Oil-Contaminated Soil Evaluation and Remediation

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***Abstract*— Humans are, unintentionally or intentionally contaminating soils from different sources. The contaminated soils are not only a challenge for the environmentalists but also for the geotechnical engineers. The surface and subsurface environment is becoming increasingly contaminated because of disposal of chemicals and waste materials produced as a result of rapid industrialization and various other human activities. All types of pollution have direct and indirect effect on soil/sub-soil. Hydrocarbon contaminated has not just affected the quality of the soil but will also alter the physical properties of oil-contaminated soil.**

Amongst the contaminants, the hydrocarbons are a major source of soil pollution; petrol and diesel being the chief contributors. A vast majority of the population use these two commodities. Amongst diesel and petrol, the consumption of diesel is higher. Therefore, diesel was selected as the pollutant and its effect on engineering properties soil (IS classification : (CL-ML) was studied and also study the effect of cement (as stabilizing agent at different percentages 3%, 7%, 11%) on the geotechnical properties of diesel contaminated soil. The soil used in the present work was obtained from Sir hind town (Punjab) and the pollutant i.e. diesel was obtained from local fuel outlet. It is apparent from the test results that the stabilization agents improved the geotechnical properties of the soil by way of cat ion exchange, agglomeration, and pozzolanic actions. UCS and CBR value of contaminated soil increased with increased cement content .This improvement in unconfined compressive strength and California bearing ratio of soil was due to neo-formations such as Calcium Silicate Hydrates (CSH, CSH_1) that coats and binds the soil particles.

Keywords—Unconfined Compressive Strength, Cement, Diesel, Soil, California bearing ratio.

I. INTRODUCTION

Contamination of land has arisen from kinds of human activity and is essentially a legacy of our recent industrial history. Sources of contamination include the deposition of waste products; industrial operations' spills and leakages, airborne contaminated dust and repeated raising and leveling of land as one industrial use supersedes another. Contaminants may be solid, liquid or gaseous and can adversely affect susceptible targets such as human, rivers, soil, sub-soil, buildings and the environment.

Hydrocarbon contamination is the most obvious concern of the industrial age. There are multiple causes for the same. The pendulum swings from oil exploration, production, processing and transportation from one end to refining, storage (surface and subsurface) transportation and distribution the other end. Petroleum contamination may also occur on right of way of the road due to leakage of diesel products from leaking oil tankers, spills due to vehicular accidents, buried pipelines, acquired properties such as rail yards an abandoned oil storage sites. The resulting environmental degradation is colossal. Not only the agricultural properties of the soil have been destroyed, the performance of soil as a construction material or as supporting material of engineering structures has been greatly affected. The detrimental effect of contaminants on properties of soil has also received attention but less than it deserves. Research has shown that leakage of hydrocarbon into sub soil directly affects the use and stability of supported structure. The unintended modification of soil properties due to interaction with contaminants can lead to various geotechnical problems (excessive settlements, loss of shear strength etc.) A sound understanding of fundamental principles of geotechnical engineering is needed to predict the behavior and performance of soil as a constructive material or as a supporting medium of engineering structures. To arrive at logical results the effect of contaminants on soil properties has got to be analyzed and studied before recommendations can be made for its employment as a constructive material/ supportive medium for structures.

By knowing the properties of such soil, applications, whether it is for structural use of as a supporting material/ medium can be decided upon economically. In India the scope of study in this field is very large. Whereas in Europe and America great strides have been made in this field, in India a concerted effort has to be made so that technologies can be developed to reclaim contaminated sites for their intended use.

II. LITERATURE REVIEW

In United States of America, US Environment Protection Agency (USEPA) carries out environment studies of selected sites. USEPA reviews all existing hydro geological aspects and can undertake test-drilling program me to define the geology of study area. They use a variety of remote sensing techniques such as Ground Penetrating Rader and Electro Magnetic Conductivity. In the United Kingdom, the Department of Environment carries out survey of land sites. They only give the environmental impact viz water contamination details, presence of toxic material, and the harmful effect on living organisms. As far as geotechnical aspects are concerned, researchers have tackled specific issues and after carrying out field and laboratory investigations, explanations have been offered for behavior of contaminated soils. Some of the details of the investigations are given in succeeding paragraphs.

Rahman.et al. (2010) studied the Influence of Oil Contamination on Geotechnical Properties of Basaltic Residual Soil. This study presented the geotechnical properties of oil-contaminated soils as well as uncontaminated soils for comparison. Testing programs performed on the studied soils included basic properties, Atterberg's limit, compaction, permeability and unconsolidated untrained triaxial tests. The base soils used were originated from weathered basaltic rock of grades V and VI. Soil samples were artificially contaminated with 4, 8, 12 and 16% oil of the dry weight of based soils. The results showed that the oil contamination decreased the liquid limit and plastic limit values for both grades of weathered soils.
Gupta M.K et al.2010) study on Evaluation of Engineering Properties of Oil-contaminated Soils journal of the institution of engineering. The study was aimed t o investigate the impact of used engine oil, a hydrocarbon and also an organic contaminant, on important engineering properties of soils. Two cohesive soils (IS classification: CL, CH) were particularly chosen for the study. Index and engineering properties of virgin (uncontaminated) soils and soil samples artificially spiked with used engine oil (at 2%, 4%, 6% and 8% of the dry weight of the soil) were determined for comparison. It was found that the permeability increased with the increasing concentrations of contaminant for both the soils, while compression index values also increased but coefficients of consolidation values decreased. Unconfined compressive strength values were found to decrease for both the soils with the increasing oil content.

Habib-ur- rehman et al.,(2007) in his paper, has focused on Geotechnical behavior of oil-contaminated fine-grained soils The comparison between uncontaminated and crude oil-contaminated clay showed that there would be a significant change in the engineering behavior of the clay if it were contaminated by crude oil. The contaminated clay behaves more like cohesion less material, owing to the formation of agglomerates. The coarse-grained soil-like behavior was obvious in the strength behavior of the oil-contaminated clay. The contamination has affected the plasticity and the cation exchange capacity (CEC) of the investigated clay. The swelling pressure of the clay after contamination suffered three times reduction, while no change was observed in the percent swelling of the contaminated clay.

Amer Al-Rawas et al. (2005) carried out studies on Stabilization of oil-contaminated soils using cement and cement by-pass dust in Management of Environmental Quality. To investigate the effect of cement and cement by-pass dust (CBPD) as a stabilizer on the geotechnical properties of oil-contaminated soils resulting from leaking underground storage tanks, or soils surrounding petroleum refineries and crude oil wells. Oil-contaminated soil (untreated soil) and a soil treated by bio-remediation (treated soil) as well as a natural soil were obtained from Northern Oman. These soils were stabilized with cement and cement by-pass dust at 0, 5, 10, 15 and 20 percent, by dry weight of the soil, and cured for seven, 14 and 28 days. Compaction, compressive strength, direct shear, permeability and leaching tests were carried out on the stabilized soils. The results indicate that cement and cement by-pass dust improve the properties of oil-contaminated soils.
Shah et al. (2003) carried out the study on Stabilization of fuel oil contaminated soil. An attempt has been made to stabilize the contaminated soil using various additives viz., lime, fly ash and cement independently as well as an admixture of different combinations. It is apparent from the test results that the stabilization agents improved the geotechnical properties of the soil by way of cation exchange, agglomeration, and pozzuolanic actions. The best results were observed when a combination of 10% lime, 5% fly ash and 5% cement was added to the contaminated soil. The improvement in unconfined compressive strength (UCS), cohesion and angle of internal friction can be attributed to neo-formations such as Calcium Silicate Hydrates (CSH) that coats and binds the soil particles. Formation of stable complex between oil and metallic cations, results in reduction of each able oil .

III. MATERIALS & METHODS

PART –I EVALUATION OF DIESEL CONTAMINED SOIL

A. Materials: Soil

The experimental work was conducted with soil, procured from Sirhind at a depth one to two maters from ground surface. The soil is classified as silt and clay of low compressibility (CL-ML) and other geotechnical properties of the soil are listed in Table 1.

Table 1: Geotechnical Properties of soil

Properties	Value
Particle size	
Clay(%)	25.7
Silt(%)	48
Sand(%)	26.3
Consistency limits	
Liquid limit(%)	27
Plasticity Index(%)	6.615
Specific gravity	2.88
Compaction characteristics	
Optimum moisture content (OMC (%))	10.3
Maximum dry density (kN/m3)	17.658
Free swell index (%)	32.5
Unconfined compressive strength (Kpa)	140.96
Soaked CBR (%)	3.67

B. Methods

Procedure of Contamination**:** Initially, the soil is air dried and hand sorted to remove the pebbles and vegetable matter, if any. It is then oven dried, ground, pulverized and sieved through a 425µ sieve. The soil is then contaminated by Diesel oil in varying percentage i.e. 4%, 8% and 12% by weights and kept for one week period of time to ensure through absorption of contaminant in soil and tested to determine their physical and engineering properties. Evaluation of engineering properties of virgin soil and contaminated soils was done as per the relevant sections of IS: 2720. Some difficulties were encountered while doing experiments with the contaminated soil samples as the oil in soil pores together with water at times required patience and innovations. The aim of the investigation is to examine the effect of contaminant Following laboratory tests have been performed to study the geotechnical properties of soil before and after contamination.

C. Experimental Work

The experimental schedule for collecting data is shown in the following tables.

Table2: Test performed on Virgin soil and contaminated Soil

Test	Virgin soil	Contaminated soil		
		D_4	D_8	D_{12}
Atterberg's Limit	√	√	√	√
Free swell	√	√	√	√
M.D.D	√	√	√	√
O.M.C	√	√	√	√
Specific gravity	√	√	√	√
U.C.S	√	√	√	√
Soaked CBR	√	√	√	√

D=Diesel Oil, Suffix is percentage of contamination

D. RESULTS & DISCUSSION

The effect of Diesel oil contamination on geotechnical properties of (CL-ML) is shown in table 3.

Table 3: Various Geotechnical Properties of virgin soil and contaminated soil

Properties of soil	Virgin Soil	Contaminated soil		
		D_4	D_8	D_{10}
Specific Gravity	2.88	2.77	2.584	2.47
Liquid Limit (%)	27	34.2	35.7	36.7
Plastic Limit (%)	20.83	29.31	30.34	32.1
Free swell	32.5	55	52	50
Maximum Dry Density(KN/m^3)	17.658	16.97	16.677	16.48
Optimum Moisture Content (%)	10.3	9	8.75	8.00
Unconfined Compressive Strength(Kpa)	140.96	90.54	63.76	33.25
CBR % (Soaked)	3.67	2.71	1.85	1.515

E . Shear strength

Shear strength of the virgin soil and also of all the soil contaminant mixes was determined by unconfined compression strength (UCS) tests on remolded samples as per IS2720- part 10. The stress- strain relationship curves of soil corresponding to virgin state and for all the contaminant mixes are presented in figures 1. It is seen from the figure that the USC values decreased for the from soil from their virgin state with increasing percentage of contaminant. The maximum decreased for 4% oil was 50%. It is thus obvious that soil lost shear strength as the contaminant percentage increased.

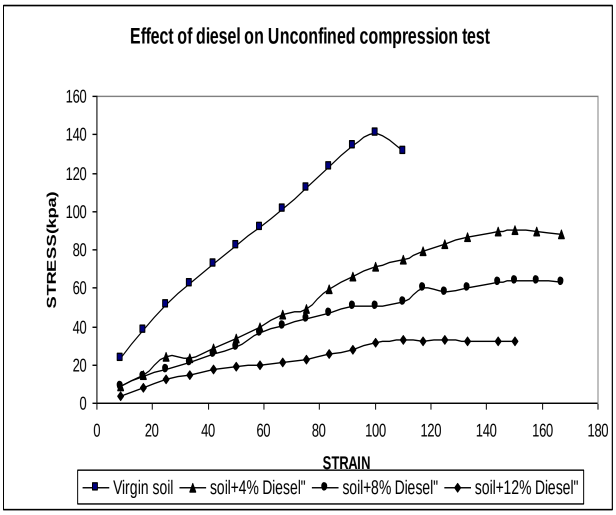

Fig -1 Effect of diesel on unconfined compression test.

F. California bearing ratio test

California bearing ratio of the treated soil samples were evaluated after curing the sample at room temperature for seven days. The CBR value (soaked) was seen to be decreasing as percentage of contaminant increased soaked CBR value reduce from 3.67% to 1.51%.

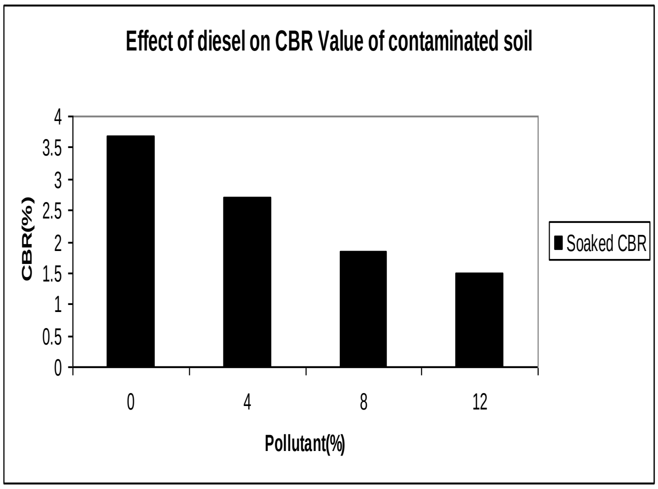

Fig -2 Effect of diesel on California bearing ratio test

PART:II REMEDATION OF DIESEL CONTAMINATED SOIL

A. Soil Samples

The experimental work was conducted with soil, procured from Sirhind at a depth one to two meters from ground surface. The soil is classified as silt and clay of low compressibility (CL-ML)

B. Diesel Sample

Diesel oil was used as contaminant. The soil was contaminated in the laboratory with varying percentage of Diesel oil as contaminant to study the contaminant's effect on various geotechnical properties of soils.

C. Cement Sample

The Ordinary Portland cement is obtained from ACC Cement Company with grade of 43 is used. Portland cement is one of the older materials used for stabilization. Cement stabilization differs somewhat from other forms of chemical stabilization. The cement hardens the soil material and structural strength is primarily obtained from the cementing action rather than from internal friction, cohesion, chemical ion exchange and/ waterproofing of the materials.

D. Quantity of Diesel and Cement

The contaminated soil with 0, 4,8,12 percentage of diesel was stabilized with cement at 0, 3, 7, and 11 percent, by dry weight of the soil. The contaminated soil was divided into 12 numbers of sets. Each set then treated with additive Portland cement at different weight percentages. Maximum amount of additives used did not exceed 20% by weight due to economic considerations. Atterberg's limits and strength parameters of the treated soil samples were evaluated after curing the sample at room temperature for seven days. Three samples were tested from each batch and the results are expressed as a mean value.

E. Experimental programmed

Table 4 Properties of diesel contaminated soil with cement

Soil Sample	OMC %	MMD (kn/m^3)	UCS (kpa)	CBR (soaked) (%)
S+0% D+3%C	10.6	17.91	1269.2	20.56
S+0%D+ 7%C	10.9	17.96	2280.1	36.56
S+0%D+11%C	11.3	18.09	2855.4	48.17
S+4%D+3% C	9.3	17.16	881.9	12.7
S+4%D+7% C	9.5	17.53	1390.8	22.5
S+4%D+11%C	10	17.75	1917.8	28.4
S+8%D+3% C	9	16.99	583.6	7.02
S+8%D+7% C	9.5	17.20	980.0	12.5
S+8% +11%C	10	17.36	1417.3	16.05
S+12%D+3%C	8.4	16.67	236.1	2.5
S+12%D+7%C	8.7	16.87	294.0	3
S+12%D+11%C	8.9	16.97	333.5	5.88

S=Soil D=Diesel C=Cement

F. Unconfined Compressive Strength (UCS)

Unconfined compressive strength test (confirming IS: 2720 (PART X) were conducted on cylindrical sample of 38mm diameter and 76mm height, prepared at maximum dry density and optimum moisture content. Each sample was cured for 8 days (7 days moist curing and one day water immersion).Samples was tested with strain rate of 1.25 m/minute. The results show that the addition of cement resulted in marked increase in UCS.

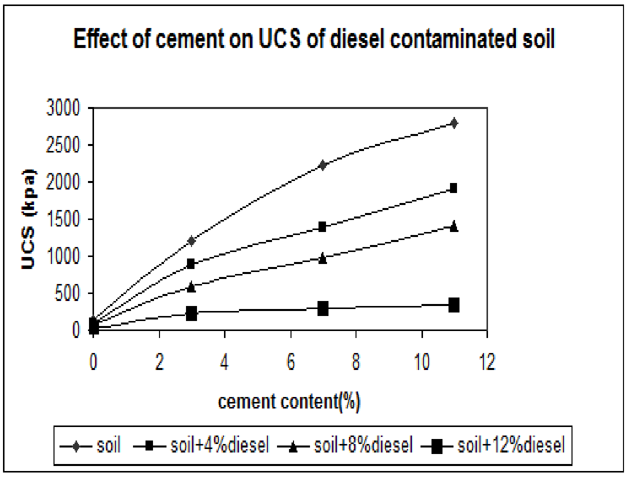

Fig 3 Effect of cement content on UCS of diesel Contaminated soil

G. California Bearing Ratio Test

As the most important engineering parameter to evaluate a sub grade or sub base material for pavement design is the California bearing ratio value of soil .The soaked C.B.R value of the diesel contaminated soil with different percentage of cement is determined. It is observed that the addition of cement increases the CBR value. From the results it is observe that when 3% of cement content, soaked CBR value of soil is 20.56% and soil + 4% diesel is treated with 7% cement and soil+ 8% diesel is improved with 11% cement the values respectively 22.5% and 16.05%.

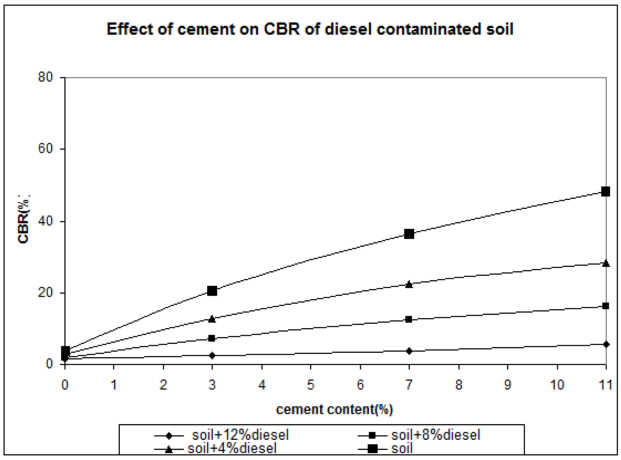

Fig 4 Effect of cement content on CBR of diesel Contaminated soil

IV CONCLUSION

In this study, the effects of oil contamination on some geotechnical properties are clearly observed. The Atterberg's limits of contaminated soils were lower than that of uncontaminated soils. The maximum dry density and optimum moisture content also dropped due to increase in oil content in contaminant soil. Similar behavior was also observed on shear strength and CBR value of soil. When stabilized with cement, the treated soil had the highest maximum dry density then non-stabilized samples. It appears that the specific gravity of un hydrated cement (3.1) relative to the soil tends to produce a higher density. Addition of cement resulted in marked increase in UCS. . The improvement in unconfined compressive strength (UCS) can be attributed to neo-formations such as calcium silicate hydrates (CSH, CSH-1) that coats bind the soil particles. It is observed that the addition of cement increases the CBR value. Soil+12%diesel not improved with this much of percentage of cement and improvement is uneconomical hence soil+12%diesel is improved by other method such as soil venting (volatilization), Soil air suction, and Bioremediation.

This study will be helpful to reuse the contaminated soil in construction application provides a safe and useful solution for the problem of the disposal of oil-contaminated soils.

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