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Effective soil stabilization using Lime Sludge

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ABSTRACT

Weak subgrade layers can decrease the designed service life of pavements significantly, and building of thicker top layers may be required. Weak local soil can be turned into an effective material by chemical soil stabilization. Class C fly ash (CF), class F fly ash (FF) and Portland cement (PC) have been used for soil stabilization. Fly ash has been used by the concrete industry, and its popularity in the industry sometimes causes temporary shortages. PC is known to be the most expensive stabilizer among other stabilizers. In this research, lime sludge (LS) was investigated as an alternative stabilizer due to the benefits of using waste materials and the uncertain future of fly ash and PC. For this purpose, LS was used alone and with other stabilizers for soil stabilization, and unconfined compressive strength (UCS), freeze-thaw (F-T), wet-dry (W-D) tests and swelling test under F-T were conducted. The UCS test results of the specimens cured up to 90 days showed that LS can be used alone to increase the strength of the soil. The UCS test results of 7-day cured specimens pointed out LS can be mixed with CF and FF for further increase in strength. Using LS and PC together decreased the effect of PC because of a low pH environment. F-T test results of 7-day cured specimens showed that relatively higher strength losses were observed in the open system compared to the closed one. In addition, test results showed that there were no considerable benefits of using LS either alone or with other stabilizers on F-T durability. According to the W-D test results, the use of LS decreased the performance of PC and caused failures. Swelling test results under F-T showed that although the use of LS decreased the performance of other stabilizers, an optimum amount of LS (around 12%) could be used alone to reduce the swelling.

Keywords*— Lime Sludge (LS), Class F Fly Ash, Portland Cement (PC), Compressive strength, Freeze-thaw*

1. INTRODUCTION

According to the Highway Statistics 2014 report published by the U.S. Department of Transportation Federal Highway Administration (FHWA), total public road length is 6,722,347 km (4,177,073 miles) in the U.S. Each year, billions of dollars are spent just to keep pavements in suitable conditions; hence, establishing a long-term development and maintenance plan for pavement systems is a national priority. In the U.S., large volumes of earthen materials are used in pavement constructions each year. These materials can be replaced with suitable waste materials such as highway paving materials, secondary materials and construction debris that are normally thrown in landfills. Reusing waste materials has several benefits such as reducing solid waste disposal costs and landfill requirements, minimizing the consumption of natural resources, obtaining added value from waste materials, and ultimately providing sustainable construction and economic growth.

Designing successful pavement systems is not only based on the quality of the top layers (asphalt or concrete) but also the foundation layers underneath such as base, subbase or subgrade. In fact, the stability of the foundation layers is the main parameter that affects the long-term pavement performance (Little and Nair 2009). In particular, the quality of the subgrade layers plays an essential role in long-term pavement performance. Weak subgrades can decrease the designed service life of pavements significantly (Milburn and Parsons 2004), and building of the thicker base, subbase or surface layers may be required in the presence of structurally poor subgrade layers (Panchal and Avineshkumar 2015). Locally available soils are generally used as the subgrade layers during pavement construction in order to decrease the construction cost. However, this would bring the quality issue regarding the subgrade layers since the locally available soils may not possess the preferred quality. Granular soils consisting of high amounts of gravel or sand are more suitable for subgrade layers than fine-grained soils containing high amounts of silt or clay (Beeghly 2003). In addition, fine-grained soils tend to be relatively more sensitive to frost action.

Permeability and capillarity are the two main mechanisms that affect the resistance of soil against frost action. Permeability of soil controls the movement of fluid flow while capillarity controls the movement of fluids against gravity towards the vadose zone (Coduto 1999). Because of their moderate permeability and capillarity, silty soils are known as frost-susceptible (Rosa 2006). Thus, geotechnical engineering properties of the subgrade layers built with silty soils must be improved to increase the service life of pavements.

There is a variety of improvement techniques that can be used when the engineering properties of local soil are not adequate to carry the loads coming from the upper layers and vehicles (Chauhan et al. 2008). One of the methods is a conventional method called excavation and replacement. It is known to be a very straightforward method; however, replacing the locally available soil with a high-quality material incurs extra construction costs. Thus, it is not always recommended (Abu-Farsakh et al. 2015; Senol et al. 2006). The other method is using stabilizers to improve the engineering properties of local soils. Unsuitable local soil can be turned into better material by improving its engineering properties via physical or chemical stabilization techniques (Little and Nair 2009). Lime, fly ash and Portland cement are the most widely-used materials in soil stabilization; however, they are not suitable for all soil types. Material availability, local soil type, experience and the desired degree of improvement are the main selection criteria of stabilizers (Selvi 2015). The Soil Stabilization Index System (SSIS) developed by the U.S. Air Force is one of the methods to select the most suitable stabilizer for specific soil types (Little and Nair 2009) (Figure A in Appendix A).

Hydration, cation exchange and pozzolanic reactions are the main reactions occurring in the stabilized soils in the presence of water. During hydration, CaO from the stabilizer reacts with water and forms $Ca(OH)_2$. Stabilized soil gets drier due to the use of water during hydration, and immediate strength gain occurs. During cation exchange, calcium (Ca^{2+}) present in $Ca(OH)_2$ replaces monovalent cations such as sodium (Na^+) and hydrogen (H^+) which are present in the soil. This replacement causes a decrease in double diffuse layer (DDL) thickness which leads to an increase of attraction between soil particles (Zhu and Liu 2008a). This increase in attraction leads to an improvement in the linking between soil particles; thus, strength increases. As time progresses, pozzolanic reactions take place between Ca^{2+} existing in $Ca(OH)_2$ and silica/alumina released from soil (silica/alumina can also be released from the stabilizer). Calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-gels which have cementitious properties are formed during pozzolanic reactions (Prusinski and Bhattacharja 1999; Mallela et al. 2004.

2. OBJECTIVE OF MAIN STUDY

The main objective of the present study is stabilization of soil by using Lime Sludge materials and their mixes can be used as sub-base material in the construction field.

- To know the geotechnical characterization of different soils from South Coastal Districts of Odisha.
- Weak local soils can be turned into an effective material by chemical soils stabilization. class C fly ash, class F fly ash and type I/II Portland cement has been used in stabilization.
- The main purpose of the project is increasing the use of lime sludge for soil stabilization to obtain the benefits of reusing waste materials and to fulfill the need for exploring alternative stabilizers because of the uncertain futures of fly ash and PC.

3. METHODOLOGY

Experimental procedures adopted in this investigation and the methodology adopted during the course of the study are briefly presented.

3.1 Materials used

The materials used in the investigation are:

(a) Lime sludge (LS)
(b) Class C fly ash (CF)
(c) Class F fly ash (FF)
(d) Portland cement (PC)

The following tests were conducted on the soil. The index and engineering properties of the soil were determined.

(a) Specimen Preparation
(b) Atterberg Limits Test
(c) Standard Proctor Test
(d) Unconfined Compressive Strength (UCS) Test
(e) Freeze-Thaw (F-T) Test
(f) Swelling Test under F-T Cycles
(g) Wet-Dry (W-D) Test
(h) pH Analysis

4. RESULTS AND DISCUSSION

Specimens are summarized and collected from various districts of Odisha and designated. The samples were subjected and index properties of the materials, the chemical composition of the materials and the test results are listed below in the table and figures.

Table 1: Chemical compositions of the materials

Material	G_s	LOI (%)	CaO (%)	$CaCO_3$ (%)	SO_3 (%)	SiO_2 (%)	Al_2O_3 (%)	MgO (%)
LOE	2.7	-	-	-	-	-	-	-
LS	2.3	-	0-3.5	>60	-	-	-	-
CF	2.7	0.16	24.31	-	0.81	39.01	21.23	5.31
FF	2.47	0	11.8	-	0.45	57.06	18.82	2.89
PC	-	-	60-67	-	1.3-3	17-25	3-8	0.1-4

LOE: loess, LS: lime sludge, CF: class C fly ash, FF: class F fly ash, PC: type I/II Portland cement

Table 2: Atterberg limits test results

Specimen Description	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
LOE	37.3	26.9	10.4
4 LS	36.7	26.6	10.1
8 LS	36.4	26.3	10.1
12 LS	36.9	26.8	10.1
20 LS	36.7	26.7	10
30 LS	37.2	27.5	9.7
40 LS	37.4	28	9.4
4 CF	37.7	28.1	9.6
8 CF	37.8	28.9	8.9
12 CF	38.1	30	8.2
4 FF	37.7	27.6	10.1
8 FF	37.6	27.9	9.7
12 FF	37.7	28.6	9.1
2 PC	40.8	31.6	9.2
4 PC	41.9	35.8	6.1
8 PC	42.3	37.6	4.7
12 PC	42.9	39	3.9
30 LS + 8 CF	38.3	29.4	8.9
30 LS + 12 CF	38.5	29.9	8.6
30 LS + 8 FF	37.7	28.3	9.4
30 LS + 12 FF	38	28.3	9.7
30 LS + 2 PC	37.8	28.8	9.1
30 LS + 4 PC	40	32.5	7.5
40 LS + 8 CF	38.3	29.5	8.8
40 LS + 12 CF	38.9	30.7	8.2
40 LS + 8 FF	37.9	28.6	9.3
40 LS + 12 FF	38	28.7	9.3
40 LS + 2 PC	38	28.4	9.5
40 LS + 4 PC	39.9	32.1	7.8

LOE: loess, LS: lime sludge, CF: class C fly ash, FF: class F fly ash, PC: type I/II Portland cement.

Table 3: UCS test results of the specimens subjected to W-D cycles

Specimen Description	Unconfined Compressive Strength (kPa)				
	7-Day Cured at w_{opt} (Dry)	After 1 Cycle Wet (Dry)	After 4 Cycles Wet (Dry)	After 8 Cycles Wet (Dry)	After 12 Cycles Wet (Dry)
2 PC	598.3 (1794.98)	358.18 (1129.04)	-	-	-
4 PC	1072.26 (2359.00)	752.79 (1539.78)	520.87 (1224.26)	-	-
8 PC	1527.64 (4201.10)	1128.12 (3365.50)	1740.36 (4566.78)	1556.49 (3904.79)	983.19 (2466.53)
12 PC	2056.84 (5759.17)	1823.08 (5646.50)	3190 (7831.75)	2678.95 (7372.48)	2332.98 (6420.33)
30 LS + 4 PC	504.52 (1720.55)	318.72 (1061.65)	-	-	-

LOE: loess, LS: lime sludge, CF: class C fly ash, FF: class F fly ash, PC: type I/II Portland cement.

Table 4: Swelling test results under F-T cycles

Specimen Description	Change in Volume (%)	
	1st Freezing	2nd Freezing
LOE	3.11	15.09
4 LS	8.10	15.78
8 LS	8.65	14.09
12 LS	9.36	11.86
20 LS	8.08	15.64
30 LS	9.03	16.60

5. CONCLUSION

Increasing the use of waste materials in pavement constructions helps the industry to reduce the costs due to the disposal of waste materials, to control possible contaminations of surrounding areas, to create new income sources and to conserve energy and sources of other commonly- used materials. Fly ash and PC have been widely used for soil stabilization. However, the uncertain futures of these materials demand to find alternative waste materials such as LS. In this research, a laboratory study was conducted to observe the usability of lime sludge in the stabilization of loess which is locally available in Iowa. Lime sludge obtained from the Ames Water Treatment Plant located in Iowa was used alone and mixed with previously mentioned stabilizers to stabilize loess in terms of strength and durability. For this purpose, UCS, F-T, swelling under F-T and W-D tests were conducted. These tests were also supported by conducting pH, XRD and SEM analyses. The observations are summarized as follows:

- Within the specimens prepared with a single stabilizer, the use of stabilizers having relatively higher CaO contents and the use of higher amounts of stabilizers provided better improvements in the PI and strength of loess. While increases in the amounts of CF, FF, and PC provided greater decreases in the PI and greater increases in the strength of loess, only the use of a high amount of LS (>20%) provided considerable improvements.
- Higher-strength values were observed in the specimens having longer curing periods. Hydration and pozzolanic reactions occurring between loess and stabilizers in the presence of water provided short-term and long-term strength gains, respectively.
- While open F-T tests were more destructive than the closed ones, the most drastic decreases in strengths were observed after the 1st cycle in both systems. In the closed system, all the strength values of the specimens prepared with a single stabilizer after 12 F-T cycles were higher than the initial ones except the specimens prepared with high LS content (>12%). In the open system, all the final strength values were lower than the initial ones. The use of PC provided the best durability in both systems.
- W-D cycles were more destructive than open F-T cycles, and only the specimens prepared with PC did not fail after the 1st wetting. Ongoing curing processes dominated the damaging effect of W-D cycles in the specimens prepared with high PC content (≥8%) and led to increases in strengths accordingly. Increase in the amount of PC increased the durability of loess against W-D cycles.
- While single uses of PC to stabilize loess showed the best improvements against swelling under F-T, the uses of LS provided the lowest improvements. The use of 12% LS gave the best improvement within the specimens prepared with LS. Relatively higher moisture contents were observed in the specimens prepared with higher amounts of LS (>12%) and this result was attributed to an increase in the water intake capacity of the specimens due to LS.

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