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Comparative Study on the Processes of Tsunami Evacuation in Biobio 2010 and that in Iquique 2014, Chile

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Abstract

Earthquakes and tsunamis are the main natural agents of urban change and put in constant danger to populations that are exposed to these risks. The 2010 Maule earthquake (8.8 Mw) occurred at 3:34:08 local time (UTC-3), Saturday February 27, and generated a tsunami which affected large part of the central coast of Chile. The tsunami caused extensive damage in the cities of Talcahuano and Dichato, however, the human losses were very low due to the timely evacuation process performed by the population.

The earthquake of 2014 Iquique Norte Grande (8.2 Mw) occurred at 20:48 local time (UTC-3) on Tuesday April 1, 2014. Due to the intensity and location of the earthquake, the Hydrographic and Oceanographic Service the Chilean Navy (SHOA) issued a "tsunami watch", the National Emergency Office of the Interior Ministry (ONEMI) ordered to evacuate coastal areas around the country, and finally waves of 2.11 meters reached in Iquique area.

Questionnaire surveys were conducted in Biobio and in Iquique aiming to clarify the factors affecting tsunami evacuation process and to improve measures to raise awareness and preparedness in Chile and in other tsunami prone countries. Tsunami evacuation tends to be faster in Chile than in Tohoku, however, it is important to address tsunami arrival time in Chile can be much faster than in Tohoku. There are about 5 to 10% of people who did not evacuate as they think tsunami would not come to their places or they want to protect homes from thieves. Also it is important to consider how to support elderly and handicapped people for evacuation. 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 tsunami safety rule. However, automobile evacuation tends to increase as car ownership and daily use of automobiles are getting more common in suburbs where evacuation places are far or in socially upper class communities. People evacuating on foot face various difficulties and threats due to the traffic jam by automobiles or fast running autos.

The two earthquakes in Chile both occurred at night time when family members were mostly at home and together. In case of a daytime earthquake, people may try to get back home to see and help elderly or children at home or in nursing schools, and such two way trips by automobiles may increase traffic jam. Study on working people and working places such as industries and offices on tsunami evacuation, plans, protocols and awareness are also important.

***Key Words**: Tsunami evacuation, the 2014 Off Iquique earthquake, the 2010 Maule earthquake, Tsunami hazard map, Means of transport, Questionnaire survey, Comparison of Chile and Japan*.

1. Introduction

This research is a comparison between tsunami evacuation processes in the cities of Talcahuano and Dichato to the 2010 earthquake (Ramos and Murakami [1], Murakami and Ramos [2]) and the that in the city of Iquique to the 2014 earthquake in Chile (Murakami, Nagase, et al. [3]).

The main objectives of the study are to compare the behavior of the population and time to evacuate the hazard zones after the earthquake, taking into account geographical conditions, knowing what were the main means of transport for evacuation, the start time of the evacuation, the time and distance of the evacuation, the quality of evacuation routes and safe places, and problems with car traffic and the tracks. Comparing both experiences to define the strengths and weaknesses experienced by people during the evacuation process, taking into account the differences between geographical areas and risk behaviors that may endanger people and affect the normal evacuation procedure.

2. Outline of the Earthquakes and the Cities Hit by Tsunami in Chile

Table 1 shows characteristics and damage conditions of Talcahuano and Dichato hit by the 2010 earthquake and Iquique city hit by the 2014 event. The 2010 Maule earthquake (8.8 Mw) occurred at 3:34:08 local time (UTC-3), Saturday February 27, and generated a tsunami which affected large part of the central coast of the country. The tsunami caused extensive damage in the cities of Talcahuano and Dichato, however the human losses were very low due to the timely evacuation process performed by the population. The 2014 Iquique Norte Grande earthquake (8.2 Mw) occurred at 20:48 (local time) on Tuesday April 1. Due to the intensity and location of the earthquake, the Hydrographic and Oceanographic Service the Chilean Navy (SHOA) issued a "tsunami watch" and the National Emergency Office of the Interior Ministry (ONEMI) ordered to evacuate coastal areas around the country, finally reached waves of 2.11 meters.

Damages by tsunami for the cities of Talcahuano and Dichato were very high (Table 1), affecting 26.6% and 65% of the urban area and more than 8900 homes destroyed. In case of Iquique city, the tsunami caused damages to docks and fishing villages and very limited effects on housing.

Table 1 - The cities affected by the tsunamis and damage conditions.
Own elaboration. Source of data: Reconstruction Plan Coastal Border region of Bío Bío PRBC18, Master Plan Dichato and Talcahuano, Government of Chile, 2011. Reconstruction plan earthquake and tsunami of 27 February 2010, Government of Chile, august 2010. Statistics medical service legal Government of Chile, Earthquake 2010, 2010.

	Talcahuano 2010 8.8 Mw	**Dichato 2010** 8.8 Mw	**Iquique 2014** 8.2 M_W
Population	**163.626 people**	**3.488 people**	**184.953 people**
Extension of urban area	**40,3 km²**	**1,22 km²**	**2242,1 km²**
Tsunami affected area	**10,72 km²**	**0,803 km²**	Serious damage to docks and fishing villages
Houses destroyed by tsunami	**7.636**	**1.343**	**-**
victims	**3**	**16**	**7**

The Iquique city has an important port to export mining resource and touristic beach with population of approximately 185 thousand. Tsunami height of about 3.57m was reported by Tomita et al [4]. In the study by Murakami and Okumura [5], results of reconnaissance survey were reported regarding damage conditions and

emergency responses of municipality and ONEMI Tarapaca Region Office, and tsunami evacuation of community people. In this study, we analyze questionnaire survey results for inhabitants in tsunami hazard zone in Iquique city and compare evacuation behavior with the results of the 2011 Great East Japan earthquake and tsunami disaster.

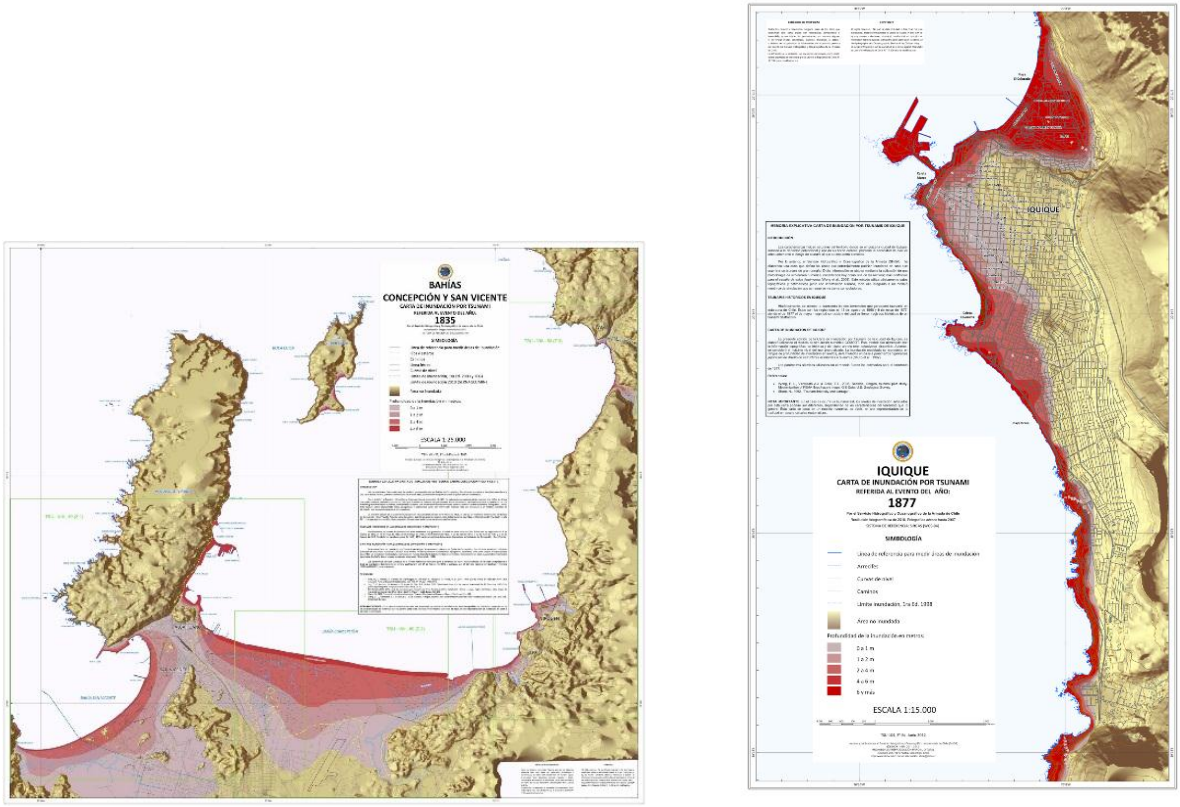

Fig. 1 - Tsunami inundation maps of Talcahuano (left) and of Iquique (right) published by SHOA, Chile, based on the historical tsunami events, source: http://www.shoa.cl/servicios/citsu/pdf/citsu_iquique.pdf

3. Questionnaire Survey on Tsunami Evacuation in the 2010 Maule Earthquake

3.1 Geographical conditions of survey area and time to start evacuation

In order to elucidate tsunami evacuation behaviors in the 2010 Maule earthquake in Chile, questionnaire survey was conducted in December 2013 for severely affected city of Talcahuano and Dichato district of Tome city with students of the University of Concepcion participating as interviewers. The survey areas are DCH (Dichato), TZ2 (Talcahuano Central), TZ3 (El Morro), and TZ4 (Salinas). Altogether 193 cases of data were collected. Conditions and survey scheme, please refer to Ramos and Murakami [1, 2]. The survey results of tsunami warning, travel means of evacuation, evacuation routes and conditions are examined here.

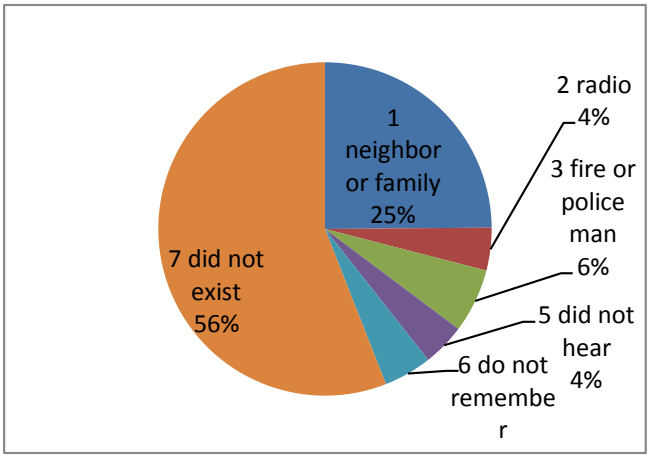

Fig. 2 - Tsunami alarm in Biobio (Q3, n=193)

Official tsunami warning did not exist in this earthquake. According to the hearing survey to disaster management section of Talcahuano municipal office by

the author (H. M.) in 2012, there was notice from ONEMI that there is no risk of tsunami and that information was broadcast via local radio station. In the hearing survey to Dichato temporary housing village at the same occasion, local people and community leaders said the same conditions. Fig. 2 indicates tsunami alarm conditions. In total, 56% of respondents say the tsunami alarm did not exist, while 25% say they got some alarm information from neighbors or family.

Fig.3 shows time to start evacuation for survey zones. In total, half of respondents started evacuation during shaking or immediately after the earthquake. Still, there are 14% of respondents who did not, or could not evacuate, which seem to have stayed upper floors of apartments or houses. Evacuation is faster in Dichato, and TZ3 El Morro, while it is slow and more respondents did not evacuate in TZ Talcahuano Central. Fig. 4 shows actions taken before starting to evacuate (MR: multiple response) in relation to disabilities. The percentage of those starting evacuation immediately is highest (61%) for the cases with no disability followed by the cases with little disability in walking and then by the cases of vision or hearing disability. Family teaching of tsunami evacuation prior to the F27 event tends to make people evacuate quicker (Fig. 5), so that it seems to be primary and basic requirement to promote quick start of evacuation.

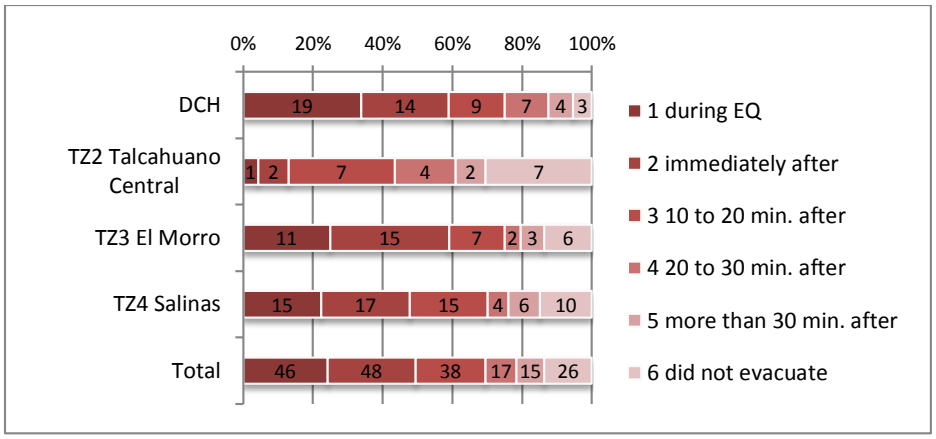

Fig. 3 - Time to evacuate vs. survey zones (Q5, n=190)

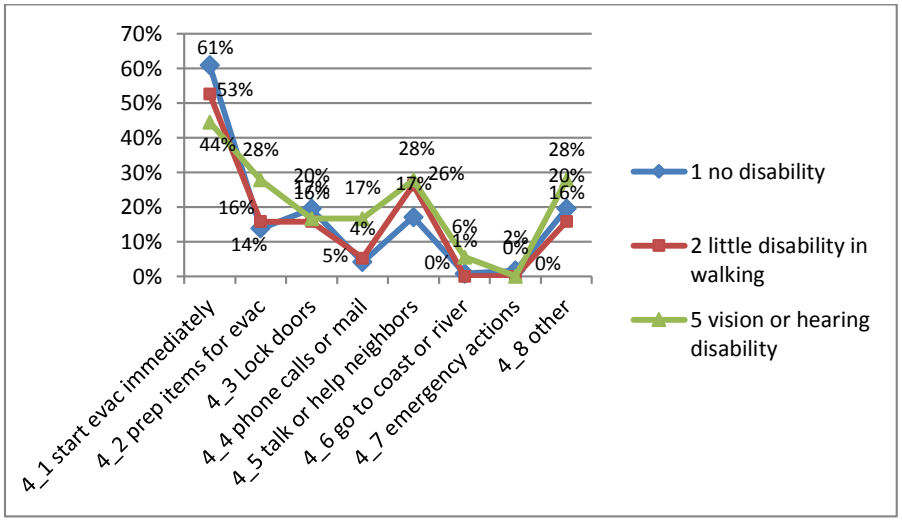

Fig. 4 - Actions taken before evacuation vs. disability (MR: multiple response, n=160)

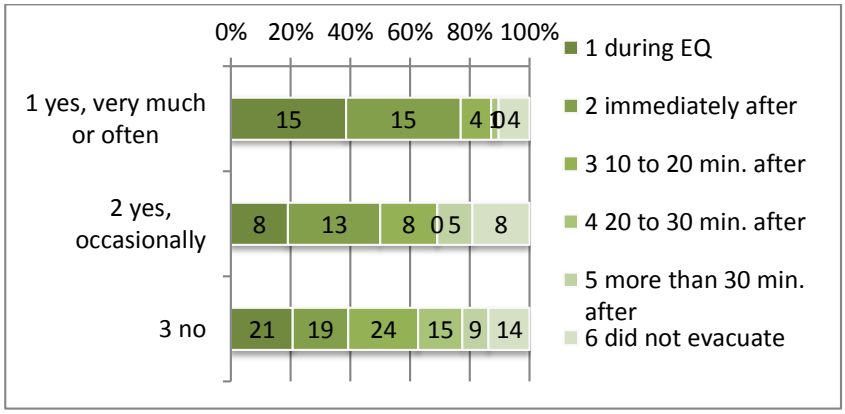

Fig. 5 - Q20 Family teaching of tsunami evacuation prior to F27 event and Q5 time to start evacuation (n=183)
P value =0.003<0.01

3.2 Travel means for evacuation

Figs 6 and 7 show topography of Talcahuano and Dichato with evacuation routes indicated. In Talcahuano, evacuation distances are short, mostly less than 500m in Zones 2 and 3, and are much longer in Zone 4. Fig. 8 depicts means of transport for evacuation. Percentage of people on foot is high in TZ3 El Morro, and TZ2 Talcahuano Central, while use of cars (4 to 7, both driving a car or pickup, and getting a car ride or a pickup ride) is highest in TZ4 Salinas, followed by DCH, Dichato. In this figure, other means those who could not or did not evacuate and stayed in the buildings. Such cases share more than 30% in TZ2 Talcahuano Central, where 3-4 story apartments are common. Traffic jam conditions (Fig. 9) vs survey zones indicate similar patterns of severe conditions in TZ4 Salinas and Dichato.

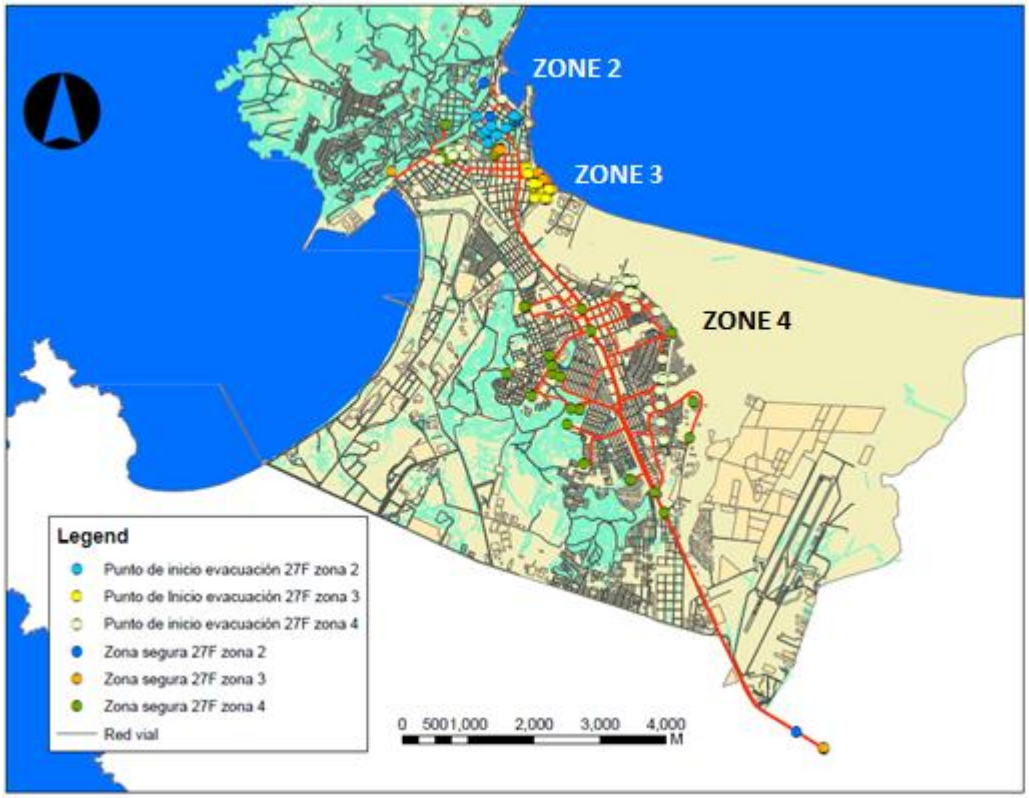

Fig. 6 Evacuation map of 27F (in the 2010 Maule earthquake and tsunami) in Talcahuano (zone 2 is central, zone 3 is El Morro, and zone 4 is Las Salinas). Circles in light color are origins and those in dark colors are destinations in security area.

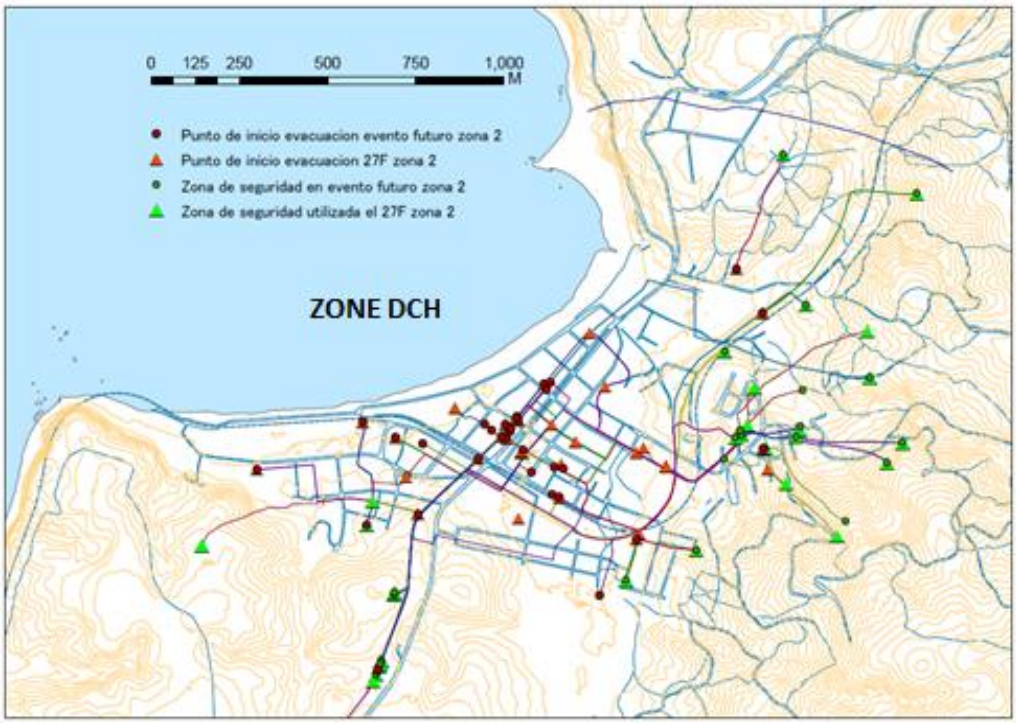

Fig. 7 - Evacuation routes of 27F (triangles) (in the 2010 Maule earthquake and tsunami) and assumed ones (round ones) for weekday earthquake in Dichato. Red ones are origins and green ones are destinations.

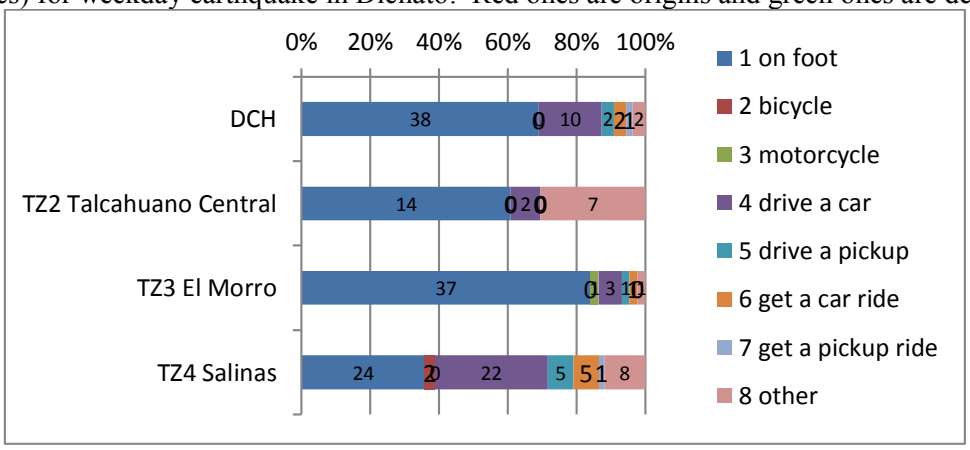

Fig. 8 - Means of transport for evacuation vs. survey zones (Q6, n=189)

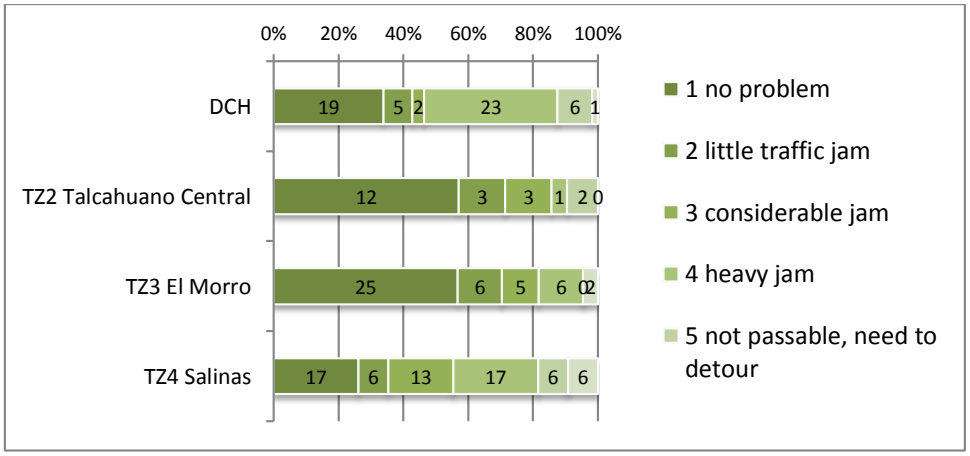

Fig. 9 - Traffic jams observation vs. survey zones (Q14, n=186)

3.3 Assumption of a daytime earthquake in weekday

The 2010 Maule earthquake occurred night time of the weekend. As for the means for commuting. 40% is on foot and 27% is by buses or trains, while private car commuters are 11%. Suppose if an earthquake should have occurred during day time of week days, means of transport and travel patterns are of critical interest (Fig. 10). The daytime evacuation pattern is shown in Fig. 10. Those who plan to go back home from work places are about 25%, and those who plan to go and see one's family and then evacuate is about 10%. A day time earthquake and tsunami threat seems to increase two way traffic to go home, to go and see family and then to evacuate, though car users may not increase much in such cities majority of commuter's still use public transportation like buses and trains.

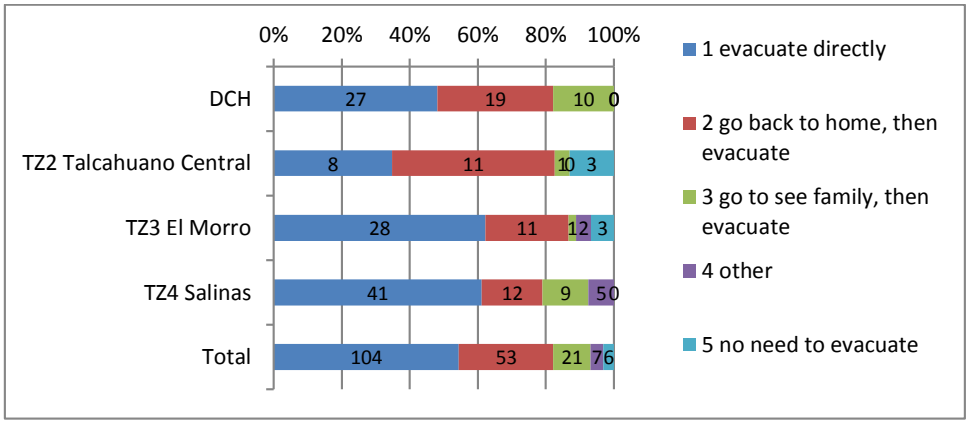

Fig. 10 - Evacuation pattern assuming day time earthquake vs. survey zones (Q24, n=191)

3.4 Summary of the findings in the Biobio tsunami evacuation

Questionnaire survey was conducted in Talcahuano and Dichato to investigate evacuation behavior after the 2010 Maule Earthquake and following tsunami.

1) Most of the people evacuated within 20 min. after the earthquake, even though there was no official tsunami warning. However, there were about 30% of cases who couldn't or didn't evacuate in due time and stayed at upper floors of apartment buildings or second floor of houses.
2) The majority, about 60% of transportation means for evacuation was on foot, while, there were about 15% by driving a car or a pickup, getting a car or pickup ride. Use of cars for evacuation is much higher in TZ4 Las Salinas and in Dichato, and correlation of use of cars to evacuation distances is obvious. Traffic jam occurred more in Dichato and TZ4 Salinas than in TZ2 Talcahuano Central and TZ3 El Morro.
3) In case of a day time earthquake, many think they would either go home or go to see family before evacuating. Such behavior may increase demand for traffic and increase traffic jam and difficulty of evacuation.
4) Family teaching of tsunami and evacuation tend to increase percentage of respondents to evacuate quickly.

4. Questionnaire Survey on Tsunami Evacuation in the 2014 Off Iquique Earthquake

4.1 Geographical conditions of survey area and risk awareness

Iquique municipality published civil protection map against tsunami (Fig. 11), which indicates evacuation routes. Tsunami hazard zone is the area of elevation less than 30m, while tsunami security area is over 30m elevation above sea level. Zone 1 located in low land is the tax free special area called ZOFRI for industry, whole sale district and a large shopping mall. Zone 2 is downtown area near the port and wide residential area. Zones 3 and 4 have good access to beaches and hotels and uptown residential area.

Fig. 11 - Iquique map for civil protection against tsunami published by Iquique municipality in 2013
Source: http://www.municipioiquique.cl/

Table 2 - Outline of the questionnaire survey for residents in tsunami hazard zone

Survey period: Pretest	In late August, 2014 (50 residents and ZOFRI workers)
Main survey	From Sep. 24 to Oct. 12, 2014
Survey organizer	Ekhos Co. with contract by JICA Chile office
Survey method	Interview with questionnaire format
Sample size	608 responses (out of which, 276 male and 332 female cases)
Age distribution	Under 19: 20 cases, 20-39 year old: 236 cases, 40-59 year old: 221 cases, Over 60 year old: 163 cases
Survey zones	303 cases in Zone 2, 203 cases in Zone 3, and 102 cases in Zone 4.

The authors conducted the questionnaire survey for inhabitants to clarify human evacuation process in 3 earthquakes of pre-shock, the main shock, and the aftershock, role of warnings, means of transport and so forth (Table 2). Survey area covers Zone 2 (downtown and central), 3 (mid-south touristic and residential), and 4 (south upper residential) out of 5 zones in the tsunami hazard map in Iquique (Fig. 11). The authors prepared original questionnaire in English based on similar studies in Tohoku [4], and in Biobio after the 2010 Maule earthquake and tsunami [5], and Spanish version was prepared by Ekhos Co. The questionnaire contains 50 questions asking location at the time of the earthquake, actions during shaking, actions prior to evacuation, tsunami warning, distances to the coast and to the tsunami security area, time to start evacuation, time to reach the security area, means of transport, danger on the route, reasons not to evacuate, evacuation in the March 16 foreshock, evacuation in the April 2 aftershock, preparedness, participation to seminars and evacuation drills, awareness of hazard map, psychological questions, etc.

Fig. 12 shows distribution of tsunami hazard map awareness. The majority of 44.1% say that they knew well the hazard map, and 36.3% say they knew it little. Fig. 13 shows tsunami hazard map awareness in Tohoku from MLIT survey for disaster restoration. Awareness is obviously higher in Rias (steep slope common along the coast) region than in Sendai coastal plain, however awareness rate of 45% in Rias is much lower than that in Iquique, that is, 80%.

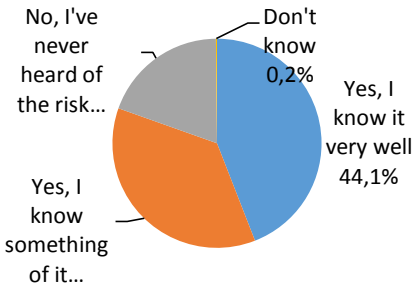

Fig. 12 - Awareness of tsunami hazard map in Iquique (n=608)

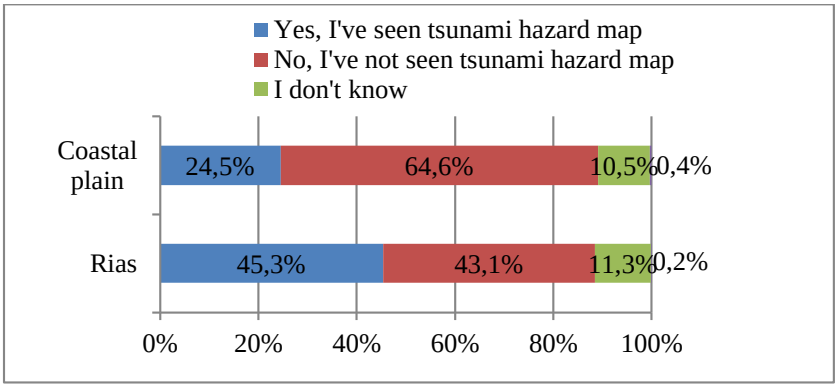

Fig. 13 - Tsunami hazard map awareness prior to the 2011 Tohoku tsunami by MLIT survey for the support of disaster recovery (n=10,603, p=0.000)

4.2 Time to start evacuation

Fig. 14 indicates evacuation rates in the 3 earthquakes and the rate of 89% is highest in the main shock. However, it is observed significant % of people who did not evacuate. Fig. 15 shows time to start evacuation in Iquique. Within 5 minutes, 68% of people started evacuation. Table 3 shows time to start evacuation in the 2011 Great Tohoku earthquake tsunami. It is clear that evacuation of Iquique people is much faster.

Fig. 16 shows relation of participation to the tsunami evacuation drill and time to start evacuation. The group of drill participation tends to start evacuation earlier than the other of no drill participation. Those participating tsunami evacuation drills may possibly live closer to the coast and in lower elevation, so that such conditions may have affected tsunami hazard awareness and earlier evacuation.

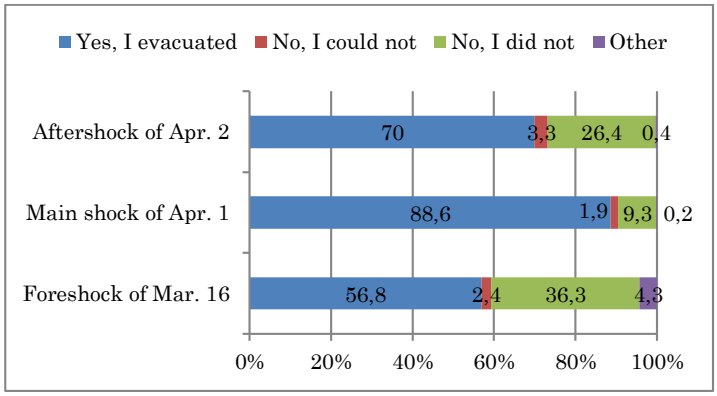

Fig. 14 - Comparison of evacuation rates among 3 earthquakes in Iquique

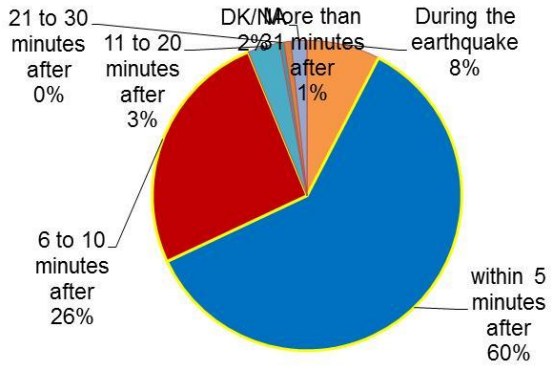

Fig. 15 - Time to start evacuation at the main shock in Iquique (n=419)

Table 3 - Time to start evacuation in the 2011 Great Tohoku earthquake tsunami by MLIT survey for disaster restoration

Tsunami risk perception after eq.	No. of cases	Average starting time after eq. (min.)	Time at which 50% of people started evacuation (min.)	Time at which 80% of people started evacuation (min.)
I thought tsunami should come, or I thought tsunami might come.	3105	18	14	29
I thought tsunami would noto come, or I didn't think about tsunami.	2411	25	24	42
Total	5524	22	14	34

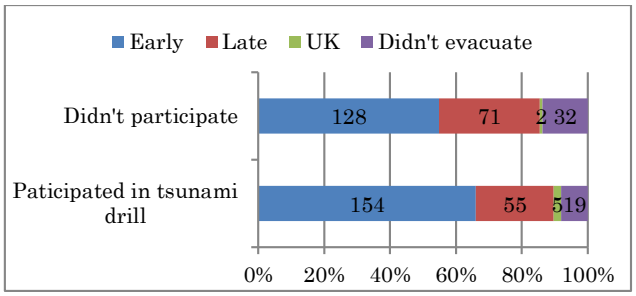

Fig. 16 - Relation of participation to the tsunami evacuation drill and time to start evacuation. Here, "early" means evacuation within 5 minutes and "late" means evacuation later than 6 minutes. UK is unknown. (n=466, p-value=0.029)

4.3 Travel means for evacuation

Means of transport for evacuation is shown in Table 4. Out of 419 cases, pedestrian is 398 cases (95%), while automobiles are 18 cases (out of which one's own or family car is 16, and other people's cars are 2 cases), other means such as bicycles are 3 cases, no evacuation is 53 cases, no response is 136 cases (most of which located at security area when they heard tsunami siren). The reasons for dominant pedestrian evacuation in Iquique are that it is rules and morals, and people tend to consider it is safer to walk than to drive or ride a car. Fig. 17 shows mobility patterns in the 2011 Great Tohoku earthquake and tsunami. Automobile evacuation was higher in the coastal plain area than in Rias region, and automobile use in Tohoku was much higher than in Iquique.

Fig. 18 shows levels of risk perception due to automobiles by pedestrian people during evacuation by zones. Risk perception gets obviously higher while evacuation distance becomes longer. Traffic jam and fast movement of many automobiles for evacuation seem to make risk to the people including elderly and children evacuating on foot. People in Iquique seem to value on rules and morals and to choose on foot evacuation. In case of future earthquakes and tsunami warning during day time, there might be cases people wish to return home by car and help family and evacuate together.

Table 4 - Means of transport for evacuation in Iquique (n=419)

	cases	%
Your own car or pickup truck	16	3.8
Other person's car or pickup truck	2	0.5
Walk	398	95
Bicycle	1	0.2
Public transport	1	0.2
Motorbike	1	0.2
Total	419	100

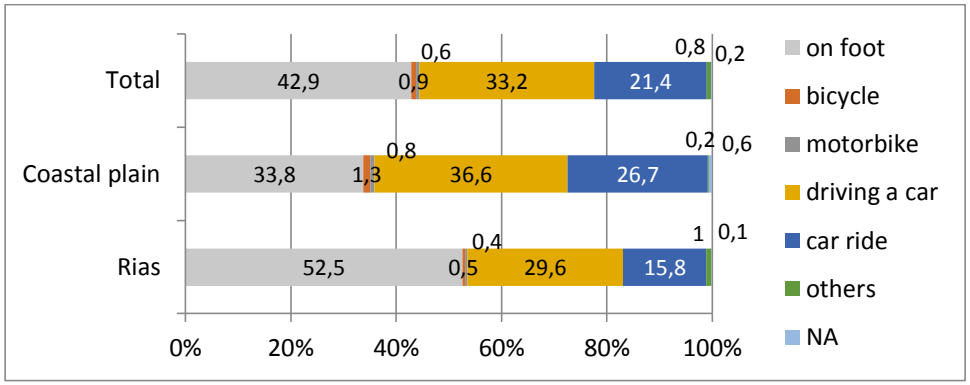

Fig. 17 - Relation of means of transport for tsunami evacuation by regional topography in the 2011 Great Tohoku earthquake and tsunami (Fukko Shien survey archive, MLIT survey, n=5524 cases)

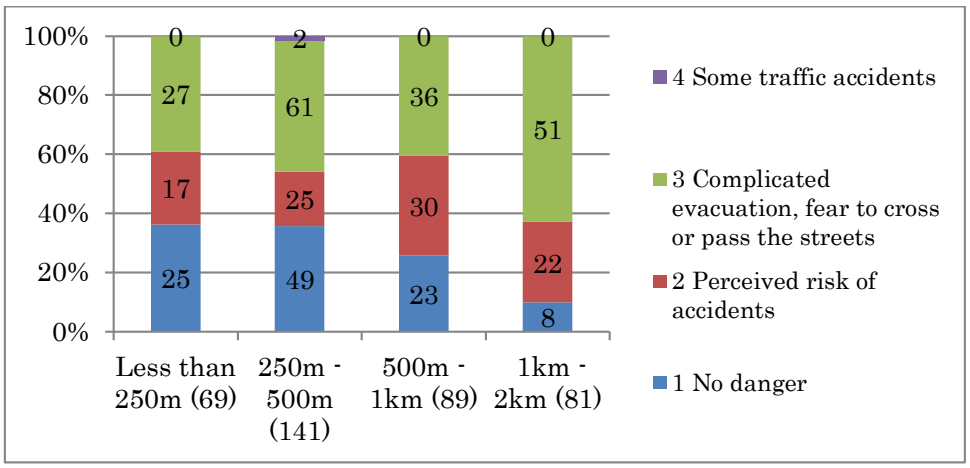

Fig. 18 - Relation of risk perception of people evacuating on foot against car evacuation vs. distance to evacuate (n=376, p-value=0.001)

4.3 Summary of findings from the Iquique evacuation survey

Questionnaire survey was conducted for the tsunami evacuation due to the 2014 Off Iquique earthquake in Iquique city for inhabitants and the following findings were indicated.

1) Time to start evacuation was affected by distance from the coast and experience of evacuation drills reflecting critical awareness.
2) There were about 10% of people who did not evacuate, as they think tsunami may not hit their place, or they protect homes from thieves.
3) Majority of people evacuated on foot, and automobile evacuation was limited, however risk of auto hitting pedestrian evacuee is serious, where evacuation distance gets longer and complicated.
4) There is significant drop of evacuation rates in foreshocks and aftershocks, and increased frequency of tsunami alert to be examined carefully.

5. Concluding Remarks

The 2010 Maule earthquake and the 2014 Off Iquique earthquake occurred causing tsunami in Chile and the questionnaire surveys were conducted in the cities of Talcahuano, Dichato and Iquique affected mostly. This study analyzed and compared tsunami evacuation behavior and affecting factors in view of urban form and evacuation environment. The findings are as follows.

Tsunami evacuation tends to be faster in Chile than in Tohoku, however, it is important to address tsunami arrival time in Chile can be much faster than in Tohoku. There are about 5 to 10% of people who did not evacuate as they think tsunami would not come to their places or they want to protect homes from thieves. Also it is important to consider how to support elderly and handicapped people for evacuation. 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 both occurred at night time when family members were mostly at home and together. In case of a daytime earthquake, people may try to get back home to see and help elderly or children at home or in nursing schools, and such trips by automobiles increase traffic jam. Studies on working people and working places such as industries and offices on tsunami evacuation are important to improve protocols and awareness on tsunami.

Acknowledgements

The study was conducted for the research project in Chile entitled “Enhancement of Technology to Develop Tsunami-Resilient Community”, which was headed by Dr. T. Tomita of Port and Airport Research Institute, supported by JST/JICA SATREPS in collaboration with Chilean researchers and counterparts. The authors acknowledge inhabitants in Talcahuano, Dichato, and Iquique who kindly answered questionnaires, Ekhos Co. in Chile who conducted the questionnaire survey, JICA Chile office and the project coordinators who continuously supported our field work in Iquique and Biobio. The authors express sincere gratitude to the students of University of Conception who participated in the survey, Ms. Alejandra Contreras, and Mr. Patricio Diaz who assisted the study by GIS mapping of evacuation routes, and Prof. Edilia Jaque who kindly provided us GIS base map data.

References

[1] Ramos, L., and H. Murakami (2014). Tsunami evacuation questionnaire survey for cities of Talcahuano and Dichato in the 2010 Maule earthquake in Chile Part 1 Background and survey scheme, Proc. 14th Japan Earthquake Engineering Symposium, paper number OS13-Fri-AM-2.

[2] Murakami, H., Ramos, L. (2014). Tsunami evacuation questionnaire survey for cities of Talcahuano and Dichato in the 2010 Maule earthquake in Chile, Part 2 Survey results, Proc. 14th Japan Earthquake Engineering Symposium ,paper number OS13-Fri-AM-3.

[3] Murakami, H., Nagase, Y., Takahashi, M., Asai, K., Ikeda, M., and Sase, K. (2015): Study on Tsunami Evacuation after the 2014 Iquique Earthquake, Chile (2) Results of Questionnaire Survey for Inhabitants, Proc. Annual Research Meeting, Chugoku Chapter, Architectural Institute of Japan, No. 38 (in Japanese).

[4] Tomita, T., Kumagai, K., Mokurani, C., Cienfuegos, R., and Matsui, H. (2014): Post field survey on the April 2014 Earthquake and Tsunami in Northern Chile, Proc. 14th Japan Earthquake Engineering Symposium, paper number OS12-Fri-AM-4.

[5] Murakami, H. and Okumura, Y. (2014): Study on Tsunami Evacuation after the 2014 Iquique Earthquake, Chile (1) Hearing Survey for Public Offices, Communities, and Shopping Center, Proc. Annual Research Meeting, Chugoku Chapter, Architectural Institute of Japan.