Effects of acids on geotechnical properties of black cotton soil

T.S. Umesha, S.V.Dinesh and P.V.Sivapullaiah

Abstract— Industrial advances in agriculture, chemical industries has lead to release of variety of pollutants into the environment contaminating the soil. Soil is being contaminated by anthropogenic sources such as leakages from waste containment facilities, accidental spills and industrial operations. This paper reports the effect of hydrochloric, phosphoric and sulphuric acids on the compaction characteristics of Black cotton soil at varying percentages. The acid contamination of soil adversely affects the geotechnical properties of soil. The geotechnical properties of soil get altered when an acid compounds gets mixed with soil. Atterberg's limits, compaction characteristics and unconfined compressive strength tests have been carried out. The results are indicative that compaction characteristics and unconfined compressive strength are altered due to acid contamination.

Keywords— Atterberg's limits, acid contamination, black cotton soil, compaction characteristics.

I.INTRODUCTION

Industrial activity is necessary for socio-economic progress of a country but at the same time it generates large amounts of solid and liquid waste. But increased industrialization, high population growth and uncontrolled exploration of natural resources have resulted in environmental degradation, bringing in unanticipated changes in engineering behavior of soils. Pollution of soil has challenged current soil mechanics concepts. A geotechnical engineer is concerned about the impact of soil as most of the effects of soil contamination are mainly due to changes in the geotechnical behavior of foundation soil. The task of geotechnical engineer has become complicated, as conventional geotechnical principles can not be extended to contaminated soil behavior. Accordingly it seems imperative that handling of potential pollution problems in soil must be based on the prediction of likely or possible impairment of the functioning of soil. In practice this implies in the first place knowledge of composition of influx as well as the soil. Next the influence of interactions of the compounds of interest with the solid phase on soil behavior is to be explored. Planning suitable preventive and remedial measures to safe utilization of the site is another challenging task. The main types of contaminants include various substances such as inorganic acids, alkalis, sulphates, organic contaminants, toxic or phytotoxic metals, and combustible substances. All types of pollutants can change the behavior of soils to some or large extent. Soil acidity is common in all regions where precipitation is high enough to leach appreciable quantities of exchangeable base forming cat ions (Ca^{2+}, Mg^{2+}, K^+ and Na^+) from the surface layers of soil. When certain minerals present in soil are disturbed or exposed to atmosphere gets oxidized to form acids. This exposure is due to mining. Acids may also be released due to some bacteria in the soil. Acidity leads to changes in anion and cation exchange capacity of soil to a small extent. Along with the change in ion exchange capacity there is alteration of the exchangeable ions or the amount of ions adsorbed. Soil acidity also results from pollution of soil. The majority of acid water is derived from acid rain, acid drainage, leakage from industries, underground reservoirs and waste disposal sites.

The unintended modification of soil properties due to interaction with pollutants can lead to various geotechnical problems. The effect of pollutants can be very similar to the effect of weathering. The nature of soil pollutant interactions depends on the mineralogy of soil and type and concentration of the pollutant. There is a need to understand the Geotechnical behavior of acid contaminated soils.

Soil waste interaction can affect almost all the properties of soils. [1] investigated tilting of phosphoric acid storage tanks in a chemical fertilizer factory in Jordan. [2] reported the effect of acid attack on the crystal structures of aluminosilicate minerals. [3] have reported the effect of phosphoric and sulphuric acids on the compaction and strength properties of black cotton soil. [4] have carried out a laboratory test to determine the effect of acetic acid on Bentonite soil used as a material for clay liner. [5] reported the heaving of soil in a fertilizer plant due to phosphoric acid leaking in to the sub grade soil from the damaged open drains with joints.
Thus it is known that all types of acids can influence the behaviour of soils, though by different mechanisms. In the present work a detailed experimental investigation is carried out to understand the effect of hydrochloric, phosphoric and sulphuric acids on the compaction and unconfined compressive strength characteristics of Black cotton soil.

II. MATERIALS AND METHODS

Black cotton soil was collected from Gulbarga, in Karnataka state. Table 1 shows the Geotechnical properties of this soil. This is an expansive soil with a liquid limit of 80. It has 60 % clay, 20 % silt 20 % and sand. This can be classified as clay of high compressibility (CH) as per IS classification. Laboratory reagent hydrochloric, phosphoric and sulphuric acids were used in concentrations of 1.25, 2.5, 5, 10 and 15 percent. The experiments were conducted to determine the Atterberg's lmits, compaction characteristics and unconfined compression strength. Atterberg's limits of the soil specimen was determined as per IS: 2720 (part 5) – 1985, Methods of test for soils: Determination of liquid and plastic limit. The Standard proctor compaction characteristics of the soil specimen was determined as per the Indian Standard specification IS: 2720 (part 7)-1980, Methods of test for soils: Determination of water content-dry density. The unconfined compression test of the soil specimen was determined as per the Indian Standard specification IS 2720 (Part 10)-1991 (Reaffirmed 1995), Methods of test for soils: Determination of unconfined compressive strength. The reported results are the average results obtained from three tests.

Table I Geotechnical properties of Black cotton soil

Sl.No.	Properties	Value
1	Particle size analysis	
	Gravel (%)	--
	Sand (%)	20
	Silt (%)	20
	Clay (%)	60
2	Liquid limit (%)	80
3	Plastic limit (%)	28
4	Plasticity index	52
5	Specific gravity	2.7
6	Compaction Characteristics	
	Optimum Moisture Content (%)	25
	Maximum dry unit weight (kN/m^3)	14.1
7	Soil classification	CH

III. PREPARATION OF ACID CONTAMINATED SOIL

The soil was mixed with1.25, 2.5, 5, 10 and 15 percent of hydrochloric, phosphoric and sulphuric acids .The soil was thoroughly mixed with hydrochloric, phosphoric and sulphuric acids and uniform acid distribution was ensured. The contaminated soil was then transferred to polythene bags and kept in the desiccator before testing.

IV. EFFECT OF ACIDS ON ATTERBERG'S LIMITS

Figure 1 shows the variation of liquid limit for various acid concentrations in the pore fluid for Black cotton soil. It is observed that with increasing acid concentration the liquid limit decreases for all the three acids. At any given acid concentration liquid limit is in the order of hydrochloric > phosphoric > sulphuric acid. A reduction in liquid limit is generally due to increase in electrolyte concentration of the pore fluid and consequent decrease in the thickness of double layer developed. However, it is observed that the reduction in liquid limit is higher with sulphuric acid than in other acids. Sulphuric acid decreases the liquid limit of soil due to predominant effect of electrolyte concentration. A reduction in liquid limit generally indicates an increase the frictional resistance and decrease in cohesion in soil.

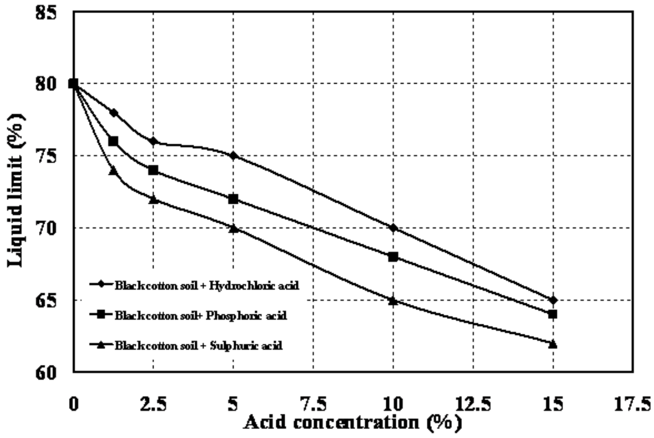

Fig. 1 Effect of acid concentrations on liquid limit

Figure 2 shows the variation of plastic limit for various acid concentrations in the pore fluid for Black cotton soil. Plastic limit increases initially till 5 percent contamination and thereafter there is a slight decrease in the values but in general it is higher than the initial value of 28 percent. At any given acid concentration plastic limit is higher in hydrochloric acid contaminated soils and lower incase of phosphoric and sulphuric acids.

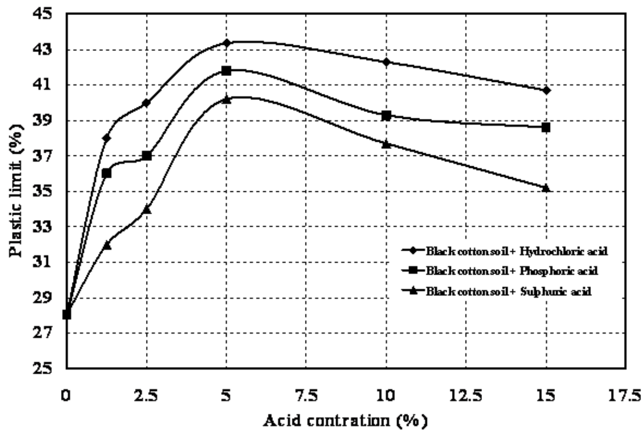

Fig. 2 Effect of acid concentrations on plastic limit

Figure 3 shows the variation of plasticity index for various acid concentrations of hydrochloric, phosphoric and sulphuric acids in the pore fluid for Black cotton soil. PI reduces from a value of 52 to a value of around 25 roughly 50 percent reduction as the concentration is varied from 0 to 15 percent irrespective of type of acid. The reduction is significant till 5 percent (more than 40%) and thereafter it is gradual.

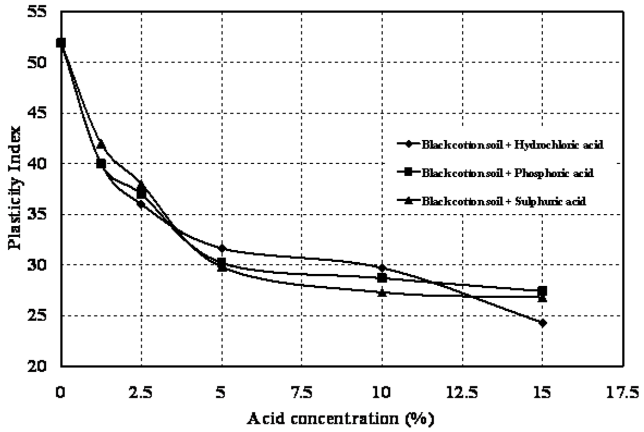

Fig. 3 Effect of acid concentrations on plasticity index

V. EFFECT OF ACIDS ON COMPACTION CHARACTERISTICS

Figures 4 to 6 shows the compaction results for hydrochloric, phosphoric and sulphuric acids respectively. It is observed that optimum water content show increasing trend up to 5 percent acid concentration and then show decreasing trend up to 15 percent acid concentration compared to soil with water. The maximum dry unit weight show decreasing trend with increase in acid concentration compared to soil with water. Further, the decrease in dry unit weight is gradual on dry and wet side when compared at optimum moisture content and hence curves exhibit less pronounced peaks. Thus the black cotton soil contaminated with any acids will have lower dry unit weight with increase in acid concentration for any given compactive effort. The reduction in optimum moisture content at higher acid concentration indicates that the soil has got less affinity or less absorption capacity for water due to increase in the electrolyte concentration in pore fluid.

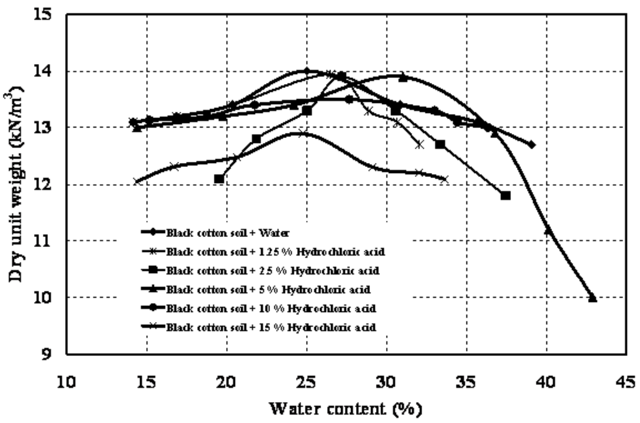

Fig. 4 Compaction curves with water and hydrochloric acid

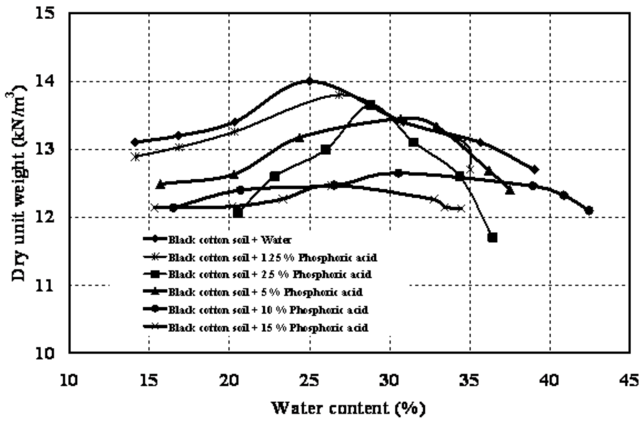

Fig. 5 Compaction curves with water and phosphoric acid

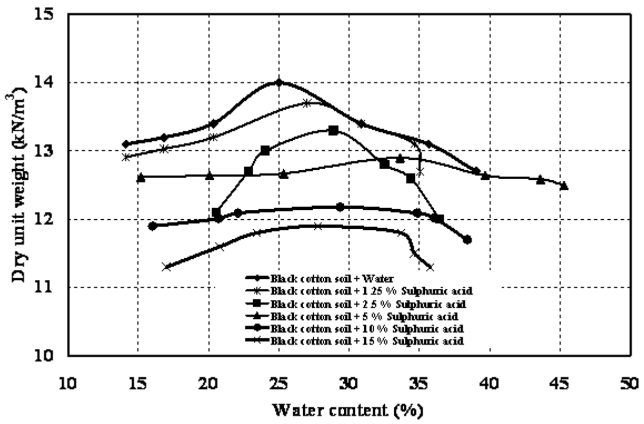

Fig. 6 Compaction curves with water and sulphuric acid

The comparison of the compaction test results for the three acids at acid concentrations of 1.25, 2.5, 5, 10 and 15 percent respectively is shown in Figs. 7 to 11. At 1.25 percent acid concentration, optimum moisture content increases and maximum dry unit weight decreases for all acids as observed from Fig. 7. The decrease in maximum dry unit weight is more for sulphuric acid than for hydrochloric and phosphoric acid at 1.25 percent acid concentration.

It is observed from Fig. 8 that for 2.5 percent acid concentration the changes in optimum moisture content and maximum dry unit weight are similar to 1.25 percent acid concentration. But the compaction curves exhibits more pronounced peaks and hence the reduction in dry unit weight is more both on dry and wet side of optimum moisture content. The same trend continues with 5 percent acids with compaction curves exhibiting less pronounced peaks as seen in Fig. 9. At higher concentration of 10 percent the optimum moisture content show decreasing trend but the value of optimum moisture content is still less than that of soil with water. The maximum dry unit weight decreases with the decrease more pronounced for phosphoric and sulphuric acid as observed from Fig.10. The optimum moisture content continues to show decreasing trend at concentrations of 15 percent but there is no significant variation in optimum moisture content when compared to that of soil with water. The maximum dry unit weight decreases for all the three acids at 15 percent and the reduction is more for sulphuric acid as seen frm Fig.11.

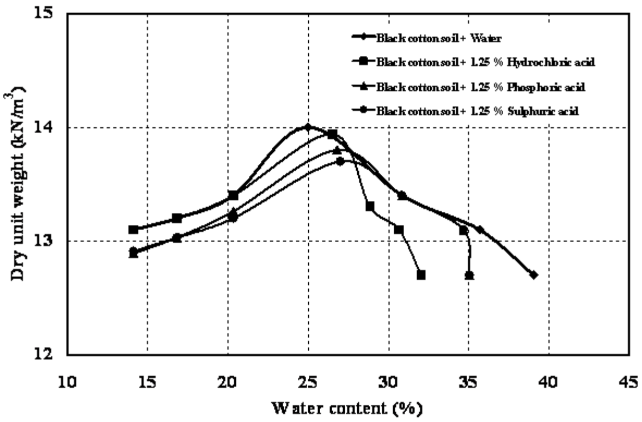

Fig. 7 Compaction curves with water and acids at 1.25 percent

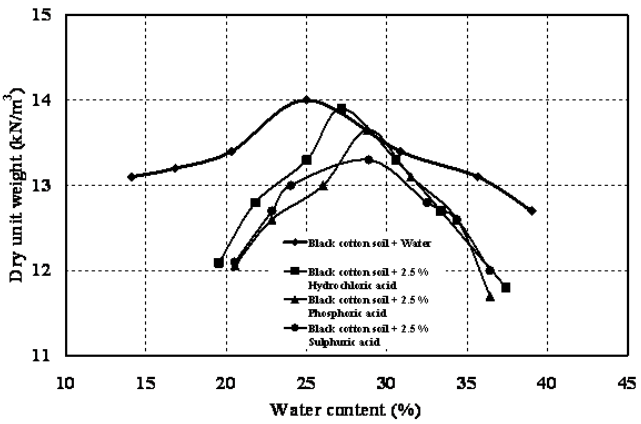

Fig. 8 Compaction curves with water and acids at 2.5 percent

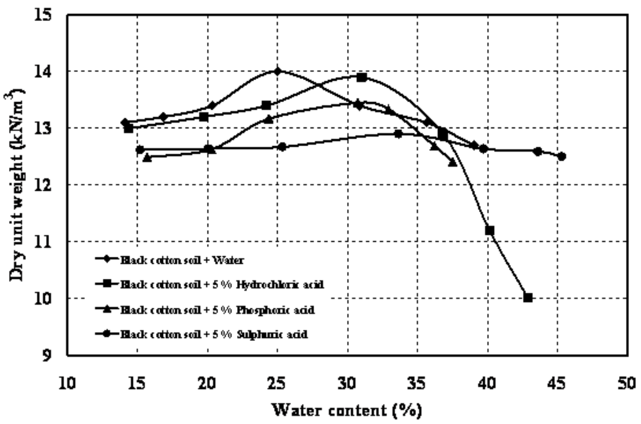

Fig. 9 Compaction curves with water and acids at 5 percent

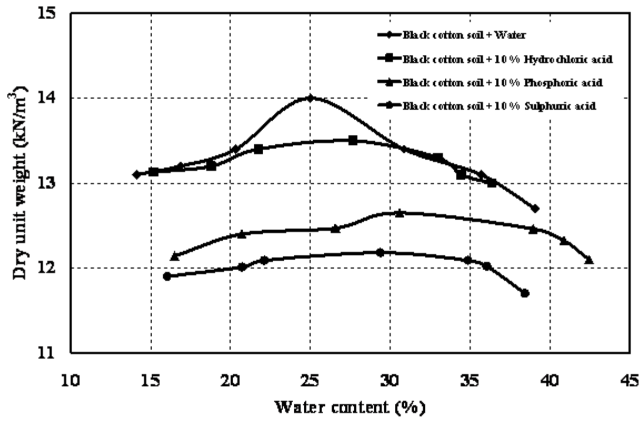

Fig. 10 Compaction curves with water and acids at 10 percent

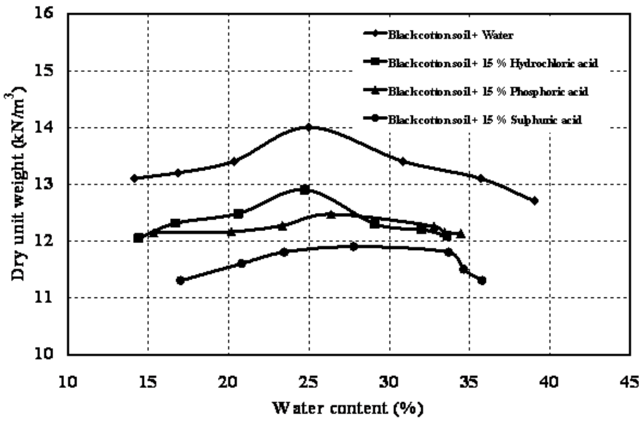

Fig. 11 Compaction curves with water and acids at 15 percent

The combined graph of dry unit weight with acid concentration and optimum moisture content versus acid concentration for black cotton soil contaminated with hydrochloric, phosphoric and sulphuric acids is shown in Fig. 12. The optimum moisture content increases in all the three cases for till 5 percent acid concentration and there after shows decreasing trend till 15 percent. This indicates that the water holding capacity increases initially till 5 percent acid concentration due to decrease in electrolyte concentration and thereafter it shows decreasing trend. The maximum dry density decreases with increase in acid concentration for all three acids. At any given acid concentration, the optimum moisture content is less for soil with hydrochloric acid. But the reduction in maximum dry density is greater for soil with phosphoric acid.

Optimum moisture content is increasing up to 5 percent acid concentration but then it is decreasing up to 15 percent acid concentration in the pore fluid. Optimum moisture content decreasing means soil has got less affinity or less absorption capacity for water. Water holding capacity is decreasing i.e. clay is disintegrating after 5 percent acid concentration in the pore fluid where as up to 5 percent acid concentrations Cat-ion exchange capacity dominates and it is actually increasing the water holding capacity. It is indicative that up to 5 percent acid concentration only ion exchange dominates. Beyond that there is a chemical interaction.

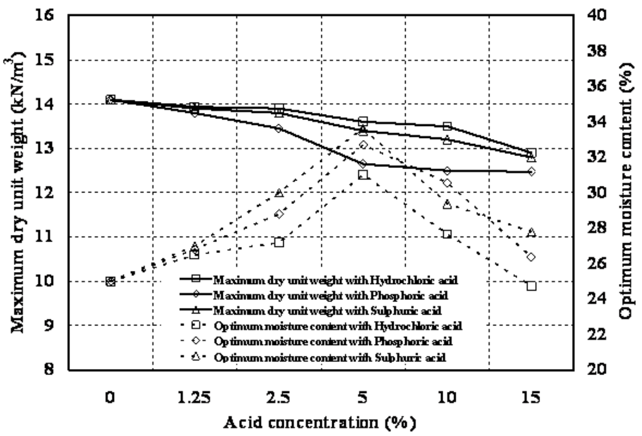

Fig. 12 Effect of acid concentration on maximum dry unit weight and optimum moisture content

VI. EFFECT OF ACIDS ON UNCONFINED COMPRESSIVE STRENGTH

Black cotton soil loses its plasticity properties due to acid contamination. There is also evidence that acid contaminated soil shows lower dry unit weight for the same compactive effort. Thus there may be a possible reduction in strength with increased acid concentration in the pore fluid. Hence a series of unconfined compression strength tests were performed on samples prepared with contaminated pore fluid containing different acid concentrations at the respective Proctor conditions.

The stress-strain curves for Black cotton soil obtained from unconfined compressive strength test for various concentrations (1.25 to 15 percent) of acid in the pore fluid along with water as pore fluid are shown in Figs 13 to 15 for hydrochloric, phosphoric and sulphuric acids respectively. The stress strain curves are linear almost up to peak stress and fail in rupture mode. The strain corresponding to peak stress and the magnitude of peak stress decreases with increase in the concentration of acid. It is also observed that at lower concentrations of contamiants (1.25 and 2.5 percent) the stiffness greatly reduces and hence the modulus of elasticity and such soils will have a tendency for large settlements.

The comparision of the unconfined compressive strength test results for the three acids at acid concentrations of 1.25, 2.5, 5, 10 and 15 percent respectively is shown in Figs. 6.25 to 6.29. The strength of soil is almost the same under identical conditions of acid concentration. The increase in strain is in the order of hydrochloric, phosphoric and sulphuric acids for different acid concentrations.

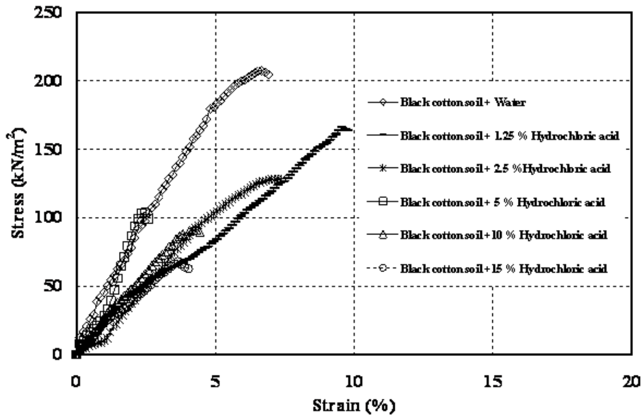

Fig. 13 Stress strain curves for hydrochloric acid contaminated Black cotton soil

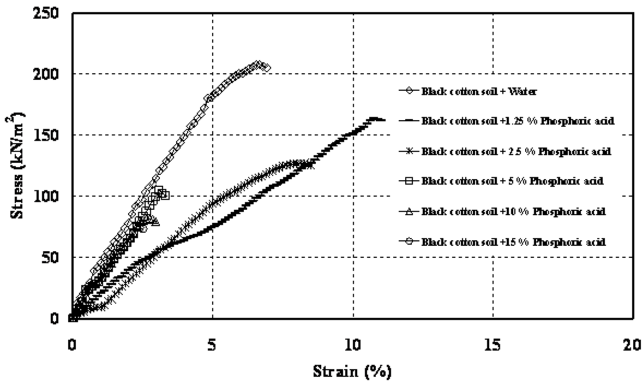

Fig.14 Stress strain curves for phosphoric acid contaminated Black cotton soil

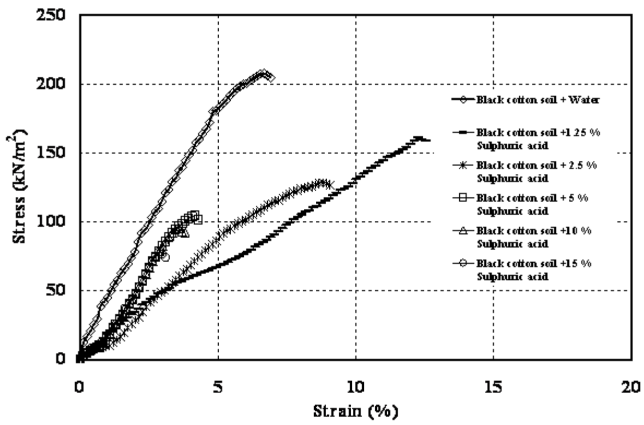

Fig.15 Stress strain curves for sulphuric acid contaminated Black cotton soil

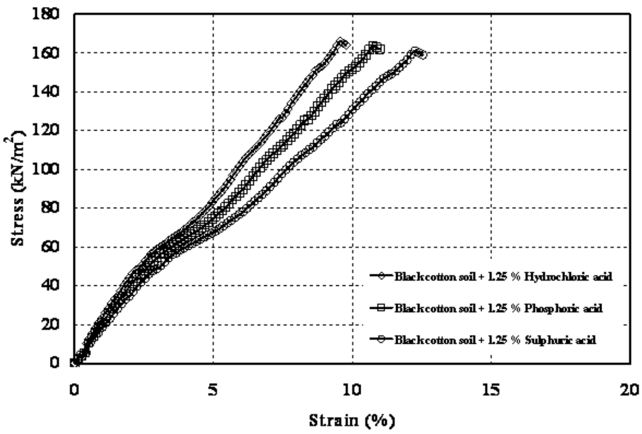

Fig.16 Stress strain curves for acid contaminated (1.25 percent) Black cotton soil

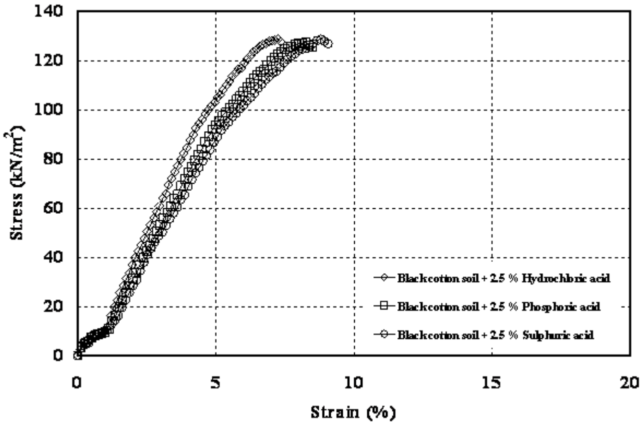

Fig.17 Stress strain curves for acid contaminated (2.5 percent) Black cotton soil

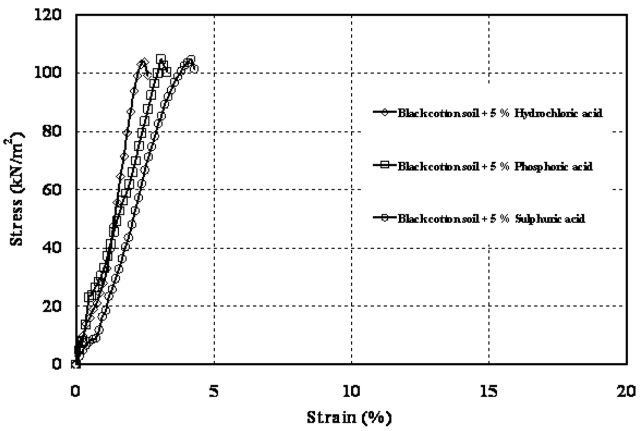

Fig.18 Stress strain curves for acid contaminated (5 percent) Black cotton soil

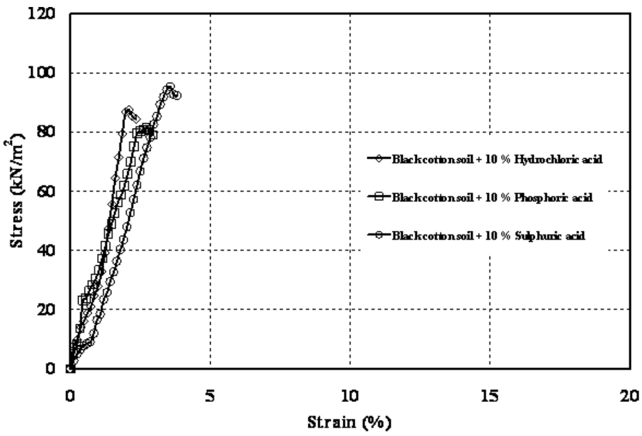

Fig.19 Stress strain curves for acid contaminated (10 percent) Black cotton soil

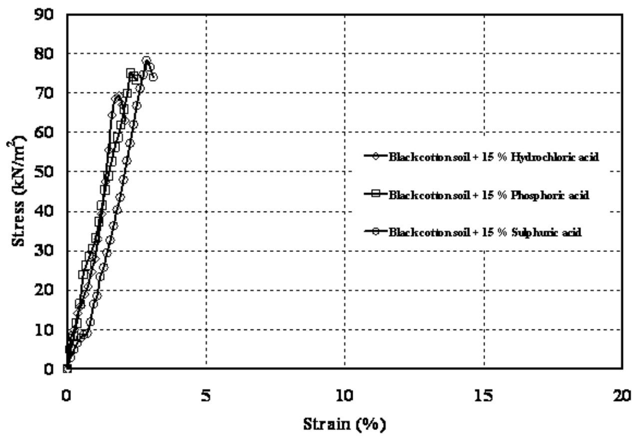

Fig.20 Stress strain curves for acid contaminated (15 percent) Black cotton soil

Fig.21 shows the variations of unconfined compressive strength of Black cotton soil at different concentrations for hydrochloric, phosphoric and sulphuric acids. There is a drastic reduction in unconfined compressive strength with increase in acid concentration for all the three acids. There is a strength reduction of more than 50 percent even with a smaller acid concentration of 5 percent in the pore fluid. The reduction in strength due to contamination is attributed to possible breakage of bonds internally.. Maximum reduction in strength (almost 50 percent) is observed for 5 percent acid contamination. Therefore, even lower acid contamination will cause significant reduction in cohesion and strength. Thus strength of soil is reduced due to the effect of acid contamination in the pore fluid.

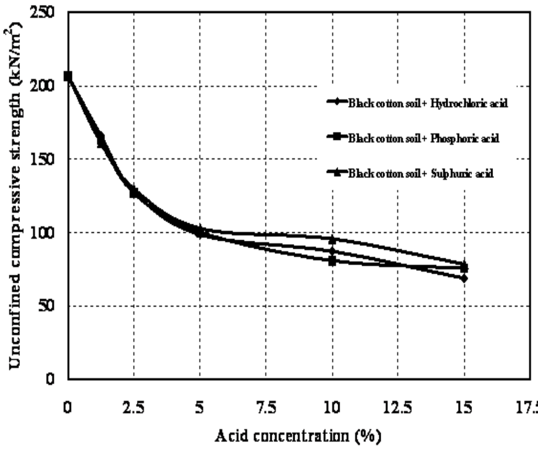

Fig. 21 Unconfined compressive strength for various concentrations of acids

The ranges of optimum water contents are different for soil with acid concentrations and the observed changes in unconfined compressive strength might partly be due to differences in their water contents. In order to understand the effect of acid type and concentration the water contents are normalized with respect to their corresponding optimum moisture content. Fig. 22 shows unconfined compressive strength with normalized water content during proctor conditions for Black cotton soil. The unconfined compressive strength for all the samples with respect to their respective unit weight and water contents are determined experimentally. There is a reduction in strength for contaminated soil when compared with soil compacted with water as pore fluid. The reduction in strength is more for soils with higher acid concentration. When the pore fluid is contaminated with acids, dielectric constant decreases leading to aggregation of particles and act much like silty soil. This interaction may be the possible reason for lower strength. All the optimum moisture contents are merged at normal water content of 1. The soil will have peak strength at respective optimum moisture content which indicates that water holding capacity of contaminated soil is becoming more prominent.

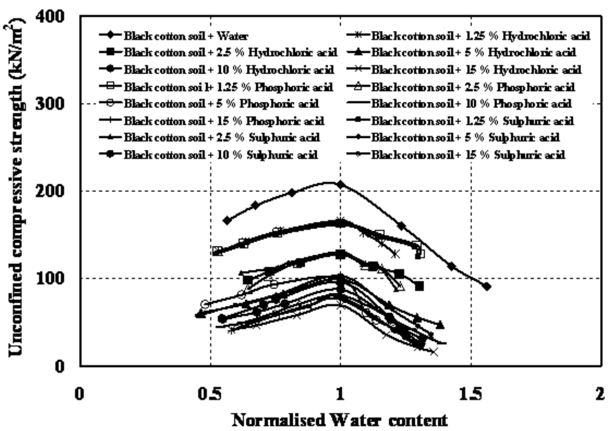

Fig.22 Unconfined compressive strength with normalized water content

VII. CONCLUSIONS

A comprehensive experimental study has been carried out to understand the effects of acids contamination on geotechnical properties of black cotton soil. The conclusions based on the study are

Liquid limit decreases with increase in any acid concentration for all the three acids.Plastic limit increases up to 5 percent of acid concentration in the pore fluid and then it decreases up to 15 percent concentrations of any acid. Plasticity index decreases up to 15 percent concentrations of any acid. Optimum moisture content show increasing trend up to 5 percent acid concentration and then show decreasing trend up to 15 percent acid concentration compared to soil with water. The maximum dry unit weight show decreasing trend with increase in acid concentration compared to soil with water. There is reduction in unconfined compressive strength for acid contaminated soil. The strength reduction is more for soils with higher acid concentration due to reduction in cohesion. The ranges of optimum water contents are different for soil with different acid concentrations and at the respective optimum moisture content all soils will give peak strength. Water holding capacity play a role in in strength reduction.

REFERENCES

[1] Abdullah Assa'ad (1998). "Differential upheaval of phosphoric acid storage tanks in Aqaba, Jordan", proceedings of journal of performance of constructed facilities. Vol 12:2:pp71-76.

[2] Grzegorz Jozefaciuk and Grzegorz Bowanko. (2002). "Effect of acid and alkali treatments on surface areas and adsorption energies of selected minerals," Clays and Clay minerals, Vol.50. No.6 pp 771-783.

[3] Ramesh.H.N. , Venkatarajan Mohan.S.D and Abdul Bari (2008). "Compaction and strength properties of alkalies treated expansive soil contaminated with acids", proceedings of Indian geotechnical conference, Vol 2 pp 466-469.

[4] Sanjeev Singh and Arun Prasad. (2007). "Effects of chemicals on compacted clay liner, proceedings of Electronic journal of Geotechnical Engineering, "Vol.l2 pp 1 -15.

[5] Sridharan A, Nagaraj T.S and Sivapullaiah.P.V (1981). "Heaving of soil due to acid contamination", proceedings of tenth international conference on Soil mechanics and foundation engineering, Stockholm, Vol 2 pp383-386.

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