Numerical Simulation Reflecting Buildings in Area Damaged by Debris flow

Bae-Dong Kang[1], *Kye-Won* Jun[2*], *Ho-Jin* Lee[3], *Chang-Deok* Jang[4] and *Hang-Il* Jo[5]

[1]Granduate School of Disaster Prevention, Kangwon National University, S.Korea
[2]Granduate School of Disaster Prevention, Kangwon National University, S.Korea
[3]School of Civil Engineering, Chungbuk National University, S.Korea
[4]CND, Samcheok-si, Gangwon-do, S.Korea
[5]Granduate School of Disaster Prevention, Kangwon National University, S.Korea

Abstract. More than 80% of average annual precipitation in South Korea occurs between June and September owing to heavy rainfall and typhoons in summer, and its land is vulnerable to mountain disasters (landslides and debris flow) as 63% of it is mountainous areas. In this study, an area damaged by debris flow in Wondeok-eup, Samcheok-si, Gangwon-do, Korea under the influence of Typhoon Mitag in 2019 was surveyed and numerical modeling was performed. Topographic data were created using the 5m grid DEM derived through the field survey data and GIS technique as well as the building data of the damaged area, and debris flow modeling was performed using the Hyper KANAKO model. A comparison with the inundation trace map showed that the simulation results based on topographic data that reflected buildings exhibited similar flow patterns and characteristics to the actual damage.

1 Introduction

Global climate change is causing larger natural disasters. South Korea is vulnerable to mountain disasters, such as landslides and debris flow, due to heavy rainfall and typhoon-induced rainfall in summer each year because mountainous areas represent 63% of its land. Representative damage cases include the mountain disasters (landslides and debris flow) caused by Typhoon Rusa in 2002, Typhoon Maemi in 2003, localized heavy rainfall in 2011, and Typhoon Mitag in 2019, which caused human casualties and property damage. Studies have been conducted worldwide to predict and reproduce areas vulnerable to mountain disasters using GIS and numerical models to reduce such damage.

Numerical models to analyze the flow characteristics of debris flow, among mountain disasters, include FLO-2D developed by O'Brien et al. (1993)[1] (Peng et al. 2013; Kim 2012)[2, 3], Debris 2D developed by Liu and Huang (2006)[4] (Wu et al. 2013)[5], KANAKO Model developed by Nakatani et al. (2008; 2012)[6, 7] (Kim 2017, Lim 2017; Jang 2019)[8, 9, 10], and RAMMS(WSL-SLF). In this study, topographic data that reflected buildings in an area damaged by debris flow were created using the Hyper KANAKO model, a numerical model developed in Japan, and the flow characteristics of debris flow were analyzed by applying the data to the model.

2 Theory of Numerical Model

The Hyper KANAKO (Naktani et al., 2012)[7] model is a general-purpose debris flow numerical model that improved user convenience and graphical user interface (GUI) based on the KANAKO-2D model developed by Nakatani et al. (2008)[6]. It is based on the governing equations of the Takahashi (Takahashi et al., 2001; Takahashi, 2007)[11, 12] model to analyze debris flow.

The model uses eq. 1 that obtains the erosion/deposition rate of debris flow by calculating temporal and spatial (x and y directions) changes in flow depth for the total volume of debris flow, and the continuity equation of eq. 2 that obtains the erosion/deposition rate of debris flow by calculating temporal and spatial (x and y directions) changes in flow depth according to the volume concentration of the deposited sediment.

$$\frac{\partial h}{\partial t}+\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}=i \quad (1)$$

$$\frac{\partial Ch}{\partial t}+\frac{\partial Chu}{\partial x}+\frac{\partial Chv}{\partial y}=iC_* \quad (2)$$

where i is erosion/deposition velocity(if $i < 0$, deposition and if $i >= 0$, erosion), h is flow depth, t is time, u is x-axis flow velocity, v is y-axis direction flow velocity, C is sediment concentration by volume in the debris flow, C_* is sediment concentration by volume in the movable bed layer.

* Corresponding author: kwjun@kangwon.ac.kr

The momentum equations of debris flow are expressed by eq. 3 and eq. 4. Spatial changes in flow velocity in the x and y directions can be expressed by the values obtained by subtracting the resistance force at the boundary from the driving force of debris flow. In addition, the riverbed change equation is given by eq. 5.

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial H}{\partial x}-\frac{\tau_x}{\rho h} \quad (3)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g\frac{\partial H}{\partial y}-\frac{\tau_y}{\rho h} \quad (4)$$

$$\frac{\partial z}{\partial t}+i=0 \quad (5)$$

where g is acceleration due to gravity, H is flow elevation ($H = h + z$), z is bed elevation, ρ is density of the fluid, τ_x and τ_y are riverbed shearing stresses in the x- and y-axis directions, respectively.

3 Application of Numerical Model

In this study, a 5m-resolution DEM was created from the 1:5,000 digital topographic map provided by the National Geographic Information Institute using ArcGIS to analyze the flow characteristics of debris flow, and it was superimposed onto building information. The binary conversion software included in the model was used to convert it into the topographic data required by the model. Total discharge, peak discharge, and sediment concentration, which are the input parameters of the model, were calculated using the empirical formulas presented by the National Institute for Land and Infrastructure Management (NILIM, 2016)[13] in Japan.

3.1 Target area

Galnam-ri, Wondeok-eup, Samcheok-si, Gangwon-do is an area close to the East Sea of Korea. It has a high terrain to the west and low terrain to the east as there is a high mountain range to the west. The watershed has an area of 0.84 km^2, a maximum elevation of 316 m, a minimum elevation of 11.6 m, an average elevation of 163 m, and an average slope of 17˚. A debris flow disaster occurred in the area due to rainfall of up to 110 mm/hr under the influence of Typhoon Mitag in October 2019. 55 houses were buried or inundated and resulted in 111 victims in the downstream area(figure 1).

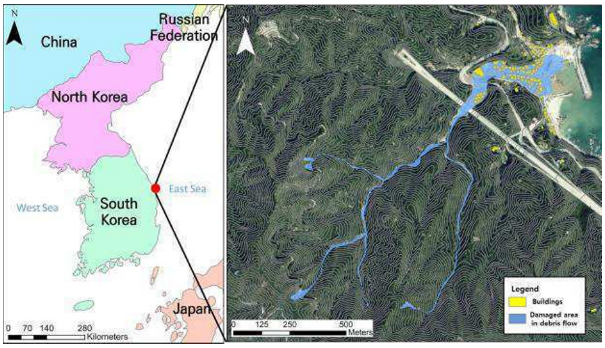


Fig. 1. Location of the study area.

3.2 Data construction

3.2.1 Topographic data

For the topographic data of the area damaged by debris flow, a 5m grid DEM was created using the contour lines of the 1:5,000 digital topographic map. Since building information was in the Shp file format, it was converted into Raster in the same 5m grid size as DEM and superimposed upon DEM(figure 2). The creation of topographic data through a digital topographic map involves difficulty in implementing the characteristics of the coast, drainage channels, and covered rivers. Therefore, it is deemed necessary to create topographic data using measuring equipment such as drones and LiDAR for more accurate modeling.

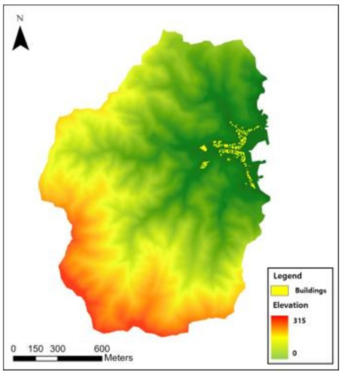


Fig. 2. DEM and convert to raster in buildings data

3.2.2 Input parameter

To perform numerical simulation on debris flow, information on input parameters, i.e., sediment yield, sediment concentration, total discharge, and peak discharge, is required. The sediment yield, the width, depth, and length of the valley (Table 1) were measured through a field survey and the equation proposed by Ikeye (1981)[14] (eq. 6) was used. The sediment yield was applied to the empirical formulas presented by NILIM to calculate the sediment concentration (eq. 7), total discharge (eq. 8), and peak discharge (eq. 9). The values in a previous study were entered for the unit weight and internal friction angle of soil and the unit weight of water (Nakase, 2004)[15]. Table 2 shows the input parameters for the Hyper KANAKO model.

$$V=\sum_{i=1}^{n}(L\times B\times D)_i \quad (6)$$

$$C_d=\frac{\rho\tan\theta}{(\sigma-\rho)(\tan\emptyset-\tan\theta)} \quad (7)$$

$$\sum Q=\frac{C_*\cdot V_{dqp}}{C_d} \quad (8)$$

$$Q_{sp}=0.01\cdot\sum Q \quad (9)$$

where V is Sediment yield(m^3), L is length of valley(m), B is breadth of valley(m), D is erosion depth of valley(m), ρ is density of the particle(kg/m^3), σ is density of the fluid(kg/m^3), $\emptyset$ is internal friction angle(°), θ is riverbed gradient(°). and riverbed gradient θ is applied an average riverbed gradation 14.9° of basin

Table 1. Estimation of sediment yield through field investigation

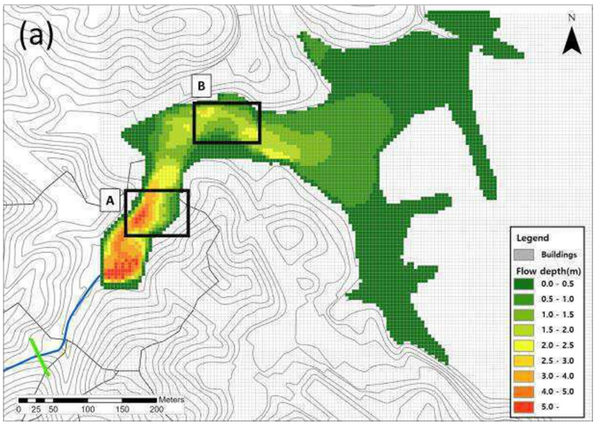
No	Length (*m*)	Depth (*m*)	Breadth (*m*)	Sediment yield (m^3)
1	0.6	13.9	80	667.2
2	2.2	12.9	339	9,620.8
3	1.7	7.5	230	2,932.5
4	0.6	10.1	298	1,805.9
5	3.4	14.0	452	21,515.2
6	1.9	9.2	1,104	17,724.7

Table 2. Summary of parameters and values used in Hyper KANAKO

Input parameter		Value
σ	Density of the particle [kg/m^3]	2,600
ρ	Density of the fluid [kg/m^3]	1200
ø	Internal friction angle [°]	35
θ	Riverbed gradient [°]	14.9
C_d	Sediment concentration by volume in the debris flow	0.53
C_*	Sediment concentration by volume in the movable bed layer	0.6
V_{dqp}	Initial volume [m^3]	54,266
Q_{sp}	Maximum discharge rate of the debris flow [m^3/s]	614.33

4 Result of Numerical Modelling

Figure 4 shows the results of the numerical simulation of debris flow in the downstream area performed using the topographic data and input parameters constructed in chapter 3. Figure 4(a) demonstrates the maximum flow depth of debris flow for topographic data that did not reflect buildings, while Figure 4(b) demonstrates the maximum flow depth of debris flow for topographic data that reflected buildings. Flow characteristics were compared for Site A where debris flow expands and Site B where the flow changes.



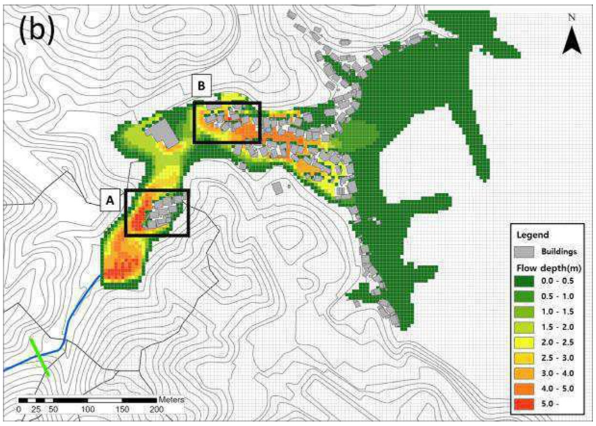


Fig. 4. Result of the simulation (max flow depth). (a) not reflect buildings (b) reflected buildings.

Topographic data that reflected buildings showed similar flow patterns to the actual damage. When the inundation trace map was compared with the maximum flow depth under the two conditions at the same points, the maximum flow depth was found to be 5.1 m at Site A and 1.4 m at Site B for topographic data that did not reflect buildings. For topographic data that reflected buildings, the maximum flow depth was found to be 7.8 m at Site A and 3.1 m at Site B, which were similar to the results of the inundation trace map (7.0 m and 2.5 m)(table 3, figure 5).

Table 2. Comparison of maximum flow depth and inundation trace by Point

	Site A	Site B
(a) Not reflect buildings	5.1 *m*	1.4 *m*
(b) Reflected buildings	7.8 *m*	3.1 *m*
Height of inundation trace	7.0 *m*	2.5 *m*

Fig. 5. The situation at the time of the damaged and height of inundation trace. (a) : Site A, (b) : Site B.

5 Conclusions

In this study, numerical simulation of debris flow was performed using the Hyper KANAKO model among debris flow numerical models, and flow characteristics in an area damaged by debris flow were analyzed under two topographic conditions. As for the input parameters of the model, sediment yield, peak discharge, and sediment concentration were used based on the field survey data. When the flow of the actual debris flow was compared with the damage estimated from the inundation trace map, it was found that topographic data that reflected buildings showed similar flow patterns and maximum flow depths. In future research, it is necessary to determine the validity of the results by creating precise topographic data and calculating input parameters using LiDAR and drones, and the applicability of the modeling results will be presented by simulating several damaged areas.

This research was supported by the program of Research Program to Solve Urgent Safety Issues (2022M3E9A1095664), through the National Research Foundation of Korea(NRF), funded by the Korean government. (Ministry of Science and ICT(MSIT), Ministry of the Interior and Safety(MOIS))

References

1. J.S. O'Brien, P.Y. Julien, W.T. Fullerton, Journal of hydraulic engineering **119**, 2 (1993)
2. S.H. Peng, S.C. Lu, Journal of Mountain Science **10**, 2 (2013)
3. N.G. Kim, *A Study on Transport and Diffusion of Debris Flow with FLO-2D*. M. S. Dissertation. Kangwon National University (2011)
4. K.F. Liu, M.C. Huang, Computational Geosciences **10**, 2 (2006)
5. Y.H. Wu, K.F. Liu, Y.C. Chen, Journal of Mountain Science **10**, 2 (2013)
6. K. Nakatani, T. Wada, Y. Satofuka, T. Mizuyama, International Journal of Erosion Control Engineering **1**, 2 (2008)
7. K. Nakatani, E. Iwanami, S. Horiuchi, Y. Satofuka, T. Mizuyama, *Development of "Hyper KANAKO", a debris flow simulation system based on Laser Profiler data,* in Proceedings of 12th Congress INTERPRAEVENT (pp. 269-280) (2012)
8. Y.H. Kim, *Sediment Discharge Analysis according to Location Change of Check Dam Using Debris Flow Numerical Model,* M.Sc. Dissertation. Kangwon National University (2017)
9. Y.H. Lim, *A Study on the Application of Numerical Simulation to Erosion Control Facility Using KANAKO 2D*, Ph.D. Dissertation. Kangwon National University (2017)
10. S.J. Jang, *Sediment-Related Disaster Risk Assessment by the Use of Physically-Based Models Considering the Effect of Tree Roots on Soil Reinforcement in a Forested Catchment*, Ph.D. Dissertation, Kangwon National University (2019)
11. T. Takahashi, *Process of occurrence, flow and deposition of viscous debris flow,* in River, coastal and estuarine morphodynamics (pp. 93-118), Springer, Berlin, Heidelberg (2001)
12. T. Takahashi, *Progress in debris flow modeling. In Progress in landslide science* (pp. 59-77), Springer, Berlin, Heidelberg (2007)
13. National Institute for Land and Infrastructure Management (NILIM). *Manual of technical standard for establishing sabo master plan for debris flow and driftwood*. Technical note of national institute for land infrastructure management, **No. 364**. Japan (2016)
14. H. Ikeya, A method for designation for area danger of debris flow (1981)
15. Y. Nakase, M. Fujimoto, S. Egashira, I. Takahiro, *A consideration of run-off prediction by debris flow,* in Conference of Japan Socity of Engineering Geology **13**, pp. 63-64 (2004)