Evaluation Studies of Flexible Pavement System Laid on Expansive Clays Treated With Different Chemical Additives

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Abstract- *Expansive soils undergo alternate shrinkage and swelling due to moisture fluctuations and posses low strength in rainy season due to poor drainage conditions. As a result, flexible pavements constructed over such soils are not only expensive but also result in poor performance and premature failures. Flexible pavement construction in expansive soils is expensive due to large pavement section resulting from low CBR values in wet condition. The volume instability of soil affects constructed pavements and demands frequent maintenance. Hence efforts are to be made for reducing large pavement section and also to suppress swelling of sub grade. Hence efforts are to be made for reducing large pavement section and also to suppress swelling of sub grade. Though the use of granular and CNS cushions in pavement construction helps in reducing volume changes affecting pavement layers it cannot reduce required large pavement sections. Hence, this paper reviews some of the key advances developed over the past 60 years in improving our understanding of the nature and methods of modifying and stabilizing expansive clay soils. The main objective of this work is to study the swelling properties of the expansive sub grade soil treated with chemicals like lime, cacl2 and also by adding Fly ash based Geopolymer in varying percentages. The swelling properties of the collected expansive soil samples were determined based on the parameters like Free Swell Index, Swell Potential and Swell Pressure.*

Keywords- Expansive soil, chemical additives, sub grade, flexible pavement

I. INTRODUCTION

Expansive soils are those soils which swell considerably on absorption of water and shrink on removal of water. The expansive soil has considerable strength in dry state, but the strength goes on reducing on absorption of water. The soil exerts considerable pressure on foundations during swelling. Expansive soils are found in some regions of India and many other countries. These soils pose major foundation problems, causing damage to the super structure if proper precautions have not been taken.

Expansive soils pose a potential threat to the structures. They have the ability to generate tremendous pressure on the structures such as concrete foundations and pavements. Experiments show that up to 15,000 pounds per square feet pressure can be generated by expansive soils that is enough to create problems to foundations. This document highlights the mechanisms involved in the formation of expansive soils. It explains about the details of clay minerals such as Smectite family, other silicate minerals and soils rich with sulfate salts. The behavior of these minerals with the addition or removal of moisture that causes expansion and shrinkage respectively. It explains about the complications faced by the engineers and damages caused by this type of soils throughout the world including heaving, differential settlement, subsidence, development of fissures in the structures. It presents the remedial measures used in the industry for stabilization of such soils and to mitigate the issues that can be created by such soils.

The main objective of this work is to study the swelling properties of the expansive subgrade soil treated with chemicals like lime, $cacl_2$ and also by adding Flyash based Geopolymer in varying percentages. The swelling properties of the collected expansive soil samples were determined based on the parameters like Free Swell Index, Swell Potential and Swell Pressure.

DAMAGES TO THE PAVEMENT SUB GRADES

Majority of the pavement failures could be attributed to the poor sub grade conditions and Expansive soil is one such problematic situation (Evans and Mc Manus, 1999). Roads running through soil regions are subjected to severe unevenness with or without cracking, longitudinal cracking parallel to pavement centerline, rutting of pavement surface, and localized failure of pavement associated with disintegration of the surface. The extensive damage to highways running over expansive and high compressible soil sub-grades is estimated to be in billions of dollars all over the world. Even railway tracks are no exception and are affected by appreciable movements due to the nature of high compressibility of the clayey soils.

Fig.1.1 - Failure of pavement due to expansive soil

II. REVIEW OF LITERATURE

Expansive soils are composed primarily of hydrophilic clay minerals, such as Montmorillonite, and with significant swelling and shrinking characteristics. Compared with the common clay, expansive soil has three characteristics, expansive, crack and over-consolidation. Crack is concentrated expression of expansion and over consolidation. With the decline of water content expansive soil will shrink and result in crack the changing of environment leads to drying and wetting effect and the crack will further develop.

S. CHAKRABORTY , S.P MUKHERJEE , S. CHAKRABARTI , B.C CHATTOPADHYAY (APRIL 2014) reported that the quality of a flexible pavement depends on the strength of its sub-grade soil. The strength of sub-grade is the major parameters for determining the thickness of pavement. In case of the flexible pavement the sub-grade must be uniform in terms of geotechnical properties like shear strength, compressibility etc. Materials selected for use in the construction of sub-grade must have to be of adequate strength and at the same time it must be economical for use. In view of the above the present investigation has been carried out with easily available materials like lime and rice husk ash mixed individually and also in combination with locally available clayey soil in different proportions at optimum moisture content (OMC). Since CBR is an important criterion in flexible pavement design, the strength improvement has been found in terms of CBR in the present study. The laboratory test results shows marked improvement of strength of soil with the addition of admixtures in respect of California Bearing Ratio (CBR) in unsoaked and soaked condition.

T.K. ROY , B.C. CHATTOPADHYAY , S.K. ROY (2009) explained that Procurement of conventional materials in huge quantity required for construction of subgrade of road is becoming very difficult in many locations due to various problems. On the other hand, due to increasing economic growth and industrialization, a huge quantity of waste materials generated needs land for disposal and from that generally creates problems for public health and ecology. So need has arisen for proper disposal of the waste materials. Utilizing these materials in the area of road construction after improving their characteristics suitably can provide useful solution of this problem. So keeping this in view, an experimental study was undertaken to explore the possibility of utilization of the alternative materials like rice husk ash by mixing with local alluvial soil by adding small percentage of lime for the construction of road sub grade as cost effective mix.

B.SUNEEL KUMAR, T.V.PREETHI (MAY 2014) carried out a research & found that In India the soil mostly present is Clay, in which the construction of sub grade is problematic. In recent times the demands for sub grade materials has increased due to increased constructional activities in the road sector and due to paucity of available nearby lands to allow excavate fill materials for making sub grade. In this situation, a means to overcome this problem is to utilize the different alternative generated waste materials, which comparison of sub grade soil strength using lime & cost analysis cause not only environmental hazards and also the depositional problems. Keeping this in view stabilization of weak soil in situ may be done with suitable admixtures to save the construction cost considerably.

MEENU PRAKASH, REKHA RAVEENDRAN (28 AUGUST 2011) exposed the possibilities of paper sludge and rice husk ash in soil improvement and comparison of the results. Both paper sludge and rice husk ash are waste materials which cannot be disposed easily. The main objective of this paper is to check which stabilizing agent will give more strength. This paper involves the detailed study with various tests such as initial soil properties and to check the strength achievement through unconfined compression test. Soil stabilization is the alteration of property of locally available soil to improve its engineering performance. Stabilization can increase the shear strength of soil and control shrink – swell properties of soil, thus improving the load bearing capacity of a sub grade to support the pavements and foundation.

ZORE T. D AND S. S. VALUNJKAR (2010) had reported about the utilization of fly ash and steel slag in road construction. In their study, it was aimed to replace natural aggregates in road construction, either for blanket courses, bases or sub bases using these waste by-products. It was concluded that steel industry waste by-product is suitable and economical for use in the road construction. Steel slag is easily available and has higher CBR value than fly ash hence saving is excess than fly ash use. The optimum mix was reported as 15% steel slag mix in sub grade and in sub base for road construction**.**

III. METHODOLOGY

MECHANICS OF SOIL STABILIZATION

Stabilization is the process of blending and mixing materials with a soil to improve the soil's strength and durability. Soil Stabilization is the alteration of soils to enhance their physical properties. Stabilization can increase the shear strength of a soil and/or control the shrink-swell properties of a soil, thus improving the load bearing capacity of a sub-grade to support pavements and foundations. Soils stabilized by additives often provide an all-weather working platform for construction operations

CHEMICAL STABILIZATION:-

Chemical stabilization includes the use of chemicals and emulsions as compaction aids to soils, as binders and water repellents, and as a means of modifying the behavior of clay. It also includes deep mixing and grouting. Chemical stabilization can aid in dust control on roads and highways, particularly unpaved roads, in water erosion control, and in fixation and leaching control of waste and recycled materials. Under this category, soil stabilization depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect. A chemical stabilization method is the fundamental of this review and, therefore, throughout the rest of this report, the term soil stabilization will mean chemical stabilization.

The following chemicals have been successfully used:

- Calcium Chloride
- Sodium Chloride
- Sodium Silicate
- Polymers
- Chrome Lignin
- Other chemicals

MATERIALS USED

Properties of soil sample

In this study expansive soil sample having high degree of swelling and shrinkage is collected from Komaragiripatnam village, Amalapuram mandal of Andhra Pradesh, India. Soil is collected at a depth of 1.5 mts below the ground level.

When a lump of sample was cut with a knife it gave a shining surface hence, it was concluded that the sample is of clayey nature. Laboratory tests were carried out as per the IS Codal Provisions by pulverizing the lumps into individual particles to determine the properties of the selected soil sample as mentioned here under**.**

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Table 1: Properties of Expansive Soil

Properties of Expansive Clay		
S. No.	Property	Value
1	Specific gravity	2.63
2	Differential free swell Index (%)	98
3	Atterberg's Limits	
	i) Liquid limit (%)	69.5
	ii) Plastic limit (%)	24.2
	iii) Plasticity index (%)	45.3
5	Grain Size Distribution	
	i) Sand Size Particles (%)	12
	ii) Silt & Clay Size Particles (%)	88
6	IS soil classification	CH
7	Compaction Parameters	
	i) Max. Dry Density (g/cc)	1.38
	ii) Optimum Moisture Content (%)	26.7
8	Penetration Parameters	
	i) CBR - Unsoaked (%)	3.4
	ii) CBR - Soaked (%)	1.7
9	Shear Parameters at OMC & MDD	
	i) Cohesion, Cu (kPa)	39
	ii) Angle of Internal Friction, Øu (Degrees)	0

Chemicals: Chloride Compound Chemicals chosen in the present study are calcium Chloride($CaCl_2$) and lime and fly ash based geopolymer. These chemicals are easily soluble in water and uniform mixing can be easily achieved. These chemicals are added to the expansive soil samples in varying percentages of 0%, 2%, 4%, 6% of dry weight of soil.

Experimental Study: Laboratory experimentation is carried out as per the procedures given in the Indian Standard Codes. Free Swell Index as per IS2720(Part XL)–1977, Max Dry Density & OMC as per IS2720(Part 7&8)-1983, Swell Pressure Testing as per IS2720(Part XLI)-1977.

Free Swell Index:
The determination of free swell index also known as differential free swellof soil helps to identify the potential of a soil to swell which might need further detailed investigation regarding swelling and swelling pressures under different field conditions. In this method 10 grams of oven-dried soil sample passing through 425 Micron sieve is poured in two graduated cylinders of 100 ml capacity. One cylinder shall then be filled with kerosene oil and the other with distilled writer up to the 100 ml mark. After removal of entrapped air by stirring with glass rod, the soils in both the cylinders shall be allowed to settle. Sufficient time (not less than 24 hours) shall be allowed for the soil sample to attain equilibrium state of volume.

Swell Potential: Swell Potential of a soil specimen is the ratio of the increase in thickness to the original thickness of a soil specimen compacted at OMC in a consolidation ring, soaked under a surcharge load of 7 KPa and is expressed as a percentage.

Swelling Pressure:

Swelling Pressure is the pressure at which the expansive soil exerts if the soil is not allowed to swell or the volume change of the soil is arrested. In this study it is determined as per IS2720 (Part XLI)-1977 using the Consolidometer method. Samples of diameter of 60mm and thickness 20 mm are used. Samples are prepared at Max Dry Density and Optimum Moisture Content. During testing sample was kept always submerged in water. Free swell of the sample is allowed for 6 days under the seating load of 5 KPa. The swollen sample shall then be subjected to consolidation under different pressures till the specimen attainsits original volume. A plot of change in thickness of expanded specimen as ordinate and applied consolidation pressure as abscissa in semi-logarithmic scale shall be made. The swelling pressure exerted by the soil specimen under zero swelling condition shall be obtained by interpolation and is expressed in KPa.

IV. RESULTS AND DISCUSSIONS

Details of the laboratory experimentation carried-out with different combinations of different chemical additives have been discussed in the previous chapter. In this chapter a detailed discussion on the results obtained from various laboratory tests done on untreated and treated expansive soil are presented.

4.1 INFLUENCE OF THE % CHEMICAL ADDITIVES (CA) ON DFSI AND ATTERBERG'S LIMITS OF EXPANSIVE CLAY

The individual influence of chemical additives (CA) on the DFSI and ATTERBERG LIMITS of expansive soil are clearly presented in Figures 4.1 and 4.2. The percentage of chemical additives (CA) was varied from 0%, to 6% with an increment of 2%. From the above graphs, it was observed that the treatment as individually with 4% and 9% chemical additives has moderately improved the expansive soil. It can be inferred from the graphs, that there is a gradual decrease in DFSI with an increment in the % Addition of chemical additives up to 6% with an improvement of about 2%. The addition of chemical additives had mobilized little amount DFSI and ATTERBERG LIMITS to the pure Clayey soil without friction.

VARIATION OF DFSI WITH CHEMICAL ADDITIVES

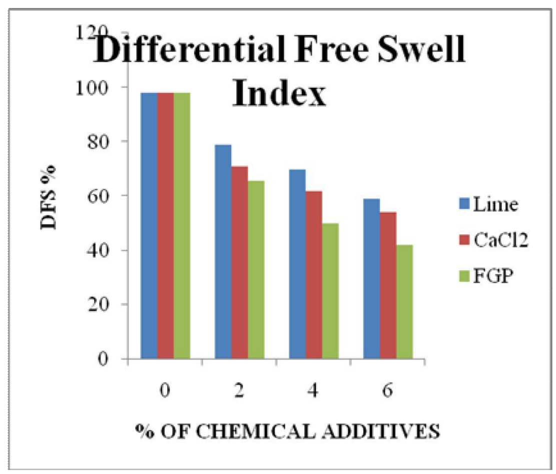


Fig 4.1 variation of DFSI with percentage addition of chemical additives

VARIATION OF ATTERBERG LIMITS WITH CHEMICAL ADDITIVES

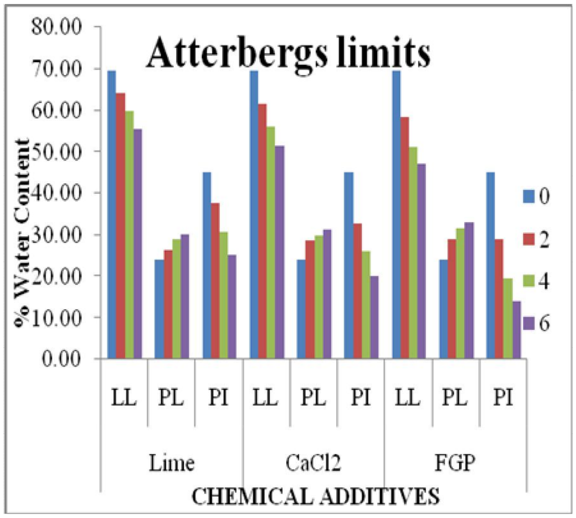


Fig 4.2 variation Atterberg limits with percentage addition of chemical additives

4.2 INFLUENCE OF THE CHEMICAL ADDITIVES (CA) ON COMPACTION, PENETRATION AND STRENGTH PARAMETERS OF EXPANSIVE CLAY

Figures 4.3 and 4.4 shows the variation of compaction parameters like MDD, OMC for addition of different chemical additives like lime. $Cacl_2$, FGP. These all chemicals are used as additives for ES from 0% to 6% with an increment of 2 %. From above figures we can conclude that the OMC get reduced for all the chemical additives. For 4% and 6% addition of chemical additives OMC get reduced and MDD increased.

VARIATION OF COMPACTION WITH CHEMICAL ADDITIVES

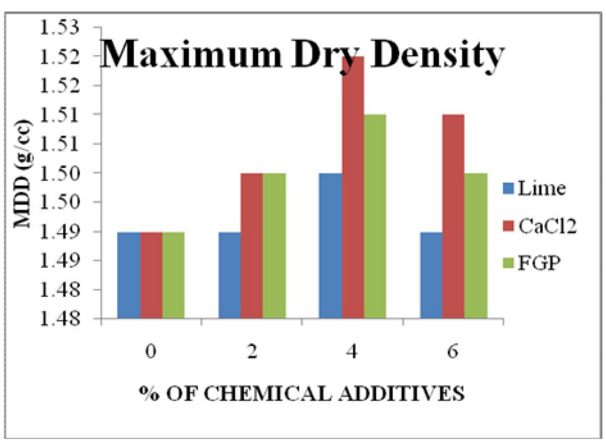


Fig. 4.3 Plot showing the variation of MAXIMUM DRY DENSITY with % addition of chemical additives to Expansive soil.

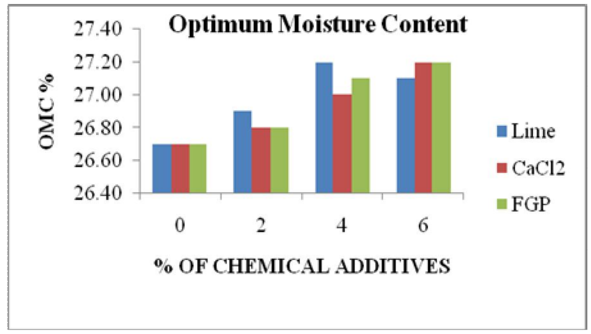


Fig. 4.4 Plot showing the variation of Optimum Moisture Content with % addition of chemical additives to Expansive soil

4.3 VARIATION OF PENETRATION PARAMETERS FOR PERCENTAGE ADDITION OF DIFFERENT CHEMICAL ADDITIVES

Figure 4.5 shows the variation of penetration parameters for UNSOAKED CBR for addition of different chemical additives like lime. $Cacl_2$, FGP. These all chemicals are used as additives for ES from 0% to 6% with an increment of 2 %. From above figures we can conclude that the CBR value increases with an increment of percentage of chemical additives in that addition of 4% and 6% addition of chemical additives got good results. For addition 4 % the UNSOAKED CBR value increased about 41%, 52% and 64% for lime, cacl2 and FGP Respectively and for 6% addition the CBR value increased about 70%, 88%, and 111% for lime, cacl2 and FGP Respectively.

VARIATION OF PENETRATION PARAMETERS WITH CHEMICAL ADDITIVES

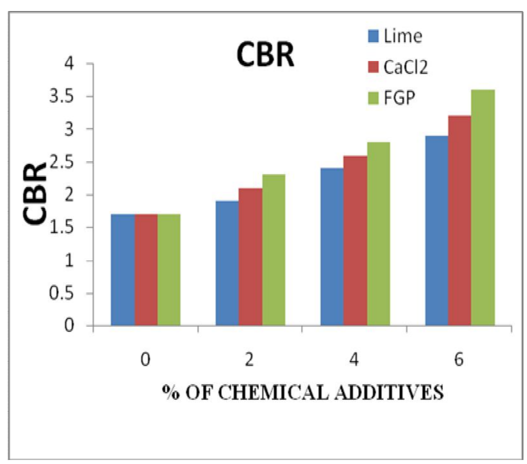


Fig. 4.5 Plot showing the variation of SOAKED CBR VALUES with with % addition of chemical additives to Expansive soil.

4.4 VARIATION OF STRENGTH PARAMETERS FOR PERCENTAGE ADDITION OF DIFFERENT CHEMICAL ADDITIVES

Table 2, Figure 4.6 shows the variation of strength parameters for UCS for addition of different chemical additives like lime. $Cacl_2$, FGP. These all chemicals are used as additives for ES from 0% to 6% with an increment of 2 %. From above figures we can conclude that the UCS value increases with an increment of percentage of chemical additives in that addition of 4% and 6% addition of chemical additives got good results. For addition 4 % the UCS value increased about 24%, 29% and 47% for lime, $cacl_2$ and FGP Respectively and for 6% addition the UCS value increased about 35%, 43%, and 74% for lime, $cacl_2$ and FGP Respectively.

TABLE 2: VARIATION OF STRENGTH PARAMETERS WITH CHEMICAL ADDITIVES

CA (%)	UCS (kPa)		
	Lime	$CaCl_2$	FGP
0	78	78	78
2	84	89	93
4	97	101	115
6	106	112	136

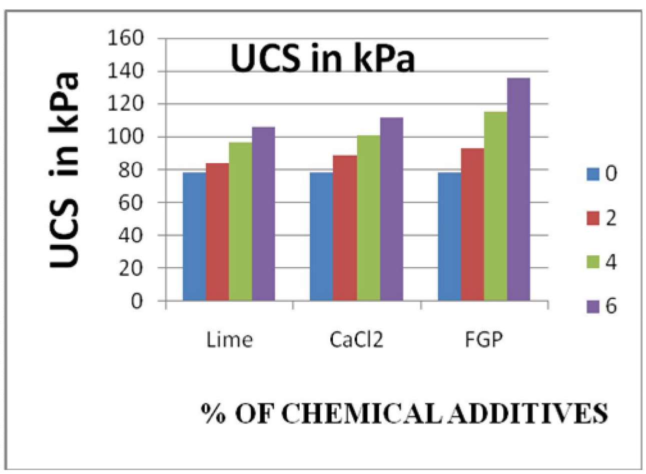


Fig. 4.6 Plot showing the variation of UCS with % addition of chemical additives to Expansive soil.

4.5 DURABILITY STUDIES - (CURING)

Figure 4.7 shows the variation of soaked CBR values for addition of different chemical additives like lime. $Cacl_2$, FGP. These all chemicals are used as additives for ES from 4% to 6% with an increment of 2 %. From above figures we can conclude that the soaked CBR value increases with an increment of percentage of chemical additives in that for the 4% and 6% addition of chemical additives soaked CBR value increases with increase in number of days. For 4% and 6% addition of chemical additives, fly ash geopolymer shows prominent results at 28 days.

Durability Studies on the Chemical Additives (CA) treated Expansive Clay

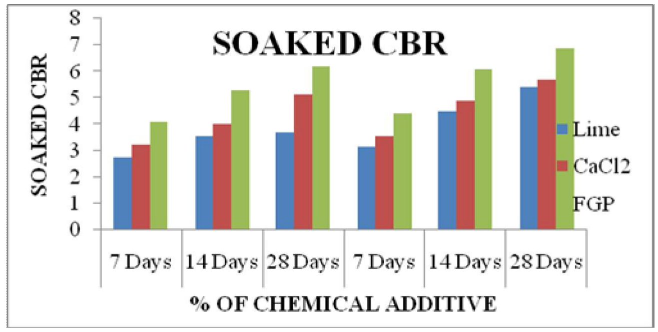


Fig 4.7 shows the soaked CBR for different curing periods

Figure 4.8 shows the variation of UCS values for addition of different chemical additives like lime. $Cacl_2$, FGP. These all chemicals are used as additives for ES from 4% to 6% with an increment of 2 %. From above figures we can conclude that the UCS value increases with an increment of percentage of chemical additives in that for the 4% and 6% addition of chemical additives UCS value increases with increase in number of days. For 4% and 6% addition of chemical additives, fly ash Geopolymer shows prominent results at 28 days.

Durability Studies on the Chemical Additives (CA) treated Expansive Clay

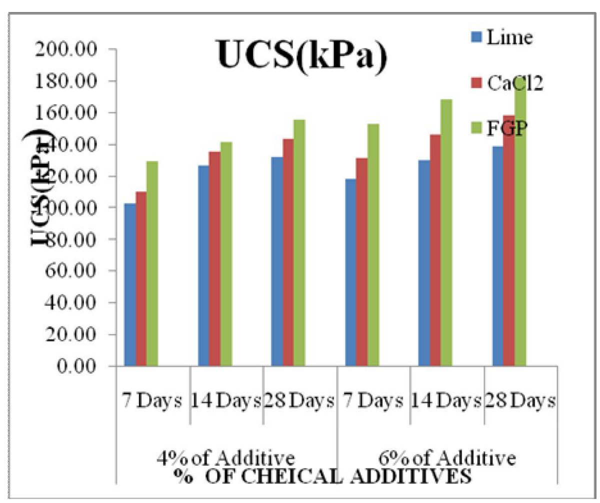


Fig 4.8 shows the UCS(kPa) for different curing periods

4.6 HEAVE STUDIES ON THE FLEXIBLE PAVEMENT SYSTEM LAID ON CHEMICAL ADDITIVES (CA) TREATED EXPANSIVE CLAY SUBGRADE

Table 3, Figure 4.9 shows the HEAVE studies for addition of different chemical additives like lime. $Cacl_2$, FGP. From the above results it can be concluded that 6% addition of chemical additives shows a prominent results. For the optimum 6% of chemical additives, heave studies were done and studies resulted that heave will be decreasing with increment of chemical additives and with an increment of number of days.

Table 3 Heave studies on the flexible pavement system laid on chemical additives (CA) treated expansive clay subgrade

Type of Chemical Additve	Heave (mm)			
	0 Days	7 Days	14 Days	28 Days
Lime	21	20	18	15
$CaCl_2$	19	17	16	13
FGP	17	15	12	10

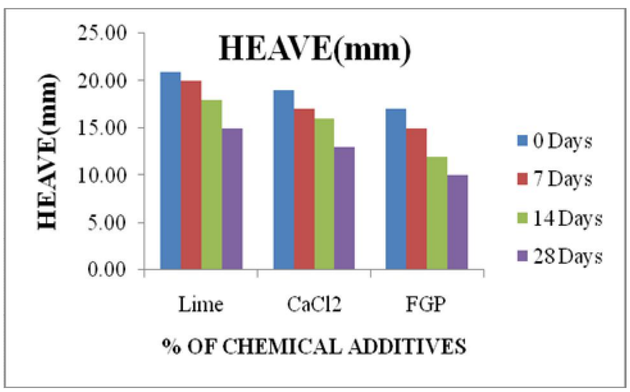


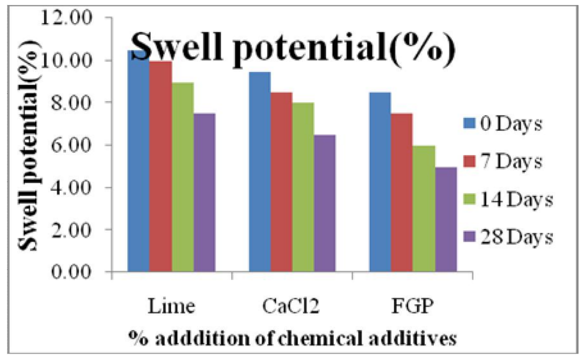
Fig 4.9 shows the HEAVE in mm to % of chemical additives for different curing periods

SWELL POTENTIAL STUDIES ON THE FLEXIBLE PAVEMENT SYSTEM LAID ON CHEMICAL ADDITIVES (CA) TREATED EXPANSIVE CLAY SUBGRADE

Table 4, Figure 4.9 shows the swell potential studies for addition of different chemical additives like lime. $Cacl_2$, FGP. From the above results it can be concluded that 6% addition of chemical additives shows a prominent results. For the optimum 6% of chemical additives, swell potential studies were done and studies resulted that swell potential will be decreasing with increment of chemical additives and with an increment of number of days.

Table 4 shows swell potential studies

Type of Chemical Additve	Swell Potential (%)			
	0 Days	7 Days	14 Days	28 Days
Lime	10.5	10	9	7.5
$CaCl_2$	9.5	8.5	8	6.5
FGP	8.5	7.5	6	5



V. CONCLUSIONS

The following conclusions are made based on the laboratory experiments carried out in this investigation.

- From the laboratory studies, it is observed that the Expansive Soil chosen was a problematic soil having high swelling, and high plasticity characteristics.
- It was observed that expansive soil treated with chemical additives has moderately improved the expansive soil.
- There is a gradual increase in maximum dry density with an increment in the % addition up to 6% with an improvement of about 2% and it was about 107% increases for fly ash based Geopolymer.
- There is an improvement in maximum dry density and also corresponding strength characteristics.
- There is an improvement in CBR values for the addition of chemical additives from 0 to 6%. In that for the 6% addition of fly ash based Geopolymer the CBR value increases about 111%.
- There is an improvement in UCS values for the addition of chemical additives from 0 to 6%. In that for the 6% addition of fly ash based Geopolymer the UCS value increases about 74%.
- Further durability studies were done on the 4% and 6% addition of different chemical additives. The laboratory result shows that CBR value increases with increase in number of days. For 4% and 6% addition of chemical additives, fly ash geopolymer shows prominent results at 28 days.

- UCS value increases with an increment of percentage of chemical additives in that for the 4% and 6% addition of chemical additives UCS value increases with increase in number of days. For 4% and 6% addition of chemical additives, fly ash Geopolymer shows prominent results at 28 days.
- Heave studies were done in a Steel Tank with 600 mm diameter and 500 mm height and the different layers and their respective compacted thickness were given below

Layer Description	Compacted Thickness (mm)
WBM-III Base Course	50
Gravel Sub base	50
Expansive Clay	200

- Heave studies done on the flexible pavement system laid on chemical additives (ca) treated expansive clay subgrade. Expansive Clay Subgrade was treated with 6% Chemical Additive (CA). For the optimum 6% addition of heave will be decreasing with increment of chemical additives and with an increment of number of days.
- Swell potential studies done on the flexible pavement system laid on chemical additives (CA) treated expansive clay subgrade. Expansive Clay Subgrade was treated with 6% Chemical Additive (CA). For the optimum 6% addition of SWELL POTENTIAL will be decreasing with increment of chemical additives and with an increment of number of days.

Finally it can be summarized that the chemical additives like lime $cacl_2$ and FGP had shown promising influence on the compaction, penetration and strength characteristics of expansive soil, In that 6 % addition of fly ash based Geopolymer shows better results compare to lime and $cacl_2$.

REFERENCES

[1] Al-Rawas, A.A., Taha R., Nelson, J.D., Al-Shab, T.B. and Al-Siyabi, H., A Comparative Evaluation of Various Additives Used in the Stabilization of Expansive Soils, Geotechnical Testing Journal, Vol. 25, No. 2, pp. 199-209, 2002.

[2] Arnold, M., (1984), "The Genesis, Mineralogy and Identification of Expansive Soils", Fifth International Conference on Expansive Soils, Adelaide, South Australia, pp. 32-36.

[3] Bohn, H. L., McNeal, B.L. and O'Conner, G. A., Soil Chemistry, 2nd Edition, John Wiley Inc., New York, 1985.

[4] Chandrasekhar, B.P., Prasad Raju, G.V.R., Ramana Murthy, V. and Hari Krishna, P. (1999). "Relative Performance of Lime and Calcium Chloride on properties of Expansive soil for pavement subgrades", Proc. Of IGC-99, Calcutta, pp 279-282.

[5] Chadda, L.R., Dhawan, P.K. & Mehta, H.S (1975).: laboratory studies on lime-clay reaction and its importance in the construction of stabilized soil road-bases, Indian highways, march.

[6] Chen, F. H., Foundations on Expansive Soils, Elsevier Scientific Pub. Co., Amsterdam, 1975.

[7] Croft, J.B. (1964): The process involved in the lime-stabilization of clay soils, proceedings of Australian road research board, vol. 2, part 2, Melbourne.

[8] Evans, R.P and Mc Manus, K.J. (1999): "Construction of Vertical Moisture Barriers to reduce expansive soil sub grade movement", TRR-1652, TRB, pp.108-112.

[9] Fredlund, D.G. and Rahardjo, H., Soil Mechanics for Unsaturated Soils, John Wiley and Sons Inc., New York, 1993.

[10] Gokhale, Y.C. (1969): "Some Highway Engg. Problems in Black Cotton Soil Region", Proc. of the Symposium on characteristics of and construction techniques in black cotton soil pp, 209-212.

[11] Gokhale, K.V.G.K. (1977): "Mechanism of Soil Stabilization with Additives", Proc, of the first national symposium on expansive soils, HBTI, Kanpur, pp. 10-1 to 10-5.

[12] DSV Prasad, Dr GVR Prasada Raju and Dr V Ramana Murthy, Use of Waste Plastic and Tyre in Pavement System, The Institution of Engineers India Journal, Vol 89,2008, 31-34.

[13] Amin Eisazadeh et al, (2012), Solid-state NMR and FTIR studies of lime stabilized montmorillonitic and lateritic clays,Journal of Applied Clay Science, volume 67-68,2012,5-10.

[14] Sivapullaiah, P.V. et al.,Role of electrolytes on the shear strength of clayey soils, Proceedings of Indian Geotechnical Conference, 1994, Warangal,India,1994,199-202.

[15] Prasada Raju, GVR,Evaluation of flexible pavement performace with reinforced and chemical stabilization of expansive soil sub grades,Doctoral Thesis, Kakitiya University, Warangal, A.P. India, 2001.

[16] Sivanna, G. S. et al, Strength and consolidation characteristics of black cotton soil with chemical additives –CaCl2& KOH, report prepared by Karnataka Engineering Research Station, Krsihnarajasagar,India.1976

[17] Katti, R.K., Kulkarni, K.R. and Radhakrishnan, N., Research on Black Cotton Soils without and with Inorganic Additives, Indian Road CongressRoad Research Bulletin, No. 10,1966, 1-97.

[18] Gray, D. H., Electrochemical Hardening of Clay Soils,Geotechnique, 20(1),1970,81-93.

[19] Ozkan, S., Gale, R. J., and Seals, R. K., Chemical Stabilization of Kaolinite by Electrochemical Injection, Proceedings of Sessions of Geo-Congress,ASCE,1998,285-297.
[20] Singh, G. and Das, B. M., Soil Stabilization with Sodium Chloride, Transportation Research Record,1999, 46-55.
[21] S. CHAKRABORTY , S.P MUKHERJEE , S. CHAKRABARTI , B.C CHATTOPADHYAY (APRIL 2014) reported that the quality of a flexible pavement depends on the strength of its sub-grade soil.
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