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Geotechnical properties of Contaminated Soil

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Abstract - *Contaminated soil poses a great threat to the environment and humans. There have been multiple sources of soil contamination including petroleum products, acid, alkali, salt, industrial effluents. Geotechnical properties of soil get modified on contamination with industrial wastes and garbage. Depending on the nature of contaminant, positive or negative effects of contaminant on the engineering properties of soils are possible. Detrimental effect of contaminated soil can cause foundation failures resulting in considerable damage to the structure built on it. On addition of some industrial waste such as textile effluent, engineering properties of soil get improved. In this review, effect of petroleum products, acids, alkalis, salts and industrial effluents on engineering properties of soil is being discussed.*

Key Words: **industrial waste, contamination, geotechnical properties, soil, petroleum products, acid & alkali, salt, industrial effluent**

1. INTRODUCTION

Large amounts of solid and liquid waste is generated due to industrial activities. Improper disposal of industrial wastes and garbage on to the land contaminates the soil and the ground water. The contaminant may be acids, alkali, salts, metals or organic matters [1-2]. Soil, being electro-chemically active, reacts with contaminant. Physicochemical interaction of soil with contaminant modifies geotechnical properties of soil. Conventional geotechnical principles cannot be applied to contaminated soil. Extent of modification of geotechnical properties of soil due to contamination depend on the quantity and chemical composition of the contaminant, partition coefficient and mineralogy, pore fluid chemistry, permeability and adsorption properties of the soil [3 -6]. Contaminant changes the properties of soil by affecting the dielectric constant, electrolyte concentration, ion exchange capacity and thickness of diffuse double layer. With increase in dielectric constant, interparticle shearing resistance decreases and liquid limit and double layer thickness of soil increases [7,8].

Detrimental effect of contaminated soil can cause extensive cracking damage to the floors, pavements and severe foundation failures resulting in considerable damage to structure built on it. Contaminant dissolved in rain water percolate the soil and damage foundation of buildings. Reduction of soil porosity and bearing capacity and increases in settlement due to soil contamination may result in failures of existing structures. The review of available literature suggests that before constructing building, road, bridge, embankment, dam etc. on contaminated soil, effect of contaminant on soil strength is to be studied. If suitable remedial measures and precautions are not undertaken, then contaminated soil may cause failure of structure built on it causing catastrophic damage [9].

Effect of some of the contaminant on geotechnical properties of soil is reviewed below:

2. CONTAMINATION WITH PETROLEUM AND REFINERY PRODUCTS:

Geotechnical properties of soil get modified on contamination with petroleum and refinery products [10-13]. Contamination of soil with crude oil has deteriorating effect on its strength, permeability, plasticity and swelling characteristics. Due to oil contamination, permeability, shear strength and Atterberg limits of CL soil got reduced. A direct correlation between oil content and angle of internal friction in CL soil and inverse correlation between oil content and angle of internal friction in SP and SM soils is reported by Mashalah et al. [14]. With increasing oil content in soil, cohesion is reduced due to loose packing of clay particles. On contamination with 16% of oil content, CL samples changed from hard consistency to soft consistency. In comparison to uncontaminated clay, aggregates of clay formed on contamination with diesel oil were having relatively loose packing of clay particles [15]. The contaminated clay behaves more like a cohesionless material. On getting permeated with heptanes, permeability of kaolinite was increased to about 1000 times.

The effect of motor oil contamination on the geotechnical characteristics of over-consolidated clay (CH) was studied by Nazir [16]. Atterberg limits were decreased significantly with increasing the duration of oil contamination up to first 3 months, after which, they remain constant due to stabilization of clay structure. The coefficient of permeability of contaminated clay increased significantly to three times the value for uncontaminated clay at low stress range of 100 and 200 kPa. At stress range higher than pre-consolidation stress, minor effect on the coefficient of permeability was reported on increasing the duration of contamination up to 24 months. The increase in permeability of contaminated clay is attributed to the reduction in the thickness of the double layer that surrounds the clay particle. Dielectric constant of motor oil is lower than that of water. Low dielectric constant of pore fluid of clay contaminated with motor oil causes shrinkage of double layer. Macrospores and cracks developed on soil shrinkage resulted in an increase in coefficient of permeability. Compression index and swelling index of contaminated clay increased with increasing duration of contamination up to first 6 months and after that these indexes became almost constant due to reorientation of structural element.

Unconfined compressive strength of clay contaminated with motor oil was reduced by about 38% as compared to the uncontaminated clay. Unconfined compressive strength kept on decreasing up to first 6 months of duration of contamination and after that it attained constant value. Loose packing of clay particles due to contamination with motor oil caused the reduction in unconfined compressive strength of clay. The effect of oil contamination on geotechnical properties of over-consolidated clay was significant up to first 6 months of contamination and beyond that the effect was very insignificant. Load carrying capacity of sand contaminated with oil decreased and it further decreased with increase in oil content.

Geotechnical properties of the lateritic soil contaminated with crude oil changes remarkably [17,18, 20]. Crude oil spills degrade lateritic soil [21]. Lateritic soil is a highly weathered natural material rich in oxides of iron, aluminium, manganese and/ or titanium [19, 21]. Crude oil is a mixture of water, hydrocarbon and organic compounds of sulphur, nitrogen and oxygen which varies in composition from place to place [22]. Variation in the composition of crude oil affects the extent to which the geotechnical properties of lateritic soil are to be changed [19]. Maximum dry density (MDD) and the optimum moisture content (OMC) of lateritic soil decreased on contamination with crude oil and it further decreased with time. Optimum moisture content and the maximum dry density of lateritic soil reduced from 11.40% and 1.98g/cm3 to 9.50% and 1.81g/cm3, respectively on contamination with crude oil. On contamination with crude oil, optimum moisture content value of lateritic soil got reduced by 17% and the maximum dry density value reduced by 9%. The adsorption of crude oil onto the lateritic soil surfaces agglomerate the lateritic soil particles thereby reducing the specific surface area, leading to the reduction in the bond strength of the lateritic soil.

The particle size was increased on contamination of lateritic soil with crude oil because the crude oil clod to the soil particles. The percentage of fines was reduced with increase in the oil content because the oil clod to different particles and prevents them from successfully passing through sieve. The grain size distribution of soil sample changes on varying the percentages of crude oil in the soil. Liquid limit (LL) and plastic limit (PL) of lateritic soil reduces on contamination with crude oil [23]. The Atterbergs limit decreased due to reduction in the cation exchange capacity (CEC) of the soil. The decrease in the value of Atterbergs limit of the contaminated soil was due to changes in cohesive forces between the particles of the lateritic soil. The Atterberg limit decreased with increase in oil percentage. The Liquid Limits (LL) of uncontaminated soil and soil contaminated with crude oil was 29.00 and 16.04 respectively.

Unconfined compressive strength and bearing capacity of soil contaminated with crude oil decreases and soil become unsuitable for supporting engineering structures. The value of California Bearing Ratio (CBR) of the uncontaminated soil was higher than that of the contaminated soil. The CBR of soil contaminated with crude oil was reduced by 50%. On burning of oil spilled on soil surface, tar mat oily scum was formed which retarded soil aeration and water infiltration into subsoil layers [24].

Geotechnical properties of clay soils changes on contamination with crude oil [25- 28]. Liquid limit, plastic limit and plasticity index of soft clay contaminated with crude oil increased by 17.9%, 6.9% and 37.5% respectively. In contaminated clay more water is to be added to change its consistency level. On contamination with crude oil, maximum dry density of soft clay increased sharply at relatively low optimum moisture content . Bulk density of contaminated clay increased linearly with sorption time. Total hydrocarbon content (THC) of crude oil influences sorption process and geotechnical properties of soft clay soils. Light crude oil samples (low value of THC) has lesser influence on the bulk density and porosity of soft clay soils than heavier crude oil samples. Due to reduction of pore sizes of the clay soil by the adsorbed oil, porosity of contaminated clay decreases with increase in sorption time and crude oil hydrocarbon content. Permeability of contaminated clay was also reduced.

The rate of swelling of soft clay contaminated with oil was lower than that of uncontaminated clay. The swelling pressure exerted by the soft clay contaminated with oil was lower than (about 32%) that exerted by the uncontaminated soft clay and it decreases with increase in both sorption time and crude oil hydrocarbon content.

Spent engine oil (SEO) is generally obtained after servicing of automobile and generator engines. Spent engine oil contains hydrocarbons and heavy metals [29, 30]. Contamination of soil with SEO had no effect on pH of the soil. Compared to uncontaminated soil, concentration of organic C, N and Mg in the contaminated soils got increased and concentration of P got decreased [31]. The oil-contaminated soils contained more heavy metals than the uncontaminated soil and on increasing the concentration of oil, concentration of heavy metals (Fe, Cu, Co, Zn and Pb) in soil got increased [32]. Metal get attached to the surface of the soil due to electrostatic attraction between positively charged metals and negatively charged clay particles [33].

3. CONTAMINATION WITH ACIDS AND ALKALI

Contamination of soil with acids and bases can cause foundation failure [34]. Cracking of floors, pavements and beams and upheaval of foundations in a fertilizer plant was found to be due to phosphoric acid as the source of contamination [35]. High phosphate content in acidic environment caused heaving of soil. Differential movement were observed in lightly and unevenly loaded structures. Hydraulic conductivity of kaolinite was reduced when it got contaminated with acetic acid.

Clay was treated with sulfuric acid solution for different periods of time, ranging from 1 to 9 months. Compressibility of clay increased significantly with a decrease in pH values. In acidic medium, the compressibility of clay decreased due to the collapse of the diffuse double layer [36].
Kawasaki mud that contains montmorillonite and Yurakucho silt that has kaolinite as the dominant clay mineral were treated with solutions of sulfuric acid for a period of 300 days. undrained triaxial compression tests were conducted on treated samples. Soil strength of Kawasaki mud increased on decreasing pH from 7.3 to 6.0. Soil strength of Yurakucho silt increased slightly on decreasing pH to 6.0 but soil strength decreased significantly on reducing pH to 4. The mineralogy of the clay fraction as well as the concentration of acid in the pore fluid influenced the stress–strain behaviour of the soils [37].

A study was carried out by Prakash et al. to determine the effects of acid and base contamination on the geotechnical properties of clay [38]. 5%, 10%, 15%, 20%, 25% and 30% by weight of 1N Sodium hydroxide (NaOH), Potassium hydroxide (KOH), Calcium hydroxide ($Ca(OH)_2$), Hydrochloric acid (HCl), Nitric acid (HNO_3) and Sulphuric acid (H_2SO_4) were added to Clay of high compressibility (CH) to study the effects of acid and base contamination on geotechnical properties of soil. On contamination with acid, liquid limit and plasticity index of clay sample decreased and it further decreased with increase in the percentage of acid content. The free swell of the acid contaminated soil increased by 28.27% whereas the specific gravity decreased by 15.56% with increase in acid content upto30%. Optimum moisture content and maximum dry density of contaminated soil decreased by 21% and 12.7%, respectively on increasing acid content up to 30%. The shear strength of clay contaminated with acid decreases by 39.5% with increase in acid content upto 30%. No significant variation is reported in shrinkage limit values. At pH below 5.5, solubility of metal ion is increased and retention of metals to soil is reduced thus increasing its availability in soil solution.

In comparison to uncontaminated clay, liquid limit and plastic limit of base contaminated clay increase by 24.5% and 12.6%, respectively with increase in base content up to 30%. The plasticity index of contaminated soil also increased with increase in the percentage of base content. Free swell values of contaminated clay did not have significant variation with increase in base concentration. The optimum moisture content and maximum dry density decreased by 22% and 3.47%,respectively with increase in base contamination up to 30%. The specific gravity and shear strength of clay contaminated with base increases by 4.2% and 22.7%, respectively with increase in base content up to 30%.

Expansive reactions between lime and sulfate-bearing clay soils induced heave. Contamination of bentonite clay with caustic soda increases the negative charge on clay particle which is indicated by the enhanced exchangeable sodium content of the contaminated clay. Increase in negative charge results in expansion of the diffuse double layer thickness responsible for higher liquid limit, swelling magnitude and swelling pressure of the contaminated clay. Increased negative charge leads to more oriented particle arrangement and lower shrinkage limit. Spillage of highly concentrated caustic soda solution caused structural damage to a building.

4. CONTAMINATION WITH SALT

In coastal regions, due to tidal movement, sea water ingress into the land mass and in sea, soil is being retained in salty water thus making the soil mass contaminated with NaCl (main constituent of sea water). Due to civil engineering activities in coastal areas, in the shallow beds of seas or in deep sea, knowledge of engineering behaviour of soils on sea shore or sea bed become necessary for cost effective construction on such soils. Soil in coastal region is generally sandy.

Ramesh et al. reported that plasticity and compaction characteristics of fine grained soils changed significantly on addition of NaCl to it [39]. Maximum dry density, plasticity and unconfined compressive strength of cohesive soil contaminated with NaCl are reported to decrease while optimum moisture content got increased on contamination of soil with NaCl [40]. Ghosh et al. reported that sorption capacity, dielectric capacity and cation exchange capacity got increased considerably while surface area of the cohesive soils contaminated with NaCl got decreased with increasing concentreation of sodium chloride [41]. George et al. reported that permeability of the cohesive soils contaminated with NaCl got increased significantly [42].

Datta et al. studied the effect of common salt on engineering properties of poorly graded sandy soil [43]. California Bearing Ratio (CBR) of the sand contaminated with NaCl is reported to increase from 6.7 to 8.1 on increasing concentration of NaCl from 0% to 10%. OMC of contaminated sand increased from 14 to 16 % on increasing the percentage of salts from 0 to 10 %. Maximum dry density of contaminated sand at optimum moisture content increased gradually on increasing concentration of NaCl from 0% to 5 % but the maximum dry density falls to a lower value when concentration of NaCl is increased to 10 %. When common salt was added to dry sand and compacted, the dry density showed a gradual increase in value with increase in NaCl concentration. In dry condition, the salt occupies void spaces and thereby increasing the dry density.

5. CONTAMINATION WITH EDTA

The effect of EDTA solution, used for remediation of Pb contaminated silty clay, on its engineering properties was studied by Wang et al. [44]. Due to industrialization, soil get contaminated by heavy metals, which reduce the soil fertility and is detrimental to animals and human health thus necessitating its remediation [45-47]. Phytoremediation, microbial remediation, chemical remediation, physical remediation and combination of physical separation and chemical extraction are being used to remediate soil contaminated with heavy metals [48]. Chemical leaching of heavy metals from contaminated soil by inorganic acids, organic acids, chelating agents and surfactant is reported to be very effective remediation techniques [49-51]. Though inorganic acids effectively remove heavy metals from contaminated soil but it increase acidity of soil and degrade engineering properties of the soil [52]. Compressibility and expansion index of the soil contaminated with acid or alkali increase with the increase of acid or alkali concentration [53]. EDTA has higher removal efficiency for heavy metals such as copper, lead, cadmium and zinc in contaminated soil than acid [54]. Extraction efficiency of eluent for heavy metal contaminated soil followed the order EDTA> DTPA> NTA> HCl. Extraction efficiency of eluent increased with the increasing eluent concentration [55].

Ion exchange between contaminated soil and EDTA results in changing microstructure and engineering properties of soil. The pH of Pb contaminated soil was reduced on addition of EDTA solution and on increasing concentration of EDTA solution from 0 to 0.15mol/L, pH of soil decreased from 7.94 to 5.12. Disodium EDTA is an acidic salt so the solution of EDTA is acidic. When soil contaminated with Pb was remediated by EDTA solution, the H^+ ions present in EDTA solution got adsorbed by the soil and the number of H^+ ions adsorbed by soil increases on increasing concentration of EDTA solution, resulting in the decreased pH of soil.

On washing of soil contaminated with Pb by different concentration of EDTA solution, the liquid limit and plastic limit increased from 21.8% and 41.6% to 23.0% and 43.3%, respectively as concentration of EDTA increased from 0 to 0.15mol/L. Due to ions exchange, thickness of the diffuse double layer increased on increasing concentration of EDTA solution, causing increase in plastic limit and liquid limit of Pb contaminated soil.

X-ray diffraction results show that on increasing concentration of EDTA solution from 0 to 0.15mol/L, content of quartz in Pb contaminated soil increased by 11.09 percent and content of montmorillonite decreased from 7.87% to 0.07%. In comparison to montmorillonite, the content of albite and illite were not decreased much. On increasing concentration of EDTA solution, pH of soil is reduced, which is responsible for dissolution of montmorillonite, illite, albite but quartz is relatively stable in acidic condition so its content got increased on increasing concentration of EDTA solution [56].

On increasing concentration of EDTA solution, cohesion of contaminated soil got decreased and the internal friction angle got increased. Cohesion of contaminated soil leached by water and 0.15mol/L EDTA were reported to be 89.5kPa and 40.67kPa, respectively. The soil cohesion is reduced on increasing thickness of diffused double layer. Thickness of diffuse double layer is increased on reduction of content of clay minerals due to increased concentration of EDTA solution [57]. The increased internal friction angle may be due to a change in soil composition. On increasing concentration of EDTA solution, coefficient of consolidation and modulus of compression got increased and void ratio decreased from 0.813 to 0.764.

6. CONTAMINATION WITH INDUSTRIAL EFFLUENT:

The effect of textile effluent, tannery effluent and battery effluent on the California Bearing Ratio (CBR) of expansive soil is reported by Narasimha Rao et al. [58].

Expansive soil was treated with textile effluent, tannery effluent and battery effluent at 0%, 20%, 40%, 60%, 80% and 100% by dry weight of the soil. The California Bearing Ratio (CBR) was determined corresponding to both 2.5 mm and 5.0 mm penetrations. The CBR of soil treated with tannery or textile effluent increased at 2.5 mm penetration and 5.0 mm penetration, which further increased with percent increase of effluent. Addition of battery effluent decreased CBR of expansive soil at 2.5 mm penetration and 5.0 mm penetration. The maximum percentage increase or reduction of CBR occurs when soil is treated with 100% of effluent.

The maximum percent increase in CBR values corresponding to 2.5 mm penetration and 5.0 mm penetration were about 50% and 45% respectively when the soil was treated with 100% tannery effluent. The maximum percent increase in CBR values corresponding to 2.5 mm penetration and 5.0 mm penetration are about 45% and 40% respectively when the soil was treated with 100% textile effluent. The maximum percent decrease in CBR values corresponding to 2.5mm penetration and 5.0mm penetration were about 21% and 17% respectively when the soil was treated with 100% battery effluent. Textile and tannery effluents can be used for stabilization of expansive soil but Battery effluent is contaminating the soil.

Engineering properties of soil are controlled by thickness of diffused double layer, which is affected by pore fluid chemistry such as, electrolyte concentration, valency of ion, radius of hydrated ion etc. Treatment of soil with industrial effluents changes the pore fluid chemistry, which in turn changes engineering properties of soil.

On mixing of soil with tannery effluent, chromium ion present in the tannery effluent got adsorbed on to the clay particles, resulting in increasing the dry density of clay and decreasing double layer thickness. The reduction of the double layer thickness brings the clay particles closer and enhance stronger bonding between clay particles, which in turn increases the CBR values of the soil.

On mixing expansive soil with textile effluent, the dry density of soil got decreased and optimum moisture content got increased. The chlorides in the textile effluent is attracted to the lower valence metallic ions in the clay mineral and causes decrease in double layer thickness. The decrease in double layer thickness causes increase in attractive forces leading to flocculated structure which causes dry density to decrease. Water holding capacity of soil got increased due to retention of water within the voids of flocculated structure, which in turn increases optimum moisture content. Strong bonding between clay mineral and dyes and cellulose of textile effluent may be responsible for increase in CBR Values of soil treated with textile effluent.

On mixing expansive soil with battery effluent, sulphate ions present in battery effluent got adsorbed on to the clay particles, making the surface of clay particles negatively charged. Negatively charged clay particle surface can hold more quantity of water as double layer resulting in expansion of double layer thickness and increase in the distance between individual soil particles. Increased distance between clay particles reduces attractive forces for holding the soil particles togather. Weak chemical bonding between clay minerals due to presence of reactive chemicals in battery effluent reduce the CBR values of soil.

Shrinkage limit decreases and liquid limit and plastic limits of clay soil contaminated with dye industry effluent increases with the increase in percentage of the effluent. Free swell index and swelling pressure also increases with increase in percentage of effluent. Free swell values of uncontaminated and contaminated soil are reported to be 50% and 100%, respectively while swell pressure increased from 0.35 Kg/sq.cm. to 0.667 Kg/sq.cm. for contaminated soil. Contaminated soil is reported to have higher content of sodium, potassium, calcium, magnesium, copper and ferrous ion. Higher swelling potential of contaminated soil may be due to presence of high concentration of sodium ion in it. Shear strength increases on increasing the valency of cation and/or electrolyte concentration but shear strength decreases on increasing ionic size and/or dielectric constant of pore fluid [59].

7. CONCLUSION

As is clear from above discussion that a particular type of contamination has different effect on different type of soil. Depending on the nature of contaminant, positive or negative effects of contaminant on the engineering properties of soils are possible. Industrial effluent discharged on the soil can improve or degrade engineering properties of soil thus affecting the stability of the supported structure. Improvement in engineering properties of soil due to presence of industrial waste in it, results in value addition to the industrial wastes by being used as a soil stablizer but if industrial waste degrade engineering behaviour of soil then solution for decontamination of soil is to be searched. Planning suitable preventive and remedial measures for safe utilization of the industrial waste and contaminated soil is to be done. At the time of geotechnical projects designing effect of contaminant on soil strength is to be taken into consideration.

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