Behavior of Black Cotton Soil with Addition of Sodium Carbonate and Calcium Carbonate

Shaik Basheer[1], Dr. V. Giridhar[2]

[1]Post Graduate Scholar, Department of Civil Engineering, KSRM College (Autonomous), Kadapa, India

[2]Associate Professor, Department of Civil Engineering, KSRM College (Autonomous), Kadapa, India

Abstract: ***The properties of Black Cotton Soil may be improved with Sand Cushions, CNS layers techniques, sand Columns, Stone Columns, Vibration Techniques and by adding Chemicals etc. Among these Chemical Stabilization is expansive than other types of stabilization methods. But the main advantage is setting time and curing time can be controlled. This paper emphasizes the effectiveness of Sodium Carbonate and Calcium Carbonate in stabilizing a Black Cotton Soil (BCS). The effectiveness of Calcium Carbonate is much better than Sodium Carbonate from Strength and stability point of View. The soil sample is prepared with chemical solution of varying percentages. Chemical solution is prepared by dissolving chemical powder in distilled water. The percentages of chemical are varied from 0%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, 3.0% by weight of the soil at 0, 3, 7 days curing. The Quantity of chemical computed corresponding to the above percentages is dissolved in distilled water and blended into soil thoroughly in order to obtain even distribution of the chemical and used for the tests.***

Keywords: Soil Stabilization, Sodium Carbonate, Calcium Carbonate, Black Cotton Soil, Compaction, UCS, Triaxial Compression Test

1. Introduction

Expansive soils in India are appreciate to farmers but problematic to civil engineers. Civil engineering structures experience large scale or damage due to change in properties of soil. Expansive soils always challenges to foundation engineers in India, these soils occupy around 20% of the total area, and it is mostly present in central part and western part of India.

Montmorillonite is the main compound in black cotton soil. BCS containing Montmorillonite absorb large amount of water molecules and high bulk density in dry condition.

The characteristics of expansive soils namely, swelling and shrinkage are due to presence of some expanding lattice type of clay minerals. The shear strength of the soil is very high in dry state and it reduces considerably in wet state. The variation in shear strength directly influences the bearing capacity. Seasonal changes cause large damage to structure built on these soils. Following damages are occurred in structures over BCS is Break up of pavements, railways lines, embankments, building foundations, reservoir lining, water tanks, sewer lines etc.,

The effectiveness of Sodium Carbonate and Calcium Carbonate in stabilizing a Black Cotton soil is presented in this paper.

Objectives of the paper

1) Determination of the Index and Engineering properties of the soil samples;
2) Determination of the Index, Strength and Triaxial shear strength of the black cotton soil blended with Sodium Carbonate ($NaCO_3$) and black cotton soil blended with Calcium Carbonate mixtures.
3) Determinations of the optimum percentage of stabilization for Sodium carbonate ($NaCO_3$) and Calcium Carbonate ($CaCO_3$) in the proposed mix.
4) To Study the quantitative changes in Triaxial test values of soil treated with Sodium Carbonate ($NaCO_3$) and Calcium Carbonate ($CaCO_3$) at 0, 3, 7 days.

2. Literature Review

Uppal and Wason (1957) were investigated the effect of addition of some surface active agents, namely soap and sulphonated castor oil to stabilize soil mixtures. They observed that the addition of these agents to the water to bring it to optimum moisture tends to increase the dry and bulk densities, resistance to the softening action of water the compressive strength and reduce volumetric shrinkage on drying of the compacted soil. As these agents are available at low cost and are simple to manufacture even at the site itself, they suggested that they can be employed as aids to soil stabilization.

Katti & Kulkarni (1966) were experimented on black cotton soils with and without inorganic additives. The studies revealed that most of the inorganic chemicals can make the black cotton soils non-plastic were greatly improve the volume change, permeability and bearing characteristics. Cement is found to be effective not only in improving the texture of the soil but also in improving the strength characteristics. The investigations also indicated that combinations of lime and cement distinctly increase the strength characteristics, considerably improved the bearing and shear properties. The soil-lime-cement mixes post tends a certain amount of flexural strength. Hydroxides and chlorides of potassium, sodium, calcium, were found to be effective. They not only improve the texture of soil but also its strength characteristics.

Michael (1968) studied on the swelling characteristics of expansive clay with access to electrolyte solution of hydroxide, sulphate and chloride. Empirical results indicated that the swelling characteristics of expansive clay may be altered by treatment with electrolytes. Swelling pressures seemed to decrease with increase of cation valency as Na^{+}: Mg^{++}: $A1^{+++}$. For any particular cations used, Swelling pressures seemed to be affected by the kind of anions present as well. The order of increasing effect in reducing swelling in reducing swelling pressure is hydroxide, sulphate and chloride. Sivanna (1976) had investigated on the strength and consolidation characteristics on the BCS using calcium chloride and potassium hydroxide. The study revealed a decreasing trend in the liquid limit and plasticity index.

Kezdi etal (1979) were reported that the soil stabilization aspects of the chemicals including resins, calcium acrylate, aniline furfural, synthetic resins and RRP (Reynolds road packer 233), calcium chloride and sodium chloride. The main objective of this chemical stabilization is intended to modify the interaction between water and soil by surface reactions in such a manner to make the behavior most favorable for the given purpose.

Sudhendu saha and prasanta saha (1991) were studied the improvement of silty clay soil by use of calcium chloride and ferric chloride contaminants. They reported that decrease of LL with increase in percentage of the chemicals, particularly predominant with ferric chloride. Further, there is little change in values of plastic limit and the plasticity index decreases showing the same trend as the liquid limit. The increases of cohesion with increase of chemical percentage are not very significant. The values of angle of internal friction reach peak values at 2% of the chemicals, with further addition of both the chemicals, the friction angle decreases.

Khare et al (2005) have carried out their experiment on determine the geotechnical properties of the soil; it is contaminated with arsenic acid and arsenic pentafluoride. They found that significant alteration of geotechnical properties when the locally available gravel soil contaminated with arsenic acid and arsenic pentafluoride. Predominantly gravel size particles broke down to silt size particle. The angle of internal friction dropped down drastically in both cases. A comparative computation of bearing capacity considering the value of internal friction, for uncontaminated and contaminated soil keeping all other parameters it shows 3 to 4 times variation in bearing capacity. Thus the drop down of shear parameter obviously has far reaching implication on the stability of structures resting on such weak soil.

3. Material and Methodology

3.1 Material

3.1.1 1 Black Cotton Soil:

The soil used for this investigation is procured from Balupalli near Chinthakomma Dinne (Mandal), Kadapa. The soil is collected at 1.5m depth below the natural ground level. It is dried and pulverized and sieved through a sieve of 4.75mm size to eliminate gravel fraction, if any. This dried and sieved soil is stored in airtight bags ready for use for mixing. The soil is classified as ‘CH’ as per IS Classification (IS 1498:1978) that it is inorganic clay of High Plasticity. Its degree of expansiveness is very ‘High’ as the Differential Free Swell Index (DFSI) is 90%.

Table 3.1: Properties of Black Cotton Soil

S.No.	Properties of the soil	Value
1.	Specific gravity	2.34
2.	Color of soil	Black
3.	**Grain size distribution**	
	Clay (%) Silt (%) Sand (%)	69% 13% 18%
4.	**Atterberg Limits**	
	a) Liquid Limit (%) b) Plastic Limit (%) c) Plasticity Index (%)	68.18 31.52 36.66
5.	Free Swell Index(DFSI)%	90
6.	Degree of expansion	High
7.	IS classification of soil	CH
8.	**Compaction Characteristics**	
	a)Optimum Moisture Content b)Maximum Dry Density (gm/cc)	27.44% 1.44gm/cc
9.	Unconfined Compression Test	$0.603 Kg/cm^2$
10.	**Tri-axial Compression Strength Test Results**	
	a) Cohesion, (kg/cm^2) b) Angle of Internal Friction (φ), Degrees c) Shear Strength, (kg/cm^2)	0.3015 2.95° 0.34

3.1.2 Sodium Carbonate

Sodium carbonate ($NaCO_3$) is a chemical compound of sodium and carbon dioxide. Sodium carbonate is a white, crystalline compound soluble in water (absorbing moisture from air) but insoluble in alcohol. It forms a strongly alkaline water solution. Soda ash is the industrial name of anhydrous sodium carbonate. Sodium carbonate decahydrate, a colorless, transparent crystalline compound, is commercially called Sal soda or washing soda. Soda Ash is produced synthetically using the ammonia soda process (Solvay process treating sodium chloride with ammonia and carbon dioxide).

3.1.3 Calcium Carbonate

Calcium carbonate ($CaCO_3$) is a chemical compound of Calcium and carbon dioxide. It is a common substance found as rock in all parts of the world and is main component of shells of marine organisms, snail, and egg shells. Calcium carbonate is active ingredient in agricultural lime, and is usually the principal cause of hard water. It is commonly used medicinally as a calcium supplement or as an antacid but high consumption can be hazardous.

4. Methodology

The soil sample was blended with chemical solution and is prepared by dissolving chemical powder in distilled water. The percentages of chemical solution are varies from 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, and 3.0% percent by weight of the soil at 0, 3, 7 days Curing. The soil and chemical are mixed thoroughly and used to perform the tests.

4.1 Tests conducted

The following tests are conducted in this investigation as per Standard Specification:

1) Specific Gravity (IS: 2720 Part 3, Section 1-1981)
2) Grain Size Analysis Test (IS: 2720 Part 4 1985)
3) Liquid limit tests (IS: 2720 Part 5 1985)

4) Plastic limit tests (IS: 2720 Part 12 1985)
5) Differential Free Swell Index Tests (IS: 2720 Part 40 1977)
6) Standard proctor Compaction tests (IS: 2720 Part 7 1980/1987)
7) Unconfined compression strength tests (IS: 2720 Part 10 1991) and
8) Triaxial compression strength tests (IS: 2720 Part 12 1981)

Importance has been accorded to qualitative magnitude of impact of stabilization, rather than to study the mechanism due to which it happens.

5. Results and Discussion

5.1 Atterberg Limits (L_L, P_L, PI)

Table 5.1.1: Plasticity characteristics of Soil admixed with Sodium Carbonate (Na_2CO_3)

Sodium carbonate (%)	LL (%)	PL (%)	PI (%)
0.0	68.18	31.52	36.66
0.5	74	35	39
1.0	72.26	33.65	38.61
1.5	71	32.52	38.48
2.0	65	31.24	33.76
2.5	63	29.47	33.53
3.0	59.74	27.46	32.28

Table 5.1.2: Plasticity characteristics of Soil admixed with Calcium Carbonate ($CaCO_3$)

Calcium carbonate (%)	LL (%)	PL (%)	PI (%)
0.0	68.18	31.52	36.66
0.5	77	33.42	43.58
1.0	73	32.73	40.27
1.5	69	31.52	37.48
2.0	64	29	35
2.5	60	27.86	32.14
3.0	57	27.43	29.57

The Variation of Liquid Limit, Plastic Limit and Plasticity Index with various percentages of Chemical Sodium Carbonate and Calcium Carbonate is presented in fig.5.1.1. From below Curves, it can be observed that 3.0 percent of Chemical either sodium Carbonate or Calcium Carbonate is effectively reducing the Plasticity characteristics.

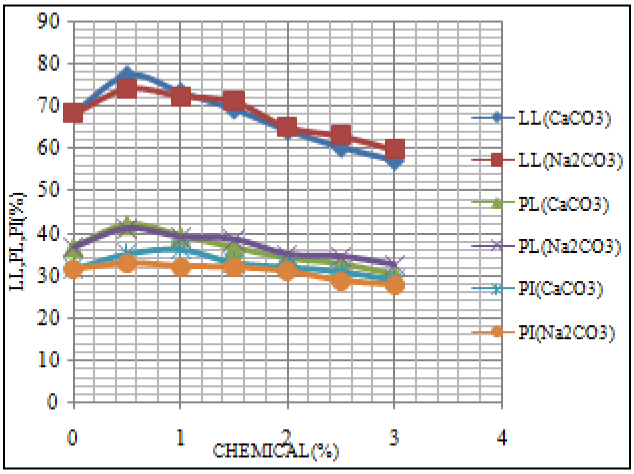

Figure 5.1.1 Variation of Liquid Limit, Plastic Limit and Plasticity Index with per cent Chemical

5.2 Differential Free Swell Test

Table.5.2.1: Swelling Characteristic of Soil with Sodium carbonate & Calcium Carbonate

% of Chemical	Differential Free Swell Index (DFSI)%, Na_2CO_3	Differential Free Swell Index (DFSI)%, $CaCO_3$
0.0	90	90
0.5	120	140
1.0	140	160
1.5	150	170
2.0	130	150
2.5	120	130
3.0	110	120

The chemicals Sodium carbonate and Calcium carbonate are not at all effective in reducing the Differential Free swell index Value of the soil up to 3.0% addition of the chemical in the tested range.

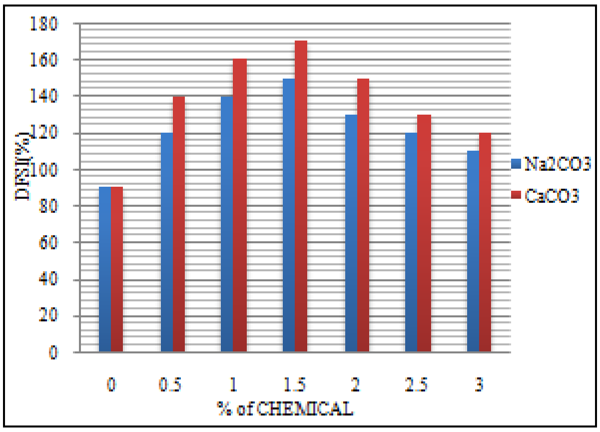

Figure 5.2.1: Variation of Differential Free Swell Index with per cent Chemical

5.3 Compaction Test

Table 5.3.1: Maximum Dry Density and Optimum Moisture Content of Soil Admixed with Na_2CO_3

Particulars	MDD (gm/cc)	OMC (%)
BCS Alone	1.44	27.54
BCS + 0.5% of $NaCO_3$	1.56	26.12
BCS + 1.0% of $NaCO_3$	1.59	24.56
BCS + 1.5% of $NaCO_3$	1.62	21.84
BCS + 2.0% of $NaCO_3$	1.58	19.78
BCS + 2.5% of $NaCO_3$	1.55	18.88
BCS + 3.0% of $NaCO_3$	1.53	18.24

The variation of Maximum dry density (γ_d) and optimum moisture content (OMC) with respect to sodium carbonate shown in table.5.3.1 and in fig.5.3.1. Addition of sodium carbonate to Black cotton soil increased in Maximum Dry Density from 1.44 to 1.62gm/cc at 1.5% chemical and then decreased to 1.53gm/cc at 3.0% chemical, and the Optimum Moisture Content (OMC) is decreased gradually from 27.54% at zero percent chemical to 18.24% at 3.0% chemical mix.

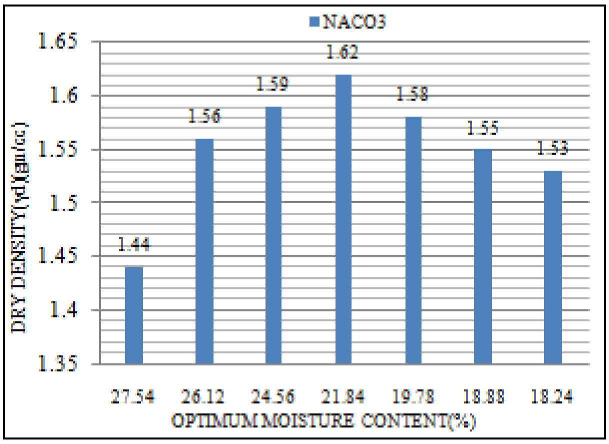

Figure 5.3.1: Variation of Maximum Dry Density and Optimum Moisture Content with per cent chemical

Table 5.3.2: Maximum Dry Density and Optimum Moisture Content of Soil Admixed with $CaCO_3$

Particulars	MDD (gm/cc)	OMC (%)
BCS Alone	1.44	27.54
BCS + 0.5% of $CaCO_3$	1.59	19.44
BCS + 1.0% of $CaCO_3$	1.67	18.53
BCS + 1.5% of $CaCO_3$	1.62	17.89
BCS + 2.0% of $CaCO_3$	1.56	17.18
BCS + 2.5% of $CaCO_3$	1.53	16.78
BCS + 3.0% of $CaCO_3$	1.52	16.07

The variation of MDD and OMC with respect to the Calcium Carbonate content is shown in table and fig. Addition of calcium carbonate to Black Cotton Soil increased the Maximum Dry Density up to 1.0% is 1.67gm/cc and then decreases up to 3.0% is 1.52gm/cc, and then decrease in optimum moisture content (OMC) from 27.54% to 16.07%.

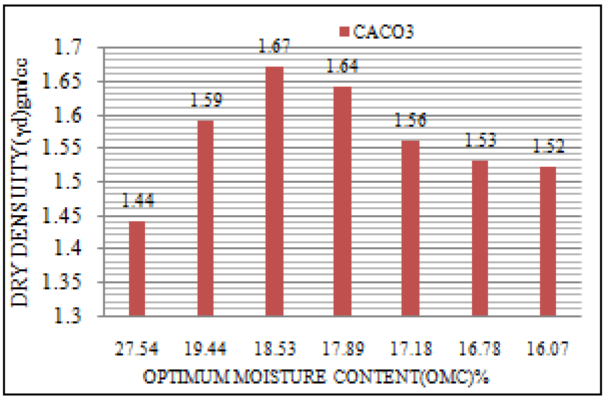

Figure 5.3.2: Variation of Maximum Dry Density and Optimum Moisture Content with per cent Chemical

5.4 Triaxial Test for Sodium Carbonate (Na_2CO_3)

Table 5.4.1: Shear parameters (C, φ, τ) of Soil Admixed with Sodium Carbonate at '0' day Curing

% of Chemical	Cohesion (Kg/cm^2)	Angle of internal friction, degrees	Shear Strength,(τ)
0% of Na_2CO_3	0.3015	2.95	0.34
0.5% of Na_2CO_3	0.344	3.0	0.38
1.0 % of Na_2CO_3	0.38	4.4	0.45
1.5 % of Na_2CO_3	0.395	6.5	0.50
2.0 % of Na_2CO_3	0.38	4.4	0.45
2.5 % of Na_2CO_3	0.29	2.85	0.33
3.0 % of Na_2CO_3	0.24	2.5	0.31

The improving percentage of sodium carbonate of cohesion is increasing from 0.3015Kg/cm^2 to 0.395 Kg/cm^2 at 1.5% and then decreasing from 0.38Kg/cm^2 to 0.24Kg/cm^2 at 3.0% and angle of internal friction increases from 2.95º to 6.5º at 1.5% and decreases from 4.4º to 2 .5° at 3.0%.

Table 5.4.2: Shear parameters (C, φ, τ) of Soil Admixed with Sodium Carbonate at '3' days Curing

% of Chemical	Cohesion (Kg/cm^2)	Angle of internal friction, degrees	Shear Strength(τ)
0 % of Na_2CO_3	0.3015	2.95	0.34
0.5% of Na_2CO_3	0.38	3.5	0.42
1.0 % of Na_2CO_3	0.40	5.45	0.49
1.5% of Na_2CO_3	0.44	8.25	0.58
2.0 % of Na_2CO_3	0.41	6.6	0.52
2.5 % of Na_2CO_3	0.39	4.2	0.45
3.0 % of Na_2CO_3	0.37	3.3	0.40

The improving percentage of sodium carbonate of cohesion is increasing from 0.3015Kg/cm^2 to 0.44 Kg/cm^2 at 1.5% and then decreasing from 0.41Kg/cm^2 to 0.37Kg/cm^2 at 3.0% and angle of internal friction increases from 2.95° to 8.25° at 1.5% and decreases from 6.60° to 3.30° at 3.0%.

Table 5.4.3: Shear parameters (C, φ, τ) of Soil Admixed with Sodium Carbonate at '7' days curing

% of Chemical	Cohesion (Kg/cm^2)	Angle of internal friction, degrees	Shear Strength(τ)
0 % of Na_2CO_3	0.3015	2.95	0.34
0.5% of Na_2CO_3	0.40	3.9	0.44
1.0 % of Na_2CO_3	0.43	6.0	0.53
1.5% of Na_2CO_3	0.51	8.9	0.66
2.0 % of Na_2CO_3	0.45	6.4	0.55
2.5 % of Na_2CO_3	0.42	5.9	0.51
3.0 % of Na_2CO_3	0.38	5.5	0.49

The improving percentage of sodium carbonate of cohesion is increasing from 0.3015Kg/cm^2 to 0.51 Kg/cm^2 at 1.5% and then decreasing from 0.45Kg/cm^2 to 0.38Kg/cm^2 at 3.0% and angle of internal friction increases from 2.95° to 8.9° at 1.5% and decreases from 6.4° to 5.5° at 3.0%.

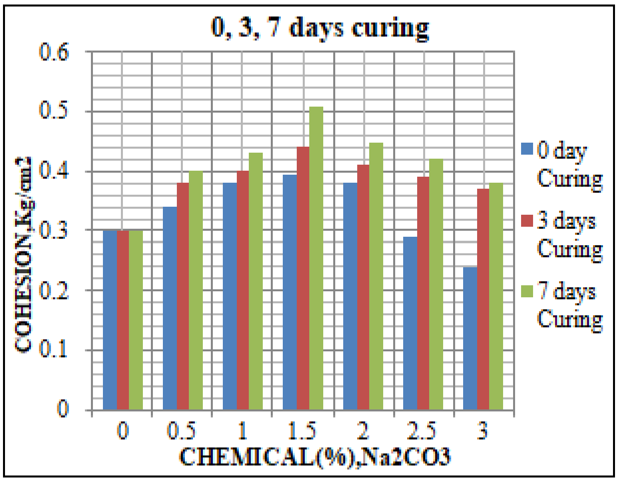

Figure 5.4.1: Variation of Cohesion with % of Na_2CO_3 for different Curing Period

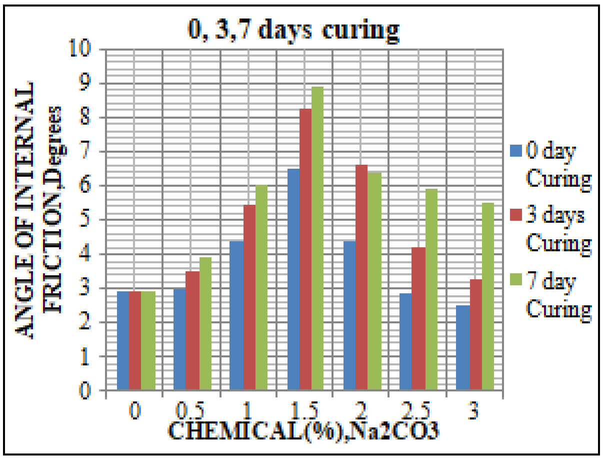

Figure 5.4.2: Variation of Angle of Internal Friction with % of Na_2CO_3 for different Curing Period

5.5 Triaxial Test for Calcium Carbonate ($CaCO_3$)

Table 5.5.1: Shear parameters (C, φ, τ) of Soil admixed with Calcium Carbonate at '0' day Curing

% of Chemical	*Cohesion (Kg/cm^2)*	*Angle of internal friction, degrees*	*Shear Strength,(τ)*
0% of Na_2CO_3	0.3015	2.95	0.34
0.5% of $CaCO_3$	0.64	4.5	0.71
1.0 % of $CaCO_3$	0.74	9.4	0.86
1.5 % of $CaCO_3$	0.68	8.5	0.85
2.0 % of $CaCO_3$	0.65	6.95	0.72
2.5 % of $CaCO_3$	0.62	4.0	0.68
3.0 % of $CaCO_3$	0.59	3.1	0.62

The improving percentage of calcium carbonate of cohesion is increasing from 0.3015Kg/cm^2 to 0.74 Kg/cm^2 at 1.0% and then decreasing from 0.68Kg/cm^2 to 0.59Kg/cm^2 at 3.0% and angle of internal friction increases from 2.95° to 9.4° at 1.0% and decreases from 8.5° to 3.1° at 3.0%.

Table 5.5.2: Shear parameters (C, φ, τ) of Soil Admixed with Calcium Carbonate at '3' days curing

% of Chemical	Cohesion (Kg/cm^2)	Angle of internal friction, degrees	Shear Strength,(τ)
0% of Na_2CO_3	0.3015	2.95	0.34
0.5% of $CaCO_3$	0.87	6.30	0.97
1.0 % of $CaCO_3$	1.34	11	1.48
1.5 % of $CaCO_3$	1.10	10	1.31
2.0 % of $CaCO_3$	0.94	9.5	1.04
2.5 % of $CaCO_3$	0.86	6	0.95
3.0 % of $CaCO_3$	0.81	5.6	0.89

The improving percentage of calcium carbonate of cohesion is increasing from 0.3015Kg/cm^2 to 1.34 Kg/cm^2 at 1.0% and then decreasing from 1.10Kg/cm^2 to 0.81Kg/cm^2 at 3.0% and angle of internal friction increases from 2.95° to 11° at 1.0% and decreases from 10° to 5.6° at 3.0%.

Table 5.5.3: Shear parameters (C, φ, τ) of Soil Admixed with Calcium Carbonate at '7' days curing

% of Chemical	Cohesion (Kg/cm^2)	Angle of internal friction, degrees	Shear Strength,(τ)
0% of Na_2CO_3	0.3015	2.95	0.34
0.5% of $CaCO_3$	1.08	7.0	1.19
1.0 % of $CaCO_3$	1.58	12.5	1.75
1.5 % of $CaCO_3$	1.42	11.2	1.65
2.0 % of $CaCO_3$	1.39	10.6	1.50
2.5 % of $CaCO_3$	1.35	9.4	1.49
3.0 % of $CaCO_3$	1.26	8.5	1.44

The improving percentage of calcium carbonate of cohesion is increasing from 0.3015Kg/cm^2 to 1.58 Kg/cm^2 at 1.0% and then decreasing from 1.42Kg/cm^2 to 1.26Kg/cm^2 at 3.0% and angle of internal friction increases from 2.95° to 12.5° at 1.0% and decreases from 11.2° to 8.5° at 3.0%.

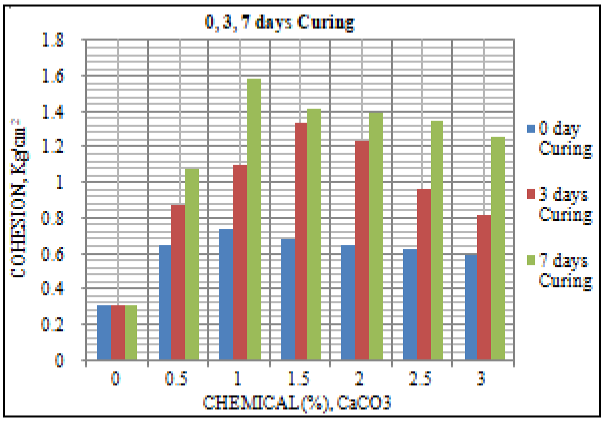

Figure 5.5.1: Variation of Cohesion with % of $CaCO_3$ for different Curing Period

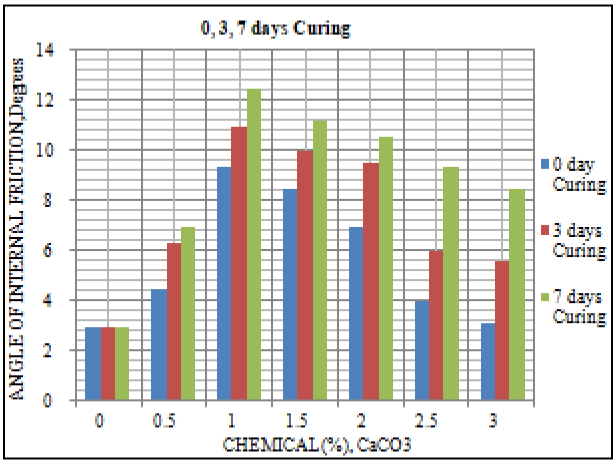

Figure 5.5.2: Variation of Angle of Internal Friction with % of $CaCO_3$ for different Curing Period

6. Conclusions

1) Calcium Carbonate is more effective than Sodium Carbonate in reducing the Optimum Moisture Content.
2) Calcium Carbonate is slightly more effective than Sodium Carbonate in increasing the Maximum Dry Density.
3) More value of Maximum Dry Density of Soil can be achieved with less amount of Optimum Moisture Content for constant Compactive effort, when the soil is admixed with a small percentage of Chemicals Sodium Carbonate and Calcium Carbonate.
4) Three percent of Chemical either Sodium Carbonate or Calcium Carbonate is effective in reducing the plasticity characteristics to certain extent in the tested range.
5) Both Chemicals are Equally Effective at Optimum Percentage of the Chemical in reducing the Plasticity Characteristics where as Sodium Carbonate is better than Calcium Carbonate in reducing the swelling

characteristics at optimum percentages of the chemical in the tested range

6) Three percent of Chemicals either Sodium Carbonate or Calcium Carbonate is effective in reducing the Differential Free Swell index.
7) The marginal amount of Improvement observed in angle of Internal Friction of 96.07%, 125.72% and 134.7% at 0, 3 & 7 days of curing with 1.5% of Na_2CO_3. Similarly same type of observations witnessed in angle of Internal Friction of 161.42%, 188.15% and 215.85% at 0, 3 and 7 days of curing with 1.5% of $CaCO_3$.
8) The marginal amount of improvement observed in cohesion of 28.49%, 41.29% and 134.7% at 0, 3 & 7 days of curing with 1.5% of Na_2CO_3. Similarly same type of observations witnessed in cohesion of 126.33%, 242.57% and 304.99% at 0, 3 and 7 days of curing with 1.5% of $CaCO_3$.
9) The effectiveness of Calcium Carbonate is much better than Sodium Carbonate from Strength and Stability point of view.

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Author Profile

Dr.V.Giridhar received his Doctorial degree and Masters degree from JNTUA,Ananthapuram. His Specialization is structures and is doing research on Innovation Concrete materials, waste materials into the concrete, SIFCON and High Strength Concrete. He Published 12 International Journals Papers and 5 National and International Conference papers.

S. Basheer is currently pursuing his M.Tech in Geotechnical Engineering of Civil Engineering department from KSRM college of engineering (Autonomous), Kadapa, Andhra Pradesh. He has completed B.tech in Civil Engineering in SVCET(Autonomous),Chittoor in 2014,during 2010-2014. His area of interest is in Foundation Engineering & Ground Improvement Techniques.