Urban and Architectural Approaches To Design against Tsunami

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SUMMARY
Although tsunamis are not new acts of nature, they have created many problems to coastline regions in recent years. Accordingly, Japan's current tsunami attracted much more attention than previously occurring tsunamis. Clearly this is not only because of the wonderment and surprising characteristics, but also because of the structures and infrastructures that failed when they were expected to resist natural disasters. Many buildings that were designed and calculated to resist high level of earthquakes were damaged quickly by this tsunami. These facts can lead us to change our attitude toward the hazards of a tsunami because of the elementally differences between this phenomenon and an earthquake. In this paper, firstly discussed are the characteristics and consequential hazards to the environment resulting from a tsunami. Secondly, preparations that could be taken to make a building more resistant to the specific forces of a tsunami are addressed. These preparations include both urban scale considerations and building scale aspects.

Keywords: *Tsunami hazards, Architectural approach, Mitigation strategies, Vertical evacuation, TEBs*

1. INTRODUCTION

Acts of nature such as tsunamis and earthquake are not actually considered to be a serious threat on a basic level. What makes them a destructive danger to humans is the unpreparedness and to not plan for them. Accordingly, preparation against any so-called phenomenon can reduce community vulnerability and as a result can consequently decrease the hazards and incurred losses. This paper is to present architectural strategies on an upper scale and to respectively offer techniques which will mitigate the losses and injuries incurred by tsunamis in coastline communities which are prone to tsunami risks. The approach of this paper is based on adopting the experiences gathered around the world by official organizations which have done research on this case. As mentioned, the concentration is on architectural aspects rather than specific structural analysis cases.

A short introduction is provided in the first part, describing the characteristics of a tsunami and in this case state-of-the-art activities are brought in short sentences as a basis to the whole paper. The next section presents several strategies and instructions to mitigate the risks of the tsunami to coastline communities in two approaches. The first approach introduces large-scale considerations such as site planning and urban design while the second approach discusses building-scale techniques considered beneficial in resisting a tsunami. The following strategies and techniques are intended for use by administrative officials, registered engineers and architects involved in planning, zoning, building regulation, community redevelopment, as well as related land use and development functions in coastal communities.

2. TSUNAMI

The Term Tsunami (soo-NAH-mee) is a Japanese word originally meaning harbor wave. Tsunamis are also called Tidal waves. This phenomenon refers to a series of traveling ocean waves caused by the displacement of a large volume of water, typically an ocean or a large lake. Earthquakes, volcanic eruptions, underwater explosions (including detonations of underwater nuclear devices), landslides, glacier calvings, meteorite impacts and other disturbances above or below water all have the potential to generate a tsunami (IOC 2008); however, more than 80 percent of tsunamis are caused by submarine earthquakes. More detailed information in this case can be found in (IOC 2008). Tsunamis are infrequent events but can be extremely destructive. 900,000 people in Alaska, California, Hawaii, Oregon, and Washington live in areas that have the risk of being inundated by a 50-foot tsunami (IOC 2008).

Most tsunamis are generated in the Pacific Ocean, in an area called the "Ring of Fire". Although 60% of all tsunamis occur in the Pacific Ocean, they can also threaten coastlines of countries in other regions, including the Indian Ocean, Mediterranean Sea, Caribbean Ocean, and also the Atlantic Ocean.
Tsunamis can be divided in two groups of local (near-source) and distant (far-source) tsunamis. The first type refers to tsunamis generated by near source causes that generally do not take a long time to reach the coast. Alternatively, the second type, called a distant (Far-source) tsunami, is fed by a distant source and may consequently take longer to reach the coastlines (Applied Technology Council 2008).

As discussed in (IOC 2008) there are three effective factors that can affect the magnitude of hazards which threaten the respective coastlines; The characteristics of the waves (such as the distance between two propagated waves, etc.), the configuration of the site and its buildings and also the properties of the ground in coastal regions and the aspects of the ocean floor including ground slopes, soil density, etc.

2.1. History

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. Indian Ocean Tsunami of December 26, 2004 created by the magnitude-9.3 underwater earthquake devastated coastal areas around the northern Indian Ocean. The tsunami took anywhere from 15 minutes to 7 hours to hit the various coastlines it affected. It is estimated that the tsunami took over 220,000 lives and displaced over 1.5 million people. Japan's recent tsunami killed about 15000 people and caused damage in the nuclear power plants. More information can be found in (IOC 2008).

2.2. Characteristics and Physics

Information from historic tsunami events indicates that tsunami behaviors and characteristics are quite distinct from other coastal hazards, and cannot be inferred from common knowledge or intuition. The primary reason for this distinction is the unique timescale associated with tsunami phenomena. Unlike typical wind-generated water waves with periods between 5 and 20 seconds, tsunamis can have wave periods ranging from a few minutes to over 1 hour (Applied Technology Council 2008).This timescale is also important because of the potential for wave reflection, amplification, or resonance within coastal features. There are common characteristics shared between tsunamis.

- Tsunami waves propagate across the deep ocean with a speed exceeding 800 kilometers per hour ([km], ~500miles per hour), and a wave height of only a few tenth of a centimeter (1 foot) or less. Tsunami waves are distinguished from ordinary ocean waves by the great length between their wave crests, which often exceed a 100 km (60 miles) or more in the deep ocean. The time between these crests, ranges from 10 minutes to one hour. As they reach the shallow waters of the coast, the waves slow down and the water can pile up into a wall of destruction tens of meters (30 ft) or more in height. see figure 1 and figure 2. The effect can be amplified in situations where a bay, harbor or lagoon funnels the wave as it moves inland. Large tsunamis have been known to rise over 30 meters (100 ft). Even a tsunami 3-6 meters (m) high can be very destructive and cause many deaths and injuries (IOC 2008).
- Tsunamis cause damage by two mechanisms: the smashing force of a wall of water traveling at high speed, and the destructive power of a large volume of water draining off the land and carrying all with it, regardless of the size of the wave.

- Terrains (such as bays, sounds, inlets, rivers, streams, offshore canyons, islands, and flood control channels) cause different behaviors in a tsunami (NTHMP 2001).
- The main causes of destruction resulting from tsunamis include multiple effective loads on buildings and barriers that are comprised of: Hydrostatic Forces, Buoyant Forces, Hydrodynamic Forces, Surge Forces, Impact Forces and Breaking Wave Forces. More detailed description can be found in (Gilbert Gedeon, Applied Technology Council 2008)

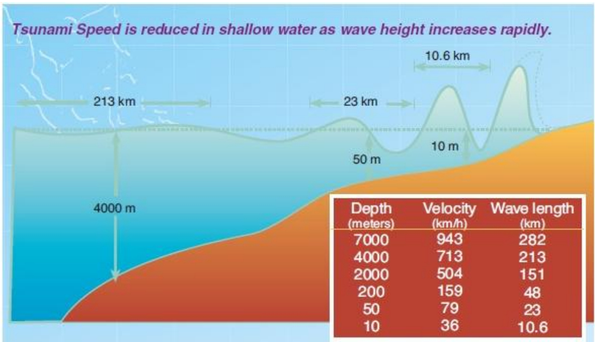

Figure 1. Chart of the relation between different tsunami characteristics. source: (IOC 2008)

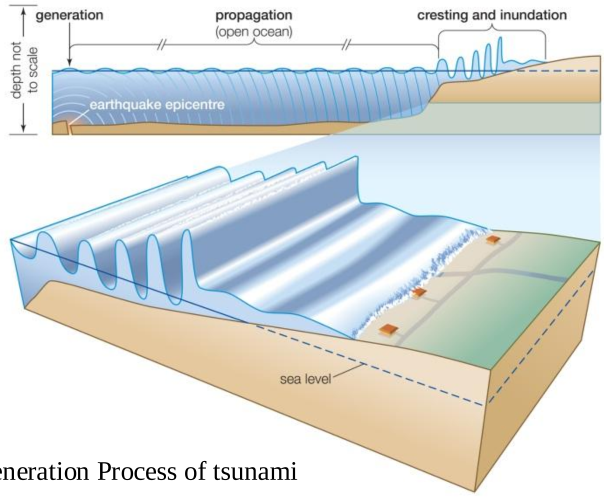

Figure 2. Generation Process of tsunami waves. source: (IOC 2008)

2.3. Generation Process:

The principal generation mechanism (or cause) of a tsunami (as shown in figure1 and figure2) is the displacement of a substantial volume of water or perturbation of the sea. This displacement of water is usually attributed to earthquakes, landslides, volcanic eruptions, glacier calving or more rarely by meteorites and nuclear tests. The waves formed in this way are then sustained by gravity. Tides do not play any part in the generation of tsunamis. The main cause of generating tsunamis in consequent of moving tectonic plates can be described by Plate Tectonic theory. The theory is based on an earth model characterized by a small number of lithospheric plates, 70 to 250 km (40 to 150 mi) thick, that float on a viscous under layer called the asthenosphere. In the tsunami generation mechanism, the consequent vertical and horizontal motion of the sea floor causes a displacement of a huge volume of water by which tsunami occurs. More information in this case may be found in (IOC 2008, Haugen K, Løvholt F, Harbitz C, K; Lovholt, F; Harbitz, C 2005, Margaritondo 2005)

3. STRATEGIES AND TECHNIQUES

Although tsunamis are a real threat to certain oceanic coastline regions, in regard to risk-hazard theory we can manage the risk factor by reducing the vulnerability variable in most cases. This paper is to present particular strategies in order to decrease vulnerability of tsunami-prone communities and to help to improve their resisting ability against hazards and the resulting risks through proper site planning, building design and construction methods. Accordingly we should first recognize the most important potential effects of tsunamis that cause the greatest loss and injury. The presented strategies and techniques in this paper are classified in two categories that at times may overlap. Also included are design standards and building codes, local as well as general that have been considered in the case respectively. In addition to the below listed tactics, there are other basic general strategies to consider in mitigating hazards which will be discussed later.

- To increase public awareness through education regarding tsunami risks
- To provide methods to reduce vulnerability in these hazards

- To inform, teach and prepare engineers, designers and official administers to plan and design efficiently against tsunamis
- To develop and update more effective warning systems and to offer new technologies in this area. information on warning systems can be accessed through (Orhan Altan, Gerhard Kemper 2008, NOAANWS 2011)

3.1. Large-Scale Considerations

This section discusses large-scale land use planning issues and considerations. It addresses site planning aspects and advanced decisions which include suggestions to official decision administers, designers and engineers involved in the planning and design of tsunami-prone coastline regions.
Tsunami risk can be mitigated most effectively by avoiding or minimizing the exposure to people and property through land use planning. Development should be prevented in high-hazard areas wherever possible. Land use planning refers to large-scale decisions and plans which determine location types and future development considerations in order to mitigate community exposure and vulnerability to tsunami hazards. These issues comprise enacting specific regulations, zoning considerations, assigning proper functions to subdivisions, etc. 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.
Following issues should be considered in proper site planning and designing:

A. To recognize the community's hazards and risks as well as the limitations and opportunities of the site

This step is the basis for the following additional items

B. To use Hazard Zone Maps to plan and decide for the site

The basic materials that can feed the planning are local hazard maps and inundation level maps, potentialities and limitations of the region such as planting area and etc.

C. To provide a proper transferring plan within the region less prone to tsunami

Locating main roads out of inundation level

D. To use tsunami hazard areas for open-space uses

E. To restrict Development through Land Use Regulations

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.

F. To implement strategies to resist against waves

There are several ways to behave against tsunami waves that each can be applied in a suitable situation and help to reduce tsunami's destructive loads on the coastline buildings. Three of these techniques contain: 1.slowing the water, 2.avoiding it or 3.let the water pass through the ground floor under the building. According to plenty of researches and experienced reports in the case, the more waves are blocked by the building walls or site barriers, the more loads must be carried. Thus the third strategy can provide better options.

G. To maintain space between buildings

Similar to last strategy, Spacing between buildings can reduce the loads on the walls and structure of the building consequently. Therefore it is suggested to observe adequate distance between the buildings in the site.

H. To locate buildings above inundation level

I. To plant within the distance between buildings and the shoreline

J. To preserve of natural barriers or dunes along coastlines.

It has been observed that planting areas are one of the best barriers against tsunami waves. Reported from several occurred tsunami events, the buildings covered by effective natural barriers mostly have been less vulnerable against waves.

K. To pay especial attention to critical facilities and important buildings
L. To provide TEBs in proper places. more information can be found in (Jay Raskin, 2009)
M. To select proper sites when determining building construction
N. To put suitable warning signs in necessary locations
O. To provide protection strategies of heritage and important buildings
P. To properly locate and protect infrastructures

Certain facilities in a community deserve special attentions 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.

Q. To plan the configuration of the buildings relative to each other
R. To enhance and develop warning centers
S. To limit additions in hazard area
T. To provide an evacuation plan and emergency managing scenario

Providing all preparations against tsunami cannot ensure us to be safe from the destructive mortal waves. Thus other strategies should be considered alternatively. Evacuation plan is one of these preparations that should be spotted. This strategy contains some parts. First is to have a proper evacuation and emergency plan of possible occurring catastrophes. Second is to determine several qualified gathering evacuation centers regarding to a suitable distribution around the site. Evacuation plans may include vertical or horizontal evacuation methods. Verticals are more proper for local and low distant tsunamis that the emergency time is limited in. to access more information in this case refer to (Applied Technology Council 2008, Jay Raskin 2009)

A vertical evacuation requires sufficient height such as a building or elevated hill in order to remove evacuees above the level of tsunami inundation, and the area must be is designed and constructed with the strength and resiliency needed to resist the effects of tsunami waves (Applied Technology Council 2008)

To provide refuge from tsunami inundation, vertical evacuation solutions must have the ability to receive a large number of people in a short time frame and efficiently transport them to areas of refuge that are located above the level of flooding. Potential vertical evacuation solutions can include areas of naturally occurring high ground, areas of artificial high ground created through the use of soil berms, new structures specifically designed to be tsunami-resistant, or existing structures demonstrated to have sufficient strength to resist anticipated tsunami effects. Nonstructural systems and contents located in the levels below the inundation depth should be assumed to be a total loss if the design tsunami occurs. If the building is required to remain functional in the event of a disaster, the loss of lower level walls, nonstructural systems, and contents should be taken into account in the design of the facility and selection of possible alternative uses.

3.2. Building Design Considerations

As discussed before, the second part’s attention is paid to building-scale considerations which include planning a building with consideration to its structural aspects, architectural cases and construction methods. The goal is to design and construct buildings prone to tsunami and resistant against its hazards by keeping its main structure stable enough to save the occupants lives. 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.

The challenges in protecting existing development 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 overtime, creating opportunities to incorporate tsunami (and other hazard) loss-prevention measures to help make communities less vulnerable in the future. The coming instructions are general and to get more detailed techniques it can be referred to relative researches done regarding to specific case studies.

According to (Tsunami Awareness Kit 2005) Schools, churches, and other critical facilities should never be located closer than 400m from the coastline, and preferably 800m in at-risk areas.

Figure 3. Shirahama tsunami evacuation structure in Japan. Photo by Professor Nobuo Shuto

Figure 4. Damage caused by impact from water-borne debris (fishing boat) in Aonae, Japan (1993 Okushiri Tsunami) (Photo courtesy J. Preuss) Shuto

3.3. Architectural and Structural Strategies

A. Construct the buildings high enough above high tide and local inundation level

As pointed before, it has been experienced in several tsunamis that one of the most effective strategies to reduce the wave loads on the structure and walls of the building through a tsunami attack, is to let the water pass through the ground floor of the building.

B. Install strong pillars or posts for the building

Strong pillars or posts can withstand the huge static and dynamic forces more than thin ones. It has been observed that the dimension of the posts' and columns' cross section plays an important role in this case.

C. Design for static and dynamic water pressure on the structural and nonstructural walls

D. Consider Impact load of debris left by tsunami's attack

One of the points that should not be underestimated is that debris impact can create huge forces to the building which may cause failure or collapse buildings. See figure 4.

E. Apply proper Details and joints in the structure

Proper joints can cause a unanimous behavior of the building against loads and may help the building to adopt most of its capacity to resist the loads.

F. Anchor buildings to foundations

Anchoring the columns to the foundation can help the constructions to withstand lateral and uplift forces that are caused by tsunami waves.

G. Strengthen and reinforce existing buildings

H. Apply reinforced concrete or heavy steel structure rather than using wooden skeleton

It is not a general rule but is has been observed that concrete structures according to their heavy weight and fixed joints have had better results against tsunami waves than other structures. Despite of locating Heavy steel structures in the second level of the priority, it does not mean that proper wooden structures are not suitable options if installed properly.

I. Use Seawalls to protect the main structure of buildings

J. Select proper forms to resist a tsunami while not blocking it entirely

Selecting proper forms is one of the most effective strategies that can reduce the vulnerability of the buildings to the hazards. Choosing a form that is consistent to tsunami wave's behavior can help the building to resist better against tsunami attacks.

K. Provide adequate openings in the ground floor of buildings to allow the waves to pass through

L. Position bearing or structural walls perpendicular to water flow.

M. Refrain from having vital and important equipment and facilities on ground levels lower than the inundation level

Inundation level is an important parameter which should be considered in different sites. Everything such as walls, equipment and facilities that are under inundation level are more prone to be attacked by the destructive waves of tsunami.

N. Allow non-structural elements at lower levels to break away rather than blocking the water

O. Avoid erosion of the soil by adopting proper methods

P. Use Proper Materials

Q. Pave the Floor

Paving the paths and the roads exposed to waves, may help them to be more resistant against soil erosion of the site which surrounds the building. Soil erosion may weaken the foundation and relative structure against wave loads. Figure 3 illustrates a proper building considering several architectural and structural points to be resistant enough against tsunamis.

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