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Mechanisms Controlling the Index Properties of Lime Treated Black Cotton Soil in the Presence of Sulphate

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Introduction

Use of lime for stabilization of fine grained soils is well known. Generally the plasticity, workability and strength properties of fine grained soils are improved by the addition of small quantities of lime (Bell, 1988a and 1988b; Diamond and Kinter, 1965). The mechanism controlling the properties of the lime stabilized soils are well investigated. Also many other chemicals like NaOH, NaCl and Gypsum have been used along with lime to further enhance the beneficial effect of lime addition. (Davidson et al., 1960; Dan Marks and Halliburton, 1970; Holm et al., 1983; Kujala, 1983). While the presence of sulphate in untreated soils and in cement treated soils (Sherwood, 1962) is known to adversely affect the volume stability of the soils, it was considered that its presence is safe enough for lime stabilization of soils. Thus calcium sulphate in the form of gypsum has been in fact used to enhance the properties of lime treated soils. But, Sherwood observed that cracking and swelling in specimens of heavy clays stabilized with 10% lime and cured at constant moisture content for one week when immersed in solutions of either sodium sulphate or magnesium sulphate at concentrations

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below 1.5% as SO_3. Also it has been reported recently that the presence of sulphate in the soil can result in loosing the beneficial effect of stabilizing the soil with lime. After elapsed time, the soil became an expansive soil and causes heave (Dal Hunter, 1988). The causes of this heave in the presence of sulphate in lime treated soils are not understood clearly. While the effect of lime on the properties of soils has been well investigated, very limited data is available on the effect of presence of sulphate (whose occurrence in soils upto about 3% is not very uncommon) on the properties of lime stabilized soils. While deleterious effects of presence of sulphates are known on untreated and cement stabilized soils, the effects of sulphate on lime stabilized soils are not well reported till recently. As part of a general programme on the presence of sulphate in lime stabilized black cotton soil has been investigated and presented in this paper.

Experimental Programme

a) Soil Tested

Naturally available black cotton soil was chosen for the study. This soil has been obtained from Davanagere, Karnataka State, India, containing expansive montmorillonite as the principle clay mineral. It may be noted that the natural soil did not contain any sulphate. The physical properties are listed in Table 1.

b) Chemical Used

The chemicals used in the present study are calcium sulphate, sodium sulphate and calcium hydroxide. Calcium hydroxide was obtained from Glaxo

TABLE 1
Physical Properties of BC Soil

Liquid Limit (%)	79.0
Plastic Limit (%)	36.0
Shrinkage Limit (%)	8.60
Free Swell Index (cc/g)	2.10
Specific Gravity	2.70

Laboratories and other chemicals were obtained from SOS Fine Chemicals (India).

c) Treatment of Samples

The physical properties of black cotton soil mixed with 0%, 0.5%, 1% and 3% of Sodium and calcium sulphate and treated with 6% of lime for each mixing of sulphate were determined both immediately after mixing and after curing for one week, one month, three months, and one year at room temperature.

d) Tests Conducted

(i) **Liquid limit** : The liquid limit was conducted by using cone penetration method (BS 1377 – 1975)

(ii) **Plastic limit** : Plastic limit was conducted as per IS Procedure IS:2720 (Part V) – 1970.

(iii) **Shrinkage limit** : This test was conducted as per IS Procedure IS:2720 (Part VI)) – 1972.

Results and Discussions

For black cotton soil, 6% of lime has been found out to be optimum content. The optimum lime content was determined based on maximum decrease in plasticity index with increasing lime content (Bell, 1988a). The effect of presence of sulphate in various concentration on the index properties both immediately and after curing for a specified period have been studied (Table 2).

Liquid limit behaviour

Since liquid limit test has been carried out on lime treated black cotton soil (Nagaraj et al., 1991; Worth et al., 1978).

Mechanisms controlling the liquid limit behaviour of clays was a subject matter of many investigations (Warkentin, 1960; Nagaraj and Somashekar, 1969; Scott, 1963). Based on detailed investigations Sridharan and Venkatappa Rao (1975) concluded that the liquid limit of clays is

TABLE 2
Basic Properties of Lime Treated Black Cotton Soil Cured with Sulphate Contents

Mixture	Property (%)	1 day	7 days	30 days	90 days	365 days
BC Soil alone	L.L.	79.0	79.0	79.0	79.0	79.0
	P.L.	36.0	36.0	36.0	36.0	36.0
	P.I.	43.0	43.0	43.0	43.0	43.0
	S.L.	8.60	8.60	8.60	8.60	8.60
BC + 6% Lime	L.L.	68.0	101.0	100.0	98.0	98.0
	P.L.	53.5	64.5	68.5	68.0	-
	P.I.	14.5	36.5	31.5	30.0	-
	S.L.	35.6	45.4	45.4	45.0	48.0
BC + 6% Lime + 0.5% Na_2SO_4	L.L.	78.6	97.0	106.0	114.0	116.0
	P.L.	56.0	61.0	68.0	77.6	81.0
	P.I.	22.6	36.0	38.0	36.4	35.0
	S.L.	35.1	40.8	42.0	41.5	46.0
BC + 6% Lime + 1% Na_2SO_4	L.L.	78.9	122.5	116.0	116.1	116.1
	P.L.	52.5	73.0	62.2	-	75.0
	P.I.	26.4	49.5	53.8	-	41.1
	S.L.	35.1	40.0	42.0	41.5	46.0
BC + 6% Lime + 3% Na_2SO_4	L.L.	82.7	137.5	119.5	120.0	120.3
	P.L.	53.2	87.6	66.5	77.0	73.5
	P.I.	29.5	49.9	53.0	43.0	46.8
	S.L.	33.0	46.3	46.0	46.0	27.5
BC + 6% Lime + 0.5% $CaSO_4$	L.L.	70.0	86.0	88.0	89.0	91.5
	P.L.	53.5	61.5	63.0	63.0	63.7
	P.I.	16.5	24.5	25.0	26.0	27.8
	S.L.	36.1	41.0	43.0	42.5	28.0
BC + 6% Lime + 1% $CaSO_4$	L.L.	73.0	93.0	93.6	95.0	96.5
	P.L.	56.0	63.0	63.6	64.0	65.3
	P.I.	17.0	30.0	30.0	31.0	31.4
	S.L.	38.0	46.0	47.0	46.0	40.6
BC + 6% Lime + 3% $CaSO_4$	L.L.	76.0	100.0	101.5	101.0	98.5
	P.L.	57.0	62.5	64.0	63.0	72.0
	P.I.	19.0	37.5	37.5	38.0	26.5
	S.L.	39.5	49.5	49.5	49.0	27.6

primarily controlled basically by two mechanisms :

(I) Shearing resistance at particle level.

(II) The thickness of diffuse double layer.

For non expanding lattice type of clay like kaolinite the contribution due to thickness of diffuse double layer is insignificant and the liquid limit is primarily controlled by mechanism (I). Though the liquid limit of montmorillonite is also governed by the shearing resistance at particle level, the water content due to the diffuse double layer over rides and primarily governs the level of the liquid limit. Addition of lime or any other salt which decreases the thickness of diffused double layer because of increased valency of the exchangeable ion or in the increase in the electrolyte concentration (Sridharan and Jayadeva, 1982) brings down the liquid limit. But, the increased attractive force which causes flocculation as in the case of curing with lime, increases the liquid limit of soils containing montmorillonite clay (Venkatappa Rao and Rekhi, 1977).

Thus the addition of lime decreases liquid limit of black cotton soil immediately because of replacement of exchangeable ions particularly monovalent ions, by calcium ions (Sherwood, 1962; Taylor et al., 1960). Replacement of monovalent ions by divalent ions decreases the thickness of the diffused double layer leading to decrease in the water holding capacity. However, with curing period, flocculation of clay particles occur and the liquid limit increases because of increased water holding capacity.

In the presence of 0.5% of Na_2SO_4 the liquid limit of lime treated black cotton soil increases (from 78.9% to 116%) immediately and after curing for one year respectively (Fig. 1). The increase is higher with higher concentration of Na_2SO_4. Obviously, the significant increase in liquid limit of lime treated black cotton soil cannot be due to electrolyte effect since increased electrolyte concentration can only lead to decrease in the liquid limit due to depression of diffuse double layer (Sridharan et al., 1986). It may not also be due to increased flocculation of already flocculated lime treated soil. In fact, some of the Na_2SO_4. can only get converted into insoluble $CaSO_4$ and thus effectively reducing the available lime. This leads to decreased flocculation in presence of Na_2SO_4 compared with lime alone. Hence the increase can only be attributed to increase in the water holding capacity due to formation of new compounds formed in the presence of sulphate which are different from reaction products of lime and soil. Actually, the formation of swelling type of compound by reaction of silica, lime and sulphate was demonstrated in the case of cement mortar (Sherwood, 1958). The new compounds may be of ettringite type which swell in the presence of water (Dal Hunter, 1988).

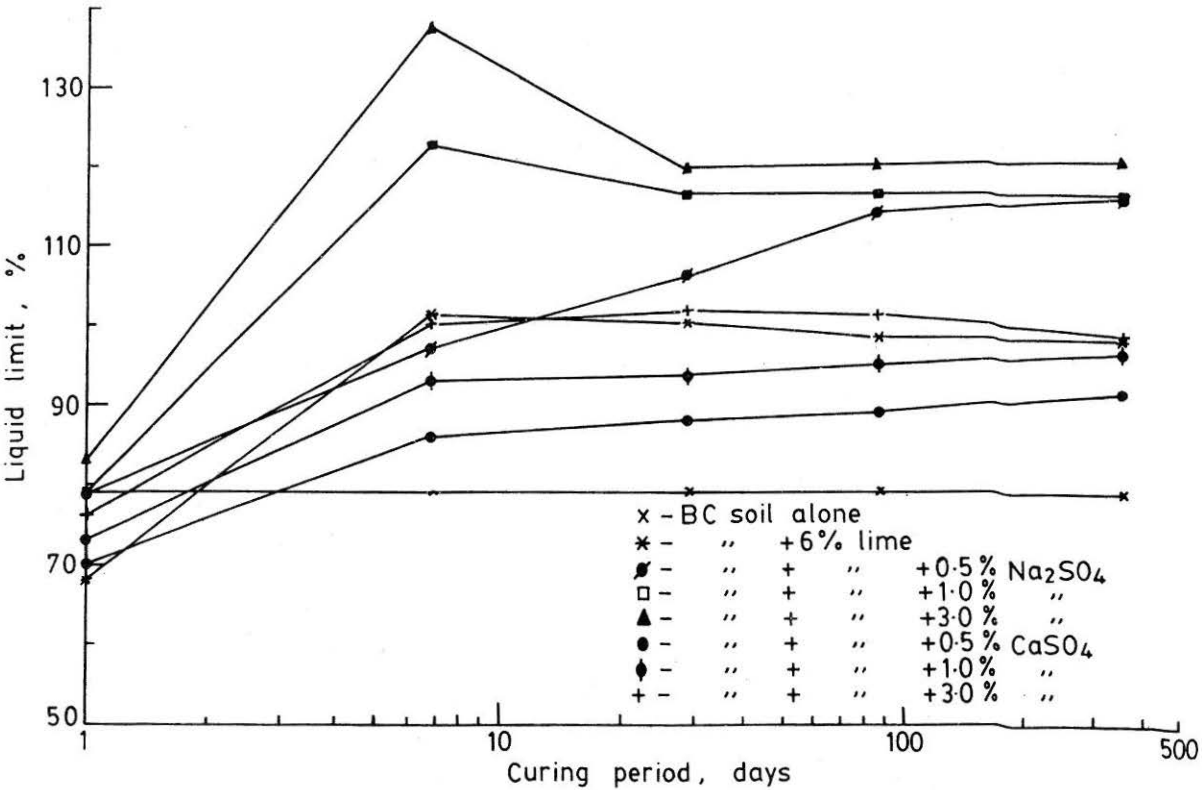

FIGURE 1 : Effect of Sulphates on the Liquid Limit Behaviour of Lime Treated Black Cotton Soil with Curing

With increase in curing period beyond one week liquid limit decreases for lime treated black cotton soil with high conc of Na_2SO_4. However, it reaches an equilibrium value after about 1 month. This may be due to decrease in the strength.

In the presence of high percentages of 3% of calcium sulphate the liquid limit of lime treated black cotton soil is higher, than with lime alone. Whereas in the presence of 0.5% and 1% of calcium sulphate the liquid limit of lime treated black cotton soil is lesser than with lime alone. The liquid limit of lime treated black cotton soil is higher with Na_2SO_4 than with the same percentage of $CaSO_4$. This further confirms that the changes in the presence of sulphate cannot be due to electrolyte concentration and flocculation but only due to alteration of the composition of cementaceious gel formed by soil-lime reactions in the presence of sulphate.

Plastic limit

Increase in the salt concentration and replacement of low valence cation by higher valence cation leads to decrease in the diffused double layer thickness and vice versa. Decrease in diffused double layer thickness of clay particles leads to increase in the shearing resistance at particles level which leads to increased plastic limit.

Depending on the attractive and repulsive forces, the fabric of clay varies also with the changes in the exchangeable cation and salt concentration. Depending upon the particles arrangement size and shape of the pores vary. Thus the flocculated structure will have higher plastic limit.

Immediately on addition of 6% lime, the plastic limit of black cotton soil increases from 36% to 53.5%. Upon curing for one year with 6% of lime, the plastic limit further increases to about 68% (Fig. 2). The initial increase is due to decrease in the diffuse double layer thickness. The increase in the plastic limit with curing is because of flocculation of the clay particles with curing period. Additional of 0.5% of sodium sulphate marginally increases the plastic limit of black cotton soil with 6% of lime. This indicates that addition of 6% of lime itself decreased the thickness of the diffused double layer and addition of 0.5% sodium sulphate cannot bring about further decrease. Thus, even increase in the concentration of sodium sulphate immediately has no influence on the plastic limit of lime treated black cotton soil. But, curing with 0.5% sodium sulphate for one year increases the plastic limit to 81%. It has been brought out that, curing with sulphate, the lime treated black cotton soil produces swelling type of compounds. The increase in plastic limit with curing may also be due to the same reason. Thus curing with increase in concentration of sodium sulphate also increase

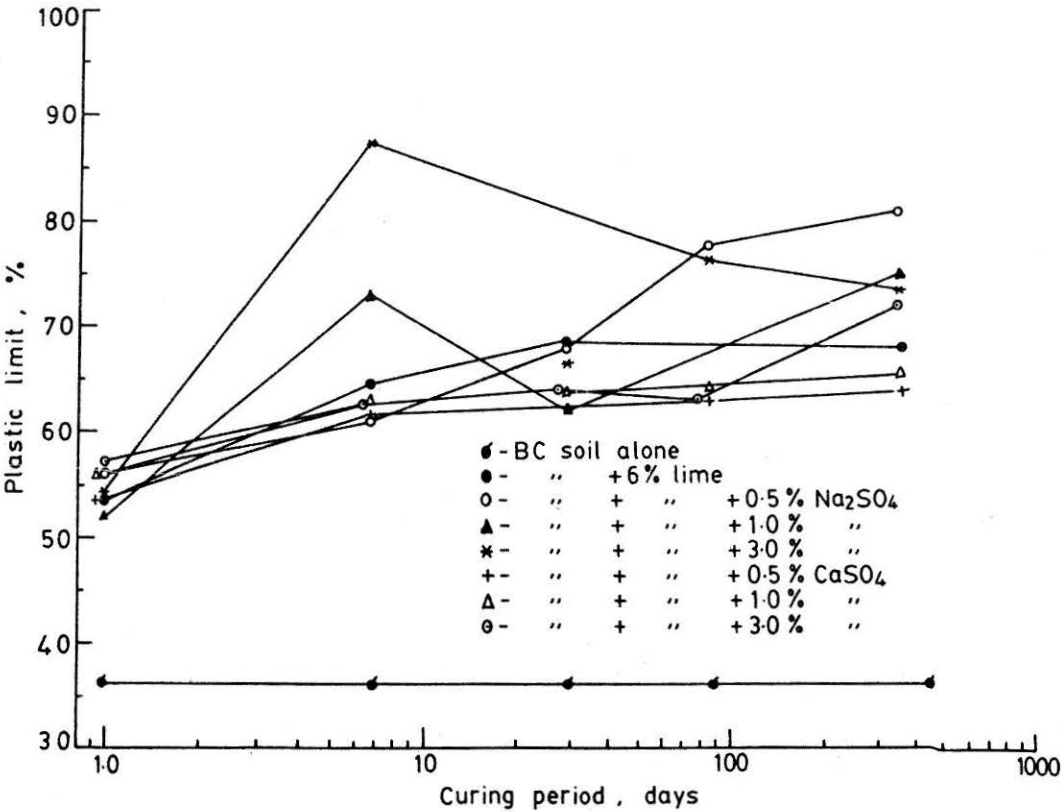

FIGURE 2 : Effect of Sulphates on the Plastic Limit Behaviour of Lime Treated Black Cotton Soil with Curing

the plastic limit. Qualitatively, the changes in plastic limit of lime treated black cotton soil are similar to those obtained in the case of sodium sulphate. The percentage of sulphate and curing period being the same, the plastic limits of lime treated black cotton soil by and large are lower in the case of calcium sulphate than with sodium sulphate.

Plasticity index

The plasticity index of black cotton soil reduces on addition of 6% of lime (Fig. 3). However, it increases with curing upto one week and slightly reduces with further curing. Presence of any concentration of Na_2SO_4 or $CaSO_4$ increases the plasticity index of lime treated black cotton soil immediately. The increases is more in the presence of Na_2SO_4 than with $CaSO_4$. Presence of Na_2SO_4 or $CaSO_4$ increases the plasticity index with increasing concentration. However, with curing the plasticity index of lime treated black cotton soil with any concentration of Na_2SO_4 is higher than the plasticity index of lime treated soil alone. The plasticity index of lime treated black cotton soil in the presence of $CaSO_4$ is equal to or lower than the plasticity index of lime treated black cotton soil alone. Thus it is interesting to note that presence of Na_2SO_4 or $CaSO_4$ brings out opposing effects on the plasticity index of lime treated black cotton soil with curing. Generally, reduction in plasticity index is desirable as it increases the workability. Compared with untreated black cotton soil, lime treated black cotton soil and lime treated black cotton soil in the presence of $CaSO_4$ gives lower values whereas lime treated black cotton soil in the presence of sodium sulphate gives higher values. This again confirms that the effect of presence of sulphate on lime treated soils cannot be due to increased electrolyte concentration.

Based on the liquid limit and plasticity index, the soils can be classified using Casagrande classification chart. The untreated black cotton soil which is on the border line between silt and clay of medium compressibility. By treating with lime, it changes it classification to MH (silt of high compressibility). Curing the lime treated soil in the presence of sulphate changes the classification to CH (clay of high plasticity). Since the properties can generally correlated with the classification of soil, it can be said that engineering properties of soils vary significantly in the presence of sulphate for lime-treated black cotton soil.

A good correlation exists between plasticity index and liquid limit of all lime treated soils in the presence of various concentration of sulphates (Fig. 4). The relationship can be written as

$$PI = 0.537\,LL - 18.73$$

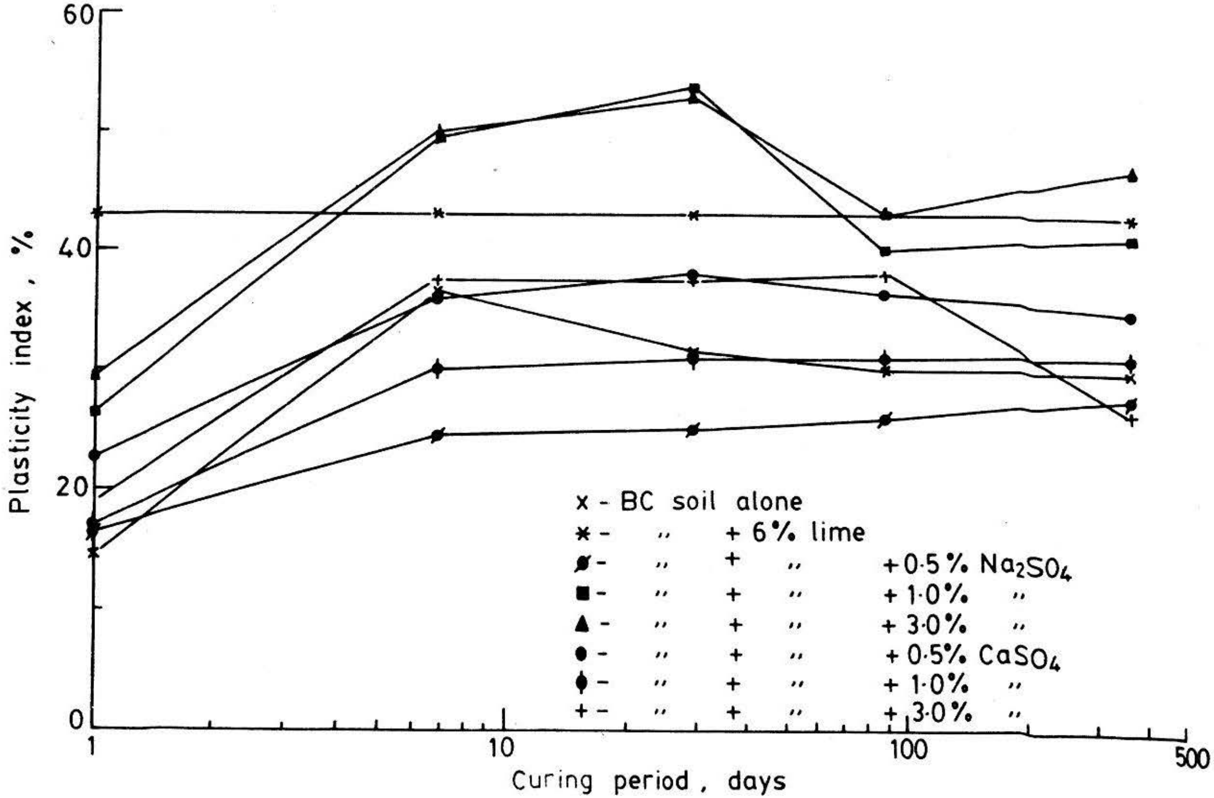

FIGURE 3 : Effect of Sulphates on the Plasticity Index Behaviour of Lime Treated Black Cotton Soil with Curing

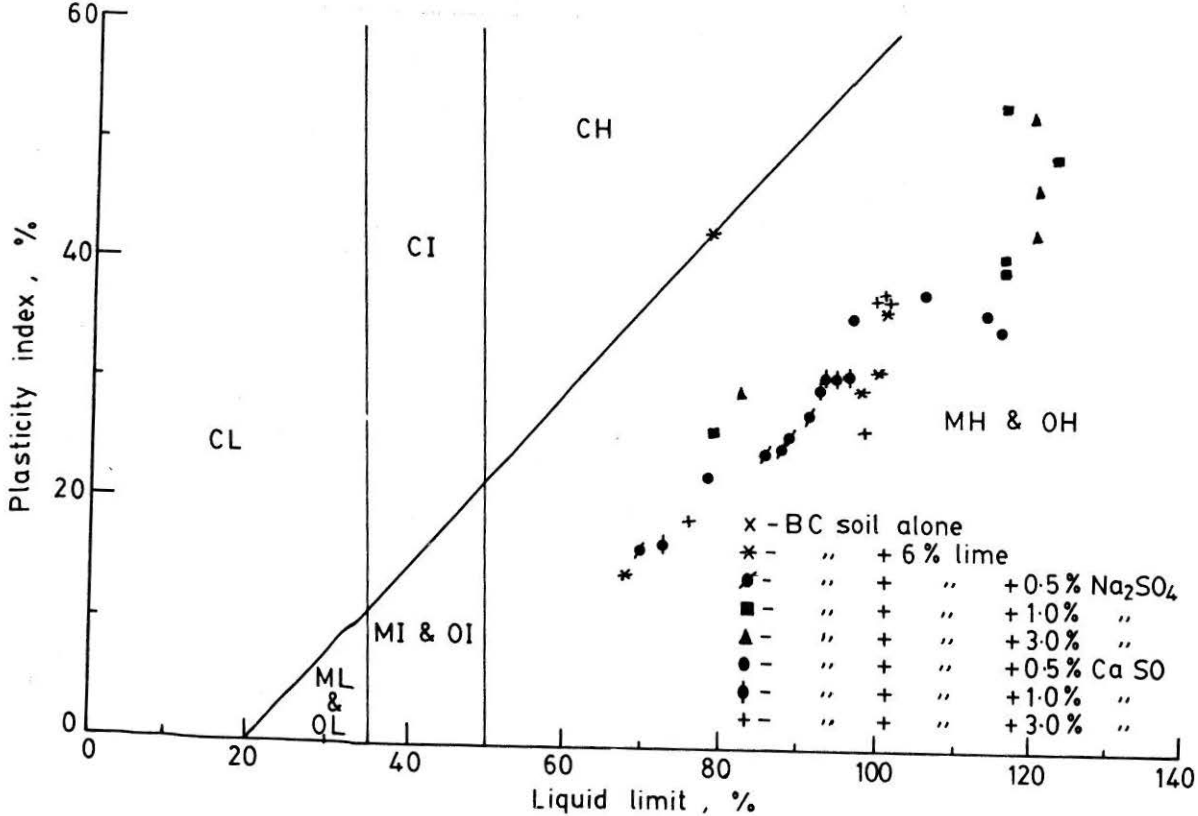

FIGURE 4 : Classification of Lime Treated Black Cotton Soil in the Presence of Sulphates with Curing

with a correlation coefficient of 0.872.

This indicates that all arguments given for variation in liquid limit could also be valid for Plasticity index.

Shrinkage limit

Lambe (1958), has shown that shrinkage limit is an extremely useful parameter in qualitatively identifying the soil fabric. Seed et al. (1960), have shown that a soil with relatively parallel array should undergo more reduction upon drying than a soil with its particles in relatively random orientation. Flocculated fabric yields a higher shrinkage limit and dispersed fabric a lower shrinkage limit. When attractive force is more higher will be the shrinkage limit and when repulsive force is more the fabric is relatively oriented and gives lower shrinkage limit. Thus the shrinkage limit of the black cotton soil which is 8.60% increases to about 35.6% on addition of lime. This further increases with curing period to about 48%. This is due to increase in the attractive forces, particles leading to flocculation of clay particles.

Presence of sodium sulphate decreases the shrinkage limit of lime treated black cotton soil immediately as well as with curing period. The decrease is particularly very high after curing beyond six months with high percentages of sodium sulphate. The decrease in shrinkage limit indicates that the swelling type of compounds might have been formed. This may be due to the formation of increased concentration of swelling type of compounds. As brought out earlier, presence of sodium sulphate gradually increases repulsive forces and leads to decrease in the shrinkage limit particularly after curing for long periods (Fig. 5). Presence of $CaSO_4$ increases slightly the shrinkage limit of lime treated black cotton soil. With curing the shrinkage limit increases upto one week and reduces slightly with three months of curing. Again here also, after curing for one year the decrease in shrinkage limit is very high at all percentages of calcium sulphate. The shrinkage limits of lime treated black cotton soil are lower in the presence of 3% of Na_2SO_4 and are lower than with 3% of $CaSO_4$. But, at 0.5% and 1% of sulphate content, the decrease is more with calcium sulphate than with sodium sulphate at high curing period. This shows that the formation of an undesirable compounds are slower with calcium sulphate than with sodium sulphate. But, after formation it is more damaging.

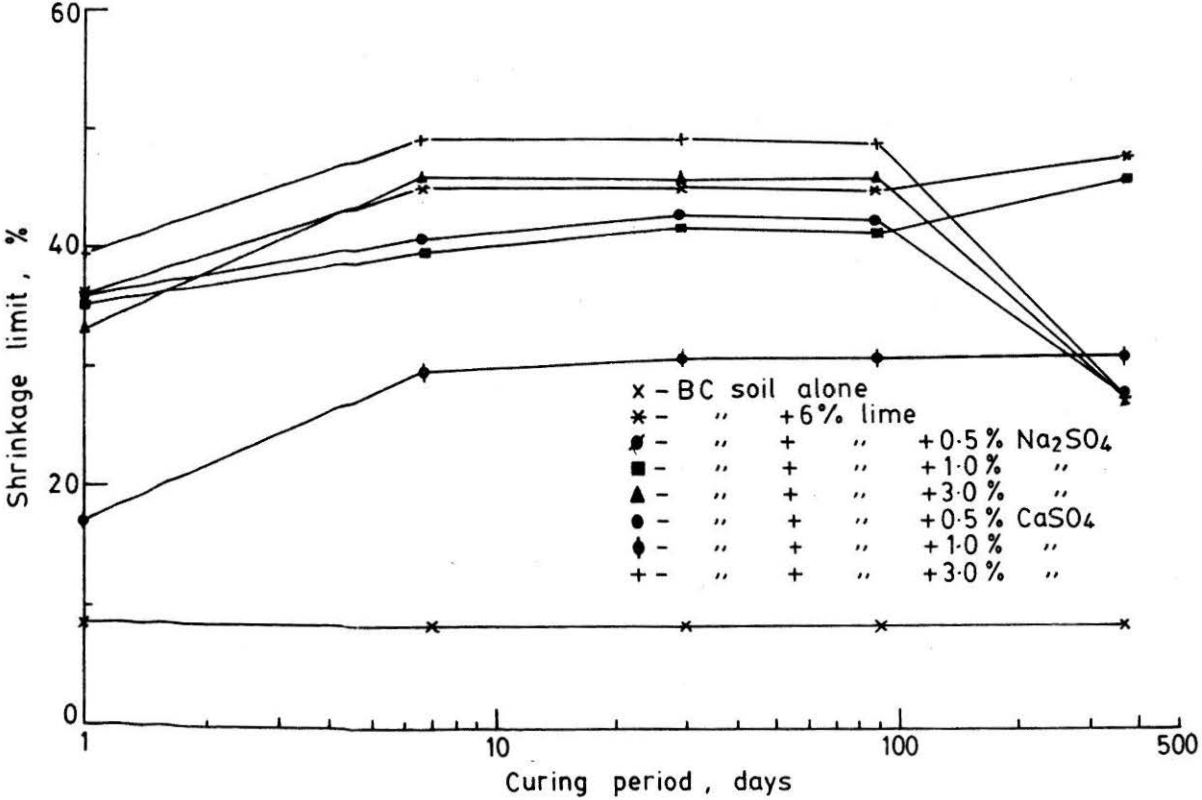

FIGURE 5 : Effect of Sulphates on the Shrinkage Limit Behaviour of Lime Treated Black Cotton Soil with Curing

Conclusions

Based on this study, the following conclusions are drawn:

1. Unusual increase in liquid limit of lime treated expansive soils occurs in the presence of high concentrations of sulphate. The increase in the liquid limit is more in the presence of Na_2SO_4 than with $CaSO_4$. With same type of sulphate the increase is more with increase in concentration.

2. Normally lime treatment reduces the plasticity index of the soils, whereas the same in the presence of sulphate increases the plasticity index which is undesirable from the workability and strength point of view.

3. Presence of Na_2SO_4 decreases the shrinkage limit significantly of lime treated black cotton soils, whereas in the presence of $CaSO_4$ it increases slightly. However, with curing period, shrinkage limit gets reduced, the decrease is substantial in the presence of Na_2SO_4. This has been attributed to formation of swelling type of compounds.

4. Presence of Na_2SO_4 causes more undesirable effects than $CaSO_4$.

5. The changes in the properties of soils, in the presence of lime and sulphate can be successfully explained based on the changes in the attractive and repulsive forces and type of reaction products formed.

6. This study brings out the significant role of presence of sulphate in natural fine grained soils from lime stabilization view point.

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