Iraqi National Journal of Earth Science

www.earth.mosuljournals.com

Improving the Geotechnical Properties of Non-Cohesive Soils Using Portland Cement and Some Composite Polymers in a Selected Location in Umm Qasr City, Basrah Governorate, Southern Iraq

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Article information

Received: 01- Mar -2024

Revised: 17- May -2024

Accepted: 15- Jul -2024

Available online: 01- Jul – 2025

Keywords:
Non-cohesive soils
Polymers
Soil improvement
Cement

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ABSTRACT

In this study, non-cohesive soils from a site in the city of Umm Qasr in Basrah Governorate, southern Iraq, are improved by adding Portland cement at a rate of 5% of the sample's weight and a polymeric mixture that included thinner as a solvent, polyvinyl acetate, unsaturated polyester, and isocyanides in proportions of 5, 10, 15, 20, and 25% of the added cement's weight through the use of geotechnical tests that include the degree of improvement in the soil's geotechnical properties, such as compaction, direct shear strength, California Bearing Ratio, and absorption, to ascertain the optimal percentage of polymer that is beneficial for improvement. The results show that the optimal moisture content values decrease from 10% to 9%, the maximum dry density values increase from 1.982 g/cm^3 to 2.162 g/cm^3, and the absorption values decrease from 28.7% to 9.6%. The addition of polymers and cement serves as a binding agent, the angle of internal friction increases from 27 to 32 degrees, and fosters the development of cohesion between the soil particles to (43.14 kPa). The California Bearing Ratio value increases from 27% to 54% by adding polymer at a rate of 20% of the cement weight and cement at a rate of 5% of the sample weight.

DOI: 10.33899/earth.2024.147307.1241, ©Authors, 2025, College of Science, University of Mosul.

تحسين الخواص الجيوتكنيكية للترب غير المتماسكة باستخدام الاسمنت البورتلاندي وبعض البوليمرات المركبة في مواقع مختارة من مدينة ام قصر، محافظة البصرة، جنوبي العراق

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معلومات الارشفة

تاريخ الاستلام: 01- مارس -2024
تاريخ المراجعة: 17- مايو -2024
تاريخ القبـول: 15- يوليو -2024
تاريخ النشر الالكتروني: 01- يوليو -2025

الكلمات المفتاحية:
الترب غير التماسكية
البوليمرات
تحسين التربة
الاسمنت

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الملخص

تضمن البحث طريقة لتحسين ترب غير متماسكة مختارة من موقع في مدينة ام قصر في محافظة البصرة جنوبي العراق بإضافة الاسمنت البورتلاندي بنسبة 5% من وزن العينة والخليط البوليمري المتكون من بولي فنايل استيت و البولي استر غير المشبع والايزو سيانيد والثنر كمذيب بنسب 5 و10 و15 و20 و25% من وزن الاسمنت المضاف لتحديد النسبة الافضل للبوليمر و التي تعد مجدية لغرض التحسين من خلال اجراء بعض الفحوص الجيوتكنيكية كالرص ومقاومة القص المباشر ونسبة التحمل الكاليفورني والامتصاص التي توضح مدى التحسين الحاصل في الخواص الجيوتكنيكية للتربة. اظهرت النتائج زيادة في قيم الكثافة الجافة العظمى من 1.982غم/ سم^3 الى 2.162 غم/ سم^3 ونقصانا في قيم المحتوى الرطوبي الامثل من 10% الى 9% وكذلك نقصانا في قيم الامتصاص من 28.7% الى 9.6 %. بينما حصل ارتفاع في قيم زاوية الاحتكاك الداخلي من 27 الى 32 درجة وظهور التماسك بين حبيبات التربة بسبب اضافة البوليمر والاسمنت حيث يعمل هذا المزيج كمادة رابطة إذ بلغت قيمة التماسك 43.14 كيلو باسكال. كما ارتفعت قيمة نسبة التحمل الكاليفورني من 27% الى 54% عند اضافة الاسمنت بنسبة 5% من وزن العينة، والبوليمر بنسبة 20% من وزن الاسمنت المضاف للعينة.

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Introduction

Soil improvement means developing the geotechnical properties of weak soils to enhance unfavorable geotechnical criteria in soils such as strength, permeability, compressibility, and durability (Al-Masri et al., 2023) to obtain stable soils with a high bearing capacity and suitable for carrying the engineering structure by increasing the strength of these soils and addressing the engineering problems they suffer from without replacing the site through physical, mechanical, and chemical means. Many researchers have resorted to improving the engineering properties of soil by using some additives such as acids, fibers, and polymers to improve weak soils (Horvath, 2000). Arasan *et al.* (2015) concluded that a deep mixing method is used to improve sandy soil by creating columns in the soil and using a polyester polymer to quickly stabilize these soils at different rates (10, 20, and 30%), and for samples treated for 3 hours, 1, 3, 7, and 28 days. The results showed that soil improved with polyester for 3-hour samples could reach a strength range similar to that of 28-day samples. Al-Maliki *et al.* (2018) investigated the impact of various polymers and Portland cement on cohesive and non-cohesive soils, demonstrating that the addition of polymers improved the soil's engineering qualities. Khudhair et al. (2022) showed that by adding basalt fibers to treated soils with Portland cement, the engineering properties of cohesive and non-cohesive soils were greatly enhanced. Liu et al. (2017) used polyurethane as a soil stabilizer to strengthen the sand. A series of tests were conducted, and the results showed that the permeability of sand reinforced with this material was reduced as this polymer forms a layer. The surface of the sand was strengthened, and the water flow rate decreased with increasing treatment time, as the polyurethane filled the spaces between the sand. Asad *et al.* (2021) added bentonite to selected samples from the banks slopes of the southern sector of the general estuary canal in southern Iraq, and then some geotechnical tests were conducted; the results show the possibility of stabilizing these slopes. Researchers like Jha and Sivapullaiah (2015) noted that the soil stabilization technique led to an improvement in the geotechnical properties, such as compression, strength, and shrinkage by adding binding materials to weak soils. By utilizing a combination of Portland cement and commercially and environmentally viable materials made of polymer composites for the first time in this study, seeks to enhance some of the geotechnical characteristics of samples of non-cohesive soils taken from the Umm Qasr City site. It also seeks to determine the impact of varying ratios of these materials on the geotechnical characteristics of these soils.

Aim of study

The study aims to improve the geotechnical properties of selected non-cohesive soils from Basrah Governorate by using environmentally and economically appropriate additives (Isocyanides, Unsaturated polyester, and polyvinyl acetate) and mixing them with cement to reach the best improvement rate as well as to reduce the economic cost.

Location of the study area

One non-cohesive soil sample (30 kg) was taken from the city of Umm Qasr in Basrah Governorate, southern Iraq. Umm Qasr is a coastal city located on Khor Al-Zubair Canal and is considered a part of the mouth of Khor Abdullah, which leads to the Arabian Gulf. Umm Qasr is about 72 km from the Basrah center and includes the largest Iraqi port (Umm Qasr Port). It is located within the intersection of longitude 46º 55' 47" east and latitude 30º 2' 30" north, as in Figure 1.

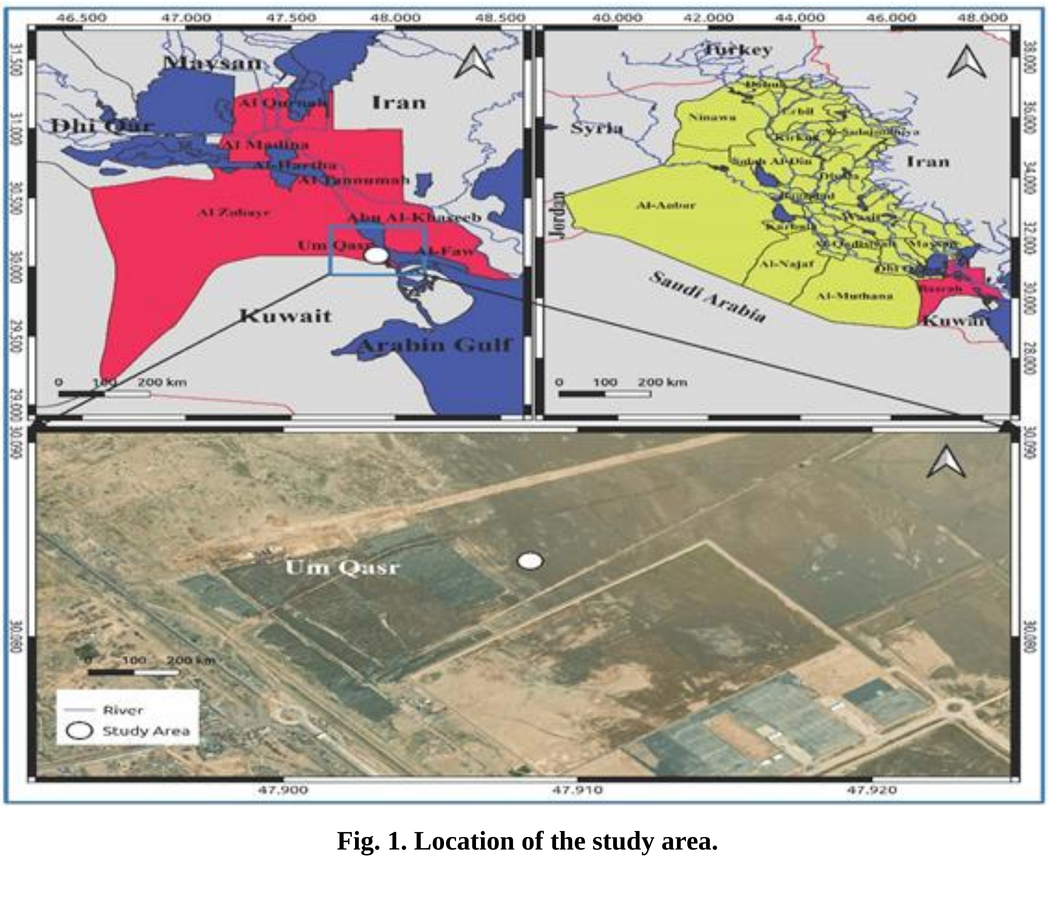


Fig. 1. Location of the study area.

Geology and Geomorphology

The study area is located within the alluvial plain in the Mesopotamian region, which is a part of the unstable shelf range in the Arabian plate, according to the tectonic division of Buday and Jassim (1987), who divided Iraq into three regions from northern Iraq to the south, which are High Folded Zone, Foot Hill Zone, and Mesopotamian Zone. The city of Basrah is located within the third region, which is also known as the Mesopotamian region, and is characterized by being less affected by the Alpine orogeny. The Mesopotamian Zone represents a complex of Quaternary sediments, as they are not subjected to the mountain-building movements. On the contrary, it was strongly affected by folding northeast toward the southwest (Buday and Jassim, 1987).

The Mesopotamian Zone is divided longitudinally into the following areas (Buday and Jassim, 1987): Tigris subzone, Euphrates subzone, and Zubair subzone.

Umm Qasr City is located in the Zubair subzone, which represents the southern part of the Mesopotamian Zone, which is characterized by a homogeneous compositional pattern in which there are subsurface geological structures. Lees and Falcon (1952) believed that the Mesopotamian Zone suffered from continuous settling processes. Karim (1991) mentioned that the alluvial plain region is witnessed by tectonic activity that led to the separation of Warba Island, the emergence of Bubiyan Creek, and the connection of Khor Al-Zubair to Khor Abdullah, due to the occurrence of tectonic subsidence to the east of Al-Zubair Ridge, as well as another tectonic subsidence in the northwest of Bubiyan Island.

Al-Rubaie (1988) divided the city of Basrah into two regions: the eastern one, called the alluvial plain region, and the western one, called Al-Batin Fan region. The city of Umm Qasr is located within the western region of Basrah Governorate, which is characterized by the spread of coarse-grained sediments (sand and gravel) deposited by the flowing rivers. The Arabian Peninsula is represented by the rocks of the Arabian Shield, which runs through Wadi Al-Batin towards the northeast. This region contains the Al-Batin alluvial fan, which is the largest fan in southern Iraq. It also contains the most important geomorphological feature represented by Jebel Sanam salt dome, which reaches a height of about 154 meters above sea level (Abdul Ameer *et al.*, 2023). The geomorphology of the region and its subsurface structures are affected by the tectonic movements that it witnessed about 1,500 years ago.

Materials and Methods

Materials

- Portland cement taken from the Basrah Cement Factory is used at a rate of 5% of the sample weight because this percentage gave good results from previous research by Al-Maliki et al., (2018)**.**
- A new compound polymer is used, which is manufactured for the first time in this study, to produce a polymeric emulsion that is insoluble in water after solidification. This product is made by mixing isocyanides with unsaturated polyester and polyvinyl acetate. The emulsion is added in proportions of 5, 10, 15, 20, and 25% of the weight of the cement added to the sample to increase the strength of the soil and to reduce the economic cost.

Preparing samples

- Several geotechnical tests are conducted on natural soil samples free of additives, namely the modified compaction test, direct shear strength, absorption, and California Bearing Ratio (CBR).
- Samples are prepared with cement added at a rate of 5% by weight of the non-cohesive soil sample selected from the Umm Qasr City site, and the same previous

geotechnical tests are re-conducted on them to determine the change in their engineering behavior.

- To ascertain the impact of this composite polymer in enhancing the engineering properties of the extracted sandy soil from the study area, samples are prepared with varying percentages of added composite polymer (5, 10, 15, 20, and 25%) by weight of cement added to the non-cohesive soil samples. The same geotechnical tests are then repeated.

Laboratory tests

The following tests are conducted in the laboratories of Al-Meqyas Engineering Services Company in Basrah on non-cohesive soil samples taken from the Umm Qasr site:

1. Grain size analysis: This analysis of non-cohesive soils is carried out by the dry sieving method according to the American standard (ASTM D-421, D-422).
2. Moisture content: Following the American standard (ASTM D2216-05), a specific weight of soil is dried for 24 hours at a temperature of 105–110°C.
3. Chemical tests: Include determining the percentage of sulfates (SO_4), the content of chlorides (Cl), pH, carbonates (CO_3), and organic content according to the Iraqi Standard for National Center for Laboratories and Construction Research (NCLCR, 2001).
4. Compaction test: Five weight percentages of water, 2, 4, 6, 8, and 10% are added to samples of natural occurrence, non-cohesive additives-free soils taken from the Umm Qasr site. They are then put through a modified Proctor test to find the ideal moisture content and maximum dry density. Then six remolded samples are prepared with 5% cement added to them and mixed with five of the weight percentages of the composite polymer, which are 5, 10, 15, 20, and 25% of the weight of the cement added to the sample, and the same previous tests are conducted again, according to the American standard. (ASTM D1557-12) to know the development of its engineering behavior.
5. Direct shear strength test: Preparing an additive-free sample of the non-cohesive soil after passing it through a No. 4 sieve with 4.75 mm openings, and a direct shear strength test is conducted on 6x6 cm cubes. Then, a remolded sample of the non-cohesive soil sample treated with 5% cement is prepared. It was left to dry for 7 days. Five samples of the soil treated with 5% cement and composite polymer were prepared at different percentages (5, 10, 15, 20, and 25%) of the weight of cement added to the sample. They are also allowed to dry for seven days before being tested. The samples are dried for 24 hours at 105°C in the oven to determine the sample's weight. The test is carried out in compliance with ASTM D-3080 of the American standard.
6. The California Bearing Ratio test: It is conducted by preparing a sample of natural, non-cohesive soil devoid of additives, adding the ideal moisture content ascertained via the modified Proctor test, and analyzing the resultant material to ascertain the California Bearing Ratio. Then, a remolded sample of non-cohesive soil is prepared, and cement is added at a rate of 5% in the same way as the natural sample above was prepared and left to dry for 7 days. Then a test was conducted on it, and five samples were prepared to which cement was added at a rate of 5% and the composite polymer was added at different rates, 5, 10, 15, 20, and 25% of the weight of cement, using the same sample preparation method mentioned previously. The samples were left for 7 days to dry, and then they were examined to determine the percentage of additives that achieved the best soil stability. The test is conducted according to the American standard (ASTM D-1883).
7. Rapid absorption test: A sample of natural non-cohesive soil free of additives is prepared, its dry weight is calculated, and the test is conducted, where it is immersed in water for 24 hours, and the wet weight of the sample is taken after immersion to determine the absorption rate. A remolded soil sample is prepared after cement is added to it at a rate of 5%. It was left for 7 days to dry and then examined. After the preparation of five samples

of non-cohesive soil, 5% cement was added, and a composite polymer was added in various weight proportions (5, 10, 15, 20, and 25%) by cement. The samples were then allowed to dry for seven days before being examined by the British Standard (BS. 1377:1975) and the previously described procedures.

Results

- **Particle size analysis test:** The analysis results show that the percentage of clay and silt is 8.8%, sand is 80.2%, and gravel is 11%, as illustrated in Figure 2.

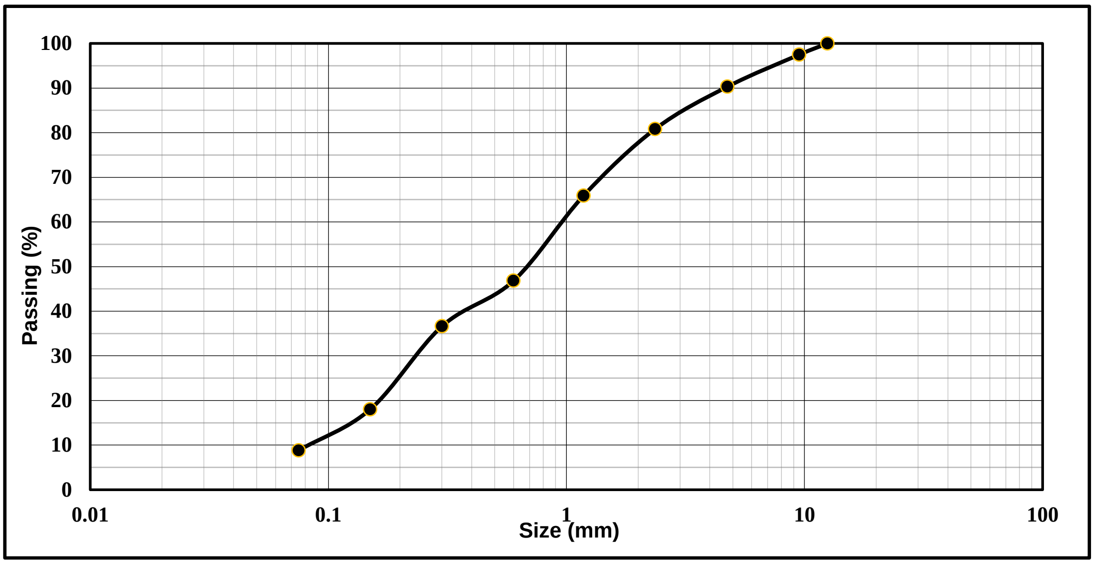


Fig. 2. Particle size analysis test.

According to the unified classification (USCS), the values of the regularity coefficient (C_u) and concavity coefficient (C_c) are 11.88 and 0.76, respectively, so the soil is classified as poorly graded sand (SP). It is known that the physical and chemical properties of soils in the world vary greatly from one site to another. Rather, the geotechnical properties are different, both horizontally and vertically, in the same location. This is due to the truth about the origins of soil and its geological history (Al-Jumaily and Al-Azzo, 2011). These deposits are mainly affected by the natural consolidation resulting from mechanical compaction caused by an increase in overburden pressure during depositional processes (Mahmood and Albadran, 2002).

- **The moisture content test:** The low groundwater level in the area contributes to the non-cohesive soil's 0.9% moisture content, as indicated by the study site's non-cohesive soil sample parameters.
- **The chemical tests:** The results show that the percentage of sulfates is 2.5%, chlorides is 0.056%, acidity is 7.84, organic content is 1.20%, and carbonates are 17.60%. According to the Iraqi specifications of the National Center for Laboratories and Construction Research (2001), they are regarded as not affecting the soil's engineering behavior.

- **Compaction test:** It can be seen from Figure 3 that the optimum moisture content (OMC) for natural soil is 10% and the maximum dry density (MDD) is 1.989 g/cm^3. The value of the maximum dry density is 2.113 g/cm³, according to the results of the limit test for non-cohesive soil treated with cement. 11% is the optimum moisture content. When cement and polymer composites were added to soil samples as shown in Figures (4 and 5), the highest maximum dry density and lowest optimum moisture content are achieved when cement was added at a rate of 5% of the sample weight and the composite polymer at a rate of 20% of the cement weight, totaling 2.162 g. cm^3. The optimum moisture content is found to be 9%.

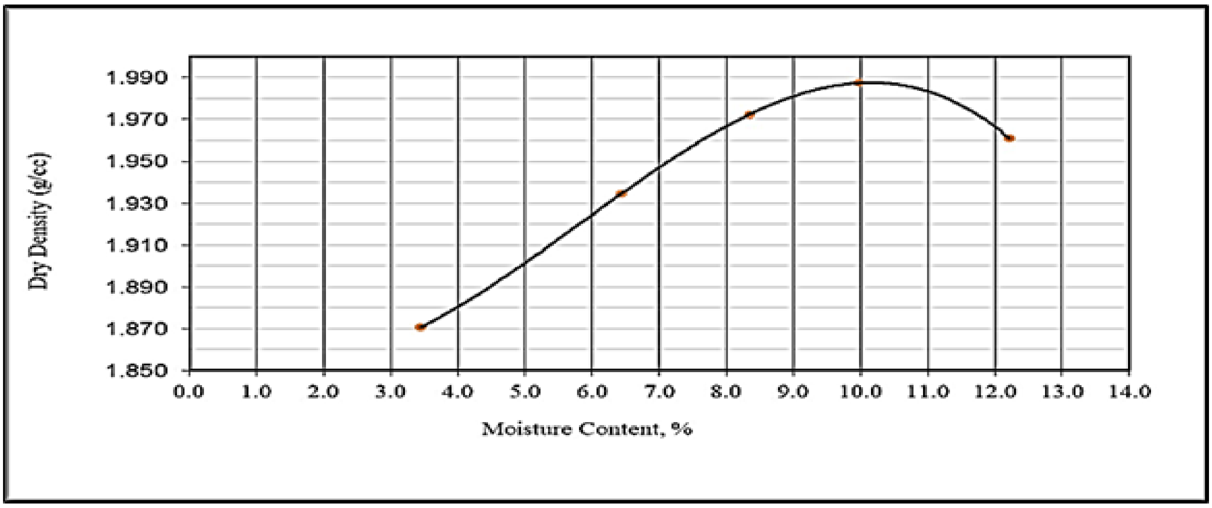


Fig. 3. Maximum dry density and optimum moisture content for naturally non-cohesive soils.

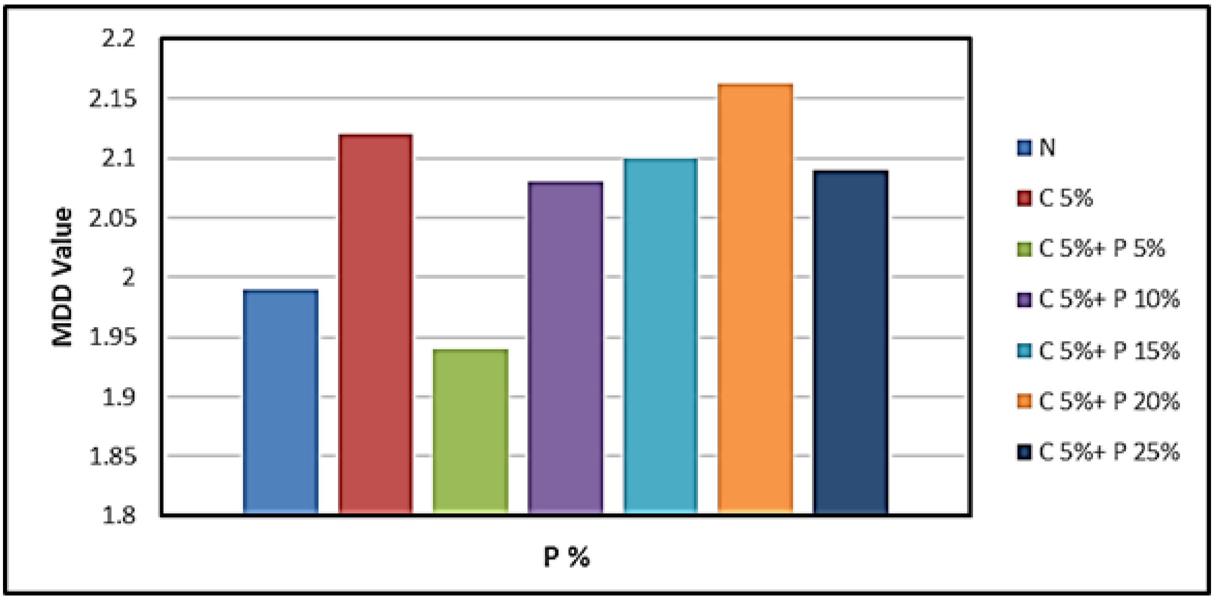


Fig. 4. Maximum dry density values for non-cohesive soil both with and without the addition of improving materials.

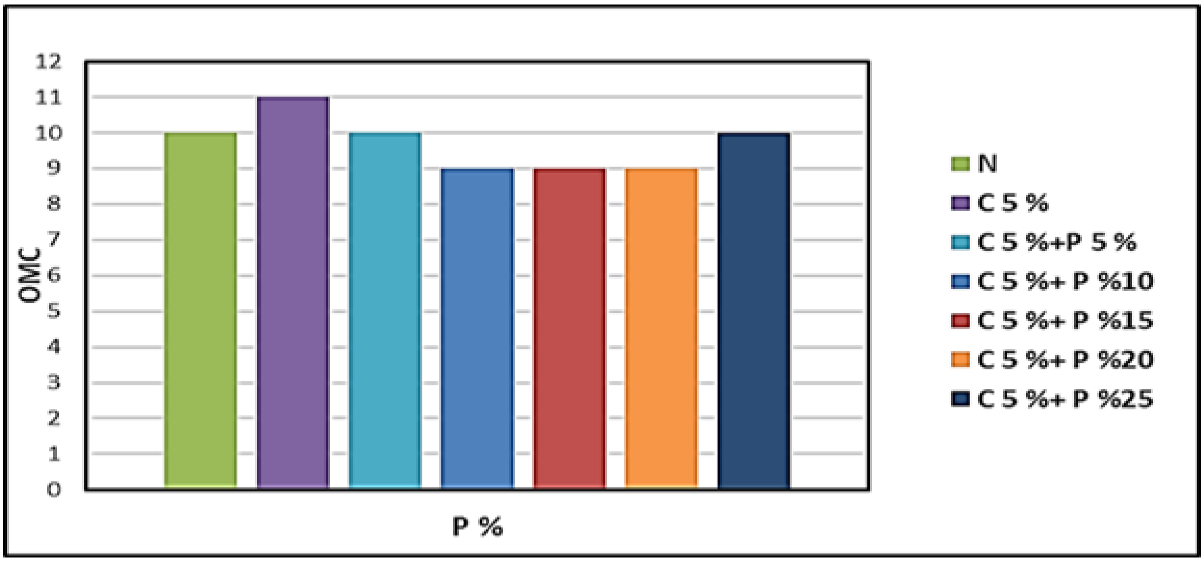


Fig. 5. Values of the optimum moisture content for non-cohesive soil both before and after adding improving materials.

- **Direct shear strength test:** According to test results and when using the following normal stresses (83, 166, and 333 kPa), natural soil has an internal friction angle of 37º and a cohesion value of 0 kPa. When 5% cement was added to the soil, it was found that the values of the cohesion and angle of internal friction increased for the samples treated with additives. The cohesion is 27 kPa, and the angle of internal friction reached 40º. The highest value of the angle of friction in the sample to which 5% of cement and 20% of the composite polymer were added is 48. 6º and the cohesion value is 43.14 kPa, as shown in Figures 6, 7, and 8. The presence of the polymer compound with cement led to their interaction together and the creation of great bond strength between the soil particles, as the interfacial strength within the soil increased with the increase in the proportions of additives, which led to a reduction in the spaces between the soil particles and thus increased cohesion.

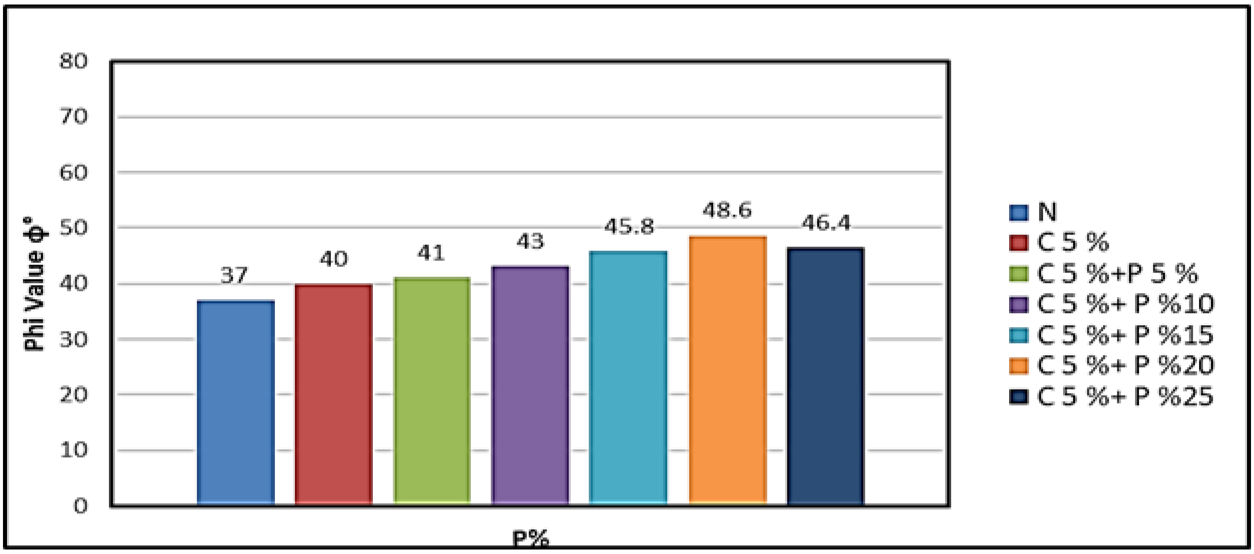


Fig. 6. Values of the internal friction angle in non-cohesive soil both before and after the addition of improving materials.

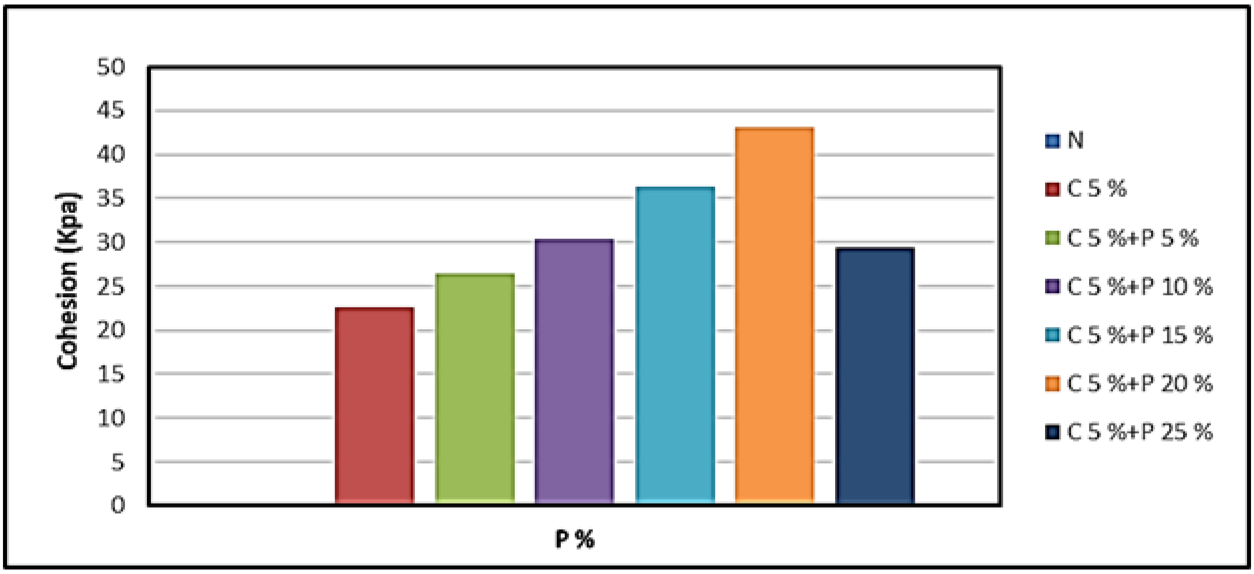
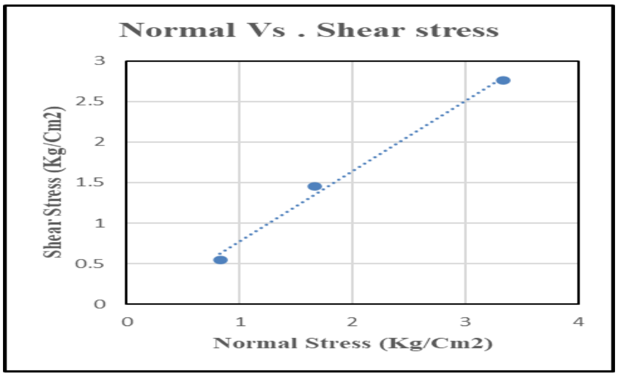
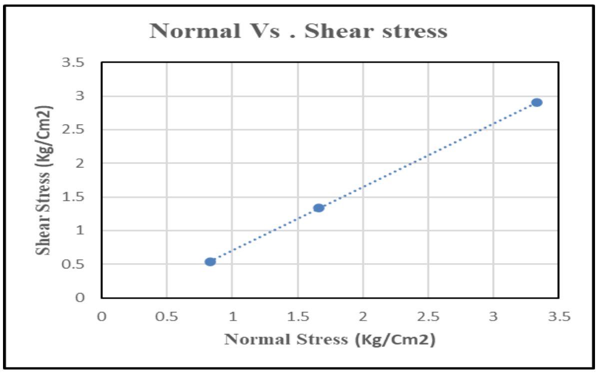


Fig.7. Values of the non-cohesive soil's cohesion both before and after adding improving materials.



(a)



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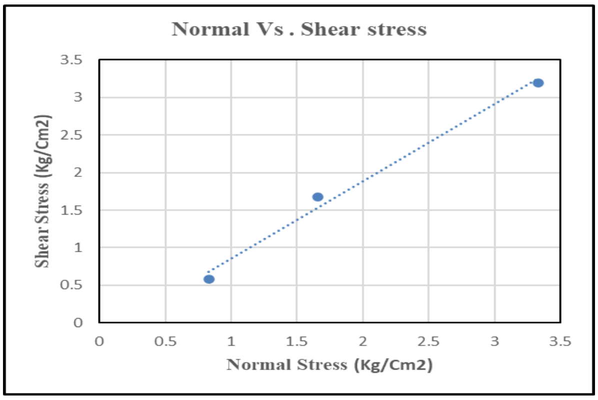

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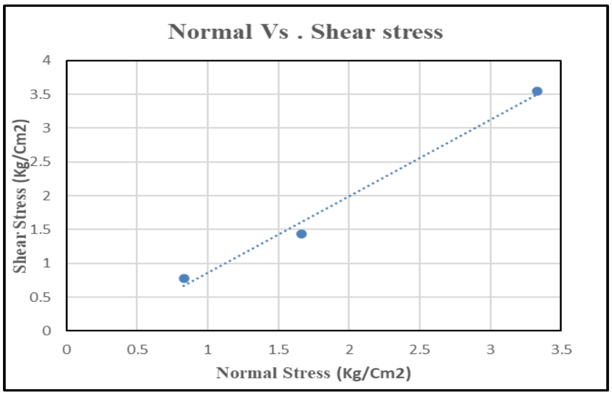

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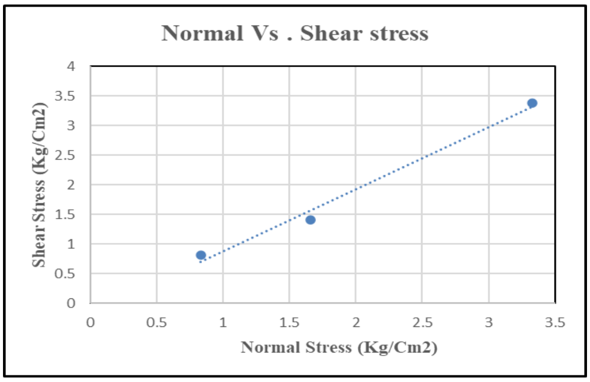

(e)

Fig. 8. Values of friction angles after using additives (where, a: 5% P+ 5%C, b: 10% P+ 5%C, c: 15% P+ 5%C, d: 20% P+ 5%C and e: 25% P+ 5%C).

- **California Bearing Ratio (CBR) test:** The results of this test, which is performed on non-cohesive soil taken from the Umm Qasr location, indicate that the natural soil's California Bearing Ratio is 27%. Its highest value is observed when adding a 5% cement mixture and a 20% composite polymer by weight of cement, reaching 54%, as in Table 1 and Figure 9.

Table 1: C. B. R values of non-cohesive soil after additives.

Additives %	NO. of blows	Dry density	CBR at 0.2	Modified dry density	0.95 M.D.D	C.B.R
C 5% + P 5%	10	1.792	30	1.94	1.843	44 %
	25	1.802	40			
	56	1.987	58			
C 5% + P 10%	10	1.853	28	2.08	1.976	42 %
	25	1.912	38			
	56	2.11	58			
C 5% + P 15%	10	1.862	28	2.100	1.995	40 %
	25	1.988	38			
	56	2.150	58			
C 5% + P 20%	10	1.965	32	2. 162	2.054	54 %
	25	2.00	50			
	56	2.210	60			
C 5% + P 25%	10	1.844	24	2.09	1.985	39 %
	25	1.933	35			
	56	2.120	46			

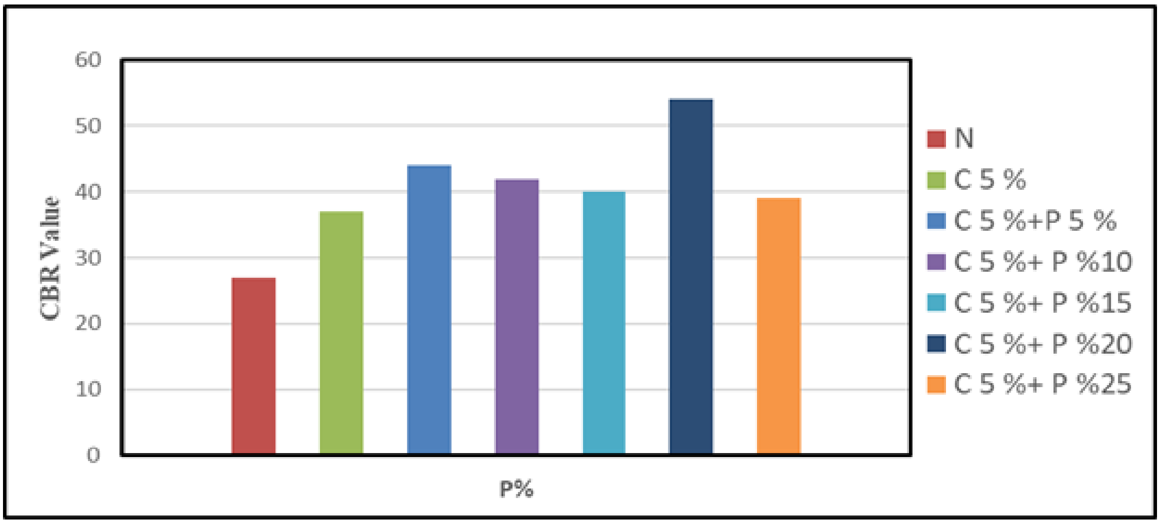

Fig.9. California bearing ratio (CBR) values for non-cohesive soil both with and without addition of improvement materials.

- **Rapid absorption test:** The natural soil's water absorption rate, according to absorption test results, is 28.7%. It is noted that this value decreased with increasing percentages of additives, reaching 17% when adding 5% of cement, and the lowest value of absorption is reached when adding a mixture of 5% cement and a composite polymer 20% of the weight of cement, which is 9.6%, as in Figure (10).

$$Absorption\ \% = \frac{w_w - w_d}{w_d} \times 100\%$$

Where, W_w: Wet weight; W_d: Dry weight.

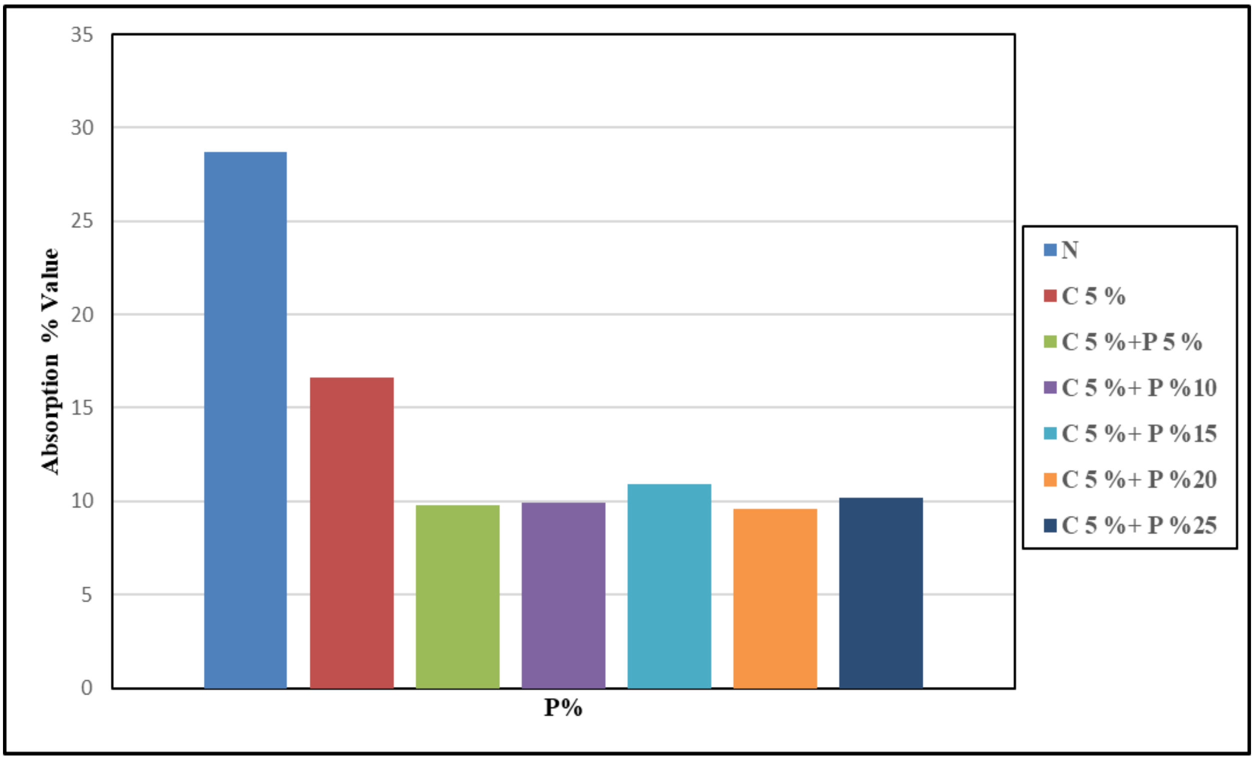

Fig.10. Values of the non-cohesive soil's water absorption rate both before and after adding improving materials.

Discussion

Adding cement at a rate of 5% of the weight of the sample and a polymeric mixture consisting of polyvinyl acetate, unsaturated polyester, isocyanides, and thinner as a solvent at a rate of 20% of the weight of cement led to an improvement in the engineering properties of the non-cohesive soil. Because this mixture functions as a binder to connect the soil's pores to create cohesion between the grains, reducing voids, and preventing water from penetrating inside the soil particles, it is observed that there is an increase in the maximum dry density, direct shear strength, and California Bearing Ratio, and a decrease in the optimum moisture content and absorption rate. This resulted in the formation of a layer of cement and polymeric mixture that coated the soil particles and prevented them from absorbing water. In addition, the compaction of the soil led to the expulsion of air, which caused an increase in the density of the soil and gave it a higher strength to withstand the stress placed on it.

Conclusion

The polymer used is effective in strengthening and activating the effectiveness of cement to bind sand grains. The use of composite polymer led to increased strength and improved geotechnical properties of the soil. The results of engineering tests show that the best percentage of polymer is 20% of the weight of cement added to the sample, as it gave the best improvement to the engineering properties of the soil.

Acknowledgments

We extend our sincere thanks to the editorial board ladies and gentlemen of the Iraqi National Journal of Earth Science for their sincere efforts in publishing this research and supporting the scientific process in Iraq.

Conflict of Interest

The authors declare that they have no conflicts of interest.

References

Abdul Ameer, H.N. and Daham, H.A., 2023. Studying Al-Faw City expansive soil (South Iraq) and their improvement by nano calcium carbonate and lime material additives. M.S. Thesis, Univ. of Basrah, Basrah, Iraq.

Al-Jumaily, M.Q. and Al-Azzo, S. 2011. Statistical treatment for complementary physical properties of soils. Iraqi National Journal of Earth Science, Vol. 11, No. 1, 2011, pp.47 -62. DOI: 10.33899/earth.2011.5503.

Al-Maliki, F.S., Mahmood, R. A. and Jabir, M.A., 2018. Improving the sub-base materials at Al-Fao port in Basrah Governorate– south of Iraq by adding some synthetic polymers and cement. Mesopotamia J. Mar. Sci, Vol. 33, Issue. 1, pp. 57-64. DOI: https://doi.org/10.58629/mjms.v33i1.59.

Al-Masri, M., Al-Dabsheh, I. and Al-Slaty, F., 2023. Effect of the addition of industrial materials on the properties of expansive soil in the Al-Azraq area, Jordan. Iraqi National Journal of Earth Science, Vol. 23, No. 1, 2023, pp 118 -131. DOI: 10.33899/earth.2023.138680.1051.

Al-Rubaie, D.J., 1988. Geological situation and surface in Basrah Governorate. Basrah Encyclopedia of Civilization, Geographical encyclopedia, University of Basrah, pp.3-20.

Arasan, S., Işik, F., Akbulut, R.K., Zaimoğlu, A.S. and Nasirpur, O., 2015. Rapid stabilization of sands with deep mixing method using polyester. Periodica Polytechnic Civil Engineering, 59(3), pp. 405-411. doi.org/10.3311/PPci.7956.

Asad, W. H., Ghalib, H. B. and Alzubaydi, J. H., 2021. Study and evaluation of geotechnical properties of soil banks slopes for Al-Masab Al-Aam channel (Southern sector) and the possibility of improving them. Journal of University of Babylon for Pure and Applied Sciences, Vol. 29, No. 3.

ASTM D-421, D-422 Standard test method for particle size distribution.

ASTM, D1557-12 Standard test methods for laboratory compaction characteristics of soil using modified effort.

ASTM, D1883-16 Standard test for California Bearing Ratio (CBR) of laboratory – compacted soils.

ASTM, D2216-05 Standard test method for laboratory determination of water (Moisture) content soil and rock mass.

ASTM, D3080-04 Standard test methods for direct shear test of soils under consolidated drained conditions.

B.S., British Standard Institutions. Methods of testing soil for civil engineering purposes. 1377: 1975 – 1990.

Buday, T. & Jassim, S. Z. (1987). The Regional Geology of Iraq, Vol.2, Tectonism, Magmatism and Metamorphism. Geological Survey & Mineral Investigation, Baghdad, Iraq, 352 p.

Horvath, J. S., 2000. Integral- Abutment bridges problems and innovative solution using EPS geofoam and other geosynthetics. Research Report, Manhattan College, Civil Engin. Dept. Bronx, N.Y, 12P.

Jha, A.K. and Sivapullaiah, P.V., 2015. Mechanism of improvement in the strength and volume change behavior of lime stabilized soil. Engineering Geology, Vol. 198, pp. 53-64. DOI: 10.1016/j.enggeo.2015.08.020.

Karim, H.H., 1991. Structural nature of lower Mesopotamian region from geophysical observations. In Proceeding of 3rd symposium on Oceanography of Khour Al-Zubair, Marine Science Center Basrah, pp. 15-25.

Khudhair, A.H., Mahmood, R.A. and Jaber, M.A., 2022. Improving some geotechnical properties of cohesive soils by adding basalt fibers and Portland cement in Basrah Governorate-Southern Iraq. Design Engineering ISSN: 0011-9342, Year 2022 Issue: 1, pp. 1509-1522.

Lees, G.M. and Falcon, N.L., 1952. The geographical history of the Mesopotamian plains. The Geographical Journal, 118(1), pp.24-39.

Liu, J., Qi, X., Zhang, D., Feng, Q., Wang, Y. and Kanungo, D.P., 2017. Study on the permeability characteristics of polyurethane soil stabilizer reinforced sand. Materials Science and Engineering, https://doi.org/10.1155/2017/5240186 .

Mahmood, R.A. and Albadran, A.A. 2002. Geotechnical classification and distribution of the Quaternary deposits in Basrah city, south of Iraq. Iraqi National Journal of Earth Science, Special Issue, Part 1, pp. 6-16.

Seracettin et al. (2015)

The Iraqi Standard for National Center for Laboratories and Construction Research (NCLCR), 2001.