Lime to improve the unconfined compressive strength of acid contaminated soil

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

Abstract— The relatively low strength of compacted dispersive silty soil (locally called Suddha soil) further reduces when contaminated with 2.5-15 percent hydrochloric, phosphoric and sulphuric acid solution. Addition of lime of about 3 percent which generally increases the unconfined compression strength of the soil is found to be ineffective to enhance the strength of contaminated soil. This has been attributed as due to non dissolution of reactive silica from soil and participates in pozzolanic reactions at low pH. Hence addition of lime is considered after neutralization of contaminated soil with addition of lime. Addition of 3 percent lime after neutralization of acid contaminated soil to different extents is considered. The soil then developed considerable strength on par with uncontaminated soil after curing. The improvement in Young's modulus of stabilized soils is better for lime treated soil than contaminated soil.

Keywords—Acid contamination, Lime, Unconfined compressive strength, Neutralization.

I.INTRODUCTION

Contamination can lead to an accumulation of contaminants in soils. It may often damage buildings, dams and highways etc situated in those sites as well as can make the site unsuitable for developmental activities. 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 behaviour 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 An-ion and Cat-ion 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] Assa'ad (1998) investigated tilting of phosphoric acid storage tanks in a chemical fertilizer factory in Jordan. [2] Sridharan *et al* (1981) 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. [3] Sanjeev Singh and Arun Prasad (2007) have carried out laboratory tests to determine the effect of Aluminium hydroxide and Acetic acid on Bentonite soil used as a material for clay liner.

The present investigation is on a local soil called Suddha soil that is present in Southern parts of Karnataka is used. It is wide spread below a depth of 1.5 m from the ground level and extends to depths greater than 10 m. It possesses good strength in dry condition and upon increase in moisture content looses strength. Many failures have been observed along canal slopes, road bases and foundations at sites where Suddha soil is present. This soil is silty sand with clay percent less than 20. The soil classification group symbol is SM. This is considered as a dispersive soil with dispersivity of about 50 percent. The study deals with effect of hydrochloric acid contamination on unconfined compressive strength and method to improve the same.

Lime is an additive that brings several beneficial changes in the engineering properties of soil such as decrease in shrink swell potential apart from improving strength characteristics. Stabilization of soil by lime is achieved through cation exchange, flocculation, agglomeration, lime carbonation and pozzolanic reaction. Cation exchange and flocculation agglomeration reactions takes place rapidly and bring immediate changes in soil properties, whereas, pozzolanic reactions are time dependent. These pozzolanic reactions involve interactions between soil silica and/or alumina and lime to form various types of cementitious products thus enhancing the strength. In the field of highways and foundation engineering lime has been used to improve the soil characteristics. Lime treatment has many beneficial effects on soils that include improvement in plasticity and strength characteristics of soil. It is observed that the lime treatment reduces the settlement and improves the strength. Hence in recent years the deep lime improvement method is introduced as a means of deep in-situ treatment in some of the problematic soils. [4] Vasquez and Alonso (1981) have reported that hydration of lime takes place during the first seven days and pozzolanic reactions don't have significance before fourteen days. [5] Brandl (1973) has adopted deep in-situ method of lime stabilization in the form of lime columns to stabilize slopes in Austria.[6] Broms and Boman (1975) used lime columns to stabilize clays. [7] Okumara and Terashi (1975) have used lime column method to stabilize thick soft marine clay deposits in a Japanese harbor area. [8] Balasubramaniam et al (1989) have adopted quicklime for the stabilization of soft Bangkok clays. They observed that unconfined compressive strength increased nearly ten times by the addition of 5 percent lime.[9] Narasimha Rao and Rajasekaran (1994) have conducted studies on the lime stabilization of soft marine clay.

II. MEHANISMM OF STABILIZATION OF SOIL USING LIME

The chemical interaction plays an important role in the lime stabilizations of soils. The following four basic reactions take place when lime is added to soil:

(1) Cation exchange

$$Ca^{++} + Clay \rightarrow Ca^{++}Clay + (Na^{+}, K^{+}) \qquad (1)$$

(2) Flocculation/Agglomaration

(3) Carbonation

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad (2)$$

(4) Pozzolanic reactions

$$Ca^{++} + 2(OH)^{-} + SiO_2 \rightarrow CSH \qquad (3)$$

$$Ca^{++} + 2(OH)^{-} + Al_2O_3 \rightarrow CAH \qquad (4)$$

Cation exchange and flocculation/agglomeration reactions takes place relatively rapidly and produces quick changes in plasticity, workability and engineering properties [10]. There will be an immediate effect on the properties of clay when lime is added to soil. The cat ion exchange starts to take place between the metallic ions associated with the surface of the clay particles and that are surrounded by a diffuse hydrous double layer, which is modified by the ion exchange of calcium, because of which there is alteration in the density of the electrical charge around the clay particles, that leads to the flocculation of particles. This process is mainly responsible for the modification of the engineering properties of clay soils treated with lime[11].

The carbonation reactions are generally undesirable because it gives weak cementing agents. The pozzolanic reaction is time dependent and it is mainly responsible for great improvement in soil properties. The long term physico-chemical changes are due to pozzolanic reactions. The pozzolanic reactions are facilitated by the lime creating highly alkaline soil pore chemistry. This promotes dissolution of silicon and aluminium from the clay. The dissolved components react with the calcium ions present in the pore water forming calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). These compounds crystallize with time that results in changes in clay plasticity, increase in shear strength and reduction in permeability [12].

In stabilization of soil using lime, quantity of lime plays a major role. The strength of the clayey soil increases with increase in lime content up to certain limit, then the rate of increase in strength can be negligible or even can decrease. This lime content is called the optimum lime content for soil and it mainly depends on the clay content of the soil and the reactive silica. The soluble silica increases as the fineness of clay increases and the lime required to completely react with this silica increases. Water content is essential for pozzolanic reaction to produce gelatinous compounds. Effective formation of pozzolanic compounds does not take place when sufficient quantity of water is not available for soil lime reaction. On the other hand when water is more than required, the soil particle distance increases which lead to lowering of strength because of ineffective binding by pozzolanic reaction compounds. Hence type of clay and water quantity present in the system influence the optimum lime content. Thus at optimum moisture content, optimum lime content required for effective stabilization of soil is found to be generally in the range of 3 to 6 percent[13]. Thus the effect of 3 percent of lime is studied to improve the strength of the soil under investigation.

II. MATERIALS AND METHODS

Suddha soil (silty soil) was collected from Hemavathi canal Zone in Karnataka State of India. Table 1 shows the Geotechnical properties of Suddha soil. Chemically pure lime obtained from standard manufacturers was used. Laboratory reagent hydrochloric, phosphoric and sulphuric acid was used in concentrations of 2.5, 5, 10 and 15 percent.

Experiments were conducted to determine the Atterberg's lmits, compaction characteristics and unconfined compressive 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 using light compaction. 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

Table I Geotechnical properties of Suddha soil

Sl. No.	**Properties**	**Value**
1	Particle size analysis	
	Gravel (%)	4
	Sand (%)	57
	Silt (%)	26
	Clay (%)	13
2	Liquid limit (%)	41
3	Plastic limit (%)	24
4	Plasticity index	17
5	Shrinkage limit (%)	22
6	Specific gravity	2.6
7	Compaction Characteristics	
	Optimum Moisture Content (%)	14
	Maximum dry density (kN/m^3)	17.8
8	Soil Classification	SM

III. PREPARATION OF ACID CONTAMINATED SOIL

The soil was mixed with 2.5, 5, 10 and 15 percent of hydrochloric, phosphoric and sulphuric acid. The soil was thoroughly mixed with 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

Fig. 1 shows the variation of liquid limit for various acid concentrations of hydrochloric, phosphoric and sulphuric acids in the pore fluid for Suddha soil. It is observed that with increase in any acid concentration the liquid limit decreases for all the three acids. 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 A reduction in liquid limit generally indicates an increase in the frictional resistance and decrease in cohesion in soil.

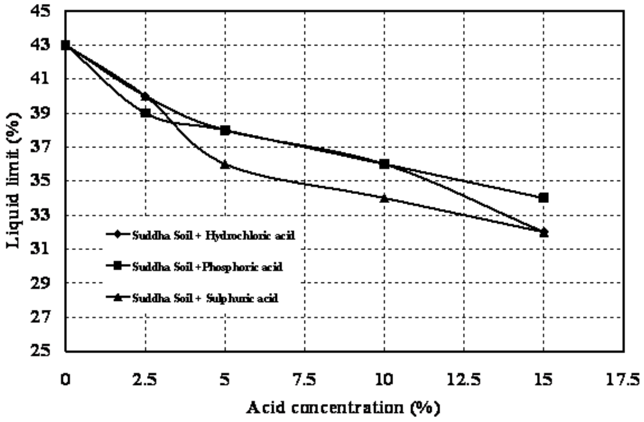

Fig. 1 Effect of acid concentrations on liquid limit

Fig 2 shows the variation of plastic limit for various acid concentrations of hydrochloric, phosphoric and sulphuric acids in the pore fluid for Suddha soil. It is observed that the plastic limit increases upto 2.5 percent of acid concentration in the pore fluid and then it decreases upto 15 percent concentrations of any acid. It is observed that the increase in plastic limit upto 2.5 percent acid concentration is higher with sulphuric acid and reduction in plastic limit after 2.5 percent acid concentration is higher with sulphuric acid than in other acids.

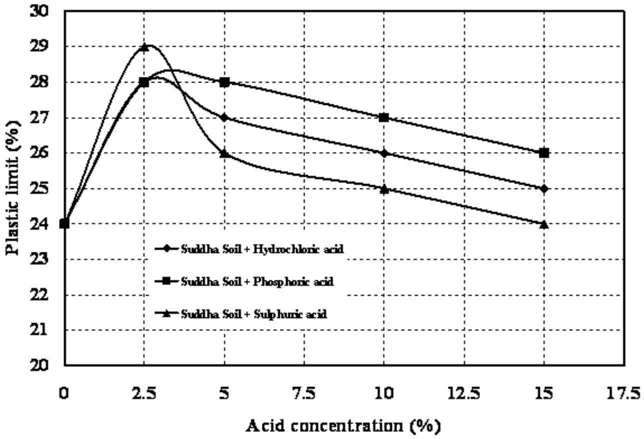

Fig. 2 Effect of acid concentrations on plastic limit

Fig 3 shows the variation of plasticity index of Suddha soil for various acid concentrations of hydrochloric, phosphoric and sulphuric acids in the pore fluid. The general trend in the variation of plasticity index is same for all the three acids. The results indicate large reduction in plasticity index for 2.5 percent of acids concentration in the pore fluid. Beyond 2.5 percent there is a gradual reduction in plasticity index. This clearly brings out the inevitable change in the plasticity characteristics even with small percentage of acid concentration in the pore fluid.

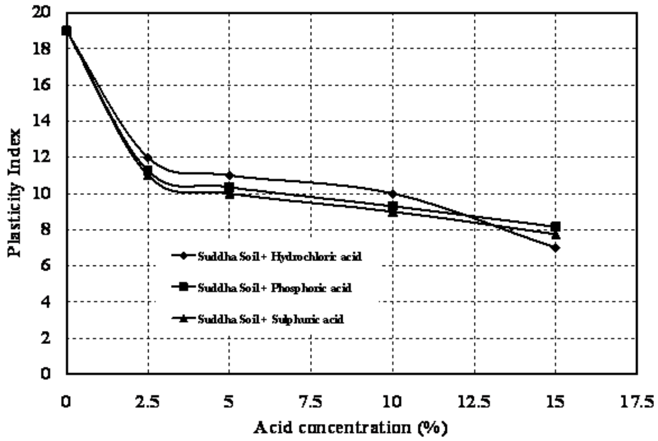

Fig. 3 Effect of acid concentrations on plasticity index

V. EFFECT OF HYDROCHLORIC ACID ON COMPACTION CHARACTERISTICS

Fig 4 to 6 show the compaction test results in the form of moisture content-dry unit weight for hydrochloric, phosphoric and sulphuric acid respectively. It is observed that the compaction curves with any acid exhibit more sensitivity to moisture content and become sharper with increase in the acid concentration in the pore fluid. It is interesting to note that both optimum water content and maximum dry unit weight show decreasing trends compared to soil with water. The optimum water content and maximum dry unit weight decreases with increase in the acid concentration from 2.5 to 15 percent in the pore fluid. At higher concentrations of 10 to 15 percent the decrease in dry unit weight on wet side of optimum moisture content is large. The decrease in dry unit weight is more on dry and wet side than at optimum moisture content. As such the decrease in optimum moisture content is less. This trend indicates that soils contaminated with any acids will have lower dry unit weight and lower optimum moisture content with increase in acid concentration for any given compactive effort. Optimum moisture content decrease indicates that the soil has got less affinity or less absorption capacity for water. This is predominantly due to increase in the electrolyte concentration in pore fluid.

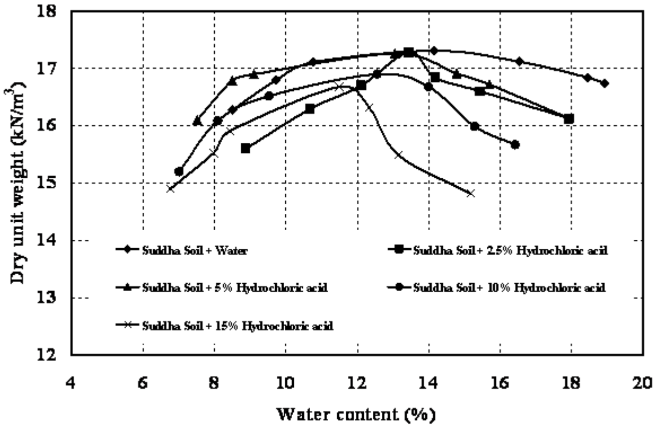

Fig. 4 Compaction curve of Suddha soil with hydrochloric acid

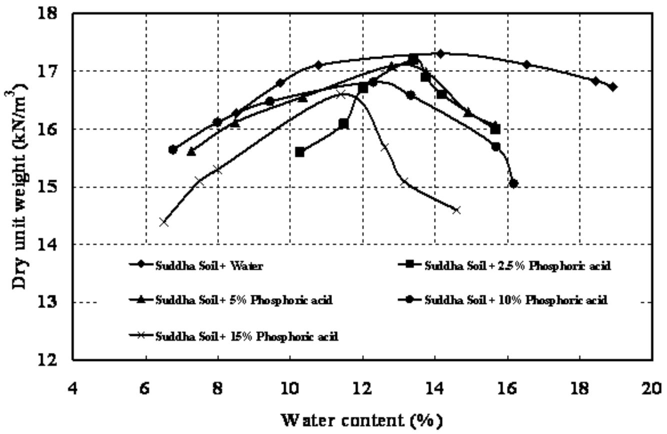

Fig. 5 Compaction curve of Suddha soil with phosphoric acid

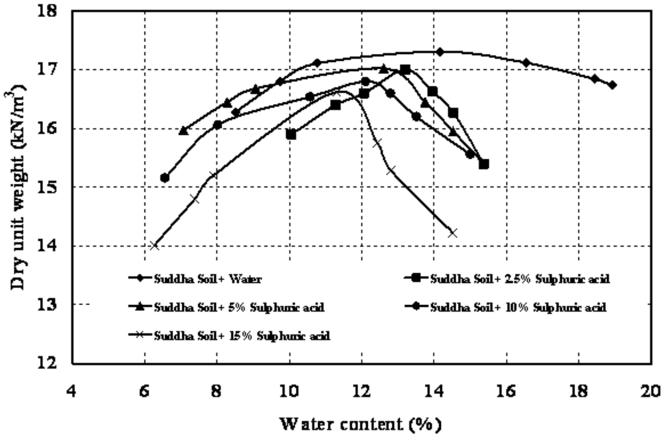

Fig. 6 Compaction curve of Suddha soil with sulphuric acid

VI. EFFECT OF ACIDS ON UNCONFINED COMPRESSIVE STRENGTH

Cylindrical samples of 38 mm diameter and 76 mm long samples were prepared by compacting Suddha soil at the respective optimum moisture contents and maximum dry densities with of 2.5, 5, 10 and 15 percent of hydrochloric, phosphoric and sulphuric acid for the determination of unconfined compressive strength. Fig 7 to 9 shows stress strain curves for acid contaminated soil. The stress strain curves are linear almost up to peak stress. It is interesting to note that though the peak stress is decreasing the strain corresponding to peak stress also decreases with increase in the concentration of acid. This indicates that the cementitious nature of the samples is not lost though the strength has decreased. Fig 10 shows the unconfined compressive strength for various hydrochloric, phosphoric and sulphuric acid concentrations for Suddha soil. It is observed the strength reduction starts even with a smaller acid concentration in the pore fluid and increases with increase in acid concentration. The reduction in strength is due loss of cohesion which has also been indicated by reduction of liquid limit of soil with increased acid contamination.

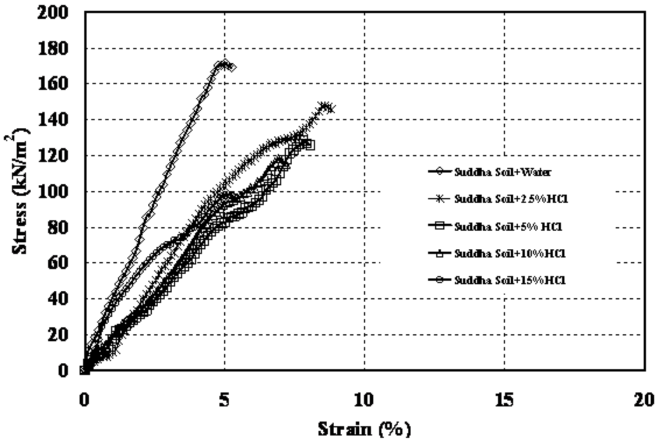

Fig. 7 Stress strain curves for hydrochloric acid contaminated soil

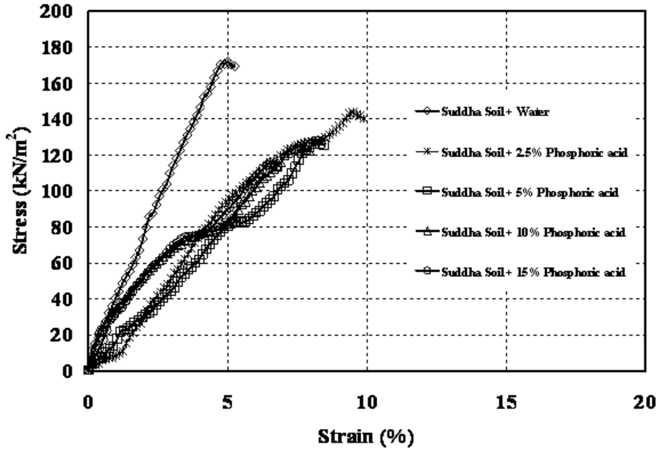

Fig. 8 Stress strain curves for phosphoric acid contaminated soil

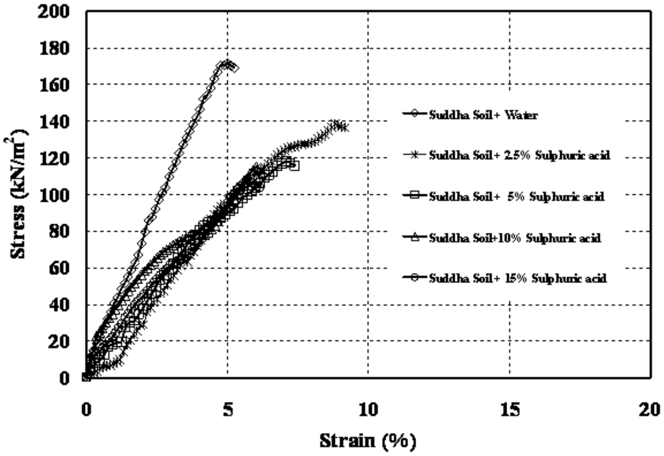

Fig. 9 Stress strain curves for sulphuric acid contaminated soil

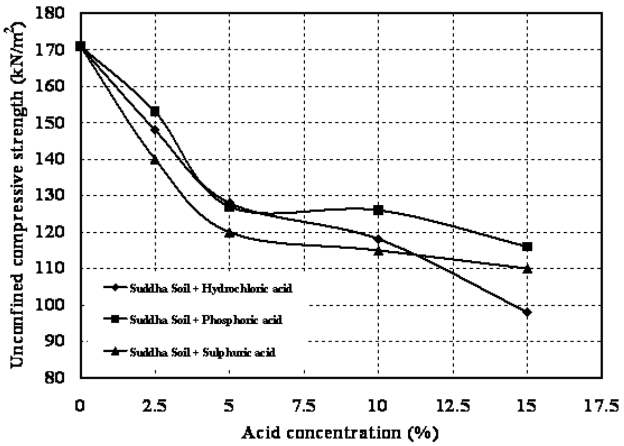

Fig. 10 Unconfined compressive strength for acid contaminated soil

VII. LIME STABILIZATION OF ACID CONTAMINATED SUDDHA SOIL

It is observed that acid concentration in the pore fluid reduces the unconfined compressive strength of Suddha soil. Hence an attempt is made to improve the strength of soil using lime as an additive to the contaminated soil. The contaminated soil was thoroughly mixed with 3 percent lime in dry condition. The compacted specimens for strength test were prepared at respective optimum moisture content and maximum dry densities corresponding to 5, 10 and 15 percent hydrochloric, phosphoric and sulphuric acid concentrations. The specimens were cured for 14 days by keeping in desiccators. Two sets of such specimens were prepared, one set was soaked in water and the other set was soaked in respective acid of similar concentration for 1 day and unconfined compression test was conducted. The stress strain curves for stabilized soil without neutralization hydrochloric, phosphoric and sulphuric acid contaminated soil are presented in Fig 10,11 and 12 respectively. It is observed that even after addition of 3 percent lime there is no considerable improvement in the peak strength of soil. Here again it was observed the strain corresponding to peak stress continuously decreases even through the peak stress decreases with increase in acid concentration.

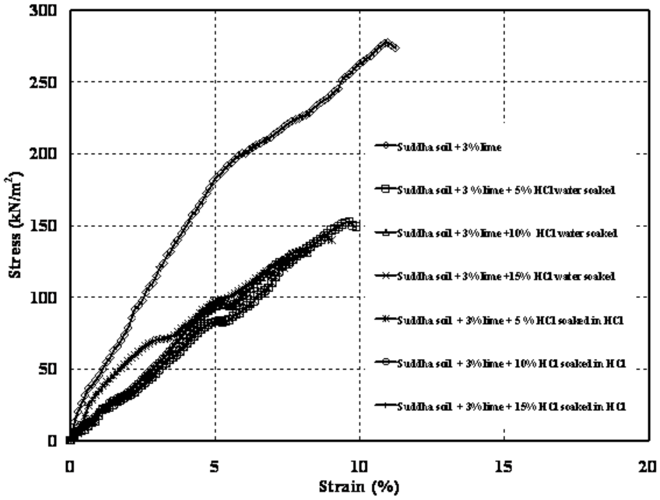

Fig. 10 Stress strain curves for stabilized soil without neutralization for hydrochloric acid contaminated soil

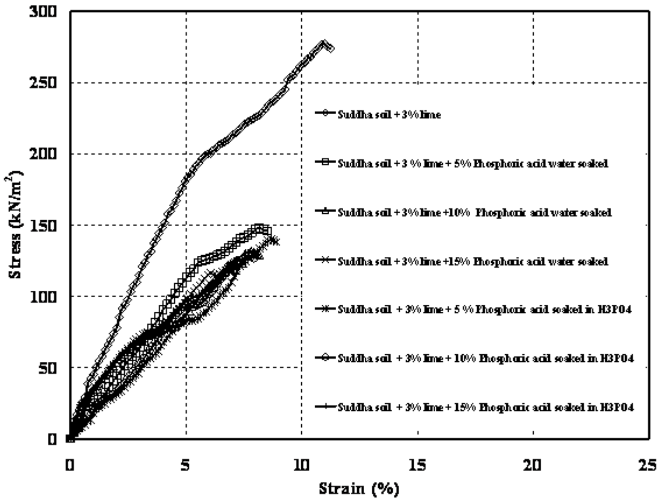

Fig. 11 Stress strain curves for stabilized soil without neutralization for phosphoric acid contaminated soil

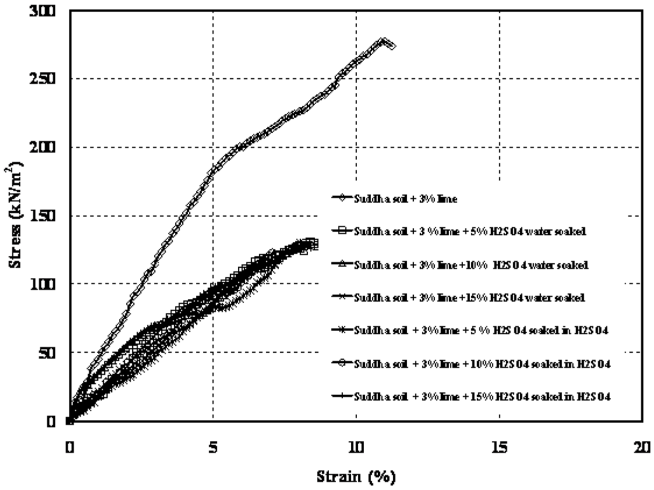

Fig. 12 Stress strain curves for stabilized soil without neutralization for sulphuric acid contaminated soil

I.PRE NEUTRALIZATION WITH LIME

It was observed that with addition of 3 percent lime there was no improvement in strength of soil. This might be due to non availability of reactive silica. It is known that silica dissolves only at higher pH. In the acidic environment silica does dissolve from soil and hence lime silica reaction can not proceed to produce calcium silicate gel. Hence soil was neutralized by adding lime to eliminate the acid effect. Lime required for neutralizing the effect of acids has been determined and shown in Table 2.

Table 2 Lime required for neutralization

Suddha soil + Acid	HCl (%)			H_3PO_4 (%)			H_2SO_4 (%)		
	5	10	15	5	10	15	5	10	15
Lime (%)	1	2	4	3	5	7	2	3	5

Unconfined compression strength test was carried out on acid contaminated Suddha soil using 3 percent lime after pre-neutralization with lime. The stress strain curves for stabilized soil with neutralization for hydrochloric, phosphoric and sulphuric acid contaminated soil are shown in Fig 13, 14 and 15 respectively.

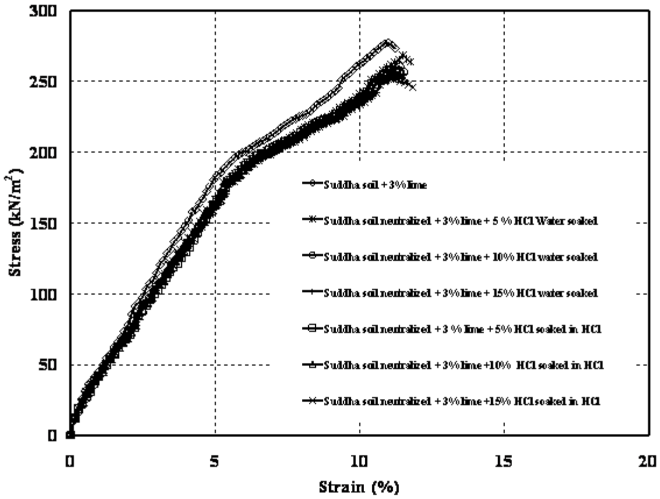

Fig. 13 Stress strain curves for stabilized soil with neutralization for hydrochloric acid contaminated soil

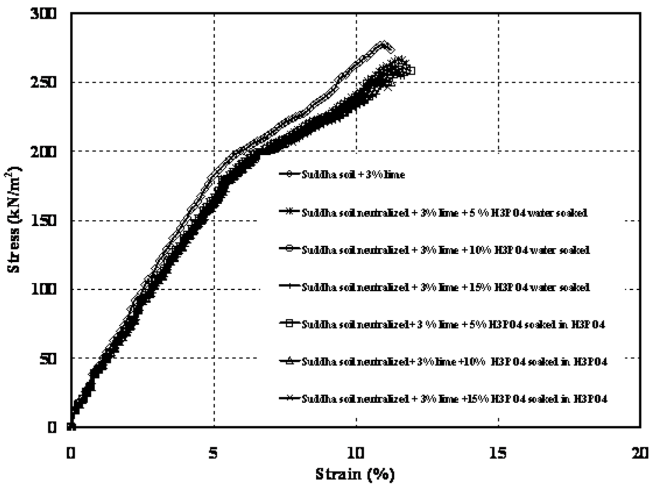

Fig. 14 Stress strain curves for stabilized soil with neutralization for phosphoric acid contaminated soil

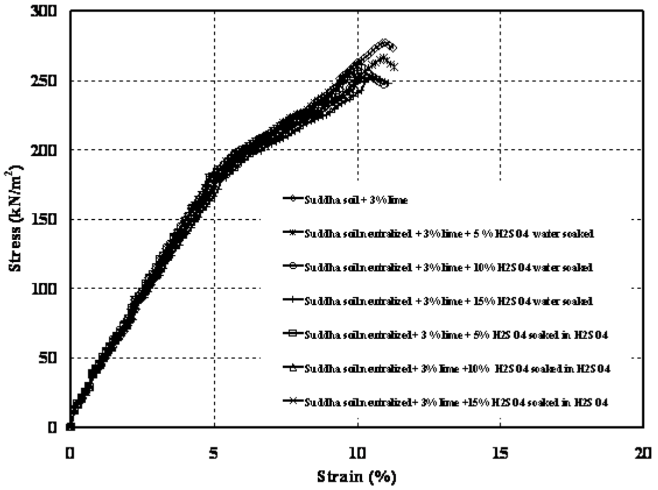

Fig. 15 Stress strain curves for stabilized soil with neutralization for sulphuric acid contaminated soil

It is observed that there is good development of strength with 3 percent lime after neutralization. It is interesting to note that even though the peak stress is increasing after addition of lime after neutralization the strain corresponding to peak stress is almost same as that for uncontaminated soil.

The results of the unconfined compression strength for untreated condition and soaked in water and hydrochloric acid with and without neutralization for hydrochloric, phosphoric and sulphuric acid contaminated soil are shown in in Fig 16, 17 and 18 respectively. It is observed that without neutralization there is no improvement in strength development with 3 percent lime. This confirms the hypothesis that the non development of strength in contaminated soil is due to non availability of silica. Once neutralized the silica is dissolved and is available for reactions with lime to produce cementitious compounds.

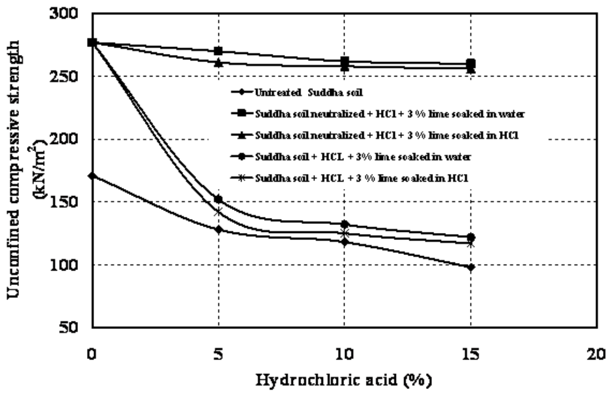

Fig. 16 Effect of lime on unconfined compressive strength of hydrochloric acid contaminated soil

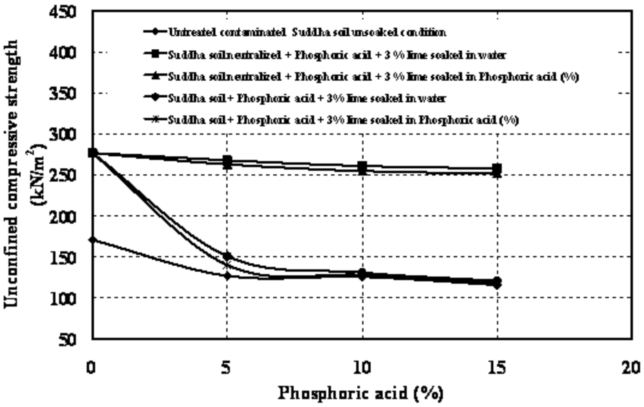

Fig. 17 Effect of lime on unconfined compressive strength of phosphoric acid contaminated soil

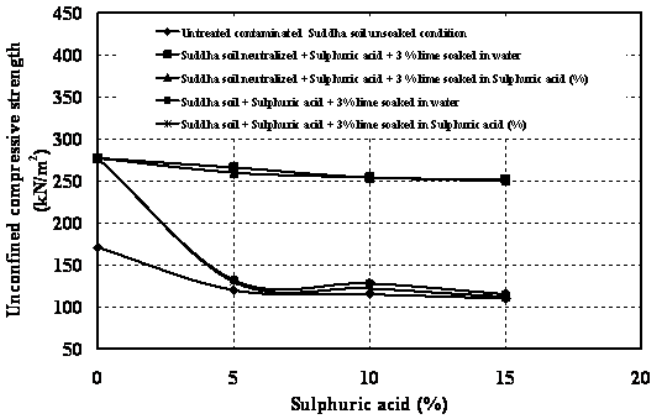

Fig. 18 Effect of lime on unconfined compressive strength of sulphuric acid contaminated soil

Further, the strength of soil treated with 3 percent lime is almost same as that of untreated soil. The effect of curing on the strength of contaminated, neutralized and with 3% lime is almost on par with uncontaminated soil after curing with 3% lime. The comparison of Young's modulus with unconfined compressive strength for Suddha soil is shown in Fig 8. It is generally seen that there is good correlation between Young's modulus and peak stress of soil under almost all conditions, viz., natural, contaminated, lime treated and lime treated after neutralization. However, the Young's modulus of contaminated soil is slightly lower than average line expected from their peak strength.

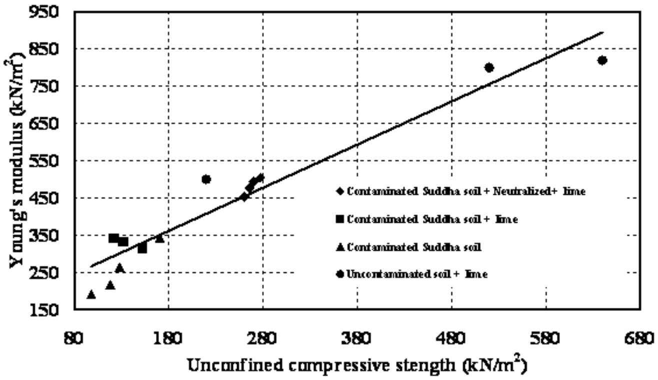

Fig. 19 Young's modulus with unconfined compressive strength for Suddha soil

VIII. CONCLUSIONS

Acid contamination reduces the strength of Suddha soil. Though the strength of soil has decreased there is no reduction in the strain corresponding to peak stress. Thus the modulus of elasticity is not reduced significantly. Lime addition of about 3 percent improves the strength of soil, but not for contaminated soil. This has been attributed to non availability of soluble silica at lower pH.The soil needs to be amended with addition lime corresponding to the amount required for neutralization which varies with the amount of contamination.The strength of lime treated contaminated soil is compared to that of uncontaminated soil treated with lime.

Good relationship is observed between the modulus of elasticity and unconfined compressive strength of contaminated soil and soil stabilized with lime.

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