Slide mechanisms of a giant ancient slide body at Huangtupo, Badong County in the Three Gorges Reservior area

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Abstract: Resettlement is one of the most important problems in the Three Gorges Project. In recent years, as one of the new locations in Badong County, Huangtupo landslide has been a regular focal point for engineering geologists from home and abroad. It has been listed as the key research item in the General Plan for Geological Hazard Prevention in the Three Gorges Reservoir Area. This paper describes the study of the slide mechanism of the Huangtupo landslide using comprehensive methods including engineering geological field investigation, measuring sections, statistical analysis of fractures, indoor observation of minerals and the microstructure of the rock, age testing and borehole verification. Research results demonstrate that Huangtupo is a giant ancient slide body composed of three sections: the upper, the middle and the lower. Achievements of this research lay a solid foundation for predicting the temporal and spatial stability of the Huangtupo landslide when sliding occurs, and preventive treatment. In addition, there are many giant ancient slide bodies similar to the Huangtupo landslide developed in the Three Gorges Reservoir area, such as giant ancient slide bodies located at Shangxiping, a new address in Wushan County and Zhaoshuling in Badong County, and others. The results in the paper provide useful experience for use on similar projects.

Résumé: Le déplacement de la population des zônes de retenue est la clèf de la réussite ou de la défaite du Projet de Trois Gorges. Depuis plus de 10 ans, le glissement de terrain loéssique au nouveau site du District de Badong est un important projet de recherche des géologistes du pays et de l'étranger. «Plan Général contre les Calamités Géologiques dans la zône du bassin de retenue du barrage de Trois Gorges» prend aussi le glissement de terrain loéssique comme l'objet des études. La présente thèse est pour objet de rechercher le mécanisme du glissement de terrain loéssique par des moyens tels que reconnaisance géotechnique sur le terrain, mesure des coupes sur place, compte des fissures, observation minéralogique et observation de microstructure des roches, test des âges, forages, etc. L'étude montre que les terrains loéssiques sont des géants paléoglissements de terrain en profondeur, qui se distinguent en haut, au millieu et en bas trois parties et le résultat de recherche donne une base solide géologique pour la prévision de stabilisation, en temps et en espace, des glissements de terrain loéssique et pour la recherche de prévention et traitement dans ce domaine . Par ailleurs, de l'effet géologique particulier, la zône du bassin de retenue du barrage de Trois Gorges dévellope une grande quantité de géants paléoglissements de terrain similaires comme ceux en loess, par exemple sur le haut Xiping, nouveau site du District de Wushan et sur les collines Zhaoshuling du District de Badong. Le résultat d'étude de la présente thèse peut fournir des expériences profitables pour des projets similaires.

Keywords: engineering geology, fractures, landslide.

INTRODUCTION

Due to being located within the inundated range of the reservoir of The Three gorges Project, Badong County, Hubei Province, China, about 69km away from the dam site of the Three Gorges Project, needs to be moved and re-constructed. In the 1970's, the authorities completed the survey and comparison of the potential new locations, and Huangtupo, 2 km west of the old town was selected. In 1980, the overall plan and design of the new town was completed, and building began in 1984. During the construction of new town, many complex environmental geological issues were discovered. Two main opinions were presented: some geologists believed that there were two isolated ancient slide bodes called Garden Spot and Transformer Substation in the new town site (Figure 1); the others took the opinion that Huangtupo entirely was a large superficial layer ancient slide body [2] (Figure 2). Two sliding events took place in Erdaogou and Sandaogou at Huangtupo on June 10, 1995 and on November 20. 1995, and $4\times10^4 m^3$ and $20\times10^4 m^3$ of soils and rocks collapsed, respectively. Nine people were injured, and 5 killed. For the above-mentioned reasons, investigations and selections were made again for new town site. But at that time, the new city at Huangtupo had already begun to take shape. It was impossible to remove all the constructed establishments.

Under this condition, a new problem was discovered: many of the buildings were located on the slope body. This raised the question of whether the ancient slide body of Huangtupo would re-activate under the effect of excavation disturbance and water level rise? Consideration must be given to how to prevent and treat any potential instability. Before studying this problem, the slide mechanism of ancient slide body of Huangtupo must be understood.

There is no a unified understanding on the slide mechanism of Huangtupo. In 2001, it was listed as the key geological hazard point for treatment in the General Plan for Geological Hazard Prevention in the Three Gorges

Reservoir Area. In the recent years, the authors have been studying on this aspect, and the results are presented in this paper.

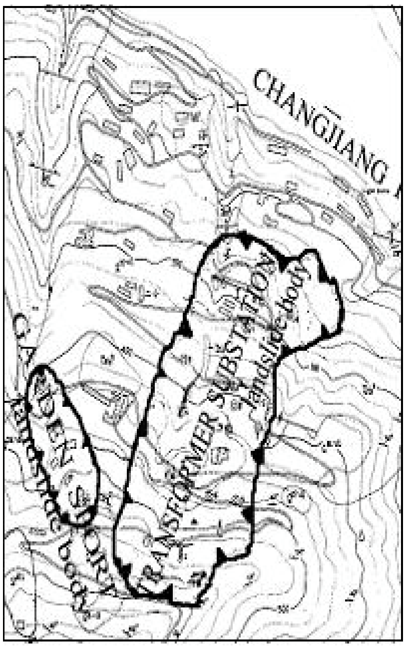


Figure 1. Garden Spot and Transformer Substation landslide

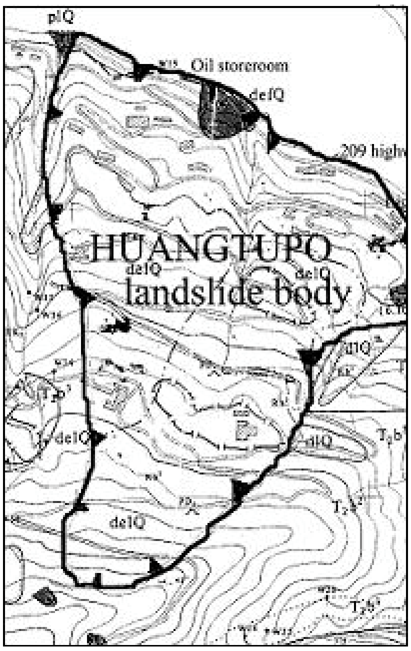


Figure 2. Huangtupo landslide

GEOLOGICAL SETTING

Huangtupo is located in the centre of Badong new town, and is between Erdaogou and Sidaogou. The area of the slide body is generally a gentle concave slope with a mean slope of 17.3°. The east of the trailing has the shape of a round-backed armchair, and with a slope about 40°. The middle part is fairly shallow, and the slope is 15~20°. The lower part is relatively steep, and the slope is 30~35°.

Jialing Jiang group of low Triassic System (T_1j), Badong group of middle Triassic System (T_2b), and Quaternary (Q) strata are exposed in the research area. The second section of Badong group(T_2b^2), with a thickness about 10m, consists of purplish red silty mudstone, mudstone, and is interlayered with greyish green mudstone. The third section (T_2b^3), about 365m in thickness, is middle-thick to thick dark marlite, and is heavily fractured. Through surveying and analysing for many years, it is widely accepted that Badong group (T_2b^2/T_2b^3) are the strata prone to sliding in this area, since the rocks are hard in the upper section and soft in the lower. Most mineral components of T_2b^2 rocks are clay minerals, quartz, and albite, and the clay minerals are (40~65%). This determines that the rocks have strong hydrophilicity and are inclined to weathering. Rock stability investigations along the bank of Changjiang in the Three Gorges region demonstrated that various rock deformations and failures are very common in the Badong group strata, and the linear density is 0.29 occurrences per km. The noted slopes found in the Three Gorges region such as Guanditduo (1231 m^3), Liulaiguan (3300 m^3) and Huanglashi (4000 m^3) are all in these strata, indicating sliding-prone characters of the strata.

Under regional tectonic influence, the major tectonic pattern of Huangtupo area is a complex fold. Most of the anticlines are tight, and some of them are inverted. The synclines are compound, secondary folds are well developed, and inter-bedding compression and displacement are strong. In the core or along the axis of the synclines mylonitization or brecciation phenomena are prevalent. The boreholes that penetrate into the bedrocks for slope survey always encounter fractured zones. The orientation of fractures in this area is controlled by the regional tectonic pattern. Four groups of steep dipped fractures are developed, their trends are N76°~84°W, N75°~85°E, N10°~20°E, and N30°~40°E, respectively. The first group is most numerous.

RANGE DELINEATION OF HUANGTUPO ANCIENT LANDSLIDE

Fracture statistics

The documents and research results by various geologists indicate that the difference of range delineation of the landslide causes the understanding divergence about the slide mechanism of the Huangtupo landslide. The rocks within the sliding mass of the landslide are often confused with the rocks below the sliding plane, since that,

- The sliding mass is great in volume;

- The entirety of the rocks within the sliding mass are often maintained after sliding because of short sliding distance of the landslide and high strength of the rocks;
  The beddings of the rocks in the sliding body are often visible, and their orientations are often coincident with that of the bedrocks (Figure 3).

Because of above-mentioned reasons, it is very easy to confuse the rock masses within the sliding masses with the bedrocks, and resulted in inaccuracy in scope, thickness, and mechanics parameters determination, and further, in understanding sliding mechanism and stability computation.

The confusion between the rock mass within the sliding masses of the landslide, with the bedrocks at the beginning of the survey and selection for new town sites of Badong and Wushan brought about improper judgement in the range of the slide body. The depths of most exploration bores were shorter than needed, producing serious influences to the resettlement project and the construction of the new town. As for the Huangtupo landslide, the apparent characteristics of a landslide are already very obscure due to later period reconstruction of geological process and weathering. Only a few of sliding characteristics are recognizable [3] [8]. So it was impossible to determine the precise range of sliding body using traditional engineering geological methods. Drillings and geophysical investigations also cannot be used widely owing to the cost and lack of precision. The paper determines the scope of the Huangtupo landslide by the methods of microcosmic analysis, fracture statistics, and macro geological phenomenon investigation.

Figure 3. Field geological features of rock bodies within sliding masses of landslide at Huangtupo

A lot of fractures would be produced in the rocks when sliding took place, and the features of fractures produced in different positions were different. The paper divided fractures in the ancient slide body, according to the order of priority of emergence and formation causes, into two types: background fractures and sliding fractures.

Background fractures are produced before the sliding of the landslide. They reflect the mechanical property, scale and direction of the tectonic movements.

Sliding fractures are those generated during the process of deformation, destabilization and failure of the slide rock mass. Some attributes of the sliding fractures are identical or similar to those of background fractures, but there are some differences between them. Thus, they can be distinguished.

Statistic analysis of fractures is carried out carefully. First, the fractures are measured on the natural outcrops. The observation items include the orientation and area of the outcrop, the orientation, length, aperture, spacing, filling, ductility, weathering, cementation and roughness of the fracture. Figure 4 shows the positions of the measuring points. Then, the genetic property of the fracture is analysed and the rose map of the fractures (Figure 5) is obtained. Finally, the background fractures and sliding fractures are distinguished on the basis of above-mentioned results and a preliminary scale of ancient slide mass is determined.

Figure 4. Engineering geological map of Huangtupo landslide

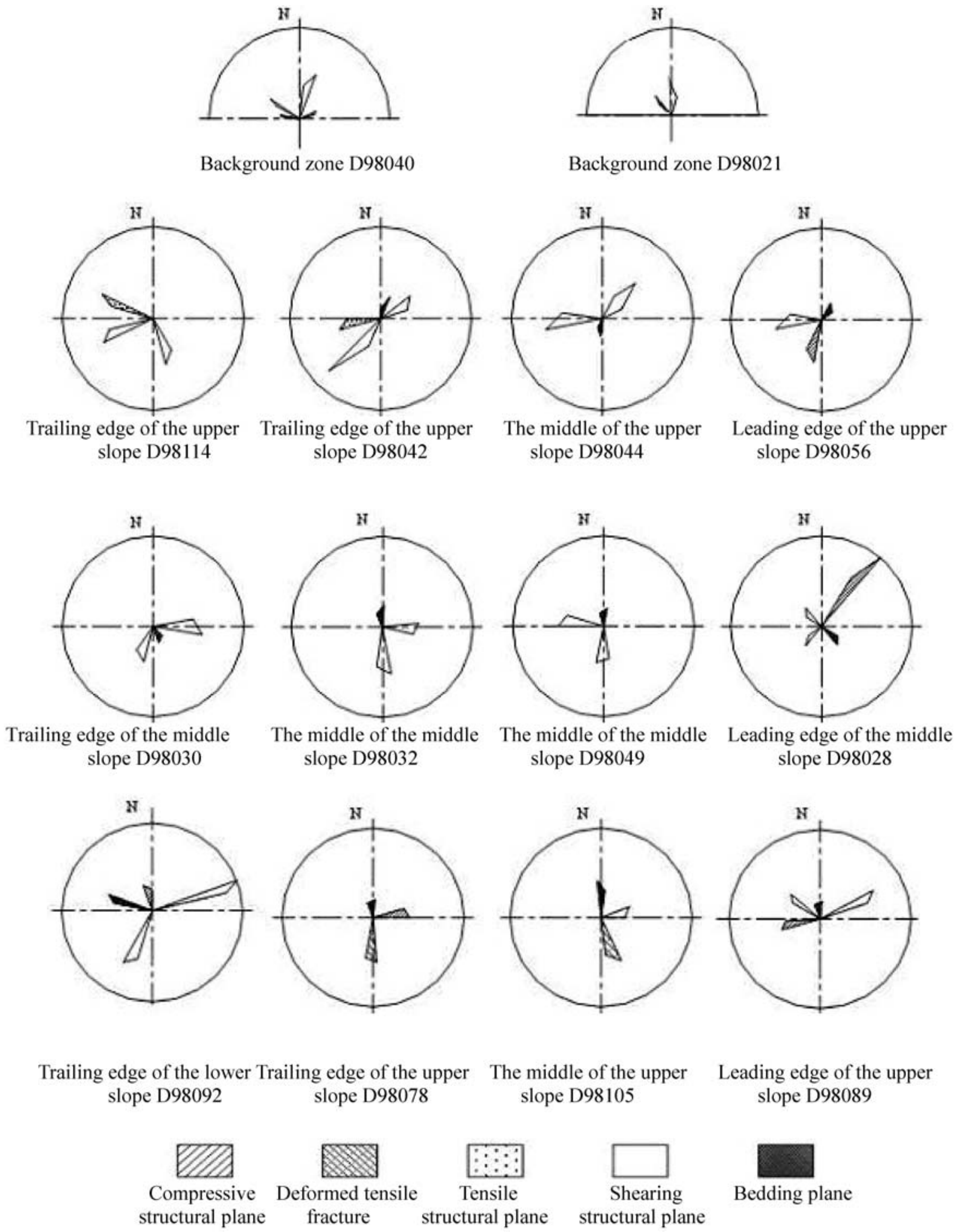


Figure 5. Joints rose of Huangtupo landslide, Badong County

According to Figures 4 and 5, there are 4 groups fractures developed in the background area of the landslide: NW, NE, NNE, and ENE. Most of them are shear fractures, and in accordance with regional tectonic pattern. In the landslide area, the number of fractures apparently increases, and the trends of them become disorderly. The directions of fractures are different in each statistic point, and the fractures show diverse mechanical features in various parts. Tension fractures (D98114), shear fractures (D98044), pressure fractures (D98049) appear respectively in trailing edge, inside, and leading edge shearing zone of the landslide. In addition, research shows that the whole Huangtupo landslide consists of 3 parts: the upper, the middle, and the lower, in term of joints attributes. Different parts of the landslide have different kinds of fractures: tensile fractures appear mainly in trailing edge, shear fractures emerge in the inside of the slide mass, and pressure fractures occur in the leading edge shearing zone.

Moreover, three engineering geological measured sections (in Figure 4, A-A', B-B', C-C') are arranged along the south-north direction. Take section A-A' for example, aereal density (the number of the fractures per unit area of outcrop) of the fractures in the background zone and landslide area are analysed along the section in this study (Figure 6). The figure shows that the statistical average value of the background fractures is about 16 on the upper part of section A-A' whose elevation is more than 600m; the average value in upper sliding body is 23, and there are 10 fractures in syncline counter-inclined segment (hereafter referred to as “the upper”), which is between leading edge of the upper sliding body and trailing edge of the middle sliding body, and 380m ~ 400m in elevation. Average value of fractures in the middle slide body is 26, and 16 in syncline counter-inclined segment (about 240m ~ 260m in elevation) between leading edge of the middle sliding body and trailing edge of the lower sliding body, 32 in the lower sliding body, and 14 between the outboard of the upper sliding body and river (about 80m ~ 100m). All of these reflect continuous deformation and failure process of engineering rock mass caused by endogenic and exogenic geological process of slope.

Microscopic investigation

Changes of microscopic geological evidences of rock masses under sliding dynamic action are studied using micropolariscope and stereoscan in microscopic research, and then identified rock masses within sliding masses of the landslide[1] [5] [6] [7]. During the course of research, at first, field oriented specimens are collected and marked upper and lower end and N, S directions using compasses; then thin section cutting is undertaken in the laboratory, and each sample is cut respectively in the horizontal and vertical directions, and marked N, S in horizontal direction and upper and lower end in vertical direction; finally, slices observation is conducted, contents of which include damage fracture property, mineral fabric feature, marginal grained effect, alteration etc. Section A-A' is chosen for gathering the background rock and oriented specimens of the rock masses within sliding masses of landslide. As space is limited, the paper presents only the results of mineral microscopic fabric feature (Figure 7).

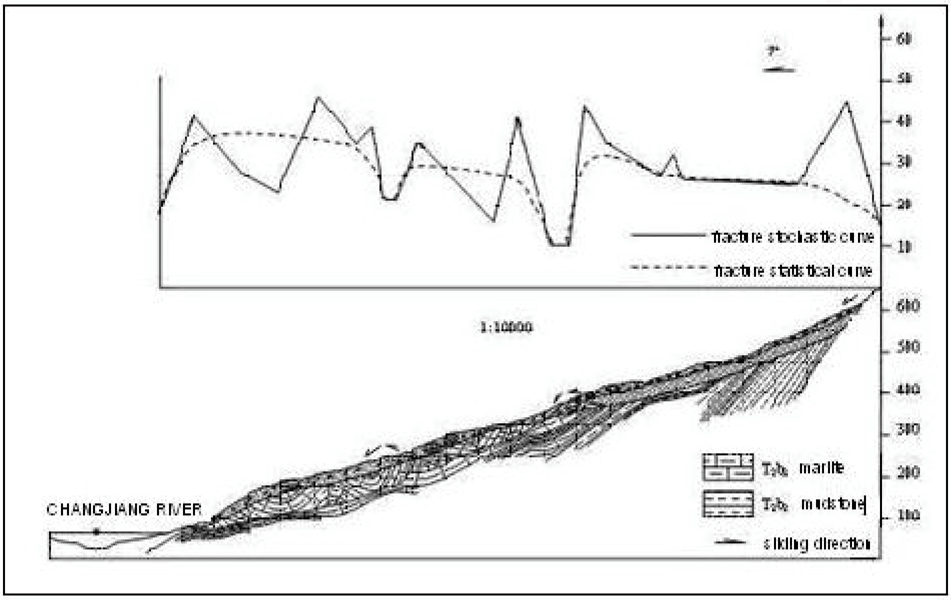


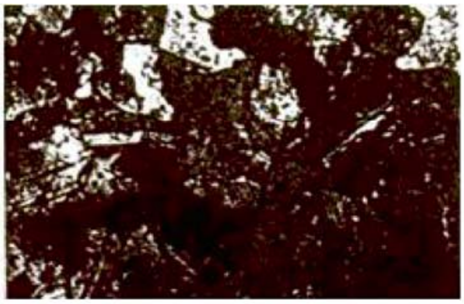
Figure 6. Fractures density on section A-A’ in Huangtupo landslide

In contrast with background rock masses, rock masses within sliding masses of landslide not only contain less calcite, more pelitic components, but mineral fabric of calcite becomes rather broken and imperfect, and mainly appears in the formation of porphyroblast. At the same time, the phenomenon that tenuous calcite grains and pelitic components construct the matrix together comes forth.

The geomorphic shape of Huangtupo landslide suffered fair damage due to natural forces as well as artificial reconstruction, but macroscopic geological features of landslides are clear in trailing edge of slope mass and partial positions of Erdaogou, Sandao, and Sidaogou. Synthesizing research achievements on macroscopic, mesoscopic, and microcosmic geological features, it was considered that the Huangtupo landslide, which is from the east side of Sidaogou in the west to the west side of Erdaogou in east and from the south side of Bagongli in south to the Yangtze River in north, is Hopei pear in planar shape. Sliding mass, the widths of leading edge and trailing edge and the length of which are about 1100m, 300m and 1780m respectively, covers an area of 1.38km^2 and is 4×10^7m^3 in bulk (Figure 4). Three subsystems (Figure 6): the upper, the middle, and the lower are developed in sliding mass. The additional boreholes have confirmed above-mentioned achievements.

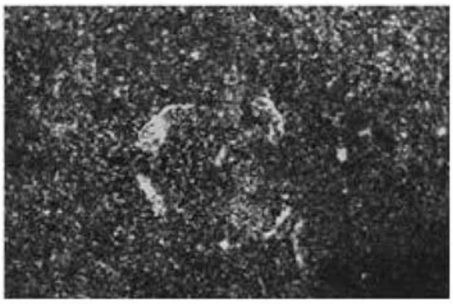
SLIDING MECHANISM ANALYSIS OF HUANGTUPO ANCIENT SLIDE BODY

By reconstructing the original landform of Huangtupo landslide, it can be inferred that general terrain is “north-high, south-low and east-high, west-low”. The contact zone of T_2b^2/T_2b^3 is located at the elevation of 460m above sea level. There is a bedrock embankment near the core of a small anticline with an altitude of 380m. North limb rock formation of the anticline is along sliding direction, and the south of it is against sliding direction. At the elevation of 240m, there is the core of another anticline, the north limb strata of which are along the sliding direction, and the south limb strata of which are against the sliding direction. Bounded by embankment and anticline, which are located at the elevation of 380m and 240m respectively, Huangtupo landslide is divided into three sliding section: the upper, the middle and the lower.



Calcite polythenthetic twin in background rock masses

Calcite porphyroclast in the upper section



Calcite porphyroclast in the middle section

Calcite porphyroclast in the lower section

Figure 7. Minerals microstructure in T_2b^3 Marlite of Huangtupo ancient sliding body

During the initial stages of slope deformation, because of gorge area upraising and the swift incision of the Yangtze River, the lower section formed an exposed face near the river; this lead to a loss of wall pressure at the face of the lower section rock mass (T_2b^3), release of elastic stress stored in slope mass, rebound and expansion of slope mass to the river direction and relaxation of the rock mass. In addition, interior stress redistribution took place near the upper surface, and resulted in stress concentration. Western and eastern boundaries were controlled by Erdaogou and Sidaogou respectively. The trailing edge of the slope is the north limb strata along the slope direction of an anticline; it is about 240m above sea level. Under the condition of rainstorm or long-period raining, slope failure, which was caused by gravity, hydrostatic pressure and hydrodynamic pressure of ground water, occurred. Debris in the lower slope is made up of cataclastic and fissured rock masses of marlite of the third member (T_2b^3), Badong group. The lower failure section is about 500m long, the maximum thickness of the sliding mass is about 50~60m, and bedding floor is gently rolling and undulating. The lower section is a retrogressive landslide. The leading edge of the slope is about 80~90m above sea level and arrives on the Changjiang River shore.

There is the bedrock contact zone of T_2b^2/T_2b^3 at the elevation of 460m. Strata are along the slope and the grade is about 40°. There is a wide and gentle anticline and its core is at 380m above sea level. The north limb of the anticline is quite steep, and the south of it is shallow. The steep strata formed the trailing edge of the middle slope. At the same time, destabilization of the lower slope not only lead to opening to the atmosphere on the middle slope toe, but a reduction of confining pressure on leading edge of the middle slope. Deformation and failure of slope rock masses occurred under the action of gravity and ground water pressure. Fuchsia coloured scattered particles of T_2b^2 cover the upper of the middle slope. The middle and the lower parts of this section are made up of cataclastic, fissured and scattered rock masses of matlite of T_2b^3. The length of the middle slope is about 600m, the maximum thickness is 70m, and a gentle slope platform is located at No.1 middle school of Badong County (Liushuping). The platform is about 350m long from the west to the east and about 100m wide from the north to the south. Terrain of the platform is higher in the southwest, and inclines to northeast by 10°. The middle section is also retrogressive. The elevation of leading edge shearing zone is about 225m.

The south limb of the core of wide gentle anticline, namely embankment, which is located at 380m is shallow, so a shearing zone on the upper surface of the upper slope was made on the steep to gentle transition along the strata: the steep slope formed by mudstone of the second member of Badong group (T_2b^2) and against slope direction erosion of the gentle slope composed of marlite of the third member of Badong group (T_2b^3). These mechanisms provided good relief conditions for slope deformation and failure. An open face was formed at the front edge of the slope because of destabilization of the middle and lower part; the incline of the upper is steep, there is about 200m between the top and the bottom and therefore huge potential energy contained in the rock mass. The strata lithology of the second member of the Badong group are soft, liable to weathering, and joints are well developed in it. The above conditions resulted in destabilization of this slope section. When slope destabilization happened, deformation was rapid in the east, since rock masses were incised, but deformation in the west was smaller due to boundary frictional resistance, namely, middle-east rock masses were sheared firstly and formed the main sliding mass during the course of sliding. Because of fractional resistance of the west rock masses, the main sliding orientation of the east sliding mass turned to the northwest, and formed "east-strong and west-weak" deformation of the upper sliding mass. Its tectonic geomorphology is characterized with an eye-catching east trending edge wall, a steep slope approximately consistent with the terrain and remaining scarps in the east sliding wall, with scattered rock masses along boundary. The west trailing edge wall and sliding wall are obscure in topographic feature. In respect of the elevation, there is no remarkable difference among sliding block, peripheral matrix and alluvial slope sediments; slope fissured rock masses with laminate structure appear near the boundary. These all reveal that the sliding distance of the west sliding mass is quite short. Because the landslide has a larger potential energy, the sliding mass slid to north with high speed after shearing and emerged with a split-flow, due to the obstruction of marlite embankment of T_2b^3 at 380m, part of the sliding block scattered over the lower slope across the embankment. After being hindered, the main flow was diverted to the west, travelling along a path of lower resistance towards the lower-lying gully. This material slid over the flanks of the third member of Badong group of the middle landslide, and formed the "redcap" feature: old strata of the second member (T_2b^2) of Badong group covers over new strata of the third member (T_2b^3) of Badong group. Masses of the slide material preserve the interface of T_2b^2 and T_2b^3 and can be observed on the bridgehead gully wall of the east of Sandaogou Driveway Bridge. In view of the above, the length of the slip of the upper sliding material is about 800m. Sliding velocity of the west part of the upper landslide was slower, the front of which was stopped by an embankment at 380m, most of the energy transferred to the west after the east slide had been blocked, and resulted in surface rock masses being diverted west 430 to 450m into an older gully; resulting in the formation of quite a thick slide, which has a gentle slope relief. The slope lies between the transformer substation and motor transport corp. platform, with a surface which is 370m long from the east to the west, 150 wide from south to the north, and inclines to river by about 8°. The topography of the transformer substation slide, referred to above, is controlled by the embankment and the inclined topography at the leading edge of the platform surface. Slope debris of this landslide segment mainly comprises purplish red mudstone and siltstone fragments. The slope is about 700m long, the maximum thickness of sliding block is approximately 50m; the slope is a tension slope, the leading edge shear zone of which is about 380m to 400m.

SEQUENCE ANALYSIS OF HUANGTUPO LANDSLIDE

- According to formation mechanism and motion form analysis, Huangtupo landslide is divided into 3 segments: the upper, the middle and the lower. The upper is developed in purplish red mudstone and siltstone of the second member (T_2b^2) of Badong group, and about 650~400m; The middle is developed in dark marlite of the third member (T_2b^3) of Badong group, and about 380~240m; The lower is developed in dark marlite of the third member (T_2b^2) of Badong group, and about 240~80m. On the basis of macroscopic, mesoscopic, and microcosmic geological features of Huangtupo slope, it is considered that the middle and the lower sliding occurred simultaneously, and the upper happened separately. Evidence for this conclusion comprises:
- Macroscopic geological feature of Huangtupo landslide is characterized by "redcap" feature: old strata of the second member (T_2b^2) lying on new strata of the third member (T_2b^3) of Badong group, and sliding distance of the upper rock of about 800m. If they had taken place at the same time, the "redcap" feature would be smaller, and purplish red debris of T_2b^2 would be mixed with dark debris of T_2b^3, rather than the second member (T_2b^2) lying on new strata of the third member (T_2b^3).
- Three sliding blocks were mobilised; most of the energy (potential energy and kinetic energy) was released after the slope material had slid away from the 380m bedrock level and relying on the lesser energy or inertia, sliding downwards or ahead it is difficult to form present deep sliding surface (60~70m)
- To a certain extent, the raised bedrock at 380m, called "embankment", hinders the upper slope. There is no established relationship between the upper, the middle and the lower masses, and there was no no significant effect on the upper mass after destabilization and failure of the middle and the lower masses. The destabilizing slide of the upper may not have happened quickly.
- The sliding mass is highly weathered and vegetation is very luxuriant on trailing edge slope wall. It can be seen clearly that latest Quaternary deposits and residual slope sediments cover the road landside to the west edge of Huangtupo slope. By all appearances, formation age of slope is earlier than the Holocene Epoch.
- Based on thermoluminescence dating test operated by hydrological and engineering geological group, Hubei Province, the upper of ancient slope system of Huangtupo was formed in middle period of Late-Pleistocene, about 150~160ka ago. The middle and the lower were formed before 130~140ka.

CONCLUSIONS

- The results of this paper indicate that the Huangtupo landslide, which is from the east side of Sidaogou in the west to the Erdaogou in the east, and from the south side of Bagongli in south to the Yangtze River in the north, is Hopei pear in shape. The widths of the leading and trailing edge, and the length of the sliding body are about 1100m, 300m and 1780m respectively. It covers an area of $1.38km^2$, and is $4\times10^7m^3$ in volume, and is a giant ancient sliding body. The conclusion lays a solid geological foundation on the stability analysis and treatment [4].
- The landslide may be divided into 3 subsystems: the upper was formed in middle period of Late Pleistocene, about 150~160ka ago. The middle and the lower were formed simultaneously before 130~140ka.
- There are many giant ancient landslides similar to the Hhuangtupo landslide in the Three Gorge Reservoir area, such as the giant ancient slide body located at Shangshuping, a new address for Wushan County. The method in this paper provides useful experiences for the study of other landslides.

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