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A LABORATORY STUDY ON THE EFFICACY OF BANANA FIBRE AND CALCIUM CHLORIDE FOR IMPROVING THE PROPERTIES OF THE MARINE CLAY AS SUBGRADE FOR FLEXIBLE PAVEMENTS

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Abstract—Marine clay is a type of clay found in coastal regions around the world. In the northern, de-glaciated regions, it can sometimes be quick clay, which is notorious for being involved in landslides. Clay particles can self-assemble into various configurations, each with totally different properties. The marine clay is suffering from high compressibility and low shear strength. The soil reinforcement is an effective and reliable technique for improving strength and stability of soil. The main object of this study is to investigate the strength characteristics before and after stabilization with banana fibre and calcium chloride. Various tests such as differential free swell, atterberg limits, modified proctor compaction test, California Bearing ratio and unconfined compression test were carried out. Also plate load tests were conducted to confirm the improvement in the load carrying capacity of the treated marine clay subgrade model flexible pavements n the laboratory.

Keywords—*Marine clay; banana fibre; calcium chloride ($CaCl_2$); Atterberg limits; OMC & MDD; California bearing ratio (CBR); unconfined compression test (UCC) and laboratory plate load tests.*

I. INTRODUCTION

Marine deposits are mainly confined along a narrow belt near the coast. In the south west coast of India, there are thick layers of sand above deep deposits of soft marine clays. The marine deposits have very low shearing strength and are highly compressible. They contain a large amount of organic matter. The marine clays are soft and highly plastic. Swelling characteristics of marine clay are also very high. For any construction work soil surrounding it plays an important role. Improvement of the soil properties can make it suitable for various purposes especially for road pavements.

Marine Clay deposits of Kakinada were collected for the testing with the aim to investigate its engineering properties and further make suitable for foundation construction or subgrades over it. The soil was collected at 4.00m depth from Kakinada Sea Ports Limited, Kakinada, A.P, India used for the investigation.

A. Literature Review

Banana fibre addition to soil improves the properties of the soil for road pavements (Sunny Teresa and Joy Annie, 2014) [1]. Coir fibre addition to soil in different proportions and length improves the geotechnical properties of soils making it suitable for road pavement (Dr.A.K.Sharma, Dr. P.K.Jain, Dr.Rakesh Kumar, Stuti Maury, 2015) [2]. Addition of RHA, Bamboo fibre and Banana fibre improves the properties of clayey soil (Navami Chandran B, Veena Viayan L., 2017)[3]. The geotechnical properties and load carrying capacity of marine clay improved with addition of GBFS (D. Koteswara Rao et al, 2009) [4]. Both untreated and rubber coated banana fibres were reinforced to soil sample to investigate the strength behavior of Kuttanad soil (Praisha .J.P, Ajitha A.R., 2016) [5]. The tensile and flexural strength of natural fibre reinforced polymer material is greater than that of glass fibre reinforced materials and proved their applications in automotive, transportation, construction and packaging industries (Begum K. and Islam M.A., 2013) [6]. Coir fibre added to marine clay improves the shear strength nearly four times than that in raw clay sample. The shear strength increase is seen up to 0.8% of coir fibre addition and increase in length up to 20mm beyond which the shear strength decreases (Bindu Sebastian, Babu.T.Jose, Sobha Cyrus, 2011) [7]. The tensile and compressive strength of blocks with addition of coconut, and oil palm fibres improved with the increase in fibre aspect ratio, whereas in the case of bagasse fibres strength decreased with the increase in fibre aspect ratio (D. Brett Martinson, Humphrey Danso, John Williams, Muhammad Ali, 2015) [8]. The saw dust ash addition to laterite soils improved the soil properties such as atterberg limits, un-confined compressive strength, California bearing ratio. The California bearing ratio obtained after addition of saw dust ash makes it suitable for subgrade and sub-base road pavements (George Rowland Otoko & Braide k Honest, 2014) [9]. Jute fibres added to lime treated black cotton soils in 1%, 2%, 5% decreased the expansive behavior of soil thereby improving the geotechnical properties of soil (Harshita Bairagi, R. K.Yadav, R. Jain, 2014) [10]. The effective and total porosities tested by tracer test showed only minor variations that is less than 10% (John E. Sevee, P.E. 2013) [11].

Addition of lime and saw dust improved the geotechnical properties of marine clay with optimum values of 15% and 4% for saw dust and lime (D. Koteswara Rao, M. Anusha, 2012) [12].

B. Objectives

The objectives of the present experimental study are

- To determine the properties of the Marine Clay.
- To evaluate the performance of Marine clay when treated with Banana Fibre as an admixture and calcium chloride as an additive.
- To study the performance of un-treated and treated marine clay sub grade flexible pavements under cyclic pressures.

C. Methodology

A brief literature on various problems posed by marine clay for the civil engineering structures have been reviewed and an outline of soil investigation and test procedure were adopted for considering the scope of study. The samples were collected and the laboratory tests were carried out on clayey soil sample with different combinations of banana fibre and calcium chloride to determine the properties of soil sample.

The stabilization of clayey soil with banana fibre is carried out by blending the soil with different percentages (0.25%, 0.50%, 0.75% and 1.00%) and optimum amount of banana fibre treated soil is further treated with varying percentages of $CaCl_2$ (0.50%, 1.00% and 1.50%) to determine the strength characteristics of soil.

II. MATERIALS AND METHODS

A. Marine Clay

The saturated Marine clay was collected from Kakinada Sea Port Limited, Kakinada, Andhra Pradesh state, India. It was collected at a depth of 4m from ground level. The Marine Clay used for the test was air dried and the Index & Engineering properties are determined as per IS code of practice.

Fig. 1 Marine Clay

B. Banana Fibre

Banana fibre is extracted from the pseudo stem Sheath of the plant. In this project we are using mechanical extraction. After extraction the fibre is shade dried for a day and it's ready to use.

Fig. 2 Banana Fibre

TABLE I
PHYSICAL PROPERTIES OF BANANA FIBRE

S.No	Properties	Values
1.	Colour	Light Brown
2.	Average diameter (mm)	0.75
3.	Average length (mm)	25
4.	Average tensile strength (N/mm^2)	11
5.	Fiber Density (g/cc)	0.62

Courtesy to Md. Ferdus Alam, Department of Textile Engineering, Southeast University

TABLE II

CHEMICAL PROPERTIES OF BANANA FIBRE

S.No	Properties	Values
1.	Tenacity	29.98 g/denier
2.	Fineness	17.15
3.	Moisture Regain	13.00%
4.	Elongation	6.54
5.	Alco-ben Extractives	1.70%
6.	Total Cellulose	81.80%
7.	Alpha Cellulose	61.50%
8.	Residual Gum	41.90%
9.	Lignin	15.00%

Courtesy to Md. Ferdus Alam, Department of Textile Engineering, Southeast University

C. *Calcium chloride*

Calcium Chloride is an inorganic compound, a salt with the chemical formula $CaCl_2$. It is a colorless crystalline solid at room temperature, highly soluble in water. The properties of Calcium chloride ($CaCl_2$) are given in the Table below:

TABLE III
PROPERTIES OF CALCIUM CHLORIDE ($CACL_2$)

Property	Value
Molar Mass	110.98 $g.mol^{-1}$
Appearance	White Powder
Odor	Odorless
Density	2.15 g/cm^3 (anhydrous) 2.24 g/cm^3 (monohydrate) 1.85 g/cm^3 (di hydrate) 1.83 g/cm^3 (tetra hydrate) 1.71 g/cm^3 (hexahydrate)
Melting Point	772-775 ^{0}C anhydrous 260 ^{0}C monohydrate 175 ^{0}C dehydrate 45.5 ^{0}C tetra hydrate 30 ^{0}C hexahydrate
Boiling Point	1,935 ^{0}C

Courtesy to International Programmer on Chemical Safety and the European Commission

D. *Gravel*

For the present investigation, the gravel was collected from Surampalem East Godavari District Andhra Pradesh State, India. The gravel was classified as well graded gravel and was used in this investigation as a sub grade on untreated, treated & reinforced marine clay sub base in all model flexible pavements.

E. *Geotextile*

Poly Propylene Woven Geotextile GWF-40-220, manufactured by M/s GARWARE WALL ROPES LTD, Pune, India, was used in the laboratory investigations for conducting of cyclic plate load test. The tensile strength of woven geotextile is 60.00kN/m for warp and 45.00kN/m for weft. In this investigation Geotextile was placed between sub grade and sub base, and between sub base and base course as a separator and reinforcement for model flexible pavement.

TABLE IV
PROPERTIES OF GRAVEL

S.No	Property	Values
1	Specific gravity	2.6
2	Grain size Distribution	
	Gravel (%)	62
	Sand (%)	28
	Silt & clay (%)	10
3	Compaction properties	
	Maximum dry density (kN/m^3)	19.82
	OMC (%)	11.45
4	Atterberg limits	
	Liquid limit (%)	22
	Plastic limit (%)	16
	Plasticity index (%)	5
5	Soaked CBR (%)	14

F. Method

The experimental work consisted of the characterization of the soils and the evaluation of the effect of various percentages of fibre and calcium chloride. The Geotechnical properties of soil such as liquid limit and plastic limit, free swell, compaction test, California bearing ratio, tri-axial test, unconfined compressive strength test and laboratory plate load tests were conducted to determine the properties of marine clay. The properties of marine clay were shown in Table: 5. It can be observed that specific gravity of soil is very low due to the presence of organic matter. Modified proctor compaction test and California bearing ratio were conducted for stabilized soils and results were analyzed.

TABLE V
PROPERTIES OF MARINE CLAY

S.No	Property	Properties
1.	Grain size distribution Gravel (%) Sand (%) Silt (%) Clay (%)	 0 5 27 68
2.	Atterberg limits Liquid limit (%) Plastic limit (%) Plasticity index (%)	 72 31 41
3.	Compaction properties Optimum Moisture Content,(O.M.C)(%) Maximum Dry Density, (M.D.D)	 40.55 1.254
4.	Specific Gravity (G)	2.37
5.	IS Classification	CH
6.	Soaked C.B.R (%)	0.75
7.	Free swell (%)	100
8.	Unconfined Compressive Strength (Kg/cm²)	0.68
9	Cohesion (C) (Kg/cm²)	0.34
10	Angle of internal friction (ø)	2º36′

III. Results and Discussions

A. Compaction Properties

Standard Proctor test was conducted on air dried marine clay soil sample with varying moisture content as per IS code: 2720 (part-XVI), 1979. Test was conducted to determine the optimum moisture content and maximum dry density. The test was conducted for Marine clay without addition of banana fibre and later with addition of banana fiber at various proportions.

TABLE VI
COMPACTION PROPERTIES OF MARINE CLAY TREATED WITH DIFFERENT PERCENTAGES OF BANANA FIBRE

Mix Proportion	OMC (%)	MDD (g/cc)
100% MC + 0% BF	40.55	1.254
99.75% MC + 0.25% BF	42.44	1.225
99.50% MC + 0.50% BF	44.93	1.175
99.25% MC + 0.75% BF	46.25	1.146
99.00% MC + 1.00% BF	4896	1.124

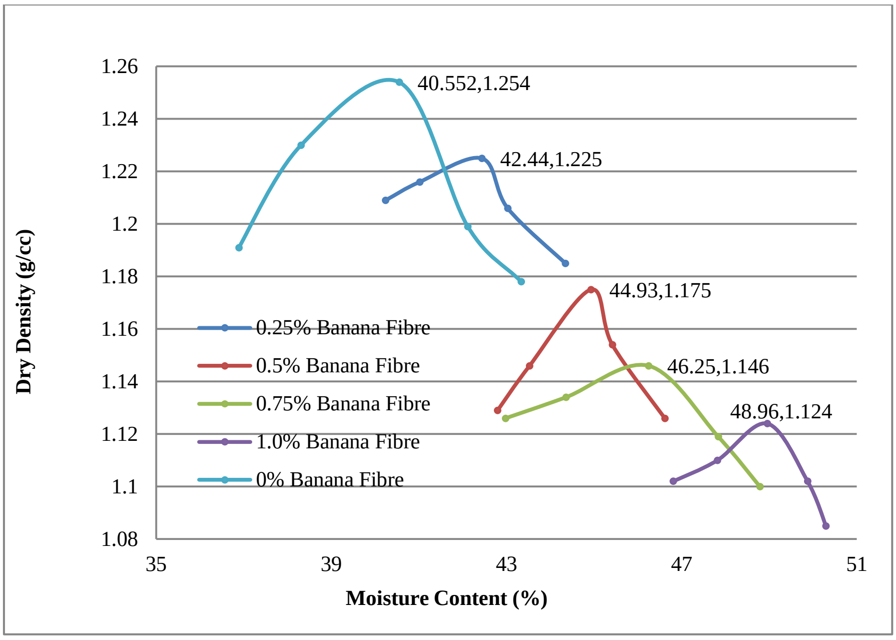

Fig. 3 OMC & MDD values of marine clay treated with percentage variation of banana fibre

It was observed from all the different combinations of Banana Fibre tried in this investigation there is a reduction in MDD values and increase in OMC values of treated Marine Clay, due to the absorption of water in Fibre.

B.California Bearing Ratio:

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). 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.

TABLE VII
CBR VALUES OF MARINE TREATED WITH PERCENTAGE VARIATION OF BANANA FIBRE

Mix Proportion	CBR value (%)
100% MC + 0% BF	0.75
99.75% MC + 0.25% BF	1.95
99.50% MC + 0.50% BF	2.40
99.25% MC + 0.75% BF	2.70
99.00% MC + 1.00% BF	2.06

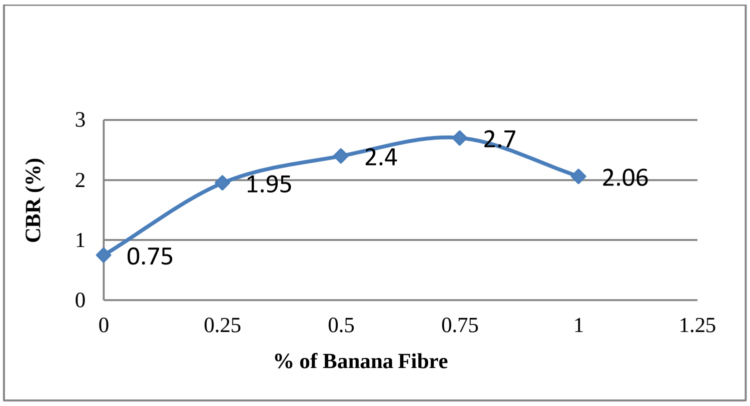

Fig. 4 CBR values of marine clay treated with percentage variation of banana fibre

Discussion 1:

- In present study, it can be observed that addition of 0.75% Banana Fibre treated Marine clay has exhibited the CBR value of 2.70% which is less as per codes of practice.
- As per IRC 37:2001 and 37:2012, the subgrade soil should possess the minimum CBR value of 6%.

- To achieve required CBR value as per codes of practice, an attempt has been taken to improve the CBR of Banana Fibre treated marine clay with percentage variation of Calcium Chloride to suit it as subgrade for flexible pavement.

C. Compaction Properties:

The Marine Clay was treated with optimum percentage of Banana Fibre and stabilized with different percentages of $CaCl_2$. The optimum value of $CaCl_2$ was obtained at 1%.

TABLE VIII
COMPACTION PROPERTIES OF MARINE CLAY TREATED WITH 0.75% BANANA FIBRE ON PERCENTAGES VARIATION OF $CACL_2$

Mix Proportion	OMC (%)	MDD (g/cc)
98.75% MC +0.75% BF + 0.50% $CaCl_2$	44.92	1.253
98.25%MC+0.75% BF + 1.00% $CaCl_2$	**39.51**	**1.29**
97.75% MC +0.75% BF + 1.50% $CaCl_2$	37.73	1.266

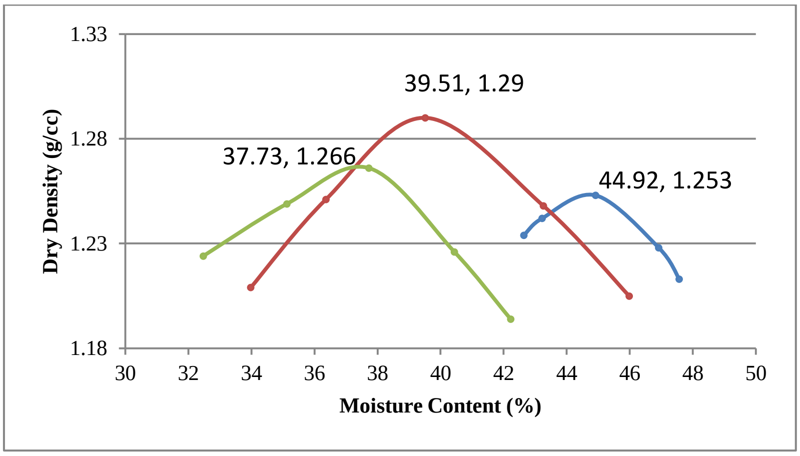

Fig. 5 OMC & MDD values of marine clay treated with 0.75% banana fibre on percentage variation of $CaCl_2$

D. California Bearing Ratio

The Marine clay was treated with Optimum percentage (0.75%) of Banana Fibre and stabilized with different percentages of Calcium chloride. The optimum value of $CaCl_2$ obtained at 1.00%. The CBR value has been increased from 2.70% to 6.164%.

TABLE IX
CBR VALUES OF 0.75% BANANA FIBRE TREATED MARINE CLAY WITH PERCENTAGE VARIATION OF $CACL_2$

Mix Proportion	CBR value (%)
98.75% MC + 0.75% BF + 0.50% $CaCl_2$	4.812
98.25% MC + 0.75% BF + 1.00% $CaCl_2$	6.164
97.75% MC + 0.75% BF + 1.50% $CaCl_2$	4.21

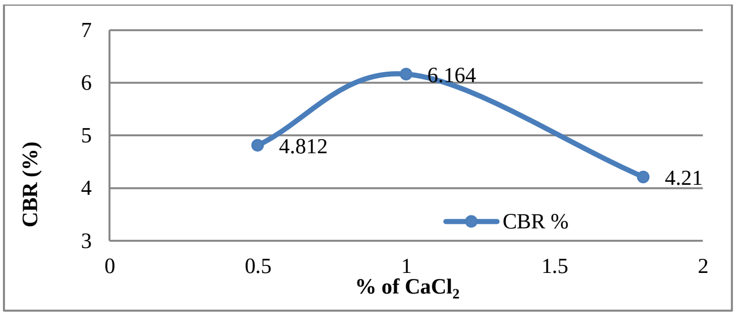

Fig. 6 CBR values of 0.75% banana fibre treated marine clay with percentage variation of $CaCl_2$

E. The properties of untreated and treated Marine clay with optimum percentages of Banana Fibre & calcium chloride:

The properties of both untreated and treated marine clay with optimum percentages of Banana Fibre & Calcium Chloride are provided in the following table 10 .

TABLE X
THE PROPERTIES OF UNTREATED AND TREATED MARINE CLAY WITH OPTIMUM PERCENTAGES OF BANANA FIBRE &$CaCl_2$:

S.No	Property	Marine Clay	99.25MC +0.75% BF	98.25MC +0.75% BF + 1.00% $CaCl_2$
1.	Atterberg limits Liquid limit (%) Plastic limit (%) Plasticity index (%)	 72 31 41	 65 34 31	 58 37 21
2.	Compaction properties O.M.C (%) M.D.D (g/cc)	 40.55 1.254	 46.25 1.146	 39.51 1.290
3.	Specific Gravity (G)	2.37	2.494	2.689
4.	IS Classification	CH	CH	CH
5.	Soaked C.B.R (%)	0.75	2.70	6.164
6.	Free swell (%)	100	80	40
7.	UCS (Kg/cm²)	0.68	1.256	1.343
8.	Cohesion (C) (Kg/cm²)	0.34	0.62	0.66
9.	Angle of internal friction (ø)	2º36’	6º08’	8º04’

Discussion 2:

- From the above study, it can be observed that 0.75% Banana Fibre treated Marine Clay has exhibited the CBR value of 6.14% on addition of 1% CaCl2 as an optimum.
- Hence this treated marine clay is suitable as subgrade for flexible pavements as per IRC 37-2001, 2012 codes of practice.

F. Cyclic Plate Load test:

Cyclic plate load tests were carried out on untreated and treated Marine clay flexible pavements in separate model tanks, a woven Geotextile was used as reinforcement and separator between subgrade & subbase and subbase & base course under cyclic pressures 500kPa, 560kPa, 630kPa, 700kPa, 1000kPa. The tests were conducted until the failure of the Marine clay model flexible pavements at OMC conditions and the results were presented in Table 11.

a. Construction procedure of model flexible pavement for conducting Cyclic Plate Load Test on untreated and treated marine clay:

Tests were carried out on model flexible pavements which were prepared in circular steel tanks of diameter 60cm. A circular metal plate of 10cm diameter was used for loading on the model flexible pavement system. The sample tank was placed on the pedestal of the compression testing machine at center of the loading frame. Hydraulic jack of 5 ton capacity was placed on the 10cm metal plate which was placed at the center of the model flexible pavement. Then arrange the two dial gauges of least count 0.01mm for obtaining the deformations as shown in the schematic diagram.

Marine clay which was used as a subgrade in this study was pulverized and passed through 4.75mm I.S sieve. The thickness of marine clay subgrade was 20cm which was obtained by compacting, each layer of 5cm thick marine clay to 2cm thickness at its OMC. On the prepared subgrade, a thickness of 5cm gravel sub base was laid, and was compacted in 2 layers up to a total thickness of 5cm. A 5cm thick WBM-III was used as base course. The geo-textile was used as a separator and reinforcement to create tensile force to offer maximum load carrying capacity and uniformly distributed over the treated sub grade.

Fig.7 Author conducting cyclic plate load test

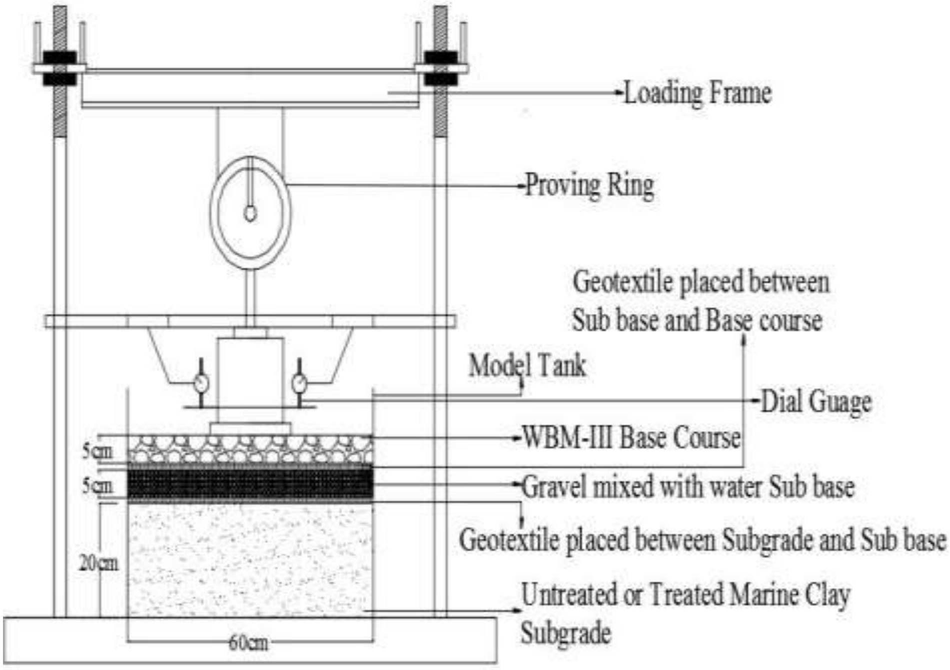

Fig. 8 Schematic diagram of model flexible pavement for conducting cyclic plate load test

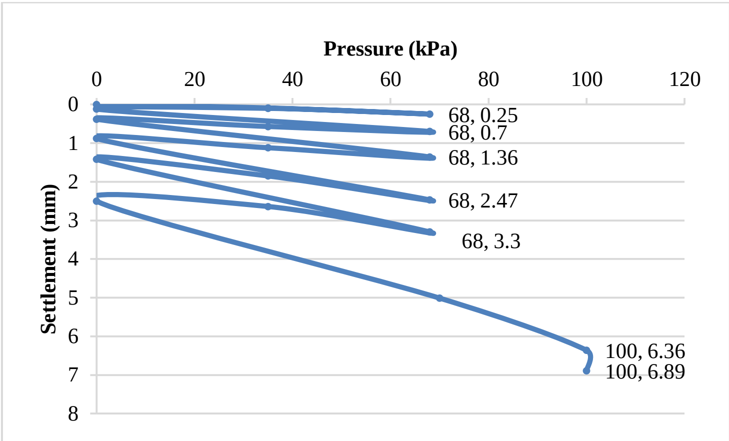

Fig. 9 Laboratory Cyclic Plate Load Test Results of Untreated Marine Clay at OMC

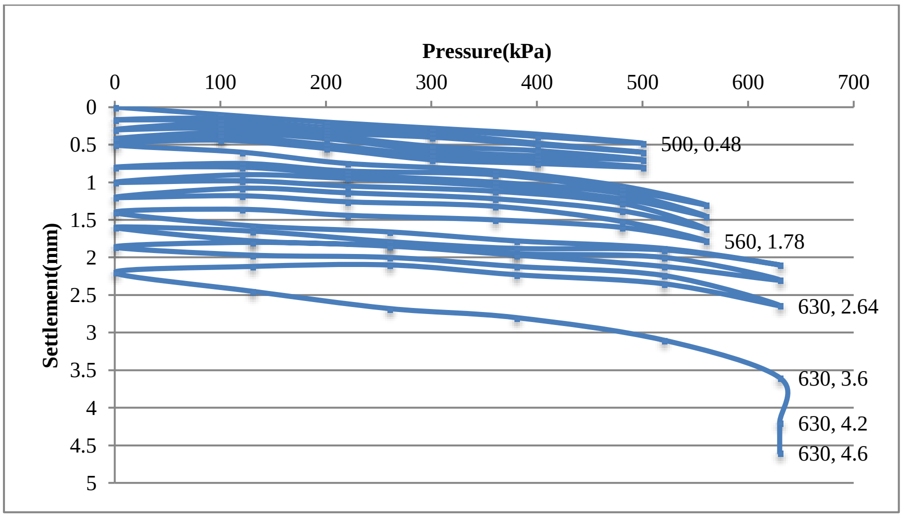

Fig. 10 Laboratory Cyclic Plate Load Test Results of Untreated Marine Clay for Model Flexible Pavement Subgrade at OMC

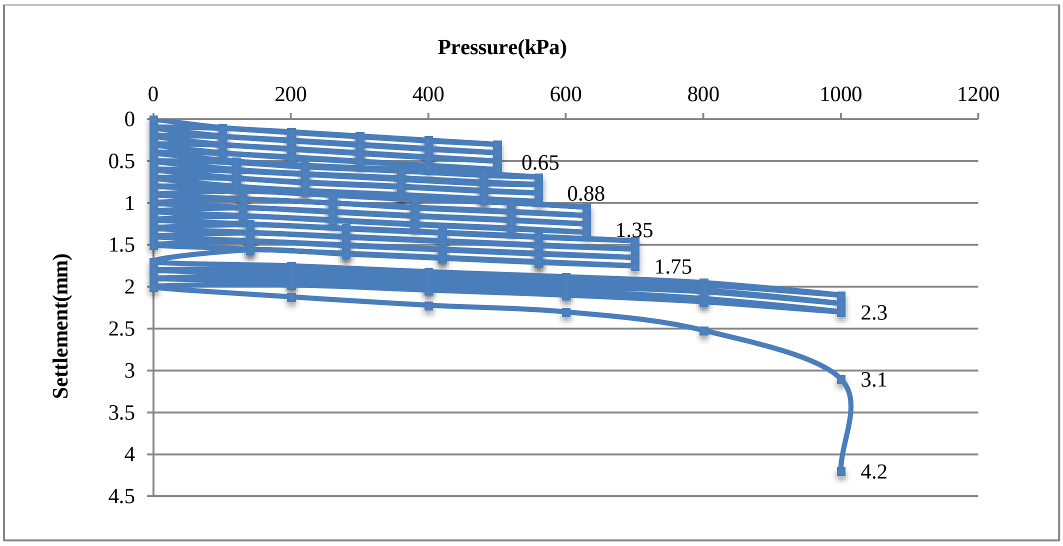

Fig. 11 Laboratory Cyclic Plate Load Test Results of Treated Marine Clay for Model Flexible Pavement Subgrade at OMC

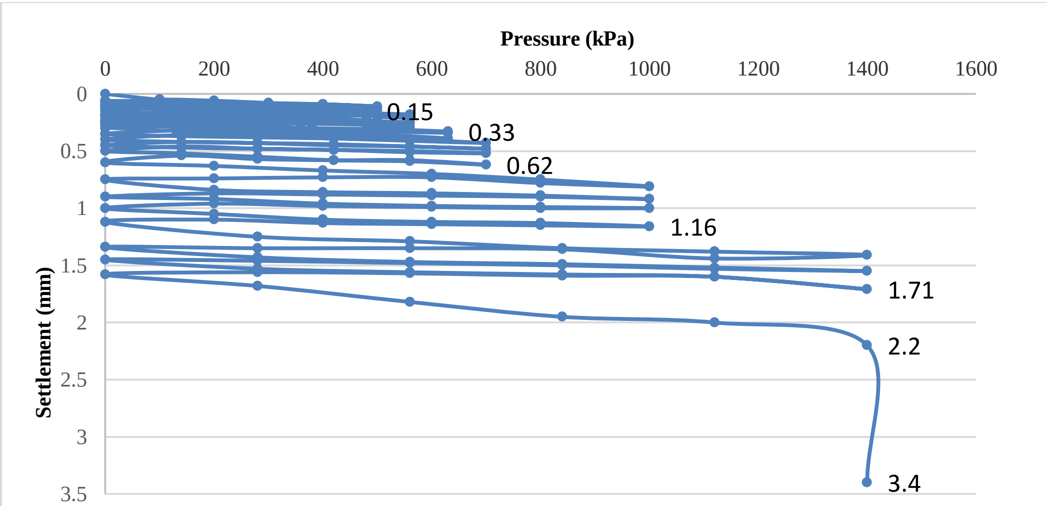

Fig. 12 Laboratory Cyclic Plate Load Test Results of Single layer Geotextile as Reinforcement and Separator for Treated Marine Clay for Model Flexible Pavement Subgrade at OMC

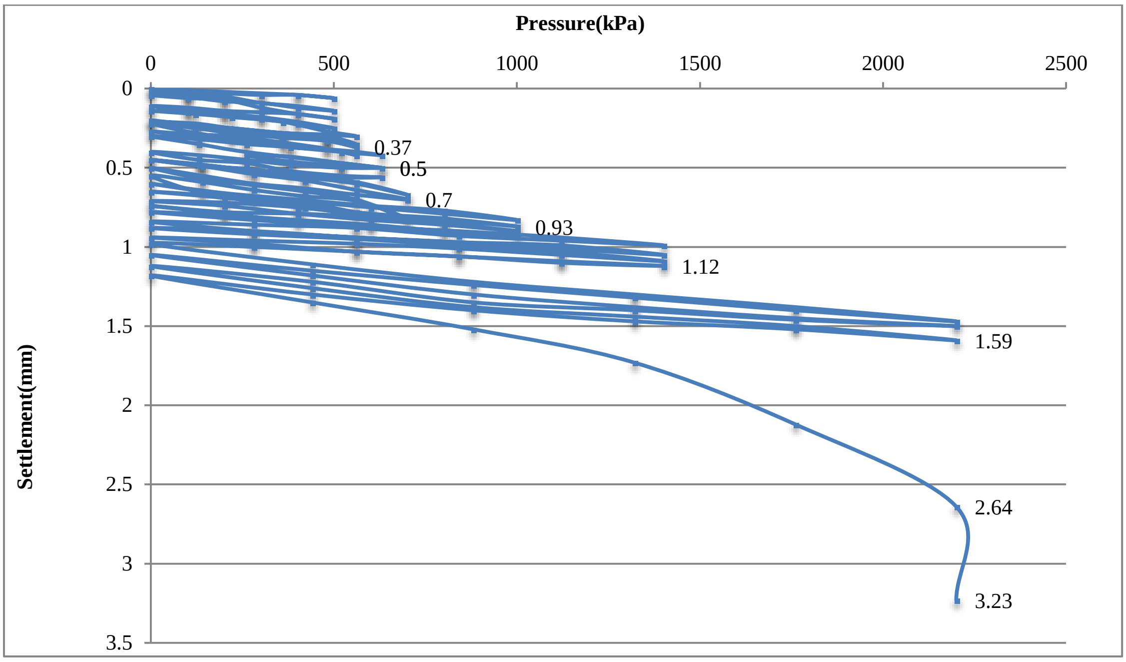

Fig. 13 Laboratory Cyclic Plate Load Test Results of Double layered Geotextile as Reinforcement and Separator for Treated Marine Clay for Model Flexible Pavement Subgrade at OMC

TABLE XI
THE LABORATORY CYCLIC PLATE LOAD TEST RESULTS OF UNTREATED AND TREATED MARINE CLAY WITH BANANA FIBRE AND CALCIUM CHLORIDE ON MODEL FLEXIBLE PAVEMENT SUBGRADES AT OMC.

S.No	Sub-grade soil	Gravel Cushion	Sub-Base	Ultimate Pressure (kN/m^2)	Settlement (mm)
1	Marine clay	----	----	68	3.30
2	Untreated marine clay	Gravel	WBM III	630	2.64
3	Treated marine clay	Gravel	WBM III	1000	2.3
4	Treated marine clay with single layered geo-textile provide as reinforcement and separator	Gravel	WBM III	1400	1.71
5	Treated marine clay with double layered geo-textile provide as reinforcement and separator	Gravel	WBM III	2200	1.59

Discussion 3:

It has been observed from the laboratory cyclic plate load test results that the doubly reinforced flexible pavement has exhibited the maximum cyclic pressure than the remaining untreated and treated flexible pavements.

IV. CONCLUSION:

1. From the laboratory studies, it was observed that the Free Swell of the marine clay has been decreased by 20% on addition of 0.75% banana fibre and further the free swell of the 0.75% banana fibre treated marine clay has been decreased by 50% with addition of 1% Calcium Chloride as an optimum when compared with the untreated marine clay.
2. It is noticed from the laboratory test results that the liquid limit of the marine clay has been decreased by 9.72% on addition of 0.75% banana fibre and further the liquid limit of the banana fibre treated marine clay has been decreased by 10.77% with addition of 1% Calcium Chloride as an optimum when compared with untreated marine clay.
3. It is observed from the laboratory test results that the plasticity index of the marine clay has been improved by 24.39% on addition of 0.75% banana fibre and further plasticity index of banana fibre treated marine clay has been improved by 32.25% with the addition of 1% Calcium Chloride as an optimum when compared with untreated marine clay.
4. It is observed from the laboratory test results that the C.B.R. value of the marine clay has been improved by 260% on addition of 0.75% banana fibre as an optimum and further C.B.R. value has been improved by 128.29% when 1% calcium chloride is added with respect to untreated marine clay.
5. It is noticed from the laboratory test results of cyclic plate load test that the ultimate pressure of treated marine clay sub grade flexible pavement has been increased by 249.20% with respect to untreated marine clay sub grade flexible pavements.
6. It is noticed from the laboratory test results of cyclic plate load test that the total deformations of treated marine clay sub grade flexible Pavement has been improved by 39.77% with respect to untreated marine clay sub grade flexible pavements.

It was found that properties of the marine clay have been improved by the addition of banana fibre and calcium chloride. So, finally it was concluded from above results that the addition of optimum amount of 0.75% Banana Fiber & 1% Calcium Chloride increases the Soaked CBR value from 0.75% to 6.164%, according to IRC 2001 the CBR value should be in between more than 6%, to be used for Subgrade, which makes it suitable for subgrade soil for road pavements.

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