

Laboratory Studies on Surfactant Enhanced Remediation of Engine Oil Contaminated Soils

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Introduction

Soil-Contaminant Interactions

Perusal of relevant literature reveals that soil-contaminants interaction can bring about drastic changes in the engineering behaviour of soils. The soil-contaminant interaction depends on several factors, some of which are:

- Nature and chemical composition of soil
- Nature and chemical composition of pore fluid
- Electrolyte concentration of pore fluid
- Type of anion, cation, ion valence, and size of hydrated radii of ions, and
- Organic matter.

Meegoda and Ratanweera (1995) concluded, through their studies on oil-contaminated soils, that contaminated fine-grained soils behave as granular soils with appreciable particle aggregation. Al Sanad et al. (1995) observed reduction in strength and permeability and increase in compressibility of Kuwaiti sand due to oil contamination. Yazi and Ramkrishna (1995) studied the effects of various chemicals and contaminants viz. NaOH, $\text{CO}(\text{NH}_2)_2$, and engine waste oil. The increase in coefficients of permeability, consolidation, and compression index has been reported. Shin et al. (2002) studied the shear strength and hydraulic conductivity of oil-contaminated sand. The investigation revealed that effective friction angle of saturated oil-contaminated sand was a function of relative density of sand and kinematic viscosity of contaminant. Shah et al. (2003) studied the effects of fuel oil on soils near petrochemical complex, Vadodara, Gujrat, India. The investigators reported drastic changes in soil properties due to oil-contamination viz. liquid limit (+11%); maximum dry density (-4%); cohesion (-66%); angle of internal friction (-23%) and unconfined compressive strength (-35%). The study also included the stabilization of oil-contaminated soils with additives such as cement, fly ash and lime.

Surfactant Washing

Surfactant washing is an ex situ process; the possible configurations include excavation of contaminated matrix, heaping on the plastic liners or other

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impermeable barriers and irrigating the piles of contaminated material with washing solutions such as surfactant. Batch washing of the contaminated soil in tanks or lined pits, and continuous flows washing in counter current or normal modes are other techniques employed. In situ flushing, on the other hand, involves the delivery of washing solution to the contaminated medium by irrigation and/or injection wells; the contaminant-laden wash solution being simultaneously pumped up for treatment by recovery wells. (Hill et al. 1973; Texas Research Institute 1979, 1985; Clarke et al. 1994; USEPA 1996).

Surface active agents or surfactants are the chemical compounds that have the potential to alter the properties of fluid interfaces. They are main ingredients of such commercial and industrial products as, soap, detergent, wetting agent, dispersant, emulsifier, foaming agent, corrosion inhibitor, antistatic agent etc. Although the use of surfactants to remediate contaminants in the subsurface is a relatively new area of application, their use in subsurface systems dates back to 1963 when petroleum sulfonates were patented for widespread use in enhanced oil recovery efforts (Rosen 1989; Al-Tabbaa and Walsh 1994).

A surfactant works as a remediation tool by lowering the contaminant-water interfacial tension and thereby causing a degree of contaminant mobility, and enhanced contaminant solubility in water. The surfactant molecule is typically composed of a strongly hydrophilic (polar, water-loving) group, or moiety and a strongly hydrophobic (apolar, water fearing) moiety (Jafvert et al. 1994; Dwarkanath et al. 1999). The entire surfactant monomer is often referred to as amphiphilic (both loving) because the polar group has a large affinity for polar solvents, such as water, whereas non-polar group has a great affinity for non-polar or hydrophobic solvents, which include most organic contaminants. The hydrophilic 'head' group often includes anions or cations such as sodium, chloride, or bromide. Hydrophobic portions or 'tails' are usually hydrocarbon chains typically containing 12 or more carbon atoms.

When a sufficient amount of surfactant is added to an aqueous solution, aggregation of surfactant monomers referred to as micelles begins. Micelles are often spherical in shape and can contain hundreds of surfactant monomers. In these aggregates or micelles, the hydrophobic groups fill the core, and the polar groups are in contact with aqueous phase water molecules. Typical micelles contain 50 to 100 surfactant molecules or monomers. The micelle formation is surfactant concentration dependent. The threshold concentration at which micelles begin to form is termed as critical micelle concentration (CMC), below CMC virtually no micelles can exist.

A micelle is formed with hydrophobic tails of surfactant monomers in the interior, away from the water, while the hydrophilic heads are on the surface. Each micelle therefore has at its interior a very tiny droplet of non-polar hydrocarbon phase. This non-polar phase is able to dissolve relatively non-polar solutes (hydrophobic compounds) such as PCBs, organic solvents, chlorinated pesticides and the like. This phenomenon is known as micellar solubilisation and is responsible for increasing the solubility of hydrophobic compounds by several times in water. The solubility of these hydrophobic compounds in water is quite small, e.g., of the order of 1 mg/l for PCBs. In surfactant solutions, on the other hand, their solubility is increased manifold, perhaps 100-1000 times, by micellar solubilization.

Present Work

Petroleum and heavy metal contaminants, including fuels, lubricants, and solvents are mainly associated with activities of transportation industry. Uncontrolled release of these compounds into soil and groundwater are frequent as a result of accidents or poor control practices. Apart from serious environmental concerns, influences of petroleum-products contamination on geotechnical properties of soils are well documented. With this objective, an investigation was carried out to study the effects (detrimental) of waste engine oil contamination on geotechnical properties of soils. The cohesive soils were particularly chosen for the study as these soils are chemically most susceptible to foreign matter and allow contaminants to reside for longer periods of time due to very small conductivity through their pore spaces. A non-ionic surfactant was chosen to study the possible decontamination of soils on account of their environmental acceptability as being the least toxic among other synthetic washing agents.

Materials

1. Soil-1, representing the low-plasticity characteristics and classified as CL as per the relevant BIS classification system.
2. Soil-2, representing the high plasticity characteristics and classified as CH as per the relevant BIS classification system.
3. Waste engine oil (trade mark: Castrol CRB 20w/40, removed from an automobile).
4. Triton X-100 [chemical formula: $C_{14}H_{22}O(C_2H_4O)_n$], a nonionic surfactant.

Methodology

The Soil-1 (from Allahabad, U.P., India) was obtained from non-vegetation depth by an open excavation, and the Soil-2 (from Sultanpur, U.P., India) was removed from the bottom of a pond. The soils were sun-dried for a few days to evaporate the surface moisture; the gravels/pebbles were handpicked and removed. Both the soils were subsequently oven dried at controlled temperature, air-cooled, pulverized and passed through BIS sieve No. 480 to remove any gravel size material.

1. Standard laboratory methods in conformity with relevant parts of BIS 2720 were used to determine index and various engineering properties of both the soil types. The soils on the basis of index properties and in accordance with BIS 1498: 1970 were classified respectively as CL and CH. The properties such as consolidation characteristics, strength characteristics, and permeability were determined on saturated (wherever required) samples remolded at the respective optimum moisture content (OMC) and maximum dry density (MDD) values.
2. Both the soil types were then mixed with varying percentages of waste engine oil (W.E.O.) by dry weights of soils and matured over a period of time for proper mixing. For this purpose 6 kg soil from each type was separately hand mixed with 120 g, 240 g, 360 g and 480 g of oil, taking care to break lumps formed due to oil, and kept for maturation in a covered container for 3 to 7 days. The uncontaminated soils and various contaminated mixes have been designated as CL-0, CL-1, CL-2, CL-3, CL-4, and CH-0, CH-1, CH-2, CH-3, CH-4 (suffix 0 for uncontaminated; and 1, 2, 3, and 4 respectively stand for contaminated CL and CH type soils.)

3. Step 1 was repeated and all the engineering properties of contaminated mixes (4 sets for each type of the soil) were determined. Tables 1 and 2 respectively list the index properties and the important engineering properties of both the soil types before and after contamination.
4. Varying strengths of surfactant (volume of surfactant mixed per liter of water, ml/l) with respect to dry weight (per kg) of contaminated mixes were initially used for finding an optimum dose for each soil-contaminant mix from the each soil type. The selection of strength of washing agent for various contaminated mixes was based on the premise that sequentially a higher strength of washing agent would be required for a higher degree of soil-contaminant mix within a soil type. Accordingly three concentrations of surfactant for each soil-contaminant mix were used and index properties of washed and rinsed soil-contaminant mixes were separately determined. The surfactant concentration which gave best results with respect to restoration of index properties vis-à-vis uncontaminated soil was designated as the optimum concentration and subsequently used for washing that particular soil-contaminant mix and determination of important engineering properties. The range of surfactant by volume of the dry weight of various contaminated mixes and corresponding optimum values are given in Tables 3A and 3B.
5. Artificially contaminated soils were decontaminated using the surfactant to obtain near virgin or the uncontaminated state for comparison with original soils. In surfactant washing process, Triton X-100 was used to wash/clean the contaminated soil in laboratory-controlled conditions. During the experiments, ratio of contaminated soil and the surfactant solution in water was kept constant at 1:4. Nearly 1 to 2 minutes of stirring of contaminated soil and the surfactant solution was done to achieve good contact and then the mixture was stood for 24 hrs to allow the settlement of particles. Surfactant solution was thereafter decanted carefully. The soil was subsequently washed two times with plain water and with the each washing cycle the suspension was stood for 24 hrs to allow the fines to settle and then decanted. Finally, the decanted soil slurry was kept for air-drying and then oven dried until the moisture in the soil was constant.
6. The OMC and MDD were first determined for each decontaminated mix by BIS light compaction test for both types of soil. Other engineering properties for all the decontaminated mixes for both the soil types were separately determined on soil samples remolded at respective OMC and MDD.

TABLE 1: Index Properties before and after Contamination
(w_L = Liquid limit, w_P = Plastic limit, w_S = Shrinkage limit, I_p = Plasticity index)

Mix Label	Sp. Gravity (G)	Grain Size Analysis (%) Finer			Atterberg's Limits (%)			I_p (%)
		4.75 mm	0.075 mm	0.002 mm	w_L	w_P	w_S	
CL-0	2.67	98.0	89.8	15.4	31.6	19.1	14.6	12.5
CL-1	2.62	98.0	87.5	13.8	33.2	21.0	16.1	12.2
CL-2	2.54	97.5	86.5	12.6	34.2	21.9	17.3	12.3
CL-3	2.49	97.0	83.8	10.8	34.9	20.8	16.2	14.1
CL-4	2.48	95.8	78.5	9.7	35.4	20.0	14.8	15.4
CH-0	2.64	100.0	96.7	26.7	60.5	27.4	11.8	33.1
CH-1	2.59	99.3	94.6	23.6	62.4	30.5	13.1	31.9
CH-2	2.51	99.1	92.5	17.5	65.5	29.4	12.5	36.1
CH-3	2.46	98.7	88.3	11.4	67.4	28.2	11.9	39.2
CH-4	2.41	98.1	84.8	9.3	69.6	26.9	11.4	42.7

TABLE 2: Important Engineering Properties before and after Contamination
 (C_c = Compression Index, C_v = Coeff. of consolidation, UCS = Unconfined Compressive Strength, k = Coeff. of permeability)

Mix Label	Compaction Characteristics		Consolidation Characteristics		UCS (kN/m ²)	k ($\times 10^{-8}$) (m/s)
	OMC (%)	$(\gamma_d)_{\max}$ (kN/m ³)	C_c	C_v ($\times 10^{-8}$) (m ² /s)		
CL-0	15.7	17.4	0.191	4.031	77.8	32.7
CL-1	14.9	17.7	0.206	3.668	72.9	30.3
CL-2	12.9	18.0	0.220	3.484	66.8	31.6
CL-3	11.8	17.6	0.231	3.445	61.2	36.3
CL-4	11.2	17.0	0.237	3.305	54.4	39.7
CH-0	20.5	14.7	0.325	1.443	137.0	4.46
CH-1	19.1	14.9	0.373	1.226	119.0	4.13
CH-2	16.4	15.2	0.393	1.091	99.5	4.86
CH-3	15.0	14.8	0.415	1.047	85.8	5.37
CH-4	13.9	14.3	0.426	1.010	78.1	6.12

Results and Discussion

All the soil properties have undergone alterations on contamination with varying percentages of waste engine oil. The alteration or modification in properties is observed in extremities, i.e. both negative as well as positive, and of moderate to a significantly high degree. The index properties consisting of specific gravity, particle size distribution, and Atterberg's limits for both the types of soils (CL and CH) in uncontaminated state as well as at varying percentages of contamination are reported in Table 1. In Table 2 important engineering properties of both soils type such as compaction characteristics, consolidation characteristics, unconfined compressive strength (UCS), and permeability in uncontaminated state and contamination with different oil percentages have been reported. Following important inferences are drawn with respect to the present study.

1. Both the soil types have become coarser in varying degrees on contamination with different percentages of oil. In case of CL-soil, the sand size has increased from 8.2% for CL-0 (uncontaminated) to 17.3% for CL-4 (480 g contamination), correspondingly silt size has decreased from 74.4% to 68.8%, and decrease in clay size has taken place from 15.4 to 9.7%. In case of CH-soil, sand size has increased from 3.3% to 16.6%, however silt size has also increased from 72.4% to 88.6% as clay size has appreciably decreased by 287% (or 2.87 times for CH-4 mix), resulting in the increase of both sand and silt sizes. Figures 1 and 2 respectively show the particle size distribution of CL and CH soils in uncontaminated state as well as contamination at different oil percentages.
2. The specific gravity shows decreasing trend on contamination with both the types of soils, which is obvious as the oil filling the pore spaces of soils has the less specific gravity than the soil.

TABLE 3A: Determination of Optimum Dose of Surfactant for Decontamination of Various W.E.O. Mixes for Soil-1 (Type: CL)

Soil Mix + Surfactant	Index Properties before Treatment with Surfactant					Index Properties after Treatment with Surfactant					Optimum Dose of Surfactant (ml)
	G	Particle Size Distribution		Atterberg's Limits		G	Particle Size Distribution*		Atterberg's Limits		
		% Sand	% (Silt + Clay)	w _L (%)	w _p (%)		% Sand	% (Silt + Clay)	w _L (%)	w _p (%)	
CL-0	2.67	8.2	89.8	31.6	19.1						
CL-1	2.62	10.5	87.5	33.2	21.0						
+ 0.5 ml Surf./l water						2.63	10.3	87.7	33.0	20.7	
+ 1.0 ml Surf./l water						2.66	8.8	89.2	32.4	19.3	1.0
+ 1.5 ml Surf./l water						2.66	8.5	89.5	32.2	19.5	
CL-2	2.54	11.0	86.5	34.2	21.9						
+ 1.0 ml Surf./l water						2.58	10.5	87.5	33.5	21.0	
+ 1.5 ml Surf./l water						2.64	9.0	89.0	32.2	19.5	1.5
+ 2.0 ml Surf./l water						2.65	8.8	89.2	33.0	19.8	
CL-3	2.49	13.2	83.8	34.9	20.8						
+ 1.5 ml Surf./l water						2.58	12.5	85.5	33.8	20.5	
+ 2.0 ml Surf./l water						2.62	10.5	87.5	31.2	19.8	2.25
+ 2.5 ml Surf./l water						2.64	9.3	86.7	32.0	18.8	
CL-4	2.48	17.3	78.5	35.4	20.0						
+ 2.0 ml Surf./l water						2.56	14.1	82.4	34.8	19.8	
+ 2.5 ml Surf./l water						2.61	10.5	86.5	34.0	20.1	3.0
+ 3.0 ml Surf./l water						2.65	8.5	88.5	31.8	19.5	

* Only the sieve analysis was carried out for particles-size distribution analysis after washing with the optimum dose of surfactant, hence % of silt and clay has been combined to compare the restoration of grain sizes after washing with surfactant.

** Contaminated soil-water ratio was kept constant at 1: 4, therefore the quantity of surfactant can be worked out for a given amount of contaminated soil to be washed.

TABLE 3B: Determination of Optimum Dose of Surfactant for Decontamination of Various W.E.O. Mixes of Soil-II (Type: CH)

Soil Mix + Surfactant	Index Properties before Treatment with Surfactant					Index Properties after Treatment with Surfactant					Optimum Dose of Surfactant (ml)
	G	Particle Size Distribution		Atterberg's Limits		G	Particle Size Distribution*		Atterberg's Limits		
		% Sand	% (Silt + Clay)	w _L (%)	w _p (%)		% Sand	% (Silt + Clay)	w _L (%)	w _p (%)	
CH-0	2.64	3.3	96.7	60.5	27.4						
CH-1	2.59	4.7	94.6	62.4	30.5						
+ 1.5 ml Surf./l water						2.60	4.0	96.0	61.8	29.5	
+ 2.0 ml Surf./l water						2.62	3.7	96.3	60.0	27.7	2.0
+ 2.5 ml Surf./l water						2.62	3.5	96.5	61.5	28.2	
CH-2	2.51	6.6	92.5	65.5	29.4						
+ 2.0 ml Surf./l water						2.56	6.0	94.0	64.3	28.8	
+ 2.5 ml Surf./l water						2.62	4.2	95.8	62.5	28.0	2.75
+ 3.0 ml Surf./l water						2.63	3.7	96.3	59.5	26.5	
CH-3	2.40	10.4	89.3	67.4	28.2						
+ 2.5 ml Surf./l water						2.52	7.6	91.6	66.8	27.5	
+ 3.0 ml Surf./l water						2.59	4.0	95.5	62.5	26.0	3.25
+ 3.5 ml Surf./l water						2.62	3.5	96.0	59.5	27.0	
CH-4	2.41	13.3	84.8	69.6	25.9						
+ 3.0 ml Surf./l water						2.50	9.7	88.8	67.0	25.0	
+ 3.5 ml Surf./l water						2.59	7.0	92.0	63.5	25.3	4.0
+ 4.0 ml Surf./l water						2.62	3.5	95.5	61.0	27.0	

* Only the sieve analysis was carried out for particles-size distribution analysis after washing with the optimum dose of surfactant, hence % of silt and clay has been combined to compare the restoration of grain sizes after washing with surfactant.

** Contaminated soil-water ratio was kept constant at 1: 4, therefore the quantity of surfactant can be worked out for a given amount of contaminated soil to be washed.

- Liquid limit consistently increases for both the soils with increasing percentage of waste oil. Liquid limit is an important index property as it relates to such engineering properties of soils as compressibility, shear strength and permeability (Sridharan and Prakash 2000). Two mechanisms viz. thickness of diffuse double layer and the mode of particle arrangement control the liquid limit. Thickness of diffuse double layer may decrease for a

variety of reasons including a reduction in dielectric constant of pore fluid (as in the case of waste oil), resulting in decrease of liquid limit. However, pore medium may also induce increase in the shearing resistance at the particle level favouring flocculation and consequently increased the liquid limit values. Plastic limits increase for CL at oil contamination of 20 to 60 g/kg soil and at 20 to 40 g/kg soil for CH and thereafter decrease from high values attained at low percentages. Soils tend to become brittle at high percentages of oil possibly because clay sizes have reduced considerably for both the soils at high soil-oil mixes. Similar trends are also shown by shrinkage limits.

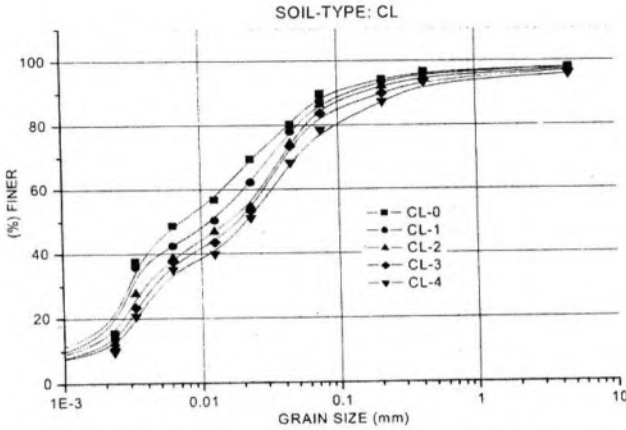


Fig. 1 Particle Size Distribution Curves for CL – Soil before and after Contamination with W. E. O

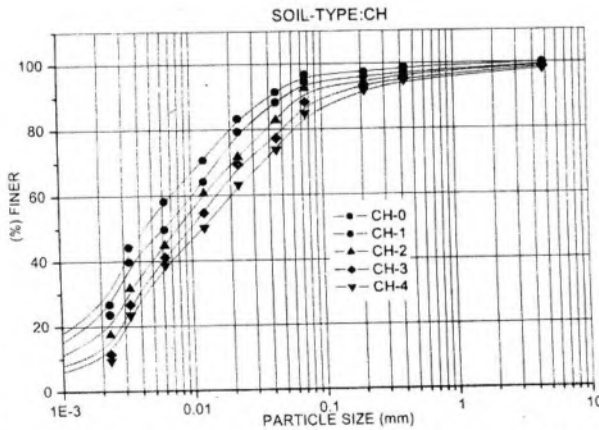


Fig. 2 Particle Size Distribution Curves for CH – Soil before and after Contamination with W. E. O

4. The OMC values decrease with increasing oil percentages for both the soils. Figures 3 and 4 respectively show the compaction characteristics of

soils in uncontaminated state and in contaminated state at various oil percentages. Oil acts as a lubricant and facilitates the slippage of particles past each other in a plastic soil; thereby less water is required to achieve compaction. The MDD values increase for oil contamination at 20 – 40 g/kg soil for CL and then decrease for 40 – 80 g/kg oil contamination from the highest value; possibly past saturation, the presence of oil decreases dry density, as oil is lighter than water and also because of flocculated structure of contaminated matrices. Same trend for MDD values is observed in case of CH-soil. Compression index (C_c) values increase for both the soils with increasing percentage of oil. The C_c values are in consonance with liquid limits and indicate that the oil-contaminated soils are much compressible. Coefficient of consolidation (C_v) values show a decreasing trend with increasing oil percentages for both CL and CH soils. The C_v being inversely proportional to total time for primary consolidation indicates a longer time for full settlement.

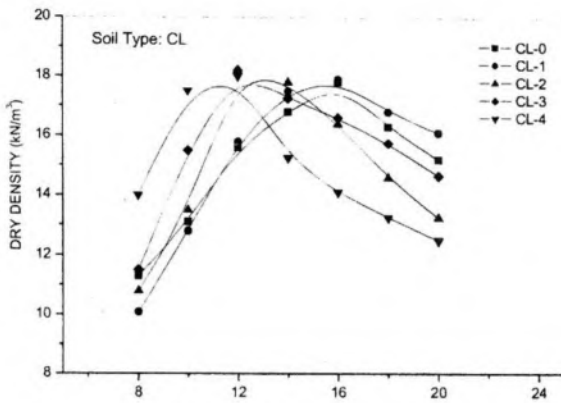


Fig. 3 Compaction Characteristics of CL – Soil before and after Contamination

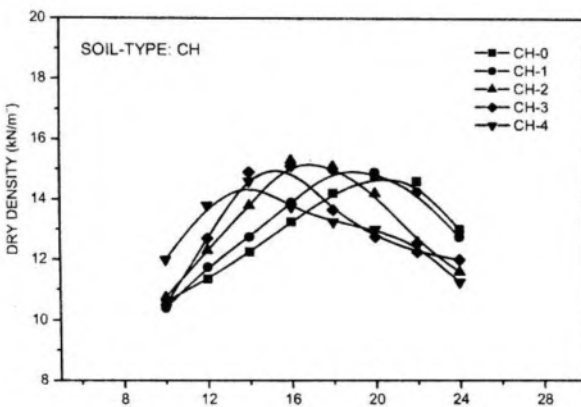


Fig. 4 Compaction Characteristics of CH – Soil before and after Contamination

5. Unconfined compressive strength (UCS) values show the decreasing trend for both the soil types. Although increase in shearing resistance at particle level due to the contaminant may have caused the increase in liquid limits, but the same is not reflected by the UCS values of the contaminated soil. The contaminated soil is more compressible, which is borne out by compressibility indices, and the increased compressibility of contaminated soil apparently caused the decrease in the shear strength and therefore in the UCS values.
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7. Coefficient of permeability (k) values decreased at 20 and 40 g/kg soil of oil contamination for CL-soil and thereafter showed an increasing trend. For CH-soil k decreased for 20 g/kg soil and subsequently increased for higher oil mixes. Initial decrease indicates the clogging of voids with contaminant and subsequent increase possibly accounts for flocculated structure at higher contaminant proportion. The increasingly flocculated structure possibly offsets the effect of clogging at higher contaminant concentrations.
8. All soil-contaminant mixes for both soils have been washed with their corresponding optimum doses of surfactant. The soil properties obtained after washing have been reported in Table 4. In Table 5 the impacts of contaminant at varying percentages for both the soils and restoration of properties after washing with corresponding optimum dose have been presented.

TABLE 4: Important Engineering Properties after Decontamination with Optimum Dose of Surfactant

Contaminated Soil Mix	Opt. Dose (% w/v)	Properties after Decontamination					
		Compaction Characteristics		Consolidation Characteristics		UCS (kN/m ²)	k (x 10 ⁻⁸) (m/s)
		OMC (%)	(γ_d) _{max} (kN/m ³)	C _c	C _v (x 10 ⁻⁸) (m ² /s)		
CL-1	10.0	15.1	17.1	0.187	3.893	74.7	31.8
CL-2	15.0	14.7	17.3	0.190	3.783	71.3	32.2
CL-3	22.5	14.1	16.9	0.201	3.765	68.4	30.3
CL-4	30.0	13.9	16.7	0.211	3.710	62.3	35.6
CH-1	20.0	19.8	14.3	0.338	1.373	128.2	4.35
CH-2	27.5	18.7	14.9	0.371	1.337	121.5	4.18
CH-3	32.5	17.8	14.5	0.358	1.291	114.0	4.17
CH-4	40.0	16.7	14.0	0.376	1.213	106.7	5.06

9. Restoration has varied for different soil properties at different soil-contaminant mixes. In case of CL-soil minimum to maximum range of restoration is from 80.1 to 98.5% at optimum surfactant doses for different soil-oil mixes. For CH-soil contaminant mixes the range of restoration is from 77.9 to 98.6% for various properties at corresponding optimum doses.

Figures 5 and 6 respectively compare for CL and CH soils the impact of different oil percentages on engineering properties and their restoration with surfactant washing.

TABLE 5: Effect of Contaminant on Soil Properties and their Restoration with Surfactant Washing

(CI = Contaminant Impact, R = Restoration)

Soil Property		Contaminated Soil Mix								
		CL-1	CL-2	CL-3	CL-4	CH-1	CH-2	CH-3	CH-4	
Compaction	OMC	CI (%)	-5.09	-17.8	-24.8	-28.7	-6.8	-20.0	-26.8	-32.2
		R (%)	96.2	93.6	90.0	88.5	96.6	91.2	86.8	81.5
Consolidatio	MDD	CI (%)	+1.7	+3.5	1.15	-2.30	+1.4	+3.4	+0.7	-2.7
		R (%)	98.2	99.4	97.1	96.0	97.3	98.6	98.6	95.2
	C _c	CI (%)	7.8	15.2	20.9	24.1	14.8	20.9	27.7	31.1
		R (%)	98.0	99.5	94.8	89.5	96.0	85.8	89.8	84.3
	C _v	CI (%)	-9.0	-13.6	-14.5	-18.0	-15.0	-24.3	-27.4	-30.0
		R (%)	96.6	93.8	93.4	92.0	95.1	92.6	89.5	84.1
UCS		CI (%)	-6.3	-14.1	-21.3	-30.1	-13.1	-27.4	-37.4	-43.0
		R (%)	96.0	91.6	87.9	80.1	93.6	88.7	83.2	77.9
k		CI (%)	-7.3	-3.4	11.0	21.4	-7.4	9.0	20.4	37.2
		R (%)	97.2	98.5	92.7	91.1	97.5	93.7	93.5	86.5

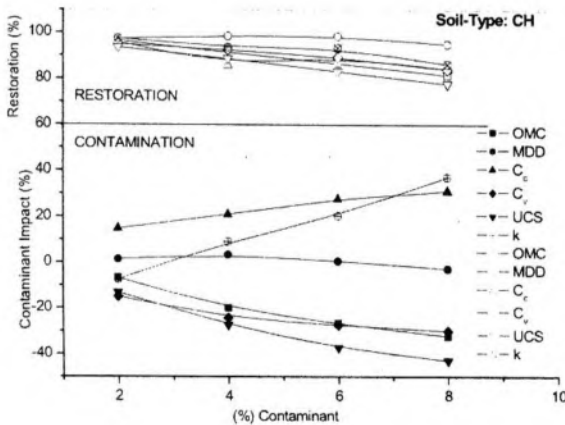


Fig. 5 Contaminant Impact and Restoration of Soil Properties after Washing with Surfactant

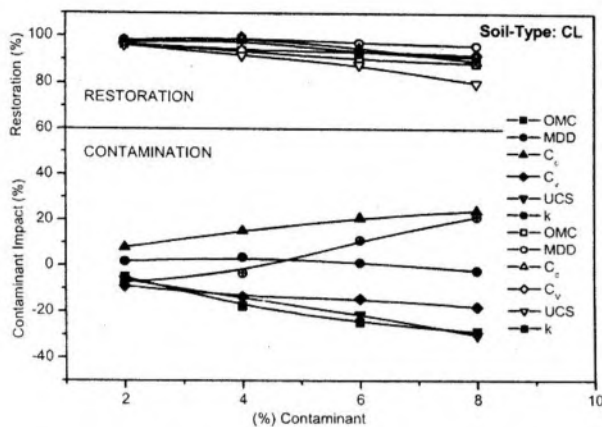


Fig. 6 Contaminant Impact and Restoration of Soil Properties after Washing with Surfactant

Conclusions

1. Soil properties with waste engine oil undergo modifications on negative as well as positive sides from moderate to appreciable degrees. The undermining of engineering properties is a cause of worry for construction in oil-contaminated soils.
2. The moderation or alteration in soil engineering properties has an important bearing on the behaviour of oil contaminated soils. The oil-contaminated soils may undergo excessive deformation on load application and at the same time may take much longer to fully consolidate.
3. The waste engine oil as a contaminant reduces the strength of soil to an appreciable degree.
4. The surfactant Triton X-100 has been found quite effective in restoring the engineering properties of the waste engine oil contaminated soils of both categories.

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