Title	中国の黄土地すべりおよびその発生機構
Author(s)	趙, 廷寧; 孫, 保平; 宜保, 清一; 王, 暁慧; 周, 金星
Citation	琉球大学農学部学術報告 = The Science Bulletin of the Faculty of Agriculture. University of the Ryukyus(47): 113-121
Issue Date	2000-12-01
URL	http://hdl.handle.net/20.500.12000/3424
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Loess landslide in China and its mechanism

Tingning ZHAO*, Baoping SUN**, Seiichi GIBO***, Xiaohui WANG** and Jinxing ZHOU**

Key words : loess landslide, mechanism of landslide, natural disasters

Summary

The area of loess covers 6.63 per cent of total land area of China and it is well known all over the world for its largeness and wide location. The frequent happening of natural disasters, such as soil and water erosion, landslide and mud-rock flow, is the major factor hindering the social and economic development of loess area. In this paper, the principal types of loess landslide and the distribution rules of loess landslide are pointed out, and the landform and relief characteristic of loess landslide influencing factors of loess landslide and its mechanism are analyzed. It emphasizes that the prevention and control of loess landslide is a key factor that will determine the sustainable development of local society and economy.

Introduction

The area of loess covers 6.63 per cent of total land area of China and it is well known all over the world for its largeness and wide location. The frequent happening of natural disasters, such as soil and water erosion, landslide and mud-rock flow, is the major factor hindering the social and economic development of loess area. In this paper, the principal types of loess landslide and the distribution rules of loess landslide are pointed out, and the landform and relief characteristic of loess landslide influencing factors of loess landslide and its mechanism are analyzed.

The general situation of loess landslide in China

China has an area of 655.3 thousand km^2 of loess area, accounting for 6.63% of its total

* Beijing Forestry University, (Visiting Researcher of the University of the Ryukyus)
** Beijing Forestry University
*** Faculty of Agriculture, University of the Ryukyus
The Science Bulletin of The Faculty of Agriculture, University of the Ryukyus, No.47 : 113~121 (2000)

land area. Continuous loess area in the Loess Plateau, consisting of eastern Qinghai Province, eastern and middle Gansu Province, southern Ninxia Hui Autonomous Region, northern and middle Shaanxi Province, western Shanxi Province, and western Henan Province, is 440 thousand km^2. The other scatters in Xinjiang uygur Autonomous Region, the Northeast, east of Taihang Mountain, Shandong Province and Nanjing City. Especially, the Loess Plateau is famous for continuum, great development of thickness, landform, relief and typical lithology composition.

There are superior conditions to establish energy resources and heavy chemical industry bases, to develop animal husbandry and forestry in loess area, for the abundant resources of mineral, water, electricity, land, light, heat and the great developing potentialities. However, loess has characteristics of loose loess lithology, large pore, developed vertical joint, and weak erosion resistance. The chronical rising of the crust of the Loess Plateau leads to severely incised valley, fragmented topography, crisscrossed gully and steep slope. Therefore, geological environment is highly frail in loess area. The main loess area is located in arid and semi-arid areas with high intensity of average annual precipitation. Under such natural condition of geography and geology, natural disasters, such as soil and water erosion, landslide and mud-rock flow happen frequently. In recent twenty years, the population in loess area increases so rapidly that it has reached 81.49 million, accounting for 7.8% of the nation's population, 16.7% higher than average annual increase in 1980 and higher than 12.8% of the nation's population increase rate. With the rapid increase of population and the development of engineering economy construction, irrational human activities, such as excavating foothill, filling hillsides and over cultivating, increase sharply, which further accelerate frequency and intensity of natural disasters. Compared with other areas in China, industry develops slowly, agriculture is at a low level, and people lead a relatively poor life in loess area. In 1985, the total output value of industry and agriculture is 809.04 hundred million yuan, accounting for 6% of that of the nation, averagely increasing by 10% as against that in 1980, lower than 12% of increase rate of the nation. Frequent natural disasters are major factors hindering the social and economic development of loess area.

Landslide is the main disaster in loess area. According to statistics, one third of whole country's landslide disasters happened in loess area. From 1949 to 1990, at least 1025 people directly died from landslide disasters merely in the part area of the three Provinces of Shaanxi, Gansu and Qinhai. On August 8, 1955, the loess landslide of Wolong Temple in Xibao Section of Longhai Railway Line damaged 230 meters roadbed and suspended the transportation for several days. On March 7, 1983, the loess landslide of Sale Mountain in Dongxiang County, Gansu Province happened in a moment, resulted in 3 counties covered up, 237 people killed, 22 people injured, over 500 houses ruined, 433 animals killed, 1000 meter roads, over 29 hm^2 farmland and 2 reservoirs destroyed. On August 11, 1990, loess landslide in lathe factory, Tianshui City, ruined 6 workshops and killed 7 people, thus paralyzing a developing enterprise. In addition, many famous large disasters such as Bailu Plateau Form landslide, Haiyuan Earthquake landslide and Jiangliu landslide happened all in loess area. landslide caused tremendous economic losses to human beings due to its extensive distribution and high frequency. In 1995, earthquakes over 6 levels happened 7 times in the mainland of China, leading to 85 people died and 11.64 hundred million yuan direct economic loss, while

landslides happened over 3000 times leading to at least 776 people died and 23.52 hundred million yuan direct economic loss. In the 90's, extremely active loess landslide has imposed a serious harm or threat on people's life. It is urgent that the loess landslide mechanism, forecast and disaster reduction measure to be studied as to promote sustainable development of ecological environment in loess area[1].

Principal types of loess landslide

Many types of loess landslides are developed in loess area. According to research results[2] that we have, several types of loess landslides as follows are developed extensively in this region in the respect of landslide material, development position of landslide surface and landslide movement mechanism (Table 1).

In the respect of landslide material, landslide body of loess landslide and loess-red layer landslide consists of loess, loess and mudstone of the third period separately. It is recorded that loess landslides account for over 70% in the Loess Plateau, while loess-red layer landslides account for less than 30%. The latter is always huge landslide, more than 1 million m^3.

In the respect of development position of landslide surface, the surface of loess landslide is developed in loess layer and mostly small, less than 100 thousand m^3. Loess-red layer contact landslide is characterized by main landslide surface developing along contact surface of loess and mudstone of the third period. Both of these landslides are mainly 100 thousand m^3. Loess-red layer consequent landslide is characterized by main landslide surface developing along red layer as against main landslide surface of loess-red cut landslide across red layer. Most of the two landslides are big, more than 1 million m^3, and even bigger, especially the latter. It is counted that the proportions of loess landslides, Loess-red layer contact landslides, loess-non-red layer contact landslides, loess-red layer consequent landslides and loess-red layer cut landslides in loess area are respectively 40%, 30%, less than 5%, 20% and less than 10%.

In the respect of landslide movement mechanism, different researchers put forward various schemes from the different aims. A large number of movement mechanisms of loess landslides already happened indicate that landslide movements have two main types. One is slow gliding landslide. It glides slowly. During gliding period, it is gradually disassembled or gliding slowly in a whole. Most of this kind is various old landslides. The minority is loess landslides or loess-red layer contact landslides. The other is collapsing-gliding landslide. It glides rapidly,

Table 1 Principal types of Loess landslide

Classified indicator	Types of landslide
Landslide material	Loess landslide
	Loess-red layer landslide
Development position of landslide surface	Loess landslide
	Loess-red layer contact landslide
	Loess-red layer consequent landslide
	Loess-red layer cut landslide
	Loess-non-red layer contact landslide
Landslide movement mechanism	Slow gliding landslide
	Collapsing- gliding landslide

both collapses and glides, mostly glides, and first collapses second glides. This kind scatters in loess area vastly, representing the majority of movement mechanisms of new loess landslide. Due to its rapid gliding, it caused severe disaster. In loess area, almost all catastrophic landslides with people died or injured and great property losses are collapsing-gliding landslides.

Distribution rules of loess landslide

Landslides in loess area, affected by geological composition, stratum lithology, landform, relief, climate and human activities, are distributed with apparent rules of time and space.

1. Space distribution rule

Landslides in loess area are distributed in a strip along plateau form, ridge, edge of loess hill and bank of valley, in a cluster around the edge of tectonic basin of the Cenozoic Era and the Mesozoic Era, and in a sheet in active earthquake zones. In addition, apparently affected by precipitation, landslides are abundant in areas with more than 400 mm of annual precipitation and sparse in areas with less than 400 mm of annual precipitation[3].

Due to favorable landform, landslides are exceedingly abundant around the edge of tectonic basin of the Cenozoic Era and the Mesozoic Era. From the edge of basin to the center, landslide is distributed from dense to sparse. Especially in red layer basin of the Cenozoic Era, mudstone of the third period is developed, easily intenerated when touching water and particular binary composition consisting of upper loess and lower red layer is beneficial to landslide development. Therefore landslides around red basin of the Cenozoic Era in loess area, such as Huangshui-Linxia Basin, Longzhong Basin, Xiji Basin, Guanzhong Basin and Shaanbei Basin, etc, are distributed densely. According to statistics, the number of landslides of more than 500 m in width is over 10 per 100 km^2[2].

In loess plateau form, ridge, loess hill and bank of valley, landslide is developed due to favorable incised topography, such as Dongzhi Plateau Form, Luochuan Plateau Form, Bailu Plateau Form, surrounding ridge, edge of loess hill, small edge of plateau form, and bank of Weihe River, Baxie River, Jing River and their branches. According to a survey, the number of landslides of more than 500 m in width is over 5 per 100 km^2. In these zones, landslides are developed more densely in mudstone of the third period[4].

In the loess plateau, there are 3 earthquake strips: north-south earthquake strip of Liupanshan Mountain in Yinchuan-Tianshui-Wudu line, west earthquake strip of Huxi, Jibei in Lanzhou-Tianshui line, east earthquake strip of Hudong, Jibei in Weinan-Xi'an-Baoji line, which are all active earthquake strips in China. The famous Haiyuan earthquake of 8.5 magnitude, Hua County earthquake of 8 magnitude, Tongwei earthquake of 7.5 magnitude and Tianshui earthquake of 7.5 magnitude all happened in these earthquake strips. Affected by earthquake, landslide is developed densely in earthquake strips. According to relevant data, earthquakes of 6 magnitude will induce a large number of landslides in loess area[5].

In northern loess plateau with less than 400 mm of annual precipitation, landslides are sparse. In the other area with more than 400 mm of annual precipitation, landslides are developed.

At the joint of earthquake strips is dense landslide developing area. It is investigated that all dense landslide areas are joints of landslide prone sections, such as Tianshui, Xining-Linxia line, peripheral Baoji-Weihe line, peripheral Xi'an, peripheral Lanzhou and peripheral Yan'an, among which landslides in Tianshui are distributed most densely and concentrated landslide area is the largest[6].

Tianshui is located in the eastern edge of the third red basin of Longzhong, and the middle reaches of Weihe River, the joint of Yinchuan-Tianshui-Wudu earthquake strip and Lanzhou-Tianshui earthquake strip. In this area, new tectonic movement and river downcut is strong, landform is fragmented, binary composition of loess and red layer is developed, and annual precipitation is 580 mm with centralized precipitation and a large number of rainstorms. Therefore, landslides are specially developed. The development of the landslide in this area amasses all characteristics of dense landslide area in loess area. Density of landslide distribution, characteristic of development and movement type is one of the most typical in loess area. Density of landslides is over 20 per 100 km^2 in the area of 100 thousand m^2.

2. Time distribution rule

Precipitation and dynamic characteristic of earthquake affects the time of landslide development in loess area distinctly.

About 90% of landslides in this area are related to precipitation and earthquake. Affected by dynamic characteristic of precipitation, landslides related to precipitation mostly happen in rainy season of July, August and September. Active period of earthquake corresponds with frequent occurrence of landslide. Every earthquake of higher than 6 magnitude induces a great number of landslides. For example, Tianshui earthquake of 7.5 magnitude in 1654, Tongwei earthquake of 7.5 magnitude in 1920 and Haiyuan earthquake of 8.5 magnitude in 1920 induced a great number of landslides.

In addition, ice-melting period from annual March to May corresponds with frequent occurrence of landslide. Famous Saleshan landslide, New Saleshan landslide and Wolongshi landslide happened in this period.

Landform and relief characteristics of loess areas having landslides

The fundamental characteristic of relief outline in China is ladder-like, namely high in the west and low in the east. The surface may be divided into three levels. The loess plateau is located in the second step. The characteristic of relief in the loess plateau mainly consisting of plateau form, ridge, edge of loess hill is as follows: first, many gullies and fragmentized ground; second, deeply incised gully, high difference in altitude and severe undulated topography; third, steep slope and large ground degree. According to incomplete statistics, the number of gullies of more than 1 km long in loess area is about 30. The density of gully is small in the Gullied Loess Plateau Region, about 2.4～2.7 km/km^2, whereas larger in the Loess Gullied Hilly Region, about 3.5～8.05 km/km^2. As for the area of gullies, 2～8 gullies of 1 km in length are located in the area of about 1 km^2. More than one forth, even a half land becomes gully. Because of severe erosion, gully is cut down to bedrock in many regions. The difference of altitude from the water divide to the bottomglade is 10～60 m in the Gullied

Loess Plateau Region, and 40～100 m in the Loess Gullied Hilly Region. By contraries, the difference of altitude from the edge to the bottomglade is large in the Gullied Loess Plateau and small in the Loess Gullied Hilly Region. The general situation is that the deeper gully, the smaller the difference of height from the water divide to the bottomglade. Therefore, the maximal difference from water divide to the bottomglade is consistent in a large scale. So fragmented loess ground and strong undulating land provide favorable conditions for landslide occurrence.

Influencing factors of loess landslide and the analysis of its mechanism

1. Topographic and geomorphic conditions

Topographic and geomorphic conditions are necessary for the development of landslide. Even if geologic structure and stratum lithology exist, landslide does not happen without topographic and geomorphic conditions of landslide occurrence.

The cut depth of ground is the largest in the edge of Loess Plateau, Qinling Mountain Region, the second largest in Lower Lishan Mountain and Bailuyuan Plateau Form, etc, and the smallest in plain. In fact, cliff exists in relatively steep slope region, gentle region, and even relatively flat region. Specially in vast loess gullied hilly region, edge of gullied loess plateau region, more than 30° steep slope exists widely.

A great deal of investigation shows that 15°～45° slope is preferential section of landslide occurrence. If slope is very sharp, gravitational landslide is easily formed. In the loess gullied hilly and gullied loess plateau, the angle of 30° slope is close to or greater than inner frictional angle of 19°～30°. Therefore, slope is in a state of weak stability, it is vulnerable to landslide formation under the action of comprehensive external forces.

2. Stratum lithology effects

Loess is soil accumulation of the fourth period, yellow or light brown and with several interlayers of reddish brown palaeosoil. Developed vertical joint, vulnerable to drought crack, high hole coefficient and low moisture content provide rainfall infiltration with favorable conditions. Because of the loess characteristics of chemical component, granule composition, structure shape, permutation and combination, inteneration and settlement when meeting water, loess is named hole-settlement loess. When loess meets water, the intensity is rapidly decreased. If the other conditions are provided, landslide may happen. Therefore loess stratum is a fundamental factor of landslide occurrence.

Red soil, mudstone, sandstone and shale are extensively in existence in lower loess stratum. With the characteristics of relatively loose lithology of these stratums, low mechanical intensity, vulnerable to inteneration when meeting water, relatively permeable-free stratum as against loess and easy transformation into layer of phreatic water, landslide surface is easily formed in loess area.

3. New tectonic movement and earthquake activity

New tectonic movement plays a dominant role in the slope development. From the later Pleistocene Epoch of the forth period, new tectonic movement is strong, mountain, hill and

plateau form rise, and river and valley cut down. All of these make the difference in altitude of slope continuously greater, and form high slope. Many valleys develop along fissure, thereby providing landslide development with topographic and geomorphic conditions. Faultage in slope section does good to landslide development because the existence of fault age promotes infiltration of the rainfall and surface runoff, faultage surface may become rip surface and slippage surface of landslide, and the activity of faultage impels creepage and distortion of slope.

Earthquake activity has close relation with landslide development. For example, Haiyuan earthquake in Ninxia induced large-scale landslide.

Strong surface tremor caused by earthquake brings the change of structure and intensity of slope body, makes rock soil loose or compacted, even liquefied, and reduces the shear resistance strength of slope rapidly. Earthquake force brings slope abrupt displacement. Therefore, earthquake makes not only slope in the state of creepage and distortion slipping, but also slope in the stable state slipping.

4. Water effect

Landslide occurrence has close relation with water effect. Water effect on landslide is discussed in the three aspects of rainfall, surface water and ground water.

Rainfall effect on the vertical infiltration of rainfall and surface runoff along the fissure makes water content of slope increase, even saturate. When a great deal of rainfall reaches confining layer to form phreatic water layer, cohesive force of soil body and frictional force of interlayer greatly decrease, and it is very beneficial to landslide occurrence. Surface water effect on mountain streams of surface and river continuously cuts down and erode, making slope become higher and steeper, then unstable. Ground water effect on the existence and change of ground water directly affects gravitational condition of slope and mechanical characteristic of rock soil, which are main factors affecting slope stability.

It is observed that when water content of red soil increases to 35%, shear resistance strength decreases by more than 60%. The decrease of shear resistance strength of mudstone or shale in saturation is 30～40% lower than that in natural state. If ground water converges into a layer on the top of confining layer, it will produce buoyancy acting on upper soil body, resulting in decreasing sliding-resistance force. Ground water dissolves diffluent material of rock soil, changes chemical components and structure of rock soil, and even forms latent erosion and corrosion. The rise of ground water level produces lenitic and dynamic pressure, then affects slope stability.

5. Human activity effect

With the development of social economy, people utilize and reform nature more and more widely. In industry, agriculture, transportation, mineral resources, irrigation works, and the exploitation of cities and counties, the problem of border slope is inevitably involved. In the respect of landslide, breakdown and mud-rock flow, human factors are playing an increasingly important role.

On the border of loess plateau form and valley slope of loess hill, flat ground is rare, building houses by cutting slopes is universal, and cave-houses are dig in steep slope formed

by cutting slope in some places. All of these reduce supporting force of the bottom of the slope, and decrease the stability of the border slope, are beneficial to landslide formation. In the catastrophic landslides and breakdown happening in recent years, a majority of landslides are related to human cutting slopes.

Digging soil in the bottom of loess slope areas is a factor of landslides occurrence. In addition, vegetation has a function of protecting slope. But in the 50's of 20th century, unwise deforestation brought about severe damage of mountain forest. Especially in low mountain area, forest resources are on the verge of extinction. Reclaiming lands brought about the damage of grasslands, resulting in landslide in reclaimed areas of higher slope.

As stated above, loess areas provide landslide formation with convenient conditions, such as favorable border slope, and infiltration of rainfall and surface runoff. Stratum lithology accelerates water conservation, unstraightway drainage of rainfall, and rising of ground water. Affected by ground water, fragile surface is formed. Soil produces shear damage surface along fragile surface with the action of gravity and external forces. The formation of sliding surface is the key to slope sliding. Sliding surface of loess landslide is mostly developed in the surface or inner of clay layer. Clay layer and upper layer is saturated and intenerated, making land change slowly. With the increasing distortion of slope body, sliding surface is formed gradually. Ground water has great role in declining shear-resistance intensity of sliding layer. Under the action of gravity and external forces, plasticity area is produced and developed, increasing the amount and rate of distortion. When the amount and rate of distortion exceed allowable value, slope body produces rheological damage along plasticity area, forming local sliding surface, which indicates that slope wriggling changes into the accelerating stage. Local sliding surface develops continuously, reaching the state of sliding preparation when perforating entirely.

Frequent occurrence, strong paroxysm, large scale, distributed in strips or sheets, and affection by topography, geomorphy, rainfall and earthquake, loess landslides impose serious threats on human livelihood and property. Therefore, the study of its mechanism and measure to prevent and control of loess landslide is an urgent task.

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中国の黄土地すべりおよびその発生機構

趙　廷寧*・孫　保平**・宜保　清一***・王　暁慧**・周　金星**

要　旨

黄土高原は，黄河の中流域に位置し，総面積が中国陸地面積の6.63％を占め，世界で最も土砂流出の激しい地域である。頻発する土壌侵食，地すべり，土石流などの土砂災害は，黄土地域の社会的経済的発展の障害となっている。本研究では，黄土地すべりの主要類型とその分布特性，および黄土地すべりの地形・比高などの地すべり発生要因を明確にした。さらに，黄土地すべりの防止が黄土区域の社会・経済発展のキーになることを指摘した。

キーワード：黄土地すべり、地すべり発生機構、自然災害

Key words : loess landslide, mechanism of landslide, natural disasters

* 北京林業大学水土保持学院（琉球大学農学部客員研究員）
** 北京林業大学
*** 琉球大学農学部
琉球大学農学部学術報告　**47**：113～121（2000）