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RESEARCH PAPER

Impact of Marble Powder on the Geotechnical Behavior of Expansive Soil

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A B S T R A C T:
In geotechnical engineering, the process of changing the characteristics of weak or undesirable soils using waste materials has gained importance. Waste materials frequently involve waste and by-product minerals, such as marble powder, which were unethically obtained in Iraq and had harmful environmental repercussions. The aim of this study is to determine how marble powder affects the geotechnical features, including consistency limits, density, shear strength parameters and swelling characteristics of clayey soils in Erbil city. Different percentages of marble powder (6%, 12%, 18%, 24%, 30%, and 36%) were used to treat the expansive soil. The outcomes indicated that marble powder could enhance the geotechnical properties. It is advised to add 18% percentage of marble powder to improve the soil as an optimized amount.

KEY WORDS: Expansive Soil; Marble Powder; Stabilization; Direct Shear Test.
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1. INTRODUCTION:

Expansive soils are one of the most common and difficult soils encountered by a geotechnical engineer (James et al., 2015). These soils are very difficult to work with during construction and have extreme swell-shrink potential. When exposed to water, such soils expand significantly and shrink as the water is lost from the soil (Seco et al., 2011, Bhuvaneshwari et al., 2014, Cokca and Engineering, 2001). Cracking and damaging of the lightweight structures, concretes and paved roads, channel linings, irrigation systems, gas pipelines, and sewer lines have all been mostly considered as a result of the expansive soil problems (Jones Jr and Holtz, 1973, Fattah et al., 2021, Zumrawi et al., 2017).

Soil stabilization is a technique that involves mixing materials with undesirable soils to improve properties of the soils (Firoozi et al., 2017, Afrin and Technology, 2017, Ramaji, 2012, Kezdi, 2016, Ibrahim et al., 2020, Ibrahim et al., 2021). Stabilization can be performed by various techniques including adding chemical materials, replacement of soil, control of compaction, control of water content, and loading of surcharge (Ramaji, 2012, Karol, 2003, Chindris et al., 2017). The use of waste material (by-product) in the construction would have a beneficial outcome for the environment, saving money, resources and financial value to the wastes (Li et al., 2018). Sustainable development must guarantee that environment, economy, and social components stay safe and balanced (Juul et al., 2013). Waste marble powder is used as a reinforcement or raw material for various uses. Brick, construction materials, ceramics, and infiltration techniques are the most prevalent fields and use (Karaşahin et al.,

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2007, Saboya Jr et al., 2007). Coarse waste marble is used as filler and aggregate in applications for asphalt pavement, and it is also used in the production of clay-based materials and polymer-modified mortars (Akbulut et al., 2007, Acchar et al., 2006). Additionally, waste marble dust is used in numerous applications as white cement, mosaic, mortar, and tile. It is also used to produce clay-based materials and polymer-modified mortars (Saygili, 2015, Marvila et al., 2021). Storage and handling of the waste materials, particularly in developed countries, has led to an increase in environmental problems ((Karaşahin et al., 2007, Saboya Jr et al., 2007, Sarkar et al., 2006, Acchar et al., 2006, Davini, 2000, Zorluer and Usta, 2003, Hwang et al., 2008, Akbulut et al., 2007, Raupp-Pereira et al., 2008, Saygili, 2015, Sutcu et al., 2015, Baker, 2017, Marvila et al., 2021, Polikreti and Christofides, 2008). Few studies have been performed to use marble powder to stabilize expansive soils. Öncü and Bilsel (2018) employed marble waste from different sources and different sizes representing different gradations of marble in different percentages (5, 10, and 20% waste marble) to improve swelling, shrinkage, consolidation, compaction and unconfined compression. The optimum ratios were found to be 10% marble powder and 5% marble dust by dry mass (Öncü and Bilsel, 2018). Rai et al. (2020) used waste marble powder (MP) and magnesium phosphate cement (MPC) to improve geotechnical properties of soils as a novel additive. They subjected the soil samples to a series of tests on which were prepared with different percentages of MPC (0%, 2.5%, 5%, and 7.5%) and MP (0%, 5%, 10%, and 15%). The results showed a wide range (2.5% - 10%) of optimal MP content for different soils properties. In addition, Sivrikaya et al. (2020) investigated the geotechnical characteristics of fine particles using dolomitic marble powder (DMP) and calcite marble powder (CMP). Consistency limits, linear shrinkage, expansion index, and one-dimensional consolidation tests were carried out on unstabilized and stabilized samples with 5%, 10%, 20%, 30%, and 50% waste CMP and DMP. The ratio of the marble that produced the greatest outcomes was discovered to be 50% (Sivrikaya et al., 2020). Additionally, Ditta et al. (explored the effects of marble dust on the properties of expansive soil. They found that the plastic limit, linear shrinkage, liquid limit, swelling pressure, and free swell index decreased as the quantity of marble dust increased, whereas the California bearing ratio increased. The usage of 30% marble dust was cost-effective to provide adequate strength to the flexible pavement subgrade (Ditta et al.). Jain and Jha (2020) studied the effect of the strength and rigidity of marble dust on fine-grained soils and coarse-grained soils. For both soaking and unsoaked conditions, the CBR measurement was utilized to evaluate the subgrade rigidity and stiffness of soils modified with varying percentages of marble dust for better understand how it interacts with soil, physicochemical investigations such as mixtures pH and electrical conductivity have been performed by (Jain and Jha, 2020). They were found that the marble dust increases the pH of two types of the soils up to 20% and reduces thereafter. Eltwati et al. (2020) investigated the impact of marble dust on the quality of subgrade. They used different percentages of marble dust to illustrate quality influence on the tests of CBR and modified proctor. Their test results revealed that the marble dust improved the soil characteristics substantially. They also discovered that adding 10% to untreated soil led to the great improvement when it compared with the samples mixed at various marble dust percentages. The current research aims to stabilize expansive soils by mixing the expansive soil with marble powder at different percentages of the dried weights of the soil samples (6%, 12%, 18%, 24%, 30%, and 36%), in order to understand more the impact of adding amount of marble powder on expansive soils.

2. MATERIALS AND METHODS

2.1. Used Materials

The expansive soil used in this study was taken in Erbil, which is located at 36.11012053 latitudes and 44.04243222 longitudes in the Kurdistan Region-Iraq. Since this land has been used for farming for a long time, the soil sample was brought from a depth of not less than 1.50 m to remove the impacts of fertilization. The soil classified as a high-plasticity clay (CH) based on the Unified Soil Classification System (USCS). The ASTM standard was followed to perform the particle size distribution curve, specific gravity, Atterberg limits, standard proctor tests, and swelling properties. The soil passed on sieve #10 to obtain particles less than 2 mm. Six different

amounts of marble powder (6%, 12%, 18%, 24%, 30%, and 36% by dry weight of the soil) were used to prepare the treated soil samples. First, the marble powder was added to the soil and mixed in a mixture for five minutes. After that, the optimum moisture content was added to the mixture. The key characteristics of the soil sample and the used marble powder used in this investigation are shown in Table 1. Figure 1 shows the particle size distribution curves for the soil sample and marble powder.

2.2 Marble Powder

Several industries in the city of Erbil produce marble powder. According to earlier researches such as Abdulla and Majeed (2021), few experiments have been done on stabilizing expansive soils using marble powder with particles smaller than 0.075 mm. In order to treat expansive soils, marble powder was chosen as the stabilizer in this study. The results of the particle size distribution curve show that approximately 90% of the marble powder's particles passed through sieve #200 see Fig. 1). The test was conducted according to ASTM_D854 (ASTM, 2010b).

3. RESULTS AND DISCUSSION

3.1. Atterberg Limits Test

The Atterberg limits test was performed (ASTM D4318) to determine the liquid limit (LL) and plastic limit (PL) of the treated and untreated soils with different percentages of marble powder (6%, 12%, 18%, 24%, 30%, and 36%) by dry weight of soil. The influence of adding marble powder on the LL, PL, and PI of the soils is shown in Figure 2. The results indicate that the LL

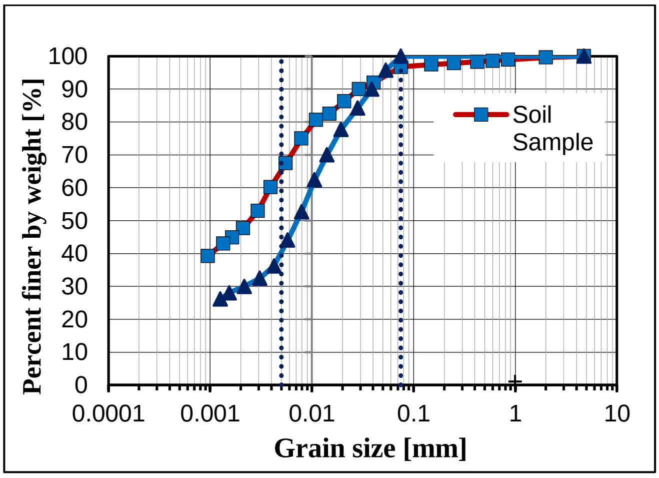

Figure 1. PSD Curves of the soil sample and marble powder.

and PI considerably decrease when the percentage of the stabilization increases up to 18%, and the PL decreases in a lower rate.

Table 1. Properties of marble and soil.

Property	Soil	Marble	Typical Abbreviation
Specific gravity	2.73	2.87	ASTM_D854 (ASTM, 2010b)
Maximum dry density	16.2	18.85	ASTM_D698 (ASTM, 2012)
Optimum moisture content [%]	20.5	14.4	ASTM_D698 (ASTM, 2012)
Passing sieve No. 200, [%]	96.6	96.7	ASTM_D6913 (ASTM, 2017)
Gravel, [%]	0.0	0.0	ASTM_D6913 (ASTM, 2017)
Sand, [%]	3.4	3.3	ASTM_D6913 (ASTM, 2017)
Silt, [%]	31.5	56.7	ASTM_D6913 (ASTM, 2017)
Clay, [%]	65.1	40.0	ASTM_D6913 (ASTM, 2017)
Liquid limit, [%]	51.0	21.5	ASTM_D4318 (ASTM, 2010a)
Plastic limit, [%]	24.0	18.0	ASTM_D4318 (ASTM, 2010a)
Plasticity index, [%]	27.0	3.5	ASTM_D4318 (ASTM, 2010a)

Additionally, it is clear from the figure that a considerable improvement occurs when 18% of marble powder was added. The rate of change of the LL and PI of the treated soil is almost constant after 18% of MP addition. This trend of change is also visible in the plasticity index. This change can be attributed to the fact that the marble powder particles coat the clay clast, fusing them together and filling the clay matrix. Consequently, it reduces the amount of voids and water content. The addition of more marble powder produces soils with friable and better workability. These two previous findings were also obtained by (Davidson and Handy, 1960) ; (Neubauer Jr and Thompson, 1972) and (Davidson and Handy, 1960, Neubauer Jr and Thompson, 1972, Ola, 1975).

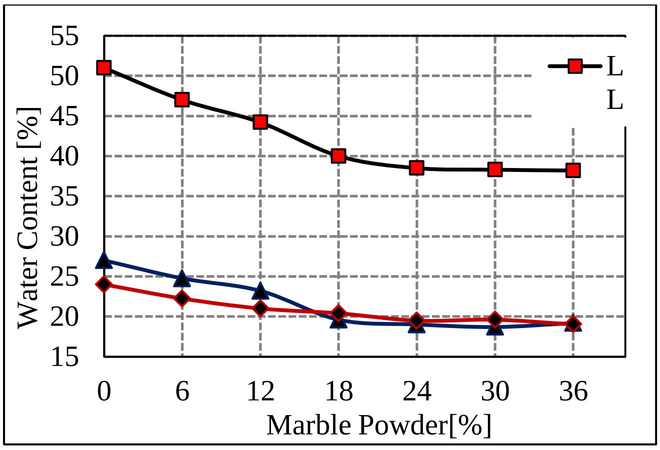

Figure 2. Variations of LL, PL, and PI against marble powder %.

3.2. Standard Proctor Test

The standard proctor compaction test was performed on the soils for treated and untreated conditions according to ASTM D698 (ASTM, 2012). Figure 3 shows the correlation between the maximum dry unit weight (MDUW) and optimum moisture content (OMC) for the soil samples with and without the addition of marble powder. Figure 3 shows that as marble powder content increased up to 18%, the maximum dry unit weight increased and the OMC reduced. Comparison, between untreated and treated soil with the addition of 18% marble powder, shows that maximum dry unit weight increased from 16.2 kN/m^3 to 16.83 kN/m^3, respectively. This improvement can be associated to the desirable changed in the gradation of the treated soil (Sridharan et al., 2006). When the marble powder is added to expansive soil, the chemical ions enter the pore fluid. At the same time, these chemical ions increase the electrolyte content in the pore water. That is why the OMC decreases and MDUW will increase. The OMC of the soils falls suddenly when marble powder passed 18%. Additionally, the porosity of the soil-marble powder matrix, which affects water holding capacity, reduces when marble powder increases, causing a reduction in the OMC. These results are consistent with the similar findings by (Neubauer Jr and Thompson, 1972, Ola, 1975, Sridharan et al., 2006, Ito et al., 2010, Vichan et al., 2013).

Figure (4) shows how the total unit weight (TUW) and the optimum moisture content vary when different MP percentage were added. Sometimes it is important to plot a parameter such as cohesion of a soil against total unit weight to understand what is going on when the soil is under loading due to continuous changing of degree of saturation and hence the void ratio (Hasan, 2016, Hasan and Wheeler, 2015). In this case, it is not an easy task to interpret the results in terms of only MDUW as can be seen in Figures 3 and 4.

Investigation of Figure 4 shows that, the TUW continuously increases as marble powder increased up to 26% and then the values of TUW became constant unlike the variation of MDUW at the corresponding MP%. This confirms that the variables of the plots should be select based on the physical meanings of soil behaviors. Figure 4 also illustrates that the optimal marble powder is 18% where the total unit weight seems to show almost constant rate of variation, whereas the optimal marble powder is not clear in Figure 3 when MDUW plotted instead TUW.

3.3. Swelling Characteristics

Swell-shrink feature of any soil is an indicator that the soil will have high volume change behavior.

These kinds of soils make the life more difficult and challenging in terms of stability of engineering projects. Results from free swelling test and the wetting-drying behavior can be used to predict to the mount of volume change (Ito et al., 2010). A conventional free swell test was carried out in the current investigation to examine the soil's swell characteristics. Figure 5 shows the variations of free swelling, MDUW and OMC against marble powder.

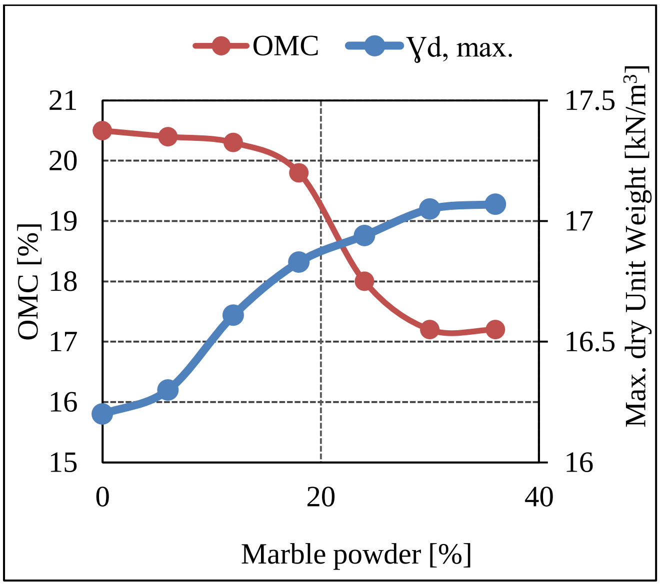

Figure 3. Modification of MDD with various amounts of marble powder with OMC variant.

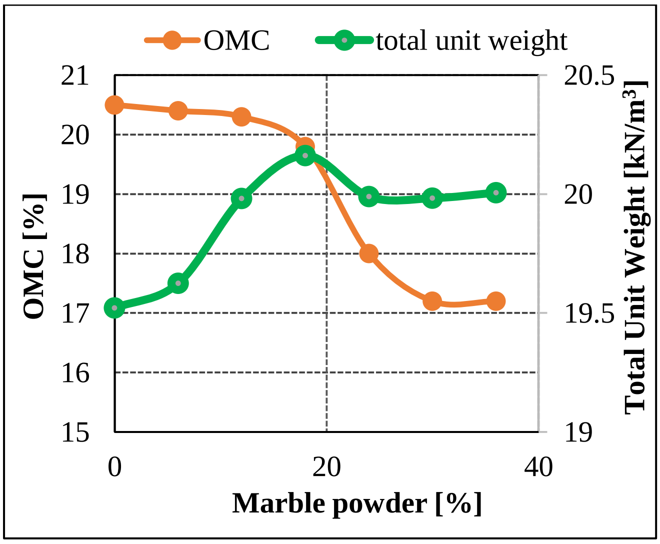

Figure 4. Modification of total unit weight with various amounts of marble powder with OMC variant.

Figure 5 illustrates that with an increase of 6% percentage of marble powder, the free swelling drops to a very high value. Same results were observed by (James and Pandian, 2016). This optimal ratio is differed from ones suggested from Atterberg Limits and compaction results.

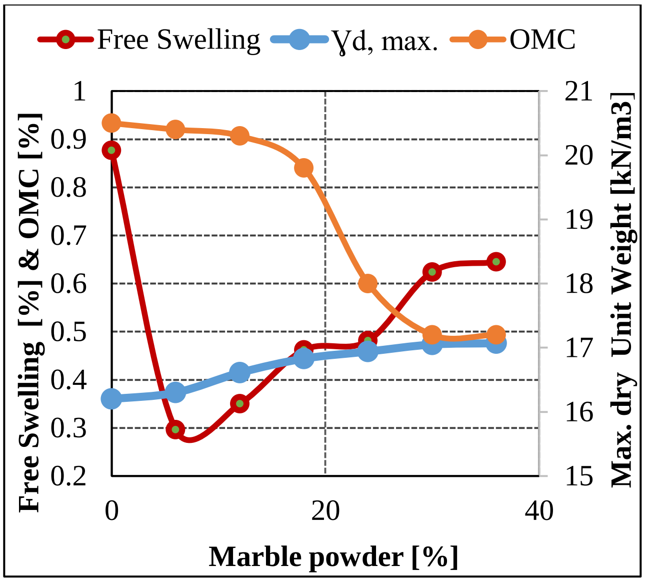

Figure 5. Variation of free swelling, MDUW and OMC against marble powder.

3.4. Direct Shear Test

Direct shear tests were carried out on MP treated soils and untreated soils to determine the shear strength parameters (cohesion and internal friction angle). Fig (6) illustrates the effect of marble powder on the cohesion and total unit weight together. Addition of the marble powder seems to improve soil cohesion in a varied trend. When marble powder is increased from 0% to 18%, the cohesion of treated soils reduced from 95.5 kPa to 81.7 kPa. Whereas, the cohesion slightly improved after treatment by adding MP to more than 18%. Fig. 7 shows the influence of marble powder on internal friction angle for MP treated soils and untreated soils. The internal friction angle was reached to its optimal value (36 º) at 6% of MP and then gradually reduced to 31.5 º at 36% of MP. This indicated that the internal friction angle has improved the shear strength of the soils in each addition of MP.

Figures 6 and 7 shows that 6% and 18% of MP can be suggested for improving internal friction angle and cohesion of the treated soils, respectively. The addition of marble powder has greatly improved the shear properties of expansive soil, which is advantageous to the soil's bearing characteristics.

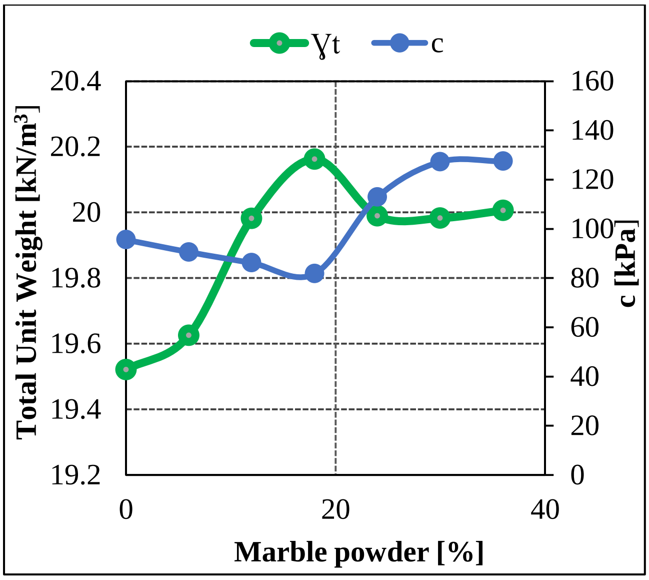

Figure 6. Marble powder stabilizes expansive soil cohesion.

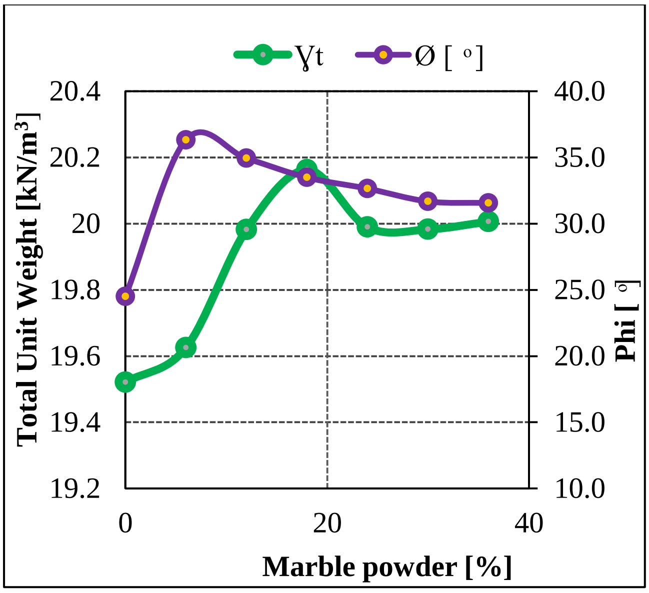

Figure 7. Marble powder stabilizes expansive soil internal friction angle.

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4. CONCLUSIONS

In this research, a series of experimental tests performed to investigate thoroughly how marble powder affects the geotechnical characteristics of expansive clay soils. The following conclusions can be derived from the testing results:

1. The suggested percentage which can be advised to stabilize most geotechnical properties of the expansive soils is 18% of the marble powder.

2. The optimum moisture content significantly reduced at the addition of 18 % MP, there is a marginable increase of the dry unit weight of the expansive soil.

3. The ability of swelling reduced to its minimum value at 6% of MP content, and then the swelling potential increased gradually.

4. The trend of improving the cohesion and the internal friction angle was different when the amount of MP increased which needs more investigation and interpretation.

5.It can be suggested that the marble powder (by-product waste material) can be used as an active additive to effectively improved ground, particularly in expansive soils, where it can be used to minimize negative environmental effects, conserving energy and resources, generating revenue from waste, and lowering costs overall.

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Conflict of Interest (1)

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