TAO, Vol. 13, No. 3, 387-395, September 2002

NOTES AND CORRESPONDENCE

A Preliminary Report on the Chiufenershan Landslide Triggered by the 921 Chichi Earthquake in Nantou, Central Taiwan

Chien-Shui Huang[1], Mien-Ming Chen[2,*], and Ming-I Hsu[2]

(Manuscript received 1 March 2002, in final form 7 August 2002)

ABSTRACT

A large-scale dip-slope landslide, the Chiufenershan landslide, was triggered by the 921 Chi-Chi earthquake on September 21, 1999. At the site, which covers some 200 hectares of incline, over thirty million cubic meters of rock masses were displaced, blocking streams to form two dammed lakes and causing more than 20 fatalities. Dip-slope topography, incompetent fault zone on slope base together with well-developed discontinuities in rock masses constitute the fundamental internal factors for sliding. The critical factor contributing to the landslide is the strong ground motion generated by the earthquake. The event is totally unexpected because there was no trace of daylight on the slope prior to slope failure. Based on detailed geological investigations followed by the collection of various on-site features, the classification and factors causing landslide were described and discussed.

(Key words: Landslide, Dip-slope, Daylight, Chiufenershan)

1. INTRODUCTION

The 921 Chi-Chi earthquake struck at 1:47 on Sept.21, 1999. With a magnitude of M_L=7. 3, it was epicentered at the town of Chi-Chi at a depth of about 8 km, causing a linear ground rupture of 100 km (Central Geological Survey 1999) roughly along the Chelungpu fault. Over 2400 people died in addition to tremendous economic losses.

The Chiufenershan landslide is one of the largest triggered by the 921 earthquake. Located in the hilly region of Nankang village, the Kuohsin township of Nantou Hsien (Fig. 1), it is basically a dip-slope translational rock slide, covering a total area of some 200 hectares, and involving the displacement of 30 million cubic meters of rock masses (photo. 1). The sliding part totaled about 75 hectares, ranging in elevations between 500 to 1000 m above

[1]Department of Environmental Design, Hua-Fan University, Shihting, Teipei, Taiwan, ROC
[2]Central Geological Survey, Ministry of Economics Affairs, ROC
*Corresponding author address: Mien-Ming Chen, Central Geological Survey, MOEA, 2 lane 109, Huahsin st.,Chungho City, Taipei County, Taiwan, ROC; E-mail: chenmm@linx.moeacgs.gov.tw

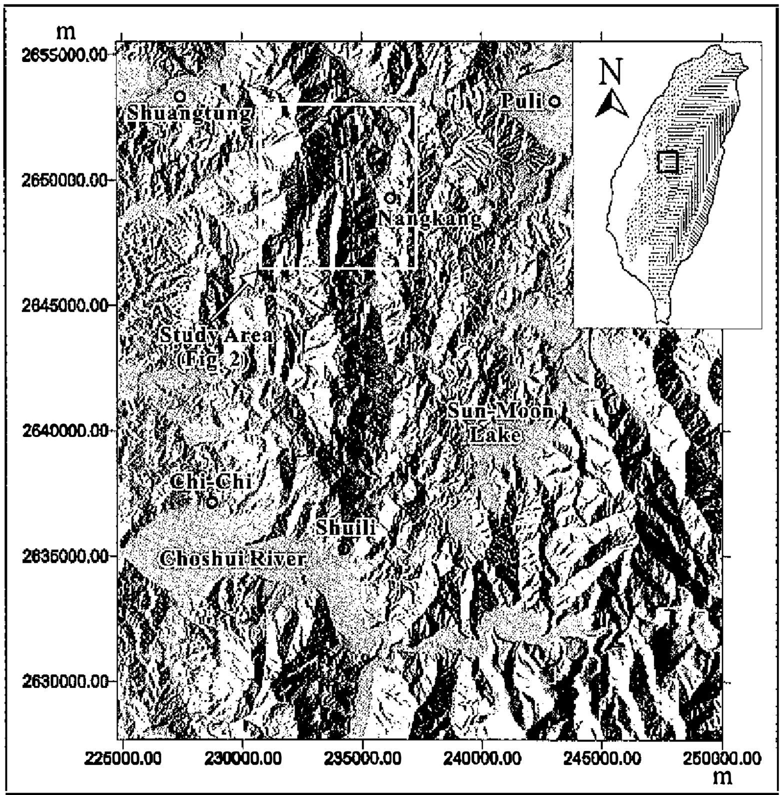

Fig. 1. Location map of the Chiufenershan Landslide. (Shaded 40-m DEM).

Photo. 1. A distant view of the Chiufenershan landslide from south toward north.

mean sea level, in which on average 30 to 50 m thick rock masses came off. Rock masses which had slid down from the upper dip-slope area were then choked and deposited on the lower narrow valley gorge, resulting in the formation of a natural earth dam with maximum height of 175 m (photo. 2). Two barrier lakes were also formed on two dammed streams (photos. 3 and 4).

About 20 local people were swept off and buried by this catastrophe. Local residents observed sliding features such as violent deafening explosion and abundant rock materials or debris with dust storms rushing upward out from the valley gorge. Consequently, they were led to believe that the earthquake depocenter was just under the slide area. In reality, the violent explosive noises and the debris rushing upward out from the gorge area were simply the result of the collision between sliding rock masses and the gorge bottom, followed by rebound. The real epicenter, in fact, is located about 13 km SSW away from the slide area, according to a later official survey and announcement by the CWB.

Structurally the slide area is a dip-slope, dipping 20 degrees on average. Although the Shetzekeng stream flows along the slope base area, there is no obvious side-cutting phenom-

Photo. 2. The Shihmen gorge was blocked to form a natural earth dam reaching 175 m high. The right ridge is the upper massive sandstone of the Shihmen Formation.

Photo. 3. The Chiutzaihu stream dammed lake.

Photo. 4. The Shetzekeng stream dammed lake.

Photo. 5. Ridge relief expressed by the three massive sandstones of the Shihmen Formation is on the middle part. It is located on the east limb of the Taanshan syncline.

enon or any artificial slope excavation before slope failure, namely, there is no "daylight" on the dip-slope. It is generally accepted that a dip-slope is considered stable if the slope is not daylighted; nonetheless, we did have here a large-scale dip-slope movement. This no doubt violates our prediction. Here we intend, on the basis of detailed geological investigation, to unravel this unusual landslide event.

2. GEOLOGICAL SETTING

Geologically the catastrophe area is situated on the eastern part of the Western Foothills of Taiwan. The north-south-striking Shuilikeng and Shuangtung faults are the two major longitudinal thrusts developed in the foothills, located respectively about 2 km east and 6 km west of the slide area (Ho et al. 1956; Huang et al. 2000). The north-south-trending Taanshan syncline, whose north segment plunges southward, is the major geological structure that controls the distribution pattern of rock formations (Fig. 2).

Rock formations exposed in the study area include, in ascending order, the Tanliaoti Shale (Tlt), the Shihmen Formation (Sm), the Changhukeng Shale (Chk) and the Kueichulin Formation (Kcl), all of middle-to-late Miocene age. Both the Tanliaoti Shale and the Changhukeng Shale are lithologically shale or siltstone-dominated, with or without interbedded thin-to-medium beds of sandstone. Three massive or thick-bedded (>30m), light gray, fine-grained muddy sandstone alternated with shale or thin interbeds of sandstone and shale constitute the Shihmen Formation (photo. 5). These massive sandstones of the Shihmen Formation always form linear steep ridges or narrow gorges when crossed by streams. The Shihmen gorge (literally rock gate gorge in Chinese), served as a natural dam on the Shetzekeng stream after sliding, is to prevent rock debris from further movement. The Kueichulin Formation consists chiefly of calcareous massive fossiliferous sandstones and is distributed on the south axial part of the syncline, which disconformably overlies the Changhukeng Shale. The compact calcareous sandstones of the Kueichulin Formation manifested itself as a precipitous massive high mountain, and the famous landmark Chiufenershan is the peak (1172m) of this area and is located on the southwest part, the west limb of the syncline.

The Taanshan syncline is an asymmetric structure whose east limb dips approximately 50° to the west and the west limb approximately 20° to the east. Where the syncline extends northward through the slide area, it gradually develops into a fault. This phenomenon is obviously deduced from the fact that both sides of the Shihmen Formation, when traced northward, show a 400 m offset along the syncline axis. The above-mentioned geological fault is a vital factor to the landslide as will be analyzed below.

There are two mutually crossed joint sets, which are ubiquitously developed in the rocks. One joint set, N8°E/78°W, is a longitudinal joint; the other one, N80°W/80°N, represents a transverse joint. The two sets of joints together with the well-developed bedding constitute the main discontinuities and partition the rock masses into rectangular blocks. If the dip-slope base is disrupted or daylighted, the rock masses will first split along the joints into rectangular blocks, and then result in rockslide along the dip direction of bedding during heavy rains or earthquakes (photo. 6).

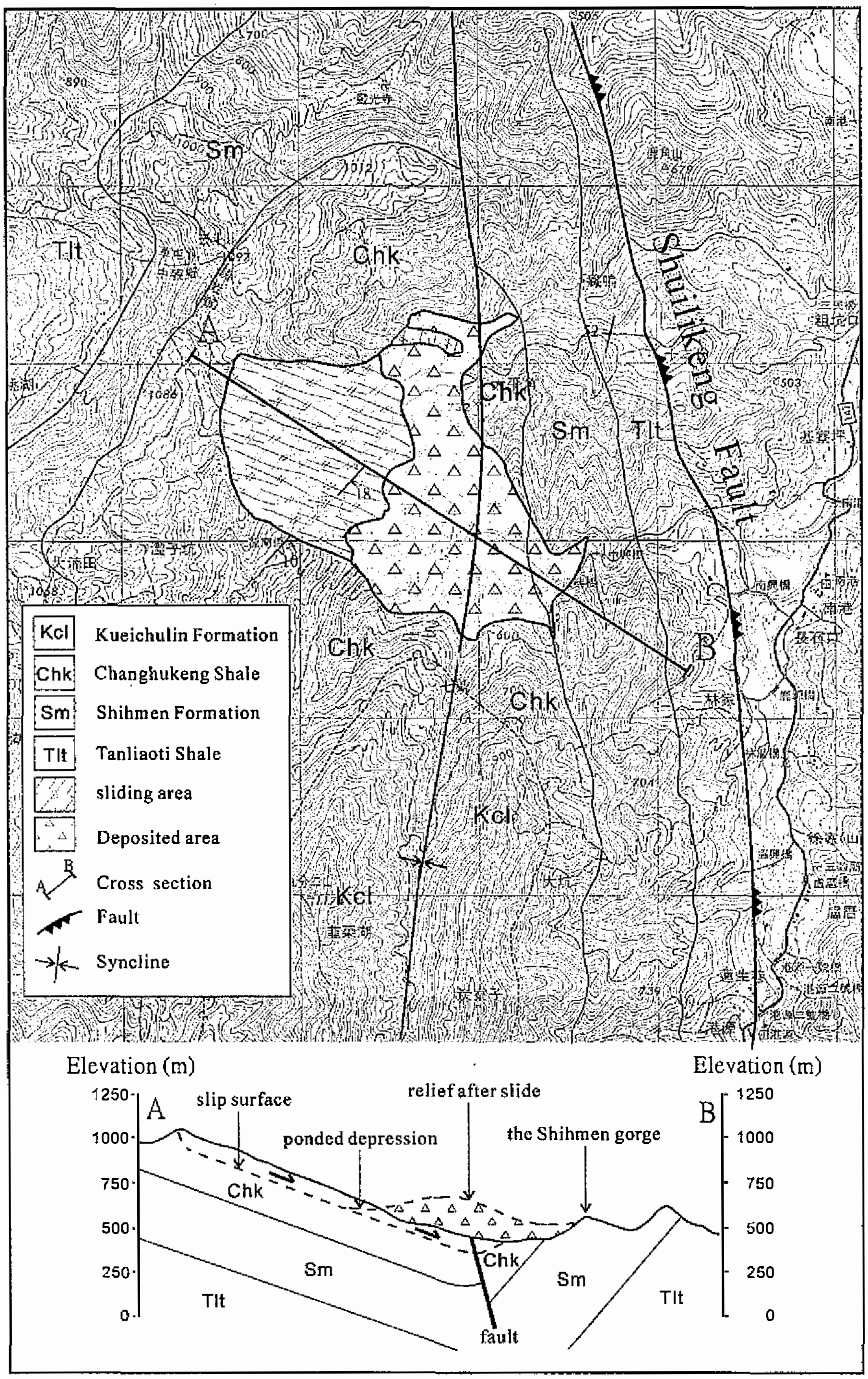

Fig. 2. Geologic map and cross section of the Chiufenershan landslide area.

3. MECHANISM AND CLASSIFICATION OF THE LANDSLIDE

It is quite evident that geological dip-slope topography together with well-developed beddings and joints constitute the essential internal requirements for slope failure. However, such rock masses on dip-slope are generally regarded as stable because they are not daylighted. It is beyond doubt that strong ground motion generated by strong earthquake is the fundamental induced factor for sliding. Therefore it is worthwhile to ask what the critical initiating mechanism is that leads to this unusually large landslide.

After looking into the geologic details, we presume the strong motion of the earthquake instantaneously weakened the fault zone located on the slope base (see Fig. 2). Eventually, the large-scale slope movement occurred in steps, slipping along bedding planes to the lower gorge valley as losing strength and collapse of the fault zone. Thus, although we have no direct information about the properties of the fault, we are still convinced that the collapse of the fault zone on the slope base is the initiating mechanism leading to immediate large-scale sliding.

Because top soils, colluviums and underlying bedrocks were all involved in the slide with bedding planes serving as sliding surfaces, according to the general landslide classification scheme (Varnes 1978), most parts of this slide may be categorized into rock or debris slide type, or a mixture of them. But if we take into consideration the changing sliding speed, caused by acceleration, some lower parts of the slide may be classified as debris avalanches.

Other types of landslide, viz rock and debris falls, were also observed, which sporadically occurred only at the north marginal part of the slide area (photo. 7). In this area, rocks first slid along the bedding immediately after the main shock with an average slide distance of about 150 m (photo. 8), followed by blocking and part bulging by the stable-standing rock strata of the east limb of the Taanshan syncline (photo. 9). Thereafter under no lateral constraint conditions, in time high-angled fissures and fractures were gradually opened and deepened along pre-existing joints (photos. 10 and 11). At about 3 a.m., the northern margin of the above transported rock masses eventually toppled and collapsed into a small adjoining gully, forming rock and debris falls of yet another landslide (photo. 7).

4. SOME CHARACTERISTIC FEATURES OF THE LANDSLIDE

The thickness of transported slope rock masses is about 30 to 50 m, including topsoils, colluviums and bedrocks. Bedrock materials constitute about 50%.

The Shetzekeng stream and its distributary the Chiutzaihu stream were both blocked, and two temporary barrier lakes were formed (photos. 3 and 4). In addition, a ponded elongated depression, located adjacent to the accumulated sliding masses, was also formed (photo. 12).

On both sides of the natural dam in the deposition area, trees and grasses were blown level, showing "comb-structure". This phenomenon indicates that the sliding must have been accompanied by a violent sweeping storm.

Over the deposition area, most rock masses have disintegrated into debris, abundant silts and dust, with some chaotic rock blocks in between; almost all the original rock structures have been destroyed (photo. 13). This fact implies that the material has travelled a rather long distance and with high sliding speed.

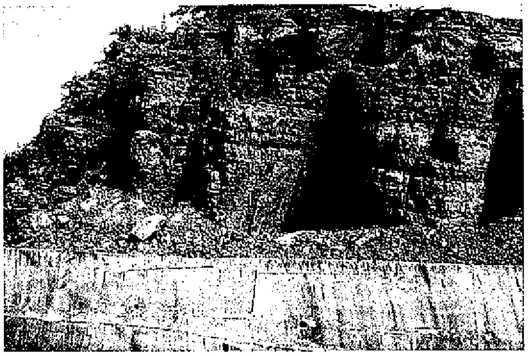

Photo. 6. Two high-angled joint sets together with well-developed bedding constitute the main discontinuities in the rock masses. The Changhukeng Shale on the northern border of slide area.

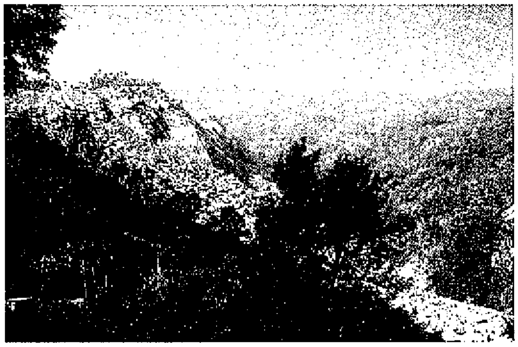

Photo. 7. Rock and debris falls occurred in the northern part.

Photo. 8. Rock slide in the northern part, showing sliding plane (the lower middle right), and toppling and rock or debris falls on the lift side.

Photo. 9. The northern rock slide and bulge, viewing from south toward north.

High-speed sliding, strong collision impact and friction on glide planes were very evident during sliding. Lin et al. (2001) reported that some pseudotachylites occur as thin layers in glide planes and as veins injected into cracks in host rocks. They further suggest that the physical conditions of pseudotachylites formation are estimated to have been <1.5 MPa corresponding to ca. 40 m depth, at a temperature of at least 1100°-1600°C.

The maximum sliding distance could reach 2 km. These high-speed, long-distance and thick-layered sliding materials could trap vaporized fluid caused by frictional heating at the base. Therefore, it seems reasonable to assume that some underlying compressed air cushions played the role as lubricant in the sliding process (Shreve 1968).

5. DISCUSSIONS AND SUGGESTIONS

The Chiufenershan landslide is a large-scale coseismic landslide of the 921 earthquake, involving a total area of about 200 hectares and over 30 million cubic meters of displaced rock

Photo. 10. The northern part of slid rock blocks, showing opened high-angled joints.

Photo. 11. A deep-seated, opened high-angle joint in the slid rock masses on the northern part.

Photo. 12. The ponded elongated depression is parallel to the slope base on the lower right. Two dammed lakes locate on the far upper left.

Photo. 13. Chaotic rock debris and blocks constitute the colluvial materials.

masses. This catastrophe occurred unexpectedly and caused great casualties and economic loss. Dip-slope topography, incompetent fault zone on slope base together with well-developed discontinuities in rock masses constitute the fundamental internal factors for sliding. The present authors presume that the initial breakdown of the weak fault zone on the slope base is the key to the slide, which caused immediately later successive large-scale slides. Strong ground motion generated by the earthquake is the critical factor leading to slide.

At present, there are still large amounts of unstable rock masses on the upper part of the slide area which will probably slide down someday during heavy rains or earthquakes. The tremendous volume of colluviums on the deposited area is vulnerable to collapse or erosion by surface runoff. The collapse or overtopping of temporary barrier lakes is also likely to occur. All the above-mentioned events may lead to serious debris or earth flows, which will be dangerous to lower reaches of the area; therefore, we strongly suggest that the authorities should pay much attention to forestall this possible hazard.

Acknowledgements The authors wish to express their sincere appreciation to Dr. H. T. Chu at the Central Geological Survey for his literal improvement of the English manuscript. Thanks are also extended to two anonymous reviewers for their comment and suggestions on the manuscript.

REFERENCES

Central Geological Survey, 1999: Geological Report of the 921 Earthguake. Published by the Central Geological survey, Ministry of Economics Affairs, 315 pp.

Ho, C. S., S. F. Tsan, and L. P. Tan, 1956: Geology and coal deposits of the Chichitashan area, Nantou, Taiwan. *Bull. Geol. Surv. Taiwan*, **9**, 1-64.

Huang, C. S., K. S. Hsieh, and M. M. Chen, 2000: Explanatory text of the geologic map of Taiwan, 1:50,000, sheet 32, Puli. Published by the Central Geological Survey, Ministry of Economics Affairs, 75 pp.

Huang, C. S., M. M. Chen, S. J. Tsao, and M. I. Hsu, 2000: The large Chiufenershan landslide, Kuoshin township, Nantou. *Landslide disasters of Taiwan*, **1**. Published by the Central Geological Survey, Ministry of Economics Affairs, 139-145

Lin, A., A. Chen, C. F. Liau, C. T. Lee, C. C. Lin, P. S. Lin, S. C. Wen, and T. Ouchi, 2001: Frictional fusion due to coseismic landsliding during the 1999 Chi-Chi (Taiwan) M_L 7. 3 earthquake. *Geophys. Res. Lett.*, **28**, 4011-4014.

Shreve, R. L., 1968: The Blackhawk landslide. *Geol. Soc. Am.*, **Special Paper 108**, 47pp .

Varnes, D. J., 1978: Slope movement types and processes. In: Shuster, R. L. and Krizek, R. L. (Eds.), Landslides: Analysis and Control. Special Report 176, Transport and Road Research Board. National Academy of Science, Washington, D.C., 11-33.