Experimental Investigation of Silty Soil Treated with Sodium Lignosulfonate

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Abstract: Soil stabilization refers to the process of changing soil properties to improve strength and durability. There are many techniques for soil stabilization, including compaction, dewatering and by adding chemicals to the soil. Out of these, chemical stabilization is one of the most effective and popular technique, which has been practiced successfully in the field. There are several chemical additives such as lime, cement, fly ash, rice husk etc. Most recently, lignin is an industrial by-product has been identified as a chemical additive for stabilization of soil mass. Besides, lignin does not have any adverse effect on the environment. In view of this, the behavior of lignin-stabilized soil has been investigated in the present study. Results obtained from unconfined compressive strength tests indicate that the performance of lignin stabilized soil increases with increase in percent of lignin content. However, it has been observed that the performance of stabilize soil reduces beyond 3% of lignin content. This is possibly because the soil particles completely get coated with lignin if it increased beyond 3% thereby mobilizes strength at the surface of two lignin particles, which has lesser bonding strength than the strength mobilized at soil lignin interface. Therefore, it can be stated that the optimum percentage of lignosulfonate giving maximum performance of stabilized soil mass should be about 3% by weight.

Keywords: lignosulfonate; soil; unconfined compressive test

1. Introduction

In India, the soil stabilization began in the early 1970s. There was a general lack of oil and aggregates. In view of this, engineers required to find the ways to improve soils instead of replacing poor soils on construction sites. Stabilization in the broadest sense involves various methods of modifying the properties of a soil to improve technical performance. Stabilization is used for various engineering works, most often in road construction, where the main objective is to increase the strength or stability of the soil and reduce construction costs by making the best use of available materials. Soil stabilization involves improving the technical properties of the soil and making it more stable. In the broadest sense, stabilization includes compaction, pre consolidation, drainage, and many other processes. Soil stabilization is used to reduce the permeability and compressibility of soil mass in the soil structure and to increase its shear strength [1-5]. The main objective of the stabilization is, however, to improve the natural terrain for motorway construction and to make a territory practicable in a short time in the event of a military or other emergency. In view of this, the behavior of lignin-stabilized soil has been investigated in the present study through laboratory tests.

2. Materials Used

Locally available silty soil in Jamshedpur is found as highly erodible and dispersive in nature, which is a major problem regarding failure of earth surface such as embankments dam, rail or road embankments, canal banks and foundation due to surface and internal erosion. In such situation adopting a suitable ground improvement technique to control soil erosion is necessary to avoid damage and maintenance cost caused by such soils. To eliminate such major problems chemical stabilization has been proven to be an appropriate and cost effective method, however the traditional soil stabilizers such as cement, lime, fly ash, slag and gypsum have been identified to cause serious environmental problems like changing of pH of soil and ground water, thus negative impact on agriculture and aquaculture and these soil tend to exhibit excessive brittleness. In this context, lignin based chemicals such as lignosulfonate have shown promising potential in stabilizing erodible and dispersive soil. The properties of silty soil and sodium lignosulfonate are presented in Table 1 and Table 2 respectively.

Table 1 Properties of silty soil

Properties	Value
Specific gravity	2.28
Liquid limit	36.2%
Plastic Limit	28.33%
Plasticity index	7.87
Soil classification	MI
O.M.C.	19.55%
M.D.D. (g/cc)	1.64
Free swell index	4.17%

Table 2 Properties of sodium lignosulfonate

Properties	Value
pH (10% solution)	4.9
Sodium	6.0%
Total sugar	3.0%
Colour	Brown
Moisture	≤7.0%
Bulk density	635 kg/m^3

3. Methodology

3.1 Unconfined Compressive Strength Test

The unconfined compression test is a special type of unconsolidated-undrained (UU) test commonly used for clay samples. In this test, compressive force applied on a cylindrical soil sample (with a height-to-diameter ratio of 2 to 2.5) in vertical direction. To encase the sample no rubber membrane is needed. This test can be performed on undisturbed cohesive soils. It cannot perform on coarse grained soils such as sand and gravel, as they cannot stand without lateral support. In addition, the test is essentially fast because it is believed that no moisture loss occurs during the test, which is performed relatively quickly.

3.2 Fall Cone Test

The fall cone test, also called the cone penetration test, is an alternative method to the Casagrande method for measuring the liquid limit of the soil. In this test, a 55 mm diameter soil sample is placed in a metal dish with a depth of 40 mm. A stainless steel cone weighing 80 grams having apex angle of 30° placed in such a way that its tip touches only the sample. The cone is released for 5 seconds to allow the soil to penetrate. According to the measurement of cone penetration depth, the undrained shear strength of soil sample can be expressed by Zhang et.al (2018) as follows.

$$S_u = K\frac{W}{h^2} \tag{1}$$

Where S_u = undrained shear strength (kPa); W = weight of cone (80 g in this study); h = penetration depth (mm); and K = fall cone factor, which was set as 1.33 in this study as suggested by Koumoto and Houlsby (2001). Equation 1 suggests that the undrained shear strength of the soil depends on weight of the cone, depth of penetration and fall cone factor. The fall cone test was carried out with the cone weighing 80 g having apex angle of 30°. Before each fall cone test, the surface was jelly coated to minimize the frictional effects. The experimental setup is shown in Fig. 1. The prepared sample was placed under the top of the cone and then the cone was slowly lowered until its tip just touched the surface of the sample. Thereafter, the cone was released and was allowed to get into the soil cup due to its own weight. The penetration time was set to 5 seconds to measure the penetration depth. The depth was measured with a graduated scale with an accuracy of 0.01 mm.

Fig. 1 Experimental setup for fall cone test

About 20 g of soil paste was taken from the cup to determine the moisture content of the test sample after penetration. For different lignin content, the fall cone test was performed on five samples with different moisture contents, including 0%, which was selected for comparison of treated and untreated soil.

3.3 California Bearing Ratio Test

This is a penetration test developed by the California division of highways, as a method for evaluating the stability of soil subgrade and other flexible pavement materials. The test results have been correlated with flexible pavement thickness requirement for highways and air fields. The CBR test may be conducted in the laboratory on a prepared specimen in a mould or in-situ in the field. The ratio of the force per unit area required to penetrate a soil mass with standard penetration plunger at a uniform rate of 1.25 mm/min, to the corresponding penetration load of the standard material or crushed stone is called CBR.

Before initiating the test, calibration of the CBR proving ring was done. 4.5-5 kg of soil was taken and mixed it well with the required amount of water (OMC) or moisture content in the field available. The separator was placed on the bottom of the mould on the base plate and a coarse filter sheet was placed on the spacer disc. Wet soil was compressed by light or heavy compaction in the mould. The collar was removed and the extra soil was removed, the clamps were removed and the compressed soil mould was raised. The filter paper was placed on the base plate, the mould compacted, the bottom turned and placed on the plate. Base and clamps were fixed. The weight of 2.5 to 5 kg was placed on the top of the mould. The mould was installed on the base plate and the same pressure weights were applied to the test sample. A complete setup was placed under the loading machine. Penetration of the piston was applied to the soil surface by applying a 4 kg load. The dial gauge of the calibration ring and the penetration dial gauge were set to 0. The load was applied at a penetration rate of 1.25 mm/min. The CBR value can be obtained as follows

$$\text{CBR}(\%) = \frac{\text{Test load} \times 100\%}{\text{Penetration load (standard material)}} \quad (2)$$

The load value and the corresponding intervention value were stored. On the x-axis a graph was drawn against the penetration depth (mm) and on the y-axis against the load (kN). Finally, the CBR was calculated from the equation (2).

4. Result and Discussion

4.1 Unconfined Compressive Strength Test Result

Influence of sodium lignosulfonate in increasing the performance of soil was investigated using a series of unconfined compressive strength test. The samples were prepared at optimum moisture content (i.e., 19.5%) with 0%, 1%, 2%, 3%, 4%, and 6% of lignin content and were cured for 14 days.

From test results, it is observe that the value of unconfined compressive strength of the silty soil was increasing up to 3% addition of lignosulfonate but as the content of lignin was increased beyond this value there was drastic downfall in unconfined compressive strength of soil (Fig. 2). It can be seen that the unconfined compressive strength of soil is found to be 143.09 kPa, and at 1% addition of lignin with 14 days curing, it increases up to 8.04% (154.59 kPa).With increase in percent of lignin additive up to 3% the strength increases up to 59.32% (227.99 kPa) beyond this, the unconfined compressive strength decreases to 197.6 and 105.85 kPa at lignin content of 4 and 6% respectively. Therefore, the optimum percent of lignin content giving maximum performance is found to be 3% (weight/weight).

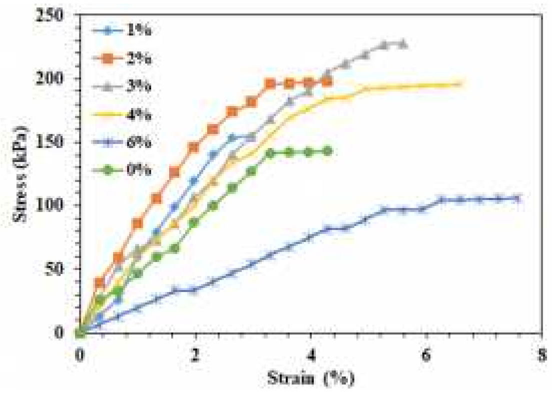

Fig. 2 Stress-strain behavior for different lignin content

Failure of sample under axial load during unconfined compressive strength test is shown in Fig. 3. It is observed that the failure in the samples made from 0%, 1%, 2%, 3% lignin content was sudden and on further addition of additive, failure pattern shifted to progressive failure. It can be seen that the heavy bulging of sample was occurring. From Fig. 3(a-c), it is clearly observed that the cracks are developed in 1%, 2%, and 3% additive samples while at lignin content of 4%, sample undergo progressive failure and no clear crack is observed (Fig. 3(d)).

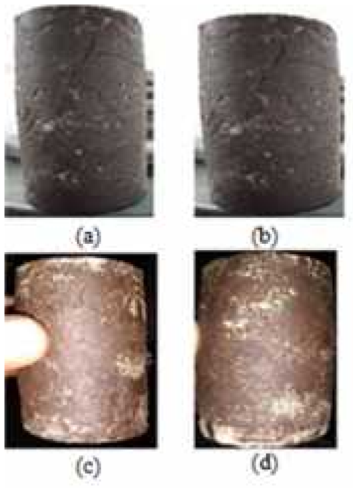

Fig. 3 (a) failure at 1% lignin (b) failure at 2% lignin (c) failure at 3% lignin (d) failure at 4% lignin

Further unconfined compressive strength test were carried out to investigate the influence of curing period on sample with optimum moisture content and optimum lignin content. Fig. 4 presented the unconfined compressive strength variation for curing period of 7, 14, 28 days. It can be seen that the strength is increases with increase in curing period. This is because the cementing property of lignin increases with increase in curing time leading to increase the unconfined compressive strength of treated soil. Similar behavior has been reported by Zhang et al. [5]. The percent increase in unconfined compressive strength is found to nearly 88% with increase in curing time from 7 to 28 days. Hence, it can be concluded that the curing time is most critical parameter for increasing the performance of treated soil mass.

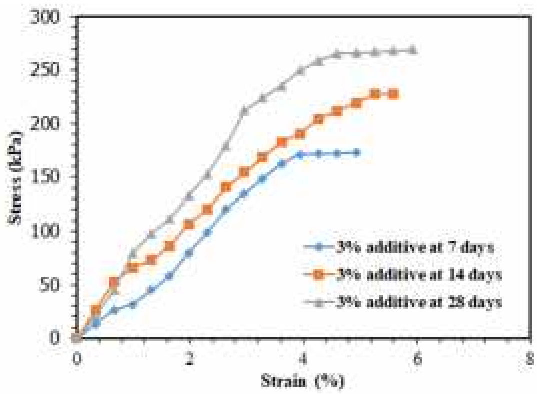

Fig. 4 Stress-strain behavior for different curing time

4.2 Fall Cone Test Result

The undrained shear strength obtained from fall cone tests are presented in Figs. 5 and 6. From Fig. 5, it has been seen that the undrained shear strength (S_u) of soil mass at 0% lignin content was 8.33 kPa, whereas, it increased to 12.3 kPa at 3% lignin content. Further, the undrained shear strength decreases with increase in the lignin content. The effect of water content on unconfined compressive strength with optimum content of lignin (3%) using fall cone tests is presented in Fig. 6. It can be seen that the undrained shear strength increases initially with increase in water content up to 19.5%, beyond which it decreases. Hence, it can be said the optimum water content giving maximum performance at lignin content of 3% can be considered 19.5%.

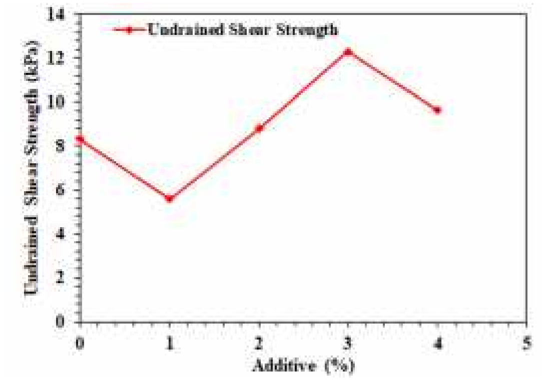

Fig. 5 Undrained shear strength using fall cone (28% water content) 14 days curing

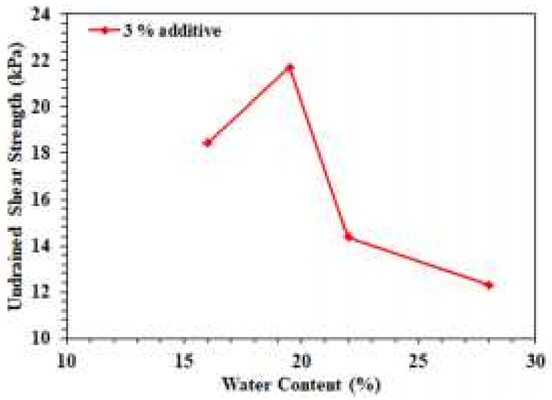

Fig. 6 Undrained shear strength using fall cone with 14 days curing at optimum lignin content

4.3 California Bearing Ratio Test Result

Unsoaked CBR tests were also conducted for silty soil with optimum percentage of sodium lignosulfonate (3%) with different curing time 7 days, 14 days and 28 days. From Fig. 7, it can be seen that with increase in curing period the load carrying capacity increases. It is in general agreement with the results obtained from undrained shear test.

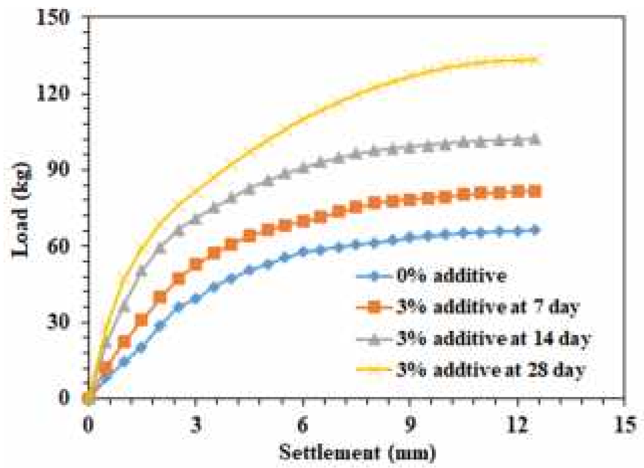

Fig. 7 Load-settlement behavior from unsoaked CBR at 3% additive of lignin with different curing time

5. Conclusion

In this study, silty soil was stabilized with sodium lignosulfonate and its performance is evaluated using a series of laboratory experiments. The conclusions obtained from the results are summarized as follows.

1. The increase in curing time and additive content generally facilitates higher undrained shear strength (q_u), CBR, and whereas this property decrease slightly when lignin content exceeds 3%.
2. The optimum percentage of lignin for silty soil in this study is found to be 3%. Under the same curing time and degree of compaction, the 3% lignin-stabilized soil exhibits superior performances relative to the untreated soil.
3. Inclusion of lignin into silty soil results in lignin-based cementing materials that create bonding and fill the pores between detached soil particles. As a consequence, a stronger soil structure formed thereby increases the undrained shear strength (S_u) of soil.
4. The optimum combination is found out to be soil plus 3% lignin for unsoaked CBR. Value of CBR is found to be increased by 30.68%, 84.1%, and 109.8% for 3% lignin with 7 day, 14 day and 28 day curing respectively.

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