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A LABORATORY INVESTIGATION ON THE EFFICIENCY OF EXPANSIVE SOIL TREATED WITH SILICA FUME AND LIME AS SUBGRADE FOR FLEXIBLE PAVEMENTS

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Abstract-- Expansive soils are extensively distributed worldwide, it cover approximately one-sixth of the total area of our country and are a source of great damage to infrastructure, buildings and pavements. Most of the time, large areas are covered with highly plastic and expansive soil which is not suitable for the construction purpose. These soils, such as black cotton soils are basically susceptible to detrimental volumetric changes with variations in moisture content. This behavior of soil is attributed to the presence of mineral montmorillonite, which exhibits large swelling and shrinkage. Understanding the behaviour of these clayey soils and adopting suitable measures to overcome the problems associated with these problematic soils have become a challenging task for geotechnical engineers. The present study deals with the strength behaviour of the expansive soil collected from Amalapuram, East Godavari district, Andhra Pradesh, India, on adding silica fume as an admixture and lime for improving the strength characteristics of the expansive soil. The laboratory tests have been carried out and results were reported in this paper.

***Index Terms*—Expansive Soil, Silica Fume, Lime, OMC, MDD, CBR**

I. INTRODUCTION

Expansive black cotton soils prevail in most part of the earth. These soils experience a large moisture related volume changes during dry and wet season. Change in the water content usually leads to changes in characteristics of these clays. Increase in moisture content causes increase in volume due to swelling. Shrinkage due to evaporation of water occurs in dry season. Swelling due to absorption of water mainly occurs in monsoon season. These soils exhibit the large amount of swelling and shrinkage characteristics to the presence of clay minerals such as Montmorillonite, Illite and Kaolinite etc. Because of the alternate swelling and shrinkage of these soils, civil engineering structures such as foundations, retaining walls, pavements, canal beds and linings founded in these soils get severely cracked, resulting in a huge amount of financial loss. The hazards caused by these soils all over the world have been recorded. In India they are called expansive soils and are predominant in the states of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra and in parts of Tamil Nadu and Uttar Pradesh. In order to overcome these problems the soil must be stabilized. Soil stabilization is one of the geotechnical methods to change the engineering properties of soil for enable their strength characteristics and durability with an addition of admixture and chemicals. Soil stabilization techniques are adopted to stabilize the expansive soils like cement, lime, fly ash etc… But these techniques became expensive so now a days adopting the special additives to stabilize the soil like Silica Fume. It is a mineral admixture, composed of submicron particles (extremely small with more than 95% of particles finer than 1 micrometer) of amorphous silicon dioxide. It is either premium of white or grey in color. Silica Fume, upon mixing with soil, can be used an effective stabilizing agent for the improvement of problematic soils for use in subgrade. By mixing with lime develops pozzolanic reactions. Several researches have been made to improve the strength of the expansive soils. From various contributions, the investigations on strength characteristics of expansive soil conducted by S. Narasimha Rao et al (1986, 1987), Sridharan et. Al (1989), Mathew et al (1997), G. Rajashekaram et al (2002), Kate J.M (2005), Ali. M. Abd-Allah (2009), Dr. Koteswara Rao. D et al (2011), Timani K.L, Patel R.M (2015), Prof. R.D.Babu et al. (2015) and several others have conducted experimental studies to improve the properties of the expansive soils using different admixtures and the tests yielded better results. The characteristics that are of concern to the design engineers are permeability, compressibility and durability. The effect of the additives and the optimum amount of additives to be used are dependent mainly on the mineralogical composition of the soils.

Fig.1 Silica Fume

Fig.2 Lime

II. OBJECTIVES OF STUDY

The objectives of the present laboratory investigation are as follows.

- To identify the strategy of techniques to overcome the problems posed by expansive soil with a view to adopt suitable methodology through critical review of literature.
- The objectives of the present laboratory investigation are to determine the properties of the expansive soil and Silica Fume.
- To evaluate the performance of expansive soil treated with optimum % of Silica Fume as an admixture on % variation of Lime as an additive.

III. MATERIALS USED

A. Expansive Soil (ES)

The soil used in this study is of expansive in nature, collected from Amalapuram, East Godavari District, Andhra Pradesh at a depth of 1.5m from ground level. The Index and Engineering properties of the expansive soil were determined as per IS codes of practice.

The geotechnical properties of the air dried expansive soil, the liquid limit, plastic limit, specific gravity, differential free swell, Compaction, CBR as per IS Codes of practice were determined and the results were tabulated as follows.

TABLE 1
GEOTECHNICAL PROPERTIES OF THE UNTREATED EXPANSIVE SOIL

SI.NO	Property		Expansive Soil
1	Gravel (%)		5
2	Sand (%)		12
3	Fines (%)	silt	24
		clay	59
4	Liquid limit (%)		61.56
5	Plastic limit (%)		25.13
6	Plastic index (%)		36.43
7	Soil classification		CH
8	Specific gravity		2.56
9	D.F.S (%)		110
10	O.M.C (%)		29.23
11	M.D.D (g/cc)		1.45
12	Cohesion (kg/cm^2)		0.55
13	CBR (%)		1.79

B. Silica Fume (SF)

For the present study the silica fume were collected from Aastra chemicals in Chennai, Tamil Nadu, India. It is a byproduct of the smelting process in the silicon and ferro-silicon industry. Which is a mineral admixture, composed of submicron particles with more than 95% of particles finer than the 1 micro meter of amorphous silicon dioxide. SF powder either premium of White or Grey colour. The SF mainly consisting of 92.68% of Silicon Oxide (SiO_2) and small amount of iron, calcium, magnesium, and alkali oxides was used in the investigation. In the present study the addition of SF was varied from 3% to 20% for stabilizing the expansive soil. The chemical composition of the silica fume were shown in table 2.

TABLE 2

CHEMICAL COMPOSITION OF SILICA FUME

SI. No	Constituent Elements	Content (%)
1	Silicon Oxide (SiO_2)	92.10
2	Aluminium Oxide (Al_2O_3)	0.50
3	Potassium Oxide (K_2O)	0.70
4	Calcium Oxide (CaO)	0.50
5	Magnesium oxide (MgO)	0.30
6	Sodium oxide (Na_2O)	0.30
7	Iron Oxide (Fe_2O_3)	0.78
8	Loss of ignition (LOI)	2.8

(Courtesy to Sandvik, Gjorv**)**

TABLE 3

PHYSICAL PROPERTIES OF SILICA FUME

SI. No	Physical State	Value
1	Colour	White or Grey
2	Specific Gravity	2.2
3	Particle Size	<1m
4	Bulk Density	
	As produced (Kg/m^3)	130-430
	Slurry (Kg/m^3)	1320-1440
	Densified (Kg/m^3)	480-720

(Courtesy to Sandvik, Gjorv**)**

TABLE 4

CHEMICAL AND PHYSICAL PROPERTIES OF LIME

Property	Value
Silicon Oxide (SiO_2)	2.5
Aluminium Oxide (Al_2O_3)	1.5
Ferrous Oxide (Fe_2O_3)	2
Calcium Oxide (CaO)	84
Magnesium Oxide (MgO)	1.5
Sodium Oxide (Na_2O)	0.5
Physical Appearance	White Dry Powder
Specific Gravity	2

(Courtesy to Margaret Thomson **)**

IV. LABORATORY INVESTIGATION

The laboratory studies were carried out on the samples of Expansive soil, Expansive soil with percentage variation of Silica fume powder and expansive soil with optimum of SF with percentage variation of Lime for obtaining the optimum mix.

A. Liquid limit

The Liquid limit test was conducted on Expansive soil, Expansive soil+5% Silica Fume, expansive soil+5% Silica fume and 8% lime mixes using Casagrande's liquid limit apparatus as per the procedures laid down in IS: 2720 part 4 (1970). *B. Plastic limit*

Similarly the Plastic limit test was conducted , Expansive soil, expansive soil with optimum of silica fume and expansive soil with optimums of Silica fume and lime as per the specifications laid down in IS: 2720 part 4 (1970). *C. Differential Free Swell:*

Differential Free Swell (DFS) is a parameter used for the identification of the expansiveness of the soil. To determine the free swell of a soil, 20g of oven dry soil passing through 425µ size sieve is taken. One sample of l0g is taken into a l00cc capacity graduated cylinder containing water, and the other sample of 10g is taken into a l00cc capacity graduated cylinder containing kerosene oil. Differential Free Swell (%) = $\frac{vd-vk}{vk} * 100$

Where,

V_d = volume of soil specimen read from the graduated cylinder containing distilled water.

V_k = volume of soil specimen read from the graduated cylinder containing kerosene.

Because kerosene is a non-polar liquid, it does not cause any swell of the soil IS: 2720 (Part III- l980) gives degree of expansion of a soil depending upon its differential free swell as under.

TABLE 5

RANGE OF DIFFERENTIAL FREE SWELL

S. No	Differential Free Swell	DFS
1	Low	<20%
2	Moderate	20-35%
3	High	35-50%
4	Very High	>50%

D. Proctor Modified compaction Test

The expansive soil was treated with different percentages of admixture i.e., the silica fume. SF was replaced with the expansive soil in different percentages varying from 3% to 20% to improve the properties of the soil. table 7 and figure 3 presents the OMC and MDD values of untreated expansive soil and also treated expansive soil with percentage variation of SF.

E. Specific Gravity Test

Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. The specific gravity of a soil is used in the phase relationship of air, water, and solids in a given volume of the soil. Specific gravity test was carried out by Pycnometer as per IS 2720 Part 3 (1980).

F. California Bearing Ratio Test

The California bearing ratio test was conducted on the soil sample with 6 varying percentages of silica fume. Silica fume were added to soil in varying percentages (3,4,5,10,15,20%) respectively. CBR value increases up to 5 % addition of silica fume and then decreases. The maximum value of CBR for 5 % addition of silica fume was obtained as 3.0%. The CBR value showed an Increase from 1.79% to 3.0% at 5% addition of silica fume. Further on addition of 8% lime to soil and 5% silica fume the CBR increased from 3.0% to 11.20% for different curing periods. The test was conducted under a constant strain rate of 1.25mm/min. The proving ring reading is noted for 50 divisions, and loading was continued until 3 (or) more readings are decreasing (or) constant. The test was conducted at Optimum moisture content. The samples were tested in soaked condition. The tests were conducted at time interval of different curing periods for (4,7,14,21,28 days) at optimum moisture content.

G. Modified Compaction Test Results

TABLE 6

OMC AND MDD VALUES OF TREATED & UNTREATED EXPANSIVE SOIL WITH PERCENTAGE VARIATION OF SF

Expansive soil with % variation of SF	MDD (gm/cc)	OMC (%)
Soil	1.450	29.23
Soil+3%MD	1.541	23.94
Soil+4%MD	1.595	23.45
Soil+5%MD	1.608	25.56
Soil+10%MD	1.635	24.71
Soil+15%MD	**1.638**	**24.51**
Soil+20%MD	1.586	24.18

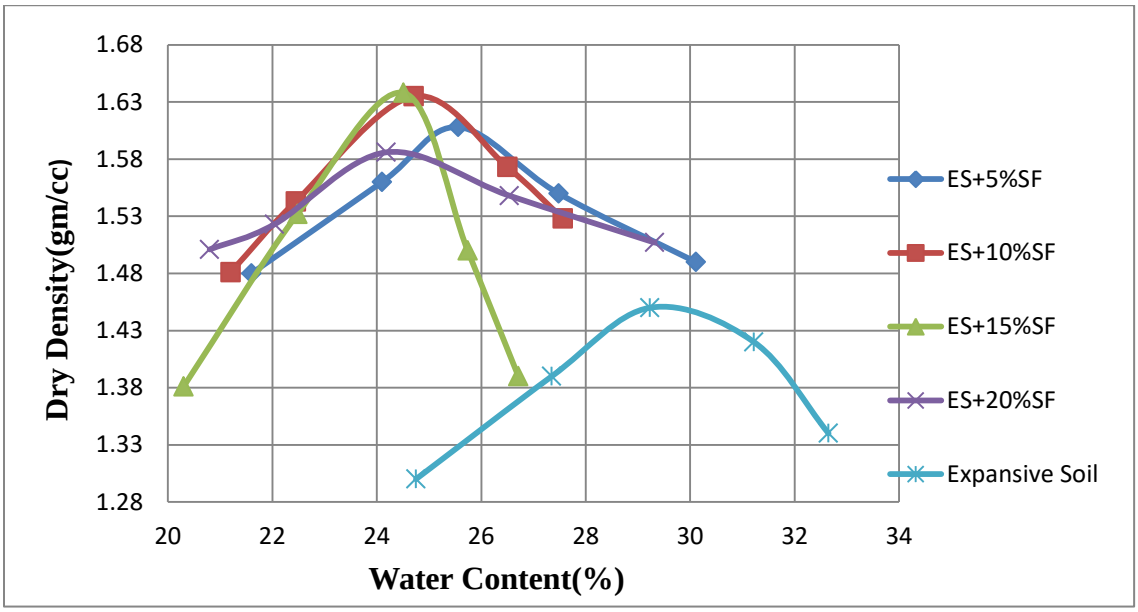

Fig.3 Present OMC and MDD values when different percentage of SF added (varying from 5% to 20%)

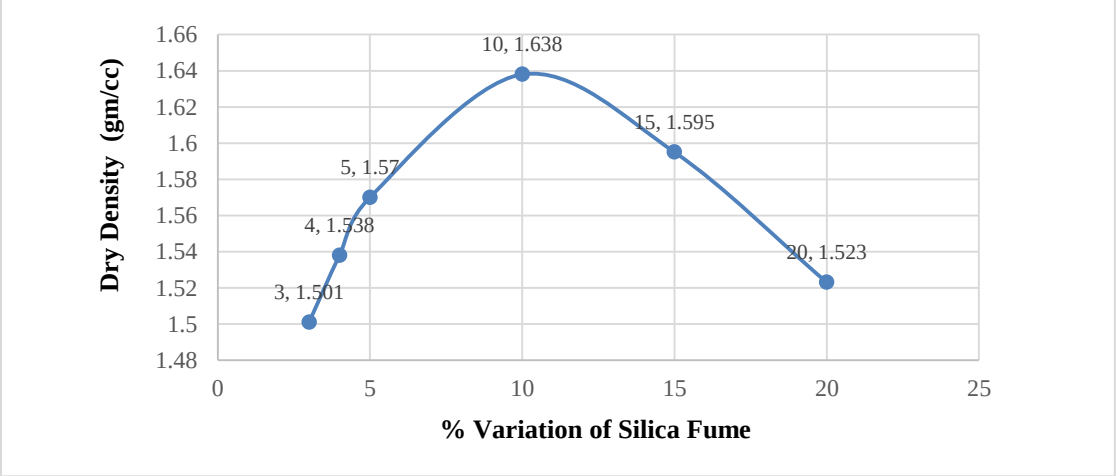

Fig.4 Present MDD Values of Expansive Soil with % Variation of Silica Fume

H. CBR TEST RESUTLS

The soaked CBR values of various mixes of Expansive Soil and Silica Fume using OMC obtained from compaction are determined. The soaked CBR after immersing in water for four days, that is when full saturation is likely to occur, is also determined. Variation of CBR with % variation in Silica Fume is presented.

TABLE 7

CBR VALUES OF UNTREATED AND ALSO EXPANSIVE SOIL TREATED WITH % VARIATION OF SSP

Expansive soil treated with % variation of SF	Soaked CBR (%)
Soil	1.79
Soil+3%SF	1.80
Soil+4%SF	2.24
Soil+5%SF	**3.0**
Soil+10%SF	2.55
Soil+15%SF	2.48
Soil+20%SF	1.35

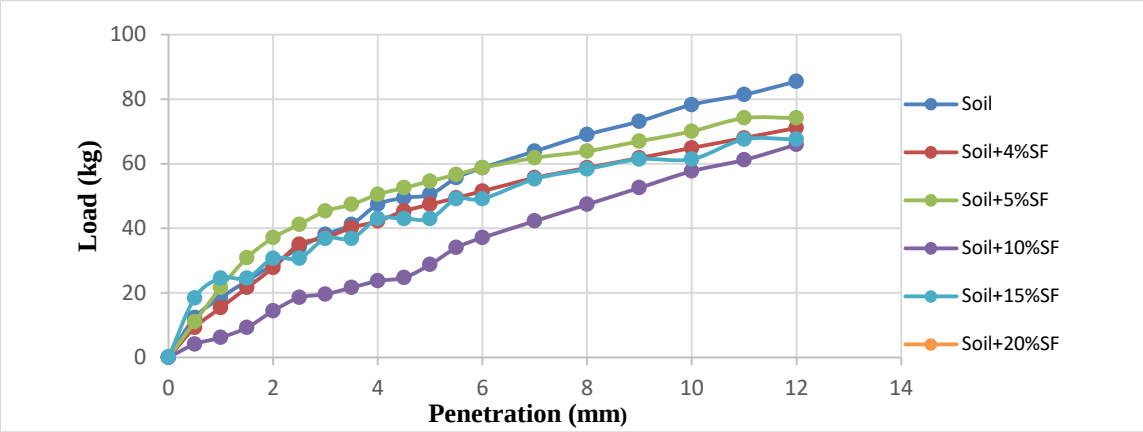

Fig.5 Present CBR values of untreated & expansive soil treated with % variation of SF

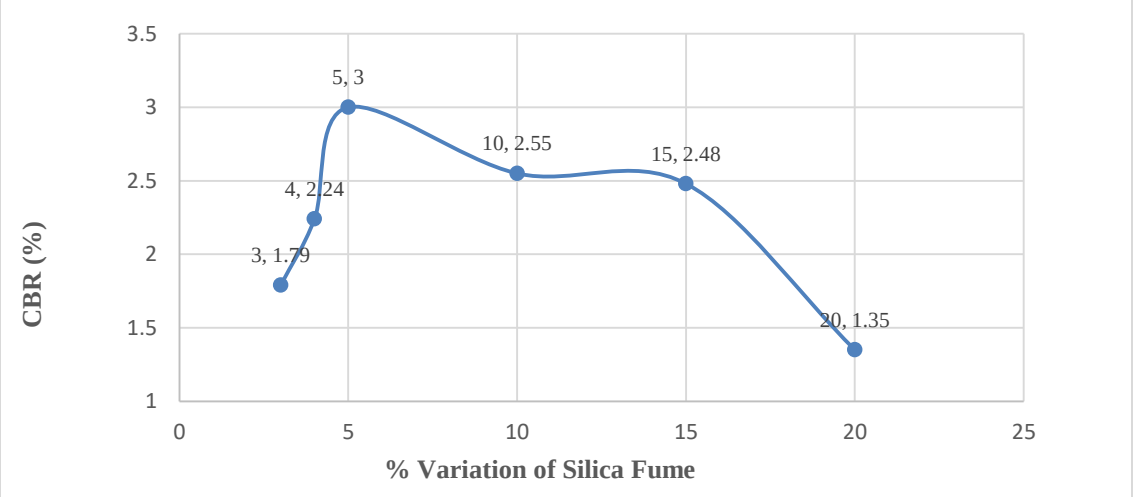

Fig.6 Present the CBR Values of Expansive Soil with % Variation of Silica Fume

DISCUSSION-1

It was observed from the laboratory test results that expansive soil treated with an optimum of 5% of SF has exhibited the CBR value of 3.00% which is less as per IS codes of practice to use this treated expansive soil as subgrade for flexible pavements. Hence it is essential to improve this treated expansive soil by taking an attempt with the addition of suitable chemical for further improving the CBR value to suit this treated soil as subgrade for flexible pavements as per IS-2720

(Part-16) and IRC:37-2012, pp:10. In the present study lime was used for further improvement in CBR value of the expansive soil treated with an optimum percentage of SF.

Initially, the OMC, MDD and CBR values were determined for the treated expansive soil with percentage variation of Ferric Chloride and the results were shown in tables 6 & 7respectively.

TABLE 8

OMC & MDD VALUES OF THE EXPANSIVE SOIL TREATED WITH AN OPTIMUM OF 5% SF AND ON ADDITION OF PERCENTAGE VARIATION OF LIME

1) OMC & MDD VALUES

SF treated expansive soil with percentage variation of Lime	MDD (gm/cc)		OMC (%)
95%Soil+5%SF+6%Lime	2.02		23.60
95%Soil+5%SF+7%Lime	2.06		21.37
95%Soil+5%SF+8Lime	**2.23**		**20.80**
95%Soil+5%SF+9%Lime	1.64		22.97

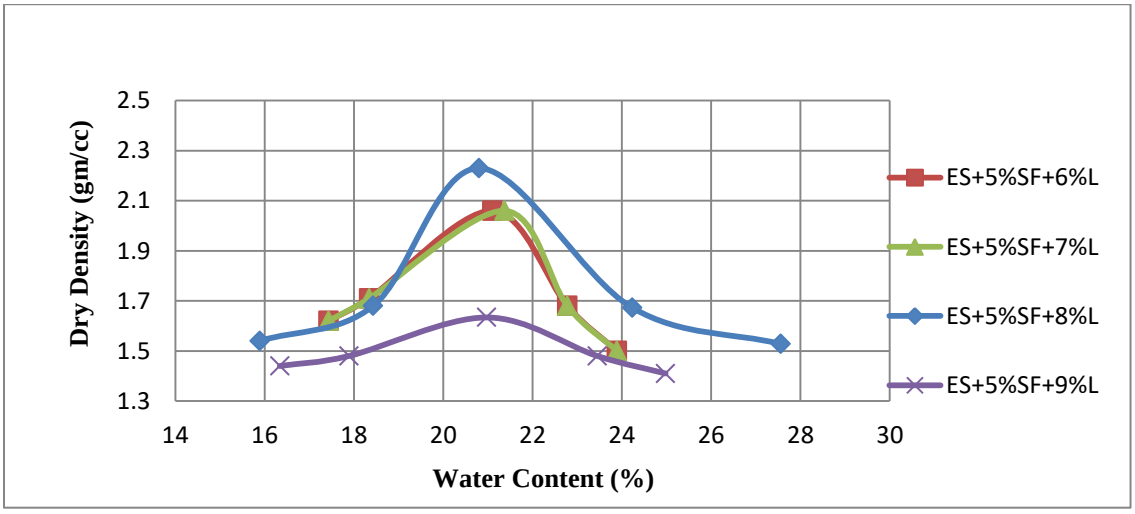

Fig. 7 Present OMC & MDD values of expansive soil treated with an optimum of 5% SF upon adding percentage variation of Lime

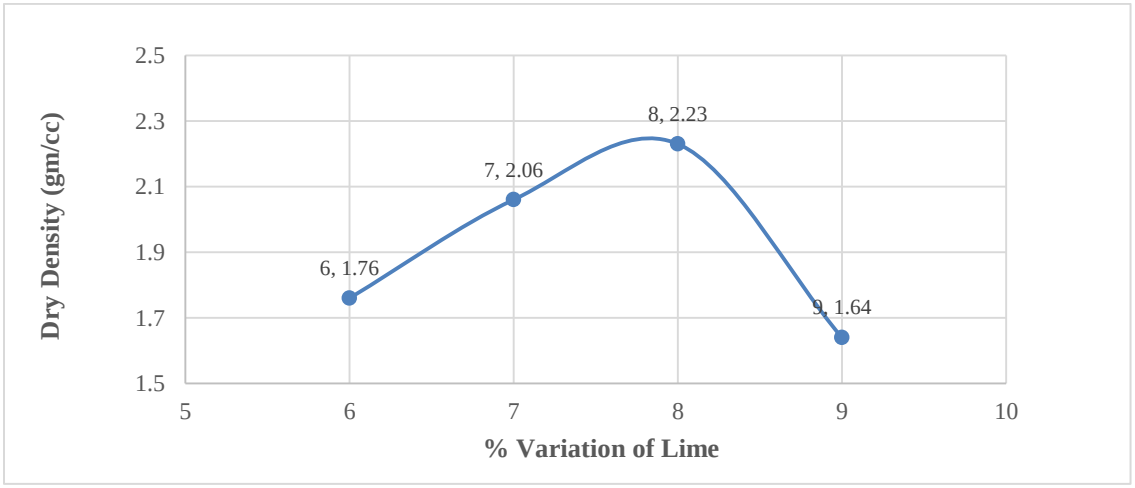

Fig.8 Present the MDD values of Expansive Soil % Variation of Lime

2) CBR TEST RESULTS

TABLE 9
CBR VALUES OF THE EXPANSIVE SOIL TREATED WITH AN OPTIMUM OF SF UPON ADDING PERCENTAGE VARIATION OF LIME

SF treated expansive soil with percentage variation of Lime	CBR (%)
95%Soil+5%SF+6%Lime	5.82
95%Soil+5%SF+7%Lime	7.17
95%Soil+5%SF+8%Lime	**8.51**
95%Soil+5%SF+9%Lime	6.72

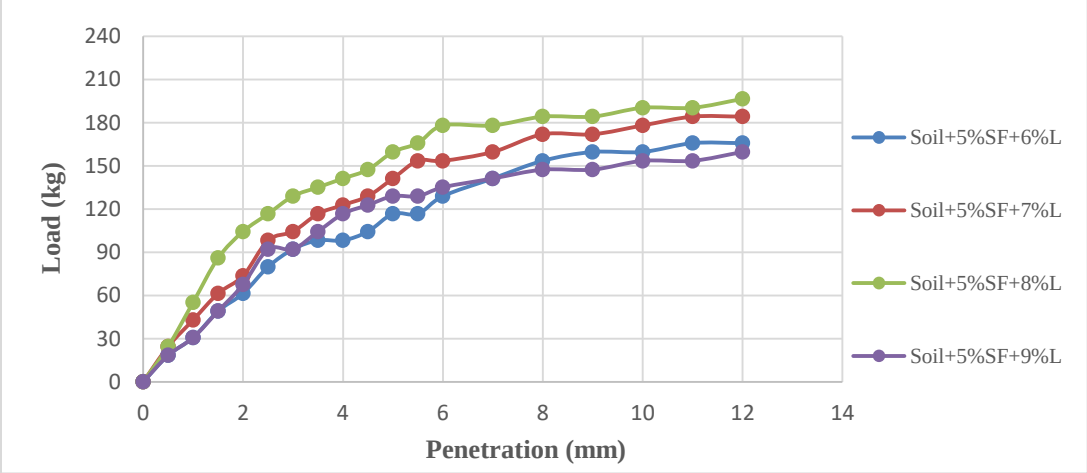

Fig.9 Present CBR test results of expansive soil treated with an optimum of SF upon adding percentage variation of Lime

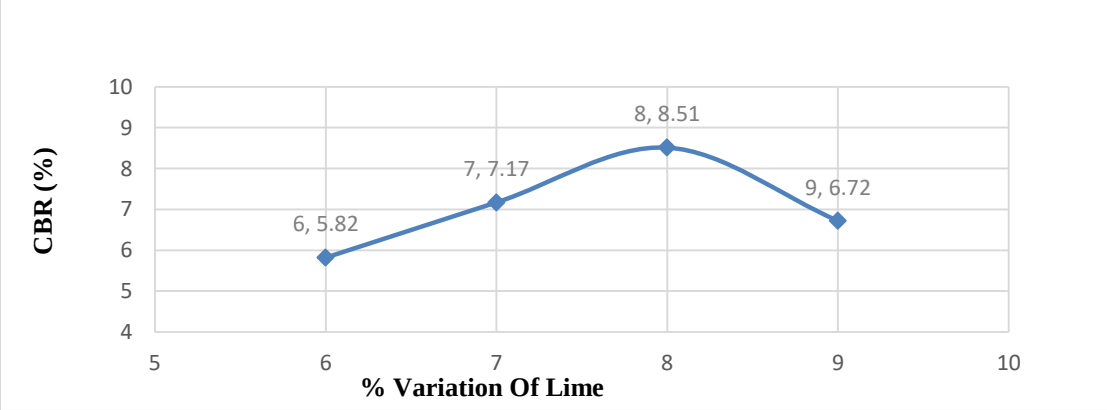

Fig.10 Present the Variation of CBR with the Percentage of Lime

TABLE 10
VARIATION OF CBR VALUES OF SILICA FUME TREATED EXPANSIVE SOIL WITH VARIOUS PERCENTAGES OF LIME

SF treated expansive soil with percentage variation of Lime	CBR (%)
95%Soil+5%SF+6%Lime	5.82
95%Soil+5%SF+7%Lime	7.17
95%Soil+5%SF+8%Lime	**8.51**
95%Soil+5%SF+9%Lime	6.72

3) CBR Test Results of Different Curing Period

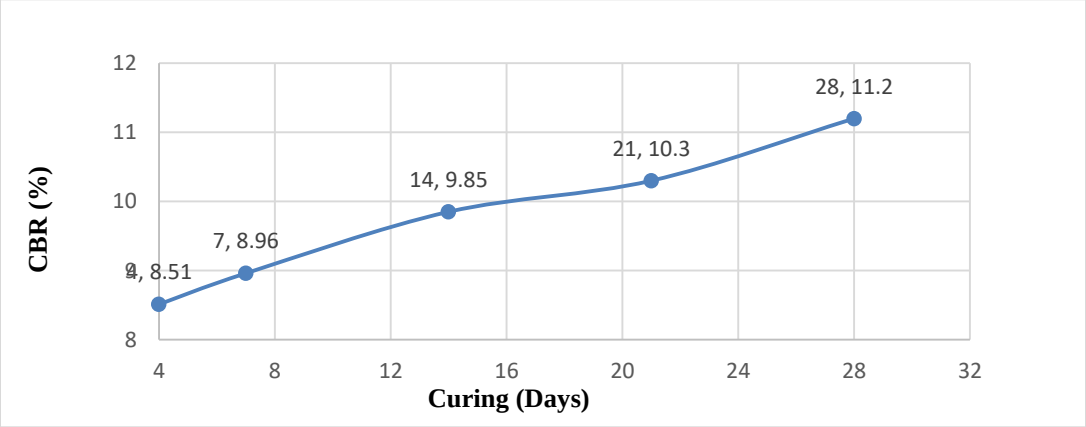

Fig.12 Presents the CBR Values of Expansive Soil with Different Curing Period of Lime

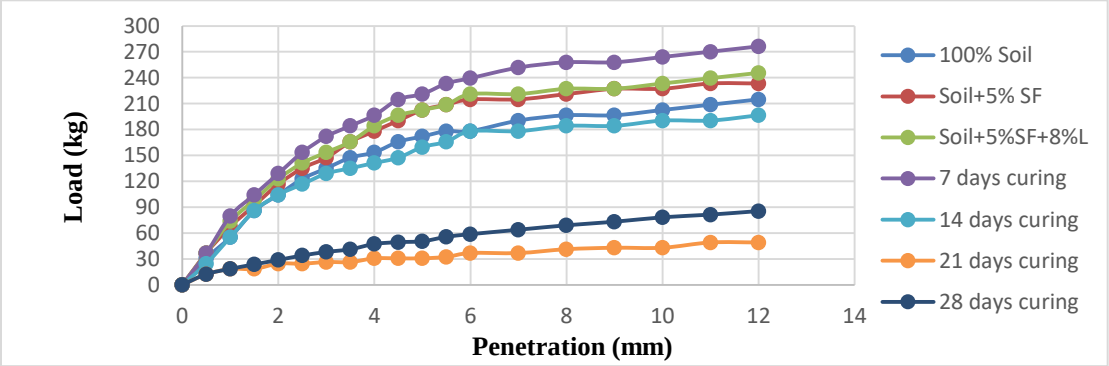

Fig.11 Presents the Influence of Different Curing Period of Lime with the Silica Fume and Expansive Soil of CBR Values

DICUSSION-2

It was observed from the laboratory test results that the expansive soil treated with an optimum percentages of 5% SF and 8% Lime has exhibited a CBR value of 11.20% which is accepted as per IS Codes of practice to use this treated expansive soil as subgrade for flexible pavement. Hence the laboratory tests Liquid limit, Plastic limit, Plasticity Index, Compaction, CBR, Specific gravity, Differential Free Swell, Cohesion, angle of shear resistance were conducted on the expansive soil treated with the optimum percentage of SF and Lime. The results were as follows:

TABLE 11
LABORATORY TEST RESULTS OF THE UNTREATED AND TREATED EXPANSIVE SOIL

Si.No	Property	Untreated expansive soil	Expansive soil treated with 5% of SF	Expansive soil treated with optimum percentages of 5% SF and 8% Lime
1	Liquid limit (%)	61.56	54	47.66
2	Plastic limit (%)	25.13	28.16	23.35
3	Plastic index (%)	36.43	25.84	24.31
4	Soil classification	CH	CH	CI
5	Specific gravity	2.65	2.72	2.81
6	D.F.S (%)	110	75	30
7	O.M.C	29.23	24.51	26.38
8	M.D.D (gm/cc)	1.45	1.638	1.623
9	Cohesion	0.7	0.61	0.42

	(C)			
10	Angle of shear resistance(ϕ)	5.5^0	17^0	23^0
11	CBR (%)	1.79	3.0	8.51

TABLE 12
CBR VALUES OF STABILIZED EXPANSIVE SOIL FOR DIFFERENT CURING PERIOD

Soil Mix Proportion	**Days of Curing**	**CBR value (%)**
100% Expansive soil	*4*	1.79
Soil+5%SF	*4*	3.0
Soil+5%SF+8%Lime	*4*	8.51
	7	8.96
	14	9.85
	21	10.30
	28	11.20

V. CONCLUSIONS

1) It is observed that the liquid limit of Expansive Soil has been decreased by 12.28% on addition of 5% Silica Fume and it has been further decreased by 22.67% when 8% Lime added.
2) It is noticed that the plastic limit of the Expansive Soil has been increased by 12.05% on addition of 5% Silica Fume and it has been decreased by7.08 % when 8% Lime is added.
3) It is observed that the plasticity index of the Expansive Soil has been decreased by 29.06% into on addition of 5% Silica Fume and it has been further decreased by 33.6% when 8% Lime is added.
4) It is noticed that the cohesion of Expansive Soil has been decreased by 47.61% on addition of 5% Silica Fume and it has been further decreased by 78.09% when 8% Lime added.
5) It is noticed that the angle internal friction of Expansive Soil has been improved by 49.07% on addition of 5% Silica Fume and it has been further improved by 167% when 8% Lime added.
6) It is found that the O.M.C of the Expansive Soil has been decreased by 16.14% on addition of 5% Silica Fume and it has been further decreased by 9.75% when 8% Lime is added.
7) It is found that the M.D.D of the Expansive Soil has been improved by 12.96% on addition of 5%, Silica Fume and it has been improved by18.82 % when 8%
8) It is observed that the C.B.R value of the Expansive Soil has been increased by 67.59% on addition of 5% Silica Fume and it has been further improved by 375.41% when 8% Lime is added.
9) It is observed from the test results that the C.B.R value of the Expansive Soil has been improved by 375.41% on addition of 5% Silica Fume and it has been further improved by 525.69% when 8% Lime of 28 days curing period as optimum when compared with the untreated expansive soil.
10) It is observed that the DFS value of the Expansive Soil, has been decreased by 50% on addition of 5% Silica Fume and it has been further decreased by 81.25% when 8% Lime is added.

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VII.BIOGRAPHIES

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Dr.D Koteshwara Rao is working as a Professor of Civil Engineering & Director, Faculty Development Centre, Jawaharlal Nehuru Technological University Kakinada. He is a " Triple Hat-Trick Best Teacher Awardee" from the Department of Civil Enginering, University College of Engineering, JNTUK Kakinada. He was awarded the "University Meritoruins teacher award -2013" by the University and aslo received National Best Teacher award-2013. Recently he has received "the State Best Teacher Award-2017 by the Government of Andhra Pradesh, India. He has published 33 research and review papers in various International journals and conferences. He has guided about 50 post graduate projects and four research scholars are working his guidance. He is a leading consulting member in the fields of Surveying, Transportation and Geotechnical Engineering.

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