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Abstract: *There is an abundance of alluvial soil in the Philippines, but it is rarely utilized. The lack of use for alluvial soil is due to the inconsistency in its composition; therefore, testing different geotechnical properties is a must to assess its suitability as a construction material. Moreover, stabilization practices can be done to increase the soil's mechanical properties. Using waste stone powder for stabilizing will allow for an economical and sustainable construction material. Assessing the effects of waste stone powder on the index properties of alluvial soil changes in the specific gravity, Atterberg Limits, optimum moisture content, maximum dry density, and grain size distribution are observed. As the amount of waste stone powder increases, the specific gravity and optimum moisture content decreases. An increase in the liquid limit and maximum dry density was also observed. The grain-size distribution of the alluvial soil contained coarser particles with the addition of the waste stone powder.*

Keywords: alluvial soil; waste stone powder; specific gravity; Atterberg Limits; compaction.

1. INTRODUCTION

In the Philippines, abundant alluvium deposits occupy approximately 15% of the land surface [1]. These alluvial soils are transported by running water and deposited into streams and floodplains, resulting in variations in soil textures. They are found to be a mix of fine-grained and coarse-grained soils [2]. Moreover, the differences in the composition of alluvial soil can also be attributed to local conditions and events in the areas where samples are located. These differences range from vegetation cover, watershed, lithology, and more that affect the soil and cause different properties [3,4]. The variability of alluvial soil forms complex subsoils with varying strength and deformation [5]. The amount of organic matter in alluvial soil is also affected by pollution and soil contamination. Contamination of soil negatively affects the soil properties, which may hinder the soil from being used as a construction material [6].

Typically, alluvial soil has a high void ratio, while its bearing capacity and shear strength are considered low [2]. This has become a challenge since it may lead to bearing capacity failures, slope instability, and excessive settlement. The bearing capacity of alluvial soil is insufficient for specific infrastructures; therefore, there is a need for proper ground treatment or soil reinforcements [7] if a structure is being built. Soil stabilization is a technique that dates back many years. It was implemented to allow soil improvement for different construction purposes. Adding soil stabilization agents helps the soil meet the properties required to be suitable as a construction material and used in construction projects [8]. Due to the variations in compositions of alluvial soil, it needs to be tested to determine its suitability for a construction project [5]. In Wierzbicki and Stefniak's [4] study, alluvial soil classified as silt has a compatibility that meets the criterion to be used in earthen structures. Additionally, alluvial soil can be used in the foundation of tall buildings. Still, there is a need for a thorough geotechnical analysis to design a foundation that optimizes the conditions and the loads [9].

Alluvial soil has also been researched as a suitable road foundation in different countries [1]. Subgrades significantly support the pavement, so its strength and quality must be maintained long-term. It must have an adequate load-bearing capacity and stability under different load-bearing conditions, and to achieve this, it must consist of soil that can adequately support pavement loading [10, 11]. Moreover, alluvial soil has been explored with stabilizing agents to produce a more economical material for road subgrades [10]. The need to reinforce soft soils decreases settlement since this is one common failure [12]. Alluvial soil was analyzed as poorly graded sand and showed no plasticity, which is required for road foundation materials. It also displayed a bearing capacity suitable as a road subbase [1]. Although having adequate bearing capacity, there is a need to address other possible failures that may be experienced, such as settlement; therefore, exploring additives to the soil is a must to increase stability [13].

In pavements, the materials used, and their design must be efficient, economical, and effective [11]. With the abundance of alluvial soil in the Philippines, applying waste materials as an additive for this soil would produce an efficient, economical, and efficient material that can be utilized in constructing road subgrades.

Waste stone powder, a waste material, has been studied to be an effective cement binder exhibiting improvements in concrete's mechanical properties and durability [8, 14]. Still, its application in soil is yet to be fully explored. There are limited studies on waste stone powder as the main additive in soils, but waste stone powder as a secondary additive shows improvements in the soil's mechanical properties. Unconfined compressive strength was increased with the rise in waste stone powder in the soil mixture [15].

The waste stone powder is needed since no proper disposal has been in place. Additionally, increasing quarrying activities across the globe consequently produce tons of waste stone powder and other byproducts. Quarrying typically involves removing materials, usually done through blasting, drilling, and crushing, producing solid materials in aggregates and dust [16, 17]. Dust produced from quarrying amounts to about 200 million tonnes per annum, suspended in the air and settling in water and land surfaces [18]. Quarrying also produces sludge from the transformation process [19], which ends up in agricultural lands, water surfaces, and underground reservoirs [20].

Waste produced from quarries is typically dumped in open fields, negatively impacting the environment [21, 22, 23]. Impacts such as land degradation, erosion, pollution, and water contamination have been observed [16, 24]. Sludge and dust reaching agricultural lands resulted in the alteration of the physio-chemical properties of the land as well as its fertility [20, 24, 25]. Moreover, quarry dust settling in water results in water contamination, which may affect the local fauna and flora near quarrying activities. Contamination of water may also lead to water sources for drinking water, which may affect the health of individuals [24]. Studies have also shown impacts on respiratory health. Dust produced in quarrying stays in the air, which can be inhaled by people, leading to lung problems such as disruptions in breathing [16, 26].

Proper disposal or use of such waste materials is necessary to reduce the impacts on the environment and the people. Research on the possible use of waste materials in the construction industry has been conducted, and improvements have been made in the mechanical properties of construction materials such as mortars. Many waste materials have exhibited pozzolanic properties, allowing for the use of mortar as a cement replacement [18, 19]. The waste stone powder has a chemical composition made up of 38–42% Lime (CaO), 20–25% Silica (SiO_2), 2–4% Alumina (Al_2O_3), 1.5–2.5% oxides (NaO and MgO), and 30–32% carbonates ($MgCO_3$ and others) [27, 28] which allows for the material to have pozzolanic properties [29]. The pozzolanic properties in waste materials such as ash and waste stone powder have increased the strength of concrete [14, 30].

Although the use of waste stone powder in concrete has been investigated by various research, studies on its use as an additive in soils are limited. This study will analyze the effects of waste stone powder on different index properties of alluvial soil, such as specific gravity, Atterberg Limits, compaction characteristics, and grain-size distribution.

2. MATERIALS

2.1 Alluvial Soil

Alluvial soil used in this study was retrieved from a flood plain near the Pampanga River in Candaba, Pampanga, Philippines.

2.2 Waste Stone Powder

Waste stone powder utilized in this study was marble dust obtained from a local company that produces countertops and furniture.

3. METHODOLOGY

3.1 Soil Mixture

Three types of soil mixtures were prepared for this study, varying in the amount of waste stone powder. Soil mixtures were produced with 0.0%, 2.5%, and 5.0% of their weight in waste stone powder. Consistency was ensured by following standardized procedures for mixing and curing as outlined in the ASTM standards. The materials used (alluvial soil and waste marble) were consistently sourced and prepared to maintain uniformity across tests.

3.2 Specific Gravity Test

The specific gravity was obtained following ASTM D854 [31]. In a volumetric flask, water was added to the calibration mark, 500 mL, then weighed. Half of the water was poured out, and the sample was poured into the flask. The entrapped air was removed by agitating the flask in boiling water. Once the air was removed, the flask was cooled. Water was added back into the flask and then weighed to the calibration mark. The mixture was transferred to an evaporating dish, weighed, and then placed in the oven to dry. Once the sample was dry, it was weighed. The recorded weights were then used to obtain the specific gravity of the samples.

3.3 Atterberg Limits Test

The Atterberg Limits was obtained following ASTM D4318 [32]. For the liquid limit, the sample was placed in the cup of the fluid limit device, about 10 mm in depth, and tamped to form a horizontal surface. The soil was grooved using a grooving tool, ensuring the sample did not crack. The cup was lifted and dropped by turning the crank until the two halves closed. The number of drops was recorded, and a slice of the specimen where it closed was removed and used to obtain the moisture content. Samples that could not reach a specific number of drops were classified as nonplastic NP. The test was redone, adding more water to the sample to obtain at least 3 points to plot a multipoint liquid limit curve. From the curve, the liquid limit of the sample was determined.

For the plastic limit, the specimen used in the liquid limit test was rolled to reduce the water content until it could be rolled without sticking to the hands. A portion of the sample was rolled into an ellipsoidal mass. Reaching a diameter of 3.2 mm, it was divided into pieces, rerolled into an ellipsoidal mass, and repeated until the sample could no longer be rolled without crumbling. The crumbled threads were gathered and placed in a container. More portions of the sample were taken and repeated until at least 6 grams of the sample were obtained. The moisture content of the sample gathered was determined.

3.4 Standard Proctor Test

The Standard Proctor test was done according to ASTM D698 [33]. The compaction mold's weight, height, and diameter were measured when preparing it. The compaction mold and the extension collar were assembled. About 3 kg of the sample passing the No. 4 sieve was obtained while preparing the sample. Water was added to the sample and compacted in the compaction mold in three equal layers. Each layer was compacted with 25 blows using a compaction rammer before adding the next layer. The extension collar was removed after compacting the third layer, and the excess sample was trimmed. The compaction mold with the sample was weighed. A portion of the samples from the top and bottom were taken to determine the moisture content. The compacted sample was broken and mixed with the excess sample. Water was added again, and the process was repeated until sufficient data was obtained to produce a compaction curve. The optimum moisture content and the maximum dry density were determined from the compaction curve.

3.5 Grain-Size Distribution Analysis

The grain-size distribution was determined following the sieve analysis in ASTM D422 [34]. Sieves were weighed. Then, the dried sample was placed in the top sieve and shaken to allow the sample to pass through the sieves. Each sieve with a sample was weighed.

4. DISCUSSION

4.1 Specific Gravity

The addition of waste stone powder has resulted in changes in the different properties of the alluvial soil. The specific gravity of the soil, which was determined to be 2.82, decreased the more waste stone powder the mixture had, as shown in Table 1.

Table 1. Specific Gravity of Soil Mixtures

Soil Mixture	Specific Gravity
0.0%	2.82
2.5%	2.59
5.0%	2.38

Obtaining the specific gravity of the waste stone powder, which was 2.42, indicates that this material is less dense than the alluvial soil without additives. The mix of the alluvial soil and waste stone powder has then decreased specific gravity as the amount of waste stone powder increases since the mixture becomes less dense due to the waste stone powder [35].

4.2 Atterberg Limits

Multipoint liquid limit curves were produced after the liquid limit test was performed on the soil mixtures (Fig. 1).

The alluvial soil without waste stone powder could not reach 25 blows, which, according to ASTM 4318, is non-plastic. Nonplastic soils possess no cohesive properties, which reduces the possibility of shear failure [36].

The Atterberg Limits obtained for the different soil mixtures are presented in Table 2. The addition of waste stone powder shows an increase in the liquid limit since the waste stone powder absorbs more significant amounts of water, increasing the soil mixture's water-holding capacity [37, 38]. Additionally, the lack of plasticity reduces the potential for swelling or shrinkage of the soil, which is a must in constructions such as road subgrades [39].

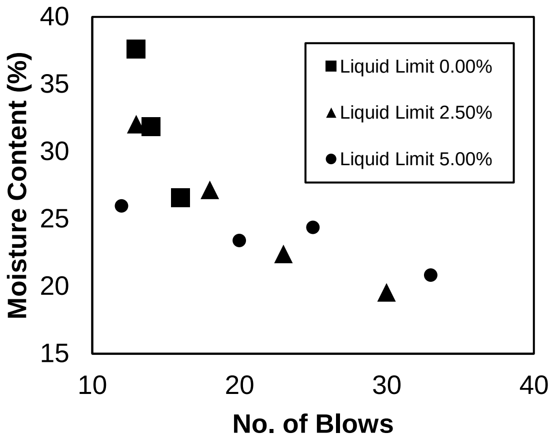

Fig. 1. Multipoint Liquid Limit Curve of 0.0% Soil Mixture

Table 2. Atterberg Limits of Soil Mixtures

Soil Mixture	Liquid Limit	Plastic Limit
0.0%	NP	NP
2.5%	22.33	NP
5.0%	23.10	NP

4.3 Standard Proctor Test

The compaction curves of the soil mixtures are presented in Fig. 2.

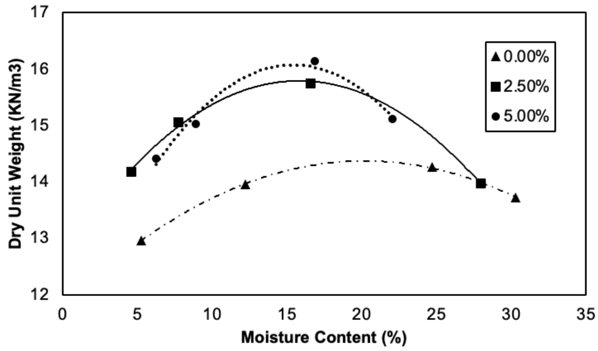

Fig. 2. Compaction Curve

The optimum moisture contents and the maximum dry densities of the soil mixture obtained from the compaction curves are tabulated in Table 3. A decrease shows the optimum moisture content observed with the addition of waste stone powder. This shows reduced surface activity due to the coarser particles in the waste stone powder. Due to this, the soil mixtures have a lower water-absorption capacity; therefore, less water is needed to achieve maximum compaction [40, 41].

Table 3. Optimum Moisture Content and Maximum Dry Density of Soil Mixtures

Soil Mixture	Optimum Moisture Content (%)	Maximum Dry Density (kN/m^3)
0.0%	20.23	14.37
2.5%	15.84	15.79
5.0%	15.42	15.17

The maximum dry density, on the other hand, shows an increase of 2.5% from 0.0% in the soil mixture. At the same time, the 5.0% shows a decrease. The increase in the maximum dry density is due to the denser waste stone powder than the alluvial soil [42].

Fig. 2 illustrates the correlation between dry unit weight and moisture content in soil mixtures containing varying percentages of waste stone powder (0.00%, 2.50%, and 5.00%). This type of graph is frequently employed in geotechnical engineering to illustrate the outcomes of a Standard Proctor Test, which is responsible for determining the maximum dry density (MDD) and optimum moisture content (OMC) of soil mixtures. At the OMC, the dry unit weight, which denotes the soil's density when dry, reaches its maximum value and decreases as the moisture content increases. Each curve represents a distinct concentration of waste stone powder incorporated into the alluvial soil, illustrating the impact of the waste stone powder on the soil's compaction parameters.

It is evident from the graph that the inclusion of waste stone powder alters the compaction profile of the soil. Under the tested conditions, the pure alluvial soil exhibits a higher compaction efficiency than the mixtures with 2.50% and 5.00%, as evidenced by the curve's peak at a higher dry unit weight for the 0.00% waste stone powder mixture. With an increase in the percentage of waste stone powder, the peak dry unit weight and the moisture content at which it occurs decrease. The waste stone powder may impede the soil's capacity to compact effectively, resulting from grain size distribution changes or the soil's particle cohesion and friction. The 0.00% and 2.50% mixtures exhibit a moderate decrease in peak dry unit weight, while the 5.00% mixture exhibits the most significant decrease. This suggests that higher concentrations of waste stone powder may result in less efficient packing and a lower density at optimal moisture levels.

4.4 Grain-Size Distribution

The grain-size distribution curves of the soil mixtures (Fig. 3) show that the curve shifts down with the addition of waste stone powder. This is due to the waste stone powder, which has coarser particles than the alluvial soil. The grain size distribution curve change can be attributed to the displacement and reduction of smaller particles in the alluvial soil caused by the waste stone powder [43].

5. CONCLUSION

The study investigated waste stone powder's effects on alluvial soil's properties, obtaining index properties of different soil mixtures.

The specific gravity of the alluvial soil, which is denser than the waste stone powder, decreased the particular gravity from alluvial soil with 0.0% waste stone powder to 5.0%. For the Atterberg Limits of the soil mixtures, the alluvial soil without waste stone powder is nonplastic, contributing to the soil's lack of cohesion. With the addition of waste stone powder, the soil mixture has a liquid limit that increased from the mix with 2.5 to 5.0 waste stone powder. Although it developed a liquid limit, the soil mixtures did not produce a plastic limit.

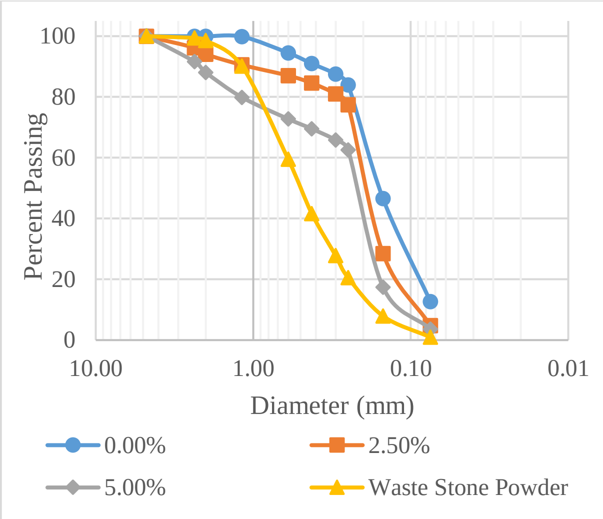

Fig. 3. Grain-Size Distribution Curve

The optimum moisture content of the soil mixtures decreases as the amount of waste stone powder increases. This is due to the water absorption of the materials, which has lowered with the addition of waste stone powder. This also indicates that less water is needed to achieve maximum soil compaction. The maximum dry density shows an increase with the addition of waste stone powder from 0.0% to 2.5%, but a decrease for the soil mixture that had 5.0% waste stone powder due to the denseness of the waste stone powder added.

Lastly, the addition of waste stone powder in the alluvial soil causes a change in the gradation of the soil mixtures. The coarser particles that can be seen in the soil mixtures, the more waste stone powder is added.

5. RECOMMENDATIONS

From the findings of this study, the following recommendations are made for future studies, such as testing soil mixtures with more significant amounts of waste stone powder to understand further the relationship between the quantity of waste stone powder added and the different geotechnical characteristics. Machine learning models and new techniques can be used for future studies [44-53].

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