Stabilization of Expansive Soil with Waste Marble Dust and Sugar Cane Molasses (Case of Modjo Town, Ethiopia)

Liben Taressa Dilgasu

A Thesis Submitted to Department of Civil Engineering

College of Civil Engineering and Architecture

Partial Fulfillment of the Requirement for the Degree of Master's in Civil Engineering

Office of Graduated Studies

Adama Science and Technology University (ASTU)

May, 2025

Adama, Ethiopia

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Declaration

I decide that this thesis entitled "***Stabilization of expansive soil by waste marble dust and sugar cane molasses in case of Modjo Town"***is my own work and has not been submitted to any University for similar purpose. The references used in this proposal are duly recognized by proper citation

Liben Taressa Dilgasu ------------------------------------- -----------

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Approval page

I /we here by certify that the recommendation and suggestion given by the thesis review committee are appropriately incorporated in to the final thesis proposal entitled "***Stabilization of expansive soil by waste marble dust and sugar cane molasses in case of ModjoTown"*** by LibenTaressa Dilgasu

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Abstract

Foundation soils need to have some desirable properties such as good stiffness, shear strength, volume stability, bearing capacity, etc. If these properties are not satisfied for the required civil engineering projects, should be stabilized with best stabilization method. Expansive soils are known for their high compressibility and low bearing capacity in the fluctuation of saturation level. In this thesis, improvement of expansive soil by adding Waste marble dust and sugar cane molasses through laboratory experiment were performed. The objectives of the thesis are to improve engineering behavior of expansive soil by mixing Waste marble dust and sugar cane molasses. Waste marble dust15%, 20%, 25% and 30%; and sugar cane molasses 4%, 6% and 8% additives added to expansive soil to obtain optimum improvement of engineering behavior of expansive soil. Utilization of waste like marble and sugar cane molasses is an alternative mechanism to protect environmental pollution, health and reduce construction cost. The findings of this thesis reveal that WMD and SCM could be used to stabilize expansive soil stabilize. As the percentage of WMD and SCM increases the engineering properties of expansive soil gets improved. Optimum amount of WMD and SCM that best improves the engineering properties of expansive soil are 25% and 8% respectively.

Key words: Expansive Soil, Waste marble dust, Sugar Cane Molasses, Soil Modification

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Acronyms

AASHTO	American Association of State Highway & Transportation Official
ASTM	American Society for Testing and Materials
CBR	Californian Bearing Ratio
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
SCM	Sugar Cane Molasses
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
WMD	Waste marble dust
ES	Expansive soil

Chapter One

Introduction

1.1 Background and Justification

Expansive soils are highly plastic material due to lack of sand and organic content. Mostly expansive soil found in tropical and subtropical areas (Bell, 2013.), (Uge, 2017). They are known for their high compressibility and low bearing capacity in the fluctuation of saturation level. As a result expansive soil should be improved before construction. Currently there are many stabilizing agents for expansive soil such as lime, cement, gypsum, fly ash, etc.

Research by (Sadique, 2023) showed that the liquid limit, plastic limit and plasticity index of the Expansive soil decrease and maximum dry density and CBR increase by on addition of 12% Molasses and 1.5% Jute Fibre as an optimum when compared with untreated Expansive Soil.

Addition of 10% Waste marble dust on expansive soil increases unconfined compressive strength up to 100%. This is due to pozzolanic reaction in the presence of water producing stable calcium silicate hydrate and reduction of clay content which increase coarser particles (Abdul waheed, Raja Abuibakar, Muhamed Usman and dr Syed shuja , September 2021).

WMD additive addition decreased the swell % to an acceptable limit of 0.3% and the cohesive properties of treated clay particles decreased as it starts behaving as granular material after soaking. Aggregation of the soil particles by the WMD and soil reaction reduces the size of pores in the soil matrix and weakens the cohesive forces; as the soaking extends, it becomes difficult for the moisture to enter the clay matrix causing the soil to swell. The strengthening of the inter particle bond due to the cementations' effect of WMD plays an important role in reducing the swelling potential of soil (Abdul waheed, Raja Abuibakar, Muhamed Usman and dr Syed shuja , September 2021).They also found that WMD decreases MDD and the OMC increases for all WMD dosages due to the low specific gravity of Waste marble dust, mechanical action, and increased water affinity of Waste marble dust and The maximum improvement of soaked CBR attained at a 10% dosage of WMD. Weak or poor soil conditions pose significant challenges in construction projects, often leading to stability issues, settlement, and bearing capacity problems (Ibrahim Haruna Umar and Hang Lin, 2024). Soil stabilization is mainly used to improve the engineering properties of soils, such as strength, stiffness, permeability, and durability and often applied to fine-grained soils prone to swelling, shrinkage, compaction, and liquefaction. Marble powder is composed of calcium carbonate, which can react with clay minerals and cement the soil particles (Ibrahim Haruna Umar and Hang Lin, 2024).Marble powder improves soil properties through pozzolanic, cation exchange and carbonation reactions that cement particles, modify plasticity, and neutralize deleterious alkalis over time. The calcium ions released play a key role in inducing these beneficial changes that increase stability (Umar & Firat, 2022)]. In addition, marble powder is an environmentally friendly and cost-effective alternative to conventional stabilizers, as it can reduce the disposal of industrial waste and the consumption of natural resources (Ibrahim Haruna Umar and Hang Lin, 2024). Marble powder can improve soil's geotechnical parameters, reducing plasticity and swelling and increasing UCS. This suggests its potential as a soil stabilizer, especially for soils with high clay content. Factors such as curing time, molding water content, and composition ratios significantly impact UCS (Ibrahim Haruna Umar and Hang Lin, 2024). For instance, UCS increases with clay content and cement–tailing ratio but decreases with molding moisture content.

1.2 Statement of the Problem

In Ethiopia 40% of the land area is expansive clay. Expansive soils are known for their swelling nature which causes numerous problems which includes foundation damage, structural problems, uneven floors, gaps below doors, etc. Ethiopia being tropical country, rainfall is seasonal and ground water table fluctuation during summer and winter season is high. As a result; structure constructed on expansive soil faces uplift pressure during summer season and shrinkage during winter season. Expansive soil causes foundation wall crack and consequently allows water to inter into basement leading water damage, plant root growth. Major structural cracks occurred as a result of settlement due to change of moisture in the soil. There are also functionality problems because of crack and swell of the expansive soil. Therefore; expansive soil should be stabilized for constructing on such soil or using such soil as construction material. There are a number of stabilization methods: cement, lime, fly ash, chemicals, cut and replace, etc. Despite their improvement they have high cost, environmental problems, feasibility issue, new methods are demanded. Waste marble dust is non-plastic fines material added to expansive soil to improve CBR, maximum dry density and unconfined compressive strength and its effect on plastic limit, liquid limit, plasticity index and free swell is limited. Whereas sugar cane molasses additive on expansive soil improves the liquid limit, plastic limit, plasticity index, swelling pressure, CBR, maximum dry density and Unconfined compressive strength. However compared to Waste marble dust, sugar cane molasses has lower effect on CBR, maximum dry density and unconfined compressive strength used as additive for expansive soil improvement. In addition sugar cane molasses is moisture susceptible, difficult to use in higher amount alone. Even though there are some researches done on stabilization of expansive soil using Waste marble dust, Waste marble dust and cement, sugar cane molasses; there is no research done by blending Waste marble dust and sugar cane molasses as additives to stabilize expansive soil. In addition each of the additives has their own role in stabilizing expansive soil; their blend effect should be known.

Even though waste materials show promising results in the laboratory, their applicability in the field is still missing or limited, except the few wastes like fly ash that is utilized in the field by few countries (Niyomukiza, Wardani, & Setiadji, 2023). Therefore; this research aimed to find stabilization mechanism to stabilize expansive soil and solve environmental problems and preserves scarce resources by using Waste marble dust and sugar cane molasses additives.

1.3 Research questions

- What are the engineering behaviors of expansive soil selected at Modjo town?
- Do Waste marble dust and sugar cane molasses improve the engineering behaviors of expansive soil selected at Modjo town?
- How much percentage of Waste marble dust and sugar cane molasses best improves engineering behavior of expansive soil?

1.4 Objectives

1.4.1 General objective

The general objective is to investigate the effect of addition of Waste marble dust and sugar cane molasses on the engineering properties of expansive soil through laboratory tests.

1.4.2 Specific objectives

- To characterize the engineering properties of expansive soil selected at Modjo town.
- To identify the effect of Waste marble dust and sugar cane molasses additives on expansive soil's engineering property.
- To obtain the optimum percentage of Waste marble dust and sugar cane molasses that best improves engineering behavior of expansive soil.

1.5 Significance of the Study

Upon completion of this research, expansive soil contributing about 40% portion of Ethiopian land could be stabilized with Waste marble dust and sugar cane molasses. The Waste marble dust that could be disposed and sugar cane molasses used for agricultural feed could be used for stabilization. This intern preserves the environment by minimizing disposal problems, carbon emission, etc. Marble producing and sugar factories could be benefited by selling their by-product.

1.6 Scope and Limitation of the Study

On this research work conclusion were drawn based on laboratory test result and field tests were not conducted due to limitation of time and resources. All tests conducted for soil sample that were collected from Modjo town. Waste marble dust15%, 20%, 25% and 30%; whereas molasses 4%, 6% and 8% by dry mass of soil were added to stabilize expansive soil. Therefore; variability of expansive soil, the chemical composition of marble and sugar cane molasses should be considered while applying this on other places. To understand the behavior of soil samples stabilized using WMD and SCM, detailed tests such as consolidation should be conducted but there is no instrument in ASTU.

Chapter Two

Literature Review

2.1 Introduction

This portion elaborates previous findings on the use of Waste marble dust and sugar cane molasses as stabilizing expansive soils. Detail literature review regarding to stabilization of expansive soil with sugar cane molasses and Waste marble dust, with the aim of finding out whether or not mix of sugar cane molasses and Waste marble dust could be used as a stabilizing agent were done. Engineering properties such as Alterberg limit, CBR, standard compaction, unconfined compression, etc of expansive soils mixed with sugar cane molasses and Waste marble dust were assessed.

2.2 Expansive soil Problems

Expansive soils are soil type which changes volume with change of moisture level, which is they shrink when dry and swell when it is wet. Expansive soil deforms more than elastic deformations and could not be known with classical elastic or plastic theories (Gizachew, 2019).

Problems of expansive soil has appeared as cracking of building foundations, channel, break-up of pavements, sewer lines, water pipe lines, gas pipe lines and irrigation systems (Ali, 2014). Expansive soils are a potential natural hazard therefore; should be stabilized well, otherwise it causes extensive to structures (A. Al-Rawas, 2002). Expansive soils causes potential natural hazard to structures, especially for light buildings and pavements, than earth quake and floods (Holtz, 1973) as reported on research of (Gizachew, 2019).

In the United States damage caused by expansive clays exceeds the combined average annual damage from floods, earthquakes, hurricanes and tornadoes (Holtz, 1973). Expansive soils damage foundation by uplift pressure when moisture increase and lift up lightly loaded and result cracks in continuous strip footings. Such uneven movement and cracking of foundation can cause distress to the rest of the structure.

Expansive soils are those that experience significant volume changes associated with changes in water contents. It expands when water is added and shrinks when they dry out. An expansive soil expands due to the presence of highly reactive clay minerals such as montmorilonite and smectite. This continuous change in soil volume can cause light structure built on this soil to move unevenly and crack.

Therefore it is necessary to improve the soil properties to avoid damages to the structure. Sugar canes molasses and marble dust are used to improve the properties of expansive soil which are available in large amount and are produced in huge amount by the sugar cane and marble industry.

The removal of expansive soils and replacement with suitable material has been widely practiced worldwide. Reasonable material is available within economic distances; however, suitable materials are not readily an available in urban areas for borrowing, which has to be hauled from a long distance. Instead of borrowing suitable soil from a long distance away, after stabilization with cost effective and readily available industrial waste materials. Such wastage products are also used to minimize environmental hazards such as CO2 in the atmosphere to minimize the percentage of industrial products used for stabilization, such as cement.

One of the major problems worldwide is the availability of natural construction material within reasonable hauling distance from the project to be planned to build. The main problems associated with construction materials in the road industry was failures of pavement before attain design period of pavement, and the engineering problems related to expansive soils have been reported in many countries, but those mostly located in arid and semi-arid regions.

The cyclic wetting and drying process causes vertical movements in expansive soils and movements to lead to the failure of pavements or structures. Such problems exist widely in Ethiopia. It’s estimated that the region covered by expansive soil in Ethiopia is 23.7 million acres (Tamiru, January 2019). Roads constructed on expansive soil also have a problem on structural layers on the embankment due to its unusual cyclic swell shrink behavior of expansive soil. This form of soil swells when it comes into contact with water, and shrinks when the water evaporates. Due to this movement, loosely loaded structures such as foundations, pavements, channels beds and linings and residential buildings constructed on then are seriously damaged.

The annual damage to civil engineering structures on expansive soil has been predicted to be \$1000 million in the US, £150 millions in UK and several billion pounds worldwide (Hassan A. M. Abdelkader, Mohammed M.A.Hussein and Haiwang Ye, 2021). Expansive soil composed of predominately of a specific types of clay soil, is one of the types of foundation soil considered troublesome. This soil swells if its water content rises and shrinks if the water table decreases due to seasonal condition, the fluctuation of moisture content occurs typically.

Either vertically or horizontally, the change in the soil volume associated with expansion or shrinkages results in deformation of soil. This deformation will lead to significant distortion of the road surface in the case of pavement.

Therefore; stabilization is needed to mitigate these issues. The pavement design assumes that the minimum defined structural quality for each material layer in the paving system will be achieved. Each layer must resists hearing, to avoid excessive deflections causing the layer or overlaying layers to crack fatigue, and to prevent excessive permanent deformation. If the consistency of a soil layer increases, the capacity of that layer to spread the load over a wider area increases, so that it is possible to reduce the necessary thickness of the soil and surface layer. Stabilization by compaction (mechanical) or stabilization by chemical additives is widely used methods of stabilizing soils.

2.3 Effect of cane molasses on properties of expansive clay soil

Because clay particles have negative charge on their surfaces, they attract and absorb positively charged ions typically calcium and magnesium ions, but in semi-arid clay, sodium ions to maintain equilibrium (Quirk, 1994), as cited in (M’Ndegwa, 2011). The average PH of clay soil dropped from 7.0 to 6.1 when molasses having PH of 5.8 was thoroughly mixed with it (M’Ndegwa, 2011). It is due to cation exchange at the surface of clay particles.

Molasses reduces plasticity index, soil PH, swelling potentials and swelling pressure and OMC and increased MDD, CBR, UCS values as molasses content is increased up to certain percentage. On the other hand, if the Molasses is increased beyond certain percentage the reverse properties are observed. Curing has an insignificant effect on the geotechnical properties of molasses stabilized soil (Devender & Jagan, 2018). Therefore; molasses could be used as standalone soil stabilizer, provided the necessary protection form water intrusion is made (Devender & Jagan, 2018).

(Suriadi, 2002) Investigated, the potential for molasses, either by itself or in conjunction with gypsum, to enhance the structural stability of sodic soils. They discovered that the soil's wet stability increased when molasses and gypsum were used together or separately. Additionally, they observed that the combined effect was the strongest. Above that the sandy clay loam's exchangeable sodium percentage (ESP) decreased from 7.9% to 4.1% (M'Ndegwa, 2011). Thus, they came to the conclusion that reducing dispersion enhanced the soil's structural stability. Because the soil understudy was also sodic, it was assumed that the same thing had occurred. Since sodicity causes dispersion, (Suriadi, 2002) found that a decrease in sodicity resulted in a decrease in dispersion and, as a result, the occurrence of flocculation.

The clay particles flocculation/aggregation was initiated due to the reduced thickness of diffuse double layer. The clay particles were then able to flocculate due to the double layer's decreased size (M'Ndegwa, 2011). In addition to lowering the amount of water adsorbed in clay, the multivalent cations that replaced the monovalent ones at the surfaces of the clay particles also decreased the water content of the clay soil's liquid limit according to (Hoddinott, 1990), as cited in (M'Ndegwa, 2011). The shrinkage limit and plastic limit, on the other hand, had higher water contents, respectively.

The hydroxyl (OH) group, which is unique and dominant in sugar and molasses, is responsible for hydrogen bond to bind soil particles together. In fact, (Suriadi, 2002) found that adding cane molasses to clay soil decreased the amount of clay in the soil, which in turn led to decrease in specific surface of soil particles. When comparing lime stabilization with molasses stabilization, it was found that in both stabilization, CBR increases as stabilizing agent increase. However; CBR value from lime stabilization were significantly higher while CBR values from molasses stabilization began to decline once 8% molasses content was reached, those from lime stabilization also seemed to show an upward tendency as lime level increased.

(Ash-Shu'Ara, M., & Ajayi, A., 2018)also found that course sand particles could solve the problem of swelling and shrinkage in expansive clay.

2.3.1 Chemical composition of molasses

Molasses is an organic matter produced from byproduct of sugar and their chemical compositions differ from factory to factory.

Table 2.1: Chemical composition of molasses

S.N	Researcher	Chemical composition percentage of molasses											
		AL_2O_3	Fe_2O_3	SiO_2	CaO	K_2O	TiO2	P_2O_5	Mgo	MnO	Na_2O	S	Cl
1.	(AMUNGA, 2020)	2.95	2.44	5.77	26.12	39.11	0.55	2.64	13.54	0.37	0.07	4.66	1.47
2	(M'Ndegwa, 2011)	0.3		0.3	1.1	3			0.15		0.02		

2.3.2Effect of Molasses on Atterberg Limits

(Devender & Jagan, 2018) found that plasticity index slightly decrease with increment of molasses and cured and uncured samples have insignificantly variation. This is the case that molasses reduced surface activities by flocculation and agglomeration of clay particles by cation exchange between molasses and soil. By addition of 6.5% of molasses, the value of liquid limit and plastic limit increased and plasticity index of modified soil reduced (M'Ndegwa, 2011). He observed that the reduced clay content due to the addition of molasses contributed to a reduction of the PI of the soil

The study by (M'Ndegwa, 2011)showed that the elements responsible for the binding of the lateritic gravel soil particles and the dust suppression were calcium, potassium, Silicon and magnesium elements which were present in large amount in sugar cane molasses.

2.3.3 Effect of Molasses on maximum dry density and optimum moisture content

The value of maximum dry density of modified soil increased due to proper rearrangement of modified mix and due to improved binding capacity (M'Ndegwa, 2011). Optimum moisture content decreases and maximum dry density increases with increase in molasses content up to optimum amount of molasses (Devender & Jagan, 2018).

2.3.4 Effect of molasses on CBR value and CBR swell

When expansive soil mixed with molasses the CBR value and load bearing ability of the soil were increased with increase of molasses content due to increase in density of modified mix, which led to soil mass having more strength (M'Ndegwa, 2011).

(Rafa'i, 2006) Used molasses to stabilize, intermediate compressible clay soil and highly compressible clay soil and the results showed that there was appreciable increment in unconfined compressive strength and CBR value for both soils. The values increased with increase in treatment duration.

As observed by (M'Ndegwa, 2011), molasses mixed with expansive clay soil reduced its swelling tendencies as well. However; lime mixed with expansive clay soil provided higher CBR values than those provided by expansive clay soil mixed with molasses.

(Abdul, A., Karthick, G., Mankandan, T., Ravi, E., & Sharma,, 2015)showed that the CBR value of soils had increment ratio of 2.0 to 3.5 in both types of soils. The values increased with increase in treatment duration.

2.3.5 Effect of molasses on unconfined compressive strength

(Suresh, T., Balakrishna, Y., & Nitesh, K., 2017) also observed that bio-enzyme when mixed with black cotton soil could improve the CBR and UCS of the soil.

(Abdul, A., Karthick, G., Mankandan, T., Ravi, E., & Sharma,, 2015) carried out a study on the effectiveness of molasses for improving the shear strength and CBR value of two types of fine grained soils i.e. the intermediate compressible clay soil and highly compressible clay soil. The results showed that with the use of molasses, the Unconfined Compressive Strength and California Bearing Ratio of both soils improved. The UCS of soil increased with increment ratio of 1.57 to 2.01 for both types of soils. CBR value of soils had increment ratio of 2.0 to 3.5 in both types of soils. The values increased with increase in treatment duration.

Table 2.2: comparison of the effect of sugar cane molasses on expansive soil

S.N	Researcher		soil classif	MDD(g/cc)	OMC	LL	PL	PI	Swelling (%)	CBR (soak	UCS(Kpa)
1	Dr. E. Ravi, AnimeshSharma, A.T.Manikandan, G.karthick, A.AbdulJameel	Untreated	CH	1.64	19.7	61.38	28.21	33.2	SL 7.6	3.3	128
			CI	1.86	18.2	45.4	16.83	28.57	SL 8.2	2.16	99
		CH+ 10% SCM		-	-	-	-	-	-	9.3	236
		CI+6% SCM		-	-	-	-	-	-	6.4	192
2	HussainSadique& Ch. Sivanarayana	Untreated	CH	1.4	26.7	80	35	45	FS 126	1.98	
		Treated 12%	CH	1.44	20.42	68	29	39	FS 82	4.09	
3	M. Devender &DepavathJagan	Untreated	CH	1.24	35.4	108	35	73	FS 150	0.77	142
		Expa + 8% SCM		1.27	31	48	24	24		6.93	289
4	(M'Ndegwa, 2011)	Untreated							1.15	1	
		E + 8% S							0.47	23	

2.4 Effect of Waste marble dust on the properties of expansive soil

Waste marble dust is mainly composed of calcium, silica, alumina, which significantly helps stabilize the soil. WMD has PI = 3.4%, liquid limit 22.20%, plastic limit 18.79% and fineness modulus 0.46% (Abdul waheed, Raja Abuibakar, Muhamed Usman and dr Syed shuja , September 2021).

By adding marble powder to clay, the liquid limit (LL) is reduced, the plastic limit (PL) and shrinkage limit (SL) are increased, and the soil's plasticity index (PI) is decreased, which lowers swelling potential. The improvement of soil properties was indicated by reduction of plasticity index (Saxena, 2017). On research by (Babu & S.S, 2017) conclude that marble dust addition showed improved performance in problematic soils with the help of cation exchange reaction and 9% marble dust addition found to be the optimum percentage for stabilizing the soil sample

Table 2.3: Chemical Composition of Waste Marble Dust

S.N	Researcher	Chemical composition percentage											
		CaO	L.O.I	SiO_2	AL_2O_3	Mgo	Fe_2O_3	P_2O_5	Na_2O	SO_3	SrO	TiO2	K_2O
1.	*Magdi M. E. Zumrawi*	54.207	43.50	1.079	0.508	0.235	0.140	0.083	0.075	0.042	0.04	0.021	0.02
2	R. Ali, H. Khan2, A. A. Shah	38.45		26.53	0.39	18.32	13.70						
	(Fathonah, Kusuma, & Hasanah, 2023)	94.13		1.53	0.13	2.85	0.3						

3	Ibrahim Haruna Umar	56.33	42.27	0.28	0.07	0.65	0.37	0.01	0.06				0.02
	(Fentaw & Geremew, 2021)	26.40	21.84	37.16	5.27	1.66	1.66	0.1	2.22			0.12	1.76

The effectivenes of soil strength in stabilization of expansive clay soil with additive depend on the proportion of SiO_2, CaO and Al_2O_3 (Amadi, 2014) and (Adeyanju & Okeke, 2019)**.** CaO is a compound needed in a chemical process with clay,producing high calcium ions that can bind and surround clayparticles. As a result, it can reduce the water drag and affects the CBR value, soil density and swelling of clay soils (Fathonah, Kusuma, & Hasanah, 2023).

Due to larger size of marble as compared to clay, addition of marble dust on clay act as filler to improve gradation of the mixture and consequently improve the properties of the soil (Fathonah, Kusuma, & Hasanah, 2023).

From point view of waste management, environmental conservation, and the economy, it is recommended that marble dust be used for stabilization of expansive soil with substantial save in the cost of construction (Hassan A. M. Abdelkader, Mohammed M.A.Hussein and Haiwang Ye, 2021).

2.4.1 Effect of Waste marble dust on dry density and optimum moisture content

Researches by (Tamiru, January 2019), (Ali, 2014), (Meenakshi, Krishna, Rajesh, Uday, & Kumar, 2023), (Gokani., Akoliya, Davera, Vaghela, & Patel, 2018)and (Magdi M. E. Zumrawi and Eman A.E.Abdalla, 2018) shows that maximum dry density increases and optimum moisture content decreases as marble dust content increases up to optimum amount. On contrast to the above research by (Fathonah, Kusuma, & Hasanah, 2023) indicated that the maximum dry density decreases and optimum moisture content increases as Waste marble dust increases.

2.4.2 Effect of Waste marble dust on Atterberg limit

Due to the Cao chemical in the Waste marble dust, which involves in the cation exchange in the presence of expansive soil, liquid limit, plastic limit and plasticity index significantly decreases as the Waste marble dust increases (Tamiru, January 2019), (Abdul waheed, Raja Abuibakar, Muhamed Usman and dr Syed shuja , September 2021), (Gokani., Akoliya, Davera, Vaghela, & Patel, 2018), etc.

(Hassan A. M. Abdelkader, Mohammed M.A.Hussein and Haiwang Ye, 2021)also found that substantial decrease Atterberg limit LL by 40%, PL by 32%, PI by 60% with increase marble dust up to 25%, however; the rate of decrease is more up to 15% of marble dust. Moreover they attain change of soil class from highly expansive to low expansive soil class.

2.4.3 Effect of Waste marble dust on CBR value and CBR swell

Study by (Tamiru, January 2019) state addition of30% marble dust into the expansive soils, increase the CBR values by 255% to 289%and soil stabilization method by applying waste product marble dust successfully improves swell and strength of expansive sub grade soil with low cost and available locally material.

2.4.4 Effect of Waste marble dust on free swell

The addition of marble dust has resulted in a reduction of the free swell of the soil and as the percentage of stabilizer increased, free swell ratio decreased (Tamiru, January 2019).

2.4.5 Effect of Waste marble dust on unconfined compressive strength

The results of (Magdi M. E. Zumrawi and EmanA.E.Abdalla, 2018) research revealed that addition of 20% marble waste powder to the soil significantly reduced the soil plasticity and free swell index by almost 12%, while the UCS greatly increased by almost 3.5 times of the initial value. Also with the addition of 30% WMD in expansive soil, unconfined compressive strength increase two times the expansive soil’s unconfined strength as reported on the research of (Ditta & Singh, 2019)and (Ibrahim Haruna Umar and Hang Lin, 2024).

Table 2.4: comparison of the effect of Waste marble dust on expansive soil

S.N	Researcher		soil classification	MDD	OMC	LL	PL	PI	Swelling (%)	CBR	UCS(Kpa)	SP
1	*Magdi M. E. Zumrawiand Eman A. E. Abdalla*	Untreated	CH	16.5	22	81	21	60	FSI 170		177.6	
		Soil +20% WMD		17.7	15	73	20	53	150		630	
2	R. Ali, H. Khan2, A. A. Shah	Untreated	CH	15.1		54	23	31	EI 13			9.02 Psi
		Soil +12% WMD		15.64		36	18	18	EI 83			5.56 Psi
3	Ibrahim Haruna Umar and Hang Lin	Untreated	CH	16.5	10	58	28.4	29.6		4.68	245	
		Soil+30% WMD		17.8	12	48	24	24		8.8	525	

4	**(Fathonah, Kusuma, & Hasanah, 2023)**	untreated		18.34	15.70	62	33	29.24		4.9		
		Soil+7% WMD		17.85	18.22	58	36	22		15.5		
5	**(Ditta & Singh, 2019)**	untreated				69	37		81	3.87	88	
		Soil+30% WMD				21	11		28	5.5	167	
6	(Gokani., Akoliya, Davera, Vaghela, & Patel, 2018)	untreated	CI	17.3	18.2	41.7	17.3		55	**8.3**		
		Soil+30% WMD		18.8	14.2	24.6	12.9		39		`	

Chapter Three

Research Methodology

3.1 Introduction

This chapter outlines the collection and analysis of data in order to ascertain the engineering properties of expansive soil when mixed and when not mixed with different proportions of sugar cane molasses and Waste marble dust. It describes the materials used and procedures followed to obtain samples from the field. It also illustrates the tests performed on those materials. The chapter examines the study area and sampling techniques used. In addition data collection and analysis of the desired variables were presented here.

Research by (Sadique, 2023) showed that the liquid limit, plastic limit and plasticity index of the Expansive soil decrease and maximum dry density and CBR increase by on addition of 12% Molasses and 1.5% Jute Fibre as an optimum when compared with untreated Expansive Soil.

Addition of 10% Waste marble dust on expansive soil increases unconfined compressive strength up to 100%. This is due to pozzolanic reaction in the presence of water producing stable calcium silicate hydrate and reduction of clay content which increase coarser particles (Abdul waheed, Raja Abuibakar, Muhamed Usman and dr Syed shuja , September 2021).

Even though waste materials show promising results in the laboratory, their applicability in the field is still missing or limited, except the few wastes like fly ash that is utilized in the field by few countries (Niyomukiza, Wardani, & Setiadji, 2023). Therefore; this research aimed to find stabilization mechanism to stabilize expansive soil and solve environmental problems and preserves scarce resources by using Waste marble dust and sugar cane molasses additives

3.2 Research Design

The research design involves determination of strength and properties of expansive soil stabilized using Waste marble dust and sugar cane molasses. The research found the quantity of Waste marble dust and sugar cane molasses that best applicable as an additive to the expansive soil. Most importantly, the research determines the optimum ratios of Waste marble dust and sugar cane molasses that would be applied to guarantee the most desirable properties. The process is shown in figure 3.1 below.

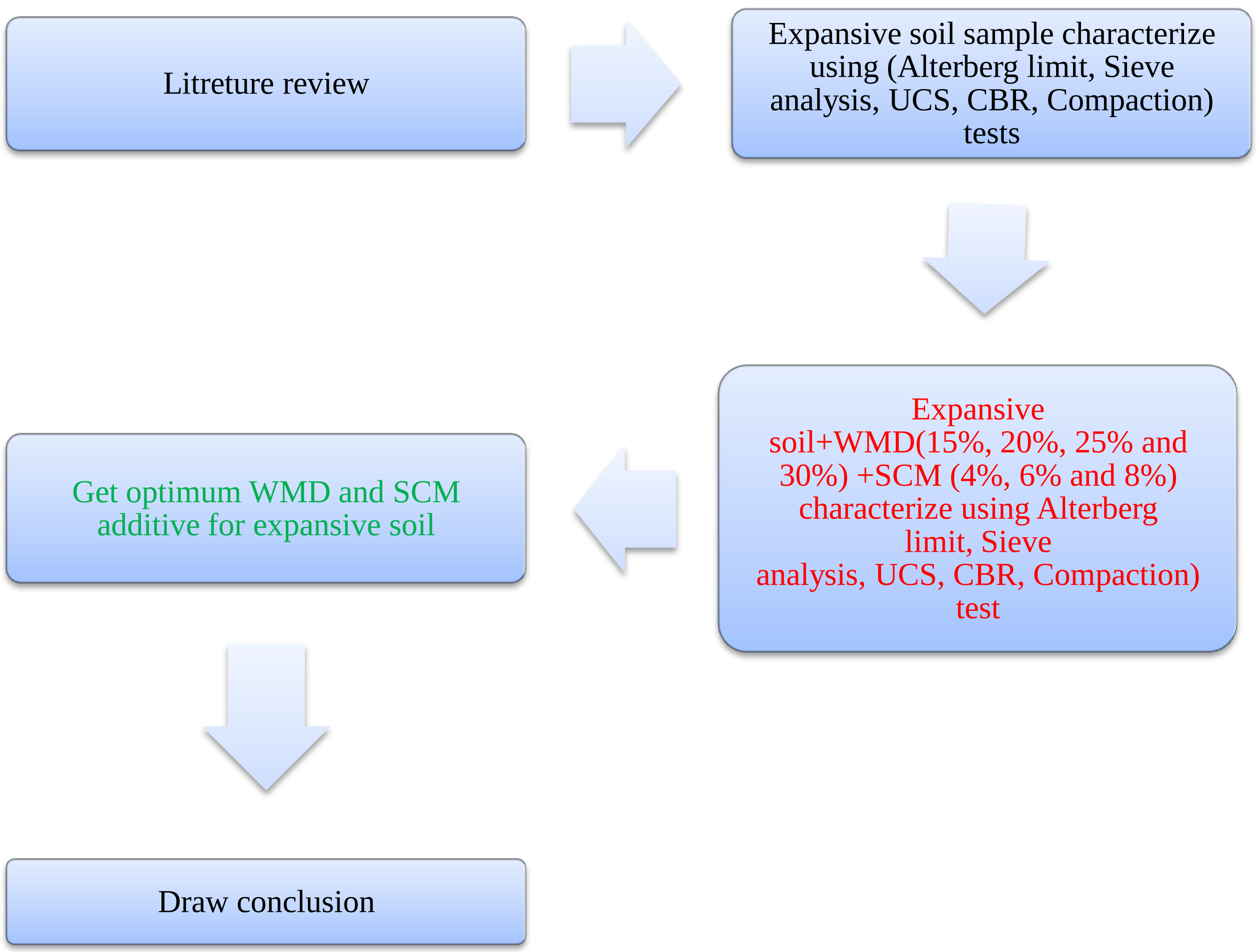

Figure 3. 1: Flow chart showing experimental process

3.3 Materials

Expansive soil was taken from pit at depth of 1.5m to 2m from ground level from Modjo town from two sites. Depth of test pit was to represent foundation depth of light structure. The site proposed purposively because of nearest to laboratory. The disturbed sample excavated in selected test pit after the removal of the overburden and the materials brought to laboratory for testing. Sugar cane molasses collected from Wonji sugar factory and Waste marble dust obtained from marble production company in Adama CHASO Marble Factory.

Initially the native soil samples collected from Modjo town were adequately air dried and classified according to the AASHTO and USC soil classification system. Then on air dried samples additive were added to obtain mixed sample.

First step: The air-dried sample mixed with the required percentage of WMD started from 15% to 30% within 5% difference and SCM started from 4% to 8% within 2% difference for all additives.

Second step: Properly mixed soil sample used for Atterberg limit, free swell index, compaction, CBR, UCS.

Figure 3. 2: Expansive soil sample and during sampling from pit at digging stage

3.5 Laboratory Tests to determine the physical and mechanical properties of expansive soil

The physical properties of expansive soil that are experimented are the particle size distribution and the atterberg limits. In addition to physical properties, the mechanical properties including the compaction test, California Bearing Ratio and the Unconfined Compressive Strength were experimented in this thesis work.

Different Laboratory tests conducted on soil specimen in order to study the properties of soil and soil mixed with varying percentage of Waste marble dust and varying percentage of sugar cane molasses as per ASTM and AASHTO standards.

Experimental method adopted for analysis of the laboratory test result conducted on specimen to draw conclusion.

In order to draw conclusion laboratory tests such as liquid limit (ASTM D4318), plastic limit (ASTM D4318), Plasticity index (ASTM D4318), standard compaction (AASHTO T-99), specific gravity (ASTM D 854), UCS (ASTM D 2166), grain size analysis (ASTM D 6913), soil classification (ASTM D 2487), and CBR (AASHTO 193) tests were conducted in this paper.

This study focused on characterization of expansive soil samples, and WMD and SCM modified samples and evaluate improved properties. Characterization of expansive soil samples done based on consistency limit, gradation, CBR and free swell. The effect of moisture on the foundation soil studied by comparing the swelling potential, California bearing ratio (CBR), and unconfined compressive strength (UCS) values of treated and untreated soil.

Figure 3.3: while testing liquid limit test and apparatus used.

Figure 3. 4: compaction test apparatus and while conducting the test

3.6 Study variables

There are two types of variables that are taken into consideration; the dependent variable and the independent variable.

Dependent variable: Are the mechanical and physical properties of expansive soil which were measured from laboratory test result.

Independent variable: percentage of Waste marble dust (WMD), Sugar cane molasses (SCM) and expansive soil.

3.7 Data collection process

The primary research data collected through laboratory tests. Whereas the secondary data are collected through the existing relevant documents or literatures tried to review and analyze the issues related to the concerned objectives of the study.

3.8 Data processing and analysis

The research conducted first by identification of the use of WMD and SCM as additive for expansive soil through literature review and then from the laboratory test experiments findings were developed.

3.9 Ethical considerations

Prior to data collection an official letter written by ASTU and given to Wonji sugar factory and marble producing company to give me SCM and WMD for the research.

3.10 Data quality assurances

Pre–test of the available instrument done before the main experimentation begin and the test conducted after gaining an awareness on how to conduct the tests by principal investigator. The test result checked with the standards.

3.11 Limitations of the study

In this research WMD and SCM used as additive material. The mechanical properties of expansive soil containing WMD 15%, 20%, 25% and 30%; and SCM 4%, 6% and 8% by weight of dry soil determined by performing laboratory tests.

Chapter Four

Result and Discussion

In this portion the test procedures followed, result and discussion elaborated in detail. The engineering characteristics of expansive soil which is collected from Modjo town stabilized with different percentage of Waste marble dust and sugar cane molasses assessed and the optimum blend proportions determined. Physical tests conducted on different blend ratios selected according to previous works as discussed in the literature review. The test results used to draw conclusions on the performance of the stabilized material and their ability to meet specifications.

4.1 Particle size distribution

Air dried sample of approximately 500mg taken from quartered samples and its mass measured to nearest 0.01 gram, washed on 75µm sieve. For those retained on 75µm sieve dry sieve test and for those passing 75µm sieve hydrometer analysis were done. Dry sieve test performed by placing air dried soil sample on top of orderly nested sieve and shaking for 10 minutes and measuring the mass retained on each sieve to the nearest 0.01gm and compute percent passing. Whereas hydrometer analysis or wet sieve test, the sample immersed in chemical for 24 hours in the cylinder and turned upside down for 1 minute and hydrometer level and temperature were recorded at interval of 0.25, 0.5, 1, 2, 4, 8, 15, 30, 60, 120, 240, 480, 1440 minutes. Percent fines computed using stoke's law as elaborated in the literature review portion.

The gradation test illustrated on figure 4.1 that the expansive soil contains gravel 0.4%, sand particle 25.7%, silt particle of 53.6% and clay particle 26.6%. Particles passing 75µm sieve is about 88.4%, which is fine grained soil group as per AASHTO soil classification system (greater than 35% passing 75µm sieve). Therefore; it is poor for foundation.

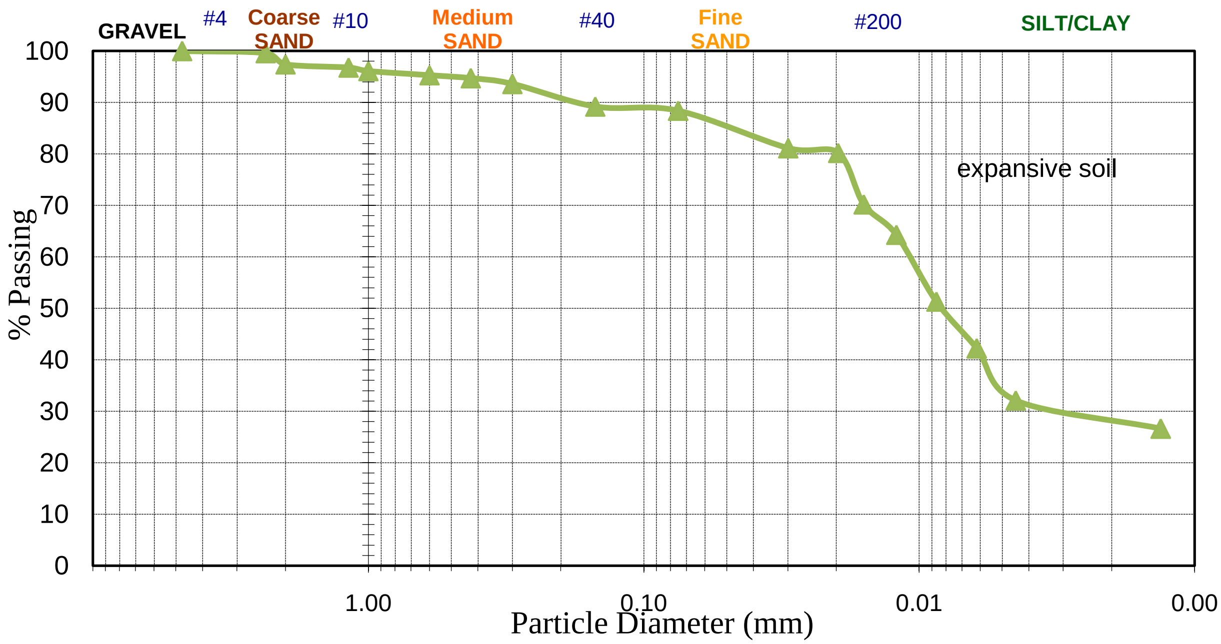

Figure 4.1: particle size distribution of expansive soil

4.2 Effect on atterberg limit

Liquid limit and plastic limit as per AASHTO T 89 and 90 standard test methods were conducted to know the effect of WMD and SCM mixed with expansive soil with different percentage. Air dried fine particles passing sieve size 0.425mm is used for liquid limit and plastic limit test. The expansive soil and WMD samples sun dried to constant mass passing sieve size 0.425mm and SCM mixed thoroughly in the required ratio by weight of dry soil before test.

The plastic limit (PL) is the minimum water content required to change state from semi solid to plastic whereas Liquid limit is the minimum water content to change from plastic state to liquid state. In the laboratory, plastic limit determined as the water content soil begins to crumble when rolled into threads of 3.2mm size and Liquid limit is the moisture content required to close groove at 25 blows using Casagrande apparatus.

The swelling behavior of soil has direct relation with plasticity index, liquid limit and plastic limit. The liquid limit, plastic limit and plasticity index of soil sample collected from Modjo town found to be 76%, 31.7 % and 44.3% respectively as shown in figure 4.2 and table 4.1.

Table 4.1 and figure 4.2 shows that as WMD and SCM content increases liquid limit decreases except for beyond 20% WMD, liquid limit for 6% SCM was little lower than 8% SCM.

Significant reduction of liquid limit from 76% to 46.8% occurred as WMD changes from 0% to 30% and SCM changes from 0% to 8%.

As illustrated on figure 4.3 and table 4.1, plastic limit slightly increases with increase of WMD and SCM content. Plastic limit increases from 31.7% to 38.2% when WMD changes from 0% to 30% and SCM changes from 0% to 8% by weight of dry mass of soil.

Figure 4.4 portrayed that plasticity index decreases as WMD and SCM amount increases. Plasticity index decreased from 44.3% to 8.6% as WMD changes from 0% to 30% and SCM changes from 0% to 8% by weight of dry mass of soil.

As demonstrated in table 4.1, and figures below, liquid limit, plastic limit and plasticity index decreases as the WMD and SCM content increases. This is the fact that SCM facilitates cation exchange, replacing weaker ions in the soil with calcium and calcium carbonate in the WMD reacts with clay mineral in the soil, altering water attraction properties, flocculation and agglomeration of clay particles and partial replacement of plastic soil particles with non-plastic materials (WMD). Therefore; the combination of WMD and SCM successfully improves the plasticity of expansive soil.

For constant SCM percentage as WMD increases liquid limit and plasticity index decreases significantly. These finding is in line with the finding of research by (Tamiru, January 2019), (Abdul waheed, Raja Abuibakar, Muhamed Usman and dr Syed shuja , September 2021), (Fathonah, Kusuma, & Hasanah, 2023) and (Gokani., Akoliya, Davera, Vaghela, & Patel, 2018).This is due to cation exchange between Cao chemical in the Waste marble dust and expansive soil. However; in this finding and research by (Fathonah, Kusuma, & Hasanah, 2023) found that plastic limit increase with increase of WMD for constant SCM.

As SCM content increases for constant percentage of WMD, plasticity index decreases and this is in the same manner with the finding of (Devender & Jagan, 2018), (Sadique, 2023) and (M’Ndegwa, 2011).This is because of reduction of surface activities by flocculation and agglomeration of clay particles by cation exchange between molasses and soil and reduction of clay content. Liquid limit decreases and plastic limit increases as SCM increases for constant WMD content. However; there are contrasting report was found among the authors with these regard. (M’Ndegwa, 2011)reported on his research that liquid limit and plastic limit increases with increase of SCM. Whereas, (Devender & Jagan, 2018)and (Sadique, 2023) found that as SCM increases, liquid limit and plastic limit increases.

Therefore; addition of WMD and SCM on expansive soil significantly reduces soil's plasticity index which improves the engineering properties of expansive soil.

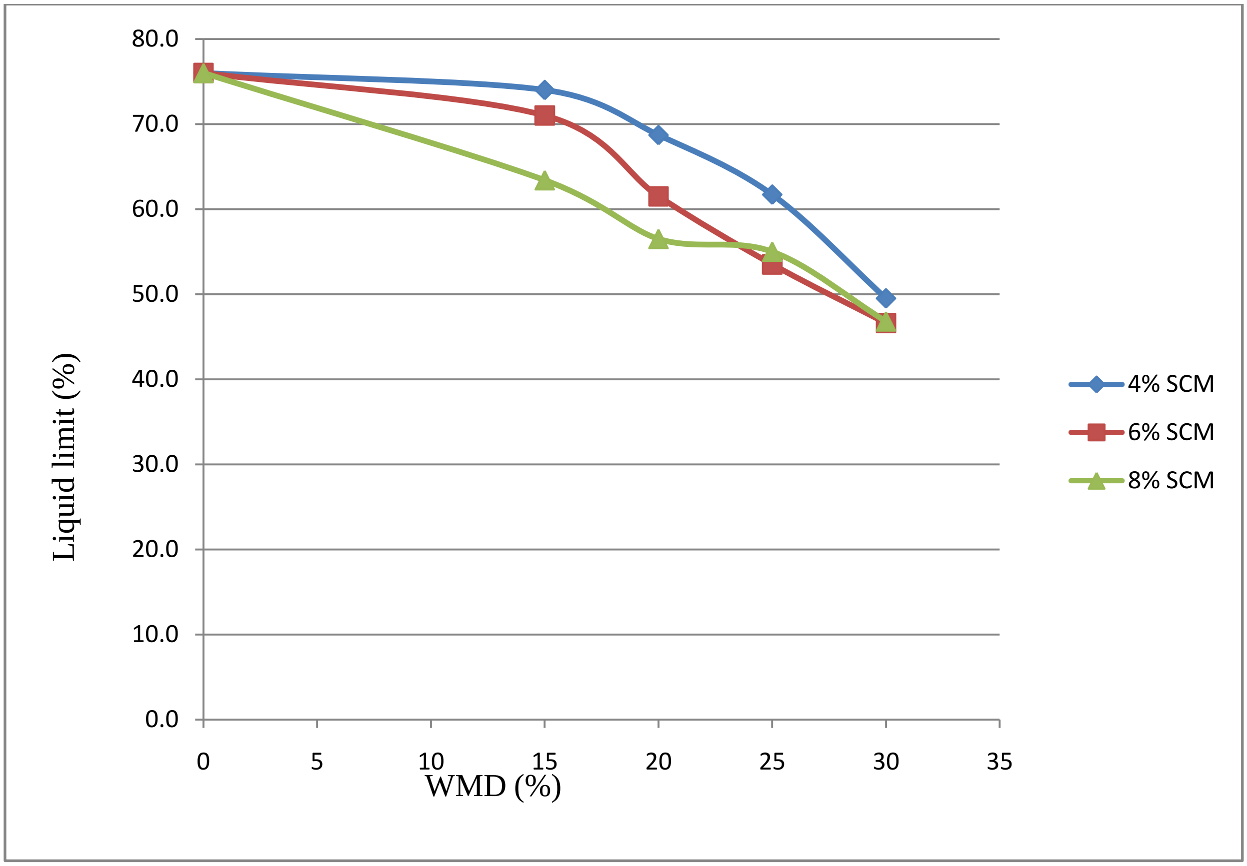

Figure 4.2: Effect of WMD and SCM on liquid limit

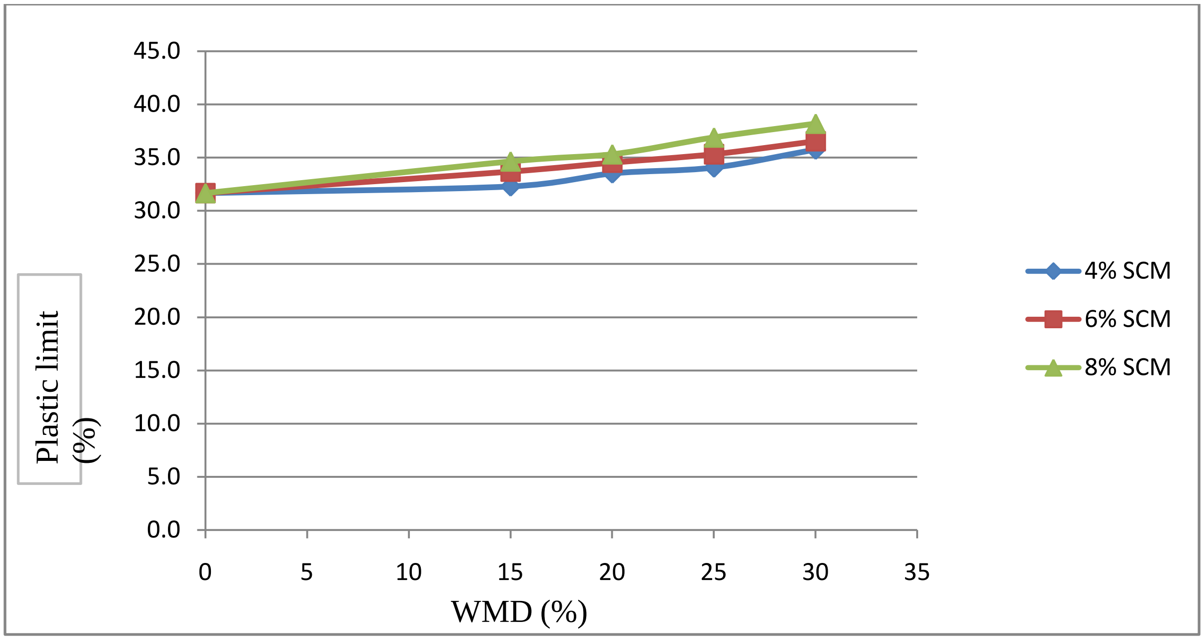

Figure 4.3: Effect of WMD and SCM on plastic limit

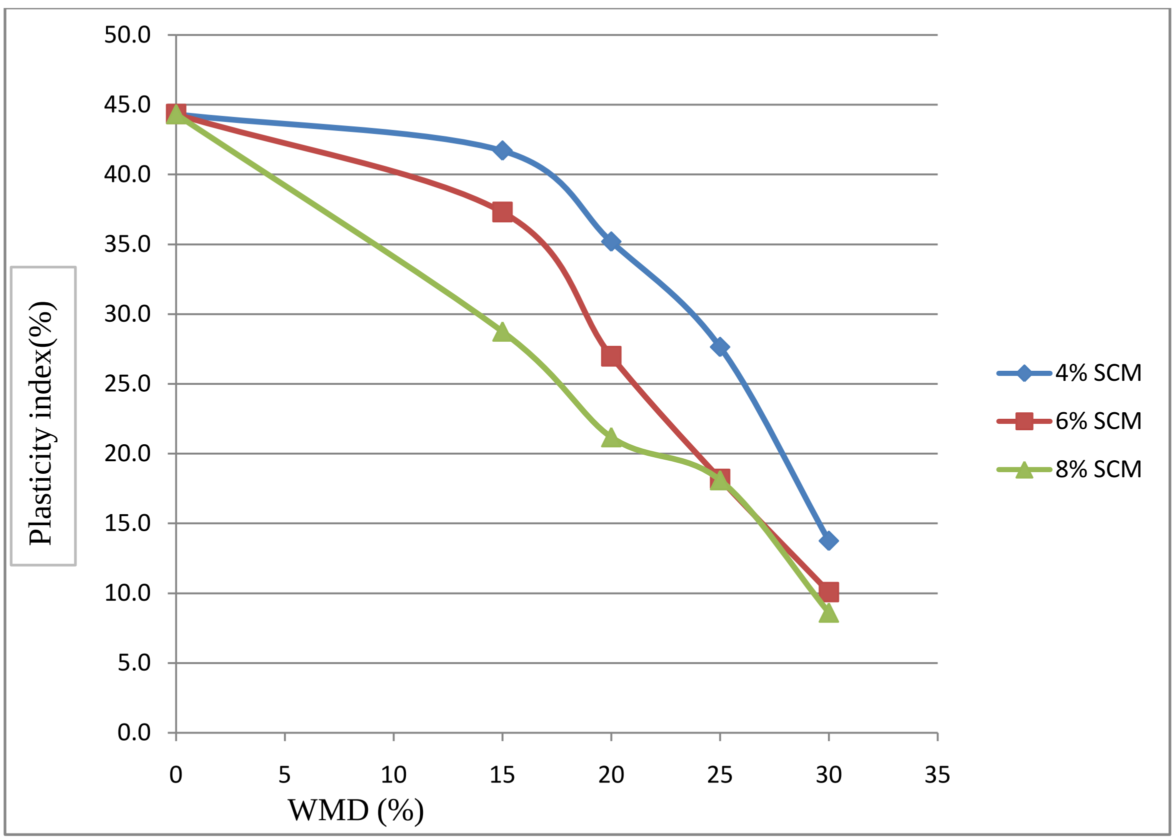

Figure 4.4: Effect of WMD and SCM on plasticity index

4.3 Effect on soil classification

Table 4.1: Summary of atterberg limit test result

Material	liquid limit	plasticity index	plastic limit
natural soil	76.0	44.3	31.7
15%WMD+4%SCM+soil	74.0	41.7	32.3
20%WMD+4%SCM+soil	68.7	35.2	33.5
25%WMD+4%SCM+soil	61.7	27.6	34.1
30%WMD+4%SCM+soil	49.5	13.8	35.7
15%WMD+6%SCM+soil	71.0	37.3	33.7
20%WMD+6%SCM+soil	61.5	27.0	34.5
25%WMD+6%SCM+soil	53.5	18.2	35.3
30%WMD+6%SCM+soil	46.6	10.1	36.5
15%WMD+8%SCM+soil	63.4	28.8	34.6
20%WMD+8%SCM+soil	56.5	21.2	35.3
25%WMD+8%SCM+soil	55.0	18.1	36.9
30%WMD+8%SCM+soil	46.8	8.6	38.2

Mostly used soil classification systems are AASHTO and Unified soil classification (USCS) system. So, the samples are classified in both soil classification systems to interpret the engineering behavior of the soil samples. Even though there are some differences in the two classifications; they use the same procedure.

In AASHTO classification system the line PI=LL-30granular material and silt-clay material. The granular material is grouped into A-1, A-2, and A-3 whereas the silt-clay material grouped in to A-4, A-5, A-6, and A-7. The smaller the group number indicates well for highway material and larger group number poor for highway material. Therefore; materials classified as A-7-5 and A-7-6 is generally regarded as the worst performers in terms of roadway construction material. As displayed in the table4.3 Except for samples containing 30% WMD+6% SCM and 30% WMD+

8% SCM which are classified as A-5 as per AASHTO classification, all samples are classified as A-7-5.

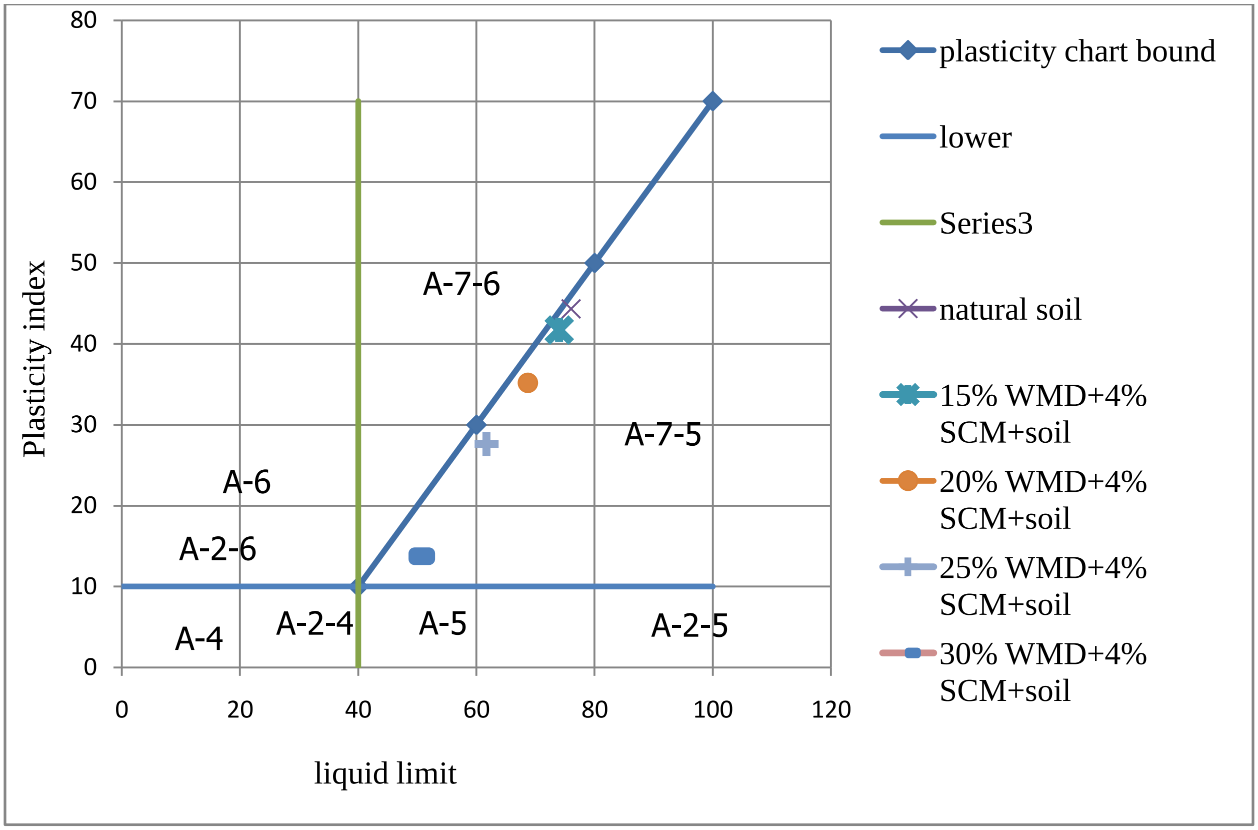

Figure 4.5: Soil classification chart according to AASHTO classification for 4% SCM

Table 4.2: Summary of Soil classification for all samples

	Atterberg limit			soil class	
Material	liquid limit	plasticity index	plastic limit	AASHTO	USCS
expansive soil	76.0	44.3	31.7	A-7-5	CH
15%WMD+4%SCM+soil	74.0	41.7	32.3	A-7-5	CH
20%WMD+4%SCM+soil	68.7	35.2	33.5	A-7-5	MH
25%WMD+4%SCM+soil	61.7	27.6	34.1	A-7-5	MH
30%WMD+4%SCM+soil	49.5	13.8	35.7	A-7-5	ML
15%WMD+6%SCM+soil	71.0	37.3	33.7	A-7-5	MH

20%WMD+6%SCM+soil	61.5	27.0	34.5	A-7-5	MH
25%WMD+6%SCM+soil	53.5	18.2	35.3	A-7-5	MH
30%WMD+6%SCM+soil	46.6	10.1	36.5	A-5	ML
15%WMD+8%SCM+soil	63.4	28.8	34.6	A-7-5	MH
20%WMD+8%SCM+soil	56.5	21.2	35.3	A-7-5	MH
25%WMD+8%SCM+soil	55.0	18.1	36.9	A-7-5	MH
30%WMD+8%SCM+soil	46.8	8.6	38.2	A-5	ML

In Unified soil classification system A line given by equation PI=0.73(LL-20) divides clays and silts and U-line given by PI=0.9(LL-8) limits the maximum of plasticity index and liquid limit values. In table 4.3 natural soils and samples containing 15% WMD +4% SCM are classified as MH according to USCS classification system. Making WMD 30% constant and varying SCM, the soil class stays constant which is classified as ML according to USC. Also adding WMD 15%,20% and 25% and SCM 4%,6% and 8%, the soil sample class laid under MH class, except for 15% WMD+ 4% SCM. This shows that addition of 30% WMD and 8% SCM on expansive soil improves the engineering properties of expansive soil.

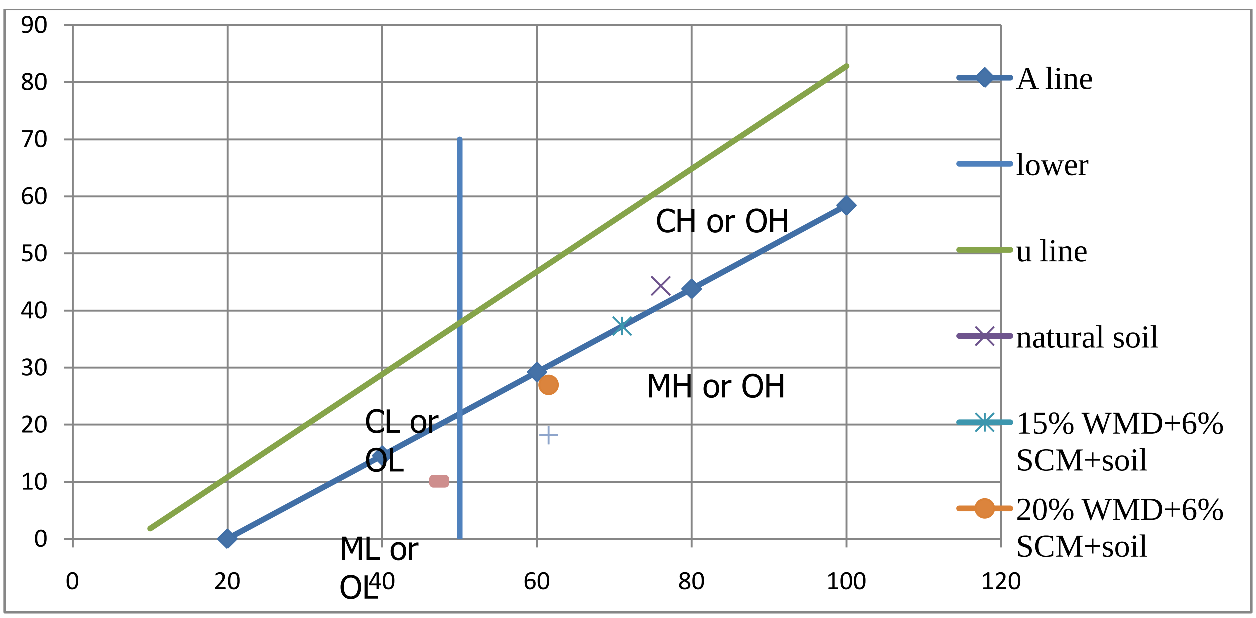

Figure 4.6:Soil classification chart according to USC classification for 6% SCM

4.4 Specific gravity

Specific gravity is the ratio of the weight in air of an equal volume at a given temperature of soil (excluding voids between particles) to distilled water.

Specific gravity of soil samples determined as per (AASHTO T100-95 or ASTM D854-83) test procedure in the laboratory. Water filled in small polymeter and weighted to nearest 0.01g (MA) and an oven dried soil sample weighted about 10g (Mo) added and shook to fully submerge in water. Then by controlling air pumper nozzle, the air gradually pumped out for 10 minutes or until air bubbles totally removed. At interval water added and shocked to check removal of air void from the sample. At last the pycnometer fully filled with water and the weight to the nearest 0.01g (MB) is measured. Specific gravity computed by equation below.

$Gs=Mo/(Mo+(MA+MB))$

As depicted in figure 4.7, specific gravity of expansive soil found to be 2.50g/cc and with the addition of WMD, specific gravity increases for similar SCM content except for 8% SCM at 15% WMD. This is due to higher density, coarser mineral particles of WMD, while expansive soil contains lower density and fines particles. SCM being organic nature, it has lower specific gravity. As a result, as SCM content increases, specific gravity decreases. However, addition of SCM improves the compaction and stability of mixed soil.

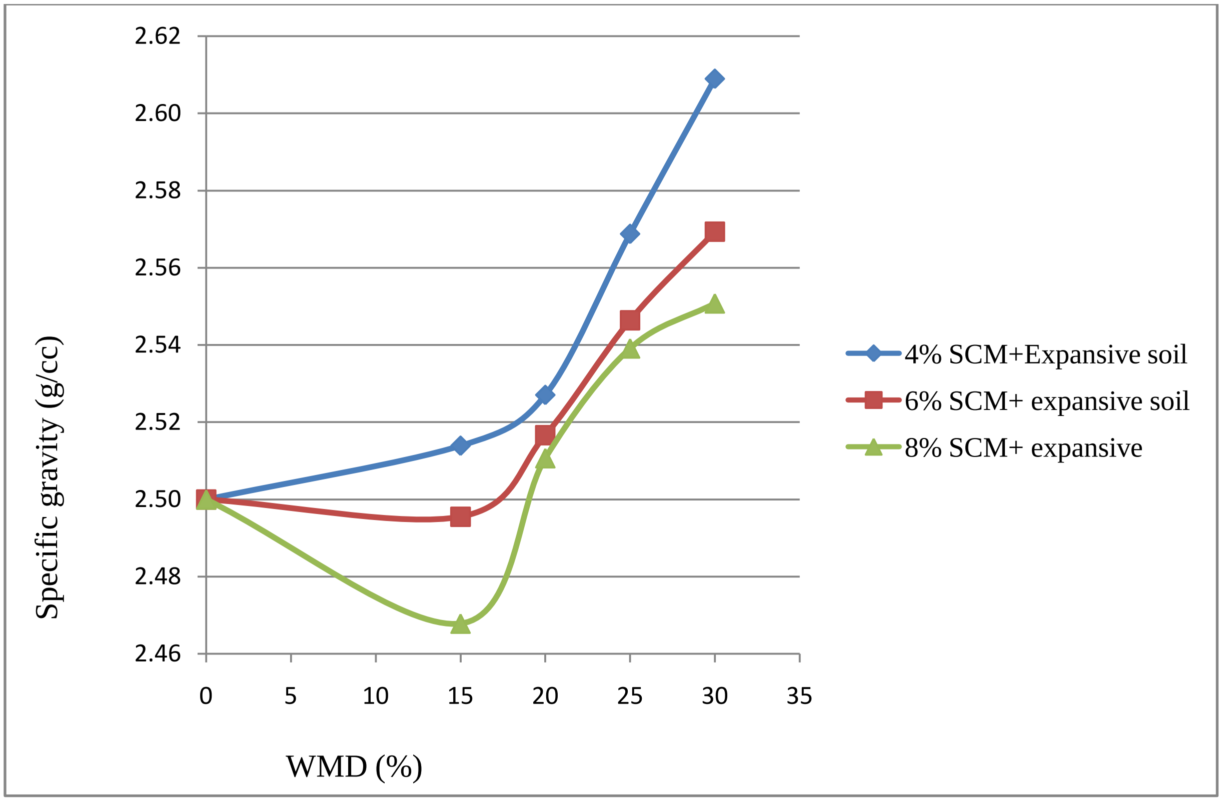

Figure 4.7: effect of WMD and SCM on specific gravity

4.5 Effect on compaction characteristics

Since the samples are fine grained soil, standard Procter test as per AASHTO T-99 or ASTM D698 method were performed to determine moisture density relationship. All samples has particles retained on sieve size 4.75mm is less than 5%, no replacement is required for coarser particles.

The test result on figure 4.8 reveal that the expansive soil collected from Modjo town has maximum dry density and optimum moisture content of 1.28gm/cc and 32% respectively. The lower dry density is due to the fact that expansive soil is fine grained soil and high moisture holding capacity.

As shown on figure 4.9, as WMD and SCM content increases up to 25% WMD, maximum dry density increases and at 30% WMD maximum dry density declines. The increase of dry density with increase of WMD content is in line with the findings of (Magdi M. E. Zumrawi and Eman A.E.Abdalla, 2018), (Ali, 2014), (Gokani., Akoliya, Davera, Vaghela, & Patel, 2018), (Fathonah, Kusuma, & Hasanah, 2023) and (Ibrahim Haruna Umar and Hang Lin, 2024).Improvement of dry density with increase of SCM content is also reported on (Sadique, 2023), (Devender & Jagan, 2018) and (Abdul, A., Karthick, G., Mankandan, T., Ravi, E., & Sharma,, 2015). The increase of maximum dry density up on addition of WMD and SCM is that WMD has coarser particles that pack more tightly together with smaller clay particle in the expansive soil, flocculation and agglomeration due to cation exchange and SCM being fluid having higher density than water acts as lubricant, resulting in less void space and a higher density when compacted.

At 4% SCM content when WMD content increases from 15% to 30%, dry density changes to 1.32, 1.396, 1.472 and 1.465 respectively. Addition of WMD and SCM in the expansive soil improves the dry density with the optimum improvement was at 25% WMD and 8% SCM which is found to be 1.542 gm/cc dry density.

Also figure 4.10 depicts that moisture content declines as WMD and SCM contents increase up to 25% WMD except for 8% SCM which increases after 15% WMD. This could be due to change of plasticity and gradation of the mixed soil.

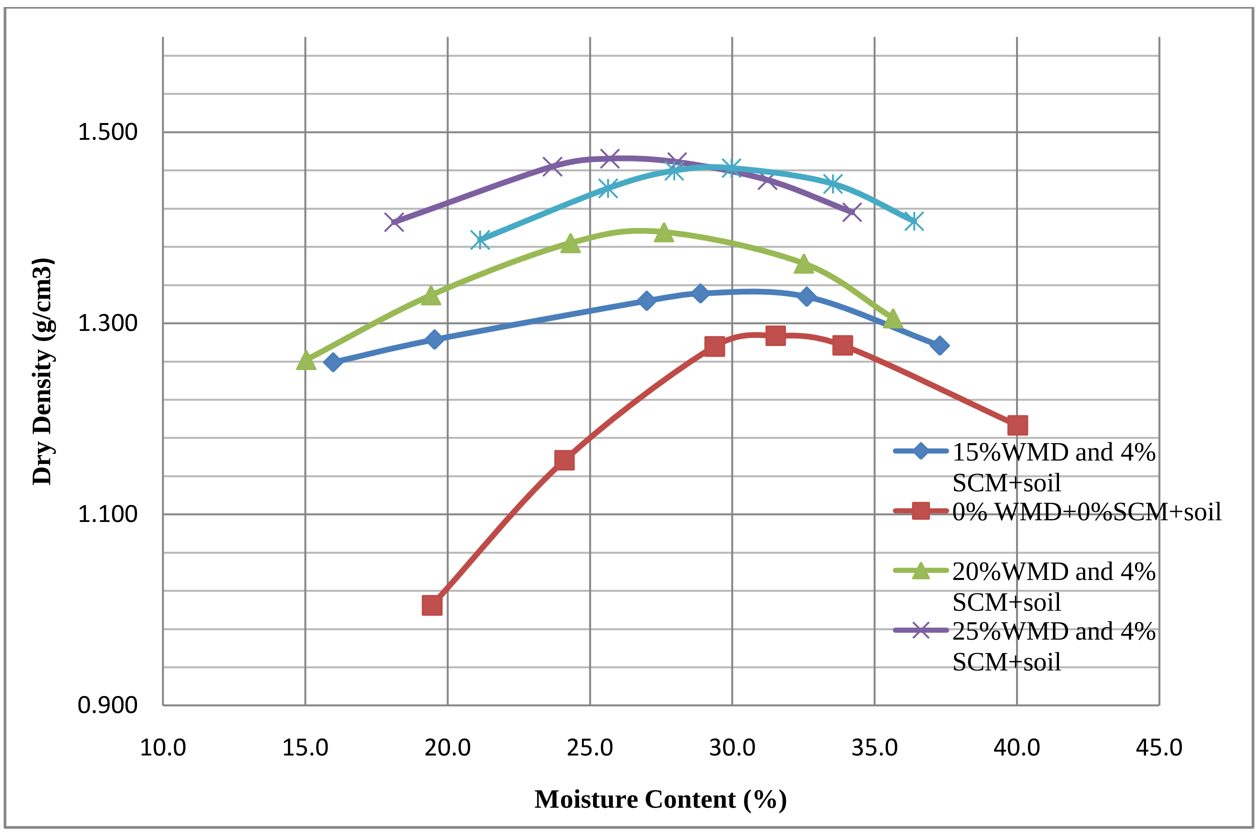

Figure 4.8: Graph of dry density vs moisture content for 4% SCM + expansive soil

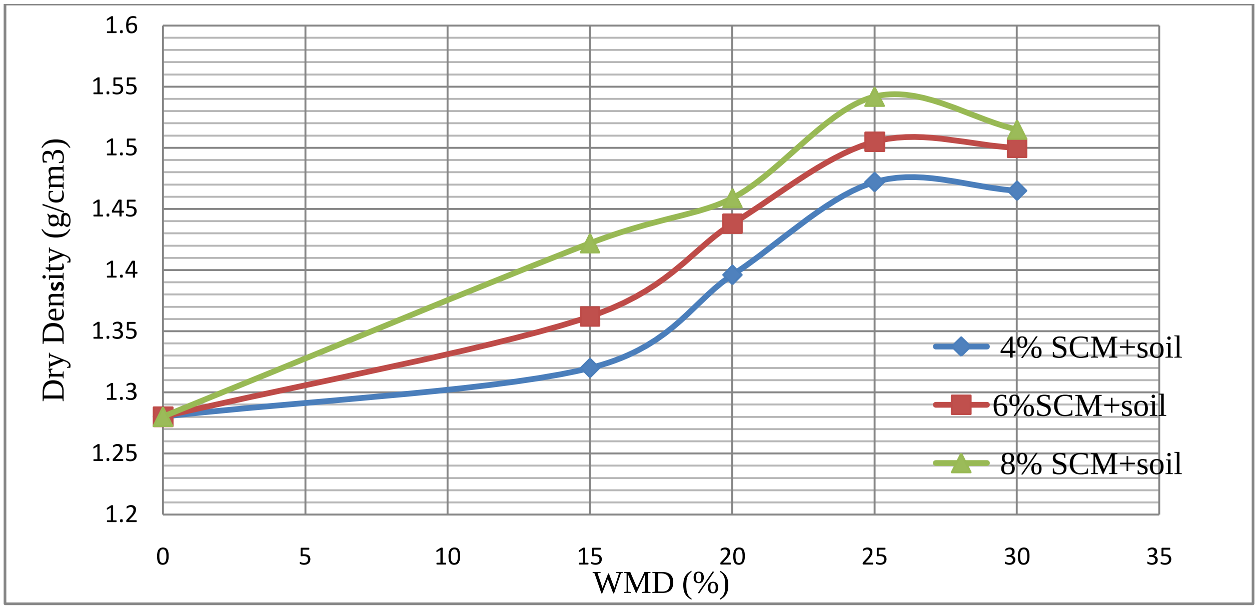

Figure 4.9: Effect of WMD and SCM on dry density

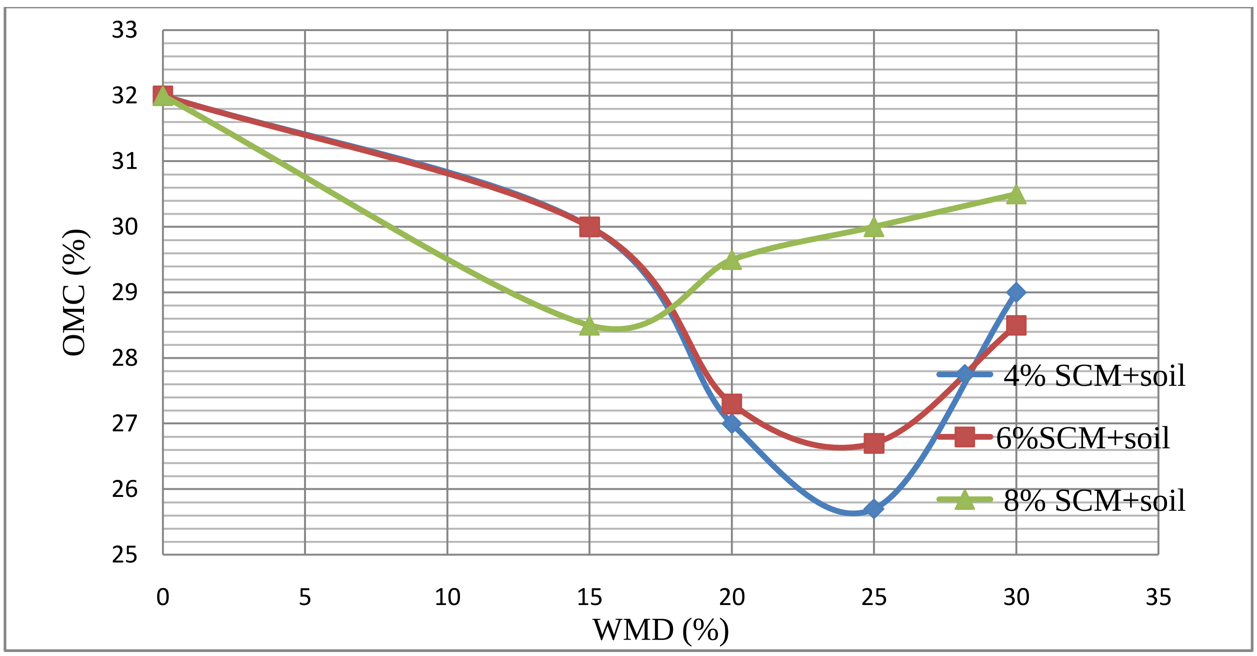

Figure 4.10: Effect of WMD and SCM on moisture content

4.6 Californian bearing ratio (CBR) and CBR swell

Californian bearing ration (CBR) is the ratio of penetration resistance of a sample to the penetration resistance of standard crushed aggregate. CBR value of sample depends on density, moisture content, and material type, soaking condition and moisture condition after soaking. The specimen soaked for four days before penetration and a surcharge load of 4.5Kg placed on the surface to represent the over burden due to structural load and self-weight. CBR swell measured during soaking to check for potential swelling.

A one-point CBR, samples compacted for 56 blows performed to assess the strength and swelling potential of the samples.

A standard piston of diameter 50mm used to penetrate the sample at a standard rate of 1.27 mm/min up to a penetration of 10mm. The CBR value determined using the corrected forces needed to penetrate the plunger 2.54 mm, and 5.08 mm into the compacted specimens. CBR value is the ratio in percent of the load needed to penetrate 2.54mm and 5.08mm to the load required to penetrate standard crushed aggregate respective depth, which is 13.2 KN, and 20 KN respectively.

The swelling potential and CBR value of the expansive soil is found to be 5.04% and 3.0% respectively as presented on figure 4.12 and figure 4.13. This value indicates that swelling potential is high and the CBR value is low which is not good for civil engineering structure foundation, especially for light weight structure. Therefore it requires stabilization by different mechanism before use as foundation material.

Figure 4.12and figure 4.13depict that as WMD content increase for fixed SCM content, CBR value increases and CBR swell decreases. This in line with research of (Ibrahim Haruna Umar and Hang Lin, 2024), (Fathonah, Kusuma, & Hasanah, 2023), (Ditta & Singh, 2019), (Gokani, Akoliya, Davera, Vaghela, & Patel, 2018) and (Magdi M. E. Zumrawi and Eman A.E.Abdalla, 2018).Also CBR value increases and CBR swell decreases as SCM percentage increases for constant percentage of WMD. This is similar with the research of (Sadique, 2023), (Devender & Jagan, 2018), (M'Ndegwa, 2011) and (Abdul, A., Karthick, G., Mankandan, T., Ravi, E., & Sharma,, 2015).In addition as WMD and SCM percentage increases The CBR value increases and swell decreases except for 30% WMD +8% SCM sample having lesser value of CBR than 25% WMD+8% SCM. This is due to the fact that WMD increases the density, reduces porosity, calcium oxide in the WMD reacts with water and ion exchange result in more rigid soil matrix capable of resistance of penetration of the plunger and mixed with clay particles and inhabit clay particle to swell in the presence of water. Optimum improvement in CBR value and swell is found at 25%WMD+ 8% SCM which are 8.2% and 1.89% respectively. These values indicate that the soil has good bearing capacity and good for foundation of structures.

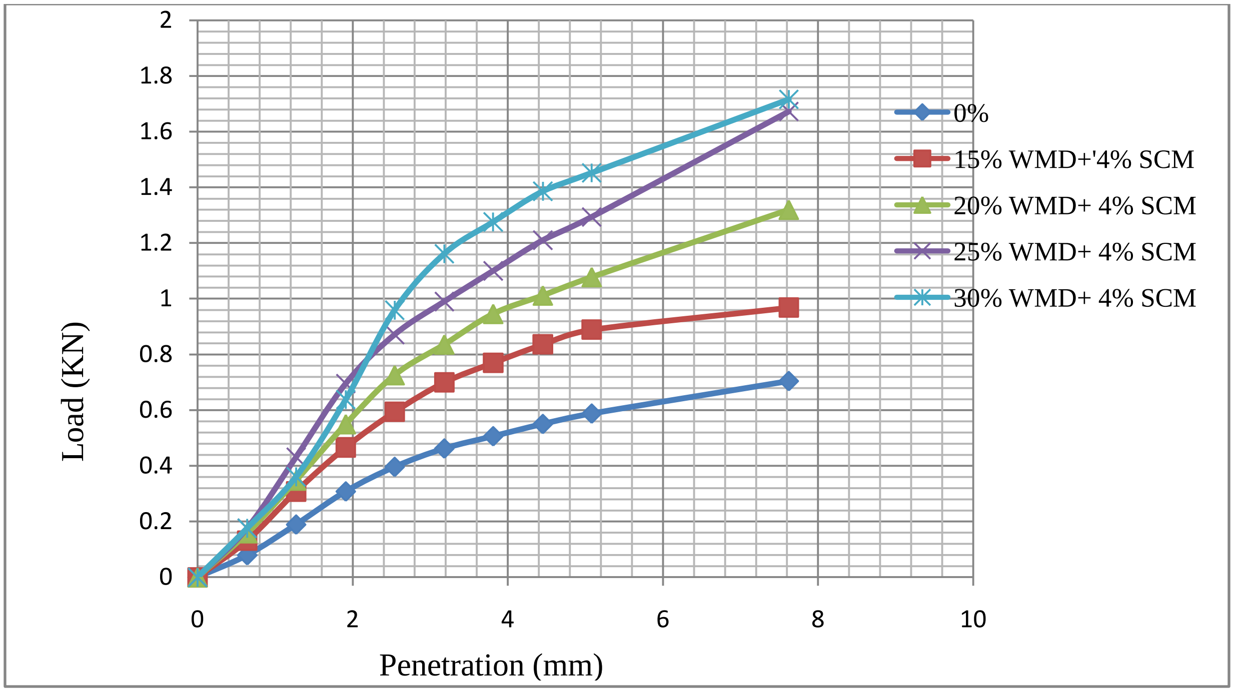

Figure 4.11: load vs penetration of 4% SCM and different percentage of WMD

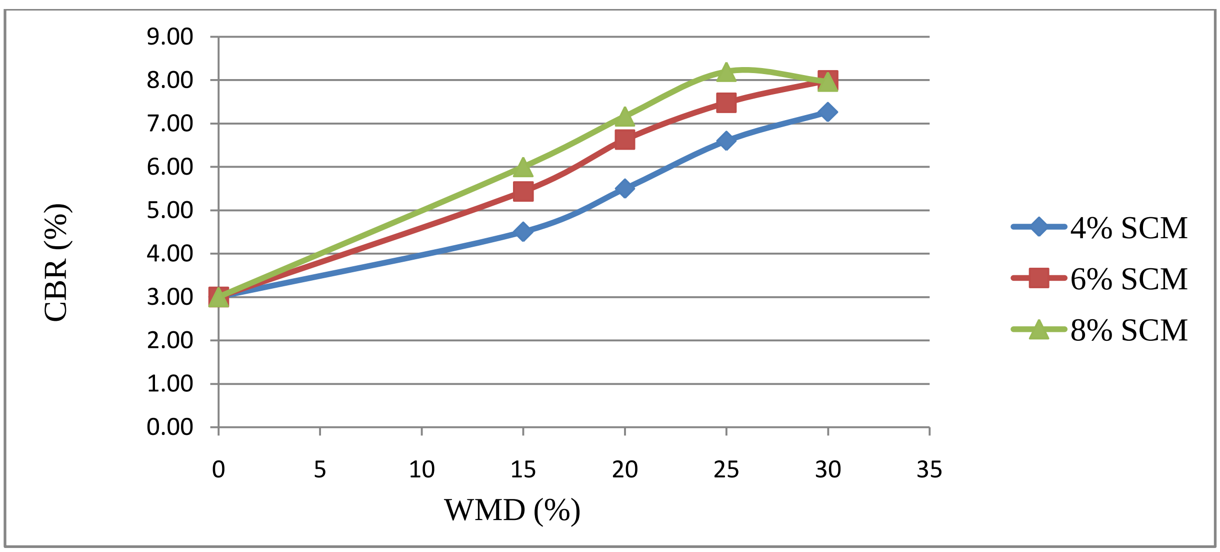

Figure 4.12: Effect of WMD and SCM on CBR

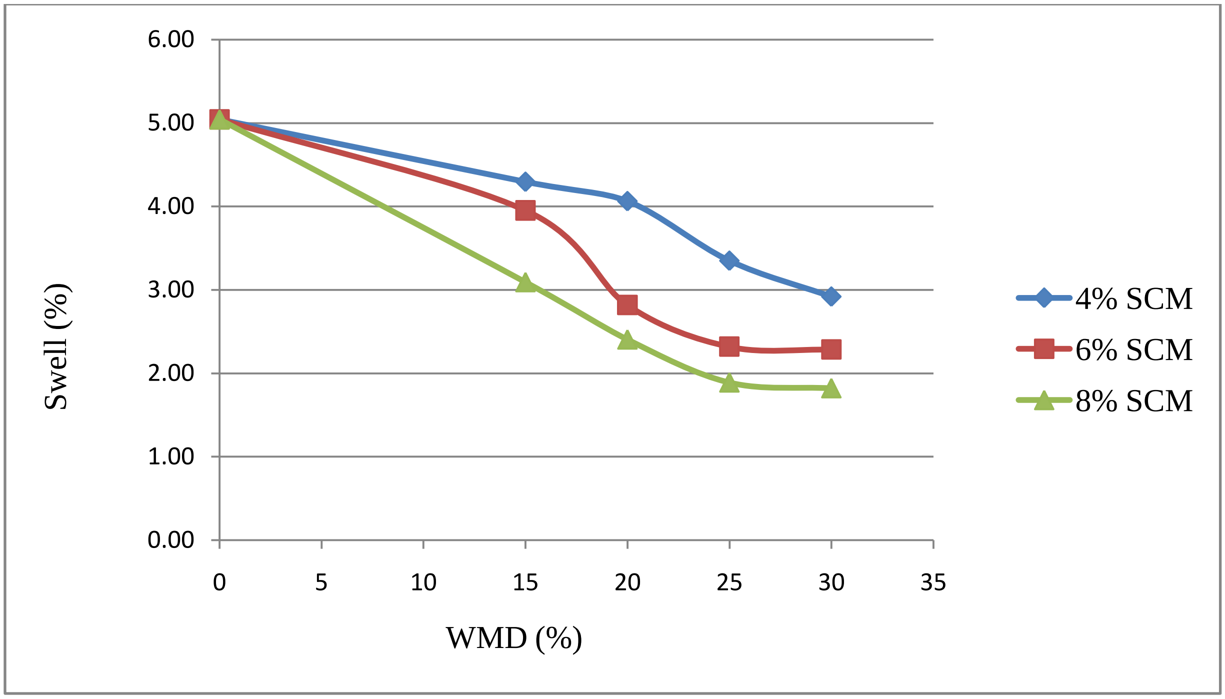

Figure 4.13: Effect of WMD and SCM on free swell

4.7 Unconfined compressive strength

Unconfined compressive Strength test conducted for cohesive soils by applying gradual increasing axial load until compacted specimen fails and the UCS is the ratio of maximum load to corrected contact area. The specimen prepared by compacting at required moisture and density level. The load is applied with the rate of 140 kN/m2 per second (kPa/s) and measure small unit force as small as 1KN until failure. The UCS is computed using formula below.

UCS = (Load (KN))/(Corrected area(m2))

UCS test result reveals that the maximum stress and strain of the expansive soil found to be 83.05KPa and 41.19% respectively as shown on figure 4.15, showing that the natural expansive soil has weaker strength in bearing load. When the percentage of WMD increases for constant SCM content, stress increases and strain decreases. The findings of (Magdi M. E. Zumrawi and Eman A.E.Abdalla, 2018), (Ibrahim Haruna Umar and Hang Lin, 2024) and (Ditta & Singh, 2019) reveal that as WMD content increases significantly improves UCS of expansive soil. For instance at 4% SCM and for WMD content of 15%, 20%, 25% and 30%, the stress found to be 119.96KN, 132.44KN, 145.44KN and 161.98KN and strain 36.75%, 39.61%, 33.97% and 28.42% respectively. On the other hand for constant WMD as SCM percentage increases, stress increases and strain decreases. (Devender & Jagan, 2018)and (Abdul, A., Karthick, G., Mankandan, T., Ravi, E., & Sharma,, 2015) confirmed that as SCM content increases, UCS value increases. In general as the percentage of WMD and SCM increases stress increases and strain decreases. This is because of ion exchange, reduction of clay content, agglomeration, reduction of plasticity of the soil and WMD act like filler creating strong bond. Maximum stress and minimum strain value obtained at 30% WMD and 8% SCM with value of stress 252.39KN and strain of 22.78%. The stress is 3 times higher and strain 55% lower than the expansive soil. This is due to improved shear strength and density because of WMD and SCM in the soil sample.

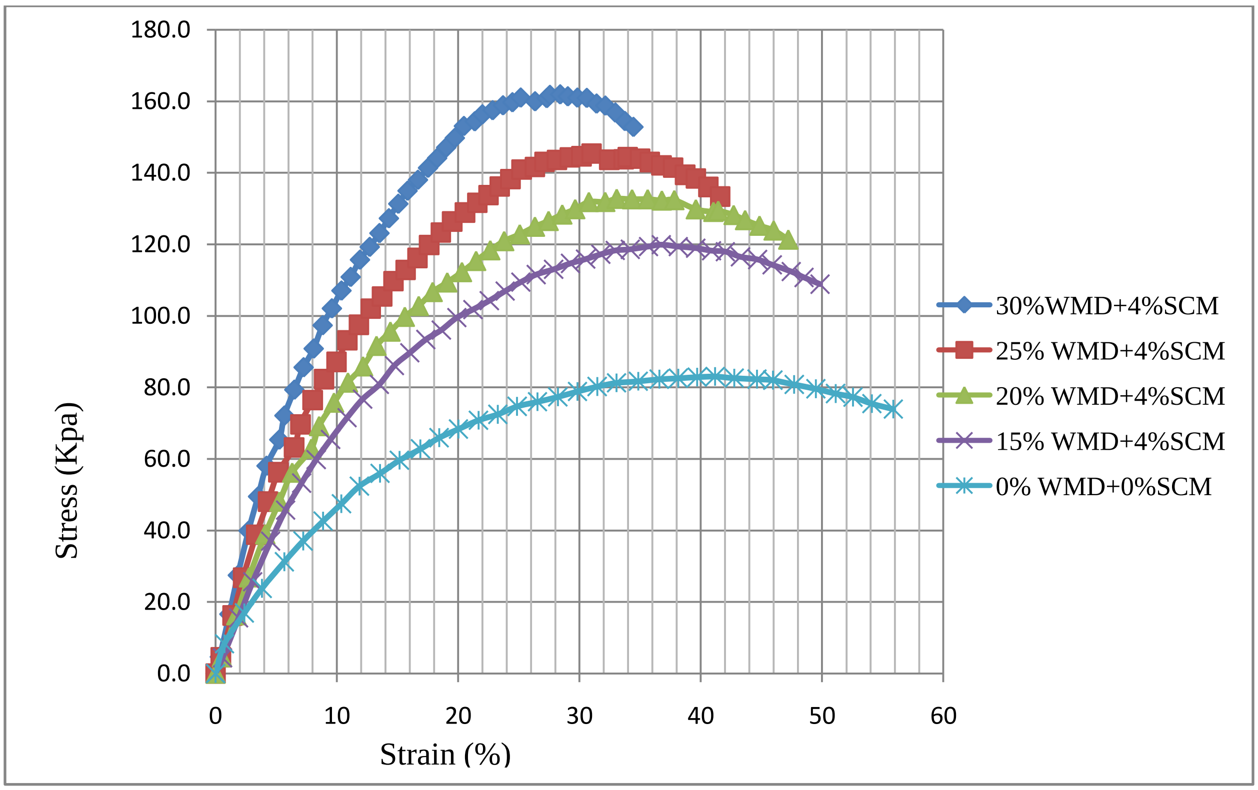

Figure 4.14: graph of stress vs strain for 4% SCM and different percentage of WMD

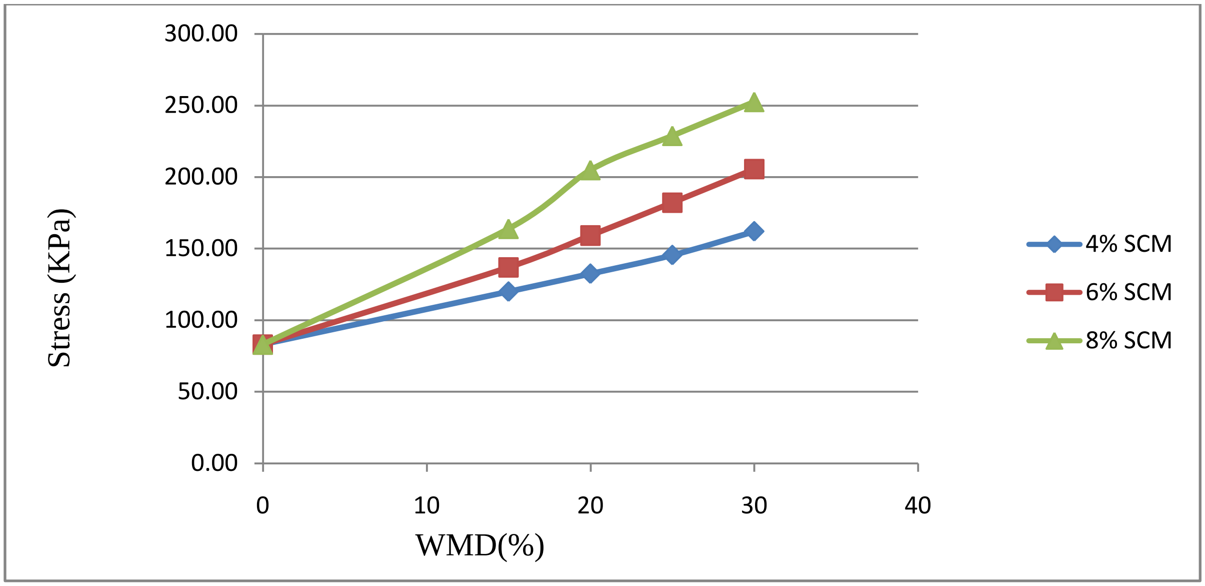

Figure 4.15: Effect of WMD and SCM on stress of UCS test

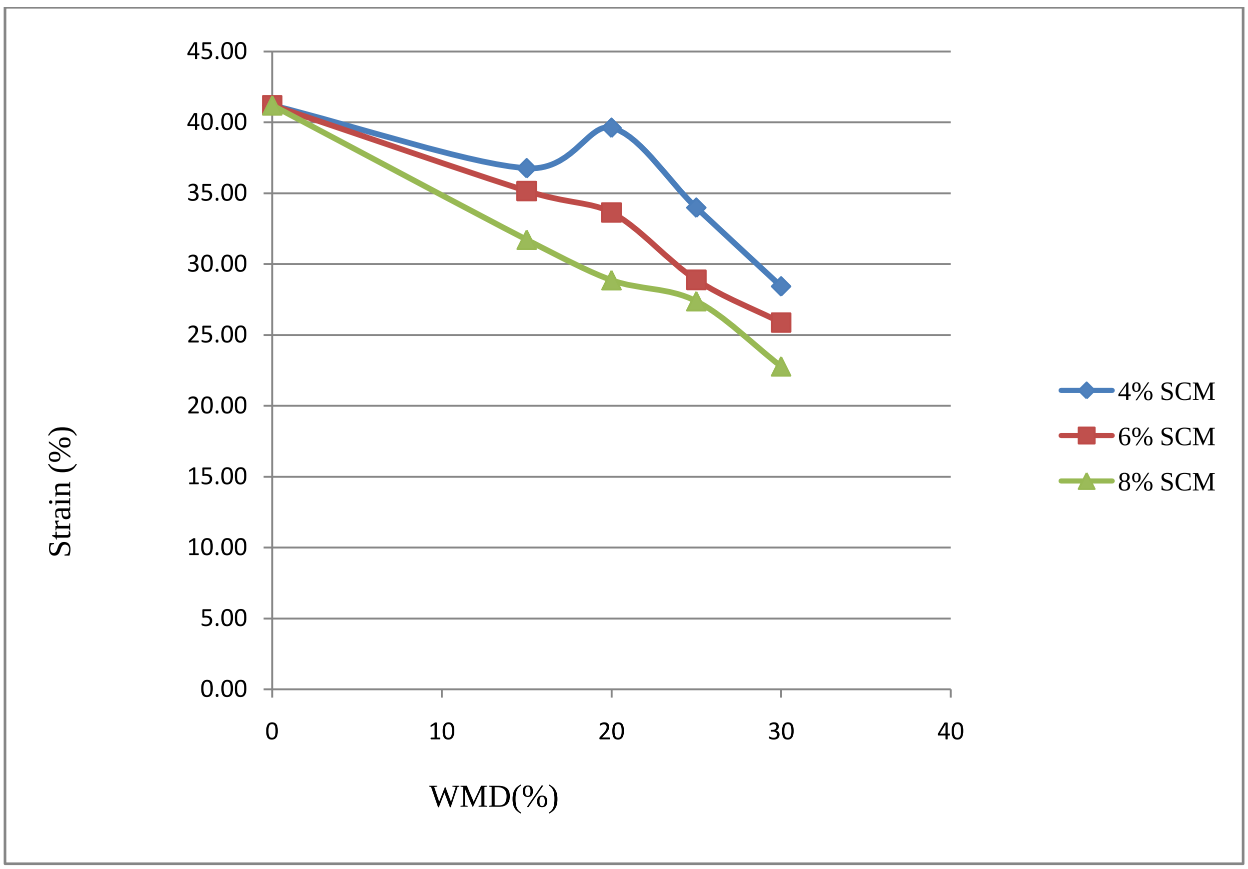

Figure 4.16: Effect of WMD and SCM on stress of UCS test

Chapter Five

Conclusion and Recommendation

5.1 Conclusion

Considering the findings covered in chapter four that are atterberg limit, gradation analysis, compaction, CBR value, CBR swell and Unconfined Compression Strength tests, the following conclusion are made.

The maximum dry density (MDD) and optimum moisture content (OMC) of expansive soil gathered from Modjo town had1.28 g/cc and 32% for respectively. The maximum dry density of expansive soil improved as WMD and SCM added. Greatest improvement of dry density is observed at 25%WMD and 8% SCM added to expansive soil which is dry density 1.542gm/cc and moisture content of 30%.

The expansive soil has CBR value of 3.0% and swelling potential of 5.04%. When WMD and SCM are added, the CBR value raises and CBR swell falls. The addition of 30% WMD and 8% SCM resulted in the best stabilization of expansive soil with WMD and SCM with CBR value of 8.2% and swelling of 2.89% respectively.

The expansive soil's maximum stress and strain were 83.05KPa and 41.19% respectively, indicating lower bearing load strength in bearing load. However; adding WMD and SCM to the expansive soil increases its stress and strain. The best improvement observed when 30% WMD and 8% SCM were added to expansive soil, which resulted in maximum stress of 252.39KN and strain of 22.78%, three times more load bearing resistance than pure expansive soil.

For the majority of the tests in this thesis, encouraging results were obtained at 25%WMDand 8% SCM. Consequently; the ideal percentage is thought to be 25%WMDand 8% SCM, which is accomplished by enhancing the majority of engineering properties of the expansive soil.

5.2 Recommendation

- To understand the behavior of soil samples stabilized using WMD and SCM, detailed tests such as consolidation should be conducted but there is no instrument in ASTU.
- The long term performance of stabilized materials requires more research.

- It is necessary to cost comparison of the current stabilization and traditional expansive soil stabilization like cement and lime.
- In order to stabilize expansive soil and safeguard the ecosystem, WMD, which is detrimental to human being and SCM which is used for animal feed will be utilized economically stabilize expansive soil without affecting the environment.
- The far away requires more research to know the durability of the treated samples stabilized using WMD and SCM.

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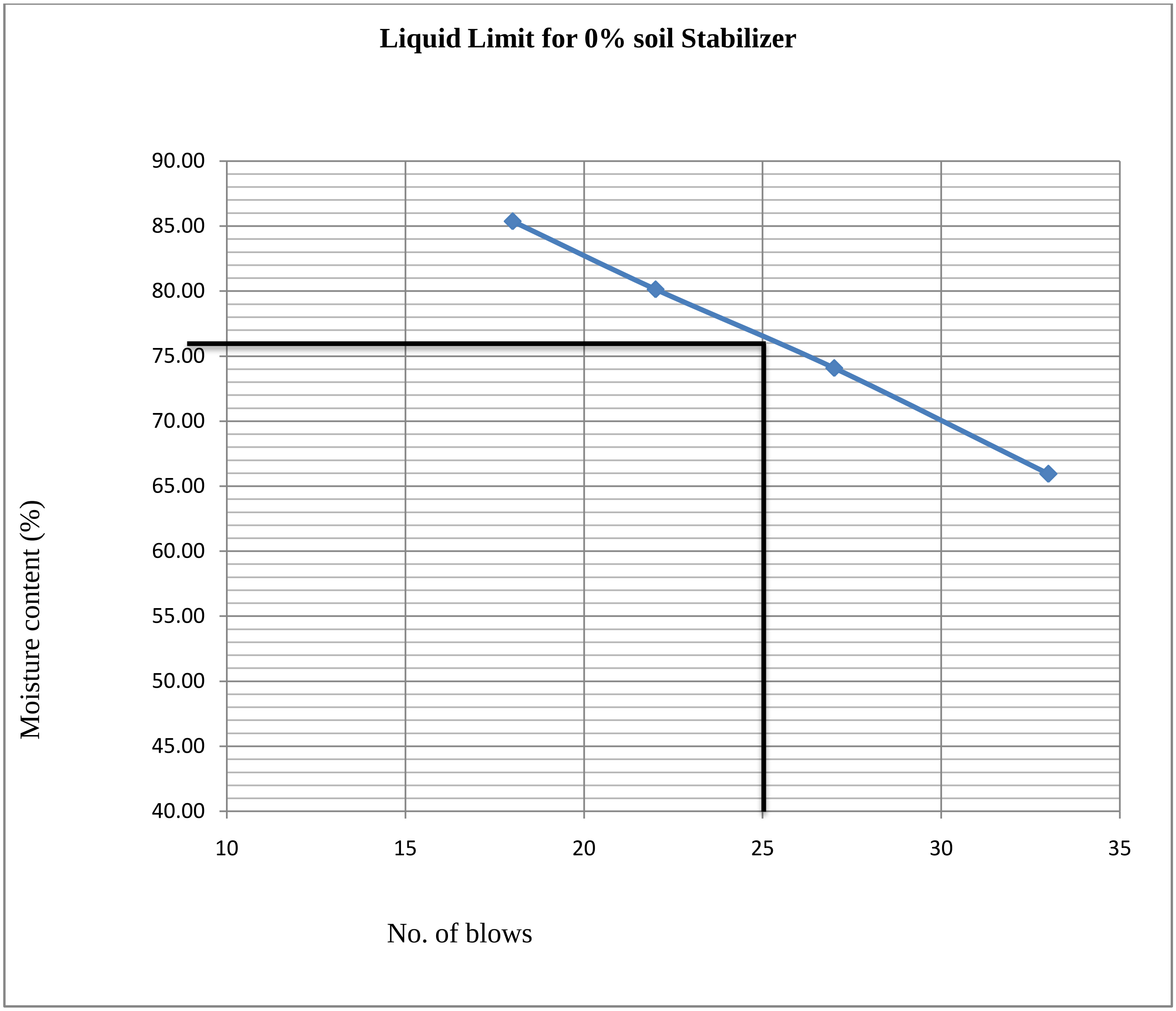
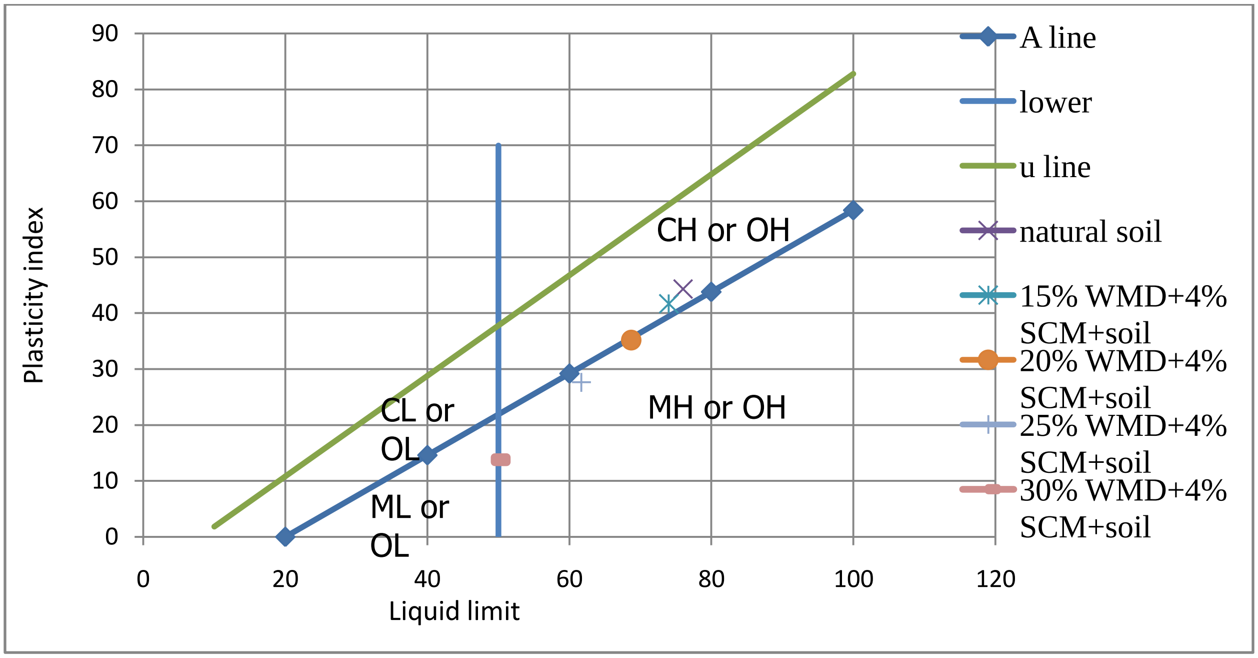
Appendix

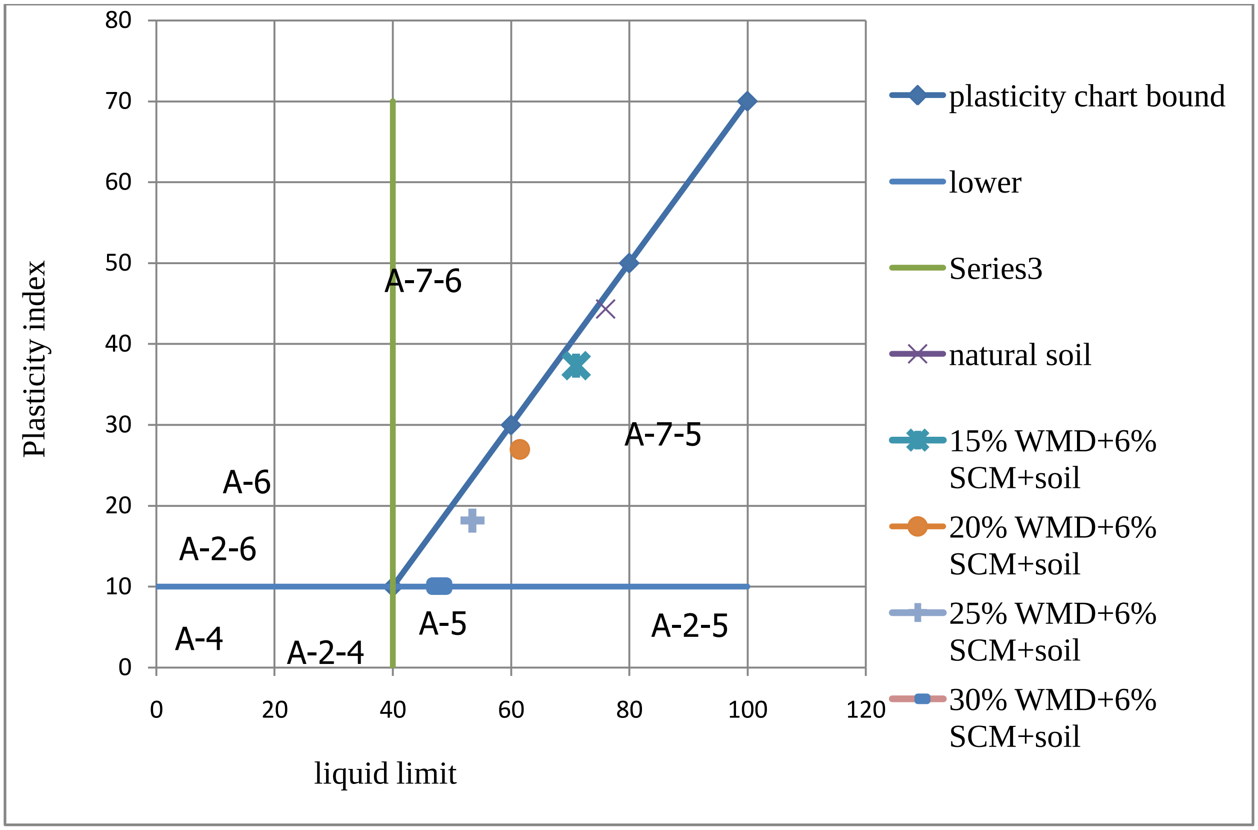
Appendix A: Atterberg limit test

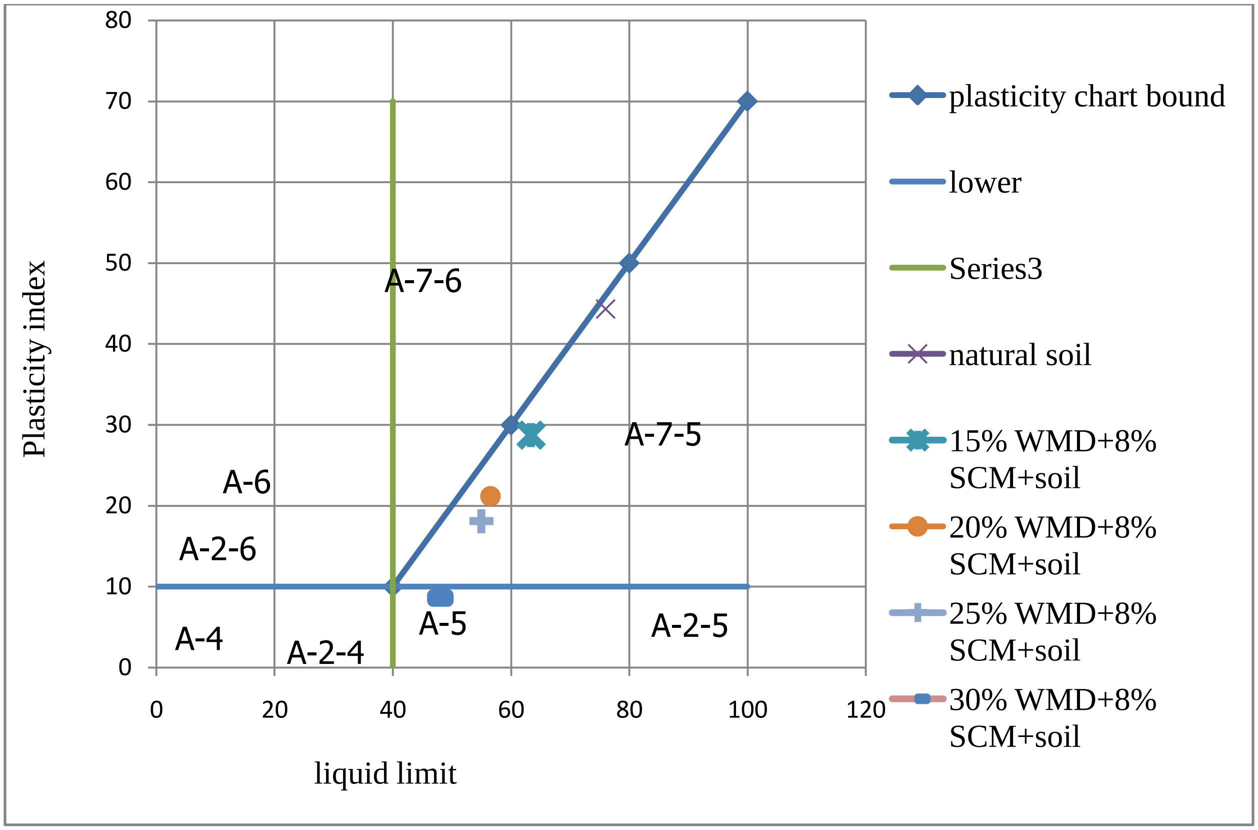
Sampled Date26/02/2025				Date Tasted: 22/03/2025		Depth : 1.5m	
Description:- Pure Black Cotton Soil				Location: Collected From Modjo town			
Material Type: 0% WMD +0%SCM+100% soil							
		liquid limit				plastic limit	
Container Number		B3	OL	67	S	CON	H
No. of Blows	33 27	22	18				
Wt. of Cont + Wet Soil	60.50	61.01	61.22	62.00	41.08	40.55	34.41
Wt. of Cont + Dry Soil	51.71	51.52	51.21	50.80	40.49	39.83	30.62
Wt. of Water	8.79	9.49	10.01	11.20	0.59	0.72	3.79
Wt. of Container	38.38	38.71	38.72	37.68	38.74	37.40	20.21
Wt. of Dry Soil	13.33	12.81	12.49	13.12	1.75	2.43	10.41
Moisture Content	65.94	74.08	80.14	85.37	33.71	29.63	36.41
	Liquid Limit	76.0			Plastic Limit	31.7	

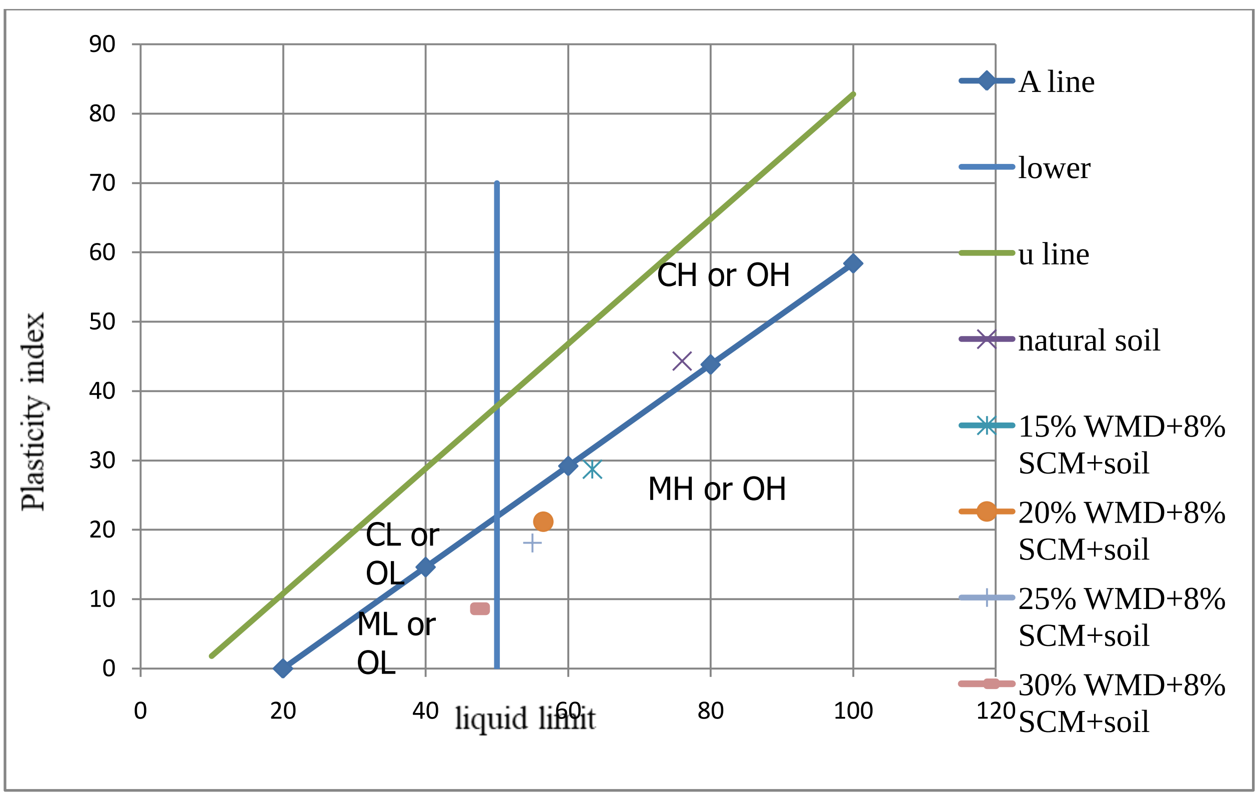

Liquid Limit for 0% soil Stabilizer
Moisture content (%)
90.00
85.00
80.00
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
10
15
20
25
30
35
No. of blows

Appendix B: Soil classification




Plasticity index
liquid limit
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
A-7-6
A-7-5
A-6
A-2-6
A-4
A-2-4
A-5
A-2-5
plasticity chart bound
lower
Series3
natural soil
15% WMD+6% SCM+soil
20% WMD+6% SCM+soil
25% WMD+6% SCM+soil
30% WMD+6% SCM+soil


Plasticity index
liquid limit
A-7-6
A-7-5
A-6
A-2-6
A-4
A-2-4
A-5
A-2-5
plasticity chart bound
lower
Series3
natural soil
15% WMD+8% SCM+soil
20% WMD+8% SCM+soil
25% WMD+8% SCM+soil
30% WMD+8% SCM+soil


Plasticity index
liquid limit
CH or OH
MH or OH
CL or OL
ML or OL
A line
lower
u line
natural soil
15% WMD+8% SCM+soil
20% WMD+8% SCM+soil
25% WMD+8% SCM+soil
30% WMD+8% SCM+soil

Appendix C: Specific gravity

Material :- Untreated Soil collected from Modjo Study area at 1.5m Depth			
Specific Gravity Determination as per ASTM D854 Standard			
		Sample No	
S/N	Particulars	T1	T2
1	Weight of Density bottle W_1 (g)	47	47
2	Weight of Density bottle with dry soil W_2(g)	64	62
3	Weight of Density bottle with dry soil and water W_3(g)	158	156
4	Weight of Density bottle full of water W_4 (g)	147	147
5	Weight of dry soil (W_2-W_1) (g)	16.8	15
6	Weight of an equal volume of water(W2-W1)-(W3-W4)	6.7	6
7	Specific gravity of the soil G= (5/6)	2.51	2.50
	Avg specific gravity	2.5	

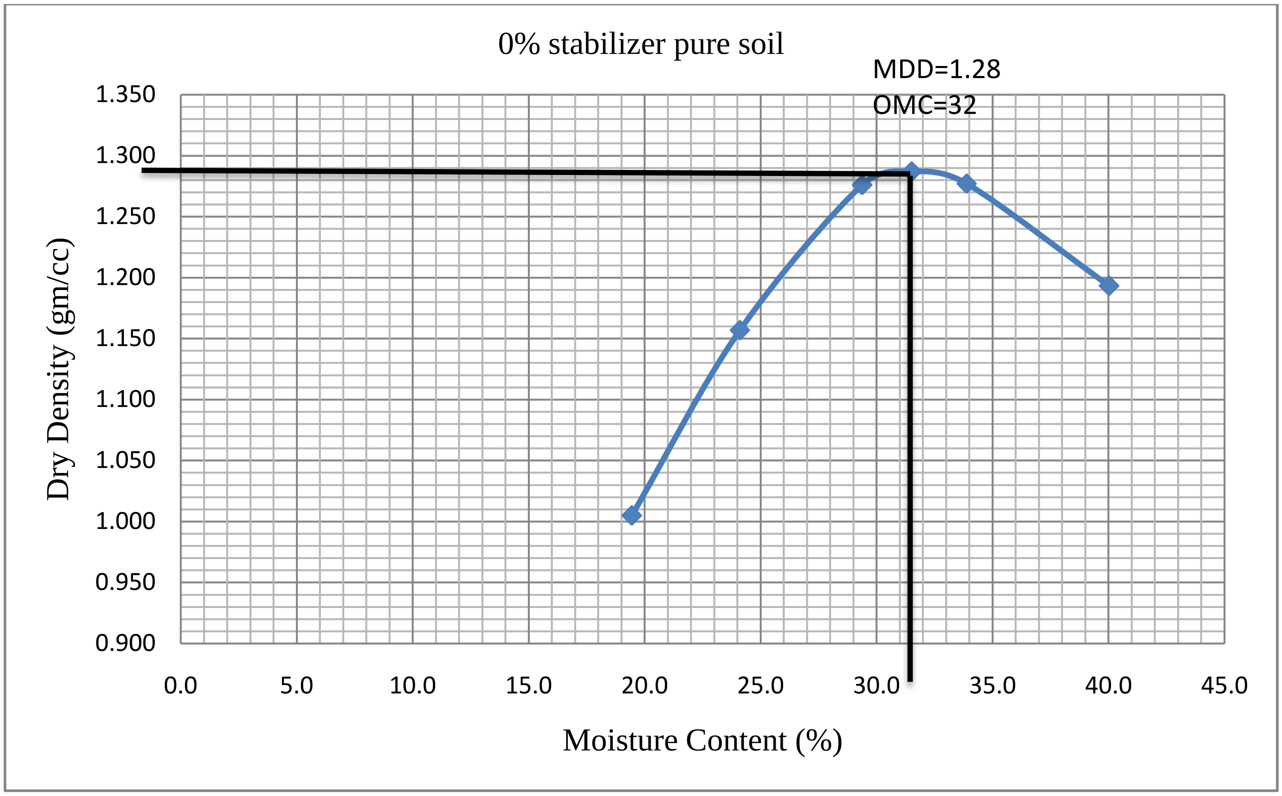
no	material type	specific gravity
1	natural soil	2.50
2	15% WMD+4% SCM	2.51
3	20% WMD+4% SCM	2.53
4	25% WMD+4% SCM	2.57
5	30% WMD+4% SCM	2.61
6	15% WMD+6% SCM	2.50
7	20% WMD+6% SCM	2.52

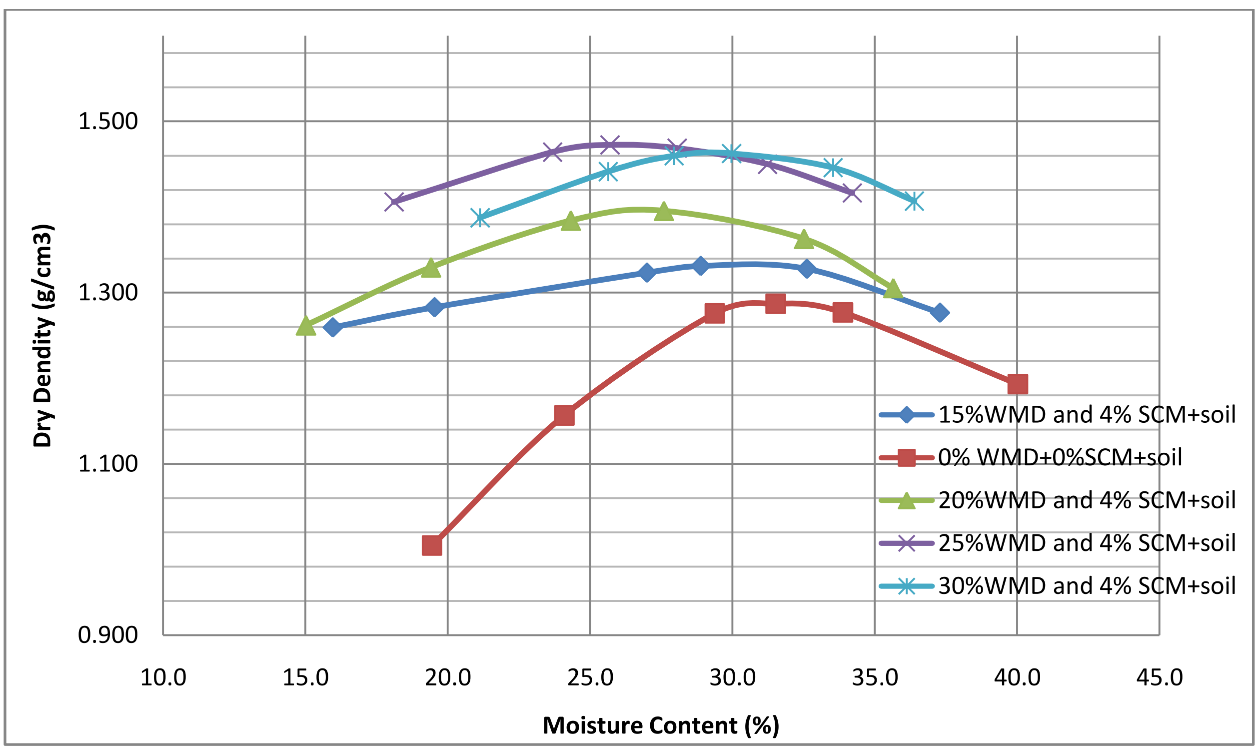
8	25% WMD+6% SCM	2.55
9	30% WMD+6% SCM	2.57
10	15% WMD+8% SCM	2.47
11	20% WMD+8% SCM	2.51
12	25% WMD+8% SCM	2.54
13	30% WMD+8% SCM	2.55

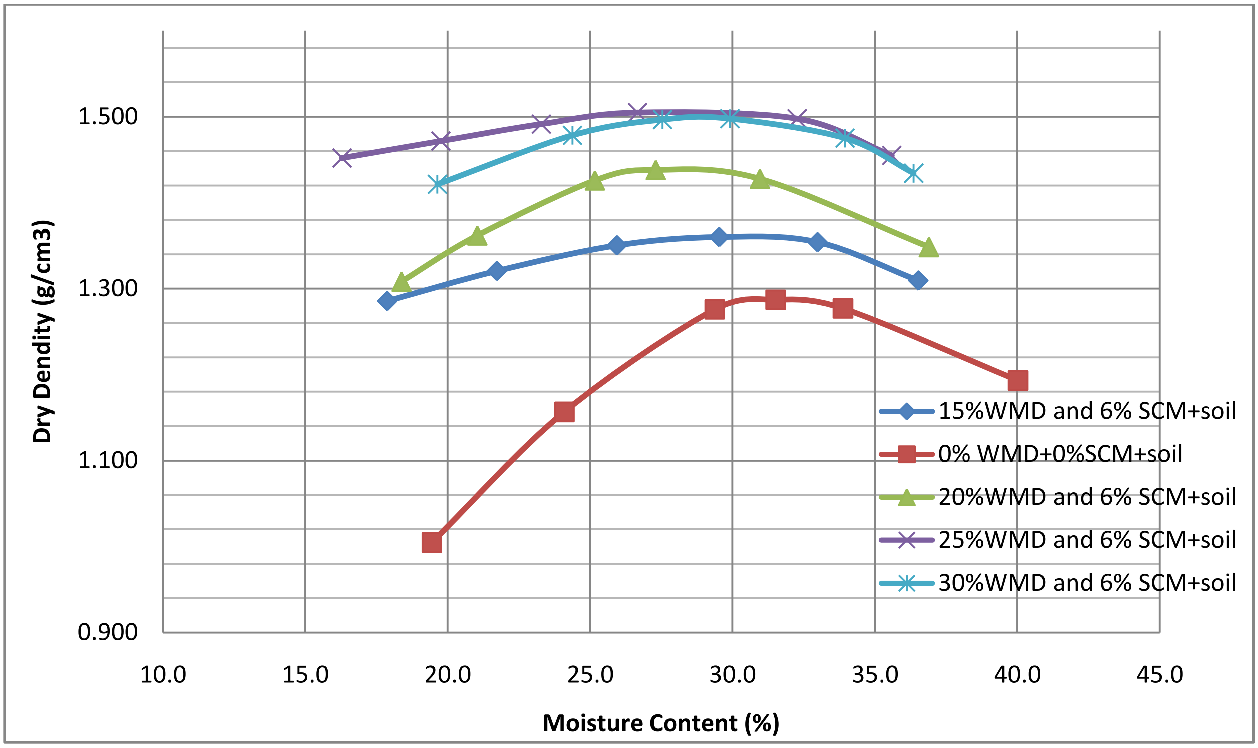
Appendix D: compaction test result

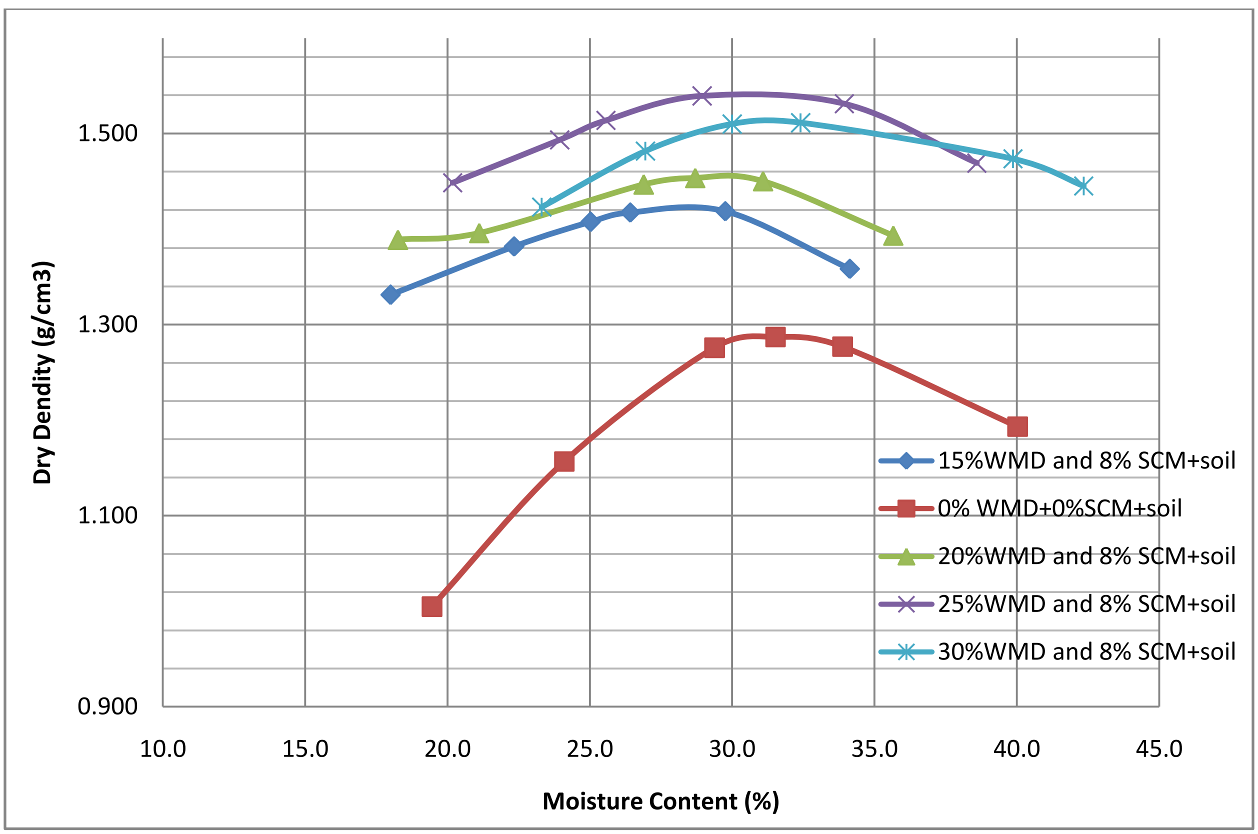
Sampled Date 9/02/2025		Date Tasted: 14/02/2025			Depth : 1.5m		
Description:- natural expansive soil		Location: Collected From Modjo Study Area			Methods:AASHTO T 99		
Material Type: 0% Molases and Marble Dust on Expansive Soil					Tested by: Libenteresa		
Compaction Energy	Hammer: 2.5Kg	Drop: 45.7 cm			Blows: 25		
Test No		1	2	3	4	5	6
Wet Sample+Mould (gm)	A	5600	5835	6050	6092	6109	6070
Wet Sample (gm) A-B	Q	1199	1434	1649	1691	1708	1669
Wt.ofMould (gm) (B)		4401	Volume of Mould(cc) (C)		999		
Water Content Determination							
Containar No		G1	T4	T5	T3	A 1	A2

Container+Wet Sample (gm)		W	106.75	108.67	110.87	110.95	116.89	118.01
Container+Dry Sample (gm)		D	99.3	99.8	100.0	98.5	103	102
Weight of Water (gm)		W-D	7.5	8.9	10.9	12.5	13.9	16.0
Can Weight (gm)		T	61	63	63	59	62	62
Weight of Dry Soil (gm)		D-T	38.3	36.8	37.0	39.5	41.0	40.0
Moisture Content	(W-D)/(D-T)x100	MC	19.5	24.1	29.4	31.5	33.9	40.0
Density Calculations								
Wet Density (g/cm3)	Q/C	WD	1.200	1.435	1.651	1.693	1.710	1.671
Dry Density	WD/[1+(MC/100)]	DD	1.005	1.157	1.276	1.287	1.277	1.193


0% stabilizer pure soil
MDD=1.28
OMC=32
Dry Density (gm/cc)
1.350
1.300
1.250
1.200
1.150
1.100
1.050
1.000
0.950
0.900
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
Moisture Content (%)


Dry Dendity (g/cm3)
1.500
1.300
1.100
0.900
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
Moisture Content (%)
15%WMD and 4% SCM+soil
0% WMD+0%SCM+soil
20%WMD and 4% SCM+soil
25%WMD and 4% SCM+soil
30%WMD and 4% SCM+soil


Dry Dendity (g/cm3)
1.500
1.300
1.100
0.900
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
Moisture Content (%)
15%WMD and 6% SCM+soil
0% WMD+0%SCM+soil
20%WMD and 6% SCM+soil
25%WMD and 6% SCM+soil
30%WMD and 6% SCM+soil

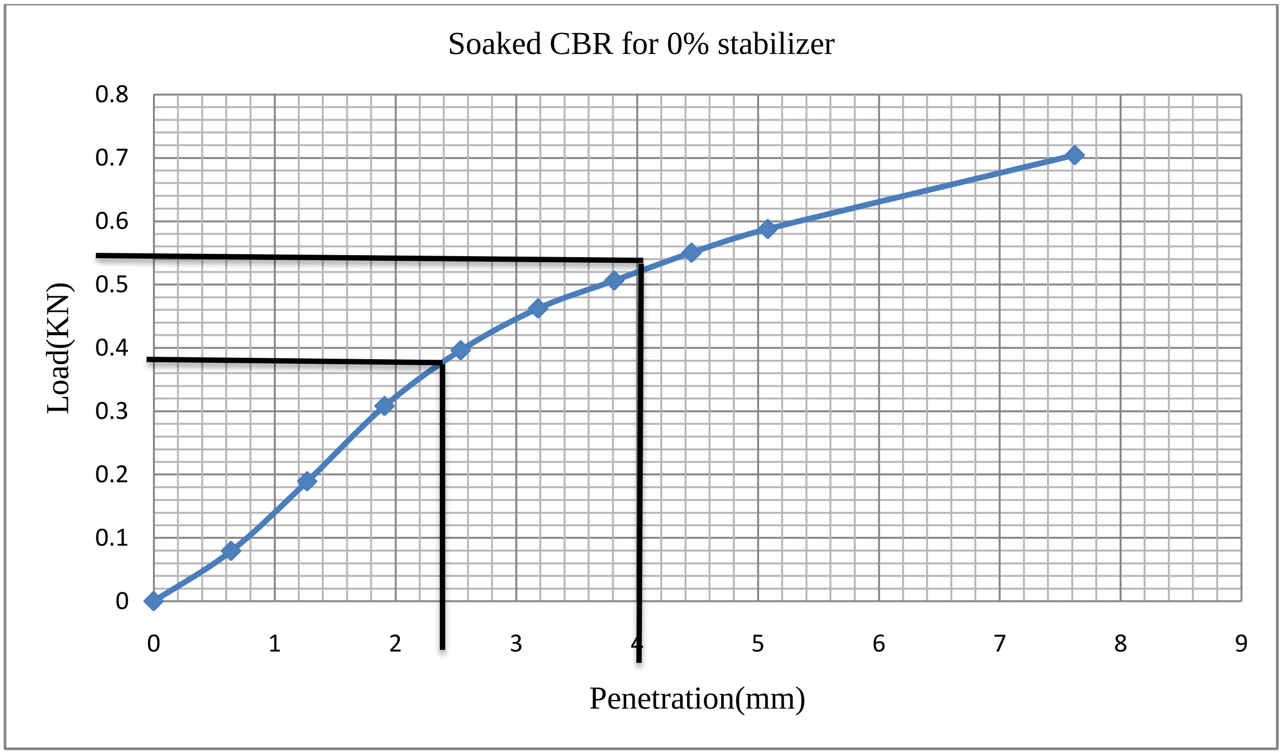

Dry Dendity (g/cm3)
1.500
1.300
1.100
0.900
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
Moisture Content (%)
15%WMD and 8% SCM+soil
0% WMD+0%SCM+soil
20%WMD and 8% SCM+soil
25%WMD and 8% SCM+soil
30%WMD and 8% SCM+soil

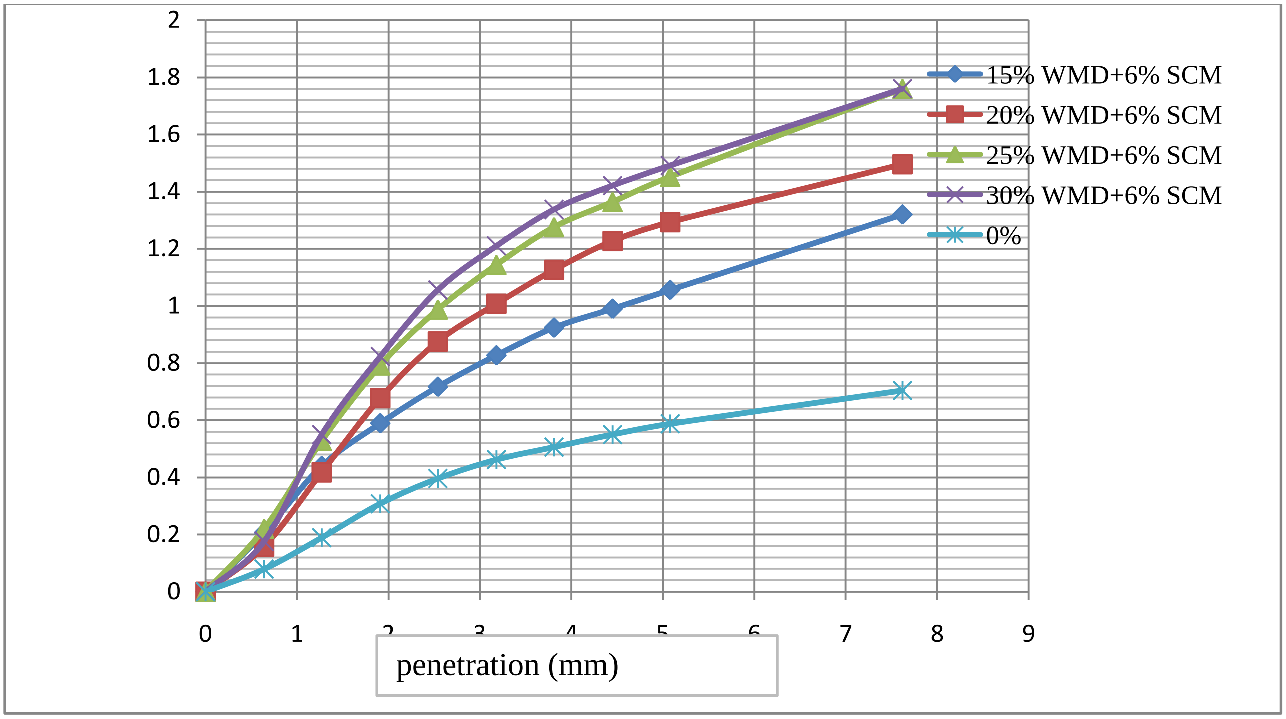
SN	Material	MDD	OMC
1	natural soil	1.28	32
2	15%WMD+4%SCM+soil	1.32	30
3	20%WMD+4%SCM+soil	1.396	27
4	25%WMD+4%SCM+soil	1.472	25.7
5	30%WMD+4%SCM+soil	1.465	29
6	15%WMD+6%SCM+soil	1.362	30
7	20%WMD+6%SCM+soil	1.438	27.3
8	25%WMD+6%SCM+soil	1.505	26.7
9	30%WMD+6%SCM+soil	1.5	28.5
10	15%WMD+8%SCM+soil	1.422	28.5
11	20%WMD+8%SCM+soil	1.459	29.5
12	25%WMD+8%SCM+soil	1.542	30
13	30%WMD+8%SCM+soil	1.515	30.5

Appendix E: CBR test result details

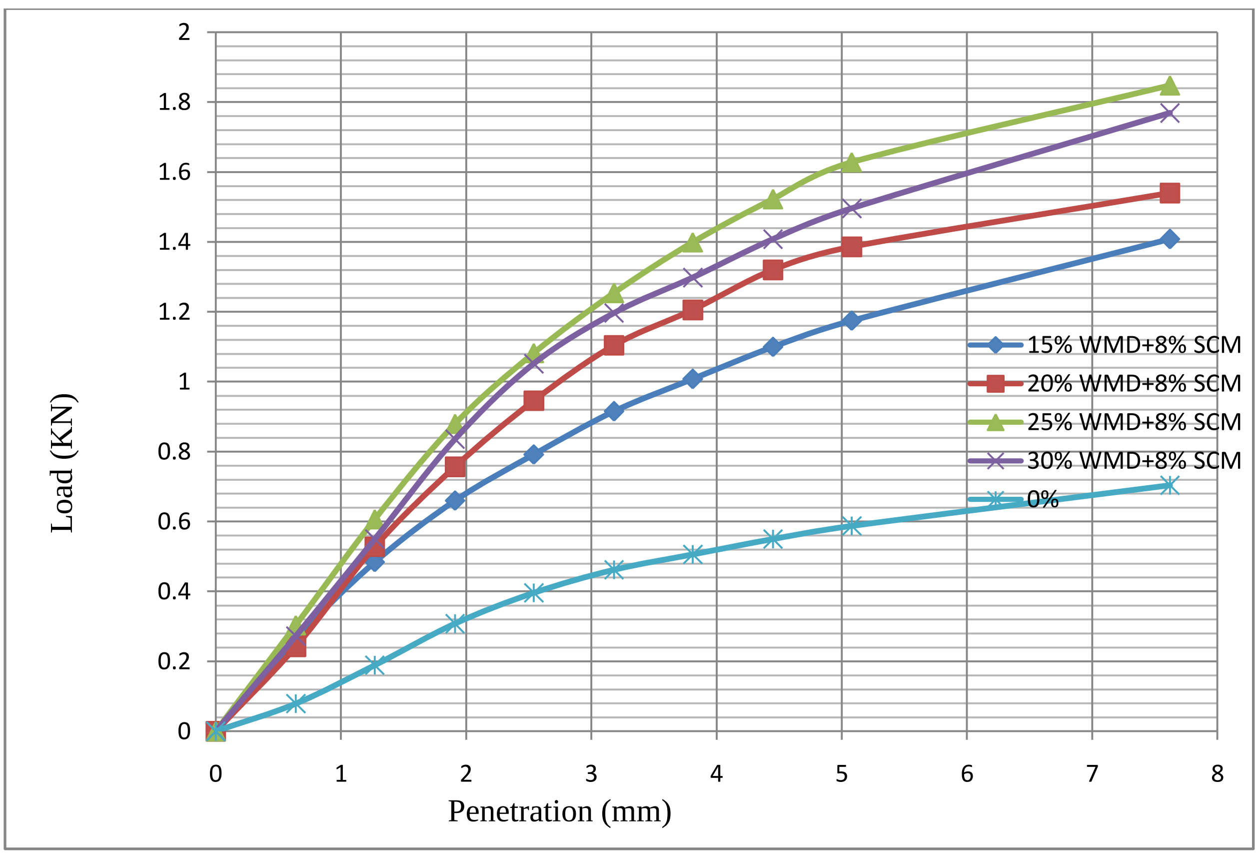
Swell % and CBR %	
Number of Blow	56
Height of specimen (mm)	116.4
RDG (Before Soaking)	0
RDG (After Soaking)	5.87

Percent Swell		5.04	
Average Percent Swell		5.04	
Standard load at	2.54mm	13.2KN	
	5.04mm	20KN	
Load at and CBR	2.54mm	0.4KN	3.0
	5.04mm	0.59KN	2.94
CBR		3.0	

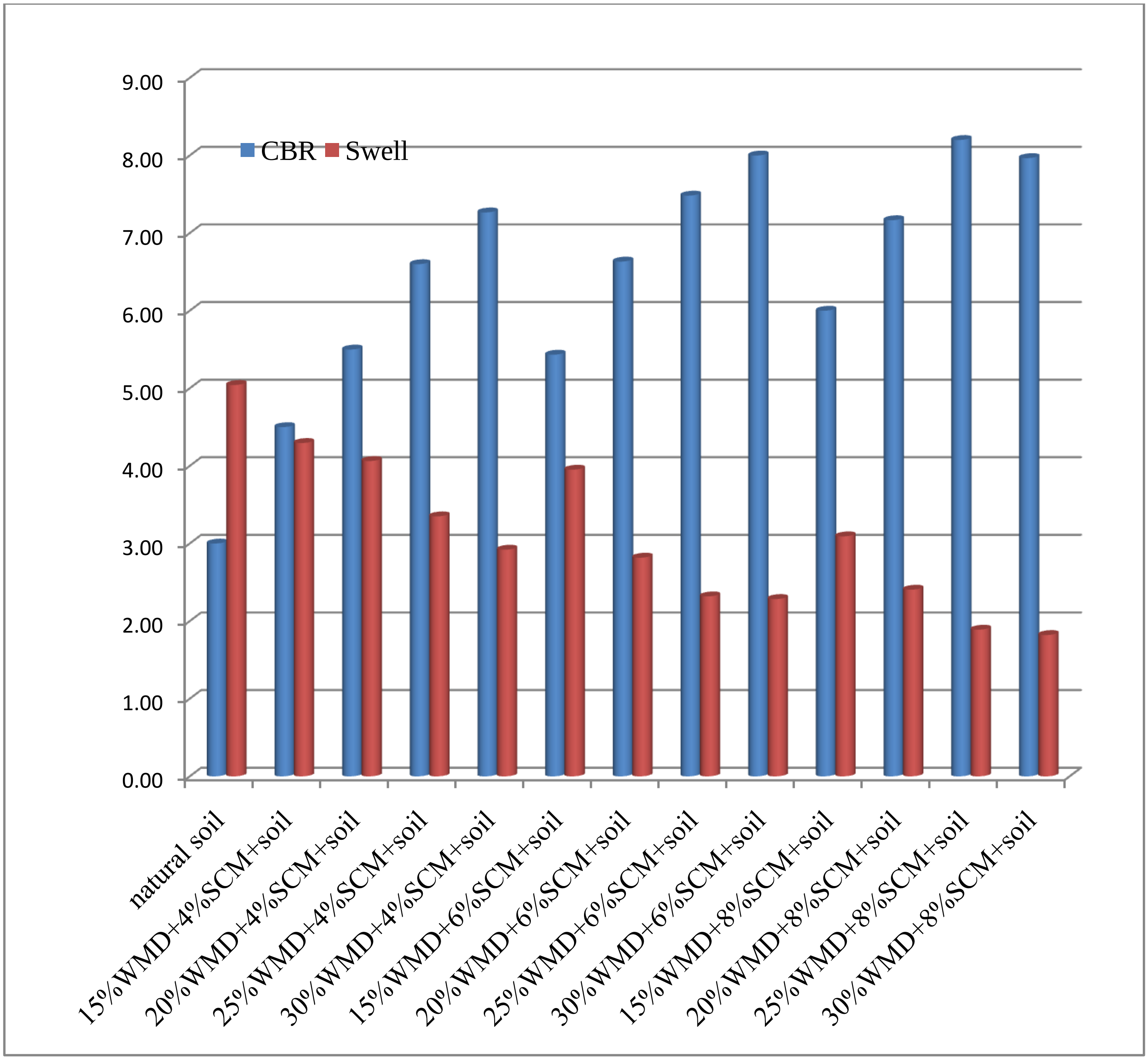




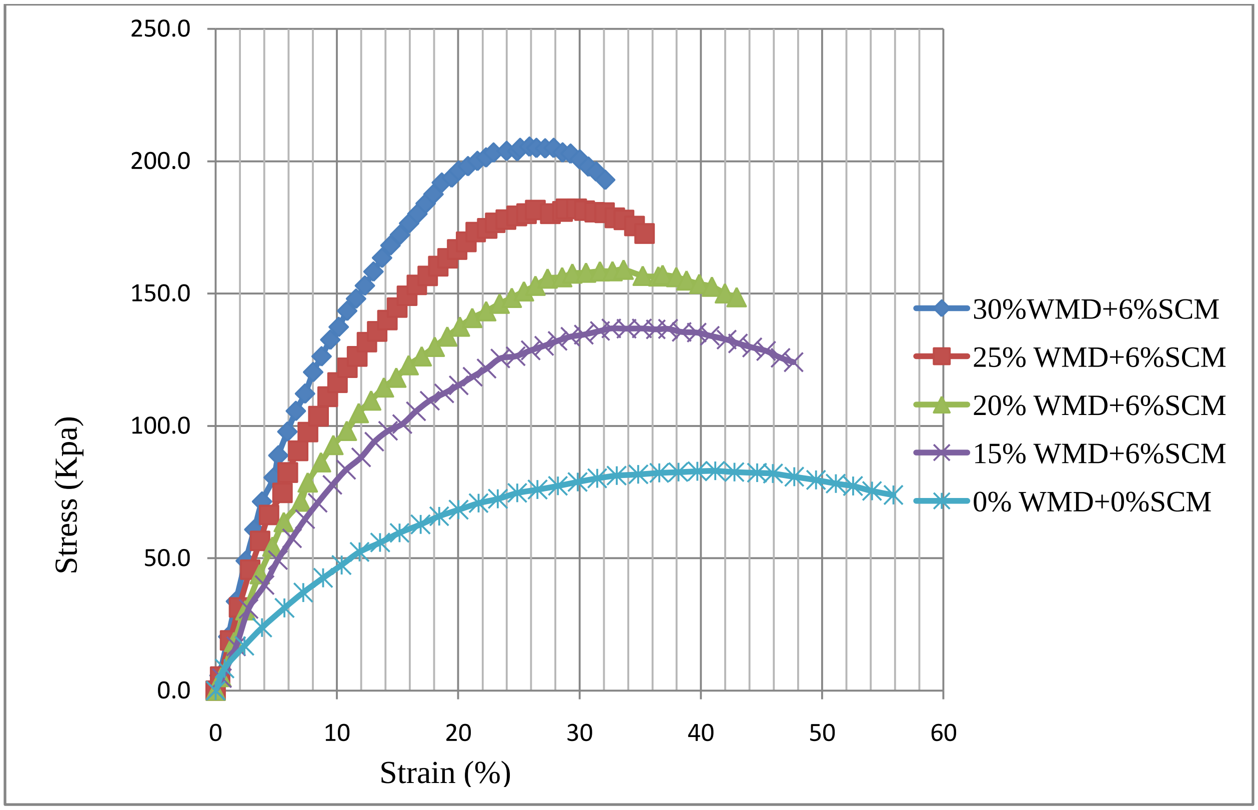
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
7
8
9
penetration (mm)
15% WMD+6% SCM
20% WMD+6% SCM
25% WMD+6% SCM
30% WMD+6% SCM
0%

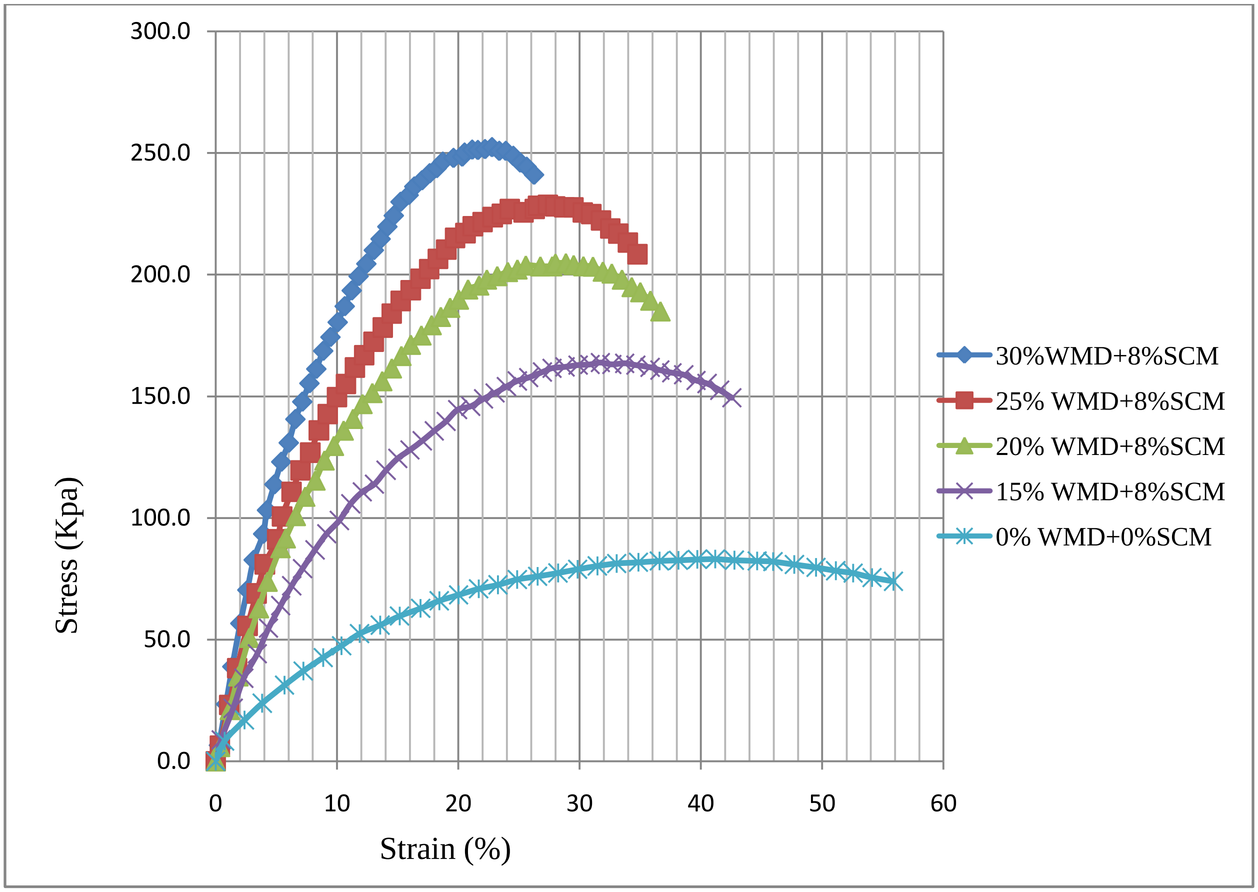


Load (KN)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
Penetration (mm)
15% WMD+8% SCM
20% WMD+8% SCM
25% WMD+8% SCM
30% WMD+8% SCM
0%

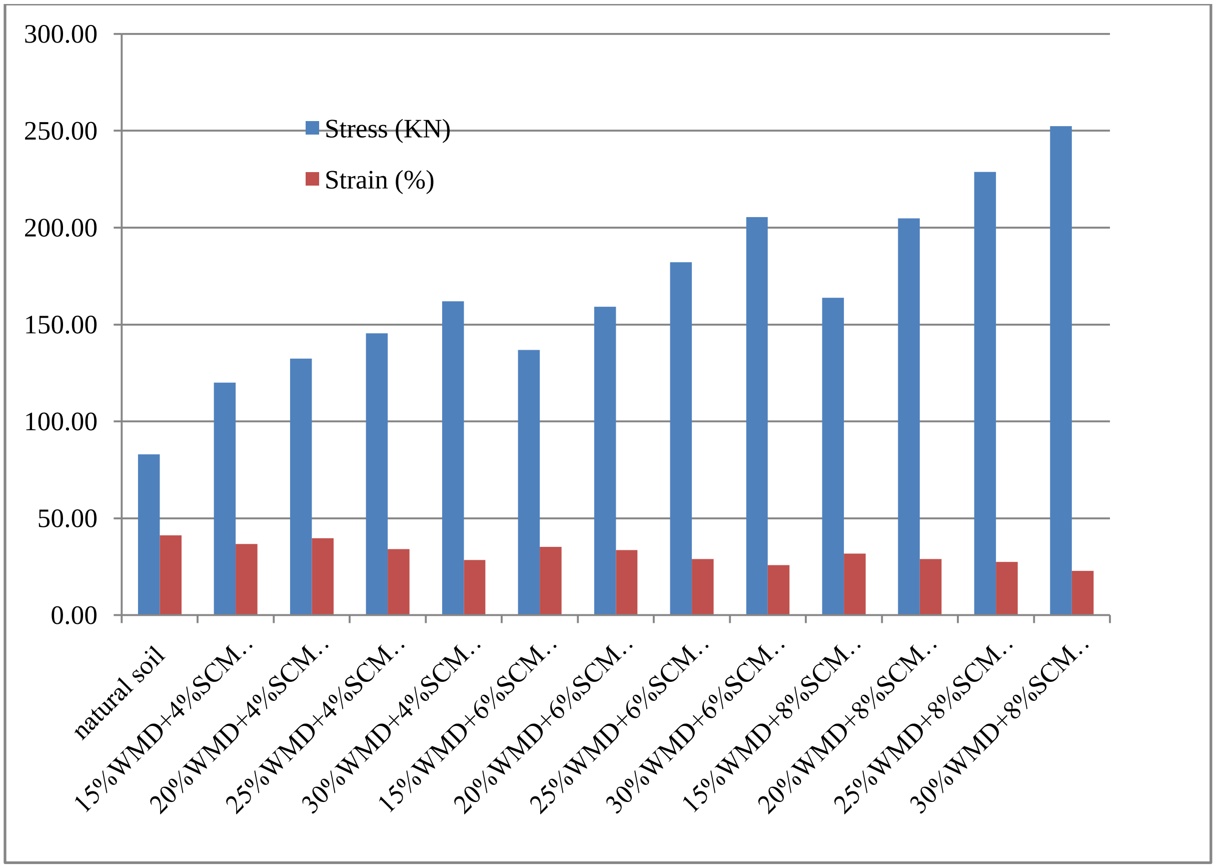

9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
CBR
Swell
natural soil
15%WMD+4%SCM+soil
20%WMD+4%SCM+soil
25%WMD+4%SCM+soil
30%WMD+4%SCM+soil
15%WMD+6%SCM+soil
20%WMD+6%SCM+soil
25%WMD+6%SCM+soil
30%WMD+6%SCM+soil
15%WMD+8%SCM+soil
20%WMD+8%SCM+soil
25%WMD+8%SCM+soil
30%WMD+8%SCM+soil

Appendix F: Unconfined compressive strength test result details




300.0
250.0
200.0
150.0
100.0
50.0
0.0
0
10
20
30
40
50
60
Stress (Kpa)
Strain (%)
30%WMD+8%SCM
25% WMD+8%SCM
20% WMD+8%SCM
15% WMD+8%SCM
0% WMD+0%SCM

)


300.00
250.00
200.00
150.00
100.00
50.00
0.00
Stress (KN)
Strain (%)
natural soil
15%WMD+4%SCM…
20%WMD+4%SCM…
25%WMD+4%SCM…
30%WMD+4%SCM…
15%WMD+6%SCM…
20%WMD+6%SCM…
25%WMD+6%SCM…
30%WMD+6%SCM…
15%WMD+8%SCM…
20%WMD+8%SCM…
25%WMD+8%SCM…
30%WMD+8%SCM…