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Characterization of Index Properties of Coarse-Grained Alluvial Soils for Permeability Test

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Abstract: *This research focused on evaluating the geotechnical characteristics of coarse-grained alluvial soil sourced from a riverside site in Norzagaray, Bulacan. Standard laboratory tests were conducted in accordance with ASTM procedures, including specific gravity, Atterberg limits, Standard Proctor, and relative density tests. The soil had a specific gravity of 2.75, indicating the presence of dense mineral components commonly found in river-deposited materials. Atterberg Limits tests confirmed non-plastic behavior, consistent with the soil's sandy and gravelly composition. From the Proctor test, the average optimum moisture content was found to be 13.10%, with a corresponding maximum dry unit weight of approximately 18.27 kN/m³, demonstrating efficient compaction potential. The relative density test showed an in-situ void ratio of 0.7896, which aligns with the target 90% relative density, signifying successful soil densification. These results highlight that, although alluvial soils are naturally loose and heterogeneous, they can be effectively compacted for engineering use when their properties are properly evaluated.*

Keywords: alluvial soil, compaction, specific gravity, relative density, geotechnical properties

1. INTRODUCTION

The Philippines, an archipelagic nation with a diverse and dynamic geological landscape, is home to 421 major principal rivers, including 18 designated as major river basins [1]. This extensive fluvial network is indicative of the country's substantial accumulation of alluvial deposits, which significantly influence the soil characteristics across many lowland and riverine areas. Alluvium, composed primarily of loose sediments such as clay, silt, sand, and gravel, is transported and deposited by the action of running water, particularly in river channels, floodplains, and deltas.

A study by Torres and Adajar reveals that approximately 15% of the Philippine land surface is composed of alluvial soils, highlighting their widespread distribution, particularly in major agricultural and floodplain regions. These soils typically form in areas where water flow slows down, allowing sediments to settle and accumulate over time. Because of their origin and mode of deposition, alluvial soils are often stratified, exhibiting varying layers of particle sizes and compositions depending on past hydrological activity [2].

Geotechnically, alluvial soils are known for their high porosity and permeability, owing to the loosely packed nature of their grains and the minimal compaction they undergo during deposition [3]. These properties make them less suitable for certain engineering applications, especially those that require low hydraulic conductivity, such as landfill liners, earth dams, or containment barriers, where water retention is critical [18]. Furthermore, the loose and unconsolidated structure of alluvial soils can pose challenges in foundation engineering, particularly in supporting heavy structures, due to risks of settlement or liquefaction under dynamic loading conditions like earthquakes [19].

The stability of earth-retaining structures, such as dams and embankments, critically depends on the control of permeability across different soil zones. While the referenced study primarily investigates delayed instability in a clay-core earth dam, its findings have direct implications for the use of coarse-grained alluvial soils in such structures. Coarse-grained soils, known for their high permeability, are typically used in drainage zones or shells rather than in core sections, where low-permeability materials like clay are preferred to minimize seepage. However, when these materials are not properly integrated—particularly without appropriate filter layers or transitions—significant permeability contrasts can develop at interfaces, potentially leading to internal erosion or piping [4].

This principle also applies to various containment and flood control structures such as canals, channels, and levees, where preventing leakage and contamination is essential. In these applications, soils must be carefully selected and engineered to control permeability. Coarse-grained alluvial soils, known for their high permeability and drainage capabilities, are often used in drainage zones or filter layers. However, when such materials are used in the structural shell of dams or flood defenses, it is crucial to reduce their permeability by compacting them to a relative density of at least 90% [6]. Achieving this level of compaction improves the soil's structural integrity, reduces void ratios, and helps limit uncontrolled seepage, thus enhancing overall stability [7].

In flood-prone areas like Metro Manila—where frequent typhoons and inadequate drainage contribute to persistent flooding—structures such as levees would benefit from using well-compacted coarse-grained soils in conjunction with impermeable cores or liners. These measures improve flood protection by ensuring that water does not percolate through the structure [20]. Moreover, modifying soil permeability using additives such as biochar can further enhance the soil's hydraulic properties, offering sustainable solutions to seepage control and flood management [8].

Understanding these spatial variations in SPT N-values allows engineers to estimate permeability profiles across a site, guiding the strategic placement of impermeable barriers, drainage zones, or filter layers to control seepage. This approach enhances the design of earth structures by reducing the risk of internal erosion, piping, and delayed instability—common issues in mixed or fissured soil environments. Integrating SPT-based soil assessments with permeability considerations ultimately leads to safer, more reliable geotechnical designs [5]. For geotechnical engineers and planners, understanding the index properties of these soils—such as grain size distribution, Atterberg limits, specific gravity, and natural moisture content—is essential for assessing their behavior under various loading and environmental conditions.

2. MATERIALS

2.1 Alluvial Soil

The coarse-grained alluvial soil will be sourced from the riverside in an ongoing bridge construction along the Norzagaray river in Norzagaray, Bulacan, Philippines.

The soil sampling procedure will follow the ASTM D5633 – Standard Practice for Sampling with a Scoop. The practice will involve removing the top layers of materials on the site up to the required depth with the use of a shovel or any similar equipment. The actual sample to be used will be collected using another clean scoop and will be placed in a clean container or sack [10].

3. METHODOLOGY

This research will adopt a quantitative experimental approach, utilizing laboratory-based testing to obtain data and analyze outcomes (see Fig. 1). The procedures and sampling techniques will primarily adhere to the standards set by the American Society for Testing and Materials (ASTM). All experimental work will be carried out at the Geotechnical Engineering Laboratory located in the St. Miguel Building of De La Salle University - Manila, situated at 2401 Taft Avenue, Malate, Manila, 1004 Metro Manila.

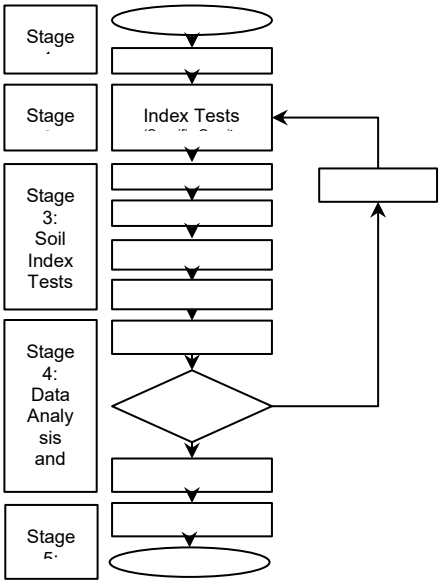

Fig. 1 Flowchart of Experiment.

3.1 Specific Gravity Tests

The specific gravity of soil is defined as the ratio of the weight of a given volume of soil to the weight of an equal volume of water, both measured in air [11]. It is a key parameter in evaluating the void ratio and the degree of saturation of the soil. The test procedure begins by weighing the empty flask and pan, followed by adding 500 mL of water into the flask and recording the combined weight. The water is then cooled to a temperature of 4°C to ensure uniformity in mass and volume. Afterward, approximately half of the water is removed from the flask, and 150 grams of low-plastic clay soil is introduced. The mixture is agitated until it becomes homogeneous. During agitation, air bubbles may form and must be removed using a vacuum system for 10 minutes. Once de-aired, the flask is refilled with water to the 500 mL mark, and the new weight is recorded. The contents are then transferred to a pan and placed in a drying oven. After complete drying, the final weight of the dried soil is measured.

3.2 Atterberg Limits Test

The Atterberg Limits test is used to determine the moisture-related consistency limits of soils, specifically the Liquid Limit, Plastic Limit, Shrinkage Limit, and Plasticity Index. These limits help define the behavior of low-plasticity clay under varying moisture conditions [12].

Liquid Limit. This is the moisture content at which soil begins to exhibit liquid-like behavior. To determine the liquid limit, the Casagrande cup apparatus will be used. The test begins by mixing oven-dried clay with water to achieve a dough-like consistency. The prepared soil is then placed into the brass cup to a depth of about 10 mm. A groove is cut along the center of the soil using the beveled edge of a standard grooving tool. The cup is mounted on the apparatus and repeatedly dropped by turning the crank at a rate of two drops per second. The process is repeated until the groove closes along a distance of ½ inch. Once this occurs, a sample weighing approximately 50 grams is collected, ideally from the center portion. Both the wet and oven-dried weights of the sample are recorded to determine moisture content.

Plastic Limit. This is the water content at which soil changes from a plastic to a semi-solid state. The equipment required includes glass plates, a spatula, moisture cans, and pans. To begin, the clay is mixed with water until a dough-like consistency is achieved. A small amount of the mixture (around 1.5 to 2.0 grams) is rolled by hand on the glass plate into a thread approximately 2.2 mm in diameter. This rolling process is repeated until the thread begins to crumble. The crumbled pieces are collected in a moisture can until a total of at least 6 grams is accumulated. Finally, the wet and oven-dried weights of the crumbled soil samples are recorded to calculate the plastic limit.

3.3 Standard Proctor Test

The Standard Proctor Test, based on ASTM D698, will be used to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the alluvial soil [15]. The procedure involves weighing the containers and mold, measuring the mold's dimensions, and preparing approximately 3 kg of soil (passing the No. 4 sieve). The soil is gradually moistened and compacted into the mold in three layers with 25 hammer blows per layer using a

standard rammer. Once the soil reaches the top of the mold, it is weighed, and samples are taken from the compacted soil for moisture content determination using a drying oven. This process will be repeated in three trials with increasing moisture content to establish the MDD and OMC.

3.4 Relative Density Test

The relative density test evaluates the degree of compactness of granular soils, such as sands and gravels, in comparison to their loosest and densest possible states. This involves determining two key parameters: the maximum index density (emin), as outlined in ASTM D4253, and the minimum index density (emax), following ASTM D4254.

To determine the maximum index density (emin) under ASTM D4253, the procedure begins by weighing and measuring the mold used for the test [13]. Soil is then placed inside the mold—poured in three layers for coarse-grained soils and in a single pour for finer-grained ones. A surcharge weight is positioned on top of the soil to simulate overburden pressure. The entire mold is placed on a vibrating table and subjected to vibration at 60 Hz for 8 minutes. After vibration, the mold with the compacted soil is weighed, and the value of emin is calculated based on the volume and mass.

For the minimum index density (emax) under ASTM D4254, the procedure also starts with weighing and recording the dimensions of the mold [14]. Soil is then introduced into the mold—dropped from a greater height for coarse particles to simulate free fall, while finer soils are poured from approximately 25 mm above the mold. No compaction, tamping, or vibration is allowed during this process. Once the mold is filled, a straightedge is used to level the soil surface. The mold with the soil is then weighed, and emax is computed accordingly.

3.5 Particle Size Distribution

For alluvial soils, particle size distribution is determined using a combination of sieve analysis and hydrometer analysis, in accordance with ASTM D6913 and ASTM D7928, respectively. These standard test methods are essential for evaluating the gradation of soil, which significantly influences properties such as hydraulic conductivity, shear strength, and compressibility.

In the sieve analysis (ASTM D6913), approximately 500 grams of alluvial soil is used. A standard set of sieves, ranging from 3 inches (75 mm) to No. 200 (75 μm), is arranged in descending order with a pan at the bottom to collect the finest particles. The sieves and pan are weighed before the sample is added to the top sieve. The stack is placed in a mechanical sieve shaker and operated for five minutes to separate the particles by size. After shaking, each sieve is weighed individually to determine the amount of soil retained on each, which is then used to construct the grain size distribution curve.

For the finer fraction of the soil that passes through the No. 200 sieve, hydrometer analysis (ASTM D7928) is used. Approximately 20 grams of the soil is mixed with water in a beaker and blended or agitated manually for 10 minutes to create a uniform suspension. The mixture is then transferred into a graduated cylinder, sealed with a rubber stopper, and agitated by rolling for one minute. The cylinder is placed in a water bath, the stopper removed, and a hydrometer is inserted. Readings are recorded at specific time intervals—2, 5, 15, 30, 60, 120, 240, and 1,400 minutes—along with temperature measurements. These readings are used to calculate the sedimentation rate of particles, which indicates their size distribution.

4. DISCUSSION

4.1 Specific Gravity

A specific gravity of 2.75 for coarse-grained alluvial soil is attained after a series of tests was done. This indicates that the soil particles are relatively dense and heavy compared to water. Specific gravity (Gs) is a dimensionless value representing the ratio of the unit weight of soil solids to that of water, and for most natural soils, it typically ranges from 2.60 to 2.80.

Table 1. Summary of Results of Specific Gravity of Coarse-Grained Alluvial Soil

Specific Gravity Test Results			
	Trial 1	Trial 2	Trial 3
Specific Gravity	2.56	2.99	2.69
Average		2.75	

A specific gravity of 2.75 suggests that the coarse-grained alluvial soil tested is primarily composed of siliceous and mineral-rich particles, such as quartz, feldspar, or dense rock fragments, which are common in river-transported sediments (see Table 1). This value falls on the higher end of the typical range, indicating that the soil has minimal organic content and may contain minerals such as magnetite, hornblende, or other heavy constituents [9].

4.2 Atterberg Limits

In the case of coarse-grained alluvial soil, which is predominantly composed of sand and gravel, the soil lacks sufficient fines (particles smaller than 0.075 mm) to exhibit plastic behavior. This indicates that the soil's behavior is governed more by its grain structure and interparticle friction than by moisture-induced plasticity [16].

The lack of fines in coarse-grained alluvial soil results in non-plastic behavior, meaning the soil does not change consistency significantly with varying moisture levels. Instead, its performance relies on the arrangement of particles and the friction between them. This makes the soil less susceptible to shrink-swell cycles, which is advantageous in maintaining dimensional stability in foundations and pavements. However, the minimal cohesion and low moisture retention can increase vulnerability to erosion and displacement, especially under dynamic loading or water flow. Therefore, while such soil types are well-suited for applications like road subbases and structural fill, they require proper compaction and adequate drainage systems to maintain long-term performance and prevent instability [17]. These findings highlight the need for engineering strategies that enhance interparticle locking and protect

against moisture-related deterioration.

4.3 Standard Proctor Test

The compaction characteristics of the alluvial soil, shown in the graph and supported by the Standard Proctor Test data, exhibit a typical trend where dry unit weight increases with moisture content up to a peak, then declines as moisture continues to rise (see Fig. 2). This behavior occurs because added water initially helps soil particles compact more efficiently, but excessive moisture eventually fills the air voids and reduces density. The optimum moisture content (OMC) across the three trials ranged between 12.82% and 13.65%, averaging about 13.10%, which represents the moisture level at which the soil reaches its highest compaction.Z

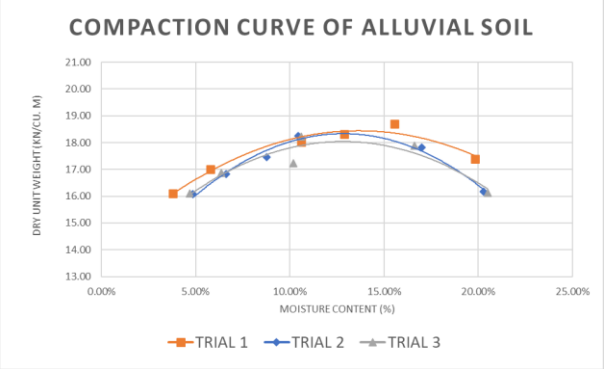

Fig. 2. Compaction Curve of Alluvial Soil

The maximum dry unit weight, or γ_{dmax} observed varied from 18.0383 to 18.4391 kN/cu.m, with an average value of approximately 18.27 kN/cu.m. These results reflect the maximum density the soil can achieve under standard compaction conditions. Minor differences among the trials suggest consistent test performance, with Trial 1 achieving the highest values and Trial 3 the lowest, possibly due to slight variations in procedure or material (see Table 2).

Table 2. Summary of Results of Standard Proctor Test of Coarse-Grained Alluvial Soil

Standard Proctor Test Results				
	Trial 1	Trial 2	Trial 3	Ave
OMC (%)	13.65	12.84	12.82	13.11
Maximum Dry Unit Weight (kN/cu.m)	18.439	18.331	18.038	13.269
Maximum Dry Density (kg/cu.m)	1.880	1.869	1.839	1.862

In practical terms, these findings are critical for construction involving alluvial soils. The identified OMC and γ_{dmax} serve as essential targets during field compaction to ensure sufficient soil strength and stability. Maintaining moisture levels around 13% during compaction is necessary to achieve optimal density, which enhances structural performance and minimizes long-term settlement. Overall, the results indicate that this type of soil can be effectively compacted within a narrow moisture range, making it suitable for engineering use.

4.4 Relative Density

The values of emin and emax define the loosest and densest possible packing states of the soil, providing a reference range within which the current soil condition can be assessed. The in-situ void ratio, calculated based on field or laboratory compaction, indicates the actual state of the soil and allows for the determination of relative density. In this case, the computed in-situ void ratio of 0.78961 falls appropriately between the average emax of 1.00179 and emin of 0.76604, corresponding closely to the target relative density of 90% (see Table 2).

Table 2. Summary of Results of Relative Density Test of Coarse-Grained Alluvial Soil

Relative Density Test Results at 90%		
	emin	*emax*
Trial 1	0.98609	0.75094
Trial 2	1.01315	0.78304
Trial 3	1.00612	0.76412
Average	1.00179	0.76604
$e_{computed}$	0.7896106	

This alignment confirms that the soil has been compacted effectively to achieve a dense state, which is desirable for ensuring strength, stability, and reduced compressibility. Coarse-grained alluvial soil is often variable in composition and prone to issues like settlement or liquefaction. The accurate assessment of void ratios is critical for evaluating compaction success and predicting soil performance under structural loads.

4.5 Particle Size Distribution

The Grain Size Distribution Curve (GSDC) for the alluvial soil sample illustrates a wide range of particle sizes, indicating that the soil is likely well-graded.

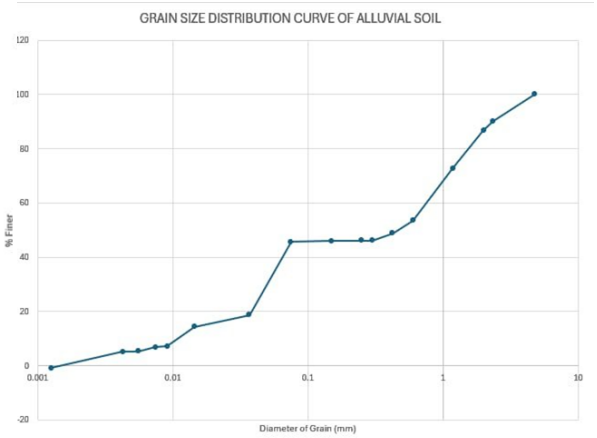

Fig. 3. Grain Size Distribution Curve of Alluvial Soil

The logarithmic x-axis represents the grain diameter in millimeters and spans from about 0.001 mm to 10 mm, covering clay-sized particles to coarse gravel. The y-axis

likely represents the cumulative percentage passing, although it is not explicitly labeled. The curve starts gradually, rises steeply between approximately 0.05 mm and 0.2 mm, flattens slightly, and then ascends sharply again past 0.5 mm, reaching near 100% passing at the larger grain sizes (see Fig. 3).

This pattern suggests a mixture of fine and coarse materials, with some intermediate particle sizes being less prevalent, possibly pointing to segments of poor gradation. Such a distribution is characteristic of alluvial soils, which are typically deposited by flowing water and can consist of a heterogeneous mix of particle sizes. The well-graded nature of this soil implies good compaction properties and moderate permeability, making it suitable for various engineering applications. However, the presence of fines could influence drainage behavior and shear strength, factors that are critical in construction and geotechnical design.

5. CONCLUSION

The geotechnical assessment of coarse-grained alluvial soil from a riverside site in Norzagaray, Bulacan, shows that this naturally loose and variable material can be made suitable for construction when carefully studied and properly compacted. With a specific gravity of 2.75, the soil contains heavier minerals typically found in river deposits, suggesting a strong and stable composition. Tests confirmed that the soil is non-plastic, meaning it lacks clay and won't easily expand or shrink with changes in moisture, which is a valuable trait for maintaining consistent performance in engineering applications.

Results from the Standard Proctor Test showed the soil compacts well, reaching an optimum moisture content of about 13.10% and a maximum dry density of 18.27 kN/m³. These values indicate that the soil responds efficiently to compaction, achieving the strength needed for use in structures like roadbeds, embankments, or levees. Additionally, the void ratio measured on-site closely aligns with the desired 90% relative density, a key benchmark for ensuring soil stability and reducing the risk of settlement.

In essence, while alluvial soils are often seen as unpredictable due to their loose nature, this study demonstrates that with the right preparation, research, and engineering practices, such soils can be transformed into dependable and advantageous materials for construction projects.

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