Engineering Properties of Lime Stabilized Swelling Soils from Sudan

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Abstract— **In this paper, the experimental results of expansive soil samples from different areas of Sudan are presented. The primary objective of this study is to study the effects of addition hydrated lime to the engineering properties soil samples. Namely Atterberg's limits, optimum moisture content, maximum dry density and Unconfined Compressive Strength (UCS). The hydrated lime has been used as a stabilizer for five soil samples obtained from different areas of Sudan. Different amounts of hydrated lime were added to the samples. The amount of hydrated lime was ranged from 0.5% to 7% of soil sample dry weight. The addition of hydrated lime showed significant effects on engineering properties of the tropical soils and development on soil strength. The soil liquid limit and optimum water content were decreased with the increase of hydrated lime content, while the soil maximum dry density was increased. Also, results have showed that the UCS of the tropical soil samples had significantly increased with an increase of the hydrated lime content, especially at the optimum hydrated lime content.**

***Keywords*— stabilization, hydrated lime, index properties, unconfined compressive strength.**

I. INTRODUCTION

Expansive clay soils cover large areas in Sudan. These areas include most of the nation's population centers and development schemes. These soils pose high risk to buildings and roads. Therefore, massive areas within the expansive soil plains are isolated during the rainy season due to poor traffic accessibility. Research was carried out to improve the engineering properties of soils by chemical additives for improving performance as foundation soils and/or road subgrades. The characteristics that affect the performance of structures laid over expansive subgrades are: the very low wetted strength; the potential of heave, especially for lightly loaded structures and the shrinkage of wetted soils upon drying [1].

The necessity to construct airfields and road pavements on swelling soils with the scarcity of suitable road building materials led search for proper pavement construction techniques. Stabilizing clay soils with lime was found to be an effective method for reducing or minimizing the deleterious effects of these soils on structures. The promising results of lime-soil stabilization led to widely developed usage of this technique in the construction of airfields, road pavements and drainage structures over extended expansive areas [1]. Extensive research was documented with regard to the engineering properties, reliability and durability of various types of stabilized material [2].

Lime stabilization causes a significant improvement in soil texture and structure by reducing plasticity and by providing pozzolanic strength gain. A significant level of long-term strength improvement in lime stabilized soils is possible and probable. This level of strength improvement can meet typical specifications required by various user agencies. This strength improvement has been verified not only by extensive laboratory testing but also, extensive field testing as well [2]. These tests define that, when lime is added to a reactive soil, strengths in excess of about 1,400 kPa are expected [2]. This strength level has been identified as one that provides significant structural benefit to the pavement. In some soils ultimate compressive strength values of as high as 7,000 to 10,000 kPa can be reached [2].

II. LITERATURE REVIEWS

Lime used as a stabilizer is manufactured in various forms, the most typically used in soil stabilization are high quality hydrated lime (Ca(OH)2, hydrated dolomitic lime [Ca(OH)2 . Mg(OH)2], quick lime (CaO) and dolomitic quick lime [CaO.MgO]. Hydrated lime is preferred as it comes in powder form, consumes no additional water for hydration and provides more free calcium for stabilization.

Previous work on lime stabilization of clay soils [3] attributed the stabilization process to four reactions: cation exchange, flocculation and agglomeration, cementitious hydration and pozzolanic reaction. Cation exchange, flocculation and agglomeration are relatively rapid and the most significant change could occur within several hours of mixing. The reduced sizes of double layer caused by the ion exchange of calcium, as well as the increased internal friction of the clay particles caused by flocculation and agglomeration lead to reduction in soil plasticity [4]. The third and fourth reactions are slow and time dependent and their effect may show up in days, months or years [5].

Recent research has shown that, lime as an effective stabilizing agent for clayey soils can effectively increase soil strength and bearing capacity, minimize soil compressibility, diminish the flow or migration of subsurface water, increase resistance to surface water erosion, improve workability of highly plastic soils and reduce swelling and shrinkage phenomena [6]. The factors that affect stabilization of clay

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soils include: clay mineralogy; stress and desiccation history; climate and the physiochemical environment existing in the soil mass and around the clay particles [6].

All types of clay minerals react with lime. However, the nature of the exchangeable cations does not make much difference in kaolinitic clays but can have significant effect on montmorillonitic clays [7] by causing immediate reduction in plasticity. The addition of lime causes immediate increase in pH of the soil water due to partial dissolution of the calcium hydroxide. The high alkalinity in the presence of water changes the physiochemical conditions of clay mineral surfaces and therefore, facilitates the development of new minerals through pozzolanic reactions responsible for the formation of the cementitious agents [7].

A. *Materials*

In this study, soil samples from five locations in Sudan were collected in attempt to represent. These samples were chosen to represent plasticity index ranging from 31% to 50%. Hydrated lime was used as an active additive. The sources of limestone collected from four locations in Sudan and tested it in central petroleum laboratories. The quality limestone source pruned at 900 0c in the electricity kiln in Building and road research institute (BRRI – university of Khartoum). The hydrated lime was kept in an air-tight container to preserve its quality.

B. *Lime*

Lime is an effective stabilizing agent for plastic soils and can be used to improve their workability, reduce settlement and increase strength. Two types of lime commonly used in stabilization are hydrated lime [Ca (OH)2] and quicklime [CaO] [1]. These limes will modify the soil through cation exchange and stabilize it after the modification process has been completed. The lime used for stabilization was construction hydrated lime of high quality produced locally and the chemical content is given in Table 1.

Table 1 Chemical content of hydrated lime used

Chemical content	Results of lime used %	Quantity (ASTM(C977)
Calcium Hydroxide ($Ca(OH)_2$)	95.10	90% min
Magnesium Oxide (MaO)	0.0	0.90% max
Calcium carbonate ($CaCO_3$)	0.09	6% max
Carbon Dioxide (CO_2)	2.75	5.0% max

C. *Soil Samples*

Soil samples from five locations in Sudan all within the extended clay plains were tested. Theses samples were collected from Alfao town in Eastern Sudan (Soil 1), Khartoum in Central Sudan (Soil 2), Rabak from White Nile state (Soil 3), Sinnar state (Soil 4) and Abyei from the south of Khrdofan (Soil 5). The locations of the samples are shown in Figure 1. The basic classification tests (Table 2) were performed according to the Unified Soil Classification System USCS show that Soil 1, Soil 2, Soil 3, Soil 4 and Soil 5 are silty clay of high plasticity (CH). The minerals constituents of the natural five soil samples were examined using X- ray diffraction. Table 3 and Figure 2, shows that soil1 is completely montmorillonite, soil 2 consist of 61 % montmorillonite, kaolinite 29 % and 10% of illite, soil 3 consist of 64 % montmorillonite, kaolinite 24 % and 8.5% of illite, soil 4 compromises of 86% montmorillonite, kaolinite 13 % and one of illite while soil 5 consist of 29 % montmorillonite, kaolinite 61 % and 6 % of illite.

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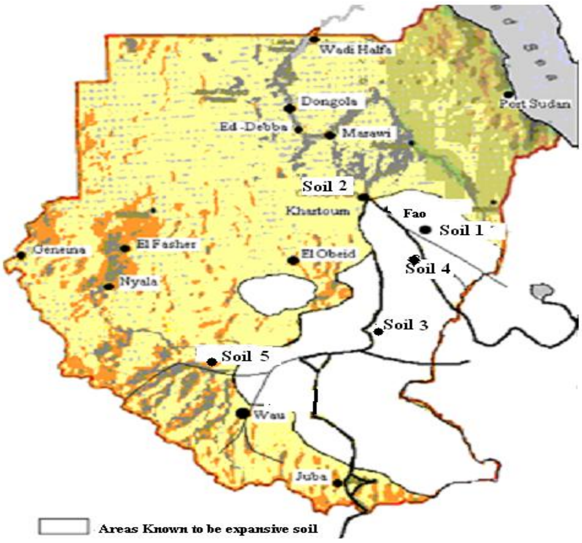

Fig.1 Soil samples locations

Table 2 Classification test results

Sample	LL	PI	Particle Size %				USCS Class
			Clay	Silt	Sand	Gravel	
Soil 1	66	37	24	65	9	2	CH
Soil 2	73	41	54	34	11.5	0.5	CH
Soil 3	64	31	48	37	15	-	CH
Soil 4	79	50	23	63	12	2	CH
Soil 5	61	32	38	48	14	-	CH

Table 3 X- ray Diffraction for untreated soils

Soils	Smectite %	Kaolinite %	Illite %	Chlorite %	Sme/Illi %
Soil 1	98	0	0.80	0	1.20
Soil 2	61	29	10	0	0
Soil 3	64	24	8.50	0	3.50
Soil 4	86	13	1	0	0
Soil 5	29	61	6	0	4

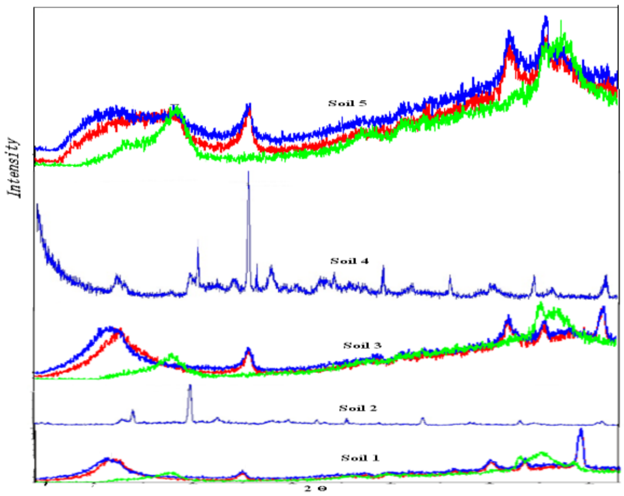

Fig.2 X-ray diffractions of soil samples

III. METOD AND DATA

Laboratory tests were carried out on untreated soil samples and treated with different percentage of hydrated lime accordance with British Standards (BS 1377-1990). The consistency limits, compaction characteristics, California Bearing Ratio and Unconfined Compressive Strength tests were conducted.

A. Atterberg Limits

The test carried out was according to the cone penetration method in BS 1377. The soil samples were sieved through Sieve No. 40. Then a percentage (by dry weight) of lime was added to the soil sample and mixed carefully with distilled water (at moisture content less than LL) and left for 48 hours to cure and obtain homogeneous paste. The tests carried out on the stabilized soils were: liquid limit, plastic limit.

B. Compaction Characteristics

Ordinary Proctor (compaction) test was carried out on the soil samples in order to obtain their moisture-density relationship, i.e. their optimum moisture content and maximum dry densities. These tests carried out according to British Standards BS 1377-1990. The soil samples were sieved through Sieve No. 4. Mechanical dry mixing method was used in mixing lime and soil at various lime contents before water. After water added, the sample mixing carefully and left it for 7 days cure in sealed plastic bags to obtain homogeneous paste.

C. Unconfined Compression Test

Soil samples were sieved through Sieve No. 4. Unconfined Compression Test (UCS) specimens were prepared by compacting the material into the cylindrical moulds as specified in BS 1924: Part 2: 1990. Mechanical dry mixing method was used in mixing lime and soil at various lime contents before adding water at Optimum Moisture Content (OMC). Soil sample left 7 days cure in sealed plastic bags.

IV. DISCUSSION OF RESULTS

A. Physical And Mineralogical Analysis

The particle size analysis (Table 1) shows that Soil 1 contains high amount of fines (89%) of which 24% is clay, Soil 4 contains 86 % of fines of which 23% is clay, Soil 5 contains 86 % of fines of which 38% is clay while Soil 2 and Soil 3 contains high clay content (88%) of which 54% is clay for Soil 2 and (85%) of which 48% is clay for Soil 3. Semi-quantitative analysis of the X-ray diffraction tests showed that smectite “montmorillonite’ is the main mineral constituent of the clay fraction of Soil 1 (89%) and Soil 4 (86%), Smectite, kaolinite and illite is the main mineral constituent of the clay fraction of Soil 2 (88%) and Soil 3 (85%) while Soil 5 contains 61% of kaolinite about 29 % of smectite.

B. Determination of optimum lime content ((Lime fixation capacity (LFC))

The lime fixation point corresponds with the point where further addition of lime does not bring further changes in the plastic limit. To find lime fixation point for each soil sample, small quantities of hydrated lime normally between 0.5 to 6.5% by dry mass of soil were added for Soil1, Soil 2 between 0.5 to 7.0%, Soil 3 between 0.5 to 6.0%, Soil 4 between 0.5 to 7.0% and for soil 5, the percentages were ranged from 0.5 to 5.5%.

The changes in plastic limit of treated soil samples at different percentages of lime are shown in Figure 3 ~7. It indicates that lime fixation capacity of 6.5% for Soil1, 7% for Soil 2, 6% for Soil 3, 7.0% for Soil 4 and 5.5% for soil 5. The variation in lime fixation capacity is dependent on the clay minerals contents. Lime fixation point ranging between 5.5 ~7%. The lowest lime fixation point 5.5% shown in Soil 5 (kaolinite soil) and the upper lime fixation point 7% appeared in Soil 2 and Soil 4 (soil consist high value of LL and PI).

C. Effect of Lime on Atterberg Limits

The results of the Atterberg Limits of the stabilized five soils are given in Tables 4 and Figures 3, 4, 5, 6 and 7 for Soil 1, Soil 2, soil 3, soil 4 and soil 5, respectively. The Atterberg Limit tests on the five samples have shown that hydrated lime addition was practically effective for the percentages ranging from 5.5 % to 7.0%. These figures showed that the general response of the five samples to hydrated lime addition is more or less having similar manner. The LL has decreased while the PL has increased with the addition of hydrated lime for the five soils. I was noted that weak response was achieved when only 0.5% hydrated lime was added. However, hydrated lime became more effective in reducing plasticity when optimum hydrated lime was added. No change in plastic limit (PL) above optimum hydrated lime. This was noted from the PI values. Soil 1, Soil 2, Soil3, Soil 4 and Soil 5 which have different in their fines contents and mineralogical composition (montmorillonite, kaolinite and mix minerals) showed different response of hydrated lime addition. Sample 5 which contain considerable amounts kaolinite and smectite showed different response to lime addition.

Figure 11 plots the drop in plasticity index (ΔPI) on addition optimum lime versus PI for the tested samples. It is evident from the figure that the drop in PI increases linearly with PI giving good correlation coefficient. The drop in plasticity index (ΔPI) divided by the plasticity index (ΔPI/PI) and the drop in liquid limit (ΔLL) divided by the liquid limit (ΔLL/LL) are given in Figure 12 for the five soil samples. The results show that ΔPI/PI value generally ranges between 0.68 to 0.82 while ΔLL/LL value ranges between 0.15 and 0.21. It is evident from the results of these tests that, unlike kaolinite clays, lime is very effective in decreasing plasticity of montmorillonite clays. Figures 3, 4, 5, 6 and 7 shows that plasticity index could drop to only 10% of the unstabilized value on the addition of optimum lime. This is an indication that workability of high plastic montmorillonite clays could improve, substantially, on the addition of small amounts of lime.

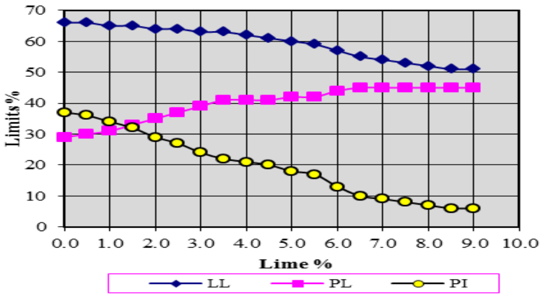

Fig.3 Atterberg limits vs. Lime content for Soil 1

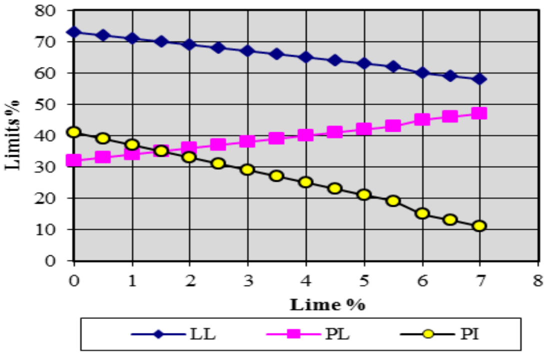

Fig.4 Atterberg limits vs. Lime content for Soil 2

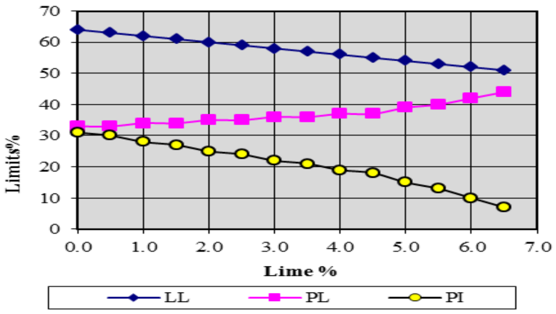

Fig.5 Atterberg limits vs. Lime content for Soil 3

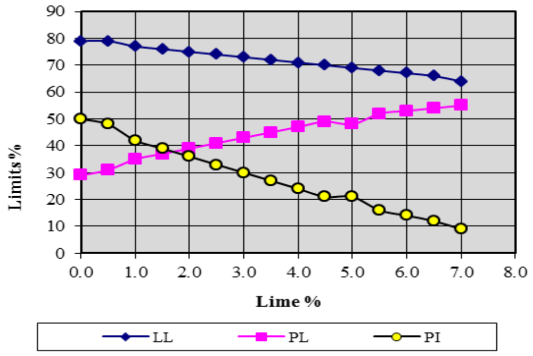

Fig.6 Atterberg limits vs. Lime content for Soil 4

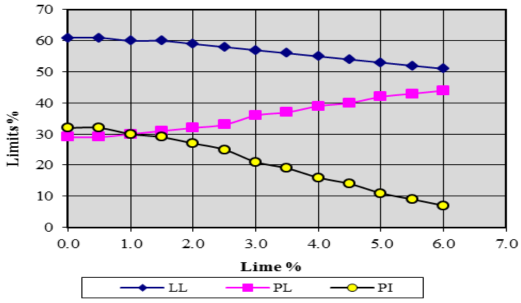

Fig.7 Atterberg limits vs. Lime content for Soil 5

D. *Compaction Characteristics*

A series of test is conducted to study the effect of hydrated lime on the compaction characteristics of different swelling soil (Table 4). The addition of lime at different percentage to clays increases their maximum dry density and reduces their optimum moisture content for the same compaction effort as shown in Figures 8 and 9 for all samples. A similar trend of behavior has also been observed for case of hydrated lime treated clay [1].

Table 4 Properties of hydrated lime for soil samples

Sample	L%	Atterberg Limits			Procter compaction		UCS (KPa)	CBR (%)
		LL	PL	PI	OMC (%)	MDD (g/cm^3)		
Soil 1	0.0	66	29	37	24.3	1.43	283	1
	3.0	63	39	24	22.0	1.50	406	89.6
	6.5	55	45	10	19.2	1.56	1560	104.7
Soil 2	0.0	73	32	41	25.7	1.53	237	1
	3.5	66	39	27	22.2	1.59	546	64.9
	7.0	58	47	11	18.9	1.62	1920	112.7
Soil 3	0.0	64	33	31	29.0	1.29	357	1
	3.0	58	36	22	26.6	1.34	641	70.8
	6.0	52	42	10	23.1	1.43	2015	102.3
Soil 4	0.0	79	29	50	28.8	1.38	154	1
	3.5	72	45	27	25.3	1.49	411	86.2
	7.0	64	55	9	22.4	1.69	1130	100.8
Soil 5	0.0	61	29	32	20.0	1.58	267	2.0
	2.5	58	33	25	18.1	1.61	386	76.8
	5.5	52	43	9	16.4	1.67	1814	116.2

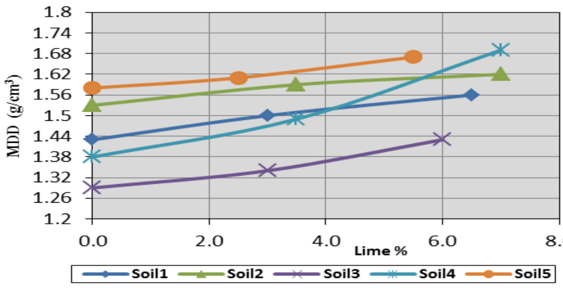

Fig.8 Max dry density versus Lime content

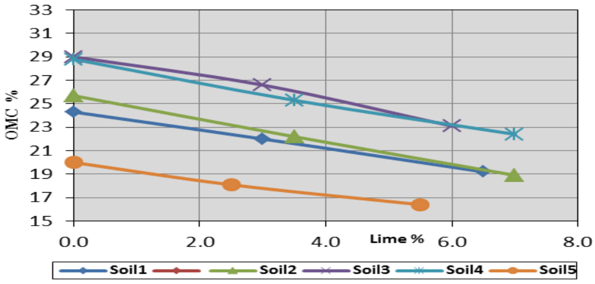

Fig.9 Moisture content versus Lime content

E. *Unconfined Compression Strength (UCS)*

UCS tests were performed on hydrated lime treated soils at various hydrated lime percentage (as shown in Table 4 and Figure 10), the UCS of lime-treated soils develops rapidly with increasing hydrated lime percentage until optimum lime content is reached. The soil samples in this study exhibit a rapid initial increase in UCS with the additions of hydrated lime. Addition of optimum hydrated lime to the natural samples further increased its UCS values from 283 to 1560 Kn/m2 for Soil 1, 237 Kn/m2 to 1920 Kn/m2 for Soil 2, 357 Kn/m2 to 2015 Kn/m2 for Soil 3, 154 Kn/m2 to 1130 Kn/m2 for Soil 4, 267 Kn/m2 to 1814 Kn/m2 for Soil 5 soil sample These results had been observed by various researchers for UCS tests [8]. Significant increase in UCS for natural and treated samples, shown in Soil 2 and Soil 3 (high clay contents and different clay minerals).

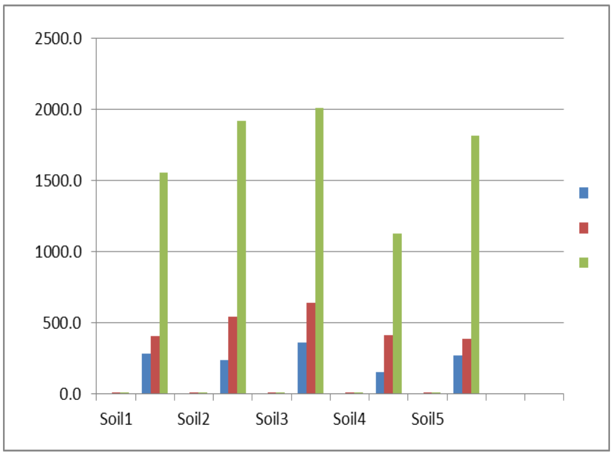

Fig.10 UCS at 7 days with various additions of lime

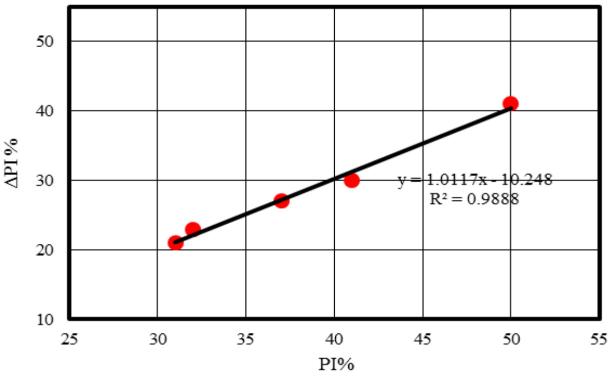

Fig.11The drop in PI vs. PI for the tested samples

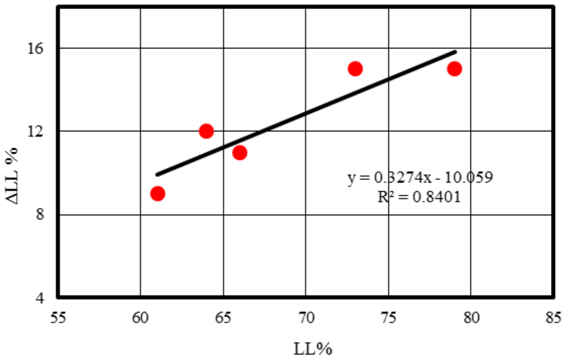

Fig.12 The drop in LL vs. LL for the tested samples

V. CONCLUSION

From the results of this study, the following conclusions have been drawn:

1. Addition of hydrated lime improved workability of potentially expansive soils by reducing their plasticity.
2. Based on tests results, the optimum hydrated lime for different tropical soils from Sudan was found to be within the limits of 5.5 ~7%, referring to the lime fixation point [9].
3. Liquid limit and plasticity index decrease substantially whereas plastic limit increases with increasing hydrated lime.
4. No significant effect of plasticity index was observed above optimum hydrated lime. The optimum gain in plasticity appears to be within the limits 7~10%.
5. The soil maximum dry density is found to increase while the optimum water content is found to decrease with an increase in the hydrated lime content.
6. A significant increase of California Bearing Ratio found with an increase in hydrated lime content, the peak increase is found at optimum hydrated lime content. Desired properties of typical Subgrade and sub base materials were attained by stabilizing the potentially expansive soils with optimum hydrated lime.

7. The Unconfined Compressive Strength of the soil is found to increase significantly with increase in hydrated lime content, especially at optimum hydrated lime content.
8. Very good relationship is found for the drops in plasticity index (ΔPI) vs. PI of the untreated samples when optimum hydrated lime was added to potentially expansive soils. This implies that the higher the plasticity index is the higher the drop in PI upon the addition of optimum hydrated lime.

REFERENCES

[1] Ingles. O. G. and Metcalf. J. B (1972). "In Soil Stabilization Principles and Practice. Butterworth Pty limited. London."

[2] Little. D. N. Males. E. H. Prusinski. J.R and Stewart. B (2000). "Cementitious Stabilization." 79th Millennium Rep. Series, Transportation Research Board.".

[3] Townsend. F. C. Manke. P. G. and Parcher. J. V (1969). "Effect of Remolding on the Properties of Lateritic Soil." Highway Research Record, 284: 76-103.

[4] Prusinski. J. R. and Bhattacharia S (1999). "Effectiveness of Portland cement and lime in stabilizing clay soils." In Transportation research Record TRR 1652: 215-227.

[5] Ola, S. (1978). "Geotechnical properties and behaviour of some stabilized Nigerian lateritic soils. In Q. J. Eng. Geol. 145-160."

[6] [6] Elsharief (2000). "Technical and economical viability of lime stabilization of expansive soils for road construction ," in Sudan. In Sudan Engineering Society Journal, Vol. 47(No. 38)

[7] De Brito Galvao T. C. , Elsharief A. and Simoes G. F. (2004) Effects of lime on permeability and compressibility of two tropical residual soils, in Journal of Environmental Engineering, ASCE, Vol. 130, No. 8, 881-885.

[8] Elhassan A.A. M. (2006) Effects of lime on the engineering properties of highly expansive soils from Sudan, M.Sc.Thesis, University of Khartoum, Sudan.

[9] Elsharief A.M. and Mohamed S. A. (2000) Technical and economical viability of lime stabilization of expansive soils for road construction in Sudan. in Sudan Engineering Society Journal, Vol. 47 No. 38, 5-16.

[10] Hill, G. H. and Davidson, D. T.,(1960) Lime fixation of clayey soils, Highway Research Board, Bull. 262, 20-32, Washington D. C.

[11] Bell.F.G (1996). "Lime stabilization of clay minerals and soil." In Engineering Geology 42: 223-237Elsevier Science.

[12] Kuo, C., and Huang, C. (2006). Three-dimensional pavement analysis with nonlinear subgrade materials. Journal of Materials in Civil Engineering, Vol.18 (4), 537-54.

[13] National Lime Association (NLA). 2004. Lime Treated Soil Construction Manual: Lime Stabilization and Lime Modification.

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