Landslide Mapping

Landslide Identification

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

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

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

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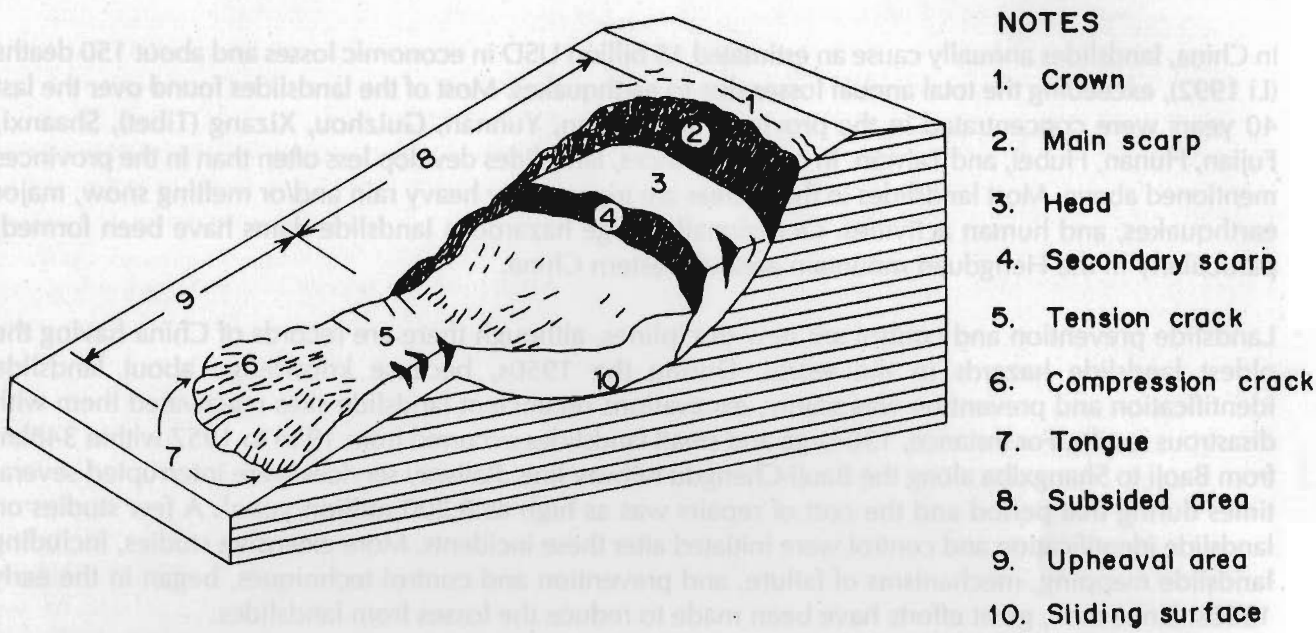
1 There are approximately eight *yuan* to the US Dollar

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

Figure 1: Schematic Figure of Typical Landslide Configuration



Source: Varnes 1978

Different Types of Landslide Maps

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

The purposes of landslide mapping are:

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

2) to represent these landslide-prone locations on maps; and

3) to disseminate landslide information to planners, engineers, and decision-makers for a better understanding of the landslide problem and more accurate hazard assessment in the region concerned.

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

Landslide Distribution Maps

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

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

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

Landslide Hazard Zonation Maps

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

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

Landslide Susceptibility Maps

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

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

High Susceptibility to Landslides. The area consists of landslide deposits and possible landslide deposits. No small landslide deposits are shown. Some of these places may be relatively stable and suitable for development, whereas others are unstable and landslides cause damage to roads, houses, and other physical features. Landslides are a common occurrence during heavy rainstorms or strong earthquakes.

Moderate Susceptibility to Landslides. Many small landslides have formed in these areas and several of them have caused significant damage to houses, roads, and farms. Slopes vary from 25° to 45°. Slopes steeper than 45° seem to be stable because they are composed of massive hard sandstone. Some places may be more susceptible to landslides if they are overlain by thick deposits of soil and slope wash. Landslides may occur during strong earthquakes and heavy rainstorms.

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

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

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

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

Techniques of Landslide Mapping

Landslide Inventory

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

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

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

Aerial Photo Interpretation

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

Table 1: Geomorphic Features Used as Indicators of Large Landslides

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

Source: Compiled from technical literature

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

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

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

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

Remote Sensing and GIS Techniques

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

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

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

Source : Compiled from technical literature

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