

## **Major landslides and associated rehabilitation measures in urban areas of the Republic of Korea**

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**Abstract** In order to study landslide disasters and associated rehabilitation measures in urban areas of the Republic of Korea, the characteristics of the major landslides triggered during last 20 years were investigated from the viewpoint of natural disaster prevention and reduction measures. There were about 30 large disastrous landslides caused mainly by heavy rainfall during the period. Among these, the landslides in the Anyang-Shihung region (adjacent to Seoul) which occurred on 8 July 1977, the landslides in the Boeun region which occurred on 22 July 1980, the landslides at Munhyon-dong (Pusan) which occurred on 5 July 1985, the landslides in the Puyo-Seochun region which occurred on 21-22 July 1987 and the landslides in the Seoul metropolitan area which were triggered on 27 July 1987, caused heavy loss of human life as well as property damage. The average annual area of landslides triggered during the last 15 years amounted to about 243 ha and resulted on average in the loss of 56 lives annually. However, landslide damage extended to about 1012 ha in 1987 and was very serious in terms of the extent of the damage and the losses of properties. For developing landslide disaster countermeasures, the Forestry Administration (Head Office of Forestry) needs to define the criterion for designating landslide risk sites/areas and implementing the Steep Slope Failure Prevention Act, particularly in urban residential area. In addition, in heavily urbanized regions such as the Seoul metropolitan area, when concrete structures are used for landslide control works, the impact of these structures on the natural environment should be carefully analysed and evaluated.

### **INTRODUCTION**

Natural disasters including floods, landslides and landslide avalanches caused by heavy rainfall and typhoons occur almost annually in the Republic of Korea. According to a previous report (Woo, 1984) which analysed the disaster statistics, the average annual loss of human life resulting from such disasters amounted to about 250. About 56 out of the total deaths during last 15 years were attributed directly to landslides. The average annual area of landslides triggered during the last 15 years amounted to about 243 ha (Anon., 1991). In 1987, several catastrophic disasters including about 1012 ha of landslides resulted from the typhoons accompanied by heavy rainfall which occurred mostly in the central part of the Republic of Korea.

Natural disaster prevention measures must, therefore, be carefully managed. The Forestry Administration in the Republic of Korea is responsible for the establishment of landslide-related disaster countermeasures. The Forestry Administration has been primarily concerned with assessments of the damaged area and deaths caused by landslides and has not analysed the cause of slope failures and landslide avalanches, etc. In recent years, the mountain lands around the urban areas have been used for large residential developments, because of the rapid expansion of the urban population. Sometimes, houses are constructed even on the upper parts of hillsides with little attention to the safe disposal of excess rain water. This kind of land use change sometimes provides a major cause of slope failure and landslide avalanches. Special types of prevention works are needed for landslide risk areas.

For this study, the author collected and analysed data concerning landslide-related disasters during the last 20 years in the Republic of Korea. The measures used for rehabilitation of landslide areas in the Seoul metropolitan region were analysed and evaluated.

## DATA SOURCES AND METHODS OF ANALYSIS

Almost all of the main landslide and disaster-related reports and records have been collected for analysis of disaster status, prevention measures and rehabilitation measures. The main sources dealing with the natural disasters, including landslides, have been published by the Ministry of Construction (MOC), the Ministry of Home Affairs (MOHA), the Ministry of Agriculture, Forestry and Fisheries (MOAFF) and the Forestry Administration (FA). Some rehabilitation schemes for landslides, including Shihung 2-dong and the Namsan Park in Seoul, were technically reviewed with field checking.

Assessment of the basic characteristics of the major significant landslides was based on the criteria of Hansen (1984), Sidle (1980) and Varnes (1978). Evaluations of individual landslide events were based on the reports of Kang & Woo (1985), Woo (1972), Woo & Belt (1978) and Woo *et al.* (1978), respectively. Analysis of prevention measures was based on the reports of Anon. (1977), KICT (1988), Woo (1984, 1985). Information on the landslides triggered in Seoul metropolitan area in 1987 was obtained from Anon. (1987) and Woo (1989). Finally, information on the assessment of landslide hazards and risk areas were based on the criteria presented in reports by Choi (1986), Dietrich *et al.* (1987), Hansen (1984b), Ma (1987), Sidle (1980) and Tsukamoto & Minematsu (1987).

The analysis focussed on the disasters associated with seven major landslides and on the development of landslide rehabilitation measures in Seoul metropolitan area during 1987.

## RESULTS AND DISCUSSION

### The characteristics of the major landslides

**Landslide disasters in the Yongin-Ansung region of Kyunggi-do** Because of concentrated heavy rainfall in the Yongin-Ansung region on 18-19 August 1972, about 20 ha of landslides occurred consisting of 632 slides within the 20 750 ha of forest land. In terms of landslide occurrence per unit area in the forest land, eight slides per 1000 ha occurred, while 925 slides occurred within the area of young forest and denuded land. The average size of the landslide scars was about 11-40 m length, 5-15 m wide, 0.5-1.0 m deep and 100-300 m<sup>2</sup> in surface area which can be considered as relatively small. In this region, another serious landslide disaster caused by heavy rainfall occurred on 21 July 1991; about 250 ha of landslides occurred in the Ansong-gun district over an area of 553 km<sup>2</sup> and 200 ha of landslides occurred in the Yongin-gun district over an area of 592 km<sup>2</sup> area.

**Landslide disasters in the Anyang-Shihung region of Kyunggi-do** On 8 July 1977, serious landslide-related disasters caused by concentrated heavy rainfall at several locations occurred in the Seoul metropolitan area, including Seoul, Anyang-Shihung and Inchon. In the Anyang district, 112 human lives were lost, 460 houses were damaged, and 21.4 ha of farmland were destroyed. On 8 July, there was a historic recording of maximum rainfall involving 432 mm in one day, and 99.5 mm in a single hour. The landslides covered about 96.47 ha (1876 sites) within the 12 700 ha drainage basin of the Anyangchon stream.

In terms of the size distribution of the landslides, 620 were into the 0.01 ha class, representing 33.0% of the total cases, 331 (17.64%) were in the 0.02-0.029 ha class, 192 (10.23%) were in the 0.03-0.039 ha class, 134 (7.14%) were in the 0.041-0.049 ha class and the remainder fell into various size categories. In particular, 18 slides were in excess of 0.5 ha. Considering the relationship between hillslope steepness and landslide incidence, 10 slides (0.53%) occurred on slopes of less than 20°, 106 slides (5.65%) on slopes of 20-25°, 570 slides (30.38%) on slopes of 25-30°, 1025 slides (54.25%) on slopes of 30-35° and 165 slides (8.79%) on slopes of over 35°. The change of land use associated with the expansion of the urban area resulted in a situation of increased susceptibility to landslides. Landslide prevention and counter-measures, particularly safe disposal of rain water in the mountain top areas, were essential. An integrated plan for landslide disaster prevention at the basin scale was required. Some large landslide avalanche-torrents also occurred on the hillslopes in the residential area of Shihung 2-dong in Seoul. This landslide disaster resulted in 15 deaths and the destruction of 20 houses.

**Landslide disasters in the Pyungchang area of Kangwon-do** On 5 August 1979, landslides caused by a heavy rainstorm caused the death of 23

persons, the disappearance of 10 persons and injury to 19 persons. The maximum rainfall per hour was 42 mm. The rainfall totalled 244.7 over a period of 18 h. Most of the landslides occurred from the upper 6/10-9/10 of the hillslope, having slopes of 25-30°. The landslides occurred more frequently on the granite areas than on the limestone areas.

**Landslide disasters in the Jinhae area of Kyungnam-do** On 25 August 1979, landslides caused by heavy rain (465 mm in one day) associated with typhoon Judy resulted in the death of 38 persons in the Jinhae area. Although there had been five previous occasions with heavy rainfall in excess of 300 mm in a day, landslides had not occurred so extensively before. Because of the heavy storm of 465 mm in one day, the landslides covered 15.3 ha consisting of 71 general sites. In terms of their geological distribution, 89% of the landslides occurred on areas underlain by andesite and 11% on areas underlain by granite. In terms of extent, 45% the total area occurred on andesite and 55% on granite. Most of the landslides occurred in forest stands of 5-15 years and a few occurred in the forested lands with stands more than 25 years old.

**Landslide disasters in the Boeun area of Choongchungbuk-do** On 22 July 1980, serious disasters associated with flood inundation and landslides caused by heavy rainfall occurred in the Choongchungbuk-do region. The total rainfall was 302.6 mm at Boeun, and this fell mainly between 11:00 and 15:00 h on 22 July. The rainfall intensity reached 90 mm h<sup>-1</sup> at Boeun but was 40-60 mm h<sup>-1</sup> in the other regions. As a result 99 persons died and 74 were injured. The landslides occupied 130 ha and involved 3290 sites in the Boeun-gun district.

**Landslide disasters in the Munhyon-dong area of Pusan** Landslides occurred due to continuous rainfall (615 mm during 15 days) on the steep slopes at Munhyon 2-dong in Pusan. The size of the slope failure which occurred on 5 July 1985 was 50 m in total length and 2.0 m in mean depth. It resulted in the death of 37 persons, serious injury to six persons, the total destruction of 19 houses, and major damage to five houses. In order to prevent such landslide-oriented disasters, a "steep slope failure prevention plan" should be established for each landslide risk area.

**Landslide disasters in the Puyo-Seochun region of Choongchungnam-do** In the "Middle-region heavy rain disaster", rainfall of 600-700 mm fell during the three days of 21-23 July 1987 in the Puyo-Seochun region. The resultant landslides covered about 115 ha in the Puyo-gun district and about 203 ha in the Seochun-gun district, resulting in the death of 38 persons. The maximum recorded rainfall was 678.5 mm in one day on 21 July. The landslides were mostly triggered in zero-order basins and hollows (Dietrich *et al.*, 1987).

## Landslide disasters and rehabilitation measures in the Seoul metropolitan area during 1987

**The characteristics of the catastrophic damage caused by the heavy rainfall and floods of 1987** In the summer of 1987, disasters caused by heavy rain occurred throughout the country and the total damage was about 1057.5 billion won (about 1.5 billion US dollars). These disasters included typhoon Celma (15-16 July), typhoon Dina (30-31 August), the so-called "Middle-region heavy rainfall disaster (Choongchung region)" and the "Seoul Metropolitan heavy rain disaster (26-27 July)". 1658 persons perished during the disasters. Landslides covering about 1012 ha and involving 700 sites occurred during 1987. Landslide-related problems must be considered in a new national policy. In the Seoul region, the total rainfall was 352 mm for the two days 26-27 July 1987. The maximum rainfall intensity was  $51.5 \text{ mm h}^{-1}$  (05:00-06:00) on 27 July. The total number of lives lost during this disaster was 36. Landslides covered about 40 ha and involved 30 sites.

**The development of landslide rehabilitation works in Seoul metropolitan area: rehabilitation measures associated with the landslide avalanches in the debris torrent area of the Mt Kwanaksan region (southern part of Seoul)** On 8 July 1977, heavy rain fell on the Seoul metropolitan region, including Anyang, Shihung, Incheon and Suwon of Kyunggi-do. A number of slope failures occurred within the various construction sites located on steep hillslopes. Serious damage by landslides and debris avalanches was observed. Stone buttressed soil arresting works were adopted mainly for rehabilitating the rocky areas of landslides in the Mt. Kwanaksan region. On the steps, erosion-resistant tree species such as *Pinus rigida*, *Alnus hirsuta* var. *tinctoria* and *Robina pseudoacacia* were densely planted. Stone structures which included stone check dams, gabion check dams, stone masonry structures for stream grade-stabilization, and channel improvement works were the principal rehabilitation method for the debris torrent areas. Most of the structures were built with stones which were readily available around the construction sites. A large-scale reinforced concrete debris dam was constructed just below the confluence of the two main streams. It has been more than 10 years since the dam was constructed, and the dam has fulfilled its function efficiently without any breaking or cracking. A number of stone check dams and other masonry structures for torrent stabilization were constructed in the denuded torrential streams. These stone structures have been almost destroyed by debris avalanches. Reinforced concrete structures rather than stone structures are recommended for stabilizing debris avalanche-torrents. Further research is required on the harmonization of concrete structures with the natural landscape.

**The development of landslide rehabilitation works in Seoul metropolitan area: landslide avalanche-torrent control works at Shihung 2-dong (southern part of Seoul)** The mountains bounding the Shihung 2-dong area

have long been considered as an area of high landslide risk. Catastrophic disasters occurred in the area in 8 July 1977. Landslide rehabilitation works mainly involved stone buttressed terraces structures on the hillslope, while masonry structures and stone stream grade-stabilization revetments were used in the denuded torrential stream. A reinforced concrete dam was constructed for debris trapping at the lowest point on the denuded torrent. Heavy rains have occurred almost every year in the ensuing 10 years and these have caused damage to the stone structures. The breakages have been repaired. However, the reinforced concrete check dam functioned well in providing erosion control on the torrent.

As a result of heavy rainfall on 27 July 1987, a translational landslide about 9 m wide and 30 m long occurred at the top of a hillslope and developed into a landslide avalanche, and finally into a landslide torrent extending about 400 m downslope. The landslide torrent caused serious damage to houses located downslope. To rehabilitate this landslide torrent, modified reinforced-concrete dams were constructed. The rock bed was bored with a rock drill and iron rod anchors ( $\Phi = 19$  mm; two rods per  $1 \text{ m}^2$  of bed) were installed along with the plywood concrete forms. In the upper part of the landslide torrent, with steep slopes where a truck could not be driven, construction materials were transported by a simple railway track. Ready-mixed concrete was transported on a trolley using a winch and then poured into the plywood form using the bucket of an excavator. These iron anchored concrete dams and the rock fall retarding structures represent new erosion control measures for the Republic of Korea. The rock fall retarding structures are constructed of round iron pipe ( $\Phi = 200$  mm) and are installed to stop large sliding stones caused by landslides. This work will contribute to the prevention of further landslide problems, along with completion of other rehabilitation works in this high risk area.

**The development of landslide rehabilitation works in Seoul metropolitan area: landslide avalanche control works on the urban hillslopes of Mt Namsan Park (central part of Seoul)** Mt Namsan (240 m a.m.s.l.) is located in the central part of Seoul. Seven translational landslides occurred due to the heavy rainfall on 27 July 1987. Several translational landslides started at the side of the Seoul Tower plaza which is located at the top of the Mt Namsan, and these developed into large-scale landslide avalanches. These avalanches caused considerable damage to the buildings and roads downslope. Stone soil-arresting structures were mainly adopted for rehabilitation of the southern hillslope scars. Young *Pinus densiflora* and *Pinus koraiensis* trees (tree height 1.5-2.0 m, 10-14 years of age, 1.5-1.8 m distance in a row) were planted on each step of the structures. On the northern hillslope of the Seoul tower Plaza, a concrete retaining wall was constructed. In the main landslide torrent, various stone structures were installed from the top to the bottom of Mt Namsan. These included stone pitching channel works, stone pitching revetments and stone check dams. Further improvement of the construction methods must be intro-

duced to improve their harmonization with the natural landscape. Some specialist companies dealing with urban erosion control works should be established.

## CONCLUSION

In the Republic of Korea, natural disasters including floods, landslides and debris flows caused by heavy rainfall associated primarily with typhoons cause serious loss of life and damage to property and the environment. Before the early 1980s, the average annual area of landslides triggered in the Republic of Korea was about 275 ha, but this has increased to 424 ha during the recent five years. Landslides covered about 1012 ha in 1987 and about 730 ha in 1991, and caused heavy loss of human life and severe damage to property. Landslide disasters appear to be an increasingly serious problem.

There were 30 large landslide disasters during the last 20 years. Landslides in these regions are caused by saturation of soil by excessive amounts of rainfall and/or by the high intensity of rainfall. Landslide prevention measures should be established in areas identified as landslide risk areas/sites.

Based on an analysis of landslide damage in the Seoul metropolitan area during 1987, it is evident that the inadequate disposal of excess rainwater from the surface area resulted in the development of slope failures-landslides-landslide avalanches-landslide torrents. Because of rapid urbanization, many steep hillslopes have been used for residential areas and some engineering structures have even been constructed on the mountain tops. The government should establish new measures for preventing natural disasters in such areas of land use change, particularly on steep slopes. For rehabilitation of landslide torrents, reinforced concrete structures and rock fall retarding screens are strongly recommended.

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