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Review Paper

Harmful Effects of Certain Industrial Wastes on Geotechnical Properties of Soils - A Review

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ABSTRACT

The geotechnical properties of soils are greatly influenced by interaction with the wastes discharged from industries, which is a matter of great concern to the geotechnical engineers. There is immense need to study the strength and deformation characteristics of soil due to different contaminants present in wastewaters from various sources. Generally, the Industrial wastes consist of acids, alkaline, sulphates, salts, urea (amides) and oil contaminants which lead to modification of soils properties. The effect of these contaminants on geotechnical properties of soils has been presented in this paper.

INTRODUCTION

The bulk wastes generated during various activities is let over the soil. When rainwater percolates through these wastes, it is mixed with organic and inorganic chemicals generating leachate. The leachate can move down under gravity and contaminate the groundwater resources. Ground contamination causes modification of soil properties. The modification of soil properties lead to various geotechnical problems such as structural cracks, ground settlement, heaving of structures, instability of slopes, depletion of strength and deformation characteristics, changes in compaction characteristics, etc.

Hence, modern construction requires not only preliminary study of the foundation material, but also a thorough knowledge of the factors, which cause the modification of soil properties during the life time of the structures supported by it. A few case studies of soil contamination with industrial wastes and its influence on geotechnical behaviour of soils are discussed below.

Kirov (1989) observed the influence of wastewater on deformation behaviour of clayey soil. He found that soils interacting with a solution of detergents undergo a large amount of deformation. Srivastava et al. (1992) observed increase in consistency limit, permeability and coefficient of compression and decrease in shear strength and bearing capacity of a soil specimen permeated with fertilizer plant effluent. This is due to decrease in cation content and increase in hardness of leaching water after interaction

Decrease of liquid limit and plasticity index of montmorillonite soil due to addition of pharmaceutical effluent to the soil has been found due to decrease of dielectric constant by contamination. Ghosh et al. (1998) reported that soil properties are deteriorated due to addition of tannery effluent to the soil. Yaji et al. (1996) have investigated the influence of sugar mill liquid wastes on the behaviour of shedi soil. At large percentages of sugar mill liquid wastes, shear strength decreases marginally. Generally the industrial wastes consist of acids, alkalines, sulphates, salts, urea (amides) and oil contaminants, which lead to modification of soils properties.

ACID CONTAMINATION

Assa'ad (1998) investigated tilting of phosphoric acid storage tanks in chemical fertilizer factory in Jordan. The foundation soil supporting the tanks was mixture of sands, gravels and boulders of igneous origin. The chemical reaction that took place between the calcium carbonate present in the soil and phosphoric acid that had leaked produced a jelly-like phosphate compound and liberated gas. The clogging of voids in subgrade soil by phosphate and building of gas pressure due to entrapment caused a volume increase and resulted in the tilting of all the storage tanks in the vicinity. Jacking of the tilted storage tanks back to their original position, installation of perforated plastic pipes to provide potential escape paths for the entrapped gas and minimizing the leakage of the phosphoric acid into the foundation soil have been recommended as corrective measures.

Sridharan et al. (1981) reported the heaving of soil, extensive cracking, damage to the floors, pavements and foundations of a light industrial building in a fertilizer plant in Kerala state due to phosphoric acid leaking into the subgrade soil from their damaged open drains with joints. Preventive measures such as close conduits and drains with properly designed filter material were suggested. Yaji et al. (1996) have investigated the influence of phosphoric acid contaminant on shedi soil. The shear strength decreases with increase in percentage of phosphoric acid.

SALT CONTAMINATION

Horta (1985) reported that crystallization of soluble salts present in the pavement or subgrade could occur due to the influence of dry atmosphere or higher evaporation in desert regions. This leads to development of blisters and heaving of the wearing course on pavements. Where salt water is available in the capillary voids of the pavement and evaporation is allowed, salt crystallization starts and crystals grow in size. Salt crystallization increases with pressure and aridity and decreases with the permeability of the base course material. This pressure causes the heaving in soils. Measures to prevent salt heaving and methods to repair salt damage have been discussed.

Barbour & Yang (1993) reviewed the influence of clay-brine interactions on geotechnical properties on soils from western Canada. Brine is the high salt content and was obtained from the ground water existing in saline soils. Two potential sources for the contamination of groundwater and soil by brines are leakage from potash tailings and from brine ponds in potash, oil and gas industries. The influence of clay-brine interactions on the index properties, mechanical properties and hydraulic properties has been described. Decrease in plasticity, increase in shear strength, reduction in volume and alteration of hydraulic conductivity have been reported.

Hofmann et al. (2004) studied the behaviour of smectite in saturated salt brines and observed that no new mineral products were formed and no modifications of the layer charge and layer-charge distribution of smectite occurred. The physicochemical properties of smectite, namely sorption capability and swelling were negatively influenced during contact with the salt brine, but not permanently destroyed. Permeability increased due to aggregation of particles upon with salt solution.

ALKALI CONTAMINATION

Soils receive high pH solutions such as caustic alkali (sodium hydroxide) from a variety of geotechnical environments as well as from industries using alkalis as processing fluids such as caustic soda manufacture industry, pulp and paper, aluminium, petroleum and textiles (including rayon), nuclear weapons manufacturing plant, soap and synthetic detergents, etc. These contaminants can cause significant changes in behaviour in some soils. The effect is particularly drastic at higher concentration of alkali interaction as it can produce changes such as formation of new compounds and/or mineralogical changes prompted by dissolution and precipitation reactions.

Ground heave of an inherently non-swelling, kaolinitic rich red soil due to prolonged spillage of concentrated (40% weight/weight solution) NaOH solution into the subsoil in an industrial establishment has been reported by Rao & Rao (1994). Loss of cementitious iron oxide coatings coupled with negative charge imparted to the subsoil particles by the seepage of the caustic soda solution has been attributed as the cause for the observed heaving. Treatment of the contaminated soil with 5% ferric chloride solution besides minimization of caustic soda spillage has been suggested as a remedial measure.

Sinha et al. (2003) reported the results of investigations on the effect of spilled liquid caustic soda during operation of an alumina plant in India on the bearing capacity of foundation rock. Plate load tests were carried out on contaminated as well as uncontaminated locations and noticed that safe bearing capacity of contaminated site is lower by about 33% compared to uncontaminated location. A detailed experimental investigation has been carried out to study the use of ferric chloride salt to control the undesirable volume changes induced by high concentrated alkali contamination on kaolinitic red earth. X-ray diffraction studies have revealed that soil alkali interactions produce mineralogical changes and formation of new mineral such as zeolite, which are responsible for observed swelling in non-swelling kaolinitic soil. Loss of ferric oxide, which is known cementing agent, has been attributed as one of the reasons for swelling in alkali contaminated soils. Neutralization of subsurface layer with 5% $FeCl_3$ solution and provision of impermeable layer under the high grade concrete has been considered as remedial measure. The high volume change induced by caustic soda solution in a non-swelling soil is controlled by the use of lime. Soil-alkali interactions, which produce mineralogical changes such as the formation of zeolite, can cause swelling in non-swelling kaolinite.

Yaji et al. (1996) have investigated the influence of caustic soda contaminant. The plastic behaviour decreases with increase in magnitude of contaminant. The coefficient of permeability, the coefficient of consolidation and the compression index increases with increasing amount of caustic soda. The swelling pressure of soil also increases with increasing amount of caustic soda.

SULPHATE CONTAMINATION

Swelling and shrinkage behaviour of marine clays impose foundation problems that may sometimes results in excessive settlements. The use of lime to improve the properties of soft clays is not new. Recently the deep lime mixing technique has been extended to coastal regions for improving the behaviour of weak marine clays. But lime treatment technique should be approached carefully for clay containing a high percentage of sodium sulphate. The presence of sulphate in lime-treated clays may result in high swelling due to the formation of the expansive mineral, ettringite and thaumasite. The heave in sulphate induced soil occurs due to the presence of primary and secondary sources of sulphate in soils. The occurrence of native sulphate in natural soils constitutes primary sulphate source. Sulphate present in construction wastes, industrial wastes and spilled chemicals constitute the secondary sulphate source. Alteration of soil-lime reactions in the presence of sulphate affects the strength development by cementation. The reduction in shear strength due to a reduction in effective cohesion intercept occurs for lime-treated soil cured with sulphate for long periods.

Lime treatment of Stewart Avenue in las Vegas, Nevasa, has induced heave in excess of 30 cm (Hunter 1988). The swelling associated with ettringite formation in lime stabilized sulphate bearing clay soils is suppressed by partial substitution of lime with ground granulated blast furnace slag (GGBS).

OIL CONTAMINATION

Crude oil contamination of soils may occur through a variety of sources such as oil leakage from damaged pipe lines, tanker accidents, damage of oil wells during exploration, discharge from coastal facilities, offshore petroleum production facilities, and natural seepage. One typical example is the oil spills in Kuwait during the Gulf war. Another example is the oil spill at Valdez, Alaska resulting from an oil tanker accident. In Saudi Arabia, soils are being contaminated by the leakage of oil from pipelines. Oil that is washed ashore contaminates the shorelines soils. Oil leakage from damaged pipe lines, oil storage tanks, and processing plants may also cause oil contamination in the surrounding soils.

Fuel oil contamination brings adverse effect on basic geotechnical properties of foundation soil. Shah et al. (2003) reported that the petrochemical complex near Vadodara city affects the geotechnical properties at site in Gujarat State, India. Here, the fuel oil contaminated soil samples exhibit drastic changes in their geotechnical parameters. Noteworthy among such deleterious changes are: decrease in maximum dry density (-4%), cohesion (-66%), angle of internal friction (-23%) and unconfined compressive strength (UCS) (-35%) and increase in liquid limit (+11%). 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 geo-technical properties of the soil by way of cation exchange, agglomeration, and pozzolanic 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, CSH-1) that coats and binds the soil particles. Formation of stable complex between oil and metallic cations results in reduction of leachable oil.

An experimental program was undertaken by Srivastava et al. (2008) to evaluate settlement characteristics of clayey soils contaminated with petroleum hydrocarbons. Four most common petroleum hydrocarbons, viz. used engine oil, diesel, gasoline and kerosene, were selected as contaminants for the study. Laboratory studies for index properties and consolidation tests were conducted on virgin (uncontaminated) soil samples and soil samples simulated to varying degrees of contamination (i.e. 3%, 6% and 9% expressed as a dry weight of soil w/w) to compare the consolidation characteristics before and after contamination. The consolidation behaviour of soils modified upon contamination. Larger settlement in the contaminated soil (except with kerosene oil) was due to increase in the value of compression index. The co-efficient of consolidation decreased for the contaminated soils. The effect of oil contamination drastically reduces the ultimate bearing capacity of sandy soils.

Yaji et al. (1996) have investigated the influence of contaminants like waste engine lubricating oil, coconut oil on the behaviour of shedi soil. The plastic behaviour decreases with increase in magnitude of contaminant. The coefficient of permeability, the coefficient of consolidation and the compression index increases with increasing amount of contaminants. The shear strength decreases with increase in amount of contaminants.

UREA CONTAMINATION

Yaji & Gowda Ramakrishna (1995) have investigated the effect of urea on plasticity, swelling and settlement characteristics of shedi soil. There is no appreciable variation in the pH value of the shedi soil when contaminated with urea. The plasticity behaviour decreases, swelling pressure increases, the coefficient of consolidation and compression index increases with increase in contamination with urea. Yaji et al. (1996) have investigated that the shear strength decreases with increase in percentage of urea.

SUMMARY AND CONCLUSIONS

The rapid growth in population and industrialization lead to waste disposal problems. One of the common modes of waste disposal is through land. Geotechnical properties both the index and engineering properties are modified when the waste is mixed with the ground. The extent of modification of properties depends not only on the nature of the contaminant, but also on the type of soil. The contaminants may be acids, alkaline, sulphates, salts, urea (amides) and oil.

At places where several small manufacturing units might have been there, large industrial complexes are coming up. The leakage of industrial effluent into sub-soil affects stability of the supported structure. Therefore, adequate geo-technical evaluation of the contaminated sites and understanding of the various implications of the behaviour of the contaminated soil is necessary.

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