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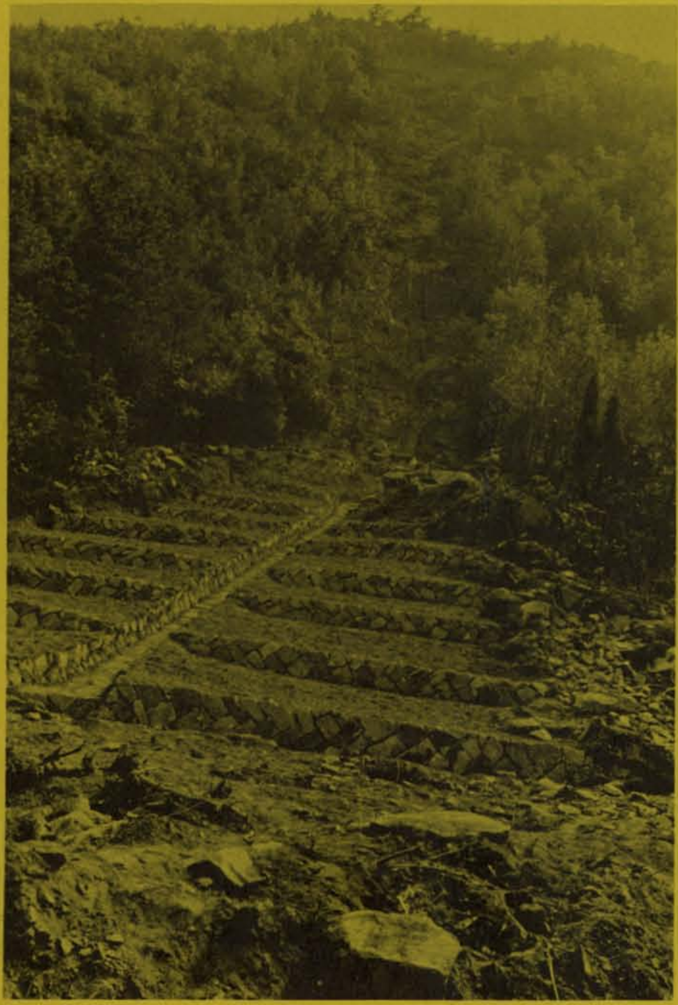
AN ANALYSIS OF LANDSLIDE DAMAGE AND SLOPE STABILIZATION NEAR SEOUL, KOREA



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ABSTRACT

Because of relatively steep slopes, shallow granitic soils and reduced vegetative cover, landslide hazard is high in some drainages near Seoul, Korea. When frontal weather associated with typhoons causes heavy rainfall, surficial landslides frequently occur, resulting in severe property damage and loss of life. The Korean government has stabilized these slopes using terraces buttressed by dry masonry walls and drained by stone-lined central channels. Recommendations for revegetating these terraces and estimating their effectiveness in reducing groundwater rise are presented. Suggestions for research projects which would be useful in identifying areas of high landslide hazard are also given.

An Analysis Of Landslide Damage And Slope Stabilization Near Seoul, Korea

by

George H. Belt and Bo-Myeong Woo

INTRODUCTION

Severe summer storms occur periodically in Korea as a result of frontal weather associated with typhoons. Typhoons reaching Korea generally move along a northeasterly track from the Philippines to Japan. When these weather systems stall over the mountainous Korean peninsula, heavy precipitation usually results. Such a storm occurred on 8 July 1977, releasing 432 mm of rainfall during a 24-hour period. On 9 July an additional 41 mm of rain fell, making a total of 473 mm for the 48-hour period. Since annual rainfall for the region averages 1224 mm, this single storm represents 38 percent of the average annual rainfall. Precipitation intensities on 8 July exceeded 90 mm per hour during the period from 1900 to 2200 hours. The magnitude of this rainfall, coupled with the intensity of delivery, resulted in large numbers of landslides near Anyang, a suburb of Seoul. The storm took more than 200 lives, injured additional hundreds, and left 60,000 homeless. Rail and highway systems were disrupted and hundreds of hectares of rice paddies were inundated or washed away (Anonymous 1977*a*). Economic losses were estimated to be in excess of $60,000,000 (Anonymous 1977*b*).

The 8 July storm was the most severe measured over a 24-hour period during 250 years of record in the Seoul area, and the largest since August 1920, when 355.7 mm of rain was recorded. Storms of lesser magnitude, which occur more frequently, also cause severe damage. For example on 19 August 1972, 273 mm of rain resulted in landslides which killed or injured 480 persons and destroyed more than 40,000 residences. The recurrent nature of such severe storms and the loss of life associated with resulting landslides have led the Korean government to seek assistance in reducing landslide hazards. Dr. Bo-Myeong Woo of the Department of Forestry, College of Agriculture at Seoul National University is directing a research program on the problem. The following analysis, in support of this program, is based on a reconnaissance survey of two watersheds near Anyang and a third drainage within the city limits of Seoul.

The objectives of this study are to describe the problem areas, identifying critical factors causing the landslide hazard, and to suggest measures which might enhance the effectiveness of stabilization work and future research.

STUDY AREA

Three drainages within 48 km of Seoul were surveyed in late October of 1977. All involve both urban and agricultural land use. The study area and the locations of landslides observed are shown in Figure 1.

The Samseong-Cheon drainage has historically been a popular recreation area for the people of Seoul. It was heavily populated by refugees during the Korean war. Consumption of litter and vegetative cover for fuel has only partially been ameliorated through reforestation. The present cover, representative of the previous mixed forest, consists of *Pinus densiflora* and oak species. Some introduced species have been planted as part of the reforestation efforts. The lower portion of this 800-ha drainage is currently a resort area, while the Department of Forestry at Seoul National University is developing the upland area as the Kwanak Arboretum, one of the few protection arboretums in the world.

The soil parent material is a heavily fractured Daebo granite, a Jurassic intrusion in the biotite-banded gneiss (Kim and Hong 1975). The soils are rocky-sandy loams ranging from 20 to 100 cm in depth. Surface litter accumulation and incorporated organic matter are slight due to

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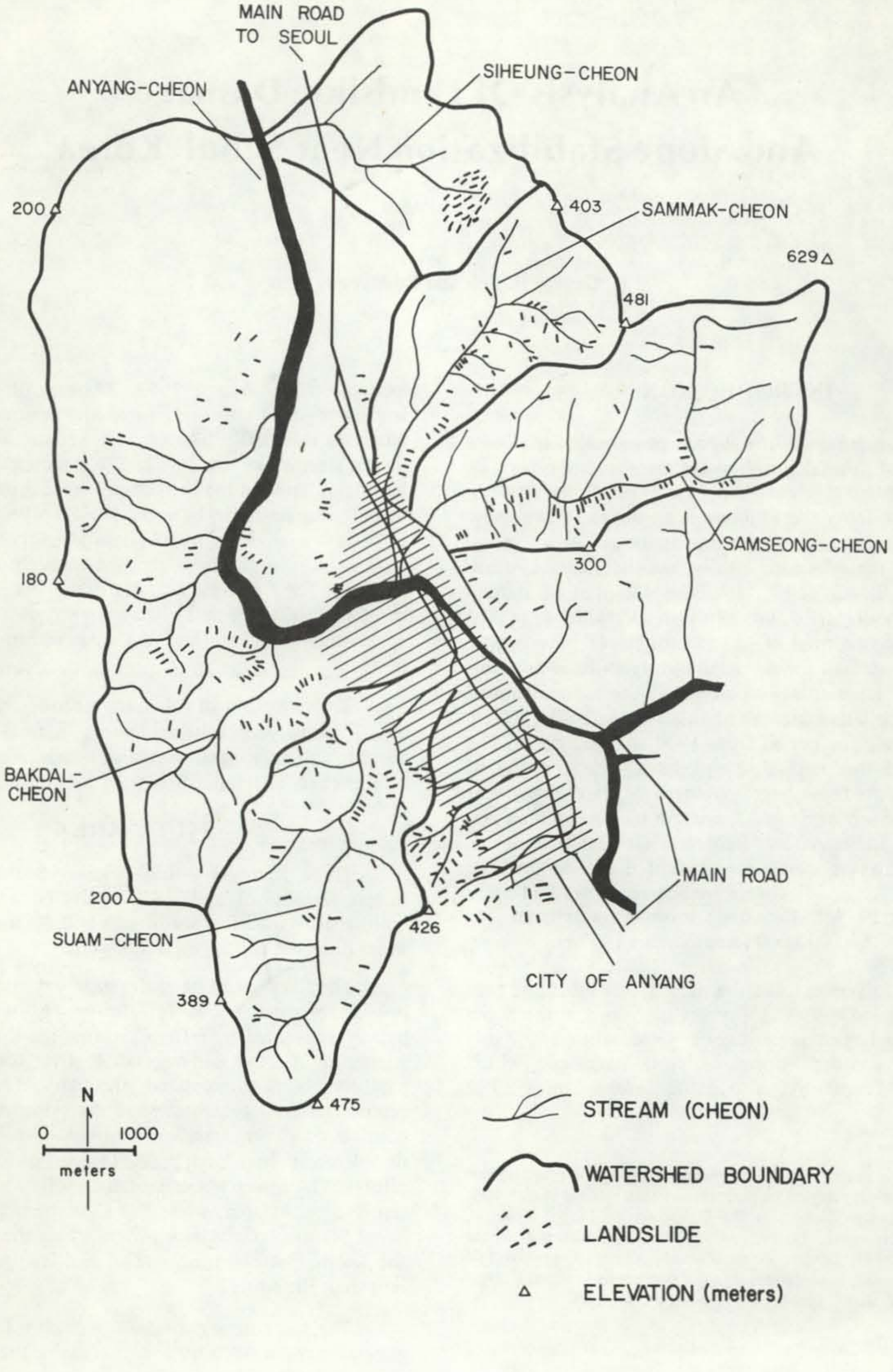


Figure 1. Map of the study area, showing locations of landslides and their proximity to Anyang.

earlier erosion. Slopes range from 50 to more than 100 percent. Stream channels are well incised, and evidence of earlier and continued mass wasting is evident. One of the more than 40 landslides observed in the drainage is shown in Figure 2. Terraces, buttressed by dry masonry walls, are being built to stabilize these slide areas.

Land use in the 930-ha Suam-Cheon drainage is dominantly agricultural; however, an active quarry and a hardboard plant are found at the lower end. The dominant geological formations are augen gneiss and muscovite schist. These highly fractured formations are overlain by 20 to 100 cm of gravelly-sandy loam. Steep slopes range from 40 to 90 percent. Vegetative cover is well below natural levels due to heavy use during and after the Korean war. Evidence of past slope instability is plentiful. A debris avalanche responsible for the deaths of several people during the July 1977 storm is shown in Figure 3. Stabilization efforts such as the rock-lined channels and grade reduction structures shown in Figure 4 and terraces shown in Figure 5 have been constructed in the Suam-Cheon watershed.

The Siheung-Cheon drainage is a densely populated area of Seoul. Approximately 7.5 ha on the upper slopes of this drainage were being rehabilitated at the time of the July 1977 debris avalanche. Failure of the partially stabilized slopes caused loss of life and severe property damage in the community below. Terraces supported by dry masonry buttresses and the single stone-lined drainage channel built in the area are shown as they appeared in October 1977 (Fig. 6). Note that houses which were immediately below the rehabilitated area (and obliterated in the slide) were not rebuilt. However other dwellings remain in the slide path.

Figure 2. Landslide damage in the upper portion of the Samseong-Cheon drainage. More than 40 similar landslides occurred in this drainage.

Figure 3. Debris from this slide in the Suam-Cheon drainage killed three people living in a home which was located between the two shown.

Figure 4. A stone-lined drainage channel has been installed in this slide area. Note walled steps, which reduce the effective channel gradient.

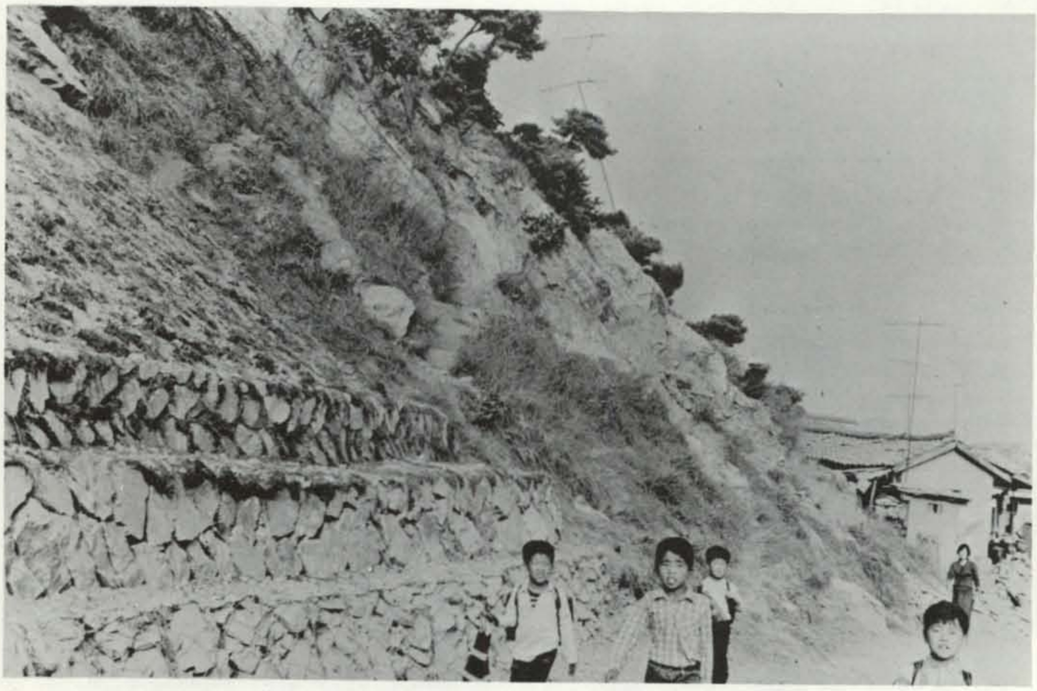


Figure 5. Children returning home from school pass stone buttressed terraces stabilizing a slope in the Suam-Cheon drainage.

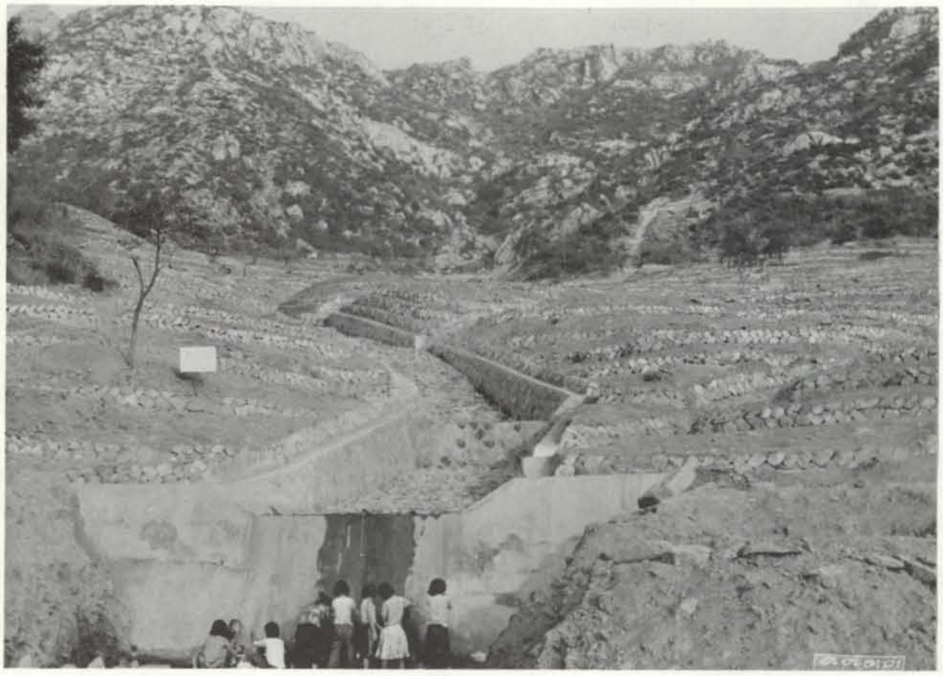


Figure 6. Large, 7.5-ha slide area on the upper slopes of the Sihueng-Cheon drainage. Dry masonry buttresses support these terraces.

Soils in this drainage are also derived from granite; they are coarse-textured and rocky. Due to heavy use and erosion, incorporated organic matter, surface litter and vegetation are minimal. The soil depth above parent material is between 50 and 100 cm. In this drainage visual observations were limited to the upper slopes and portions of the channel due to urban development on the lower slopes.

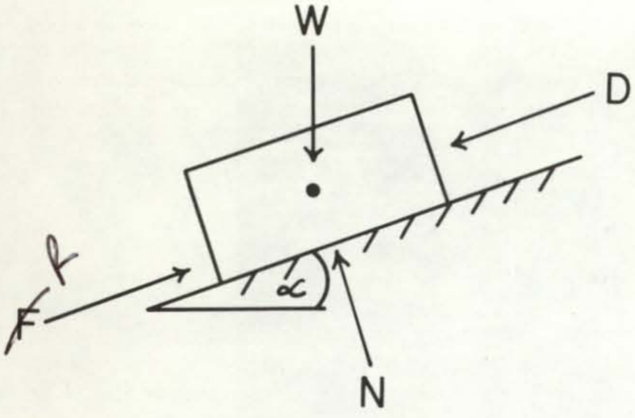
ANALYSIS

Landslides observed in this study result from the instability of surface soil and rock, not the failure of geological faults or bedrock. This type of planar slide, commonly referred to as a debris avalanche, frequently occurs along with other mass wasting processes such as rotational slumps and debris flows in the western United States, Japan and other parts of Asia (Kohno et al. 1968, Bailey 1971, Gonsior and Gardner 1971, Swanston 1974*b*, Burroughs et al. 1976, Megahan et al. 1978). In Korea these slides have been extensively described on the Ansong-Cheon watershed near Suwon (Woo 1972) and in the Kwanak-San area (Woo and Belt 1978). For a detailed review of these and similar mass wasting processes, the reader is referred to Woo's article and the several preceding references.

Characteristically, debris avalanches occur on landforms having oversteepened slopes and shallow, coarse-textured soils. Frequently, these slopes have poor drainage and are underlain by a less permeable layer of parent material which reduces water movement. The study areas previously described often have slopes that exceed 60 percent and are underlain by a compact layer of soil and fractured bedrock. With sandy soils derived from weathered granite, these areas typify situations where mass wasting hazard is high. The critical factors under these conditions are the intensity and duration of rainfall.

High intensity storms which are common during the rainy season in Korea, trigger mass wasting processes. As rainfall infiltrates shallow soil surface layers, two major factors decrease stability of the soil mantle. Cohesion between soil particles is reduced as water pressure in the soil pores is increased. At the same time, frictional resistance to sliding between the mantle and the subsurface layer is lessened as the lower portion of the mantle becomes saturated. Coarse-textured, cohesionless soils are especially susceptible to loss of stability because soil particle cohesion is already small; the buoyant force of water reduces shear strength rapidly if a saturated layer develops in the lower portion of the soil mantle. When gravitational forces exceed the shearing force holding the mantle on the slope, failure occurs. The resistive force opposing downward movement is basically a function of the texture and weight of the soil mass. The additional shearing strength added by roots and structural irregularities, e.g., benches or imbedded rocks of the underlying surface, is also important. However, for situations where steep slopes and shallow soils exist, the key factor is soil water content. High intensity storms such as those recorded on 19 August 1972 and 8 July 1977 are more than sufficient in duration to increase soil water content and trigger numerous debris avalanches.

The critical role that rainfall can play in altering slope stability can be shown by examining the mechanisms involved. Because specific data for the study areas were not



The stability relationship can then be expressed in terms of:

α = the slope (degrees)

W = the weight of the soil volume (kg)

D = the force exerted by the soil volume parallel to the surface

$$D = W\ (\sin \alpha)\ (\text{kg/m}^2) \tag{1}$$

N = the force exerted by the soil volume normal to the slope (kg/m^2)

$$N = W\ (\cos \alpha) \tag{2}$$

F = the frictional resistance to sliding or shear strength (kg/m^2)

$$F = N\ (\tan \phi) + C \tag{3}$$

ϕ = the angle of internal friction which is characteristic of the soil mass (degrees)

C = shear strength of the clay fraction (kg/m^2)

Figure 7. Slope stability relationships using a unit soil block analogy.

available, appropriate values of soil cohesion, C, and the internal angle of friction, ϕ, were estimated from the literature (Burroughs et al. 1976). The following illustrative calculations should be interpreted only as first approximations.

For a planar failure such as a debris avalanche, the stability of the slope can be analyzed using the analogy of a unit soil block on a slope as shown in Figure 7. When F, the frictional resistance to sliding, is greater than D, the gravitational force component acting parallel to the slope, the slope is considered stable and not a hazard. When F is less than D, the slope is unstable, and a hazard exists. This relationship is usually expressed by the ratio F/D and termed the factor of safety, FS. To illustrate changes in stability that can occur due to increases in soil water content, F and D were evaluated as functions of soil water content and slope. Results of these calculations are presented graphically in Figure 8. Dry soil density was estimated to be 1700 kg per m^3. A friction angle of 32 degrees was used.

Curves for dry soil in Figure 8 show that when soil water is absent surficial failures can be expected on slopes exceeding 32 degrees (70%). However, when the soil water content is near saturation (estimated conservatively as 30% by volume), failures can be expected on slopes exceeding 16 degrees (35%). For a soil layer 50 cm in depth, 150 mm of soil water should saturate the layer. As previously noted, the August 1977 storms developed intensities averaging 80 mm per hour over several hours and resulted in more than 400 mm of total precipitation. Even at low infiltration rates and low initial soil water storage, this volume is more than enough to saturate a 50-cm soil layer, or for that matter, a 100-cm deep layer. During the October survey of the Samseong-Chon and Suam-Chon watersheds where soil depths were typically a meter or less, all but one of the 48 slides observed occurred on slopes greater than 11 degrees (24%). Only one slide was observed on a slope exceeding 32 degrees (70%). A similar range of slopes included most of the surficial slides on the nearby Anson-Chon watershed. Here 96 percent of the more than 600 observed failures were found on slopes less than 40 degrees (89%) (Woo 1972). Given the relatively shallow, cohesionless soil, reduced cover, and steep slopes in the Samseong-Cheon and Suam-Cheon drainages, there can be little doubt that high intensity storms create and will continue to create conditions leading to highly destructive slope failure.

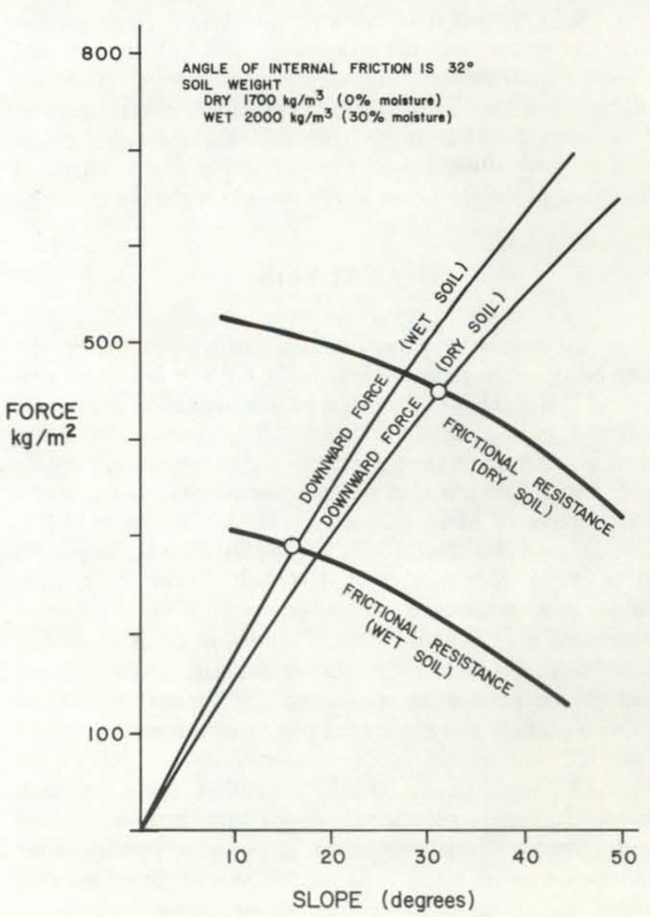


Figure 8. Changes in frictional resistance, F, and downward force, D, in relation to slope and soil water content.

HAZARD REDUCTION

Structural Control

Coates (1977) recently summarized methods for prevention and control of landslides into five categories:

1) **Avoidance** – by-passing the unstable area, removing existing dwellings or activity;
2) **Water control** – decreasing the amount of surface water moving into the slide area, reducing subsurface water through drainage;
3) **Excavation** – removing material from the head of the slide, regrading to reduce slope and hillside benching or terracing;
4) **Restraining structures** – applied at or near the toe of the slope, these include: a) rock or earthfill buttresses, b) shear keys which are compacted fill or buttresses on particular areas of the slide, c) retaining walls primarily as a preventive measure–e.g., cribs, bulkheads, dikes, etc., and finally, in limited cases, pilings and rock bolts;
5) **Miscellaneous methods** – for special cases including drainage of silt soils by electroosmosis, grouting to enhance cohesion and freezing to stabilize during construction.

Vegetative Control

It is generally recognized that vegetation has three primary functions in slope stabilization:

1) Reduction of soil water through evapotranspiration,
2) Maintenance of high infiltration rates,
3) Consolidation of the soil mass by root systems.

While few quantitative data are available, a recent study by Burroughs and Thomas (1977) emphasized the importance of root strength as a factor in slope stability. In the western United States, studies of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) root systems suggest that tensile strength per unit area of soil declined from 1700 kg per m^2 to about 230 kg per m^2 after harvest. This change occurred over a 30-month period and suggests the substantial role root systems have in consolidation of the soil mass. For an excellent in-depth discussion of this topic the reader is referred to a review article by Gray (1978), "The Role of Woody Vegetation in Reinforcing Soils and Stabilizing Slopes."

Perhaps the best summary statement about the role of vegetation with regard to planar slides is provided by Swanston (1974*a*): "In the absence of geological controls produced by bedrock benches or berms, rooting structures of trees and other vegetation anchor and bind materials to the slope and stand out as the most important (natural) contributor to failure resistance."

In summary, hazard reduction can be accomplished by a number of techniques, many of which are appropriate in combination. Where substantial risk to human life exists, avoidance is usually preferable, but expensive. Where avoidance is neither feasible nor necessary, a combination of drainage, structural measures and vegetative control is normally employed after a thorough analysis of the specific problem. In areas where the primary hazard is to the land, vegetative control with supplemental structural measures, or drainage is more commonly employed for economy.

DISCUSSION

There are no simple solutions to the slope stability problems in the Samseong-Cheon, Suam-Cheon and Siheung-Cheon drainages. The relatively steep slopes, shallow sandy soils and reduced vegetative cover, when impacted by high intensity storms during the typhoon season, will continue to produce substantial numbers of surficial landslides. Management of the landslide problem should consist of 1) a hazard evaluation and prediction effort to identify areas which are most likely to slide in the future, and 2) a slope stabilization program to rehabilitate areas where slides have already occurred. The slope stabilization programs already undertaken by the Korean government in the three drainages–combining structural measures, drainages and revegetation–address this latter need.

It was impossible to make a thorough analysis of the many rehabilitated landslide sites viewed in the survey; however, the slope stabilization measures appeared to be generally well designed and constructed. Good use was made of on-site materials and inexpensive hand labor. The basic design included, with minor variations, stone-buttressed terraces and a central stone-lined drainage channel. Views of typical channels in Figures 4 and 6 show the grade reduction structures without and with mortar, respectively. Note that the stone buttresses supporting terraces are built on the contour and without mortar, permitting subsurface water drainage to appear as surface flow on the terrace below. Terraces of this design should enhance slope stability by increasing frictional resistance to downslope movement (particularly where the buttresses are keyed into the subsurface layer), and by reducing the build-up of pore pressure through more rapid drainage. Cost effectiveness for the current structural rehabilitation program could be measured in terms of construction costs and the reduction in groundwater rise (soil pore pressure) resulting from the drainage channel and terrace installation. Similarly, hazard prediction would be greatly enhanced if the relationship of groundwater rise to given amounts of rainfall were investigated. These topics should be considered in future development of a research program.

At the time of this survey vegetation had not been established on many terraces. The role of vegetation in slope stabilization should not be overlooked. In particular, further study of mechanical reinforcement of the soil mass by root systems of native species is warranted. Indeed, the key to greater overall slope stability for highly unstable drainages may well be in a combined program of vegetative reestablishment and structural measures on the more unstable slopes.

Avoidance (removal of housing) has been used to a degree on the Siheung-Cheon site, but a major threat to other housing still remains. In the Samseong-Cheon drainage, a substantial channelization project is in progress in addition to the slope stabilization effort. The concrete revetments, overflow basins and dams included in this project should reduce the flood impact if slope stabilization is successful. Otherwise, the masonry work could contribute to the debris moving through the drainage, increasing rather than decreasing downstream damage.

Recommendations

1. Terraced areas should be revegetated as soon as possible, adding topsoil and fertilizer as necessary for establishment. If practical, both perennials and annuals should be seeded to ensure early and successful establishment of vegetative cover to reduce surface erosion. Both grasses and woody species should be used to provide a deep and dense root mass, enhancing both tensile strength and transpiration rates. Suggested species are:

Grasses
Themeda japonica
Arundinella hirta var. *ciliata*
Miscanthus sinensis

Woody plants
Pinus rigida
Alnus tinctoria
Robinia pseudoacacia
Lespedeza cyrtobotria
Juniperus koidy
Parthenosissus tricuspidata

2. A hazard evaluation and prediction study should be made which includes: a) a comprehensive investigation of rainfall frequency and intensities for these drainages, b) characterization of the relationship between rainfall and groundwater rise (pore pressure) as affected by basin size and shape, c) summarization of soil properties and topographic data to facilitate estimation of the slope stability index, FS (factor of safety).

3. Subject to findings in 2 above, cost-effectiveness of cross-slope drains should be evaluated for a) existing terraced systems, b) land to be rehabilitated in the future.

4. Regional prescriptions or guidelines for stabilization of landslide areas should be developed based on soil type, slope, vegetation and rainfall intensity. These prescriptions would serve as models for field personnel; they should emphasize principles but include case studies. Specific suggestions for structures, vegetation, etc., appropriate to each region should also be included.

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