REMOTE SENSING INVESTIGATION AND MECHANISM RESEARCH OF TIANTAI LANDSLIDE IN SICHUAN PROVINCE

YANG Rihong[a,*], WANG Zhihua[a], LI Zhizhong[a], YANG Jinzhong[a]

[a] China Aero -Geophysical Survey and Remote Sensing Center for Land and Resources
No.31 Xueyua Road, Haidian District, Beijing, PR China, 100083 –
yangrihong@sina.com

Commission SS-5

KEY WORDS: Remote Sensing, Engineering, Landslides, Application, Visualization, Interpretation, Disaster.

ABSTRACT:

The large rainstorm happened on Sep. 3, 2004 at Tiantai village of Xuanhan County, Sichuan province, which lead to a oversize landslide. The foreside of landslide slid into the Qian river and formed a dam about 20m height, jammed the Qian river and caused heavy damage and loss. Based on the digital landslide and 3D Visualization Technique, the research of the landslide was started by using the high resolution satellite images of pre-landslide (INKONOS image) and post-landslide (QUICKBIRD image). Remote sensing investigation, human-machine interactive interpretation was used to confirm the borderline, form, feature and area of the landslide, the twin characteristic dots was used to deduced slip direction and slip distance. The paper makes good use of geology theory to discuss the formation and mechanism of landslide, Synthetically analyzing the characteristic of deposit, it is deduced Tiantai landslide is a large typical drag and along-bedding slope landslide. The slide mode of distortion and breach is belonged to plastic flow-tensile fracturing of slope.

1. INTRODUCTION

The large rainstorm happened on Sep. 3, 2004 at Tiantai village of Xuanhan County, Sichuan province, it lasted three days and the rainfall reached at 395.5mm on Sep 05, 2004, which lead to a oversize landslide. The Tiantai landslide continued about 11 hours, and the foreside of landslide slid into the Qian river and formed a dam about 20m height, jammed the Qian river and caused heavy damage and loss(FAN Xuan-mei,2006). Based on the advanced remote sensing image digital processing technique was applied to the high resolution remote sensing images pre-landslide which is INKONOS image and to the one post-landslide which is QuickBird image.The technique of digital landslide, 3D visualization and man-machine interactive interpretation were used to analyze the geomorphologic feature of the landslide on remote sensing images (Franco,1996; LU

Junko,2001;Jie-tang,2002; WANG Zhi-hua,2005). The paper makes good use of geology theory and the characteristic dots of landslide to discuss the formation and mechanism of landslide.

2. GEOLOGICAL SETTING

The geological map data and satellitic image of ETM was used to interpret the areal geology and structure of the area of Tiantai landslide. On areal structure it is locates on the southwest margin of Daba mountain arc fold belt and the northwest margin of east Sichuan folding structure belt, concretely it is locates on eastsouth side of Wubao anticline.According to remote sensing interpretation and field survey found the stratum of the Tiantai slope is Suining group belong to upper Jurassic of mesozonic, the upper lithology is including brown-red, purple-red silt mudstone, argillaceous sandstone with the interlayered purple-gray granule quartzoze sandstone, and the lower is brown-red, purple-red granule feldspar quartzoze sandstone with big thick stratum. The stratum tend towards between 110°～120° and lean to between 5°～10°. There are a lot of tectonic joints and rotten cranny along with tectonic effent, so the stratum is incised into rock body and many arenaceous clay, sand, gravel on the slope of landslide.

3. METHOD AND TECHNIQUE

3.1 Data Sources

Two type data sources were used to investigate the landslide, one is remote sensing data, including ETM+, INKONOS image and QuickBird image. The other is geographic control data, including relief map and 504 GPS control points which were measured in field (Tab.1).

3.2 Image Processing Technology

Based on the relief map with a scale of 1: 10000 and used the image processing software of MapGis,PCI and ENVI to process remote sensing data, the image was processed, including geometric precision correction, orthophoto registration and color matching, etc. After the processing, the DEM of pre-landslide, the digital orthophoto image was formed, which is vivid, transitional nature, highness harmonious contrast and reflect actual object. According to investigation of field survey and the digital orthophoto QUICKBIRD image, based on the 504 GPS control points and used the software of Surfer to process DEM of post-landslide with Kriging interpolation method.

* Corresponding author.Tel.:+86-01-82329273;Fax:+86-01-82329035.E-mail address:yangrihong@sina.com
Fund project: Sponsored by the Large-scale Investigation of Land and Resources（200416000003）

Data type	Spatial Resolution (Scale)	Acquisttion Date	Main Use
ETM	Band1-5,Band7:30m,Band6:60m, Band8:15m	Jan.24 2004	The geological setting interpretation
IKONOS-2	Muatispestral:4m; Pan:1m	Jan.21 2004	Characteristics of pre-Landslide
QUICKBIRD	Muatispestral:2.44m; Pan:0.61m	Nov.2 2004	Characteristics of post-Landslide
Relief Map	1:10000	1980	Obtain reference point and DEM

Table.1 Characteristic of remote sensing data for the landslide of Tiantai countryside

3.3 Method of Interpretation

According to the high resolution digital orthophoto images and the DEM which taken pre-landslide and post-landslide, the technique of digital landslide, 3D visualization and man-machine interactive interpretation were used to analyze the geomorphologic feature of the landslide. Detailedly speaking, it is used 3D information system software (for example ERDAS and ARCGIS) to set up 3D diorama which can dynamic browse the surface of slope and the deposit of landslide from different altitude or angle, so it is better to observe the micro-geomorphologic features on the slope. Combined with 2D and 3D display window on the computer which connected double displays, the characteristic of landslide was interpreted, and the result become much more credibility and higher precision. The main micro-geomorphologic features on surface of the slope and landslide features (including displaced material, borderline, form, main scarp, verge scarp and slide fracturing minor scarps, etc.) are extracted. Simultaneity some twin characteristic dots can be found from the images of INKONOS and from the QUICKBIRD. The dots show their location pre-landslide and post-landslide. One twin characteristic dot connected shows its slip direction. Their connected length shows its slip length.

4. INFORMATION EXTRACTION OF CHARACTERISTICS OF LANDSLIDE

4.1 The slope features of pre-landslide

According to the interpretation from satellite images ETM and INKONOS (Figure 1, left), it can be found that the landslide area is in moderate mountain district where tectonic erosion on middle cutting scale take place. The absolute height of the summit is around 1100m; the height of front valley is 365m and the width is 80 to 120m; the relative difference of height is about 800m. It can be concluded that the difference of slope tendency, between 80° to 120°, is significant by carrying on slope and aspect analysis based on DEM model pre-landslide. Most of the slope is between 12° to 13° in the extend of 0° to 20° and the mean value is 13.5°. The front valley is steep-stepped topography whose height is between 40m to 60m. As the main natural drain in landslide area, there are four large flush ditches distribute naturally from south to north, the Yujia river ditch, the Maliushu ditch, the Liangshui ditch and the Dahe ditch. The three ditches in south area together with the Dahe ditch developed in the form of many-canals-one-headstream and pooled in the watershed in back of the landslide (Figure 1, left). The surface water and the ground water of original slope are so rich that there are 32 valleys with length from 88m to 1217.9m that cut the slope in landslide area into dozens of little blokes, 19 pools with area from 105m^2 to 1669m^2 and paddy farmland covered the 40% of the surface (including paddy field and arid land, approximately 44 hm^2). Synthetically analyzing leads to the conclusion that the slope of Tiantai village is a comparative stable slope pre-landslide. The reason is that although there are basic conditions for landslide such as landslide matters, structures, free face and abundant water, but the weathering mud and sandstone covering on the slow slope in Quaternary is intensively cut by the gully and separated by the outcropped bedrock.

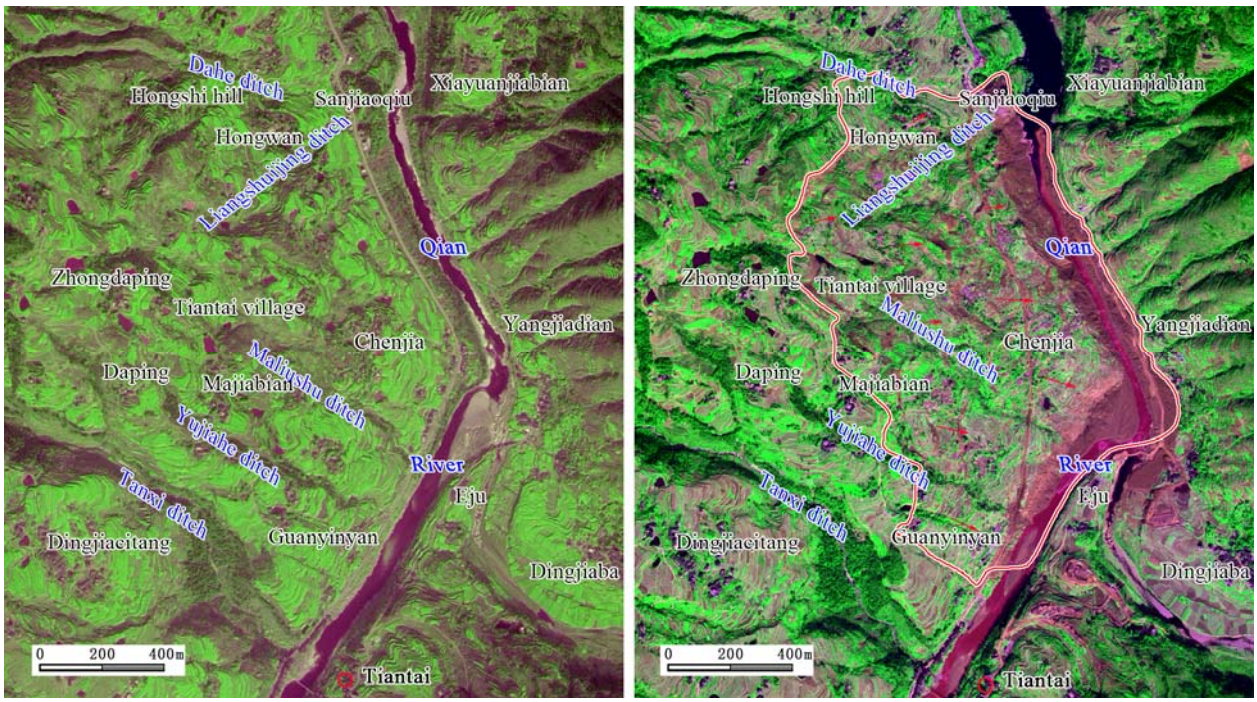

Figure 1. The IKONOS (left) and QUICKBIRD (right) images of Tiantai landslide

Figure 2. The scenic of soil-ridge and tensile fracturing scarps on Tiantai landslide

4.2 The deposit features of post-landslide

4.2.1 The boundline of landslide: The lower left boundary of the landslide body is Dahe ditch and its upper body via Hongwan to the back of the landslide, arc shaped, The lower right boundary of the landslide body is Yujia ditch and its upper body via Majiabian to the back of the landslide, tracking the geotechnical body of southern Guanyin rock to slip downward. The front reaches across the river. In general, the boundary of Tiantai landslide is distinct to the back of the steep wall, assuming quadrilateral, and the height of lateral and posterior is between 1m to 20m (Figure 1).

4.2.2 The deposit feature of landslide: The surface of the slope have changed a lot post-landslide. It is easy to figure out from QUICKBIRD image that the green farmland and the plants pre-landslide have modified into pink and brown deposit. The deposit with distinctive slide body and grade has been interpreted into fourteen slide body, each of which has a small back verge scarp in different incline direction and whose interior structure comes into being beam and penitent rock (Figure 2). In general, the deposit has large surface relief and terrain is extremely complicated. It can be found thirty multi-grade scarps without large scale of it (Figure 3). The back verge of landslide extended about 650m. The slope orientation has not changed much but the surface of slope with 11° mean gradient that figured out from the slope map, became slower after landslide happened.

Figure.3. The plot of tensile fracturing minor scarps on Tiantai landslide

4.3 The movement feature of post-landslide

The best way for remote sensing techniques to get movement feature of landslide is to acquire some twin characteristic dots, which can be found from the images of INKONOS image and from the QuickBird image, the dots show their location pre-landslide and post-landslide.One twin characteristic dot of pre-landslide and post-landslide connected shows its slip direction. Their connected length shows its slip distance. Due to the landslide slip velocity is slow, the most of deposit keep slip integrallty. There are 604 twin characteristic dots was taken, from those twin characteristic dots we can to study the movement feature quantitatively.

4.3.1 The slip derection of landslide: By studying the characteristic dot of landslide, we can get not only the slide direction of the characteristic dot but also every
sliding body. The slip direction in the north is about 78°～90°, 90°～105° in the middle and 105°～120° in the South (Figure 4).

4.3.2 The slip distance of landslide: According to connected length of the twin characteristic dot of landslide, we can calculate the slip distance of different slide body. The front middle sliding body is comparative large, between 200 to 240m, the middle sliding body is 100 to 160m and the back part is less than 40m (Figure 4).

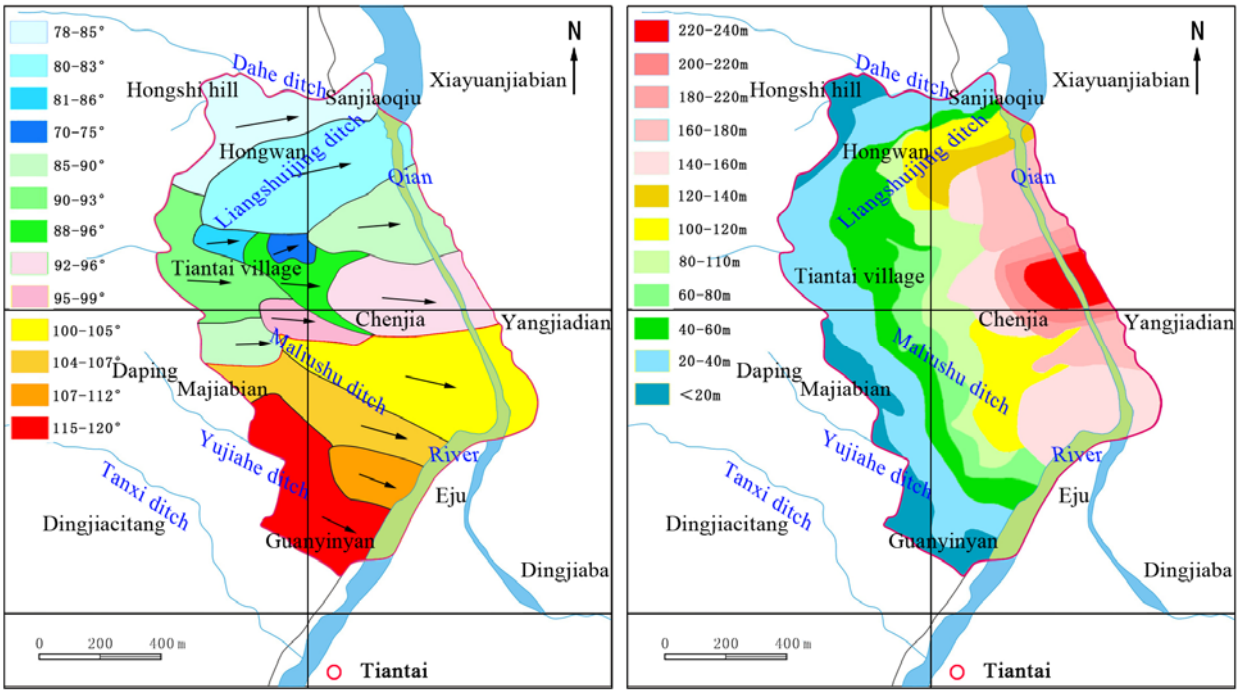

Figure 4. The slide direction (left) and distance (right) of each parts of Tiantai landslide

4.3.3 The slip velocity of landslide: The Tiantai landslide began from 2:00 pm Sep. 5,2004 to 1:00 am Sep. 6, together about 11 hours, belonging to middle velocity landslide. The slip direction and distance is different from one point to another as well as its velocity. The velocity of front-middle part is comparatively high on 22m/h, the middle part is about 10-16m/h on average and the back part is less than 4m/h.

5. FORMATION AND MECHANISM OF THE LANDSLIDE

5.1. Analysis the inducing factor of landslide

5.1.1 The effective free-face of landslide: From the relief map (the scale is1: 10000), ETM and INKONOS satellite images, it can be found the Tiantai slope is gentle gradient and the mean value is 13.5°. The length of slope is 1500 m and correspondingly altitude is 200m between toe and head of landslide borderline. But the front part of slope is steep-stepped topography whose height is between 40m to 60m, formed height and steep free-face. the along-bedding stratum is outlet alonged the Qian river about 2km, that is to say, there is enough effective free-face for landslide sliding.

5.1.2 The easy to sliding stratum matter and structure of landslide: The stratum of the original ground is Suining group in Jurassic, including interbedded sandstone and mud. It is weak rock and rigid rock alternatively. This stratum belongs to an along-bedding slope on the right of Qian river. there are a lot of tectonic joints and rotten cranny along with tectonic effent, and its lead to water inleakage (H.Chen,2003; G.B.Crosta,2004; ZHANG Yan-jun,2006). These stratum and structure is cause the landslide easily.

5.1.3 The triggering factor of landslide: Synthetically analyzing it cam be deduced a new road was build and its dug weaken the balance of the original ground (HUANG Run-qiu, 2005). Especially the continuous heavy rainfall is the main direct triggering factor.

5.2. Analysis the process of deformation and destruction of landslide

Because of the continous and heavy rainfall, the rain water can't drainage out the slope quickly along ditch and maked the rotten accumulation saturation. The cohesion and friction force will decline rapidly, that is to say, the shear strength decline. Under the continous and heavy rainfall, the surface water filter ground along with the joint and cranny on the slope, and the pore pressure become more larger (Aldo Clerici,2000; H.Chen,2004). There is a lot of paddy farmland with watertight mud stratum on the slope, the next stratum is dank rotten sandstone,which is on the upper of granule feldspar quartzoze sandstone with big thick stratum. So the groundwater is flowage on the cranny and stratum of rotten sandstone. The groundwater cann't drain when the heavy rainstorm continous, there is formed confined groundwater in the rotten sandy soil and mud stratum on the upper of thick sandstone.which made the shear strength decline to the condition of the static equilibrium instantaneously. The slope began to quick debacle, disintergration and failure when the pore pressure augmented enough, and the slide body movement and disintergration. Based on the geological theory, according to the characteristic of distributing of deposit, deformation and disintergration of slide body, it can be deduced Tiantai landslide is a large typical drag and along-bedding slope landslide. The slide mode of distortion and breach is belonged to plastic flow-tensile fracturing of slope.

6. CONCLUSION AND DISCUSSION

Used the dagital landslide technique, the characteristic information of pre-landslide and post-landslide can be extracted,the main micro-geomorphologic feature on surface of the slope and landslide feature (including displaced material, borderline, form, main scarp, verge scarp and slide fracturing

minor scarps, etc.) are interpreted. Especially the feature of movement (including slip derection, slip distance and slip velocity etc.) can be deduced by some twin characteristic dots. The paper combine with the field survey and geological theory to analyze the formation condition of landslide, discuss the mechanism of deformation and destruction of landslide. There are taken some advance by the technique of remote sensing, some characteristic of lanslide extrated quantificationlly. But the remote sensing technique can'nt take the thickness and inside structure of deposit, the phycical and mechanical characters of displaced deposit, etc.. It is block the mechanism research of landslide, restrict forecast and prewarning, disaster prevention and reduction for landslide hazard. In short, combine with geological engineering prospecting, rock and soil test, numerical simulation, etc., make good use of the technique of remote sensing is advantaged to study the mechanism of deformation and destruction, So the investigation can afford scientific evidence to forecast and prewarning, disaster prevention and reduction for landslide disaster

ACKNOWLEDGMENT

The author wish to thank academician Xianlin Liu and Prof. Zhihua Wang for her tutor, care and kind helps during the course of my doctoral study.

REFERENCES

FAN Xuan-mei, XU Qiang, HUANG Run-qiu, 2006. The formation mechanism of the Tiantai landslide induced by precipitation in Xuanhan , Sichuan and the design of drainage [J]. Journal of Chengdu University of Technology (Science & Technology Edition), 33(5), PP: 448～454. (in Chinese)

Franco Mantovani,Robert Soeters,C.J.Van Westen, 1996. Remote sensing techniques for landslide studies and hazard zonation in Europe [J]. Geomorphology, 15, PP: 213～225.

Junko Iwahashia，Shiaki Watanabeb, Takahiko Furuya, 2001. Landform analysis of slope movements using DEM in Higashikubiki area, Japan [J]. Computers & Geosciences, 27, PP:851～865.

LU Jie-tang, WANG Zhi-hua， ZHOU Cheng-hu, 2002. A Tentative Discussion on the Monitoring of the Yigong Landslide-blocked Lake with Satellite Remote Sensing Technique [J].Acta Geoscientia Sinica, 23(4) , PP:363～368. (in Chinese)

WANG Zhi-hua, 2005. Digital Landslide Technology and its Application [J]. Geoscience, 19(2) , PP:157～164. (in Chinese)

H.Chen，C.F.Lee, 2003. A dynamic model for rainfall-induced landslides on natural slopes [J]. Geomorphology, 51, PP: 269～288.

G.B.Crosta，H.Chen，C.F.Lee, 2004. Replay of the 1987 Val Pola Landslide, Italian Alps [J]. Geomorphology , 60, PP: 127～146.

ZHANG Yan-jun, 2006. The Study of the Analysis Method of Seepage Coupled Deformation in Slope and Its Appl ication [J]. Journal of Jilin University(Earth Science Edition),36(1) , PP:103～107.

HUANG Run-qiu, ZHAO Song-jiang, SONG Xiao-bing, 2005. The formation and mechanism analysis of Tiantai landslide, Xuanhan County, Sichuan Province [J]. HYDROGEOLOGY AND ENGINEERING GEOLOGY, (1),PP:13 ～ 16. (in Chinese)

Aldo Clerici，Susanna Perego, 2000. Simulation of the Parma River blockage by the Corniglio landslide (Northern Italy)[J]. Geomorphology, 3, PP:1～23.

H.Chen，C.F.Lee, 2004. Geohazards of slope mass movement and its prevention in Hong Kong. Engineering Geology, 76, PP:3～25