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Alleviating the Problems of Excessive Soil Compressibility Using a Blend of Lime and Marble Dust

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ABSTRACT

Incorporating blends of some waste materials in soil improvement efforts could alleviate the problems of excessive soil compressibility. This paper presents the results of compressibility parameters of two expansive soils (peat and marine clays) stabilized with a blend of lime and marble dust in various percentages. One-dimensional consolidation test was conducted to determine the compression index, recompression index, and coefficient of volume compressibility of the stabilized soils after preliminary tests had been conducted to determine physical and index properties of the soils. The results showed optimal reduction in compression index, recompression index, and coefficient of volume compressibility of 71.3, 67, and 61.4%, respectively at a blend of 6% lime and 8% marble dust for peat clay; while for marine clay, a maximum reduction of 45.5, 65.3, and 76.7%, respectively were obtained at a blend of 4% lime and 6% marble dust. Thus, a percentage blend of 6:8 and 4:6 is recommended for reducing the compressibility of peat clay and marine clay, respectively.

1. Introduction

Excessive soil compressibility and its related problems are mostly associated with expansive soils. Expansive soils are those soils that undergo significant volumetric changes when water is added to or removed from them (Jones & Jefferson, 2012). According to Puppala *et al.* (2004), these soils are primarily made of minerals in the Illite, Montmorillonite, and Kaolinite groups. In the Niger Delta, Abam (2016) revealed that weak formations at 0-10m indicate that Peat clay and marine clay are common types of expansive soils found mostly in lowlands, coastal corridors and other maritime hinterlands. They are associated with high settlement and poor bearing characteristics, requiring stabilization to withstand loads placed on them (Ali *et al.*, 2013). Interestingly, the conscious efforts to incorporate as much waste materials as possible in both soil stabilization and concrete improvement have yielded quite significant and acceptable results. Apart from addressing the issues of waste disposal and management, the use of these waste materials can greatly reduce costs of construction, maintenance or remediation especially in coastal regions. Agro-wastes like bagasse ash (Moses, 2008); rice husk ash (Otoko & Precious, 2013); and groundnut shell ash (Adetoro & Dada, 2015) have yielded positive results in improving strength and shearing resistance. Industrial wastes like silica fume and marble dust (Amin *et al.,* 2014); fly ash (Amadi *et al.* 2021); and quarry dust (Jaja *et al.,* 2023) have similarly performed well in terms of improving strength characteristics by acting as reinforcement with the soil structure. However, there is still a high dependence on conventional chemical agents such as lime and cement in large scale construction or stabilization efforts due to skepticism and availability of alternatives.

Marble Dust is a waste material obtained from marble stone processing operations. According to Babu and Sharmila (2017), the quantity of marble dust produced on a yearly basis, ranges from 5 million to 6 million tons. The potential of marble dust application in stabilization of expansive soils is dependent on its physical and chemical composition. By implication, the physical, mineralogical, and chemical composition of marble dust varies from one plant to another, because of the methods, raw materials, and fuel(s) used. Marble dust is known to have pozzolanic properties, which make it acceptable for use in soil stabilization efforts as several studies (Amin *et al.,* 2014; Sachin & Sharma, 2017) have shown. Singh and Yaday (2014) reports that the incorporation of marble dust in percentages (0 - 10%) reduced the liquid limit of soil samples from 68 to 52%; plasticity index was reduced from 37 to 10%, while swell potential was reduced from 60 to 14%. Similarly, Sivrikaya *et al*. (2020) showed that Dolomite Marble Powder (DMP) and Calcite Marble Powder (CMP) when used in varying percentages (5 - 50%) reduced plasticity index of clay samples by 48%; while swell potential was reduced by 60%. This is similar to that reported by Sabat & Nanda (2011) and Saygili (2015).

However, there is insufficient evidence in the literature that the application of a blend of lime and marble dust reduces the compressibility of expansive soils. Thus, there is need for further studies on how to alleviate the problems of excessive soil compressibility using a blend of lime and marble dust. This is because, if comparable results with those found in the literature using other waste materials could be obtained, incorporating blends of lime and marble dust in soil improvement efforts would be encouraged.

This research was aimed at reducing the compressibility of expansive soils using blends of lime and marble dust. The specific objectives of this research include:

i. Determination of compression index (c_c);
ii. Determination of recompression or swelling index (SI); and
iii. Determination of coefficient of volume compressibility (m_V)

2. Materials and Methods

2.1 Materials

The materials used for this study include expansive clays (peat clay and marine clay), and additives (marble dust and lime).

2.2 Methods

2.2.1 Sampling

The Peat clay was obtained from Eagle Island (4.7828°N, 6.9827°E) Port Harcourt, and Deltaic marine clay from Rumuolumeni (4.8115°N, 6.9478°E) Obio-Akpor Local Government Area, all in Rivers State. The disturbed samples were collected using a hand auger at a depth of 1.5m. Samples were collected into polythene bags to prevent loss of natural moisture. The collected samples were taken to the Soil Mechanics Laboratory of the Department of Civil Engineering, Rivers State University, Port Harcourt for testing and classification. For stabilization purposes, two additives were used; lime and marble dust. The lime used was quicklime or calcium oxide (CaO), which transformed to slaked lime or calcium hydroxide $Ca(OH)_2$, when mixed with water. Marble dust was obtained from the local marble processing plant at Diobu, Port Harcourt.

2.2.2 Sample Preparation

The specimens to be subjected to consolidation were prepared first without mixing with stabilizing agents, and then mixed with stabilizing agents. This technique is useful for choosing an economical blend of materials for various soil conditions and material requirements. For the consolidation test, the samples were mixed with lime and marble dust separately using 2 to 10% at 2% increments by weight of sample. Afterwards, samples were mixed with a blend of lime and marble dust at varying percentages (L/MD: 2–10%) by mass of samples at 2% increments. However, for each increment, lime content was kept constant while varying percentages of marble dust was added. Each increment of lime to be blended with 2 to 10% marble dust was designated Blend A to Blend E. The same can be said of marble dust as shown in Table 1.

Table 1: Blending schedule of lime and marble dust for consolidation test

Unstabilized	Lime (%)				
0	2	4	6	8	10
Marble Dust (%)	Lime-Marble Dust Blends				
	Blend A	Blend B	Blend C	Blend D	Blend E
2	2:2	4:2	6:2	8:2	10:2
4	2:4	4:4	6:4	8:4	10:4
6	2:6	4:6	6:6	8:6	10:6
8	2:8	4:8	6:8	8:8	10:8
10	2:10	4:10	6:10	8:10	10:10

2.2.3 Classification and Consolidation Tests

The tests were conducted in accordance with specifications set out by the British Standards (BS 1377, 1990). Preliminary and classification tests were conducted in line with BS 1377-2 (1990) to determine the physical and index properties of the soils for proper characterization. The tests conducted for this purpose include Natural moisture content, Atterberg limits, specific gravity, and sieve analysis. One-dimensional consolidation test was conducted on samples mixed with lime and marble dust blends. This was to determine the compressibility properties of the soils in accordance with BS 1377-6 (1990).

3. Results and Discussion

3.1 Characteristics of the Peat Clay, Marine Clay, Lime, and Marble Dust

The classification of the expansive clays used for this study is as shown in Table 2 while the major chemical compositions of the marble dust and lime used are shown in Table 3.

Table 2: Physical and index properties of Peat and Marine Clay

Property	BH 1 (Peat Clay)	BH 2 (Marine Clay)
Sand (%)	0.5	4.6
Silt (%)	9.3	44.6
Clay (%)	90.2	49.2
Moisture content (%)	105	60.1
Liquid Limit (%)	130.0	70.0
Plastic Limit (%)	47.3	31.0
Plasticity Index (%)	82.7	39.0
Specific Gravity (G_s)	1.81	2.21
Void Ratio (e)	4.73	0.95
Bulk Density (kg/m^3)	1459	2225
Dry Density (kN/m^3)	3.15	11.33
Organic Content (%)	90	7.2
USCS	Pt	CH

BH, Borehole; CH, High Plasticity Clay; Pt, Peat; USCS, Unified Soil Classification System

Table 3: Major mineral oxides of lime and marble dust

Lime		Marble Dust	
Oxide	Percentage	Oxide	Percentage
CaO	74.23	CaO	42.45
MgO	0.74	SiO_2	26.35
Fe_2O_3	0.17	Fe_2O_3	9.40
SiO_2	0.14	MgO	1.52
AL_2O_3	0.11	AL_2O_3	0.52

3.2 Effect of Lime-Marble Dust Blends on Compression Index

The variation of compression index (c_c) of peat and marine clays with various blends of lime and marble dust is illustrated in Figure 1a and 1b. For peat clay (Figure 1a), it was observed that with Blend A, c_c reduced by a minimum of 28.7% and a maximum of 45%. Blend B reduced c_c by a minimum of 44.2% and a maximum of 56.3%. Similarly for Blend C, c_c reduced by a minimum of 57.2% and a maximum of 71.3%. Also, for Blend D, c_c varied by a minimum of 55.8% and a maximum of 70.3%. Lastly for Blend E, c_c reduced by a minimum of 54.8% and a maximum of 68.3%.

It was also observed that c_c of marine clay reduced with increasing blends (Figure 1b). With Blend A, c_c reduced by a minimum of 7.3% and a maximum of 37.8%. For Blend B, we see a minimum reduction of c_c by 31.2% and a maximum of 45.5%. Also, for Blend C, c_c is reduced by a minimum of 24.5% and a maximum of 42.6%. For Blend D, c_c varied by a minimum of 22.7% and a maximum of 39.6%, while for Blend E, C_c reduced by a minimum and maximum of 20.8% and 28.8% respectively.

Generally, the compression index of peat and marine clays showed linear decrements with addition of stabilizing agents. The c_c of peat reduced from 0.8 to 0.2 at optimum blend while that of marine clay reduced from 0.4 to 0.19 at optimum blend. The most effective blend was observed to be 6:8 for peat; and 4:6 for marine clay. The reduction in c_c shows a positive influence of the stabilizing agents on compressibility of the soils. It was also observed that the c_c of peat and marine clays stabilized separately with lime performed better than it did with marble dust. This indicates that lime was more effective than MD in reducing compressibility. Additionally, the c_c of lime-MD blends gave even better results in comparison to separate additions. However, the optimum content of lime and MD for stabilizing peat clay was 6% and 8% respectively; while 4% and 6% was observed for marine clay as further additions did not further improve c_c.

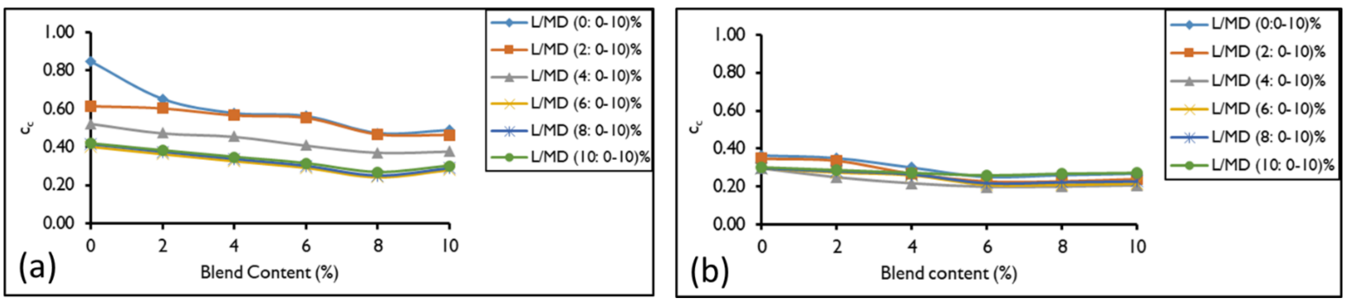

Figure 1: Variation of compression index (c_c) with lime and MD blends for (a) Peat Clay and (b) Marine Clay

3.3 Effect of Lime-Marble Dust Blends on Swelling Index

The changes in swelling index (SI) of peat and marine clays stabilized with various blends of lime and marble dust is shown Figure 2a and 2b. Figure 2a shows that the SI of peat clay mixed with Blend A reduced by a minimum of 44% and a maximum of 59.6%. With Blend B, we see a minimum and maximum reduction of 55.9% and 61.9% respectively. Also, for Blend C, SI reduced by a minimum of 62.4% and a maximum of 67%. For Blend D, SI varied by a minimum and maximum of 62.1% and 65.9% respectively; while for Blend E, SI reduced by a minimum of 61.7% and a maximum of 64.6%.

The SI of marine clay also decreased with increasing blends compared to the unstabilized soil (figure 2b). Blend A reduced SI by a minimum and maximum of 40% and 58% respectively. With Blend B, a minimum and maximum reduction of 43.8% and 65.3% was observed. Similarly for Blend C, SI reduced by a minimum of 47.3% and a maximum of 53.6%. Blend D reduced SI by a minimum and maximum of 45.9% and 50.7% respectively; while Blend E reduced SI by a minimum and maximum of 42.4% and 48.1% respectively.

There was a linear decrease in the swelling index of peat and marine clays with various blends of lime and marble dust. The reduction in swelling index indicates a positive influence of the stabilizing agents against swell potential of the soils. It was observed that the SI of peat and marine clays stabilized separately with lime performed better than that with marble dust. This also indicates that lime is more effective than MD in reducing swell potential. The trend shows that the optimum content of lime and marble dust was 6% and 8% respectively, with the most effective lime/MD blend being 6:8 for peat; and 4% and 6% respectively, with the most effective blend being 4:6 for marine clay. The SI of peat and marine clays reduced from 0.04 to 0.02 at optimum blends. It is important to highlight that the SI values ranged between about one-tenth and one-fifth their corresponding c_c values. Dhowian & Edil (1980) considers this as particularly vital when considering the preloading of peat deposits in connection with improving its strength and compressive properties.

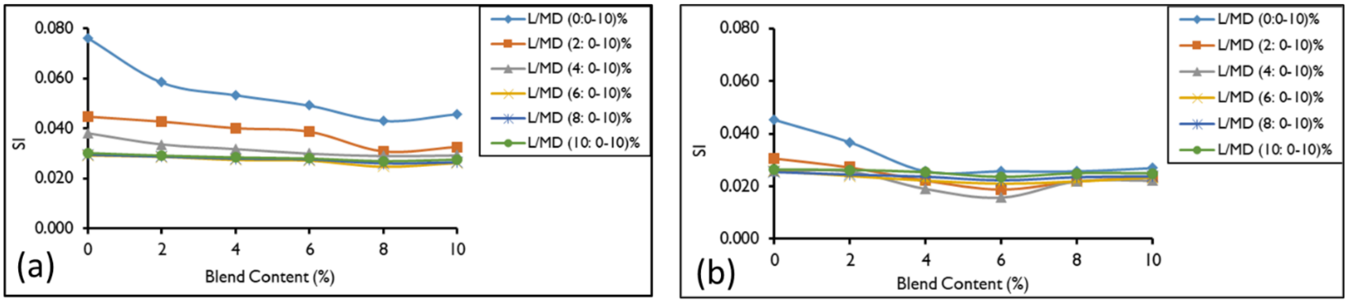

Figure 2: Variation of swelling index (SI) with lime and MD blends for (a) Peat Clay and (b) Marine Clay

3.4 Effect of Lime-Marble Dust Blends on Coefficient of Volume Compressibility

The variation of coefficient of volume compressibility (m_v) of peat and marine clays mixed with various blends of lime and marble dust is shown in Figure 3a and 3b. The m_v of peat clay improved considerably compared to the unstabilized soil with each blend (figure 3a). Blend A reduced m_v by a minimum of 23.6% and a maximum of 40.9%. With Blend B, we see a minimum reduction of 36.7% and a maximum of 49.8%. Similarly for Blend C, m_v is reduced by a minimum of 43% and a maximum of 61.4%. Blend D reduced m_v by a minimum and maximum of 41.7% and 60.3% respectively; while Blend E reduced m_v by a minimum and maximum of 32.2% and 52% respectively.

Figure 3b shows that m_v also improved considerably compared to the unstabilized soil. Addition of Blend A reduced m_v by a minimum of 32.3% and a maximum of 65.1%. With Blend B, we see a minimum reduction of m_v by 45.8% and a maximum of 76.7%. Addition of Blend C reduced m_v by a minimum of 40.4% and a maximum of 70%. Also with Blend D, m_v reduced by a minimum and maximum of 36.7% and 63.4% respectively; while Blend E reduced m_v by a minimum and maximum of 35.6% and 51.2%, respectively.

The reductions in coefficient of volume compressibility (m_v) of both soils upon addition of lime and marble dust blends indicate a positive effect of the additives on the property. It is observed that m_v was reduced from >1.5 m^2/MN, which is characteristic of organic clays and peat, to as low as 0.9 m^2/MN which is characteristic of normally consolidated clays. It was also observed that the degree of influence of lime on m_v of peat is greater than that of marble dust. The optimum values were observed at blends of 6:8 for peat; and 4:6 for marine clay. The reason for the decrease in m_v can be attributed to the cementation bonds formed during the stabilization reactions. This agrees with Sudhakar & Shivananda (2005) conclusion on compressibility of weak clay stabilized with lime.

Overall, lime and marble dust blends reduced the compressibility of both soils under consideration. Venuja *et al.* (2017) and Kolay *et al.* (2011) attributed this effect to cementation and pozzolanic reactions between the soil and the stabilizing agent. This implies that in addition to the bonding properties of the lime, MD offers additional stiffness through pozzolanic reactions. The results agree with that of Haakel *et al.* (2019) in which the c_c of peat soil stabilized with fly ash using a deep soil mixing technique improved by up to 39.4%. Similar results were also observed in Almurshedi *et al.* (2019).

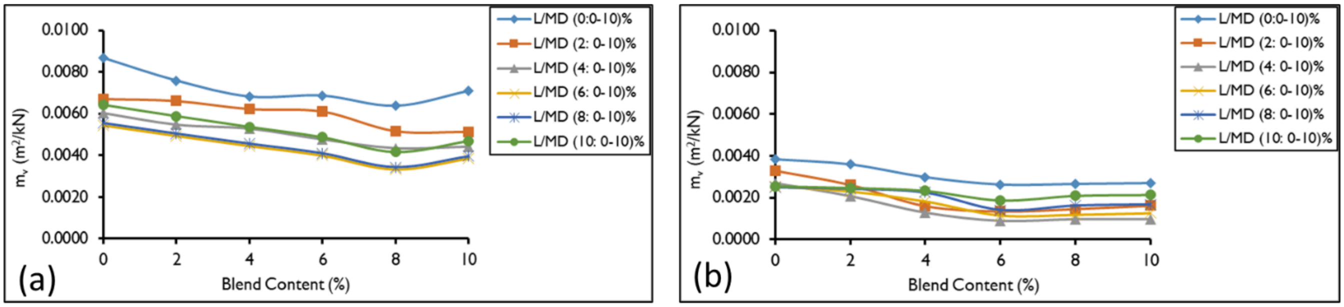

Figure 3: Variation of coefficient of volume compressibility (m_v) with lime and MD blends for (a) Peat Clay and (b) Marine Clay

4.0 Conclusions

The improvement efforts reported in this study deals specifically with the common expansive soil types found in the coastal areas of the Niger Delta, Nigeria. The following conclusions have been drawn based on the results obtained.

i. The threshold content for improving compressibility of peat is 6% lime and 8% marble dust.

ii. The threshold content for improving compressibility of marine clay is 4% lime and 6% marble dust.

iii. Based on c_c and m_v values, Lime and marble dust blends improved the compressibility characterization of the expansive soils from organic clays and peat (m_v >0.0015 m^2/kN) to clays of medium compressibility (0.0003 < m_v <0.0015 m^2/kN; c_c < 0.8).

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