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ANALYSIS OF DEBRIS FLOW CHARACTERISTICS THROUGH DATABASE CONSTRUCTION IN KOREA

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ABSTRACT

In recent years in Korea, Typhoon Rusa (2002), Typhoon Maemi (2003), and the localized extreme rainfall followed by Typhoon Ewiniar in 2006 devastated residential areas, roads, and agricultural lands in Gangwon province where 90% of the area is in mountainous regions. Most of the economic losses and casualties were concentrated in the area near the mountain valleys and creeks due to the floods and debris flows. In this study, DATABASE, which includes a total 153 debris flow events in the Gangwon area, was created by collecting the hazard records and field investigations of existing debris flow sites. Based on these data, we analyzed geomorphic characteristics of the initiation zone, the initiation and transportation mechanism, and the threshold of rainfall for an early warning system. Analysis results showed the potential for further use of the DATABASE in the development of hazard mapping to predict debris-flow susceptible areas and the assessment of hazard severity in those areas.

Key words: *debris flow, DATABASE, field investigation, rainfall threshold*

INTRODUCTION

In Korea, over 70% of the land is in mountainous regions. There are many casualties and significant property loss due to slope failures or debris flows resulting from typhoons or regional intensive rainfall during the summer between June to September. Recent disaster reports show that there were a total 321 casualties and a 4.3-billion dollar property-loss damage during Typhoon 'Rusa' in 2002 (NIDP,2002) and 132 casualties with 3.99-billion dollar property-loss damage during Typhoon 'Maemi' (NIDP, 2003). In 2006, regional intensive rainfall following Typhoon 'Ewinia' caused 61 casualties with a 1.8-billion dollar property-loss damage. These damages are frequent in Gangwon province where 90% of the land is mountainous (Fig. 1). Considering that Gangwon occupies only 17% of Korean territory, the area is quite vulnerable to disasters such as landslides or debris flows.

Korean government agencies and other organizations have recognized the severity of the slope disasters and have set forth national projects for preventing and mitigating these disasters. NIDP (National

Fig. 1 - Research area. (Gangwon province, Korea)

	Total in Korea		Gangwon Province		Percentage (%)	
	Casualties	Property Loss (1 mil$)	Casualties	Property Loss (1 mil$)	Casualties	Property Loss
Typhoon Rusa (2002)	321	4308	178	2115	55.5	49.2
Typhoon Maemi (2003)	132	3994	13	692	10.3	17.3
Regional Rainfall (2006)	61	1797	42	1319	68.9	73.4

Tab. 1 - Statistics of Damages by Heavy Rainfall

Classification	Field	Obtained by
Initiation	Initiation type Slope angle Failure volume	Field survey
Transportation	Average Gradient Transportation distance	Topographic map Field survey
Basin	Basin area Average area Average Gradient Direction Average soil depth	Topographic map
Rainfall	Max. hourly rainfall Continuous rainfall 3 days cumulative rainfall 28 days cumulative rainfall	AWS (Automatic Weather Station)

Tab. 2 - Structure of DATABASE

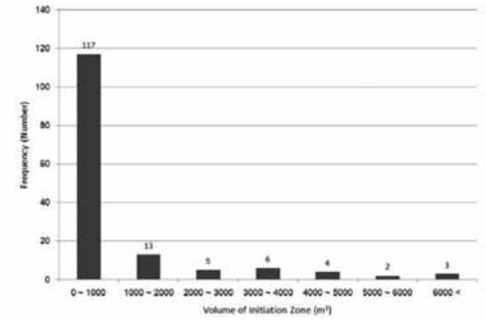

Fig. 2 - Volume of initiation failure in Gangwon province

Institute for Disaster Prevention) and KIGAM (Korea Institute of Geoscience and Mineral Resources) have been carrying out researches on slope disaster prevention. NIDP and KEC (Korea Expressway Corporation) are jointly researching the mitigation of debris flows. The authors of this paper, members of these national research institutes, have been involved in research projects on the debris flow DATABASE construction and have also participated in the analysis of characteristics of debris flow by field survey.

The main objective in this study was to create DATABASE, a widely accessible source of disaster cases in Gangwon province, where slope failure and debris flow have occurred most frequently in Korea. DATABASE's records include field survey data, rainfall data, topographical, and geological data. Using DATABASE, debris flows in Gangwon province are analyzed especially in the aspect of initiation, transportation, and triggering rainfall.

DATABASE CONSTRUCTION

Field investigations on initiation and transportation zones of debris flow including rainfall data at 67 basins, which contains 153 sites where debris flows have occurred, have been carried out. DATABASE is continuously updated with ongoing investigation results.

Investigations focused on the sites where debris flow occurred and damaged the roads. For the selected sites, field investigation mainly focused on where debris flows were initiated and transported. For the initiation zone, the types of debris flow being initiated were investigated, and the slope angle and the volume of this zone were measured. For the transportation zone, the average gradient at every 20-30 m distance and the direction of the debris flow were measured.

Using topographic maps, the area, average gradient, and direction of the drainage basin were obtained. The effective soil depth and soil type in the drainage basin were also obtained using geologic maps.

Rainfall data were obtained from the AWS (Automatic Weather Stations) which are operated by the KMA (Korea Meteorological Administration). Rainfall data used in used in constructing DATABASE were maximum hourly rainfall, continuous rainfall, 3-day cumulative rainfall, and 28-day cumulative rainfall data. Table 2 shows the structure of DATABASE.

CHARACTERISTICS OF DEBRIS FLOW

VOLUME OF INITIATION FAILURE

Slope failure-initiated debris flows occurred at 150 sites whereas debris flow initiated by gully erosion were only at three sites among 153 sites. For the slope failure type, the volume of the initial failure is shown in Fig. 2. The minimum, maximum, and average volume were 16 m^3, 11,310 m^3 and 969 m^3, respectively. As shown in Fig. 2, the volume at 117 sites, 78% of 150 sites in total were less than 1,000m^3.

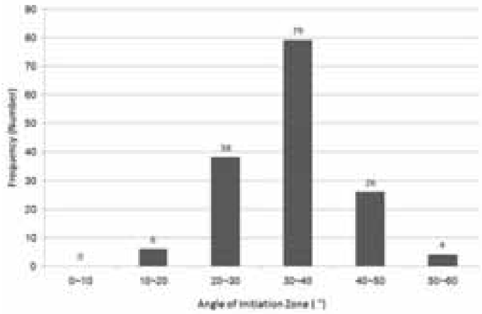

Fig. 3 - Angle of initiation zone in Gangwon province

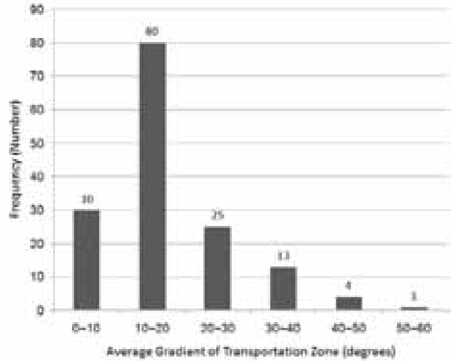

Fig. 4 - Average gradient of transportation zone in Gangwon province

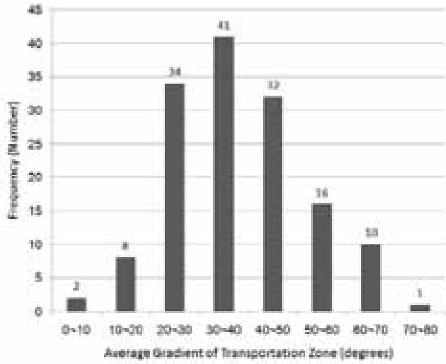

Fig. 5 - Average gradient of transportation zone in Alps region. (Swiss, 144 sites) (Data from Zimmermann *et alii, 1997)*

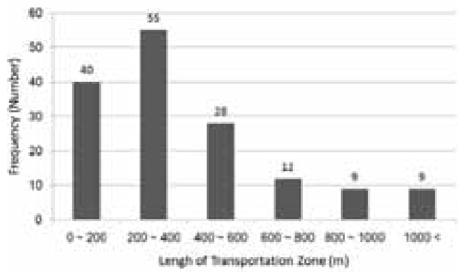

Fig. 6 - Length of transportation zone in Gangwon province

ANGLE OF INITIATION ZONE

Slope angles at the initiation zones of 153 sites were analyzed. The result reveals that the angles of the initiation zones ranged from 10 to 56 degrees. The most probable angle was 38 degrees and the average value was 33.5 degrees. Sorting by every 10 degrees of angle, the most probable angle ranged from 30 degrees to 40 degrees (79 sites, 51.6%) as shown in Fig. 3.

Considering the facts from previous studies that the most probable frequency of debris flow initiation occurred at 26 to 30 degrees in Korea (Kim *et alii*, 2006) and 10 to 20 degrees in Japan (Ikeya, 1989), it is apparent that debris flow in Gangwon province is occurring at relatively steep slopes.

AVERAGE GRADIENT OF TRANSPORTATION ZONE

Gradients of a total of 153 transportation zones based on the database were analyzed. The result indicates that gradients of transportation zones ranged from 2 to 55 degrees. The gradient on which debris flow was frequently transported was 13 degrees and the average gradient was 16.9 degrees. When it was sorted by 10 degrees, the most probable frequency (80 sites, 52.3%) of gradient of a transportation zone occurred between 10 to 20 degrees as shown in Fig. 4, while the most probable frequency (28.5%) of gradient was between 30 to 40 degrees in the Swiss Alps region (Fig. 5). We accordingly concluded that debris flows occurring in Gangwon province are transported at relatively gentler slopes than those of the Swiss Alps.

LENGTH OF TRANSPORTATION

We investigated the length where debris flow initiated and then moved through the transportation zone. The result suggests that the lengths of transportation ranged from 41 to 1,451 m and the average transportation length was 408 m. When it was sorted by the length of 200 m, the most probable frequency (55 sites, 35.9%) occurred at 200-400 m as shown in Fig. 6. The frequency on which debris flow moved more than 600 m was very low (19.6%).

The results of previous studies showed that in the Kamikamihori valley of Mt. Yake in Japan, 57.1% of total debris flows occurred at 600-800 m while in the Swiss Alps, most of the debris flows occurred at

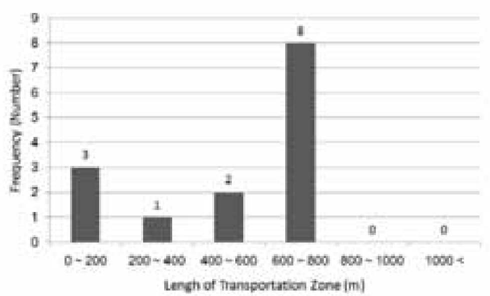

Fig. 7a - Japan, Mt. Yake, Kamikamihori Valley (14 Debris flows) (Data from Okuda & Suwa, 1984)

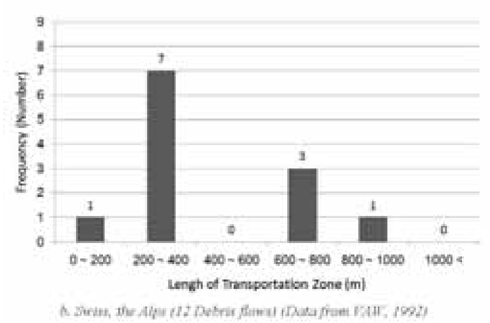

Fig. 7b - Length of transportation zone. Swiss, the Alps (12 Debris flows) (Data from VAW, 1992)

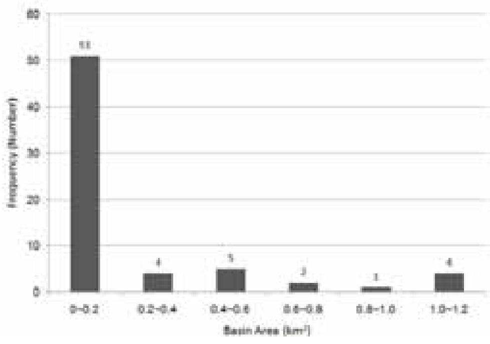

Fig. 8 - Basin area of the debris flow in Gangwon province

200400 m, which is similar to the Korean cases. Based on the slope angles of the initiation zone, it is judged that the debris flows in Japan have volcanic characteristics so that they occur at a relatively gentle slope compared with the steeper slopes in Gangwon province which move a longer distance.

BASIN AREA

Figure 8 shows a total of 67 basins sorted into 0.2 km^2 with frequency of debris flow occurrence. The most probable frequency (76.1%, 51 sites) is in the range of 0-0.2 km^2. The rest of the basin area indicates a very low frequency without significant tendency. Compared with the Swiss Alps (Fig. 9), basin areas in Gangwon province are approximately ten times smaller than those of the Swiss Alps where the number of debris flows tend to decrease remarkably in proportion to the increase of basin area.

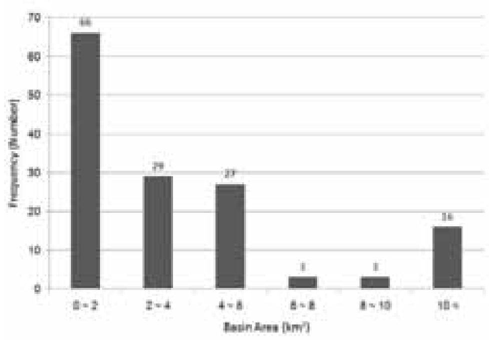

Fig. 9 - Basin area of the debris flow in Swiss. (Swiss, 144 sites)(Data from Zimmermann et alii, 1997)

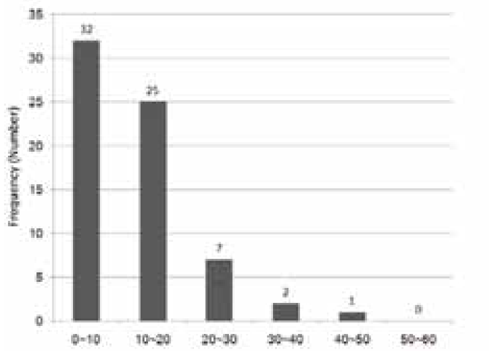

Fig. 10 - Average basin gradient in Gangwon province (67 sites)

AVERAGE BASIN GRADIENT

The average basin gradients at 67 sites where debris flows occurred were obtained by taking the average gradient of the mesh (10 m x 10 m) from the Digital Elevation Map data of each site. The gradient of basins ranged between 5 and 46 degrees as shown in Fig. 10. The frequency tended to decrease as the gradient of the basin increased. The highest frequency was at 6 degrees and the average of all data was 12.8 degrees.

BASIN AREA AND AVERAGE GRADIENT

Fig. 11 shows the relationship between basin area and average basin gradients with different lithological

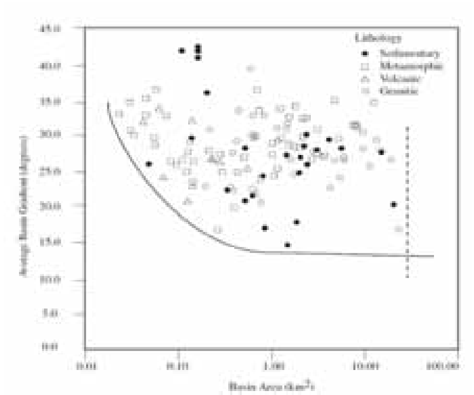

Fig. 11 - Relations between basin area and average basin gradient of basins producing fire-related debris flows in the western U. S. (Cannon & Gartner, 2005)

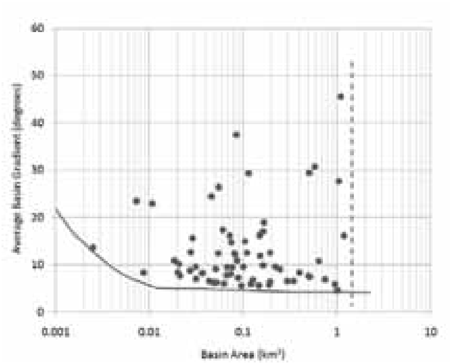

Fig. 12 - Relations between basin area and average basin gradient of basins producing debris flows in Gangwon province

conditions in the Western United States where basins were reported to have experienced fire-related debris flows (Cannon & Gartner, 2005). The heavy line indicates threshold conditions, above which runoff-initiated debris flows can be expected. However, it is known that the threshold for landslide-initiated debris flow is not delineated because of insufficient data. Debris flow producing basins range in area from 0.02 km^2 up to 25 km^2. Debris flows were not observed at the outlets of basins larger than about 25 km^2, indicated by the dotted vertical boundary. Rock types are not likely to significantly affect the characteristics of the basin area and average gradient. Fig. 12 illustrates those data from debris flow sites in Gangwon province.

Comparing those figures, we see that the distributions of data and threshold conditions are quite similar except the scales of basin area and average basin gradient. The average values of basin area and average basin gradient in the western United States are greater than those values from Gangwon province. This might be caused by different characteristics between runoff-initiated debris flow related to fire and landslide-initiated debris flows.

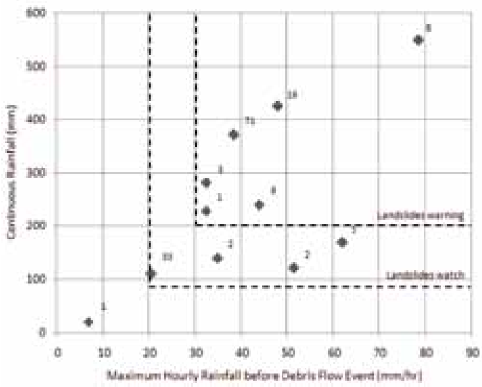

Fig. 13 - Relations of the maximum hourly rainfall intensity and antecedent cumulative rainfall before occurrence of debris flow. (Rainfall threshold lines representing landslide watch and warning respectively proposed by KFS)

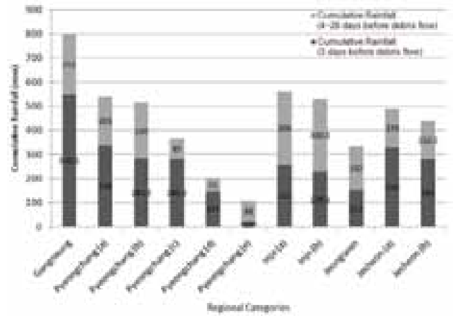

Fig. 14- Cumulative rainfall for regions in Gangwon province

	Hourly rainfall	Daily rainfall	Cumulative rainfall
Landslides watch	<20 30	<80 100	<100 200
Landslides warning	>30	>150	>200

Tab. 3 - Landslide forecast by KFS

RAINFALL TRIGGERING DEBRIS FLOW

Using the available rainfall data at each of the debris flow sites, the relations of the maximum hourly rainfall intensity and antecedent cumulative rainfall before occurrence of debris flow are shown in Fig. 13. In this figure, cumulative rainfall tends to increase with the maximum hourly rainfall intensity. All of data except a single point in Fig. 13 are within the landslide threshold lines which are proposed by the Korea Forest Service, as shown in Table 3. From this figure, it can be noticed that debris flow in Gangwon province usually occurs during a storm event having greater rainfall than the threshold triggering landslide.

As shown in Fig. 14, rainfall events with cumulative rainfalls during three days and from four to twenty-eight days before occurrence of debris flow for regions in Gangwon province were analyzed to investigate the effect of antecedent cumulative rainfall on the occurrence of debris flow. Amounts of cumulative rainfall during three days are greater than those from four to twenty-eight days before occurrence of debris flow; thus, rainfall events during three days appear to be dominant to initiate debris flows. In addition, the amounts of rainfall from four to twenty-eight days before the occurrence of debris flows, ranging from 55 mm to 301 mm, might increase the degree of saturation in the ground and subsequently result in the occurrence of debris flows. More work in the future is needed to verify details of rainfall effects on debris flow.

CONCLUSIONS

Based on data obtained from 153 sites where debris flow occurred recently in Gangwon province in Korea, geomorphic characteristics of the initiation zone, initiation and transportation mechanism, and the thresholds of rainfall for an early warning system were analyzed and the results are summarized as follows.

1. Volumes of the debris flow initiation zone are in the range of 16-11,310 m^3 and most of them are less than 1,000 m^3.
2. Debris flows are initiated in relatively steep slopes, and are associated with the geomorphic characteristics of Gangwon province. They travel along mountain streams having a relatively gentle gradient of 16.9 degrees on average and relatively short distances averaging 408 m.
3. Basin areas are less than 1.2 km^2 being quite small in comparison with the scale in Western United States and the Swiss Alps. The average basin gradient is 12.8 degrees.
4. Rainfall events triggering debris flows have greater rainfall than threshold boundaries, categorized to induce landslides, proposed by the Korea Forest Service. Amounts of cumulative rainfall during three days are so severe that it may be the dominant factor in inducing debris flow.

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