PART 1.2

TSUNAMIS

This chapter of the module is designed to:

- *enhance your knowledge of the causes and characteristics of tsunamis*
- *contribute to your understanding of the threat to human lives and settlements*
- *expand your awareness of the predictability of tsunamis and the importance of warning systems*
- *provide options for reducing the impact of tsunamis on humans, structures and infrastructure.*

Introduction

Tsunami is a Japanese word meaning “harbor wave”. Tsunamis are popularly called tidal waves but they actually have nothing to do with the tides. These waves, which often affect distant shores, originate from undersea or coastal seismic activity, landslides, and volcanic eruptions. Whatever the cause, sea water is displaced with a violent motion and swells up, ultimately surging over land with great destructive power.

TSUNAMI

Tsunami Hazard Data Sheet

Casualties and damage for selected tsunamis

In 1992 and 1993 alone, tsunamis caused nearly US $1 billion in property damage.

Year	Location	Number of deaths	Damage
1945	Pakistan[1]	4,100	
1960	Hawaii[2]	61	537 buildings destroyed
1960	Chile[2]	2,000	
1976	Celebes Sea	7,000	
1987	Papua New Guinea	many	3,000 people homeless
1992	Nicaragua	170	1,500 houses destroyed
1992	Flores Island, Indonesia	2,080	many villages destroyed
1993	Okushiri Island, Japan	185	700 houses destroyed
1994	Java, Indonesia	222	1,226 houses destroyed

[1] A non-Pacific tsunami

[2] This tsunami originated in Chile

Causes

The geological movements that cause tsunamis are produced in three major ways. The most common of these is fault movement on the sea floor, accompanied by an earthquake. A fault is defined as a planar zone of weakness passing through the earth's crust. To say that an earthquake causes a tsunami is not completely correct. Rather, both earthquakes and tsunamis result from fault movements.

Probably the second most common cause of tsunamis is a landslide either occurring underwater or originating above the sea and then plunging into the water. The highest tsunamis ever reported were produced by a landslide at Lituya Bay, Alaska in 1958. A massive rock slide produced a wave that reached a high water mark of 535 meters above the shoreline!

The third major cause of tsunamis is volcanic activity. The flank of a volcano, located near the shore or underwater, may be uplifted or depressed similar to the action of a fault. Or, the volcano may actually explode. In 1883, the violent explosion of the famous volcano, Krakatoa in Indonesia, produced tsunamis measuring 40 meters which crashed upon Java and Sumatra. over 36,000 people lost their lives as a result of tsunami waves from Krakatoa.

Although tsunamis caused by landslides and volcanic activity may be very destructive near their sources, most have relatively little energy, decreasing rapidly in size and becoming almost unnoticeable at great distances. The giant tsunamis that are capable of crossing oceans are nearly always created by movement of the sea floor associated with earthquakes which occur beneath the sea floor or near the ocean. The degree of motion depends on how fast the earthquake occurs and how efficiently energy is transferred to the ocean water.

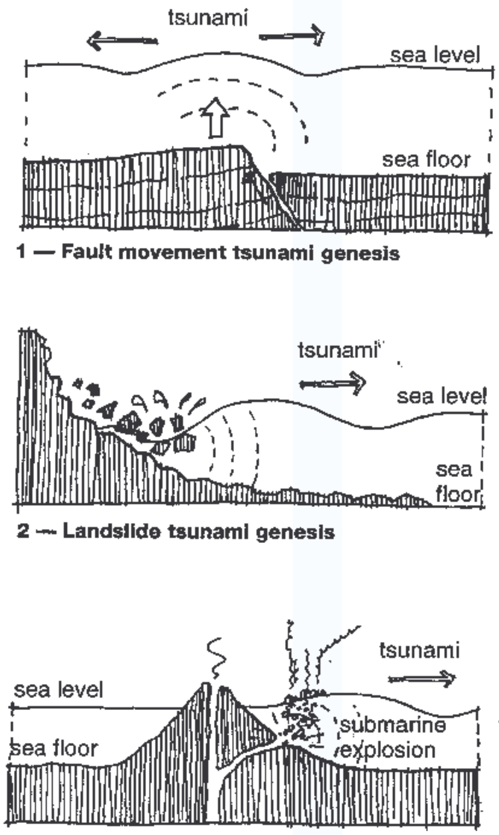


Figure 1.2.1
Genesis of tsunamis

Q. *What are the three main causes of tsunamis?*

A. ____

General characteristics

Tsunamis differ from ordinary ocean waves, which are produced by wind blowing over water. Normal waves are rarely longer than 300 m from crest to crest. Tsunamis, however, may measure 150 km between successive wave crests. Tsunamis travel much faster than ordinary waves. Compared to normal wave speed of around 100 km per hour, tsunamis in the deep water of the ocean may travel the speed of a jet airplane – 800 km per hour! And yet, in spite of their speed, tsunamis increase the water height only 30–45 cm and often pass unnoticed by ships at sea. In 1946, a ship's captain on a vessel lying offshore near Hilo claimed he could feel no unusual waves beneath him although he saw them crashing on the shore.

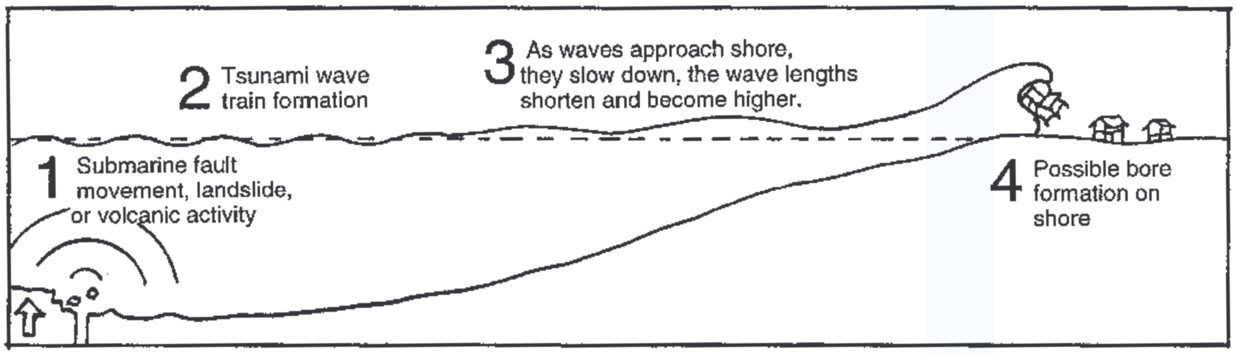


Figure 1.2.2
Tsunami wave train formation

Contrary for to popular belief, the tsunami is not a single giant wave. It is possible for a tsunami to consist of ten or more waves which is then termed a "tsunami wave train". The waves follow each other between 5 and 90 minutes apart.

As the waves approach the shore, they travel progressively slower. The final wave speed depends on the water depth. Waves in 18 meters of water travel about 50 kph. The shape of the nearshore seafloor influences how tsunamis will behave. Where the shore drops off quickly into deep water, the waves will be smaller. Areas with long shallow shelves, such as the major Hawaiian islands, allow formation of very high waves. In the bays and estuaries, the water may slosh back and forth (these phenomena are called *seiches*) and can amplify waves to some of the greatest heights ever observed.

The initial onshore sign of a tsunami depends on what part of the wave first reaches land: a wave crest causes a rise in the water level and a wave trough will cause a recession. The rise may not be significant enough to be noticed by the general public. Observers are more likely to notice the withdrawal of water which may leave fish floundering on the seafloor. A tsunami does not always appear as a vertical wall of water, known as a *bore,* as typically portrayed in drawings. More often the effect is that of a incoming tide that floods the land. Normal waves and swells may ride on top of the tsunami or the tsunami may roll across relatively calm inland waters.

The flooding produced by a tsunami may vary greatly from place to place over a short distance due to a number of variables. These include submarine topography, shape of the shoreline, reflected waves, and modification of waves by seiches and tides. Flooding may extend inland by over 300 meters and may affect one coastal community while others see no wave activity.

Tsunamis have occurred in all oceans and in the Mediterranean Sea, but the great majority of them occur in the Pacific Ocean simply because the rim of the Pacific Ocean Basin is the most geologically active region in the world.

The Hilo tsunami of 1946, originating in the Aleutian trench, produced 18 meter waves in one location and only half that height a few kilometers away.

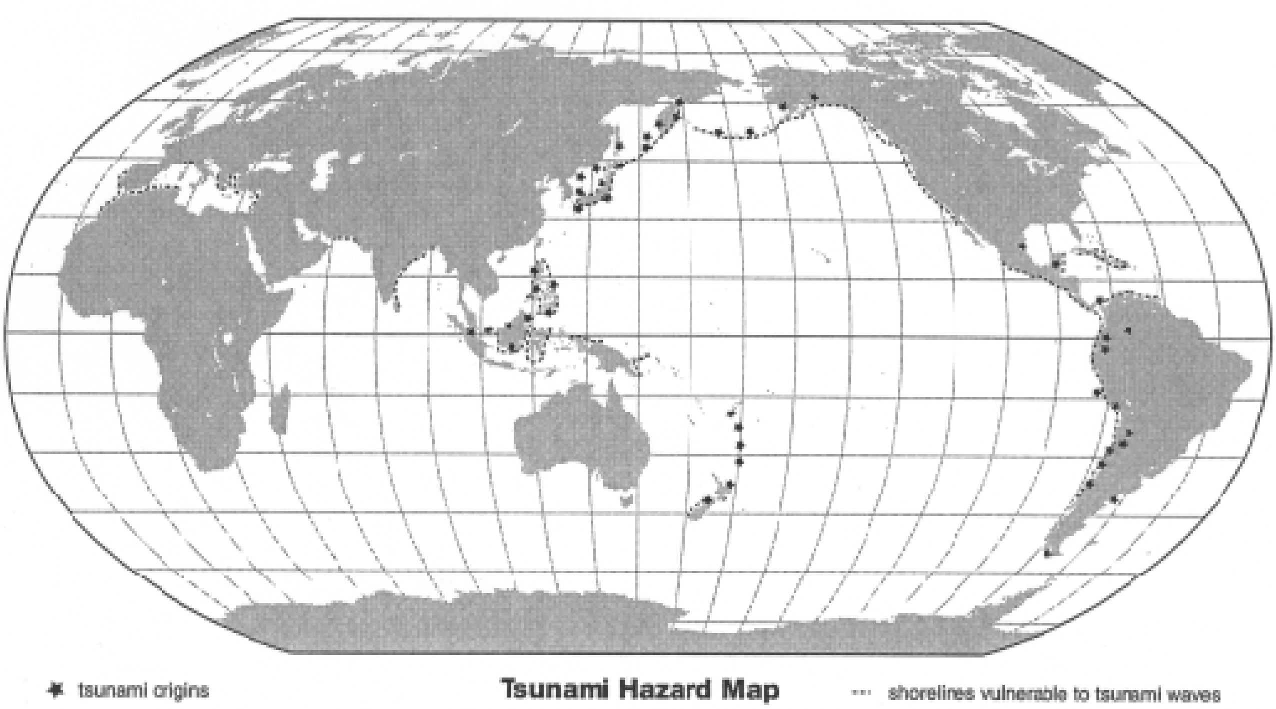
The sequence of the largest wave in the tsunami wave train also varies and the destructiveness is not always predictable. The first wave may not be the largest in a series of waves. In 1960 in Hilo, many people returned to their homes after two waves had passed only to be swallowed up in a giant bore which, in this case, was the third wave.

Predictability

Tsunamis have occurred in all oceans and in the Mediterranean Sea, but the great majority of them occur in the Pacific Ocean. The zones stretching from New Zealand through East Asia, the Aleutians and the western coasts of the Americas all the way to the South Shetland Islands are characterized by deep ocean trenches, explosive volcanic islands and dynamic mountain ranges. Between 1900 and 1996, tsunamis caused casualties and significant damage on the Pacific coasts of Mexico, Guatemala, El Salvador, Nicaragua, Indonesia, Costa Rica, Panama, Colombia, Ecuador, Peru, Chile, The United States, Japan, Papua New Guinea, Kamchatka, the Philippines and even along the coasts of Pakistan and Puerto Rico.

Since scientists cannot predict when earthquakes will occur, they cannot predict exactly when a tsunami will be generated. However, studies of past historical tsunamis indicate where tsunamis are most likely to be generated, their potential heights, and flooding limits at specific coastal locations. shortly after the 1946 Hilo Tsunami, the Pacific Tsunami Warning System (PTWS) was developed with its operational center at the Pacific Tsunami

Figure 1.2.3
Tsunami origins and vulnerable shorelines.



Warning Center (PTWC) near Honolulu, Hawaii. There are 26 member countries in the Pacific Basin. The objective of the PTWS is to detect, locate and determine the magnitude of potentially tsunami-producing earthquakes in the Pacific basin or its margins. Earthquake information is provided by internationally cooperating seismic observatories.

The PTWC is able to alert countries several hours before the tsunami strikes. A tsunami warning is issued when the location and magnitude of an earthquake meet the criteria for tsunami generation. The warning includes predicted arrival times at selected coastal communities where the tsunami could travel in a few hours. A tsunami watch is issued with subsequent arrival times to other geographic areas.

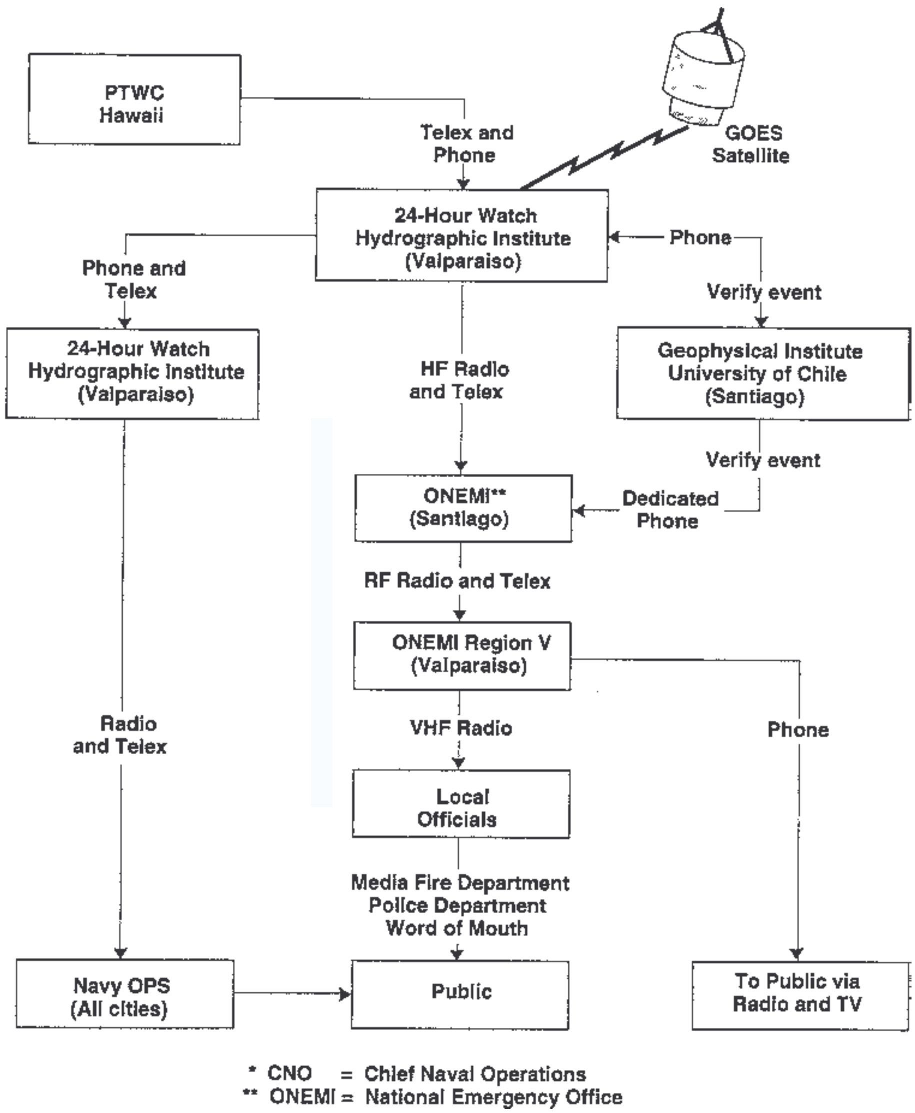


Figure 1.2.4
National Tsunami Warning System Communications of Chile

ANSWER (from page 32)

The three main causes of tsunamis are:

1. Fault movement on the sea floor
2. Landslides, either above or below water
3. Volcanic activity

The Chilean Government in recent years has experimented with use of satellite technology to provide nearly immediate warnings of potentially tsunamigenic earthquakes. Project THRUST (Tsunami Hazards Reduction Utilizing Systems Technology) can provide lifesaving tsunami hazard information in an average elapsed time of two minutes within its communication radius. In conjunction with this satellite communications network, historical data, model simulations and emergency operations plans are used (more details are provided in the preparedness section of this chapter).

These broken utility pole and bent parking meters were the result of tsunami waves which occurred May 22, 1960 at Hilo, Hawaii.

U.S. Navy photo.

Factors contributing to vulnerability

The major factors contributing to vulnerability to tsunamis are:

- Growing world population, increasing urban concentration, and larger investments in infrastructure, particularly on the coastal regions. Some of these settlements and economic assets sit on low-lying coastal areas likely to be affected by tsunamis.
- Lack of tsunami-resistant buildings and site planning.
- Lack of a warning system or lack of sufficient education for the public to create awareness of the effects of a tsunami and unpredictable intensity. For example, having observed relatively moderate tsunamis in 1952 and 1957, citizens at Hilo in 1960 actually converged on the coast to watch the waves come in with catastrophic results.

Typical adverse effects

Physical damage

Local tsunami events or those less than 30 minutes from the source cause the majority of damage. The force of water in a bore (a steep fronted wave which moves inland at high speed) can raze everything in its path with pressures of up to 10,000 kg per square meter. It is the flooding effect of a tsunami, however, that most greatly effects human settlements by water damage to homes and businesses, roads and infrastructure.

Withdrawal of tsunamis also causes significant damage. As the waves withdraw towards the ocean, bottom sediments are scoured out collapsing piers and port facilities and sweeping out foundations of buildings. Entire beaches have disappeared and houses carried out to sea. Water levels and currents may change unpredictably and boats of all sizes may be swamped, sunk or battered. Damage to ports and airports may prevent importation of needed food and medical supplies.

Casualties and public health

Deaths occur principally from drowning as water inundates homes or neighborhoods. Many people may be washed out to sea or crushed by the giant waves. There may be some injuries from battering by debris and wounds may become contaminated. Some people may develop pneumonia from aspirating polluted water. There is little evidence of tsunami flooding directly causing large scale health problems.

Water supply

Sewage pipes may be damaged causing major sewage disposal problems. Open wells and other groundwater may be contaminated by salt water and debris or sewage. Normal water supplies may be inaccessible for days due to broken water mains.

Crops and food supplies

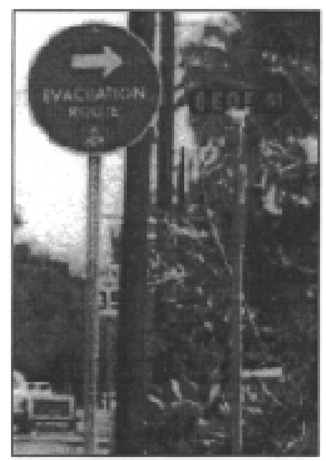
Flooding and damage by tsunamis may result in the following:

- an entire harvest may be lost, depending on time of year
- land may be rendered infertile due to salt water incursion from the sea
- food stocks not moved to high ground will be damaged
- animals not moved to high ground may perish
- farm implements may be lost hindering tillage
- boats and fishing nets may be lost
- facilities to import food may be destroyed.

Possible risk reduction measures

Some systematic measures to protect coastlines against tsunamis include:

1) Site planning and land management for development of coastal areas.
2) Establishment of building codes or guidelines such as construction of houses on stilts to survive the waves, or use of reinforced concrete structure. Buildings, such as the hotels in Hilo bay are specially constructed with first floor living area elevated above potential wave height. Ground floor and basement will be inundated. Structural columns resist the impact while other walls are expendable.
3) Building barriers or buffers such as special breakwaters or seawalls. Potential inundation areas may be designated as a park or sports area.



Tsunami evacuation route sign.
Dudley and Lee, *Tsunami!*

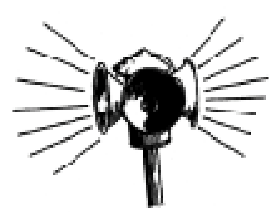
Specific preparedness measures

Hazard mapping and evacuation routes and procedures

Historical incidence may be studied to determine the areas most vulnerable to tsunamis. A hazard map should be created designating areas expected to be damaged by flooding or waves. Evacuation routes should constructed if necessary and mapped. Detailed plans should be made for actual evacuation procedures.

Early warning systems

Tsunami watch, warning and information bulletins are issued by PTWC and disseminated to local, state, national and international users as well as the media. These users then disseminate the information to the public generally over the radio and television channels. 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 instructions should a warning be issued. The public should not return to low lying areas until the tsunami threat has passed and the “all clear” is announced by local authorities.



One weakness in the warning system may be at the local level where capacity to disseminate the information may be limited. In addition, sometimes tsunamis follow earthquakes in less than 15 minutes. There exists sufficient knowledge and technical expertise to develop early ‘real-time’ tsunami warning systems. A real-time seismic network permits accurate and almost instantaneous determination of the source parameters of all damaging earthquakes all over the world. Many difficulties arise, however, in transferring scientific results to operational procedures.

It has been of great concern to experts that tsunamis occurring in areas of the globe other than the Pacific have not been focused on. Some of these tsunamis, such as those striking Greece and surrounding areas, were disastrous and resulted in loss of lives. The PTWC encourages establishment of similar organizations and warning systems in other tsunami prone areas.

Community preparedness

In areas where modern communication networks do not exist, the local population must be educated to recognize the signs of an approaching tsunami and what action to take. However, even in areas where modern networks exist, people may not understand the warnings or choose to ignore them. The following information should be disseminated:

- Ground shaking signals the occurrence of an earthquake. Move away from low lying coastal areas since a tsunami may accompany the earthquake. Do not wait for a tsunami warning to be announced. A local or regional tsunami could strike some areas in a few minutes.
- Stay away from rivers and streams that lead to the ocean.
- Some tsunamis are preceded by a sudden drop in sea level.
- The waves at one beach may be much larger than at adjacent beaches.
- A tsunami may have a dozen or more destructive waves. Stay away from the area for at least two hours. Do not stay to watch the waves, or you may not escape them.
- Advice for mariners: if you are at sea and a tsunami warning is issued for your port, do not return to it. Move your boat to deep water and return to the harbor when safe conditions are verified.
- Have respect for tsunami warnings issued and follow emergency evacuation plans and procedures.

Typical post disaster needs

The initial response by local authorities includes:

- Implement warning and evacuation procedures
- Perform search and rescue in the disaster area
- Provide medical assistance
- Conduct disaster assessment and epidemiological surveillance
- Provide short term food, water, shelter.

Secondary responses include:

- Repair and reconstruct buildings and harbor and airport facilities.
- Reestablish employment.
- Provide assistance for agricultural areas.

■ CASE STUDY

Project THRUST

Earthquakes in Chile result from subduction of the Nazca plate beneath the South American plate. The seismic potential in the Chilean trench is not completely known. In the past, tsunamis generated by local seismic activity, have struck the coast of Chile within 10 minutes. The National Tsunami Warning System in Chile could not be activated in less than 30 minutes. This situation led to an experimental installation of Project THRUST (Tsunami Hazards Reduction Utilizing Systems Technology) to upgrade the warning and response capacity. The benefits resulted from a systems approach to tsunami hazard mitigation and included:

1. **Preparedness measures,** including historical base studies, numerical model simulations and emergency operations plan development.
2. **Instant local hazard assessment** by using seismic triggers which activate a satellite to transmit signals to a ground station processor. (The average cost of hardware for the most basic system configuration consisting of a seismic station and a tsunami warning station was US$ 15,000.)
3. **Rapid dissemination of information** to local officials. The professor alerts the station manager and can also activate lights, alarms, telephone dialers and other emergency responses, thus providing rapid dissemination of information to local officials.

Using tsunami hazard maps of probable inundation areas combined with street maps to identify security areas, hospitals and evacuation routes, a THRUST Project Tsunami Emergency Operations Plan for Chile was devised. The plan listed measures to be taken upon issuance of the tsunami warning and long term relief efforts to be taken after the tsunami had receded, including responsibilities and functions of every disaster agency involved in a tsunami emergency.

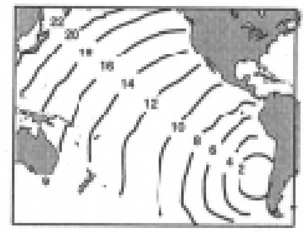
This plan was tested by means of an exercise scenario and a control team which generated news or problems to the participants. A lack of coordination between several agencies was revealed by this exercise and necessitated a detailed revision of the plan which was later adopted. Emergency operations in Chile are organized on a regional, provincial and community basis and each administrative level has an Emergency Operating Center. It was found to be more advantageous to move the coordinating responses from the regional to the community level. Other weaknesses in the plan, such as lack of baseline inundation studies in some communities, were discovered.

What strong points this project, as described, have in preparing for tsunamis?

1. Improved technology was incorporated into an already existing system which might have resulted in lower costs and more local acceptance than a completely new system.
2. The plan touched on the entire emergency system, not just technological areas.
3. Representatives of every concerned government and non-government agency were consulted about the plan and had an opportunity to test it in the simulation.
4. The simulation identified weaknesses in the emergency management system which may eventually save lives.

What are the weak points?

1. The project lacked a research component to work on further defining the seismic zones in Chile and conducting inundation studies on all of the villages.
2. The plan did not address issues of future planning and development in the inundation zones, or methods to lower risks to buildings and infrastructure.
3. No means of educating the general public about the tsunami hazard and emergency plan were mentioned.



Calculated tsunami travel times for an earthquake occurring off the coast of Chile. Each concentric curve represents two hours of tsunami travel time.

After an illustration in "Tsunami – The Great Waves", 1995.

Source: Bernard, Eddie N., "Assessment of Project THRUST: Past, Present, Future", **Natural Hazards,** 4: 285-292, 1991.

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■ RESOURCES

The International Tsunami Information Center sends materials around the world to assist in tsunami preparedness education programs. Materials may be obtained by writing to:

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Honolulu, Hawaii 96813-3213 USA
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