Structure and Stability of Zhangmu Deposit in Tibet

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Abstract

Zhangmu Port is situated at southwest of Tibet, and is the only trading port between China and Nepal. However, this important area has been faced the threat of geological disasters like landslides occurred in Zhangmu deposit over a long time. Evaluation of the structure and stability of the Zhangmu Deposit was undertaken to elucidate the causes of the deposit and its engineering geological characteristics based on field survey, and the stability of the deposit is analyzed mainly based terrain, the surface deformation features and material components of the deposit. Results show that, structure of Zhangmu deposit is not a simple single soil structure, but includes colluvial, residual and glaciofluvial deposits amongst others, and the slope is less likely to slide as a whole, but will mainly slip partially controlled by local hazard factors such as slope gradient, lithology, human engineering activities, and concave lateral erosion action.

Key words: Zhangmu Port, Zhangmu Deposit, landslide, structure, stability.

1. Introduction

The importance of Zhangmu Deposit cannot be over emphasized as the Zhangmu Port which is the only overland trading port between China and Nepal and also the only international trade port with particular scale in Tibet is located within its vicinity. Zhangmu Port is situated at the southwest of Tibet where is the end of National Highway No.318, the most southern Tibetan Plateau, left bank of Boqu River in the southern slope on the middle of the Himalayas (Fig.1). It has a total area of about 70 km^2, 80km away from Kathmandu, capital of Kingdom of Nepal, to Shigatse 450km, and to Lhasa 780km. Zhangmu town is not only an important border trade port but also a significant cross-border tourism city connecting China and Nepal and this means a lot to economy development of Tibet (Tubden K, Liu YJ, 2011). Because of the topographical constraints and the needs of foreign trade, the main administrative institutions including government offices and residential apartments are all built on the gentle terrain of the Zhangmu Deposit (Fig.2). In recent years however, local deformation and landslides (Fig.3) have happened frequently on the Zhangmu Deposit with the rapid development of the urban construction, which severely threatens lives, properties and the economic development in Zhangmu County (Ma DT, Tu JJ, Cui P, et al., 2004). The instability of the slopes and occurrence of landslides has become a major problem which impacts the survival and development of the port.

Since 1993, a lot of investigation and prevention work has been done for Zhangmu Deposit, and so much fundamental data and research results have been accumulated (Xie LP, Li DH, Qiao G, et al, 2003; Jia ZY, Liu YP, Lei Y, et al, 2006; Shang WT, Hou T, Feng X, et al., 2011; Wang D, Feng X, Yang FX, et al., 2011; Zhu J, Cai QE, Jiang HB, 2010; Mao CW, 2008; Yi SM, Tang HM, 1996). However, previous studies did not find out the material composition and the structure of slope, and there is dispute on the determination of landslides. The disaster prevention work stays at a “take stop-gap measures” state, which blocks the radical cure of slope deformation and failure. Therefore further research work to elucidate the causes of Zhangmu Deposit and its engineering geological characteristics thereby speeding up the comprehensive disaster prevention has become the key to achieve significant development for Zhangmu County and the whole Tibet area at large. Thus, in this work, exploration depth was increased and material components and its effect to slope stability particularly discrimination of potentially unstable slopes were focused on to provide scientific support for overall utilization of Zhangmu Deposit.

2. Geology Condition and Previous work

The study area is belonging to middle-high mountain topography type, and has a large latitude difference from 1700m～3646m, with a cutting depth up to 2000m. It is ravinated strongly, and the bedrocks are mainly granite gneiss and granite amphibolite gneiss (Chen NS, Hu GS, Deng W, et al., 2013). There are two main ravines distributed at the north and south of the deposits respectively named Zhangmu Gully and Dianchang Gully, and the latter one is also the main tributary of Boqu River in this area (Fig.4).

Fig.1 Traffic location map of Zhangmu Port

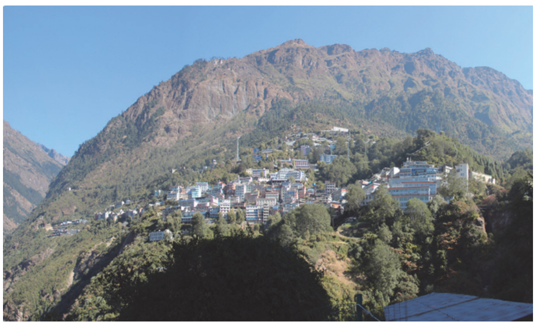

Fig.2 Full view of Zhangmu County

Fig.3 Talus slide in Zhangmu

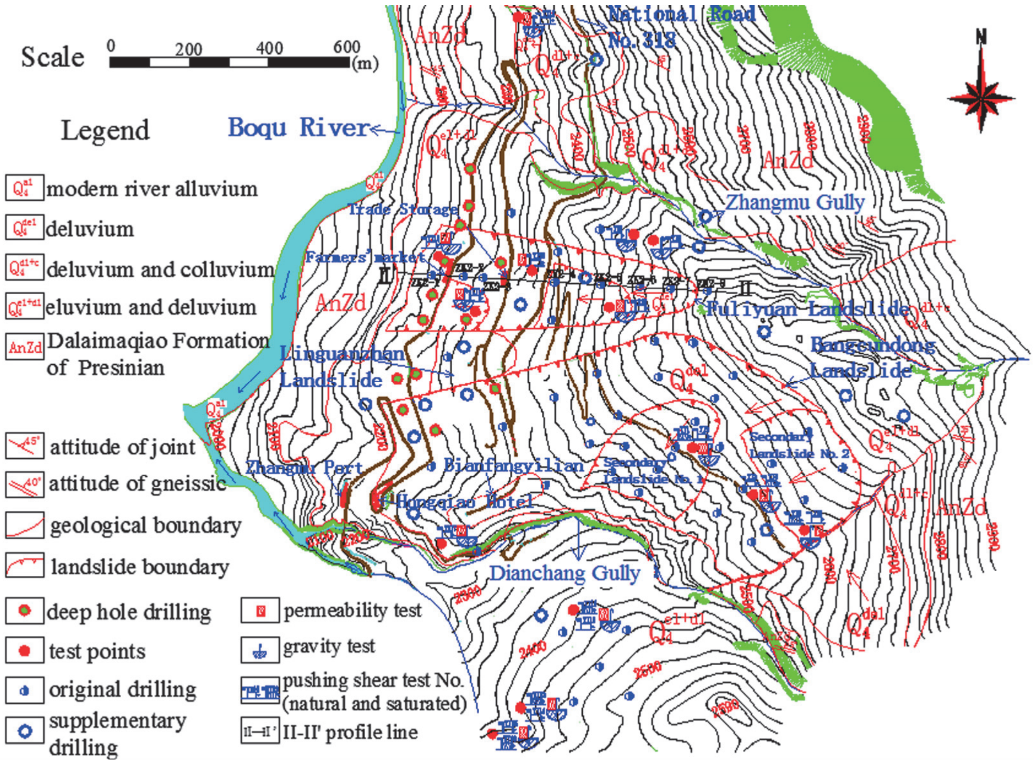

Fig.4 Engineering geological plane of Zhangmu

Zhangmu County is on a relatively gentle slope zone composed by quaternary loose deposits with good vegetation cover, in which all existing surface deformation and landslides are developed. It is very important to identify the structure of the accumulated layers for determining the stability of slopes. Previous investigation works (Xie LP, Li DH, Qiao G, et al, 2003; Jia ZY, Liu YP, Lei Y, et al, 2006) have shown that the deposit is primarily composed of eluvial slope materials, mainly distributed in the slopes outside of Zhangmu ancient slide area. The lithology is gravelly soil with silty clay and block stones with mixed sizes (the largest diameter of 5 m) which are mainly composed of mica and quartz schists(Fig.5). The deposit is loose on the surface layer and medium to slightly dense in the lower part. The silty clay is in a plastic-hard plastic state and some local landslide masses exists in the lower part of the slope and its material resources are mostly eluvial slope materials from the upper part. The deposit is thicker in the upper slope and thinner in the lower slope, with an average value of about 20-30 m up to a maximum of 60 m or more. However, the geological structure of the deposit is quite complex, the depth of investigation from previous work is inadequate for the precise study on the material composition and cause types of the deposit.

3. Discussion of material components and structure

For further research, supplementary field work was carried out on the basis of preliminary investigation. It includes 31 new boreholes (5 are deep drilling boreholes), 14 trial trenches, and 20 test points of in-site push shear tests, permeability tests, sieve tests and gravity tests distributed in different deformation areas (Fig.4). Through the field investigation, it was observed that the constituents of the deposit are not so simple. The typical section shows that the deposit is not entirely eluvial slope materials (Fig.5). Generally, the upper part of the deposit is mainly gravel soil, mostly tawny, with large content of block stones of different diameter sizes from 5 cm to 5 m. The rocks are angular in morphology and mainly composed of mica schist and quartz schist, and the fine part is mainly silty clay. Beneath this layer of soil, a layer of grey silty clay with a certain amount of gravel is generally developed. This layer has a transitional relation with the underlying bedrock, and the interface between them is blurred (Fig.6). It became obvious that Zhangmu Deposit is not just a single eluvial slope material, but composed of the upper grey-tawny colluvial deposit and lower grey weathered residual deposit. On the east side of Line Bianfangyilian to the old fire brigade, the overall thickness of the deposit is much bigger. The upper colluvial deposit has a maximum thickness of 42-55 m and the particle size ranged from 45 to 100 cm, and the block stone content is between 60 and 80%. Large stone content is reduced in the lower weathered residual deposit which has a maximum thickness of 28-34m and is mainly composed of gravels of 2-10 cm sizes. On the west side, the overall thickness of the deposit is thinner. The upper colluvial deposit has a maximum thickness of 20-29 m and the particle size ranged from 20 to 40 cm, with block stone content of 20 to 25 %. Large stone is rarely seen in the lower weathered residual deposit which has a maximum thickness of 15-20 m, gravel content of about 60 % and average particle size of 2-6 cm.

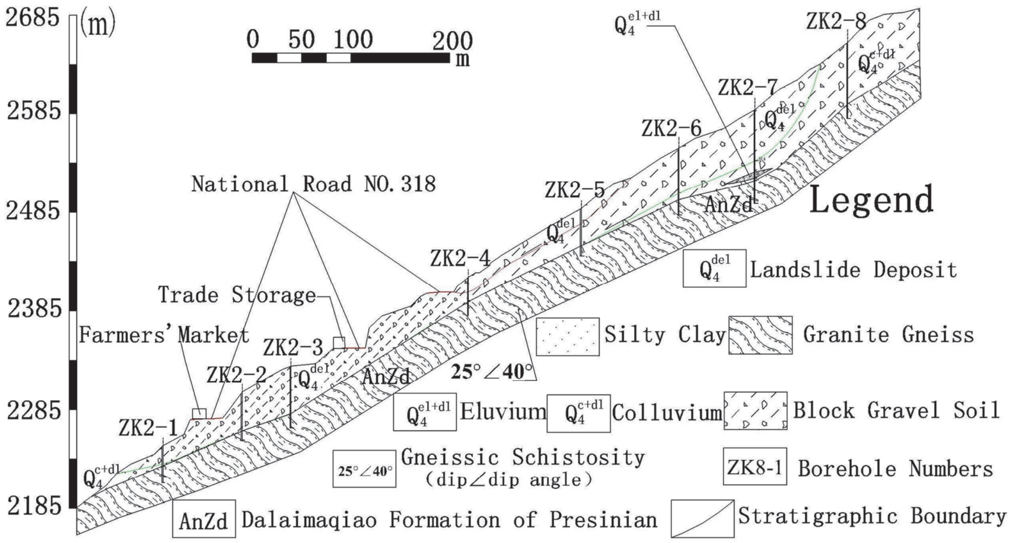

Fig.5 A typical engineering geological section (Line II-II')

Fig.6 Weathered profile opposite Hongqiao Hotel

The research shows that, two obvious terraced terrains exist on the Zhangmu Deposit (Fig.7), and the boundary is located approximately along the line of Bianfangyilian-Bangcun neighborhood committee building. Although the ground surfaces up and down the scarp are all composed of colluvial deposit, there are still some differences in material compositions. Deposits at upper part of scarp generally has coarse particles, big content of angular stones, small content of fine-grained materials and dense trees on it; but at the lower part, the slope deposit weathered severely and has relatively small particles, less block stone, more fine-grained materials, fewer trees and more grass on it (Fig.8). It suggests that the colluvial deposits up and down the scarp are formed in different collapsed periods. Historically there are two main concentrative collapsing periods, and the lower colluvial deposit is obviously formed earlier than the upper one, and the formation processes are shown in Fig.9.

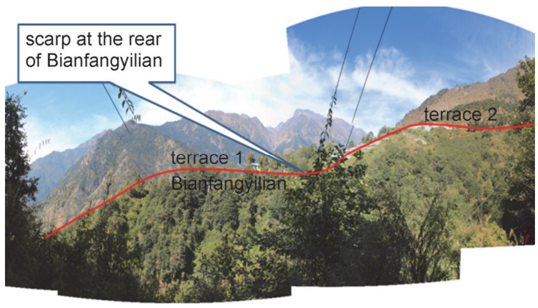

Fig.7 Two terraces on Zhangmu Deposit

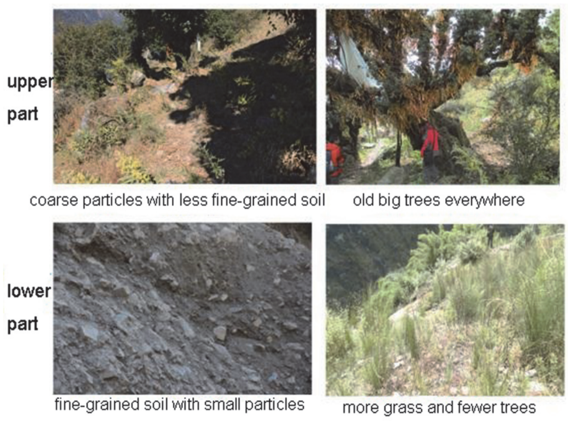

Fig.8 Colluvium features up and down the scarp

It's worthy to note that, a mélange of deposits of fluvial facies and outwash facies referred to as glaciofluvial deposit, because the two kinds of deposits are indistinguishable, was found on the platform along Bianfangyilian in the lower part of the slope (Fig.10). The deposit is mainly distributed on the terrain platform which is in the east of Hejia Hotel north gully, west of Dianchang Gully and south of Bianfangyilian (Fig.11), with an area of about 0.14 km^2, a volume of 18,400 m^3 and consists of gravelly soil, silty clay with gravel stone and silty clay in composition, and is well cemented. Most of the gravel is rounded, and the average roundness is sub-angular and some up to sub-rounded, with a significant action of water flow which has obvious differences in the appearance with other gravel in colluvium. The glaciofluvial deposit has a wide range of grain size, and is mainly in 2-60 cm (about 40%-50%), very large particles above 60 cm about 15%, and fine particles less than 2 mm about 35%.

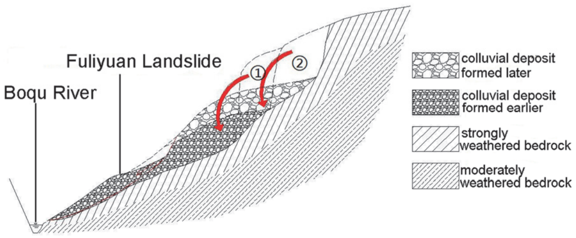

Fig.9 Formation process diagram of Zhangmu colluvium

Fig.10 Glaciofluvial deposits in the north gully of Hejia Hotel

In summary, Zhangmu Deposit is composed of colluvial deposit, residual deposit, glaciofluvial deposit and landslide deposit (Fig.12). However, since residual deposit is mainly buried under the ground, it's not marked in the figure.

4. Slope deformation features of Zhangmu Deposit

Previous surveys indicate that, two big ancient landslides respectively named as Fuliyuan Landslide and Bangcundong Landslide which also developed some secondary landslides, and a big deformation body named Linguanzhan Landslide exist on the Zhangmu Deposit (Fig.4).

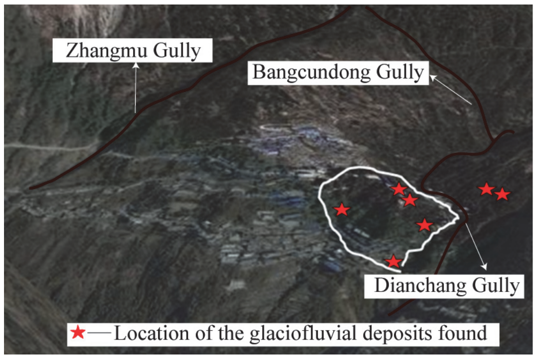

Fig.11 Distribution diagram of glaciofluvial deposits

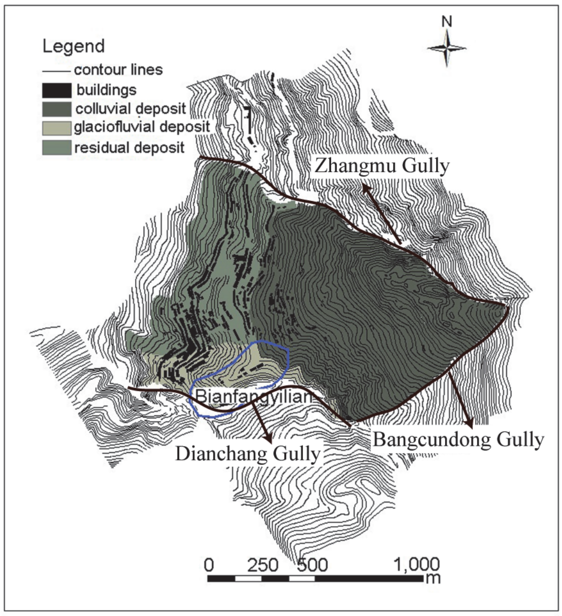

Fig.12 Causation types distribution of Zhangmu Deposit

However, this survey found that the strata in which these landslides developed is the same with upper colluvial deposit, thus the landslides can be said to have formed latter than the upper colluvial deposit and are therefore not ancient landslides. In addition, the Bangcundong Landslide just has a less obvious chair-like terrain in the landscape, and there is no significant deformation on the slope except the two secondary landslides. The evidence of integral slip is not enough, so Bangcundong Landslide actually doesn't exist, there are just two small shallow landslides named Bangcundong NO.1 and

NO.2.

Based on preliminary ground surface deformation monitoring data, deformation law of the deposit initially studied shows that, surface deformation of Zhangmu Deposit is mainly concentrated on the middle and lower part of the slope along Fuliyuan-Linguanzhan and the east slope of Bangcundong (shown as the grey-dark part in Fig.13), and the deformation is small on the upper and lower slope. Reasons adduced for this situation include that: this area is a transition terrain with big slope gradient, and the slope stability is poor; houses concentrate on this area and human engineering activities is intense; and concave lateral erosion action of Dianchang gully is the main reason of Bangcundong slope's instability. The deformation of the area around Fuliyuan Landslide is almost as big as that of landslide area. So, from the deformation angle, the range of the Fuliyuan Landslide can be enlarged to the black line as shown in Fig.13. On the area of so-called Bangcundong ancient landslide, there is no uniform deformation and the deformation amount is small, therefore, the justification for its existence is insufficient. From the displacement vector diagram (Fig.14) we can also get the same conclusions which shows that the displacement direction is almost the same along Fuliyuan area and shows relatively intact integrity and obvious landslide characteristic, towards Boqu River (on the left side of the figure); while on Bangcundong landslide area, the displacement vector direction is in chaos and poor in consistency.

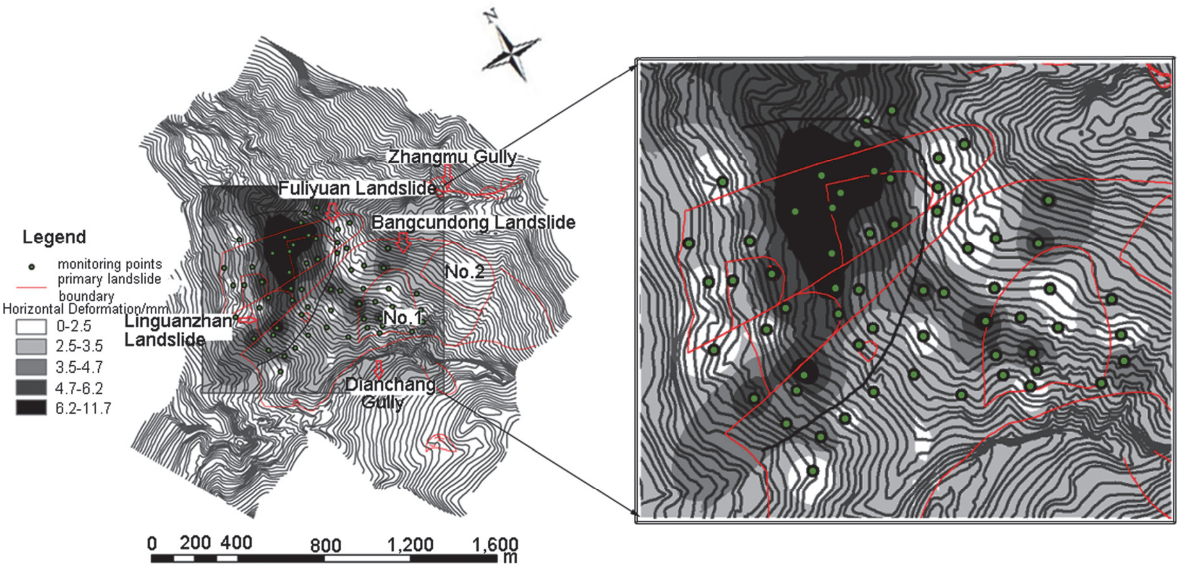

Fig.13 Surface displacement grading figure on Zhangmu Deposit

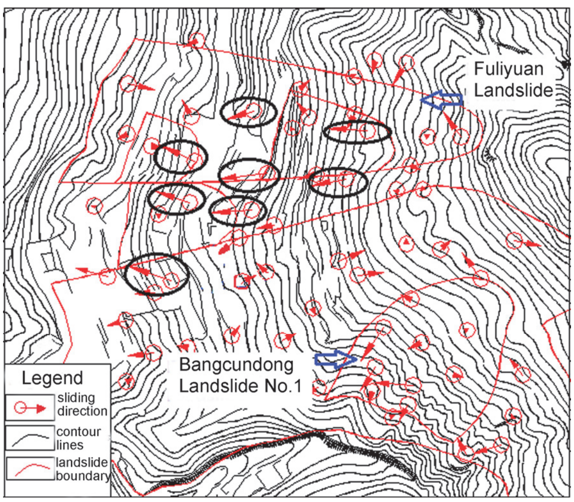

Fig.14 Displacement vector diagram

5. Preliminary Analysis of Slope Stability

With regard to the stability of "Zhangmu Landslide", controversy of overall or local slip always exists. The fundamental basis of the former is the existence of a relatively protruding topography on the landscape. From the present survey, it is believed that Zhangmu Deposit is unlikely to have overall slip mainly based on the following:

1) As earlier mentioned, the main materials of Zhangmu Deposit are from collapsed accumulation of the upper mountain. There are two concentrative collapsing stages, and they formed the slope with two micro-terraces. So, the protruding topography is not formed by the landslide.

2) There was no obvious sign of sliding found around the landslide boundary.

3) Slope surface displacement shows no integrity but partial slip characteristic (Fig.14).

4) Most importantly, glaciofluvial deposit is

found at the lower part of the slope, cemented and is formed clearly earlier than the upper colluvium, and its presence indicates that the slope has never been overall slipped in the history; otherwise the glaciofluvial deposit would have not been preserved. On the other hand, the glaciofluvial deposit cemented well and formed a relatively stable gravel terrace. It not only changed the slip shape of the deposit, but also played a role in sliding resistance to some extent (Fig.15). The presence of gravel terrace also separated the deposit laterally, and blocked its overall slipping (Fig.16).

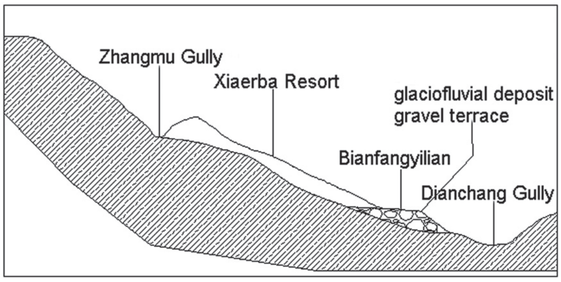

Fig.15 Longitudinal section schematic view of Zhangmu Deposit

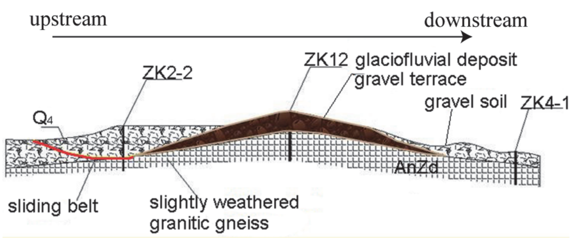

Fig.16 Cross section schematic view of Zhangmu Deposit

Therefore, overall landslide is hard to develop on the Zhangmu Deposit, and its stability is mainly controlled by the local hazard factors. According to analysis, the main factors of restricting slope local slip include slope gradient, lithology, groundwater activity, human engineering activities, and concave lateral erosion action. Based on these, a preliminary evaluation of slope stability of Zhangmu Deposit was studied and from the result (Fig.17), it can be seen that, the stable slope area is mainly distributed on the top of the slope and Bianfangyilian terrace connected with it where has flat terrain and less disturbance slope. The top of the slope is mainly composed of newly collapsed deposit and Bianfangyilian terrace mainly composed of well cemented glaciofluvial deposit. They are both in a good topographic and geologic condition and both have good slope stability, suitable for urban land development and utilization. The unstable slope area is mainly distributed on Fuliyuan landslide and Bangcundong slope. It has severe surface deformation and intense human engineering activities, and slides frequently. Therefore, the slopes have poor stability, and need necessary reinforcement. Areas outside these two areas mentioned above have moderate stability.

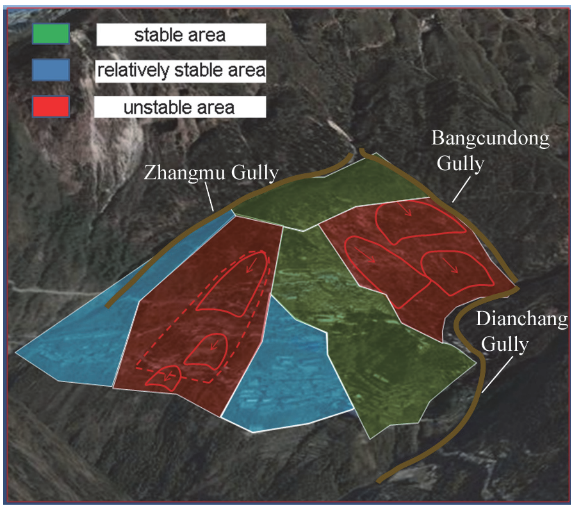

Fig.17 Slope stability zoning map of Zhangmu Deposit

6. Conclusions

Evaluation of the structure and stability of Zhangmu Deposit with the aid of field survey with deeper borings to elucidate the causes of Zhangmu Deposit and its engineering geological characteristics has led to the following conclusions.

1) Zhangmu Deposit is mainly composed of colluvial deposit, weathered residual material and outwash sediment presented as layer distribution in section and three concentrated parts in the plane. The colluvial deposit is the main part of the deposit, and it was formed in two focus collapse events while the lower part is formed earlier than the upper part and they are different in material composition. The weathered residual material is not exposed on the surface, and is mostly located beneath the colluvial deposit with the outwash sediment supposedly formed earlier in time and showing good cementation and stability, mainly distributed on the tableland near Bianfangyilian.

2) The surface deformation of the deposit is mainly concentrated on the middle-lower part of the slope, like Fuliyuan-Linguanzhan area and east slope of Bangcun, while deformation in other places is small. The direction of displacement along Fuliyuan area is relatively consistent, showing good integrity, while the displacement vector in Bangcundong landslide is in chaos and poor in consistence. However the monitoring time employed confers some limitations on these views.

3) Subject to various factors, Zhangmu Deposit is unlikely to slip as a whole, but dominated by local slip deformation.

4) The slope stability of Zhangmu Deposit is mainly controlled by slope gradient, human engineering activities, lithology, groundwater activity, and concave lateral erosion action. Areas with good stability are mainly distributed on the top of the slope and Bianfagnyilian terrace connected with it, while areas on Fuliyuan landslide and Bangcundong have poor slope stability.

It has to be pointed that, conclusions above are mainly some preliminary understandings obtained from analysis of geological survey, and need to be tested by further engineering geomechanics analysis.

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