EARTHQUAKES AND TSUNAMIS, WAYS OF REDUCING RISK

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ABSTRACT

Earthquakes occur along tectonic plate boundaries. In the past 500 years three million people have died in major earthquakes. The rapid growth in population and industrial and harbor facilities increase the earthquake and tsunami hazards. Tsunamis triggered by undersea earthquakes or volcanic eruptions have killed some 52 thousand people around the Pacific basin in the past 100 years. Systems that warn populations of an approaching tsunami must work quickly since most deaths caused by the tsunami waves occur in the first 20 minutes and less than 100 kilometers from the source. Late tsunamis occurred in Nicaragua, Indonesia and Japan in 1992 and 1993, with hundreds of victims, has shown that actual tsunami warning systems are not sufficient to save human lives within the near-field.

In 1966, IOC established the International Coordination Group for the Tsunami Warning System in the Pacific, which identified the U.S. Seismic Sea-Wave Warning System, in operation since 1948 at the Seismological Observatory near Honolulu, as the Pacific Tsunami Warning Center (PTWC). The operational objective of PTWC is to detect and locate major earthquakes in the Pacific region, to determine whether they have generated tsunamis, and to provide timely and effective tsunami information and warnings to the population of the Pacific to minimize the hazards of tsunamis, especially to human life and welfare.

No such a warning system exists for major earthquake occurrence yet. Researchers are looking for proper signs of the when and where of them. Monitoring by instruments is performed all over the world looking for better forecasting.

There are several ways of reducing risk from tsunami hazards. One is assessing vulnerability, which can be attained through two methods: evaluation of historical impact from tsunamis and numerical simulation. Tsunami risk is essentially a function of land uses interacting with tsunami characteristics. There are two approaches to tsunami risk reduction: construction of barriers and risk management policies.

The development of regional and national tsunami warning centers using new operational concepts will reduce the time needed to evaluate the tsunami hazard, make decisions, and disseminate the warnings.

Most of the mentioned risk reduction measures are expensive and take a lot of time to implement. Developing countries, most of which are located at the rim of the Pacific basin, have a better chance to reduce earthquake and tsunami hazard through a comprehensive education program on both natural hazards.

INTRODUCTION

Throughout history, natural disasters have killed, injured, and displaced people of every nation on the globe. Rapid onset natural hazards, such as earthquakes, landslides, tsunamis, hurricanes, tornadoes, floods, volcanic eruptions, and wildfires, have claimed more than 2.8 million lives worldwide in the past 25 years and have adversely affected 820 million people. The world's vulnerability and the social and economic cost of these hazards will only increase in the future because of population growth and urban concentration, increased capital investment coupled with new technologies, the existence of vulnerable critical facilities and fragile lifelines, and increasing interdependence of local, national, and international communities (Housner, 1987).

Major earthquakes occur almost every year producing hundreds and sometimes thousands of victims, vast destruction and huge economic losses in the epicentral area.

Tsunamis pose an unique natural disaster threat in that they are capable of major destruction not only in the near source region, but also at coastal areas far removed from the source, often encompassing the entire Pacific Basin within a matter of hours.

Generation of a tsunami occurs when a large portion of the sea floor is suddenly displaced during an earthquake (or, of lesser import, during a volcanic eruption or a submarine landslide). Such a displacement, which may be tens of meters over tens of thousands of square kilometers, imparts tremendous potential energy to the fluid which results in a train of very long-period waves (reflecting the size of the source region).

The wave train expands outward into the open ocean at speeds of several hundreds kilometers per hour. During this phase of its existence, the tsunami is of very small amplitude (usually less than 30 cm in height) and goes unnoticed by ships. Upon reaching a coastline, however, the long-period tsunami is transformed, becoming a bore of great height which rushes up the beach and inflicts widespread destruction and flooding. Local effects are dependent upon local coastal geometry, with bays and harbors being especially sensitive.

HAZARDS FROM EARTHQUAKES

The world's earthquakes are not randomly distributed around the Earth. There is a definite order to the distribution of seismic activity. World seismicity is concentrated in narrow zones which delineate the boundaries of the thick plates of the Earth's crust which are in constant motion.

Hazards associated with earthquakes include the phenomena of ground shaking, surface faulting, earthquake-induced ground failures, and tsunamis. Earthquakes have the potential for causing great sudden economic loss. Within 1 to 2 minutes, an earthquake can impact part or all of a city.

Depending on its location and magnitude (an indication of the energy released), an earthquake can damage buildings and homes valued collectively in billions of dollars, can cause loss of life and injury to tens of thousands, and can disrupt social and economic functions of communities.

Each year, several million shocks happen throughout the world, varying in size from minor tremors that are perceptible only to sensitive instruments to a few great earthquakes that cause considerable damage, injuries, and loss of life. The theory of plate tectonics can explain earthquakes. In this theory the "solid" Earth is broken into several major plates. These rigid plates or segments of the Earth's crust and upper mantle move slowly and continuously over the interior of the Earth, meeting in some areas and separating in others. As these plates move, strain accumulates. Eventually, faults along or near plate boundaries slip abruptly and an earthquake occurs producing ground shaking.

The size of the geographic area affected by ground shaking depends on the magnitude of the earthquake and the rate at which the amplitudes of seismic waves decrease as distance from the causative fault increases.

Most of the spectacular damage that takes place during earthquakes is caused by partial or total collapse of buildings as a result of ground shaking. In addition, ground shaking can induce destructive ground failures. Old existing buildings that fail to meet present standards for earthquake resistance face the greatest threat from ground shaking. The number of such buildings in the world is very large. Applying loss-reduction measures to these sub-standard buildings is a major unresolved problem because of economic, social, and political factors. The primary choices for reducing losses from sub-standard buildings include (1) engineering redesign and retrofitting to strengthen the structure, (2) reduction in intensity of use, and (3) removal.

To reduce losses in new buildings, the primary choices include (1) avoiding the areas of most severe ground shaking, (2) land-use zoning either to prohibit certain types of structures susceptible to damage or to reduce the density of certain uses in areas having a high probability of severe ground shaking, (3) incorporating the earthquake-resistant design codes during construction, and (4) earthquake insurance.

Throughout the world, ground failures induced during earthquakes have caused many thousands of casualties and millions of dollars in property damage. Loss of life has been especially high in some countries. For example, soil-flow failures induced during the 1920 Kansu, China, earthquake killed an estimated 200,000 people. Another problem arising from the occurrence of big earthquakes is liquefaction which is not a type of ground failure; it is a physical process that takes place during some earthquakes that may lead to ground failure. As a consequence of liquefaction, clay-free soil deposits, primarily sands and silts, temporarily lose strength and behave as viscous fluids rather than as solids.

When the soil supporting a building or some other structure liquefies and loses strength, large deformations can occur within the soil, allowing the structure to settle and tip. The most spectacular example of this took place during the 1964 Niigata, Japan, earthquake. During that event, several four-story buildings of the Kwangishicho apartment complex tipped as much as 60 degrees.

Another source of seismic hazards comes from earthquake-induced landslides. Most clays lose strength when disturbed by ground shaking, and, if the loss of strength is large, some clays may fail. Five large landslides that affected parts of Anchorage during the 1964 Prince William Sound, Alaska, earthquake are examples of spectacular failures of sensitive clays. The most abundant types of earthquake-induced landslides are rock falls and slides of rock fragments that form on steep slopes.

Large earthquake-induced rock avalanches, soil avalanches, and underwater landslides can be very destructive. Rock avalanches originate on over-steepened slopes in weak rocks. One of the most spectacular examples occurred during the 1970 Peruvian earthquake when a single rock avalanche killed more than 18,000 people.

We should also remember that earthquakes do not need to be large to be destructive. The 1963 Skopje earthquake in the former Yugoslavia, with only a moderate magnitude of 6.0, damaged 10 percent of the buildings in that city, and about 60 percent of the other buildings sustained damage beyond repair

The Morocco earthquake of 1960, with a magnitude of 5.5, caused severe damage to the city of Agadir The Caracas earthquake, in Venezuela, in 1967, with a magnitude of 6.3, caused extensive damage to Caracas and to the northern coastal region of Venezuela, as well as claiming numerous lives. Many more examples exist of moderate earthquakes which have caused extensive damage. They illustrate the problem of earthquakes that occur near congested urban areas and cause severe damage to the economy and welfare of a country.

HAZARDS FROM TSUNAMIS

A tsunami is a system of gravity waves formed in the sea as a result of a large-scale disturbance of sea level over a short duration of time. In the process of sea level returning to equilibrium through a series of oscillations, waves are generated which propagate outward from the source region.

A tsunami can be generated by submarine volcanic eruptions, by displacement of submarine sediments, by coastal landslides into a bay or harbor, by meteor impact, or by vertical displacement of the earth's crust along a zone of fracture which underlies or borders the ocean floor. The latter is by far the most frequent cause of tsunamis and for all practical purposes the primary cause of tsunamis capable of propagation across an ocean basin. The rupture of the earth's crust will also generate a major earthquake which can be detected and measured by seismic instrumentation throughout the world. However, not all coastal or near coastal earthquakes produce tsunamis. At present, there is no operational method to determine if a tsunami has been generated except to note the occurrence and epicenter of the earthquake and then detect the arrival of the characteristic waves at a tidal stations network.

Tsunamis travel outward in all directions from the generating area, with the direction of the main energy propagation generally being orthogonal to the direction of the earthquake fracture zone. Their speed depends on the depth of water, so that the waves undergo accelerations and decelerations in passing over an ocean bottom of varying depth. In the deep and open ocean, they travel at speeds of 500 to 1,000 kilometers per hour. The distance between successive crests can be as much as 500 to 650 kilometers; however, in the open ocean, the height of the waves may be no more than 30 to 60 centimeters, and the waves pass unnoticed. Variations in tsunami propagation result when the propagation impulse is stronger in one direction than in others because of the orientation or dimensions of the generating area and where regional topographic features modify both the wave form and rate of advance. Tsunamis are unique in that the waveform extends through the entire water column from sea surface to the ocean bottom. It is this characteristic that accounts for the great amount of energy transmitted by a tsunami.

The successive waves of a tsunami in the deep sea have such great length and so little height they are not recognizable from a surface vessel or from an airplane. The passing waves produce only a gentle rise and fall of the sea surface.

Upon reaching shoaler water, the speed of the advancing wave diminishes, its wave length decreases, and its height may increase greatly, owing to the piling up of water. Configuration of the coastline, shape of the ocean floor, and character of the advancing waves play an important role in the destruction wrought by tsunamis along any coast, whether near the generating area or thousands of kilometers from it.

The earliest tsunami cataloged occurred in 173 AD near China and was observed in three countries. The most recent event was the July 12, 1993 Hokkaido Nansei-Oki earthquake and subsequent tsunami that ravaged parts of Japan and which caused damage to other countries surrounding the Sea of Japan. The known toll of life and property directly attributable to tsunamis during this period is enormous. The Great Hoei Tokaido-Nankaido tsunami of 1707 claimed 30,000 lives and washed away over 8,000 houses. The Kamchatka tsunami of 1737 rose 30-60 meters in some places, with consequent loss of life and property. The Great Meiji Sanriku tsunami (1896) caused 27,000 deaths and nearly 10,000 injuries and destroyed or damaged 13,000 houses. In the same area, the Great Showa Sanriku tsunami killed over 3,000 in 1933. The Great Aleutian tsunami of 1946 killed 173 persons in distant Hawaii where heights as great as 17 meters were recorded.

Two great tsunamis occurred within four years in recent times. The 1960 Chilean tsunami killed thousands and spread general devastation over a large segment of Chile's coast. Over 300 were killed or injured in Hilo, Hawaii where 500 structures were damaged and US$ 22 million lost. In Japan, where the tsunami arrived after almost twenty-four hours of travel, 200 persons, 5,000 structures, and 7,500 boats were lost. The 1964 Alaskan tsunami inflicted perhaps US$ 100 million in damage to the North American coast as far south as Southern California.

The arrival of a tsunami at a shoreline may cause an increase in water level as much as 30 meters or greater in an extreme case. The large increase in water level, combined with the surge of the tsunami, can impose powerful forces on shore protection structures and on structures located near the shoreline. Structures may be seriously damaged or destroyed by the tsunami. Damage may be caused by strong currents produced by waves overtopping the structures, by the direct force of the surge produced by a wave, by the hydrostatic pressure created by the flooding behind a structure combined with the loss of equalizing forces at the front of a structure due to extreme drawdown of the water level when the waves recede, and by erosion at the base of the structure. Major damage may also be caused by debris carried forward by the tsunami in the nearshore area.

The force and destructive effects of tsunamis should not be underestimated. At some places, the advancing turbulent front is the most destructive part of the wave. Where the rise is quiet, the outflow of water to the sea between crests may be rapid and destructive, sweeping all before it and undermining roads, buildings, and other works of man with its swift currents. Ships, unless moved away from the shore, can be thrown against breakwaters, wharfs, and other craft, or washed ashore and left grounded during withdrawals of the sea.

To determine the potential damage to structures located along a shoreline, the probable increase in water level caused by the tsunami, i.e., the runup height, must be estimated. Estimates of tsunami runup are also needed for flood zone planning along the shoreline, and for emergency operations to evacuate people from endangered areas.

A tsunami is not one wave, but a series of waves. The time that elapses between passage of successive wave crests at a given point usually is from 10 to 45 minutes. Oscillations of destructive proportions may continue for several hours, and several days may pass before the sea returns to its normal state.

During the period from 1900 to 1993, 256 tsunamis were observed or recorded in the Pacific Ocean. Fifty-seven caused casualties and damage near the source only; nine caused widespread destruction throughout the Pacific. The greatest number of tsunamis during any 1 year was 11 in 1938, but all were minor and caused no damage. Only 9 years of the period were free of tsunamis, but this apparent freedom may be due to poor detection.

Twenty-nine percent of the total tsunamis were generated in or near Japan. The distribution of tsunami generation in other areas is as follows: South Pacific, 18 percent; South America, 9 percent; Philippines, the island of Taiwan and the Ryukyu Islands region, 11 percent, Kuril Islands and Kamchatka, 11 percent; Mexico and Central America, 7 percent; Alaska and Aleutian Islands, 6 percent; Indonesia 6 percent; West Coasts of Canada and the United States, 2 percent; and Hawaii, 2 percent.

SEISMIC WARNING

There has been astonishing progress in understanding how and why earthquakes happen. Some seismologists are raising hopes that reliable earthquake forecasting is not far away. Others insist that forecasting is a side issue; that there is little point in predicting when cities will fall down, and that we should concentrate upon making them stand up.

Both schools of thought agree that we need a sound knowledge of the habits of earthquakes.

An effort to understand the physical conditions that precede an earthquake was initiated in the United States of America following the destructive Prince William Sound, Alaska, earthquake of March 27, 1964. This effort had the objective of predicting the size, time, and location of an impending shock. It was increased after the damaging San Fernando, California, earthquake of February 9, 1971.

Earthquake prediction is a rapidly emerging scientific field offering great promise for loss reduction. Although accurate predictions of the size (magnitude), time, and location of future earthquakes may still be years away, scientific information needed for making reliable predictions within the next decade are emerging from studies by earth scientists from many different institutions in several countries, including the United States, Japan, China and the Russian Federation.

As with most new technological developments, earthquake prediction must be approached carefully. Earthquake prediction will save lives; this has already been demonstrated by the successful prediction of the destructive earthquake that struck Haicheng, China, on February 4, 1975. However, in some countries a prediction can cause serious socioeconomic problems if it is not properly implemented.

TSUNAMI WARNING

While there is no way to prevent tsunami generation, it is conceivable that the degree of loss, especially the loss of life, can be greatly reduced. A warning system that can give many hours of advance notice is the primary way to reduce losses. Land-use zoning of coastal areas is another way used to reduce losses from tsunamis. Such zoning is based on the heights of expected tsunami waves.

As early as 1965, the Intergovernmental Oceanographic Commission (IOC) of UNESCO decided to play a role in mitigating the effects of this natural hazard in the Pacific, where the frequency of recurrence is highest. Prior to 1960, countries such as USA, Japan, and the former USSR had established rudimentary national warning systems, with the responsibility of warning primarily their own civil defense authorities and protecting their own national interests. These systems had limited data collection capabilities, limited communications within their own national jurisdictions, and limited warning dissemination capability.

The great destruction caused by the May 1960 Chilean tsunami prompted a large number of countries and territories to express to IOC their interest in joining the rudimentary Pacific Tsunami Warning System, at least by contributing some data and information and receiving warnings in exchange. The great Alaskan earthquake and tsunami of 1964 focused additional attention to the need for a well coordinated International Tsunami Warning System.

A working group on the international aspects of the Tsunami Warning System in the Pacific met during the month of April 1965, in Honolulu and recommended that an International Tsunami Information Center be established on a permanent basis to collect and interpret seismic and sea-level data on a real-time basis to act as a source from which national centers may obtain data on which to base their warnings, and further that the United States Government be asked to strengthen its existing tsunami warning service based at the Honolulu Observatory to enable it to act, in addition, as the International Tsunami Information Center. Furthermore, the working group recommended the formation of an International Coordination Group.

The International Coordination Group for the Tsunami Warning System in the Pacific (ICG/ITSU) was formed as a subsidiary body of IOC to coordinate and review the activities of the International Tsunami Warning System. Initially 11 Member States appointed National Contacts to serve as liaison with IOC and the proposed International Tsunami Information Center. Today, 26 Members States hold its sessions every two years. Fourteen Sessions of the ICG/ITSU have taken place since the formation of the Group, with IOC sponsorship.

The operational objective of the International Tsunami Warning System is to detect and locate major earthquakes in the Pacific region, to determine whether they have generated tsunamis, and to provide timely and effective tsunami information and warnings to the population of the Pacific to minimize the hazards of tsunamis, especially to human life and welfare. The Pacific Tsunami Warning Center (PTWC) serves as the operational center collecting and evaluating data provided by participant countries, and issuing appropriate informational bulletins to all participants regarding the occurrence of a major earthquake and possible or confirmed tsunami generation.

IMPROVEMENT OF EXISTING WARNING SYSTEM

Considering the level of today's technology, it should, with an appropriate distribution of warning centres, be possible to achieve warning distribution to affected populations within 20 minutes of tsunamigenesis. However, there are several places around the Pacific Basin where there is no regional or local tsunami warning facilities to meet this goal. An special effort should be given to improve and increase the number of the present regional and local systems.

There are two areas of generic deficiencies in the current communications of the Tsunami Warning System. The first of these is the almost exclusive dependence on commercial telephone or telegram/telex for the acquisition of confirming tide information. The first place that a Warning Centre will look for these data will be in the area of origin and this is the place most likely impacted by the potentially tsunamigenic earthquake. There is a high probability that the earthquake will destroy or badly damage the infrastructure, and this will severely complicate the process of getting data out of the source region. The second deficiency is in the international dissemination of information generated by the Warning Centres. The number of locations where there is a two-way exchange of data are extremely limited.

In the case of tsunami warning and data transmission, satellites offer the most suitable means, provided that transmission pattern of the satellite is within the area of interest and, a data collection system similar to the Geostationary Operational Environmental Satellite (GOES) is on board. Several institutions and goverment departments presently employ successfully real time data transmission utilizing satellite technology. This type of communication's facilitity should be implemented as much as possible throughout the Pacific Basin.

EDUCATION - A COMPLEMENTARY WAY OF REDUCING NATURAL HAZARDS

There are several factors that are related with the reduction of the effects of natural hazards. Some of them are: the development of new technologies and their transfer to operational staff; a global network of sensors and their interconnection through reliable communication means that in real time provides data to regional and local centers; an appropriate capability of data processing and modeling; and others. All of this is much advantageous under an international coordinating body.

But there is a "masterpiece" in all this and that is " THE INDIVIDUAL " who, before the occurrence of a natural hazard will face a critical situation, common to the moment.
The survival probability of a man encouraging an adverse situation is directly proportional to the favorable and rational attitude attained. To have this capability as part of man behavior, he needs to be educated in advance and periodically trained.

People having good capabilities, and almost unlimited to gather knowledge are children. For that reason, it seems beneficial to initiate an effort to incorporate under school programmes the appropriate matters dealing with natural hazards. In second term, the general public also can be educated by means of public communication media through a systematic and pedagogical well structured process. And after that, population will only need to be remembered about the ever existing probability of facing potentially catastrophic natural hazards.

In the case of Tsunami, and as a contribution to IDNDR, IOC gave support to an initiative of the International Coordination Group for the Tsunami Warning System in the Pacific, to develop a Public Education and Awareness Program. The original proposal belongs to CHILE, nation with permanent seismic activity and that has been hit several times by mayor tsunamis.

The program went through the development of educational programmes for pre-elementary , primary and high schools students, and the preparation of references for teachers. A pilot project was run last year at several schools of a region in CHILE, ending with fruitful results, thus contributing actively with the aim of IDNDR. At this stage, the originals of Spanish and English version of educational text books are with IOC for publishing in the near future and to circulate among all UN Member States.

We think that efforts pointing toward the strengthening of the education in this matters, have a valuable impact in reducing the effects of natural hazards, primely helping to save lives.

CONCLUSIONS

The International Tsunami Warning System is the result of IOC's involvement and active coordination. It is one of the most successful international scientific programs with the direct responsibility of mitigating the effects of tsunamis, the saving of lives and the preservation of property. It is an operational program with a direct humanitarian objective. Its value in the protection of human lives in the International Community of Pacific Nations, cannot be overemphasized.

Education should be considered as a very important tool to properly handle the effects and impact of natural hazards.

For the implementation of most of the suggested improvements for the earthquake and tsunami hazards mitigation, provision of funds from international agencies or through bilateral arrangements are essential factors. However, the enthusiasm and willingness of all participating Member States, ensuring that the affected population is made continuosly aware of the dangers caused by earthquakes and tsunamis, is perhaps the most important factor to be considered.

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