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Effects of Quarry and Recycled Concrete Waste as Rapid Use Stabilizers for Clay Soils

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Abstract*– Construction in clay subgrades is challenging due to their shrinkage, swelling and strength behavior. The production of cement and lime for ground improvement has a significant negative environmental impact and thus there is a need to find novel, sustainable and economical soil stabilization approaches. The increase in the use of construction and demolition waste materials in the design and construction of infrastructure has helped to preserve our environment by reducing the number of wastes deposited in landfills and supports the conservation of our rapidly diminishing natural resources. The objectives of this research are to stabilize expansive clay with dosages (1, 5, 10, 20%) of cement, limestone dust and recycled concrete aggregate (RCA) fines; and to evaluate the short-term (12hrs) mechanical properties of the stabilized soil in the laboratory. It was found that for rapid use, the stabilized material showed improvement at estimated optimal dosages of 9% cement, 10% limestone dust and 11% recycled concrete aggregate. It was further revealed that optimum dosages resulted in high compaction density, improved strength, and limited swelling, while the cement was shown to be the most stable in improving the plasticity index. In summary, unconventional waste material stabilizers mostly improve the mechanical properties of natural soil. These outcomes of the study are principally useful to road designers since it validates that the construction waste aggregates can be implemented as a replacement with or without cement for the stabilization of clay soils. It further demonstrates the potential for recycling and reuse of construction, quarry, and asphalt plant waste as aggregates, to be efficient methods that are beneficial in protecting natural resources and the environment, thereby improving waste management. The economic validation of including recycled concrete aggregate fines and limestone dust as cement replacement would differ for each country, nevertheless, the reduction in carbon emissions is its undoubted merit, which is a significant contribution to a country's climate change ambitions to achieve low carbon footprints.

***Keywords--* Clay Stabilization, Construction waste, Quarry waste, Recycled aggregate, Sustainability.**

I. Introduction

Expansive clay as a subgrade is a difficult material to build civil engineering structures on because it changes volume significantly when exposed to variations in water content. Expansive clay is estimated to cause billions of dollars in damage to buildings and other infrastructure each year [1]. When expansive clay soils are used as pavement subgrade, we see rutting, unevenness, cracking, and potholes, which often necessitates road maintenance and, in some cases, replacement [2]. There is a need to implement procedures to mitigate the expected volume increase. The replacement of difficult soil with suitable soil is a method for soil improvement. This method, however, is expensive, prompting the search for alternatives [3]. Soil stabilization is the process of combining soil with other materials to improve its engineering properties.

One of the most common chemical stabilization techniques is to mix weak soils with cement to improve their properties. The soil-cement method has been used for nearly a century. Ref. [4] used cement kiln dust to stabilize weak subgrade, and the use of this by-product increased the CBR value of the weak subgrade, resulting in a reduction in pavement layer thickness and cost. Ref. [5] observed construction savings from reducing pavement thickness when the use of waste materials was considered. The increased use of recycled concrete aggregate (RCA) and other construction and demolition waste materials is very welcome because it helps to preserve our environment by reducing the number of wastes deposited in landfills and conserving our rapidly depleting natural resources [6,7]. However, unlike lime, there is no mellowing period when stabilizing with cement because hydration in cement occurs faster, allowing for instantaneous strength gain. Compaction of soil-cement samples is usually done within two (2) hours of mixing. The strength gained during compaction may be less than the ultimate strength of a soil-cement sample. However, the cement-stabilized soil will continue to strengthen over the next few days [3,8,9,10].

Many researchers investigated the effect of lime stabilization on the compaction properties of expansive clay soil [11,12,13,14] and it was discovered that the inclusion of lime caused a decrease in the maximum dry density and an increase in the corresponding water content of expansive soil when adding dosages of lime content ranging from 0 to 7%. Several other studies have reported excellent results in improving the swell-shrink behavior of expansive clay soil treated with lime [15,16]. Although traditional materials like cement and lime have been proven to work for centuries, the environmental impact of these materials is quite significant. Cement production consumes a lot of energy and is not environmentally friendly [17]. Although there are numerous advantages to using cement and lime stabilization techniques, Ref. [18] highlighted the environmental consequences of lime use. It raises total energy consumption and CO_2 emissions by 8.27% and 13.16%, respectively. Furthermore, it consumes a large amount of non-renewable raw materials, and it is estimated that cement production accounts for 5-6% of all carbon dioxide greenhouse gas emissions produced by human activities.

Mixing additive materials makes soil stronger and more durable. The use of waste materials such as limestone dust and RCA fines provides environmental and economic benefits in this case. These waste materials can serve as adequate substitutes for lime and cement stabilizers. The purpose of this experimental study is to investigate the effect of limestone dust, cement, and recycled concrete aggregate as stabilizing agents on the mechanical properties of expansive clay soil. A variety of tests are performed on both untreated and treated soil samples. Atterberg limits, density, unconfined compressive strength (UCS), free swelling index, and linear shrinkage are among the tests performed.

II. MATERIAL AND METHODOLOGY

A. *Material Specification*

The Princess Town Clay from Trinidad and Tobago was used in this study. Table 1 shows that it has been classified as an expansive soil material with geotechnical properties. The cement used was Trinidad Cement Limited's Type 1 Portland-Pozzolan Cement (TCL). This cement contains 15-40% pozzolan by weight (fly ash). Limestone dust aggregates used in this work are sourced from National Quarries Company Limited waster/quarry spoil, which is extracted and processed at Scott's Quarry in Trinidad. This local fine quarry waste material has a greyish appearance, is hard, and is highly weather resistant. Fig. 1 shows a fine grain particle size form of waste material with a specific gravity of 2.576 and a water absorption rate of about 0.746. The concrete wastes were obtained from concrete cylindrical and cubic samples that had been tested. The materials used to make the RCA fines had compressive strengths of more than 25 MPa. It should be noted that the samples were crushed using a mechanical jaw crusher due to the large size of the concrete debris fragments. The crushed samples were sieved, and particle sizes passing through the No.50 sieve (0.30 mm) were used, as shown in Fig. 1(d). According to laboratory records and investigations, the source concrete material contained Type I Portland cement and had a specific gravity of 2.266 and a water absorption rate of approximately 3.014.

TABLE I
PROPERTIES OF PRINCES TOWN CLAY SOIL

Soil Parameter	Value
Max Dry Density - MDD (kg/m^3)	1485
Optimum Moisture Content - OMC (%)	20
Linear Shrinkage (%)	17.2
Free Swelling Index (%)	37.4
Plastic Limit (%)	12.5
Plasticity Index (%)	59.8
Liquid Limit (%)	72.3
Unconfined Compression Test - UCS (kN/m^3)	52.5
Friction Angle (°)	24
Cohesion	24
pH	8

(a) (b) (c) (d)

Fig. 1 Study materials (a) clay (b) cement (c) limestone dust (d) RCA fines.

B. Sample Preparation

After determining the properties of the natural clay soil, it was mixed with cement, limestone dust, and RCA fines. Each stabilizer was mixed at 1%, 5%, 10%, and 20% dry weight of natural clay soil, and samples were cured at room temperature for 12 hours. The short curing time was intended to simulate the rapid application of a construction load to the material following the application of a stabilizing agent. The properties of the treated samples were then established, and the results were analyzed. For each test, at least three specimens were prepared to increase the credibility of the results.

ASTM-D2166 was used to conduct the uniaxial unconfined strength (UCS) test. In a split mould, test specimens with heights of 75 mm were reconstituted in layers vertically aligned. The OMC measured in the compaction test was used to calculate the moisture content required for each treated stabilized sample. The linear shrinkage test, performed in accordance with ASTM-C356, measures the change in linear dimensions that occurs in test samples after 24 hours of heat exposure. Without any external constraints on submergence in water, the free swelling index tests allow us to identify the increase in volume of a soil. The soil sample was immersed in kerosene oil as well as distilled water. Enough time (at least 24 hours) was allowed for the soil sample to reach an equilibrium state of volume without further change in the volume of the soils. The swell potential was calculated after reading the final volume of soils in each of the cylinders. The Atterberg limits, which include the liquid limit, plastic limit, and plasticity index, are a measure of the moisture content of fine-grained soils. These values are used to evaluate and identify soil permeability, strength, and expansiveness. The test was carried out in accordance with ASTM-D4318 specifications.

III. Results And Discussion

A. Compaction

A test was performed in accordance with ASTM D-698 to determine the maximum dry density (MDD) and optimum moisture content (OMC) properties of natural and treated soil samples. The compaction data for clay soil and stabilizer-clay mixtures shown in Fig. 2 show that increasing the stabilizers results in higher optimum water content but varying maximum dry densities. It should be noted that the treated clay compaction tests were carried out within 15 to 30 minutes of wetting. The addition of cement increased the MDD up to 9% dosage, with a gradual decrease after that. This increase in MDD could be attributed to the substitution of cement for clay soil, which has a higher specific gravity. At 5% cement, the maximum OMC is obtained, and this increase is attributed to the moisture required for the hydration reaction between cement and soil particles, as similar behaviors are articulated by [19,20].

The maximum MDD for the limestone dust stabilizer was discovered to be at 4% dosage, followed by a continuous decrease. This is because the cation exchange reaction occurs when flocculated soil particles occupy large spaces, increasing the volume of voids and decreasing MDD. The OMC increases as the limestone dust content rises, and this increase is attributed to the need for moisture to complete the cation exchange reaction, as shown in similar works [21,22]. As the stabilizer dosage was increased up to 20%, the density of the treated RCA fines clay soil increased. This trend can be attributed to fines filling void spaces in soil. The highest OMC was obtained with a 10% RCA dosage.

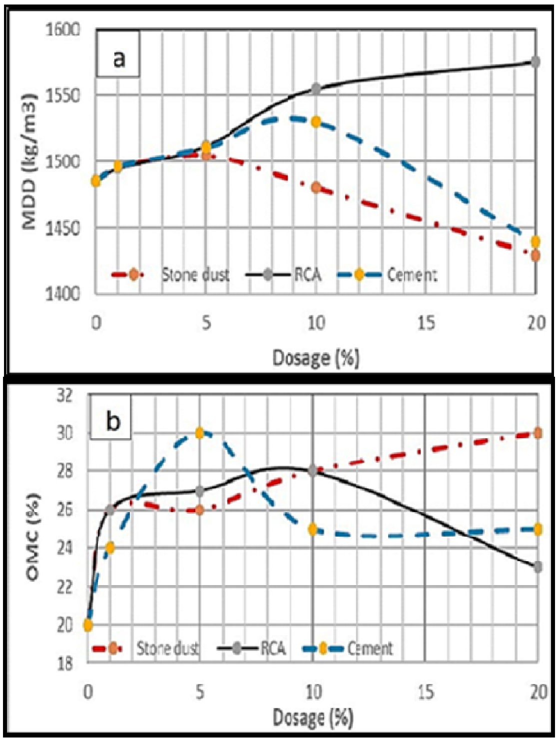

Fig. 2 Compaction properties of treated clay (a) MDD (b) OMC.

B. Atterberg Limits

The results of the Atterberg Limits test are the liquid limit, plastic limit, and plasticity index. The natural soil had liquid limit (LL), plastic limit, and plasticity indices of 72.3%, 12.5%, and 59.8%, indicating a clay soil with high plasticity. However, when mixed with the various stabilizers, the liquid limit is reduced, as shown in Fig. 3(a). The plastic limit (PL), as shown in Fig. 3(b), improved for all mixtures. This decrease in plasticity of treated soil for cement and limestone dust can be attributed to cation exchange between soil and stabilizers, which results in a decrease in diffuse double layer thickness. Fig. 4 depicts the reduction in plasticity index of treated clay soil, and this reduction in plasticity index applies to the various stabilizers, with cement performing best, followed by limestone dust and RCA. This decrease indicates sensitivity to changes in moisture content, which is an improvement in the soil's engineering properties.

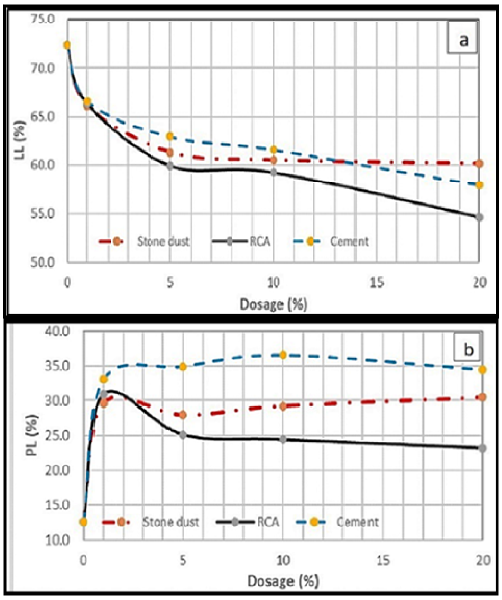

Fig. 3 Stabilizers effects on (a) liquid limit (b) plastic limit.

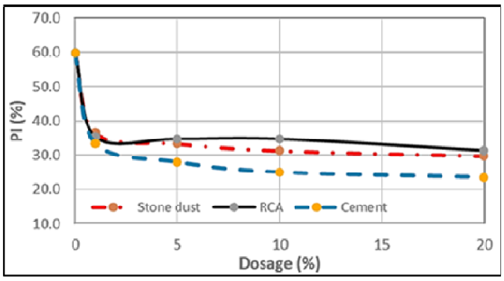

Fig. 4 Stabilizers effects on plasticity index.

C. *Unconfined Compressive Strength (UCS)*

Fig. 5 depicts an improvement in the UCS for all stabilizers. In the case of cement, increasing the cement content up to a dosage of 20% resulted in an increase in UCS. This behavior is caused by the binding of soil particles due to the formation of cement gel between the soil particles [19]. The maximum UCS for both limestone dust and RCA was observed at 5% dosage, and further dosing resulted in a decrease in UCS. Even though [21,23] found a similar trend for limestone dust, this study achieved UCS at optimum limestone dust and RCA fines content of 5%.

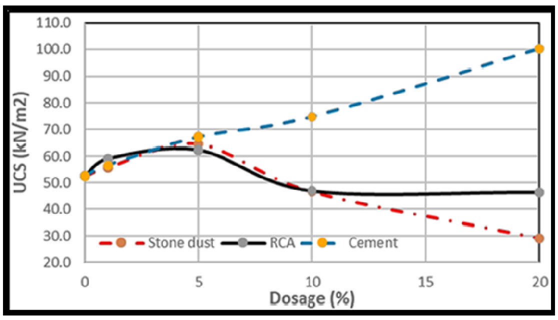

Fig. 5 Unconfined compressive strength vs stabilizer content.

D. *Swelling and Shrinkage*

The natural clay soil has a linear shrinkage (LS) of 17.2. As illustrated in Fig. 6(a), the addition of stabilizers reduces the shrinkage tendency of expansive clay soil, with cement outperforming RCA fines and limestone dust. Because of flocculation and agglomeration caused by the addition of stabilizers, the fine clay particles become coarser and lose plasticity, resulting in a decrease in linear shrinkage. The free swell index (FSI) results, as shown in Fig. 6(b), showed that all stabilizers used reduced the swelling potential of expansive clay soil. Limestone dust performed best at 10% doses, with a 51% reduction in free swelling index from 37.4 to 18.2. The reduction in free swell index for treated soil demonstrates significant improvement in the soil's engineering properties.

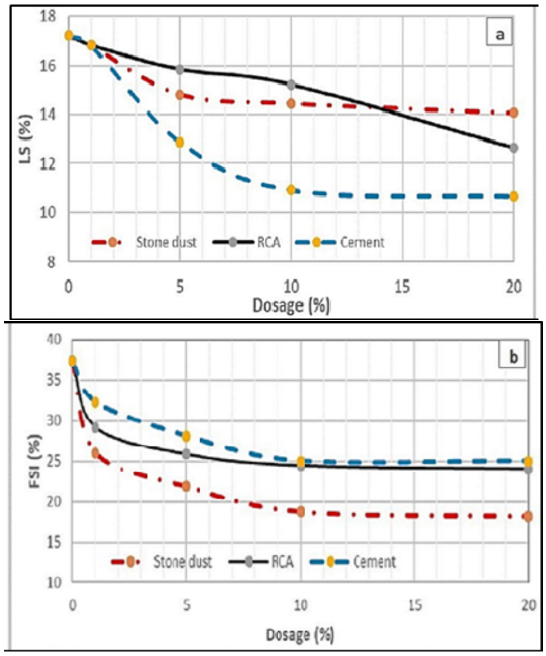

Fig. 6 Stabilizers effects on (a) Linear shrinkage (b) Free swelling index.

IV. CONCLUSIONS

This paper investigates the suitability of non-conventional materials; limestone dust and recycled concrete aggregate (RCA) fines as stabilizers for clay soil improvement. Based on the findings, the following conclusions were reached:

- Density of the compacted clay was improved using the dosages of limestone dust (4%) and recycled concrete aggregate (20%) stabilizers.
- The soil's plasticity index is reduced by 50% at dosages of stabilizers greater than 1%.
- The RCA and limestone dust stabilizers significantly increased the compressive strength of the clays during the 12 hours curing period.
- The addition of 10% stabilizers resulted in reduction of the clay soil linear shrinkage and the free swelling index.

This research further enhances the evidence of the potential for recycling and reusing waste from construction, quarry, and asphalt plants as aggregates. These approaches are effective and have positive effects on natural resources and the environment, leading to improved waste management. The economic rationale for including RCA fines and limestone dust as substitutes for cement will differ from country to country. Nevertheless, the clear advantage of reducing carbon emissions considerably supports a nation's aspirations to achieve low carbon footprints and address climate change.

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