Stabilization of Marine Clay Using Ferric Chloride and Quarry Dust

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Abstract- Civilization is always developed around the coastal regions, these are covered with thick soft marine clay deposits. This clay has less strength and possesses high deformation, low permeability and limited bearing capacity. Due to the poor engineering characteristics of these clays, they pose several foundation problems to various coastal structures. As this Marine clay is widely occupied in costal corridor, it is inevitable to constructing pavements and foundations on them due to the population density. This clay, because of their specific Physico-chemical make-up, subjected to volume changes with the changes in their ambient environment. By reinforcing the industrial waste to this soil the constructional properties can substantially enhance. Therefore, the present experimental work aims to investigate the efficacy of Ferric Chloride in stabilizing the marine clay thereby improving its strength and swell characteristics. Total cost of construction is reduced and also providing solution for environmental problem. From the experimental results it was observed that 1.0% $FeCl_3$ treatment individually along with the combination of 20% Quarry Dust with marine clay had effectively improved the CBR value. It was noticed that, the load carrying capacity of the treated marine clay sub grade model flexible pavement has been increased by 254% at OMC and 225% at FSC. The total deformation of the treated marine clay sub grade model flexible pavement has been decreased by 40% at OMC and 38% at FSC when compared with the untreated marine clay sub grade model flexible pavement.

Keywords: Marine clay, $FeCl_3$, deformation, flexible pavement.

I. INTRODUCTION

Vast areas, particularly along the coast are covered with thick soft marine clay deposits having very low shear strength and high compressibility. In view of the developments on coastal areas in the recent past, large number of ports and industries are being built. 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. 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, because of the specific physicos-chemical make-up, are subjected to volume change with the changes in their ambient environment. 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. The marine clays are not suitable as pavement sub grade and foundation soil beds and pose problems due to their inability of strength criteria. Continued efforts have been made all over the world to devise ways to means 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.

The marine deposits have very low shearing strength and are highly compressible. The marine clays are soft and highly plastic. The deposits generally need a pre-treatment before application of any external load. The performance of these soft fine grained deposits under different conditions of environment varies over wide limits. In order to improve the engineering behavior of soils, several improvement techniques are available in geotechnical engineering practice. The fact that the selection of anyone of these methods for any problem can be made only after a comparison with other techniques proves that the method is well suited for a particular system. Hyde AL et.al (1993), presented the Engineering properties and stability criteria for marine clay under cyclic loading. 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 behavior 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. D. Koteswara Rao et al.(2012) studied the efficiency of Rice Husk Ash & Ferric Chloride with marine clay and the test results concluded that load carrying capacity of the marine clay foundation soil bed has been improved.

In this work it is attempted to study the effect of FERRIC CHLORIDE and QUARRY DUST on the properties of marine clay.

II. METHODOLOGY

The properties of marine clay, ferric chloride and Quarry dust are presented. The cyclic plate load tests were conducted on untreated, treated and reinforced model flexible pavements.

Marine Clay: The marine clay used as sub grade and foundation soil for this study. The marine clay was collected at a depth of 0.30m to 1.00m from ground level from Kakinada Sea Ports limited, Kakinada, and Andhra Pradesh State, India. The properties of soil are presented in the Table 3.1. All the tests carried on the soil are as per IS specifications.

Quarry Dust: The quarry dust used in this study was brought from Padmavathi crusher unit situated at Yeleswaram around 40 Km away from Kakinada.

Ferric Chloride ($FeCl_3$): Commercial grade ferric chloride (consisting of 69% ferric chloride + 16% sodium chloride + 15% calcium oxide) was used in this study. The quantity of ferric chloride was varied from 0 to 1.5% by dry weight of soil.

Ferric Chloride Preparation:

An hydrous iron (III) chloride may be prepared by union of the elements:

$2\ Fe(s) + 3\ Cl_2(g) \rightarrow 2\ FeCl_3(s)$

Solutions of iron (III) chloride are produced industrially both from iron and from ore, in a closed-loop process.

1. Dissolving pure iron in a solution of iron(III) chloride
   $Fe(s) + 2\ FeCl_3(aq) \rightarrow 3\ FeCl_2(aq)$
2. Dissolving iron ore in hydrochloric acid
   $Fe_3O_4(s) + 8\ HCl(aq) \rightarrow FeCl_2(aq) + 2\ FeCl_3(aq) + 4\ H_2O$
3. Oxidation of iron (II) chloride with chlorine
   $2\ FeCl_2(aq) + Cl_2(g) \rightarrow 2\ FeCl_3(aq)$
4. Oxidation of iron (II) chloride with oxygen
   $FeCl_2(aq) + \frac{1}{4}O_2 + HCl \rightarrow FeCl_3(aq) + \frac{1}{2}H_2O$

Like many other hydrated metal chlorides, hydrated iron(III) chloride can be converted to the anhydrous salt by refluxing with thionyl chloride. Conversion of the hydrate to anhydrous iron(III) chloride is not accomplished by heating, as HCl and iron oxychlorides are produced.

Table 1.1: Properties of Marine clay

S.No	Property	Value
1.	Grain size distribution Sand (%) Silt (%) Clay (%)	 6 27.5 66.5
2.	Atterberg limits Liquid limit (%) Plastic limit (%) Plasticity index (%) Shrinkage limit (%)	 72.9 31.89 39.7
3.	Compaction properties Optimum Moisture Content, (%) Maximum Dry Density, (g/cc)	 29.9 1.41
4.	Specific Gravity (G)	2.44
5.	IS Classification	CH
6.	C.B.R (%)	1.12
7.	Shear Strength Parameters Cohesion (t/m²) Angle of internal friction (^{0})	 10 4

Table 1.2 Properties of Quarry dust

S.No	Property	Value
1.	Grain size distribution Gravel(%) Sand (%) Fines (%)	 14.6 84.94 0.46
2.	Atterberg limits Liquid limit (%) Plastic limit (%) Plasticity index (%) Shrinkage limit (%)	 NP NP NP NP
3.	Compaction properties Optimum Moisture Content, (%) Maximum Dry Density, (g/cc)	 12.40 2.04
4.	Specific Gravity (G)	2.906
5	IS Classification	SW
6.	C.B.R (%)	9.26
7.	Shear Strength Parameters Cohesion (t/m²) Angle of internal friction (^{0})	 0.5 22

Table 1.3 Complete details of the Ferric Chloride properties.

Molecular formula	$FeCl_3$	Density	2.898 g/cm^3 (anhydrous) 1.82 g/cm^3 (hexahydrate)
Molar mass	162.2 g/mol (anhydrous) 270.3 g/mol (hexahydrate)	Melting point	306 °C (anhydrous) 37 °C (hexahydrate)
Appearance	green-black by reflected light; purple-red by transmitted light hexahydrate: yellow solid aq. solutions: brown	Boiling point	315 °C (anhydrous, decomp) 280 °C (hexahydrate, decomp) (partial decomposition to $FeCl_2$+ Cl_2)
Odor	slight HCl	Viscosity	40% solution: 12 cP
Solubility in water	74.4 g/100 mL (0 °C) 92 g/100 mL (hexahydrate, 20 °C)	Solubility in acetone Methanol Ethanol Diethyl ether	63 g/100 ml (18 °C) highly soluble 83 g/100 ml highly soluble
Crystal structure	hexagonal	GHS hazard statements	H290, H302, H314, H318
Other anions	Iron(III) fluoride Iron(III) bromide	Other cations	Iron(II) chloride Manganese(II) chloride Cobalt(II) chloride Ruthenium(III) chloride
Related coagulants	Iron(II) sulfate Poly aluminum chloride		

III. EXPERIMENTATION

The soil was initially air dried prior to the testing. The tested the behavior of marine clay, when it was untreated and treated for the modal flexible pavements.

Problems Associated With Marine Clays

Among the various damages, the damage caused by the marine soft soils to the pavements and also for foundation beds are high compressibility and swelling nature of the marine clay soils on inhabitation of water during the monsoon and reduce density or shrinkage occurs because of evaporation of water in summer and become hard due to increased density and this trend 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 1.5m, 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.

Damages to the Pavement Sub Grades

Majority of the pavement failures could be attributed to the poor sub grade conditions and marine clay, roads running through marine clays regions are subjected to severe unevenness with or without cracking, longitudinal cracking parallel to pavement centerline, rutting of pavement surface, and localized failure of pavement associated with disintegration of the surface. The extensive damage to highways running over expansive and high compressible soil sub-grades. Even railway tracks are no exception and are affected by appreciable movements due to the nature of high compressibility of the marine clay soils. Some of common problems are [i] Rutting [ii] Longitudinal cracks [iii] Damages to the building foundation. Some of the remedial measure to overcome problems associated with the marine clay soils are [i] Soil replacement [ii] Sand cushion method [iii] Stiffing the foundation and super structure [iv] Mat foundation [v] Stone columns [vi] Heat treatment [vii] Stabilization and [viii] Reinforcement. Among different stabilization methods chemical stabilization plays a vital role due to its industrial waste utilization for improve the clay properties.

Chemical Stabilization

Chemical stabilization consists of bonding the soil particles with a cementing agent that is produced by a chemical reaction within the soil. The reaction does not necessarily include the soil particles, although the bonding does involve intermolecular forces of the soil. Most of the clay soils are the sodium cations in exchange complex and probably, the most effective chemical stabilization of soft soils occurs, when sodium ions are replaced by divalent or trivalent cations. However, Ferric Chloride stabilisation gained prominence for modification of marine clays during the past few decades, due to the availability of Ferric Chloride and its adaptability. As a matter of fact, Ferric Chloride is sparingly soluble (about 1.2 g/litre at 21^0C) in water and free calcium ions available for substantial cation-exchange reactions are meagre and most of the Ferric Chloride settles at the bottom of bore holes.

Rao and Subba Rao (1994) recommended 5% Ferric chloride ($FeCl_3$) solution to treat the caustic soda contaminated ground of an Industrial building in Bangalore. Srinivas et.al (2005), studied the influence of KCL, $CaCl_2$ and $FeCl_3$ on the properties of expansive soil in the laboratory. As a part of the testing procedure, swell and strength tests were conducted, and they concluded that $FeCl_3$ showed the best performance.

IV. RESULTS AND DISCUSSION

Experiments were conducted by using different percentages of Ferric Chloride and Quarry Dust with a view to determine the optimum percentages of Ferric Chloride and Quarry Dust. The cyclic plate load tests were conducted on marine clay sub grade model flexible pavements. The effect of addition of Ferric Chloride and Quarry Dust to the marine clay, on compaction, CBR properties and strength properties were estimated.

Effect of Ferric Chloride and Quarry Dust on Compaction and CBR Properties of the Marine Clay: The individual influence of Ferric Chloride and combination with Quarry Dust on the compaction and CBR properties of marine clay as observed. It was noticed that 1.0% Ferric Chloride treatment as individually and with the combination of 20% Quarry Dust with marine clay has effectively improved the laboratory CBR value. Compaction tests were conducted to get the Optimum moisture content and maximum dry density of different proportions of marine clay and Ferric Chloride using modified proctor compaction apparatus. As shown in Fig. 1, the $FeCl_3$ increases dry density is increased and optimized at 1% .

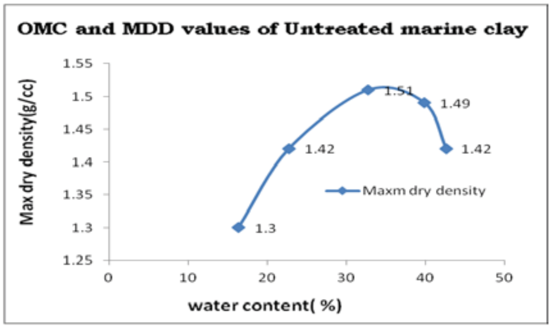

Fig.1 (a): OMC and MDD of untreated marine clay

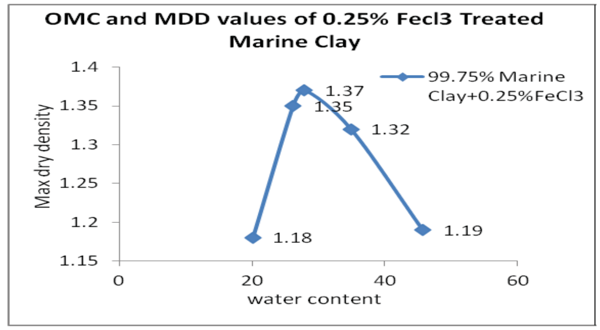

Fig. 1 (b): OMC and MDD of 0.25% $FeCl_3$ marine clay

Optimum moisture content = **32.76%**
Maximum dry density = **1.51 gm/cc**

Optimum moisture content = **27.89 %**
Maximum dry density = **1.37 gm/cc**

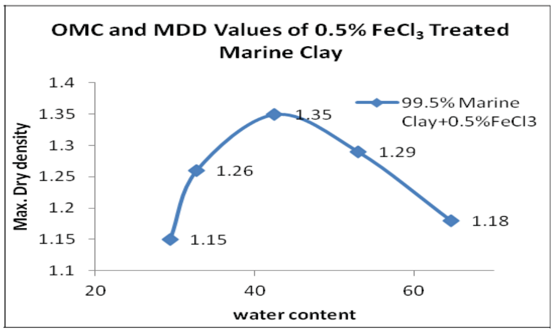

Fig. 1 (c): OMC and MDD of 0.25% FeCl3 marine clay

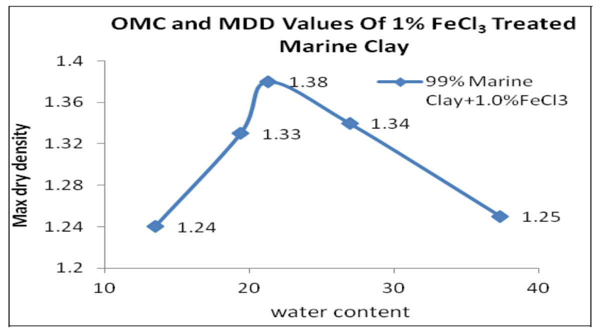

Fig. 1 (d): OMC and MDD of 0.25% FeCl3 marine clay

Optimum moisture content = **42.51 %**
Maximum dry density = **1.35 gm/cc**

Optimum moisture content = **21.29 %**
Maximum dry density = **1.38gm/cc**

By adding the Quarry dust to the marine clay the CBR is increased as shown in Fig. 2

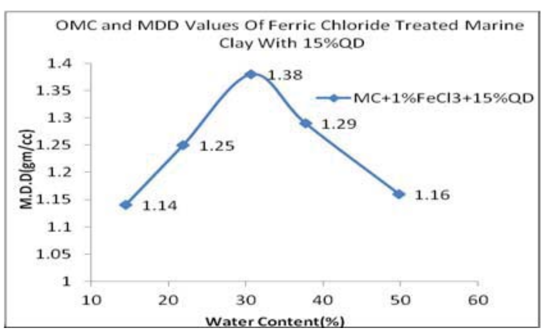

Fig.2 (a): OMC and MDD of Quarry dust

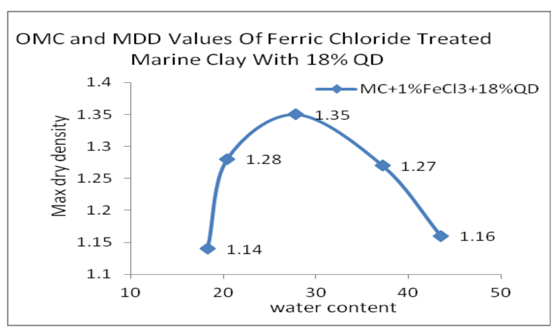

Fig. 2 (b): OMC and MDD of Quarry dust

Optimum moisture content = **30.65 %**
Maximum dry density = **1.38 gm/cc**

Optimum moisture content = **27.83 %**
Maximum dry density = **1.35 gm/cc**

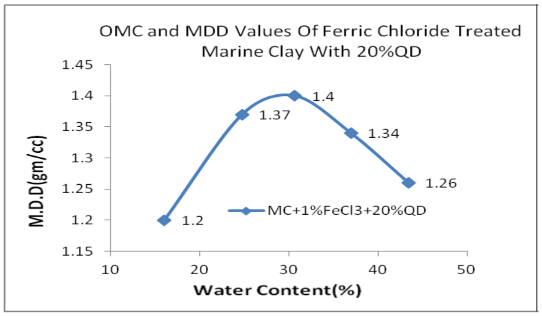

Fig. 2 (c): OMC and MDD of Quarry dust

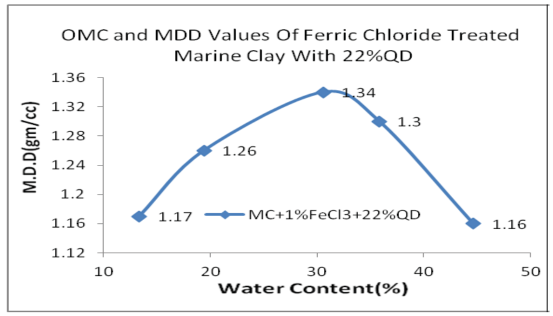

Fig. 2 (d): OMC and MDD of Quarry dust

Optimum moisture content = **30.66 %** Optimum moisture content = **30.55%**
Maximum dry density = **1.4 gm/cc** Maximum dry density = **1.34 gm/cc.**

It was observed that 1.0% Ferric Chloride treatment as individually with marine clay has effectively improved the CBR value. However, beyond the addition of 1.0% Ferric Chloride no significant improvement in CBR values of the marine clay were observed as depicted in the Fig. 3.

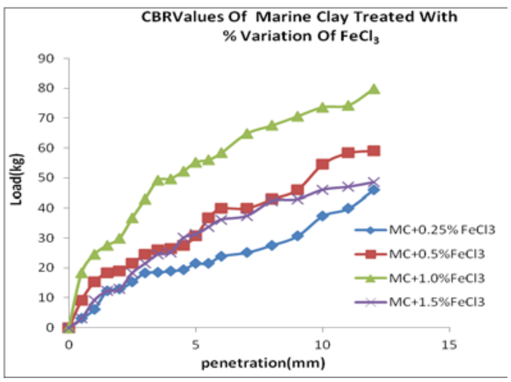

Fig.9: CBR Value of marine clay with FeCl3

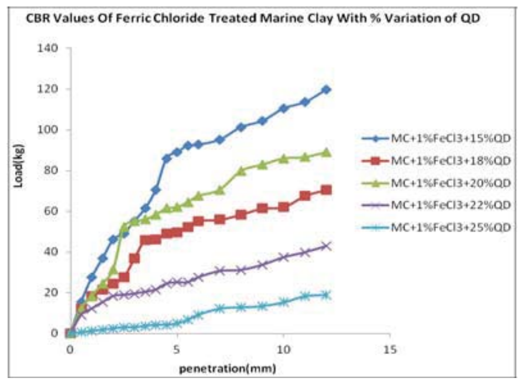

Fig.9: CBR Value of marine clay with Quarry dust

The soaked and un soaked CBR values of various mixes of Ferric Chloride treated marine clay and Quarry Dust using OMC obtained from compaction tests are determined. The soaked CBR after immersing in water for four days , that is when full saturation is likely to occur, is also determined. It was observed that 1.0% Ferric Chloride treatment as individually and with the combination of 20% Quarry Dust with marine clay has effectively improved as shown in Fig. 4. It was observed that out of the different combinations tried in this investigation, 1%$Fecl_3$ is found to be optimum. However beyond the addition of 1%, there is reduction in M.D.D values of treated Marine clay.

V. CONCLUSIONS

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

1. It was observed that the liquid limit values are decreased by 7% and 23% on the addition of 1% Ferric Chloride and 1% Ferric Chloride +20% Quarry dust respectively with respect to the untreated marine clay.
2. It was observed that the Plasticity index values are decreased by 33% and 17% on the addition of 1% Ferric Chloride and 1% Ferric Chloride +20% Quarry dust respectively with respect to the untreated marine clay.
3. It was noticed from the laboratory cyclic plate load test results that, the load carrying capacity of the treated marine clay model flexible pavement has been increased by 254% at OMC and 225% at FSC when compared with untreated marine clay sub grade model flexible pavement.
4. It was noticed from the laboratory results that, the total deformation of the treated marine clay model flexible pavement has been improved by 40% at OMC and 38% at FSC when compared with the untreated marine clay sub grade model flexible pavement.

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