Assessment and Mitigation Measures of Landslide Dam Failure Disasters

The natural damming of rivers by landslides is a significant hazard in many mountain areas of China, and it is particularly common in the high rugged Hengduan Mountains of southwestern China. Many landslide dams have failed catastrophically, causing severe flooding downstream and the loss of many lives (Li et al. 1986).

Formation of Landslide Dams

Landslide dams result from a broad range of mass movements in different physiographic settings. Most landslide dams are formed by rock and earth slumps and slides, debris and mudflows, and rock and debris avalanches. Large landslide dams are formed by earth and rockslides/slumps and debris avalanches, commonly occurring on steep slopes and attaining high velocities that lead to stream blockages before the material can be sluiced away. The heights of landslide dams range from a few metres to hundreds of metres, and they are primarily controlled by the volume of failed mass and the geometry of the valley.

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

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

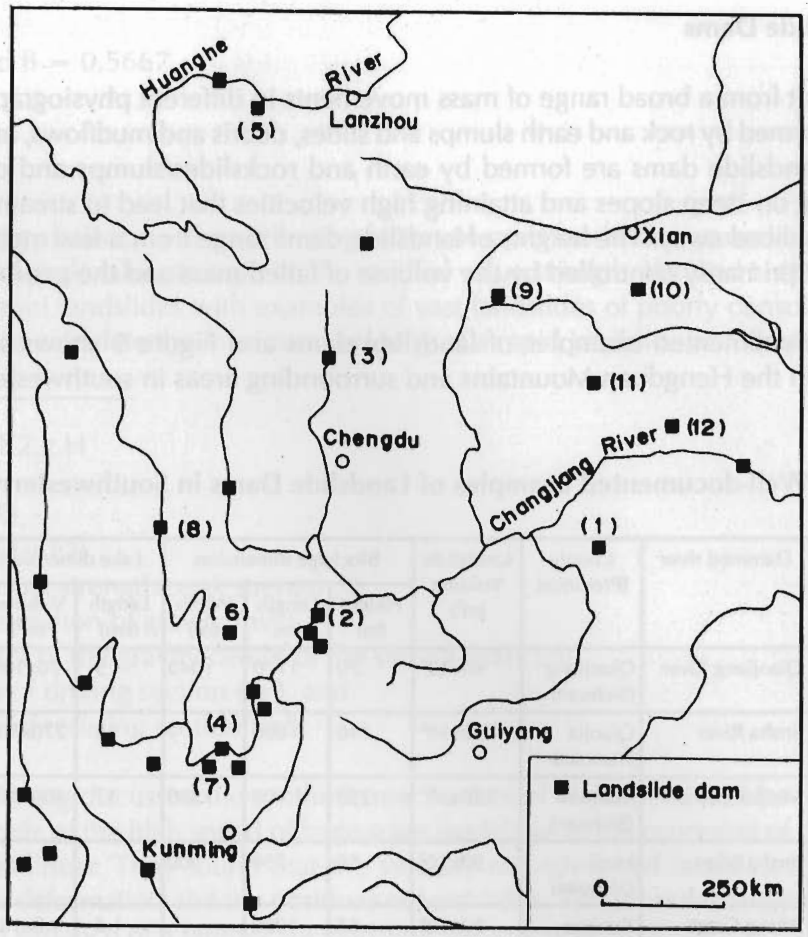
Name of landslide	Year	Dammed river	County (Province)	Landslide Volume (m^3)	Blockage dimension			Lake dimension		Dam failed?	References
					Height (m)	Length (m)	Width (m)	Length (km)	Volume (m^3)		
Daluba (1)	1856	Qianjiang River	Qianjiang (Sichuan)	$40x10^6$	70	1170	1040	5	$70x10^6$	No	Liu 1990
Shigaodi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

Source: Li and Wang 1992

Assessment of Upstream and Downstream Floods of Landslide Dams

Landslide dams create conditions for two very different types of flooding: (1) upstream flooding as the impoundment fills and (2) downstream flooding as a result of dam failure. The threat to life from upstream flooding is minimal because the water level behind the dam rises relatively slowly, although property damage can be substantial as the basin of the natural impoundment fills. Downstream flash floods, resulting from the failure of landslide dams, are usually much larger than those originating directly from snowmelt or rainfall and constitute a significant threat to life and property.

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



NOTES

1. Numbers correspond to those in Table 4

Source: Li and Wang 1992

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

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

Nine days later, the lowest part of the dam crest was overtopped by the rising water; although the entire dam did not fail, it breached to a depth of 88m over a 13-hour period. The resulting disastrous flood flowed 1,000km downstream along the Yalong and Changjiang rivers to the city of Yibin. The height of the frontal wave of the flood was 50.4m at a point six kilometres downstream from the landslide and 16.5m at Xiaodishi, 551km from the blockage. The maximum discharge of the flood, downstream from the blockage, was a phenomenal 53,000m³/s (Table 5 and Figure 10).

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

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

Source: Investigation Team of the Tanggudong Landslide Dam, 1967

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

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

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

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

$$Q = 0.063P$$

where:

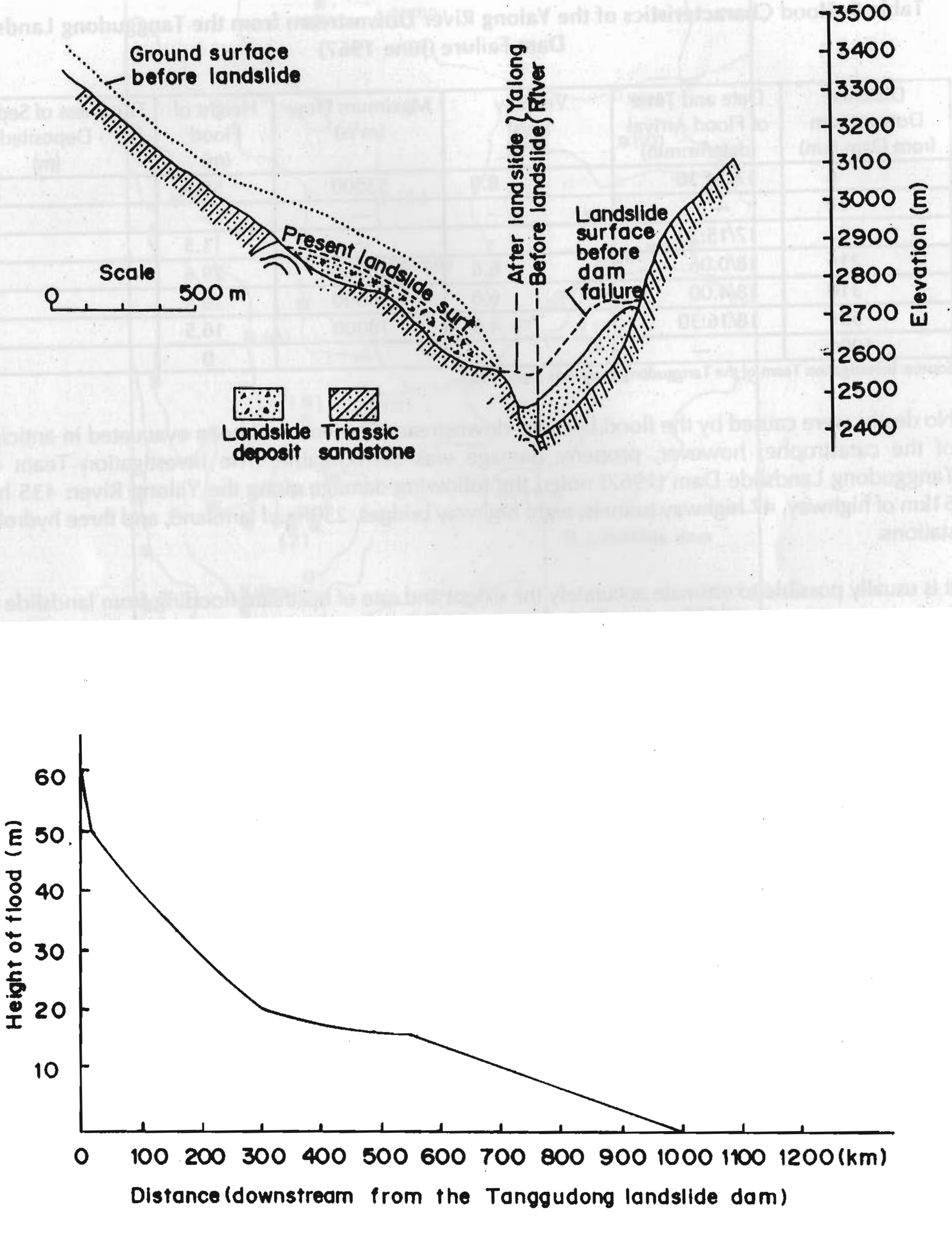
Q is peak discharge in cubic metres per second and P is potential energy in joules.

The potential energy is the energy of the lake water behind the dam prior to failure and can be computed as the product of dam height (metres), volume (cubic metres), and specific weight of water.

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

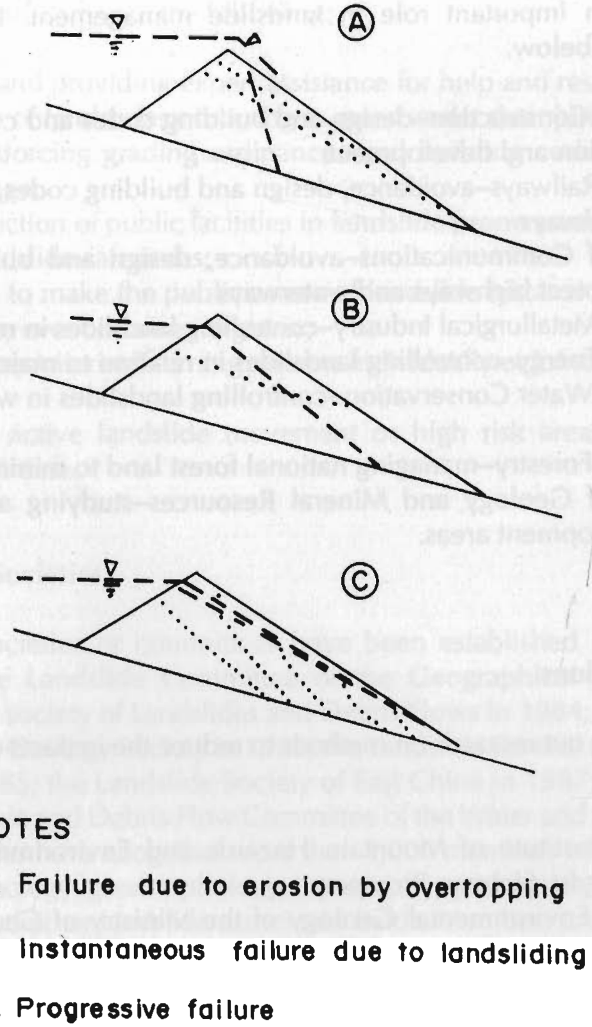
- Type and characteristic of the landslide dam
- Size of the lake (length, width, depth, and volume of the lake)
- Size of the dam (length, width, height, and volume of the dam)
- Physical characteristics of geological materials making up the dam
- Estimation of the mechanism of the dam failure
- Nature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

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



Source: Investigation Team of the Tanggudong Landslide Dam 1967

Figure 11: Three Types of Landslide Dam Failure Process



Source: Kuang 1993

Methods to Prevent Landslide Dam Failure and Subsequent Flooding

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