Improvement of Engineering Properties of Expansive Soil Modified with Scoria

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ABSTRACT

Expansive soil is known for its high susceptibility to shear failure, unexpected differential settlement and experiencing low bearing capacity, which makes it an unsuitable soil for a variety of engineering uses. This soil is characterized by considerable volume changes due to seasonal variations and moisture content. Lightweight structures cannot exert the necessary counter load to overcome the swelling from expansive soil. Therefore, this study aims to evaluate the improvement in some engineering properties of expansive soil modified with scoria. Soil properties were collected from the field for laboratory analysis of Atterberg limit, unconfined compression strength (UCS), consolidation test, California Bearing Ratio and compaction characteristics following ASTM testing procedures. Mixing of scoria with expansive soil with different percentages decreases the free swell, liquid limit, plastic index, optimum moisture content and increases plastic limit and maximum dry density. Similarly, unconfined compression strength, CBR value and consolidation increased up to 20% of scoria mix; then, as the percentage of scoria increased beyond this value, reverse properties are observed. Analysis of the results shows a significant improvement of geotechnical properties of scoria-stabilized soil. The results revealed that 20% of scoria is the optimum percentage used for improving engineering properties of expansive soil.

KEYWORDS: Engineering properties, Expansive soil, Stabilization, Scoria.

INTRODUCTION

Soft to very soft clays are mostly associated with substantial difficulties in construction activities. Since these soils are sensitive to deformations and have very small shear strength, they result in structural damage during the execution as well as throughout the life of projects, especially in urban areas (Karkush et al., 2020; Islam et al., 2018; Lakshman Teja et al., 2018). This soil needs either replacement with other suitable soils or treatment with suitable mechanisms to acquire enough bearing capacity and strength to support the loads imposed upon it. Soil strength generally refers to the soil ability to support the loads imposed by buildings or structures perfectly without failure. Treated soft soil behaves differently with different loads resulting in varying degrees of initial strength gain and final strength development to support foundations for building purposes (Salvant Raj, 2017; Lakshman Teja et al., 2018; Seyedesmaeil and Leong, 2015; Gartner and Macphee, 2011; Sabat, 2012; Vishwas et al., 2017).

Expansive soil has potentials for swelling and shrinking due to changing moisture conditions. This causes more damage to structures, predominantly light buildings and pavements, than any other natural threats. Ethiopia is amongst the list of countries where the occurrence and spatial distribution of expansive soil is recognized as significant. This soil exposes problems worldwide on engineering structures. It is well known that it can be found in many parts of the world. Ethiopia is one of the countries where expansive soil is widely found (Lakshman Teja et al., 2018). This soil is found throughout the world and is commonly found in arid/semi-arid regions, where there are high suctions and potentials for large water content charges, as water can cause significant volume changes (Salvant Raj, 2017). Expansiveness of soils depends on the presence of clay minerals. Clay particles have sizes of 0.002mm or less. Clay minerals are crystalline hydrous alumino-silicates

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derived from parent rock by weathering. The basic building blocks of clay minerals are the silicate tetrahedron and the alumina octahedron, combined into tetrahedral and octahedral sheets to form the various types of clays. Kaolinite, illite and montmorillonite are the common groups of clay minerals most important in engineering studies. As these minerals are exposed to moisture, water is absorbed between interlayering framework structures and apply upward pressure. This upward pressure, known as swelling pressure, causes most of the damages associated with expansive soils (Ali and Koranne, 2012; Reddy et al., 2006; Islam et al., 2018; Fitsim Markos, 2018; Huang et al., 2017).

Soil stabilization is a geotechnical technique of increasing and maintaining the stability of soil mass using chemical or mechanical techniques. Stabilization increases soil strength, decreases plasticity, lowers or sometimes increases permeability, hence resulting in higher soil strength, lower volume changes due to temperature or moisture variations and increase in workability of soil. The soil available for construction of any civil engineering structure often does not meet the requirements for construction. The process by which the properties of soil are improved so as to meet the construction requirements is called stabilization (Vrunda Sule, 2018; Manish Dixit and Kailas Patil, 2016; Ali Aliabdo, 2014; Ali and Koranne, 2012; Islam et al., 2018; Babita and Ravi, 2014; Sapna and Prathap, 2020; Manish Dixit and Kailas, 2016). Different methods have been conducted to enhance and treat the properties of expansive soils (such as strength and stiffness) by treating them *in situ*. These methods include densifying treatments (such as compaction or preloading), pour water pressure reduction techniques (such as dewatering or electro-osmosis), bonding of soil particles (by ground freezing, grouting and chemical stabilization) and use of reinforcing elements, such as geo-textiles and stone columns (Ayush and Shalinee, 2019; Gartner et al., 2011; Vrunda Sule, 2018; Agarwal, 2015; Sachin and Bhavsar, 2014; Maiasa and Ibrahim, 2017; Sachin et al., 2014; Fikiri and Wu Li, 2010). These methods are relatively expensive to afford by developing nations and the best way is to use locally available materials with relative cheap costs affordable by internal funds.

Scoria, a result of explosive volcanic eruptions, has been used as a construction material in the world for centuries (Warati et al., 2019). Several studies have been conducted to investigate the use of scoria as a building material in the manufacturing of concrete. Scoria aggregate is widely available in most parts of Ethiopia and is being used for limited purposes. Since the 1970s, Ethiopians have used scoria as a road-building material (Luo et al., 2020). Unlike natural or river sand, scoria quarry sites are limited to the use of sub-base road construction and are located 0.5 to 4.2 kilometers from adjacent towns, like Adama, Bishoftu and Mojo in Ethiopia (Warati et al., 2019). Therefore, this study aims to conduct laboratory investigations of scoria to improve the engineering properties of expansive soil for buildings and subgrade construction activities.

MATERIALS AND METHODS

Research Design

For this study, the purposive sampling technique was used to obtain a representative soil sample. Disturbed soil samples for detail laboratory testing were collected from one test pit at a depth of 1.5m from Jimma Town. Excavation was made by hand using a shovel and samples were collected manually and taken to Jimma University soil testing laboratory. The study used one test pit from Jimma Town. Then, laboratory experiments were carried out according to ASTM and AASHTO soil testing standard procedures. In order to obtain the final results, materials' modifying, preparation and testing were performed. Then, soil modifying and proportioning were done by using different percentages of scoria (5%, 10%, 15%, 20%, 25% and 30%). The selection of sites for excavation is based on visual identification and secondary data collected from previous research that was conducted on the investigation of engineering properties of soil found in Jimma Town.

Data obtained from laboratory tests was used to investigate and compare the performance of expansive soil modified with scoria. The soil and scoria samples were collected from Jimma Town and Adama Town, respectively. Laboratory tests were conducted to investigate the effect of scoria on the Atterberg limit, swelling behaviour, consolidation, unconfined compression, CBR and compaction characteristics (MDD and OMC) of expansive soil.

Sample preparation prior to treatment and testing was done according to AASHTO T87-86 procedures. This method involves air drying of samples and/or oven drying at 60ºC or less, breaking up the soil aggregates by rubber-covered mallet. Then, sieve analysis was performed to separate the dry soils. The first group involves preparing uniform samples for Atterberg limit test, swelling behavior test, consolidation test, unconfined compression test, compaction characteristics and California bearing ratio tests. Then, soil and scoria were mixed manually to get a uniform mix ratio for each test. Based on the theories and laboratory tests performed, the results obtained were analyzed, compared and thoroughly discussed.

RESULTS

Geotechnical Properties of Expansive Soil

Table 1 shows the geotechnical properties of expansive soil. Based on the results obtained, the virgin soil exhibits high swelling potential, high compressibility and low strength. Figure 1 shows the grain size distribution curve of expansive soil at Jimma Town.

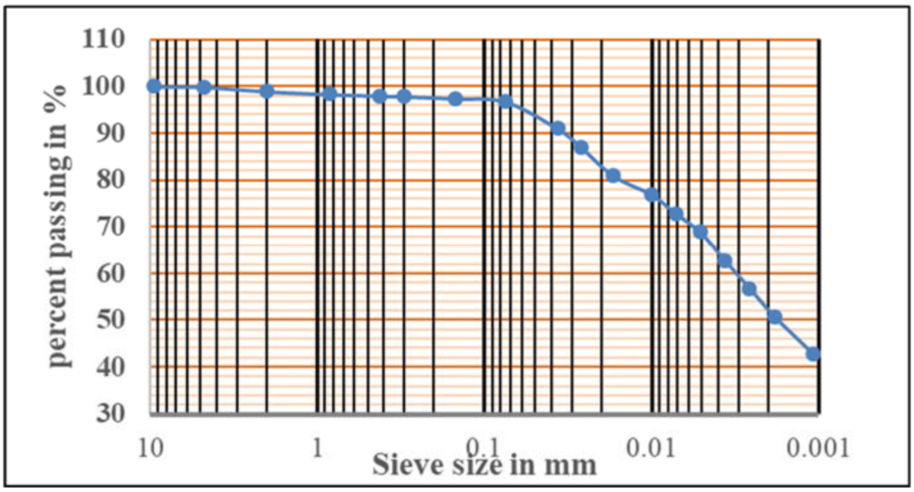

Figure (1): Grain size distribution curve for expansive soil

Table 1. Geotechnical properties of expansive soil for one test pit

Soil Sample		Value	Test Procedure
Moisture Content (%)		37.36	ASTMD4442
Free Swell Test (%)		102.00	IS 2720 part 40
Specific Gravity		2.46	ASTMD792
Atterberg Limit	LL (%(	103.73	ASTMD4318
	PI (%)	67	ASTMD4318
Compaction	OMC (%)	36.7	ASTMD4318
	MDD (g/c.c)	1.34	ASTMD5080-20
CBR (%)		1.78	ASTMD1883
Unconfined Compression Strength (UCS), kPa		91	ASTMD2166-00
Consolidation Test (kPa)		445	ASTMD4186

Chemical Properties of Scoria

Scoria is abundantly accessible in Ethiopia's central towns, particularly in the rift valley regions. In Ethiopia, scoria has been used as a construction material to replace sand in concrete and to enhance the foundation course for road construction. Warati et al. (2019) investigated the feasibility of scoria as a fine aggregate for concrete production and its impact on concrete characteristics.

The scoria was subjected to routine laboratory tests to clarify its chemical properties using XRD machine. In order to determine the mineralogical phases present in the scoria samples, X-ray diffraction analysis was carried out. Representative oven-dried scoria samples were crushed until a powder passing the no. 200 (0.075 mm opening) sieve was attained. The powder samples were step-scanned from 10° to 75° (2θ) with a time step of 1 second and a continuous scanning speed. The software program Match! 3 was also used to help identify the minerals present in the samples. Testing and analysis were conducted by setting the voltage at 30 kV with a current of 25 mA and a scanning rate of 0.02 °/sec for XRD. According to the findings (Table 2), scoria powder has the highest proportion of silicon dioxide (53.7%), followed by aluminum oxide and ferric oxide, with 14.8% and 10.1%, respectively.

Table 2. Chemical composition of scoria

Type of chemical	Chemical formula	Percentage %
Silicon dioxide	SiO_2	53.7
Aluminum oxide	Al_2O_3	14.8
Ferric oxide	Fe_2O_3	10.1
Calcium oxide	$Ca\ O$	5.1
Phosphorus pentoxide	P_2O_5	4
Magnesium oxide	$Mg\ O$	3.7
Dipotassium oxide	K_2O	2.3
Titanium oxide	TiO_2	2
Disodium oxide	Na_2O	1.8
Barium oxide	$Ba\ O$	1.2
Strontium oxide	SrO	1
Manganese oxide	$Mn\ O$	0.7

The Effects of Scoria on Engineering Properties of Expansive Soil

The Effect of Adding Scoria on Free Swell Index

Figure 2 shows the effect of varying the percentage of scoria on swelling potential of expansive soil. The test result indicates that the free swell index values of the expansive soil decreased with the increase in the percentage of scoria. Free swell value for untreated soil is 102%. The sample has free swell values >50%, which is categorized as a problematic soil for construction purposes. It is observed that addition of scoria with soil has resulted in a decrease in the free swell index of the soil. With 15% scoria treatment on soil, the free swell values become below 50%. Here, it can be seen that the addition of scoria beyond 15% to the samples has well improved the swelling potential of the problematic soil from the class of problematic soils to that of non-problematic soils, indicating a satisfactory and required range for construction suitability.

The Effect of Adding Scoria on Atterberg Limits

The variations in soil consistency properties, such as liquid limit, plastic limit and plasticity index of the expansive soil treated with scoria, are shown in Figure 2. It is observed that the liquid limit and plastic index decreased, while the plastic limit increased with increasing the percentage of scoria. The Atterberg limits of the soil show great variation when adding of scoria to the expansive soil. When the percentage of scoria has increased from 5% to 30%, the plastic limit of the soil-scoria mixture has increased from 36.7% to 51.4% and its liquid limit has decreased from 103.7% to 63% due to the pozzolanic reaction of (CaO) in cement kiln dust with high-silica, aluminium-containing soil-scoria mixture, forming calcium silica hydrated and calcium aluminium hydrated bond (Warati et al., 2019). Decrease in plastic index is probably due to the reduced surface activity as a result of flocculation and agglomeration of clay particles caused by cation exchange.

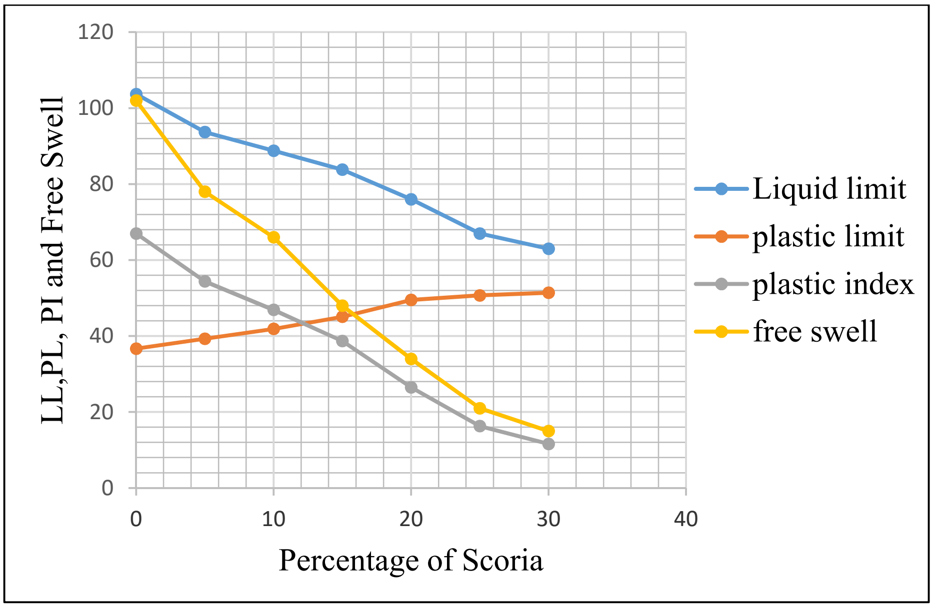

Figure (2): Effect of scoria on swelling potential, liquid limit, plastic limit and plastic index of expansive soil

Effect of Adding Scoria on Unconfined Compressive Strength (UCS)

The unconfined compressive strength of untreated and scoria-treated soils is shown in Figure 3. After the soil is blended with scoria, significant unconfined compressive strength improvements are observed. The unconfined compression strength (UCS) values of soil when treated with scoria changed to 91kPa, 93kPa, 103kPa, 109kPa, 110kPa, 94kPa and 91kPa for untreated, 5%, 10%, 15%, 20%, 25% and 30% treatments, respectively. Unconfined compression strength of scoria-treated soil increased up to 20% of scoria and then decreased. Therefore, 20 percent of scoria is the optimum percentage used to improve UCS of expansive soil. The unconfined compressive strength of soil changed from medium to stiff consistency. This increment of UCS was due to cation exchange, flocculation and agglomeration of the mix (Warati et al., 2019).

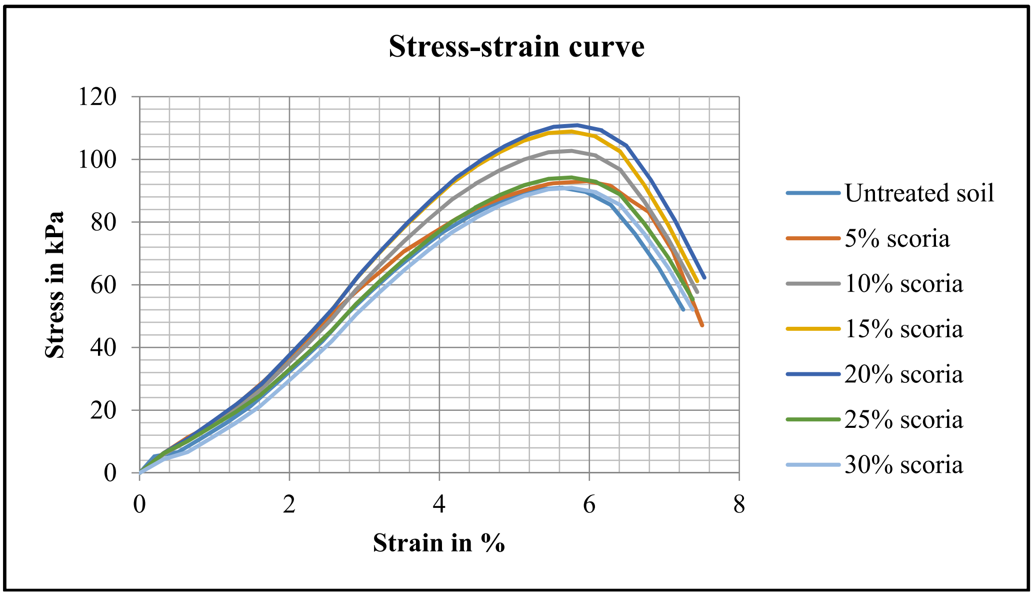

Figure (3): UCS of different % of scoria-treated expansive soil

The Effect of Scoria on Soil Consolidation

The effect of adding scoria to expansive soil on pre-consolidation pressure is shown in Figure 4. The pre-consolidation pressure for the soil samples was determined from the void ratio *versus* log pressure curve using Casagrande's method. The pre-consolidation pressure of soil is defined as the highest stress the soil ever felt in its history. It is the pressure at which major structural changes including the breakdown of inter-particle bonds and inter-particle displacements begin to occur. The practical significance of the pre-consolidation load appears in calculating the settlements of structures. In Figure 4, the consolidation pressure values of expansive soil changed to 445kPa, 560kPa, 600kPa, 615kPa, 620kPa, 590kPa and 550kPa for untreated, 5%, 10%, 15%, 20%, 25% and 30% treatments, respectively. It is observed that the consolidation pressure values of scoria-treated soil increased up to 20% of scoria and then decreased.

The Effect of Adding Scoria on CBR Value

The Californian bearing ratio (CBR) of expansive soil stabilized with scoria is presented in Figure 4. The addition of scoria to expansive soil caused an increase in strength of the soil. The CBR value of non-stabilized expansive soil shows too low value of CBR, which is 1.73 percent. The soacked CBR value of expansive soil when reinforced with scoria increases to 4.92%, 8.93%, 14.25%, 21.65%, 16.23% and 10.75% for 5%, 10%, 15%, 20%, 25% and 30%. Addition of scoria to expansive soil shows that the CBR value of expansive soil increases as the percentage of scoria increases. The maximum dry density (MDD) value increases until it reaches the optimum. At 20 percent of scoria, the optimum values of MDD and CBR were achieved. When the optimum scoria percentage is added to this soil, the value of CBR changed to 21.65 percent.

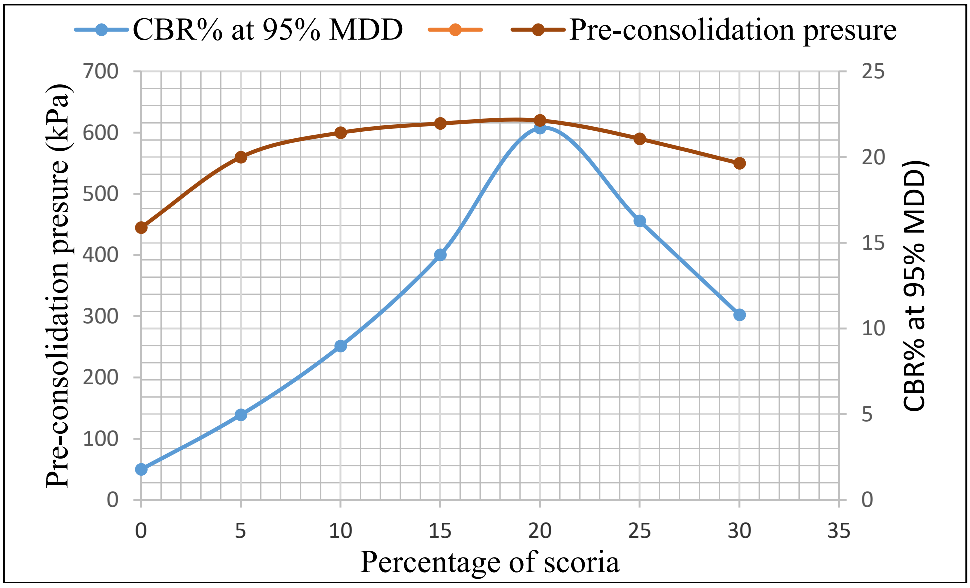

Figure (4): Variation of pre-consolidation pressure and CBR value with different percentages of scoria

The Effect of Adding Scoria on Compaction Characteristic of Expansive Soil

The optimum moisture content and maximum dry density of expansive soil stabilized with scoria are presented in Figure 5. The maximum dry density value for un-stabilized expansive soil is 1.34 g/cc. When the soil sample is modified with scoria, maximum dry density (MDD) increases to 1.38g/cc,1.44g/cc, 1.46g/cc,1.53g/cc, 1.55g/cc and 1.6g/cc, respectively, for 5%, 10%, 15%, 20%, 25% and 30 %. The optimum moisture content value of expansive soil when mixed with scoria decreased to 26.75%, 24.99%, 25.17%, 24.65%, 22.05% and 21.55 % for 5%, 10%, 15%, 20%, 25% and 30 %, respectively. It is found that the optimum percentage of scoria to improve compaction characteristics of sub-grade expansive soil is 20 percent. When scoria is added to the soil, aggregation and agglomeration take place, which leads to more course aggregate formation and reduction in clay colloidal content, which reduces the moisture uptake of the mix.

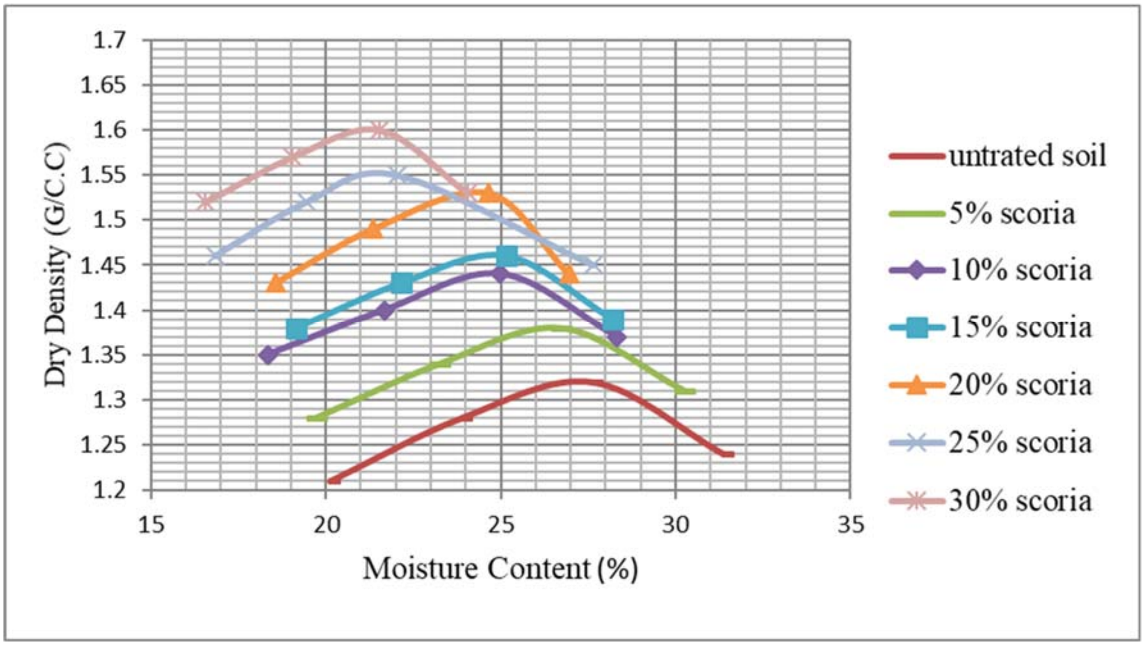

Figure (5): The effect of scoria on the compaction of the soil

CONCLUSIONS

The present study indicates that the soil in Jimma Town is a highly expansive soil. This soil is not good for every type of structure. So, stabilizing this soil with scoria is crucial in improving the engineering properties of expansive soil. From the addition of scoria to expansive soil, the following conclusions were drawn:

1. The free swell index (FSI) of expansive soil decreases with the addition of scoria in different percentages.
2. It has been observed that the liquid limit decreased from 104% to 63% with the addition of 20% scoria.
3. The maximum dry density (MDD) increases and the optimum moisture content (OMC) decreases as the percentage of scoria increases.
4. The maximum increase of 21.65% in CBR from 1.73% of natural soil is observed when virgin soil is reinforced with 20% scoria, thus altering the soil from being very unsuitable to suitable for construction.
5. Impact of scoria on expansive soil is positive. 20% dry weight of scoria gives maximum improvement in the engineering properties of expansive soil. Therefore, stabilization of expansive soil with scoria is promising.
6. The extraction of substantial amounts of non-renewable natural resources for construction creates significant damaging impacts on the local environment and its inhabitants. Therefore, effective use of scoria can significantly reduce waste disposal problems and help preserve environmental sustainability.

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