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Urban Evacuation Tsunamis: Guidelines for Urban Design

Leonel Ramos Santibáñez[1]

Abstract

Earthquakes and tsunamis are the main natural agents of urban change and directly affect the sustainable development of cities. Buildings must be becoming stronger to withstand the seismic energy released during an earthquake and coastal cities at risk of tsunami should be better prepared to facilitate the process of evacuation of people at high and safe areas in the shortest time possible before the arrival of the first waves.During SATREPS / JICA 2012-15 "Tsunami Reserch Project", was worked with Dr. Hitomi Murakami of Japan, in the application of surveys in Chilean cities affected by earthquakes and tsunamis of 2010 and 2014 and Japanese cities affected by the earthquake and Tohoku tsunami of 2011with the aim to understand the behavior of the population during a tsunami evacuation and visualize the response of urban structures, especially evacuation routes and safe areas.Coastal cities should facilitate processes are tsunami evacuation as fast, safe and efficient, so that the population is made shelter in the shortest possible time previously established locations with the minimum equipment to support the emergency.These guidelines proposes to incorporate urban design in planning coastal cities values of urban resilience to earthquakes and tsunamis and minimum standards to ensure that future threats, the population will be safer and better prepared to face a new urban tsunami evacuation; this is one of the main tasks to prevent future disasters.

Keywords: earthquake, tsunami, Evacuation Routes, Safe place, recilience.

1. Introduction

Earthquakes and tsunamis are still one of the main natural events that generate more human lost and significant economic damages on countries that are periodically submitted to these risks.Last two greatest earthquakes and tsunamis, on 2010 in Chile and 2011 in Japan, made clear both strengths and weaknesses that existed in that time, from the point of view of the response that buildings had in facing earthquakes and at the moment of evacuation of the population at the moment of a tsunami. In both countries, a strict seismic regulation permitted that structures of buildings and urban infrastructures had, in general, a proper seismic behavior, which allowed to save human lives and avoid total paralyzation of affected cities; nevertheless, at the moment of evacuation due to tsunamis, weaknesses at the coastal areas were detected, in both urban design, which facilitated the quick evacuation of people to higher and safer ground zones, and also the fact that population evacuated slowly, or simply did not evacuate at all.

[1]Researcher Architect, PHD (C) urbanism & Professor at University of Concepcion, Chile. lramos@udec.cl

Another factor that affected evacuation was the overuse of automobiles which caused enormous traffic jams on escape routes, inducing chaos on people that evacuated on foot. Coastal cities with tsunami risks must consider, in their urban planning, the differentiated distribution of the low areas under risk of flooding, and the safe areas emplaced over the mark of 30 meters above sea level. Uses for lower areas could be ports, airports, non-contaminant industries, commercial and office areas, tourism areas and mitigation coastal parks. In the case of higher areas over the mark of 30 meters, residential zones, schools, hospitals, fire departments, town halls, culture and tourism (Table 3).

Regarding the design of the evacuation plan due to tsunami, it must be considered as a priority the time that people need (elderly, sick, disabled, children and adults) to move from a determined point in a risk zone, to a higher and safer place. Once an earthquake is finished people should be in a secure place in no more than 15 to 20 minutes. The faster the process, the greater will be the success of the evacuation (Fig.2).

Another important aspect is to define a micro zoning of the major area of flooding, in order to define more accurately the characteristics of each place in relationship with the population's density, the closer escape routes and the access of secure places to evacuate. The need to have better designed coastal cities that allow and facilitate processes of evacuation due to tsunamis, are still a priority need and is a developing task that this guide pretends to contribute.

2. Urban evacuation due to tsunamis in coastal cities

Coastal cities with tsunami risk must avoid human casualties and material damages to facilitate both urban and emotional recovery of the population after being affected by a tsunami. A city resilient towards tsunamis would have a more sustainable development in time, allowing a quick recovery after a disaster and a sustained development of its economy, and would also be more efficient in maintaining works and productivity, which are essentials in a recovery process. It is important that these coastal cities keep the patrimonial memories alive, which will allow the strengthening of the identity of the population and have in mind the "tsunami history" that the city has experienced through time (Fig.1).

For the purpose of prevention and recovery, coastal cities have to improve their buildings and tsunami mitigation urban infrastructure, and population must be prepared to answer in the minimum time to an alarm of evacuation, knowing the evacuation plans and participating in tsunami simulations.

Table 1: Time to start evacuation in tsunamis 2010 and 2014 in Chile. Study surveys SATREPS/JICA, L. Ramos & H. Murakami 2014

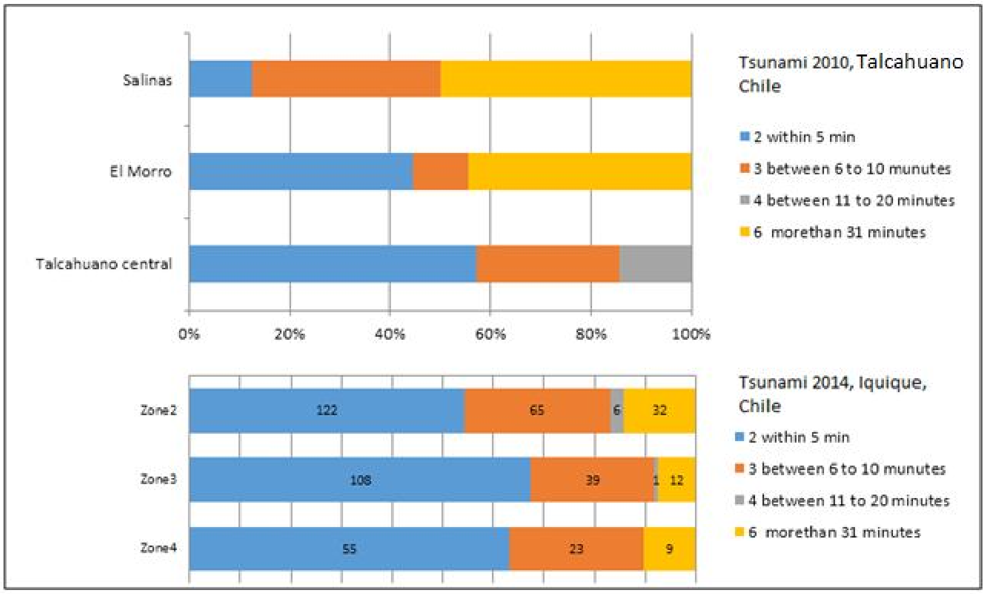
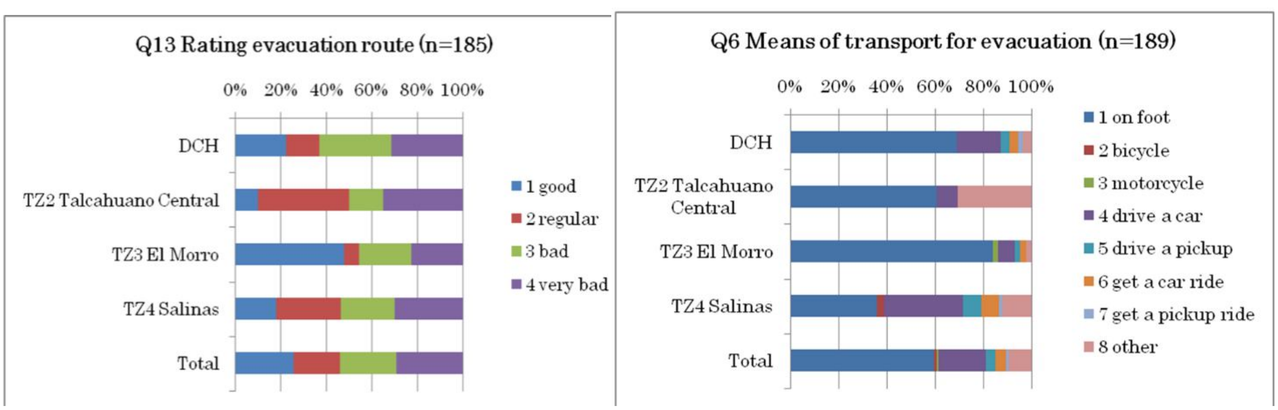
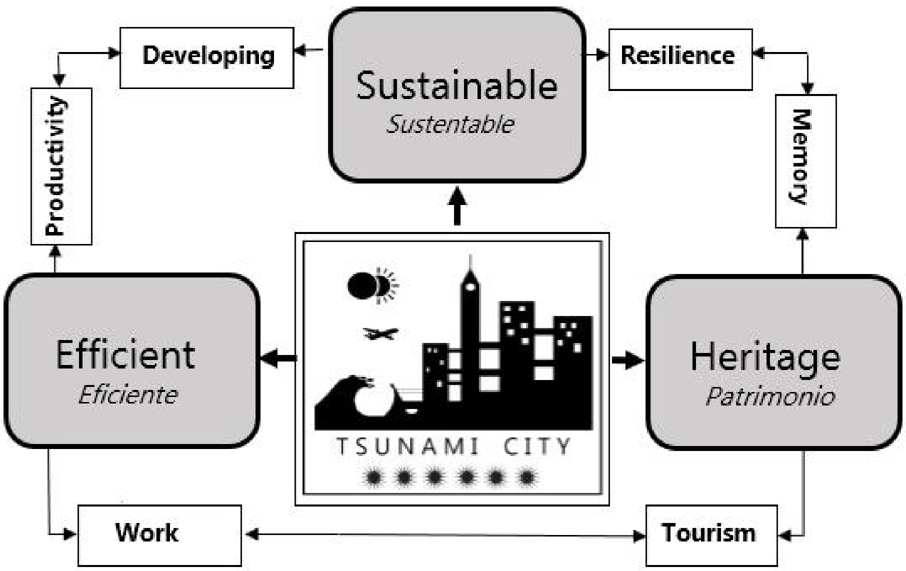


Table 2: Rating evacuation routes in tsunami 2010 in Talcahuano and means of transport for evacuation in Talcahuano city. Study surveys in Talcahuano, SATREPS/JICA, L.Ramos & H. Murakami 2014.



For 2010 and 2014 earthquakes in Chile's population was in danger zone quickly tsunami inundation evacuated to higher ground to avoid human losses (Table 1). The evacuation was conducted primarily on foot and using escape routes marked in the city, the perception of the population regarding the quality of the escape routes was bad or very bad, since they were damaged after the earthquake and they blocked with rubble caused by the earthquake (Table 2).

Figure 1: Coastal cities resilient to tsunamis.



Source:Author

Coastal cities resilient to tsunamis must consider, in their urban planning, a difference in the permitted uses, in lower and flooding zones should be placed ports, airports, non-polluting industries, markets and business offices, touristic activities and mitigation parks with tall, compact buildings, and a route structure that allow evacuation to safe zones; and in higher grounds, over 30 meters above sea level, residential areas, schools, universities, hospitals, fire departments, town halls, cultural and touristic areas would be placed (Table 3).

Table 3: Urban uses in coastal cities with risk of tsunamis, *Usos urbanos en ciudades con riesgo de tsunamis.*

Uses low zone Tsunami risks. Coastalmitigationworks	Ports/Airport	Uses high zone +30m	Housing
	Nonpollutingindustry		Schools/Universities
	Commerce/offices		Hospitals/firemen
	Tourism		Culture/ Municipality
	Parksmitigation		Tourism
	Evacuation route		Safe places

Source: Author

2.1 Horizontal evacuation on hills

Horizontal evacuation on hills is an ancient process, and while cities have proper evacuation routes and high, safe places prepared to receive a considerable amount of people; it will still be an excellent way to protect physical integrity of the population.

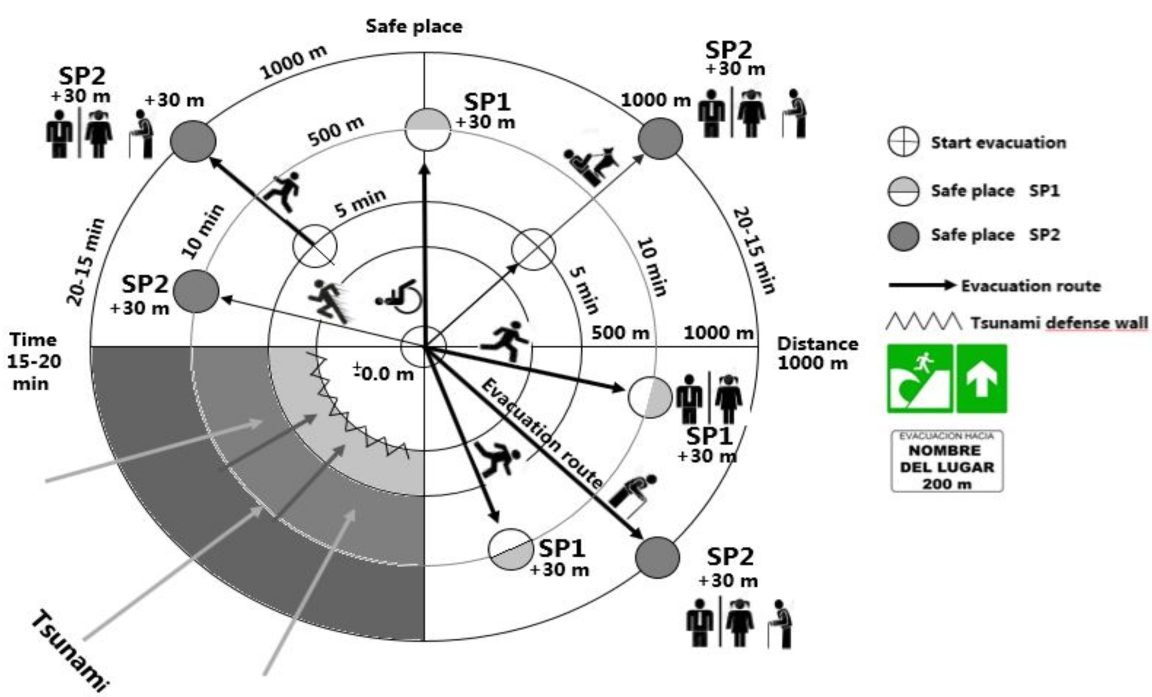
If the city has close hills with a minimum height of 30 meters above sea level and no more than 1 kilometer from the most unfavorable point of the coast, horizontal evacuation on hills is usually the most efficient way to be protected of a tsunami.

After an earthquake happens, and evacuation alarms are activated, population disposes of 15 to 20 minutes to arrive to safe places. Population's moving should be mainly pedestrian and as fast as possible, in direction to high and safe places that should be prepared for receiving a determined number of people (Fig.2).

A continuous system should be thought, so that evacuation routes conduct to higher zones as directly as possible, facilitating the movement of all types of people, elderly, sick, disabled, children and adults.

According to statistic studies of the last tsunamis of 2010 and 2011 in Chile and Japan, respectively, demonstrate that the main means to evacuate is by walking, then the use of automobiles and finally bicycles. The problem that the excessive use of automobiles presents is that streets quickly collapse; producing great jams that do not contribute to the proper evacuation of zones with flooding risk. Due to this is that it is recommended to use automobiles in a rational way, and only in cases of emergency.

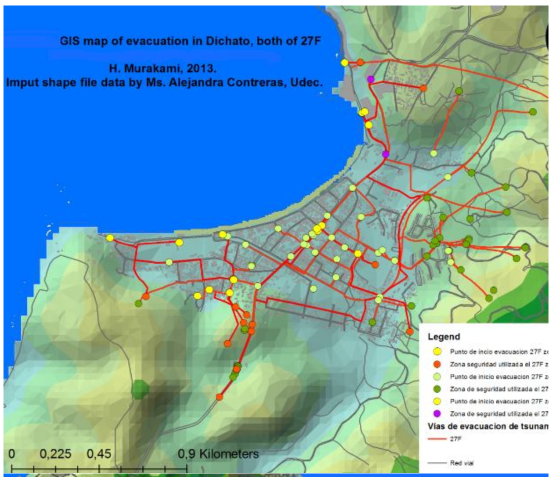
Figure 2: Time and Distance for evacuation on hills

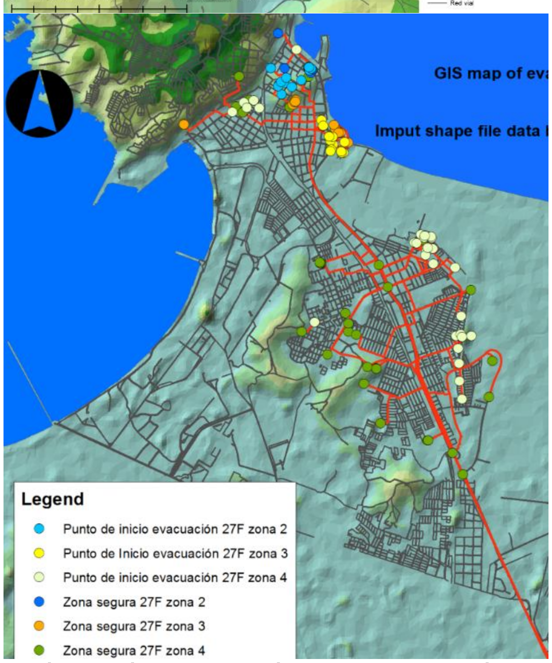


Source: Author

2.2Evacuation routes

GIS map, Evacuation routes intsunami 2010 in Talcahuano and Dichato. Study surveys in Talcahuano-Dichato, SATREPS/JICA,, L. Ramos & H. Murakami 2014





Iquique city, tsunami 2014, Evacuation routes intsunami 2014.Studysurveys in Iquique, SATREPS/JICA, H. Murakami, 2014

Evacuation routes are streets specially designed for the rapid and efficient movement of people that goes to areas of high and safe after an earthquake.

After an earthquake happens, and evacuation alarms are activated, population disposes of 15 to 20 minutes to arrive to safe places (Fig2). Population's moving should be mainly pedestrian and as fast as possible, in direction to high and safe places that should be prepared for receiving a determined number of people. These routes have existed ever since the foundation of coastal cities, and have been escape routes when facing tsunamis. Most of them count with the historical recognition of the population and are located in the older urban centers, next to squares and zones with high density and plenty of commercial activity, these old routes should be catalogued and treated as patrimonial public spaces, which would facilitate to maintain higher standards con them (Fig.3).

These routes of patrimonial characteristics and main urban hierarchy, must allow universal movement, and their proper design will permit to distribute the different types of flows, pedestrian, emergency vehicles and bicycles.

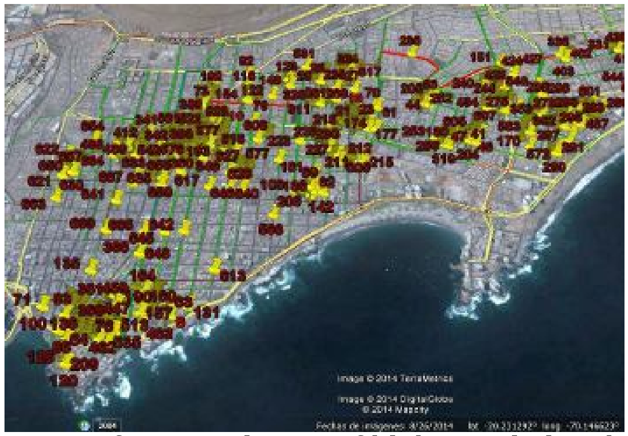
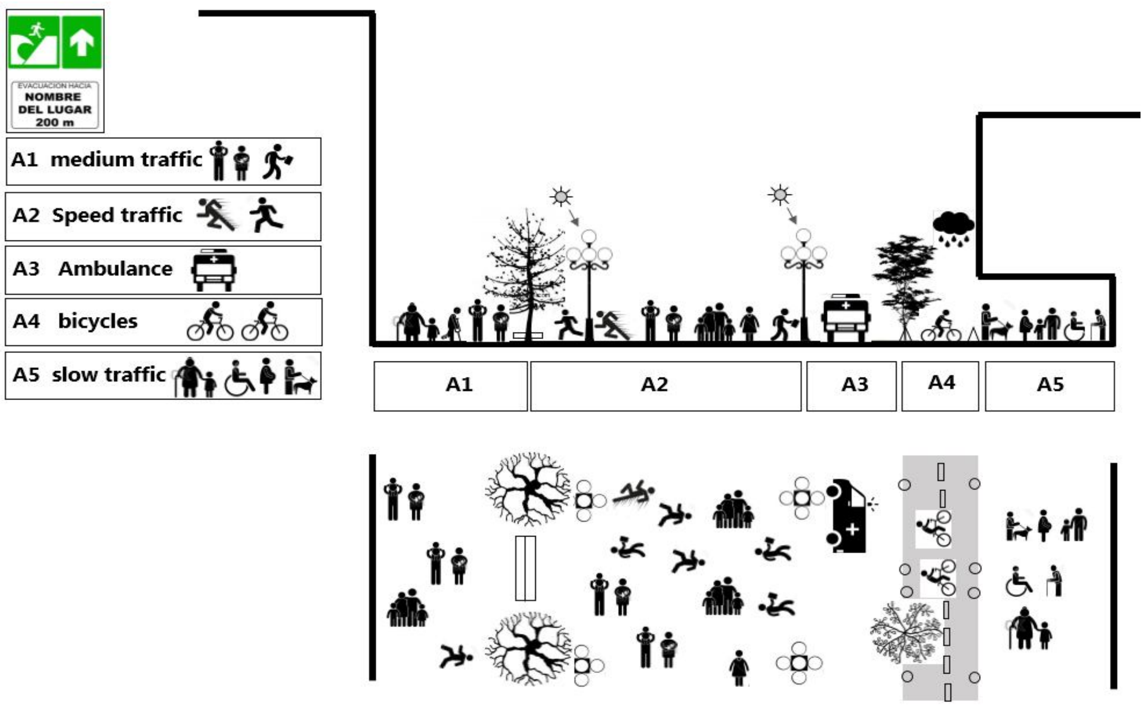


Figure 3: Evacuation route for coastal areas of high population density (commercial center).Profile walking evacuation route with heritage characteristics.



Source: Author

Evacuation routes must be distinguished with their respective signs, free of elements that could be detached or collapsed at the moment of an earthquake, must have electric autonomy in order to be constantly illuminated during night time and remain clear to allow the movement of differentiated flows, in order to avoid frictions that delay evacuation. A good measure is that the design of urban space considers zoning of the constructions and vegetation in order to facilitate the directed movement to safe zones.(Fig.3 y Fig.4).

Figure 4. Evacuation route forcoastal areasof high populationdensity (commercialcenter, Tourism).Profilewalkingevacuationroute withcentralpark.

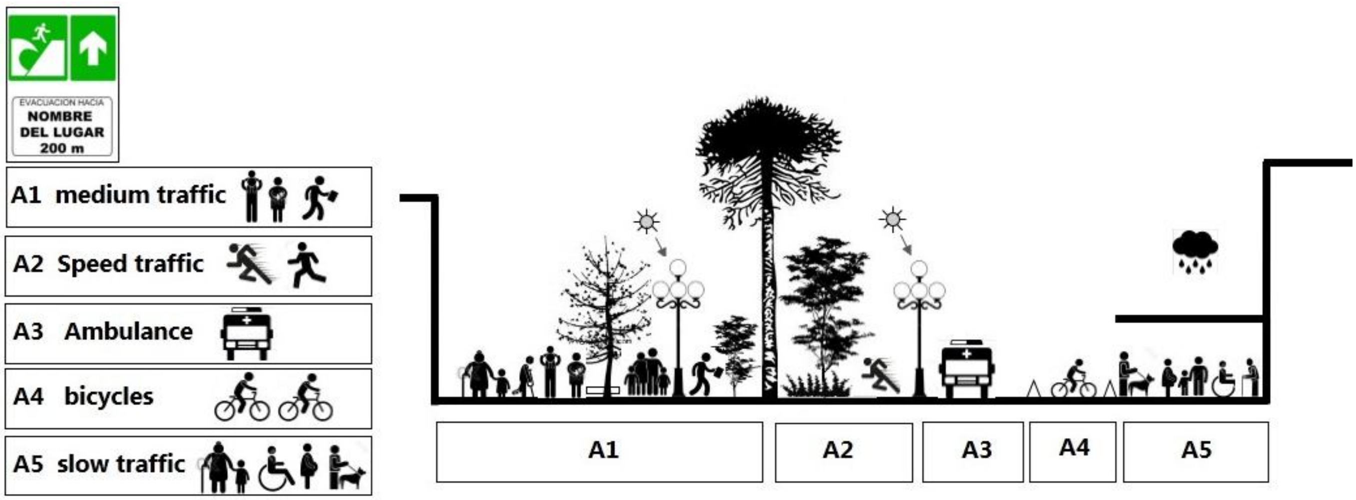


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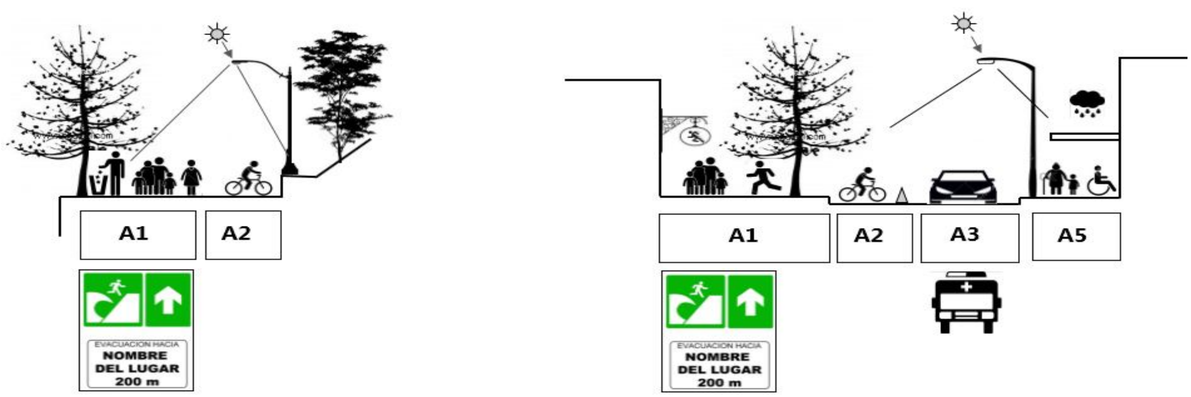
Figure 5: Evacuation route forcoastal areasof low populationdensity. Profilewalkingevacuationrout



Source:Author

2.3 Safe Places

Safe places for evacuation due to tsunamis are spaces distributed in higher zones of the city, over the mark of 30 meters and are the last point of an evacuation route. Their capacity to shelter people is directly related to the density of population of the zone to which it serves. These places must have the higher standards in terms of health services and energy autonomy, are destined to contain a determined number of people and allow, during an emergency due to tsunami, the permanence of the population from hours to weeks.

A safe place for evacuation could be a belvedere square that allows the permanence of people during a period of hours or days (Fig. 6), or a park square with a community center that allows the shelter of a higher number of people during an extended period of days or (Fig. 7).

Figure 6: Safe place on hill. Permanencehourstoday's**SP1**.

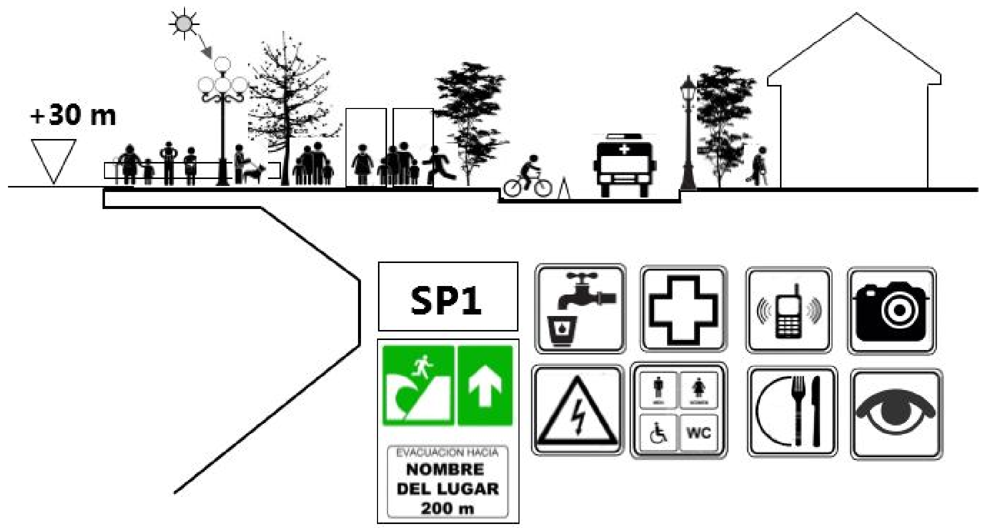


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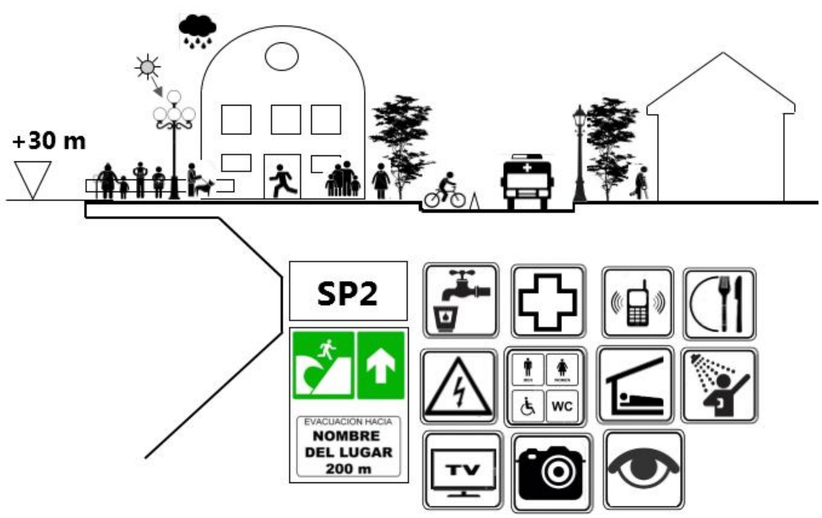
Figure 7: Safe place on hill. Community center or gymnasium, permanence day's aweek's**SP2**.



Source:Author

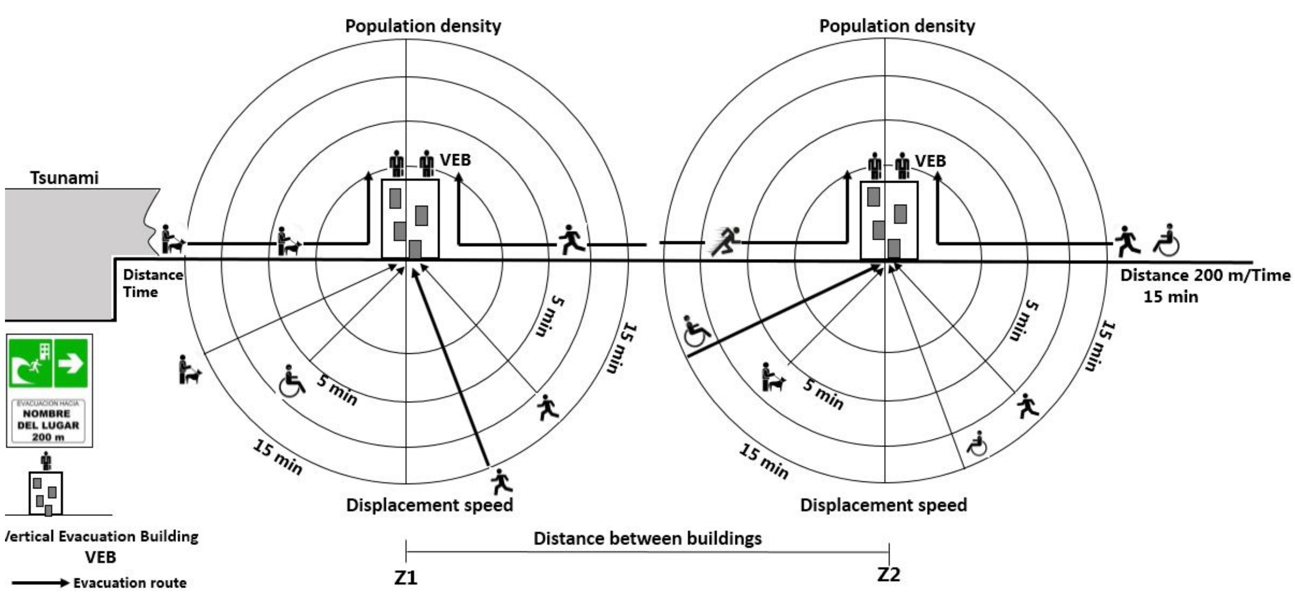
3. Vertical evacuation buildings VEB

Vertical evacuation in **VEB** buildings is a very good alternative to keep population lives safe in facing a threat by tsunami. It is important to point out that buildings that are defined for that purpose, must fulfil with all of the structural standards that assure a proper behavior towards the efforts to which will be submitted during a tsunami; not only the strength of the ocean, but also all of the debris that the waves catch.

To define VEB buildings, these must have a capacity to shelter a number of people that is equivalent to the density of population that remain in the located zone, and being in a distance ratio that allows pedestrian to arrive in no more than 10 to 15 minutes (Fig.8).

VEB buildings must be properly marked and have a direct Access from the public road, in order to assure that people can get to a safe place as soon as possible, these shelters are thought to harbor people for a short period of time (Fig.9).

Figure 8. Verticalevacuationbuildings **VEB**



Source:Author

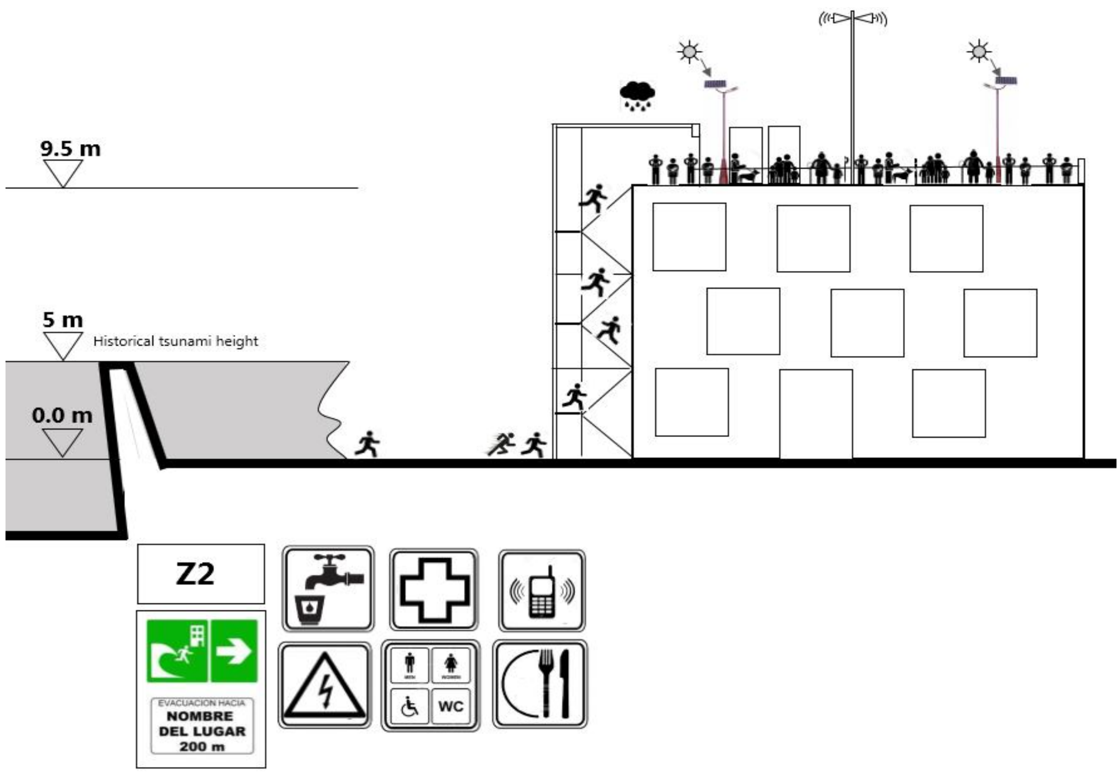
To determine the height of the buildings that will be used for vertical evacuation VEB, in this guide it is proposed the method established by the Guidelines for Design of Structures for Vertical Evacuation from Tsunamis, FEMA Federal Emergency Management Agency and the National Oceanic & Atmospheric Administration, NOAA. Washington, D.C(Table4).

Table 4: Design elevations for zone of refuge VEB. Example for an area with historical wave height of 3 and 5 meters

Zone	Historic floodtsunami	Plus 30% + 3m	Design ElevationVEB
Z1	3 m	0.9 m + 3 m	6.9 m
Z2	5 m	1.5 m + 3 m	9.5 m

Source:FEMA, 2008, *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis,* FEMA Federal Emergency Management Agency and the National Oceanic & Atmospheric Administration, NOAA. Washington, D.C.

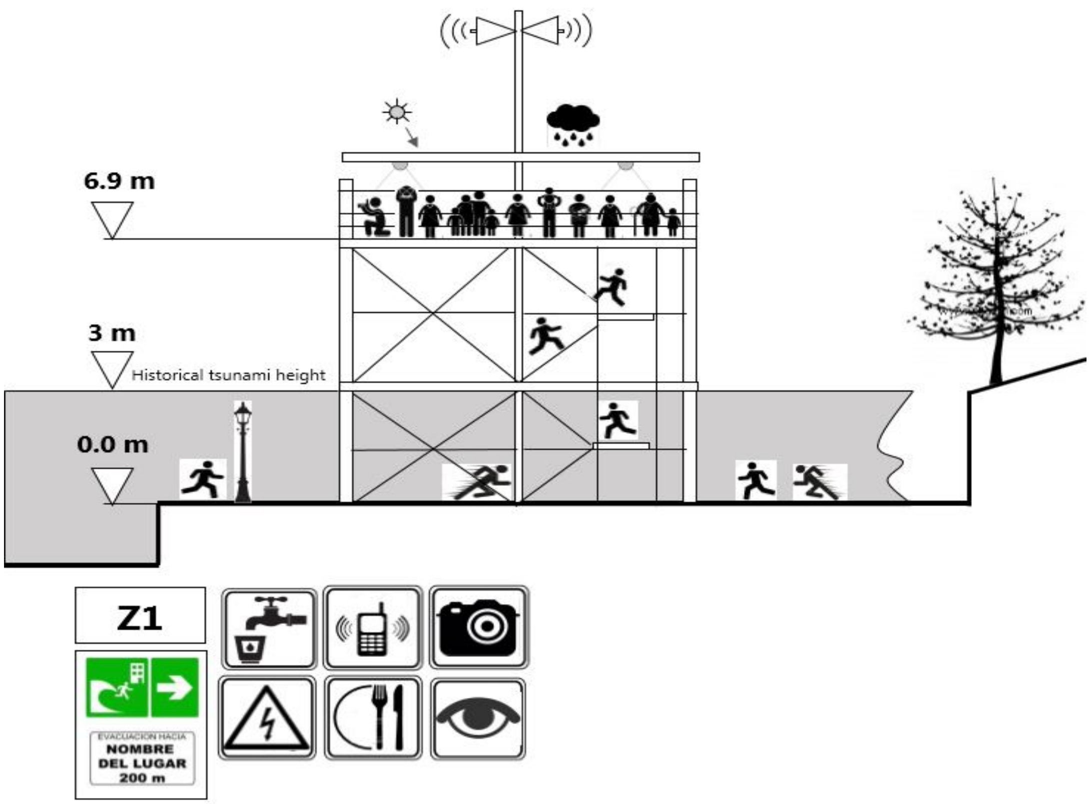
Figure 9: Elevation vertical evacuation on buildings **VEB.**Areasof commerce and industry.Example for an area with historical wave height of 5 meters



Source:Author

In coastal zones with touristic activities of beaches, or ports/airports activities, it is advisable to build towers for vertical evacuation (Fig.10).These structures must have the highest structural standards to assure the proper functioning when facing the impact of a tsunami wave. These towers, that in some cases might be parking lots, are thought to evacuate tourists or workers that stay on zones with risk of flooding, and are thought to evacuate and protect life as fast as possible, and shelter people for a short period of time.

Figure 10: Elevation vertical evacuation on tower. Areas of tourism,industry, airport andports.Example for an area with historical wave height of 3 meters

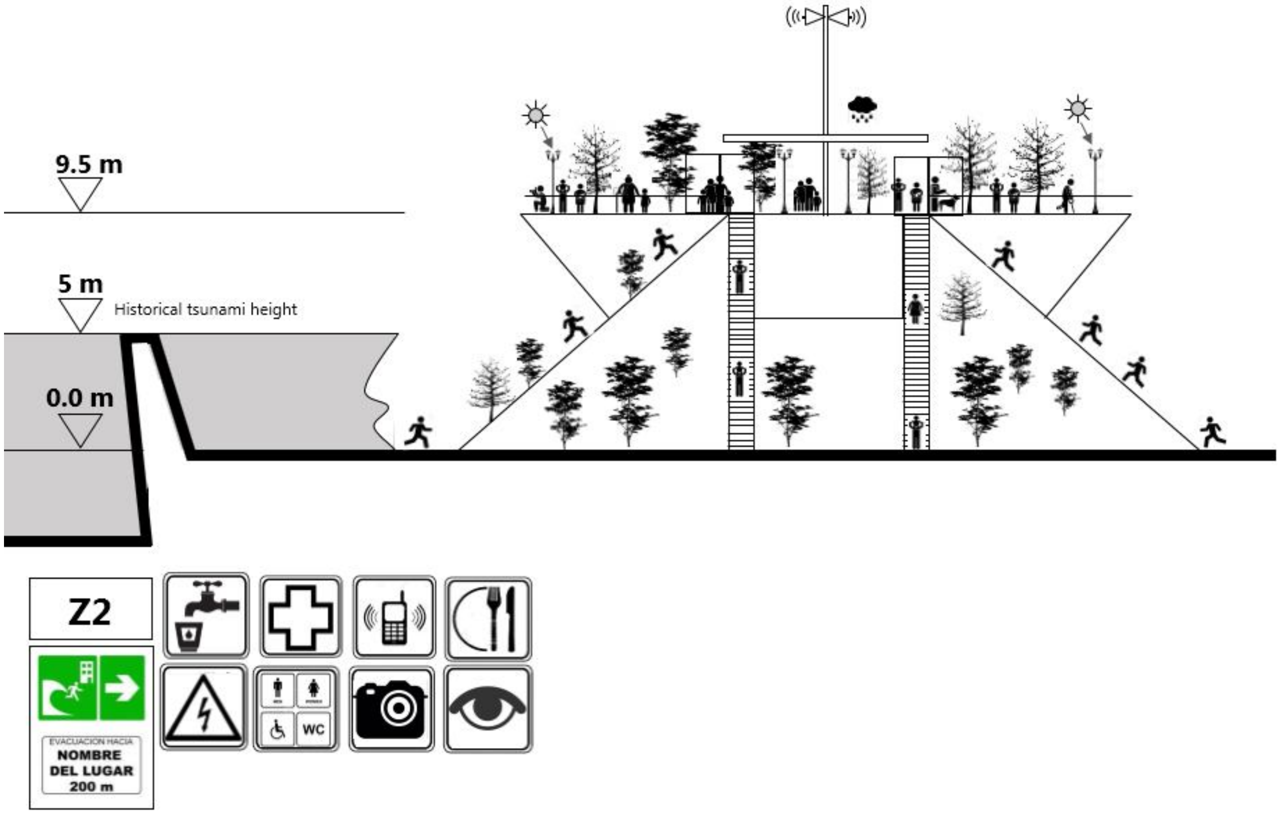


Source:Author

Mitigation parks are a good alternative to use zones with risk of tsunami, may decrease the impact of tsunami waves and discourage the use of houses in coastal borders (Photo1).These green zones must have a tsunami mitigation structure, with coastal walls and high places (Fig.11) that allow to evacuate people as fast as possible. These structures are designed to shelter people for a short period of time.

Photo 1.Numasucity,Japan. L.Ramos

Figure 11: Elevation vertical evacuation in Elevated Squareon touristarea or parks. Example for an area with historical wave height of 5 meters.

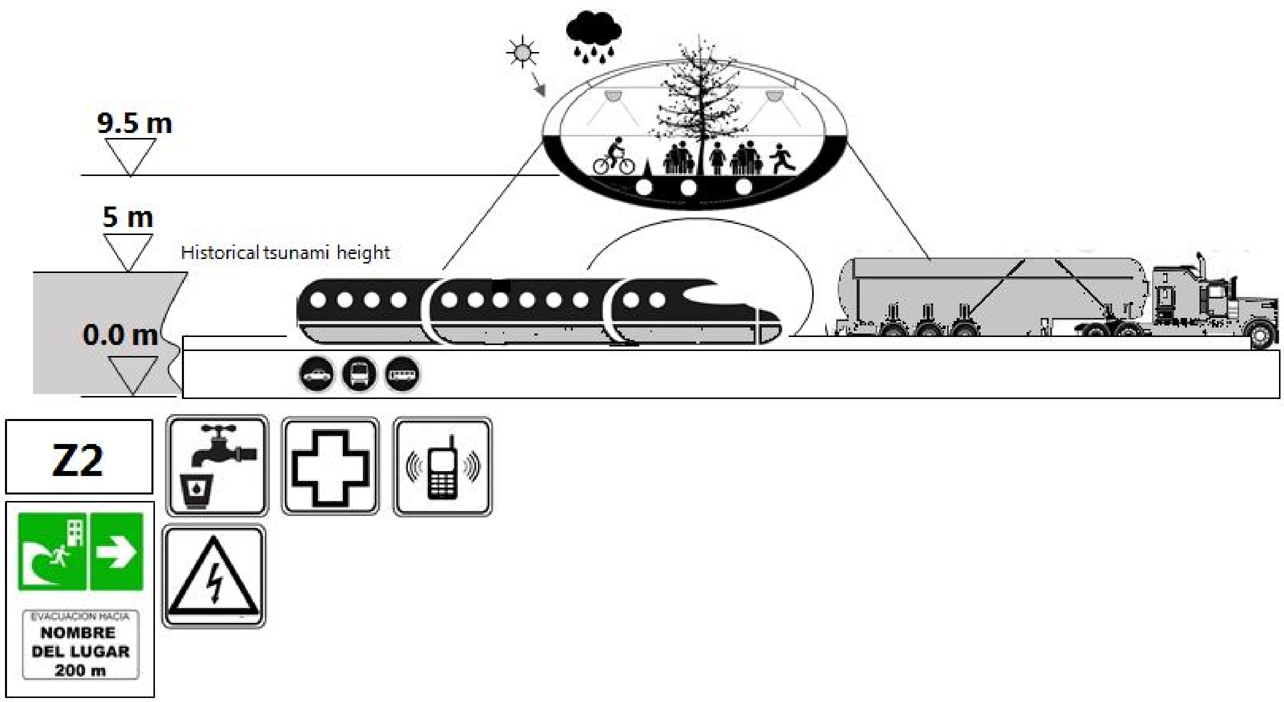


Source:Author

Photo 2: Numasu city, Japan. L.Ramos

The main concept that an evacuation process must have is the functional continuity, that is to say, that the evacuation routes conduct as directly as possible to safe zones (Photo2). An evacuation route should never be crossed with a railway or a highway, and if this occurs should be transformed into an elevated pedestrian route (Fig.12) in order to avoid jams in crosses, and that people does not lose time during the evacuation. It is also recommended that its height considers the concept of vertical evacuation in buildings.

Figure 12: Footbridge over traintracks and highways.Example for an area with historical wave height of 5 meters



Source:Author

4. Conclusions

The evacuation routes were severely disrupted and blocked by the rubble of the earthquake, however, people looked for ways to reach as soon as possible to safe areas in the nearby hills and so avoid encountering the destructive tsunami. Safe areas that were defined for the evacuation were not prepared to contain the population, did not exist the basic services no electricity, the people despite the bad conditions of the place were kept for days, weeks and months.

Tsunami warning system in Chile is developing fast and now people are getting more frequent warnings than before in smaller seismic intensities. As for the travel means, majority of people evacuate on foot as they respect it is a basic rule. However, automobile evacuation tend to increase as car ownership and daily use of automobiles are common in suburbs where evacuation places are far or in social Upper class communities. People evacuating on foot face various difficulties and risks due to the traffic jam by automobiles or fast running autos. The two earthquakes (2010 and 2014 in Chile) both occurred at night time when family members were mostly at home and together.

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