Plasticity and Compaction Characteristics of Soil Mixtures Comprising Of Expansive Soils and A Cohesive Non-Swelling Soil

Dr. Ch. Sudha Rani[1] & G. Suresh[2]

[1]Associate Professor, Dept. of Civil Engineering, S. V. U. College of Engineering, Tirupati – 517 502
[2]Post Graduate Student, Dept. of Civil Engineering, SV University, Tirupati, India

ABSTRACT

Soil is naturally occurring material that is used for the construction of structures except the surface layers of pavements. This naturally occurring soil may not suit the design requirements of ongoing project. So, soil is to be prepared to meet the requirements called soil stabilization. Stabilization is the process of blending of different soils or mixing of additives to a soil to improve characteristics of the soil such as gradation, strength, durability, workability, plasticity etc. and thus making it more stable. It is required when the soil available for construction is not suitable for the intended purpose. The present paper emphasized on investigation of soil mixtures comprising of three expansive soils mixed with a cohesive non-swelling soil pertaining to plasticity characteristics, compaction characteristics, Soil-mixtures are prepared with expansive soils adding different percentages of cohesive non-swelling soil varying from 15% to 35% by weight of expansive soil with 5% interval.

Keywords: soil mixtures, soil stabilization, Liquid Limit, Plastic Limit, Light Compaction Test

I. INTRODUCTION

There are numerous methods by which soils can be stabilized; however, all methods fall into two broad categories. They are mechanical stabilization and chemical admixture stabilization. Some stabilization techniques use a combination of these two methods. Mechanical Soil Stabilization relies on physical processes to stabilize the soil, either altering the physical composition of the soil by mixing another soil and mixer (soil blending) or placing a barrier in or on the soil to obtain the desired effect (such as establishing a sod) cover to prevent dust generation. Chemical stabilization relies on the use of an admixture to alter the chemical properties of the soil to achieve the desired effect (such as using lime to reduce a soil's plasticity). Mechanical stabilization involves by compaction an interlocking of soil-aggregate particles. The grading of the soil-aggregate mixture must be such that a dense mass is produced when it is compacted. Mechanical stabilization through soil blending is the most economical and expedient method of altering the existing material. Mechanical stabilization can be accomplished by uniformly mixing the material and then compacting the mixture. As an alternative, additional fines or aggregates may be blended before compaction to form a uniform, well- graded, dense soil-aggregate mixture after compaction. The choice of methods should be based on the gradation of the material. In some instances, geotextiles can be used to improve a soil's engineering characteristics. The three essentials for obtaining a properly stabilized soil mixture are i) proper gradation, ii) A satisfactory binder soil and iii) proper control of the mixture content.

Hence the objectives of the present investigation are determination and study the effect on Plasticity and Compaction characteristics soil-mixtures without and with addition of different percentages cohesive non -swelling on expansive soils selected.

II. BACKGROUND INFORMATION

Ground modification techniques have become a major part of civil engineering practice over the last 30 years (Haussmann, 1990). Improvement of sites with weak or high compressible or high swelling or any other such problematic soils is commonly done by removing the problematic soils and replacing them with more competent ones such as compacted gravel, crushed rock, or lightweight aggregates to increase the load bearing capacity (Kukko, 2000). Although this is considered a good solution, usually has the drawback of high cost due to the cost of the replacement materials. In India, expansive soils are found in regions where the annual rainfall ranges from 300 to 900 mm. Subba Rao et al. 1985 have emphasized that the Montmorillonite content is the predominant clay fraction in these soils. The Cation Exchange Capacity of these soils vary from 80 to 130 m.eq/100 gm and their consistency limits vary from 53% to 100%, 20% to 50% and 7% to 18% for liquid limit, plastic limit and shrinkage limit respectively. The specific gravity varies from 2.7 to 2.9 for black cotton soils. The clay fraction of black cotton soils is very rich in silica (60%) with only 15% iron and 15% alumina. During monsoon, these soils especially near the surface, imbibe water, under-go heave, loose density and become slushy when more water is available. Conversely, during summer, the soils desiccate, shrink, gain density and become very hard. The decreasing dry density and the loss of strength on monsoon and the gain thereof in summer tend to decrease with depth (Katti, 1978). During summer, polygonal shrinkage cracks appear at the surface which may extend to a depth of about 2m to 3.5m, indicating the active zone in which the volume changes occur. According to Pandian et.al (2002) The addition of fly ash to BC soil increases the CBR of the mix up to the first optimum level due to the frictional resistance from fly ash in addition to the cohesion from BC soil. The swelling phenomenon is considered as one of the most serious challenges which the foundation engineer faces, because of the potential danger of unpredictable upward movements of structures founded on such soils (Seed et al., 1962). Katti (1978) has developed a technique where by removal of about 1m of expansive soil and replacement by cohesive non-swelling soils (CNS) layer beneath foundations has yielded satisfactory results. Katti has successfully adopted it for prevention of heave and resultant cracking of canal beds and linings and recommends it for use in foundations of residential buildings also. According to Katti cohesive forces of significant magnitude are developed with depth in an expansive soil system during saturation which is responsible for reducing heave and counteracting Swelling Pressure. The behaviour is mainly attributed to the influence of electrical charges present on the surface of clay particles and the dipolar nature of water molecules, producing absorbed water bonds that give rise to cohesion. Moorum is a typical example of CNS material. The cohesive bonds develop around the particles at a faster rate than the ingress of water molecules into the interlayer of the expanding lattices of montmorillinite, thereby reducing heave. R.K.Katti made a massive research study on expansive soil (Black cotton soil) behavior around 20 years and developed the concept of using a cohesive non swelling (CNS) soils to reduce effects of swelling V.Ramana Murty and G. V. Praveen studied, the use of CNS Soil as cushion below the light weight structures founded on Expansive soil by chemical stabilization (CaCl2 –RHA). I

III. MATERIALS AND METHODS

The usage of cohesive non-swelling soils is popular method of soil improvement owing to its availability, low cost and applicability to wide range of soils. However from literature review it is clear that only a few investigators considered the study of improvement of expansive soils Present investigation aims at studying the variation of study the Plasticity and Compaction characteristics soil-mixtures without and with addition of different percentages cohesive non -swelling on expansive soils for mechanical stabilization by adding different proportions of cohesive non-swelling soils. To achieve the said goals a series of tests are conducted in the laboratory. The details of the tests conducted, soils used, and the tests procedures are given in the following sections.

3.1 Soils Used

In this section, the details pertaining to soil, and CNS used in this investigation are discussed. The soils are collected from different places of Andhra Pradesh, like first at Atmakur; near Kurnool, soil2 at Gajulamandyam, near Tirupathi, soil3 at Tiruchanoor near Tirupathi and soil4 from vedhapatasala in Tirupathi. The soils are designated as S1,S2,S3 and S4for reference. The details of soil location and their designation are given in table 1.

Table 1 Details of soil Used

Soil Designation	Locations
S1	Atmakur, near Kurnool, (at 2.9 m depth)
S2	Gajulamandyam, near Tirupathi (at 3 m depth)
S3	Tiruchanoor near Tirupathi (at 2.9 m depth)
S4	Vedhapatasala in Tirupathi (at 2.5 m depth)

S1, S2 and S3 soils are expansive soils selected for investigation. S4 and S5 soils are selected mixing with the above mentioned soils. Among these two soils, S4 is used for preparing soil mixtures as this soil in formed to be Non-swelling of Cohesive in nature.

3.2 Tests Conducted

The following tests are conducted in order to meet the objectives of the present investigation.

- Liquid Limit,
- Plastic Limit,
- Light Compaction Test,
- Free Swell Odeometer Test,
- Triaxial Test,

Unconfined Compressive Strength Test, Consolidation Swelling Pressure Tests are aimed at studying the soil-mixtures. For this purpose Cohesive Non- Swelling Soil (S4) having Liquid Limit of 26% is mixed with three different expansive soils S1, S2 and S3 having Liquid Limits 57%, 144% and 61% respectively. The expansive soils are mixed with Cohesive Non Swelling soil which is coarser than 425m as it will have influence on Liquid Limit of the soil. The soil mixtures are prepared by mixing S1, S2, and S3 soils with 0%, 15%, 20%, and 25%, 30%, 35% of S4 soil. Percentage of cohesive Non-

Swelling soil was varying from 0% to 35%. The details of soil mixtures and the tests conducted on soil-mixtures are given in table 2

4. RESULTS AND DISCUSSIONS

4.1 Plasticity Characteristics :

Expansive clays impose various foundation problems due to their sensitiveness to changes in moisture content. These soils pose problems on account of their high compressibility and low shear strength also. The objective of the present investigation is to study the properties of soil-mixtures comprising of Cohesive Non- Swelling (S4) soil and expansive soils mixtures by studying the behavior of soil alone and soil mixtures in general. Three series of tests were conducted on soil mixes varying the percentage of S4 soil mixed with expansive soils (S1,S2, and S3). The results of these test series are presented and discussed in following sections Chapters.

4.1.1 Expansive Soils and Cohesive Non-Swelling Soil Mixtures Properties: Expansive Soils in nature may contain coarse fraction in varying proportions. Fraction coarser than 425µ has no effect on plasticity characteristics but has on mechanical properties. I.S Light Compaction test, Triaxial Shear Test, Unconfined Compression Test were conducted on three expansive soils namely S1, S2 and S3 with and without adding S4 soil. The proportions of the S4 soil added are kept equal to 15%, 20%,25%,30% and 35% by weight of expansive soil. The S4 soil used in this investigation is locally available soil other than expansive soil, so that the plasticity characteristics of the soils remain same even after its addition. The index properties of the soils used are already presented in chapter 3, Table 3.4. All three soils are classified as MH, SC, and CH as per I.S Classification method with Liquid Limits of 57%, 144%and 61% respectively. The results -pertaining to Compaction Characteristics, Strength Characteristics are presented in subsequent sub sections respectively.

4.1.2 Plasticity Characteristics

The Liquid Limit, Plastic Limit and Plasticity Index variation of S1, S2 and S3 soil- mixed with 0%, 15%, 20%, 25%, 30% and 35% of S4 soil are shown in figs 4.1 to 4.3. The graph depicts decrease in the Liquid Limit with increase in percentage of S4 soil for all the three soils mixes. This is due to increase in coarse fraction of soils due to mixing of S4 soil. The Liquid Limit of soils S1, S2 and S3 are alone 57%, 144%, and 61% respectively. For S2-,S4 mixes the percentage decrement in Liquid Limit is drastic. i.e 59.07%at 15% of S4 soil-mix and then decrement is very nominal. i.e. The 67.36% at 35% of S4 soil addition. The percentage decrement Liquid Limit is 19.29% to 29.82% for S1-S4 soil-mixes and 6.56% to 18% for S3- S4 soil mixes. The decrement in Liquid Limit for all the three soils mixes at different percentages of S4 soils presented in Table 4

4.1.2.1 Plastic Limit

The Plastic Limit variation of S1, S2 and S3 soil-mixed with 0%, 15%, 20%, 25%, 30% and 35% of S4 soil are shown fig in 4.2. The graph depicts decrease in the Plastic Limit with increase in percentage of S4 soil for all the three soils mixes. This is due to increase in coarse fraction of soils due to mixing of S4 soil. The Plastic Limit of soils S1, S2 and S3 are alone 31.18%, 63%, and 18% respectively. For S2-S4 mixes the percentage decrement in Plastic Limit is drastic. i.e. 75.80%at 15% of S4 soil-mix and then decrement is very nominal. i.e. The 74.69% at 35% of S4 soil addition. The percentage decrement Plastic Limit is 20.14% to 27.64% for S1-S4 soil-mixes and 16.60% to 20.62% for S3- S4 soil mixes. The decrement in Plastic Limit for all the three soils mixes at different percentages of S4 soils presented in Table 5

4.1.3 Plasticity Index

The Plasticity Index of S1, S2 and S3 soil mixes with 0%, 15%, 20%, 25%, 30% and 35% of S4 soil is shown in fig 4.3. From graph, it can be observed that the Plasticity Index is decreasing with percentage increase of S4 soil, for all three soil mixtures. Plasticity Index is decreasing from 25.82% to 16.48% for S1-S4 soil mixtures and 81% to 31.06% for S2 -S4 soil mixtures and 43% to 28.29% for S3-S4 soil mixtures. The percentage decrement in Plasticity Index for all the three soils mixtures with varying percentage of S4 soil is presented in Table 6.

4.2.Compaction Characteristics of Soil Mixtures

4.2.1 Introduction

Compaction is a process by which the soil particles are artificially arranged and packed together in to closer state of contact by mechanical means in order to decrease the void ratio of the soil and thus increase its Dry Unity Weight. There exists a definite relationship between the Water Content and degree of Dry Unit Weight to which a soil might to be compacted, and thus for specific amount of compactive energy applied on the soil, there is water content termed the Optimum Water Content(OMC) at which a particular soil attains Maximum Dry Unit Weight(MDD).

4.2.2 Compaction Characteristics

Standard proctor compaction tests are conducted for soil mixtures S1-S4, S2-S4 and S3-S4 in three series. The compaction curves are plotted for Dry Density and Water Content at different percentages of S4 soil, to find Maximum Dry Density and Optimum Moisture Content for each soil-mixture. The variation of Optimum Moisture Content and

Maximum Dry Density with S4 soil (CNS) is shown in figures 5.1&5.4. The Optimum Moisture Content is decreasing S1&S3 soils but increasing with Water content for S2 soil. Since the S2 soil high percentage of coarse fraction and increase in S4 soil percentage to S2 soil the intergranular contact between grains decreases so MDD decreases with increase in moisture content. The percentage increase is form 1.673 percentages to 5.678 percentages for S1-S4 soil-mixes and from 1.734 percentages to 6.574 percentages for S3-S4 soils-mixes. The maximum dry density is decrease from -1.848percentage to1.028 percentage for S2-S4 soil-mixes.

Table 2 Details of tests conducted on soil mixtures

S. No	Soil Mixtures: Mixtures using S_1	Mixtures using S_2	Mixtures using S_3	Tests conducted
1	S_1 + 0 % S_4	S_2+ 0 % S_4	S_3+ 0 % S_4	Liquid Limit, Plastic Limit, Free Swell Index, Odometer Test (Consolidation Test), Light Compaction Test, Tri-axial Test, Unconfined Compression Test, ,Swelling Pressure, Permeability Test, pH values
2	S_1+ 15% S_4	S_2 + 15% S_4	S_3+ 15% S_4	
3	S_1+20 % S_4	S_2+20 % S_4	S_3+20 % S_4	
4	S_1+ 25% S_4	S_2+ 25% S_4	S_3+ 25% S_4	
5	S_1+ 30% S_4	S_2+ 30% S_4	S_3+ 30% S_4	
6	S_1+ 35% S_4	S_2+ 35% S_4	S_3+ 35% S_4	

Table 3 Properties of the Soils Used

S.No.	TESTS	S1	S2	S3	S4	S5
1	Sieve Analysis					
	a) Gravel,(%)	1.00	1.70	1.00	3.68	15.00
	b) Sand,(%)	11.36	75.9	24.0	73.5	56.50
	c) Silt + Clay,(%)	87.84	22.4	75.0	23.83	28.50
2	Liquid Limit, (%)	57	144	61	26	69
3	Plastic Limit, (%)	31.18	63	18	16	20
4	Plasticity Index, (%)	25.82	81	43	10	49
5	IS Classification of Soil	**MH**	**SC**	**CH**	**SC**	**SC**
6	Free Swell Index (%)	50	270	100	10	180
7	Degree of expansion	LOW-MEDIUM	VERY HIGH	MEDIUM HIGH	LOW	HIGH
8	Optimum Moisture Content (%)	13.5	10.5	14.5	14	12
9	Maximum Dry Density (kN/m^3)	16.73	18.48	17.34	18.16	18.26
10	Undrained Strength Parameters					
	a) Cohesion (C, in (kPa))	192.68	84.61	77.60	75.65	80.75
	b) Angle of Internal friction (Φ, in degrees).	12.58	10.72	9.86	13.56	10.97
11	Consolidation					
	a) Compressive Index (C_c)	0.039	0.06	0.106	0.053	0.223
	b)Recompression Index,(C_r)	0.035	0.023	0.0315	0.014	0.265
	c)Swelling Pressure,(kN/m^2)	85	112	195	0.00	195
12	Coefficient of Permeability, (k)	8.532×10^{-6}	1.17×10^{-7}	1.33×10^{-6}	1.01×10^{-6}	1.179×10^{-4}
13	P^H values	8.00	9.9	9.26	9.01	6.71
14	Chlorides (% by mass)	0.24	0.47	0.71	0.69	0.2
15	Sulphates(% by mass)	0.21	0.49	0.25	0.22	0.36

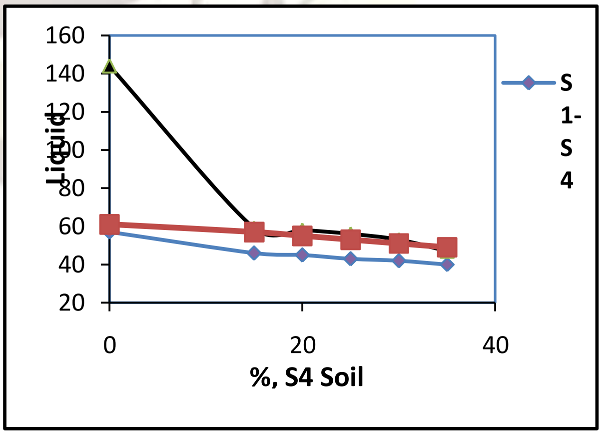

FIG.1 Variation of Liquid Limit for Soil-mixes (S_1-S_4, S_2-S_4, and S_3-S_4)

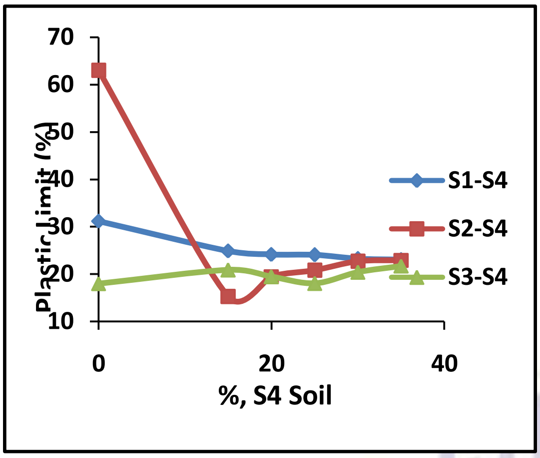

FIG.2 Variation of Plastic Limit for Soil-mixes (S_1-S_4, S_2-S_4, and S_3-S_4)

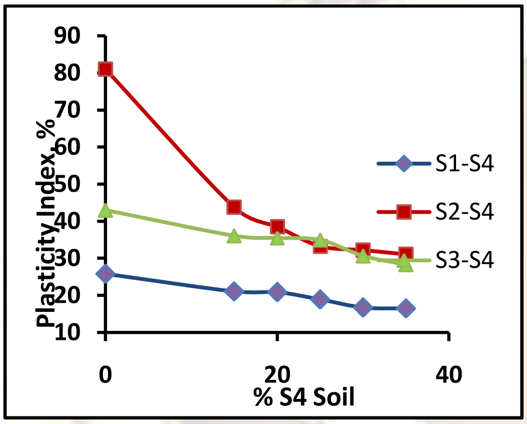

FIG. 3 Variation of Plasticity Index for Soil-mixes (S_1-S_4, S_2-S_4, and S_3-S_4)

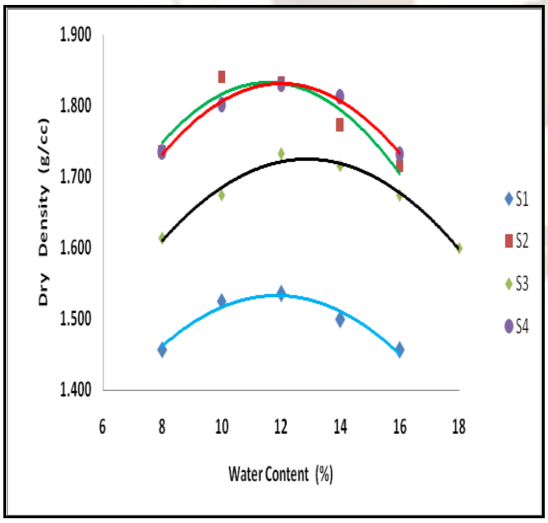

FIG. 4. Compaction curves of S1,S2, S3 and S4 soils alone

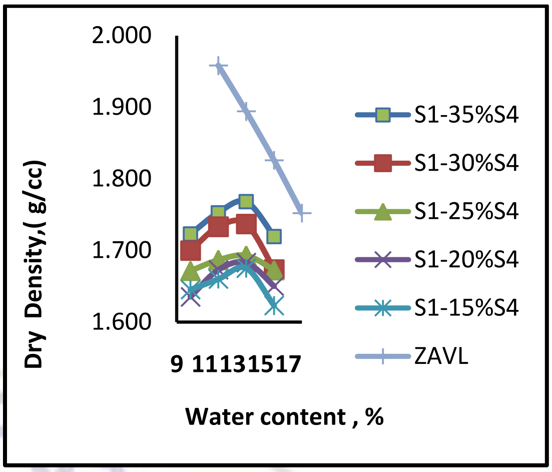

FIG 5.Variation of Dry Density with Water Content for S_1-S_4 soil-mix

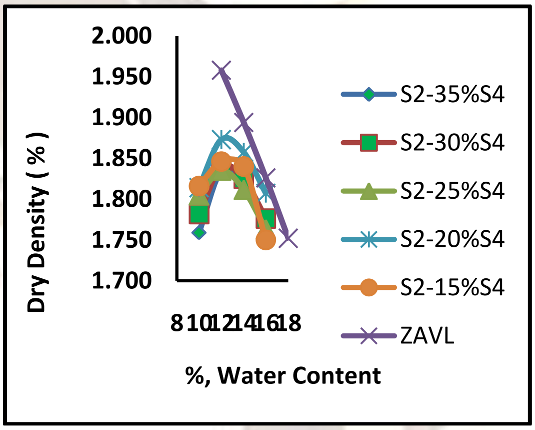

FIG.6. Variation of Dry Density with water content for S_2 –S_4 soil-mix

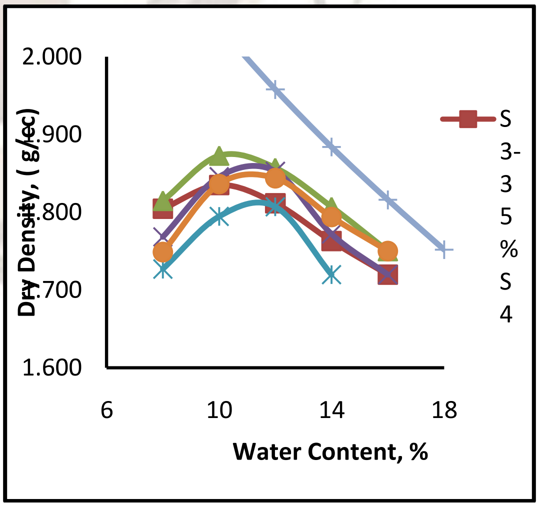

FIG .7. Variation of Dry Density with water content for S_3-S_4 soil-mix

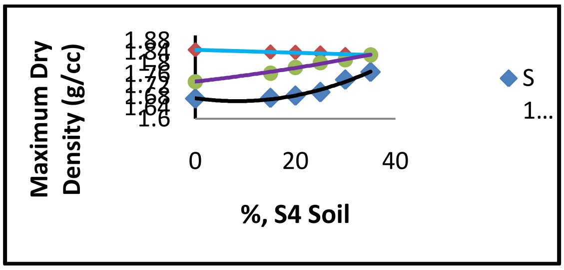

FIG. 8. Variation of MDD for soil-mixes (S_1-S_4, S_2-S_4, and S_3-S_4)

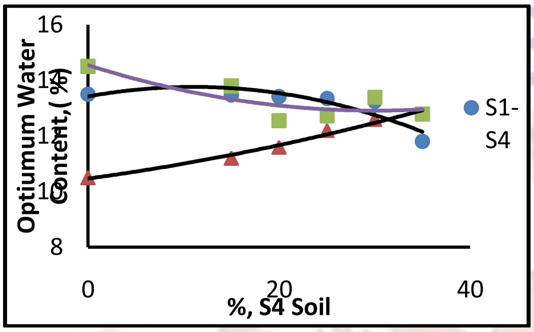

FIG. 9.Variation of OMC for soil-mixes (S_1-S_4, S_2-S_4, and S_3-S_4)

Table 3 Properties of S1-S4 Soil- Mixes

S. No :	Description	S1	S1+15%S4	S1+20% S4	S1+ 25% S4	S1+ 30% S4	S1+ 35% S4
1	Plastic Limit (%)	31.18	24.9	24.15	24.07	23.27	22.56
2	Plasticity Index (%)	25.82	21.1	20.85	18.93	18.45	17.44
3	Free Swell Index (%)	50	40	30	20	15	10
4	Degree of Expansion	Low-medium	low	low	low	low	low
5	Swelling Pressure, kN/m^2	220	190	176	169	162	130
6	Optimum Moisture Content (%)	13.50	13.48	13.42	13.35	13.25	11.8

7	Maximum Dry Density, (kN/m^3)	16.73	16.75	16.83	16.95	17.41	17.68

Table 4 Properties of S2-S4 Soil- Mixes

S No	Description	S2	S2+15%S4	S2+20% S4	S2+ 25% S4	S2+ 30% S4	S2+ 35% S4
1	Liquid Limit (%)	144	59	58	56	53	47
2	Plastic Limit (%)	63	15.24	19.48	22.71	20.82	15.94
3	Plasticity Index (%)	81	43.75	38.52	33.29	32.17	31.06
4	Free Swell Index (%)	270	200	180	160	110	100
5	Degree of Expansion	VERY HIGH	HIGH	HIGH	HIGH	HIGH	MEDIUM - HIGH
6	Optimum Moisture Content (%)	10.5	11.2	11.6	12.2	12.6	12.8
7	Maximum Dry Density, (kN/m3)	18.48	18.39	18.38	18.36	18.30	18.26

Table 5 Properties of S1-S4 Soil- Mixes

S No	Description	S3	S3+15%S4	S3+20% S4	S3+ 25% S4	S3+ 30% S4	S3+ 35% S4
1	Liquid Limit (%)	61	57	55	53	51	50
2	Plastic Limit (%)	18	20.89	19.47	18.04	20.38	21.71
3	Plasticity Index (%)	43	36.11	35.53	34.96	30.62	28.29
4	Free Swell Index (%)	100	95	80	105	115	120
5	Degree of Expansion	medium -high	medium	medium	high	high	high
6	Optimum moisture content (%)	14.5	13.8	12.56	12.43	12.14	11.2
7	Maximum Dry density, (kN/m^3)	17.34	17.63	17.48	18.02	18.12	18.48

IV. CONCLUSIONS

The present work emphasized on investigation of soil mixtures comprising of three expansive soils (S1,S2,S3) mixed with a Cohesive Non-Swelling(S4) soil pertaining to Plasticity Characteristics, Compaction Characteristics, Soil-mixtures are prepared by adding different percentages of cohesive non-swelling (S4) soil varying from 15% to 35% by weight of expansive soil with 5% interval to the selected expansive soils. The soil-mixtures are designated as S1-S4, S2-S4 and S3-S4 throughout the work for reference Tests are conducted on the prepared soil-mixtures as per procedures laid down in IS Codes. The Liquid limit, Plastic limit and Plasticity Index values all the soil mixtures (S1-S4, S2-S4 and S3-S4) decreased with the increase in percentage of Cohesive Non-Swelling soil(S4).There is decrease in Optimum Water Content with increase in Cohesive Non Swelling soil (S4) for S1-S4 and S3-S4 mixes whereas Optimum Water Content increased for S2-S4 soils combinations. The maximum Dry Unit Weight of the soil mixtures increase slightly with increase in percentage of Cohesive Non Swelling soil (S4)) for S1-S4 and S3-S4 mixes. For S2-S4 mixes decreased attributing to increase in the coarse fraction with the addition of Cohesive Non-Swelling Soil.

REFERENCES

[1] Acosta, H.A., Edil, T.B., Benson, C.H. (2003). "Soil stabilization and drying using FlyAsh".Geo Engineering Report No. 03-03 Department of Civil and Environmental Engineering, University of Wisconsin-Madison.

[2] Anon,(1985)."Lime stabilization construction manuals," English edition. National lime association, Arlington, VA.

[3] ASTM (1993)."Standard specification for Fly Ash and Raw or Calcined natural pozzolan for use as a mineral Admixture in Portland cement concrete," Annual books of ASTM standards,618-93, vol.02,Philadelphia,PA,USA,PP.310-312.

[4] Broms,B., and Boman,p. (1975) "Lime stabilized columns" 5th Asian regional conference on SM and FE. Bangalore, India 227-234.

[5] Broms, B., and Boman,p. (1993) ,"Lime columns-a new foundation method". Journal of Geotechnical Engineering division, ASCE 105,PP.539-556.

[6] Chen, F. H. (1988). "Foundations on expansive soils", 2nd Ed., Elsevier Science, New York.

[7] Cokca, E. (2001). "Use of Class C fly ashes for the stabilization of an expansive soil." Journal of Geotechnical and Geoenvironmental Engineering, 127(7), 568-573.

[8] Eades,J.L., and Grim,R.E.(1960)."Reaction of hydrated lime with pure clay minerals in soil stabilization". Highway Res. Bull.No 262. Washington, D.C.,51-63.

[9] Eades, J. L. and Grim, R. E. (1966) A quick test to determine lime requirements for lime stabilization, Highway Res. Record 3, 61-70.

[10] Eggestad,A. and Sem,H.(1976)."Stability of excavations improved by salt diffusion from deep wells," Proc. Of the 6th European Conf. on SM & FE, Vienna, Australia,vol.1,pp.211-216.

[11] Hausmann, M. R. (1990)."Engineering Principles of Ground Modifications". New York: McGraw Hill.

[12] Holm,G., Trank,R and Ekstrom,A.,(1983)."Improving lime column strength with Gypsum," Proc. of the 8th European Conf. on SM & FE,Helsinki,Finland,Vol.2, pp.903-907.

[13] Holm,G., Trank,R and Torsteensson,B.A.(1983)."Lime columns under Embankments-A full scale test. Proc. of the 8th European Conf. on SM & FE,Helsinki, Finland,Vol.2, pp.909-912.

[14] Katti,R.K.(1969),"Shear strength and swell pressure characteristics of expansive soils,"Proceedings of the 2nd International Res. And Engg. Conf. on expansive clay soils, Texas,A and M University press,pp.334-347.

[15] Katti,R.K.(1978),"Search for solutions to problems on Black Cotton soils,,1st L.G.S Annual lecture, Indian Geotechnical society, New Delhi, India.

[16] Kukko, H. (2000). "Stabilization of clay with inorganic by-products." Journal of Materials in Civil Engineering, 12(4), 307-309.

[17] Khanna and Justo(1987), "Highway Engineering", Nemchand and Brother, Roorke(U.P).

[18] Mackiewicz,M., and Glen Ferguson,E.(2005)."Stabilization of soil with self-cementing coal ashes," world of coal ash (WOCA), Lexington, Kentucky, USA. pp.11-15.

[19] Misra, A.,Biswas, D.,and Upadhyaya, S. (2005). "Physico-mechanical behaviour of self cementing class C fly ash-clay mixtures" Fuel, 84 (11), 1410-1422.

[20] Nalbantoglu, Z., and Tuncer, E., (2001), "Compressibility and Hydraulic Conductivity of a Chemically Treated Expansive Clay," Canadian Geotechnical Journal, Vol. 38, pp. 154-160.

[21] Nalbantoglu,Z.(2002). "Utilization of industrial waste in Calcareous expansive clay stabilization," Geotechnical Testing Journal, vol.25,No.1,pp.78-84.
[22] Narasimha Rao,S., Somayajulu,J.R., and Rajasekaran,G.(1991)."Stabilization of soft Marine clays using deep in-situ lime column method",10 th Int. Conf on offshore Mech. and Archetec Engg.pp:91-388 Narwey.
[23] Narasimha Rao,S. and Rajasekaran,G.,(1996)."Lime Stabilization Technique for improvement of Marine clay soils and Foundations", Japan 37,149-160.
[24] Nieminen,P.(1978). "Soil stabilization with Gypsum lime," Proc. Of the International Conf.on the use of By-products and waste in Civil Engg., Paris, France, vol.1, pp.229-235.
[25] Pandian,N.S.,Krishna,K.C.,and Sridharan,a.,(2001)," California Bearing Ratio Behaviour of soil fly ash mixtures".Journal of Testing and Evaluation, vol.29, No.2,2001,pp.220-226.
[26] Pandian,N.S.,Krishna,K.C.& Leelava thamma B., (2002). "Effect of Fly Ash on the CBR Behaviour of Soils", Indian Geotechnical Conference , Allahabad , Vol.1,pp.183-186.
[27] Pandian, N. S., (2004)."Fly ash characterization with reference to geotechnical Applications", Journal Indian Institute of Science, 84, 189–216.
[28] Pandian, N.S. (2004) "Stabilization of Expansive Soil with Fly Ash," Proceedings of National Symposium on Advances in Geotechnical Engineering, Karnataka Geotechnical Center of Indian Geotechnical Society, India, pp. 81–89.
[29] Pandian, N.S. (2004) "Stabilization of Expansive Soil with Fly Ash," Proceedings of National Symposium on Advances in Geotechnical Engineering, Karnataka Geotechnical Center of Indian Geotechnical Society, India, pp. 81–89.
[30] Phanikumar, B.R. and Sharma, R.S., (2004). "Effect of fly ash on engineering properties of expansive soils". Journal of Geotechnical and Geoenvironmental Engineering ASCE, 130 (7), 764--767.
[31] Phani kumar,B.R., Rekha, V.A. (1995), "Swelling behaviour of a remoulded expansive clay," Journal of Institution of Engineers (India).Civil Engineering division, vol.76,pp.1-5.
[32] Phanikumar, B. R.(2009) "Effect of lime and fly ash on swell, consolidation and shear strength characteristics of expansive clays": a comparative study', Geomechanics and Geoengineering, 4: 2, 175 -181.
[33] Seed,H.B., WoodWord R.J., and Londegren, R.(1962)." Prediction of swelling potential for compacted clays ",procendings ASCE SM & FE , devision 88 no.SM3,pp.53-67.
[34] Senol, A Edil TB,Bin – Shafque, M.S,Acosta,H.A,Benson,C.H (2006),Soft grades " Stabilization by using various fly ashes" Resour conserve recycling ,Vol,46.pp.365-376.
[35] Sivapullaiah, P.V., Prashanth, J.P. and Sridharan, A.(1995) "Optimization of lime content for fly ash", Journal of Testing and Evaluation, ASTM, 23: 222-227.
[36] Sivapullaiah, p.v., Prasanth,J.p., and Sridharan ,A.(1996). "Ëffect of fly ash on the index properties of Black cotton soils, journal of soils and Foundations. Japan, vol.36,N0.1,pp.97-103.
[37] Sivapullaiah, P.V., Prashanth, J.P. and Sridharan, A.(1998) "Reactive silica and strength of fly ashes,"Geotecnical and geological engineering,16: pp.239-250.
[38] Sivapullaiah, p.v.(2002)," Effect of Muddanur fly ash on Index and Compaction behaviour of expansive soils,"Indian Geotechnical conference,Allahabad,Dec, Vol.1, pp.249-252.
[39] Sridharan, A. and Nagraj, H.B.(2001), "Compressibility behaviour of remoulded, fine-grained soils and correlation with index properties", Can. Geotech. J. , No. 38, 1139-1154.
[40] Subba Rao,K.V.,(1985)."Physico-Chemical Behaviour of Lime treated soils", phD thesis, Indian Institute of Technology, Madras, India.
[41] Sudha Rani Ch and V. Phani Kumar (2011) " Prediction of Compression Index of Soils Using Artificial Neural Networks (Anns)", International Journal of Engineering Research and Applications(IJERA),Vol 1, Issue 4, Pg.no. 1554-1558.
[42] Sudha Rani Ch.and K Mallikarjuna Rao(2012), "Compositional And Environmental Factors Role On Compression Index ",International Journal Of Civil Engineering And Technology (IJCIET), Volume 3, Issue 2, July-December (2012), pp. 392-403.
[43] Sudha Rani Ch (2013), " Prediction of Swelling Pressure Of Expansive Soils Using Compositional and Environmental Factors", International Journal Of Civil Engineering And Technology (IJCIET) Volume 4, Issue 3, May - June (2013), pp. 134-142.
[44] Sudha Rani Ch and K Mallikarjuna Rao(2013),"Statistical Evaluation of Compression Index Equations", International Journal Of Civil Engineering

And Technology (IJCIET), Volume 4, Issue 2, March - April (2013), pp. 104-117.

[45] Sudharani, Ch., etal (2009),"Identification of Expansive Soils and Assessment of Expansion Potential by Fuzzy Approach", Electronic Journal of Geotechnical Engineering(EJGE),Vol. 14 [2009],Bund. L.

[46] Sudharani Ch . etal (2010), " SIVACS: Knowledge Based System Developed for Soil Identification and Assessment of Volume Change Characteristics", Electronic Journal of Geotechnical Engineering(EJGE), Vol. 15 [2010], Bund. J.

[47] Sudharani Ch . etal (2013), " Artificial Neural Networks (ANNS) For Prediction of Engineering Properties of Soils", International Journal of Innovative Technology and Exploring Engineering (IJITEE), Volume-3, Issue-1, June 2013, .pp 123-130.

[48] Terashi,M and Tanaka,H(1981)."Ground improvement by Deep mixing methods ",Proceedings of the 11th International conference on SM &FE,Stockholm, Sweden,vol.3,pp 777-780.