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EVALUATION METHOD OF EVACUATION SAFETY PERFORMANCE FOR TSUNAMI UNING AREA-WIDE MESH

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ABSTRACT

By the East Japan great earthquake disaster that occurred on March 11, 2011, it was human damage more than approximately 20,000. More than 90% of damage depended on a tsunami.

In this paper, the method that a regional tsunami evacuation risk was quantified was studied. It evaluated a tsunami evacuation risk of area-wide mesh of the region from data such as evacuation completion rate, inundation depth, tsunami arrival time, evacuation start time, distance of tsunami evacuation facilities and evacuation time to tsunami evacuation facilities.

The evaluation of tsunami evacuation was constructed as an indicator "relationship of deaths rate and depth tsunami inundation".

Then, by using the evaluation method of tsunami evacuation, the tsunami risk areas in Japan was evaluated.

As a result, the change of the tsunami evacuation evaluation was shown by performing the parameters analyzed for the elevation of the evacuation sites and tsunami evacuation consciousness.

INTRODUCTION

By the East Japan great earthquake disaster that occurred on March 11, 2011, it was human damage more than approximately 20,000. More than 90% of damage depended on a tsunami.

In Japan, it is estimated that the earthquake of magnitude 9.0 by the Nankai trough will occur in future. By this earthquake, a massive tsunami is generated, and it is expected that damage with more than of East Japan great earthquake disaster occurs.

The estimation of structure damage is calculated from earthquake intensity and structure fragility. The human damage assumption of the tsunami changes by a evacuation behavior and a regional characteristics. The human damage is not decided only by earthquake intensity and tsunami height.

Studies on the human damage caused by the tsunami, there is a study of the Evaluation Method of Human Loss by Naoya SHISHIDO et al.(2010) and colleagues calculated the number of deaths due to tsunami damage estimation of Nankai Trough earthquake by the Cabinet Office(2012).

In this paper, the method that a regional tsunami evacuation risk was quantified was studied. It

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VALUATION ITEMS OF TSUNAMI EVACUTATION RISK

The tsunami evacuation of inhabitants is constituted by starts evacuation and does the movement to the facilities of evacuation and arrives at the place of evacuation and is completed. The process of evacuation is shown in figure1.

Tsunami evacuation procedures can be classified into vertical evacuation and horizontal evacuation.

Horizontal evacuation is the evacuation of toward the beyond the location of the tsunami. For tsunami inundation range is wide with a flat land, vertical evacuation is a case of evacuation horizontal evacuation is difficult. It is a refuge to the tsunami evacuation buildings in the inundation range.

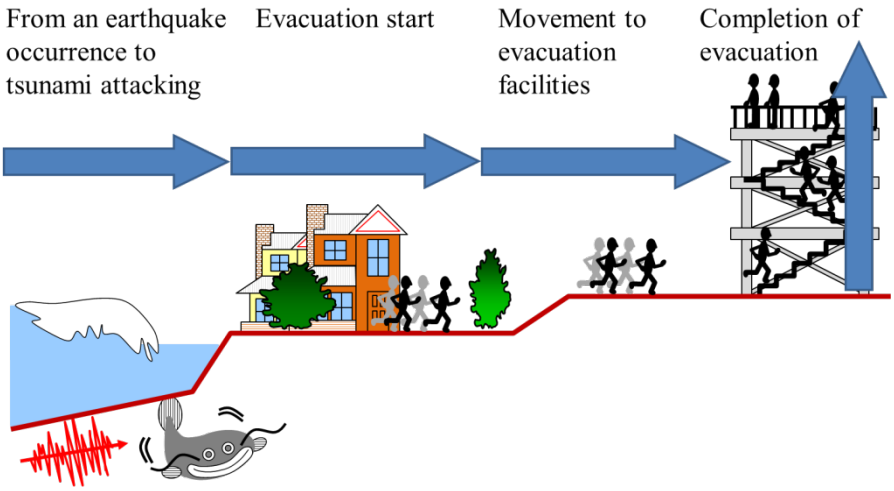

Figure1. Tsunami evacuation of inhabitants

The factor of risk evaluation and classification time of evacuation behavior of each stage is composed as follows.

① Time to start evacuation from the occurrence of the earthquake (First stage of evacuation) :
The start time of the evacuation, is affected by the occurrence time zone and earthquake evacuation consciousness of inhabitants.

② Move to the evacuation facilities (The second stage of the evacuation):
Time it takes to evacuation facilities from whereabouts. Evacuation speed and distance involved in evacuation risk assessment.

③ Evacuation complete (The third step of the evacuation):
Inhabitants arrive at the tsunami evacuation facilities by the horizontal evacuation. Then, evacuation is completed by the vertical evacuation to a position higher than the depth of inundation.

A success of tsunami evacuation is when tsunami evacuation time is shorter than tsunami arrival time.

EVALUATION METHOD OF TSUNAMI EVACUTATION RISK

In this study, the evaluation of the tsunami evacuation risk is carried out by dividing the area-wide mesh.
Figure 2 shows a diagram about the evacuation facility and the area-wide mesh in the region.

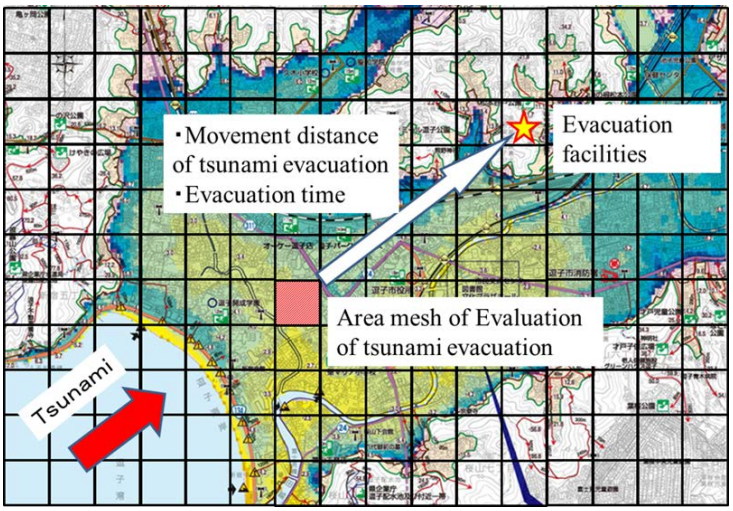

Figure2. Area-wide mesh of evaluation

The area-wide mesh is evaluated by various items in the evaluation of tsunami evacuation risk. And, tsunami evacuation risk of the region is evaluated by the sum of the risk of these area-wide meshes.

The evaluation main items of the tsunami evacuation risk of the area-wide mesh are evacuation walking speed and distance of evacuation facility.

Distance to the evacuation facility is calculated by multiplying the coefficients road congestion, the city fire condition, the collapsed building condition, a wide road condition and a wide river condition in a straight line distance to evacuation facility from the mesh.

The speed of the evacuation walking is calculated by taking into account density of evacuation route from population density, walking speed reduction from the age structure of the area-wide mesh, the elevation of the evacuation facility, on the basis of the walking evacuation speed of the Great East Japan Earthquake.

Average tsunami evacuation time Te by residents, is calculated from the evacuation walking speed V_w and distance to the evacuation facility $L_{d.}$

$$\text{Average tsunami evacuation time Te} = \frac{\text{distance to the evacuation facility } L_d}{\text{the evacuation walking speed } V_w} \quad (1)$$

Tsunami arrival time T_t to the mesh after the occurrence of earthquake is calculated by the sum of the arrival time to mesh from the coastline that takes into account the regional characteristics T_{a1} and tsunami arrival time of the coastline after the occurrence of earthquake indicated by the damage estimation T_{a2}.

$$\text{Tsunami arrival time } T_t = \text{tsunami arrival time of the coastline } T_{a1} + \text{arrival time to mesh from the coastline } T_{a2} \quad (2)$$

Tsunami evacuation incomplete rate is created by comparing the time of evacuation of inhabitants and the tsunami arrival time to evacuation mesh.

The tsunami incomplete evacuation rate may be taken into account (including the level of evacuation awareness) time to start evacuation from earthquake occurrence. In this study, the setting of the tsunami incomplete evacuation rate was set to reference is shown in figure 3 by a tsunami incomplete evacuation rate of the Cabinet Office（2012）.

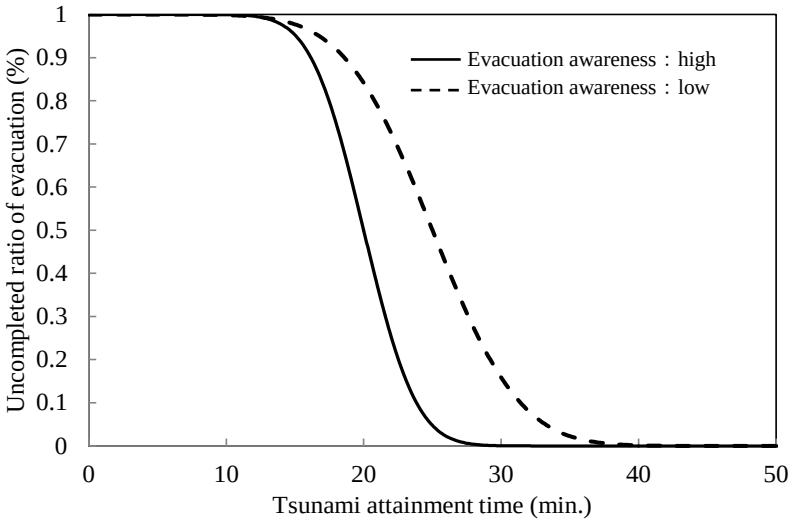

Figure3. Function of Uncompleted evacuation ratio（Cabinet Office）

Human damages of the tsunami can be obtained by creating a "tsunami evacuation fragility curve" from the relationship of " human damage －tsunami inundation depth " and "this tsunami incomplete evacuation rate" . Function of "human damage －tsunami inundation depth " by Koshiyama(2009) is shown in figure 4.

Indicator of tsunami evacuation risk evaluation of the area-wide mesh is indicated by this tsunami evacuation fragility curve.

Flow chart of evaluation of tsunami evacuation risk are shown in figure 5.

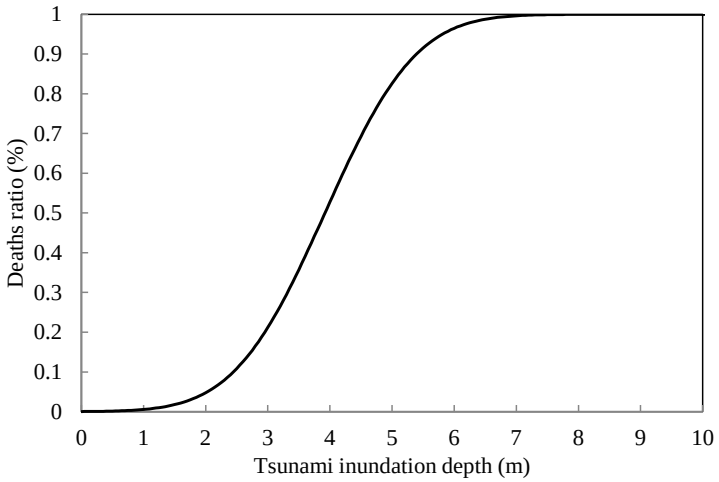

Figure4. Function of deaths

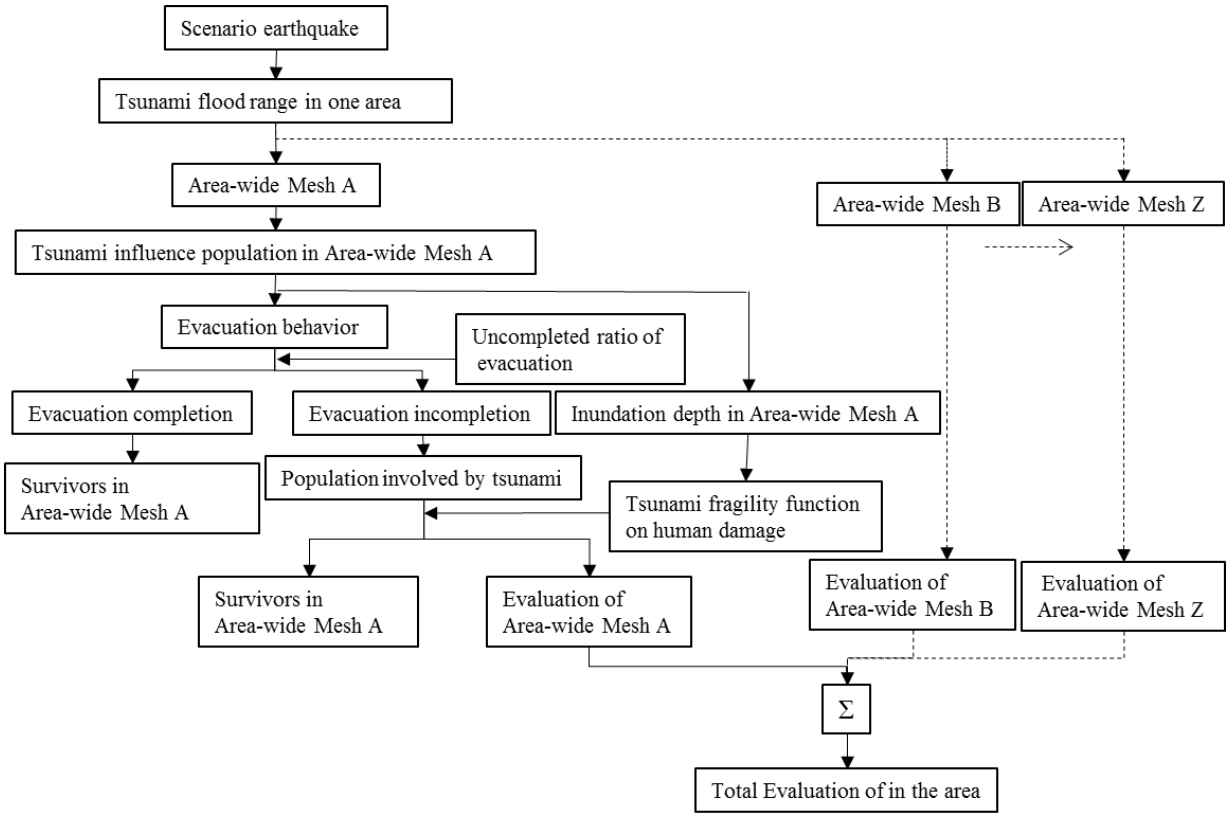

Figure5. Flow chart of evaluation

APPLICATION OF THE EVALUATION METHOD

Using the proposed method, it is applied to area where the occurrence of tsunami is expected.
In this study, Target area is Zushi, Kanagawa Prefecture in Japan. Figure 6 shows the tsunami hazard map of Zushi (2013).
Various conditions of the region, as follows from the expected damage and the hazard map of Zushi .

- Scenario earthquake：Meiou type earthquake
- Earthquake magnitude：8.4
- Initial arrival time of the coast (minutes)：8
- Depth of inundation(m)：5～6
- Mesh area (m^2)：200
- Mesh Population: 3,340
- Distance from the coast to mesh (m)：500
- The average walking speed (m / s)：5.4

The time of evacuation, it is assumed that evacuation of daytime. For evacuation walking speed, if elevation difference is more than 15m, it was decided to decrease 1% to evacuation walking speed per 1m, 50% up to reduce the speed.

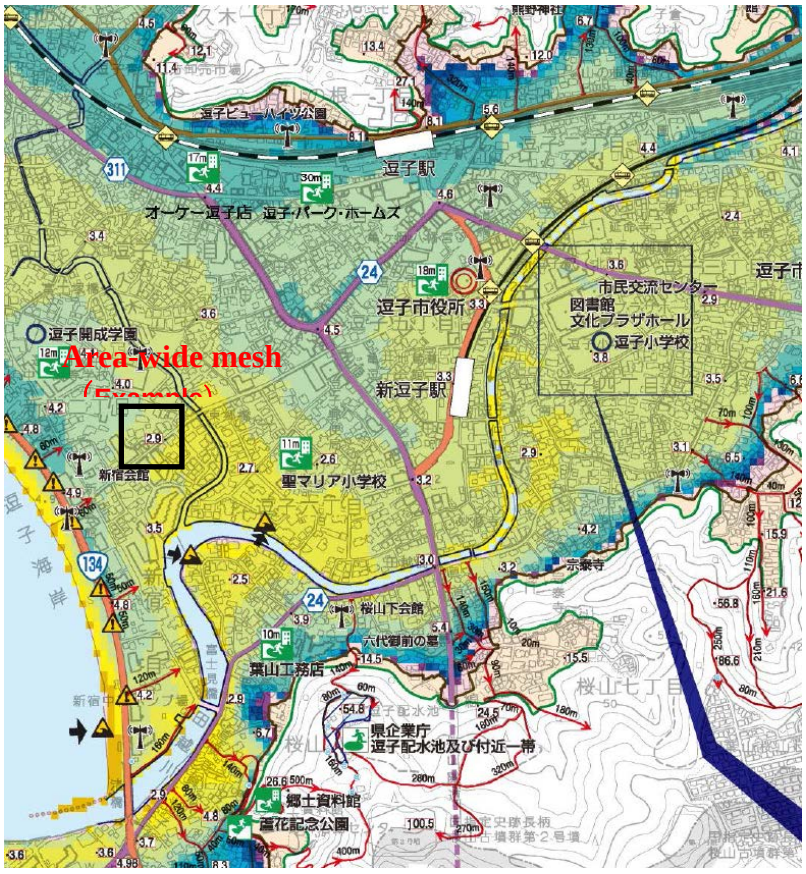

Figure 6.Tsunami hazard map of Zushi

First, as an evaluation of the tsunami human damage, the difference of the human damage caused by elevation difference of evacuation sites is studied.
To compare the difference by setting the area-wide mesh of the three elevations of evacuation sites is different.

Analysis is carried out as a evacuate to the altitude 7.5m, 11.5m, 44.5m from the mesh of 4.5m above sea level.

The conditions of the analysis are shown in Table 1. Become generally safe elevation of evacuation sites is high, but evacuation distance is extended.

Table.1 Conditions of the analysis for difference in elevation

	Area-wide mesh A	Area-wide mesh B	Area-wide mesh C
Distance from the coastline(m)	500	500	400
Straight-line distance to the evacuation facility(m)	250	350	300
Elevation difference between the evacuation facility(m)	3	17	40
Corrected evacuation distance(m)	375	525.3	451.8
Tsunami inundation depth (m)	3	3	3

Shown in figure 7, the results of differences in the human damage caused by elevation difference of evacuation sites are studied.
From this figure, when you run away to evacuated altitude of 3m, dead rate is about 04, in 5m depth inundation. Then, when you run away to evacuated altitude of 17m, dead rate is about 0.45 . Also, the dead ratio is 0.54 to about when to flee to evacuated altitude of 40m.
The altitude of the evacuation site is in comparison with the 40m and 3m, dead rate increases about 9%.
Human damage was increased elevation of evacuation sites is high.
To escape to the high evacuation site is a safe for tsunami. However, by escaping to the high places, so

that the risk increases evacuation distance is increased.
In this case, it is necessary to reduce the human evacuation by specifying the evacuation buildings nearby.

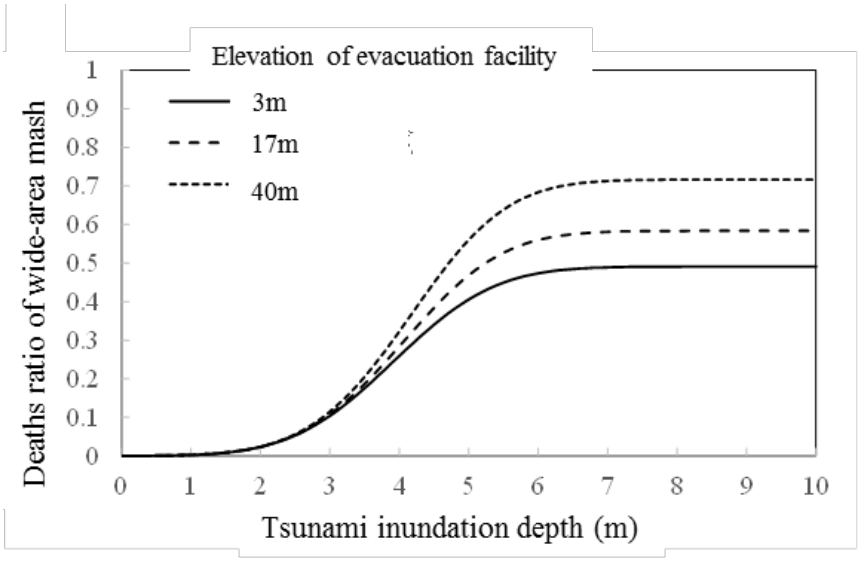

Figure7. Human damage caused by elevation difference of evacuation sites

Then, as the evaluation of tsunami human damage, the difference of human damage caused by evacuated consciousness of inhabitants is studied.
Elevation of the area-wide mesh is 3m. Elevation of the evacuation site is 6m.
And straight line distance to the evacuation site is the 250m. And, evacuation distance is analyzed as 375m by multiplying factor of 1.5.
Evacuation awareness of inhabitants is classified into four categories.
Classification is classified into the following four from the data by the Great East Japan Earthquake.
①Evacuation immediately after the earthquake (Evacuation awareness is high) ②Evacuation after finished the work (Evacuation awareness is low) ③Urgency evacuation (Evacuation awareness is low) ④Do not evacuation (Evacuation awareness is low)

Evacuation awareness is classified into three. Classification is the low high, and average.
The ratio of the population due to the difference in the evacuation awareness used in this study is shown in Table 2.

Table.2 Population ratio of evacuation consciousness

Evacuation awareness	Percentage of evacuation awareness(%)			
	evacuation immediately after the earthquake (Evacuation awareness : high)	evacuation after finished the work (Evacuation awareness : low)	Urgency evacuation (Evacuation awareness : low)	do not evacuation
High	**80**	**10**	**5**	**5**
Average	**50**	**25**	**15**	**10**
Low	**15**	**35**	**30**	**20**

Result of human damage caused by the difference in evacuation awareness is shown in figure 8.
Dead ratio in the case of evacuation awareness inhabitants the average is about 0.4 in 5m depth of inundation. But evacuation consciousness becomes higher, the dead ratio becomes about 0.67.
Awareness of evacuation is increased, the Human damage of the mesh greatly reduced. With regard to Human damage reduction by tsunami, improvement of evacuation consciousness is an effective means.
And, enhancement of disaster reduction education is important for the evacuation awareness.

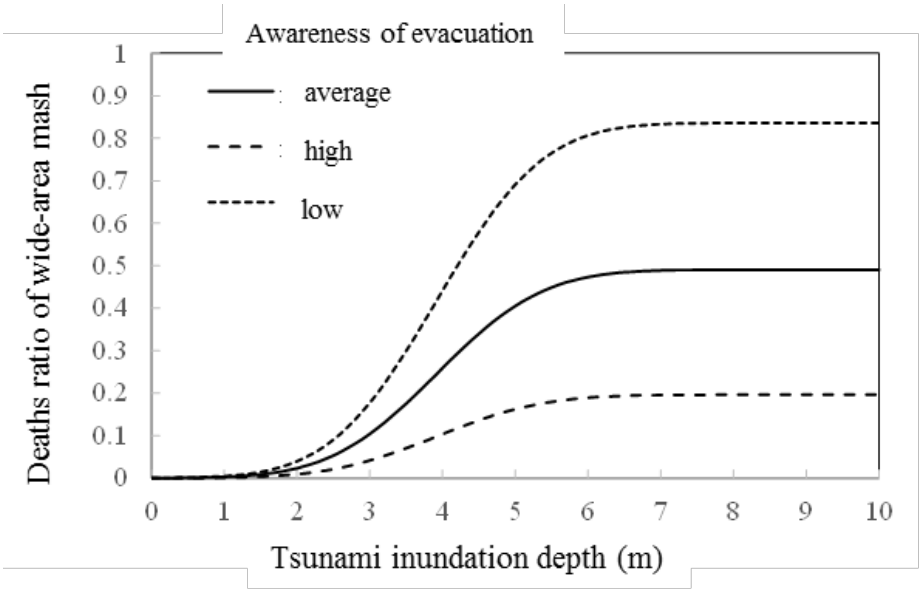

Figure8. Human damage caused by the difference in evacuation awareness

CONCLUSIONS

In this paper, study has been carried out for the purpose of having to build a evaluation method in the region related to tsunami evacuation.

In this method, the region is divided into the area-wide mesh first. And human damage is evaluated by taking into account the conditions of evacuation of the area-wide mesh.
The results are shown below is obtained.

① The tsunami evacuation evaluation method of mesh proposed to calculate the relationship between the "depth of tsunami inundation and death rate."
It is possible to use this relationship as an index of evaluation of the tsunami risk area.

② From the analysis of tsunami evacuation evaluation, changes in tsunami evacuation risk due to the difference in elevation of the evacuation sites have been revealed.
In general, it is possible to evacuation to high altitudes in tsunami evacuation is safe. However, to go to the place of evacuation at high altitudes, distance is extended evacuation, evacuation speed is also slowly. Inhabitants have an increased potential to become the victim of the tsunami for that.
It was shown that from the analysis of this study, to specify to evacuation sites the high altitudes is unsafe unconditionally.

③ Differences in tsunami evacuation risk of evacuation awareness became clear from the evaluation of tsunami evacuation.
Since the evacuation awareness is high, a significant reduction in death rate has been shown by making a quick evacuation after the earthquake
By this, it is possible to understand the importance of Disaster Reduction education.

Future studies extended to macro evaluation of region from the evaluation of tsunami evacuation of the mesh in the proposed method. And, it is planned to build a tsunami evacuation risk curve using the tsunami hazard curve and tsunami evacuation evaluation of this region.

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