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# Recycling of Construction Waste Concrete as a Stabilizer for Gypseous Soils

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**ABSTRACT**

This study presents the possibility of recycling Crushed Waste Concrete resulting from the demolition of buildings, and making practical use of these abundantly available materials, by grinding them and adding them in different proportions to gypseous soils to increase their maximum bearing capacity and reduce compressibility. A laboratory model with dimensions (300*300 *600mm) of galvanized steel, 4 mm thick, was used to study the effect of mixing (0%, 2%, 4%, 6%, and 8%) Crushed Waste Concrete with three types of water-flooded natural gypseous soils with different percentages of gypsum (30%, 46%, and 66%). Loading tests were carried on square steel footing (70*70mm) and 9mm thick, placed on these soils. More than 15 tests were conducted on the laboratory model, in addition to the usual classification tests on the soils used in the study. All tests were carried after submerging gypseous soils due 24 hours. The study showed a clear improvement in the susceptibility of the three gypseous soils using all the addition percentages of concrete powder, the best percentage was 8%, while the improvement rates were less using 2%, 4%, and 6%. As the bearing capacity of the soil increased after mixing it with this ratio due to filling the voids formed as a result of melting gypsum during the water immersion process, which compensated for it at this stage. Mixing gypseous soil with crushed waste concrete by 8% increases ultimate bearing stress about 8 times, while it is 2.5 times for model mixed with 2% of this additive, compared with the untreated one.

## 1. INTRODUCTION

Gypseous soils are considered to be metamorphic soils whose properties change by changing the surrounding conditions. It is highly compressible and has great shear resistance and low compressibility when dry due to the interlocking of soil particles with hard gypsum. The physical properties of these soils change when they are moistened or immersed in water due to the disintegration of the gypsum bonds that permeate the soil grains as a result of their dissolution. The rate of solubility varies according to the components of those salts. There are iron salts, lime salts, sulfur salts, and table salt, sodium chloride, which is the most soluble among them. All of them are salts that cause structural problems if they are present in the soil in high proportions.

Gypseous soils constitute about 6% of the total soils in the world. It abounds in areas of southwest Asia, especially in Syria, Iraq, Saudi Arabia, and Iran [1]. The limestone formations of the soils and their spread as a result of the melting of limestone rocks are the reason for the formation of this type of soil in such areas. The percentage of gypsum in mid areas of Iraq reaches more than 60%. Which is of highly soluble sulfur salts, with a melting rate of 2.6 grams per liter at a temperature of 30 degrees Celsius, and its melting increases with increasing temperature. There are many structures exposing to dangerous risks due to the presence of gypseous soil underneath the foundation, and when the soil is exposed to water from any source, gypsum particles inside the soil are dissolving [2]. However, this problem causes cracks and failure or tilting in building structure and this problem appears in Mosul dam, North of Iraq, as shown in Figure 1.

**Figure 1.** The collapse in Mousil Bridge North of Iraq

Moreover, different structures constructed on gypseous soil are exposed to failure, as the training center and water storage in Tikrit, the communication center of Dujail, and the tourist village of Habbaniyah [3], and the wall of Tikrit hospital, Iraq, as shown in Figure 2.

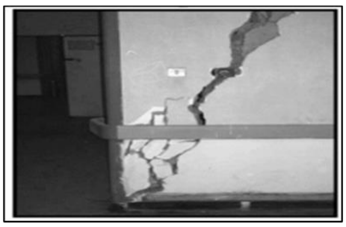

**Figure 2.** The collapse of a wall in Tikrit hospital in Salah Al-Deen governorate, Iraq

Also, some cracks are noticed in the runways of the College of Air Force in Salah Al-Deen Governorate, Iraq [4]. In addition, many problems appear in a construction that is built on gypsum soil, such as cracks, tilting, collapse, and leaching, in such a region. Additionally, cracks and settlements are found in the Village of Habbaniyah, Al-Anbar University, west of Iraq, and some houses in Al-Ramadi city. Damages caused by gypseous soils are noticed in different regions around the world especially in Syria, Russia, Chine, the USA, and Spain. Moreover, there is the problem of collapse that takes place in constructions build on gypseous soil such as railways, channels, bridges, and roads. Such problems take place when groundwater or rain infiltrates gypseous soil.

The problem of gypseous soils appears when exposed to flooding from any source of water, such as a rise in the groundwater level, rainwater, or as a result of broken water pipes, causing a noticeable change in its engineering properties and thus affects the engineering facilities built on it [5]. Therefore, there was a need to find practical ways to reduce the collapse of such problematic soils. Mostly, these soils are treated with some additives and stabilizers like lime [6] or Nano Silica Fume [7], some of which are physical treatments such as compaction and reinforcement with geogrid or geotextiles or with nets or plastic tapes, and the others are chemicals such as adding lime or cement [8] or oil derivatives [9] or crude oil [10] or resin derivatives or kerosene [11], another treatment for gypseous soil is by grouting [12]. Most of these additives or materials are pollutants to soil and the living environment, in addition [13], that they are expensive and impractical materials because some of them have little durability and some do not serve the desired purpose, especially when submerging these soils with water, or after leaching [14]. In addition, some of these methods did not show good efficacy in treating these soils. Therefore, there was a need to find a practical, effective, and at the same time economical treatment for this type of soil. The use of construction waste as a stabilizer for soft soils has become common in the last two decades, especially after the increased accumulation of these materials and the necessity of recycling and reusing them, and it gave promising results in improving the properties of some weak clay soils.

This study deals with the possibility of using Crushed waste Concrete to stabilize gypseous soils during soaking.

The aims of the study are to recycle concrete construction waste that is usually disposed of as rubble, and use it as stabilizers for gypseous soils subjected to wetting, and make it suitable soil from a structural point of view and at the same time contribute to protecting the environment by using these waste materials, and making practical use of them.

## 2. EXPERIMENTAL WORK

### 2.1 Material used

2.1.1 Soil

The soils used in this study were natural gypseous soils brought from different regions north of Baghdad, Iraq. Three soils were used with different gypsum contents (soil 1 with 30%, soil 2 with 46%, and soil 3 with 66%). A series of laboratory tests are achieved on these soils to specify the physical and chemical and engineering tests as well as their compositions. All results for the physical and chemical tests on the three soils are shown in Table 1 and 2.

**Table 1.** Physical test result for soils used

| Properties | Magnitude | | |
|---|---|---|---|
| | Soil 1 | Soil 2 | Soil 3 |
| Soil Type (USCS) | SM | SP | SM |
| Specific gravity of soil, | 2.52 | 2.4 | 2.34 |
| Relative density γ (kN/m$^3$) | 15 | 14.5 | 14 |
| Void ratio (e) | 0.68 | 0.55 | 0.71 |
| Ø in dry soil | 36 | 34 | 27 |
| Soil cohesion, C dry soil | 10 | 11 | 11 |
| Ø in soaking test | 27 | 29 | 23 |
| cohesion, C, in soaking | 5 | 4 | 8 |
| Collapse Potential CP% | 5.2 | 7.7 | 9 |

**Table 2.** Chemical test results for soils used in the study

| Component | Soil 1 | Soil 2 | Soil 3 |
|---|---|---|---|
| (T.S.S.) % | 33 | 48.1 | 68.1 |
| Gypsum content% | 30 | 46 | 66 |
| Sulphate content% | 13.6 | 21.3 | 30.4 |
| Organic materials % | 0.2 | 0.18 | 0.21 |
| pH value | 7.1 | 8.2 | 8 |

2.1.2 Crushed waste concrete

The particle size of crushed waste concrete used in the study was passing through (0.45mm) sieve after grinding. The specific gravity for this substance is 2.7. Since this material depends on the proportions of the components of the concrete mixture, a full chemical analysis of its components is needed. Table 3 shows the chemical composition of this substance.

**Table 3.** Chemical composition of waste concrete

| Element | Concentration (%) |
|---|---|
| C | 12.93 |
| O | 54.16 |
| Na | 0.16 |
| Mg | 0.46 |
| Al | 1.40 |
| Si | 2.42 |
| K | 0.22 |
| Ca | 27.45 |
| Mn | 0.06 |
| Fe | 0.7 |

### 2.2 Laboratory model components

In this study, a laboratory model made from steel was used and it consisted of the following parts: (1) Steel container; (2) loading frame; (3) Hydraulic compression jacks; (4) load cell (S-shape); (5) digital indicators. All parts and accessories used in the tests for the laboratory model are shown in Figure 3.

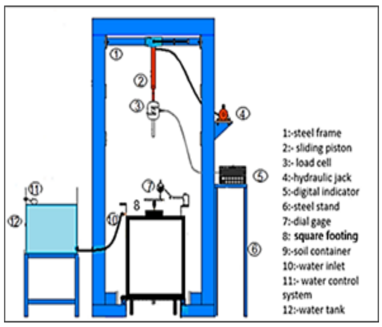


**Figure 3.** Components and accessories used for laboratory model tests

2.2.1 Steel container

The steel container used in the present study is locally manufactured and has a square shape, with dimensions (300*300*600 mm), and 4mm thickness for the steel plates used in the container.

2.2.2 Loading frame

The loading frame was made from Steel rods which are connected to the frame by four bolts for holding a manual hydraulic jack which is used to apply vertical pressure on a square footing with dimensions of 70 * 70 mm. The loading frame columns are connected from the bottom by transverse steel bars that are securely attached to the concrete floor of the laboratory in a way that allows the steel container to be pulled smoothly for sample preparation for model tests.

2.2.3 Hydraulic compression jack

The hydraulic jack connected to the loading frame was used for settlement test for a square foundation placed on the gypsum soil. This system is used to push the oil to the piston fixed by a steel rod that is connected to the load cell, to apply different stresses on the square foundation placed on the surface of the soil. The load cell is linked with the digital screen indicator to display the amount of load to be recorded for stress control. As shown in Figure 6.

2.2.4 Electronic loading cells and settlement gage

The load cell (S-shape load cell) used in the study was SS300, with a maximum capacity of 500 kg, rated output (2+0.005 m V/V), excitation (15V), combined error of 0.03%. it was used together with the manual jack to control stress. The digital load cell used in the study is shown in Figure 4.

**Figure 4.** The compression load cell used in the study

A digital indicator with model SI (4010) with a brand name (SEWHA), was connected to the digital load cell for measuring compression loads subjected to the footing used as shown in Figure 5.


**Figure 5.** The digital indicator used in the study

**2.3 Soil Preparation for model tests**

The used soil was dry and sieved in sieve No.4(4.75mm) to remove any undesirable parts from the soil. The unit weight used in this study is known from the compaction test ($\gamma$=15kN/m$^3$). The total soil weight which is determined based on the soil unit weight and the volume of the model used (rectangular steel tank) is divided into ten similar parts that are equal to the layers of the used container which is drawn on the internal face of the steel tank. The thickness of each layer was 5cm. Each part of soil weight from the five parts above is poured inside the steel container. After leveling its surface in suitable form; the soil is compacted by using the mechanical compactor until it occupies the thickness of each layer as drawn on the wall of the container. After completing the compaction process of each soil layer, the surface of the layer is leveled in a suitable form (via using a leveled device) before putting the next part of the weight. This process continues until finishing all the layers of the soil specimen. The form of compaction and its energy is distributed in the same system for all the soil layers inside the steel tank to reach the required unit weight of soil and to keep the soil layers in the same condition as much as possible to present a homogeneous specimen of soil.

**2.4 Test methodology for laboratory model**

When the soil deposit setup is complete, the soil container is fixed under the steel frame at the steel base of the frame to keep the container constant through the steps of the test. After that, a steel square footing 70*70mm and 5mm thickness was placed at the surface of the soil at the center point. The load is applied gradually un till reaching ultimate. The load was controlled by a load cell, fixed to the footing from the bottom. The piston of the hydraulic jack is lowered using the manual part of the jack until it became in touch with the load cell. The load is applied by actuating the manual part of the hydraulic jack which is fixed at the side of the loading steel frame, The loading system in the manufactured device is strain control, by means of a fixed descent of the hydraulic jack of 1 mm per minute, as it is easy to control the stress and strain readings, so that the settlement of the foundation is controlled, and in return it is easy to read the corresponding pressure, in addition, through this The system is able to know the extent of the failure of the model. This system is usually used to load large laboratory models, where it is difficult to control the time of model failure.

The soil inside the model is submerged by water and the loading test started after, and to permit gypsum particles for a full dissolution. After 24 hours. A dial gauge is placed over the footing and fixed to the steel frame to permit settlement measurement. The jack is fixed at the steel frame via four bolts to examine the footing by the concept of control strain test. After completing the examination of load settlement test for footing, the soil specimen is set up again with the addition of waste concrete with different percentages, all test steps were repeated for stabilized models as in the untreated one.

**3. RESULTS AND DISCUSSION OF EXPERIMENTAL MODEL**

In this study, three natural soils were used. Laboratory tests were conducted to identify the physical and chemical properties in addition to classification tests. The results revealed that all soils used were gypseous soils. The first soil is SM soil with 30% gypsum content, the second one is SP with gypsum content of 46%, and the third soil is of type SM with gypsum content of 66%. The loading test was carried out using a manufactured laboratory model, represented by a square foundation placed on a soil surface inside an iron container that is loaded using a loading platform specially designed for this study. The immersion test was conducted for the treated and untreated samples of concrete residues. Different mixing ratios of this material (0%, 2%, 4%, 6%, and 8%) were used to study the extent of soil improvement by increasing its bearing capacity and reducing its collapse, while at the same time contributing to the recycling of these unwanted waste materials, making them useful and practical.

### 3.1 Results of gypseous soil with 30% gypsum content

The loading test of the first soil was applied using a square footing placed on the surface of the gypsum soil with a gypsum content of 30%, loading test was carried out immersing gypseous soil model in water for 24 hours.

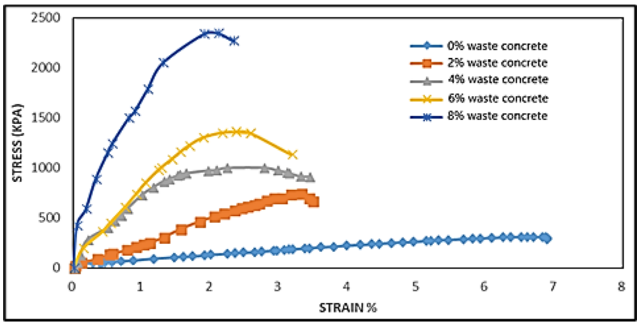


**Figure 6.** Stress-strain curves for soil 1 with 30% gypsum

Figure 6 represents the failure curves for first soil models treated and untreated with crushed waste concrete powder with different mixing ratios. The results showed a clear improvement after mixing the soil with this material. Where the settlement of the foundation was reduced and the bearing capacity of the soil was increased. The control strain technique was used in the loading of the foundation in order to control the reading of the maximum stress of the soil before the failure of the model. Figure 6 shows the results of the tests for treatment models with mixing ratios (0%, 2%, 4%, 6% and 8%). stress was applied until the failure of the model occurs. ultimate stress was recorded upon examination for each model. The results showed an increase in the bearing capacity of the soil for the model mixed with 8% of the crushed waste concrete by 8 times compared to the untreated model, while the increase in the bearing capacity of the soil was 5 times for the model mixed with 6% of this material. And 3 times for the model mixed with 4% of crushed waste concrete, and 2.5 times for the model mixed with 2% of this material. This is a significant and reliable improvement for these types of problematic collapse soils. The presence of water in this type of soil causes the dissolution of gypsum salts that permeate the soil particles, which leads to weak soil as a result of forming weak gaps of dissolved gypsum. By adding concrete residue powder to these soils, it fills the voids that permeate the soil particles. The soil improvement mechanism by crushed concrete can be considered as a physical and chemical process at the same time. Where this waste resulting from the demolition and grinding of concrete structures was selected for improving gypseous soil, the non-aqueous cement mortar contained in it may be the main material responsible for soil stabilization processes. On the other hand, the increase in ultimate stress after adding concrete residues in various proportions can be attributed to the higher strength of the crushed concrete particles and also to the increased induced inter-linking between the recycled concrete and the remaining fine particle mortar containing Higher than the non-aqueous residual cement.

### 3.2 Results of gypseous soil with 46% gypsum

Figure 7 shows the relationship between stress and strain for the footing constructed on gypseous soil with a gypsum content of 46%, treated with several percentages of mixing with Crushed Waste Concrete: (0%, 2%, 4%, 6%, and 8%). From the figure, it can be seen that the failure of the model treated with 8% of the crushed concrete residues is 1400 kPa, while it was (1000 kPa, 900 kPa, 600 kPa and 200 kPa) for the other models mixed with (6%, 4%, 2% and 0%) of this additive respectively. The failure stress of the laboratory models used in this study is considered an important criterion in the improvement of mechanical properties, as it was adopted as a criterion for improvement of this soil.

It can be recognized from the stress-strain curve that: by mixing soil with 8% of Crushed Waste Concrete, the bearing capacity of the soil increased 4 times, and by mixing it with 6% of this material, the bearing capacity of the soil increased 3 times, while mixing gypseous soil with 4% of this material, the bearing capacity of the soil increased by 2.8 times. And by mixing the soil with 2% of Crushed Waste Concrete, the bearing capacity of the soil increased by about two times when compared to the untreated model with this material (0%). It can be observed from these results that the improvement rates for the second soil using such additive with different mixing proportions were less than for the first soil, and the reason for this is that the amount of gypsum increased from 30% to 46%, and its compressibility was more for the second soil model, which leads to more gypsum melting that permeate soil particles.

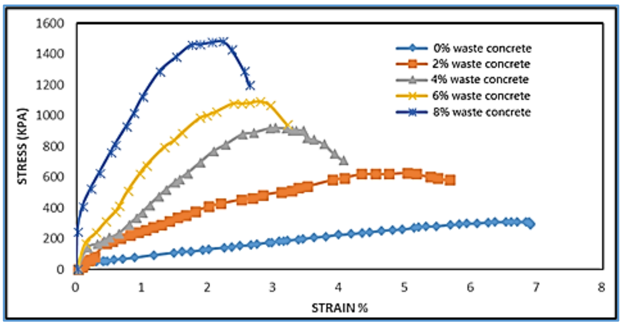


**Figure 7.** Stress-strain curve for soil 2 with 46% gypsum

### 3.3 Results of gypseous soil with 66% gypsum

Figure 8 represents the failure curve of the treated models of the third soil with a gypsum content of 66%, using concrete construction waste material. Where the results that were conducted on the laboratory model showed a good improvement in the bearing capacity of the soil after adding this material, and the highest improvement rate was achieved by adding 8% of this additive, where the bearing capacity of the soil increased by about 5 times compared to the model without treatment, while the bearing capacity increased to 3.5 times For the model mixed with 6% of this material, the increase was 2.5 times for the model treated with 4% of the Crushed Waste Concrete, While the increase in soil bearing capacity was 1.5 times for the model treated with 2% of this additive. We can infer from these results that the improvement in the bearing capacity of the third gypseous soil was reduced by increasing the proportion of gypsum, because most of the components of this soil are gypsum materials with high collapsibility when exposed to water, due to the melting of gypsum, which increased the compressibility of the soil subjected to loads. However, the improvement by using this additive was good and obvious. Therefore, these materials can be considered fair to use and recycled by making them useful in improving the collapsibility of gypseous soils when exposed to wetting from any source.

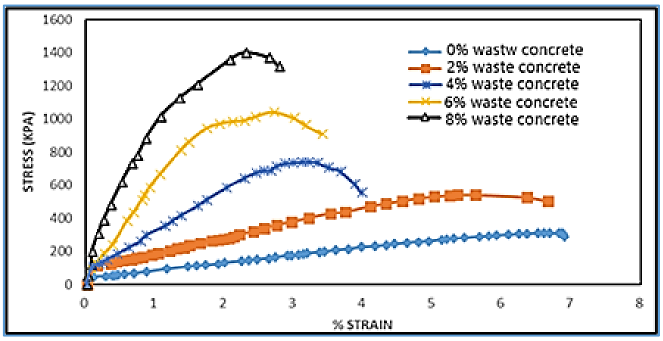


**Figure 8.** Stress-strain curves for soil 3 with 66% gypsum

The results showed a clear increase in the bearing capacity of all used soils, after adding Crushed Waste Concrete in general, and the best percentage of mixing was 8%, where the ultimate stress of the treated model increased about 8 times for the first soil and 4 times for the second soil and 5 times for the third soil. This is a significant and pronounced improvement for these problematic collapsible soils. The presence of water in this type of soil causes the dissolution of gypsum salts that permeate the soil particles, which leads to weak soil due to the formation of weak gaps of dissolved gypsum. By adding the powder of concrete residues to these soils, it fills the voids that fill the soil.

The crushed concrete soil amendment mechanism can be considered as a physical and chemical process at the same time. By using this waste resulting from the demolition and grinding of concrete structures, the bearing capacity of the soil increases and its compressibility decreases after adding concrete residues in different proportions due to the high strength of the crushed concrete particles and also to the increase of the induced bonding between the recycled concrete and the gypseous soil particles used in this study. The density of the soil and its bearing capacity increases after mixing it with the additive as a result of filling the voids Herein lies the physical therapy. On the other hand, crushed concrete is considered a good stabilizing agent when added to the soil in different proportions, as the non-camouflaged cement mortar in the additive interacts with the water in the gypseous soil when immersed, which leads to an increase in the bearing capacity of those soils. The increase in the higher soil stress test value can be due to the higher strength of the recycled concrete particles and also to the increased induced inter-linking between the recycled aggregate and the remaining fine particle slurry (<5 mm) containing higher amounts of residual non-aqueous cement which The chemical self-bonding property was derived from it, as this bonding material reacts after immersing the soil with water to form a material with good mechanical properties that increases the bearing capacity of the soil and in this case lies the chemical treatment.

Figure 9 shows the relation between the ultimate stress applied and the mixing ratios of construction waste used in the study for three gypsum soils with different ratios to show the effectiveness of this additive in reducing collapse and increasing the maximum bearing capacity on these soils.

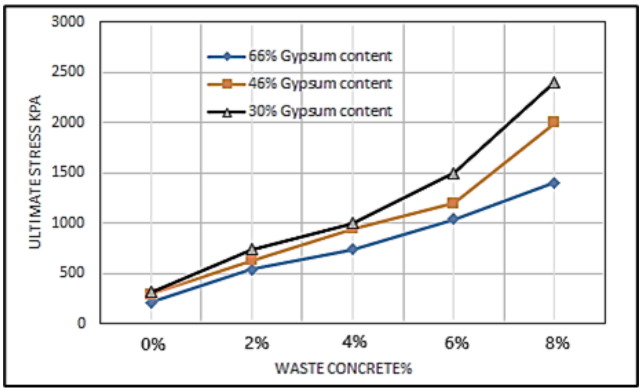


**Figure 9.** Relation between Crushed Waste Concrete mix percent and ultimate stress for three gypseous soils

## 4. CONCLUSIONS

In this study, a laboratory model was used and designed in a way that serves the engineering requirements as an alternative to the traditional laboratory devices, so that this model is closer to reality for the real behaviour of these types of soils with engineering problems that appear the moment they are immersed in water.

The presence of concrete construction waste in abundance constitutes a great burden on the living environment, so it has become necessary to find effective solutions to recycle these harmful materials and to think of a practical way to benefit from them in treating gypseous soils and reduce their compressibility during loading, by mixing them in certain proportions, where the results obtained from this study shows the possibility of benefiting from those unwanted materials resulting from demolition waste and harnessing them by making them useful materials that are environmentally friendly and economical at the same time, equal to or even exceeding the use of known costly stabilizers such as geogrid, geotextile or chemical additives that may cause great harm on the environment of living organisms. The use of crushed concrete construction waste and mixing it with the gypsum soil used in this study with a mixing ratio of 8% increases the bearing capacity of that soil for more than 6 times, which proves the effectiveness of these materials in improving the engineering properties of this collapsing soil.


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## REFERENCES

[1] Rezaei, M., Ajalloeian, R., Ghafoori, M. (2012). Geotechnical properties of problematic soils emphasis on collapsible cases. International Journal of Geosciences, 3(1): 105-110. https://doi.org 10.4236/ijg.2012.31012

[2] Abrahim, M.J., Mahmood, M.S. (2021). Effect of wetting progress on the potential collapse of gypseous sand using modified oedometer. International Journal of Engineering. Transactions C: Aspects, 34(12): 2636-2641. https://doi.org/10.5829/ije.2021.34.12c.08

[3] Nashat I.H. (1990). Characteristics of some gypseous soils in Iraq. Baghdad University, Civil Engineering Department Engineering Ph.D. Thesis.

[4] Ismail, H.N. (1994). The use of gypseous soils. Symposium on Gypsiferous soils and their effect on structures (Iraq: NCCL Baghdad).

[5] Abd-Awn, S.H., Abbas, H.O. (2021). Behavior of gypseous soil under static and dynamic loading. International Journal of Engineering, 34(8): 1882-1887. https://doi.org/10.5829/IJE 2021.34.08B.09

[6] AL-Zory, E.A. (1993). The effect of leaching on lime stabilized gypseous soil. M.Sc Thesis. Mosul University.

[7] Al-Murshedi, A.D., Karkush, M.O., Karim, H.H. (2020). Collapsibility and shear strength of gypseous soil improved by nano silica fume (NSF). Key Engineering Materials, 857: 292-301. https://doi.org/10.4028/www.scientific.net/kem

[8] Al-Deffaee, A.H. (2002). The effect of cement and asphalt emulsion mixture on the engineering properties of gypseous soils. M.Sc. Thesis. Department of Civil Engineering, Al-Mustansiriya University.

[9] Al-Hassany, H.Y. (2001). Gypseous soil improvement using fuel oil. M.Sc. thesis. Building and Construction Department, University of Technology, Baghdad.

[10] Al-Adili, A., Alsoudany, K.Y., Shakir, A. (2017). Investigation of crude oil pollution effect on stiffness characteristics of sandy and gypseous soil. Soil Mechanics and Foundation Engineering, 54(4): 276-282. https://doi.org/10.1007/s11204-017-9469-x

[11] Al-Aqaby, M.D. (2001). Effect of kerosene on properties of a gypseous soil. Doctoral dissertation, M. Sc. Thesis, Department of Civil Engineering, University of Baghdad.

[12] Fattah, M.Y., Al-Ani, M.M., Al-Lamy, M.T.A. (2014). Studying collapse potential of gypseous soils treated by grouting. Soils and Foundations Journal, 54(3): 396-404. https://doi.org/10.1016/j.sandf.2014.04.008

[13] Li, X.Y., Ning, S.Q., Zhang, P., Yang, W.L. (2020). Environmental pollution and health risks of heavy metals in the soil around a construction waste landfill. International Journal of Design & Nature and Ecodynamics, 15(3): 393-399. https://doi.org/10.18280/ijdne.150312

[14] Sözer, H., Sözen, H., Utkucu, D. (2020). Waste potential of a building through gate-to-grave approach based on life cycle assessment (LCA). International Journal of Sustainable Development and Planning, 15(2): 165-171. https://doi.org/10.18280/ijsdp.150206

## NOMENCLATURE

| | |
|---|---|
| C.P | Collapse potential of gypseous soil |
| T.S.S% | Total soluble salts percent in gypseous soil |

### Greek symbols

| | |
|---|---|
| $\phi$ | Angle og internal resistance of soil |
| $\gamma$ | Soil density kN/m$^3$ |