Indian Geotechnical Journal, 27 (4), 1997

The Role of Dolomitic Impurity on the Properties of Lime Treated Soil

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Introduction

Soil stabilization by various methods involves the alteration of properties of soil-water-air system, to those desired for a particular application. Since lime is a product that can be manufactured cheaply, it has been widely used to stabilize soils. Lime as a soil additive, brings several beneficial changes to soil containing silt and clay particles (Thompson, 1966). The mechanism of lime stabilization of soils is well understood. Many factors, soil gradation, type and amount of clay minerals present, organic matter, nature of exchangeable ions, pH, moisture content, temperature, curing period and type and amount of lime affect soil-lime stabilization (Bell, 1988). Relatively the effect of type of lime is least known. Chemically lime can be quick lime or hydrated lime. Quick limes are more effective than hydrated limes for stabilization of soils. The effect of various admixtures are well studied (Davidson et al., 1960). The effect of impurities of lime on stabilization of soils is not known. A common impurity in lime stone (calcite) is magnesium carbonate in dolomitic rocks which yield dolomitic lime. i.e., lime with magnesium oxide content. The degree to which a lime is calcitic or dolomitic can be expressed by calcium-magnesium ratio. There is conflicting evidence of the effect of magnesium oxide in the stabilization of soils. Mateos (1964) reported that calcite limes are more effective in the modification and dolomitic limes are more effective in the cementation. This conclusion was reached

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based on results obtained with dolomitic lime containing a particular MgO content. Hence it is proposed to study, in this paper, the effect of different MgO contents in the calcitic lime in the stabilization of soils.

Experimental Programme

Soil used

Naturally occurring black cotton soil obtained from Davanagere, Karnataka State was used. This is a highly swelling soil with high plasticity. The soil was collected by open excavation from a depth of one meter from natural ground level. The soil dried and passed through IS sieve of 425 micron. The physical and chemical properties of soil are listed in Table 1. The reason for selecting this soil is that it requires modification of properties.

Chemicals used

Chemically pure calcium hydroxide and magnesium oxide were obtained from Glaxo Laboratories and SOS Fine Chemicals (India) respectively.

Table 1
Properties of Black-Cotton Soils

Liquid Limit, %	81.0
Plastic Limit, %	33.5
Plasticity Index, %	47.5
Shrinkage Limit, %	8.8
Base Exchange Capacity, meq/100g	
Sodium	2.3
Potassium	0.5
Calcium	16.2
Magnesium	10.4
Total	29.1

Index properties

Black cotton soil was mixed with required quantities of lime and/or MgO and water was added to bring the soil to about liquid limit consistancy and thoroughly mixed. The total quantity of additive was kept constant at 6%. Atterberg limits of the treated soil were determined immediately and after curing for one week as per the standard procedures.

(i) Liquid limit : The liquid limit test was conducted using cone penetration method as per BS:1377-1975.

(ii) Plastic limit : Plastic limit was determined as per IS:2720(Part-V)-1970 method.

iii) Shrinkage limit : Shrinkage limit was obtained as per IS:2720(Part-VI)-1972 method.

(iv) Free Swell Index : The test was done as per the procedure of Sridharan and Rao (1985).

The soil was poured into 100ml graduated cylinders containing about 40 ml of distilled water. The cylinders were stoppered and left undisturbed for the suspension to settle. The equlibrium sediment volume was recorded for 7 days taking the readings for every 24 hours.

Consolidation test

The soil with additive was brought to liquid limit consistency and hand molded into the consolidation rings of 76.2 mm dia and 3.81 mm height and trimmed. Bottom and top filter papers were placed. The ring was then placed on a 10mm thick porous stone. A top cap with bottom being porous was placed above the top of the soil sample. The entire assembly was mounted in the consolidation cell and positioned with loading frame. After equilibrium has attained as indicated by nearly constant readings in the vertical dial, pressure increment was applied. A pressure increment ratio of unity was adopted with each pressure being maintained for two days. In case of unloading, one day was maintained for each pressure decrement.

Vane shear test

Vane shear tests were conducted on soil with 5% lime + 1% MgO and on soil with 6% lime without any curing period. The soil was mixed with required quantity of additive and with sufficient water and remould into the container and trimmed. The sample container was kept on the base of the vane shear apparatus and clamped firmly. The shear vane was lowered gradually without disturbing the soil sample so that the top of the vane is atleast 10mm below the top of the sample. The maximum pointer was brought in contact with the strain indicating pointer. Torque was then applied until the specimen failed, which is indicated by the return of the strain indicating pointer. The difference between initial and final readings of maximum pointer gives the angle of torque of spring in degrees and multiplied by spring constant gives the torque applied. Using this torque, strength of the soil was calculated.

Triaxial test

For trixial shear test, soil and chemical mix was prepared with water content nearly equal to its liquid limit. This wet soil was remolded in steel tubes having internal diameter of 38.1mm and height of 150mm. These filled tubes were covered with polythene bags and were kept in a air tight container to prevent the further loss of moisture and carbonation. After the remolded samples gain strength, samples were extruded with help of sample extractor. These extracted samples were trimmed flat and normal to its axis to a height of 76.2mm. These individual samples were covered with a wet cotton cloth, and were stored in a air tight plastic container for curing.

For testing the samples GDS triaxial system was used, the system having the triaxial cell of Bishop-Wesley type. In this test drainage was allowed from top and bottom of the sample. To increase the rate of consolidation vertical drainage has been provided in the form of 5mm width filter paper strips. To prevent the clogging of porous stones, two filter paper strips were provided between soil and porous stones. Top of the sample was connected to one of the digital controller, which is a microprocessor controlled hydraulic actuator for the precise regulation of liquid pressure and liquid volume change. Then trixial cell was filled with distilled water. Digital controllers were connected to cell pressure application valve and back pressure application valves.

The sample was saturated by back pressure technique. This was done by applying 50kPa of back pressure with an effective cell pressure of only 5kPa. After saturating the sample, top drainage valve was closed and cell pressure was raised to desired value. Plunger was adjusted in such a way that it must be in contact with the ball arrangement of the top cap. The compressive force was applied at a constant rate of axial strain by raising the pedestal with hydraulic pressure. Readings of deviator stress, pore pressure and axial strains were taken. The test was repeated on three/four identical samples under the effective cell pressures of 50kPa to 400kPa.

Results and Discussions

It was found out that 1% ef lime is the lime fixation point and 6% of lime is the optimum lime content for black cotton soil containing about 35% of predominantly montmorillonitic clay. (Hult and Davidson, 1960; Metcalf,

Table 2

Effect of Lime and Magnesium Oxide on Index Properties of Black Cotton Soil

	Liquid Limit (%)		Plastic Limit (%)		Plasticity Index (%)		Shrinkage Limit (%)		Free Swell Index (cc/gm)	
	Curing Period (in days)									
	0	7	0	7	0	7	0	7	0	7
BC + No additives	81.0	81.0	33.5	33.5	47.5	47.5	8.8	8.8	2.15	2.15
BC + 6% Lime	68.0	101.0	53.5	64.5	14.5	36.5	31.8	45.4	2.70	4.15
BC + 5% Lime + 1% MgO	69.0	78.3	48.9	55.1	20.1	23.2	28.8	39.9	2.35	3.55
BC + 4% Lime + 2% MgO	73.1	84.0	52.0	56.0	21.1	28.0	26.3	32.7	2.25	3.20
BC + 3% Lime + 3% MgO	76.1	84.8	53.2	58.9	22.9	25.9	20.4	27.1	2.15	3.00
BC + 2% Lime + 4% MgO	81.4	87.2	55.8	60.8	25.6	26.4	15.1	20.9	2.18	2.77
BC + 1% Lime + 5% MgO	86.1	89.0	52.5	56.5	33.6	32.5	12.3	15.6	2.20	2.30
BC + 6% MgO	88.7	92.0	51.4	55.1	37.3	36.9	10.8	9.6	2.30	2.10

1972). The lime fixation point and optimum lime content were determined based on maximum plastic limit and lowest plasticity index respectively. The effect of substitution of lime by MgO keeping the total additive as 6%, on the properties of black cotton soil is discussed.

Index Properties

The effect of gradual substitution of lime by MgO on the index properties of black cotton soil without any precuring and after 7 days of curing is shown in Table 2.

When lime is replaced by magnesium oxide in the total quantity of additive, keeping the total admixtures added (lime + magnesium oxide) to 6%, the liquid limit of black cotton soil increases, without any curing, with increasing percentage of magnesium oxide (Fig. 1). The liquid limit of the soil decreases immediately on addition of lime due to cation exchange and increased electrolyte concentration. Substitution of lime with MgO offsets this decrease, may be due to quick flocculation, by magnesium oxide. Hence the liquid limit of black cotton soil increases with MgO content without curing. The effect of curing, which increases the liquid limit, is maximum with 6% lime and least with 6% MgO. The effect of curing decreases with MgO content. The liquid limit of soil in the cured samples is maximum with 6% lime and is lower with any MgO content.

Plastic limit of black cotton soil is not much affected by substitution of lime by magnesium oxide (Table 2). The small variations in the fabric of the clay particles do not influence the plastic limit of the soil. Also, on curing, the plastic limit is unaffected except in the case of black cotton soil treated with lime alone. This also confirms that maximum flocculation occurs with lime alone. Since plastic limit is not affected much, the variation of plasticity index follows the same trend to that of variation in liquid limit.

Any substitution of lime with magnesium oxide decreases the shrinkage limit (Fig. 2). However, it was shown that substitution of lime with magnesium oxide has increased the liquid limit. The decreased shrinkage limit indicated that the increased flocculation is not sufficiently bonded to resist the capillary stresses. On curing, the increase in shrinkage limit increases with increase in lime content. There is no effect of curing with MgO alone. This further confirms that the effects of lime are more significant than those of magnesium oxide.

Lime addition increases the free swell index of soil. As lime is substituted by magnesium oxide the free swell index of soil, decreases both with and without any curing time (Fig. 3). The immediate effect of substitution of lime by magnesium oxide which causes flocculation (indicated by increase in liquid limit) is not seen here. This is because, as indicated earlier, the

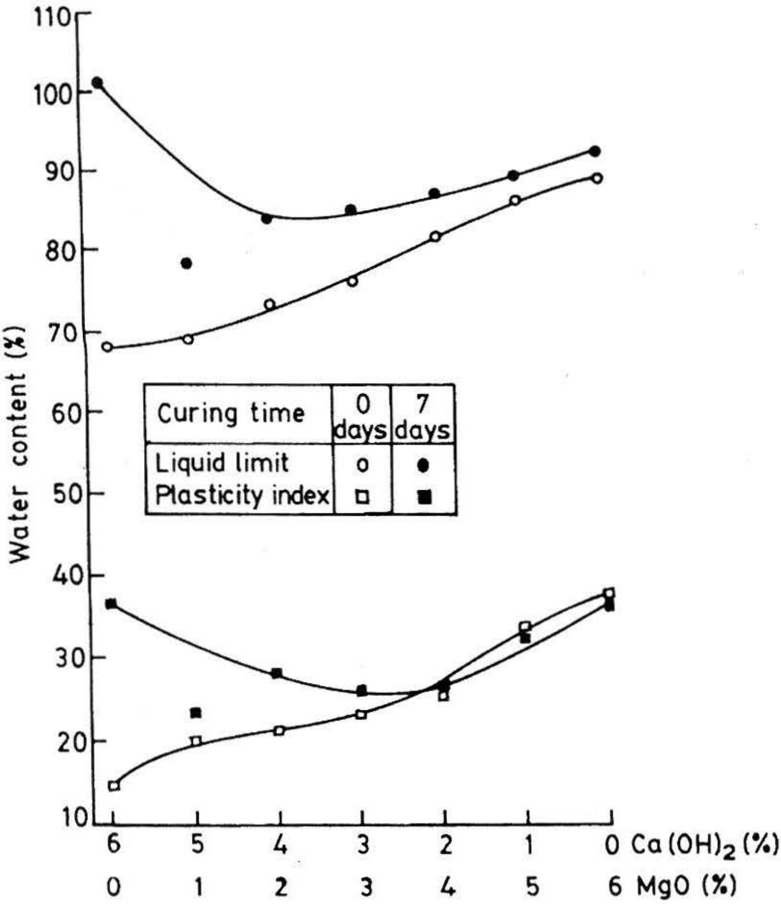

FIGURE 1 : Effect of Lime and Magnesium Oxide on Liquid Limit and Plasticity Index

flocculation if not sufficiently bonded can disappear during free swell index test. The free swell index values decreases with increase in percentage of lime substitution by magnesium oxide. The free swell index volumes obtained after one week, clearly demonstrates that the flocculation increases only on curing with lime. Thus, at any combination of lime-magnesium oxide, the curing effect is only because of lime. Thus free swell index volumes of soil increases with lime content.

Volume Change Behaviour

It has been shown that the liquid limit of magnesium oxide treated black cotton soil was higher than that of lime-treated black cotton soil. Thus

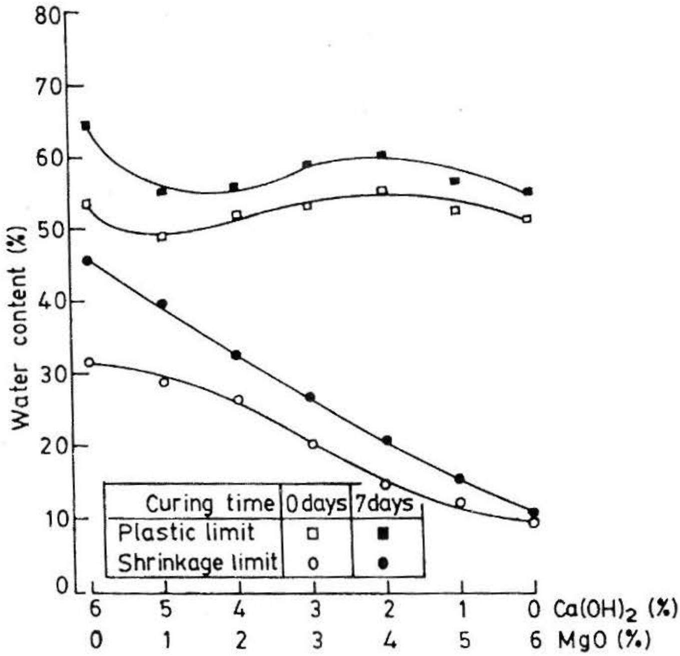

FIGURE 2 : Effect of Lime and Magnesium Oxide on Plastic Limit and Shrinkage Limit

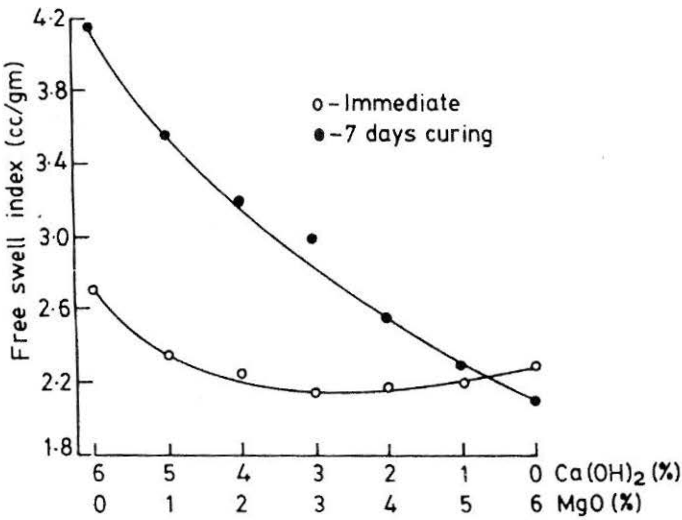

FIGURE 3 : Effect of Lime and Magnesium Oxide on Free Swell Index

it has been concluded that magnesium oxide causes flocculation earlier than lime. The trend of variation is not affected by the quantity of magnesium oxide. Hence volume change of behaviour is not affected by the quantity of magnesium oxide. Both aspects of volume change behaviour viz. (1) the ratio at which the process of volume change occurs and (2) the correlation between the amount of consolidation and the specific stress condition.

Time - Compression Curves

Figures 4 and 5 show the time vs. compression results of black cotton soil with lime and with lime plus MgO. It can be seen that the compression for each pressure increment is quite small and the initial compression increases significantly with increase in the pressure increment. Further, the compression other than initial compression increases marginally for each pressure increments. In both the cases, these curves do not conform to standard inverse 'S' shape, indicating that the substitution of lime by MgO does not have significant influence on the nature of the time-compression curves.

Void Ratio - Pressure Curves

Addition of 6% of lime significantly reduces the compression. Substitution of 1% lime by magnesium oxide increases the compressibility of lime treated soil (Fig. 6). The behaviour of lime treated soil is controlled by shearing resistance at particle level. Thus the increase in the volume change of black cotton soil with lime and MgO indicates that slight decrease in the bond strength through substitution of MgO occurs.

$\Delta e/(\Delta \log p)$ *and Coefficient of Volume Change*

Substitution of 1% lime with magnesium oxide increases the $\Delta e/(\Delta \log p)$ at any applied pressure (Fig. 7). The increase may be due to decrease in the amount of lime. MgO replacement can neither enhance the lime reactivity nor can substitute for lime. Because of these actions coefficient of volume change has also increased by replacing 1% lime with magnesium oxide (Fig. 8).

The secondary compression coefficient bears a good linear relationship with $\Delta e/(\Delta \log p)$ for black cotton soil treated with lime with or without MgO. The relationship can be given by equation

$$C_{\alpha\varepsilon} = 0.000252 + 0.005334\{\Delta e/(\Delta \log p)\}$$

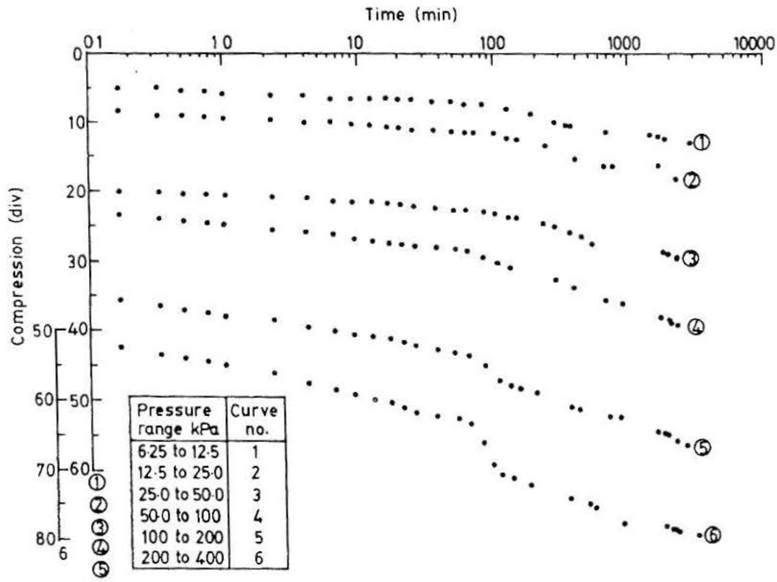

FIGURE 4 : Time-Compression Curves of Black Cotton Soil with 6% Lime for Various Pressure Increments

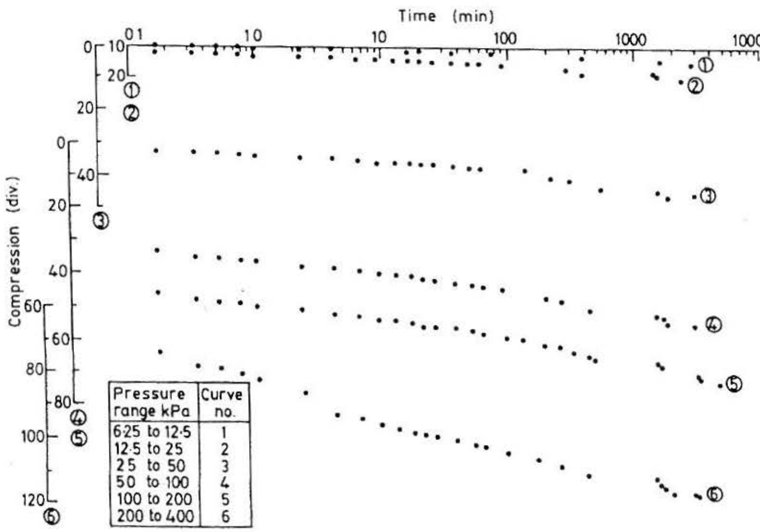

FIGURE 5 : Time-Compression Curves of Black Cotton Soil with 5% Lime + 1% MgO for Various Pressure Increments

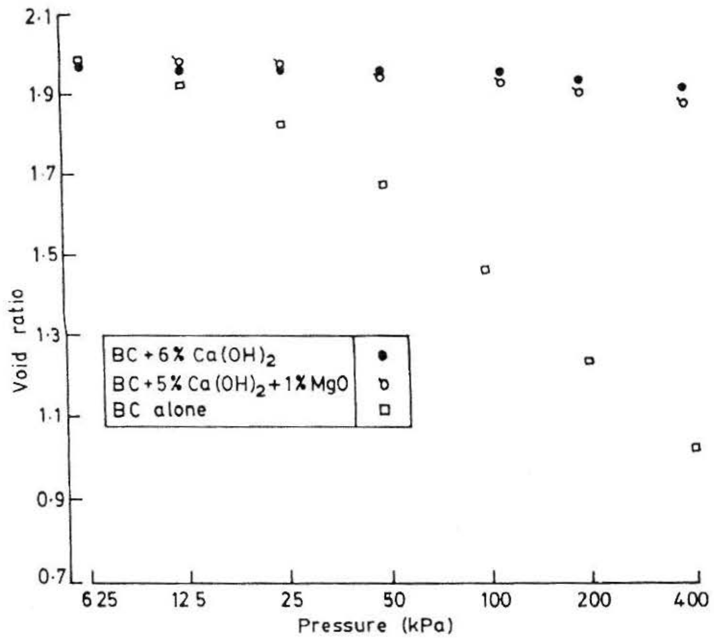

FIGURE 6 : Void Ratio Pressure Curves

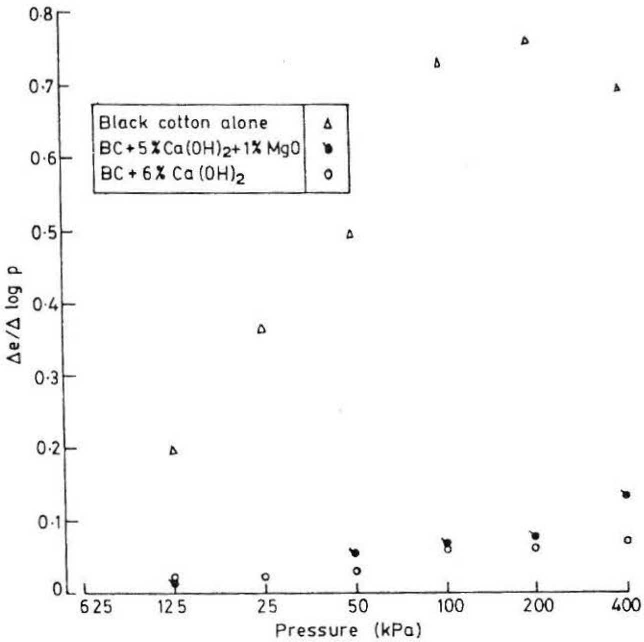

FIGURE 7 : Variation of $\Delta e/\Delta \log p$ with pressure

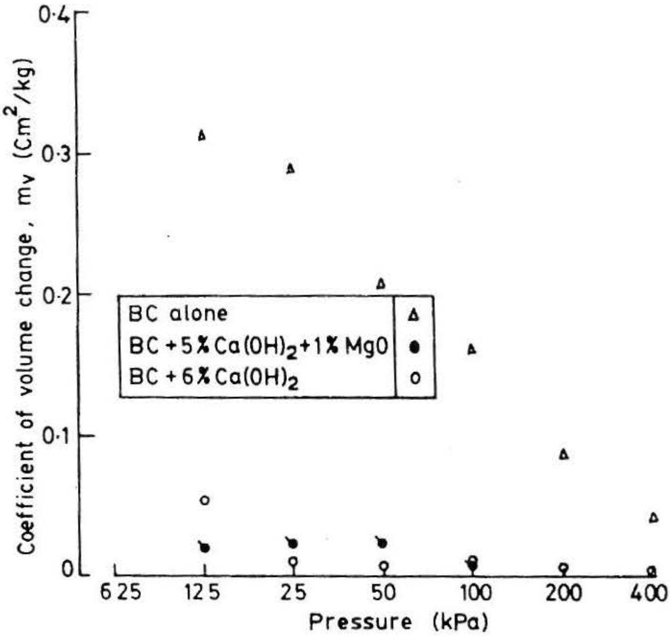

FIGURE 8 : Variation of Coefficient of Volume Changes with Pressure

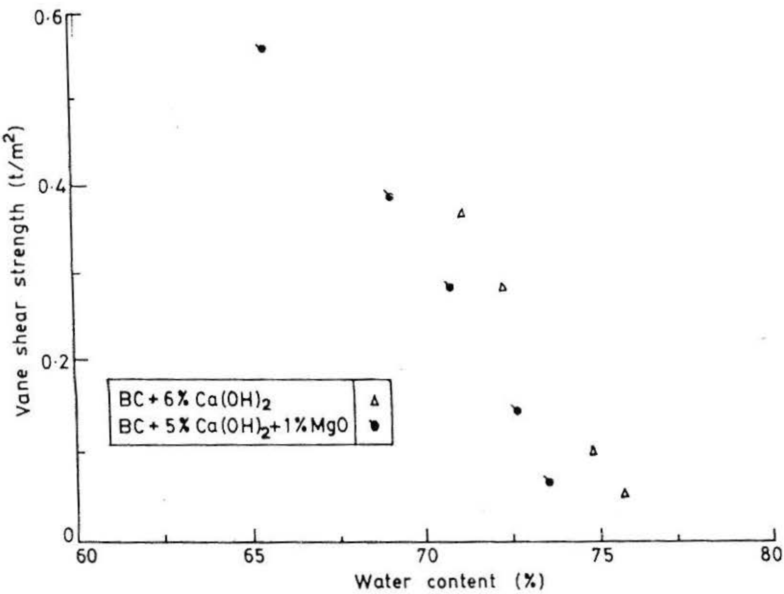

FIGURE 9 : Variation of Undrained Shear Strength with Water Content

Vane Shear Strength

The variations in the vane shear strength of black cotton soil with lime alone and lime with MgO are shown in Fig. 9. The vane shear strength of black cotton soil decreases immediately on the addition of lime at any particular water content, because of decrease in water holding capacity/viscous resistance. Compared with 6% lime alone, 5% lime + 1% magnesium oxide further reduces the vane shear strength (undrained).

Triaxial Shear Strength

The samples with 6% lime and 5% lime and with 1% magnesium oxide were mixed nearly at liquid limit water contents and cured for 7 days and 30 days. Even at higher water content, the strength mobilisation was sufficient for extrusion of samples from sampling tubes after 2 or 3 days curing. The samples were cured in desiccators (at 100% relative humidity) for the remaining periods taking care not to change its water content.

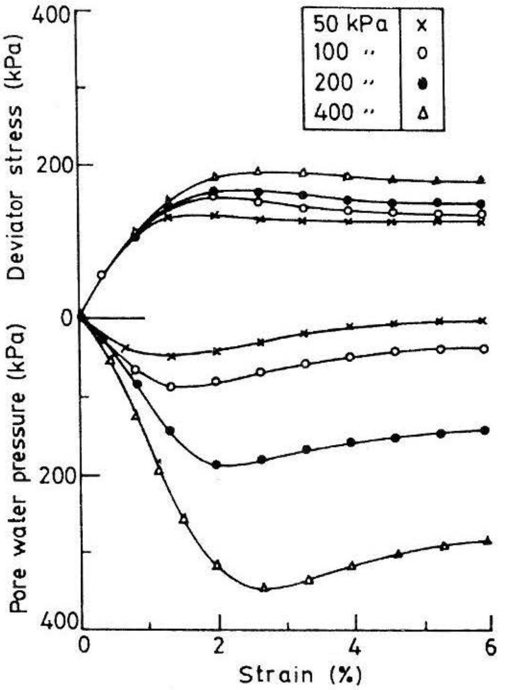

FIGURE 10 : Typical Deviator Stress-Strain Axial and pure Water Pressure–Axial Strain Relationships

Stress-Strain Behaviour

Figure 10 shows the typical deviator stress vs axial strain, and pore water pressure vs axial strain curves obtained from consolidated undrained triaxial test on remolded specimens cured for 30 days. It can be seen from these figures that while cell pressure has got profound effect on pore water pressure response, it has got little effect on deviator stress. Also, the cell pressure has no effect on initial tangent modulus. The deviator stress has a pronounced peak at high cell pressures. The failure stress has increased in lime + MgO treated soil compared with 6% lime alone after 7 days of curing. However, the failure stress with lime and magnesium oxide is very high 340kPa for 100kPa cell pressure. The quick increase in strength with lime and magnesium oxide may be due to the catalytic action of magnesium oxide on soil-lime reactions. After 30 days curing, the failure stress is lower than with 6% lime alone (Fig. 11). This supports that magnesium oxide can only accelerates the lime-soil reaction, but can not improve the lime stabilization. Thus, only in the case of lime + magnesium oxide, the failure stresses decrease with curing. Andrews and O'Flaherthy (1968) have also obtained lower strength with lime containing magnesium oxide than with high calcium limes for montmorillonitic clays.

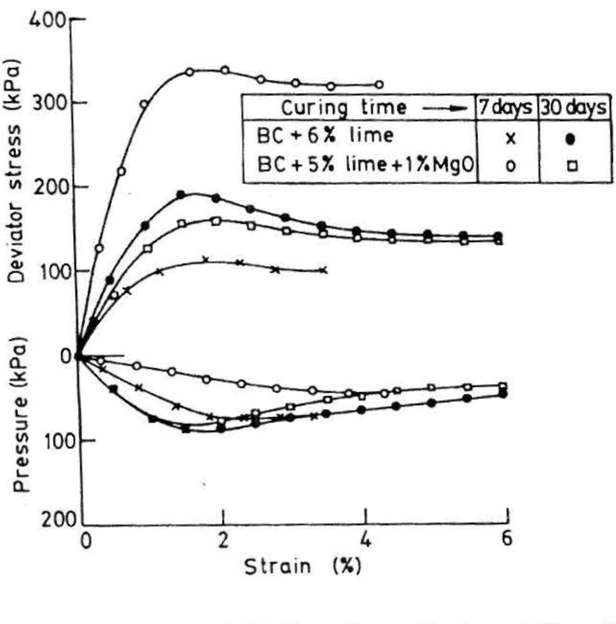

FIGURE 11 : Effect of MgO on Stress-Strain and Pure Water Pressure–Strains Relationships of Lime Treated Black Cotton Soil

Strength Parameters

The strength envelopes were plotted using modified Mohr-Coulomb method in terms of both total and effective stresses. These plots are shown in Fig.s 12 and 13. In these plots, the effect of different chemical admixtures are compared. For the sake of clarity, the enlarged scales are presented to show the relative variation in cohesion and angle of shearing resistence. On substitution of 1% of lime with MgO the angle of shearing resistance increases the cohesion of black cotton soil after one week of curing.

The computed values of strength parameters are presented in Table 3. The dry density and failure water contents are given in Table 4.

Total strength parameters

Black cotton soil cured for one week with 6% lime has a cohesion of 16 kPa and an angle of shearing resistance of 11.7°. Substitution of 1% of lime with MgO increases the cohesion and angle of shearing resistance. Distinct trend is available from results of samples tested after 30 days curing (Table 3, Fig. 12). The cohesion remains unaffected whereas ϕ has actually decreased by substitution.

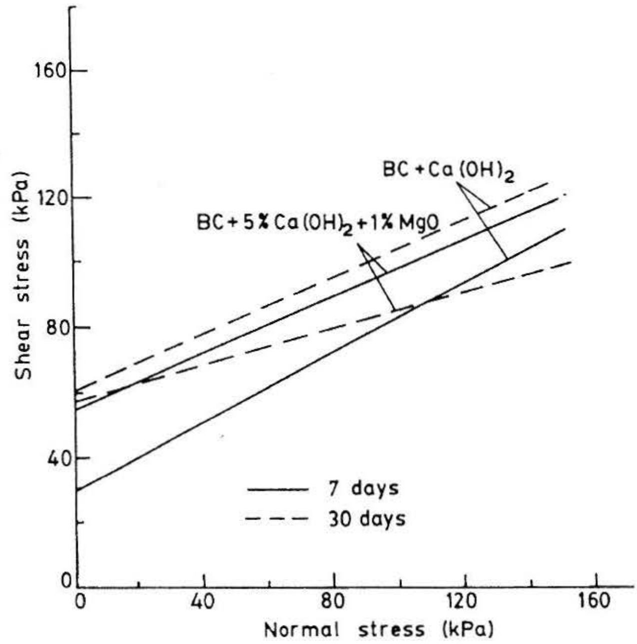

FIGURE 12 : Modified Mohr Envelops for Total Shear Strength Parameters

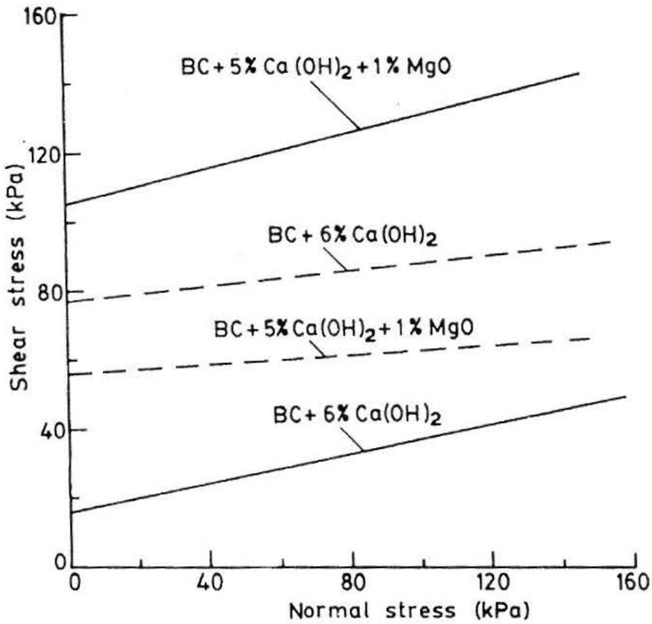

FIGURE 13 : Modified Mohr Envelops for Effective Shear Strength Parameters

Effective Strength Parameters

After one week of curing, the cohesion has increased with substitution compared with 6% lime alone, whereas the angle of shearing resistance is almost the same or slightly decreases (Table 3, Fig. 13). All the reasons attributed for the variations in the total strength parameters are also valid for effective stress parameters. The variation in the effective stress parameters after 30 days curing follows same trend as the variation in the total stress parameters after 30 days curing.

Conclusions

Based on the study the following conclusions are drawn :

1. Substitution of lime with MgO significantly alters the index properties of lime treated black cotton soil. Quick increase in liquid limit, plasticity index and free swell volume has been attributed as due to capacity of MgO to effect early flocculation compared to lime. However this flocculation is not sufficiently converted as indicated by lower shrinkage of lime treated with higher MgO content. With curing the effects of lime are better than MgO.

Table 3
Comparison of the Effect of Lime and Dolomitic Lime on Strength Parameters of Black Cotton Soil

	7 days curing				30 days curing			
	C (kPa)	ϕ (deg.)	C′ (kPa)	ϕ' (deg.)	C (kPa)	ϕ (deg.)	C′ (kPa)	ϕ' (deg.)
Black Cotton Soil	13.0	1.0	13.0	6.0	13.0	1.0	13.0	6.0
BC + 6% Lime	16.0	11.7	29.4	27.8	77.0	5.5	60.1	23.8
BC + 5% Lime + 1% MgO	105.3	14.4	105.5	23.3	56.0	4.0	57.1	15.5

Table 4
Failure Water Contents

	7 days curing		30 days curing	
	Dry Density (gm/cc)	Water Content (%)	Dry Density (gm cc)	Water Content (%)
Black Cotton Soil	1.086	45.8	1.086	45.8
BC + 6% Lime	0.819	84.3	0.819	82.7
BC + 5% Lime + 1% MgO	0.844	79.0	0.846	76.3

2. Substitution of 1% lime with MgO does not significantly alter the volume change behaviour of black cotton soil as compared with 6% lime.

3. After one week of curing, black cotton soil develops better strength with 5% lime + 1% MgO than with 6% lime. However the ultimate strength is higher with lime alone. The changes in strength are reflected essentially in cohesion intercept.

4. Dolomitic lime, which is cheaper than pure lime, can be advantageously used where early strength is needed.

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