Developing probability curves of fatality during the 2011 Great East Japan tsunami in Sendai plain

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1. Introduction: The 2011 Great East Japan tsunami caused a wide range of devastating tsunami with maximum tsunami height of 40 m and 19,000 casualties especially along the Tohoku coast in the east coast of Japan. The Tohoku coast comprises of two coastal topography types namely, Sanriku ria-coast and Sendai plain. Difference in the coastal topography type leads to difference in tsunami characteristic and personal characteristic of evacuation. The tsunami characteristic is a factor of tsunami height, tsunami arrival time, coastal topography type, etc. and the personal characteristic is a factor of age, gender, preparedness, occupation, etc. A relationship between fatality and influential factors should be proposed for contributing to insurance society for future tsunami loss assessment such as the Nankai tsunami. A simple-characteristic area of Sendai plain, such as Miyagi and Fukushima, should be a prior study which is different from a complex-characteristic area of Sanriku ria-coast as shown in Fig. 1. From past studies, it was found that tsunami height is a key factor which has a significant effect on a trend of fatality ratio. This is a good chance to develop the probability curves of fatality in Sendai plain based on tsunami height considering the effect of age and gender.

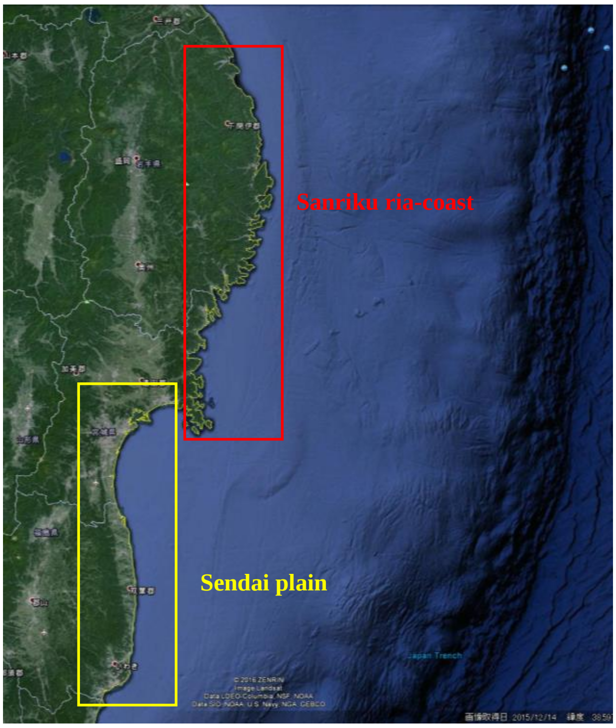

Fig. 1 Coastal topography type (Google Earth)

2. Data and method:

2.1 Fatality data and tsunami height: Fatality data collected by prefectural police was obtained from Iwate and Fukushima (Tani, 2012). In order to compare with insured data from an insurance company, the selected data comprise of 27210 people data in which details of fatality data are provided for 14 towns individually in Sendai plain as shown in Table 1. As can be seen in Table 1, fatality data is classified into number of fatality (D) and population (N) in each inundated area, which is the population data obtained from census in 2010 (Tani, 2012). In addition, tsunami inundation simulation was performed by means of nested-grid system of mesh size, i.e. 1350 m, 450 m, 150 m, and 50 m in order to obtain maximum tsunami height at each town.

Table 1 Fatality data and tsunami height in Sendai plain

City	Town	N	D	Tsunami
Ishinomaki	Sakana	130	3	7.87 m
	Shiotomi	862	5	4.87 m
Onagawa	Onagawahama	1778	175	13.91 m
	Izushima	465	14	10.11 m
Higashi-Matsushima	Omagari	7019	313	6.04 m
	Miyato	950	11	5.58 m
	Shintona	1024	34	3.48 m
Shiogama	Uratosabusawa	161	3	3.61 m
Shinnichigahama	Hanabushihama	1726	15	8.34 m
Watari	Arahama	4080	132	8.12 m
Yamamoto	Sakamoto	3975	218	8.37 m
Soma	Iwanoko	583	1	3.1 m
	Obama	2460	54	8.07 m
Shinchi	Yachigoya	1997	33	8.15 m

2.2 Developing probability curve: From Table 1, fatality data of all people was rearranged to personal data of each people in binary format (0=survive, 1=fatality) as shown in Table 2. Binary logistic regression analysis was performed to develop probability curves of fatality in personal level from tsunami height. The probability (P) of fatality is given either by Eq. (1) – (3):

$$P(x_1) = \frac{1}{1+e^{-(a+bx_1)}} \quad (1)$$

$$P(x_1, x_2) = \frac{1}{1+e^{-(a+bx_1+cx_2)}} \quad (2)$$

$$P(x_1, x_3) = \frac{1}{1+e^{-(a+bx_1+dx_3)}} \quad (3)$$

where, x_1 represents tsunami height at location of town that people lives, x_2 stands for age of that people defined as three groups of categorical parameter (e.g., 1 = less than 15 years old, 2 = between 15 and 60 years old, 3 = over 60 years old), and x_3 stands for gender of that people defined as two groups of categorical parameter (e.g., 1 = male, 2 = female). Three estimating equations in Eq. (1) – (3) are the probability of fatality based on tsunami height with a and b constant values. However Eq. (2) also includes the effect of age with c constant value and Eq. (3) also includes the effect of gender with d constant value:

Table 2 Personal data of each people in binary format

People ID	Age	Gender	Fatality	Tsunami
1	1	1	1	7.87 m
2	2	1	0	7.87 m
3	2	2	0	7.87 m
4	3	2	0	7.87 m
5	1	1	1	4.87 m
6	2	1	0	4.87 m
7	3	2	1	4.87 m
8	3	2	0	4.87 m
⋮	⋮	⋮	⋮	⋮
27210	3	2	0	8.15 m

3. Results and discussions:

From the fatality data of 27210 people in Sendai plain, 27153 data were used to develop the probability curves of fatality including the effect of age and gender as shown in Fig. 2 and 3 respectively. The rest of 57 data are lack of age and gender. From Table 1, 14 towns have maximum tsunami height from 3.10 m (Iwanoko) to 13.91 m (Onagawahama) in Sendai plain. In general, the probability curve was developed from Eq. (1) estimating probability of fatality from only tsunami height. As can been seen in Fig 2 and 3, the probability in general curve (black line) increases with higher tsunami height and reaches to 0.085 at tsunami height 14 m.

Considering the effect of age, three curves were developed from tsunami height and age in which probability in the case of age over 60 years old (green line) increases rapidly for higher tsunami height as shown in Fig. 2. The probability in the case of age over 60 years old is higher than that of the general curve (black line) and reaches to 0.15 at tsunami height 14 m, whereas the rest of two curves (red and blue line) is lower than the general curve.

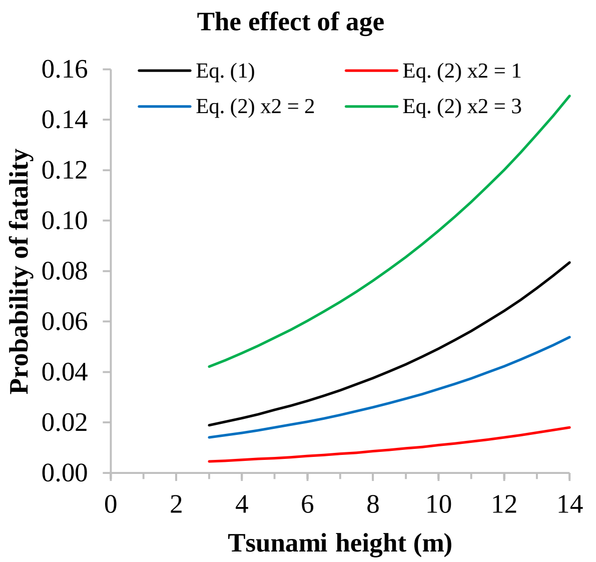

Fig. 2 The effect of age on probability of fatality

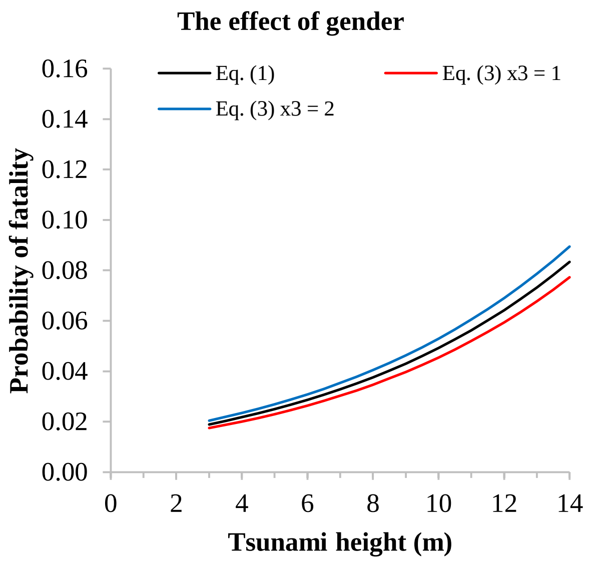

Fig. 3 The effect of gender on probability of fatality

Considering the effect of gender, two curves were developed from tsunami height and gender in which probability in this two curves is hardly different from the general curve (black line) as shown in Fig. 3. However, the probability in the case of female (blue line) is a little higher than that of male (red line).

On the other hand, the probability of fatality including the effect of age is more different in higher tsunami height as shown in Fig.2. As can be seen in Fig. 2, the probability in the case of age less than 15 years old increases slowly with higher tsunami height. In Fig. 3, the probability of fatality including the effect of gender is almost similar for lower tsunami height.

4. Conclusions and recommendations:

This study developed probability curves of fatality based on fatality data of 27210 people in Sendai plain. The constant values of proposed equation for estimating probability of fatality are shown in Table 3. For Eq. (1) and Eq. (3), the constant values of *a* and *b* are not different relating with the results of probability curves in Fig. 3. At the same tsunami height, higher probability of fatality is found due to increasing of age as shown in Fig. 2. The constant values of *a* and *b* in Eq. (2) are different from those of Eq. (1) relating with the results of probability curves in Fig. 2. Contributing to insurance society, it was found that age of people have a significant effect on tsunami loss assessment rather than gender of people. These findings can be applied to construct a policy of insurance for future tsunami.

Table 3 Summary of constant values in Eq. (1)-(3)

Equation	*a*	*b*	*c*	*d*
1	-4.371	0.141	-	-
2	-6.887	0.126	1.128	-
3	-4.616	0.141	-	0.161

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