The formation and development in Vietnam debris flows

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Abstract

So far most of the research consider that debris flow is a special kind of flash flood slope, where the density of debris in water is more than 60%. But the danger of debris flows compared with flash floods multiplied times. It is because of high energy in debris flow. Particularly, danger is the large rocks moving with great kinetic energy (with large boulders the size of 3-5 m).

Following debris flows occurring in recent years (since debris flow in Muong Lay in 1996 we recorded), the experts said that debris flows associated with landslides. But the real (Nam Luc Commune, in 2012, Ban cavity, 2013) showed that the formation and development of debris flows concern to many special causes. In [11] the authors identified debris flows developed mainly in the neck Proluvium and Colluvium layers or the tectonic debris layer. However, the authors did not analyze deeply the mechanism of formation and development of debris flows in mountains locating in northern Vietnam. In this paper, the authors analyze in depth natural conditions and development of some typical debris floods that happened in Tan Nam, Xin Man 2002, in Pac Nam, Bac Kan, 2008, Nam Luc, Lao Cai, 2012 and in Ban Khoang, Sa Pa in 2013, from which to identify causes and mechanism of formation of debris flows in the mountains of northern Vietnam.

1. Current status of some typical flood debris

Topography, geology and damage of debris flows

Debris flows occuring in Tan Nam, Xin Man district, Ha Giang at Night of 08/07/2002 killed 13 people, dozens of homes were destroyed and hundreds of hectares of rice and vegetables were buried by sand and gravel. Debris flows occurred in both Na Vai and Lung Chun. However the low zone of Lung Chun also happened the mixture sweeping flood should still greater damage and the death increases.

According to topography, both Na Vai and Lung Chun are located in 100-300 m elevation. Slope of the terrain is sbout $10\text{-}15^0$. There are many Colluvium-Proluvium necks, it proved that debris flows occurred in the past.

Based on geology, we see Thac Ba formation consists of quartz sericite schist, quartz-biotite schist-garnet, quartzite (Figure 1). This collection have weathered heterogeneously with many large boulders. Magmatic rocks of the Chay River Formation consists of biotite granites gneise form with larger particles, easy weathering make up the great stone. The ancient stone of the An Phu formation including marble contain graphite, marble dolomite, biotite-muscovite schist alternating, schist with feldspar-calcite strongly weathered. With this block can develops the Colluvi-Proluvium layers which causes large landslides and debris flow generation.

The collapse - Sliding block in Khen Nin, Pac Nam, Bac Kan that happened at night of 3/7/2009 killed nine people and destroyed many homes and cultivation. This is a typical collapse - Sliding block in areas with very small surface flow (Figure 2).

Following topography, the Khen Nin Village located at 1400-1500 m elevation, slope is less than 10^0. The whole area of peaks from 1300 m to 1600 m the surface flow is very small, not even find on a map 1: 50,000. So completely absorbed rain water flows down into the groundwater. The Colluvium layer thickness is very great. The People in Khen Nin village have evacuated from Cao Bang provine since 1979. This topography is very advantage to build house and make production.

Based on geology, Khao Loc, Mia Le formations include the metamorphic rocks of terrigenous sediments, marine sediments. Metamorphic rocks formed with very weak sericite. Between the rock formations have Magma block should increase the metamorphical ability and rocks fracture.

The collapse - Sliding block in Khen Nin if having large surface runoff will form the great debris flows.

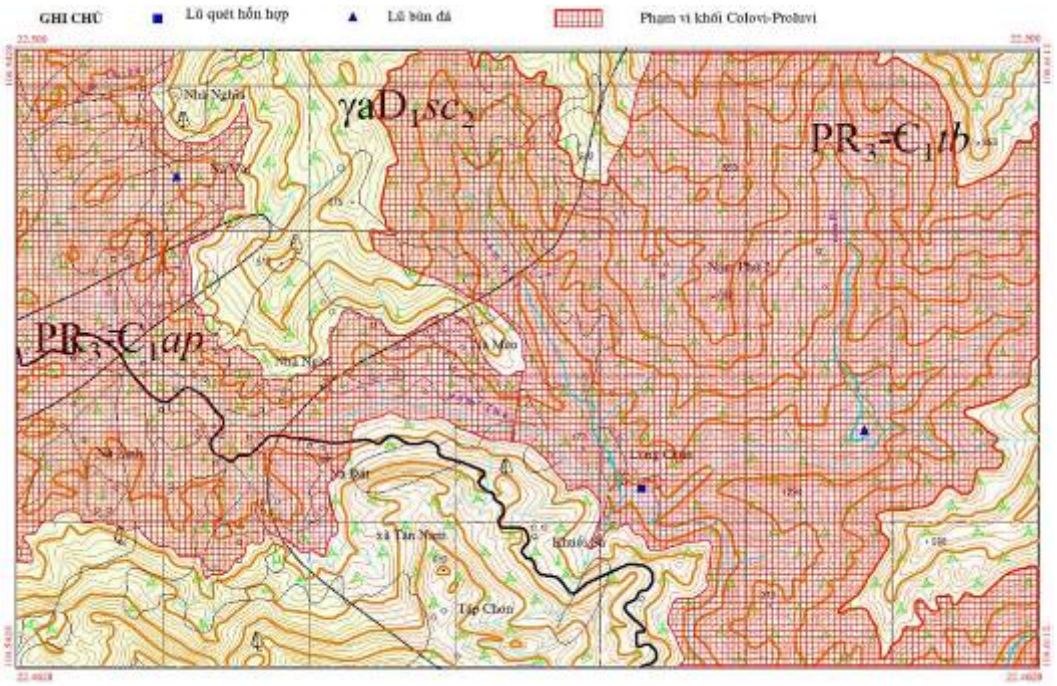

Figure 1. Topography, geology and Colluvium layer area in Tan Nam

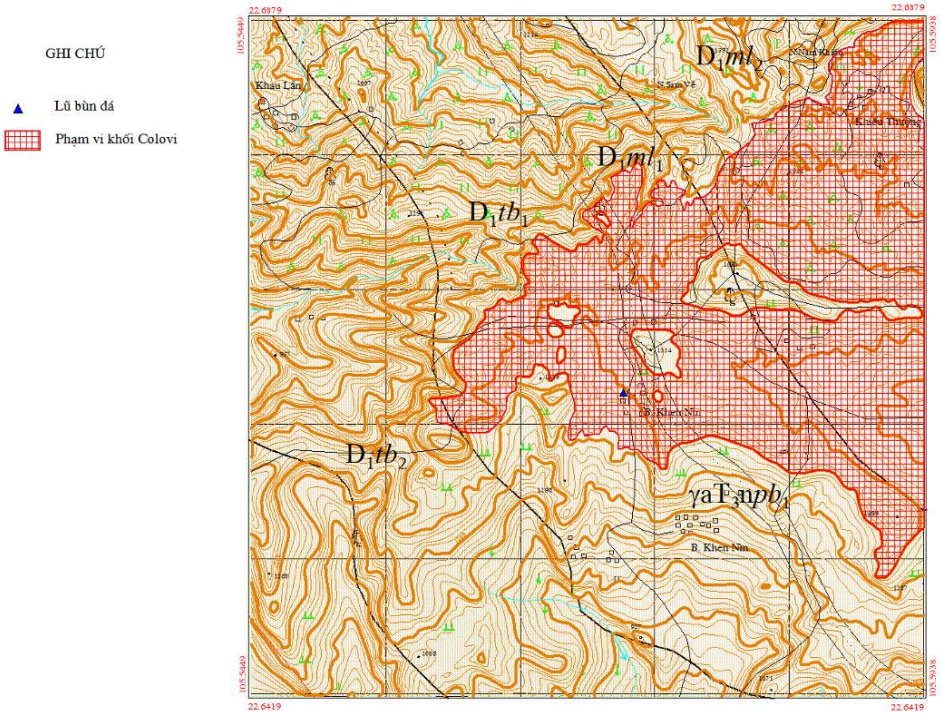

Figure 2. Topography, geology and Colluvium layer area in Khen Nin

Figure 3. Overview of the Colluvium layer in Khen Nin (photos in 8/2013)

The Debris flows occurred at night og 8/31/2012 in Nam Luc, Lao Cai, killed 10 people, 10 houses were swept away by the whole property, sweeping away more than 10 hectares of rice fields, damaging some road and irrigation constructions in two Nam Cham and Nam Nhu villages.

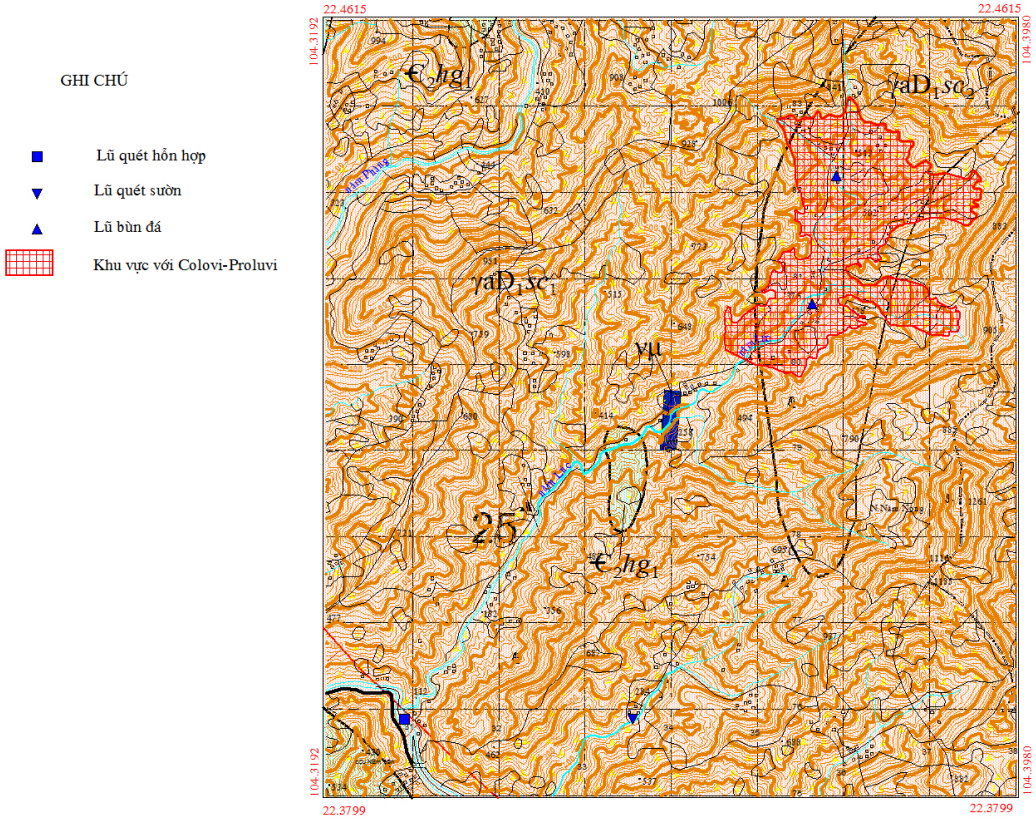

Figure 4. Topography, geology and Colluvi-Proluvium layers in Nam Luc, Bac Ha, Lao Cai

According to topography, Nam Cham Village is located at 300-400 m elevation, slope is from 10-15^0. The slope of the stream bed is lower, the slope of Nam Luc steam is approximately 5-10^0, the slope of Nam Cham stream is about 11^0. Nam Luc bed is suitable to accumulate Proluvium from stream branch.

Following, we again encountered Magma metamorphic shape of Chay River formation. Colluvium-Proluvium layer next to Nam Luc stream bed contains many large stones. The Proluvium layer in stream bank had the pebbles size to 20-50 cm. However Colluvium layers have the more large boulders with sharp and rounded shape.

Figure 5. Colluvi-Proluvium layer in the stream Nam Luc bank (photos 3/2013)

Figure 6. View of the position after debris flow (photo right after debris flow)

The debris flow in Ban Khoang at night of 09.04.2013 occured with very special context. In the morning of next day opening new course of the basis school. Debris flow destroyed entirely teacher dormitory and a part of the Can Ho Village below. It also killed 11 people, 17 people were injured, 10 houses were destroyed, 15 homes were damaged. Flash floods destroyed entirely building supplying clean water, electricity network and canal system; 3 cars and 17 motorcycles were swept away, destroying salmon fishing farms measuring about 900 m^2.

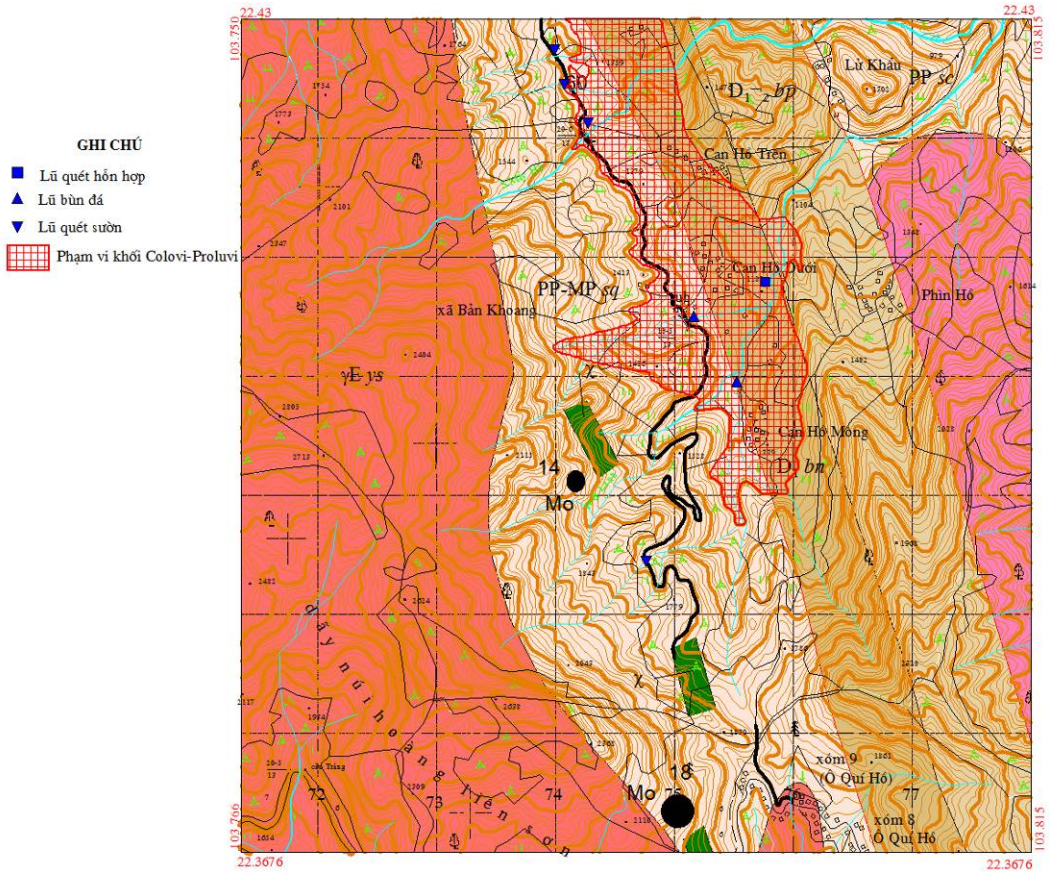

Figure 7. Topography and geology sector of debris flow occurring in Ban compartment

Figure 8. Block Colluvi under foundation class junior high school (photos 1/2015)

A part of Can Ho village below also stands mixed sweeping floods so some people were scrolled downstream to 20 km. Up Can Ho and Phin Ho villages are located at elevation from 1100 m to 1400 m with the slope from 10-15^0. This area is suitable for development Colluvium layers.

Colluvi-Proluvium layers developed mainly in the ancient rock shapes in the Sinh Quyen and Ban Nguon formations. Ancient metamorphic rocks belong to the Sinh Quyen consists of migmatite gneiss, biotite gneiss, biotite quartz schist, two mica schist. The Ban Nguon formations composed of shale, siltstone, sandstone, siltstone lime, limestone lenses. On the other hand fracture the quasi meridian fault actively influences in forming Colluvium layers.

The medical station and basis schools are located on the Colluvium layer. The Down Can Ho and Mong Can Ho villages are similar. This is also a warning for the region is on the debris flows and landslides.

Figure 9. Colluvium layer at stream bank (Debris flows occurred, photos 1/2015)

Figure 10. Debris filled the road 155 (Ban Khoang - photos after debris flow)

Debris flow development

Most insiders felt that before and during the disaster have strong shocks like earthquakes.

According to Tran Quang Sang - The basis School headmaster of Ban Khoang, said floodwaters swept away by teacher building together entire properties. When floods happened, at about 8:30 pm 09/04/2013, he was sitting in committee house to prepare the new course of basis school. Water overflows in power station and caused a loud explosion, He felt the ground under his seat shook strongly. Electricity went out, heard cries speechless, he and civil defense run to school. "The sight was so terrifying, flood waters flow very fast, no one to come near. Just seeing colleagues helped went out the houses they supported the victims", Mr Sang said. The A Can Ho people at 4/9 night almost sleepless, people went along the stream to find and rescue the victims. According to residents, where floods swept through before only little streams of water, but this was extended to 30 m, a depth of 6-7 m.

About mixture sweeping flood in Below Can Ho village, teacher Doan Quang Trung and his wife Bui Thi Thu Ha are surviving victims. Mrs Ha said she was pregnant until 7th, at Night 4/9, flood arrived when the couple was in the room. "There must die together," thought he could just hug his wife. Specifically, the couple was pushed away in the flood. The moment she buried in the water, Mr Trung tried his best to push her up to breathe.

According to Mrs. Li Su May (born 1969, Dao people), all the assets in the house were swept away, just left a ruined wall. She is still haunted by waters roar at 4/9 night: "At first, hear the roar, I just think the biggest auto run through as always, but more and more clearly heard, time after losing power again he knew debris flood ".

At the Nam Cham, Nam Luc as described by Mrs. Ly Thi Nhon, 29 ages "was sleeping, suddenly heard the explosion, water flowed rumbling, rolling stones rattling, I just woke up husband, then hands grabbed two children slept next, run out of the pouring rain, running up the hill, narrowly escaped death. "

Thus, through the testimonies of witnesses, the formation and development of debris flows related to strong shocks due to the motion of the debris blocks downstream.

2. Identify the initial cause and mechanisms of debris flows

Apart from the debris floods that happened a long time before, with two recent debris flows in Nam Luc and Ban Khoang we did not notice the large landslide tracks in the watershed. So which is the motivation and source materials where born in the formation and development of debris flows. Currently there are two opinions about starting debris flows:

Due to landslides

Landslides are the original impetus of debris flows. This phenomenon is evident from the debris flood in Huoi Lo stream, Muong Lay town (Lai Chau). It is possible that the stream landsliding blocks. The water is not large enough to carry all the material downstream. Impact landsliding block to shift work involves sliding of the stream banks. This is why giant mass exists in the stream bed and at the stream door.

Figure 11. Field after debris flood in Muong Lay town
(Photo 8/1996, shortly after LBD)

The collapse - Sliding block in Khen Nin (Pac Nam) is a next example. Because the area has very little surface runoff should not constitute debris flows. However The collapse - Sliding block caused to major disasters as burying the Khen Nin village.

If the notion that the debris block only by a landslide in upstream, the sliding blocks are huge enough to fill the stream bed and downstream. However unobserved large sliding blocks so often the source of the stream.

Due to shocks from large boulder

This phenomenon is consistent with the phenomenon occurs in Nam Luc and Ban Khoang. In the traces left in the field with huge boulders from 2-4 m. These rocks can be located on both sides of the stream or higher upstream due to imbalance that rolled down the stream. This large block hits against to block Colluvium or Colluvi-Proluvium layers when saturated with water causing drag on consecutive landslides. The rocks along streams were excited and full flow downstream.

So regardless of starting from a sliding block or a large boulder, Colluvium or Colluvi-Proluvium layers along streams affected and drag consecutive landslide downstream. Landsliding blocks can not

start large, but enough energy to initial impact on the Colluvi-Proluvium layers below. In order to form the debris flows, to have a large enough of water as flash floods in the stream.

3. Environmental and geotechnical characteristics of Colluvium and Colluvium-Proluvium layers

Conditions of formation

Proluvium blocks formed in stream beds with proper slope. Often these products are formed and accumulated annually at a certain height above the stream bed. Slope streams suitable for storage Proluvium products about 5-10%. With the steeper stream bed, then this product exists at the stream door, where streams joint rivers and streams with the higher level or the mountainous valley. Often Proluvium layers have not large surface slope. Its shape is generally triangular. Proluvium products on streams exist for long time stable mechanically. But when it is saturated the inner friction and cohesion easily weakened by the pore water pressure. Figure 5 shows the structure of the Proluvium layer in the stream bank of Nam Luc stream. Next up is higher Colluvi-Proluvium layers. This is a material souses supplying to debris flows.

Collovium layers exist on the slopes and in the stream bed. It is accumulation of material on the slopes as landslides, rock roll, rock dump, abrasive products by the water or rain. It filled the streams which are mostly shallow streams. But when it rains the groundwater increasing. In the right conditions of surface runoff and groundwater flow constituted the stream landslide and debris flows. Colluvium layers are attended by scientists in the world, [1, 5, 6, 7, 8]. In the northern mountains of Vietnam, Colluvium layers are often formed in the slopes at about $<20^0$. In geomorphology, this area is equivalent to surface erosion and accumulation.

There are three basic causes concerning to form of Colluvium and Colluvium-Proluvium layers. First, it is geological conditions. In the weak formations of ancient metamorphic rocks such as shale forming from terrigenous sedimentary rocks, sedimentary or volcanic rock. The most Unstable shale are Sericite schist. Some younger rocks formed in orogenic stage as from middle-late Triassic to cretaceous ages (T_{2-3}, K) to have poor durability. The second is due to tectonic and neotectonic activity. Due to tectonic activity, rocks was destroyed and easily broken and detached fragments. Often in the regions with the tectonic or neotectonic faults Colluvium layers formed widely. Third, that is hydrometeorology. The change in temperature and humidity are increased the weathering process, rain and flow did move the debris blocks. The process of gradual accumulation over time formed the large Colluvium Colluvi-Proluvium layers.

However, not all of which are formed debris flows. Structure of Colluvium layers as the stream shapes are suitable to develop the debris flows. in order to form this Colluvium layers have to special conditions:

- Stream bed is deep eroded by neotectonic activity or highly concentrated surface flows as tube floods.
- The surrounding geological formations mechanically weak, easy to weathering as block foundation.

- The topographical slope is enough large in order to occur boulders or landslides.

The set of these conditions may be suitable to Northwest and North region of Vietnam. So far debris flows formed mainly focus in this area.

The other types of Colluvium structures only facilitate landsliding as in Khen Nin.

Physical and mechanical properties of Colluvium

In geological engineering, Eluvion-Diluvium products contain clays, sand and crushed gravel. However, the Colluvium processes are stronger and related to the large displacement of geological products which have the large boulder size.

Colluvium layers is weaken cohesive level depending on the age and formation condition. The coarse particles form from the pebbles, gravel, crushed gravel and rock blocks as boulders. There have been many studies of the Colluvium layers in the wworld but only some Colluvium certain types, service stability studies of slopes and road foundation, [7]. Colluvium and Proluvium layers are reduced durable seriously when saturated.

The field studies of authors point out that, in Nam Luc Colluvium layers, Khen Nin and Lung Chun are a mixture of Diluvium products and boulders which are various lithological composition and size of 100-120 cm. Colluvium layers in Nam Coong were built with boulders weathered from sandstone and conglomerate of Yen Chau sediments. Colluvium layers in Huoi Lo, Muong Lay are mainly boulders derived from metamorphic rock of Nam Co formations. The size of boulders change within large zone, 20-30 cm and 100-120 cm, even much bigger.

Properties of Colluvium and Colluvi-Proluvium layers change from unconsolidated soil mixture to the Neogene rocks depending on the age and condition of its formation. In Vietnam there is not any research project details on Colluvium layers and which is considered a special form of sediment. In Hong Kong, [6] it was the age of the middle and late Pleistocene and Holocene. The author has also published a number of experiments on dry densities of several Colluvium layers. Colluvium layers of Holocene age have dry densities reached 12.6-13.8 KN/m^3; Colluvium of Pleistocene late age have dry densities ranged from 15.8-16.6 KN/m^3; Colluvium of Pleistocene middle age have dry densities reached 16.3-18.9 KN/m^3. The humidity varies from 12% -20%.

Figure 12. Cross section of Colluvium along the road from Lai Chau to Tam Duong (Photo on 1/2015)

Figure 13. Cross section of Colluvium from Dien Bien to Tay Trang road (Photo on 1/2015)

Product of gravel and crushed gravel in Colluvium can be laterization in humid tropical conditions and create secondary elements increasing the bearing capacity. This is different from the Colluvium in temperate zones. But the durability of products is still decreases due to the action of pore water pressure.

In the study of Irfan CO, KY Tang, 1992, [5], the authors summarize the direct shear test large specimen, the 3-axis cutting and field experiments to determine the effect of group coarse particles to the intensity of Colluvium layers. By the experimental data tested in the last half century ago, the author, [5] concluded:

- Volume of coarse particles affect the intensity of Colluvium;
- The impact is not great when coarse particles below 20%. The small influence when the content of 20-30%. The strong influence when the content of greater than 30%.
- The increasing influence on the largest particle size increases. However it is difficult to quantify the results.

Summarizing the experimental cutting large blocks and field experiments, the authors showed the results of the mechanical properties for Colluvium in Hong Kong: C = 2.5-12.5 KPa, $\varphi = 15\text{-}45^0$, with σ_n <50KPa. It can be seen that Colluvium mechanical properties are different from the other sediment soils.

In rock mechanics, there are rock types called fragmentation (Disintegrated rock), it is less associated rocks, severely cracked and is a combination of small blocks with rounded edges, [4]. The Colluvi-Proluvium layers are different with rocks is a combination of the various components and associated products through the weathering soils. However, on the mechanical nature we can see it in common. The authors proposed this model can take to determine the mechanical properties of Colluvium and Colluvi-Proluvium layers. Necessary to have additional studies as intact rock strength is taken into soil or any other component.

According to the model of Hoek, [2], The GSI (Geological Strength Index) of this type of rock is about 7-15. GSI's Hoek index is determined according to the classification of Bienavski 1976 and 1989, [4].

$$\begin{aligned} GSI &= RMR_{76} \\ GSI &= RMR_{89} - 5 \end{aligned} \tag{1}$$

Strength criterion of Hoek and Brown 1983 is represented by the equation:

$$\begin{aligned} \sigma_1^{'} &= \sigma_3^{'} + \sigma_{ci}\left(m_b\sigma_3^{'}/\sigma_{ci} + s\right)^a \\ m_b &= m_i \exp\left(GSI - 100/28 - 14D\right) \\ s &= \exp\left(GSI - 100/9 - 3D\right) \\ a &= \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right) \end{aligned} \tag{2}$$

Deformation module, the coefficient of friction and cohesive forces of the rock masses were calculated using the formula:

$$\begin{aligned} E_m(GPa) &= \left(1 - \frac{D}{2}\right)\sqrt{\frac{\sigma_{ci}}{100}}.10^{((GSI-10)/40)} \\ \varphi^{'} &= \sin^{-1}\left[\frac{6am_b\left(s + m_b\sigma_{3n}^{'}\right)^{a-1}}{2(1+a)(2+a) + 6am_b\left(s + m_b\sigma_{3n}^{'}\right)^{a-1}}\right] \\ c^{'} &= \frac{\sigma_{ci}\left[(1+2a)s + (1-a)m_b\sigma_{3n}^{'}\right]\left(s + m_b\sigma_{3n}^{'}\right)^{a-1}}{(1+a)(2+a)\sqrt{1 + \left(6am_b\left(s + m_b\sigma_{3n}^{'}\right)^{a-1}\right)/((1+a)(2+a))}} \end{aligned} \tag{3}$$

Among them:

$$\begin{aligned} \sigma_{3n}^{'} &= \sigma_{3\max}^{'}/\sigma_{ci} \\ \frac{\sigma_{3\max}^{'}}{\sigma_{cm}^{'}} &= 0.72\left(\frac{\sigma_{cm}^{'}}{\gamma H}\right)^{-0.91} \quad for\ tunnel \\ \frac{\sigma_{3\max}^{'}}{\sigma_{cm}^{'}} &= 0.47\left(\frac{\sigma_{cm}^{'}}{\gamma H}\right)^{-0.94} \quad for\ slopes \\ \sigma_{cm}^{'} &= \frac{\left(m_b + 4s - a(m_b - 8s)\right)\left(m_b/4 + s\right)^{a-1}}{2(1+a)(2+a)} \end{aligned} \tag{4}$$

In the formula of (2) - (4):

$\sigma^{'}$ - is the effective stress;

σ_{ci}, $\sigma_{cm}^{'}$ - Compressive strength for intact rock and rock masses;

$\varphi^{'}$, $c^{'}$ - Effective inner friction angle and cohesion of the rocks masses;

γ - Unit weight volume of rock masses;

H - With the Tunnel H is the depth from the ground surface, with the slope H is the depth from the top of the slope.

D - factor of disturbance (disturbance factor) depends on the quality of rocks and construction methods, D = 0-1.0. D = 0 when rock surrounding is undisturbed, D = 1 as strongly disturbed during the construction, [3].

In general formulas from (2) - (4) are only suggested for calculating the mechanical properties of Colluvium and Colluvi-Proluvium blokes. However require massive field experiment to determine them.

4. Some remarks for conclusion

- Debris flow that is a type of geological disaster is very serious. Its consequences affect both on people death and economic - environmental damages.
- It is very difficult to forecast debris flows because it depends on many factors containing topography, geology, meteorology, economy and human activities. But to argue, debris flows originate mainly in Colluvium-Proluvium and Colluvium layers, researchers set out to determine the scope and nature of this strata and allows somewhat to warnings and forecasting debris flows.
- Research environmental geotechnical properties of Colluvium and Colluvium-Proluvium layers in mountains is not only mitigation of the damage caused by geological disasters, mainly landslides and debris flows, but also partly to prevent and protect it. On the other hand research Colluvium properties is very practical service developed infrastructure built in the mountains, enhancing regional stability and the construction work.

The article is written according to the topic KC 08:09/11-15.

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