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ARTICLE

Utilization of Marble Dust for Improving The Geotechnic Characteristics Of Collapsible Soil

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ABSTRACT

An environment friendly and cost effective factor of collapsible soil stabilization with the help of industrial waste has been widely adopted in this research. Buildings which are constructed on collapsible soils are subjected to large deformations and shear failure. Collapsible soil can be broadly categorized as those soils susceptible to a large reduction in volume upon wetting. The mechanism usually involved in rapid volume reduction entails breaking of bonds at coarse particle contacts by weakening of fine-grained materials brought there by surface tension in evaporating water. This research presents the effects of using marble dust on the geotechnical properties of Collapsible soil as a new stabilizing technique. A series of experimental tests are carried for samples of collapsing soil with and without stabilization using marble dust for dry and soaked conditions. The collapsible soil was mixed with marble dust at different contents of (0, 10, 20, 30%,40% and50%). The results indicated that, The optimum water content decreases by 20.67% at marble content of 50%, liquid limit decreses by35.41% at marble content of 50%and frictional angle for soaked soil decreases by 66.09% at marble content of 50% while un soaked soil decreases by54.68% at marble content of 50%. The maximum dry density increases 5.91% at marble content of 50% and cohesion for soaked increases314.2% at marble content of 50% while un soaked soil increases 206.7% at marble content of 50%. It has been found that the adopted marble has a good effect in controlling the collapsing potential which is reduced by as much as 64.32% at marble content of 30%.

1. Introduction

Collapsible soils cover naturally over 10% of the earth's surface This consider it a global problem and it is essential that engineers identify and control collapsibility prior to construction. In Egypt, collapsible soils are observed in northern portion of the western desert such as Borg El-Arab city, New Ameria city, six-of-October city, tenth-of-Ramadan and sidi Barany, etc district as stated by Sakr et al [1]. Many researchers have defined collapsible soils: Bara [2], Rollins [3] and Rogers; Tadepalli [4] et al., which all to be briefed as soils pose potential threat to structures built on them when wetted. At their natural state they pose stiffness and high apparent shear strength; but upon wetting, they could exhibit a sig-

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nificant decrease in volume (collapsing, hydroconsolidation or hydrocompression) at low levels of stresses.

An emphasis on collapsible soils stabilized with admixtures is reviewed below as the research objective is directed to investigate the effect of using Marble dust on the collapse potential and other geotechnical properties of the collapsible soils The researcher use several methods to minimize collapse of a collapsible soil. These methods include: Compaction control, Prewetting, Moisture control, Soil replacement and Chemical stabilization or grouting. Anayev and Volyanick, 1986 [5], reported that soil replacement is a sample solution to deal with volume moisture sensitive soil. Simply excavate to the required depth and remove the collapsible soil. The removed soil can be compacted and used as the foundation soil. Such technique is commonly used particularly when collapsible soil occurs at shallow depth. The replaced soil should be compacted to a degree of compaction of 95-100 % (AASHTO Specifications). Elkasaby and Elsaadany [6] investigate the effect of addition different percentages of rice husk ash to collapsible soils in order to improve their poor properties; they concluded that rice ash may be used successfully in dealing with the stabilization of collapsible soils for road bases and sub-bases and also for constructing house buildings on these soils. AlRefeai and Alkarni [7] studied the effect of adding different percentages of cement kiln dust (CKD) on the engineering properties of collapsible soils; they concluded that collapse potential is significantly reduced with increasing CKD content especially with high initial unit weight. Nazir [8] studied the effect of oil using different engine oil contents to stabilize the collapsibility of soil; the results indicated a decrease in collapse potential, Atterberg limits, maximum dry density, optimum moisture content and frictional angle concluded while the cohesion of soil is increased significantly. Mohamed Ayeldeen [9] et al., 2017; studied effect biopolymer to improve the mechanical characterizations of collapsible soil Two types of biopolymers were used in this study (xanthan gum and guar gum). the results indicated, with increasing the solution concentrations for both guar gum and xanthan gum The dry density reduce and the optimum water content is increases. Mixing the soil with 2% biopolymer concentration leads to a reduction in the collapsible potential from 9% to about 1%.SAKR et al 2014 [10], studied effect of using fiber on some of the geotechnical properties of collapsible soils. the results indicated; The Collapse potential, maximum dry unit weight and frictional angle for soaked soil decreases with increasing of fiber content. Increasing fiber content in collapsible soils causes increase in the optimum moisture content and cohesion for un soaked and soaked soil.

Jennings and Knight [11] suggested a procedure to evaluate the collapse potential of a soil using the double-oedometer for an undisturbed specimen at natural moisture content by placing it in a consolidometer ring; then the collapse potential (C.P) is expressed in the percentage as:

$$\mathrm{CP} = \frac{\Delta H}{H_{\circ}} + \frac{\Delta \mathrm{e}}{1+e_{\circ}} * 100\% \quad (1)$$

ΔH: change in height of the soil specimen upon flooding,

$H_{\circ}$: Original height of the soil specimen,

Δe: Change in void ratio of soil in an oedometer test on inundation at stress of 200Kpa, and $e_{\circ}$: Void ratio of soil in an oedometer test on inundation at stress of 200Kpa before inundation They also suggested a classification of the potential severity of collapse based on the collapse potential as shown in table 1.

Table 1. Collapse potential and severity of collapse, after Jennings and Knight

Severity of collapse	No Problem	Moderate Trouble	Trouble	Severe Trouble	Very Severe Trouble
Collapse Potential (C.P %)	0-1	1-5	5-10	10-20	>20

It is evident from the literature that, no paper deals with marble dust as a stabilizer for the collapsibility behavior, so this research target is directed to propose a new solution for improving collapsible soils by using marble dust and to figure out its effect on the geotechnical properties of collapsing soils. This new method if succeeded will be considered more economical to other expensive methods and efficient utilizing the combined effect of soil replacement and soil reinforcement. The authors assess collapse potential, liquid limit, compaction characteristics and shear strength parameters for the collapsible soils before and after adding marble dust to investigate its effect on the geotechnical properties of such soils.

Based on the paper in literature it can be seen that there are variety of different methods used to improve the collapsing potential of collapsing soil like cement, polymer, Nano clay, oil, nanomaterial and chemical stabilization. But the utilization of marble dust for improving the collapsing soil cannot be thoroughly investigated as an available waste material and environmentally acceptable. Where the there is a lot of such material in range of 200ton per year as waste product in marble factory in Egypt. Therefore in this research the marble dust can be applied to enhance the geotechnical characteristics of collapsing soil that located in Egypt and control the collapse potential.

2. Testing Equipment and Materials

2.1 Equipment

The main principle is to prepare a reconstituted soil having a certain marble dust content and a certain dry density, to be compacted then to be charged in the cell of oedometer. The apparatus of compaction of material is presented in figure 1it is composed of a disk having a diameter slightly smaller than the ring, fixed to guide stem mutton in the form of disc(as stated and adopted by references Ayadat and Bellili [12], Ayadat and Belouahri [13], Ayadat et al. [14] and Ayadat and Benkadja [15]. The mutton of 136 g slid alongside the rod, falls from 15cm height and comes to strike the disc of 50.2 mm of diameter by compacting material.

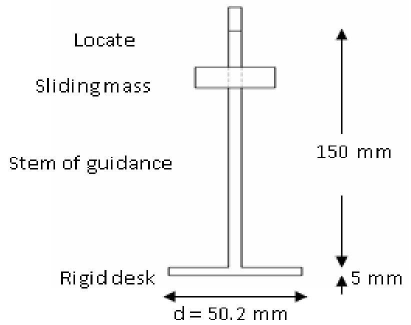

Figure 1. Apparatus of compaction

2.2 Testing Materials and Sample Preparation

The tested soil samples were obtained as disturbed samples recovered from a test pit at a site in Al- Gharbaneyat area, Borg El-Arab city, 60 km west of Alexandria, Egypt where several sinkholes have been developed. Soil samples were air dried for 15 days [1]. After this period, grain size distribution of the tested soil was determined as presented in Figure 2. The geotechnical and mineralogy properties for the soil are shown in Table 2and table 3. Samples were mixed with marble dust which passing from sieve 75 micron in amounts by weight of the dry soil samples gradually increased from 0% up to max decrease in the collapse potential. In order to prepare a consolidation sample the mixture is poured in the cell of oedometer, then using the device described previously, the material is compacted in two layers with the same energy, 10 blows/layer. The tested sample is leveled inside the ring of oedometer cell taking into consideration keeping the upper surface as a plane surface. The last procedure is putting back the ring of the oedometer in the cell on which the test of compressibility described by Jennings and Knight 1975. These attempts consist to load the soil gradually, until a constant pressure of 200 kPa, then inundation by water for 24 hrs. The axial deformations of the collapsible soils were recorded by a dial gauge having a precision of 0.01 mm.

Table 2. Characteristics of collapsible soil

Finer than 2µm	16
%Liquid Limit,L.L	48
%Plastic Limit,P.L	29.59
Plasticity index,P.I	18.41
Specific gravity,Gs	2.65
Maximum Dry Unit Weight,KN/m3	17.57
Optimum moisture Content,Wc%	16.3
%Gravel	2%
%Sand	44%
%Silt	38%
% Clay	16%

Table 3. Collapsible soil mineralogy

Calcite	Dolomite	Quartz	Illite	Gypsum	Kaolinite	Montmorillonite
33.9%	6.8%	27.1%	11.4%	9%	7.5%	4.3%

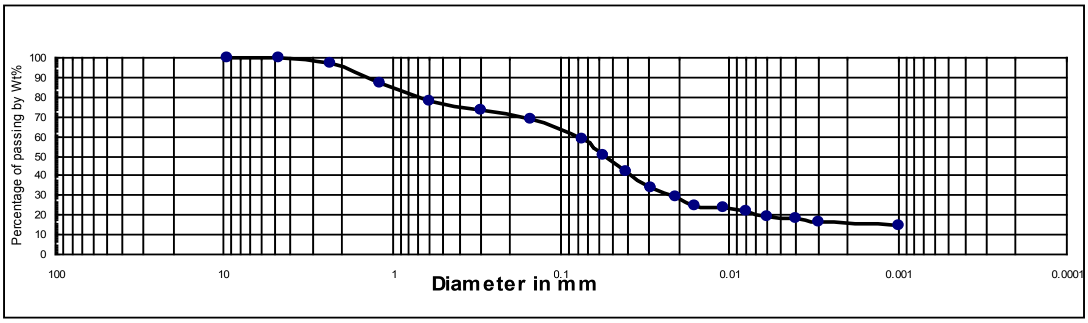

Figure 2. Grain size distributions curve for tested soil

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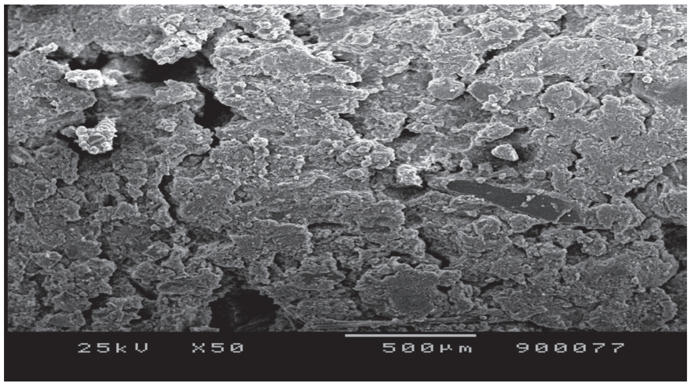

Figure 3. Scanning electron microscopy (SEM) of Collapsible soil

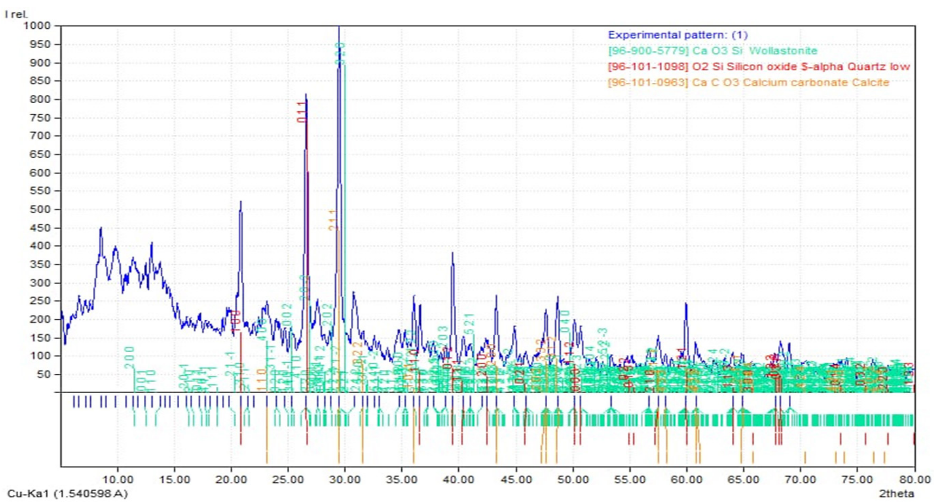

Figure 4. X Ray Diffraction (XRD) of Collapsible soil

3. Marble Dust

The stabilizer material used in this study was marble dust. The marble dust was obtained from a marble cutting and polishing industry located at shak el thoaban (cairo). The main objective of this study was to utilize the waste material like marble dust to improve the characteristics of collapsible soil. Marble dust was dried at 105˚C for 24 hours, sieved on sieve 0.075 mm and mixed with Collapsible soil at different percentages.

Table 4. Marble dust mineralogy

Calcite	Dolomite	Quartz	Illite
41.4%	37.9%	11.3%	9.4%

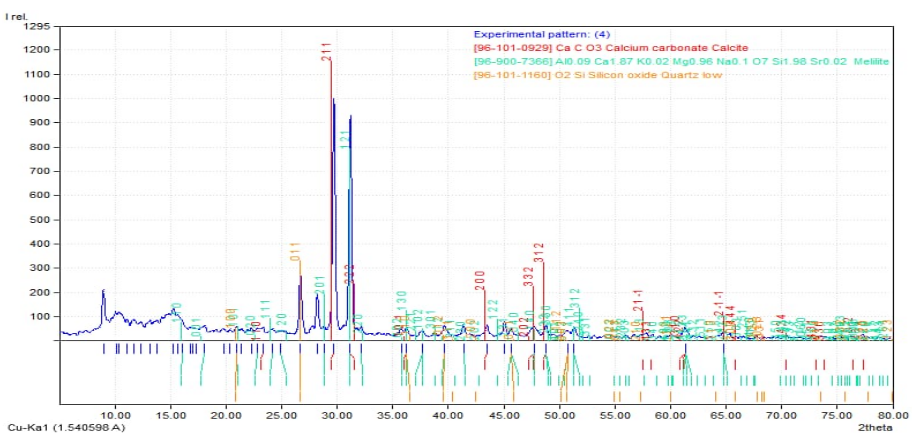

Figure 5. X Ray Diffraction (XRD) of Marble dust

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4. Results and Discussion

4.1 Influence of Marble Dust on the Compaction Characteristics

Standard proctor compaction tests (ASTM-D698) [16] were carried on soils after mixing with 0%, 10%, 20%, 30%, 40% and 50% marble dust content. The results are plotted in figure10 in form of dry unit weight versus water content curves. figure 11 it has been found, The maximum dry density is sharply increased at 10%marble dust content. The percentage increase in maximum dry density is found to be 2.50% while at marble dust content of 20, 30%, 40%, 50%, this increase in maximum dry density are found to be 3.18%, 3.35%, 5.29% and 5.91% respectively of its initial value of normal sample with out marble dust. However figure12 show decrease in optimum water content at 10% marble dust content, The percentage decrease in optimum water content is found to be 1.34%. While at marble dust content of 20, 30%, 40%, 50% this decrease in optimum water content are found to be 9.44%, 12.63%, 14.84% and 20.67% respectively of its initial value of normal sample with out marble dust.

4.2 Influence of Marble Dust on the Atterberg Limits

Atterberg limits or consistency limits are characterized by plastic and liquid limits and plasticity index. These limits control the consistency of the soil as wetting conditions change. according to (ASTM-D4959) [17] were performed on marble dust content -soil samples with different marble dust contents. Figure 13 in form of water content versus number of blowes. It has been found, Liquid Limit decrease with increasing marble dust content, and figure 14 shows a reduction in Liquid limit of 12.5%, 20.83%, 27.08%, 29.16 and 35.41% from its initial value with increasing marble dust content to 10%, 20%, 30%, 40% and 50% respectively.

4.3 Influence of Marble Dust on the Collapse Potential

The collapsibility behavior of soil was observed at its natural state and after addition of marble dust contents with different percentages. At its dry state (in room dried condition) with out any treatment, a significant settlement takes place upon flooding in water, the collapse test shows that the collapse potential is reached to 9.25%; where the severity of collapse is classified as trouble, according to table (1), figure 15 shows the results of five tested samples treated with marble dust in five percentages of 10%, 20%, 30%,40%and50% from dry weight of soil respectively. Figure16 shows reduction in collapse potential at a soaking pressure of 200KPa with increasing marble dust content: The collapse potential reduced to 7.65%, 4.3% and 3.3% respectively, then increase the collapse potential to 3.65and 4.7 in addition to 40% and 50% of marble dust respectively. in addition to 10%marble dust content, the collapse potential is reduced by 17.29%, while at marble dust 20%, 30% the collapse potential reduced by 53.51%, 64.32% respectively of its initial value of normal sample with out marble dust, while at marble dust 40%,50% the collapse potential reduced by 60.54%, 49.18% respectively of its initial value of normal sample with out marble dust. from the obtained results, its seems that the use of marble dust to stabilize the collapsible soils is valuable until 30%of marble content. So to it is more realistic to study the effect of using marble dust to stabilize the collapsible soils on the other geotechnical characteristics in addition to the collapsing criteria.

4.4 Influence of Marble Dust on the Shear Strength of Soil

Direct shear tests according to (ASTM-D 3080) [18] were carried out to find the effect of fiber stabilization on shear strength parameters. The tests were performed in square shear box 60 mm x 60 mm x 20 mm.In order to prepare shear sample, the soil-marble dust mixture is poured in the shear box, and then the soil is compacted in two layers to obtain samples with a unit weight of 75% from the maximum dry unit weight. The tested sample is leveled inside the shear box taking into consideration keeping the upper surface as a horizontal surface. The samples were tested at normal stresses of 25, 50 and 100 kPa. Shear strength parameters, cohesion and friction angle for each tested sample, are determined from the intercept and the slope of the failure envelop obtained from normal stress-shear stress relation. The resulting values of cohesion and angle of shearing resistance against marble dust content in soil samples are shown on Figures17, 18. From figures (19a) it's clearly observed that the cohesion for unsoaked soil initially increases. The rate of the cohesion increase is about 118.5%, 139.3%, 176.8%, 187.2% and 206.7% for marble dust content 10%, 20%, 30%, 40% and 50% respectively compared to the cohesion of untreated soil. Figure (19b) observed that the cohesion for soaked soil it increases with the increase in marble dust content. The rate of the cohesion increase is about 221.1%, 235.8%, 290.1%, 311.3 and 314.2 for marble dust content 10%, 20, 30%, 40% and 50% respectively compared to the cohesion of untreated soil. From figure (20a) it's clearly observed that the frictional resistance for unsoaked soil decreases significantly with the increase of marble dust

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content. The rate of frictional resistance decrease is about 80.14%, 73.69%, 63.77%, 59.87 and 54.68 for marble dust content 10%, 20%, 30%, 40% and 50% respectively compared to the frictional resistance of untreated soil, Figure (20b) observed that the frictional resistance for soaked soil a significant decrease with the increase of marble dust content. The rate of frictional resistance decrease is about 96%, 78.7%, 73.23%, 70.58 and 66.09 for marble dust content 10%, 20%, 30%, 40% and 50% respectively compared to the frictional resistance of untreated soil. The obtained shear parameters for the soaked and unsoaked tested samples are given in Table 5.

Table 5. Shear parameters of tested samples

Sample state	Un soaked(dry)						Soaked(wet)				
Marble dust content	0%	10%	20%	30%	%40	%50	0%	10%	20%	30%	%40	%50
Cohesion, KPa	11.2	13.27	15.6	19.8	20.97	23.15	5.55	12.27	13.09	16.1	17.28	17.44
(C treated/C untrated)%	100	118.5	139.3	176.8	187.2	206.7	100	221.1	235.8	290.1	311.3	314.2
Friction angle, ϕ º	40.3	32.3	29.7	25.7	24.13	22.04	32.5	31.2	25.6	23.8	22.94	21.48
(ϕ ºtreated/ ϕ ºuntreated)%	100	80.14	73.69	63.77	59.87	54.68	100	96	78.7	73.23	70.58	66.09

5. Micro Structure Behavior

The sample structures were elucidated by many sophisticated techniques, including scanning electron microscopy (SEM) and X Ray Diffraction (XRD). These techniques were applied to study and characterize the behavior of the samples before and after marble dust stabilization.

Figure 3, Figure 4 and table 3 could be attributed to the sudden collapse of soil structure when water is added at stress level (200kpa) because dissolution of gypsum in water lead to increase the volume of voids due to bonds breaking between soil particles, subsequently lead to increase in the collapse potential. (Schanz and Nasif 2012)

Figure 6, Figure 7 and table 6 show improvement in collapse potential, this improvement due to present of clay minerals (illite metal) which may coat the soil particles and fill the voids that occur during the dissolution of gypsum (Schanz and Nasif 2012), the lackof gypsum content is due potasium element which found in illite metal is more reactive than calcium element Which found in gypsum metal so replace it.

$$\mathrm{Caso_4 + 2K \rightarrow K_2so_4Ca} \quad (2)$$

Figure 6, Figure 7 and table 6 show improvement in collapse potential too, this improvement due to marble dust mixed with collapsible soil in the presence of water, a set of reaction occure that result in the dissociation of lime (cao). In the precence consist of calcium silicate hydrate gel(CSH),calcium aluminate hydrate gel(CAH). CSH,CAH fill of voids lead to decrease of collapse potential.(Al-janaby 2014 report)

$$\mathrm{Caco_3 \rightarrow Cao + co_2} \quad (3)$$

$$\mathrm{Cao + H_2O \rightarrow Ca + 2OH} \quad (4)$$

$$\mathrm{Ca + 2OH + Sio_2 \rightarrow CaSiO_3.H_2O(\ CSH)} \quad (5)$$

$$\mathrm{Ca + 2OH + Al_2o_3 \rightarrow CaAl_2o_3.H_2O(CAH)} \quad (6)$$

Figure 8, Figure 9 and table 7 report, Due to insufficient availability of silica or alumina in the soil for pazzolanic reaction, subsequently increase volume of voids lead to increase of collapse potential.(Al-janaby 2014 report)

Table 6. Collapsible soil mineralogy mixed with 30%marble dust

Calcite	Dolomite	Quartz	Illite	Gypsum	Kaolinite	Montmorillonite
23.5%	29.5%	15.2%	18.6%	6.3%	5%	1.9%

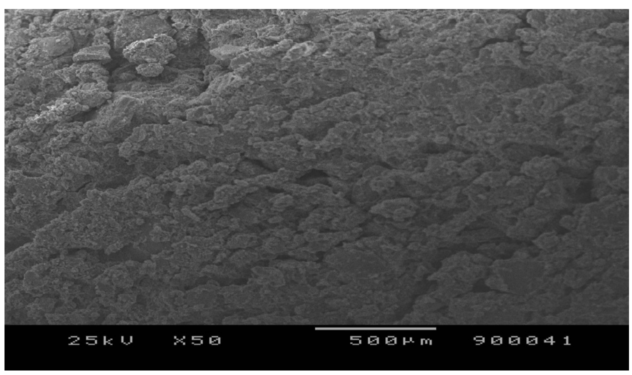

Figure 6. Scanning electron microscopy (SEM) of Collapsible soil mixed with 30%marble dust

6. Overburden correction factor

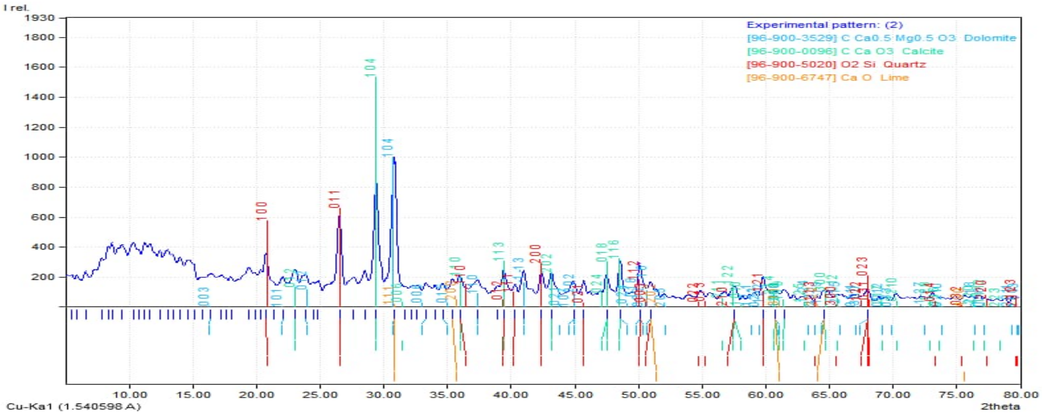

Figure 7. X Ray Diffraction (XRD) of Collapsible soil mixed with 30%marble dust

Table 7. Collapsible soil mineralogy mixed with 50%marble dust

Calcite	Dolomite	Quartz	Illite	Gypsum	Kaolinite	Montmorillonite
18.9%	28.6%	10%	12.3%	17.7%	11.1%	1.4%

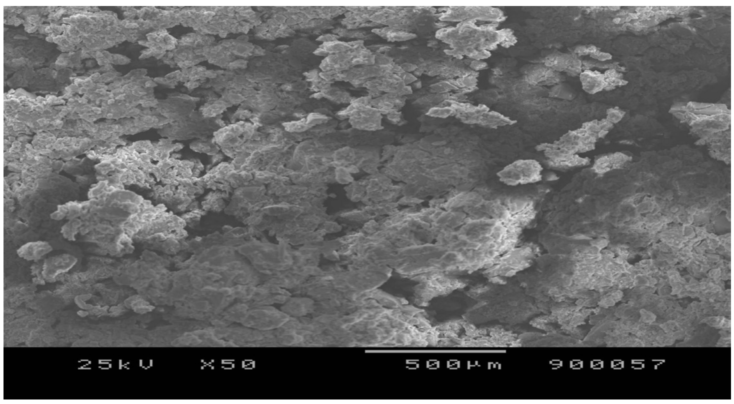

Figure 8. Scanning electron microscopy (SEM) of Collapsible soil mixed with 50%marble dust

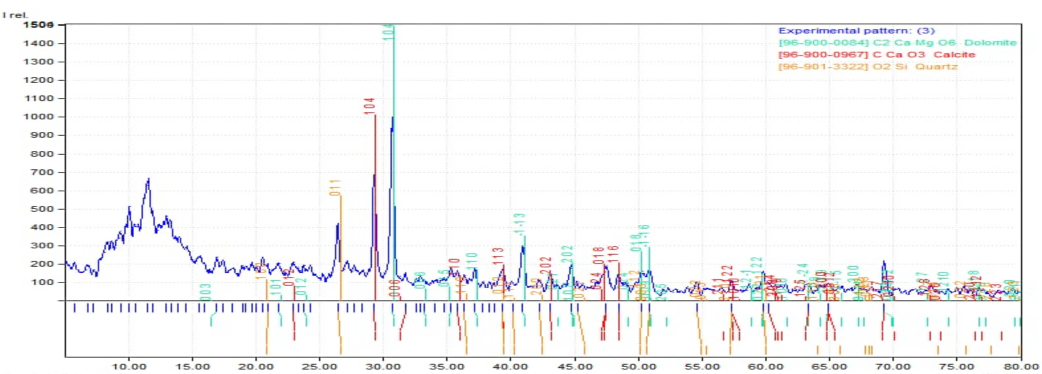

Figure 9. X Ray Diffraction (XRD) of Collapsible soil mixed with 50%marble dust

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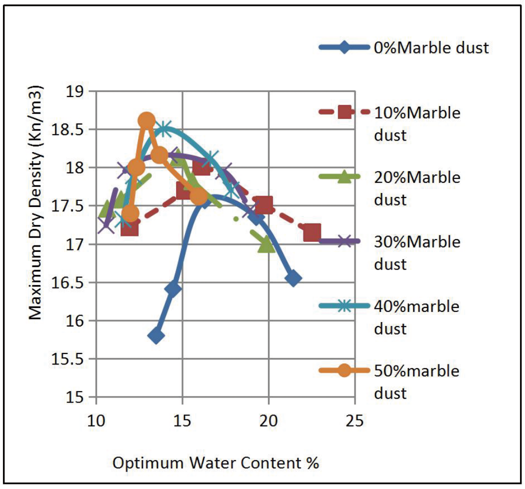

Figure 10. Compaction curves for marble dust –soil mixture

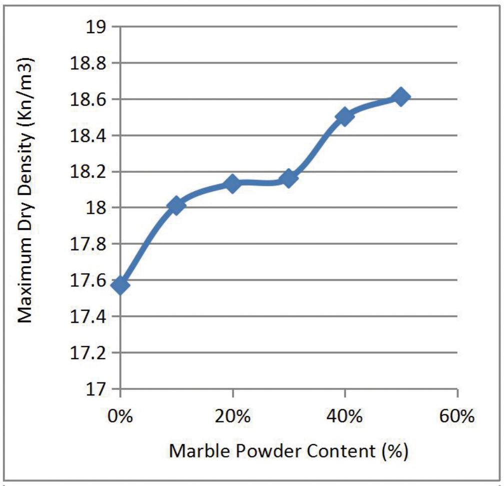

Figure 11. Influence of marble dust on maximum dry density

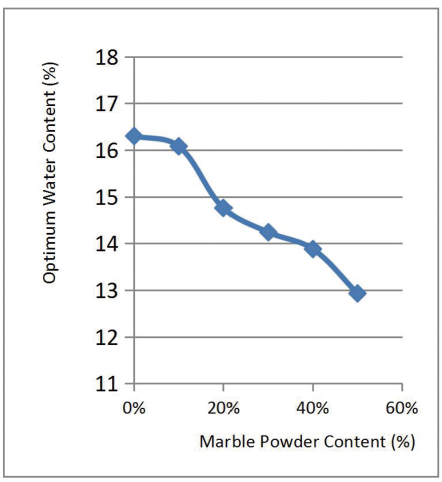

Figure 12. Influence of marble dust on optimum water content

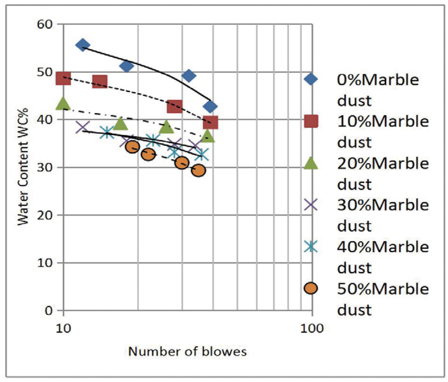

Figure 13. Liquid Limit curves for marble dust soil mixture

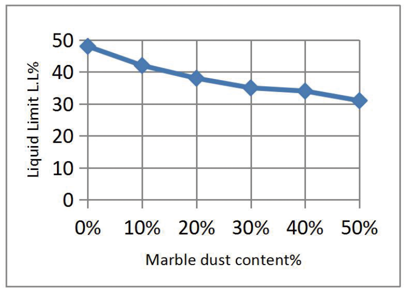

Figure 14. Influence of marble dust on Liquid limit

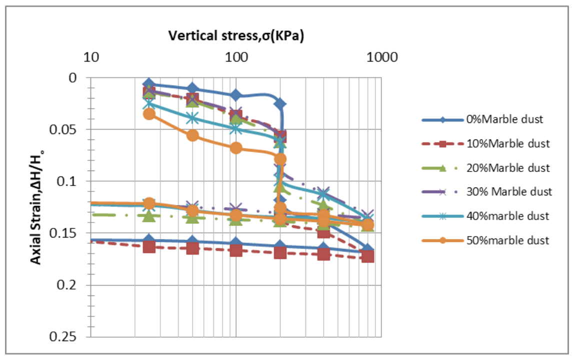

Figure 15. Collapse potential curves for marble dust - soil mixture

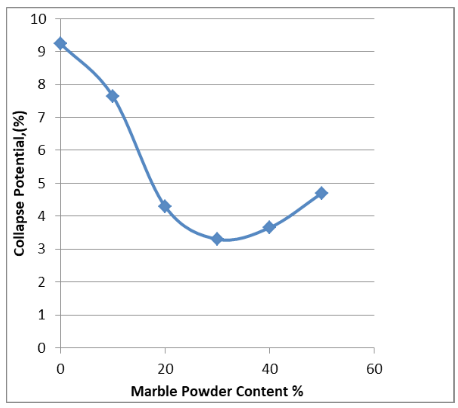

Figure 16. Influence of marble dust on collapse potential

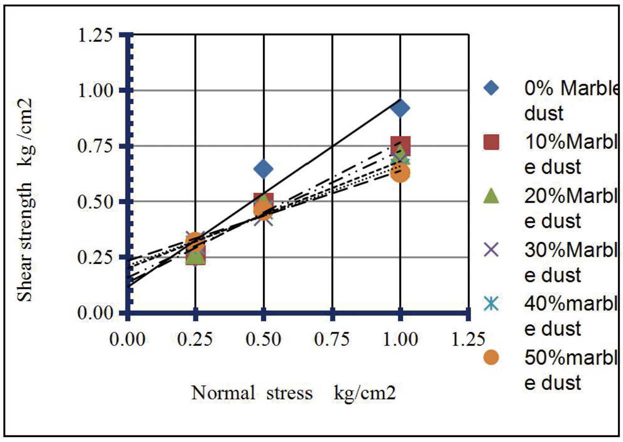

Figure 17. Direct shear curves for marble dust - soil mixture (un soaked state)

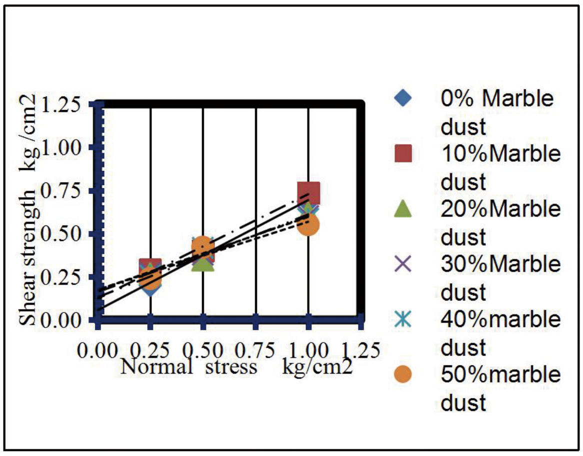

Figure 18. Direct shear curves for marble dust - soil mixture (Soaked state)

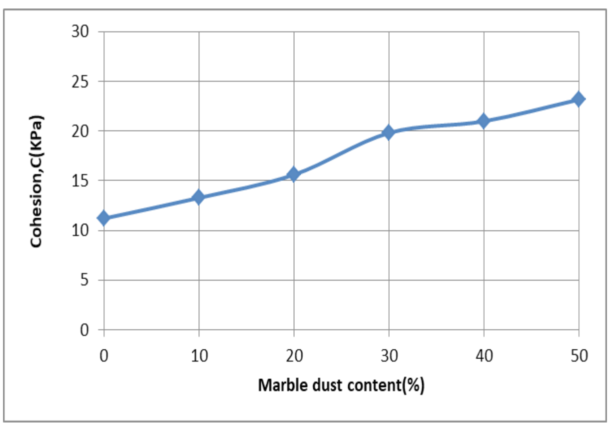

Figure 19a. Influence of marble dust on cohesion of marble dust-soil mixture(un Soaked state)

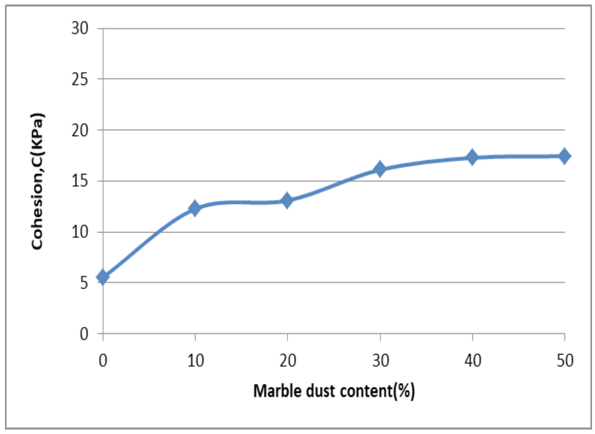

Figure 19b. Influence of marble dust on cohesion Of marble dust - soil mixture (soaked state)

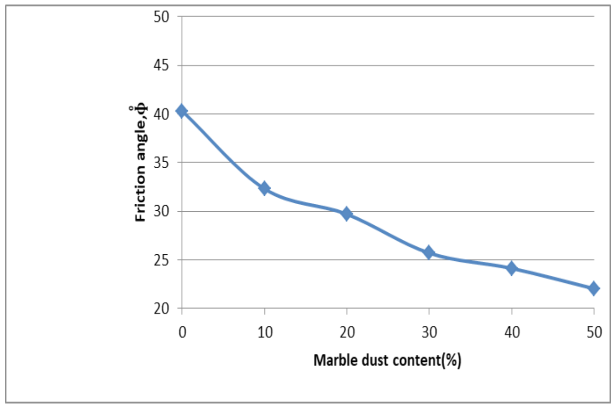

Figure 20a. Influence of marble dust on internal friction of marble dust -soil mixture(unsoaked state)

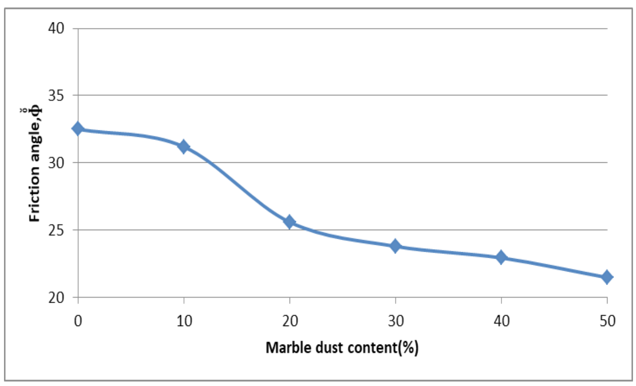

Figure 20b. Influence of marble dust on internal friction of marble dust -soil mixture (soaked state)

7. Conclusions

An extensive laboratory testing program was carried out to study the effect of marble dust stabilization on collapsible soil.The amount of of 0to50%by weight of air dried

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soil samples was selected for marble dust. The following conclusions based on these tests are drawn:

(1) The Collapse potential decreases with increasing of marble dust content until 30%then increase with increasing of marble dust content. This behavior can be attributed to presence marble dust particles between collapsible soil voids. Increasing marble dust in collapsible soil reduce the severity degree from trouble to moderate trouble.

(2) Liquid limit decrease with increasing marble dust content. This behavior can be attributed to marble dust nature which affects soil particles interpenetration.

(3) increasing marble dust content in collapsible soils increase maximum dry density. This behavior is attribute to the chemical reaction between the marble dust and the pore water fluid,and also change in the weight of soil.The particles move closer to each other leading to an increase in the maximum dry unit weight,and a reduction in the voids between particles.

(4) increasing marble dust content in collapsible soils reduce optimum water content. The decrease of the optimum water content was due to the absorption of the excess water by the marble dust particles within the soil samples during the initial chemical reaction.The exchange of the ions with clay particles confirmed the soil's - additive interaction.

(5) increasing marble dust content in collapsible soils increase cohesion for soaked and un soaked soil and cause a reduction in frictional angle for soaked and unsoaked soil. The decreasing behavior in unsoaked and soaked state could be attributed to the cohesion of the clay marble dust particles that covers the loss in cohesion of soil due to the dissolved gypsum bond and slightly decreases of angle of internal friction (Φ).

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