Effects of Industrial Wastes on Geotechnical Properties of Clayey Soil

Mahmoud S. Abdul Kareem
Civil Engineering Department
Baghdad University
mahmoudshakir7992@yahoo.com

Mahdi O. Karkush
Civil Engineering Department
Baghdad University
mahdi_karkush@yahoo.com

Abstract

The present work focused on studying the effects of liquid industrial waste on the geotechnical properties of clayey soil. The intact clayey soil samples, disturbed and undistutbed had been obtained from countryside city of Alexandria in 2013, which is located to the north of Babylon Governorate. While, the liquid industrial waste is side product disposed from of Al-Musayyib Thermal Electric Power Station, which includes solutions of acidic, alkaline and hydrocarbons. The clayey soil samples were contaminated artificially with four percentage (10, 20, 40 and 100) % by weight of water used in soaking process. The soaking process continued for 30 days. Based on the results of tests, the following observations are obtained: the different percentages of contaminant have slight effects on the chemical and physical properties of soil, but have significant effects on the mechanical properties such as shear strength parameters, where the shear strength parameters decreased by (5-35) %, and consolidation properties, where the coefficient of vertical consolidation increased by (7-28) % in compare with the properties of intact soil. The modulus of subgrade reaction decreased by (4-27) %.

Key Words : Industrial wastes, soil contamination ‹geotechnical properties ‹clayey soil.

الخلاصة

يهدف العمل الحالي الى دراسة آثار النفايات الصناعية الملوثة السائلة على الخواص الجيوتكنيكية للتربة الطينية .تم الحصول على عينات مشوشة وغير مشوشة من التربة الطينية غير الملوثة من ريف مدينة الاسكندرية في عام ٢٠١٣ شمال محافظة بابل. أما النفايات الصناعية فهي عباره عن مواد سائلة تطرح كناتج عرضي من محطة كهرباء المسيب الحرارية والذي يتضمن مواد حامضية وقاعدة هايدروكاربونية .تم تلويث عينات التربة الطينية مختبريا وذلك باضافة اربعة نسب مئوية من الملوث 10) و 20 و 40 و (100 ٪ من وزن الماء المستخدم في عملية غمر النموذج. حيث استمرت عملية الغمر لمدة ثلاثون يوما .استنادا إلى نتائج الفحوصات يمكن استنتاج الملاحظات التالية :النسب المئوية المختلفة لها تأثيرات طفيفة على الخواص الكيميائية والفيزيائية للتربة مثل الوزن النوعي وحدود اتربرك والتوزيع الحجمي لحبيبات التربة ,ولكن لها تأثير كبيرعلى الخواص الميكانيكية مثل معاملات مقاومة القص للتربة ,حيث انخفضت معاملات مقاومة القص بنسبة (5-35) ٪ ومعامل رد فعل التربة التحتية انخفض بنسبة (7-28) ٪ .بينما ازداد معامل الانضمام العمودي للتربة بنسبة (4-27) ٪ وذلك بالمقارنة مع خصائص التربة غير الملوثة .

الكلمات المفتاحية: النفايات الصناعية، تلوث التربة، الخواص الجيوتقنية، التربة الطينية

1. Introduction

Geoenvironmental engineering is the application of newly developed environmental concepts in the geotechnical engineering. Contamination of soil can be defined as the build-up of persistent toxic compounds, chemicals, salts, or radioactive material. The development of modern life especially due to the connected of industries and other developments have given rise to large risks of soil contamination. The example includes erratic emissions/discharges of pollutant from industries, automobiles, indiscriminate disposal of solid/hazardous waste especially in developing countries and explosions or accidents hazardous substances (Rowe, 2001).

Khamehchiyan et al. (2007), they found that the effect of contaminant on shear strength parameters was not uniform, and it was depended on the type of soil. Gratchev and Towhata (2009) studied the effects of acidic contamination on the consolidation properties of marine deposits. The acidic contamination affected the compressibility of the clays and the factors determining the degree of such changes were clay mineralogy, soil structure, and the duration of clay-acid interaction. Rahman et al. (2010) studied the effects of different percentages of oil contamination on the geotechnical properties of weathered basaltic rock of grads (V and VI). The results showed that oil contamination causes decreasing Atterberg's limits and undrained shear strength (c_u). Karkush et al. (2013) studied the effects of four types of contaminants (kerosene, ammonium hydroxide, lead nitrate, and copper sulphate) on the geotechnical properties of clayey soil, they concluded that contaminants have different effects on the geotechnical properties of soil depending on the type and concentration of contaminant. Each contaminant was added in two percentages 10% and 25% of dry weight of clayey soil. Iraq has several thousand of contaminated sites resulting from a combination of general industrial activities, military activities and post-conflict damage and looting (UNEP Report 2005). The present work focusing on measuring the effects of liquid industrial waste on the geotechnical properties of intact clayey soil and due to increasing the industrial activities in Alexandria city, it will be used as case study.

2. TYPES OF SOIL CONTAMINATION

Soil contamination is caused by the presence of man-made chemical or other alteration in the natural soil environment. The major sources of soil contamination are (Sharma and Reddy, 2000):

- Agricultural activities;
- Urban activities;
- Industrial effluents and solid waste.

The industrial effluents and solid waste causes:

- Dangerous chemicals entering underground water;
- Ecological imbalance;
- Release of pollutant gases;
- Release of radioactive rays causing health problems;
- Increase salinity of soil;
- Reduced vegetation;

Aqueous liquids (miscible liquids) containing inorganic chemicals (acids, bases, salts) that are miscible in water; Non aqueous liquids (immiscible liquids) containing organic compounds immiscible in water. A liquid phase of contaminant can be recognized as light non aqueous phase liquid (LNAPL) or dense (DNAPL) in compared with density of water or separate phase which is neutrally buoyant depending on temperature (Sharma and Reddy, 2004).

3. FIELD WORK

3.1 Material Used

The soil samples obtained from countryside of Alexandria city, which is located to the north of Babylon province, to study the effect of industrial contaminant on the geotechnical properties of the soil. The location of soil samples is determined by using GPS (UTM: 33N0488377, 2302942). While, the contaminant is an industrial waste disposed from Al-Musayyib thermal power plant which is consist of hydrocarbons alkaline and acidic wastes. The chemical compositions of soil samples and contaminant are important to understand the behavior of contaminated soil samples. The results of chemical analysis for contaminant is given in Table 1.

Table 1: Chemical analysis of contaminant.

Concentration						pH	Density kg/m^3
%	Mineral	%	Mineral	%	Mineral		
0.00841	K	0.0071	Zn	0.0228	Na	2.65	1001.3
0.0040	Mg	0.0001	Cr	0.0200	NO_3		
0.0000	Pb	0.0002	Ni	0.1172	SO_3		
0.2101	Ca	ND	Cd	0.1578	SO_4		
0.0000	ALK	0.1517	Fe	0.0180	Cl^{-1}		
0.3960	EC	ND	Cu	ND	CaO		

3.2 Drilling and Sampling

The soil samples obtained from a depth of 4m below the natural ground level to avoid organic material and roots of plants, also it is located under the ground water table. The drilling was achieved by using an excavation machine by open an area of 10 m length and 8 meters width. The soil samples were putted in tighten plastic containers and transported to the laboratory.

3.3 Field Tests

The field tests include measuring the field unit weight and natural moisture content. The field unit weight (ASTM D2937-00) is 19.3 kN/m^3 and the moisture content (ASTM D2216) is 32 %.

4. LABORATORY WORK

4.1 Soaking Process

The contaminant was added in four percentages of (10, 20, 40, 100) % by weight of the distilled water used in soaking process of the soil samples for 30 days in plastic covered containers. The chemical solution contains a specific percentage of contaminant and completed with distilled water to get the sufficient quantity which enough to cover the soil samples and in order to facility the penetration of contaminant into the soil. The soil samples tested in the present study were designated as C_o, C_1, C_2, C_3 and C_4 for intact and contaminated soil with (10, 20, 40 and 100) % respectively.

4.2 Physical Tests

The physical properties tested in the present work are: particle size distribution (ASTM D422); liquid and plastic limits (ASTM D4318); specific gravity (BS: 1377, 1975, Test 6B) and the maximum dry density and optimum moisture content (ASTM D 698).

4.3 Mechanical Tests

4.3.1 Consolidation Tests

The oedometer test was conducted on undisturbed intact soil and remolded contaminated soil samples to determine the compressibility characteristic according to ASTM (D2435).

- **Shear Strength Tests**

The undrained shear strength was measured by unconfined compression test (UCT) (ASTM D2166) and direct shear test (DST) (ASTM D3080-72), these tests were conducted on undisturbed intact soil samples and remolded contaminated soil samples.

Also, vane shear tests (VST) (ASTM D4648) were conducted in the laboratory on remolded soil samples of both intact and contaminated soils.

4.3.3 Plate Loading Test

To determine the modulus of subgrade reaction (Ks), a plate loading tests (ASTM D1196) had been conducted on remolded soil samples by using the hydraulic press, load cell, digital weighing indicator, and dial gauge have 0.002 mm/division degradation and of 12.7 mm capacity.

5. RESULTS AND DISCUSION

5.1 Results of X-Ray Diffraction and Chemical Tests

The results of X-ray diffraction tests are given in Table 2. This test included determination the d-spacing between different planes of atoms in the crystal lattice in (A^0). There is a small decrease in the distance between soil grains for some of the major and minor minerals in the intact and contaminated soil samples such as talc and montmorillonite. X-ray tests results have shown major reflections at (2.48, 2.88, 3.02, 3.33, 4.25, 7.15 and 14.04) $\mathring{A}$. This data reveals the presence of montmorillonite, kaolinite, feldspar and dolomite as major clay minerals and quarts, calcite, and orthoclase as minor non-clay minerals.

Table 2: Results of X-ray diffraction tests.

Minor Mineral		Major Mineral		Soil Sample
d-Spacing $\mathring{A}$	Mineral	d-Spacing $\mathring{A}$	Mineral	
4.24	Quartz	14.81	Montmorillonite	C_o
3.02	Calcite	7.15	Kaolinite	
3.34	Orthoclase	4.02	Philipsite	
2.48	Talc	3.19	Feldspar	
-	-	2.88	Dolomite	
4.25	Quartz	14.8	Montmorillonite	C_1
3.02	Calcite	7.20	Kaolinite	
3.33	Orthoclase	4.252	Philipsite	
3.133	Talc	3.203	Feldspar	
-	-	2.698	Dolomite	
3.333	Quartz	14.04	Montmorillonite	C_2
3.022	Calcite	7.049	Kaolinite	
3.368	Orthoclase	4.323	Philipsite	
2.485	Talc	3.190	Feldspar	
-	-	2.88	Dolomite	
3.333	Quartz	14.04	Montmorillonite	C_3
3.024	Calcite	7.0491	Kaolinite	
3.748	Orthoclase	4.24	Philipsite	
2.486	Talc	3.196	Feldspar	
-	-	2.88	Dolomite	
3.333	Quartz	14.38	Montmorillonite	C_4
3.030	Calcite	7.14	Kaolinite	
3.757	Orthoclase	4.24	Philipsite	
2.489	Talc	3.194	Feldspar	

- -	2.835	Dolomite	

The results of chemical tests on soil samples are given in Table 3. The pH value of soil samples decreased with increasing the percentage of contaminant, because the chemical solution is acidic medium with pH equal to 2.65. The contents of SO_3, NO_3 and Na increased slightly, while Cl^{-1} and TDS contents were decreased with increasing the percentage of contaminant. Sulfates play a significant role both in the chemical industry and in biological systems. The increasing of Na ion depends on the presence of sodium ion in high concentration in the contaminant solute. The TDS decreased due to the effect of salts flocculating on the surfaces of soil particles. A slight change was noticed in the CaO content after soil contamination because the lower percent of CaO in contaminant solute.

Table 3: Results of the chemical tests for soil samples.

NO_3 %	CaO %	pH value	TDS %	Cl^{-1} %	Na %	SO_3 %	Soil Sample
0.08	0.10	8.76	0.50	0.18	0.10	0.10	C_o
0.09	0.11	8.58	0.44	0.13	0.12	0.14	C_1
0.10	0.11	8.44	0.42	0.07	0.13	0.16	C_2
0.10	0.11	8.41	0.41	0.07	0.14	0.16	C_3
0.11	0.11	8.39	0.39	0.07	0.14	0.16	C_4

5.2 Results of Physical Tests

The results of particle-size distribution, specific gravity, Atterberg's limits and compaction tests are given in Figure 1 and Table 4. In particle size distribution, the percentage of finer less than 0.001 mm in intact soil is greater than fifty percent, but in contaminated soils is less than forty percent. Because of the particles size of an insoluble salts are greater than clayey particles, Therefore the soil more quickly condense in a hydrometer during testing period. Consequently, the proportion of particles less than 0.001 mm decreases with the increase of the salts present in the industrial contaminants.

The contaminant causes slight decrease in specific gravity, this action is due to the low density of the contaminant. Also, the contaminant causes moderately decreasing the values of liquid limits with increasing the percentage of contaminant added to the soil sample. This action is due to the increasing in sizes of soil particles, which causes decreasing the surface area of solid particles and the need for additional water content to allow soil to start flow. While, the plastic limit increased slightly with increasing the percentage of contamination. The variation of LL, PL and PI with percentage of contaminant are presented in Figure 2.

Table 4: Results of physical tests.

ω_{opt} %	$\gamma_{d,max}$ kN/m^3	PI %	PL %	LL %	USCS	Clay %	Silt %	Sand %	Gs	Soil Sample
19.0	16.96	33	23	56	CH	89	7	4	2.72	C_o
20.0	16.90	30	24	54	CH	63	33	4	2.70	C_1
22.0	16.70	29	24	53	CH	72	24	4	2.70	C_2
22.7	16.64	24	25	49	CL	70	26	4	2.70	C_3
19.0	16.96	22	26	48	CL	65	31	4	2.69	C_4

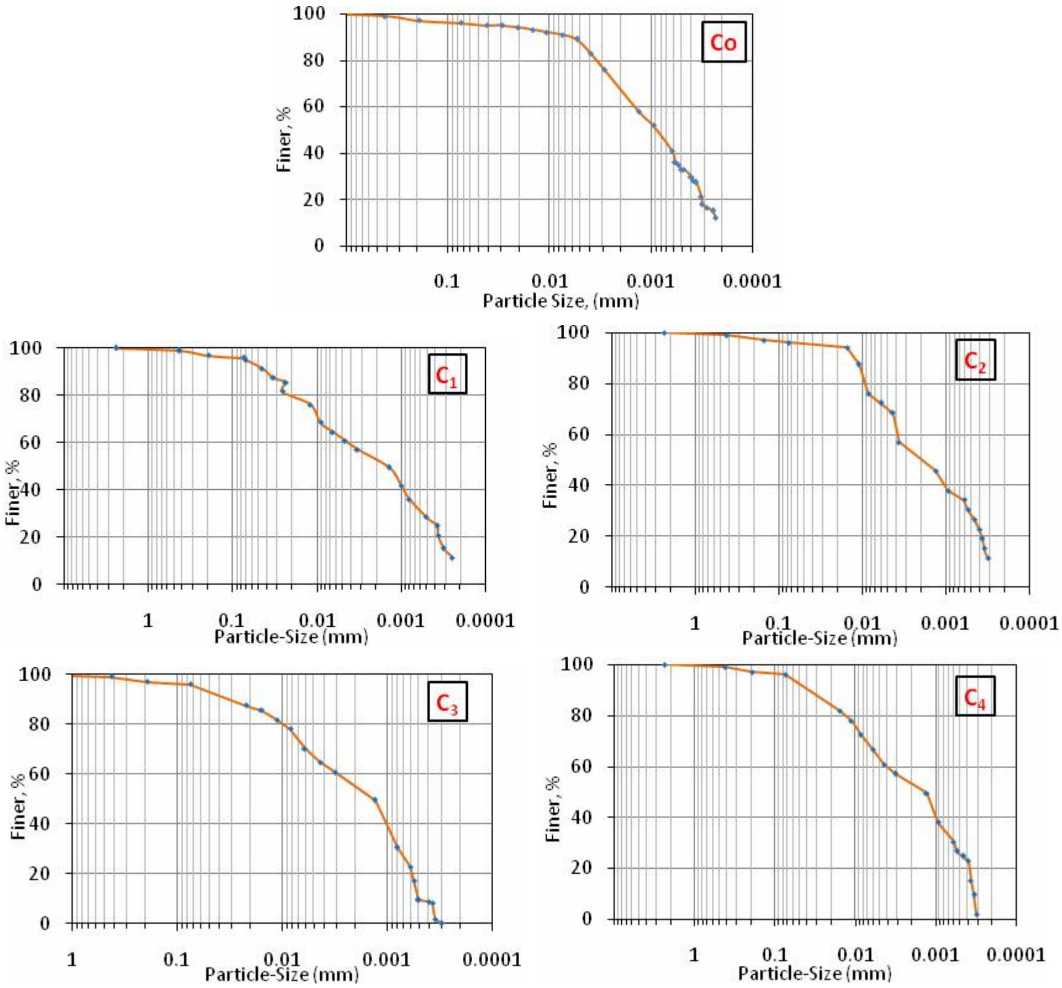

Figure 1:Particle-size distribution curves for soil samples.

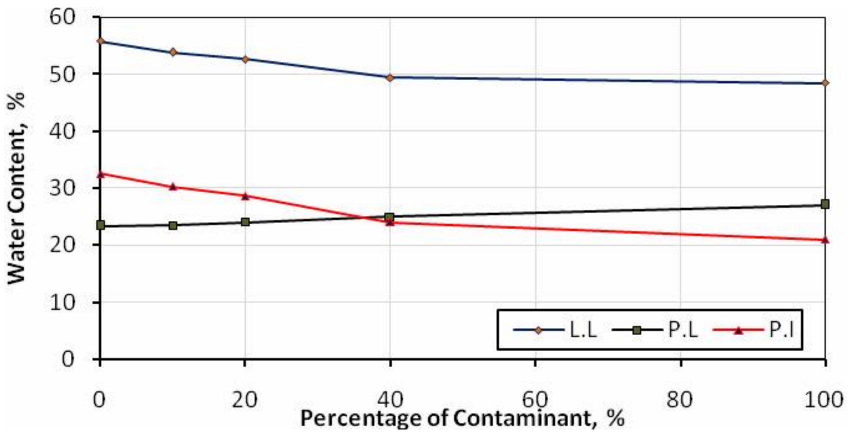

Figure 2:Effects of contamination on Atterberg's limits.

In compaction tests, the contaminants causes a slight decrease in the maximum dry density with increasing the optimum moisture content due to the containment of contaminated on calcium chloride and sodium chloride, which preserve on decreasing the rate of water evaporation and maximum dry density.

5.3 Results of Mechanical Tests

5.3.1 Consolidation Test

The compressibility characteristic, the coefficient of consolidation, the permeability and modulus of elasticity obtained from oedometer tests are given in Table 5.

Table 5: Results of consolidation tests.

$E \times 10^3$ kN/m²	$m_v \times 10^{-5}$ m²/kN	e_f	e_o	$K \times 10^{-8}$ cm/sec	C_v cm²/sec	Soil Sample
11.95	8.367	0.65	0.86	1.54267	0.001822	C_o
11.71	8.539	0.61	0.83	1.66037	0.001954	C_1
10.28	9.726	0.577	0.81	2.19473	0.002230	C_2
9.84	10.162	0.565	0.81	2.48857	0.002420	C_3
7.40	13.514	0.538	0.80	3.45380	0.002526	C_4

The coefficient of consolidation (C_v) increased by (7, 18, 24, and 28) % for contaminated soil samples. The coefficient of permeability (K) increased with (8, 29, 38, and 47) %. While, the modulus of elasticity (E) decreased by (2, 14, 18, and 38) % in compared with intact soil for soil samples C_1, C_2, C_3, and C_4 respectively. The contaminant causes increasing the coefficient of permeability by increasing the connectivity between voids which lead to increasing the vertical consolidation in spite of approximately constant void ratio.

- **Shear Strength Tests**

The results of shear strength tests are given in Table 6. Generally, the undrained shear strength decreased significantly with increasing the percentage of contamination. From the results of UCT, the undrained shear strength decrease by (7-30) % and modulus of elasticity by (8-35) %. While, the results of DST indicated a decreasing of cohesion, c, by (5-27) % and the angle of internal friction (φ) by (6-29) %. The undrained shear strength of soil measured by VST were decreased with increasing the percentage of contaminant by (8–35) % in compare with the undrained shear strength of intact soil.

Table 6: Results of shear strength tests.

VST	DST		UCT		Soil Sample
Cu kN/m²	φ degree	Cu kN/m²	E MN/m²	Cu kN/m²	
102	23.8	78	9.50	90	Co
94	22.5	74	8.75	84	C_1
87	21	71	8.00	79	C_2
79	20	66	7.80	72	C_3
66	17	57	6.20	63	C_4

5.3.3 PLATE LOADING TEST

Soil contamination led to reduction the modulus of subgrade reaction and this reduction increased with increasing the percentage of contamination. The decrease in Ks resulted from square plate of 150mm side was (4, 13, 21, 27) % and from square plate of 125mm side was (7, 11, 20, 34) % for (10, 20, 40, 100) % of contamination respectively. The results of plate loading test are given in Figure 3 and Table 7.

Figure 3: Pressure versus vertical settlement from plate loading tests.

Table 7: Results of plate loading tests.

Ks (MN/m^3)		Soil Sample
From 125 mm plate	**From 150 mm plate**	
34.60	33.80	C_o
32.30	32.30	C_1
30.77	29.23	C_2
27.70	26.92	C_3
23.00	24.62	C_4

6. CONCLUSIONS

The liquid industrial waste disposed from thermal electric power station in Al- Musayyib has diverse effects on the geotechnical properties of clayey soil. This diversity ranged from slight on some properties to significant on other properties of soil. Also, increasing the percentage of contaminant causes increasing the diverse effects on soil properties. The conculsion can be summarized in the following points: (i) the contaminant causes slight decrease in pH value, SO_3, NO_3 and Na, but Cl^{-1} and TDS increased with increasing the percentage of contaminant; (ii) the contaminant causes decreasing the percentage of finer less than 0.001mm in size; (iii) the decreasing in percentage of finer causes reduction in liquid limit and decreasing plastic limit; (iv) the shear strength parameters, cohesion and angle of internal friction, decreased significantly with increasing the percentage of contaminant and (v) the same trend happened with respect to the coefficient of vertical consolidation and coefficient of subgrade reaction.

REFERENCES

- Annual Book of ASTM Standards (2003), "Soil and Rock; Building; Stone; Peats".
- BS 1377 (1976), "Methods of Testing for Civil Engineering Purpose", British Standards Institution, London.
- Gratchev I. B. and Towhata, I. (2009)," Effects of Acidic Contamination on the Geotechnical Properties of Marine Soils in Japan", University of Tokyo, Proceedings of 19th International Offshore and Polar Engineering Conference, pp. 21-26.
- Head, K. H. (1984), "Manual of Soil Laboratory Testing", Vol.1, Pentech Press, London: Plymouth.
- Head, K. H. (1988), "Manual of Soil Laboratory Testing", Vol.2, Pentech Press, London: Plymouth.
- Karkush, M. O., Zaboon, A. T. and Hussien, H. M. (2013), "Studying the Effects of Contamination on the Geotechnical Properties of Clayey Soil", Coupled Phenomena in Environmental Geotechnics, Taylor & Francis Group, London, pp. 599-607.
- Khamehchiyan, M., Charkhabi, A.M. and Tajik, M. (2007), "Effects of crude oil contamination on geotechnical properties of clayey and sandy soils", Eng. Geol. 89: pp.220-229.

- Reddi, L. N. and Inyang, H. I. (2000), "Geoenvironmental Engineering: Principles and Applications", Kansas State and Massachusetts Lowell University of Lowell, Massachusetts, New York, Basel.
- Sharma, H. D., and Reddy, K. R. (2004), "Geoenvironmental Engineering: Site Remediation, Waste Containment, and Emerging Waste Management Technologies", John Wiley & Sons, Hoboken, New Jersey.
- Rahman Z. A., Hamzah U., Taha M. R., Ithnain N. S., and Ahmad N., (2010), "Influence of Oil Contamination on Geotechnical Properties of Basaltic Residual Soil", American Journal of Applied Sciences Vol. 7, pp. 954-961.
- Rowe, R. K. (2001), "Geotechnical and Geoenvironmental Engineering Handbook", Springer Science and Business Media, New York.
- UNEP Report, (2005), "Assessment of Environmental “Hot Spots” in Iraq", Report ISBN 92-807-2650-1, France.