EVALUATION OF TRAFFIC CONTROL MEASURES DURING TSUNAMI EVACUATION USING TRAFFIC SIMULATION

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Abstract

The 2011 off the Pacific coast of Tohoku Earthquake occurred on 11 September 2011 and caused extensive tsunami damage along the Pacific coast of Japan. Many citizens used their cars to evacuate from the tsunami. This caused traffic congestion on the roads, preventing smooth evacuation and consequently leading to increased human casualties. This highlighted the dangers of using cars during tsunami evacuation. The purpose of this study is to verify the hazards of car use during tsunami evacuation and to evaluate the limitation of car use. The study was conducted in the western part of the old-Kitakamigawa River in Ishinomaki City, where there was significant tsunami inundation damage and traffic congestion has been reported. A tsunami evacuation simulation of the target area was constructed using the open-source software SUMO. Questionnaire survey data from the Tsunami Evacuation Joint Study Group of the Japan Association for Earthquake Engineering were used to analyse evacuation behaviour such as place of departure and destination, and means of transport, and the results were used in the simulation. Scenarios were set up by controlling vehicle traffic at intersections and generated traffic volume. The simulation results suggest that traffic control at intersection where congestion is expected, may reduce the risk of evacuation by automobiles. The hazards of car-dependent evacuation were also confirmed, suggesting that the number of vehicles that can be used is extremely limited.

Keywords: tsunami evacuation, traffic simulation, traffic control

1 Introduction

Japan is an earthquake-prone country, and there are concerns about the devastating tsunami damage caused by a massive earthquake such as the Nankai Trough Earthquake. It is reported that the Great East Japan Earthquake that occurred on March 11, 2011, caused traffic congestion in many places due to a large number of automobiles evacuating from the tsunami. Meanwhile, since many people were able to evacuate by automobiles, the current basic policy for tsunami evacuation is “On foot in principle”.
The “Tsunami Countermeasures Manual Examination Report (2013)” by the Central Disaster Management Council of the Cabinet describes the circumstances requiring evacuation by automobiles and the need for consensus building among the relevant stakeholders with prior discussions.
However, the policy of “tsunami evacuation on foot in principle” is not always adhered to, as seen in the Noto Peninsula earthquake on January 1, 2024, when many people evacuated by automobiles. In addition, only a limited number of municipalities are considering the use of automobiles during tsunami evacuation.

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In order to advance the studies on how to use automobiles during tsunami evacuation in each region and district, it is necessary to clarify the conditions (target population for automobile evacuation, possible generation, evacuation destination, and traffic flow control) to realize smooth evacuation by automobiles.
Therefore, in this study, an evacuation traffic flow simulation was built to recognize the risks of evacuation by automobiles and to evaluate the possibility of smoothing the evacuation through traffic control at intersections and reduction in traffic volume generated.

2 Previous studies

So far, there are many studies developing evacuation simulator to assess the evacuation plan and estimate damage of human resources.
For example, Hanajima et al. [1] evaluated the effectiveness of controlling evacuation by traffic signals during evacuation from flooding. It was concluded that traffic control by the signals is effective in reducing the number of evacuees along the evacuation route when many evacuees move to a specific point, such as an evacuation shelter. Fukuda et al. [2] conducted an evacuation simulation by automobiles for a coastal area that could be affected by a Nankai Trough earthquake, and pointed out that a large number of vehicles would be unable to evacuate if major roads became impassable, indicating the need to reduce the use of automobiles. Makinoshima et al. [3] built a tsunami evacuation simulation for a waterfront urban area that considered multiple modes of transportation: pedestrians, bicycles, and automobiles. The results showed that evacuation by bicycle was the smoothest in the study area. It was also shown that it is important for pedestrian evacuees to have space in the road space to move smoothly, and that a high rate of car use during evacuation delays the completion of the evacuation.
Takabatake, et al. [4] mentioned that evacuation by vehicle is helpful for vulnerable people who cannot walk fast and they developed an agent-based tsunami evacuation model that considers the behaviour of both pedestrians and car evacuees. The model developed was validated through comparisons with the actual traffic jams observed at Tagajyo City, Japan during the 2011 Tohoku Earthquake Tsunami. They applied the model to another city to investigate the effectiveness of an evacuation plan that considers vehicle use for evacuation during a future Nankai-Tonankai Earthquake Tsunami. It was concluded that considering the capacity of evacuation places and the choice of route is important for a successful evacuation. Meanwhile, Wang, et al. [5] proposed realistic agent-based tsunami evacuation simulation by considering uncertainties in seismic damages to all links in the transportation network, the pedestrian–vehicle interaction, walking speed variability, and speed adjustment for both the pedestrian and car according to traffic density, and several different population sizes.
Furthermore, Fathianpour, et al. [6] developed a micro-simulation evacuation model to assess the effectiveness of local tsunami evacuation processes and test the results with a velocity-based theoretical model. The developed evacuation model can consider both pedestrian and vehicle interactions and their interactions with each other. The models were used to assess the evacuation scenarios for a tsunami-prone city Napier, in New Zealand. As the results, factors such as evacuation method, lane and sidewalk capacities, and interactions between individuals affect the individuals' ability to safely evacuate.
In addition to the above studies, many other research outcomes have been accumulated to achieve safe evacuation. In this study, a tsunami evacuation simulation reflecting actual evacuation behavior at the time of the Great East Japan Earthquake is built by referring to the existing research outcomes, and the effects of traffic flow control at busy intersections and reduction of car use are evaluated.

3 Data regarding tsunami evacuation

The western part of the former Kitakamigawa River in Ishinomaki City, Miyagi prefecture was focused on this research since there were significant inundation damage and severe traffic congestion. Figure 1 shows the tsunami hazard map of Ishinomaki City with the study area of this study indicated by a white box. Except for a small hill in the eastern part of the white box, all areas are designated as tsunami inundation zones. The posting survey regarding evacuation behavior was conducted by the Joint Survey Group about the Tsunami Evacuation of the Great East Japan Earthquake established under Japan Association for Earthquake Engineering.
This survey data contains detailed information on evacuation, including the starting point of evacuation, starting time of evacuation, destination of evacuation, means of transportation, companions during evacuation, and evacuation routes. In this study, the data on the starting point, the destination, and the means of evacuation were mainly utilized.

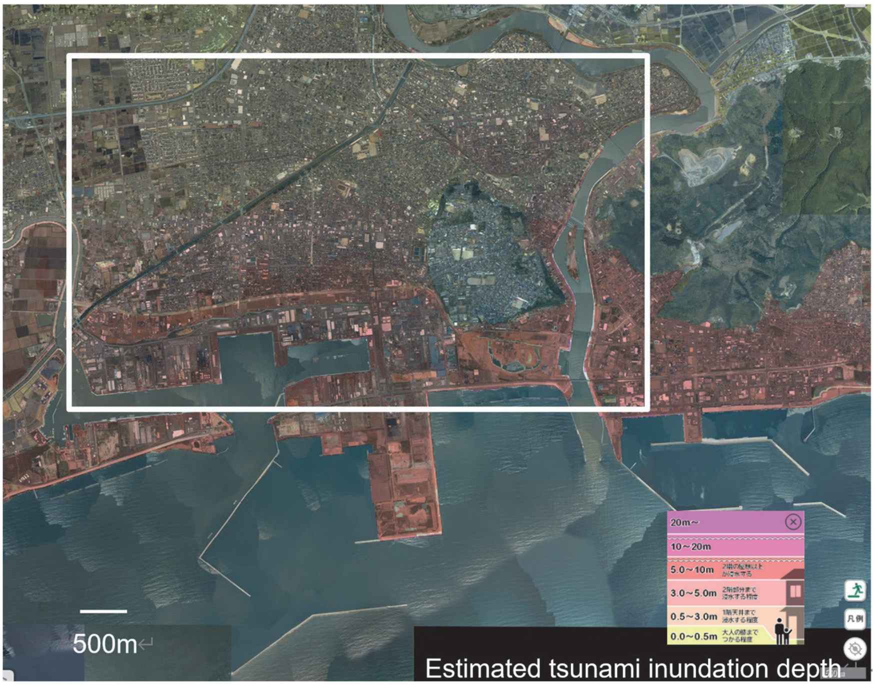

Figure 1 Tsunami hazard map of Ishinomaki-city and study area of the research

4 Tsunami evacuation simulation

4.1 Network configuration

In this study, SUMO (Simulation of Urban Mobility) is used as the simulation software. The OSM (Open Street Map) Web Wizard was also used to extract the road network in the study area. In this simulation, highways, national and prefectural roads, and general roads with two or more lanes were considered. In other words, the simulation did not consider residential roads. The road network used in the simulation is shown in Figure 2. The number of nodes is 247, the number of links is 612, and the number of intersections with traffic signals is 27.

4.2 Origin & destination, and traffic volume

There are 14 residential districts in the study area. Based on the results of the survey, the ratio of the destination chosen for evacuation was calculated for each of these residential areas. The number of people who evacuated by automobile was calculated by multiplying this ratio by the total residential population based on the 2010 National Census (Statistics Bureau, Ministry of Internal Affairs and Communications), and then by the ratio of people who used automobiles during evacuation (51%) in the study area. Furthermore, the number of vehicles moving from the residential district to the evacuation destination was determined by assuming that the number of persons seated in each vehicle was two, referring to other report on tsunami evacuation. As a result, the number of vehicles generated for tsunami evacuation simulation was 7,996.
The generation points for evacuation vehicles are set in the small zones that consist of residential districts. In Figure 3, 46 blue circles indicate origin points and 29 red circles indicate destinations for evacuation. The number of vehicles evacuated from the origin to the destination was set according to the percentages of the evacuees who evacuated by automobile from each residential district.

Figure 2 Road network considered in simulation

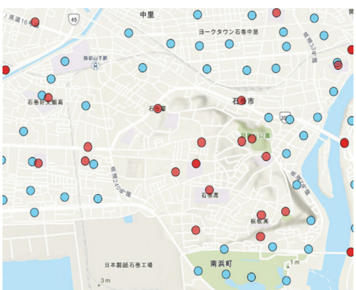

Figure 3 Origin (Blue points) and Destination (Red points)

4.3 Route setting

Since the evacuation was conducted under a major tsunami warning, it is assumed that it was difficult to make rational decisions. Moreover, as shown in the left figure of Figure 4, many roads were congested with traffic, and it was not possible to select a route according to the situation. Therefore, in this study, the route from Origin to the destination was set based on the shortest route search.

4.4 Confirmation of reproducibility

The reproducibility of the simulation was confirmed by comparing the locations of traffic congestion. Figure 4 shows the actual congestion locations witnessed on the left side and the simulated congestion locations on the right side. It is concluded from these figures that the simulation is generally able to reproduce congestion at intersections on major roads.

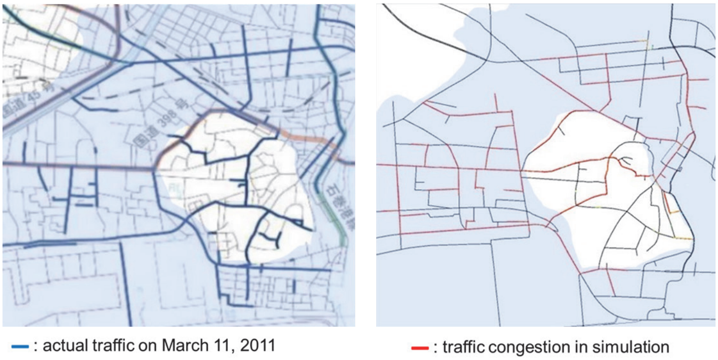

Figure 4 Confirmation of reproducibility of traffic congestion

5 Evaluation of evacuation facilitation measures

A slightly elevated hill in the study area that was not inundated by the tsunami can be seen in the center of Figure 4. On the road leading to this hill, there was a traffic congestion due to the concentration of vehicles for evacuation. Therefore, a simulation was conducted to evaluate the effect of reducing the number of vehicles heading for the hill. Specifically, control of traffic flow at the intersection marked by the green circle shown in Figure 5 was implemented. The destination of evacuation vehicles passing through this intersection was changed to another destination that can be accessed without passing through this intersection.
The results are shown in Figure 5. It can be seen that traffic congestion around the intersection was reduced when traffic flow control was applied (right side) compared to the case where traffic flow control was not applied (left side). Although the number of congested sections has been reduced, congestion still occurs. Therefore, it was evaluated to what extent the reduction of the generation of vehicles improves the safety of evacuation. Two evaluation indicators were used. The first one is the number of vehicles in the inundated area at one hour after the earthquake when the tsunami reached the study area, and the second one is the percentage of vehicles that could get out of the inundated area by one hour after the earthquake.
The results are shown in Figure 6. The horizontal axis shows the total number of vehicles, with three cases from left to right: no reduction (7,996 vehicles), 25% reduction (5,997 vehicles), and 50% reduction (3,998 vehicles). The blue bar graph shows the number of vehicles in the inundated area at one hour after the earthquake, and the red line graph shows the evacuation success rate. The figure shows that the evacuation success rate increased significantly by drastically reducing the number of vehicles during the evacuation. These results suggest that the safety of evacuation by automobiles can be improved by appropriately controlling traffic flow and the number of vehicles.

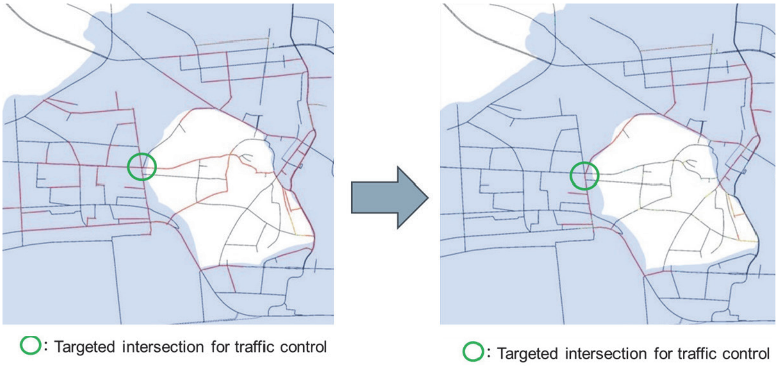

Figure 5 Changes in congested sections by controlling traffic flow at intersection

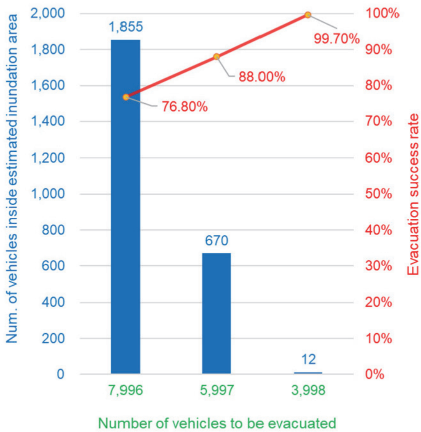

Figure 6 Effects of controlling the traffic volume generated on evacuation safety

6 Conclusion

In spite of the fact that experts have pointed out the risks of excessive usage of automobiles for tsunami evacuation, traffic congestion still occurs when a tsunami warning was issued even after the Great East Japan Earthquake. In this study, by using the results of a questionnaire survey of evacuees from the Great East Japan Earthquake, a simulation reflecting the situation of evacuation by automobiles was constructed to reconfirm the risks of evacuation by automobiles and to verify the feasibility of smooth evacuation by automobiles. As a result, it was confirmed that traffic flow control to reduce the number of vehicles entering a congested intersection and countermeasures to control the amount of vehicles generated are effective in increasing the safety of evacuation by automobiles.
However, changes in evacuation destinations and evacuation routes in response to congestion and other road conditions were not considered in this study. In further studies, it will be necessary to improve the reproducibility of evacuation action by taking into account dynamic selection of evacuation destinations and routes in order to faithfully reflect actual evacuation behavior.

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