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Geotechnical Properties of Clayey Soil Contaminated with Copper

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Abstract— In this research, the effectsof coppersulfate contamination on the chemical, physical and mechanical properties of cohesive soil have been studied and compared with the properties of intact soil. Soil sampleswere obtained from Al-Ahdab oil field in Wasit governorate, located in the east of Iraq. In the laboratory, the soil specimens were contaminated artificiallywith three quantities of copper sulfate) $CuSO_4.5H_2O$) (100, 200 and 400) gm. The contaminantwas dissolved in 10 liters of distilled water and then added to the intact soil. The intact soil samplekept soaked with the contaminantfor 30 days. Several tests were conducted onthe soil samples (intact and contaminated) to measure the effects of copper sulfate on the geotechnical properties of clayey soil. The results of tests showed significant effectsfor copper on the studied soil properties. The copper sulfate causesdecreasing the percentage of fine particles in the soil, Atterberg s limits, permeability and optimum water content. Inaddition, the copper sulfate causes increasing thespecific gravity andmaximum dry density of soil. The shear strength parameters of soil are measured by using direct shear test, unconfined compression test and unconsolidated undrained triaxial test are decreased with increasing the concentration of copper sulfate in soil. Also, its noted increasing the initial void ratio, the compression index and recompression index with increasing concentration of contaminant in soil.

Keywords— Heavy metals, Copper, Soil contamination, Clayey soil, Geotechnical properties.

1. Introduction

In recent years, soil contamination with heavy metals is one of the main problemsfacingthe environmental scientists. Agricultural, industrial and military activities are the main sources to contaminant the environment with heavy metals and other types of contamination [1&3]. Heavy metals (HMs) are considered the most harmful contaminants and classify as carcinogenic material. There are two types of HMs, thefirst typeimportant to life and human health, but when it is higher than the permissible limits lead to the negative effectsandthe second typeof heavy metals are not useful and may be cause many problemsat low concentrations. Also, HMs cause the negative effect on the physical and mechanical properties of soil, relying on the chemical activity and mobility of contaminant in the soil, especially when contaminants presence in soil above the range level [1&2]. In Iraq, there are several sites contaminated with heavy metals like Al Suwaira, Khan Dhari, Al Mishraq and Ouireej, so it is very important to investigate the impacts of these contaminants on the soil properties [3]. The availability of soil that is clean from any type of contaminants reduced because of the urban and industrial development and use soil in various engineering projects, so it would be advantageous to utilize the contaminated soil in the foundations and embankments of buildings, and roads, but it requires the special and thorough knowledge of their geotechnical properties[4].

The incidence of contaminations in soil is not important for the environmentalists but also cause diverse changesin the geotechnical properties of soil. Cohesive soils which are electro-chemically active and influenced whenever the environment is contaminated by wastes. The introduce of contaminant in the soil or in groundwater are effect by the permeability of soil and adsorption properties of the soil solids. The amount of contaminant in the soil depends on the properties of soiland chemical properties and composition of contaminants [8]. There are several researches studied the impacts of differenttypes of contamination on the geotechnical properties of soil:

Ali [5] and Khamehchiyan et al. [6] studied the impacts oil on the geotechnical properties of cohesive and cohesionless soils. The results showed a decrease in shear strength parameters, permeability, maximum dry density, optimum moisture content and Atterberg s limits.Karkush et al. [1] described the effectsofdifferent contaminants suchaskerosene, ammonium hydroxide, lead nitrate, and copper sulfate on thechemical, physical and mechanical properties of soil. The results indicated high impacts of contaminants on the geotechnical and slight impacts on the chemical properties of cohesive soil samples. Karkushand Altaher [7] studied the impacts of total petroleum hydrocarbons (TPH) on the geotechnical properties of clayey soil samples contaminated in the field. The results demonstrated that the TPH have significant effect on the different properties of a clayey soil sample (chemical, physical, and mechanical).

Karkush and Abdul Kareem [8] studied the impactsof medium fuel oil (MFO) on the2geotechnical properties of silty clay soil. The soil specimens are contaminatedartificiallywith two percentages of (MOF) 10 and 20 % by dry weight of soil. The results of tests showed that the fuel oil has slight effects on the chemical and physical2properties of soil and significant impacts on the2mechanical properties of soil.In the present study, the impacts of three percentages of coppersulfate contaminantonthe chemical and geotechnical2properties of silty clayey soil have been studied in details by conducting most of traditional laboratory soil tests. The intact soil samples are brought from the site of Al-Ahadab oil field located in Wasit governorate.

2. Soil Sampling and Material Used

The intact soil samples are brought from the site of Al-Ahadab oil field that located in Al-Ahrarcity located in the north west of Wasit. The GPS coordinates of soil samples location measured by using GPS device is (E=569974, N=359254).The disturbed and undisturbed soil samples wereobtained by excavation to a depth of 3mbelow existing ground level (EGL).The disturbed soil samples were placed in tighten plastic containers, while the undisturbed soil samples extracted by using Shelby tubes are coveredwith wax, then the soil samples are labeled and transported to the laboratory. The field unit weight and water content measured according to ASTM D2937 are 19.47 kN/m3 and 28.6% respectively.

The intact soil was classified as silty clay of high plasticity (CH) according to the unifiedsoil classification system (USCS). Thecohesivesoil used in this study is preferred due to the highly response of such soil tothe environmental changes. Also, the chemical reactions between this type of soil and contaminants are higher than other soil types. The clayey soil has a large specific surface area, a high number of available active sites and a dynamiccrystalline structure[4&9].Copper sulfate was added to soil samples with different quantities (100, 200, and 400) gm to study theeffectsof various concentrations of copper sulfate on the geotechnical properties of soil. Copper sulfate has the following properties: chemical formula (CuSO4.5H2O), solubility in water (230.5 gm/L), density (2.29 gm/cm3), and molar weight (249.68gm/mol).

3. Preparation of Contaminated Soils

Three disturbed soil samples wereplaced in three plastic containersand soaked with the contamination solution and covered with tighten covers and left for one month to allow the adsorption of pollutants by soil. The soil in container weighs about 15kg. The chemical solution consists of the contaminant and distilled water, wherethe concentration of copper sulfate in soil samples are (6666.67, 13333.33 and 26666.67) ppm. The designation of soil samples used in the present study is given in Table 1. The distilled water used to mix with copper sulfate is 10L. The reasons of usingthis quantity of distilled water are: (1) The distilled water must besufficient to coverthe soilsample and provide the height of water above the soil surface about equal to 3cm in order to allow contaminant topenetrate deeper in the soil and (2) to help the mixing of contaminant inthe soil easily [1 & 10]. Figure 1 shows thepreparation ofclayey contaminated soil sample.

Table 1: Designation of soil samples

Symbol	Definition
H0	Intact soil sample
H1	Soil sample contaminated with 100gm of $CuSO_4.5H_2O$
H2	Soil sample contaminated with 200gm of $CuSO_4.5H_2O$
H3	Soil sample contaminated with 400 gm of $CuSO_4.5H_2O$

Figure 1: Preparation of contaminated soil samples

4. Soil Testing

A specific laboratory-testing program had been conducted on the intact and contaminated soil samples. The disturbed soil samples are used for testing the physical and chemical properties of intact and contaminated soil samples. The undisturbed soil samples are used for testing the mechanical properties of intact soil, while remolded soil samples are used for testing the mechanical properties of contaminated soil. The remolding or constituting of soil samples are based on the field unit weight and water content. The soil tests carried out in this research can be divided into three major groups: chemical tests; physical tests and mechanical tests.

5. Results and Discussion

5.1 *Chemical Analysis Results*

The chemical tests results are given in Table 2. The concentration of SO3, Cl-1, OM, TSS and gypsum increased in contaminated soil samples, while the pH value of soilisslightly affected by the contamination. Also, the copper sulfate causes decreasing of CaCO3 and increasing the percent of Quartz and clay minerals. The geochemical factors affect the absorption of contaminants, so it is important to know the chemical composition of the intact soil. The main geochemical factors are organic matter content, cation exchange capacity (CEC), pH value and clay minerals [11].

Table 2: Resultsof chemicaltests.

Soil sample	SO_3 %	Cl^{-1} %	SiO_2 %	CaO %	OMC %	Gypsum %	TSS %	pH value
H0	0.036	0.5442	32.37	18.31	0.620	0.04	3.6	7.6
H1	0.620	0.836	32.58	17.93	0.610	0.043	3.53	7.5
H2	0.326	0.758	32.49	17.67	1.103	2.4	4.11	7.4
H3	0.293	1.187	31.64	18.11	0.656	3.56	6.92	7.3

5.2 *Results of Physical Tests*

5.2.1 Particle-size distribution

The results of particle-size distribu-tion of tested soil are given in Table 3 and shown in Figure 2. The re-sults showed the soil samplescova-lent bonds with oxygen atoms on any particular mineral surface causes increasing the sizes of soil particles which resulting in increas-ing the percentage of silt and de-creasing the percentage of clay par-ticles. The results showed that the presence of Cu in soil samples in-creases the percentages of grains coarser than 0.005mm in the soil sample [12]. Organic matter (OMC) and calcium carbonate (CaCO3) represents main cement-ing agents between particlesof soil.Theseagents have the ability to increase both the sticking between soil particles and stability of soil aggregate [13].The electronegative is a main factor in determin-ingwhich of the trace metals chemi-sorbs on mineralswith the highest preference.The ability of metal to make the strongest covalent bonds with oxygen atoms on any particu-lar mineral surface increases with the electronegative factor increas-ing.Copper metal (Cu) has a great-er ability toadsorbed on clay sur-faces more than other type of heavy metals and createa cation bridge between clay particles, lead-ing toincrease the stability of ag-gregates.

Table 3: Index properties ofsoil samples.

Soil Sample	Silt %	Clay %	LL %	PL %	GS	ρ_{dmax} gm/cm³	ω_{opt} %	k×10^{-8} cm/sec
H0	26	74	55	27	2.74	1.678	21.6	3.22
H1	35	65	50	27	2.77	1.692	21.4	1.63
H2	37	63	48	27	2.79	1.766	15	1.16
H3	48	52	46	23	2.82	1.8	14.5	1.06

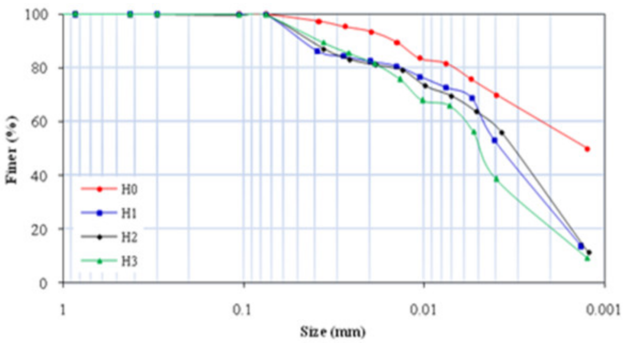

Figure 3: Particles-size distrubution curves of soil samples.

5.2.2 Atterberg s limits

Atterberg s limits are described by liquid limit (LL) and plastic limit (PL). The results of Atterberg s lim-its are given in Table 3. The results indicated that the copper sulfate causes reduction Atterberg s lim-itswithincreasing the concentration of contamination in soil. There are several factors effects on liquid and plastic limits, the clay content is amain factor and when reduced, leading to reduction in Atterberg s limits and the HMs coated the clay particle and the salt solutions tend-ed to reduce the thickness of dif-fused double layer and flocculate the clay particles [14].

5.2.3 Specific gravity

The specific gravity (Gs) tests re-sults are given in Table 3 for intact and contaminated soil samples. For contaminated soil samples, it can be noticed that the specific gravity increases with the concen-tration of contaminant increasing. Thisactivity because ofthe high density of the contaminantthat present in the soiland lead to in-crease the density of soil [1].

5.2.4 Permeability of soil

The results of falling head test (FHT) are given in Table3. Ac-cording to the results, the permea-bility of contaminated soil samples is less than that of intact soil. The reduction in the permeability of soil sampleH1is 49% and this de-crease continues with increasing the percentage of contamination. The contamination of soil with HMs causes filling the voidsbe-tween particles with salts [15].

5.2.5 Compactiontest

The compaction is a process that reduces the voids ratio of a soil through removingthe air voids by applying mechanical force. The re-sults of standards Procter compac-tion tests are shown in Fig.3 and Table 3. Increasingthe contamina-tion causes increasing the maxi-mum dry densityand decreasing the optimum moisture content (OMC). The decrease in optimum moisture content resulted from re-duction the voids between particles due to sedimentation of salts in pores. The reduction in OMC causes increasing the maximum dry density. When the heavy met-als entered into the clay soil, it covered the pointsof contact on the clay molecules that were frequently taken up by water molecules with more stable ions thereby affecting the engineering performance and lowering the desire of clay for dis-sociating water molecules. The contamination of clayey soil with HMs will take more time or need more compaction effort to get the desired maximum dry density [16].

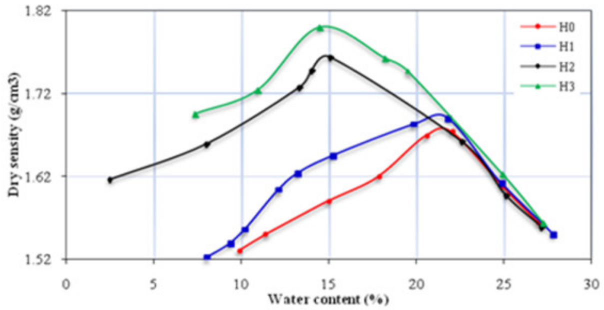

Figure3: Compaction curvesof soil samples.

5.3 *Mechanical Properties*

5.3.1 One-dimensionalconsolidation

Undisturbed soil sample is used to measure the compressibility char-acteristics of intact soil sample, while remolded soil samples are used for contaminated soils. The remolding of soil samples is based on the field unit weight and water content. Theresults of 1-D consoli-dationtests: the initial void ratio (eo), compression index (CC), recompression index (Cr), pre-consolidation pressure (PC) and coefficientof consolidation (CV) are given in Table4 and shown in Figure 4.

Table 4: Results of consolidation tests

Soil Samples	e_o	Cc	Cr	P_C (kPa)	m_v (m^2/kN)	Cv (cm^2/ sec)
H0	0.816	0.100	0.033	69	0.0002	0.00054
H1	0.881	0.123	0.033	45	0.00027	0.00018
H2	0.895	0.143	0.047	69	0.0005	0.00013
H3	0.893	0.125	0.034	33	0.00046	0.0001

A noticeable decrease in the coeffi-cient of consolidation are indicated from the results of consolidation tests with increasing the concentra-tion of HMs in the soil samples. This decrease may have attributed to thedecrease in permeability of contaminated [15]. Also, theresults showed increasing the initial void ratio, compression index and recompression index. The eo may be increased due to the reduction in percentage of fine particles and create alarge space between soil particles of contaminated soil samples. Also, the increasing in Cc and Cr because of the present of HMs in the soil voids as a lubri-cant agent lead to the sliding of soil particlesor may be due to the basis charge of the particles and the na-ture of the fluid which affects the adsorbed cat ions [7&18].

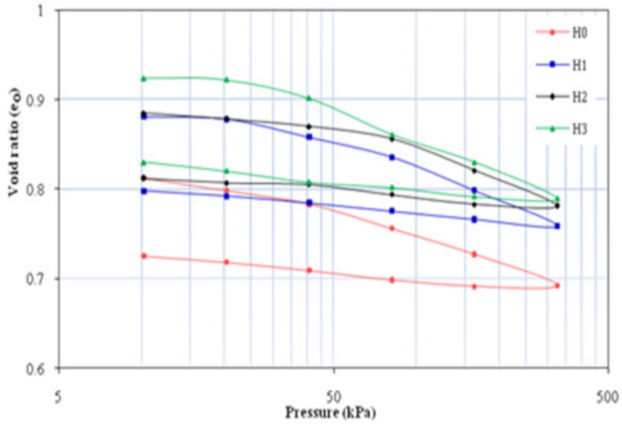

Figure 4: Variation of void ratio versus pressure of soil samples.

5.3.2 Shear strength

The results of shear strength testsare given in Table 5. Undisturbed soil sample is used to measure the shear strength pa-rameters of intact soil sample, while remolded soil samples are used for contaminated soils. The remolding of soil samples is based on the field unit weight and water content.

5.3.2.1 Direct shear test (DST)

Direct shear was conducted to ob-tain the shear strength parame-ters, cohesion (c) and angle of in-ternal friction (φ). The results indi-cated to reduction in c and φ, which resulted fromthe lessening in friction and bond that grips the soil particles together in soil mass.The heavy metal contami-nants are infiltrate between the particles of soil in the voids when it spills on soil and form a thin layer of coats around the particles, in this way prevent the expansion of the cohesive forces between molecules that responsible about the bond of the particles of cohe-sive soil [19].

Table 5: Results of shear strength tests.

Soil Sample	DST		UCT			UUT
	c (kPa)	ø (Deg)	ε (%)	q_u (kPa)	c_u (kPa)	c (kPa)
H0	108	13.4	11.05	161	81	125
H1	53	5	9.276	131	66	95
H2	18	7.8	18.75	58	29	26
H3	8	3.4	17.039	38	19	24

5.3.2.2 Unconfined compression test (UCT)

The unconfined compression test was conducted on undisturbed in-tact soil sample and remoldedcon-taminated soil samples to measure the effects of remolding on the co-hesion between particles of intact soil. The variation of stress-strain relation of soil samples are shown in Fig.5. The heavy metals contam-ination has negative effects on co-hesion of soil. This behavior may be attributed to the coating of the surface of soil solids with heavy metals that causes a reduction in bonding between particles and slipping of solid particle.

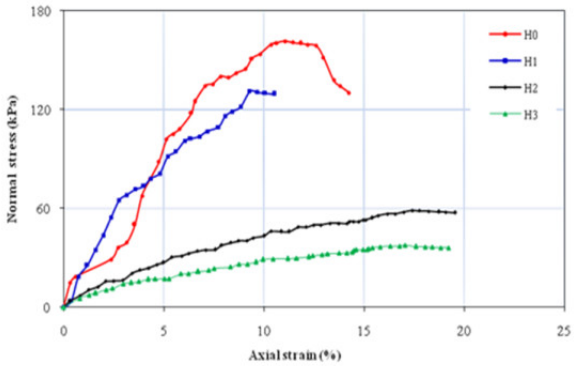

Figure5: Stress-strain relationship of unconfined compression test.

5.3.2.3 Triaxial test (UU-Test)

The triaxial isrunby saturating the soil, applying the confining pres-sure (σ3) and then applying the de-viator stress until the failure hap-pens. The deviator stress-strain re-lations obtained from UU tests are shown in Figure 6 and Table 6. The contamination of soil samples with copper causes a significant lower-ing in the cohesion. The reduction in cohesion may be attributed to the dissolution of salts that cause brokenbonds between soil parti-cles.

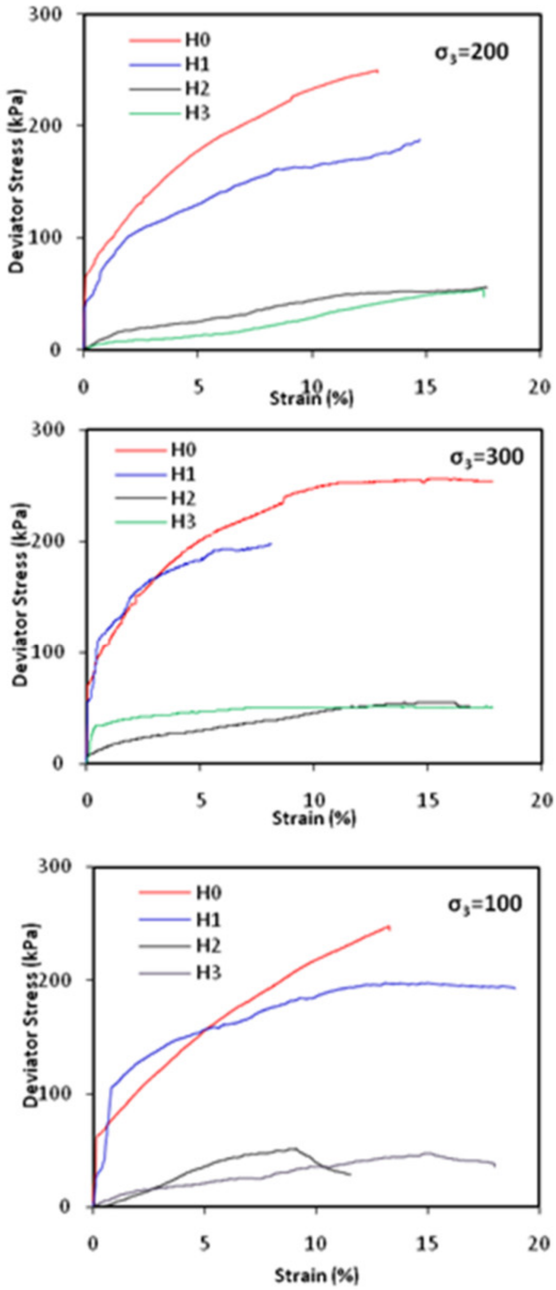

Figure 6: Deviator stress versus stain ob-tained from UU tests.

6. Conclusions

The presence of soil contaminant has diverse effects on different properties of soil (physical, chemi-cal and mechanical). The impacts mainly rely on the concentra-tionand thetype of contaminant in the soil and the type of soil. The geotechnical2properties of soil are become more influencedwith in-creasing the percentage of contam-inant. The results indicated de-creasing the percentage of finepar-ticles (size less than 0.005 mm) with increasing the percentage of copper sulfate in soil. Also, con-tamination with copper sulfate causes reductioninthepermeabil-ityof soil, optimum water content, but the contaminants lead to in-creasing the specific gravity and maximum dry unit weight of soil. The coefficient of consolidation de-creases for soil contaminated while the initial of void ratio, compres-sion and swelling index and coeffi-cient of volume change are in-creased, but the effect of contami-nation on Cc, Cr and mv for H3 begin to decrease, but remain the values of these parameters higher than their values in intact soil.At the end, the shear strength parame-ters (cohesion and angle of internal fraction) are decreasedin contami-nated soil samples.

References

[1] Karkush, M. O., Zaboon, A. T., and Hussien, H. M., 2013, "Studying the effects of contam-ination on the geotechnical properties of clayey soil", Cou-pled Phenomena in Environ-mental Geotechnics, Taylor & Francis Group, London, pp.599-607.

[2] Uddin, M. K., 2016, "A review on the adsorption of heavy metals by clay minerals, with special focus on the past dec-ade", Chemical Engineering Journal, Vol.308, pp.438-462.

[3] UNEP report, 2005, "Assess-ment of environmental "Hot Spots" in Iraq", Job No. DEP/0755/GE, Imprimerie Chirat, France.

[4] Shehzad, A., Khan, A. H. and Rehman, Z. U., 2015, "Charac-teristics of low plastic clay con-taminated by industrial efflu-ents", International Journal of Advanced Structures and Ge-otechnical Engineering, Vol.4, No.3, pp.138-147.

[5] Ali, H. A., 1999, "Some ge-otechnical properties of oil con-taminated soil", M.Sc. thesis, Department of Civil Engineer-ing, College of Engineering, University of Baghdad, Baghdad.

[6] Khamehchiyan, M., Charkhabi, A. H., and Tajik, M., 2007, "Ef-fects of crude oil contamination on geotechnical properties of clayey and sandy soils", Engi-neering Geology, Vol.89, No.3-4, pp.220-229.

[7] Karkush, M. O., and Altaher, T. A., 2017, "Geotechnical evalua-tion of clayey soil contaminated with industrial wastewater", Archives of Civil Engineering, Vol. LXIII, Issue 1, pp. 48-60.

[8] Karkush, M. O. And Abdul Kareem, Z., 2017, "Investigate the impacts of fuel oil on the geotechnical properties of Co-hesivesoil", Engineering Jour-nal, Vol. 21, Issue 4, pp.127-137.

[9] Chandrasekaran, A., and Ravisankar, R., 2015, "Spatial distribution of physico-chemical properties and function of heavy metals in soils of Yelagiri hills, Tamilnadu by energy dis-persive X-ray florescence spec-troscopy (EDXRF) with statis-tical approach", Spectrochimica Acta Part A: Molecular and Bi-omolecular Spectroscopy, Vol.150, pp.586-601.

[10] Zhou, D. M., Deng, C. F. and Cang, L., 2004, "Electroki-netic remediation of a Cu con-taminated red soil by condition-ing catholyte pH with different enhancing chemical reagent", Chemosphere Vol.56, No.3, pp. 265-273 .

[11] Defo, C., Yerima, B. P. K., Bemmo, N., 2016, "Investigat-ing soils retention ratios and modelling geochemical factors affecting heavy metals retention in soils in a tropical urban wa-tershed,Environment, Devel-opment and Sustainabil-ty,Vol.19, No.5, pp.1649-1671.

[12] Hussien, H. M, 2011, "Stud-ying the effects of some contam-inants on geotechnical soil properties by testing and re-mote sensing", M.Sc. thesis, Department of Civil Engineer-ing, College of Engineering, University of Baghdad, Bagh-dad.

[13] Craig, R. F., 2004, "Craig s soil mechanics", 7th ed., Spon Press: imprint of Taylor and Francis Group, London and New York .

[14] Sasikumar, J., 2016, "A study on the effect of salt solu-tions on certain geotechnical properties of two clays", Inter-national Journal of Scientific Research in Science, Engineer-ing and Technology, Vol.2, No.5, pp.133-136.

[15] Khan, M. I., Ifran, M., Aziz, M., and Khan, A. H., 2016, "Geotechnical characteristics of effluent contaminated cohesive soils", Journal of Environmen-tal Engineering and Landscape Management, Vol. 25, No.1, pp. 75-82.

[16] OTA, J. O., 2013, "The ef-fect of light crude oil contami-nation onthe geotechnical prop-erties of kaolinite clay soil", Ph.D. thesis, College of Engi-neering, Anglia Ruskin Univer-sity .

[17] Head, K. H., 1994, "Manual of soil laboratory testing, vol-ume 2: Permeability, Shear Strength and Compressibility Tests", 2nd ed., Hasted Press: an impirnt of John Wily and Sons, New York.

[18] Grim, R. E., 1953. "Clay min-eralogy", McGraw-Hill book Co., New York.

[19] Oyegbile, O. B. and Ayi-ninuola, G. M., 2013, "Labora-tory studies on the influence of crude oil spillage on lateritic soil shear strength: a Case study of Niger Delta area of Ni-geria", Journal of Earth Scienc-es and Geotechnical Engineer-ing, Vol.3, No. 2, pp. 73-83.

الخواص الجيوتقنية للتربة الطينة الملوثة بالنحاس

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الخلاصة – في هذا البحث تم دراسة تأثير النحاس وهو من المعادن الثقيلة على الخواص الكيميائية والفيزيائية والميكانيكية للتربة المتماسكة ومقارنة النتائج مع خصائص التربة السليمة. تم الحصول على عينات التربة المشوشةوغير المشوشة من موقع الأحدب في محافظة واسط التي تقع في شرق العراق. تم تلويث عينات التربة بشكل اصطناعي في المختبر بثلاثة كميات من كبريتات النحاس ($CuSO_4.5H_2O$) وهي (100 و200 و400) غم. تم حل كل كمية من الملوث في 10 لترات من الماء المقطر، ثم تمت إضافة المحلول الملوث إلى التربة السليمة وتبقى عينات التربة غارقة في الملوثات لمدة 30 يوما. وأظهرت النتائج أن ملوث النحاس له تأثير كبير على خواص التربة الجيوتقنية. فيما يتعلق بالخصائص الفيزيائية، فإن النحاس يسبب انخفاضا في كل من نسبة الحبيبيات االناعمة وتصبح التربة أكثر خشونة، والوزن النوعي ((Gs وحدود أتربيرغ(LL and PL) والنفاذية ويؤدي أيضا أضافة النحاس الى التربة التقليل محتوى الماء الأمثل (ω_{opt})، ولكن هذه النوع من الملوثات يؤدي الى زيادة الكثافة العظمىالجافة للتربة وفيما يتعلق بالخصائص الميكانيكية، يسبب الملوث انخفاضا في معامل الانضمام للتربة وزيادة في معاملات الانضغاط والانتفاخ ومعامل التغير بالحجم التي تم الحصول عليهم من فحص الانضمام للترب الملوثة وكذلك ادى اضافة كبريتات النحاس الى النقصان في معامل الاحكتاك (Φ) ومعامل التماسك ((C التي تم الحصول عليهما من فحص القص المباشرDST)) وفحص الانضغاط غير محصور(UCS) و فحص القص ثلاثي المحاور(UUT).

الكلمات المفتاحية: النحاس، التربة الطينية، التلوث، الخواص الجيوتقنية.