

TSUNAMI EVACUATION SIMULATION CONSIDERING AREA-SPECIFIC REGULATORY EVACUATION

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INTRODUCTION

The Great East Japan Earthquake of 2011 caused serious damage, causing over 19,000 people dead or missing. The majority of the dead and missing were caused by the tsunami inundation. From the Tohoku tsunami, a combination of hard and soft measures has been implemented to defend against L2 tsunamis (1000 year return period tsunami). The most effective way to protect human life among the measures against L2 tsunamis is evacuation. Therefore, it is necessary to make an appropriate evacuation plan and to know how people move to evacuation areas. According to Takabatake et al. (2017), it is likely that reducing congestion would decrease the number of casualties. In addition, Makinoshima et al. (2022) have simulated tsunami evacuation with evacuation guidance and with different evacuation start times. However, there is few studies using an evacuation simulation considering a combination of evacuation start area and time-delayed evacuation. Therefore, in this study, tsunami evacuation simulations with time-delayed evacuation and region are conducted to quantitatively evaluate the number of fatalities and evacuation completion rate.

METHODS

The target area was the Shishiori district of Kesenuma City, Miyagi Prefecture. The coast of Kesenuma City is a rias coast, which is prone to high tsunami waves, and the Shishiori area has a river, which may cause tsunamis to run up the river. In this study, evacuation analysis was performed using Artisoc, a multi-agent simulation platform.

The tsunami inundation calculations were performed for the Great East Japan Earthquake that occurred on March 11, 2011, using COMCOT. Topographic data was obtained from GEBCO in 2019. COMCOT is a numerical model that discretizes the nonlinear long wave equation in cartesian or spherical coordinates, and can numerically calculate the generation, propagation, and inundation of tsunami. In this study, three hours of inundation were simulated using the fault model of the Great East Japan Earthquake by the Geospatial Information Authority of Japan (GSI), Ministry of Land, Infrastructure, Transport and Tourism, and one hour of that data was used for the tsunami evacuation simulation.

First, evacuation routes were set up. Each agent's destination was chosen at random from among a total of six evacuation centers and temporary shelters (Figure 1), and the shortest route was taken. The shortest route was calculated using the distance-weighted Dijkstra method. The moving speeds of 1.0 m/s and 0.5 m/s were used from the guidelines for tsunami evacuation planning provided by the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications. 0.5 m/s represents the walking delay of persons with walking difficulties, the physically disabled, and others. We considered people 65 years of age and older as having difficulty walking con-

sidering the aging population in this district. The speed reduction due to crowd density is based on Mori and Tsukaguchi (1977), which showed that the speed decreased by 1/3 when the crowd density became 1.5 persons/m².

Table 1 - Simulation case settings

case	start time for evacuation			
	all together	near ocean	middle	inner land
a1	immediately	-	-	-
a2	3min later	-	-	-
a3	10min later	-	-	-
a4	15min later	-	-	-
a5	20min later	-	-	-
a6	28min later	-	-	-
a7	30min later	-	-	-
a8	40min later	-	-	-
b1	-	immediately	-	3min later
b2	-	immediately	-	10min later
b3	-	immediately	-	28min later
b4	-	3min later	-	10min later
c1	-	immediately	-	3min later
c2	-	immediately	-	10min later
c3	-	immediately	-	28min later
c4	-	3min later	-	10min later
d1	-	immediately	3min later	28min later
e1	delayed start: immediately, 3min later, 28min later			



Figure 1 - Location of shelters

Two types of evacuees were considered: those over 65 years old and those under 65 years old. A total of 4,923

agents were evacuated from each node. The proportion of the elderly was assumed to be 32%.

Table 1 shows simulation cases. There were three cases to divide the area for staggered evacuation: simply divide the area in half (people near ocean evacuated earlier and people inner land area evacuated later) (case b), divide the area into a lowland zone that has not been raised and other area based on urban planning (case c), and divide the area into three areas from urban planning (case d). The one closer to the ocean was assumed to evacuate first, respectively. Eight patterns of simultaneous evacuation at 0, 3, 10, 15, 20, 28, 30 and 40 minutes after the earthquake (a1-8), 4 patterns of time-delayed evacuation per area (0 and 3 minutes, 0 and 10 minutes, 0 and 28 minutes, 3 and 10 minutes) for both half and lowland areas (b1-4, c1-4), In the case (d1), evacuation start time was 0 minutes, 3 minutes and 28 minutes later in the case where the evacuation was divided into three halves by the lowland zone and bypass. In the case one (e1), evacuation start time was 0 minutes, 3 minutes and 28 minutes later in the case where the evacuation was not divided into areas. For mortality conditions, the number of casualties was calculated depending on whether the area was flooded or not, considering the more hazardous side.

RESULTS

A total of 18 cases were simulated for tsunami evacuation in this study. Due to the random selection of evacuation sites, five times simulations were performed for each case. Figure 2 shows the number of casualties and Figure 3 shows the percentage of people which can arrive at the evacuation sites. The number of casualties increased as the start time of evacuation was delayed. For example, the number of casualties for (a1) and (a8) is about 83.2 and 1,467.8, respectively. This indicates that early evacuation can decrease the casualties.

In the cases (b1-4), the people near ocean zone evacuated earlier than people located near inner area. By comparing the cases (a1-8) and (b1-4), it can be said that staggered evacuation can be effective to reduce the number of casualties. In the cases (c1-4), people in the lowland area evacuated earlier than in the high elevation. However, overall, the casualties in the cases (c1-4) are larger compared with cases (b1-4). This indicates that the evacuation planning should be set according to the distance from the coast line rather than height of the land in order to reduce the casualties caused by tsunami inundation in this district. Comparing (d1) and (e1), the number of casualties decreased in (d1), where the area was divided into three. Then, the number of casualties was lower when the area was divided into areas. Therefore, staggered evacuation and division of land area to start the evacuation can reduce the number of casualties associated with tsunami inundation.

Figure 4 shows the horizontal distribution one hour after the earthquake in case c3. It is clear that few people have encountered tsunamis on the coast, while the people were drowned in inner area during the evacuation.

CONCLUSION

In this study, tsunami evacuation simulations were conducted for the Shishiori district of Kesenuma City, Miyagi Prefecture, using different evacuation start times

and different areas. The results indicate that staggered evacuation with separate evacuation areas can be effective

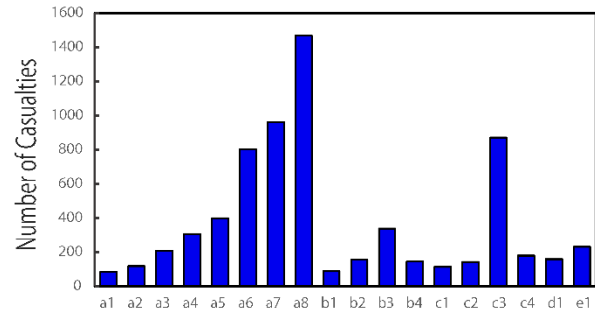


Figure 2 - Number of casualties in each case

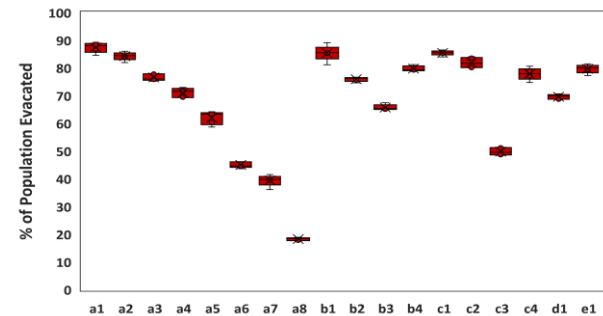


Figure 3 - Percentage of people which can arrive at the evacuation sites.

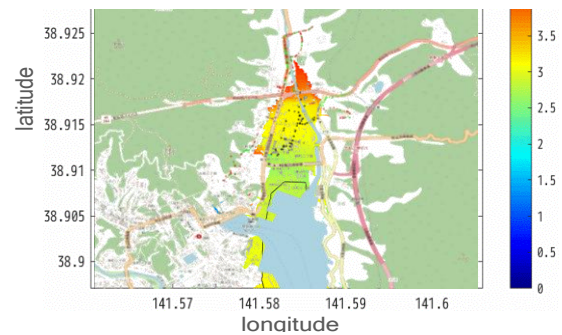


Figure 4 - the horizontal distribution one hour after the earthquake in case c3

in reducing the number of casualties and saving lives. It can be said that the staggered evacuation with division of land area for evacuation order has the potential to decrease the number of casualties associated with tsunami inundation.

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