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Expansive Soil Stabilization by Waste Marble Dust and Volcanic Ash: Experimental Approach in the Case of Lachi Area, Mekelle, Ethiopia

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Abstract

Expansive soil deposits in the study area imposed multiple problems to various civil structures and require geotechnical solutions. The main objective of this study was to evaluate the possibility of utilizing waste marble dust and volcanic ash as soil stabilizers which are plentifully available in the vicinity. The evaluation was carried out with the addition of a predetermined percentage of the stabilizers up to 30% by mass measurement. The effects of the stabilizers on the different properties of the *in-situ* expansive soil sample were evaluated via experiments. The investigation showed that the physical properties and selling characteristics of the problematic soils have been improved significantly. Therefore, this study indicated that both waste marble dust (marble by-product) and volcanic ash (locally available material) can be used as stabilizers. It is also observed that the waste marble dust is more effective stabilizer than the volcanic ash for stabilizing the expansive soils of the study area due to the high concentration of calcium in the waste marble dusts. In the process, a base exchange occurs with the calcium ions of waste marble dust replacing sodium on the surface of the expansive clay particle.

Keywords: Waste marble dust • Volcanic ash • Expansive soil • Soil stabilization • Swelling potential

Introduction

Expansive soils are problematic for construction purposes because of their cyclic heave during wet season and shrink during dry season behaviour [1]. Expansive soils are a worldwide threat that poses several challenges for civil engineers [2]. They are considered as potential natural hazards which can cause extensive damage to structures if not adequately treated [3]. Expansive soils cause more damage to structures, predominantly light weight structures than any other natural hazard, including earthquakes and floods [4].

Stabilization is the process of improvement of the expansive soil behaviour using different stabilization methods. In other words, stabilization means incorporating various techniques to alter the engineering properties of the soil [5]. Generally, different types of stabilizers are available and used in the field of geotechnical engineering for stabilization of expansive soils. Recently due to the high demand of industrial construction products, industrial solid waste generation is a big challenge which causes environmental hazards such (air, land and water pollution) [3]. For instance, Devdutt indicated the generation of waste marble dust during block production at the quarries raises 40-60% of the overall production volume as a result of the demand for marble production in the world.

Ethiopia has numerous marble deposits with more than 15 types comprising different colours and patterns that are well- known to the world. Specifically, in the northern part of Ethiopia, there is large marble deposit and productions that consequently results into large amount of waste marble dust during the production process. Saba dimensional stone PLC, which produces marble and related construction finishing products in the Tigray region, (which is northern part of Ethiopia) is one of the waste marble dust producers estimated to generate about 9824.7 tons annually. On the other hand, there is also a large concentration of volcanic ash in the Tigray region, which is causing environmental and air transportation problems [6].

Thus, the application of locally available materials (e.g., volcanic ash) and industrial wastes (e.g., waste marble dust) for soil stabilization is paramount importance that has a significant benefit to the environment. The excess dependence on industrially manufactured soil improving additives (cement, lime etc.) has kept the cost of construction of stabilized buildings financially high [7]. These yet have continued to discourage the underdeveloped and poor nations of the world from providing accessible buildings to meet the need of their people. [8].

In this study, the suitability of two stabilizers namely waste marble dust and volcanic ash on the engineering performance of expansive soils are evaluated. The purpose is to experimentally examine the engineering properties of natural expansive soils treated with various percentages of waste marble dust and volcanic ash to evaluate the effectiveness and applicability of the stabilizers in the local area.

Materials and Methods

For the present study, the methodology used is summarized in the flowchart shown in Figure 1.

Expansive soil samples

The soils used in this study were expansive soils collected from Tigray region in the north part of Ethiopia in Mekelle city at a local place known as Lachi Addis Safer as presented in Figure 2. The disturbed samples were collected after removing the top 50 cm soil from a depth of 3 m. The samples were sealed in polythene bag to retain the natural moisture content during transportations to the laboratory. Further, the samples were air dried, pulverized and sieved with Sieve No. 200 (0.75 mm sieve) as required for laboratory test according to ASTM.

Waste marble dust and volcanic ash samples

The waste marble dust and volcanic ash used for this research were

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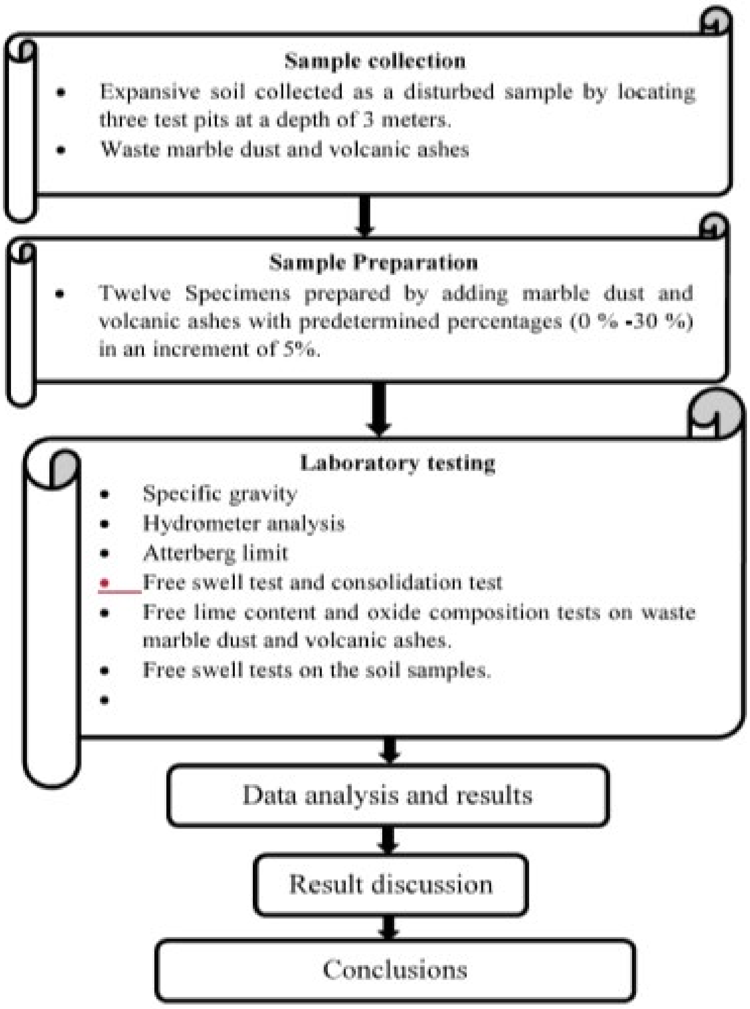

Figure 1. Methodology employed in the research.

Figure 2. Location of the study area.

collected from Sheba dimensional stone plc. (140 10’N, 380 54’E) and Chelekot area (130 22’N, 390 28’E) of the Tigray region. The waste marble dust additive mainly composed of carbonates ($CaCO_3$ and $MgCO_3$) while the volcanic ash consisted of $MgCO_3$ and $FeCO_3$. The results of the oxide composition test are shown in Table 1.

Preparation of Specimens

The expansive soil samples collected from the study area were tested for their *in-situ* properties and then twelve specimens were prepared by adding waste marble dust and volcanic ash up to 30% with increment of 5% as shown in Table 2.

Experimental Program

Experimental study of this research comprised the experimental programs stated in Table 3.

Results and Discussion

Test results

The summary of test results for the hydrometer tests, Atterberg limit tests, specific gravity tests are shown in Table 4. Using these test results, the percentages of clay-sized and silt-sized particles were determined. Moreover, the soil sample was classified according to (ASTM D 2487-00, 2013) and (AASHTO M 145, 2017) [9] standards shown in Table 4.

Free lime content test on stabilizers

One of the reasons in using waste marble dust and volcanic ash as a stabilizer is its pozzolanic activity because of its lime content. In order to determine lime content of the test samples ASTM C25 is used. By means of free lime content test on stabilizers, it was detected that there is some lime content in both waste marble dust and volcanic ash, which decreases the swell potential of the expansive soil with an average available lime content of 4% for the waste marble dust and 3% for that of volcanic ash.

Table 4 shows Effect of addition of waste marble dust and volcanic ashes on liquid limit, plastic limit and plasticity index respectively. This shows that after adding waste marble dust to the natural soil there is a continuous reduction of all the above properties of the expansive soil and after volcanic ash addition the above properties increases. Moreover, the specific gravity of the sample increases after addition of the stabilizers.

Table 5 shows the free swell, swelling pressure test, and compressibility behavior test results. For untreated and treated soil specimens.

Results of available lime test showed a considerable amount of lime on the stabilizers that can reduce the swelling potential of the expansive soil. In addition, after addition of waste marble dust and volcanic ash to the natural soil there was a reduction of free swell property of the expansive soil as shown in Table 5.

In addition, Table 5 shows reduction of swelling percentage and swelling potential after the addition of the stabilizers to each sample according to the consolidation test results.

Effects of stabilizers on the Atterberg limit

There has been a significant decrease on the Liquid Limit (LL) of the stabilized soil specimens the tested specimens with the addition of increasing

Table 1. Results of chemical analysis of waste marble dust and volcanic ash.

	Type of Materials Used	
Element Composition (%)	Waste Marble Dust	Volcanic Ash
Mg	1.07	3.26
Al	0.002	0.0018
Si	0.0053	0.0024
Ca	18.76	0.73
Fe	0.772	3.78

Table 2. Specimens used in the experimental study.

No.	Soils Samples (%)	Waste Marble Dust (%)	Volcanic Ash (%)
Sample	100	0	-
5% WMD	95	5	-
10% WMD	90	10	-
15% WMD	85	15	-
20% WMD	80	20	-
25% WMD	75	25	-
30% WMD	70	30	-
5% VA	95	-	5
10% VA	90	-	10
15% VA	85	-	15
20% VA	80	-	20
25% VA	75	-	25
30% VA	70	-	30

Table. 3 Standards used for testing.

Experiment No.	Experiment Name	Standard Used
1	Free lime content	ASTM C25 2013
2	Hydrometer Test	(ASTM D7928- 17, 2013)
3	Atterberg limit WL and WP tests	(ASTM D 4318, 2013)
4	Specific gravity	(ASTM D 854, 2013)
5	Swelling pressure test (*via* consolidation test)	(ASTM D 2435-00, 2013)

Table 4. Properties of samples.

Sample	Composition %			Atterberg Limit Tests			Classification	
	Clay	Silt	Gs	LL (%)	PL (%)	PI (%)	USCS	AASHTO
Sample	15	74.3	2.45	71.4	48.3	23.1	MH	A-7-5
5% WMD	10	78.9	2.5	65.2	50	15.2	CH	A-7-6
10% WMD	10	74.3	2.5	61.5	50	11.2	MH	A-7-5
15% WMD	10	73.4	2.51	61.2	49	12.2	CH	A-7-6
20% WMD	11	74.3	2.54	47	31.8	15.2	CL	A-7-6
25% WMD	31	39.4	2.55	53.9	31.6	22.3	MH	A-7-6
30% WMD	11	75.8	2.58	53.8	36.4	17.4	MH	A-7-5
5% VA	34	57.7	2.47	61.6	26	35.6	MH	A-7-6
10% VA	36	46.2	2.49	65.1	28.5	36.6	MH	A-7-5
15% VA	38	44.2	2.5	58.7	20	38.7	MH	A-7-5
20% VA	24	58.4	2.5	59.5	27.7	31.8	CH	A-7-6
25% VA	24	55.9	2.51	53.7	26.7	27	CH	A-7-6
30% VA	13	57.6	2.52	51	25.4	25.6	CH	A-7-6

Table 5. Free swell and consolidation test results.

Test Sample	Free Swell FS (%)	Swelling Percentage (%)	Swelling (mm)	Compression Index (Cc)	Swelling Index (Cr)
Sample X	102.6	21.7	0.71	0.26	0.06
5%WMD	93.8	-	-	-	-
10% WMD	96.3	-	-	-	-
15% WMD	98.7	-	-	-	-
20% WMD	67	18	0.68	0.19	0.05
25% WMD	70	-	-	-	-
30% WMD	58.7	18.55	0.69	0.23	0.053
5%VA	96.6	-	-	-	-
10%VA	98.7	-	-	-	-
15%VA	91.2	-	-	-	-
20% VA	93.4	19.29	0.65	0.25	0.09
25% VA	93.3	-	-	-	-
30% VA	63.2	18.87	0.7	0.2	0.04

amount of waste marble dust percentages. Similar effects were reported from the studies by [6,10]. A maximum decrease to LL=17.6% occurred with the addition of 20% waste marble dust stabilizer. The reduction in the LL is due to the flocculation of clay particles of the expansive soils and pozzolanic reactions of the stabilizers.

Furthermore, with the addition of volcanic ash, the liquid limit of the stabilized soil specimens also decreased. The maximum reduction to LL=20.4% occurred at addition of 30% volcanic ash stabilizer. This drop in the LL is due to the flocculation of clay particles of the expansive soils and addition of silt-sized particles to the soil. Figure 3 shows the effects of the incremental addition of the stabilizers on liquid limit of the soil sample.

Furthermore, addition of 5% incremental waste marble dust stabilizer to the specimens resulted in decreased Plastic Limit (PL) of the specimens with a maximum reduced value of PL=36.4% attained at 30% addition of the waste marble dust stabilizer (Table 4) (Figure 4). This is attributed to the flocculation of clay particles of the expansive soils and pozzolanic reactions. Similarly, addition of 5% incremental volcanic ash stabilizer to the specimens reduced the plastic limit with increasing rate. The addition of a 30% volcanic ash stabilizer caused reduction to PL=25.4% which is about 90.2% reduction compared with the specimen without the stabilizer (Table 4) (Figure 4). The decrement of the PL is due to the flocculation of clay particles of the expansive soils and addition of silt-sized materials to the soils.

Hence, it is evident that both stabilizers affect the plasticity index (PI) of the samples as a result of the effects on the liquid limit and plasticity index. The variation of the PI for both stabilizers with the incremental stabilizers is shown in Figure 5. From Figure 5, it can be inferred that the increase in marble dust stabilizer amount up to about 10% reduced the PI and further increase in the stabilizer showed to increase the PI. Figure 5 showed the reverse behavior that addition of volcanic ash stabilizer up to about 15% increased the PI and the decreased with further increment of the percentages.

Effect of waste marble dust on specific gravity

Figure 6 shows the effect of incremental percentage addition of the stabilizers to the specimens. As can be seen from the figures, both stabilizers strictly increased the specific gravity with increase in the amount of the stabilizers. The marble dust stabilizer increased the specific gravis to Gs=2.58 while the volcanic ash stabilizer increased to Gs=2.52 with the addition of 30% stabilizer. In comparison with the study by [11,12], the specific gravity of the expansive soil increased with increase in the amount of the waste marble dust.

Effect of waste marble dust on swelling percentage, Compression Index and Swelling Index

Table 5 shows the summary of the changes in the swelling percentage, compression index and swelling index on the addition of 20% and 30% of the stabilizers. After observing the effect of stabilizers on the different index tests these stabilizes have got a considerable effect on the soil after the addition of 20% - 30% percent of stabilizers. Therefor consolidation test was conducted for this specified percentage.

Swell percentage of sample decreased with the addition of waste marble dust. Such a reduction in swell percentage is due to the high calcium content of waste marble dust. This matches to the result from [10,13] usage of waste marble dust in improving problematic soils (especially swelling) will be an alternative and economic method in highly active clayey zones.

The result of consolidation test of both treated soil and natural soil shows

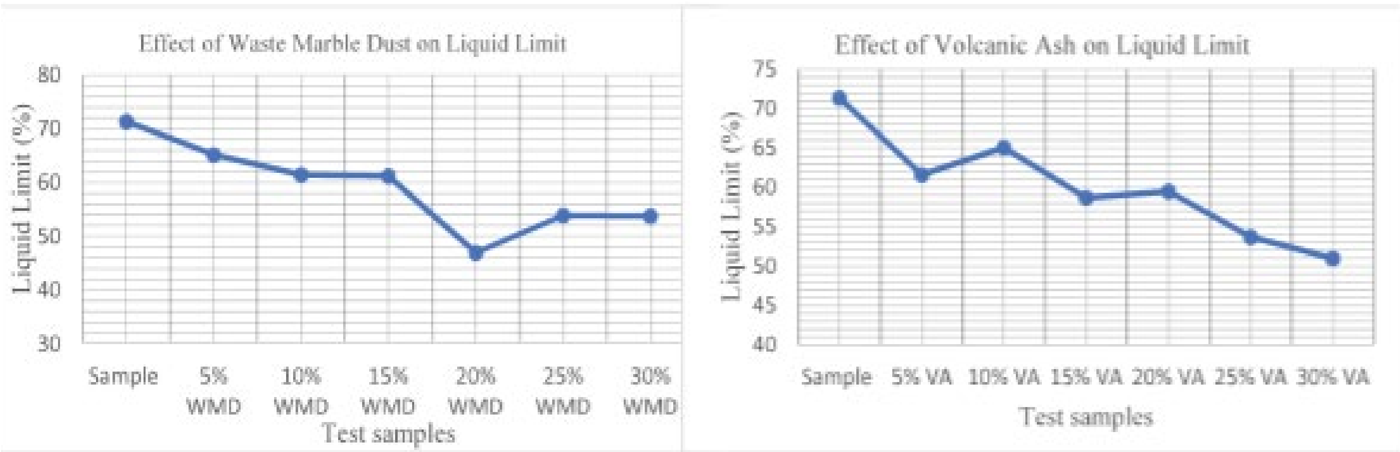

Figure 3. Effect of waste marble dust and volcanic ash on liquid limit.

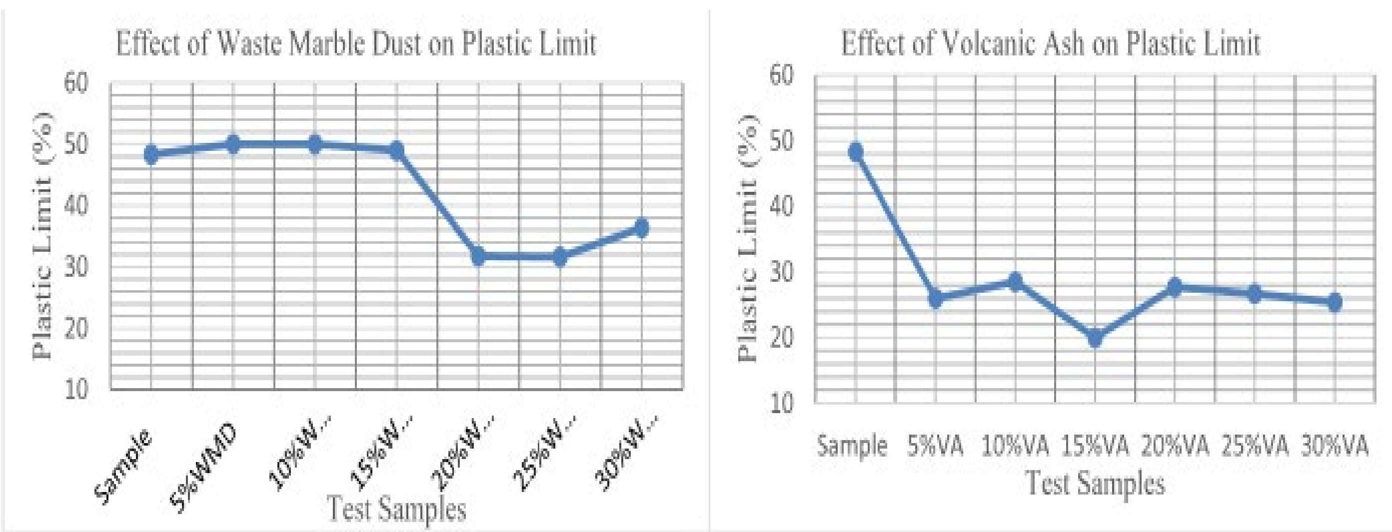

Figure 4. Effect of waste marble dust and volcanic ash on plastic limit.

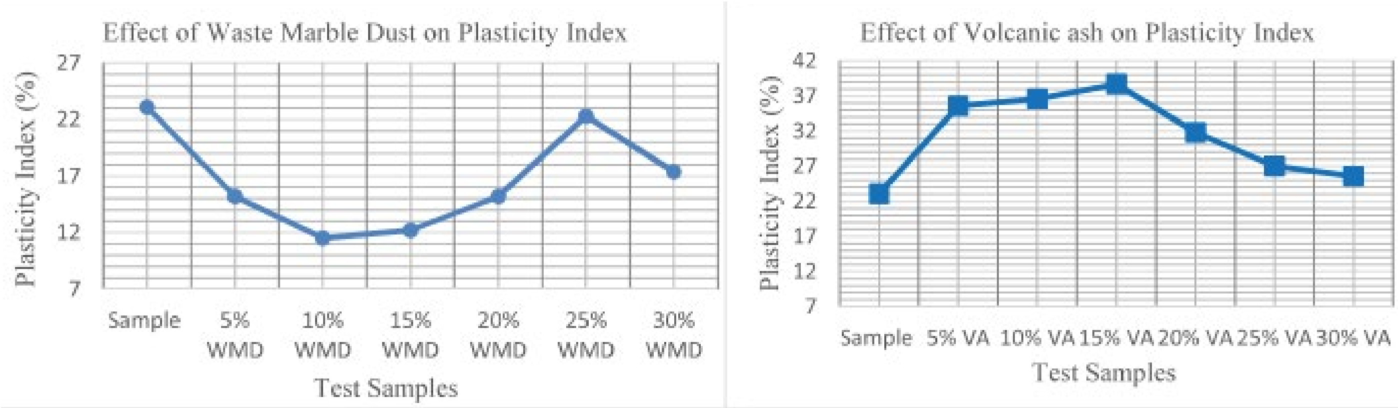

Figure 5. Effect of waste marble dust and volcanic ash on plasticity index.

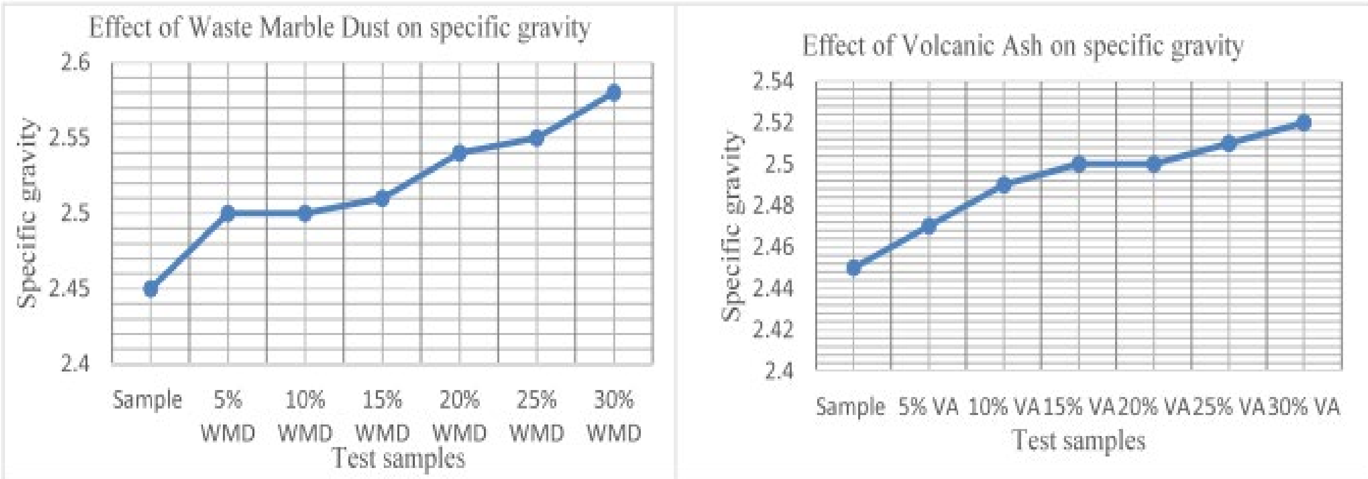

Figure 6. Effect of waste marble dust and volcanic ash on specific gravity.

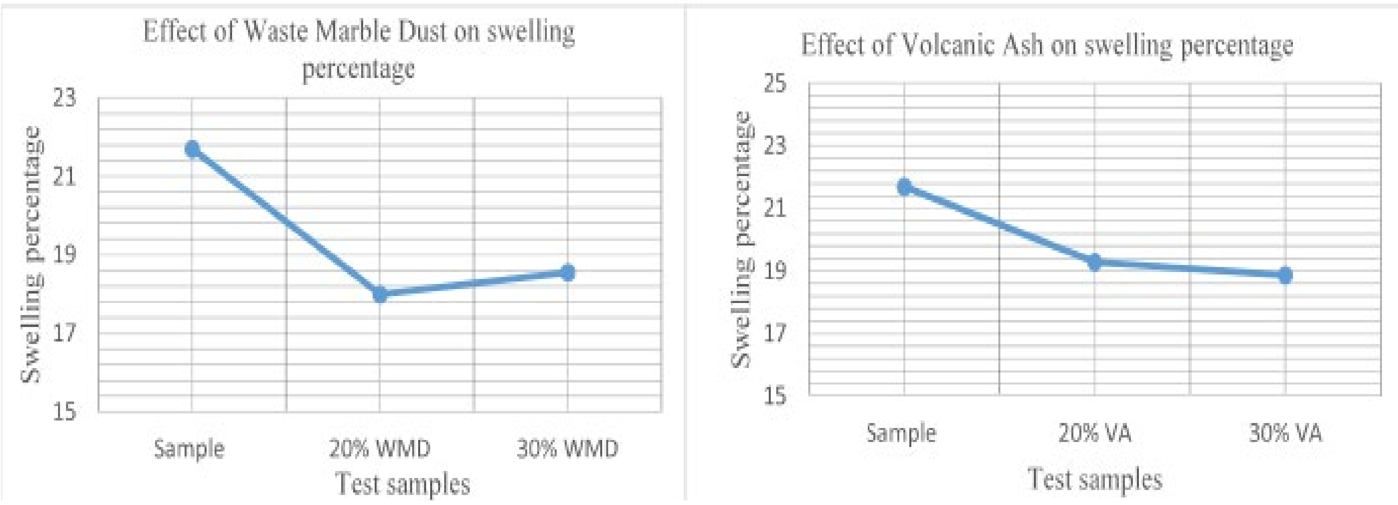

Figure 7. Effect of waste marble dust and volcanic ash on swelling percentage.

that the compressibility index and swelling index of the soil decreases after addition of the stabilizers as shown in Figure 7.

Waste marble dust related result discussion

The addition of waste marble dust to the expansive soil reduces the clay content and a corresponding increase in the percentage of coarse particles. It also reduces the Liquid Limit (LL) Plasticity Index (PI) and swelling potential of the soil.

In the process, a base exchange occurs with the calcium ions of waste marble dust replacing sodium on the surface of the expansive clay particle. The net result is a low Base Exchange capacity for the particle with a resulting lower swelling potential. Addition of waste marble dust resulted in the formation of aggregation, which reduced the swelling potential of the soil (i.e., particle size distribution). Addition of waste marble dust is more effective in reducing swelling percentages, compressibility and swelling indexes than addition of the same amount of volcanic ash.

Volcanic ash related result discussion

The addition of volcanic ash to the expansive soil increases the clay content and a corresponding reduction in the percentage of coarse particles.

It also reduces the liquid limit (LL) plasticity index (PI) and swelling potential of the soil. Addition of volcanic ash resulted in the formation of aggregations, which reduced the swelling potential of the soil (i.e., particle size distribution). Addition of volcanic ash is less effective in reducing swelling percentages, compressibility and swelling indexes than addition of the same amount of waste marble dust.

Conclusion

Considering the experimental results, this research concludes the following:

1. Shifting of grain size distribution curves to coarser side was observed with the addition of waste marble dust because of the addition of silt size particles and chemical reactions. However, addition of volcanic ash shifted the curves to the finer sides.

2. Plasticity index first decreased with the addition of waste marble dust but further addition resulted into increasing of the PI. This is because of the flocculation of particles. However, with the addition of volcanic ash plasticity index increased at the beginning but decreased with further increase in the stabilizer. Thus, these results show that there is an optimum stabilizer amount which results into stable PI value.

3. The compression index (Cc), swelling (expansive) index (Cr) and the swelling percentage for the treated soil decreased compared with the untreated soil. This is due to the presence of lime. However, as waste marble dust has high calcium cation content compared with the volcanic ash, the waste marble dust has high pozzolanic property than volcanic ash. Which results in different rates of responses on the various properties?

Finally, following these experimental investigations, it can be concluded that both stabilizers (i.e., waste marble dust and volcanic ash) are effective materials for stabilizing expansive soils but the effectiveness of these stabilizers depends on the selection of optimized amount. This in turn decides the amount of the chemical composition of each stabilizer. It has been observed that waste marble dust is more efficient than volcanic ash for stabilization of expansive soil with all aspects.

Data Availability Statement

All data, models, or code generated or used during the study are available from the corresponding author by request.

List of available data:

- Physical and chemical characteristics of materials
- XRF analysis results (Chemical Composition)
- Atterberg Limits raw data and results
- Consolidation test data's

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