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Effect Of Lignosulfonate On Strength And Deformation Behavior of Swelling Soil

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Abstract. In the present study, the efficacy of using Ca-lignosulfonate in stabilizing the swelling soil is evaluated. Artificial swelling soil was prepared by mixing bentonite and fly ash in a ratio of 1:4 (by weight). Different dosages of lignosulfonate (LS) were added to the soil to arrive at the optimum dosage. The influence of placement condition on the untreated and treated soil was assessed by evaluating the engineering properties of the soil specimen compacted at 2% wet and 2% dry side of optimum with a standard Proctor compaction energy. The plasticity, swelling, compressibility, and stress-strain responses of swelling soil at a different dosage of LS were examined. The strength gain during the curing period was also determined. From the test results, LS was found to reduce the plasticity, swelling, and compressibility of the swelling soil but with a considerable increase in the unconfined compressive strength.

Keywords: Expansive soil; lignosulfonate; swelling; consolidation; unconfined compressive strength.

1 Introduction

In arid and semi-arid regions, the expansive soil undergoes swelling and shrinkage due to adverse climatic conditions. The volumetric deformation of structures over these soils can damage buildings, pipes, roads, and other structures. Expansive soil mainly consists of reactive montmorillonite minerals have open sites for the attraction of positive charge is neutralized by the absorption of mono- or divalent cations. For achieving the desirable geotechnical properties, stabilization is the economical and long-lasting method. Traditional stabilizers have been proved to be effective but may pose danger to the environment (like, increase in soil pH, brittle failure, contaminated groundwater) possibly due to the formation of ettringite and thaumasite [1]. This made researchers and field engineers focus on environment-friendly stabilizers.

The use of non-traditional stabilizers is becoming popular because of the non-toxic and environmentally friendly nature like lignosulfonate, enzymes, polymers, tree resins . Lignosulfonate (LS) is produced as the by-product in the pulp industry and therefore is an economical and readily available polymer [2]. Lignosulfonate has been proven beneficial for expansive soils [3],[4]. The optimum dosage of lignosulfonate may need to be decided based on tests like swell, permeability, consolidation, unconfined compressive strength, and CBR tests. [5] performed wetting-drying cycles on highly plastic clays treated with lignosulfonate for direct shear and unconsolidated undrained triaxial tests. It was reported that with the increase in wet-dry cycles, shear strength parameters (cohesion and angle of internal friction) do not change significantly but at the end of the 4th cycles, the cohesion has increased by 30 kPa proving the efficiency of chemical in increasing strength. However, literatures including the effect of LS on UCS have not estabilished the details other than the optimum amount of chemical which is fixed based on basic geotechnical properties test s [6]. Hence, there is a need to establish a beneficial aspect of adding LS to the expansive soils. The objective of the present study is to investigate the efficacy of lignosulfonate for the stabilization of expansive soil. The engineering properties of expansive soil with different dosages of LS were evaluated. From the test results, the optimum dosage of the chemical needed for enhancing the strength and deformation of expansive soil was quantified.

2 Materials Used

The artificial swelling soil used in the present study was prepared by mixing 20% sodium bentonite and 80% fly-ash (by weight). The mix proportion was decided based on the swelling and permeability property of the mix ([6], [7]). The soil mix comprises more than 60% of particles that are less than 2 mm in diameter. The liquid limit (LL) and plasticity limit (PL) of the bentonite is 574% and 66%, respectively. The PI of bentonite indicates that the bentonite is a very highly plastic material and has high swelling potential. The fly-ash(type C) used in the present study was collected from Panki thermal power plant. . Table 1 provides a summary of the index and engineering properties of the soil tested following the ASTM standards.

3 Methodology

The artificial swelling is prepared after oven-drying of constituent soils at 105°C to constant mass and sieving through 1mm. .

Free-swell index test is performed according to IS:2720 (Part 40) 1977. The oven dried soil passing through 425 micron and chemical is mixed in 1:4 proportion. Test is performed for 0,1,2,3% chemical mix. Two cylinders are taken one is filled with kerosene and other with water(3 trials). Soil is added gradually in cylinder filled with water. The time given for each subsequent addition of 0.1gms is 5minutes.Relative change with respect to volume attained in kerosene is calculated to find the free swell index.

For tests to be performed according to placement conditions, calculated quantity of Ca-lignosulfonate was mixed with water to prepare the LS solution of the chosen dosage. The soil and the prepared LS solution were mixed thoroughly and compacted to the required density in a consolidation ring to obtain a sample size of 60 mm diameter and 20 mm thickness for conducting the swell-consolidation test. After compaction, the specimen along with the consolidation ring was wrapped in a plastic sheet and kept in constant-water content condition by cutting off the air-supply for 24 hours. After the moisture equilibrium period, water was allowed to flow through the soil under a seating pressure of 5 kPa [12]. Due to the intake of moisture, soil specimen tends to swell which was measured using the dial gauge. The measurements were taken until the values become constant.

Cylindrical soil samples of 38 mm in diameter and 76 mm in height were used for the unconfined compressive strength (UCS) test. The chemical dosages adopted for the UCS test are 0, 1, 2, 3% LS. The samples were sealed in a polythene sheet and cured under constant water content condition for 7, 14, 28 days. After curing, the specimen was sheared at 0.210 mm/min until failure [14].

Table 1. Summary of index and engineering properties of swelling soil

Property	ASTM code used for evaluation	Soil (20B80FA)
Liquid limit (%)	[8]	108
Plastic limit (%)	[9]	40
Shrinkage limit (%)	[10]	20
Maximum dry density (gm/cc)	[11]	1.2
Optimum moisture content (%)		29.22
Swell (%)	[12]	9.9% (OMC-2%); 2.8% (OMC+2%)
Compression index	[13]	0.473 (OMC-2%); 0.172 (OMC+2%)
Unconfined compressive strength (kPa)	[14]	416.8 (OMC-2%) 315.28 (OMC+2%)

4 Results And Discussion

4.1 Effect of lignosulfonate on plasticity

According to the cone-penetration test, the liquid limit is defined as the water content corresponding to the depth of penetration of 20 mm. Fig. 1 shows the variation of the liquid limit of soil at various dosages of LS chemical. A significant reduction in the liquid limit was noticed up to the dosage of 3% LS but beyond which negligible change in liquid limit can be observed. The plastic limit of soil at different dosages of the chemical was found to be almost constant, hence the plasticity index decrease with the increase in the chemical dosage. Fig. 2 shows the plasticity chart with the position of the treated soils. It can be noticed that soil classification has changed from CH (with LL =108%, PI = 68%) to MH and ML depending on the dosage of chemicals, which shows the significance of LS in reducing the plasticity nature of the soil.

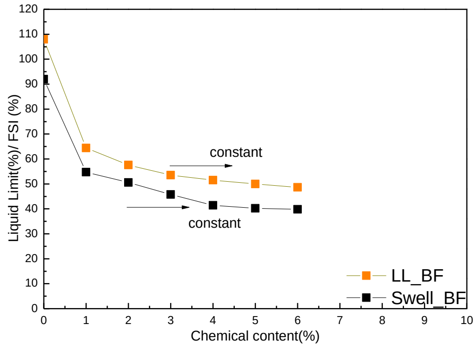


Fig. 1. Variation of liquid limit and FSI of soil with LS content

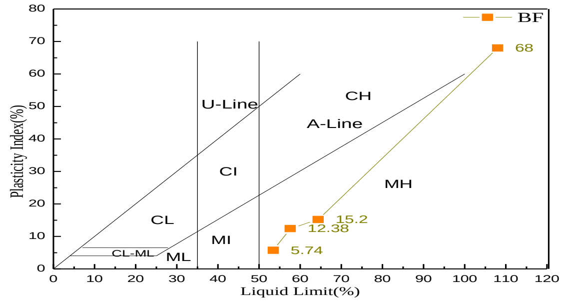
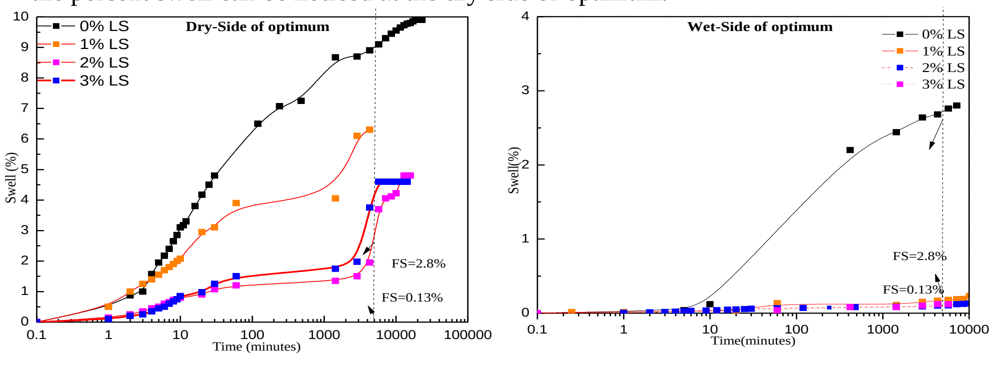


Fig. 2. Soil classification with variation in LS content

4.2 Effect of lignosulfonate on swelling property

The free swell index (FSI) of the soil is the index when soil is allowed to freely swell with water relative to the original volume occupied by the soil in non-polar liquid like kerosene. The variation of the FSI of soil with different dosages of LS is also shown in Fig. 1. It can be noticed that FSI follows the same trend as the liquid limit, which implies, swelling nature of the expansive soil can be controlled with the addition of LS but the extent of reduction in swelling depends on the dosage of chemicals. The influence of placement condition (wet/dry side of optimum) and the surcharge loading on the swelling characteristics of soils can be obtained from the 1D swell-consolidation test and the results are shown in Fig. 3. It can be noticed that the percent swell is relatively higher for the dry side of the optimum (OMC-2%) than the wet side of optimum (OMC+2%), irrespective of the chemical dosage. The swelling is relatively less in the wet side of optimum could be due to the presence of dispersed structure as compared to the dry side of optimum where the flocculated structure is dominant. Moreover, with the increase in the chemical dosage, the percent swell has decreased significantly, irrespective of the placement condition. At 2% of the chemical, a significant reduction in the percent swell can be noticed at the dry side of optimum.

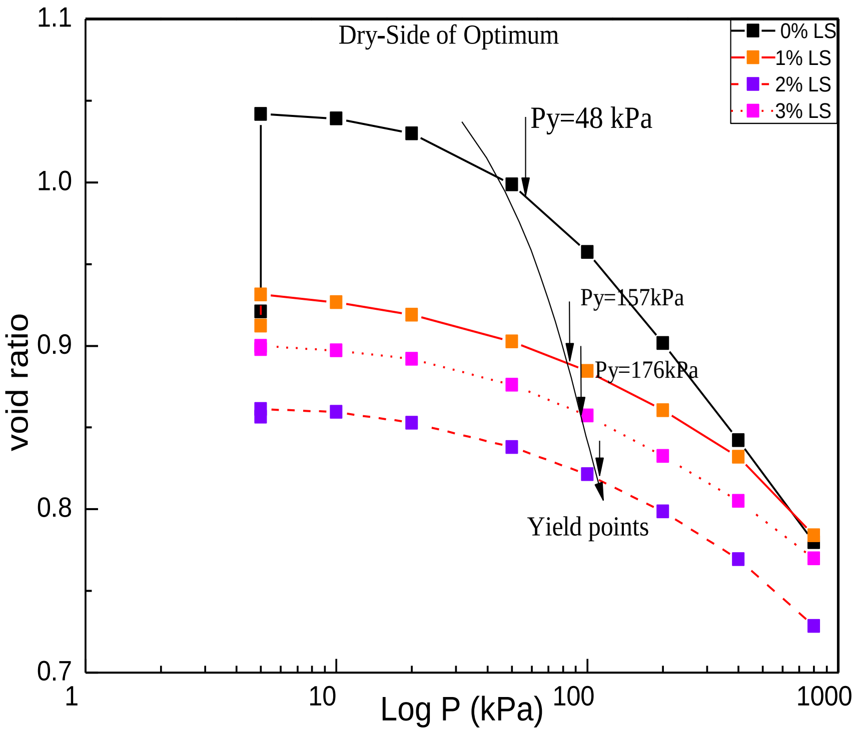


(a) (b)

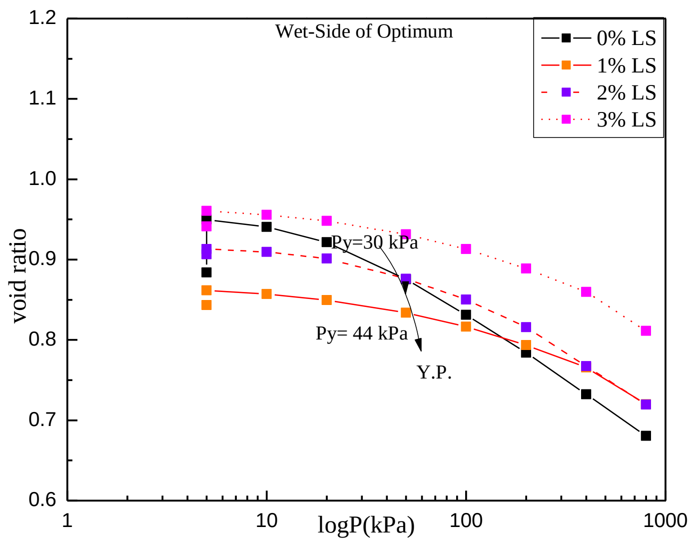
Fig. 3 Variation of percentage swell of untreated and treated soils compacted at (a) dry and (b) wet side of optimum with time

4.3 Effect of lignosulfonate on consolidation characteristics

Fig. 4 shows the consolidation characteristics of untreated and treated soils. It also shows the swelling pressure of the soil. The swell pressure (Ps) is the pressure required to bring the void ratio of the soil to the initial state of compaction. As expected, the swelling pressure of untreated soil is higher at the dry side of optimum (1.61 kPa) when compared to the wet side of optimum (0.31 kPa). With the addition of LS, the swell pressure of soil has been drastically reduced. The maximum reduction in the swell pressure at the dry side of optimum (91.92%) was noticed for 3% of LS while at the wet side of optimum maximum reduction was noticed at 3% of LS when compared to untreated soil. The compression index (Cc), which is the slope of the virgin compression curve was found to decrease with the increase in the chemical dosage. Table 2 provides a summary of the swell pressure and the compression index of the untreated and treated soil at various placement conditions. The yield stress or the pre-consolidation pressure can be determined from the 1D consolidation test. It can be noticed that preconsolidation pressure increases with the increase in the chemical dosage. The maximum increase in the pre-consolidation pressure at the wet and dry side of optimum was found to be 25% and 72.72% at LS percentage of 3%.



(a)



(b)

Fig. 4. Consolidation characteristics of untreated and treated soil at (a) dry and (b) wet side of optimum

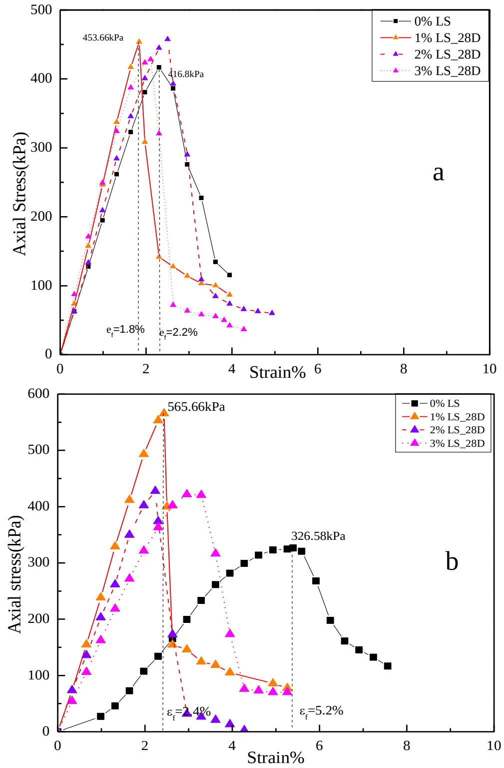
Table 2. Swell-Consolidation properties of soil

Chemical % in soil	Dry side of optimum		Wet side of optimum	
	Ps (kPa)	Cc	Ps (kPa)	Cc
0	161	0.473	30	0.172
1	30	0.127	14	0.084
2	13	0.116	10	0.16
3	10	0.104	10	0.129

4.4 Effect of lignosulfonate on strength characteristics of soil

Fig. 5(a.) and 5(b.) shows the variation of axial stress with axial strain for soil samples treated with different dosages of LS under unconfined condition. The results are shown for samples cured for 28 days. The UCS of treated soil was found to be relatively higher than the untreated soil but the enhancement in the strength depends on the dosage of the chemical. The amount of chemical which has given the least increase in strength is termed as the critical amount of chemical, while the amount of chemical which satisfies the minimum criteria of is termed as the optimum amount of chemical. At the LS dosage of 1%, the maximum increase in the UCS of soil compacted at the dry and thewet side of optimum was found to be 50 kPa and 200 kPa respectively. Similarly at a 2% LS dosage increase is 40kPa at dry side of optimum and 100kPa at wet side of optimum. Interestingly, at a 3% LS dosage, a minimum increase in the UCS was observed at both dry and wet sides of optimum. Therefore, the critical and optimum amount of LS chemical was found to be 3% and 2% respectively. The toughness is measured as the area under the stress-strain curve. The toughness of soil was found to increase significantly at the wet side of optimum than the dry side of optimum but the decrease in the toughness depends on the dosage of the chemical. The wet side of optimum has 43.86% more toughness compared to the dry side of optimum after 28days curing period for 1%LS. While with subsequent addition, it is found to increase for dry side of optimum by 400kPa upto 3%LS and 200kPa at wet-side of optimum.

The effect of the curing period on the stress-strain characteristics of the soil was evaluated by conducting the UCS test on soil samples mixed with a critical dosage of chemical (3% LS) at the end of 7, 14, and 28 days curing period. Fig. 5(c.) and 5(d.) shows the stress-strain curve of soil samples compacted at the dry and wet side of optimum. After addition of LS, toughness decreases from 937.28kPa to 730.69kPa for 1%LS as the peak is achieved in smaller strain values at dry side of optimum while decrease is 300kPa at wet side of optimum. for 3%LS, the toughness increases for dry side of optimum by 200kPa while for wet side of optimum decreases by 50%. For each of the samples, three identical specimens were tested. The unconfined compressive strength of soil obtained from the three trials was found to be almost the same. The plots for stress-strain used here belongs to the values of lowest peak strength.



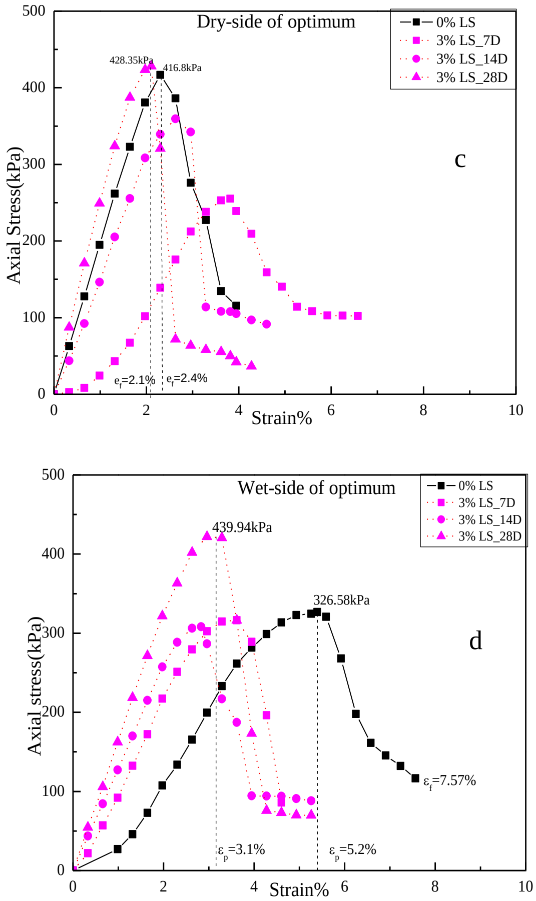


Fig. 5. Stress versus strain curve for soil specimen compacted at (a) dry-side and (b) wet-side of optimum with varying amount of lignosulfonate for 28 days curing (c) dry-side and (d) wet-side of optimum with a critical amount of chemical for different curing periods

4.5 Optimum dosage of lignosulfonate

Fig. 6 shows the optimum dosage of lignosulfonate for effective stabilization of expansive soil in terms of various engineering properties. The permissible values of each of the engineering properties are also shown in Figure. The optimum dosage of LS in terms of percentage swell is found to be 2% (Fig. 6a). The percentage swell is found to be constant beyond 2% LS for both dry and wet side of optimums. Interestingly, with the addition of LS to the swelling soil, the compression index of treated soil was found to be less than the permissible value, irrespective of the dosage of chemical and placement conditions (Fig. 6b). A minimum dosage of 1% LS is sufficient for soil stabilization considering the compression index. For 2% and 3%LS, the decrease in compression index is approaching constant close to 0.15 at dry and wet side of optimum. The coefficient of permeability of soil was found to increase with the increase in chemical amount, irrespective of the placement condition (Fig. 6c). A significant increase in the permeability of the order of one was observed when the dosage of chemical increases from zero to 3%. As the UCS (fig. 6d) of the treated soil is significantly higher (> 50kPa) than the untreated soil, the optimum dosage of chemical in terms of UCS is 1%LS. It can be observed for 1%LS in the wet side of the optimum significant increase is 100kPa, while in dry-side of optimum the increase is 30kPa, and approx. 50kPa increase for 2% and 3%LS at dry side of optimum.

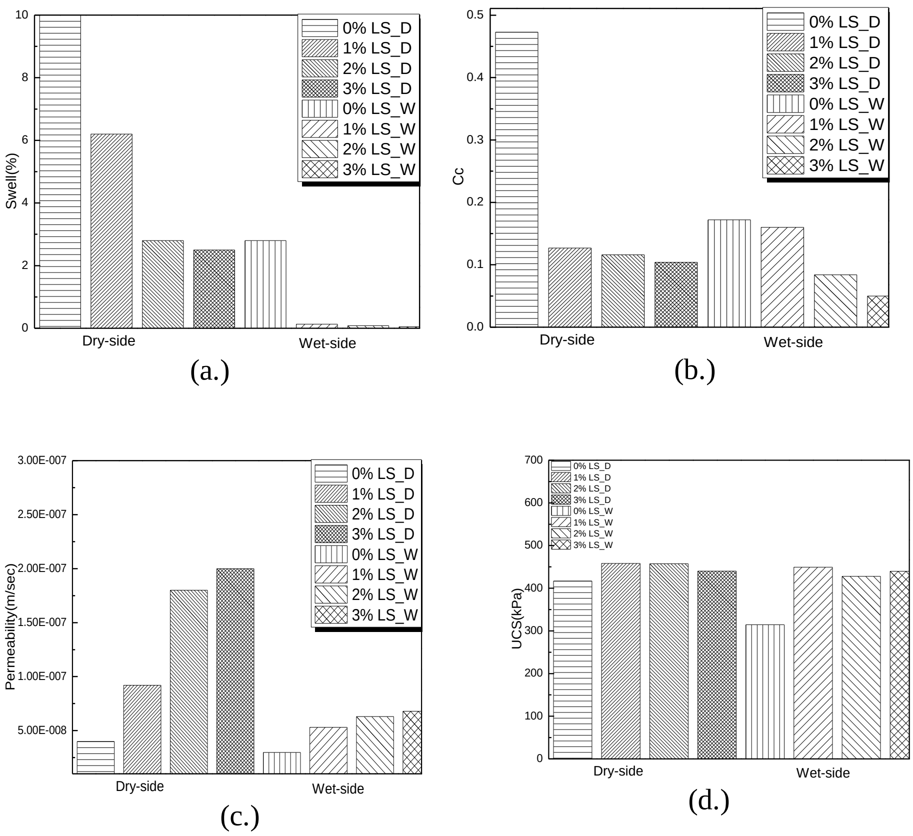


Fig. 6. Optimum dosage of lignosulfonate considering (a) percent swell, (b) compression in dex, (c) permeability, and (d) UCS

5 Conclusions

The efficacy of using lignosulfonate in stabilizing the swelling soil was assessed in this study. The index and the engineering properties of untreated and treated soils were evaluated. Based on the experimental results, following conclusions are made:

1. Treatment of the high plasticity clay with the LS, results in an increase in the optimum water content and a decrease in maximum dry unit weight with change in soil type from highly plastic(CH) to medium(MI) and low plastic (ML) silt.
2. Free-swell index decreased from 90%(high swelling) to 40% (medium-low swelling) at 2% and 3%LS. While the swell% under compaction state, is found to reduce from 161kPa to 31kPa at dry side of optimum and 30kPa to 10 kPa at wet side of optimum for 1%LS and 10kPa for 2% and 3%LS addition.
3. From the unconfined compressive test, it can be observed that with increasing the LS-percentage from 0 to 3, the UCS increase from 400 kPa to 460 kPa (i.e., the relative maximum increment was up to 15%) at dry-side of optimum and 328 to 565kPa (72% increase) at wet-side of optimum. The major contribution to this increase in UCS is attributed to the formation of coat around the particles which prevent water to come in contact with the smectite group in the soil.
4. It can be concluded that 2%LS addition to soil changes the soil type from CH to MI decreasing swell-index from 90- 40% bringing the soil type to silty. The Swell% has been decreased from 9.9% to 4% more than 50% at dry side of optimum and negligible swelling at wet side of optimum. The swell% is observed to follow a constant trend after increase beyond 2%LS. The compression index for 2%LS addition is 50% from 0.473 to 0.127 at dry-side of optimum and wet side of optimum has Cc value of 0.15. UCS has found to be 50kPa more than untreated at dry-side of optimum and 100kPa after 28days of curing. Therefore addition of 2% lignosulfonate to the soil is found to be optimum dosage according to swell%, permeability, compression index and strength enhancement.

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