Analysis of Strength Properties of Cement Stabilized Soil at Different Moulding Water Contents

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Abstract. In the present study, an attempt is made to evaluate the strength properties of red soil mixed with ordinary portland cement. A series of Standard Proctor Tests, Unconfined compression strength Tests, Direct shear tests and Split tensile strength tests were performed on samples of red soil with a mixture of 6%, 9% and 12% at an increment of 3% of ordinary portland cement. The tests were conducted on red Soils with Specific Gravity of 2.59 subjecting those to above-specified tests as per Indian Standards IS: 2720. At each mixture of each percentage of ordinary portland cement sand. Peak frictional angle and soil cohesion were found out by conducting direct shear tests. Most of the direct shear tests were conducted to shear strain in excess of 30%, the stress-strain response was observed and recorded. Also in the present work, the comparison in strength properties was done between the soils at wet of optimum and dry of optimum for all above-mentioned tests. The present trend of results was also matched with those of previous works.

Keywords: Red soil, Ordinary portland cement, Peak friction angle, Soil cohesion, wet and dry of optimum.

1 Introduction

Rammed earth walls are formed by compacting damp soil between temporary forms. Together with other forms of unbaked earthen construction, such as mud-brick, rammed earth has a long and continued history throughout many regions of the world. Major centers of rammed earth construction include North Africa, Australasia, regions of North and South America, China and Europe, including France, Germany, and Spain. Earth has been used as a construction material since ever because it is a low-cost material, available almost everywhere, recyclable, incombustible and providing good thermal and acoustic insulation. Today, more than half of the world's population still lives in earth houses. In industrialized countries, a revival of this type of construction has emerged in the last decades due to energy and environmental concerns, coupled with a rising interest in the architecture of this type of construction.

Rammed Earth is a natural building method that is thousands of years old and has been used in all of earth's continents. Rammed Earth buildings have many favorable qualities. They are low-tech construction process and economical to build. They need low maintenance and they are suitable for the cold and hot climate.

Earth architecture is vernacular architecture. It includes various types of earth buildings in the world such as Rammed earth buildings, Cob, Adobe, Wattle, and Daub, Poured earth. Rammed earth is an ancient construction technique that consists of unsaturated loose soil compacted inside a formwork.

Rammed earth construction solves the problem of economic issues, non-renewable resource consumption, and energy consumption. Soil is compacted in removable formwork to make the homogeneous wall. The Stabilized Rammed Earth provides an ecological and sustainable envelope structure for colder regions.

Rammed earth is an ancient construction technique that utilizes only the earth to create thick, durable walls, which can be load bearing, low-cost, heat-storing and recyclable. It was developed independently in many parts of the world, and is also commonly known by its French name “Pise”.

Excavations in China have uncovered rammed earth constructions dating from the 7th century B.C. as parts of The Great Wall of China, begun more than 5,000 years ago were built of stone and rammed earth. Rammed earth technique was used in the arid regions of North Africa and the Middle East, where the earth was the only logical building material, where the massive high walls with their small openings protect them from the heat and dust of the desert.

Basgo fort possibly constructed before 1357 in Ladakh, India. Leh fort constructed around 1555 constructed by Tashi Namgyal.

1.1 Literature Review

Bui et.al, [1] (2011) worked on the Influence of water on the mechanical characteristics i.e., compressive strength, Young’s modulus and Poisson ratio of rammed earth material with a greater variation of water content: from the wet state just after manufacturing (11%) to dry state in atmospheric conditions (2%). The samples in this study were manufactured and tested in unconfined compression at different water contents which correspond to different values of suction.

Delage et.al [2], (1996) studied a qualitative and quantitative study of the microstructure of compacted silt. Samples have been statically compacted at three water contents i.e., at the optimum, on the dry side and wet side of optimum water content. The wet sample has the matrix type structure, with a clayey fraction filling the voids and adhering to the silt-sized grains, whereas the other samples display a structure characterized by a skeleton made of silt grain aggregates linked together by clayey bridges.

Horpibulsuk et.al [3], (2010) studied the strength development in cement-stabilized Silty clay based on microstructural considerations. A qualitative and quantitative study on the microstructure is carried out using a scanning electron microscope, mercury intrusion pore size distribution measurements, and thermal gravity analysis.

Three influential factors in this investigation are water content, curing time, and cement content. Cement stabilization improves the soil structure by increasing inter-cluster cementation bonding and reducing the pore space.

Reddy et al. [7] (2010) investigated on “Cement stabilized rammed earth, compaction characteristics and physical properties of compacted cement stabilized soils”. To study the effect of characteristics of soil by addition of cement, delayed compaction on compaction characteristics, the variation of the strength of stabilized rammed earth with a time lag and the influence of moulding water content, cement content and density on strength.

Reddy et.al, [8] (2011) investigated the Strength and behavior of cement stabilized rammed earth (CSRE) is a scantily explored area, focusing the strength and elastic properties of CSRE. Also examined the influence of moisture content, cement content and density on strength. And found that there is a considerable difference between dry and wet compressive strength of CSRE and the wet to dry strength ratio depends upon the clay fraction of soil mix and cement content, and strength of CSRE is highly sensitive to density and for a 20% increase in density the strength increases by 300-500%.

In the present study, an attempt is made to study the influence of stabilizer on strength property of rammed earth and the influence of moisture content on strength properties for cement stabilized soil both dry and wet side of compaction curve for a chosen density were compared.

2 Materials

2.1 Natural red soil

For the present study red soil is collected from Gaddanakeri LT, Bagalkot district in Karnataka. The natural red soil is collected at a depth of 10cm below the ground surface. The Properties of red soil are done as per IS: 2720 recommendations and are as shown in Table 1.

Table 1. Properties of Red Soil

Soil Property	**Value**
Specific Gravity	2.59
Grain Size Distribution Sand Clay Silt Classification	 57.9% 14.1% 27.9% Well graded coarse grained soil
Liquid Limit (LL)	34.2%
Plastic Limit (PL)	26%
Natural Moisture Content (w)	2.14%
Compaction Characteristics Maximum Dry Density (γ_{dmax}) Optimum moisture Content (OMC)	 18.24 kN/m^3 18.7%

3 Methodology

A series of Standard-Proctor tests, Unconfined compression strength tests, Direct shear tests and Split tensile strength tests were performed on samples of red soil with mixture of 6%, 9% and 12% at an increments of 3% of Ordinary Portland Cement (OPC), The effect of curing is also bought out by testing the samples after curing of 28 days, and also the influence of moisture content on strength properties for a cement stabilized soil both dry and wet side of compaction curve are studied.

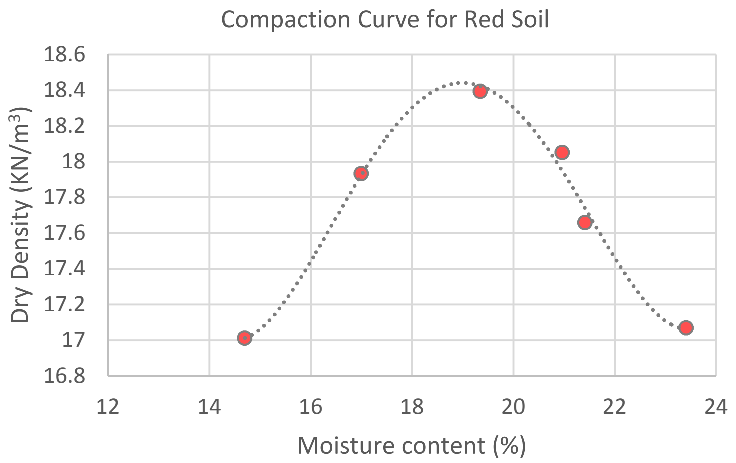

Fig. 1. Compaction for the Selected Red Soil alone.

The maximum dry density and optimum moisture content of the soil were found to be 18.24 kN/m^3 and 18.7% respectively. To investigate the effect of moulding water content on the Strength properties of Red Soil i.e., at optimum moisture content, dry and wet of optimum, here 95% of the MDD was selected as the dry densities and the corresponding water contents are taken as the dry and wet of optimum respectively for further studies as shown in Table.2.

Table 2. Dry densities and Moisture contents

Observation	Dry density (kN/m^3)	Moisture content (%)
At optimum	18.24	18.7
At dry of optimum	17.328	15.8
At wet of optimum		22.4

In order to study the effect of moulding water content on the strength properties of the red soil, the soil is mixed with their respective water contents along with the variation of OPC from 6% to 12% at an increments of 3% and specimens were prepared which are later tested under unconfined compression strength testing machine. The stress-strain response was plotted as shown in Fig. 2-4.

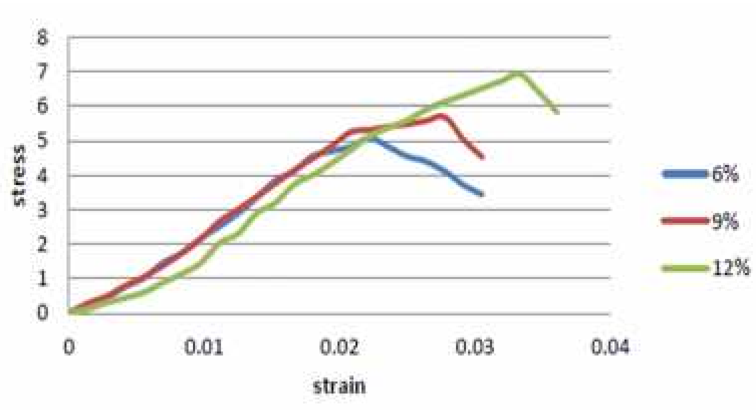

Fig. 2. Stress-strain response for soil compacted at dry of optimum.

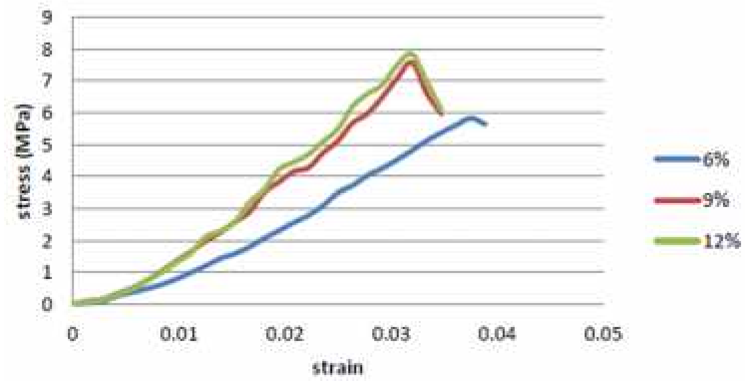

Fig. 3. Stress-strain response for soil compacted at optimum.

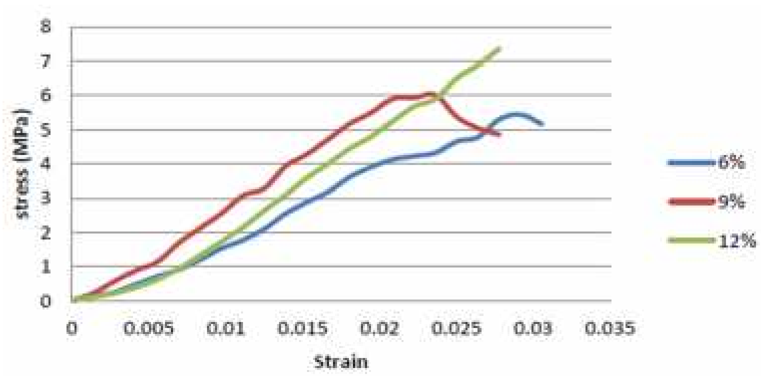

Fig. 4. Stress-strain response for soil compacted at wet of optimum.

From above Fig.'s 2-4 it is clear that the Stain undergone by the soil to reach maximum stress is lesser for soils at wet of optimum and higher for soils at optimum and intermediate for soils at dry of optimum. Hence, the soils compacted at optimum will carry maximum stress and failure will not be sudden i.e., it will undergo larger stains.

Fig. 5. The UCS tested sample before and after failure.

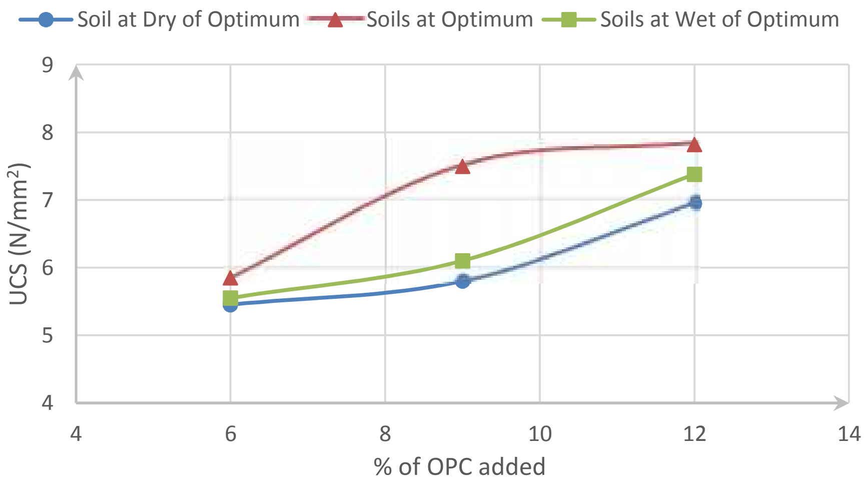

Fig. 6. Variation of UCS at different moulding W.C with varying OPC content.

The comparison of compression strength of soils mixed with different percentages of OPC at each of moulding moisture content is as shown in Fig. 6. From this, it can be observed that with an increase in the OPC content in the soil, the UCS of the soil increases and soil compacted at wet of optimum than that of the soils compacted at dry of optimum, but, soil has maximum UCS at its optimum water content.

In order to study the variation of the tensile strength, The Split tensile strength test is carried out on the soil specimens at different moulding moisture content with varying OPC Content is as shown in Fig. 6.

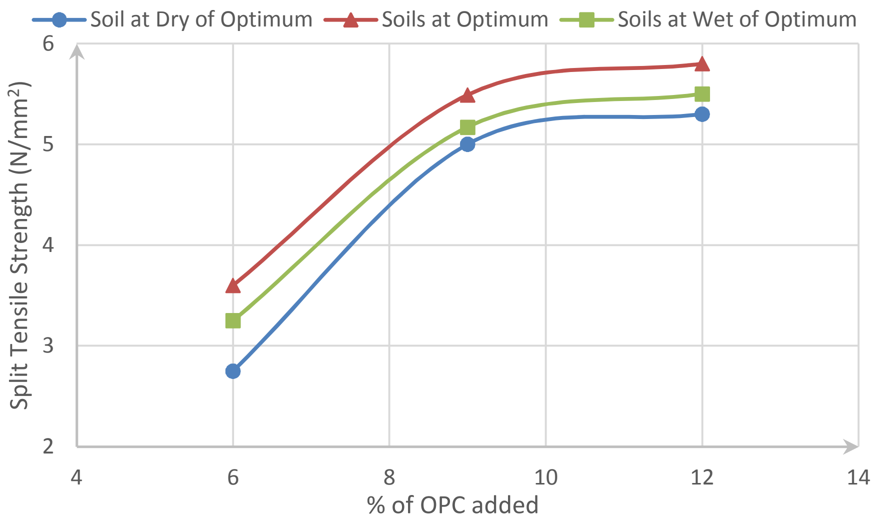

Fig. 7. Variation of split tensile strength at different moulding W.C with varying OPC content.

The comparison of Split tensile strength (STS) of soils mixed with different percentages of OPC at each of moulding moisture content is as shown in Fig. 7. From this, it can be observed that with an increase in the OPC content in the soil, the STS of the specimen increases and the soils have higher STS when mixed with wet of the optimum when compared to other two cases.

In order to study the variation of the shear strength of the soils, The direct shear test is carried out on the soil specimens at different moulding moisture content with varying OPC content is as shown in Fig. 8. Also, the variation of shear strength parameters of the soils is also studied as shown in the Fig. below.

From Fig.'s 8-9, it was found that for a soil mixed with a fixed amount of OPC for normal stress up to 100 kPa the maximum shear strength is achieved when mixed with optimum water content, But for normal stress greater than 100 kPa the soils have maximum shear stress when mixed with wet of optimum. But, always the soils have maximum shear stress values when mixed with wet of optimum than that of soil mixed with dry of optimum until the soils are mixed with the OPC content of 9%.

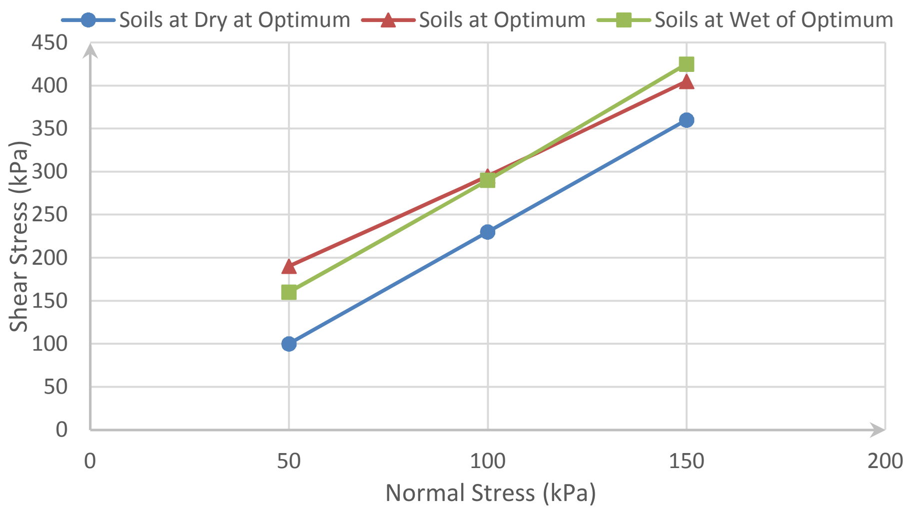

Fig. 8. Variation of shear strength at different moulding W.C with OPC of 6%.

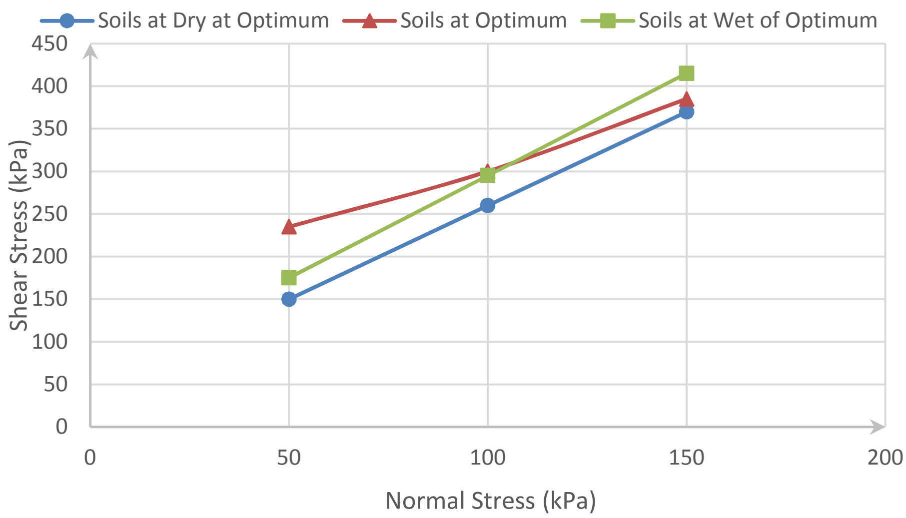

Fig. 9. Variation of shear strength at different moulding W.C with OPC of 9%.

But from Fig. 10, it is found that when the soils are mixed with higher OPC content of 12%, the maximum shear strength is achieved for the soils at optimum water content, than that compared to other moulding water content.

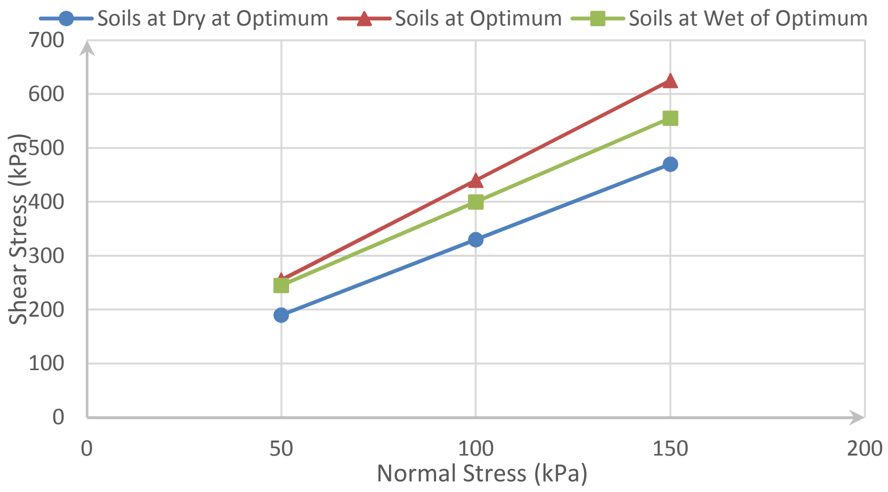

Fig. 10. Variation of shear strength at different moulding W.C with OPC of 12%.

The variation of shear strength parameters i.e., cohesion (C) and angle of internal friction (ϕ) for each of the soils specimens with the variation of OPC contents mixed with different moulding water content is as shown in Fig. 11.

With the increase in the moulding water content and OPC content in the soil, the marginal increase in the cohesion was found. Hence, W.C and OPC content doesn't have a drastic effect over the improvement of the cohesion of red soils.

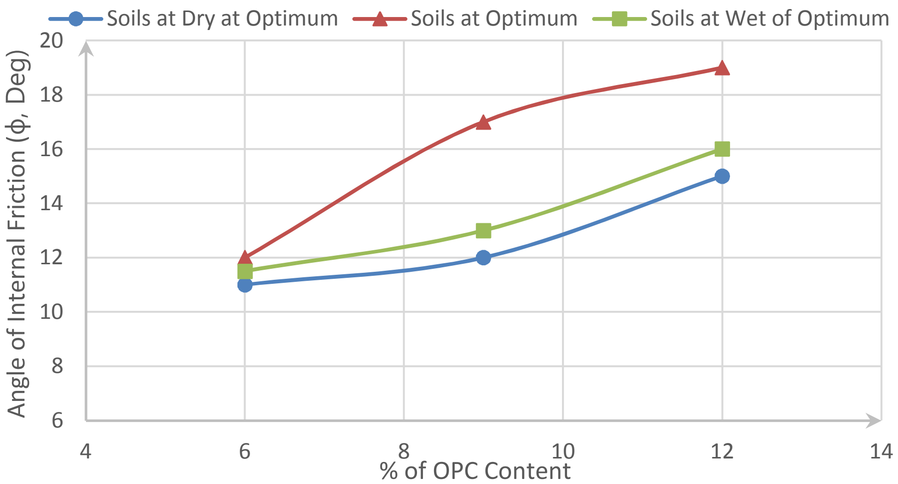

Fig. 11. Variation of the angle of internal friction with at different moulding W.C with varying OPC content.

7 Correlations

In order to know the behavior of the soil at different moulding moisture content i.e., wet of optimum and dry of optimum are done. The comparison is also made to study the variation of % increase in the corresponding parameters (i.e., unconfined compressive strength (UCS), Split tensile strength, shear strength) with respect to the wet of optimum to that of dry of optimum, with the variation of OPC content is as shown in the Fig. 12.

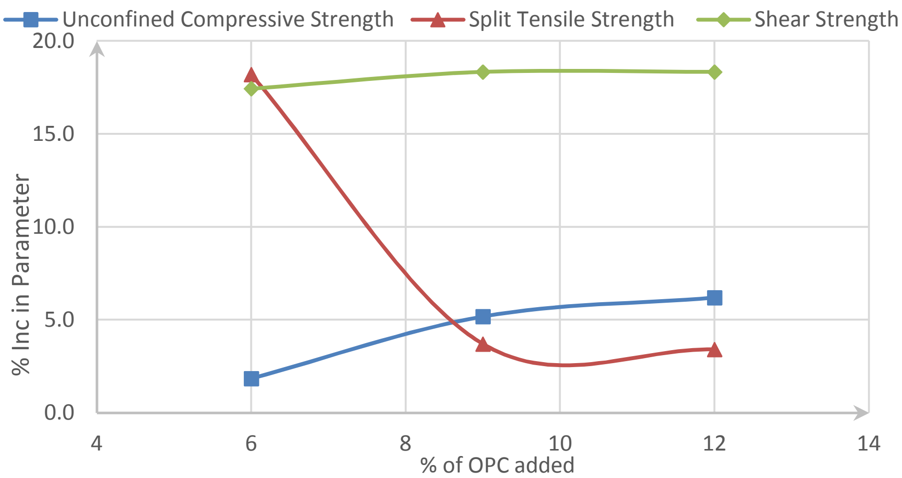

Fig. 12. The trend of the behavior of cement stabilized soil for different parameters in between wet of optimum and dry of optimum.

In the above Fig., the comparison is made between variations of the increase in selected parameters corresponding the moulding water content of wet of optimum to that of the dry of optimum, with the variation of OPC content in the soil mixture the formula is as shown in the equation below.

$$\text{Increase in the parameter} = \left(\frac{\text{Value Corresponding to (Wet of Optimum} - \text{Dry of Optimum)}}{\text{Value corresponding to Dry of Optimum}}\right) 100 \quad (1)$$

With an increase in the OPC content, the unconfined compressive strength, split tensile strength and shear strength of the soil corresponding to wet of optimum is greater than that of the dry of optimum. Because, the addition of the slightly higher amount of water will lead to the development of the cohesion between the soil particles than that compared to dry of optimum, leading to the development of all kind of strength.

With the increase in the OPC content, the increase in the UCS value increases. This is due to the increase in the cementing material between the soil particles resulting in the increase in the resistance to soil movement leading to the development of higher compressive strength.

With an increase in the OPC content, the increase in the split tensile strength of the soil decreases. This is due to the tight packing of the soil particles leading to the brittle nature causing the cement soil mixture to smaller tensile strength.

With an increase in the OPC content, the increase in the shear strength value increases. This is due to the increase in the cohesion (C) and the angle of internal friction (ϕ) increases leading to the development of higher shear strength for the cement-soil mixture.

8 Conclusions

- The mechanical properties such as compressive strength, tensile strength, and direct shear strength increases for soil stabilized with cement.
- The investigation on comparison of strength properties for a cement stabilized soil both dry and wet side of compaction curve for a chosen density of 1.735gm/cc with varying cement content at the increment of 3% (6%, 9%, 12%) shows that strength at wet side of compaction curve is maximum that may be due to excess water available for the hydration process.
- The UCS of soil Increases with increase in OPC content, this is due to the filling of the finer cement particles in the voids between the soil particles which in the presence of water leads to increase in the hydration process resulting to the higher compressive strength.
- The addition of the OPC to the soil will lead to the marginal increase in the cohesion of the mixture but, lead to the drastic increase in the angle of internal friction.
- The strength of soil compacted at optimum is more than the strength at the wet side of the compaction curve.
- The increase in the strength on the wet side of the compaction curve could decrease the compaction energy for the considered density.

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