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Characteristics of low plastic clay contaminated by industrial effluents

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Abstract: According to the PCSIR (Pakistan council of scientific and industrial research), there are over 1200 registered industries in Pakistan, which produce different kinds of products as of 2001-02 EPA report. Out of these about 90 percent of the industry is leaking their contaminants into the neighbouring soil. Soil contamination due to these industrial contaminants has a direct impact on the Geotechnical properties of the affected soil and, therefore, on the already existing structures such as embankment foundations, basements and clay liners. In addition, it is a common practice in Pakistan to use contaminated soil as a fill material or roadway sub-base material due to its availability and low price. Therefore, it is the need of the time to investigate the effects of industrial contaminants on the physical and mechanical properties of the affected soil. This paper is an effort in predicting the effects of industrial contaminants on the strength and deformation characteristics of low plastic clay. Prior studies have shown the drastic effects on shear strength and Physio-chemical properties of soils due to certain effluents. The effects are predicted due to the change in pore fluid chemistry and sometimes due to the chemical changes in soil structure. However, the number of studies are very limited, especially when it comes to the geotechnical properties of soils.

Introduction:

Human activities lead to soil contamination due to the discharge of industrial contaminants, consequently changing the soil geotechnical properties. When the contaminants are discharged into the soil, they flow through the layers of soil and are held in the soil matrix system through chemical absorption and are trapped within pore spaces surrounding the soil grains. The introduction of the industrial contaminants into the soil pore spaces has gained a lot of attention recently. However, in most of the studies that have been conducted, researchers have focused on the movement of contaminants in soil rather than their effect on the soil properties. Only in a limited number of studies were examined the effects of contamination on soil geotechnical properties of fine-grained soils. Prior studies demonstrated that the behaviour of the fine-grained soils, especially those with the higher specific surface area, were found to be related to the properties of the pore fluid due to charges on grain surfaces and associated inter-particle surface. Due to urban and industrial development, the use of soil in various engineering projects and the increasing discharge of contaminants into soil decrease the availability of soil. Therefore, it would be beneficial to use the contaminated soil in the foundations and embankments of buildings and roads, but it requires the special and thorough knowledge of their mechanical properties. This soil may be improved if required for special purposes where strength is needed. Soil contamination or soil pollution is caused mainly due the presence of human-made industrial effluents or other alterations in the natural soil minerals due to environmental change. It is typically caused by some industrial activity, disposal of industrial of home generated waste and due chemicals usage in agriculture. Due to the imbalance between the economic development and environmental protection, Pakistan's environmental issues are increased upto a disturbing level. Pakistan is a large consumer of fossil fuels and the current environmental issues of Pakistan include industrial wastes, sewage water, soil erosion and desertification. Main industrial effluents in Pakistan include textile and fertilizer industry effluents. Pakistan is a rich country in the field of textile but the effluents generated from textile industry are not disposed off to a safest place instead are disposed off to the surrounding lands. The construction in these lands pose challenge to the geotechnical engineers due to low shear strength and poor consolidation properties. Second largest industry of Pakistan is pharmaceutical industry. All of these industries pose threat to our environment. The behavior of soil contaminated by effluents can be a surprise so to know the actual soil behaviour, soil properties should be studied before construction.

Narasimha (2012) studied the geotechnical characteristics of expansive soils that were treated with textile, tannery and battery effluents [2]. It was an important study which was conducted in India as India has a large network of industries and many more are planned in the near future. So million tons of industrial effluents are disposed of into soil daily. Similarly Shah (1998) studied the effects of various effluents on the physical and chemical properties of Nandesari Gujrat area soil [3]. In his research, he concluded that the soil properties are modified when treated with effluents and the extent of modification depends upon the type of clay and the nature of effluent. Murugaiyan (2009) explored the effects of pharmaceutical effluents on the commercially available soils (bentonite and kaolinite) [4]. As India is country with rich industrial resources especially in the field of pharmacy, so, the study was very important in keeping view of contamination. Gomes et al. (2006)

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studied Geotechnical characteristics and mechanical behaviour of granitic residual soils that involved the effect of chemical contaminants [5]. The aspects of soil that were studied include grain size analysis, the structure of soil, compressibility and stress strain behaviour. Granitic residual soil was blended with lime and wasted lubricating oil and also when it is subject to saturation by using BETX components (petrol). J. R. Oluremi et al. analyzed the geotechnical properties of waste water contaminated soil [6]. The results of the study showed that contamination has early effects on the Atterberg's limits but the soil regains its shear strength after biodegradation and volatilization. Contamination increases the plasticity properties of the soil, reduces the maximum dry density and increases the optimum moisture content of soil. Based on these results, it is evident that contamination has severe effects on the plasticity and thereby making the soil unfit as a construction material.

Ismael (1998) studied some effects of leaching on the geotechnical properties of cemented sand deposits in Kuwait. Two sites were selected for samples collection with different cementation level. The including cementing salts were carbonates, sulfates and chlorides. Shear strength and consolidation tests were performed on natural and leached specimens. The results of the study showed a increase in compressibility and the decrease in effective shear strength parameters C' and ϕ'. The effect was due to leaching of salts into the pores. Gratchev (2013) investigated the effects of acidic contamination on the natural soils possessing different mineral composition. Stress-strain behavior on montmorillonite and the other kaolinite clay. Undrained triaxial tests were performed on leached acidic contaminated samples. The results showed that acidic contamination had a lot of influence on the shear strength as well as the chemical composition of the soil. PH values decreased a significant amount and the shear strength values also decrease. Nazir (2010) studied the effects of motor oil contamination on the geotechnical properties of over consolidated clay. Atterberg limits, unconfined compression strength, coefficient of permeability and compressibility characteristics. 38% reduction in the unconfined compressive strength was observed due to the loosening the packing of clay particles. Coefficient permeability increased and atterberg limits decreased due to contamination mixing.

The area of kot lakhpat contains several industries in Quaid-e-Azam industrial estate Lahore. These industries include textile, rubber, paper, pharmaceutical, polyvinyl, shoes and leather industries and many more. These industries discharge their liquid effluents through minor drains into a main drain which drags it to the outfall sewer and for final disposal and treatment plant. But the precautionary measures are not well enough as the minor drains leak out and dispose the effluents directly into the nearby soil. As discussed earlier, these effluents either enhance or decrease the engineering properties of the soil. So the effect of effluent contamination needs to be predicted before their further use.

Aiming at a better knowledge of the affinity between the effluents and the soil; a detailed testing scheme was developed to understand the effect of effluents on the shear strength and deformation characteristics of low plastic clay. For this purpose three types of effluents were selected containing textile, rubber (tyre & tube) and paper industry effluents. These effluents were mixed in a ratio of 5, 10 and 20% to check their effect on geotechnical properties of low plastic clay.

Methodology:

The methodology adopted to gain the objectives is described below. Unconfined compression tests and UU triaxial tests were performed to check the effect of effluents on the shear strength of soil. Moreover consolidation tests were performed to check the deformation characteristics of soil. Following procedure was adopted step by step to complete the research under study.

- Collection of liquid effluents from three industries, namely paper, textile and tyre & tube industries.
- Selection of site for samples collection in Quaid-e-Azam industrial estate Lahore.
- Excavation of test pits in Quaid-e-Azam industrial estate for the collection of raw soil samples. Plan is shown in figure (1).
- Undisturbed and disturbed samples collection from test pits.
- Physiochemical characterization like PH, TDS, BOD, COD of paper, textile and rubber effluents.
- XRD analysis of raw soil samples collected from test pits to check the minerals present in soil.
- Basic laboratory testing of soil samples like sieve analysis, atterberg limit tests and compaction tests.
- Mixing of soil samples with effluents in proportions of 5, 10 & 20%.
- Modified proctor tests on mixed soil samples to find out OMC and MDD.
- Shear strength tests i.e. triaxial compression test and unconfined compression test on effluent mixed soil samples.
- Deformation characteristics, i.e. one dimensional consolidation test.

Results:

Collection of Liquid Effluents:

Liquid effluents were collected from the minor drains which take the effluents of these industries to the main drain. The collected effluents are shown in figure. These effluents were then brought into an environmental engineering laboratory (The University of Lahore) for Physio-chemical characterization of effluents.

Figure 1: Effluents collected from industry and used in research

Figure 2: Collection of effluents from minor drains

Site selection and samples collection:
A suitable site was selected nearby each of the three industries (paper, textile and rubber industry) and two test pits of 2×2 m cross section and 2 m depth were dug to get the representative raw soil samples for further laboratory testing fig. (3, 4)
In the figure; EC_1, EC_2, EC_3: Drains for effluents collection from paper, textile and rubber industry respectively. TP-1, TP-2 represent two test pits for raw soil samples collection and 2x2 m cross section of test pit is also shown.

Figure 3: Areal view of site location for samples collection

Figure 4: Working in a test pit for Raw samples collection

Physio-chemical characterization of effluents:
The effluent parameters, namely, PH, color, total solids, total dissolved solids (TDS), total volatile solids (TVS), chloride, sulphate, chemical oxygen demand (COD) and biological oxygen demand (BOD), were estimated for characterizing the three effluents table I. The parameters given below are comprehensive and sufficient to characterize the effluent and to understand their effect on soils. The procedure for the analyses of the parameters below was followed as per Standard Methods (APHA, 2005) [7].

***Table I**. Characteristics of industrial effluents used in research*

Parameters	**Paper & pulp industry**		**Textile industry**		**Rubber industry**	
	Values	Permissible limits EQ(SIER, 1979)[8]	Values	Permissible limits EQ(SIER, 1979)[8]	Values	Permissible limits EQ(SIER, 1979)[8]
$(BOD)_5$ mg/L at 20 ^{0}C	280	50	190	50	120	50
COD mg/L	990	100	4000	100	16000	100
Colour	Brown	-	Brownish black	-	Pale brown	-
PH	6.5	5.5-9.0	7.5	5.5-9.0	10.2	5.5-9.0
Suspended Solids mg/L	565	100	775	100	850	100
Total Dissolved solids mg/L	1125	1980	995	1200	470	500
Total Nitrogen mg/L	120	170	105	120	615	800 (2.1%)
Total Phosphorous mg/L	95	0-80	190	150	Nil	5.26

XRD Analysis of Raw Soil Samples:

XRD analysis of four soil samples was done using the facilities at Government College University Lahore XRD lab. Four powdered soil samples namely raw soil samples, paper, and textile and rubber industry effluent mixed soil samples were tested under standard conditions of temperature and pressure. Qualitative analysis of the soil samples was performed to check the minerals present in each soil sample using a suit of computer program DAJUST [9]. The results of XRD analysis are presented below in table II and XRD graphs are shown in figure 5 (a, b, c, d).

***Table II**. Minerals present in soil samples evaluated by XRD*

Soil sample	Raw soil sample	Paper contaminated	Textile contaminated	Rubber contaminated
Minerals present	Illite, Quartz, Albite, Chromium, Mercury, Nitrogen hydrogen sulphate, Calcium hydrogen phosphate	Illite, Quartz, potassium, Calcium hydrogen sulfate, Nitrogen hydrogen sulphate.	Illite, N, SiO_2, Pd, Quartz, Nitrogen hydrogen sulphate.	Illite, SiO2, Al2Fe3, hg, Quartz, Nitrogen hydrogen sulphate, Cu-Ni

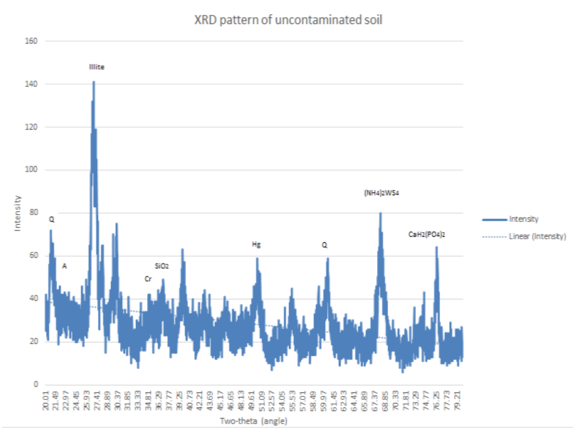

Figure 5(a): XRD pattern of uncontaminated soil

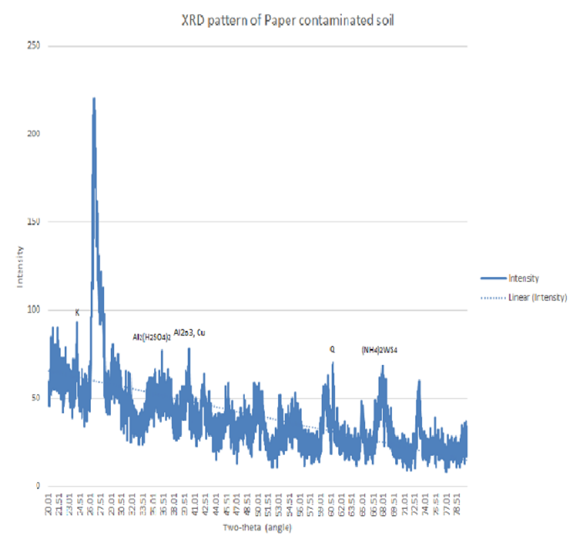

Figure 5 (b): XRD pattern of paper contaminated soil

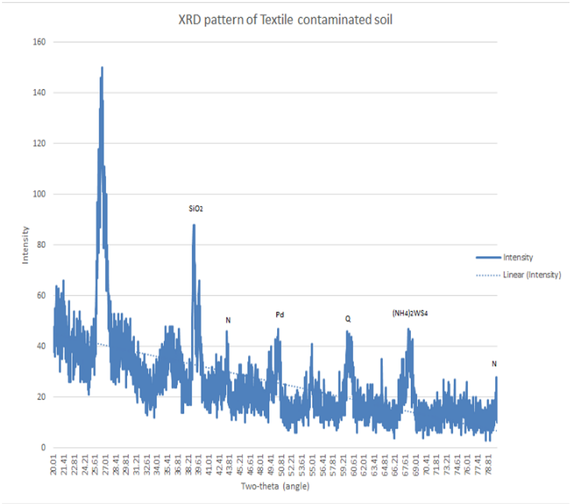

Figure 5(c) XRD pattern of textile contaminated soil Figure 4

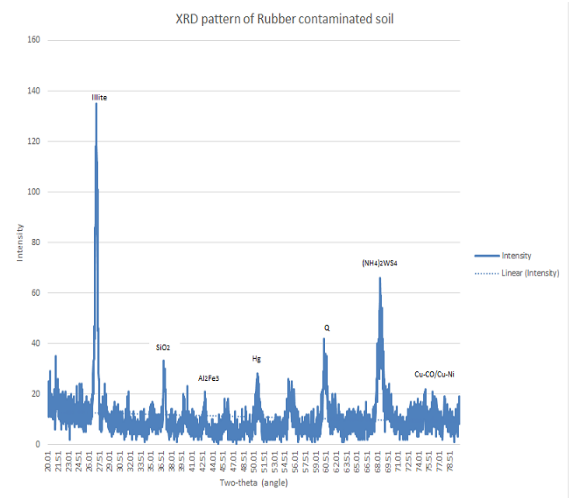

Figure 5(d) XRD pattern of rubber contaminated soil

Basic soil tests:

The soil samples used for the testing were assumed to be uncontaminated and basic soil tests were performed to check the soil classification and atterberg limits table III, fig. (6) The results of testing are given below.

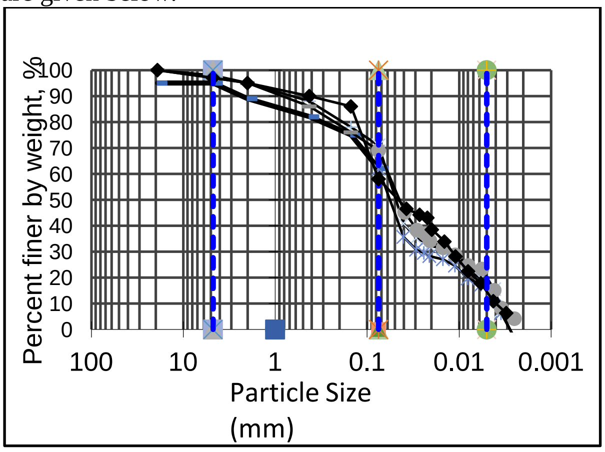

Figure 6: GSD curves of soil samples used in research

***Table III**. Particle size analysis of soil*

Depth of sample (ft.)	Particle size distribution (percentage)		USCS symbol [10]	AASHTO symbol	Index properties	
1	Gravel	2	CL	A-7-5	LL	33
	Sand	27			PI	17
	Silt & Clay	71				
2	Gravel	5	CL	A-7-5	LL	28
	Sand	33			PI	11
	Silt & Clay	62				
3	Gravel	3	CL	A-7-5	LL	26
	Sand	28			PI	11
	Silt & Clay	69				
4	Gravel	3	CL	A-7-5	LL	30
	Sand	39			PI	12
	Silt & Clay	58				

Sample preparation:

The collected soil samples were oven dried for 24 hours and then passed through sieve no. 4 for further use. Then the soil samples were mixed with the liquid effluents that were collected from the relevant industries situated in Quaid-e-Azam industrial estate kot lakhpat Lahore Fig. (1). The liquid effluents were mixed in a percentage of 5, 10 & 20% with the soil and then the soil was left for air drying for 48 hours Fig. (3). The dry soil samples were remolded for further shear strength and consolidation tests. Pictures given below show the sample preparation.

Figure 7: Mixing of effluents into soil

Liquid Limit Results:

Liquid limit and plasticity index are those important parameters which help in understanding the consistency and plasticity of a soil. Although shear strength is a constant parameter but it varies with the variation of plasticity index. As we go through the results, we see that the liquid limit decreases from 25.5 % to 23.5% with the variation of paper industry effluent from 5% to 20%. Similarly liquid limit decreases from 25.5% to 22.35% and from 25.5% to 20.71% with the decrease of effluent percentage from 5% to 20% for textile and rubber industry effluents respectively table (5) and figure (7). The standard procedure for finding liquid limit of soil according to ASTM standard was followed [11].

***Table IV**. Effect of effluents on plasticity*

Sample type	GS	LL
Uncontaminated	2.67	25.5
Paper 5%	2.67	25.14
Paper 10%	2.67	24
Paper 20%	2.65	23.5
Textile 5%	2.67	24.1
Textile 10%	2.66	23.5
Textile 20%	2.66	22.35
Rubber 5%	2.67	24.61
Rubber 10%	2.65	22
Rubber 20%	2.65	20.71

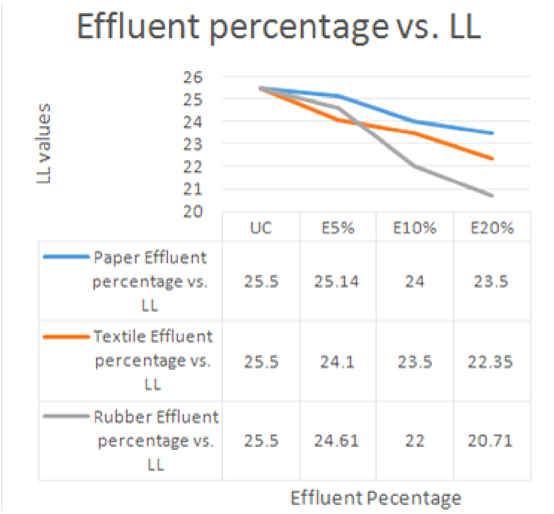

Figure 8: Effluent percentage vs. LL graph

Unconfined Compression Test:

This is an important test to measure unconfined compression strength of a cohesive soil where lateral confining pressure is always zero. It is considered as one of the fastest and cheapest method of measuring shear strength. The effluent mixed soil samples were remolded in a specific mold for unconfined compression test and tested under standard method of unconfined compression test [12]. The results of the study are given below.

***Table V**. Unconfined compression test conditions*

ASTM standard	ASTM D 2166-00
Test type	Unconfined compression test
Soil specimen type tested	Remolded uncontaminated and effluent mixed soil samples
Specimen size	D= 36mm, H= 76mm
Specimen area (mm2)	1017
Specimen preparation	Disturbed soil samples were pulverized, passed through sieve no.4, air dried, mixed with three effluents in percentages of 5%, 10% and 20% and remolded at max. dry density in sampler for triaxial test performance.

***Table VI**. Unconfined compression test results*

Sample type	**q_u (kPa)**	**C (kPa)**
UC	1079.16	539.58
P5	1004.68223	502.3411
P10	982.355958	491.178
P20	948.87	474.435
T5	1060.49791	530.249
T10	993.519094	496.7595
T20	886.80576	443.4029
R5	986.571408	493.2857
R10	975.486336	487.7432
R20	964.401264	482.2006

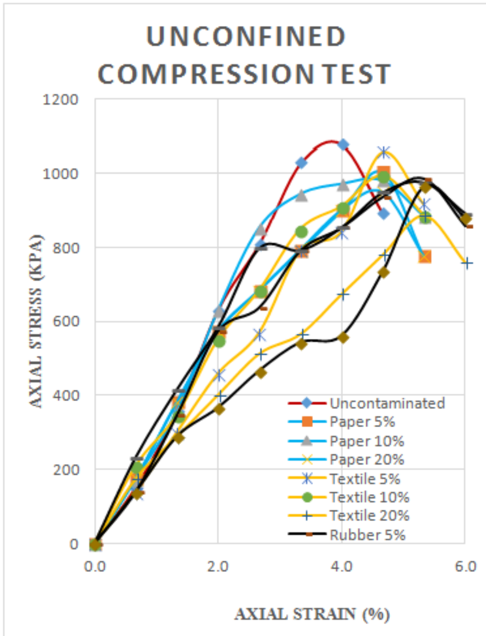

Figure 9: Unconfined compression stress strain curves

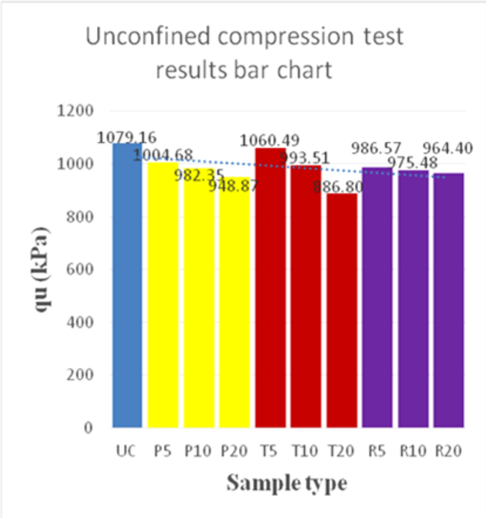

Figure 10: Bart chart for unconfined compression test results

Triaxial Compression Test:

It may be one of the most versatile test in the field of Geotechnical engineering, which can address soil response across a wide range of engineering applications. The stress state of the testing soil could be defined clearly now. Stiffness and shear strength of soil and rock could be determined with ability to control the specimen drainage by taking the measurements of pore water pressure. The triaxial compression test mostly involves placing a soil specimen cylindrical in shape, ranging from 38mm to 100mm diameter into digital cell that could be pressurized [11]. The testing program included 30 samples in total tested for shear strength parameters. The results of the study are presented under. The unconsolidated undrained triaxial test was performed according to ASTM standard procedure [13].

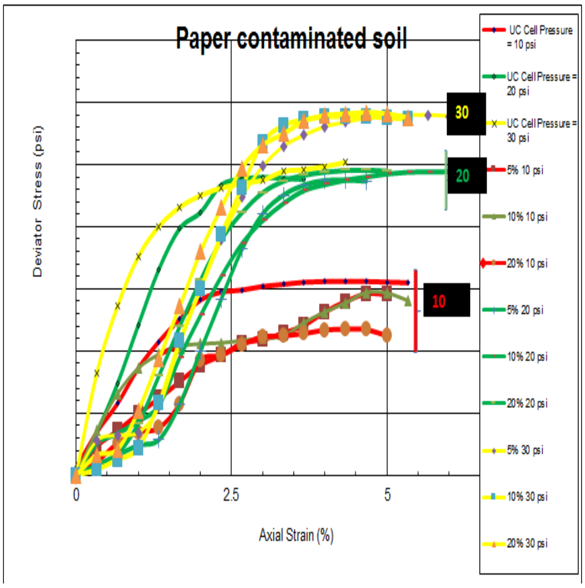

Figure 11 (a): Deviator stress graph for paper contaminated soil

***Table VII**: Test conditions for triaxial test*

ASTM standard	ASTM D 4767-02
Test type	Consolidated undrained
Soil specimen type tested	Remolded uncontaminated and effluent mixed soil samples
Specimen size	D= 36mm, H= 76mm
Specimen area (mm2)	1017
Specimen preparation	Disturbed soil samples were pulverized, passed through sieve no.4, air dried, mixed with three effluents in percentages of 5%, 10% and 20% and remolded at max. dry density in sampler for triaxial test performance.

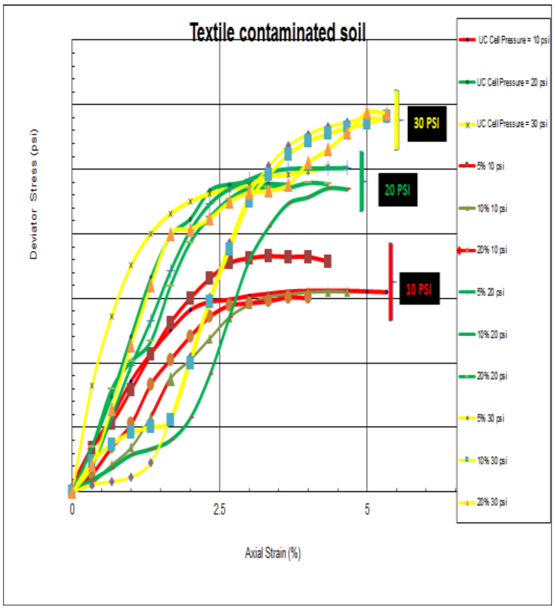

Figure 11 (b): Deviator stress graph for textile contaminated soil

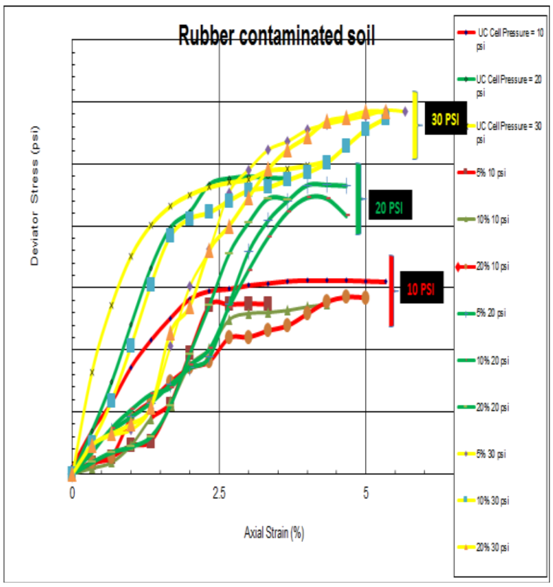

Figure 11 (c): Deviator stress graph for rubber contaminated soil

Table VIII: *Shear strength parameters variation with effluent percentage as found out by triaxial compression test*

Effluent type	Effluent percentage	Shear strength parameters	
		C	ϕ
Uncontaminated	0%	7	25
Paper industry	5%	6	23.5
	10%	5.5	24
	20%	5	33
Textile industry	5%	9.5	20
	10%	6.5	23
	20%	6	24
Rubber industry	5%	4.5	25.4
	10%	4.2	25.5
	20%	4.3	24.7

Consolidation test results:

The main purpose of consolidation test is to gain the necessary information needed for finding the compressibility properties of a saturated soil which is further used in finding the settlement characteristics of the soil and settlement rates of associated structure. Consolidation and swell potential tests were performed to understand the deformation characteristics of soil. Silts differ from clays mainly in properties. This is reflected mostly is the property of compressibility. Consolidation test was performed according to ASTM standard using incremental loading [14].

Table IX*: Test conditions for consolidation test*

ASTM standard	ASTM D 2435-03
Test type	Incremental loading
Soil specimen type tested	Remolded uncontaminated and effluent mixed soil samples
Specimen size	D= 38.1mm, H= 19.05mm
Specimen area (mm2)	1140
Specimen preparation	Disturbed soil samples were pulverized, passed through sieve no.4, air dried, mixed with three effluents in percentages of 5%, 10% and 20% and remolded at max. dry density in sampler for consolidation test performance.

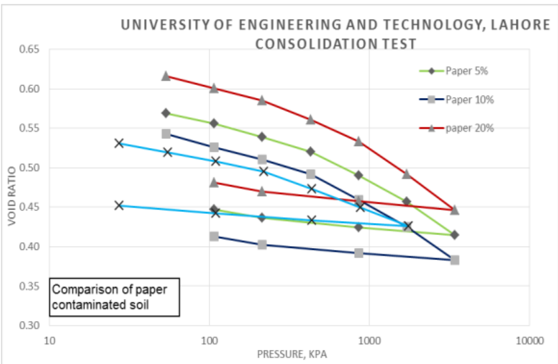

Figure 12 (a): Consolidation curves for paper contaminated soil

Generally, the higher the liquid limit of a slit the more compressible it is. The liquid limit of a bulky grained organic silt is about 30% or closer; whereas, highly micaceous or diatomaceous silts (elastic silts), consisting mainly of flaky grains, may have liquid limits that could be as high as 100 percent. Given results depict that a decrease in LL values was observed with the increase in effluent percentage but the variation was not on a bigger scale and the coefficient of consolidation increases with the increase in effluent percentage figure (.6,7,8), table (5,6,7).

Table X*. Consolidation characteristics of paper contaminated soil*

Sample type	Consolidation parameters		
	Cc	Cv	Cs
Uncontaminated	0.075	12.522	0.005
Paper 5%	0.11	33.704	0.025
Paper 10%	0.12	49.9	0.035
Paper 20%	0.15	35.64	0.07

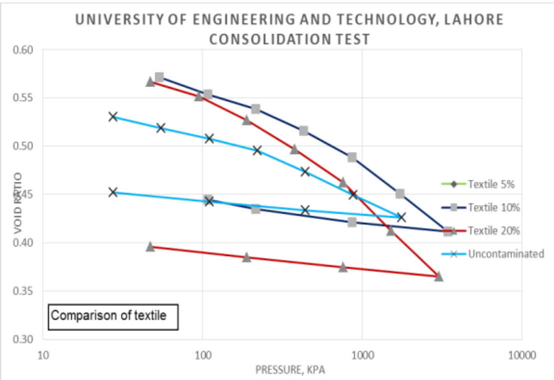

Figure 12 (b): Consolidation curves for textile contaminated soil

Table XI: *Consolidation characteristics of textile contaminated soil*

Sample type	Consolidation parameters		
	Cc	Cv	Cs
Uncontaminated	0.075	12.522	0.005
Textile 5%	0.11	41.207	0.01
Textile 10%	0.12	15.12	0.03
Textile 20%	0.17	25.01	0.03

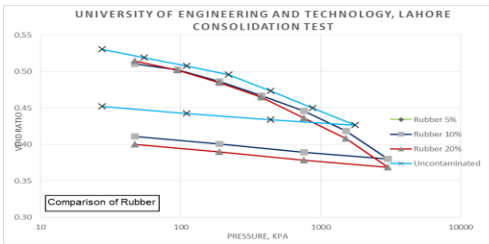

Figure 12 (c): Consolidation curves for rubber contaminated soil

***Table XII**. Consolidation characteristics of rubber contaminated soil*

Sample type	Consolidation parameters		
	Cc	Cv	Cs
Uncontaminated	0.075	12.522	0.005
Rubber 5%	0.08	24.3	0.01
Rubber 10%	0.1	15.35	0.013
Rubber 20%	0.11	35.64	0.02

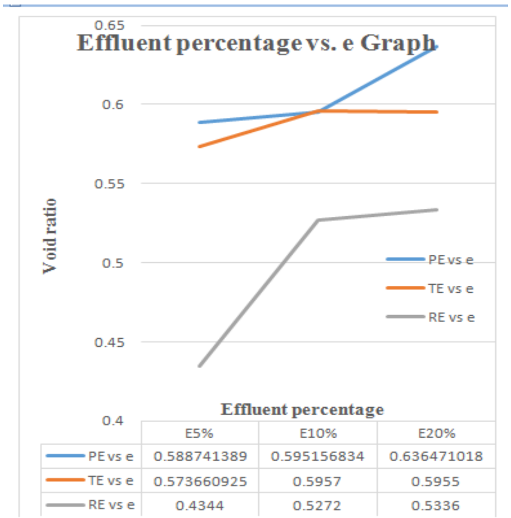

Figure 12 (d): Effluent percentage vs. initial void ratio in the initial test

Discussion:

It has been noted that all the discussed soil properties reduce when mixed with the effluents. Consolidation parameters increase and the shear strength of soil decreases. The pollutants in the study involved are a mixture of organic and inorganic solvents. The decrease in the soil properties is due to the increase in void spaces, soil water affinity and replacement of soil particles with effluent. As void ratio increases with the increase in effluent percentage, fig 12(d). The increase in the compressibility with the application of effluents may be due to the increased surface area which would reduce the inter-particle friction and help make particles slip over each other [13]. Both positive and negative effects of organic pollutants on the engineering properties of clays and silts are possible. The problem of clay/silt organic molecules interaction need further concentrated research to improve understanding of the mechanism involved. The soil in the Quaid-e-Azam industrial estate is mostly contaminated by the effluents released from different industries. The soil pits dug in the area show that it is contaminated almost upto a depth of 5ft, below which uncontaminated soil samples could be obtained.

Conclusions:

The shear strength and deformation characteristics of a low plastic clay from Quai-e-Azam industrial estate Lahore, Pakistan were studied using three industrial effluents (paper industry, textile industry and tyre & tube industry effluents). These effluents were mixed in a percentage of 5, 10 & 20% and the remolded soil samples were tested. The following conclusions can be drawn from the study.

The LL values decrease with the increase in effluent percentage. Although there is no marked difference but there is decrement.

The compression index (Cc) values increase with the increase in effluent percentage with all the three effluents. This increase is more significant with paper and textile industry effluents but not so appreciable with the tyre & tube industry effluents.

The coefficient of consolidation (Cv) values does not show a marked trend but a fluctuating behavior is observed. Although it could be concluded that the Cv values are much greater when mixed with effluents as compared to uncontaminated soil.

According to the results obtained by unconfined compression test, the cohesion values decrease with the increase in effluent percentages. The values decrease from 539.58 kPa to 474 kPa with the increase in paper effluent percentages, with textile industry effluents, values decrease from 539.58 kPa to 443 kPa and from 539.58 kPa 482 kPa with rubber industry effluents percentage. The decreasing trend may be due to pore fluid effluents replacing the soil particles.

A rather random behavior is observed in case of shear strength parameters. The uncontaminated soil have C = 7kPa & $\phi = 25^o$. The C values decrease from 7 to 5 kPa, from7 to 6 and from7 to 4.3 with increase in effluent percentage from 5 to 20% for paper, textile and rubber industry effluents respectively table (8,9). A marked decrease in angle of internal friction is also observed with the increase in effluent percentage for all the three effluents. So, overall a decrease in the shear strength of soil is observed with the three effluents. This decrease is due to the replacement of soil particles with liquid effluents.

Future Recommendations:

Contaminations disturb our daily life in many ways. Underground water which is for drinking purposes is being polluted through effluents percolation. Soil contaminated by the industrial effluents becomes unfit for construction purposes. Soil properties must be discovered before construction on these soils. Present study deals with just three types of effluents. There are many other industrial effluents which alter the soil properties in drastic ways. Pharmaceutical industry is one of the major industries in Pakistan causing lot of the soil areas contaminated.

Pakistan is an agricultural country where cotton and wheat are its main resources. However to grow such products a lot of different kind of fertilizers are poured into the soil without knowing their geotechnical impacts on soil. Also the areas near fertilizer industries are being effected by the discharge of effluents. So, it would be worth studying the geotechnical effects of fertilizer industry effluents on the nearby soil for future concern. Further research evaluating other factors should be done with more sophisticated techniques for soil sampling and effluent collection.

The effect of same effluents could be done on pure clay soil and pure sand. Moreover, greater percentages of effluents could be employed for better understanding of the effluent effects.

The present study deals with on three industries present in the area but there are other industries located in the Quaid-e-Azam industrial estate Lahore. The effect of their effluents could also be studied on the locally available soil.

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