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ANALYSIS OF THE START OF EVACUATION BY PEOPLE INSIDE A BUILDING DURING THE 2014 IQUIQUE EARTHQUAKE TSUNAMI

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Abstract

The past historical tsunamis have killed many people, who were not able to or did not evacuate from the calamity. This study aims to reveal the relationship between the first actions caused by an earthquake and the tsunami evacuation. People in a building generally try to protect themselves against falling objects during strong earthquake shaking. Accordingly, some of them try to exit the building in fear of building collapse. This study uses interviews, security footages, and an evacuation simulation to analyze thousands of people, who stayed in the shopping center, “Mall ZOFRI”, in Iquique, Chile during the 2014 off Iquique earthquake and tsunami. The results reveal a close relationship between them. We cannot discuss tsunami evacuation in the case, where many people in a building escaped outdoors, without considering the first actions caused by the earthquake. Their relationship can be discussed from three aspects: (1) how the reality outdoors of imminent emergency was, which prompted the need for the start of the tsunami evacuation; (2) how much of the percentage of people, who escaped outdoors, was needed to start the tsunami evacuation or go back indoors; and (3) can people who went back indoors start the tsunami evacuation or not.

Keywords: start of evacuation; strong shaking of an earthquake; 2014 Iquique earthquake and tsunami; tsunami evacuation; evacuation simulation

1. Introduction

Past tsunamis have taken away many lives, especially of those who were incapable and those who did not evacuate from the calamity. This study aims to determine the relationship between the first evacuees' actions caused by the earthquake and the tsunami evacuation. People in a building generally try to protect themselves against falling objects during an earthquake. Some of them try to exit a building in fear of building collapse. Even if these behaviors are different from those exhibited during a tsunami evacuation, clarifying the relationship toward the realization of the quick start of tsunami evacuation is important because both behaviors can be assumed to be closely related. Ohta et al.[1)] stated that the psychological/behavioral responses to strong earthquake shaking have been actively researched since the Niigata earthquake in Japan in 1964. However, the authors did not focus on the relationship to be discussed in this study.

The present research aims to determine this relationship. We use interviews, security footages, and an evacuation simulation to analyze thousands of people, who stayed in the "Mall ZOFRI" shopping center in Iquique, Chile during the 2014 off Iquique earthquake and tsunami.

2. 2014 Off Iquique Earthquake and Tsunami

This Mw 8.2 earthquake occurred at 20:46 on April 1, 2014 (local time) in Chile. The reported Modified Mercalli (MM) intensity in Iquique was 7[2)]. The tidal station in Iquique observed a 2.11 m-high tsunami about 19 min after the earthquake occurrence. The research survey reported a flat, low-lying area near the ports of Iquique with an inundation height of 2.84–3.15 m[3)]. No people were killed in the tsunami, but six died because of collapsed walls or fire caused by the earthquake. The strongest aftershock at Mw 7.7 occurred on April 2, 2014.

3. Interview

This section describes the interview as regards the evacuees' behaviors in Mall ZOFRI just after the earthquake occurred. The authors interviewed ZOFRI staff to understand the situation inside and outside of the mall during the period between the earthquake occurrence and the start of the tsunami evacuation.

3.1 Methodology

The authors interviewed two staffers (i.e., Mr. A and Mr. B) from the administrative office of ZOFRI on April 23, 2014. Mr. A evacuated on foot when the earthquake occurred during his working time in the office. His testimony was assumed to be based on the review after the evacuation because he did not know all the details of the situation both inside and outside of the mall after the earthquake. Meanwhile, Mr. B was at home during that time. They attended the staff meeting on the damages and the evacuation in Mall ZOFRI. Therefore, they had various information based on many staff's testimonies.

In this section, we summarized the testimonies from staff of Mall ZOFRI and categorized them into basic information, including the total number of evacuees, evacuation routes, and evacuee behaviors. This interview was a part of the survey on evacuation behaviors in the 2014 off Iquique earthquake and tsunami, which was attended by one of the authors[4)].

3.2 Basic information regarding Mall ZOFRI

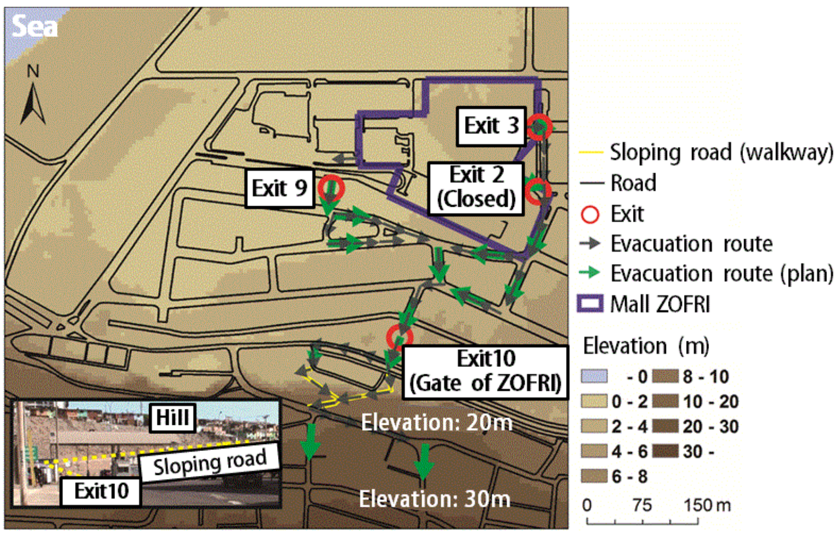
Mall ZOFRI is located in the Northern part of Iquique, Chile. It has an elevation of 3 m and is located inside the special economic zone (ZOFRI). ZOFRI comprises industrial, shopping, and wholesale areas with more than 2,000 companies and 660 warehouses. About 30,000 people come to the shopping area of Mall ZOFRI in a day. Accordingly, 40% of the customers and staff use buses as the common transportation to reach Mall ZOFRI. The rest drive their own vehicles. Mall ZOFRI opens at 11–21 o'clock, with a shop holiday during Sundays.

3.3 Basic evacuee information

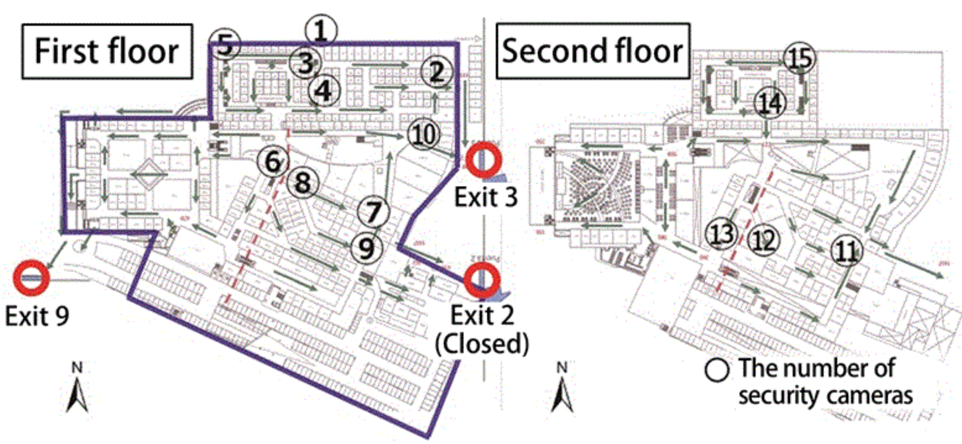
Most of the staff in the industrial area had already returned home because the earthquake occurred after the office hour. Mall ZOFRI was just about to close during that time. According to the testimonies, about 9,000 people were still in the ZOFRI area that time. About 5,000 of them were in Mall ZOFRI (i.e., staff: 1,200; customers: 3,800; and others: 80). About 400 cars were parked in the Mall ZOFRI parking space. Accordingly, about 100 cars were left at the parking area on the next day, which indicated that ~300 cars were used to evacuate from the tsunami. This finding was supported by testimonies. Using a car for tsunami evacuation was actually prohibited in Chile.

3.4 Basic evacuation route information

The green arrows in Figs. 1(a) and (b) show the planning evacuation routes. The black arrows indicate the actual evacuation routes according to the testimonies in Fig. 1(a). Most of the evacuees went through exit 3 or 9 on foot. They went through exit 10, which was one of the ZOFRI gates, after which. Subsequently, the evacuees walked on the sloping road (walkway width: 3–5 m) (Fig. 1(a)) with yellow lines toward the hill.



(a) The map around Mall ZOFRI. The photo (left below) is that of a hill and a sloping road taken at the east side of exit 10.



(b) The map inside Mall ZOFRI and location of security cameras.

Fig. 1 – Map of Mall ZOFRI

3.5 Behaviors just after the earthquake occurrence

Table 1 summarizes the evacuees' behaviors inside and outside of Mall ZOFRI just after the earthquake. The blue words in the table represent evacuation-related events. A total of 18 pieces of information were obtained. Of which, 12 (A01–A12) focus on the period of evacuees' behaviors indoors. The others (B01–B06) focus on the period of behaviors outdoors. A02 shows the behavior of Mr. A.

Table 1 – Behaviors inside and outside Mall ZOFRI just after the earthquake

<A. Period of indoor behaviors: 20:46–20:51>	
A01	People's fear rose because the building made a loud noise during the strong earthquake shaking.
A02	(I thought) tsunami would come here, and evacuation using the car was dangerous. I directly went home after I had finished evacuation on foot. People are supposed to evacuate (from the tsunami) as soon as they feel unable to stand because of the strong shaking. They escape outdoors because they think staying inside the buildings was dangerous.
A03	People had started evacuation before the strong shaking stopped.
A04	Blackout took place about 15 s after the strong earthquake shake started.
A05	I was worried about the lights. This earthquake occurred at night, but the evacuation drill was conducted during daytime.
A06	Lights were provided by the emergency electric power source after a while.
A07	Pedestrians first went to exit 3 or 9. Most people were not confused, and they smoothly evacuated; so did the wheelchair users.
A08	On April 2, baby buggies with something people had bought and ice-creams were left in the building.
A09	Some people recorded videos with their cell phones during their evacuation.
A10	There were evacuation guidance signs indoors. However, I feel that it took more time than I expected to escape outdoors because some people did not know where the exits were.
A11	All of the staff did not necessarily guide the customers.
A12	It took about 5 min to escape outdoors (exit 3 or 9).
<B. Period of outdoor behaviors: 20:51–21:00>	
B01	People walked toward exit 10 from exit 3 or 9.
B02	There were 12 lights that used solar batteries. Nine of them worked and lighted the roads outdoors.
B03	The ZOFRI staff manually turned on the siren system urging tsunami evacuation because it did not automatically work.
B04	The sounds of the siren seem to keenly increase peoples' fears.
B05	Many people arrived at the hill about 15 min after the earthquake. It took less time than in tsunami evacuation drills.
B06	People walked smoothly on April 1 despite the crowd just before the sloping road in the evacuation drill. We think that the crowdedness was caused by the narrowness of the sloping road.

*Blue words indicate evacuation-related events.

3.6 Discussions focusing on the start of tsunami evacuation

People were supposed to evacuate from the tsunami as soon as they feel unable to stand because of strong shaking (A02). Most testimonies actually showed that people felt fear not from the tsunami but from the strong earthquake shaking. Several people may have been aware of the coming tsunami and started evacuation as soon as they felt the strong shaking. Most people were assumed to want to escape outside as soon as possible because they feared that the building might collapse. This assumption was based on the testimonies that "People had started evacuation before strong shaking stopped" (A03) and "Baby buggies with something people had bought and ice-creams were left in the building" (A08). Accordingly, Mr. A also said that "People are supposed to evacuate (from tsunami) as soon as they feel unable to stand because of strong shaking". Furthermore, "the building made a loud noise when the strong shake of the earthquake occurred" (A01) and blackout (A04) were assumed to significantly increase the fear level.

Meanwhile, the testimonies revealed that "Some people recorded videos with their cell phones during their evacuation." (A09). In addition to testimony (A07), it can be assumed that most people smoothly evacuated. Testimony (B05) also indicated that most of the people possibly arrived at the hill, which took a lesser time than during tsunami evacuation drills.

4. Analysis of security footages

This section describes the analysis of security footages (15 security cameras; 5 min around the earthquake occurrence; silence) in Mall ZOFRI to grasp the situation and behavior just after the earthquake. Fig. 1(b) shows the locations of 15 cameras.

4.1 Methodology

The authors distinguished each person caught by security cameras using visual judgment. We focused on (1) whether or not people's escape outdoors was associated with the earthquake or not and (2) whether or not people went to the hill without going back to the building.

Fig. 2 shows the snapshots taken with security camera 7, which helped judge the case of escaping outdoors because of the earthquake. Group A started running as soon as they felt shaking (Fig. 2(a)). This behavior cannot be taken as part of the tsunami evacuation but as part of escaping outdoors in fear of building collapse. The authors in this study considered behaviors, such as "starting running just after the earthquake", "supporting each other", and "escaping", as escaping outdoors because of the earthquake. Fig. 2(b) shows that woman B held the door during shaking; woman C came inside after going outside the shop; and woman D hid under the desk. These behaviors were considered to belong to the staying indoors category just after the earthquake. The total targets were 265 people taken from 15 security cameras.

Fig. 3 shows the snapshots taken with security camera 1, which helped judge the start of the tsunami evacuation as soon as arriving outside. People can be seen walking/running toward the hill. However, a woman encircled in red in the figure came back after going outside. We took the behavior of not coming back indoors as the start of tsunami evacuation. The total targets are 214 people taken from security camera 1, which was located at the exit.

4.2 Earthquake shaking and blackout

The security footages showed that the strong shaking lasted for about 50 s. In addition, it also showed that the aftershocks lasted for about 15 s from 140 s after the occurrence of main shock.

Feeling fear toward the strong earthquake shaking was taken as protecting themselves against the shaking and falling objects rather than tsunami evacuation. All security footages showed that a blackout 15 s after the earthquake. The blackout lasted for 15–20 s, which was in a good agreement with testimony (A04).

4.3 Escaping outdoors because of strong shaking and staying indoors

Fig. 4(a) shows the ratio of the behaviors within 15 s between the earthquake and the blackout (N = 265). The security footages revealed that 90% of the people escaped outdoors because of the earthquake. Some people stayed indoors to protect themselves. Some people came back to the shops, put things away, and locked the

(a) 5 s after (Example of Escaping outdoors due to the earthquake)

(b) 10 s after (Example of staying indoors)

Fig. 2 – Snapshots taken with security camera 7 just after the earthquake

(a) 120 s after

(b) 130 s after

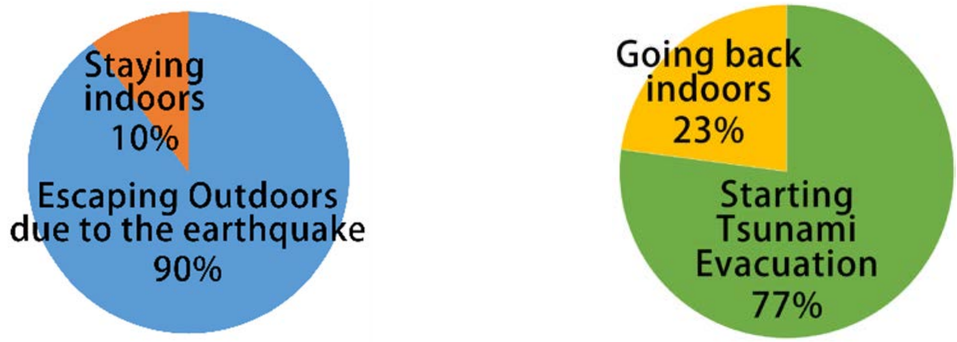
Fig. 3 – Snapshots taken with security camera 1 focusing on the exit about 2 min after the earthquake

doors when the shake weakened. All 15 security footages that the authors used focused on the isles. Therefore, the ratio of escaping outdoors because of the earthquake may be less than 90% because this study did not consider the situation inside each shop. The questionnaire survey conducted by Murakami[4)] showed that 45% of the ZOFRI staff evacuated toward safer places just after the earthquake.

4.4 Escaping outdoors and tsunami evacuation

Focusing on behaviors as soon as getting outside, Fig. 4(b) shows that 77% of the people started tsunami evacuation. Accordingly, 77% was assumed to comprise not only people who were aware of the coming tsunami since the time of the earthquake occurrence but also those who were aware of the tsunami right after they escaped outdoors. Escaping outdoors enabled people to feel something unusual (e.g., many people walked/ran toward the hill) because of those who were aware of the coming tsunami and those who were not aware of the coming tsunami at first. Therefore, a number of people who were not aware of the coming tsunami at the time of the earthquake occurrence were able to reach the hill.

Considering the aforementioned, it might be summarized that the process to start tsunami evacuation both indoors and outdoors was shifted (Fig. 5): (1) usual mode, (2) protect against the earthquake mode, and (3) tsunami evacuation mode. Authors mentioned the similar process in the past studies[5)].



(a) Behaviors just after the earthquake (b) Behaviors after escaping outdoors

Fig. 4 – Ratios of the behaviors just after the earthquake and after escaping outdoors. (a) Ratio of the behaviors taken with 15 security cameras within 15 s between the earthquake occurrence and the blackout (N = 265); (b) ratio of the behaviors as soon as getting outside taken with security camera 1 (N = 214).

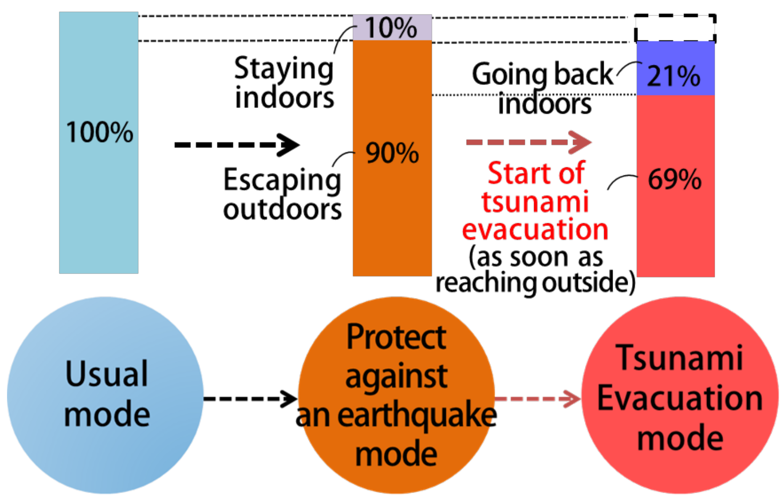


Fig. 5 – Process to start the tsunami evacuation (values are the results of this study)

5. Evacuation Simulation

This section describes the evacuation simulation conducted to explain the relationship between the start of tsunami evacuation and behaviors because of the strong earthquake shaking. The simulation also considered the interview's results and the analysis of security footages. The simulation enabled the authors to reveal both whole and partial evacuation situations not sufficiently revealed from the previous section.

5.1 Methodology

The authors of this study applied the evacuee behavior model based on the distinct element method (DEM) developed by Kiyono et al.[6]. This model was suitable for simulating behaviors in relatively narrow spaces like inside Mall ZOFRI because it can express basic human behaviors (e.g., avoiding obstacles and passing others). Parameters were set with respect to previous bodies of research[7), 8)] (Table 2). Considering the security footages, it was expected that walking velocity indoors was faster than that outdoors because of the imminent dangers indoors (e.g., fears of building collapse). The walking velocity at the crossing just before the traffic lights turned

Table 2 – Setting the walking velocity[7), 8)]

	Ave. (m/s)	Standard deviation	Min (m/s)	Max (m/s)
Indoor	1.85	0.59	1.15	4.11
Outdoor	1.21	0.30	0.67	2.40

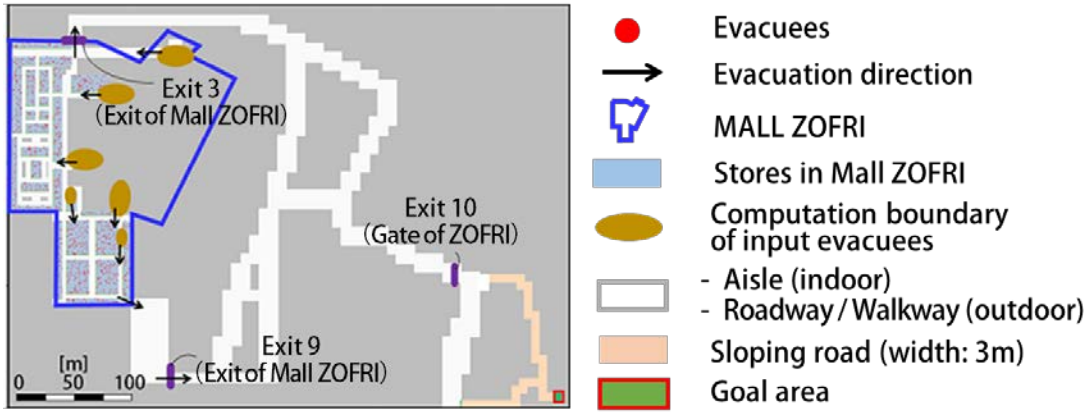


Fig. 6 – Spatial model of the target area

into red was used in this simulation[7)]. We also set the normal walking velocity using the velocity outdoors because the outside area of Mall ZOFRI was not as imminent as the inside. Moreover, the evacuees were assumed to not be affected by cars.

5.2 Spatial model and evacuee generation

Fig. 6 shows the spatial model of this simulation. A total of 4,100 and 900 evacuees were assumed to evacuate on foot and using cars, respectively. The real building shape of the Mall ZOFRI was complicated. As regards the building interiors, we only modeled the first floor, except the north east side of the floor, using the procedure that follows. Considering the ratio of the floor area of Mall ZOFRI, we first supposed that there were 1,025 people (one fourth of the walking evacuees) in the computation area when the earthquake occurred. The influx of 3,075 people (3/4 of the walking evacuees) at the computation boundary enabled us to express each evacuee's behavior using the approximate equation of the number of people going through exit 3 taken with the security camera (Fig. 7).

5.3 Results

Fig. 8 shows the ratio of having finished the tsunami evacuation. Some evacuees reached the goal area about 10 min after the earthquake occurrence and about 15 min after the earthquake struck. The ratio increased to 49% (about 2,000 evacuees). This result basically agreed with testimony (B05), which states that "many people arrived at the hill about 15 min after the earthquake struck". Accordingly, the finishing evacuation ratio would significantly drop (94% to 73%) by 20 min after the earthquake (expected tsunami arrival time) if the whole starting evacuation was 3 min late.

The result also revealed that evacuees can move smoothly inside and outside Mall ZOFRI. Most of the evacuees went through exit 3 or 9 on foot (exit 2 was closed). Therefore, it can be assumed that, whether or not exit 2 was open, it had a low impact on the ratio of having finished the tsunami evacuation.

5.4 Discussions

In Section 4, the authors proposed ideas on the process of starting the tsunami evacuation (usual, protect against the earthquake, and tsunami evacuation modes). Many people, who escaped outdoors because of the strong

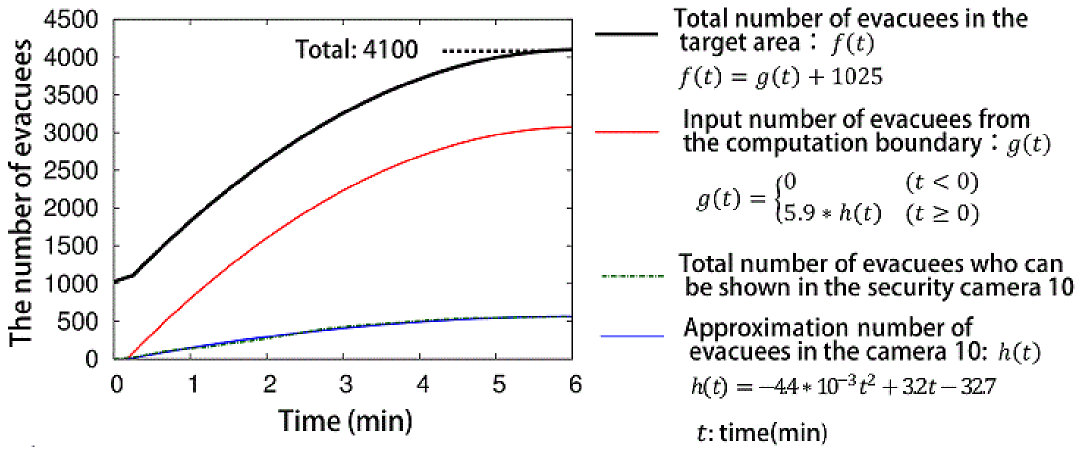


Fig. 7 – Number of evacuees in the computation area

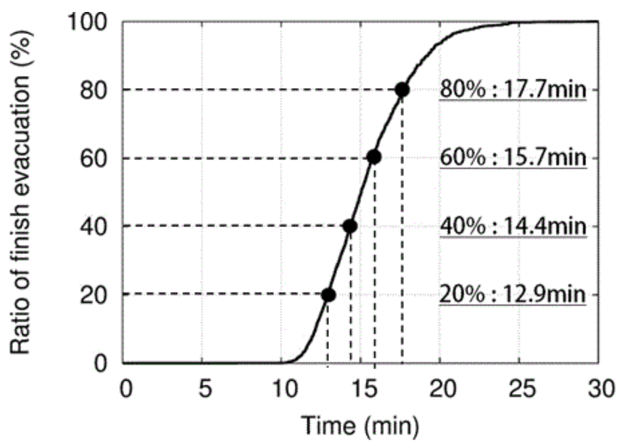


Fig. 8 – Ratio of having finished the tsunami evacuation

earthquake shaking, convinced those who were not aware of the coming tsunami just after the earthquake to start the tsunami evacuation. The result of this simulation revealed that the finishing evacuation ratio was significantly decreased by the expected time of tsunami arrival without quickly starting the tsunami evacuation.

6. Relationship between the start of the tsunami evacuation and the behaviors caused by the strong earthquake shaking

We described the evacuees' behaviors caused by the strong earthquake shaking and the start of the tsunami evacuation in the shopping center using interviews, security footages, and the evacuation simulation in the previous sections (3-5). The results revealed the close relationship between them. Meanwhile, it is needed to recognize that these both are different behaviors. We cannot discuss tsunami evacuation in the case, where many people in a building escaped outdoors, without considering the behaviors caused by the strong earthquake shaking. Their relationships can be discussed from three aspects: (1) how the reality outdoors of imminent emergency was, which prompted the need for the start of the tsunami evacuation; (2) how much of the percentage of people, who escaped outdoors, was needed to start the tsunami evacuation or go back indoors; and (3) can people who went back indoors start the tsunami evacuation or not.

(1) The reality is based on the concept of "Co-construction of social reality"[9]. This concept means that all stakeholders in our society, including each evacuee, construct the reality of imminent emergency which prompts the need for evacuation. In the case of Mall ZOFRI, the reality of imminent emergency was constructed by the

sounds of the siren, evacuation guidance by staff, extraordinary situation where many people walk to the hill, etc. The previous sections revealed that most of people escaped outdoors because of strong shaking of an earthquake. Meanwhile, it can be assumed that some of them were not be aware of tsunami. As a result of escaping outdoors, not only evacuees being aware of tsunami but also evacuees being not aware of it accessed the reality and can start tsunami evacuation.

(2) 77% of those who went outside Mall ZOFRI went to the hill and did not go back to the building (Fig. 4). Murakami[10)] conducted questionnaire survey in Iquique focusing on the behaviors after the 2014 Iquique earthquake. The survey reported that 40% of the people in Iquique started tsunami evacuation just after the earthquake occurrence. This percentage is much lower than that of our results. In the case of Mall ZOFRI, it can be assumed that the customers could not enjoy shopping because of the imminent indoor dangers (e.g., fears of building collapse) and they did not need to go back to the building. In Murakami's survey, most of people who answered the questionnaire were assumed to be at home when the earthquake occurred. It can be assumed that some of them would like to go back indoors to take things away, get information by TV, etc.

(3) 23% of those who went outside Mall ZOFRI went back to the building (Fig. 4). A similar situation was reported in the 2011 Tohoku Tsunami. Okumura et al.[8)] focused on the case of the elder care facility heavily damaged by tsunami. It revealed that staff and elder users in the building escaped outdoors in fear of falling objects, and then, they went back indoors because of cold weather outdoors. 160 s before tsunami reached the building, a few staff found tsunami hit the town and they start evacuation, shouted others to evacuate, helped elder users on evacuation. Finally, 41 elder users per 69 were killed by tsunami. In the case of Mall ZOFRI, fortunately tsunami did not reach. However, based on the case of the elder care facility, it is a critical issue that people who went back indoors can start the tsunami evacuation or not.

7. Conclusions

Focusing on the thousands of people who were in Mall ZOFRI during the 2014 off Iquique earthquake and tsunami, the authors reveal the relationship between the start of the tsunami evacuation and the behaviors because of the strong earthquake shaking using interviews, security footages, and the evacuation simulation. The main conclusions of this study had been presented.

[1] A close relationship is found between the start of the tsunami evacuation and the behaviors caused by the strong earthquake shaking. We cannot discuss the tsunami evacuation without considering the first actions caused by an earthquake in the case, where many people in a building escaped outdoors.

[2] Their relationship can be discussed from three aspects: (1) how the reality outdoors of imminent emergency was, which prompted the need for the start of the tsunami evacuation; (2) how much of the percentage of people, who escaped outdoors, was needed to start the tsunami evacuation or go back indoors; and (3) can people who went back indoors start the tsunami evacuation or not.

[3] The security footages showed that 90% of the people in the building took actions (e.g., tried to go outside despite the continued strong shaking). These actions can be caused by fears of strong shaking rather than the tsunami.

[4] Moreover, 77% of those who went outside Mall ZOFRI went to the hill and did not go back to the building. Escaping outdoors because of the strong earthquake shaking was an important behavior, which influenced those who were not aware of the coming tsunami just after the earthquake to start tsunami evacuation.

[5] We proposed the conceptual diagram on the start of the tsunami evacuation from a building considering the behaviors caused by the strong shaking (Fig. 5). Three types of atmospheres were considered: usual, protect against the earthquake, and tsunami evacuation modes.

[6] The evacuation simulation results suggested that the finishing evacuation ratio sharply decreased by the expected time of the expected tsunami arrival without the quick start of the tsunami evacuation triggered by the first action caused by the earthquake.

Acknowledgments

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