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Influence of Soil Physical Properties on Rainfall Induced Landslide Susceptible Areas along Cagayan de Oro-Bukidnon-Davao City Route Corridor, Philippines

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ABSTRACT

The Cagayan de Oro (CDO)-Bukidnon-Davao City route corridor plays a vital role in the movement of commerce and trade in the region by linking the two major economic centers of Mindanao, the CDO and Davao Cities. However, this national highway traverses the mountainous ranges of Bukidnon which is prone to rainfall-induced landslides. This study aims to characterize the grain size distribution (GSD), soil consistency (Atterberg Limits) and the influence of moisture content on the yield stress of rainfall-induced landslide prone areas along the route corridor. Majority of the landslide prone areas are dominated by high clay content characterized by high plasticity and high potential to swell (PI > 23 and LL > 50). The yield stress of slip prone clayey soil areas along the CDO-Bukidnon-Davao city highway soil decreased either linearly or exponentially with increasing moisture content. All samples showed critical moisture content which ranged from 60 to 80 % in which a sudden drop of the yield stress was observed. Hence, this study could provide necessary information for various government agencies to come up with pro-active implementation of landslide risk mitigation and management so that cost, hassles and exposure to such risks may be reduced.

Keywords: Atterberg Limits, clayey soil, Grain Size Distribution (GSD), Yield Stress, Soil Moisture

INTRODUCTION

Landslides are among the major geologic hazards in the Philippines which resulted in thousands of lives lost and millions of pesos of economic damage over the years. Most landslides in the Philippines are associated in the areas with steep slopes and relatively moist condition of soils due to abundant rainfall. The commonly observed slope failures in the country include block slide, debris slide and earth creep. Among the most notable landslides that occurred in the Philippines are the Cherry Hills Landslide Tragedy in Antipolo City in 1999 (Morales *et al.,* 2001) and the Guinsaugon landslide in Southern Leyte in 2006 (Ueno *et al.,* 2007). On the other hand, landslides are also the main reason for the frequent closure every year of the Kennon Road, which is the fastest route in going to Baguio City; and the CDO-Bukidnon-Davao route corridor. Hence, the development of hazard map delineating the threat area is essential to reduce significantly the risk from potential geological hazards especially from landslides.

In Mindanao, the Philippines, the CDO-Bukidnon-Davao City route corridor which connects the two major economic centers of Mindanao, the Cagayan de Oro, and Davao Cities, plays a vital role in the movement of commerce and trade in the region by linking the provinces of Misamis Oriental, Bukidnon, and Davao to other provinces in Mindanao. This is evident by the large volume of traffic passing along this national highway. However, this national highway traverses the mountain ranges of Bukidnon, which is prone to rainfall-induced landslides. Over the last decade, the flow of traffic has been disrupted many times due to landslides which resulted in loss of lives. In addition to the loss of human life, the direct and indirect costs from landslides, such as repair, replacement and maintenance of infrastructure, and loss of industrial, agricultural and forest productivity and natural environment, are also high (Lepore *et al.,* 2012).

The intensity of landslides is getting more severe since most of the lofty hill ranges, steep valleys, cliffs, and gorges are eroded and weathered due to rampant illegal logging and agricultural intensification. Landslides triggered by high incidence of rainfall prior to its occurrence and high sensitivity of surrounding soils to absorb water suggest that the residual soils which are commonly found in the mountainous regions in the Philippines have high plasticity and swelling potential due to enhanced weathering over the last two decades (Morales *et al.,* 2001 and Ueno *et al.,* 2007). The weathering of slate, for example, causes a progressive disaggregation to silty clay in which the plasticity of completely weathered material is controlled by the mineralogy of the parent slate. Highly plastic clay soils are locally developed on a non-chloritic slate (Cattell, 1998).

On the other hand, rainfall-induced landslides occur when the excess load generated by water in saturated soil overcomes the yield stress of the soil. The infiltrated water excess in the soil (decrement of the pore pressure) produces a yield stress decrement, and the internal load overcomes the decremented yield stress (Mendez-Sanchez *et al.,* 2009). The saturation of soil with water has an exponential decrement of yield stress which was observed in slip prone areas in the region of Teziutlán-Puebla-México. An abrupt reduction of its yield stress with increasing in water content up to 50% of its initial value was observed which is possible to elucidate an increment in the landslide risk since the sample has changed from solid-plastic to solid-viscous behavior (Mendez-Sanchez *et al.,* 2009).

In this context, this study aimed to characterize the soil physical properties such GSD, soil consistency and examine the influence of moisture content on the yield stress of soils along the landslide prone areas of the CDO-Bukidnon- Davao City route corridor. However, studies concerning the identification of areas with high landslide susceptibility coupled with soil physical properties which are beneficial for the Philippines for better management of its territory particularly its economically important road networks are still lacking. Hence, this study is essential since it could provide a substantial basis for proper design and construction of highways and roads along the critical areas where the landslides would likely to occur. Figure 1 presents the conceptual framework of the study.

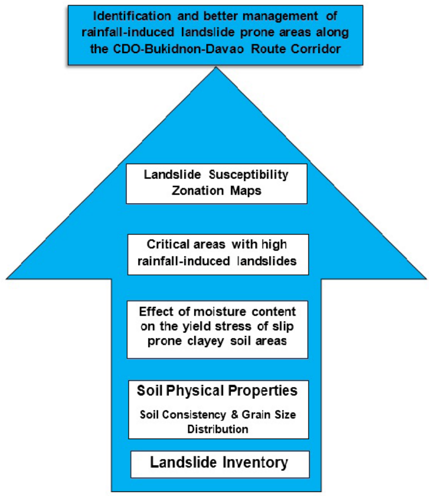

Figure 1. Conceptual Framework of the Study.

METHODOLOGY

Location of the Project Study

The project study was conducted along the Cagayan de Oro-Bukidnon-Davao City national highway. The highway is geographically lying between 124^0 30' 0" to 125^0 30' 0" E longitude 7^0 30' 0" to 8^0 30' 0" N latitude from Cagayan de Oro City and passing through the municipalities of Impasug-ong, Kitaotao, Malaybalay City, Manolo Fortich, Maramag, Quezon, Sumilao and Valencia City which are all located in Bukidnon; Arakan of North Cotabato; and Davao City (Figure 2). The study was started on November 22, 2012, and terminated last May 21, 2014.

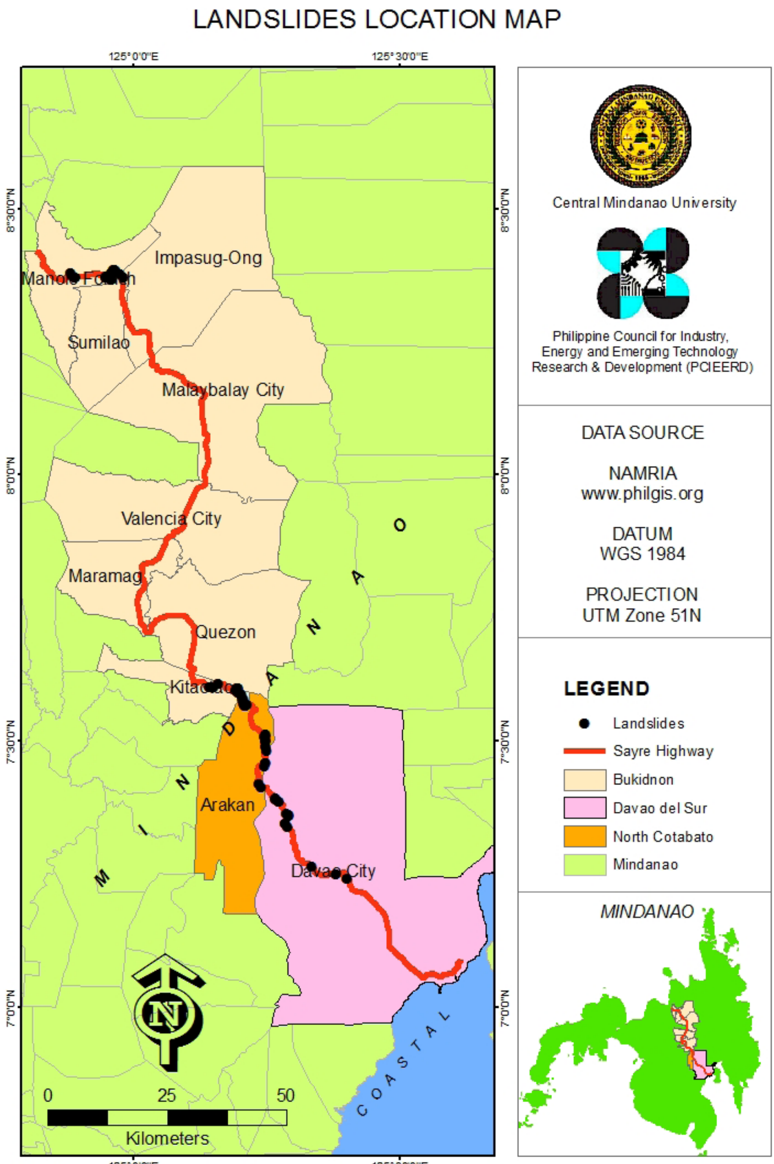

Figure 2. Location Map of the Slip and Landslide Occurrences along the Cagayan de Oro – Bukidnon - Davao City Route Corridor.

Landslide Inventory

Landslide inventory was done by gathering data from DPWH and site survey. Extensive ground validation of the area was done by surveying the road from Cagayan de Oro to Davao City via Bukidnon for every one-kilometer distance. The landslide location map shows the location of slip and landslide occurrences along the study area.

A total of 78 landslide occurrences were inventoried after noting the coordinates of the landslide location using the global positioning system (GPS). During the period covered, one hundred percent (100%) count was conducted within the buffered zones of 250 meters from both sides of the highway. As shown on the landslide location map (Figure 1.), most of the slips and landslide occurrences happened in the southern part of the study area which covers mostly the municipalities of Kitaotao, Arakan, and Davao City. There were also slip and landslide occurrences recorded in the northern part of the study area covering the municipality of Manolo Fortich and between Sumilao and Impasug-ong municipalities. In the central part of the study area covering the Municipalities of Malaybalay, Valencia, and Maramag in Bukidnon, there were no recorded slips and landslide occurrences since the studied road path along these municipalities traverses the gently rolling to flat terrain.

Collection of Soil Samples

The slip prone clayey soils were collected in the vicinity along CDO-Bukidnon-Davao City route corridor using a method of disturbed sampling. The shovel was used in getting the soil from the site, and steel tube of 2.5 inches (63.5 mm) in diameter and 32 inches (800 mm) high was bored into the soil to obtain the undisturbed sample from the site for unit weight determination. The soil was sent to the laboratory to determine the unit weight.

Sample Preparation

The slip prone clayey soils were air-dried and pulverized using a rubber mallet to pass sieve no. 8 (2.36 mm opening) before mixing. The soils were prepared by mixing the required mass per sample depending on the kind of test. The digital weighing scale and non-digital weighing scale were used to determine the required amount of soil.

Soil Consistency and GSD Determination

The liquid limit test was determined using ASTM D4318-10 Standards Test Methods using the Casagrande cup device. The moisture content corresponding to 25 blows graph from the semi-log scale determines the liquid limit of the soil.

The plastic limit and plasticity index of the soil samples was obtained using ASTM D4318-10 as the basis of the study. The soil is rolled in a smooth glass to obtain 3.2 mm diameter before oven drying for the determination of water content that will give the plastic limit of the sample. The value of the plasticity index is given by the formula PI=LL-PL; where PI is the plasticity index, LL is the liquid limit and PL is the plastic limit.

The grain size distribution was performed using sieve analysis. Grain size analysis was conducted according to ASTM D421. A set of sieves was prepared by stacking test sieves one above the other with the largest openings as the first sieve followed by smaller sieves successively and a pan at the bottom. A sample of dry soil was poured onto the top sieve and was shaken by hand or mechanical device. The retained soil on each sieve was determined by weighing the retained soil. From the retained soil, cumulative weight retained above each sieve was also determined. Then the equivalent percent passing on each sieve was also computed.

Yield Stress Determination

The collected soil samples from slip prone areas were sieved with a standard No. 8 (2.36 mm) mesh to eliminate larger debris. The soil samples were pulverized first before sieving. Samples of 0.3 kg of soil were prepared at 30-40 wt% of water concentration, and slump test experiments were carried out as suggested by Pashias *et al.* (1996). The method consisted of filling a cylindrical frustum with the material to be tested in a specified way; lifting the frustum off and allowing the material to collapse under its weight. The height of the final slumped material was measured, and the difference between the initial and final heights is called the slump height (s) Yield stress value (Ty) was calculated by following expression suggested by Pashias *et al.* (1996), where p is the material density, g is the gravity, s is the slump height, and H is the frustum height. In this case, the slump height was measured immediately after lifting the frustum.

$$\tau_y = \rho \mathrm{gH} \left[\frac{1}{2} - \frac{1}{2}\sqrt{\frac{s}{H}}\right]$$

RESULTS AND DISCUSSION

Soil Consistency and Grain Size Distribution

Soil consistency and grain size distribution (GSD) are one of the major contributing factors in the slip prone areas of the corridor. Moreover, the lithology of soil which includes the particle size of the soil attributes are very important in determining the shear strength, permeability and other characteristics of soil and rock materials. These soil characteristics can affect the slope stability (Varnes, 1984) and the Atterberg limits of the soil (Msilimba, 2007).

There were 20 sampling sites selected based on the Landslide Susceptibility Index Zonation (LSI) map generated that consider different landslide-inducing factors and landslide history (Opiso *et al.,* 2014). Depending on the water content, soil may behave as a solid, semi-solid, plastic or liquid. The amount of water needed to change the behavior depends on the type of clay mineral present (Selby, 1993). Liquid and plastic limits are significantly controlled also by the clay content and clay mineralogy (Wahono, 2010). Table 1 shows the soil consistency of the 20 soil samples. Most of the soil sampling sites are located in the southern part of the study particularly the soil samples from Maluko, Maloos, Lorega, Sitio Balite and Datu Salomay. These soils showed plasticity index (PI) values of 33.07, 32.90, 32.54, 32.94, and 47.66, respectively. Based on IS 1498, the degree of expansion of soil in the study areas ranged from high to very high. Hence, these areas are not suitable for road construction or might be suitable but with the proper application and good blending ratio of cement materials for road construction. Moreover, soil samples from Kibalang, Kabalansihan, and Brgy. Lacson exhibited PI values of 27.36, 23.19, and 23.78 respectively. Because the study area is mountainous, soil with PI >25 and LL > 50 have high potential to swell and expand when in contact with water (Das, 2010). According to Handy and Spangler (2007), when the soil moisture content exceeds the liquid limit in the field, this event generates the dangerous and prospectively devastating results as the soil appears to be stable but can unexpectedly break away when distressed.

Table 1. Atterberg Limit and Grain Size Distribution of the 20 Selected Sampling Sites of Cagayan de Oro –Bukidnon – Davao City Route Corridor

Sample No.	Sampling Site	Atterberg Limits			Grain Size Distribution		
		Liquid Limit	Plasticity limit	Plasticity index	Gravel	Sand	Silt & Clay
S_1	Lower Tankulan	37.41	21.74	15.67	1.1	37.22	61.68
S_2	Upper Tankulan	52.00	33.33	18.67	9.72	39.59	50.68
S_3	Maluko	66.93	33.86	***33.07***	0.96	14.49	84.56
S_4	Sitio Angeles	27.52	19.95	7.58	33.68	21.64	44.67
S_5	Mangima/Dalirig	44.94	23.10	21.84	5.48	39.56	54.96
S_6	San Vicente	35.45	20.51	14.94	4.15	45.59	50.26
S_7	Palacapao	38.91	21.25	17.66	1.55	47.46	50.99
S_8	Overview	36.49	21.23	15.25	3.35	36.29	60.37
S_9	Sitio Krusher	45.70	24.52	21.18	2.06	37.88	60.06
S_{10}	Maloos	62.06	29.16	***32.90***	0	13.41	86.59
S_{11}	Maloos Bridge	53.51	34.03	19.48	4.93	28.14	66.93
S_{12}	Kabalansihan	49.55	26.37	23.19	0	13.93	86.07
S_{13}	Sitio Balite	60.31	27.38	**32.94**	0	19.47	80.53
S_{14}	Kibalang	50.73	23.27	27.36	0	30.72	69.28
S_{15}	Ladian	54.86	35.30	19.56	0.17	14.22	85.61
S_{16}	Lorega	68.02	35.49	***32.54***	0	13.62	86.38
S_{17}	Datu Salomay	87.89	40.24	***47.66***	0.26	9.7	90.04
S_{18}	Marahan	64.68	42.99	21.69	0	6.83	93.17
S_{19}	Marahan unahan	38.28	24.22	14.06	2.3	27.78	69.93
S_{20}	Brgy Lacson	50.84	27.06	23.78	3.12	20.32	76.56

On the other hand, the highest percentage of clay and silt particles were observed in the soil samples obtained from Datu Salomay (90.04%) as shown in Table 2. This result supports the aforementioned Atterberg limit test in which Datu Salomay also obtained the highest plasticity index. All the soil samples showed a passing percentage of more than 10% for sieve no. 200, which may also, indicates the high degree of expansiveness of the soils along the slip prone clayey soil areas along the Bukidnon-Davao City Highway. Thus, the expected high clay content of the landslide areas with high degree of expansion suggest that the type of clays in the study area can absorb a large amount of water causing the infiltrated rainwater to be accumulated. This will eventually result to slope instability particularly in areas with slope percent of greater than 45% since the absorb water can increase the unit weight of the soil.

Yield stress vs. Soil moisture

The yield stress of the soil is the fundamental parameter that governs the stability of soil slopes, and is the minimum stress for irreversible deformation and flow to occur. At the moment rainwater penetrates the soil that is originally in an unsaturated condition, several parameters will be adversely affected. The infiltration process of rainfall influences the results in changing soil suction, positive pore pressure, ground water table, as well as increasing the weight of soil unit, diminishing shear strength of rock and soil (Wahono, 2010). The slump test method is a simple way of estimating the yield stress of the soil since the yield stress is expressed as a function of water content, height of cylindrical frustum, slump height and material density (Mendez-Sanchez, 2012).

The use of slump test method in the yield stress determination of slip prone clayey soil areas along the Cagayan de Oro-Bukidnon-Davao City Highway showed the influence of moisture content on the yield stress of the soil. The results showed that the increasing moisture content in the soil can significantly reduce its yield stress which is due to the colloidal interaction between water and clay particles in the soil, particularly during long and heavy rainfall. This condition will eventually lead to a sudden drop of its yield stress and will trigger a mass movement of soils. The results also showed that the yield stress of the soil samples ranged from around 2300 N/mm2 to slightly above 500 N/mm2 with corresponding moisture content ranging from 30 to 90% as shown in Figure 3. Except for Datu Salomay and Kibalang, the critical moisture content which corresponds to the sudden decrease in yield stress is between 60 to 70% while that of the two sites mentioned above ranged between 80 to 85%. The results also suggest that an equivalent amount of rainfall ranging between 210 to 300 mm could reach the critical moisture content assuming that the total rainfall is the source of the moisture content of the soil and produces a homogenous mixture.

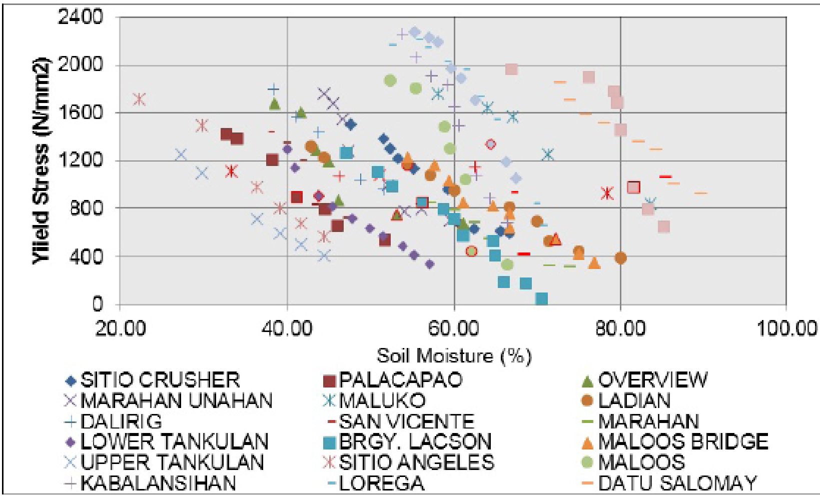

Figure 3. Yield Stress of the Soils Samples as Influence by Moisture Content.

CONCLUSIONS

The Atterberg limits test showed that Datu Salumay of Davao City obtained the highest plasticity index with the value of 47.66 followed by Maluko, Sitio Balite, Lorega, Kibalang, Kabalansihan with the plasticity index of greater than 23. The majority of the landslide prone areas are dominated by high plasticity and high potential to swell (PI > 23 and LL > 50) type of mountain soils. The highest percentage of clay and silt particles was also observed from Datu Salomay (90.04%). These properties can influence the rate of water movement and the capacity of soil to hold water.

The yield stress of the soil samples ranged from around 2300 N/mm2 to slightly above 500 N/mm2 with corresponding moisture content ranging from 50 to 90%. Except for Datu Salomay and Kibalang, the critical moisture content which corresponds to the sudden decrease in yield stress is between 40 to 70% while that of the two sites mentioned above ranged between 80 to 85%. The results also showed that the increasing moisture content on the soil can significantly reduce its yield stress which is attributed to the colloidal interaction between water and clay particles in the soil, particularly during long and heavy rainfall.

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