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Using High-Density Polyethylene and Novolac Polymers to Improve the Properties of Gypseous Soil

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Abstract

This study explores the impact of adding high-density polyethylene (HDPE) and Novolac polymers to gypseous soil from Tikrit City, Iraq, to enhance its geotechnical properties. The soil contained 38% gypsum, and the polymers were added in varying proportions (1%, 3%, 6%). Both polymers improved maximum dry density, optimum moisture content, and reduced collapse potential (Ic). The collapse potential was reduced by 64%, 77.7%, and 83.2% at 1%, 3%, and 6% HDPE content, respectively. The collapse potential was reduced by 82.3%, 74.8%, and 51.9% at 1%, 3%, and 6% Novolac polymer content, respectively. In the dry conditions, the internal friction angle increased by about 22.9% and 5.7% as the HDPE content was increased by 3% and 6% respectively. Adding Novolac polymer also increased the internal friction angle by about 5.7% by the addition of 3% Novolac polymer. In soaked conditions, the best increase in internal friction angle (ϕ) was 30% with the addition of 3% HDPE polymer. the internal friction angle increased by about 26.7% by adding 1% and 3% of Novolac polymer. The study concludes that adding HDPE and Novolac polymers can improve geotechnical properties, but their effect on CBR is complex and depends on the polymer percentage added and soil moisture state.

Keywords: Gypseous Soil, HDPE Polymer, Novolac Polymer, Geotechnical Properties, CBR.

استخدام بوليمر البولي إيثيلين عالي الكثافة وبوليمر النوفولاك لتحسين خواص التربة الجبسية

ماهر مهدي خزعل، قاسيون سعد الدين محمد شفيق

الخلاصة:

تستكشف هذه الدراسة تأثير إضافة بوليمر البولي إيثيلين عالي الكثافة (HDPE) وبوليمر النوفولاك إلى التربة الجبسية من مدينة تكريت في العراق لتعزيز خواصها الجيوتقنية. تحتوي التربة على ٣٨٪ جبس، وتم إضافة البوليمرات بنسب متفاوتة (١٪، ٣٪، ٦٪). قام كلا البوليمرين بتحسين الكثافة الجافة القصوى ومحتوى الرطوبة الأمثل وتقليل احتمالية الانهيار (Ic). تم تقليل احتمالية الانهيار بنسبة ٦٤٪ و٧٧,٧٪ و٨٣,٢٪ عند محتوى HDPE بنسبة ١٪ و٣٪ و٦٪ على التوالي. تم تقليل احتمالية الانهيار بنسبة ٨٢,٣٪ و٧٤,٨٪ و٥١,٩٪ عند محتوى بوليمر نوفولاك ١٪ و٣٪ و٦٪ على التوالي. وفي الظروف الجافة، زادت زاوية الاحتكاك الداخلي بحوالي ٢٢,٩٪ و٥,٧٪ مع زيادة محتوى HDPE بنسبة ٣٪ و٦٪ على التوالي. كما أن إضافة نوفولاك بوليمر أدى إلى زيادة زاوية الاحتكاك الداخلي بحوالي ٥,٧٪ وذلك بإضافة ٣٪ نوفولاك بوليمر. في الظروف المغمورة، كانت أفضل زيادة في زاوية الاحتكاك الداخلي (ϕ) هي ٣٠٪ مع إضافة ٣٪ بوليمر HDPE. وزادت زاوية الاحتكاك الداخلي بحوالي ٢٦,٧٪ وذلك بإضافة ١٪ و٣٪ بوليمر نوفولاك. وخلصت الدراسة إلى أن إضافة بوليمرات HDPE وNovolac يمكن أن تحسن الخواص الجيوتقنية، ولكن تأثيرها على CBR معقد ويعتمد على نسبة البوليمر المضافة وحالة رطوبة التربة.

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1. Introduction

Gypseous soil is a type of soil that is known to collapse when it gets wet. This is a problem for engineers who are building structures on this type of soil because the collapse can damage them. Gypseous soil is found in many dry and semi-dry areas, and it is a real challenge for engineers to work with because of the different problems that it can cause. The composition, mineral content, and arrangement of soil particles in gypseous soil affect how much it will deform when it gets wet. This is because the water changes the way that the soil particles are arranged [1], [2]. In an effort to enhance the engineering characteristics of gypseous soil, including its collapsibility, permeability, and shear strength, researchers have explored the possibility of treating the soil with polymers. These polymers possess desirable attributes such as strong adhesion between soil particles, resistance to pressure, and high tensile strength. Furthermore, they exhibit excellent resistance to water and chemicals [3], [4], [5], [6], [7]. For example, research conducted at the University of Baghdad involved treating soil with a gypsum content of 36% using varying percentages (3%, 6%, 9%) of Copolymer and Styrene-butadiene Rubber. The findings indicated a significant enhancement in the collapsibility, permeability, and bearing capacity of the soil treated with these polymers, as compared to the untreated soil [6]. A further investigation was conducted to examine the durability of gypseous soil to repeated cycles of soaking and drying subsequent to its treatment with polyurethane polymer. The results of the study revealed that the incorporation of varied proportions of polyurethane polymer significantly enhanced the soil's susceptibility to collapse and its resistance to the detrimental effects of wetting and drying under various curing durations [8]. A study demonstrated that gypseous soils treated with xanthan gum exhibited a reduction in collapse potential by 30% to 45%. Furthermore, the direct shear results indicated an increase in the shear strength parameters for soils treated with this biopolymer. These findings suggest that xanthan gum biopolymer could serve as an eco-friendly solution for enhancing the engineering properties of gypseous soils [9]. In another study, casein biopolymer was utilized as a new binder for the improvement of gypseous soil. The soil, with varying gypsum contents, was treated with different concentrations of casein. The findings indicated that the collapse potential of soil treated with casein was 65–80% lower than that of untreated soil. Additionally, a notable augmentation in the shear strength of the soil treated with casein was seen in both dry and wet conditions [10]. Gypseous soils have also been treated with other polymers. For instance, one study explored the use of Pectin, a biopolymer, for this purpose. The research revealed that the collapse potential of gypseous soils doubles when soaked in brine compared to pure water. Biopolymers such as Agar, Xanthan, Chitosan, and Guar, among others, have been utilized to create hydrogen bonds. These bonds form the branching structure of polymeric chains within the soil structure, resulting in a water-insoluble gel [11]. This study aims to examine how adding HDPE and Novolac polymers affects the properties of gypseous soil, including its maximum dry density, California Bearing Ratio (CBR), internal friction angle (ϕ), cohesion (c), and collapse potential (Ic).

2. Materials

2.1. Gypseous Soil

The research made use of gypseous soil with a moderate gypsum content, The soil samples were procured from Tikrit City, located in Salah Al-Din Governorate of Iraq. These specimens were gathered from a depth ranging between (0.5 - 1) m beneath the natural ground surface. the gypseous soil was tested at the national center for construction laboratories and research soil in Baghdad, Iraq to determine its physical and chemical properties.

2.2. High-Density Polyethylene HDPE

Polyethylene is a basic polymer that consists of repeated -CH_2- units. Polyethylene is made by joining together many molecules of ethylene, with the chemical formula (CH_2=CH_2). This process is called addition polymerization. The polyethylene characteristics are shaped by the polymerization method of ethylene. High-density polyethylene (HDPE) is produced when ethylene is polymerized employing organometallic compounds under moderate pressure. HDPE is known for its strength and rigidity due to its high molecular weight. Based on its chemical structure, polyethylene is classified as an organic polymer. Its basic repeating unit consists of two carbon atoms and four hydrogen atoms. Polyethylene is recognized for its softness, lightness, simplicity in production, durability, low water absorption, and its chemically inert characteristics (meaning it remains undissolved in any solvent at room temperature). It also exhibits strong resistance to both acidic and basic substances. and has a low glass transition temperature of -120 C°. These characteristics, coupled with its electrical properties, render polyethylene both flexible and highly impervious to moisture [12], [13]. HDPE polymer has a variety of physical and chemical properties, which are summarized in Table (1) and Table (2), respectively.

Table (1): HDPE's Physical Properties

Colour	White
Density (g/cm³)	0.960
Tensile strength (psi)	4300
Solubility	Soluble in xylene or toluene, but insoluble in water
Flow index (at190°C), g (10 min)$^{-1}$	1.5
Appearance (Form)	Powder
Chemical formula	$(C_2H_4)n$

Table (2): HDPE's Chemical Properties *

Element	Content %
Carbon	99.31

2.3. Novolac Polymer

Novolacs are synthesized through a two-step process. Initially, phenol and formaldehyde are combined in an acidic solution to create a prepolymer.

This prepolymer is then subjected to heat to evaporate water and form the final polymer. The properties of Novolac polymers [6], [14] are as follows:

1. The Novolac polymer, with its porous structure, may exhibit lower mechanical properties due to the presence of small voids. While this could decrease its rigidity, it also has the potential to make it lighter and more resistant to cracking.
2. Novolac polymer is lighter than soil because it has a lower density. It is also acidic material, with a pH below 7. Novolac polymer can be yellow or orange in colour.
3. Novolac polymer is a lightweight, flexible, and easy-to-shape thermoplastic polymer with low molecular weight. It is also chemically resistant and electrically insulating, making it suitable for a wide range of industrial applications.
4. Novolac polymers are known for their excellent adhesion to a variety of surfaces, which makes them advantageous in bonding applications. They are commonly utilized in the creation of adhesives that bond materials such as wood, metal, and plastics.
5. Novolac polymer curing reaction is initiated at temperatures above 100°C.

The physical properties of Novolac polymer are listed in Table (3), and the chemical properties are listed in Table (4).

Table (3): Novolac's Physical Properties

Colour	Varying (yellow-orange)
Tensile Strength (psi)	6380 to 7980
Density (g/cm³)	1.54 – 1.57
Solubility	Soluble in xylene or toluene, but insoluble in water
Appearance (Form)	Solid or powder
Chemical formula	$(C_6H_4(OH)CH_2)n$

Table (4): Novolac's Chemical Properties *

Element	**Content %**
Oxygen	3.96
Nitrogen	4.95
Carbon	91.09

* The test was administered in the Department of Physics at the College of Science at Al-Nahrain University.

3. Experimental Work

3.1 Compaction Test

Standard proctor compaction tests were conducted on both untreated and treated gypsum soil with varying percentages of HDPE and Novolac polymer, using the ASTM D 698 method A. A cylindrical mould 16.5 cm high and 10 cm in diameter was used in the tests, and gypseous soil samples were compacted in three layers, each receiving twenty-five blows from two and a half kilograms weights hammer being released from a height of 30.5 cm and allowed to free fall. This compaction test was performed to determine the maximum dry density and optimum moisture content of the soil.

3.2. Collapse Test

Collapse tests were performed on gypseous soil samples, both untreated and treated, with varying percentages of high-density polyethylene (HDPE) and novolac polymer in accordance with ASTM D 5333 [16]. These tests were conducted using an oedometer apparatus. The collapse potentials (Ic) of the soils were determined through double oedometer tests at a stress of 200 kPa. Table 5 presents the severity of collapse potential (Ic) as classified by Jennings and Knight (1975) [17].

Table (5): Severity of Collapse [17]

Severity	**No problem**	**Moderate**	**Trouble**	**Severe**	**Very severe**
Collapse Potential (Ic), (%)	0-1	1-5	5-10	10-20	20 <

3.3. Direct Shear Test

According to ASTM D 3080 [18], Direct shear tests were conducted on gypseous soil specimens (treated with polymers and untreated) to determine the cohesion (c) and the internal friction angle (ϕ) in dry conditions and soaked conditions (for 24 hours in water, the soil specimens were soaked). The specimens (60 × 60 × 20 mm in size) were compacted to their maximum dry density.

3.4. California Bearing Ratio (CBR) Test

The CBR mould utilized in this research measured (Height 17.8 cm, and Diameter 15.2 cm) and was equipped with a cellar. the CBR test was performed according to the ASTM D1883 standard [19] to measure the CBR value of gypseous soil samples (untreated and treated). This test measures the force needed for a standard plunger to penetrate a material at a specific moisture content and density. For the CBR test preparation, a soil sample weighing approximately 4.5 kg was measured. the polymer in various proportions was mixed with the dry soil, at its optimum moisture content until a homogenous mixture was achieved. The gypseous soil specimens were compacted in a three-layer, with each layer subjected to 56 blows (the compaction was carried out in accordance with ASTM D698). A 2.5 kg hammer was used for compaction through free fall. Surcharge weights of 4.5 kg were placed on the final layer. In the soaked condition, the mould was submerged in water for a duration of 96 hours prior to its placement in the CBR apparatus. A 19.4 cm² cross-sectional area of the CBR piston, was employed to penetrate the soil at a speed of 1.28 mm/min. The CBR examination was performed by applying a load and noting down the penetration measurements at 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, and 7.5mm.

4. Physical and Engineering Properties of Gypseous Soil

Laboratory physical tests were conducted on the untreated gypseous soil to ascertain its engineering properties, with the results presented in Table (6). The specific gravity (Gs) of the soil was determined in compliance with the standards set by ASTM D854/02 [20]. However, due to the solubility of gypsum in water, Kerosene was used as a substitute for water [21]. The soil was classified following ASTM D422 [22] through grain size distribution testing. As depicted in Fig. 1, According to the Unified Soil Classification

System (USCS), the soil is identified as silty sand (SM) [23].

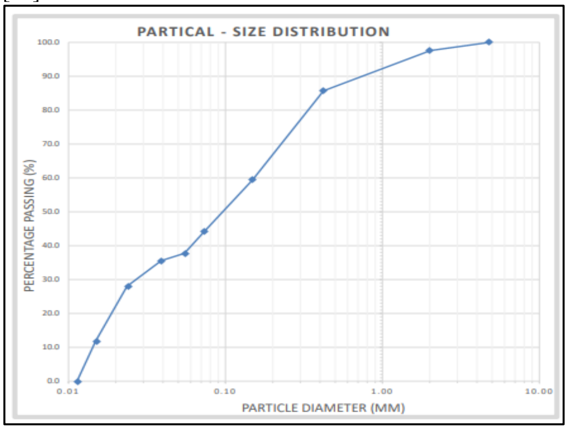

Figure (1): Grain Size Distributions of Gypseous Soil

Table (6): Gypseous Soil Physical Properties

The Property	The Result	Standard
Gravel Sand Silt	0% 56% 44%	ASTM D 422
Classification According to Unified Soil Classification System (USCS)	SM	ASTM D 2487
Liquid Limit (L.L.)%	N.P.	ASTM D 4318[24]
Plastic Limit (P.L.)%	N.P.	
D10	0.015	-------
D30	0.027	-------
D60	0.15	-------
Coefficient of curvature, Cc	0.324	-------
Coefficient of uniformity, Cu	10	-------
Specific Gravity, Gs	2.49	ASTM D 854/02
Maximum Dry Density (MDD), (kN/m³)	16.38	ASTM D 698 Method A
Optimum Moisture Content (%)	7 %	
CBR %	21.5 (Dry) 4.3 (Soaked)	ASTM D 1883
Collapse Potential (Ic) %	5.2 %	ASTM D 5333
Cohesion, c (kPa)	30 (dry) 30 (soaked)	ASTM D 3080
The internal friction angle, ϕ°	35° (dry) 30° (soaked)	

4.1. Chemical Test and EDX Test

Chemical tests were conducted following the methodologies described by [25], [26]. In addition to these, Energy Dispersive X-ray spectroscopy (EDX) tests were also performed on the gypseous soil samples. The chemical tests were carried out at the National Center for Construction Laboratories and Soil Research in Baghdad, while the EDX tests took place in the Physics Laboratory at the college of science, al-Nahrain University. Tables 7 and 8 contain the results of these tests.

Table (7): The chemical characteristics of gypseous soil

Tests	Result (%)	Standard
Gypsum Content (%)	38.032	Al Mufty and Nashat [24]
Organic Matters (O.M.) (%)	0.485	BS 1377:3
pH value	8.31	BS 1377:3
Total Soluble Salts (T.S.S.) (%)	60.786	Earth Manual [27]
CL (%)	0.078	BS 1377:3
Sulphate Salts (SO_3)	18.081	BS 1377:3

Table (8): Elemental Analysis of Natural Gypseous Soil by EDX

Element	Wt.(%)	Wt.(%) sigma
Iron (Fe)	1.54	0.13
Magnesium (Mg)	1.92	0.21
Oxygen (O)	1.94	0.96
Aluminum (Al)	4.19	0.32
Carbon (C)	5.75	2.43
Silicon (Si)	10.11	0.58
Calcium (Ca)	15.05	0.56
Sulfur (S)	15.36	0.69
Antimony (Sb)	44.14	1.50

5. Results and Discussion

5.1. Compaction Test

The results of the compaction tests (Maximum Dry Density (M.D.D) values and Optimum Moisture Content (O.M.C) values) are presented in Fig. 2 & 3, and Table 9.

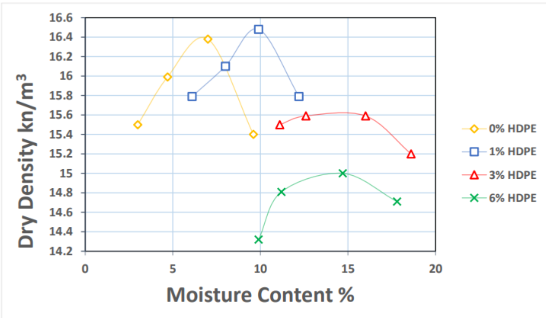

Figure (2): Compaction Test Results for Gypseous Soil, Both Untreated and Treated with HDPE

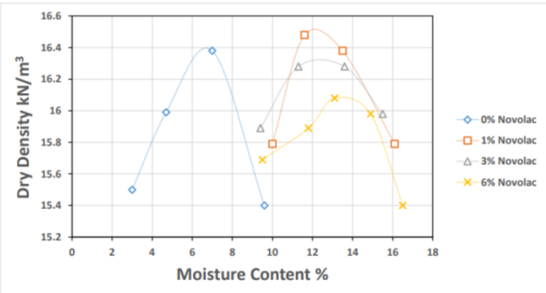

Figure (3): Compaction Test Results for Gypseous Soil, Both Untreated and Treated with Novolac Polymer

Table (9): Compaction Test Results

Type of Materials	Percentage of Polymer Added (%)	M.D.D (kN/m³)	O.M.C (%)
Gypseous Soil	0	16.38	7
Gypseous Soil + HDPE	1	16.49	10.2
	3	15.62	14.6
	6	15	14.7
Gypseous Soil +Novolac Polymer	1	16.52	12.3
	3	16.34	12.5
	6	16.1	13.8

5.2. Collapse Test

To prepare the specimen for the collapse test, an untreated soil specimen with (38%) moderate gypsum content was compacted under the condition of its maximum dry density of 16.38 kN/m³ and 7% optimum water content. The specimen had a collapse potential of 5.2%, considered a trouble degree of severity of collapse according to Jennings and Knight (1975) [17]. The collapse potential was reduced when HDPE and Novolac polymers were added, with the reduction dependent on the quantity of polymers used. Fig. 4 illustrates the relationship between increasing HDPE polymer content and collapse potential. Fig. 5 illustrates the relationship between increasing Novolac polymer content and collapse potential. Table (10). Illustrates the double oedometer test (DOT) results.

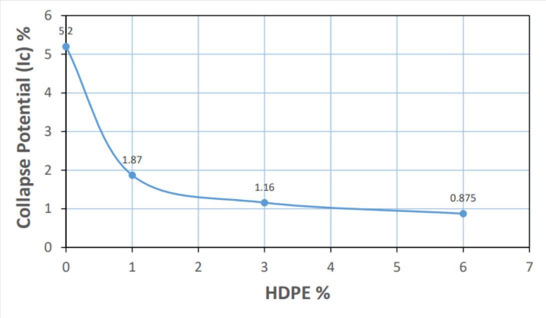

Figure (4): The relationship between increasing HDPE polymer content and collapse potential.

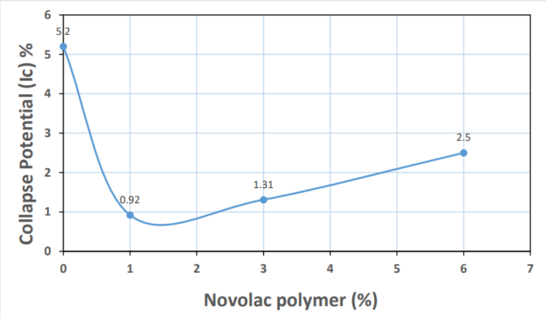

Figure (5): The relationship between increasing Novolac polymer content and collapse potential

Table (10): The double oedometer test (DOT) results

Type of Materials	Percentage of Polymer Added (%)	Collapse Potential (%)	Collapse Potential Reduction (%)
Gypseous Soil	0	5.2	0
Gypseous Soil + HDPE	1	1.87	64
	3	1.16	77.7
	6	0.875	83.2
Gypseous Soil + Novolac Polymer	1	0.92	82.3
	3	1.31	74.8
	6	2.5	51.9

5.3 Direct Shear Test

The results of direct shear tests are shown in Fig.6, Fig. 7, Fig. 8, Fig. 9, Table(11)., Table(12)., Table(13)., and Table(14).

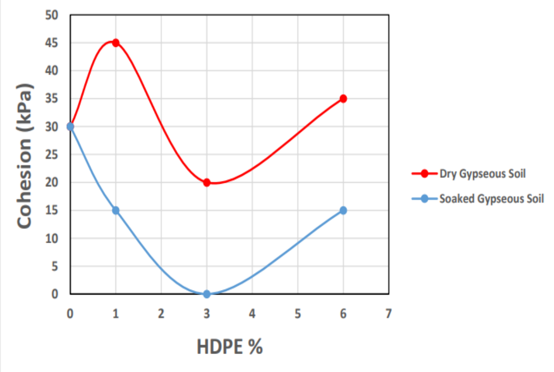

Figure (6): The relationship between increasing HDPE polymer content and the Cohesion (Dry and Soaked Conditions)

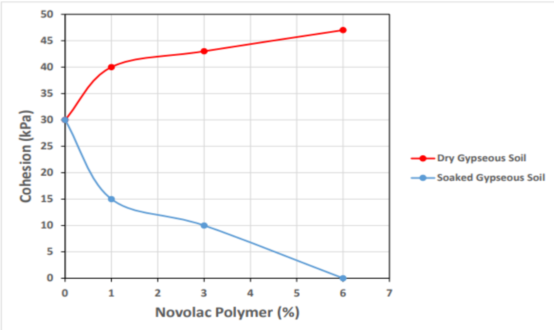

Figure (7): The relationship between increasing Novolac polymer content and the Cohesion of Gypseous Soil (Dry and Soaked conditions)

Table (11): Impact of HDPE and Novolac Polymer Additives on Gypseous Soil Cohesion (c) (Dry conditions)

Type of Materials	Percentage of Polymer Added (%)	The Cohesion (c), (kPa)	The Impact of Polymer Addition on the Cohesion (c) (%)
Gypseous Soil	0	30	0
Gypseous Soil + HDPE	1	45	+50
	3	20	-33.3
	6	35	+16.67
Gypseous Soil + Novolac	1	40	+33.3
	3	43	+43.3
	6	47	+56.7

Table (12): Impact of HDPE and Novolac Polymer Additives on Gypseous Soil Cohesion (c) (Soaked Conditions)

Type of Materials	Percentage of Polymer Added (%)	The Cohesion (c), (kPa)	The Impact of Polymer Addition on the Cohesion (c) (%)
Gypseous Soil	0	30	0
Gypseous Soil + HDPE	1	15	-50
	3	0	-100
	6	15	-50
Gypseous Soil + Novolac	1	15	-50
	3	10	-66.7
	6	0	-100

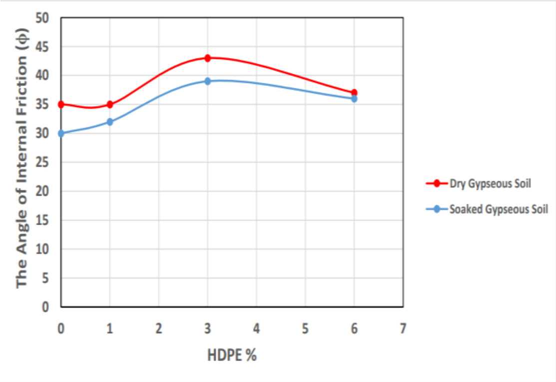

Figure (8): The Relationship between Increasing HDPE Polymer Content and the Internal Friction Angle (ϕ°) (Dry and Soaked Conditions)

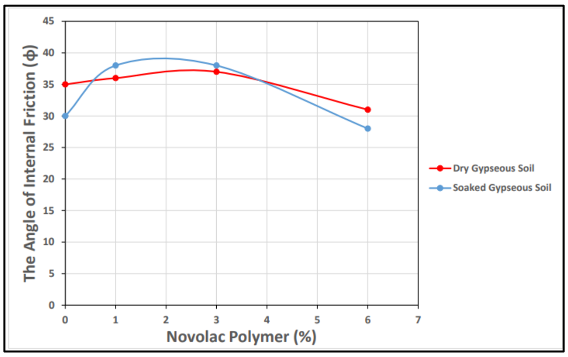

Figure (9): The Relationship between Increasing Novolac Polymer Content and the Internal Friction Angle (ϕ°) (Dry and Soaked Conditions)

Table (13): Impact of HDPE and Novolac Polymer Additives on the Internal Friction Angle (ϕ °) (Dry conditions)

Type of Materials	Percentage of Polymer Added (%)	The Internal Friction Angle (ϕ°)	The Impact of Polymer Addition on the Internal Friction Angle (ϕ°) (%)
Gypseous Soil	0	35	0
Gypseous Soil + HDPE	1	35	0
	3	43	+22.9
	6	37	+5.7
Gypseous Soil + Novolac polymer	1	36	+2.9
	3	37	+5.7
	6	31	-11.4

Table (14): Impact of HDPE and Novolac Polymer Additives on the Internal Friction Angle (ϕ °) (Soaked Conditions)

Type of Materials	Percentage of Polymer Added (%)	The Internal Friction Angle (ϕ°)	The Impact of Polymer Addition on the Internal Friction Angle (ϕ°) (%)
Gypseous Soil	0	30	0
Gypseous Soil + HDPE	1	32	+6.67
	3	43	+22.9
	6	37	+5.7
Gypseous Soil + Novolac polymer	1	38	+26.7
	3	38	+26.7
	6	28	-6.7

5.4. California Bearing Ratio (CBR) Test

Results of the CBR tests are shown in Fig. 10, Fig.11, Table 15. and Table 16.

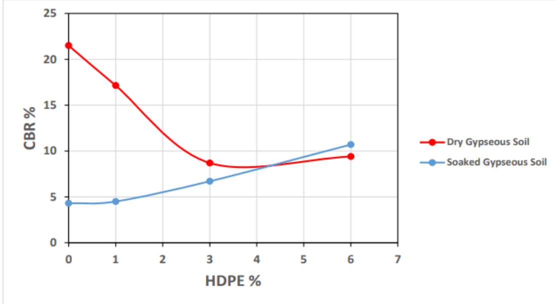

Figure (10): The Relationship between Increasing HDPE Polymer Content and the CBR

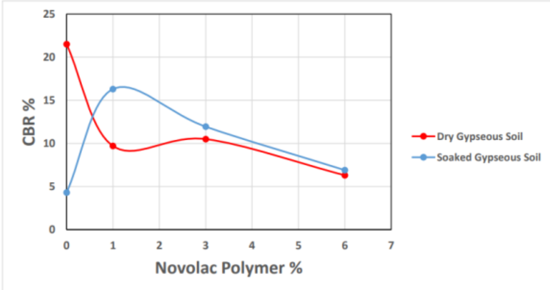

Figure (11): The relationship between increasing Novolac polymer content and the CBR

Table (15): Impact of HDPE and Novolac Polymer Additives on the CBR of Gypseous Soil (Dry Conditions)

Type of Materials	Percentage of Polymer Added (%)	CBR (%)	Percentage of decrease %
Gypseous Soil	0	21.5	0
Gypseous Soil + HDPE	1	17.14	20.3
	3	8.7	59.5
	6	9.4	56.3
Gypseous Soil + Novolac polymer	1	9.7	54.9
	3	10.5	51.2
	6	6.3	70.7

Table (16): Impact of HDPE and Novolac Polymer Additives on the CBR of Gypseous Soil (Soaked Conditions)

Type of Materials	CBR (%)	Percentage of increasing %
Gypseous Soil	4.3	0
Gypseous Soil + HDPE	4.5	4.7
	6.7	55.8
	10.7	148.8
Gypseous Soil + Novolac polymer	16.3	279.1
	11.94	177.7
	6.9	60.5

6. Conclusions

1- The addition of 1% HDPE and 1% Novolac polymer to the soil resulted in a small improvement of maximum dry density, increasing it by about 1%. Decrease in maximum dry density when the additives were increased to 3% and 6% for both polymers.

2- The optimum moisture content increased with the addition of HDPE polymer increased. The increase was 45% at 1% HDPE, 108.6% at 3% HDPE, and 110% at 6% HDPE. The increase was also observed in the Novolac polymer. The increase was 75.7% at 1% Novolac, 78.6% at 3% Novolac, and 97.1% at 6% Novolac.

3- The collapse potential (Ic) of gypseous soil when treated with HDPE was reduced by 64%, 77.7%, and 83.2% at 1%, 3%, and 6% HDPE content, respectively. The collapse potential (Ic) of gypseous soil when treated by Novolac was reduced by 82.3%, 74.8%, and 51.9% at 1%, 3%, and 6% Novolac polymer content, respectively.
4- Adding HDPE and Novolac to the gypseous soil sample affected its cohesion in different ways. The cohesion, in the dry state, increased by 50%, decreased by 33.3%, and increased by 16.67% when 1%, 3%, and 6% of HDPE was added, respectively. The cohesion increased by 33.3%, 43.3%, and 56.7% when adding 1%, 3%, and 6% of Novolac polymer, respectively.
5- The cohesion of gypseous soil in the soaked state decreased by 50%, 100%, and 50% when HDPE polymer by percentages 1%, 3%, and 6% were added, respectively. It also decreased by 50%, 66.7%, and 100% when 1%, 3%, and 6% of Novolac polymer was added, respectively.
6- The HDPE polymer additive by 1% in a dry condition didn't change the internal friction angle (ϕ), but adding more HDPE polymer (3%, and 6%) increased it by 22.9% and 5.7% respectively. Increase the internal friction angle by about 2.9% with 1% of Novolac polymer, and 5.7% with 3% of Novolac, but decrease by about 11.4% with 6% of Novolac polymer.
7- adding 1%, 3%, and 6% of HDPE polymer on soaked conditions, increased the internal friction angle (ϕ) by about 6.67%, 30.0%, and 20.0%, respectively. Adding 1% and 3% of Novolac polymer also increased the internal friction angle by about 26.7%. However, the addition of 6% Novolac polymer resulted in a reduction of the internal friction angle by approximately 6.7%.
8- the additive of polymers to the gypseous soil (in dry conditions) led to a reduction in CBR. The 1% HDPE polymer addition resulted in a 20.3% decrease in CBR, while the addition more of HDPE polymer (3%, and 6%) led to a decrease in CBR of 59.5% and 56.3% respectively. Similarly, the addition of 1% Novolac polymer caused a 54.9% decrease in CBR, and the addition of 3% and 6% Novolac polymer led to a decrease of 51.2% and 70.7% respectively.
9- Adding 1% HDPE polymer to gypseous soil (in soaked conditions) led to a 4.7% rise in CBR, while the addition more of HDPE polymer (3%, and 6%) resulted in CBR increases of 55.8% and 148.8%, respectively. Similarly, the addition of 1% Novolac polymer to gypseous soil led to a 279.1% rise in CBR, while the addition more of Novolac polymer (3%, and 6%) resulted in CBR increases of 177.7% and 60.5%, respectively.

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