SUBWAY INUNDATION AND WHHELCHAIR USER EVACUATION DURING TSUNAMI BY NANKAI TROUGH EARTHQUAKE

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ABSTRACT

Cabinet office of Japan issued that Nankai trough earthquake will occur near future and it will bring high level tsunami to urban area. In urban area, people use subway and underground spaces. These areas are likely to be inundated by tsunami and it will be very dangerous. So, people must evacuate from subway stations or underground spaces after tsunami warning. However, it is very hard for wheelchair users to evacuate from underground spaces. Elevators are not available after earthquake so that people must carry wheelchair users through stairs. West area of Osaka city is low-lying area. So, this area is prone to inundation by tsunami. In this paper, inundation depth and starting time of flood water intruding into subway stations are calculated by 2D shallow water model. Lead time for safe evacuation was figured out and safety evacuation for wheelchair users was also investigated. From the results it is found that lead time is too short to make a safe evacuation at some stations. This means that appropriate evacuation plan for wheelchair users should be made as soon as possible.

Keywords: subway station, underground space, tsunami inundation, Nankai Trough Earthquake, evacuation

1. INTRODUCTION

Japan has been suffered severe damage by natural disaster such as earthquakes, typhoons and heavy rains. Japanese metropolitan cities like Tokyo, Nagoya and Osaka etc. are surrounded by rivers and coasts. Most of population in these cities is concentrated in flood prone areas. So, it is very vulnerable to water related disasters. In urban area, there are a lot of underground walkway connected subway stations. Underground space is likely to be inundated by flood water. Also, there are people who are elderly, pregnant women, blind and wheelchair users in underground space. Elevator is not available in the case of earthquake so that it is very difficult for wheelchair users to evacuate from underground spaces. At least 4 people are needed to help a wheelchair user for climbing stairs. The purpose of study is to investigate safe evacuation of wheelchair users from underground space in the case of tsunami inundation.

2. STUDY AREA AND SUBWAY LINES

2.1 Study area

Study area is Osaka city, Japan. Figure 1 shows topography of Osaka city on the basis of data issued by Geospatial Information Authority of Japan. Osaka city is surrounded by rivers and coasts. Ground elevation of the west side area is below the mean sea-level (Terada et al,2018). These zones can be inundated for long time by tsunami. Osaka city is very vulnerable to tsunami inundation. It is assumed that the tsunami caused by Nankai Trough Earthquake will attack study area in 110 minutes after the occurrence.

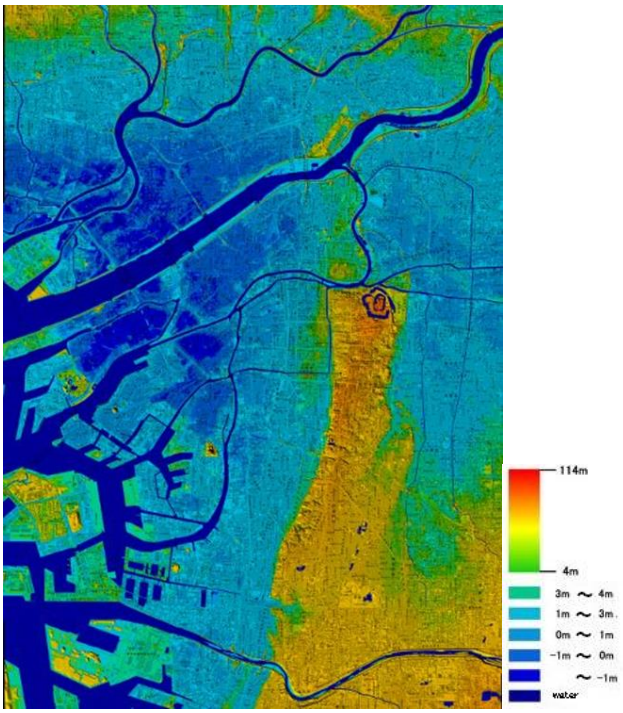

Figure1. Topography of study area

2.2 Subway lines

Figure 2 shows subway network in Osaka and station numbers (OsakaMetro,2020). These lines are Midosuji line (M15~30), Tanimachi line (T11~36), Yotsubashi line (Y11~21), Sennichimae line (S11~24), Chuo line (C15 ~23), Sakaisuji line (K11~20), Nagahori-Tsurumi ryokuchi line (N11~27), Imazatosuji line (I11~21), JR Tozai line (H1~6), Hanshin line (HS1~3, HS42~44 and A1~3) and Keihan line (KH1~3, KH51~54). As these lines are connected each other, inundation water would spread through the network.

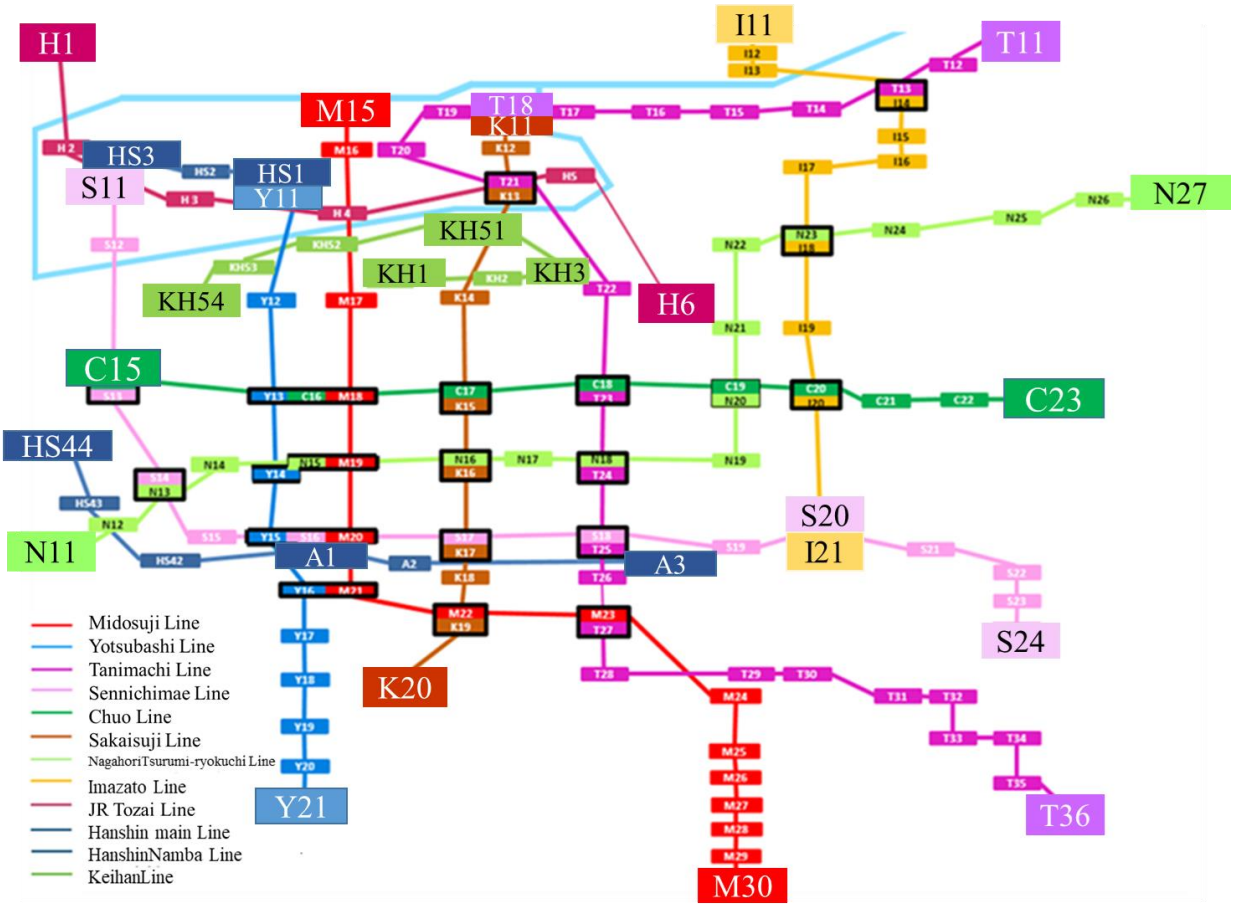

Figure 2. Subway network in Osaka

3. SIMULATIONMODEL

Cabinet office of Japan issued the data of 11 patterns of faults caused by the mega earthquake. In cases of 3, 4, 5, and 10, it is predicted that the giant tsunami will attack the study area. These four of simulation data were used here. Two-dimensional shallow water model with nesting scheme is employed. Finest resolution of topographic data is 30m. The water level of Osaka Bay is +0.90m at high tide. However, the peak water level of rivers in Osaka is higher than that of Osaka Bay. Considering this reason, the initial water level was uniformly adjusted to +1.20m. Levees of the simulation model are neither destroyed nor sank down. Water gates were not considered in the simulation. Tsunami inundation over levees is calculated by Honma's formula.

4. RESULTS

4.1 Inundation depth on the ground

Comparing the results of the four cases, result of the case 10 shows the highest inundation depth and the largest inundation area. Figure 3 shows the maximum inundation depth by the case 10. Inundation area was about 117.4 km^2 and almost all of the west part of Osaka city was inundated. According to the result, 16 subway stations were inundated.

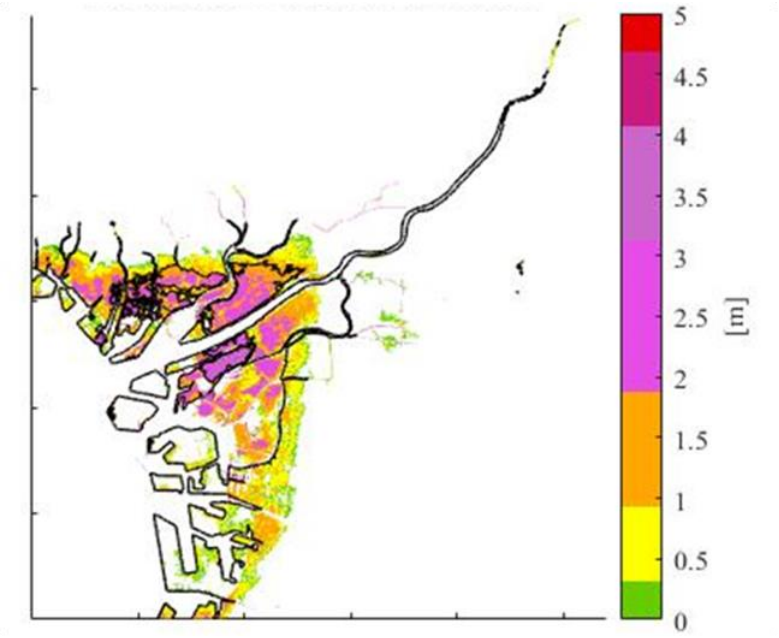

Figure 3. Maximum inundation depth of study area (case10)

Figure 4 shows profile of the inundation depth of the four stations of Nagahori Tsurumi-ryokuchi line. N11, N13 and N23 were inundated at 119 minutes after the earthquake occurred. These three stations were inundated earlier than that of any other inundated subway stations. As shown in Figure 4, N11 had the highest inundation depth at these three stations. It was found that N11 was significantly vulnerable to inundation by tsunami.

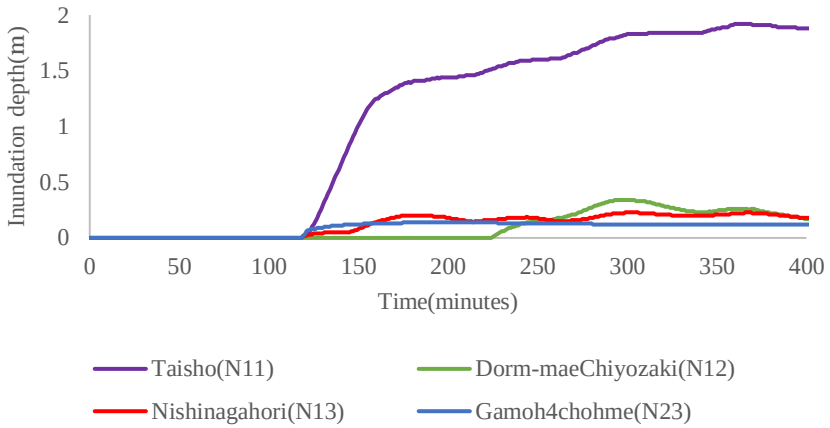

Figure 4. Time series of ground inundation depth at stations of NagahoriTsurumi-ryokuchi line

Figure 5 shows depth of inundated four stations of Hanshin line. Inundation depth on the ground of HS44 was higher than that of any other station in the area. Since the inundation depth was over 2.0m, people must evacuate to higher than 2nd floor of building.

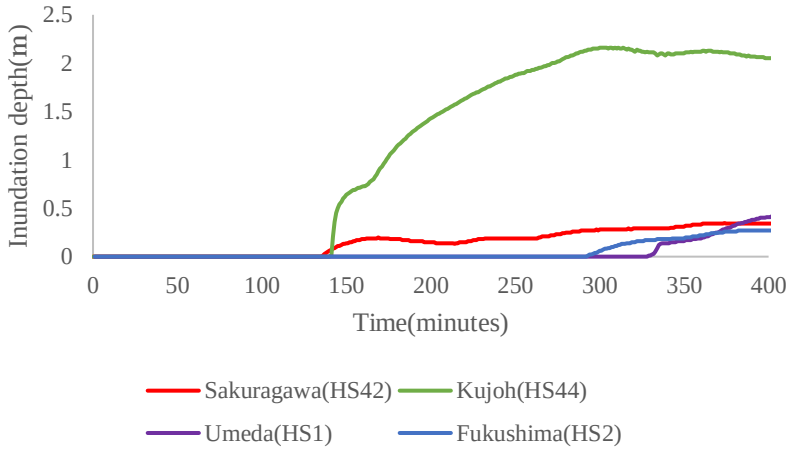

Figure 5. Time series of ground inundation depth at stations of Hanshin line

Next, the time when inundation started at each entrance was compared. Figure 6 shows the profile of inundation depth at the entrances of Taisho station (N11) and Figure 7 shows location of each entrance. The profile shows that entrance No.1 and No.3 of N11 were inundated at 119 minutes after the earthquake occurred. People have to evacuate from the station until that time.

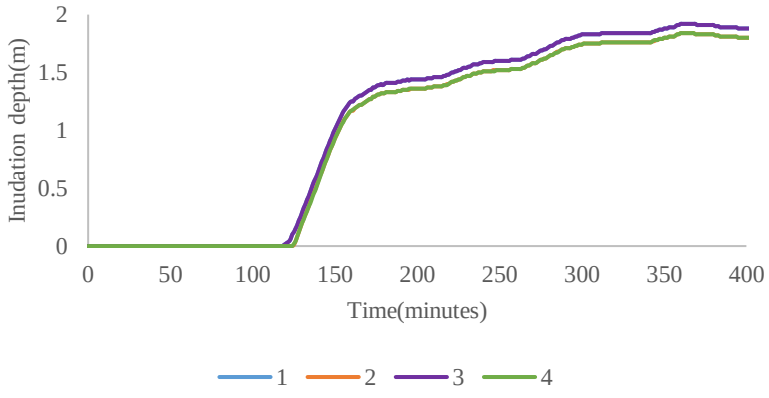

Figure 6. Time series of ground inundation depth at each entrance of Taisho (N11) station

Figure 7. Location of four entrances of Taisho(N11) station

Figure 8 shows inundation depth of each entrance of Kujo(HS44) station and Figure 9 shows the location of entrances. Entrance No.1 was inundated at 141minutes after the earthquake occurred and entrance No.2 was inundated at 143 minutes. Moreover, inundation depth of these entrances increased rapidly. Thus, it is too late to evacuate from HS44 station at 141 minutes after the occurrence.

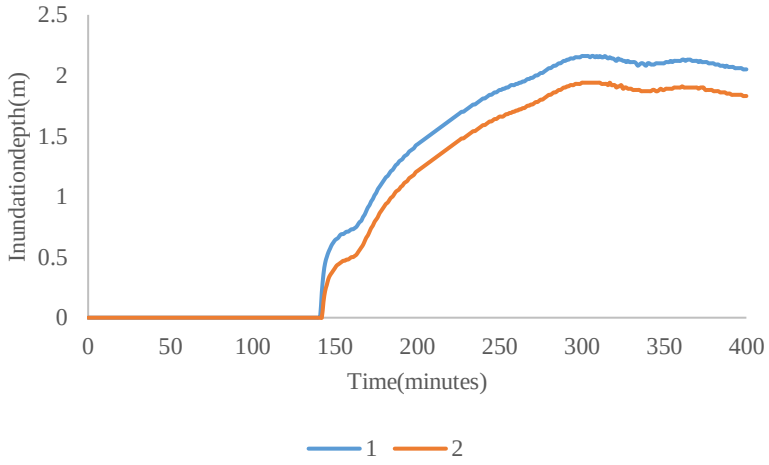

Figure 8. Time series of ground inundation depth at each entrance of Kujo(HS44) station

Figure 9. Location of two entrances of Kujo(HS44) station

4.2 Timeline of evacuation

The more water level increases in underground space, the more difficult wheelchair users evacuate from there (Kawanaka et al.,2017). Thus, people must evacuate from underground space by the time when subway station inundated. Figure 10 shows timeline of evacuation. In this study, it is presumed that people remain subway station after the earthquake occurs and that they decide to evacuate from there at stage 1 (110 minutes after the earthquake). At the latest, people must finish evacuation until stage 3. The time between stage 1 and stage 3 is defined as lead time. And, evacuation time of wheelchair users is the time between stage 1 and stage 2. In the case of earthquake, elevator is not available so that people must use stairs. In this survey, it takes a second for 4 people to climb a step of stair with wheelchair and its users, and speed of wheelchair is 0.5m per second on the floor of subway stations in the case with assistant. However, the evacuation time was measured without considering crowded situation. Also, subway station may be dark because of electricity lost after the mega earthquake. Therefore, it will take more times to evacuate from subway stations.

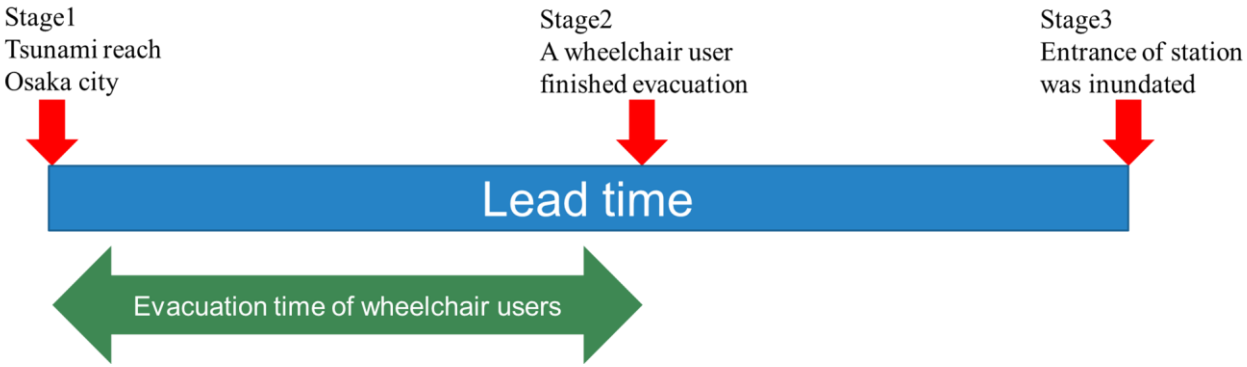

Figure 10. Timeline lead time of evacuation

Table 1 shows the lead time and time to evacuate for wheelchair users in inundated stations. The lead time of the N11, N13 and N23 station was only 9 minutes. It was not enough for wheelchair users to evacuate from these subway stations. From the results, it is concluded that people should evacuate from subway stations after shaking of the earthquake finishes.

Table 1. The lead times of flooded stations and the time required to evacuate wheelchair users in those stations.

Station	Lead Time(minutes)	Evacuation time of wheelchair users(minutes)
Taisho (N11)	9	7
Dorm-mae-chiyozaki(N12)	114	6
Kujo (HS44)	31	5
Mitejima(H47)	22	6
Nodahanshin(S11)	45	3
Sakuragwa(S15, HS42)	27	7
Ebie(H46)	45	5
Nishinagahori (S14, N13)	9	6
Shinfukushima(H45)	24	7
Tamagawa(S12)	19	3
Awaza(S12)	52	5
Fukushima (HS2)	182	4
Gamoh4chome(N23, I18)	9	6
Kitakagaya(Y22)	17	4
Umeda(M16,HS1,Y11,T20)	176	5
Kashima(H48)	35	6

5. CONCLUSIONS

Lead time of several stations was not enough to evacuate for wheelchair users in the case that people decide to evacuate from these stations. Thus, people should decide to evacuate from subway stations to taller than 3rd floor of buildings after the shaking of mega earthquake finished. In order to execute safe evacuation of people, station staff should be trained to guide people including wheelchair users and other disabled persons.

REFERENCES

Kawanaka, R., Ishigaki T., Ozaki, T. and Toda, K. (2017), Safe Evacuation of Wheelchair Users from Underground Mall by Pluvial Flooding, Proceeding on the symposium on underground space ,22, 123-126. (in Japanese)

Osaka Metro, Route Map, https://subway.osakametro.co.jp/img/osakametro_rosenzu_20191001.pdf,Accessed: 25/02/2020

Terada, M., Okabe, R., Ishigaki, T., Ozaki, T. and Toda, K. (2016), Subway Inundation by Pluvial Flooding in Urbanized Area, Journal of Japan Society of Civil Engineer, Ser. B1(Hydraulic Engineering), Vol. 72, No.4, ppI_1357_I_1362. (in Japanese)