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Geological Aspect of Slope Failure and Mitigation Approach in Bireun - Takengon Main Road, Aceh Province, Indonesia

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Abstract – A soil and rock slope assessment survey was conducted along Bireun – Takengon main road in Aceh Province, Indonesia. The slope assessment survey was carried out to determine the geological condition, verify and identify the potential areas of slope failure and to study what type of slope stability and protection method could be applied to the road. Several research methodologies were conducted in the field such as rock and soil identification, and slope assessment. The survey was conducted in four selected areas along Bireun – Takengon main road. In study area I, soil creep occurred because of a presence of montmorillonite clay. The mitigation methods to reduce soil creeping in this area are building a retaining wall and pile. The shotcrete, wire mesh, net rock bolting, and rock removal method is suitable to apply in study area II. The shotcrete and soil nails were used because the type of rocks in those areas is sedimentary rock such as shale, sandstone, siltstone, and a boulder of a volcanic rock. The same approach shall be applied in study area IV. study area III was the best spot to learn about the mitigation approach for slope stability and provides many lessons learned. Aceh Province experience active tectonic movement, high intensity of rain, geological structures, a high degree of weathering, and high intensity of earthquake,as primary factors which trigger landslides. The techonology of slope stabilizing and protection methods can be applied to mitigate landslides.

Keywords: Slope failure; Applied geology; Aceh road; Slope stability

Introduction

The slope failure or landslide is a phenomenon when a slope collapses due to weakened self-retain ability of the earth to the influence of rainfall or an earthquake. Varnes (1978) defines landslide will include all types such as gravity-induced mass movements, rock falls, slides/slumps, avalanches, and flows. Another type of landslide are subaerial, and submarine mass movements triggered mainly by precipitation (including snowmelt), seismic activity, and volcanic eruptions. According to Varnes (1978), there are several factors that will trigger the slope failure; (i) geological conditions (composition/type of rock and soil weathering), (ii) morphology or dip, (iii) land use, (iv) drainage system, (v) rainfall, (vi) cutting of slopes, and (vii) deforestation. The geological condition, morphology and rainfall intensity were primary triggers of slope failure in Aceh Province. Land use, cutting of slope, deforestation and drainage system were the minor trigger. According to Thornbury (1954), there was an active and passive factor that cause land movement/landslides. The active factors are water circulation and anthropogenic factors, the passive factor includes lithology, stratigraphic, topographic, geologic structure and climate.

Slope failure/landslide and land movement often occur in Aceh Province due to the tropical climate with high intensity of rain and a high degree of rock weathering. This condition will affect the degree of weathering of rock and a thick layer of soil become comfortable to move and failure if the intensity of rain increases. This condition also will increase the pore water pressure beneath surface and weight of soil. In this state, the slope failures occur due to decreasing of friction force and cohesion between the layer and the soil itself. However, the geological structure is also involved in triggering slope failure in Aceh province.

Slope failure hazard cause direct damage to people and infrastructure such as damage to public facilities, agriculture, and loss of life. This hazard also causes indirect damage that crippled economic activities and development in the affected and surrounding areas.

To study the trigger factors of landslides along Aceh Province road, the survey was conducted in selected areas. This survey was conducted in Bireun – Takengon to examine the geological condition, and to verify and identify the potential areas of slope failure. The other objective is to determine the type of slope stability and protection method that could be applied to the slope of Bireun – Takengon main road. The Bireun – Takengon road was selected because this road is the main road connecting the eastern and central regions of Aceh province.

Materials and Methods

The geological survey conducted along Bireun – Takengon main road of Aceh Province is a preliminary slope assessment. In the field we mapped the landslide potential zone, including the type and geometry of slope failure, slope weathering and the type of rock, vegetation cover and related features of the landslide. Rock and soil identification; is essential in determining the suitable method that will be applied. Different types of rock and soil will have a different method of slope stability and protection. For example, for claystone, which has a high degree of weathering, shotcrete is the suitable method.

Slope assessment was conducted to review the condition of slope including the steepness of slope, terrain, and prediction of the suitable slope stability method.. The slope assessment was based on the office data card published by Swanston and Howes (2001). The office data card consists of landslide data identification and physical characteristic of study area.

Landslide data identification

In the landslide identification form, several check box have to be answered such as (i) identification if landslide is present, i.e. identify either landslide occurrence in area/similar terrain nearby or landslide impacted the stream. (ii) Identify source of data, such as forest inventory map, terrain map, soil map, landslide inventory map, bedrock geology map, and air photo. This source of data will be very important to determine the morphology, land cover, soil type, and the geological conditions around the landslide area. (iii) Identify the type of landslide; fall, creep, and slump. Different type of landslide will have different types of mitigation approach. The type of landslide was determined in the field based on Varnes (1978). (iv) Describing the character of landslide initiation site;, including the slope angle from terrain map, location, the type of material (till, colluvium, fluvial, fluvial/glaciofluvial, residual soil, and bedrock), drainage condition (rapid/well, moderately well-imperfect, poor), and land use (natural, clear-cut, and road) in surrounding area.

Physical characteristics identification

The description of the physical characteristics of landslides in the study area include (i) Identify the source of data including the forest inventory map, terrain or morphological map, soil type map, landslide inventory map, geologic map, and air photo, (ii) slope angle (including the shape; concave, convex, or straight), measurements using clinometers of geological compass, (iii) Overburden (type, depth, texture, and drainage), this data is derived from observation in the field, (iv) bedrock (exposure or subsurface); type, geological structures and features, and stratigraphy. This measurement helps to determine the depth of bedrock acting as a sliding surface. Geological equipment such as compass, clinometers, measurement tape, loop, hammer and GPS navigation were used in this research in order to determine the physical characteristic of the landslide.

Result and Discussion

Geology of Aceh Province

Geologically, Aceh province is situated within the Sumatra Fault Zone, which ruptures from the Semangko bay to the Andaman Sea. In the western part of Aceh province, there is the subduction zone between the Indo-Australian Plate with the Eurasian Plate. The Indo-Australian plate moves northward and subducts beneath Eurasia plate at a rate of about 5 cm/year (McCaffrey, 2009) as shown in figure 1. The oblique movement of the Indo-Austalia plate relative to the trench separates Sumatra Island into two partsdivided along the Sumatra Fault Zone (Yeats *et al.*, 1997; Natawidjaja, 2002). Natawidjaja (2002) divides the Sumatra fault zone into several segments in Aceh Province. The first segment is Tripa Segment, which is located in Aceh Tengah district, Gayo Lues district, and Aceh Tenggara district. The second segment is Aceh Segment which is situated in the districts of Aceh Tengah, Pidie and Aceh Besar. The third segment was Seulimuem segment, which is located in the Aceh Besar district. Those segments of the Sumatra fault

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have contributed to slope failure in Aceh province in the past. Faults and the structural complexity of an area are often the main factors characterizing landslide-prone conditions (Grelle *et. al*, 2011).

According to the Geological Map, published by Cameron *et. Al.* (1983) the Bireun – Takengon main road is part of the Lhoksemawe and Takengon quadrangle of the geological map of Sumatra. According to the map, the older to younger rock formations found in those areas are Keutapang formation and a member of Seumpo sandstone that formed in the late Miocene epoch (±5 million years ago). Enang-Enang and Lampahan unit that formed in the Pleistocene epoch (±1.5 million years ago), and Telong unit that formed in the Holocene epoch (less than 10.000 years ago). The Keutapang formation consists of sedimentary rocks deposited in littoral and deltaic environments. The types of rock in this formation are conglomerates, sandstone, siltstone, claystone, and shale. Enang-Enang and Lampahan units formed by extrusive igneous rock (pumiceous to massive andesitic flows and ashes) and reworked volcanic deposits (breccias, conglomerates, and sandstones). The Telong unit consists of extrusive igneous rock deposited by subaerial processed such as pyroclastic flows. The Enang-Enang, Lampahan, and Telong unit comprise a characteristic younger volcanic deposit; that consists of loose sediment and is vulnerable to sliding. The geological map and position of the study area as well as geologic sequences from Bireun to Takengon is shown in Figure 2.

Because of the complex geology and structural setting, Aceh province needs special assessment for slope stability. Researchers and engineers have to rethink about suitable slope stability and protection methods which will apply in slopes around Aceh province. High frequency and magnitude earthquakes and high intensity of rain are the primary factors that trigger landslides. Several slope stability and protection methods have to be applied to the slope, but the suitable method is a challenge for engineers. The geology and structure of slopes are the main predisposing factors controlling the mass movement/landslide development (Fookes and Wilson, 1966; Zaruba and Mencl, 1969; Varnes, 1978 in Grelle, 2011). After conducting surveys of several slope failure prone areas in Bireun – Takengon main road,four characteristic study areas will be discussed in this paper.

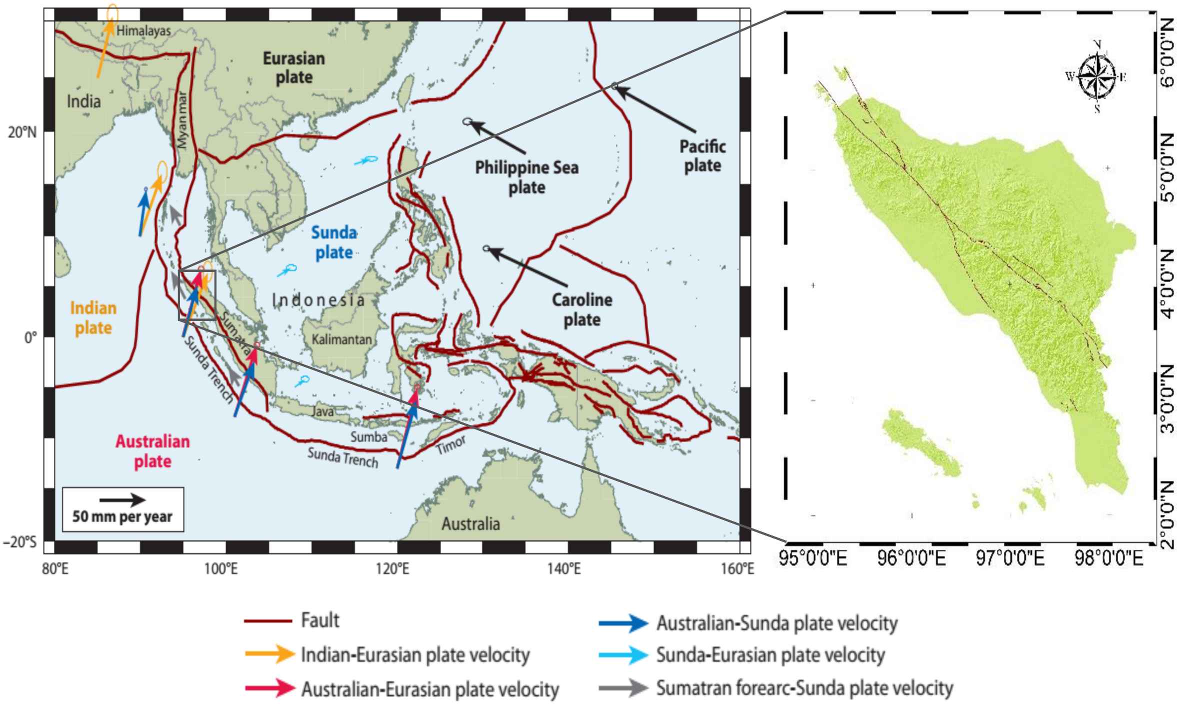

Figure 1. Plate tectonic setting of Indonesia, Vectors show relative velocities of plate pairs as labeled and Aceh province map (Modified from McCaffrey, 2009)

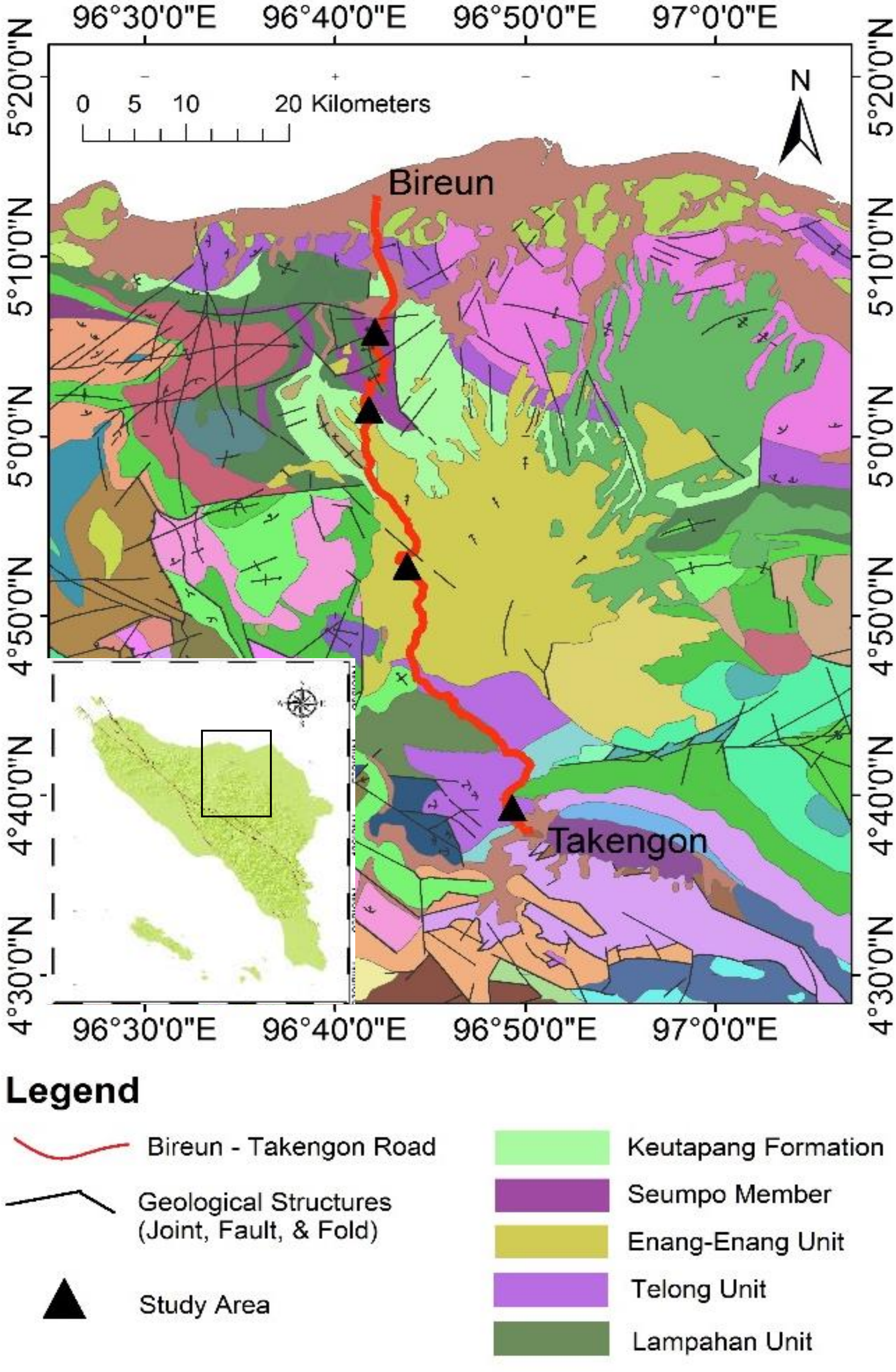

Figure 2. The geological map, the track of Bireun – Takengon main Road and The location of study (Modified from Cameron *et al*, 1983)

Case study I

This first case study area administratively was part of the Juli sub-district in the Aceh Jeumpa district of Aceh Province. It is located at coordinate 96°42'25.1" E and 05°06'23.7" N. The morphology of the study area is a transition zone from the platteland to the hilly land. The roads have north – south direction and on the western and eastern side of the road is a ravine. The lithology of the rocks that appear in this location is dominated by calcareous mudstone with sheeting joints structure.

Figure 3. (a) Swelling clay cause soil creeping on the road, and (b) Swelling clay destroy the retaining wall in the Juli Sub – District

The type of landslide on this site is soil creep because of montmorillonite clay present in the subsurface of the road. The montmorillonite is a swelling clay. When it is in contact or saturated with water, the volume of clay will increase about 39% (Aksu et. al, 2015). In this case, the road was constructed, when the montmorillonite clay was saturated with water and in swelling condition. In the dry season, the groundwater decreased, and the volume of montmorillonite clay will shrink and collapse the road (Figure 3). The annual cycle of wetting and drying seasons in the tropical climate causes swelling and shrinking of montmorillonite clay each year.

In addition, the geological map of the Lhokseumawe quadrangle showed the geological structures in this area such as faults and folds. Fold axess have a general north – south directions. An east-west orientated fault indicates a right-lateral strike slip fault (dextral) with the offset being visible along the cut fold axis. The fault has a younger age compared to the fold (Syncline) because it was offset by the fault. Folds and faults are characteristic of a weak zone with the possibility of water saturating the surface layers of soil and rock or soil moving on the sliding plane.

The step of mitigation it takes to reduce soil creeping is to build a retaining wall and pile. The foundation of those buildings shall be constructed beneath the zone of water content fluctuation. The reason is two-fold: the first way is to provide for sufficient skin friction adhesion below the area of drying. The second way is to resist upward movement when the surface soils become wet and begins to swell. Another way of mitigating swelling clay problems is to collect surface runoff and to limit surface infiltration (Roger, 1993).

Case study II

Case study II was conducted in Bireun district of Aceh province and is commonly named Cot Panglima. The type of rock in this location is sedimentary rock; shale, sandstone, siltstone and a boulder of a volcanic rock. Geology and geological structural settings of slopes are the main predisposing factors controlling the mass movement development (Fookes and Wilson, 1966; Varnes, 1978). The strike of sedimentary rock layers in this location is parallel to the line of the road. This condition will increase the possibility of sliding and toppling landslides. Even though this area is far away from the Sumatra Fault Zone (SFZ), in some adjacent area awe discovered synclines – and anticlines with north/ south orientation. Joints were also found in several areas, and it indicate an active land movement area with a high risk of landslide. Figure 4 shows the fold (Syncline/anticline), joint and normal fault in Cot Panglima road slope.

Highly jointed or fractured rock of the slopes with principal joints and fracture surfaces parallel to or dipping with the slope provide low mechanical support to overlying materials. It creates avenues for concentrated subsurface water movement. Jointing also provides avenues for deep penetration of surface and ground water (Swanston and Howes, 2001).

Because of the sedimentary rock type in this location, suitable slope protection and stability can be provided by shotcrete, wire mesh, net rock bolting and rock removal in several areas. On some slopes, the hanging rock/soil shall be removed and re-profiled. To reduce the risk of the existing slopes, the drainage on the slopes shall be steep enough to avoid water ponding and also to prevent infiltration of ponded water that increase the pore water pressure. It is also recommended that any cracks at the top of the slope be sealed with grout or asphalt (West T.R, 2007). Another method which could possibly be applied in this zone is

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biotechnical slope protection approaches. Biotechnical slope protection can be implemented on the slope. This method consists of two types, biotechnical stabilization and soil bioengineering stabilization. Both of which entail the use of live materials, particular vegetation (Gray and Sotir, 1996 in Schuster *et al.*, 2004).

Figure 4. Geological Structure in Cot Panglima. a) Syncline, b) Joint, c) Normal Fault

Case study III

This third study area, is administratively part of Pintu Rime Gayo sub-district of Bener Meriah district. The exact coordinates of this study area are 96° 43' 40.3" E and 04° 53' 11.3" N. The morphology is mountainous and roads are built on the slope of the hill. The lithology of the rock in this study area is dominated by volcanic sandstones and a thin top soil layer. Based on the geological map of the Takengon quadrangle, there are fault structures striking North West - Southeast and this area is a part of the Enang-Enang unit. Based on the lithological conditions and geological structures rock falls and toppling of rock can occur along this slope.

Figure 5. (a) The gabion and (b) Drainages built to prevent slope failure.

Mitigation and prevention efforts will be implemented on this side. The slope is very steep, but the government has constructed retaining walls and a gabion to withstand the slope failure. At the footstep of the slopes, there are drainage channels which very useful to keep the roads from being inundated and control runoff (Figure 5). High vegetation cover in this area can also function as a binder of the soil and the rock. Vegetation cover influences the amount and intensity of rainfall reaching the surface, the quantity of water stored in the overburden, and the strength developed along a potential failure surface. Root systems of trees and other vegetation may increase the shear strength of unstable overburden by anchoring through the mass into fractures in bedrock. It will provide continuous long-fiber binders within the overburden (a fiber reinforcing effect) and tying the slope together across zones of weakness or instability (Swanston and Howes, 2001).

Case study IV

This location is administratively located in Kebayakan sub-district at kilometer 92 of the Bireun – Takengon main road. The morphology of this area is mountainous, and the road is built on slopes of the hill. A gentle slope is exposed on the downhill side of the road while a steeper slope occurs on the uphill side.. The lithology in this area is dominated by young volcanic sandstone with a primary composition of loose pyroclastic deposits. There is also a boulder of igneous rock contained in this slope, and this deposit is not well lithified especially on the surface.

In July 2nd, 2012, several landslides occurred in this area due to a 6.1 Mw earthquake (Figure 7). Keefer, D.K (1984) noted that, in 40 historical worldwide earthquakes, there were fourteen types of landslides. The most common type of landslide due to seismic activities are rock falls, disrupted soil slides, and rock slides(?). In this case with very loose pyroclastic sediment exposed, debris avalanches dominated the area. Slope angle is a primary factor of t stability at these sites. Slopes at or above the internal friction angle of the overburden material indicate a highly unstable natural state even in the absence of excess water (Swanston and Howes, 2001).

The mitigation measures that can be applied in this area are, shotcrete, soil nails, re-profiling and trimming. Shotcrete and soil nails can be used in this study area due to the loose pyroclastic sediment. Shotcrete is a slope surface protection method to prevent the rainfall infiltrating the slope and soil nails can be used to support contact between soil and shotcrete (Abramson *et al.*, 2002). If shotcrete and soil nail protection are not possible, re-profiling and trimming are the appropriate methods. Reprofiling is the re-design of a slope to determine a height and inclination that is economical and that will remain stable for a reasonable lifetime.

Figure 7. Landslide/slope failure along The Study area due to July 2nd, 2012 earthquake

Conclusions

Active tectonic movement and high intensity of rain, the presence of geological structures, a high degree of weathering, and high intensity of earthquakes were the main factors that trigger landslide/land movement in Aceh province. The slope stability and protection method are the engineers approach to mitigate landslides. The type of method depends on the rock/soil that forms the slope and its condition; i.e. soil or rock slope will have different characteristics of stability and suitable protection measures.

In case I, Shotcrete, wire mesh, net rock bolting and rock removal are the suitable method to stabilize the slope. Considering that highly weathered roc andresidual soil form those slopes, some areas need re-profiling and rock removal. Case II is different from case I, since most of the slope is formed by highly fractured rock. The appropriate slope stability and protection method is rock bolt, anchor, dowel and in some places,rock removal and re-profiling. In case study III, the mitigation approaches already (?)

implemented are the retaining walls, the gabion and high cover of vegetation. Loose material is found on the slope in the area of case study IV.. Here, shotcrete, soil nail or re-design of the slope to prevent slope failure can be applied. Future research of these study areas is essential and should include rock mass rating, slope mass rating and kinematic analysis to further mitigate landslide risks in Aceh province.

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