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Verification for Improvement of Crowd Evacuation Conditions by Evacuation Guidance during Tsunami Disaster

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Abstract

Improvement for disaster information transmission and verification method against evacuation problems are continued through the various efforts. In addition, it is also necessary to verify the evacuation problems during disasters. Announcement of evacuation sites using hazard map and disaster mitigation education such as evacuation training are important as previous countermeasure for the disasters. On the other hands, evacuation guidance is effective for the crowd evacuation condition. However, it is necessary to verify to countermeasures during disasters because few research results were provided so far. Hence, this research verifies the effect of optimize deployment of evacuation guides.

Multi-Agent simulation was used for the verification, and numerical data model of urban zone was replaced the numerical network model. As widely known, bottleneck of road network is most important factor on the crowd evacuation condition. Therefore, this verification pic-upped the bottleneck sites in the urban area during crowd evacuation condition, and the deployment of evacuation guides was decided based on the results of crowd evacuation simulation. As a specific of deployment criterion, the number of cumulative population density was calculated based on the simulation without evacuation guides. The results of the numerical simulations show that the concentration of evacuee crowd at particular evacuation roots are improved by the deployment of evacuation guides based on this research results. In addition, total evacuation time is reduced comparing with in the case of simulation without evacuation guiding.

Keywords: Tsunami Disaster, Crowd evacuation, Evacuation guidance, Multi-Agent Simulation

1. Introduction

In Japan, Disaster Countermeasures Basic Act is reconsidered drastically based on terrible damages for pacific side coast area in 2011. In addition, Center Disaster Management Council undertakes the revision for Basic Disaster Management Plan. For the countermeasures against tsunami disaster, it is required to predict the maximum class tsunami wave based on scientific knowledge in this plan. It is also required to prepare the countermeasures for both hard side and soft side based on the evacuation during disasters. Moreover, some local governments already prepared the countermeasures against tsunami disaster before the act of center government. For instance, the map showing the areas expected to be flooded in the coast is published in Kanagawa prefecture as a “Hazard map”.

Many researchers investigates the evacuation problems during disaster based on experiments and analyses. In the recent years, evacuation simulation is focused as one of effective method to verify the problems. As typical calculation method, flood model and particle model were developed with many numerical verifications. However, these numerical verifications have many unsolved problems as a human action based on psychology during disasters in particular. According to the researches of the past, it is important to verify based on the reasonable terms for the consistency of crowd behavior between experiment and numerical calculation.

Thus improvement for disaster information transmission and verification method against evacuation problems are continued through the various efforts. In addition, it is also necessary to verify the evacuation problems during disasters. Announcement of evacuation sites using hazard map and disaster mitigation education such as evacuation training are important as previous countermeasure for the disasters. On the other hands, evacuation guidance is effective for the crowd evacuation condition. However, it is necessary to verify to countermeasures during disasters because few research results were provided so far. Hence, this research verifies the effect of optimize deployment of evacuation guides.

Verifications for the method of evacuation guiding and the effect of evacuation guides in buildings are progressed by many researcher, however, evacuation guiding in some section of a coast area is necessary to verify as one of wide area disaster problems. Therefore, this study simulated crowd evacuation in coast area to verify the evacuation guiding method based on the quantitative evaluation.

2. Summary of numerical simulation

For evacuation simulation, road network data of urban zone is replaced by numerical network model, and optimization of evacuation guiding is verified in this study. Congestion and staying may occur at connection point of several roads and narrow width roads under the crowd evacuation condition. Continuing of congestion influence on the extension of evacuation time. Therefore this research focuses the congestion at bottlenecks on the evacuation route, and the method of improving evacuation condition is discussed based on the evacuation guiding.

In this research, deployment of evacuation guides is applied as the method of improving evacuation condition. Where, prevention of evacuee’s crowding for certain route is defined the role of evacuation guides. Premise result of evacuation simulation is necessary to decide the deployment of evacuation guides. Authors have been verified the qualitative evaluation for crowd evacuation condition. However, quantitative results is required to deploy the evacuation guides on huge numerical network space. Hence, this study verifies the quantitative evaluation method for crowd condition of simulation. In addition, the deployment of evacuation guides is decided based on the premise simulation result.

3. Evaluation of evacuation congestion

Several evaluation index is used for congestion condition of road network. For example, traffic congestion [MLIT, 2010] is calculated based on person trip survey or survey on origin-destination, and pedestrian congestion [Tsukada et al., 2006] is showed by NILIM. This research defines custom parameter in order to evaluate the crowd evacuation congestion as below.

$$CON = \sum \rho_n \tag{1}$$

Where, *CON*: evacuation congestion, ρ_n: population density per second (unit: population/m^2/sec). *CON* is cumulative of population density for total evacuation time at each node. Large value of this index shows that high population condition continues for a long time, therefore crowd evacuation congestion is evaluated quantitatively as numerical parameter in the calculation.

In order to confirm *CON* as the effectiveness of index, fundamental simple simulation was conducted. For the fundamental simulation, several lattice-like network models were prepared as shown in Fig. 1, and *CON* was calculated at every nodes. Evacuation route of agent was calculated based on the algorithm of graph theory. However, this algorithm depends on the length of link, then aspect ratio of lattice-like network should change except for 1:1. Moreover, road widths for every link were defined in order to consider the spot traffic volume. These parameters were changed as shown in Table 1.

Table 1 – Verification cases of lattice-like network model

	Road width	**Aspect ratio of links (vertical : horizontal)**
Case 1	3 m	1 : 0.9 or 1.1
Case 2	4 m	1 : 0.9 or 1.1
Case 3	3 m	0.9 or 1.1 : 1
Case 4	4 m	0.9 or 1.1 : 1

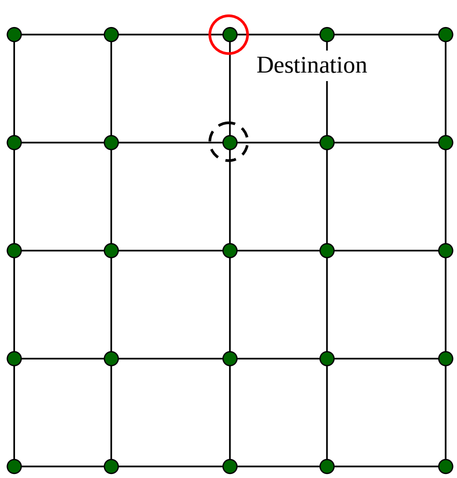

Fig. 1 – Lattice-like network model

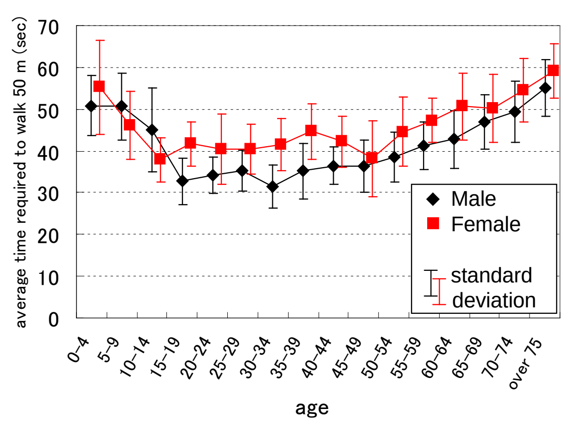

Fig. 2 – Required time per 50m by walking

On the other hand, the walking speed of the gender and the generation is estimated based on the research data which is provided by Akutsu [Akutsu, 1975] as shown in Fig. 2. In addition, relationship between wakling velocity and population density is also defined in the calculation based on Kimura's verification [Kimura et al., 1937]. Moreover, avoidance behavior algorithm which is to avoid that different evacuee agents contact each other is calculated [Kitahara et al., 2013]. 10 evacuee agents were deployed at every node except of destination node.

Fig. 3 shows the history of evacuation congestion at node marked broken line circle in Fig.1. Vertical axis shows the value of evacuation congestion normalized by cumulative value, and simulation time is normalized by total time for horizontal axis. In addition, the results of Case 1 and Case 3 are normalized by the values of Case 2 and Case 4, respectively. Evacuation routes in the case of same aspect ratio become same routing, therefore simulation results are normalized in order to focus the influence of road width. The value of evacuation congestion in Case 1 and Case 3 is greater than Case 2 and Case 4 as shown in Fig. 3. The results shows road width affects the evacuation congestion in the cases of same evacuation routing. Moreover, the results shows the effectiveness as the evaluation index of evacuation congestion.

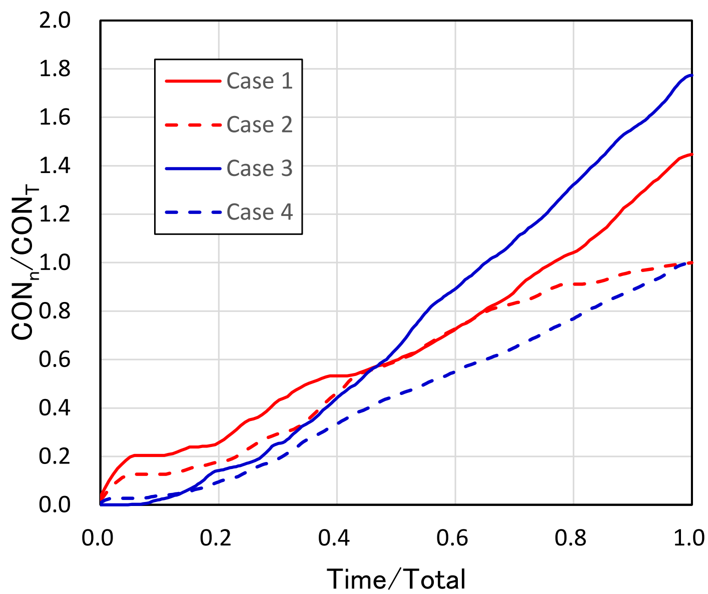

Fig. 3 – History of evacuation congestions

4. Verification for improvement of crowd evacuation condition

4.1 Numerical modeling of coast area network

Numerical simulation in actual coast area is conducted in order to verify the influence of deploying evacuation guides for crowd evacuation condition. Effectiveness of *CON* is already confirmed as described in previous chapter, therefore this index is applied for the simulation. The numerical data model of evacuation simulation space is replaced by numerical network model as shown in Fig. 4, where the intersections are replaced by the nodes and the roads are replaced by links. In addition, every link is defined the road width based on field survey.

6 destinations of numerical simulation are defined as the evacuation places as shown in Fig. 5. Evacuation routes are calculated previously based on the algorithm of graph theory as same as previous chapter. Walking speed is also defined as same as previous chapter. For the number of evacuee agent, 4,201 evacuee agents are defined from demographic data of target area.

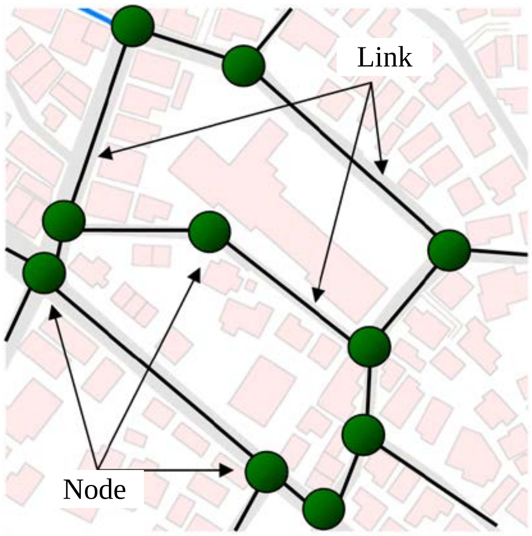

Fig. 4 – Consept of network model

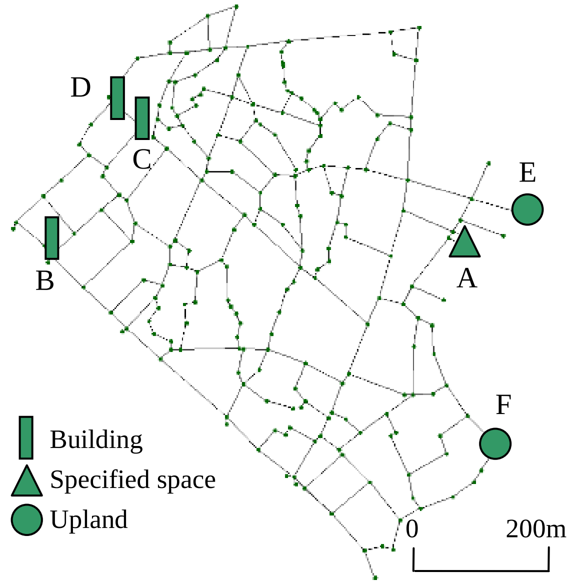

Fig. 5 – Whole of network model and evacuatin places

4.2 Verification for deployment of evacuation guides

Crowd evacuation simulation is conducted to calculate the evacuation congestion at each node before deciding the deployment of evacuation guides. Fig. 6 shows the evacuation congestion at each node, and the values of evacuation congestion are varied. Criterion for the value of evacuation congestion is necessary to decide the deployment of evacuation guides, however, the number of verification sample [ex. Fruin, 1971] is few in order to define the criterion. Hence, 1000 is used as the provisional criterion for fundamental study.

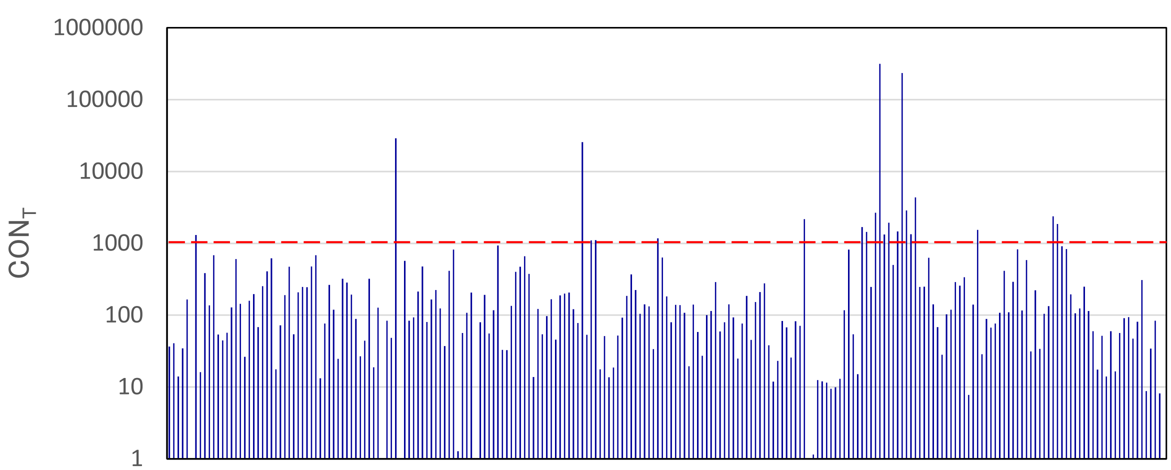

Fig. 6 – Values of evacuation congestions for all nodes

The role of evacuation guides is limited as guiding for bypass route. Therefore two simple conditions are provided as the condition of evacuation guide deployment. One is the node has bypass route, and other is the node links the node which CON is greater than 1000 directly. As the results of decision the deployment of evacuation guides based on previous condition, three nodes are selected as shown in Fig. 7.

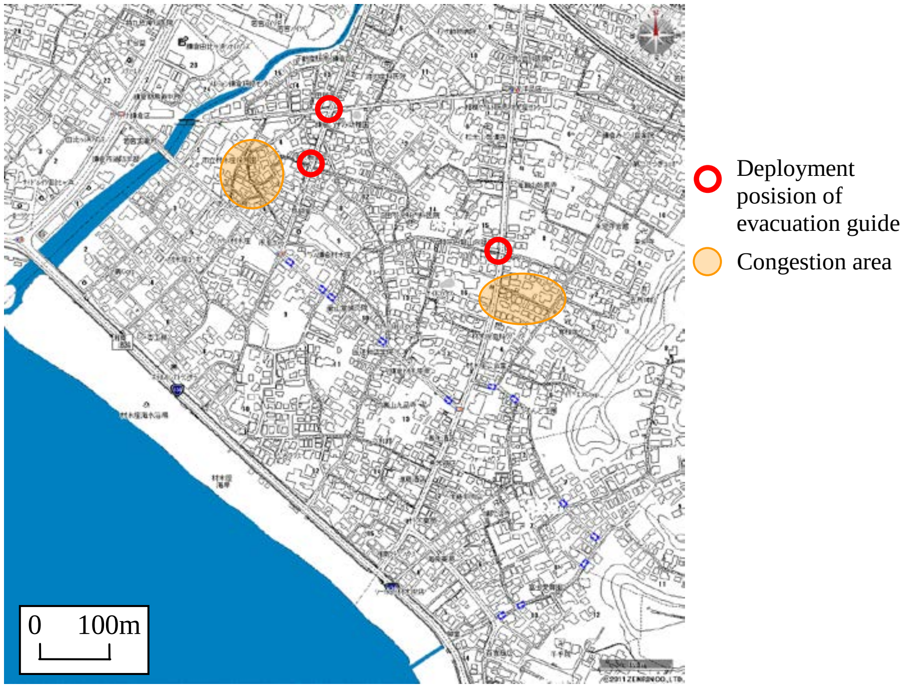

Fig. 7 – Deployment of evacuation guides

4.3 Influence of evacuation guides deployment

Fig. 8 and Fig. 9 show the results of evacuation simulations with or without the deployment of evacuation guides. In both figures, red point shows the each evacuee agent, and evacuation crowd is indicated red line shaped in the figures. These figures show the evacuation routes in the circle are changed by deployment of evacuation guides.

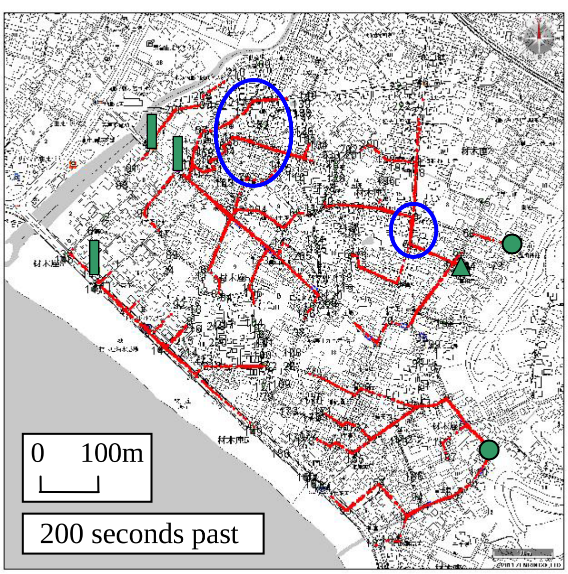

Fig. 8 – Simulation result with evacuation guding

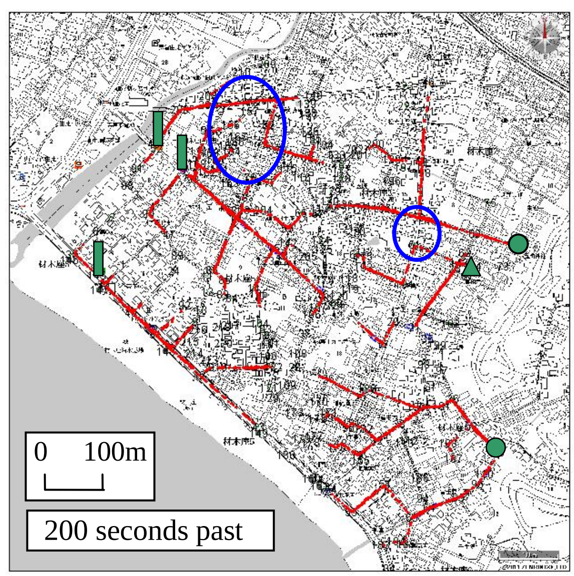

Fig. 9 – Simulation result without evacuation guding

Fig. 10 shows the difference of the number of evacuated agent at evacuation places. The numbers at Place A and Place C decrease by deployment of evacuation guides. On the other hand, the numbers at Place D and Place E are increased. Fig. 11 shows the difference of total evacuation time for with or without the evacuation guides. The result shows the evacuation guiding prevents the congestion of evacuation crowd for certain routes, and total evacuation time is reduced due to deployment of evacuation guides. As the general result of this verification, crowd evacuation condition is improved by evacuation guiding.

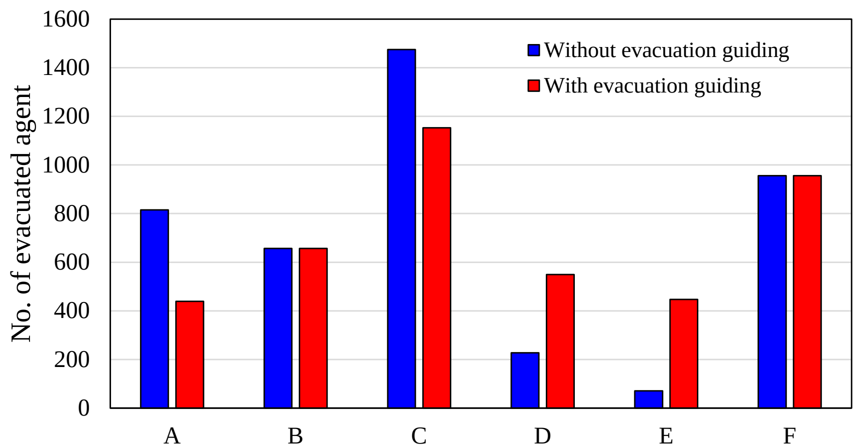

Fig. 10 – Number of evacuated agent for each evacuation place

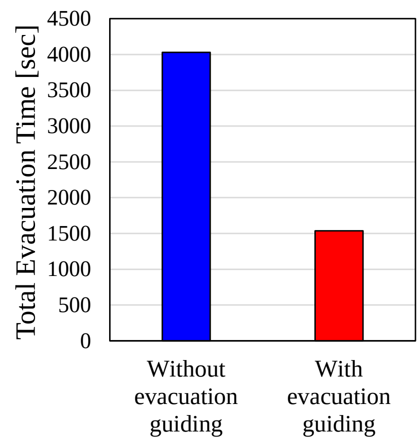

Fig. 11 – Total evacuation time

In this study, evacuation routes of numerical simulation are calculated previously based on graph theory. However, actual evacuation routes may be momently changed depending on the environmental conditions during disasters. For future study, consideration for influence of condition changes is necessary to verify the simulation.

4. Conclusions

This study simulated crowd evacuation in coast area to verify the evacuation guiding method based on the quantitative evaluation. Conclusions of this verification are summarized as follows.

(1) In order to evaluate the crowd evacuation condition of numerical simulation, evacuation congestion is defined as the quantitative index.

(2) 2 simple premise conditions are defined for the deployment of evacuation guides based on the evacuation congestion index.

(3) As the effects of the evacuation guiding, crowding evacuee for certain routes is prevented and total evacuation time is reduced. Crowd evacuation condition is improved by evacuation guiding.

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