A study of the mechanism of landslides in the reservoir region of the three gorges project on the Yangtze River

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Abstract: The mechanism of landslide occurrences is divided into the three types: (1) landslides controlled-by a sliding plane, (2) landslides controlled-by a sliding mass and (3) landslides controlled-by a combination of both according to investigations of 310 cases in the reservoir region of the TGP on the Yangtze River. Landslides controlled-by a sliding plane result from loss of cohesion and friction before formation of a boundary during heavy rainfall in the summer until a rapid movement along weak structural planes. Such landslides are characterized by the absence of any warning and/or a thin-sliding mass, medium-high angle and with no signs of slickensides or friction crust on the plane. For example, the Wupingzhen landslide, smaller than $1000m^3$, which occurred in Fengdu County on 7 August 1998, destroyed 11 houses in the village and caused 7 deaths. The landslide, controlled by a sliding mass resulting from large, potentially weak surfaces around the boundary of the sliding mass, would eventually lead to rapid movement on the plane with loss of the cohesion and friction. The landslide is characterized by pre-existing boundaries consisting of such free surfaces as gullies, faults or regional joints and cliffs, with signs of slickensides or friction crusts on the sliding plane. For instance, the Baiyangou landslide, which occurred in the Badong County on 20 July 1998, destroyed an 80m long the newly built highway. The landslide controlled by a combination of types may be produced by weak surfaces around the boundary and with loss of cohesion and friction. Examples are the repeated occurrences of old rapid landslides at Huangtupo, Huanglashi and Zhaoshuling.

Résumé: Le mécanisme des occurrences d'éboulement est divisé en trois types : (1) éboulements commandé-par un avion coulissant, (2) éboulements commandé-par une masse coulissante et (3) éboulements commandé-par une combinaison de tous les deux selon des investigations sur 310 cas dans la région de réservoir du TGP sur le fleuve de l'Yang Tsé Kiang. Éboulements commandé-par un résultat plat coulissant de la perte de cohésion et de frottement avant formation d'une frontière pendant des précipitations lourdes en été jusqu'à un mouvement rapide le long des avions structuraux faibles. De tels éboulements sont caractérisés par l'absence de n'importe quel avertissement et/ou d'une masse mince-coulissante, milieu-haut angle et sans des signes des slickensides ou de la croûte de frottement sur l'avion. Par exemple, l'éboulement de Wupingzhen, plus petit que 1000m3, qui s'est produit dans le comté de Fengdu 7 août 1998, détruit 11 maisons dans le village et causé les 7 décès. L'éboulement, commandé par une masse coulissante résultant de grandes, potentiellement faibles surfaces autour de la frontière de la masse coulissante, mènerait par la suite au mouvement rapide sur l'avion avec la perte de la cohésion et du frottement. L'éboulement est caractérisé par des frontières préexistantes se composant des surfaces libres telles que les caniveaux, défauts ou joints et falaises régionaux, avec des signes des slickensides ou des croûtes de frottement sur l'avion coulissant. Par exemple, l'éboulement de Baiyangou, qui s'est produit dans le comté de Badong 20 juillet 1998, a détruit des 80m longs la route nouvellement construite. L'éboulement commandé par une combinaison des types peut être produit par les surfaces faibles autour de la frontière et avec la perte de cohésion et de frottement. Les exemples sont les occurrences répétées de vieux éboulements rapides chez Huangtupo, Huanglashi et Zhaoshuling.

Keywords: site investigation, case studies, landslides, erosion, collapse, deformation

INTRODUCTION

A study of landslide mechanisms and triggering process is a key problem acknowledged by the whole world (Ersmann 1979; Sassa 1988; Cheng and Peng 1999; Huang 2004). Landslide research based on theory of rock mass fracture mechanics and dynamics has a dominant place (Hu 2000; Hu & Yang 2000), while the study of the processes and triggering mechanism of landslide from the view of rainfall and hydro-dynamics is attaching more importance (Floris, Mari, Romeo & Gori 2004; Brand, Premchitt & Phillipson 1984; Zhang 2000). For example, Wang Lansheng's five types of mechanism of landslide deformation based on geomechanics model (Wang & Huang 2004) and Yan Tongzhen's(1994) nine models of landslide mechanism are representative of this type of approach. This paper explores the mechanism and deformation of landslides from three basic structure components: sliding plane; sliding mass and sliding boundary. The mechanism of landslide occurrences is divided into the three types: (1) landslides controlled-by a sliding plane, (2) landslides controlled-by a sliding mass and (3) landslides controlled-by a combination of both according to site investigation, case studies and the statistical analyses of more than 310 landslides and dangerous rock-fall in the Fengdu county and Badong county of the reservoir region of TGP on the Yangtze river in the last five years.

MECHANISM OF LANDSLIDES CONTROLLED BY A SLIDING PLANE

Landslides controlled-by a sliding plane result from loss of cohesion and friction before formation of a boundary during a heavy rainfall in the summer until a rapid movement along weak structural planes. Such landslides are characterized by the absence of any prior symptoms and/or thin-sliding mass, medium-high angle (≥30º), with no signs of slickensides or friction crust on the plane. This kind of sliding always occurs on the surface of the precipitous bedding plane rock slope. Especially in the concentration period of rainfall, rain infiltrating into relatively water-resisting layer, which makes rock and soil masses soften and weaken, combined with the influence of pore water pressure, consequently losing strength along weak structural planes, superposed with the erosion of the surface flow on the slope result in the landslide occurrences. For example, there were 62 large scale landslides occurred during rainstorm in the Aug.6-8 1998 in the Fengdu County (Figure 1), and most of these belonged to landslides controlled-by a sliding plane (Fig.1, No33, No18, No23, et al). Of them, the Wupingzhen landslide smaller than $1000m^3$, which occurred in the Fengdu County on 7 August 1998 destroyed 11 houses in the village and caused 7 deaths (Figure 1,No. 23). Before the landslide, there was no sign of fracturing and deformation in rock and soil mass of the slope, and natural vegetation was under good condition, but during the rainstorm the potential-slipping bedding plain was intenerated, weaken and under the washed out of the surface water, which made the sliding plane lose its cohesion, and resulting in land sliding suddenly occurred in the slope.

During every summer rainstorm season, there are a large number of landslides controlled by a sliding plane occurrence in the reservoir region of TGP on the Yangtze River. These landslides are under the control of potential sliding planes, without a clear sliding mass boundary before the slippage. Therefore, it is difficult to identify the potential landslide sites through investigation. But, since there is a close relationship with rainfall, the landslides can be researched and forecasted though statistical analysis of rainfall data.

MECHANISM OF LANDSLIDES CONTROLLED-BY A SLIDING MASS

These landslides are controlled by sliding mass resulting from large potentially weak surface around the boundary of the sliding mass, eventually leading to rapid movement on the plane with loss of the cohesion and friction. The landslides are characterized by pre-existing boundaries consisting of such free surfaces as gullies, faults or regional joints and cliffs, with signs of slickensides or friction crust on the sliding plane. This kind of landslide is associated with long-term relief fracture, weathering disintegration (especially tectonic denudation along the fracture and joint fissure), erosion and washout (gullies, free surfaces). They may be affected by manual cut slopes, which leads to boundary rupturing and local collapse of the gliding mass. Rapid movement occurs finally on the slope, triggered by gravity and other outside factors (for example rainfall, earthquake, etc.)

The mechanism of landslides controlled-by a sliding mass can be divide into three types based on the process of start-up in different parts of sliding mass: the mechanism of the frontal margin towing and rear margin driving as well as controlled-by a combination of both (Figure 2).

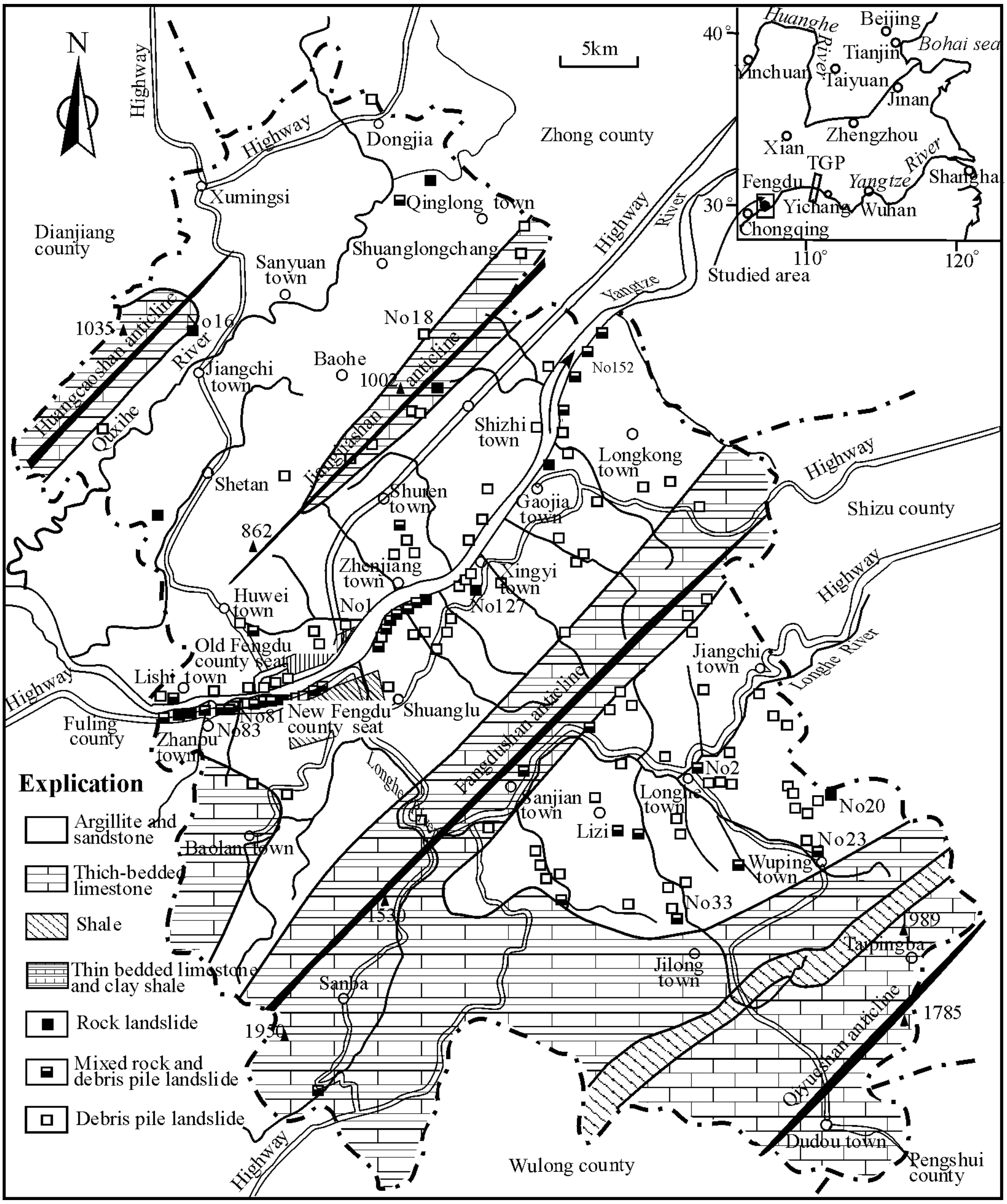

Figure 1. Map showing distribution of the landslides of the Fengdu county in the reservoir region of the Three Gorges project on the Yangtze River

The mechanism of frontal margin towing is that rupture and local collapse occurred first in the frontal margin of potential sliding mass, as a result of erosion of the river, manual cut, reservoir backwater or fluctuation of water level (Figure 2a), then result in a rapid movement of the whole sliding mass. The typical representative landslides are Baiyangou landslide in Badong County and Yangliusi landslide (Figure 1, No. 127) in Fengdu County. Baiyangou landslide located at the west side of Baiyan gully with the elevation range from 320m to 410m in Badong county seat. The slope is facing the Yangtze River and Baiyangou gully in the north and east, and there are clear relief fissure and weathering erosion alone the joint plane at the boundary of the west side of the landslide. This means the boundary of three sides in the potential slide mass is clearly defined. The whole slope's direction is about NE50° with the angle about 30° . The landslide is developed in marlstones with thin mudstone layers and sandstone bands of the second segment of Badong group; the bedrock dips to the north at around 38°. In the 1998, the Zhonghuan highway of the new county seat in Badong went through the west position of the Baiyangou gully, the highway cut the slope and formed a manual slope with 3-8m high. This altered the original slope structure and stability. Under the influence of gravity and relief, the rock rupture in the west position and local collapse occurred in frontal margin of the slope, until rainy season of 1998, mass sliding occurring on 20 July 1998, destroying an 80m length of the newly built highway, and posing a threat to the bridge of Baiyangou gully and a building near the highway. In the process of the fast sliding of the gliding mass, slickensides or friction crust formed on the sliding plane.

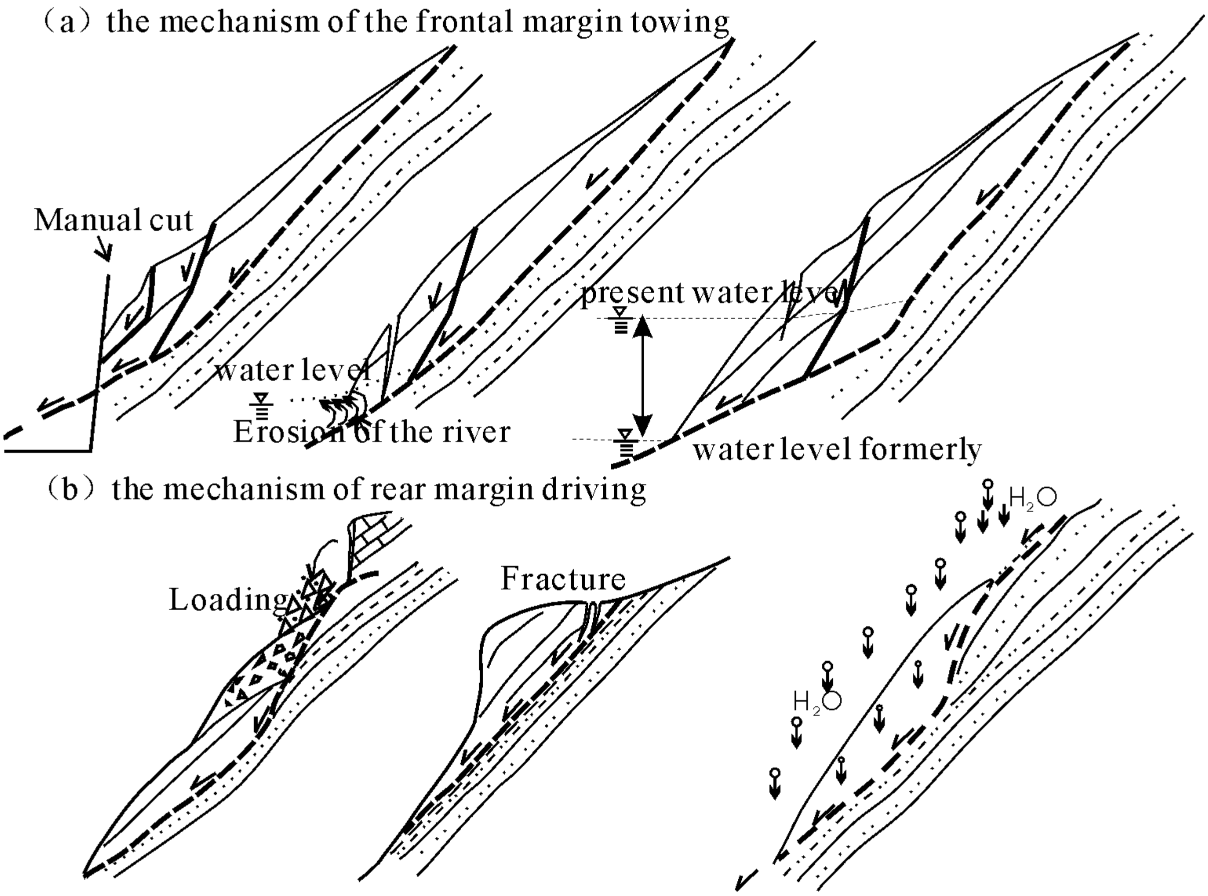

Figure 2. Scheme of the mechanism of the frontal margin towing and rear margin driving in the sliding mass

The mechanism of rear margin driving means that the pre-existing boundary in the rear margin of the slope is clear. As well as the endangered rock falling the slope adding load to the rear part of the sliding mass, surface water sinking occurs along the boundary of rear margin in the rainy season (Fig.2b), driving the potential sliding mass keep to slide down slow and local cracking of rear margin, until rapid movement. The typical representatives are Erdengyan landslide (Figure 1, No. 81) and Sandengyan landslide (Figure 1, No. 83) near the new Fengdu County seat, and also the famous Xintan landslide (Yan 1994).

Both the boundary of the frontal margin and rear margin of the sliding mass are clear, and there is influence of erosion, caving and water level changes in the frontal margin, together with the influence of ruptured rocks adds the load and rainfall sinking in the rear margin, which leads to the rapid movement of the landslide. The typical representative of this landslide are Xinmiao landslide (Figure 1, No. 16) in the Rensha town, Fengdo County and Qianjingping landslide occurred in the Zigui County on the July 13th 2003 (Yin, 2004).

MECHANISM OF LANDSLIDES CONTROLLED-BY A COMBINATION TYPE

The mechanism of landslides controlled-by a combination type means that some old landslides and potentially unstable slopes with the sliding boundary and sliding plane appear the sliding and creep deformation controlled by the combination of the boundary and sliding plane, until mass sliding occurring. This kind of landslide always passes through a long process of creep deformation, rupture and local collapse, then a rapid movement triggered by rainfall or manual caving. The process can simply be divided into three passing phase: slow creep deformation (seasonal rainfall has a little influence of the landslide), seasonal deformation and rapid deformation.

Phase of slow creep deformation: It is an accumulative transfiguration period during which the old landslide changes from stability to new movement. When a landslide keeps it's slowly transfiguration with no influence of seasonal rainfall, it is in a stable status. During this phase, the lower the sliding plane angle, the longer the period of creep deformation. Around 30% of the old landslides in the Fengdu County are under this phase (Wu, Jin, Zhang, et al. 2004). Zhaoshuling landslide of Badong County is also under this phase (Wu, Shi, Wang, et al. 2001).

Phase of seasonal deformation: slide displacement is obviously influenced by the rainfall and manual projects. Seasonal changes are clear; the landslide deformation is under the sensitive status or the sub-critical stability. For example, Longhe town landslide of Fengdu County belonged to this phase of seasonal transfiguration. The frontal margin was affected by river erosion, especially during rapid flooding from the up-stream reservoir, combined with construction in the rear margin added load, which lead a re-transfiguration, local collapse and sliding of the old landslide (Figure 1, No. 2). Maoping landslide of Qingjiang river region and Huangtupo landslide in the Badong County is attributed to this phase (Tan, Wang & Wu, 1999).

Phase of rapid deformation: Once the sliding mass is under this phase, there are obvious phenomenon of boundary new rupture and extension, displacement and local sinking, which means sliding mass is under the dynamic critical status.

The famous landslides in the reservoir region of TGP, such as Xintan landslide (Yan 1994), Huanglashi landslide (Wu, et al. 2001), Huangtupo landslide (Tan, et al.1999) and Zhaoshuling landslide belonged to the landslide controlled by the combination type.

CONCLUSION

The mechanism of landslide occurrences is simply divided into the three types in this article: (1) landslides controlled-by a sliding plane, (2) landslides controlled-by a sliding mass and (3) landslides controlled-by a combination of both.

The landslides controlled-by a sliding plane result from loss of cohesion and friction before formation of a boundary during a heavy rainfall in the summer until a rapid movement along weak structural planes. Such landslides are characterized by an absence of any prior symptoms and/or thin-sliding mass, medium-high angle, with no signs of slickenside or friction crust on the plane.

Landslides controlled by sliding mass result from large potentially weak surface around the boundary of the sliding mass, eventually leading to rapid movement on the plane with loss of the cohesion and friction. The landslides are characterized by pre-existing boundaries consisting of such free surfaces as gullies, faults or regional joints and cliffs, with signs of slickenside or friction crust on the sliding plane.

Landslides controlled by the combination type may be produced by weak surfaces around the boundary and with loss of cohesion and friction. This kind of landslide always passes through a long process of creep deformation, rupture and local collapse, then a rapid movement triggered by rainfall or manual caving. The process can simply be divided into three passing phase: slow creep deformation (seasonal rainfall has a little influence of the landslide), seasonal deformation and rapid deformation. Most of the old landslides, repeated landslide and potentially unstable slopes with the sliding boundary and sliding plane belong to this kind.

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