Landslide Hazard Mapping and Management in China

Li Tianchi

International Centre for Integrated Mountain Development
Kathmandu, Nepal
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Cover Photograph: Houses, farmland, and a highway damaged by rainfall-induced debris flow - Aba Tibetan Autonomous Region, Sichuan Province

Inset: Villages and farmland affected by deep-seated landslides adjacent to deeply-incised ravines — large quantities of material are transported to the lower watershed and cause serious damage every year - Dongchuan, Yunnan Province

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Preface

The inherently unstable nature of mountain areas of the Hindu Kush-Himalayas is well recognised. The steep slopes, unstable geology, and intense monsoon rains combine to make the Hindu Kush-Himalayas one of the most hazard-prone areas in the world. Although natural hazards of varying intensity have occurred frequently in the past in Hindu Kush-Himalayan countries, more recently there has been an increase in human settlement of hazard-prone areas as a result of population pressure, as well as improvements in accessibility by road and the onset of other infrastructural developments. Consequently, natural and man-made disasters are on the increase and each event affects an even greater number of people than before. Floods and landslides during the monsoon season are the most common natural disasters affecting this region, often resulting in substantial economic and environmental losses and causing great suffering to many people.

Despite all this the present levels of understanding and systematic analysis of these disastrous events are very poor and data bases are non-existent. No monitoring activities are carried out even in cases where such monitoring can be of direct benefit to project-related management activities. Investments in developing practical guidelines for managing such events as well as in forecasting them have been inadequate.

Since its inception, ICIMOD has been promoting the development of a better understanding of natural hazards. Various activities have been undertaken so far. These include several training programmes dealing with mountain risk engineering, focussing on improving road construction along unstable mountain slopes, a review of landslide hazard management activities in China, and field assessment of landslides and flood events in south central Nepal following the extreme climatic events that took place in July 1993.

One of the goals set by ICIMOD in its Mountain Natural Resources' programme is to "Improve the conditions of mountain resources and environments by halting and eventually reversing their degradation." Programme activities envisaged to achieve the above goal are directed to:

- identification of measures to mitigate different types of natural hazards which result in the loss of natural resources;
- promotion of skills and methodologies for natural hazard assessment; and
- improvement of public awareness for better disaster preparedness in mountain areas.

ICIMOD's programme on "Landslide Hazard Management and Control" focusses on these concerns to help protect valuable natural resources from different types of natural hazards. This programme is based on activities already introduced at ICIMOD in 1994 with support from the Government of Japan.

This programme is concerned not only with examining the types and extent of landslide events but also with measures for their mitigation and control; and in addition the skills and methodologies needed for natural hazard assessment.

To improve the knowledge base on Landslide Hazard Management and Control, state-of-the-art reviews were commissioned in four countries of the Hindu Kush-Himalayan Region. These countries are China, India, Nepal, and Pakistan.

Suresh Raj Chalise of the Mountain Natural Resources' Division at ICIMOD coordinated the work carried out on these reviews and the current document entitled "**Landslide Hazard Mapping and Management in China**" was prepared by Prof. Li Tianchi of the Institute of Geology of the Chinese Academy of Sciences. Prof. Li Tianchi has produced a comprehensive document on a topic that is crucial to the development of mountain areas and the well-being of mountain inhabitants.

Abstract

Landslides are one of the main natural disasters in China, responsible for huge social and economic losses for mountain populations. This paper reviews the available information on effective measures for reducing economic and social losses caused by landslides. These measures include landslide mapping (identification, types of landslide maps, techniques of mapping); physical prevention and control measures (problem avoidance, surface-water drainage works, subsurface drainage, support structures, excavation, river structure works); landslide hazard anticipation (long-, medium-, and short-term prediction; prediction of the extent of landslides); and assessment and mitigation measures for landslide-dam failure disasters.

Institutions concerned with landslide hazard mapping and control, forecasting, mitigation, research, and training (government agencies, research institutions, central and provincial governments, NGOs, and scientific societies) have also been listed.

Contents

List of Figures

List of Tables

Introduction

The recorded history of landslides in China goes back almost 4,000 years to 1789 B.C. The landslide of Wudu in Central China, which killed 760 people in 186 B.C., is probably the oldest of such disasters. Since that time, landslides have been a major source of social and economic loss for the population in mountain areas of China. Earthquakes and rainfall are the basic causes of landslides. However, in the past 40 years, other factors have contributed to landslide hazards. The population pressure in China has necessitated the expansion of agriculture, at the expense of forests, on to steeper slopes. At the same time, financial investment in development projects in mountain areas, such as road and reservoir construction and exploitation of mineral resources, has caused impacts that have led to increased landslide damages (Li Tianchi 1990).

In China, landslides annually cause an estimated 15 billion USD in economic losses and about 150 deaths (Li 1992), exceeding the total annual losses due to earthquakes. Most of the landslides found over the last 40 years were concentrated in the provinces of Sichuan, Yunnan, Guizhou, Xizang (Tibet), Shaanxi, Fujian, Hunan, Hubei, and Taiwan. In other provinces, landslides develop less often than in the provinces mentioned above. Most landslides in these areas are triggered by heavy rain and/or melting snow, major earthquakes, and human activities. Occasionally, large hazardous landslide dams have been formed, particularly in the Hengduan mountain area of western China.

Landslide prevention and control are new disciplines, although there are records of China having the oldest landslide hazards in the world. During the 1950s, because knowledge about landslide identification and prevention was scanty, excavations on ancient landslide sites reactivated them with disastrous results. For instance, 136 large and small landslides occurred from 1954 to 1957 within 348km from Baoji to Shangxiba along the Baoji-Chengdu railway line. Railway services were interrupted several times during that period and the cost of repairs was as high as 8,200 million *yuan*[1]. A few studies on landslide identification and control were initiated after these incidents. More extensive studies, including landslide mapping, mechanisms of failure, and prevention and control techniques, began in the early 1960s. Since then, great efforts have been made to reduce the losses from landslides.

This paper reviews the available information on effective mitigative measures used in China to reduce the economic and social losses from landslides, including landslide mapping, physical control measures, anticipation of landslide hazards, assessment, and mitigation measures of landslide dam failure disasters.

Landslide Mapping

Landslide Identification

Identifying the presence of ancient and active or potential landslides and landslide types is essential to landslide mapping and mitigation.

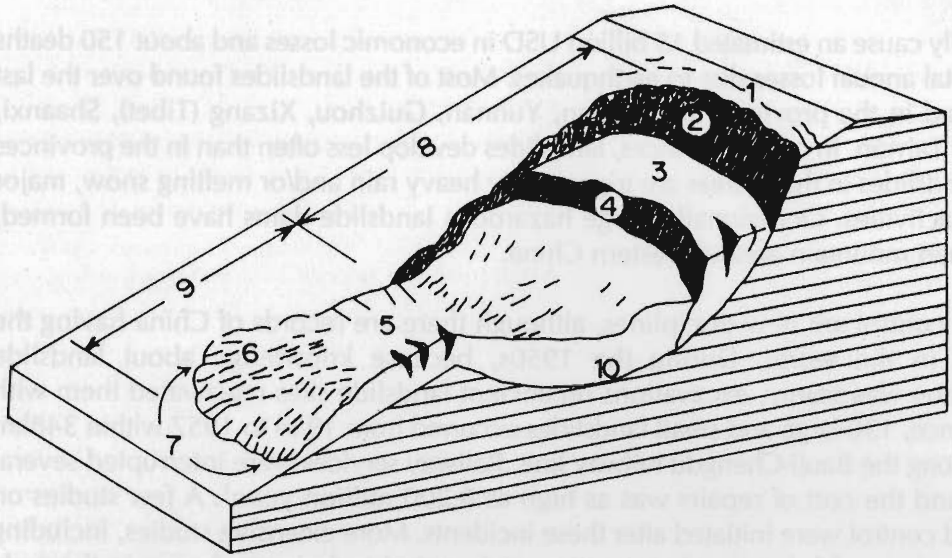
A landslide is a natural geologic-geomorphological phenomenon in which the soil and/or rock mass resting on top of a sliding surface starts to slowly or rapidly move downslope because of the pull of gravity. By the time a landslide movement ceases, a specific topography associated with the landslide will have formed. Landslide movement has the following characteristics: a gentler slope gradient, slow movement of soil and/or rock mass while retaining original shape in most cases, and repetitive occurrence on the same slope. Figure 1 shows a typical landslide configuration.

Identification of landslides depends on accurate evaluation of the geology, hydrogeology, landforms, and interrelated factors such as environmental conditions and human activities. Indicators of active landslides include slope cracks, curved tree trunks, tilted poles, tilted walls, and the presence of wet or seepage

1 There are approximately eight *yuan* to the US Dollar

areas. Ancient landslides are marked by old scars covered with vegetation on the upper parts and a hummocky topography on the lower parts of the slopes (Li and Wang 1992). These indicators can be easily identified in the field by landslide experts.

Figure 1: Schematic Figure of Typical Landslide Configuration



NOTES

1. Crown
2. Main scarp
3. Head
4. Secondary scarp
5. Tension crack
6. Compression crack
7. Tongue
8. Subsided area
9. Upheaval area
10. Sliding surface

Source: Varnes 1978

Different Types of Landslide Maps

In the last 20 years, landslide mapping for various purposes at various levels, from provinces to small watershed areas, has been carried out by a number of organisations.

The purposes of landslide mapping are:

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

2) to represent these landslide-prone 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.

The content, method, and scale of landslide maps depend, above all, on their purpose. For regional landslide distribution and hazard assessment, small-scale maps (less than 1:200,000) are suitable. For detailed landslide inventory, hazard zonation, urban development, and land-use planning, medium-scale maps are suitable. Large-scale maps (larger than 1:5000) are for landslide case studies and stabilisation works. Landslide maps prepared or published in China can be classified into three types: (1) landslide distribution (inventory) maps, (2) landslide hazard zonation maps, and (3) landslide susceptibility maps.

Landslide Distribution Maps

Maps showing the distribution of landslides caused by earthquakes, in the areas of Luhuo, in Sichuan (1973); Zhaotong, in Yunnan (1974); Longling, in Yunnan (1976); and Songpan, in Sichuan (1976), were prepared by scientific staff from the Institute of Mountain Hazards and Environment, CAS. They have identified that landslide types and areas judged highly susceptible to earthquake-generated landslides have slopes steeper than 30°, and that the safest zone in a mountain area would be in a region with slope angles of less than 25° (Li 1979a and b).

A map on a scale of 1:7,500,000, prepared by the Northwest Institute of the Chinese Academy of Railway Sciences in cooperation with other institutions (1978), showing landslide distribution throughout the Chinese railway system, gives an example of one landslide type and provides information about the kind of materials involved, such as bedrock, debris, or earth, and the size and general direction of landslide movement.

Maps of detailed landslide inventories showing landslide distribution in the reservoir areas of the Ertan Hydroelectric Power Station on the Yalong River and the Three Gorges Hydroelectric Power Station on the Changjiang River provide information on the landslide type, state of activity, and volume of material involved. The maps were prepared by interpreting aerial photographs and examining landslide features in the field. The advantages of these maps are that they are quick and inexpensive to prepare even for large areas, they show where landslide processes seem to be concentrated, and, correspondingly, they show where more detailed studies are likely to be undertaken in future (Wang 1988).

Landslide Hazard Zonation Maps

In 1991, Li and Liu published a map on a scale of 1:6,000,000, showing landslide hazard distribution and zonation in China. The Map of Tectonic Systems and Seismology of China, on a scale of 1:4,000,000, compiled by Comprehensive Brigade 562 of the Chinese Academy of Geology, used to be the basic map showing the strata, lithology, and geological structures, especially the active fault systems, as the geological background of landslides. The locations of more than 3,000 typical landslides, from technical and historical records of landslides in China as well as from the research and investigation results of the Institute of Mountain Hazards and Environment in the past 20 years, were represented on the map. The volumes of the landslides were divided into four magnitudes, i.e., extraordinarily large (>10 million cubic metres), large (1-10 million cubic metres), medium (0.1-<1 million cubic metres), and small (<0.1 million cubic metres). According to natural environment, distributive density, damage, and recurrence of landslide hazards, seven first order zones of landslide hazards are distinguished as most heavy; heavy, less heavy, much less heavy, light, weak, and basically landslide-free. Basic characteristics of landslides' potential damages and the impacts on the environment and economic development are listed for each zone. The seven major zones are further divided into 28 subzones with respect to their varied large geomorphological units.

In 1985, Li and Don published a map on a scale of 1:12,000,000 to show the landslide zonation of the entire Gansu Province, based on the geological conditions of landslide development, the feature and strength of which were affected by endogenic and exogenic forces as well as the frequency and intensity of landslide distribution. The province was divided into three regions and six subregions. A similar map to show the landslide hazard zonation of Shaanxi Province was prepared by the Disaster Prevention Association of the Province in 1991.

Landslide Susceptibility Maps

A landslide susceptibility map differs from other landslide maps. It depicts areas likely to have landslides in the future by correlating some of the principal contributing factors, such as steep slopes and weak geologic units, with the distribution of landslides which occurred in the past. These maps are generally more useful for planners and decision-makers than landslide inventory maps, because they 'weigh' the severity and location of the landslide hazard in terms that are more readily understood than the language on landslide inventory maps.

In 1989, Li et al. published a coloured map on a scale of 1:50,000 to show the landslide susceptibility of the Wanxian area, as part of a large-scale project for land-use planning in Wanxian City, Sichuan Province. In preparing the map, geological units were used as the primary map units and were then subdivided on the basis of slope to form a geology/slope unit. This unit was then reclassified with respect to past landslide behaviour to provide the ultimate units of landslide susceptibility (Plate 1). This map shows four different susceptibilities to landslides. An explanation of the map units is presented below.

High Susceptibility to Landslides. The area consists of landslide deposits 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 are a common occurrence during heavy rainstorms or strong earthquakes.

Moderate Susceptibility to Landslides. Many small landslides have formed in these areas and several of them have caused significant damage to houses, roads, and farms. Slopes vary from 25° to 45°. Slopes steeper than 45° 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 slope wash. Landslides may occur during strong earthquakes and heavy rainstorms.

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

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

The method for preparing this map is simple, rapid, and relatively successful in providing a regional assessment of landslide hazards at a level suitable for basic planning decisions.

In recent years a statistical model and an information model have been developed by Yan (1984, 1988) and Yin and Yan (1991), respectively, for landslide mapping. The statistical model is based on the regular recurrence of landslides in the study area. It can be used for spatial prognoses of regional landslides and the maps are applied in land use and linear engineering alignment planning. The advantage of a statistical model is that regional landslide prognoses can be made without time consuming and costly site investigations. The statistical model is only valid for the type of geology for which it is made. Therefore, different statistical models are required for different geological regions.

Techniques of Landslide Mapping

Landslide Inventory

A clear understanding of landslide conditions and a more detailed assessment of the landslide hazard of the area concerned are essential to make a systematic landslide inventory. All landslides recorded in historical and technical documents, investigated in the field and identified in the field or by aerial photographic analysis, should be registered in analog form.

The first systematic inventory of the landslides occurring along the Chinese railways was carried out from 1974 to 1976 by several teams of geologists and geomorphologists from various institutions. More than 1,000 medium- and large-scale landslides were documented in terms of the date of landslide occurrence, landslide locality, geologic and hydrological data, dimensions of the landslide, and so on.

A landslide inventory of the reservoir area of the Three Gorges' Hydroelectric Power Station was undertaken from 1985 to 1987 by scientific staff from the Institute of Mountain Hazards and Environment and other institutions. Two hundred and thirty large-scale landslides and rockfalls were registered in detail (Li and Liu 1987).

Aerial Photo Interpretation

The analysis of aerial photography is a quick and valuable technique for identifying landslides, because it provides a three-dimensional overview of the terrain and indicates human activities. Generally, aerial photographs are used to identify specific geomorphic features that reflect landslide topography. Important geomorphic features are those associated with the failure of large, deep-seated landslides involving bedrock and thick soil as well as large rockslide and rockfall deposits. Table 1 outlines geomorphic features used as indicators of landsliding on stereoscopic pairs of aerial photographs. Sometimes, landslide features are not easily recognised due to dense tree cover, alteration of the terrain by human activities, or surface erosion that modifies landslide features.

Table 1: Geomorphic Features Used as Indicators of Large Landslides

Area of Landslide	Geomorphic Features	Landform Description as Seen on Aerial Photos
Head region	Main scarp, transverse cracks, minor scarps, grabens, fault blocks	Steep crescent-shaped surface that is concave downslope; minor scarps, grabens, fault blocks, and trees that lean uphill
Landslide interior	Unit surface, closed depressions, slump blocks, hummocky topography, longitudinal cracks, pressure ridges, lateral margins, small ponds just above the foot	Relatively flat hillside areas, circular or oval hillside ponds, lakes, or wet areas; consists of original slump blocks; generally uneven hillside terrain with transverse ridges, secondary scarps and small ponds; linear hill slide depressions or ridges running perpendicular to the slope
Foot region	Toe, transverse cracks, pressure ridges, zone of earth flow	Crescent-shaped ridge that is convex downslope; trees that lean downhill or at various angles; sometimes often displaces stream channel

Source: Compiled from technical literature

The scales of aerial photographs for landslide hazard mapping depend on the aim of the project and the method used.

Scales of from 1:2,500 to 1:10,000 are excellent for detailed landslide mapping and site-specific investigation prior to development or control works. Geomorphic features of all landslides, such as the head, toe, lateral margins of the deposits, and main scarp, can be interpreted. These scales are too large for reconnaissance landslide mapping of large areas.

Scales of from 1:10,000 to 1:30,000 often provide a good depiction of small and large landslides, have good area coverage, and are excellent for landslide mapping for large development projects and watershed management (Plate 2). The location and shape, fundamental landslide structures, state of activity, estimated thickness of material involved, and mutual time relation between two landslides if they come into contact with others can be interpreted.

Scales smaller than 1:30,000 are useful for identifying large individual landslides and regional features of the landslide process. Small and shallow landslides cannot be seen on the photographs. Table 2 shows the aerial-photographic scales and usefulness of landslide mapping.

Remote Sensing and GIS Techniques

The available information on remote-sensing applications indicates that satellite remote sensing has little to contribute towards landslide mapping in China (Cheng 1986, Wang 1988, and Zhang 1993). Important reasons, when attempting to map a landslide using satellite remote sensing, are the size of the landslide and its geomorphic features. Landslides vary greatly in size, from a few square metres up to several square kilometres, and most small landslides and the geomorphic features of large landslides do not constitute remote-sensing targets, they are smaller than the pixel size of any readily available satellite imagery. The cost of satellite imagery may also be a significant factor in its usefulness for landslide mapping because, at present, most satellite images are currently supplied on computer tapes which require expensive tape drives to read the images into a computer. Landslides were more effectively mapped through conventional ground techniques, supported possibly by low-level aerial photography.

Table 2: Aerial-photographic Scales and Usefulness of Landslide Mapping

Scale	1:2,500 to 1:10,000	1:10,000 to 1:30,000	<1:30,000
Landslide mapping for hazard assessment in large areas	Poor	Good	Excellent
Landslide mapping for large development projects and watershed management	Good to excellent	Good to poor	Poor
Detailed landslide mapping for landslide control	Excellent	Poor	Very poor

Source : Compiled from technical literature

The recent development of GIS technology for data integration, combined with the availability of digital elevation models (DEM) of acceptable quality to analyse geographical and geological data, has greatly increased the applicability of techniques for landslide hazard assessment and mapping. Most of the conventional GIS techniques for landslide mapping are based on 'map overlaying', which only allows for the comparison of different maps on the same location and scale by placing them one on top of the other and using the criteria for landslide assessment. Examples are the landslide susceptibility map of Wanxian Area, Sichuan, prepared by Li et al. (1989) and the zonation map of slope instability hazards of Chongqing, Sichuan, by Yin and Yan (1991). The maps were made by the qualitative overlay of several input maps, e.g., a landslide inventory map, geological map, and slope map.

Landslide Prevention and Control

The control works actually carried out in landslide areas are primarily to save lives; secondly, to preserve public structures and buildings; and, thirdly, to prevent the disruption of road traffic and flooding in the event of a landslide damming a river. Based on the findings of the detailed landslide survey, relating to the characteristics and locations of landslide movements and rupture zones as well as the distribution and levels of groundwater, etc, landslide prevention and control works are implemented to stop or slow down landslide movement or avoid landslides in order to prevent any further damage by landslide movement.

The landslide control works to be undertaken must be carefully selected, taking the mechanism of the landslide in question into full consideration. The Ministry of Railways and the Ministry of Water Conservancy have studied the problem and developed many techniques for landslide control. The prevention and control methods used in China fall into seven categories, and these are shown in Table 3.

Avoiding Landslides

Avoiding existing landslides is an important step in reducing the impact of landslides. From the 1960s to 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 stabilise them before construction.

Table 3: Summary of Landslide Prevention and Control Works Used in China

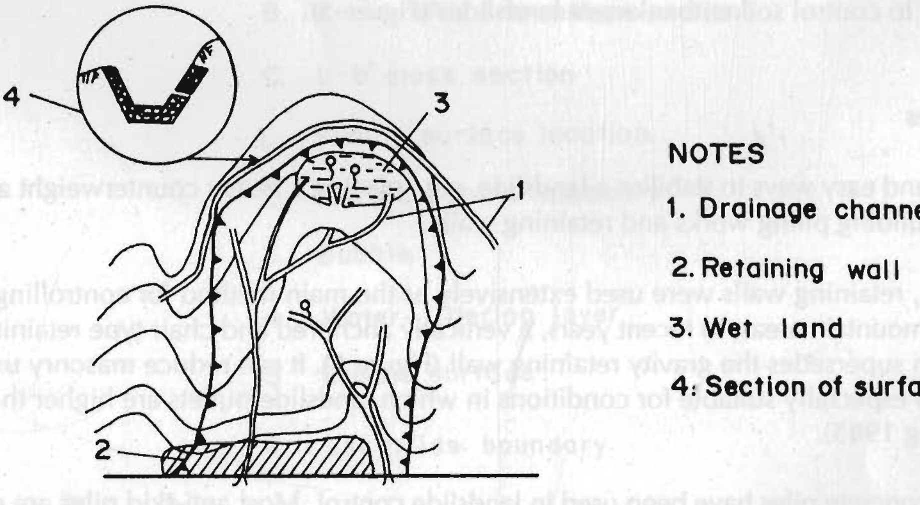
Category	Landslide Prevention and Control Works
Problem avoidance	Avoiding existing landslides, relocation
Surface-water drainage works	Channels or ditches, seepage-water prevention works
Subsurface drainage	Tunnels, subsurface trenches, deep-seated counterfort drains, drill vertical drainage holes, horizontal boreholes, slope-seepage ditches, drainage wells of ferroconcrete, drainage wells with liner plates, water catchment well works
Support structures	Retaining walls, anchored retaining walls, cribworks, gabions, stabilisation trenches, piling works (driven piles), caisson pile works
Excavation	Removal, flattening, and benching
River structure work	Erosion control dams, consolidated dams, revetment groins, spur dikes, groundsel works, groyne works
Other methods	Planting vegetation, blasting, and hardening, etc

Source: Compiled from technical records

Surface Drainage

A rise in the groundwater level, caused by infiltrated rainwater that also reduces effective soil strength, is a major cause of landslides. Therefore, draining runoff water and preventing it from entering stable areas through landslide areas is often carried out to control landslides, and this is the least expensive technique. The methods of surface drainage include reshaping of slopes, construction of ditches, and sealing all tension cracks so that rainwater cannot get inside and build up porewater pressure. Figure 2 shows the typical arrangement of surface drainage with a combination of other methods to stabilise an earth landslide. The practice indicates that surface drainage is successful in controlling shallow debris and earth landslides (Li and Liu 1982).

Figure 2: Typical Arrangement of Surface Drainage



Source: Li and Liu 1982

The following drainage construction practices create ideal conditions for landslides.

- Inadequately sized or poorly maintained ditches or the lack of them
- Culverts that are too far apart, poorly located, not maintained, or undersized
- Problems associated with the discharge points of culverts and ditches

Ditches should be inspected after any heavy runoff and pulled if necessary. Relatively minor blockages can lead to spectacular erosion and landslides. Unlined catch drains have sometimes reactivated landslides when they are choked due to poor maintenance, and they may become sources of groundwater. Contrary to expectations, they will help in the fast development of perched water tables above bedrocks. Thus, choked catch drains can lead to reactivation of landslides. Therefore, well constructed and maintained drainage systems are the real key to preventing landslides in mountainous areas.

Subsurface Drainage

Draining groundwater to reduce water pressure is the main purpose of subsurface drainage. The methods used to drain underground water include tunnels, subsurface trenches, deep-seated counterfort drains, vertical and horizontal boreholes, and water catchment well works.

The deep-seated counterfort drain is the main measure used to treat small- and medium-scale landslides. It is also an important subsidiary measure in treating large-scale landslides, because it not only drains underground water but also has a strong supporting force against sliding. Figure 3 shows the structure of a deep-seated counterfort drain. The counterfort drain has been designed as an inverted filter because, once the drain is choked with fines, it is no longer effective. The outermost layer is of clean coarse sand, followed by gravel inside, and the innermost core consists of boulders. The drain is connected to a mortar masonry wall. The choked drain system is practically the biggest factor causing landslide reactivation. It should be emphasised that improperly built drains can endanger the stability of landslides.

The best method for draining underground water from a rock landslide is to drill drainage holes, and it should be the first choice. If the water pressure in the tension cracks and the sliding plane is reduced to zero, the safety factor of the landslide will improve significantly. Figure 4 illustrates a horizontal borehole for draining groundwater from a rock landslide. The drainage holes are plugged with perforated plastic pipes to prevent choking of the holes. At present, the use of horizontal drill holes is limited in China because of the lack of suitable drills. In recent years, lime piles and lime-sand piles have been used as drainage methods to control soil embankment landslides (Figure 5).

Support Structures

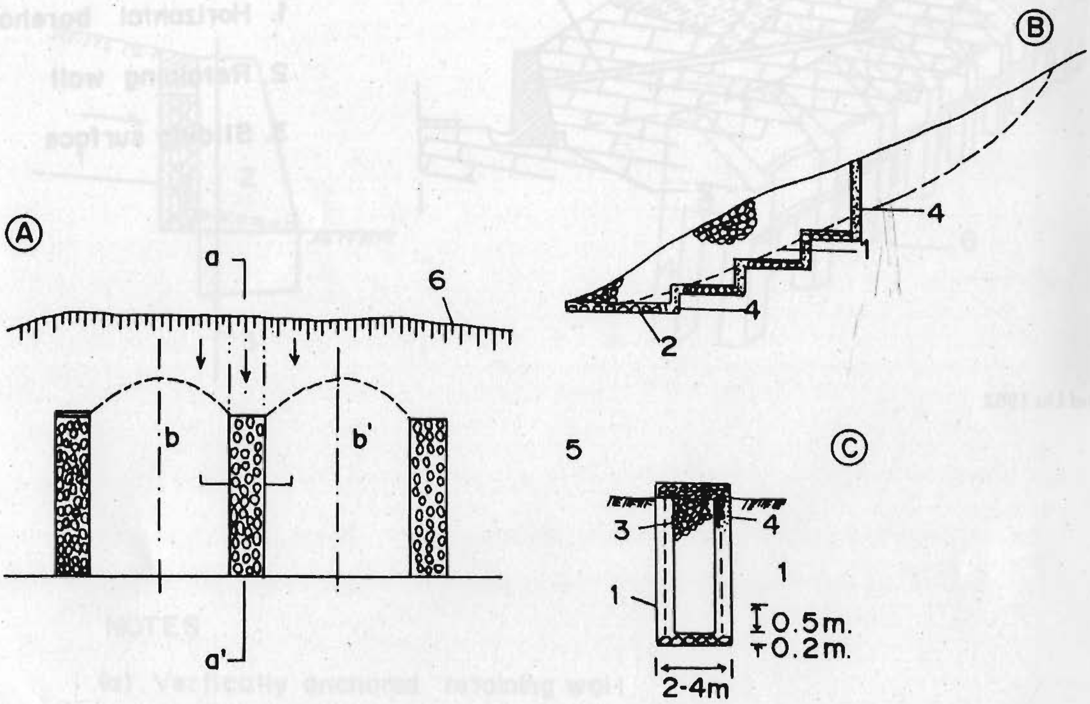
There are natural and easy ways to stabilise a landslide, e.g., placing a heavy counterweight at the toe of the landslide or building piling works and retaining walls.

During the 1960s, retaining walls were used extensively as the main method for controlling landslides along railways in mountain areas. In recent years, a vertically anchored and chair type retaining wall has been tested which supersedes the gravity retaining wall (Figure 6). It can reduce masonry use by about 20 per cent and is especially suitable for conditions in which landslide outlets are higher than the base of the slope (Wang 1985).

Since the 1960s, concrete piles have been used in landslide control. Most anti-skid piles are driven piles and have large rectangular sections of 1 x 1m to 2 x 3m (Plate 3). The depths of the piles are from 10 to 30m depending upon the thickness of the sliding body. The biggest piles used are 3.5 x 7m in section and 47m in length; piles of this size are used on the Zhao Jiantang landslide. The interval between piles is normally 2.4 times the pile width (Pan 1988). In the beginning, one or more rows of single piles are 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 because of its capacity to resist slides, the low amount of masonry needed, convenient construction, and the fact that it can easily be constructed manually using simple instruments, for example, in Panzhihua City, Sichuan Province (Lin 1989 and Zhu et al. 1989) and on the Second Automobile Works' Site, western Hubei (Liu and Jin 1989). The formation and action of the piles are similar to the so-called shaft works (deep foundation piping with broad diameters) used in Japan.

Figure 3: Deep-seated Counterfort Drain



NOTES

A. Plan

B. a-a' profile (downslope section)

C. b-b' cross section

1. Sliding surface location

2. Mortar bubble masonry

3. Bubble

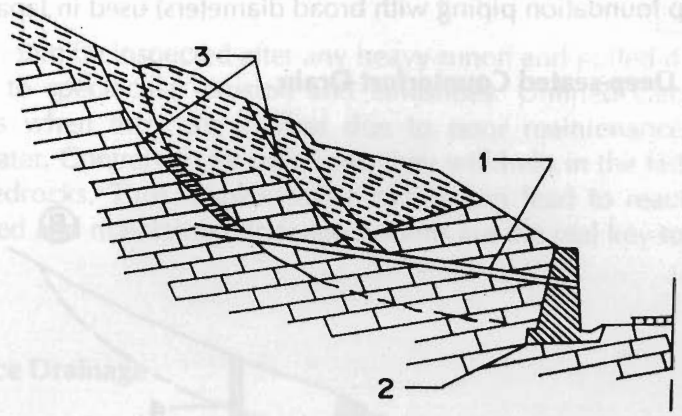
4. Water-filtering layer

5. Ground surface

6. Landslide boundary

Source: Li and Liu 1982

Figure 4: Horizontal Borehole for Draining Underground Water



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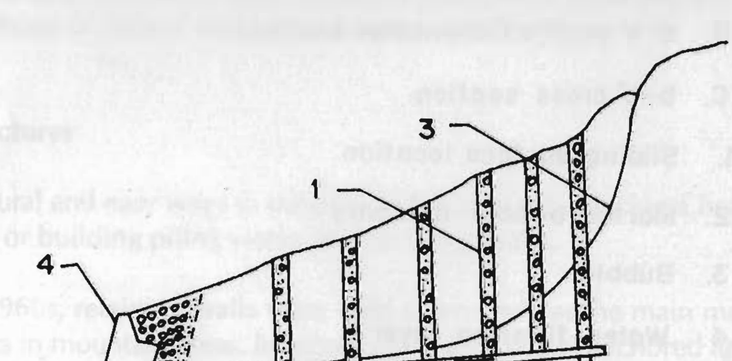
1. Horizontal borehole
2. Retaining wall
3. Sliding surface

Source: Li and Liu 1982

Figure 5: Lime-sand Piles and Horizontal Boreholes for Controlling Soil Embankment Landslides

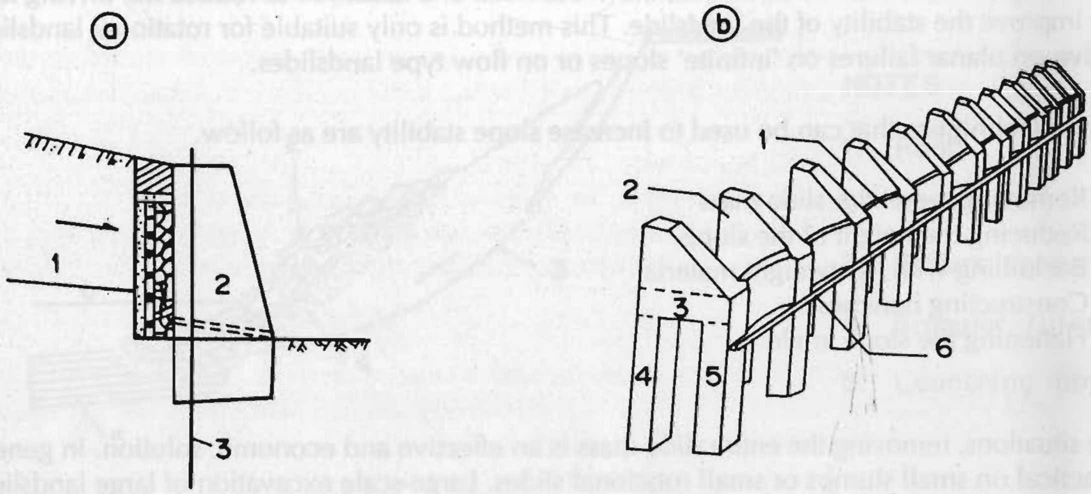


NOTES

1. Lime-sand
2. Horizontal borehole
3. Sliding surface
4. Retaining wall

Source: Wang 1985

Figure 6: Vertically Anchored Retaining Wall (A) and Chair-type Retaining Wall (B)



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(a) Vertically anchored retaining wall

1. Sliding surface location
2. Wall
3. Anchor

(b) Chair-type retaining wall

1. Arch bar
2. Upper wall
3. Bearing stand
4. Inside wall bed
5. Outside wall bed
6. Side ditch

Source: Wang 1985

However, the diameters of the piles for stabilising landslides are generally very large (more than one metre); therefore, at present, this method may not be technically and economically feasible for controlling landslides along rural roads in mountain areas.

Excavation and Fill

Excavation is the removal of rock and soil from the head of a landslide to reduce the driving force and thereby improve the stability of the landslide. This method is only suitable for rotational landslides. It is ineffective on planar failures on 'infinite' slopes or on flow type landslides.

Excavation techniques that can be used to increase slope stability are as follow.

- Removing the entire slide mass
- Reducing the height of the slope
- Backfilling with lightweight material
- Constructing benches
- Flattening the slope angle

In some situations, removing the entire slide mass is an effective and economic solution. In general, it is only practical on small slumps or small rotational slides. Large-scale excavation of large landslide areas is usually not recommended.

In some cases, correct excavation of landslide materials can improve landslide stability and may even increase the stability.

The following guidelines are mostly applicable to the control of rotational landslides where the head, toe, and side boundaries are apparent.

- In general, the head of an actual or potential landslide should be unloaded and its toe loaded.
- The head of a large landslide should be full-benched and the material end-hauled. No sidecasting should take place in the landslide area.
- As far as possible, the toe of the landslide should be built up with end-hauled fill material and cuts made as small as possible.

Corrective fills at the toe of the landslide are generally preferable to corrective cuts at its head for several reasons.

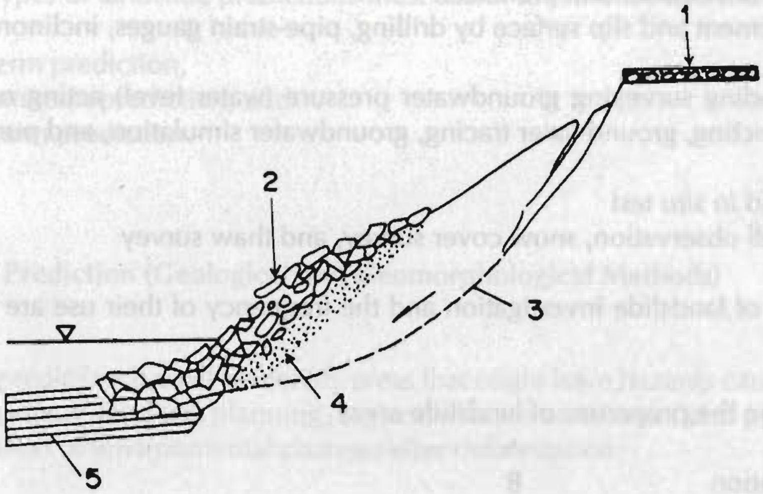
- The increase in the 'factor of safety' is greater with fills.
- Fill stability improves with time, whereas cut slope stability decreases with time.
- In large complex landslides with more than one potential sliding surface, toe loading will protect against all failures, but a cut may destabilise some sliding surfaces.
- In general, a combination of soil removal from the head with fills at the toe of the landslide is most suitable for controlling medium-sized rotational slides.

River Structure Works

In China, many railways and highways run along river valleys. Landslides caused frequently by river erosion damage the roads and interrupt traffic. The construction of river structure works is to prevent river erosion and increase the resisting forces of landslides.

River structure works include revetment groins, spur dikes, groundsel works, etc. The best method for controlling landslides on river banks is to construct a riprap at the toe of a landslide. A riprap is relatively easy to construct and effective on many types of eroding banks and landslides (Figure 7). Heavy riprapping keyed into the slope acts as a permeable toe buttress, increasing resistance to failure. The minimum riprap size may be estimated from the largest boulders in the river bed. Where rocks of the right size are not available, gabions or wire mesh baskets can be constructed and filled with boulders.

Figure 7: A Riprap to Control Landslides on a River Bank



Source: Li and Liu 1982

Checkdams are small or large sediment storage dams built in the channels of steep ravines. Checkdams have the following functions:

- storing sediment and reducing sediment discharge by arresting debris from landslide or erosion areas;
- stabilising landslides and potential slope failure by back siltation behind the dam;
- preventing downcutting of the valley bed by arrested sediment; and
- dissipating the fast-flowing water by creating small waterfalls.

Many landslides and debris flows in different watersheds have been controlled by these methods (Wu 1983 and Zhang et al. 1985). Checkdams can be constructed of reinforced concrete or log cribs. Lateral stream erosion and scour by spillway water are the main causes of checkdam failure. During construction, the concrete wing walls and log crib ends must be tied securely into the canyon wall and stream bed to withstand backfill pressure and lateral scour. The foundation of the dam should have a minimum width of one third of the total height of the dam and should be deeper than any scour holes likely to develop. Plates 4 to 8 show the different types of checkdams used to control landslides and debris flows on various ravines in the provinces of Yunnan and Sichuan.

Other Methods

Biotechnical methods of landslide stabilisation include planting trees and grass reseeding, etc; the roots of the plants tend to reinforce the loose deposits and also enter into joints of the bedrock. This live reinforcement will increase the cohesion of the loose material to the extent of 0.5t/m. Thus the slope may develop more factors of safety against sliding. Under certain natural conditions, shallow landslides can be stabilised by planting trees, but these methods cannot replace structural methods of landslide control. A combination of biotechnical methods and structural methods is the best way to stabilise landslides.

In any high risk situation, where a landslide may endanger lives or property, a detailed investigation must be undertaken to understand the landslide fully before undertaking any stabilising work. Detailed landslide investigation into the overall characteristics of the landslide area includes the following.

1) Aerial-photo interpretation and mapping
2) Underground temperature survey
3) Seismic prospecting
4) Natural radioactivity prospecting
5) Electric prospecting
6) Electric logging
7) Surface measurement by extensometer and tiltmeter
8) Surveying the earth displacement and slip surface by drilling, pipe-strain gauges, inclinometer, and movement meter
9) Groundwater survey, including surveying groundwater pressure (water level) acting on the slip surface, groundwater prospecting, groundwater tracing, groundwater simulation, and pumping test
10) Water quality analysis
11) Soil tests: laboratory test and *in situ* test
12) Hydrological survey: rainfall observation, snow cover survey, and thaw survey

The survey items and methods of landslide investigation and the frequency of their use are described below.

1) Survey to roughly determine the properties of landslide areas

▸ Field investigation	A
▸ Aerial-photo interpretation	B
▸ Seismic prospecting	B
▸ Underground temperature	C

2) Survey of ground surface displacement

▸ Detailed ground study	A
▸ Measurement by extensometer	A
▸ Measurement by tiltmeter	A
▸ Aerial photogrammeter	B

3) Surveying displacement in the earth and sliding zone

▸ Drilling	A
▸ Measurement by pipe-strain gauge	A
▸ Measurement by inclinometer	A
▸ Measurement by movement meter	A
▸ Tunnelling	C

4) Survey groundwater and bearing

▸ Groundwater prospecting	A
▸ Groundwater tracing	B
▸ Water quality analysis	C
▸ Pumping test	C
▸ Groundwater simulation	C

5) Surveying groundwater pressure acting on sliding zone

▸ Groundwater level measurement	A
▸ Porewater pressure measurement	C

6) Soil and rock test

▸ Physical test	A
▸ Strength test	A

7) Hydrological observation

▸ Precipitation observation	A
▸ Snow cover observation	B
▸ Thaw observation	C

Frequency A is used at almost all sites, frequency B is used at most sites, and frequency C is used where required.

Anticipation of Landslide Hazards

The three types of landslide predictions most useful to planners and the general public are:

1) long-term prediction,
2) medium-term prediction, and
3) short-term prediction.

Long-term Prediction (Geological and Geomorphological Methods)

Long-term prediction is used to identify areas that might have hazards caused by landslides in the future, for the purpose of land-use planning, regional hazard assessment and prevention, urban development, and evaluation of environmental changes after deforestation.

One important principle of long-term prediction is that the past is the key to the future. This means that landslides will probably occur as a result of the same geologic, geomorphic, and hydrologic situations that led to past and current landslides. Based on this assumption, it is possible to estimate the types, frequency of occurrence, extent, and consequences of landslides within a given area.

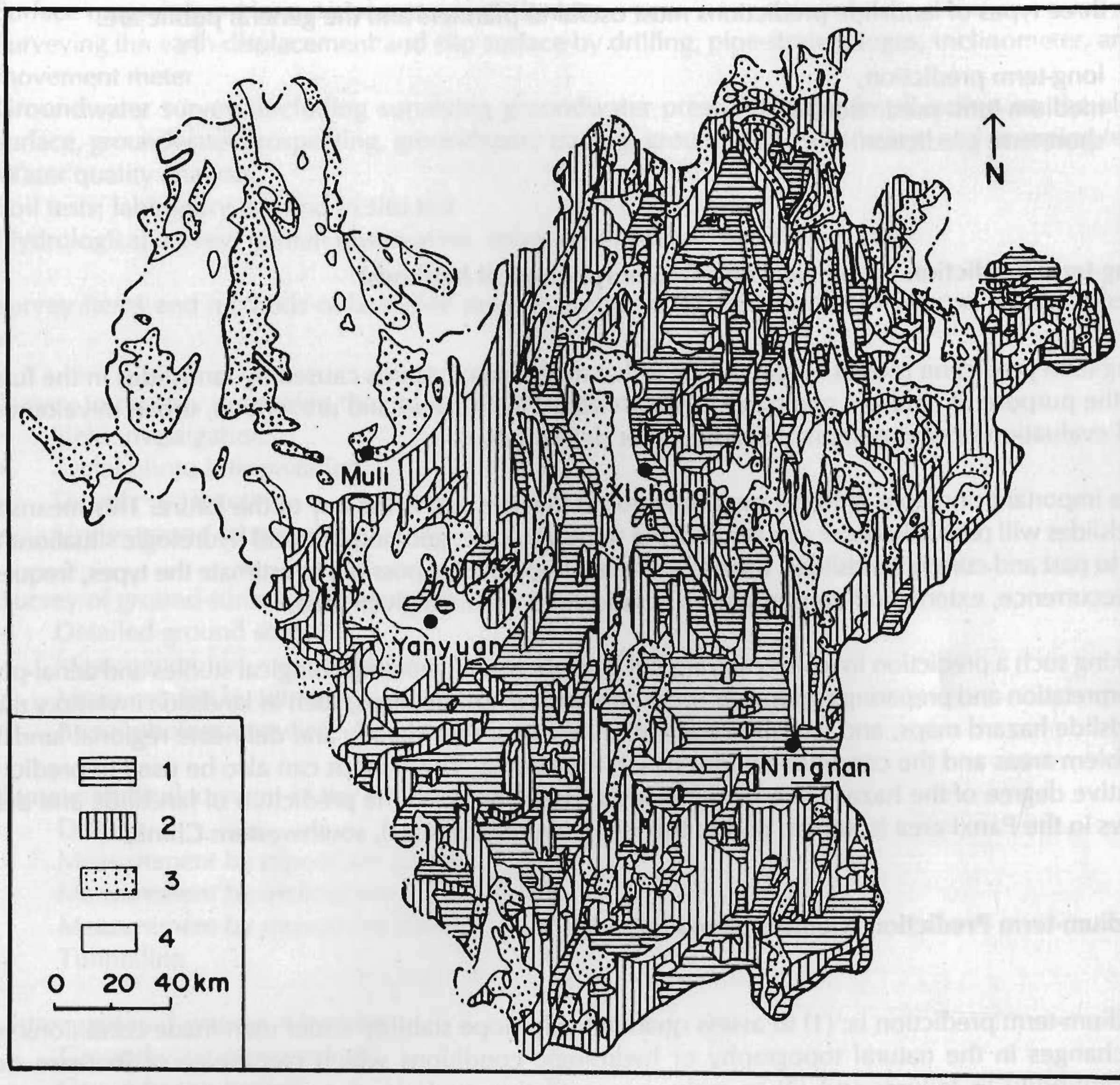
Making such a prediction involves carrying out geological and geomorphological studies and aerial-photo interpretation and preparing regional or reconnaissance landslide maps, such as landslide inventory maps, landslide hazard maps, and landslide susceptibility maps, that identify and delineate regional landslide problem areas and the conditions under which they occur. These maps can also be used to predict the relative degree of the hazard in a landslide area. Figure 8 shows the prediction of landslide and debris flows in the Panxi area (southern part of the Hengduan Mountains), southwestern China.

Medium-term Prediction (Geotechnical Methods)

Medium-term prediction is: (1) to assess quantitatively slope stability under man-made conditions such as changes in the natural topography or hydrologic conditions which can create or increase slope susceptibility to failure; and (2) to make a quantitative analysis of a slope or old landslide under anticipated seismic or meteorologic conditions.

When making such assessments, it is important in all aspects of the study, including geologic definition, stability evaluation, and monitoring evaluation, to understand the relationship between the landslide subsurface geometry and strength parameters of the slide plane with changes in natural conditions. Due to the high cost, this method can only be applied to those slopes on which large risks are anticipated according to the long-term prediction, or on which economically important engineering operations are being carried out. For instance, such a landslide prediction has been made in the reservoir area of the Longyang Gorge Hydroelectric Power Station, located on the upper reaches of the Huanghe River on the boundary of Gonghe and Gude counties, eastern Qinghai. The locations, volumes, and sliding velocities of potential landslides were made on the basis of quantitative analyses of the slopes, characteristics of rocks and soil, changes in reservoir water level, and physical and mathematical model studies. This medium-term prediction suggested raising the water level to 10m and ensuring the safe operation of the Hydroelectric Power Station (Qing 1987 and Wang 1989).

Figure 8: **A Map Showing the Prediction of Regional Landslide Activities in the Panxi Area in Southwest Sichuan**



Source: Tan et al. 1994

NOTES

1. Extraordinarily active area

2. Most active area

3. Active area

4. Less active area

Short-term Prediction

Generally, short-term prediction is used for evacuation before an imminent large-scale landslide, so it is also called 'time prediction of landslide occurrence'. Such predictions are usually based on (1) field measurements of displacements and rainfall and porewater pressures and (2) forerunning indications of landslides. At present, only the method based on the observation of displacement by extensometers and distance measurement equipment can be applied to predict the time of landslide occurrence.

Landslides are monitored or instrumented to provide timely warning of incipient hazards and to minimise property losses. Instruments used for monitoring include inclinometers, extensometers, tiltmeters, and pipe-strain gauges.

Successful predictions of large-scale landslides, based on measurements of surface displacement and displacement rates, have been presented by Luo (1988), Cheng (1988), and Cheng and Sun (1988). For instance, a measurement system for the Xintan landslides, composed of eight monitoring survey points and a triangulation network, were added in July 1984. Based on the measurement data and other indications of forerunning slope failure, a landslide of 20 million cubic metres on the upper slopes of Xintan Town, which occurred on June 12, 1985, was accurately predicted. The warning was given before the event so that all of the 1,371 inhabitants of the town were safely evacuated. This kind of success in landslide prediction is rare (Chen 1989 and Luo 1988).

Another successful example was the Jimingshi landslide predicted in 1991 on the basis of more than a year's observation and surface deformation measurement. The warning was given one day before large-scale sliding and more than 2,000 inhabitants from the town of Guojiaba were safely evacuated.

In predicting the time of landslide occurrence, the biggest difficulty is in determining the critical rate of displacement; the problems of providing such data are due to (1) the variation in characteristics and type of movement of each landslide and (2) insufficient available data on which to base the criteria for warning. To solve this problem, the criteria for the rate of displacement can be established on the basis of previous displacement records and the records of the sliding velocity of some landslides. The initial criteria can be checked and re-established during the monitoring period.

Prediction of the Extent of Major Rapid Landslide Disasters

When we make a time prediction of landslide occurrence, we should estimate the extent of area affected by the landslide. The pattern of deposits of a minor rockfall or landslide generally consists of an irregular halfcone of debris at the foot of the parent cliff. The geometry of deposits of a major landslide, on the other hand, is similar to that of a glacier or lava flow. The extent of most major landslides of high velocity is well beyond the base of the steep slopes where the landslide originated. Field observations show that the distance travelled and morphologies of deposits of a major landslide are mainly influenced by the volume, vertical drop, and relief of the deposit area. In recent years, many methods have been developed in China to estimate the sliding velocity, travel distance, and area covered by sliding deposits.

Empirical Model

In 1983, Li discovered a relationship between landslide volume and the spreading area of the landslide mass, by using a statistical method for predicting the hazard area as well as the travel distance. The correlation of the volume (V in m^3) of landslide to the ratio of the maximum vertical drop (H) to the maximum horizontal distance travelled (L in m) was given as:

$$\lg(H/L) = A + B\lg V$$

with:

$A = 0.6640$ and $B = -0.1529$.

The correlation of the covered area (S in m^2) to the volume (V in m^3) of a landslide possesses the form:

$$\lg S = A + B \lg V$$

with:
A = 1.8807 and B = 0.5667.

Analytical Model

According to the energy balance and contributing factors of rapid landslides caused by liquefaction, and the effect of the rate of peak value strength on the residual value strength, Wu and Li (1986) demonstrated the mechanism of rapid landslides with examples of vast landslides of poorly consolidated rocks; they proposed a formula to calculate the maximum velocity of a rapid landslide as follows.

$$V_{max} = \sqrt{2K1.K2.g.H}$$

where:

K1 = (1 - R),
K2 = F1/(F1 + F2),
R = Residual strength/peak strength,
g = Acceleration of gravity (m/s),
H = Height of the gravity centre of the sliding mass (m),
F1 = Area of driving section (m^3), and
F2 = Area of resisting section (m^3).

In 1989, Wang and Wang discussed the synthetic mechanism of high-speed and far-reaching landslides through energy analysis of the high speed of large-scale landslides in the processes of pregnancy, sliding, development, and stillness. They found that the velocity of high-speed landslides was related to the presence of forces of deformation and the positions of landslides. The formulas suggested for calculating the speed and travel distance of a large-scale landslide are as follow.

$$V = \sqrt{2U/M + 2g(H - fL)}$$

$$L_{max} = (1/gf) \times U/M + H/f$$

where:

V = velocity,
Lmax = maximum travel distance,
M = mass,
g = acceleration of gravity,
f = friction factor,
L = horizontal travel distance,
U = deformation energy of assisting sliding, and
H = height of sliding position.

The methods mentioned above are applicable for the approximate prediction of the sliding velocity and travel distance of an anticipated major landslide. However, it is difficult for these methods to take account of the influences of the ground conditions, the degree of saturation of the landslide mass, and the micro-topography.

Assessment and Mitigation Measures of Landslide Dam Failure Disasters

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 (Li et al. 1986).

Formation of Landslide Dams

Landslide dams result from a broad range of mass movements in different physiographic settings. Most landslide dams are formed by rock and earth slumps and slides, debris and mudflows, and rock and debris avalanches. Large landslide dams are formed by earth and rockslides/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. The heights of landslide dams range from a few metres to hundreds of metres, and they are primarily controlled by the volume of failed mass and the geometry of the valley.

Table 4 gives well-documented examples of landslide dams and Figure 9 shows some of the major landslide dam sites in the Hengduan Mountains and surrounding areas in southwestern China.

Table 4: Well-documented Examples of Landslide Dams in Southwestern China

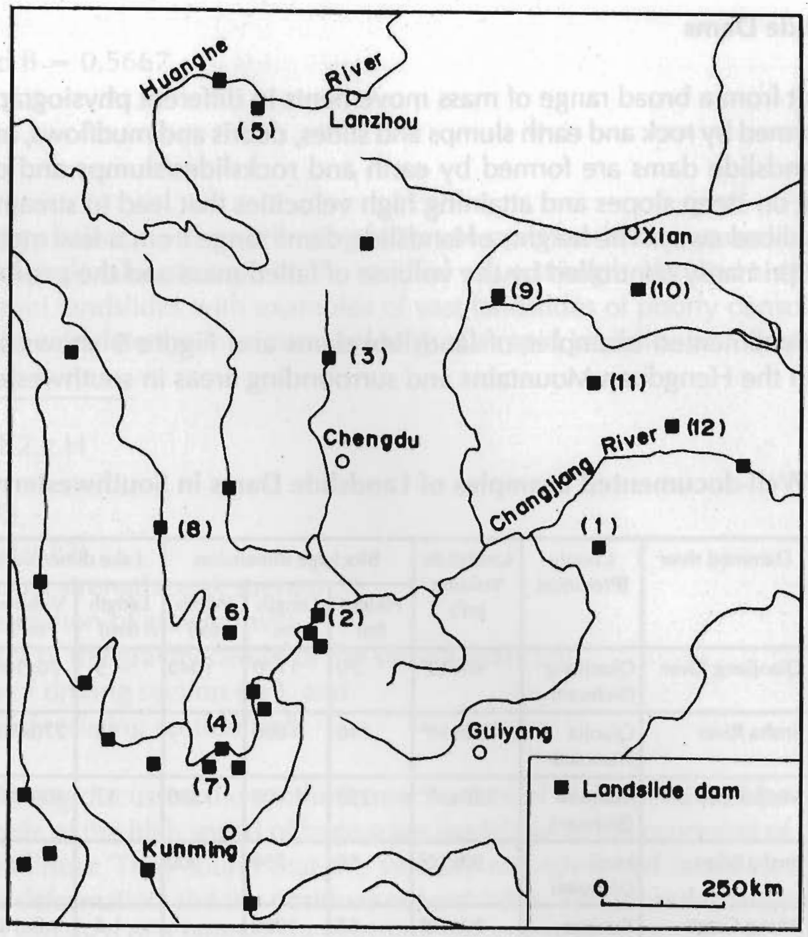
Name of landslide	Year	Dammed river	County (Province)	Landslide Volume (m^3)	Blockage dimension			Lake dimension		Dam failed?	References
					Height (m)	Length (m)	Width (m)	Length (km)	Volume (m^3)		
Daluba (1)	1856	Qianjiang River	Qianjiang (Sichuan)	$40x10^6$	70	1170	1040	5	$70x10^6$	No	Liu 1990
Shigaodi (2)	1881	Jinsha River	Qiaojia (Yunnan)	$530x10^6$	110	1000	-	50	$270x10^6$	Yes	Lin 1990
Diexi (3)	1933	Minjiang River	Maowen (Sichuan)	$150x10^6$	255	400	1300	17	$400x10^6$	Yes	Chang 1934 Li et *al.* 1986
Luchedu (4)	1935	Jinsha River	Huili (Sichuan)	$90x10^6$	50	250	500	-	-	Yes	Lin 1990
Bitang (5)	1961	Bitang Creek	Xunhua (Qinghai)	$80x10^6$	65	1000	-	1.5	$4.2x10^6$	No	Li et *al.* 1986
Zepozhu (6)	1965	Donghe River	Xichang (Sichuan)	$7.2x10^6$	51	-	650	1	$2.7x10^6$	Yes	Li et *al.* 1986
Pufu (7)	1965	Pufugou Stream	Luguan (Yunnan)	$450x10^6$	179	1100	800	1.8	$5x10^6$	Yes	Li 1990
Tanggudong (8)	1967	Yalong River	Yajiang (Sichuan)	$68x10^6$	175	650	3000	53	$680x10^6$	Yes	Li et *al.* 1988
Guanjiayuan (8)	1981	Changgou River	Mianxian (Shaanxi)	$2x10^6$	30	250	200	-	$10x10^4$	Yes	Han *et al.* 1988
Liangjiazhuang (10)	1983	Gancha River	Zhenan (Shaanxi)	$4.12x10^6$	68	80	350	1.5	$1.5x10^6$	Yes	Zhong 1989
Diaobanya (11)	1988	Baisha River	Wanyuan (Sichuan)	$100x10^4$	38	75	100	0.5	-	No	Xu and Wei 1988
Zhongyangchun (12)	1988	Xixi River	Wuxi (Sichuan)	$765x10^4$	30	150	600	-	-	Yes	Tian et *al.* 1988

Source: Li and Wang 1992

Assessment of Upstream and Downstream Floods of Landslide Dams

Landslide dams create conditions for two very different types of flooding: (1) upstream flooding as the impoundment fills and (2) 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 to life and property.

Figure 9: Some of the Major Landslide Dam Sites in the Hengduan Mountains and Surrounding Areas in Southwest China



NOTES

1. Numbers correspond to those in Table 4

Source: Li and Wang 1992

The Diexi landslide dam was caused by a complex landslide of 150 million cubic metres triggered by an earthquake (M =7.5, August 25, 1933) in northwestern Sichuan. The landslide dam was 255m high, 400m long (cross-river), and 1,300m wide (down-river). The maximum size of the lake formed was about 17km long, attaining a maximum volume of 400 million cubic metres; 45 days later, the dam was overtopped, causing severe flooding downstream. The wall of water was about 60m high, three kilometres downstream from the blockage. Attaining an average velocity of about 30km/h en route, this wave reached the town of Maowen, 58km downstream, in two hours. The total length of the Diexi flood was 253km, and the average velocity throughout was 20 to 25km/h (Li et al. 1986). Records are incomplete, but at least 2,423 people were killed by this flood in three downstream counties. In two of these counties, about 1,075 homes were destroyed (Chang 1934, Li 1979a, and the Earthquake Bureau of Sichuan Province 1983).

The Tanggudong landslide occurred on 8 June, 1967, on the east bank of the Yalong River (a major tributary of the Changjiang River) about 300km WSW of Chengdu, Sichuan. The 68 million cubic metres of debris slide/avalanche, in colluvium and slope wash from Triassic sandstone, formed a large dam of loose rock and soil across the Yalong, 355m thick on the west side, 175m thick on the east side (low point on the crest of the dam), and extending three kilometres along the river. The impounded lake attained a maximum length of 53km and a maximum volume of 680 million cubic metres (Investigation Team of the Tanggudong Landslide Dam 1967) (Li Tianchi 1990).

Nine days later, the lowest part of the dam crest was overtopped by the rising water; although the entire dam did not fail, it breached to a depth of 88m over a 13-hour period. The resulting disastrous flood flowed 1,000km downstream along the Yalong and Changjiang rivers to the city of Yibin. The height of the frontal wave of the flood was 50.4m at a point six kilometres downstream from the landslide and 16.5m at Xiaodishi, 551km from the blockage. The maximum discharge of the flood, downstream from the blockage, was a phenomenal 53,000m^3/s (Table 5 and Figure 10).

Table 5: Flood Characteristics of the Yalong River Downstream from the Tanggudong Landslide Dam Failure (June 1967)

Distance Downstream from Dam (km)	Date and Time of Flood Arrival (date/hr:min)	Velocity (m/s)	Maximum Flow (m^3/s)	Height of Flood (m)	Thickness of Sediment Deposited (m)
6	17/14:30	8.9	53000	50.4	23
19	—	-	—	–	5
33	17/15:30	-	—	1.5	-
214	18/0.06	6.8	30000	29.6	-
310	18/4.00	6.8	26000	20.4	-
551	18/16:30	4.0	18000	16.5	-
1000	—	-	—	0	-

Source: Investigation Team of the Tanggudong Landslide Dam, 1967

No deaths were caused by the flood because downstream residents had been evacuated in anticipation of the catastrophe; however, property damage was considerable. The Investigation Team of the Tanggudong Landslide Dam (1967) noted the following damage along the Yalong River: 435 homes, 51km of highway, 47 highway tunnels, eight highway bridges, 230ha of farmland, and three hydrological stations.

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 the topography upstream from the dam.

The peak discharge of downstream flooding resulting from landslide dam failure depends on the process of the dam failure. The failure process can be classified into three types: failure caused by erosion of overtopping, instantaneous failure by sliding, and progressive failure by piping (Figure 11) (Kuang 1993).

For the 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):

$$Q = 0.063P$$

where:

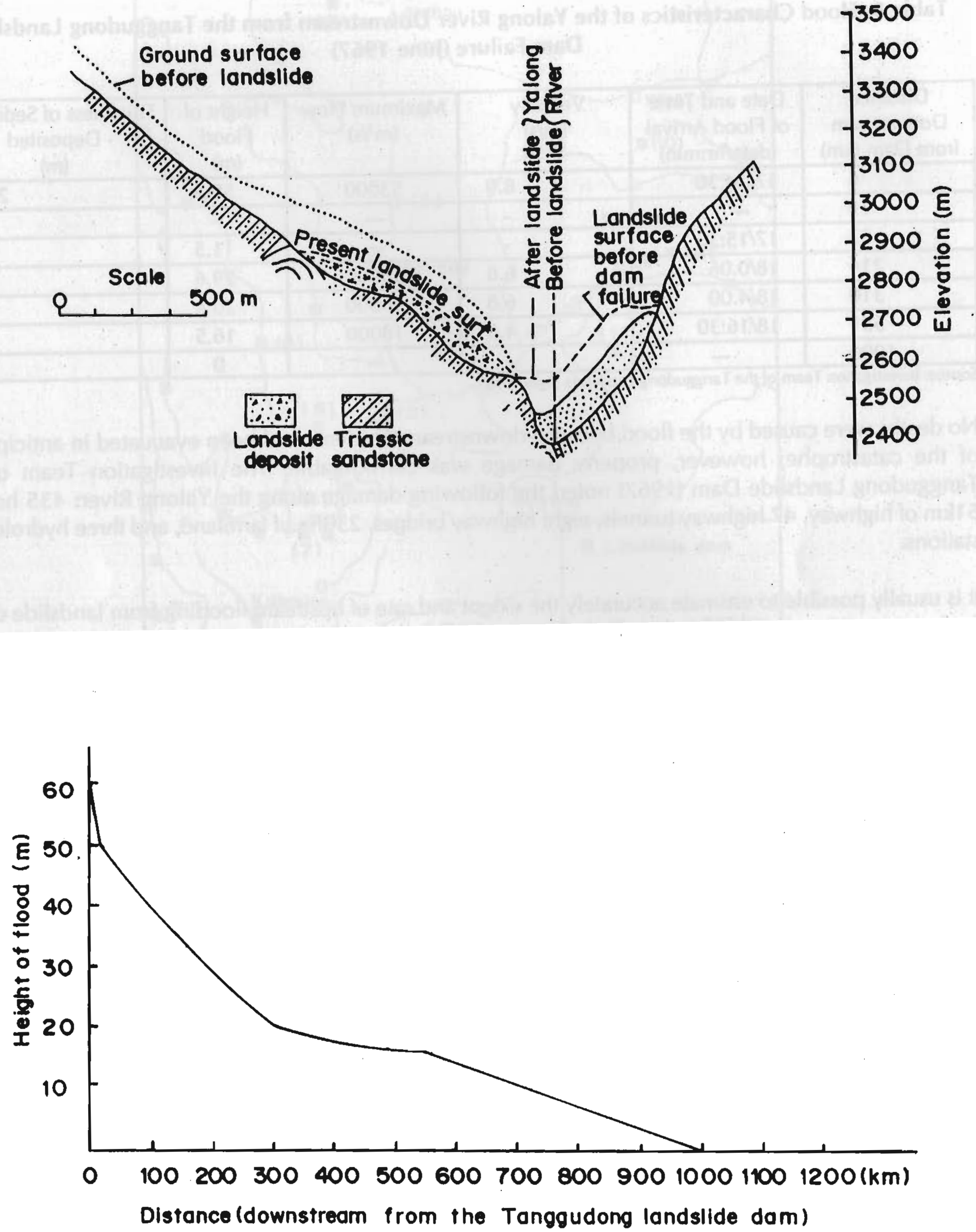
Q is peak discharge in cubic metres per second and P is potential energy in joules.

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.

When assessing downstream floods, the following should be taken into full account.

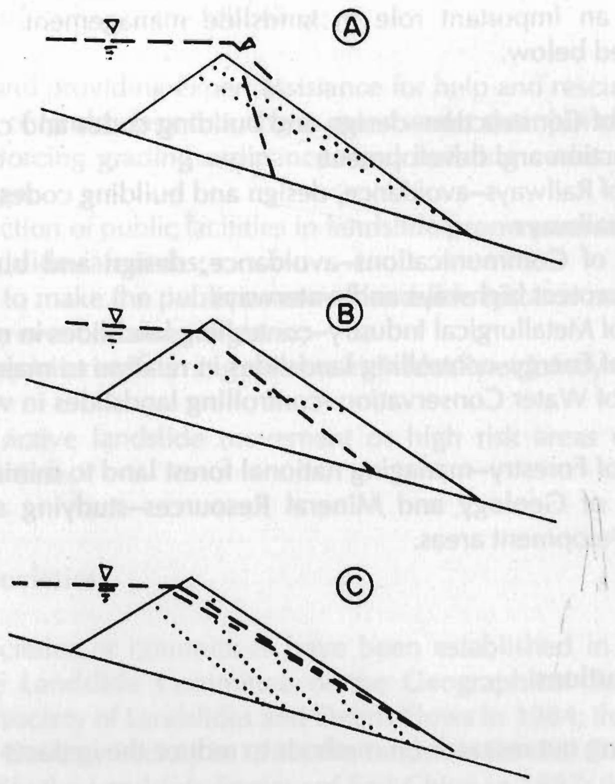
- Type and characteristic of the landslide dam
- Size of the lake (length, width, depth, and volume of the lake)
- Size of the dam (length, width, height, and volume of the dam)
- Physical characteristics of geological materials making up the dam
- Estimation of the mechanism of the dam failure
- Nature of the valley downstream
- Rates of sediment and water flow into the newly-formed lake and rates of seepage through the dam

Figure 10: Cross Section through the Tanggudong Landslide Dam on the Yalong River and the Height of Flood from the Landslide Dam Failure



Source: Investigation Team of the Tanggudong Landslide Dam 1967

Figure 11: Three Types of Landslide Dam Failure Process



NOTES

A. Failure due to erosion by overtopping

B. Instantaneous failure due to landsliding

C. Progressive failure

Source: Kuang 1993

Methods to Prevent Landslide Dam Failure and Subsequent Flooding

Due to the 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 common methods. Pipes, tunnels, outlets, and diversions have also been used to prevent dam failure and control discharge from landslide-dam lakes in many places. 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 (Li and Hu 1981).

Institutions Concerned with Landslide Hazard Mapping, Control, Forecasting, Mitigation, Research, and Training

Landslides threaten lives, public structures, and economic development and the prevention and control works of landslides are multidisciplinary; therefore a significant reduction in landslide losses can only be achieved through the collective effort of public agencies, institutes, and the people concerned. In China, there are a number of institutions responsible for landslide mapping, forecasting, and reducing the cost of damage caused by landslides. Some of these institutions and their roles are listed below.

Role of Government Agencies

Public agencies play an important role in landslide management. Important agencies and their responsibilities are listed below.

- The Ministry of Construction–design and building codes and controlling landslides related to urban construction and development
- The Ministry of Railways–avoidance, design and building codes, and controlling landslides for protection of railways
- The Ministry of Communications–avoidance, design and building codes, and controlling landslides to protect highways and waterways
- The Ministry of Metallurgical Industry–controlling landslides in relation to specific mining areas
- The Ministry of Energy–controlling landslides in relation to major hydroelectric power stations
- The Ministry of Water Conservation–controlling landslides in watersheds of rural areas where necessary
- The Ministry of Forestry–managing national forest land to minimise landslide damage
- The Ministry of Geology and Mineral Resources–studying and mapping of landslides in important development areas.

Role of Research Institutions

Some institutions carrying out research on methods to reduce the impacts of landslide disasters are given below.

- The Chengdu Institute of Mountain Hazards and Environment, the Chinese Academy of Sciences, Chengdu, Sichuan Province
- The Centre for Environmental Geology of the Ministry of Geology and Mineral Resources, Beijing
- The Debris Flow Prevention Institute of Dongchuan City, Yunnan Province
- The Institute of Geology, the Chinese Academy of Sciences, Beijing
- The Northwest Branch of the Chinese Academy of Railway Sciences, Lanzhou, Gansu Province
- The Research and Coordination Centre for Geological Hazards of Gansu Province, Lanou, Gansu Province
- The Institute of Rockfall and Slides of Hubei Province, Yichang, Hubei Province

These universities and colleges also carry out studies on landslide disaster mitigation, individually or jointly with the institutions mentioned above.

The duties of these institutions are:

- to undertake research on landslide mechanisms;
- to conduct research on real time predictions for landslides and debris flows;
- to develop landslide inventory and mapping methods;
- to develop landslide risk assessment methods;
- to develop and improve design and construction techniques for controlling landslides and minimising landslide damage;
- to provide expert advice to public agencies and local governments;
- to provide technical and training assistance;
- to disseminate research results to planners, decision-makers, governments, and communities; and
- to develop a landslide information base.

Role of Central, Provincial, and Local Governments

Provincial and local governments carry out the following:

- mobilising resources and providing expert assistance for help and rescue operations;
- compiling inventories of landslides occurring in areas under their jurisdiction;
- promulgating and enforcing grading ordinances and building codes to minimise landslide occurrence and damage;
- preventing the construction of public facilities in landslide-prone areas and relocating obsolete public facilities in landslide-safe areas;
- providing information to make the public aware of landslide hazards and coordinating private sector resources in the event of an emergency;
- establishing landslide monitoring/warning systems individually or jointly with research institutes; and
- designating areas of active landslide movement or high risk areas of such movement as landslide-threatened areas.

Role of NGOs and Scientific Societies

Recently, several landslide societies or committees have been established in those provinces most susceptible to landslides. The Landslide Committee of the Geographical Society of Sichuan was established in 1982; the Gansu society of Landslides and Debris Flows in 1984; the Landslide and Debris Flow Committee of the Shaanxi Geology Society in 1985; the Landslide Control Committee of the Shaanxi Civil Engineering Society in 1985; the Landslide Society of East China in 1987; the Landslide Society of Hubei in 1988; and the Landslide and Debris Flow Committee of the Water and Soil Conservation Society of China in 1990. These societies have altogether more than 1,000 members who are mainly researchers and engineers specialising in geology, geomorphology, topography, geophysics, civil engineering, erosion control, forestry, agriculture, and other landslide-associated fields. Members are from research institutes, universities and colleges, public organisations, consulting agencies, and government agencies. They hold national or provincial symposia and seminars, together or separately, to share and exchange information on landslide processes and control methods. International Symposia have been held, such as the China-Japan Field Workshop on Landslides in 1987; the International Symposium on Landslides and Geotechniques in Wuhan in 1991; and the East Asia Symposium and Field Workshop on landslides in 1994 (Li Tianchi 1990).

Overall Conclusions and Recommendations for a Practical Training Programme

Overall Conclusions

In China, landslides cause an estimated 15 billion USD in economic losses and about 150 deaths annually, exceeding the total annual losses due to earthquakes. Most landslides found over the last 40 years have been concentrated in the provinces of Sichuan, Yunnan, Guizhou, Xizang, Shaanxi, Fujian, Hunan, Hubei, and Taiwan. In other provinces, landslides develop less often than in the provinces mentioned above. Most landslides in these areas are triggered by heavy rain and/or melting snow, major earthquakes, and human activities. Occasionally, large hazardous landslide dams have been formed, particularly in the Hengduan mountain area of southwestern China. Financial investment in development projects in mountain areas, such as road and reservoir construction and exploitation of mineral resources, have accelerated landslides and increased landslide damage. The impacts of landslides on development are great and, apparently, growing.

Landslide hazard zonation maps are essential for assessing potential damage and quantifying risks and could be used by planners and decision-makers in planned development areas in hill and mountain countries. Scientific forecasting for landslide prediction and early warning also depends to a great extent on landslide hazard zonation maps. The content, method, and scale of landslide mapping depend, above all, on the map's purpose. Landslide susceptibility maps or hazard zonation maps are generally more useful for planners and decision-makers than for landslide inventory maps.

The analysis of aerial photography is a quicker and more valuable technique for identifying landslides than satellite remote sensing, because it has a relatively large scale and provides a three-dimensional overview of the important geomorphic features. Therefore, landslides are more effectively mapped with conventional ground techniques supported possibly by low-level aerial photography.

Most conventional GIS techniques for landslide mapping are based on 'map overlaying', which only allows for the comparison of different maps on the same location and scale by placing one on top of the other and using the criteria for landslide hazard assessment and mapping.

Landslide damage has been effectively reduced by avoiding hazards or reducing damage potential. This is primarily achieved by four mitigative approaches: (1) avoiding landslides (2) preventing destabilisation of potential landslides and slopes, (3) using physical measures to prevent or control landslides, and (4) development of landslide prediction and warning systems. Not a single method for managing landslides or unstable terrain, but a variety of techniques is needed by the engineer. One of the most significant landslide and debris flow prediction and warning systems in China has been developed on the middle and upper reaches of the Changjiang River (Yangtze River) by the Changjiang River Planning Committee in cooperation with the Institute of Mountain Hazards and Environment.

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. The vast majority of landslide dams are formed by rock and earth slumps and slides. Assessment of upstream and downstream floods is essential for 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 the topography upstream from the dam. Downstream floods can be estimated by specific empirical equations. In order to prevent dam failure and subsequent flooding, spillways are the most simple and common methods. Pipes, tunnels, outlets, and diversions have also been used to prevent dam failure and control discharge from landslide-dam lakes.

Recommendations for a Practical Training Programme

To achieve a dramatic reduction in landslide disasters there is a strong need to develop skills in landslide mapping, hazard zonation, control, and prediction. For this purpose, a practical training programme is proposed as follows.

1) The training programme is primarily designed to integrate the training course with field experience by

   - visits to problem sites, development of programmes to solve the problems, and field experience;
   - lectures/talks by experienced programme planners and project directors/managers about their experiences in project planning and project implementation; and
   - on-the-job training at possible project sites.

2) The main item of training may be any of the following.

   - Use of aerial-photographs for landslide identification
   - Landslide hazard zonation and mapping
   - Uses of landslide maps for hazard mitigation
   - Landslide and debris flow prediction, i.e.,
     - place prediction,
     - real time prediction, and
     - prediction of extent of landslide motion.

- Landslide disaster assessment
- Landslide hazard mitigation

    - Engineering control works
    - Bioengineering stabilisation
    - Non-technical methods

- Social science and interdisciplinary aspects of landslides
- Planning measures and landslides
- Land use and landslides

3) Visits and study tours to different landslide control project sites

The trainees will benefit from seeing different approved practices and from hearing lectures and talks by experienced programme planners and project directors/managers about their experiences in project planning and project implementation.

4) On-the-job training at possible project sites

Every trainee should undergo an on-the-job training programme in the following fields.

- Landslide mapping and hazard zonation
- Landslide monitoring and observation
- Moving debris flow, prediction, and warning system
- Planning and control works for landslides

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Plates

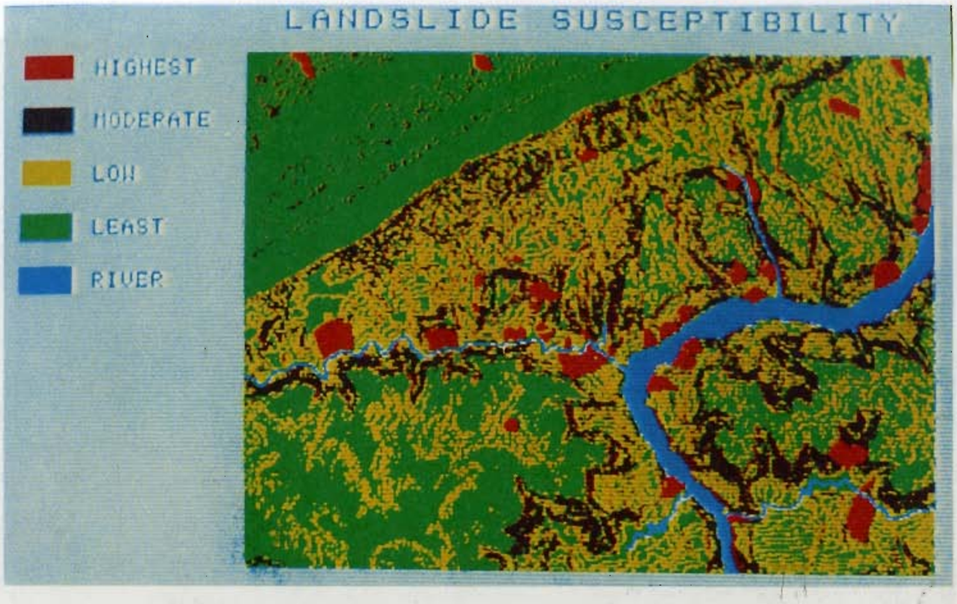

Plate 1: Landslide Susceptibility Map of Wanxian Area

Key: High : high susceptibility to landslides
Moderate : moderate susceptibility to landslides
Low : low susceptibiity to landslides
Least : least susceptibility to landslides
Explanation of the map units is presented in the text (after Li et al. 1989)

Plate 2: Aerial Photography (left) and Interpretation of the Aerial Photography (right) to Identify the Geomorphic Features of Landslides in Haiyuan Area, Ningxia 1 - Main Scarp; 2 - Slide Mass

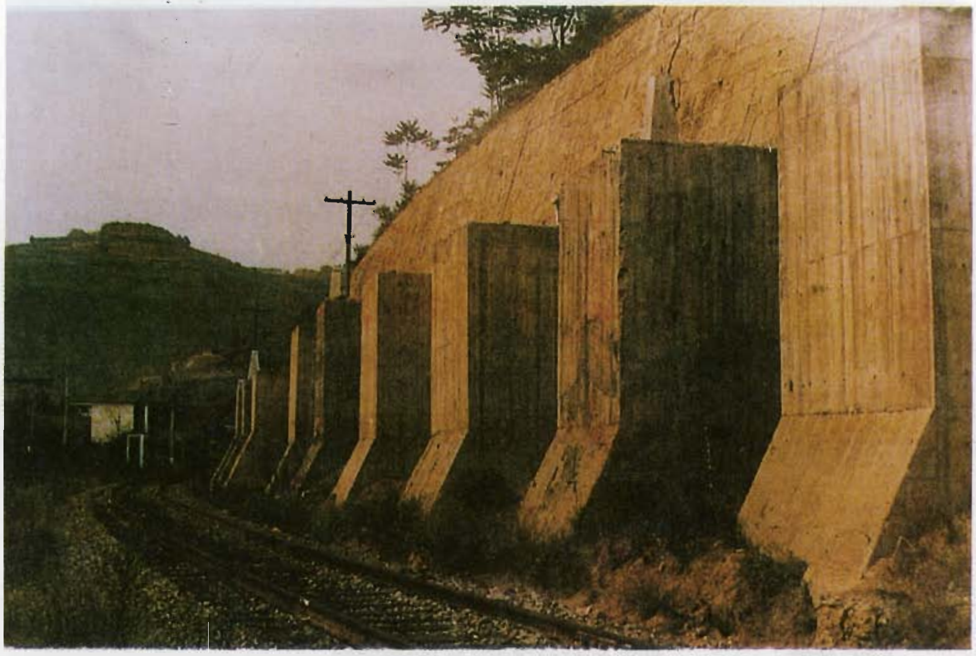

Plate 3: The Use of Skid-Resistant Piles and a Retaining Wall to Stabilise the Landslide, Hangcheng Power Plant, Shaanxi - *Ma Shouxin*

Plate 4: Stepped Checkdams to Control Landslides and Debris Flow in the Daqing Ravine of Daxueshan, Yongbi County, Yunnan - *Li Deji*

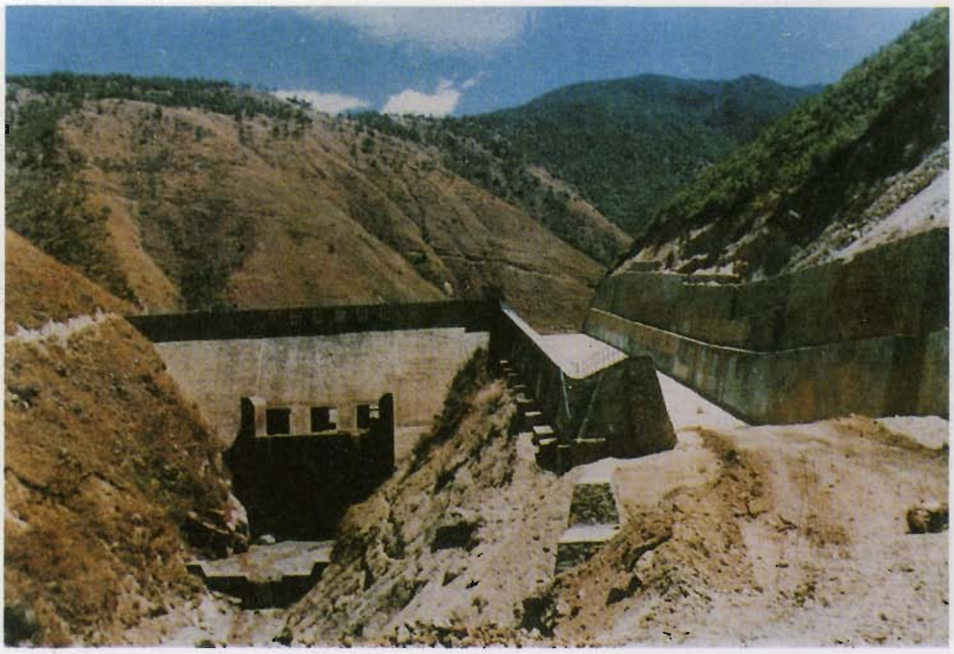

Plate 5: A Checkdam of 40m High with a Large Weir in the Yangjing Ravine, Mianning County, Sichuan - *Li Deji*

Plate 6: An Arched - Foundation - Masonry - Sifter Type Checkdam, 23m high, in Babuli Ravine, Jinchuan County, Sichuan - *Li Deji*

Plate 7: A Sawtooth-Type Checkdam, 10m High in the Babuli Ravine, Jichuan County, Sichuan - *Li Deji*

Plate 8: A Sparse - Tooth Checkdam on the Bashan River, Yongsheng County, Yunnan - *Li Deji*

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Other publications on natural hazards are:

- Landslide Hazard Management and Control in Pakistan
- Landslide Hazard Management and Control in India
- Landslide Studies and Management in Nepal
- Climatic Atlas of Nepal

Participating Countries of the Hindu Kush-Himalayan Region

* Afghanistan
* Bhutan
* India
* Nepal
* Bangladesh
* China
* Myanmar
* Pakistan

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