Strength Characteristics of Subgrade Stabilized With Lime, Fly Ash and Fibre

Innovative Research Publications

International Journal of Engineering Research
Volume No.5, Issue Special 1 pp : 74-79

ISSN:2319-6890(online),2347-5013(print)
8 & 9 Jan 2016

Strength Characteristics of Subgrade Stabilized With Lime, Fly Ash and Fibre

P.P.Nagrale, A.P.Patil, Shubham Bhaisare
Department of Civil Engineering, Sardar Patel College of Engineering, Mumbai, India
Email: atulya.patil@yahoo.com

Abstract - India is experiencing tremendous growth in infrastructure including road network and highways. Roads are to be designed with good reliability to fulfill the long term performance during the design period. Long term performance of flexible pavement depends on the soundness of the underlying subgrade soil. Unstable, poor or weak soil can create significant problems for the pavement. Weak soil has low California bearing ratio (CBR) which will lead to more layer thicknesses of the pavement section. Considering an escalating cost of the aggregates, utilization of weak soil by imparting additional strength by way of stabilization technique is a need of time. Present research study insights on the evaluation of benefits of stabilization of subgrade soil. Two types of soil (Soil A and Soil B) having CBR of 1.45 and 4.67 and three types of stabilizers namely hydrated lime, class F fly ash and polypropylene fibre (aspect ratio of 100) were selected for the laboratory investigation. Experimental program consisting of Atterberg limit, compaction, california bearing ratio and unconfined compressive strength tests were carried out. These tests were performed on unstabilized as well as stabilized subgrade soil at different percentages of stabilizers by dry weight of soil. Percentage of lime varied from 1.5, 3.0, 4.5 and 6 %, for fly ash stabilization it was 5, 10, 15 and 20 % whereas percentage of fibre varied from 0.25, 0.50, 0.75 and 1 %. Results of laboratory investigation revealed that 4.5 % lime, 10 % fly ash and 0.5 % of fibre were optimum for the improvement of strength characteristics of subgrade soil stabilization.

Keywords - flexible pavement, california bearing ratio, stabilization, subgrade

1.Introduction

Lack of adequate road network to cater to the increased demand and increase distress in road leading to frequent maintenance have always been big problem in our country. Evolving new construction materials to suit various traffic and site conditions for economic and safe design is a challenging task in road construction. Effective utilization of local weak soils by imparting additional strength using stabilization materials enable reduction in construction cost and improved performance for roads. Exploring the feasibility of such materials for sub grade and embankment stabilization will help the road building sector to evolve a stronger, durable and economic design.

Aggregate is generally expensive therefore it is often important to minimize the aggregate layer thickness for a given service life. This can be achieved by incorporating stabilization technique. This stabilization technique can increase the service life for a given aggregate layer thickness. Therefore, parameters considered in a stabilization structure are service life, thickness of aggregate layer and types and properties of stabilizing materials.

Stabilization is a technique introduced many years ago with the main purpose to render the soils capable of meeting the requirements of the specific engineering projects. Stabilized materials may be used as improved sub grades or capping layers or sub-bases for road or airfield pavements. It is the alteration of one or more soil properties, by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. Soils may be stabilized to increase strength and durability or to prevent erosion and dust generation. Purpose of the stabilization of flexible pavement resting on weak and troublesome soil is to acquire desirable properties of sub grade which are high compressive and shear strength, permanency of strength under all weather and loading conditions, ease and permanency of compaction, ease of drainage and low susceptibility to volume changes and frost action. Since sub grade soils vary considerably, the interrelationship of texture, density, moisture content and strength of sub grade materials is complex.

1.1 Lime stabilization

In depth laboratory studies on effect of stabilization on engineering properties of soils have been carried out. Lime stabilization on a selected reclaimed soil of Dhaka city indicates that with an increase in lime content, maximum dry density reduced and optimum moisture content increased (Ansari and Hasan 2011). Lime and cement addition to the clayey soil and silty soils cause a decrease in the maximum dry density and increase in optimum moisture content. Maximum strength was obtained at 4% of lime for the clayey soil (Khattab et al. 2011). Dry density of soil decreases with lime content and C.B.R. value of soil increases from 1% to 2.74, 3.89 and 6.51% due to stabilization with 2.5, 5 and 7.5% lime content (Nagrale and Srivastava 2009).

Lime stabilization of geo-materials by producing cohesive materials in the soil increases the strength and decreases material plastic properties and hence these materials can be used for projects where high strength and high performance materials are desirable. The increase in strength of lime stabilized materials in compression as well as tension is attributed to the reactions between clay particles and lime. The clay lime compound provides the cemented material in soil (Arbani and Karami 2007). In geotechnical investigation on soil with cement, lime and rice husk ash and cement lime admixture, stress strain response was strongly influenced by the Cement Lime Rice husk

ISSN:2319-6890(online),2347-5013(print)
8 & 9 Jan 2016

ash contents and effective confining pressure (Younes et al.2014).

Thickness of soil-cement base / soil lime base reduces for a particular number of repetition and CBR. When CBR increases from 3 to 5/7/10, the thickness of soil cement base / soil lime base reduces significantly for any particular number of repetitions and CBR (Bagui 2012). Lime could be effective in the improvement of compressibility and swelling properties of soil and optimum results are achieved by adding 3% of lime (Saeida 2012). Tests on expansive clay soil to determine the optimum quantity of lime and the optimal percentage of lime-Eggshell Powder combination show that lime stabilization at 7% is better than the combination of 4% ESP+ 3% lime (Amu et al. 2005). Findings of investigation with lime stabilization on high plasticity clay shows an increase in shear strength of soil as lime concentration increased up to 4% (Youssef et al. 2012). Laboratory investigation on the stabilization of marine clay using saw dust and lime resulted in an increase in CBR value of marine clay by 129.76% on addition of 15% sawdust and it has been further improved by 283.12% when 4% lime is added (Koteswara et al. 2012). Large amount of increase in compressive strength was observed due to addition of lime and cement to fibre reinforced soil (Lima et al. 1996).

1.2 Fly ash stabilization

Fly ash has been used successfully in many projects to improve the strength characteristics of soils. Fly ash can be used to stabilize bases or subgrade, to stabilize backfill to reduce lateral earth pressures and to stabilize embankments to improve slope stability. The primary reason fly ash is used in soil stabilization applications is to improve the compressive and shearing strength of soils. Trivedi. et al. (2013) carried out experimental studies to investigate optimum utilization of fly ash for stabilization of subgrade soil and concluded that OMC attains its highest value of 29.27 % for 10 % of fly ash as compare to 21.38 % for unstabilized soil whereas, CBR value increases from 5.64 % to 20.53 % for 20 % of fly ash. Sharma **(**2012) studied the sub grade characteristics of locally available expansive soil mixed with fly ash and randomly distributed fibers. As per the results of investigation, it was reported that proportion of 70 % soil and 30 % fly ash was the best proportion having maximum dry density and maximum CBR value. Phanikumar and Sharma (2004) investigated the effect of fly ash on engineering properties of expansive soils and stated that optimum moisture content decreased and maximum dry unit weight increased with an increase in fly ash content. Mackiewicz and Ferguson **(**2005) studied the stabilization of soil by self-cementing coal ashes and reported that self-cementing class C fly ash can be effectively and economically used as stabilization agent for a wide range of construction applications. The reduction in maximum dry density and strength was dependent on the fly ash hydration rate and could vary significantly between different ash sources.

1.3 Fibre stabilization

The primary purpose of reinforcing soil mass is to improve its stability, increase its bearing capacity and reduce settlements and lateral deformation (Hausman 1990; Prabaker and Sridhar 2002).

(Brown 1974; Leonards and Bailey 1982; Freitag 1986; Maher 1990; Sear 2001**)** have also investigated the effect of fibres in improving the engineering properties of soil utilizing fibers for soil stabilization.

Effect of on engineering properties due to addition of polypropylene fiber and lime admixture on expansive soil concludes that with increase in lime and fiber content, OMC increases and MDD decreases (Twinkle and Sayida 2011).

2. Material and Methodology

2.1 Material Selection

Two types of soil namely subgrade Soil A and subgrade Soil B available near Ulwa, Navi Mumbai and Taloja, Phase I, Navi Mumbai respectively are procured. The properties of both soils used in present study are given in Table 2.1. As per the AASHTO soil classification system, Soil A is A-7-5 and Soil B is A-2-5. The index properties; liquid limit, Plastic limit and plasticity index were determined as per [IS 2720-Part (5)-1985]. The Standard Proctor tests were conducted as per [IS 2720-Part (7)-1980] for deciding the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC) for soils.

Table 2.1 Physical properties of soils used in the present study

S. N.	Property	Soil-A	Soil-B
1.	Liquid Limit (%)	96	42.8
2.	Plastic Limit (%)	35	33.19
3.	Plasticity Index (%)	61	9.61
4.	MDD (kN/m3)	12.4	16.5
5.	OMC (%)	28	20
6.	CBR (%)	1.45	4.67
7	Soil Classification as per AASHTO	A 7-5	A 2-5
8	Typical name	clayey soil	silty gravel sand

Both the soils are mixed with different percentages of stabilizers by dry weight of soil as shown in Table 2.2

Table 2.2 Different percentages of stabilizers mixed with soil

Stabilizer	Percentage of Stabilizer by dry weight of soil			
Lime	1.5	3	4.5	6
Fly Ash	5	10	15	20
Fiber	0.25	0.5	0.75	1

2.2 Effect of stabilizer on Liquid Limit and Plastic Limit of subgrade soil

2.2.1 Liquid limit test [IS: 2720-Part 5]

It is the water content at which soil changes from liquid state to plastic state. At the liquid limit, the clay is practically like a liquid, but possesses a small shearing strength. The liquid limit of soil depends upon the clay mineral present.

doi : 10.17950/ijer/v5i1/017

ISSN:2319-6890(online),2347-5013(print)
8 & 9 Jan 2016

About 120 gm of pulverize soil sample passing through 425 micron IS sieve is weighed and mixed thoroughly with distilled water on a marble plate to form a thick paste. Portion of the paste is placed in the cup of liquid limit device and smoothened the surface with spatula to a maximum depth of 1cm. Groove is cut through the sample along the symmetrical axis of a brass cup, in one stroke using Casagrande's apparatus. Handle of the apparatus is turned at the rate of 2 revolutions per second and counted the number of revolutions until the two parts of the soil come in contact at the bottom of the groove along a distance about 13 mm and number of blows were counted. About 10-15gm of soil sample is collected from the edged of the grooves, for the determination of the dry weight of soil by drying in oven. The temperature is controlled at 105°C to 110°C. Similar steps are repeated for different percentage of lime and fly ash and results are presented in Table 2.3

2.2.2 Plastic Limit Test [IS: 2720-Part 5]

Plastic limit is the moisture content below which the soil stops behaving as a plastic material as well as is the water content at which a soil when rolled into thread of smallest diameter possible, starts crumbling and has a diameter of 3 mm. At this water content, the soil loses its plasticity and passes to a semi-solid state.

About 20 gm of air dried soil passing through 425 micron is taken and placed in a dish. It is mixed with enough water to make it of uniform consistency. A small quantity of this wet soil is taken; a ball is made out of it and rolled on a glass plate with palm of the hand to form the soil mass into a thread of uniform diameter of 3 mm approximately. When the thread is broken, the soil is reworked into ball again and re- rolled it into the thread. The procedure is repeated till the thread starts crumbling. The moisture content of the crumbled thread is determined by oven drying method. The procedure is repeated for three samples and average moisture content was the plastic limit. Difference between the liquid limit and the plastic limit is the plasticity index of a given soil.

Table 2.3 Effect of Lime and Fly ash Stabilization on Liquid Limit, Plastic Limit and Plasticity Index

Lime (%)	Fly Ash (%)	Subgrade Soil-A			Subgrade Soil-B		
		LL	PL	PI	LL	PL	PI
0	-	96	35	61	42.8	33.19	9.61
1.5	-	86.5	59.39	27.11	40.93	29.80	12.13
3.0	-	76	60.73	15.27	-	-	-
4.5	-	75.91	59	16.91	-	-	-
6.0	-	70.27	51.66	18.62	-	-	-
-	5	91.15	40.87	50.28	41.94	35.84	6.10
-	10	83.67	41.15	42.52	40.96	37.14	3.82
-	15	82.82	39.50	43.32	39.77	36.09	3.68
-	20	78.90	39.84	39.06	36.35	35.42	0.93

The result shows that liquid limit consistently decreases as the percentage of lime and fly ash increases. The decrease in liquid limit with increasing lime content has been reported by (Jan and Walker 1963; Wang et al. 1963).The liquid limit of neat subgrade soil-A is 96 % which decreases to 70.27 % at 6 % lime content. Also the liquid limit of unstabilized subgrade soil-B is 42.8 % which decrease to 40.93 % at 1.5 % lime and there after soil-B behaves like non plastic material.

Same trend is also observed when subgrade soils are mixed with fly ash. Liquid limit of neat subgrade soil A reduces from 96 % to 78.90 % when mixed with 20 % fly ash whereas for subgrade soil B, it decreases from 42.8 % for raw subgrade soil to 36.35 % at 20 % fly ash content.

Plastic limit of unstabilized subgrade soil A which is 35, increases to 60.73 at 3% lime content and there after it decreases whereas it attains maximum value of 41.15 at 10 % fly ash after which it decreases. It can be observed from Table 2.3 that there is significant reduction in plasticity index when both the subgrade soils are stabilized with lime as well as fly ash as compared to unstabilized soils. The reduction in plasticity index is attributed to the change in soil nature (granular nature after flocculation and agglomeration) (Little et al., 1995; Mallela et al., 2004; Lund and Ramsey, 1958; Taylar and Arman, 1960)

2.3 Effect on dry density and optimum moisture content due to lime, fly ash and fibre stabilization

2.3.1 Compaction Test [IS: 2720 (Part 7) – 1980]

To assess the amount of compaction and the water content required in the field, compaction tests are performed on the same soils in the laboratory. Compaction of soils is a mechanical process by which the soil particles are constrained to be packed more closely together by reducing the air voids. Soil compaction causes decrease in air voids and consequently increase in dry density. This may result in increase in shearing strength. The possibility of future settlement or compressibility decreases and also the tendency for subsequent changes in moisture content decreases. Degree of compaction is usually measured quantitatively by dry density.

The empty mould with the base but without collar is weighted. About 2.5 kg of air dried soil passing 4.75 mm sieve is taken in a mixing pan. A small quantity of moisture is added to the soil and the soil is placed in the mould with collar attached, to about half full. The surface of the soil is made smooth and compacted with 25 evenly distributed blows of 2.6 kg hammer using 30.0 cm fall. Each compacted layer is scratched at its surface with a straight edge. The collar is removed and the soil is trimmed off with the straight edge. Before removing the collar, it is rotated to break of the bond between it and the soil. The mould surface is cleaned and the mould is weighted with the sample. The soil is removed from the mould and moisture content of the representative samples is determined by oven drying method. The representative samples consist of the soil sample collected from the surface, the middle and the bottom of the mould. The soil sample is broken from the mould and some more moisture is added (about 2-3% by weight) and the compaction test is

ISSN:2319-6890(online),2347-5013(print)
8 & 9 Jan 2016

repeated. The dry density- moisture content relations are plotted for each test. Variation of maximum dry density and optimum moisture content for unstabilized and stabilized subgrade soils at different stabilizer contents are summarized in Table 2.4

Table 2.4 Effect of Lime, Fly Ash and Fibre Stabilization on Dry Density and Optimum Moisture Content

Lime (%)	Fly Ash (%)	Fibre (%)	Subgrade Soil-A		Subgrade Soil-B	
			MDD (gm/cc)	OMC (%)	MDD (gm/cc)	OMC (%)
0	-	-	1.24	28	1.65	20
1.5	-	-	1.276	26	1.632	20
3.0	-	-	1.317	32	1.631	22
4.5	-	-	1.312	32	1.630	22
6.0	-	-	1.30	32	1.627	22
-	5	-	1.298	22	1.727	16
-	10	-	1.474	18	1.695	18
-	15	-	1.432	6	1.537	14
-	20	-	1.429	6	1.578	14
-	-	0.25	1.234	22	1.673	18
-	-	0.5	1.227	24	1.695	18
-	-	0.75	1.211	22	1.724	16
-	-	1.0	1.195	20	1.705	16

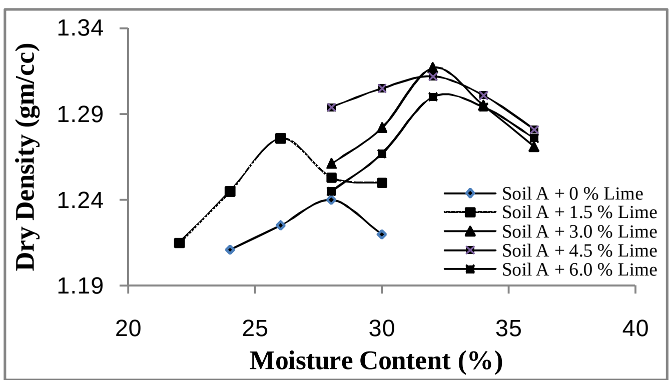

Figure 2.1 Typical graph showing variation of MDD and OMC for soil-A stabilized with Lime

Fig. 2.1 shows the compaction curves of lime – soil mixtures for subgrade soil A. In case of subgrade soil A, the value of maximum dry density and optimum moisture content increases with increase in lime content, whereas in case of subgrade soil-B, the value of maximum dry density decrease and moisture content increases with increase in lime content. The value of maximum dry density of unstabilized subgrade soil-A is 1.24 gm/cc, it increases to 1.317 gm/cc at 3 % lime by weight of dry soil and thereafter it start decreasing, whereas the value of maximum dry density of unstabilized subgrade soil-B is 1.65 gm/cc. It consistently decreases with increase in percentage of lime as shown in Table 2.4

2.4 Effect on CBR Values due to lime, fly ash and fibre stabilization

2.4.1 Soaked CBR Test [IS 2720 Part -16 (1987)]

The California Bearing Ratio (CBR) test is a simple strength test that compares the bearing capacity of a material with that of a well graded crushed stones. It was developed by the California Division of Highways around 1930 and was subsequently adopted. The batch of soil is mixed with optimum moisture content. The spacer disc is placed at the bottom of the mould and a filter paper above it. The processed soil sample is compacted by static compaction. The collar is removed and the excess soil at the top of layer is struck off using straight edge. For soaked test the filter paper is placed on the base plate and mould is turned upside down. Soaking is done for 4 days (96 hours). The test consists of a cylindrical plunger of 50 mm diameter to penetrate a pavement component material at 1.25mm/minute. The load values for 2.5 mm and 5.0 mm penetration are recorded. CBR values at different stabilizer content and percentage increase in CBR with respect to unstabilized soil-A and soil-B are presented in Table 2.5.The test result shows that, the CBR value of unstabilized subgrade Soil-A is 1.45 %. This value increases to 2.04, 6.86, 7.70 and 7.60 % due to addition of 1.5, 3, 4.5 and 6 % lime respectively.

Similarly, the CBR value of unstabilized soil B is 4.67 %. This value increases to 8.17, 14.89, 15.91 and 12.40 % due to addition of 1.5, 3, 4.5 and 6 % lime respectively. Maximum improvement in CBR is observed in both subgrade soil-A and soil-B, when stabilized with 4.5 % of lime, 10 % fly ash and 0.5 % fibre stabilization as shown in Table 2.5

Fig 2.2 is typical graph showing the effect of lime stabilization on CBR values of soil-A.

Table 2.5 Effect of Lime, Fly Ash and Fibre stabilization on CBR Values

Lime (%)	Fly Ash	Fibre	Soil-A		Soil-B	
	(%)	(%)	Max CBR (%)	% Increase	Max CBR (%)	% Increase
0	-	-	1.45	-	4.67	-
1.5	--	-	2.04	40.68	8.17	74.95
3.0	-	-	6.86	373.10	14.89	218.84
4.5	-	-	7.70	431.03	15.91	240.68
6.0	-	-	7.60	424.14	12.40	165.52
-	5	-	2.82	94.82	5.973	27.90
-	10	-	3.68	153.79	8.13	74.09
-	15		2.60	79.72	6.45	38.11
-	20	-	1.63	12.62	5.68	21.63
-	-	0.25	3.94	171.72	8.03	71.94
-	-	0.5	4.23	191.72	8.47	81.73
-	-	0.75	3.13	115.86	6.28	34.47
-	-	1.0	2.84	95.86	5.69	21.84

International Journal of Engineering Research
Volume No.5, Issue Special 1 pp : 74-79

ISSN:2319-6890(online),2347-5013(print)
8 & 9 Jan 2016

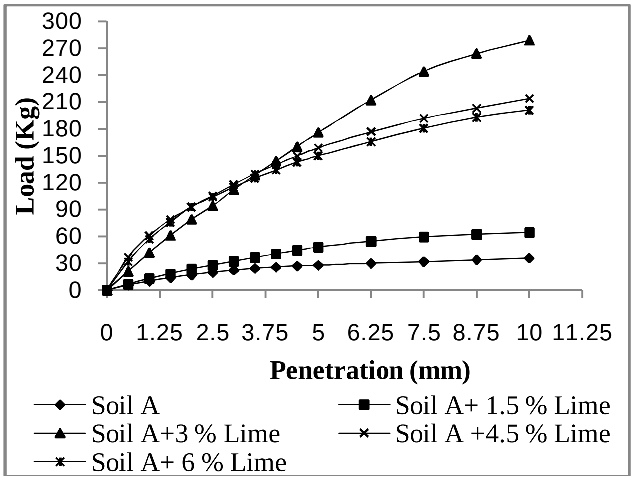

Figure 2.2 Typical graph showing the effect of lime stabilization on CBR values of soil-A

2.5 Effect on unconfined compressive strength due to lime, fly ash and fibre stabilization

2.5.1 Unconfined compressive strength test [IS 2720 Part-10 (1991)]

This test is a special form of triaxial test in which the confining pressure is zero. Soil is sieved through IS 4.75 mm sieve and samples are prepared at optimum moisture content. The compaction is static in nature. The required specimens are obtained with help of 1.5" dia. hollow cutters and specimen extractors.

The cylindrical specimen is having height to diameter ratio equal to two. The specimen is placed in the compression testing machine. The compressive load is applied till the specimen as indicated by decrease in reading of the proving ring or if the sample fails by bulging

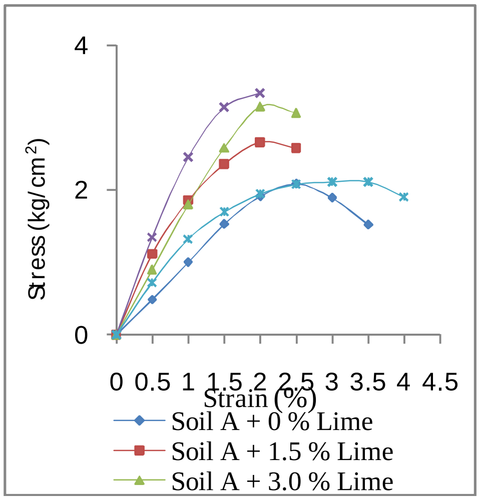

Fig 2.3 Typical graph showing the effect of Lime stabilization on UCS of soil A

Table 2.6 Effect of Lime, Fly Ash and Fibre stabilization on UCS

Lime Content (%)	Fly Ash (%)	Fibre (%)	Subgrade soil-A Failure Stress (Kg/cm^2)	Subgrade soil-B Failure Stress (Kg/cm^2)
0	-	-	2.084	1.564
1.5	-	-	2.66	2.244
3.0	-	-	3.1505	2.444
4.5	-	-	3.341	2.457
6.0	-	-	2.108	2.412
-	5		2.823	3.947
-	10	-	3.315	4.37
-	15	-	-	2.77
-	20	-	-	2.51
-	-	0.25	2.429	4.582
-	-	0.5	3.195	6.015
-	-	0.75	3.037	4.03
-	-	1.0	2.20	3.99

From UCS test, it is observed that, the stress value of unstabilized subgrade Soil-A is 2.084 Kg/cm^2. This increases to 3.341 Kg/cm^2 at 4.5 % lime and then drops whereas unconfined compressive strength value of subgrade soil B increases from 1.564 Kg/cm^2 to 2.457 Kg/cm^2 at 4.5% beyond which it decreases. Variation in failure stress due to fly ash and fibre stabilization can also be studied from Table 2.6

Fig 2.3 illustrates the effect of lime stabilization on UCS of soil-A. Maximum value of failure Stress is observed in both subgrade soil-A and soil-B, when stabilized with 4.5 % lime, 10 % fly ash and 0.5 % fibre.

3. Conclusions

When both the subgrade soils are stabilized with lime as well as fly ash, there is significant reduction in plasticity index as compared to unstabilized soils which is attributed to the change in soil nature due to flocculation and agglomeration. Variation in dry density and moisture content of subgrade soil due to stabilization depends on nature of soil and type as well as stabilizer percentage. Based on the laboratory investigation it is deduced that 4.5 % lime, 10 % fly ash and 0.5 % fibre are optimum stabilizer content. Soil stabilization technique is more effective for weak soil as compared to moderate one. Fly ash which is not only waste material but hazardous to environment, can be efficiently incorporated as stabilizing agent to improve the characteristic strength of subgrade soil.

References

i. *Amu, O.O., Fajobi, A.B., and Oke, B.O. (2005). Effect of eggshell powder on the stabilizing potential of lime on an expansive clay soil. Journal of Applied Sciences, 5(8), 1474-1478.*

ii. *Ansari, M.A. and Hasan, K.A. (2011). Lime stabilization on soil of a selected reclaimed site of Dhaka city. Journal of Geotechnical Engineering, 1(1), 1-6.*

iii. *Arbani, M.and Karmani, M.V.(2007). Geomechanical properties of lime stabilized clayey sands. The Arabian Journal for Science and Engineering, 32(1B), 11-25.*

iv. *Bagui, S.K. (2012). Pavement design for rural low volume roads using cement and lime treatment base. Jordan Journal of Civil Engineering, 6, (3), 293-302.*

v. *Brown, S. F. (1974). Repeated load testing of a granular material. Journal of Geotechnical Engineering, 100 (7), 825–841.*

vi. *Freitag, R.A. (1986). Soil randomly reinforced with fibers. Journal of Geotechnical Engineering., 112(8), 823–826.*

vii. *Hausmann, M. R. (1990). Engineering principles ground modifications. McGraw – Hill, New York.Jan, M.A. and Walker, R.D. (1963). Effect of Lime, Moisture and Compaction on a Clay Soil. Highway Research Record No. 29, pp: 1-12.*

viii. *Khattab, S.A., Ibrahim, M., Abderrahmane, H. and Al-Zubaydi (2011). Effect of fibers on some engineering properties of cement and lime stabilized soils. Engineering & Technology Journal, 29(5),886-905, 2011.*

ix. *Koteswara, R.D., Anusha, M., Pranav, P.R.T. and Venkatesh, G. A laboratory study on the stabilization of marine clay using saw dust and lime. International Journal of Engineering Science & Technology, 2(4), 851-862.*

x. *Leonards, G. A.and Bailey, B. (1982). Pulverized coal ash as structural fill. Journal of Geotechnical Engineering, 108(4), 517–531.*

xi. *Lima, D.C., Bueno, B.S. and Thomasi, L. (1996). Mechanical response of soil – lime mixture reinforced with short synthetic fibre, Proceeding, 3rd International Sympson on Envirnmental Geotechnology, Vol. I, pp 868 – 877*

xii. *Little, D.N., Scullion, T., Kota, P.B. and Bhuiyan, J. (1995). Guidelines for mixture design and thickness design for stabilized bases and subgrades. Texas A and M University, Austin, Texas.*

xiii. *Lund, O. and Ramsey, W.J. (1958). Experimental lime stabilization in Nebraska. Nebraska Department of Roads.*

xiv. *Mackiewicz, S. M., and Ferguson, E.G. (2005). Stabilization of soil with self-cementing coal ashes. World of Coal Ash, Lexington, Kentucky, USA, 2005.*

xv. *Maher, M. H. and Gray, D. H. (1990). Static response of sands reinforced with randomly distributed fibers. Journal of Geotechnical Engineering, ASCE, 116(11), 1661–1677.*

xvi. *Mallela,J., Harold, V.Q., Smith, K.L., and Consultants, E. (2004). Consideration of Lime-stabilized Layers in Mechanistic-empirical Pavement Design. The National Lime Association, Arlington, Virginia, USA.*

xvii. *Nagrale, P. and Shrivastava, P. (2009). Design of lime stabilized flexible pavements. Indian Highways, 19-26.*

xviii. *Phani Kumar, B. R. and Sharma, R.S. (2004). Effect of fly ash on engineering properties of expansive soils. Journal of Geotechnical and Geo-environmental Engineering, ASCE, (30), 764-767.*

xix. *Prabakar, J., Shridhar, R. S. (2002). Effect of random inclusion on sisal fiber on strength behaviour of soil. Journal of Construction and Building Materials, 16(2), 123-131.*

xx. *Saeid, A. Amin,C., and Hamid, N. (2012). Laboratory investigation in the effect of lime on compressibility of soil. International conference on Civil and Architectural applications (ICCAA2012),89-93.*

xxi. *Sear, L. K. (2001). The properties and use of coal fly ash, Telford,London, 1–50.*

xxii. *Sharma, R. (2012). Subgrade characteristics of locally available soil mixed with fly ash and randomly distributed fibers. International Conference on Chemical, Ecology and Environmental Sciences,Bangkok.*

xxiii. *Taylor, W. and Arman, A.(1960). Lime stabilization using preconditioned soils. Highway Research Board Bulletin, 262, 1-19.*

xxiv. *Trivedi, J. S., Nair, S.,and Iyyunni, C. (2013). Optimum utilization of fly ash for stabilization of sub-grade soil using genetica algorithm. Procedia Engineering, 51, pp.250-258.*

xxv. *Twinkle, S.and Sayida, M.K.(2011) Effect of Polypropylene Fibre and Lime Admixture on Engineering Properties of Expansive Soil. Proceedings of Indian Geotechnical Conference, pp. 393-396, 2011.*

xxvi. *Wang, J., M., Mateos and Davidson, D, (1963). Comparative effects of hydraulic, calcitic and dolomitic limes and cement in soil stabilization. Stabilization of Soil with Lime and Fly Ash. Highway Res. Board, Washington, 29: 42-54.*

xxvii. *Younes,B.,Fauziah,A. and Ismail, M.A.(2014).Strength and mechanical behavior of soil-cement-lime-rice husk ash (Soil-CLR) mixture. Journal of Material and structures 47(2), 55-66.*

xxviii. *Youssef,N.A., Omar,N.M., and Khaldon,O. (2012). Soil stabilization by lime." Electronic Journal of Geotechnical Engineering, 17,1747-1757.*

.