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The effect of chemical contamination on soil strength

L'effet de la pollution chimique sur la résistance du sol

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SYNOPSIS While the principle of the base exchange capacity of soils has been used extensively in civil engineering in the area of admixture stabilisation of soils, the related problem of the detrimental effects of chemical contaminants on the mechanical properties of soils has not been adequately addressed. Recent case histories of structural damage to industrial buildings resulting from chemical contamination of soils serve to emphasise the importance which needs to be attached to the consideration of the problem. Some evidence has been presented to indicate that drastic decrease in shear strength of soils could be one of the consequences of contamination which results in an increase in pH of the soil. Careful planning of storage, handling and disposal facilities for industrial chemicals and effluent has been suggested as a way of mitigating the problem.

INTRODUCTION

The principle of base exchange capacity of soils has found wide application in the fields of agronomy, ceramics and engineering following the pioneering work on the subject by Thompson (circa, 1850) and Way (1850). Until recently, however, the main application of the principle in civil engineering has been in the area of chemical stabilisation of soils for highway and air-field construction. Consequently, initial efforts were directed towards the investigation of the influence of chemical additives on the consistency limits of soils (Winterkorn, 1941; Lambe, 1953; Katti et al, 1962; Fossberg, 1963). In recent years, however, the related problem of the influence of chemical contaminants on other engineering properties of soils has begun to receive considerable attention from geotechnical engineers. Sherard et al (1972) discussed the influence of pore water chemistry on the erosion susceptibility of soils. Wagener et al (1981) described an interesting case history in which the properties of a dispersive clay were altered by cation exchange in the field during the rehabilitation of a dam which failed by dispersive piping, while Anderson (1982) discussed the possibility of changes in the permeability of clay liners in industrial landfills as a result of prolonged contact with organic liquids. By comparison, however, the influence of chemical contaminants on the strength and deformation properties of soils has received relatively little attention.

This paper discusses some aspects of the effect of chemical contaminants on the mechanical properties of soils and suggests the need for geotechnical engineers to take measures to prevent possible long-term effects of chemical contamination of the subsoils resulting from careless storage, handling and disposal of industrial chemicals and effluent.

EFFECT OF CHEMICAL CONTAMINANTS ON THE MECHANICAL PROPERTIES OF SOILS

With the possible exception of efforts aimed at stabilising soft clays using the principle of base exchange (Katti et al, 1981; Matsuo and Kamon, 1981) the effect

of chemical contaminants on the mechanical properties of soils does not appear to have received the attention it deserves, given current global emphasis on detailed studies addressing environmental problems relating to all aspects of the disposal of hazardous waste and other highly aggressive industrial effluents. This has resulted in some expensive foundation failures. Lukas et al (1972) gave a detailed account of the foundation failures of three industrial buildings as a result of chemical reactions between the subsoil and accidental chemical spillages, which were acidic in two of the cases and basic in the other. They attributed the large settlements recorded in each case, to soil losses as a result of the dissolution of either the limestone in glacial till or the high silica sand subsoils in the chemical contaminants. They also recorded substantial reductions in SPT blow-counts in borings made after the chemical contamination compared with the original borings. Shridharan et al (1981) also discussed a case history of extensive cracking damage to light industrial buildings in a fertilizer factory as a result of the heaving of the potentially expansive foundation soils because of acid contamination resulting from leakage of industrial effluents into the subsoils.

A similar case of accidental seepage of highly concentrated caustic soda solution and lye into the subsoils as a result of spillages, and seepage through cracked drains in an industrial establishment in Tema, Ghana, caused considerable structural damage to light industrial buildings in the factory, in addition to localised subsidence of the affected area. The foundation soils consisted of about 1.5 m of dark-green plastic clay overlying light-brown friable silty clay containing calcium carbonate concretions - both soil types being decomposition products of the underlying granite-gneiss rock which was encountered at a depth of 8m. The ground water table at the site was struck at a depth of some 6m. The pH of the uncontaminated soil was 6.5. Measurement of pH profiles at two locations close to each other within the affected area, shown in Fig 1, indicate the appreciable rate of contamination. Trial pits sunk in the affected area also showed seepage of caustic soda at certain depths, thus implying the existence of erosion channels within the otherwise intact foundation soil.

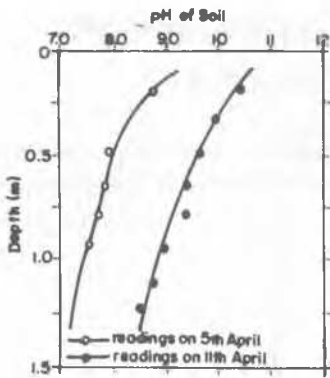


FIG 1 Typical pH Profiles

Among the possible causes of structural distress was the deterioration in soil strength as a result of chemical reactions in the soil. In order to investigate this possibility, a laboratory investigation of the effect of caustic soda contamination on the strength and consistency limits of soils was undertaken.

LABORATORY INVESTIGATION

Materials Tested

Three different types of soil were used in the experimental work. These were;

- (a) A greyish mottled clay derived from the decomposition of Accra Shales.
- (b) A reddish micaceous silty clay formed as a weathering product of biotite granite from Kumasi, and
- (c) an alluvial silty clay

The particle size distributions and the consistency limits of the raw soils are given in Fig 2.

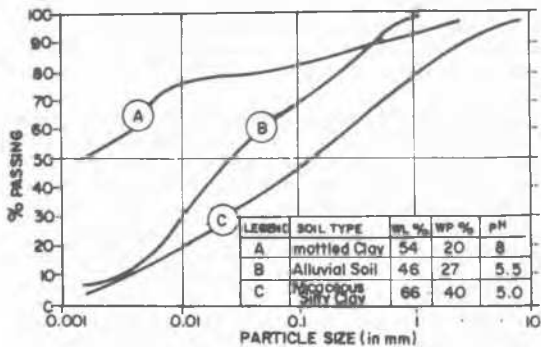


FIG 2 Particle Size Distribution Curves.

It has not been possible carry out chemical and mineralogical analyses on the soil samples. However, according to de Graft-Johnson et al (1967) the predominant clay mineral in the Accra Shale is kaolinite, while unpublished results of analyses carried out by the Ghana Geological Survey showed that the most common clay mineral in most of the local residual soils is kaolinite.

It is therefore reasonable to suppose that the predominant clay mineral in all three samples is kaolinite.

Sample Preparation

The minus No.36 (B.S.) sieve portion of each soil was repeatedly washed with distilled water until the pH of the supernatant water, determined after 24 hours of soaking, was approximately 7, indicating a neutral condition. In doing this, particular care was taken to ensure that loss of fines is prevented.

The soil samples so prepared were oven-dried and divided into various portions which were then mixed with caustic soda solutions of varying concentrations, produced by dissolving caustic soda pellets in distilled water. The pH of the soil-caustic soda mixtures were determined prior to their storage in plastic containers to cure for seven days before testing.

Experimental Technique

Using the GEONOR type of Cone Penetrometer device, a relationship was established between the cone penetration and moisture content, for each soil type in both the contaminated and the raw states, and for moisture contents around the liquid limits of the raw soils. The liquid limits of the contaminated soils were determined from the cone penetration values, as were the undrained shear strengths of the soils, using the relationship established by Hansbo (1957).

DISCUSSION OF RESULTS

Effect of Caustic Soda Contamination on the Liquid Limit

Increasing concentration of caustic soda contamination generally caused a decrease in the liquid limits of the soil as shown in Fig 3, with the decrease more marked in the case of the mottled clay than the other two soil types.

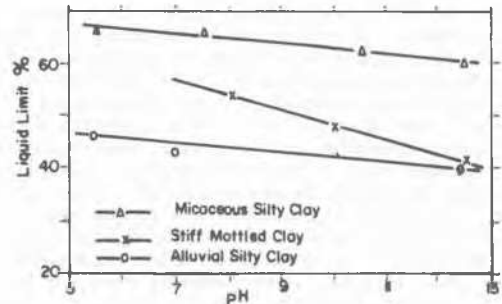


FIG 3 Variation of Liquid Limit with pH Concentration

This decrease in liquid limit with increasing degree of caustic soda contamination, also noted by other researchers, is clearly a reflection of the experimental observation that the soil samples became more friable with increasing concentrations of caustic soda contaminant.

Variation of Undrained Shear Strength with Level of Caustic Soda Contamination

All three soils types showed a general decrease in undrained shear strength with increasing pH concentration. Fig 4 shows the variation for the decomposed clay shale and the alluvial soil. In this case also, the decrease in undrained shear strength displayed by the decomposed clay shale is more marked than that shown by either the alluvial soil or the decomposed granite, both of which contained considerably less clay sized particles, and probably less clay minerals. The present study focussed only on the shear strengths of the soils around

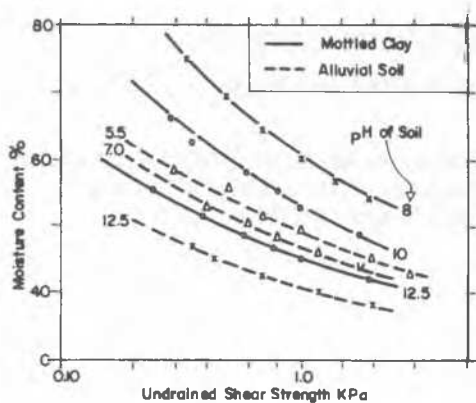


FIG 4 Variation of Undrained shear strength with pH Concentration.

the liquid limit, mainly in a desire to obtain more uniform samples for testing. There is no reason to suppose that the trend of the results obtained will be any different at lower consistencies.

CONCLUDING REMARKS

Since the caustic soda acts as a dispersing agent, it is to be expected that increasing the pH of the soil/water system would lead to a reduction in the inter-particle forces, which would, in turn account for the friable nature of the contaminated soil and the recorded reduction in undrained shear strength. Clearly, in a given situation, the extent of the deterioration in strength will be a function of the soil chemistry, the nature and concentration of the contaminant and the level of the groundwater table and its range of fluctuation, since the groundwater will not only influence the concentration of the contaminant, but would also aid the removal of some of the products of the chemical reaction. In general, the effects of chemical contamination of soils would be more serious in situations of deep water table.

It has not been possible to investigate the effect of caustic soda contamination on the compressibility characteristics of the soils under test, but it is reasonable to expect increased settlement with prolonged caustic soda contamination as a result of the reduction in equilibrium void ratios for a given stress level, particularly in the case of more heavily loaded foundations.

Storage, handling and disposal of industrial chemicals and effluents need to be carefully considered at the planning stage of industrial establishments, not only from the standpoint of environmental safety but also as a safeguard against drastic adverse changes in geotechnical properties of the foundation soils during the service life of the facility. In certain soil types, especially highly permeable formations, prolonged seepage of such contaminants into the soil could cause structural distress in many structures in the vicinity of the industrial establishment.

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