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Geotechnical Characteristics of Fine-Grained Soils Due to Artificial Contamination of Surfactant Effluent

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Abstract

The geotechnical characteristics (index properties and unconfined compressive strength) of five fine-grained soils, before and after (artificial) contamination due to surfactant effluent, were determined, using one-dimensional soil columns. Various Hydraulic Retention Times (HRTs), concentrations and modes of operation were considered. The effect on the index properties differs and depends on the nature of the soil, whereas, reduction in unconfined shear strength is observed on all soils, mainly due to prolonged periods of effluent contamination. This study helps to understand the interactions of soils and pollutants, present in various industrial effluents and their effect on the geotechnical properties of soils, which helps to avoid failure of foundations/structures due to chemical pollutants.

1. Introduction

Indiscriminate disposal of liquid and solid wastes, especially on land, has caused serious environmental problems [1].Failure of foundations/ structures due to ground contamination/accidental spill of chemicals etc., has been reported [2] - [6]. The inorganic and organic pollutants present in industrial effluents, has been generally established to affect various geotechnical characteristics of fine-grained soils [7] and [8]. Critical review of published literature for the past two decades, have revealed that very few studies have been reported on the effect of industrial effluents, especially on natural soils. Further, no effort has been made to simulate the process of contamination close to the field conditions in laboratory studies [9] – [11]. An understanding of the soil-pollutant interactions and the effect of various contaminants/industrial effluents on geotechnical properties of soils, helps for various engineering applications. Hence, the influence of an industrial surfactant effluent on the geotechnical characteristics (index properties and unconfined compressive strength) of five fine grained soils have been experimentally investigated considering various Hydraulic Retention Times (HRTs), concentrations of effluent and modes of operation, in a single soil-column.

2. Experimental investigations

2.1 Source and Collection of Effluents

The Surfactant effluent samples were collected (i.e. before treatment) in 50 litres plastic cans (air tight containers) from the equalization unit of a process industry located near Pondicherry, India, continuously for a period of one year, at intervals of every three months and stored in a deep freezer. The samples thus collected were diluted to get the required concentrations for characterizing and further investigations.

2.2 Effluent Parameters

The effluent parameters, namely, pH, Electrical Conductivity (EC), alkalinity, total solids, Total Dissolved Solids (TDS), Total Volatile Solids (TVS), chloride, sulphate, Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD), were estimated as per APHA Standard Methods (2005), for characterizing the effluent, and to determine the outflow from the experimental set-up (i.e. soil-column which is described later), at specified intervals. Table 1.shows the characteristics of the surfactant effluent as determined, which seems to be highly alkaline in nature and has a high concentration of total solids.

2.3 Selection of Soils

Based on a preliminary survey of existing soil types carried out in the region (i.e. Pondicherry) and earlier reports in literature, the influence of effluents seems to be generally predominant only in fine-grained soils. Such soil types were identified in three different locations in the region and their samples were collected and stored in air tight containers under room temperature, until actual use.

Table 1 Characteristics of the surfactant effluent

Parameter	Value
pH	6 – 12.1
EC (µS/cm)	15000 - 45000
Alkalinity (as $CaCo_3$)	1000 - 5000
Total Solids (mg/L)	8100 - 16400
Total Dissolved Solids (mg/L)	5000 – 10000
Total Volatile Solids (mg/L)	1200 - 4800
Chloride (mg/L)	1900 - 2500
Sulphate (mg/L)	200 - 4500
Nitrite (mg/L)	600 - 1000
COD(mg/L)	10200 - 14500
BOD (mg/L)	5000 – 10000

The collected soils are referred as S1, S2 and S3, in this paper. Two other fine grained soils readily available in the market (referred as S4 and S5) were also considered. Analyses of soil samples were carried out as per the procedure detailed in [12]. Table 2 and 3 presents the characteristics of the chosen soils.

Table 2. Characteristics of Natural Soils (S1 to S3)

Soil properties	S1	S2	S3
(A)Index properties			
Liquid Limit (%)	62.4	60.6	69.5
Plastic Limit (%)	27.9	22.4	36.9
Shrinkage Limit (%)	15.7	15.9	10.6
Volumetric Shrinkage (%)	126.9	231.1	117.3
Specific gravity	2.7	2.7	2.65
(B)Sieve analysis			
Hydrometer Analysis			
% of clay	54.4	35.17	4
% of silt	45.6	64.83	96
MDD (kN/m^3)	15.5	14.55	16.54
OMC (%)	21.1	31.7	27.0
UCC ($q_{u,}$ N/mm^2)	0.191	0.27	0.148
(E) Classification			
Compressibility	CH	CH	CH
(based on liquid limit)	High	High	High

Table 3. Characterization of Commercial soils (S4 and S5)

Soil properties	S4	S5
(A)Index properties		
Liquid Limit (%)	33.0	157.0
Plastic Limit (%)	20.7	69.0
Shrinkage Limit (%)	9.2	54.0
Volumetric Shrinkage (%)	79.9	99.4
Specific gravity	02.7	02.8
(B)Sieve analysis		
Hydrometer Analysis		
% of clay	11	38
% of silt	89	62
MDD(kN/m^3)	17.7	14.7
OMC(%)	20.0	24.1
UCC($q_{u,}$ N/mm^2)	0.012	0.24
(E) Classification		
Compressibility	CH	CH
(based on liquid limit)	Low	High

2.4 Experimental Set-Up

One-dimensional column method is considered best suited to understand soil-pollutant interactions, as it permits investigations of various flow rates and retention times. Although several investigators have adopted one-dimensional soil-column, the methodology [13] (who have investigated the variation of flow rate and concentration of pollutant/(s) with respect to hydraulic travel times) is considered here but only as a ‘conceptual model’ since their methodology is not a true representation of field conditions relevant to the present study. Further modifications were made to it, to suit the present investigations so as to represent/simulate the field conditions, in the laboratory model.

2.5 Description of Experimental Set-Up

The experimental set-up consisted of number of batteries of soil-columns. Each battery consisting of six soil-columns (identical in dimensions) were fabricated using perspex pipes with an anti-corrosive coated MS (mild steel) hopper portion and a wire mesh between the soil–column and the hopper portion. The hopper portion, was fixed with an outlet control valve to regulate the outlet flow, and connected to a drain outlet. A drain pipe was provided to collect the effluent from the drain outlet. The effluent to the soil-column was fed through a feed tank fitted with an inlet control valve at the bottom and an inlet feed which connects the soil-column to the feed tank. Fig. 1 shows the schematic view and Fig. 2 shows the photographic view of the experimental set up.

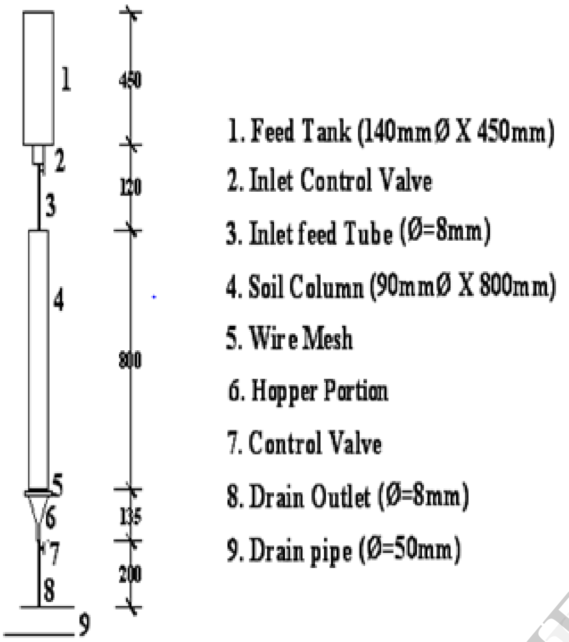

Fig. 1 Schematic Diagram of the Single soil column of Experimental Set-up

2.6 Preparation of Soil Specimen and Operating Schemes

The fabricated experimental set-up was used for two modes of study, namely: (i) batch- mode and (ii) continuous-mode, with varying Hydraulic Retention Times (HRTs). 'HRT' is defined as the time taken by the first droplet of the effluent to flow from inlet to outlet of the soil-column. Batch-mode was operated to study the chemical equilibrium that gets established between the various types of soils and pollutants of the effluents, whereas, continuous-mode aims at analyzing and reporting soil-pollutant interactions (with respect to HRT) as applicable to field conditions (i.e. discharge of effluent on soil is continuous with varying flow rate and concentration of pollutants). Eight hour HRT normally represents one shift in a process industry and it also represents a shock-load imparted to the soil (sample) at maximum flow rate and concentration of pollutants. Higher HRTs represent a situation where in the flow and the concentrations of pollutants are likely to be minimum. Hence, the effect of 8 hr and 16 hr HRT and 25 % and 50 % concentrations on soil-pollutant interactions were investigated.

Fig.2 Schematic Diagram of the Experimental Setup

Soil samples were mixed with the effluent, (the quantity added corresponds to the respective optimum moisture content for each type of soil) and filled to a height of 650 mm in the respective soil-column. Chemical analysis was carried out on the effluent collected from the outlet of the soil-columns marked as CT and soil analysis was performed on the soil samples collected from soil-columns marked as ST for the respective soils. Soil samples were collected at intervals of 15 days during both the modes of operation. Effluent samples from the outlet of soil-columns were collected at intervals of 24 hr during the batch-mode and at intervals of 8 hr, 12hr and 16hr during the continuous mode of operation. An effluent volume of 1.2 litres was used to fill the feed tanks for batch-mode of operation. However, for continuous-mode of operation, flow rates for the various soils and for the various HRTs considered, were calculated, based on the porosity of the soil samples, at the end of the batch-mode. Table 4 summarizes the flow rates obtained for various types of soils.

Table 4 Flow Rates for Continuous Mode of Operation

Effluent	HRT (h)	Flow rates (ml/min) for different soil				
		S1	S2	S3	S4	S5
Surfactant	8	0.90	1.05	1.10	1.00	0.70
	16	0.45	0.50	0.55	0.50	0.35

3. Results and discussion

3.1 pH and Alkalinity

Variation in pH from 1st to 40th day was in the range of 7.0 to 11.0 for S1 and S2 ; 7.3 to 8.8 for S3, and steady state was attained between 83rd and 90th day, for all natural soils. Variation in alkalinity was in the range of 179 to 4296 mg/L for S1 and S2; 259 to 3579 mg/L for S3, and alkalinity attained the steady state on the 57th day, for all natural soils. This behaviour is attributed to the decrease in hydrogen ion concentration due to the permeation of salts from the soil. pH and alkalinity got stabilized between the 83rd and 90th day. The results so obtained are alike to the experimental results reported by [14].

3.2 Effect of Retention Time and Concentration of Effluent on Soils

As the focus of this paper is mainly on the geotechnical characteristics of fine grained soils due to (artificial) contamination of surfactant effluent, pH concentration and alkalinity, chloride and sulphate (inorganic pollutants) and COD (organic pollutant) alone were considered, from among the various parameters of the effluent determined during experimental investigation.

3.2.1 Soil - S1

Surfactant effluent did not show appreciable retention of chloride and sulphate even at 16 hr HRT, at 50 % concentration. This behaviour (especially of sulphate) may be due to low concentration of sulphate content in the effluent and also slower rate of reaction of sulphate in an alkaline medium (available in the effluent). Nevertheless, the effluent at both 25 % and 50 % concentrations and at 8 hr and 16 hr HRT was seen to show a high retention of COD, on Soil - S1, which may be attributed to the high clay content present in S1.

3.2.2 Soil - S2

Retention times (8 hr & 16 hr HRT) and concentrations (25% & 50 %) of the effluent had no influence on Soil - S2, with respect to chloride and sulphate retention, Lower retention of COD on S2 (at 50% concentration and at 16 hr HRT) was observed, may be due to lower clay content present in Soil - S2 than that of Soil – S1.

3.2.3 Soil - S3

Surfactant effluent showed a overall maximum retention of chloride (900-1000 mg/L), on Soil – S3 at 50 % concentration and at 16 hr HRT, compared to that of Soils – S1 and S2. This may be due to the physical interception and subsequent built up of chloride aggregation on Soil – S3 because of advection and adsorption process. The effluent (at 25 % and 50% concentration and at 8 hr 16 hr HRTs) does not seem to show appreciable variation in the retention of sulphate on Soil – S3, may be due to low clay content and alkaline nature of the effluent. Lower HRT (8 hr HRT) and concentrations of the effluent (25 % and 50 %) do not show an appreciable influence on the retention of COD on Soil – S3.

3.2.4 Comparison of Interactions: (S1 To S3) Vs S4 And S5

i. The interaction of inorganic pollutants (i.e. chloride) present in the effluent on Soil – S2 is found to be critical when compared to the Soils S1 and S3.
ii. The interaction of organic pollutant COD in the effluent on Soil – S1 shows a larger variation in retention when compared to the Soils - S2 and S3. Soil - S1, is comparable to Soil - S5.
iii. Retention of sulphate in Soil – S5 undergoes a larger variation compared to chloride, before attaining the steady state. This interaction is expected to have a performed influence on the geotechnical characteristics of various soils.

3.3 Effect on the Index Properties of Soil

3.3.1 Liquid Limit (LL) of Soils

Variation of LL Vs time (in days) is shown in Fig. 3 for all soils. Soil – S5 has exhibited significant changes in LL with time, for at least 150 days, beyond which it remained almost constant, may be due to the presence of sulphate and chloride in the effluent and their interaction with the Soil – S5. whereas LL of Soil – S4 remained constant up to 160 days after contamination, which may be due to its non- interactive nature. The LL of Soils S1 to S3 increased significantly up to 75 days of contamination and lessened up to 165 days which may be attributed to the very high concentration of chloride and sulphate in the Surfactant effluent.

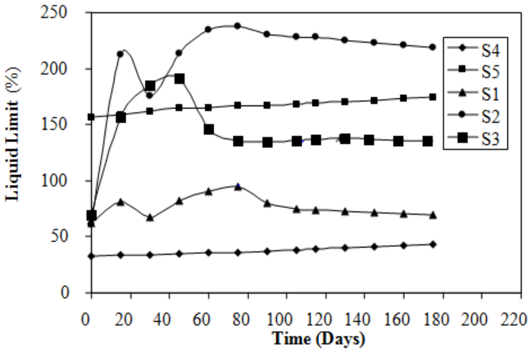

Fig. 3 Variation of liquid limit with time due to artificial contamination of surfactant effluent on commercial (S4 & S5) and natural soils (S1 - S3)

3.3.2 Plastic Limit (PL) of Soils

Variation in Plastic Limit Vs Time is shown in Fig. 4. During the period of contamination, PL for Soils S4 and S5 are found to be in the range of 20 to 25 and 67 to 75, respectively, identical to the trends observed for LL of Soils S4 and S5; S1 to S3 are found to be in the range of about 30-60; 22-75 and 36-68, respectively. This clearly shows that the PL of Soil S2 is highest among Soils S1 and S3 and the Soils attain nearly equal values of PL, within the period of contamination.

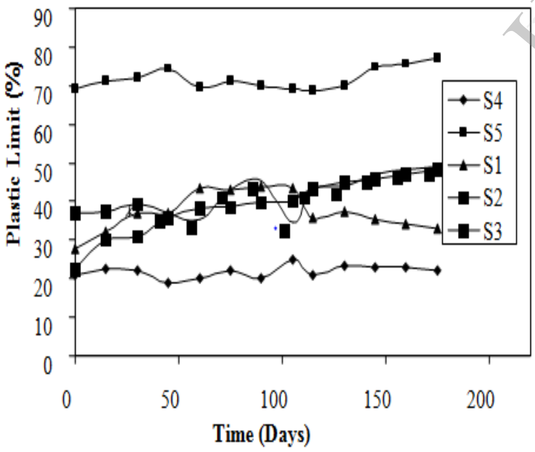

Fig. 4 Variation of plastic limit with time due to artificial contamination of surfactant effluent on commercial (S4 & S5) and natural soils (S1- S3)

3.3.3 Shrinkage Limit (SL) of Soils

Variation of SL with Time is shown in Fig. 5. Due to effluent contamination, Soil - S5, shows a 'negative influence' i.e. from 'better' to 'worse' ;Soils S1 to S3, show a 'positive influence', i.e. from 'worse' to 'better', with respect to the actual values of SL.

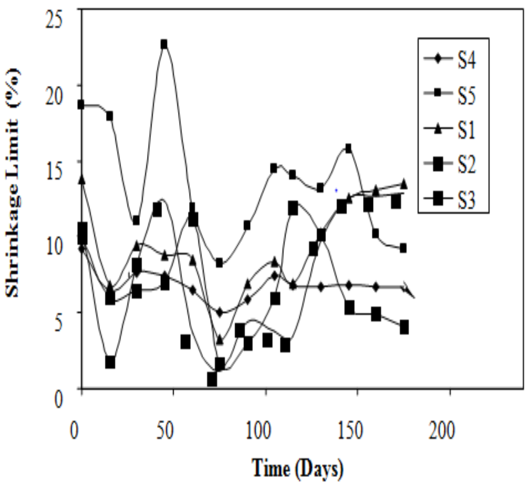

Fig. 5 Variation of shrinkage limit with time due to artificial contamination of surfactant effluent on commercial (S4 & S5) and natural soils (S1 - S3)

3.4 Effect on the Shear Strength of Soils

Variations of Unconfined Compressive Strength (UCC) with Time for all soils are shown in Fig 6. UCC values generally show a moderate increase up to 30 days of contamination and thereafter decreases gradually, for all five soils, except Soil S4.

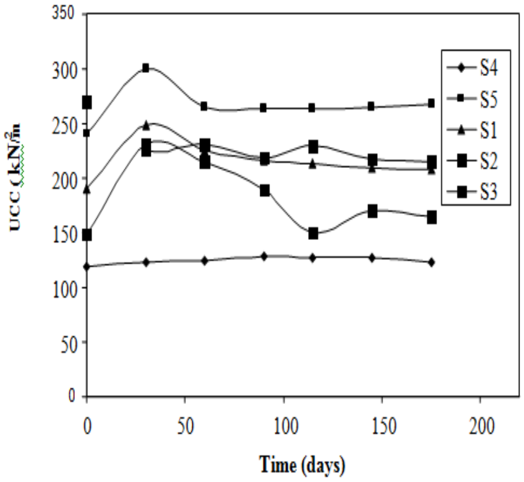

Fig. 5 Variation of UCC with time due to artificial contamination of surfactant effluent on commercial (S4 & S5) and natural soils (S1 - S3).

4. Conclusions

- Surfactant effluent has no influence on the accumulation of chloride and sulphate due to artificial contamination on Soil - S5. Further, retention times and concentrations of effluent do not influence the accumulation of the above said pollutants.

- Surfactant effluent exhibits an unique interaction with Soils S1 to S3, with respect of sulphate retention in the above said soil mass. Sulphate retention is found to increase in the order: S1>S2>S3, mainly due to percentage of clay content present in the soils. Retention times and varied effluent concentration has no influence on sulphate retention in S3.
- Overall assessment of the interaction between the inorganic pollutant i.e. chloride present in the effluent and the three soils namely S1 to S3, indicates the interaction of the effluent on Soil - S2 to be critical, compared to the other two soils (i.e. S1 and S3).
- Variation of retention times and concentrations of the effluent has no influence on the retention of COD on Soil - S3. On the other hand, the influence of retention time and concentrations of the effluent influences the retention of organic content (COD) on Soils S1 and S2. Further, the retention of COD on Soil - S1 is greater than on Soil - S2, due to higher clay content in Soil - S1.
- The effect of the Surfactant effluent on all five soils (S1to S5), are found to be similar (i.e., shows an increasing trend with time), with respect to liquid limit and plastic limit of the soils, after contamination. However, the effect on index properties of Soil - S2 is found to be closer to that of Soil - S5, due to (artificial) contamination of the effluent.
- The effect of Surfactant effluent on shrinkage limit of S1 and S3 are found to be insignificant; whereas, a significant effect on Soils S5 and S2 are observed. (i.e. shrinkage limit values becomes higher to lower) and hence, the soils become ‘better to worse’ from the geotechnical perspective. So it is suggested that the test for shrinkage limit may be considered as a “ distinctive” test from among the index properties to identify the effect of industrial effluents on soils
- The effect of surfactant effluent is to increase the UCC values of all soils, up to 30 – 90 days of contamination and thereafter, to decrease it up to 180-200 days, which is attributed to the interaction of the soil and the pollutants of the effluent. The effect of the effluent on all the Soils S1 to S5 is to reduce the UCC values by about 20 % (within the period of contamination). Hence, it is recommended that the interaction of the soil and pollutants of the effluent should be allowed to be complete, before the strength values (i.e., UCC) are determined and used for any engineering based conclusions.

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