A Study on the Comparative Analysis of the FLO-2D Model According to Debris Flow Sediment Amount

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

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

Abstract. It is very important to predict the extent of the damage in order to reduce or prevent damage by the debris flow. In the Republic of Korea, various methods are used to understand the characteristics and to estimate the occurrence of the debris flow in an undamaged area, such as simulating disasters using the estimation of debris flow sediment amount based on field survey data. In this study, the runout distance of debris flow was analyzed by using different methods for estimating the debris flow sediment amount, at Wondeok-eup, Samcheok-si, Gangwon-do, where debris flow occurred due to Typhoon Mitak in 2019. The simulation results of the damage area were compared with the actual damage area. The result showed that the simulations generally corresponded to the actual area of damage caused by the sedimentation of debris flow. However, the estimation of damage area varied according to the used method of calculating the debris flow sediment amount.

1 Introduction

In the Republic of Korea, debris flow was classified as a type of landslide in the disaster risk management. Earnest studies on the damage caused by debris flow have been carried out in the wake of the landslide at Umyeonsan mountain in 2011, which drew public attention. A prediction of the area of occurrence and extent/scale of the damage is necessary in order to mitigate the debris flow damage. Therefore, many researchers have studied the methods of debris flow sediment amount estimation generated, analyzed(March. 2004; NILIM. 2016)[1,2] debris flow risk by applying the characteristics of the watershed to the SINMAP(Oh et al. 2013; Kim P.G et al. 2017)[3,4], and analyzed the flow characteristics using the numerical model of debris flow FLO-2D(Kim et al. 2011; Peng et al. 2013;)[5,6]. The study area of this study is Wondeok-eup, Samcheok-si, Gangwon-do, where debris flow damage occurred due to Typhoon Mitak [in 2019]. Runout distance of the debris flow was analyzed by using two different methods; applying a general field survey on the debris flow sediment amount generated, and using the universal approach to estimate the occurrence of debris flow to predict the risks of development sites. Topographical data applied to the FLO-2D model were constructed using field survey data and the numerical topographic map provided by the Korea National Geographic Information Institute.

2 Study Area

The study area for this study is around Sinnam Village, located in Wondeok-eup, Samcheok-si, Gangwon-do, Republic of Korea. Due to the landing of Typhoon Mitak in October 2019, accumulated rainfall of 487mm (2 – 3 October) and maximum rainfall intensity of 110mm/h caused the landslide in the mountainous upstream area that resulted in the debris flow damage. The location of the study area and the site of the landslide are shown in Fig. 1.

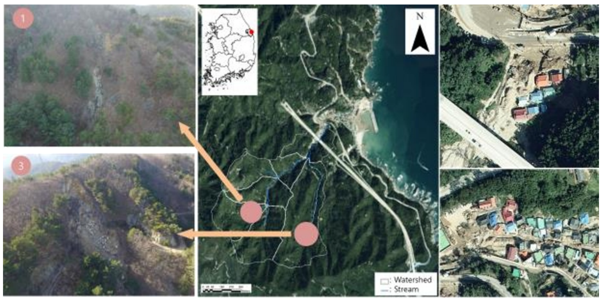

Fig. 1. Location of the Study Area

The area of the watershed is 0.84 km^2, the average elevation is 163 m, and the average slope is 17 degrees. Debris flow occurred by the collapse of many areas of the mountain slopes at the top of the Sinnamcheon stream passing through Sinnam Village. It quickly flowed to the downstream area and caused flooding or burial damage to 55 out of 101 housing units in Sinnam Village. The Korean government declared a special disaster zone for the area, and provided additional support for damage recovery. Maintenance and repair were carried out for the upstream perimeter facilities and

* Corresponding author: cdjang79@gmail.com

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the downstream section of Sinnamcheon, and housing site development was carried out for the buried housing areas.

3 Theory of Numerical Model

The FLO-2D(O'Brien et al. 1993)[7], developed at the University of Colorado, USA, is a physical model based on the finite difference method, which enables the tracking of rainfall-runoff and flood-hydraulic curves in the surface and river channels. It is a two-dimensional numerical analysis program that is defined in 8 flow directions, and the governing equations consist of a continuity equation and two momentum equations as follows.

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

$$S_{fx}=S_{ax}-\frac{\partial h}{\partial x}-\frac{\partial u}{g\partial t}-u\frac{\partial u}{g\partial x}-v\frac{\partial u}{g\partial y} \quad (2)$$

$$S_{fy}=S_{ay}-\frac{\partial h}{\partial y}-\frac{\partial u}{g\partial t}-u\frac{\partial u}{g\partial x}-v\frac{\partial u}{g\partial y} \quad (3)$$

Where i is rainfall intensity, h is flow depth, u is x-axis flow velocity, v is y-axis flow velocity, S_{ax}, S_{ay} is floo r slope, S_{fx}, S_{fy} is flow direction and orthogonal to flow of friction slope.

4 Application of Numerical Model

In order to apply the FLO-2D model to the study area, topography was constructed by using a 1:5,000 numerical map, and the watershed was distinguished. The physical properties of the generated debris flow (viscosity, coefficient of yield stress, and concentration) were calculated for debris flow simulation. In addition, this study carried out the comparison of the analyzed results of the flow characteristics by using two methods; Case1, the method of estimating the debris flow sediment amount through field surveys that can be applied in an area where debris flow occurs, and Case2, the method of estimating through the SINMAP analysis that is generally used in Korea for areas where there no debris flow has occurred.

4.1 Physical properties of debris flow

4.1.1 Concentration of Debris flow

The soil density calculation method proposed by NILIM was used to estimate the concentration of debris flow.

$$C_d=\frac{\rho\tan\theta}{(\sigma-\rho)(\tan\emptyset-\tan\theta)} \quad (4)$$

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. Input variable of debris flow density

Input parameter		Value
σ	Density of the particle [kg/m^3]	2600
ρ	Density of the fluid [kg/m^3]	1200
ø	Internal friction angle [°]	35
θ	Riverbed gradient [°]	14.9

4.1.2 Viscosity and yield stress

The yield stress and viscosity coefficient vary depending on the topography and soil conditions of the watershed, and O'Brien proposed 16 types(O'Brien. 1988[8]nts α_1, α_2, β_1 and β_2 of the study area to be used in the equations to calculate the yield stress and the viscous coefficient, the values corresponding to Aspen Watershed that can be applied in general mountainous areas were applied.

$$\tau_y=\alpha_1 e^{\beta_1 C},\ \eta=\alpha_2 e^{\beta_2 C} \quad (5)$$

Table 2. Yield Stress and Viscosity (O'Brien, 1988)[8]

Source	$\tau_y=\alpha_1 e^{\beta_1 C}$		$\eta=\alpha_2 e^{\beta_2 C}$	
	α_1	β_1	α_2	β_2
Aspen Pit1	0.181	25.7	0.0360	22.1
Aspen Natural Soil	0.152	18.7	0.00136	28.4
Aspen Watershed	0.0383	19.6	0.000495	27.1

4.1.3 Debris flow sediment amount

The estimation of debris flow sediment amount through the field survey was presented in a precedent study as 61,433m^3. This study also made an estimation through the analysis of the slope stability index using the SINMAP, which is generally used for areas where there no debris flow has occurred. In doing so, areas with collapse risk grades 4 to 6, where the calculated slope stability index was less than 1.0, were selected as the collapse area and included in the estimation of debris flow sediment amount.

1) Estimation of debris flow sediment amount using SINMAP

The SINMAP model is based on the infinite slope stability model, and it requires parameters such as the numerical elevation data (Digital Elevation Model: DEM) representing the topography, the angle of repose of the soil (Φ), the complex adhesion between the roots and the soil (C), and the ratio of the saturated permeability coefficient of the soil and the groundwater refill rate (R/T). The most distinctive feature of the SINMAP model is that the groundwater saturation process is simulated hydrologically in consideration of surface runoff from mountain slopes due to heavy rainfall. Risk analysis is performed by infinite slope stability analysis based on the simulated groundwater saturation process, as well as in consideration of the adhesion between soil and vegetation, the internal friction angle of the soil, the weight of the soil, the permeability coefficient and the groundwater filling rate, etc.

$$FS = \frac{C + \cos\theta\left[1 - \min\left(\frac{R}{T\sin\theta}\frac{a}{}, 1\right)r\right]\tan\phi}{\sin\theta} \qquad (6)$$

The SINMAP analysis result is presented in Fig. 2. The areas with collapse risk grades 4 to 6, with a slope stability index less than 1.0, were selected as the collapse risk areas, and the collapse area for each grade was calculated as shown in Table 3. Using the available soil depth of the precision soil map (Fig. 3), the debris flow sediment amount was estimated as 170,525 m^3

Table 3. Classes of slope stablity based on value of the Stability Index (Pack,2001)[9]

Predicted State	Area	Rate	Volume
Stable slope zone	15.10ha	17.2%	82,575m^3
Moderately stable slope zone	8.20ha	9.3%	43,362m^3
Quasi-stable slope zone	21.61ha	24.5%	108,893m^3
Lower threshold slope	41.20ha	46.8%	164,450m^3
Upper threshold slope	1.95ha	2.2%	6,075m^3
Defended slope zone	0	0	0

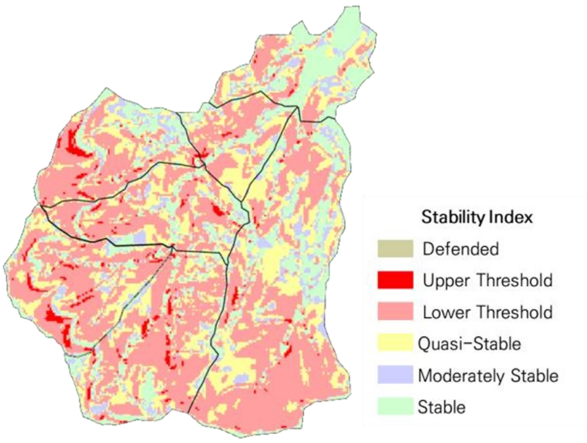

Fig. 2. Stability Index

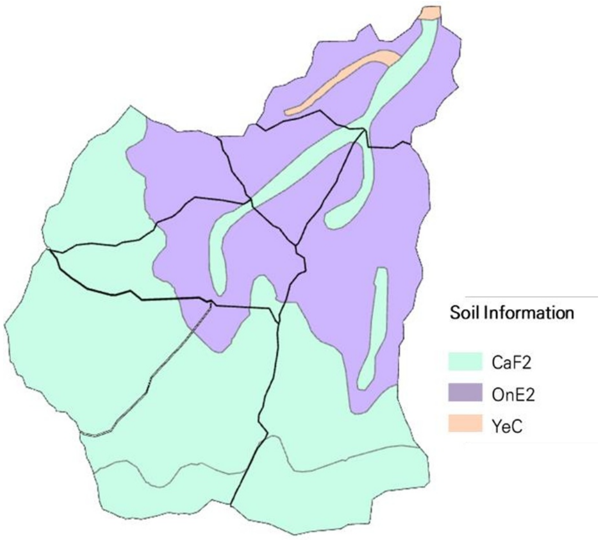

Fig. 3. Soil Information

5 Simulation Result of Debris Flow

5.1.1 Flow Velocity

Flow velocity the maximum flow velocity in the sediment was 9.9m/s of Case 1, and 12.4 m/s of Case 2 (a difference of 2.5 m/s occurred).The soil density calculation method proposed by NILIM was used to estimate the concentration of debris flow.

5.1.2 Flow Depth

It shows a difference of about 1.8m between the maximum flow depths that were calculated Case 1 (6.5m), and Case 2(8.3m).

Table 4. Max Velocity and Max Flow Depth

	Max Velocity	Max Flow Depth
Case 1	0.1 ~ 9.9m/s	0.1 ~ 6.5m
Case 2	0.1 ~ 12.4m/s	0.1 ~ 8.3m
Error	2.5m/s	1.8m

5.1.3 Damaged Area

Fig. 4. shows the analyzed results of the damage area, using the estimated debris flow sediment amount through the field survey and through the SINMAP analysis. The actual damage area of the debris flow area was 46,775 m^2, and the calculated damage area was 67,825 m^2 when the estimated debris flow sediment amount through the field survey was applied, and 77,450 m^2 when the estimated debris flow sediment amount through the SINMAP analysis was applied. That is, the damage area there was a difference of about 45% in the case of applying the estimated debris flow sediment

amount through the field survey, and about 65% in the case of applying the debris flow sediment amount estimation through the SINMAP analysis, confirming the tendency of overestimation (Table 5)

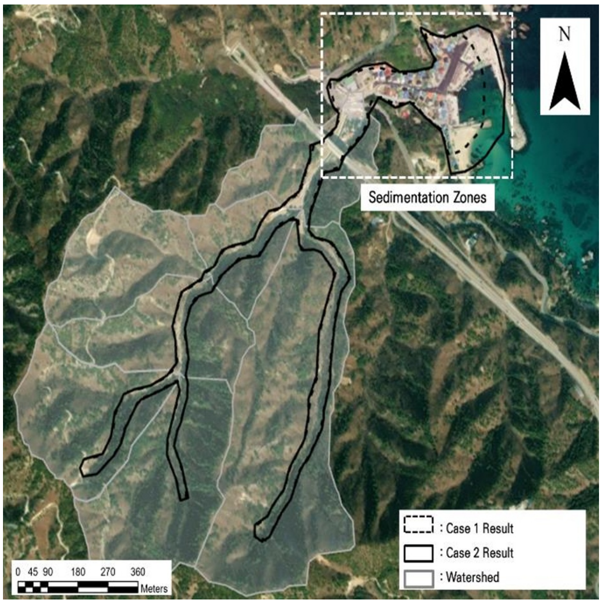

Fig. 4. Result of FLO-2D

Table 5. Damaged Area

	Damaged Area	Error
Actual Affected Area	46,775ha	-
Case 1	67,825ha	45%
Case 2	77,450ha	65%

6 Conclusions

This study applied and compared two methods for estimating the debris flow sediment amount, through the field survey and the SINMAP analysis. The result showed that debris flow sediment amount in the study area was estimated as 61,433m^3 when applying the field survey estimation and 170,525 m^3 when applying the SINMAP analysis, respectively. Considering that the method using the SINMAP analysis calculated the debris flow sediment amount to be rather large, caution would be required when applying the SINMAP analysis to the FLO-2D model in Korea, to avoid the tendency of overestimation.

As a result of applying these values to the FLO-2D model, the damage area was found to be 67,825 m^2 in the case of applying the estimation through the field survey, while it was overestimated by about 14% (77,450 m^2) when applying the estimation through the SINMAP analysis. The flow velocity and flow depth were analyzed as 9.9 m/s and 6.5 m when applying the field survey estimation, and 12.4 m/s and 8.3 m when applying the SINMAP analysis, respectively. It confirmed that the simulation results using the field survey method showed more similar characteristics to the actual debris flow damage on site.

A limitation of this study is that it did not reflect the flow rate and the debris flow sediment amount out to the drainage culvert in the coverage section of Sinnamcheon, as well as the debris flow sediment amount out to the coast.

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