A Comparative study of different Fibre Inclusions in the Strength Improvement of Treated Marine Clays

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Abstract- *India being peninsular country has large area coming under coastal region and also it has been the habitat for considerable percentage of population. The marine clays are generally found in the states of West Bengal, Orissa, Andhra Pradesh, Tamilnadu, Kerala, Karnataka, Maharashtra and some parts of Gujarat. Marine or soft clays exists in these region are weak in nature. Generally, the natural water content of the marine clays is always greater than its liquid limit. In addition to these, the problems arising out of high compressibility and low shear strength of these weak marine deposits expose geotechnical engineers to considerable changes in the construction of various coastal and offshore structures. All over the world, problems of marine clay have appeared as cracking and break-up of pavements, railway and highway embankments, roadways, building foundations, irrigation systems, water lines, canal and reservoir linings. The estimated damage was very expensive to the pavements running over the marine clay sub grades. Improving the strength of the marine clays by the stabilization techniques was performed by many researchers and their respective demerits prompted further studies to arrive at better techniques. The present study deals with testing of a typical Marine clay deposit of Kakinada with the aim to investigate its engineering properties and further stabilize it to be suitable for foundation constructions or as sub-grades by using GGBS, Lime & Waste Tire Inclusions (WTI).*

I. INTRODUCTION

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 view of the developments on coastal areas in the recent past, large number of ports and industries are being built. In addition, the availability of land for the development of commercial, housing, industrial and transportation, infrastructure etc. are scarce particularly in urban areas. This necessitated the use of land, which has weak strata, wherein the geotechnical engineers are challenged by presence of different problematic soils with varied engineering characteristics. Many of these areas are covered with thick soft marine clay deposit, with very low shear strength and high compressibility.

Majority of the population 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.

The marine clays are not suitable as pavement sub grade & foundation soil beds and pose problems due to their inability of strength criteria. More and more construction projects are encountering soft clays and hence there is a need to better quantifying the properties of marine clays.

Objective

- To identify the strategy of techniques to overcome the problems posed by marine clays with a view to adopt suitable methodology through critical review of literature.
- To study the impact of proposed additives and admixtures on the properties of marine clays through laboratory experimentations.
- To evaluate the performance of marine clay when stabilized with proposed additives and admixtures and their suitability for fill material and sub grade material.
- To investigate the suitability and adoptability of Waste Tire Inclusions (WTI) as discrete reinforcement.

II. REVIEW OF LITERATURE

For any developing nation like India transportation and communication facilities are vital. The technology of road construction is subjected to changes to cope up with the vehicular pattern, construction materials and sub grade condition. Sub grade soil 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 give adequate support to the pavement and for this the sub grade should possess sufficient stability under adverse climate and loading conditions. The formation of waves, corrugations, rutting and the phenomena of pumping, blowing and consequent cracking of cement concrete pavements are generally attributed due to the poor sub grade conditions.

PROBLEMS ASSOCIATED WITH MARINE CLAYS

- Damages to the Pavement Sub grades
  - Rutting
  - Longitudinal cracks
- Damages to the building foundations
- Damages to super structure
- Cracks in buildings

REMEDIAL MEASURES TO OVERCOME PROBLEMS OF MARINE CLAY

If soil has a high deformation, the preventive measures are required. These measures can be broadly classified into the following categories.

- Avoiding highly compressible soils
- Alterations to these soils

In case of foundations, Sand Cushion method, Stiffening the foundation by adopting Alterations, Mat Foundations, Heat treatment, Chemical stabilization, soil replacement technique are some of the remedial measures to overcome the problems of compressible marine clay soils.

In case of Pavement sub grades, stabilization techniques can be adopted using various industrial waste considering the economy and also chemical additives for easy mixing and early results. The reinforcement techniques also plays vital role in improving the load carrying capacity of the marine clay beds.

- Soil Replacement
- Sand Cushion Method
- Stiffening the Foundation and Super structure
- Mat Foundation
- Stone Columns
- Heat Treatment
- Stabilization

Figure 1. Marine Clay Showing Cracks

STABILIZATION

Stabilization is the process of improving the engineering properties of the soil and thus making it more stable. Although there is an immediate strength improvement due to textural changes, stabilization involves the formation of cementitious compounds within the clay structure over time. Stabilization alters the following engineering properties.

- Increases load bearing capacity and shear strength of the soil
- Decreases the permeability and compressibility
- There are different types of stabilization. They are:
- Mechanical stabilization
- Cement stabilization
- Lime stabilization
- Bituminous stabilization
- Chemical stabilization
- Thermal stabilization

STUDIES ON MARINE CLAY

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. It is essential to study the various techniques for the improvement of marine clays, especially in case of infra-structure development.

Shridharan A et.al (1989), reported the Engineering properties of Cochin and Mangalore Marine Clays. A research has been done on the Physico-Chemical effects on the engineering behavior of Indian marine clays by Rao, M.S et.al (1992)

Thiam-Soon et al (2002), reported on improving the strength of the marine clay by the stabilization technique. Chu, J et.al (2002), reported the consolidation and permeability properties of the Singapore marine clay based on the laboratory and field investigations.

Balasubramaniam, A.S et.al (2003), proved the effects of additives on Soft Clay behaviour and concluded that the strength characteristics of the soft clays are improved by using various additives.

Oh, E.Y.N et.al (2006), presented the engineering properties and the characterization of marine clay for road embankment design in coastal area and the engineering properties of the marine clay were improved using various stabilization techniques.

Matchala Suneel et.al (2008), represented the compressibility characteristics of Korean marine clay. W.L. Sing et.al (2008), reported an improvement in the engineering properties of peat soils stabilizing with cement and ground granulated blast furnace slag and proved a remarkable increase in the pH and unconfined compressive strength, significant reduction in linear shrinkage, compressibility and permeability of the stabilized peat soils.

Basack,S et.al (2009), reported that the Engineering characteristics of marine clay collected form Visakhapatnam, India and the physical, chemical and mineralogical properties were presented and the strength, stiffness of the soil water matrix were established.

D. Koteswara Rao et al.(2011) studied the efficiency of CaCl2,KCl,GBFS with marine clay and the test results concluded that load carrying capacity of the marine clay foundation soil bed has been improved.

D. Koteswara Rao et al.(2012) studied the efficiency of Rice Husk Ash & Lime with marine clay and the test results concluded that load carrying capacity of the marine clay foundation soil bed has been improved.

III. METHODOLOGY

In this we will discuss about the properties of different types of materials used during the laboratory experimentation were presented. And a brief description of the experimental procedures adopted in this investigation and the methodology adopted during the course of study are briefly presented.

Materials Used and Their Properties

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

Marine Clay

The marine clay used in this study and was typical soft clay. The marine clay was collected at a depth of 0.30m to 1.00m from ground level from YETIMOGA area, Kakinada, Andhra Pradesh State, India. The properties of soil are presented in the Table of Marine Clay properties All the tests carried on the soil are as per IS specifications.

Table 1.

Table: Properties of Marine clay

S.No	Property	Value
	Grain size distribution	
1	Sand (%)	4
	Silt (%)	28
	Clay (%)	68
	Atterberg limits	
2	Liquid limit (%)	67.5
	Plastic limit (%)	32.5
	Plasticity index (%)	35
	Compaction properties	
3	Optimum Moisture Content, (%)	33
	Maximum Dry Density, (g/cc)	1.32
4	Specific Gravity (G)	2.68
5	IS Classification	CH
6	Soaked C.B.R (%)	0.64
7	Differential free swell (%)	18
	Shear Strength Parameters	
8	Cohesion (kN/m²)	38
	Angle of internal friction (^{0})	0

GGBS

For the present study, Ground Granulated Blast-furnace Slag (GGBS) brought from Vizag Steel Plant, Visakhapatnam.

Specific Gravity – 1.95

The Physical properties and Chemical composition of GGBS are shown in two different tables below.

Table 2. Properties of GGBS

S.No	Property	Value
Grain size distribution		
1	Sand (%)	27
	Silt (%)	66
	Clay (%)	7
Atterberg limits		
2	Liquid limit (%)	48
	Plastic limit (%)	NP
	Plastic index (%)	NP
Compaction properties		
3	Optimum Moisture Content, (%)	19.7
	Maximum Dry Density, (g/cc)	1.45
CBR Properties		
4	Un Soaked CBR	9.9
	Soaked CBR	2.85

Table 3.
Table: Chemicals Present in GGBS

S.No.	Chemical	Composition
1	CaO	30-50%
2	SiO_2	28-38%
3	Al_2O_3	8-24%
4	MgO	1-18%
5	MnO	0.68%
6	TiO_2	0.58%
7	K_2O	0.37%
8	N_2O	0.27%

Lime

Commercial grade lime mainly consisting of 58.67% of Cao and 7.4% Silica was used in the study. The quantity of lime was varied from 0% to 12% by dry weight of soil + GGBS.

Waste Tire Inclusions

In the present study, locally available tire waste collected from various dumping yards was used. The waste tyres were cut into small strips of 50mm length, 3mm wide and 1mm thickness. The quantity of these waste tyre strips was varied from 0% to 1.5% by dry weight of soil + GGBS + Lime, with an increment of 0.5%.

List of Laboratory Tests

- The grain size distribution
- Specific gravity
- Swell Tests- Differential Free swell
- Index properties –Liquid Limit, Plastic Limit
- Compaction tests
- Penetration tests- California bearing ratio tests.
- Strength tests- Tri- axial shear tests

SAMPLE PREPARATION

The soil was initially air dried, pulverized and then was sieved through 4.75mm sieve, prior to the testing. The samples were prepared by mixing the pulverized and sieved soil with the needed stabilizing agents in dry condition and then required amount of water is added to make a consistent mix by thorough mixing. The following tests were conducted as per IS Codes of practice to assess the influence of GGBS, Lime and Waste Tire Inclusions (WTI) on the Soft Marine Clay.

i. Compaction tests
ii. Penetration tests- California Bearing Ratio test.
iii. Strength tests- Tri-axial shear test

The following table lists the different variables and their respective contents used in the present study.

Table 4.
Table Different variables studied

S.No.	Stabilizing Agent	% Content
1	Ground Granulated Blast furnace Slag (GGBS)	0, 5, 10, 15, 20 & 25
2	Lime	0, 4, 8 & 12
3	Waste Tire Inclusions (WTI)	0, 0.5, 1.0 & 1.5

IV. RESULTS AND DISCUSSIONS

Details of the laboratory experimentation carried-out with different combinations of materials have been discussed in the previous chapter including the laboratory proctor's test and tri axial tests on untreated and treated marine clay.

Table 4.
Table4.1 Variation of OMC & MDD with % of GGBS

S. No.	% of GGBS	OMC (%)	MDD (gm/cc)
1	0	33	1.32
2	5	28.1	1.37
3	10	26.3	1.42
4	15	24	1.44
5	20	23.2	1.47
6	25	22.1	1.45

Table 5.
Table 4.2 Variation of OMC & MDD with % of Lime to the Soil + GGBS optimum mix

S. No.	% of Lime	OMC (%)	MDD (gm/cc)
1	0	23.2	1.47
2	4	25	1.49
3	8	26	1.52
4	12	27.3	1.51

Table 6.
Table 4.3 Variation of OMC & MDD with % of WTI to the Soil + GGBS + Lime Optimum mix

S. No.	% of WTI	OMC (%)	MDD (gm/cc)
1	0	26.1	1.52
2	0.5	26	1.51
3	1	25.8	1.49
4	1.5	25.4	1.48

Table 7.
Table 4.4 Variation of Cohesion with % of WTI

S. No.	% of WTI	C_u (Kpa)	% increase in C_u
1	0	84	-
2	0.5	93	10.7
3	1	104	23.8
4	1.5	101	20.2

Table 8.
Table 4.5 Variation of Angle of Internal Friction with % of WTI

S. No.	% of WTI	$Ø_u$ (Degrees)	% increase in $Ø_u$
1	0	9^0	-
2	0.5	12^0	33.3
3	1	15^0	66.6
4	1.5	14^0	55.5

Table 9.
Table 4.6 Variation of CBR values with % of WTI

S. No.	% of WTI	Soaked (%)
1	0	8.9
2	0.5	9.6
3	1	11.4
4	1.5	11.3

Table 10.
Table4.7 Variation of OMC & MDD (g/cc) with various mix proportions

S. No.	Mix Proportions (P)	OMC (%)	MDD
1	Only Soil (P1)	33	1.322
2	Clay+20%GGBS (P2)	23.2	1.47
3	Clay+20%GGBS+8%Lime (P3)	26.1	1.52
4	Clay+20%GGBS+8%Lime+0.5%WTI (P4)	26	1.51
5	Clay+20%GGBS+8%Lime+1.0%WTI (P5)	25.8	1.49
6	Clay+20%GGBS+8%Lime+1.5%WTI (P6)	25.4	1.48

Table 11.
Table4.8 Variation of Shear Parameters with various mix proportions

S. No.	Mix Proportions (P)	C_u	AIF
1	Only Soil (P1)	38	0^0
2	Clay+20%GGBS (P2)	68	4^0
3	Clay+20%GGBS+8%Lime (P3)	84	9^0
4	Clay+20%GGBS+8%Lime+0.5%WTI (P4)	93	12^0
5	Clay+20%GGBS+8%Lime+1.0%WTI (P5)	104	15^0
6	Clay+20%GGBS+8%Lime+1.5%WTI (P6)	101	14^0

Table 12.
Table4.9 Variation of Unconfined Compressive Strength with various mix proportions

S. No.	Mix Proportions (P)	UCS (kN/m^2)
1	Only Soil (P1)	76
2	Clay+20%GGBS (P2)	145
3	Clay+20%GGBS+8%Lime (P3)	197.4
4	Clay+20%GGBS+8%Lime+0.5%WTI (P4)	230
5	Clay+20%GGBS+8%Lime+1.0%WTI (P5)	271.4
6	Clay+20%GGBS+8%Lime+1.5%WTI (P6)	258

Table 13.
Table4.10 Variation of Soaked CBR with various mix proportions

S. No.	Mix Proportions (P)	CBR Soaked
1	Only Soil (P1)	3.34
2	Clay+20%GGBS (P2)	4.8
3	Clay+20%GGBS+8%Lime (P3)	8.9

4	Clay+20%GGBS+8%Lime+0.5%WTI (P4)	9.6
5	Clay+20%GGBS+8%Lime+1.0%WTI (P5)	11.4
6	Clay+20%GGBS+8%Lime+1.5%WTI (P6)	11.3

Table 14.
Table4.11 Variation of Safe Bearing Capacity with various mix proportions

S. No.	Mix Proportions (P)	SBC (kN/m^2)
1	Only Soil (P1)	93.5
2	Clay+20%GGBS (P2)	171.98
3	Clay+20%GGBS+8%Lime (P3)	328.82
4	Clay+20%GGBS+8%Lime+0.5%WTI (P4)	436.55
5	Clay+20%GGBS+8%Lime+1.0%WTI (P5)	576.31
6	Clay+20%GGBS+8%Lime+1.5%WTI (P6)	530.53

Table 15.
Table4.12 Variation of Thickness of Pavement with various mix proportions

S. No.	Mix Proportions (P)	Thickness (Cm)
1	Only Soil (P1)	104.77
2	Clay+20%GGBS (P2)	36.12
3	Clay+20%GGBS+8%Lime (P3)	24.88
4	Clay+20%GGBS+8%Lime+0.5%WTI (P4)	23.67
5	Clay+20%GGBS+8%Lime+1.0%WTI (P5)	21.04
6	Clay+20%GGBS+8%Lime+1.5%WTI (P6)	21.17

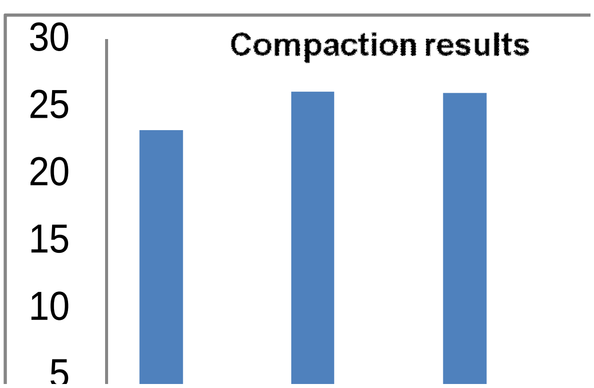

Figure 2. Bar chart showing the effect of GGBS, Lime & WTI on compaction parameters of marine clay

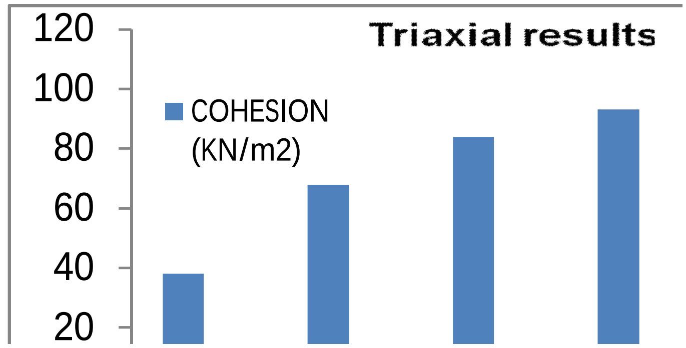

Figure 3. Bar chart showing the effect of GGBS, Lime & WTI on Tri-Axial parameters of marine clay

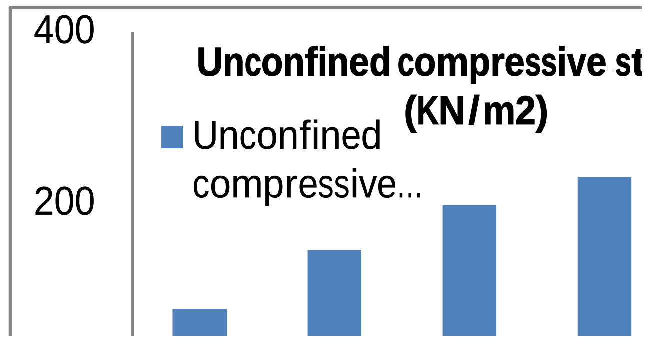

Figure 4. Bar chart showing the effect of GGBS, Lime & WTI on unconfined compressive strength of marine clay

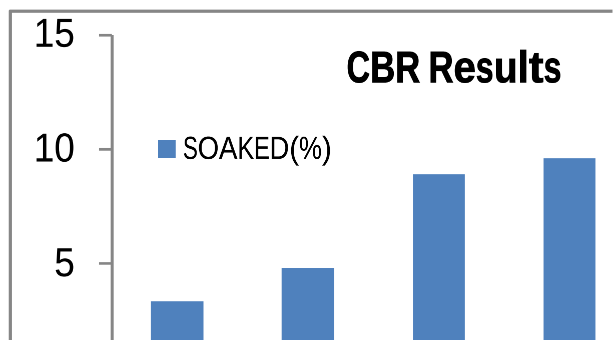

Figure 5. Bar chart showing the effect of GGBS, Lime & WTI on CBR results of marine clay

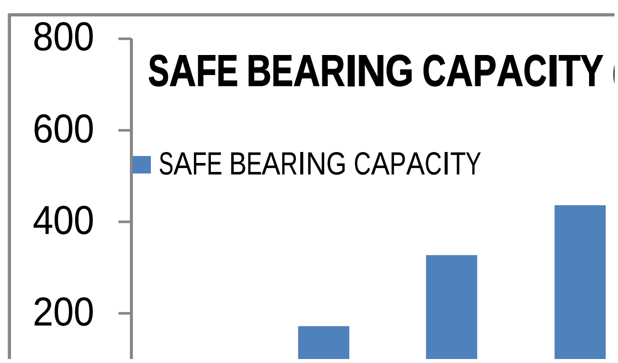

Figure 6. Bar chart showing the effect of GGBS, Lime & WTI on Safe Bearing Capacity of marine clay

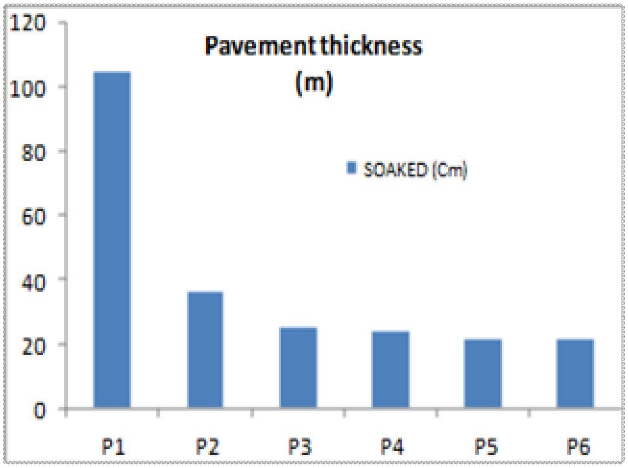

Figure 7. Bar chart showing the effect of GGBS, Lime & WTI on Pavement Thickness under soaked condition of marine clay

EFFECT OF GGBS, LIME, WASTTE TIRE INCLUSIONS ON THE BEHAVIOUR OF MARINE CLAY

Table 4.7 to Table 4.12 shows the summarized results of the behaviour of marine clay stabilized with GGBS, GGBS + Lime, GGBS + Lime + Waste Tire Inclusions. From the table it is evident that the addition of GGBS to the virgin marine clay showed an improvement in maximum dry density by about 3.2% and on further blending it with lime, it increased to 12%. The corresponding optimum moisture content reduced for only GGBS mixing and then increased slightly when lime is added to GGBS - clay mix. The shear parameters also were improved with the addition of GGBS, lime – GGBS and lime – GGBS – Waste Tire Inclusions.

There is an improvement of 80% in cohesion when the original clay was replaced with 20% GGBS and when it is further blended with lime, it improved by about 24% further. The angle of internal friction was further improved by about 66% when the mix was blended with 1% Waste Tire Inclusions and also the cohesion has improved by about 173% when compared to that of virgin marine clay. The corresponding unconfined compressive strength was improved by about 257%. There is an improvement in soaked C.B.R values also by about 21 times.

Figures 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6 shows the bar chart of various parameters studied to assess the behaviour of marine clay when treated with optimum contents of GGBS and lime i.e., 20% and 8% respectively and further mixing it with different percentages of Waste Tire Inclusions i.e. from 0% to 1.5% with an increment of 0.5%. From the figures, it is clear that the problematic marine clay was improved by stabilizing it with GGBS, lime, and Waste Tire Inclusions. The GGBS replacement in the marine clay has reduced the plastic nature of the marine clay and upon further blending lime with optimum mix of GGBS–marine clay, the plasticity was even reduced.

This results in reducing the construction material by effective utilization of waste materials, solving the problem of waste disposal to some extent. From the above discussions, it can be summarized that the materials GGBS, lime, and Waste Tire Inclusions had shown promising influence on the properties of soft marine clay, thereby giving a two-fold advantage in improving problematic marine clay and also solving a problem of waste disposal.

V. CONCLUSIONS

The following conclusions are made based on the laboratory experiments carried out in this investigation.

From the laboratory studies, it is observed that the Marine Clay chosen was a problematic soil having high compressibility, with high plasticity and low strength characteristics.

There is a gradual increase in maximum dry density with an increment in the % replacement of GGBS up to 20% with an improvement of 3.2% and upon further increment there is a marginal decrease in MDD value. The corresponding optimum moisture content values decreased with a % reduction of 30%.

There is an improvement of 80% in cohesion when the original clay was replaced with 20%GGBS and when it is further blended with lime, it improved by about 24% further. The angle of internal friction was further improved by about 66% when the mix was blended with 1% Waste Tire Inclusions and also the cohesion has improved by about 173% when compared to that of virgin marine clay.

The corresponding unconfined compressive strength was improved by about 257%. There is an improvement in soaked C.B.R values also by about 21 times.

It is evident that there is a significant reduction in pavement thickness by about 77% in soaked CBR condition.

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