BU R&D Journal
22 (1): 25-32, July 2019 | ISSN (Print): 0016-4139
journal.bicol-u.edu.ph

Geotechnical Characterization of the Soil along the Banks of the Sagumayon River in the Province of Albay, Philippines

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Abstract

The effects of pollution, weather and climate, and societal pressures had changed drastically the physical characteristics and use of the Sagumayon River, an important river network in the city of Legazpi. This study aimed to obtain relevant geotechnical engineering properties of the soil along the river banks, which could provide an indication of its vulnerability to erosion, settlement, and slope failure. *In-situ* and *ex-situ* tests conducted in four areas of the river along an 800-m stretch within the Bicol University–Main Campus revealed a granular type of soil, poorly graded sand with silt (SP-SM) of low SPT N-value (from 2–20 blows/ ft), friction angle of 27° to 33° and Soil Bearing Capacity of 74 ~ 217 kPa. The riverbank soils are susceptible to certain modes of erosion, settlement, and slope failure. The soil is comprised of 82% sand and 18% silt. Borehole sites with shallow groundwater table have been found to exhibit high soil moisture content values. Structures that will be built on the area should be designed to allow a tolerable, even settlement of 25 mm and up to 37.5 mm of maximum differential settlement. The study recommends that the index properties obtained be used in conjunction with cross-sectional survey data of the river banks to analyse the stability of the slopes. Remedial measures should be provided to secure against further surface erosion. In the design of structures to be built on the area, there is a need to validate the soil properties by drilling more bore holes to ensure stability of structures.

Keywords: *cohesion, erosion, friction angle, N-value, Sagumayon River, settlement, slope failure, soil bearing capacity*

Introduction

Owing to its geographic location, the province of Albay is historically known to be vulnerable to natural disasters and the ill effects of climate change. Earthquakes, tsunamis, typhoons, and volcanic eruptions are among the natural hazards that pose a threat to the locals' lives and properties. The climatic and geographic conditions in the province can be attributed to the frequent occurrence of typhoons, monsoon rains, and thunderstorms. These causes the province to experience more pronounced precipitation during the rainy season and no distinct dry season (Espinas, 2013).

The Sagumayon River stretches all the way from Daraga, traversing the Bicol University–Main Campus over an 800-m stretch winding through the Albay District area and spills out into the sea. During heavy rains and especially during typhoons, the river becomes flooded (DENR-EMB Region V, 2014). Over the years, degradation of the said river has led to scouring, bank collapse, erosion, and sedimentation that pose direct risk to lives and properties within the university and the communities along its path. Intensive seasonal rainfall could lead to the failure of natural slopes which are principally caused by the rise of the groundwater level and the loss of the inbound shear strength of the soil (Tsuchida, 2014).

The present state of the Sagumayon River provides the university with a natural laboratory to study and apply geotechnical and hydrologic engineering theories and principles to reduce hazards and mitigate disasters brought about by flooding and erosion. By conducting a thorough investigation in terms of topographical, hydrological, and geotechnical aspects, a comprehensive engineering plan may be drawn-up and implemented to rectify the causes of the river's degradation and identify the different structural characteristics of the underlying strata (Perri *et al.*, 2014). Opportunities for the rehabilitation of the river system exist since what happens to the portion of the river within the university is affected by what happens upstream and downstream

(DENR-EMB Region V, 2014).

In the not so distant past, with its pristine and healthy state, the Sagumayon River was intimately interwoven into the social aspects of the Legazpeños' way of life. The physical condition and hence usage of the Sagumayon River has changed drastically through the years because of pollution and the physical effects of rains and typhoons that led to scouring, erosion, and sedimentation.

This study sought answers to the current concerns regarding the geotechnical condition of the Sagumayon River. Through this research, the college will acquire design and planning experience that will address similar cases in other river systems in the Bicol Region. The region, being one of the most frequently visited areas by typhoons in the country, benefits significantly from this research.

The study is related and supportive of the Bicol University (BU) Comprehensive Development Plan by providing basis for a sound development strategy in terms of disaster reduction and risk mitigation for the affected area, which is the target of development expansion of the university. It also supports the Sagumayon River Management Council's objective to rehabilitate Sagumayon River as an eco-tourist attraction in the province of Albay showcasing a society that works as one for a balanced ecosystem towards the improvement of life for succeeding generations (Nasayao, 2012).

In reducing risks and assessing the vulnerability of the Sagumayon River, the study aimed to obtain the relevant engineering characteristics of the soil along the banks of the Sagumayon River, which could provide an indication of its vulnerability to erosion, settlement, and slope failure. Similarly, results of the geotechnical properties in this area are vital for design purposes and will be an input in the slope stability analysis of the banks. Available hazard maps in the region do not usually consider geotechnical inputs, particularly the soils' strength characteristics. Shear strength parameters must be considered under different conditions which need to be taken into account (Tsuchida, 2014) in assessing the vulnerability of a slope to failure. Studying the underlying condition of soils will also help and guide designers to design an appropriate structure for a particular area (Long *et al.*, 2009).

Specifically, the study aimed to determine the soil's shear strength parameters (friction angle, cohesion) based on the properties obtained from field tests conducted and determine the soil bearing capacity as basis in the design of structures, determine the geotechnical physical properties of the representative soil samples along selected points in terms of specific gravity, particle size distribution, engineering classification, moisture content, void ratio, porosity, and unit weight; and relate the soil's geotechnical characteristics to its susceptibility to erosion, settlement, and slope failure.

Materials and Methods

The conduct of geotechnical investigation (*in-situ* and *ex-situ*) gives accurate information for the underlying substrata (Fauchard & Meriaux, 2007). To obtain the relevant engineering properties of the soil along the bank of the Sagumayon River, *in-situ* and laboratory tests conforming to American Society of Testing Materials (ASTM) standards were conducted. Borehole samples were obtained from four sites strategically located along the river.

Field Test: Standard Penetration Test (SPT) – ASTM D-1586

The SPT procedure consist of driving a standard split spoon sampler into the ground by blows in three (3) successive 150 mm intervals using a drop hammer of mass 63.5 kg falling "free" from a height of 760 mm. The sampler is driven to penetrate 150 mm into the soil and recorded until the third interval, and the number of blows (N) required to drive the second and third interval are added to give the N-value. The number of blows (N) is called the standard penetration number, which measures the density or consistency of the underlying soils (Bowles, 1996; Budhu, 2011; Das & Sobhan, 2014).

Laboratory Test

The following standard tests were used for the determining the various properties of the soil:

a. Specific Gravity of Soils (Test for Specific Gravity of Soil Solids, ASTM D-854)

b. Particle Size Distribution/Analysis of the Soil (Particle Size Analysis of the soil, ASTM D-422)

c. Classification of Soils for Engineering Behavior (Unified Soil Classification System, ASTM D-2487)

d. Laboratory Determination of Moisture Content of Soils (ASTM D-2216)

In determining the soil's shear strength parameters based on the field test, correlation of N-value from the field test were used. The value of friction angle was correlated and computed alongside the N-value acquired from *in-situ* test. SPT N-Value corrected and correlated by Peck and colleagues (1974) and approximated by Wolff (1989) was used.

$$\varphi'(\text{deg}) = 27.1 + 0.30(N_1)_{60} - 0.00054[(N_1)_{60}]^2$$

Similarly, Terzaghi's Bearing Capacity Equation was used in the calculation for the allowable soil bearing capacity as basis in the design of structures which mostly provide an acceptable result (Salahudeen & Sadeeq, 2016).

$$q_{ult} = cN_c + qN_q + \frac{1}{2}\gamma BN_\gamma$$

Table 1. Correlation of N-Value, γ, Dr, and φ for Coarse–Grained Soils (Budhu, 2000; Das & Sobhan, 2014)

N –Value	Description	γ (kN/m3)	Dr (%)	φ (°)
0 – 5	Very Loose	11–13	0–15	26–28
5 – 10	Loose	14–16	16–35	29–34
10 – 30	Medium	17–19	36–65	35–40
30 – 50	Dense	20–21	66–85	38–45
>50	Very Dense	>21	>86	>45

To relate the soil's geotechnical characteristic to its susceptibility to erosion, settlement, and slope failure, topographic survey and hydrological survey results were compared and analysed along with the results of the geotechnical investigation (Table 1).

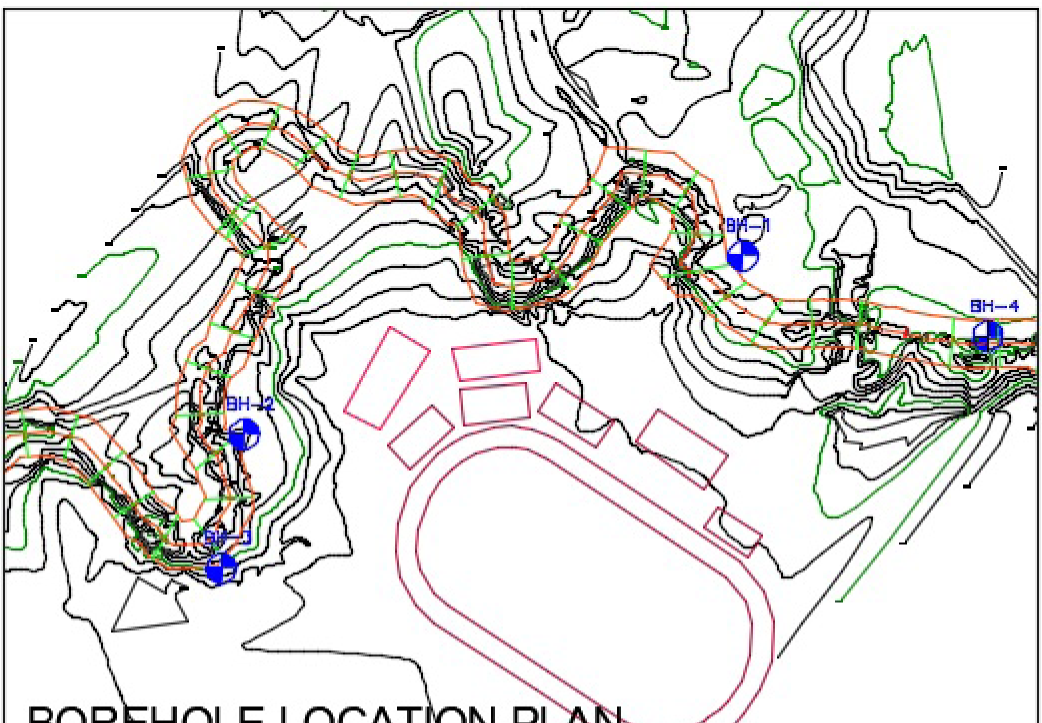

Figure 1. Plan Showing the Portion of the Sagumayon River Inside the BU–Main Campus & Soil Sampling Locations

Results and Discussion

In-Situ Test of Shear Strength Parameters

Four borehole tests were conducted at sites BH-01, BH-02, BH-03 and BH-04 as shown in Figure 1. The results of the standard penetration test showing the N-value and the description of the soil is presented in Figure 2 and Table 2. The groundwater table location is also shown in the SPT diagram (Figure 2).

From the particle size distribution and analysis conducted, the soil along the riverbank has an average soil composition of 82% sand and 18% silt and clay. Thus, the soil can be generally classified (per Unified Soil Classification System) as Poorly Graded Sand with Silt (SP-SM). Hence, for the shear parameters, only the friction angle will have a value and the cohesion will be considered zero (Rogers, 2006). Friction angles and soil bearing capacity was calculated from Peck and Terzaghi's equations, respectively. Table 2 tabulates the N-value versus depth and the corresponding friction angle and bearing capacity for each borehole.

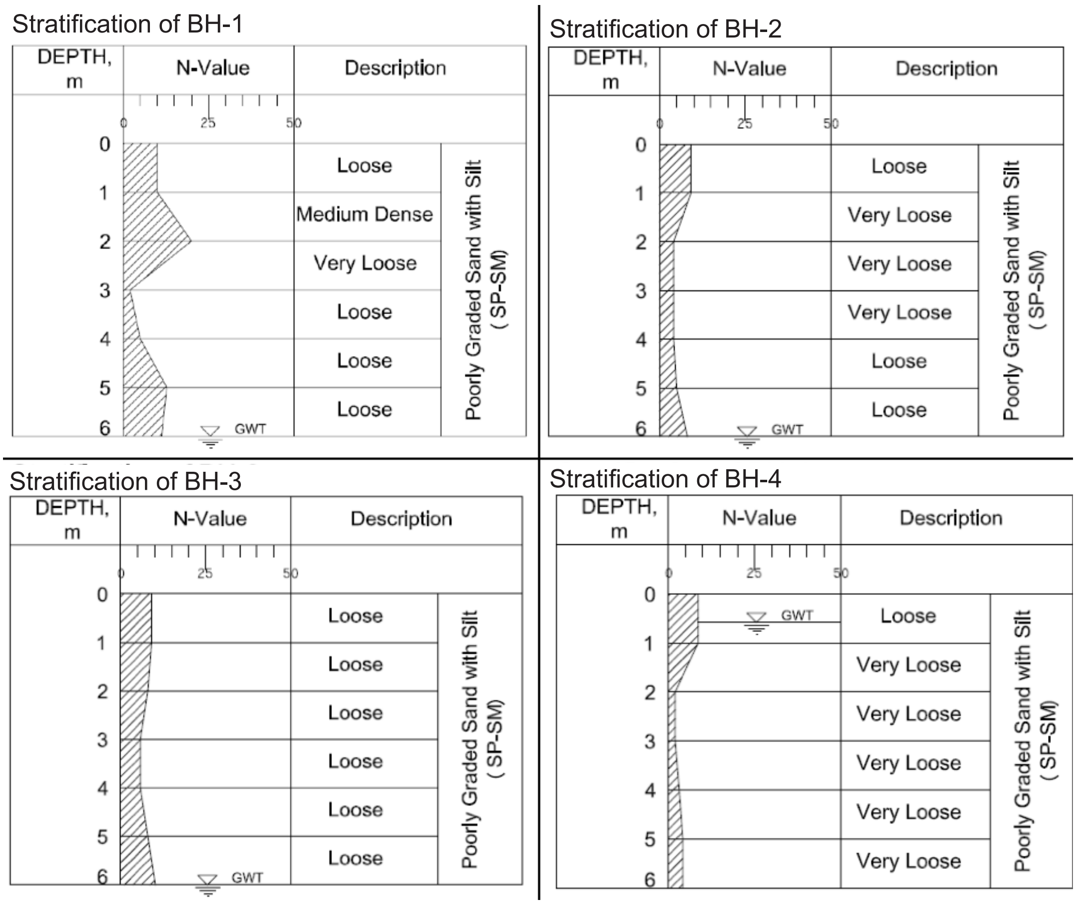

Figure 2. Stratification of Soil Profile for the Four Boreholes Drilled Along Sagumayon River Showing N-Value, Soil Classification and Soil Description Report

BU R&D Journal, Vol. 22, July 2019
ISSN (Print): 0016-4139
journal.bicol-u.edu.ph

Table 2. SPT N-Value Results vs. Depth (m) with the Corresponding Values for Friction Angle and Soil Bearing Capacity

Borehole No.	Depth	SPT N-Value (blows/ ft)	Friction Angle (Degrees)	Soil Bearing Capacity (kPa)
Borehole #1 (Station 0+180)	0 – 1	10	30	128
	1 – 2	20	33	217
	2 – 3	2	27	74
	3 – 4	5	29	144
	4 – 5	12	31	160
	5 – 6	11	30	136
Borehole #2 (Station 0+640)	0 – 1	9	30	124
	1 – 2	4	28	77
	2 – 3	4	28	77
	3 – 4	4	28	77
	4 – 5	5	29	144
	5 – 6	7	29	166
Borehole #3 (Station 0+680)	0 – 1	9	30	124
	1 – 2	8	29	166
	2 – 3	6	29	160
	3 – 4	6	29	160
	4 – 5	8	29	166
	5 – 6	9	30	124
Borehole #4 (Station 0+040)	0 – 1	8	29	166
	1 – 2	2	27	74
	2 – 3	2	27	74
	3 – 4	3	28	76
	4 – 5	4	28	77
	5 – 6	4	28	77

The SPT N-Value of a soil is an indication of its susceptibility or resistance to settlement. According to the National Structural Code of the Philippines, an N-Value of <6 indicates that the soil is compressible (NSCP, 2010). Several strata, especially at BH-2 and BH-4, have N-values lower than 6. Thus it can be said that the area under investigation is susceptible to settlement.

Geotechnical Physical Properties of the Soil Along the Riverbank

Laboratory tests were conducted to determine specific gravity, water content, void ratio, porosity, and unit weight of the soil samples from the boreholes (Table 3). The soil properties derived from tests show that the volume of voids is much larger than the volume of soil particles in most of the sampling sites. The unit weights, meanwhile, have values that belong to the low range of typical soil unit weight values. These corroborate the *in-situ* findings that the soil along the Sagumayon River is loose and easily compressible. Any structure that will be built on a very loose area should be designed to tolerate soil settlement of 25 mm and a maximum differential settlement of 37.5 mm (Bowles, 1982).

Table 3. Geotechnical Properties for Sagumayon River Soil

Borehole Number	ω (%)	Specific Gravity, (G_s)	Void ratio (e)	Porosity (n)	Unit Weight, (kN/cu.m)
1	38.12	2.30	0.88	0.54	16
2	54.62	2.22	1.26	0.56	14
3	56	2.25	1.16	0.56	15
4	56.86	2.13	1.26	0.47	13

Susceptibility to Erosion, Settlement, and slope Failure

The soils' shear strength parameters, geotechnical properties, and cross-sectional configuration can be used to gauge susceptibility to erosion, settlement, and slope failure.

Soil Erosion. The soils in the study site have high sand content. Sandy types of soils are the most susceptible to soil erosion (Lujan, 2003). Particle sizes between 0.063 to 0.250 mm are the most vulnerable to detachment. Streambank erosion is evident on-site. Authors and co-workers report that bank scouring was evident in the widening distances between banks as observed throughout the years in various portions of the river. Water erosion can also be a consequence of degradation of the soil structure, especially the functional attributes of soil pores to transmit and retain water. Cipriano (2018) reports that the average velocity of water along the Sagumayon River is 0.447 m/s, while the average discharge is 0.135 m^3/s.

Settlement. The SPT N-value of the soil can be directly related to its compressibility and susceptibility to settlement. The low N-value of the soil in the four boreholes indicates that they have low bearing capacity and high compressibility.

Slope Failure. The topographical characterization reports that the riverbank slope can be characterized as rolling to slightly steep. The average slope of the riverbank is estimated at 65.24%. Riverbank sections with riprap protection have slopes as steep as 70%. Although no slope stabilization analysis is included in this report, it can be pointed out that the shear strength parameters and soil properties derived from the tests indicate that the soil might exhibit slope failure in the near future. Riverbank slope failures usually occur during periods of heavy or prolonged rains. The failures of natural slopes are mainly caused by the rise of groundwater level and the loss of inbound shear strength of soils due to intensive seasonal rainfalls (Tsuchida, 2014).

Conclusion

Based from the field test conducted using Standard Penetration Test (SPT), the type of soil at the site is Poorly Graded Sand with Silt (SP-SM). The soil's shear strength parameters, friction angle, and cohesion were correlated from the SPT N-Value. Since the soil is granular, the soil's cohesion is considered to be zero. The soil's friction angle on the other hand ranges from 27° to 33°. The soil bearing capacity's lowest and highest value is 74 kPa and 217 kPa, respectively. Soil bearing capacity is an important parameter in designing structures. These values will guide designers in coming up with appropriate retaining structures for the riverbank. Building structures to be built near the area should follow the guidelines of the National Structural Code of the Philippines regarding construction sites with soils that are compressible and highly susceptible to settlement.

The specific gravity (G_s) value obtained for each boreholes are 2.13, 2.22, 2.25, and 2.30. The particle size distribution and classification analyses show that all borehole test site have consistently similar values. Moisture content was comparatively higher (ω = 56.86%) for the borehole wherein the groundwater table was shallow. Void ratio values range from 0.88 to 1.26 which are high values. This means that the volume of voids (air and water) is higher compared to the volume of soil particles. On the average the soil is 50% porous. Porosity has a direct relationship with permeability. For the unit weight of soil, the lowest and highest values are 13 kN/m^3 and 15 kN/m^3, respectively. Values for the unit weight of soil are essential in the design of retaining structures and calculations for the bearing capacity of soil.

If we are to relate and characterize the susceptibility to erosion, settlement, and slope failure of the soil along

Sagumayon River based on the *in-situ* and *ex-situ* tests conducted, it can be said that indeed that the soil and the whole site are vulnerable. The sandy types of soil present at the site with a particle diameter range of 4.75 to 0.075 mm are susceptible to detachment or erosion. The SPT graph and diagrams show that the majority of the soil strata are loose. The low N-values indicate that the soil is soft or loose at the test sites. These values also indicate poor soil bearing capacity and susceptibility to settlement. The NSCP code states that if N<6 the soil is considered compressible.

Although few data were obtained from the limited number of borehole samples, it is recommended that remedial measures be implemented to ensure the protection of the University's assets along the Sagumayon River from erosion, slope failure, and settlement.

The index properties obtained should be used in conjunction with cross-sectional survey data of the banks of the river to analyze the stability of the slopes of the riverbank. Similarly for the unprotected slopes, remedial measures need to be provided to secure against further surface erosion. In the design of structures to be built on the area, there is a need to validate the soil properties by drilling more bore holes to ensure stability of structures.

There are areas at the southern part of the Bicol University that need immediate attention to prevent further deterioration of the physical condition of the river. River encroachment due to house constructions should be strictly monitored so as to prevent narrowing of the river and decrease in river capacity.

A possible mitigation is to invest in the conservation of biodiversity along the Sagumayon river, especially trees (Galias *et al.*, 2018) which are known to maintain a healthy soil and water balance. Kalikasan Park, a large expanse of secondary growth forest proximate to Bicol University, also rely on the Sagumayon river for the provision of important water and soil nutrients. Reciprocally, the Kalikasan Park is home to a variety of flora and fauna such as birds (Serrano *et al.*, 2019), bryophytes (Membreve *et al.*, 2019) and ferns (Mirandilla *et al.*, 2018).

Acknowledgment

This research endeavor has been conducted under the auspices of the Research and Development Center of the Bicol University.

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