Tsunami Evacuation Study | Viña del Mar Zone 1

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EERI Learning From Earthquakes Travel Study Program, Chile 2017

ABSTRACT

In the wake of the substantial fatalities and economic and environmental losses of recent natural disasters like the earthquakes and tsunamis of Maule 2010 in Chile and Tohuko 2011 in Japan, natural hazard mitigation research has focused on assessments of the preparedness of the existing built environment and infrastructure and the efficiency of hazard mitigation measures. Among the most important tsunami hazard mitigation measures are tsunami evacuation procedures. Tsunami evacuation time in the inundation zone compared to its arrival time is crucial to determining the number of casualties during a tsunami event. Public awareness, early warning system efficiency, topographical characteristics of the inundation zone, and the efficiency of patency of tsunami evacuation routes are a few of the several factors that affect tsunami evacuation time. Several research studies have tackled the efficiency of tsunami evacuation procedures through numerical agent-based modeling. However, few studies have focused on field investigations of tsunami evacuation efficiency. The current report presents a field investigation of the efficiency of tsunami evacuation routes in the City of Viña del Mar on the pacific coast of Chile. It also presents a field survey of public awareness of tsunami evacuation procedures and routes. While local residents appeared to be aware of evacuation procedures and routes, tourists generally appeared to be unaware of the significant tsunami risk in the area and the proper tsunami evacuation procedures and routes. Additionally, some of the designated tsunami evacuation routes in Zone 1 in Viña del Mar had reduced efficiency due to the presence of route obstacles. Tsunami evacuation time during a physical evacuation drill performed by the authors varied between 15 and 20 minutes, which exceeds the short tsunami arrival time of 7-15 minutes estimated by Chilean researchers, indicating a potential life hazard. This study provides valuable information for decision makers and emergency officials in Chile and provides future researchers a resource to validate and calibrate agent-based numerical simulation of tsunami evacuation.

1. INTRODUCTION

A significant number of mortalities have been caused by earthquakes followed by tsunamis. The tsunamis Indian Ocean Aceh 2004, Japan's Tohuko 2011, and Chile 1960 had death tolls of 280,000, 15,000 and 2000, respectively. In 2010, the 8.8 M_w Maule earthquake and the following tsunami in Chile caused 500 deaths combined. Tsunami hazard mitigation research has focused on assessing the preparedness of the existing built environment and infrastructure and the efficiency of tsunami hazard mitigation measures. Among the most important tsunami hazard mitigation measures are tsunami evacuation procedures and routes.

Public awareness, early warning system efficiency, topographical characteristics of the inundation zone, and the efficiency of patency of tsunami evacuation routes are a few of the several factors that affect tsunami evacuation time. Tsunami evacuation time in the inundation zone compared to its arrival time is crucial to determining the number of casualties during a tsunami event. When tsunami warning/arrival time is relatively short due to a near-shore epicentered event, estimation and optimization of the tsunami evacuation time and efficiency becomes critical. Several research studies have focused on tsunami evacuation procedures through numerical agent-based modeling. However, few studies have performed field investigations of tsunami evacuation efficiency. The limited number of field studies is attributed to their higher cost, the longer preparation time, the lack of standardized procedures, the higher risk involved in physical simulation, and the limited possible evacuation scenarios (Triatmadja and Nasution 2014). On the other hand, numerical simulations, particularly the large-scale ones, lack sufficient field data for verification and calibration, reducing their reliability.

A large body of literature on agent-based tsunami evacuation models is available for several regions (WIJERATHNE et al. 2013; GOTO et al. 2012; NGUYEN et al. 2012b; ABUSTAN et al. 2012; LA¨ MMEL et al. 2010; MEGURO and ODA 2005; KATADA et al. 2004). Some recent studies are referred to herein.

Triatmadja and Nasution 2014 conducted multi-agent numerical simulations to assess the tsunami evacuation of Bengkulu City, Indonesia. They tested five evacuation scenarios: normal conditions where the people were assumed to follow the existing evacuation sign boards, normal conditions but with alternative directions of evacuation, normal conditions with increased population, a condition with obstacles during peak hours at a market, and evacuation during night time. The simulation indicated that under normal conditions, most of the people reached the shelter in less than the 20 minutes estimate of tsunami arrival time. The alternative evacuation direction performed slightly better. The obstacles due to cars that were parked along the roads slightly increased the number of casualties. Evacuation scenarios at night also increased casualties due to limited vision, especially along the lanes. They concluded that, in general, the tsunami evacuation routes in Bengkulu City are efficient for the current population.

Mas et al. 2015 applied agent-based model to assess tsunami risk and evacuation scenarios in Indonesia, Thailand, Peru and Japan.

Chilean research groups have proposed 1.8 million scenarios for tsunami simulations, which is approximately 90 years of computer simulation effort. Thus, the most probable 8000 scenarios have been selected by Chilean researchers. The Chilean Navy tsunami early warning system is equipped to compare an actual event to these 8000 provided numerical simulations to recognize and issue timely warnings [1]. Based on the most probable scenarios in Viña del Mar, the tsunami arrival time could be as short as 7-15 minutes. This includes the time needed by the tsunami warning system (Fig. 1) to process the input wave and issue the warning. During past tsunami events in the city, many have casualties occurred. Accordingly, it is of absolute importance to assess the actual tsunami evacuation routes and time needed to evacuate in Viña del Mar to have a clear idea about the actual fatality risk and the effectiveness of the current evacuation procedures and routes.

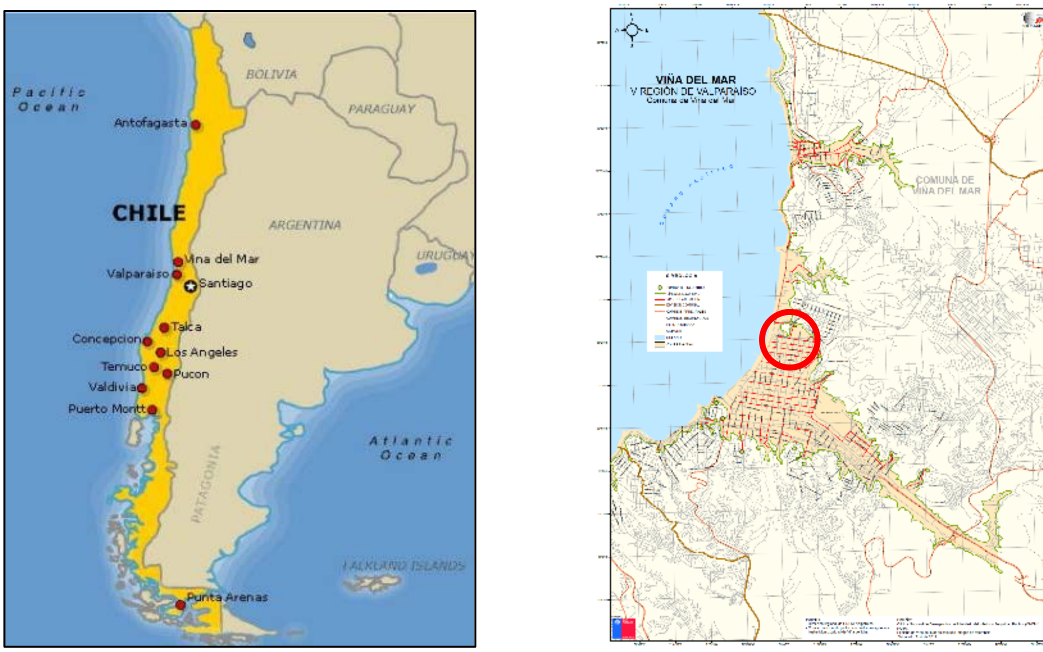
The current report presents a field investigation of the efficiency of tsunami evacuation routes in the city of Viña del Mar on the pacific coast of Chile. It also presents a field survey of public awareness of tsunami evacuation procedures and routes. Local residents seemed aware of evacuation procedures and routes. However, most tourists appeared unaware of the significant risk and the proper tsunami evacuation procedures and routes. Some designated tsunami evacuation routes in Zone 1 in Viña del Mar suffer reduced efficiency due to presence of route obstacles. Tsunami evacuation time during a drill performed by the authors varied between 15 and 20 minutes, which exceed the short tsunami arrival time of 7-15 minutes estimated by Chilean researchers, which poses significant life hazard in during a tsunami event.

2. OBJECTIVES OF THE STUDY

The current investigation aims to assess the efficiency of the designated evacuation routes in Zone 1 of the city of Viña del Mar. This assessment is conducted through the simulation of multiple evacuation scenarios through a controlled evacuation drill experiment and field evaluation of the physical condition, obstacles, signage, and patency of the tsunami evacuation routes. The study also aims to evaluate the awareness of the population of the tsunami hazard risk through field surveys of local residents and visitors in the study zone. The potential of alternative evacuation strategies such as vertical evacuation was also assessed.

3. DESCRIPTION OF EVACUATION ZONE 1

The Zone 1 evacuation zone in the city of Viña del Mar corresponds to the evacuation routes from the beach through streets 12 Norte, 13 Norte, 14 Norte and 15 Norte to meeting point 3 on the hillside on Quillota Avenue. A map of Chile including the location of Viña del Mar is shown in **Fig. 1**(a). Zone 1 is circled on the tsunami evacuation zone map in **Fig. 1**(b). The coastal stretch in zone 1 features about a 100 meter wide sandy beach that extends for about 400 meters, as shown in the Google map image in **Fig. 2**. The evacuation routes start at the beach and extend up to higher ground. The main road parallel to the beach is Avenida San Martin which is a two-way six-lane street full of mid-rise and high-rise buildings. The access from the beach to the 14 Norte and 12 Norte Streets required only crossing the Avenida San Martin Road; however, there was no direct access to 13 Norte Street from the beach since there was a significant high-rise complex blocking the access to 13 Norte which started behind that complex; see **Fig. 3**. At the inland end of the evacuation routes at Quillota Avenue, there are multi-flight staircases leading from the evacuation route level to the safe meeting point. Within the Zone 1 inundation zone, a major hospital was located at 13 Norte Street, about one block from Avenida San Martin Road. A large shopping mall was located on 14 Norte Street evacuation route, one block from the beach.



(a) (b)

Fig. 1. (a) Location of Viña del Mar, (b) Evacuation Zone 1

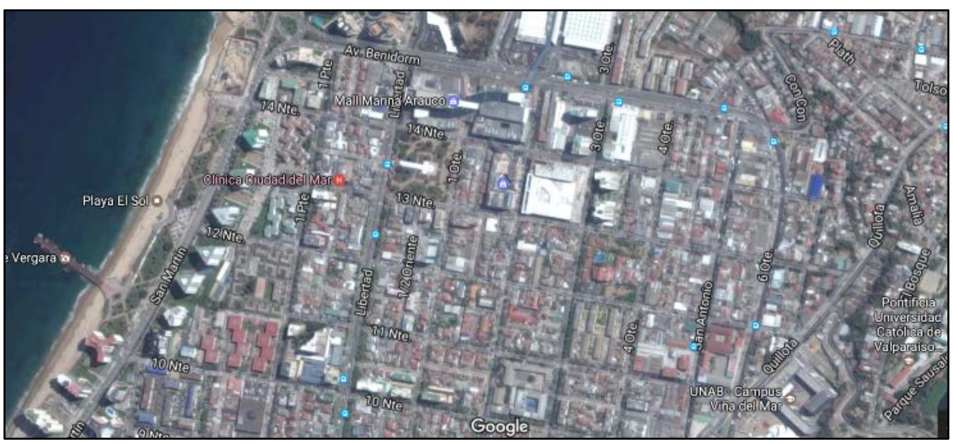


Fig. 2. Google earth view of Zone 1

Fig. 3. A close-up of Routes 12, 13 and 14 Norte where the blockage of 13 Norte by a residential complex in highlighted.

4. ASSESSMENT METHODOLOGY

4.1 Field Assessment of Evacuation Routes

The first tsunami evacuation assessment method adopted in this study utilized field investigations of three different evacuation routes in Zone 1 (12, 13 and 14 Norte routes). The physical condition and topography, including those parameters believed to have an impact on evacuation efficiency, was documented for each of these routes. These parameters included evenness of the streets and sidewalks, traffic and tsunami hazard/evacuation signage, possible physical blockage of the route by illegitimate means (e.g. parking violation vehicles or restaurant tables) or natural means (e.g. steepness of the route, the presence of stairs), and the presence of heavily populated facilities along the route (e.g. retail buildings or malls). Such parameters were surveyed, photographed, and documented in this report. The field assessment started at the beach where a full survey of the beach conditions including access, possible escape routes, signage, and evacuation obstacles was conducted. The evacuation simulation resumed from the beach along the 14 Norte route going uphill towards the "safe" meeting point 3 designated by the city. The assessment of 13 Norte Street evacuation route took place on the way from meeting point 3 back to beach. An emergency care physician was interviewed in a hospital along this 13 Norte route. The third simulation began from the beach along the 12 Norte route. This route was video-recorded throughout the duration of this final simulation. It is noteworthy that the field assessment took place on Sunday when some businesses, restaurants, and cafes were closed.

4.2 Field Interviews

The second assessment method consisted of a simple field questionnaire given to local residents and tourist in the area. The main questions asked during interviews addressed whether the interviewee was aware of the natural hazard/tsunami risk of the area and whether he/she was aware of the evacuation procedures and nearest routes in the case a tsunami evacuation warning sounded. In selecting the interview targets, various age groups, residence status (locals vs. visitors), and social status (singles vs. families) were accounted for to ensure a representative sample. The interview sample size consisted of 9 parties (subjects) with a total of 16 people. The ages of the sample subjects ranged from 9 to nearly 70 years. About 20% of the sample consisted of tourists while the remainder consisted of local residents. A special emphasis was placed on interviewing a healthcare professional at a local hospital in the inundation zone. The interview questions for the healthcare professional were more detailed to assess the preparedness of the healthcare system to respond to a tsunami warning.

4.3 Tsunami Drill

The third assessment method used in this study consisted of a controlled drill experiment. This experiment consisted of evacuations from the beach to a safe meeting (assembly) point designated by authorities via two of the official tsunami evacuation routes (12 Norte and 13 Norte streets). The drill started at the beach waterline taking the 12 Norte route inland. The evacuation drill and timing of route 13 Norte started from its assembly point inland downhill towards the beach but was concluded at the intersection of 13 Norte and Avenida San Martin (the main road about 100 m from the beach) after exceeding the tsunami theoretical arrival time. The drill experiment was conducted, timed, and videoed by two of the authors. The drill was conducted at an average walking pace by a healthy male and female in their mid- to late-twenties. It is noteworthy that the drills took place on Sunday when some restaurants and cafes were closed.

5. ASSESSMENT RESULTS AND DISCUSSION

5.1 Field Assessment of Evacuation Routes Results

The field observations of evacuation routes 12 Norte to 14 Norte revealed significant information to help assess the efficiency of evacuation through these routes and to help validate numerical agent-based models.

5.1.1 Physical Conditions and Obstacles

The beach area was quite crowded with people on a Sunday in summer time (**Fig. 4**). In the beach area observed for this study, there was only one staircase for beach access (**Fig. 10**) along nearly a 400 meter beach stretch that represents Zone 1, despite the steepness of the slope from the street level to the beach. Dirt trails up a small berm were also used to enter and exit the beach (**Fig. 6**(a)). These trails were relatively steep and not located along the street evacuation routes. Many street vendors occupied the walkway at the beach with their merchandise comprising possible obstacles during tsunami evacuation. It is noteworthy that many restaurants and cafes were closed on Sunday, so the possibility of blocking the sidewalks with their tables was not assessed.

Many sidewalks were observed to be uneven with a number of uplifted cracks. These cracks may cause a tripping or stumbling hazard on a major evacuation route. An especially large pothole was observed on route 12 Norte. On evacuation route 12 Norte, these cracks are spray painted in yellow to enhance their visibility. The condition of roads and paths along route 12 Norte were also in significantly better condition than those of other evacuation routes in Zone 1. Spray painting these cracks on the other evacuation routes may increase their visibility.

Fig. 4. Number of people at beach.

Fig. 5. Blockage of car.

Illegally parked cars on sidewalks were observed near the beach access and along all the evacuation routes (**Fig. 6**(b)). Many cars were parked next to the beach (**Fig. 5**), some of which were illegally parked and blocked the escape route from the beach. This is a law enforcement challenge that appears to be one of the most hindering obstacles along the routes. Proper parking signs were posted along the routes, yet illegal parking appeared to be a problem. It could be these parking regulations were not enforced on Sundays. These parked cars narrowed the sidewalks significantly and could be potential bottle necks during a real evacuation. Garbage disposal bins that occupied a significant portion of the sidewalk were observed at some locations along the evacuation routes (**Fig. 7**), which also represent evacuation obstacles.-The authors' observation of illegally parked cars and motorcycles on sidewalks was also observed in the other evacuation zones in the city (Zones 2, 3, 4) surveyed by other groups in the project.

(a)

(b)

Fig. 6. Limited access to the routes.

Curb ramps were provided at most intersections. These ramps delimited the crosswalks at each intersection. The ramp conditions varied between fair and moderate. However, some of these intersections only allowed pedestrians to cross on one side of the street, which may hinder an evacuation. These deviating paths may not have ramps on both sides of the street.

The last block of all three routes had moderately steep slopes. Stairs were located at the end of each evacuation route (**Fig. 14**). These stairs were relatively narrow and many steps were uneven. The stairs and slopes represent a challenge for the elderly, disabled, and families with children/strollers. It is unclear whether these stairs were supposed to be climbed at the end of each evacuation route because there was no signage to indicate arrival at the safe meeting point. However, a subsequent interview with a local girl showed that the meeting point is just at the stair bottom. Proper signage is a necessity in this regard. At the end of evacuation routes uphill at Quillota Avenue, there was also no signage indicating the end of the evacuation route and the location of the meeting point.

A major shopping mall was located on 14 Norte Street on the evacuation route, one block from the beach. The area around this mall was highly populated and could represent a major demand on the evacuation route 14 Norte during an actual event. In light of the short tsunami warning time in this area, alternative detours to other evacuation routes seems impractical. A vertical evacuation in the area of the shopping mall might be considered if future numerical agent-based models indicate the mall has a significant impact on the 14 Norte route. A University of Viña del Mar campus was also located on 14 Norte Street. The assessment was performed on Sunday during summer time so the actual population of the campus could not be properly assessed. However, it is speculated that the university campus, similar to the shopping mall, may pose a significant evacuation demand and risk on route 14 given that both the university and the shopping mall are in the same route. A major construction site near the beach along San Martin Av. also lacked proper signage to detour possible evacuee from the beach around the site to the nearest evacuation route.

Fig. 7.

Route 13 Norte did not extend completely to Avenida San Martin (Fig. 1). It ended at gated communities a block away from the main road (Avenida San Martin). Thus, no beach access for 13 Norte could be used during actual tsunami evacuation. Given the long distance between routes 12 Norte and 14 Norte, proper detour signage at the beach to direct evacuees to 13 Norte route is essential. A review of the evacuation route on 13 Norte Street revealed a hospital located one block from the beach in the inundation zone (**Fig. 8**).

Fig. 8.

5.1.2 Tsunami Evacuation Signage

There were no tsunami hazard zone signs or tsunami evacuation instruction signs on the beach or even near the beach access along the entire stretch of Zone 1 (e.g. a sign used by ONEMI, **Fig. 11**). Thus, tourists or non-locals may not be able to find the beginning of the evacuation routes during an actual tsunami warning. This explains that most of the fatalities due to past tsunamis in the region were tourists. A single tsunami evacuation sign was located on the long crowded sea pier across 12 Norte route (Fig. 1).

The first tsunami evacuation route street sign (**Fig. 11**) was located next to the shopping mall on route 14 Norte. One street later there was a second tsunami evacuation route sign (**Fig. 12**). Similarly, 13 Norte route had only two non-uniform evacuation signs. However, route 12 Norte had five signs that were all well distributed to the meeting point. The poor signage on 14 and 13 Norte streets could represent a major obstacle for evacuees. At the end of the evacuation routes at Quillota Avenue, there was also no signage indicating the end of the evacuation route or the meeting point location. Poor tsunami warning and evacuation signage at the beach, along evacuation routes, and near the meeting zone was a common observation by other groups who surveyed evacuation Zone 2, 3 and 4 within the same projects.

Fig. 9. No sign of tsunami awareness.

Fig. 10. Only one stair.

Fig. 11. Sign next to Mall.

Fig. 12. Second sign of evacuation.

5.1.3. Description of Evacuation Meeting Points

At the end of each evacuation route, the authors had great difficulty finding the "safe" assembly or meeting point 3. It is still unclear where the final meeting point was located at the ends of the routes. No visible signage to the meeting point was found on any of the routes. According to a map distributed to the authors by city officials, these meeting points required evacuees to make a right turn. However, no signage showed this turn location. Stairs located at the end of these routes further made accessing these meeting points difficult. However, there was a civil defense building located near the safe point (**Fig. 15**). A local girl of about nine years of age was interviewed near the assumed meeting point location at the end of route 13 Norte. She stated that her house was in a safe area (based on information given to her at school), and that the ground above the 13 Norte Street sign was considered a safe place (**Fig. 13**). On 13 Norte Street, one block from 14 Norte Street, there was an area that could have been a meeting point, but there was no sign to designate it as such (**Fig. 14**). Signage designating the safe zones was also missing, even though they may be mandatory signs.

Fig. 13. No sign to show safe meeting point.

Fig. 14. Possible meeting point (assembly area).

Fig. 15. Civil Defense Building

5.2 Field Interviews at the Evacuation Zone Results

The purpose of the interviews was to assess the awareness of both local residents and visiting tourists regarding the tsunami hazard in the area and their familiarity with the evacuation procedures and nearest routes. Most of the interviews took place on the beach and at the crowded pier along 12 Norte Street. One interview took place at the hospital in 13 Norte Street (an emergency care physician) and another one at the end of 13 Norte Street near the meeting point (a nine year old girl). The main two questions asked during the interviews were: 1) *Are you aware that you are in a natural hazard/Tsunami zone? and 2) Do you know about an appropriate evacuation procedure and the routes you can take in case of an emergency alert?* The questions were asked to nine parties and the responses are summarized in **Table 1**.

Table 1. Field Interview Responses

ID	Age Group	Local/Tourist	No of People in Party	Response to Question 1	Response to Question 2	Notes
1	60-70	Local	5 adults 1 kid	Y	Y	
2	60-70	Local	2	Y	Y	
3	30-40	Tourist (Russia)	1	Y	N	
4	20-30	Local	2	Y	N	Although he knows that it’s a tsunami hazard area but feels it is not significant
5	5-15	Local	1	Y	Y	She is a resident at the end of the route 13 Norte which is a safe zone.
6	60-70	Tourist (Colombia)	2	Y	N	She was able to speculate the actions to be taken but was not sure.
7	20-30	Local	2	Y	Y	
8	30-40	Local	1	Y	Y	Details in Hospital Notes

It can be observed from the responses in the table that locals appear very aware of the tsunami hazard risk and are quite familiar with evacuation procedures and routes. There was only one exception, where a local felt that the tsunami hazard was not high due to misinformation that the bay surrounding in Viña del Mar was ble to protect the beaches from a tsunami. Accordingly, he did not pay enough attention to the routes to know any emergency evacuation procedures or how to locate the nearest evacuation route. It is noteworthy that although some bay configurations protect these bays from tsunamis as the energy makes regular frequency waves in the bay, some other bay configurations are not that protective [1]. The tsunami risk at the Viña del Mar bay is considered high. Moreover, edge waves trapped near the shore and late arrival waves due to reflection could be very dangerous in this area.

Tourists were vaguely aware of the magnitude of tsunami risk in the area and were totally unaware of designated tsunami evacuation procedures and routes. Some tourists were able to speculate that they should go to “high ground” in the case of a tsunami alert. The local government has arrangements with communication providers to send the tsunami alerts via cellular phones. However, tourists seemed unaware and unequipped to benefit from this procedure. Similar results about locals vs. tourists’ awareness of the tsunami hazard and evacuation protocols were observed by other research groups who surveyed Zone 2, 3 and 4 of Viña del Mar within the same project. However, the other groups observed a greater number of local residents in Zones 2, 3 and 4 underestimated the tsunami hazard risk and were again misinformed by the amount of “bay protection.” An awareness campaign by the local government may correct this misinformation.

5.2.1 Detailed interview with a healthcare official

The authors were able to interview a healthcare professional (emergency care physician) at the City Hospital in route 13 Norte (Fig. 1). It is noteworthy that the hospital is in the inundation zone. The interview questions were more detailed and thorough to assess the preparedness of the healthcare facility and personnel to respond to earthquake and tsunami emergencies. The doctor was fully aware of the risk and had gone through some training to respond to an emergency. He was not completely aware of all evacuation procedures, but he knew the assigned emergency leading personnel that he should follow once the earthquake occurred or the tsunami alarm was issued. Based on other interviews with doctors in Santiago, designation of assigned leaders to lead the evacuation process seems to be the standard procedure for healthcare facilities in Chile. Employees and staff are trained with the safety protocols upon joining the hospitals.

The conversation with the doctor regarding the evacuation process provided some insight into the procedure. The standard evacuation process is a vertical evacuation because many patients’ conditions may not allow them to be evacuated along official routes towards the safe zones. The patients who are able to walk take the stairway to higher floors. Other patients are transferred upstairs by healthcare professionals. Those that cannot walk are taken to the second floor as a response to initial sirens. They are then taken to the third if the warning sirens continue. Elevators, if they are still working, would be used after the earthquake shaking had stopped. Those patients with the most severe injuries would be taken to a room and physically protected by healthcare professionals. Directly after an earthquake, a meeting point outside the hospital was mandated for certain healthcare professionals to evacuate to protect them as high priority respondents in the case of structural damage to the hospital. If the communication was down, medical personnel would communicate and coordinate with NOVA by radio. The hospital has evacuated patients during alerts after earthquakes in 2014 and 2015. The physician stated that the process was quite successful and without any significant loss.

5.3 Tsunami Evacuation Drill Results

As described in Section 4.3, two drills were performed. The first was along the 12 Norte route starting from the beach to the hills and the other was along route 13 Norte from the hills to San Martin Road.

The evacuation drill took 14 minutes and 41 seconds from the beach to the meeting point via the 12 Norte route. However, this time included short stops to consider traffic at intersections. The time was taken at a relatively moderate walking pace of two young adults. The evacuation drill was filmed to visually and audibly described during the routes. Considering an actual evacuation via this route of vast population ages, abilities, health conditions, family company, and night or rush-hour evacuation, actual evacuation via 12 Norte will likely exceed the 7-15 minute estimate of tsunami arrival time predicted by researchers [1].

A downhill time evacuation drill via the 13 Norte route took approximately 20 minutes. This time ended at Avenida San Martin about 100 meters from the beach and not at the beach itself. The evacuation drill was completed by two young adults in the downhill slope direction without reaching the beach. However, the theoretical tsunami arrival time was greatly exceeded by the evacuation time of 20 minutes. It is speculated the evacuees via this route during an actual event may have small chance of survival. The increased distance and topographical and geographical characteristics of other evacuation routes in Zones 2, 3 and 4 (Fig. 1) may make these evacuation routes even longer. This was confirmed by an evacuation drill performed by project partners in Zone 4 that took nearly 50 minutes to reach the meeting point. The results of these tsunami evacuation drills suggested that vertical evacuation may be a valuable option to explore. Several high-rise buildings located on San Martin Avenue (Fig. 1) and surrounding streets could serve as possible vertical evacuations shelters. However, thorough numerical simulations and design reviews of these buildings subjected to seismic and tsunami loads should be performed to assess their suitability to act as vertical evacuation shelters.

6. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the limited field study described herein, the following concluding remarks could be drawn:

1. The obstacles observed along the tsunami evacuation routes in Zone 1 in the city of Viña del Mar could significantly hinder or block the evacuation process during an actual tsunami event. These obstacles include illegally parked cars and motorcycles occupying sidewalks, some cracked and uneven sidewalk surfaces, and the presence of a highly populated commercial shopping mall and a university campus along the evacuation route.
2. Beach access is inadequate in Zone 1. Beach evacuation could be difficult due to limited beach access stairs (one staircase per 400 meters of beach stretch in Zone 1) and the steep dirt slope from the beach to the street.
3. Tsunami hazard signage is poor on the beach and along the evacuation routes. Tsunami evacuation signage is acceptable along some evacuation routes (such as 12 Norte), while it is insufficient along other routes.
4. Signage to designate safe evacuation zones and to direct evacuees to meeting points is non-existent in Zone 1. Similar observations were noticed in Zones 2, 3 and 4.
5. Moderate slopes and multi-flight staircases at the end of each evacuation route represent major obstacles for the evacuation of the elderly, disabled, and families with small children.
6. Times evacuation experiments from the beach to the assumed meeting points varied between 15 and 20 minutes in Zone 1 and up to 50 minutes in zone 4. This time exceeds the predicted 7-15 minute minimum tsunami arrival time estimated by Chilean researchers. Vertical evacuation procedures could be a possible solution for this problem. However, an advanced cascading earthquake-tsunami hazard structural review of the designated vertical evacuation buildings has to be performed to verify the suitability of these structures.
7. Tourists are at a greater risk of tsunami hazard due to their unawareness of the tsunami evacuation procedures and routes.
8. Local residents seem aware of the tsunami risk and the potential evacuation routes. However, many surveyed local residents have expressed an underestimation of the tsunami hazard due to misinformation about “bay protection” of Viña del Mar Bay.

9. Healthcare professionals in the area seem well aware of the earthquake and tsunami risks and the evacuation protocols and routes.

The following recommendations are suggested to improve the evacuation process and route efficiency based on the results of the current investigation.

1. Provide more access staircases at the beach and more accessibility to the evacuation routes.
2. Improve tsunami risk signage, evacuation route signage and detour signage at the beach and along the evacuation routes.
3. Provide sufficient pavement maintenance particularly along the evacuation routes.
4. Provide proper signage for the safe zone at the end of evacuation routes and direction arrows to the assembly meeting point.
5. Review the structural safety of the hospital in the inundation zone that was constructed prior to the 2010 earthquake. This review should take into account cascading earthquake-tsunami hazard that includes the possibility of plastic deformation from previous earthquake loading and the impact of debris bearing tsunami waves.
6. Strictly enforce legal car parking through heavy fines and visible law enforcement officers.
7. Consider vertical evacuation as an alternative (or perhaps primary) evacuation protocol. A cascading earthquake-tsunami hazard structural review must be conducted to verify existing building suitability.
8. Enhance awareness of local residents through social media, text messages, flyers, and posters of the tsunami risk.
9. Educate children at schools about the tsunami risk and evacuation procedures.
10. Increase awareness of tourists about tsunami risks and evacuation procedures through proper signage and flyers at the beach and airport.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Earthquake Engineering Research Institute (EERI) in California, USA, for arranging the Learning from Earthquakes Travel-Study Program in Chile, which this study constitutes a part of. The authors also want to acknowledge the coordination and facilitation of the study provided by the National Research Center for Integrated Disaster Management (CIGIDEN), Pontificia Universidad de Católica de Chile.

REFERENCES