

Numerical Simulation Model of Group Walking for Tsunami Evacuees

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Abstract: The purposes of this study are to conduct a field survey on behaviour of group walking, and to propose a numerical simulation model for group walking of tsunami evacuees. A field survey was conducted, and time-series data of group walking for tsunami evacuees were obtained at a tsunami evacuation drill using an evacuee tracking system. It was found that 90 percent of the evacuees walked in groups, and the others walked in a single or in a pair. Although the system needs accuracy enhancement of measurement, it was confirmed that each group was different in speed from the other groups. And it was also found that the group which passed through the measurement area first was the fastest in speed, the last group was the slowest in speed, and the other group was in the middle speed of the first group and the last group. A model of group walking including a synchronization parameter was proposed, and a numerical simulation was conducted. It was found that the results of the simulation agree with the facts based on the field survey, although there were a few differences between the results of the simulation and the field survey in view of the speed of the group. Several reasons could be considered such as an effect of an evacuation leader at the front of the first group, and an applicability limit of the synchronization parameter model for groups consist of two or three persons.

Keywords: Group walking, tsunami, evacuation, numerical simulation

1 Introduction

Ministry of Land, Infrastructure, Transport and Tourism of Japan [1] conducted a questionnaire survey to tsunami evacuees after the 2011 Tohoku earthquake. According to the survey, it was found that approximately 29 % of evacuees on foot evacuated by himself or herself alone in Kamaishi City, Iwate Prefecture. This means approximately 71 % of evacuees on foot evacuated in group. It was also found that 48 % of evacuees on foot evacuated in group in Sendai City, Miyagi Prefecture. Thus, in the two cities, the percentage of people who evacuated in group reaches about half or more of evacuees.

To continue this article, it is necessary to examine a definition of a term, ‘group walking’. We defined the term as a pedestrian activity of small group which consists of several or a dozen people at a maximum. In that sense, group walking differs from ‘multitude walking’, a pedestrian activity in congestion. In the field of the

research of multitude walking, many studies have been made and some valuable models of correlation between speed v and density ρ of pedestrians have been proposed, such as the power-law model, the linear model, and the others [2] [3]. Although valuable models of multitude walking have been proposed as stated above, characteristics of group walking has not yet been discussed enough.

Tsunami evacuation simulation is useful for planning tsunami-resilient communities. Although tsunami evacuation simulations include model/models of multitude walking, it apparently do not include effect of the group walking. In consideration of the fact discussed in the preceding paragraphs, developing a model of group walking for tsunami evacuees and integrating tsunami evacuation simulation with the model are important to modify the simulation.

2 Past Studies on Group Walking

Togawa [4] conducted field observations on group

walking of pedestrians. According to the results, Togawa found that the speeds of two persons are adjusted, and they walk at the average speed of the two or slightly more slowly than that. In case two persons walking at 1.5 m/s and 1.3 m/s, their speed may come the range of 1.35-1.4 m/s. When three persons are walking in group, their speed will be slightly slower than the average of the natural speeds of the three. In case the natural speeds of the three are 1.5 m/s, 1.4 m/s and 1.3 m/s, the average speed will be roughly 1.35 m/s. And this tendency will be much stronger when the group consists of four, five or more persons; All may adjust their average speed to that of the lowest in speed. Togawa [4] also stated about crowd walk of one way flow through wide passage. Groups were generated naturally, and he called the phenomenon ‘group of comets’. Fig. 1 is an illustration of a birds-eye snapshot quoted from the thesis, and Togawa explains a formation process as follows; A group of slow walkers forms a nucleus at the head. There are a group of people who easily fall in suit following around this nucleus. This continues in a chain form spreading out to the width of the passageway and compose a comet-like group. Togawa also pointed out that the comets move at different speed. In case a rectangular region of 50 m in length and 20 m in width, shown in Fig.1, the number of pedestrians were 1,364 and speed of comets distributed from 0.5 m/s to 0.7 m/s.

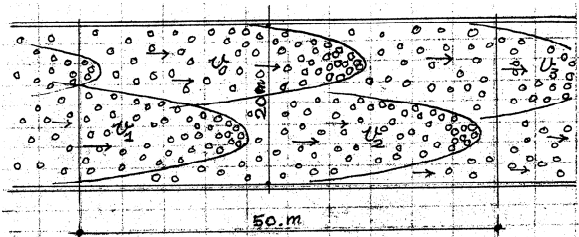


Fig. 1 Group of comets (Togawa [4])

Mashita et al. [5] conducted field observation of one way flow in a shopping street, and they reported that a natural walking speed of person isolated was increased by 25 % compared to a speed of group walking. The average speeds are 1.009 m/s and 0.805 m/s, respectively. But few field surveys of this type have apparently been published to date, and there are very few reports about speed of group walking. More detailed research is required for group walking, especially for that of tsunami evacuees.

Togawa [6] introduced a concept of psychological factor for decision making to outstrip a person who walks ahead. According to his idea, if a person is in ‘synchronization’ psychologically, the person will fol-

low the person walk ahead and slow down. In contrast, if the person is in ‘repulsion’ psychologically, the person will outstrip the other. Cristiani et al [7] conducted study on an interaction between group of pedestrians, which they call ‘social group’, and crowds. They pointed out that a group consisted of 3-4 members deploy themselves in V-like formation naturally, because member of the group wants to keep verbal contact with the others. When they move in crowded environment, the group re-arrange itself taking a river-like configuration rather than keeping ease of communication. Takayanagi et al. [8] also conducted study on the river-like configuration in a crowded environment, and proposed a model of pedestrians who try to keep optimum velocities in crowded space. Their model includes two states such as ‘track phase’ and ‘follow phase’. According to their model, pedestrians use the two phases alternately and form small groups, because they want to pass through crowded space with comfort. A pedestrian attempts to catch up a pedestrian who walks ahead and to reduce a distance with the target. If the tracker come closer with the target, his or her track phase is switched to the follow phase, and the tracker becomes a follower and keep the distance with the target. Although an applicability of these ideas for forming groups to tsunami evacuees is not clear, it could be useful to apply this simple idea to modelling group walking of tsunami evacuees.

The purpose of this study is to conduct an experimental survey on behaviour of group walking, and to propose a numerical simulation model for group walking of tsunami evacuees. In the following paragraph, the experimental survey was conducted on an event of tsunami evacuation drill by using an evacuee tracking system. Since the tsunami event is rare, it seems to be reasonable to observe behaviours of evacuees on tsunami evacuation drill as an alternative of an actual tsunami evacuation. In the fourth paragraph, a numerical simulation model was proposed for group walking of tsunami evacuees, and was applied to the result of the evacuee tracking for a validation of the model. In the fifth paragraph, we summarized conclusions of this study.

3 Evacuee Tracking on Tsunami Evacuation Drill

3.1 Evacuee Tracking System

Fig. 2 is a conceptual diagram of an evacuee tracking system developed in this study. The system consisted of two laser range sensors, a PC, wireless LAN network

and some batteries. Table 1 shows details of the equipment for the system.

One laser range sensor installed one side of a street, and the other installed the opposite side of the street. A laser was projected to the horizontal direction from the optical source of the sensor, and a scan area was fan-like shape on horizontal plane. A measurable range from the sensor to a target object was approximately 30 m for the maximum, and the range was enough to apply for a wide street. The optical source was set at approximately 1 m in height from the ground level. The sensor was adapted to the class 1 regulation of safeness for laser products by FDA, USA [9], and it means that the sensor was safe enough for evacuee to see the optical source directory without any laser-protective glasses. In case two or more evacuees overlap in a straight line from the optical source of the sensor, only one evacuee's location can be detected and it was impossible to measure the other evacuees by using a single sensor. Then we adopted two sensors for the system we developed. In principle, three or more sensors can be install the system in view of accuracy in measurement, but we adopted two because of avoiding complex handling to measure and disadvantage of increasing cost. A horizontal distance between the two sensors was measured by an ultrasonic range meter.

Wireless LAN network was used to transmit data from the laser range sensors to the PC. Each equipment which were consisted of the wireless LAN network was compatible with the laws and the regulations for outdoor-use of wireless communication technology in Japan. Because of adopting the non-contact laser range sensors and

the wireless LAN network, the evacuee tracking system has no physical impact to the traffic flow on the street.

Recording software had been installed in PC, and the software provided a real-time monitoring of the result on the screen of the PC, and recording the time-series of results in HDD of the PC.

A video camera was used for a confirmatory purpose, and we recorded evacuee's behaviour from a fixed point by the camera from the start of the drill to finish.

3.2 Tsunami Evacuation Drill

In this study, a survey area for the evacuee tracking was a residential area of Shimoda city, Shizuoka Prefecture of Japan, because the area was low flat land and has been at a high risk of an inundation due to a Nankai trough earthquake tsunami.

In December 1, 2013, the tsunami evacuation drill was started at Sunday morning, 9 AM. At first, an announcement message from the city office was broadcasted through speakers of a disaster warning system and advised residences to join the evacuation drill and to evacuate immediately. Residents of Yamato community, one of the voluntary organizations for disaster prevention, and some members of a volunteer fire corps gathered at a meeting point (see Fig. 3 (a)). They joined a short briefing about the drill, and started evacuation just after the briefing. Their goal was a designated evacuation site which was approximately 135 m away from the start point. The number of residents and volunteer fire corps was 51 in total, and all persons walked on foot.

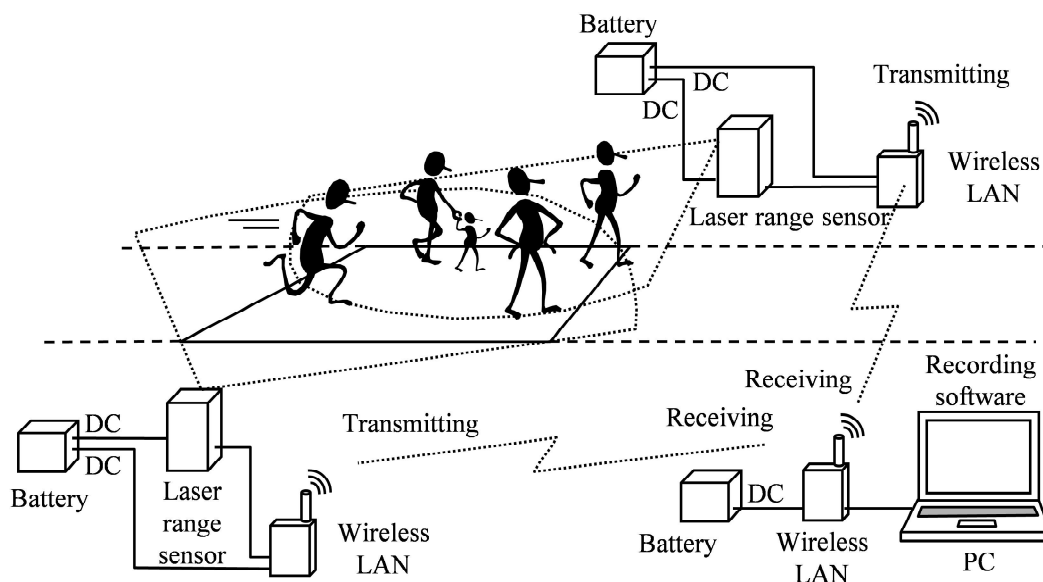


Fig. 2 Evacuee Tracking System

Table 1 Equipment list

Name of Device	Name of Product/ Manufacturer
Laser range sensor	UTM-30LX-EW/ Hokuyo Automatic Co., Ltd.
Recording software	Flow Radar_2 Version 1.2.15.0/ Hokuyo Automatic Co., Ltd.
PC	CF-AX2/ Panasonic Corporation
Wireless LAN	Aterm WR8175N(HP)/ NEC Corporation Aterm WL300NE-AG/ NEC Corporation
Battery	YTX12-BS/ GS Yuasa International Ltd.
Ultrasonic range meter	VERTEX IV/ Haglof Sweden AB
Video camera	HDC-TM85/ Panasonic Corporation

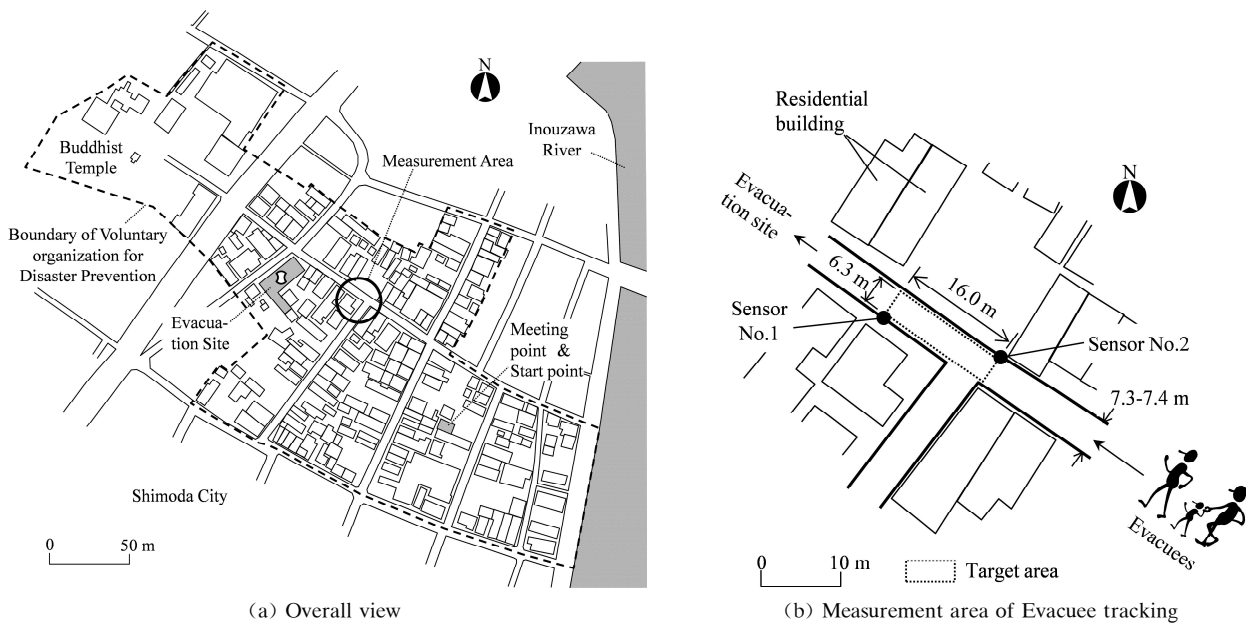


Fig. 3 Survey area



Fig. 4 Equipment used

A measurement area was set in the middle of the evacuation route. A distance from the start point to a centre of the area was approximately 100 m. The size of the area was 16.0 m in length and 6.3 m in width of rectangular shape, as shown in Fig. 3 (b). Black round-marks in the figure are the locations of the laser range sensors No. 1 and No. 2, and Fig. 4(a) and Fig. 4(b) show the sensors and the other equipment used, respectively.

3.3 Results of Tracking

The first evacuee arrived in the measurement area at 9:10 AM, and all evacuees left the area until 9:12 AM. It was approximately 80 s from when the first evacuee entered in the area, until the last one left the area. During the 80 seconds, two automobiles, one motorbike and one bicycle passed through the measurement area. But we decided to omit their effect to results of track-

ing, because they had no relation with the evacuation drill and it seems that they had no effect on the behaviour of the evacuees.

Fig. 5 is a time-series set of snapshots taken by the video camera from a viewpoint close to the sensor No. 2. We defined 9:10:49 AM as a time $t = 0$ s. Eight photos of Fig. 5 show the snapshots for $t = 0, 10, \dots, 70$ s, respectively. The sensor No. 2 can be found on the lower right corner of the photos, and the evacuees walked from the left hand side to the right hand side of the photos. According to the photos, it was found that many evacuees walked in groups, and the others walked in a single or in a pair; the first group, Group No. 1, passed

through at $t = 0-10$ s, single or a pair of evacuees walked independently in low traffic density at $t = 20$ s, the second group, Group No. 2, passed through at $t = 30$ s, a single evacuee walked at $t = 40$ s, and the last group passed through at $t = 50-70$ s. In the Fig. 5(a), there was an evacuation leader carrying a white flag and walking at the front of the first group.

Fig. 6 is a time-series set of snapshots measured by laser range sensors. Each figure in Fig. 6 shows a bird-eye view of the measurement area, and the evacuees walked from the left hand side to the right hand side of the figure. Circles with an Arabic number in the figure indicate positions of evacuees at t , and the Arabic

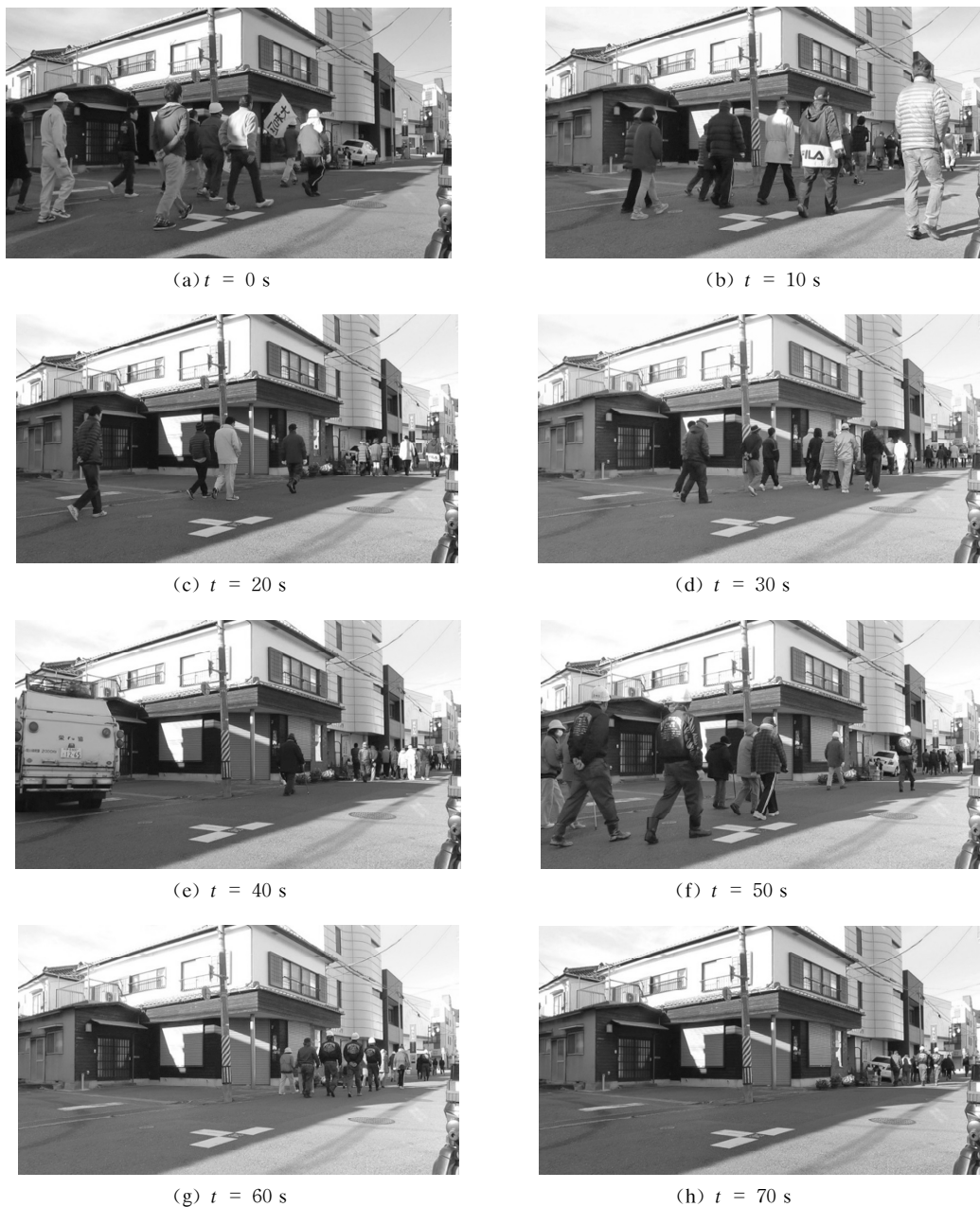


Fig. 5 Snapshots of Tsunami Evacuation Drill

numbers are ID numbers which were allocated automatically to the evacuees by the recording software. Arrows drawn from the circle centre show directions of the evacuees' movement, and positions of the arrow head mean positions where the evacuees arrive at after 1 s. It should be noted that the two sensor system could not always capture all evacuees and arrows, because there were limitation of measurement such as a blind area effect and the other problems. For example, it was

found that two person on the far left of Fig. 5(a) were not captured by the sensors in comparing with Fig. 6 (a). It was also found that several evacuee in Fig. 6(a) had no arrow. Although the two sensor system needs accuracy enhancement of measurement to know the accurate number of evacuees or vectors of motion, but the system provided us enough to monitor a speed of group walk.

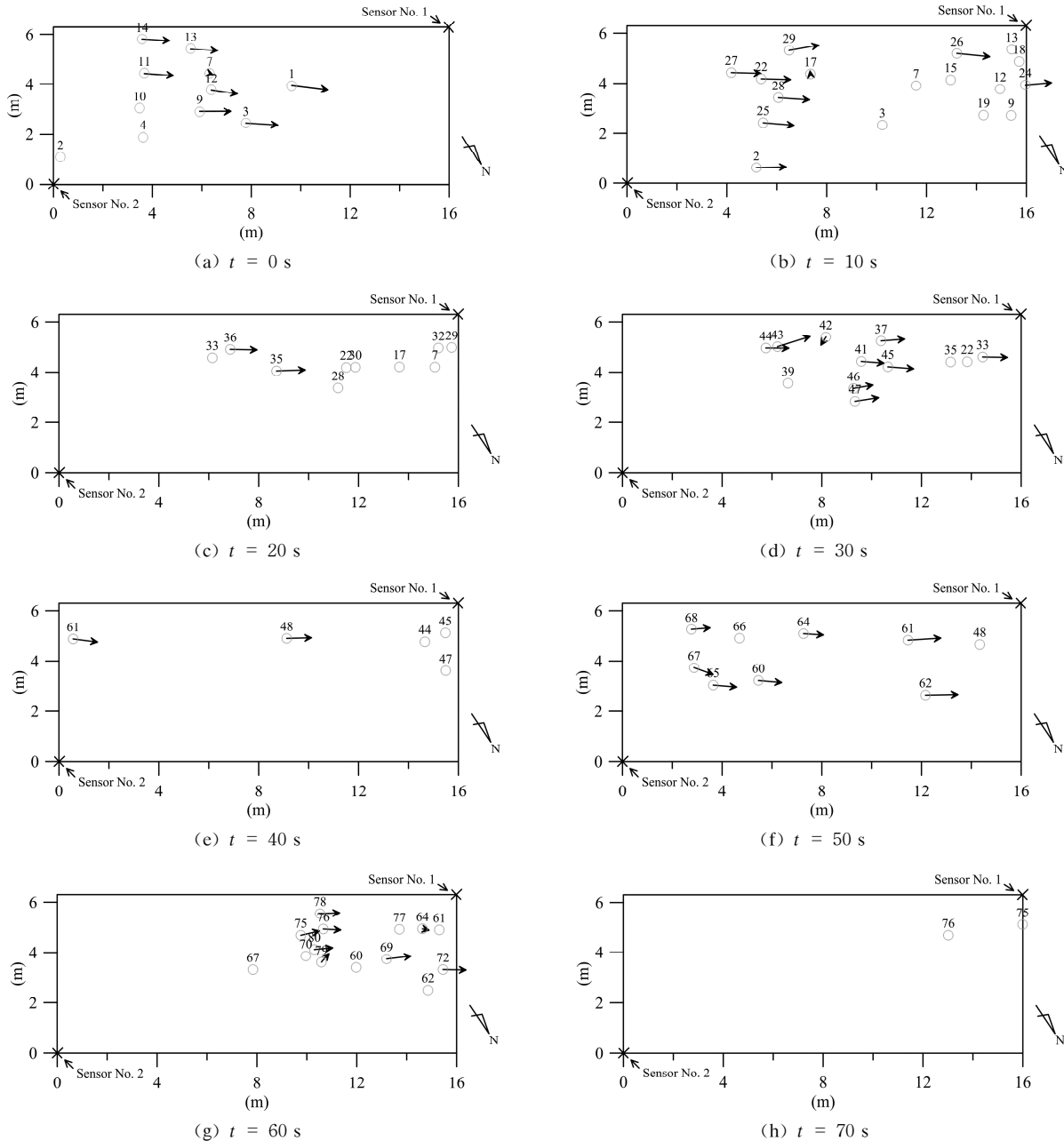


Fig. 6 Results of Capture

Fig. 7 draw tracking results of 4 or 5 evacuees which represented the three groups, Group No. 1-3, for consecutive 5 seconds. Table 2 shows walking speeds of the evacuees calculated based on the results of Fig. 7.

For Group No. 1, the walking speed observed was at the range of 1.141-1.306 m/s and the average speed was 1.223 m/s. For Group No. 2, the walking speed was at the range of 0.985-1.134 m/s and the average speed was

1.063 m/s. And for Group No. 3, the walking speed was at the range of 0.739-0.962 m/s and the average speed was 0.861 m/s. The average speed for all was 1.050 m/s. According to the table, it was confirmed that the each group of evacuees moved at different speed with the other groups. This result agree with the knowledge which was pointed out by Togawa [4]. And it was found that Group 1, the group which passed through the measurement area first, was the fastest in speed, Group 3, the last group, was the slowest in speed, and Group 2, the second group, was in the middle speed of Group 1 and Group 3.

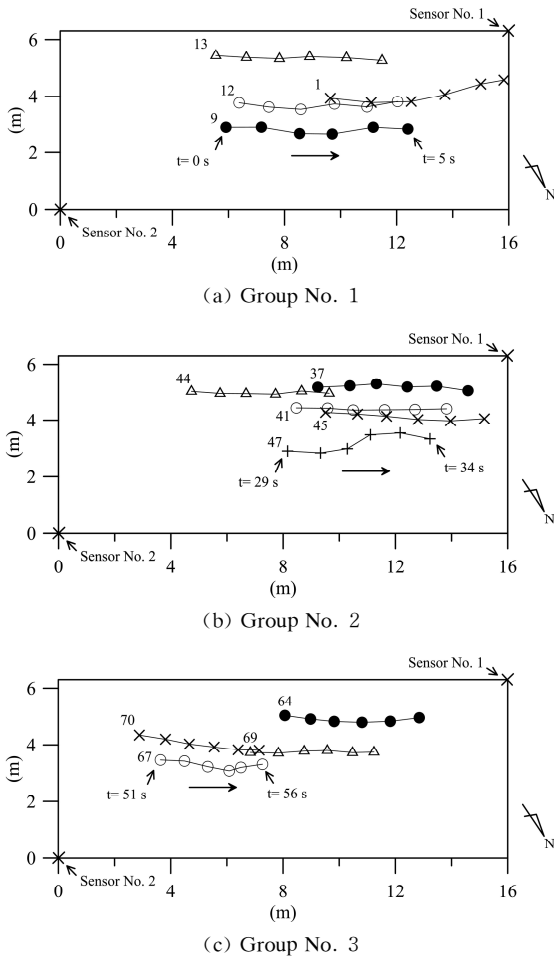


Fig. 7 Results of Tracking

In this chapter, the time-series data of group walking for tsunami evacuees were obtained at the tsunami evacuation drill by the field observation using the evacuee tracking system. It was found that many evacuees walked in groups, and the others walked in a single or in a pair. Although the system needs accuracy enhancement of measurement, it was confirmed that the each group of evacuees moved at different speed with the other groups. And it was also found that the group which passed through the measurement area first was the

Table 2 Walking speed

Evacuee's ID	Group	Speed (m/s)		
		Observed	Averaged for Group	Averaged for all
1		1.258		
9	No. 1	1.306	1.223	
12		1.141		
13		1.188		
37		1.075		
41		1.071		
44	No. 2	0.985	1.063	1.050
45		1.134		
47		1.048		
64		0.962		
67	No. 3	0.739	0.861	
69		0.882		
70		0.862		

fastest in speed, the last group was the slowest in speed, and the second group was in the middle speed of the first group and the last group.

4 Numerical Simulation of Group Walking for Tsunami Evacuees

4.1 Model of Group Walking

Fig. 8 shows a flow diagram of a numerical simulation of group walking for tsunami evacuees which was developed in this study.

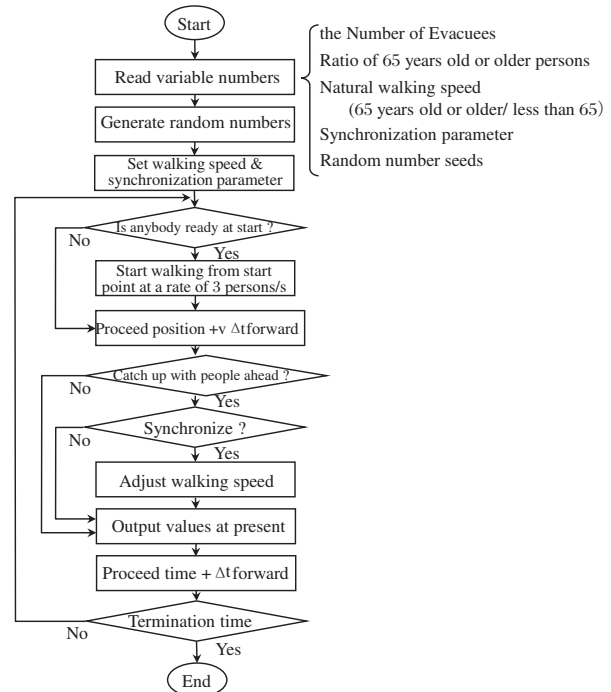


Fig. 8 Flow diagram of Numerical Simulation

First of all, the simulation program read variable numbers; the variable numbers were the number of evacuees; N , a ratio of 65 years old or older persons; R_1 , average values of a natural walking speed for 65 years old or older (V_1) and for less than 65 years old (V_2), an average value of a synchronization parameter; S , and seeds to generate random numbers; x_1 - x_3 .

Evacuee i had two characteristic values: natural walking speed v_i and synchronization parameter S_i . v_i was determined according to one's age, whether less than 65 years old or not. Random number X_{1i} was generated for evacuee i by using x_1 , and evacuee i was sorted into whether less than 65 years old or not, based on a magnitude relationship of X_{1i} to R_1 . We employed a simple assumption that a class of v_i ($i = 1, 2, \dots, N$) distributed in a standard normal distribution, a median value μ of the class equalled to V_1 or V_2 , and deviation σ of the class was determined in the manner that a value of cumulative probability of standard normal distribution from 0 m/s to $\mu + 0.25$ m/s became 0.99. It should be noted that a magnitude of the value 0.25 m/s is a hypothetical value in present, because sufficient information about the distribution of natural walking speed could not be obtained from the past studies. It is the subject for a future study. S_i is a constant number for a evacuee i , and represented a probability of synchronization or repulsion for decision making to outstrip a person who walks ahead; if S_i equals to 0, the evacuee i always outstrip a evacuee j who walks ahead. And if S_i equals to 1, the evacuee i always follows the evacuee j . We employed a simple assumption that a class of S_i ($i = 1, 2, \dots, N$) distributed in a standard normal distribution, μ equalled to S , and σ was determined in the manner that a value of cumulative probability of standard normal distribution from 0 to $\mu + 0.3$ became 0.99. It should be noted that a magnitude of the value 0.3 is a hypothetical value in present. Whenever evacuee i catches up evacuee j , a random number X_{2k} is generated for this event k by using x_2 , and evacuee i decides to outstrip j or to follow j based on a magnitude relationship of X_{2k} to S_i . In case of outstripping, evacuee i kept his or her speed. In contrast, in case of following, the speed of evacuee i was adjusted to a speed of j or a speed of a group in which j was included. This method to adjust the speed of the evacuee i is based on the knowledge: "in case that the group consists of four, five or more persons, all may adjust their average speed to that of the lowest in speed", which was provided by Togawa [4]. But the model was still in the first step in view of rules to adjust speed especially for group consisted of two or three, be-

cause Togawa [4] also pointed out that the speeds of two persons are adjusted at the average speed of the two or slightly more slowly than that, and that when three persons are walking in group, their speed will be slightly slower than the average of the natural speeds of the three. As these information remained qualitative explanations, we applied the simple rule to adjust speed at a first step. Although this synchronization parameter model is simple, we hope that this model will be useful to provide a new views of evacuation simulation.

A network of a street was a straight link from a start point to an evacuation site with no branch. In case that evacuee or evacuees waiting at the start point, three persons were input to the network at every second. A time step Δt was 1 s, and evacuee i proceeded his or her position $v_i \Delta t$ forward. This process was repeated until when evacuee i arrives at the evacuation site or a termination time t_{term} .

4.2 Cases of Numerical Simulation

Table 3 shows items, symbols and values for two cases of the numerical simulation. Results for the first case, reference case, will be introduced in the section 4.4, and results for the second case, comparative case, will be discussed in the section 4.5. Because the numbers of evacuee who took part in the evacuee drill was 51 as stated in the section 3.2, we configured a value of N as 51. R_1 is set to 33 % based on the average composition of population at the region. The values of V_1 and V_2 are 0.96 m/s and 1.19 m/s respectively, based on experimental results of Kamino [10]. A value of Synchronization parameters S for the first case was 0.25 and it was a temporal value in present, because there was no proper report on an evaluation of psychological condition for tsunami evacuees. It seems to be important to discuss about the effect of a value S , we calculate comparative case and discuss about its results in the section 4.5. A termination time t_{term} was decided in consideration of a length of path from a start point to an evacuation site; the path was approximately 135 m in length, and 600 s could be enough to simulate the behaviour of pedestrians.

4.3 Computation Environments and Processing Time

Computation Environments for running the simulations were Intel Core i7-950 Processor (3.06GHz, 8MB L3 Cache), 9.00 GB RAM, and Windows Vista Home Premium 64bit. A programming language was Intel Parallel

Table 3 Cases of Numerical simulation

Item	Symbol	Values for Reference case	Values for Comparative case
The number of evacuees	N		51
Condition to start evacuation	–	Input 3 persons/s at start point	
Ratio of evacuees 65 years old or older	R_1		0.33
Average value of Natural walking speed for evacuees 65 years old or older	V_1		0.96 m/s
Average value of Natural walking speed for evacuees less than 65 years old	V_2		1.19 m/s
Average value of Synchronization parameter	S	0.25	0.15
Termination time	t_{term}		600 s
Time step	Δt		1 s

Studio XE 2015 Composer Edition for Fortran with Microsoft Visual Studio 2010. A processing was affected by magnitudes of N , t_{term} and Δt . The processing time was very short, less than 1 s, to calculate at conditions $N = 51$, $t_{term} = 600$ s and $\Delta t = 1$ s, shown in Table 3.

To calculate cumulative probability of standard normal distribution for v_i and S_i in the section 4.1, Fortran programs from a mathematical library provided by Kurose et al [11] were referenced.

4.4 Results of the Numerical Simulation

Fig. 9 shows a result of the numerical simulation for

reference case. The horizontal axis is a length from the start point in the unit of meter, and time-series of snapshots are drawn in the longitudinal direction from $t = 0$ s to $t = 240$ s at every 20 s. The measurement area in the Chapter 3 starts at 127 m and ends at 143 m from the start point on the horizontal axis. Evacuees walk from the left hand side to the right hand side in the figure. Circles in the figure indicate positions of a evacuee walking independently or group of evacuees at t . It is possible to distinguish group of evacuees from evacuee walking independently, when a black triangle is attached below the circle.

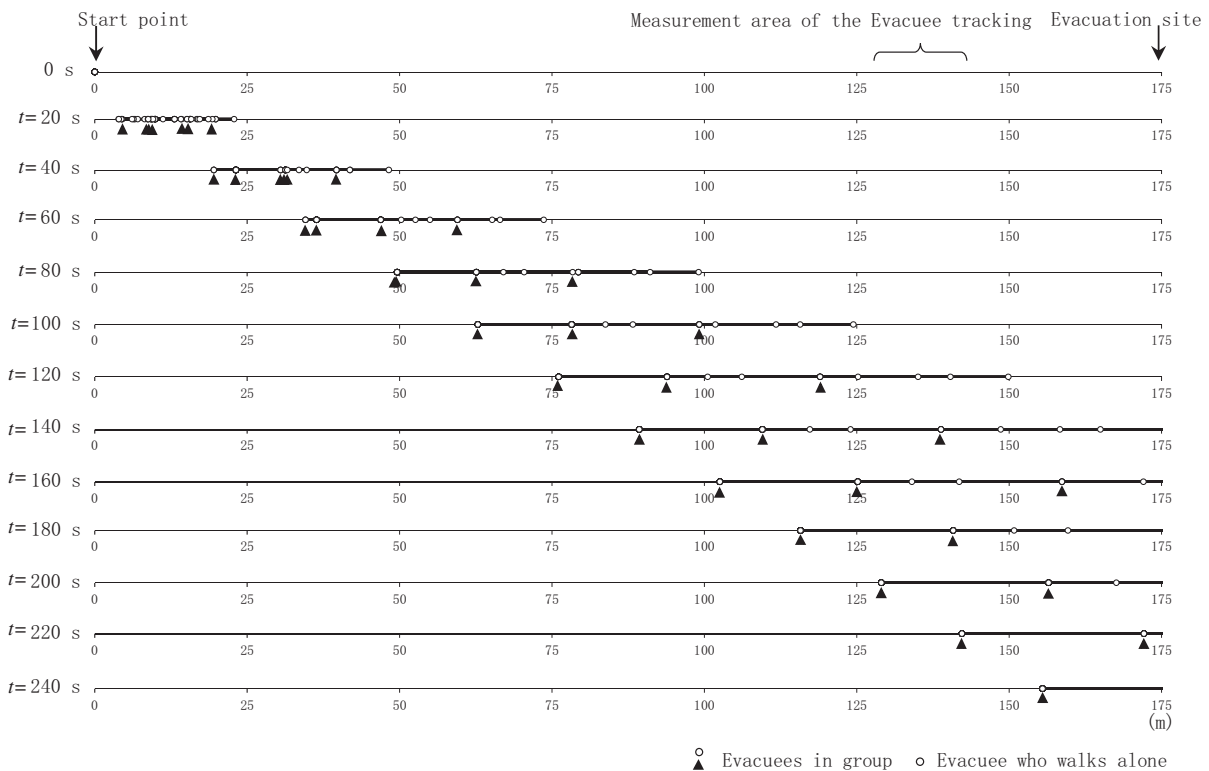


Fig. 9 Result of Numerical Simulation (Reference Case)

According to the figure, several evacuees walking independently entered the measurement area at $t = 100$ s. Following them, three groups passed through the area. Between the first group and the second group, we can find several evacuees walking independently. No evacuee were found between the second group and the third group. There were some differences between the results of the simulation and the facts of the field survey. For example, the several evacuees walking independently preceded the first group in the simulation, but no person preceded the first group in the field survey. The reason is not clear, but it could be one of the reasons that there was an evacuation leader carrying the flag in front of the first group in the field survey. Although there were some differences between the results of the simulation and the field survey, the results of the simulation almost agree with the facts based on Fig. 5 of the field survey.

According to the results of the simulation, walking speeds of the three group were 0.992, 0.782 and 0.662 m/s at $t = 160$ s, respectively. The group walking speed were 1.223, 1.063 and 0.861 m/s, respectively, in Table 2 based on the field survey. It means that the group walking speeds based on the results of the simulation were equivalent to 74 %-81 % of those of the results based on the field survey. According to the results of the simulation, the first group arrived the area at approximately $t = 130$ s and the last evacuee left the area approximately $t = 220$ s, e.g. it took approximately 90 s from the first group entered in the area, until the last one left the area. The amount of time required, 90 s, was relatively longer than 80 s based on the result of the field survey. Because amount of time required becomes longer to pass through a specific area if walking speed is slower, it seems to be a reasonable results. The reason for the difference of group walking speed between the simulation and the field survey is not clear, but the synchronization parameter model we proposed could be one of the reasons. Whenever an evacuee i followed an evacuee or a group j , a speed of i was adjusted automatically to a speed of j , and it did not depend on the number of j . But Togawa [4] pointed out that the speed was adjusted at the average speed or slightly more slowly than that in case that two or three pedestrians makes a group. Further study is necessary to clarify the reasons. According to Table 2, a differential of speed between Group 1 and Group 2 was 0.160 m/s, and that of Group 2 and Group 3 was 0.202 m/s. In the simulation, the differentials were 0.210 m/s and 0.120 m/s at $t = 160$ s. In view of a differential of group walking speeds, the magnitude of the differentials of the simulation were in

the same range with that of the field survey.

According to the simulation, the number of the evacuees was 15 for the first group, 5 for the second group, and 25 for the third group. The number of evacuees of three group was 45 in total. Because N equalled to 51, a percentage of evacuees who walk in group was approximately 88 %.

In this section, the numerical simulation for reference case was conducted. It was found that the results of the simulation agree with the facts based on the field survey, although there were a few differences between the results of the simulation and the field survey. Reasons were not clear, but several reasons could be considered such as an effect of an evacuation leader at the front of the first group, and an applicability limit of the synchronization parameter model for groups consist of two or three persons.

4.5 Discussion

According to the simulation for the reference case in the previous section, the percentage of evacuees who walk in group was 88 %, and it was relatively high than that of Kamaishi City (71 %) or Sendai City (48%) in the 2011 Tohoku earthquake tsunami. Since parametric study on an effect of the synchronization parameter S to a percentage of group walking is important, a comparative case shown in Table 3 was conducted. The value of S was set to 0.15, and the other parameters were the same to the reference case. The simulation for the comparative case gave us approximately 73 % as the percentage of group walking, and it was similar value to that of Kamaishi City.

In view of a group walking speed, the fastest of the three was 0.838 m/s, and the value was slightly smaller than that of the reference case. Because the simulation included stochastic processes, more detailed research is required to evaluate the effect of S to a speed of group walking.

In the end of this section, we mention subjects for future studies on the numerical simulation of group walking. Triggers to generate or glow up a group of evacuee is not limited to catch up and follow but also to slow down at a congestion in an intersection, to force to stop due to traffic signal, and the others. And a speed of evacuee walking independently will be changed if the evacuee collects information from his or her environment and think that the situation is not serious. These behaviours will require extra models or modification of the program for the numerical simulation of group walking.

5 Conclusion

The purposes of this study are to conduct a field survey on behaviour of group walking, and to propose a numerical simulation model for group walking of tsunami evacuees.

A field survey was conducted, and time-series data of group walking for tsunami evacuees were obtained at the tsunami evacuation drill using the evacuee tracking system. It was found that 90 percent of the evacuees walked in groups, and the others walked in a single or in a pair. Although the system needs accuracy enhancement of measurement, it was confirmed that each group was different in speed from the other groups. And it was also found that the group which passed through the measurement area first was the fastest in speed, the last group was the slowest in speed, and the other group was in the middle speed of the first group and the last group.

A new model of group walking including a synchronization parameter was proposed, and a numerical simulation was conducted. It was found that the results of the simulation agree with the facts based on the field survey, although there were a few differences between the results of the simulation and the field survey in view of the speed of the groups. Several reasons could be considered such as an effect of an evacuation leader at the front of the first group, and an applicability limit of the synchronization parameter model for groups consist of two or three persons.

And a parametric study on the synchronization parameter of the numerical simulation was conducted. As a result, a percentage of group walking was changed when the synchronization parameter was changed, and that the percentage was a similar value to one of the facts observed in the 2011 Tohoku earthquake tsunami. We have conducted only one case of parametric studies, and it is necessary to continue more detailed investigation.

Acknowledgements

The authors would like to acknowledge to the residents and the members of the volunteer fire corps of Yamato community, the voluntary organizations for disaster prevention in Shimoda City, Shizuoka Prefecture, the Municipal section and the Construction section of the Shimoda City Office, and Shimoda Branch Office of Shimizu Port Office, Chubu Regional Development Bureau of Ministry of Land, Infrastructure, Transport

and Tourism for providing information and assistance to conduct the field surveys. The first and the second authors were former senior researcher and research engineer of National Institute for Land and Infrastructure Management (NILIM), and the field survey was conducted as a research activity of NILIM. The authors also would like to acknowledge to NILIM for utilizing the data of the field survey. The authors would like to express appreciation to Miss Fuko Nakai, Graduate School of Informatics, Kyoto University for a discussion and a considerable advice.

References

- [1] Ministry of Land, Infrastructure, Transport and Tourism of Japan: Data archive for research and support of rehabilitation, <http://fukkou.csis.u-tokyo.ac.jp/>, Operated by Center for Spatial Information Science of Tokyo University, 2012. [accessed in Feb. 28, 2016]
- [2] Kimura K. and Ihara S. : Observation on Flow of Crowd in Buildings, *Journal of Architectural Institute of Japan*, Vol. 5, pp. 307-316, 1937.
- [3] Pushkarev B. and Zupan J. M. : *Urban Space for Pedestrians*, the MIP Press, pp. 81-84, 1975.
- [4] Togawa K. : Study on Fire Escapes basin on the Observation of Multitude Currents, PhD Thesis, University of Tokyo, pp. 28 and pp. 101-102, 1963.
- [5] Mashita N., Takayanagi H., Kimura K., Hayashida K. and Watanabe Y. : Influence which Pedestrian's Group Composition and Attribute Exert on Pedestrian Action, *Proceedings for annual meeting of Tohoku branch, Architectural Institute of Japan*, pp. 1077-1078, 2000.
- [6] Togawa K. : Psychological Matters related to Crowd Research, *Building Engineering, Building Institute of Ministry of Construction*, No. 184, pp. 121-126, 1966.
- [7] Cristiani E., Piccoli B. and Tosin A. : *Multiscale Modeling of Pedestrian Dynamics, Modeling, Simulation & Applications Volume 12*, Springer, pp. 47-51, 2014.
- [8] Takayanagi H., Nagayama J. and Watanabe H. : A Study on Pedestrian Walk Flow Model with Pedestrian's Optimum Velocity Behavior-The Analysis based on Track-follow Phase Transition Patterns in Crowd's Small Group Formations-, *Journal of Architectural Planning, Architectural Institute of Japan*, No. 606, pp. 63-70, 2006
- [9] U. S. Food and Drug Administration (FDA): *Laser Products, 21CFR1040. 10, Code of Federal Regulations, Title 21, Vol. 8*, 1985.
- [10] Kamino K. : *Design of Pedestrian Movement and Urban Area*, Shokokusha Publishing Co., Ltd., pp. 128-132, 1980.
- [11] Kurose K, Matsusima I. and Matsuo T. : *Sub-routine Libraries for Fortran 90*, Morikita Publishing Co., Ltd., pp. 112-115, 1998.