# The Influence of Steel Slag on Improving The Properties of Marine Clay For Foundation Beds

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***Abstract***- *Majority of the population vast areas, particularly along the coast, are covered with thick soft marine clay deposits having very low shear strength and high compressibility. India has large coastline exceeding 6000kms.In general, the soils which are existing in the coastal corridors are Soft Marine Clays formed by the deposits and generally weak and possesses high deformation values in nature. Soft soils are generally labeled as 'problematic' because they have poor resistance to deformation, low permeability and limited bearing capacity. The properties of marine soil depend significantly on its initial conditions. Due to the poor engineering characteristics of these deposits, they pose several foundation problems to various coastal structures.*

*In India depends on road-based transport. There are many deposits of fine clays on coastal corridor and those soils are suffering from high saturation, low density, low shear strength, sensitivity, and deformation problems and are normally consolidated. These soils are widely occupied in costal corridor and not easy to avoid marine clay regions for the construction of pavements and foundations due to the population density.*

*In any developing country infrastructure, transportation and communication facilities play a major role for the development. Majority of the population in India depends on road-based transport. The stability and performance of a pavement is reflected by the soil sub grade. Roads constructed on Marine Soils, have poor strength and high deformation character, are bound to fail resulting in poor pavement performance and increased maintenance costs. Problematic soils are unstable for any civil engineering construction including for construction of the pavements and foundation soil beds. Such soils have been treated with different kinds of additives to produce new materials, which impart stability and durability to the pavements and foundation soil beds.*

*On the other hand, accumulation of various waste materials is now becoming a major concern to the environmentalists. The situation of environmental pollution has become alarming and it is the foremost task to think regarding the disposal of waste materials. The generation, handling and disposal of solid wastes are now a severe concern in the country. In these circumstances, there is a need to explore the possibility of utilization of these waste materials in bulk. Highway construction is one such field where waste materials can be used in abundance, reducing the total cost of construction in addition to providing a solution to an environmental problem*

*A substantial literature has concluded the severity and extent of damage inflicted by soil deposits of soft soils in the nature, to various structures, throughout the world (Ganapathy, 1977; Jones.D.E, 1982; Shridharan et.al, 1989; Abduljauwad, 1995; Osama and Ahmed, 2002; Supakij Nontananandh et.al, 2004; Zhuge et.al, 2007; Ameta,N.K, 2007; Basack et. al,2009; Kamruzzaman et.al,2009 and Fairfax Country, Virginia,2010). The loss caused due to the damaged structures proved the need for more reliable investigation of such soils and necessitates methods to eliminate, or reduce, the effect of settlements.*

*Keeping in view the research findings outlined above, in the present work, experimentation was carried out to investigate the efficacy of different additives, viz., Steel Slag, in stabilizing the marine clay, thereby, improving the strength, swell characteristics of the marine clay. A systematic methodical process was followed, involving experimentation in the laboratory under controlled conditions.*

*It was observed that 13% Steel Slag with marine clay has effectively improved the laboratory CBR value.*

***Keywords***- Majority of the population Vast areas, particularly along the coast, are covered with thick soft marine clay deposits having very low shear strength and high compressibility. India has large coastline exceeding 6000kms.In India depends on road-based transport. There are many deposits of fine clays on coastal corridor and those soils are suffering from high saturation, low density, low shear strength, sensitivity, and deformation problems and are normally consolidated. These soils are widely occupied in

costal corridor and not easy to avoid marine clay regions for the construction of pavements and foundations due to the population density.

## I. INTRODUCTION

Marine clays are soft and highly deformable deposits found along the coastal areas. These have very weak with low shear strength and high compressibility. Marine clay beds are generally found along the costal line of states like West Bengal, Orissa, Andhra Pradesh, Tamilnadu, Kerala, Karnataka, Maharashtra and some parts of Gujarat. India being the largest peninsular country, it is having a coast line of more than 6000 km. Leaving those areas as barren lands is not possible and hence Geotechnical Engineers are working a lot for the development of those problematic areas with varying engineering characteristics for the construction of large number of commercial, housing, industrial buildings and transportation criteria also, as majority of the population depends upon Road transport.

Marine clays suffer from the problems of high saturation, low density, low shear strength, sensitivity, and deformation, normally consolidated and possess specific physic-chemical make-up which are subjected to volume changes with the environment accordingly. Irrespective of the problems in view of the population density it is not possible to avoid the construction of pavement and foundation on them.

High shrinkage and swelling nature of the marine clay soils on inhabitation of water during the monsoon changes its density. Shrinkage occurs because of evaporation of water in summer and become hard due to increased density and this nature of soil decreases with depth. The volumetric deformation in these soils is attributed to seasonal variations in the ground water profile resulting in changes in moisture content.

During summer, polygonal shrinkage cracks occurs near the surface, extending to depth of about 1.5 m, indicating a high potential for compressibility. The depth of cracking indicates the depth of active zone in which significant volume change occurs, which is defined as thickness of soil in which moisture deficiency exists.

The entire stratum of marine clay soils in the field may not be active. Besides, as most soils do not respond quickly to the climate changes, the depth of active zone is greater than the depth of seasonal moisture fluctuations. Posses stability problem could mentioned as hydraulic structures resisting on marine clays in which case the problem arises mainly because of unlimited quantity of water being readily available to the foundation soil. Similarly, buildings in marine soils have posed serious problem of distortion and cracking throughout the world. Even though they are not suitable as pavement sub grades and foundation soil beds due to their inability of strength criteria as more construction projects are encountering soft clays there is a need of quantifying the properties of marine clays. If constructions are made without taking proper precautionary steps then will be simply in vain.

Continuous efforts have been made all over the world to find out the means of ways to solve the problems of marine clays. Placement of adequate surcharge load, chemical stabilization and using various reinforcement techniques are some of the tried and tested remedial measures to avoid problems posed by the marine clays.

A comprehensive review of literature indicates that considerable amount of work related to determinate of engineering behavior of marine soils has been carried out worldwide since last 50 years. Amongst various contributions, the investigations on physical, chemical and mineralogical properties of marine clay conducted by Eden et al. (1957), Noorani (1984), Shridharan et al.(1989), Mathew et al.(1997) and Chew et al. (2004) are worthy of note. Significant research on strength and stiffness characteristics was performed by Koutsoftas et al. (1987) and Zhou et al. (2005); Zhuge et al. (2007); Ameta, 2007; Basack et al.(2009); Kamruzzaman et al. (2009) and Fairfax country, Virginia, 2010. The loss caused due to the damaged structures proved the need for more reliable investigation of such soils and necessitates methods to eliminate, or reduce, the effect of settlements. To overcome these problems, there is no other alternative, except to improve the sub-soil or sub grade for expected loads with suitable treatment to the in-situ soil.

In this work it is attempted to study the effect of STEEL SLAG on improving the properties of marine clay.

## II. IDENTIFY, RESEARCH AND COLLECT IDEA

Transportation and communication facilities are necessary for any developing countries like India. The technology of road construction depends mainly upon the vehicular pattern, construction materials and sub grade condition.

Sub grade is an integral part of the road pavement structure as it provides the support to the pavement from beneath. The main function of the sub grade is to provide adequate support to the pavement and for this the sub grade should possess sufficient stability under any adverse climate, loading and deformation loading conditions. The performance of these soft fine grained deposits under different conditions of environment varies over wide limits. Due to the poor sub grade conditions formation of fractures, fissures, rutting and the phenomena of pumping, blowing and consequent cracking of cement concrete pavements occur.

Effects of marine clay have appeared as cracking and break-up of pavements, railway and highway embankments, roadways, building foundations, irrigation systems, water lines, canals and reservoir linings. The estimated damage was very expensive to the pavements running over the marine clay sub grades. So, considerable changes have to be made in the construction of various coastal and offshore structures. In order to improve the engineering behaviour of these soils, several improvement techniques are available in geotechnical engineering practice. The selection of any of these methods to overcome any problem can be proved to be efficient only after the comparison of that with other techniques, then it can be said that the particular method is well suited for a specific system.

Sustained efforts are being made all over the world on highway research field to evolve more promising treatment methods for proper design and construction of pavements running over the soft clay sub grade. In the present work, the efficiency of Ferric Chloride and Air Cool Slag as stabilizing agents, for improving the properties of marine clay.

Since 1999, ArcelorMittalTuberao has carried out technical developments with the support of a consulting company called Kaeme Empreendimentos e Consultoria Ltd a aiming at correcting the main problem in the use of LD slag - its expansion in contact with free oxides. The process developed by Arcelor Mittal Tuberao and Kaemeinside ArcelorMittalTubarão's premises makes the free oxides be partially inert reducing slag expansion capacity, thus making it possible to use it inroad works as road sub-base and base or even as asphalt concrete. Upon reaching a satisfactory expansion rate according to technical regulations the process is interrupted and the material is made available to the market under the name ACERITA.

**SOURCE: IBS 1998**
**Environmental Aspect Studies**

- No substantial leaching of the slag metal content to underground or surface water
- Representing little or no concern regarding potable water quality.
- Slag has no impact on animals or other forms of life in the areas of use or areas nearby. There is no bioaccumulation of metals present in the slag in the soil.
- LD slag can be safely used in aquatic environments such as rivers, lakes and water streams with no impact on the quality of the water or aquatic life. Such environments allow enough dilution (at least 1,000 times) to protect against high pH alteration. It is necessary to be careful when using the slag in smaller water bodies with low water flow such as wet terrains or shallow channels.
- Health risks connected to steel slag use are not significant for urban and rural populations or maintenance, industry and construction workers potentially exposed.
- Slag used in cement manufacturing has partially replaced the use of clinker reducing energy consumption and, therefore CO2 emissions.
- Environmental impacts caused by mineral extraction can be eliminated with the use of slag.
- LD slag analyzed by X-ray diffraction has not shown traces of crystalline silica (structure sanding).

## III. STUDIES AND FINDINGS

### MATERIALS USED AND THEIR PROPERTIES

The details of the various materials and chemicals used in the laboratory experimentation are reported in the following sections.

### SOIL AND ITS COMPOSITION

The Marine clay used in this study is typical soft clay collected at a depth of 0.3m to 1.0m from ground level in Kakinada Sea Ports limited, Kakinada, and Andhra Pradesh, India. The properties of soil are presented in the Table 3.1. All the tests carried on soil as per IS specifications.

### STEEL SLAG

Steel making slag is a product resulting from the industrial processes carried out to produce first pig iron and second steel. LD slag is generated in the steel-making process resulting from the transformation of pig iron in liquid steel. The letters LD come from the fact that the steel is produced in an LD type oxygen converter, LD meaning **LINZ AND DONAWITZ**, towns in Austria where the process was invented.

The refining process is used to control carbon content and to eliminate impurities that may alter steel quality. For such, fluxing agents are added to the converter metallic load (molten pig iron and scrap). These fluxing agents are responsible for the fixation of the oxides formed in the reactions; the main fluxing agents used are lime (CaO) and fluorite (CaF2).

**Plate 3.1 Steel Slag**

The melting and refining of the load are processed through oxidation reactions of steel impurities such as silicon, (Si), phosphorus (P), sulphur (S) and Manganese (Mn) and through the reduction of carbon content. These oxides formed combine with the dissolved CaO forming stable slag separated from the metallic bath. The resulting liquid steel and slag separate inside the converter due to their different densities. This is used to remove them separately from the converter: the steel is tapped into a ladle and the slag into the slag pot (cast iron vessel transported by railroad). However, in the slag pot there is still approximately 6% of free metal (FeO) mixed with the slag which can be reused after being processed.

**Properties of Marine Clay**

| S. No | Property | | Properties |
|---|---|---|---|
| 1. | **GRAIN SIZE DISTRIBUTION** | | |
| | Fines | Sand (%) | 8 |
| | | Silt (%) | 28 |
| | | Clay (%) | 64 |
| 2. | **ATTERBERG LIMITS** | | |
| | Liquid limit (%) | | 70.70 |
| | Plastic limit (%) | | 32.92 |
| | Plasticity index (%) | | 37.78 |
| 3. | **COMPACTION PROPERTIES** | | |
| | Optimum Moisture Content (O.M.C) (%) | | 28.45 |
| | Maximum Dry Density (M.D.D) (g/cc) | | 1.32 |
| 4. | Specific Gravity (G) | | 2.53 |
| 5. | IS Classification | | CH |
| 6. | Soaked C.B.R (%) | | 1.12 |
| 7. | Differential Free Swell (%) | | 70 |
| 8. | Cohesion (C) (t/m²) | | 2.7 |
| 9. | Angle of internal friction (ø)(°) | | 3 |

**Chemical Properties of Steel Slag**

| S.NO | Constituent elements | Percent content (%) |
|---|---|---|
| 1 | Silica as $SiO_2$ | 14-18 |
| 2 | Alumina as $Al_2O_3$ | 1-1.5 |
| 3 | Calcium as CaO | 48-50 |
| 4 | Iron as $Fe_2O_3$ | 14-22 |
| 5 | Magnesium as MgO | 9-12 |
| 6 | Manganese oxide as MnO | 1-1.5 |
| 7 | Phosphorus as $P_2O_5$ | 1-2 |

**Courtesy to Visakha Steel Plant, Vizag, A.P.**

**Physical Properties of Steel Slag**

| S.NO | Property | Value |
|---|---|---|
| 1 | Specific Gravity | 2.312 |
| 2 | **Composition Properties** | |
| | Maximum Dry Density (g/cc) | 1.81 |
| | Optimum Moisture Content (%) | 18.33 |
| 3 | **Atterberg Limits** | |
| | Liquid limit (%) | 35.8 |
| | Plastic Limit (%) | NP |
| 4 | Soaked CBR (%) | 31.77 |
| 5 | Cohesion (t/m²) | 1.6 |
| 6 | Angle of Internal friction (ø)(⁰) | 35.57 |

**LABORATORY EXPERIMENTATION**

Tests were conducted in the laboratory on the marine clay to study the behavior of marine clay, when it is treated with Steel Slag.

The following tests were conducted as per IS code of practice.

**ATTERBERG LIMITS:**

**LIQUID LIMIT**

The liquid limits of Marine clay and optimum percentage of Steel Slag i.e. (13%) by dry weight mixed with the Marine clay were determined as per IS: 2720 (part-5)-1985.

Liquid limit is the moisture content at which 25 blows in standard liquid limit apparatus will just close a groove of standard dimensions cut in the sample by the grooving tool by specified amount. The flow curve is plotted in the log-scale on the x-axis, and the water content in the arithmetic scale on y-axis. The flow curve is straight line drawn on the semi-logarithmic plot, a nearly as possible through three or more plotted points. The moisture content corresponding to 25 blows is read from this curve rounded off to the nearest whole number and is reported as the liquid limit of the soil.

**PLASTIC LIMIT**

The Plastic Limits of Marine clayand optimum percentage of Steel Slag i.e. (13%) by dry weight mixed with the Marine clay were determined as per IS: 2720 (part-6)-1972.

Plastic limit is the moisture content at which a soil when rolled into thread of smallest diameter possible, starts crumbling and has a diameter of 3mm.

The Plastic limit ($w_p$) is expressed as a whole number by obtaining the mean of the moisture contents of the plastic limit.

**COMPACTION TEST**

From the compaction test, the maximum dry density (MDD) and Optimum Moisture Content (OMC) of the Marine Clay are found for the selected type and amount of compaction. Indian standard codes of practice I.S:2720 (Part VIII – 1983). The compaction test is carried out at different proportion of Steel Slag % (10%, 13%, 15%, 18%, and 20%) and corresponding MDD and OMC is figured out from the graph.

The weight of mould with moist compacted soil is W gm.
Weight of empty mould = $W_m$gm.
Volume of mould = $V_m$ cc

Wet density,
$$\gamma_m = \frac{(w - w_m)}{v_m} g/cc$$

Let the moisture content be = w %
Then dry density,

$$\gamma_d = \frac{\gamma_m}{\left(1 + \frac{w}{100}\right)} = \frac{(w - w_m)}{v_m\left(1 + \frac{w}{100}\right)} g/cc$$

- The OMC of the soil indicated the particular moisture content at which the soil should be compacted to achieve maximum dry density. If the compacting effort applied is less, the OMC increases and the value can again be found experimentally or estimated.
- In field compaction, the compacting moisture content is first controlled at OMC and the adequacy of rolling or compaction is controlled by checking the dry density achieved and comparing with the maximum dry density. Thus compaction test results (OMC and maximum dry density) are used in the field control test in the compaction projects.
- Compaction, in general in considered most useful in the preparation of sub grade and other pavement layers and in construction of embankments in order to increase the stability and to decrease settlement. There is also a soil classification method based on the maximum dry density in the standard (proctor compaction test lower values indicating weaker soil).

**FREE SWELL (FS)**

To determine the free swell index of soil as per **IS: 2720 (Part XL) – 1977**. Free swell or differential free swell, also termed as free swell index, and is the increase in volume of soil without any external constraint when subjected to submergence in water.

**Free swell index = $\{[V_d - V_k] / V_k\} \times 100\%$**

Where,

$V_d$ = volume of soil specimen read from the graduated cylinder containing distilled water.
$V_k$ = volume of soil specimen read from the graduated cylinder containing kerosene.

**STRENGTH TESTS**

***CBR TEST***

The CBR is a measure of shearing resistance of the material under controlled density and moisture conditions. The load-penetration curve for each specimen is plotted on natural scale. The load values at 2.5 mm and 5.0 mm are obtained from the load penetration curve to compute CBR values using the following equation.

**CBR (%) =**

$$\frac{\text{Load carried by soil sample at defined penetration level}}{\text{Load carried by standard crushed stones at the same penetration level}} X100$$

Based on extensive CBR test data collected, empirical design charts were developed by the California State Highway Department, correlating the CBR value and flexible pavement thickness requirement. For various traffic volumes different design thickness curves are available.

The California bearing ratio tests (as per IS: 2720 (part-16)-1979) were conducted on all the combinations listed in table, at the end of the curing period (all the samples were soaked for 4 days).

Samples were prepared by compacting different mixes to the maximum dry density of the soil. The initial moisture content for these samples was maintained at optimum moisture content of the soil. The amount of Steel Slag to be added to the amount of water was arrived at based on the optimum moisture content of the natural soil and the Steel Slag prepared. This Steel Slag was added to the air dry soil and the mixture was thoroughly mixed.

**TRI-AXIAL TEST**

Shear tests are generally carried out on small samples in the laboratory to evaluate the strength properties of the element in the soil mass. The strength parameters, namely the cohesion and angle of shearing resistance are usually found from these tests.

The tri axial test specimen is subjected to the all-round pressure equal to the lateral pressure, $\sigma_3$ and the applied vertical stress or deviator stress $\sigma_d$ such that the total vertical stress is $\sigma_1 = \sigma_d + \sigma_3$. Mohr stress circles are plotted at normal stress intercepts $\sigma_3$ and $\sigma_1$ or with diameters equal to deviator stresses. From the Mohr's envelope, the cohesion C and the angle of internal friction φ of the soil can be derived.

- The shear strength parameters c and φ of the materials may be used to find the shearing resistance of the material, using Coulomb's equation.

**$S = c + \sigma \tan\phi$**

- In flexible pavement design, the E value of sub grade soils is to be found from triaxial test.
- Triaxial test is used in the design of bituminous mixes.

Samples were prepared by compacting different mixes to the maximum dry density of the soil. The initial moisture content for these samples was maintained at optimum moisture content of the soil. The amount of Steel Slag to be added to the amount of water was arrived at based on the optimum moisture content of the natural soil and the Steel Slag was prepared. This solution was added to the dry soil and the mixture was thoroughly mixed.

**Soil Samples for Conducting Tri axial Compression Test**

**Plate 3.6 Tri axial Test**

**SPECIFIC GRAVITY TEST**

Specific gravity of solid particles (G) is defined as the ratio of the mass of a given volume of solids to the mass of an equal volume of water at 4°C.

The specific gravity of solid particles can be determined in a laboratory using a density bottle fitted with a stopper. The mass of bottle, including that of stopper, is taken. About 20g of oven dry sample of soil is taken in bottle and weighed. Distilled water is then added to cover the sample. The soil is allowed to soak. More water is added until the bottle is half full. Air entrapped in the soil is expelled by applying a vacuum pressure in vacuum desiccators. More water is added to the bottle to make it full. The stopper is inserted and the mass is taken. The bottle is emptied, washed and then refilled with distilled water. The bottle must be filled to the same mark as in the previous case. The mass of water filled with water is taken.

$G = (M_2-M_1)/ [(M_2-M_1) – (M_3-M_4)]$

Where

$M_1$=Mass of Empty bottle
$M_2$=Mass of bottle and dry soil
$M_3$=Mass of bottle, soil and water
$M_4$=Mass of bottle filled with water

## IV. RESULTS

### LABORATORY TEST RESULTS

To find the optimum percentage of Steel Slag with Marine Clay, CBR tests were conducted by using different proportions of soil and Steel Slag.

**Modified Proctor Compaction and CBR Test Results of untreated Marine Clay and Marine Clay treated with Steel Slag**

**Modified Proctor Compaction Test Results**

Many modified proctor compaction tests were conducted to obtain the OMC and MDD values of Marine Clay and also Marine Clay treated with % variation ofSteel Slag.

**Optimum Moisture Content and Maximum Dry Density of Untreated Marine Clay**

Table 4.1 and Fig 4.1 present the optimum moisture content and maximum dry density of the air dried untreated Marine Clay.

**Table 4.1 Optimum Moisture Content and Maximum Dry Density of Untreated Marine Clay**

| S .No | Water Content (%) | Dry Density(g/cc) |
|---|---|---|
| 1. | 20.12 | 0.9 |
| 2. | 24.63 | 1.19 |
| 3. | **28.45** | **1.32** |
| 4. | 31.85 | 1.24 |
| 5. | 34.19 | 1.05 |

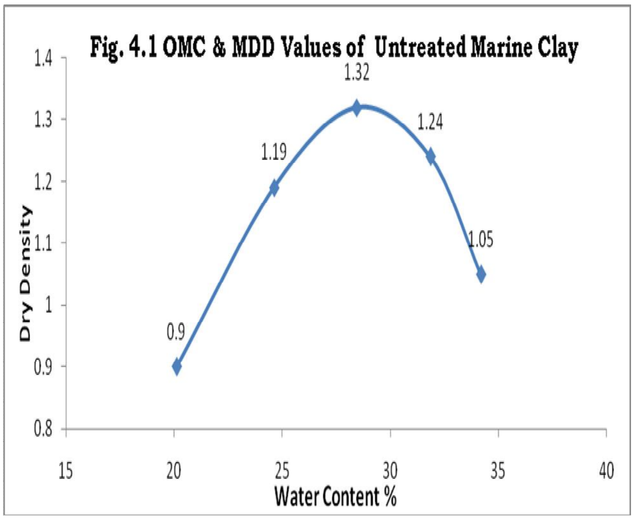


**Fig. 4.1 OMC & MDD Values of Untreated Marine Clay**

Optimum Moisture Content = 28.45%
Maximum Dry Density = 1.32 gm/cc

**Optimum Moisture Content and Maximum Dry Density of Marine Clay Treated with 10% Steel Slag**

Table 4.2 and Fig 4.2 present the optimum moisture content and maximum dry density of Marine Clay treated with 10% Steel Slag.

**Table 4.2 OMC & MDD values of Marine Clay Treated with 10%Steel Slag**

| S.No | Water Content (%) | Dry Density(g/cc) |
|---|---|---|
| | 13.046 | 1.521 |
| 1 | 17.58 | 1.62 |
| 2 | **21.383** | **1.67** |
| 3 | 25.585 | 1.625 |
| 4 | 32.173 | 1.514 |

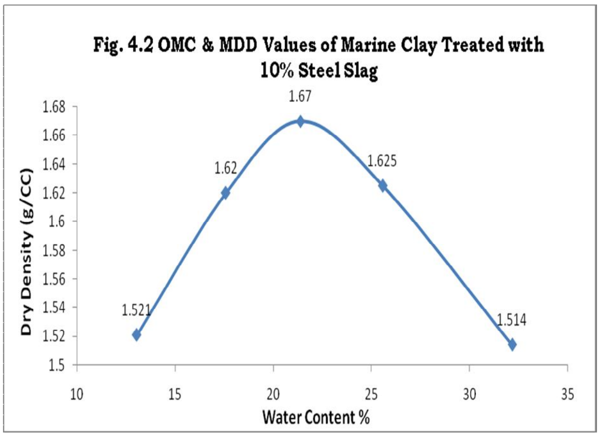


**Fig. 4.2 OMC & MDD Values of Marine Clay Treated with 10% Steel Slag**

Optimum Moisture Content = 21.38%
Maximum Dry Density = 1.67 gm/cc

**Optimum Moisture Content and Maximum Dry Density of Marine Clay treated with 11% of Steel Slag**

Table 4.3 and Fig 4.3 present the optimum moisture content and maximum dry density of Marine Clay treated with 11% of Steel Slag

**Table 4.3 OMC & MDD values of Marine Clay treated with 11% Steel Slag**

| S.No | Water Content (%) | Dry Density(g/cc) |
|---|---|---|
| 1 | 14.84 | 1.636 |
| 2 | 16.89 | 1.657 |
| 3 | **20.423** | **1.682** |
| 4 | 24.68 | 1.654 |
| 5 | 26.85 | 1.634 |

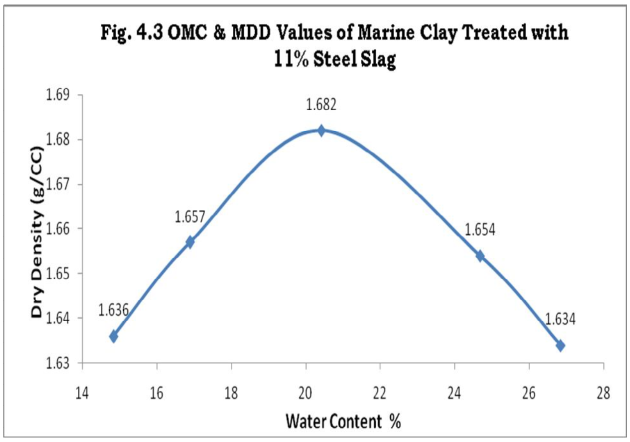



**Fig. 4.3 OMC & MDD Values of Marine Clay Treated with 11% Steel Slag**

Optimum Moisture Content = 20.423%
Maximum Dry Density = 1.682 gm/cc

**Optimum Moisture Content and Maximum Dry Density of Marine Clay Treated with 13% Steel Slag**

Table 4.4 and Fig 4.4 present the optimum moisture content and maximum dry density values of treated Marine Clay with 13% Steel Slag

**Table 4.4 OMC & MDD values of Marine Clay treated with 13% Steel Slag**

| Sl. No | Water Content (%) | Dry Density(g/cc) |
|---|---|---|
| 1. | 18.02 | 1.624 |
| 2. | 18.542 | 1.658 |
| 3. | **19.352** | **1.699** |
| 4. | 20.08 | 1.648 |
| 5. | 20.49 | 1.622 |

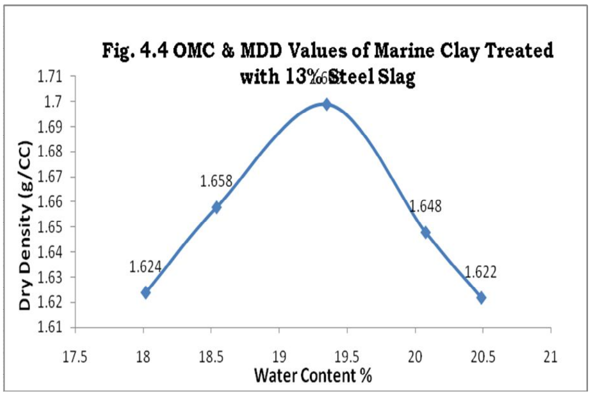



**Fig. 4.4 OMC & MDD Values of Marine Clay Treated with 13% Steel Slag**

Optimum Moisture Content = 19.352%
Maximum Dry Density = 1.699 gm/cc

**Optimum Moisture Content and Maximum Dry Density of Marine Clay Treated with 14% Steel Slag**

Table 4.5 and Fig 4.5 present the optimum moisture content and maximum dry density values of treated Marine Clay with 14% Steel Slag.

**Table 4.4 OMC & MDD values of Marine Clay Treated with 14% Steel Slag**

| S. No | Water Content (%) | Dry Density(g/cc) |
|---|---|---|
| 1. | 18.12 | 1.594 |
| 2. | 20.87 | 1.643 |
| 3. | **23.56** | **1.689** |
| 4. | 25.73 | 1.652 |
| 5. | 28.02 | 1.598 |

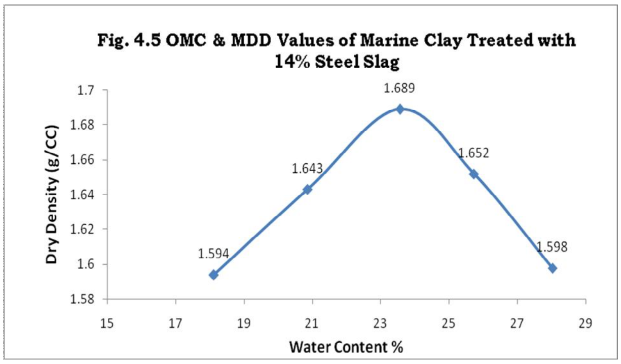



**Fig. 4.5 OMC & MDD Values of Marine Clay Treated with 14% Steel Slag**

Optimum Moisture Content = 23.56%
Maximum Dry Density = 1.689gm/cc

**Optimum Moisture Content and Maximum Dry Density of Marine Clay Treated with 15% Steel Slag**

Table 4.6 and Fig 4.6 present the optimum moisture content and maximum dry density values of Marine Clay treated with 15% Steel Slag.

**Table 4.6 OMC & MDD values of Marine Clay treated with 15% Steel Slag**

| S. No | Water Content (%) | Dry Density(g/cc) |
|---|---|---|
| 1. | 22.68 | 1.579 |
| 2. | 24.34 | 1.632 |
| 3. | **26.308** | **1.675** |
| 4. | 27.96 | 1.628 |
| 5. | 29.08 | 1.567 |

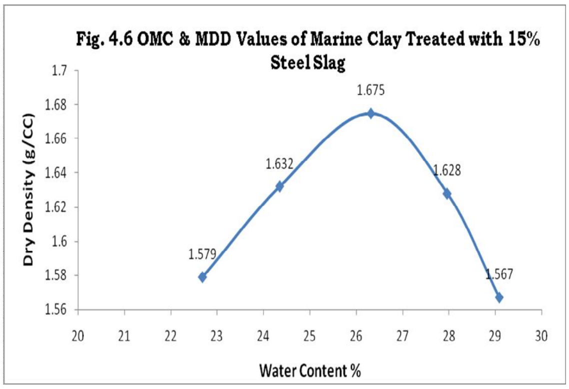



**Fig. 4.6 OMC & MDD Values of Marine Clay Treated with 15% Steel Slag**

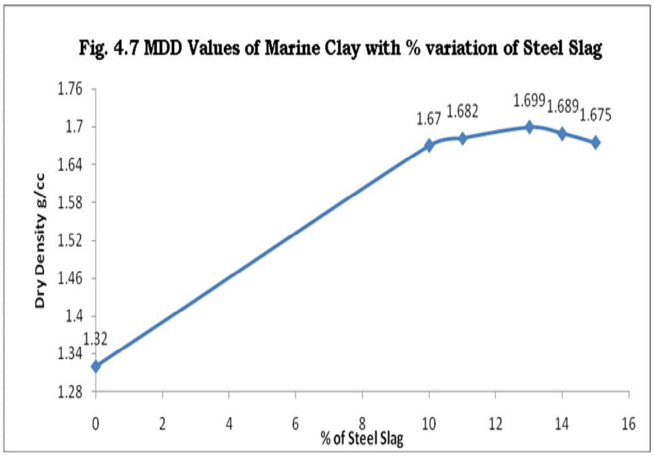
Optimum Moisture Content = 26.308%
Maximum Dry Density = 1.675gm/cc

**Optimum Moisture Content and Maximum Dry Density of marine clay treated with % variation of Steel Slag**

Table 4.7 and Fig 4.7 show the optimum moisture content and maximum dry density values of marine clay treated with % variation of Steel Slag.

**Table 4.7 Optimum moisture content and Maximum Dry Density values of Marine Clays Treated with % variation of Steel Slag**

| Mix proportion | OMC (%) | MDD (gm/cc) |
|---|---|---|
| Only MC | 28.45 | 1.32 |
| MC+10%SS | 21.383 | 1.67 |
| MC+11%SS | 20.423 | 1.682 |
| **MC+13%SS** | **19.352** | **1.699** |
| MC+14%SS | 23.56 | 1.689 |
| MC+15%SS | 26.308 | 1.675 |

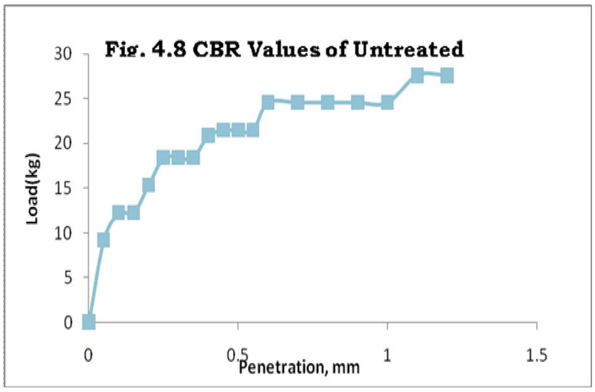



**CBR TEST RESULTS OF UNTREATED AND TREATED MARINE CLAY WITH % VARIATION STEEL SLAG**

The CBR values of untreated Marine Clay and Marine Clay treated with % variation of Steel Slag were determined, using OMC& MDD values obtained from IS modified compaction test.

**CBR Values of Untreated Marine Clay**

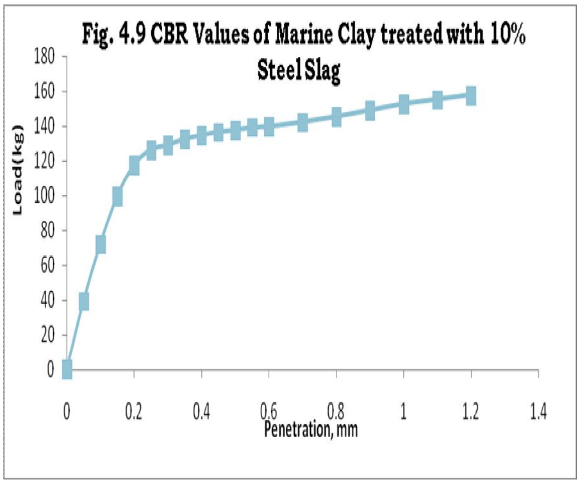
CBR values of untreated marine clay were present in Fig 4.8.




Soaked CBR = 1.12%

**CBR Value of Marine Clay Treated with 10% of Steel Slag**

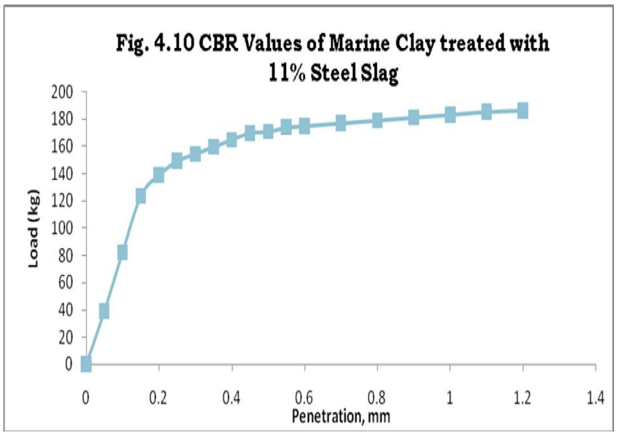
CBR values of marine clay treated with 10% Steel Slag were presented in Fig 4.9




CBR = 9.346%

**CBR Values of Marine Clay Treated with 11% Steel Slag**

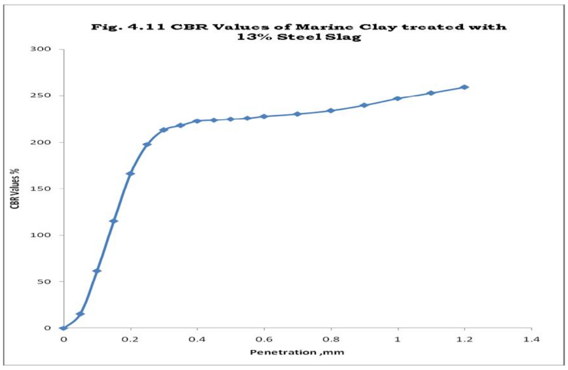
CBR values of Marine Clay Treated with 11% Steel Slagwere presented in Fig 4.10




CBR = 10.901%

**CBR Value of Marine Clay Treated with 13% Steel Slag**

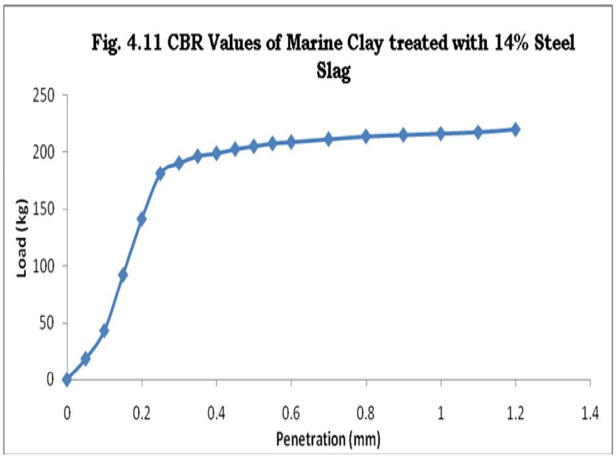
Fig. 4.11 present the CBR values of Marine Clay treated with 13% Steel Slag




CBR = 14.435%

**CBR Value Marine Clay Treated with 14% Steel Slag**

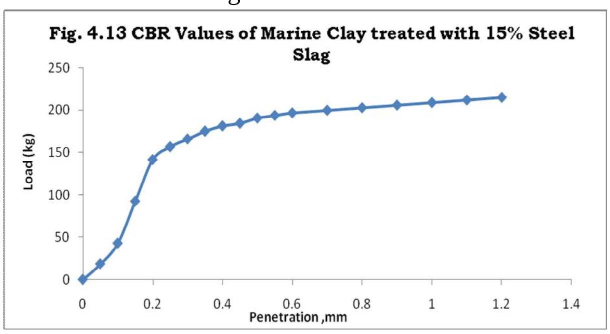
CBR values of Marine Clay treated with 14% Steel Slag were presented in Fig 4.12




CBR = 13.221%

**CBR Value of Marine Clay Treated with15% Steel Slag**

Fig. 4.13 present the CBR values of Marine Clay treated with 15% Steel Slag



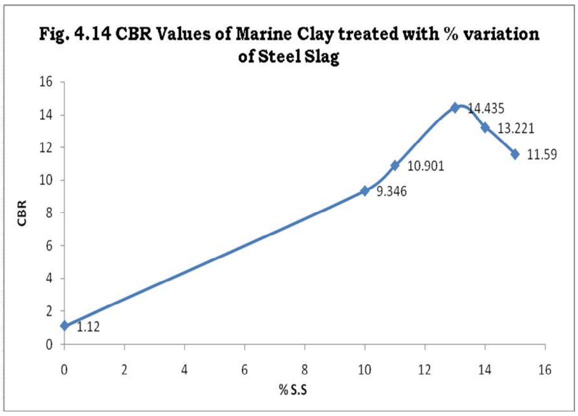

CBR = 11.59%

**CBR Values of Untreated and Treated Marine Clay with % variation of Steel Slag.**

Table 4.8 present the CBR values of Marine Clay treated with different percentages of Steel Slag.

**Table 4.8 CBR Values of Marine Clay treated with % Variation of Steel Slag**

| Sl. No | Mix proportion | Soaked CBR |
|---|---|---|
| 1 | 100% soil | 1.120 |
| 3 | MC + 10%SS | 9.346 |
| 4 | MC + 11%SS | 10.901 |
| **5** | **MC + 13%SS** | **14.435** |
| 6 | MC + 14%SS | 13.221 |
| 7 | MC + 15%SS | 11.590 |




**PHYSICAL PROPERTIES OF UNTREATED MARINE CLAY AND MARINE CLAY TREATED WITH AN OPTIMUM OF 13% STEEL SLAG**

Table 4.9 present the properties of untreated Marine Clay and Marine Clay treated with an optimum of 13% Steel Slag.

**Table 4.9: Properties of Untreated Marine Clay and Marine Clay treated with an optimum of13% Steel Slag**

| S.No. | Property | Untreated Marine Clay | Treated M.C+13%S.S |
|---|---|---|---|
| 1 | Liquid Limit (%) | 70.7 | 57.75 |
| 2 | Plastic Limit (%) | 32.92 | 22.01 |
| 3 | Plastic Index (%) | 37.78 | 35.74 |
| 4 | Soil Classification | CH | CH |
| 5 | Specific Gravity | 2.53 | 2.55 |
| 6 | Optimum Moisture Content (%) | 28.45 | 19.355 |
| 7 | Maximum Dry Density (g/cc) | 1.32 | 1.699 |
| 8 | Cohesion (t/m²) | 2.7 | 2.6 |
| 9 | Angle of Internal Friction (°) | 3 | 4°30' |
| 10 | CBR Value (soaked) (%) | 1.12 | 14.435 |

## V. CONCLUSION

Conclusions of the various laboratory test results were presented.

i. It is noticed from the laboratory test results that the liquid limit of the marine clay has on decreased by 18.31% on addition of 13% steel slag when compared with untreated marine clay.
ii. It is observed that the plasticity index of the marine clay has been decreased by 5.4% on addition of 13% steel slag when compared with untreated marine clay.
iii. It is observed that the C.B.R. value of the marine clay has been increased by 92.24% on addition of 13% steel slag when compared with untreated marine clay.

## VI. ACKNOWLEDGMENT

This is an acknowledgement of the intensive drive and technical competence of many individuals who have contributed to the success of my thesis.

I am thankful to all other esteemed faculty of the Department, for helping me to get relevant information.

I also thankful to supporting staff of soil mechanics laboratory for their cooperation during my research work.

I am thankful to my Family members and my friends for their continuous encouragement to complete the course.

Finally, I acknowledge all those who have helped me directly or indirectly for the completion of this dissertation work.

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