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# Improvement Of Engineering Properties Of Expansive Soil Using Iron Ore Tailings

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*Abstract:* Expansive soils, (especially black cotton soil) create major difficulties in geotechnical engineering because of their high swelling and shrinkage tendencies, low bearing strength, and poor workability. To overcome these issues, the present study examines the influence of adding iron ore tailings (IOT) (a waste material generated from mining operations) as a stabilizing component to improve the compaction and plasticity behavior of black cotton soil. The soil was blended with different proportions of IOT (0%, 4%, 8%, 12%, 16%, and 20% by dry weight) and evaluated through standard geotechnical tests such as the Standard Proctor Compaction Test, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS) Test, and Atterberg Limits (Liquid Limit, Plastic Limit, and Plasticity Index).The experimental findings indicated that the Maximum Dry Density (MDD) increased consistently while the Optimum Moisture Content (OMC) decreased with IOT addition up to 16%, reflecting improved compaction characteristics. This improvement is mainly due to the higher specific gravity and granular structure of IOT, which enhance particle arrangement and minimize voids within the soil mass. Regarding plastic limit, the Liquid Limit and Plasticity Index reduced as the IOT content increased. These changes suggest a decrease in clay activity and soil expansiveness, resulting from the dilution of clay minerals and reduced water absorption. With increasing IOT, the soil progressively shifted from highly plastic to moderately plastic behaviour. In summary, incorporating iron ore tailings significantly improves the compaction properties and lowers the plasticity of black cotton soil, enhancing its suitability for applications such as subgrade layers and embankment construction. Additionally, this approach supports sustainable engineering practices by promoting the efficient reuse of industrial waste, offering a cost-effective, environmentally friendly, and sustainable method for soil stabilization.

***Index Terms*** – Expansive soil, Iron ore Tailings, Soil Stabilization, Unconfined compressive strength (UCS), California Bearing Ratio (CBR)

## 1.INTRODUCTION:

Expansive soils—especially Black Cotton Soil (BCS)—are widely distributed in several parts of India as well as other tropical regions. These soils contain a significant amount of clay minerals, predominantly montmorillonite, which are known for their high swelling and shrinkage tendencies with changing moisture levels. Because of this behavior, BCS often performs poorly in geotechnical works and can lead to problems such as surface cracking, uneven settlement, and deterioration of foundations, pavements, and embankments. To address these limitations, various soil stabilization methods have been adopted. Although conventional stabilizers like cement, lime, and fly ash improve soil performance, they may not always offer cost-effective or environmentally friendly solutions.

In recent years, the use of industrial waste products in soil stabilization has gained attention due to their economic and ecological benefits. Iron ore tailings (IOT), a waste material generated during iron ore processing, are produced in large quantities and pose disposal challenges for mining operations. These tailings are mainly composed of silica, iron oxides, and other inert minerals, and generally exhibit non-plastic behavior, low clay content, and relatively high specific gravity. Because of their granular nature and favorable physical characteristics, IOT can enhance soil density and reduce the plasticity of expansive soils when incorporated at suitable percentages. This study evaluates the compaction and plasticity characteristics of Black Cotton Soil treated with varying proportions of iron ore tailings. The objective is to determine the most effective mix ratio that improves compaction properties—specifically Maximum Dry Density (MDD) and Optimum Moisture Content (OMC)—while also decreasing key plasticity parameters such as Liquid Limit, Plastic Limit, and Plasticity Index. The research aims not only to enhance the engineering performance of BCS but also to encourage the beneficial reuse of iron ore tailings, promoting sustainable waste management and supporting circular economy practices. The outcomes of this study are expected to offer a practical and economical method for improving Black Cotton Soil in civil engineering applications, particularly in areas where both BCS and IOT are readily accessible.

## 2.OBJECTIVES:

The main objectives of the study are: -

- To evaluate the effect of iron ore tailings (IOT) on the compaction behaviour of black cotton soil by determining the changes in Maximum Dry Density (MDD) and Optimum Moisture Content.
- To study the plasticity Behaviour of black cotton soil with and without addition of iron ore tailings and identify an optimum percentage of IOT required for maximum strength enhancement of black cotton soil
- **To contribute toward sustainable and economical soil stabilization** by utilizing industrial waste materials like Iron Ore Tailings.

## 3.LITERATURE REVIEW:

1.Yohanna et al. (2021) carried out an extensive investigation to assess how iron ore tailings (IOT) influence the plasticity and compaction properties of selected tropical soils. Their work aimed to provide a sustainable alternative for soil improvement, considering both the environmental concerns associated with the disposal of iron ore tailings and the weak geotechnical behaviour of soils such as black cotton soil. Different tropical soils were blended with varying amounts of IOT, and tests were conducted on Atterberg limits and compaction characteristics. The findings showed a consistent reduction in the plasticity index as the IOT content increased, indicating enhanced suitability for engineering applications.

2.Supritha et al. (2016) examined the potential of iron ore tailings as a stabilizing additive for black cotton soil. Their research targeted the improvement of the strength and overall stability of expansive soil, which typically presents high plasticity and significant swelling issues. The study revealed that incorporating IOT lowered the plasticity index and enhanced compaction behaviour, making the treated soil more appropriate for construction purposes. They concluded that IOT serves as a reliable and sustainable stabilizer for problematic soils.

3.Etim et al. (2017) analyzed the combined effect of lime and iron ore tailings in improving black cotton soil, which naturally exhibits undesirable characteristics such as high plasticity, low bearing strength, and excessive volume changes. Laboratory investigations—including Atterberg limits, compaction, UCS, and CBR tests—were performed to assess soil improvements. Their results demonstrated that using lime along with IOT markedly decreased the plasticity and significantly improved strength and bearing capacity. Lime functioned as the main stabilizing agent, while IOT acted as a filler material, enhancing the overall performance of lime-treated soil.

## 4.MATEIAL AND METHODOLOGY:

### 4.1. Collection of Materials

- Black Cotton Soil (BCS**):** Collect from a Raajmahal, Jharkhand local site where expansive soil is naturally found.
- Iron Ore Tailings (IOT): Obtain from a Tata steel industry Jamshedpur.

### 4.1.1 SOIL

Black cotton soil is a highly expansive clayey soil commonly found in the central and southern regions of India. It is formed from the weathering of basaltic rocks and is characterized by a very high percentage of montmorillonite clay minerals. This mineral composition gives the soil its distinct property of swelling when wet and shrinking considerably upon drying. Such volumetric changes often lead to surface cracks, uneven ground movement, and instability, making the soil challenging for construction and geotechnical applications.

The soil is usually dark grey to black in colour and has high plasticity, low bearing capacity, and poor drainage. During the monsoon season it becomes soft and sticky, while in the dry season it becomes extremely hard. These seasonal variations create difficulties in designing foundations, pavements, and embankments over black cotton soil. Despite its problematic behaviour, black cotton soil is widely studied due to its large geographical occurrence and its impact on infrastructure development. Engineering improvements such as stabilization with industrial by-products, cementitious materials, and chemical additives are often required to enhance its strength and reduce its swelling potential. Understanding the physical, chemical, and mechanical characteristics of black cotton soil is essential for safe and economical design in civil engineering projects.

### 4.1.2 IRON ORE TAILINGS

Iron ore tailings (IOT) are the by-products generated during the beneficiation and processing of iron ore. After the extraction of usable iron, the leftover fine particles—composed mainly of quartz, hematite, silica, alumina, and traces of clay minerals—are discharged as waste. These tailings are usually deposited in tailing ponds, creating large storage areas that require continuous monitoring to avoid environmental pollution and land degradation. Their physical nature varies from sandy to silty, with low plasticity, moderate density, and relatively stable chemical behaviour.

In recent years, iron ore tailings have gained significant attention as a potential alternative material in construction and geotechnical engineering. Due to their granular structure and mineral composition, tailings can be utilized in soil stabilization, embankment fill, pavement sub-base layers, bricks, and concrete production. Using IOT not only reduces the burden on natural resources but also supports sustainable waste management practices. Incorporating these materials in engineering applications promotes circular economy concepts by converting industrial waste into valuable resources. Furthermore, the reuse of iron ore tailings helps minimize environmental risks associated with waste dumping and contributes to cost-effective construction solutions. As a result, IOT is increasingly recognized as a promising material for sustainable engineering applications.

### 4.2 METHODOLOGY

Following experiments are conducted in this study:

1. XRF analysis of the sample.
a. Black cotton soil (BCS)
b. Iron ore Tailings (IOT)
2. Specific Gravity Of soil
3. Determination of Atterberg Limit
a. Liquid limit by Casagrande’s Apparatus
b. Plastic limit
3. Particle size distribution by Wet Sieve Analysis.
4. Standard proctor test
5. Unconfined Compression Test
6. California bearing Ratio Test

## 5. RESULT AND DISCUSSION:

**Table 5.1 XRF Analysis of Black cotton soil**

| SL.NO. | Chemical Composition | % mass |
|---|---|---|
| 1 | $Na_2O$ | 0.2377 |
| 2 | MgO | 1.4123 |
| 3 | $Al_2O_3$ | 20.8911 |
| 4 | $SiO_2$ | 61.1305 |
| 5 | $P_2O_5$ | 0.3434 |
| 6 | $K_2O$ | 3.5856 |
| 7 | CaO | 1.520 |
| 8 | $TiO_2$ | 1.096 |
| 9 | MnO | 0.08 |
| 10 | $Fe_2O_3$ | 9.699 |

**Table 5.2 XRF Analysis of Iron Ore Tailings**

| SL.NO. | Chemical Composition | Mass (%) |
|---|---|---|
| 1 | $Na_2O$ | 0.0543 |
| 2 | MgO | 0.0638 |
| 3 | $Al_2O_3$ | 4.654 |
| 4 | $SiO_2$ | 4.890 |
| 5 | $P_2O_5$ | 0.1254 |
| 6 | $K_2O$ | 0.0978 |
| 7 | CaO | 0.0843 |
| 8 | $TiO_2$ | 0.1147 |
| 9 | MnO | 0.1566 |
| 10 | $Fe_2O_3$ | 89.758 |

**Table 5.3 Index Properties of Natural Black Cotton Soil**

| **Properties** | **Result** |
|---|---|
| Natural Moisture Content (%) | 4.7 |
| Soil Classification | CH |
| Percentage of soil particles passing through sieve size 75 micron | 90.2 |
| Free Swell Index (%) | 63.63 |
| Shrinkage Limit (%) | 12 |
| Specific gravity | 2.45 |
| Liquid limit (%) | 52.87 |
| Plastic limit (%) | 26.36 |
| Plasticity index (%) | 26.51 |
| Optimum moisture content (%) | 17.04 |
| Maximum dry density (gm/cm3) | 1.6 |
| California bearing ratio (%) | 1.3 |
| UCS(Kpa) | 46 |

**Table 5.4 Index Property of Iron Ore**

| | |
|---|---|
| Specific gravity of Iron ore | 4.23 |
| Natural moisture Content (%) | 5 |

## 5.1 SPECIFIC GRAVITY

Table 5.5 combined value of specific gravity with IOT

| SERIAL NUMBER | COMBINATIONS | SPECIFIC GRAVITY |
|---|---|---|
| 1 | 100% BCS | 2.45 |
| 2 | 96% BCS+ 4% IOT | 2.49 |
| 3 | 92% BCS+8% IOT | 2.55 |
| 4 | 88% BCS+ 12% IOT | 2.59 |
| 5 | 84% BCS+16%IOT | 2.64 |
| 6 | 80% BCS+20% IOT | 2.69 |

The specific gravity of natural soil is 2.45

The variation of specific gravity of soil shows that it increases with increases the addition of iron ore tailings (IOT) from 4% to 20%.

The graph for combined specific gravity with IOT is shown below.

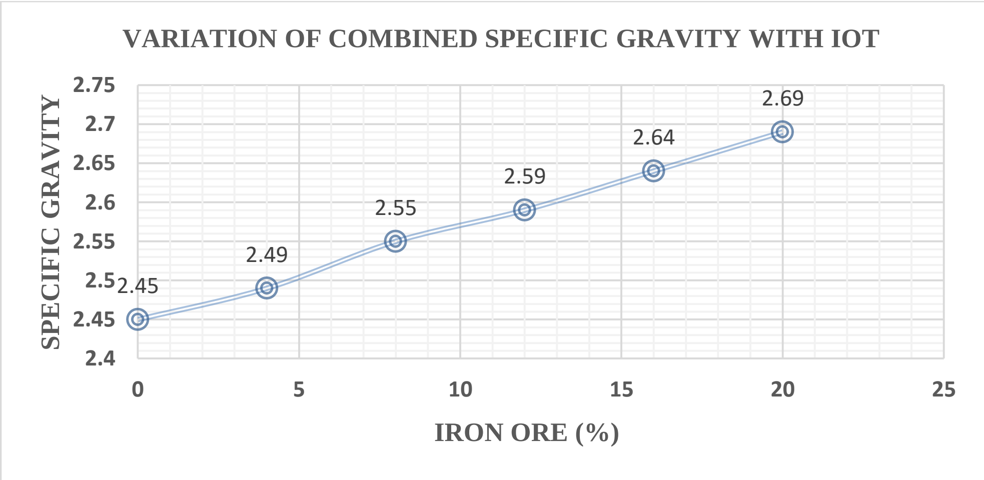



**Figure: 5.1 combined specific gravity graph with IOT**

## 5.2 ATTERGBERG LIMIT

Liquid limit of natural soil is found to be 52.87%

Plastic Limit of natural soil is 26.36%

Plasticity index of natural soil is 26 %

The soil is classified as Clay of high Plasticity

**Table 5.6 combined value of Atterberg limit with IOT**

The graph for variation of liquid limit with IOT is shown below

| Sl. No | Combinations | Liquid limit (%) | Plastic Limit (%) | Plasticity Index (%) |
|---|---|---|---|---|
| 1 | 100% BCS | 52.87 | 26.36 | 26.51 |
| 2 | 96% BCS+ 4%IOT | 47.96 | 23.93 | 24.03 |
| 3 | 92%BCS+8%IOT | 44.51 | 21.50 | 23.01 |
| 4 | 88% BCS+12%IOT | 39.01 | 19.06 | 19.95 |
| 5 | 84%BCS+16% IOT | 35.29 | 16.63 | 16.23 |
| 6 | 80% BCS20% IOT | 31.86 | 14.25 | 17.61 |

- The Liquid limit of natural soil is found to be 52.87%.
- The variation of liquid limit of soil show that it decreases with addition of iron ore.

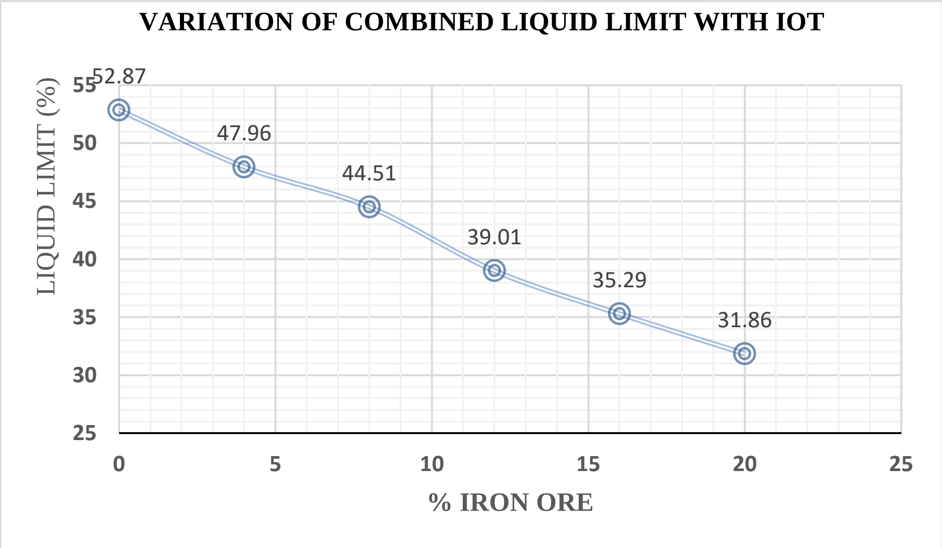



**Figure: 5.2 combined liquid limit graph with IOT**

- The plastic limit of natural soil is 26.36%.
- The variation of plastic limit of soil shows that it decreases with addition of Iron ore tailings (IOT)
- The graph for variation of plastic limit with different percentage of IOT is shown below

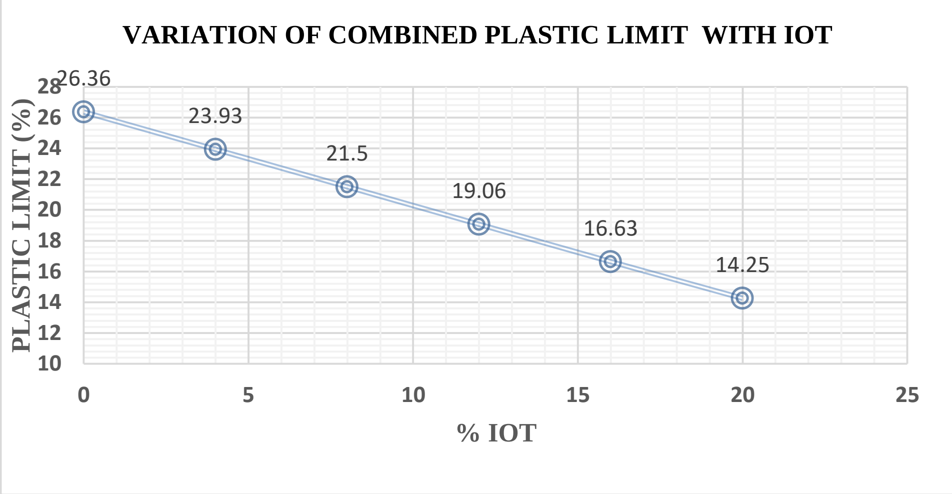



**Figure: 5.3 combined plastic limit graph with IOT**

- The plasticity index of natural soil is 26.51%.
- The variation of plasticity index of soil shows that it decreases with addition of Iron ore tailings (IOT)
- The graph for variation of plasticity index with different percentage of IOT is shown below

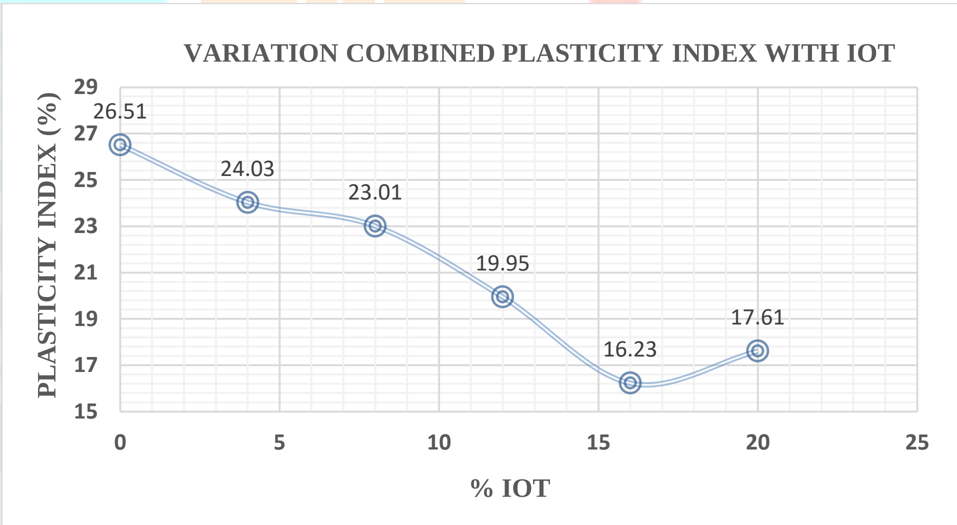



**Figure: 5.4 combined Plasticity index graph with IOT**

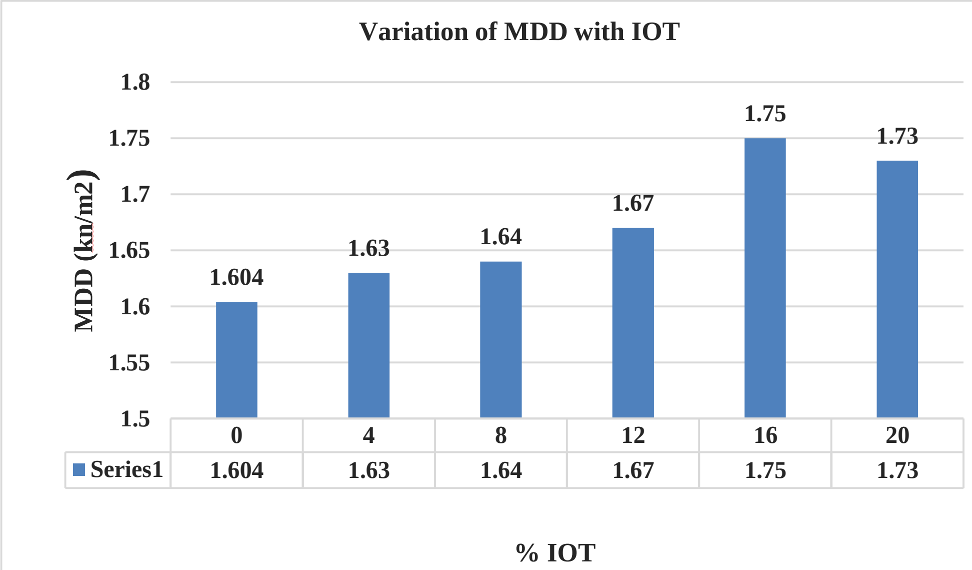
## 5.3 STANDARD PROCTOR TEST

**Table: 5.7 Combined OMC and MDD Value with IOT**

| COMBINATIONS | MDD (gm/cc) | OMC (%) |
|---|---|---|
| 100% BCS | 1.604 | 17.04 |
| 96% BCS+4% IOT | 1.63 | 19.84 |
| 92%BCS+8%IOT | 1.64 | 20.34 |
| 88%BCS+12%IOT | 1.67 | 18.88 |
| 84%BCS+16%IOT | 1.75 | 13.07 |
| 80%BCS+20%IOT | 1.73 | 12.7 |

- The Maximum dry density (MDD) and optimum moisture content (OMC) of natural soil are found to be 1.604 g/cc and 17.04% respectively.
- The variation of maximum dry density shows that it increases with addition of iron ore tailings and become maximum at 16% IOT and then decreases for further addition.

**Figure: 5.5 combined MDD graph with IOT**




The variation of optimum moisture content it shows increases upto 12% of IOT and then decreases for further increases.

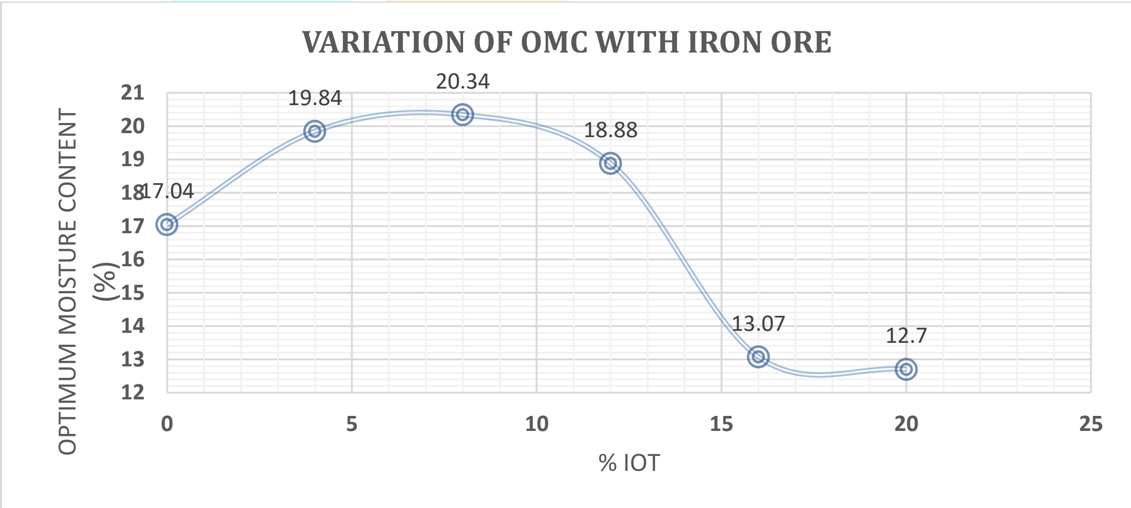



Figure: 5.6 combined OMC graph with IOT

## 5.5 CALIFORNIA BEARING RATIO

**Table 5.8 Combined value of CBR With IOT**

| SERIAL NUMBER | Combinations | CBR (%) |
|---|---|---|
| 1 | 100% BCS | 1.3 |
| 2 | 96% BCS+4% IOT | 2 |
| 3 | 92% BCS+8% IOT | 2.6 |
| 4 | 88% BCS+12% IOT | 3.2 |
| 5 | 84% BCS+16% IOT | 3.8 |
| 6 | 80% BCS+20% IOT | 2.4 |

- The unsoaked CBR value of natural soil is 1.3%.
- The value of CBR increases with addition of IOT and it becomes maximum at 16% IOT and then decreases on further addition of IOT.
- The variation of unsoaked CBR value are shown below

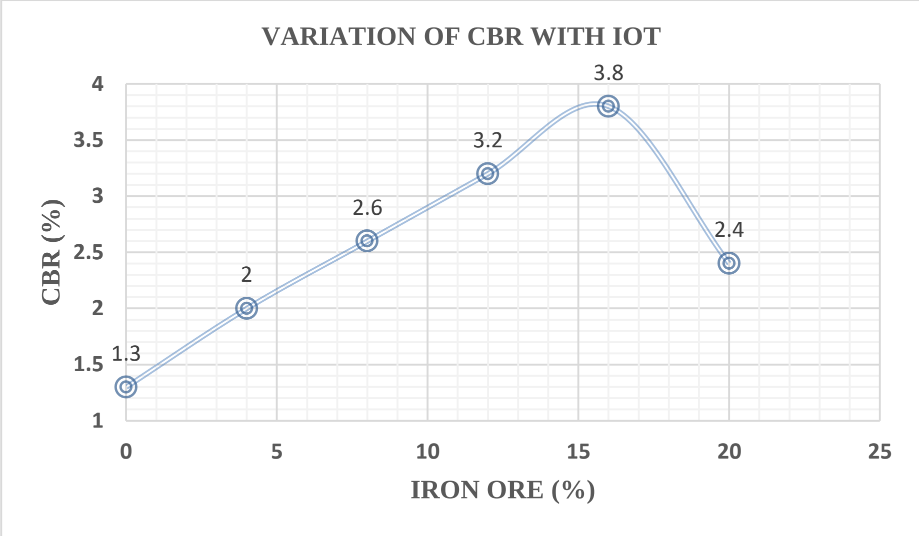



**Figure: 5.7 combined CBR with curve IOT**

### 5.4 UNCONFINED COMPRESSION TEST

**Table 5.9 Combined Value of UCS Value with IOT**

| SERIAL NUMBER | Combinations | UCS (KN/m2) |
|---|---|---|
| 1 | 100%BCS | 46 |
| 2 | 96% BCS+4% IOT | 50.84 |
| 3 | 92% BCS+8% IOT | 54.79 |
| 4 | 88% BCS+12% IOT | 61.78 |
| 5 | 84% BCS+16% IOT | 64.98 |
| 6 | 80% BCS+20% IOT | 52.07 |

- For natural soil, unconfined compressive strength is found to be 46 KN/$m^2$ and shear strength is 23 KN/$m^2$.
- The value of unconfined compressive strength increases with addition of IOT and maximum value 64.98 KN/$m^2$ is found to be at 16% IOT and then decreases on further addition of IOT.
- The variation of unconfined compressive strength with different percentage of IOT is shown below

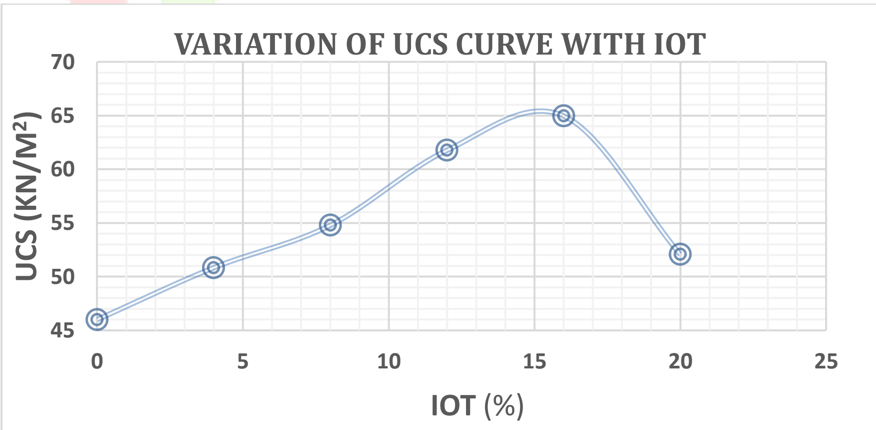



**Figure: 5.8 combined UCS curve with IOT**

## 6.CONCLUSION:

- The Result of the Atterberg's limit (Liquid limit plastic limit and plasticity index) test shows that it decreases with addition of the iron ore tailings up to 20% of IOT. This reduction is attributed to the non-plastic, granular nature of iron ore tailings, which helps modify the clay structure and minimize moisture sensitivity.
- The Result for standard proctor test shows that MDD of soil increases from 1.604 g/cc to 1.75 g/cc at 16% IOT then decreases for further addition of iron ore and optimum moisture content (OMC) Value shows that it increases with addition of IOT up to 12% then decreases for further addition.
- The result of UCS test show that it increases with addition of IOT up to 16% and value is found to be 64.98 KN/$m^2$ and then decreases for further addition of IOT
- The CBT test shows that CBR value of soil increases with increase in IOT up to 16% and then decreases for further addition of IOT.
- From the above conclusion shows that 16% of IOT is the best effective and optimum dose for the enhancement of strength parameters of expansive soil such as Shear strength, California bearing ratio and unconfined compressive strength of black cotton soil, Making the soil suitable for various geotechnical application such as pavement, embankment and foundation designs and promote the eco-friendly, cost effective and sustainable development.

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