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EXPERIMENTING ON THE GEOTECHNICAL PROPERTIES OF BAHIR DAR BLACK COTTON SOIL STABILIZED WITH QUARRY DUST

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Abstract: Main objective of this study is to test and analyze effectiveness of Quarry dust as stabilizer on the Geotechnical properties of Black Cotton soils in Bahir Dar; intentionally Black Cotton Soils converted to upsetting worldwide problem. Speedy progression of population, debauched expansion and more building of setups has requesting virtuous quality accessible terrestrial. No alternative to use soft and weak soils nearby their for assembly actions. Such soil owns meager shear strength and great swelling & shrinkage. The mechanical performance of such Mother Nature of soil has to be upgraded by applying stabilization and reinforcement methods. Black cotton soil is one of the key concern in Ethiopia. When open to deviation in wetness they experience high swelling and shrinkage creating it more problematical. Quarry dust is a kind of solid surplus material. The dumping of such trashes produces lots of harms to the atmosphere and community. Considering this aspect an experimental schoolwork was accompanied on locally accessible black cotton soil by mixing it with Quarry dust. The results confirms that quarry dust can be efficiently make use of as a preservative for black cotton soils with optimum quarry dust content of 30% for highly expansive soils and up to 20% for soils of low to marginal swelling potential. Grounded from the outcomes of this research Quarry dust can be well-matched as a sustainable alternative for stabilization of foundation bases and subgrade founded on black cotton soils after piloting strength tests. It will predominantly aid use of negligible materials where they met standard specifications are overpriced and incredible to get within a reasonable cost.
Keywords: Geotechnical properties, Black cotton soil, quarry dust, soil stabilization, optimum quarry dust content

1. INTRODUCTION

Around the world, there are many structurally unstable and problematic geo-materials which are sources of worry to engineers working with or on them. They are considered problematic mostly because they are characterized by unusual in-service behavior, including such geo-technical phenomena as heaving, swell, collapse, dispersion, erosion, excessive creep, subsidence, high compressibility etc. such behavior could be attributed to factors such as composition, nature of pore fluids, fabric and mineralogy, etc. Prominent among these problem soils are the potentially expansive soils such as weathered shale's, stiff fissured clays, black cotton soils, etc. (Gidigasu, 1987)

Soil is a mixture of various sizes of particles like gravel, sand, silt and clay. Gravel and sand are among the coarse fractions and they are considered inert materials because of their significant surface activity. (Venkataramana, 2003) In contrast, clay and silt clays are particles of ultra-fine size in the form of platelets. They carry an unbalanced negative electric charge on their surface. This electric charge and large specific surface they possess render them highly active. They can absorb water as well as the positively-charged ions from the salts in water to neutralize the electric charge they carry on their surface. The amount of water absorbed depends on the type of the clay mineral present in the soil. Three most common minerals present in clay are Kaolionite, Illite and Montmorillonite and their capacity to adsorb water increases in that order, therefore, the greater the percentage of Montmorillonite mineral present, the greater would be the expansive nature of the soil. (Venkataramana, 2003)

Expansive soils in general are clay soils that have potential for swelling and shrinkage under changing moisture conditions. Black cotton soils or shrink-swell clays are special types of potentially expansive soils which classify as vertisols in pedological parlance and have been found to occur in all major climatic zones of the world. These soils are considered - problematic and sometimes as - potential natural hazard because they are susceptible to seasonal volumetric changes, exhibit severe cracking when dry, swell and yield low bearing strengths when wet, etc. These problems causes extensive damage to light structures founded on them and estimated cost of damage due to expansive soils in general runs into billions of dollars annually. The clay mineral that swell when wetted and shrink when dried is mostly responsible for expansiveness belongs to the Montmorillonite group. (Ahmed, 2009)

The expansive nature of the clay in the study area (Bahir Dar) is less near the ground surface where the profile is subjected to seasonal and environment changes. These soils in most localities absorb more water in wet seasons and increases their volume and shrink when they dried out. The volume change resulting from swelling and shrinking caused damages to visible structures founded on them. (Tibebu, 2015)

Stabilization of expansive soil with waste materials generated from industries like lime, sea shells powder, sea salt, cement and fly ash, silica fume, blast furnace slag, cement kiln dust, bagasse ash etc. are currently suggested economical methods for improving the characteristics of expansive soil. Quarry dust is one of the waste material produced from aggregate crushing industries. Quarry dust therefore can be used for stabilizing agent of problematic soils to improve their physical engineering characteristics.

Soil stabilization is the process of improving the engineering properties of the soil and thus making it more stable for specific material. It is required when the soil available for construction is not suitable for the intended purpose. In its broadest senses, the term stabilization includes compaction, pre-consolidation, drainage and many others. However, the term stabilization is generally restricted to the processes which alter the soil material itself for improvement of its properties. (Arora, 2003/4). A cementing material or a chemical is added to a natural soil for the purpose of stabilization.

2. OBJECTIVES

- Experiment and analyze the effectiveness of Quarry Dust in improving the Geotechnical properties of Black Cotton Soils in Bahirdar.
- Review of literatures on the engineering properties of Black Cotton Soils and the effect of Quarry Dust stabilization on their properties.
- Evaluate the geotechnical characteristics of the Black Cotton Soils of Bahirdar.
- Distinguish variations in geotechnical properties (like Atterberg's Limits, Index properties, compaction characteristics, shrinkage behavior and swelling) of the treated Black Cotton Soil with Quarry Dust.
- Determination of Optimum Percentage of Quarry Dust to be used in the stabilization with the intension of minimizing swelling potential.
- Suggest some relevant and concrete recommendations regarding the use of Quarry Dust as stabilization material for Black Cotton Soils for the benefit of geotechnical practice in Bahird.

3. MATERIALS, METHODS AND PROCEDURES

The black-cotton soil cast-off in this study was mixed with quarry dust in different proportions and a series of laboratory tests were conducted on samples containing various percentages of quarry dust i.e. 0%, 10%, 20%, and 30% by dry weight of the black cotton soil. The Liquid limit, Plastic limit, Linear shrinkage, Free swell, Specific gravity and CBR, Compaction characteristics (OMC and MDD) tests were conducted on black cotton soil and quarry dust mixes as per relevant ASTM and IS codes of practice. The materials used and the methods adopted in this research work are discussed as follows.

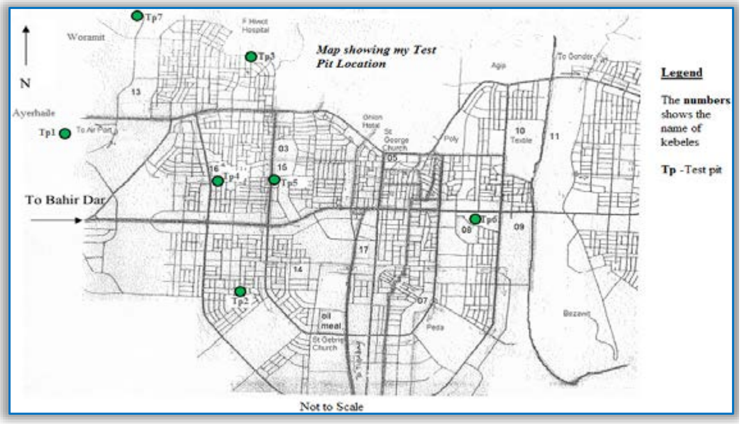

Figure 1. Map of Bahirdar City (Courtesy of Municipality of Bahirdar (Fasil, November 2003) – Showing sites for soil sample collection

— Black Cotton Soil

Disturbed Black Cotton soil which is expansive in nature was collected from seven different Kebeles of Bahir Dar city as shown in figure 1 below and an experiment was performed on the natural black cotton soil and on various percentage addition of quarry dust with the black cotton soil such that the index properties of the natural soil and that of the soil-quarry dust mixture was determined.

— Quarry Dust

Quarry dust is the by-Product comprising minerals and trace elements, gained from the crushing operation of stones, usually processed by natural or mechanical means. The quarry dust material used as a stabilizing agent in this study was obtained from Kembaba stone crushing industry located some 30 kilo meters from Bahirdar city is produced from basaltic bed rock.

Figure 2. Sample quarry dust material

4. RESEARCH METHODOLOGY

The methodology utilized for this research work was applied on both natural soil samples and on the different variations of soil quarry dust mixes. Initial soil testing was conducted on natural soil samples and the planned tests were performed on different variation mixtures of (5%, 10%, 15% and 25%) quarry dust added to find out the effect of the various amount of stabilizer on the index properties. After the tests were conducted it shows a specific evaluation of test results and discussion in following sections.

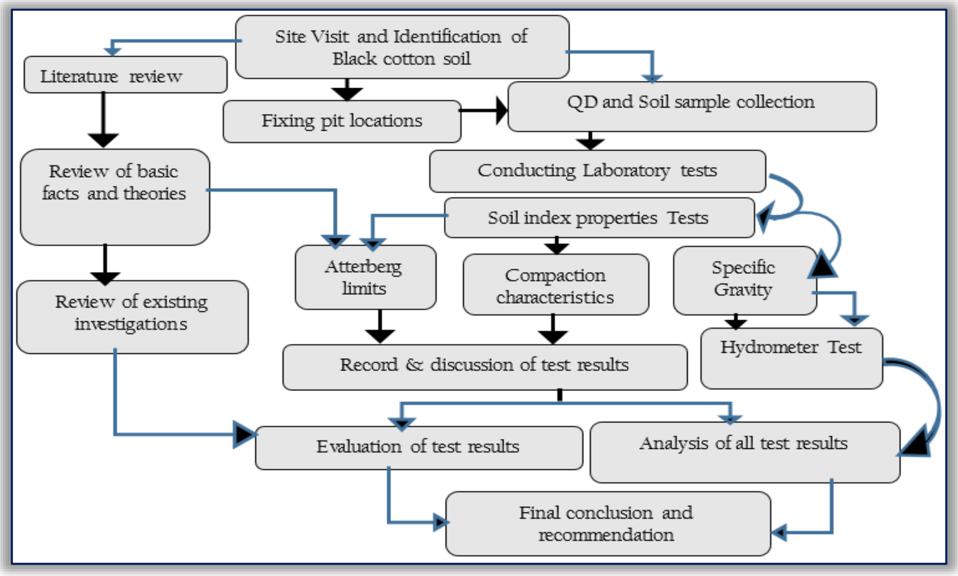

Figure 3. Flow Chart of the Research Methodology

The predominant research method used in this study is experimental. The data collected from the experiment is analyzed to aid in making sound conclusions and inferences in addressing the research objectives.

5. TEST RESULTS AND DISCUSSION

— Geotechnical Characteristics of Untreated Expansive Soils and Quarry Dust

≡ Natural Moisture Content

The NMC rages from 27.90% and 60.17% which is in the rage of NMC of Bahirdar Expansive Soil in accordance with previous research.

Table 1. Laboratory test results of insitu moisture content of the untreated Expansive Soil of Bahirdar.

Test Pit No.	Location	Depth(m)	Color	NMC (%)	Sample condition
TP 1	Ayerhaile	1.80	Black	39.29	oven dried
TP 2	Kebele 14 (Gudobahir)	1.70	Light Black	32.15	
TP 3	Kebele 13 (Hospital)	2.50	Black	27.90	
TP 4	Kebele 16 (Tana)	1.00	Black	39.50	
TP 5	Kebele 15(Gebeya)	2.60	Black	57.64	
TP 6	Kebele 8 (Gambey)	1.50	Brown	60.17	
TP 7	Woramit	2.00	Gray	36.93	

≡ Atterberg and Shrinkage Limit Tests (LL, PL and PI)

The maximum Liquid Limit test result of the untreated Black Cotton Soil from the seven pits is 123.65% which is the Black Clay Soil of Kebele 15 around Gebeya. However, the minimum Liquid Limit is 78.27% (the soil of Woramit).

The maximum and minimum Plastic Limit value of the untreated Black Cotton Soils are 53.96% and 28.54% for the soils of Ayerhaile and Woramit respectively. Moreover, a maximum Plasticity Index of the untreated Black Cotton Soil is 85.64% recorded for the soil of Kebele 15 around Gebeya and the minimum are 45.4% and 45.82% for BCS of Tana Kebele and Kebele 8 around Gambey Hospital.

≡ Linear Shrinkage and Free Swell

The laboratory test result shows almost all soil samples collected from the seven pits have the same Linear Shrinkage results ranging from 16.07% to 21.07%. On the other hand, the Free Swell values of the untreated Blak Cotton Soil of Ayerhaile, Kebele 14 (Gudobahir) and Kebele15 (Gebeya) soils displays Free Swell values above 100%. This indicates that the soils have a high swelling potential.

≡ Grain size Analysis

The hydrometer analysis determines the relative proportions of fine sand, silt and clay contained in a given soil sample. The Grain Size analysis method used in this research is the hydrometer analysis because the particle size of all soils collected from the seven pits are finer than 0.075mm or passes on № 200 sieve.

≡ Soil Classification by Grain size

The soils taken from some test pits in this study are classified as (MH – Highly plastic inorganic Silt) and some are (CH - highly plastic inorganic Clay) based on Unified soil classification system, and A-7-5 based on AASHTO soil classification system.

≡ **Soil Classification by Activity**

The test results exhibited that the Activity of untreated Expansive soils of Bahirdar are classified normal to inactive according to Activity as shown in Table 2 below.

Table 2. Activity of the Natural Black Cotton soils

Pit No	TP1	TP2	TP3	TP4	TP5	TP6	TP7
Activity	1.11	1.02	1.09	0.78	1.36	1.28	0.90
Soil type	Normal	Normal	Normal	Normal	Active	Active	Normal

≡ **Soil Classification by Plasticity**

The untreated expansive soils of Bahirdar are classified as highly plastic based on plasticity index.

≡ **Specific Gravity**

The maximum and minimum specific gravity test results for untreated expansive soils obtained are 2.61 for Kebele 16 (Tana) and 2.40 for both Kebele 15(Gebeya) and Kebele 8 (Gambey) respectively.

≡ **Compaction Characteristics**

The laboratory test result shows that the Optimum Moisture Content of all the untreated Black Cotton Soils ranges from 27.2% and 36.3% and Maximum Dry Density ranges from 1.21g/ cm^3 and 1.43g/ cm^3.

≡ **Summary of Untreated Expansive Soil Properties**

Table 3. Geotechnical characteristics of the untreated expansive soil of Bahirdar.

Properties	Index Properties						
	Test Pit No.						
	TP1	TP2	TP3	TP4	TP5	TP6	TP7
NMC	39.29	32.15	27.9	39.5	57.64	60.17	36.93
Gs	2.50	2.48	2.59	2.61	2.40	2.40	2.57
OMC	34.3	27.2	27.5	31.7	30.4	36.3	36.0
MDD	1.34	1.30	1.43	1.38	1.37	1.21	1.27
Grading (%)							
Gravel Size	0	0	0	0	0	0	0
Sand Size	3.33	2.81	2.26	0.14	0.57	7.43	0.15
Silt	43.07	41.86	47.34	41.93	36.56	56.72	44.60
Clay	53.60	55.33	50.40	57.93	62.87	35.85	55.25
Atterberg Limits							
LL	113.67	87.28	85.87	92.78	123.65	86.52	78.27
PL	53.96	31.05	30.91	47.38	38.01	40.7	28.54
PI	59.71	56.23	54.96	45.4	85.64	45.82	49.73
LS	21.07	21.07	19.29	20.71	21.07	19.64	16.07
FS	110	110	85	100	135	95	70
Activity	1.11	1.02	1.09	0.78	1.36	1.28	0.90
Classification							
AASHTO	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-6
USCS	MH	CH	CH	MH	CH	MH	CH

Note: (MH – Highly plastic inorganic silt) and (CH - highly plastic inorganic clay)

— **Geotechnical Characteristics of Quarry Dust**

As we have observed from the test results the Quarry Dust material used in this study is a non-plastic and non-cohesive material.

Table 4. Some Geotechnical characteristics of the Quarry Dust material

Consistency Limit (%)					Grading (%)				Specific Gravity	Compaction characteristics	
LL	PL	PI	LS	FS	Gravel	Sand	Silt Size	Clay Size	Gs	OMC (%)	MDD (g/cc
Nil	Non-plastic	Non-plastic	Nil	Nil	4.95	20.25	71.35	3.45	3.01	5.98	2.25

— **Geotechnical Characteristics of Treated Expansive Soils**

Under this topic to observe the effectiveness of Quarry Dust Stabilization for the Black Cotton Soil; first fix the applicability of the optimum percentage of Quarry Dust used. The selection of optimum percentage of Quarry Dust is mainly affected by the availability and cost of Quarry dust. It on the other hand is affected by availability of quality row material, Crushing Machinery and Transportation costs. Due to these and other reasons I have fix the Optimum percentage of Quarry Dust used is 30% applicable for this study. After fixing the optimum percentage of Quarry Dust content used; select one test pit from the seven which has high swelling behaviour (TP5-Gebeya was selected) and also select one Index property as a controlling test (Free Swell has been taken as a controlling test) and conduct tests on the soil sample with 10%,20% and 30% Quarry Dust variations.

— **Effect of Quarry Dust on Consistency (Atterberg) Limit Tests**

The variations in the Atterberg limits of the treated Black Cotton Soil are presented in following subsequent tables and the results are compared to each other using subsequent charts below.

Note that in considering results of Atterberg limits, it is helpful to note the typical variability encountered in measuring. Strictly speaking, during testing and measuring the results it may vary greatly or in small extent due to the materials consistency, skill of technician, equipment quality etc. Hence, much of the difference in the Atterberg limits between the untreated and QD treated soil samples can be attributed to the usual variability encountered in these laboratory measurements.

— **Free Swell Test (Controlling Test)**

Here we have observed that the application of Quarry Dust up 30% by weight of the Black Cotton Soil reduces the free swell of the untreated soil from 135% to 75%, which means that the high Swelling Potential of this soil were changed to Marginal Swelling Potential with optimum addition of QD content and it indicates that the use of Quarry Dust specifically taken from Kimbaba as a stabilizer is an effective and cost saving method for the black cotton soil of Bahir Dar.

The Consistency limit laboratory test results on the controlling pit for both the untreated and QD treated Black Cotton Soils at various addition of QD are compared using the following chart.

Table 5. Effect of Quarry Dust on Free Swell (Controlling Test)

Test Pit No	Addition of QD	Untreated	10%	20%	30%
TP5-Gebeya (Kebele 15)	Free Swell (FS)	135%	110%	90%	75%

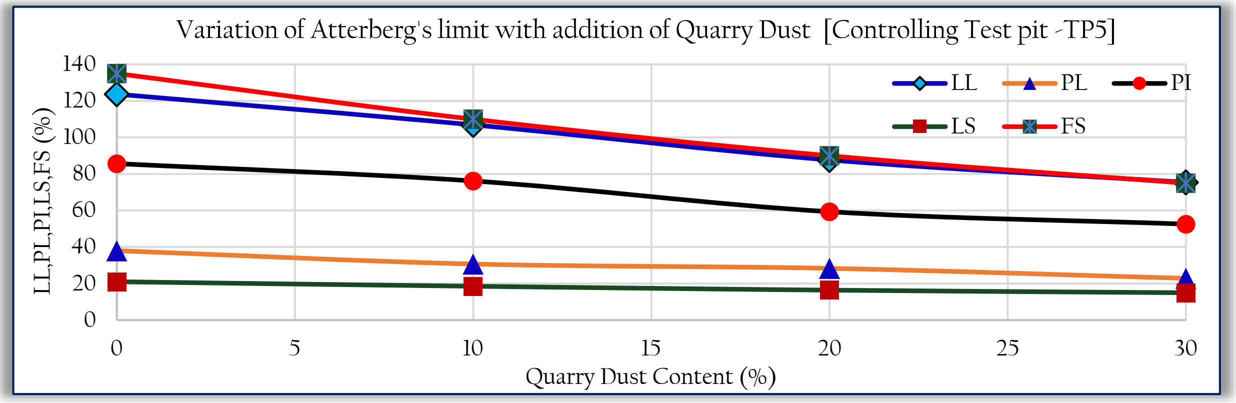

Figure 4. Effect of QD treatment on Atterberg limit

Lastly having determine the effectiveness of applying Quarry Dust content up to 30% on the selected soil and controlling index test; I have also applied and have observed that this percentage of Quarry Dust content has shown best modification on all index property tests for all the test pits.

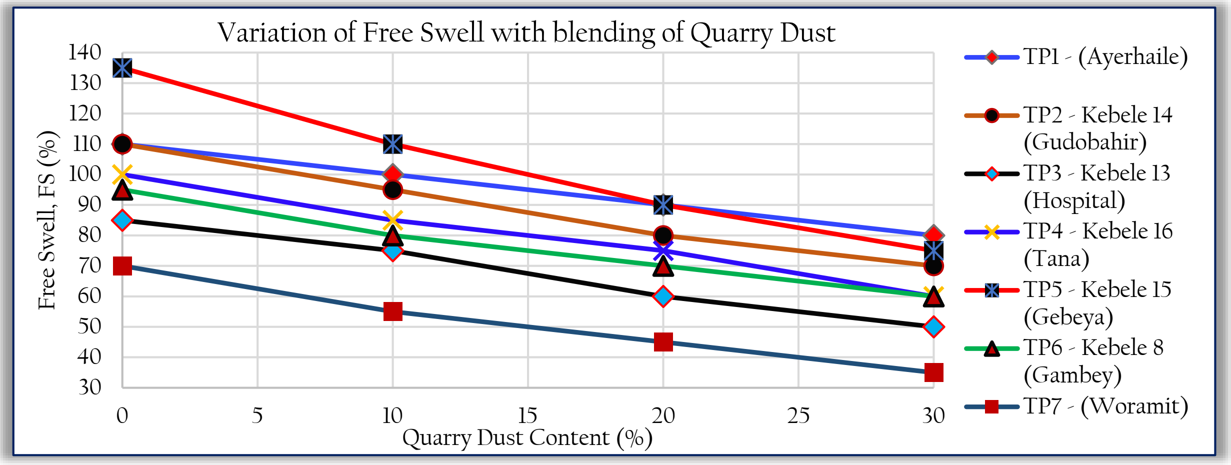

Figure 5. Effect of QD treatment on Free Swell of soil samples

— **Liquid Limit, Plastic Limit and Plasticity Index**

The quarry dust treated Black Cotton Soil sample of Kebele 15 (controlling pit) around Gebeya has shown a maximum reduction of (48.23%) in LL value from 123.65% to 75.42% with addition of QD at Optimum percentage of 30% by weight of the Black Cotton Soil. In general the use of QD content up to 30% for the untreated Expansive Soil of all pits has a significant reduction in the Liquid Limit. A graphical comparison of QD treated as well as untreated samples is shown.

The Plastic Limit as well as the Plasticity Index of samples treated with QD has shown substantial improvements. It is noted that as QD content increases there was an accompanied reduction in the Plastic Limit with subsequent reduction in the Plasticity Index. In general the addition of QD for the untreated Black Cotton Soil has a significant reduction in the Liquid Limit, Plastic Limit and Plasticity Index.

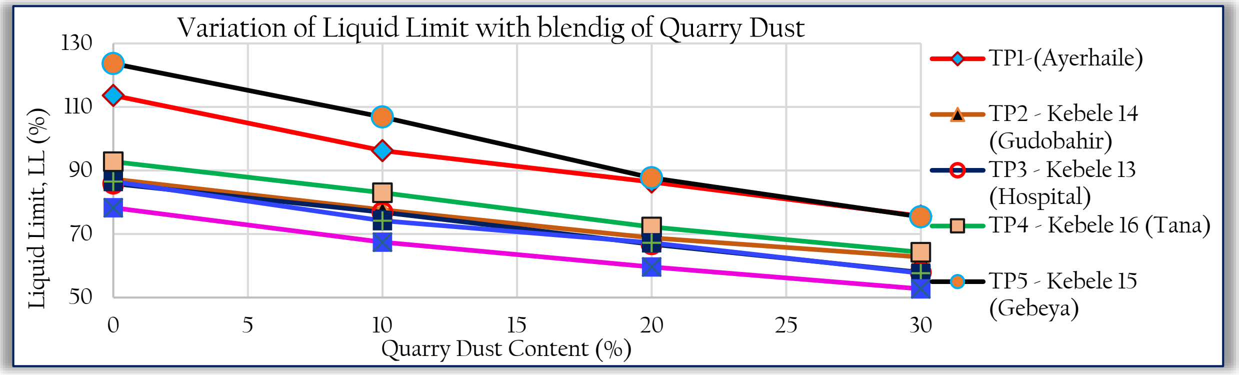

Figure 6. Effect of QD treatment on Liquid Limit of soil samples

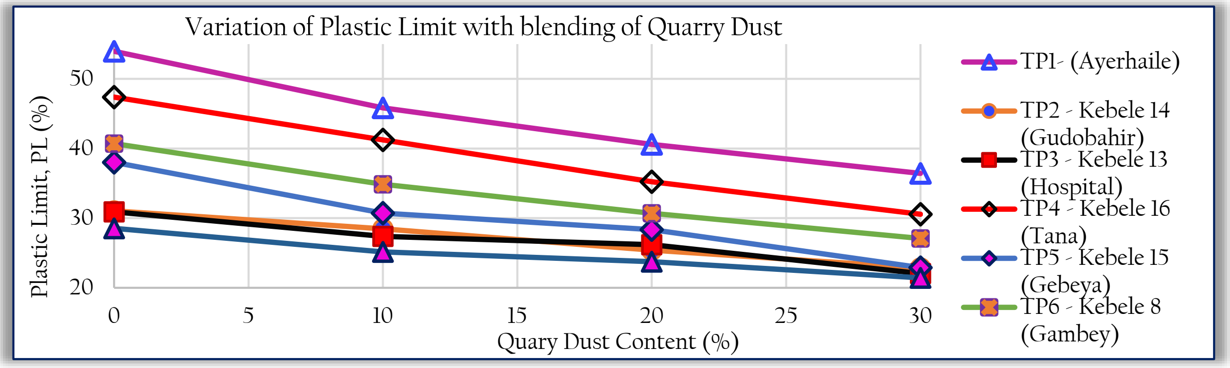

Figure 7. Effect of QD treatment on Plastic Limit of soil samples

Except the soils sampled from Kebele 13 (Hospital), Kebele 8 (Gamby) and Woramit all exhibits a high plasticity based on plasticity classification system of Expansive soil even after treated with various Quarry Dust content.

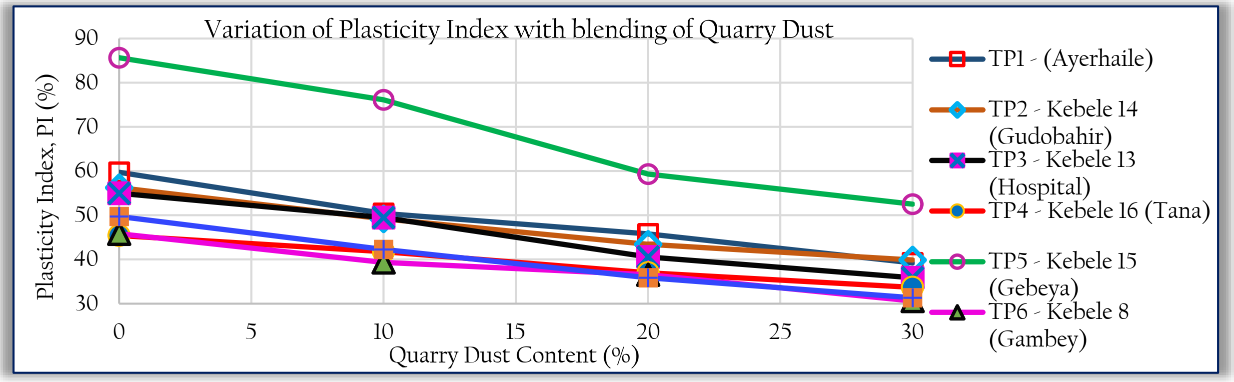

Figure 8. Effect of QD treatment on Plasticity Index of soil samples

— **Linear Shrinkage**

The Linear Shrinkage value of the untreated soil is reduced from 21.07% to 15% with the increase of QD content up to optimum for all the test pit soil samples.

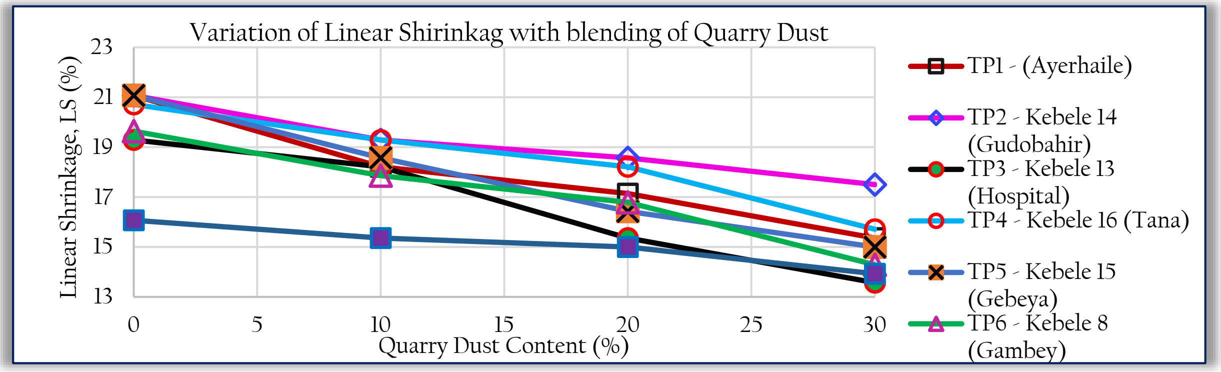

Figure 9. Effect of QD treatment on Linear Shrinkage of soil samples

Table 6. Summary of Atterberg limit test results of QD Treated Black Cotton Soil of all Test pit

Test pit No.	Addition of QD (%)	Atterberg limit Test results				
		FS (%)	LL (%)	PL (%)	PI (%)	LS (%)
TP1-Ayerhaile	Untreated	110	113.67	53.96	59.71	21.07
	10	100	96.25	45.83	50.42	18.21
	20	90	86.36	40.59	45.77	17.14
	30	80	75.63	36.42	39.21	15.36
TP2-Kebele14 (Gudobahir)	Untreated	110	87.28	31.05	56.23	21.07
	10	95	77.64	28.46	49.18	19.29
	20	80	68.82	25.40	43.42	18.57
	30	70	62.74	22.85	39.89	17.50
TP3-Kebele13 (Hospital)	Untreated	85	85.87	30.91	54.96	19.29
	10	75	76.86	27.38	49.48	18.21
	20	60	66.77	26.20	40.57	15.36
	30	50	57.89	22.04	35.85	13.57
TP4-Kebele16 (Tana)	Untreated	100	92.78	47.38	45.40	20.71
	10	85	82.99	41.23	41.76	19.29
	20	75	72.21	35.23	36.98	18.21
	30	60	64.25	30.57	33.68	15.71
TP5-Kebele15 (Gebeya)	Untreated	135	123.65	38.01	85.64	21.07
	10	110	106.86	30.72	76.14	18.57
	20	90	87.67	28.36	59.31	16.43
	30	75	75.42	22.90	52.52	15.00
TP6-Kebele 8 (Gambey)	Untreated	95	86.52	40.70	45.82	19.64
	10	80	74.20	34.86	39.34	17.86
	20	70	67.22	30.69	36.53	16.79
	30	60	57.67	27.08	30.59	14.29
TP7-Woramit	Untreated	70	78.27	28.54	49.73	16.07
	10	55	67.42	25.15	42.27	15.36
	20	45	59.61	23.75	35.86	15.00
	30	35	52.74	21.42	31.32	13.93

LL-Liquid Limit, PL-Plastic Limit, PI- Plasticity Index, LS-Linear shrinkage,
FS-Free Swell, QD- Quarry Dust, TP-Test Pit

— **Specific Gravity**

The Specific Gravity of the Quarry Dust material used in this study is 3.01. The laboratory test result shows that, there is a dramatic increase in Specific Gravity of the untreated Black Cotton Soil with 10%, 20% and 30% addition of QD.

This increase in Specific Gravity of the Soil-Quarry Dust mixes is due to the higher value of Specific Gravity of Quarry Dust. The Specific gravity test results of the Black Cotton Soils are presented in Table 7 below.

Table 7. Variation of Specific Gravity (Gs) with Addition of QD content

Test Pit No	Addition of QD			
	Untreated	10%	20%	30%
TP1– Ayerhaile	2.5	2.59	2.68	2.78
TP2 – Kebele 14 (Gudobahir)	2.48	2.54	2.63	2.75
TP3 – Kebele 13 (Hospital)	2.59	2.63	2.69	2.78
TP4 – Kebele 16 (Tana)	2.61	2.66	2.73	2.8
TP5 – Kebele 15 (Gebeya)	2.4	2.5	2.61	2.73
TP6 – Kebele 8 (Gambey)	2.4	2.48	2.56	2.63
TP7 – Woramit	2.57	2.61	2.7	2.75

A graphical comparison of the untreated with the Quarry Dust treated BCS is presented as follows.

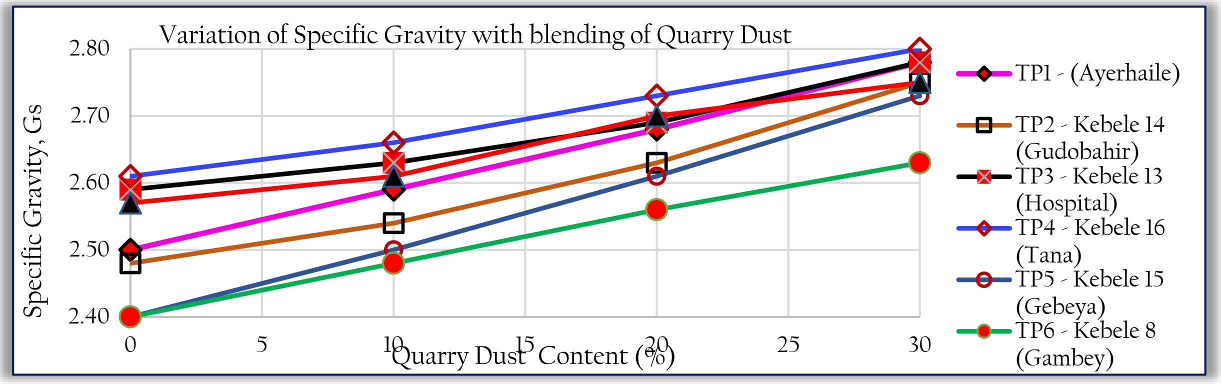

Figure 10. Effect of QD treatment on Specific Gravity of soil samples

— **Compaction Characteristics**

The compaction characteristics of the Quarry Dust treated Expansive soils are presented in Table 8 and Figures 8 and 9 below.

Table 8. Summary of results of standard proctor compaction tests

Test Pit No.	Variation of (MDD)(g/cm³) Vs (OMC)(%) with the Addition of (QD)							
	Untreated		10% Content		20% Content		30% Content	
	OMC	MDD	OMC	MDD	OMC	MDD	OMC	MDD
Tp1- Ayerhaile	34.3	1.34	26.2	1.39	25.7	1.44	17.6	1.52
Tp2- Gudobahir	27.2	1.30	23.6	1.36	26.5	1.42	25	1.48
Tp3- Hospital	27.5	1.43	18.5	1.45	29	1.49	26	1.52
Tp4- Tana	31.7	1.38	28.7	1.43	19.2	1.56	15.6	1.64
Tp5- Gebeya	30.6	1.37	28	1.39	26.2	1.42	25.8	1.45
Tp6- Gambey	36.3	1.21	39.1	1.26	33.5	1.29	31.1	1.34
Tp7- Woramit	36	1.27	31.3	1.35	30.4	1.38	25.2	1.43

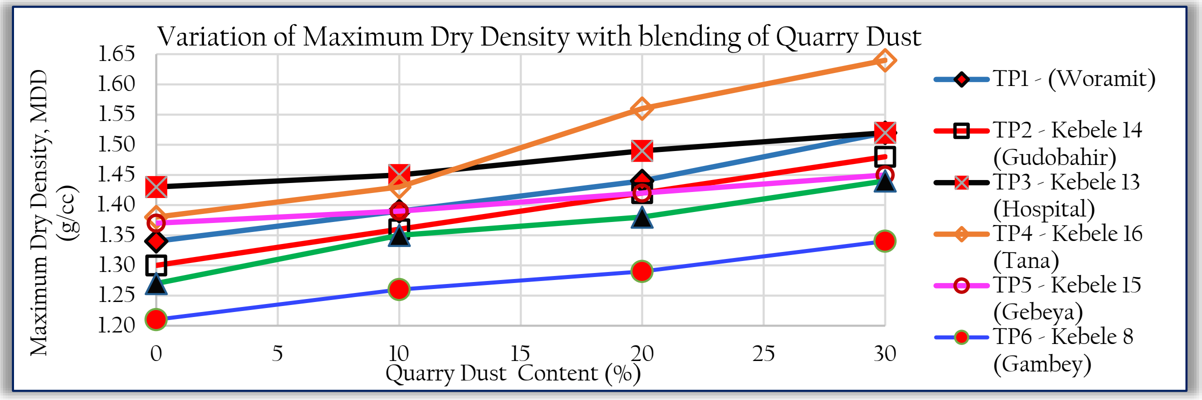

Figure 11. Effect of QD treatment on Maximum Dry Density of soil samples

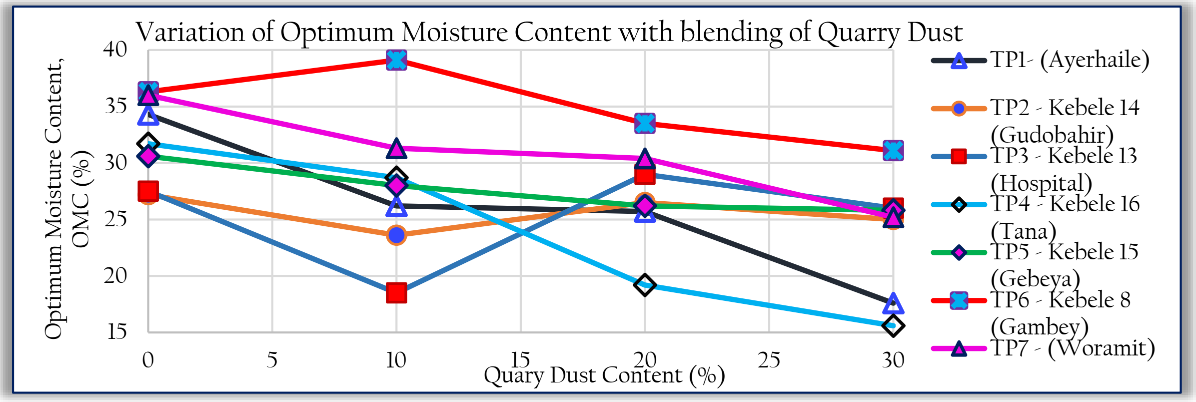

Figure 12. Effect of QD treatment on Optimum Moisture Content of soil samples

It is noted that as Quarry Dust content increases, there is an increase in the maximum dry density (MDD) and a reduction in the optimum moisture content (OMC). However for some soils there is no regular reduction or increment in the optimum moisture content for the addition of QD content as demonstrated by Figure 12 below. The increase in MDD and reduction in the OMC could be attributed to the fact that, as the low density particle of black cotton soils are replaced by a high density quarry dust (specific gravity of 3.01). The effects brought on the sample tests are presented in "Figures" 11 and 12.

— **California Bearing Ratio (CBR)**

A typical test results are illustrated in Figure 13 below. In some instances, the initial penetration takes place without a proportional increase in the resistance to penetration and the curve may be concave upward. In such cases to obtain the true stress-strain relationships, correct the curve having concave upward shape near the origin by adjusting the location of the origin by extending the straight line portion of the stress-strain curve downward until it intersects the abscissa. But here the plunger is perfectly bedded in the specimen no need for correction and the loads used to penetrate each 2.54mm and 5.08mm are just read directly. Finally CBR is calculated using its formula and the result is tabulated as follows.

Table 9. Summary of results of California Bearing Ratio tests

CBR Value Determination for soil specimen soaked about 96 Hours				
	Untreated BCS		30% QD Treated BCS	
Penetration(mm)	2.54mm	5.08mm	2.54mm	5.08mm
Blows	CBR Value (%)			
10	0.76	0.89	3.11	3.13
30	1.40	1.65	5.52	4.87
65	3.11	3.30	7.43	7.20

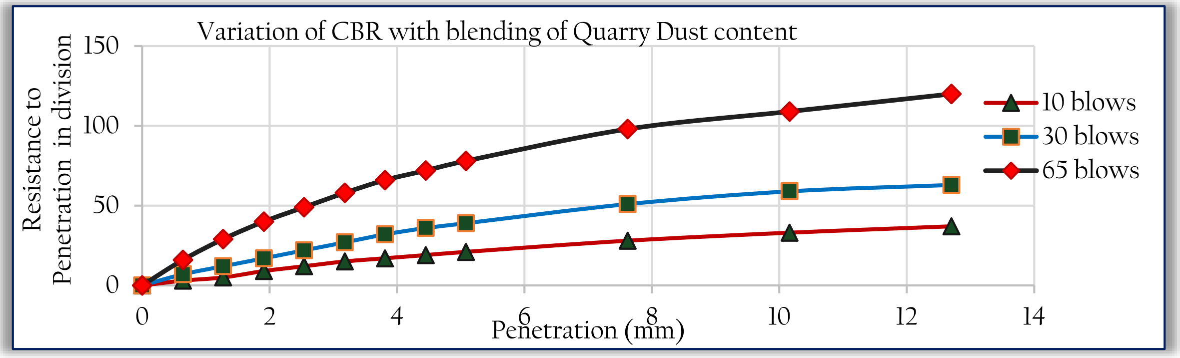

Figure 13. Typical CBR Test Result of Untreated BCS of TP5-Kebele 15 (Gebeya)

For the Untreated Black Cotton Soil all the CBR values for all blows at 5.08mm penetration is greater than 2.54mm penetration. Since the CBR for the three trials are greater for 5.08mm penetration, the CBR corresponding to 5.08 mm penetration should be taken for design. On the other hand for the 30% QD treated case the CBR values of 30 and 65 blows are greater at 2.54mm penetration and hence these values are taken for design.

The CBR values of the Untreated and 30% QD treated soils at 95% Dry Densities are 0.9% and 3.7% respectively. The lower values of CBR at 95% Maximum Dry Density even after the application of 30% QD content is attributed to the reason that soaking could have a weakening effect with minimum percentages of stabilizers. The CBR value less than 5% shows that the material if used as sub grade is very poor as per table 9. A small CBR value indicates that the thickness of pavement shall be increased in order to spread the traffic load over a greater area of the weak sub grade. This is important to prevent the weak sub grade material from excessive deformation and road pavement failure.

The CBR swell for the untreated Black Cotton Soil is 7.03% and that for the 30% QD treated BCS is 5.47%.

6. CONCLUSIONS

Based on the laboratory studies carried out and the analysis and interpretation of results obtained, the following conclusions can be drawn:

— The Black Cotton Soils booked from the six pits investigated in this study are classified as A-7-5 and the rest one (BCS of Woramit) is A-7-6 according to AASHO and CH/MH according to USCS classification systems.
— The hydrometer test results revealed that all expansive soils investigated in this study contains clay and silt fractions as their governing pioneer particles and very small amounts of fine sand sized particles.
— It is observed that, the Atterberg limits (liquid limit, plastic limit, plasticity index, linear shrinkage and free swell) values are reduced significantly with the addition of Quarry Dust content due to the Non-plastic property of Quarry Dust used.
— Specific gravity & Maximum Dry Density values are increased with addition of Quarry Dust content.
— The use of Quarry Dust as a stabilizer is not that much effective both on the CBR and CBR swell values.
— From the experimental analysis it is found that Quarry Dust obtained from Kimbaba up to 30% can be utilized for strengthening the Black Cotton Soil of Bahirdar with a substantial save in cost of construction.
— Hence, from this research, it can be concluded that the Black Cotton Soil of Bahirdar can be used as a foundation base and if no another best choice it can be used as sub grade soil for road construction after Stabilizing up to 30% Quarry Dust content occupied from Kimbaba.
— It can be inferred that Quarry Dust has a potential to modify the characteristics of Expansive Soils like Black Clays and to make these soils suitable in many civil engineering applications.
— Interpretations made in present study leads us sustainability of soil and structure on Black Cotton Soil will increase with the addition of Quarry Dust.
— It is well known that depletion of waste as a Stabilizer can reduce the cost of stabilization process and also due to use of waste it do not affect the environment.

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