Study on Research on Simulation of Shallow Collapse Behavior with Particle Flow – Case Study of Hongye landslide, Taiwan

Kuo-Lung WANG[1*], Jun-Ting LIN[1], Yi-Hsuan LEE[1] and Tsung-Wen CHEN[1]

[1]*Department of Civil Engineering, National Chi Nan University*

klwang@ncnu.edu.tw

Abstract

In this study, in 2017, the unmanned aerial vehicle (UAS) monitoring and on-site investigation of the Landslide of Donghongye Village in the background before the 1011 heavy rain disaster. The geological characteristics of the study area were analyzed with unmanned vehicles to produce orthophotos, and the impact range of the landsldie. The image-supervised classification and analysis were used to circle the exposed bare areas and evaluate the particle size of the soil and sand. Slope stability analysis was performed using numerical terrain produced by UAS images, and particle flow simulation was used to simulate shallow landslide behavior to assess the possible impact range of the collapse.

1 INTRODUCTION

1.1 Motivation

Study area is located in the landslide of Hongye Village, Taitung County, eastern Taiwan. This research area suffered a severe shallow landslide after typhoon Moranti in September 2016. This area also occurred again due to the heavy rainfall of 1011 in 2017. In order to avoid casualties caused by the disaster, it is necessary to understand the occurrence process and trigger mechanism of the landslide, analyze the historical slide and perform the impact assessment of the slip.

1.2 Literature review

AS has proven capable of producing valuable landslide information, such as cracks or displacements on the collapsed surface (U. Niethammer et al., 2012). In addition, UAS can be used to produce numerical terrain models that can be compared with different time series. Historical numerical terrain was compared before and after, and then the quantity of slope failure was analyzed (Barlow et al., 2016).

Aerial information collected through unmanned vehicles can provide useful terrain information for slope stability or dynamic numerical model analysis, including slope status, discontinuities, geometry, or difficult-to-measure locations (Barlow et al., 2017 Wang et al., 2016). Obtaining the slope section profile and intercept point data from the DTM can be used as a mechanical parameter for slope stability analysis, such as Barlow et al.(2017) using this method to analyze sea cliffs and coastal terrain..

1.3 Study area

This study takes the landslide of Hongye Village in Taitung, eastern Taiwan as an example. The location of the sliding area is only 4.3 km from the Luye fault. This fault is an inverse fault, which is approximately southward. Its geological age is the Eocene or earlier, and it is the Biyu mountain layer. Slate is the main lithologies, but thick metamorphic sandstone layers are sandwiched between metamorphic sacrolite layers, among which are limestone and feldspar sandstone.

In 2016, typhoon Moranti, affected by long-time delayed rainfall, caused a large-scale landslide of the slope above Hongye Village. The accumulated rainfall in the area was about 513.5mm, and the maximum rainfall was 19mm/hr (Luye Station). Beds and slopes of rivers, streams, and surface water flowed into the houses of various households. At that time, the Soil and Water Conservation Bureau assessed the loss of the disaster. The landslide area was about 4.8 hectares, and the volume of earthwork was about 80,000 m^3. Roads were buried about 200 meters, and agricultural land was buried about 0.5 hectares.

The Moranti event occurred in October 2017. In October 2017, heavy rain caused the exposed area of landslide at the upper edge of the area inducing the soil and sand slippage on the road. The 1011 heavy rainfall analyzed in this study, and the area ’s adjacent rainfall observation records Luye Station The accumulated rainfall is about 900 mm, and the maximum rainfall is 62.5mm/hr.

2 METHODOLOGY

This research is aimed at shallow collapse sites, using the Unmanned Aircraft System (UAS) for aerial photography and on-site investigations, collecting aerial images before and after the 1011 heavy rain landslide, and establishing image analysis before and after the disaster, further numerical simulation of shallow collapse behavior with particle flow.

2.1 Landslide investigation with UAS

In this study, the unmanned vehicle DJI Phantom 3 Advance equipped with a digital camera and GPS was used to obtain aerial photos of 2017/3/24 and 2017/12/9, as a comparison before and after the 1011 heavy rain collapse. The route planning of different elevations is adopted according to the local terrain fluctuations, as shown in Figure 1. The purpose is to improve the image resolution to improve the sharpness of the photographs due to the differences in terrain elevation fluctuations. It is between 0.038m and 0.2m, and the resolution of the image taken on 2017/12/9 is between 0.0052m and 0.16m.

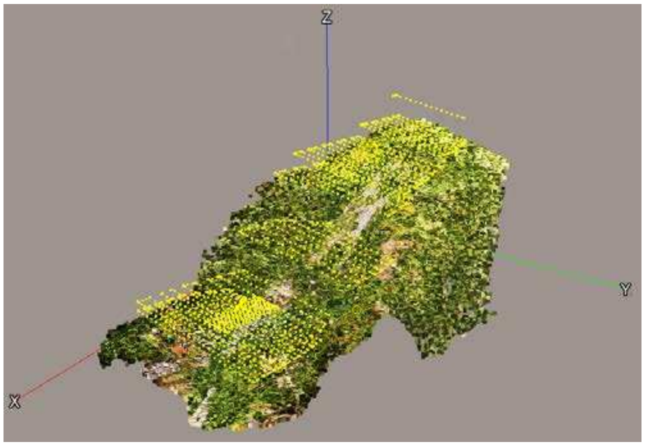


Figure 1. The image capture plan of UAS

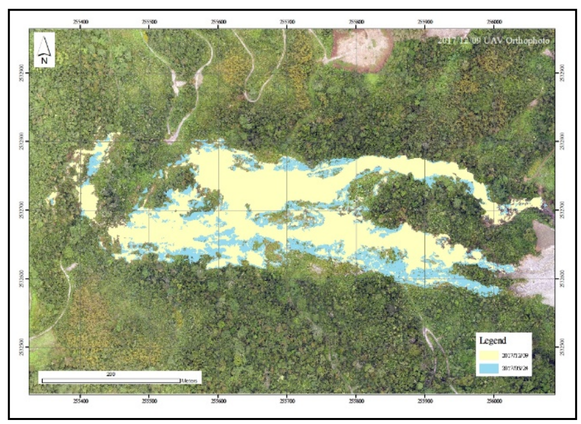
The unmanned aerial vehicle is equipped with a GPS signal for positioning, but its accuracy is low, which may affect the image resolution and terrain coordinate elevation error of subsequent numerical terrain construction. In order to increase the terrain accuracy of the model results after aerial imagery, ground control points were set around the study area at the same time. The distribution is shown in Figure 2 and the GNSS positioning system was used verify the accuracy of the coordinate elevation of the numerical surface model. The three-dimensional root-mean-square error of the control point of 2017/3/24 is 0.0049m, and the three-dimensional root-mean-square error of 2017/12/9 is 0.0077m.

Figure 2 Layout of control points

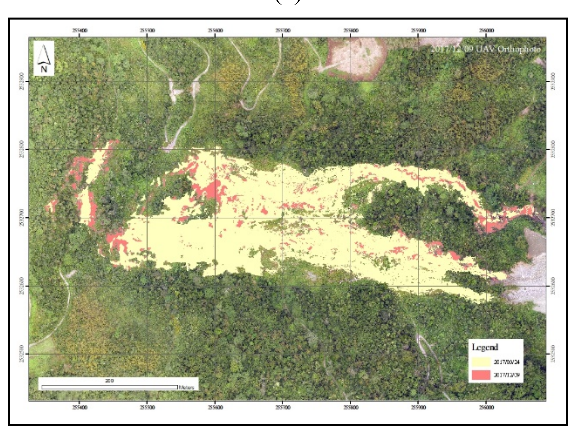
In this study, Bentley Context Capture and Pix4D Mapper were used to perform aerial triangulation to solve the feature points and produce a three-dimensional model. The orthophotos, 3D models, and numerical terrain models before and after the heavy rain disaster in the landslide area in 2017 were obtained by Context Capture. Numerical surface model DSM, with grid size of 0.092m in 2017/3/24 and 0.056m in 2017/12/9; numerical surface model DSM produced by Pix4D Mapper, with grid size of 0.094m in 2017/3/24, 2017 / 12/9 is 0.0604 m, and the numerical terrain model DEM grid size is 0.49683 m for 2017/3/24, and 0.30192 m for 2017/12/9.

2.2 Supervised classification assessment of collapse area and slope material composition assessment

In this study, geographic information software was used to analyze the landslide orthophotos taken by the two dates. The supervised classification tool can speed up the processing of the maximum similarity classification. This study uses the orthophotos produced by the 2017 aerial photography (2017/03 / 24, 2017/12/09), use the supervised image classification tool to map the exposed bare area, track the range change and material status of the collapsed area; as shown in Figure 2, two phases of collapse comparison, the blue area can show two The decrease of the exposed area between periods indicates that there is a restoration of vegetation around the landslide. The red area can show the newly exposed area in the two periods, and the upper edge of the collapse has a new trend of expansion.



(a)



(b)

Figure 3 Post-disaster landslide and vegetative recovery. Vegetation restoration in the blue area(a); new life in the bare area in the red area (b)

In order to set the material parameters of the subsequent numerical simulation of the slope of the landslide area, such as the size of the rock, the range of the source of the material, the range of the wood, etc., this study uses the UAS aerial photos to make 2017/3/24 orthophotos, supervised classification studies the size and distribution of the exposed stones. As shown in Figure 4, the rocks identified in the landslide exposed areas still have errors in the interpretation of the boundaries. In the study, the rock characteristics of the errors in interpretation were found. Most of them are concave polygons, and a concave polygon has a longer side length as a filtering mechanism when it has the same size and area as a convex polygon.

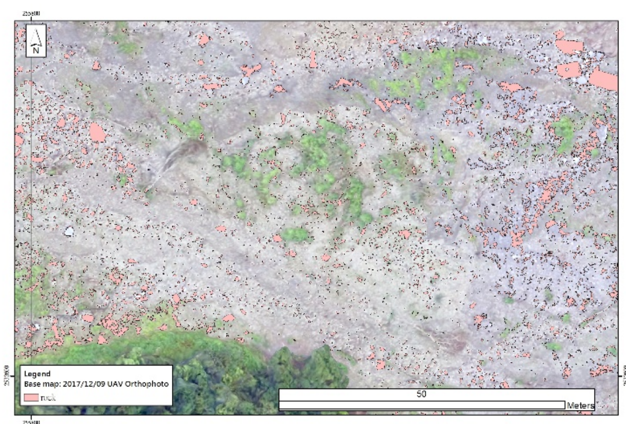
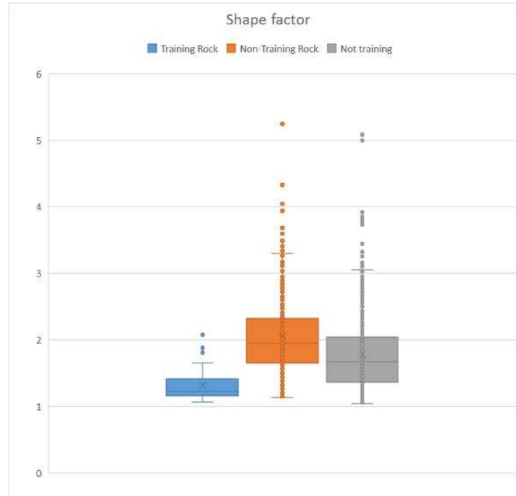
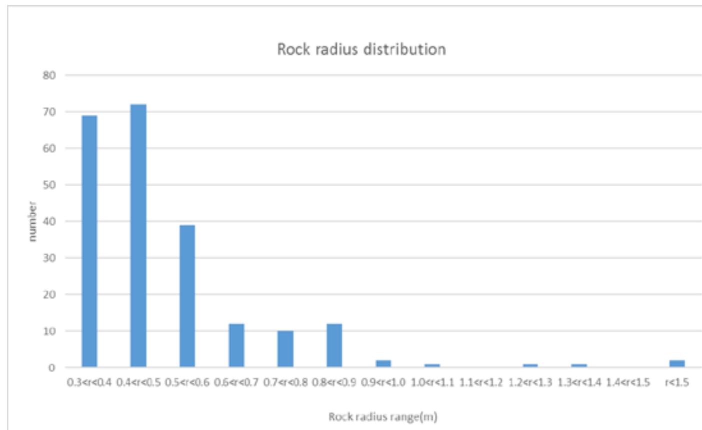


Figure 4 The rock size identified by supervised classification in 2017/3/14 images

This study uses the area of the rock feature to calculate the perimeter of the area when the figure is circular. It is defined as the assumed circumference (PC), and the perimeter calculated by the rock feature is defined as the true perimeter. Divide the perimeter by the assumed perimeter to obtain the perimeter ratio (P / PC), and take 36% of the features as the training area for manual interpretation. The perimeter ratio of rock and non-rock is obviously different, as shown in Figure 5. (a). The perimeter ratio of the rocks in the training area Q1 (first quartile) and Q3 (third quartile) are used as the basis for the interpretation of the rock. If the perimeter ratio is between Q1 and Q3, it is rock, and vice versa The perimeter ratio is non-rock when it is outside Q1 to Q3. The distribution of possible particle sizes in rocks exposed to statistics is shown in Figure 5 (b).



(a)



(b)

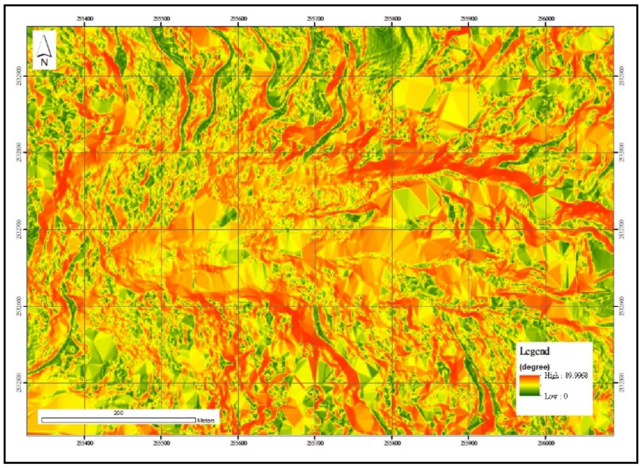
Figure 5 The distribution of P/PC

3 RESULTS AND DISCUSSION

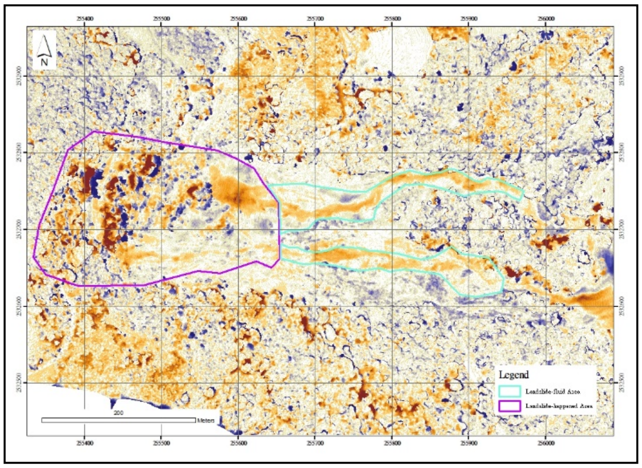
3.1 Volume and displacement analysis

Based on the digital surface model (DSM) before and after the disaster, the terrain elevation change after the 1011 heavy rain collapse is obtained (Figure 6a), and the map of the terrain slope on December 9 after the disaster (Figure 6 b). Location of soil and sand transport, and assess the amount of soil and sand transport caused by the landslide.

The soil-sand migration phenomenon on March 24 and December 9 includes the landslide occurrence section (potential source) and the soil-sand flow section as shown in Figure 6a; the area of the landslide occurrence area is approximately 50,184m^2, of which landslide and erosion. The area accounts for 76%, the maximum erosion depth is 6.87m, and the amount of lost earthwork is 13,939.17 m^3; the accumulation area accounts for 24%, the maximum accumulation height is 4.89m, and the total accumulation is 2,526.70m^3.



(a)



(b)

Figure 6 The slope gradient(a) and soil-debris transportation(b)

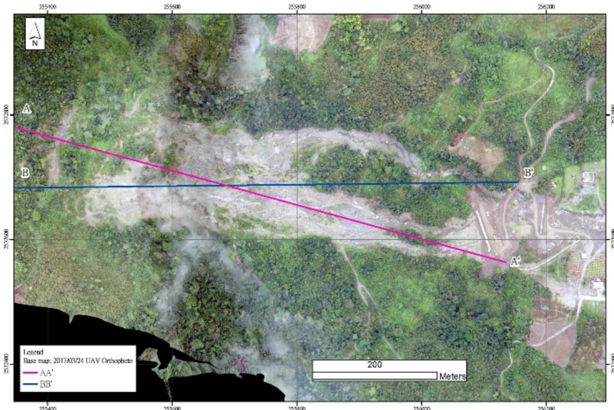
The area of soil-sand flow area is about 17,692m^2 and there is obvious erosion. The erosion area accounts for 81%, the maximum erosion depth is 5.76m, and the amount of lost soil is 6,537.87 m^3. The amount is 612.48 m^3, and the ratio of erosion and accumulation area between the landslide occurrence section and the soil sand flow section is shown in Table 1. Observing the movement of soil and sand in the early and late stages, it can be found that there is loss of soil and sand in the landslide occurrence section and the flow area. After deducting the accumulation amount staying in the two sections, 17,337.86m^3 of soil and sand volume is still lost.

Table 1. Proportion of soil erosion area and accumulation area generated by the landslide

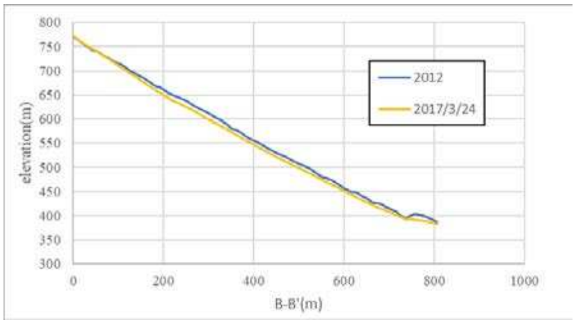
Location	Area (m2)	Landslide/erosion (m^2)	Deposition (m^2)	Erosion ratio(%)	Deposition ratio (%)
Source area	50,184	37,896	12,288	75.51	24.49
Flow area	17,692	14,288	3,404	80.76	19.24

3.2 Numerical Simulation Analysis of Particle Flow Slope and Evaluation of Impact Range

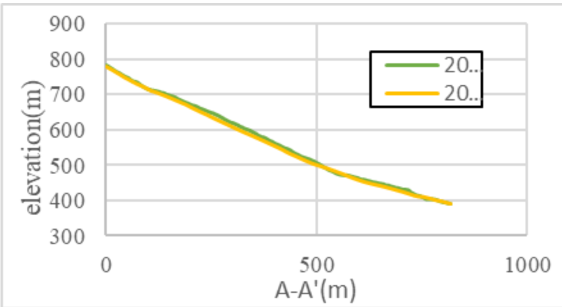
This study uses Rockyfor3D for numerical simulation analysis of particle flow slopes. Rockyfor3D is a particle flow simulation program that can show the real integration effect of the barrier effect of trees on falling rocks. The simulation is a spatially distributed, probabilistic, process-based process. And use digital terrain model (DEM) to represent the terrain and grid map as input parameters. The main calculations performed by Rockyfor3D include: simulating the 3D motion trajectory of rocks, the horizontal and rotational speed along its orbit, the rebound of slopes or tree effects The energy loss during the period (ecorisQ, 2018). In RockFor3D simulation analysis, it is necessary to set the collapsed source area. In this study, the aforementioned volume analysis and terrain profile (Figure 7) are used as the basis for setting the source area. In the subsequent analysis, only the rocks in the source area will roll and cause damage or erosion.



(a)



(b) Profile of B-B’

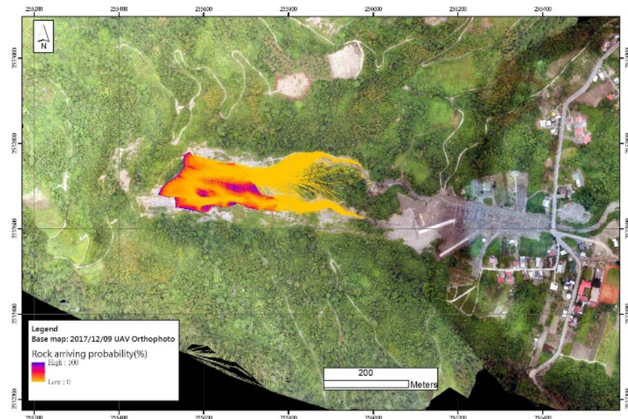


(c)Profile of A-A’

Figure 7 The location of profile sections

This study uses the aforementioned analysis of rock particle size, assuming the rock is a cube, and assuming that the sides of the cube are 0.51m (average particle size), 0.7m (average plus 1 standard deviation), and 0.32m (average minus 1 standard deviation).) Three particle size parameters, numerical simulation analysis with DEM in 2012 and correction parameters based on 2017/3/24 production results, the results show that 0.51m is the hypothesized particle size parameter that is closest to the current situation in 2017/3/24. This particle size was used as a subsequent simulation parameter to perform numerical terrain numerical simulation on 3/24/2017. Comparing the analysis results (Figure 8) with the numerical terrain and orthophotos of 2017/12/09, it can be found that the simulation results are consistent with the local conditions as shown in Figure 9. The simulation was verified.

(a)



(b)

Figure 8 The number of transported rocks(a), and the possibilities of rock passing(b)

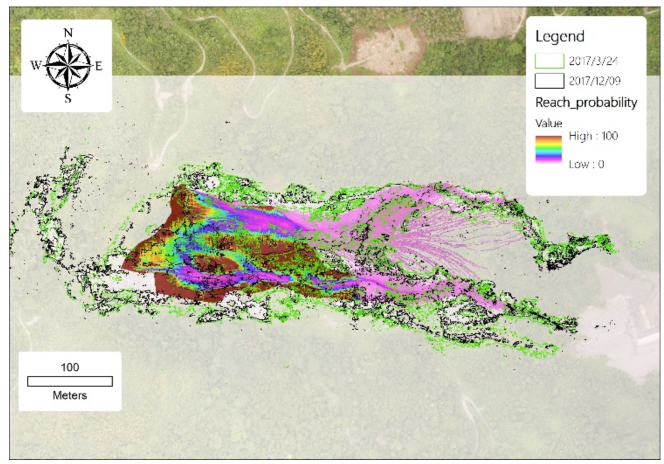


Figure 9 The comparison of simulated covering area with sliding areas mapped from two different periods

4 CONCLUSIONS

Establishing a three-dimensional numerical model with UAS technology can achieve accuracy within the centimeter level, which can accurately assess the movement of soil and sand in a collapse disaster; the orthoimage produced by it can also observe the changes in surface characteristics on a large scale, and even evaluate The composition materials of the bare slope can effectively replace the high-cost surface survey operations as the particle size composition assessment of the geological materials in the most preliminary landslide area; digital topographic and orthophotos produced by UAS images are added to the evaluation For slope materials, numerical simulation analysis of the slope is carried out in the form of particle flow, which can simulate the possible influence range and path probability of slope material sources if similar shallow collapse events continue to occur in the future.

REFERENCES

Wang, K.L., Huang, Z.J. (2016), “Discover failure mechanism of a landslide dam using UAV,”Proceedings of the 16th International Conference on Computing in Civil and Building Engineering (ICCCBE 2016). MOST 103-2625-M-260-001.

Niethammer U., James M.R., Rothmund S., “UAV-based remote sensing of the Super-Sauze landslide:Evaluation and results,” Engineering Geology 128: 2–11, 2012.

Barlow, J., Gilham, J., Cofrã, I.I. (2017), “Kinematic analysis of sea cliff stability using UAV photogrammetry,” International Journal of Remote Sensing, 38:2464–2479