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The Influence of Calcium Chloride on the Reinforced Marine Clay for Foundation Soil Beds

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Abstract
Weak marine soil deposits have been found both on the coast and in several offshore areas spread over many parts of the world. When clay particles precipitate in salt water, there is a tendency for the clay particles to flocculate and stick together giving rise to some sort of edge-to-face arrangement. As a result, clay, silt, and fine sand particles settle almost at the same rate and the final sediment formed consists of particles with a very loose card house-like structure. Hence the marine sediments can be considered loose sediments, usually formed with high void ratios. Problems are associated with these fine-grained soils deposited at a soft consistency. Fine-grained soils are very sensitive to changes in the stress system, moisture content and system chemistry of the pore fluid. 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. In this present investigation, the performance of the potassium chloride on the strength characteristics of the marine clay has been studied and also the reinforcement effect on the improvement of load bearing capacity of the $CaCl_2$ treated marine clay has been studied.

Keywords: *OMC, MDD, FSC, $CaCl_2$, Load Bearing Capacity, Strength Characteristics*

Introduction
The marine clay is available at fully saturated condition in the costal corridor and the natural water content of the marine clays is always greater than its liquid limit A comprehensive review of literature indicates that considerable amount of work related to determination 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). Marine clay deposits of Ongole were used for the testing with the aim to investigate its strength characteristics and load bearing capacity and further make suitable for foundation constructions over it. The soil was collected at 0.3m to1.0m depth from the Ongole Sea, A.P, India.

Objectives
This investigation has been carried with the following objects.
To study influence of$CaCl_2$ on the Marine Clay +ACGBFS mix for the foundation Soil beds.
To investigate the efficiency of geotextile as a reinforcement and separator in the treated marine clay foundation soil bed.
To indentify the improvement in the load carrying capacity of the untreated and treated marine clay foundation soil bed at OMC & FSC.

Materials Used
Marine Clay: The marine clay used in this study is a typical soft clay which is collected at a depth of 0.30m to 1.00m from ground level in, Ongole, Andhra Pradesh, India. The properties of soil are presented in the Table 3.1. All the tests carried on the soil are as per IS specifications.

Geo-Textile: PP woven Geo-textile-GWF-40-220, manufactured by GARWARE –WALL ROPES LTD, Pune, India, was used in this investigation. The tensile strength of woven geo-textile is 60.00kN/m for warp and 45.0 kN/m for weft and was used in this investigation as a separator between sub-grade, sub-base and base.

Calcium Chloride: Laboratory grade calcium chloride consisting of 98% $CaCl_2$ was used in this work. The amount calcium chloride was varied between 0 to 2.0% by dry weight of soil.

Table 1: Properties of Untreated and Treated Marine Clay

S. No	Property	Untreated Marine Clay	1.0% $CaCl_2$ Treated Marine Clay	20% ACBFS + 1.0%$CaCl_2$ treated MC
1.	Atterberg limits Liquid limit (%) Plastic limit (%) Plasticity index (%) Shrinkage limit (%)	 76.4 25.16 51.24 9	69.5 27.45 42.05 10.24	46.82 28.05 18.77 12.98
2.	Compaction properties Optimum Moisture Content (%) Maximum Dry Density (g/cc)	33.790 1.443	23.09 1.496	21.44 1.62
3	Specific Gravity (G)	2.42	2.51	2.61
4.	IS Classification	CH	CH	CI
5.	C.B.R (%)	0.87	2.04	4.23
6.	Differential free swell (%)	70	50	30
7	Shear Strength Parameters Cohesion (t/m²) Angle of internal friction (^{0})	12.25 3	9.65 5	7.5 9

Gravel

Locally available gravel has been used as cushion on the treated marine clay soil for conducting static plate load test. The physical properties of gravel were presented in the table 3.

Laboratory

Experimentation Index Properties

The atterberg limits of the untreated and treated marine clay were determined as per the procedures laid down in IS 2720(Part –V), 1970. It was observed that the liquid limit and the plasticity index of the treated marine clay have been decreasing when compared with the untreated marine clay as shown in the table 1.

Compaction Properties of Treated Marine Clay with AGBFS and Calcium Chloride

It was noticed from the results that the marine clay has exhibited the maximum dry density (MDD) up to the addition of 20% AAGBFS as presented in the table 4& Fig 1& 2 and further the MDD of the 20%ACGBFS + marina clay mix has been increased with addition of $CaCl_2$ up to 1% and beyond the addition of 1% $CaCl_2$, the MDD values of the 20%AGBFS
+ Marine clay mix has been decreased as presented in the table 5 & Fig 5&6.

Table 2: Physical Properties of ACGBFS

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 (%)	 19.072 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 (kN/m²) Angle of internal friction (^{0})	5 22

Table 3: Physical Properties Of Gravel

S. No	Property	Value
1.	Grain size distribution Gravel (%) Sand (%) Fines (%)	 60 30 10
2.	Atterberg limits Liquid limit (%) Plastic limit (%) Plasticity index (%)	 23 17 6
3.	Compaction properties Optimum Moisture Content, (%) Maximum Dry Density,	11.55 1.992
4.	Specific Gravity (G)	2.67
5	IS Classification	GW
6.	C.B.R (%)	15

Table 4: OMC and MDD Values of Marine Clays and $CaCl_2$

Sl. NO	Mix Proportion	OMC (%)	M D D(g/cc)	CBR (%)
1	100% soil	33.792	1.443	0.87
2	99.5%Soil+0.5%$CaCl_2$	27.40	1.470	1.38
3	99%Soil+1%$CaCl_2$	23.09	1.496	2.04
4	98.5%Soil+1.5%$CaCl_2$	23.45	1.492	1.67
5	98%Soil+2%$CaCl_2$	26.47	1.445	1.41

It was observed that the CBR values of marine clay has been increased with addition of $CaCl_2$ up to 2% and beyond the addition of % 2 $CaCl_2$, the CBR values of the marine clay has been decreased as presented in the table 4 & Fig 3and 4. Further the CBR value of the 20%AGBFS + marine clay mix has been increased with addition of $CaCl_2$ up to 1% and beyond the addition of 1% $CaCl_2$, the CBR values of the 20%AGBFS + marine clay mix has been decreased as presented in the table 5 & Fig 7 and 8.

Table 5: O M C and MDD Values of 20%ACGBFS + Marine Clay Mix with % Variation of calcium Chloride

Mix proportion	OMC (%)	MDD (g/cc)	CBR (%)
Untreated Marine Clay	33.792	1.443	0.87
1.0%$CaCl_2$ treated Marine clay with 18%ACBFS	23.07	1.60	3.79
1.0%$CaCl_2$ treated Marine clay with 20%ACBFS	**21.44**	**1.62**	**4.23**
1.0%$CaCl_2$ treated Marine clay with 22%ACBFS	24.00	1.59	3.89
1.0%$CaCl_2$ treated Marine clay with 24%ACBFS	26.98	1.57	3.50

Compaction Curves

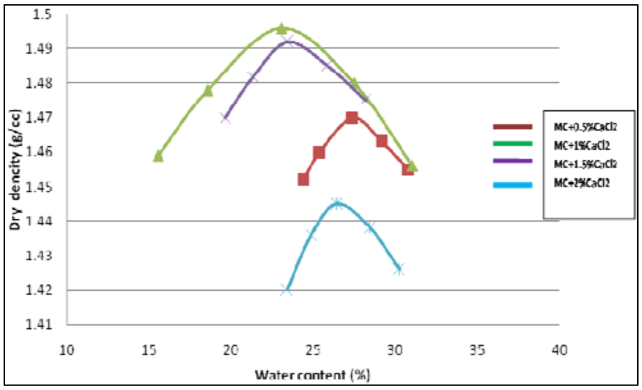
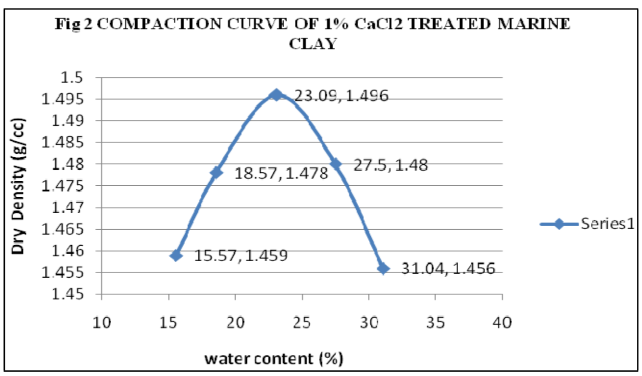


Fig 1: Variation in MDD Values of Marine Clay with Different % of $CaCl_2$



Optimum moisture content = **23.09%**
Maximum dry density = **1.496 g/cc**

Soaked CBR Test Results

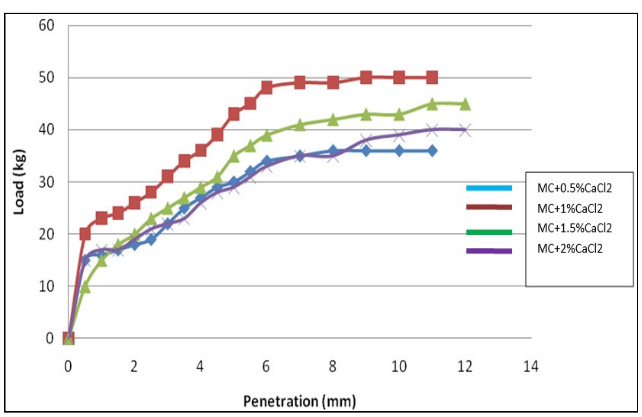
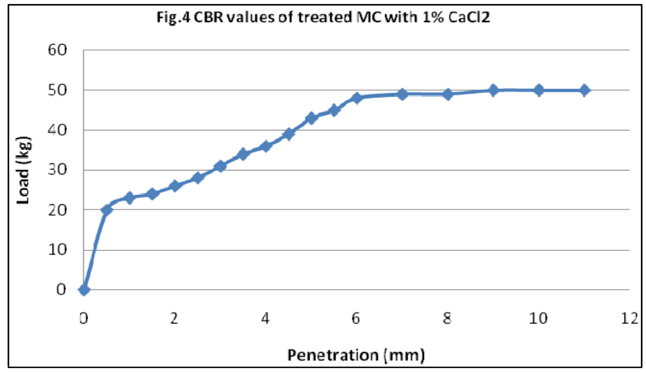


Fig 3: Load Vs penetration of Marine Clay with Different % of $CaCl_2$



CBR (soaked) value**: 2.04%**

Compaction Curves

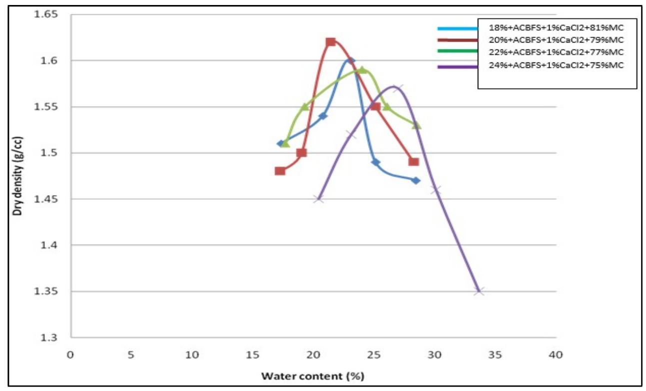
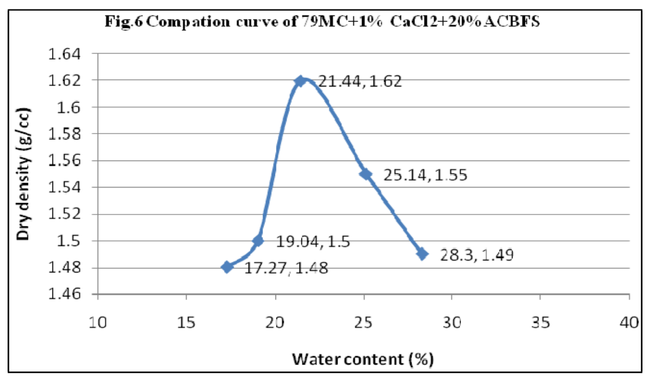


Fig 5: Compaction Curves of 20% ACGBFS+ Marine Clay Mix with % Variation of Calcium Chloride



Optimum moisture content = **21.44 %**
Maximum dry density = **1.62 g/cc**

Soaked CBR Test Results

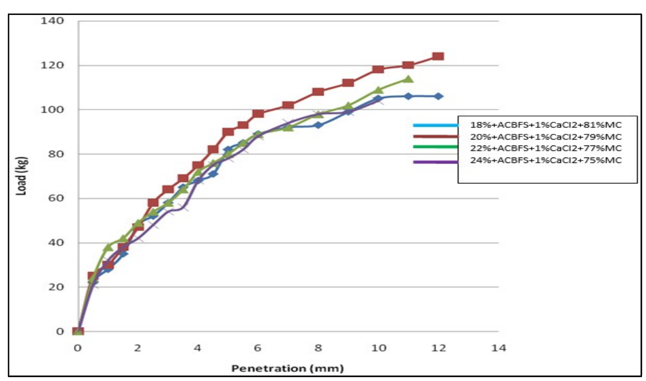
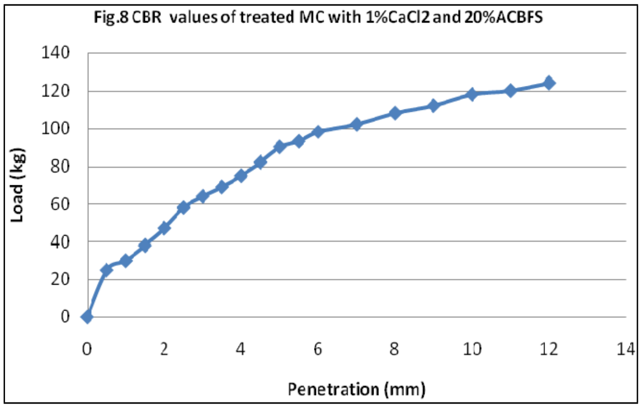


Fig 7: CBR Curves of 20% GBFS + Marine Clay Mix with % Variation of $CaCl_2$



CBR (soaked) value**: 4.23%**

Plate Load Tests On Model Foundation Soil Bed General: Four model foundation soil beds were prepared in the laboratory by using 60cm diameter mild steel tank with different alternatives as presented in table 6 for this investigation. The gravel was used as cushion in the four models and was laid uniformly on the untreated and treated & reinforced marine clay foundation soil bed. The tests were conducted at OMC and fully saturated condition (FSC).

Preparation of Foundation Soil Bed: The untreated and treated marine clay was compacted in layers of 5cm thickness at its OMC and MDD to a total compacted thickness of 30cm. In case of preparing untreated marine clay and "marine clay +ACGBFS" mix, the OMC of the natural marine clay and "marine clay + ACGBFS" mix were used respectively and the required quantity of chemical (1%$CaCl_2$) was dissolved in marine clay first and then only the ACGBFS was mixed. On the prepared foundation soil a sand layer of 1.0 cm thickness is provided and then the geotextile was placed. The geotextile was anchored to create the tensile force to offer max load carrying capacity and distributed equally over the stabilized foundation soil.

Preparation Of Gravel Cushion For Foundation Soil Bed: On the prepared untreated and treated & reinforced marine clay foundation bed, uniformly mixed gravel at OMC was laid in each layer of 5cm compacted thickness for a total thickness of 15.0cm. The gravel cushion layer was compacted to its MDD and OMC and the Plate.1 presents a prepared marine clay model foundation soil bed.

Static Plate Load Test: Static plate load tests were conducted in a model tank of circular in shape, having 60 cm diameter and 45 cm height as shown in the plate 2. The load was applied through the circular plate of 15cm diameter on to the untreated and treated & reinforced marine clay foundation soil bed at OMC and FSC.

Plate 1: Prepared Model Foundation Soil Bed

Plate 2: Static Plate Load Test Setup

A 15cm diameter circular metal plate with extension rod was placed centrally over the prepared model foundation soil bed (Plate 2) and a hydraulic jack of 50kN capacity was centrally placed over the circular plate for conducting the static plate load test. Two dial gauges were placed on the metal plate welded to the extension rod on opposite sides to measure the deformation. The static Plate load tests were carried out to determine the ultimate load carrying capacity of the untreated and treated & reinforced marine clay foundation soil bed. Each pressure increment was placed only till, no significant change in deformation was observed between consecutive load increments. The testing was further continued till the failure for knowing the ultimate load bearing capacity of the untreated and treated & reinforced marine clay foundation soil bed and the results are presented in the table 6 and Fig 9, Fig10

Table 6: Load Carrying Capacity of the Marine Clay Foundation Soil bed with various mix Proportions and their Settlements at OMC and FSC

S. No	Sub grade	Sub Base	Base course	Ultimate Cyclic Pressure (KN/m^2)		settlements (mm)	
				OMC	FSC	OMC	FSC
1	Marine Clay	----	------	**60**	**40**	**2.84**	**4.8**
2	Untreated marine clay	Gravel	WBM-III	**620**	**400**	**2.63**	**2.88**
3	Treated marine clay (1%$CaCl_2$ +20%ACBFS)	Gravel	WBM-III	**1000**	**600**	**1.87**	**2.04**
4	Treated marine clay (1%$CaCl_2$+20%ACBFS) and Geotextile provided as reinforcement & separator between sub grade and sub base	Gravel	WBM-III	**1400**	**700**	**1.71**	**1.94**

Fig.9 Laboratory cyclic plate load test results of 1% CaCl2+20 %ACBFS+Geotextile treated marine clay model flexible pavement at OMC

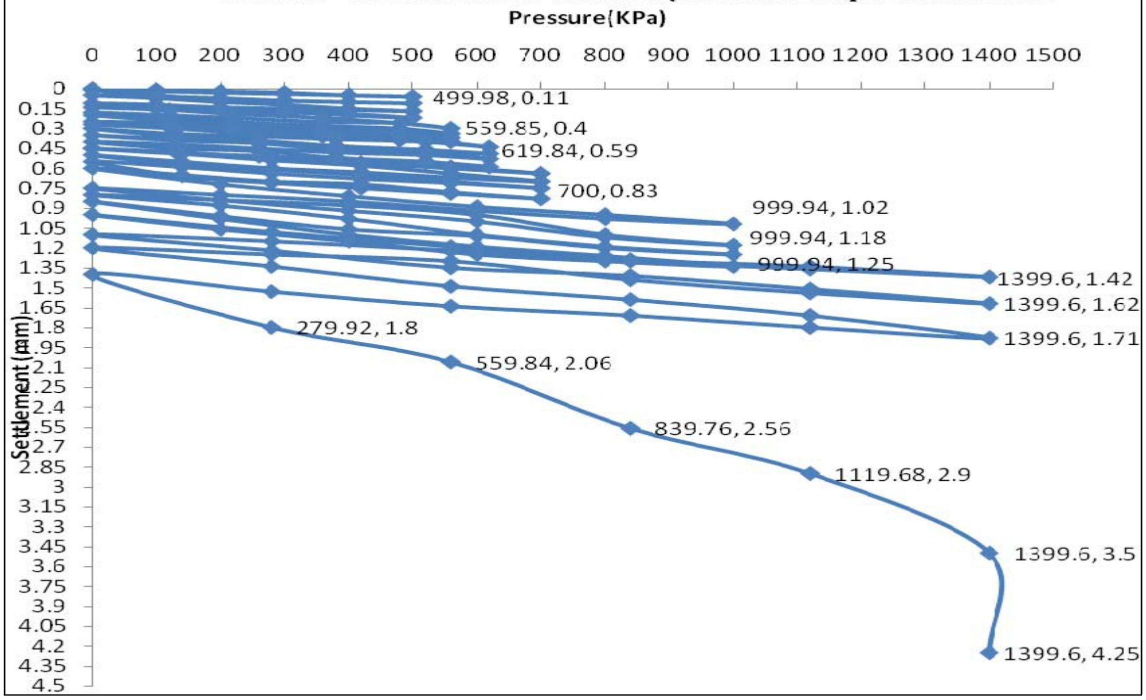
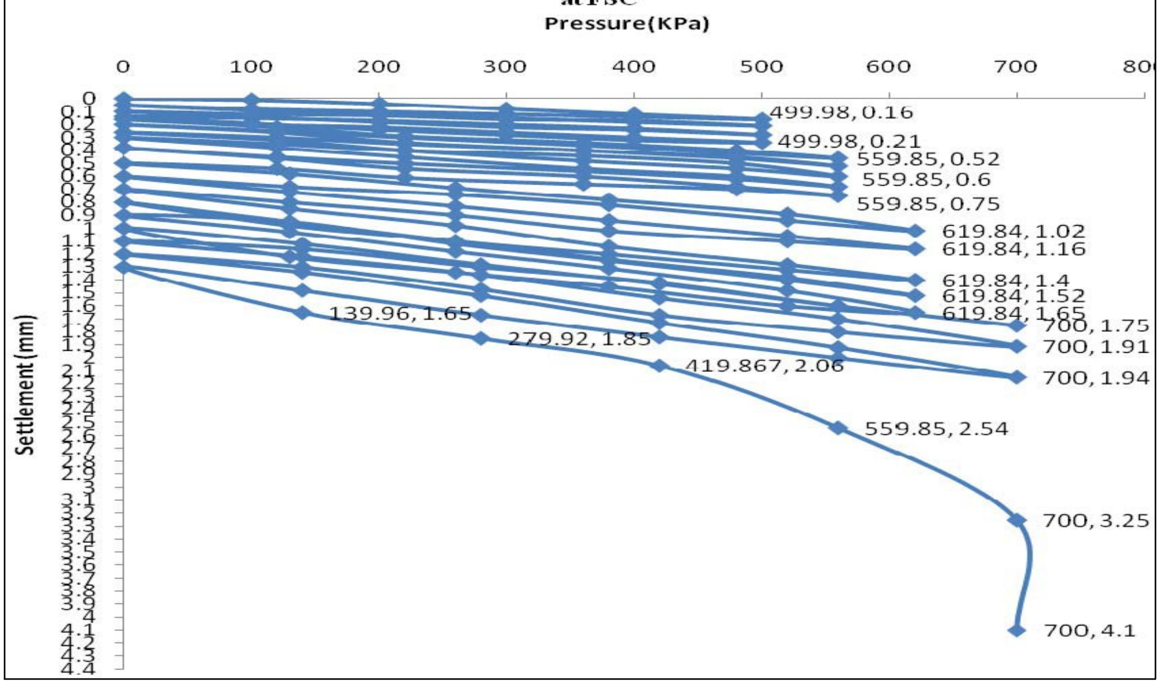


Fig 10 Laboratory cyclic plate load test results of 1% CaCl2+20% ACBFS+Geotextile treated marine clay model flexible pavement at FSC



Conclusions

The following conclusions were drawn based on the laboratory studies carried out on this work.

1. It was observed that the liquid limit of treated Marine Clay has been improved by 9.03% with the addition of 1.0% $CaCl_2$ and 38.71% on the addition of 1.0% $CaCl_{2+}$20% Air Cooled Slag respectively when compared with the untreated marine clay.
2. It was observed that the Plasticity index of the treated Marine clay has been improved by 17.93% with the addition of 1.0% $CaCl_2$ and 63.36% with addition of 1.0% $CaCl_{2+}$20% Air Cooled Slag respectively when compared with respect to the untreated marine clay.
3. It was observed that 1.0% $CaCl_2$ treatment as individually and with the combination of 20%ACBFS with marine clay has improved the laboratory CBR value.
4. It is observed laboratory cyclic load test results that the load carrying capacity of the treated marine clay sub grade flexible pavement has been improved by 161.29% at OMC and 150% at FSC when compared with the untreated marine clay sub grade flexible pavement.
5. It is noticed from the test result of cyclic load test, that the deformation of treated Has been decreased by 28.89% at OMC and 29.16% at FSC of compared with the untreated marine clay sub grade flexible pavement

Discussions

The reductions in deformation values were due to the chemical reactions between the added chemical and the replacement of clay mineralogy by ACGBFS.

Further, an increase in the load carrying capacity was observed by introducing the geotextile as reinforcement & separator. The reason for appreciable improvement in the load carrying capcity of the treated marine clay foundation soil bed was that the load was equally distributed on treated marine clay foundation soil by providing the geotextile as separator & reinforcement.

Form the results it was clearly observed that the efficiency of the geotextile as a reinforcement & separator.

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