VNU Journal of Science, Earth Sciences 25 (2009) 1-9

Heavy rainfall induced landslides in Bac Kan and Binh Dinh provinces

Do Minh Duc*

College of Science, VNU

Received 09 January 2009; received in revised form 3 February 2009

Abstract. Landslides is one of the most severe hazard in Vietnam, among that a major number of landslides are induced by heavy rainfall The paper deals with heavy rainfall induces shallow landslides at the excavated slopes in Bac Kan province and at the natural slopes in Binh Dinh province. Landslides in Bac Kan can happen when the amount of rainfall is 180mm continuously. Landslides of natural slopes in Binh Dinh can only occur when rainfall makes the slopes almost saturated. This can happen when the amount of rainfall reach over 1260mm. Landslides induced by heavy rainfall also depend on the initial water content (i.e. antecedent rainfall), geological settings, and plant cover. Therefore rainfall path and critical rainfall can vary in a given range in a place, and can vary widely from place to place.

Keywords: Heavy rainfall; Slope; Landslide; Unsaturated soils.

1. Introduction

Landslides and flooding are the most severe geohazards in Vietnam. Annually, landslides alone cause a damage of nearly 100 millions USD [6]. The serious hazard often takes place during storms or tropical depressions. Storms and landslides had destroyed 448 bridges, 789 culverts, strongly damaged 6 millions m2 of highway surface, 2.7 millions m^3 of soils and rocks had to be cleaned during the period from 1990 to 1995. More seriously, landslides along with debris flows can cause severe fatality. As showing in table 1 the hazards of landslides and debris flows are very severe and can occur in all mountainous areas of Vietnam. A remarkable situation is that all of them only occurred during heavy rainfall. The ongoing climate changes have the potential to significantly increase the country's risk exposure to geohazards. Extreme weather events induced by climate changes are happening more frequently and with higher intensities. Heavy rainfall and cloudbursts are leading to more floods and landslides. Local livelihoods experience set-backs. The events are counterproductive and are threatening the sustained economic development of Vietnam. It may be as a consequence of climate change landslides have recently occurred with higher frequency and intensity.

* Tel.: 84-912042804.
E-mail: ducdm@vnu.edu.vn

Table 1. Recent recorded severe landslides & debris flow in Vietnam

Location	Date	Type	No. of deaths & missing	Damages
Nam Cuong, Cho Don (Bac Kan province)	23 Jul. 1986	Debris flow & landslides	07	120 ha rice fields, 20 km of roads
Lai Chau town	27 Jun. 1990	Debris flow & Landslide	Over 100	607 houses, 5 bridges, 10km^2 of town demolished
Nam Muc & Muong Lay (Lai Chau province)	17 Jul. 1994	Debris Flow & Landslides	20	-
Muong Lay town (Lai Chau province)	17 Aug. 1996	Debris flow & Landslide	55	The commune had to move to another place
Highway No. 27 (Lam Dong province)	10 Oct. 2000	Debris flow & landslides	-	37 severe landslides in 55 km, 500 m highway fully destroyed
Ialy hydropower plant (Kon Tum province)	since 2002	Landslide	-	causing damage of billions of VND each year
Du Tien & Du Gia, Yen Minh (Ha Giang province)	19 Jul. 2004	Debris flow & landslides	48	33 houses, 627 ha rice fields
Sung Hoang (Phin Ngan, Bat Xat, Lao Cai province)	13 Sep. 2004	Landslides	23	4 houses destroyed
Nghia Lo, Van Chan (Yen Bai province)	28 Sep. 2005	Flash Flood & Landslides	42	Cat Thinh commune & Nghia Lo tơn were severely damaged
Bat Xat, Sa Pa, Bao Thang, Bao Yen (Lao Cai province)	09 Aug. 2008	Flash Flood & Landslides	65	Many communes were destroyed

2. Heavy rainfall induced landslides in Bac Kan province

Bac Kan - a northeast mountainous province belongs to the northeast-folding region with complex geological settings. The geological activities, especially neotectonic movements have created the variable and complex topographical characteristics in Bac Kan province. In this study, the Cau river basin is mainly focused. It stretches from Cho Don to Cho Moi district (along national highways No. 3 and No. 257) in the length of 103km. The area of study region is about 110km^2. The geomorphology in the region is characterized by two main types: erosive relief at hills and mountains and accumulative relief along Cau river and streams [2]. Most of study area is characterized by erosive relief with the elevation of 200-500m and the common slope angles of 35-40°. The area of over 500m high is very limited.

In the region, bedrocks are diversified with 5 formations (Phu Ngu - O_3-S_1*pn*, Bac Bun - D_1*bb*, Mia Le - D_1*ml*, Song Hien - T_{1-2}*sh* and Ha Coi - J_{1-2}*hc*) and Quaternary sediments. Among that, landslides often occur in the weathering crust and highly cracked bedrocks of Phu Ngu and Mia Le formations. The weathering crust on Phu Ngu formation is variable in thickness, ranging from 0 to over 10m. The popular thickness is 1.5-2.5m. The Mia Le formation is characterized by clay sericite shale, silty sandstone, cherty schist, and thin beds of limestone. 600-700m thick. The weathering crust thickness is smaller than 1m, landslides only occur along weak surfaces in cracked rock masses. The tectonic activities, especially the deep-seat fault along highway No. 3 have intensively weakened the strength of rock masses and made intensification of weathering process. The bedrocks were strongly cracked causing some rockslides with slip surfaces of opposite direction to bedding surfaces.

Table 2. Geotechnical properties of residual soils in Bac Kan

Properties	Value
D_{60} (mm)	0.46
D_{10} (mm)	0.01
Water content (%)	31
Wet density (KN/m^3)	18.5
Void ratio	0.759
Effective angle of friction (deg.)	28
Effective cohesions (KPa)	5.5
Saturated coefficient of permeability (m/s)	2 x 10^{-6}

The database is mainly achieved from several investigations along some national highways No. 3 (from Cho Moi to Bac Kan town), No. 257 (Bac Kan town - Cho Don) and some segments of No. 256 (Bac Kan town – Na Ri) in 2001 and 2002. It contains geological settings of the region, levels of weathering, physical mechanical properties of soils and rocks. The most important data is a set of 72 recorded large landslides. The detail investigation was carried out for each landslide and the retrieved data contains the location, dimensions of landslide, slope angle, characteristics of soils and rocks, plant coverage and human activities affecting the landslide. During the investigation, 40 disturbed and 80 undisturbed samples of residual soils and rocks were also taken for further analysis in the laboratory. Geotechnical properties of soils are showing in table 2 and Fig. 1.

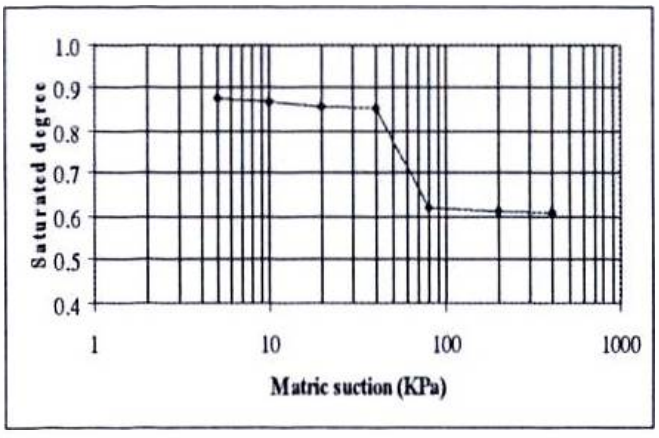


Fig. 1. Soil water characteristic curve of residual soils in Bac Kan *(dry curve)*.

Monitoring data of daily rainfall in 2001 are retrieved from 9 stations. However, only 3 stations, including Phuong Vien, Dong Vien and Bac Kan are dealt with the current research. The research was conducted by using various methods. The remote sensing & GIS method is applied to classify the areas of different heights, inclined angles and assume the potential areas of landslides for further research. Geological methods permit elucidating lithological composition of rocks, their ability of weakening due to weathering and define the cracked zones caused by tectonic movements. Then, the site investigation was deployed, including measurement of landslide dimensions, taking samples and field test of soil, rock mass shear strength. The samples, subsequently, were analyzed in the laboratory to define physical, mechanical properties of soils and rocks. Afterwards, the achieved data in combination with transient slope infiltration were used for slope stability assessment.

2.1. Rainfall in the storm No.7 (3 and 4 July 2001)

Bac Kan has two distinct seasons in term of rainfall. The wet season stretches from April to October occupying 85-90% of the total rainfall. The remaining period of time (November to March next year) is dry season. The amount of rainfall and can be a hundred times more or less from year to year. The average rainfall in Bac Kan is 1400-1800 mm/y. It reduces from west to east and from higher locations to lower ones. Long-term monitoring of rainfall shows that rain intensity is concentrated in 3 months from June to August, accounting for 75% of the total (Fig. 2). However, rainfall is mainly contributed by several rainstorm events. In a surge storm, rain intensity can reach hundreds of millimeters per day. The 3 and 4 July 2001 rainstorm event, focused in this study, is a typical example.

The event started lately on 2 July 2001 when the surge storm No. 2 landed onto the

mainland. The recorded data every 6h at 3 stations show that the early average rainfall intensity is 2mm/h for the first 18h. It reached to the highest figure of about 15mm/h at the early of 4 July (Fig. 3). The event was then stopped at the end of 4 July. Finally, the rain intensity during storm was 261.1, 191.1 and 133.7mm at Bac Kan, Dong Vien, and Phuong Vien stations, respectively. The rainfall intensity was the highest daily rainfall since 1996. In the storm No. 2 in 2001, there were 11 large landslides with the total volume of about 16,000 m^3. These ones led to the interrupts in the national highway No. 3 and many other national highways for a long time. The cost of damage was over several billion VND. Along the road No. 3, No. 256 and No. 257 over 30 landslides were recorded to be occurred in this surge storm.

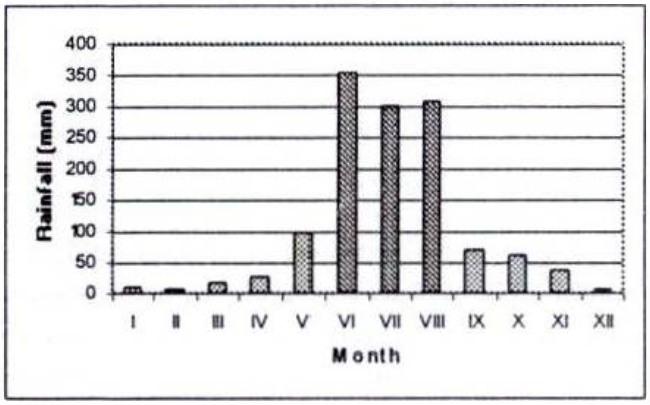
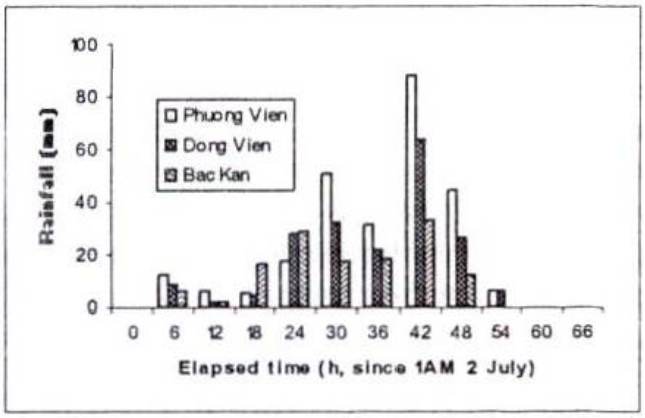


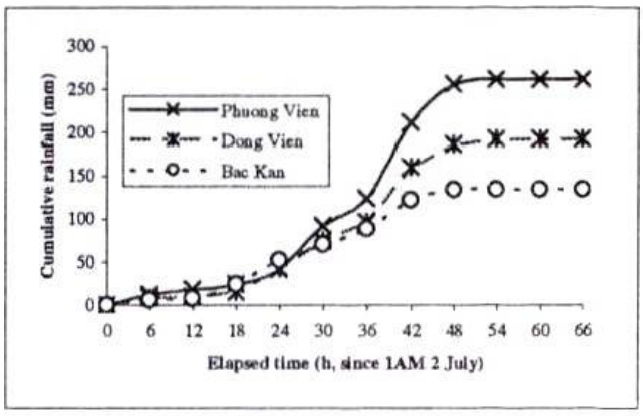
Fig. 2. Monthly rainfall in Bac Kan province.

2.2. Landslide Property

Landslides in Bac Kan province are often occurred at the slopes of national highways, and only take place in rainy seasons. They can occur either in the weathering crust or in the highly cracked rock masses. The slip surfaces have arc shape in the weathering crust (Fig. 4a) and they coincide with bedding surfaces in high weathered rock masses. The landslides with large volumes often have complex slip surfaces including both arc and flat bedding slip surfaces (Fig. 4b). The volumes range from tens m^3 to over 5,000m^3, among that the volumes of 100-500 m^3 are dominant. Some typical landslides in the storm No. 2 are shown in table 1. The 72 recorded landslides distribute mainly in 7 regions (3 regions in Cho Don district, 2 in Bac Kan town and 2 in Cho Moi district). The site investigation indicated that the landslides only occurred where bed rocks strongly influenced by faults or the direction of bedding surface coincides with inclined direction of slopes; the slopes are constituted by residual soils or highly cracked rocks; the thickness of weathering crust of over 5m usually met at landslides over 500m^3. The high density of vegetable coverage is taken place at almost landslides. Therefore, the role of vegetable coverage in slope instability is not significant. The prior research has defined 4 zones of different possibility of landslide, which are very high, high, medium and low possibility, respectively [4].



a) Rain fall intensity

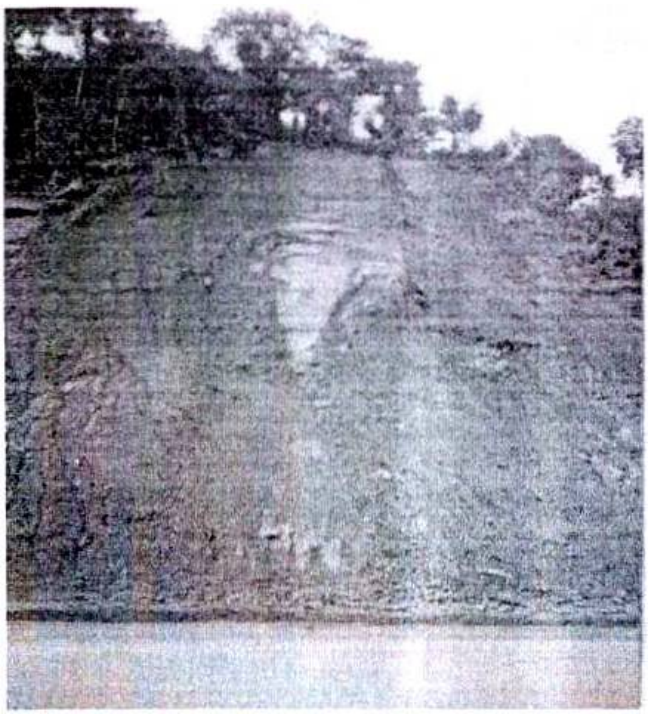


b) Cumulative rainfall

Fig. 3. Intensity and accumulation of the rainstorm [3].

In short, the storm in the 3 & 4 July 2001 caused the highest daily rainfall in Bac Kan province during the period 1996-2001. It triggered about 30 landslides along the national highways No.3, 256 and 257. Shallow landslides can occur when the rainfall amount is higher than 180mm and PWP is still in negative values [3].

a) Arc slip surface



b) Complex slip surface

Fig. 4. Slip surfaces of landslides.

3. Heavy rainfall induced landslides in Binh Dinh province

Heavy rainfall in Binh Dinh province from 12 December to 15 December 2005 caused serious damages. Landslides caused traffic jams at many roads, 03 persons were killed by flooding. A vast landslides occurred at a mountain of Canh Lien commune, Van Canh district, killed 4 bulls, filled up some rice field. Fortunately, there was not any fatality. Nearly the same at the opposite site of the mountain there was also a series of large landslides. Especially, the landslides occurred with several loud explosions. The fact has lead to serious nervousness of the resident population. Landslides took place at the natural slopes with slope angles of 28-31^0. The vegetable cover was very loose.

The geological settings are very complicated. The region distributes 3 formations such as Xa Lam Co (AR*xlc*), Mang Yang (T_2*my*), and Quaternary (Q). Most of the area is constituted by igneous rocks that belong to 4 complexes, including Van Canh (G-sG/T2*vc*), Chaval (GbT3n*cv*), Deo Ca (G/K*dc*), Cu Mong (Gb/E*cm*). The fault system especially the semi-longitude fault leads to many cracking blocks of the bed rocks. The heterogeneous distribution of cracking system has lead to the different thickness of weathering crust and makes potetial slip surface for large landlsides.

Table 3. Geotechnical properties of residual soils in Binh Dinh

Properties	Value
Water content (%)	19
Wet density (KN/m^3)	18.7
Void ratio	0.75
Effective angle of friction (deg.)	28.9
Effective cohesions (KPa)	15
Saturated coefficient of permeability (m/s) (samples taken at 0.3-0.5m deep)	5 x 10^{-5}

The database is mainly achieved from the investigation in Van Canh district from August 2006 to June 2007. It contains geological settings of the region, characteristics of weathering, physical mechanical properties of soils and rocks. The detail investigation was carried out at 05 large landslides. During the investigation, 60 disturbed and 50 undisturbed samples of soils and rocks were taken for further analysis in the laboratory (Table 3). Monitoring data of daily rainfall in 2005 is retrieved from the Van Canh station which is 20km away from the sliding site. In addition, the data of meteorology and rainfall from 1977 to 2003 was also taken into account.

3.1. Rainfall in the period of September - December 2005

As mentioned above a series of large landslides occurred in the middle of December 2005. So as to elucidate a relation between rainfall and this phenomenon the rain data from September to December 2005 is taken into account. The total rainfall in Sept. 2005 was 287.3mm, a normal figure in comparison to other years. In Oct. 2005, the figure was 1016.8mm which is larger than the normalized rainfall with the frequency of 5% (1015mm). Therefore the rainfall in Oct. 2005 was above the figure occurred once every 20 years. The number of rainy days in this month was 20 days continuously. Especially, the rainfall in 3 days (23-25 Oct.) reached to the total of 566.5mm (Fig. 5). However no large landslides occurred during that month. The rainfall in Nov. and Dec. 2005 was 627.6 and 829.0mm, respectively (Fig. 6). The rainfall in Nov. 2005 is also a normal fact. But the one of Dec. 2005 is very remarkable. It is a figure that can only meet once every 50 years. Therefore all of the large landslides occurred in a month with a very high amount of rainfall.

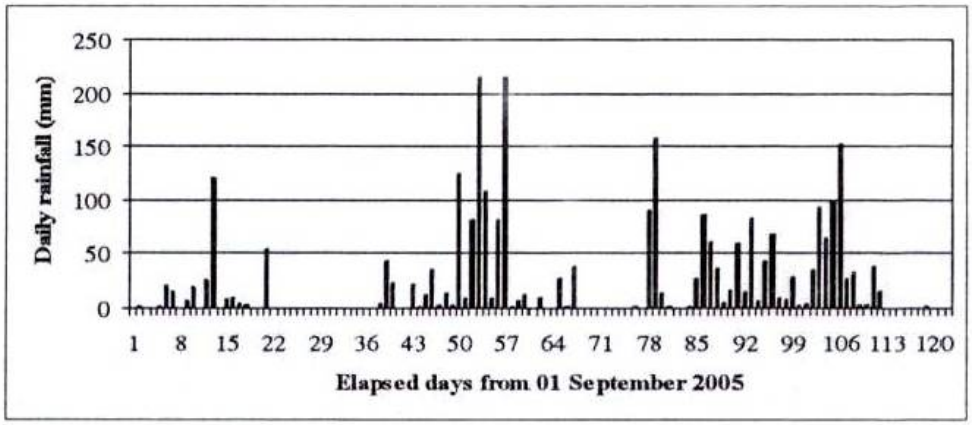


Fig 5. Rainfall from 01 September 2005 to 31 December 2005.

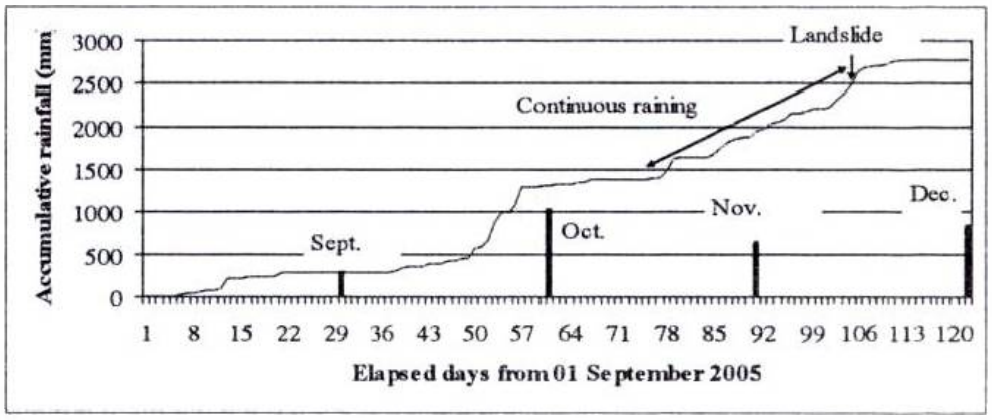


Fig 6. Monthly and accumulative rainfall.

The above results show that the landslides occurred after 3 months of heavy rain from Sept. to Dec. 2005. The total rainfall of one month before the failure (17 Nov. 2005 - 15 Dec. 2005) was over 1260mm. The average daily rainfall was 43.4 mm/day.

3.2. Landslide properties

The largest landslide took place in Lang Chom with the volume of about 22,000 m^3 (Fig. 7). The landslide occurred with a serious explosion. It might derive from the relieve of compressive pressure in the slope. Other sounds were induced by the movement of soil and rock masses after sliding. The top sliding surface situates in the weathering crust however most of sliding surface is the interface of intact igneous rocks. Residual soils are weathered from rocks of Deo Ca complex with the thickness of 4-6m. The slope is 65 high, and slope angle of $27^0 - 32^0$. Lots of rock masses of about $10m^3$ were transported down slope along the distance of hundreds meters. The sliding materials then destroyed a local road segment and filled up the Lau stream near the slope causing an increase of 2-3m of the stream water level. Fortunately, there was no debris flow due this phenomenon.

At the same time in Ka Bung (the opposite site of the mountain) there was a series of large landslides (Fig. 8). The thickness of residual soils is 6-9m. The slope angle is $27^0 - 32^0$. The average volume of these landslides is $10,500m^3$. The landslides took place far from resident area and did not cause any fatality.

The initial results show that the natural slopes in Binh Dinh can be instable when the rainfall in a period of time reaching over 1260mm, and the heavy rainfall of 200-300mm in 2-3 days occur at the end of this period. The slopes with the inclined angle of 30^0 or more steep have very high potential of sliding in such situation.

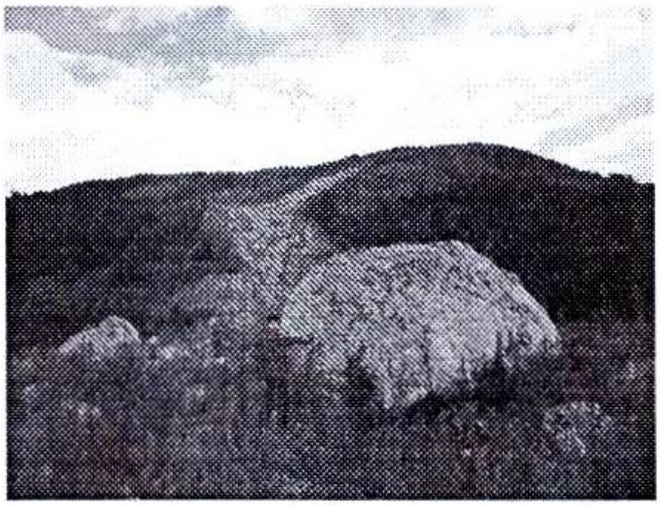


Fig. 7. Landslide in Lang Chom.

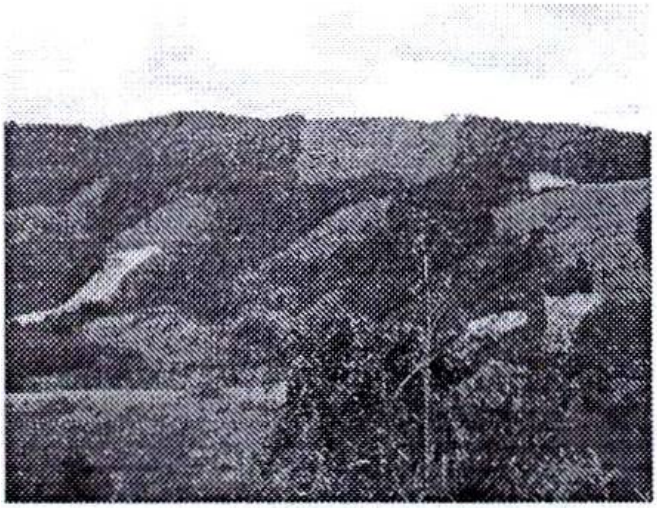


Fig. 8. Landslides in Ka Bung.

4. Discussions

Heavy rainfall therefore can trigger landslides at both excavated and non-excavated (natural) slopes. Empirically, the critical rainfall is 180mm continuously in Bac Kan province. This can meet during the extreme climate events such as storms and tropical depressions [5]. The time of raining is about 2-3 days with the highest intensity of 15 mm/h. The threshold herein is considered as a daily rainfall. The figure is very low in comparison to the situation in some places such as Hong Kong (75mm/h) [1] or Singapore (80mm/h) [7]. Heavy rainfall

also induces many shallow landslides along the roads in Binh Dinh province. However the threshold can not establish because of limited data.

Regarding the excavated slopes in Bac Kan, along with the role of heavy rainfall one reason should be emphasized is the slope angle. The slopes herein are stable when the slope angles are lower than 35^0 [4]. But all of slope angles are more than 45^0, and most of them over 60^0. Surprisingly, the fact is common not only at the highways but also at the residential sites. This derives from the effort to reduce excavated volume. That leads to a quite low critical rainfall because the landslides can occur when the pore water pressure (PWP) in the slopes is still negative.

The initial saturated degree (S) of residual soils in slopes plays an important role. As see in the Fig. 1 the residual suction of soils in Bac Kan province is about 80KPa and a dry soil slope can only increase the PWP to about -60 KPa under the rainfall of 180mm. Meanwhile the slopes can be instable when the average PWP is -6 KPa [3]. However rain can occur every month at the same time the temperature is low in the dry (winter) season in Bac Kan province. Therefore the saturated degree of soils is always high. The samples taken in December have the average S of 0.75-0.8. And the initial PWP interpolated from Fig. 1 is about -45 KPa. In the contrary, the rainfall is very small and the evaporation is remarkable in Binh Dinh province. The S of soils is only 0.3-0.4 in dry season. The heavy rainfall at the beginning of wet season can only increase the water content but can not make the soils mostly saturated. In fact, the rainfall in October 2005 was larger than in December 2005 but the landslides did not occur in October. An interesting fact is that the effective internal angle of soils is about $28\text{-}31^0$ (28.9^0 in average), and the slope angles of landslides were about $28\text{-}30^0$. So the landslides were triggered when the slopes were almost saturated.

The influence of geological settings is also remarkable beside two reasons of slope angle and heavy rainfall. The bed rocks of schist and clay shale in Bac Kan play the role of an impermeable layer below residual soils (Fig. 4b). When rainy water penetrate into the slopes and reach to that layer it will be accumulated and make a flow down slope. This leads to more rapid increase of PWP in the slopes. In Binh Dinh province this layer is taken place by some intact igneous rocks (Fig.9).

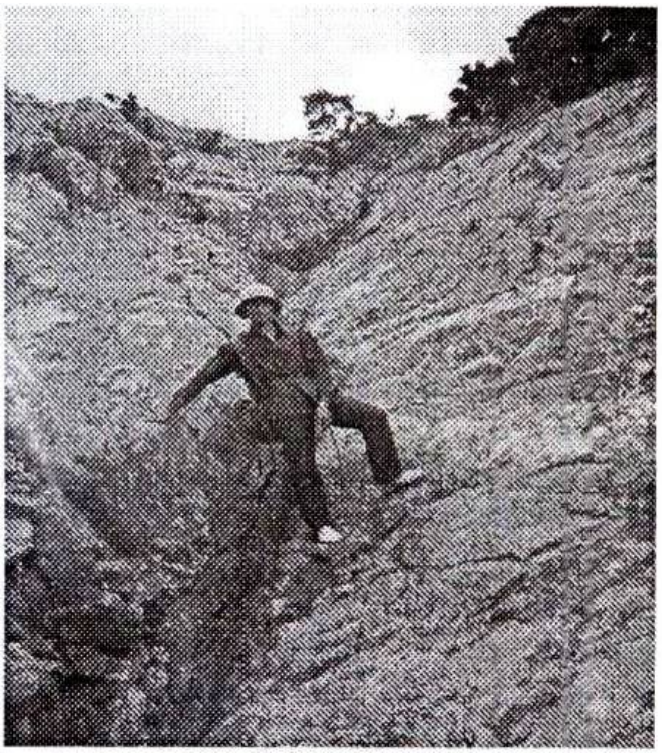


Fig. 9. Slip surface at the interface of intact bedrock in Lang Chom, Binh Dinh.

The results give a recommendation for the early warning of landslides. In Bac Kan province the monitoring data of 6-hourly rainfall can be mainly used. The hourly data is also necessary because the intensity sometimes reaches over 15mm/h. The warning system has 3 levels for example level 1 - 125mm, level 2 - 150mm and level 3 - 175mm. Therefore the

local authority and residents can arrange time to remove and save their property. For natural slopes in Binh Dinh province the daily rainfall is used and when the rainfall can reach to the threshold an early warning must establish for the residents to go far away from the slopes with the slope angles of over 30^0.

5. Conclusions

1. Heavy rainfall can cause severe landslides at the excavated or natural (non-excavated) slopes. Heavy rainfall induces shallow landslides of small volumes at the excavated slopes. In natural slopes the volume of landslides induced by heavy rainfall can be large or very large.

2. Landslides in Bac Kan can happen when the amount of rainfall is 180mm continuously. PWP in the slopes is still negative when the failure occurs. This fact can be early warning by the available rain monitoring stations in the region. Landslides of natural slopes in Binh Dinh can only occur when rainfall makes the slopes almost saturated.

3. Landslides depend on the initial water content (i.e. antecedent rainfall), geological settings, vegetable cover. Therefore rainfall path and critical rainfall induce slope failure in a place can vary in a given range.

Acknowledgements

The paper is supported by the Vietnam National University, Hanoi's Special Project coded QG-08-16.

References

[1] H. Chen, C.F. Lee, Geohazards of Slope Mass Movement and its Prevention in Hong Kong, *Engineering Geology* 76 (2004) 3-25.

[2] N.M. Dong, H.N. Duong, L. Minh, *Report on Environment of Bac Kan Province,* 2000. (in Vietnamse)

[3] D.M. Duc, *Landslides Triggered by the 3 and 4 July 2001 Rainstorm Event in Backan Province, Northeast Vietnam,* Hanoi GeoEngineering 2005, Hanoi, 25 November 2005.

[4] D.M. Duc, *Numerical Simulation for Slope Stability Analysis and Landslide Prediction in Bac Kan Province, Northeast Vietnam,* International Symposium on GeoInformatics for Spatial-Infrastructure Development in Earth and Allied Sciences, Hanoi, Vietnam, September 2004.

[5] N.T. Huong (editor in chief), *Characteristics of Mẹteorology and Hydrology in Binh Dinh Province,* 2004. (in Vietnamese)

[6] D.M. Tam, *Flooding and Landslides at the Highways of Vietnam*, Inter. Workshop on "Saving Our Water and Protecting Our Land". Hanoi, 20-22 Oct. 2001.

[7] H. Rahardjo, K.K. Aung, E.C. H. Leong, R.B. Rezaur, Characteristics of residual soils in Singapore as formed by weathering, *Engineering Geology* 73 (2004) 157-169.