THE ASSESSEMENT OF DEBRIS FLOW HAZARD IN KOREA USING DEBRIS 2D

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ABSTRACT

This paper is the result of the cooperation between NCDR in Taiwan and KIGAM in Korea to assess the debris-flow hazards in Korea. We adopt the Debris2D model to simulate the debris-flow hazard in Inje-gun, South Korea. From the field investigation, the debris volume of final deposition is about 11,533 m^3 and these materials came from three landslides upstream. The debris is mostly composed of gravel materials with sand and mud occupying less than 20% of total volume. The maximum diameter of the gravel is greater than one meter. The result of the simulation shows that the debris flow would invade houses and roads downstream, and the range of the debris flow coincides with the field investigation very well.

Key Words: Debris-flow assessment, Numerical simulation, Landslide

INTRODUCTION

This study is the result of cooperation between Taiwan and South Korea to assess the debris-flow hazards in Korea. In 2006, a heavy debris-flow hazard occurred in Inje, and National Emergency Management Agency (NEMA) in South Korea paid very close attention to this hazard. In order to establish a complete debris-flow early warning system and the capability to assess debris-flow, NEMA promoted the opportunity for the Landslides Hazards and Research Team from Korea Institute of Geoscience and Mineral Resources (KIGAM) to cooperate with Slopeland Disaster Reduction Division from National Science and Technology Center for Disaster Reduction (NCDR) in Taiwan to assess the debris-flow by using Debris2D (Liu and Huang, 2006). In November 2008, researchers of NCDR held a seminar to introduce Debris2D to KIGAM researchers. After many discussions with Korean researchers, KIGAM researchers run several cases of debris-flow hazards in Korea with the help of NCDR researchers. These simulation results were compared with the field investigation to validate the capability of Debris2D to assess the hazards in Korea.

DEBRIS 2D MODEL

Governing equation

The governing equations for Debris2D are conservation of mass and momentum. We assume two dimensional long-wave motions. The constitutive law was proposed by Julien and Lan

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(1991) which added the quadratic term of strain rate to modify the Bingham model to interpret the effects of particle collisions in the motion of solid-liquid mixture.

$$\tau_{ij} = \left(\frac{\tau_0}{|\varepsilon|} + \mu_d + \mu_c |\varepsilon| \right) \varepsilon_{ij} \quad \text{for } |\tau| \geq \tau_0 \tag{1a}$$

$$|\varepsilon| = 0 \qquad \text{for } |\tau| \geq \tau_0 \tag{1b}$$

where $|\varepsilon| = \left(\frac{1}{2} \varepsilon_{ij} \varepsilon_{ij} \right)^{1/2}$ and $|\tau| = \left(\frac{1}{2} \tau_{ij} \tau_{ij} \right)^{1/2}$

ε_{ij} is strain rate tensor, τ_0 is yield stress, μ_d and μ_c are dynamic viscosity and turbulent-dispersive parameter respectively. Eq. (1a) shows the condition that shear stress is greater than yield stress. Usually, that corresponds to the region near bed, called shear layer. On the other hand, Eq. (1b) represents the portion far away from the bed and shear stress is less than yield stress, called plug layer. Huang (2003) found that in mostly in-situ cases the thickness of shear layer is about 4% of total thickness, so that the shear layer could be ignored. After ignoring the shear layer, the governing equations become

$$\frac{\partial H}{\partial t} + \frac{\partial (uH)}{\partial x} + \frac{\partial (vH)}{\partial y} = 0 \tag{2}$$

$$\frac{\partial (uH)}{\partial t} + \frac{\partial (u^2 H)}{\partial x} + \frac{\partial (uvH)}{\partial y} = -gH \cos\theta \left(\frac{\partial B}{\partial x} + \frac{\partial H}{\partial x} \right) - gH \sin\theta - \frac{\tau_0 u}{\rho \sqrt{u^2 + v^2}} \tag{3}$$

$$\frac{\partial (vH)}{\partial t} + \frac{\partial (uvH)}{\partial x} + \frac{\partial (v^2 H)}{\partial y} = -gH \cos\theta \left(\frac{\partial B}{\partial y} + \frac{\partial H}{\partial y} \right) + \frac{\tau_0 v}{\rho \sqrt{u^2 + v^2}} \tag{4}$$

where θ is the slope angle of topography, ρ is density of debris-flow, g is gravitational acceleration, H is flow thickness, B is the elevation of river bed, u and v are depth averaged x and y velocity respectively. Eq.2 is the mass conservation equation in the conservative form. Eq.3 and Eq.4 are x and y momentum conservation equations, and there are convective terms in LHS, and pressure, gravitational and shear stress terms in RHS. Due to the existence of yield stress in the constitutive law, motion can only start if the bottom stress exceeds the yield stress.

$$\left(\frac{\partial B}{\partial x} + \frac{\partial H}{\partial x} - \tan\theta \right)^2 + \left(\frac{\partial B}{\partial y} + \frac{\partial H}{\partial y} \right)^2 > \left(\frac{\tau_0}{\rho g \cos\theta H} \right)^2 \tag{5}$$

In Eq.5, the first derivatives of B and H of x and y represent the pressure effects, and $\tan\theta$ is the gravitational effect. If the pressure and gravitational effects are greater than yield stress, the debris-flow would start to move. So far, the bottom erosion from river bed is not considered.

Numerically, this model adopted the finite difference method to discretize the governing equations. For the sake of the computing efficiency, we use 3rd-order Adams-Bashforth method in time. To prevent shock phenomenon, 1st-order upwind method is used for the convective terms in momentum equations. However, there could be dry bed and near stationary region, we change to central difference in space.

Model graphic user interface

Including datum and parameters, there are a lot of data pre-processing needed in order to run Debris2D. We developed a graphic user interface (GUI) for user to follow the steps to input

all required data and parameters to make the pre-process of simulation more easily and efficiently. A sample user interface is showed in Fig.1.

All inputs are categorized into five categories. Basic info are topography and simulation range. Mass source information such as location, volume and types of deposition are also needed. Rheological parameter such as yield stress is essential. Simulation parameters such as output time interval, specified output points setups are required for the sake of output. All the inputs mentioned above are listed in Table 1. The interface will guide users step by step to complete all required input. Once data is provided by user, the GUI program will start to process all the inputs, and connect them with simulation program. Users don't have to know anything about DEBRIS2D itself, they can still use the program through this interface. This was proven during the corporation with KIGAM.

Table 1 All inputs for Debris2D model

Steps		Inputs
1	Topography	Input DEM file for interpolation to get grids, two or more DEM files are also available
2	Simulation range	Typing or circling by mouse from the screen to set the simulation range.
3	Mass information	• Select the types of deposition • Input mass locations and volumes.
4	Material parameter	Input the yield stress of mass
5	Ouput setup	• Set the time interval of output • Set the locations information of specified output point • Set if output the final deposition and velocity or flow thickness distribution or not after the end of simulation

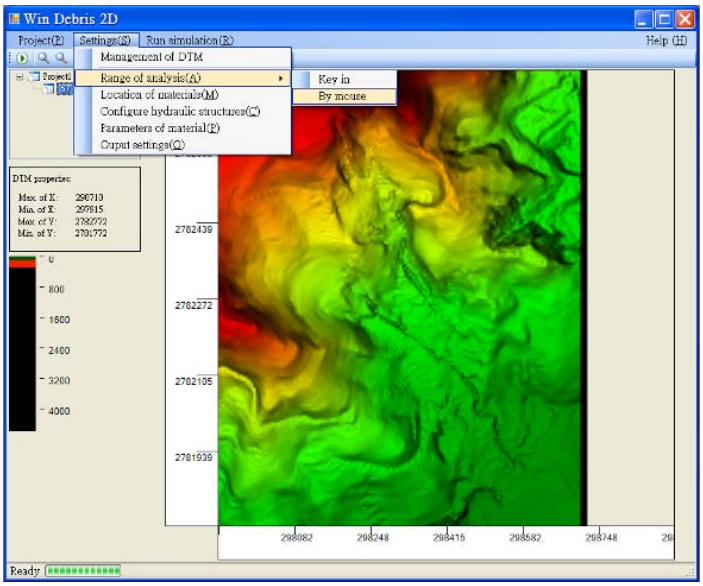

Fig. 1 The Windows® GUI of Debris2D

INTRODUCTION OF CASE INJE

The case we simulated for KIGAM is the debris-flow hazard occurred at River Buk-Hangye, Inje-gun, Kangwon-do where the eastern-north of South Korea. In the meanwhile of this hazard, the debris-flow flowed along river Buk-Hangye and No. 44 highway of Korea, and caused a lot of damages of lives and properties along the highway. According to the data of Korea Meteorological Administration, the rainfall had accumulated 793mm during July 11 to

July 15 2006 when this hazard occurred. Due to the annual accumulative rainfall was between 1200mm and 1500mm, it was unusual for such a heavy rainfall in that duration in Inje. Besides the annual accumulative rainfall, the daily accumulative rainfall also reached 200mm and 83mm for maximum hourly accumulative rainfall. This condition was very rare in that area. This unusual heavy rainfall was one of many important causes for the hazard.

The geological framework in Inje is almost weathered surface rocks, and the dominant material of composition of soil is granite. There are many cliffs along the streamside in that area. Due to the fragile formation, debris and rocks would slide down from and deposit on the riverbed with overland flow or sufficient rainfall. The depositions of such piles are composed of gravels and pebbles. The large quantity of debris on the riverbed is another important cause of the debris-flow hazard. Debris flow existed in this region can be easily seen from observation of the exposed geological conformation. Fig.2 shows larger particles deposited on top of smaller ones. The geologists concluded that there were several debris-flow events in that area before.

In the event we simulated, the mass came from three landslide site upstream and total volume was about 11,533 m^3. The locations and volumes for these landslides are listed in Table 2. The widths of these three trigger sites of landslides (the renovated condition is showed in Fig.3) were about 40-50m wide, 2m thick, and have 25-35° bottom slope. After disaster, the deposition is composed of large quantity of gravels with less than 20% sand and mud. The maximum diameter of gravels is larger than one meter. The scene of the deposition in the midstream after disaster is showed in Fig.4.

Fig. 2 The geological framework of the riverbed washout by the debris-flow.

Table 2 The debris volumes and locations of three landslides upstream

E Coordinates	N Coordinates	Debris Volume(m^3)
131395.00	510326.58	4360
131457.89	510264.95	3504
131401.29	510239.80	3669

Fig. 3 Renovation of the slope where generated the mass

Fig. 4 Deposition of midstream of Buk-Hangye river after hazard.

The aspect of the topography in this area is steep upstream but mild downstream. The elevations are 480m upstream, 320m midstream and 250m downstream. The slope angle of the riverbed is 20-25° upstream, and reduces to 10-15° and 0-5° downstream. So far, from the properties of the local geological framework, soil composition and the topography, we can reconstruct the occurrence of this hazard is due to landslides triggered by heavy rainfall. Then these material deposited along riverbed was initiated by large discharge in the stream to form debris flows.

PARAMETERS SETUP AND INPUTS

Before simulation, we had to process all inputs, included datum and physical and model parameters. Two kinds of datum are essential, such as digital elevation model (DEM) of topography and mass source information. The area for present simulation is about 16,000 ha, and we interpolated the resolution of 15m $\times$ 15m DEM provided by KIGAM into the 10m $\times$ 10m grid size for our simulation. And then, before distributing the mass, we knew the volumes of dry debris for each landslide was about 11,533m^3. Applying the equilibrium

concentration relation (Takahashi, 1981) of debris-flow, we can find out the debris-flow volume for each site. The concentration relation is listed below.

$$C_{d\infty} = \frac{\rho \tan\theta}{(\sigma - \rho)(\tan\phi - \tan\theta)} \leqq 0.603 \tag{6}$$

where $C_{d\infty}$ is the solid volume concentration at equilibrium; ρ is density of water, 1.00g/cm^3; σ is density of gravels, around 2.65g/cm^3; ϕ is the friction angle, about 37°; θ is in-situ bottom slope angle and it is 25° in our case. With all the value above, we find $C_{d\infty}$ to be 0.984 from eq. (6). Therefore, by the limit of Takahashi's theory, we use 0.603 So the total volume of debris-flow is 19,126m^3 in this case. And then we distribute the mass source as in Table 1 on the topography, and the initial distribution is shown in Fig.6.

From the field investigation after hazard, the material of mass source is mainly large gravels, and the maximum dimension of them exceeds one meter, and between 30 and 50 cm in average. In the rest of the mass, the mixture of sand and mud is less than 20% of total volume. From the composition of the soil, we sue 1000(dyne/cm^2) for the yield stress in our case. Finally, we set the time interval of output to be one second real time. We also specified three points in the upstream, midstream and downstream part of the river for result output to observe the flow velocity and flow height in time at these points.

After collecting and checking all the inputs and parameters, we started to use GUI for all inputs. The information for inputs is listed in Table 3.

Table 3 All inputs for the case of Inje

	Steps	Inputs
1	Topography	Input the 10m × 10m DEM file (after interpolated)
2	Simulation range	Manual input 129980 and 131650 for the maximum and minimum x-coordinate, 509510 and 510570 for y-coordinate.
3	Mass information	• the type of mass distribution is surface deposition • from the Table 2 to distribute three volumes modified by the balance concentration on each location
4	Material parameters	Set 1000(dyne/cm^2) ◦
5	Output setup	• set the time interval of output to be one second • there are three specified output points (E:131114, N:509897),(E:130707, N:509888) and (E:130134, N:509852), each of these points are show in Fig.6 as A,B and C points in order.

SIMULATION RESULTS AND HAZARD RANGE

As the simulation result shows, the total process of the transport of this debris-flow is about 180 minutes. The distance is about 1.3 kilometers from the landslide trigger sites to the deposition site in the downstream. The maximum velocity nearby the trigger sites is about 3.6 m/s. The red region E in Fig.5 is the initial mass distribution. After 10 min, the whole flow reaches point A in Fig.5, and invaded the houses near point A at 14 minute. At the impact time, the flow depth is about 4 meters. After 46 min, flow passed point B in Fig.5 , and destroyed those houses close the river in another 14 min. The average flow depth is about 3 meters at that time. Now, a portion of flow stopped on the riverbed, as showed in point D in Fig.5, due to the mild local slope. And the rest part of flow continued downstream. Around 90 min, the houses near the joint of tributary were destroyed. Debris flow keeps flowing and stopped before the bridge 180th minute after its initiation. The average thickness of the front

of deposition is between 2 and 3 meters, and the location is at the point C in Fig.5. This whole time series come from the numerical simulation.

Now we shall compare simulation results with field investigation after hazard. From field investigation data, the final deposition site of debris-flow was E:130134.11 and N:509852.73, that is the point C in Fig.5, and the maximum width and maximum thickness are about 50m and 4m. The location of deposition of simulation result coincided with the field investigation very well, but the length, width and thickness of the simulation result are different from the field investigation with an 20% error. There may be many reasons for this. But one of the fact we did not input is the original deposition around the riverbed near point C. These uncounted mass would induce an over-estimation for the volume of debris from. However, a 20-30% error of depth but 95% precision on the location of hazard would be a great help for hazard mitigation.

The blue region in Fig.5 shows all regions with debris-flow passed through. This information pinpoints the dangerous house. The flow depth was about 3 meters, as showed between point A and D in Fig.5. Fig.6 shows the houses damaged by the debris-flow after disaster. the traces on the wall caused by the debris-flow flowing through reaches one story high. That trace is 3 meters high, and this coincides with the simulated depth very well. From the deposition position and the flow condition of debris-flow, we could validate the model being able to assess the debris-flow hazard in Korea.

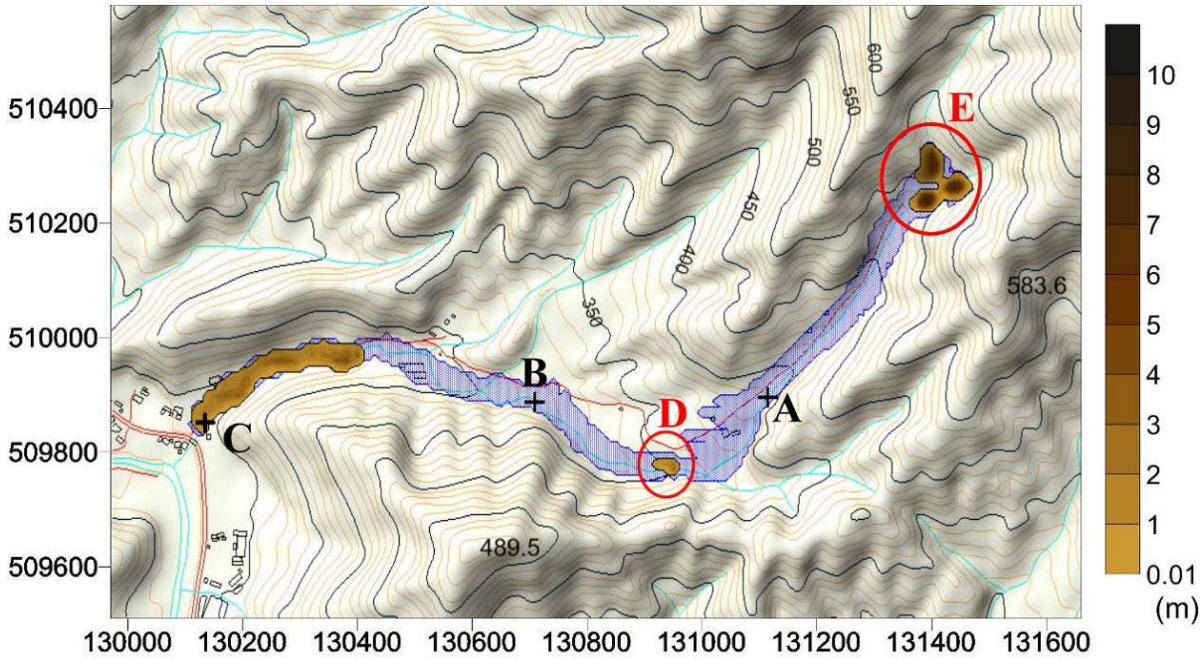

Fig. 5 Simulation results. (Point A, B, C are the specified-output points in the upstream, midstream and downstream respectively, especially point C is the front of final deposition from the field investigation. Circle E represents the initial mass distribution. Point D represents the mass deposit separated from other mass during the flowing. The range of blue-colored represents all the area debris-flow flowed over.)

Fig. 6 The house invaded and damaged by debris flow after hazard

CONCLUSION

As the simulation results show, we found that Debris2D is applicable for the assessment of debris-flow deposition and flow condition in case Inje, Korea. We believed that Korean researchers could use this model to assess more cases in Korea. The interface program GUI has also proven to be very useful for non-experience users.

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