EFFECT OF WASTE MARBLE POWDER TO IMPROVE ENGINEERING CHARACTERISTICS OF EXPENSIVE SOIL

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ABSTRACT: Expansive soils occurring in arid and semi-arid climate regions of the world cause serious problems on civil engineering structures. Such soils swell when given an access to water and shrink when they dry out. Several attempts are being made to control the swell-shrink behavior of these soils. Soil stabilization using chemical admixtures is the oldest and most widespread method of ground improvement. In this study, waste limestone dust and waste dolomitic marble dust, by-products of marble industry, were used for stabilization of expansive soils. The expansive soil is prepared in laboratory as a mixture of kaolinite and bentonite. Waste limestone dust and waste dolomitic marble dust were added to the expansive soil with predetermined percentage of stabilizer varying from 0 to 30 percent. Grain size distribution, consistency limits, chemical and mineralogical composition, swelling percentage, and rate of swell were determined for the samples. Swelling percentage decreased and rate of swell increased with increasing stabilizer percentage. Also, samples were cured for 7 days and 28 days before applying swell tests. Curing of samples affects swell percentages and rate of swell in positive way.

Keywords: Expansive Soil, Soil Stabilization, Swelling Potential, Waste Limestone Dust, Waste Dolomitic Marble Dust

I. INTRODUCTION

Expansive soil deposits occur in the arid and semi arid regions of the world and are problematic to engineering structures because of their tendency to heave during wet season and shrink during dry season (Mishra et al. 2008).

Expansive soils are a worldwide problem that poses several challenges for civil engineers. They are considered a potential natural hazard, which can cause extensive damage to structures if not adequately treated (Al-Rawas, 2002). Expansive soils cause more damage to structures, particularly light buildings and pavements, than any other natural hazard, including earthquakes and floods (Jones and Holtz, 1973).

During the last few decades damage due to swelling action has been observed clearly in the semi arid regions in the form of cracking and breakup of pavements, roadways, building foundations, slab-on-grade members, and channel and reservoir linings, irrigation systems, water lines, and sewer lines (Çokça, 2001).

Clay Mineralogy

The term clay can refer both to a size and to a class of minerals. As a size term, it refers to all constituents of a soil smaller than a particular size, usually 0.002 mm in engineering classifications. As a mineral term, it refers to specific clay minerals that are distinguished by (1) small particle size, (2) a net electrical charge, (3) plasticity when mixed with water and (4) high weathering resistance (Mitchell and Soga, 2005).

The basic idealized crystalline structural unit of a clay mineral is composed of a silica tetrahedron block and an aluminum octahedron block. Aluminum octahedron block may have Aluminum (Al3+) or magnesium (Mg2+). If only aluminum is present, it is called gibbsite [Al2(OH)6]; if only magnesium is present, it is called brucite [Mg3(OH)6]. Various clay minerals are formed as these sheets stack on top of each other with different ions bonding them together (Oweis and Khera, 1998). A silica tetrahedron and a silica sheet, also an octahedron and an octahedron sheet are presented in Figure 1.1. Also, these figures consist of schematic representations of silica and octahedron sheets.

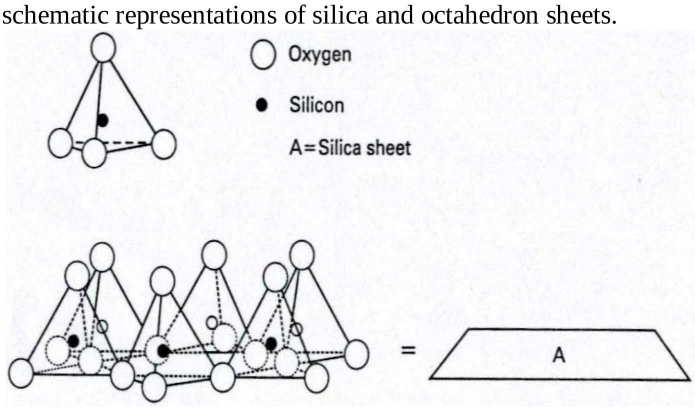

Figure 1.1 A Silica Tetrahedron and a Silica Sheet

Kaolinite group

Kaolinite crystals consist of tetrahedron and octahedron sheets. The bonding between successive layers is by van der Waals forces and hydrogen bonds. The bonding is sufficiently strong that there is no interlayer swelling in the presence of water (Mitchell and Soga, 2005).

Mica-like group

Illite has a basic structure consisting of a sheet of alumina octahedrons between and combined with two sheets of silica tetrahedrons. In the octahedral sheet there is partial substitution of aluminum by magnesium and iron, and in the tetrahedral sheet there is partial substitution of silicon by aluminum. The combined sheets are linked together by fairly weak bonding due to (non - exchangeable) potassium ions held between them (Craig, 1997).

Smectite group

Montmorillonite is formed from weathering of volcanic ash under poor drainage conditions or in marine waters. The basic building sheets for smectite are the same as for illite except there is no potassium ion present. The space between the combined sheets is occupied by water molecules and exchangeable cations. There is a very weak bond between the combined sheets due to these ions. Considerable swelling of montmorillonite can occur due to additional water being absorbed between the combined sheets (Craig, 1997; Oweis and Khera, 1998).

Mechanism of Swelling

Swelling of clay minerals is directly related with diffused double layer and cation exchange capacity of them.

Double Layer of Clay Minerals

The negatively charged clay particle surface and the concentration of positive ions in solution adjacent to the particle form what is referred to as a diffuse double layer or DDL (Bohn et al. 1985). Overlapping DDLs between clay particles generate interparticle repulsive forces or microscale “swelling pressures”. Interaction of the DDL and, hence, swelling potential, increases as the thickness of the DDL increases (Mitchell, 1976). The thickness of DDL is associated with valence of cations, concentration of cations, temperature and pH.

II. LITERATURE REVIEW

Al-Rawas, A.A., Taha et al, “A Comparative Evaluation of Various Additives Used in the Stabilization of Expansive Soils”. Geotechnical Testing Journal, Vol. 25,2002 :- This paper investigates the effectiveness of using cement by-pass dust, copper slag, granulated blast furnace slag, and slag-cement in reducing the swelling potential and plasticity of expansive soils. The soil used in this study was brought from Al-Khod (a town located in Northern Oman) where structural damage was observed. The first stage of the experimental program dealt with the determination of the chemical, mineralogical, and geotechnical characteristics of the untreated soil. The soil was then mixed with the stabilizers at 3, 6, and 9% of the dry weight of the soil. The treated samples were subjected to liquid limit, plastic limit, swell percent, and swell pressure tests. Furthermore, the cation exchange capacity, exchangeable cations (Na+, Ca++, Mg++, and K+), and pH of the treated samples were also measured.

Almeida N. et al.“Recycling of Stone Slurry in Industrial Activities: Application to Concrete Mixtures, Building and Environment”, Vol. 42, 2007:- In recent years, large amounts of stone waste have been generated in natural and artificial stone industry with significant environmental impacts. To solve the problems, stone waste in different forms could be used in different industrial activities in particular construction industry and other activities such as paper, ceramics industry (faience), paints, plastics and polymers, glass. Rubber, siderurgy, sugar, pharmaceutics, textiles or in articles such as soaps or candles. Further it could be applied as agriculture soil corrective, acid water treatment and dumpsites sealing . This paper reveals an overview of current solutions of reducing environmental and economical disadvantages of this kind of by-product.

Çelik, M.Y. at all “Marble Deposits and the Impact of Marble Waste on Environmental Pollution”, Journal of Environmental Management, Vol. 87, 2008:- The Portland cement manufacturing process is a major contributor to greenhouse gas emissions and depletion of natural resources. Waste Marble Dust (WMD) on the other hand is cheap and environmental demeaning form of marble processing units, which if used in civil works will create Sustainable Structures (SS) and will save our environment from degradation with positive impact on our country’s Gross Domestic Product (GDP).

Çetiner, S. et al. Stabilization of Expansive Soils by Çayırhan Fly Ash and Desulphogypsum, M.S. Thesis, METU, Turkey, 2004 :- Expansive soils are one of the most serious problems which the foundation engineer faces. Several attempts are being made to control the swell-shrink behavior of these soils. One of the most effective and economical methods is to use chemical additives. Fly ash and desulphogypsum, both of which are by-products of coal burning thermal power plants, are accumulating in large quantities all over the world and pose serious environmental problems

Çokça, E. et al. “Use of Class C Fly Ashes for the Stabilization of an Expansive Soil”, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 127, 2001 :- Excessive heave associated with swelling of expansive soils can cause considerable distress to lightweight civil and highway engineering structures. Several methods have been suggested to control this problem.

III. METHODOLOGY

Chemical Stabilization

Soil stabilization using chemical admixtures is the oldest and most widespread method of ground improvement. Chemical stabilization is mixing of soil with one of or a combination of admixtures of powder, slurry, or liquid for the general objectives of improving or controlling its volume stability, strength and stress-strain behavior, permeability, and durability (Winterkorn and Pamukçu, 1990).

Pozzolanic Reactions

Time depending pozzolanic reactions play a major role in the stabilization of the soil, since they are responsible for the improvement in the various soil properties (Show et al., 2003). Pozzolanic constituents produces calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH).

$Ca^{2+} + 2(OH)^- + SiO_2$ (Clay Silica) @ CSH

$Ca^{2+} + 2(OH)^- + Al_2O_3$ (Clay Alumina) @ CAH

The calcium silicate gel formed initially coats and binds lumps of clay together. The gel then crystallizes to form an interlocking structure thus, strength of the soils increases (Hadi et al, 2006; Sivapullaiah, 2006).

Marble and Production of Waste Marble Dust

Stone-masons often apply the term marble to any rock which can be easily polished (Oates, 1998). Limestones, schistes, travertines or even granites can be considered as marble in the business world (Onargan et al., 2005). Waste marble dust produced from marble plants can be either of these natural stones’ dust. Thus, in order to distinguish the stabilizers used, stabilizers were named as waste limestone dust and waste dolomitic marble dust in this study.

Marble (Real Marble)

Marble or real marble is a metamorphic rock that consists predominantly of calcite and/or dolomite (cited in Dietrich and Skinner, 1979). Marble may be considered as metamorphosed limestone (i.e. limestone which has been fully re-crystallized and hardened under hydrothermal conditions) (Oates, 1998). In this study waste dolomitic marble dust was used.

Production of Waste Marble Dust

The production of fine particles (<2 mm) while cutting marble is one of the major problems for the marble industry. When 1 m³ marble block is cut into 2 cm thick slabs, the proportion of fine particle production is approximately 25 % (Kun, 2000).

While cutting of marble blocks water is used as cooler. But, the fine particles can be easily dispersed after losing humidity, under atmospheric conditions, such as wind and rain. Thus, fine particles can cause more pollution than other forms of marble waste (cited in Çelik and Sabah, 2007).

Figure - Views from waste marble dust disposed sites

Soil Stabilization Using Waste Marble Dust

Extensive literature is available on soil improvement by the application of additives, notably cement and lime. Lately, many researchers have reported on additives that could substitute lime as a soil modifier. Such materials include fly ash (Çokça, 1999; Indraratna et al. 1991, 1995), rice husk (Muntohar, 1999); (Muntohar and Hantoro 2000), marble dust (Okagbue and Onyeobi, 1999), and limestone ash (Okagbue and Yakubu, 2000) (Cited in Okagbue, 2007).

Oedometer Methods to Determine Swell Properties

The most satisfactory and convenient method of determining the swelling properties of an expansive clay is by direct measurement. Direct measurement of expansive soils can be achieved by the use of the conventional one-dimensional consolidometer (Chen, 1975).

According to ASTM D4546 - 03 (Standard Test Methods for One- Dimensional Swell or Settlement Potential of Cohesive Soils), test methods for swell properties can be grouped into three; Method A, Method B and Method D. Initially, the terminology of experiments is presented.

Swell, L = Increase in elevation or dilation of soil column following absorption of water

Free swell, % = Percent heave, □ h h *x*/100 water at the seating pressure.

Primary swell, L = An arbitrary short-term swell usually characterized as being completed at the intersection of the tangent of reverse curvature to the curve of a dimensional change-logarithm of time plot with the tangent to the straight line portion representing long-term or secondary swell (Fig. 3.2).

Secondary swell, L = An arbitrary long-term swell usually characterized as the linear portion of a one dimensional change-logarithm of time plot following completion of short-term or primary swell (Fig. 3.2).

Swell Pressure, kPa: A pressure preventing the specimen from swelling.

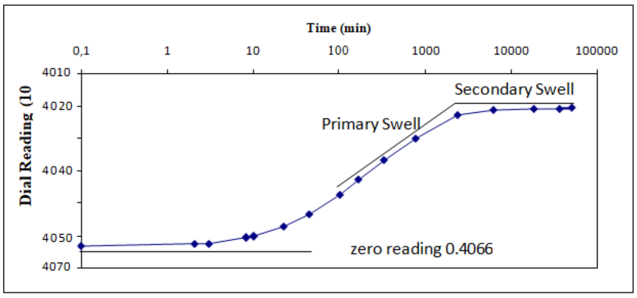

Figure - Time - Swell Curve

IV. EXPERIMENTAL INVESTIGATIONS

Purpose

The purpose of this experimental study is to investigate the effects of the addition of waste limestone dust and waste dolomitic marble dust on Atterberg limits, grain size distribution, swell percentage, and rate of swell of an expansive soil sample; and also, to investigate the effect of curing on swell percentage and rate of swell of an expansive soil stabilizated with waste limestone dust and waste dolomitic marble dust.

Preparation of the Test Samples

In nature, expansive soils are widely present. However, possible non- homogeneity or disturbance of these soils may prevent to show actual effects of the stabilizers. Thus, an artificially expansive soil sample (Sample A) was prepared using kaolinite and bentonite in laboratory.

By dry mass, Sample A was composed of 85% kaolinite and 15% bentonite. In the beginning of the preliminary studies, waste limestone dust and waste dolomitic marble dust as stabilizer, were pre-tested and the results showed that these materials could be considered as stabilizing agents for Sample A.

Each sample was prepared by addition of waste limestone dust or waste dolomitic marble dust to Sample A with different percentages to obtain a sample with predetermined percentage of stabilizer varying from 0 to 30 percent (by dry weight of the sample).

Free Lime Content Test on Stabilizers

Pozzolanic activity is the one of the main factors using of waste limestone dust and waste dolomitic marble dust. Lime content of these stabilizers plays major role for pozzolanic activity. ASTM C 25 (Standard Test Methods for Chemical Analysis of Limestone, Quicklime and Hydrated Lime) was used as a reference to determine the hydrated lime content of test samples.

To determine hydrated lime in stabilizers, the following steps can be summarized;

Neutralized sugar solution is prepared. (40 g sugar is dissolved in 100 ml CO2-free water, several drops of 4% phenolphthalein indicator and 0.1 N NaOH is added to sugar solution).

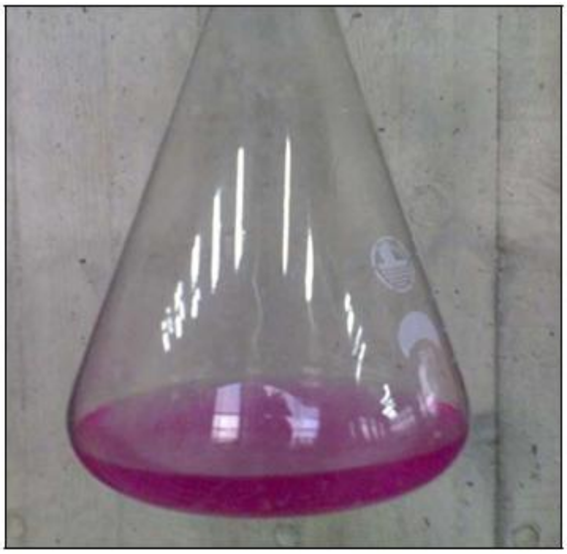

Figure - A view of neutralized sugar solution

2.804 g of sample is brushed in 40 ml of CO_2-free water and 100 ml of neutralized sugar solution is added to this mixture. The mixture is left for reactions for 15 min. and in 5 min. intervals it is swirled.

After 15 min. the mixture is titrated with HCl, until the first disappearance of the pink color, which persists for 3 s.

Available lime [$Ca(OH)_2$], % = $\frac{N x V x 3.704}{W}$

Where; N: normality of acid solution (= 1 in this study)
V: standard HCl (1.0 N), ml
W: weight of sample, g (= 2.804 g in this study)

Experimental Program
Experimental study was conducted in seven phases:

- Free lime content test was performed on stabilizers
- Analyses for stabilizers were performed by METU Central Laboratory and General Directorate of Mineral Research and Exploration (MTA).
- Hydrometer tests, Atterberg limit tests, and specific gravity tests were applied to the samples.
- Free Swell Ratio Test was applied to the samples.
- Free swell tests were applied to the samples without cure.
- Free swell tests were applied to the 7 days cured samples.
- Free swell tests were applied to the 28 days cured samples

V. RESULT & DISCUSSIONS

Test Results
Results of available lime test are presented in Figure . free swell ratio test results are presented. Effect of addition of waste limestone dust and waste dolomitic marble dust on liquid limit (LL), plastic limit (PL), plasticity index (PI = LL-PL), shrinkage limit (SL) and shrinkage index (SI = LL - SL) are presented in Fig.5.3, 5.4, 5.5, 5.6 and 5.7, respectively.

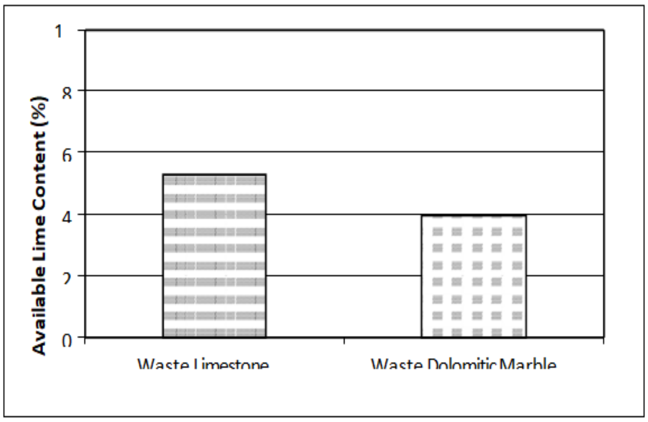

Figure - Results of Available Lime Test

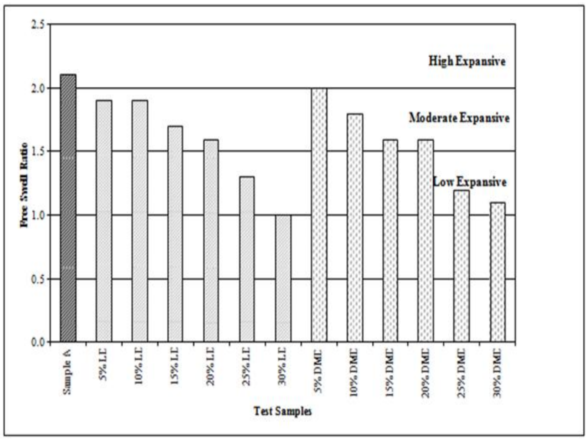

Figure - Effect of Addition of Waste Limestone Dust and Waste Dolomitic Marble Dust on Free Swell Ratio of the Samples

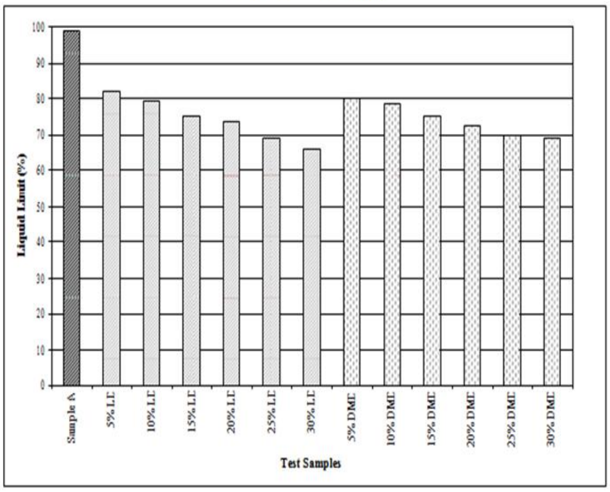

Figure - Effect of Addition of Waste Limestone Dust and Waste Dolomitic Marble Dust on the Liquid Limit (LL) of the Samples

Swell percentage vs. time relationship for Sample A, a typical swell percentage vs. time graph, is presented in Figure. For swell percentage calculations dial readings recorded in free swell test were subtracted by initial readings and ΔH/H vs. time graph was plotted. Swelling percentage vs. time relationships of the waste limestone dust and waste dolomitic marble dust added samples are presented in Appendix B.

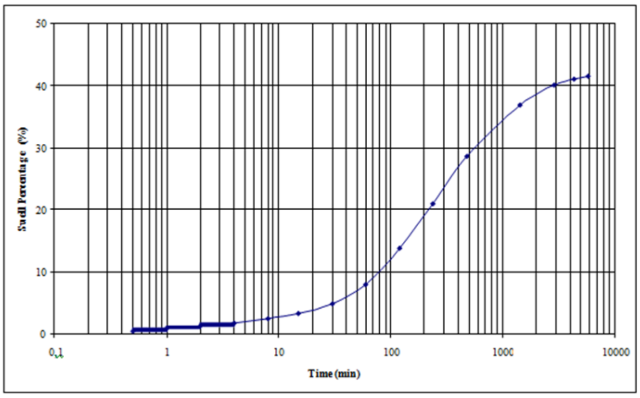

Figure - Swelling Percentage versus Time Relationship for Sample A

Calculations for Prediction of Swell Percentage

A typical log time vs. percent swell relationship generally follows a standard "S" shape. This "S" shape curve can be divided into 3 phases; Initial, primary and secondary swelling. Initial swelling is generally less than 10% of total swelling. This is essentially due to swelling of the bentonite clay particles within the voids of the coarser non-swelling fractions. This swelling of particles does not cause an increase in the volume of the sample. Primary swelling develops when the voids can no longer accommodate further clay particle swelling. After the primary swelling complete slow continued swelling, secondary swelling occurs. In time/free swell vs. time graphs after some time elapsed, a straight-line relationship is apparent (Sivapullaiah, et.al, 1996). The slope of straight-line part of time/free swell vs. time graphs can be used to predict maximum swell. Swelling percentage vs. time graph and time/free swell vs. time graph for 7 days cured 25% LD sample as examples are presented in Fig. , respectively. Predicted and measured free swell percentages and difference between them are presented in Table and those graphs are presented in Figure

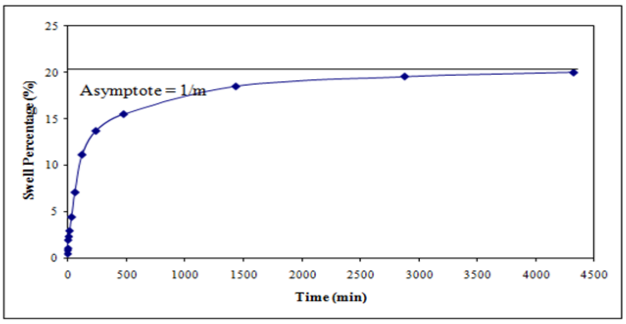

Figure - Swell Percentage vs. Time Graph of 7 days Cured 25 % LD Sample

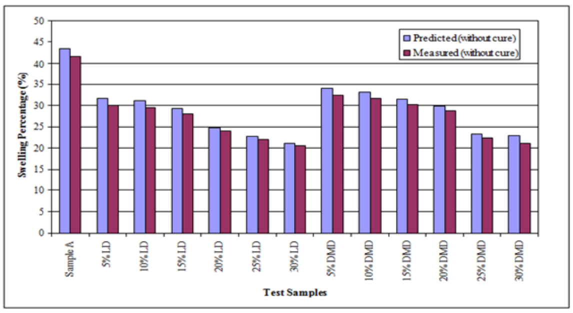

Figure - Measured and Predicted Swelling Percentage Graph for Test Samples

Table 5.1 Predicted and Measured Swell Values for the Test Samples

Sample	Samples without Cure			7 Days Cured Samples			28 Days Cured Samples		
	Measured Swell (%)	Predicted Swell (%)	Difference (%)	Measured Swell (%)	Predicted Swell (%)	Difference (%)	Measured Swell (%)	Predicted Swell (%)	Difference (%)
Sample A	41.5	43.5	2.0	38.4	40.2	1.8	37.3	38.9	1.6
5% LD	30.0	31.6	1.6	26.1	27.6	1.5	23.5	24.2	0.7
10% LD	29.6	31.2	1.6	24.8	26	1.2	21.6	21.9	0.3
15% LD	28.1	29.3	1.2	22.8	23.5	0.7	19.1	19.6	0.5
20% LD	23.9	24.9	1.0	20.9	21.3	0.4	17.5	17.8	0.3
25% LD	22.1	22.8	0.7	20.0	20.6	0.6	16.5	16.8	0.3
30% LD	20.6	21.1	0.5	19.0	19.5	0.5	15.7	16.1	0.4
5% DMD	32.4	34.0	1.6	27.1	28.6	1.5	26.9	27.8	0.9
10% DMD	31.6	33.1	1.5	26.1	27.1	1.0	25.8	26.8	1.0
15% DMD	30.2	31.5	1.3	24.9	25.7	0.8	24.5	25.1	0.6
20% DMD	28.7	29.9	1.2	23.3	24.0	0.7	22.2	22.7	0.5
25% DMD	22.4	23.3	0.9	20.2	20.9	0.7	19.6	20.0	0.4
30% DMD	21.1	22.9	1.8	19.5	19.9	0.4	18.1	18.2	0.1
(%) Mean of Differences	1.3			0.9			0.6		
(%) Standard Deviation of Differences	0.440			0.457			0.396		

VI. CONCLUSIONS

In this study, the suitability of waste limestone dust and waste dolomitic marble dust as stabilizers for swelling potential of an expansive soil was studied. Waste limestone dust and waste dolomitic marble dust added to Sample A. According to test results, the following outcomes can be summarized:

- Addition of waste limestone dust and waste dolomitic marble dust decreased liquid limit, plasticity index and shrinkage index, increased plastic limit and shrinkage limit of Sample A.
- Activity of samples decreased by addition of stabilizers. Activity of Sample A decreased more as waste limestone dust percentage increased. However, there is no consistent relationship between activity and the percentage of waste dolomitic marble dust.
- Free swell ratio of Sample A decreased with addition of stabilizers. As the percentage of stabilizer increased, free swell ratio decreased.
- By addition of stabilizers, the swelling percentage decreased considerably. The reduction was higher for waste limestone added samples having more lime content.
- By addition of stabilizers, the t_{50} values were decreased. In other words, samples having more stabilizers reached the 50 % of total swell quicker.
- Swelling percentage and rate of swell of samples decreased by curing. Curing was more effective for waste limestone dust added samples. Also, curing was more effective for rate of swell of samples than swelling percentage.
- The predicted swell and measured swell percentages

of samples were close to each other.
- Both waste limestone dust and dolomitic marble dust can be used as stabilizers for expansive soils. But, the effectiveness of stabilizers depends on their chemical content.

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