摘 要

過去莫拉克風災造成臺灣多處大規模崩塌事件，經濟部中央地質調查所過去已針對受災區，運用空載光達數值地形資料，進行潛在大規模崩塌判釋，針對可能發生區位已精確找出多處影響重力邊坡變形重要地形特徵，惟具有地形特徵之潛在大規模崩塌，是否有機會轉換成快速運動之災害性崩塌？目前仍無法確認尚待研究。為有效篩選潛在大規模崩塌地區，具有較高活動性或發生潛勢者，以做為未來土地管理、防災熱點之參考。

本計畫整合目前新進之觀測技術，以建立大規模崩塌活動性的進階觀測技術，共有四項工作項目，包括：(1)利用多年期日本 ALOS、ALOS-2 衛星影像，以 TCP-InSAR 解算技術，進行重點邊坡地表變形解算，完整建置具有時間序列之地表變形量、精度評估與檢核; (2)利用無人機遙測技術，包含無人機載光達與無人機影像空拍，來獲取經指定區域之高解析度數值地形及影像資料; (3)搭配經濟部中央地質調查所於 99~104 年度以空載光達技術測製完成之全臺 1 米解析度數值高程(DEM)及數值地表(DSM)成果，將光達地形資料進行資料合併加值及視覺化之處理; (4)針對經濟部中央地質調查所既有之 5 處潛在大規模崩塌地表位移觀測工作，包含:竹林、達來、茶山、車心崙以及梵梵等區域，以單頻 GPS 技術觀測來分析坡面之地表位移量。透過前述各項工作所蒐集之訊息，嘗試整合分析潛在大規模崩塌地區之發生度與活動性，應可建構出更合理的潛在大規模崩塌地區活動特性大數據，也可做為劃設山崩與地滑地質敏感區更新之準則與依據。

其中，工作項目一使用 2007-2011 年間 ALOS 衛星雷達影像及 2014-2018 年間 ALOS-2 衛星雷達影像，針對特定二處潛在大規模崩塌區，進行長期地表平均變形速率解算，並取得潛在大規模崩塌區詳細地表變形資訊。二處重點邊坡經 TCP 解算後，已完成長期地表平均變形速率成果，其中南投縣-仁愛鄉-D036 於 2007-2011 年 ALOS 升軌地表變形速率為-40.3±8.9 mm/yr ，2014-2018 年 ALOS2 升軌地表變形速率為-20.5±1.6 mm/yr；高雄市-六龜區-竹林地區於於 2007-2011 年 ALOS 升軌地表變形速率為-7.9±6.8 mm/yr mm/yr ，2014-2018 年 ALOS2 升軌地表變形速率為-18±2.7 mm/yr.

使用鄰近 GPS 連續測站，進行時序地表變形量精度評估與檢核

工作中。南投縣-仁愛鄉-D036 使用 MFEN 測站當作 GPS 參考站，以 LSAN 測站 GPS 和 ALOS 影像期程之統計誤差為 1.1±3.4mm，與 ALOS2 影像期程之統計誤差為-14.6±6.2mm。以 HUAN 測站 GPS 和 ALOS 影像期程之統計誤差為 15.7±11mm，與 ALOS2 影像期程之統計誤差為 7.4±4.6mm。高雄市-六龜區-竹林地區使用 PAOL 測站當作 GPS 參考站，以 TAYN 測站 GPS 和 ALOS 影像期程之統計誤差為 13.4±9.4mm，與 ALOS2 影像期程之統計誤差為 14.2±7.6mm。以 GS52 測站 GPS 和 ALOS 影像期程之統計誤差為 34.7±16.1mm，與 ALOS2 影像期程之統計誤差為 1.6±8.1mm；此外，本年度完成雲林縣-古坑鄉-D008 七處地面角反射器架設，結合去年架設之三處，共計十處角反射器。

工作項目二之無人機光達系統已完整地整合，本年度已完成高雄竹林地區之無人機光達掃瞄工作，掃瞄之總面積約 57 公頃，並完成微地形之構造地形分析。光達資料可判釋之山崩構造線崖位置，尤其於山崩區冠部附近細緻之構造線型，以及因山崩區坡地變形引致之波浪狀徵地形，可清楚呈現。運用質點影像測速法(Particle Image Velocimetry, PIV)於竹林地區之地形變異分析，結果指示自 2010 以來，本區之地表水平及垂直變異量均指示本區仍持續運動中。針對梵梵成地區，完成無人機影像地形建模及無人機光達掃瞄資料之收集，相關微地形之構造地形將於下一年度計畫內完成。針對竹林地區之無人機光達掃瞄區，計畫內亦以定翼型無人飛行載具來進行區內無人機影像拍攝及建模。竹林地區至今年六月為止，各於 107 年 7 月、12 月及 108 年 6 月，一共進行了三次拍攝，其中 12 月及 6 月之單一次拍攝面積均大於 30 平方公里。本年度之無人機影像拍攝及資料處理，其中草嶺地區於 107 年 9 月及 108 年 10 月兩期汛期後之影像地形資訊收集完成，單期之總面積均大於 20 平方公里。透過草嶺地區無人機影像航拍及地形建模數年度的成果，其資料顯示本區一直仍持續活動，應宜持續監測。

工作項目三為地調所既有光達數值地形資料合併及視覺化之處理，今年度規劃需完成台灣本島北部區域共 897 幅五千分之一圖幅範圍，期中累計完成 666 幅，期末累計完成 897 幅，達全案 100%。內容包括水域資料位相處理、DEM/DSM 多方向陰影圖及陰影鑲嵌、光達成果品質分析圖、數值地形坡度圖、DEM/DSM 降階後全臺數值地

形成果。另外，關於無人機光達與空載光達成果比較及無人機光達之作業規範將延續去年度之比較分析後，並納入歷次審查委員意見，嘗試量化呈現無人機光達掃瞄成效。本案成果發表會於 8 月 9 日在高雄科學工藝博物館辦理完成。今年適逢莫拉克風災 10 週年紀念，本次成果發表會共規劃 2 個專題與 6 個地調所大規模崩塌相關計畫講題，同時針對近年來環境劇變所衍生之新型態地質災害與莫拉克風災發生後，地調所主導進行之臺灣地區空載光達地形模型建置過程及產製成果進行專題演講，會議圓滿成功。

工作項目四為經濟部中央地質調查所既有之 5 處潛在大規模崩塌地表以單頻 GPS 技術觀測來分析坡面之地表位移量。目前持續穩定進行現場環境維護整理及現地收集資料，並對於監測坡面增加單頻接收儀之佈設，加密監測的數量，逐月統計各監測站位移量及結合降雨量進行整體分析，藉以了解觀測坡面降雨量與空間上位移的關係，評估整體作業於深層崩塌初步調查與分析之效益。

Abstract

Typhoon Morakot caused several large-scale landslides in Taiwan during 2009. The Central Geological Survey of Ministry of Economic Affairs has investigated the affected slopes using airborne LiDAR DEM and has found gravitational slope deformation features in many of the sites. However, it is still unclear whether these feature-rich potential large-scale landslides will turn into fast-moving catastrophic landslides.

This study integrated several advanced observation techniques to monitor the activities of large-scale slopes. The multi-temporal ALOS and ALOS-2 images were calculated by TCP-InSAR technique to reveal the slope deformation. UAV-borne camera and LiDAR were employed to collect high resolution optical images and high point density data, respectively, of several slopes. The 1 m resolution Taiwan LiDAR DEM and DSM data, collected in 2010 - 2015, were mosaicked and rendered for visualization. Single frequency GPS techniques was applied to monitor the surface deformation of 5 slopes in Zhulin, Tavatavang, Chashan, Fanfan, and Chesinlun, respectively. By combining the information collected from aforementioned monitoring techniques, the prediction for the activities of the potential large-scale landslides are attempted. The results can be used as guidelines for updating the zoning of geologically sensitive region for landslide.

This project has adopted the satellite imagery of ALOS (2007-2011) and ALOS2 (2014-2018) to estimate the average long-term ground deformation rate and detailed deformation data of two selected deep-seated landslide sites. Upon completion of the estimation of two selected key slopes, we have completed the TCP calculation of their respective average long-term deformation rate. Among them, the long-term deformation rate of Site “Nantou County-Renai Township-D036” between 2007 to 2011 is -40.3±8.9 mm/yr based on the ALOS ascending data; and between 2014 to 2018 is -20.5±1.6 mm/yr based on the ALOS2 ascending data. As for Site “Kaohsiung City-Liugui District-Zhulin area”, its long-term deformation

rate between 2007 to 2011 is -7.9±6.8 mm/yr based on the ALOS ascending data; and between 2014 to 2018 is -18±2.7mm/yr based on the ALOS2 ascending data.

The precision of the estimated deformation data of these two slops are examined and verified using nearby cGPS data. Site “Nantou County-Renai Township-D036” has used Station MFEN as its referential GPS station. The difference between the values obtained through the measurement of Station LSAN with ALOS data is 1.1±3.4mm and with ALOS2 data is 14.6±6.2mm data. The difference between the values obtained through the measurement of Station HUAN with ALOS data is 15.7±11mm and with ALOS2 data is 7.4±4.6mm data. Site “Kaohsiung City-Liugui District-Zhulin area” has used Station PAOL as its referential GPS station. The difference between the values obtained through the measurement of Station TAYN with ALOS data is 13.4±9.4mm and with ALOS2 data is -14.2±7.6mm data. The difference between the values obtained through the measurement of Station GS52 with ALOS data is 34.7±16.1mm and with ALOS2 data is 1.6±8.1mm data. In addition, we completed the installation of 7 ground corner reflectors at Site “Yunlin County-Gukeng Township-D008”. Together with the 3 corner reflectors established last year, there are 10 corner reflectors installed at this site.

The UAS LiDAR system has been completely integrated. This year, the LiDAR scanning mission of the Kaohsiung Zhulin area has been completed, for an area about 57 hectares. The landslide micro morphotectonic analysis is completed, accordingly. The landslide associated geological structure lineament is completed, especially for the scarp lines near the crown area, and the hummocky terrain caused by the deformation of the landslide area can be clearly demonstrated. Using the particle image velocimetry (PIV) method to analyze the topographic deformation in Zhulin area, the results indicate that since 2010 the area is still in motion, both for the horizontal and vertical deformation. For the Fanfan area, the UAS optical imagery and UAS LiDAR scanning is accomplish, the detail structural analysis will be completed in the next

year's project. Accompanied with the UAS LiDAR scanning in Zhulin mission, the fixed-wing drones are also used to carry out for geoinformatic dataset production. Three missions, in July, December 2018, and in June 2019, finished in Zhulin and Baolai area with an area over 30 Km2. The Tsaoling landslide UAS imagery missions in September 1, 2018, and in October 2019 have been completed. Through the UAS mission in Tsaoling area since 2016, the results indicate that the area is continue deformed and remains active. As a result, it is still worthwhile to be monitor continuously.

There are 897 tiles with 1/5000 scale of the 1m Taiwan LiDAR DEM mosaicked and rendered for this project. Specifically, the water area topology, hillshade map of DEM/DSM, LiDAR quality map, gradient map, down-sampled resolution DEM/DSM are produced. The comparison between UAV and airborne LiDAR data was conducted as previous year. Quantitative comparison was conducted according to reviewer comments. The SOP of UAV LiDAR were also completed. This year is the 10th anniversary of Typhoon Morakot causing devastating hazard in Taiwan. Results of this project were showcased along with 6 other large-scale landslide related projects at National Science and Technology Museum on 9th of August in 2 sessions. Presentations regarding the data production of CGS-lead Taiwan LiDAR DEM project were given.

Single frequency GPS observation system has been made use for surface deformation analysis of 5 slopes by Central Geology Survey.Receivers were installed on the slope surfaces to increase the data density.System maintenance and data collection are continuous operating.With daily deformation and rainfall data, the relationship between rainfall and deformation has been analyzed to evaluate time and spatial variation.Finally, the system is making use to identify the activity of the potential deep-seated landslide area.