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Article · January 2008

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The 12th International Conference of
International Association for Computer Methods and Advances in Geomechanics (IACMAG)
1-6 October, 2008
Goa, India

Soil-Leachate Interaction and Their Effects on Hydraulic Conductivity and Compaction Characteristics

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Keywords: shedi soil, leachate, contamination, compaction and hydraulic characteristics

ABSTRACT: Leachate is the most dangerous component of the solid waste management process. In a small landfill, the amount of leachate generated may not create a serious problem. As the size of landfill and variety of solid wastes disposed increases, large amounts of leachate will be generated and create environmental problems such as leaching of nutrients and heavy metals into the soil which leads to soil and ground water contamination. The problem of change in behaviour of soils on one hand and the contamination of ground water on the other is a cause of concern for geotechnical and environmental engineers. In this paper, results of a laboratory study to determine the effects of leachate contamination on the hydraulic conductivity and compaction characteristics of shedi soil (also known as lithomargic clay) have been presented. The study has indicated that leachate can modify the soil properties and significantly alter the behaviour of soil. There is a general deterioration in soil properties which is attributed to the chemistry of leachate and of soil. The interaction of leachate with soil is responsible for the modified behaviour of the soil.

1 Introduction

Shedi soils (also called as lithomargic clay) constitute an important group of soils in the coastal districts of Karnataka, India, (Dakshina Kannada and Udupi districts). Inadequate disposal schemes of solid and liquid wastes have resulted in pollution of soil and groundwater in the coastal districts of the west coast of India. Substantial releases of leachate from dump yards have occurred during the past few years. These releases may have also covered extensive areas adjacent to the dumping area resulting in ground contamination. The study area is situated in southwest coast of India (Latitude 12º 52'N, Longitude 74º 49'E). Large areas of land are currently used for open dumping purpose. At one of the dumping yard around 250 MT of municipal solid waste is being dumped without shredding and segregation (Ravishankar et al., 2005). The dump yard receives animal carcasses, chemical, and industrial wastes. Shedi soils constitute an important group of soils of this region. The high precipitation (3500 mm annually) coupled with open dumping of solid and liquid wastes increases the chance of soil and ground water pollution.

In connection with any possible applications, knowledge of the geotechnical properties and behavior of contaminated soil is required. During the preliminary investigation the main focus of this study was to determine the effect of leachate contamination on hydraulic and compaction characteristics of shedi soil. Past work (Sridharan et al, 1981; Kumapley and Ishola, 1985; Foreman and Daniel,1986; Gnanapragasam et al, 1995; Kirov, 1989; Uppot and Stephenson, 1989; Al-Tabbaa and Walsh, 1994; Kamon et al, 1996; Sivapullaiah and Savitha, 1997; Soule and Burns, 2001; Roque and Didier, 2006; Sunil et al, 2006;) has shown that some types of contaminants change the index and engineering properties of their host soils and this behavior has been shown to be dependent on the concentration of the contaminant solution.

Open dumping is extensively practiced in India. The leachate generated from such landfill sites pose serious environmental risks to the surroundings by causing contamination of soil and groundwater systems.

This paper presents the results of a laboratory testing program carried out to determine the short term effect of leachate contamination on the hydraulic conductivity and compaction characteristics of shedi soil. To select a representative leachate produced in landfills, a database was prepared from published literature (e.g. Khan et al., 1994; Ravishankar et al., 2005). The leachate used in the present study was simulated in the laboratory. The soils for hydraulic conductivity were prepared and studied at standard Proctor maximum dry density $(\gamma_d)_{max}$ using optimum moisture content (w_{opt}). A Light compaction test was employed to study the compaction characteristics.

2 Methodology

During this investigation the main focus of this study was to determine the effect of leachate contamination on hydraulic and compaction characteristics. The study of hydraulic conductivity and compaction characteristics of shedi soils has been done on the basis of the results obtained in an extensive experimental program. To attain the study objectives, the following steps were followed:

a) Studying geotechnical characteristics of shedi soil.
b) Preparing leachate with a chemical composition most representative as possible of that observed in real leachates.

The Table 1a (appendix) summarizes the instrument used, methodology and reference in determining chemical characteristics of soil and leachate.

2.1 Leachate

With the purpose of selecting representative municipal solid waste (MSW) leachate produced in landfills, a database was prepared from real leachates published in the literature (Khan et al., 1994). A study by Khan et al (1994), reports the characteristics of solid waste (Table 1) and composition of leachate generated from domestic solid waste (Table 2). The characteristics of the MSW leachate (as shown in Table 3) at a dump yard were reported by Ravishankar et al., (2005). These studies were taken as the basis to prepare leachate in the present study.

Table 1. Characteristics of solid waste (Khan et al., 1994)

Component		Percent by weight [°]
Metal		0.30
Rags and clothes		8.20
Plastics		1.53
Rubber		0.14
Glass		0.82
Wood		3.48
Garbage		58.52
Paper		25.54
Unclassified		1.47
Percentage moisture		68.00

Table 2. Composition of leachate from domestic solid waste (Khan et al., 1994)

Substances extracted			Maximum concentration in –[mg/L]	
Chloride			1110	
Calcium			875	
Ammonia-N			1094	
Total solids			18252	
COD			22125	
Volatile acids			10028	
pH			5.3-7.8	

Table 3. Composition of leachate from dump yard (Ravishankar et al., 2005)

Substances extracted			Maximum concentration in –[mg/L]	
Electrical conductance			15.16 to 18.45 [mS/cm]	
Total solids			10300 to 14530	
Total dissolved solids			6700 to 10530	
BOD			200 to 1200	
COD			22125	
Ammonia-N			900	
Sodium (Na)			1000	
Potassium (k)			1000	
Iron content			50	
pH			8.1	

BOD - Biochemical oxygen demand; COD - Chemical oxygen demand

Table 4 shows concentration of each constituent of the leachate selected for this study. Chemicals were used in the preparation of leachate, and distilled water was used in its dissolution and dilution. The mass of each chemical product was obtained on a balance with a sensitivity of ± 0.001 g. The quality of the distilled water was periodically controlled during each preparation of the acid leachate.

Table 4. Chemical composition of synthetic MSW leachate

Concentration [mg/l]						Other characteristics	
Cl^-	Mg^{2+}	Ca^{2+}	NH_4^+	TDS	COD	pH, 25 ºC	EC 25 ºC [µS/cm]
1400	2500	832	820	13020	20000	7.5-8.5	18600

TDS- Total dissolved solids; COD- Chemical oxygen demand; EC- Electrical conductance.

2.2 Soil

Representative shedi soil sample were obtained from test pits of 1.2 m to 1.5 m depth. The soil was air dried and passed through 425 µm sieve before using the same for laboratory tests. Table 5 show the index properties of shedi soil (average of two samples) selected for this study. The maximum dry density and optimum moisture content values were established for uncontaminated soil. To vary the degree of contamination the dry soil samples were mixed with 5%, 10% and 20% leachate by weight of dry soil. A light compaction and hydraulic conductivity tests were carried out on shedi soil samples after 48 hours of contamination. To study the hydraulic characteristics of shedi soils after contamination with leachate the soil specimens were compacted to corresponding standard Proctor maximum dry density using standard Proctor optimum moisture content (w_{opt}).

Table 5. Index properties of shedi soil sample selected for the study

Sample	G_s	Atterberg limits			Grain-size distribution			
		w_L[%]	w_P[%]	w_S[%]	Gravel [%]	Sand [%]	Silt [%]	Clay [%]
1	2.65	59	38	26	-	59	23	18

G_s- Specific gravity of soil solids; w_L- Liquid limit; w_P- Plastic limit; w_S- Shrinkage limit;

2.3 Compaction characteristics

The compaction characteristics of shedi soils were studied in the laboratory using standard Proctor test. The equipment used in the test consists of cylindrical mould (with detachable base plate) having an internal diameter of 100 mm and 127.5 mm effective height, whose internal volume is 1000 ml. The rammer has a mass of 2.6 kg with a drop of 310 mm.

2.4 Hydraulic characteristics

Permeability tests were carried out on uncontaminated and contaminated soil samples to study the hydraulic conductivity compacted to standard Proctor maximum dry density in the permeability mould.

Before the beginning of the seepage stage, a filter paper was placed on each face of the soil specimen so as to prevent the clogging of the perforated disks by the soil fines. After placing the bottom and top plate of the permeameter, the nuts were fastened and assembled properly. The permeameter is then connected to stand pipe (when testing uncontaminated soil the stand pipe was filled with distilled water and during testing of contaminated soil the stand pipe was filled with leachate); the soil is saturated by allowing distilled water/leachate to flow continuously through the sample from the stand pipe. Saturation of the soil sample was ensured under steady state flow conditions. The following method was followed:

a) the heights h_1, h_2 and $\sqrt{h_1 h_2}$ are marked on the stand pipe (the heights are measured above the centre of the outlet);

b) the stand pipe is then filled with distilled water/ leachate and the time intervals is recorded for the level to fall from height h_1 to $\sqrt{h_1 h_2}$ and from $\sqrt{h_1 h_2}$ to h_2.

These two time intervals will be equal if a steady flow condition has been established. This was repeated at least twice changing the heights h_1 and h_2.

The termination criteria of the tests followed in this study were as follows:

a) flow rate of water proportional to hydraulic gradient;

b) volume of water proportional to time.

The hydraulic conductivity values were calculated using the following equation.

$$k = \frac{2.303aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)$$ where,

k- coefficient of permeability in cm/sec; a- cross-sectional area of the stand pipe in cm^2;
A- cross-sectional area of the sample in cm^2; t - time taken for the drop from height h_1 to h_2 in sec; h_1- initial height of the fluid in stand pipe in cm; h_2 - final height of the fluid in stand pipe in cm after time t.

3 Results

3.1 Compaction characteristics

Standard Proctor compaction tests were carried on soils after 48 hours, after mixing with 5%, 10% and 20% leachate by weight. The results are plotted in Fig.1, in the form of dry density versus water content curves. The maximum dry density for shedi soil is 15.89 kN/m^3 at the optimum moisture content of 20.10 %. The maximum dry density of shedi soil decreases with increasing concentration of leachate and optimum moisture content increases with increasing concentration of lechate as shown in Fig. 1. This has been attributed to the chemical reaction between the leachate and the soil particles. Change in nature of the pore fluid has effect on shedi soil properties.

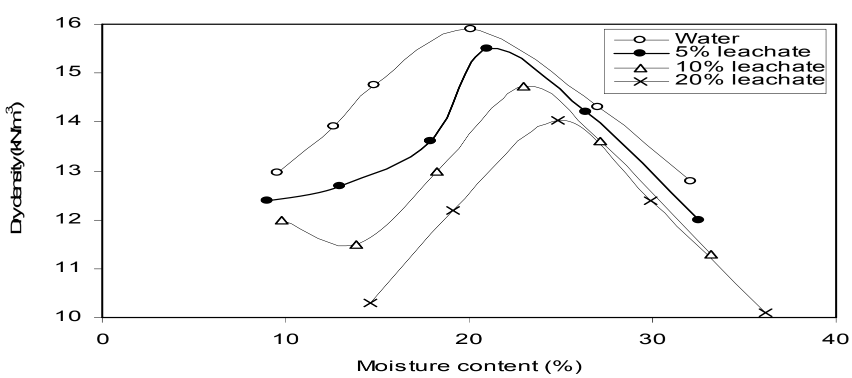

Figure 1. Compaction curves for shedi soil with different leachate content.

3.1 Hydraulic conductivity change due to leachate contamination

With increase in leachate concentration the hydraulic conductivity of the shedi soil increases (Fig. 2). This increase in hydraulic conductivity of the soil is attributed to chemical reaction between the leachate and the clay minerals. It is reported in literature that strongly acidic and strongly basic liquids can dissolve clay minerals (Uppot and Stephenson, 1989). The dissolution of clay mineral particles by leachate increases the effective pore space and hence the hydraulic conductivity increases.

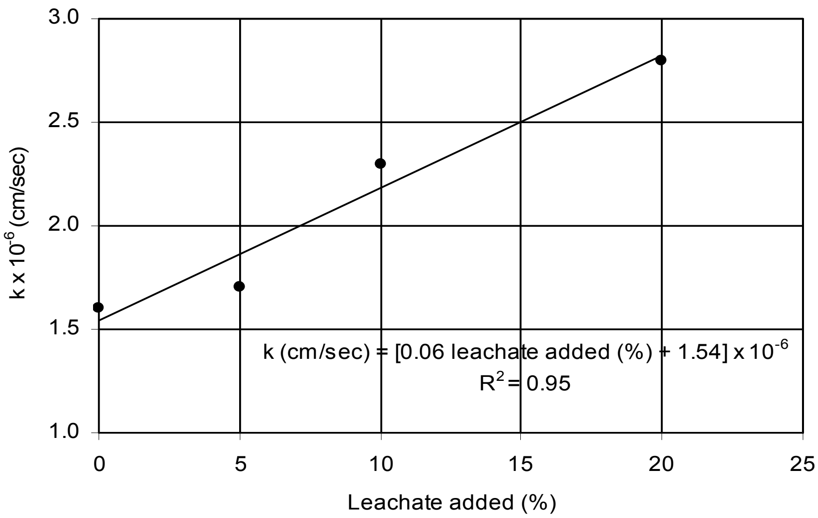

Fig. 2 Variation of hydraulic conductivity with leachate added

Bibliographical information (Uppot and Stephenson, 1989; Sunil et al., 2006) indicates that the cementing agents in soils help to bind the finer particles together to form aggregates. However, strongly acidic conditions lead to the destruction of soil structure. As the particles are transported by permeant, they clog pore space. But, as dissolution progress in the zones of clogging, particles will be removed and the hydraulic conductivity increases. Volume changes of in situ soil with regard to the effects of inflow and contamination by effluents has been reported by Sridharan (1981).

4 Discussion

The preceding results present the short-term effect of leachate contamination on the hydraulic and compaction characteristics of shedi soil. The results indicate increase in hydraulic conductivity decrease in compaction characteristics of the soil.

Open dumping is extensively practiced in this region and the present status of dump yards indicates that leachate infiltration is taking place without any hindrance. With heavy rain during monsoon the leachate mixed with water flows to other areas causing more contamination over a large surface area. The leachate flow will be very high during the monsoon and during summer and winter the flow reduces. As there is no system for the collection of the leachate at dump yard the leachate makes its way out of the dump yard through small trenches. During summer the generation is not sufficient and the leachate infiltrates within short distance out of the landfill.

Batch tests were used to study the short-term or immediate effect of leachate contamination on the properties of shedi soil. It is anticipated that during summer the leachate generation is not sufficient and due to evaporation the residues would remain into the soil.

5 Conclusions

The purpose of this work has been to investigate the effect of leachate on the properties of the shedi soil. An extensive laboratory testing program was carried out to achieve these objectives. To vary the degree of contamination, the amount of leachate mixed with soil varied up to 20%. The following important conclusions are made based on test results:

- Leachate contamination leads to increase the hydraulic conductivity of the soil tested. This is attributed due to the chemical reactions with the leachate and the soil particles. In the present investigation it was observed that at 5% leachate concentration the hydraulic conductivity of shedi aoil increased to 1.7 x 10^{-6} cm/sec (6.25% increase when compared with base value). At 10% leachate concentration the hydraulic conductivity of the soil tested increased to 2.3 x 10^{-6} cm/sec (43.75 % increase when compared with base value). Similarly when the soil was mixed with 20% leachate the increase in hydraulic conductivity was about 75% when compared with the base value. Highly acidic or basic leachate can have significant effect on the index and engineering properties of the soil. However more studies are required so as to know the effect of leachate on the soil properties in the case of leachate pH=7.0.

- Experimental results indicated that with the increase in percentage of leachate, maximum dry density $(\gamma_d)_{max}$ decreased from an initial value of 15.89 kN/m^3 to 14.03 kN/m^3 and optimum moisture content increased to 24.8% from an initial value of 20.1% when the soil was mixed with 20% leachate by weight.

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Appendix

Table 1a. Methodology and Reference used in determining chemical characteristics of soil and leachate.

Sl No.	Parameter	Instrument used	Methodology	Reference
1	pH	ELICO make Digital pH meter	-	-
2	Conductivity	ELICO make Micropro-cessor based Water analysis kit		-
3	Cation exchange capacity (CEC) (meq/100g)	-		Compendium of Indian Standards on Soil Engineering (Part 1) p. 243-246.
4	Calcium Carbonate	-		Compendium of Indian Standards on Soil Engineering (Part 1) p. 252-252
5	Ammonia Nitrogen as NH_4-N	LOVIBOND make spectrophotometer	Nesslerization	Standard Methods p.356
6	Chloride as Cl^-	-	Argentometric Method	Standard Methods p. 4-67
7	Calcium as Ca^{2+}	SYSTRONICS make micropro-cessor based Flame photometer	Flame photometric method	-
8	Magnesium as Mg^{2+}		Calculation method	Standard Methods p. 3-83
9	Total dissolved solids	ELICO make Micropro-cessor based Water analysis kit	-	-
10	Chemical oxygen demand	LOVIBOND make spectrophotometer and digester	Closed reflux colorimetric method	Standard Methods p.5-17