Landslide Prevention and Control

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

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

Avoiding Landslides

Avoiding existing landslides is an important step in reducing the impact of landslides. From the 1960s to 1970s, based on field investigations, ancient large-scale landslides, or sections where landslides were concentrated, were avoided as much as possible while siting mountain railways, highways, and other public works. For example, during the alignment of the Chengdu-Kunming railway line, about 100 large-scale landslides were avoided. Where large landslides could not be avoided, control measures were taken to stabilise them before construction.

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

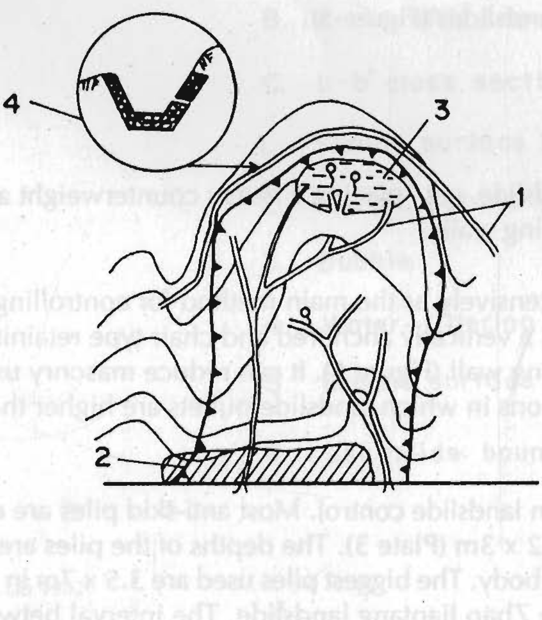
Category	Landslide Prevention and Control Works
Problem avoidance	Avoiding existing landslides, relocation
Surface-water drainage works	Channels or ditches, seepage-water prevention works
Subsurface drainage	Tunnels, subsurface trenches, deep-seated counterfort drains, drill vertical drainage holes,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

Source: Compiled from technical records

Surface Drainage

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

Figure 2: Typical Arrangement of Surface Drainage



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1. Drainage channel
2. Retaining wall
3. Wet land
4. Section of surface drainage

Source: Li and Liu 1982

The following drainage construction practices create ideal conditions for landslides.

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

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

Subsurface Drainage

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

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

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

Support Structures

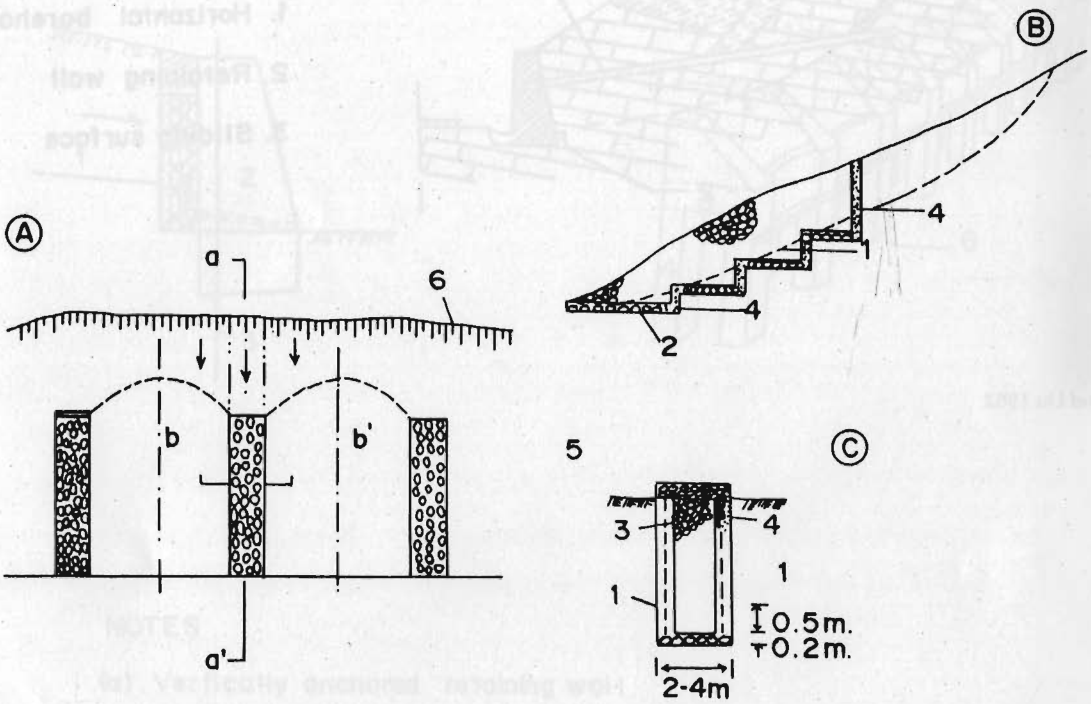
There are natural and easy ways to stabilise a landslide, e.g., placing a heavy counterweight at the toe of the landslide or building piling works and retaining walls.

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

Since the 1960s, concrete piles have been used in landslide control. Most anti-skid piles are driven piles and have large rectangular sections of 1 x 1m to 2 x 3m (Plate 3). The depths of the piles are from 10 to 30m depending upon the thickness of the sliding body. The biggest piles used are 3.5 x 7m in section and 47m in length; piles of this size are used on the Zhao Jiantang landslide. The interval between piles is normally 2.4 times the pile width (Pan 1988). In the beginning, one or more rows of single piles are used and later on two or more piles, joined by concrete blocks, are used to increase the slide resistance (Wang

1985). In recent years, this kind of pile has been used extensively for landslide control in many places in China because of its capacity to resist slides, the low amount of masonry needed, convenient construction, and the fact that it can easily be constructed manually using simple instruments, for example, in Panzhihua City, Sichuan Province (Lin 1989 and Zhu et al. 1989) and on the Second Automobile Works' Site, western Hubei (Liu and Jin 1989). The formation and action of the piles are similar to the so-called shaft works (deep foundation piping with broad diameters) used in Japan.

Figure 3: Deep-seated Counterfort Drain



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A. Plan

B. a-a' profile (downslope section)

C. b-b' cross section

1. Sliding surface location

2. Mortar bubble masonry

3. Bubble

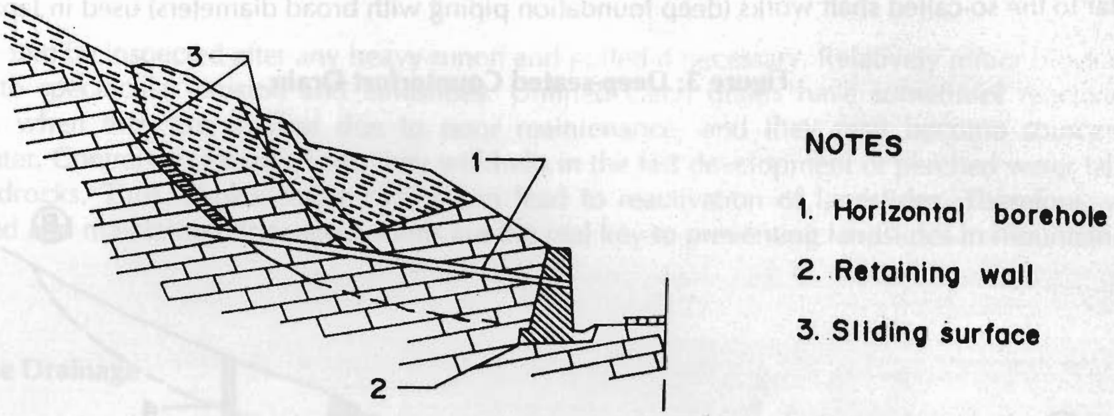
4. Water-filtering layer

5. Ground surface

6. Landslide boundary

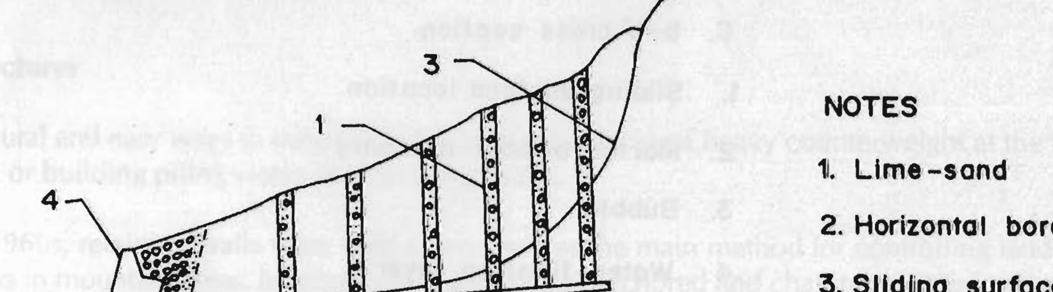
Source: Li and Liu 1982

Figure 4: Horizontal Borehole for Draining Underground Water



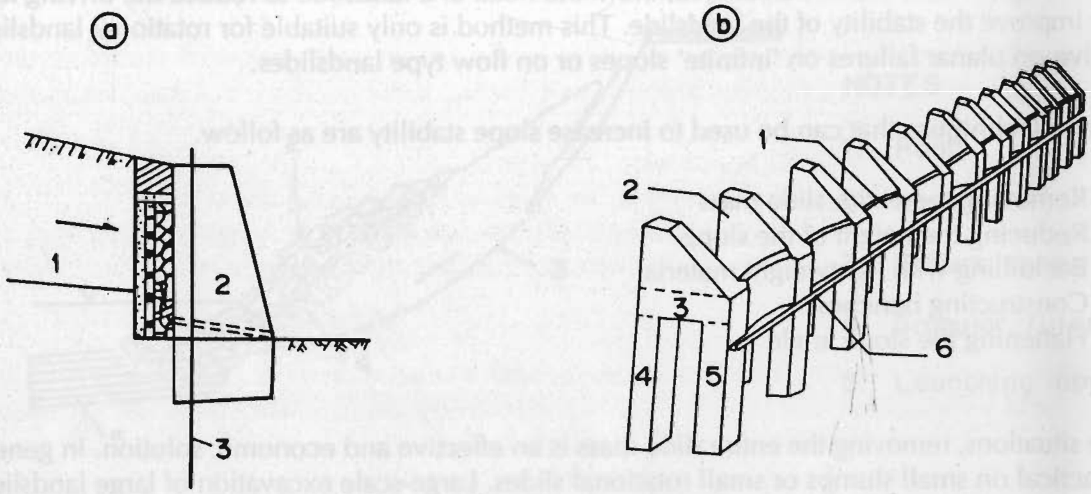
Source: Li and Liu 1982

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



Source: Wang 1985

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



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(a) Vertically anchored retaining wall

1. Sliding surface location
2. Wall
3. Anchor

(b) Chair-type retaining wall

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

Source: Wang 1985

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

Excavation and Fill

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

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

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

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

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

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

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

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

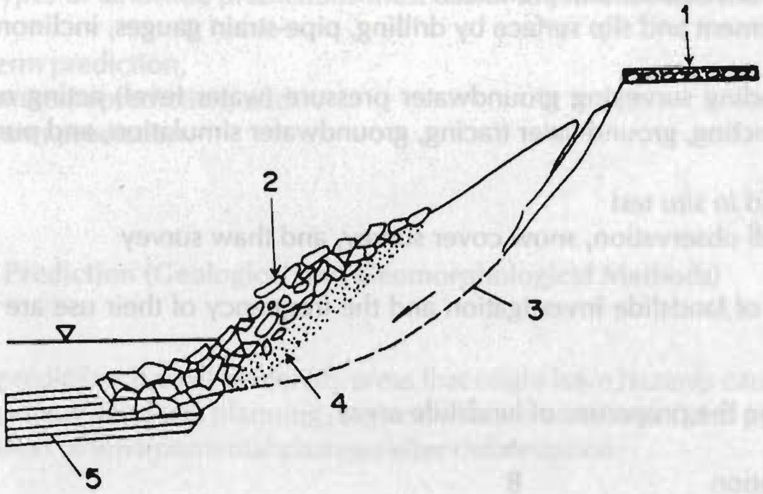
- The increase in the 'factor of safety' is greater with fills.
- Fill stability improves with time, whereas cut slope stability decreases with time.
- In large complex landslides with more than one potential sliding surface, toe loading will protect against all failures, but a cut may destabilise some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

River Structure Works

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

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

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



Source: Li and Liu 1982

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

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

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

Other Methods

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

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

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

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

1) Survey to roughly determine the properties of landslide areas

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

2) Survey of ground surface displacement

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

3) Surveying displacement in the earth and sliding zone

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

4) Survey groundwater and bearing

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

5) Surveying groundwater pressure acting on sliding zone

▸ Groundwater level measurement	A
▸ Porewater pressure measurement	C

6) Soil and rock test

▸ Physical test	A
▸ Strength test	A

7) Hydrological observation

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

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