A Laboratory Study on The Influence of Steel Slag on Improving The Properties of Marine Clay As Subgrade Under Cyclic Pressures For Flexible Pavements

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Abstract- *India being a peninsular country has large area coming under coastal region and also it has been the habitat for considerable percentage of population. 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.*

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.

The present study deals with the engineering properties of the Marine Clay collected from Kakinada Sea Port Ltd, Kakinada, A.P., India. The Physical and Chemical properties, the strength characteristics and also the load carrying capacity of the Marine Clay have been determined in this study before after stabilization with Steel Slag.

Keywords- Steel slag, Marine clay, Stabilization.

I. INTRODUCTION

Marine clays are soft and highly deformable deposits found along the coastal areas having low shear strength and high compressibility. These 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.

Marine clays suffer from the problems like high saturation, low density, low shear strength and deformation, normally consolidated and have specific physic-chemical make-up which under-go volume changes with the environment accordingly.

During Monsoon high shrinkage and swelling nature of the Marine clay soils changes its density. Shrinkage is due to evaporation of water in summer and becomes hard as density increases. The said nature of soil decreases with increase in depth. The volumetric deformation in these soils is attained due to seasonal variations in the ground water profile resulting in moisture content changes.

In summer, polygonal shrinkage cracks occurs near the surface till 1.5 m depth, indicating a high potential for compressibility. The depth of cracking indicates the depth of active zone in which significant volume change occurs where moisture deficiency exists.

Continuous efforts are being made all over the world to overcome 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.

In this work an attempt is made to study the effect of STEEL SLAG in enhancing the properties of Marine clay.

II. REVIEW OF LITERATURE

The sediments laid down by rivers, sea or lakes are called soft clays. These deposits are characterized by bedding and laminations and are usually subject to repeated desiccation and wetting near the surface. The environments in which soft clays exist are as follows:

- Near the sea coasts of low land areas
- Near the rivers, particularly those which have been subjected to meandering.
- In local depression where the runoff is restricted and the soil contains appreciable amount of organic matter.

The fraction of solid particles whose size is smaller than 2 μm is referred to as clay, and according to Norwegian practice, when the fraction of clay particles in a soil is greater than 30% of the total weight, then the soil is classified as clay. The term clay refers both a size of soil particles and a category of minerals. Though clay constitutes the smaller fraction of solid particles of a soil, but its small presence also significantly influences the soil's behavior.

One of the most protruding distinctions between the clay minerals and non-clay minerals is that the former are generally platy, or in few cases needle-shaped, whereas the latter are usually bulky. Additionally, the clay minerals have a negative net electrical charge and they possess high weathering resistance interact with water. The most common clay minerals are kaolinite, illite, smectite and chlorite.

2.1 Behavior of Marine Clays

The Marine clays are highly compressible soft clays and also exhibit moderate swelling when they interact with moisture. This nature is due to the presence of clay minerals with expanding lattice structure. WhenMarine clay is dry it is too hard but sheds its strength on damping.

Plate 2.1 Showing Cracks in Marine clay on Drying

2.2 Geo-Technical Characteristics of Marine Clay

Soft clays are highly plastic fine grained soils with moderate to high clay fraction. They are characterized by high compressibility and low shear strength(Generally less than 25 kPa) .They has following typical characteristics-

i) Predominantly fined grained i.e. more than 50% of soil passing through 75μ IS sieve
ii) High liquid limit (W_L) & plastic limit (W_p) values
iii) High natural Water Content (NMC) and even higher than the liquid limit.
iv) Low material permeability but the overall permeability can be more
v) Low shear strength which usually varies with depth. Based on the values of undrained strength, soft soil are classified into two categories-
   Undrained strength less than 12 kParepresents the very soft soil.
   Undrained strength less than 25 kPa represents the soft soil.
vi) Highly compressible, organic content increases the compressibility.

2.3 PROBLEMS ASSOCIATED WITH MARINE CLAYS

2.3.1 General

The damages caused by Marine soils inPavements and in foundation beds are discussed below:

2.3.2 Damages to the Pavement Sub Grades

MostlyPavement failures are due to the poor sub grade conditions and Marine clay is one among them. Pavements along Marine clay regions are subjected to intense unevenness. General problems sighted are longitudinal cracks, rutting of Pavement surface, and localized failure of Pavement associated with disintegration of the surface. Brief explanation about those damages is discussed below. Due to the nature of high compressibility of the Marine clay soils even railway tracks are affected by their movement.

2.3.2.1 Rutting

Rutting is generally due to the consolidation of Pavement layers and also due to continuous repeated application of wheel load along the same path which results in the deformation of Pavements. The deformation in sub-grade or subsequent layers depends on the width and depth of ruts.

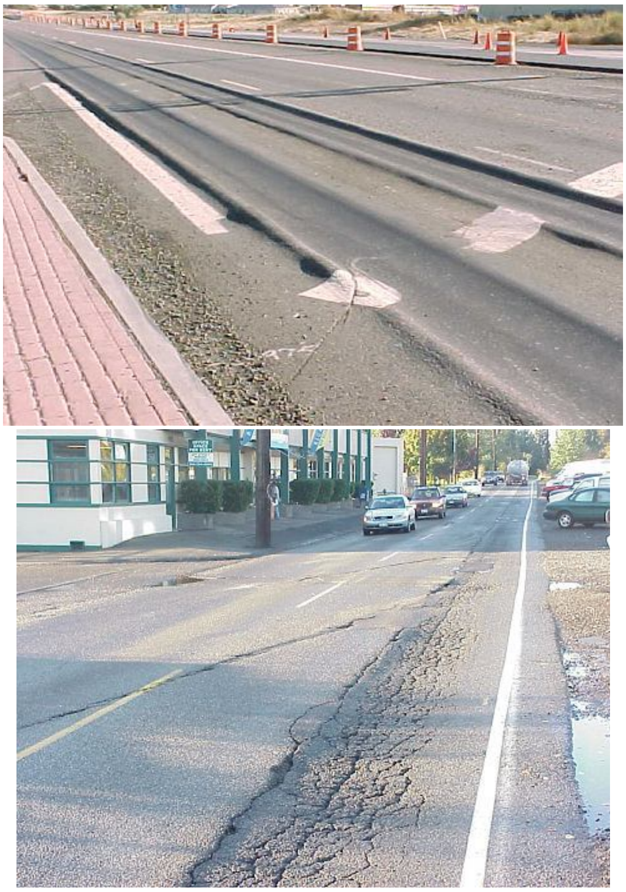

Plate 2.2 Rutting on Pavement of Subgrade

2.3.2.2 Longitudinal Cracks

Longitudinal cracking occurs parallel to Pavementcenterline which is due to differential volume changes in soils, these characteristics of the Marine soils results in cracking throughout the full Pavement thickness.

Plate 2.3 Failure Crack

2.4 Damages to Building Foundations

A clay soil shrinks and expands depending on the climatic variations. In summer, where rainfall is reduced and evaporation increased due to temperature increase. In winter, volume of soil raise as rainfall increases and evaporation decreases. These natural processes are called seasonal fluctuations.

Plate 2.4 Settlement Cracks in SuperStructure Lay on Marine Clay Foundation Bed

Damage occurs in buildings through the distortion of its structure; these are generally due to foundation movement. The 2 main actions of soil movement which results in building damage are subsidence and heave. In simple terms, contraction of the soil is subsidence and expansion of the soil is termed as heave.

If the entire building structure moves together then damage is unlikely to occur. In such cases damage generally occurs when only a section of foundation deflects and the remaining section stayscyclic. This results in a distortion of the structure which results in damages like cracks in walls.

III. SOIL STABILIZATION

The soil stabilization means the improvement of stability or bearing power of the soil by the use of controlled compaction, proportioning or the addition of suitable admixture or stabilizers.

Mechanical stabilization:

This method involves the correctly proportioning of aggregates and soil, adequately compacted to get mechanically stable layer. The basic Principles of mechanical Stabilization are correct proportioning and effective compaction.

Soil Cement Stabilization: Soil-cement is an intimate mix of soil, cement & water, compacted to form a strong base course. Cement modified soil refers to the compacted mix when cement is used in small proportions to impart some strength.

Soil Lime Stabilization: Soil-Lime is used as modifier in high plasticity soils in lime stabilization. It also imparts binding action even granular soils. Lime could be used in powder form or pulverized form with soil to make a homogenous blend.

Soil Bituminous Stabilization: The basic Principles of this Stabilization are water proofing and binding. By water proofing inherent strength and other properties could be retained. Bitumen stabilized layer may be used as Sub-base or base course for all the roads. Most commonly used materials are Cutback and Emulsion.

Thermal Stabilization: Thermal change causes a marked improvement in the properties of the soil. Thermal stabilization is done by heating the soil or cooling.

Chemical Stabilization:

Soils are stabilized by different chemicals. The advantage of chemical stabilization is that setting time and curing time can be controlled.

3.1 MATERIALS USED AND THEIR PROPERTIES

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

3.1.1 Soil

The Marine clay usedin this study is typical soft clay collected at a depth of 0.5m to 1.0m from ground level in Kakinada Sea Ports limited, Kakinada, Andhra Pradesh, India. The properties of soil are presented in the Table 3.1. All the tests carried on soil as per IS specifications.

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Table 3.1 Properties of Untreated Marine Clay

S.No.	PROPERTY	VALUE
1.	**GRAIN SIZE DISTRIBUTION**	
	Sand (%)	10
	Silt (%)	25
	Clay (%)	65
2.	**ATTERBERG LIMITS**	
	Liquid limit (%)	68.92
	Plastic limit (%)	31.68
	Plasticity index (%)	37.24
3.	**COMPACTION PROPERTIES**	
	Optimum moisture content, O.M.C.(%)	27.65
	Maximum Dry Density, M.D.D. (g/cc)	1.331
4.	**Shear strength parameters**	
	Cohesion (C) (t/m²)	11.40
	Angle of internal friction(Ø) (⁰)	2
5.	Specific gravity(G)	2.41
6.	IS classification	CH
7.	C.B.R. (%)	1.32
8.	Free Swell(%)	76

3.1.2 STEEL SLAG

Steel slag is a by-product obtained when pig iron and steel are produced. 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. During refining process to control the carbon content fluxing agents are added. Lime and fluorite are the main fluxing agents used.

Plate 3.1 Steel Slag

Ground Granulated Blast Furnace Slag (GGBS) is a byproduct of the steel industry. Blast furnace slag is defined as "the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace." In the production of iron, blast furnaces are loaded with iron ore, fluxing agents, and coke. When the iron ore, which is made up of iron oxides, silica, and alumina, comes together with the fluxing agents, molten slag and iron are produced. The molten slag then goes through a particular process depending on what type of slag it will become. Air cooled slag has a rough finish and larger surface area when compared to aggregates of that volume which allows it to bind well with portland cements as well as asphalt mixtures. GGBS is produced when molten slag is quenched rapidly using water jets.

Table 3.2 Physical Properties of Steel Slag

S. N	Property	Value
1	Specific Gravity	2.196
2	**Particle size distribution**	
	Gravel (%)	0
	Sand (%)	92
	Silt (%)	5
	Clay (%)	3
3	**Compaction Properties**	
	Maximum Dry Density (g/cc)	1.92
	Optimum Moisture Content (%)	17.86
4	**Atterberg Limits**	
	Liquid limit (%)	33.86
	Plastic Limit (%)	NP
5	CBR (%)	30.72
6	Cohesion (t/m^2)	1.40
7	Angle of Internal friction (ø)(°)	37

3.2 LABORATORY EXPERIMENTATION

Tests were conducted in the laboratory on the untreated Marine clay to study the behavior of Marine clay, when it is treated with Steel Slag. All tests were conducted as per IS code of practice**.**

TESTS CONDUCTED

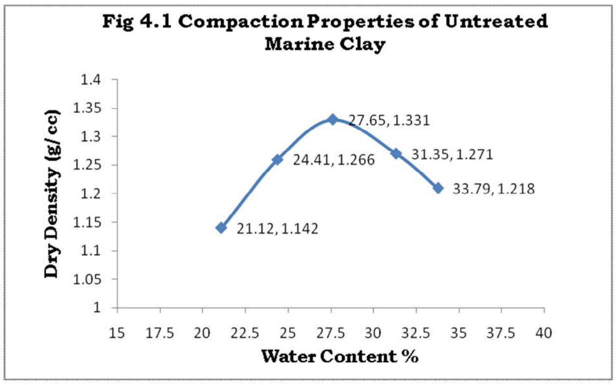
1. DFSI
2. ATTERBERG LIMITS
3. COMPACTION
4. CBR
5. PLATE LOAD TEST

IV. RESULTS AND DISCUSSIONS

In the laboratory, index tests, swell tests and strength tests were conducted by using different percentages of Steel Slag with a view to determine the optimum percentages of Steel Slag. The cyclic plate load tests were conducted on different model foundation beds. The effect of Steel Slag to the Marine clay, on compaction, CBR properties, Atterberg limits, swell properties and strength properties were discussed in detail in the following sections

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

Fig 4.1 Compaction properties of untreated Marine Clay



Optimum Moisture Content = 27.65%
Maximum Dry Density = 1.331gm/cc

Fig 4.2 MDD Values of Marine Clay with % Variation of Steel Slag

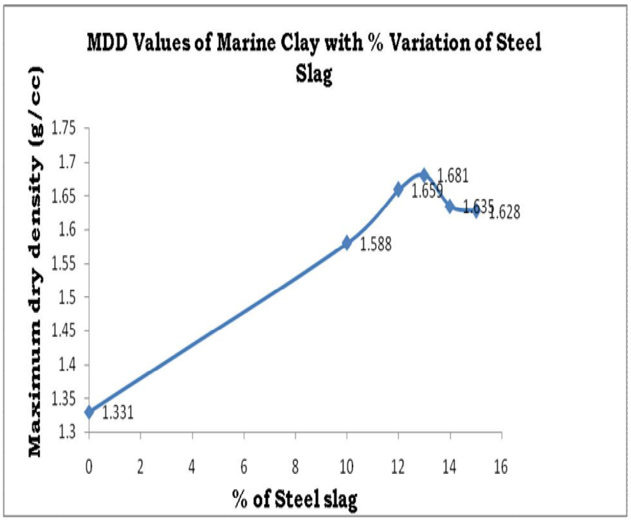
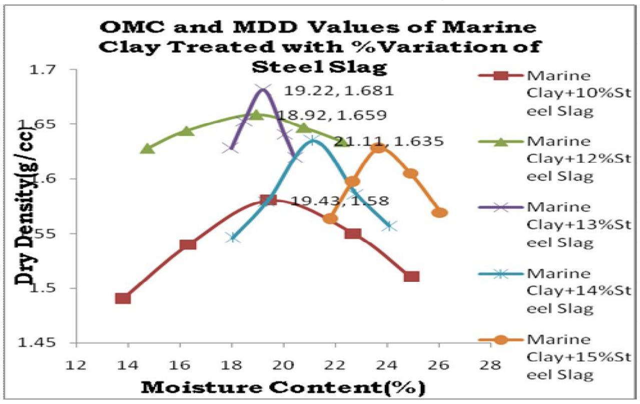


Fig 4.3 OMC and MDD Values of Marine Clay Treated with %Variation of Steel Slag



4.2 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.

Fig 4.4 CBR Values of Untreated Marine Clay

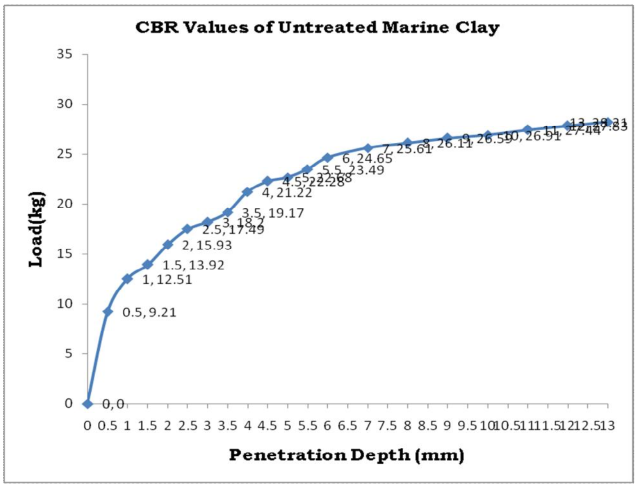
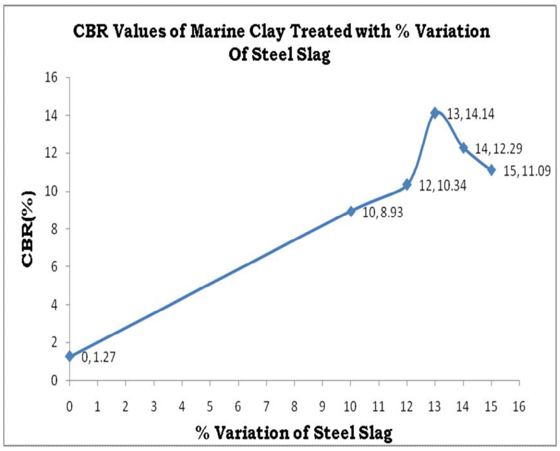


Table4.1: CBR Values of Untreated and Treated Marine Clay with % variation of Steel Slag.

S.N	Mix proportion	CBR(%)
1	Untreated Marine Clay	1.27
2	Marine Clay + 10% Steel Slag	8.93
3	Marine Clay + 12% Steel Slag	10.34
4	**Marine Clay + 13% Steel Slag**	**14.14**
5	Marine Clay + 14% Steel Slag	12.29
6	Marine Clay + 15% Steel Slag	11.09

Fig 4.5 CBR Values of Marine Clay Treated with % Variation of Steel Slag



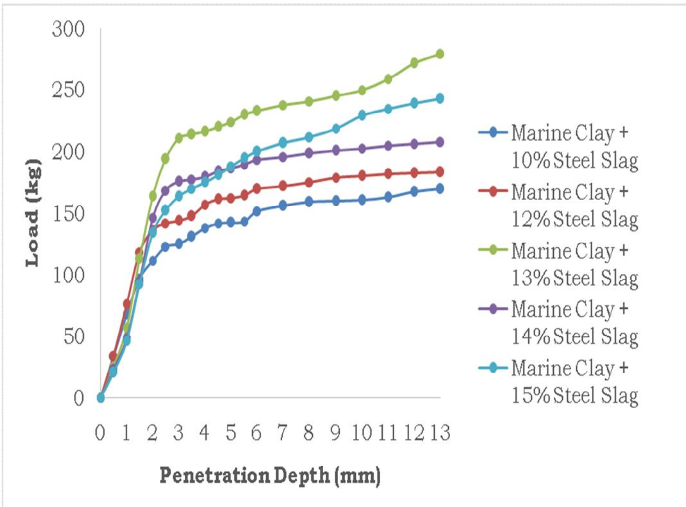


Table 4.2: Properties of Untreated Marine Clay and Marine Clay treated with an optimum of13% Steel Slag

S.No	Property	Untreated Marine Clay	M.C+13%S.S
1	Liquid Limit (%)	68.92	55.74
2	Plastic Limit (%)	31.68	33.26
3	Plastic Index (%)	37.24	22.48
4	Soil Classification	CH	CH
5	Specific Gravity	2.41	2.44
6	Optimum Moisture Content (%)	27.65	19.22
7	Maximum Dry Density (g/cc)	1.331	1.681
8	Cohesion (t/m^2)	11.40	10.70
9	Angle of Internal Friction (^{0})	2	3°30'
10	CBR Value (%)	1.27	14.14

Discussion:

1. CBR value of Marine Clay on stabilizing with steel slag is found to be 14.14%.
2. According to the IRC: 37-2001, the CBR value of the subgrade soil should be in between 6-7%. In the present study, the CBR value of the treated Marine Clay is 14.14%. Hence 13% steel slag treated Marine Clay is suitable as subgrade for flexible pavements.

4.3 A STUDY ON LABORATORY CYCLIC PLATE LOAD TESTS ON UNTREATEDMARINE CLAY AND MARINE CLAY TREATED WITH AN OPTIMUM OF 13% STEEL SLAG USING MODEL TANKS

Laboratory cyclic plate load tests were conducted on only Marine Clay, Marine Clay as sub-grade with Gravel cushion and also treated Marine Clay as sub-grade with Gravel cushion as Flexible Pavement. The tests were conducted until the failure of the Flexible Pavement sub-grade at OMC condition

Fig 4.6 Laboratory Cyclic Plate Load Test Results of Untreated Marine Clay at OMC

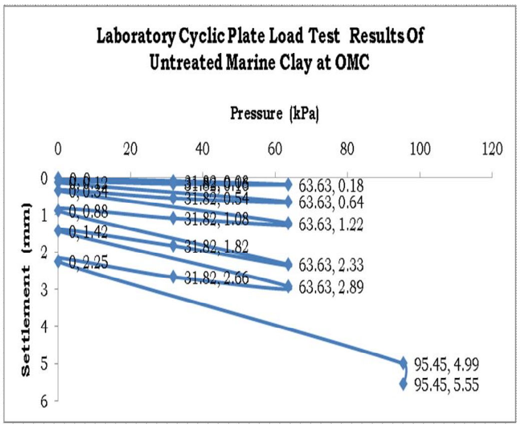


Fig 4.7 Laboratory Cyclic Plate Load Test Results of Untreated Marine Clay Model Flexible Pavement at OMC

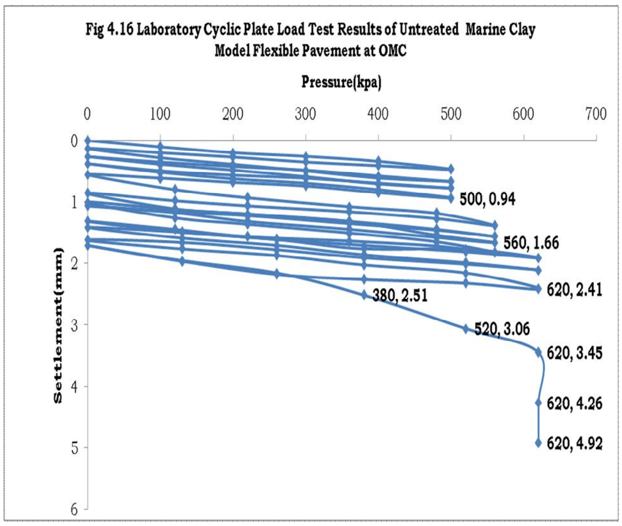


Table 4.3 Laboratory Cyclic Plate Load Test Results of Untreated and treated Marine Clay Flexible Pavements at Optimum Moisture Content

S. No	Type of Sub-grade	Sub-base	Base Course	Pressure (kPa)	Settlement (mm)
1	Marine Clay	----	----	63.63	2.89
2	Untreated Marine Clay	Gravel	WBM - III	630	2.41
3	Marine Clay + 13% Steel Slag	Gravel	WBM - III	1400	2.39
4	Marine Clay + 13%Steel Slagand Geotextile provided as reinforcement & separator	Gravel	WBM - III	2200	1.57

V. CONCLUSIONS

Conclusions of the various laboratory test results were presented. It is observedfrom the laboratory test results that the liquid limit of the Marine clay has decreased by 19.12% with the addition of 13% steel slag when compared with untreated Marine clay.

i) It is noticed that the plasticity index of the Marine clay has been decreased by 7.43% with addition of 13% steel slag when compared with untreated Marine clay.
ii) It is observed from the results that the C.B.R. value of the Marine clay has been increased by 1013.70% on addition of 13% steel slag when compared with untreated Marine clay.
iii) It is noticed that from laboratory cyclic plate load test results that the load carrying capacity of the treated Marine Clay sub-gradeFlexible Pavement has been improved by 249.20% when compared with the untreated Marine Clay Flexible Pavement.
iv) It is observed from the laboratory results that the total deformations at ultimate load carrying capacity of the treated Marine Clay model Flexible Pavement has been decreased by 34.85% at OMC, when compared with the untreated Marine Clay model Flexible Pavement.
v) It is noticed in case of the cyclic plate load test highest reduction in the values of total deformation was observed for the treated Marine Clay Flexible Pavement with 13% Steel Slag and geo-textile as separator and reinforcement at OMC.

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