CROWD REFUGE SIMULATION TAKING INTO ACCOUNT DIFFERENCE IN HEIGHT FROM TSUNAMI HAZARD

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ABSTRACT

Recently, coast areas in Japan have a crisis of tsunami disaster caused of huge ocean-trench earthquake. Then, the autonomous communities have to prepare the refuge plan immediately. In order to take refuge smoothly in disasters, it is important to carry out refuge practices and emergency trainings preliminarily. On the other hand, calculating crowd refuge simulation using the numerical model is advanced as one of the verifying methods of the problem. Hence, this paper discusses the crowd refuge simulation from tsunami disaster. In this research, the refuge simulation is calculated by multi-agent system, because the many factors will be influenced on the crowd refuge during earthquake. In addition, Dijikstra's algorithm is applied for calculation method of route selection. The number of refugee agents are divided two routing type which one is calculating only horizontal distance and other is considering the difference in height.

Keywords: Crowd refuge, multi-agent simulation, tsunami disaster, difference in height.

1. INTRODUCTION

Great East Japan Earthquake occurred on March 11th, 2011, and this huge ocean-trench earthquake causes terrible damages around the coast areas in front of pacific side by tsunami. Since 1995, many verifications of retrofit and seismic reinforcement for the structures are conducted, however, the importance of the measurement against tsunami disaster is reminded by this earthquake.

Coast areas in Japan have a crisis from tsunami disaster, and the measurement against flood inundation is focused recently. Moreover, occurrence of inland earthquake in South Kanto area is predicted by technical investigation of Central Disaster Prevention Council in Japan. Then, the autonomous communities have to prepare the refuge plan immediately. For example, the map showing the areas expected to be flooded in the coast is published in Kanagawa prefecture.

On the development and implementation of the measurement against the tsunami hazard, it is necessary to consider the hard side and the soft side, however, many problems like a mental state

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are remain to decide the outline plan of refuge. In order to refuge smoothly in disasters, it is important to carry out refuge practices and emergency trainings preliminarily. However, it is difficult to conduct these training with a lot of people. Then, calculating crowd refuge simulation using the numerical model is advanced one of the verifying methods of the problem.

Several kinds of the numerical calculation methods are already developed to conduct the refuge simulation during disasters. For example, the crowd refuge simulation during fire was conducted by fluid-flow model by Fujita (Fujita, 1976). Moreover, Shiizuka introduced the application of the refuge simulation based on the Petri Net theory (Shiizuka, 1990).

On the other hand, the verifications using the multi-agent simulation are increasing to simulate the crowd refuge behavior in recent years. Multi-agent system is possible to calculate the interaction of the information between the many factors. Then, this system is able to simulate the complex situations in the disasters. For example, Chikata et al. evaluated the action of the pedestrians and leader for escape from underground space using multi-agent system (Chikata et al., 2008).

However, the simulation method which considering the difference in terrain height is under investigation. Hence, this paper discusses the crowd refuge simulation taking into account difference in height from tsunami disaster using multi-agent system.

2. REFUGE SIMULATION

2.1. Target area

Target area of the refuge simulation as shown in Figure 1 is adopted from the map showing the areas expected to be flooded in the coast of Kamakura city. This hazard map is made by Kanagawa prefecture (Kanagawa Pref., 2012), and the map is based on the disaster records of Meio earthquake which was ocean-trench type earthquake and occurred in 1498. The numerical data model of refuge simulation space was replaced the numerical network model as shown in Figure 2, where the intersections and the roads are replaced the nodes and the edges.

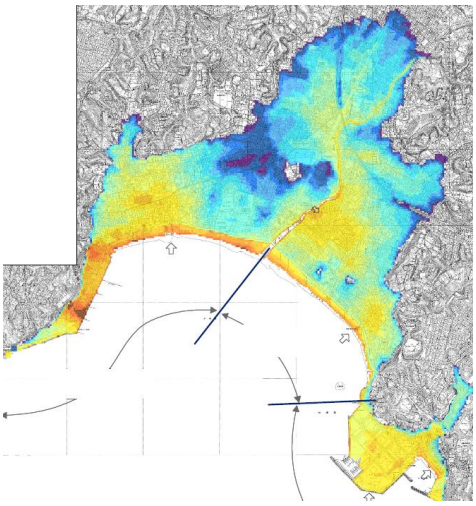


Figure 1: Predicted flood area in coast of Kamakura city

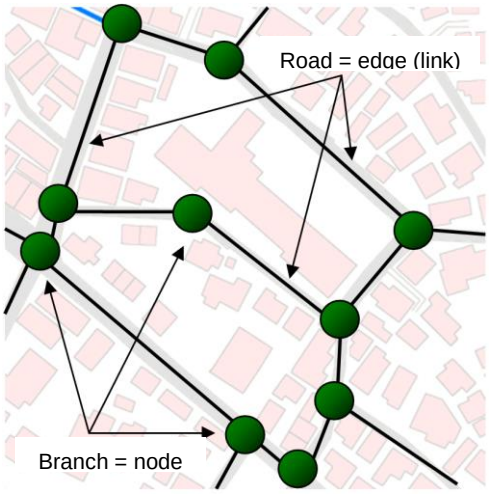


Figure 2: Numerical network model of urban zone

2.2. Verification method

Multi-agent system was used to make the numerical simulation model. The costs of each edge were calculated by Dijikstra's algorithm, and the refugee behavior is routing the shortest path to the refuge areas. In this simulation, the difference in height between node and node is considered in the cost calculation as following equation.

$$C_{ij} = \alpha \cdot h_{ij} + \beta \frac{v_{\max} - v_{ij}}{v_{\max}} h_{ij} \tag{1}$$

where, C_{ij} is the cost of each edge, h_{ij} is the horizontal distance of each edge, v_{ij} is the difference in height of each edge, v_{max} is the maximum value of the difference in height of the simulation space, α is the coefficient of the horizontal distance, β is the coefficient of the difference in height.

The transportation of refugee agents is limited only walking in this simulation. The gender and the generation of refugee are considered as the fluctuating parameter of walking speed, and 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 Figure 3.

Murayama et al. reported the change of the walking speed which depends on inclined angle of the slope of road. Then, the changing ratios of the walking speed of the refuge agents are assumed as shown in Table 1 which based on research data of Murayama et al. (Murayama et al., 2000).

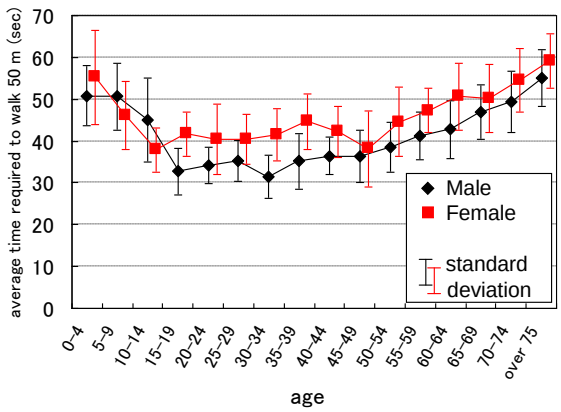


Figure 3: Required time per 50m by walking

Table 1:Rate of change of walking speed with inclined angle

Inclined angle	Rate of change
20	0.66
10	0.88
0	1.00
-10	1.11
-20	1.12

2.3. Conditions of Analysis

The number of refugee agents in the simulation is assumed as the population of the target area, and the ratios of the gender and the generation are also assumed based on demographic data of Kamakura city.

The number of refuge areas is estimated from the hazard map published by Kamakura city, and the upland which is located outside of the areas expected to be flooded and higher than the 10 m of

altitude above sea level are also assumed as the refuge area in the numerical simulation. The number of formers is 29 areas and the latter is 19 areas.

Two route selection methods of refugee agent are prepared that one is the route which refugee agents follows the shortest horizontal distance to the refuge areas and other is the route which refugee agents give preference to move the higher altitude over present location. These route selection methods are figured out based on the equation 1, and the values of the coefficients including equation 1 are defined that (α, β) = (10, 0) is used in routing shortest horizontal distance, (α, β) = (1, 9) is used in routing with consideration the difference in height.

The avoidance behavior algorithm which is to avoid the contact between refugees is calculated in the simulation, and Figure 4 shows the conceptual diagram of the avoidance behavior algorithm. The avoidance behavior algorithm is calculated as follow. The personal space of refugee is defined ahead 180 degree of direction of movement. Then, refugee agents take avoidance behavior in case of recognition of other refugee agent in the personal space.

Authors confirmed the effect that the evacuation time is influenced of the range of personal space. The range of personal space is assumed as 1.0 m from prevent verification.

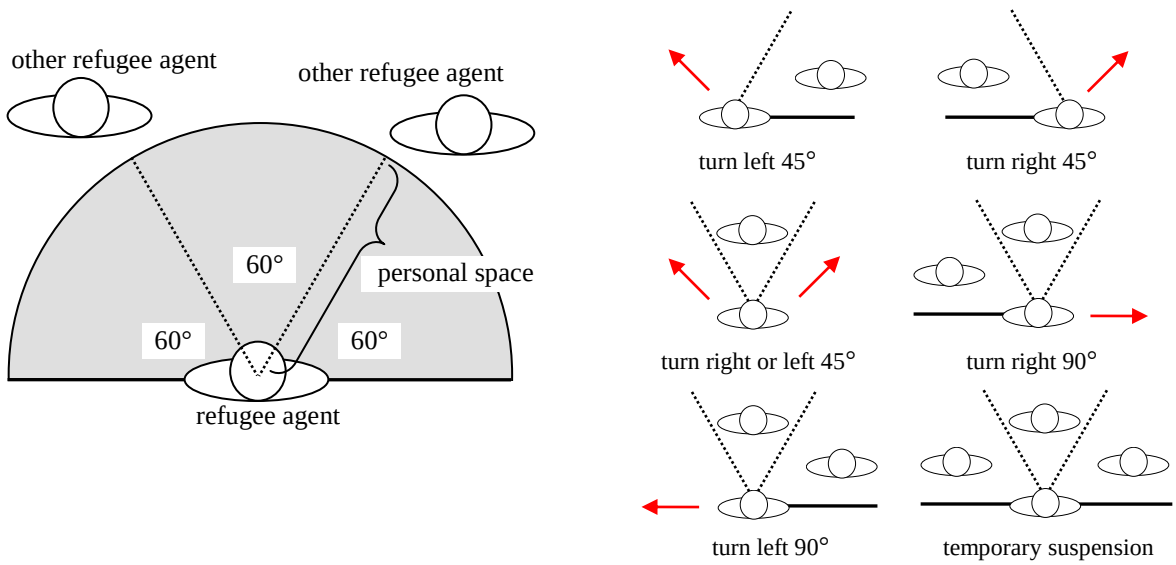


Figure 4: Avoidance behavior rule of refugee agent

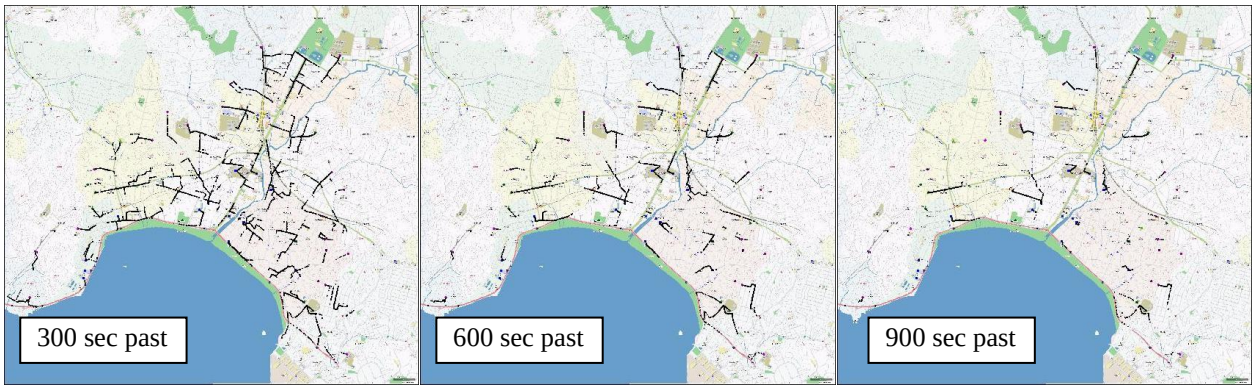
2.4. Analysis cases

All refugee agents are migrated to the refuge areas as a precondition in the simulation, and refugee agents are identified two types based on the refuge route selection methods. The ratio of the number of refugee agents which considers the deference in height of route is changed in the simulation, and 3 analytical cases which are 0%, 50% and 100% of the ratio are conducted. However, understanding the actual configuration of refugees is difficult. Then, the initial configuration of refuge agents which considers the parameters of the gender and the generation are arranged using random number, and the each analytical case was calculated 10 times in the simulation.

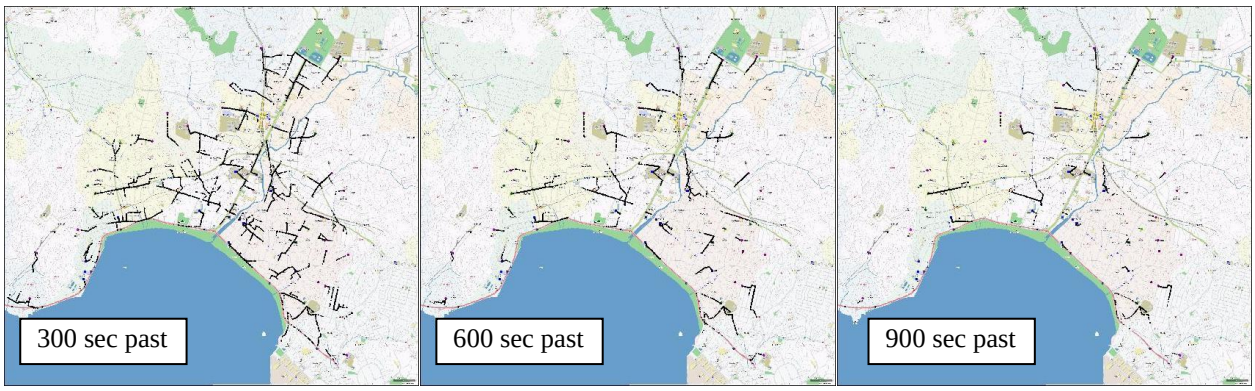
3. RESULTS OF NUMERICAL SIMULATIONS

3.1. Refuge conditions of the numerical simulations

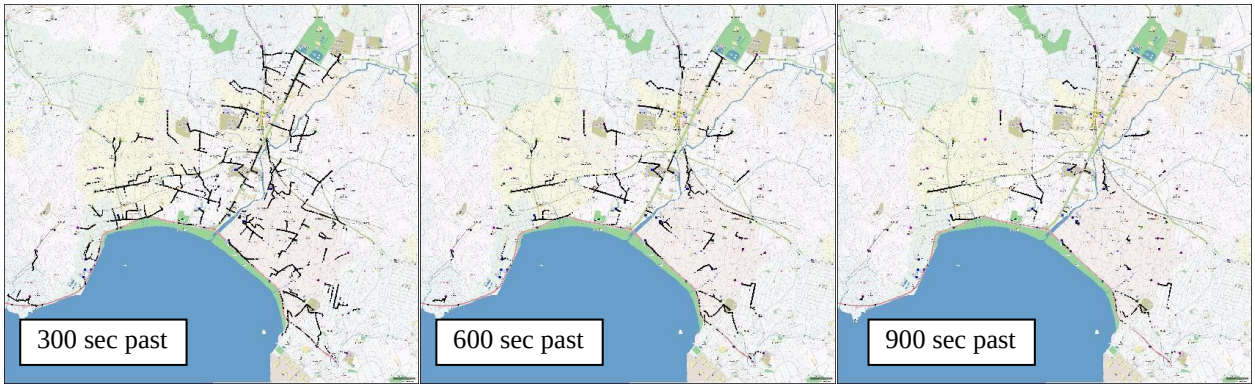
Figure 5 shows the refuge conditions with the elapsed time of the numerical simulations of each analytical case, where, black point on the maps is evacuating crowd. The number of refugee agents on the map is decreasing with time elapsing due to reach the refuge areas. On the other hand, focusing the difference of the route selection methods, the refuge conditions of every analytical case are similar. The number of the evacuated agents of 26 refuge areas shows the same value in the simulations which are considered the difference of the route selection methods.



(a) Ratio of the number of refugees considering the difference in height = 0 %



(b) Ratio of the number of refugees considering the difference in height = 50 %



(c) Ratio of the number of refugees considering the difference in height = 100 %

Figure 5:Refuge condition of each analytical case

Figure 6 shows the historical data of the number of the evacuated agents at refuge area F. The historical curves of 3 analytical cases are similar, because some edges have long distance which is not affected the difference in height. In addition, the number of refuge areas is large and these refuge areas are distributed nearly each other. Then, these conditions are affected the results of the simulations similarly. However, the effect of psychological condition during disaster is not considered as the numerical parameter of the difference in height. For the future study, it is necessary to consider the psychological condition.

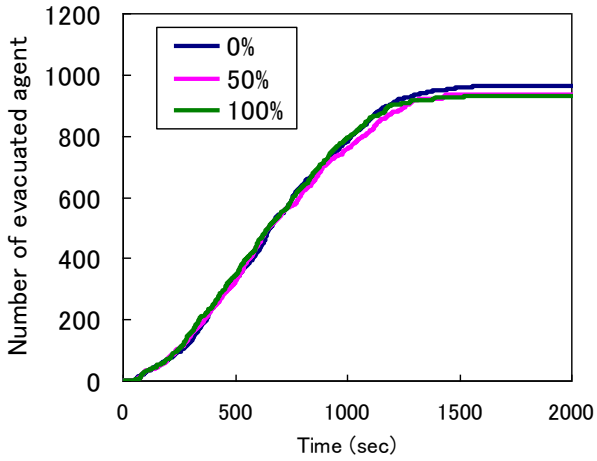


Figure 6:Number of evacuated agents- evacuation time at refuge area F

3.2. Effect of the difference of route selection methods for the number of evacuated refugees

Figure 7 shows the location of 8 refuge areas, the differences of the number of evacuated agents of different routing of these refuge areas are larger than others. In addition, the numbers of the evacuated agents at each refuge area are showed in Figure 8.

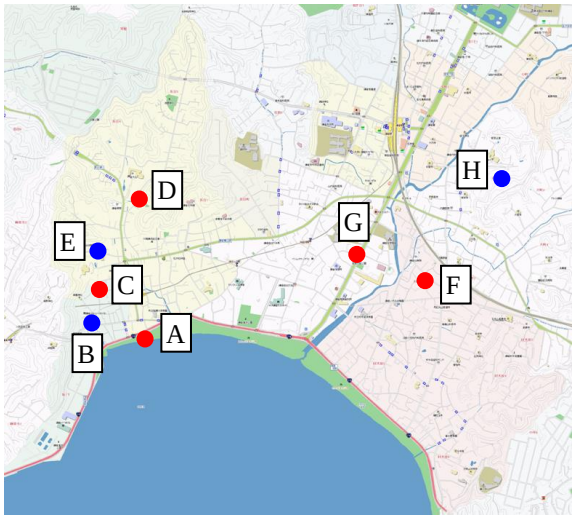


Figure 7:Location of refuge areas

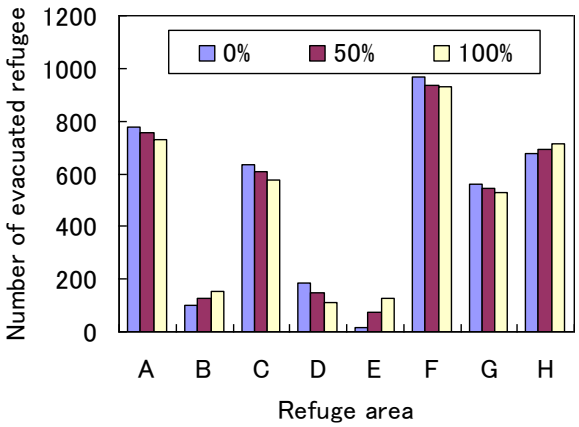


Figure 8:Number of evacuated refugees of each refuge area

The number of the evacuated agents at refuge area A is increasing with increasing the number of refugee agents that gives priority to select the shortest horizontal distance to the refuge areas as the route selection. On the other hand, the number of the evacuated agents at refuge area B is decreasing. Comparing the locations of the refuge area A and B, refuge area B is located farther away from sea coast. Then, the number of the evacuated agents at the refuge area B is increased due to consider the difference in height and select to the higher altitude above sea level.

Refuge area C and D are also located farther away from sea coast, however, the number of the evacuated agents is largest in case of the route selection method which is calculated the shortest horizontal distance to the refuge area C and D. In contrast, the number of the evacuated agents at refuge area E which is also located farther away from sea coast is decreased in the same analytical case. Compare the altitude above sea level of the 3 refuge areas, refuge area E is located on the highest place. Therefore, the number of evacuated agents that consider the difference in height is increasing.

Refuge area F and G are located near the Kamakura station on the plain which is farther away from sea coast. Thus, the number of the evacuated agents is largest in case of the selection the shortest horizontal distance to the refuge area F and G by refugee agent. However, the number of the evacuated agents at refuge area H which is also located in high altitude and farther away from sea coast is decreased in the same analytical case. These results show that the number of the evacuated agents on each refuge area is affected the difference of the number of the refugee agents that considered the difference in height. Moreover, the reflection of geographical properties is influenced to add the second term for the cost calculation equation with consideration the difference in height, and refuge condition is also affected.

4. CONCLUSION

The refuge simulation in Kamakura city is conducted as one of the estimations from tsunami hazard. In the numerical calculation, the parameters which are considered the difference in height are incorporated for the route selection methods, however, the psychological factors are not concerned in the simulation.

1. General refuge conditions in numerical simulations are not affected the changing the ratio of the number of the refugee agents that routing with consideration of the difference in height.
2. The number of the evacuated refugee agents for the refuge areas which are located high altitude above sea level is increased in case of the consideration of the difference in height as the route selection method.
3. Addition the second term for the equation of Dijikstra’s algorithm is possible to consider the difference in height in the refuge simulation. Then, it is possible to reflect the geographical properties for refuge simulation.

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