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Soil Improvement Using Lime Material: A Case Study in Saudi Arabia

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***Abstract*—Soil improvement techniques have been widely used to enhance the engineering properties of weak soils that do not satisfy construction conditions, mainly in terms of bearing capacity. In our case, a weak soil classified as Lean Clay with Sand (AASHTO classification system) was improved adding Lime with different percentages in terms of weight of the dry soil.**

In order to assess the level of achieved improvement, the various samples, with 2, 4, and 6% added Lime was tested and assessed in comparison to the reference soil, i.e. disturbed with no addition of Lime. The sieve analysis, the Atterberg limit, the chemical analyses, i.e. Sulphate, Chloride contents and PH value, are carried out.

The fourth sample with 6% added Lime illustrated the best results. On the one hand, based on the sieve analysis, the original soil classified as A-6, indicating very weak soil, was improved to A-1-b class that represents well-graded sand, which indicates an excellent soil. On the other hand, the more the added Lime, the lower the resulted water content, liquid limit, and plastic limit, where the 0% added Lime sample is mutually compared with the 6% added Lime one. The water content lost 80.43% of its measured values, dropping from 8.79% to 1.72%. While, the liquid limit has dropped 20% between the original and 4% added Lime sample, the behavior has completely changed for the fourth sample that became non-liquid. Similarly, the plastic limit almost dropped 14% between the 0% and 4% added Lime samples, the behavior has utterly changed to be non-liquid for the 6% added Lime sample.

Keywords*— *Soil Improvement, Lime, AASHTO classification, Atterberg Limits, Sulphate content, Chloride content, PH value.

I. Introduction

Soil improvement techniques can be divided into temporary techniques (e.g., dewatering, ground freezing, … etc.) and permanent techniques, which in turn can be achieved with adding some material (Lime, cement, soil replacement, sand/gravel/lime columns, grouting, reinforcing elements, … etc.) or even without using any metrical but targeting the in situ soil itself (e.g., soil compaction, thermal treatment, … etc.) to improve the engineering and physical/chemical properties of the soil [1].

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Soil improvement techniques by adding improving material, in particular using the Lime material, are widely used to enhance the soil properties. Using lime material in soil improvement enhances the workability and, most importantly, the load-bearing characteristics, more over both the soil stability and impermeability are increased [2].

The original weak soft clay soil has been precisely classified to be lean clay with sand. According to the American Association of State Highway and Transportation Officials (AASHTO) classification, such soil is A-6 and represents a very weak soil and consequently it is not suitable for construction.

Different percentages of the Lime material were added to this weak soil then the necessary tests before and after the additions of Lime were carried out. The Lime was added as a percentage, in terms of the soil dry weight, as 2, 4, and 6%, in which the 0% Lime refers to the original soil without any additives [3,4].

The relevant laboratory tests, discussed in the following section, were carried out in order to assess the various Engineering and mechanical properties before and after using the Lime. Then, the results obtained from our case-study in Saudi Arabia, i.e. improving a weak soil adding different percentages of the Lime, in terms of the soil dry weight, are reported, and followed by a thorough discussion. Relevant conclusions are drawn in the last section.

II. Tests

In order to assess the soil properties prior and posterior to adding the Lime, various laboratory tests were conducted. Four (4) main tests, namely, the Sieve analysis, Atterberg limits (liquid limit and plastic limit), water (moisture) content, and chemical tests (Sulphate content, Chloride content, and the PH value) were carried out.

The sample preparation and the procedure of the execution of each test are performed following the standards of soil mechanic testing [5] then discussed in the following subsections, while the tables that summarize the results will be reported in the Results section.

A. *Sieve Analysis*

The sieve analysis (aggregate gradation) aims to find the distribution of particle sizes expressed in terms of percentages of the total dry weight of the classified soil. The soil gradation is expressed on basis of the total percent of dry weight passing, which indicates the total percent of aggregate by weight that will pass a given sieve size. Sieve No. 8 (2.36 mm) is an essential sieve, in which all the materials retained on and

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above are called the "Coarse Aggregate" and all the materials passing from it are called the "Fine Aggregate".

Regarding the sample preparation, the tested soil sample was dried in an oven at a temperature of 230°F (110ºC). Then, the dried soil was well weighed and expressed in grams [5].

B. *Atterberg limits (liquid limit and plastic limit)*

The Atterberg limits are empirical tests, which are used to indicate the plasticity of fine-grained soil by the differentiation between highly plastic, moderately plastic and non-plastic soils. The tests enable both the classification and identification of the soil to be carried out and give a rough guide to the engineering properties. As the moisture content of a soil decreases, the soil passes from a liquid to a plastic state and furthermore to a solid state. On the one hand, the range of moisture contents where the soil is considered plastic is used as a measure of its plasticity index. On the other hand, the points at which a soil changes from one state to another are called the liquid limit and plastic limit, respectively.

For the determination of the Atterberg limits, the soil must first be sieved through the sieve No. 40 (0.425 mm). A rule of thumb is to first test the liquid limit. On one side, the Liquid Limit is the water content where the soil changes from plastic to viscous (liquid) state that corresponds to a total of 25 drops to bring together a 13 mm section of a groove cut into the soil sample. On the other side, the Plastic Limit is the water content at the boundary between the semi-solid state and plastic (flexible) one. It is determined as the gravimetric water content at which a soil sample can be rolled by hand into a thread of 3.2 mm diameter without breaking.

C. *Water (Moisture) Content*

The determination of the soil water content is one of the most commonly performed analyses as it affects many, if not all, soil properties. There are various techniques to directly measure the water content and most of them are based on removing the water from a sample by evaporation, leaching, or chemical reaction, with the amount of water removed being determined.

One of the most common methods of soil water content determination is the gravimetric method with oven drying, weighing a moist sample and the dry one after oven drying it at 105°C for 24-48 h, then calculate the mass of evaporated water as a percentage of the mass of the dried soil [5].

D. *Chemical Analysis*

Chemical testing of aggregates and soils within the construction and civil engineering industry has wide-ranging implications for remediation works and general project timelines and budgets, therefore it is important that the test results comply with national standards. Some materials testing laboratories can provide chemical analysis of Sulphate, PH measurement, Chloride levels and organic matter. However, not all of them can provide the additional option of testing to recognized construction industry standards [6].

On the one hand, the Sulphate content is expressed in terms of the percentage of the sulfur trioxide (SO3) present in the tested soils. The British Standard BS 5328: Part 1, "Guide to Specifying Concrete", stated requirements for concrete exposed to sulfate attack depending on the concentration of the sulfate in the surrounding soil or in water. These requirements state the type of cement to be used, the minimum cement content, and maximum free water to cement ratio. On the other hand, the Chloride content will be measured in terms of the presence of the (Cl).

There is no widely accepted view on the concentration, which chloride becomes significant in soil or groundwater, but limited experience in the region suggests it may be as low as 0.05%, in particular to the situations where alternate wetting and drying or capillary rise affect the concrete [7]. However, it is important to ensure that the maximum limits for chlorides and sulfates in the aggregate components and in the concrete, are not exceeded.

In conclusion, Chlorides do not react expansively with Portland cement, as do Sulfates. Their presence increases the risk of corrosion of embedded metals of which the greatest volume used is steel reinforcement. They can be tolerated in plain concrete, although when present in large amounts, some surface dampness may result, but the recorded widespread and serious damage has been caused by the use of Chloride-contaminated aggregates in reinforced concrete [8]. The corrosion products occupy more than twice the volume of steel, and their formation can be accompanied by very high tensile pressures as great, resulting in cracking of the concrete, frequently followed by spilling of the cover. In severe cases of corrosion, there may be a reduction in the section of the reinforcing bars, leading to a loss of tensile strength of the concrete. The Construction Industry Research and Information Association (CIRIA) guide to concrete construction in the Gulf region recommended a maximum limit of chlorides in the coarse and fine aggregates used for concrete as 0.03% and 0.06%, respectively [9].

Moreover, the CIRIA guide recommended maximum limits for total Chloride content in concrete from all sources expressed as a percentage by weight of cement as 0.15% for the reinforced concrete made with Portland Cements containing less than about 4% C3A (e.g. sulfate resisting Portland Cement) and 0.30% for reinforced concrete made with Portland Cements containing 4% or more C3A (OPC and ASTM type I and II usually contain more than 4% C3A). For non-reinforced concrete, the limit is just 0.6%.

III. Results

The results of lab tests are reported and discussed.

A. *Sieve Analysis*

The total dry weight of the original disturbed soil, i.e. 0% added Lime, and the 2%, 4%, and 6% added Lime are equivalent to 260, 620, 860, and 973 g, respectively. The results of the sieve analysis are reported in Table **1**, where only the sieves belated to the retained soils are stated. The graphical representation of all the sieve analyses is displayed in Figure **1**.

From the results of the sieve analysis, the one can perform the particle size analysis, according to the ASTM D422-63, as reported in Table **2**.

B. *Atterberg Limits*

First, the percentages of the soil passing from sieve No. 40, as documented in Table **3**, are calculated to be 93.84% for the first sample, 83.51% for the second sample, 56.57% for the third sample, and 38.53% for the fourth sample.

Then, the Atterberg limits, i.e. the liquid limit and the plastic limit, and the designated plasticity index calculations, according to the ASTM D4318-10, are computed and documented in Figure **2** and Table **3**.

C. *Water Content*

According to the ASTM D2216-10, the water content test was carried out and the results are summarized in Table **3**.

D. *Chemical Analysis*

According to the BS 1377-3:1990, the chemical analysis was performed and the results are in Table **4**.

Table 1: The Sieve Analysis.

Sample [% Lime]	***Sieve Size [mm]***	***Weight (Retained Soil) [g]***	***Percent (Retained Soil) [%]***	***Cumulative (Retained Soil) [%]***	***Cumulative (Passing Soil) [%]***
First [0%]	6.3	0.000	0.000	0.000	100
	4.75	10.270	1.027	1.027	98.973
	2	13.699	1.370	2.397	97.603
	0.425	37.671	3.767	6.164	93.836
	0.075	191.096	19.111	25.274	74.726
Second [2%]	25	0.000	0.000	0.000	100
	19	15.360	1.536	1.536	98.464
	9.5	8.893	0.889	2.425	97.575
	4.75	38.804	3.880	6.306	93.694
	2	16.168	1.617	7.922	92.078
	0.425	85.691	8.569	16.491	83.508
	0.075	411.479	41.148	57.640	42.361
Third [4%]	16	0.000	0.000	0.000	100
	12.5	20.000	2.000	2.000	98.000
	9.5	24.286	2.429	4.429	95.571
	4.75	64.286	6.429	10.857	89.143
	2	81.429	8.143	19.000	81.000
	0.425	244.286	24.429	43.429	56.571
	0.075	405.7143	40.571	84.000	16.000
Fourth [6%]	6.3	0.000	0.000	0.000	100
	4.75	2.786	0.279	0.279	99.721
	2	14.856	1.486	1.764	98.236
	0.425	597.029	59.703	61.467	38.533
	0.075	352.832	35.283	96.750	3.250

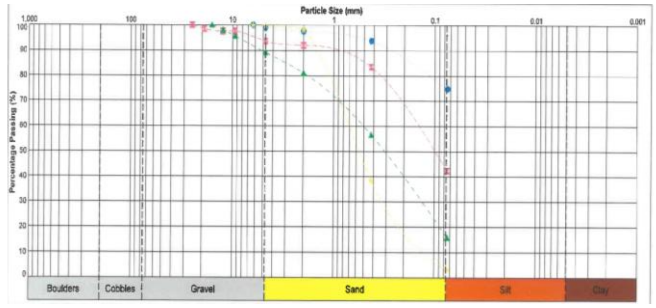

Figure 1: The graphical representation of the sieve analysis, blue circles, red and green triangles, and yellow stars represent the first, second, third, and fourth sample, respectively.

Based on the measured Sulphate contents, the tested samples are classified as Class (1), i.e. sulfate content is considered not significant. Therefore, no special requirements concerning the cement type and content or water to cement ratio are recommended. As shown in Table **4**, insignificant Chloride content (less than 0.05%) was observed. Therefore, it is advisable that the minimum concrete cover for steel reinforcement is adopted in the buried construction members to protect the steel from the ingress of the chlorides present in the surrounding environment. Surface protection and sealing of the concrete and any steel elements should also be considered.

In the end, the measured PH values indicate that all the foundation soils are slightly alkaline, i.e. PH values are higher than 7 and less than 9. These values are considered not detrimental to steel.

IV. Discussion

After performing the designated tests, the results illustrated the following facts:

- The first sample (0% added Lime) is weak to very weak, therefore it is definitely not fit to build on;

Table 2: The particle size analysis of the four tested samples.

Symbol	***Sample [% Lime]***	***Depth [m]***	***Description***	***Gravel [%]***	***Sand [%]***	***Silt/Clay [%]***
	First [0%]	1.5	Lean Clay with Sand (CL)	1.0	24.2	74.4
	Second [2%]	1.5	Clayey Sand (SC)	6.3	51.3	42.4
	Third [4%]	1.5	Silty-Clayey Sand (SC-SM)	10.9	73.1	16.0
	Fourth [6%]	1.5	Well-Graded Sand (SW)	0.3	96.5	3.2

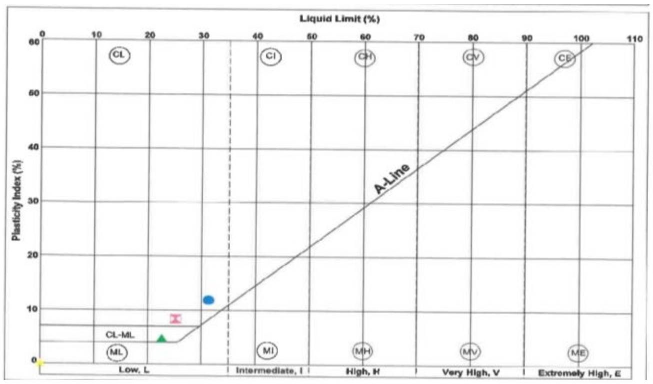

Figure 2: The graphical representation of the liquid limit and the plasticity index, blue circles, red and green triangles, and yellow stars represent the first, second, third, and fourth sample, respectively.

- The second sample (2% added Lime) was classified as A-4 according to the AASHTO classification. The A-4 soil is certainly better compared to the first sample but, on the other hand, it is still classified as fair to weak and such a type of soil is considered not fit to build on and consequently, it is always rejected;
- The third sample (4% added Lime) indicates noticeable improvements as, according to the AASHTO, it has been classified as A-2-4. Such a soil class is widely accepted in small to medium construction projects because it is safe to build on it, but it can not bear to carry heavy loads;
- The last sample (6% added Lime) clearly illustrated the best results as the best soil class classification i.e. A-1-b was obtained, according to the AASHTO classification. The A-1-b class indicates that such a soil is excellent and, for sure, is very suitable to construct upon.

Moreover, all of the water content as well as the liquid limit and plastic limit have drastically decreased when we mutually-compare the reference sample, i.e. the original disturbed sample with 0% added Lime, with the fourth sample, i.e. 6% added Lime.

The water content lost 80.43% of its measured values, dropping from 8.79 to 1.72%. While, the liquid limit has almost dropped 20% between the original sample and the third sample, i.e. 4% added Lime, the behavior has completely changed for the fourth sample that became non-liquid. Similarly, the plastic limit has almost dropped 14% between the 0% and 4% added Lime samples, the behavior has utterly changed to be non-liquid for the 6% added Lime.

I. Conclusion

The one can definitely confirm that the 6% addition of Lime material to the soil has changed it from being weak to very weak, i.e. A-6, to an excellent soil, i.e. A-1-b, according to the AASHTO classification.

Table 3: The Atterberg Limits.

Sample [% Lime]	***Passing Sieve #40 [%]***	***Blows***	***Weight (Wet soil + tare) [g]***	***Weight (Dry soil + tare) [g]***	***Weight (tare) [g]***	***Water content [%]***
First [0%]	93.84	15	52.5	48.01	34.66	33.63
	-	24	52.73	48.55	35.30	31.55
	-	35	49.94	45.98	32.67	29.75
	Water Content		1240	1150	125.5	8.79
	Plastic Limit	19.46				
	Liquid Limit	31.31				
Second [2%]	83.51	15	54.91	50.75	35.86	27.94
	-	24	53.09	49.31	34.56	25.63
	-	35	52.32	48.80	33.90	23.62
	Water content		1596	1501	93	6.75
	Plastic Limit	16.85				
	Liquid Limit	25.23				
Third [4%]	56.57	15	53.35	49.87	35.86	24.84
	-	24	52.10	48.87	34.78	22.92
	-	35	52.87	49.82	35.58	21.42
	Water content		1360	1290	95	5.86
	Plastic Limit	17.94				
	Liquid Limit	22.67				
Fourth [6%]	38.53					
	Water content		1102	1086	153	1.72
	Plastic Limit	Non Plastic				
	Liquid Limit	Non Liquid				

On the other hand, the more the added Lime, the lower the resulted water content, liquid limit, and plastic limit, when the reference sample (0% added Lime) is mutually-compared with the fourth sample (6% added Lime). The water content lost 80.43% of its measured values, as it dropped from 8.79 to 1.72%. While, the liquid limit has almost dropped 20% when the original sample is compared to the third sample (4% added Lime). Moreover, the soil behavior has completely changed for the fourth sample that became non-liquid. Similarly, the plastic limit has dropped 14% between the 0% and 4% added

Lime samples, the behavior has utterly changed to be non-liquid for the fourth sample (6% added Lime).

Table 4: The Chemical Analyses.

Sample [% Lime]	Sulphate (SO3) content [%]	Chloride (Cl) content [%]	PH value
First [0%]	0.16	0.013	7.0
Second [2%]	0.33	0.016	7.5
Third [4%]	0.22	0.018	8.2
Fourth [6%]	0.24	0.020	8.5

Finally, after the cross-comparison of the various percentages of the added Lime, the one can conclude that the improved soil using such a ratio is considered much better than the original sample (in relative terms to the added 2, 4, and 6% Lime). Until, the bearing capacity is computed for the various samples, the one cannot confirm that the 6% added Lime is the optimum percentage to improve the concurrently tested soil.

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