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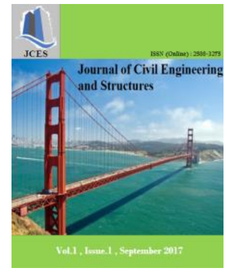

Physical specifications and Mechanical Behavior of Swelling Gypsiferous Soils

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Abstract: Swelling soils which are outspread all over the world cause irrecoverable damages to buildings. This type of problematic soils exits in south west of Mashhad and seems to be the main reason of some damages including cracks in buildings and pavements. The soil profile in this region is mainly gypsum and fine which can be classified as…SM and CL. However, in some parts course aggregates are observed. The present research is an attempt to identify the characteristics and swelling property of gypsum soil of this region. To examine this issue, 10 samples containing different gypsum percent were taken from various places in this region. The geotechnical properties of the samples including gypsum content, Atterberg Limits, natural unit weight, dry unit weight and density were investigated. The influence of gypsum amount on swelling potential was then studied. All samples were moulded with identical moisture content and unit weight. The impacts of some other factors such as compaction and cycles of dry and wetting on swelling potential were also investigated.The results of the present research indicate with increasing gypsum content and degree of compaction, swelling potential increases rapidly. It is also shown that with increasing number of cycles the magnitude of maximum swelling potential increases so that after a few cycles remains mainly constant.

Keywords: Gypsum soil, Swelling, Compaction, Cycle of wetting and drying.

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1. Introduction

In general, soils that undergo settlement (volume reduction) or swelling (increase in volume) after saturation, are categorized as problematic soils [13].The swelling behavior is usually seen in soils containing enough fine particles. In their natural state, clays may to some extent show swelling (if wet) or contraction (if dry) behaviors [7]. Swelling of this soil type is mainly due to movement of soil particles away from each other in the presence of water as a result of osmotic laws and consequently formation of a thin membrane of water around the soil [12]. Such soils cause a lot of problems around the world, most notable examples of such problems include damage to buildings, roads and pavements. These problems have driven researchers to conduct extensive studies in this field.

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Anhydrite or dry calcium sulfate also turns into gypsum or hydrated calcium sulfate ($CaSO_4.2H_2O$) after absorption of water and experiences 30 to 60% volume increase [5]. In many cases in nature, anhydrite and clay materials are combined (such as clay –sulfate stones) and undergo swelling. Therefore, gypsiferous soils are also categorized as problematic soils. One of the major problems of such soils is associated with their potential to convert calcium sulfate or anhydrite to gypsum and vice versa. In order to reduce swelling and overcome the problems caused by it, the most basic step is to understand the mechanism of swelling and the factors that affect it [2]. Factors such as clay percentage and type [10] density, moisture content and soil structure affect soil swelling [2].

Ions in the structure of clay minerals also affect the rate of swelling. Monovalent ions such as sodium play a more significant role in swelling compared to divalent ions such as calcium. For example montmorillonite with ions of K^+, H^+, Na^+ and NH_4^+ are far more swelling than illite with ions Ca_2^+ and Mg_2^+ [1]. The highest rate of swelling occurs in complete saturation [8] so that reduction in the amount of water, leads to reduction in soil swelling [4,7].

One of the notable points in this case is the impact of wet and dry cycle on swelling of gypsiferous soils. In general, in clays, swelling rate and potential reduces with any increase in wet cycles and drying [9]. However, in clays containing gypsum any rise in wetting cycle followed by drying has an inverse impact on swelling. Compaction is one of the techniques to improve performance of loose soils. But, in gypsiferous soils any rise in density upon relative saturation leads to significant swelling [11].

Soil stabilization is one of the Strategies used to deal with the problem of soil swelling. Chemical improvement of soil has received a lot of attention in recent decades. Currently lime is one of the most important stabilizer additives due to its abundance and inexpensiveness. The greatest impact of lime on soil is shrinkage that can be achieved by saturation of soil particles with calcium ions. In some studies, the optimal amount of lime to have the greatest impact on swelling reduction ranges from 2 - 8% [6]. In some cases, addition of 6% lime to soil decreased swelling rate by 100% [3]. Cement is another stabilizers used to improve the swelling soils. Research results show that adding 3 - 9% cement to soil can reduce swelling pressure by 40 – 60%.

2. Objectives of the Study

Considering the extensive and irreparable damage that gypsiferous soils impose to structures and Flooring, investigation of the behavior of these soils is of particular importance. In the present study, the following topics are discussed in order to understand the behavior of gypsiferous soil:

- The main geotechnical specifications of gypsiferous soils including the amount of gypsum, Atterberg Limits, specific gravity and density.
- The effect of gypsum volume on free swelling
- The effect of wetting-drying cycles on the level of free swelling.
- The effect of density on the level of free swelling.

3. Experimental Studies

This study is organized as follows:

- Sampling and selection of different samples to determine the effect of gypsum percentage, density and wetting - drying cycles on swelling
- Soil Gradation, classification and determination of mechanical properties and the amount of gypsum in samples
- Measurement of free swelling

The experimental studies and their results are discussed in detail below:

3.1 Sampling and sample selection techniques

According to the literature, 20 samples were taken from areas with low-high values of gypsum in southwest of Mashhad. As for soil color and texture, the samples were divided into buff and gray groups. The gypsum Available in gray samples is in the form of crystalline particles and can be seen clearly. However, in the buff samples, gypsum particles are not visible separately.

After determining the amount of gypsum, the samples are codified in terms of gypsum percentage. It should be noted that the codification of samples is based on the amount of gypsum in them, in such a way that the first number shows the percentage of gypsum in the sample (rounded towards the lower number) and the second number shows the sample No. in equal gypsum percentages. For example, S8-2 contains nearly 8 percent gypsum and is the second sample with this amount of gypsum. As Table 1 shows, S0-1 contains the lowest amount of gypsum (less than 1 percent) and S12-1 contains the highest amount of gypsum (more than 12 percent).

3.2 Preliminary tests

To classify samples, some tests were performed on them, and the class of samples was determined according to the results. Table 1 and Figure 1 show the Geotechnical properties and gradation diagram of selected samples respectively. The following conclusions can be drawn from Table 1:

- The gypsum level has no significant impact on soil specific gravity.
- Any increase in the percentage of gypsum leads rise in actual density of soil.
- Any increase in percentage of natural gypsum leads to a rise in natural soil moisture.
- Changes in plasticity index don't follow a specific trend with any increase in the percentage of gypsum.

Table 1. Geotechnical and physical properties of selected samples

USCS[c]	Moisture percentage	Atterberg Limits			specific gravity	specific weight (g/cm^3)		sample
		PI(%)	PL(%)	LL(%)		dry	natural	
CL	1.3	12.68	22.03	34.71	2.48	1.63	1.65	S0-1
SC	4.5	8.54	19.72	28.26	2.59	1.55	1.62	S1-1
CL	2.6	12.07	41.87	33.94	2.61	1.44	1.48	S1-2
CL	4	10.31	20.33	30.64	2.58	1.52	1.59	S3-1
ML	4.8	11.27	26.40	37.67	2.51	1.54	1.62	S4-1
CL	17.7	14.31	22.35	36.74	2.43	1.62	1.9	S8-1
SC	8	9.54	30.09	39.63	2.6	1.58	1.71	S8-2
SM	16	3.01	36.86	39.86	2.58	1.50	1.75	S9-1
SM	15	NP	NP	NP	2.53	1.17	1.35	S11-1
CL	1.2	12.37	20.62	33.99	2.58	1.60	1.62	S12-1

USCS[c]: Unified Soil Classification System

3.3 Measurement of gypsiferous soil's swelling potential

The level of swelling can be determined by measuring the rise in sample height using the consolidation device or other similar devices. Due to the high volume of tests, a device similar to consolidate devices that was capable of measuring swelling with and without applying overhead was employed. The main features of this device include easy production in large numbers and multiple testing potential. The device performance is quite similar to that of the consolidation device and the results are acceptable.

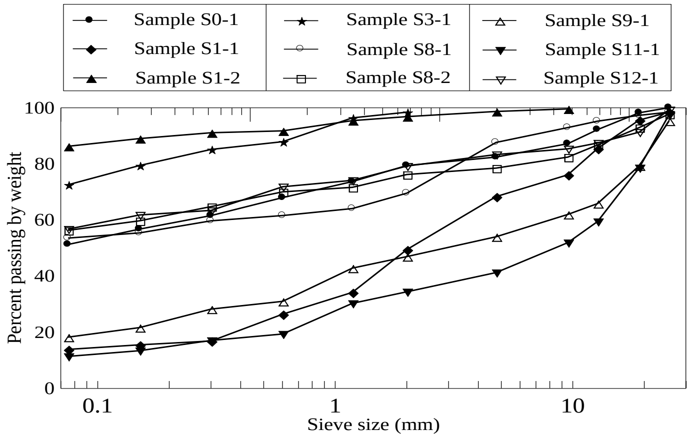

Figure 1. The sample gradation diagram

The device consisted of a double-plate aluminum mold and a gauge for reading. The mold consists of two PVC cylinders, with the inner diameter of 9 cm and height of 4 cm which are mounted on each other. This mold is presented in Figure 2. Two perforated aluminum plates are placed on either side of the mold to accelerate the saturation of soil samples. Aluminum plate under the mold is attached to it by 4 screws and the faceplate is placed on the prepared samples without being attached to the mold in order to allow for accurate readings at each step. Before attaching the underside plate to the case, a cotton cloth is placed between the mold and the aluminum plate to prevent leakage of fine soil grains and water.

Figure 2. The swelling mold used in the study

The upper Aluminum plate is marked at 4 points (3 points on the perimeter and 1 point in the middle) for swelling reading. A Schematic image of the swelling mold used in this study is presented in Figure 3.

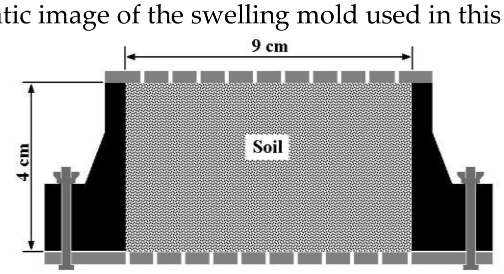

Figure 3. Schematic image of swelling mold used in the study

In this study, all the prepared samples had natural moisture content and specific dry density of 1.7 g / cm^3. A simple device was developed in order to unify the test conditions and the density of the samples. The device consists of two knockers and a PVC cylinder. The surface area of each knocker is equal to the surface area of the swelling mold and in case it vertically hits the samples, a uniform density forms across its surface. The inner diameter of the cylinder is equal to the outer diameter of the swelling mold and is mounted on the mold during its operation. This process is conducted in order to create uniform density at all heights of the sample. After the sample is prepared in the mold, first the cotton cloth and then reticular plate is placed on it. Afterwards, the mold and prepared samples are placed in a container filled with water such that water covers the surface of the mold and water drainage and absorption is possible from both sides.

Figure 4. Swelling reading procedure

After placing the samples in the water four points selected on the aluminum plate were read at different times by a gauge with an accuracy of 0.01 mm. sample reading continued until the gauge changes were fixed. Figure 4 shows how to read the changes in the height of samples.

4. Test Results

4.1 Swelling percentage

Swelling of each sample was measured after a specific period until the swelling was approximately fixed. Figure 5 shows the percentage of changes in the swelling rate for different amounts of gypsum in the test samples.

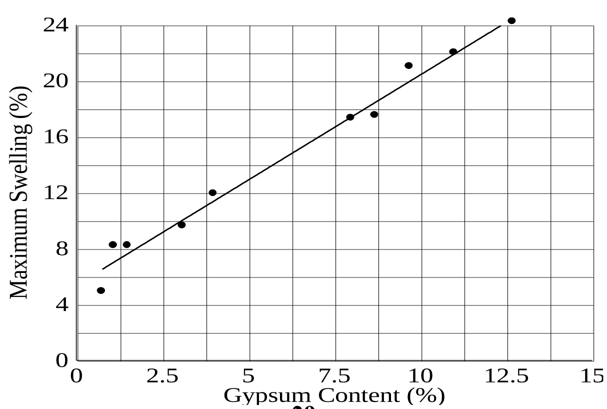

Figure 5. Maximum sample swelling percentage for different gypsum amounts

As the figure shows, swelling percentage rises with any rise in the percentage of gypsum and this can mainly be attributed to the presence of water. In other words, with any rise in the percentage of gypsum and saturation of the samples, the soil desire to absorb water rises and more calcium sulfate reacts with water, which leads to rise in calcium sulfate swelling.

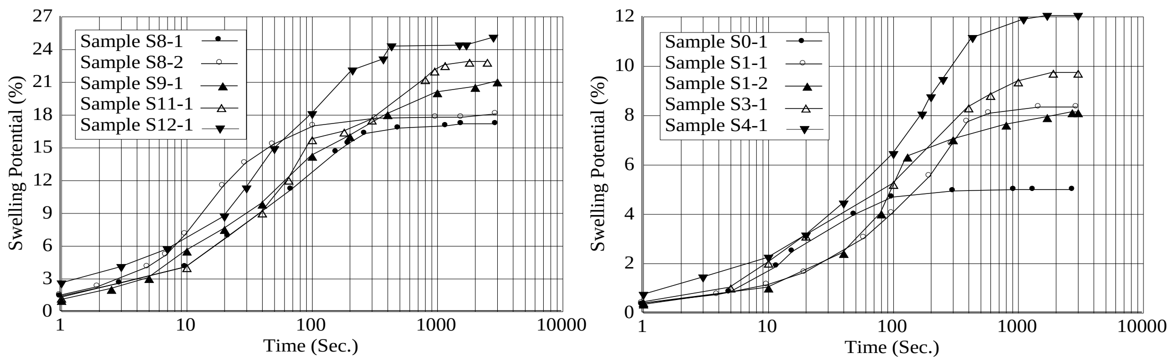

Figure 6. Percentage of samples swelling per minute in logarithmic scale

In order to investigate the swelling trends, the sample swelling changes over time are shown in Figure 6. As you can see, swelling changes over time follows a particular trend. The swelling-time trend schematically shown in Figure 7, can be divided into three parts: 1, 2 and 3. According to the figure, [art 1 follows an incremental trend and features a less steep slope compared to part 2. This part covers 10 – 20 initial minutes of testing in different samples and enters part 2. In this part, the slope is steeper than other two parts and covers 10 – 150 initial minutes of the test for different samples. The third part that begins after the end of part 2, features a less steep slope that reaches zero in some cases. As you can see, the highest swelling rate occurs in the first hours of the saturation.

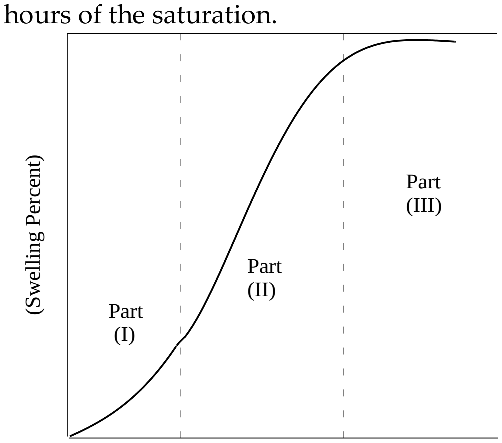

Figure 7. Schematic diagram of samples swelling percent per minute in logarithmic scale

4.2 The impact of drying on swelling level

In order to investigate the impact of gypsum level on swelling reduction after loss of moisture, four samples S0-1, S8-1, S4-1 and S12-1 were selected. After reaching the maximum swelling, the samples were first dried in the environment and then incubated to lose their moisture completely. Figure 8 shows the results of these tests. As can be seen, in all samples, swelling is not completely gone after drying. However, the residual swelling varies according to the percentage of gypsum in the soil. In other words, S12-1 with the largest percentage of gypsum has experienced 14% swelling reduction and S0-4 with the lowest percentage of gypsum has experienced 40%. Swelling reduction. In other words, the amount of residual swelling is directly correlated with the percentage of gypsum in the samples and samples with higher gypsum percent experience less significant swelling reduction after drying.

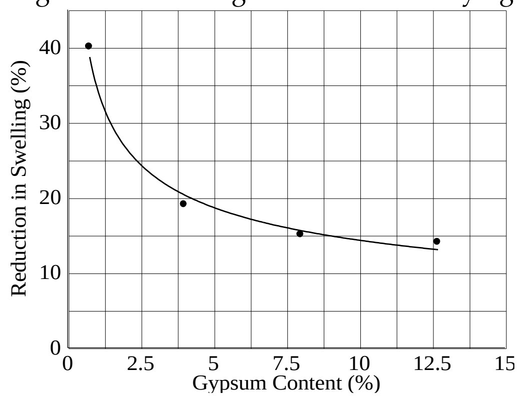

Figure 8. Variations in Post-drying swelling reduction according to the gypsum percentage

4.3 The impact of density on swelling rate

To evaluate the effect of dry specific density on swelling rate as well as the effect of gypsum on these variations, three samples S4-1, S8-1 and S12-1 containing approximately 4%, 8% and 12% gypsum were selected respectively. Sample preparation at this phase, was just like the first phase of testing. In the next stage, Additional tests such as evaluation of maximum swelling percent as well as post-drying swelling reduction rate were conducted on samples at 5 different specific weights. The Results are shown in Figure 9. According to the results, it can be argued that:

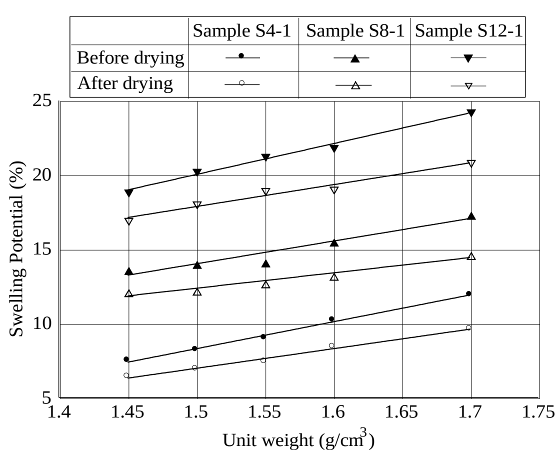

Figure 9. Swelling percent variations based on specific weight in S4-1, S8-1 and S12-1

Although compaction of soil could lead to reduction in settlement, the results indicate increased soil swelling with any rise in dry specific weight of the soil. Therefore compaction is not a useful technique for improving soil swelling.

- Any increase in dry specific weight of soil, leads to an increase in post-drying swelling reduction.
- Sample Saturation followed by sample drying, can only remove about 15 to 20 percent of soil swelling.

Therefore, saturation is one of the techniques used to improve swelling soils. In other words, in areas where saturation can lead to soil swelling, soil saturation followed by drying can provide favorable conditions for construction of lightweight structures (such as canals).

Figure 10, shows the maximum swelling time for the three samples at different specific weights. As you can see, with any increase in the specific weight of dry soil, the time needed to reach maximum swelling decreases significantly. In other words, as soil becomes denser, it can reach maximum swelling in a shorter period of time

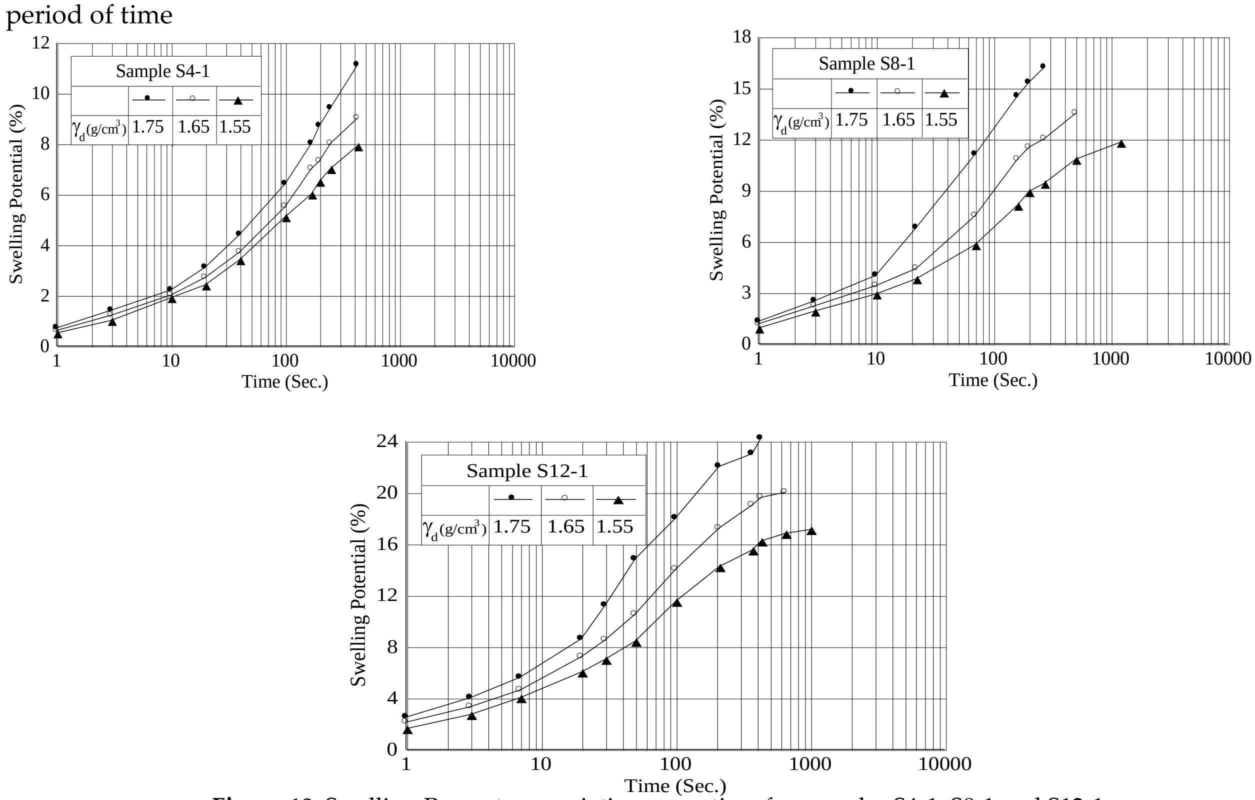

Figure 10. Swelling Percentage variations over time for samples S4-1, S8-1 and S12-1

4.4 The impact of wetting - drying cycles on swelling

In order to investigate the impact of wetting - drying cycles on swelling, S12-1 sample was selected and compacted at specific weight of 1.7 g / cm^3.in the next phase, the saturated samples that reached the maximum swelling level were incubated at a low temperature so that their moisture is gradually lost and swelling drop rate is reaches a fixed level. This trend was carried out on the samples in 6 wetting-drying cycles. The test results provided in Figure 11 show that the highest swelling rise rate (about 40%) and the rise in swelling due to wetting and drying has followed an incremental trend up until the fourth cycle and has then remained constant. No significant rise is observed in swelling rate in the next cycles.

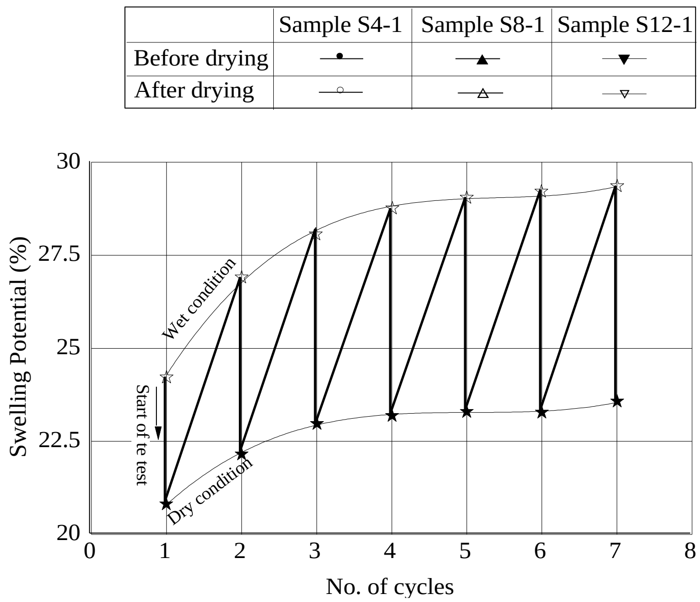

Figure 11. Swelling rate according to the number of wetting – drying cycles in sample S12-1

5. Conclusion

Soils that naturally contain gypsum show special mechanical behaviors that depend on several factors, such as gypsum level, actual specific weight, moisture content and the soil type. Many urban areas around the world contain this type of soil, which not only has brought damage to structures, but has many adverse environmental effects [9]. Tests conducted on these soils led to the following conclusions:

• General swelling rate increases with any rise in the amount of gypsum. In other words, samples with negligible gypsum and samples with 13% gypsum experienced 5% and 24% swelling respectively.Therefore, swelling impacts of gypsum must be taken into account in construction of vast areas like parks or construction of light-weight structures.

• According to the model considered for this type of soil, much of the swelling has occurred in the first 3 hours of the saturation, and controlling the swelling can help us reduce the damages.

• Density has a direct impact on swelling potential. For a soil with specific gypsum level, any rise in density can increase swelling. This is the main cause of damage to light structures. Obviously, however, soil should be compacted in order to avoid settlement. Thus, according to test results, in case the overhead of the structure that is to be built on the soil of this area exceeds the swelling pressure, construction of the structure will not cause any specific problem. But if the structure is lightweight, soil compaction (that is the most common method to avoid settlement of porous soils) will lead to swelling and consequently damage to the structures. The best solution in this case is to replace the gypsiferous soil with high quality soil or retrofit it with an additive (e.g., cement) in order to suppressing soil swelling.

• the impact of wetting - drying cycles that somehow models climate change in different seasons, won't reduce swelling, but will increase it by 10 to 15 percent. Thus, these techniques will not be reliable as way to retrofit soil.

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