Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering

doi:10.3233/978-1-61499-656-9-2331

Engineering properties of soil contaminated with TCE and decontaminated with surfactants

L'Ingénierie des propriétés de sol contaminé avec TCE et décontaminé avec surfactants

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ABSTRACT

This study presents the results of an experimental investigation undertaken to evaluate the effect on engineering properties of soil contaminated with trichloroethylene (TCE) and decontaminated with surfactant SDS and liquid organic cleaner (LOC). Soil has been taken from different locations in dry state. 4% of TCE (w/w) has been used to simulate the effect of contamination on soils under laboratory controlled conditions. Each sample of the contaminated soil were examined for various engineering properties like, consistency limits, specific gravity, OMC, permeability, shear strength and consolidation etc. It has been observed that engineering properties of the contaminated soil like consistency limits, specific gravity, permeability, shear strength and cohesion decreases whereas MDD increases as the concentration of TCE increased. In order to decontaminate the contaminated soils, 0.2%, 0.4% (w/v) surfactant SDS and LOC were used separately. It was observed after decontamination, the engineering properties of the contaminated soils were found quite near to the original soil. It was also observed that 0.4% LOC was more effective as compared to the 0.4% SDS.

RÉSUMÉ

Cette étude présente les résultats d'une enquête expérimentale entreprise pour évaluer l'effet sur les propriétés de construction mécanique de sol contaminé avec trichloroethylene (TCE) et décontaminé avec surfactant SDS et l'appareil de nettoyage organique liquide (LOC). Le sol a été pris de différents endroits dans l'état sec. 4 % de TCE (w/w) a été utilisé pour simuler l'effet de contamination sur les sols dans les conditions contrôlées de laboratoire. Chaque échantillon du sol contaminé a été examiné pour les propriétés différentes de construction mécanique comme, les limites de consistance, la densité, OMC, la perméabilité, la force de tondage et la consolidation etc. Il a été remarqué que les propriétés de construction mécanique du sol contaminé comme les limites de consistance, la densité, la perméabilité, la force de tondage et la cohésion diminuent alors que les augmentations de MDD comme la concentration de TCE ont augmenté. Pour décontaminer les sols contaminés, 0.2 %, 0.4 % (w/v) surfactant SDS et LOC ont été utilisés séparément. Il a été observé après decontaminati

1 INTRODUCTION

One of the legacies of the past in industrialized countries is that land has been contaminated. Contaminated land has come about because, industry and society tended to dispose of their waste with little regard for future consequences. It is land which contains substances which can cause harm to living organism, pollute water or interfere with the ecosystem. It can take many forms, and can be variable in nature across a site, and each site has its own characteristics. The term soil contamination can have different connotations because anthropogenic sources of contaminants have affected virtually every natural ecosystem in the world; a commonly held view is that contamination occurs when the soil composition deviates from the normal composition. Other specialists have defined soil pollution as the presence of some constituent in the soil, caused by human activity, at such a concentration that there is a significant risk of damage to users of the soil or a restraint of its free use.

Trichloroethylene is a synthetic compound that does not occur naturally in the environment. However, trichloroethylene is a common contaminant found at various concentrations and locations throughout most of the industrialized world. Trichloroethylene may be present either in the soil, water, or atmosphere, which gives rise to a variety of environmental impacts and concerns. The greatest impact of trichloroethylene in the environment is its threat to human health and the potential risks associated with it. TCE is a halogenated aliphatic organic compound which, due to its unique properties and solvent effects, has been widely used as an ingredient in industrial cleaning solutions and as a "universal" degreasing agent. TCE, perchloroethylene (PCE), and trichloroethane (TCA) are the most frequently detected volatile organic chemicals (VOCs) in ground water in the United States (Al-Tabba & Walsh, 1994).

Trichloroethylene is a volatile, non-flammable, colourless liquid. Most persons can smell it at 100 parts of TCE per million parts of air (ppm), which is equivalent to about 560 mg of TCE per cu.m. of air. TCE is somewhat soluble in water and is miscible with most organic solvents. The Physical and Chemical Properties of Trichloroethylene is given in below Table1.

In the present study a typical alluvial soil from north India has been contaminated with 4% (w/w) of TCE and then decontaminated with 0.2% and 0.4% (w/v) of surfactants SDS and LOC. A comparision of engineering properties of contaminated and decontaminated soil has been made.

2 EXPERIMENTAL WORKS

2.1 *Soil Washing Using Surfactant*

Surfactant is a surface-active substance such as detergent. Surfactants are organic molecules with positive and or negative charges. Surfactants act by the lowering of the surface tension of the cleaning solutions there by enabling a better wetting of the surfaces to be cleaned (Rosen, 1989).

It also assists the solution to penetrate the smallest pores by capillary action. A large number of studies have been carried out on surfactants and its effect on geotechnical properties of soil (Abumaizar & Khan, 1996; Evangeliista & Zownir, 1989; Ellis et all, 1985). The surfactants have got a cleaning effect on oils and grease, contaminated soils. Basically surfactants are anionic, cationic, and non-ionic surfactants (Dworkin et all, 1988). Some

of the commonly available surfactants are SDS, Tween – 20, Triton X–100 etc (Jafvet et all, 1994; Meegoda & Ratnaweera, 1994, 1995).

Table: 1 Physical and Chemical Properties of Trichloroethylene.

Property	Characteristic
Molecular weight	131.40
Colour	Clear, Colourless
Physical state	Liquid (at room temperature)
Melting point	-87.1°C
Boiling point	86.7°C
Density at 20°C	1.465 g/ml
Odour	Ethereal, chloroform-like, sweet
Odour threshold: Air	100 ppm
Solubility: Water at 20°C at 25°C Organic solvents	 1.070 g/l 1.366 g/l Miscible with many common organic solvents (such as ether, alcohol, chloroform)
Vapour pressure at 25°C	74 mm Hg
Conversion factors Air at 20°C Water	 1mg/m^3 = 0.18 ppm 1ppm = 5.46 mg/m^3 1ppm (weight per volume) = 1 mg/L
Amount of sorption on a unit carbon basis. K_{oc}	2.42

The soil has been taken from MNNIT campus, Allahabad which is collected from 3.5 feet below the top surface with the aim of getting true sample of actual soil strata as the topsoil is quite affected by human activities such as agriculture, land excavation and various other sources. From the physical observations the soil is light brown in colour and contains clay, silt and fine sand. 2% and 4% trichloroethylene is used as contaminants for this study. Then geotechnical properties of treated contaminated soils can be compared with those of virgin or uncontaminated soils.

Results from this study are expected to be the same as for those contaminated soils obtained from contaminated sites where the soils were in contact with TCE contamination for years. These artificially contaminated soils were decontaminated using the surfactant to obtain near virgin or the uncontaminated state for comparison with original soils. If a particular treatment method was able to bring back the soil to its original state, the treated soils should have the same grain-size distribution and other geotechnical properties. Therefore the comparison of geotechnical properties of virgin soil and treated soil should indicate whether the selected treatment method is capable of decontaminating soil to bring back its virgin or near virgin state.

3 EXPERIMENTAL PROCEDURES

3.1 Contamination *and Decontamination Procedure*

In this experimental study soil samples were prepared with TCE by mixing 4% of dry weight of the soil which is of 40 gm per kg of soil. In surfactant washing process, SDS and Liquid Organic Cleaner (LOC)s separately has been used to wash/clean the contaminated soil in laboratory controlled conditions. During the experiment contaminated soil and surfactant/soap solution (0.2% and 0.4% w/w) ratio was kept constant at 1:4. Nearly 10 minutes stirring of contaminated soil and surfactant solution has been done to make good contact of surfactant with soil and kept the mixture for 24 hr. for proper settling of soil. Surfactant/soap solutions were decanted carefully and again soil was washed with fresh water. Finally, the decontaminated soil was kept for drying at 60^o C until the moisture in the soil was constant.

4 TEST RESULTS

Grain size analysis, consistency limit tests and hydrometer tests were performed on virgin, contaminated and decontaminated soils for identification and classification of soil. OMC and maximum dry density has been determined which was useful for preparing the remolded soil samples. Consolidation tests were also carried out at maximum density and optimum moisture content state of virgin, contaminated and decontaminated soils. Also UCS and unconsolidated undrained triaxial tests were conducted on soil. The test results of virgin soil are presented in Table 2.

5 RESULTS AND DISCUSSIONS

5.1 *Grain Size Distribution Analysis*

500 gm of virgin soil is taken for performing grain size distribution test, which is washed with water and sieved through sieve size 0.075 mm. The amount of soil, which retained on the sieve, is used for dry sieve analysis and 50 gm of soil sample from the portion passed through the 0.075 mm is taken for hydrometer analysis. Same procedure is followed on all other contaminated and decontaminated soils. From the grain size distribution analysis, results have been drawn for diameter of particles in mm on x-axis and % finer on y-axis. The following (Fig.1 & 2) are representing the grain size distribution curves for virgin (VS), contaminated (CS4) and decontaminated (DC2 & DC4, both with surfactant and LOC) soils.

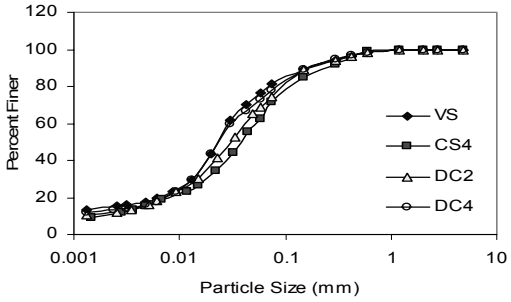

Fig.1 Combined Particle Size Distribution Curve for Virgin, Contaminated and Decontaminated (with SDS) Soil.

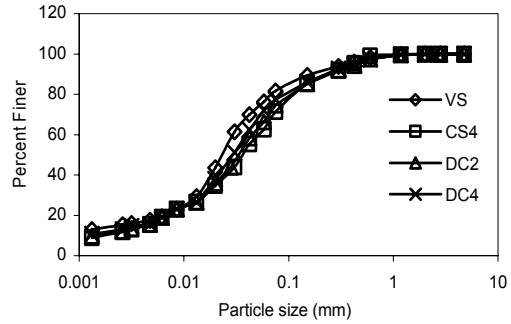

Fig.2 Combined Particle Size Distribution Curve for Virgin, Contaminated and Decontaminated (with LOC) soils.

Grain size distribution for virgin soil summarizes the fine sand, silt, and clay fractions and classified as clay with low plasticity (CL) based on IS classification system. The treatment with surfactant made the particle size distribution of decontaminated soil very similar to that of virgin soil.

5.2 *Specific Gravity*

Specific gravity of virgin, contaminated & decontaminated soils were found using the density bottle method. Results were showing much improvement of sp. gravity for contaminated soils. The surfactant treatment made it behave like the virgin soil.

5.3 *Consistency Limits*

The Casagrande's liquid limit apparatus was used to obtain liquid limit and the 3mm thread method for plastic limit (IS 2720). The LL and PL for the virgin soil were measured 31.6 and 20.0. The test results show that soil treated with 0.4% LOC was similar to the consistency limits of virgin soils. For same contaminant percent LOC is observed more effective than SDS.

5.4 *Compaction Tests*

Mixing the dry soil with TCE formed the samples used for the compaction tests. Samples of all concentrations were tested for their compaction behavior using the IS light weight compaction mould. Soil was compacted in a 100 mm diameter, 127.3 mm height mould using 25 blows on each of three layers. A plot of dry density against moisture content is shown in (Fig.3, 4) for virgin, contaminated and decontaminated soil. Results observed that the OMC decreases & MDD of contaminated soil were increases as compared to the virgin soil.

After washing with surfactant SDS & LOC, there is reasonable improvement in the property of contaminated soil which is near to virgin soil. Variations in OMC & MDD observations are shown in Fig.3 & 4. It has been observed that values of both OMC & MDD reached almost the values of virgin soil after washing with surfactant. Comparatively contaminated soil treated with LOC has been observed more effective to SDS.

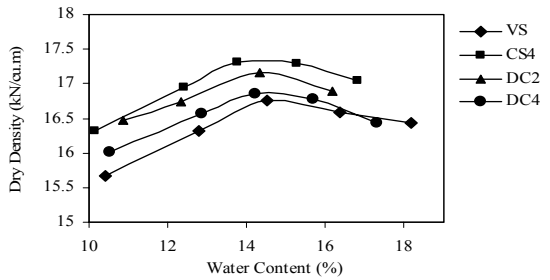

Fig.3 Compaction Curve for Virgin, Contaminated and Decontaminated (SDS) Soil.

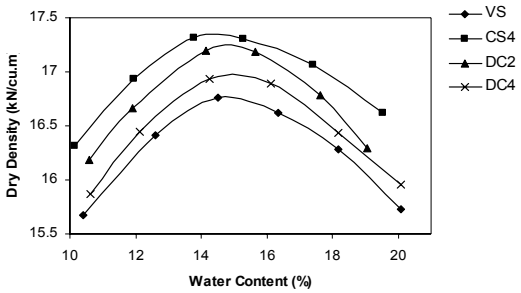

Fig.4 Compaction Curve for Virgin Contaminated and Decontaminated (LOC) Soil.

5.5 *Unconfined Compressive Strength (UCS)*

The 38mm x 76mm size statically compacted soil samples were tested on the unconfined strength test apparatus for their UCS. The results of UCS values for contaminated soils shows decreasing trend and decontaminated soil showed much improvement.

5.6 *Unconsolidated Undrained Triaxial Shear Tests*

The UU triaxial shear tests were carried out on 38mm x 76mm soil samples. The confining stress in virgin, contaminated and decontaminated samples was varied from 49.05 kN/m^2 to 98.1 kN/m^2 (two tests for strength envelope). The samples were tested at a rate of deformation of 1.25 mm/min. The addition of TCE causes decreasing trends in both the cohesion & angle of internal friction values.

The surfactant treated soils showed the near virgin soil shear parameters. The stress-strain variation of the peak strengths of virgin, contaminated and decontaminated soil samples for same confining stress was observed. The contaminated soil samples showing low peak strength than virgin. Also the surfactant treated soils shows high peak strength as compared to contaminated soil.

5.7 *Consolidation Behavior of Soil*

The soil-contaminant mixture was statically compacted in a consolidation ring to get a sample at OMC and MDD. Same procedure is followed for all other soil samples. The samples were then saturated by keeping, it in the water bath in the consolidometer. One dimensional consolidation tests were carried out, by increasing the vertical stress gradually up to 784.8 kN/m^2. The e-log p curves were drawn for all the test results. Coefficient consolidation (C_v) values were found out by root time method. Compression index values were observed decreasing trends with increasing TCE concentration. After surfactant washing, values were reaching near to virgin soil. The C_v values of contaminated soil showing decreasing trend and after washing with surfactant treated soils were shown similar behavior of virgin soils.

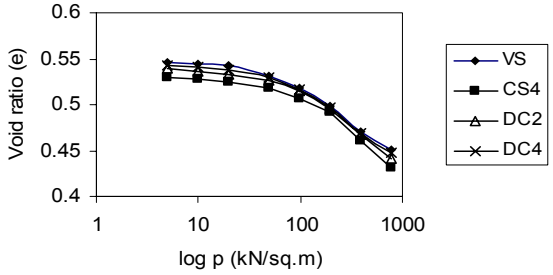

Fig.5 Combined e-log (p) Curve for Virgin, Contaminated and Decontaminated (SDS) Soils.

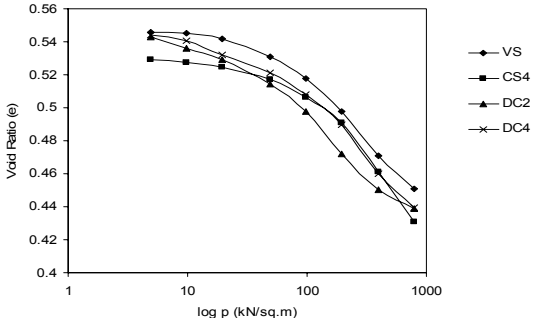

Fig.6 Combined e-log (p) Curve for Virgin, Contaminated and Decontaminated (LOC) Soils

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Table 2 Geotechnical Properties of Virgin, Contaminated and Decontaminated Soils Tested.

Property	Virgin Soil	Contamination with T.C.E	Decontamination			
			4 % T.C.E		4 % T.C.E	
		4 %	0.2% SDS	0.2 % LOC	0.4 % SDS	0.4 % LOC
Consistency Limits						
Liquid Limit (%)	31.60	30.10	30.36	30.86	31.2	31.34
Plastic Limit (%)	21.06	20.12	20.47	20.66	20.87	20.96
Shrinkage Limit (%)	19.94	18.46	18.83	18.94	19.38	19.48
Plasticity Index (%)	10.54	9.98	10.15	10.20	10.33	10.38
Specific Gravity (G)	2.67	2.42	2.49	2.53	2.58	2.59
Grain Size Analysis						
Sand (%)	18.30	28.60	25.50	25.21	22.0	22.31
Silt (%)	66.80	60.90	63.00	63.18	65.0	64.70
Clay (%)	14.90	10.50	11.50	11.62	13.0	12.99
Compaction						
O.M.C (%)	14.60	14.30	14.42	14.48	14.51	14.56
M.D.D (kN/cu.m)	16.77	17.36	17.17	17.26	16.87	16.97
Triaxial Shear Test						
c (kN/m^2)	30.41	19.62	23.64	24.52	26.68	28.44
ϕ (Degrees)	30.0	20.0	24.0	25.0	27.5	26.50
U.C.S Test						
q_u (kN/m^2)	81.22	71.12	73.47	75.04	74.85	77.89
Consolidation Test						
c_c	0.147	0.119	0.129	0.138	0.141	0.142
c_v (cm^2/sec.)	8.45×10^{-4}	7.08×10^{-4}	8.12×10^{-4}	7.93×10^{-4}	8.02×10^{-6}	8.14×10^{-4}
Permeability						
k (cm/sec.)	1.085×10^{-5}	6.007×10^{-6}	7.35×10^{-6}	8.0×10^{-6}	9.01×10^{-6}	9.43×10^{-6}

5.8 *Permeability*

Based on the relationship between coefficient of consolidation and permeability, vertical permeability values (k_v) were calculated. Test result shows TCE contamination causes decrement in the values of vertical permeability. The surfactant treated soil shows results closer to virgin soil permeability

6 CONCLUSIONS

This study presents the results of experimental investigation on the geotechnical properties of soils contaminated with variable concentrations of trichloroethylene. Following are the main conclusions.

- Grain size distribution for virgin soil comprises the fine sand, silt and clay fractions. Contaminated soil shows increase in coarser percent due to formation of TCE film on the soil particles. Meanwhile decontaminated soil shows decreasing in coarser percent and attained near to virgin soil.
- Specific gravity of virgin, contaminated and decontaminated soil was examined. It was observed that the values were decreases with addition of TCE and increases after washing with surfactant.
- Due to increasing of TCE concentration the maximum dry density increases and optimum moisture content decreases, because the lubricating effect of TCE reduces the OMC. The OMC and MDD of contaminated soil further improved by washing with surfactant.
- The liquid limit, plastic and shrinkage limit of the virgin soils decreases with the increase of trichloroethylene concentration. It was due to decrease of clay fraction. These values further improves after washing with surfactant solution.
- The consolidation properties such as coefficient of consolidation (Cv) and Compression Index (Cc), shows a decreasing trend with the contamination of TCE. Decontaminated soil shows an improvement in compression index as well as coefficient of consolidation.
- It was observed that the Shear strength parameters of contaminated soil decreases as compared to Virgin soil. By using surfactant, the strength of the decontaminated soil improved near to virgin soil.
- 0.4% liquid soap is found to be more effective as compared to the SDS in the remediation process.

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