CHARACTERIZATION OF POTENTIAL SLOPE FAILURES ON LATERITIC SOILS

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ABSTRACT

Lateritic soils are commonly consist of unsaturated or partly-saturated soils that have been formed by a very intensive weathering process on a parent rock in a tropical climate with high temperature and rainfall intensity as well that enabling a leaching of heavy minerals and supergene enrichment. The geological structures as indicated by shear zones may form a highly serpentinized rock referred to as mylonite layer as a talc-carbonates-altered rock that having a consistency of very soft to soft. The slope failures (landslides) are commonly occurred on lithologic contacts (interface of limonite-saprolite and saprolite-bedrock as well) in which the failure mechanisms are presumed controlled by presence of a thin soft soil layer with high water content. The erratic ground profiles on the lateritic soils such as undulating, irregular, and anisotropic layers, presence of water table, existence of soft soils on a shear zone, and insufficient of geotechnical investigation program lead some difficulties to determine a potential slope failure in the slope stability analysis. A geological modelling that introducing specific valuable information regarding the position of the shear zones, phreatic lines, ground profiles, and lithologic contacts should be taken into account to obtain a more reliable slope stability analysis result. By a proper geological modeling approach, the potential slope failures and its mechanism can be mitigated prior to the landslide occurs.

Keywords: Lateritic soils, lithologic contact, shear zone, slope failure, geotechnical investigation.

1. INTRODUCTION

There are a lot of number of landslide events occurred in lateritic soils that commonly caused by high rainfall intensity within a long term period. Several failures on a slope excavation had involved a change of slope geometry (height of bench, width of safety berm, angle of individual slope, inter-ramp slope, and overall slope), lithologic contacts (interface of limonite-saprolite and saprolite-bedrock), uncertainty of erratic ground profiles, and presence of a water table on site. Some author's personal notes concluded the slope failures of the lateritic soils are due to either any uncertainty of geological model, presence of an unrecognized soft soil layer, high rainfall intensity within a long term period, and improper geotechnical analysis approach.

To mitigate recurrence of the landslide disaster incidents mainly in lateritic soils, characterization of the potential slope failures should be well organized by means of a systematic geotechnical investigation program to obtain a sufficient data for geotechnical slope stability analysis purpose.

2. LITERATURE REVIEW

Lateritic soils is a residual soil rich in sesquioxides of iron with some mineral enrichment that have been developed in the process of chemical weathering and supergene enrichment under a tropical climatic conditions (Ahmad, 2006). It is commonly consist of unsaturated or partly-saturated soils that have been formed by intensively weathering process on a parent rock with high temperature and rainfall intensity as well that enabling a leaching of some heavy minerals.

Tuncer (1976) has empirically explained a relationship between shear strength parameters of lateritic soils as represented by mechanical properties (cohesion and angle of internal friction) with index properties such as specific gravity, void ratio, and moisture content shown in the Figure 1. Referring to the data, maximum cohesion about 30 psi (or equal with 207 kPa) were achieved in a specific gravity value about 3.0, meanwhile angles of internal frictions increased slightly corresponding with the increasing of the specific gravity, and cohesion values archly decreased as void ratio and moisture content increased.

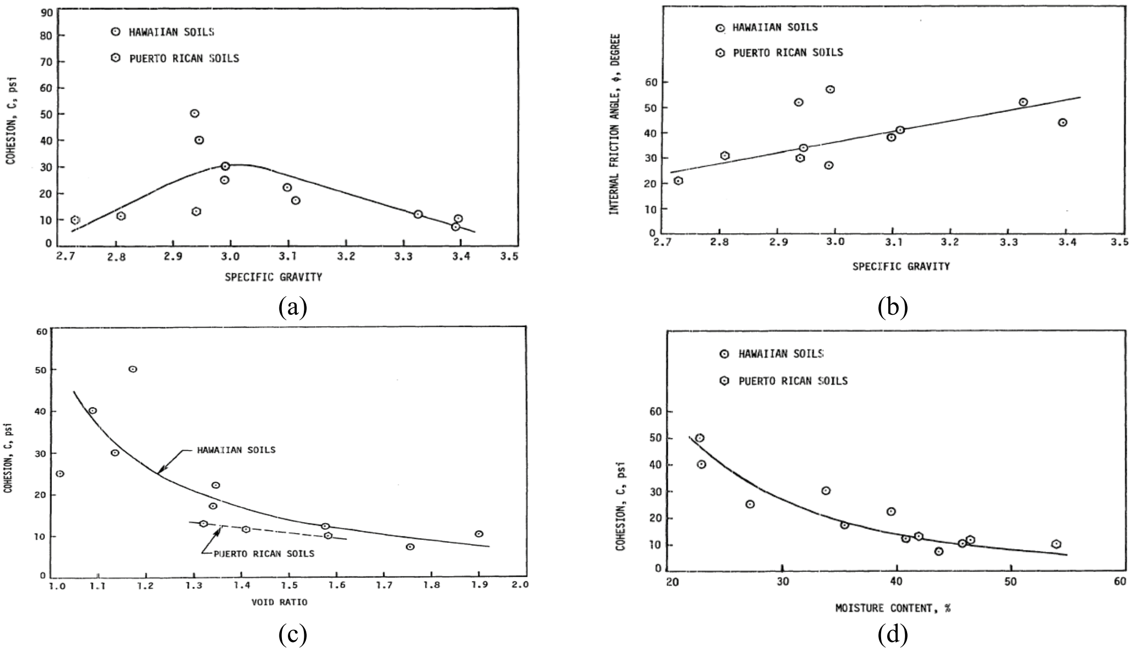
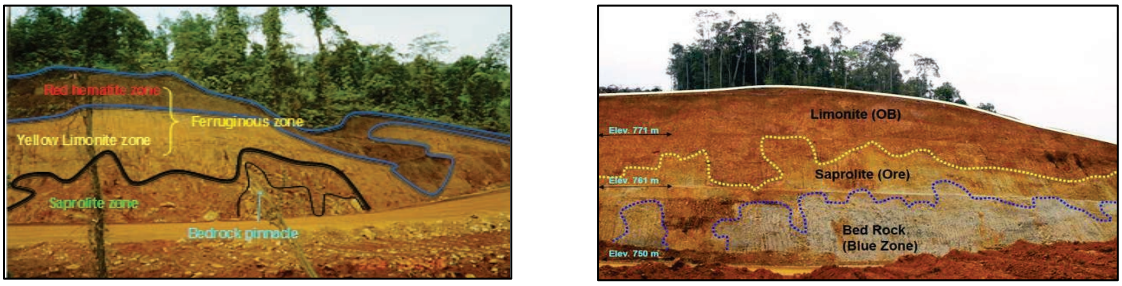


Figure 1. Relationship between: (a) cohesion vs specific gravity, (b) internal friction angle vs specific gravity, (c) cohesion vs void ratio, and (d) cohesion vs moisture content.

It is well recognized that the soils behavior as aforementioned is attributed to the variation in soil structure with varying moisture content, such that, as the soil dries out part of the hydrated colloidal iron and aluminum oxides dehydrates and forms strong bonds among certain soil grains which, in turn, causes an increase in strength (Tuncer, 1976). A weakest thin layer (very soft to soft clayey materials) is commonly encountered in a transitional zone close to the lithologic contact between limonite and saprolite in which the water table fluctuated along the years. The situation becomes more complicated when the problematic soils present in the cut of slope in which topographic depression (commonly a swampy area, sag ponds, and small basins) constitutes a tectonic product of pull-apart structure occasionally appears on the top hill. In this zone, runoff water have been trapped in the depression within a hydrate environment, therefore weathering becomes very intensively formed a montmorilonite clay soil or called as black cotton soils (Wesley, 2010).

Haryanto, et al. (2010) explained the lateritic soils profile is commonly divided into some layers referring to the exploration data and former investigation, as follows: (1) overburden layer that occupies the upper layer, soft and reddish brown to dark, comprises association of goethite and limonite mineral, and occasionally hematite, (2) limonite layer that occupies below overburden layer, fine grained, reddish brown to yellow, slightly soft, rich of iron oxides from limonite cover up the whole area with the thickness until tens meter. Some manganese oxide mineral and occasional talc, tremolite, chromiferous, silica, and gibbsite mineral are encountered in this layer, (3) saprolite layer which has brownish yellow and slightly reddish color, brittle, medium stiff to stiff, occupies the underneath of limonite layer with thickness averages about 7 m, formed by leaching of fine grained limonite and garnierite, silica, manganese oxides deposit of transitional zone from limonite to bedrock, occasionally quartz mineral encountered fill crack & fissures, weathering of major mineral, chlorite, and garnierite; structure and texture of origin rock is commonly can be distinguished obviously, and (4) bedrock layer, constitutes a bottom of the laterite profile as fresh peridotite bedrock with no weathering process occurred, yellow pale until greenish grey, very dense to massive. In this bedrock, strongly fracturing affect opening structure that filled by garnierite and silica minerals.

Typical of laterite profile is generalized into a red limonite soils (hematite) and a yellow limonite soils (goethite) as ferruginous zone, saprolite as supergene enrichment zone, and blue zone as a bedrock layer shown in the following Figure 2 below (Haryanto, et al., 2010; 2016).



(a) (b)

Figure 2. Typical of laterite profiles: (a) at SRK site, (b) at PTA site.

Haryanto, et al. (2016) explained some difficulties to retrieve a very thin soft soil layers in lateritic soils as a potential slip surface by means of the standard penetration test (SPT) in a geotechnical exploratory drilling program. The carefulness of a drilling operator to operate the whole field tests and engineering geologist during undertaking description of the core samples to collect a valid and reliable data is absolutely required. For the first 10 m depth, the N-SPT are commonly ranging from 0 – 3 blows/foot (soil consistency very soft) then relatively increased with depth until 5 – 8 blows/foot (soil consistency soft to medium stiff) meanwhile the shear strength parameters in effective stress such as cohesion about 5 – 15 kPa and angle of internal friction about 15 – 20°. For the next deeper position after penetrating a capillary fringe zone that commonly as lower limonite up to saprolite layer in which the water table fluctuated (partly saturated), the presence of a thin soft layer should be identified by recognizing appearance of the shear zone (highly serpentinized) that characterized by colors of greenish grey mylonite clays, brecciated, and high water content.

3. METHODOLOGY

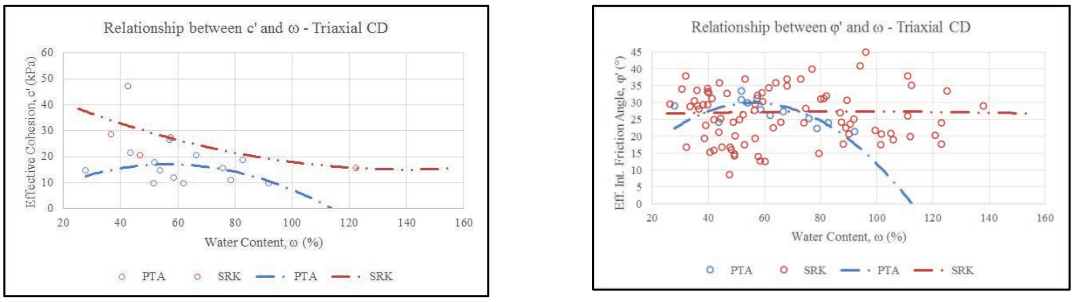
To characterize a potential slope failure on a cut of slopes of lateritic soils, an advanced geotechnical investigation as should be optimized by extending scope of current geotechnical investigation method by means of: (1) increasing number of effective shear strength parameters (since undrained shear strength parameters are not applicable), (2) identifying shear zone, (3) discovering lithologic contacts, and (4) recognizing the extrinsic contributing factors on the slope failures.

However, the geotechnical exploratory drilling program is still the most reliable method to observe soil/rock engineering properties and identifying some critical information to be used in a slope stability analysis as part of landslide hazard mitigation. In addition, a geophysical method e.g. electrical resistivity tomography (ERT) is introduced to retrieve subsurface condition accurately.

4. RESULT AND DISCUSSION

There are several approaches to characterize the potential slope failures on lateritic soils; one of the common methods is geotechnical exploratory drilling to sink core barrel and retrieving undisturbed soil samples (UDS) to obtain index and mechanical properties of soil and/or rock mass for engineering purposes. For cut of slope stability design, the effective stresses parameter (effective cohesion, c' and effective angle of internal friction φ') are compulsory to be explored extensively since the slope geometries would be designed for long term utilization due to the water table allowed to percolate and dissipated gravitationally. However, the undrained shear strength parameters (S_u) from standard penetration test (SPT) and triaxial-UU (undrained unconsolidated) tests are not allowed because the analysis result would be much different with the actual slope condition.

In an effective stress condition that represented by some triaxial CD (consolidated drained) tests, the existence of water content is playing a significant role that commonly influencing shear strength parameters. At least, the 60% of water content is considered as optimum moisture content to contribute the peak strength as shown in the following Figure 3 below.



(a) (b)

Figure 3. Relationship between: (a) effective cohesion and water content and (b) effective angle of internal friction and water content.

Refer to the chart as abovementioned, after exceeding 60 – 80% of water content, the effective stresses parameter decrease significantly. A value of the water content more than 100% in the lateritic soils becomes a serious concern as an indicative data for assuming further geotechnical models. The statement is emphasized by a discovery of carbonaceous clay layer and plenty of organic material with high water content even more than 120% until tens meters thickness. For the slope stability concern, this problematic soil should be carefully assessed in effective condition. Furthermore, the high water contents of lateritic soils are commonly encountered in 7 – 35 m depth following the water table as shown in the following Figure 4.

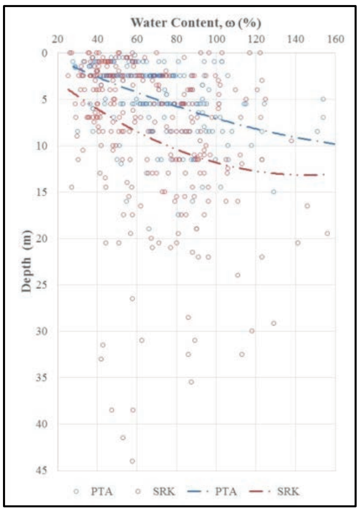
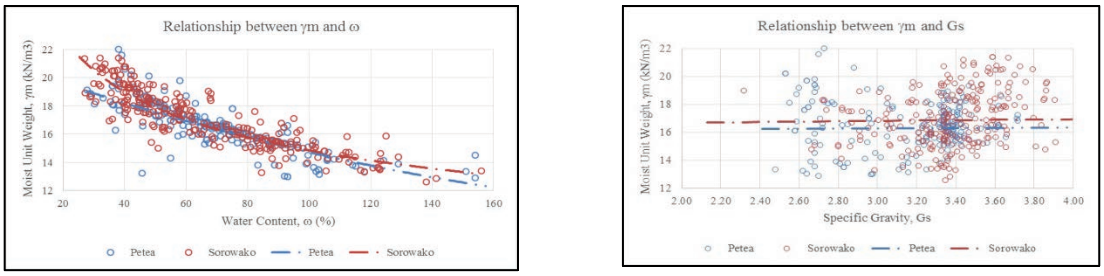


Figure 4. Relationship between water content and depth.

Relationship between water content and unit weight of moisture soils is inversely correlated in which the higher water content the lower unit weight, meanwhile the unit weight of moist soils are relatively not influenced by difference of specific gravity value as shown in Figure 5 below.



(a) (b)

Figure 5. Relationship between: (a) moist unit weight and water content, and (b) moist of unit weight and specific gravity.

The presence of a very moist clayey layer with soft consistency and appearance of shear zones in lateritic soils should be taken into account and well recognized by geotechnical engineers prior to do geotechnical modeling. Based on author's empirical experiences at some slope failures on lateritic soils, a very moist soft clay layer with low to medium plasticity were a slip surface with presence of groundwater seepage on the scarps. In the same way, the shear zones as characterized by a greenish grey mylonite clayey layer were a slip surface as well in which the material mostly wet, friable, and partly altered.

(a) (b)

Figure 6. Core samples: (a) reddish brown clayey silt (MH) at 3.50 – 4.00 m depth in limonite layer, soft, medium plasticity, very moist, and (b) greenish grey mylonite clay (CH) at 20.00 – 20.50 m depth in saprolite layer, very soft consistency, very moist.

The intrinsic factor that contributing the slope failures on the lateritic soils is presence of lithologic contacts or geological structures (i.e. crack, fault, folding, discontinuities, and others) referred to as interface of limonite-saprolite and saprolite bedrock layers. The contacts can be obtained by distinguishing homogeneity of the core samples taken from geotechnical exploratory drilling that characterized by similarity of physical and chemical properties for example color, texture, structure, consistency, weathering degree, presence of certain minerals, and others. Accordingly, the drill-holes data and lithologic contacts shall be used to calibrate an advanced geophysical electrical resistivity tomography (ERT) survey to obtain a more accurate subsurface condition for geotechnical modeling purposes and slope stability analysis as shown in the following Figure 7 below.

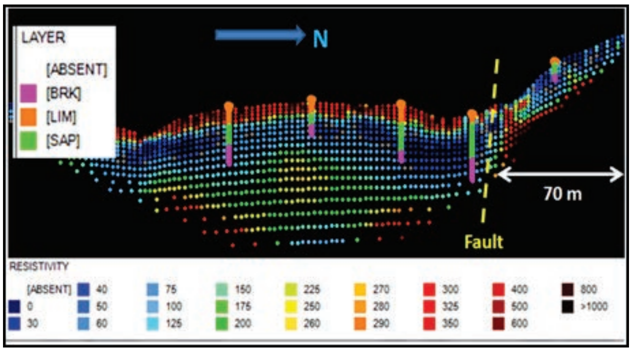


Figure 7. The lateritic soils profile based on ERT and drill-holes
(LIM = Limonite, SAP = Saprolite, BRK = Bedrock)

The subsurface condition including lithologic contacts and geological structures that resulted from reconciliation of the geotechnical exploratory drilling and ERT survey are considered as a reference to presume the probable slip surfaces and potential slope failures in the slope stability analysis.

Several extrinsic factors that can be contributing the slope failures on the lateritic soils such as high rainfall intensity within a long term period, poor drainage system on the crest and toe of slopes, presence of earthquake, and changes of land use and tributary system. The extrinsic factors should be considered in geotechnical modeling and mitigation programs.

5. CONCLUSION

Some critical information that should be taken into account in a geotechnical investigation program such as lithologic contacts (interface of limonite-saprolite and saprolite-bedrock), presence of water table, problematic soils, shear zone (serpentinization), slicken sides, and others that should be recorded in the drill-logs. The problematic soils should be explored more extensively for example: presence of swelling clays, clayey shales (expansive soils), scaly clays, carbonaceous clays with high organic content, and others that occasionally encountered in the lateritic soils.

Carefulness in geotechnical modeling should be a concern when water content of the soils exceeding 100% due to the shear strength parameters drops significantly. For the slope stability concerns on the problematic soils should be assessed in effective condition and cut slopes should be conducted by staging in a long time frame.

As it is known, a geotechnical investigation program has limitation to deliver more accurate data; therefore one of geophysical survey methods becomes another option to overcome the information gaps in between of the geotechnical drill-holes by means of electrical resistivity tomography (ERT) to scanning subsurface condition and geological structures by reading out the electrical resistivity of the ground profile.

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