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GEOTECHNICAL CHARACTERIZATION OF ALLUVIAL SOIL AS AN ALTERNATIVE ROADWAY CONSTRUCTION MATERIAL

*Emerzon S. Torres[1] and Mary Ann Q. Adajar[1]

[1]Department of Civil Engineering, Gokongwei College of Engineering, De La Salle University, Philippines

* Corresponding Author, Received: 28 May. 2020, Revised: 03 Jan. 2021, Accepted: 13 Feb. 2021

ABSTRACT: The rapid infrastructure development in the Philippines over the past years poses problem on construction cost due to the limited supply of suitable road foundation materials within economic haul distances. An economic and sustainable solution is to use locally available but suitable materials. This study utilized the naturally-occurring alluvial soil along the Angat Riverbanks as a potential road foundation material. Geotechnical characterization of the alluvial soil was performed including direct shear and California bearing ratio (CBR) tests. The findings of the index properties showed that the alluvial soil is 92% sand, non-plastic, and was classified as poorly-graded sand. A CBR of 41% makes the river sand a suitable subbase course material. However, the sample failed on the gradation requirement for subbase application due to lacking of coarse aggregates. From the direct shear tests, the soil showed brittle failure that yields peak shear stress and dilative volume change behavior. The critical state friction angles for dry and saturated conditions are 37.52° and 36.61°, respectively. Morphological analyses were also performed to further evaluate the material composition of the alluvial soil. The sedimentological analysis found that the sample is both texturally and compositionally immature. Sediments are angular to subrounded and moderately sorted. Correspondingly, the SEM-EDX revealed flocculation with flakey particles and small inter granular voids that justifies the shear strength of the sand. It is recommended to blend coarse aggregates with the alluvial soil to meet the gradation requirements and possibly increase its bearing strength for base course applications.

Keywords: Alluvial soil, Road foundation, CBR, Direct shear strength, Morphology

1. INTRODUCTION

The "Build, Build, Build" program of the Department of Public Works and Highways (DPWH) of the Philippines promises a significant construction development in the Philippines. In the recent Philippine Infrastructure Report of 2017, strong growth in the construction and infrastructure industry was predicted to occur over the next five years. The report shows that the real growth will reach 12.5% between 2017 and 2021, while the average annual growth will reach 11.2% for the construction sector [1]. The Philippine Development Plan launched in 2017, aims to change the Philippine income trend as an upper-middle-income country by 2022 [1]. This trend resulted in the urge to developing infrastructure and therefore boost the construction industry in the country [2,3].

It follows that there is a greater need for construction materials such as embankment and road foundation aggregates. However, there are three emerging challenges on sourcing of aggregate materials for road construction: (1) geographical distribution of natural deposits of high-quality aggregates needed for road construction is uneven in nature and not found in some areas, (2) in areas where high-quality aggregates exist, gravel mines and rock quarries are being either lost to another land uses or restricted from mining due to public perception and conservation efforts, and (3) higher quality standards may further reduce the amount of usable aggregates mined from specific sources [3,4].

Searching for alternative construction materials is considered a sustainable way of development if secondary material is free from hazardous components and does not have any adverse long-term effects [5,6]. Road construction costs can be very high because of the limited opportunity of locating suitable road base material within economic haul distances [3]. It is preferable and economical to use and to stabilize, if necessary, locally available but abundant materials than to import conventional aggregates.

One thing that is abundant in the Philippines is its alluvial deposits of soils. The alluvium occupies approximately 15 percent of the land surface of the archipelago [6]. The alluvium is the soil transported by water and settled along riverbanks. It is usually most extensively developed in the lower part of the course of a river, forming floodplains and deltas, but may be deposited at any point where the river overflows its banks.

Alluvial soil was already researched for its suitability as an alternative road foundation aggregate in various countries [7,8]. However, alluvial soils in the Philippines are yet to be explored. Due to its archipelagic characteristics, Philippine lands is composed of approximately 15% alluvium. The country experiences the rise of rivers and streams during the rainy season, which results in the formation of floodplains and thick alluvial deposits.

The province of Bulacan alone, the house of the 153-km Angat River with a catchment area of 1,085 km2, is composed mainly of alluvial orders of soil. Alluvial soils along the rivers are considered part of the lowland soils, and these soils represent the heavy use of land resources being easily accessible to the general populace.

Alluvial soils are mainly used for agricultural purposes. However, problems arise when some of the soils possess high permeability that crops cannot grow. This is attributed to the sandy soil types, such as Quingua and Obando soil series, present along the Angat River [9]. With a thickness of 2 to 4 meters and covers more than 810 hectares, this fine sandy soil is a potential source of road embankment materials [9].

The main objective of this study was to characterize and assess the potential of the naturally occurring alluvial soils when used as a road subgrade, subbase course, and embankment materials. The DPWH Standards was the major reference on the classification of the alluvial soil on its suitability [10]. Table 1 shows the parameters and requirements based on the DPWH specifications for subgrade, subbase course, and for select granular backfill of mechanically stabilized earth.

2. MATERIALS AND METHODS

2.1 Source of Alluvial Soil

The alluvial soils were gathered from a vacant land in Brgy. Laog in the municipality of Angat, Bulacan. The soils are located along the riverbanks. Disturbed samples were used since the roadway construction materials are actually blending of different materials with specific gradation. The oven-dried and moist-tamped soil is shown in Fig. 1.

a. oven-dried soil b. moist soil

Fig. 1 Soil sample used in this study

2.2 Experimental Program

Table 1 DPWH Standards for road foundation [10]

Parameter	Requirement	
Subgrade course		
Gradation	All particles are finer than 75mm	not more than 15 mass percent will pass the 0.075 mm sieve
Atterberg limits	PI not more than 6	LL not more than 30
Unit weight	greater than 7.85 KN/m^3	
Subbase course		
Gradation	All particles are finer than 50mm	not more than 12 mass percent will pass the 0.075 mm sieve
Soaked CBR	not less than 30% at MDD condition	
Dust ratio	Less than or equal to 2/3	
Atterberg limits	PI not more than 12	LL not more than 35
Select granular backfill		
Gradation	all particles must be smaller than 100mm	
	particles finer than 0.0425mm must be 0 – 60 percent by mass	
	at most 15% of the particles are finer than 0.075mm	
Friction angle	not less than 34%	

The laboratory tests performed on the samples are enumerated in Table 1. These procedures were based from either ASTM or AASHTO standards to establish a reference in evaluating the index properties and strength of the alluvial soil. Morphology includes the SEM-EDX analyses, texture, and mineral identification. These material analyses supported the results of laboratory tests and explained the soil behavior that is important for long-term applications.

CBR tests in accordance with AASHTO T193 were performed for the alluvial soil compacted at the maximum dry density and under soaked conditions to simulate the worst possible scenario in the field. Moreover, specimens were soaked for 96 hours (4 days). However, a shorter immersion period of not less than 24 hours was applied, as suggested by the AASHTO standards, if the shorter period did not affect the test results.

Direct shear tests in accordance with ASTM D 3080 were performed for the alluvial soil to complete its geotechnical characterization. This study considered fully saturated conditions to simulate the worst-case scenario and dry condition to see the strength of the alluvial soil at the most possible condition. The samples were subjected to varying vertical stresses: 13.63 KPa, 27.75KPa, and 83.25 KPa. The first vertical stress would capture the low-stress condition while the second and third vertical stress will simulate the 1.5m and 4.5m overburden pressure in the field. The relative compaction will be 60%, 80%, and 90% to represent the medium dense, dense, and very dense conditions, respectively. Moist tamping was done to achieve the desired density of the reconstituted sample. For the saturated condition, the specimen was soaked in distilled water before transferring to the direct shear apparatus tank filled with water. Unconsolidated undrained condition was performed because of the non-plastic and cohesionless property of the soil sample. The test ran at 1.25 mm/min rate of shearing.

Table 2 Experimental program for alluvial soil

Test	Test Standard
Grain Size Analysis	ASTM D6913
Specific Gravity Test	ASTM D854
Atterberg Limits Test	ASTM D4318
Compaction test	ASTM D698
Max. Index Density Test	ASTM D4253
Min. Index Density Test	ASTM D4254
CBR Test	AASHTO T193
Direct Shear Test	ASTM D3080
SEM-EDX	-
Sedimentology	-

3. RESULTS

3.1 Particle Size Distribution

Figure 2 shows a typical particle size distribution curve. Generally, a soil is referred to as well graded if the uniformity coefficient (Cu) is larger than about 4–6 and coefficient of curvature (Cc) is between 1 and 3 [11]. The alluvial has a Cu of 5.11 and Cc of 1.2. It has an effective grain size (D_{10}) is 0.29. Based on its D_{10}, the soil falls on a medium size sand [11]. The alluvial soil comprises of 92% sand, 6% gravel, and 1% silt. Based on the gradation requirements of DPWH, the soil is not suitable for subbase course application due to its insufficient amount of coarse particles.

3.2 Soil Constants

The material constants is presented in Table 4. The specific gravity of 2.60 is common to sandy soils [13]. The zero plasticity that is common to sand – silt particles complies with the low plasticity requirement for the road foundation materials. The modified effort was employed during compaction to concur with the DPWH standards for subbase/base course materials. The alluvial soil reached a maximum dry density of 19.66 KN/m^3 at an optimum moisture content of 10.65%. It absorbs water and produces a wide range bell-shaped curve that falls on well-graded to fine sands [11].

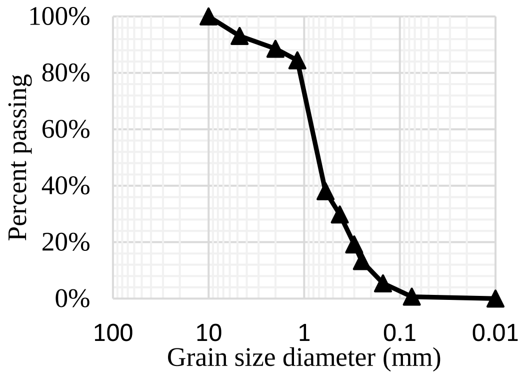


Fig. 2 Particle size distribution curve

Table 3 Soil Constants

Soil Property	Value
Specific Gravity, Gs	2.60
Liquid Limit, LL %	Non-plastic
Plastic Limit, PL %	Non-plastic
Min. Void Ratio, e_{min}	0.48
Max. Void Ratio, e_{max}	0.91
Max. Dry Unit Weight,γ_{dmax} kN/m^3	19.66
Optimum Moisture Content, ω_{opt} %	10.65

3.3 Soil Classification

According to the Unified Soil Classification System (USCS), the alluvial soil is a poorly-graded sand. On the other hand, the AASHTO classified it under A-1-b with group index of zero. Considered granular material, the alluvial soil had a rating of excellent to good subgrade material according to the AASHTO classification system.

3.4 Soil Strength

3.4.1 California bearing ratio

Stipulated by the DPWH (2013) standard specifications, the bearing strength is defined by the CBR value obtained from AASHTO T93 provisions. The alluvial soil obtained CBR values at 2.54mm and 5.08mm penetrations of 30.77% and 41.03%, respectively. These values correspond to the typical CBR of poorly graded sand classified by the USCS and of A-1-b soils identified by AASHTO [10]. Based on these CBR values, the alluvial soil had a bearing strength suitable for subbase course application as per the DPWH specifications.

3.4.2 Direct shear strength

In regards with the direct shear test, for both dry and saturated conditions, it was observed that as the normal load increases the value of the critical state shear stress or the shear stress at failure increases. The shear strength or the critical state shear stress is the shear strength at which the volume change ceases.

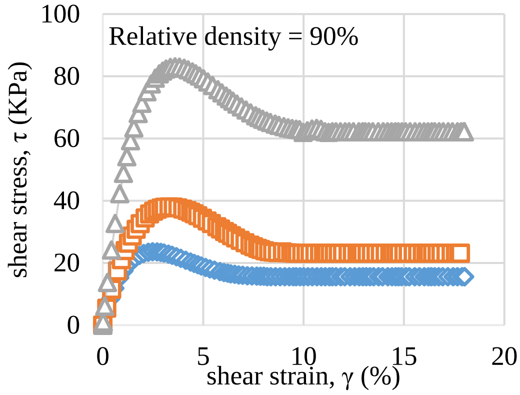
For the dry condition, stress-strain curves follow a similar pattern. As the shear strain starts to manifest, the dry soil behaves elastically (linear curve) until yielding occurs. At this point, the linear region starts to form a curvature as it approach a peak as shown in Fig. 3a. This phenomenon is called strain-hardening. Furthermore, after the soil reach a peak shear stress, a strain-softening phenomenon happened before it approach the critical state. This is attributed to the particle crushing and reorientation [12,13]. It can also be observed from the volumetric strain-shear strain plots in Fig. 3b that during strain hardening the soil changes its volumetric behavior from compression to expansion. Moreover, the dry samples exhibit dilation continuously until the graphs asymptotically approach a critical region where volume change stops. This is known as the critical state.

It is noticeable that the 13.63 kPa normal load soil sample experiences the greater volumetric expansion. Thus, it is concluded that the increasing normal load directly affects the volumetric expansion of the soils.

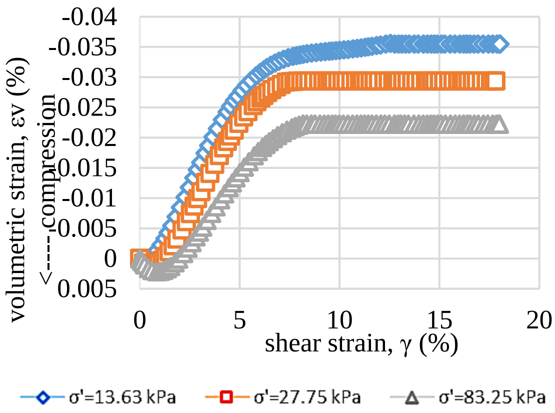
Figure 4 displays the stress-strain and volume change relationships of the saturated alluvial soil subjected to direct shear test. Slight variations from the results of the dry condition can be observed. First, the reduction of shear strength is very obvious since at saturated condition soil loses strength because of the presence of water as shown in Table 4. Second, the stress-strain curves for the 60% relative-density soils show no peak stress under the highest normal load (83.25KPa). In addition, dilation were not observed in this test sample. The reason for this is that a higher normal load can suppress the peak stress and the dilatancy [12,13].

From Table 4, critical shear strength at different initial relative densities are almost the same for a particular effective normal stress. Secondly, the effective normal stress varies directly with the critical shear strength. Moreover, the densest soil specimens (Relative density = 90%) experience the largest volumetric expansion. Negative values of volumetric strain denotes soil expansion. The idea is that dense soil has the greater chance to expand than to compress upon shearing [12,13].

From the direct shear test, the critical state friction angle for dry condition is 37.52° while the saturated alluvial possess a 36.61° angle of internal friction. These values fittingly fall on the typical range of friction angle for sand of 27° to 37° [12,13]. From the DPWH standards, the soil sample used in this study is a suitable select granular backfill material.



a. Shear stress – shear strain curve



b. Volumetric strain – shear strain curve

Fig. 3 Stress-strain and volume change behavior of alluvial soil for very dense dry conditions.

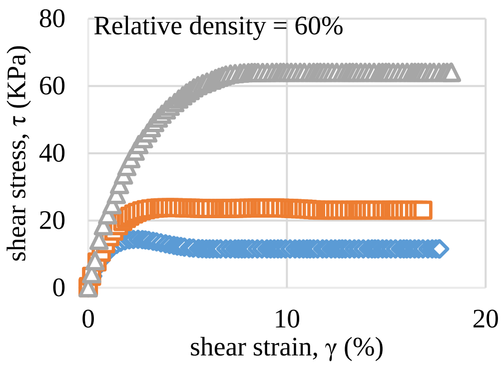
3.5 Morphology

3.5.1 SEM-EDX

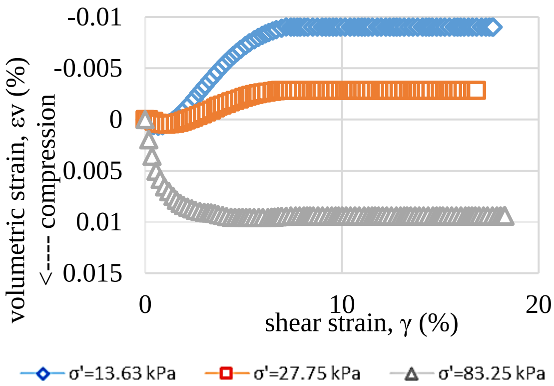
Figure 6 depicts the micrographs of the alluvial soil sample. The soil contains many components such as blocks of minerals, clay, clay accessory minerals, and organic materials. There are highly varied shapes and size ranges as shown in Fig. 6a. Soil exhibits small inter granular voids. It has flocculation with flakey particles usually associated with clay as well as plagioclase laths and an indication of early stages of weathering as shown in Fig. 6b. Lastly, Fig. 6c revealed inter granular voids with flakes and that is common to clay minerals in sedimentary soils [11].

Table 4 Critical state values

Alluvial soil	Normal effective stress, KPa	Dr = 90%	Dr = 80%	Dr = 60%
Critical state shear strength (kPa)				
Dry condition	13.63	15.58	15.58	15.63
	27.75	23.11	24.44	24.05
	83.25	62.16	59.58	64.97
Saturated condition	13.63	13.61	12.28	11.55
	27.75	22.45	21.44	23.05
	83.25	60.96	57.69	64.02
Critical state volumetric strain (mm/mm)				
Dry condition	13.63	-0.035	-0.026	-0.018
	27.75	-0.029	-0.024	-0.017
	83.25	-0.022	-0.021	-0.012
Saturated condition	13.63	-0.013	-0.014	-0.009
	27.75	-0.009	-0.008	-0.002
	83.25	-0.001	0.002	0.009



a. Shear stress – shear strain curve

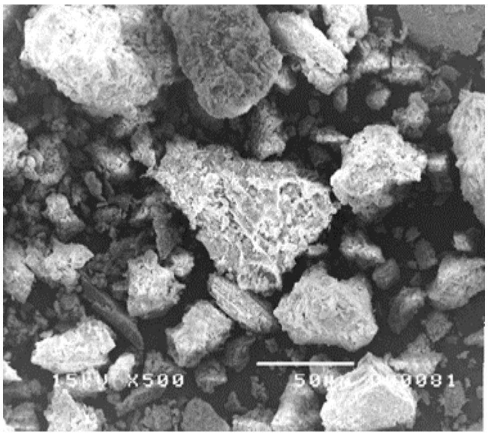


b. Volumetric strain – shear strain curve

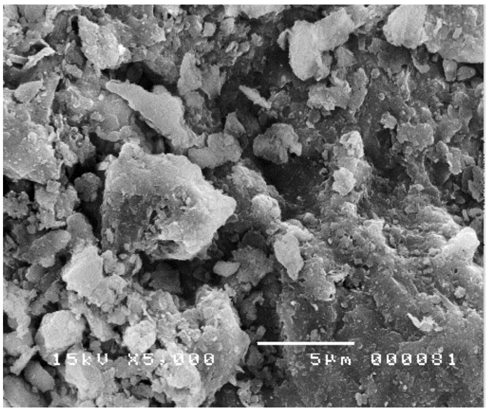
Fig. 4 Stress-strain and volume change behavior of alluvial soil for medium dense saturated conditions.

3.5.2 Sedimentology

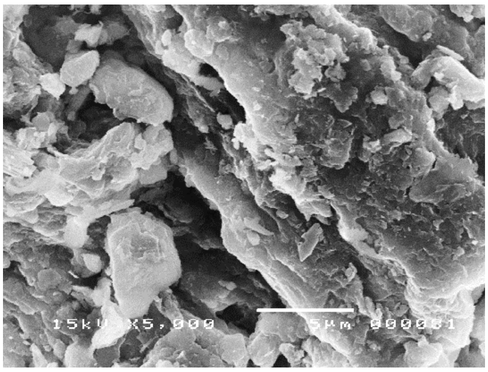
The analysis revealed a texturally and compositionally immature sedimentary soil. Texture and composition are two components to describe maturity. Texture provides a description of how rounded and sorted the sample is. Composition describes how much the soil composition is changing towards more stable minerals and components. An immature soil has the greater chance to breakdown and undergo weathering. The grain-size curve as shown in Fig. 2 validates the immaturity of the alluvial soil grains [11].



a. 500x magnification



b. 5,000x magnification (larger than 0.075mm)



c. 5,000x magnification (finer than 0.075mm)

Fig. 6 SEM micrographs of the soil sample

About the composition, the altered fragments are composed mainly of silicified, quartz, and chloritized fragments. Lithic fragments are basaltic in composition with varying textures. The sample have sparsely distributed broken chips of plagioclase with quartz, augite, epidote and hornblende the result of EDX shows a soil that is made up mainly of oxygen, carbon, silicon, aluminum, iron, and magnesium with small amounts of calcium and titanium. All of these elements correspond with the mineralogical analysis.

4. CONCLUSION

Based on this study, the following conclusions can be drawn:

The alluvial soil sample is a poorly graded sand with textural and compositional immature grains of quartz, basalt, chloritized, and altered fragments. It has no plasticity and the alluvial soil reached a maximum dry density of 19.66 KN/m^3 at an optimum moisture content of 10.65%.

The bearing strength based on the CBR value at 5.08mm penetration of 41.03% revealed that the alluvial soil is a suitable subbase course aggregate based on the DPWH Standards. However, the soil failed on the gradation requirement for subbase course because the number of coarser particles is insufficient.

For the direct shear strength, the critical state friction angle for dry and saturated conditions are 37.52° and 36.61°, respectively. Both brittle and ductile failure were observed from the test data which allows the stress-strain behavior to experience peak and dilatancy for the volume change behavior.It is a suitable select granular backfill material.

Further work on this research is recommended to focus on the blending of alluvial soil with coarser aggregates to comply with the gradation requirements and to possibly promote its application to base course.

5. ACKNOWLEDGMENTS

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