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Survey Report:

Landslide Investigation Results in Sapa Town, Lao Cai Province, Vietnam in December 2019

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Every year, especially in the rainy season, landslides occur quite often in Lao Cai – a northern mountainous province of Vietnam. Specifically, in the year 2019, several landslides were observed to occur near the Sapa Ancient Rock Field in Hau Thao commune, Sapa town, Lao Cai province. In December 2019, a landslide investigation was conducted to examine the mechanism and possible causes of the landslides. Besides that, as the landslide distribution in this area is still unclear, this study will also aim to show the landslide denseness in a 700 m × 700 m square map as well as survey results in 2019 of two main landslides in such map. According to the survey, the landslide is the main phenomenon of geomorphological development in this area, being a combination of multiple different landslides with varying sizes and dissimilar triggers. The first survey landslide is about 50 m wide and 350 m long and has still been going on in recent years, with annual horizontal displacement being around 0.8 m. Meanwhile, the second one is a typical flash-landslide caused by rainfall. Despite being quite small in scale, about 15 m × 40 m, its characteristics indicate a dangerous implication in the future. This information will be the basis for further ongoing studies.

Keywords: landslide survey, landslide distribution, field experiments, terraced field landslide, Sapa

1. Introduction

Landslides have been a serious disaster not only in the mountainous areas of Lao Cai but also of the northern provinces of Vietnam in general [1–4]. Landslides in the Lao Cai province have been studied in some researches, which provide important knowledge for both governmental management and researchers. In particular, in the Lao Cai province, landslides have occurred widespread due to its topographic characteristics and geographic position. These landslides have mainly occurred during heavy rainfalls of tropical typhoons, in steep sloping mountain sides, small and narrow valleys, and across the road system [1]. Some of these landslides have been studied by some researchers [1, 5, 6], however, they only focus on a few specific landslides. Moreover, an area of Hau Thao commune, Sapa town, Lao Cai province has been suffering from such natural disasters for recent years, some landslides here were studied by Tran et al. [2], Nguyen and Tran [7], and Giao and Hanh [8]. Similar to previously mentioned studies, they also only clarified the characteristics of a single landslide near the Sapa Ancient Rock Field. Therefore, in this study, based on the analysis technique of images taken by an unmanned aerial vehicle (UAV) and from Google Earth, a small landslide distribution map in this area is proposed. Besides that, the results of some field soil tests such as vane cone shear test, soil hardness test, and soil volumetric water content measurement are also published.

2. The Investigation Site

The survey site is located about 10 km southeast of the Sapa town center. The mountain surface here is mainly terraced rice field of the local people of the Hmong ethnic. In this area, some landslides occurred on the border of Hau Thao commune and Ta Van commune, scattered along provincial road No.152 connecting the region with its surrounding areas. The largest of them, a landslide

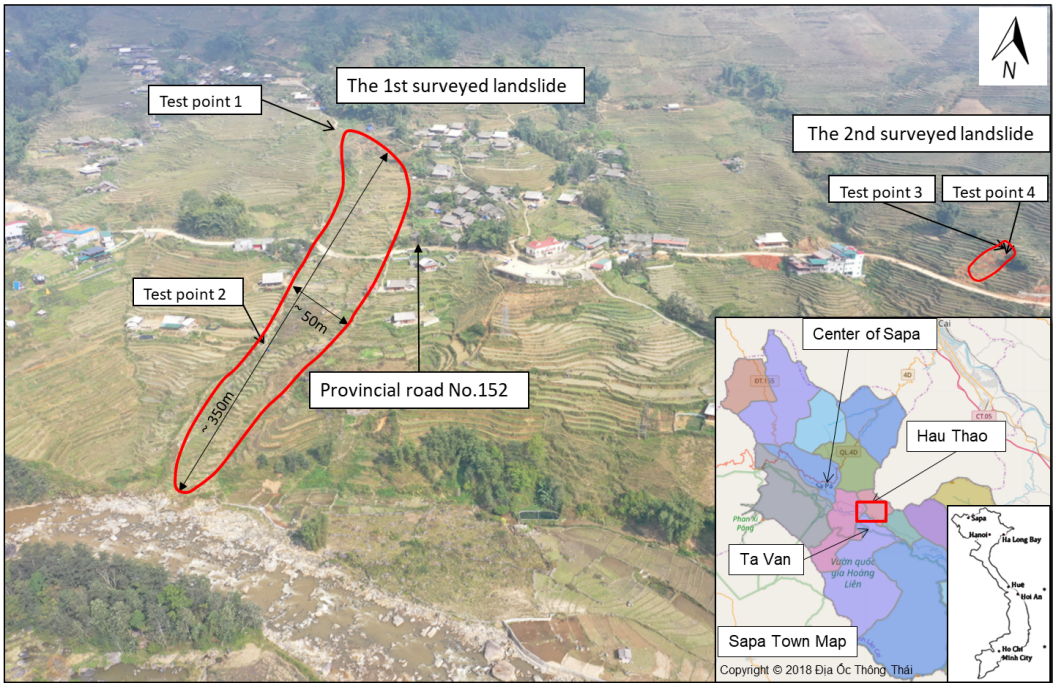


Fig. 1. The surveyed landslides site.

Table 1. The coordinates of the experimental points.

Name	*Name*	*Latitude*	*Longitude*
Landslide 1	Test point 1	22.30641°N	103.89771°E
Landslide 1	Test point 2	22.30386°N	103.89675°E
Landslide 2	Test point 3	22.30314°N	103.90094°E
Landslide 2	Test point 4	22.30313°N	103.90091°E

near the Sapa Ancient Rock Field, that extends across provincial road No.152 and has been going on for many years. There are also some smaller landslides occurred in 2019 due to rain. Some field experiments were conducted at four points in **Fig. 1**, whose coordinates listed in **Table 1**.

3. The Geology and Climate in the Region

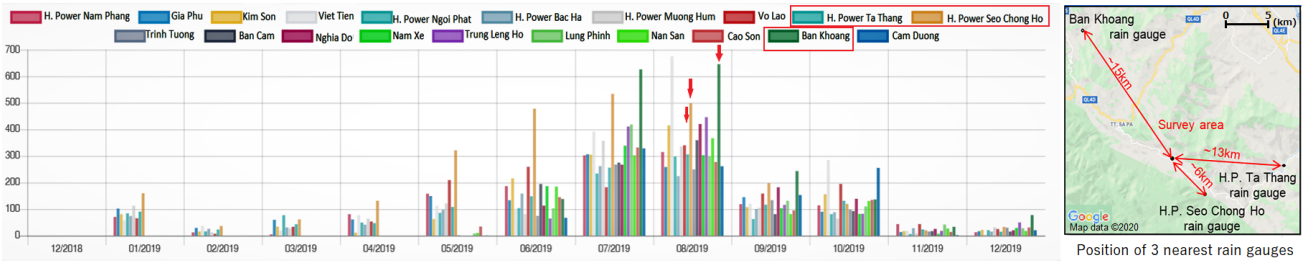
3.1. The Geology

The survey area has a relatively complex geology with many types of intertwined strata. The geological formations here have different origins, ages and are directly related to tectonic and cleavage in the region. In the area, there appear to be large-scale sliding soil blocks being cracked by many tectonic faults, which are mostly in the Northwest–Southeast direction. This was mapped in the research of My and Hoanh [9]. In addition, a geological profile along the first surveyed landslide was presented by Giao and Hanh [8], which showed that the study area has many alternating layers of varying thickness. Particularly, it includes the saturated organic top-soil layer (1); followed by the yellowish-brown, reddish-brown firm lean clay layer (2); the highly weathered rock layer (3); the moderately weathered rock layer (4); the slightly weathered marble rock (5); and the last layer of very un-weathered to slightly weathered marble bedrock (6). Based on the investigation, some small landslides occurred in 2019 due to rainfall in the area, along with road number 152. Those were collapsed in the depth of around 3 to 4 m, which is in layers (1) and (2). At these landslides, the collapsed soil parts are clay mixed with gravel with loose weathering structure, soft and semi-solid state.

3.2. The Climate

Sapa town is located in northern part of Vietnam, which is normally influenced by the humid monsoon tropical climate. However, due to Sapa town lies on a high terrain area, the weather here depends on season, with a subtropical climate in the summer and a temperate climate during the winter. Furthermore, Sapa is classified as a 'subtropical highland climate (Cwb)' area following the Köppen-Geiger updated climate classification [10]. In general, Sapa town has a lower temperature than the national average value throughout the year due to its high altitude, with the mean annual temperature of 16.2°C. The warmest months of the year is July, with the average temperature of 21.2°C, and at 9.3°C on average, January is the coldest month of the year [11]. In recent years, it has often had snow on the high mountain peaks.

The study area is located in the Hoang Lien Son mountain area with high precipitation, with total annual rainfall from 2000 to 3600 mm [1]. In common with the rest of northern Vietnam, the rainy season in the region lasts



The highest daily rainfall in August of three rain gauges (4th August): 86.0 mm (H. P. Seo Chong Ho), 31.8 mm (H. P. Ta Thang), 114.0 mm (Ban Khoang)
The highest monthly rainfall of three rain gauges: 533.6 mm in H. P. Seo Chong Ho (July), 306.0 mm in H. P. Ta Thang (August), 645.4 mm in Ban Khoang (August)

Source: https://vrain.vn, developed by Water Resources Development and Consulting Company (WATEC)

Fig. 2. Rainfall data in 2019 of 20 rain gauges of Lao Cai province (mm).

from May to September, with the largest rainfall occurring in June, July, and August that accounts for around 80–85% of the total annual rainfall. For example, following the rainfall data referred from 20 rain gauges of Lao Cai Province in 2019 [12], the precipitation in June, July, and August are obviously much higher than that of the remaining months in the year (**Fig. 2**).

Specifically, the three nearest rain gauges from the investigation site are at Hydroelectric Power Seo Chong Ho (H. P. Seo Chong Ho), Hydroelectric Power Ta Thang (H. P. Ta Thang), and Ban Khoang (**Fig. 2(b)**). All of these rain gauges have high recorded rainfall data, which are depicted in **Fig. 2(a)** by the colors orange, dark teal, and dark green, respectively. The rainfall data of the Ban Khoang rain gauge (about 15 km from the surveyed site) are the highest, with the monthly amount being more than 600 mm in July and August 2019. The figures for the nearest rain gauge station, H. P. Seo Chong Ho, are the second largest, approximately 500 mm in June, July, and August of the year.

4. Landslide Distribution Map

Normally, a landslide landform consists of a steep slope, a so-called head scarp, and a relatively flat slope so-called landslide body. It is also considered that the deformation of rivers and galleys adjacent to the landslide body is evidence of landslide activity.

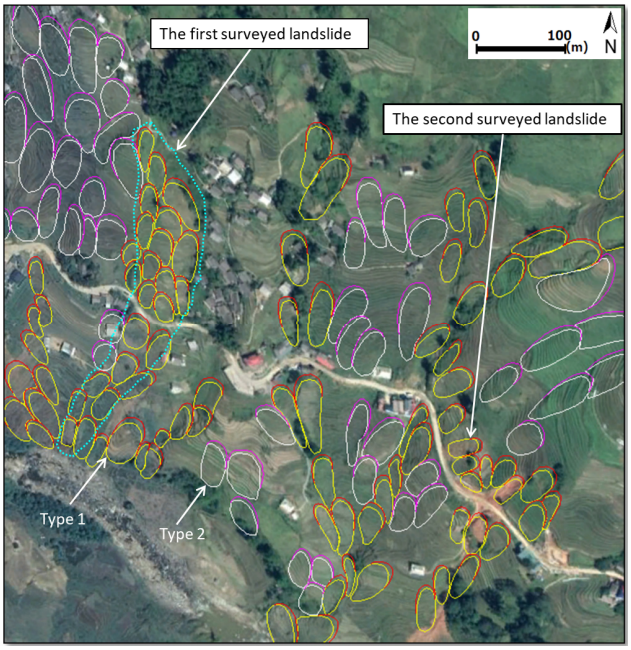
We extracted such landforms from satellite images of Google Earth over time history and the UAV images taken in the investigation, some supposed slide blocks were sketched in a 700 m × 700 m area of the surveyed site. In such area, two types of landslide blocks are shown, type 1 is the landslide with clear signs of movement and type 2 is the proposed landslide with unclear signs of displacement (**Fig. 3(a)**). They are superimposed on a 1-m interval-contoured digital elevation model (DEM) map in order to create a landslides distribution map (**Fig. 3(b)**). It is indicated that there are various-sized landslides in this area however most of them are shallow in depth and small in scale. These landslides size ranged from 15 m × 35 m to 30 m × 70 m, and either formed independently with their own scarp and body or developed together to become a combined block. These potential sliding blocks are concentrated on terraced fields of both the positive and negative talus of the provincial road No.152, therefore, landslides in this area are prone to occur under triggered rain conditions. Two active landslides in this area were investigated.

The first surveyed landslide is near the Sapa Ancient Rock Field, which is reported that there were about 200 stones of various dimensions concentrated in the area. Some of them have been found engraved with antique symbols and, therefore, it has been paid attention to by many scientists and tourists (**Fig. 4**).

This site is mainly composed of hillsides with terraced fields, geology made of dilute sand mixed macadam of reddish-brown, dark grey, and white-gray color. Its dimension is about 350 m long and 50 m wide (**Fig. 1**), extending from the positive talus, cut through the provincial road No.152 down to the Muong Hoa stream. It consists of small sliding blocks with dimensions from 15 m × 35 m to 30 m × 50 m (**Fig. 4C**).

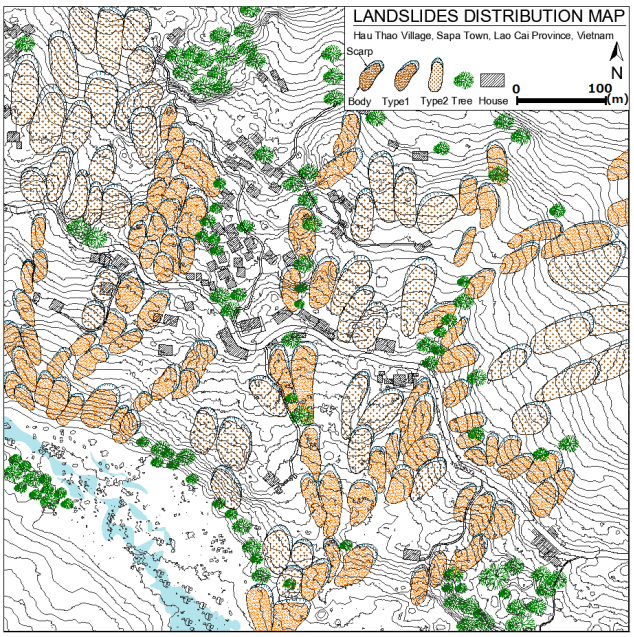
The Google Earth Images in **Figs. 4A** and **B** do not clearly provide the movement of the sliding block in this site from 2014 to 2019. However, in recent years, the displacement of the provincial road No.152 in this area has been observed and it is reported that the landslide has been causing road displacement of more than 1 m in the vertical direction and around 6 to 8 m in the horizontal direction (**Fig. 4D**). It causes the road to be bent downwards to the negative talus, affecting the main traffic route connecting the local area with the surrounding regions. In addition, the weathering profile of marble in the depth of 5 to 7 m is considered to be the weak layer, along which a transitional landslide would typically occur in this area [8].

The second surveyed landslide is one of the translational landslides that occurred in 2019, located in Den Village, Hau Thao Commune, about 400 m southeast of the first one (**Fig. 5**). It is revealed that these three landslides occurred from April to October 2019, coinciding with the rainy season in the North of Vietnam. Site B is the smallest scale of approximately 20 × 20 m, appeared



Source: Google Earth© Image 2020 CNES/Airbus© Image 2020 Maxar Technologies

(a) Supposed slide blocks based on historical images of Google Earth



The DEM data is used AW3D with 1 m accuracy (partially 5 m accuracy) generated from satellite imagery. https://www.aw3d.jp/en/

(b) Supposed blocks combined with 1-m DEM

Fig. 3. A 700 × 700 m sized landslides distribution map.

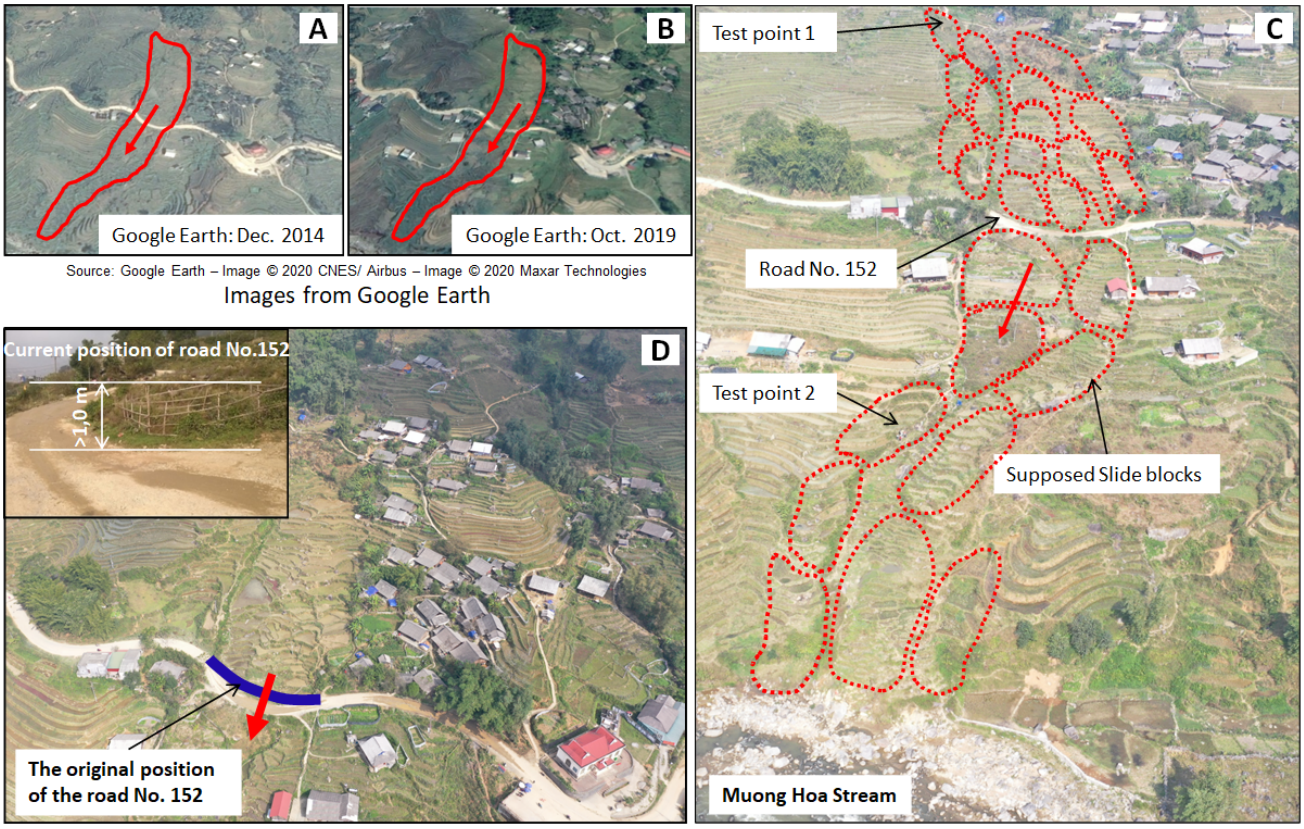
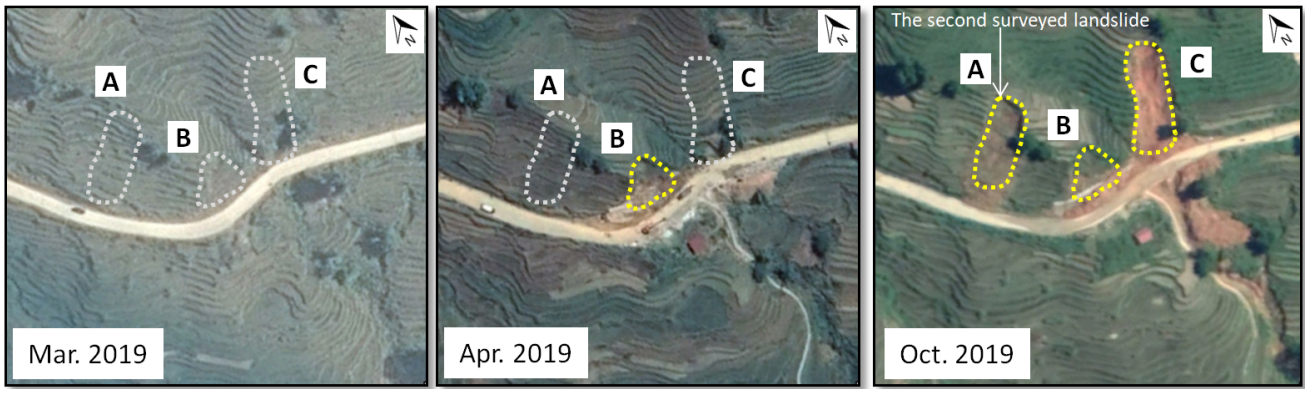
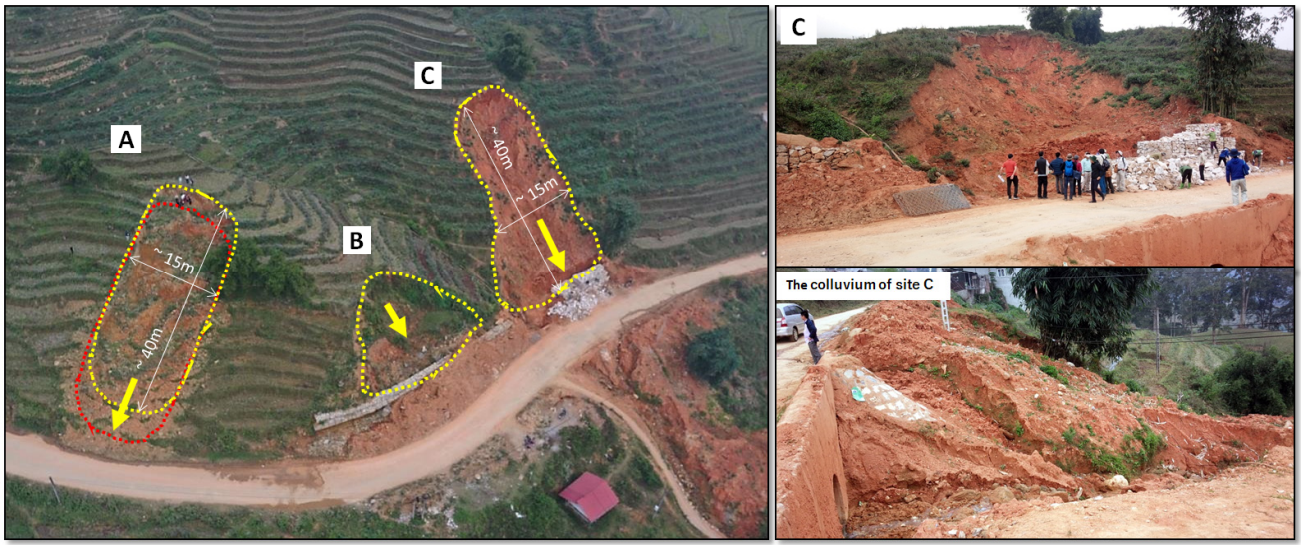


Fig. 4. The characteristics of the first surveyed landslide in Hau Thao commune.



Source: Google Earth© Image 2020 CNES/Airbus© Image 2020 Maxar Technologies

Fig. 5. Images of an area in Den village, Hau Thao commune, Sapa town in 2019.



(a) UAV image of landslides

(b) Body and colluvium of Site C

Fig. 6. Three landslides in Den Village, Hau Thao, Sapa in December, 2019.

in April. Besides this one, sites A and C are of similar dimensions, about 15 m wide and 40 m long, which occurred before October of that year (**Fig. 6(a)**). Meanwhile, according to local media, those were caused by the impact of typhoon No.3 (August 2019). Specifically, at about 9 AM on 5th August 2019, prolonged heavy rain of typhoon No.3 caused soil mass from the positive talus to slide to the provincial road 152, causing the death of a local resident, who was riding a motorbike through that place [13]. The incident was the result of continuous torrential rain that lasted for several days after a severe storm attacked Lao Cai province [2].

The daily rainfall of the H. P. Seo Chong Ho, H. P. Ta Thang, and Ban Khoang rain gauges on 4th August were so high, at 86.0 mm, 31.8 mm, and 114.0 mm, respectively (**Fig. 2**). Moreover, site C is deeper and steeper, and most of its colluvium was cleaned and eroded (**Fig. 6(b)**). By contrast, site A looks shallower, gentler slope, and most part of the landslide mass is still remaining. Compared with the landslide phenomenon recognized around this area, site A is more typical. According to these characteristics, we decided to choose site A for additional field investigation, which is shown in **Fig. 7**. The depth of the main scarp of the landslide is approximately 3 m, and the average slope angle is about 15 to 20°. The collapsed soils are mainly reddish-brown, dark gray, clay mixed with gravel in the soft-plastic and semi-solid state. The weathered stone bedrock of this landslide is estimated to be in 5 to 7 m depth. This depth also coincides with the depth of the weathered soil layer indicated in the study by Giao and Hanh [8].

5. Field Experiment Results and Discussion

Most of the slope disasters are caused by a phenomenon called “surface collapse” where a few meters of the surface layer of the slope collapses thinly. Therefore, the

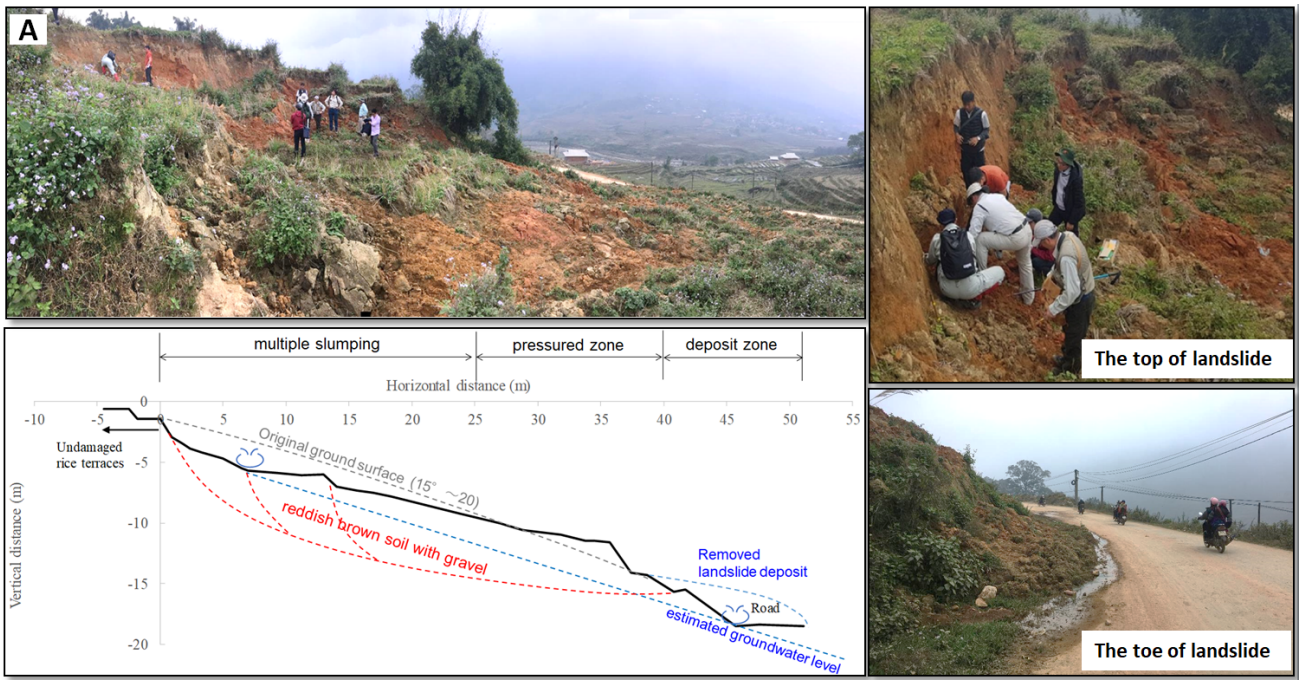


Fig. 7. Site A and its collapsed estimation.

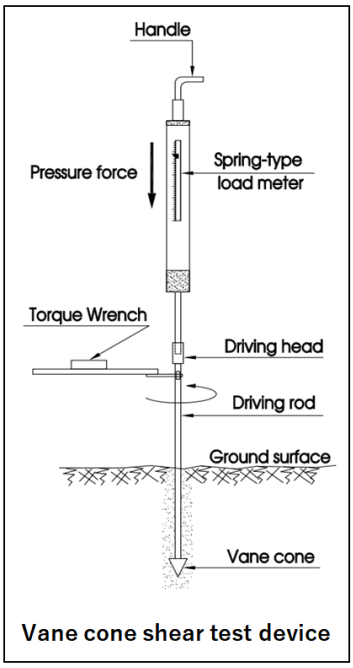
characteristics of the topsoil layer such as the depth, soil strength, slope, soil cohesion, and internal friction angle of the soil are to be investigated in detail. The investigation team uses a convenient and simple device, namely "soil layer strength measuring instrument" (*Dokenbou* in Japanese), developed by the Public Works Research Institute of Japan to evaluate cohesion values and internal friction angle of soil (**Fig. 8**). This instrument has a soil inspection rod, in which a vane cone is attached to the tip of the rod. The vane cone shear test is conducted by pushing the penetration vane cone into a target depth to keep the pressure force at a constant value and rotating it with a torque wrench to shear the soil, then the pressing force and rotation torque values are recorded. When doing each trial, the pressure force was kept constant in four levels of load (5000, 10000, 15000, 20000 cN). From the measured values, the soil cohesion c, and soil friction angle ϕ can be easily estimated from the relationship between shear strength and stress of soil. The estimated values of each trial at some test points are depicted in **Fig. 8**.

The soil moisture at four points was quantified by a compact and handy soil moisture meter C-HS2-12. This test was conducted in two points on the top-soil layer of the first landslide and in both the original and collapsed parts of the second one. The averaged values of volumetric water content are shown in **Fig. 9**. Besides that, hardness, one of the physical properties of soil, at the second landslide is measured by a Yamanaka soil hardness tester DIK-5552. When a cone is pressed perpendicular to the plane of the soil surface, both the depth of the conical force and the corresponding soil reaction (spring force) are measured as variables, and from these, the theoretical hardness value (kg/cm^2) is calculated. The averaged values of soil hardness at two test points are in **Fig. 9**.

In general, factors affecting slope failure due to rainfall include: (1) an increased self-weight of the soil mass, (2) decreased strength of the ground owing to increased water content in the slope, and (3) an increased seepage force due to the elevated level of groundwater [14]. Although the estimated values of cohesion and friction angle at the time of the test are quite large (**Fig. 8**) and the volumetric water content values are also not high, about 40% (**Fig. 9**). However, at the time of the second landslide, the volumetric water content value was much higher as stated in the study by Tran et al. [2]. Besides that, this site surface was mainly covered by the terraced paddy which was in the growing season at the time of the collapse. Actually, the terrace fields often have contours to hold the surface water to retain on the soil surface longer for cultivation. Additionally, according to [12], there were scattered rains during July and August 2019 in Sapa, which possibly caused the cover soil layer above the impervious layer to be saturated at the time of the landslide. Therefore, this led to the decline in shear strength of soil, and thus landslides occurred. As can be seen in **Fig. 9**, the soil hardness strength of the collapsed part is also significantly smaller than that of the original part, with 2.59 kg/cm^2 and 8.7 kg/cm^2, respectively.

6. Conclusions

The survey shows that the first investigation landslide is still active and is gradually moving down the negative talus of Provincial Road No.152, while the remaining others occurred due to the continuous rainfall in early August




At the 1st test point (the 1st landslide)


At the 3rd test point (the original part of the 2nd landslide)

The 1st test point (at the 1st landslide)		
Trial	Estimated cohesion value c (KN/m2)	Estimated friction angle ø (°)
1	14.0	32.0
2	18.0	22.0
3	15.5	28.9

The 2nd test point (at the 1st landslide)		
Trial	Estimated cohesion value c (KN/m2)	Estimated friction angle ø (°)
1	11.5	34.5

The 3rd test point (at the 2nd landslide)		
Trial	Estimated cohesion value c (KN/m2)	Estimated friction angle ø (°)
1	17.6	35.7

Fig. 8. Vane cone shear test at field and results.


Soil moisture meter C-HS2-12


Soil hardness meter DIK- 5552


Measuring volumetric water content (VWC) and soil hardness test

The 1st test point (at the 1st landslide)	
Trial	VWC (%)
The averaged value	38.66

The 2nd test point (at the 1st landslide)	
Trial	VWC (%)
The averaged value	36.66

The 3rd test point (at the original part of the 2nd landslide)		
Trial	VWC (%)	Hardness strength of soil (kg/cm²)
The averaged value	35.62	8.70

The 4th test point (at the collapsed part of the 2nd landslide)		
Trial	VWC (%)	Hardness strength of soil (kg/cm²)
The averaged value	40.6	2.59

Fig. 9. Volumetric water content of soil and soil hardness test and results.

2019. Furthermore, the study area has a relatively complex geology with many soil layers. The upper layer is mainly clay mixed gravel, with the reddish-brown or dark gray color in a semi-solid state, which absorbs water easily. It has a weak soil layer in the depth of 5 to 7 m that is estimated to be a potential slip surface. In addition, the surface of terraced fields in this area inadvertently makes the soil layers being in a high degree of saturation in the rainy season as the discussion above. Therefore, they are prone to collapse when subjected to rainfall. Furthermore, the landslide distribution map discloses that there are many potentially risky sliding blocks of different sizes in this area. There are some different causes of landslides in this place however the rainfall is still believed to be the main triggering factor. This is an initially needed study for further research of landslides here.

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