GEOTECHNICAL CHARACTERISTICS OF EFFLUENT CONTAMINATED COHESIVE SOILS

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Abstract. In developing countries like Pakistan, raw industrial effluents are usually disposed-off directly into open lands or in water bodies resulting in soil contamination. Leachate formation due to rainfalls in openly dumped solid waste also adds to soil contamination. In this study, engineering behavior of soils contaminated by two industrial effluents, one from paper industry (acidic) and another from textile industry (basic), has been investigated. Laboratory testing revealed significant effects of effluent contamination on engineering behavior of tested soils. Liquid limit, plasticity index, optimum moisture content and compression index of tested soils were found to increase with effluent contaminant, indicating a deterioration in the engineering behavior of soils. Whereas maximum dry density, undrained shear strength and coefficient of consolidation of the contaminated soils showed a decreasing trend. The dilapidation in engineering characteristics of soils due to the addition of industrial effluents could pose serious threats to existing and future foundations in terms of loss of bearing capacity and increase in settlement.

Keywords: soil contamination, industrial waste, engineering behavior, effluent waste, leachate.

Introduction

Industries play a vital role in the development of any country. However, the industrial waste, if released to the environment untreated, may result in several environmental and health hazards. In developed countries, reinforcement of environmental laws and ample resources ensure proper treatment of industrial waste before releasing it to the environment. However, the industrial effluents are often discharged untreated which contaminate water channels and ultimately the soil through seepage.

Industrial sector of Pakistan contributes about 24% of GDP and a huge volume of effluent waste is being generated from various industries. This contaminated effluent waste may carry poisonous or harmful substances like chromium, sulfides, free chlorine, lead, chromium etc. (Bond *et al.* 1973). Although environmental regulations, outlining the necessary treatment for industrial effluents exist in the country, yet their implementation in true sense remains distant from reality. Unfortunately, most of the waste from industries is discharged to the local environment untreated. Besides their effects on the quality of drinking water, which always remains the prime concern, effluents also affect the engineering properties of surrounding soils through seepage. Previous work (Adebisi, Fayemiwo 2010; Gratchev, Towhata 2009; Jia *et al.* 2011; Khamehchiyan *et al.* 2007; Naeini, Jahanfar 2011; Nazir 2011; Olgun, Yıldız 2010; Patel 2011; Reddy *et al.* 2011; Sunil *et al.* 2006, 2009) has shown that the index and engineering properties of contaminated soils tend to alter due to chemical reactions between the soil minerals and the contaminant. Soil contamination may also be detrimental to foundation material (Sunil *et al.* 2006, 2009). Rapid urbanization in various metropolitans of Pakistan is forcing the developers to construct at places which have been used as dumping sites of such industrial effluents. Special considerations, with reference to the modifications in engineering behavior of such soils, are required to be taken into account for design and construction of foundations on such soils.

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The main objective of this study is therefore to explore the effects of industrial effluents on the geotechnical properties of local cohesive soils. Considering the widespread paper and textile industry in Pakistan, effluents from these industries are employed in this study. Contaminated soil specimens were prepared by adding various proportions of industrial effluents in the virgin soil samples and their effects on various engineering properties of contaminated soils are investigated.
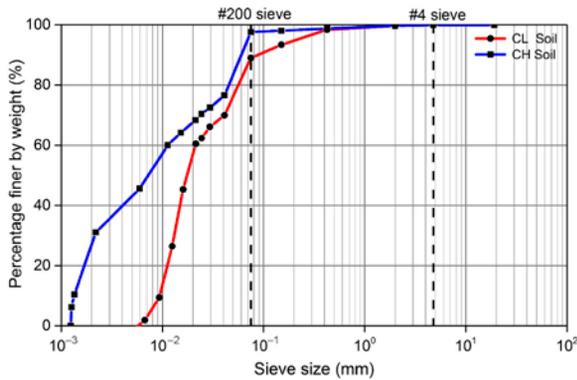

Fig. 1. Grain size distribution of D.G Khan (CL) and Nandipur (CH) soil samples

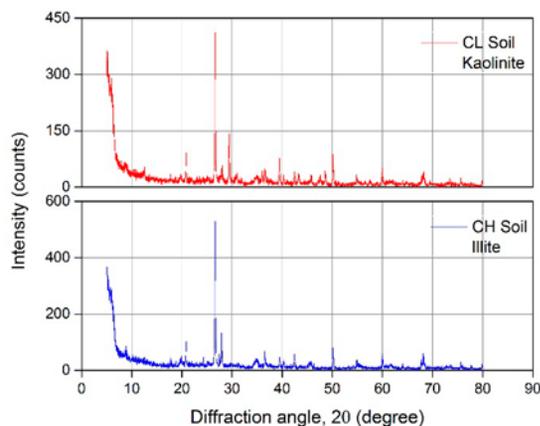Fig. 2. Photographs (a) Soil sample from D.G. Khan (CL), (b) Soil sample from Nandipur (CH)

Fig. 3. X-ray diffraction analysis of soil samples

1. Materials

1.1. Soil samples

Soil samples were collected from D.G. Khan and Nandipur (Pakistan). Grain size distribution of both soils are shown in Figure 1 and were classified as CL / A-6(10) and CH / A-7-6 (20) as per USCS / AASHTO soil classification systems, respectively. Actual photographs of both soil samples are shown in Figure 2. Soil samples were collected from test pits at 0.6 m depth. The samples were not collected from natural ground surface in order to avoid the presence of any organic matter in the form of roots, vegetation, leaves etc. X-ray diffraction (XRD) analysis of soil samples (Fig. 3) revealed the presence of kaolinite in CL soil and illite in CH soil as dominant mineral. Physical and Chemical Properties of soil samples are summarized in Table 1.

Table 1. Physical and chemical properties of the soil samples tested as per respective ASTM standard

Description	Units	D.G. Khan Soil	Nandipur Soil
Natural moisture content, NMC	%	6	10
Fine contents (Silt + Clay)	%	89	98
Liquid limit, w_L	%	37	58
Plastic limit, w_P	%	21	27
Plasticity index, I_P	%	16	31
Specific gravity	–	2.645	2.717
USCS soil classification	–	CL	CH
AASHTO soil classification	–	A-6 (10)	A-7-6 (20)
Maximum dry unit weight, γ_{dmax}	kN/m³	18.41	17.18
Optimum moisture content, OMC	%	12.82	17.13
pH value	–	7.5	7
Electrical conductivity, EC	μ Simen	849	228
Sulphate content, SO_4	%	0.04	0.02
Chloride content, Cl	%	0.123	0.015
Organic matter content	%	0.140	0.135
Calcium content, Ca	%	0.014	0.007
Magnesium content, Mg	%	0.004	0.002
Total dissolved solids, TDS	%	0.011	0.005
XRD analysis (dominant clay mineral)	–	Kaolinite	Illite

1.2. Industrial effluents

The main objective of this study was to investigate the effects of effluents from paper industry (Fig. 4 (a)) and textile industry (Fig. 4 (b)) on engineering properties of
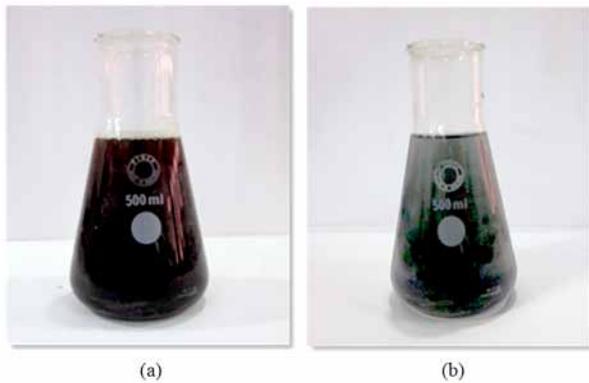
Fig. 4. (a) Effluent from paper industry (acidic in nature),
(b) Effluent from textile industry (basic in nature)

cohesive soils. Effluents from paper industry are typically observed to be acidic (Kumar 2005), while the effluents from textile industry are commonly basic (Choudhury 2006). The representative industrial effluents were collected from Century Paper Mill, Lahore and Denim Textile, Lahore (Pakistan). The collected effluent samples were subjected to chemical examination, the summary of which as well as the respective national standards according to NEQS (2000) are presented in Table 2.

Table 2. Chemical properties of effluent samples

Description	Units	Textile Industry Effluent	Paper Industry Effluent	NEQS (2000)
Calcium content, Ca	%	0.002	0.012	–*
Magnesium content, Mg	%	0.001	0.031	–*
Chloride content, Cl	%	0.098	0.125	0.10
Sulphate content, SO_4	%	0.012	0.016	0.10
pH	–	11	3	6–9
Total dissolved solids, TDS	%	0.145	0.015	0.35

Note: * National guidelines do not exist.

2. Experimental program

A systematic procedure was established for the preparation of contaminated soil samples. Cohesive soil samples were first oven dried and pulverized. Industrial effluents were then mixed with soil samples in specified proportions of 0, 5, 10, 15 and 20% by dry weight of soil. The soil-effluent mixture was left for 48 hours to bring the moisture in equilibrium before laboratory testing. The contaminated soil samples were then air dried and sieved through 4.75 mm sieve. By adding different proportions

of each effluent in each soil type, a total of 16 contaminated samples were prepared. A systematic nomenclature was adopted to represent the contaminated soil samples. The first two letters represent the soil type, either low plastic (CL) or high plastic (CH). Third letter represents the source of effluent (paper industry (P) or textile industry (T)) and the digits at the end represent the percentage of effluent in each soil sample e.g. "CHP5" represents a high plastic clay sample with 5% contamination from paper industry. The contaminated soil samples plus the two original uncontaminated soils were then subjected to various tests in order to explore the effects of effluent contamination. Soil properties evaluated as part of this study included specific gravity, Atterberg limits, modified compaction, one-dimensional consolidation, unconfined compression, pH and electrical conductivity. All tests were performed according to the relevant ASTM standard.

3. Results and discussions

3.1. Effect of contamination on Atterberg's limits and soil classification

The addition of acidic (paper industry) and basic (textile industry) contaminants increased the plasticity of soil as shown in Figures 5 and 6. The liquid limit of CL soil increased by 13.5% and 10.8% with 20% acidic and basic contamination respectively. However, the corresponding increase in liquid limit of CH soil was not as pronounced and the increase in liquid limit was limited to 6.9% and 5.2% for acidic and basic contamination addition respectively.

Similarly, the plasticity index of both the soils showed an increasing trend with the addition of contaminants. The plasticity index of CL soil increased by 37.5% with the mixing of 20% acidic and basic contamination. However, the corresponding increase in plasticity index of CH soils was not as pronounced and the increase in plasticity index was limited to 22.6% and 19.4% for acidic and basic contaminants respectively.
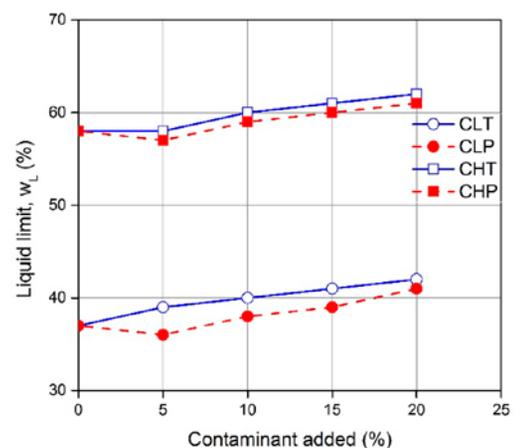

Fig. 5. Effect of contamination on liquid limit

With effluent contamination, an increase in liquid limit is followed by a corresponding increase in plasticity index. Therefore, soil classification, as shown in Figure 7 does not change due to contamination.

The increase in Atterberg limits of soil is mainly because of the chemical action between soil particles and effluent. The increase in liquid limit indicates an increase in consolidation potential of contaminated soils (Terzaghi, Peck 1948). High plasticity of contaminated soils also causes problems related to increased swell potential and high collapsibility (Gibbs, Bara 1967). Contamination by industrial effluents would therefore deteriorate the quality of soil as an engineering material.
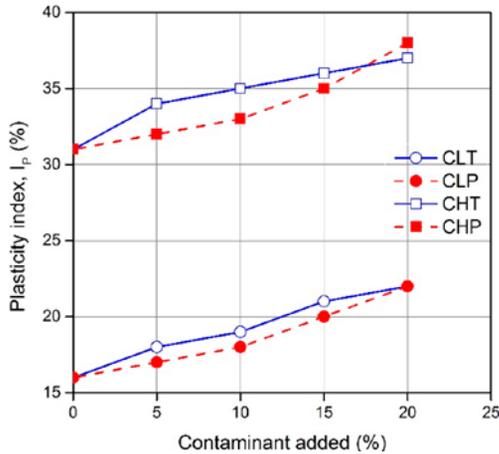

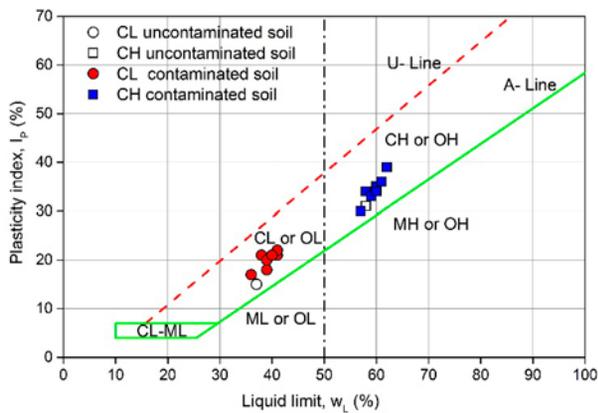Fig. 6. Effect of contamination on plasticity index

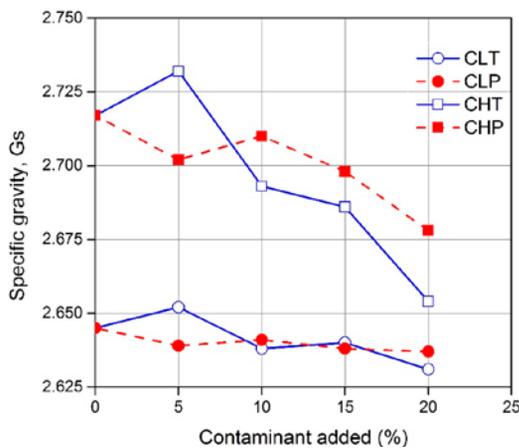Fig. 7. Effect of contamination on soil classification

Fig. 8. Variation of specific gravity with concentration of contaminant

3.2. Effect of contamination on soil specific gravity

The effect of contaminants on specific gravity of both soils is summarized in Figure 8. In general, the specific gravity of CH soils was observed to decrease slightly with the addition of contaminants. Quantitatively, the specific gravity of CH soil decreased by 1.4% and 2.3% with the addition of acidic and basic contaminants, respectively. However, the specific gravity of CL soil was unaffected by the addition of contaminants. This behavior can be associated with both the effluents having nearly the same specific gravity as CL soil.

3.3. pH value of contaminated soil

The industrial effluents used in this study were recovered from a textile and a paper industry. The effluent recovered from textile industry was basic in nature whereas the effluent from paper industry was acidic in nature. The overall pH of soil samples was affected accordingly with the addition of these effluents. Effect of contaminant on pH is summarized in Figure 9. The pH of CL and CH soil samples increased by 5.3% and 5.7% with the addition of 20% textile waste effluent. On the contrary, the pH of both the soil samples decreased with the addition of effluent from paper industry because of its acidic nature. The observed decrease in pH of CL and CH soil samples with 20% contamination of paper effluent was 5.3% and 7.1% respectively. This behavior is consistent with the findings of Sunil et al. (2009).
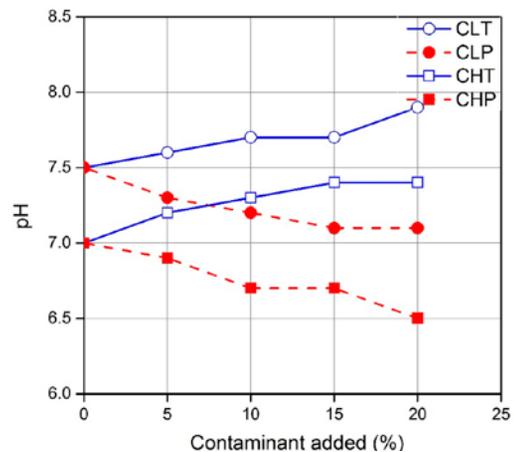

Fig. 9. Variation of pH with concentration of contaminant

3.4. Effect of contamination on electrical conductivity

The effect of contamination addition on the electrical conductivity of both soils is illustrated in Figure 10. The electrical conductivity of both the soil samples increased with the addition of contaminants. Quantitatively, the specific gravity of CL soil increased by 1.2% and 1.4% with the addition of acidic and basic contaminants respectively. However the corresponding increase in electrical conductivity of CH soils was more pronounced and it was 4.0% and 5.8% for acidic and basic contamination addition respectively. The increase in electrical conductivity of contaminated soils compared to the parent soil, may be associated to the presence of more free ions in the acidic/basic contaminated soils.

3.5. Compaction characteristics of contaminated soils

The effect of contamination addition on the compaction characteristics of both soils is represented in Figures 11 and 12. In general, the optimum moisture content was observed to increase by around 10% for CL soil and around 7.5% for CH soil with the addition of contaminants. On contrary, maximum dry unit weights of both cohesive soils were found to decrease with the addition of contaminants. The decrease in maximum dry unit weights of both the soils with the addition of 20% acidic/basic effluent was quite identical at around 4%.

The variation in the compaction characteristics of cohesive soils because of contaminant addition can be explained on the basis of soil plasticity. Optimum moisture content of cohesive soils increases whereas the maximum dry unit weight obtained through compaction tests decreases with plasticity index of soil (Berawala, Solanki 2010; Pandian *et al.* 1997; Sridharan, Nagaraj 2005). As discussed previously in Section 4.1, increase in contamination concentration makes the soil more plastic, thereby leading to an increase in optimum moisture content and a decrease in maximum dry unit weight. From engineering applications perspective, this means a high water demand to attain optimum moisture in the field; which, in general, increases the project cost and is typically undesirable. In other words, soil with high contaminant concentration would be difficult to compact and would yield a lower unit weight compared to uncontaminated soil under the same compactive effort and moisture conditions.

3.6. Effect of contamination on unconfined compressive strength

Addition of contamination to cohesive soils was found to adversely affect shear strength as illustrated in Figure 13. In general, unconfined compressive strength of both CL and CH soils showed a slight decrease on the addition of effluent contamination. Unconfined compressive strength of CL and CH soils decreased by around 5% and 6%,

respectively with contamination. The reduction of strength due to contamination is attributed to possible breakage of internal bonds (Umesha *et al.* 2012). Typical photographs of specimens before and after the unconfined compression test are shown in Figure 14.
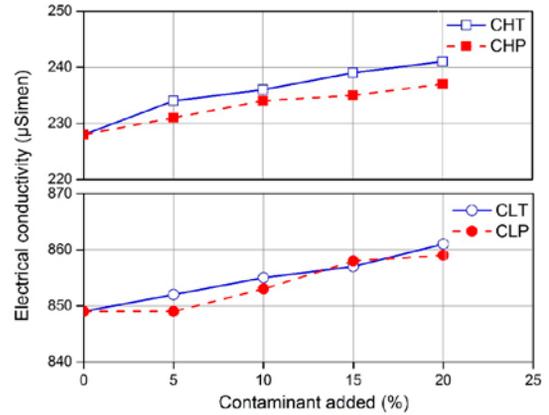

Fig. 10. Effect of contamination on electrical conductivity of soil
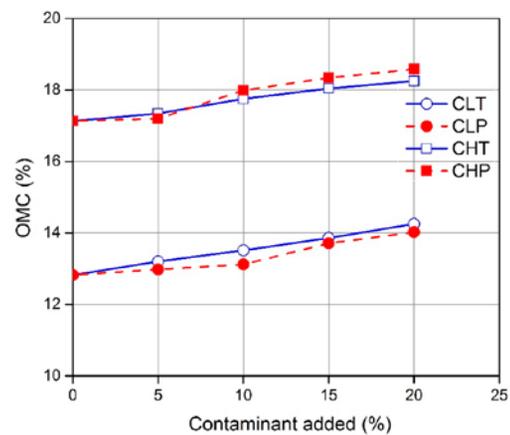

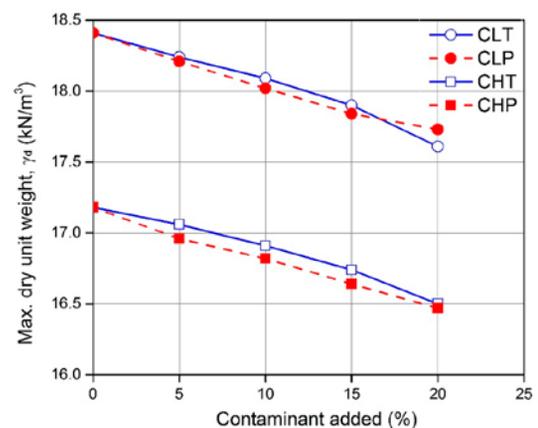Fig. 11. Variation of OMC with effluent contamination

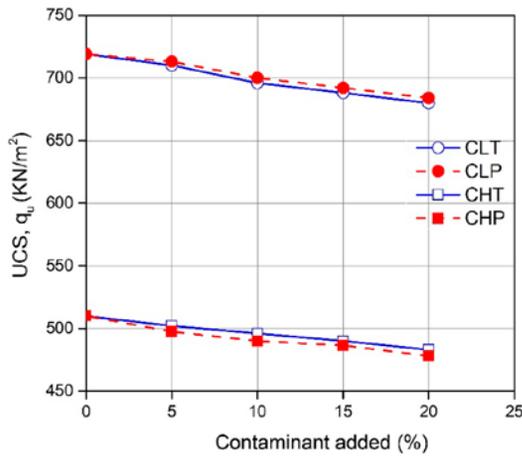Fig. 12. Variation of maximum dry unit weight with effluent contamination

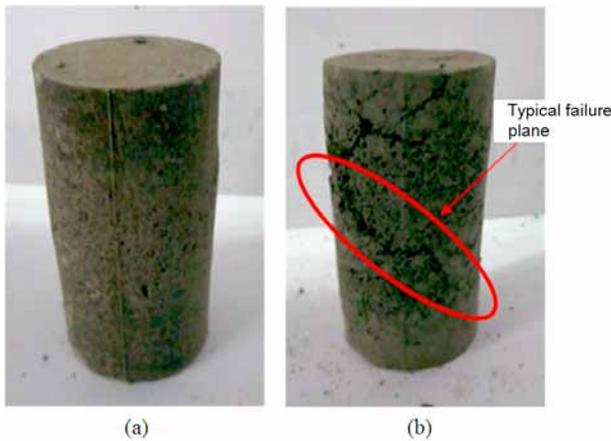Fig. 13. Effect of contamination on unconfined compressive strength

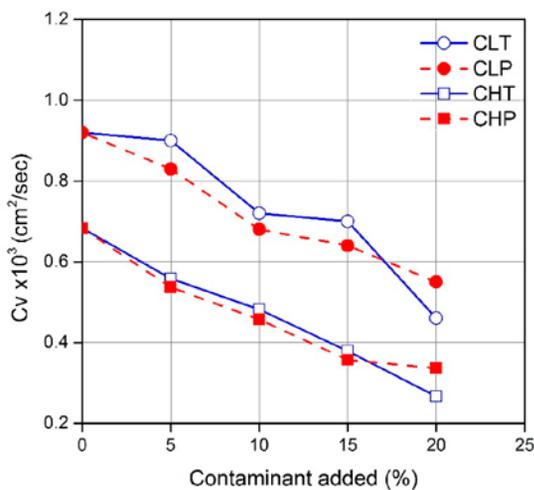Fig. 14. Typical unconfined compression test specimens (a) before test (b) after test

3.7. Consolidation characteristics of contaminated soils

The consolidation characteristics of industrial effluent contaminated soils were evaluated by performing one-dimensional consolidation test on original, and contaminated soil specimens. The effect of effluent contamination on the rate of consolidation (represented by coefficient of consolidation, C_v), and the magnitude of consolidation (represented by compression index, C_c) are illustrated in Figures 15 and 16 respectively.

With the addition of acidic (paper industry) and basic (textile industry) contaminants, C_v of CL soil decreased by 40.2% and 50.0%, and that of CH soil decreased by 50.8% and 60.9% respectively. Time required for the consolidation of contaminated soil would therefore be greater than that required for the completion of same degree of consolidation in the parent soil. C_v is an indirect measure of soil permeability as well. Decrease in C_v also indicates a reduction in the hydraulic conductivity of contaminated soil. Suspended solids in the industrial waste typically have very small particle size. These particles might clog the inter-particle space in parent soil sample thereby reducing the hydraulic conductivity.

The compression index (C_c), represented in Figure 15, demonstrates an increase in the magnitude of consolidation with contaminant concentration. The increase in C_c of CL soil ranged from 7.5% to 11.3% whereas the corresponding increase for CH soil was from 9.4% to 11.1%, for 20% addition of acidic/basic contaminant. This indicates the consolidation potential of contaminated soils to be higher than uncontaminated soils. The same behavior could also be deduced from the increase in soil plasticity with effluent contamination (Fig. 5), since C_c is a direct function of soil plasticity (Terzaghi, Peck 1948).
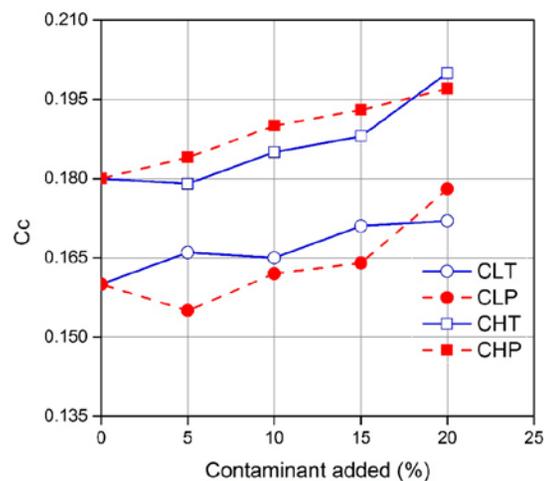

Fig. 15. Variation of Cv with the addition of acidic and basic contaminants

Fig. 16. Variation of Cc with the addition of acidic and basic contaminants

Conclusions

The main objective of this research was to study the effects of industrial contamination on local cohesive soils. The test results showed a significant change in the geotechnical properties of contaminated soils when compared with the parent soil samples. The conclusions drawn from this research work are as follows:

- The increase in liquid limit and plasticity index of cohesive soils is mainly attributed towards an increase in specific surface area of soil due to contaminant addition which leads to high adsorption of water affecting the Atterberg's limits values.
- Addition of acidic and basic contaminants vary the pH of soil accordingly. Due to the presence of more free ions in contaminated soils, electrical conductivity is also increased.
- Due to chemical reaction between contaminant and soil particles, soil becomes more plastic in nature which causes a decrease in maximum dry unit weight and an increase in optimum moisture content. A corresponding decrease in unconfined compressive strength of contaminated soils was also observed.
- The chemical reaction between effluents and soil particles also affect the consolidation characteristics of soil. Contamination makes the soil highly compressible as indicated by an increase in compression index. However, a decrease in the coefficient of consolidation of contaminated soils indicate a decrease in the permeability of contaminated soil. This implies that contaminated soils would take longer to accomplish a certain degree of consolidation.
- In general, the soil properties have been found to deteriorate because of being contaminated by industrial effluents. Special considerations would therefore be required for constructing on such soils. The loss of bearing capacity indicated by a decrease in unconfined compressive strength, and an expected increase in the magnitude of consolidation settlement should be carefully considered while designing foundations on such soils. The increased chemical aggressivity of contaminated soils can also be a concern for foundation concrete.

Acknowledgements

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