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An Experimental Study of Compaction and Strength of Stabilized Cohesive Soil by Stone Powder

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ABSTRACT

The In this experimental study, natural stone powder was utilized to improve a cohesive soil's compaction and strength properties. According to the significant availability of limestone in the globe, it has been chosen for the purpose of the study, in addition to considering the existing rock industry massive waste. Stone powder was used in percentages of 4, 8, 12, 16% replaced from the soil weight in dry state. Some of cohesive soil's consistency, shear, and compaction properties were depicted after improvement. The outcomes yielded in significant amendments in the experimented geotechnical properties after stone powder addition considering 60 days curing period. Cohesion and friction angle were notably increased by 12% and 21% respectively. This study can provide an experimental basis for the stabilization mechanism of the fine-grained soil, and guidance for the better stabilization scenario by available cheap natural resources and waste.

Keywords: Cohesive soil, Stabilization, Stone powder, Shear, Compaction.

دراسة تجريبية لضغط وقوة التربة المتماسكة المستقرة بوساطة مسحوق الحجر

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الخلاصة

في هذه الدراسة التجريبية ، تم استخدام مسحوق الحجر الطبيعي لتحسين خواص ضغط وقوة التربة المتماسكة. نظرا لوفرة الحجر الجيري في العالم، فقد تم اختياره لغرض الدراسة، بالإضافة إلى وجودها في النفايات الضخمة الحالية لصناعة الصخور. وقد تم استخدام مسحوق الحجر بنسب 4، 8، 12، 16٪ حيث تم استبداله من وزن التربة في حالتها الجافة. وقد تم وصف بعض خصائص الاتساق والقص والضغط للتربة المتماسكة بعد التحسين. وقد أسفرت النتائج عن تعديلات مهمة في الخصائص الجيوتقنية المجربة بعد إضافة مسحوق الحجر مع الأخذ في الاعتبار فترة المعالجة التي أستغرقت 60 يومًا. وبالنتيجة تم زيادة التماسك وزاوية الاحتكاك بشكل ملحوظ بنسبة 12٪ و 21٪ على التوالي. ويمكن أن توفر هذه الدراسة أساسًا تجريبيًا لآلية تثبيت التربة الدقيقة الحبيبات، ومرشدا لسيناريو التثبيت الأفضل من خلال الموارد الطبيعية القليلة التكلفة والمتاحة والنفايات ايضا.

الكلمات الرئيسية: تربة متماسكة، استقرار، مسحوق الحجر، القص، الضغط.

1. INTRODUCTION

Commonly in engineering projects, soils are very common materials. Soils can be used in extensive quantities for projects such as highways, railways, and embankments. Globally, clayey soils cover the majority of the ground surfaces (**Ramos, et al., 2015; Rashed, et al., 2017; Behnood, 2018; Salih, 2020**). The demand of civilization leads to construction world development, which requires desire soil capability conditions to be suitable for large and mega structures. However, not always the foundation soils for structures are strong enough to be utilized as long-term foundations (**Bilal and Ahmad, 2020**). Therefore in some cases, improvement of the unsuitable soil properties is necessary. Stabilization can be via compaction or adding materials to increase cohesion and/or friction angle (**Hossain and Khandaker, 2011**).

From a long period of time, various natural, manufactured (fly ash, lime, hydrated lime), and waste materials (blast furnace slag, cement kiln dust, dust of limestone, crushed limestone) have been used to stabilize different soil types (**Cokca, 2001; Phanikumar and Sharma, 2007; Sivrikaya, et al., 2014; Kavak and Bilgen, 2016; Mujtaba, et al., 2018; Pastor, et al., 2019; Ahmed, et al., 2020; Abdalqadir, et al., 2020; Abdalqadir and Salih, 2020; Salih and abdalla, 2020; Jha and Sivapullaiah, 2020; Oliga, 2021**). Also, using manufactured materials in addition to other various stabilization agents to construction materials helps in preventing many dangerous states from happening, decrease building costs, and have a positive effect on the environment (**Salih nd abdalla, 2020; Abdalqadir, et al., 2020; Jha and Sivapullaiah, 2020; Oliga, 2021**). Similarly, positive impacts have been proven when hydrated lime is utilized for amendment of undesired properties of clays (**Ahmed, et al., 2020; Abdalla and salih, 2020; Salih and abdalla, 2020**).

From some industrial processes, solid wastes are generated, which have negative effects on the environment. Hence, over the past few years using solid wastes significantly considered for soil improvement purposes (**Seda, et al., 2007**), like limestone powder and waste dolomitic marble powder (**Baser, 2009**), ground granulated blast furnace slag (**Sivrikaya,**

et al., 2014; Kayak and Bilgen, 2016; Mujtaba, et al., 2018; Pastor, et al., 2019; Oliga, 2016; Abdalqadir and Salih, 2020), and limestone dust (**Sabat and Muni, 2015**).
Although various studies carried out on using natural or materials such as limestone, there is still some stabilization aspects have not considered yet. This study aim is to characterize stone powder (SP) role to improve cohesive soil's consistency, compaction (optimum moisture content, and maximum dry density), cohesion (C) and friction angle (Ø) after curing for 60 days (after **Salih and Abdalla, 2022**).

2. Study Methodology

2.1 Utilized in-situ Soil

In-situ soil sample was obtained from Raparin area in Sulaimani Governorate, northern Iraq (Approximately E = 45°20`08.6``, and N = 35°35`02.3``). From 2.0 meters depth, the in-situ soil samples were collected. Collected (disturbed and undisturbed) samples were stored in plastic bags and transported to geotechnical laboratory for testing. The utilized sample was clayey soil with low plasticity. More properties are presented in **Table 1.** and **Fig. 1**.

2.1.2 Stone Powder

Natural limestone blocks were obtained from Sarchinar Area, borough of Sulaimani City (south east side), Northern Iraq. The chemical analysis of the used stone is presented in **Table 2.** The stone blocks were crushed into a powder, then the prepared powder was sieved through No. 40 (0.425 mm). The passed stone powder (SP) from the sieve was utilized by percentages of 4, 8, 12, and 16% as replaced mass from the dry mass sample for the preparation purpose of testing samples.

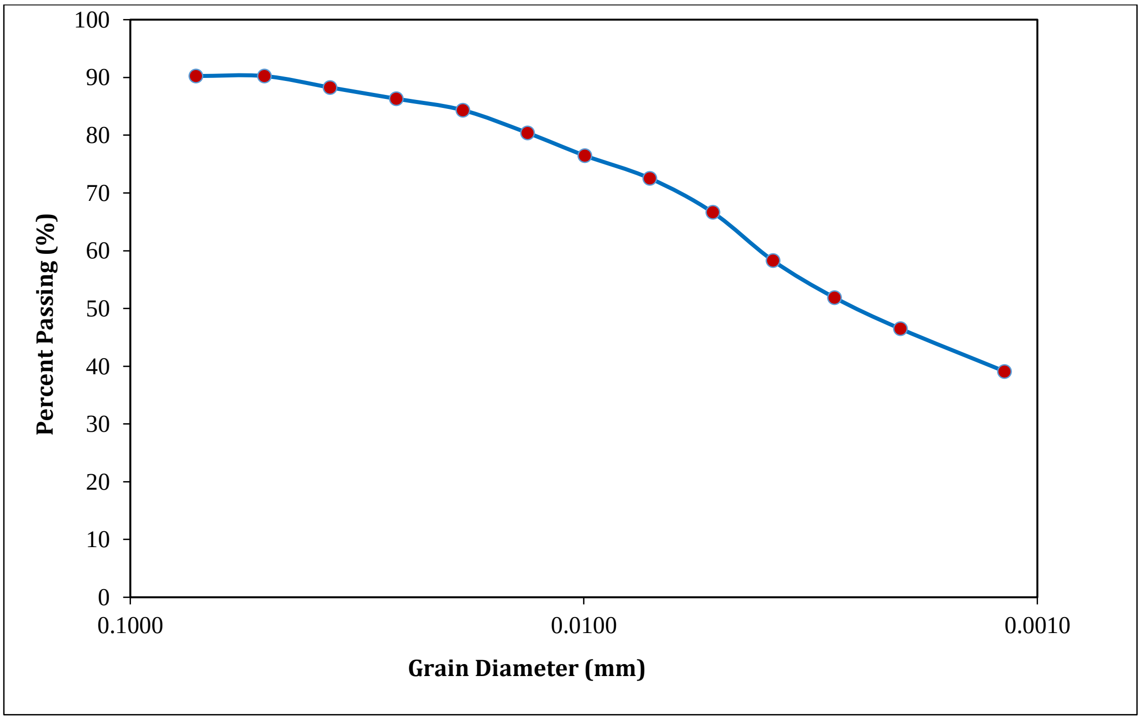

Figure 1. Distribution of the soil sample's particle size.

Table 1. Properties of the used in-situ soil sample obtained from laboratory experiments.

Properties	Values	Standard (Reference)
LL (Liquid Limit) (%) PL (Plastic Limit) (%)	45.6 22.14	ASTM D4318 (2017) ASTM D4318 (2017)
Cohesion, C (kPa) Friction Angle, ϕ (Degree)	41.88 35.41	Head and Epps (2011) Head and Epps (2011)
MDD (gm/cm^3) OMC (%)	1.699 18.86	ASTM D698 (2014) ASTM D698 (2014)
Field Dry Density (gm/cm^3)	1.66	ASTM D 2937 (2010)
Natural Moisture Content (%)	14.75	ASTM D2216 (2010)
G_s (Specific Gravity)	1.62	ASTM D854 (2014)
USCS (Unified Soil Classification System)	CL	ASTM D422 (1990)

Table 2. Chemical analysis for the used stone powder sample.

Chemical Composition	Value (%)
$CaCo_3$ (%)	91.81
SiO_2	2.94
Fe_2O_3	0.75
Al_2O_3	1.88
CaO	52.16
MgO	0.4
SO_3	Negligible
K_2O	0.09
Na_2O	Negligible
L.O.I	40.75

3. OBTAINED RESULTS AND THEIR DISCUSSIONS

3.1 Consistency Parameters Changes

In-situ soil sample LL, and PL values are 45.6%, and 22.14% respectively. From Figs. 2 – 4, the reductions of LL are 7.68%, 12.24%, 17.41% and 21.07%; PI reductions are 19.01%, 33.33%, 46.63% and 59.46%; and PL increase are 4.16%, 9.19%, 11.93% and 16.39%; respectively. In general, when SP used, powder's cations (calcium) will take the location of will pick the soil cations location till the soil become filled with calcium, resulting soil's LL to decrease drop, which resulted due to a large reduction in the diffuse double layer thickness (**Okagbue, 2007**). Some studies outcomes were similarly achieved the same state **(Agrawal and Gupta, 2011; Negi, et al., 2013; Satyanarayana, et al., 2013; Sivrikaya, et al., 2014; Pastor, et al., 2019; Sabat and Muni, 2015; Ahmed, et al., 2020; Hussein, et al., 2020)**. According to **Dixit and Patil (2016)**, the stone dust inclusion reduces LL. Utilization of gravel dust reduces soil-gravel dust mixture's ability to bond as well as its capability to hold moisture (**Kashoborozi, et al., 2017**). In accordance to the study of **Abdalqadir and Salih (2020)**, the reduction LL and PL values with increase of limestone dust was because of a reduction in clay particles double layer thickness. So, limestone and gravel dusts reduce soil's PI generally. This is owing to the fact that clay fines are reduced with the addition of both dusts type (**Tugume, et al., 2018**).

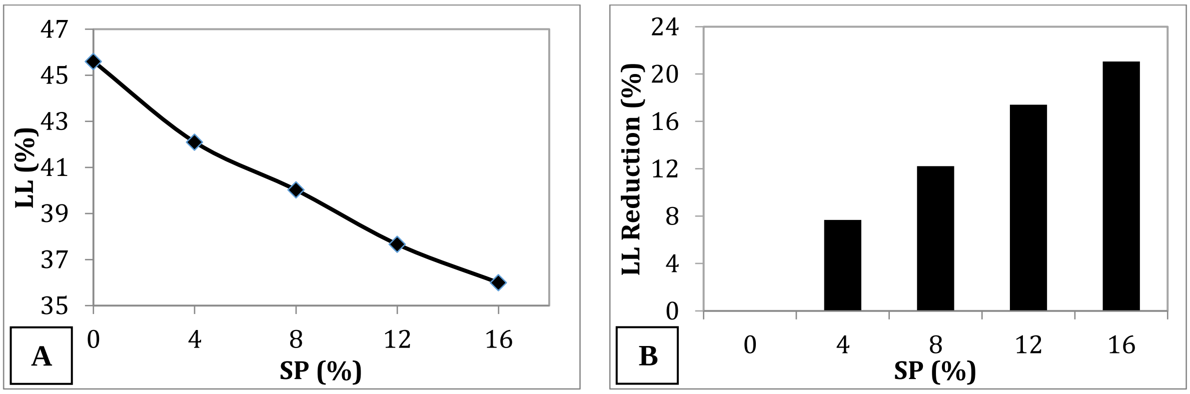

Figure 2. Effect of stone powder on sample's liquid limit, A: LL versus SP, B: LL reductions due to SP percentages.

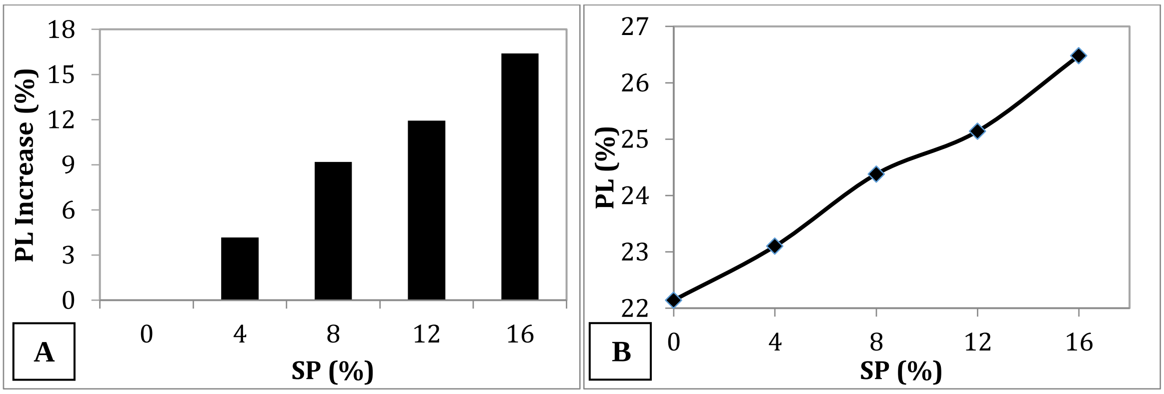

Figure 3. Effect of stone powder on sample's plastic limit, A: PL versus SP, B: PL Increase due to SP percentages.

3.3 Compaction Parameters Changes

The **Figures 4 and 5** illustrate the relationship between MDD and OMC for the in-situ and treated samples with SP. The values of MDD and OMC in the in-situ sample were 1.6694 gm/cm^3 and 18.87% respectively. In general, increase of SP percentage decreases OMC value and increases the MDD value. Similarly, **Abdalqadir and Salih (2020)** mentioned that the increase in the MDD value could be attributable to a number of factors. As the diffused double layer thickness reduced, the soil grains become closer to one another, increasing the MDD value. As a result, particles pack with each other result in dry density increase with the same amount of compaction effort. The OMC values tend to decrease as particles became closer together and their water holding capacity reduced.

The addition of SP coarsened the soil, resulting in a greater MDD value (**Ahmed, et al., 2020**). Mixing clay and limestone dust results in better compaction of clay within low levels of moisture, which result in a denser structure and a lower void ratio and higher density (**Ogila, 2016**). Similarly, researchers like **Agrawal and Gupta (2011)**, **Memon, et al. (2015), and Bazarbekova et al. (2021)** obtained similar outcomes.

Conversely, MDD value decreased with SP percent increase utilized in the mixture. While, previous results of studies of **Tugume, et al. (2018), Satyanarayana, et al. (2018),**

Sharma and Hymavathi (2016), Santos, et al. (2011), and Hussein, et al. (2020) are not in agreement with current study results, which concluded that the rise in OMC value is related to the soil's desire to obtain more moisture in order to complete the exchange process of cation and lubricate the soil gains for successful compaction.

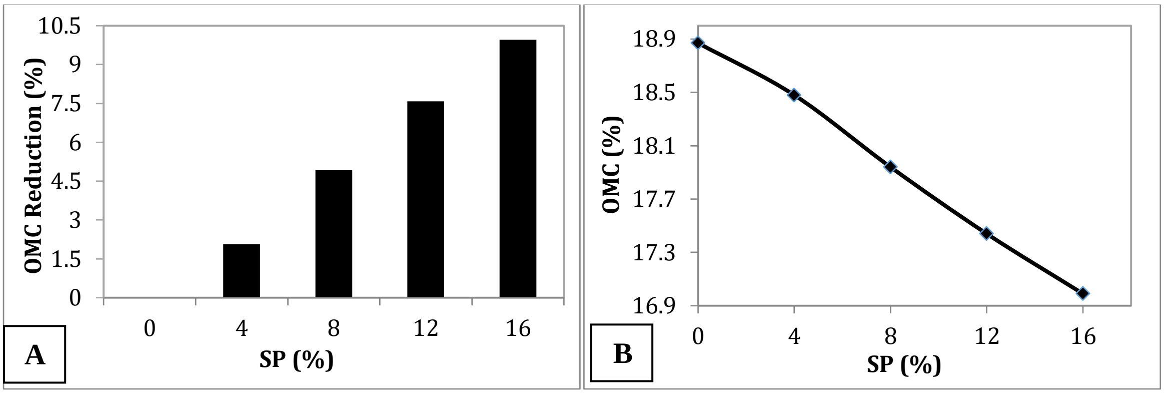

Figure 4. SP impacts on OMC values of the compacted soil sample.

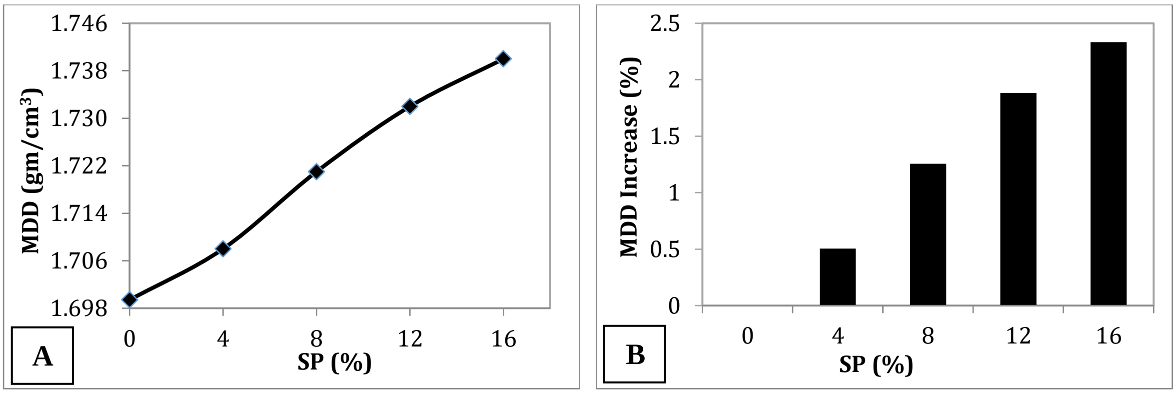

Figure 5. SP impacts on MDD values of the compacted soil sample.

3.4 Shear Strength Parameters Changes

The soil samples with varied amounts of SP subjected to unconsolidated un-drained test. **Figs. 6 – 7** present the in-situ and improved soil samples results. Increasing the SP percent lead to an increase in cohesion (C) and friction angle (ϕ) values of the improved soil.

The values of ϕ and C of the in-situ soil sample were found to be 35.41° and 41.88 kPa respectively. **Figs. 6 & 7** shows that the values of ϕ and C were increased due to 16% SP to the values of 44.98° and 47.55 kPa respectively.

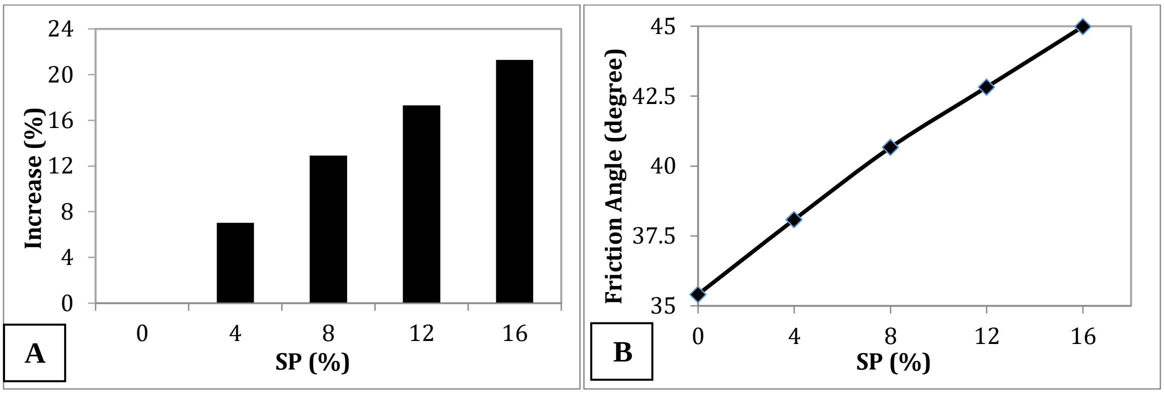

Figure 6: Effect of utilization of SP on friction angle of the utilized soil sample.

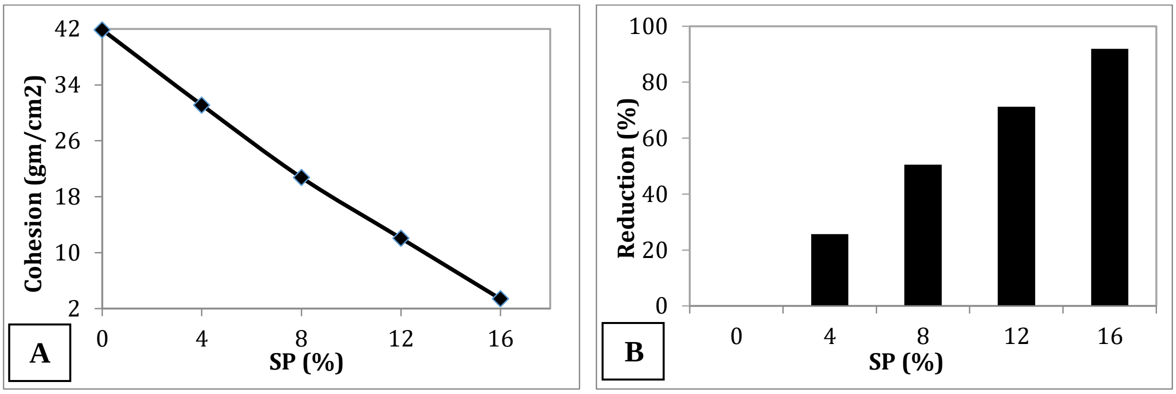

Figure 7. Effect of utilization of SP on cohesion of the utilized soil sample.

3.5 Comparison of the Results' Optimum Values

Fig. 8 and **Table 3**. present the conducted comparison among the achieved reductions/increases values of the tested geotechnical characteristics. SP improves soil geotechnical characteristics due to it has a pozzolanic nature, in addition it contains coarse particles (passed sieve No. 40), which modifies MDD and OMC values and decreases the plasticity characteristics. Almost all of the examined properties were amended due to the utilization of SP; the best improvement level obtained the plasticity Index value (see **Table 3**.). Clay Activity (Ac), free swelling (FS) also significantly improved, while bearing capacity (BC) was improved in a lower level (see **Fig. 8**).

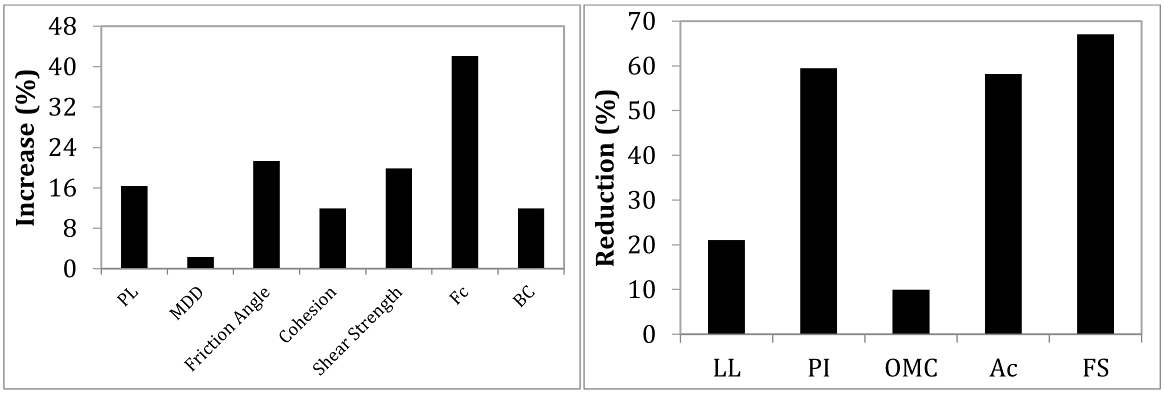

Figure 8. The obtained reductions/increases for various geotechnical characteristics due to stone powder utilization.

Table 3. The achieved changes in some checked geotechnical parameters.

SP (%)	Soil Name (USCS)	Plasticity Index (PI)	Liquidity Index (LI)	Relative Consistency (Cr)
0	CL	23.46	-0.29393673	1.29393673
4	CL	19	-0.43947368	1.43947368
8	CL	15.64	-0.6157289	1.6157289
12	ML	12.52	-0.8298722	1.8298722
16	ML	9.51	-1.23343849	2.23343849

According to the achieved outcomes shown in **Table 3.**, sample liquidity state is still is still below the liquid limit within the utilization of SP. However, LI values decreased with SP percent increase, which means the SP acting notable to reduce the influence of water absorption by the soil particles, in addition to relatively harder state will be gained, and the soil firmness will be increased. Also, as Cr value increases, the soil firmness state, and/or the soil shear strength of also increases (**C272, 2012**). Moreover, the soil name according to replacement some soil mass by SP resulted in transverse alteration in the sample name. The soil type changed from CL-lean clay to ML-silt, which means that the clay particles reduced that replaced by SP and resulted in better soil state, which appeared after 12% SP percent. Also, the soil state altered from high plasticity to low plasticity as shown in the achieved decreases in the PI values.

4. Conclusions

After the experimental work conduction, below conclusions can be drawn:

- Addition of 16% of stone powder after 60 days curing resulted in liquid limit improvement by 19%, while plastic limit improvement by 22%.
- Utilization of 16% stone powder after 60 days curing yielded to 2.87% increased value of MDD (1.69 gm/cm^3 - 1.74 gm/cm^3), and OMC decreased value by 9.96% (18.87% - 16.99%), respectively.

- Stone powder effectively increases the soil's cohesion, stone powder addition by a rate of 16%, resulted in the cohesion value increase to 47.55 kPa from 41.88 kPa, which improved by 11.92%.
- Stone powder notably increases the soil's friction angle, SP addition by a rate of 16%, resulted in friction angle increase to 44.99º from 35.41º, which improved by 21.29%.
- The study found that using stone powder as a stabilization material in the geotechnical applications can be notable successful as it it controlling the consistency of the soil that result in relatively harder state and increase the soil firmness.

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Conflicts of Interest: The author declares that no conflict of interest.

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