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TSUNAMI FRAGILITY ANALYSIS FOR INDUSTRIAL AND COMMERCIAL PROPERTIES

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Abstract

Tsunami risk quantification techniques have been developed mainly for probabilistic tsunami hazard assessment and building fragility assessment. However, research areas related to fragility assessment of assets other than buildings (machinery, structure, movable property, etc.) have not been developed yet for commercial and industrial sectors. In this study, using the results of the questionnaire survey conducted by the Regional Innovation Research Center (RIRC) at the Graduate School of Economics and Management, Tohoku University, we analyzed the actual damage of industrial and commercial properties caused by the earthquake and tsunami in the Great East Japan Earthquake in 2011. Detailed building damage data was obtained from the Ministry of Land, Infrastructure and Transportation and Tourism (MLIT) and contains building size, numbers of stories, construction material and interpolated measured maximum flow depth. After grasping the detailed characteristics of the earthquake and tsunami at the time of the disaster, the actual damage (physical damage amount) was organized, and a tsunami fragility function for commercial and industrial facilities was constructed. The results of this research will contribute to the advancement of tsunami risk quantification methods for commercial and industrial facilities.

Keywords: tsunami, fragility analysis, risk assessment

1. Introduction

Tsunami risk quantification techniques have been developed mainly for probabilistic tsunami hazard assessment and building fragility assessment [1][2]. However, research areas related to fragility assessment of assets other than buildings (machinery, structure, movable property, etc.) have not been developed yet for commercial and industrial sectors. In this study, using the results of the questionnaire survey conducted by the Regional Innovation Research Center (RIRC) at the Graduate School of Economics and Management, Tohoku University, we analyzed the actual damage of industrial and commercial properties caused by the earthquake and tsunami in the Great East Japan Earthquake in 2011. Detailed building damage data was obtained from the Ministry of Land, Infrastructure and Transportation and Tourism (MLIT) and contains building size, numbers of stories, construction material and interpolated measured maximum flow depth.

2. Used data

2.1 Data reduction for replacement cost of all property

Our main data source is the 1st and 2nd The Tohoku University Earthquake Recovery Firm Survey (TERFS) that was designed and conducted by the Regional Innovation Research Center (RIRC) of the Graduate School of Economics and Management at Tohoku University of Japan[3][4]. The four waves of this panel survey were conducted annually from July 2012 to October to November 2015. We use the 1st one that was conducted in

July of 2012 and 2nd one that was conducted from August to September of 2013. This wave contains information on loss amount of corporate assets.

The following companies were excluded from the analysis:

- Companies with offices other than headquarters (because assets / damage other than headquarters cannot be separated)
- Companies whose damages are unknown
- Companies established on or before 1959 (because it is difficult to estimate the replacement cost)

The replacement cost of property, plant and equipment of the target company was estimated using the figures for property, plant and equipment during the fiscal year before the earthquake (2008-February 2011), using the following procedure:

1. If property, plant and equipment is depreciated by the indirect method, the acquisition cost shall be used, excluding accumulated depreciation that is recorded negatively.
2. If tangible fixed assets are depreciated by the direct method and the cumulative amount of depreciation is found in the footnote, the total is taken as the acquisition price.
3. If tangible fixed assets are depreciated by the direct method and the accumulated depreciation is not known by footnotes, the depreciation cost / depreciation amount is calculated based on the asset acquisition timing estimated in the latter part of 4. The estimated depreciation period was used, and the accumulated depreciation and acquisition cost were estimated by multiplying by the amount of depreciation and depreciation implemented.
4. Regarding the timing of asset acquisition, in cases where the accumulated depreciation amount is known as in 1. and 2., and where the amount of depreciation or depreciation is known, the accumulated depreciation by simply deducting the amount of depreciation or the amount of depreciation implemented, the depreciation period and asset acquisition timing were estimated simply.
5. For cases where the amount of depreciation and depreciation is not known or for case 3 above, the acquisition period was simply estimated by applying the period from the establishment of the company to the settlement period by calculate the depreciation period in the previous fiscal year and calculate the ratio of the period from the establishment of the company to the closing period, and calculate the ratio for each case.
6. Replacement costs as of 2011 were estimated from the acquisition price referring to the MLIT cost deflator[5] for buildings and the Bank of Japan Corporate Price Index[6] for other than the building in accordance with the asset acquisition time estimated in 4..

As a result, the replacement value (building and equipment) and loss amount of 157 tsunami-affected companies have been arranged.

2.2 Data reduction for properties other than buildings

In this section, the data on corporate assets and damages extracted in 2.1 are separated into buildings and non-buildings using the following procedure (shown as Fig.1):

7. The following items (A) were confirmed from the following data (B) as company building information.
   A: Maximum inundation depth, Damage level, Building area, Structural material, Number of floors, Number of tsunami inundation floors, Building elevation plan
   B: The detailed data of tsunami damage buildings collected during field surveys by MLIT[5]
   Photos before and after the disaster (Google Street view™, Google Earth™)

8. After that, Loss ratio and representative inundation depth of contents (except building cost) are delivered (N=117). Fig.2 shows the type of industry in the population. It turns out that the construction industry accounts for about 60%.

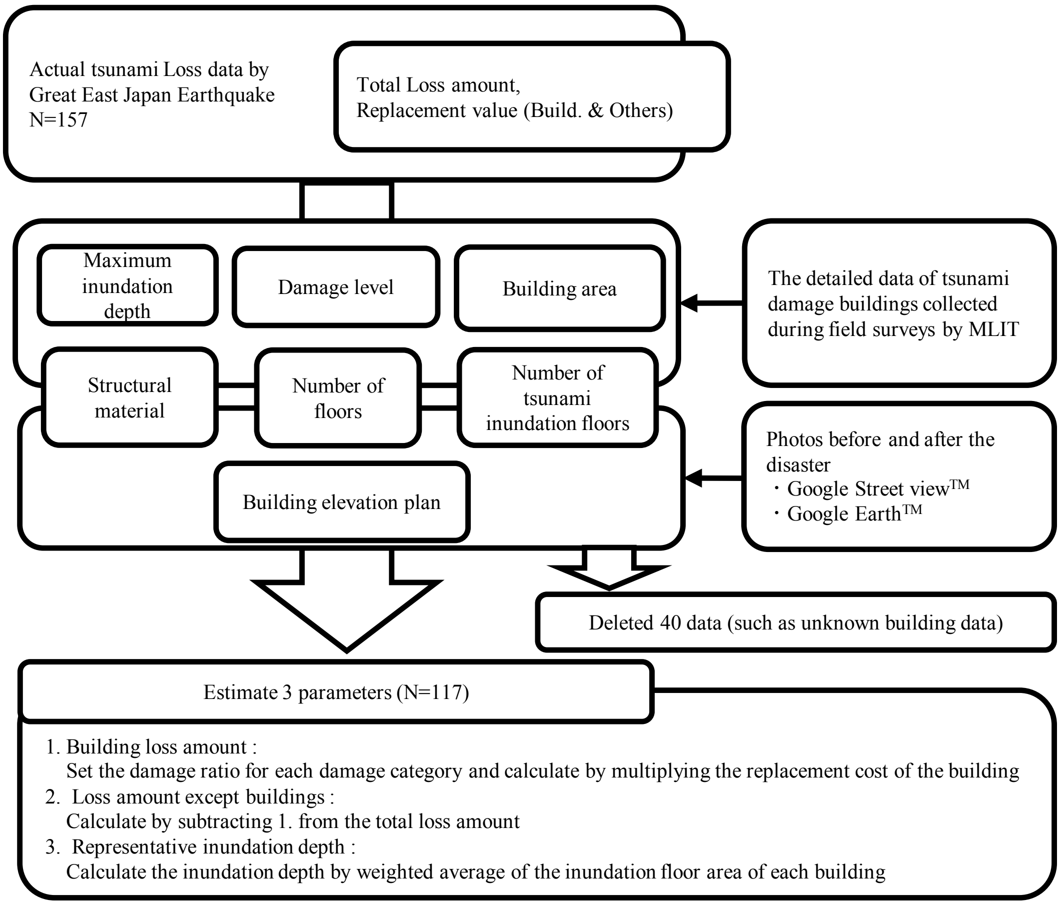

Fig. 1 – Flow of facilities tsunami loss curve calculation

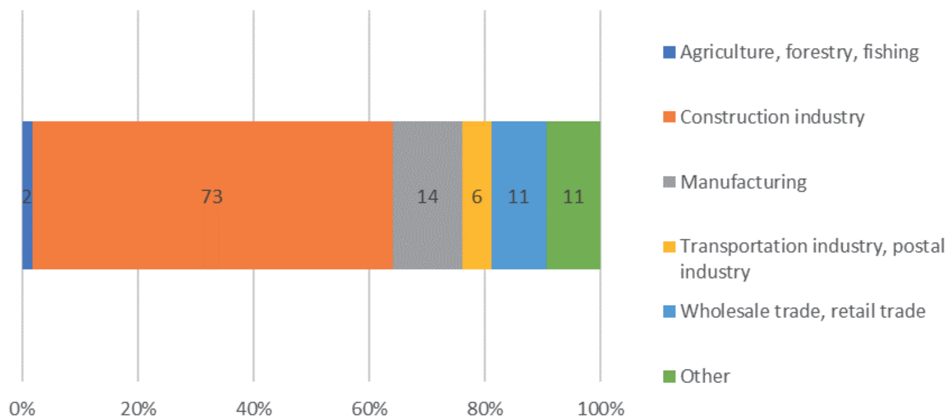

Fig. 2 – Percentage of industry sectors

3. Parameters Estimation

3.1 Parameters Estimation

Maximum likelihood estimation was performed to develop the fragility function. In this study, 'Loss ratio (*L*)' is defined as the asset loss divided by the asset replacement cost calculated in last section. For the link function of the loss curve, a log-normal distribution was adopted with reference to previous studies [1][2]. The Loss ratio *L* of occurrence of damage is given either by Eq. (1):

$$L(d) = \Phi(\frac{\ln(d) - \ln M}{\beta}) \tag{1}$$

where Φ represents the standardized normal distribution function, d represents the tsunami maximum inundation depth, and $ln(M)$ and β represents the mean and standard deviation of $ln(d)$, respectively.

First, the loss curves of all industries were estimated by maximum likelihood estimation. Considering the distribution of industries, the maximum likelihood estimation was performed separately for the construction industry that accounts for more than half and the others. Table 1 shows the regression coefficients of the regressed tsunami loss curve, and Fig. 3 shows the damage plot of the actual damage and the regressed tsunami loss curve.

Table 1 – Estimated parameters for tsunami loss curves (Except building cost)

Item	All industry	Construction industry	Other industry
M	0.083	0.108	0.038
β	5.142	4.419	6.936
AIC	135	84	105

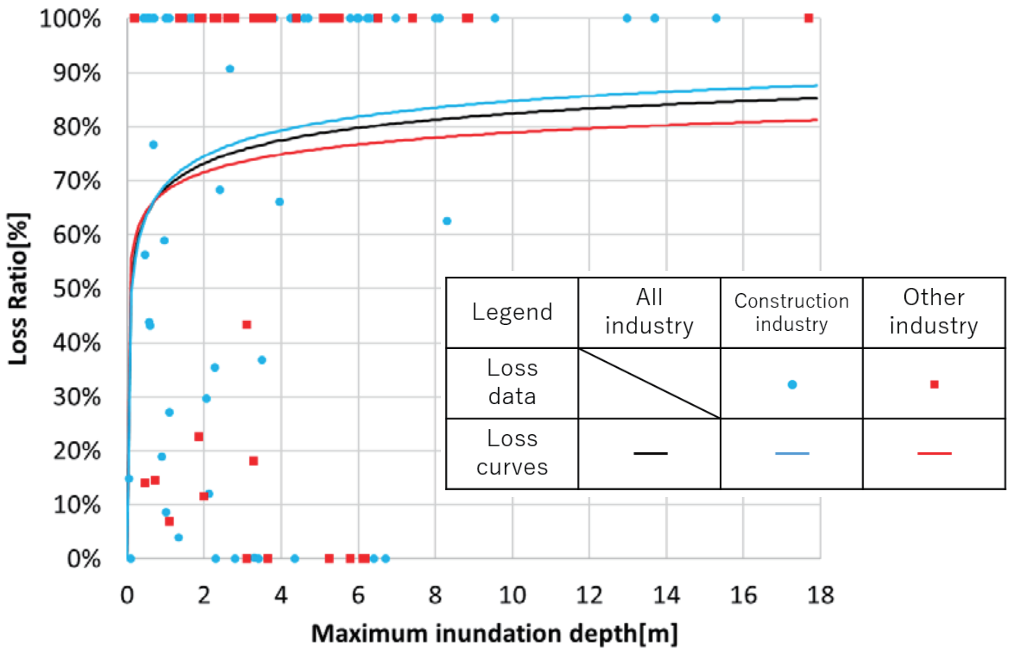

Fig. 3 – Loss ratio curves (Except building cost)

3.2 Discussion

Fig. 4 shows a comparison between the building loss function of Okuno et al.[2] and this study. It can be seen that, at 2 m, loss ratio of this study's curve is about 73% which is much larger than Okuno et al.. The results shows that facilities tsunami loss curves are more vulnerable than building ones. The following can be considered as the above factors:

- Because many assets (machinery, vehicles, etc.) outside the building are included
- Uncertainty remains in estimating the asset value, which is the denominator of the damage degree

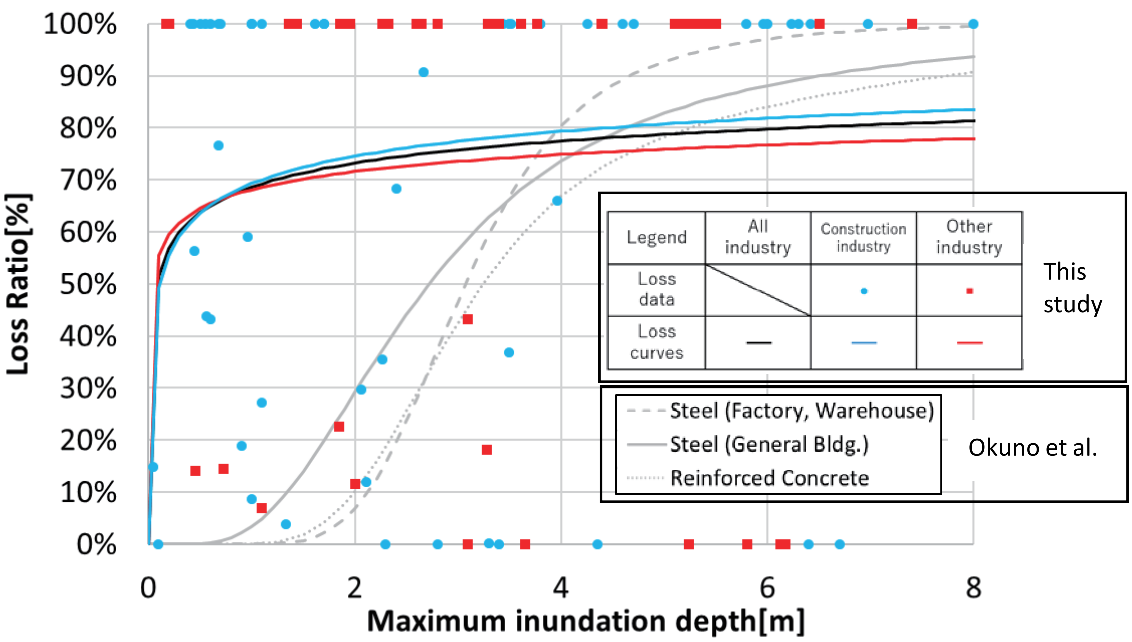

Fig. 4 – Comparison of loss ratio curves (Except building (this study) vs. Building (Okuno et al.))

4. Conclusions

In this study, tsunami loss curves for commercial and industrial facilities was constructed using economic damage of buildings data from RIRC and maximum inundation depth and building materials, etc. from MLIT. A comparison with the typical fragility functions for different structural type shows that facilities tsunami loss curves are more vulnerable than those of buildings. The cause for large variation of loss curves should be investigated more. The results of this research would contribute to the advancement/improvement of tsunami risk quantitive evaluation for commercial and industrial facilities.

5. Acknowledgements

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collected during the damage surveys of the 2011 Tohoku tsunami conducted by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

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