A study on disaster and restoration of debris flow landslides at Inje, Kangwon Province, Korea

Une etude sur le catastrophe et la restauration des glissements de l'affluence des débris à Injé, Province de Kangwon, Corée du sud

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ABSTRACT
A series of site investigations have been carried out to study the characteristics of debris flows and losses occurring during heavy rainfall in the summer of 2006 at Inje, Kangwon Province, Korea. It has been found that major losses are caused by discharge of soil and rock fragments from debris flow landslides. During the record-high rainfall, precipitation of 113.5 mm/hour and 355 mm/day was recorded, which might occur at intervals of 80-500 years. It has also been found that occurrence of the landslides is directly related to heavy rainfall by comparing the record of rainfall with the time of the landslides. At present, several debris barriers have been built in valleys and natural slopes have been protected by the seed spray method.

RÉSUMÉ
Une collection des recherches du site était exécutée pour étudier les caractéristiques de l'affluence des débris et les déficits arrivés durant les fortes chutes de pluie pendant l'été 2006 à Injé, la Province de Kangwon, en Corée du sud. Il était découvert que les déficits majeurs sont causés par les décharges du sol et les éclats du roche venant des glissements de l'affluence des débris. Durant la chute de pluie, la précipitation de 113,5mm/heure et 355mm/jour était le record, qui pourrait arriver à 80-500 ans d'intervalle. Il étiat également découvert que l'apparition des glissements est directement liée aux fortes chutes du pluie en comparant le record de la précipitation avec du temps des glissements. En ce moment, les plusieures barrières des débris étaient construites dans la vallée et les côtes naturelles étaient protégées par la méthode de la bombe aérosol du grain.

Keywords : Debris flows, Debris barriers, Heavy rainfall, Landslides

1 INTRODUCTION

In recent years, heavy rainfall has frequently been recorded in Korea, perhaps due to global earth shocks and climate changes, resulting in substantial damage related to debris flow landslides. In Korea, the annual precipitation amounts to about 1000-1850 mm and 50-60 % of annual rainfall is concentrated between July and August (Park, 2007). The heavy rainfall during the summer season, in particular typhoons, can cause a number of landslides and great damage. Over the last 10 years, there have been a number of large-scale disasters with debris flow landslides triggered by typhoons and highly localised heavy rainfall Kangwon Province, Korea, resulting in severe loss of human life and properties. The average annual death toll due to slope-related disasters is about 30, and significant financial losses have also occurred (Park, 2007). In particular, the July 2006 heavy rainfall at Inje, Kangwon Province, caused tremendous debris flows resulting in record-breaking loss of life and properties (total death toll: 29, property losses: approx. 0.3 billion US$). In the current research, a series of site investigations of debris flow landslides have been conducted by studying traces of the debris flows, engineering and geological characteristics, and geometry of valleys and slopes. Based on the investigations and other relevant work, the engineering characteristics of the landslides have been analysed. An insight into the main characteristics of the Inje debris flows and restoration of the damage is reported and discussed.

2 LOSSES DUE TO LANDSLIDES IN KOREA

Damage related to natural disasters such as floods, rock falls, landslides and debris flows in Korea is mainly concentrated in the rainy season (July-September). In particular, serious damage has occurred due to heavy rainfall at Kangwon Province perhaps triggered by global warming, highly localised rainfall and the El Niño effect. Figure 1 shows the annual death toll related to natural disasters and deaths due to slope-related accidents recorded over the last 10 years in Korea (Park, 2007). In total, 321 persons have been killed due to landslide-related disasters, this being about 27 % of the whole death toll related to natural disasters. In this study, 196 landslides that recently developed on natural slopes in Kangwon Province were analysed. Generally, landslides developed when the slope angles were 25-35 degrees. Surprisingly, only 4 landslides were recorded on slopes with a high angle of more than 40 degrees. The lengths of the failed slopes were normally in the range of 20-200 m, amounting to about 76 % of all failed slopes. In addition, the widths of the landslides were 10-40 m, mostly about 10-20 m. Among various patterns of landslides, debris

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flow was dominant (about 80 %) and rock fall and/or movement of rock mass was less than 20%.

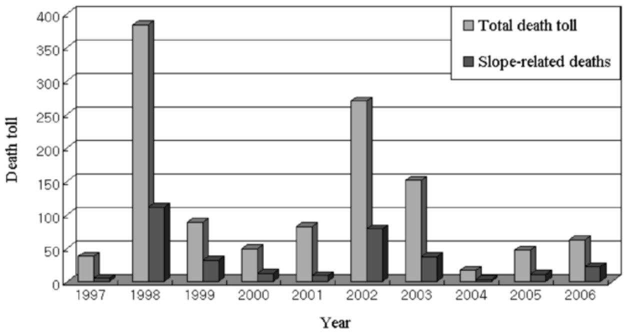

Figure 1. Annual death toll in Korea related to natural disasters.

In July 2006 there were 1 typhoon and 3 case of continuous heavy rainfall at Inje, Kangwon Province causing substantial loss of human life. In particular, in the heavy rainfall during 14-20th July, a number of large-scale landslides developed resulting in many casualties of people living downstream of the valleys. Figure 2 shows a location map of Inje and Figures 3 and 4 present an overview of debris flow affecting villages and a trace of such flow, respectively. Many natural and man-made cut slopes collapsed due to the heavy rainfall, a total of 20 persons died and 9 person were missing, a total financial loss of about 0.3 billion US$ was caused. Also, several public infrastructure items including bridges, roads, water supplies, drainage and so on were damaged.

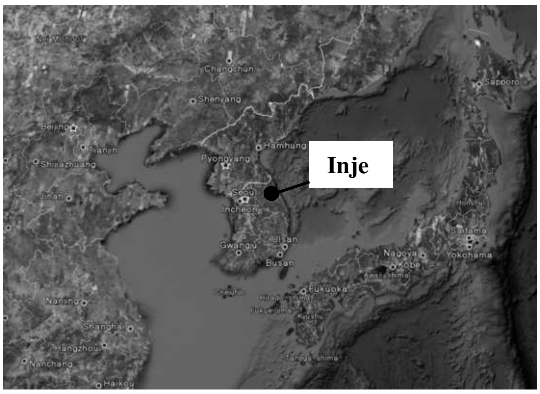

Figure 2. Location map of Inje, Kangwon Province, Korea.

Figure 3. Overview of debris flow affecting a rural community.

Figure 4. Trace of a typical debris flow.

3 CHARACTERISTICS OF RAINFALL AND GEOLOGICAL CONDITIONS

Tables 1-2 show rainfall records during July 2006 at Inje. The rainfall records show highly localised characteristics and record-breaking high rainfall at some measuring points. Between 12th and 17th July 2006, a record-high rainfall of more than about 500mm was recorded. Most of the rainfall was concentrated in 15-17th July and the majority of the damage occurred during this time. A maximum total precipitation of 722 mm was recorded and a maximum precipitation of 113.5mm/hour was also monitored. Furthermore, in some local areas the maximum rainfall per day was 355 mm, which might occur at intervals of 80-500 years.

Table 1. Maximum rainfall record for 24 hours at Inje during July 2006 rainfall (14/7 – 20/7) (unit: mm)

	1 hr	3 hrs	6 hrs	12 hrs	24 hrs
Rainfall (mm)	113.5	241.0	265.0	288.0	355.0
Period (yr)	500	500	500	80	80

Table 2. Rainfall records from 6 measuring points (A-F) at Inje (unit: mm)

Date	Avg	A	B	C	D	E	F
12/7/06	143	166	165	151	136	83	157
13/7/06	33	9	56	8	41	3	84
14/7/06	31	61	13	48	20	30	14
15/7/06	163	174	191	176	194	135	111
16/7/06	106	110	123	94	105	79	127
17/7/06	147	135	174	128	179	90	175
Total	623	655	722	605	675	420	668

At Inje a 1-2 m thick colluvium and/or weathered soil existed at the slope surface. Hence, the degree of saturation of the unsaturated topsoil 1-2 m in thickness was perhaps increased and pore water pressure increased when there was heavy rainfall, thereby reducing the shear strength of the topsoil. Therefore the development of the landslides was very likely related to the reduction in the shear strength of the topsoil. Furthermore, this soil is very susceptible to soil erosion during heavy rainfall. Further, the depth of the tree roots was very shallow (rooted to 1-2 m to the soil layer) and hence soil reinforcement effects supplied by the tree roots might not be expected. These several features perhaps easily initiated the development of the debris flows. Underneath the soil layer were weathered rock and soft rock, which were not affected much by the heavy rainfall. A detailed explanation of the rainfall records and geological characteristics of the topsoil at Inje has been reported by Park (2008).

4 RESULTS FROM SITE INVESTIGATIONS

In the current research, a systematic site investigation programme has been conducted to survey several locations where severe debris flows occurred. The site investigations were conducted between 2007 and 2008 as demonstrated in Figure 5. The sites were selected where initiation of debris flows and transportation and sedimentation could still be identified. The investigation of the debris flows was conducted by recording the locations of the valleys and slopes where debris flows developed. Furthermore, the engineering characteristics of the topsoil layer were analysed. The trace of the debris flows was monitored by using a highly advanced GPS system. The GPS system could records the coordinates of each measuring location and the dip and strike of slopes. In addition, the width, depth and erosion and sedimentation characteristics were recorded. The debris flow landslides at Inje were found to be classified as typical canalised debris flows due to concentration of surface water in the valleys.

In the current research, the survey location was divided into two main streams (A and B) and each stream had two substreams (A-1 and A-2, B-1 and B-2) at Duksanri of Inje. The main stream A starts from GPS coordinates of N38.09668/E128.21645 (A-1) and N38.09375/E128.21013 (A-2), respectively. In addition, the other main stream B starts from GPS coordinates of N38.09673/E128.22137 (B-1) and N38.09407/E128.22156 (B-2), respectively (see Figure 6).

Figure 5. Site investigation.

4.1 *A-stream*

The total length of the A-1 stream was 1.8 km and 14 slope failures were identified. Among these 9 slopes were protected by a seed spraying method, while the other slopes at the upstream of the valley were left untouched. The lengths of the slopes were 45.5-143.2 m, while the slope angles were 19-41 degrees.

Slopes at the A-1 stream have total lengths of 45.5 m and 66.4 m, while the lengths of slopes at the A-2 stream were 92.7 m and 143.2 m, respectively. The lengths of the slopes at the upstream were generally shorter than those at the downstream. The inclinations of the slopes were in the range of 30-40 degrees, consistent with previously reported angles of 20-45 degrees (Jakob & Hungr, 2005). Soil and rock debris were transported to the main stream of the valley and then moved down the downstream of the valley. The upstream was subjected to erosion, while the soils and rocks were deposited at the downstream. This was found by measuring the average angle of valleys (upstream: 30 deg; downstream: 35 deg) and analysing the particle size distribution. The average inclination angle of the downstream is 18 degrees. Soil and rocks at the base of the valley at the downstream showed clear evidence of sedimentation. Perhaps this is due to sedimentation of soil/rock debris leaving large size particles. The A-2 stream is 0.83 km in length. In total, 6 landslides occurred. A-1 and A-2 valleys were found to have different rock particle size distributions.

4.2 *B-stream*

The B-1 stream is 0.65 km in length and the length of the B-2 stream is 0.32 km. In total, 5 landslides occurred (B-1: 3; B-2: 2). All slopes were left untouched. The lengths of slopes were 23.5-42.5 m, while the slope angles were 27-41 degrees. Unlike the A-valley all failed slopes were located upstream of the valley. Similar to the slopes A-1 and A-2, soil and rock debris were transported to the main stream of the valley and then moved down to the downstream of the valley mixed with water and wood. As reported previously regarding the A-1 and A-2 slopes, the B slopes also showed soil erosion at the upstream of the valley, while soil sedimentation was found at the downstream of the valley.

5 RESTORATION OF LOSSES

For the restoration of the losses due to the Inje debris flow landslides, a total of about 0.5 billion US$ has been spent. Generally, there are several ways or restoration of slope damage, such as debris barriers, seed spray and a monitoring system (Park, 2008). Sustainable and eco-friendly restoration was the main concern among the engineers involved. A number of different debris barriers have been adopted to prevent debris flow by considering characteristics of slopes, geological condition, etc. At present, concrete check dams, buttress check dams, slit check dams, shell-type barriers and gabion walls have been built at various points along the valleys. In addition, natural slopes where small-scale landslides developed were protected by the seed spray method. Figure 7 shows typical debris barriers built after the landslides and a slope protected by seed spray.

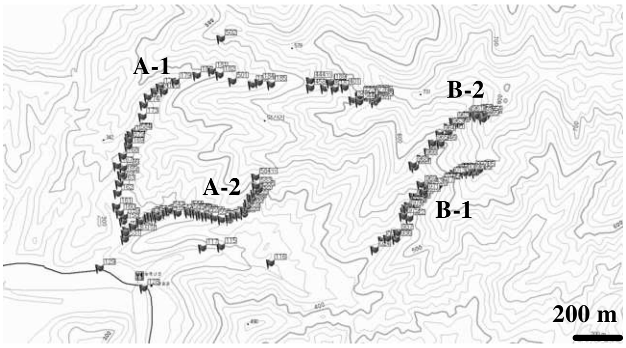

Figure 6. Traces of landslides at A and B streams recorded using the GPS system during site investigations.

6 SUMMARY AND CONCLUSIONS

Tremendous debris flows occurred at Inje, Kangwon Province, Korea during the summer of 2006. The current research has analysed the debris flow landslides by conducting a series of site investigations and other relevant work. It has been found that the debris flows were triggered by the highly localised record-breaking heavy rainfall, which could occur at intervals of 80-500 years. The 1-2 m thick unsaturated soils near the slope surface are mostly composed of colluvium and weathered soil. Hence, substantial soil erosion and reduction in shear strength are caused during heavy rainfall, resulting in initiating landslides. The site investigations showed that the debris flows were affected by soil deposits on the slopes, conditions of rainfall, topography and geology and, in particular, terrain deposits. At present, several debris barriers have been built at the valleys where major debris flows occurred at Inje. In addition, natural slopes have been protected by the seed spray method.

The findings from this study indicate that the investigation of debris flows should be conducted by using rigorous methods to find the causes and characteristics of the debris flows. To do this, engineering and geological features of the soil and rock mass in slopes should be incorporated in the analysis of the debris flows. Hence, the importance of an analysis based on detailed field investigations cannot be overestimated. The reliability of an analysis without sufficient information may not be high enough, and it will probably need to be reappraised. It would be very helpful to use the latest IT technology in monitoring debris flows.

a) A slit-type debris barrier

b) A shell-type debris barrier

c) A slope protected by the seed spray method

Figure 7. Debris barriers and slope protection.

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REFERENCES

Park, E. S. 2008. Study on disaster and recovery of landslides in a localized downpour: focused on the Gangwon-do Inje area. Master Thesis, Kangwon National University, Korea (*in Korean*)

Park, N. S. 2007. A study on characteristics of landslide of debris flow in Gangwon-do. Master Thesis, Kangwon National University, Korea (*in Korean*).

Jakob, M. and Hungr, O. 2005. Debris-flow Hazards and Related Phenomena.