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USING CEMENT AS A MODIFIER AGENT TO IMPROVE THE SWELLING POTENTIAL OF GYPSUM SILTY SOILS

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Abstract

The extensive damages to the super structures caused by the swelling soil, has attracted special attention of researchers. Stabilization of swelling soil using different agents is becoming more popular around the world. The modification methods of such problematic soils to enhance their engineering properties is well recognized and widely practiced. Among the various stabilizing efforts, mechanical and chemical stabilization investigated by numerous researchers. A wide range of chemical agents is employed for soil properties improvement, among which lime and cement are the most prominent agents. Most gypsum soils, which possess high porosity, will settle down if they are relatively heavily loaded, and swell if they are compacted.

The present research examines the effects of compaction and various unit weights on swell potential and swell pressure. In addition, adding lime and cement to gypsum soil to improve their swelling properties are studied. The test results revealed that although compaction effort leads to settlement reduction, but increases swell potential. Meanwhile, lime and cement can be used to improve such problematic soils and reduce, but not totally eliminate, swell potential and swell pressure.

Keywords: Swelling potential, improvement, gypsum, swell pressure, lime, cement.

1. Introduction

The study of collapsible and expansive clay soils has attracted a great deal of attention in the last few decades. Besides the purely scientific interest in these types of soil, the growth of the cities has led to dedicate more attentions towards the investigation in this area, for it causes both technological and social troubles. Problematic soils, including swelling soil, cause extensive damage to structures worldwide annually. The nature of swelling soil was not entirely known until 1930 [1]. In 1938, for the first time, the United State Bureau Reclamation recognized the problem of swelling soil. Since then it was well perceived that swelling soils are responsible for many of the cracks and movements of lightly loaded structures. The subsequent researches focused on the

practical improvement methods to reduce and eliminate damages to the super-structures.
The gypsum swelling soil of South West of Mashhad has induced many problems for structures during the last decades; resulting from either excessive settlement or expansion. Such soils when given an access to water either swell if appear with low porosity or settle if exist with high porosity. The swelling and shrinkage phenomenon depends on several factors, including type and amount of clay minerals and cations, moisture content, dry density, soil structure, and loading conditions. The gypsum soil in this area is fine and mainly classified as CL and ML. In the previous research, the CL type was studied and its mechanical properties, as well as two common methods of improvement, including compaction (mechanical stabilization) and adding lime as a stabilizer agent (chemical stabilization) were investigated [2].

The present research investigates the swelling properties of ML gypsum soil in this region, and examine the influence of adding lime and cement, as stabilizer agents, for improvement its properties. Many soil samples were gathered from different parts of the region. Chemical and complementary tests were conducted to determine the gypsum percent. The test results reveal that the specific gravity of gypsum soil in this region is low and will markedly settle down due to the load application. Also absorbing water and compaction of this soil increases the swelling potential. It is revealed that adding lime to the gypsum in two steps reduces the swelling potential. Cement, as alternative stabilizer agent, acts much better than lime and reduces the swelling potential more effective.

2. Basic Geotechnical Properties

In order to investigate the influence of lime and cement as additives on gypsum soil improvement, many samples were gathered from different places in South West region in city of Mashhad, where the shrink-swell potential were estimated to be medium to very high. Based on the gypsum content, six samples were selected. Figure 1 illustrates the sieve analysis, according to ASTM C33 designation [3], for six samples.

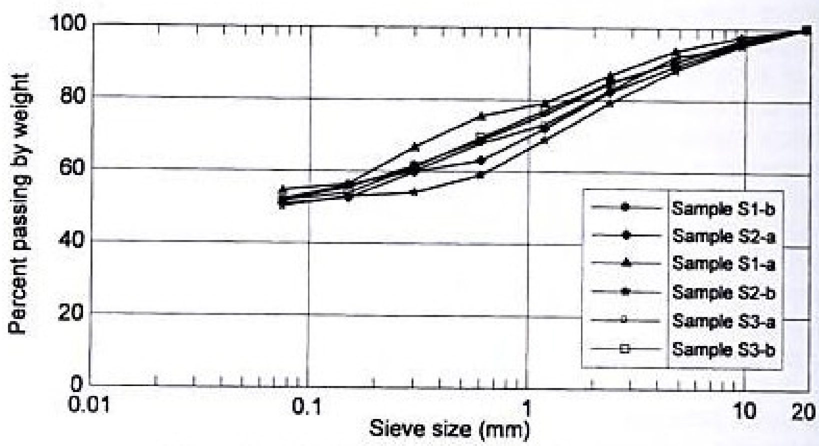

Figure 1: Grain size distribution for all samples.

Also given in Table 1 is the chemical analysis of samples for which their size distribution is shown in figure 1.

Table 1: Chemical analysis of samples

Sample	S1-a	S1-b	S2-a	S2-b	S3-a	S3-b
Gypsum ($CaSo_4$) %	6.06	7.18	8.31	9.78	10.57	11.13

In addition, geotechnical and mechanical properties, including index properties and soil classification of the samples are summarized in Table 2.

Referring to Tables 1 and 2 the following points can be drawn:

- The gypsum soils in this region are mostly fine and silty.

- The magnitude of specific gravity is not influenced by the gypsum amount.
- The nature of the soils is mainly porous and the presence of gypsum reduces the in-situ unit weight, i.e. the more gypsum the less unit weight. The high porosity of soil in this area is evidently responsible for excessive settlement of structures.
- The magnitude of PI is not significantly influenced by the amount of gypsum. The previous study, however, showed that in the clayey gypsum soil, the presence of gypsum decreases PI [2].

Table 2: Geotechnical and mechanical properties of samples

Sample	Dry density (gr/cm^3)	Specific gravity	Consistency limits			USCS[a]
			LL (%)	PL (%)	PI (%)	
S1-a	1.64	2.59	35.9	33.3	2.6	ML
S1-b	1.58	2.68	30.4	23.8	6.6	ML
S2-a	1.49	2.71	48.4	36.7	11.7	ML
S2-b	1.49	2.60	36.3	26.4	9.9	ML
S3-a	1.33	2.61	26.8	22.6	4.2	ML
S3-b	1.34	2.65	31.8	24.5	7.3	ML

[a] USCS=Unified Soil Classification System

3. Swelling potential and swelling pressure measurement

The in-situ test results, as shown in Table 2, indicates that the in-situ (natural) unit weight of soils in this region varies from 1.3 to 1.6 gr/cm^3, which is very low. Even in some places, a value of about 1.2 for natural unit weight has been observed [2]. The high porosity of such soils, which is clearly responsible for huge settlement, should be eliminated by compaction effort. The relative compaction, however, may result in expansion. In an effort to observe the volume change of soils due to the compaction, either shrinkage or swelling, samples with different unit weights must be prepared and subsequently saturated.

Many researches have used the term "swelling potential"; however, a clear definition of this term has not been established [4]. Generally, swelling potential has been used to describe the ability of a soil to swell, in terms of volume change or the pressure required to prevent swelling. Therefore, it has two components:

- The *swell percent* that is defined as the percentage increase in height in relation to original height. The swell percent may be measured using the *loaded swell method* [5]. In this method the consolidation cell was assembled in the odometer equipment with surcharge of 25 kPa. The increase in vertical height of a sample, expressed as a percentage, due to the saturation was designated as *swell percent*, i.e. swell percent=$\Delta h/h_o$ where Δh is the change in height and h_o is the initial height.
- The *swelling pressure* that is designated as the pressure required preventing swelling. This can be measured by *constant volume method* [5], using the consolidation cell. In this method the volume of soaked specimen is kept constant by continues addition of loads at each vertical expansion of the tested sample. The *swell pressure* is calculated when the expansion ceased.

The swelling potential and swelling pressure are measured based on ASTM D-4546 Method A, using consolidation apparatus. In this method samples are compacted in the consolidation ring to the desired unit weight. Samples are subsequently soaked to be fully saturated. Volume change is measured employing a dial gage in 0.1, 0.2, 0.5, 1, 2, 4, 8, 15, 30, 60, 120, 240, 480, 1440, 2880 and 4320 minutes. The test results including swelling potential and swelling pressure are discussed in the coming sections.

4. The impact of degree of compaction

To investigate the effects of compaction on swelling potential and swelling pressure, 10 samples for each type of soils, listed in Table 1, (60 samples in total) are prepared with identical initial moisture content (7.5±1%) but different dry unit weights. This helps to study the impact of gypsum content and degree of compaction on swelling phenomena.

The mold, in which the sample was compacted, was then fully soaked. This process allowed the water to be distributed uniformly within the sample, resulting in saturation and subsequent volume change.

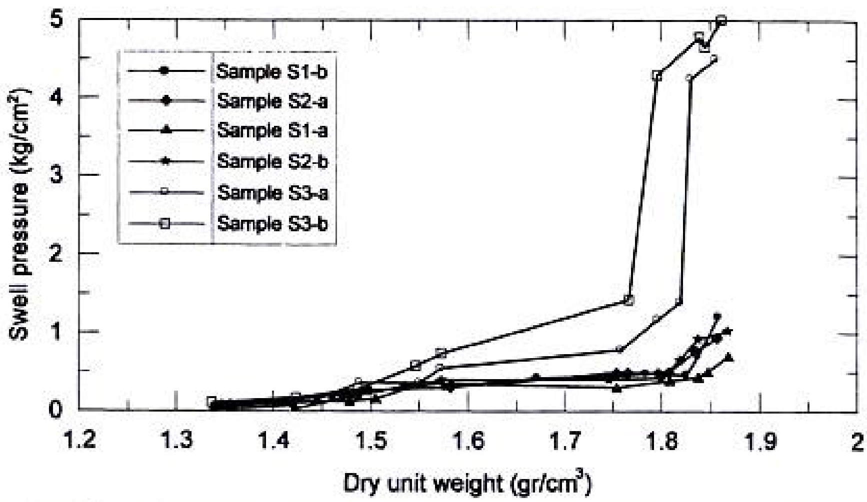

Figure 2: Variation of swell pressure with different magnitudes of dry unit weight for all samples.

Figure 2 shows the variation of swell pressure for all samples re-compacted at different unit weights. Figure 3 illustrates the free swelling (with applying the least surcharge as suggested by ASTM equal to 1 kPa) for all samples re-compacted at different unit weights. The test results clarify the following features:

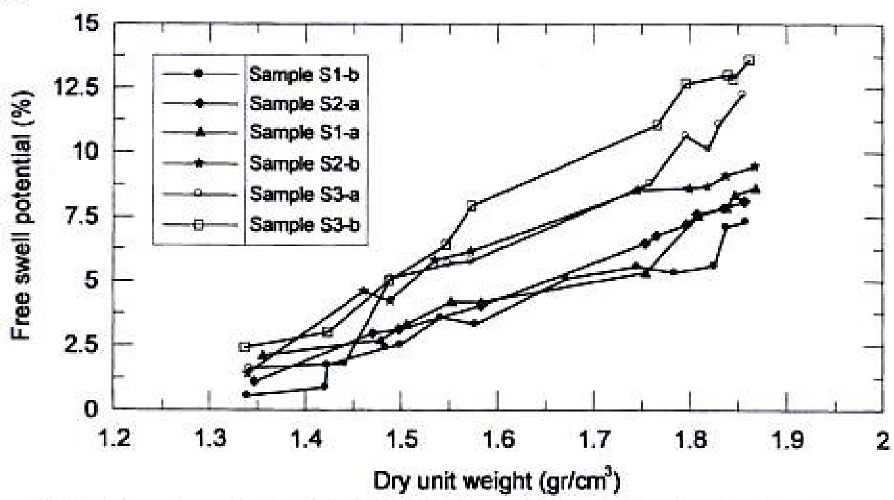

Figure 3: Variation of swell potential with different magnitudes of dry unit weight for all samples.

- The main reason of swelling of soils in this area is the presence of gypsum. Even if the soil is compacted at relatively low density, the presence of water and subsequent saturation results in swelling.
- As the relative density increases, the magnitude of swelling increases, implying that compaction may eliminate settlement but in the case of saturation, the swelling would be predominant phenomenon.
- The magnitude of swell pressure increases with degree of compaction. This is mainly due to the void reduction increasing
- The variation of free swell potential is almost linear with dry unit weight for all samples, implying that compaction may eliminate settlement but in the case of saturation, the swelling would be predominant phenomenon. For a given unit weight, the amount of swelling potential increases as the gypsum content increases.

- Most of swelling occurs in early hours of saturation. The time required the swelling to be ceased is less than 4 days.

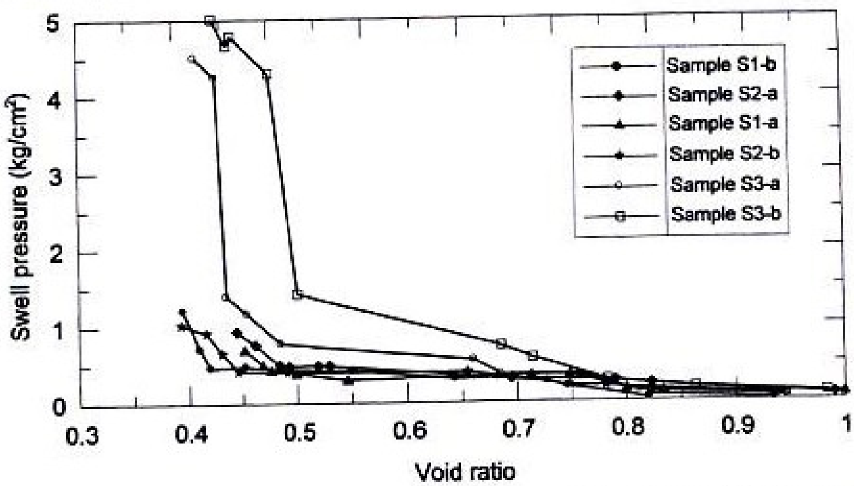

Figure 4: Variation of swell pressure with different magnitudes of dry unit weight for all samples.

Also shown in Figures 4 and 5 are the variations of void ratio with swell pressure and free swelling for all samples containing different magnitudes of gypsum.

The general trends of swell pressure and swell potential are similar to those observed in Figures 2 and 3. Again, Figures depict the significant influence of compaction and gypsum content on swelling phenomena.

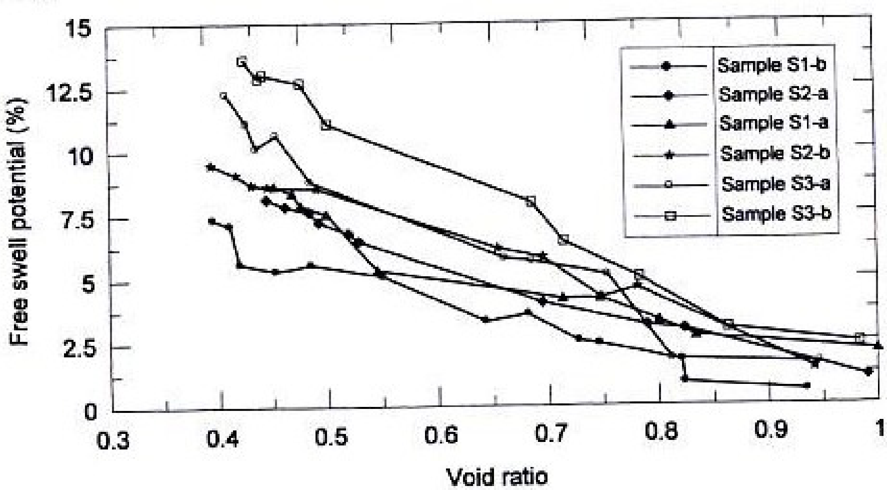

Figure 5: Variation of swell potential with different magnitudes of dry unit weight for all samples.

5. Different methods of improvement

Problematic soils, such as swelling soils, cause extensive damages to the superstructures when they are constructed on problematic soils without any modification of soil layers. Many treatment procedures are available for stabilizing swell-shrink soils [6]. Removal of such problematic soils and replacement with a non-expansive material is a common method of reducing swell-shrink risk. However, frequently if the soil stratum is thin, it is too great to remove economically. In addition environmental considerations restrict the removal of problematic layer soils. Chemical additives such as lime, cement, fly ash and other chemical compounds have been used for many years at various level of success [7]. The degree of improvement of soils stabilized with these additives depends on the soil mineralogy, stabilizer properties, the adapted method of stabilization and type of construction.

Lime stabilization has been used extensively in highway and other engineering projects. While the addition of lime modifies some soil properties, some other properties due to the chemical reaction may alter and new problems arise. Other additives, such as cement, has been also used to stabilize problematic soils.

It should be also pointed out that the method of adding and mixing the additives with soil may influence the degree of improvement. In the following section the different methods of stabilization are described.

5-1 Method A

To investigate the influence of lime as additive for stabilization of gypsum soil, 1, 2, 3 and 4 percent of lime was mixed with sample S3-a, congaing 10.57 percent gypsum. Lime, as an additive, is used in form of quicklime, CaO, which reacts quickly with water, producing the moisturized lime, $Ca(OH)_2$, and generating much heat and thus causing an increase of volume. In method A, lime was mixed with soil and the moisture content of the sample was subsequently increased up to 7.5%. The mold, in which the sample was compacted, was then fully soaked for free swell or swell pressure measurement (Method A).

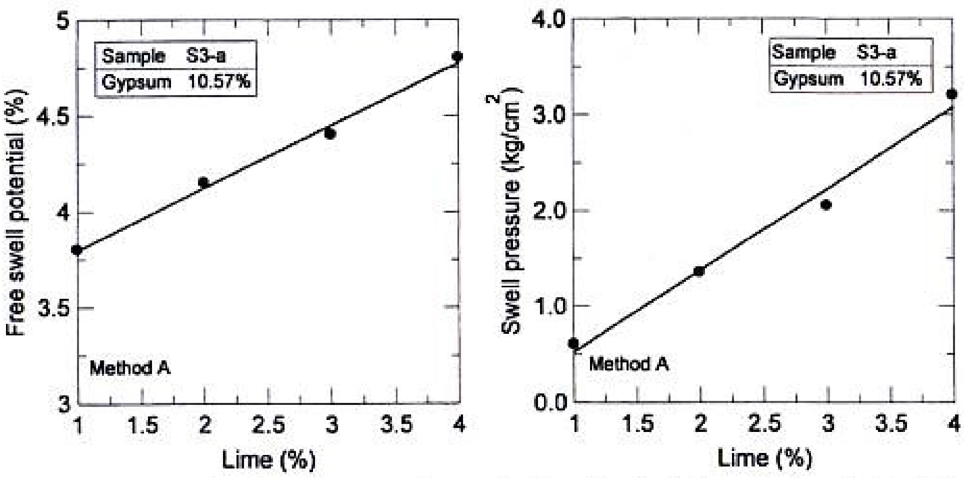

Figure 6: Free swell and swell pressure for sample S3-a after stabilizing with lime (Method A).

It is well recognized that fine-grained soils stabilization with lime, decreases elasticity, increases workability, reduces swell, and increases strength. These general improvement soil properties are the result of chemical reaction, including cation exchange, cementation and carbonation [7]. Figure 6 depicts the test results for this series of tests. The test results indicate that adding lime leads to free swell and swell pressure reduction in comparison with no adding lime. It is, however, evident that with increasing lime free swell and swell pressure increase.

5-2 Method B

In this method, lime was added in two steps; in the first step fifty percent of lime, i.e. 0.5, 1, 1.5 and 2 percent lime was added and the moisture content of the sample was subsequently increased up to 7.5%. The samples was kept in special bags and sealed to prevent any reduction in moisture content. This process continued for 30 days to make sure initial reactions were occurred. The improvement technique was completed by adding the fifty percent-remained lime after 30 days. The samples were ready for free swell or swell pressure measurement (Method B).

Figure 7 shows the test results for this series of tests. The test results indicate that adding lime in two steps reduces free swell and swell pressure. It can be, therefore, considered as a successful method of improvement. Adding lime to clay soil can improve the shear strength parameters and reducing the settlement. This is mainly due to the increase of internal friction angle and cementation [8].

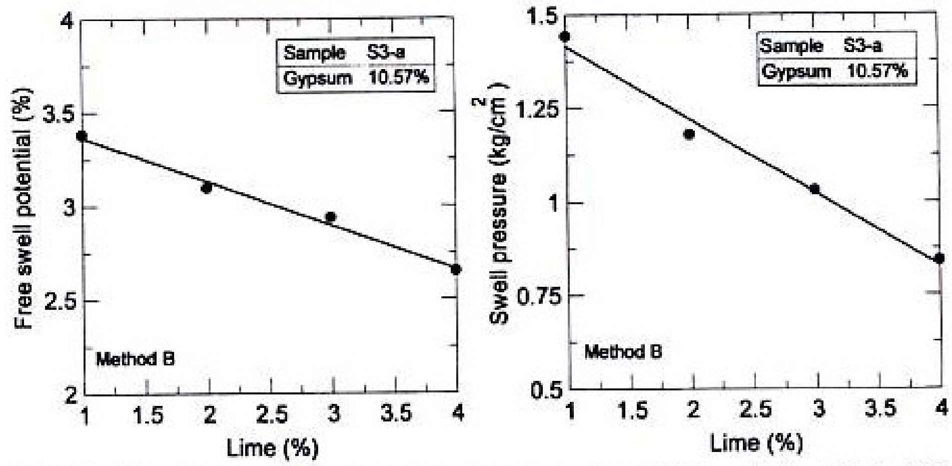

Figure 7: Free swell and swell pressure for sample S3-a after stabilizing with lime (Method B).

5-3 Method C

In the last method, for stabilization of gypsum soil, 1, 2, 3 and 4 percent of cement was mixed with sample S3-a, congaing 10.57 percent gypsum. In method C, similar to method A, after mixing cement with soil, the moisture content of the sample was subsequently increased up to 7.5%. Figure 8 shows the test results for this series of tests.

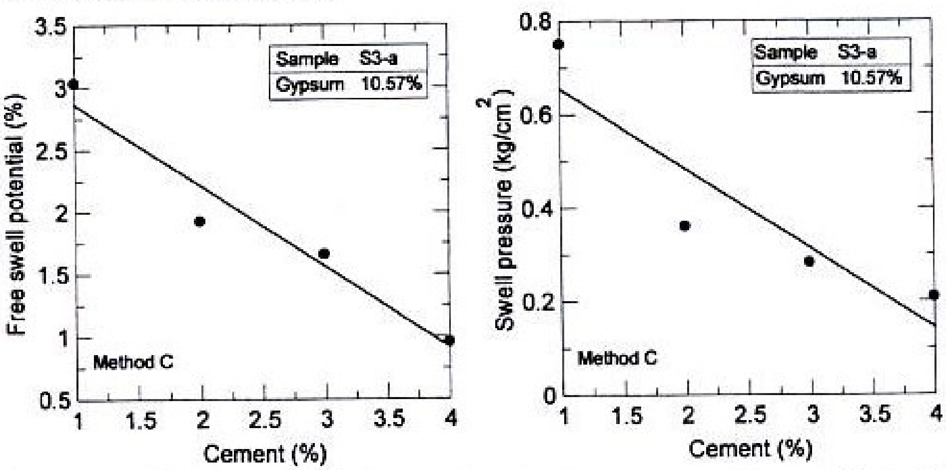

Figure 8: Free swell and swell pressure for sample S3-a after stabilizing with cement (Method C).

As can be seen adding cement to gypsum soil, results in significant reduction in swelling potential and swelling pressure. With comparison Figures 7 and 8 it can be deduced that cement is more effective in stabilization of gypsum soil than lime. The test results indicate that adding cement is more effective in comparison with two last methods.

6. Conclusions

The present research examined the influences of mechanical and chemical improvement methods on gypsum soils. The following general conclusions can be drawn from the test results

- The gypsum soil in this region has high porosity resulting in increase settlement markedly if it is not compacted.
- Compaction as a mechanical improvement method may reduce the settlement but causes more swell potential as the degree of compaction increases. If structures constructed on such

compacted soil are relatively high loaded no problem will arise, otherwise the swell pressure causes dramatic damages.

- Adding lime to gypsum soil as a chemical improvement method, increases he shear strength and workability and reduce settlement potential but increases swell pressure.
- The complementary test results (which are not reported due to pages limited) clearly shows that if lime is added in two different phases, the swell potential will reduce markedly.

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