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Influence of Iron Furnaces Slag on Collapsibility and Shear Strength of Gypseous Soil

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A B S T R A C T

Gypseous soil is one of the soils that suffer from problems and suffers from a reduction of shear strength and collapse when exposed to water immersion or water filtration in it. Many researchers have tried to solve these problems in different ways and by using many materials as additives to improve the performance and efficiency of this soil. In this research, the behavior of soil with a high content of gypsum (61.49%) is examined, using iron slag which is a by-product of the iron making process in melting furnaces, used as an additive in proportions (2, 4, 6, 8, 10., 12) %, by dry mixing method with soil. Tests are carried out to determine the effect of this substance on the shear strength parameters. The effect of water immersion on soil cohesion (c) is reduced until it reaches (c) in the case of immersion a value very close to the value in the dry state at slag ratio (10) %. This is the optimum ratio of slag to improve the value of (c). Whereas for the value of (ø), with the increase of the slag rate for both wet and dry cases, the value of (ø) increases, where (ø) reaches the highest value at; the slag rate (10) % for the dry state, and the slag rate (8) % for the soaked case. Whereas for the collapse potential (Cp), adding the slag reduces the value of the soil collapse potential (Cp), from (10.6) to the soil without additives until (0.95) for the slag rate (12) %. Then the soil becomes problematic soil.

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تأثير خبث أفران الحديد على قابلية الانهيار وقوة القص في التربة الجبسية

جودت كاظم عباس / قسم الهندسة المدنية , كلية الهندسة , جامعة تكريت , العراق
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الخلاصة

التربة الجبسية هي واحدة من الترب التي تعاني من المشاكل وتعاني من انخفاض قوة القص والانهيار عند تعرضها لغمر الماء أو ترشيح الماء خلالها. حاول العديد من الباحثين حل هذه المشكلات بطرق مختلفة وباستخدام العديد من المواد كإضافات لتحسين أداء وكفاءة هذه التربة. في هذا البحث، تم فحص سلوك التربة التي تحتوي على نسبة عالية من الجبس (61.49 ٪)، وذلك باستخدام خبث الحديد الذي هو نتيجة ثانوية لعملية صناعة الحديد في أفران الصهر، وتستخدم كمضافات بنسب (2، 4، 6، 8، 10، 12) ٪، بواسطة طريقة الخلط الجاف مع التربة. تم إجراء اختبارات لغرض تحديد تأثير هذه المادة على معلمات قوة القص التي تأثرت بوضوح بإضافة الخبث. تم تقليل تأثير غمر الماء على تماسك التربة (c) حتى تصل قيمة (c) في حالة الغمر إلى قيمة قريبة جدًا من قيمتها في الحالة الجافة عند نسبة الخبث (10) ٪. هذه هي نسبة الخبث المثلى فيما يتعلق بقيمة(c) ، بينما بالنسبة لقيمة(ø) فإنها تزداد بزيادة نسبة الخبث لكل من الحالات المبللة والجافة، حيث تحصل القيم الأعلى لمقدار (ø)عند (10) ٪ نسبة الخبث للحالة الجافة، و (8) ٪ نسبة الخبث للحالة الغارقة. اما فيما يتعلق بإمكانية الانهيار(Cp) ، فإن إضافة الخبث يقلل من قيمة احتمال الانهيار للتربة(Cp) ، من (10.6) للتربة بدون إضافات حتى (0.95) لنسبة الخبث (12) ٪. ثم تصبح التربة تربة غير إشكالية.

الكلمات الدالة: التربة الانهيارية، خبث افران الحديد، الترب الجبسية، مقاومة القص، الغمر.

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1. INTRODUCTION

There are many problems encountered by the facilities that are built on gypseous soils, some of them are large, including those that lead to structural failure or impose expensive maintenance of these structures. The most important problems in gypseous soils are the decrease of shear strength when exposed to water or immersion, as well as decline or collapse, which may suddenly happen when the soil is soaked with water or when filtration occurred through the soil [1]. Gypsum is a sulfuric acid salt, its chemical symbol is ($CaSO_4.2H_2O$) [2], and it has a hardness value (2.0) on Mohs' scale [3]. Also, it has specific gravity of (2.32). It is white semi-transparent mineral salt [4], [5], and [6]. The solubility of water gypsum is very low (1.8 to 2.4 g / L) [7]. The terms "gypseous soil" and "gypsiferous soil" are synonymous terms [8]. The gypseous soil covers more than (20) % of the territory of Iraq [9]. Buringh [10] drew the first map on the distribution of gypseous soil in Iraq as shown in Fig. 1.

Many researchers tried to study the effect of many additives on the behavior of gypseous soils, Ibrahim in 2017 examined the improvement of gypseous soil properties by using the silicone oil to minimize the effect of moisture on these soils [11]. Awn in 2012 tried to improve the gypseous soil with a high gypsum content by reducing the collapsibility by adding Portland cement (resistant- salts) [12]. Aziz in 2011 concentrates on the suitability of fuel oil in improving gypseous soil [13]. Iron furnaces slag (IFS) or blast furnaces slag (BFS) is defined by (ASTM C 989-99, 2003) as "non-metallic product consisting essentially of calcium silicates and other bases, developed in a molten condition simultaneously with pig iron in a blast furnace" [14]. The main oxides in (BFS) are silica, alumina, and magnesia; also, there are some secondary oxides as sulfur oxides and iron oxides [15], [16]. Thus, the aims of this paper is to study and evaluate the effect of "Blast Furnaces Slag (BFS)" on the collapsibility and shear strength parameters of the gypseous soil.

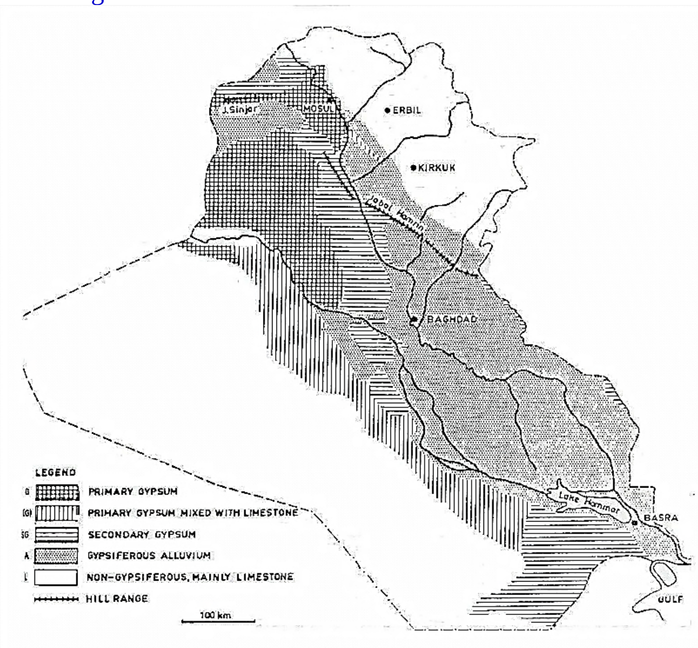

Fig. 1. Distribution of gypseous soil in Iraq (Buringh, 1960)[10]

2. MATERIALS

Soil: The soil sample was collected from the site of the University of Tikrit / Salah Al-Deen governorate west-north of Iraq. It is collected after removing the upper soil for a depth of (1.2) m until reaching a natural soil with high gypsum content as obvious by vision, the tests were conducted in the laboratories of Tikrit University / College of Engineering, the properties of the soil are shown in Table 1. Also, an (XRD) examination was conducted in the geological survey laboratories / Ministry of Industry / Baghdad. The results for soil are present in Table 2.

The iron furnaces slag sample was brought from the industrial zone near Zakho north of Iraq, its grinding was done after drying it at the temperature of (40) C°. Table 1 presents the physical test (Gs). Table 3 shows the results of the slag oxides test. Whereas the (XRD) scan results for the slag are presented in Table 4. This material, which is an accidental product of the iron industry and stacking it outdoors, which negatively affects the environment, for benefiting from it.

3. EXPERIMENTAL WORK

The work included conducting tests on soil specimens, before and after mixing them with the weighted proportions of the proposed slag percentage, for each one of the direct shear tests in both dry and soaked conditions, as well as for the collapsibility test.

3.1 Direct Shear test

The direct shear test is carried out according to the standard (ASTM D 3080-98) [17]. The specimens are prepared by mixing the soil with the slag and then left for (24) hours inside a plastic wrap tightly sealed. The specimen shall be placed inside the apparatus box and the test begins in the dry state directly. While, in the soaked case, after placing it in the test apparatus box, the specimen is immersed in water for one hour and then testing it [7].

3.2 Collapsibility test

The collapsibility is one of the most important characteristics of gypseous soils. There are many methods to determine the soil collapsibility; the most important and the most widely used is "one-dimensional oedometer test", which includes two methods [18]:

1- "Single Oedometer Test, (SOT)", An examination proposed by "Knight" in 1963. In this research this test is adopted, this test is conducted by using the oedometer apparatus. The mixture was put inside the mold of the device with compacting until the sample reached to the density of the field. The determinations must be done and drew the relationships that represent (e -log σv). For both dry and immersed parts in the same scheme and note that there is a vertical line on the stress axis when the stress value is (200) kPa, this dropped line represents the collapse index or collapse potential when the amount is divided by the original height of the specimen [19]. Then the collapse potential (C_P) is calculated as the following formula:

$$CP = \left(\Delta e \div (1 + e°)\right) * 100\% = (\Delta H \div H°) * 100\% \quad \ldots\ldots\ldots\ldots (1)$$

Where: Δe: change in voids ratio due to water immersion, $e°$: initial voids ratio, ΔH: the change specimen height due to water immersion, $H°$: The original specimen height .

2- "Double Oedometer Test, (DOT)". An examination proposed by [20], they classify the collapsible soil according to the amount of the collapse index, which is named according to the American standard (ASTM) [19], called (Ic), as in Table 5.

Table 1
Results of tests on soil and slag

Chemical Tests on Soil Sample					
No	**Test**	**Test Name**		**Value**	**Unit**
1	Gypsum content	SO_3 content		58	%
2	Gypsum content	Method of Al Mufty and Nashaat (2001) [3]		64.98	%
	average of gypsum content			61.49	%
Physical And Mechanical Tests On Soil and Slag Sample					
No	**Test**	**Test Name**	**Specification**	**Value**	**Unit**
1	Soil field density (γ_{field})	sand – cone test method	ASTM - D 1556 -90	1.45	g/cm³
2	water content of soil (ω)	moisture content	ASTM D - 2216 -71	5.5	%
3	field dry density of soil ($\gamma_{.d}$)	sand - cone method	ASTM - D 1556 -90	1.374	g/cm³
4	specific gravity (Gs) of soil	Specific gravity of soil	ASTM D - 854 -92	2.488	
5	AASHTO Classification of soil			A-3	
6	USCS Unified classification of soil			SP	
7	specific gravity (Gs) of Slag	Specific gravity of slag	ASTM C-127	1.835	

Table 2
Mineral in the soil, XRD test results

Symbol	**G**	**Q**	**C**
Name of Mineral	Gypsum	Quartz	Calcite
Chemical composition	$CaSO_4$	SiO_2	$CaCO_3$

Table 3
Chemical composition of (BFS) sample

No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	others
Percent On (BFS) %	22.16	8.37	6.11	28.96	4.15	0	30.25

Table 4
Mineral in the Slag, XRD test results

Symbol	**Q**	**F**
Name Of Mineral	Quartz	Feldspar
Chemical Composition	SiO_2	$CaAl_2Si_2O_8$

Table 5
Collapse index classification according to Jennings and Knight, 1975 [20] and (ASTM D-5333 -03). [19].

Jennings and Knight, 1975 [21]		ASTM (D5333-2003) standard [20]	
C_p, (%) at 200 kPa	Severity of problem	I_C, (%) at 200 kPa	Degree of collapse
0-1	No problem	0	None
1-5	Moderate trouble	0.1-2.0	Slight
5-10	Trouble	2.1-6.0	Moderate
10-20	Severe trouble	6.1-10.0	Moderately severe
More than 20	Very severe trouble	More than 10.0	Severe

4. RESULTS AND DESCUSSION

4.1 Direct shear test

The test of direct shear was performed using the ratios of the additives mentioned above. The Table 6 confirms the results for dry and immersed cases. Fig. 2 represents the relationship of (cohesion force (c)) with (slag ratio %) for (dry and soaked conditions). While for the friction angle (ø) Fig. 3 represents the relationship of (internal friction angle) with (slag ratio %) for (dry condition) and (soaked condition).

As obvious when the slag percentage becomes equal to (10) %, as shown in Table 6 and Fig. 2, in the soaked state the value of (c) increases significantly until it reaches its highest value in the curve. This value is close to the (c) value at the same ratio of slag in the dry state. From the above, it can be concluded that, the slag ratio (10) % is the optimum ratio for improving the cohesion value of (c) in sandy soil with high gypsum content. This can be attributed to the fact that when the slag is added to the soil, the fine slag particles will surround some of the particles and grains of the soil and gypsum grains, the quantity of these surrounded particles is proportional to the amount of added slag ratio, (means, the surrounded particles are increased by increasing the amount of added slag), thus reducing the cohesion of gypsum particles and then decreasing the value of cohesion by increasing slag content in the dry state while at the same time giving the role for slag particles as a new bonding material in the soaked state. As for the change in the result of the slag ratio (12%) compared to the result of the slag ratio (10%), it may be due to the difference in the diameters of the soil granules and slag or from the difference in the intensity of mixing between the soil and the slag. While for the value of the internal friction angle (ø) under effecting of soaking, it went down to nearly half of its value in the dry state when the content of slag was (0) %, the effecting of immersion is decreased as concerned with the (ø) value by increasing the ratio of slag until it reaches the highest value of (ø) when the slag ratio equaled (8) %. From this it can be concluded that the best slag ratio to improve the value of the gypseous soil internal angle of friction is the slag ratio (8) %. The internal friction is coming from the interlocking phenomenon between the soil particles [21], the cause of the slag effect on the values of friction angle (ø) is that the slag particles are made up of quartz powder and feldspar which has sharp angles, the interlocking property is approximately equal to or similar to that in sandy soils, these slag particles are surrounding the soil granules, and that gives the mixture a new internal friction; this is attributed to the slag features with difficulty of dissolving of slag particles in water. It can be concluded that the values of (c) and (ø) can be improved by using the slag ratio of (10) % as shown in Table 6, and figures Fig. 2 and Fig. 3.

4.2 Collapse Potential test

The double oedometer test method may give an exaggerated potential collapse results to approximately 10%. This is why selecting the single oedometer test may have been more useful in the study [22] and [23]. The tests were conducted to measure the values of collapse potential (Cp). The test was re-carried out for each approved added percentage of slag. The ratios of slag were used in the tests were as follows; (2, 4, 6, 8, 10, and 12) %. The figures which represented the relations of (strain- log app. stress) for each of slag ratio are shown in the figures starting from Fig. 4 to Fig. 10. These data are used to obtain Table 7 which represents the (Cp) values for each percentage of slag which were added to the gypseous soil, and the degree of improvement (ID) obtained from it by calculating it by equation (2). The reader can note the differences in the performance and efficiency of slag proportions in gypsum soils in terms of probable breakdown (Cp), which is shown by making charts for ease of comparison and to determine the direction of the process more clearly, as shown in Fig. 11.

Improving degree $ID = \left((Cpx) - (Cp°)\right) \div Cp°$.... (2)

Where; Cpx = collapse potential for soil with X % slag ratio, $Cp°$ = collapse potential for soil with 0% slag ratio.

From the results presented above, the potential collapse (Cp) for the gypseous soil amounts to (0.95) when the slag ratio equaled (12) %, which according to the specifications specified in Table 5, the soil becomes without problems of a collapse. For illustration of the decrease that happened in the potential collapse values of that soil by adding the slag, adding of the slag is leading to be surrounding the soil particles by the slag particles and forming what looks like a cover around the gypsum granules, which prevents the contact between the gypsum with water or reduces it significantly, therefore that the gypsum particles solubility in water was reduced, which leads to reduce the value of (Cp), and the increase of added slag ratio. This means increasing the number of slag particles surrounding the gypsum particles, and that decreases the value of the (Cp) of soil. The general line direction of the process is moving towards a decrease of (Cp) values with an increase in the slag ratio.

Table 6
Cohesion and friction angle of the soil with slag percentages. (dry and soaked)

Test No.	**Slag ratio**	**dry state**		**soaked state**	
		c kPa	**ø degree**	**c kPa**	**ø degree**
1	0%	14.786	27.434	8.5425	15.147
2	2%	12.553	27.713	8.2265	15.088
3	4%	13.377	31.07	8.853	17.380
4	6%	11.698	31.437	6.662	20.4756
5	8%	12.204	33.177	5.5565	21.067
6	10%	11.276	34.165	10.807	19.305
7	12%	10.688	34.078	7.8795	20.037

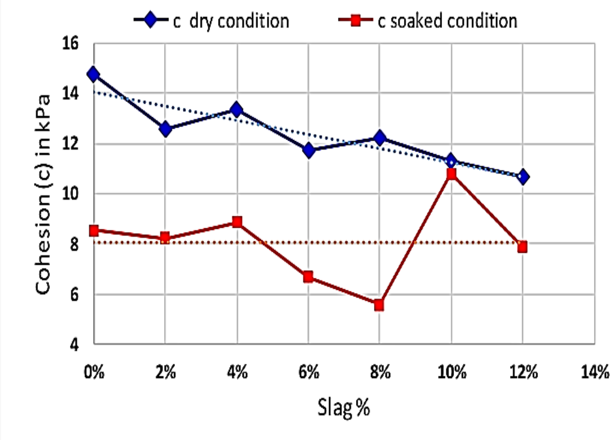

Fig. 2. Relation of c – Slag%. For dry and soaked condition

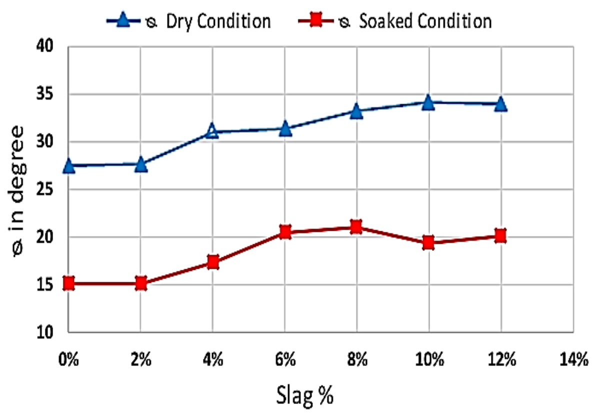

Fig. 3. Relation of Ø –Slag%. For dry and soaked condition

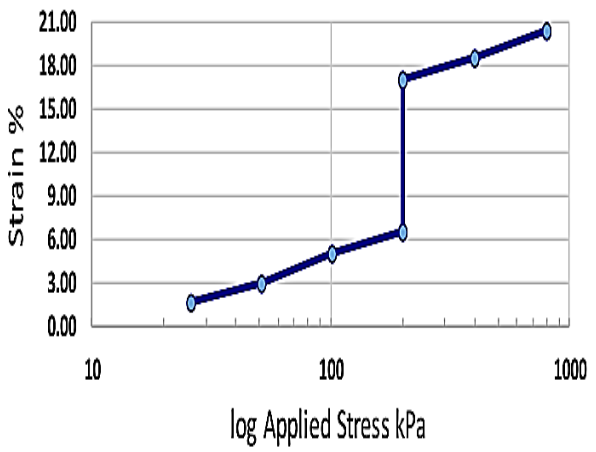

Fig. 4. Strain- log stress relation for the gypseous soil with 0% slag as additive

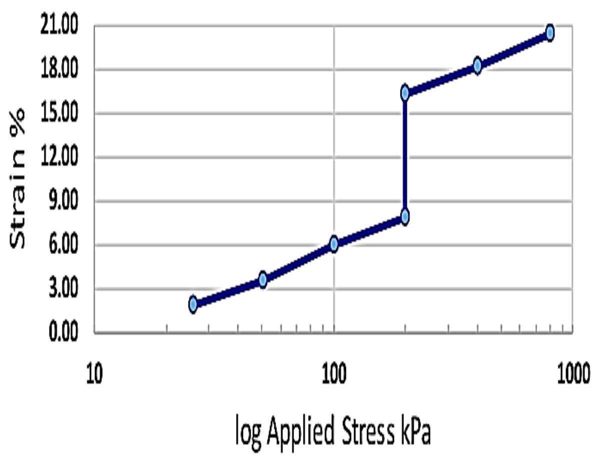

Fig. 5. Strain- log stress relation for the gypseous soil with (2%) slag as additive

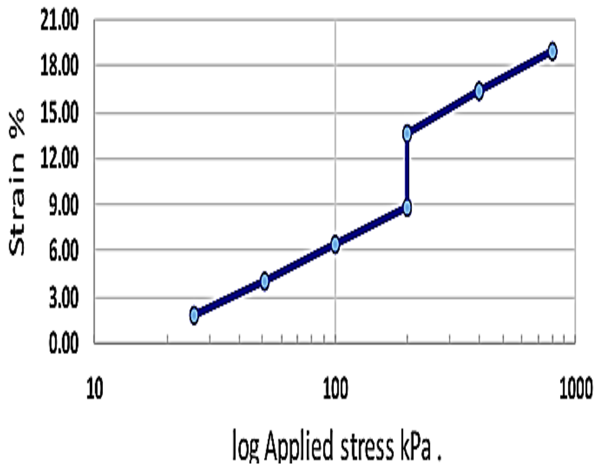

Fig. 7. strain- log stress relation for the gypseous soil with (6%) slag as additive

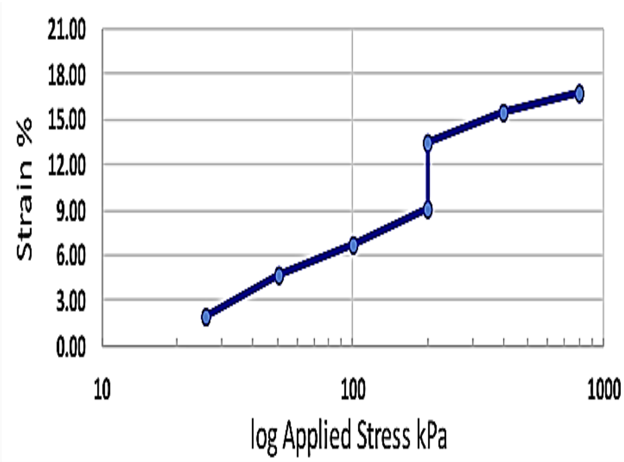

Fig. 8. Strain- log app. stress relation for the gypseous soil with (8%) slag

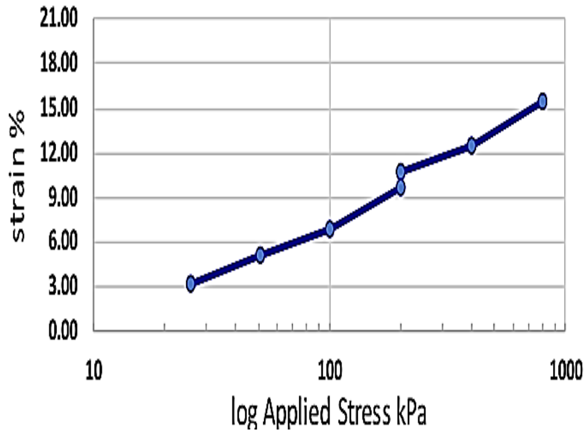

Fig. 9. Strain- log app. Stress relation for the gypseous soil with (10%) slag as additive

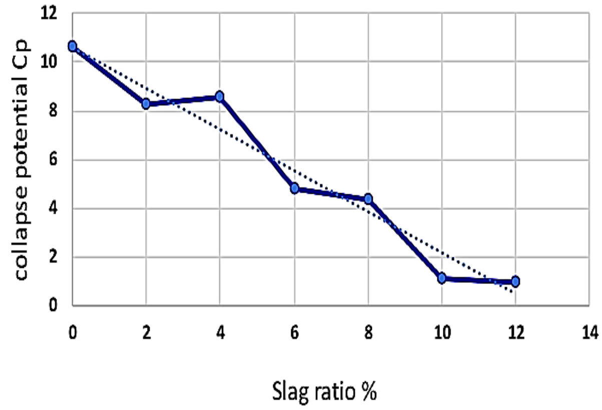

Fig. 10. Strain- log app. Stress relation for the gypseous soil with (12%) slag as additive

Table 7
Collapse potential and degree of improvement for different slag ratio

No.	Slag %	Collapse Potential (Cp)	Improvement Degree (ID) %
1	0	10.6	0.000
2	2	8.25	22.170
3	4	8.55	19.340
4	6	4.8	54.717
5	8	4.35	58.962
6	10	1.1	89.623
7	12	0.95	91.038

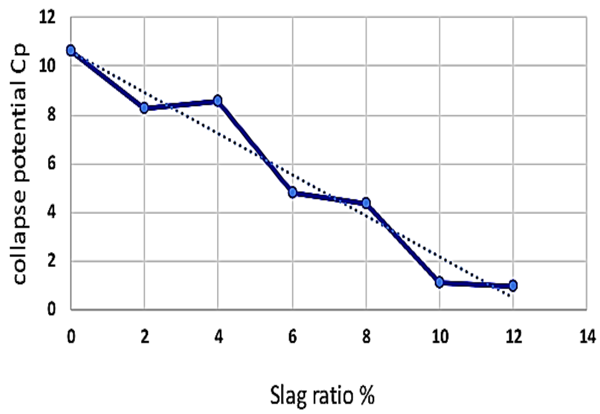

Fig. 11. Collapse potential (Cp) – Slag ratio % relation

5. CONCLUSION

The effects of slag on the values of (c) and (ø) and collapse potential (Cp) are as follows:

- In dry case, the cohesion value (c) decreases as compared with its value without the additives. The loss in value of c equals (23.74) % which happens when the slag ratio is (10) %. It is the best slag ratio to improve the (ø) value
- In dry case, the highest internal friction angle (ø) is got when the slag ratio is equal to (10) %.
- In wet case, the peak of increase in the cohesion (c) happens when the slag ratio is (10) %
- In wet case, the angle of internal friction (ø) reaches its peak increase at the slag ratio (8) %.
- The decrease in (Cp) values continues with the increase of the slag percentage until the value of the potential collapse (Cp) equals to (0.95) when the slag ratio is equal to (12) % and here the degree of improvement (ID) in the values of collapse potential reaches (91.04) %.
- The optimum percentage of slag as an additive is (10) %.

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