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Recycling of construction and demolition gypsum wastes as stabilizer of soft clay soil and effects of drying-rewetting frequency on the treated soil stability

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Abstract

The continuous growth in civilization and population have led to upsurge in generation of construction and demolition (C&D) wastes. A considerable part of C&D wastes is gypsum wastes that together with its derivatives are classified as a group of binding agents in soil stabilization and immobilization and upgrading soil durability. In this study, the possibility of using gypseous wastes as a binding agent was investigated. Moreover, soil stabilized with recycled gypsum was tested under different dry-wet cycles as well as multiple dry-rewetting to assess the stability of improved soil. Different amounts of gaseous waste (0, 5, 10, and 20%) and 5% cement and 5% lime were added to clay soil at various curing conditions (0, 7, 14, and 21 days). Then, durability of samples was tested by wetting/drying cycles (0, 1, 2, and 3 cycles). Soil characteristics including compaction, unconfined compression strength, Atterberg limits and soil durability were assessed for all samples. Results demonstrated significant increase of the unconfined compressive strength in clay by addition of gypsum waste, cement, and lime. However, we detected a significant reduction in the unconfined compressive strength of the samples in the third cycle of wetting-drying test.

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Introduction

Sustainable development is only practical when environmental aspects are considered. The growing trend of civilization and population growth have led to new constructions in the residential areas. Each construction has a fixed lifetime after which it requires repair or it should be completely demolished for reconstruction (Esa et al., 2017). This generates a significant amount of solid wastes called construction and demolition (C&D) wastes which can create environmental and sanitary problems in the society when not attended to reasonably. Also, management and disposal of C&D can become so expensive and these debris may produce hydrogen sulfide gas at landfill sites (Leškevičienė et al., 2003; Wu et al., 2015).

According to USEPA, wastes from construction activities are debris and unwanted materials from construction and demolition of buildings, bridges, roads which mostly consist of heavy and bulky materials such as cement, wood, asphalt, gypsum, metals, bricks, glasses, plastics, etc. (Agency, 2017). Recycling is one of the important waste management strategies (Tam and Tam, 2006; Ural et al., 2014). C&D wastes are among those solid wastes that are amenable to reuse or recycling (Spoerri et al., 2009). One of the appropriate practices of C&D wastes is using them in other constructional activities. This reduces the intake of raw materials, the volume of C&D wastes, the required space for C&D wastes' landfilling, waste management cost, and the capital required for implementation of construction projects (Fatta et al., 2003; Sandler, 2003). C&D wastes can also be used in geotechnical projects (Arulrajah et al., 2012a; Arulrajah et al., 2012b; Jiménez-Rivero and García-Navarro, 2016). The soil is the main basis for the foundations of structures and machinery. The soils with problem can pose limitations for construction foundations in many areas for which soil improvement activities are expected (Rezaei et al., 2012; Wilkinson et al., 2010).

When the soil moisture rises, its mechanical properties also change. In some cases, this causes specific phenomena to happen and end in severe damages. This type of soils are called water-sensitive problematic soils and generally include swelling soils, dispersive soils, liquefaction soils and collapsible soils (Groosi et al., 2013). These soils can pose many technical and engineering problems including building fracturing or collapse, differential settlement of the structures and raised water table which may subsequently damage the foundation in low elevation areas due to site heaving.

Soils with problems comprise a significant part of clayey soils in which moisture changes have stark effects on their strength and durability (Tabatabaie, 2014). Since these types of soils exist in many areas of the world, there is an inevitable need to improve soil specifics before use.

Increasing the strength of such soils can be achieved by stabilizing them using binder materials (Mosavat et al., 2012; Wilkinson et al., 2010). Recently, cement and lime binders have been broadly used due to their low-cost and abundance. One of potential binding materials is gypsum that can well bind the soil particles together so that the soil strength and bearing capacity is considerably improved. In the past few years, much attention has been paid to the use of gypsum for stabilizing clayey soils (Ahmed, 2013, 2015; Ahmed and Issa, 2014; Ahmed and Ugai, 2011; Ahmed et al., 2011; Attom and Al-Sharif, 1998; Kamei et al., 2013; Khattab et al., 2008; Kobayashi et al., 2015; Muntohar, 2009). A substantial part of the C&D debris are gypseous wastes, hence exploring the practicality of their use as a binder agent in problematic soils has been drawn considerable attention (Papailiopoulou et al., 2017). Of the main research lines we can cite evaluation of the type of the required additive, the effect of different gypsum contents on soil strength, curing conditions, and durability of the stabilized soils during dry-wet, freeze-thaw, and extensive soaking tests.

However, application of gypseous wastes is a recent worldwide issue; and so far little research has been carried out on the use of gypsum waste as soil stabilizer. Ahmed and Ugai (2011) investigated the effect of freeze-thaw cycles of the silty sand stabilized by recycled gypsum. They added different amount of gypsum (0-20%) to cement to make cylindrical samples cured for 7 days before the freeze-thaw cycles. Their results showed the destructive effect of freeze-thaw cycles was much more severe than the wet-dry cycles. Also, samples stabilized by gypsum with no cement were weak during the wet-dry and freeze-thaw cycles. Further, other studies were implemented by Ahmed et al. (2011) to show the effect of recycled gypsum and plastic strip waste on the poorly graded sandy soil and silty sand as well as Bassanite and to unveil the compressive strength, tensile strength, and its mixture of weak clay for the use in road construction (Ahmed, 2013; Ahmed et al., 2011). Kamei et al. (2013) studied the durability of the recycled gypsum-furnace cement mixture. They showed that the compressive strength and durability of the clay samples enduring wet-dry cycles are boosted by adding gypsum-furnace cement mixture, and the increase of gypsum to soil ratio brings about higher compressive strength. Furthermore, the strength and durability improved more for samples with 5% cement than those with 10% cement. Ahmed and Issa (2014) assessed the effect of soaking on the durability of recycled gypsum-stabilized soft clayey samples. They tested different mixtures of cement and lime with Bassanite and clay in dry condition to evaluate the effect of humid environments on the strength and durability of the stabilized clay. Ahmed (2015) concentrated on the microstructure and the mineralogical composition of the gypsum-stabilized soft clay. He conducted X-ray powder diffraction (XRD), scanning electron microscopy (SEM), and unconfined compressive strength tests. He showed that addition of recycled gypsum addition increases the soil strength. Furthermore, his results were close to those acquired through XRD and SEM analyses. Ahmed (2011) also used XRD analysis and showed that when he added Bassanite, various cement compounds are formed in the soil, the amount of proportion of which is important when the compressive strength improvement is considered. Besides the importance of reusing gypseous wastes, no attempt has been made to determine the optimum amount of gypseous wastes to enhance soil properties based on durability test with different curing time.

The primary aim of this study was assessment of the feasibility of using gypseous wastes in stabilizing soft clayey soils. We also assessed the effect of the gypseous amount on clayey soil stabilized by lime and cement as well as the effect of wet-dry cycles on stabilized samples.

Materials and methods

Materials used

In this study, the synthetic soil was prepared using Kaolinite soil SZWMK1 obtained from Khak Chini Iran Company as fine clay. The soil specific gravity test, particle size analysis (hydrometry), and Atterberg limits and moisture content were tested based on ASTM D854-02, ASTM D422-07, and ASTM D4318-10, and ASTM D2216-10 respectively (Table 1). The particle size distribution is shown in Figure1. Chemical and mineralogical analysis of the clay is shown in Tables 2 and 3.

Table 1. Properties of tested SZWMK1 clay

Parameter	Specific gravity	LL	PL	PI	moisture content
Value	2.57	52%	31%	21%	0.83%

Table 2. Chemical composition of SZWMK1 clay

Material	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	LOI
Percent	63±1	24±1	0.55±0.1	0.04±0.01	1.2±0.2	0.55±0.06	0.4±0.1	0.3±0.1	9±1

Table 3. Mineralogical composition of SZWMK1 clay

Mineral	Kaolinite	Quartz	Calcite	Other minerals
Percent	2±64	2±27	0.5±2.1	1±6

Recycled gypsum was prepared by heating the gypseous panel residues at 140-160°C for 24 h. We first crushed the gypseous wastes; we then removed the impurities and finally, sieved the sample. The heating was performed to evaporate 75% of water in the gypsum ($CaSO_4.2H_2O$) that changed it to calcium hemihydrate ($CaSO_4.0.5H_2O$) also called Bassanite.

X-ray powder diffraction (XRD) analysis (Siemens D5000) was performed on the resulting sample showing that Bassanite is formed in the process (Figure 2). Table 4 displays the chemical composition of the synthesized Bassanite.

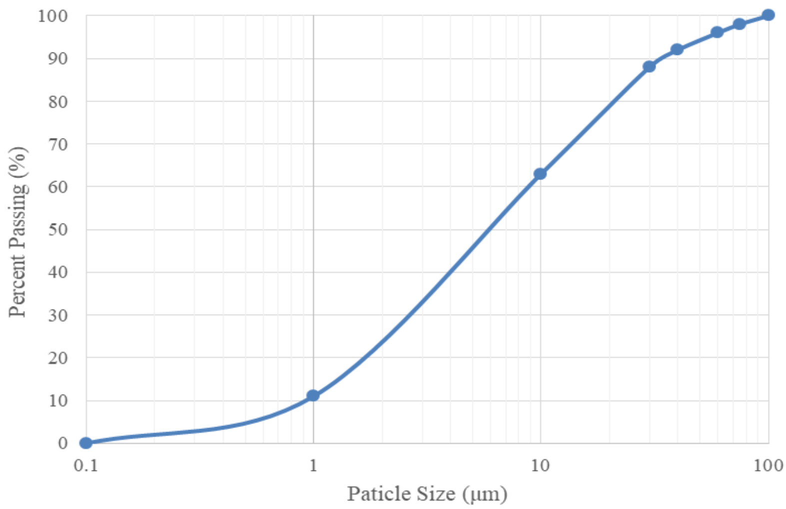
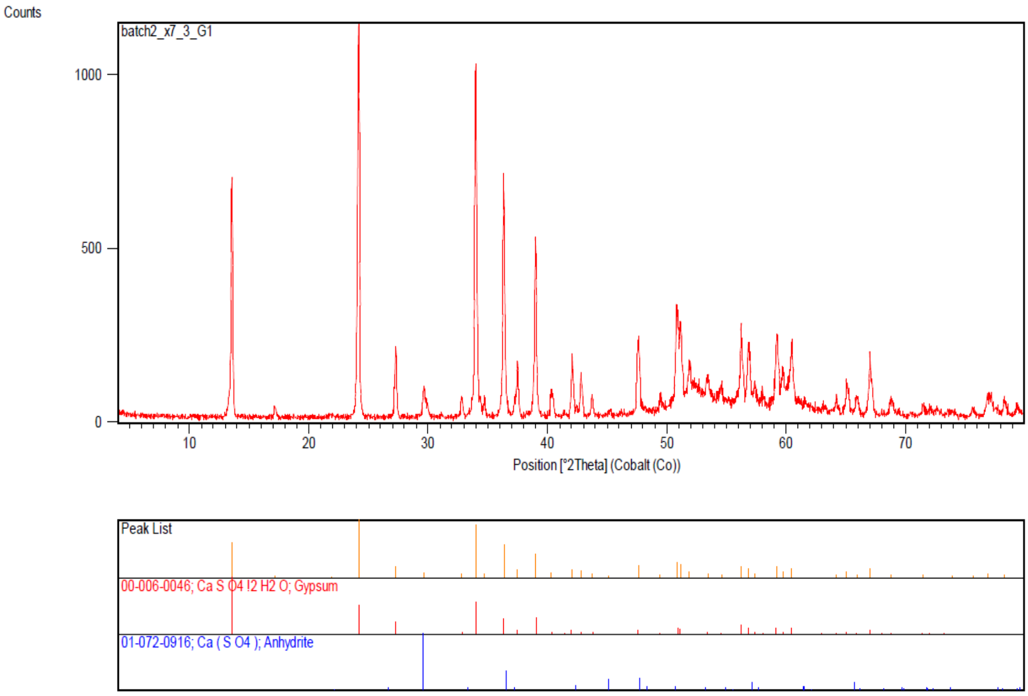


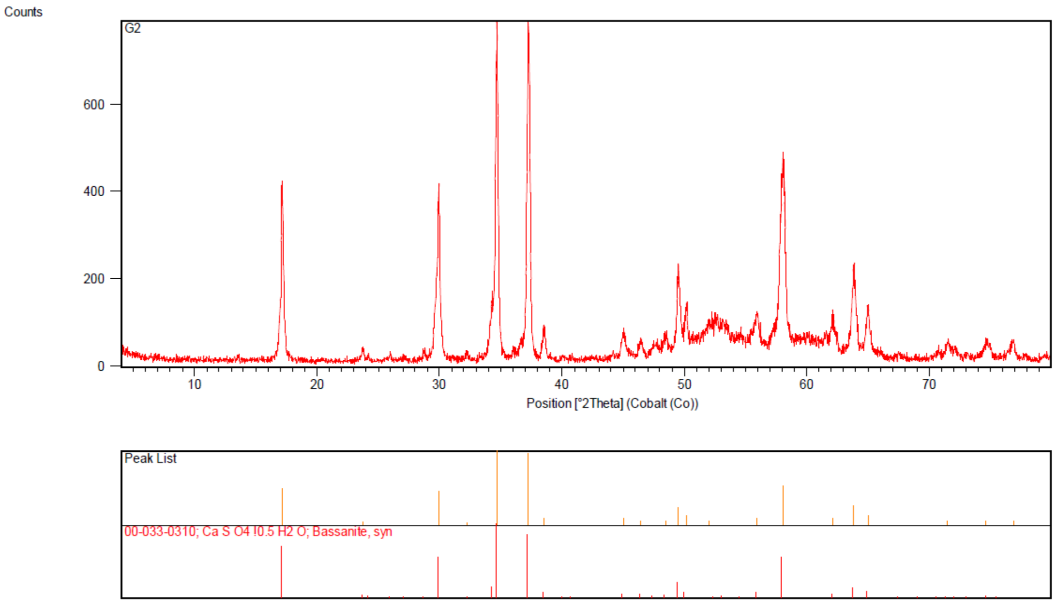
Figure 1. Grain size distribution of the Kaolinite clay based on hydrometry test

Table 4. The chemical composition of the applied recycled gypsum

Composition	CaO	SO_3	H_2O
Percent	38.62	55.17	6.21



(a)



(b)

Figure 2. XRD pattern for (a) the recycled gypsum and (b) the synthesized Bassanite

We used Portland cement type 2, manufactured in Shomal Cement Co. Table 5 illustrates the chemical composition of the cement. According to ASTM, this kind of cement is hydraulic cement formed by grinding the clinker which is made of silica, alumina and iron oxides. We obtained lime from Pars Shimi Co with its chemical analysis showed in Table 6.

Table 5. Chemical analysis of Type 2 Portland cement produced by Shomal Cement Co.

Composition	SiO_2	SiO_3	Al_2O_3	K_2O	Fe_2O_3	Na_2O	CaO	MgO	C_3S
Percent	22.4	2.10	4.82	0.80	3.56	0.22	63.4	2.5	16

Table 6. Chemical analysis of the applied lime

Composition	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	P	S	CO_2
Percent	91.11	3.49	1.01	0.20	0.05	0.054	0.189	2.48

Sample preparation

We used Table 7 for weighing the required amounts of kaolinite, cement, and gypsum were weighed and then mixed them in dry conditions. The amount of cement and lime was selected constant as 5% during the experiments only to delay the dissolution of gypsum when it contacts with water. The recycled gypsum was added by 0, 5, 10, and 20 weight percent of the dry soil, and then 5% cement and lime were added to the mixture as well. In general, nine different mixtures were made using the soil and additives.

Table 7. Various soil and additives compositions used in our experiments

Composition No.	Composition Code	Bassanite to soil weight ratio (B/S)	Cement to soil weight ratio (C/S)	Lime to soil weight ratio (L/S)
1	C0L0B0	0%	0%	5%
2	C0L5B0	0%	0%	5%
3	C0L5B5	5%	0%	5%
4	C0L5B10	10%	0%	5%
5	C0L5B20	20%	0%	5%
6	C5L0B0	0%	5%	0%
7	C5L0B5	5%	5%	0%
8	C5L0B10	10%	5%	0%
9	C5L0B20	20%	5%	0%

Compaction tests

Standard compaction test (method A from ASTM D698-07) was performed to obtain the relation between moisture content and dry density of both stabilized and un-stabilized samples. We then derived the change in maximum dry density and optimum moisture from the results. Using these results, we prepared samples for the unconfined compressive strength test.

Unconfined compressive strength test

To study the effect of cement and gypsum addition on clayey soil strength, the unconfined compressive strength test was performed according to ASTM D2166-11. In this test, a sample of the wanted soil was exposed to an axial load in a strain-controlled way until it fractured. The strength of the sample was calculated according to the total stress in the sample at the moment of fracturing. In the unconfined compressive test, we used the maximum dry density, optimum moisture, and mold volume to calculate the specific amount of the mixtures in the mold. The mold used in this study was obtained from ELE Co. England and samples were 38 mm in diameter and 84 mm in height. Each sample was labeled with a number and put inside the steam bath (40°C, 100% humidity) and treated for maximum 21 days. Samples were taken out of the steam bath after 7, 14, and 21 days and were exposed to 0, 1, 2, and 3 wetting-drying cycles and then they were sent for the unconfined compressive strength test. Totally, 9 different soil compounds, 4 different curing conditions (0, 7, 14, and 21 days), and 4 wetting-drying cycles (0, 1, 2, and 3 cycles) gave 144 different samples.

Wet-dry cycles test

Wet-dry cycles were conducted according to ASTM D559-15. The samples for unconfined compressive strength were immersed in 22°C water for 24 h after curing (for 0, 7, 14, and 21 days). Next, we were oven-dried them at 70°C for 24 h. We assumed that the overall process was a wetting-drying cycle. After applying a certain number of cycles (0, 1, 2, and 3), the specimens were subjected to the unconfined compressive strength test.

Results and Discussion

Results of compaction test

The standard compaction test was conducted on 9 different soil mixtures (Table 7). Figure 3 shows the changes of maximum dry density of the clayey soil stabilized by cement/lime plus various amounts of Bassanite while Figure 4 shows the alterations in its optimum moisture content.

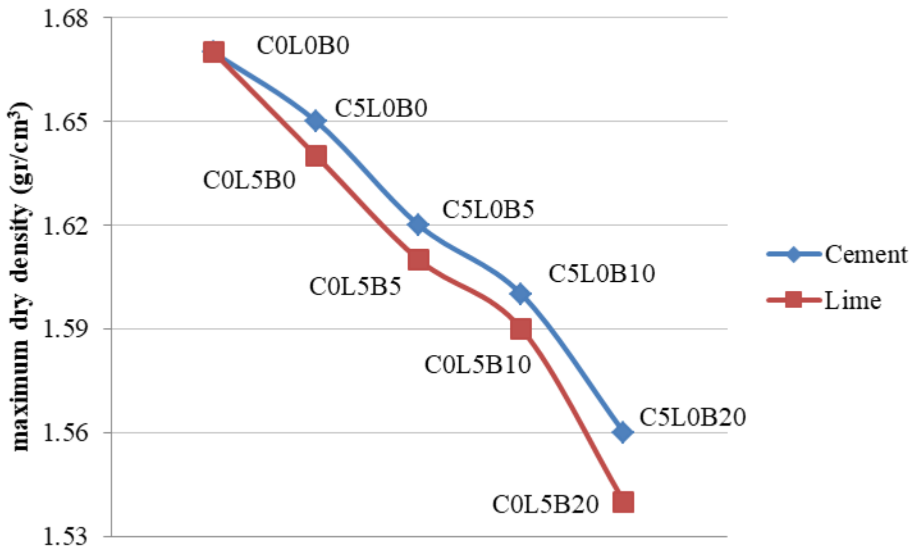


Figure 3. Variation of maximum dry density against cement, lime, and Bassanite percent

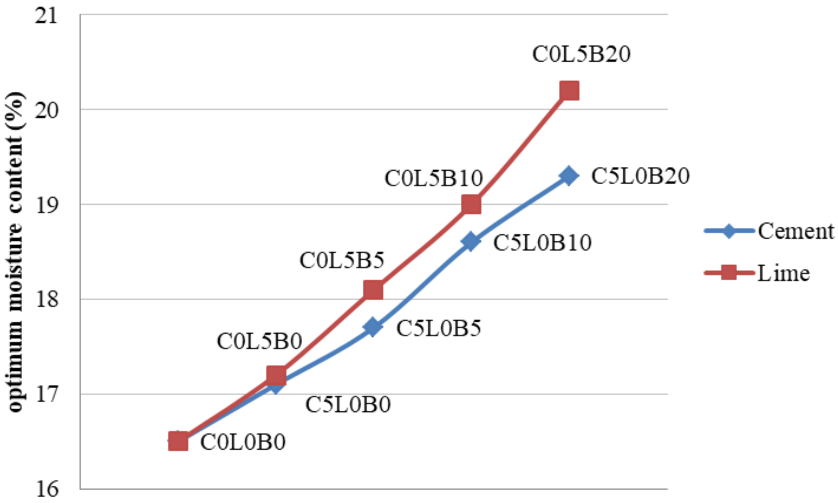


Figure 4. Variations of optimum moisture content against cement, lime, and Bassanite dosage

As can be seen in Fig. 3, adding lime and cement to the clay samples lowers maximum dry density. For example, in the un-stabilized sample C0L0B0, the maximum dry density was approximately 1.67 g/cm^3 whereas in the case of 5% lime addition, the value decreased to 1.65 g/cm^3. Adding 5, 10, and 20% Bassanite changes maximum dry density by 1.61, 1.59, and 1.54 g/cm^3, respectively.

We found a similar trend for cement-stabilized samples, while adding 5% cement to the clayey soil lowered the value of maximum dry density to 1.65 g/cm^3. The addition of 5, 10, and 20% Bassanite to this sample altered the maximum dry density to 1.62, 1.60, and 1.56 g/cm^3, respectively.

As seen in Figure 4, adding Bassanite to the lime-cement stabilized samples enhanced optimum moisture content in the clay samples. For example, the optimum moisture content in the un-stabilized sample C0L0B0 was about 16.5% which was elevated to 17.2% when 5% lime was added and reached 18.1, 19, and 20.2% when 5, 10, and 20% Bassanite was added, respectively.

The trend is the same for the cement-stabilized samples. Adding 5% cement raised the optimum moisture content to 17.1%, and the value was enhanced to 17.7, 18.6, and 19.3% as 5, 10, and 20% Bassanite was added, respectively. Table 8 summarizes the variations of maximum dry density and optimum moisture content via cement, lime, and Bassanite content.

Adding lime and cement to the soil resulted in prompt reactions in the form of cation exchange and clay particles flocculation. Sliding these floccules over one another was difficult so that there was a gap in between. Therefore, more energy was needed during compaction, and in a certain energy level, smaller density was obtained. On the other hand, the specific gravity of lime and cement particles were lower than the soil; and consequently, their substitution in the soil reduced the density. Moreover, more water was required to slide the flocculated particles over one another and filling in the subsequent gap. As a result, we observed a higher optimum moisture.

Based on our data, we saw a higher effect when Bassanite was added to lime-stabilized soils compared to that of cement-stabilized soils. The results were similar with those suggested by Ahmed (2013), Kobayashi et al. (2015), and Makkarchian et al. (2015).

Table 8. Variations of maximum dry density and optimum moisture content for various clay samples

Sample Code	Maximum dry density (gr/cm^3)	% variation	Optimum moisture content (%)	% variation
C0L0B0	1.67	-	16.5	-
C0L5B0	1.64	-1.80	17.2	4.24
C0L5B5	1.61	-3.59	18.1	9.70
C0L5B10	1.59	-4.79	19	15.15
C0L5B20	1.54	-7.78	20.2	22.42
C5L0B0	1.65	-1.20	17.1	3.64
C5L0B5	1.62	-2.99	17.7	7.27
C5L0B10	1.6	-4.19	18.6	12.73
C5L0B20	1.56	-6.59	19.3	16.97

Results of unconfined compressive strength tests

Unconfined compressive strength tests (UCS) were implemented over clay samples according to ASTM D2166-11. We used a camera during these tests, to film the pressure gauge movements. Some of the un-stabilized clay samples and some stabilized samples which had endured curing and wetting-drying cycles could not bear the cycles and were demolished without applying compressive strength test on them (Figure 5).

Figure 5. Clay samples demolished due to wetting-drying cycles

The effect of Bassanite addition on the unconfined compressive strength of the kaolinite clay

In this section, variations of unconfined compressive strength in both stabilized and un-stabilized clay samples were studied. Results of unconfined compressive strength test over the samples are given in Figure 6, 7, 8, and 9.

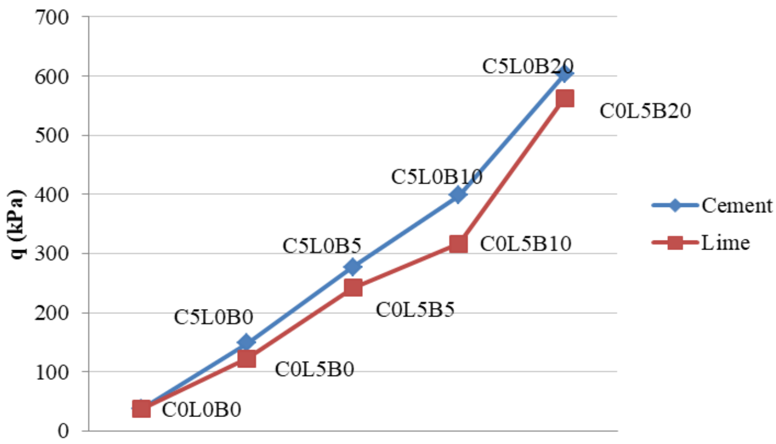


Figure 6. Variations of the unconfined compressive strength of the uncured clayey soil

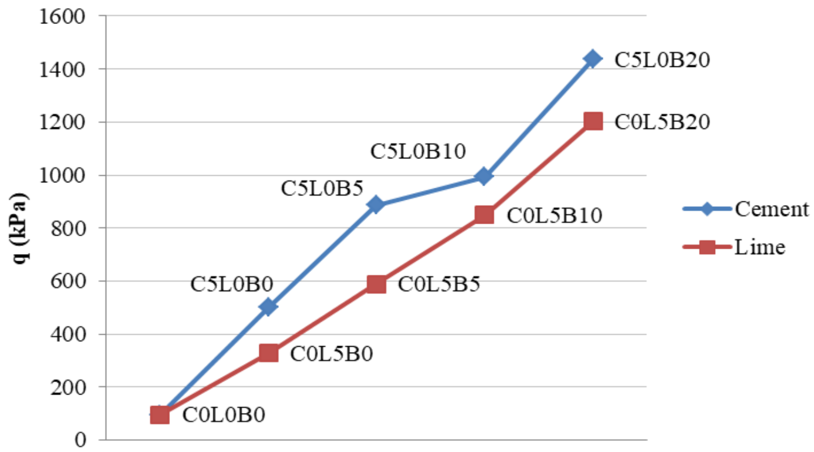


Figure 7. Variations of the unconfined compressive strength of 7-day cured clayey soil

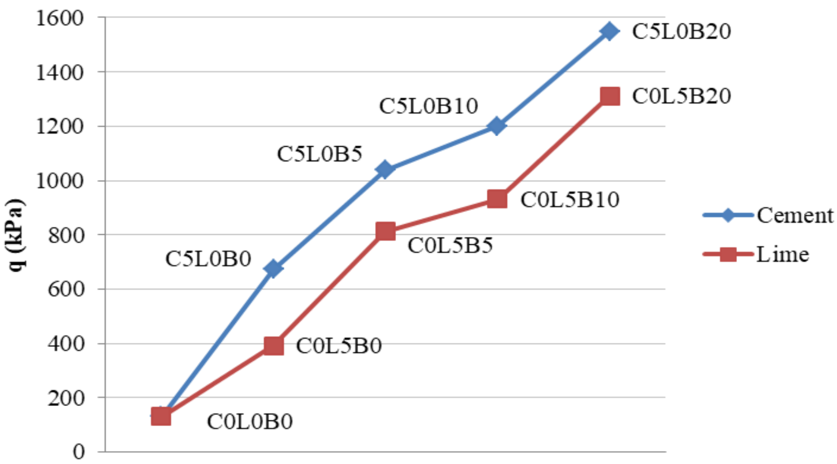


Figure 8. Variations of the unconfined compressive strength of 14-day cured clayey soil

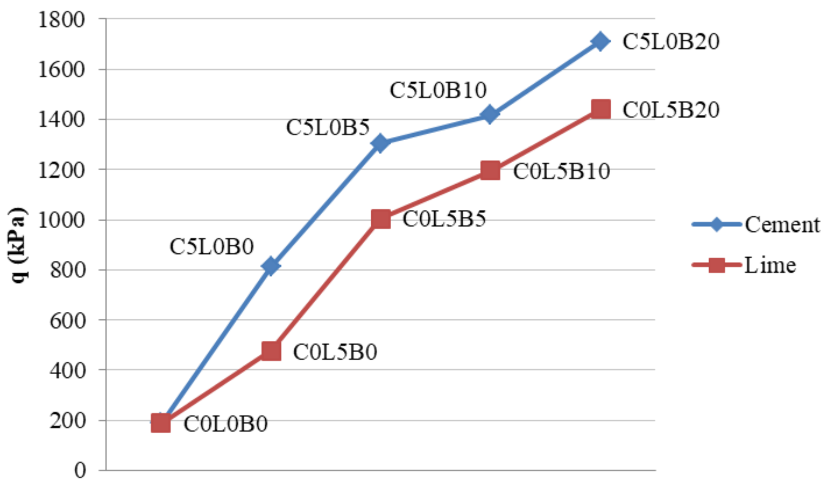


Figure 9. Variations of the unconfined compressive strength of 21-day cured clayey soil

As can be seen, the addition of cement, lime, and Bassanite led to improvement in unconfined compressive strength of both treated and untreated samples. The compressive strength of uncured and un-stabilized clay was rather small and about 37 kPa. When 5% lime was added to the soil (sample C0L5B0), it became about 4 times as much reaching 123 kPa. Adding Bassanite to the soil with certain lime content increased compressive strength significantly up to 242, 317, and 563 kPa for 5. 10, and 20% Bassanite content, respectively. Generally, the effect of cement on unconfined compressive strength was higher than lime. The compressive strength of untreated 5% cement-stabilized clay was 26 kPa greater than that of 5% lime-stabilized one. Such difference was 35, 81, and 40 kPa in the case of 5, 10, and 20% Bassanite containing samples. We also saw this trend in cement-Bassanite, and lime-Bassanite stabilized samples. The curing at 40°C in a steam bath condition led to pozzolanic reactions between soil, lime, cement, and Bassanite.

Investigating the effect of curing time on the unconfined compressive strength of Bassanite-stabilized clay

Figures 10 and 11 illustrate unconfined compressive strength in lime-cement stabilized samples containing the various dosage of Bassanite against curing times. Results showed that as the curing time expanded, the compressive strength was remarkably enhanced. The unconfined compressive strength in C0L0B0 sample after 7, 14, and 21 days of curing reached 96, 131, and 189 kPa, respectively from the initial strength of 37 kPa. A similar trend was observed in stabilized samples as the unconfined compressive strength of the sample C0L5B20 (5% lime-20% Bassanite) reached 1202, 1311, and 1441 kPa after 7, 14, 21 days of curing, respectively while its initial value was 563 kPa. Based on the diagrams, the growth rate of compressive strength was higher for the first 7 days, and practically the soil attained its main strength in this period. However, the corresponding rate for the un-stabilized sample was nearly constant, since no stabilizing agent existed.

We also investigated the effect of curing time (q) on the unconfined compressive strength via unconfined compressive strength of uncured samples (q_0). Figures 12 and 13 show q/q_0 variations for un-stabilized and lime/cement stabilized samples.

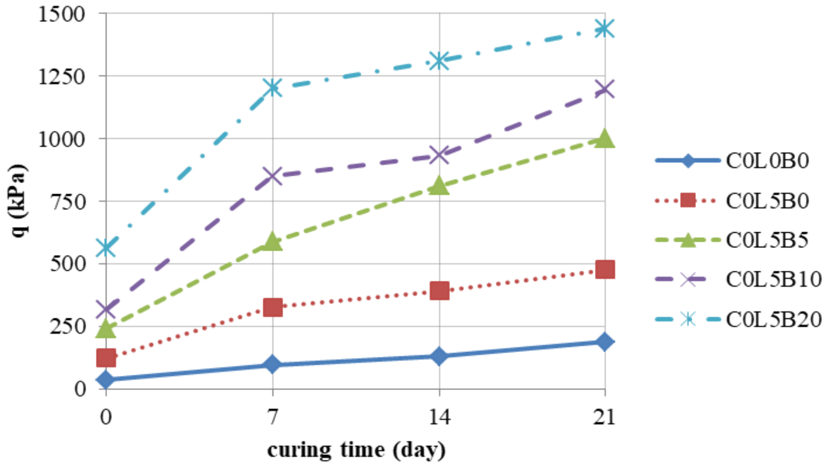


Figure 10. Variations of the unconfined compressive strength of lime-Bassanite stabilized clay by curing time

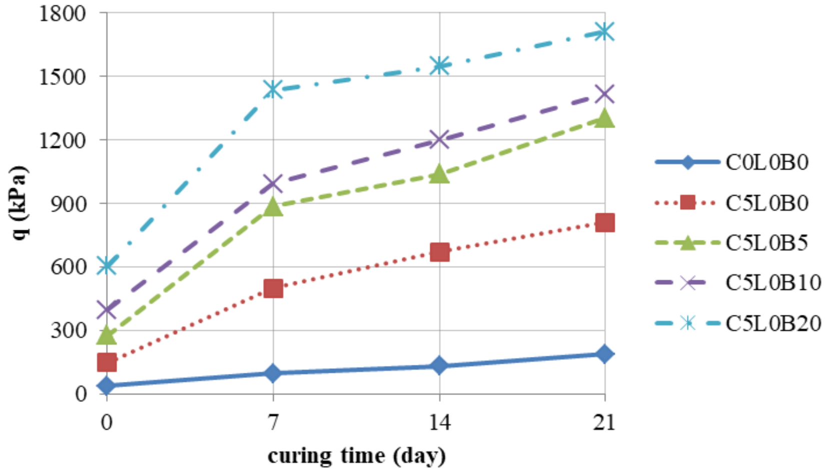


Figure 11. Variations of unconfined compressive strength of cement-Bassanite stabilized clay by curing time

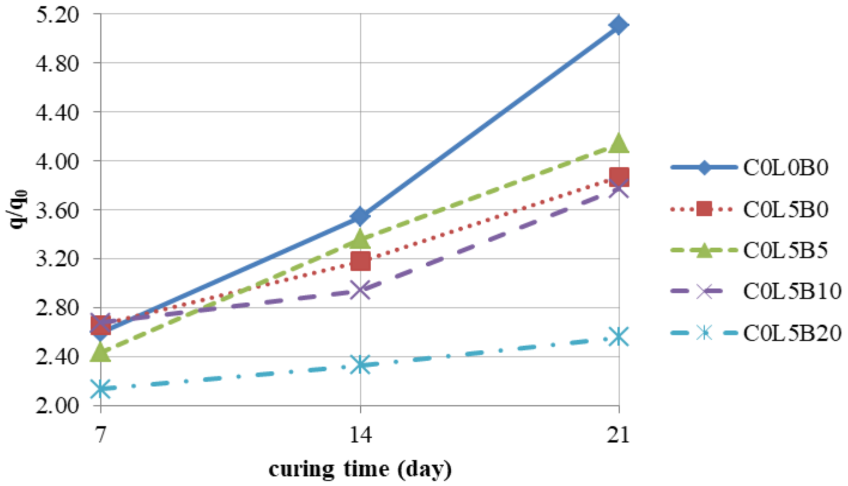


Figure 12. Variations of ratio of the unconfined compressive strength of the uncured to cured samples in un-stabilized and stabilized (lime and Bassanite) cured clay

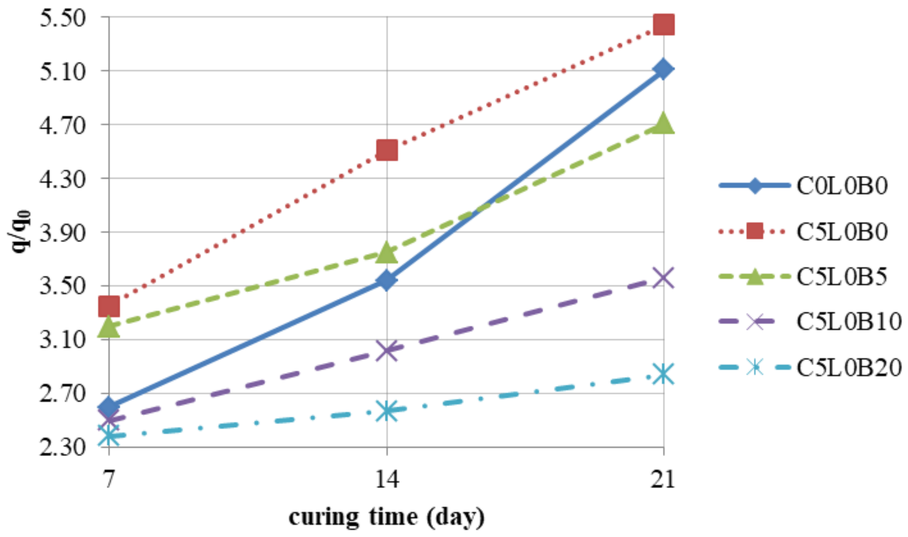


Figure 13. Variations of ratio of the unconfined compressive strength of the uncured to cured samples in un-stabilized and stabilized (cement and Bassanite) clay

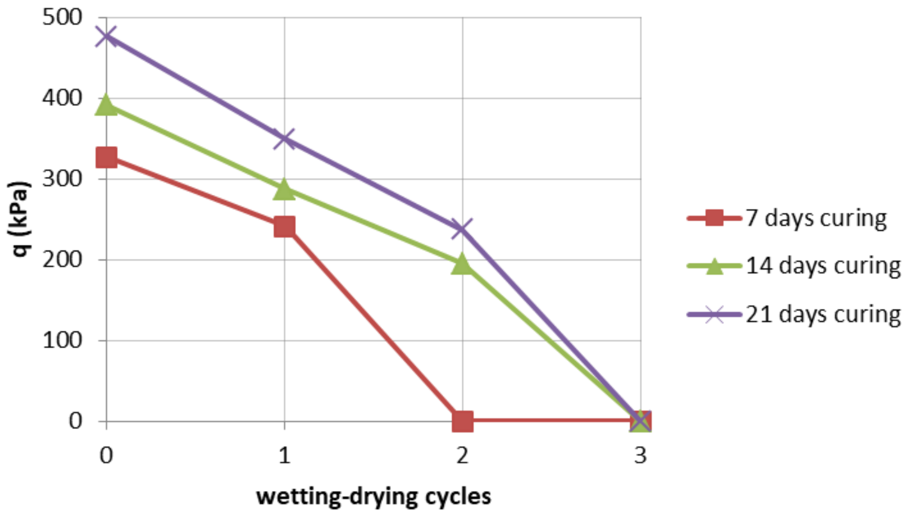


Figure 14. Unconfined compressive strength variations in lime-stabilized clay (with 0% Bassanite) for the various wetting-drying cycles

We can see that with increase in curing time, the ratio of unconfined compressive strength in cured samples to the uncured samples was increased. For lime containing stabilized samples, the maximum corresponding ratio was due to soil containing 5% Bassanite and no Bassanite soil, and in cement-stabilized specimens, the maximum improvement was observed in no Bassanite soil and soil containing 5% Bassanite.

Investigating effect of wetting-drying cycles on unconfined compressive strength of Bassanite-stabilized clay

The samples made for unconfined compressive strength test were immersed in water for 24 h at 22°C after specific curing time (0, 7, 14, and 21 days). Next, the samples were taken out and oven-dried for 24 h at 70°C (a single wetting-drying cycle). After a certain number of cycles (0, 1, 2, and 3 cycles) the samples were subjected to unconfined compressive strength test. Those samples demolished after the cycles were given a zero value for the compressive strength on the diagrams. In the case of uncured samples, none of the samples (either stabilized or un-stabilized) were able to sustain wetting-drying cycles, and the whole samples were demolished prior the compressive strength test. Therefore, there are no graphs for the uncured samples. Figures 14 to 17 illustrate the unconfined compressive strength variations in the lime-stabilized clay at various Bassanite dosage versus wetting-drying cycles.

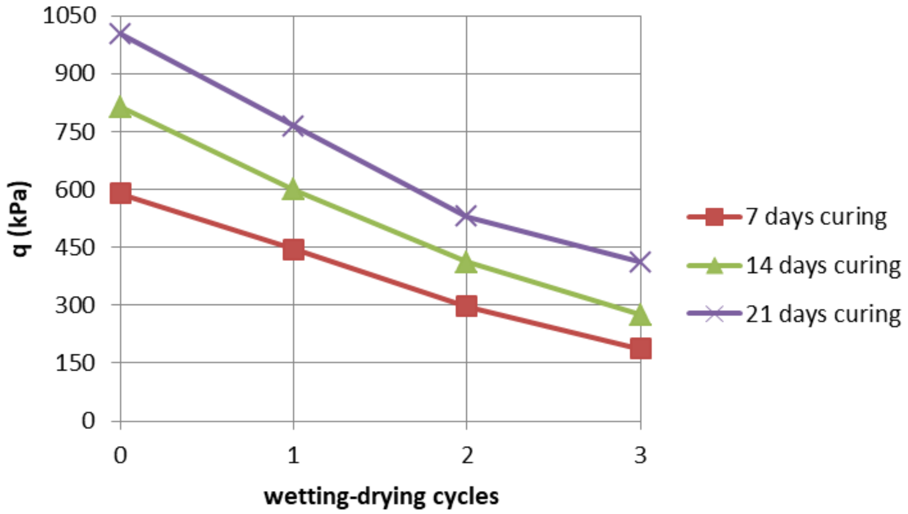


Figure 15. Unconfined compressive strength variations in lime-5%Bassanite stabilized clay for the various wetting-drying cycles

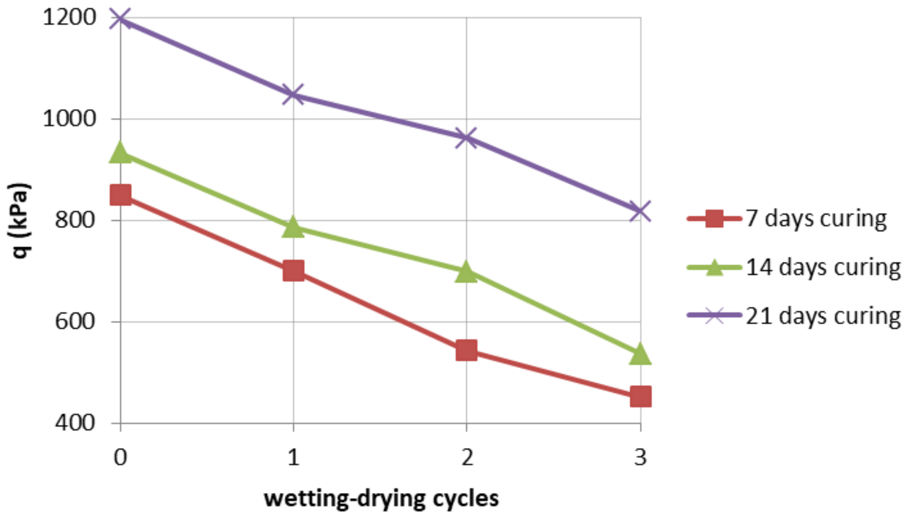


Figure 16. Unconfined compressive strength variations in lime-10% Bassanite stabilized clay for the various wetting-drying cycles

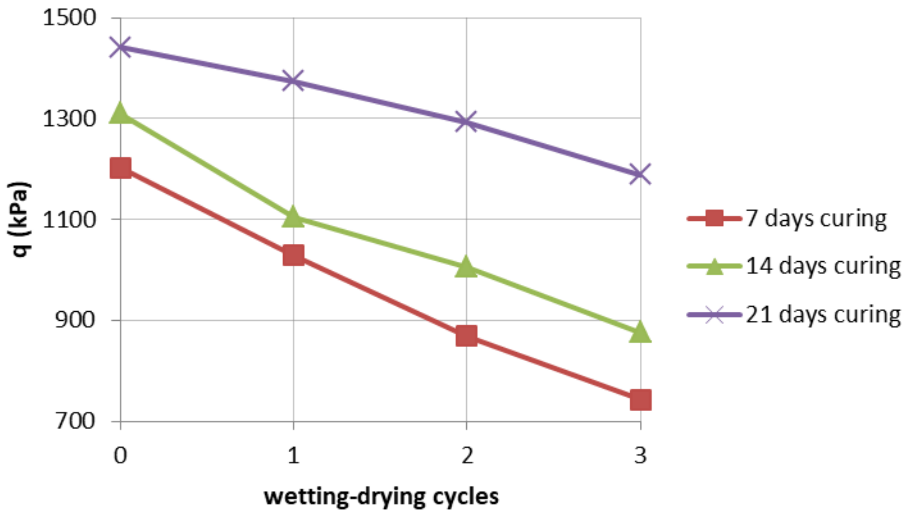


Figure 17. Unconfined compressive strength variations in lime-20% Bassanite stabilized clay for the various wetting-drying cycles

We can see that the increase has been effective in some wetting-drying cycles on the strength of lime-Bassanite stabilized clay samples and led to a notable reduction in their unconfined compressive strength. As the unconfined compressive strength of C0L5B0 sample (containing 0% Bassanite) after 7, 14, and 21 days of curing were determined as 327, 391, and 476 kPa, respectively. However, by applying a single wetting-drying cycle, unconfined compressive strength was decreased to 241, 287, and 349 kPa for 7, 14, and 21 days of curing, respectively. During the next cycle, the sample already cured for 7 days was smashed, and its unconfined compressive strength was supposed to be zero. However, the unconfined compressive strength in the 14 and 21-day cured samples reached 195 and 237 kPa, respectively. Both samples were demolished in the next cycle.

For Bassanite-cement stabilized samples, an increase in wetting-drying samples profoundly affected the stabilized clay strength and led to a noteworthy drop in the unconfined compressive strength of the samples. The unconfined compressive strength of C5L0B0 (sample with 0% Bassanite) reached 499, 672, and 811 kPa after 7, 14, and 21 days of curing. By applying a wetting-drying cycle to these samples, unconfined compressive strength reached 393, 513, and 624 kPa, for the corresponding curing systems. In the second and third cycles, unconfined compressive strength altered to 272, 417, 513 kPa, and consequently 153, 291, and 375 kPa.

Conclusions

We aimed at finding if we can recycle and reuse gypseous wastes for improving soil properties. We collected gypseous wastes and exposed them to treatments until they were modified to Bassanite. Then, various amounts of two stabilizing agents (cement and lime) were compared to each other when applied together with Bassanite to the kaolinite clay. The change in compaction characteristics and the unconfined compressive strength of the stabilized clayey soil under different curing conditions and wetting-drying cycles were examined. The main reason for using cement and lime in the soil mixture by Bassanite was to prevent Bassanite dissolution in a wet condition by forming stabilized bounds. Moreover, cement and lime enhanced the durability of clay and diminished the heavy metal leaching due to Bassanite addition. Results showed that adding Bassanite together with cement and lime lowered the maximum dry density of the pure clay from 1.67 g/cm^3 to 1.54 g/cm^3 (for the sample stabilized with cement and 20% Bassanite) and 1.56 g/cm^3 (for the one stabilized with lime and 20% Bassanite). Moreover, optimum moisture content was increased from 16.5% for the pure clay to 20.2% and 19.3% for the samples stabilized with cement and 20% Bassanite and lime and 20% Bassanite, respectively. The addition of Bassanite changed soil liquid and plasticity limit up to 5.2% and 9%, respectively. Furthermore, we found a considerable increase in the unconfined compressive strength of the stabilized soils from 37 kPa to 603 kPa. One more effective factor on the unconfined compressive strength was the soil specimens curing in the steam bath at 40ºC having humidity near 100%. This treatment caused a substantial increase in unconfined compressive strength of the stabilized and unstabilized soil as much as 2 to 5 times (according to the soil sample and number of curing days). The wetting/drying cycles over the stabilized samples decrease in the unconfined compressive strength (according to the soil specimen and number of wetting/drying cycles) by 15-70%. Based on the results, we can conclude that utilization of gypseous wastes is a proper method to lessen the amount of landfilled C&D wastes and for reuse of these materials that not only drops the landfill costs but also meaningfully decreases the production costs of the materials used in soil stabilization and improvement.

Adding Bassanite to the cement-lime stabilized soil could improve unconfined compressive strength in clayey soil samples, due to quick reactions and production of cement-like materials reinforcing the soil texture. Calcium in lime and cement reacted with silica and alumina of clay and produced cementation compounds. These reactions increased the strength, improved elastic properties, and lowered swelling potential of the treated soil. Moreover, application of gypseous wastes led to a noteworthy increase in durability and compressive strength of the soft clay and enhanced its engineering characteristics within the moist environment.

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