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LANDSLIDE MANAGEMENT IN THE MOUNTAIN AREAS OF CHINA

Li Tianchi

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Landslide Management in the Mountain Areas of China

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1. Debris flow from the watershed temporaily blocked the Xiao River (immediate foreground). View looking westwards of large landslide above Xiabeini Ravine on hillside; alluvial fan of debris flow (centre).

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Foreword

Natural hazards are inherent in mountain environments. Of these, landslides probably constitute the most common and dreaded hazard for mountain people everywhere. This is particularly true for the mountainous regions of the Hindu Kush-Himalayas where the mountains rise suddenly from near sea level to close to tropospheric heights within a span of 200 km or less. Such a high energy environment with very steep slopes is the home of millions of people and loss of life and property due to landslides is almost an integral feature of life in these mountains.

Landslides are estimated to cost more than US $ 1 billion in economic losses and to cause more than 200 deaths each year (30 per cent of the world total of such fatalities) in the Himalayan Region. Large-scale deforestation, unplanned urban growth, and badly engineered mountain roads have been major contributing factors more recently. Nearly every country in the Region is prone to serious damage from landslides. In China alone, the annual loss due to landslides is estimated at 0.5 billion U.S. dollars, and the number of landslide-related deaths per year is estimated to exceed 140.

Although it could be said that the occurrence or non-occurrence of landslides depend mainly on natural causes and factors, such as the geological and geohydrological characteristics of any locality (or region), exogeneous factors such as intense precipitation over a short time interval and earthquakes also trigger and accelerate landslides. Similarly, growing human and animal populations in the mountainous regions of the Hindu Kush-Himalayas have also created other imbalances such as deforestation and encroachment on to steep slopes. More recently, construction and mining activities have also increased as have the factors that cause landslides. Hence, the complexity of these causes has increased, due to natural and human factors, and along with these the human and economic consequences of such incidents have also become more damaging, adding to the miseries of people who are already in the grip of poverty. It is in this context that a proper understanding of the physical processes, as well as human interventions, that lead to increased incidences of landslides along with the methods and techniques of managing and monitoring landlsides, to minimise loss of life and property, is a priority for all concerned with the well being and development of the mountain people.

ICIMOD's primary concern being the sustained and balanced development of the people of the Hindu Kush-Himalayas, one of its major concerns is the minimisation and mitigation of hazards - whether natural or man-made. Considering that, for rapid development, human interventions in the mountains will increase, ICIMOD considers it important to have a better understanding of the geophysical and man-made processes that cause landslides as well as of the enhanced ability to provide technical solutions to such problems.

The Mountain Environmental Management Programme of ICIMOD is endeavouring to respond to some of these challenges facing the mountain environment in this Region. To examine these and other major issues concerned with environmental management in the mountains an **International Symposium on Mountain Environmental Management in the Hindu Kush-Himalayan Region** was organised by ICIMOD under this programme from 11 to 14 April, 1989. This paper was prepared within the framework of ICIMOD's ongoing programme on Mountain Environmental Management and was also presented at the Symposium as one of the theme papers along with others dealing with major issues of the mountain environment.

Professor Li Tianchi, who, until recently, was associated with ICIMOD as Head of the Mountain Environmental Management Division, has a great deal of experience in Landslide Monitoring and Management in China. As he has pointed out in his paper, China has made significant achievements in the management of landslides and has developed new methods of predicting, mapping, and preparing inventories of landslides. It was therefore felt that much could be learnt from China's rich experience in this field by the publication of this work in an occasional paper. It is hoped that this will highlight the diverse issues related to landslides in the Hindu Kush-Himalayas and contribute to enhancing the capability of reducing the disastrous consequences of landslides within the limits of technological innovations and human ingenuity vis-a-vis unalterable natural causes and factors. Although the emphasis is on the Hindu Kush-Himalayan Region, it is also hoped that this publication will be of interest to all who are involved and concerned with landslides in mountain environments elsewhere.

Dr. E. F. Tacke
Director

Abstract

Located on the east coast of the largest continent (Eurasia) and on the western margin of the largest ocean (the Pacific), China has a land area of about 9.6 million km^2 and a population of more than one billion. In China, 66.5 per cent of the total land area is mountainous, and contains 33 per cent of the total population and 40 per cent of the total cultivated land. Landslides are of critical significance, especially in the Hengduan Mountain Areas of Southwestern China, the Loess Plateau Area, and Taiwan Island; including the Provinces of Sichuan, Yunnan, Guizhou, Hubei Xizang, Gansu, Shaanxi, Shanxi, and Taiwan.

Landslides are the result of a complex interaction of geologic and geographical environments, and have a variety of causes: heavy rains, melting snow or ice, earthquakes, volcanoes, deforestation, and human activities. Among these, earthquakes and heavy rainstorms constitute two of the most important landslide-inducing agents in the mountain areas of China. In addition, landslides are also triggered by road construction, deforestation, overgrazing, and exploitation of mineral resources. Increased population and construction in mountain terrains expose more people to the landslide problem and the economic consequences can often be quite serious.

Landslides destroy or damage residential and industrial developments, agricultural and forest land, and railways and highways. They also have a negative impact on the quality of water in rivers and streams. In China, landslides caused at least US $ 0.5 billion in economic losses per year during the period from 1951 to 1987. Damages to transportation facilities, mainly railways and highways, constitute a significant part of total landslide costs.

Apart from the substantial loss of property, landslides killed an average of 140-150 people annually during the period from 1951 to 1987. Mortality figures due to landslides exceeded 257,000 during the period from B.C. 186 to A.D. 1987. The large number of landslide deaths in China is related to earthquakes, very heavy rainfall, and flooding due to the destruction of landslide dams.

Since the 1960s, a great deal of effort has gone into the reduction of landslide hazards. Many mitigative techniques, such as regional landslide studies and mapping, monitoring and warning systems, and landslide control works, have been developed.

Regional landslide studies and mapping are considered to be the first step in coping with landslide disasters on a regional basis. During the last ten years, regional landslide investigations at various levels, from the provincial to the small local watershed areas, have been carried out. Consequently, it has been possible for various government organizations to publish landslide distribution and susceptibility maps on different scales by using a variety of parameters.

Since the 1970s, a number of landslide and debris flow observation and monitoring stations have been established. The most common methods of monitoring include field observation and surface measurement; and, in addition, the use of inclinometers, extensometers, tiltmeters, and pipe strain gauges. A monitoring system for Xintan Landslide, Western Hubei, 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 monitoring data, a landslide of 20 million m^3 on the upper slopes of Xintan Town, which occurred on June 12, 1985, was accurately predicted. The 1,371 local inhabitants of Xintan Town were safely evacuated.

The relationship between antecedent precipitation and rainfall intensity has been established to predict debris flow by the Dongchuan Debris Flow Observation Station of the Chinese Academy of Sciences. The accuracy of debris flow forecasting is as high as 85 per cent. Debris flow and landslide warning systems have also been installed in some ravines that are susceptible to

debris flow and in potential landslide areas along the railway lines from Chengdu to Kunming and from Tianshui to Baoji. When the specified safety conditions are exceeded, the railways are closed.

The control of landslides in China is undertaken as follows:

- by avoidance: by relocating, bridging, tunnelling;
- by surface drainage: channelling or ditching, preventing water leakages;
- by sub-surface drainage: tunnelling, deep seated counterfort drains, vertical and horizontal drilling of drainage holes;
- by support structures: retaining walls, anchoring of retaining walls, crib work, gabion stabilizing trenches, piling works;
- by excavation: removing, flattening, and benching;
- by river structure work: damming for erosion control and consolidation: consolidation of dams; revetment bolts, vaulting, and construction of spur dikes; and
- by other methods: planting vegetation, blasting, and hardening.

Physical landslide control measures actually carried out in the landslide areas are based on certain concepts. Priority is given to preventing the loss of human life; followed by the preservation of public structures, buildings, and roads. Flooding control measures are undertaken in areas where slides are likely to dam rivers. The best methods of preventing landslides in watershed areas are the reforestation of slopes and construction of check dams in the valleys.

China has a natural disaster insurance programme that covers losses from landslides. This programme assists those whose dwellings and farmlands have been damaged by landslides or other natural hazards.

In recent years, losses from landslides have increased. This is largely due to the fact that residential and industrial developments have expanded on to steeply sloping terrain, and these areas are prone to landslides. Although the recent progress in landslide control techniques has made it possible to solve some landslide problems, there remains a great deal to be done in order to reduce landslide hazards in mountain areas.

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I. Introduction

In China, 66.5 per cent of the total land area is mountainous and geologically complex. Rocks from the Precambrian to the Holocene Age have been deformed repeatedly since Paleozoic times resulting in extremely complicated geologic structures. Because of complex and weak geologic structures and rugged mountain topography, high-intensity rainfall and frequent earthquakes contribute to the significant vulnerability to landslides in the Chinese mountain areas, especially in the Hengduan Mountain Region of Southwestern China, the Loess Plateau Area, and Taiwan Island.

On the other hand, there are abundant resources such as water for power; mineral and forest resources; and rare animals and plants in the mountain areas. Thirty three per cent of the total national population live in mountain areas on 40 per cent of the cultivated land. Due to restrictive geographical conditions and differences in historical and social conditions, economic development is both uneven and slow to take place. Since the 1950s, to eliminate inequalities between the mountain and lowland areas of China, and to use the natural resources available in mountain areas, a great deal of effort has gone into developing and promoting their economy and culture. Rapid population growth, large-scale deforestation, and infrastructural development contributed to an increase in the damage caused by landslides. In recent years, huge quantities of geologic materials have been disturbed by the construction of large buildings; by quarrying and mining; and by building dams, reservoirs, and canals.

Other countries in the Hindu Kush-Himalayan Region, such as India, Nepal, and Pakistan, have also been subjected to serious damage from landslides (Bhandari 1987; Sharma 1974; and Shroder 1989). It is a problem that is aggravated by lack of environmental awareness, inadequate warning systems, incapacity to recognise hazards, and lack of infrastructure for disaster mitigation. It is now increasingly emphasized that there is an urgent need to improve the capacity to reduce landslide disasters in the vulnerable Hindu Kush-Himalayan Region.

This paper reviews the available information on the causes and impacts of landslides on mountain development and the techniques of landslide mitigation carried out in China. The purposes of the study are :

- to increase awareness by assessing the social and economic impacts of landslides;
- to develop a geologic and socioeconomic understanding of landslide problems associated with sound integrated mountain development; and
- to share this knowledge with other countries in this region in order to facilitate safer and cost-effective development in the Himalayas.

II. The Landslide Problem

In China, the recorded history of landslides goes back almost 4,000 years to B.C. 1789. The landslide of Wudu in Central China, which killed 760 people in B.C. 186, is probably the oldest record of such a disaster. Since that time, landslides have been a major source of social and economic loss for the mountain populations of China. Earthquake and rainfall-triggered landslides, used to be considered sensational events. However, during the past 40 years, other factors have added to landslide hazards. Population pressure forced the expansion of agriculture, at the expense of the forests, on to steeper slopes, and, at the same time, development projects in mountain areas, such as road and reservoir construction and exploitation of mineral resources, have accelerated the landslide process and increased the economic cost of landslide damage. Landslides have now become so widespread and commonplace that people in mountain areas consider them a part of their daily lives.

Major Fatalities due to Landslides

The large number of deaths from landslides in China is related to earthquakes, very heavy rainfall, and flooding caused by the failure of landslide dams. The landslide at Wudu in Central China, in B.C. 186, has already been mentioned above, but, during the present era, the Xintan Landslide in Zhigui killed more than 100 people in 100 A.D. In the 11th century, over 900 people were killed by the Shizipo Landslide which occurred in 1072 in Huaxian, Shaanxi Province.

Before the 18th Century, the greatest loss of life from landslides occurred in 1310, in Zhigui District, Western Hubei, when 3,466 people were killed. Similarly, more than 1,000 people were killed in 1561 by a landslide on the north bank of the Changjiang (Yangtze) River near Xintan, Zhigui District, Western Hubei Province.

The largest loss of life and property from landslides, however, took place in the 18th century. The first instance occurred when a group of loess landslides was triggered by the Tongwei Earthquake that occurred in 1718 in Gansu Province, Northwestern China, and that had a magnitude of 7.5 (M = 7.5). At least 40,000 people were killed on that occasion. The second event was related to flooding caused by a landslide and consequent dam failure at Momianshan in Luding, Western Sichuan. The flooding was caused by the earthquake of Kangding-Luding (M = 7.5) in 1786, and the resulting landslide dammed the Dadu River for ten days. When the landslide dam was overtopped and the dam failed, the flood extended 1,400 km downstream into Western Sichuan Province. The earthquake itself only killed 400-500 people but the flood took as many as 100,000 lives (Qui and Liu 1985).

During this century, the Haiyuan Earthquake (Dec. 16, 1920; M = 8.5), in Ningxia, triggered 675 large loess landslides and created more than 40 lakes (27 of them still exist). Close and McCormick (1922) reported that the landslides killed at least 100,000 people, accounting for half of the 200,000 deaths from this event.

An earthquake centred near Diexi, in Northwestern Sichuan Province (August 25, 1933, M = 7.5), caused a number of landslides and killed 6,800 people. In the town of Diexi, all but one of the 577 residents were buried by a huge landslide (Chang 1934). The Diexi Landslide formed a dam 250m high across the valley, along the upper reaches of the Min River, and created a lake. The dam was overtopped 45 days later and a flood of water rushed down the valley for a distance of 250 km, killing at least 2,423 people (Li et al. 1986).

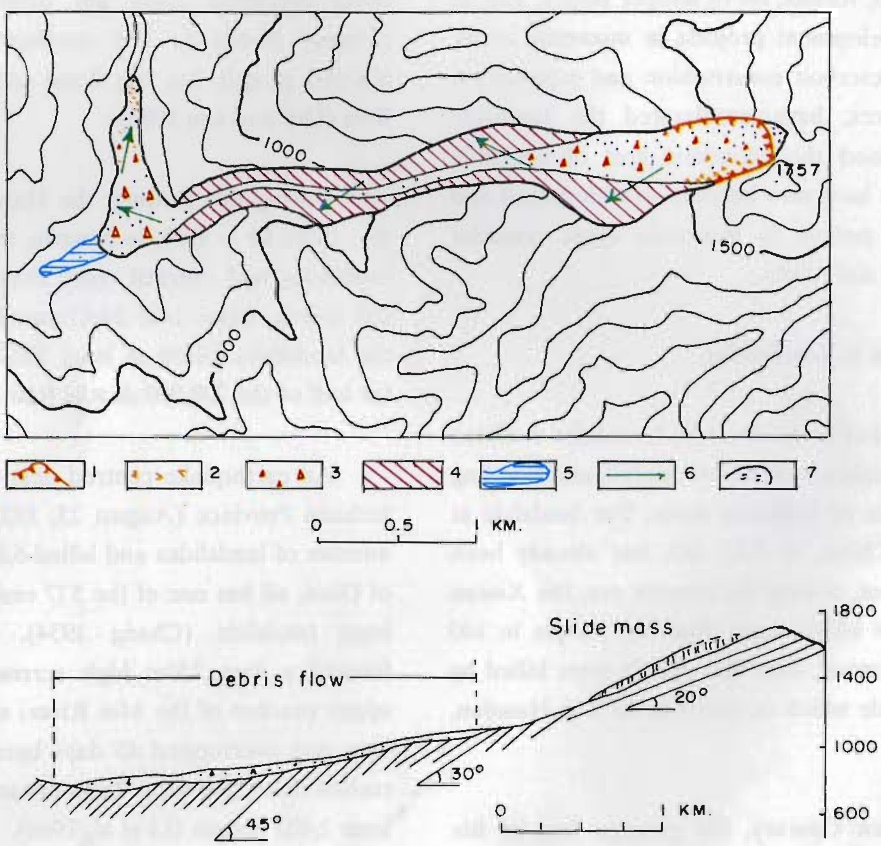
In May 1951, on the Chin-Shui Chi River, in Eastern Taiwan, several days of intense rainfall led to the overtopping and failure of the Tsao-Ling Rock Slide Dam. (The rockslide had been caused by an earthquake in December 1941). In the subsequent flood, 154 people were killed and 564 homes and 3,116 ha of croplands were damaged. The total loss was estimated at about U.S. $ 0.4 million (Sheng 1966 and Chang 1984).

In recent years, most deaths have been caused by major individual landslides. In the July of 1964, a large mudflow occurred in Lanzhou, the capital of Gansu Province; it killed 137 people, buried 366m of railway line, and disrupted railway traffic for 34 hours (Tang 1987).

In November 1965, a huge landslide at Luguan County in the northern part of Yunnan, ocurring in a rock mass of Permian basalt and tuff, created a sliding mass two kilometres wide with a volume of 450 million m^3. It advanced at high speed over a distance of six kilometres, buried four villages, and killed 444 people.

The Baimeiya Landslide, with a moving mass of 7 million m^3, occurred in Nanjiang County, Northern Sichuan, in September 1975, on a slope formed from Triassic carbonate. The rock slide moved 3.5 km at high speed (estimated to be 40 m/s) and killed 195 people (Fig. 1) (Li et al. 1984).

Figure 1: Sketch Map (A) and Cross-Section (B) of the Baimeiya Landslide in Nanjian District, North Sichuan



Source : Li et al. 1984.

Notes :

1. Head Scarp Area.
2. Remaining Slide Deposits.
3. Debris Flow Deposits.
4. Multiple-stroke Dive and Upthrust Area.
5. Slide-dammed Lake.
6. Direction of Landslide Movement.
7. Potential Landslide Area.

More recently, on July 3, 1980, a rockslide occurred on the upper reaches of the Yanchi River in Yuenan County, in the western part of Hubei Province. A rock mass of about 700 thousand m^3 fell from 200m and advanced about 38 m up the opposite slope. The slide destroyed buildings belonging to Yanchihe Phosphorite Mine and claimed 284 lives (Fig. 2) (Sun and Yao 1984).

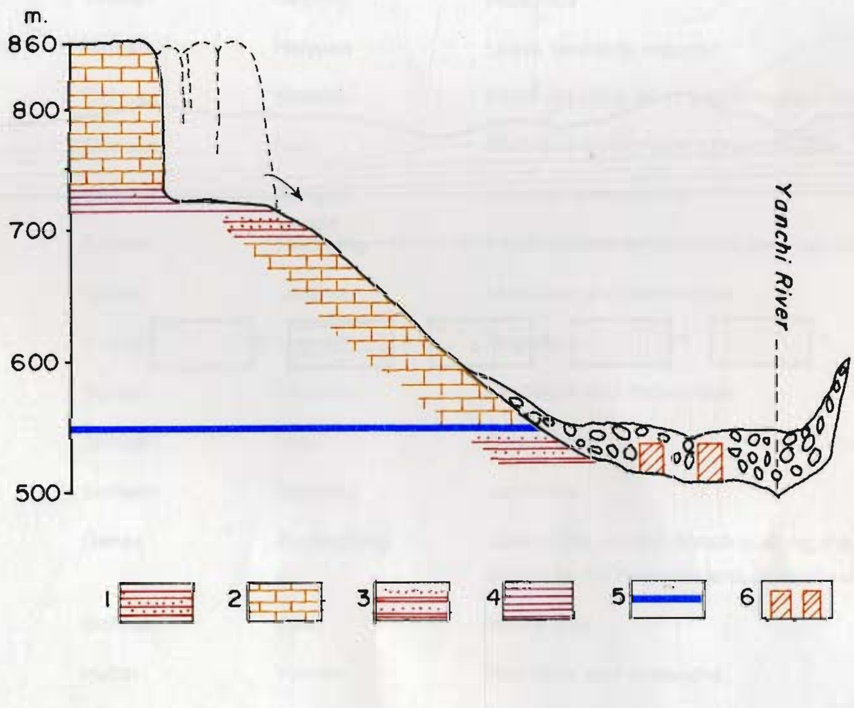
A loess landslide occurred at Saleshan on March 7, 1983, in Dongxiang County of Gansu Province. The total volume of the landslide was about 35 million m^3, and it covered an area of 2.7 km^2, buried four villages, filled two reservoirs, and killed 277 people (Fig. 3).

During the rainy season of 1984, heavy rainfall triggered more than 1,000 landslides in Wudu and Tianshui prefectures, in the southern part of Gansu Province. In Wudu Prefecture alone, there were 570 landslides that placed 14,245 families, with a total of 70,049 people, at risk. Two hundred and thirty-one landslides were severe enough to necessitate the evacuation of 6,019 families. In the same year, 300 landslides took place in Xiheli County, and 15,000 buildings collapsed with a consequent loss of 128 lives.

In 1984, unusual amounts of rain caused a number of landslides in the Loess Plateau Area of Shaanxi Province. More than 99 people were buried by landslides in Yulin and Tongchuan prefectures, although pre-landslide forecasting and subsequent rescue work saved many lives (Han and Hu 1985).

Although there have been some very large and catastrophic slope failures in the Qinghai-Xizang Plateau Region, most have occurred in the high mountains where few people live. However, recently, there have been two notable exceptions. The first was in July, 1954, when a flood was caused by a glacier-dam failure at Sewang in

Figure 2: Dolomite Rock Fall/Slide in the Yanchi River Valley of Yuenan District, Hubei Province



Source : Sun and Yao 1984.

Notes :

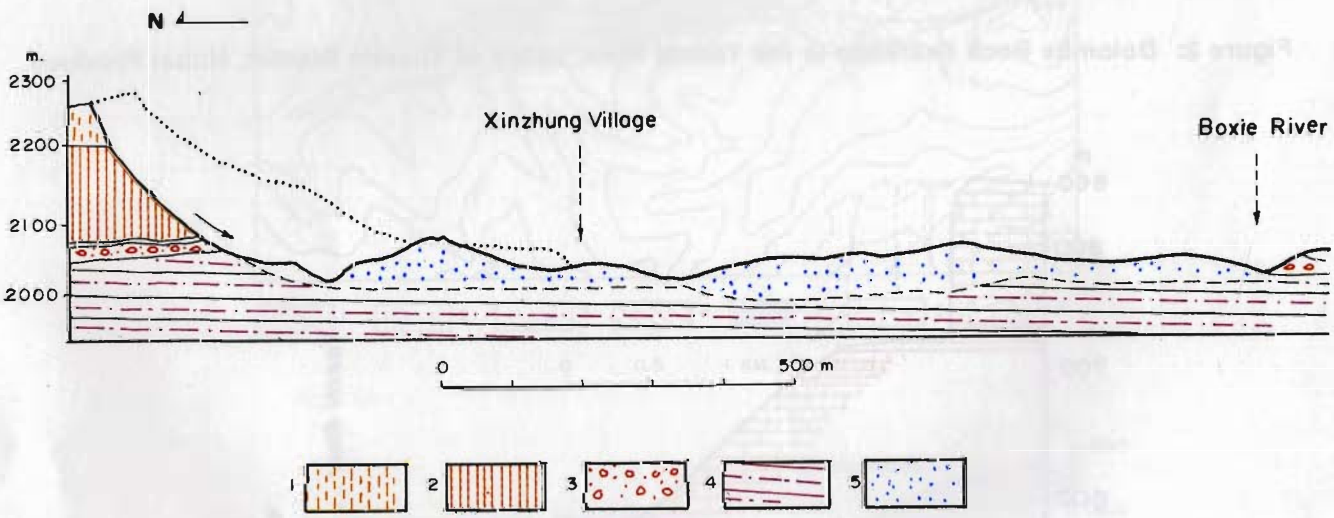
1. Silty Shales.
2. Thick Dolomite.
3. Mudstone and Silty Shales.
4. Thin Platy Dolomite.
5. Phosphorite Deposits.
6. Buildings of the Yanchi River Phosphorite Mine.

Jiangzhi District, South Xizang. At least 450 people were swept away by the flood. The second was a catastrophic rock avalanche in the Karakorum Mountains of Northwest Xizang, during construction of the Karakorum Highway in the 1960s. About 150 soldiers were buried by the avalanche.

Some of the best-documented of the major catastrophes, derived from historical and technical records as well as the author's experiences, are presented in Table 1. The Table lists all the landslide disasters since 186 B.C. that have claimed more than a 100 lives. The total number of deaths was more than 257,000, during the period from 186 B.C. to 1987 A.D.

According to the technical records of the eight provinces that are most severely affected, a rough estimate of the number of deaths, caused by all kinds of landslides gave a figure of over 4,000 for the 36-year period from 1951 to 1987 (Fig. 4). An average of more than 110 people per year were killed by landslides. In fact, the deaths caused by landslides are not adequately reflected by the figures given above because there are some events that are recorded, but unknown to this

Figure 3: Loess Slide at Saleshan in Dongxiang District, Gansu Province



Source : Wu and Li 1986.

Notes :

1. Loess
2. Older Loess.
3. Gravel and Loam.
4. Mudstone.
5. Slide Deposits.

Table 1: Landslides with Mortality Rates of At Least One Hundred People

No.	Year	Province	Affected Area	Type of Slope Failure	No.of deaths
1.	B.C. 186	Gansu	Wudu	Rock and debris avalanche	760
2.	100	Hubei	Zhigui	Rockslide and avalanche	>100
3.	689	Shaanxi	Huaxian	Loess and rockslide	>100
4.	1072	Shaanxi	Huaxian	Rockslide and avalanche	>900
5.	1310	Hubei	Zhigui	Rockslide and avalanche	3466
6.	1558	Hubei	Zhigui	Rockslide and avalanche	>300
7.	1561	Hubei	Zhigui	Rockslide and avalanche	>1000
8.	1718	Gansu	Tongwei	Earthquake-induced landslide	40,000
9.	1786	Sichuan	Luding	Flood resulting from landslide-dam failure	100,000
10.	1847	Qinghai	Beichuan	Loess and rockslide	Hundreds of deaths
11.	1856	Sichuan	Qianjiang	Rockslide induced by earthquake	>1,000
12.	1870	Sichuan	Batang	Rockslide induced by earthquake	>2,000
13.	1897	Gansu	Ningyuan	Loess and rockslide	>100
14.	1971	Yunnan	Daguan	Rockslide	1,800
15.	1920	Ningxia	Haiyuan	Loess landslide induced	100,000
16.	1933	Sichuan	Maowen	Flood resulting from landslide-dam failure	2,429
17.	1935	Sichuan	Huili	Rock and debris slide by earthquake	250
18.	1943	Qinghai	Gonghe	Loess and mudstone	123
19.	1951	Taiwan	Tsao-Ling	Flood caused by landslide-dam failure	154
20.	1964	Gansu	Lanzhou	Landslide and debris-flow	137
21.	1965	Yunnan	Luguan	Rockslide	444
22.	1966	Gansu	Lanzhou	Landslide and debris-flow	134
23.	1972	Sichuan	Lugu	Debris flow	123
24.	1974	Sichuan	Nanjiang	Landslide	195
25.	1975	Gansu	Zhuanglong	Loess slide caused flooding along the shores of the reservoir and downstream	>500
26.	1971	Sichuan	Yaan	Debris flow	114
27.	1980	Hubei	Yunnan	Rockslide and avalanche	284
28.	1983	Gansu	Tongxiang	Loess landslide	277
29.	1984	Yunnan	Yinmin	Debris flow	121
30.	1984	Sichuan	Guanlue	Debris flow	>300
31.	1987	Sichuan	Wushuan	Rock avalanche	102

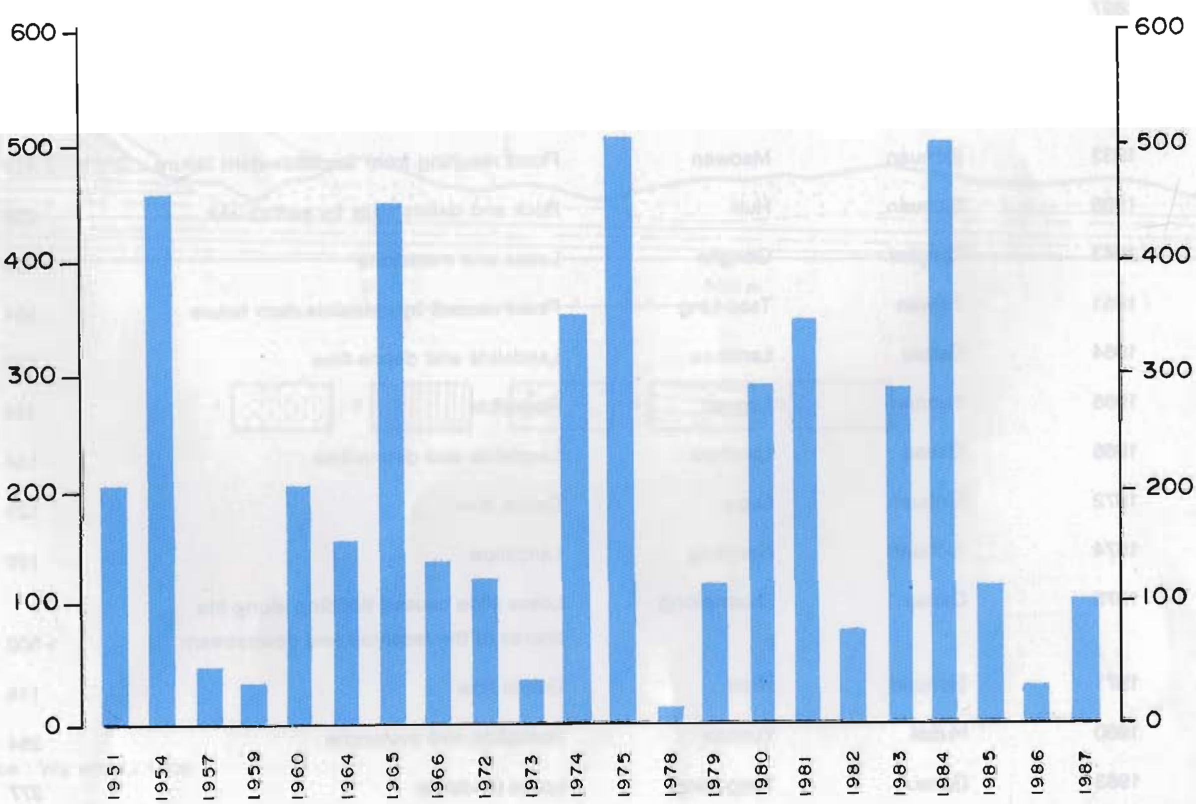
Source : Collated by author from historical and technical records.

author, and others that have never been recorded at all. Conservatively speaking, the number of deaths caused by landslides annually in China over the past 36 years could be in the region of 150 (Li 1989).

Impact of Landslides in Other Regions of the World

Deaths caused by catastrophic landslides are a worldwide phenomenon, and the rapid increase of population during this century has augmented the problem. Varnes (1981) reported that, during the period from 1971-1974, an average of nearly 600 people per year, worldwide, were killed by landslides. In Japan, 150 people per year died as a result of landslides during the period from 1967 to 1982 (Ministry of Construction 1983) (Table 2). Table 3 gives an indication of the number of deaths and the extent of damage caused, from 1938 to 1981, by the most catastrophic landslides in Japan. In the United States, the number of landslide-related fatalities exceeds 25 annually (Schuster and Fleming 1986). In Nepal, the statistics show that 60 lives have been lost annually from 1970 to 1980 (Dikshit 1989). Eisbacher and Clague (1984) compiled more than 100 case histories derived from historical and technical records on major landslides that had taken place in the Central European Alps over the last 2,000 years. Some of the best-documented of the major catastrophes are presented in Table 4. In comparison with fatalities caused by landslides in the above mentioned countries, the available information shows that China has suffered more fatalities from landslides than any other nation in the world.

Figure 4: Mortality from All Types of Landslides (1951 to 1987)



Source: Collected by the author from the statistical records of the eight concerned provinces.

Impact of Landslides on Development

Since the 1950s, in order to develop the economy and to use the abundant natural resources in mountain areas, large-scale financial investments have been made in development projects in mountain areas. At the same time, landslides have been triggered by road construction, deforestation, overgrazing, and exploitation of mineral resources. In the mountain areas of many provinces of China, landslide impacts on development are great and are apparently growing. Landslides destroy or damage residential and industrial developments, agricultural and forest land, and railways and highways; they also have a negative impact on the quality of water in rivers and streams.

Impact on Mountain Urban Development

Some of the large mountain cities, such as Chongqing, Wanxian, Dukou, Lanzhou, and Baoji, are located in landslide-prone areas or dangerous debris flow and mudflow areas. Landslides in urban areas have been particularly costly.

In July 1964, a large mudflow in Lanzhou, the capital of Gansu Province, killed 137 people, buried

Table 2: Deaths in Japan Caused by Floods and Landslides (1967 - 1982)

Year	(A) Deaths Caused by Floods and All Types of Landslides	(B) Deaths due to Mudflows and Debris Flows	(C) Deaths Caused by Other Types of Landslide	Percentage of Deaths Caused by Landslides (B+C)/[A] (x100 per cent)
1967	603	297	158	75.4
1968	259	154	5	61.4
1969	183	32	82	62.3
1970	175	22	27	28.0
1971	376	53	171	59.6
1972	637	194	239	68.0
1973	81	19	18	45.7
1974	239	40	129	70.7
1975	202	71	49	59.4
1976	242	72	81	63.2
1977	54	12	8	37.0
1978	110	16	24	36.4
1979	202	4	23	13.4
1980	114	0	25	21.9
1981	92	13	20	35.9
1982	508	152	185	66.3
Total deaths	4,077	1,151	1,244	
Average no. of deaths/year	355	72	78	
Overall percentage of deaths caused by landslides				59

Source: Ministry of Construction 1983.

Notes: Unpublished data from 1982 provided by the Ministry of Construction (Japan). For this 16-year period, landlisdes caused 59 per cent fo all deaths due to floods and landslides combined.

Table 3: Losses Caused by Major Landslide Disasters in Japan (1938-81)

Date	Prefecture	Severely Affected Area	Number of Dead or Missing	Number of Houses Destroyed or Badly Damaged
July 1938	Hyogo	Mount Rokko (Kobe area)	505	130,192
July 1945	Hiroshima	Kure City and its environs	1,154	1,954
Sept. 1947	Gumma	Mount Akagi	271	1,538
July 1951	Kyoto	Kameoka	114	15,141
June 1953	Kumamoto	Mount Aso	102	-------
July 1953	Wakayama	Arita River	460	4,772
Aug. 1953	Kyoto	Minamiyamashiro	336	5,122
Sept. 1958	Shizuoka	Kanogawa River	1,094	19,754
Aug. 1959	Yamanashi	Kamanashi River	43	227
June 1961	Nagano	Ina Valley Region	130	3,018
Sept. 1966	Yamanashi	Lake Saiko	32	81
July 1967	Hyogo	Mount Rokko	92	746
July 1967	Hiroshima	Kure City and its environs	88	289
July 1972	Kumamoto	Amakusa Island	115	750
Aug. 1972	Niigaa	Kurokawa Village	31	1,102
July 1974	Kagawa	Shodo-shima Island	29	1,139
Aug. 1975	Aomori	Mount Iwaki	22	28
Aug. 1975	Kochi	Niyodo River	68	536
Sept. 1976	Kagawa	Shodo-shima Island	119	2,001
May 1978	Niigata	Myoko-Kogen	13	25
Oct. 1978	Hokkaido	Mount Usu	3	144
Aug. 1979	Gifu	Horadani	3	16
Aug. 1981	Nagano	Ubara	10	56

Source: Ministry of Construction 1983.

Notes: All these disastrous mass movements were caused by heavy rainfall, most commonly related to typhoons; none were triggered by earthquakes or volcanic activity.

three kilometres of railway track, disrupted railway traffic for 34 hours, and inflicted considerable damage on the city. In August 1968, Lanzhou again suffered substantial loss of life and $ 1.1 million (U.S.) in damages because of a mudflow. During the past 35 years, 335 people have been killed by landslides and mudflows in Lanzhou City.

In Chongqing City, one of the largest cities in China, there have been more than 30 landslides during the past 30 years. In 1960, a landslide damaged a large transformer station, two workshops of the Chongqing Steel Plant, and other public property. In recent years, two landslides occurred in the central part of the city, damaged about 300 houses, and caused about $1.2 million (U.S.) in damages.

In Wanxian City, Eastern Sichuan, landslides, have caused $ 0.2 million (U.S.) in damages annually during the five year period from 1970-1975. Another $ 1 million (U.S.) was spent on stabilising a single landslide in the central city where a department store, cinema, bookstore, and several hundred private houses were destroyed in 1972 and again in 1973.

Panzhihua (Dukou) City, located on the boundary of Sichuan and Yunnan Province along the Jingsa (Yangtze) River, is an important industrial base for iron and steel. Since the city was built in the 1960s, 89 landslides have occurred and a great deal of damage has been caused (Lin 1989). A rough statistical estimate places the cost of landslide damages in Panzhihua City somewhere in the region of $ 0.3 million (U.S.) annually for the period from 1965 to 1985 (Li 1989).

In addition to the above, there are more than 100 county towns that are endangered and plagued by landslides and other mountain hazards. Most of these towns are located in the mountain areas of Sichuan; and the most notable among them are Baoxing, Daxian, Dege, Derong, Chengkou, Hanyuan, Heishui, Luding, Jinchuan, Kangding, Nanping, Ningnan, Xiangcheng, Xide, Xichang, Wushan, and Yaan. Altogether debris flows and landslides have caused economic losses to these towns of more than 30 million dollars (U.S.) during the past 40 years. Other areas affected include a dozen county towns in Yunnan, such as Dali, Deqing, Dongchuan, Nanjian, Qiaojia; more than ten cities in Gansu, such as Linxia, Tianshui, Wudu, and Zuoni; and Bomi, Dasu, Dingri, Jiangzi, Linzhi, Yadong, and Yigong in Xizang.

Impact on Transportation

Before 1949, there were 21,800 km of railway lines concentrated along the coastal areas of Eastern China and throughout the northeastern plain of China. There were no railways in the vast mountain

Table 4: Major Landslide Catastrophes in the Alps of Central Europe (1219 - 1963)

Year	Location	Type of Slope Failure	Number of Deaths
1219	Plaine d'Oisans (Romanche River Valley) France	Failure of landslide dam resulting in downstream flooding	"thousands" of casualties[a]
1248	Mount Grainer, France	Rock avalanche	1,500-5,000
1348	Dobratsch Massif, Austria	Earthquake-triggered rock falls and rock avalanches	Heavy loss of life[a]
1419	Ganderberg-Passeier Wildsee (Passer Valley)	Failure of rock-slide dam resulting in downstream flooding	At least 400
1486	Zarera (Val Lagune), Switzerland	Rock avalanche	300
1499	Kienholz (Brienzer See), Switzerland	Debris flow	~400
1515	Biasca (Val Blenio), Switzerland	Failure of rock-avalanche dam, resulting in downstream flooding	~600
1569	Hofgastein (Gastein Valley), Austria	Debris flow	147
1569	Schwaz (Inn Valley), Austria	Debris flow	140
1584	Corbeyrier-Yvorne (Tour d'Ai),Switzerland	Debris flow	328
1618	Piuro (Val Bregaglia), Italy	Rock-debris avalanche	~1,200
1669	Salzburg, Austria	Rock topple/rock fall	250
1806	Goldau (Rossberg Massif), Switzerland	Rock avalanche	457
1814	Antelao Massif (Boite Valley), Italy	Rock avalanche	300
1881	Elm (Sernf Valley), Switzerland	Rock avalanche	115
1892	St. Gervais (Arve Valley), France	Ice-debris flow	117
1963	Vaiont Reservoir (Piave Valley), Italy	Rock slide caused flooding along the shore of the reservoir and downstream	At least 1,900

Source: Eisbacher and Clague 1984.

Notes: a - Exact number of deaths is uncertain.

areas of Southwest and Northwest China, which were formerly less accessible to modern transport, and they were economically underdeveloped. In the past 30 years or more, improvement of transport facilities and the geographical distribution of transport lines were major strategies in national economic development; especially for mountain development. As a result, railway lines were constructed in the vast mountain areas.

In the mountain areas of the Southwest, the Chengdu-Chongqing, Baoji-Chengdu, Chongqing-Guiyang, Guiyang-Kunming, and Chengdu-Kunming railways were built, and, in the mountain and plateau areas of the Northwest, the Lanzhou-Xining, Xining-Golmul, and Lanzhou-Urumqi lines were opened, providing railway traffic for the first time to Qinghai, Xinjian, and Ningxia provinces. In the past 40 years, 261,100 km of lines have been laid, and most of them are located in mountain areas.

During the 1950s, because knowledge about landslide identification and prevention was scanty, excavations on ancient landslides reactivated them with disastrous results, causing tremendous damage to railway construction and transport. For instance, from 1954 to 1957, 2,163 large and small landslides occurred along an 848 km section of the Baoji-Chengdu Railway between Baoji and Shangxiba. Railway services were interrupted several times during that period, and the cost of repairs was 8,200 million *yuan* or $2,200 million (U.S.). Landslides have disrupted traffic for a total of 4,679 hours over the past 40 years on a 154 km section of the Baoji-Tianshu Railway, and the cost of repairs was $675 million (U.S.) (Ju and Gu 1987).

Based on the appropximate estimates collected from 1974 to 1976, China's mountain railway lines were subjected to more than 1,000 medium and large-scale landslides during that period (Fu 1982). Table 5 gives the number of landslides controlled along some of the mountain railways and Table 6 gives an indication of the cost of stabilising eight large individual landslides; the average cost of each stabilisation was about $ 1.75 million (U.S.). Based on the above figures, it is calculated that the total cost of more than 1,000 landslide stabilisations was approximately $ 2 billion (U.S.).

According to statistics collected by the Chengdu Railway Administration Bureau, in 1980 alone there were 963 slope failures which caused damage to railways in Southwestern China and interrupted the traffic for a total of 1,656 hours. Direct losses were at least $ 6 million (U.S.), the cost of interruption of transportation was $ 3 million (U.S.), and the cost of repairs was estimated to be about $ 9 million (U.S.).

Table 5: Landslides Controlled along Some of the Mountain Railways in China (1956 to 1987)

Name	Between	(Kilometres) (of track km)	Landslides
Baocheng	Baoji in Shaanxi and Chengdu in Sichuan	671	245
Chengkun	Chengdu in Sichuan and Kunming in Yunnan	1083	184
Guikun	Guiyang in Guizhou and Kunming in Yunnan	634	62
Chuanqian	Chongqing in Sichuan and Guiyang in Guizhou	425	96
Xiangyu	Xiangfan in Hubei and Chongqing in Sichuan	840	64
Xiangqian	Zhuzhou in Hunan and Guiyang in Guizhou	820	69
Yingxia	Yintan and Xiamen in Fujian	694	55
Waifu	Laizhou and Fuzhou in Fujian	192	20
Kunhe	Kunming and Hekou in Yunnan	469	62
Chengyu	Chengdu and Chongqing in Sichuan	505	56
Qiangui	Guiyang in Guizhou and Guilin in Guangxi	296	17

Source : Li and Xia 1987.

Table 6: The Cost of Stabilising Eight Large Individual Landslides

Name of Landslide	Name of Railway	Cost of Stabilization In Million $ (U.S.)
Xionjiahe	Baocheng	2.2
Junshimiao	Baocheng	0.9
Shizishan	Chenkun	0.4
Tiexi	Chengkun	6.6
K 118	Chuanqian	1.7
Dazhongxi	Xiangyu	0.23
Zhaojiatang	Xiangyu	1.53
K 163	Yingxia	0.44

Source : Li and Xiao 1987.

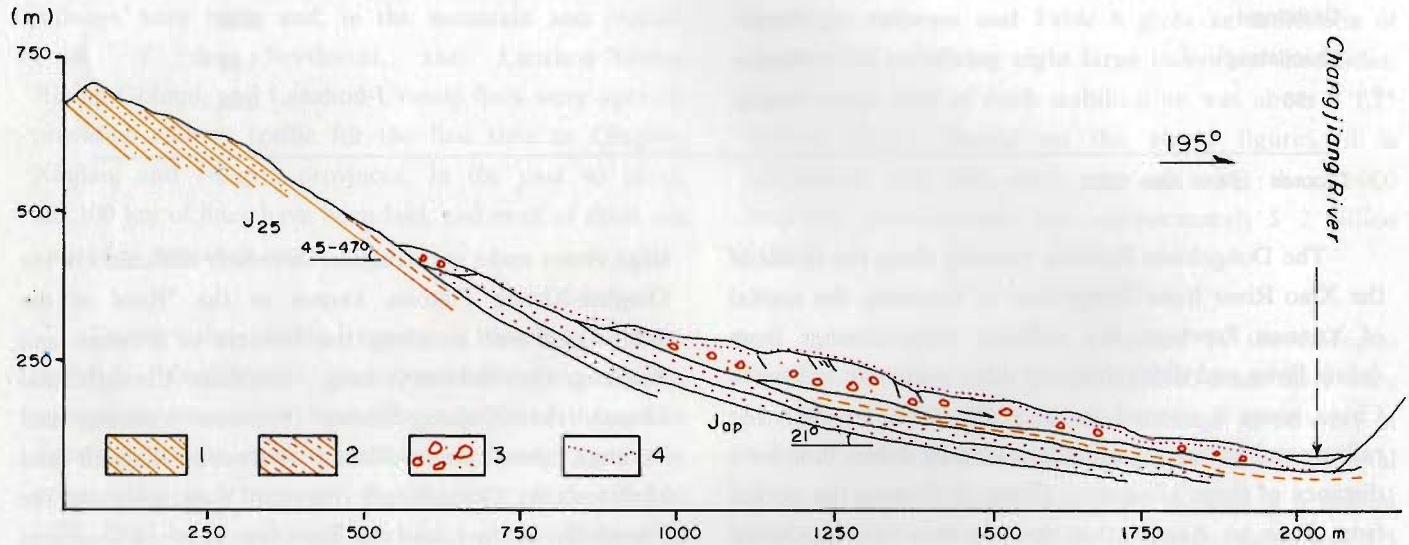
The Dongchuan Railway, running along the banks of the Xiao River from Dongchuan to Kunming, the capital of Yunnan Province, has suffered more damage from debris flows and slides than any other mountain railway in China, since it opened in the early 1960s. In 1981, the railway embankment was undermined by debris flow for a distance of three kilometres (Plate 1). During the period from June to August that year, intense storms caused debris flows in several tributaries of the Xiao River. One debris flow surged across the Xiao River from Dabaini Ravine and temporarily blocked the river, resulting in subsequent flooding and a dam that filled two railway tunnels, on the opposite side of the Xiao River, with sediment. The railway embankment was destroyed by the debris flows and was undermined in many places for a distance of several Kilometres (Plates 2 and 3). During 1985, the same railway line suffered an estimated 3 million dollars (U.S.) in damages, and it was closed for more than 240 days. The total losses were more than $ 10 million (U.S.). In 1986, the Dongchuan Railway again suffered a great deal of damage from landslides, and this time 180m of railway embankment was destroyed along with two railway bridges (Plate 4). Because the present railway has been disrupted by debris flow and landslides from time to time, the construction of an alternative alignment is being considered. The estimated construction cost for the new alignment is $ 27 million (U.S.).

China has paid particular attention to highway building in mountain areas, where the high mountains and large rivers make construction extremely difficult. On the Qinghai-Xizang Plateau, known as the "Roof of the World", as well as along the borders of Yunnan and Xinjiang, the Sichuan-Xizang (between Chengdu and Lhasa), the Xinjiang-Xizang (between Yecheng and Burang), the Yunnan-Xizang (between Xiaguan and Markam), the China-Nepal (between Yangbajing and the Friendship Bridge), and the Tianshan (between Dushanzi and Kugal) highways have been built during the past 40 years. According to 1985 statistics, there are 942,400 km of highways and roads in China; giving 11 times more roads than railways. The cost of damages caused by landslides on highways in China is, perhaps, greater than the cost for those caused on railways.

In many mountainous areas, highways and roads are closed by landslides in the rainy season. For example, in 1982, 894 landslides occurred along 848 km of roads and highways in the Fenjia District, Sichuan Province, and the total losses incurred were $ 1.2 million (U.S.). In 1984, about 3,244 landslides and debris flows damaged the main highways in Wudu and Tianshui prefectures and destroyed 457 bridges and culverts. In this same area, from 1964 to 1978, large debris flows killed 1,142 people, buried 17,544 buildings, and destroyed 2,266 ha of farmland.

The Sichuan-Xizang Highway, which starts at Chengdu in the east and extends 2,413 km westwards to Lhasa, has suffered seriously from landslides, avalanches, and debris flows year after year. In 1984, avalanches and

Figure 5: The Jipazi Slide (1982) on the North Bank of the Changjiang (Yangtze) River in Yunyang County, Sichuan



Source : Li and Liu 1987.

Notes :

1. Sandstone.
2. Mudstone.
3. Slide Deposits.
4. Slope Surface before Sliding.

debris flows in Belong destroyed three steel bridges, five suspension bridges, 10 km of highway, and many trucks. The traffic was disrupted for about seven months, and the total cost of this disaster was approximately $ 3 million (U.S.).

Impact on Mining Activities

Landslides have a significant impact on mining activities, and usually cause serious disasters; especially in the coal fields of Guizhou, Sichuan, Shaanxi, and Liaoning provinces. For instance, in the coal mining area of Liupanshi in West Guizhou, the direct costs of 19 landslides over the past 15 years have been estimated at $1.25 million (U.S.), and, over the same time period, indirect losses have been about $ 13 million (U.S.). In the Weibei Coal Fields of Shaanxi Province, 160 landslides have occurred since coal mining began in 1950. A large number of buildings has been destroyed and 54 people killed. More recently, the Xiangshan Landslide, located in the Hancheng Coal Mining Area, caused substantial economic loss when the foundation and upper structure of the Hangcheng Power Plant was deformed along with a ventilation shaft and railway tunnel; the damage cost $ 3 million (U.S.), and the cost of stabilisation was estimated to be about $ 25 million (U.S.); one of the highest in China (Wang 1987). In the Fushun Western Open Mine, Liaoning Province, 60 landslides have taken place since 1929, and the total cost incurred by the collective damage caused was estimated to be over $ 100 million (U.S.); excluding the indirect costs (Wu 1988).

More recently, on July 3, 1980, a rock slide occurred on the upper reaches of the Yanchi River in Yuenan District, in the western region of Hubei Province. A rock mass of about 700,000 m^3 fell from a height of 200m and rolled up on to the opposite hill slope for about 40m. The debris covered about 63,000 m^2 of the valley floor with a thickness of about 38m. The slide destroyed buildings belonging to the Yanchihe Phosphorite Mine and claimed 284 lives. Because of this landslide disaster, mining activities were disrupted for 3 years.

Impact on Navigation of Waterways

Mountain rivers are also adversely affected by landslides. The Changjiang (Yangtze) is China's most valuable river in terms of navigation. Linking many industrial cities and carrying a lot of passenger and freight traffic, this 6,300 km river is navigable throughout the year, but at least five large landslides have seriously obstructed navigation since 377 A.D. (Table 7).

The Jipazi Landslide was one of the biggest to take place along the Changjiang River. It occurred in 1982 in the Yunyang District of East Sichuan on a slope of sandstone and claystone formed during the late Jurassic period; its volume was 15 million m^3 (Fig.5). It destroyed 755 acres of farmland, a refrigeration plant, a hospital, and many other buildings resulting in a direct economic loss of $ 1.25 million (U.S.) (Plates 5-7). The front section of the slide had a volume of 2.3 million m^3 and slid down into the Changjiang River forming a barrier to navigation. The total costs for landslide stabilisation and dredging came to $ 32 million (U.S.) during the period from 1982 to 1986.

Floods from Rapidly Breached Landslide Dams

In the mountain areas of Southwest China, large landslides have frequently dammed the rivers, causing massive floods both upstream and downstream (Li et al. 1986). According to the historical records of various countries, the Min River in Northwestern Sichuan was dammed in 12 B.C., in 1436 A.D., and in 1713 A.D. In 1786, the Dadu River, in Western Sichuan, a major tributory of the Min River, was dammed for 10 days by an earthquake-induced rock slide/avalanche at Momianshan in Luding. The landslide dam was subsequently overtopped, causing a huge flood that spread 1,400 km downstream. The earthquake killed 500 people only, but the overtopping of the landslide-dam caused a flood that swallowed up as many as 100,000 people (Qui and Liu 1985). In 1880, the Jinsha River was completely blocked for three days by a major landslide and formed a lake more than 50 km long; when the blockage breached, flooding occurred for several hundred kilometres downstream. Figure 6 shows some of the major landslide-dam sites, including five major 20th century landslide blockages which occurred on the following Changjiang tributaries: Zhouqu Landslide Dam on the Bailong River (1981), Diexi Landslide Dam on the Min River (1933), Tanggudong Landslide Dam on the Yalong River (1967), Zepozhu Landslide Dam on the Dong River (1967), and Jiangjia Canyon Debris-Flow Dam on the Xiao River (1968).

The Flood Caused by Diexi Landslide Dam Failure (1933). An earthquake in Diexi (M=75), in the northwestern region of Sichuan Province, on August 25, 1933, triggered many landslides which resulted in three large landslide blockages on the Min River (Chang 1934, Li 1979a, and Earthquake Bureau of Sichuan Province 1983). From upstream to downstream, the three landslides and their corresponding blockages were named Yinping, Dachao, and Diexi (Fig. 7). The landslide dams and their complete or partial failures, due to overtopping and breaching, resulted in a complex story of lake formation, dam failure, and downstream flooding.

The Yinping Landslide Dam was formed by two rock slides/rock avalanches of metamorphic rocks descending the steep mountain sides on both sides of the river. The Yinping Blockage consisted of coarse rock debris, including large boulders (maximum diameter: 5m; average diameter: 0.8-1.0m), derived from metamorphic rocks with some dolomite. The original height of the Yinping Blockage was 156m; its length (cross-river) was 800m and its width (down-river) was 1,700m. Because the Yinping Landslide Dam was the farthest upstream of the three dams, it was the first to fill, impounding Da ("large") Lake (Fig. 7). The filling of Da Lake led to a sequence of events in September and early October (1933); these are described below (Chang 1934).

6 September - Da Lake was 12.5 km long and had a maximum width of about 1 km.

14 September - Da Lake overtopped Yinping Landslide Dam and flowed into the basin behind the Dachao Blockage forming a new, much larger lake (Fig. 7) that submerged three villages between the two blockages. Because the Yinping Dam was made up of

Table 7: Chronological Table Describing the Impact of Landslides on the Navigation of the Changjiang (Yangtze) River

Year	Location	Volume of Landslide Down to River (10^4 x m^3)	Impact on Navigation
377	Xintan Area	2600[a]	Dammed the river for a short time, forming a lake about 50 km long and obstructing navigation for many years.
1029	Xintan Area	1500[a]	Dammed the river for a short time and obstructed navigation along a 15 km section of the river for about 22 years.
1542	Xintan Area	860[a]	Blockage 2 km long obstructed navigation for 82 years and prevented navigation during the dry season.
1896	Xinglongtan	600[a]	Formed large rapids, obstructed navigation for 10 years, and prevented navigation during the dry season.
1982	Jipazi	180[a]	Formed low rapids and obstructed navigation for 4 years.
1985	Xintan	200	Flowed into the river, but did not impede navigation

Source: Li and Liu 1987.

Notes: a. Estimated volume based on field investigation.

Figure 6: Map Showing Locations of Various Landslide Dams in the Hengduan Mountain Area, Southwest-Central China

Source: Li and Liu 1987.

erosion-resistant rocks, much of which consisted of large blocks, this dam did not breach. Dachao Landslide Dam was formed by the Diexi Landslide, a deep-seated slump in rock and river sediments. It was lower than Diexi landslide dam, by about 30m.

30 September - Dachao Landslide Dam was overtopped. Water began to fill the entire basin behind the Diexi Landslide Dam (Fig. 7), and this was due to a 150 million m^3 complex landslide in bedrock and river sediments. The blockage was 255m high, 400m long (cross-river), and 1,300m wide (down-river). The largest lake formed (it was called Diexi Lake) was about 17 km long and attained a maximum volume of 400 million m^3.

7 October - At 7:00 p.m., Diexi Lake overtopped its landslide dam, which breached rapidly, causing severe flooding downstream. Three kilometres downstream from the blockage, the wall of water was about 60m high. Attaining an average velocity of about 30 km/hr en route, this wave reached the town of Maowen, 58 km downstream, in two hours. The total length of the Diexi Flood was 253 km and the average velocity throughout was 20-25 km/hr (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, a total of about 1,075 homes were destroyed.

The Flood Caused by the Tanggudong Landslide Dam Failure. The Tanggudong Landslide (Fig. 8) occurred on 8 June, 1967, on the east bank of the Yalong River (a major tributary of the Changjiang River) about 300 km WSW of Chengdu (Sichuan). The 68 million m^3 debris slide/avalanche was composed of colluvium and slope wash from sandstone formed during the Triassic period. Its deposits created a large dam of loose rock and soil across the Yalong that was 355m thick on the west side, 175m thick on the east side (low point on the crest of the dam), and that extended three kilometres along the river. The impounded lake attained a maximum length of 53 km and a maximum volume of 680 million m^3 (Investigation Team of the Tanggudong Landslide Dam 1967).

Nine days later, the lowest part of the dam crest was overtopped by the rising water; and, although the entire dam did not fail, it breached to a depth of 88 m over a 13 hour period. The resulting flood continued 1,000 km downstream along the Yalong and the Changjiang rivers to the city of Yibin. The height of the frontal wave of the flood was 50.4 m at a point six kilometres downstream from the landslide and 16.5 m at Xiaodishi; 551 km from the blockage. The maximum discharge of the flood, six kilometres downstream from the blockage, was a phenomenal 53,000 m^3/sec. Characteristics of the flood at several downstream stations are presented in Table 8.

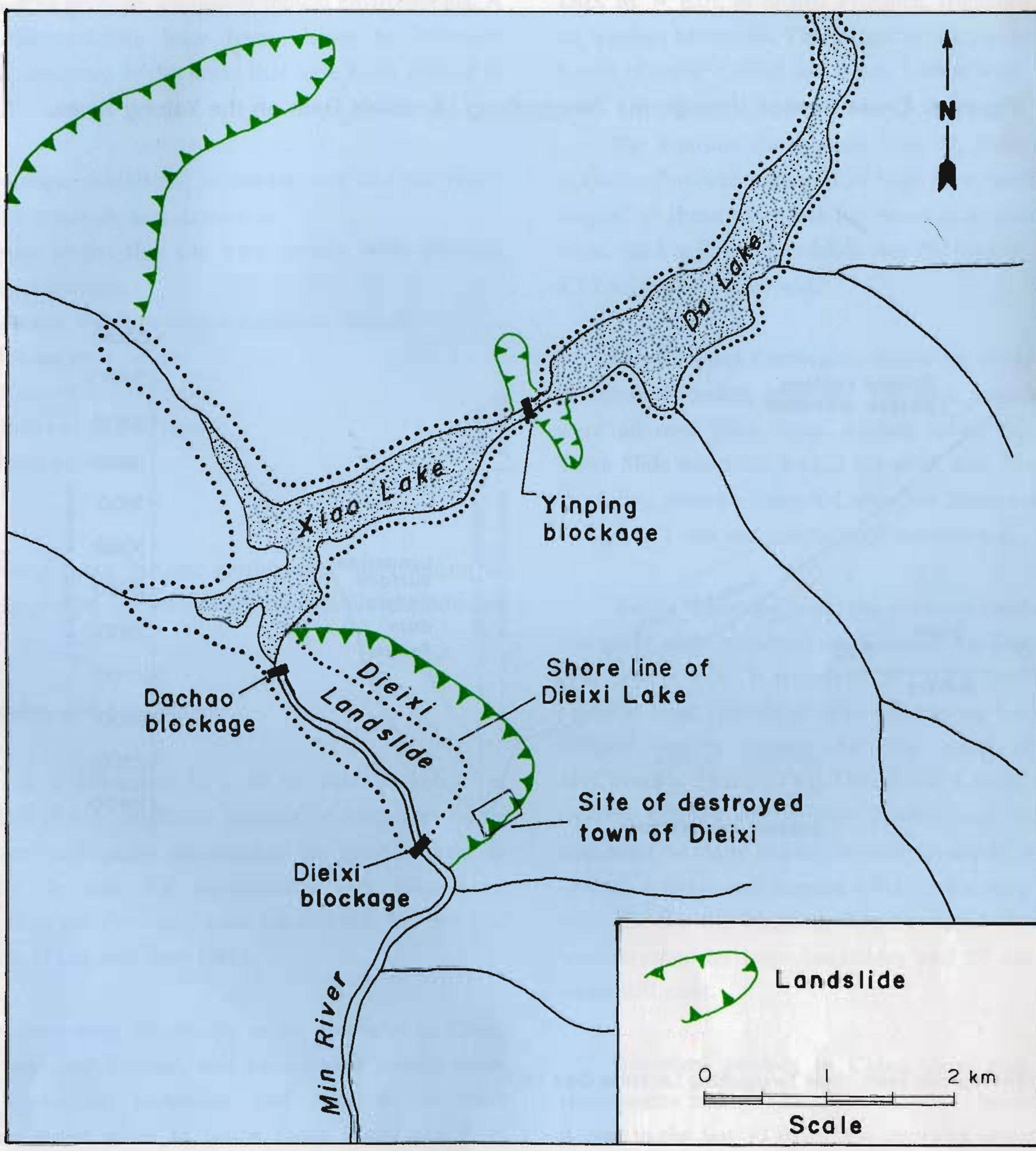
No deaths were caused by this flood because the downstream residences had been evacuated in anticipation of the catastrophe. However, damage to property was considerable, and the Investigation Team of the Tanggudong Landslide Dam (1967) noted the following damage along the Yalong River: 435 homes, 51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

Table 8: 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/sec	Maximum Flow. Qmax m^3/sec	Height of Flood, m.	Thickness of Sediment Deposited, m.
6	17/14:30	8.9	53,000	50.4	23
19	----------	---	-------	---	5
33	17/15:30	---	-------	1.5	---
214	18/0.06	6.8	30,000	29.6	---
310	18/4:00	6.8	26,000	20.4	---
551	18/16:30	4.0	18,000	16.5	---
1000	----------	---	-------	0	---

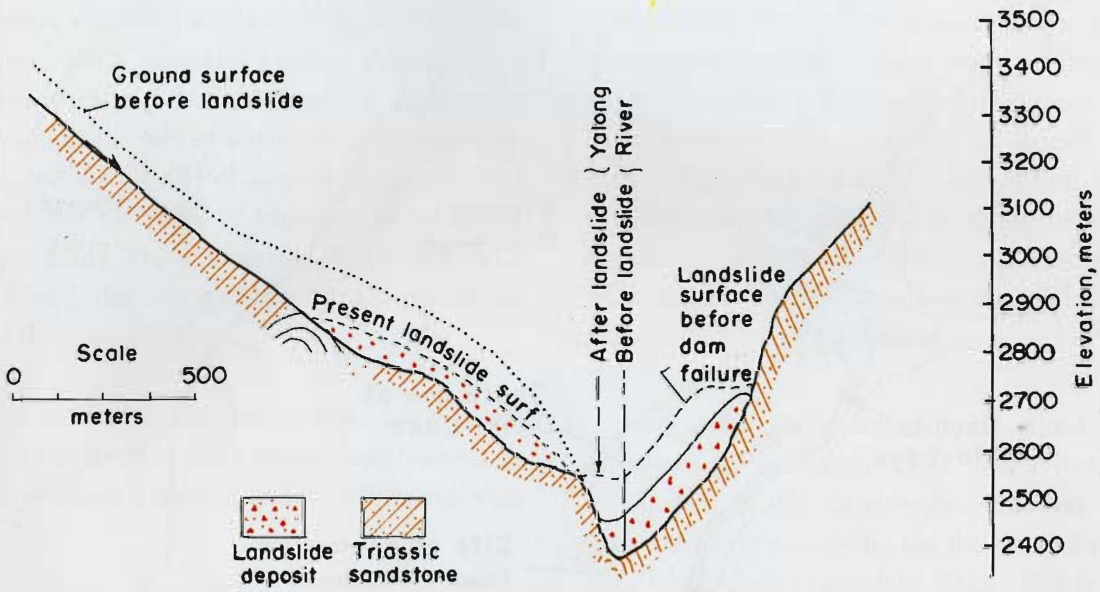
Source: Investigation Team of the Tanggudong Landslide Dam 1967.

Figure 7: Map Showing Landslide Blockages on the Min River Caused by the 1933 Diexi Earthquake, Northwest Sichuan Province



Source : Li et al. 1986.

Figure 8: Cross Section through the Tanggudong Landslide Dam on the Yalong River.



Source: Investigation Team of the Tanggudong Landslide Dam 1967.

III. Factors Causing Landslides

Landslides are the result of the comprehensive interaction of geologic and geographical environments. A number of variables have been shown to influence landslide processes in the areas that have been studied in China.

- Geologic conditions; including rock and soil types, their strength, and structures.
- Slope angle; this can vary greatly with different material types.
- Amount, duration, and intensity of rainfall.
- Melting snow or ice.
- Effects of earthquakes.
- Effects of deforestation.
- Man's activities.

Among these factors, earthquakes and rainstorms constitute two of the most important landslide-inducing agents.

Earthquakes and Landslides

China is subjected to a lot of earthquakes. It is recognized that a significant number of landslides occur only when earthquake magnitudes are greater than six (M = 6.0). At least 656 earthquakes with magnitudes greater than six (M = 6.0) took place from 780 B.C. to 1976 A.D. (Feng and Guo 1985).

The two most seismically active provinces in China are Sichuan and Yunnan, and earthquakes usually cause many large-scale rockslides and rockfalls in their mountain areas; some of which block rivers and form lakes. Landslides and avalanches were widespread during the earthquakes listed in Table 9.

Another seismically sensitive region is the Loess Plateau, (Northern China) where thousands of earthquakes have been recorded. Many of them have triggered large, disastrous landslides, and some of these are described below.

The earthquake in Hontong County (September 17, 1303, M = 8.0), in Shanxi Province, triggered landslides on Xunbao Mountain. The largest of the slip bodies had a length of about 1,600m and it was 1,400m wide.

The Tianshui Earthquake (July 21, 1654, M = 8.0) in Gansu Province triggered 59 huge loess landslides. The longest of these extended for more than 500m. Among them, the Luojiapao Landslide was the biggest, and it was 4.5 km long and 2 km wide.

The Tongwei Earthquake (June 19, 1718, M = 7.5) in Gansu Province, triggered 337 large landslides which were all over 500m long. Among them, the Yongning Town Slide was 8 km long, 3 km wide, and 7 km^2 in area; its sliding distance extended over five kilometres, burying Yongning Town and killing 2,000 inhabitants.

Within recorded time, the greatest earthquake has been one that occurred in Haiyuan on December 16, 1920 (M = 8.5). It triggered 675 loess landslides that killed at least 100,000 people; accounting for half of the 200,000 deaths caused by this event (Close and McCormick 1922). The Dangjiaca Landslide in Siji County slipped northwards 2,300m and then turned southeast at right angles, moved forwards about 950m to dam a river, and formed a lake 5 km long and 380m wide. In the Siji-Jingning Region, more than 40 lakes were created by large landslides and 27 out of the 40 lakes still exist.

Historical records in China show that numerous earthquakes have produced thousands of landslides, but it is only in the last 30 years that intensive investigations of these slope failures have been carried out (Li 1979a; Li 1979b; and Zhu 1989).

Between 1973-1978, a study was made of the landslides triggered by earthquakes, and it was found that there is a direct correlation between earthquake magnitude (M) and the total area (S) where seismogenic landslides and collapses might develop. It has been

Table 9: Some Historic Earthquakes of Southwest China and Their Effects

Date	Approximate Epicentre	Magnitude	Effects
February 26, 1713	Xundin (Yunnan)	6.5	Ground fissures, many slumps, and shallow slides in upper watershed of Xiao River.
August 2 1733	Dongchuan (Yunnan)	6.75	Fault rupture 100 km long. Many landslides; one large landslide buried a village on the Daqiao River, killing 40 people.
October 10 1786	Kangding-Luding (Sichuan)	7.5	Many landslides in the Dadu River and its tributaries. One huge landslide dammed the Dadu River for 10 days, causing a big flood downstream.
September 6 1833	Songming (Yunnan)	8	Ground fissures, liquefaction (sand boils), many landslides, and reactivated ancient landslides in upper and middle watersheds of Xiao River.
June 10 1856	Qianjiang	6	Many huge landslides and falls, one huge landslide dammed the Qianjiang River, forming a lake 10 km long which still remains.
April 11 1870	Batang (Sichuan)	7.5	Many major landslides and rock avalanches in the Jinsha River Valley dammed the river.
February 6 1973	Luhuo (Sichuan)	7.6	More than 200 landslides; 20 km highway destroyed by landslides and rock falls.
May 11, 1974	Zhaotong (Yunnan)	7.1	Extensive rock falls, slumps, and slides.
May 29, 1976	Longling (Yunnan)	7.4	Extensive shallow slides and slumps in weathered granite rocks.
August 16	Songpan (Sichuan)	7.2	170 landslides; three landslide-dammed lakes formed.

Source : Collated by author from historical and technical records,

calculated by using the standard least-squares method as applied to the logarithmic data values (S in km^2). The equations of the correlation can be given as :

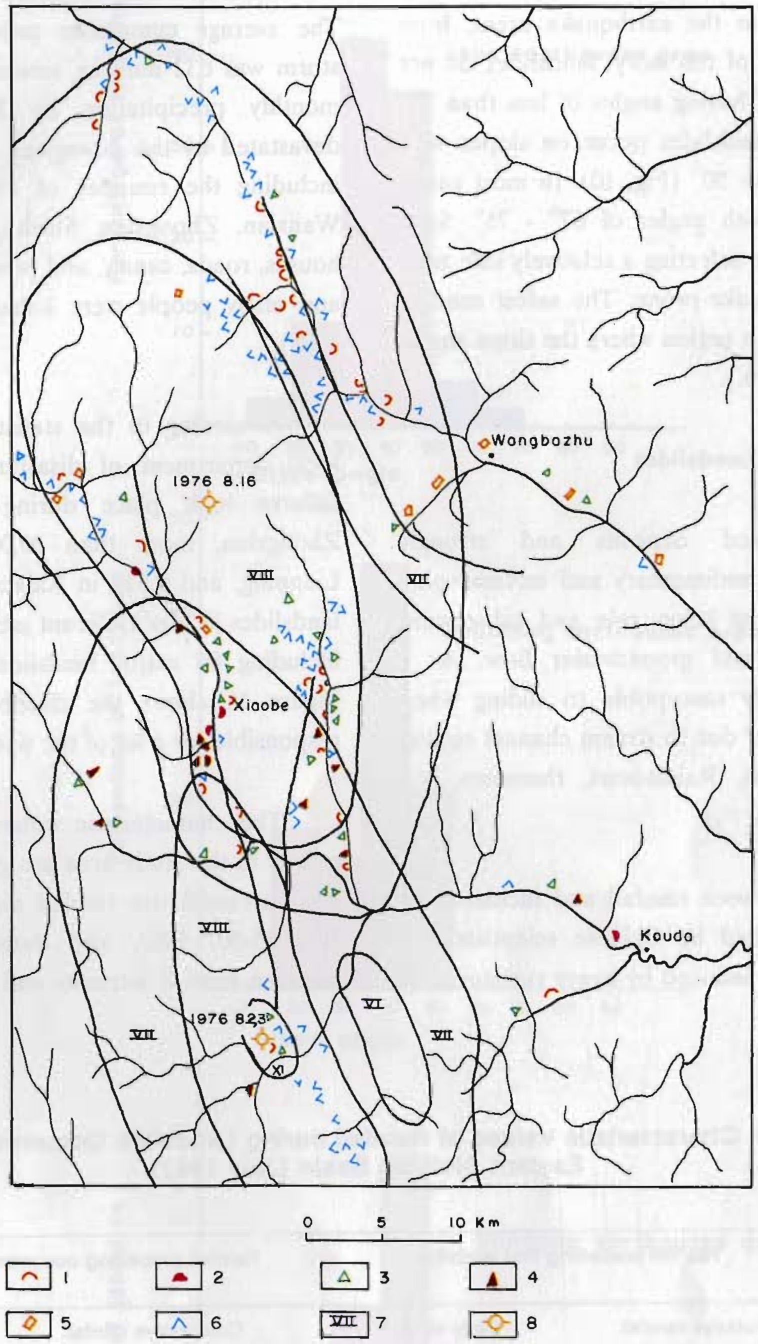
$$\log S = 0.9246\, M - 3.1089 \quad (1)$$
$$\log S = 1.0719\, M - 3.5899 \quad (2)$$

Equation (1) is applicable to mountain areas of Southwest China and equation (2) to North China (Li 1979a).

Apart from earthquake characteristics themselves (i.e., seismic accelerations, continuous time of shock, focal depths, and angle and direction of the approach of seismic waves), environmental factors, such as landform and drainage, play an important role in the formation of landslides triggered by earthquakes.

Geologic influences are reflected in both geologic structure and lithologic character. The landslides triggered by the Songpan Earthquake (August 16, 1976, M = 7.2), in the northwest of Sichuan Province, can be taken as an example. The earthquake induced more than 170 slumps, slides, and falls that occurred predominantly along the active tectonic faults in the strong seismic region (Fig. 9). On slopes consisting of loosened limestone and igneous rocks, the falls occurred readily, but, on the slopes consisting of claystone, shale, and phyllite, the falls were few in number.

Figure 9: Map Showing the Distribution of Landslides Induced by the Songpang Earthquake in 1976



Source : Li 1979b.

Notes:

1. Slide.
2. Ancient Slide.
3. Major Fall.
4. Ancient Fall Deposit.
5. Failed Larger Stone.
6. Shallow Slide.
7. Earthquake Intensity.
8. Earthquake Epicentre.

The types of slope and slope angles have a great influence upon the frequency of landslides and falls. Straight slopes seldom have landslides and falls, but they are common on convex, concave, and complex slopes, occurring mostly near the turning points of slopes. The statistical data gathered in the earthquake areas, from 1973 to 1976, tell us part of the story: landslides do not generally occur on slopes having angles of less than 25^o and 90 per cent of all landslides occur on slopes with angles ranging from 30^o to 50^o (Fig. 10). In most cases, falls happen on slopes with angles of 67^o - 75^o. Such figures are of great help in selecting a relatively safe zone in an area that is earthquake-prone. The safest zone in any mountain area falls in a region where the slope angles are less than 25^o (Li 1979 b.).

Monsoon Rainstorm and Landslides

Loose unconsolidated deposits and strongly weathered and fractured sedimentary and metamorphic rocks become saturated by heavy rain and subsequent excessive surface water and groundwater flow. As a result, they are especially susceptible to sliding when slopes are too steep, either due to stream channel cutting or man-made excavations. Rainstorms, therefore, are frequent landslide triggers.

The relationship between rainfall and incidence of landslides has been studied by Chinese scientists. An investigation of landslides induced by heavy rainstorm, in the eastern part of Sichuan Basin, about 240 km NNW of Chengdu, in 1982, can be cited as an example.

From 15-30 July, 1982, the eastern part of the Sichuan Basin was subjected to a continous rainstorm. The average cumulative precipitation from that single storm was 632 mm; an amount that exceeded the mean monthly precipitation by 340 per cent. The area devastated by the downpour covered about 21,000 km^2; including the counties of Fengjie, Kaixian, Liangping, Wanxian, Zhongxian, Shizhu, and Fengdu. Farmlands, houses, roads, canals, and power stations were destroyed, and many people were killed by landslides (Li and Li 1985).

According to the statistical data collected by the local department of disaster prevention, 81,199 slope failures took place during this event : 29,930 in Zhongxian, more than 20,00 in Yunyang, 11,100 in Lianping, and 8,517 in Kaixian. Three hundred and ten landslides in four different areas throughout the counties, including 85 major landslides, were studied in detail. Figure 11 shows the distribution of larger landslides responsible for a lot of the damage.

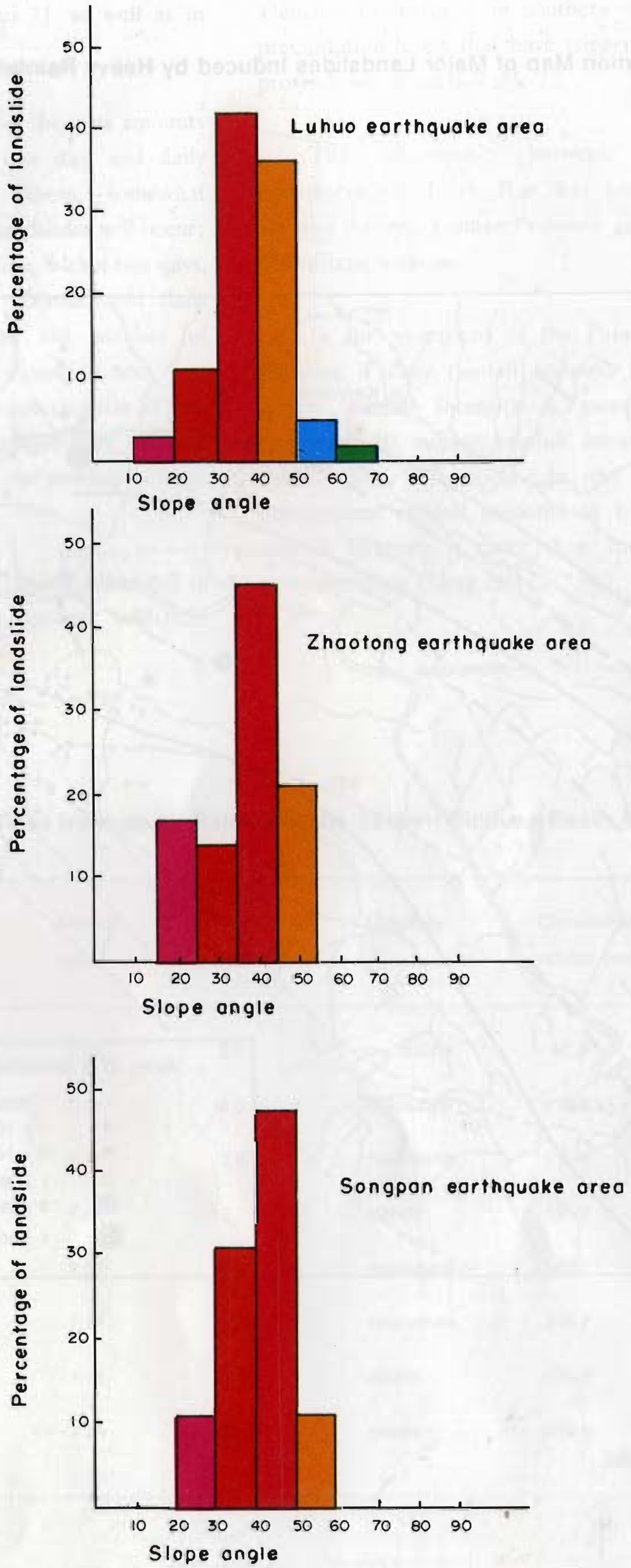
The characteristic values of precipitation for each county in the study area are given in Table 10. Figure 12 gives a cumulative rainfall diagram for the period from July 15-30, 1982, and demonstrates the relationship between rainfall intensity and landslide frequency. Table

Table 10: Characteristic Values of Rainfall during Landslide Occurrence in the Eastern Sichuan Basin (July 1982)

Location	Rainfall preceding first landslide		Rainfall preceding occurrence of numerous landslides	
	Cumulative rainfall (mm)	Daily rainfall (mm)	Cumulative rainfall (mm)	Daily rainfall (mm)
Zhongxian	139.0	139.0	289.7	138.2
Yunyang		277.7	205.6	
Kaixian	53.4	51.4	280.8	153.8
Liangping	177.0	177.0	279.3	102.3
Fengdu	99.0	88.0		
Fengjie	113.7	47.9	218.9	10.1

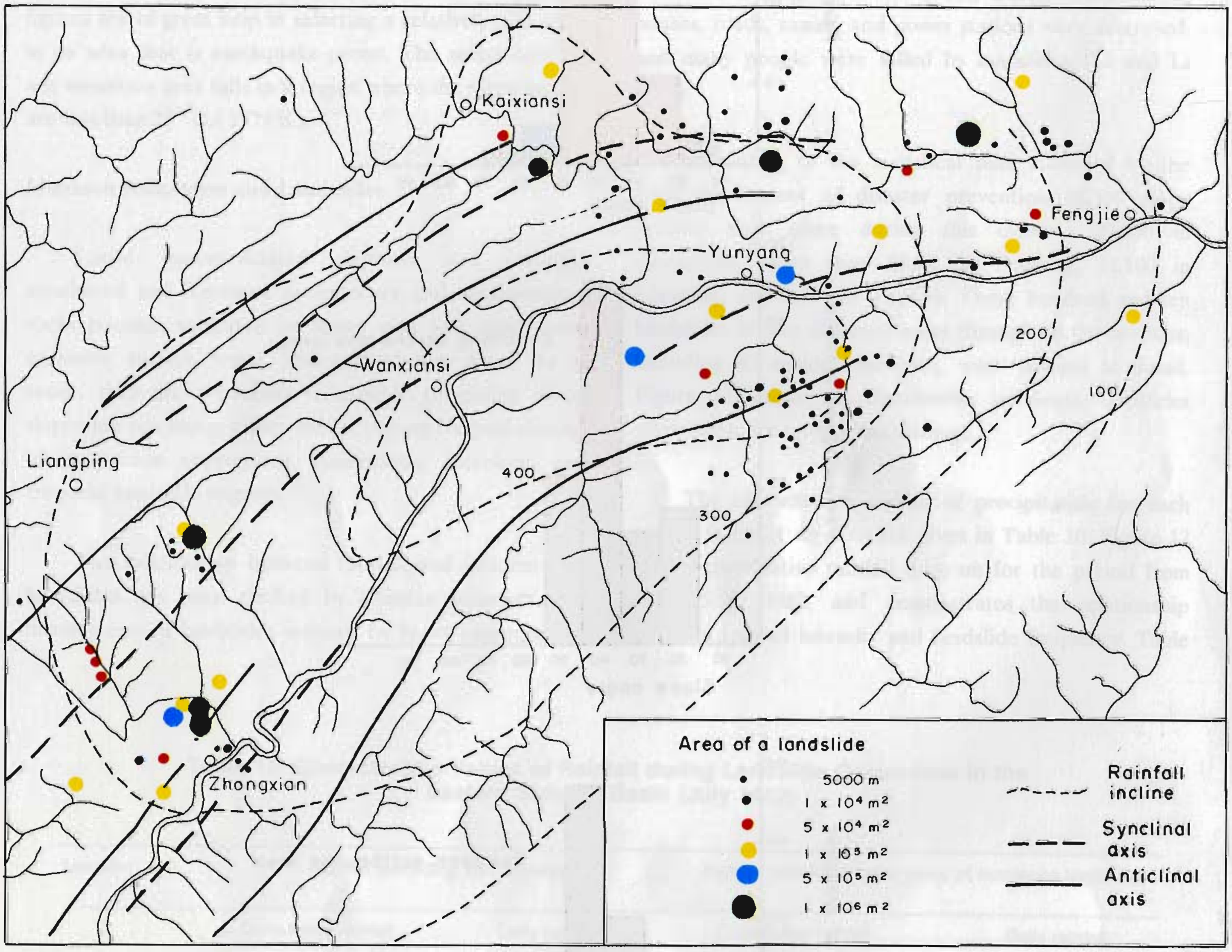
Source: Li and Li 1985

Figure 10: Relationship between Percentage of Earthquake-Induced Landslides and Slope Angle



Source : Li 1979a.

Figure 11: Distribution Map of Major Landslides Induced by Heavy Rainfall in Eastern Sichuan (July 1982)



Source: Li and Li 1985.

11 records typical examples of landslides induced by rainfall during this event.

From the data in Tables 10 and 11, as well as in Figure 12, Li and Li (1985) inferred :

- that if cumulative precipitation of the area amounts to from 50mm to 100mm in one day, and daily precipitation is more than 50mm, somewhat small-scale and shallow debris landslides will occur;
- that when cumulative precipitation, within two days, amounts to from 150mm to 200mm, and daily precipitation is about 100mm, the number of landslides will increase with precipitation; and
- that when cumulative precipitation exceeds 250mm in two days, and has an average intensity of more than 8mm per hour in one day, the number of large landslides increases abruptly.

Heavy rainfall also frequently triggers landslides in the Loess Plateau Area. In 1978, several landslides occurred in succession during the rainy season in Tianshui, Gansu Province. In 1984, during the rainy season, more than 1,000 landslides occurred in Wudu and Tianchui Prefectures, in southern Gansu. Some of the precipitation levels that have triggered landslides in this province are given in Table 12.

The relationship between rainfall and the occurrence of debris flow has been observed in the Jiangjia Ravine, Yunnan Province and the mountain area of Western Sichuan.

In the watershed of the Pabone Valley, Western Sichuan, if daily rainfall amounts to 30mm, maximum hourly rainfall intensity is more than 10mm, and maximum 10 minute rainfall intensity is above 5mm, debris flow will occur. In the Jiangia Ravine, if antecendent rainfall amounts to 10mm and 10 minute rainfall intensity is more than 2mm, debris flow will certainly occur (Tang and Li).

Table 11: Typical Landslides Induced by Rainfall in the Eastern Sichuan Basin (July 1982)

Name of Landslide	Location	Month day	Volume (10^6 m^3)	Lithology	Cumulative rainfall (mm)	Daily rainfall (mm)
Nanzhuba	Fengdu	7.16	0.7	mudstone	90.0	88.0
Shankou	Zhougxian	7.17	18.0	mudstone	310.8	171.8
Yijian	Zhougxian	7.17	2.8	mudstone	310.8	171.8
Jipazi	Yunyang	7.18	13	debris	331.0	164.1
Tianbo	Yunyang	7.17	6.2	mudstone	283.0	101.6
Geling	Yunyang	7.17	9.5	mudstone	345.7	94.9
Baigou	Fengjie	7.16	1.2	debris	138.3	58.5
Guadouzai	Liangping	7.28	5.62	debris	210.5	83.2

Source : Li and Li 1985

Table 12: Precipitation Levels Preceding Landslides in Gansu Province

Location	Day, Month, Year	Lithology	Cumulative Rainfall (10 days prior to landslide)	Maximum Daily Rainfall within the month (mm)
Tianshui	21.7.1978	Loess	82.9	200.00
Huixian	21.8.1981	Mudstone	284.0	120.00
Tianshui	3.8.1984	Loess	63.1	52.7

Source: Li and Liu 1987

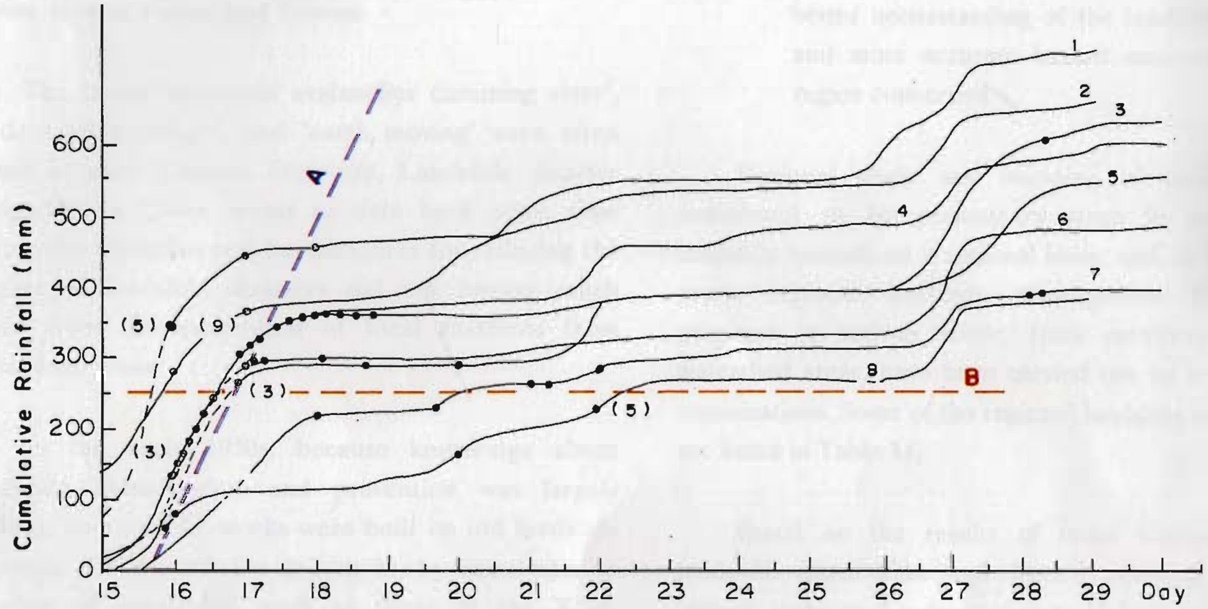
Using the data mentioned above and other statistical data, Li and Liu (1987) calculated the threshold precipitation levels that were critical in triggering landslides in different rock types in China (Table 13).

Table 13: Rainfall Thresholds for Rainfall-Triggered Landslides in Different Rock Types in China

Types of Landslide	Rainfall Intensity (mm/h)	Daily Rainfall (mm)	Cumulative Rainfall (mm) for 1 - 2 days
Small landslide of debris and loess	6.0	50.0	50 - 100.0
Medium landslide of debris and loess and fractured rocks	10.0	120.0	150.0 - 200.0
Large landslide of debris and bedrock	15.0	150.0	250.0

Source: Li and Liu 1987

Figure 12 :Cumulative Rainfall Diagram for the Eastern Sichuan Basin Based on Rainfall Records of Local Meteorological Stations (July 15-30, 1982).



Source: Li and Li 1985.

Notes :

A. Intensity of rainfall exceeding 8.5 mm/h., triggering numerous landslides.

B. Cumulative precipitation of more than 250 mm in two days, triggering numerous landslides; the individual landslide numeral in brackets is the number of landslides induced.

1. Kaixian
2. Lianghe.
3. Fengjie
4. Zhimation

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 :

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

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.

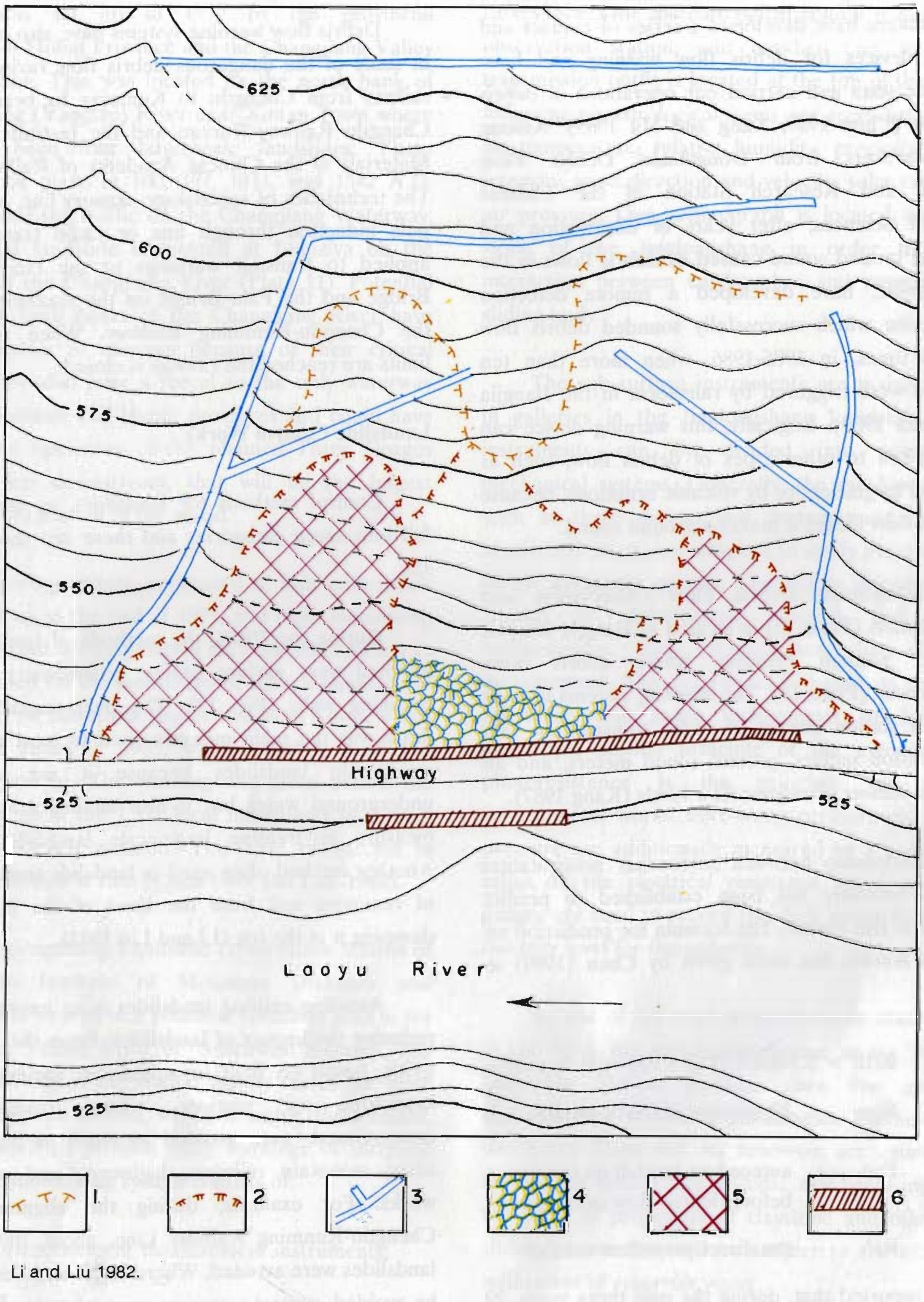
Landslide Control Works

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:

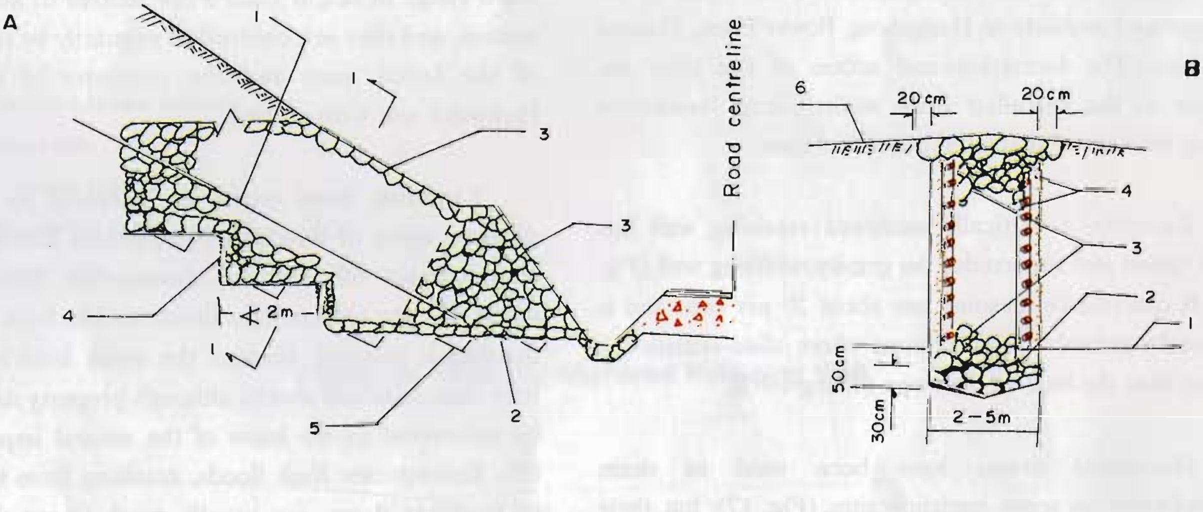
1. Scarp of fossil landslide.
2. Scarp of new landslide.
3. Drainage channel.
4. Mortar bubble masonry.
5. Wooden pile fence.
6. Retaining Wall.

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

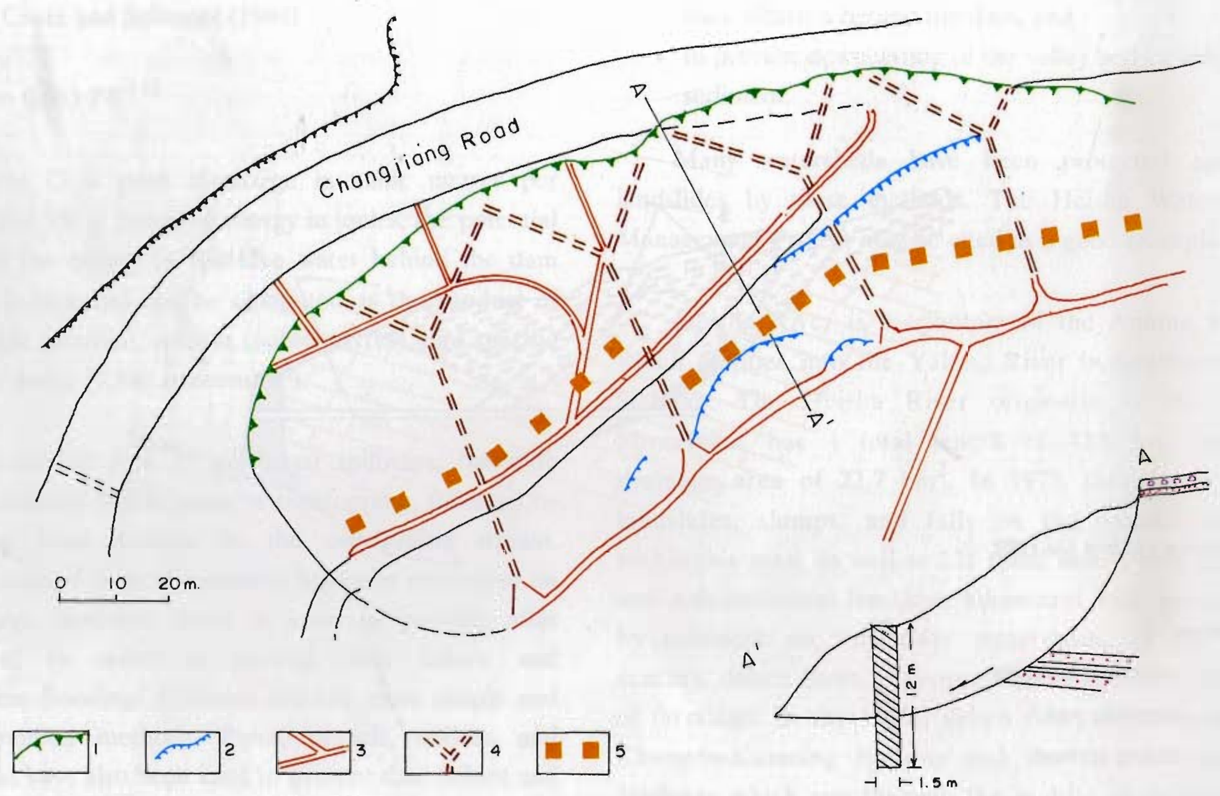
The natural damming of rivers by landslides is a significant hazard in many mountain areas of China, and it is particularly common in the high rugged Hengduan Mountains of Southwestern China. Many landslide dams have failed catastrophically, causing severe flooding downstream and the loss of many lives.

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)

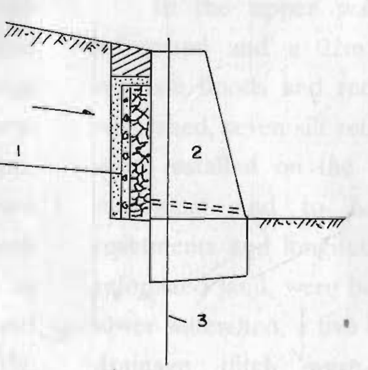


Source: Based on Lin 1989 and Zhu et al. 1989.

Notes :

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

Figure 16: Vertically Anchored Retaining Wall

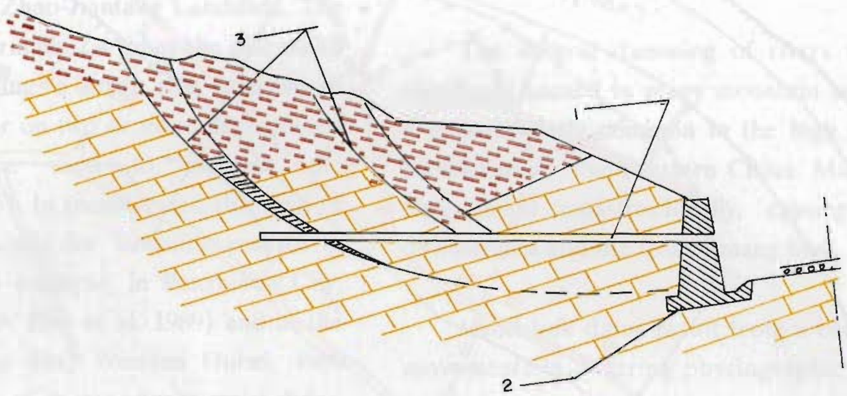


Source: Wang, G. 1985.

Notes:

1. Sliding surface location.
2. Wall.

Figure 17: Horizontal Borehole for Draining Groundwater

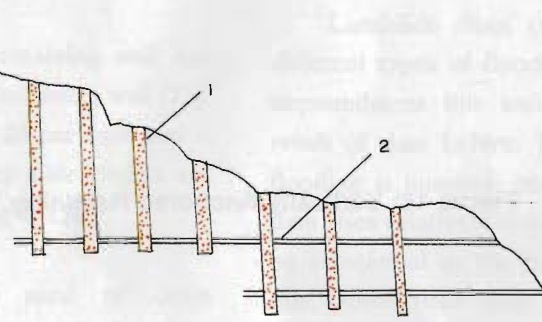


Source : Li and Liu 1982.

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 (Ton/km^2)	Barren Land: Erosion Modulus (Ton/km^2)	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

V. Institutions

In China, there are a number of institutions responsible for reducing the cost of damages caused by landslides and some of these are listed below:

Public Agencies

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

- The Ministry of Urban and Rural Construction and Environmental Protection - design and building codes and control of landslides related to urban construction and development.
- The Ministry of Railways - avoidance, design and building codes; as well as control of landslides for protection of railways.
- The Ministry of Communications - avoidance, design and building codes; as well as control of landslides for protection of highways and waterways.
- The Ministry of Metallurgical Industry - control of landslides in relation to specific mining areas.
- The Ministry of Energy - control of landslides in relation to major hydro-electric power stations.
- The Ministry of Water Conservation - control of landslides in the watersheds of rural areas where necessary.
- The Ministry of Forestry - managing national forest land to minimize landslide damage.
- The Ministry of Mines and Geology - mapping of landslides in important development areas.

Research Institutions

The institutions that carry out research activities on methods of reducing the impact of landslide disasters have been given below.

- The Chengdu Institute of Mountain Disasters and Environment.
- The Centre for Environmental Geology of the Ministry of Mines and Geology.
- The Debris Flow Prevention Institute of Dongchuan City, Yunnan Province.
- The Geological Institute of the Chinese Academy of Sciences.
- The Northwest Institute of the Chinese Academy of Railway Sciences.
- The Research and Coordination Centre for Geological Hazards of Gansu Province.

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 methods of landslide inventory and mapping,
- to develop methods of landslide risk assessment,
- to develop and improve design and construction techniques for the control of landslides and to minimize landslide damage,
- to provide expert advice to public agencies and local governments,
- to provide technical assistance and training assistance, and
- to disseminate research results to planners, decision makers, governments, and communities.

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

Provincial and Local Governments

Provincial and local governments carry out the following responsibilities :

- establishment of landslide monitoring/warning systems,
- mobilisation of resources and provision of expert assistance for help and rescue operations,

- compilatin of inventories of landslides occurring in areas under their jurisdiction,
- promulgation and enforcement of grading ordinances and building codes to minimize landslide occurrence and damage,
- prevention of the construction of public facilities in landslide-prone areas and relocation of obsolete public facilities in landslide-safe areas,
- provision of information to make the public aware of landslide hazards, and
- coordination of private sector resources in the event of an emergency.

Landslide Societies

There is no national landslide society in China as yet. Recently, several landslide societies or committees have been established in those provinces that are 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 Shaanxi Civil Engineering Society in 1985, the Landslide Society of East China in 1987, and the Landslide Society of Hubei in 1988. These societies have more than 1,000 members altogether, mainly composed of researchers and engineers specializing in geology, geomorphology, topography, geophysics, civil engineering, erosion control, forestry, agriculture, civil engineering, and other landslide-associated fields. Members are drawn from research institutes, universities and colleges, public organizations, consulting agencies, and government agencies. They hold national or provincial symposia and seminars, together or separately, for the exchange of information on landslide processes and control methods. International symposia have also been held such as the China-Japan Field Workshop on Landslides that took place in 1987.

VI. Conclusion

China has suffered more fatalities from landslides than any other nation in the world. More than 150 people per year have been killed by landslides in China over the past 36 years. In the mountain areas especially, the impacts of landslides on development are great and are apparently growing. They destroy or damage residential and industrial developments, agricultural and forest land, and railways, and have caused at least $ 0.5 billion (U.S.) in economic losses annually during the period from 1951 to 1987.

Earthquakes and rainstorms constitute two of the most important landslide-inducing agents. It is well recognized that a significant number of landslides occurs only when earthquake magnitudes are greater than 6.0. The two most seismically active regions are the Hengduan Mountain Area of Southwestern China and the Loess Plateau of Northern China where thousands of earthquakes have been recorded. Earthquakes trigger many large-scale rockslides or loess slides in the two regions; some of these block rivers and form lakes. Apart from the characteristics of the earthquakes themselves, environmental factors, such as geology, landform, and drainage, play an important role in the formation of landslides induced by earthquakes. In addition, the information on rainstorms shows :

- that if cumulative precipitation amounts to from 50mm to 100mm in one to two days and daily precipitation to about 50mm, somewhat small-scale and shallow landslides of debris and loess will occur;
- that when the cumulative precipitation within two days amounts to from 150mm to 200mm, and daily precipitation to about 100mm, the number of medium-scale landslides of debris and loess and fractured rocks has a tendency to increase with precipitation; and
- that when cumulative precipitation exceeds 250mm within two days, and has an average intensity of more than 8mm per hour in one day, the number of large and vast landslides of debris and bedrock increases abruptly.

Management of landslides is an integral part of environmental conservation and development activities in mountain areas. The methods for reducing the impact of landslide disasters in China have been summarized in the text. Considerable progress has been made during the past 40 years, especially in respect to:

- regional landslide studies and mapping and
- stabilization of landslides

Significant advances have been made especially in respect to regional landslide studies during the last ten years. Examples of the regional landslide programmes in China are shown in Table 14. Landslide susceptibility and risk maps are generally more useful for planners and decision makers than other landslide maps.

New and improved methods have been developed to monitor areas affected by landslides. The landslide monitoring systems at Xitan, Hubei Province, and the warning systems at Jianghia Ravine, Dongchuan, Yunnan Province are good examples. The main requirements for monitoring devices are that they should be simple, rugged, and inexpensive.

Advances have also been made in stabilization techniques. The effectiveness of different stabilization methods depends on understanding the driving mechanism of a landslide. A number of different stabilization methods can often be used for shallow slides and deep-seated slides, but the deep-seated counterfort drain is the main measure used to treat medium and small-scale landslides. In recent years, driven piles with large rectangular sections have been used extensively to control landslides. This involves the use of large volumes of rocks because of their capacity to resist landslides, the low amount of masonry needed, and the fact that they are easily constructed manually. The best and most common methods of landslide control in watershed areas are the reforestation of slopes and the construction of check dams in the valleys.

In China, although a great deal of effort has been expended in landslide mitigation since the 1960s, losses from landslides are increasing. This is largely due to residential and industrial developments that have expanded on to steeply sloping terrain which is most prone to landslides and partly due to the unusually heavy rainfall that has occurred in recent years. As development processes and interventions continue and even accelerate mountain environments will be further subjected to landslide hazards.

Despite the improvement in landslide management systems and the progress made in techniques for reducing the costs and damages brought about by landslides, the problem is far from solved. It will take years of sustained work to achieve a dramatic reduction in landslide disasters in such a vast country. The following landslide hazard management programmes are deemed necessary in order to effectively meet the need for reducing losses from landslide disasters.

- Identification of landslide hazard areas; compilation of landslide inventories and landslide mapping.
- Rehabilitation of lands subjected to landslides and development of regulations controlling unstable terrain.
- Specific standards of design and construction of physical control measures in the public and private sectors.
- Formulating land-use regulations in hazardous mountain areas.
- Strong support from research in the context of the mechanics of the landslide process, transport and deposition, mitigation measures, and warning systems.
- Provision of a central clearing-house for collection and distribution of publications and guidelines to professionals, agencies, and local governments.
- Development of a national landslide-loss reduction programme and the identification of a central organization for management of the programme.

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Plate 1: **View Looking Southwards from the Embankment of Dongchuan-Kunming Railway Downstream from Dade Ravine, Yunnan Province**

The embankment was undermined by debris flow and flooding following breaching of a debris flow dam formed on 30 June, 1981.

Courtesy of Yang Wenke

Plate 2: **Embankment of Dongchuan-Kunming Railway Destroyed by a Landslide near Laogan on 1 July, 1985**

Courtesy of Kang Zhicheng

Plate 3: **Debris Flow Undermining the Embankment of Dongchuan-Kunming Railway (1 July, 1985)**

Courtesy of Kang Zhicheng

Plate 4 : **Forward Movement of the Railway Embankment by 100m and Destruction of Two Railway Bridges at Dalisu in Dongchuan District (Oct. 6, 1986)**

Courtesy of Yi Chongquing

Plate 5: Looking North across the Changjiang River Towards the Jipazi Landslide

The total volume of the landslide is more than 15 million m^3 (centre). The front section of 2.3 million m^3 separated off from the slide channel and slid down below the flood level of the Changjiang River (foreground) to form low rapids that obstructed navigation for about 5 years. The photograph was taken in May, 1985, after stabilization of the landslide.

Photograph by Li Tianchi

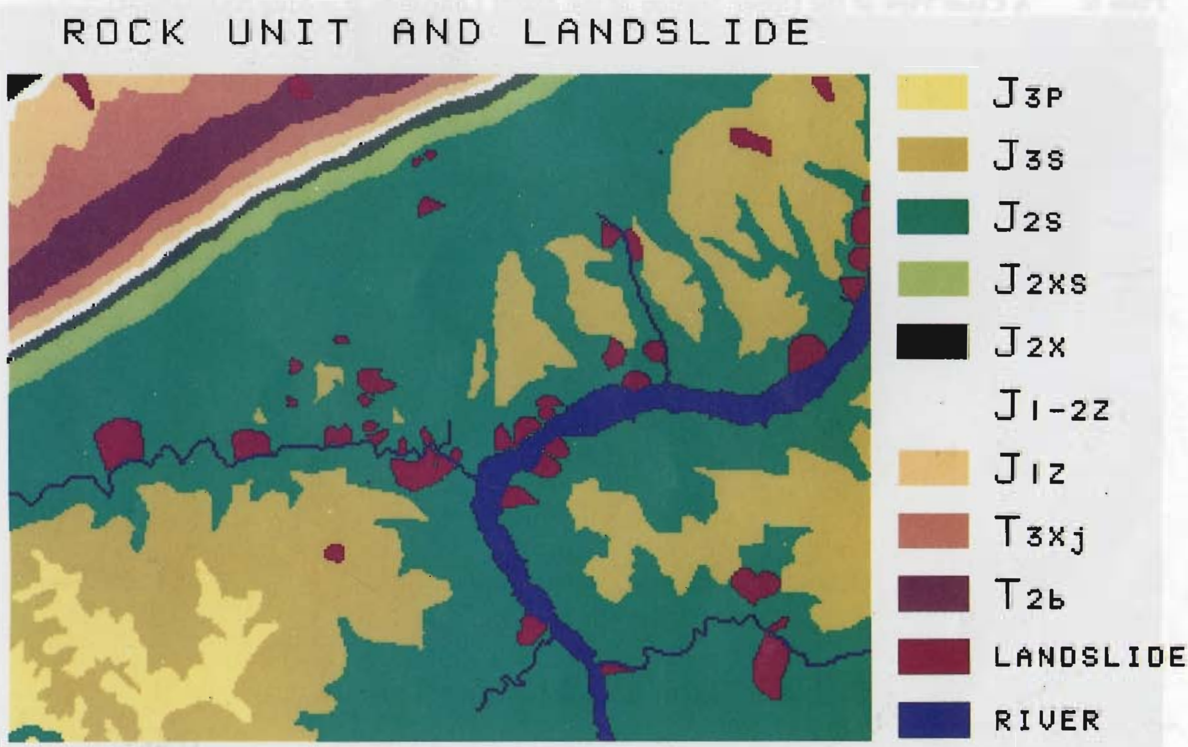
Plate 6: A Close View of the Upper Section of the Jipazi Landslide (Looking Northwards)

The sliding bed is composed of mudstone. Courtesy of Wang Zhihua

Plate 7: **A Close View of the Middle Section of the Jipazi Landslide (Looking Southwards)**

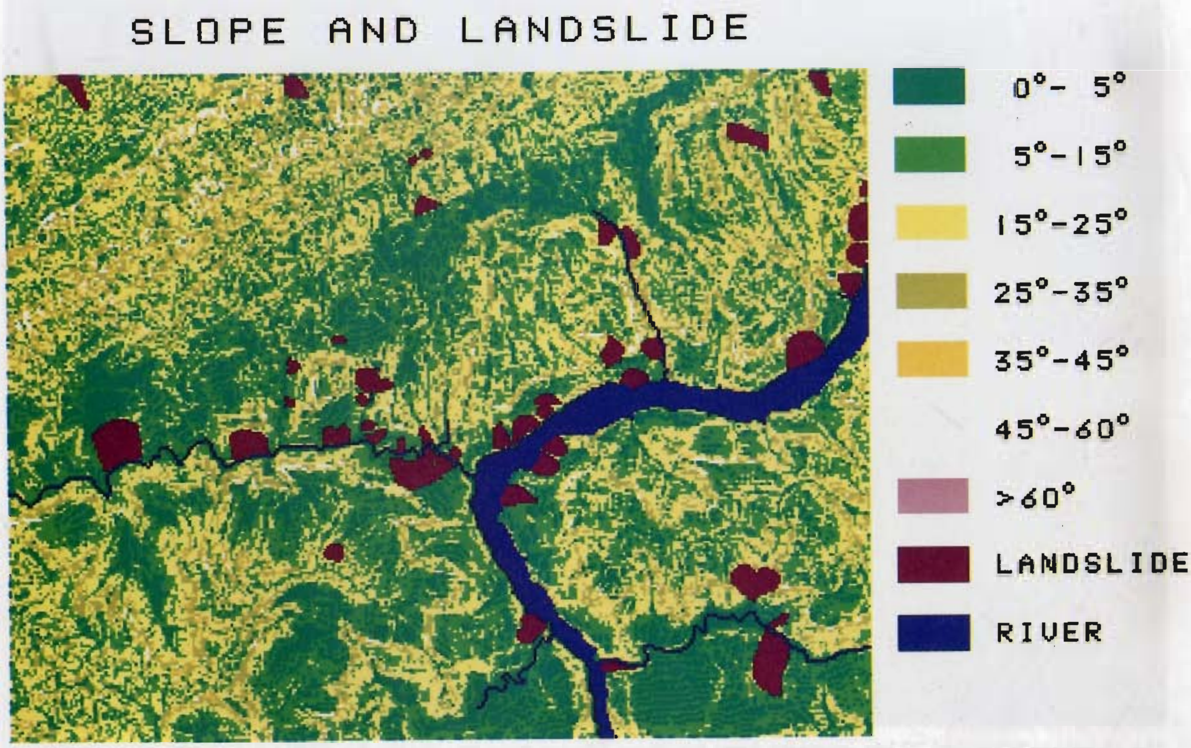
The landslide is shown in the foreground, the Changjiang River in the middle background, and the county site of Yangyang on the banks of the Changjiang River in the background - to the right. Courtesy of Wang Zhihua

Plate 8: **Map Showing Rock Units and Landslides in the Wanxian Area (Sichuan Province)**



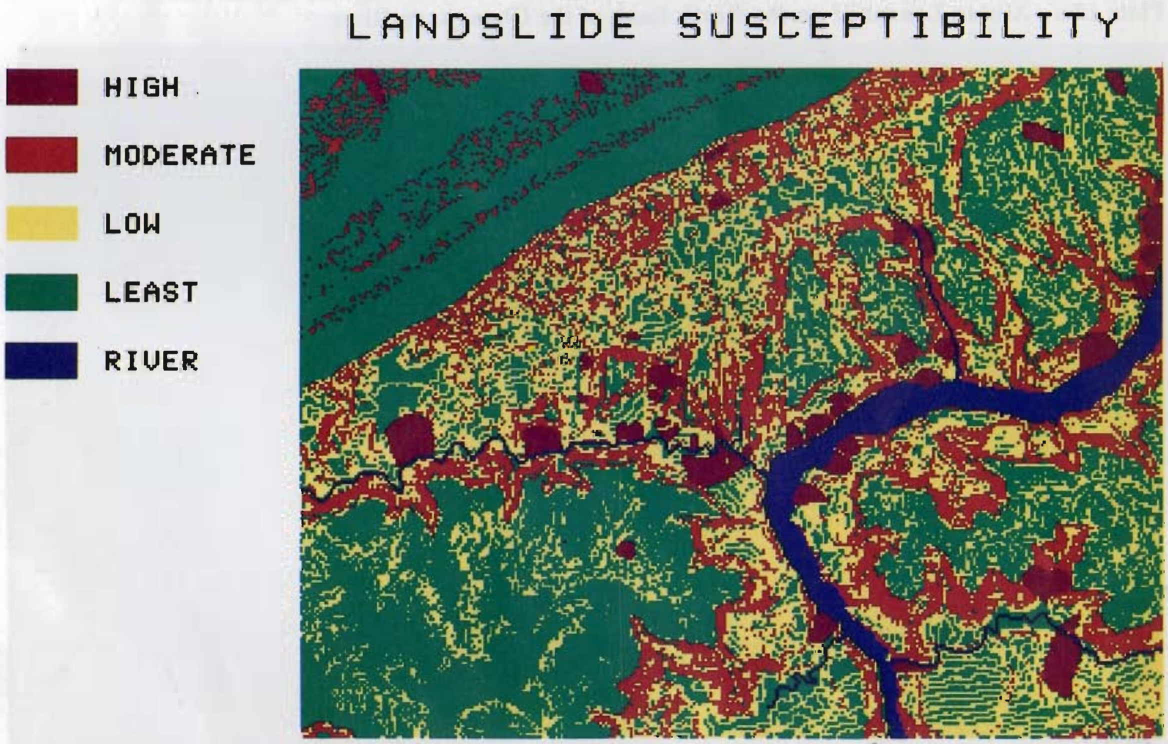
J3p Ponglaizhen Group, J3s-Sulning Group, J2s-Shamiaogi Group A, J2x-Xintangou Group, J1-1-22-Zilioujin Group, Jiz-Zhengzhuchong Group, T3xj-Xujiahe Group, T2b-Badong Group. Source : Li et al. 1989

Plate 9: **Map Showing Slope Angles and Landslides in the Wanxian Area**



Source : Li et al. 1989

Plate 10: **Map Showing Landslide Susceptibility Spots in the Wanxian Area**



Key:
High: high susceptibility to landslides.
Moderate: moderate susceptibility to landslides.
Low: low susceptibility to landslides.
Least: least susceptibility to landslides. Explanation of the map units are presented in the text.

Source: Li et al. 1989

Plate 11: View from the East of the Lianziya Limestone Rockmass

The rockmass is located 27 km upstream from the Three Gorges Dam Site on the South Side of the Changjiang River directly across from the Xintan Landslide, (Hubei Province). The rockmass appears to be undergoing a slow geological process of toppling, sliding, or falling. Photograph by Li Tianchi

Plate 12a: Xintan Landslide on the North Bank of the Changjiang River

The landslide destroyed Xintan Town (middle background), Hubei Province Photograph by Li Tianchi

Plate 12b: A Close View Looking Northwards of the Upper Part of the Xintan Landslide

Photograph by Li Tianchi

Plate 13: Dongchuan Debris Flow Observation Station Looking Westwards from the Lower Watershed of Jiangia Ravine

Photograph by Li Tianchi

Plate 14: **Debris Flow in the Watershed of Jiangjia Ravine**

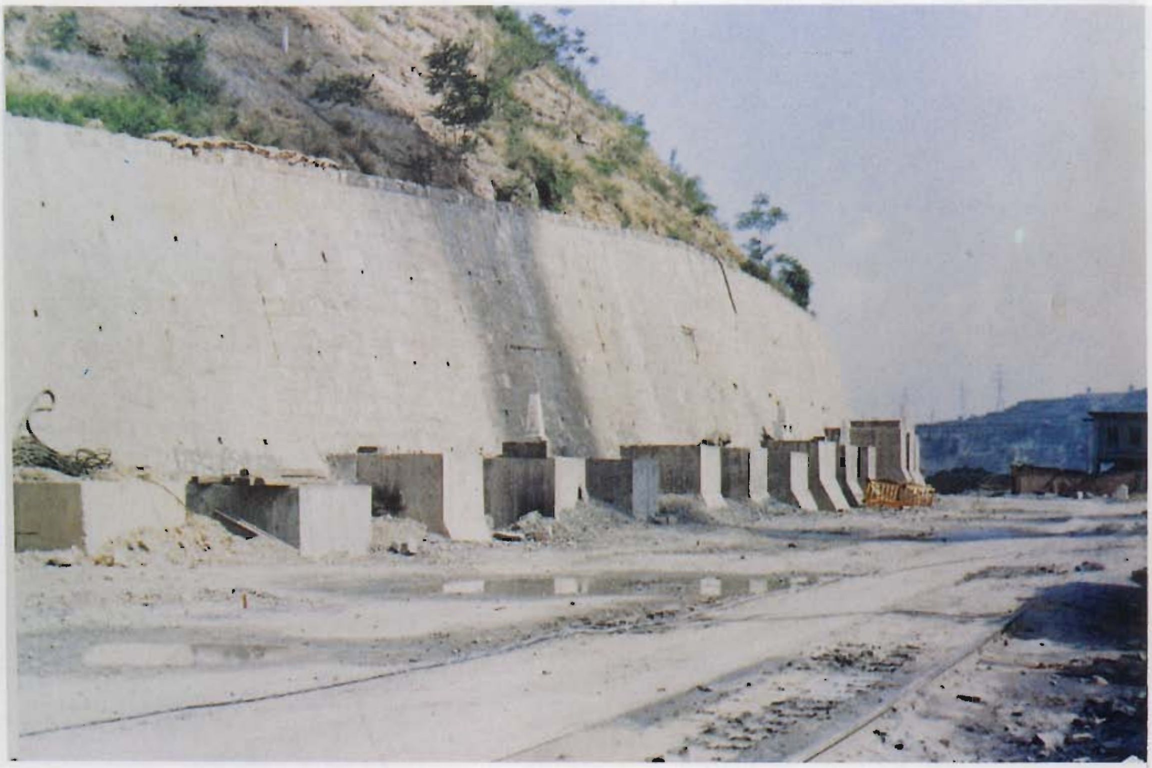
Photograph by Li Tianchi

Plate 15: **Control Works at the Jianjiyan Landslide, Songzao Coal Mining Area, Sichuan Province**

The use of anchor-rope driven piles (centre, background) to stabilise landslides

Courtesy of Wang Gongxiann

Plate 16: Control Works of the Xiangshan Lanslide, Hangcheng Power Plant, Shaanxi



The use of driven piles and a retaining wall (centre, background) to stabilize the landslide

Courtesy of Wang Gongxian

Plate 17: Looking Southwards from the Geling Landslide Dam (Sichuan Province)

The landslide dam formed in July 1982 during heavy rainstorms in Eastern Sichuan. This photograph shows the lake (foreground), remains of the Geling landslide dam (foreground), and the landslide (background).

Photograph by Li Tianchi

Plate 18: Yinping Landslide Dam (Sichuan Province)

Xiao Lake (foreground) is about 0.5 km wide here. The remains of the dam (centre) and Da Lake (middle ground) are shown as they were in 1985 (September) when this photograph was taken.

Photograph by Li Tianchi

Plate 19: Landslide in Dabeini Ravine (Yunnan Province)

The landslide occurred at the head and on both sides of the valley, transporting large quantities of material into the ravines, and creating serious damage in the lower watersheds.

Photograph Li Tianchi

Plate 20: Landslides and Debris Flows in Xiaobeini Watershed (Yunnan Province)

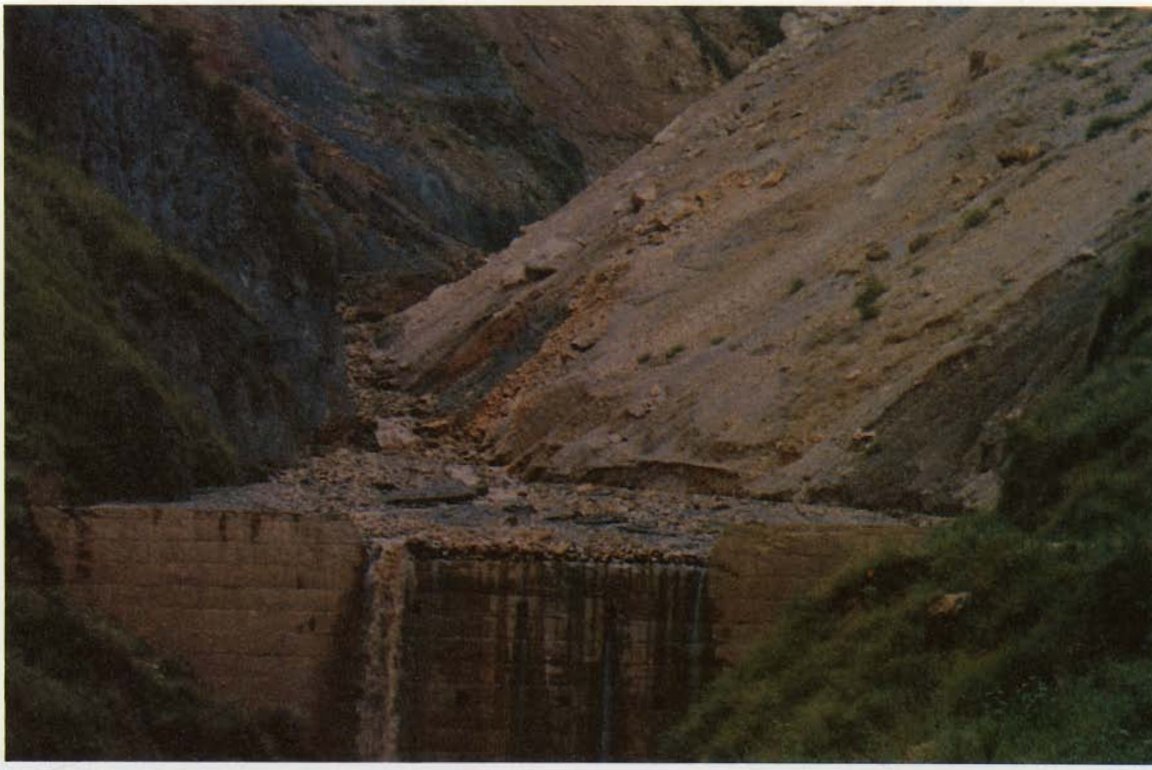
Debris flow from the watershed temporarily blocked the Xiao River (immediate foreground). View looking westwards of large landslide above Xiabeini Ravine on hillside; alluvial fan of debris flow (centre).

Photograph by Li Tianchi

Plate 21: Reforestation in the Upper Watershed of the Dade Ravine (Yunnan Province)

Courtesy of Yang Wenke

Plate 22: Check Dam in the Middle Watershed of Dade Ravine (Yunnan Province)



Courtesy of Yang Wenke

The Author

Li Tianchi is presently working as an Associate Research Professor in Chengdu Institute of Geography, Chinese Academy of Sciences. He was associated with ICIMOD as Head of its Mountain Environmental Management Divison for two years between 1988 and 1990.

Educated in Geography and Geology in China, Professor Li had also received higher education and training in West Germany and the USA. His experience in research and studies, related to engineering geology and geomorphology, and particularly in landslide and slope stability, spans over two decades. His contributions in these fields are well-known and several of his research results and papers are published in Chinese and international journals.

Professor Li Tianchi is currently involved and interested in landslide research, including landslide mapping using remote sensing techniques, and in slope stabilization, hazard assessment, and mitigation at specific sites where large-scale constructions, such as high dams, reservoirs, and hydropower stations, are being established.

Founding of ICIMOD

ICIMOD is the first International Centre in the field of mountain area development. It was founded out of widespread recognition of the alarming environmental degradation of mountain habitats and consequent increasing impoverishment of mountain communities. A co-ordinated and systematic effort on an international scale was deemed essential to design and implement more effective development responses based on an integrated approach to mountain development and mountain environmental management.

The establishment of the Centre is based upon an agreement between His Majesty's Government of Nepal and the United Nations Educational Scientific and Cultural Organisation (UNESCO) signed in 1981. The Centre was inaugurated by the Prime Minister of Nepal in December 1983, and began its professional activities in September 1984, with the support of its founding sponsors:

HMG Nepal, the Government of Switzerland,
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- Nepal
- India
- Bhutan
- Bangladesh
- China
- Pakistan
- Myanmar
- Afghanistan

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