IV. Reducing Impact From Landslide Disasters

It is well known that landslides are of appreciable significance in the mountain areas of Southwest China and the Loess Plateau Area in Northern China and Taiwan; including the Provinces of Sichuan, Yunnan, Guizhou, Xizang, Gansu, Shaanxi, Shanxi, Qinghai, Hubei, Hunan, Fujian, and Taiwan.

The terms "mountain avalanches damming river", "slide sinking village", and "earth moving" were often found in early Chinese literature. Landslide disaster mitigation in China seems to date back some time before the Christian era, but measures for reducing the impact of landslide disasters did not involve much apart from the evacuation of local residents from hazardous areas.

In the early 1950s, because knowledge about landslide identification and prevention was largely lacking, some public works were built on old landslide deposits. Excavation for public works reactivated a number of landslides, such as those at the Xipo, Tanjiazhuang, Baishuijiang, and Lueyang railway stations along the Baoji-Chengdu Railway Line. These landslides disrupted train services several times and made geologists, civil engineers, and decision makers aware of the magnitude of landslide problems. Systematic study of landslide control was introduced after these incidents. Since the 1960s, great efforts have been made to reduce the losses from landslides. Now it is generally recognized that the management of landslides is an integral part of environmental conservation and development activities in the mountain areas. The methods used to reduce the impact of landslide disasters in China are summarized below.

Regional Landslide Studies and Mapping

The purpose of regional landslide studies is :

(1) to identify the areas where landslides are either statistically likely or immediately imminent;

(2) to represent these hazardous locations on maps; and

(3) to disseminate landslide information to planners, engineers, and decision makers for a better understanding of the landslide problem and more accurate hazard assessment in the region concerned.

Regional study and mapping of landslides are considered to be preliminary steps in coping with landslide hazards on a regional basis, and, in the past 20 years, regional landslide investigations for various purposes at various levels, from provinces to small watershed areas, have been carried out by a number of organizations. Some of the regional landslide programmes are listed in Table 14.

Based on the results of these regional studies, landslide distribution and hazard zonation maps, of various scales and using a variety of factors, have been prepared or published by different research institutions and government organizations. Some of these are listed below.

Map Showing Landslide Distribution along the Chinese Railways (1:7,500,000) by the Northwest Institute of the Chinese Academy of Railway Sciences in cooperation with other institutions (1978).

Map Showing Landslide Distribution in the Reservoir Area of Longyangxia Hydro-electric Power Station on the Yellow River (1:100,000) by Chengdu Institute of Mountain Disasters and Environment, the Northwest Hydro-electric Design and Investigation Institute, and the Chengdu College of Geology (1984).

Map Showing Landslide Distribution in the Reservoir Area of Ertan Hydro-electric Power Station on the Yalong River (1:200,000) by Chengdu Institute of Mountain Disasters and Environment and Chengdu Hydro-electric Design and Investigation Institute (1984).

Table 14: Examples of Regional Landslide Programmes in China

Name of the Programme	Purpose of the Programme
Chinese Railway Landslide Investigation (1974-1976)	Landslide inventory and classification.
Earthquake-Induced Landslides in the Provinces of Sichuan, Yunnan, and Hebei (1974-1977)	Studying the relationship between earthquakes and landslides.
Debris Flows in Xizang and the Hengduan Mountains (1976-1985)	Formation and distribution of debris flows and their impacts on development.
Landslide Investigation in the Mountain Areas of Western Hubei (1980-1983)	Regional analysis of landslides and their impacts on mountain development.
Landslide Study in the Reservoir Area of Lonyangxia Hydro-electric Project on the Yellow River (1980-1983)	Forming mechanism of landslides in semi-unconsolidated rocks and their impact on the Hydro-electric Project.
Landslide Study of Ertan Hydro-electric Project on the Yalong River (1981-1983)	Inventory of landslides and analysis of impact of landslides on the Hydro-electric project.
Debris Flow Study in the Xiao River Watershed (1981-1984)	Watershed Management Planning.
Landslide Investigation of the Planned Three Gorges Hydro-electric Project on the Changjiang River (1984-1986)	Environmental impact assessment and the impact of landslides on the project.
Mountain Hazard Studies in the Four Provinces of Sichuan, Yunnan, Guizhou, and Guangxi in Southwestern China (1985-1989)	Impact of mountain hazards on economic development and strategies for reducing losses from mountain hazards.
Study of Landslide and Debris Flow in the Loess Plateau Area (1985-1988)	Soil Erosion and Watershed Management.
Landslide Studies on the Sichuan - Xizang Highway (1986-1989)	Highway Reconstruction

Source: Author's compilation from regional and technical records.

Map Showing Debris Flow and Landslide Distribution in the Xiao River Watershed (1:200,000) by Chengdu Institute of Mountain Disasters and Environment (1987).

Map Showing Distribution of Landslide and Hazard Zonation of the Reservoir Area of the Planned Three Gorges Hydro-electric Power Station on the Changjiang River (1:200,000) by Chengdu Institute of Mountain Disasters and Environment (1988).

The recent development of hardware and software packages to analyse geographical and geological data conveniently , combined with the availability of digital elevation models of acceptable quality, have made available statistical multivariate models for preparing landslide susceptibility and risk maps. These maps are generally more useful for planners and decision makers than are landslide inventory maps, because they "weigh" the severity and location of the hazard in terms that are more readily understood than the language on landslide inventory maps (Brabb 1984).

In 1987, a set of computer maps (Plates 8,9,10), showing the landslide susceptibility of the Wanxian Area (Sichuan Province), was prepared by Li et al. (1989) on a scale of 1:50,000 to 1:200,000, as part of a large-scale project for land use planning in Wanxian City, Sichuan.

Plate 8 is part of a landslide inventory map of the Wanxian Area which was prepared by:

(1) identifying landslides on aerial photographs having scales of 1:15,000 to 1:30,000,

(2) transferring the extent of landslide scarps and deposits on to a topographical map with a 1:50,000 scale, and

(3) digitizing the boundaries of landslide deposits and transferring them to a geological map on the same scale.

This map demonstrates the relationship between landslide and rock unit. The study area contains nine different lithologic units. The landslide deposits are not distributed homogeneously in space; they are more abundant in the outcrop area of the J2S Group of soft mudstone-sandstone and shale from the Jurassic period. No landslide deposits were found in the area composed of massive hard sandstone from the Jurassic period or of limestone from the Triassic period.

Plate 9 is part of a slope map of the Wanxian Area which was generated from a digital elevation model. This slope map represents the frequency distribution of slope angles which is considered to be one of the important factors controlling the spatial distribution of landslides; it also shows wide variations in the range of slope angles from 15^o to 45^o. A lot of landslides are located in areas with slope angles of less than 35^o.

Plate 10 is part of a susceptibility map of the Wanxian Area which was based on the landslide inventory geological and slope maps. This map shows four different susceptibilities to landslides. An explanation of the map units is presented below.

High Susceptibilty to Landslides: The area consists of landslides and possible landslide deposits. No small landslide deposits are shown. Some of these places may be relatively stable and suitable for development, whereas others are unstable and landslides cause damage to roads, houses, and other physical features. Landslides occur commonly during heavy rainstorms or strong earthquakes.

Moderate Susceptibilty to Landslides: Many small landslides have formed in these areas and several of them have caused significant damage to homes, roads, and farms. Slopes vary from 25^o to 45^o. Slopes steeper than 45^o seem to be stable because they are composed of massive hard sandstone. Some places may be more susceptible to landslides if they are overlain by thick deposits of soil and slopewash. Landslides may occur during strong earthquakes and heavy rainstorms.

Low Susceptibilty to Landslides: Several small landslides have formed in these areas and some of them have caused extensive damage to homes, roads, and farms. Slopes vary from 5^o to 25^o. Most of these areas are suitable for development.

Least susceptibility to landslides: Very few small landslides have occurred in these areas. Formation of large landslides is unlikely. Slopes are generally less than 5^o but may include some areas with 15^o to over 25^o slopes that seem to be underlain by stable rock units. These areas are suitable for development.

Landslide Monitoring and Warning Systems

Since the 1970s, landslide monitoring systems and debris flow warning systems have been established in some landslide areas or dangerous debris flow ravines in the provinces of Hubei, Yunnan, Sichuan, and Qinghai. The monitoring and warning systems were set up for the following purposes :

- to provide early warning of incipient hazard from the slope in question and to minimize property losses,
- to identify a moving zone on a wide slope and study the mechanism of the landslide, and
- to confirm the effect of control works installed at the landslide site.

Landslide Monitoring Systems

In China, the most common methods of landslide monitoring are field observation and surface measurement; instruments used include inclinometers, extensometers, tiltmeters, and pipe strain gauges. The monitoring systems at Xintan (Hubei Province) and

Jinglongshan (Sichuan Province) can be cited as examples.

A long-term precision monitoring system for Xintan Landslide was set up in 1977 by the provincial government of Hubei Province and the Changjiang Valley Planning Office. This was located on the north bank of the Changjiang (Yangtze) River near Xintan Town where there have been four large-scale landslides. These landslides took place in 100, 377, 1031, and 1542 A.D. and interrupted the traffic on the Changjiang Waterway. One potential landslide is located at Lianziya on the south bank of the Changjiang River (Plate 11). Potential landslides on both banks of the Changjiang River have become a matter of concern because of their critical locations. They also pose a threat to the only waterway connecting Sichuan and Hubei provinces and could have effects on the operation of the planned Three Gorges Project, 27 km downstream, that will be the largest hydropower installation in the world.

A monitoring system, composed of four collimation lines, was set up at the end of 1977, and eight monitoring survey points and a triangulation network were added in July 1984. Based on the measurement data, a landslide of 20 million m^3 on the upper slopes of Xintan Town, which occurred on June 12, 1985, was accurately predicted (Plates 12a and b). The warning was given before the event so that all of the 1,371 local inhabitants of Xintan Town were safely evacuated. This kind of success in landslide prediction is rare (Chen 1989 and Luo 1988).

The Jinglongshang Landslide Observation Station of the Chengdu Institute of Mountain Disasters and Environment is located in a potential landslide area in the Valley of the Yalong River in Southwest Sichuan. The monitoring system of the station mainly serves the main Ertan Hydropower Station, which is under construction, and is expected to provide early warnings of incipient hazards. The monitoring system consists of:

(i) slope movement measurement instruments;

(ii) wirebound data-transmission equipment with integrated sub-controllers (computers) and relays; and

(iii) computer data analysis and recording facilities.

The measurement instruments can be divided into surface and sub-surface systems. Surface instrumentation includes meteorological stations, stereophoto exploration equipment, and distance measurement by light wave surveyance. One meteorological station is located at the observation station, and another one with a radio transmission outfit is located at the top of the slope. The following meteorological items are recorded day by day: air temperature, relative humidity, precipitation and its intensity, wind direction and velocity, solar radiation, and air pressure. One seismograph is located on the upper slope of the Jinglongshang in order to study the interaction between earthquakes and movement in the sliding body.

The sub-surface instruments are mainly distributed in galleries in the Jinglongshang Landslide area. The instruments can be divided into automatic and mechanical systems. Generally, the mechanical systems, such as three dimensional measurement points along cracks and joints, are attached to verify the data provided by the automatic systems. The gallery instruments mainly consist of deformeters, vertical and horizontal inclinometers, and extensometers for displacement measurement. The deformeter is based on the electrical resistance strain gauge. Inclinometers are based on the gyroscopic motion principle of the gyrocompass, and photoresistance is the principle on which the extensometer works. Pore-water pressure and joint-water pressure are additionally measured by a probe that also relies on the electrical resistance strain gauge. Water gauges are used to record the daily water flow and water quantity level for the galleries.

As one of the most comprehensive observation sites in the field, the monitoring system at the Jinglongshan Landslide Station provides data that enhance the understanding of sliding phenomena. Furthermore, after the Ertan Dam and its reservoir are established, the monitoring system will become extremely important for the study of properties of claystone and other potential sliding planes that will be subject to the effects of the infiltration of reservoir water.

Debris Flow Warning Systems

In recent years, many scientific research institutions and productive sectors (in China) have been engaged in the study of debris flow warning systems. The Chengdu Institute of Mountain Disasters and Environment of the Chinese Academy of Sciences, Chengdu Railway Bureau, Kunming Railway Branch, Southwest Institute, and the Institute of Building Materials of the Chinese Academy of Railway Sciences have developed a series of contact and contactless devices for debris flow warning and have made on-site tests and carried out operations in debris flow ravines (Chen 1989; Kang and Hu 1989). Among them, researchers from Dongchuan Debris Flow Observation and Research Station of the Chinese Academy of Sciences, after years of observation and study on the ground sound caused by debris flows in the Jiangjia Ravine, have developed a remote detection warning device which successfully sounded debris flow alarms 460 times, in 1985-1986, when more than ten debris flows were triggered by rainstorm in the Jiangjia Ravine (Chen 1989). Logically, this warning device can also be applied to other types of debris flow, such as those caused by glaciers or by volcanic eruptions, because if the debris flow moves it makes a ground sound.

The Dongchuan Debris Flow Observation and Research Station (Plate 13) is located at Jiangjia Ravine, Dongchuan, Yunnan Province where debris flows frequently occur (Plate 14). The warning systems used at the research station consist of radio transmission rain gauges, vibration meters, ground sound meters, and an indicator for remote ultrasonic flow levels (Kang 1987).

The relationship between antecedent precipitation and rainfall intensity has been established to predict debris flows in this ravine. The formula for prediction on the Jiangjia Ravine has been given by Chen (1989) as below :

$$Ri10 > 5.5-0.091\,(Pao+Rt) > 0.5\text{mm}/10\text{m}$$

where R_{i10} - 10 minutes of heavy rainfall

Pao - antecedent rainfall on the day before debris- flow occurrence

Rt - the direct precedent rainfall

It was reported that, during the past three years, 29 debris flows occurred on more than 100 rainy days during the prediction period. Twenty-seven debris flow predictions were made, of which 25 were correct, one was inaccurate, and four were missing. The shortest advance prediction time is 17 minutes; the longest 200 minutes. In most cases, the advance prediction time is about 40 minutes, and the predictions are correct over 85 per cent of the time (Chen 1989).

Debris flow warning systems have also been installed in some of the dangerous debris flow ravines along the railway from Chengdu to Kunming by branches of the Chengdu Railway Bureau and the Institute of Building Materials of the Chinese Academy of Railway Sciences. The techniques of seismology, sensory line, and mid-level pole induction through line or radio transmission are applied to transmit warnings to the Heijinlong River Bridge and the Fala Bridge on the southern section of the Chengdu-Kumming Railway. When the specified limits are reached the railway is closed.

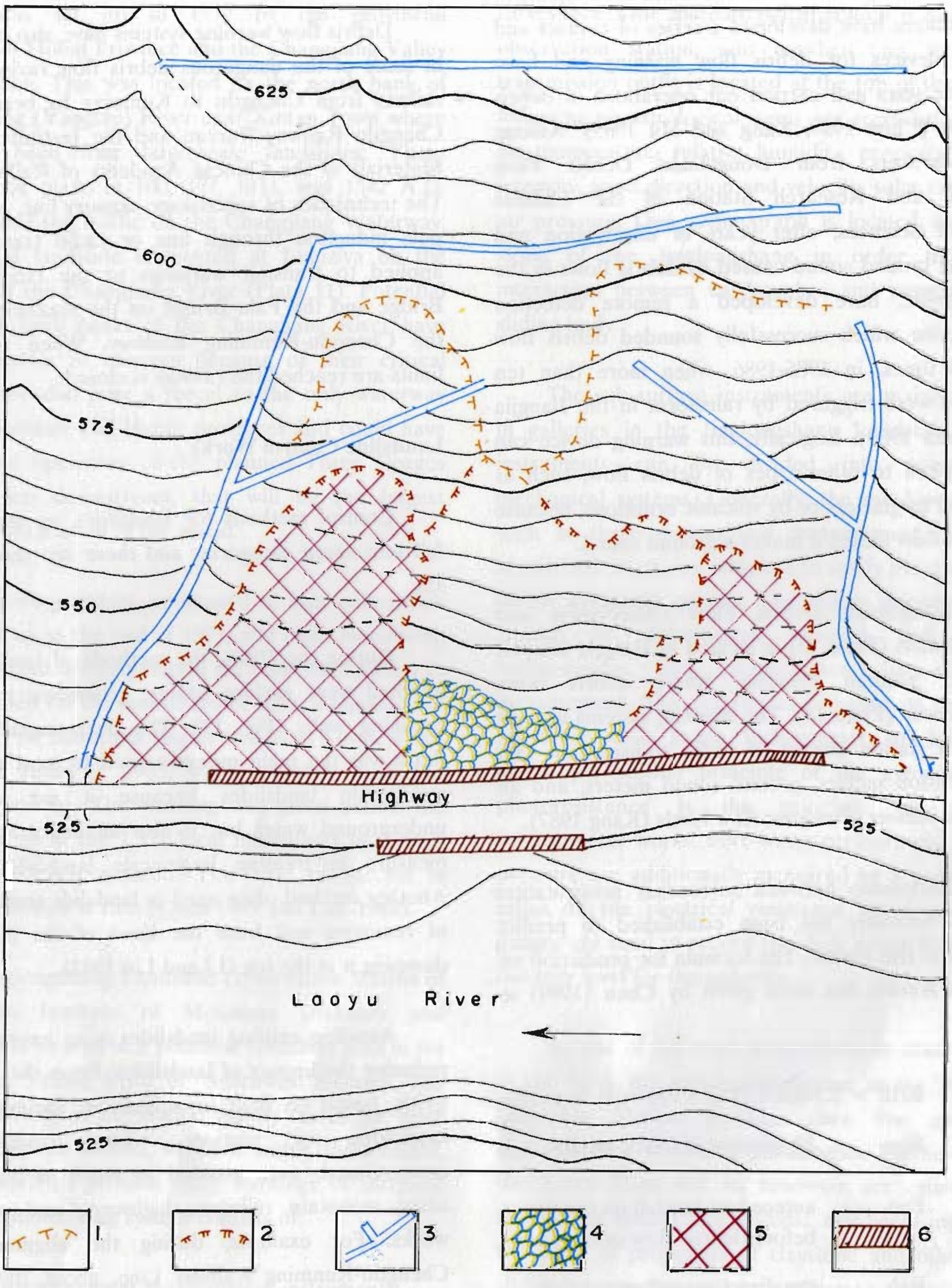
Landslide Control Works

Control methods for landslides, as used in China, fall into seven categories and these are shown in Table 15.

During the 1950s, the methods of landslide control adopted were surface drains, groundwater drains, and retaining walls (Fig. 13). The deep-seated counterfort drain was the main measure used to treat medium and small-scale landslides because it not only drains underground water but is also an important subsidiary measure in treating large-scale landslides (Fig. 14). Another method often used in landslide treatment is that of removing soil from the head of the landslide and dumping it at the toe (Li and Liu 1982).

Avoiding existing landslides is an important step in reducing the impact of landslides. From the 1960s to the 1970s, based on field investigations, ancient large-scale landslides, or sections where landslides were concentrated, were avoided as much as possible while siting mountain railways, highways, and other public works. For example, during the alignment of the Chengdu-Kunming Railway Line, about 100 large-scale landslides were avoided. Where large landslides could not be avoided, control measures were taken to stabilize them before construction. During this period, the two Ministries of Railways and Water Conservation studied the problem and developed techniques for landslide control.

Figure 13: Map Showing the Measures Taken to Control Landslides on the West Bank of Laoyu River, Shaanxi Province



Source: Li and Liu 1982.

Notes:

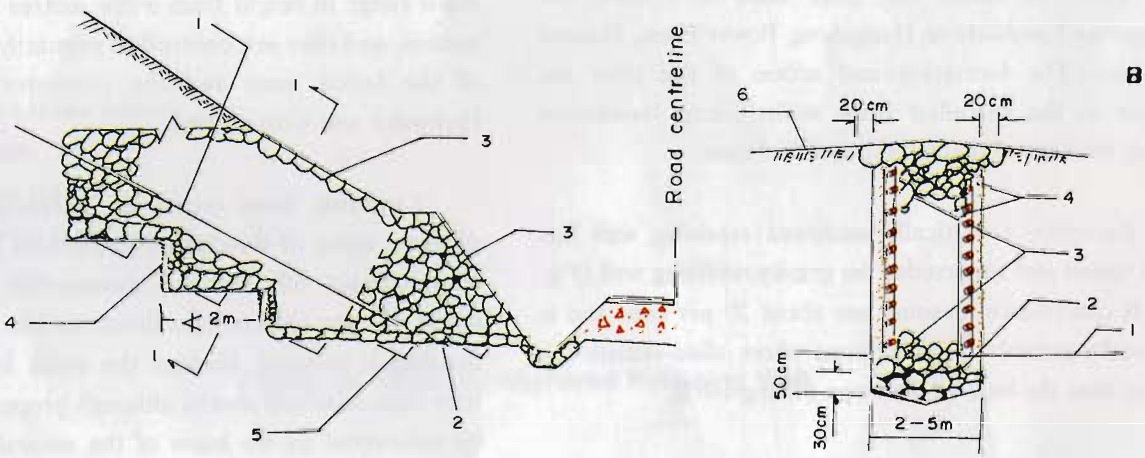
1. Scarp of fossil landslide.
2. Scarp of new landslide.
3. Drainage channel.
4. Mortar bubble masonry.
5. Wooden pile fence.
6. Retaining Wall.

Table 15: Summary of Landslide Control Works Used in China

Category	Landslide Control Works
Avoidance of Problem	Relocation, bridging, tunnelling
Surface Drainage	Channel or ditch, prevention of water leakage
Sub-surface Drainage	Tunnels, sub-surface trenches, deep-seated counterfort drains, drill vertical drainage holes, horizontal bore holes, slope-seepage ditches, drainage wells of ferroconcrete, drainage wells with liner plates
Support Structures	Retaining walls, anchored retaining walls, cribworks, gabions, stabilization trenches, piling works (driven piles)
Excavation	Removal, flattening, and benching
River Structure Work	Erosion control dams, consolidated dams, revetment groins, spur dikes
Other Methods	Planting vegetation, blasting, and hardening

Source: Author's compilation from technical records

Figure 14: Deep-Seated Counterfort Drain



Source: Li and Liu 1982.

A. Profile (downslope section); B. I-1 Cross Section.

B. 1. Sliding surface location.
 2. Mortar bubble masonry.
 3. Bubble.
 4. Water filtering layer.
 5. Stone tooth.
 6. Ground surface.

Since the 1960s, concrete piles have been used in landslide control. Most of the anti-slide piles are driven piles and have large rectangular sections of 1x1m to 2x3m, The depth of the piles being 10-30m depending upon the thickness of the sliding body. The biggest piles used are 3.5mx7m in section and 47m in length; piles of this size were used on the Zhao-Jiantang Landslide. The interval between piles is normally 2.4 times the pile width (Pan 1988). At the beginning, a single row or more of single piles is used and later on two or more piles, joined by concrete blocks, are used to increase the slide-resistance (Wang 1985). In recent years, this kind of pile has been used extensively for landslide control in many places in China; for example, in Panzhihua City, Sichuan Province (Lin 1989; Zhu et al. 1989) and at the Second Automobile Works Site, Western Hubei, 1989 (Liu and Jin 1989), because of its capacity to resist slides, the low amount of masonry needed and convenient construction, as well as the fact that it is easy to construct manually with the use of simple instruments. Figure 15 shows the anti-slide piles used for controlling landslides in Chongqing City, Sichuan Province. Plate 15 shows anchor-rope driven piles used for controlling the Jinjiyan Landslide in the Songzao Coal Mining Area, Sichuan, and Plate 16 shows the piles used to control the Xiangshan Landslide at Hangcheng Power Plant, Shaanxi Province. The formation and action of the piles are similar to the so-called shaft works (deep foundation piping with broad diameters) used in Japan.

Recently, a vertically anchored retaining wall has been tested and supersedes the gravity retaining wall (Fig. 16). It can reduce masonry use about 20 per cent and is especially suitable for conditions where slide outlets are higher than the base of the slope (Wang 1985).

Horizontal drains have been used to drain groundwater on some landslide sites (Fig. 17), but their use is limited because of the lack of suitable drills in China at present.

Chemical grouting to strengthen soil masses for controlling landslides is being tested. In recent years, lime piles and lime-sand piles have been used as methods of controlling soil embankment landslides (Fig. 18).

The control works that are actually carried out in the landslide areas are primarily for the purpose of saving life, secondly for the preservation of public structures and buildings, and thirdly to prevent the disruption of road traffic and to prevent flooding in the event of a landslide damming a river.

Methods of Preventing Flooding from Landslide Dams

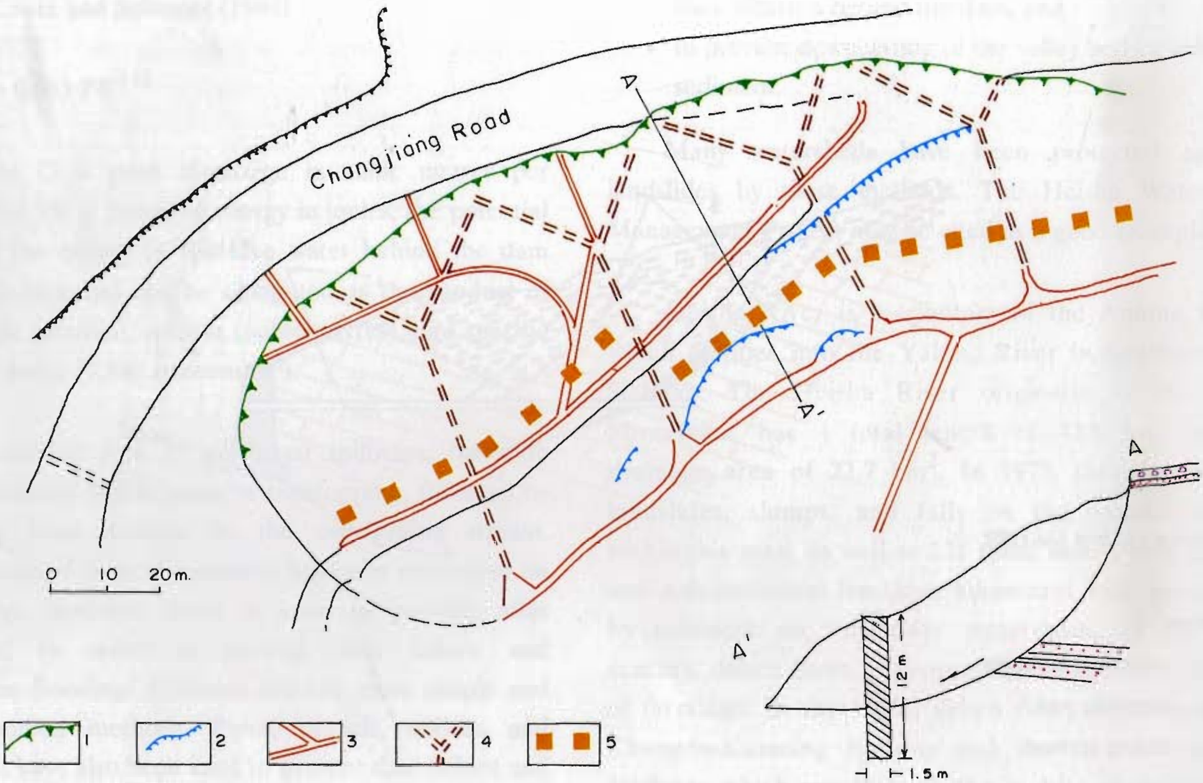
The natural damming of rivers by landslides is a significant hazard in many mountain areas of China, and it is particularly common in the high rugged Hengduan Mountains of Southwestern China. Many landslide dams have failed catastrophically, causing severe flooding downstream and the loss of many lives.

Landslide dams result from a broad range of mass movements in differing physiographic settings. The vast majority of landslide dams are formed by rock and earth slumps and slides, debris and mudflows, and rock and debris avalanches (Plates 17 and 18). Large landslide dams are formed by earth and rock slides/slumps and debris avalanches, commonly occurring on steep slopes and attaining high velocities that lead to stream blockages before the material can be sluiced away by river action. The sizes of landslide dams range in height from a few metres to hundreds of metres, and they are controlled primarily by the volume of the failed mass and the geometry of the valley (Schuster and Costa 1986).

Landslide dams create the potential for two very different types of flooding: (i) upstream flooding as the impoundment fills and (ii) downstream flooding as a result of dam failure. The threat to life from upstream flooding is minimal, because the water level behind the dam rises relatively slowly, although property damage can be substantial as the basin of the natural impoundment fills. Downstream flash floods, resulting from the failure of landslide dams, are usually much larger than those originating directly from snowmelt or rainfall and constitute a significant threat.

It is usually possible to estimate accurately the extent and rate of upstream flooding from landslide dams. Such estimates require knowledge of the height of the dam crest, rates of streamflow into the dam-lake, rates of seepage through or beneath the dam, and information on topography upstream from the dam.

Figure 15: Map Showing the Measures Undertaken to Control Landslides in Chongqing City (Sichuan Province)

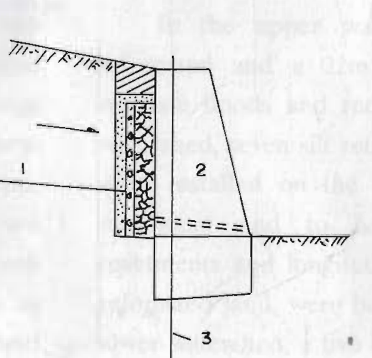


Source: Based on Lin 1989 and Zhu et al. 1989.

Notes :

1. Remnant of new landslide.
2. Small cliff.
3. Drainage channel.
4. Counterfort trench.
5. Driven piles.

Figure 16: Vertically Anchored Retaining Wall

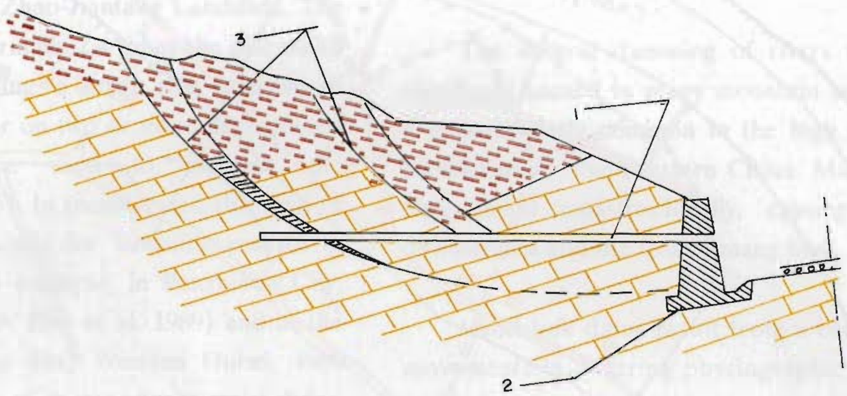


Source: Wang, G. 1985.

Notes:

1. Sliding surface location.
2. Wall.

Figure 17: Horizontal Borehole for Draining Groundwater



Source : Li and Liu 1982.

Notes:

1. Horizontal borehole.
2. Retaining wall.
3. Sliding surface.

Figure 18: Lime-Sand Piles and Horizontal Boreholes for Controlling Soil Embankment Landslides

Source : Wang, G. 1985.

Notes:

1. Lime-Sand.
2. Horizontal Borehole.

For the purpose of rapid assessment of downstream flood potential, the peak discharge of downstream flooding can be estimated by the regression equation given by Costa and Schuster (1988) :

$$Q = 0.063\,PE^{0.42}$$

where Q is peak discharge in cubic metres per second, and PE is potential energy in joules, the potential energy is the energy of the lake water behind the dam prior to failure and can be computed as the product of dam height (metres), volume (cubic metres), and specific weight of water (9,810 newtons/m^3).

Because of lack of protected spillways, landslide dams commonly fail because of overtopping, followed by breaching from erosion by the overflowing stream. Construction of control measures has been attempted on many large landslide dams as soon as possible after formation, in order to prevent dam failure and subsequent flooding. Spillways are the most simple and most common methods. Pipes, tunnels, outlets, and diversions have also been used to prevent dam failure and to control discharge from landslide-dam lakes in many countries (Sager and Chambers 1986; Schuster and Costa 1986). In a few cases, extensive blasting measures have been used to excavate new river channels through landslide dams. In 1984, this technique was used to excavate a channel through the Zhouqu Landslide Dam on the Bailong River in Gansu Province, China (Li and Hu 1981).

Landslide Control in Watersheds

Landslides occur frequently on natural slopes of deforested watersheds. Generally, landslides occur at the head and on both sides of a ravine (Plate 19). These landslides can transport large quantities of material into ravines. During intense storms, high runoff may mobilise this material into debris flows that create serious damage in the lower watersheds (Plate 20). To counteract these landslides and debris flows, check dams, revetments, drainage ditches, benching, and revegetation works are carried out (Wu 1983; Zhang et al. 1985). It has been found that reforestation of the watershed (Plate 21) is as effective as building check dams (Plate 22) in gullies and ravines (Wieczorek et al. 1987). A check dam has the following functions :

- to reduce sediment discharge by arresting debris from a landslide area,
- to stablize landslide and potential slope failure by back siltation behind the dam, and
- to prevent downcutting of the valley bed by arrested sediment.

Many watersheds have been protected against landslides by these methods. The Heisha Watershed Management Project may be cited as a good example.

Heisha River is a tributary of the Anning River which empties into the Yalong River in Southwestern Sichuan. The Heisha River originates in the Luji Mountains, has a total length of 12.6 km, and a drainage area of 22.7 km^2. In 1975, there were 180 landslides, slumps, and falls on the natural slopes within this area; as well as 135 small debris flow gullies and a depositional fan three kilometres wide produced by sediment on the lower watersheds. In the last century, debris flows destroyed five villages and 200 ha of farmland. In the 1960s, debris flows threatened the Chengdu-Kunming Railway and the Sichuan-Yunnan Highway which run through the middle of the fan. In addition, communication lines, factories, villages, and farmlands were also subjected to damage from debris flow.

To reduce the damage from debris flows in the Heisha Watershed, a comprehensive control project was undertaken in the 1970s based upon studies of the occurrence mechanisms of debris flow, of natural processes, and types of damage. This project was funded by the Government of Sichuan Province and undertaken by the Chengdu Institute of Geography of the Chinese Academy of Sciences in collaboration with the Government of Xizang.

In the upper watershed, 800 ha of land were reforested and a 22m high dam was constructed to regulate floods and reduce flood peaks. In the middle watershed, seven silt retention dams and five check dams were installed on the steep ravines to prevent debris movement and to help stabilize landslides. Seven revetments and longitudinal dikes, backed by 400 ha of reforested land, were built to reduce soil erosion. In the lower watershed, a five kilometre flow-direction dike and drainage ditch were constructed to convey the sediment-laden flows on to the depositional fan.

This comprehensive control project was completed by 1978, and since then there have been no debris flows in the Heisha Watershed. The control results from reforestation measures are presented in Table 16.

The local people living in the watershed area also obtained direct economic benefits from the project; these are outlined below.

- In the drainage area, grain output increased 1.93 per cent, whereas cultivated land decreased 30 per cent for the entire basin as a consequence of cultivated land replaced by reforested land in the upper watershed.
- Grain output increased 100 per cent in the lower watershed area, as a result of the improvement of 140 ha of strip farmland and the reclamation of 140 ha of wild land in the agricultural area of the lower watershed.
- By 1978, the economic value of the 10 year old forest land equalled 14 per cent of the cost of afforestation.

Increasing Public Awareness

To increase the level of public awareness, concerning landslide and debris flow hazards, a series of cinema and video films on debris flow movements, major landslides, and debris flow disasters have been produced by the Film Studio of Science and Education in Shanghai and by the Science Press in Beijing.

Provincial landslide societies hold national or provincial symposia and seminars on the results of studies on landslide processes and control methods. They also submit recommendations to the central and provincial governments to encourage relevant government agencies to pay attention to landslide hazard mitigation and landslide crisis intervention.

Technical Consulting Services

The National Expert Group for Landslide Prevention and Control, which was established in 1987, provides consulting and extension services for major landslide programmes. Professional institutes and provincial landslide societies also provide consulting services to local governments to help solve the problems created by landslides.

Insurance Programmes

Insurance programmes, of course, do not directly reduce landslide hazards but they can minimize losses by reducing the impact to individual property owners by spreading the losses over a wide base (Schuster and Fleming 1986). In China, a natural disaster insurance programme has been established by the People's Insurance Company of China. This insurance programme assists those whose dwellings and farmlands have been damaged by earthquakes, landslides, floods, and other natural hazards.

Table 16: Result of Reforestation in the Heisha Watershed

Time of Observation (Day, Month, Year)	Daily Precipitation (mm)	Barren Land Runoff Coefficient	Barren Land Erosion Modulus (Ton/km²)	Reforested Land (Pinus yunnanensis) Runoff Coefficient	Reforested Land (Pinus yunnanensis) Erosion Modulus
01. 9. 1975	29.5	0.82	11,900	0.44	3.800
06. 9. 1976	50.3	0.72	30,502	0.11	34
17. 7. 1977	45.2	0.74	285	0.01	16
12. 7. 1978	60.2	0.79	18,002	0.01	211

Source: Chengdu Institute of Geography 1981