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Stabilization of Subgrade Pavement Layer Using Silica Fume and Nano Silica

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ABSTRACT—Many investigations have been carried out on clay subgrade soil; using several types of stabilizers. Due to the increase in traffic loads and the importance of subgrade layer in strengthen the pavement section to prevent the earlier damage. In this study the first step (based on the designed experimental program) samples were prepared with and without any additives; the used additives were lime (L), silica fume (SF), and nanosilica (NS). The tried percentages of lime were 2, 4, 6 and 8% and 5, 10 and 15% for SF, while 1, 2 and 3% used for NS. The second step was to examine the physical and mechanical properties of the prepared mixes using modified proctor test, Atterberg limits test, free swelling (FS%) test, unconfined compressive strength (UCS) and California Bearing Ratio (CBR) tests. Finally, direct shear (DS) test was carried out on the optimum mixes from the second step. All mixes were tested after two curing periods 7 and 28 days using UCS and FS%. The results indicated that the optimum moisture content (OMC) increased, while the maximum dry density (MDD) dramatically decreased for all used additives and plasticity index (P.I) decreased. The FS% decreased, and the maximum reduction in FS% was occurred at the two combinations (8% L + 15% SF) and (8%L+3%NS). The UCS increased by adding both SF and NS activated by lime to the test soil , and the optimum percentages of the two combinations were occurred at 6%L+10%SF and 6%L+3%NS for traditional and nanomaterials additives respectively. So, control samples and the two optimum combinations have been prepared for CBR and DS tests. The DS test was carried out at dry and submerged conditions, while CBR test was carried out at soaked condition. The results indicated that the maximum value of CBR occurred at 8% L + 10% SF, while DS results indicated that adding 6L+10SF and 6L+3NS, the soil parameters (cohesion and internal friction angle) have been improved.

Index Terms— Clayey (soil), Lime (L), Nano silica (NS), Silica fume (SF), Subgrade, Strength, Swelling.

1 INTRODUCTION AND BACKGROUND

The improvement of soil can be classified into several categories, modification or stabilization or both. The modification can be conducted by compaction or replacement of the original soil or mixing soil with another. While stabilization is the treatment of soils to enable their strength and durability to be improved such that they become totally suitable for construction. Stabilization of pavement subgrade soils has traditionally relied on treatment with lime, cement, or waste materials such as fly ash, slags, silica fume, etc. Many researchers have been looking for waste and economical materials to employee in soil stabilization. Cement and lime are the familiar materials used for stabilizing soils. These materials have rapidly increased in price especially cement due to the sharp increase in energy cost. Since silica fume (SF) is considered one of the cheaper materials in Egypt, therefore, it can be used in several branches of civil engineering, concrete enhancement and soil stabilization.

SF also referred as micro-silica, is a product resulting in reduction of high purity quartz with coal in an electric arc furnace in the manufacture of silicon or Ferro-silicon alloy. SF rises as an oxidized vapor, it is cooled, condensed and is collected, it is fine grey in color powder sometime similar to Portland cement or fly ashes. Condensed SF is essentially silicon-dioxide (more than 90%) in non-crystalline form. It is very fine material with a particle size less than 0.1 micron and specific surface area of about 20,000m²/kg. It is a by-product material with huge quantities in most countries. Many researchers have been used traditional stabilized materials in stabilization of weak soils such as lime, cement, fly ash, rice hush as, etc. Recently, nanotechnology has been widely used in most branches of science; one of these concerns appears in creation of a varied collection of nanomaterials (NM), which encompass nanoparticles (NP) along with nano objects. NM is known to be 100 nm lower in terms of dimensions. An example of this phenomenon can be observed through carbon nanotubes. The most common types of nanomaterials in Egypt are Nanoclay, nanosilica and nanocarbon. Also, some researchers investigated the effect of using nanomaterials in soil stabilization and enhancement of durability and strengthen of concrete mixtures. Using of nanomaterials relied on its few amount of additives compared with high price of cost. This paper reviews the application of using traditional and nanomaterials in soil stabilization. The selected traditional materials were L and SF, while the selected nanomaterial was NS. Also, the combination of SF and L has been

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studied; in addition, using the combination of NS and L has been investigated.

The soil improvement technique is basically used for improving the geotechnical properties of soil such as sub grade characteristics, shear strength, swelling and shrinkage characteristics, and bearing capacity. The engineering properties have been changed by adding stabilizers depending on the stabilizer type, soil type, stabilizer amount and curing conditions. This study reviews the effect of high percentages of SF and few percentages of NS activated by lime at the same content of lime. Sherwood (1993), Roger et al (1993), EuroSoilStab (2002) and Hicks (2002) studied the effect of using L on the change of soil properties which have clay minerals. Also, Negi et al. (2013) studied the change of engineering properties of clay soil using SF, the used percentages were 5%, 10%, 15%, 20% and 25% by dry weight of soil. From that investigation it can be concluded that the SF as a potential to improve the characteristics of black cotton soil. The properties of expansive soil as volumetric change due to seasonal moisture variation in expansive soil have been reported by Haussmann (1990). Choudhary et al (2011) showed the improvement in CBR values of expansive soil sub grade using geo synthetics. Many researchers evaluate using fly as in soil stabilization such as, Cokca (2001), White (2005), Bhuvaneshwari (2005), Edil et al (2006), Chauhan et al (2008), Brooks (2009), and Bose (2012) , they showed the effect of fly ash on the geotechnical properties of expansive soil. Similarly many researchers , Al-Azzawi et al.(2012), Kalkan et al. (2004),Qamruddin et al.(2013), Chaya Gupta C., and Sharma R.K., (2014) investigated the effectiveness of SF on the geotechnical properties such as swelling characteristics ,sub grade characteristics, unconfined compressive strength (UCS) of soil. Abass (2012), Karimi at al. (2011) and Abd.El- Aziz M.et al (2004) noted that the combination of L and SF improved the engineering properties of clayey soils. Fattah Y. et al. (2013), Francis A. and Venantus A. (2013) noted that using rice hush ash in soil stabilization, the engineering properties of soil have been changed. Oltulu M. et al. (2011) and Qing Y. et al. (2005 investigated the effect of using NS on the engineering properties of concrete mixes. From the outcomes of the state of art, SF with and without L and NS with and without L have been used in soil stabilization.

2 MATERIALS AND METHODOLOGY

The soil used in this study was obtained from Belbies city – Sharkia – Egypt and SF was obtained from Sika – Egypt company- Egypt, while NS was obtained from Faculty of Science – Bani Suef University – Egypt, finally L was obtained from 10th of Ramadan city-sharkia-Egypt. The soil was classified into two gradations, soil (1) which passed sieve (40) was used in free swelling (FS%) and plasticity characteristics, while soil (2) which passed sieve (8) was used in UCS, California bearing ratio (CBR), compaction , and direct shear (DS) tests. The specific gravities for the materials used were 2.60, 2.30, 2.11 and 2.21 for soil, L, NS and SF respectively. Table (1) shows the physical properties of the test soil, while table (2) shows the chemical composition of soil, L, SF and NS. The particle size distribution test was carried out using the hydrometer for the two gradations of the test soil as shown in figures (1), (2).

Table (1) Physical Properties of the used soil.

Physical Properties	Test Result
Liquid Limit (L.L)	73.00
Plastic Limit (P.L)	28.42
Plasticity Index(P.I)	44.58
Maximum Dry Density (MDD)gm/cm3	2.025
Optimum Moisture Content (OMC) %	12.20
AASHTO classification	A-7-6

Table (2): Chemical Properties of tested soil, silica fume, nano silica and hydrated Lime.

Component	L	SF	NS	Soil
SiO_2	1.92	89.54	98.00	52.39
TiO_2	0.03	0.05	0.01	2.72
AL_2O_3	0.15	<0.01	0.02	12.40
Fe_2O_3	0.62	0.04	0.45	17.32
MnO	0.01	<0.01	0.09	0.27
K_2O	0.24	0.01	0.22	1.45
Na_2O	1.71	3.94	<0.01	0.47
MgO	0.31	<0.01	0.03	2.61
CaO	50.71	0.52	0.01	3.84
P_2O_5	<0.01	<0.01	0.01	0.13
SO_3	12.63	0.29	0.07	001

**Data supplied by Egyptian Mineral Resources Authority

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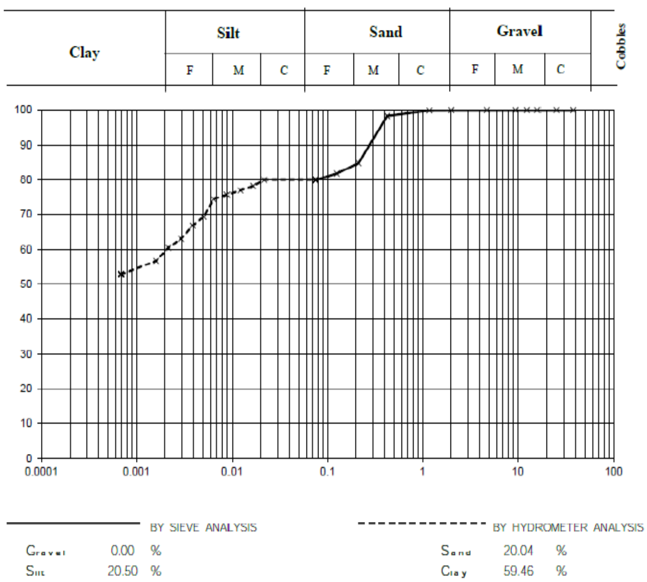

Figure (1): Grain size distribution of soil (1)

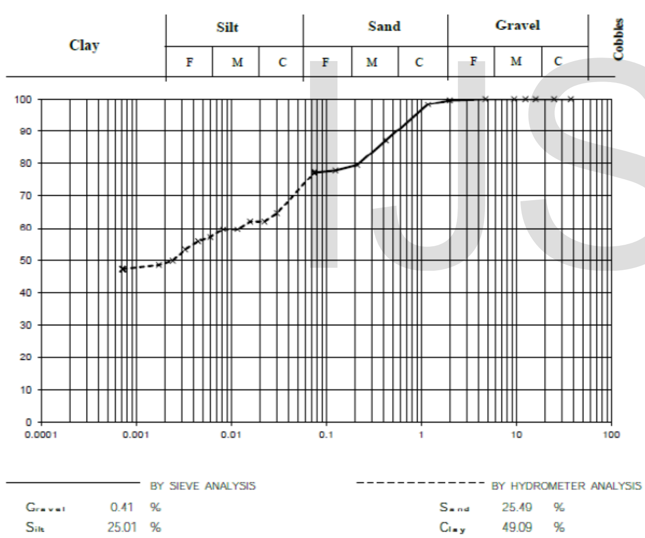

Figure (2): Grain size distribution of soil (2)

3 Results and Discussions

3. 1 Compaction Test

The modified proctor test was performed in laboratory in accordance to BS 1377: 1990.The relationship between SF activated by L and maximum dry density (MDD) is shown in figure (3), while MDD versus NS activated by L is shown in figure (4). Figure (5) shows the relationship between the optimum moisture content (OMC) and total additives (L+SF), while figure (6) shows the relationship between the OMC and total additives (L+NS). It was observed that generally, MDD decreases with an increase in L percentage, whether the activator was SF or NS. Also, the reduction percentage in MDD was greater in case of SF as the percentages of SF added were higher than the NS. This may be due to the unit weight of soil is higher than SF or NS. Hence, the percentage of SF replacement is higher than NS; therefore, the reduction in MDD is greater at the same L percentages. Like Ouf (2001) and Abd.El- Aziz et al (2004), the addition of L and combination of (L+SF) to the test soil decreased the MDD and increased the OMC. Unlike Majeed and Taha (2011), they noted that adding NM to the test soil increased the MDD and OMC.

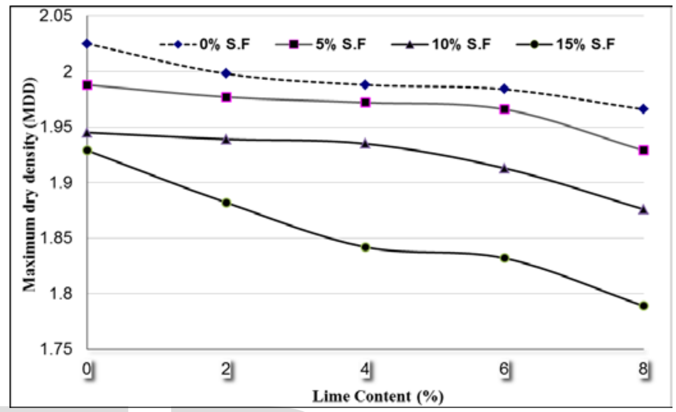

Figure (3): Effect of adding L&SF on the MDD of the test soil

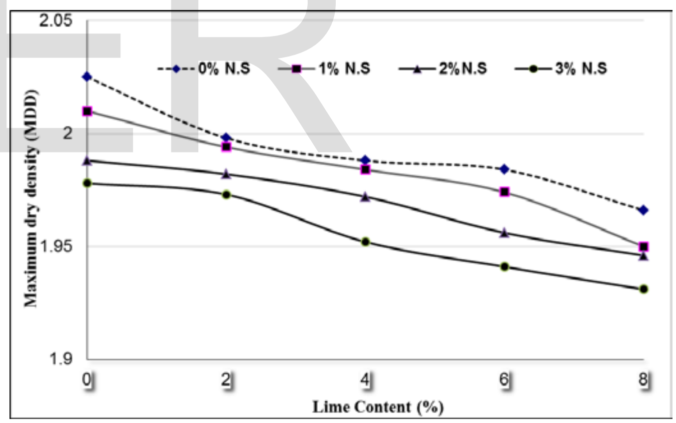

Figure (4) Effect of adding L&NS on the MDD of the test soil

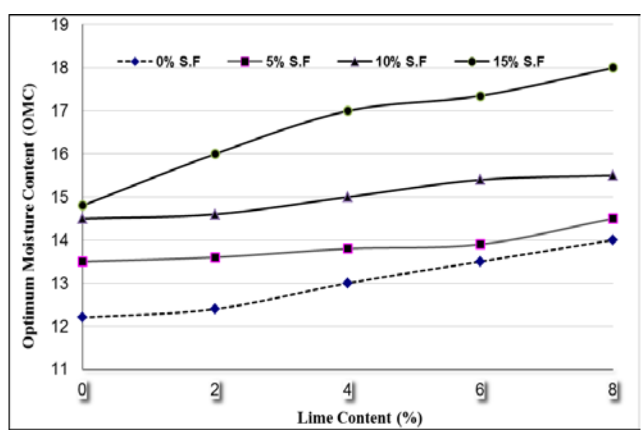

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Figure (5): Effect of adding L&SF on the OMC of the test soil

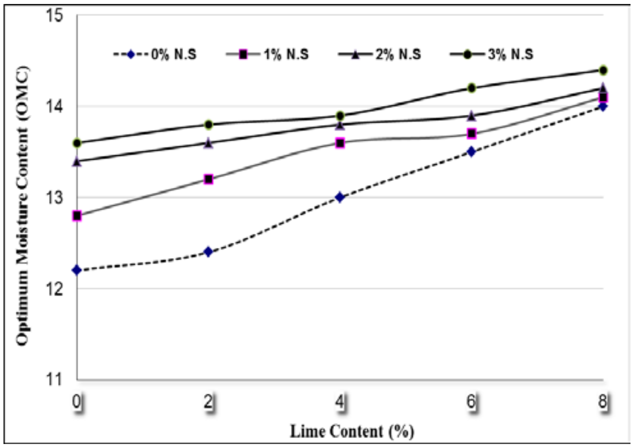

Figure (6) Effect of adding L&NS on the OMC of the test soil

3.2 PLASTICITY TESTS

The Atterberg limit test was carried out in accordance with ASTM D 4318 - Standard Test Method for Liquid Limit (L.L), Plastic Limit (P.L), and Plasticity Index (P.I) of Soils. Table (3) shows the results of L.L, P.L and P.I for samples treated with L only and combination of L and SF, while table (4) shows Atterberg limit test results for the combination of L and NS. Like Muntohar and Hantoro (2000) and Abd.El- Aziz et al (2004), the L.L slightly decreased , while P.L increased , thus a reduction in P.I was obtained , whether adding L , combination of L and SF or L and NS to the test soil. No lime fixation point was observed in all combinations of additives.

Table (3): Atterberg limits of using L and SF.

Liquid Limit (L.L)				
Lime %	0% SF	5% SF	10% SF	15% SF
0.0	73.00	59.60	62.00	63.80
2.00	62.00	58.60	59.56	62.00
4.00	61.44	57.00	62.00	56.80
6.00	54.32	56.40	54.00	60.00
8.00	54.00	56.00	59.00	56.50
Plastic Limit (P.L)				
0.0	28.42	33.04	30.82	32.17
2.00	33.27	30.50	31.90	32.34
4.00	35.85	28.67	32.00	43.14
6.00	36.83	41.74	39.01	41.80
8.00	42.70	37.32	44.00	44.77
Plasticity Index(P.I)				
0.0	44.58	26.56	31.18	31.63
2.00	28.73	28.10	27.66	29.66
4.00	25.59	28.33	30.00	13.66
6.00	17.49	14.66	14.99	18.20
8.00	11.30	18.69	15.00	11.73

Table (4): Atterberg limits of using L and NS.

Liquid Limit (L.L)				
Lime %	0% NS	1% NS	2% NS	3% NS
0.0	73	62.20	63.00	64.40
2.00	62	55.60	60	61.60
4.00	61.44	58.80	56.00	59
6.00	54.32	52.60	54.40	63.00
8.00	54	55.40	62.00	62.50
Plastic Limit (P.L)				
0.0	28.42	30.04	30.00	33.30
2.00	33.27	31.83	32.50	31.60
4.00	35.85	34.20	34.00	37
6.00	36.83	34.25	39.53	42.89
8.00	42.70	36.115	43.89	46.77
Plasticity Index(P.I)				
0.0	44.58	31.80	33	31.10
2.00	28.73	23.77	27.50	30
4.00	25.59	24.60	22	22
6.00	17.49	18.35	14.47	20.11

8.00	11.30	19.28	18.11	15.73

3.3 FREE SWELLING TESTS

The results of FS% test are shown in figures (7) and (8) for curing periods of 7 and 28 days. It was found that the FS% percentages dramatically decreased by adding L only to the test soil, and the reduction percentages exceeded after 28 days comparing with 7 days curing. Also, Ouf (2001) and Justin Milburn and Robert (2004) agreed with the obtained results. FS% also reduced when adding combination of L and SF, while no significant change in FS % was observed when adding SF only. Abd.El- Aziz et al (2004) found that the addition of SF with and without lime to the test soil decreased the FS%. FS % also decreased with an increase in NS only, the reduction percentages increased after 28 days curing. The addition of L and NS decreased the FS% after 7 and 28 days curing. The optimum percentages in reduction in FS were at combination of 8% L and 15% SF in traditional additives and 8% L and 3% NS for nano additives.

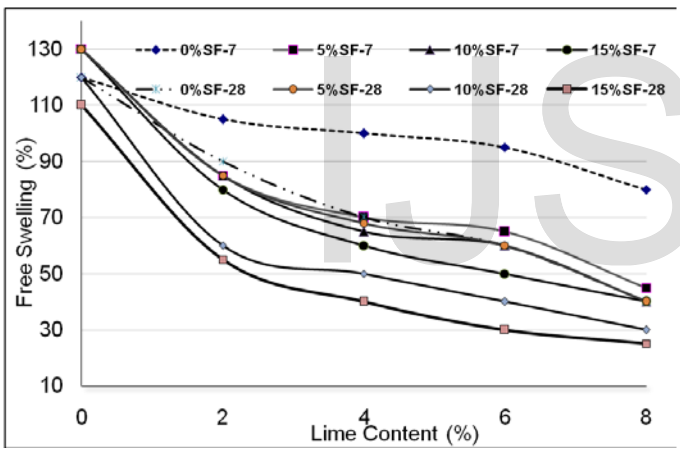

Figure (7) Effect of adding L&SF on FS of the test soil (7, 28) days

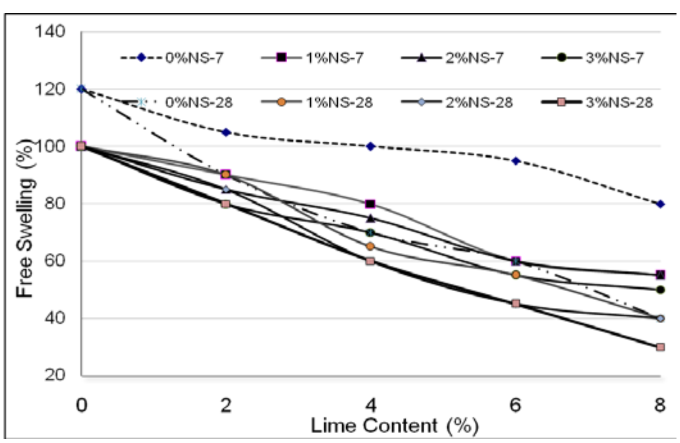

Figure (8) Effect of adding L&NS on FS of the test soil (7, 28) days

3.4 UNCONFINED COMPRESSIVE STRENGTH (UCS) TEST

UCS is the most common method of evaluating the strength of stabilized soil. It is the recommended test for the determination of the required amount of additives to be used in stabilization of soil, Singh and Singh (1991). Figures (9) and (10) show the effect of adding L and SF, L and NS on the UCS of the test soil respectively after 7 and 28 days curing. The results indicated that the UCS increased with an increase in L and SF to a maximum value at 6% L and 10% SF, then decreased. Almost similar relationship was observed when adding L and NS to the test soil and the maximum obtained UCS was at 8% L and 3% NS, see figure (10). The increase in the UCS is attributed to the formation of cementitous compounds between the calcium (Cao) present in lime and silica present in soil, SF and NS. This decrease in UCS after addition of 10% SF may be due to the excess of SF introduced to the soil and therefore forming weak bonds between the soil and the cementitious compounds formed. The obtained test results from adding L and SF are compatible with the findings of Yadu et al. (2011), Ouf (2001) and Abd.El- Aziz M.et al (2004) for L, while the test results of NM additives are agreed with Majeed and Taha (2011).

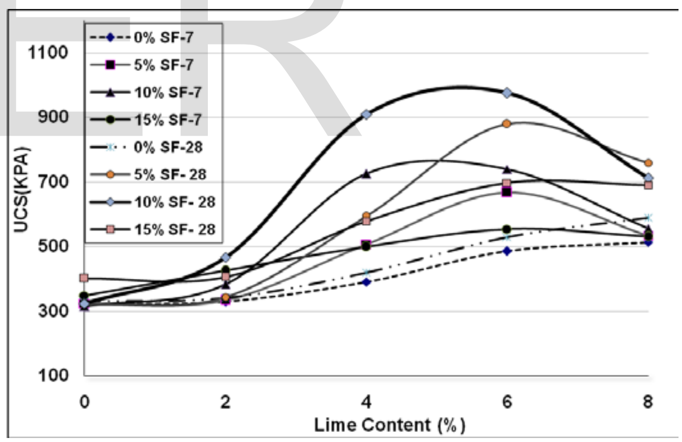

Figure (9) Effect of adding L&SF on UCS of the test soil (7, 28) days

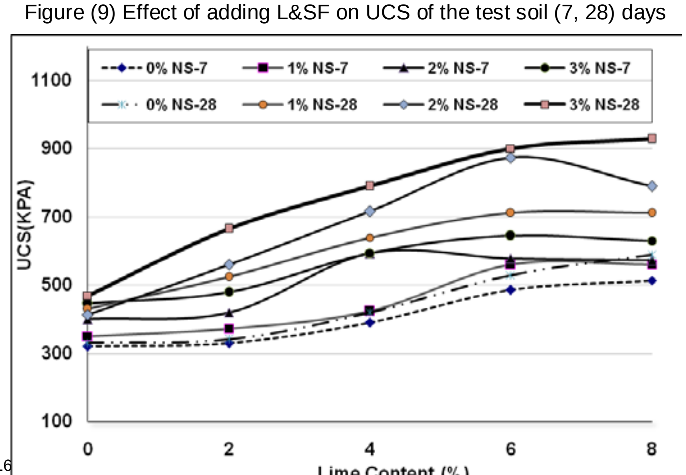

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Figure (10) Effect of adding L&NS on UCS of the test soil (7, 28) days

3.5 Effect of adding additives (L, SF and NS) on Young's modulus of the test soil

From the test results of UCS test, young's modulus of the tested soil can be calculated from the below equation as noted by Azadegan et al. (2013):

Young's Modulus = Maximum stress/ corresponding strain

Figures (11) and (12) show the effect of adding the two combinations (L + SF) and (L + NS) on the young's modulus of the test soil after 7 and 28 days curing. The calculated young's modulus is secant modulus (E_{secant}) at failure stage. From the obtained results, it was found that E_{secant} increased with an increase in addition of L and SF to a maximum value at 6% L and 10% SF. while, the maximum values of E_{secant} of NM was at 6 % L and 3% NS. It was observed that the increase in E_{secant} takes the same trend of UCS.

From the results of the UCS test , it can be concluded that the maximum strength values have been occurred at combination of 6% L and 10% SF for the traditional materials, while the nanomaterials additives gave the maximum values of UCS at 8% L and 3% NS. Also, it was found that the maximum value of young's modulus occurred at 6%L and 3% NS, so, the combination of 6%L and 3%NS was considered the optimum value of L and NS.

From the test results presented, CBR and DS tests have been carried out on the optimum combinations of used L, SF and NS.

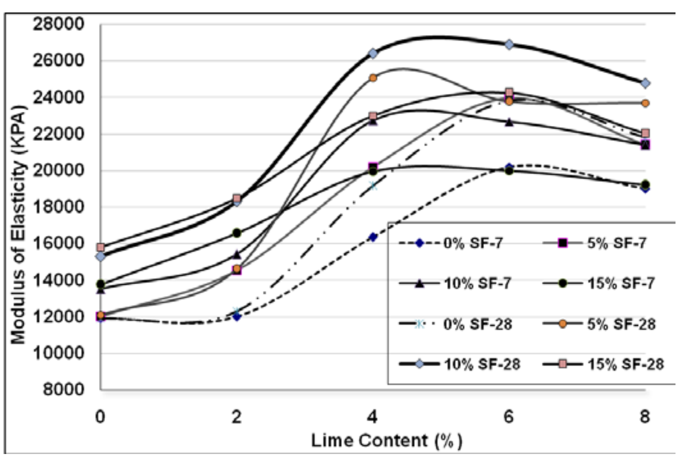

Figure (11) Effect of adding L&SF on E_{secant} of the test soil (7, 28) days

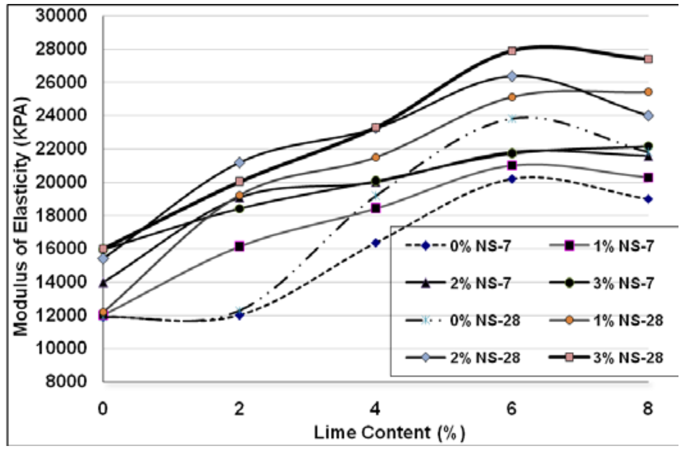

Figure (12) Effect of adding L&NS on E_{secant} of the test soil (7, 28) days

3.6 California bearing ratio (CBR) test

The California Bearing Ratio Test (CBR Test) is a penetration test developed by California State Highway Department (U.S.A.). The CBR test always carried out at un-soaked and soaked conditions. The case of soaked condition has been carried out in this study. Figure (13) shows the values of CBR for all additives L, SF and NS. It was concluded that adding additives has a significant changes in C.B.R values. Adding L only increased C.B.R value from 2.03% to 13.45% at 8%L, while adding SF only slightly increased CBR, adding 10% SF to the test soil increased CBR to 3.07%, while adding the combination of L and SF has a major effect in increase CBR. After adding 10% SF and 8% L, CBR increased to 16.41%. While, adding the combination of L and NS has a major effect in increase CBR, it was observed that adding 3% NS and 8% L increased CBR to 14.45%. While adding NS only slightly increase CBR, at 3% NS, the CBR was 4.49%. These test results are agreed with the outcomes of Chaya Gupta, and Sharma, (2014), Negi et al. (2013), Karimi at al. (2011) and Abd.El-Aziz et al (2004).

3.7 Direct shear (DS) test

The effect of adding additives (L, SF and NS) to the test soil on the soil parameters (cohesion (C) and internal friction angle (φ)) have been studied in this paper. The results concluded that a significant increase has been occurred after adding total additives (L, SF and NS). From the previous sections, it was investigated that the two optimum combination of total additives were (6%L+10%SF) and (6%L+3%NS), So, samples with the two optimum combinations have been prepared and tested by direct shear box test at dry and submerged conditions. The results of this test have been showed in figure (14). It was found that adding additives to the test soil enhanced the soil parameters at all conditions. Control sample gave values in dry case, and was failed when submerged in water. The values of C and φ of control sample were 30 Kpa and 36.97° in the dry case respectively. On the other hand, adding 6% L and 10% SF enhanced the soil parameters in two conditions, at dry case the values were 130 Kpa and 52° with improvement 333.33% and 40.65% respectively. Also, after adding 6% L and 3% NS the soil parameters values changed to 75 Kpa and 27.14° with improvement of 150% and 9.82% respectively. At submerged condition, both additives resist the water effect, but the combination of L and SF gave higher values compared with combination of L and NS as shown in figure (14).

Also, the effect of adding additives to the test soil on the shear strength (τ) of both cases dry and submerged was studied in this paper. The control sample was failed when submerged in water as noted above, where its shear strength value was 113.55 Kpa. These values at combination of L and SF were 272.07kpa and 131.90kpa for dry and submerged conditions respectively. In addition, these values of combination of L and NS were 155.14kpa and 106.27kpa for dry and submerged conditions respectively. Figure (15) showed the calculated values of shear strength of the control and treated samples. The value of shear strength can be determined by the following equation:

$$\tau = c + \sigma \tan \varphi$$

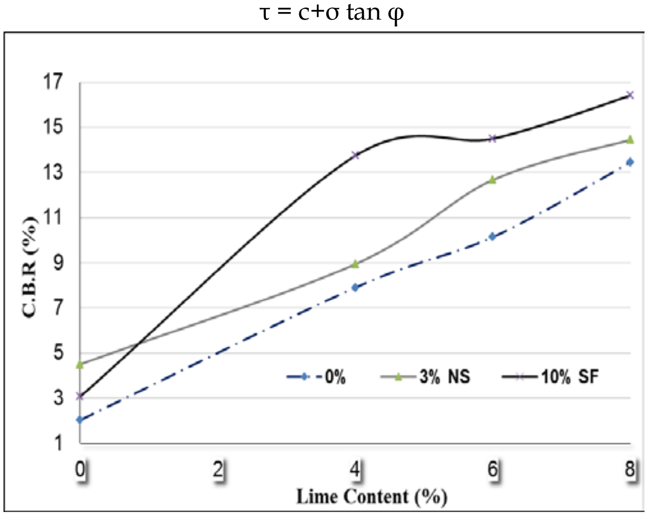

Figure (13) Effect of adding L, SF and NS on CBR of the test soil

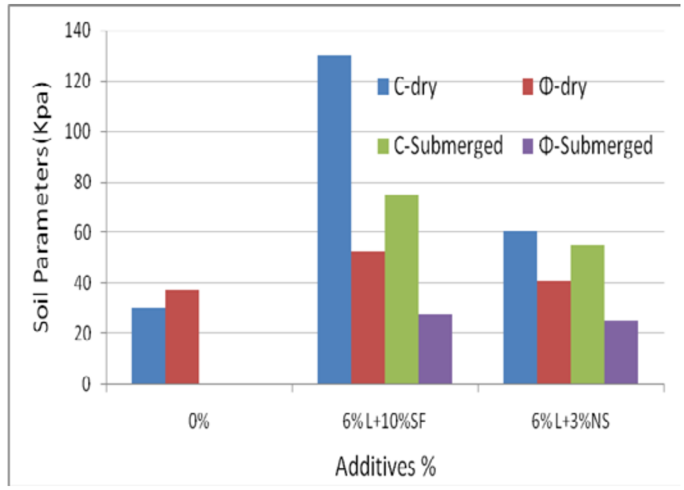

Figure (14) Effect of adding L& SF and NS on the soil parameters

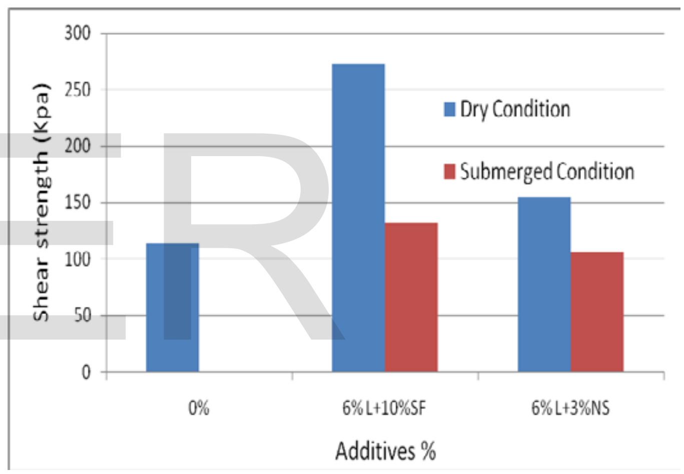

Figure (15) Effect of adding L& SF and NS on the soil shear strength

4 Conclusions

1- Adding L, SF and NS to the test soil decreased the MDD and increased the OMC.
2- Adding L, SF and NS to the test soil decreased the P.I.
3- The maximum reduction in FS% occurred at combination of 8%L, 10% SF and 8%L, 3%NS when using traditional and nano materials additives respectively.
4- Adding lime alone to the test soil increased the values of UCS and E_{secant} at 7 and 28 days curing.
5- Adding SF and NS individually to the test soil slightly increased the UCS and E_{secant} values for all curing periods.
6- Both combinations of (L and SF) and (L and NS) increased the UCS and E_{secant} at 7 and 28 day, while CBR also increased.

7- Both combinations of (L, SF) and (L, NS) increased soil parameters (C and φ) and shear strength (τ) at dry and submerged conditions.

8- The enhancement of soil parameters and shear strength of L and SF was higher than L and NS in both cases (dry and submerged).

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