Assessment of Stone quarry waste and Teff Straw Fiber Stabilization of Expansive Soil (Case of Modjo Town, Ethiopia)

Wubalem Ayele Legese

A Thesis Submitted to the Department of Civil Engineering

College of Civil Engineering and Architecture

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

Specialization of Geotechnical Engineering Stream

Office of Postgraduate Studies

Adama Science and Technology University (ASTU)

May, 2025

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DECLARATION

I hereby declare that this MSc thesis entitled " Assessment of stone quarry waste and teff straw fiber stabilization of expansive soil (case of Modjo town, Ethiopia)" is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Wubalem Ayele	___________________	_______________
Student Name	Signature	Date

RECOMMENDATION

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "Assessment of stone quarry waste and teff straw fiber stabilization of expansive soil (case of Modjo town, Ethiopia)" prepared under my/our guidance by Wubalem Ayele submitted in partial fulfillment of the requirements for the degree of Masters of Science in Civil Engineering (Specialization of Geotechnical Engineering Stream). Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Siraj Mulugeta (PhD) ________________ ________________

Major Advisor Signature Date

Name ___________________ ________________

Co-Advisor Signature Date

APPROVAL PAGE

I, the advisor of the thesis entitled "Assessment of stone quarry waste and teff straw fiber stabilization of expansive soil (case of Modjo town, Ethiopia)" prepared under my/our guidance by Wubalem Ayele hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Siraj Mulugeta (PhD) _______________ _______________

Advisor Name	Signature	Date

APPROVAL OF BOARD OF EXAMINERS

I/We, the undersigned, members of the board of examiners of the thesis defense by Wubalem Ayele, have read and evaluated her thesis entitled "Assessment of stone quarry waste and teff straw fiber stabilization of expansive soil (case of Modjo town, Ethiopia)" and examined the candidate. This is therefore to certify that the thesis was accepted in partial fulfillment of the requirement of the degree of Master of Science in Civil Engineering (Specialization of Geotechnical Engineering Stream).

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Finally, approval and acceptance of the dissertation is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the candidate's Department Graduate Council (DGC) and School Graduate Committee (SGC).

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ABSTRACT

Expansive soils are one of problematic soil for foundation especially for light weight structure in due to high compressibility and low bearing capacity in the fluctuation of saturation level. Because of the increasing cost and environmental effect of traditional methods, such as cut and replace with select material, gypsum, fly ash, lime, and cement stabilization, new additives are required that have a promising effect and preserve the environment. Utilization of waste like stone quarry dust and agricultural byproduct of TSF is an alternative mechanism to improve properties of expansive soil and protect environmental pollution and health and reduce construction costs. The objectives of the thesis are improving the engineering behavior of expansive soil by adding stone quarry dust (10%, 15%, 20%, and 25%) and teff straw fiber (0.4%, 0.6%, and 0.8%) by dry mass of soil. The laboratory tests conducted were as sieve, specific gravity, liquid limit, plastic limit, compaction, CBR, free swell, UCS and XRD. Inclusion of SQW and TSF significantly improves liquid limit, plasticity index, dry density, CRB, free swell, UCS and enhances the crystalline content of the soil mixture, possibly contributing to improved structural stability and reduced plasticity. The highest quartz peak intensity and suppressed clay signals indicate the best mineralogical improvement, which was achieved with 20% SQW. In this thesis work, the promising results were attained at 20%SQW +0.6% TSF for most tests. Therefore, 20%SQW +0.6% TSF is considered as the optimum percentage, which is achieved by improving most of the geotechnical properties of expansive soils.

Key words: XRD, expansive soil, SQW, TSF, soil stabilization

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ACRONYMS

AASHTO	American Association of State Highway & Transportation Officials
ASTM	American Society for Testing and Materials
CBR	Californian Bearing Ratio
CH	Highly compressible clays
DGC	Department Graduate Council
EEC	Ethiopian Engineering Company
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
OPGS	Office of Postgraduate Studies
PI	Plasticity Index
PL	Plastic Limit
SD	Stone dust
SEM	Scanning Electron Microscope
SGC	School Graduate Committee
SQW	Stone quarry waste
TSF	Teff straw fiber
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
XRD	X-ray Diffracted

CHAPTER ONE

INTRODUCTION

1.1 Background and Justification

Because of their capacity to absorb water, expansive soils can undergo seasonal volumetric changes, which can result in ground movement, uplift pressure, and damage to buildings. Low-rise structures are particularly vulnerable to this issue because they lack the weight necessary to withstand it. Furthermore, because of the variations in the quantity and duration of precipitation and evaporation, the impact of such occurrences is particularly apparent in dry and semi-arid regions (Jefferson, 2001). According to the (Wyoming Multi-Hazard Mitigation Plan, 2014), the annual average cost of losses caused by tornadoes, floods, earthquakes, and hurricanes combined has surpassed the cost of widespread soil degradation in the United States.

The process of stabilizing natural soil involves either blending two or more materials to change the particle size distribution or using stabilizing additives to meet the necessary engineering properties (Guyer, 2011). There are currently a variety of stabilizing agents for expansive soil, including fly ash, cement, gypsum, lime, and others.

According to (Pradhan, Kar, & Naik, 2011), the reinforcements in the soil matrix are effective in increasing the soil's shear strength and decreasing its deformation. There are numerous implications for both natural and engineering operations when soils are reinforced with fibers or straws. Because of its easy adaptability, repeatability, and economic value, fiber-based soil strengthening is considered an effective ground supplementation technique (Prakbakar & Sridhar, 2012).

When agricultural materials like fibers and straws stabilize soil, geotechnical engineers take notice (Arega, 2020). Wheat and teff are among the many agricultural products widely distributed in Ethiopia. Most Ethiopian rural communities use the cereal crops' byproduct locally to support mud house walls (Arega, 2020).

Adding stone quarry waste up to 30% improves the behavior of expansive soil such as specific gravity, liquid limit, plastic limit, plasticity index, maximum dry density, optimum moisture content, swelling index, compressibility, and unconfined compression, and is used as construction material (SALAH, 2018).

Therefore, the purpose of this thesis proposal is to enhance the behavior of expansive soil by using stone quarry waste as an additive and teff straw fiber as reinforcement. Physical and mechanical properties were implemented for carrying out the study, which includes the alterberg limit, swell, CBR and unconfined compressive strength.

1.2 Statement of the Problem

Ethiopia located in tropical region which gets seasonal rainfall and most of the high lands are covered with expansive soil, suffer frequent failure of structures such as building and roads such as gaps beneath doors, uneven flooring, structural issues, and damage to foundations.

The most common stabilization method in the nation is cut and replace, and cement or lime stabilization has drawbacks. For example, stabilization of cement or lime is impacted by shrinkage cracks that may spread to the surface; therefore, a stress-relieving layer is required between the stabilized and surface layers. Cut and replace method also has to deal with the high cost of material transportation, construction accidents, environmental contamination, and the challenge of figuring out the depth of moisture fluctuations. Despite their advancements, they are still expensive, have environmental issues, are not always feasible, and require new approaches.

Despite the fact that stone quarry waste is good for construction material as filler and is non-plastic in nature, it is typically disposed of near quarry waste. Quarry waste, a byproduct of the quarry, causes a number of issues, including land filling, impacts the local vegetation, and poses health risks to the local society. In Ethiopia, teff is a commonly grown cereal crop, and its byproduct, teff straw fiber, is primarily used for agricultural purposes. However, studies suggest that farmers could benefit from using teff straw fiber as a soil reinforcement to enhance expansive soil.

Even though there are numerous researches studies done on stabilization of expansive soil using stone quarry alone and teff straw fiber with other additives, there is a gap in using the blend of stone quarry waste and teff straw fiber to stabilize expansive soil.

Therefore, this research aimed to find a stabilization mechanism to stabilize expansive soil and solve environmental problems and preserve scarce resources by using stone quarry waste as additives and teff straw fiber as reinforcing material.

1.3 **Research questions**

In order to achieve the research objectives, the following research questions were proposed.

1. What are the engineering behaviors and mineralogy of expansive soil selected at Mizan Jerba, Modjo town?
2. Do stone quarry waste and teff straw fiber improve the engineering behaviors of and crystalline of expansive soil selected at Mizan Jerba, Modjo town, and
3. What is the optimum percentage of stone quarry waste and teff straw fiber that best improves the expansive soil?

1.4 Objectives

1.4.1 General objective

The general objective is to assess the engineering properties of expansive soil with the addition of stone quarry waste and teff straw fiber through laboratory tests.

1.4.2 Specific objectives

- To characterize the engineering properties of expansive soil selected at Mizan jerba, Modjo town.
- To identify the engineering behavior of expansive soil treated with stone quarry waste and teff straw fiber.
- To obtain the optimum percentage of stone quarry waste and teff straw fiber that best improves expansive soil.

1.5 Significance of the Study

Upon completion of this research, expansive soil contributing about 40% of Ethiopian land could be stabilized with stone quarry waste and teff straw fiber. The stone quarry waste that is disposed of in the quarry site and teff straw fiber used for agricultural feed could be used for stabilization. This in turn preserves the environment by minimizing disposal, agricultural, and health problems. Quarry producing, and farmers benefited by selling their by-product.

1.6 Scope and Limitation of the Study

In this research work, conclusions drawn based on laboratory tests and field tests were not conducted due to limitations of time and resources. All tests were conducted for the soil sample that was collected from Mizan Jerba, Mojo town. Therefore, variability of expansive soil should be considered while applying this in other places. In addition, microstructural studies of expansive soils stabilized by stone quarry waste and teff straw fiber, materials mineralogical studies and durability tests were not conducted due to availability of tests, time and budget limitations. In addition scanning electron microscopy (SEM), consolidation, triaxial, linear shrinkage, tensile strength, etc. tests were not conducted because of resource and time limitation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This portion details a thorough examination of the previous findings on the use of stone quarry dust and Teff straw fiber as stabilizing expansive soils. The negative impact of expansive soil as foundation material and how to mitigate its impact through stabilization elaborated in detail.

2.2 Identification of Expansive Soil

Expansive soil could be identified in the field without conducting tests through wide and deep shrinkage crack, high dry strength and low wet strength, cohesiveness, appearance of crack in structures, black or gray color (Musso., 2014).

Nowadays it is evident that soil deposits can be recognized in the field through visual inspection. Important observations include wide or deep shrinkage cracks, high dry strength and low wet strength, stickiness, low traffic ability when wet, cut surfaces having shiny appearance, appearance of cracks in nearby structures, they usually have a color of black or gray and as a rough guide the presence of distinct cracks on light weight buildings (Musso, 2014).

In addition exact identification of the expansive soil can be recognized by conducting physical tests (Atterberg limits, Free swell index, and potential volume change), and conducting mineralogical tests and chemical properties of soils (Niyomukiza, Wardani, & Setiadji, 2023). Based on physical properties, (Holtz & Gibbs, 1956) developed a general relationship between Atterberg limit tests (shrinkage limit, liquid limit, and plastic limit), and potential volume change for easy identification of expansive soils, as shown in Table 2.1 below. The amount of expansion generally grows with the increase in soil's plasticity index (Ameta & A.Wayal, 2008). Swelling soil can practically control any type of soil behavior if the amount of clay is more than 5% by weight (Rigers & Olshansky, 2013).

Table 2-1: The relationship between Atterberg limit tests and potential volume change

Shrinkage Limit (SL)	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity index (PI)	Activity (A=PI/2μm)	Volume change potential
>15	20-35	<18	20	<0.75	Low
10-15	35-50	15-28	20-31	0.75-1.25	Medium
7-2	50-70	25-41	31-39	>1.25	High
<1	>70	>35	>39		Very high

2.3 Soil improvement Techniques

Poor soil condition could be improved by different soil improvement techniques which are replacing with selected material, lowering water table or saturated throughout the year, ground freezing, electro-osmosis, compaction control, chemical stabilization and soil reinforcement (Mirzababaei, 2013). In the early days of construction of high ways, bridges and buildings, soil replacement methods were widely employed. However, with increasing use of land and growth of cities, highways and industrial zones, decisions to avoid use of poor grounds are less frequently made and ground improvement methods have been developed extensively.

2.4 Soil reinforcement

The essential mechanism of reinforced earth involves the inception of frictional forces between the soil and reinforcement. The soil transfers the forces developed in earth mass to the reinforcement by means of friction; as a result tension is developed. The soil develops virtual cohesion within the direction during which strengthening is placed and thus the cohesion is proportional to tension developed in reinforcements (Mirzababaei, 2013). The experimental conducted by (Mirzababaei, 2013) shows that, carpet waste fiber improved the unconfined compression strength of the clay soils by controlling the dry unit weight and moisture content of the fiber reinforced soil. Also he noted improvement of Shear strength parameters of fiber reinforced soil with addition in fiber content. Fiber reinforced soils showed increased ductility and better energy absorption capacity compared to those of non-reinforced soils with brittle failure. The projected ductile behavior of fiber reinforced soils was manifested in reduced size of main cracks with apparent increase in number of small cracks (Mirzababaei, 2013).

(Prakbakar. & Sridhar, 2012) Research on sisal fiber reinforced soil portrayed that; sisal fiber reinforced soil improved shear stregth behavior of C-ϕ soils with increase of cohesion.

The properties of expansive soil improved with the addition of wheat straw fiber and cement up to optimum amount of wheat straw fiber 3% and cement 7% by dry weight of soil (Tefera, 2022). However beyond 4% wheat straw fiber and decreasing cement content, the improvement of soil decreased and to improve the bonding quality, degradation property with time and extraction of certain amount of chemical constituents, wheat straw fiber were pretreated 3% of sodium hydroxide (NaOH) and Hot Water (30min) (Tefera, 2022). Recently use of natural fiber such as wheat straw, rice straw and barley as reinforcement for stabilization of expansive soil received the attention of researchers due their cost efficiency, availability, light weight and low environmental impact (Chougan & Ghaffar, 2020).

However; pretreatment of natural fiber is mandatory to increase tensile strength, durability, elastic modulus, toughness and reduce degradability of wheat straw fiber (Chougan & Ghaffar, 2020).

2.5 Potential application and merits of fiber reinforcements

Fiber reinforced soils can be extensively used in different geotechnical and civil engineering projects involving slope stabilization, road construction, construction of embankments, repairing or construction of landfill covers and crack controlling (Mirzababaei, 2013).

Advantages of using fiber reinforcement (Mirzababaei, 2013)

- Could be applicable using conventional construction equipment
- Unlike to Conventional stabilizers such as lime, cement, fly ash or other chemical agents; fibers due to their neutral compositions are not significantly sensitive to changes in weather condition.
- Fibers are relatively cheaper material compared to other reinforcing material such as geotextiles and geo grids or stabilizing agents like lime and cement.

2.6 Stabilization of expansive soil using waste material

Waste tires, sawdust, and sawdust ash, and fly ash as stabilizing agents for expansive soils improved index properties, compaction characteristics, strength, and compressibility features of expansive soils (Niyomukiza, Wardani, & Setiadji, 2023). Besides, the use of these wastes as stabilizing agents could reduce the number of wastes discarded directly to the environment or taken to landfills, thus minimizing the health and environmental problems caused by the poor disposal of these wastes. They also indicated that the optimum content of the waste materials to stabilize the soil depends on the properties of the soil. They have found that the waste tires, sawdust, and sawdust ash, and fly ash showed success in the laboratory, and some of them, like fly ash, demonstrated success in both the laboratory and the field. They have recommended that attention for field application of these wastes instead of only focusing on laboratory studies.

2.7 Expansive soil Problems

Structures constructed on expansive soil subjected to different damages including crack and settlement because of low bearing capacity, low shear strength, swell and shrink behavior of expansive soil (Madurwar, Dahale, & Burile, 2013). The swelling nature of expansive soil could be improved by use of admixtures (Jones, Survey, & Jefferson, 2012). To stabilize weak soil commonly cement and lime are used to strengthen the weak soil but their cost of stabilization is very costly (Firoozi & Olgun, 2017).

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).

Damage from expansive clays in the United States is greater than the average yearly damage from hurricanes, tornadoes, earthquakes, and floods combined (Jones & Holtz, 1973). Expanding soils cause cracks in continuous strip footings by causing uplift pressure when moisture levels rise and lifting up lightly loaded soils. It is possible for the rest of the structure to be distressed by such unequal movement and foundation cracking.

Soils that sustain large volume changes in response to variations in water content are considered expansive soils. When water is introduced, they expand, and when they dry out, they shrink. The presence of highly reactive clay minerals like smectite and montmorilonite causes an expansive soil to expand. Light structures placed on top of this soil may move unevenly and shatter as a result of the constant change in soil volume. Therefore it is necessary to improve the soil properties to avoid damages to the structure. Stone quarry waste and teff straw fiber are used to improve the properties of expansive soil which are available in large amount and are produced in huge amount by the quarry material production and agricultural farms respectively.

All around the world, expansive soils have been removed and replaced with appropriate material. Reasonably priced material can be found within reasonable travel distances, however appropriate materials are difficult to find and must be transported from a great distance in urban regions. After stabilization utilizing affordable and easily accessible industrial waste materials, rather than obtaining suitable soil from a great distance away.

The percentage of industrial items used for stability, like cement, is reduced by using such waste materials, which also reduce environmental threats like CO_2 in the atmosphere.

One of the biggest issues in the globe is finding natural building materials that are within an acceptable driving distance of the project that needs to be built. Pavement failures prior to the pavement's design period were the primary issues with building materials in the road industry. Engineering issues with expansive soils have been documented in many nations, but they are primarily found in arid and semi-arid regions.

Pavements or other constructions may fail as a result of the vertical motions in expansive soils brought on by the cyclic wetting and drying process. There are many of these issues in Ethiopia. 23.7 million acres are thought to be covered by expansive soil in Ethiopia (Tamiru, January 2019). The unique cyclic swell-shrink characteristic of expansive soil makes it problematic for structural layers atop embankments when roads are built on it. When water comes into contact with this type of soil, it swells, and when the water evaporates, it shrinks. Residential buildings built on lightly loaded structures including pavements, channels, beds, and linings, as well as foundations, sustain significant damage as a result of this movement.

According to Hassan, Abdelkader, Hussein, & Haiwang (2021), the annual damage to civil engineering structures on expansive soil is estimated to be $150 million in the UK, $1000 million in the US, and many billions of pounds globally. One of the forms of foundation soil that is thought to be problematic is expansive soil, which is primarily made up of a certain type of clay soil. This soil expands when its water content increases and contracts. A typical occurrence of moisture content fluctuation is when the water table falls as a result of seasonal conditions.

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.

In order to minimize these problems, stability is required. Every material layer in the paving system is assumed to have the minimum specified structural quality by the pavement design. Every layer must be able to withstand shearing in order to prevent severe permanent deformation and excessive deflections that could cause the layer or surrounding layers to split from fatigue. Reducing the required thickness of the soil and surface layer is achievable if a soil layer's uniformity increases since it can distribute the load over a larger region. Both mechanical compaction and chemical additive stabilization are popular techniques for soil stability.

2.8 Effect of stone quarry dust on strength of expansive clay soil

Additionally, Ash-Shu'Ara and Ajayi (2018) observed that course sand particles could address the problem of expansive clay's swelling and shrinkage.

Quarry dust additions of 10, 20, and 30% improved the swell behavior atterberg limits (SALAH, 2018). Additionally, as the QD fraction increased, the compressive strength and water absorption during the swell decreased.

Table 2-2: summary of research on effect of SQW on expansive soil

S.N	Researcher		MDD	OMC	LL	PL	PI	Swelling (%)	CBR	UCS(Kpa)
1	(Muhammad Bilal, 2020)	untreated	1.84	12.4	40.7	20.7	20	8.4		
		Expansive +18% SD	2.16	6.2	31.9	25	8.4	4.4		
2	(Abubekir JEMAL, 2019)	untreated	1.32	30.9	80.1	35.3	44.8	3.2	1.82	
		Expansive +35% SD	1.61	22.13	48.5	22.9	25.6	1.39	5.58	
3	(H.Venkat	untreated						100	1.2	

	eswarlu, 2015)	Expansive +10% SD						83	6.7	
4	(Ankit Kumar Maurya, 2023)	untreated	1.54	22.23	65.4	26.8	38.6	133.6	2.9	165.2
		Expansive +30% SD	1.53	18.5	56.8	20.1	36.7	119	10.7	200.6

2.9 Effect of Teff straw fiber on strength of expansive soil

Laboratory experiment conducted by (Arega, 2020) indicated that unconfined compressive strength and unsoaked CBR of expansive soil increases with increase in teff straw content up to optimum value of 0.6% by 21.8% and 35.8% respectively. He also noted reduction of liquid limit and plastic limit for the optimum straw content of 0.6%, 16.83% and 20.97% respectively compared to the natural soil. However; the maximum dry density showed reduction with addition of straw which is associated with light weight of teff straw.

(Sifan & Yadeta C., 2022) reported that unconfined compressive strength of the soil increases when fiber content increases from 0% to 0.75%, length of fiber increase from 20mm to 60mm and decreases when fiber content increases beyond 0.75%. They also identified that the strength of soil also increased with increasing lime content from 0% to 4% and decreased for further increase to 6%. On their research, the combination of fiber reinforcement and lime treatment produced high increase in strength of the soil as compared to lime treatment or fiber reinforcement alone.

(Jili, ChencaiLi, BaoshiLiu, XinxingChen, MingLi, & Zhaowei., 2013) has conducted research on the effect of random inclusion of wheat straw (fibers) of 1 year old (0.1–0.4 % by weight of dry soil) with four section lengths of 5, 10, 15, 20 mm (aspect ratio: l/d = 1.67, 3.33, 5, 6.67) used as reinforcement on shear strength characteristics of Shanghai cohesive soil. Based on direct shear test, the wheat straw fiber reinforced soil increases the shear strength to one degree or another and maximum strength was noticed at 0.3 % of wheat straw fiber for length 15–20 mm (aspect ratio: 5–6.67) (Jili, ChencaiLi, BaoshiLiu, XinxingChen, MingLi, & Zhaowei., 2013).

Experimental research investigation conducted by (Shaokun, Huan, Benfu, Liping, & Shao, 2025) on the effect of biochar on the strength of expansive soil showed that the expansion potential and plasticity index decreased by 56.5% and 34.1% as the biochar content increased from 0% to 10% and also water-retention capacity has been improved. The expansive soil linear shrinkage decreased from 11.1% to 3.2%, the cohesion increased by 78.1%, and the UCS increased by 64.3% with the addition of 8% biochar and 0.3% bagasse fiber (Shaokun, Huan, Benfu, Liping, & Shao, 2025).

Palm fiber reinforced red clay soil showed enhanced properties of UCS by 43.4% and residual strength; also soil damage changed from brittle damage to ductile damage at 0.45% palm fiber with a length of 20 mm (Aijun, Chuanyang, & Shanshan, 2023).

Table 2-3: summary of research on effect of teff straw fiber on expansive soil

S.N	Researcher		soil classification	Specific gravity	MDD(g/cc)	OMC	LL	PL	PI	CBR	UCS(Kpa)
1	(Arega, 2020)	Untreated	CH	2.71	1.41	26	101	39	62	16	198
		CH+ 0.6% TSF			1.31		89.35	35.12	54.23	21.88	241.4
2	(Sifan & Yadeta C., 2022)	untreated	CH	2.78	1.45	24	81.8	32.18	49.62		52
		CH+ 0.75% TSF									90

2.10 Limitation of using waste materials for stabilization in the field (Niyomukiza, Wardani, & Setiadji, 2023)

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. The limited usage is attributed to the following reasons;

1. There are no clearly documented guidelines by the governing bodies (relevant authorities) on their usage.

2. There is no clear standard or optimum quantity of the wastes documented to stabilize soft soils effectively.

3. There is inadequate data published by independent researchers or organizations concerning the use of the waste materials to stabilize soils.

2.11 Mineralogical analysis of Expansive soil

Mineralogical properties of soil could be assessed using scanning electron microscopy (SEM), X-ray diffraction (XRD), Fourier transform infrared (FTIR) to determine minerals responsible for expansiveness of expansive soils (Nitini tiwari, 2020).

Expanding and shrinkage behavior of expansive soil could be identified in the microstructure and morphology of the soil (Corey, 2010).

X-ray diffraction analysis in the research of (Nitini tiwari, 2020) shows that, the peak of quartz is at 20.86^0, 21.98^0, 26.64^0, 39.42^0, 50.1^0, 59.94^0 and 67.96^0, and for the montmorillonite 5.76^0, 19.72^0, 23.58^0, and 27.68^0, for the calcite 29.44^0, 35.72^0, 39.42^0 and 48.62^0 and Hematite 24.42^0, 35.72^0 and 39.42^0. It was observed that 39.42^0 is the common peak for the quartz, hematite, and calcite, and the illite clay mineral diffraction peak was observed at 21.42^0. The intensity pattern with multiple sharp peaks implies a mix of crystalline minerals, often including feldspar, calcite, and clay minerals.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

In this chapter, sampling techniques, data collection and analysis of data were briefly discussed. In addition it describes the materials used and procedures followed to obtain samples from the field, tests performed, study area.

3.2 The study area

Modjo town is located in the East Shewa zone, Oromia regional state, Ethiopia. The town is located in the geographic coordinates of latitude and longitude of 8.5870183 and 39.1231459, respectively (8^0 $39^{'}$N and 39^0 $5^{'}$ E).

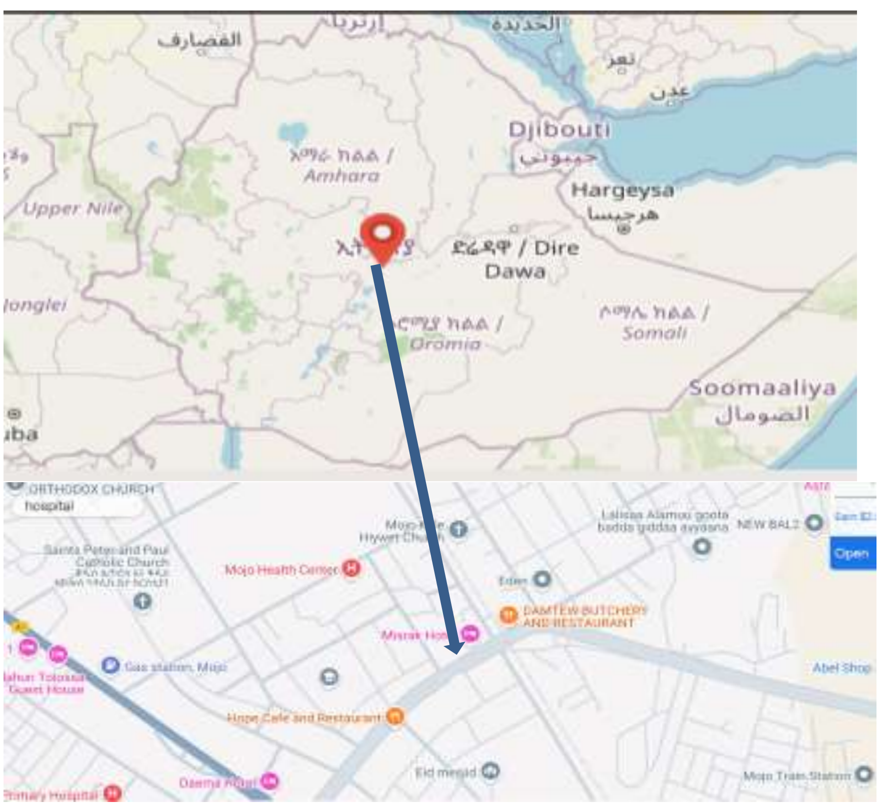

Figure 3.1: Map of study area

Expansive soil collected from a pit at a depth of 1.5m to 2m from ground level from Modjo town behind Mizan Jerba. Depth of the test pit is to represent the foundation depth of the light structure. The site was proposed purposively because it was nearest to the laboratory.

3.3 Research Design

The research design involves determination of the strength and index properties of expansive soil stabilized using stone quarry waste and teff straw fiber through laboratory tests. Also mineralogical analysis of expansive soil and SQW blended samples were assessed. The research is aimed to answer research questions and find out new methods to stabilize expansive soil with locally available material such as stone quarry waste and teff straw fiber. Specifically, the research is designed to determine the optimum ratios of stone quarry waste and teff straw fiber that best stabilize expansive soil. The process is shown in figure 3.2 below.

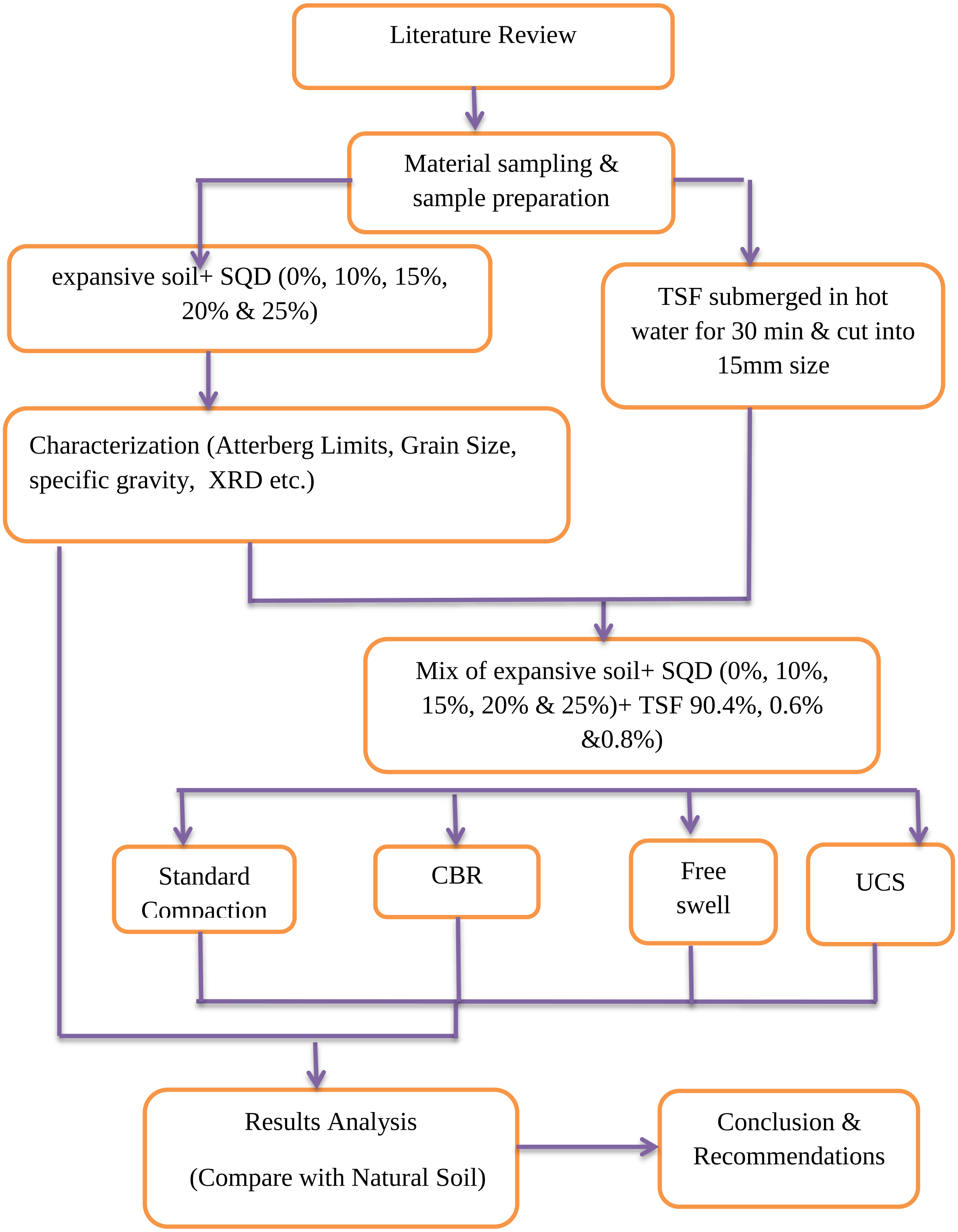

Figure 3.2: Flowchart showing experimental process

3.4 Sampling technique

The disturbed sample was excavated in the selected test pit, as shown in figure 3.2, after the removal of the overburden, and the materials were brought to the laboratory for testing. Stone quarry waste (SQW) was collected from a quarry site near Adama Industry Park, and teff straw fiber (TSF) was collected from farmers near ASTU. The teff straw fiber was submerged in hot water for up to 30 minutes to reduce water absorption and degradability (Tefera, 2022). Then sun dried and ground into 15mm size using mechanical means in the laboratory.

Figure 3.3: Sampling of expansive soil from test pit

Figure 3.4: Photos while TSF prepared

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

The physical properties of expansive soil tested are the particle size distribution; free swell index and the atterberg limits. The mechanical properties include the compaction test, California Bearing Ratio, and the unconfined Compressive Strength.

Different Laboratory tests were conducted on soil specimen in order to study the properties of soil and soil mixed with varying percentages of stone quarry waste and varying percentages of teff straw fiber as per ASTM and AASHTO standards.

The experimental method was adopted for analysis of the laboratory test result conducted on the specimen to draw a conclusion. Disturbed samples were collected from two test pits at mizan jerba, Modjo town.

Liquid limit (ASTM D4318), plastic limit (ASTM D4318), Plasticity index (ASTM D4318), compaction (ASTM D689), free swell index, specific gravity (ASTM D854), UCS (ASTM D2166), Atterberg limits, grain size analysis (ASTM D6913), soil classification (ASTM D2487), CBR (AASHTO193) and unconfined compression strength tests are conducted in this paper. Also X-ray diffraction (XRD) tests were conducted to assess the mineralogical change in using SQW as additive to stabilize expansive soil.

This study focuses on characterization of expansive soil samples and SQW and TSF modified samples and evaluating improved properties. Characterization of soil samples was done based on consistency limit, gradation, CBR and free swell. The effect of additives on the engineering properties was studied by comparing the swelling potential, California bearing ratio (CBR), and unconfined compressive strength (UCS) values of treated and untreated soil.

Figure 3.5: Plastic limit and liquid limit test apparatus while performing the test in the lab.

Figure 3.6: Photo while performing compaction test in the lab

3.6 Study variables

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

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

Independent variable: percentage of stone quarry waste (SQW), teff straw fiber (TSF) and expansive soil.

3.7 Data collection process

The primary research data is collected through laboratory tests and 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

From literature review, stabilization of expansive soil using stone quarry dust and teff straw fiber were identified. Then the probable percentage of each additive selected and their effect were determined through laboratory tests.

3.9 Ethical considerations

Prior to data collection, an official letter was written by Adama Science and Technology University (ASTU) and given to the quarry producing company to give me stone quarry waste for the research and Ethiopian Engineering Company (EEC) to conduct some of laboratory tests.

3.10 Data quality assurances

A pretest of the available instrument was done before the main experimentation began and the test was conducted after gaining an awareness of how to conduct the tests by principal investigator. The test result was checked with the standards and approved.

3.11 Scope of the study

In this research, SQW and TSF are used as additive material. The mechanical properties of expansive soil containing SQW 10%, 15%, 20%, and 25% and TSF 0.4%, 0.6% and 0.8% by weight of dry soil were determined by performing laboratory tests.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter discusses in detail the laboratory test results, and discussion in detail. The engineering properties of expansive soil stabilization with different percentages of stone quarry waste (SQW) and teff straw fibers (TSF) are examined, and the optimum replacement proportions were determined, and conclusions were drawn based on the analysis.

4.1 Particle size distribution and gradation

The expansive soil first air dried and a representative sample reduced to a mass required for testing and their masses were measured to the nearest 0.01 gram. Dry sieve test were performed for a samples retained on sieve of 75μm and hydrometer analyses were done for samples passing a sieve of 75μm. On the dry sieve test, the sample is placed on sieves nested in decreasing order and shaken sufficiently to ensure all materials having dimensions less than the sieve size pass. The mass retained on each sieve measured to the nearest 0.01 gram and percent passing on each sieve was calculated. For the materials passing 75 μm, wet sieving was performed. The results of both wet and dry sieve test combined and chart were drawn to check with the specification. Even though gradation test is simple, it point out the behavior of soil such as workability, permeability, and compaction characteristics, etc. .

As shown in figure 4.1, the expansive soil sample contains sand particles of about 8.64%, silt particles of 61.9% and clay particles of 28.22%. Particles passing the 75μm sieve are about 90.12%, and the soil classified as silty clay as per the AASHTO soil classification system (greater than 35% passing 75μm sieve) and its engineering properties are weak.

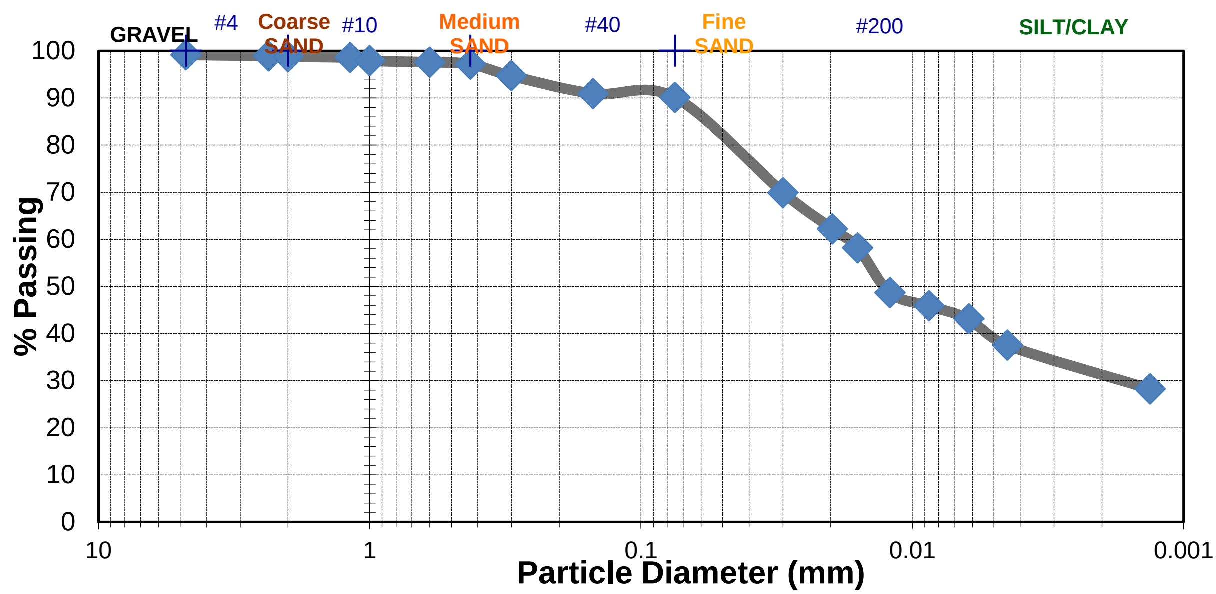

Figure 4.1: Particle size distribution of expansive soil

4.2 Atterberg limit test

Atterberg limit such as liquid limit and plastic limit were conducted as per AASHTO T 89 and 90 standard test methods, respectively. Then, plasticity index were computed by deducting the plastic limit from the liquid limit. The expansive soil and the SQW sieved with a 0.425mm sieve and those passing this sieve were used for the test. The plastic limit (PL) of a soil shows the nature of soil to act as plastic, and it is the minimum water content required for the sample to changes its state from semi solid to plastic. Plastic limit determined by measuring the moisture content at which a paste rolled without crumbling to make thread of 3mm rolling using glass plate and fingers. Liquid limit is the moisture content at which, repeatedly dropped a cup containing a soil sample, grooved by a groove closed at 25 blows. Liquid limit is the minimum water content at which a soil sample changes from a plastic state to a liquid state. It is found that the liquid limit, plastic limit, and plasticity index of expansive soil samples are 77%, 37.4 %, and 39.6%, respectively, as shown in figure 4.2.

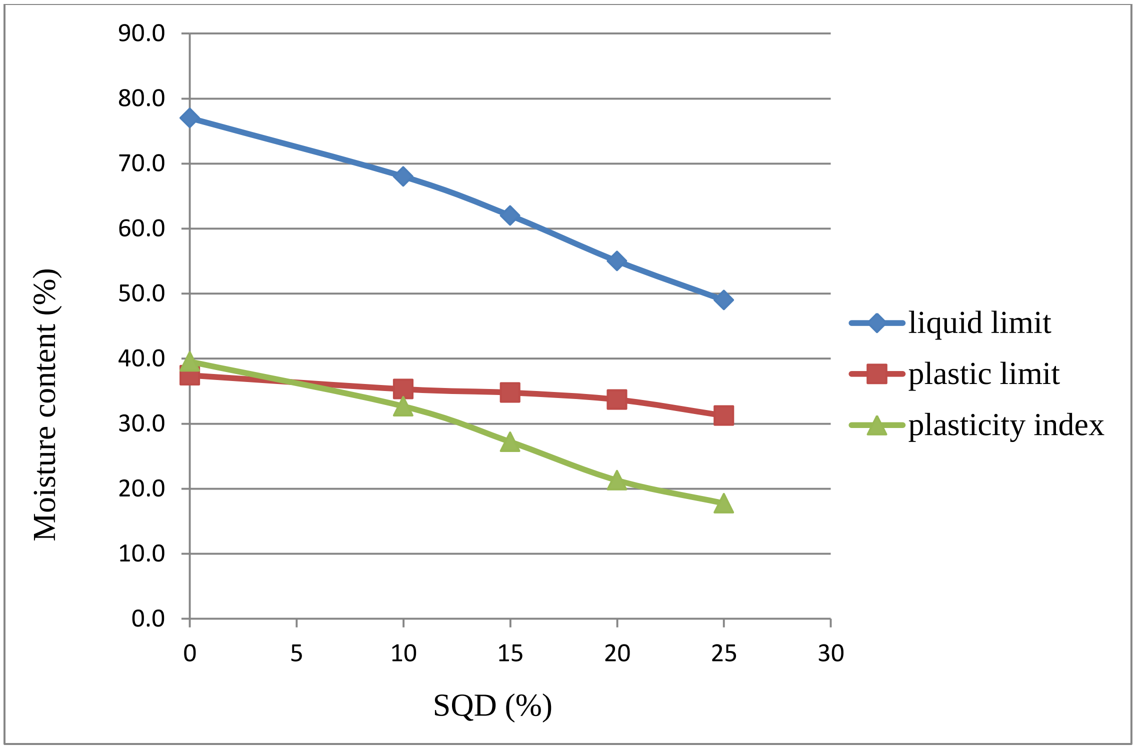

Figure 4.2: Effect of SQW on liquid limit, plastic limit and plasticity index

The result shows that, liquid limit, plastic limit and Plasticity index decreases with increase of SQW content. This result is in agreement with the research (SALAH, 2018) , (Abubekir JEMAL, 2019) and (Ankit Kumar Maurya, 2023). It is because of the higher percentage of non-plastic, coarser particles and lower clay content in the SQW particles, whereas expansive soil with higher clay content has higher ability to bind with water and exhibit plasticity.

4.3 Soil classification

Soil classification serves to group soils with similar properties; their potential use for civil engineering projects. In this thesis, the soil samples were classified based on AASHTO and Unified soil classification (USCS) system.

In AASHTO classification system, a soil sample classified based on gradation, liquid limit, and plasticity index. Percent passing sieve 75µm of the samples were greater than 35%, it is fine grained soil, further grouped as A-4, A-5, A-6, and A-7. A-6 and A-7 are separate by line define by the equation PI=LL-30. The materials classified as A-7-5 and A-7-6 is generally week for construction. As shown in the figure 4.3, the expansive soil and samples stabilized with 10%, 15%, 20% and 25% SQW are classified as A-7-5.

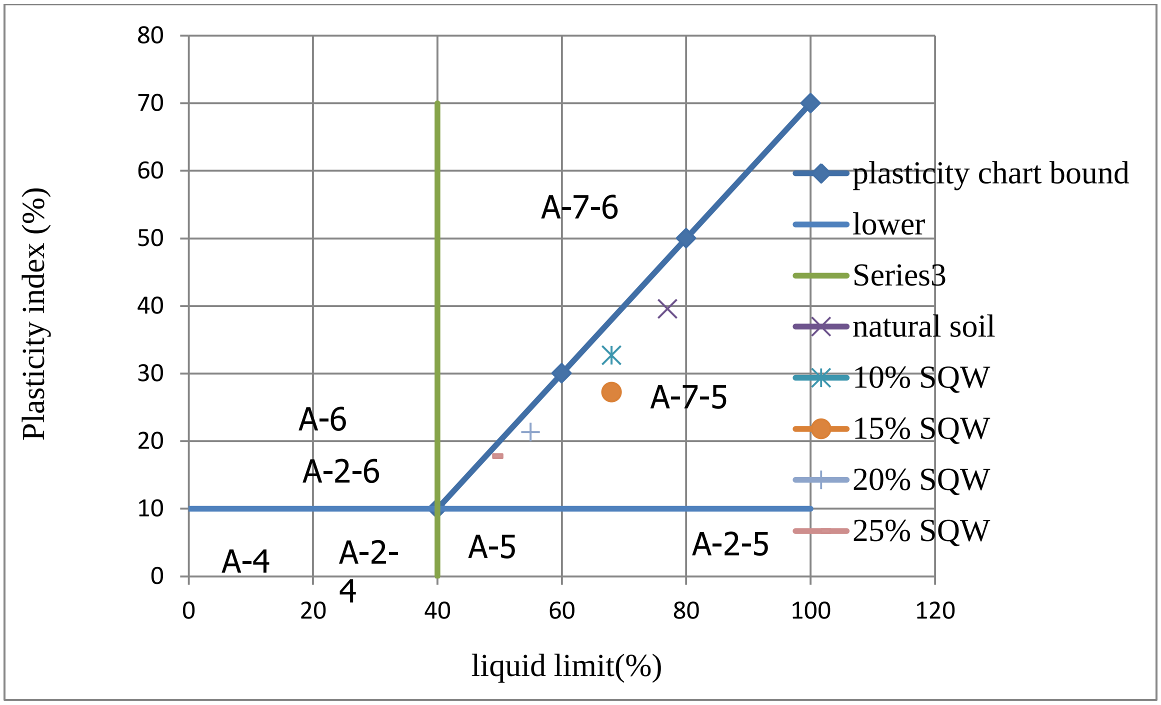

Figure 4.3: AASHTO soil classification for soil samples

In Unified soil classification system, particle passing more than 50% sieve 75µm, classified as fine grained soils (clay and silt). Clay (C) and silt (M) separated by A line given by equation PI=0.73(LL-20), and U line given by PI=0.9(LL-8) separates high plasticity (H) and low plasticity (L). The figure 4.4 below shows that except samples containing 25% SQW, which is classified as ML, all the samples are classified as MH according to USCS classification system.

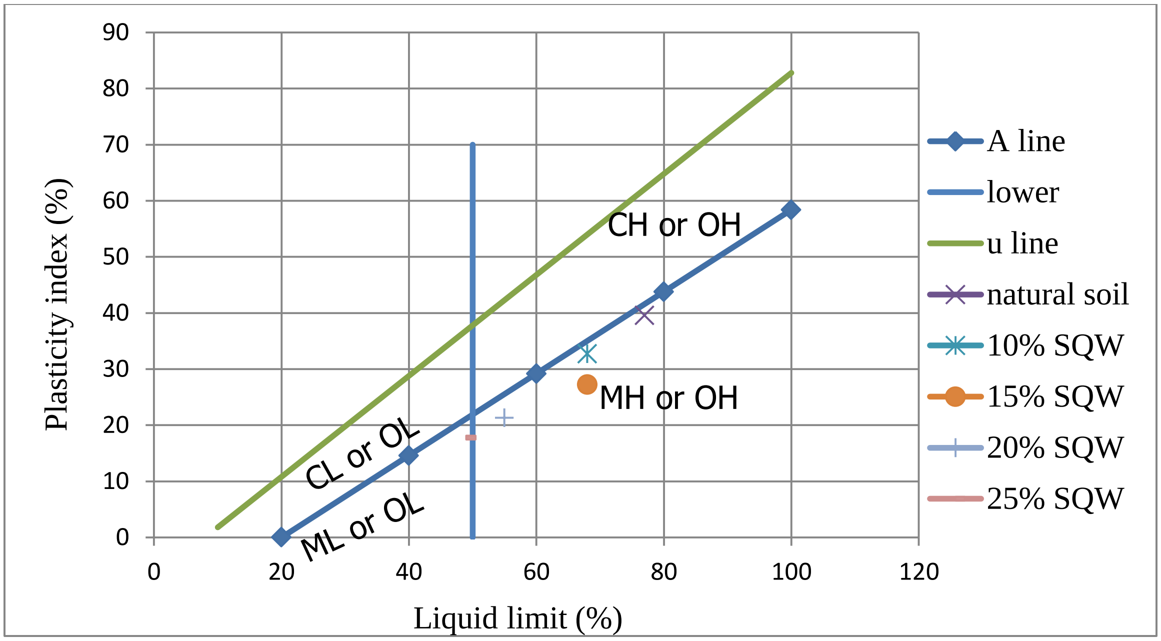

Figure 4.4 USCS soil classification for soil samples

4.4 Specific gravity

Specific gravity of the soil samples was determined in laboratory according to (AASHTO T100-95 or ASTM D854-83). Distilled Water is filled in small pycnometer and weighted to the nearest 0.01g (MA) and about 10g (Mo) of oven dried soil sample added into pycnometer to fully submerge in water. By using compressor, air bubbles completely removed, pycnometer fully filled and its weight measured (MB). Specific gravity determined as below.

$$Gs = \frac{Mo}{Mo+(MA+MB)}$$

As depicted in figure 4.5, specific gravity of expansive soil found to be 2.52g/cc and specific gravity increases up on addition of SQW, which similar trend with the researches of (SALAH, 2018) and (Abubekir JEMAL, 2019). This is due to denser, coarser mineral particles of SQW, while expansive soil contains lower density and fines particles. The specific gravity of the sample changes from 2.52 to 2.64 as SQW increases from 0% to 25%.

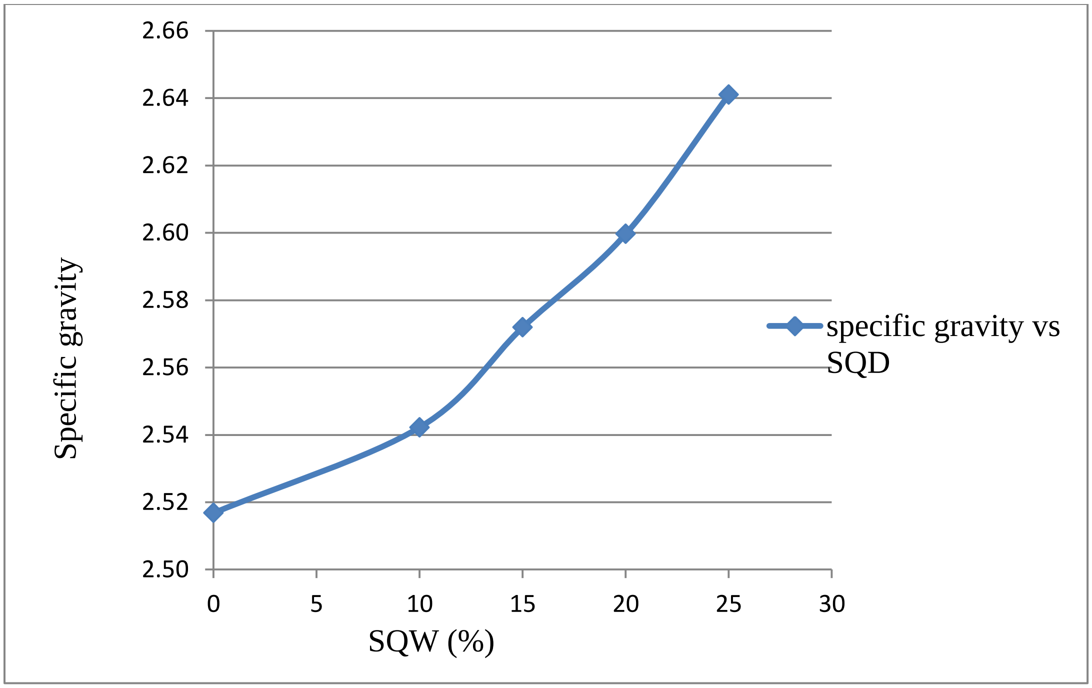

Figure 4.5: Effect of SQW on specific gravity

4.5 Free swell index

Free swell index as per IS 2720 (part 40) was done to know the swelling potential of the expansive soil sample and samples stabilized with SQW. Free swell index is the ratio of increase of volume of soil sample when submerged in water, compared to its volume when submerged in kerosene. Two soil sample of oven dried, passing sieve size 0.425mm of about 10gm for each mix ratio were poured in two cylinders. One cylinder filled with kerosene and the other distilled water up to 100ml and stirred with glass rod to remove entrapped air. After 24 hours the volume of soil in each cylinder measured and free swell index computed as follows.

$$\text{Free swell index} = \frac{\text{volume of soil in distilled water} - \text{volume of soil in kerosene}}{\text{volume of soil in kerosene}} * 100\%$$

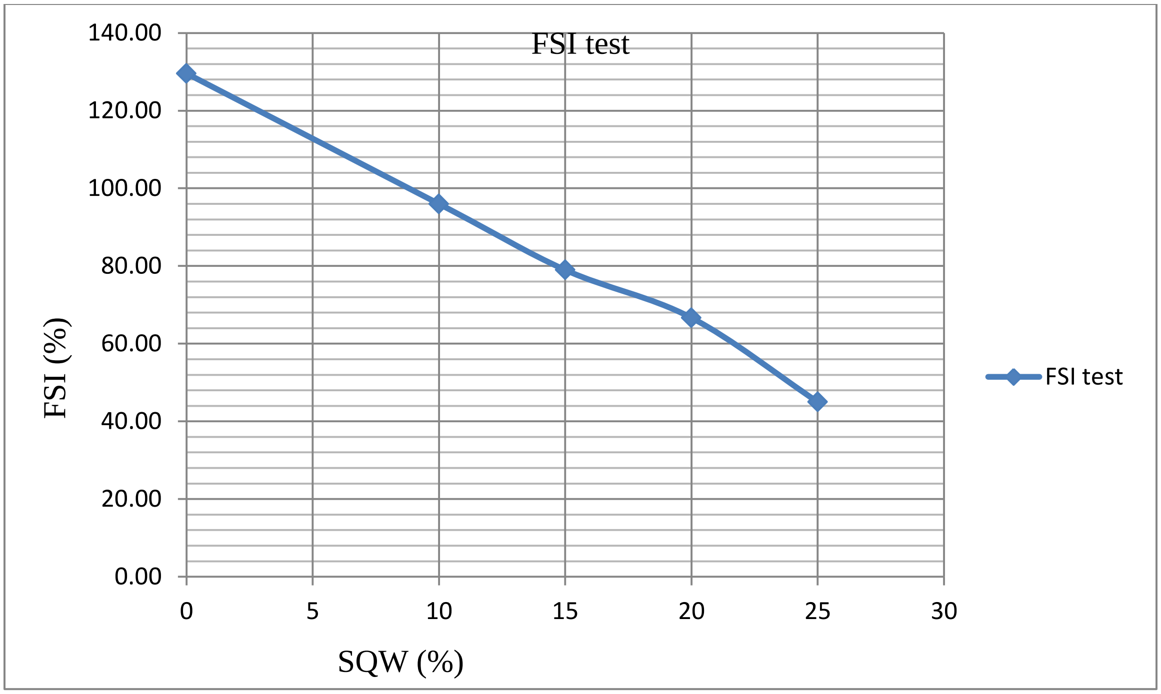

Figure 4.6: Effect of SQW on free swell index

Soils having free swell index above 100% highly expansive, between 100% to 50% medium expansive and below 50% low expansive class. As shown in figure 4.6 the free swell index of the expansive soil was 129.6%, which indicates the soil is highly expansive. Up on addition of SQW, the swelling index reduced significantly, it changes from 129.6% to 45% when SQW increase of from 0% to 25% at increment of 5%. As SQW content increases free swell index decreases continuously. Samples containing 10% to 20% SQW were classified as medium expansive and samples containing 25% SQW classified as low expansive soil based on free swell index. The result of this study is in line with the research of (Ankit Kumar Maurya, 2023).

4.6 Moisture density relation ship

Standard Procter as per AASHTO T-99 or ASTM D698 Method was performed to determine moisture density relationship of the soil samples due to fine gradation of the sample. As shown in figure 4.1, percent passing 4.75mm sieve is less than 5%, no replacement is required. Figure 4.7 and figure 4.8 depict that, the pure expansive soil's maximum dry density and optimum moisture content found to be 1.27 g/cc and 32%, respectively. This is due to gap graded nature of the soil and moisture holding capacity of the soil. With the increase of SQW on expansive soil, maximum dry density generally increases for all percentage of TSF, except for samples containing 0% TSF and 0.4% TSF beyond 20% SQW, shows decreasing of the maximum dry density. This is in agreement to the research of (Muhammad Bilal, 2020) and (Abubekir JEMAL, 2019). In contrary to this, (Ankit Kumar Maurya, 2023) reported on their research, the maximum dry density decrease with increase of SQW. The increase of maximum dry density up on addition of SQW is that SQW has coarser particles that pack more tightly together with smaller clay particle in the expansive soil, resulting in less void space and a higher density when compacted.

Addition of small percentage of TSF in the expansive soil improves the dry density with the maximum improvement is obtained at 0.4% for all SQW percentage. The sample containing 0.4% TSF and 20% SQW shows optimum improvement of dry density with value of 1.45 g/cc. However, beyond 0.4% TSF content, the maximum dry densities of the samples are lower than the expansive soil's maximum dry density for all SQW content. This is in agreement with the finding of (Arega, 2020) and (Sifan & Yadeta C., 2022). Because addition of small percentage of TSF shows higher packing ability, increased shear strength and reduced void space. Samples containing 0.6% and 0.8% TSF as SQW percentage increases, dry density increases continuously. However, those samples containing 0% TSF and 0.4% TSF, dry density increases up to 20% SQW and then starts to decline. Optimum improvement in dry density is found at 20% SQW and 0.4% TSF which is 1.45 g/cc. It is due to SQW's coarser particle nature pack more tightly together with smaller clay particle in the expansive soil; non-plastic particle improves workability and compaction characteristics, pozolanic reaction, and improvement of gradation and bonding capability of TSF. As shown in figure 4.8, optimum moisture content decreases up to 15% of SQD and then increases, this is due to decrease of surface area with optimum amount of SQD and further increase of SQD creates void space which could be filled with water.

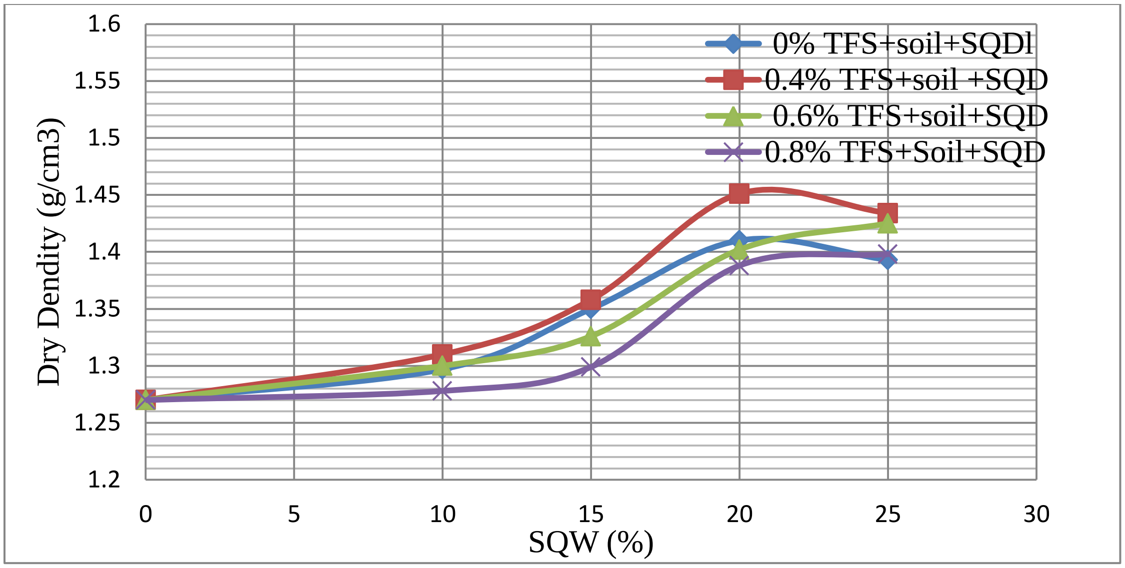

Figure 4.7: Effect of SQW and TSF on maximum dry density

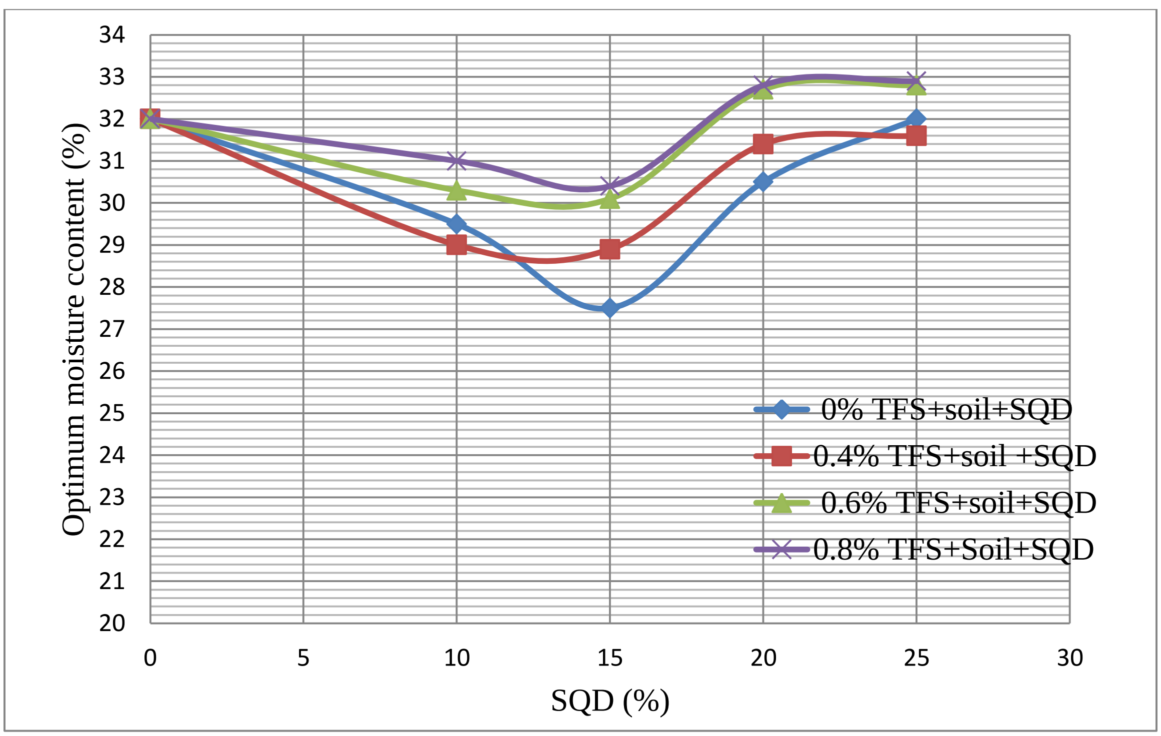

Figure 4.8: Effect of SQW and TSF on moisture content

4.7 Californian bearing ratio (CBR)

CBR measures the penetration resistance of a soil sample compared to penetration resistance of standard crushed aggregate. Soil sample passing 20mm sieve compacted at maximum dry density, soaked for four days under surcharge load of 4.5Kg and the force needed to penetrate measured and compared to the standard resistance. Swelling potential determined by measuring change of height while soaking. The impact of surface smoothness on penetration resistance is corrected by shifting the origin by drawing straight-line tangent to the maximum curvature; extend to cross the abscissa on stress strain graph.

A standard piston of 50mm is used to penetrate the soil sample at a rate of 1.25 mm/min up to a penetration of 10mm and penetration resistance is measured. The CBR value is determined by dividing the corrected forces needed to penetrate the plunger 2.54 mm, and 5.08 mm by the standard penetration resistance of crushed aggregate, 13.2 KN, and 20 KN at respective depth.

As illustrated in figure 4.9 and figure 4.10 the swelling potential and CBR value of the expansive soil is found to be 5.97% and 2.83% respectively. The 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.

The addition of SQW significantly improves CBR value and CBR swell reduces for all percentage of TSF and similar with research of (Abubekir JEMAL, 2019), (Ankit Kumar Maurya, 2023), (Muhammad Bilal, 2020), and (H.Venkateswarlu, 2015). This is due to the fact that SQW increases the density and reduces porosity resulting 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. CBR value increases and CBR swell decreases as TSF percentage increases up to 0.6% for all percentage of SQW. This is supported by findings of (Arega, 2020). The reason is that TSF acts as reinforcement, increasing soil’s resistance to penetration and create network which resists swelling in the soil. Optimum stabilization of expansive soil with TSF and SQW found with addition of 0.6% TSF and 25% SQW with value of CBR and CBR swell 6.30 and 2.09 respectively.

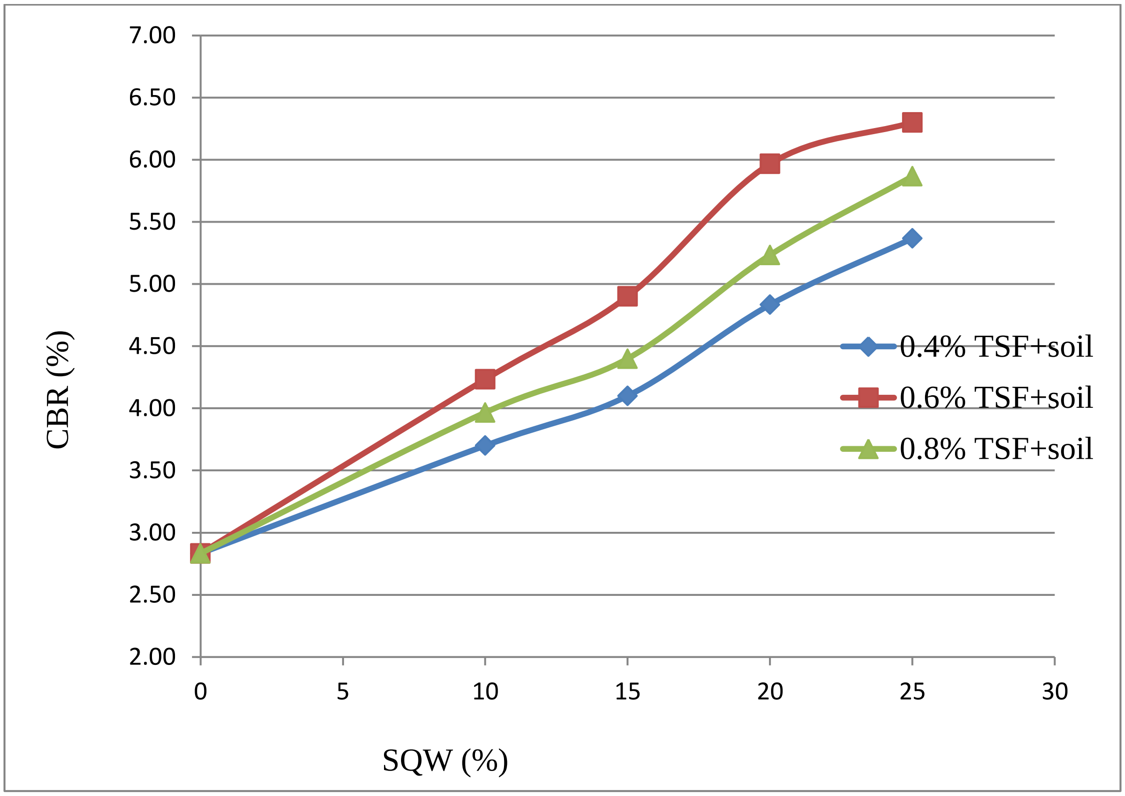

Figure 4.9: Effect of SQW and TSF on CBR value

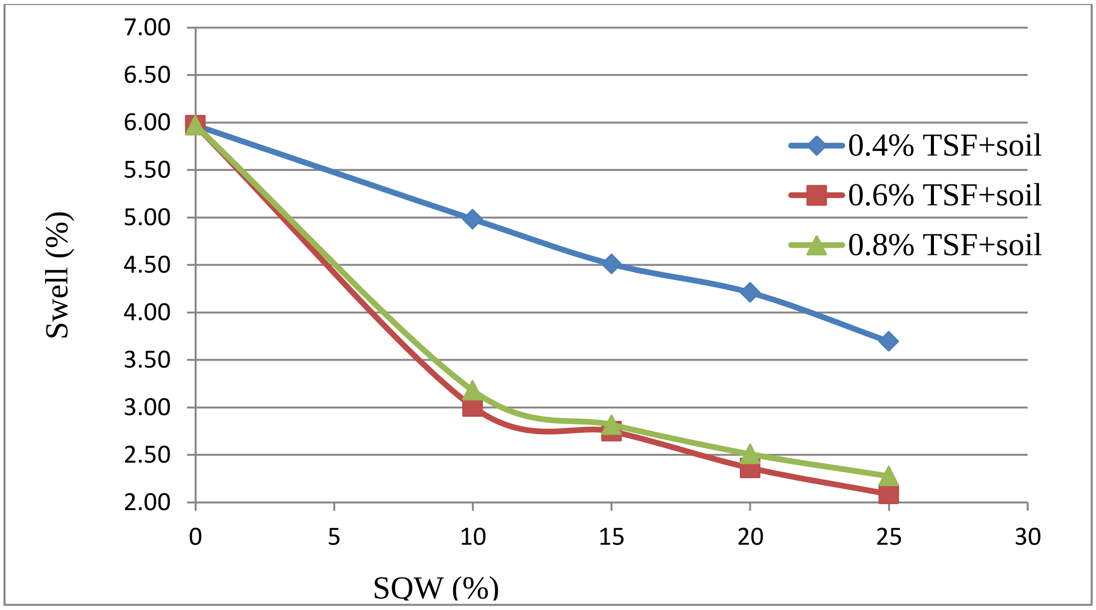

Figure 4.10: Effect of SQW and TSF on CBR swells

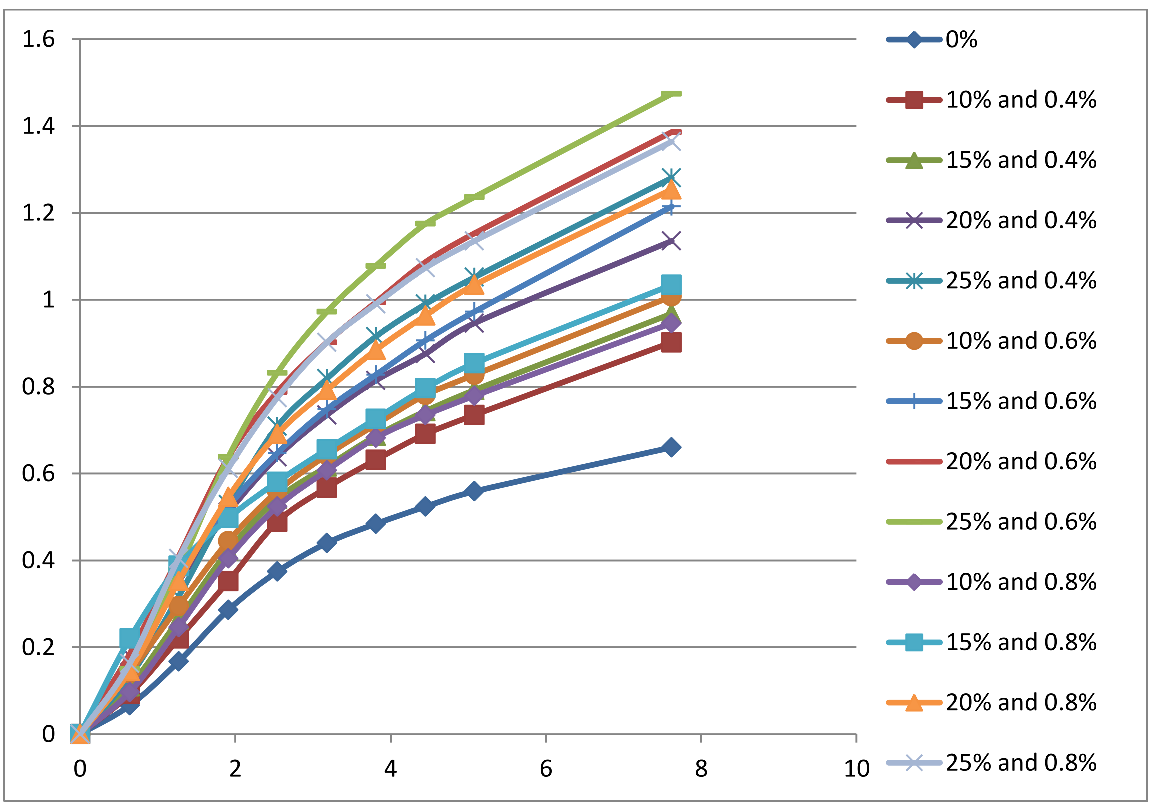

Figure 4.11: CBR results for all samples

4.8 Unconfined compressive strength (UCS)

Unconfined compressive Strength is the maximum axial compressive stress a specimen can bear under zero confining stress. Disturbed sample prepared (mixed, compacted and cured) and load to an increasing load until failure and the ratio of maximum load over area is called unconfined compressive strength. 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.

$$\text{UCS} = \frac{Load\ (KN)}{\text{Corrected area}}\ (Kpa)$$

As shown in the figure 4.12, figure 4.13 and figure 4.14 the UCS test result reveals that the maximum stress and strain of the expansive soil found to be 80.36KPa and 41.56% respectively, showing that the expansive soil alone had weaker strength in bearing load. With the addition of SQW in the expansive soil improves the stress and reduces strain for all percentage of TSF. This is in line with the research of (Ankit Kumar Maurya, 2023). Also with addition of TSF stress increases and strain decreases except for samples containing SQW more than 20%, in which strain increase with increase of SQW. This value is in agreement with the finding of (Arega, 2020) and (Sifan & Yadeta C., 2022). Optimum improvement found by adding 25% SQW and 0.8% TSF in the expansive soil with maximum stress of 172.7Kpa and strain of 28.7%, which is more than twice load bearing resistance than pure expansive soil resistance. This is due to improved shear strength and density because of SQW and TSF in the soil sample.

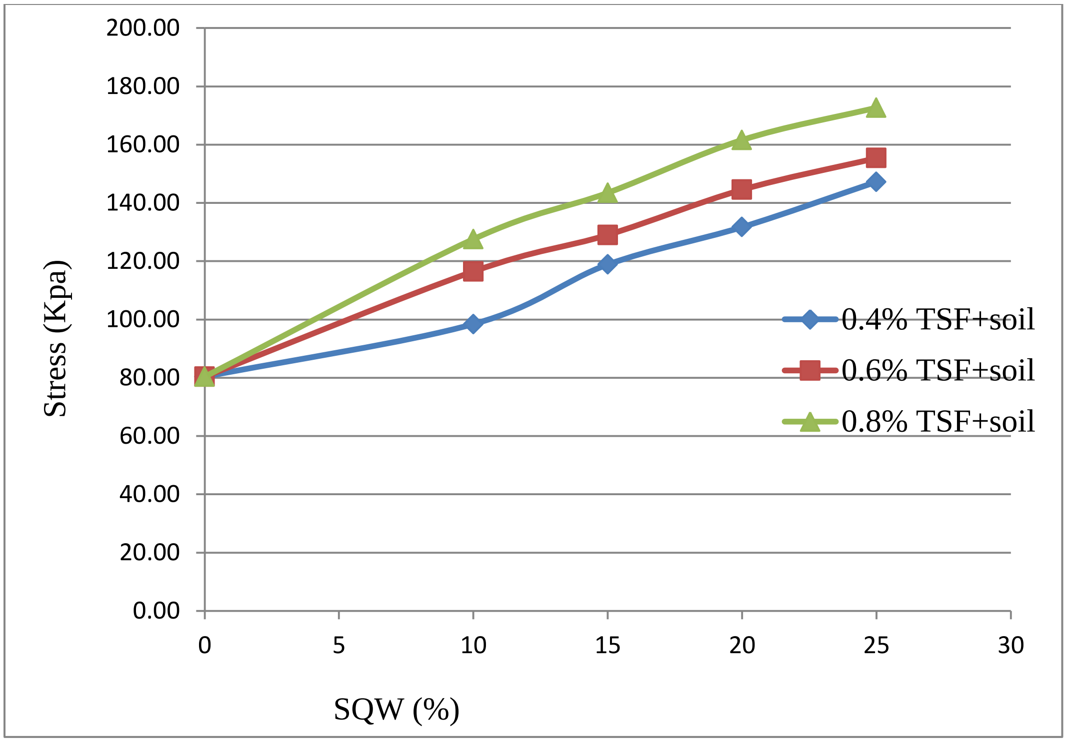

Figure 4.12: Effect of SQW and TSF on Stress of unconfined compressive strength test

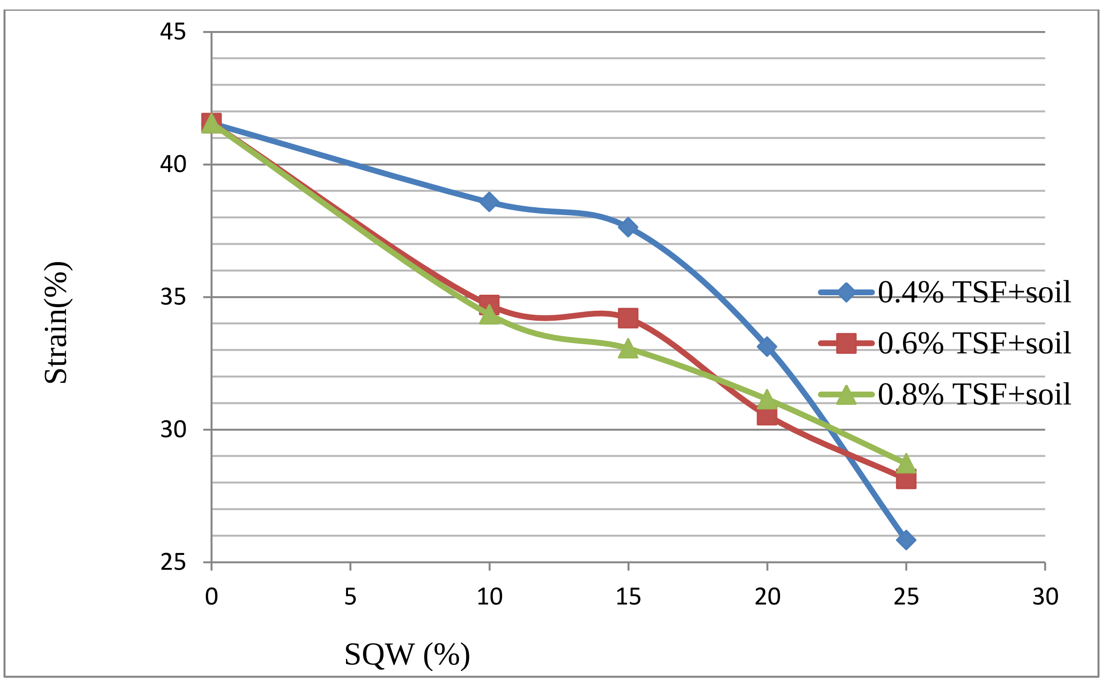

Figure 4.13: Effect of SQW and TSF on Strain of unconfined compressive strength test

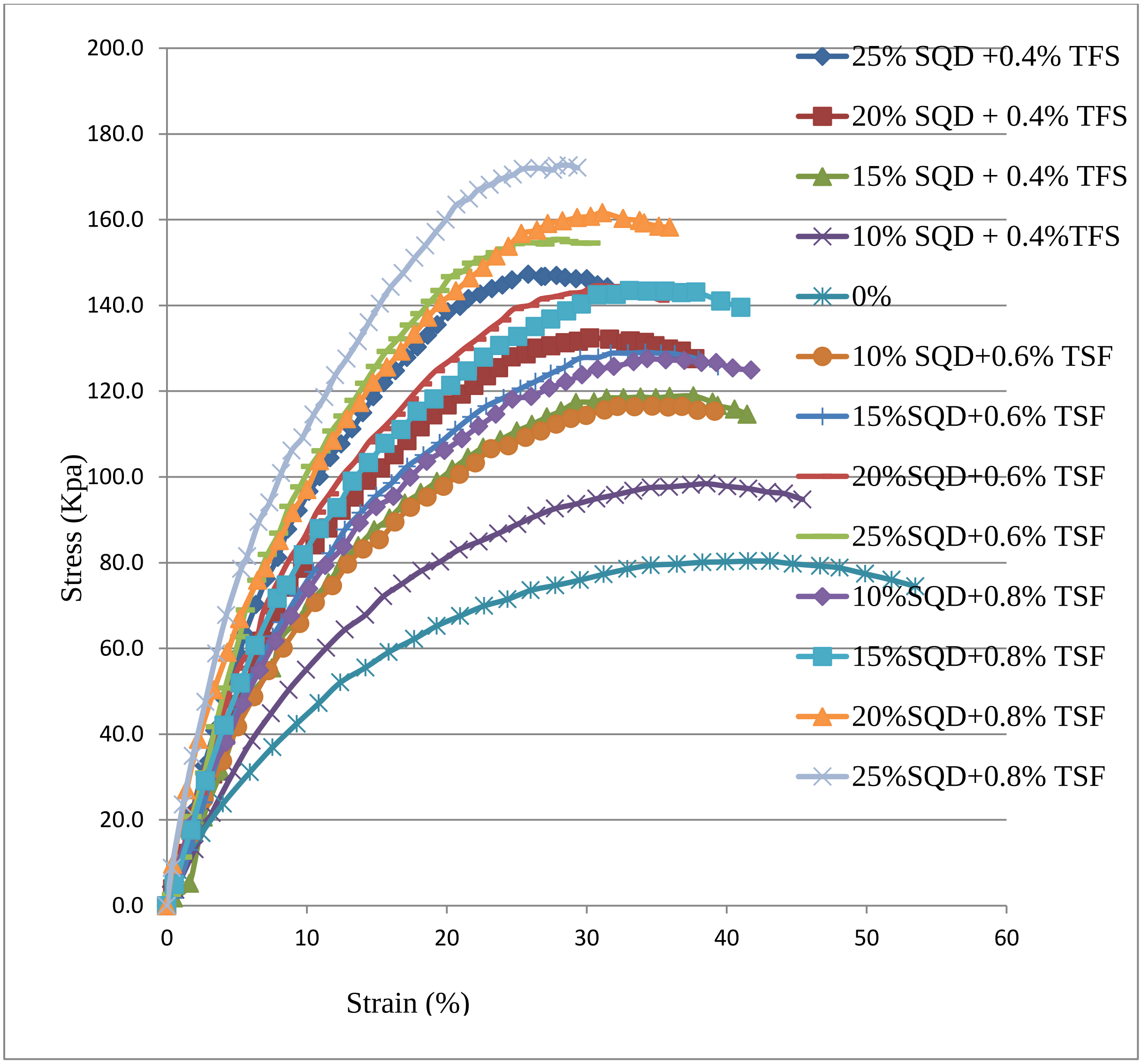

Figure 4.14: Detail of UCS test result for all samples

4.9 X-ray diffraction (XRD) test result

Dry soil sample were grinded to fine powder and transfer to a sample holder and placed in the XRD instrument. Then the X-ray directed at the sample and diffracted ray detected by detector and the intensity and angles of the diffracted x-rays are recorded in diffraction pattern. Then the diffraction pattern analyzed using High Score software to identify the minerals present in the soil sample.

X-ray diffraction (XRD) analysis was conducted to investigate the mineralogical changes occurring in expansive soil when blended with varying percentages of stone quarry dust (SQW). Four samples were analyzed: pure expansive soil, pure SQW, a blend of 20% SQW + 80% expansive soil, and 25% SQW + 75% expansive soil. XRD tests were performed to know the microstructural of the soil was and determine the responsible mineral for the swell shrinkage behavior of the soil.

In the following figures, X-axis (2θ) represents the diffraction angle and Y-axis represents the number of X-ray counts (intensity) detected, indicating the presence of crystalline phases. Sharp Peaks indicates crystalline materials and the more intense and sharp the peaks, the more crystalline the phase is. While broad/Low Peaks indicate amorphous or poorly crystalline materials.

As shown in figure 4.15, the pure expansive soil's Peaks observed between 20° and 30° 2θ, with moderate intensity (250 max), indicating likely mineralogy of montmorillonite, kaolinite, and quartz, which are common in expansive soils. Also the crystallinity is relatively low as it has many small peaks indicating mixed fine-grained clay minerals, poorly crystalline structure and amorphous content. This pattern is consistent with the amorphous and fine-grained nature of expansive soils, which contributes to their high plasticity and swelling behavior. The lack of well-defined crystalline peaks confirms the soil's inherent structural instability in its natural state.

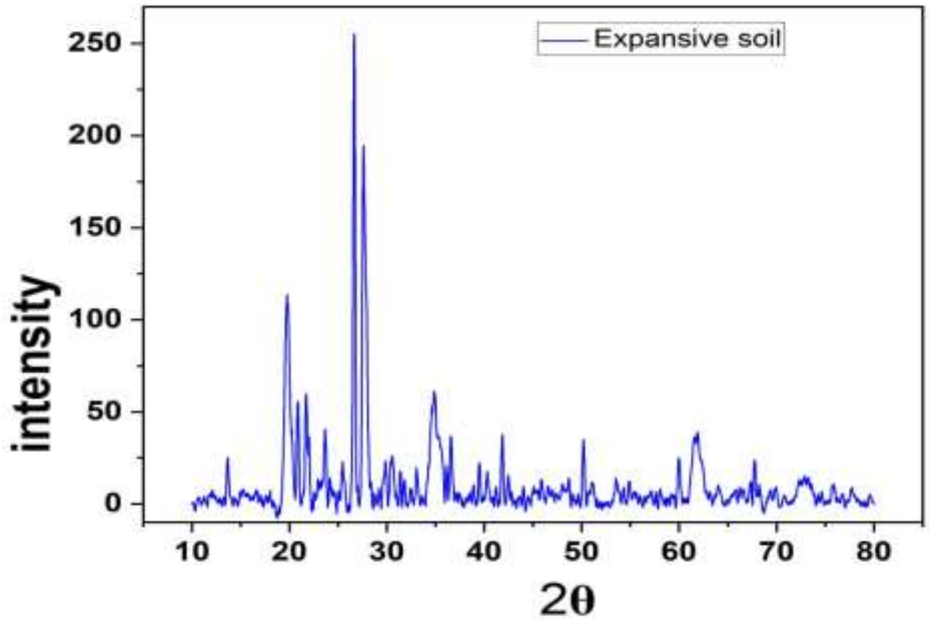

Figure 4.15: X-ray diffraction (XRD) pattern for an expansive soil sample

Figure 4.16 shows that the Peaks of stone quarry dust is high-intensity around 27° and 21° 2θ, which is dominantly contains quartz and feldspar minerals. It also has a high sharp and well-defined peak indicating a crystalline material. The intensity Peaks exceed 900, indicating much more crystalline material than expansive soil. These minerals contribute to the angular and inert characteristics of SQW when mixed with soil.

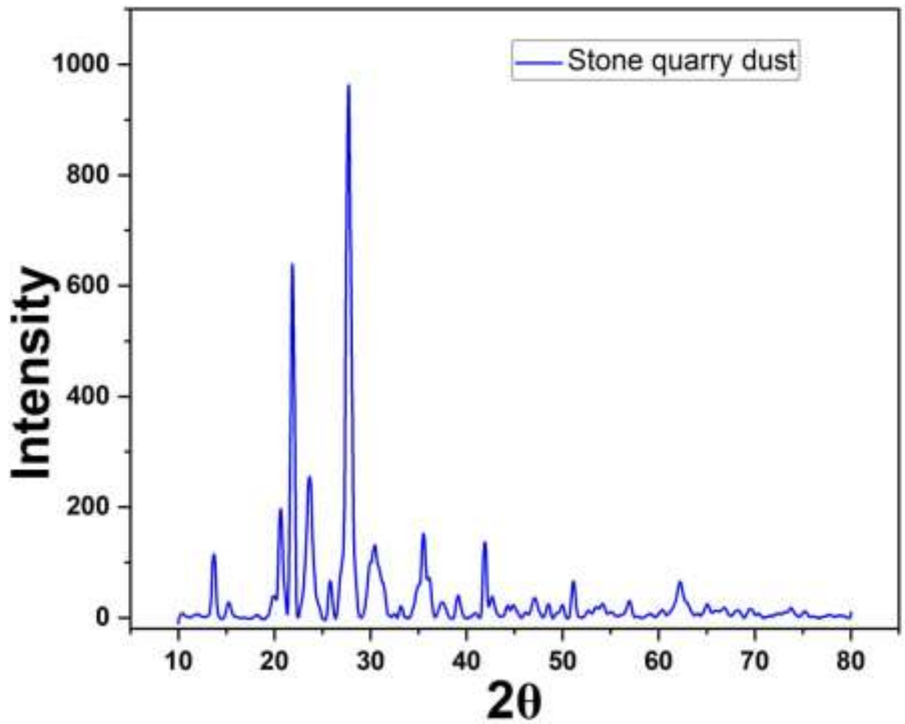

Figure 4.16: X-ray diffraction (XRD) pattern for stone quarry dust sample

Figure 4.17 illustrated that addition of 20% SQW in expansive soil, a significant increase in peak intensity is observed, particularly at positions matching those of quartz. The sharp peak was around 27° and 31°, similar to SQW. Maximum intensity approaches 1400, significantly higher than pure soil. This suggests that even a relatively low addition of SQW substantially enhances the crystalline content of the soil mixture, possibly contributing to improved structural stability and reduced plasticity. Therefore; incorporation of SQW enhances crystallinity, as quartz signal becomes dominant, indicating a structural change.

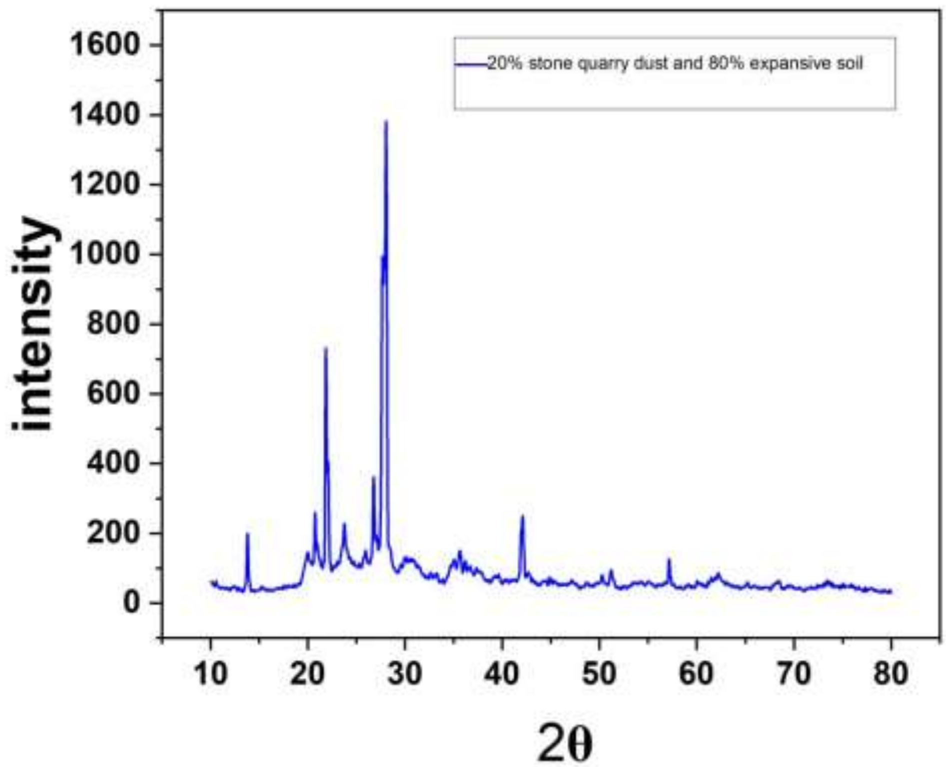

Figure 4.17: X-ray diffraction (XRD) pattern for 20% SQW +80% expansive soil

Figure 4.18 displays that with addition 25% SQW, Sharp peaks was found around 27° and 31°, similar to 20% SQW + 80% expansive soil. However, maximum intensity approaches 950, higher than pure soil and lower than 20% SQW + 80% expansive soil. Therefore; incorporation of 25% SQW shows continued dominance of quartz and feldspar. The reduction in intensity could be attributed to overlapping peaks or mineral interaction at higher replacement levels

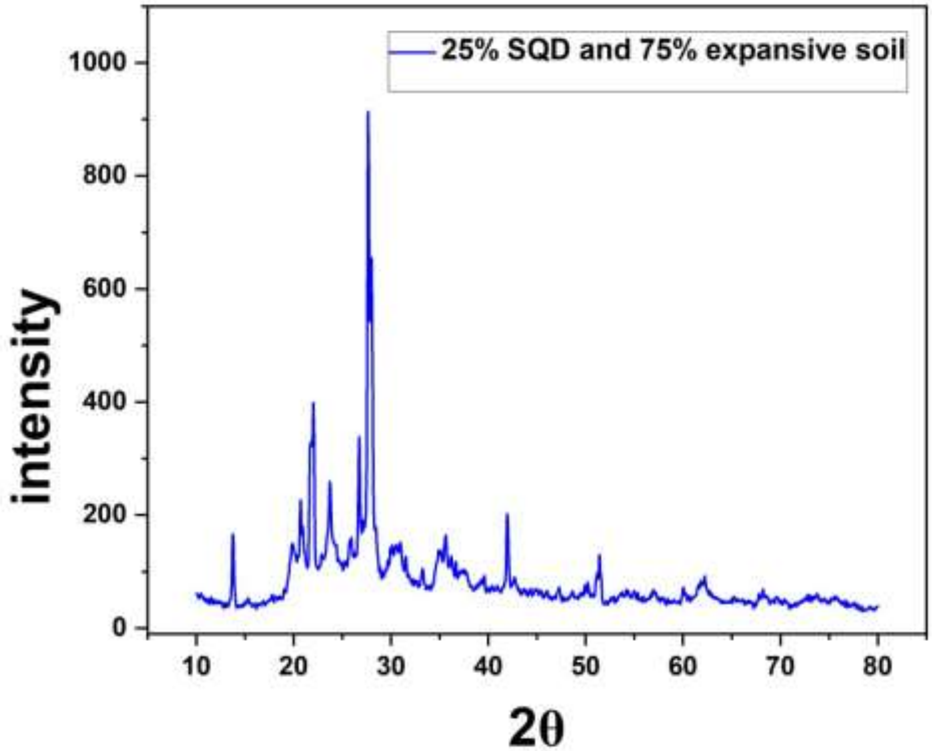

Figure 4.18: X-ray diffraction (XRD) pattern for 25% SQW and 75% expansive soil

In general incorporation of stone quarry dust significantly increases crystallinity, as seen in increased peak intensity and sharper diffraction patterns, as the quartz content becomes dominant, altering the mineralogical structure of the expansive soil. This change suggests potential improvement in soil stability and mechanical properties, as indicated by reduction of swell, plasticity index, liquid limit and improvement of compaction, CBR value and UCS. Among the blends analyzed, the 20% SQW+80% expansive exhibits the highest crystallinity, suggesting a potentially optimal ratio for soil stabilization

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on results discussed on chapter four which are atterberg limit, gradation analysis, free swell index, compaction, CBR value, CBR swell, Unconfined Compression Strength and XRD tests the following conclusion are made.

The expansive soil collected from mezan jerba has maximum dry density (MDD) and optimum moisture content (OMC) 1.27 g/cc and 32% for respectively. When SQW is added on expansive soil, maximum dry density increases up to 20% and then begins to decrease. Addition of TSF in the expansive soil improves the dry density with the maximum improvement found to be at 0.4% for all SQW percentage. Maximum dry density is found for sample of 20% SQW and 0.4% TSF.

Upon addition of SQW, free swell index significantly decreases and the soil class changes from highly expansive to low expansive potential.

The swelling potential and CBR value of the expansive soil was 5.97% and 2.83%. With the addition of SQW, CBR value increases and CBR swell decreases. CBR value increases and CBR swell decreases as TSF percentage increases up to 0.6%. Optimum improvement in CBR value and reduction of swell of expansive soil with TSF and SQW found with addition of 0.6% TSF and 25% SQW with value of CBR and CBR swell 6.30 and 2.09 respectively.

The maximum stress and strain of the expansive soil found to be 80.36KPa and 41.56% respectively, showing weaker strength in bearing load. On the other hand adding SQW and TSF in the expansive soil improves UCS of the soil with optimum improvement found by adding 25% SQW and 0.8% TSF in the expansive soil with maximum stress of

172.7Kpa and strain of 28.7%, that is more than twice load bearing resistance than pure expansive soil resistance.

The XRD results shows undesirable swelling characteristics of pure expansive soil are a result of its high clay mineral content and low crystallinity. Addition of SQW in expansive soil significantly enhances the crystalline content of the soil mixture, possibly contributing to improved structural stability and reduced plasticity. The highest quartz peak intensity and suppressed clay signals indicate the best mineralogical improvement, which is achieved with 20% SQW.

In this thesis work the promising results attained at 20%SQW +0.6% TSF for most tests. Therefore; 20%SQW +0.6% TSF is considered as optimum percentage and which achieves by improving most of the geotechnical properties of expansive soils.

5.2 Recommendation

Detail tests such as Scanning electron microscope (SEM), consolidation, permeability, triaxial, linear shrinkage, tensile strength, etc should be done to know the behavior of a soil sample stabilized with SQW and TSF. The effect of TSF length and different percentage of TSF should be carried out and long term performance of stabilized material needs further study.

The cost comparison between current stabilization mechanism and traditional stabilization such as lime and cement needs to be known.

SQW which is harmful to surrounding society in the quarry site could be used to stabilize expansive soil as a result, the environmental impact reduced in using this material for stabilization.

The impact of degradability of TSF on the strength of stabilized material should be assessed application off this method.

Reference

A.Gunes. (2018). Investigation of the Effect of Recycled Asphalt Pavement Material on Permeability and Bearing Capacity in the Base Layer. *Advances in Civil Engineering., Volume 2018*, page 6.

Abubekir JEMAL, E. C. (2019). Utilization of crushed stone dust as a stabilizer for subgrade soil: case study Jima town. *International journal of engineering*.

AH, A. A. (2010). Building Materials Laboratory Manual. Gaza: Islamic University of Gaza.

Aijun, C., Chuanyang, D., & Shanshan, a. Z. (2023, December). Influence of palm fiber on strength and crack characteristics of red clay. *Journal of Engineered Fibers and Fabrics*.

Ali, R. (2014). Expansive Soil Stabilization Using Marble Dust and Bagasse Ash.,. *International Journal of Science and Research (IJSR), 3*(6).

Almeshet, B. (2019). Flexible Pavement Response Analysis and Pavement Remaining Life. Addis Ababa, Ethiopia.

Ameta, N., & A.Wayal. (2008). Effect of bentonite on permeability of dune sand. *Electronic journal of Geotechnical Engineering*.

Ankit Kumar Maurya, M. K. (2023). Evaluation of stone dust for stabilization of expansive soil for pavement construction. *International Research Journal of Engineering and Technology (IRJET), 10*(04).

Arega, A. (2020, June). THE EFFECT OF RANDOM INCLUSION OF TEFF STRAW ON SHEAR. ADDIS ABABA INSTITUTE OF TECHNOLOGY, SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING.

Ash-Shu'Ara, M., & & Ajayi, A. ((2018)). Effect of addition of course sand particles on engineering properties of clay soil. *International journal of Civil, Structural, International journal of Civil, Structural*, *8*(4), 23-30.

Bennert, T. a. (2005). *The Development of Performance Specification for Granular Base and Subbase Material.* department of Transportation.Trenton,NJ, NewJersey.

Bowles, J. (1992). Engineering Properties of Soils and Their Measurement. In McGraw-Hill. New York.

Chougan, & Ghaffar, e. a. (2020). Wheat straw pre-treatments using eco-friendly strategies forenhancing the tensile properties of bio-based polylactic acid composites. *Industrial Crops and Products*, 1-10.

Cooley, D. A. (2005,). Effects of Reclaimed Asphalt Pavement on Mechanical Properties of Base Materials. Master Thesis.

Corey, A. (2010). *Measurement of water and air permeability in unsaturated soil.* Retrieved from https://doi.org/10.2136/sssaj1957.03615995002100010003x.

Ethiopian Roads Authority. (2013). Flexible Pavement Design Manual Volume I: .

Firoozi, A., & Olgun, C. e. (2017). Fundamentals of soil stabilization. *International journal of Geo-Engineering.*

Guyer, J. (2011). Introduction to soil stabilization in pavements.

H.Venkateswarlu, D. D. (2015). Study on Geotechnical Properties of Stabilized Expansive Soil-Quarry Dust Mixes. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 12*(6), PP 104-110.

Hassan, A. M., Abdelkader, M. M., Hussein, & and Haiwang, Y. (2021). Influence of waste marble dust on the improvement of expansive clay soils. *Advance in civil engineering*.

Holtz, W., & Gibbs, H. (1956). Engineering properties of Expansive clays. 641–677.

Hoyos, L. P. (2011). Characterization of Cement-Fiber-Treated Reclaimed Asphalt Pavement Aggregates: Preliminary Investigation.,. *Journal of Materials in Civil Engineering, Vol. 23 (7)*, pp. 977-989.

Jefferson, I. (2001). Problematic Soils. In T. Telford (Ed.), *Proceedings of the Symposium.* London.

Jili, Q., ChencaiLi, BaoshiLiu, XinxingChen, MingLi, & Zhaowei., Y. (2013). Effect of Random Inclusion of Wheat Straw Fibers on Shear Strength Characteristics of Shanghai Cohesive Soil. *Journal of Geotech and Geoleng*.

Jones, D., & Holtz, W. (1973). Expansive soils, the hidden disaster. *American Society of Civil Engineering Journal*, 87-89.

Jones, L., Survey, & Jefferson, a. (2012). Expansive Soils. *Geotechnical engineering principles, problematic soils and site investigation, vol 1*. (I. J. (Ed.), Ed.) ICE Publishing.

M. Alireza, A. A. (2014). Laboratory evaluation of the use of cement-treated construction and demolition materials in pavement base and subbase applications. *Journal of Materials in Civil Engineerin, vol. 27, no. 6, .*

Madurwar, Dahale, & Burile, a. (2013). Comparative Study of Black Cotton Soil Stabilization with RBI Grade 81 and Sodium Silicate. *International Journal of Innovative Research in Science Engineering and Technology, 2*(2), 493-499.

Mirzababaei, M. (2013). Unconfined compression strength of reinforced clay with waste carpet fiber. *Journal of Geotechnical and Geoenvironmental Engineering*.

Mousa, E. (2007). Laboratory Characterization of Reclaimed Asphalt Pavement for Road Construction in Egypt. *Canadian Journal of Civil Engineering.*

Muhammad Bilal, D. N. (2020). Effectiveness of Stone Dust as an Expansive Soil Stabilizer. *2nd Conference on Sustainability in Civil Engineering (CSCE'20).* Islamabad, Pakistan: Capital University of Science and Technology.

Musso. (2014). Guidelines to Identify and Quantify Expansive Soils in Civil Infrastructure. *Engineering Geology for Society and Territory*.

Nataatmadja, A. (2002). Foamed Bitumen Mix: Soil or Asphalt. . *Proceedings of 9th International Conference on Asphalt Pavements.* Copenhagen, Denmark.

Nitini tiwari, S. K. (2020). An experimental study on micro structural and geotechnical characteristics of expansive clay mixed with EPS granules.

Niyomukiza, J. B., Wardani, S. P., & Setiadji, B. H. (2023). Recent advances in the stabilization of expansive soils using waste materials: A review. *Earth and Environmental Science.* IOP Conf Series.

Potturi, A. (2006). Evaluation of Resilient Modulus of Cement and Cement-Fiber Treated Reclaimed Asphalt Pavement (RAP) Aggregates Using Repeated Load Triaxial Test. Thesis for Master Degree, The University of Texas at Arlington.

Pradhan, P., Kar, R., & Naik, A. (2011). Effect of Random Inclusion of Polypropylene Fibers on Strength Characteristics of Cohesive Soil. *Journal of Geotech Geological engineering*.

Prakbakar, J., & Sridhar, R. (2012). effect of sisal fiber on strength behavior of soil. *Journal of construction& building materials, India*.

Rathje, E. R. (2001). *Recycled Asphalt Pavement and Crushed Concrete Backfill: State-of-the-Art Review and Material Characterization.* Department of Transportation, Texas.

Rigers, J., & Olshansky, R. (2013). Damage to foundations from expansive soils. *Technical paper*. Missouri University of Science and Technology.

Saeed, A. (2008). *Performance-Related Tests of Recycled Aggregates for Use in Unbound Pavement Layers.* . Transportation Research Board, NCHRP REPORT 598.

SALAH, Y. M. (2018). EFFECT OF QUARRY DUST ENHANCEMENT ON ENGINEERING BEHAVIOR OF EXPANSIVE CLAYS.

Shaokun, M., Huan, Y., Benfu, H., Liping, L., & Shao, a. Y. (2025, February). Engineering Properties and Microscopic Mechanism of Expansive Soils Improved by Biochar and Bagasse Fibers. *Journal of Materials in Civil Engineering, 37*(5).

Sifan, T., & Yadeta C., C. (2022). Experimental Investigation on the Effect of Teff Straw Fiber and Lime on Strength and Compressibility of Black Cotton Soil. *Ethiopian Journal of Science and Sustainable Development, 9*(2).

Soleimanbeigi, A. E. (2014). Engineering Properties of Recycled Materials for Use as Embankment Fill. . *Proceeding of Geo-Congress.* Atlanta, Georgia.

Tamiru, G. (January 2019). Effect of Marble Dust for Stabilization of Expansive Soil. *CIKITUSI JOURNAL FOR MULTIDISCIPLINARY RESEARCH, 6*(1).

Tefera, E. B. (2022, February). Utilization of wheat straw fiber and cement as soil stabilizer for expansive soil: - a case of robe town.

Wyoming Multi-Hazard Mitigation Plan. (2014). Wyoming State: Wyoming Office of Homeland Security.

Appendix

Appendix A: Sieve analysis test result

Table A.1: Sieve test result of expansive soil

Wet Sieve analysis: Collected from Modjo Study Area at 1.5m Depth

ASTM D422

Wt. Before washing (TW) =500gm

Wt. After Washing= 49.37gm_____

Sieve ASTM	Sieve Size (mm)	Weight of grains Retained (WR) (g)	Retained %(WR/TW*100)	Passing % ((TW-WR)/TW))*100
No.4	4.75	4.20	0.84	99.16
No.8	2.36	1.20	0.24	98.92
No.10	2.00	0.75	0.15	98.77
No.16	1.18	0.99	0.20	98.572
No.18	1.00	3.30	0.66	97.912
No.30	0.600	1.53	0.31	97.606
No.40	0.425	2.00	0.40	97.206
No.50	0.300	12.50	2.50	94.706
No.100	0.150	18.90	3.78	90.926
No.200	0.075	4.00	0.80	90.126
Pan		450.63	90.13	0.00
Total		500.0	100	

Weight (TW) (gm)			
Loss=0gm			

Table A.2: Hydrometer test result

Elapsed Time (T) in minute	Temp. (oC)	Actual Hydrmo. Rdg (Ra)	Hyd. Correction for Meniscus	L From Table 1	K From Table 2	D(mm)	CT From Table 3	a from Table 4	Corr. Hydr Rdng(Rc)	% Fine	% Adjusted Finer (PA)
2	24.5	40	41	9.7	0.01357	0.02988	1.15	1.03	37.65	77.56	69.9008
5	24	36	37	10.4	0.01365	0.01969	1	1.03	33.5	69.01	62.196
8	23.5	34	35	10.7	0.01373	0.01588	0.85	1.03	31.35	64.58	58.2043
15	23	29	30	11.5	0.01381	0.01209	0.7	1.03	26.2	53.97	48.6428
30	23	27.5	28.5	11.8	0.01381	0.00866	0.7	1.03	24.7	50.88	45.8579
60	23	26	27	12	0.01381	0.00618	0.7	1.03	23.2	47.	43.0

										79	73
120	23	23	25	12.5	0.01381	0.00446	0.7	1.03	20.2	41.61	37.5032
1440	23	18	19	13.3	0.01381	0.00133	0.7	1.03	15.2	31.31	28.2203

Hydrometer analysis used for particles whose median diameters smaller than 4φ (0.0625mm), which includes silt and clay size particles and utilizes Stoke's Law of settling velocity for spherical particles in a fluid.

$$V = \frac{2}{9}\frac{g(\rho_s - \rho_f)}{\eta}\left(\frac{D}{2}\right)^2$$

where;

V= settling velocity (cm/s);

ρ_s = density of the solids (g/cm3) ;

ρ_f = density of the fluid (g/cm3) ;

η = dynamic viscosity of the fluid (dyn . s/ cm2) ;

g = acceleration due to gravity (980.7 cm/ s^2) ;

$$D = \sqrt{\frac{18\eta V}{g(\rho_s - \rho_f)}}$$

$$D = K\sqrt{\frac{L}{t}}$$

D = particle diameter (cm)

The dispersing agent, sodium hexametaphosphate (or Calgon), is added to neutralize the particle charges on fine clay particles and prevent flocculation.

Calculate percent finer, P = (RC*a)/ (Ws) *100

P = Calculate percent finer

Rc = Ra - Zc + C_r

C_r = temperature correction from table 2.5

Zc= zero correction

a = correction factor for particle density from table 2.4, a=1.03

Ra= actual hydrometer reading

Ws = the weight of soil sample in grams

PA = adjusted percent fines as follows, PA = P *F200/100

F200 = % finer of #200 sieve as percent

L = Effective length from table 2.7

K = Constant from table 2.6

Table A.3: Properties of distilled water (η) source (Bowles, 1992)

Temp., °C	Unit weight of water, g/cm^3	Viscosity of water, poise*
4	1.00000	0.01567
16	0.99897	0.01111
17	0.99880	0.01083
18	0.99862	0.01056
19	0.99844	0.01030
20	0.99823	0.01005
21	0.99802	0.00981
22	0.99780	0.00958
23	0.99757	0.00936
24	0.99733	0.00914
25	0.99708	0.00894
26	0.99682	0.00874
27	0.99655	0.00855
28	0.99627	0.00836
29	0.99598	0.00818
30	0.99568	0.00801

Table A.4: correction factor a for unit weight of solids source (Bowles, 1992)

ϵ_s of soil solids	Correction factor a
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.04

Table A.5: Temperature correction factor Cr source (Bowles, 1992)

Temp., °C	C_T
15	1.10
16	−0.90
17	−0.70
18	−0.50
19	−0.30
20	0.00
21	+0.20
22	+0.40
23	+0.70
24	+1.00
25	+1.30
26	+1.65
27	+2.00
28	+2.50
29	+3.05
30	+3.80

Table A.6: Value of K for several unit weight of solids and temperature combinations source (Bowles, 1992)

Temp., °C	ϵ_s of Soil Solids							
	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.0151	0.0148	0.0146	0.0144	0.0141	0.0139	0.0137	0.0136
17	0.0149	0.0146	0.0144	0.0142	0.0140	0.0138	0.0136	0.0134
18	0.0148	0.0144	0.0142	0.0140	0.0138	0.0136	0.0134	0.0132
19	0.0145	0.0143	0.0140	0.0138	0.0136	0.0134	0.0132	0.0131
20	0.0143	0.0141	0.0139	0.0137	0.0134	0.0133	0.0131	0.0129
21	0.0141	0.0139	0.0137	0.0135	0.0133	0.0131	0.0129	0.0127
22	0.0140	0.0137	0.0135	0.0133	0.0131	0.0129	0.0128	0.0126
23	0.0138	0.0136	0.0134	0.0132	0.0130	0.0128	0.0126	0.0124
24	0.0137	0.0134	0.0132	0.0130	0.0128	0.0126	0.0125	0.0123
25	0.0135	0.0133	0.0131	0.0129	0.0127	0.0125	0.0123	0.0122
26	0.0133	0.0131	0.0129	0.0127	0.0125	0.0124	0.0122	0.0120
27	0.0132	0.0130	0.0128	0.0126	0.0124	0.0122	0.0120	0.0119
28	0.0130	0.0128	0.0126	0.0124	0.0123	0.0121	0.0119	0.0117
29	0.0129	0.0127	0.0125	0.0123	0.0121	0.0120	0.0118	0.0116
30	0.0128	0.0126	0.0124	0.0122	0.0120	0.0118	0.0117	0.0115

Table A.7 Value of L for ASTM hydrometer 152H source (Bowles, 1992)

Original hydrometer reading (corrected for meniscus only)	Effective depth L, cm	Original hydrometer reading (corrected for meniscus only)	Effective depth L, cm	Original hydrometer reading (corrected for meniscus only)	Effective depth L, cm
0	16.3	21	12.9	42	9.4
1	16.1	22	12.7	43	9.2
2	16.0	23	12.5	44	9.1
3	15.8	24	12.4	45	8.9
4	15.6	25	12.2	46	8.8
5	15.5	26	12.0	47	8.6
6	15.3	27	11.9	48	8.4
7	15.2	28	11.7	49	8.3
8	15.0	29	11.5	50	8.1
9	14.8	30	11.4	51	7.9
10	14.7	31	11.2	52	7.8
11	14.5	32	11.1	53	7.6
12	14.3	33	10.9	54	7.4
13	14.2	34	10.7	55	7.3
14	14.0	35	10.5	56	7.1
15	13.8	36	10.4	57	7.0
16	13.7	37	10.2	58	6.8
17	13.5	38	10.1	59	6.6
18	13.3	39	9.9	60	6.5
19	13.2	40	9.7		
20	13.0	41	9.6		

Appendix B: Atterberg limit test results

Table B.1: Liquid limit and plastic limit test result for pure expansive soil

Sampled Date 22/02/2025		Date Tasted: 19/03/2025				Depth : 1.5m	
Description:- Pure Black Cotton Soil		Location: Collected From Modjo Study Area behind Mizan Jerba					
Material Type: 0% SQW +100% soil							
		LIQUID LIMIT				**PLASTIC LIMIT**	
Container Number		A	C	D	G	E	N
No. of Blows		33	27	22	18		
Wt. of Cont + Wet Soil	(gm)	79.74	78.52	84.50	82.95	34.00	37.00
Wt. of Cont + Dry Soil	(gm)	73.10	70.90	73.40	69.80	30.90	32.00
Wt. of Water	(gm)	6.64	7.62	11.10	13.15	3.10	5.00
Wt. of Container	(gm)	59.60	60.00	61.00	57.12	22.12	19.37
Wt. of Dry Soil	(gm)	13.50	10.90	12.40	12.68	8.78	12.63
Moisture Content	(%)	49.19	69.91	89.52	103.71	35.31	39.59
		Liquid Limit	**77.0**			**Plastic Limit**	**37.4**

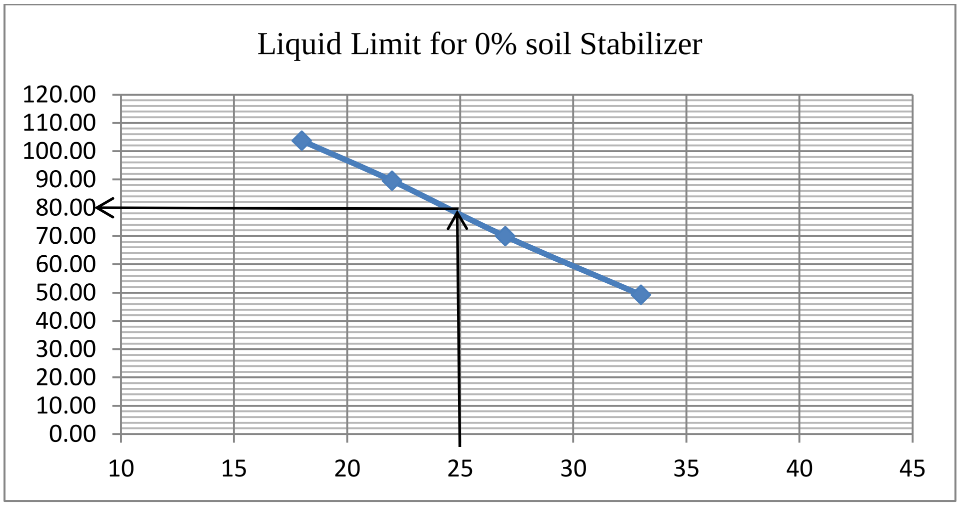

Figure B.1: chart of liquid limit test result for expansive soil

Table B.2: Liquid limit and plastic limit test result for Soil + 10% SQW

Sampled Date 22/02/2025		Date Tasted: 19/03/2025				Depth : 1.5m	
Description:- Soil + 10% SQW		Location: Collected From Modjo Study Area					
Material Type: 10% SQW on the given expasive subgrade soil							
		LIQUID LIMIT				**PLASTIC LIMIT**	
Container Number		10	11	12	13	A	B
No. of Blows		34	28	23	17		
Wt. of Cont + Wet Soil	(gm)	54.00	57.00	49.00	61.00	40.50	42.00
Wt. of Cont + Dry Soil	(gm)	42.61	42.80	37.15	42.00	35.25	36.50

Wt. of Water	(gm)	11.39	14.20	11.85	19.00	5.25	5.50
Wt. of Container	(gm)	19.98	20.00	21.00	19.99	20.72	20.56
Wt. of Dry Soil	(gm)	22.63	22.80	16.15	22.01	14.53	15.94
Moisture Content	(%)	50.33	62.28	73.37	86.32	36.13	34.50
		Liquid Limit	**68.0**			**Plastic Limit**	**35.3**

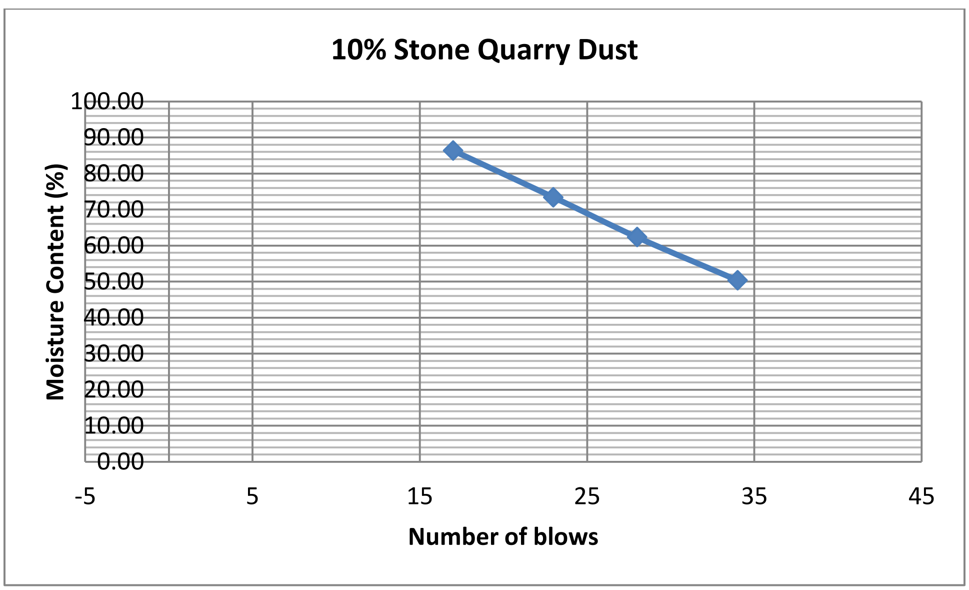

Figure B.2: chart of liquid limit test result for expansive soil+10% SQW

Table B.3: Liquid limit and plastic limit test result for Soil + 15% SQW

Sampled Date 22/02/2025		Date Tasted: 19/03/2025		Depth : 1.5m			
Description:- Soil + 15%Stone Qurry Dust		Location: Collected From Modjo Study Area					
Material Type: 15% SQW on the given expasive subgrade soil							
		LIQUID LIMIT				**PLASTIC LIMIT**	
Container Number		C -30	C-40	C-50	C-0	N	M
No. of Blows			35	29	24	18	
Wt. of Cont + Wet Soil	(gm)	61.10	59.70	57.50	68.80	42.10	39.89
Wt. of Cont + Dry Soil	(gm)	49.35	45.90	43.25	47.55	36.41	35.42
Wt. of Water	(gm)	11.75	13.80	14.25	21.25	5.69	4.47
Wt. of Container	(gm)	20.08	19.98	21.00	20.02	22.00	20.56
Wt. of Dry Soil	(gm)	29.27	25.92	22.25	27.53	14.41	14.86
Moisture Content	(%)	40.14	53.24	64.04	77.19	39.49	30.08
		Liquid Limit	**62.0**	**Plastic Limit**		**34.8**	

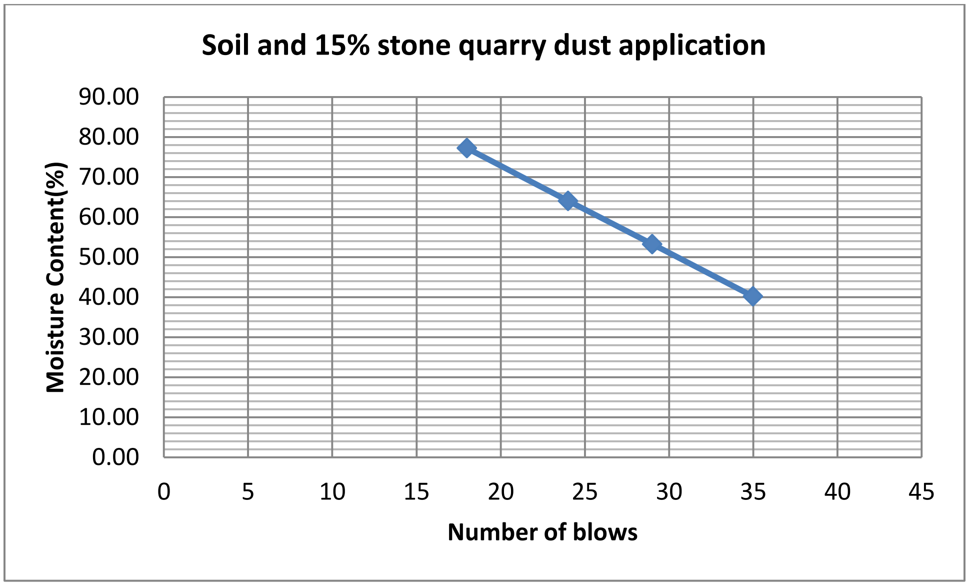

Figure B.3: chart of liquid limit test result for expansive soil+15% SQW

Table B.4: Liquid limit and plastic limit test result for Soil + 20% SQW

Sampled Date 22/02/2025		Date Tasted: 19/03/2025		Depth : 1.5m			
Description:- Soil + 20% Stone Quarry Dust		Location: Collected From Modjo Study Area					
Material Type: 20% SQW on the given expasive subgrade soil							
		LIQUID LIMIT				**PLASTIC LIMIT**	
Container Number		1	2	3	4	35	39
No. of Blows			34	27		23	19
Wt. of Cont + Wet Soil	(gm)	47.80	51.20	49.58	54.20	34.37	38.20

Wt. of Cont + Dry Soil	(gm)	40.15	40.45	38.65	41.45	30.79	33.68
Wt. of Water	(gm)	7.65	10.75	10.93	12.75	3.58	4.52
Wt. of Container	(gm)	22.00	19.98	20.00	21.60	20.20	20.23
Wt. of Dry Soil	(gm)	18.15	20.47	18.65	19.85	10.59	13.45
Moisture Content	(%)	42.15	52.52	58.61	64.23	33.81	33.61
		Liquid Limit	**55.0**		**Plastic Limit**	**33.7**	

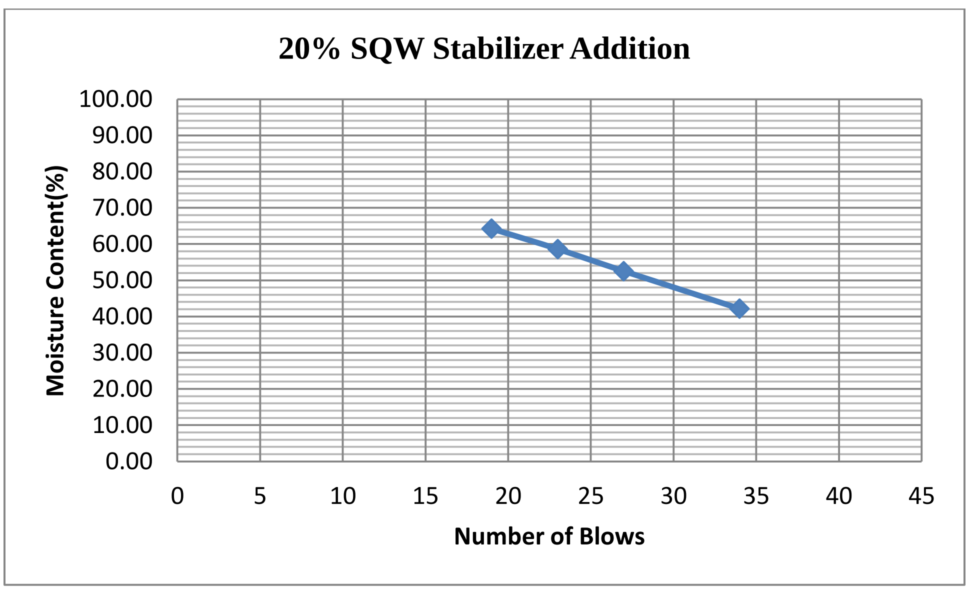

Figure B.4: chart of liquid limit test result for expansive soil+20% SQW

Table B.5: Liquid limit and plastic limit test result for Soil + 25% SQW

Sampled Date 22/02/2025		Date Tasted: 19/03/2025			Depth : 1.5m		
Description:- Soil + 25% SQW		Location: Collected From Modjo Study Area					
Material Type: 25% SQW on the given expasive subgrade soil							
		LIQUID LIMIT			**PLASTIC LIMIT**		
Container Number		W-1	W-2	W-3	W-5	O	P
No. of Blows		34	29	23	17		
Wt. of Cont + Wet Soil	(gm)	56.54	59.59	54.51	61.70	40.00	39.50
Wt. of Cont + Dry Soil	(gm)	46.70	48.00	42.70	46.80	35.45	35.10
Wt. of Water	(gm)	9.84	11.59	11.81	14.90	4.55	4.40
Wt. of Container	(gm)	21.00	22.00	19.98	22.00	20.90	21.00
Wt. of Dry Soil	(gm)	25.70	26.00	22.72	24.80	14.55	14.10
Moisture Content	(%)	38.29	44.58	51.98	60.08	31.27	31.21
		Liquid Limit	**49.0**		**Plastic Limit**	**31.2**	

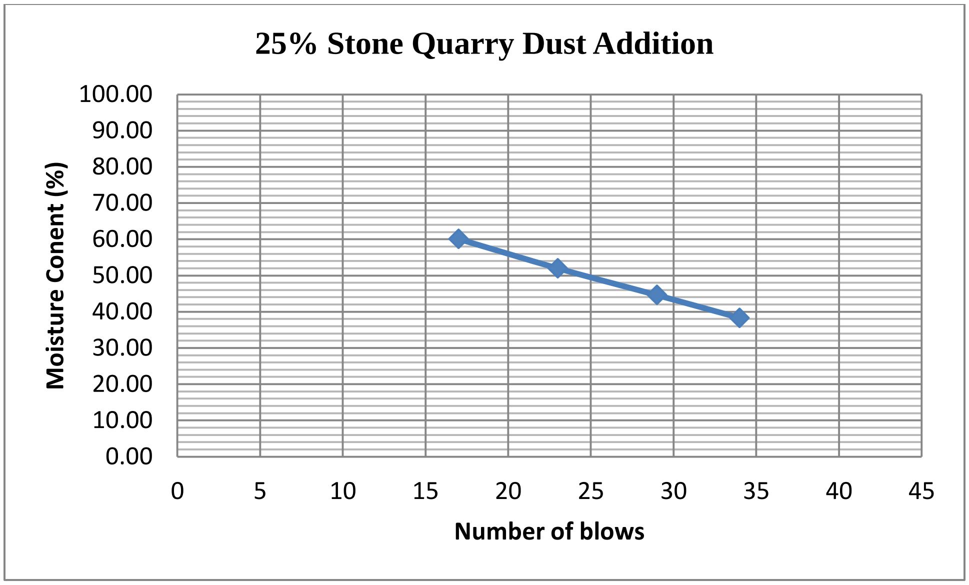

Figure B.5: chart of liquid limit test result for expansive soil+25% SQW

Table : Summary of atterberg limit test result of the samples

material	Percent of SQW	liquid limit	plasticity index	plastic limit
natural soil	0	77.0	39.6	37.4
10%SQW	10	68.0	32.7	35.3
15% SQW	15	62.0	27.2	34.8
20% SQW	20	55.0	21.3	33.7
25% SQW	25	49.0	17.8	31.2

Appendix C: Specific gravity test result

Table C.1: Specific gravity test result for pure expansive soil

Material :- Untreated Soil collected from Modjo Study area at 1.5m Depth (100% Pure soil)		
Specific Gravity Determination as per ASTM D854 Standard		
		Sample No
S/N	Particulars	Trial one
1	Weight of Density bottle W1 (g)	57
2	Weight of Density bottle with dry soil W2(g)	72
3	Weight of Density bottle with dry soil and water W3(g)	176
4	Weight of Density bottle full of water W4 (g)	166.96
5	Weight of dry soil (W2-W1) (g)	15
6	Weight of an equal volume of water(W2-W1)-(W3-W4)	5.96
7	Specific gravity of the soil G= (5/6)	2.52

Signature……………………date:11/03/2025	Therefore Gs at 20 degree centigrade = K*Gt=0.9993*2.54= 3.538

Table C.2: Specific gravity test result for expansive soil+10% SQW

Material :- 10% SQW stabilizer application on the given soil		
Specific Gravity Determination		
		Sample No
S/N	Particulars	10% SQW and 90% Soil
1	Weight of Density bottle W1 (g)	50.35
2	Weight of Density bottle with dry soil W2(g)	65.4
3	Weight of Density bottle with dry soil and water W3(g)	167.73
4	Weight of Density bottle full of water W4 (g)	158.6
5	Weight of dry soil (W2-W1) (g)	15.05
6	Weight of an equal volume of water(W2-W1)-(W3-W4)	5.92
7	Specific gravity of the soil G= (5/6)	2.54

Table C.3: Specific gravity test result for expansive soil+15% SQW

Material :- 15%SQW stabilizer application on the given soil		
Specific Gravity Determination		
		Sample No
S/N	Particulars	15% SQW and 85% Soil
1	Weight of Density bottle W1 (g)	57
2	Weight of Density bottle with dry soil W2(g)	72.2
3	Weight of Density bottle with dry soil and water W3(g)	176.09
4	Weight of Density bottle full of water W4 (g)	166.8
5	Weight of dry soil (W2-W1) (g)	15.2
6	Weight of an equal volume of water(W2-W1)-(W3-W4)	5.91
7	Specific gravity of the soil G= (5/6)	2.57

Table C.4: Specific gravity test result for expansive soil+20% SQW

Material :- 20%SQW stabilizer application on the given soil		
Specific Gravity Determination		
		Sample No
S/N	Particulars	20% SQW and 80% Soil
1	Weight of Density bottle W1 (g)	57
2	Weight of Density bottle with dry soil W2(g)	72

3	Weight of Density bottle with dry soil and water W3(g)	166.38
4	Weight of Density bottle full of water W4 (g)	157.15
5	Weight of dry soil (W2-W1) (g)	15
6	Weight of an equal volume of water(W2-W1)-(W3-W4)	5.77
7	Specific gravity of the soil G= (5/6)	2.60

Table C.5: Specific gravity test result for expansive soil+25% SQW

Material :- Stone Quarry Dust (SQW)		
Specific Gravity Determination		
		Sample No
S/N	Particulars	100% SQW
1	Weight of Density bottle W1 (g)	57
2	Weight of Density bottle with dry soil W2(g)	72
3	Weight of Density bottle with dry soil and water W3(g)	167.12
4	Weight of Density bottle full of water W4 (g)	157.5
5	Weight of dry soil (W2-W1) (g)	15
6	Weight of an equal volume of water(W2-W1)-	5.38

	(W3-W4)	
7	Specific gravity of the soil G= (5/6)	2.79

Table C.6: Summary of Specific gravity test result

Material :- Untreated Soil collected from Modjo Study area at 1.5m Depth (100% Pure soil)						
Specific Gravity Determination as per ASTM D854 Standard						
S/N	Particulars	Natural soil	10% SQW	15% SQW	20% SQW	25% SQW
1	Weight of Density bottle W1 (g)	57	50.35	57	57	50.45
2	Weight of Density bottle with dry soil W2(g)	72	65.4	72.2	72	65.53
3	Weight of Density bottle with dry soil and water W3(g)	176	167.73	176.09	166.38	166.15
4	Weight of Density bottle full of water W4 (g)	166.96	158.6	166.8	157.15	156.78
5	Weight of dry soil (W2-W1) (g)	15	15.05	15.2	15	15.08

6	Weight of an equal volume of water(W2-W1)-(W3-W4)	5.96	5.92	5.91	5.77	5.71
7	Specific gravity of the soil G= (5/6)	2.52	2.54	2.57	2.60	2.64

Appendix D: compaction test result

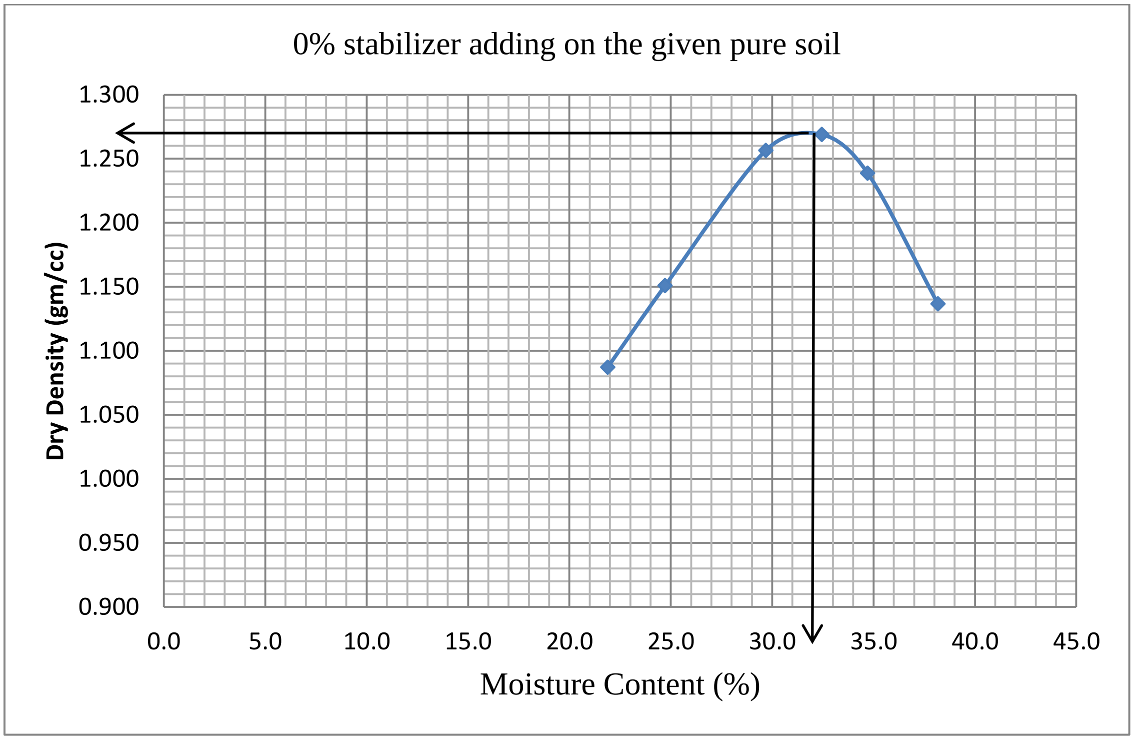

Figure D.1: Dry density-moisture relation curve of the pure expansive soil

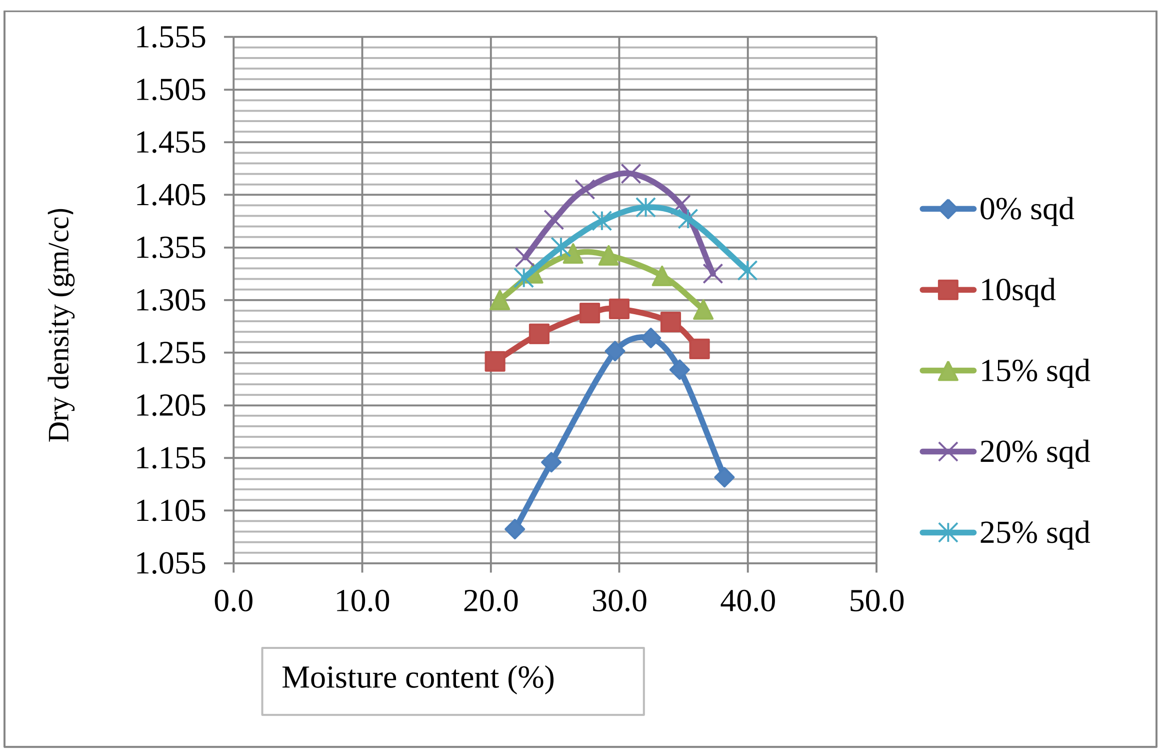

Figure D.2: Dry density-moisture relation curve for expansive soil+SQW

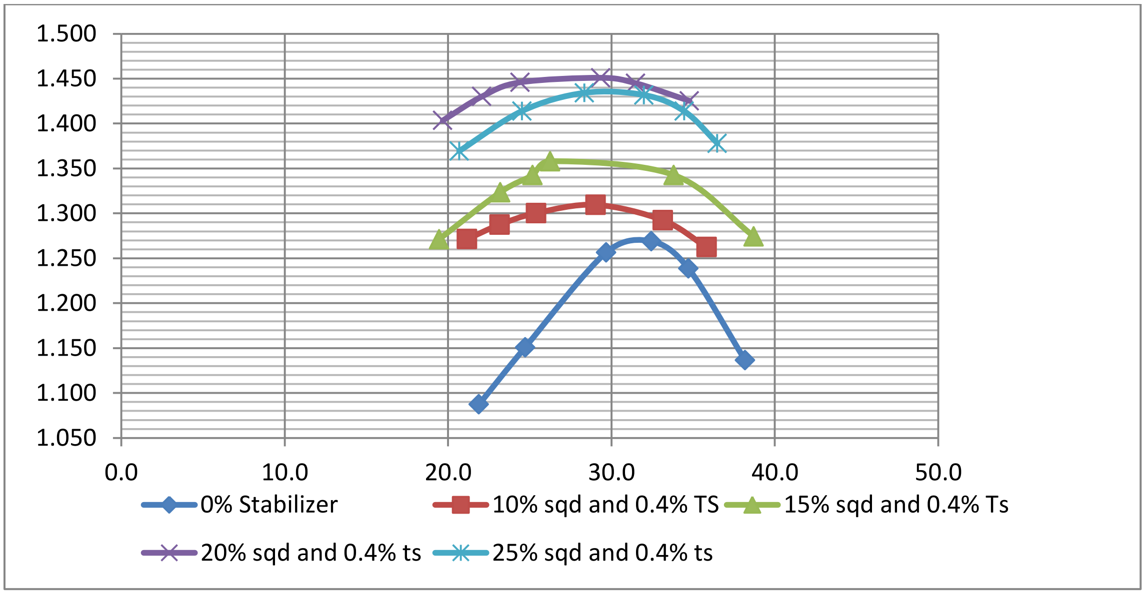

Figure D.3: Dry density-moisture relation curve for expansive soil+SQW+0.4% TSF

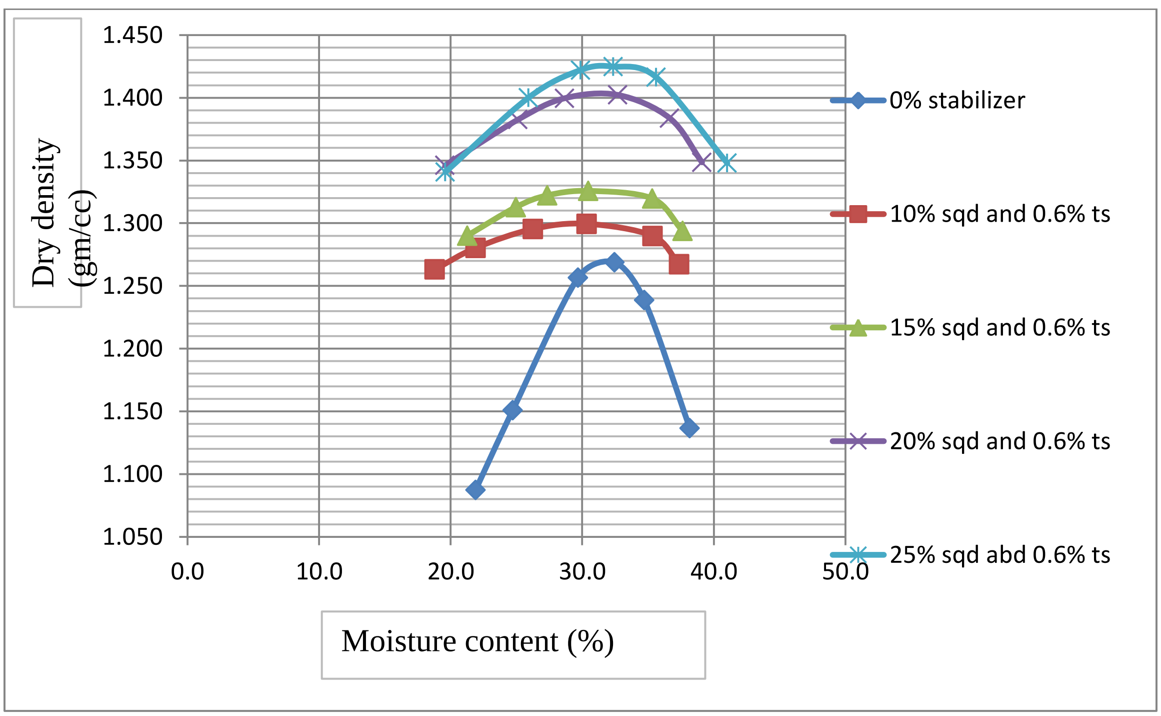

Figure D.4: Dry density-moisture relation curve for expansive soil+SQW+0.6% TSF

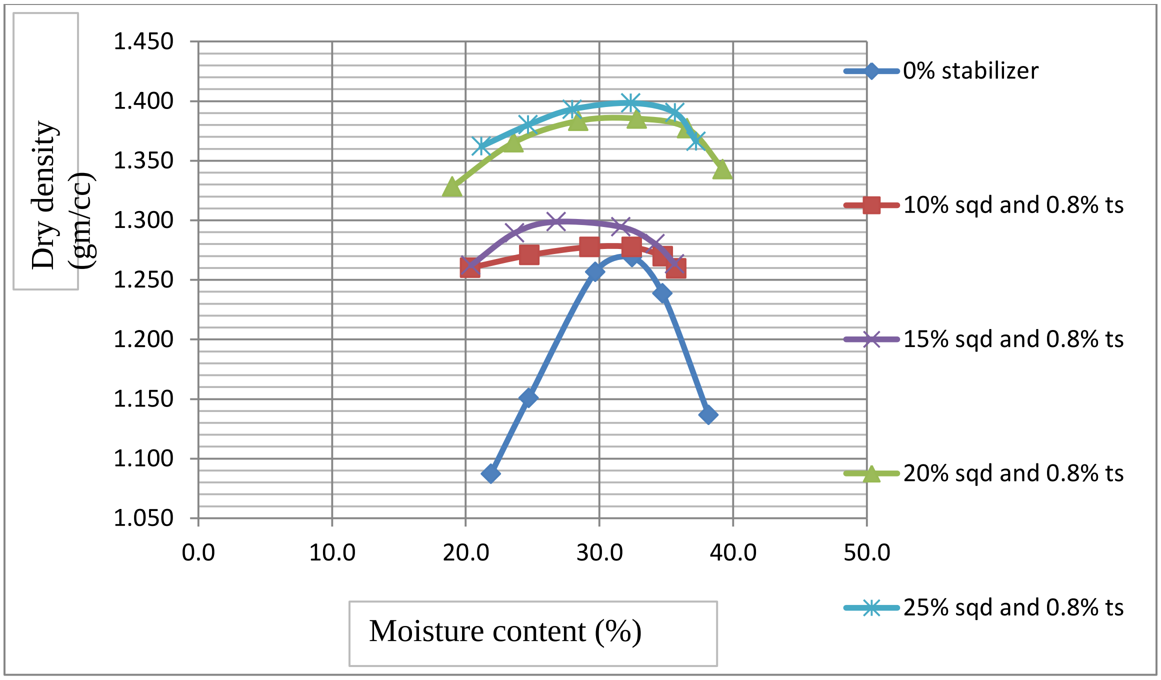

Figure D.2: Dry density-moisture relation curve for expansive soil+SQW+0.8% TSF

Table D.1: Summary of compaction test for all samples

SN	sample type	maximum dry density	optimum moisture content
1	natural soil	1.27	32
2	10% SQW+ soil	1.297	29.5
3	15% SQW+ soil	1.35	27.5
4	20% SQW+ soil	1.41	30.5
5	25% SQW+ soil	1.393	32
6	10% SQW+ soil+0.4%TSF	1.31	29
7	15% SQW+	1.358	26.3

	soil+0.4%TSF		
8	20% SQW+ soil+0.4%TSF	**1.451**	**29.5**
9	25% SQW+ soil+0.4%TSF	1.434	28.4
10	10% SQW+ soil+0.6%TSF	1.3	30.3
11	15% SQW+ soil+0.6%TSF	1.326	30.5
12	20% SQW+ soil+0.6%TSF	1.402	32.7
13	25% SQW+ soil+0.6%TSF	1.425	32.4
14	10% SQW+ soil+0.8%TSF	1.278	31
15	15% SQW+ soil+0.8%TSF	1.299	26.8
16	20% SQW+ soil+0.8%TSF	1.388	32.8
17	25% SQW+ soil+0.8%TSF	1.398	32.4

Appendix E: CBR test results

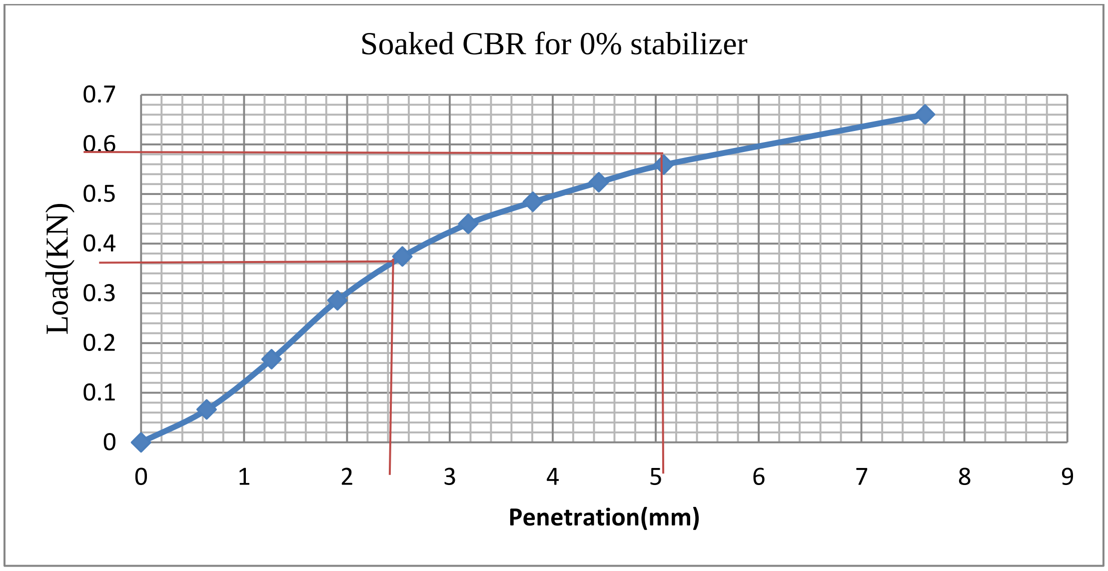

Figure E.1: Stress strain graph for pure expansive soil

Table E.1: Swell potential of expansive soil

Swell % and CBR %	
Number of Blow	56
Height of specimen (mm)	132
RDG (Before Soaking)	0
RDG (After Soaking)	6.95
Percent Swell	5.97
Average Percent Swell	5.97
CBR	2.83

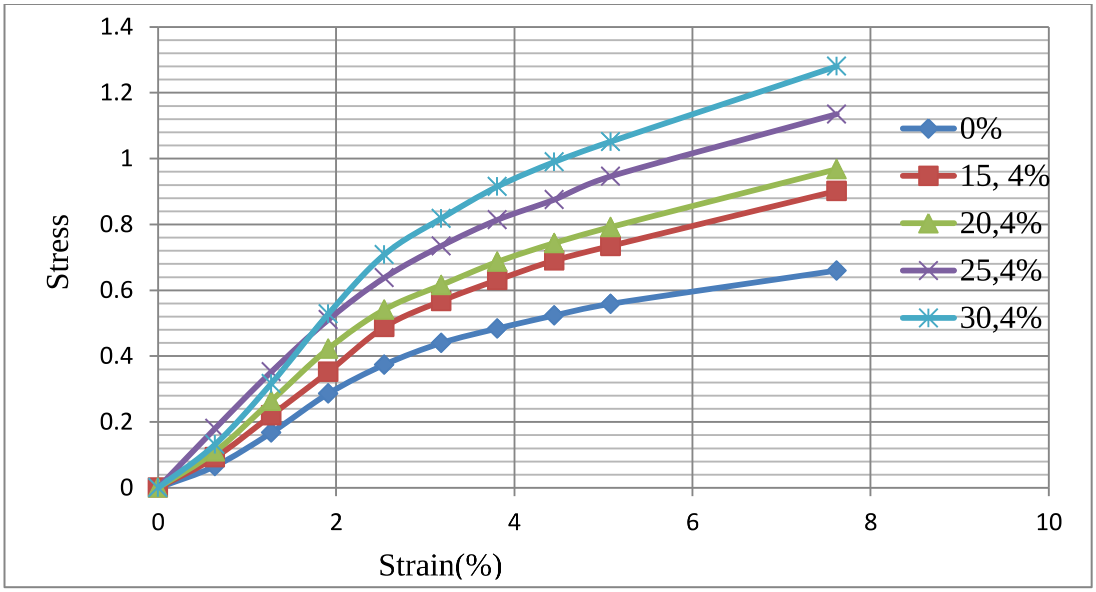

Figure E.2: Stress strain graph for expansive soil+SQW+0.4% TSF

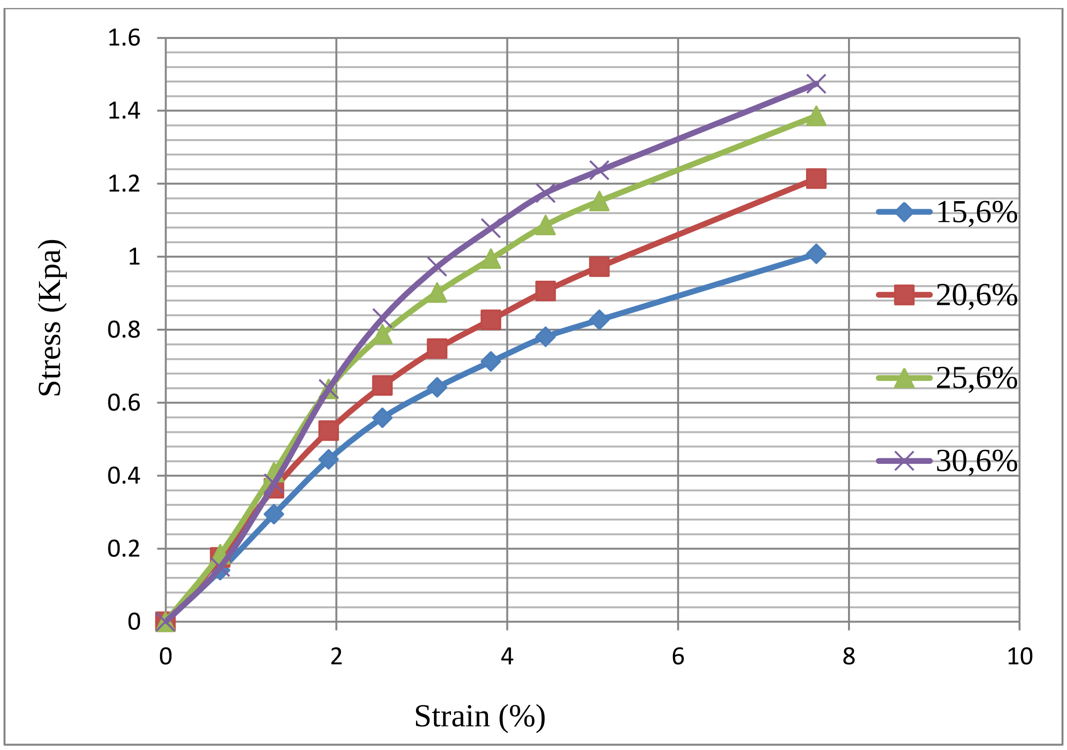

Figure E.3: Stress strain graph for expansive soil+SQW+0.6% TSF

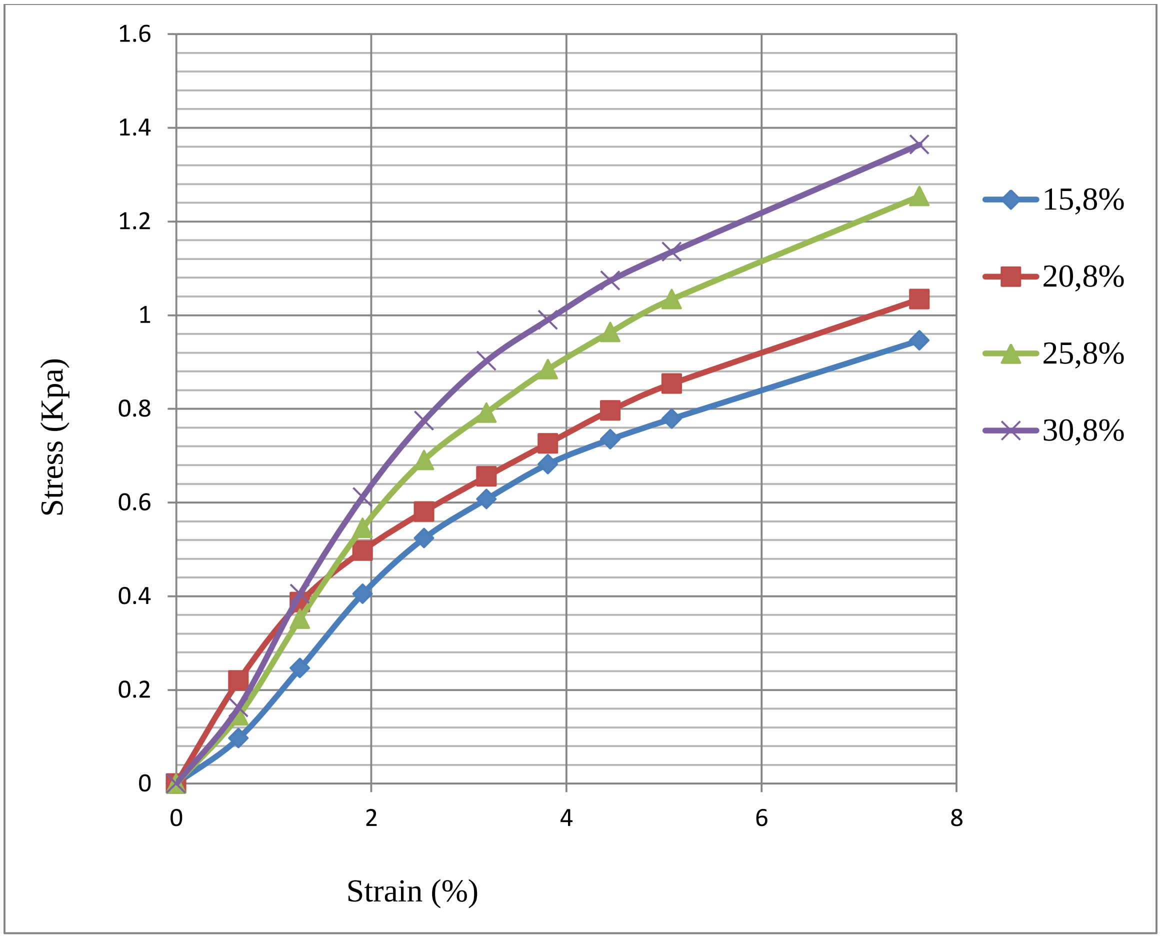

Figure E.4: Stress strain graph for expansive soil+SQW+0.8% TSF

Table E.2: Summary of CBR value and CBR swell test result for all samples

SN	sample type	CBR	CBR Swell
1	natural soil	2.83	5.97
2	10% SQW+ soil+0.4%TSF	3.70	4.98
3	15% SQW+ soil+0.4%TSF	4.10	4.51
4	20% SQW+ soil+0.4%TSF	4.83	4.21
5	25% SQW+ soil+0.4%TSF	5.37	3.69
6	10% SQW+ soil+0.6%TSF	4.23	3.01
7	15% SQW+ soil+0.6%TSF	4.90	2.75
8	20% SQW+ soil+0.6%TSF	5.97	2.36
9	25% SQW+ soil+0.6%TSF	**6.30**	**2.09**
10	10% SQW+ soil+0.8%TSF	3.97	3.18
11	15% SQW+ soil+0.8%TSF	4.40	2.82
12	20% SQW+ soil+0.8%TSF	5.23	2.51
13	25% SQW+ soil+0.8%TSF	5.87	2.28

Appendix F: Unconfined compressive strength test results

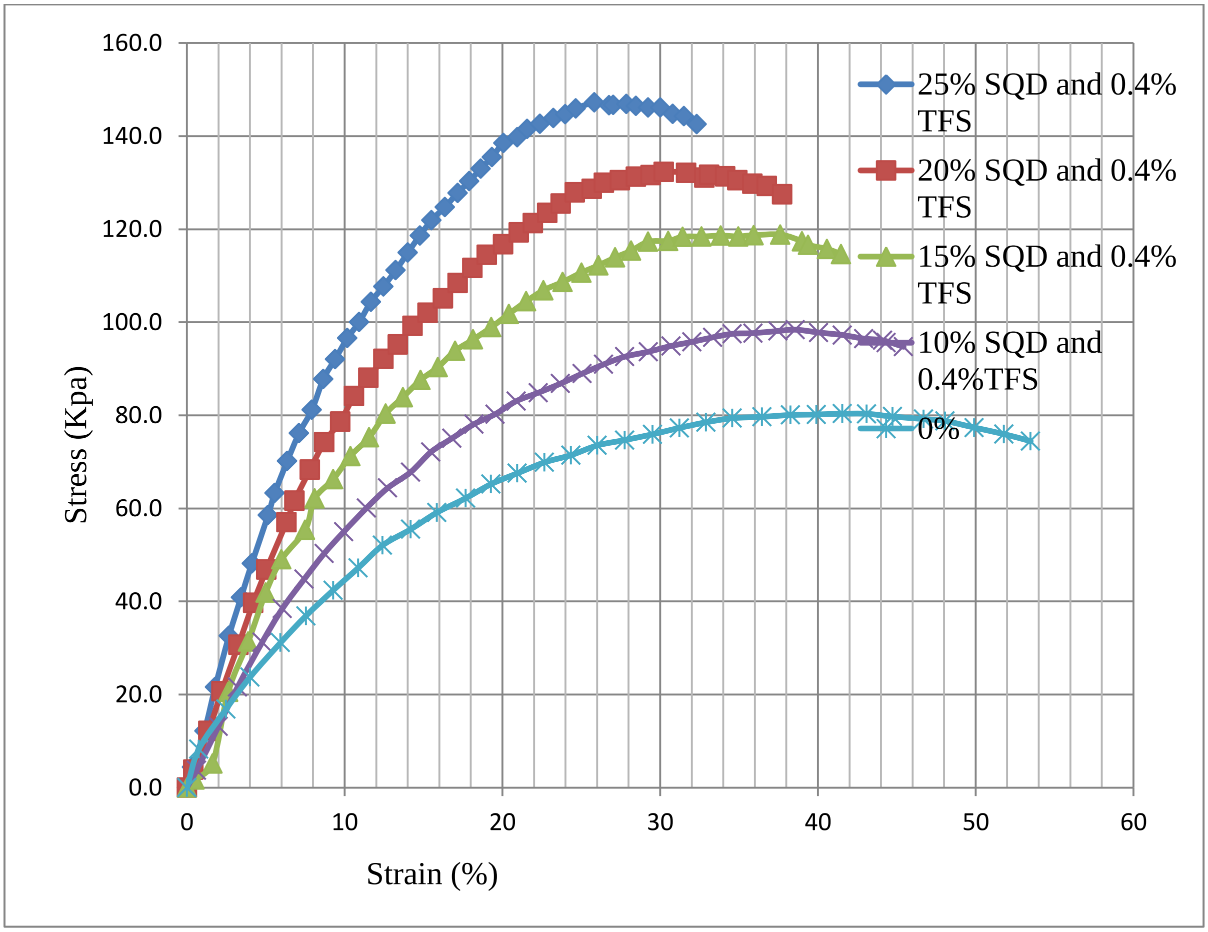

Figure F.1: Summary of UCS test result for different percentage of SQW and 0.4% TSF

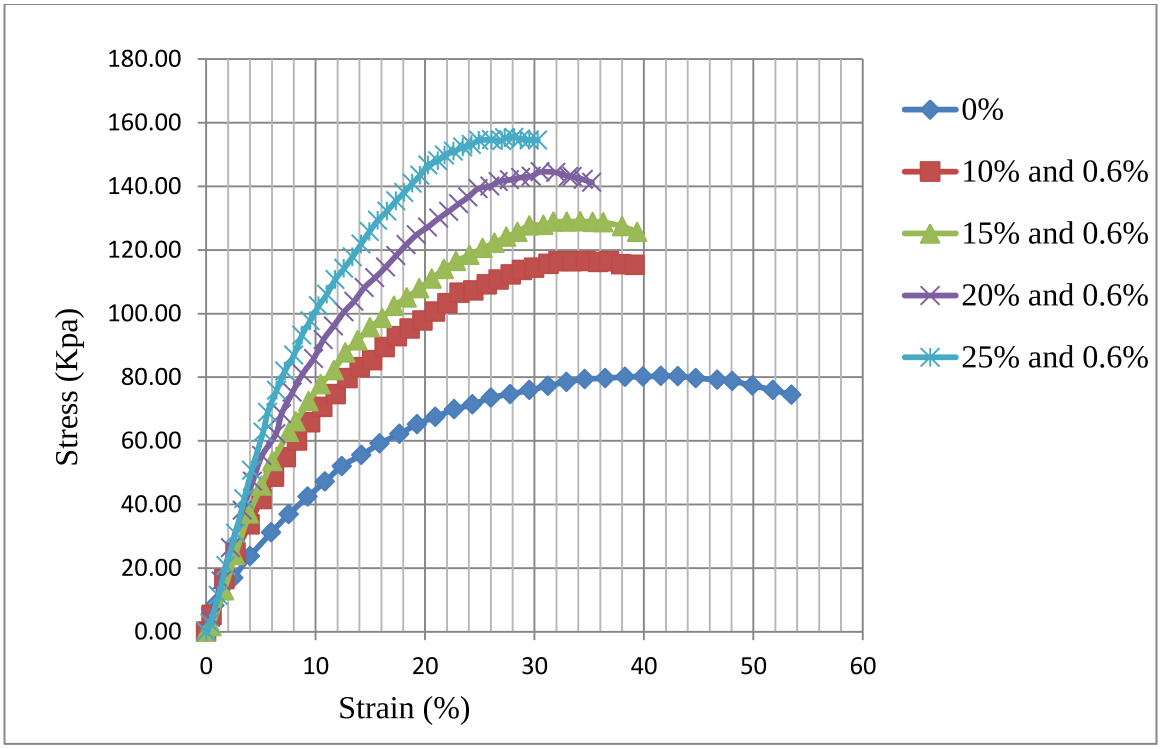

Figure F.2: Summary of UCS test result for different percentage of SQW and 0.6% TSF

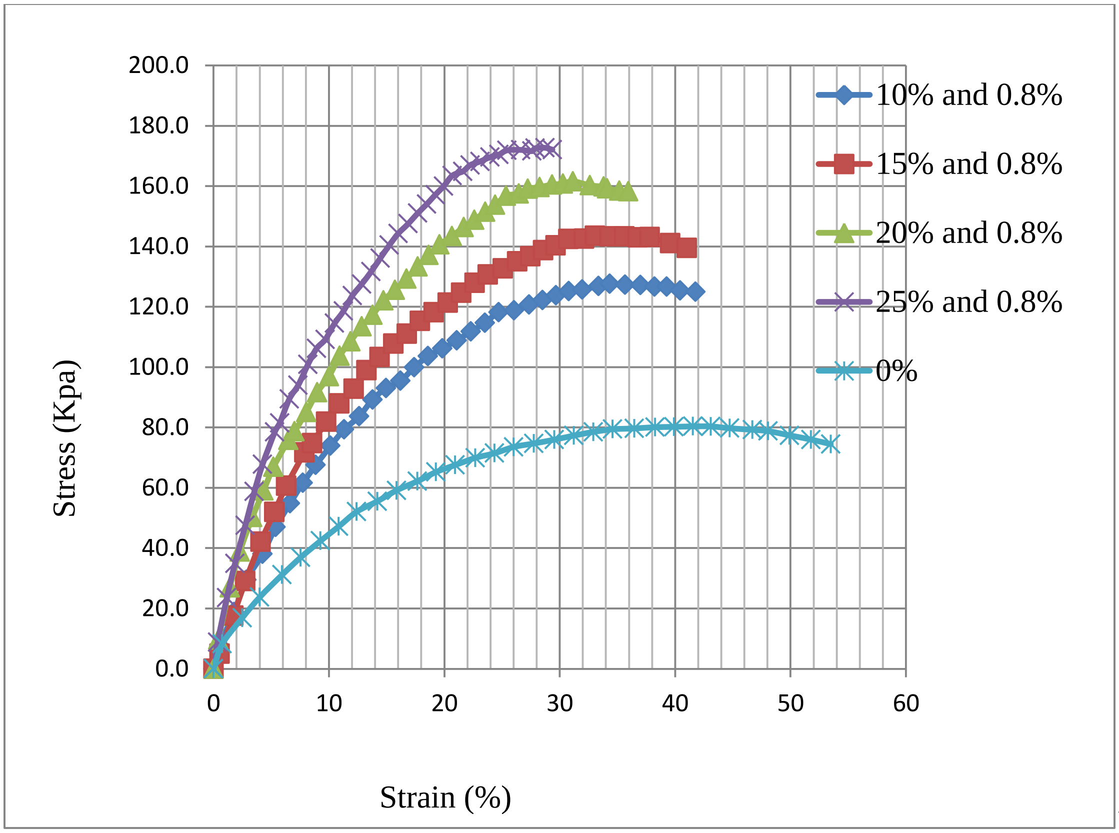

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Figure F.3: Summary of UCS test result for different percentage of SQW and 0.6% TSF

Table F.1: Detail UCS test result for expansive soil sample

Diameter (D) (cm)			3.80		
Length (Lo) (cm)			7.60		
Area (Ao)= ((3.142*d2)/(4)) cm2			11.335	0.0011335	
Volume (V) = A0*L0			86.15		
Moisture content			32.22		
Wet Density (¡b) =			1.677		
Dry Density (¡d)= ((¡b)/(1+w))			1.269		
Reading No.	Sample Deformation (mm)	Strain %	Corrected Area Ac= ((A0)/(1-Σ))	Load (kN)	Stress (Kpa)
0	0.00000	0	0.00113354	0	0.00
1	0.05782	0.761	0.00114223	0.009	8.30
2	0.18902	2.487	0.00116245	0.020	16.91
3	0.30465	4.009	0.00118088	0.028	23.78
4	0.45142	5.940	0.00120512	0.038	31.16

5	0.57372	7.549	0.00122610	0.045	36.93
6	0.70492	9.275	0.00124943	0.053	42.42
7	0.82501	10.855	0.00127157	0.060	47.20
8	0.94286	12.406	0.00129409	0.067	52.08
9	1.07851	14.191	0.00132100	0.073	55.53
10	1.20527	15.859	0.00134719	0.080	59.14
11	1.34314	17.673	0.00137687	0.086	62.20
12	1.46544	19.282	0.00140432	0.092	65.23
13	1.59220	20.950	0.00143395	0.097	67.56
14	1.72340	22.676	0.00146597	0.102	69.91
15	1.85015	24.344	0.00149828	0.107	71.45
16	1.97690	26.012	0.00153206	0.113	73.54
17	2.11033	27.767	0.00156929	0.117	74.70
18	2.24375	29.523	0.00160838	0.122	75.94
19	2.37273	31.220	0.00164807	0.127	77.31
20	2.50171	32.917	0.00168976	0.133	78.52
21	2.62846	34.585	0.00173284	0.138	79.40

22	2.77078	36.458	0.00178391	0.142	79.69
23	2.90865	38.272	0.00183634	0.147	80.09
24	3.03318	39.910	0.00188641	0.151	80.20
25	**3.15771**	**41.549**	**0.00193929**	**0.156**	**80.36**
26	3.27557	43.100	0.00199215	0.160	80.34
27	3.40010	44.738	0.00205121	0.164	79.74
28	3.54909	46.699	0.00212666	0.168	79.22
29	3.65360	48.074	0.00218298	0.172	78.79
30	3.79370	49.917	0.00226333	0.175	77.39
31	3.93602	51.790	0.00235124	0.179	75.99
32	4.06499	53.487	0.00243703	0.181	74.46

Appendix G: Free Swell Index test result

DETERMINATION OF FREE SWELL INDEX OF SOILS (IS 2720 part 40)	
Description of Material : Expansive soil collected from Modjo Study area	Sampling No:- 01 to 12 Sampled Weigt passed through (0.075mm)=10gm
Tested by :-	Date of Testing :…11 to 18/**03/2025**

Determination No.	Measuring Cylinder No.in mm		Reading After 24 Hours in mm		Free Swell Index ,%
	Kerosene (V_k)	Distilled Water (V_d)	Kerosene(V_k)	Distilled Water(V_d)	
Untreated soil	9.8	10	9.8	22.5	129.59
10% SQD& 4% TS	10	10	10	20	100.00
15% SQD & 4% TS	10	10	10	19	90.00
20% SQD & 4% TS	10	10	10	17.5	75.00
25% SQD & 4% TS	10	10	10	16	60.00
10% SQD& 6% TS	10	10	10	19.6	96.00
15% SQD & 6% TS	10	10	10	17.9	79.00
20% SQD & 6% TS	9.6	10	9.6	16	66.67
25% SQD & 6% TS	10	10	10	14.5	45.00
10% SQD& 8% TS	10	10	10	20	100.00
15% SQD & 8% TS	9.6	10	9.6	17.7	84.38
20% SQD & 8% TS	9.9	10	9.9	16.5	66.67
25% SQD & 8% TS	10	10	10	15.1	51.00

Remarks :-Degree of expansiveness for untreated subgrade soil was Very High