International Journal of GEOMATE, Aug., 2020, Vol.19, Issue 72, pp. 1 - 7
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2020.72.5514
Special Issue on Science, Engineering and Environment

A STUDY ON HUMAN DAMAGE IN EVACUATION FROM TSUNAMI CONSIDERING STREET-BLOCKADES CAUSED BY DESTROY OF BUILDINGS

Ken-ichi Fujita[1]and Harumi Yashiro[2]

[1] Faculty of Engineering, Nagasaki Institute of Applied Science, Japan;
[2,3] School of Systems Engineering, National Defense Academy of Japan, Japan

*Corresponding Author, Received:14 Aug. 2019, Revised: 19 Nov. 2019, Accepted: 25 Feb. 2020

ABSTRACT: Damage estimation and disaster prevention plan for a Nankai megathrust earthquake which occurrence is assumed in the future have been formulated cabinet office of Japan based on lesson learned from the huge human damage caused by the tsunami of The Great East Japan Earthquake in 2011. Damage estimation for earthquake and tsunami is usually evaluated independently. For the damage estimation by tsunami, the human damage in evacuation from tsunami has been carried out. However, street-blockades have not been considered in many studies and damage estimations. When evacuation routes are changed by the street-blockades, configuration of the human damage in evacuation from tsunami seems to be different in no street-blockades. To evaluate total damage in whole area, unified treatment of the human damage by the both disasters seems to be significant. This study presents an evaluation method of human damage in evacuation from tsunami considering street-blockades using area-wide mesh. The author's method considering variances of tsunami run-up speed and walking speed is used to the evaluation. The street-blockades of evacuation routes are evaluated by using fragility curves of buildings for earthquake. Moreover, the difference in configuration of the human damage by consider the street-blockades and no blockades is discussed.

Keywords: Tsunami evacuation, Human damage, Street-blockade, Human damage probability, Area-wide mesh

1. INTRODUCTION

In disaster prevention planning for large scaled natural disasters such as mega-class earthquake, tsunami and eruption, estimation of buildings damage and human damage is extremely important. Damage estimation for the natural disaster in cabinet office and local governments of Japan has been usually evaluated independently for each disaster [1], [2]. Using the damage estimation results, disaster prevention planning for both structural measures and non-structural measures are projected.

The disaster prevention planning for tsunami are as follows; construction of tide embankment, relocation to higher ground of town, education on evacuation and so on. Evacuation planning from tsunami is especially important item for tsunami disaster prevention. Evaluation of human damage for tsunami is carried out for evacuation action to safety area. In evaluation of the human damage, difference between evacuation time and tsunami arriving time to evacuation facilities is usually used. In evaluating of human damage in evacuation from tsunami, the effect of damage of buildings by earthquake before arriving tsunami has not been considered in many studies and damage estimation. In evacuation planning from tsunami, to consider street-blockade by destroy of buildings, fallen down of street walls and fire caused by large earthquakes becomes important. The street-blockade has been considered to lifesaving activities and fire-fighting in the disaster estimation for large earthquakes [3]. When the street-blockades are caused a change of evacuation routes, configuration of the human damage in evacuation from a tsunami seems to be different in no street-blockades.

This study presents an evaluation method of human damage in evacuation from tsunami considering the street-blockades by destroy of buildings. Area-wide mesh is used to evaluate an overview of the human damage in tsunami evacuation under the street-blockades from a view point of macro-perspective. The author's method [4]-[6] for the human damage taking account of variances of tsunami run-up speed and walking speed is also used to the evaluation considering the street-blockades. Moreover, the difference in configuration of the human damage between the street-blockades and no street-blockades by using the evaluation method.

2. EVALUATION FLOW OF HUMAN DAMAGE

The area-wide mesh is used to the evaluation of the human damage. Population composition, height above sea level, tsunami inundation depth, seismic

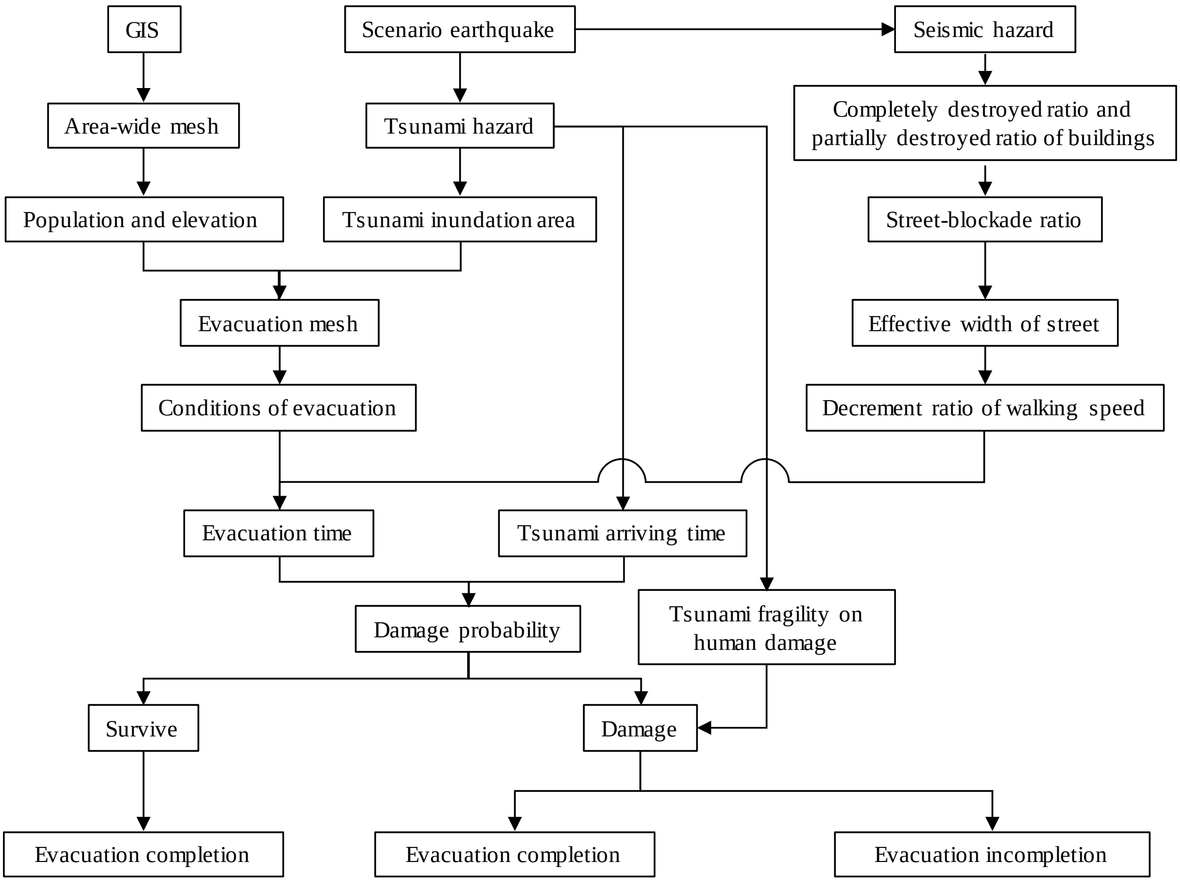


Fig.1 Evaluation flow of human damage in evacuation from tsunami considered street-blockade

intensity, street-blockade ratio, and evacuation awareness are set up for each mesh based on a real area data. The population composition and the height above sea level of GIS (Geographic Information System) data are used.

Evacuation route from an evacuation mesh to an evacuation facility is defined as the route along the mesh. Evacuation distance including difference of elevation between mesh is assumed to be 1.5 times of length of plane distance. The human damage probability is evaluated by using relation between evacuation time and tsunami arriving time after earthquake occurrence. The human damage ratio to tsunami inundation depth in each mesh can be obtained from the tsunami fragility curve [7]. The street-blockade is evaluated by using the fragility of buildings for earthquakes [8]. Decrement of the walking speed is determined by effective sidewalk width which passing is possible. From the above, the evaluation flow on the human damage can be shown in Fig.1.

The following assumptions are used in this study.

1) The human damage is counted when a person is caught up with tsunami.
2) The evacuation is only walk. The walking is only permitted on sidewalk.
3) The evacuation facility is designated for each evacuation mesh. The facilities are not damaged to earthquakes.
4) The street-blockades are occurred by destroy of buildings by large earthquakes
5) The evacuation direction is not toward to coast.
6) In emergency, to across any railroad crossing is prohibited because crossing gates keeps down.

3. HUMAN DAMAGE PROBABILITY

3.1 Damage Probability of Human in Evacuation

The human damage probability is evaluated by the Author’s method [5], [6]. The probability is defined by a function of evacuation time and tsunami arriving time after earthquake occurrence. The evacuation time and the tsunami run-up time from coast to evacuation facilities are assumed to follow the normal distribution. The tsunami arriving time is divided into the time of tsunami propagation and run-up. The evacuation time and the tsunami run-up time can be evaluated from walking speed and tsunami run-up speed, respectively. The variation of the tsunami run-up speed is considered for evaluation of the tsunami arriving time. The tsunami run-up time can be obtained by the relation of the run-up speed and the minimum distance between coast and evacuation facilities. The mean

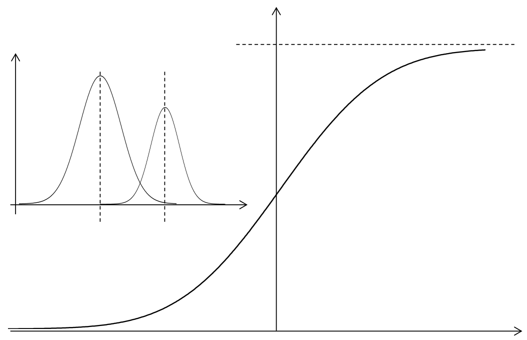


Fig.2 Probability function of human damage

value of the run-up speed can be determined by the tsunami inundation depth [9]. Average tsunami inundation depth from the coast to the evacuation facilities is considered in this study. The standard deviation of the run-up speed is evaluated by the geometric standard deviation [10] which indicates the adaptation between tsunami height marks on land and tsunami simulation results.

In this study, the reliability evaluation method for structures [11] applied to the evaluation of the human damage. The evaluation equation of the human damage can be provided the following equation.

$$P_R = 1 - \Phi(\mu_P / \sigma_P) \quad (1)$$

where, Φ is the standard normal distribution function with the mean value 0 and the standard deviation 1. The function of Φ is also shown in Fig.2. In the figure, $f_e(t)$ is the probability function of evacuation time and $f_t(t)$ is the probability density function of tsunami arriving time. μ_P and σ_P are provided by the following equations, respectively;

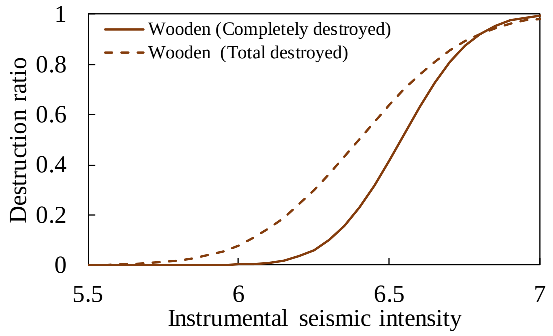
$$\mu_P = \mu_T - \mu_E \quad (2)$$

$$\sigma_P = \sqrt{\sigma_T^2 + \sigma_E^2} \quad (3)$$

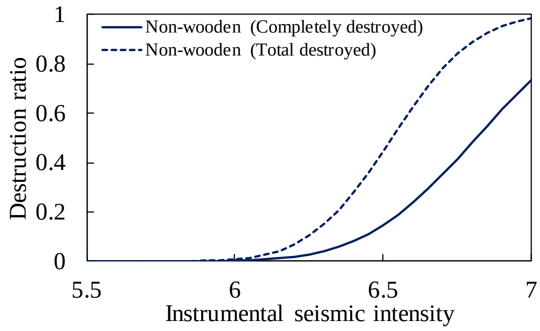
where, μ_E and μ_T are the mean value of total evacuation time and the tsunami arriving time to evacuation facilities after earthquake, respectively, σ_E and σ_T are the standard deviation of μ_E and μ_T, respectively.

4.2 Street-Blockade by Destroy of Buildings

In this study, the street-blockade is assumed to be caused by completely destruction and partial destruction of buildings. The destroy ratio can be obtained by using fragility of buildings for wooden and non-wooden structures shown in Fig.3 [8]. The partial destruction ratio is also obtained by a difference completely destruction number and partial destruction number of buildings. The street-blockade ratio is evaluated for each mesh by using the completely and partially destruction ratios. Effective sidewalk width W_{es} by the street-blockade of each mesh can be obtained from the following equation;



(a) Wooden structure



(b) Non-wooden structure

Fig.3 Fragility curves of structures for earthquake [8]

$$W_{es} = (1 - R_d) W_s \quad (4)$$

where, W_s is the sidewalk width in normal period, R_d is the street-blockade ratio which given for range of W_s represented by the following equation;

$$R_d = \begin{cases} 1.28 D_{rb} & (W_s < 3m) \\ 0.604 D_{rb} & (3m \le W_s < 5.5m) \\ 0.194 D_{rb} & (5.5m < W_s \le 13m) \end{cases} \quad (5)$$

where, D_{rb} is the destruction ratio represented by the following equation [3];

$$D_{rb} = D_c + D_p / 2 \quad (6)$$

where, D_c and D_p are the completely and partially destruction ratio of buildings, respectively.

Deterioration of the walking speed is assumed to be proportional to the effective width. The deterioration ratio of the speed maybe expressed by using consideration of the decrement ratio of walking speed of crowded with people [12]. In this study, the sidewalk width is assumed to be proportional to the crowded with people per area. In evacuation, no deterioration of the walking speed is considered for W_{es} more than 1.5m, the speed is linearly deteriorated with proportional to W_{es} within 0.5m to 1.5m and impassable for less than 0.5m. The Deterioration ratio R_w may be evaluated by the following equation;

$$R_w = \begin{cases} 1.0 & (1.5m < W_{es}) \\ 0.8W_{es} - 0.2 & (0.5m \le W_{es} \le 1.5m) \\ 0 & (W_{es} < 0.5m) \end{cases} \quad (7)$$

The walking speed in evacuation is evaluated by multiplying R_w the walking speed in normal period.

5. EVALUATION OF HUMAN DAMAGE

5.1 Evaluation Conditions

The human damage in evacuation from tsunami using the method in this study is discussed under conditions of street-blockade and no street-blockade. The area-wide mesh and population distribution of target area [13] is shown in Fig.4. The mesh size is 250m x 250m and the population is 23,345.

Tsunami inundation depth and seismic intensity used in this study are based on a Meio type scenario earthquake (moment magnitude scale, Mw 8.4) and a scenario earthquake along the Miura peninsula faults (Mw7.0), respectively. To investigate the maximum case of the human damages considered the effect of the street-blockade, two types scenario earthquakes which are the maximum case of the damage estimation in the target area [13] is selected. Tsunami inundation depth and seismic intensity (JMA seismic intensity scale) are shown in Figs.5 and 6, respectively. In addition, the maximum tsunami height is 8.94m. Though tsunami arriving time to coast is 59 minute [13], to clear the difference of evacuation awareness, tsunami arriving time in this study is set to 20 minute.

Buildings and roads are uniformly allocated to each mesh because of the evaluation to be simplification. Total number of buildings in the area is 9,256 (wooden: 6,664, non-wooden: 2,592). Road area including sidewalk per mesh is 7,375m^2 which is 11.8% of one mesh area.

Population ratio of the evacuation activity is divided into four type; evacuation immediately, evacuation after work, urgency evacuation and no evacuation [14]. The population ratio is set up by combining the following three types evacuation awareness; strong awareness, average awareness and weak awareness. The evacuation awareness and the start time of evacuation after earthquake occurrence are shown in Tables 1 and 2, respectively.

The mean value and standard deviation of walking speed is shown in Table3. The values are the obtained by the statistics of walking speed in normal period [15]. In addition, the mean value is deteriorated by the effect of the street-blockade and the standard deviation is assumed to be not variable for the blockade in this study. Mean value of tsunami run-up speed υ_t is evaluated by the following equation [9];

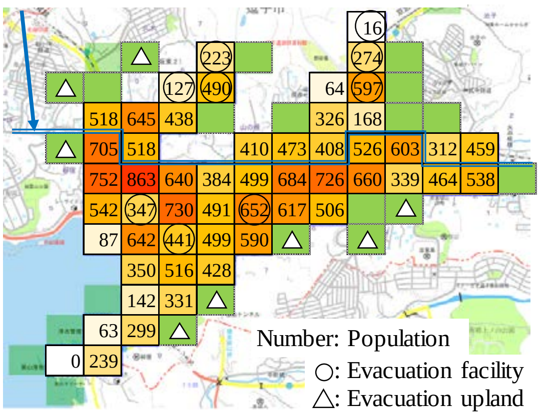


Fig.4 Area-wide mesh and population distribution

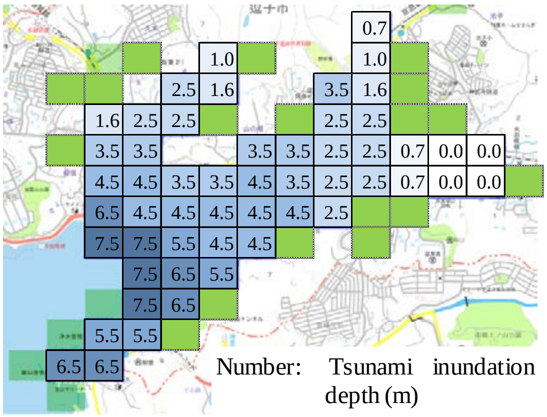


Fig.5 Tsunami inundation depth

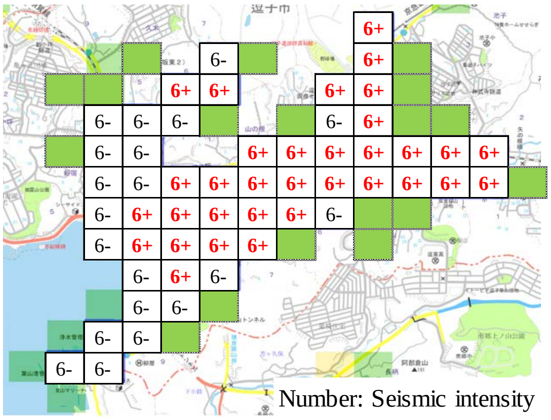


Fig.6 Seismic intensity

Table 1 Population ratio for evacuation awareness

Evacuation awareness	Evacuation immediately		Urgency evacuation (Weak awareness)	No evacuation (Weak awareness)
	After earthquake (Strong awareness)	After work (Weak awareness)		
Strong	80%	10%	5%	5%
Middle	50%	25%	15%	10%
Weak	15%	35%	30%	20%

Table 2 Evacuation start time after earthquake occurrence

Evacuation immediately after earthquake	Evacuation immediately after finished the work	Urgency evacuation
5min.	15min.	Tsunami arriving time

Table 3 Mean value and standard deviation of walking speed

Mean value	Standard deviation
1.34m/s	0.167m/s

$$\upsilon_t = 1.1\sqrt{gh} \quad (8)$$

where, g is the gravitational acceleration and h is the tsunami inundation depth. Standard deviation of the tsunami run-up speed is evaluated by using the Aida's equation [10].

5.2 Evaluation Results without Street-Blockade

The human damage for several evacuation awareness under no street-blockade condition is shown in Fig.7. The large number of the damage is also shown with deep color. The number of the damage with the strong awareness is the minimum. The damage near the evacuation area is less than that of the other mesh. The damage on mesh of the coast and the railroad crossing becomes large.

The number of the human damage is shown in Table 4. The human damage with the strong awareness decreased to 22% of the damage with the weak awareness. The evacuation awareness is large influence to decrease the human damage.

5.3 Evaluation Results with Street-Blockade

The street-blockages ratio by destroyed of buildings is shown in Fig.8 The ratio becomes large for strong seismic intensity. In addition, the numbers of destroyed buildings simulated in this study are 1,801 for completely destroyed and 1,114 for partially destroyed. The decrement ratio of the walking speed by the blockade is shown in Fig.9 The number shown in the figure represents the destined walking speed ratio for each evacuation mesh population. The ratio is variable with the scale of the blockades.

Table 4 Total number of human damage

Evacuation awareness	No blockade	Blockade
Strong	2,631	4,181
Middle	6,543	8,401
Weak	11,997	13,857

Unit: person

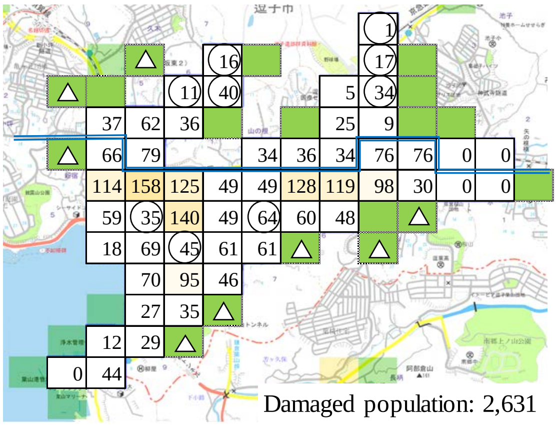
The human damage for several evacuation awareness under street-blockade condition is shown in Fig.10 The human damage becomes large in spite of the evacuation awareness compare to that of the no blockage. The number of the damage with the strong awareness is the minimum.

The number of the human damage for the blockade is also shown in Table 4. The damage is increased to 1.58, 1.28 and 1.16 times for the strong, middle and weak awareness, respectively. To consider the decrement of walking speed by the blockage is important for the human damage estimation from tsunami. Enhancing of evacuation awareness as well as seismic strengthening of buildings become the one way to decrease the human damage in evacuation.

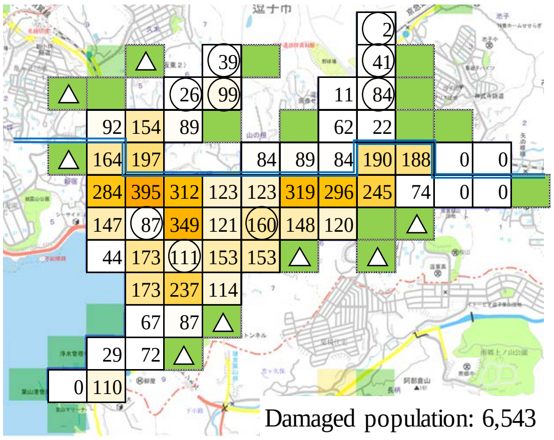
6. CONCLUSIONS

An evaluation method of the human damage considering the street-blockade by destroy of buildings is proposed. The human damage in evacuation from tsunami is discussed for the street-blockade and no street blockade conditions. The following conclusions can be drawn.

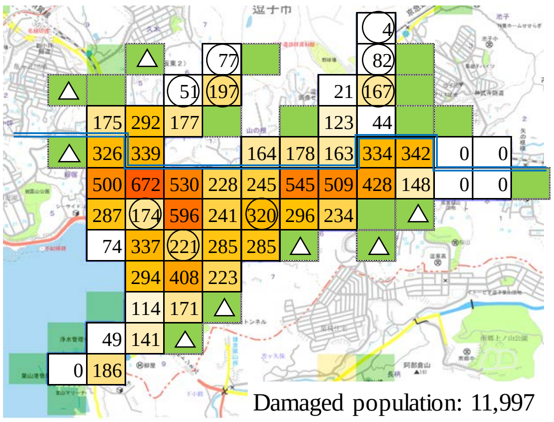
1) The human damage under the street-blockade becomes large compared to that of no street-blockade because of decrement of the walking speed by the blockade.
2) To consider the effect of the street-blockade in evacuation planning is important.
3) The human damage in evacuation from tsunami can be decreased by enhancing evacuation awareness for evacuation and education on disaster prevention.



(a) Strong awareness



(b) Middle awareness



(c) Weak awareness

Fig.7 Human damage distribution without street-blockade

4) Seismic strengthening of buildings is the one way to decrease the street-blockade for large earthquakes.

[1] Kanagawa Prefecture, Manual of Tsunami Inundation Forecast, 2012. (in Japanese)
[2] Cabinet Office, Report of Damage Estimation of Nankai Trough Earthquake (2st. Report), 2013.

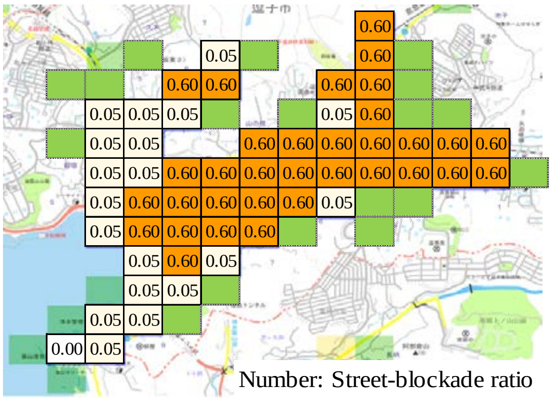


Fig.8 Street-blockade ratio by destroy of buildings

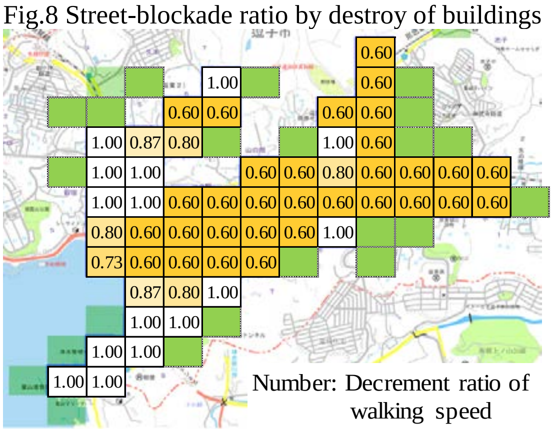
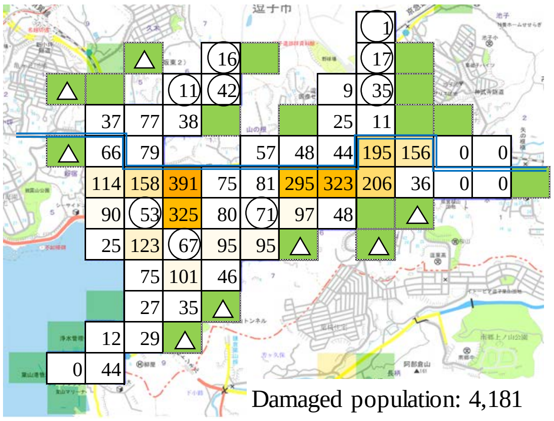
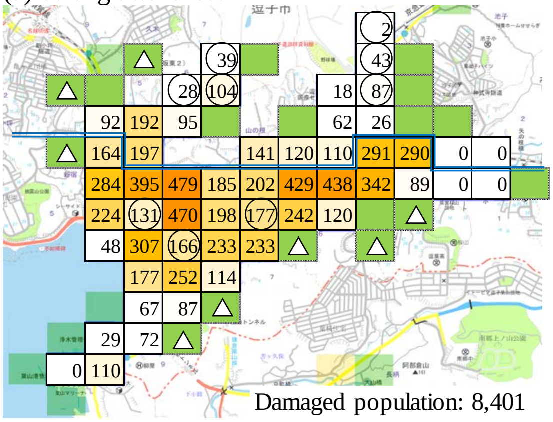


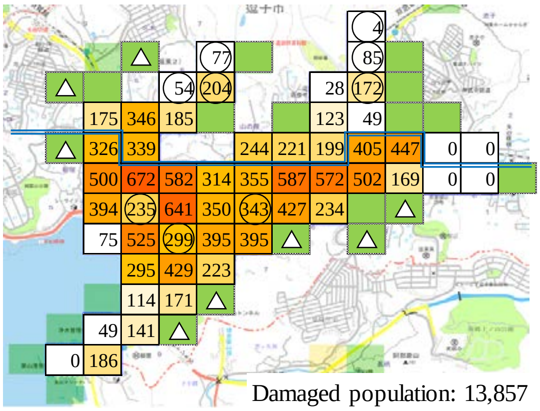
Fig.9 Decrement ratio of walking speed by street-blockade



(a) Strong awareness



(b) Middle awareness



(c) Weak awareness

Fig.10 Human damage distribution with street-blockade

7. REFERENCES

[3] Cabinet Office, Report of Damage Estimation of Nankai Trough Earthquake (1st. Report), 2012.

[4] Yashiro H., Fujita K., Evaluation Method of Evacuation Safety Performance for Tsunami using Area-Wide Mesh, Second European Conference on Earthquake Engineering and Seismology, CD-ROM, 2014, pp.1-9.

[5] Fujita K., Yashiro H., A Study on the Number of Installed and Installation Location of Tsunami Evacuation Facilities Using Area-wide Mesh, Journal of Japan Society of Civil Engineers, Ser. F6 (Safety Problem), Vol. 72, No.2, 2016, pp.I_151-I_156.

[6] Fujita K., Yashiro H., Evaluation of Human Damage in Tsunami Evacuation Considered the Variance of Walking and Tsunami Run-up Speeds, Internet Journal of Social Management Systems, Issue 11 Vol.1, sms17-8200, 2017, pp.213-223.

[7] Koshimura S., Namegawa Y., Yanagisawa H., Fragility Functions for Tsunami Damage Estimation, Journal of Japan Society of Civil Engineers, ser. B, Vol.65 , No.4 , 2009, pp.320-331.

[8] Midorikawa S., Ito Y., Miura H., Vulnerability Functions of Buildings Based on Damage Survey Data of Earthquake after the 1995 Kobe Earthquake, Journal of Japan Association for Earthquake Engineering, Vol.11, No.4, 2011, pp.34-43.

[9] Shuto N., Imamura F., Koshimura S., Satake K., Matsutomi H., Encyclopedia of Tsunami, Asakura Publishing Co., Ltd., 2007.

[10] Aida I., Simulations of Large Tsunamis Occurring in the Past off the Coast of the Sanriku District, Bulletin of the Earthquake Research Institute, Univ. of Tokyo, Vol.52, No.1, 2009, pp.71-101.

[11] Hoshiya M., Ishii K., Reliability Based Design for Structures, Kajima Institute Publishing Co., Ltd., 1986.

[12] Cabinet Office, Report of Simulation results on return home action, 2007.

[13] Zushi City Homepage, http://www.city.zushi.kanagawa.jp/

[14] Ministry of Land, Infrastructure, Transport and Tourism, Report of Present State Survey in Tsunami Affected Area of the Great East Japan Earthquake (3rd. Report), Results of Actual Survey on Tsunami Evacuation (Preliminary), 2011.

[15] Matsumoto N., Kiyota S., Ito M., Relationship between the Characteristics of Streetscape and Walking Speed, Journal of Architecture and Planning, Vol.74, No.640, 2009, pp.1371-1377.