Effect of Soil Stabilization on Subgrade Soil Using Cement, Lime and Fly Ash

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Abstract: Subgrade soil plays an important role in road structural design; therefore, poor subgrade soil may cause insufficient support for the pavement and may reduce its life. The poor properties subgrade soil should be replaced with a strong soil to improve the pavements properties and this cost a lot. Considering that, improving the poor subgrade soil properties by mixing it with different additive materials in site and stabilize it may be a better solution. This study was carried out to improve sample subgrade soil properties by stabilizing it using three different additive materials with different properties and quantities. For this purpose (ordinary portland cement), (limestone powder) and (fly ash) with percentages of (3%, 6% and 10%) were utilized. The modified mixture test results of (proctor test), Unconfined Compression Strength (UCS) and California Bearing Ratio (CBR test) showed that stabilization of the subgrade soil using different percentages of those additives improved the mechanical properties of the subgrade soil. Utilizing the above additive percentages, the CBR values improved from (5.25%) to (44.3%, 71%, 102.5%) while cement was utilized and to (8.75%, 9%, 10.2%) when fly ash was utilized and to (9.95%, 10.94%, 12.6%) with lime used.

Keywords: Soil Stabilization, Ordinary Portland Cement, Fly Ash, CBR, Limestone Powder, Water Content, Additives

1. Introduction

1.1 Background

Soil stabilization is the process of developing the durability and strength of the subgrade soil in which the physical properties of the soil are changed. It is important that the process of soil stabilization should be cost-efficient, eco-friendly, and gives optimum results. For all engineering projects, it is strongly recommended to increase the soil strength to extend the service life of the structures and reduce the thickness of the pavement layers (Rajoria & Kaur, 2014). After the stabilization of the soil, the Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR) values, and the soil shear strength will be greatly affected and can rise up to 4-6 times (Gupta, Saxena, Saxena, Salman, & Kumar, 2017).

The main methods for the stabilization of soils are:

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1. chemical soil stabilization and
2. mechanical soil stabilization

Both methods will increase the engineering properties of the soil with weak strength. The process of mechanical stabilization is a technique that the materials are proportioned to acquire the desired mixture of gradation and plasticity. The correct proportion of materials (aggregate and soil) can be fully compacted so that a mechanically stable pavement layer is formed (SP-89, 2010). There are other mechanical strategies which have been offered in which some properties for the poor soil is gained such as the substitution of the soil, controlling the water content, stabilization of soil using geosynthetics, controlling the compaction, pre-wetting, and treatment of the random soil (Malekzadeh & Bilsel, 2014; Thyagaraj, Rao, Sai Suresh, & Salini, 2012). Otherwise, chemical soil stabilizations include adding additives like lime, cement, fly ash, and adding some other additives to the soil (de Paiva, de Assis Lima, de Vasconcelos Xavier Ferreira, & de Melo Ferreira, 2016; Kumar & Janewoo, 2016; Thyagaraj et al., 2012; Zha, Liu, Du, & Cui, 2008).

Facts have proved that soil stabilization is economical because it can offer cheap materials for the construction of low-cost roads. There are numerous soil stabilization techniques, such as soil stabilization using cement which is one of the important methods. Since it is easy to mix and requires less amount of cement, it has been proven that this method is very effective in sandy soils. Stabilization using cement refers to the use of Portland cement to stabilize the soil. The main reaction is that the cement reacts with water in the soil, in result cementitious material is formed (Pundir & Prakash, 2015).

Fly ash has proved to be successful when it is used in stabilizing clayey soil (Arora & Aydilek, 2005). After stabilization tests like Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) are used to measure the strength characteristics of the stabilized soil. The stabilizing using fly ash showed improvement of the soil properties with amount between 15 to 30% according to the soil type (Misra, 1998).

1.2 Aim & Objective

The aim of this study is to find the effects of adding different types of additives to a subgrade soil using in road construction. Improving the subgrade soil layer will help in constructing better pavements with lower costs, also using by product materials will help environmentally to make our projects eco-friendly projects. Modifying the local materials will help un-disturb the site and limit the using of borrow pit materials. Three types of additives with three different percentages (3%, 6% and 10%) were used and tested in CBR, Proctor and UCS tests for the soil subgrade with and without adding the additives. The results were recorded, calculated, and compared for evaluation purposes.

2. Literature Review

This section deals with the previous studies done on different stabilization materials such as cement, fly ash and lime. The increase in strength obtained in the soil using cement stabilizers is the same as that of using lime stabilizers. Cement contains the required calcium for providing the pozzolanic reaction; yet, the source of the required silica for the pozzolanic reaction is different. Through stabilization with cement, the cement already contains silica without decomposing the minerals of the clay. Thereby, cement stabilization has nothing to do with soil properties; the only condition is that the soil should contain some water to start hydration (Balkis & Macid, 2019; Patel & Patel, 2012).

According to a study conducted by Afolayan (2017) in Ogbomoso (Nigeria), the CBR of stabilized soil with cement increased from 6.28% to 29.48% and 53.16% after adding (5% and 7.5%) cement (Afolayan, 2017). In a study conducted by Okunkwa et al. (2015) concerning soil type A-2-6 which is in group of A-2 and contains clayey or silty sand, it was mentioned that the soil will provide the required CBR value when stabilized with cement addition of 5.36% for subbase and 6.48% for base (Okonkwo & Nwokike, 2015).

According to a study of Kumar et al. (2005) on Roorkee soil, it was found that the value of CBR for soils which have poor gradation is increased from 11.42% to 18.57% when stabilized with 75% fly ash + 25% soil, and increased to 22.85% when stabilized with both fly ash + 4% lime (Kumar, Mehendiratta, & Rokade, 2005). According to a study conducted by Afolayan (2017) in Ogbomoso (Nigeria), after adding lime to the soil the CBR value increased from 6.28% to 7.57% and to 7.46 after adding (2.5% and 5%) lime respectively (Afolayan, 2017)

Misra (1998) studied the use of fly ash for subgrade clayey soil and has proved to be successful when used in stabilizing clayey soil (Arora & Aydilek, 2005). After stabilization using fly ash tests like Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) are used to measure the strength characteristics of the stabilized soil. It was found that the content of using fly ash has improved the soil properties with values between 15 to 30% according to the soil type (Misra, 1998).

3. Methodology

3.1 Materials Used

The following sections deal with the materials used in this study to investigate the use of additives on the physical properties of the soil.

3.1.1 Subgrade Soil

The soil that has been used in this study is a sample of soil that was taken from the main road of Baban Highway Project also knows as (100m Road) connecting Tasulja with Arbat. And it is known as one of the most important highway projects for Sulaymaniyah city. The road to be constructed is dual carriage ways with 4 lanes for each direction. The physical properties of the soil are shown in Table 1.

Table 1: Physical properties of subgrade soil

properties	values
physical properties	
Optimum Water content	13.7%
Maximum Dry Density	1.83
Liquid limit	35%
Plastic limit	28%
Plasticity index	7%
Specific Gravity	2.1

3.1.2 Ordinary Portland Cement

The chemical composition of the ordinary Portland cement is listed in Table 2.

Table 2: Properties of class Ordinary Portland Cement

properties	values %
Chemical composition	
MgO	2.55
Al2O3	6.5
SiO2	21.44
CaO	64.86
free lime	1.65
Fe2O3	3

3.1.3 Fly Ash

The fly ash used in this study was class F fly ash (FA). The properties of the fly ash are listed in Table 3.

Table 3: Properties of class F fly ash

properties	values
physical properties	
fineness	3.5 cm^2/g
specific gravity	2.41
Chemical composition	% value
K2O Na2O	1.56 0.08
MgO	1.27
Al2O3 P2O5 SO3	25.39 0.16 0.37
SiO2	47.69
CaO MnP	7.93 0.14
Fe2O3	11.72
L.O.I	3.34

3.1.4 Limestone Powder

The lime powder that was used in this study was the powder which was taken from limestone rock crushed in the factories in Erbil city without taking any chemical composition and the specific gravity was found equal to 2.94.

3.2 Tests Procedures

First, soil properties were determined before adding the additives. Table 4 shows the tests conducted using AASHTO and ASTM standards for the virgin soil to find out the grain size distribution, the

Optimal Moisture Content (OMC), Maximum Dry Density (MDD) and the California bearing ratio (CBR) before and after adding the different rates of the three additives.

Table 4: AASHTO and ASTM test designation

Name of Test	AASHTO Test Designation	ASTM Test Designation
Water content	T-265	D22-16
Specific Gravity	T-100	D-854
Sieve Analysis	T-87, T-88	D-421
Liquid Limit	T-89	D-4318
Plastic Limit	T-90	D-4318
Modified Proctor Compaction	T-180	D-1557
California Bearing Ratio (CBR)	T-193-99 & T-180-01	D-1883

3.3 Tests Procedures and Proportion of the Mix

A total of 9 different proportions was used in this study. Three for each of the additives (cement, fly ash and limestone powder) were used for soil stabilization (3%, 6% and 10%) separately. The mixing of the soil and the additives took place separately before applying each test. The amount of soil needed for each test was calculated first, and then before applying the test the soil was mixed with the additives according to the mentioned percentage amounts.

4. Calculations and Results

The properties of the subgrade soil before mixing with the additives was designated according to standard tests procedures and the results are listed in Figure 1 and 2, and Tables 5 and 6.

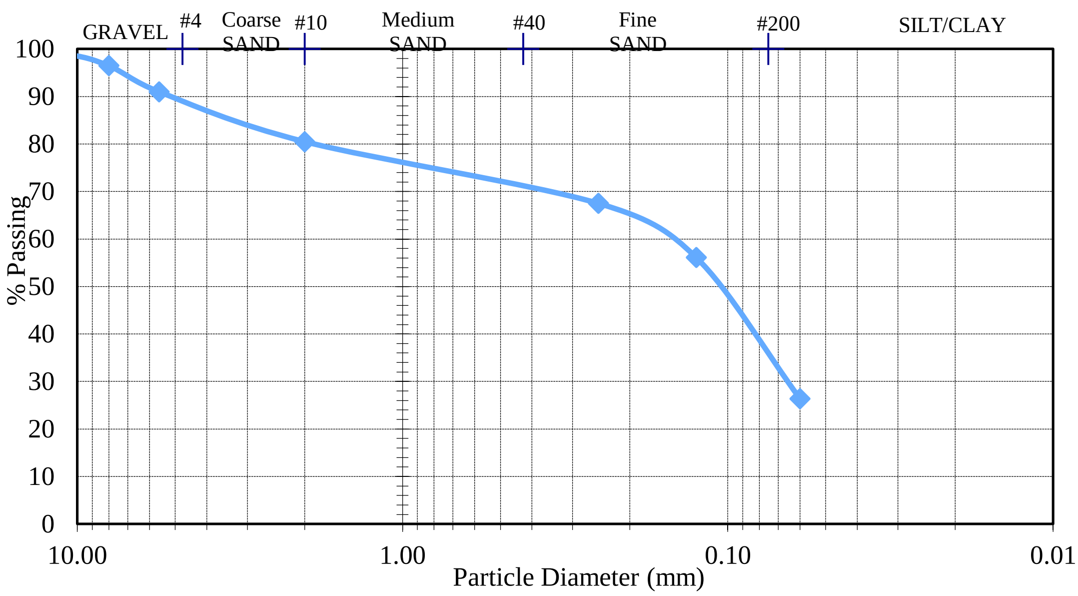


Figure 1: Grain Size Distribution Curve for the used soil

Table 5: Grain size distribution of the soil

	Weight of Dry Sample (g):	1000.0		
Sieve Number	Diameter (mm)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
7/8"	22.40	0.000	0.000	100.000
7/16"	11.20	10.000	1.000	99.000
5/16"	8.00	70.000	7.000	92.000
#3	5.60	80.000	8.000	84.000
#10	2.00	255.000	25.500	58.500
#60	0.25	374.000	37.400	21.100
#120	0.13	120.000	12.000	9.100
#230	0.060	71.000	7.100	2.000
Pan		20.000	2.000	0.000
	TOTAL:	1000.0	100.0	

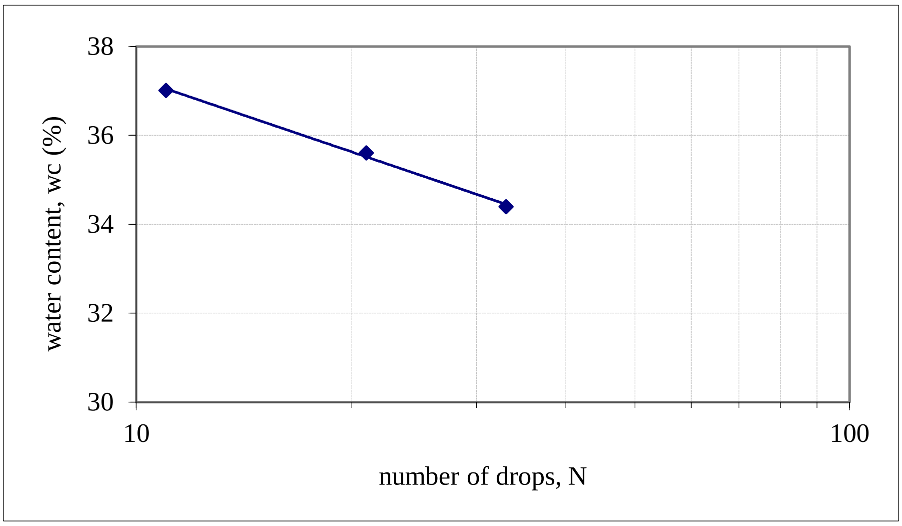


Figure 2: Water content vs number of drops

Table 6: Liquid limit, plastic limit, and plasticity index of the soil

	Test 1	Test 2	Test 3		Group 1	Group 2
Number of drops	11	21	33	Tare name	1	2
Log (N)	1.04	1.32	1.52	Tare mass (g)	57.68	64.78
Tare name	1	2	3	Tare + wet sample (g)	60.33	67.69
Tare mass (g)	59.93	59.31	59.73	Tare + dry sample (g)	59.75	67.05
Tare + wet sample (g)	68.00	67.86	67.74	Wet mass (g)	2.65	2.91
Tare + dry sample (g)	65.82	65.62	65.69	Dry mass (g)	2.07	2.27
Wet mass (g)	8.07	8.55	8.01	Water content	28.02	28.19
Dry mass (g)	5.89	6.30	5.96			
Water content	37.01	35.61	34.40			
				PLASTIC LIMIT:	28	
LIQUID LIMIT:		35				
				PLASTICITY INDEX:	7	

Specific Gravity test T-100

The specific gravity test for the soil and the limestone powder was calculated according to AASHTO standards which are listed in Table 5.

Specific Gravity calculation: $\frac{(W2-W1)}{((W4-W1)-(W3-W2))}$

For soil = $\frac{(187-166)}{((660-166)-(673-187))}$ =2.63

For limestone powder = $\frac{(182.96-159.42)}{((688.25-159.42)-(703.77-182.96}$ = 2.94

Table 7: Specific gravity test

specific gravity of soil	
Weight of empty pycnometer = W1	166
Weight of empty pycnometer + weight of soil = W2	187
Weight of empty pycnometer + weight of soil + full water = W3	673
Weight of empty pycnometer + full water = W4	660
specific gravity	2.63

specific gravity of limestone powder	
Weight of empty pycnometer = W1	159.42
Weight of empty pycnometer + weight of soil = W2	182.96
Weight of empty pycnometer + weight of soil + full water = W3	703.77
Weight of empty pycnometer + full water = W4	688.25
specific gravity	2.94

Modified Proctor compaction test (T-180)

Proctor test was followed on the subgrade soil according to AASHTO (T-180) standard without any additives to find the optimal moisture content (OMC) and maximum dry density (MDD) of the soil shown in Figure 3. Then the additives were added with different proportions and tested again. The results recorded are shown in Figures 3, 5 and 6.

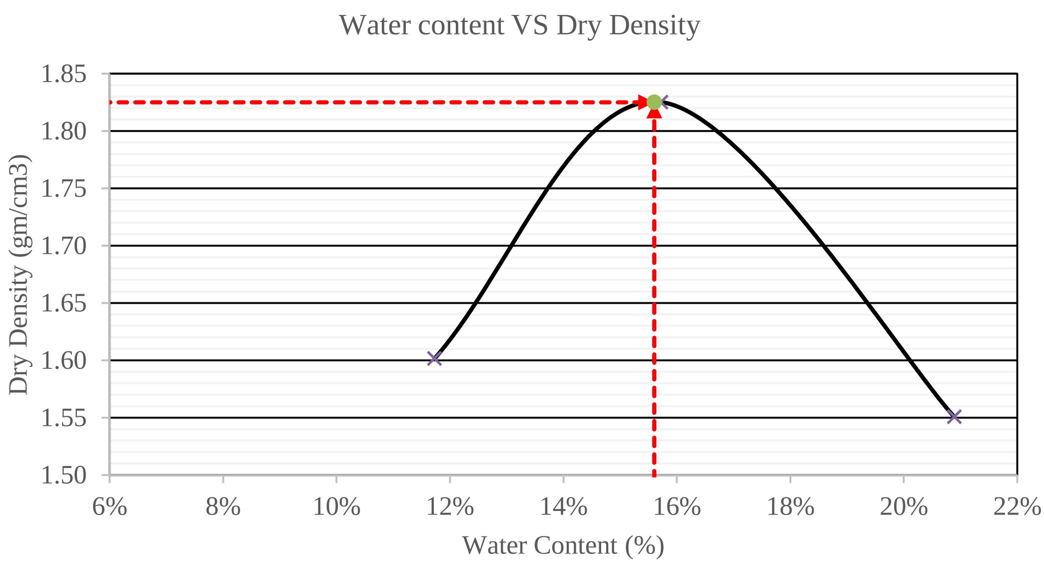


Figure 3: The proctor test for the soil to find OMC and MDD

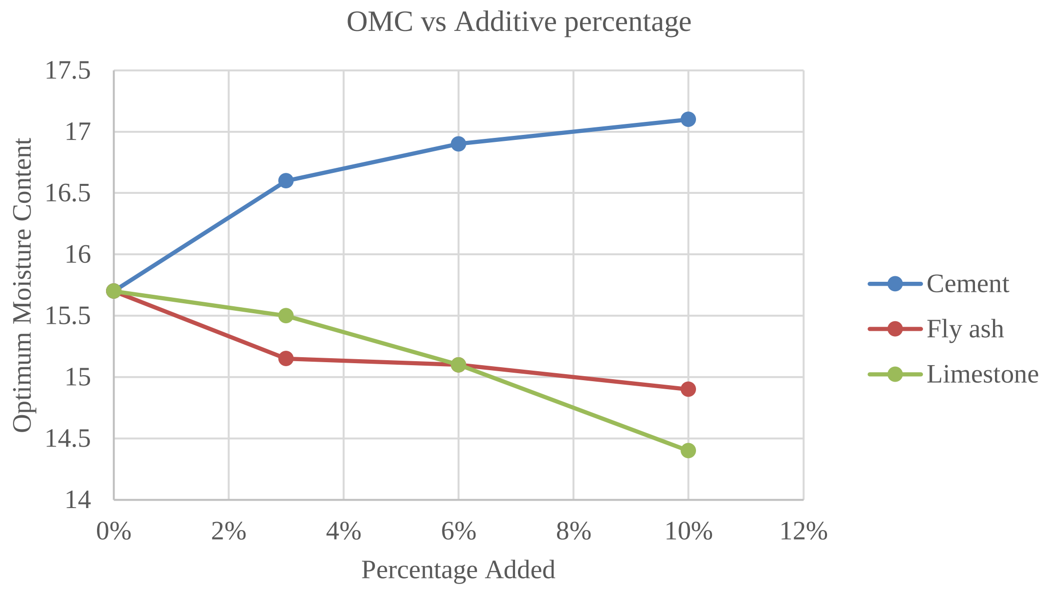


Figure 5: The difference in the OMD before and after adding different types of additives with different percentages to the soil subgrade

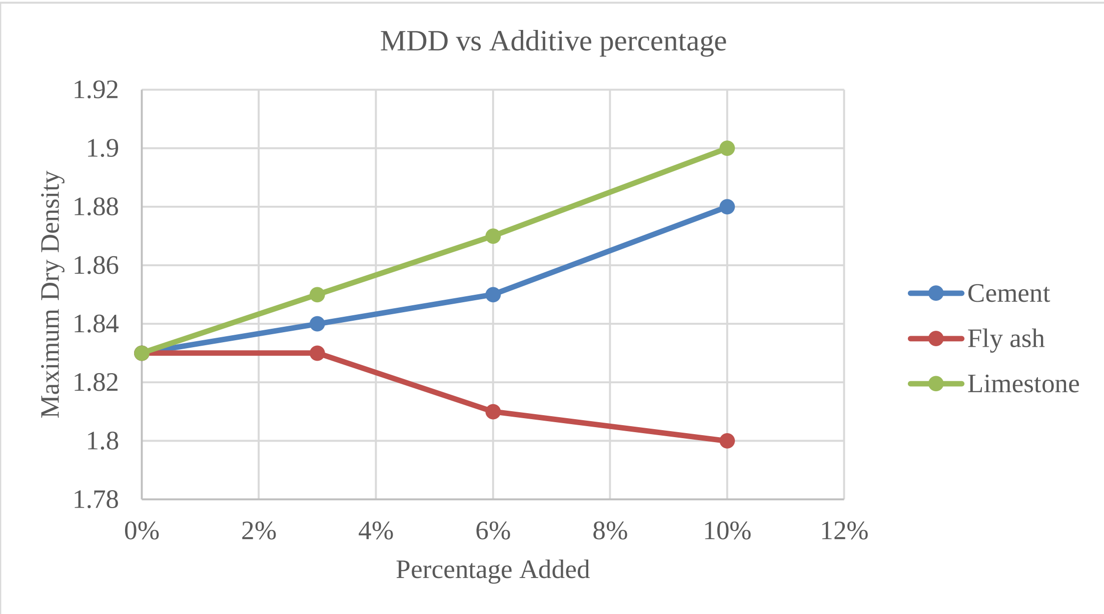


Figure 6: The differences in the MDD before and after adding different types of additives to the soil subgrade

Through Figure 4a we can see that the OMC using cement increases while using lime and fly ash decreases. Figure 4b shows that MDD increased by adding different proportion of cement and limestone powder; however adding fly ash will decrease it.

4.1 California Bearing Ratio Test (CBR) (T 193-99)

CBR test evaluated the soil subgrade strength after soaking the sample into water for 96 hours. At first, the CBR value of the virgin soil subgrade was found according to AASHTO, then after adding different proportion of each additive the CBR test was applied again and the results were recorded. Figure 7, 8, 9 show the difference in the penetration curve and CBR values.

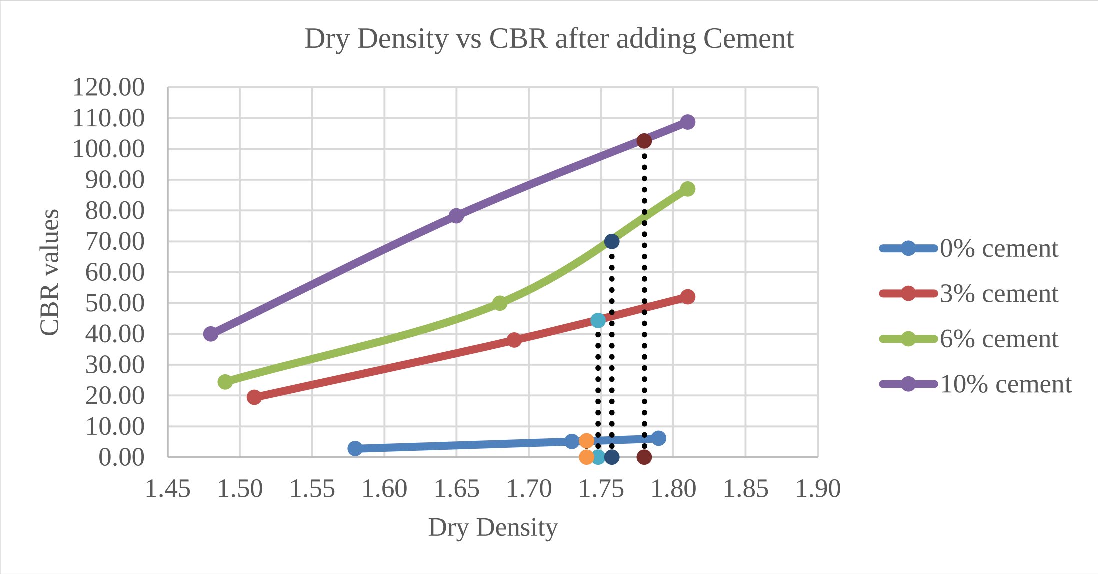


Figure 7: Dry Density vs CBR value for soil subgrade vs soil subgrade after adding Cement

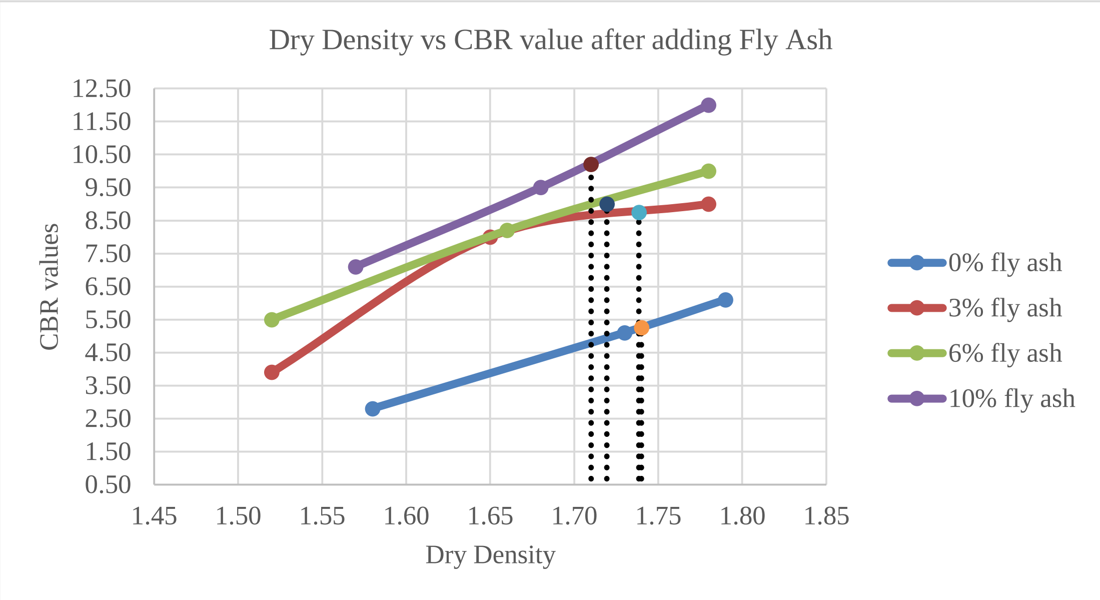


Figure 8: Dry Density vs CBR value for soil subgrade vs soil subgrade after adding FA

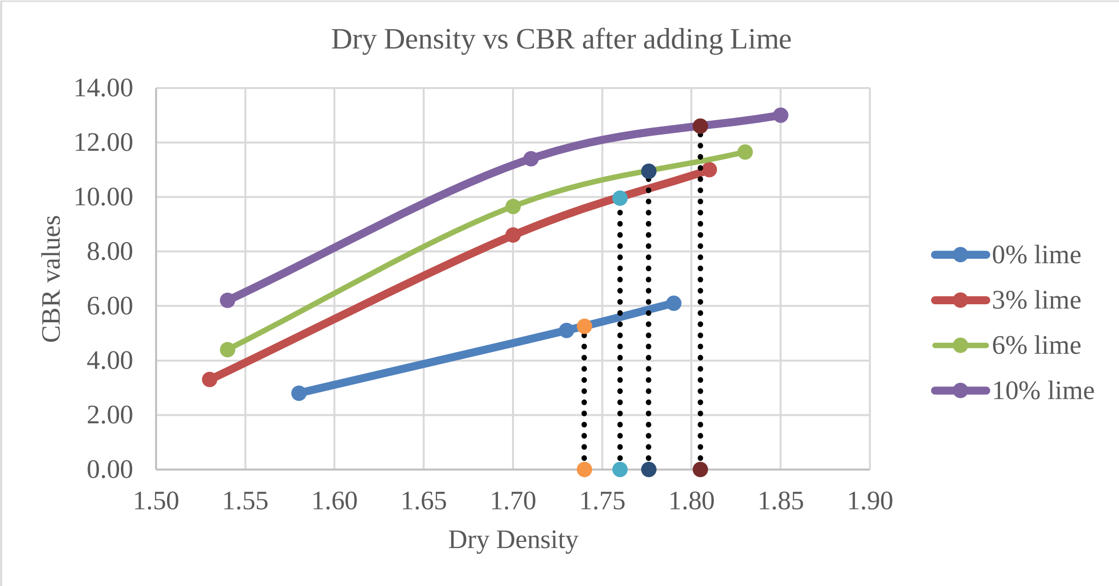
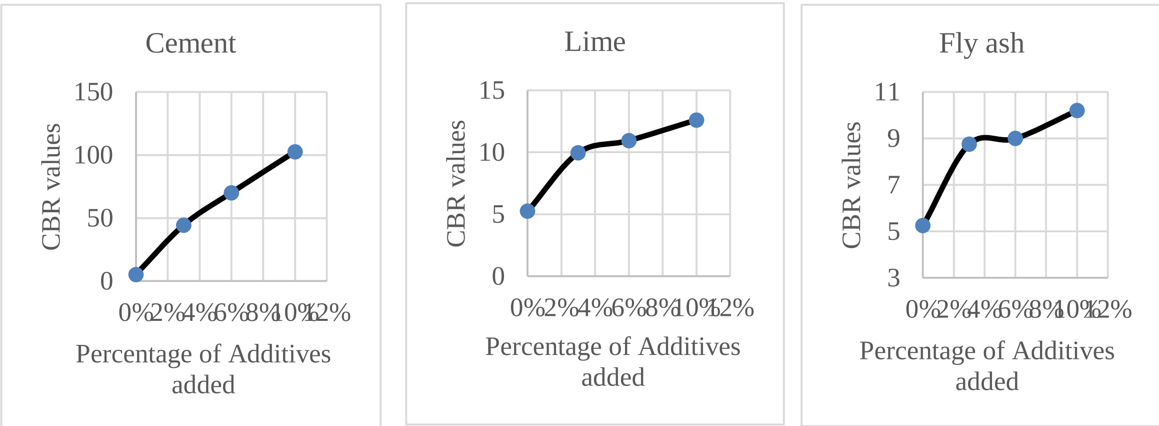


Figure 9: Dry Density vs CBR value for soil subgrade vs soil subgrade after adding Lime

From the curves, it was noticed that the strength of the soil increases significantly when cement is added and also increases with adding FA but it was noticed that the strength of soil subgrade is higher after adding limestone powder.



In Figure 10, the differences in CBR value of the soil is shown. It was noticed that the CBR value of soil will increase after adding all three kind of the additives. And the graphs show that adding cement increases CBR value more than limestone powder and Fly ash (FA).

4.2 Swelling Test

Adding Cement affected positively on swelling but the other two additives were affected randomly on the soil swelling property (Table 8) and (Figure 11).

Table 8: Percentage of swelling

	Blows per layer	10	30	65
% of swelling	Soil	2.10	1.42	3.26
	3% cement	0.30	0.19	0.27
	6% cement	0.23	0.15	0.29
	10% cement	0.15	0.09	0.30
	3% fly ash	2.16	3.06	2.10
	6% fly ash	1.89	2.10	1.94
	10% fly ash	1.62	1.13	1.78
	3% lime	2.32	1.88	1.67
	6% lime	2.42	1.97	1.72
	10% lime	2.53	2.06	1.78

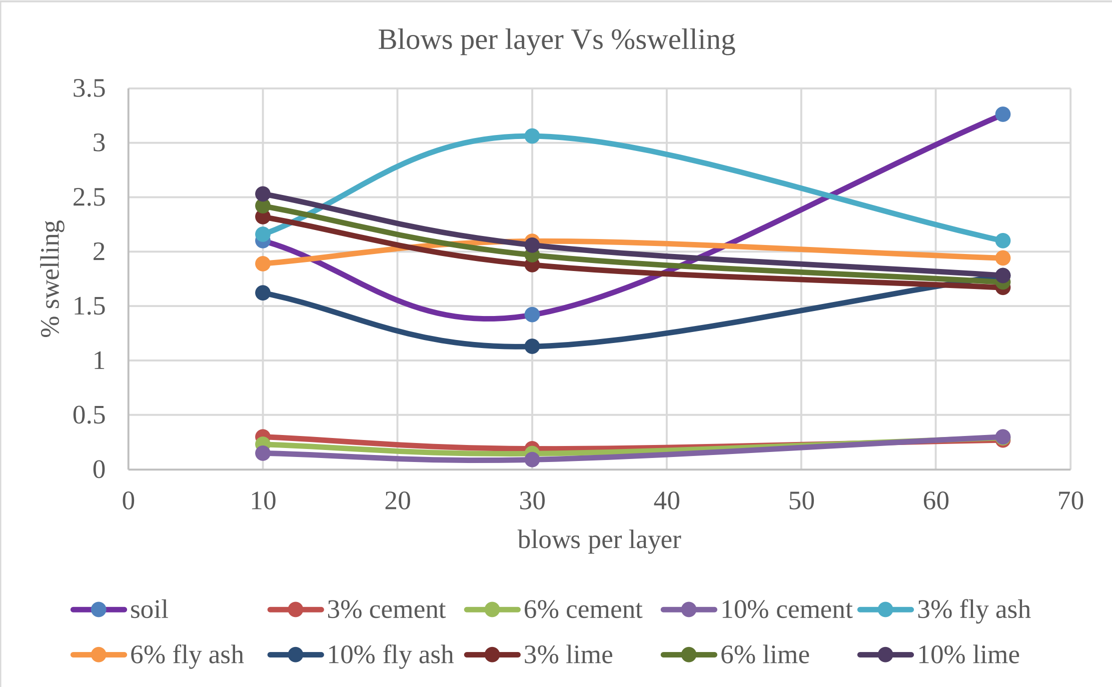


Figure 11: Change in swelling after adding additives

5. Discussion

From the experimental works the following points were concluded:

- According to AASHTO soil classification the untreated soil subgrade is listed in A-5 it was found that the soil type is Silty Soil.
- It was noticed that the OMC of untreated soil was 15.7 while different additives were added the values were changed. After adding (3%, 6%, 10%) cement the values increased to (16.6, 16.9, 17.1) respectively while fly ash was added it decreased to (15.15, 15.1, and 14.9) respectively. While lime was added it changed to (15.5, 15.1, 14.4).
- Test showed that adding different types of additives will change the Maximum Dry Density (MDD). The MDD of the untreated soil was 1.83 after adding (3%, 6%, 10%) of the additives this value changed. For Cement MDD changed to (1.84, 1.85, 1.88) respectively and for Fly ash

it changed to (1.83, 1.81, 1.8), for lime it changed to (1.85, 1.87, 1.9). We noticed that after adding Cement and Lime, the MDD increased especially after adding lime. However, it decreased after adding Fly ash.

- The California Bearing Ratio (CBR) value of the untreated soil was 5.25%; however, after adding the additives we noticed a great change in the value. After adding (3%, 6%, 10%) cement, the CBR changed to (44.3%, 71%, 102.5%) respectively, for (3%, 6%, 10%) Fly ash changed to (8.75%, 9%, 10.2%), and for (3%, 6%, 10%) lime changed to (9.95%, 10.94%, 12.6%) respectively. We noticed that the CBR value increased to very high value after adding cement, also after adding lime and fly ash the value increased but to a certain point.
- Swelling of soil changes after adding different types of additive. Adding cement will dramatically decrease the swelling. Adding fly ash will slightly decrease while adding lime will increase the swelling.

6. Conclusion

Soil strength and CBR value increased after adding different types of additives. For our soil which was Silty and Clayey Gravel and Sand soil type, after adding (3%, 6%, 10%) cement the CBR value changed from 5.25% to (44.3%, 71%, 102.5%) respectively. Adding Fly ash changed to (8.75%, 9%, 10.2%), and for adding lime the CBR changed to (9.95%, 10.94%, 12.6%) respectively. We noticed that CBR value increased to required purpose by adding additives, so it might not be necessary to remove the weak soil and exchange it with good soil. Sub grade soil stabilization is eco-friendly activity and it served time and money. It was also noticed that for this type of soil adding additives affected on the swelling property in better direction for saving structures from disruptions. Also adding cement increased the OMC of the soil while adding fly ash and lime will decrease it.

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