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).

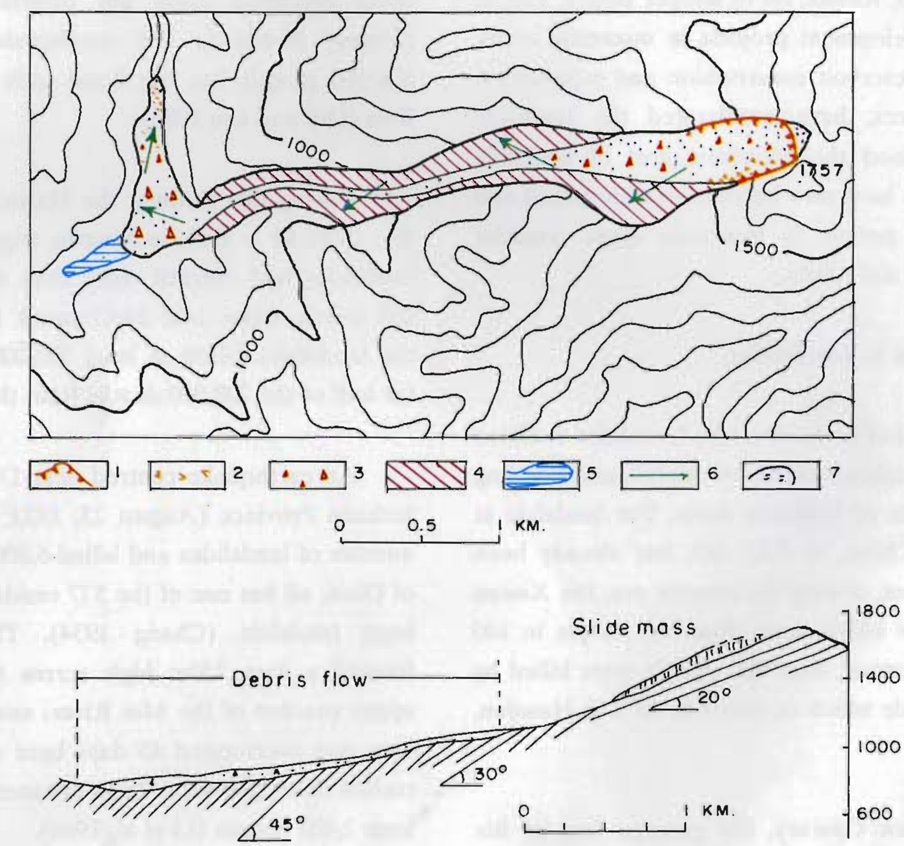
In May 1951, on the Chin-Shui Chi River, in Eastern Taiwan, several days of intense rainfall led to the overtopping and failure of the Tsao-Ling Rock Slide Dam. (The rockslide had been caused by an earthquake in December 1941). In the subsequent flood, 154 people were killed and 564 homes and 3,116 ha 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).

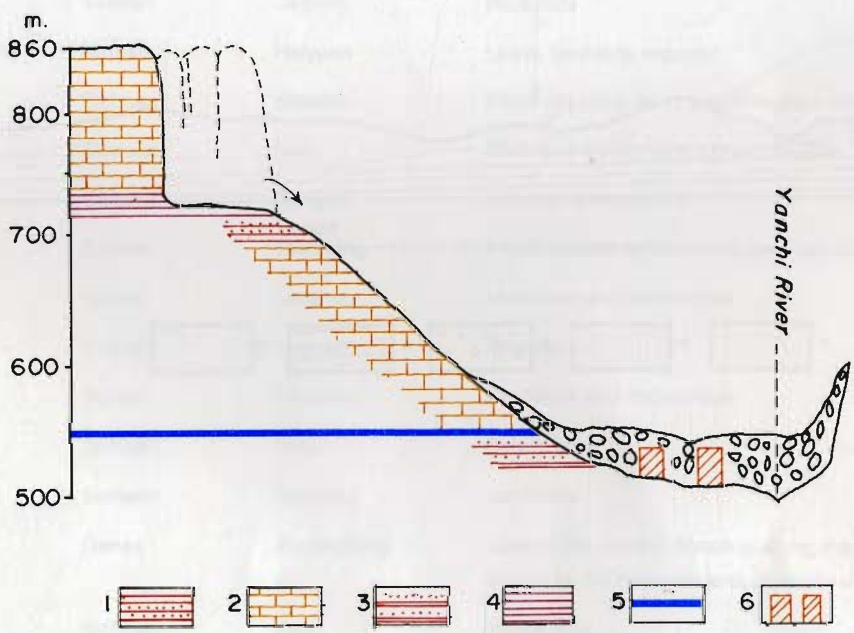
A loess landslide occurred at Saleshan on March 7, 1983, in Dongxiang County of Gansu Province. The total volume of the landslide was about 35 million m^3, and it covered an area of 2.7 km^2, buried four villages, filled two reservoirs, and killed 277 people (Fig. 3).

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 :

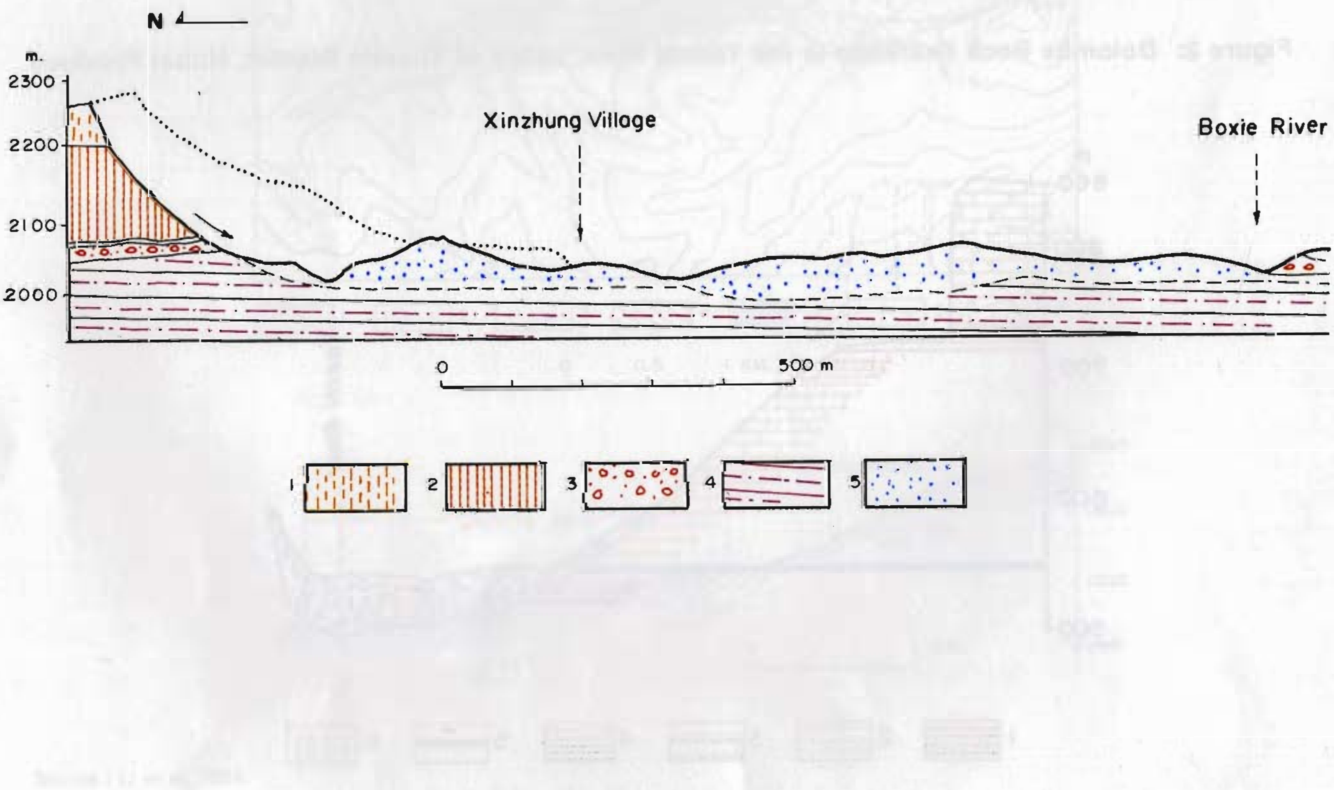
1. Silty Shales.
2. Thick Dolomite.
3. Mudstone and Silty Shales.
4. Thin Platy Dolomite.
5. Phosphorite Deposits.
6. Buildings of the Yanchi River Phosphorite Mine.

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

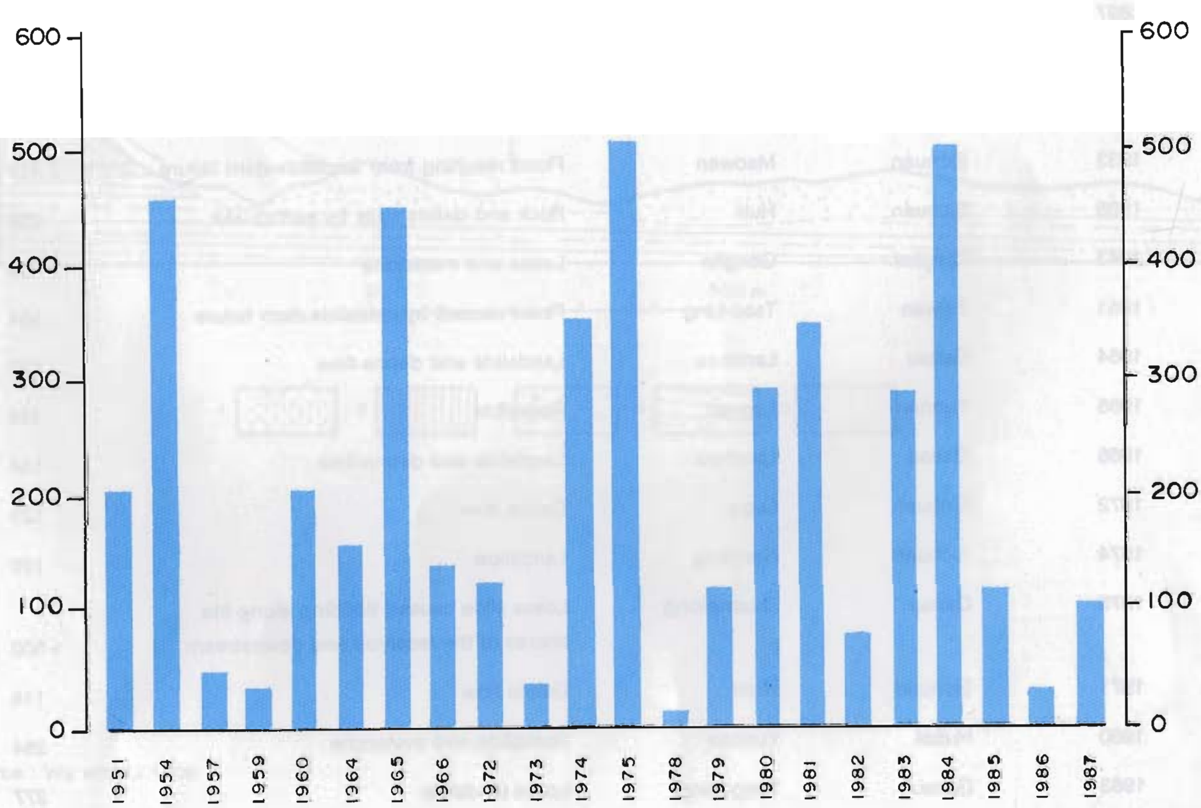
Source : Collated by author from historical and technical records.

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.

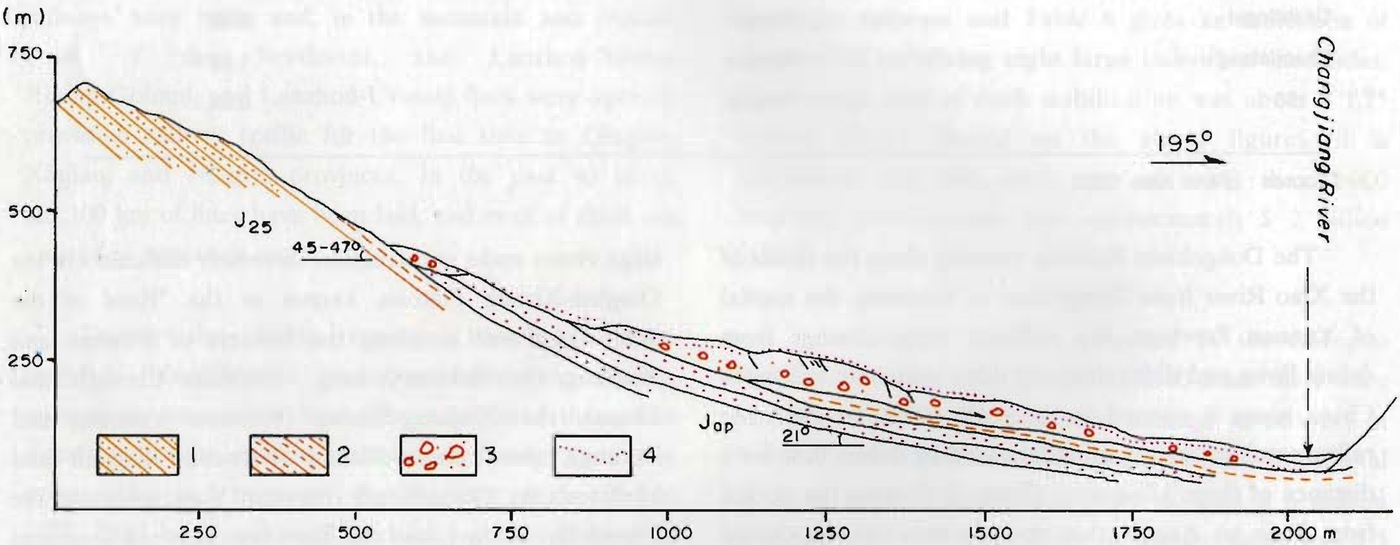
The Dongchuan Railway, running along the banks of the Xiao River from Dongchuan to Kunming, the capital of Yunnan Province, has suffered more damage from debris flows and slides than any other mountain railway in China, since it opened in the early 1960s. In 1981, the railway embankment was undermined 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 ($10^4 \times m^3$)	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.

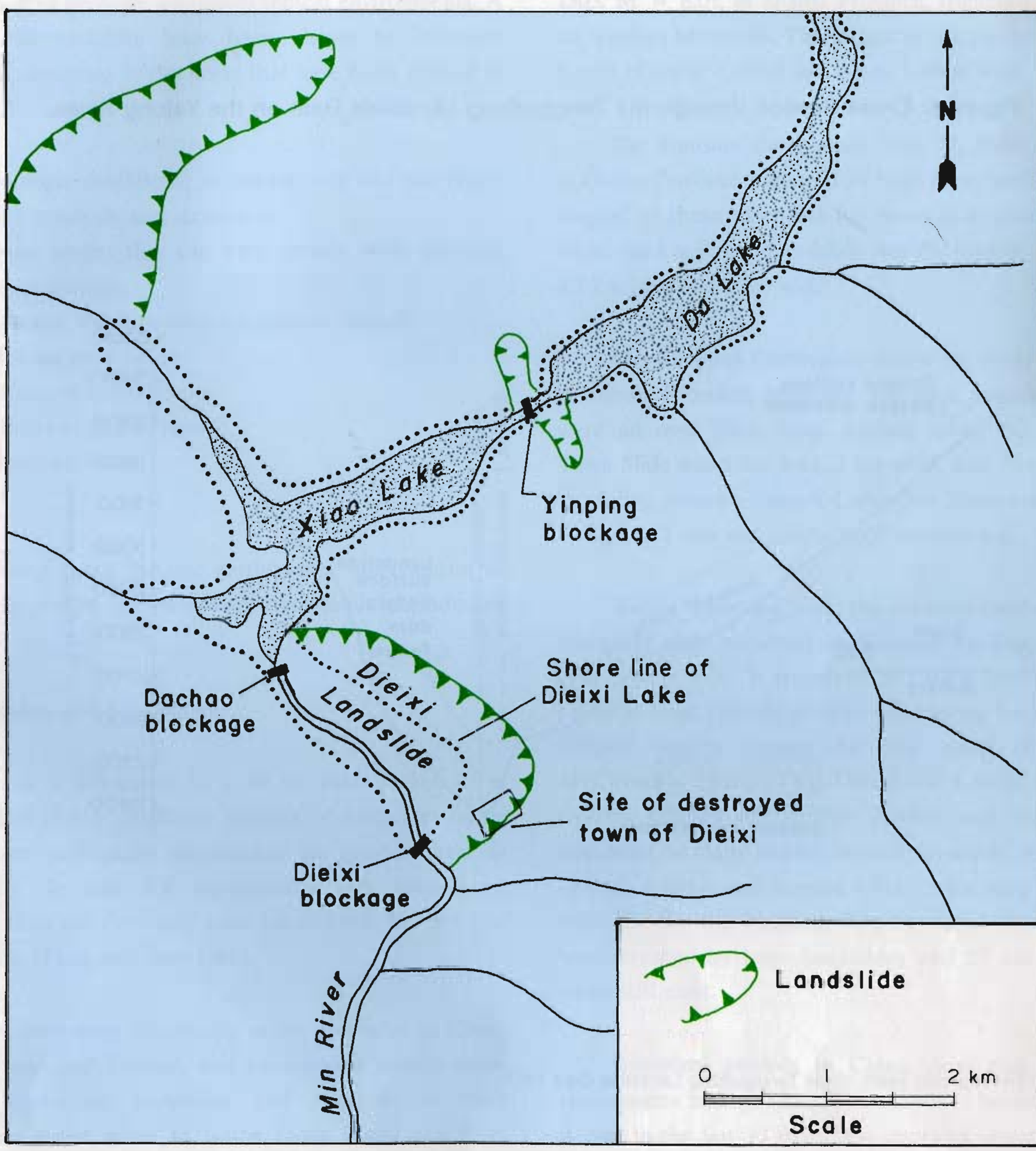
No deaths were caused by this flood because the downstream residences had been evacuated in anticipation of the catastrophe. However, damage to property was considerable, and the Investigation Team of the Tanggudong Landslide Dam (1967) noted the following damage along the Yalong River: 435 homes, 51 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	---

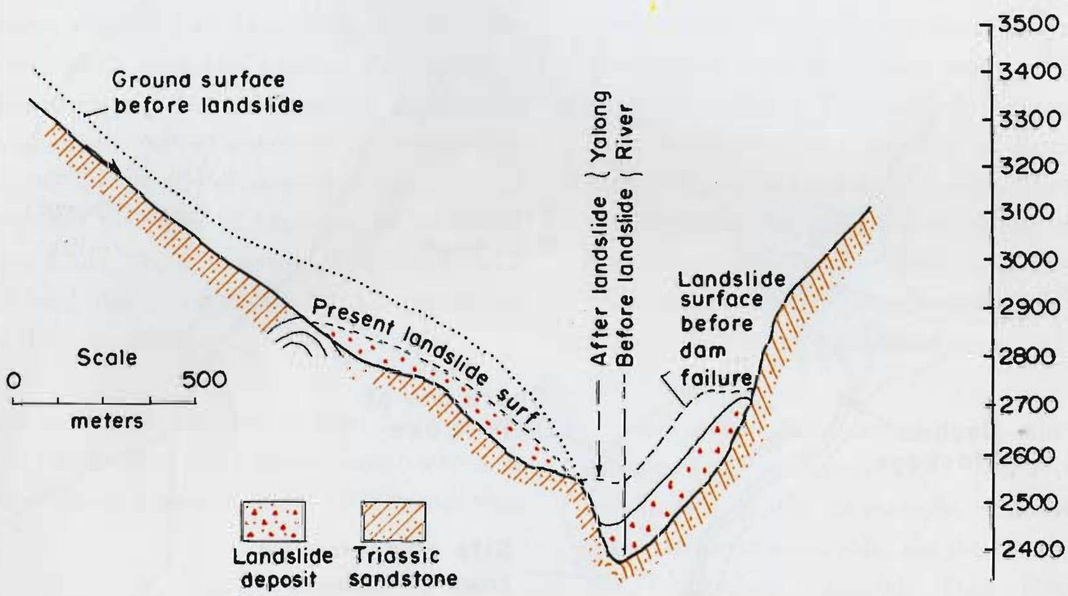
Source: Investigation Team of the Tanggudong Landslide Dam 1967.

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.