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Improvement of Gypsum Soil Properties by using Novolac polymer

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Abstract

This paper is a tamped to improve the engineering properties of gypseous soil by adding novolac polymer. The soil samples brought from the west of Karbala city with 36% of gypsum content. The research was carried out by adding a different percentage of novolac polymer (3%, 6%, 9% w/W) respectively and comparing the results with other samples treated with cement in the same percentages. The targeted engineering properties are permeability, shear strength, and collapsibility. The results showed that 3% w/W of novolac gives the best improving in collapsibility which is improved to 57.8 while 6% w/W of novolac improved both the bearing capacity and the permeability which improved to (25.2 and 86.2%) respectively.

Keywords: *Gypseous Soil , Collapsibility, Permeability , Novolac Polymer,cement*

1. Introduction

The gypseous soils are specifically considered as difficult unsaturated soil that hard to deal with during the construction of roads, strategic projects, and buildings which need in site improvement. The mechanical and physical properties of the gypseous soil affected by the amount of the gypseous in the soil and, the higher gypsum percent made this soils more sensitive to water [1]. Generally, Gypseous soils are widespread in different places of the world especially in dry and semi-dry areas where (Calcium Sulphate sources) when no enough amount of water for the washing process and it can be spread on the surface or in different depths of the soil [2], [3] .In natural condition, gypseous soil appears to be clearly strong, hard and capable to support a heavy load with small deformation but unfortunately, these mechanical properties affected when the water seeps to soil and start changing the arrangement of their molecules [4]. Moreover, the soil begins to deform and dissolution of the cementing gypsum occurs as the voids filled with water which finally increases incompressibility and reduces the bearing capacity. In the dry state, the strength in mechanical properties of the gypsum soils referred to first, the gypsum bond (cementation gypsum) between the particles second, the void filled with gypsum become stronger under the influence of compaction [5]. Some researchers set a lower rates limit to the percent of gypsum that effect on the engineering and mechanical properties of soil such as (2%, 4%, and 6%) [6], [7]. However, to diminish the damage level caused by gypseous soils to the construction and building the soil improved. Commonly, there are two improving procedures: mechanical and chemical. In the past two decades, the properties of gypseous soils have been developed for the purpose of engineering construction. Many traditional materials used to improve the engineering properties of the gypseous soil such as cement, lime, fly ash. Even though these additive have good improvement results still consuming time and have to be in large quantities to achieve the improvement purpose [8] which made researches looking to use non-traditional materials such as Polymers that have good properties in terms of the tensile strength, pressure, and adhesion between the soil particles. Also, the polymers have good resistance to the effects of water and other chemicals. Some researchers studied the effect of polymer on a different type of soil like:

In 2010, Al-Neami [9] used (2, 4 and 6%) clinker additive to treat gypsum soil from Al-Exandria, Babylon and found that the best clinker ratio was (4%) which decreased the collapsibility of soil.

In 2010, AL-Numani [10] took a soil sample from Najaf that contains 35% of gypsum and treated it with different rates of cement content (4-8%). The conducted laboratory tests indicated that increasing the cement content produced an increase in both the optimum water content and maximum dry density to (23.3 and 7.6%).

(A. Zandieh, 2010) [11] Used two types of polymer to improve sandy soil and his results showed an increase in compression strength by (0.03 - 5.2) mPa.

In 2017, Ibrahim and Schanz [12] used mixture of 30% of Silber sand and 70 % of Pure Gypsum and treated it with different percentage of silicone oil to improve the engineering properties. The study results showed the silicone oil was able to improve the collapsibility and shear parameters of the gypseous soil.

Chao Xing1, 2018 [13] Who used polymer on the sand in a dry and wet condition and his results showed an increase in strength.

(Mohanned Waheed1, 2018) [14] Found that polymer is more suitable in coarse-grained soils, besides it is less effective in the soft soils.

In 2018, AL- Hadidi and AL-Maamori [15] used gypsum soil sample with 42.55% gypsum from Karbala city. Different water cement ratios (W/C) were used to decrease the collapsibility of earth canal and the results showed that 2 % of W/C led to decrease the collapsibility of soil.

In 2018, Vahid and Mohsen [16] took sand samples from Kerman city, Iran and mixed them with 2, 4, and 6% of polymer with different period of treatment (3, 7, and 28 days). They found that when the polymer content increased to 6%, the unconfined compressive strength increased by (66.31 %) in 28 days compared with 3 days.

In 2018, Al-Hadidi. and Ibrahim [17] used 6, 10, and 12% of polyurethane to reduce the soil erosion of irrigation canal which was made from gypsum soil in Karbala city with 41% gypsum. The researchers found the best percentage to use was 10% which reduced the erosion by 86.2%.

The main goal of this study is to improve the properties of gypsum soil (collapsibility, permeability, bearing capacity, and compaction parameter) with small quantities and suitable prices by using new non-traditional materials novolac polymer

2. The Material Used and Experimental Work
A. Materials

2.1. Gypseous Soil

To achieve the purpose of study, natural gypseous soil of 36% gypsum; is taken from one location about 100 km southwest of Baghdad (west of Karbala city on the edge of Anbar province). The samples were taken from depths (0.5 – 1) m below the natural ground surface. The unit weight of the soil in the location was 14.5 kN/m^3 and the natural water content 5%.The undisturbed soil samples were air dried, made homogenous, put in plastic bags and transported to soil mechanics laboratory at civil engineering department, college of engineering at AI-Qadisiyah University to evaluate the engineering properties of the soil. Figure (1) shows an image from Google earth for the location of soil sample.

Figure (1): Site of soil sample

2.2. The Cement

For results comparing purposes, normal Portland cement has been used in this study to improved gypseous soil properties of. A Portland cement ratio of (3, 6, 9) % has been used during the tests. Table (1) showed the chemical composition of the used cement.

Table 1. The result of chemical test for cement

Element	percentage
SiO_2	20.21
Al_2O_3	5.97
C_3S	40
C_2S	38
C_3A	2.9
C_4AF	11.7
MgO	4.3
K_2O	1.98
Fe_2O_3	4.1

2.3. Novolac Polymer

Novolac polymer defined as the reaction between phenol-formaldehyde and phenol in acid catalyst media and consists of (5-6) % of gasoline rings per molecule. The common properties of Novolac polymer are:

1. It has a small molecular weight and thermoplastic, which made it widely used in industry and binder for carbon bonding refractories because of his chemical resistance and electrical insulation [18].
2. Porous structure with less mechanical properties.
3. The curing reaction for the novolacs polymer is carried out over 100 °C.
4. It has a density of (1- 2) % of the density of soil with color ranged from yellow to orange and PH number less than (7) [18].

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Figure.2 Novolac polymer

B. Experimental Work

1.Compaction Test

Standard Procter compaction test was carried out in accordance with (ASTM 698) method A [19]. A mold of 10 cm in diameter and 16.5 cm in height was used. The samples were compacted in three layers with 25 blows for each layer using a 2.5 kg hammer which is dropped from 30.5 cm height and this test was carried out for treated and untreated soils.

2.Collapse Test

Single collapse test was carried out according to the guide proposed by Jennings and Knights [20] and ASTM D5333 [21] on natural compacted and treated gypseous soil samples with various ratios of co-polymer, novolac polymer. The dry weight of specimens was obtained to determine the change in compressibility properties of gypseous soil by using specimens equipped with a ring which was 50 mm in diameter and 19 mm in height. The samples were left in the water for 24 hours with a pressure of 200 kPa and then additional static load was applied until it reached 800 kPa then samples were unloaded. The collapse index is obtained from the formula below by using (e-log p) graph under the effect of a certain stress level.

$$C.P = \frac{\Delta e}{(1 \oplus e^{o})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where:
C.P = Collapse Potential.
Δe= void ratio before and after soaking.
e^{o}= Initial voids ratio.

3. Permeability Test

Permeability test was performed for all samples (treated and untreated soil) according to ASTM D-2434 [22] .A mould with 10 cm in diameter and 13 cm in height was used. The mould was connected at the top inlet to a water source at a height of 180 cm. The mould had a side outlet at the bottom for the water to flow out of the sample. The quantity of flow for a certain time period was collected and recorded. The permeability coefficient was calculated using the equation:

$$K = \frac{Q}{(A \times I)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where:
k = coefficient of permeability.
Q = V/T quantity of water discharged.
L = the height of mold.
A = cross-sectional area of mold
t = total time of discharge.
h = the loss of water.

3. Physical and Engineering properties of Gypseous Soil

In order to determine the engineering properties of the soil has to be treated (gypseous soil), physical tests have been carried out in the lab and the results listed in Table (2). The specific gravity of the soil is determined according to BS 1377[23], but Kerosene was used instead of water due to the dissolution action of gypsum in water.

The soil was subjected to grain size distribution test according to ASTM D422 [24] to classify the soil. Figure (3) clearly shows that the soil can be classified as poor grade sand (SP) according to the Unified Soil Classification System (USCS).

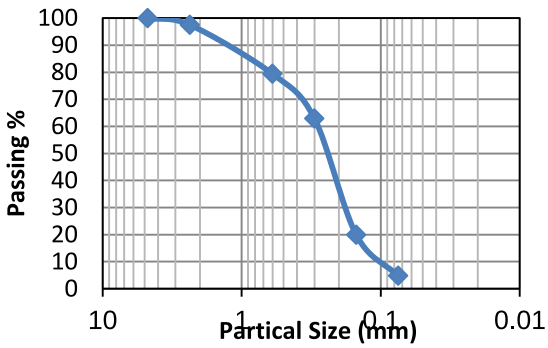


Figure .3 Grain size distributions of gypseous soil

Table2: The results of physical properties tests of gypseous soil.

Physical Property	Value
Specific gravity, G_S	2.54
D_{10}	0.1
D_{30}	0.19
D_{60}	0.3
Coefficient of curvature, C_c	1.203
Coefficient of uniformity, C_u	3
Unified Classification system	SP
Maximum Dry Unit Weight $\gamma_{d(max}$ (kN/m^3)	16.28
Optimum Water content ω_{opt} (%)	11
Permeability(cm/sec)	1.7×10^{-3}
Direct Shear (c (kN/m^2) and ϕ°)	C=1.33 ϕ=30.2°
Single Collapse (%)	9.47

3.1. Chemical Tests

The chemical and X-ray tests were carried out on gypseous soil used as shown in the results (see Table (3) and Table (4)). The chemical tests carried out at two different laboratories that specialize with this kind of tests the first one is located at the Karbala university of where the other one is the state company of Iraq Geological Surveying and Mining Baghdad lab.

Table3: The results of chemical properties tests of gypseous soil

Chemical Property	Value
Total (SO_4%)	13.87
Total soluble salts (T.S.S %)	9.8
Gypsum content (%)	36
PH value	8.21
CL (%)	0.00319
O.M (%)	0.86

Table 4: The results of X_ ray test of gypseous soil

Element	Wt. %	Wt. % sigma
O	53.46	0.3
Na	0.56	0.07
Mg	1.8	0.07
Al	3.4	0.08
Si	20.08	0.18
S	5.06	0.1
K	1.64	0.07
Ca	11.65	0.14
Ti	0.13	0.06
Fe	2.23	0.12

4. Results and Dissection

4.1. Compaction test

The results showed little change in maximum dry unit weight in improved soil where it increases with the increase of the cement content to (5.22%) at (9%) of cement. In another hand, the novolac polymer result showed that increasing the polymer content lead to a decrease in the maximum unit weight to (1.72 %) at (9%) novolac polymer In case one, this increase can be attributed to the fact that the cement-filled the void between the soil particles. In case two, the decreasing the polymer results can be also returned to the reason that the polymer has a lightweight and this light density leading to replace some of the soil partial with novolac polymer creating a new soil structure with different volume .In another hand, the results showed a continuous increase in water content with both additive materials compares to natural soil this increasing due to increase in fine materials and water that required for the cement and novolac hydration.. Table (5) and figures (4 and 5) showed all the results of compaction tests for the soil in a natural state and after improving.

Table (5) : The result of compaction test of gypseous soil treated by cement and Novolac polymer

Materials	Maximum dry unit weight(kN/m^3)	Optimum moisture content (%)
Untreated soil	16.28	11
Soil +3% cement	16.49	12.5
Soil +6% cement	17.13	13
Soil +9% cement	17.28	15
Soil +3% novolac polymer	17.18	13
Soil +6% novolac polymer	16.5	16
Soil +9% novolac polymer	16	17

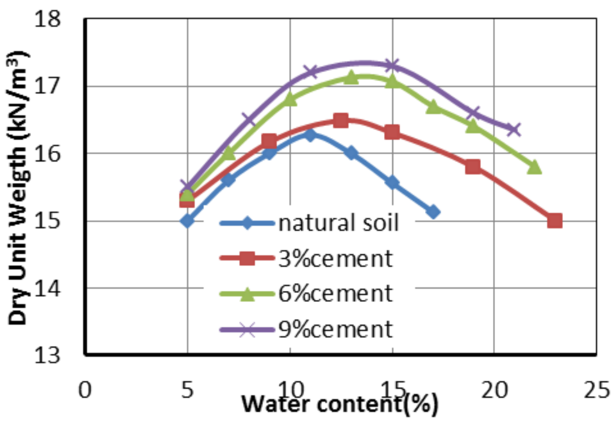


Figure 4: The Result of compaction test of gypseous soil treated by cement

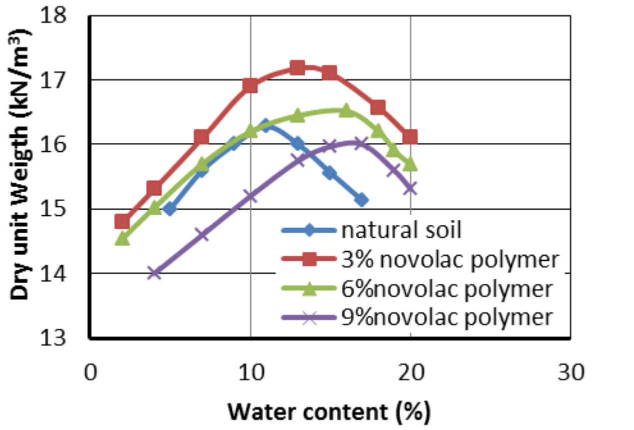


Figure 5: The result of compaction test of gypseous soil treated by Novolac polymer

4.2. Collapse Test

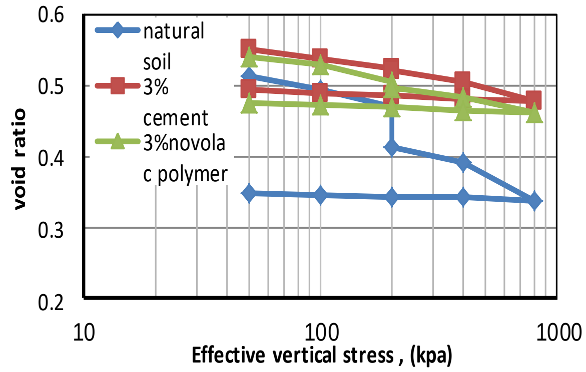
The collapse test was carried out for both natural and improving samples. All used samples were compacted to (16.28 kN/m3) maximum unit weight and (11%) optimum water content. It has been noticed that the collapse potential decreased to (64.4%) at (6%) of cement. Also, the results showed that additive cement starts to work inversely on collapse after that. However, compared to cement the novolac polymer results showed opposite behaviour where the collapse potential increased by increasing the polymer content. The results showed that adding (3%) of novolac polymer decreased the collapse by (57.8%). The reduction in collapse potential with additive cement can be assigned to the fact that the cement work on increasing the connection between soil particles creating a stronger structure. In novolac polymer the reduction can be assigned to the fact that the polymer flocculates the soil particles by spreading and sliding them resulting in fewer connections between them which is finally lead to an increase in the volume of samples and reduction in dry unit weight. Tables (6), (7) and Figure (6) below shows the collapse test results to all tested samples.

Table (6): The result of collapse potential (%)

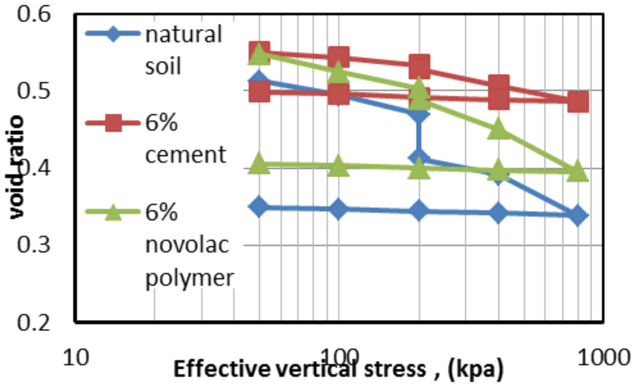
Case	Collapse potential (%)
Untreated soil	9.47
Soil+3%cement	4.26
Soil+6%cement	3.37
Soil+9%cement	3.53
Soil +3% novolac polymer	4
Soil +6% novolac polymer	4.58
Soil +9% novolac polymer	6.8

Table (7): Summary of the percentage of improving in the collapse potential (%)

Percentage added	3%	6 %	9%
Material			
Cement	55	64.4	62.72
Novolac polymer	57.8	51.85	28.19



(a)



(b)

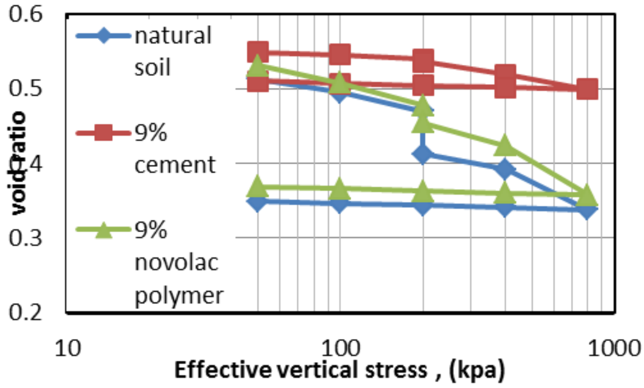


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Figure 6(a,b,c): Single collapse test of gypsous soil treated by cement and novolac polymer

4.3 Permeability test

All the permeability tests result details are shown below in the Table (8 and 9). The test has been contacted to natural and treated soil that compacted to the maximum dry unit weight. It has been noticed that the permeability coefficient decreased as the additive cement content increased. The results showed that (9%) of additive cement able to decrease the permeability coefficient by (88.65 %).In another hand, (6%) of novolac polymer help to minimize the permeability coefficient by (86.2%) as the best improvement value compares to others. Both materials work as waterproofing by covering the gypsum particles and filled the voids among them resulting in a reduction in the dissolution of gypsum in water and reduction in the destruction of soil mass structure.

Table (8) : The result of permeability test of gypseous soil treated by cement and novolac polymer compare to natural soil

Material	3 %	6%	9%
cement	3.5×10^{-4}	3×10^{-4}	1.93×10^{-4}
Novolac polymer	5.31×10^{-4}	2.35×10^{-4}	3.69×10^{-4}
Natural soil under compaction	1.7×10^{-3}		

Table (9): The summery of improving in permeability factor compare to natural soil

Material	3 %	6%	9%
Cement	79.4	82.35	88.65
Novolac polymer	68.8	86.2	78.3

4.4 Direct shear test

The bearing capacity has been studied for both natural compacted and improved soils using Terzaghi equations and the shear strength parameters which are calculated in the laboratory by running the direct shear tests [25]. It' has been noticed that increasing both cement and novolac polymers contents to (6%) able to improve the bearing capacity of soil by (104 and 25.2 %) respectively. any farther increments result in a decrease in the bearing capacity of the tested samples .This improvement in results can be assigned to the fact that these materials work on increasing the bonding and cementation between the soil particles resulting in a high value of cohesion parameter.(see Table (10)and (11)).

Table (10) : The result of bearing capacity of gypseous soil treated by cement and novolac polymer

Material	3 %	6%	9%
Cement	403.76	644.63	536.45
Novolac polymer	310.57	395.46	279.1
Natural soil under compaction	315.95		

Table (11) : The summery of result of changing the bearing capacity compare to natural soil under compaction

Material	3 %	6%	9%
Cement	27.8	104	69.8
Novolac polymer	-1.7	25.2	11.66

5. Conclusion

1. The change in maximum dry unit weight was no clear enough (increase/decrease) where the results showed that the maximum dry unit weight increased by increasing the cement content while it behaved reversely with novolac polymer (decreased by increasing the additive amount).
2. The additive materials contribute to redact the collapse potential where the results showed that (6%) of cement content able to minimize the collapse by (64.4%) while only (3%) of novolac polymer helps to decrease it by (57.8%).
3. The permeability coefficient decreased with increasing the amount of both additive materials especially at (9%) of cement and (6%) of the novolac polymer.
4. The bearing capacity has been increased with both additives (cement and novolac polymers) where the results showed that only (6%) of each cement or novolac able to improve the bearing capacity by (104% and 25.5%) respectively.
5. In terms of cost, novolac material is expensive. The basic structure of this material is oil derivatives and the high price of it is due to the technology used in the manufacturing and importing as mentioned before. However, if there is a production factory inside the country that provides such kind of additives, the cost might be lower or even close to the cement price.

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