TSUNAMI EVACUATION SIMULATON OF TOURISTS AND LOCAL RESIDENTS BY USING EXPECTED TSUNAMI OF NANKAI TROUGH EARTHQUAKE

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INTRODUCTION

The catastrophic Nankai Trough earthquake is expected to occur between the Philippine Sea Plate and the Eurasian Plate with 70-80% probability of occurring within 30 years from now. Under the worst-case scenario, the earthquake and tsunami are estimated to kill about 320,000 people and cause economic losses amounting to nearly 134 trillion yen. Due to potential catastrophic damage, many of Japanese leading tourist destinations, such as Osaka, Aichi, and Shizuoka prefectures, predicted the estimated inundation area. In the event of a major earthquake, tourists are more likely to be vulnerable to disaster than local residents who can usually check hazard maps and other warning services.

According to the damage survey report of the 2010 Chilean earthquake and tsunami, many tourists did not evacuate or did not know the place where to go to shelter. This example shows that tourists should prepare to evacuate from coastal hazards in their destination. If a disaster occurs while many tourists are in the area, an increase in the number of evacuees will cause serious congestion along the evacuation routes, and the evacuation of local residents is likely to be difficult at the same time.

Therefore, the purpose of this study is to quantitatively evaluate the damage and impact on tourists by using evacuation simulation based on possible catastrophic tsunami disaster. This study also evaluates the impact of the start time of evacuation and congestion on the fatality of tourists. The study location is the town of Shirahama which is tourist spot and is potentially affected by the Nankai trough earthquake tsunami.

METHODOLOGY

1. Target area

The Shirahama town in Wakayama prefecture is located in central south area of Japanese Archipelago (Fig. 1). It is a nationally famous tourist spot.

2. Tsunami and evacuation simulation

COMCOT was used for tsunami simulation. This model is the nonlinear long wave equation discretized in spherical coordinate systems. In this study, we used the earthquake case 3 presented by the Nankai Trough Large Earthquake Model Study Group, in which the rupture initiation point closest to the town of Shirahama was set. The simulation four domains were set to cover the northwestern Pacific Ocean as shown in Table 1. A multi-agent system, Artisoc v.4.2.1 standard, specialized for artificial society construction, was used for the evacuation simulation.

Table 1. Calculation range for each domain

	North latitude	East longitude
Domain1	30～35	130～140
Domain2	31.50～34.50	133～138
Domain3	33.50～33.90	135.10～135.50
Domain4	33.64～33.735	135.30～135.395

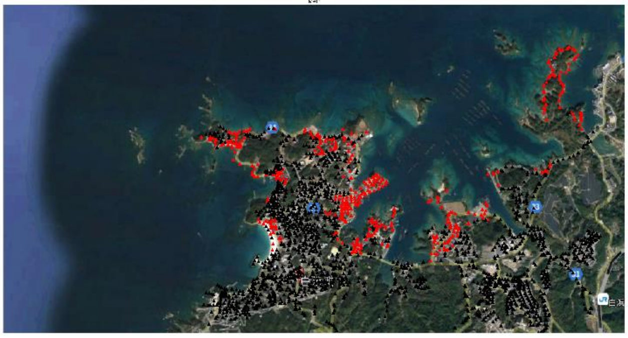

Figure 1. Study area (Red dots shows finally flooded points)

3. Initial conditions

3.1 Generation of local residents

Local population distribution based on the 2020 census from Japanese government were reflected on Artisoc. The number of evacuated local residents was 8,062.

3.2 Generation of tourists

The number of tourists in the entire the town of Shirahama area was taken from the 2021 Tourist Survey Report. Fourteen tourist sites within the simulation area of Artisoc were selected as the start locations of tourist agents. Also, the number of evacuated tourist agents was set to 3,432 on the Artisoc model according to Wakayama Prefecture (2023).

3.3 Evacuation routes and evacuation sites

In this study, it is assumed that the shortest path to the final destination was calculated from the initial location of evacuation. The A* algorithm was used to effectively find the shortest route from the initial location to the destination location. The evacuation sites (the final destination locations) were designated by referring the tsunami hazard map prepared by the town of Shirahama. Ten simulations were performed because the evacuees were randomly assigned in the initial location for evacuation.

4. Modeled Scenarios

This study quantitatively evaluates the effects of the delay in the start time of evacuation and the congestion caused by evacuation. Three scenarios were set based on considering the different start time of evacuation. Scenario 1 was based on a street survey of the expected tsunami arrival time according to Terumoto (2020), and the time was set to 7, 10, and 15 minutes after the earthquake (T1 scenario). Scenario 2 assumes immediate evacuation after the tsunami warning is issued because tsunami warnings are generally issued 3 minutes after the earthquake (T2 scenario). In the scenario 3 (T3 scenario), tourist started to evacuate at 20, 30, and 45 minutes, while local residents start to evacuate from 7, 10, and 15 minutes (The same as T1 scenario). This scenario referred to the street survey ((Terumoto, 2020) which studied the tourist perception for tsunami awareness. The free walking speed was set to 1.19 m/s with reference to Kumagai (Kumagai, 2014). The walking speed changed by congestion was set as following equations according to Older (Older, 1968).

$$v = v_0 \qquad (\mathrm{d} < 0.5)$$

$$v = v_0 - \left\{\frac{(v_0 - 0.2)(d - 0.5)}{2.5}\right\} \qquad (0.5 \le \mathrm{d} < 3.0)$$

$$v = 0.2 \qquad (3.0 \le \mathrm{d})$$

here v is walking speed (m/s), v_0 is free walking speed (m/s), and d is crowd density (the number of persons/m^2).

In this study, 10 meters resolution grid was employed. Each evacuee agent counted the number of other evacuee agents within 100 square meters, and the congestion level was considered based on this count.

RESULTS & DISCUSSION

The results of evacuation were described in four different cases. The different scenarios produced the different trend of fatalities of evacuees.

・ Case1 (T1 scenario + consideration of congestion): The simulation results showed that 297 tourists and 63 local residents were killed (Fig. 2). The number of killed tourists was larger than local residents. It is mainly because tourists were evacuated from just 14 locations and many tourists were densely packed even when evacuation was carried out. So, a lot of these people were drowned at same time when their position was inundated (shown in the results in Fig. 3). This leads to a larger number of killed tourists. Indeed, the severe damage was calculated in the rapid inundation area, such as the northwestern part of the Shirahama town.

・ Case2 (T1 scenario + no consideration of congestion): To evaluate the effect of congestion on evacuation, simulations were performed without considering congestion. Other conditions were the same as in case 1. As a result, the number of fatalities did not change compared with Case 1. This result shows that the effect of congestion was limited in this study area because the evacuation period was not significantly longer compared to previous studies.

・ Case3 (T2 scenario + consideration of congestion) Immediate evacuation was assumed after a warning service was issued, the number of fatalities of both local residents and tourists decreased. The effectiveness to reduce the fatalities was shown when immediate evacuation was conducted on quick decisions of local residents.

・ Case4 (T3 scenario + consideration of congestion) The results showed a 27% increase in the number of fatalities compared to the T1 scenario. Delayed evacuation and misunderstanding expected in the tourist were shown to significantly increase the likelihood of being affected.

CONCLUSION

This study indicates that tourists are more likely to be killed by a large earthquake than local residents. The time of the

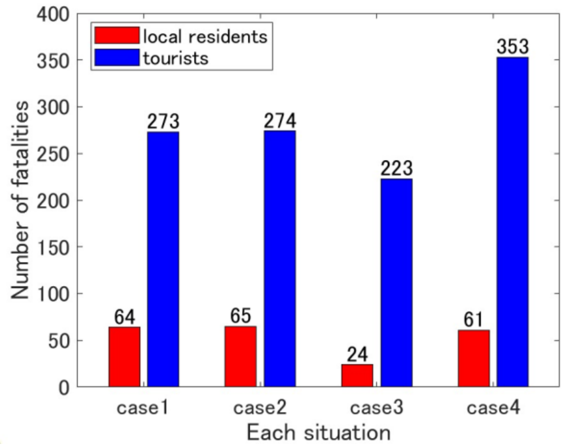

Figure 2. The number of fatalities in evacuation simulations under different cases.

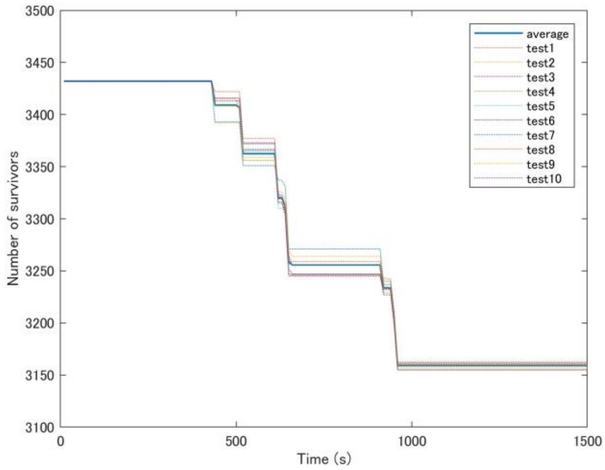

Figure 3. Number of survivors per elapsed time for tourists in Case1. Dashed line is individual results, and solid line shows average of 10 times.

start of evacuation can have the greatest impact on the number of fatalities. It is because tsunami arrival times vary by region, it can be important for tourists to obtain accurate information of evacuation. Also, it can be said that the tourists can be densely packed in the famous tourist spot which can be potentially led to the large mass of casualties.

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