

IDENTIFICATION AND IMPROVING THE CHARACTERISTICS OF DISPERSIVE SUBGRADE SOILS USING CEMENT

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ABSTRACT

This study assessed the effects of cement on the behavior of dispersive soil collected from Gidole road project in ArbaMinch area, Ethiopia. Such soils are easily erodible and keep apart due to variation in moisture content and exchangeable sodium. The quality and strength of a pavement is greatly affected by the type of sub grade soil over which such pavements are to be constructed. To resolve failures related

to dispersive soils or improve the strength of sub grade soils, replacing such problematic soil with cohesionless soil is one solution. But in most regions such solutions are not cost effective due to non availability of non-cohesive soils easily. Therefore, this study focuses on stabilizing of dispersive soil with cement material for improving sub-grade of road. The study shows that the cement provides better index properties in terms of liquid limit, plastic limit, plasticity index and reduces sodium cation and dispersivity properties and also It improves California Bearing Ratio and unconfined compression strength. The sub-grade soil of untreated sample was classified as A-7-5 by the AASHTO and MH, CH as per USCS systems which is considered as poor subgrade quality. The subgrade soil was changed to GC and GM groups of soil after different percentage of cement treatment for the first 7 days and 14 days curing periods. Therefore, it can be concluded that cement can improve the engineering properties of dispersive soils. The study shows that the effective cement content should be 5% of dry soil weight as it provides high quality of subgrade pavement rating.

KEYWORDS: Dispersive soil, Cement, Stabilization, Subgrade, Improvement.

1. INTRODUCTION

The soils that are highly subjected to erosion and containing high percentage of exchangeable sodium ions are called Dispersive soils. In such soils, special phenomenon happens due to moisture content increment that sometimes inflicts major damages on construction projects. The physico-chemical characteristics of the particles in dispersive soils cause them to disperse and separate from each other upon mixing of water. If dispersive clays are not accurately identified, they may drive catastrophic damages and failures in any project.

This type of clay soil is facilely eroded and exhibit low level stress conditions and low hydraulic gradient (Foster et al. 2000). Clay naturally contains calcium, manganese and potassium. The dispersive clay contains mainly sodium (Sherard et al. 2000).Dispersion in clay happens in sophisticated chemical and physical mechanisms and is associated with the absorption quality of its particular mineral structure and ion exchange capacity. Water addition trigger these mechanism that causes the minerals in dispersive clay turn into suspended (Ouhadi and Goodarzi, 2006).The process by which soil characteristics are improved so as to meet the construction requirement is called stabilization. In its broadest sense, soil stabilization may also be defined as a method used to change one or more properties of soil in order to improve the desired performance of the soil. Soil stabilization is broadly classified into chemical (lime, cement and asphalt) and mechanical (compaction, excavation and replacement, mixing of different soils) stabilization (Mittal, 2013).

Addition of cement increases the unconfined compressive strength with respect to curing period (Imran et al. 2007). The results show that sample cured for 14 days had higher unconfined compressive strength compared to curing for 7 days (Sadek et al.2008). The Soil Conservation Service laboratory dispersion test, also called as the double hydrometer test is one of the first methods developed to examine dispersion of clay soils (Volk, 1937). The particle size distribution is prior outcome using the standard hydrometer test in which the soil specimen is dispersed in distilled water with a chemical dispersant namely sodium hexa metaphosphate.

A parallel hydrometer test is then done on an identical soil specimen, but without sodium hexa metaphosphate. The percent dispersion is the ratio of the dry mass (particles smaller than 0.005 mm diameter) in a test without dispersing agent to the mass (particles smaller than

0.005 mm diameter) in a test with dispersing agent expressed as a percentage. Procedures for performing the test are outlined in USBR 5405, Finding dispersibility of clayey soils by the Double Hydrometer Test Method (Kinney, 1979). The assessment criterion of dispersion degree using outcome from double hydrometer test are shown in Table 1. Test results indicate that a high percentage of soils with dispersive characteristics, exhibited 30 percent or more dispersion when tested by this method (Decker and Sherard, 1977).

Table 1: Degree of dispersion using results from double hydrometer test.

Percent dispersion	Degree of dispersion
<30	Non-dispersive
30 to 50	Intermediate
>50	Dispersive

The chemical test of the soil pore water is performed to observe the concentration of different ions. The electrolyte concentration of the soil pore water is interrelated to the presence of exchangeable ions, the presence of high sodium concentration brings the soil more dispersive. Therefore, to check the chemical compatibility, Sodium Absorption Ratio (SAR) and Percent Sodium (PS) parameters are used (Lashkaripour and Soloki, 2003).

$$\text{SAR} = \frac{Na}{0.5(Ca+Mg)} \quad \text{with units of meq/L} \quad (1)$$

All soils were dispersive if SAR exceeded 2

$$(\text{PS}) = \frac{Na(100)}{\text{TDS}} \quad \text{with TDS} = Ca + Mg + Na + K \quad (2)$$

With all units in meq/L of saturation extract

Soils were dispersive if PS exceeded 60%

2. MATERIALS AND METHODOLOGY

Characterization of the main materials applied in this investigation is essential to forecast the necessary behavior of treated soil. The Portland pozzolana cement used in this study was produced by Mughar Cement Factory. The component of Portland pozzolana cement registered on the enterprise website was 5% gypsum and pumice (15% - 30%). The chemical and mineralogical compositions of Portland pozzolana cement of the Mughar Cement Factory (Table 2) have confirmed and adopted as per analysis (Dinku and Gudissa, 2010).

Table 2: Chemicals and Mineralogical composition of Muger Portland Pozzolana Cement.

Chemical composition	Percentages (%)
SiO ₂	22.15
Fe ₂ O ₃	3.43
Al ₂ O ₃	5.76
CaO	65.05
MgO	1.05
SO ₃	1.04
Others	1.52
Mineralogical composition	Percentages (%)
C ₃ S	47.11
C ₂ S	27.96
C ₃ A	9.46
C ₄ AF	10.44

The study deals with stabilization of soil called dispersive soil that is located in the Southern Nations, Nationalities and Peoples Regional State (SNNPRS) in Arba Minch area and Derashe Woreda, Ethiopia. It is wide spread below a depth of 1.0 m from the ground level and extends to depth greater than 15 m. It has sufficient strength in dry situation on the contrary it shows loose strength due to increase in moisture content. Many failures were observed along the road surface in which this soil is present. The soil was collected from the above said area as the main material for the present research work. It was stabilized with Portland pozzolana cement. Characterization of the soil was necessary for establishing the effect of cement stabilization, and therefore, it was done by conducting various tests described in the next sections. Five test pits were made abbreviated as p-1, p-2, p-3, p-4 and p-5 for simplification. This soil was Clayey in nature presence of with Silt and was considered as a problematic soil under saturated condition.

Figure below show the slope cut landscape of dispersive soil in the road.

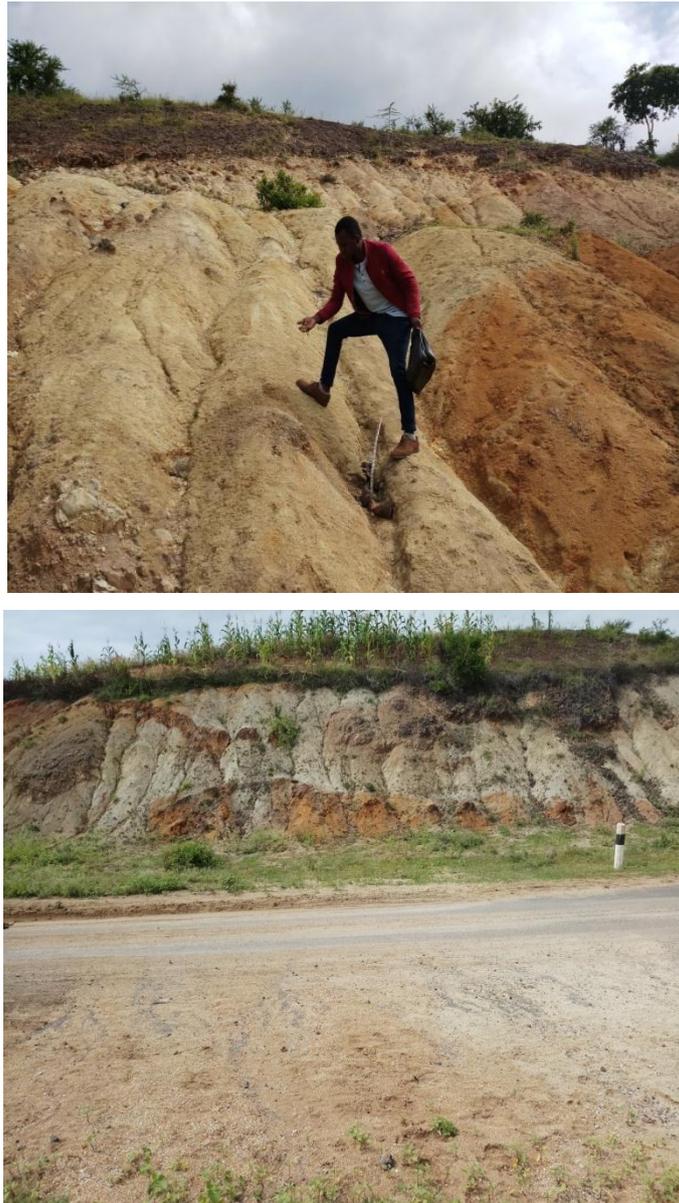


Fig. 1: View of dispersive soil slope cuts of the road.

3. RESULTS AND DISCUSSIONS

The study deals how the use of cement could improve the geotechnical properties [including consistency limits, compaction properties, unconfined compressive strength, Dispersive properties, Chemical property, durability, California bearing ratio (CBR) and grain size distributions properties] of dispersive subgrade soil collected from Wozeka Gidole road project.

3.1. Double Hydrometer Test for the Determination of Dispersion

Table 3 shows high percentage of soils with dispersive characteristics, exhibited dispersion when tested by Double hydrometer test. Fig.2 shows the untreated dispersive soil with

standard hydrometer and parallel hydrometer test with an identical soil specimen, but without chemical dispersant.

Table 3: Dispersion of Untreated Subgrade Dispersive soil.

Sample (pits)	P-1	P-2	P-3	P-4	P-5
Dispersion (%)	54.7	69.2	58.8	66.3	48.8

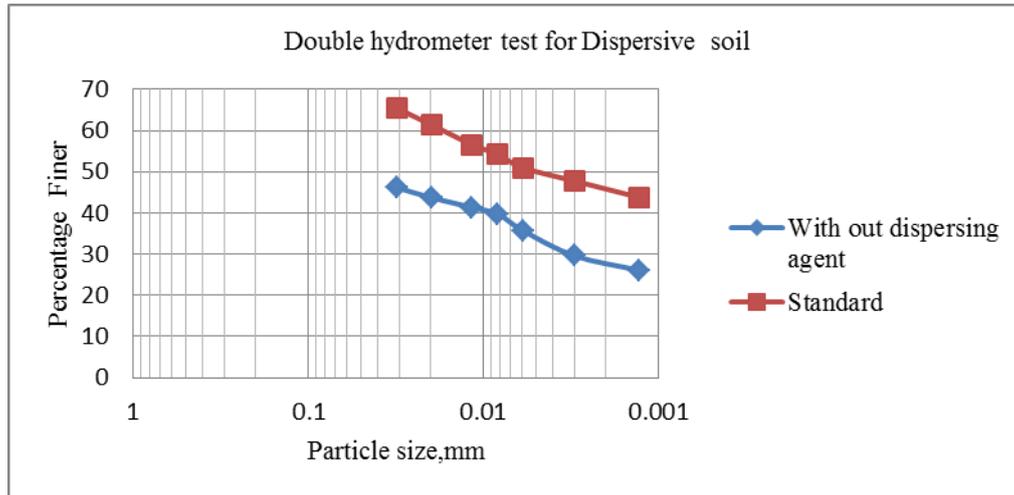


Fig. 2: Double Hydrometer test of Dispersive soil.

Fig. 3 shows view of conducting double Hydrometer Test on dispersive soil with standard hydrometer and parallel hydrometer test.



Fig. 3: View of conducting double Hydrometer Test on dispersive soil.

3.2. Chemical Analyses of Soil

1 g of sample was placed in 250 ml digestion flask. The first step was to heat the sample to 95⁰C with 10 ml of 50% HNO₃ without boiling. After cooling the sample, it was refluxed

with repeated additions of 65 % HNO₃ until no brown fumes were given off by the sample. After cooling, 10 ml of 30% H₂O₂ was added slowly without allowing any losses. The mixture was refluxed with 10 ml of 37% HCl at 95⁰C for 15 minutes. The digestate obtained was filtered through a 0.45 µm membrane filter paper, diluted to 100 ml with deionized water and stored at 4⁰C for analyses. The filtrates were also analyzed for Ca, Mg, Na and K by using atomic absorption spectroscopy method. Table 4 below shows the variation of exchangeable cations for the untreated soil. Soil dispersivity is mostly due to the existence of exchangeable sodium present in the structure. The erosion due to dispersion of soil depends on mineralogy and clay chemistry and the dissolved salts in pore water.

Table 4: Exchangeable cations in untreated soil samples.

Test Pit No.	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	SAR	PS	Description
P-1	0.44	0.26	5.54	2.68	15.8	62.11	Dispersive
P-2	0.56	0.31	6.21	2.10	14.3	67.65	Dispersive
P-3	0.49	0.28	5.51	1.89	14.31	67.44	Dispersive
P-4	0.42	0.21	6.40	2.30	20.32	70.1	Dispersive
P-5	0.39	0.18	5.40	2.80	18.94	61.6	Dispersive

3.3. Classification of Subgrade Soil

Table 5 shows the basic properties and soil classification of the different pit representative samples summarized for untreated subgrade soil. All representative soil samples collected from each pit along the road contain more than 70% of fine grained soil passing through sieve No. 200 (0.075mm opening) as obtained from wet sieve grain size analysis. The hydrometer analysis was performed to identify the amount of silt and clay passing sieve No.200 (0.075mm opening). Therefore, based on AASHTO and USCS soil classification systems, all representative samples fall under two classes of soil material types which is very high plastic soil of clayey materials and high plastic silty soil under group index of A-7-6 and A-7-5 respectively.

Double hydrometer and exchangeable sodium ion play an important role in soil identification and classification. These parameters indicate to some of the geotechnical problems such as dispersivity, excess sodium ion and sodium absorption. One of the principle aims of this study was to evaluate the changes of dispersion and exchangeable cation with addition of cement.

Table 5: Classification of Untreated Subgrade soil.

Description	P-1	P-2	P-3	P-4	P-5
Percentage of passing 4.75mm sieve size(No.4)	100	100	100	100	100
Percentage of passing 2.36mm sieve size(No.10)	94.6	95.2	98.6	92.6	95.8
Percentage of passing 0.075mm sieve size(No.200)	82.4	70.6	84.2	82	86.2
Natural water content,%	29.03	34.67	38.57	31.68	26.08
Specific gravity	2.7	2.72	2.74	2.75	2.76
Gravel size	0	0	0	0	0
Sand size	17.6	29.4	15.8	18	13.8
Silt size	43.75	29.39	20.1	35	38.79
Clay size	38.65	41.21	64.1	47	47.41
Liquid Limit (%)	75.03	76.98	67.88	67.41	60.57
Plasticity Index (%)	31.97	32.39	33.19	31.89	16.72
Classification According to AASHTO system	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5
Group Index	31.61	26.15	32.74	30.51	20.3
According to USCS system	MH	MH	CH	CH	MH
Material type	Clayey and Silt Material				
Dispersion by Double hydrometer (%)	54.7	69.2	58.8	66.3	48.8
Sodium Absorption Ratio (SAR) (%)	15.8	14.3	14.31	20.32	18.94
Percentage sodium (PS) (%)	62.11	67.65	67.44	70.1	61.6

3.4. Effect of cement on Dispersion of the dispersive soil

The soil dispersivity were studied by performing Double hydrometer tests and the dispersivity of the soil goes on decreasing with increasing additions of cement from 69.2% to 31.11% and from 66.3% to 27.8% for sub grade material (MH soil) and (CH soil) respectively for 14 day curing presented in Table 6.

Table 6: The effect of cement in curing period.

Cement content	Dispersion(%) of MH soil			Dispersion(%) of CH soil		
	5day curing period	7day curing period	14day curing period	5day curing period	7day curing period	14day curing period
0%	69.2	69.2	69.2	66.3	66.3	66.3
3%	61.56	58.32	57	61.4	59.2	56.6
5%	47.21	42	38.2	42.3	40	38.2
7%	44	39.6	33.2	32	35	32.61
9%	41.4	35.23	31.11	30.33	29.8	27.8

3.5. Effect of cement on chemical properties

Soil dispersivity is mostly due to the existence of exchangeable sodium present in the structure. The erosion due to dispersion of soil depends on mineralogy and clay chemistry and the dissolved salts in pore water. Tables 7 and 8 below show the variation of exchangeable cations for the soil cement combination at different percentages. In the samples

the sodium ion concentration was replaced by the calcium ions supplied by addition of cement. And hence the values of SAR and PS were very less and classified as non dispersive, with all exchangeable cation units in meq / L of saturation extract.

Table 7: Variation of exchangeable cations in treated soil, at 7 day curing period.

Cement content	MH Soil					
	Ca+	Mg ²⁺	Na+	K+	SAR	SP
0%	0.56	0.31	6.21	2.1	14.3	67.65
3%	0.76	0.83	6.11	1.81	7.68	64.25
5%	2.14	2.38	4.3	2.57	1.9	37.75
7%	2.56	2.66	4.1	2.59	1.57	34.42
9%	2.76	2.69	3.8	2.61	1.39	30.04

Table 8: Variation of exchangeable cations in treated soil, at 14 day curing period.

Cement content	MH Soil					
	Ca+	Mg ²⁺	Na+	K+	SAR	SP
0%	0.56	0.31	6.21	2.1	14.3	67.65
3%	2.71	2.1	4.42	2.38	1.84	38.1
5%	2.74	2.38	4.11	2.27	1.6	35.74
7%	2.86	2.56	3.89	2.31	1.43	33.48
9%	2.97	2.62	3.21	2.38	1.15	28.71

3.6. Effects of the cement on Atterberg's limits

The effect of cement on soil plasticity was also studied by performing Atterberg's limits tests. Figure 4 shows that the liquid limit and plasticity decreases while slight increase in plastic limit for the cement –treated soil is noticed with increase in cement content from 3% to 9%.

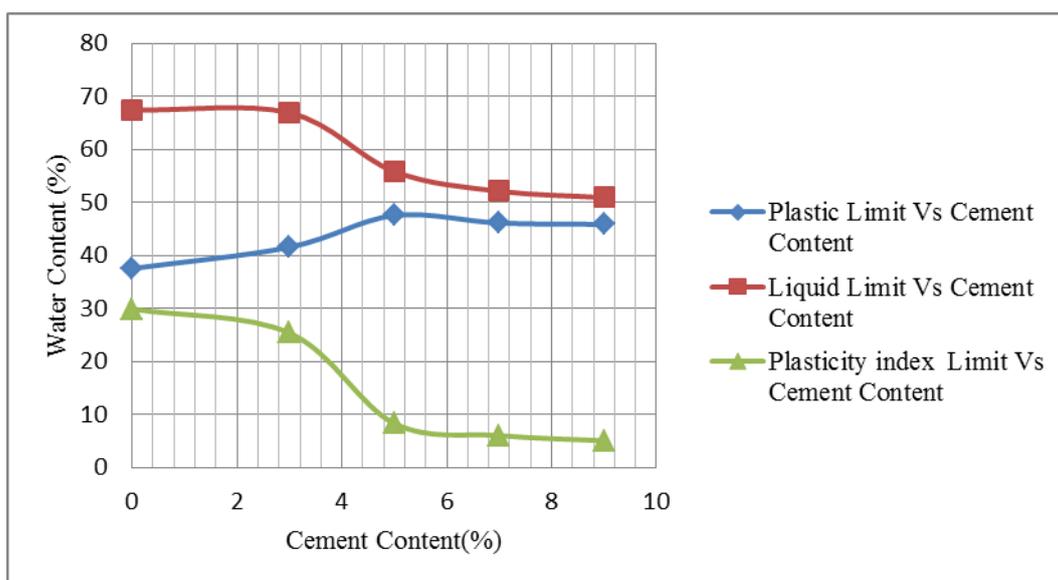


Fig. 4: Effect of cement content on Atterberg limit.

As the concentration of cement is increased, there is a reduction in clay content and thereby corresponding increase in the percentage of coarse particles. These results in a reduction of Plasticity Index at cement content of 5%. A maximum reduction in Plasticity Index to 8.28% was obtained. When the cement content was increased beyond 5%, there was no further change in Plasticity Index.

The results shown in Figure 5 for the soil samples show that the addition of cement to the natural samples decreased their liquid limit, plastic limit and consequently reduced their plasticity index.

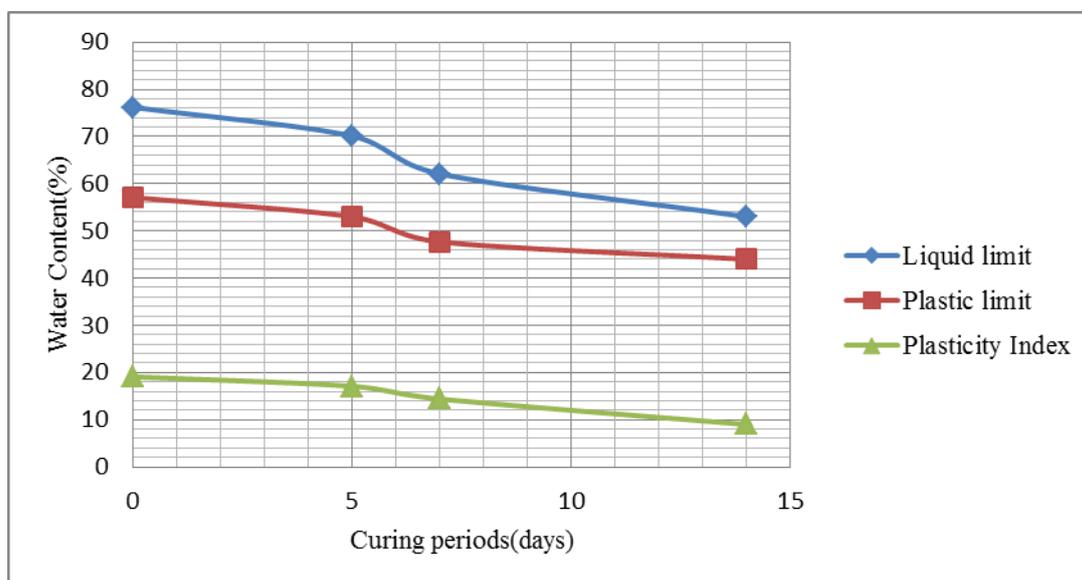


Fig. 5: Effect of Curing Periods on Atterberg's Limit.

From the findings of laboratory result, it can be concluded that 5% of cement content is optimum dosage of cement content to reduce the plasticity index of dispersive subgrade significantly.

3.7. Effect of cement on compaction of treated Soils

The effect of cement on soil was studied through the Modified Proctor tests. The variation in results related to dry density and water content for different curing period 5, 7 and 14 days are presented in Fig.6. The addition of cement to dispersive subgrade materials (MH soil) increases their optimum moisture content from 18.50% to 27.6% at 9% cement content and its maximum dry density decreases from 1.98g /cc to 1.18g /cc for the same compactive effort at day 14curing period.

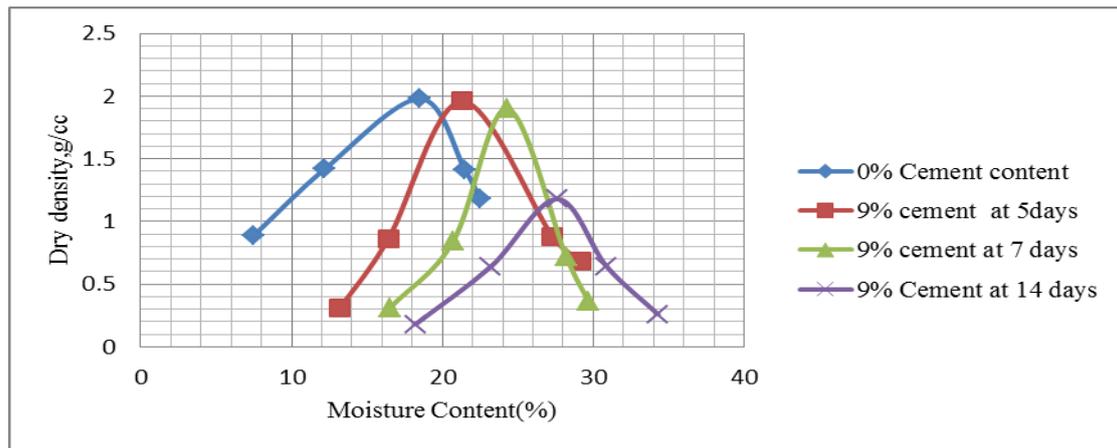


Fig. 6: Compaction curve for cement treated dispersive CH soil based on curing period.

Figure 7 shows addition of cement to dispersive subgrade materials (MH soil) increases their optimum moisture content from 14.98% to 25% at 9% cement content and its maximum dry density decrease from 1.76g /cc to 0.81g /cc.

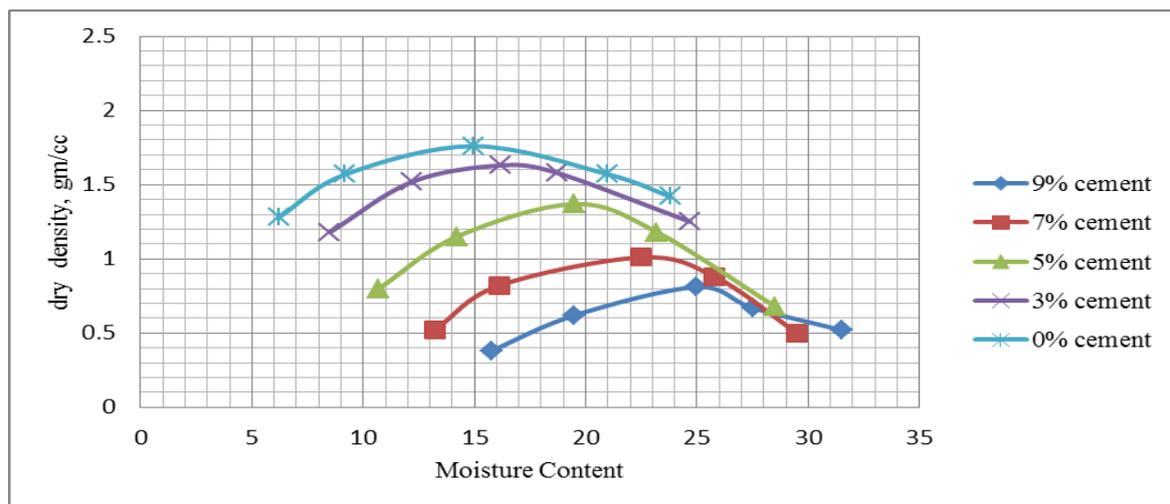


Fig. 7: Compaction curve for Treated and Untreated MH Soils by Different Percentage of Cement.

3.8. Effect of cement on grain size distributions of subgrade materials

Based on laboratory results, the samples treated and untreated with cement were classified according to the Unified Soil Classification and AASHTO classification system by conducting wet sieving tests and hydrometer analysis by following ASTM D 422-63 standard. The alteration of particle size distribution curves occurs for all stabilizers. In general, the soil-cement mixtures showed reductions in the clay fraction. Table 9 shows the clay fractions reduced from 41.21% to 21.3%, Sand fraction increase from 29.4% to 56.1%,

Gravel fraction increase from 0% to 3.20 at 7 day curing period of sub grade CH soil after addition of 3%, 5%, 7% and 9% of cement.

Table 9(a): Soil cement treated classification.

MH soil	Specific Gravity	Grain Size Distribution				Atterberg's Limit		
		Gravel	Sand	Silt	Clay	Liquid Limit	Plastic Limit	Plastic Index
		(%)	(%)	(%)	(%)	LL (%)	PL (%)	PI (%)
0% Cement	2.72	0	29.4	29.39	41.21	76.98	44.59	32.39
3% Cement	2.68	0.56	50.40	20.72	28.32	70.67	45.80	24.87
5% Cement	2.64	1.86	52.0	20.20	25.94	66.65	47.90	18.75
7% Cement	2.62	2.56	53.80	24.32	19.32	58.68	48.20	10.48
9% Cement	2.61	3.20	56.10	19.40	21.30	53.80	48.10	5.70

Table 9(b): Soil Cement treated classification.

Grain Size Distributions No. 200 pass	Classification		Materials type	Sub grade rating
	According to AASHTO	According to USCS		
70.6	A-7-5	MH	Mostly Clay soils	Fair to poor
52.60	A-7-5	MH	Mostly Clay soils	Fair to poor
48.26	A-7-5	GC	Mostly Clay soils	Fair to poor
45.26	A-5	GM	Mostly Silty soils	Fair to poor
41.94	A-5	GM	Mostly Silty Soil	Fair to poor

3.9. Effect of cement on unconfined compression strength of subgrade materials

The unconfined compressive strength of the natural subgrade soil performed in the laboratory result was varied from 55KPa to 100 KPa which indicate medium rating subgrade quality. Cement-soil mixture strengths varied widely, depending on the soil, cement percentage, and curing period. Figure 8 shows Unconfined Compression Strength with cement content for 5, 7 and 14 days under soaking condition. The strength of soil increases at higher percentage of cement content and curing period.

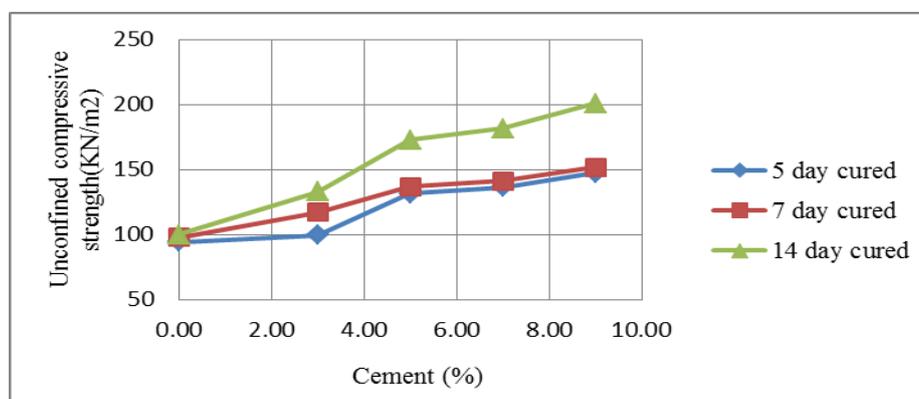


Fig. 8: Unconfined compression strength of dispersive soil with cement.

Unconfined compressive strengths of untreated compacted soils are interpreted in the context of the general relationship between the unconfined compressive strength and the consistency (quality) of the soils used in pavement applications. It was observed from Table 10 that there is improvement in Unconfined Compressive Strength of dispersive soil with addition of cement.

Table 10: Unconfined Compressive Strength at different cement content and curing period.

CH Soil	Cement content	5 Days	7 days	14 Days
	0%	94.11	97.60	99.90
3%	99.62	116.90	132.60	
5%	131.30	136.61	172.73	
7%	136.10	141.20	181.60	
9%	147.20	151.72	200.82	

Findings of this study imply that cement is a suitable additive to stabilize dispersive soils. The gain in strength is observed at 5% cement content.

3.10. Effect of cement on CBR of subgrade materials

The CBR values obtained for cement and soil mixture was remarkably higher than the values for untreated samples. Table 11 shows CBR value increase from 3% to 24.31% at 14 day curing period with an increment 87.65%. Figure 9 shows the influence of cement stabilized dispersive clay on CBR.

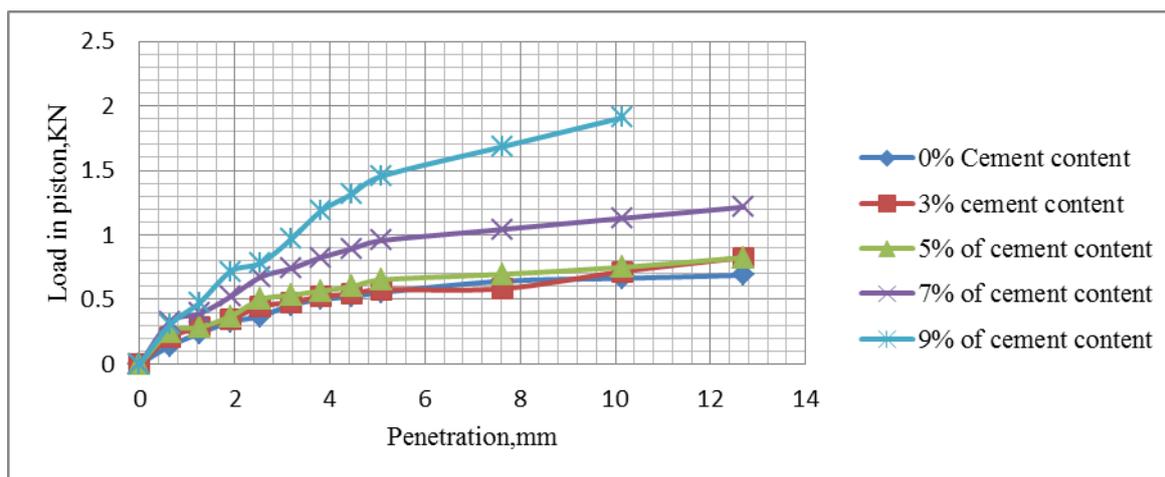


Fig. 9: Variation in CBR result of penetration vs load after 7 days curing period.

Table 11: Variations of CBR result at different cement content and curing periods.

MH soil Cement Content	5 Days Curing		7 Days Curing		14 days curing	
	CBR (%)	Swelling (%)	CBR (%)	Swelling (%)	CBR (%)	Swelling (%)
0%	3	14.33	3	14.33	3	14.33
3%	3.45	12.43	3.78	11.14	5.61	8.66
5%	4.21	9.56	4.5	7.73	9.33	4.21
7%	4.98	7.65	5.10	6.85	12.79	3.1
9%	5.55	5.33	6.67	4.22	24.31	0.76

The CBR value of soil-cement treated was increased significantly at 5% cement content in 7 days as well as 14 days.

4. CONCLUSION

This paper explore on dispersive sub-grade soils which pose severe problems to pavements which are constructed over them. Because these soil are easily erodible and also segregate due to variation in moisture content. Such soil also have low load bearing capacity during wetting. Dispersive soils have been a big challenge to the road construction sector in Ethiopia. There is also the scarcity of suitable fill material within economic hauling distances and labor cost in force to initiate the use of chemicals to stabilize sub-grade. The outcome of this study suggests that cement provides promising results in improving the engineering properties of the sub-grade soil. The dosage of 5% cement is enough to stabilize the dispersive sub-grade soil pavement of roadbed.

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