Development of Debris flow Vulnerability Curve for Data-driven Method

Chang-Ho Song[1], *Ji-Sung* Lee[1], *Ho-Hong Duy* Nguyen[1], *Yong-Soo* Ha[1] and *Yun-Tae* Kim[1*]

[1]Department of Ocean Engineering, Geo-systems Engineering Laboratory, Pukyong National University, Busan 48513, Republic of Korea

Abstract. Various landslide disasters due to abnormal climate are increasing all over the world, and the inflow of debris flow is causing great damage to human life and social infrastructure. As such, in order to preemptively respond to debris flow, it is necessary to conduct a vulnerability assessment of the hazardous area based on the vulnerability curve. Therefore, in this study, the hazard intensity (depth, velocity, and impact pressure of debris flow) was analysed by performing back analysis using the DAN3D numerical model for 27 debris flow disaster areas in Korea from 2011 to 2020. And the vulnerability curve for the building was developed through the relationship between the degree of damage to the building and the impact pressure obtained through the case analysis of debris flow disasters.

1 Introduction

Due to recent climate change, the probability of slope disasters is increasing due to many typhoons and torrential rains. In particular, in Korea, most of the rainfall is concentrated between June and September, and a lot of debris flow occurs. Therefore, in order to reduce damage caused by debris flow and to take a preemptive response, it is necessary to analysis the hazard intensity of debris flow with high reliability and develop a vulnerability curve.

In general, in order to evaluate the vulnerability to a sediment disaster, an area with a high probability of occurrence of a sediment disaster is identified, and sediment flow analysis and vulnerability curve are used. Currently, many researchers have conducted research related to the vulnerability curve through risk intensity analysis based on debris flow disaster cases [1-3].

In the case of Korea, the proportion of mountainous areas is high and the population is concentrated along the mountain boundaries. In addition, from the past to the present, many developments have been made in the vicinity of mountainous areas to solve the housing shortage and transportation, which is more exposed to the risk of landslides. In particular, in 2020, many landslide disasters occurred nationwide due to intensive rainfall between July and August. Of these, in August, accumulated rainfall of about 300 to 500 mm nationwide caused many landslides, and many houses exposed to the risk of landslides suffered damage. Therefore, in this study, As shown Figure. 1, a risk intensity analysis was performed targeting 27 debris flow from 2011 to 2020, and a vulnerability curve was developed by analysing the relationship with the damage level of the damaged building.

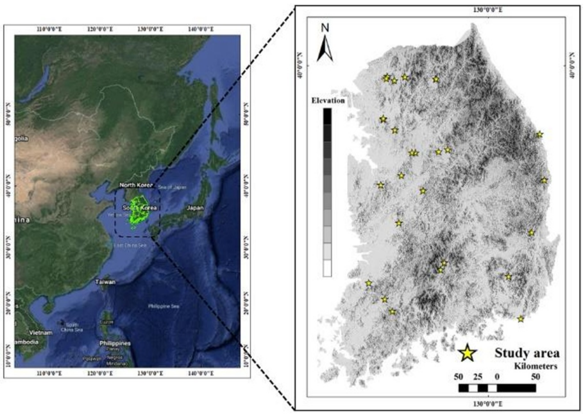

Fig. 1. Location map of study area

2 Methodology

This study is divided into 3 steps. First, perform spatial data analysis of the debris flow disaster area. And by performing the numerical method through topographic analysis, back analysis of the debris flow disaster area and the hazard intensity(flow depth, flow velocity, impact pressure) of the disaster area are analysed. Second, the degree of damage to the damaged building and the type of building(RC / Non-RC) are analysed through Field survey or photos of the debris flow disaster. Finally, through the relationship analysis of step 1 and step 2, a vulnerability curve according to the type of building is derived. Also develop Vulnerability function.

---

* Corresponding author: yuntkim@pknu.ac.kr

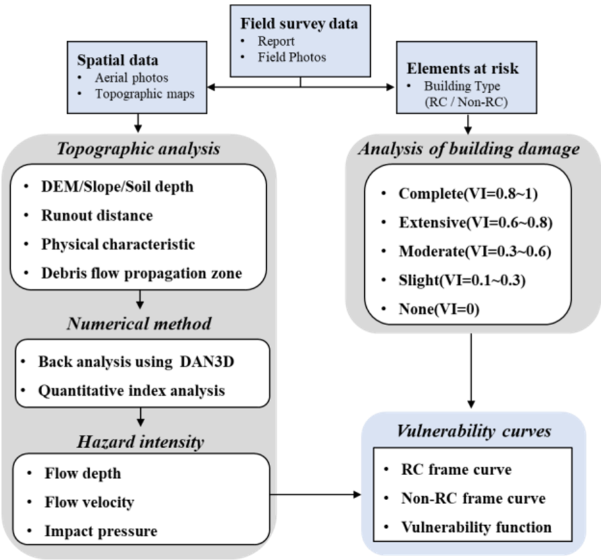

Fig. 2. Method of this study.

2.1 Topographic analysis

The topographic characteristics were produced with a resolution of 5m by obtaining a 1:5,000 numerical map provided by the National Geographic Information Institute (NGII). First, the DEM data were produced from the numerical map, and the slope was produced through topographical analysis. And the soil depth was constructed by extracting it through the universally used S-model. And the initiation volume, final volume, runout distance, propagation zone was established through comparative analysis of aerial images before and after the occurrence of debris flow.

2.2 Numerical method

There are various models as commercial programs used for the analysis of debris flow. However, in this study, the 3D topography and entrainment action can be considered, and the DAN3D program that provides 5 rheological models was selected. In DAN3D, in order to consider the entrainment (1) equation. it is assumed that the volume increases exponentially according to the distance the debris flow. And the frictional model is used, and two parameters are required: friction angle and pore water pressure ratio as shown in the following (2) equation. Input variables were calculated based on field surveys and data provided by the National Institute of Agricultural Sciences.

$$\overline{E} = \frac{1n(v_f/v_0)}{\bar{s}} \tag{1}$$

$$\tau_{zx_{(z=b)}} = -\sigma_{z_{(z=b)}}(1-\gamma_u)(1-\gamma_u)_{(z=b)}tan\emptyset \tag{2}$$

2.3 Hazard intensity analysis

In order to secure the reliability of the risk intensity analysis of debris flow through reverse analysis, Fig. As shown in Fig. 4, reverse analysis was performed on the area where the debris flow occurred, and the velocity and depth of the debris flow actually observed were verified.

When a debris flow disaster occurred in Mt. Umyeon in 2011, the velocity was 28 m/s and the depth was 3 to 4 m in the Raemian apartment, and the velocity was 18 m/s and the depth was 2 to 3 m in the Shindong-a apartment. As a result of comparative analysis of the observed values and the intensity of debris flow analysed through inverse analysis, both Raemian Apartments and Shindonga Apartments gave similar interpretations to the measured values. Therefore, the velocity and depth of the debris flow were analysed through the back analysis.

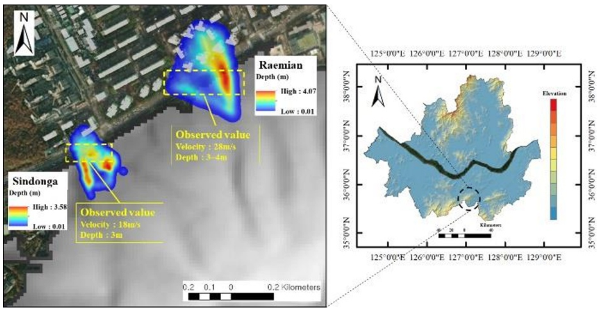

Fig. 3. Numerical method results in Umyeon Mt..

Finally, an important hazard intensity in the Vulnerability curve is the impact pressure. The impact pressure is usually calculated using (3) equation. [4] suggested an empirical coefficient through an experiment as shown in the figure, and calculated the impact pressure through the following (4) equation.

$$P_s = \alpha\rho_s v^2 \tag{3}$$

$$\alpha = 5.3F_r^{-\frac{3}{2}} \tag{4}$$

where P_s impact pressure(kPa), α is empirical coefficients, ρ_s is the density of the debris flow (kg/m^3), v is debris flow velocity.

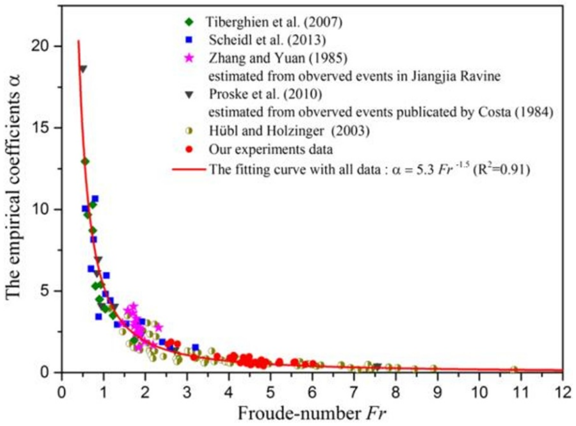

Fig. 4. Relationships between Froude number and empirical coefficients(Cui et al., 2015).

https://doi.org/10.1051/e3sconf/202341505025

2.4 Analysis of building damage

The evaluation of the physical vulnerability of a building due to a debris flow disaster can be evaluated through a vulnerability curve that contains information on factors that cause debris flow and the degree of damage to the building. The vulnerability index for a building means the degree of damage to the building, and has a value between 0 and 1 depending on the degree of damage to each building.

For the value of the vulnerability index corresponding to the damage to the building, the relationship of the vulnerability index to the degree of damage to the building was referred to in Table 1.

Table 1. Classification of damage to building caused by debris flow [5-6].

Damage class (Vulnerability index)	Damage description
Complete (0.8-1.0)	Partly or totally destructed, evacuation necessary, complete reconstruction
Extensive (0.6-0.8)	Partly destructed, loss of parts of external and internal walls, evacuation necessary, reconstruction of destructed parts
Moderate (0.3-0.6)	Cracks in the wall, stability not affected, reparation not urgent, flooding of the internal rooms and damage to the furnishing
Slight (0.1-0.3)	Slight non-structural damage, stability not affected, furnishing or fitting damaged

3 Results and discussion

3.1 Hazard intensity

The hazard intensity (flow depth, flow velocity) analysed through DAN3D was analysed. In order to apply the empirical coefficient proposed by Cui et al., 2015, Froude-numbers for 27 debris flow disaster were calculated. Froude-number calculated through the back analysis was calculated in the range of 0.6 ~ 4.74, and it was found that it was included within the range as a result of fitting with the existing cases [7]. Therefore, the impact pressure of 79 buildings was calculated through the empirical coefficients.

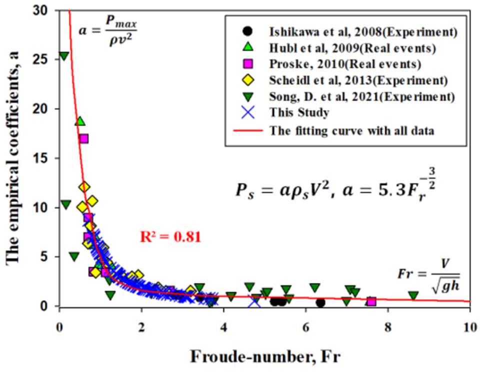

Fig. 5. Relationships between Froude number and empirical coefficients.

3.2 Vulnerability curve

In general, debris flow disaster vulnerability curve is expressed in the form of an S-shaped sigmoid function by applying a regression model. In many previous studies, the vulnerability curve was developed using linear and nonlinear regression models [1-3, 8-9]. In this study, vulnerability curve was developed using the regression model with the highest coefficient of determination by comparing a total of six linear and nonlinear regression models

Overall, for each structural system, the same high coefficient of determination was derived in the order of Avrami equation, Logistic, Weibull, Exponential, Power law, and Univariate. Based on these results, the Avrami equation, which has the greatest statistical significance, was used in the development of the debris flow vulnerability curve in this study(Fig. 6).

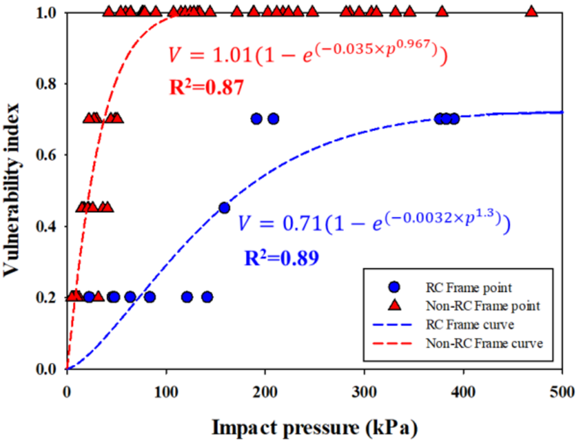

Fig. 6. Debris flow vulnerability curve.

4 Conclusions

The frequency of occurrence of landslides around the world is increasing, and the scale is gradually increasing accordingly. Therefore, in order to prevent damage caused by landslides, it is necessary to preemptively respond to technology.

In this study, 27 cases of location data that caused damage to buildings due to landslides from 2011 to 2020 were collected to develop a vulnerability curve through a data-based method.

First, topographic and physical characteristics were established for the analysis of debris flow disaster, and the hazard intensity of debris flow was analysed through back analysis. And from the analysis of the correlation between the analysed impact pressure and the degree of damage to the building, a vulnerability curve was derived through a data-driven method.

Based on these results, it is judged that it will be possible to prepare an advanced-level response system by providing accurate information such as vulnerability determination, improving response velocity, and preparing a disaster response system by establishing its own evaluation index.

This work is supported by the Korea Evaluation Institute of Industrial Technology(KEIT) funded by the Ministry of Public Administration and Security grant (No. K_G012001951201).

References

1. Quan Luna, B., Blahut, J., van Westen, C. J., Sterlacchini, S., van Asch, T. W. J., and Akbas, S. O, Nat. Hazards Earth Syst. Sci., **11**, 2047-2060, (2011)
2. Kang, H. S., and Kim, Y. T, Natural Hazards, **80**, pp. 1475-1493, (2016)
3. Papathoma-Köhle M, Keiler M, Totschnig R, and Glade T, Nat Hazards, **64**, 2083–2105, (2012)
4. Cui, P., Zeng, C., Lei, Y, EARTH SURFACE PROCESSES AND LANDFORMS, **40**, 1644-1655, (2015)
5. Hu, K. H., Cui, P., and Zhang, J. Q, Nat. Hazards Earth Syst. Sci., **12**, 2209-2217, (2012)
6. Leone, F., Aste, J. P., and Leroi, E. Vulnerability Assessment of Elements Exposed to Mass-movement: Working Toward a Better Risk Perception. A.A. Balkema In: Senneset K (ed) Landslides, **1**, 263-269, (1996)
7. Proske, D., Suda, J., & Hübl, J, Georisk, **5**, 143-155, (2011)
8. Barbolini, M., Cappabianca, F., and Sailer, R, *Empirical estimate of vulnerability relations for use in snow avalanche risk assessment*. In: Brebbia C (ed) Risk analysis IV. WIT Press, Southampton, 533–542, (2004)
9. Fuchs, S., Heiss, K., and Hubl, J, Nat. Hazards Earth Syst. Sci., **7**, 495-506, (2007)