patterns. The depth of tsunami inundation, speed of currents, presence of breaking wave or bore conditions, debris load, and warning time can vary greatly from site to site.

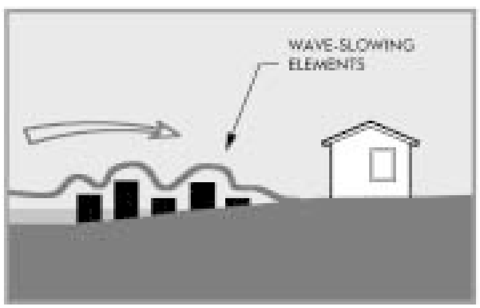
The site analysis phase can be used to establish site plan parameters for tsunami mitigation. Many communities have mapped hazard areas. Within these areas, communities may also have more detailed plans that include site analysis. The analysis typically includes geographic conditions, critical infrastructure (see Principle 6), area access and egress (see Principle 7), and existing and future development patterns. The analysis may also include economic feasibility and community design objectives.

Regional hazard maps can identify many of these at-risk areas, but typically they do not reflect the catastrophic potential of a tsunami that is accompanied by other disasters. Besides inundation, near-source earthquakes can cause damage and possibly lower the elevation of the entire region, causing flooding. Fires, broken infrastructure, liquefaction, mudslides, erosion, and other hazardous conditions can create scenarios that make communities even more vulnerable to tsunami waves. Therefore, each site assessment should identify other hazardous conditions besides elevation and shoreline configuration.

Principle 3: Locate and configure new development that occurs in tsunami run-up areas to minimize future tsunami losses



Avoiding



Slowing

3) Choose a Mitigation Strategy for the Site

Many communities work with project sponsors to select a mitigation approach during the site planning process. Generally, this includes siting solutions that avoid, slow, steer, or block inundation. These can be blended with building design and engineering that provides hardened or passive ways of handling the force of a tsunami (see Principle 4).

Specific Site Planning Strategies to Reduce Tsunami Risk

There are four basic site planning techniques that can be applied to projects to reduce tsunami risk:

1) **Avoid inundation areas**
2) **Slow water currents**
3) **Steer water forces**
4) **Block water forces**

These basic strategies can be used separately or be combined into a broader strategy. The methods can be used in passive ways to allow tsunamis to pass through an area without causing major damage, or they can be used to harden structures and sites to withstand the force of a tsunami. The efficacy of these techniques depends on the intensity of the tsunami event. If the tsunami hazard is underestimated, development in the area may still be vulnerable to a larger event.

Strategy 1: Avoiding

Avoiding a tsunami hazard area is, of course, the most effective mitigation method. At the site planning level, this can include siting buildings and infrastructure on the high side of a lot or raising structures above tsunami inundation levels on piers or hardened podiums.

Strategy 2: Slowing

Slowing techniques involve creating friction that reduces the destructive power of waves. Specially designed forests, ditches, slopes, and berms can slow and strain debris from waves. To work effectively, these techniques are dependent on correctly estimating the inundation that could occur.

Principle 3: Locate and configure new development that occurs in tsunami run-up areas to minimize future tsunami losses

Strategy 3: Steering

Steering techniques guide the force of tsunamis away from vulnerable structures and people by strategically spacing structures, using angled walls and ditches, and using paved surfaces that create a low-friction path for water to follow.

Strategy 4: Blocking

Hardened structures such as walls, compacted terraces and berms, parking structures, and other rigid construction can block the force of waves. Blocking, however, may result in amplifying wave height in reflection or in redirecting wave energy to other areas.

Mitigation Strategies by Type of Development

The following describes various types of new development that may be exposed to tsunami damage and identifies possible mitigation strategies for these different types of development.

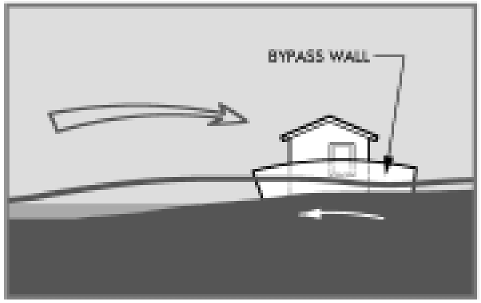
1) Infill Housing

In small communities, individual homes and infill housing are the most common forms of development. Often, there is great political pressure to allow development of smaller sites that do not permit locating development out of the hazard area. Communities can require that these smaller projects be raised above inundation levels and that engineering features be added to their design. However, they can still be vulnerable to damage from debris and other structures that may break free and collide with them. In some cases, new infill buildings can be sited on the high side of a lot to avoid being hit by another structure.

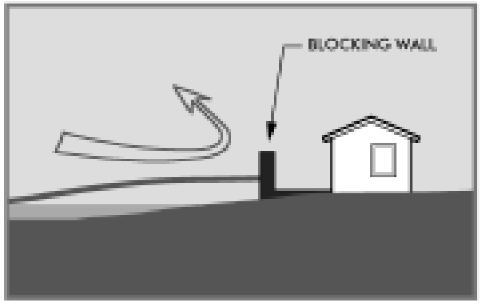
2) New Neighborhoods and Subdivisions

To reduce tsunami damage, the layout of new subdivisions in shoreline areas can include:

- providing maximum spacing between buildings
- elevating buildings above inundation levels
- placing houses behind a tsunami control forest or larger hardened buildings



Steering



Blocking

Elevated restaurant in Hilo, Hawaii. Lower level is designed to allow waves to pass through. Credit: Mintier & Associates

- siting primary access roads outside inundation areas and secondary access roads perpendicular to the shore

3) High-Rise Hotels

New hotels in coastal areas are typically multi-level concrete frame structures. The lower levels of these buildings can be designed for public areas such as lobbies and support uses (such as parking) for upper level rooms. In Hawaii, for example, lower levels of hotels have been designed to allow waves to pass through the ground floor parking, lobby, and service spaces, leaving upper level rooms and meeting spaces undamaged. These buildings must be designed to withstand both tsunami and earthquake forces.

4) Resorts

Resorts can include a broad range of facilities and services, such as small-scale cottages, large hotels, tennis facilities, swimming pools, golf, and beach-related recreation. Resort planning can draw on a variety of mitigation methods, including open space and tsunami forests, elevating or locating structures above estimated inundation levels, and buffering smaller buildings with larger hotels and waterfront structures.

5) Community Commercial

The downtowns of most coastal communities are located adjacent to piers and beach areas. The primary access roads typically follow the coastline and are lined with commercial enterprises. Both of these development patterns are susceptible to damage by tsunamis. Strengthening and expanding harbor structures can help protect adjacent commercial areas. Depending on the tsunami, however, breakwaters can be swamped by the rising tide and be ineffective. New buildings can be elevated above inundation levels or hardened and designed to withstand tsunami forces.

6) Industrial

Dry docks, refineries, power plants, and other shoreline industrial facilities are of special concern. Destruction or flooding of industrial facilities can add another environmental dimension to a tsunami disaster with burning oil, toxic chemicals, and other hazardous materials. Floating buildings, debris, and boats can crush pipes and tanks. Protecting industrial facilities with walls and stronger anchoring can help; however, locating these types of uses outside of inundation zones is the most effective mitigation technique.

7) Essential and Critical Facilities

Fire stations, power substations, hospitals, sewage treatment facilities, and other critical infrastructure generally should not be located in inundation zones. Relocation of these types of facilities out of inundation areas should be an integral part of any tsunami mitigation plan. Where essential service facilities such as fire stations or permanent lifeguard stations must be located in tsunami hazard areas, they should be designed or retrofitted to survive tsunami damage. This topic is discussed in more detail under Principle 6.

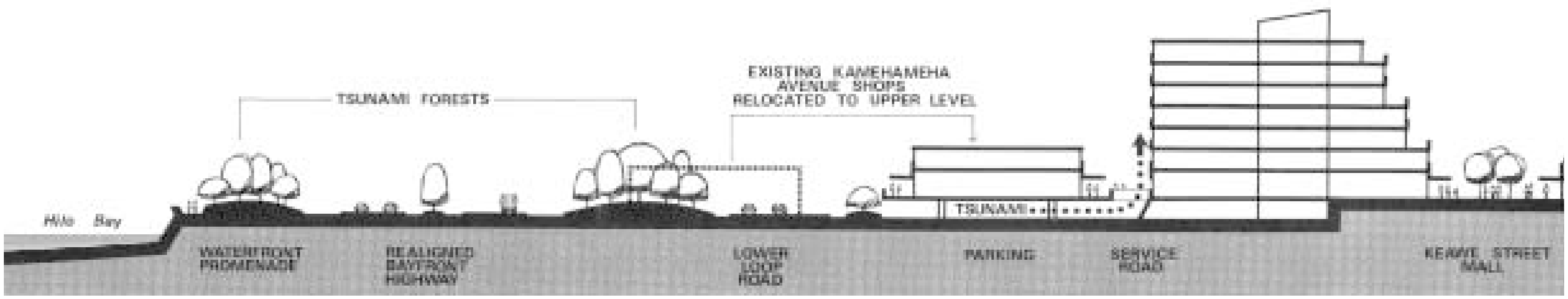
Damage to port facilities in Seward, Alaska, from the 1964 tsunami. Locating industrial facilities outside of inundation zones is the most effective mitigation technique. Credit: U.S. Army Corps of Engineers

Principle 3: Case Study

Case Study: Hilo Downtown Development Plan

The Hilo Downtown Development Plan was adopted in 1974 to guide efforts to revitalize the downtown core of Hilo, Hawaii. The Plan established a Safety District based on the 1946 and 1960 tsunami inundation lines. All redevelopment in the Safety District was subject to urban design and building design standards. Any structure below the 20-foot elevation contour line was required to be designed to withstand the force of a major tsunami. A Parking District was also designated in the Plan to provide parking for downtown businesses and to use parking structures as a protective barrier from a tsunami for inland structures. Parking facilities have been constructed in accordance with the Plan.

In 1985, the Hilo Downtown Development Plan was superceded by the Downtown Hilo Redevelopment Plan under the authority of Chapter 27, Flood Control, of the Hawaii County Code.



A section through the lower downtown area from the *Hilo Downtown Development Plan*. Credit: County of Hawaii

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Principle 4: Design and construct new buildings to minimize tsunami damage

Damage to building in Hilo, Hawaii, from the 1960 tsunami. Although there are engineering techniques and materials that can be used to resist tsunami forces and inundation, in cases of intense tsunamis, they will reduce losses but not prevent severe damage. Credit: Pacific Tsunami Museum

Where buildings are to be constructed in a tsunami hazard area, the design and construction of the buildings–including construction materials, building configuration, and tsunami-specific design features–can reduce loss of life and property damage.

The Role of Construction Design in Reducing Tsunami Risk

As discussed under Principles 2 and 3, in areas subject to tsunamis and damaging run-up, the most effective mitigation technique is to locate new buildings away from potential inundation areas. Where this is not possible, building design and construction will play a critical role in the performance of structures in the event of a tsunami.

Performance Objectives

A performance objective for a building depends upon several considerations:

- location of the building and its configuration (size, shape, elevations, and orientation)
- intensity and frequency of the tsunami hazard selected for design
- structural and non-structural design standards
- choice of structural and finish materials
- reliability of utilities
- professional abilities of designers
- quality of construction
- level of confidence in these factors

Hospitals, fire stations, and schools would be assigned higher performance objectives than those assigned to tourist accommodations.

Potential tsunami damage to buildings can be minimized during the early project design stage where performance objectives are decided, governing standards are reviewed, and the configuration of the building is chosen. These decisions govern the building's final design and its actual construction. However, while special engineering techniques and materials can be used to resist tsunami forces and inundation, in the case of an intense tsunami, they will reduce losses but not prevent severe damage.

Principle 4: Design and construct new buildings to minimize tsunami damage

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Building Codes

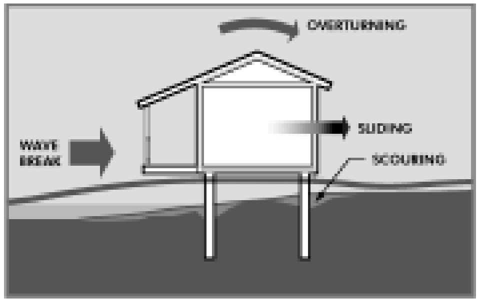
Building construction in the United States is governed at the local level by building codes. Building codes establish minimum acceptable requirements for protecting life, addressing property damage, and preserving the public health, safety, and welfare in the built environment. Building codes are applied to new construction as well as to existing buildings undergoing reconstruction, repair, rehabilitation, or alteration, or when the nature of the use is changed to a new occupancy that increases the risk or exceeds the structural capability of the building.

Process for Implementing Construction Design Strategies

1) Adopt and Enforce Appropriate Building Codes and Design Standards

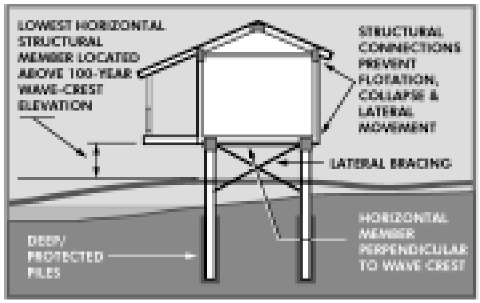
Most local building codes used in the Pacific states are based on the Uniform Building Code (UBC) prepared by the International Conference of Building Officials (ICBO). In California, Oregon, and Washington, the state governments mandate code adoption and enforcement at the local level. Alaska only mandates adoption of a fire code, and Hawaii does not mandate the use of a model code, leaving the option to county governments. All the counties in Hawaii and the larger cities in Alaska have adopted a version of the UBC. The states mandating the use of the UBC allow local government amendments that are more stringent than the mandated code provisions.

The UBC includes design requirements and standards for fire, wind, floods, and earthquakes, but it does not contain requirements for tsunami-resistant design. While a few communities have adopted tsunami-resistant building design standards, the vast majority of coastal communities have not. The City and County of Honolulu has adopted special requirements for floods and tsunamis as part of its Revised Ordinances. With appropriate modifications to reflect local conditions, these could serve as a general model for other states and municipalities. Guidance for architects and engineers in the design for tsunami forces is included in FEMA's *Coastal Construction Manual,* also known as FEMA 55. The manual deals with tsunamis in a manner similar to the Honolulu ordinance but uses more current information.



Forces on structures created by tsunamis

Principle 4: Design and construct new buildings to minimize tsunami damage



Design solutions to tsunami effects

2) Ensure That Codes and Standards Address the Full Range of Potential Hazards

While these guidelines emphasize tsunami loss prevention, other hazards such as earthquake groundshaking should, of course, also be addressed in the design of new buildings. Landslides, liquefaction, and other ground failures are potential problems in many coastal areas, as are seasonal floods where rivers and streams enter the ocean. Loss-prevention measures have already been adopted for most of these hazards, and it is important to recognize them in the effort to minimize direct tsunami losses.

3) Apply Locally Valid Tsunami Hazard Information

Where a tsunami hazard study has been prepared to inform local design decisions, the information can be used to decide whether to permit construction at a given site. If construction is to be permitted, the building design must address tsunami-related forces, including water pressure, buoyancy, currents and waves, debris impact, scour, and fire. The analyses will vary depending on location, building size, and type of construction, such as reinforced concrete, wood, light metal, and others.

4) Select the Intensity of Design Events

It is essential in the local hazard study to estimate tsunami intensity for various return intervals. Small tsunamis are less damaging, but they may be more frequent than occasional greater events. Smaller tsunamis might serve as the basis for designing most buildings. However, the rarer large events with higher water levels and stronger forces should be the basis for designing critical facilities, such as hospitals, fire stations, and refineries.

5) Define the Building's Performance Level

Performance levels describe expectations of owners, occupants, and regulators relative to the amount of damage a building could sustain from a tsunami and the building's ability following a tsunami event to support the uses for which it was intended. The design of a building to achieve a particular performance level involves a set of decisions that begins with determining the importance of the building and understanding the consequences of damage to the building.

Principle 4: Design and construct new buildings to minimize tsunami damage

There are four performance levels that can be considered for buildings: minimum, safety, reoccupancy, and operational levels.

Buildings located, designed, and constructed to the *minimum level* should withstand water forces without being moved off their foundations or sites, but they could still be damaged by debris, flooding, ground failures, or other effects.

Buildings constructed to perform at a *safety level* should withstand water forces, debris and wave-break impacts, earthquake shaking, ground failure, and fire without significant structural damage. People in taller buildings would be able to evacuate vertically above the level of wave action resulting from a locally-generated tsunami.

Buildings constructed to a *reoccupancy level* should meet the safety level of performance, but additional precautions should be taken so they can be reoccupied within a few days to weeks after cleanup, minor repairs, and the restoration of utilities. This level requires the careful choice of the building location and the use of flood-resistant materials.

Finally, the most demanding requirements are used to design buildings to meet the *operational level* of performance. These buildings should be capable of resisting all expected forces and hazards. They must also have backup emergency systems and utilities so they can be used immediately following a tsunami.

Specific Design and Construction Strategies to Reduce Tsunami Risk

Strategy 1: Choose Appropriate Design Solutions Based on Expected Tsunami Effects

Design and construction of new buildings should address forces associated with water pressure, buoyancy, currents and waves, debris impact, scour, and fire.

Substantially constructed buildings of concrete, masonry, and heavy steel frames are likely to perform fairly well in a tsunami unless compromised by earthquake shaking. Wood-frame buildings,

Damage to buildings in Hilo, Hawaii, from the 1946 tsunami. Credit: Pacific Tsunami Museum manufactured housing, and light steel-frame structures at lower elevations close to the shoreline are likely to fare poorly in a tsunami. Not every area affected by tsunami run-up, however, will experience damaging forces. Buildings in less hazardous areas affected by shallow run-up water depths should survive with repairable damage if they are designed and constructed well. The force of currents and breaking waves, fast-moving waterborne debris, and scouring currents may exceed the resisting capabilities of most buildings unless the buildings are constructed with specific design elements and materials.

The table on page 35 lists the possible effects of tsunamis on structures (such as flooding, water pressures and forces, buoyancy, debris impacts, foundation scouring) and suggests possible design solutions for each of the potential effects (such as elevating and anchoring buildings; designing for water forces, pressures, and impact loads; and using deep piles or piers). As noted above, it is important that the design measures be based on the local hazard study so that expected forces determine the design solutions.

Strategy 2: Require Qualified Architects and Engineers to Design Large Buildings

Building design is governed by engineering principles and practices and by building codes that establish minimum standards relating to public health and safety; however, codes are no substitute for competent engineering, design, construction, and quality assurance.

Specialized expertise is often needed when designing and constructing large, complex, or unusually shaped buildings. Communities should identify proposed projects that require specially qualified and licensed professionals, see that the owning/developing organizations secure such assistance early in the project planning phase, and help locate sources of qualified assistance. Professional associations can help local officials find needed experts such as architects and geotechnical, coastal, and structural engineers who are familiar with coastal design and construction issues.

Some jurisdictions require that such professionals be involved in building design and be identified on the building's plans and specifications. The use of such experts is especially important when codes and standards are absent or inadequate, or when the proposed building is intended to exceed the minimum life safety standards contained in commonly used codes and standards.

Strategy 3: Inspect Construction to Assure Requirements are Met

Construction inspection is important to ensure that buildings are constructed according to the appropriate standards. Independent inspections can be provided in several ways: 1) use of qualified permitting agency staff; 2) use of independent technical experts retained by the governing jurisdiction; or 3) requiring the owner to use such experts whose reports would be provided to the governing jurisdiction for review and acceptance. In some areas, licensed construction inspectors and consulting engineers provide these services.

Principle 4: Design and construct new buildings to minimize tsunami damage

Tsunami effects and design solutions

Phenomenon	Effect	Design Solution
Inundation	• Flooded basements • Flooding of lower floors • Fouling of mechanical, electrical, and communication systems and equipment • Damage to building materials, furnishings, and contents (supplies, inventories, personal property) • Contamination of affected area with waterborne pollutants	• Choose sites at higher elevations • Raise the building above the flood elevation • Do not store or install vital material and equipment on floors or basements lying below tsunami inundation levels • Protect hazardous material storage facilities that must remain in tsunami hazard areas • Locate mechanical systems and equipment at higher locations in the building • Use concrete and steel for portions of the building subject to inundation • Evaluate bearing capacity of soil in a saturated condition
	• Hydrostatic forces (pressure on walls caused by variations in water depth on opposite sides)	• Elevate buildings above flood level • Anchor buildings to foundations • Provide adequate openings to allow water to reach equal heights inside and outside of buildings • Design for static water pressure on walls
	• Buoyancy (flotation or uplift forces caused by buoyancy)	• Elevate buildings • Anchor buildings to foundations
	• Saturation of soil causing slope instability and/or loss of bearing capacity	• Evaluate bearing capacity and shear strength of soils that support building foundations and embankment slopes under conditions of saturation • Avoid slopes or provide setback from slopes that may be destabilized when inundated
Currents	• Hydrodynamic forces (pushing forces caused by the leading edge of the wave on the building and the drag caused by flow around the building and overturning forces that result)	• Elevate buildings • Design for dynamic water forces on walls and building elements • Anchor building to foundations
	• Debris impact	• Elevate buildings • Design for impact loads
	• Scour	• Use deep piles or piers • Protect against scour around foundations
Wave break and bore	• Hydrodynamic forces	• Design for breaking wave forces
	• Debris impact	• Elevate buildings • Design for impact loads
	• Scour	• Design for scour and erosion of the soil around foundations and piles
Drawdown	• Embankment instability	• Design waterfront walls and bulkheads to resist saturated soils without water in front • Provide adequate drainage
	• Scour	• Design for scour and erosion of the soil around foundations and piles
Fire	• Waterborne flammable materials and ignition sources in buildings	• Use fire-resistant materials • Locate flammable material storage outside of high-hazard areas

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Principle 5: Protect existing development from tsunami losses through redevelopment, retrofit, and land reuse plans and projects

Astoria, Oregon, at the mouth of the Columbia River. Many of the tsunami risk mitigation techniques used for new development can be applied to existing development, but their application will be limited by site constraints and building conditions. Credit: Army Corps of Engineers

The challenges in protecting existing develop ment from tsunami losses are many and complex. For coastal communities that are nearly built out, protecting existing development may be the only real mitigation option available. However, land uses, buildings, and infrastructure change over time, creating opportunities to incorporate tsunami (and other hazard) loss-prevention measures to help make communities less vulnerable in the future.

The Role of Renewal in Reducing Tsunami Risk

Efforts to renew communities can take many forms, including redefining permitted land uses, changing zoning standards, changing building uses and occupancies, retrofitting and rehabilitating buildings, and redeveloping districts to improve their economic vitality. There may also be special considerations in tsunami-vulnerable areas such as protecting landmarks and historic structures, creating scenic vistas, providing improved access to coastal amenities, improving services, and accommodating needed housing and commercial activities.

While many tsunami mitigation techniques used in new development can be applied to existing development, their application will be limited by site constraints and building conditions.

The reconstruction process following a disaster provides an opportunity to create or modify land uses, implement redevelopment plans, rehabilitate buildings, and vacate high-hazard lands subject to repetitive losses–all with the intent of reducing future losses.

Process for Reducing Vulnerability Through Renewal Efforts

1) Inventory At-Risk Areas and Properties

If not already available, an inventory should be completed of buildings, critical facilities, and infrastructure elements in the potential tsunami inundation area (see Principle 1 for a more detailed discussion of this topic). More than a simple tally, this inventory should take into account the type of structure, its age, size and configuration, construction material, and use.

Principle 5: Protect existing development from tsunami losses through redevelopment, retrofit, and land reuse plans and projects

For risk-mitigation purposes, it is important to assess the condition of buildings and their construction characteristics. Significant deterioration may demand replacement, but retrofit and rehabilitation may be appropriate in other cases.

Some buildings are complex, having been modified or expanded over time. It is rare that adequate drawings of older buildings are available. This usually means that an engineering study is needed to determine the actual characteristics of the building before project-specific rehabilitation or retrofit plans can be made.

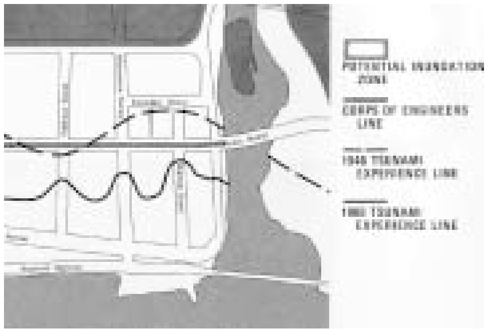
2) Evaluate and Revise Plans and Regulations to Address Redevelopment, Retrofit, and Reuse Issues

Periodically, communities perform an in-depth review and revision of their land use, comprehensive, and growth management plans. The periodic plan updates provide a broad context within which redevelopment and renewal policies and plans can be developed.

Building codes primarily address new construction; generally, they do not address renovations and retrofitting comprehensively or in detail. Local building codes should be amended to fully address risk mitigation in the context of building renovation. As a starting point, there are several examples of code amendments concerning retrofitting buildings for earthquake hazards that can be adapted for tsunami hazards. The Federal Emergency Management Agency (FEMA) sponsored the preparation of a multiple-volume guide on rehabilitating buildings to resist earthquake forces. Several states and communities have also adopted laws and ordinances governing the retrofitting and rehabilitation of existing buildings to reduce future losses from earthquakes.

Anchor bolts. Measures to resist earthquake shaking, such as anchoring and bracing buildings, can also help to reduce tsunami damages. Credit: Northridge Collection, Earthquake Engineering Research Center, University of California, Berkeley

Principle 5: Protect existing development from tsunami losses through redevelopment, retrofit, and land reuse plans and projects



An excerpt from the tsunami inundation map in the *Hilo Downtown Development Plan*. Credit: County of Hawaii

Specific Renewal Strategies to Reduce Tsunami Risk

Strategy 1: Adopt Special Programs and Development Regulations

There is a variety of specific development regulations and programs that local communities can implement to minimize tsunami risk, including:

- redesignating and rezoning land in tsunami hazard areas for uses more consistent with the risk as non-conforming uses are phased out
- limiting additions to existing buildings in tsunami hazard areas
- buying specific properties in tsunami hazard areas and removing or relocating buildings

Strategy 2: Use Redevelopment Strategies to Reduce Tsunami Risk

Redevelopment land acquisition and financing powers can be used on a district-wide scale to reconfigure uses or infrastructure, retrofit specific buildings, or remove buildings altogether in tsunami hazard areas.

Strategy 3: Use Incentives and Other Financial Measures to Support Loss Prevention

One key to the success of redevelopment and other renewal measures is helping building owners bear the cost of the proposed changes. There are many commonly used incentives that help spur renewal, such as reduced property taxes, waiving of permit and inspection fees, and low interest loans. Local officials should ensure that whatever incentives are used include risk mitigation as an eligible purpose.

Strategy 4: Adopt and Enforce Special Provisions for the Retrofit of Existing Buildings

Retrofit of existing buildings should be encouraged when the effort will improve tsunami resistance to a level capable of meeting identified performance objectives, or to minimize floating debris that can damage nearby buildings. Retrofitting may be required for all buildings within a hazard zone, or may be mandated only when substantial modifications are made to existing structures or when there are changes in building occupancy.

Principle 5: Protect existing development from tsunami losses through redevelopment, retrofit, and land reuse plans and projects

The complexities associated with strengthening existing structures may require the development, adoption, and implementation of special codes, standards, and procedures. Moreover, special purpose requirements may exist, such as codes governing the rehabilitation of historic buildings, that may or may not contain provisions for protecting against hazards. Flexibility may be needed to ensure that effective mitigation techniques can be applied to such properties without seriously disrupting their original characteristics.

The standards for upgrading buildings involve the same factors as constructing new buildings; however, upgrading to achieve a selected performance objective is more expensive to implement after initial construction is completed. Dealing with the vulnerability of existing buildings is difficult because of the limited number of alternatives and cost of remedial measures that will withstand hydrodynamic and impact loads.

Measures that improve resistance to tsunamis in combination with other more frequently occurring hazards are more likely to be feasible. These include elevating buildings above the base flood elevation, improving foundations to resist scour and erosion, and anchoring and bracing the buildings to resist earthquake shaking. Although these measures can reduce tsunami damage, especially in the statistically more-frequent small tsunamis, they will not ensure that a building is able to withstand the intense forces associated with larger events.

Strategy 5: Require Qualified Architects and Engineers to Design Effective Measures to Protect Existing Development

As discussed under Principle 4, specialized expertise should be used to help design measures to reduce future losses. Such expertise is important when considering measures to strengthen existing development because of the complexities associated with such projects and the greater reliance placed on experience and judgment. Design professionals and engineers who specialize in rehabilitation and retrofit practices can be located through professional associations and contacts with local practitioners.

P•6 Principle 6: Take special precautions in locating and designing infrastructure and critical facilities to minimize tsunami damage

Bore advancing through the railroad bridge at the Wailuku River in Hilo, Hawaii, during the 1946 tsunami. Credit: Pacific Tsunami Museum

Certain facilities in a community deserve special attention in the planning and design process to minimize damage to them. Infrastructure such as transportation systems for people and goods, and utility systems such as communications, natural gas, water supply, power generation, and transmission/ distribution systems are essential to the continued operation of a community and need to be functional—or easily and rapidly repairable—following a disaster.

Other facilities in the community are considered critical because of their occupants or the functions they contain. These include: 1) essential service facilities such as fire stations; 2) hazardous facilities such as chemical plants or fuel storage tanks; and 3) special occupancy structures with uses such as government functions important to sustaining a community, buildings with large numbers of occupants, or buildings such as convalescent homes with occupants who cannot evacuate the premises readily.

The Role of Infrastructure and Critical Facility Location and Design in Reducing Tsunami Risk

Infrastructure and critical facilities are often located on the coast within tsunami hazard areas. In some cases, such as fire stations, the facilities may need to be located in tsunami hazard areas; in other cases, they could just as easily be located outside the tsunami hazard area.

Because of the services these facilities provide—or the harm they could cause—to the community, their performance during natural hazard events is a community-wide concern that needs to be considered as part of a tsunami risk management effort.

Process for Implementing Infrastructure and Critical Facility Location and Design Strategies

1) Understand Tsunami Mitigation Responsibilities

Managing the tsunami risk is a responsibility shared by the government and private sectors. Depending

on the community, infrastructure systems and critical facilities may be owned and managed by local or state agencies, special districts, private companies, nonprofit organizations, federal departments and agencies, joint powers authorities, or others. Mitigation programs need to involve all participants in the planning process.

2) Understand and Describe the Nature and Extent of the Tsunami Hazards for Infrastructure and Critical Facilities

Principle 1 provides background information on local tsunami risk studies and hazard scenarios. In such studies, it is important to include information about infrastructure and critical facilities and to identify who is responsible for their location, design, construction, operation, and maintenance. This work includes the following:

- Define the tsunami hazard (see Principle 1) and describe it by intensity (expected effects) and probability of occurrence.
- Inventory and gather data about infrastructure elements and critical facilities in the potential damage area and describe why their functions make tsunami resistance an important issue for the community and what makes each facility vulnerable to damage from tsunami forces.
- Identify the responsible organizations and include their representatives in the mitigation process.

3) Adopt Comprehensive Risk Management Policies

Communities should adopt policies to manage the tsunami risk and integrate them into coastal management programs, land use plans, floodplain zoning, capital outlay plans, building regulation programs, and other procedures used to control the use and safety of facilities near the shoreline.

Essential service facilities should be operational following a hazard event. This concept already is contained in the Uniform Building Code (UBC) and could be adapted for tsunami hazards. The UBC requires the use of enhanced seismic and wind forces for design, and enhanced structural inspection during construction of essential service facilities. To ensure stronger structures, the UBC uses

A boat washed up over 400 feet onshore from the wharf by the 1946 tsunami in Hilo, Hawaii. Credit: Pacific Tsunami Museum

Examples of infrastructure and critical facilities

INFRASTRUCTURE

Transportation Systems

- Roads, highways, bridges, parking lots and structures, and traffic control systems
- Railroads track beds, bridges, and rail and switching yards for freight and passengers
- Transit systems (rail, trolley, tram, and motor coach), storage and maintenance facilities, power systems and substations, control systems, bridges, tunnels, and tubes
- Airports and control towers
- Maritime ports, and maritime traffic control systems, marine terminals, loading/unloading facilities, storage facilities (including tank farms), docks, and ship moorings, piers, seawalls, and bulkheads

Utility Systems

- Electrical generation, transmission, substations, and distribution systems
- Natural gas production, processing, storage, transmission, pump, and distribution systems
- Land line communication systems: switching stations, trunk lines, and data lines

(cont.)

an "importance factor" to increase the force levels by 15 to 50 percent over those calculated for other occupancy categories.

4) Adopt a Comprehensive Infrastructure and Critical Facility Plan

Communities should revise or adopt measures that deal with existing and new infrastructure, critical facilities, and waterfront-dependent uses in relation to tsunami hazards. These comprehensive infrastructure and critical facility plans should define performance objectives for the various types of existing and planned facilities in the community. Strategies should include relocating or, if possible, strengthening existing infrastructure and critical facilities against tsunami forces. They should also include providing redundant facilities and emergency response measures to lessen the impact of losing infrastructure and critical facilities that remain at risk.

Proposals for new critical facilities and infrastructure located in tsunami hazard areas should be considered carefully to determine whether the performance expected is acceptable once feasible design measures are implemented. Proposals for new infrastructure should be evaluated in terms of the increased risk because of induced growth. For example, construction of new buildings and facilities may be facilitated by the provision of new water or wastewater collection services in the hazard area.

Existing infrastructure and critical facilities are particularly problematic. It is difficult and expensive to improve the tsunami performance of existing facilities and infrastructure, and relocation is usually impractical, especially in the short term. However, understanding the risk to these existing facilities and anticipating the consequences of tsunami events can lead to long-term risk-reducing strategies (see Principle 5 for a more detailed discussion of issues related to existing buildings).

Because of the varied nature and differing importance of infrastructure systems and critical facilities, an effort must be made to rank their relative importance to the community and to establish performance objectives to help guide mitigation actions. This work includes the following:

- Determine appropriate performance levels (i.e., acceptable damage condition for a given tsunami intensity and probability). See Principle 4 for a discussion of performance levels.
- Determine how each existing system and facility has addressed tsunami and earthquake mitigation plus any important site hazards, such as potential landslides or soil failures.
- Establish a scale of relative importance to help focus mitigation efforts (e.g., preventing losses of the potable water systems may be more important than preventing losses of the wastewater system).
- Set acceptable outage intervals for each element (e.g., the community hospital must be minimally functional within one hour of the event, but a major street could be bypassed for two weeks).
- For new infrastructure and critical facilities, determine appropriate performance levels and whether their use is dependent on a waterfront location.
- For existing infrastructure and critical facilities, determine which mitigation options or combination of options can reduce the risk and whether the remaining risk would be acceptable.

Specific Infrastructure and Critical Facility Location and Design Strategies to Reduce Tsunami Risk

Strategy 1: Locate New Infrastructure and Critical Facilities Outside the Tsunami Hazard Area or Design to Resist Tsunami Forces

- Examine plans for infrastructure and critical facilities to see if other, equally efficient alternative locations, alignments, and routes can be used. Most critical facilities need not be located in a tsunami hazard area to serve their intended purpose. Some essential facilities may need to be located in a tsunami hazard area because alternative locations will not serve the day-to-day needs of the community.
- Reserve sites for infrastructure and critical facilities either outside the tsunami hazard area or in areas where the risk can be reduced through feasible measures.
- Prohibit new critical facilities in tsunami hazard areas unless: 1) they are waterfront dependent and the design can mitigate the vulnerability to such an extent that the resulting facility will perform as needed; 2) risk is reduced through

Examples of infrastructure and critical facilities (cont.)

- Cellular systems, switching stations, antenna, and towers
- Cable systems for television, radio, and data
- Satellite systems for television and data
- Potable water systems: wells, water supply sources, storage, pumps, and treatment and distribution systems
- Sewerage collection, mains, pumps, treatment facilities, and outfalls
- Pipelines that transport oil, fuels, and other petroleum products
- Storm water runoff facilities, drainage, and pipelines

CRITICAL FACILITIES

Essential Services

- Police stations
- Firehouses
- Hospitals with surgery, acute care, or emergency rooms
- Emergency operations and communications facilities and equipment
- Garages and shelters for emergency vehicles and aircraft

(cont.)

Examples of infrastructure and critical facilities (cont.)

- Standby power-generating equipment for essential services
- Tanks or other structures containing water or other fire-suppression material or equipment required to protect essential, hazardous, or special occupancy facilities
- Permanent lifeguard stations

Special Occupancy Structures

- Schools
- Universities and colleges
- Residential treatment centers and nursing and convalescent homes
- Retirement communities
- Large-occupancy structures
- Power-generating stations and other utility facilities needed for continuous operations

Hazardous Facilities

- Fuel docks and storage
- Spent nuclear fuel storage
- Chemical storage facilities
- Rail tank cars and trucks with chemicals
- Munitions storage, loading docks, and harbors

mitigation and emergency planning measures; or 3) the need for the facility outweighs the consequences of its loss during a tsunami (e.g., a small hospital in a remote, tsunami-prone area may be justified because it needs to be close to the population for routine emergencies).

- Prohibit infrastructure improvements that will encourage construction of other facilities that cannot withstand the tsunami hazard.
- Consider the impact of new infrastructure on hazard intensity and distribution. For example, does it change drainage patterns, increase exposure to inundation, or channel currents in a way that will increase the hazard?
- Provide redundant facilities and infrastructure outside tsunami hazard areas where elements and facilities must serve high-hazard areas.
- Employ design professionals qualified in coastal, structural, and geotechnical engineering on infrastructure and critical facility projects in high-hazard areas. Communities should identify proposed projects that should involve specially qualified and licensed professionals, see that the owning organizations secure the specialized assistance as early as possible in the project planning, and locate both local and distant sources of qualified assistance that can be contacted when needed.
- Where it is impractical to locate infrastructure and critical facilities outside tsunami hazard areas, ensure that adequate mechanisms exist to isolate the damaged area, such as shutoff valves, detours, and others.

Strategy 2: Protect or Relocate Existing Infrastructure and Critical Facilities

- Do not allow expansion or renovation of existing facilities in tsunami hazard areas without requiring measures to reduce the risk.
- Construct barriers (reinforced walls and columns) to protect against impact forces and scour.
- Elevate existing facilities above the inundation elevation.
- Relocate portions of at-risk facilities.
- Take advantage of the eventual obsolescence of existing infrastructure and critical facilities as an opportunity to phase out the facility, relocate the facility, or incorporate design standards that will allow for acceptable performance following a tsunami.

Principle 6: Take special precautions in locating and designing infrastructure and critical facilities to minimize tsunami damage

Strategy 3: Plan for Emergencies and Recovery

- **Prepare emergency plans to cope with the emergency situation and expedite recovery.**
- **When waterfront-dependent infrastructure and critical facilities cannot be newly designed or retrofitted to withstand tsunami forces, they should be considered expendable and planning should be undertaken for evacuation, emergency response, recovery, and replacement facilities. It is important to remember that in a tsunami an expendable building may turn into debris that can batter people and non-expendable structures.**

Petroleum tank on fire due to damage from the 1964 tsunami on Highway 101 near Crescent City, California. Credit: Del Norte Historical Society

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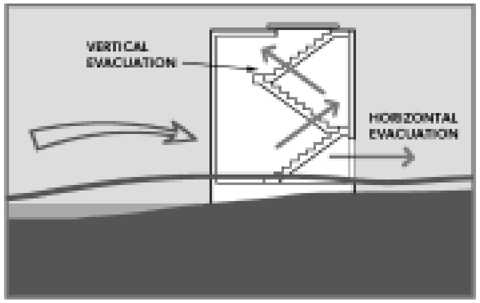
Principle 7: Plan for evacuation



Vertical and horizontal evacuation

The primary strategy for saving lives immediately before tsunami waves arrive is to evacuate people from the hazard zone. Two methods are generally available:

- horizontal evacuation–moving people to more distant locations or higher ground
- vertical evacuation–moving people to higher floors in buildings

Horizontal evacuation and other emergency response measures are outside the scope of these guidelines and have been addressed in other publications (see Resources and Bibliography at the end of the guidelines). Vertical evacuation, however, is addressed in these guidelines since it is linked to issues of land use, siting, and building design and construction.

The Role of Vertical Evacuation in Reducing Tsunami Losses

Evacuating people can save lives and reduce injuries, but it will have little, if any, effect on reducing property and economic losses. In coastal areas where building and population densities are high, where roads, bridges, and other horizontal evacuation methods are limited, or where warning time may be insufficient, vertical evacuation may be needed as an alternative or supplement to horizontal evacuation. Land use planning, site planning, and building design discussed in the previous principles play an important role in a community's ability to rely, at least partially, on vertical evacuation to protect people.

Process for Implementing a Vertical Evacuation Strategy

1) Inventory Existing Buildings

The building stock for vertical evacuation varies greatly across communities. Thus, it is critical that a community inventory and assess buildings that could serve as vertical evacuation shelters. This may be difficult because important information about existing buildings, such as drawings and calculations, may not be available. Professional engineers play a key role in evaluating the capacity of structures to

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resist expected forces, and their reports often lead to rehabilitation and retrofit work designed to strengthen the buildings. This topic is discussed in more detail under Principle 5.

2) Ensure Adequate Standards Apply to New Buildings

New buildings to be designated as vertical evacuation shelters must have sufficient structural integrity to resist expected tsunami forces and earthquake groundshaking for tsunamis originating locally. Building codes and other applicable standards should ensure the tsunami and earthquake resistance of new buildings. These standards should go beyond the minimum life safety requirement of most locally-adopted codes.

Communities and building owners should also secure the assistance of qualified professionals in the fields of geotechnical, coastal, and structural engineering. Further information about building siting and design can be found under Principles 3, 4, 5, and 6.

3) Designate Emergency Services Personnel to Lead the Program

Vertical evacuation, while dependent on structures for its success, is primarily an emergency preparedness and response measure. It is important, therefore, that those community officials responsible for planning and managing emergency programs and operations take lead responsibility for vertical evacuation planning. In addition, it is extremely important to involve building owners and tenants in the process of establishing a vertical evacuation program.

4) Resolve Related Issues

There are several other issues that are important to vertical evacuation. These vary among communities and states, but include emergency preparedness requirements, standards of care for evacuees, access to designated shelters, and liability of public agencies and building owners.

Tsunami evacuation route sign in Crescent City, California. Credit: FEMA

Specific Vertical Evacuation Plan Strategies to Reduce Tsunami Exposure for People

Strategy 1: Identify Specific Buildings to Serve as Vertical Shelters

Some existing buildings can serve as vertical shelters and newer ones can be located, designed, and constructed with that use in mind. Local building officials and consulting engineers can help inventory the community's stock of candidate buildings, evaluate the buildings' tsunami- and earthquake-resistant capabilities, and establish criteria and standards for rehabilitation or new construction that meet the expected hazard forces so the buildings will be able to serve as shelters.

Factors to be considered in determining a building's suitability include size, number of stories, access, contents, and available services. Only those buildings judged able to withstand the potential tsunami and earthquake forces and that meet other occupancy criteria should be designated as shelters. For example, if expected tsunami wave heights will not exceed one story (about 10 feet), then open-floor designs can be used to allow the waves to pass through with minimal impact on the building. Further information about evaluating the tsunami resistance of existing buildings is discussed under Principle 5.

Strategy 2: Work Out Agreements and Procedures with Building Owners

To a large extent, vertical evacuation shelters will be designated in privately owned buildings. For a program to be effective, therefore, appropriate agreements should be negotiated with the owners, and the owners or their representatives should be involved in the creation and maintenance of the program. While they will vary among communities and states, issues related to notification, standards of care, compensation, duration of occupancy, security, and liability will be important to the owners.

Strategy 3: Ensure Procedures Exist to Receive and Disseminate Warnings

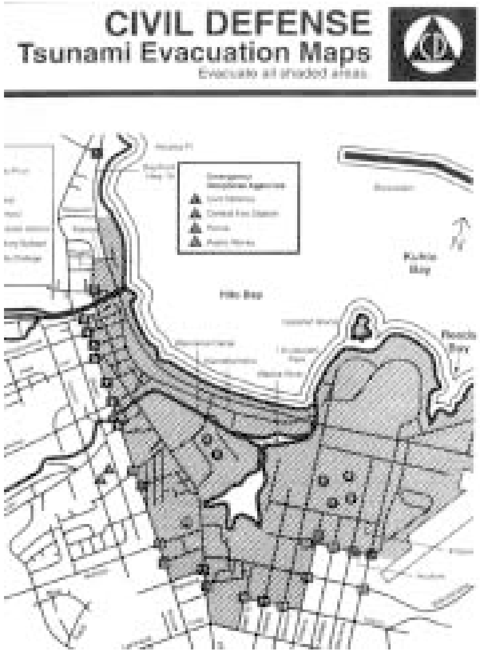
It is very important that tsunami-vulnerable communities have adequate procedures and systems for notification by official warnings so appropriate actions can be taken, sometimes many hours in advance for distant tsunamis. Local tsunamis pose special problems because insufficient time might preclude official warnings. Some communities are advising and training their residents and visitors to evacuate immediately whenever earthquake shaking is felt. If no tsunami warning is issued, people can return after a short time.

Strategy 4: Implement Effective Information and Education Programs

Communities can use brochures, single-page instructions, periodic warning system tests, electronic and print media information, signs, and emergency response exercises to maintain awareness and instill effective response behavior. Some of this information will be directed towards specialized institutions, such as schools, hospitals, and convalescent-care facilities, and non-English speaking community members. Because of seasonal tourism in many coastal communities, some information is designed especially for tourists. Depending on the community's needs, it is important that information and education efforts be routine, comprehensive, and tailored for special facilities and populations.

Strategy 5: Maintain the Program Over the Long Term

Tsunamis are rare events, but their impacts on coastal communities can be devastating. It is a challenge to maintain emergency preparedness programs and procedures when the threat is perceived as remote. It is, therefore, important that vertical evacuation measures be integrated into community response plans and that they be reviewed and revised regularly. Since cooperation is essential, these reviews should include building owners and others involved in the program. Periodic simulations are a valuable learning exercise, and regular informational and instructional materials should be provided to those occupying potential tsunami damage areas.



Tsunami evacuation map from the civil defense section of the Hilo, Hawaii, telephone book

Case Study: Tsunami Warning Programs

The following is a description of tsunami warning programs. This topic is not directly related to vertical evacuation, but provides helpful background information.

As part of an international cooperative effort to save lives and protect property, the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service operates two tsunami warning centers. The West Coast and Alaska Tsunami Warning Center (WCATWC) in Palmer, Alaska, serves as the regional tsunami warning center for Alaska, British Columbia, Washington, Oregon, and California.

The Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii, serves as the regional tsunami warning center for Hawaii and as a national/international warning center for tsunamis that pose a Pacific-wide threat. This international warning effort became a formal arrangement in 1965 when PTWC assumed the international warning responsibilities of the Pacific Tsunami Warning System (PTWS). The PTWS is composed of 26 international member states that are organized as the International Coordination Group for the Tsunami Warning System in the Pacific.

The two tsunami warning centers coordinate the information being disseminated. The objective of the tsunami warning centers is to detect, locate, and determine the magnitude of potentially tsunamigenic earthquakes. Earthquake information is provided by seismic stations. If the location and magnitude of an earthquake meet the known criteria for generation of a tsunami, a tsunami warning is issued to warn of an imminent tsunami hazard. The warning includes predicted tsunami arrival times at selected coastal communities within the geographic area defined by the maximum distance the tsunami could travel in a few hours. A tsunami watch with additional predicted tsunami arrival times is issued for a geographic area defined by the distance the tsunami could travel in a subsequent time period.

continued on next page

Tsunami hazard zone logo

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Case Study: Tsunami Warning Programs, cont.

If a significant tsunami is detected by sea-level monitoring instrumentation, the tsunami warning is extended to the entire Pacific Basin. Sea-level (or tidal) information is provided by NOAA's National Ocean Service, PTWC, WCATWC, university monitoring networks, and other participating nations of the PTWS.

Tsunami watch, warning, and information bulletins are disseminated to appropriate emergency officials and the general public by a variety of communication methods:

- **Tsunami watch, warning, and information bulletins issued by PTWC and WCATWC are disseminated to local, state, national, and international users as well as the media. These users, in turn, disseminate the tsunami information to the public, generally over commercial radio and television channels.**
- **The NOAA Weather Radio System, based on a large number of VHF transmitter sites, provides direct broadcast of tsunami information to the public.**
- **The U.S. Coast Guard also broadcasts urgent marine warnings and related tsunami information to coastal users equipped with medium frequency (MF) and very-high-frequency (VHF) marine radios.**
- **Local authorities and emergency managers are responsible for formulating and executing evacuation plans for areas under a tsunami warning. The public should stay tuned to the local media for evacuation orders should a tsunami warning be issued. And, the public should not return to low-lying areas until the tsunami threat has passed and the local authorities announce the "all clear."**

GLOSSARY

Amplitude:
The tsunami's rise above or drop below the ambient water level as read on a tide gauge.

Bore:
Traveling wave with an abrupt vertical front or wall of water. Under certain conditions, the leading edge of a tsunami wave may form a bore as it approaches and runs onshore. A bore may also be formed when a tsunami wave enters a river channel, and may travel upstream penetrating to a greater distance inland than the general inundation.

Harbor Resonance:
The continued reflection and interference of waves from the edge of a harbor or narrow bay. This interference can cause amplification of the wave heights and extend the duration of wave activity from a tsunami.

Horizontal Inundation Distance:
The distance that a tsunami wave penetrates onto the shore. Measured horizontally from the mean sea level position of the water's edge, it is usually measured as the maximum distance for a particular segment of the coast.

Inundation:
The depth, relative to a stated reference level, to which a particular location is covered by water.

Inundation Area:
An area that is flooded with water.

Inundation Line (limit):
The inland limit of wetting, measured horizontally from the edge of the coast, defined by mean sea level.

Local/Regional Tsunami:
Source of the tsunami is within 1000 km of the area of interest. Local or near-field tsunami has a very short travel time (30 minutes or less), mid-field or regional tsunami waves have times on the order of 30 minutes to 2 hours. Note: "local" tsunami is sometimes used to refer to a tsunami of landslide origin.

Period:
The length of time between two successive peaks or troughs. May vary due to complex interference of waves. Tsunami periods generally range from 5 to 60 minutes.

Run-up:
Maximum height of the water onshore observed above a reference sea level. Usually measured at the horizontal inundation limit.

Seiche:
An oscillating wave in a partially or fully enclosed body of water. May be initiated by long period seismic waves, wind and water waves, or a tsunami.

Tidal Wave:
Common term for tsunami used in older literature, historical descriptions, and popular accounts. Tides, caused by the gravitational attractions of the sun and moon, may increase or decrease the impact of a tsunami, but have nothing to do with their generation or propagation. However, most tsunamis (initially) give the appearance of a fast-rising or fast-ebbing tide as they approach shore, and only rarely appear as a near-vertical wall of water.

Travel Time:
Time (usually measured in hours and tenths of hours) that it took the tsunami to travel from the source to a particular location.

Tsunami:
A Japanese term derived from the characters "tsu" meaning harbor and "nami" meaning wave. Now generally accepted by the international scientific community to describe a series of traveling waves in water produced by the displacement of the sea floor associated with submarine earthquakes, volcanic eruptions, or landslides.

RESOURCES

RESOURCES FOR LOCAL GOVERNMENT OFFICIALS AND THE PUBLIC

Compiled by Lee Walkling, Library Information Specialist, Washington Department of Natural Resources, Division of Geology and Earth Resources

BOOKS

American Institute of Professional Geologists, 1993. *The Citizens' Guide to Geologic Hazards—A Guide to Understanding Geologic Hazards, Including Asbestos, Radon, Swelling Soils, Earthquakes, Volcanoes, Landslides, Subsidence, Floods, and Coastal Hazards*. Arvada, CO: American Institute of Professional Geologists. (Good overview and easy-to-understand explanations)

Myles, Douglas, 1985. *The Great Waves.* New York: McGraw-Hill Book Company. (For the general public)

Mileti, Dennis S., 1999. *Disasters by Design—A Reassessment of Natural Hazards in the United States.* Washington, D.C.: John Henry Press. (Preparedness and mitigation)

Atwater, Brian F.; Marco V. Cisternas; Joanne Bourgeois; Walter C. Dudley; James W. Hendley, II; Peter H. Stauffer, compilers, 1999. *Surviving a Tsunami—Lessons from Chile, Hawaii, and Japan.* U.S. Geological Survey Circular 1187.

U.S. Federal Emergency Management Agency, 1998. *The Project Impact Hazard Mitigation Guidebook for Northwest Communities—Alaska, Idaho, Oregon, Washington.* Washington, D.C.: U.S. Federal Emergency Management Agency. (Good list of additional resources and websites and books in the appendix)

U.S. Federal Emergency Management Agency, 1993. *Are You Ready? Your Guide to Disaster Preparedness.* Washington, D.C.: U.S. Federal Emergency Management Agency.

U.S. Federal Emergency Management Agency, 1998. *Property Acquisition Handbook for Local Communities.* 3 vol. poster (FEMA 317). Washington, D.C.: U.S. Federal Emergency Management Agency. (For more information: http://www.fema.gov/mit/handbook/)

U.S. Federal Emergency Management Agency, 2000. *Coastal Construction Manual—Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas.* 3rd. ed., 3 vol. (FEMA 55) Washington, D.C.: U.S. Federal Emergency Management Agency. (For more information: http://www.fema.gov/MIT/bpat/bpn0600e.htm)

PERIODICALS

Natural Hazards Observer (print and online versions)
(http://www.colorado.edu/IBS/hazards/o/o.html)

The bi-monthly newsletter of the Natural Hazards Center. It covers current disaster issues; new international, national, and local disaster management, mitigation, and education programs; hazards research; political and policy developments; new information sources; upcoming conferences; and recent publications.

TsuInfo Alert Newsletter

The bi-monthly newsletter of the National Tsunami Hazards Mitigation Program is distributed to approximately 250 emergency managers of the five Pacific coastal states. Back issues are online: http://www.wa.gov/dnr/htdocs/ger/tsuinfo/index.html

RESOURCES

WEBSITES

http://www.geophys.washington.edu/tsunami/intro.html
University of Washington Geophysics Program - many links to other tsunami sites.

http://www.fema.gov/library/tsunamif.htm
FEMA tsunami fact sheet and links.

http://www.pmel.noaa.gov/tsunami/
NOAA/PMEL Web site, with links to inundation mapping, modeling, events, forecasting and the National Tsunami Hazards Mitigation Program sites.

http://www.pmel.noaa.gov/tsunami-hazard/links.html
Important links to major tsunami sites.

http://www.redcross.org/disaster/safety/guide/tsunami.html
Red Cross tsunami site, with overview, discussion of warning systems, and good preparedness information.

http://www.geocities.com/CapeCanaveral/Lab/1029/
The Tsunami Page of Dr. George P.C. (Pararas-Carayannis)
Just about everything you'd need to know about tsunamis!

http://www.fema.gov/mit/handbook
Property Acquisition Handbook for Local Communities (FEMA 317).

VIDEOS

Forum: Earthquakes and Tsunamis (2 hrs.)
CVTV-23, Vancouver, WA (January 24, 2000)
Two lectures: Brian Atwater describes the detective work and sources of information about the January 1700 Cascadia earthquake and tsunami; Walter C. Dudley talks about Hawaiian tsunamis and the development of warning systems.

Tsunami: Killer Wave, Born of Fire (10 min.)
NOAA/PMEL.
Features tsunami destruction and fires on Okushiri Island, Japan; good graphics, explanations, and safety information. Narrated by Dr. Eddie Bernard (with Japanese subtitles).

Waves of Destruction (60 min.)
WNET Video Distribution
An episode of the "Savage Earth" series. Tsunamis around the Pacific Rim.

Disasters Are Preventable (22 min.)
USAID
Ways to reduce losses from various kinds of disasters through preparedness and prevention.

Tsunami: Surviving the Killer Waves (13 min.)
DOGAMI
Two versions, one with breaks inserted for discussion time.

Raging Planet; Tidal Wave (50 min.)
Produced for the Discovery Channel in 1997, this video shows a Japanese city that builds walls against tsunamis, talks with scientists about tsunami prediction, and has incredible survival stories.

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