DEBRIS FLOWS: Disasters, Risk, Forecast, Protection

Proceedings
of the 7th International Conference

Chengdu, China, 23–27 September 2024

Edited by
S.S. Chernomorets, K. Hu, K.S. Viskhadzhieva

Geomarketing LLC
Moscow
2024

СЕЛЕВЫЕ ПОТОКИ: катастрофы, риск, прогноз, защита

Труды
7-й Международной конференции

Чэнду, Китай, 23–27 сентября 2024 г.

Ответственные редакторы
С.С. Черноморец, К. Ху, К.С. Висхаджиева

ООО «Геомаркетинг»
Москва
2024

泥石流：

灾害、风险、预测、防治

會議記錄

第七届国际会议

中国成都, 2024年9月23日至27日

編輯者
S.S. Chernomorets, K. Hu, K. Viskhadzhieva

Geomarketing LLC
莫斯科
2024

УДК 551.311.8
ББК 26.823
С29

Debris Flows: Disasters, Risk, Forecast, Protection. Proceedings of the 7th International Conference (Chengdu, China). – Ed. by S.S. Chernomorets, K. Hu, K.S. Viskhadzhieva. – Moscow: Geomarketing LLC. 622 p.

Селевые потоки: катастрофы, риск, прогноз, защита. Труды 7-й Международной конференции (Чэнду, Китай). – Отв. ред. С.С. Черноморец, К. Ху, К.С. Висхаджиева. – Москва: ООО «Геомаркетинг», 2024. 622 с.

泥石流：灾害、风险、预测、防治. 會議記錄 第七届国际会议. 中国成都. 編輯者 S.S. Chernomorets, K. Hu, K.S. Viskhadzhieva. – 莫斯科: Geomarketing LLC. 622 p.

ISBN 978-5-6050369-6-8

Ответственные редакторы: С.С. Черноморец (МГУ имени М.В. Ломоносова), К. Ху (Институт горных опасностей и окружающей среды Китайской академии наук), К.С. Висхаджиева (МГУ имени М.В. Ломоносова).

Edited by S.S. Chernomorets (Lomonosov Moscow State University), K. Hu (Institute of Mountain Hazards and Environment, CAS), K.S. Viskhadzhieva (Lomonosov Moscow State University).

При создании логотипа конференции использован рисунок из книги С.М. Флейшмана «Селевые потоки» (Москва: Географгиз, 1951, с. 51).

Conference logo is based on a figure from S.M. Fleishman’s book on Debris Flows (Moscow: Geografgiz, 1951, p. 51).

Hazard potential change for rain-induced debris flow in silty clay mudstone environment after large earthquake and continuous rainfall sediment deposit

B.-S. Lin, H.-C. Hsu, W.-Y. Chiu, F.Y. Kuo

Feng-Chia University, Taichung, Taiwan, China, maggiehsu111@gmail.com

Abstract. Due to strong earthquake (M6.8) and heavy rainfall in Southeast Taiwan, Silty clay mudstone area which has been already delineated as debris flow potential area is strongly affected by continues repeat sediment deposit, which changes the landscape that might cause future secondary sediment disaster. Therefore, by the use of InSAR and LIDAR result for finding vulnerability analysis for slope loosen sediments downward a large-scale potential landslide area which form debris flow and conduct FLO2D simulation model and field investigation result, dividing site area into different analysis unit for debris flow impact potential, and finally giving different mitigation treatment suggestions, including no measures are being selected for setting the best benefit analysis under risk assessment.

Key words: *earthquake, secondary sediment disaster, InSAR, FLO2D, large scale potential landslide, risk assessment*

Cite this article: Lin B.-S., Hsu H.-C., Chiu W.-Y., Kuo F.Y. Hazard potential change for rain-induced debris flow in silty clay mudstone environment after large earthquake and continuous rainfall sediment deposit. In: Chernomorets S.S., Hu K., Viskhadzhieva K.S. (eds.) Debris Flows: Disasters, Risk, Forecast, Protection. Proceedings of the 7th International Conference (Chengdu, China). Moscow: Geomarketing LLC, 2024, p. 285–301.

Изменение опасности селевых потоков дождевого генезиса, формирующихся в алеврито-глинистых отложениях после сильного землетрясения и продолжительных осадков

Б.-Ш. Линь, Х.-Ч. Хсу, В.-Ю. Чиу, Ф.-И. Ко

Университет Фэн Чиа, Тайчжун, Тайвань, Китай, maggiehsu111@gmail.com

Аннотация. Из-за сильного землетрясения (M6.8) и проливных дождей в юго-восточной части Тайваня территория, где развиты алеврито-глинистые отложения и которая ранее уже была отнесена к потенциально опасной с точки зрения селеформирования, сильно пострадала. Здесь, в частности, накопились большие объемы рыхлого материала, что в будущем может привести к чрезвычайным ситуациям в случае выпадения обильных осадков. В работе для оценки селевой опасности были использованы результаты анализа данных InSAR, LIDAR, моделирования в программе FLO2D и полевых исследований.

Ключевые слова: *землетрясение, вторичная катастрофа, InSAR, FLO2D, потенциальный крупномасштабный оползень, оценка риска*

Ссылка для цитирования: Линь Б.-Ш., Хсу Х.-Ч., Чиу В.-Ю., Ко Ф.-И. Изменение опасности селевых потоков дождевого генезиса, формирующихся в алеврито-глинистых отложениях после сильного землетрясения и продолжительных осадков. В сб.: Селевые потоки: катастрофы, риск, прогноз, защита. Труды 7-й Международной конференции (Чэнду, Китай). – Отв. ред. С.С. Черноморец, К. Ху, К.С. Висхаджиева. – М.: ООО «Геомаркетинг», 2024, с. 285–301.

Introduction

Large scale potential landslide mitigation and monitoring has been an important job for Taiwan slope management for recent years. East part of Taiwan, the geology of Hai-An Mountain basis of silty clay, therefore, underground water and surface runoff play an important role for these landslide potential areas. Thus, due to continuous sediment transport and deposit, it has not been noticed that, the riverbed slope and deposit depth has great changes without notice. This study conducts the method of surface survey and continues monitoring result behavior compare to modify a debris flow event due to accumulate sediment deposit and slope changes which will seriously change the risk potential of exist disaster prevention management benchmark value for site future safety.

Materials and methods

In this study, the usage of monitoring device such as rain gauge system, water pressure meter surface tilt meter, bore hole tilt meter, airborne UAV image DSM, site survey, InSAR satellite images and from the usage of monitoring statistic result help analysis the slope mass movement detail for landslide potential areas to find out where the movement is taking place and how rapid it is moving and how the recent slope bed sediment deposit effect the formation of debris flow and downstream region. And by calculating the time interval to establish the small area shallow potential landslide prevention work.

Site review and survey

From 2018, the monitor site in southeast Hualien County silty clay landslide potential area has been set (Fig. 1). Therefore, by monitoring the surface movement and underground water and bore hole displacement, establish the area disaster prevention management mechanism.

In this study, the usage of monitoring device such as rain gauge system, water pressure meter surface tilt meter, bore hole tilt meter, airborne UAV image DSM, site survey, InSAR satellite images and from the usage of monitoring statistic result help analysis the slope mass movement detail for landslide potential areas to find out where the movement is taking place and how rapid it is moving and how the recent slope bed sediment deposit effect the formation of debris flow and downstream region. And by calculating the time interval to establish the small area shallow potential landslide prevention work.

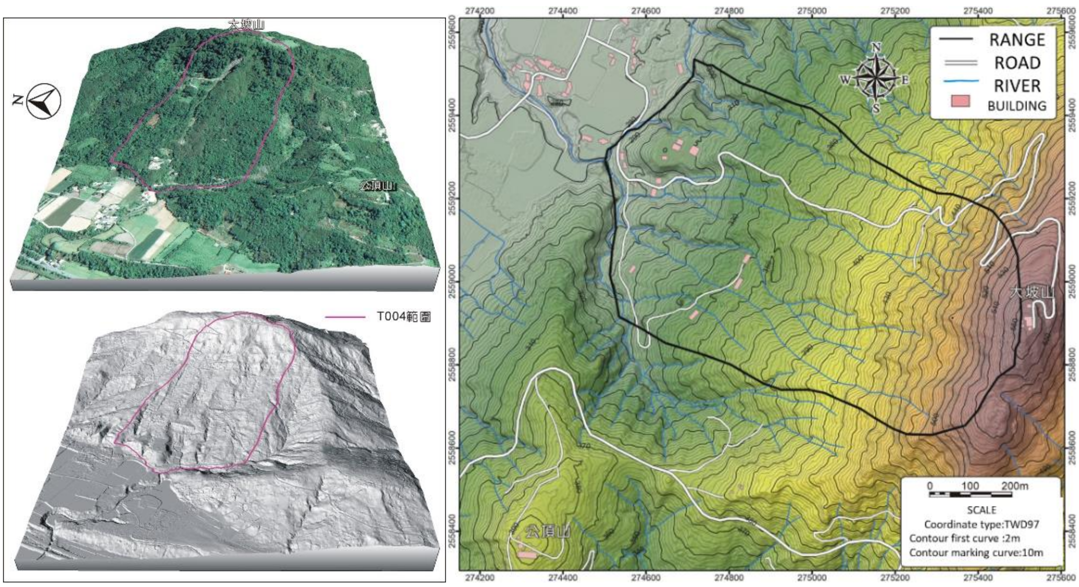


Fig. 1. 3D topographic map of Lixiang T004 (Dian-Tai Mountain) large-scale landslide potential area and terrain

Topography and geology

Terrain

The Dian-Tai Mountain research scope is located in Funan Village, Fuli Township, Hualien County, and belongs to the northwest slope of Dapo Mountain in the Dapo River basin, a tributary of the right bank of the Xiuguluan River. The topography of the T004 (Dian-Tai Mountain) landslide potential area is shown in Fig. 2. The 3D terrain simulation is as shown in Fig. 2. The overall terrain is with Dapo Mountain (elevation 573) on the southeast side of the site area as the highest point. The terrain from the head of the site area to Dapo Mountain is relatively steep, mostly grade 6 or 7 slopes. The slope starts from the southeast side of the site area. It slowly drops to the northwest to the Huadong Longitudinal Valley Plain area and near Highway Line 9. The main slopes are mostly third- and fourth-level slopes, and the terrain is steeper in local gully erosion areas.

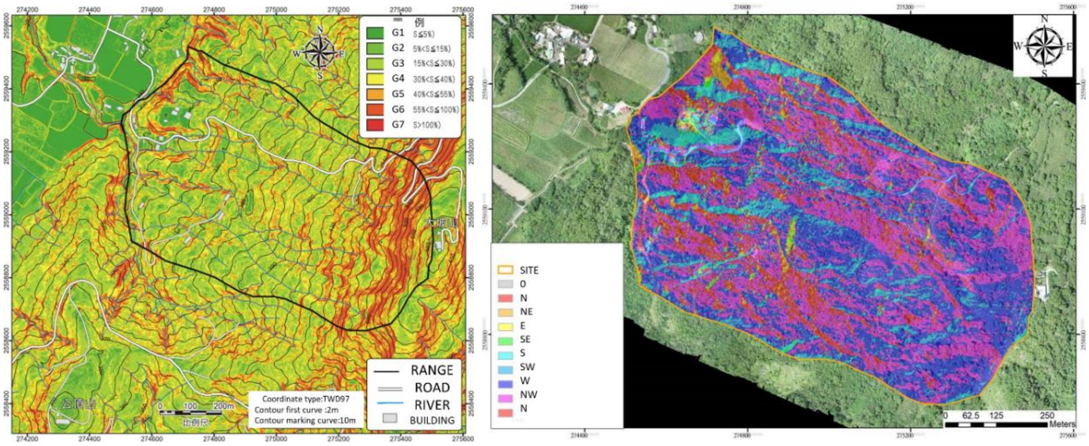


Fig. 2. Slope grading and aspect

Regional geology

Fuli Township T004 (Dian-Tai Mountain) large-scale landslide potential area is located in the area slightly south of the Coast Mountains. It belongs to the Coast Mountains geological area. The strata distributed in the surrounding areas are mainly the Fanshuliao Formation, Liji Formation, terrace accumulation layer and alluvial layer. etc. The geological structures are mainly Chishang Fault and Yongfeng Fault. The regional geological map is shown in Fig. 3.

The scope of this research is mainly located on the Liji layer. The Liji Formation is mainly composed of blue-gray or gray-black mudstone, which contains various sedimentary rock blocks and ophiolite blocks. The lithology of the sedimentary rock mass is similar to that of the Fanshuliao Formation. These quartzite greywacke blocks may have originally been deposited in sediments at the continental margin. In summary, the Ligi Formation was originally a mixed layer in front of the island arc. Later, the collision between the volcanic island arc and the continent caused the deformation and rupture of the sedimentary layers on the continental margin to form the Ligi Mixed Formation. Its shape, organization and content were all affected by later changes. Strata that have been severely damaged or even changed due to tectonic movements.

The geological structure is located between the Chishang Fault (Huadong Longitudinal Valley Fault) and the Yongfeng Fault. The Chishang Fault is a northeast-southwest trending left-moving reverse fault, which belongs to the first type of active fault announced by the Central Geological Survey. This fault is located on the west side of the site, only about 120 meters from the nearest edge of the site area. The Chishang Fault extends from the southeastern area of Ruisui to the south-southwest to the southeast of Chishang. The fault surface presents an eastward inclined surface with a steep upward slope and a gentle downward slope, with an inclination of about 60 degrees close to the surface. It turns to be nearly horizontal at a depth of about 25–30 kilometers. The hanging wall of the fault is a Liji mixed layer hundreds of meters to several kilometers wide, thrust overlying the late Pleistocene conglomerate or Holocene gravel layer. The Yongfeng Fault is located on the east side of the research scope, about 810 meters away from the nearest point of the research scope. To the east of the Yongfeng Fault is the distribution range of the Fanshuliao Formation.

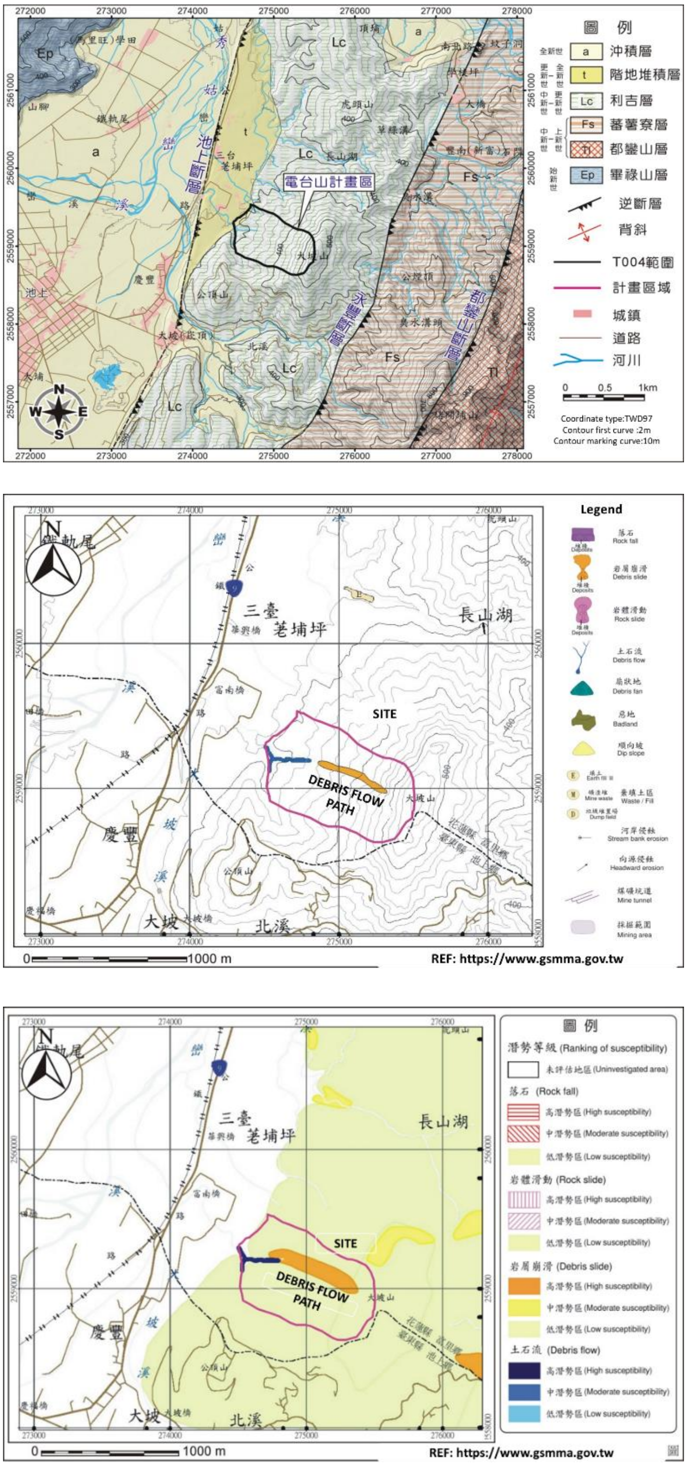


Fig. 3. Regional geological map and basic environmental geological map and geological hazard potential map of large-scale landslide potential areas

Environmental geology

According to the geologically sensitive area information announced by the Central Geological Survey, there is a geologically sensitive area for landslides and landslides within the Taidaishan site area. It is mainly located in the north-central part of the site area at an altitude of 335 to 470 meters. The overall appearance is as follows: It is long and narrow, covering an area of about 2.6 hectares. This geologically sensitive area is also located in the T004 large-scale collapse area. In addition, within the scope of this research, there is a stream with landslide potential numbered Huaxian DF055, which has high disaster potential The basic environmental geology map of the Geological Survey Institute of this region is shown in Fig. 3. It can be found that the aforementioned geologically sensitive area for landslides and ground slides was originally a debris avalanche disaster area. In terms of geological disaster potential, the geologically sensitive areas within the T004 large-scale collapse area belong to the high-scale landslide potential area of debris avalanche, while the remaining areas belong to the low-scale landslide potential area

Field investigation results

2018 survey

In 2018, the Soil and Water Conservation Bureau planned 7 geological boreholes from TH-1 to TH-7 in this area, with a total drilling depth of 300 m. The borehole layout and investigation purpose are shown in Fig. 4. In addition, the ground resistance detection includes 4 measuring lines such as H1~H4. The length of the measuring lines ranges from 200 m to 450 m, and the total length of the measuring lines is 1150 m. Drilling results show that the lithology within the site area is mainly blue-gray or gray-black mudstone, mixed with a large number of brecciated rock blocks. The composition of the rock blocks can be seen as tuffaceous sandstone, hard shale, andesitic clastic rock and ophiolite [*CGS, 2018; SWCB, 2018*]. Its heterogeneous rock blocks, with particle sizes ranging from several centimeters to several meters, are relatively fragmented due to strong shearing. Excerpts of borehole configuration and geological profile results are shown in Fig. 4.

2022 survey

The base surface is composed of lithic layer and Liji layer mudstone intercalated with exotic rock blocks and thick layers of exotic sandstone blocks. This thick layer of sandstone blocks is mainly located on the east side of the site area, and the sandstone blocks have relatively poor erosion resistance. The mudstone is high, and towering independent mountain tops are formed due to differential erosion.

According to the core analysis of drilling in 2018, the thickness of the debris layer in the large-scale landslide potential area ranges from 17.4 meters to a maximum depth of more than 40 meters. It is mainly composed of colluvial gravel and broken rock layers. The gravel composition is composed of igneous rock blocks, mainly sandstone blocks and mudstone blocks. Since the mudstone of the Liji Formation has no bedding and the surface is composed of lithic layers, there is no bedding position data within the scope of this research. According to the surface geological survey and drilling results of the large-scale landslide potential area, it is shown that the scope of this research should be an old large-scale landslide potential area. It is speculated that it is a collapse in the debris layer, which is an arc-shaped sliding type. The area where it occurs (i.e., the head) is an independent hilltop composed of sandstone blocks located on the east side of the collapse area, and is determined to be the earliest location where the collapse occurred.

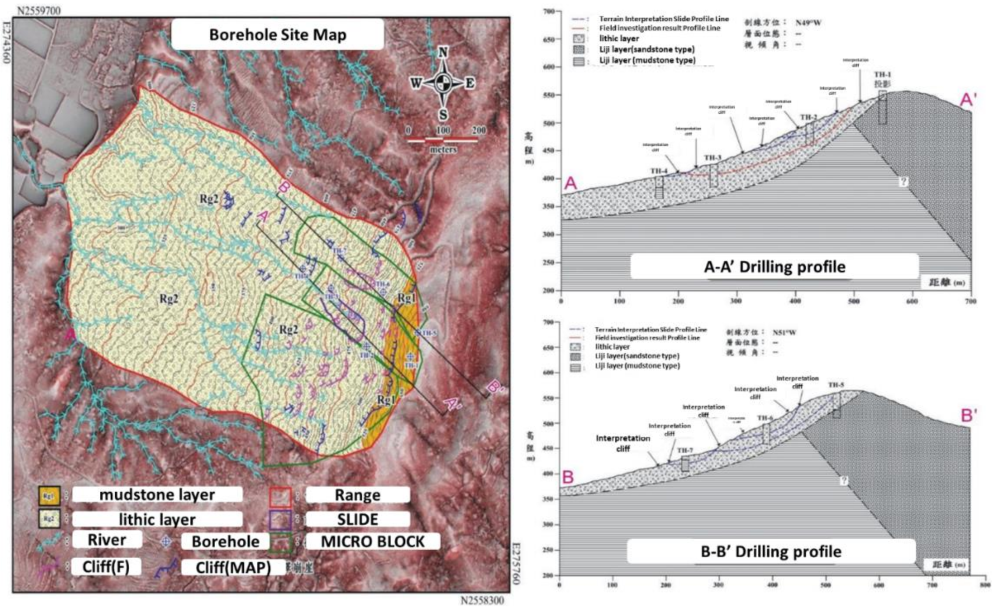


Fig. 4. Excerpts of the past-year geological survey results of T004

Geological plan and cross-section

With reference to the preliminary survey and geological exploration results, and in conjunction with the current stage surface geological survey and terrain analysis and other comprehensive research and judgment results, the geological plan and section of the Dian-Tai Mountain site area are drawn in Fig. 5. The rock plate in the large-scale landslide potential area is mainly composed of the Liji layer. According to different lithology, it is divided into Liji layer mudstone (Ms), sandstone (Ss) and mudstone interspersed with sandstone layer (Ms/Ss). The slope surface Covered by colluvium (Cv), the flat terrain below the slope is distributed with terrace accumulation layers (t) (CGS, 2018: 2013), of each rock formation are explained as follows:

(A) Liji Formation Mudstone (Ms): The lithology is mainly blue-gray to gray-black mudstone, containing various sedimentary rock blocks and ophiolite blocks. It is mainly exposed at the toe of the slope in the site area. in a nearby ravine. In geological boreholes, it mainly appears in 2018 boreholes TH-3, TH-4 and TH-7.

(B) Sandstone (Ss): The lithology is layered sandstone, with layer thickness ranging from more than ten centimeters to dozens of centimeters. The lithology is still hard, but the surface is weathered and turns yellow-brown and its strength is reduced. According to the survey results of various outcrops on the surface, the positions of the sandstone layers are quite close and distributed throughout the ridge area, showing that they are rock layers with a certain volume. It is speculated that they are the Fanshuliao Formation rock blocks that fell into the Liji Formation during plate movement. In geological boreholes, it mainly appears in boreholes such as TH-1 and TH-5 in 107, and there are often shear weak zones in the cores.

(C) Mudstone interspersed with sandstone layer (Ss-Ms): The surface of this layer is not exposed and should be covered by vegetation. It is mainly derived from the inferences of geological drilling results such as TH-2 and TH-6. The lithology is composed of Liji layer mudstone and sandstone. The layers appear alternately, and the lithology is sheared and broken. It is speculated that it should belong to the transition zone between the mudstones of the Liji Formation and the sandstone blocks of the Fanshuliao Formation.

(D) Rock debris layer (Rg): Mainly composed of yellow-brown to gray sandy or silty soil, intercalated with sandstone or other lithological rock blocks. The structure is loose and messy, and it generally covers all slopes in the site area. On the surface. In geological boreholes, the thickness is usually less than ten meters. However, since the boreholes are mostly located in the upper half of the slope, it is inferred from the terrain characteristics that the thickness of the colluvium layer in the lower half of the slope should increase.

(E) Terrace accumulation layer (t): It is a flat area distributed under the slope. There are currently no outcrops and drilling data. It is speculated that it should be composed of unconsolidated gravel, sand, mud, etc., and its thickness is unknown.

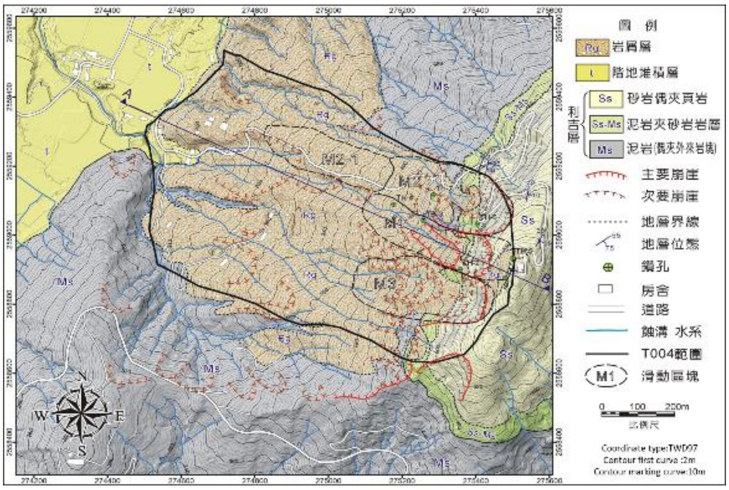


Fig. 5. Geological plan and Geological profile of T004 (6) Investigation of surface fissures

Investigation results of surface fissures

The surface fissure investigation mainly focuses on the investigation of cracks, deformation and damage phenomena on the surface and structures within the research scope. Cracks on the ground surface and structures can directly reflect the stability of slopes and are important items in the investigation and analysis of large-scale landslide potential areas. However, there are many reasons for the occurrence of fissures, which must be carefully filtered and analyzed to clarify their causes and provide effective data for the study and judgment of the activity of large-scale landslide potential areas. However, cracks in the surface and structures may be caused by various factors and are not necessarily related to landslides or collapse damage. Cracks may occur due to local topographic factors, structural defects caused by poor engineering quality, inadequate backfilling, insufficient thickness of concrete pavement, etc., as well as the rolling pressure of heavy vehicles or large machinery. These fissures are sometimes difficult to distinguish from fissures caused by stratigraphic sliding. It is necessary to conduct comprehensive research and judgment based on the distribution of surrounding fissures, geological topography, environmental factors, etc., in order to obtain more accurate results. In addition, because these cracks generally only appear on rigid surfaces such as man-made surfaces, pavements, or structures, and are difficult to form or easy to heal quickly on natural soil surfaces, their distribution locations are only for reference.

The survey results and on-site photos of surface fissures in the Dian-Tai Mountain site area last year (2023) are shown in Fig. 6. It can be found from the survey results that surface cracks are mainly located on the connecting roads leading to the top of the slope, mostly in the form of road cracks, and cracks also occur in local retaining walls. The distribution of cracks is mainly concentrated on the road pavement in the middle section of the slope. The types are mainly longitudinal cracks and irregular cracks. Damage to drainage ditches can also be seen in local areas (Fig. 6); damage to retaining walls is mainly concentrated in the location of area B in Fig. 7. Although there are many cracks in the remaining areas of this survey area, such as the road surface near the top of the slope and around the radio station, and the farm road near the toe of the slope, they should be related to the construction quality or local terrain, rather than caused by ground slippage.

Generally speaking, surface fissures in the Dian-Tai Mountain site area are mostly distributed near the middle section of the slope, and are less likely to occur in the sandstone layer area on the top of the slope. The reason may be that these cracks are mostly caused by shallow sliding, so they mostly occur in the colluvium accumulation area in the middle section of the slope.

Other surface damage phenomena

During this year's on-site investigation, a newly generated debris avalanche was discovered on the road slope near the boundary of the T004 large-scale landslide potential area. The failure pattern was arc-shaped sliding, with the collapse area being about 0.1 hectares and the sliding depth Within 3 meters, there is shallow damage (photos *a*, *b*, *c* in Fig. 7). After the collapse, a loose debris layer is exposed. The cause of the collapse is speculated to be poor geological conditions, steep terrain, and slope failure after heavy rain. There is a road passing above the collapse site (photo *d* in Fig. 7). No obvious abnormality was found in the investigation results, indicating that the collapse is a local damage phenomenon and the scope of impact has not yet extended to surrounding areas.

An erosion trough developed below the M1 collapse area, extending roughly along the center of the survey area. Earth-rock flows occurred in the early days, but currently only the main erosion gully, which is about 2 to 3 meters wide and 1 to 2 meters deep, remains, and much of the erosion gully has been covered with vegetation (photos *e* and *f* in Fig. 7). Since the slope surface is a loose rock debris layer that is easily affected by erosion, continued attention should be paid to the subsequent development of this erosion gully

Changes in surface behavior

The preliminary plan was to investigate surface fissures in the area in March 2018, and then conduct a supplementary investigation in October of the same year, mainly to examine the changes in surface damage in the investigation area after the 918 earthquakes. The investigation results found that the new damage on the surface after the earthquake was mainly distributed in the middle section of the slope, that is, the original crack-intensive area. Most of the damage was the expansion of the original pavement cracks, and there were also new cracks on the local pavement. As for the cracks in the existing retaining wall, the visual changes are not obvious. There is no obvious damage near the top of the remaining slopes, and the newly built retaining wall above the collapse area has no abnormal appearance.

A surface fissure survey was conducted in early March of this year (2012), and it was found that the survey points had little change compared with the situation in October 2011. This may be because no major natural disasters occurred during this period. This year's rainy season saw many typhoons hitting eastern Taiwan, bringing abundant rainfall. The survey was conducted again in mid-October and found that there was little difference between the survey results at each survey point and the survey results in March, indicating that this year's heavy rain had little impact on the changes in surface fissures in this region. In addition, since 2011, some pavements and retaining walls have been gradually re-paved and constructed, so many cracks no longer exist. Since this year, no new cracks have been seen in the newly paved roads.

Fig. 7 shows the results of the investigation of fissure changes in this area from October 2011 to October 2020. The description is as follows:

1. There are no obvious changes in the existing cracks in the road surface in the middle and lower sections of the slope (photos *a* and *b* in Fig. 7). After repairing part of the road surface damaged by the earthquake, there were no new cracks in the filled areas (photo *c* in Fig. 7.
2. There is no obvious change in the cracks in the road retaining wall in the middle section of the slope (photos *d* and *e* in Fig. 7). Some of the damaged retaining walls in this section have been repaired and rebuilt, and no cracks are found in the new retaining walls.
3. The road pavement in the middle section of the slope was originally an area with developed cracks. The pavement was re-paved in mid-2011, but new cracks were

discovered during the investigation in October 2011. During the survey in March of this year (2012), it was found that the road surface had been re-paved. When the survey was carried out again in October, no new cracks were found in the road surface (Fig. 7, photos *f*, *g*).

4. The survey results of the road surface on the upper slope of the survey area showed no significant changes (photo *h* in Fig. 7); there was also no significant change in the road surface around the radio station on the top of the slope (photo *i* in Fig. 7).

5. There are no signs of damage or other abnormalities in the newly constructed retaining wall in the upper slope improvement research of the M1 sliding area, and the surrounding sliding soil is gradually revegetated (photo *j* in Fig. 7).

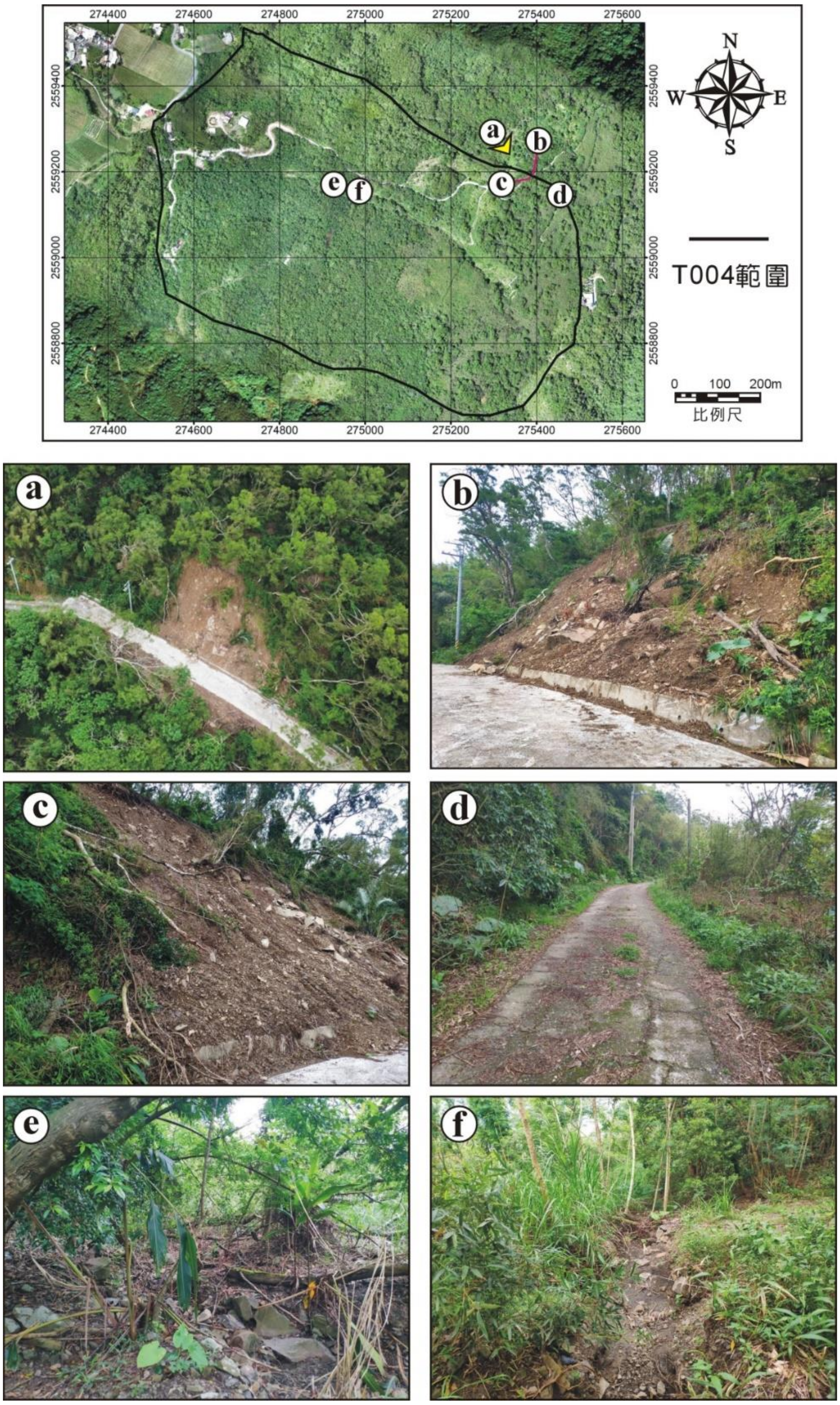


Fig. 6. Shallow damage and erosion in T004 (2023.10.15)

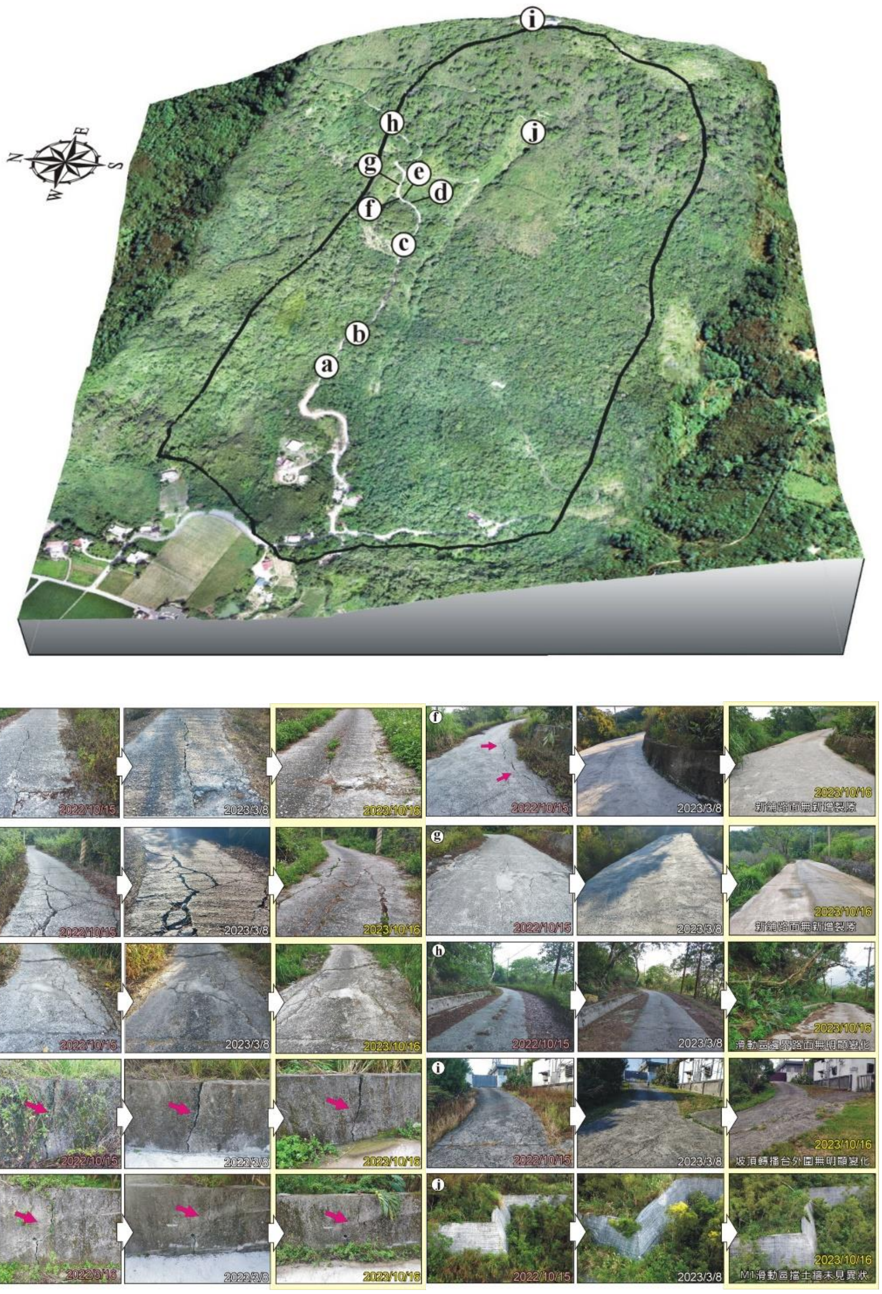


Fig. 7. Comparative photos of changes in surface fissures

Sliding block division

Referring to the previous survey results of this research scope, there are two large-scale landslide potential areas, M1 and M2, on the upper slope of the T004 range. In 110, Dian-Tai Mountain was divided into blocks, and it was found that there was a potential collapse area on the right side of the M1 block. Sliding block, so the M3 sliding block was added. However, since the M3 block has no accessible road and the signs of sliding are unclear, it is tentatively planned not to conduct relevant monitoring. Based on the results of high-precision numerical terrain interpretation, this plan considers the sliding direction and impact area of slope soil, as well as the location and direction of water systems and ridge lines, and re-targets the sliding blocks M1, M2 and M3 in the T004 large-scale landslide potential area. The boundaries are divided, and the result is shown in Fig. 8 Among them, considering the investigation results of surface damage phenomena, an additional sliding block M2-1 was designated on the middle slope below the M2 block. The delineation results are shown in Fig. 8 and the current 3D terrain and slope surface are shown in Fig. 9.

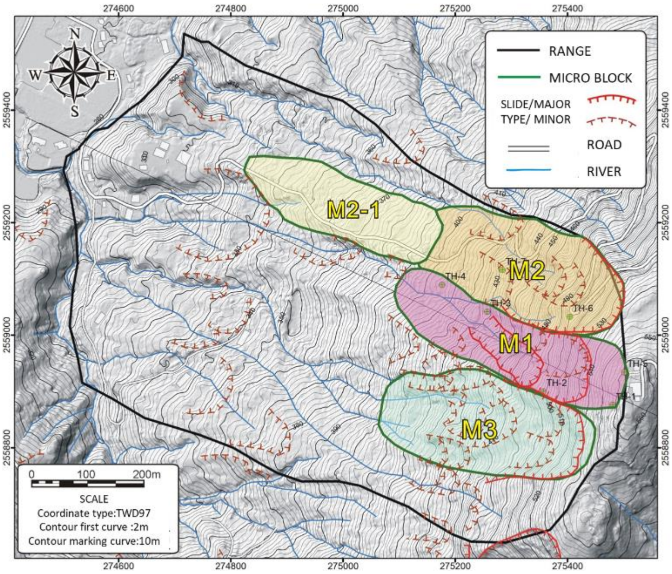


Fig. 8. Division of sliding blocks in T004

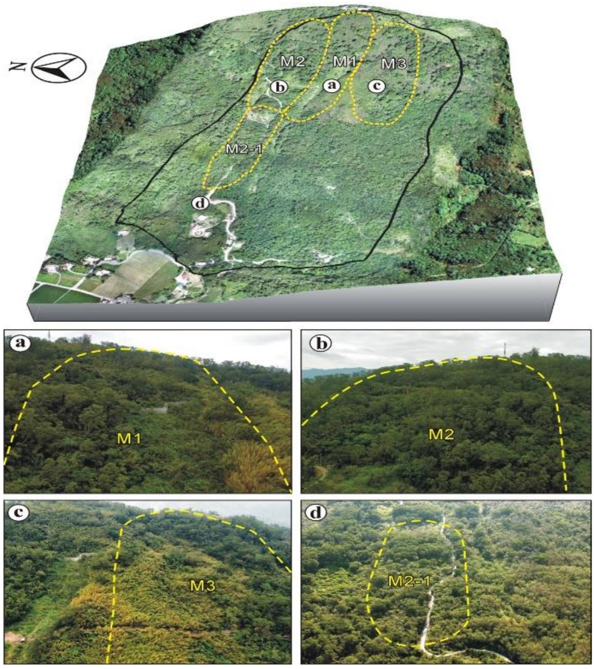


Fig. 9. Full view T004 Sliding block division (2023.10.15)

From 2018, three monitor sites in southeast Hualien County silty clay landslide potential area has been set. Therefore, by monitoring the surface movement and underground water and bore hole displacement, establish the area disaster prevention management mechanism.

For Dian-Tai Mountain during the Typhoon rail the entire area was under warning, and for during two different earthquakes, the upper region underground water level had become highly effected, but from surface deformation result, nothing much had changed due to correct construction method that help cease the landslide movement that makes pre-warning system more reliable shown in Fig. 3.

Rainfall statistics

Due to the increasing trend of rainfall in extreme events in recent years, this plan estimates that from 2007 to 2023, the maximum continuous 24-hour rainfall in the landslide potential area was 500 mm (Typhoon Compass in 2021), followed by 475 mm (Typhoon Lepus in 2021). The maximum hourly rainfall of a typhoon event is 67.5 mm/h (Typhoon Meranti in 2016); the maximum continuous rainfall for 6 h is 188 mm (Typhoon Lepus in 2013); the maximum continuous rainfall for 12 h is 284.5 mm (Typhoon Lepus in 2013) typhoon). Judging from the cumulative rainfall of events, this year's Typhoon Dusuri's 799 mm is currently the event with the highest cumulative rainfall [*SWCB*, *2023*]

Results analysis and discussion

InSAR analysis

During the analysis, the area larger than the Dian-Tai Mountain monitoring area was cut, and only the vertical deformation was used to discuss the sliding situation of the overall slope during the process. Due to the Guanshan Chishang earthquake in September 2022, the vertical deformation was divided into long-term (from April 2017 to April 2017) May 2023), co-seismic and post-seismic vertical deformation are discussed in three-time intervals, and the solution results are drawn as shown in Figs. 10–13. From Fig. 11, the long-term vertical deformation produced is local or shallow deformation. Observed from Fig. 13 of co-seismic deformation, there is an obvious elevation drop at the slope toe. However, the deformation range is less related to collapse and may be more related to the earthquake surface deformation. The vertical deformation after the earthquake is shown in Fig. 10. As shown in 75, the overall downward deformation occurs below the middle section of the 2/3 slope, and the vertical deformation value is low. We can continue to observe whether there is an obvious collapse location transition in the future.

The main slope of Dian-Tai Mountain is towards the northwest. The incident azimuth angle of the ascending orbit of the Sentinel-1A satellite in this area is 79.4 degrees and the inclination angle is 38.3 degrees. The incident azimuth angle of the descending orbit is –79.3 degrees and the inclination angle is 35.3 degrees. The Sentinel-1A satellite is looking left., based on the satellite's geometric conditions and main slope orientation, the following descent orbit analysis is selected to be more reliable. However, the slope is not a single slope orientation. Possible changes in slope orientation should be considered and included in the ascending orbit analysis.

From this analysis to September 2023, the analysis results of the ascending orbit from the previous period to the end of this analysis are shown in Fig. 12. The decrease in head elevation can also be observed on the slope, but it is limited by the satellite incident direction. and the slope aspect within the range, a descending rail analysis must still be performed; the descending rail analysis results are shown in Fig. 13 [*SWCB*, *2023*]. For past event of No21 Typhoon in 2021 and 0323 and 0918 earthquake (> M6.8) in 2022, the surface deformation can be seen that the slope slides from southeast to northwest, in Fig. 14 and the solution results will be that the head falls and the toe rises, and the reaction may exist Multiple sliding surfaces or partial sliding blocks can be supplemented and verified by underground monitoring.

Site monitor result

For Dian-Tai-San during the Typhoon rail the entire area was under warning, and for during two different earthquakes, the upper region underground water level had become highly effected, but from surface deformation result, M2 block surface deformation had changed due to earthquake and from past underground monitor result, there is rapid movement at the belly part and toe part of landslide potential mass. Although correct construction method can help cease the landslide from expanding, put from exist debris deposit surface movement is still important to take precaution, and for entire area unstable sediment pre-warning system setup, it is more reliable to put emphases in long term monitor [*SWCB, 2023–2018*].

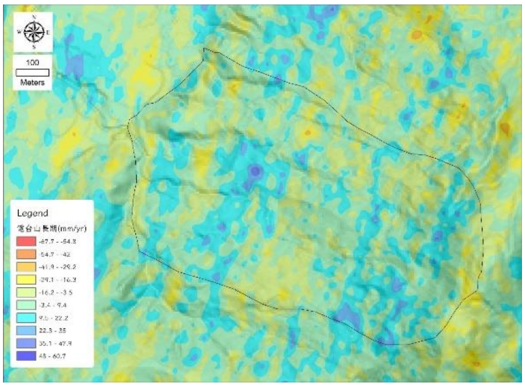


Fig. 10. Site long-term vertical deformation rate (mm/yr)

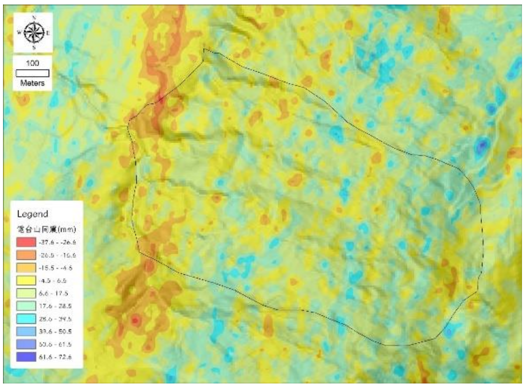


Fig. 11. Coseismic vertical deformation of site after earthquake in September 2022 (unit: mm)

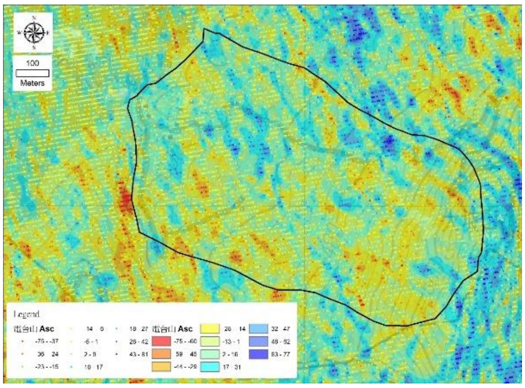


Fig. 12. Vertical deformation of the rising rail satellite from 2023/5 to 2023/9 (unit: mm)

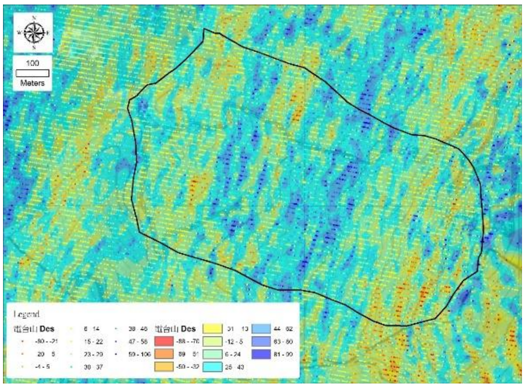


Fig. 13. Vertical deformation of the lower rail satellite from 2023/5 to 2023/9 (unit: mm)

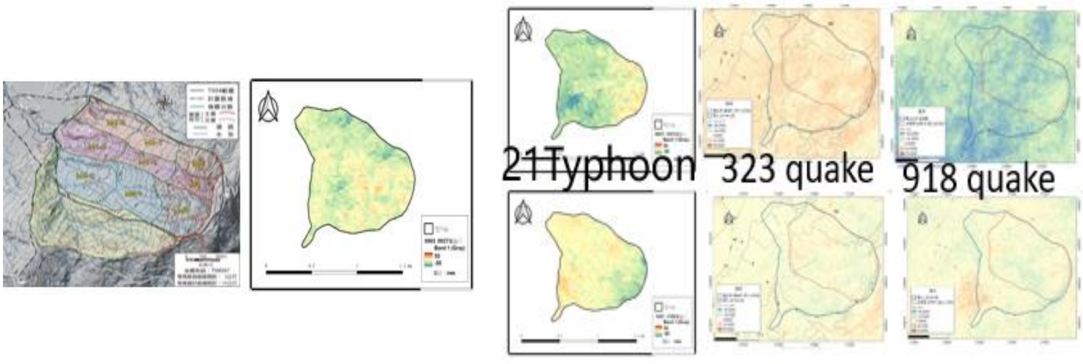
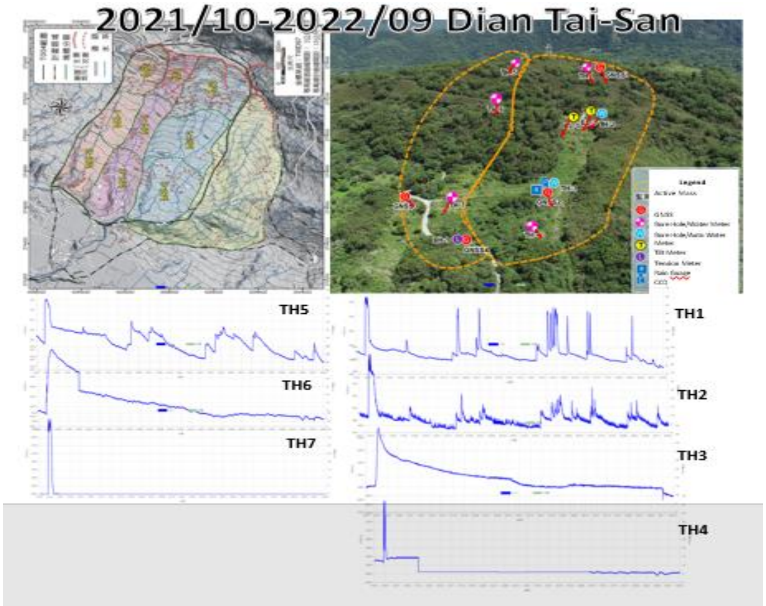


Fig. 14. Comparison of InSAR result under three nature events



1日	21Typh	323	918	1日	21Typh	323	918
RAIN	845	0	0	GNSS1	NA	NA	0.456
TH5	5.43	0	0	TH2	3.57	-0.021	0.032
GNSS2	NA	NA	0.531	EL1	0.1	0	0
TH6	3.21	0.007	0,014	EL2	0.4	0	0.1
GNSS3	NA	NA	0.348	TH3	2.72	-0.24	1.1
TH7	2.21	0.026	0.72	GNSS4	NA	NA	0.543
				TH4	4.78	-0.22	1.78

Fig. 15. Site underground water monitor result

Flow2D result

From above monitor result, surface displacement in different potential region has been monitored, and under each different event, sediment transfer has become obvious effect to the surrounding safety. Therefore, from typhoon rainfall which form surface runoff and continuous sediment deposit, with the help of strong earthquake shaking which loosen the upper region sediment supply and withdraw the help of residential ignorance of sediment deposit, debris flow formation has become a safety issue which might lead to hazardous disasters.

By looking at the surface deformation result for each modify rainfall scouring event and considering the deposit depth and exist levee or riverbank structure height, his research use return times debris flow simulation and alongside sedimentation analysis to setup risk map if site sediment deposit has not been dealing. From Table 1 we divide the sediment deposit depth and spreading area into four category level, and letting the rainfall amount (680 mm/24hr) for triggering debris flow the same amount at each modify event. But, for the landscape elevation changes, each simulation uses the last result and simulate again and again. Fig. 17 show the exist debris flow deposit effect potential range hazard, and in Fig. 18 we show by using the current DEM result for first debris flow event simulation, and find the sedimentation difference at midstream deposit. Therefore, at second and third and fourth return event, we find the high-risk potential spot changes downward but due to slope decreasing and longitude reduce, the deposit height and effect area will also decrease due to lack of energy potential shown in Fig. 19 and effect will shrink at the fourth stage return.

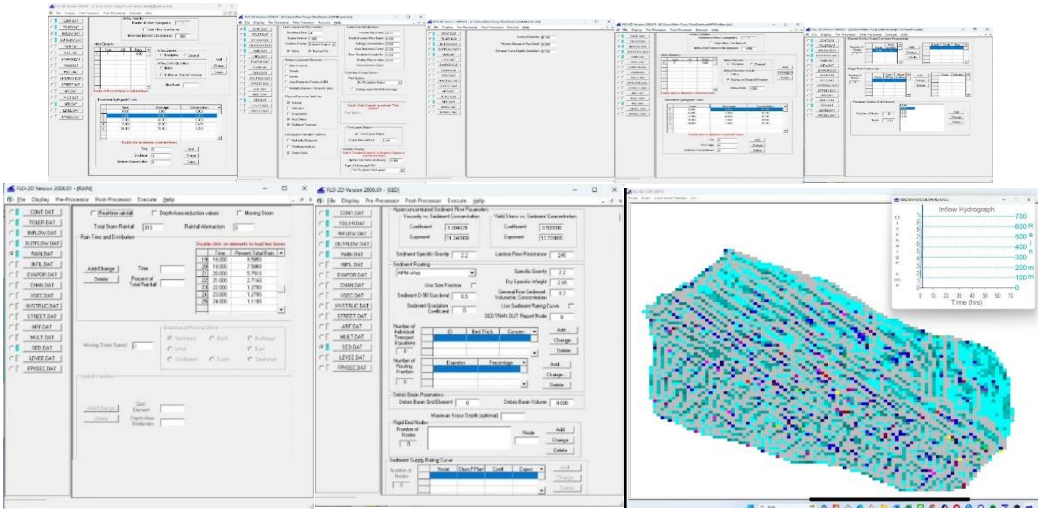


Fig. 16. Flo2D simulate procedure for return erosion debris flow formation

Fig. 17. Site debris flow deposit effect range

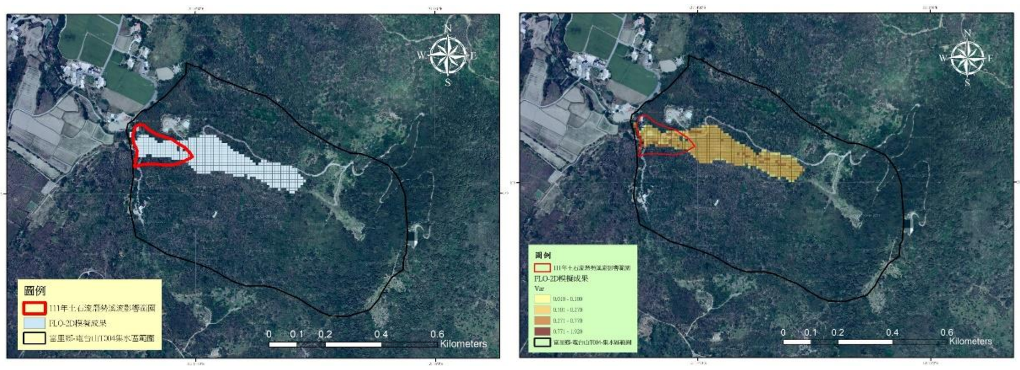


Fig. 18. Flo2D Simulate relationship between the current status for the first time and the impact range of landslides

Table 1. Deposit hight potecial scater comparion

Deposit area, %	Deposit depth, m			
	High (> 3 m)	Medium high (1–3 m)	Medium (0.5–1 m)	Low (< 0.5 m)
High (> 75%)				
Medium high (50–75%)				
Medium (25–50%)				
Low (< 25%)				

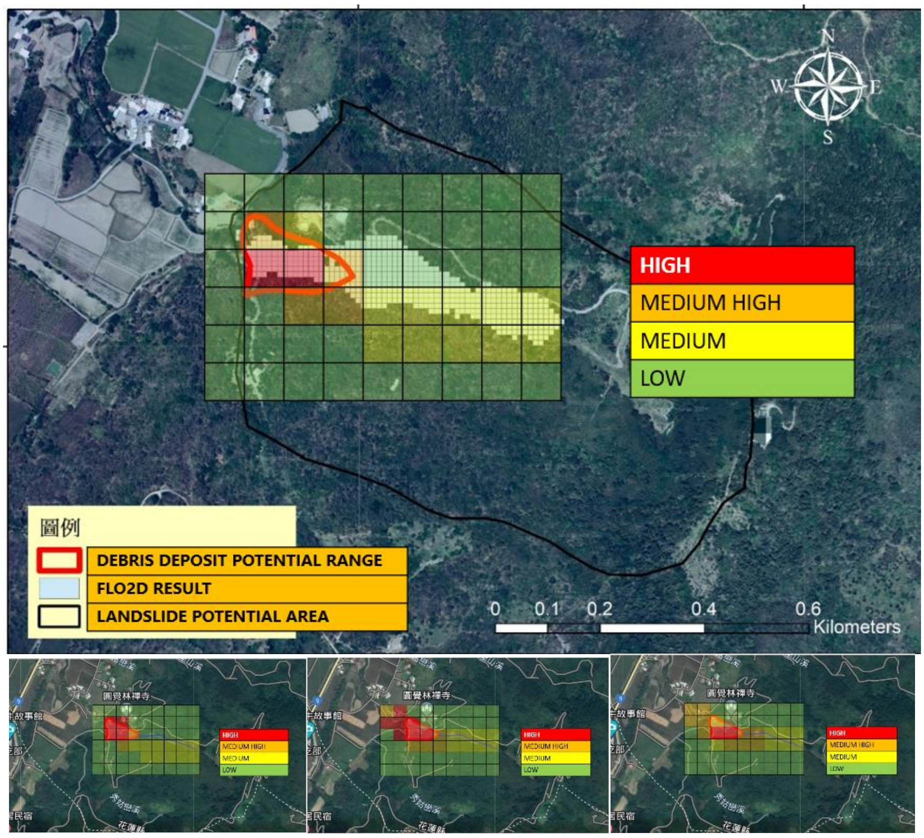


Fig. 19. Flo2D Simulate relationship between the current status for the first to forth time sedimentation impact of landslides

Conclusions

From continuous monitoring result analysis and conducting the real time endanger site precaution underground and surface observation management mechanism, can help the government agency to establish the landslide potential area site pre-warning system, and make preparation for evacuation plan before and after hazard event.

References

The Hualien Branch of Soil and Water Conservation Bureau of the Agriculture Committee of the Executive Yuan (SWCB), the monitoring survey and maintenance plan of the large-scale collapsed areas at T004, Luoshan Village, and Antong D018, Yuli Town, Hualien County, Fuli Township, Hualien County, 2023.

The Hualien Branch of Soil and Water Conservation Bureau of the Agriculture Committee of the Executive Yuan (SWCB), the monitoring survey and maintenance plan of the large-scale collapsed areas at T004 of Tiaodian Mountain, Fuli Township, Hualien County, and D018, Antong, Yuli Township, 2022.

The Hualien Branch of Soil and Water Conservation Bureau of the Agriculture Committee of the Executive Yuan (SWCB), Hualien County-Yuli Town-Antong Hot Spring Settlement (D018) Large-scale Collapse Area Investigation and Treatment Planning, 2020.

The Hualien Branch of Soil and Water Conservation Bureau of the Agriculture Committee of the Executive Yuan (SWCB), the monitoring and investigation of the landslides of Radio Mountain in Fuli Township and Shiping Tribe in Zhuoxi Township, 2018.

The Hualien Branch of Soil and Water Conservation Bureau of the Agriculture Committee of the Executive Yuan (SWCB), Hualien County-Yuli Town-Antong Hot Spring Settlement (D018) Large-scale Collapse Area Investigation and Treatment Planning, 2018.

Central Geological Survey Institute of the Ministry of Economic (CGS), Ministry of Economic Affairs Geological Relics Geologically Sensitive Area Delineation Plan H0017, 2016.

Institute of Geological Survey, Ministry of Economic Affairs, Research on the Development and Application of Landslide Observation Technology (2/4), 2016.

The Hualien Branch of Soil and Water Conservation Bureau of the Agriculture Committee of the Executive Yuan (SWCB), Antong Hot Spring Collapse and Detailed Planning of Wild Creek Treatment, 2013.

Central Geological Survey Institute of the Ministry of Economic Affairs (CGS), National Land Conservation Survey and Analysis Plan for Geologically Sensitive Areas–Analysis of Geologically Sensitive Characteristics of Non-Morakot Typhoon-affected Areas (1/3), 2013.

Soil and Water Conservation Bureau of the Agriculture Committee of the Executive Yuan, Quantitative Evaluation and Observation Plan for Soil and Water Conservation and Conservation Effects (1/3), 2008.

Central Meteorological Bureau of the Ministry of Communications, "Annual Report on Climatic Data (Part 1 – Ground Data)", 2008~2020.