

A Laboratory Investigation on the Influence of Calcium Chloride on Silica Fume Treated Marine Clay as Sub-Grade for Flexible Pavements under Cyclic Pressures

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Abstract

Marine clay is highly deformable soil in nature, available along the coastal corridor. Marine clays are highly compressible and possess moderate swelling behavior. Marine clays are moderate in expansive nature due to the presence of chlorite, illite, kaolinite and montmorillonite. The natural water content of the marine clay is always greater than its liquid limit. The properties of marine clay differ significantly in moist and dry conditions. Due to the poor engineering characteristics of these marine clay soil deposits causes several problems in pavement design and has potential to destroy building foundations in almost all the countries. Marine clays are fully saturated, soft and sensitive which possess low density and low shear strength due to which they are consolidated over a period of time. The present study deals with the experimental work on the influence of calcium chloride on silica fume treated marine clay as subgrade for flexible pavements under cyclic pressures.

KEYWORDS— Marine Clay, Silica Fume, Calcium Chloride, OMC& MDD, CBR, Cyclic Pressures, Deformation, Atterberg Limits, Grain Size distribution.

1. INTRODUCTION

Transportation play a vital role in the development of any country. In every country, transportation consumes large portion of budgets in case of maintenance and replacement of pavement. Methods for maintaining pavement and reducing cost of construction can help in maintaining better road networks which helps the transportation department. Modern pavements are expected to provide high level safety to the users. Pavements are designed according to the empirical approach which helps in selecting appropriate soil and pavement parameters. Variations in the thickness sub base can occur and are to be expected gradually over short distances depending on the geological conditions of the surface soil. Higher variations in sub grade soil characteristics may lead to poor performance of pavements which cost in higher maintenance estimates. To minimize these problems, some of the methods have been developed to minimize the variability in sub grade characteristics.

The soil formed in the ocean bed as well as located on shore can be classified as marine clay. The properties of saturated marine clay may vary considerably from moist soil to dry soil. Marine clay is microcrystalline in nature, it contains clay minerals like chlorite, illite, kaolinite and non-clay minerals like quartz and feldspar are present in marine soil. Marine clay imposes great problems in pavement design due to uncertainty associated with their performance. Marine clays tend to swell when wetted and may shrink when dried. These volume changes may create problems in structures that come in to their contact.

Several remedial measures like soil replacement, pre-wetting, moisture control, chemical stabilization have been done in various degrees of success. Unfortunately the limitation of these techniques questioned their adaptability in all conditions. So, work is

being done all over, to evolve more effective and practical treatment methods, to alleviate the problems caused to any structures laid on marine clay strata.

The comprehensive review of literature says that a considerable amount of work, related to the strength characteristics, deformation characteristics and consolidation characteristics has been carried out worldwide almost from past 50 years. From the various contributions, the investigation on marine clay conducted by S. Narasimharao et al.(1987,1996), Mathew et al., (1997), Investigation on chemical stabilization has been conducted by (Petry and Armstrong, 1989; PrasadaRaju, 2001) revealed that electrolyte like potassium chloride, calcium chloride and ferric chloride may be effectively used in place of conventionally used lime because of their readiness to dissolve in water and supply adequate cations for cation exchange.

Babu T. Jose, A. Sridharan and Benny Mathews Abraham (1988) reported the engineering properties of Cochin marine clays and concluded that these marine clays are characterized by high Atterberg limits and natural water contents. They are moderately sensitive with liquidity indices ranging over 0.46 to 0.87. The grain size distribution shows almost equal fractions of clay and silt size with sand content varying around 20%. The pore water has low salinity which results in marginal changes in properties on washing. Consolidation test results showed a preconsolidation pressure of up to about 0.5 kg/cm with high compression indices..., these clays have very low undrained shear strength.

Aswanikumar and Mehata (1998) reported by the laboratory investigation that the stabilize granulated blast furnace slag is used in road construction and concluded that the load carrying capacity has been improved on addition of fly ash when lime and cement has been used as admixture.

NarasimhaRao et al., (1996) stated that the permeability (k) values shows an enormous improvement by using lime column technique and the permeability value was improved up to 23times. This shows good promise for improving the soft coastal deposits and the offshore deposits.

Phani Kumar and Radhey Sharma (2004) reported that fly ash can be used as additive in improving the engineering characteristics of soils. They observed that there is decrease in plasticity and hydraulic conductivity and increase in penetration resistance of blends with increase in Fly ash content. Basak and Purkayastha (2009), reported that the engineering characteristics of marine clay collected from visakhapatnam, India and the physical, chemical and mineralogical properties were presented and the strength, stiffness of the soil matrix were established. e. Improving the strength of soil by stabilization technique was performed by Rajasekhar.G and NarasimhaRao.S (2000) and SupakjiN, Sanupong B et.al (2004), Dr. D. Koteswara Rao (2011, 2012) and further, made suitable for construction of foundations over it and also for the flexible pavement sub grades.

Dr. D. Koteswara Rao (2011) studied the efficiency of calcium chloride, potassium chloride, GBFS with marine clay and the test results concluded that load carrying capacity of marine clay foundation bed has been improved.

Dr. D. Koteswara Rao (2012) studied the efficiency of lime and rice husk ash treated marine clay and the test results concluded that the ultimate load carrying capacity of the treated marine clay model flexible pavement has been compared with untreated marine clay model flexible pavement.

Dr. D. Koteswara Rao (2012) studied the efficiency of rice husk ash and ferric chloride with marine clay and the test results concluded that load carrying capacity of marine clay foundation soil bed has been improved.

Dr.D.KoteswaraRao(2013)studied the efficiency of Vitriified Polish Waste with marine clay and the test results concluded that marine clay can be used as pavement sub

grade if this VPW treated marine clay is treated with optimum percentage of chemicals or by reinforcing the pavement.

Wong et al., (2014) reported that when marine Clay treated with Calcium chloride-Cement mixture the bearing capacity of the Marine Clay improved greatly.

Nor ZurairahettyMohdYunus et al., (2015) presented the efficiency of lime for improving the strength and compressibility behavior of the marine clay (Iskandar Malaysian Region), Int.J.of GEOMATE.

J. Sangeetha et al., (2016) reported that Marine Clay treated with percentage variation of jerofixthe CBR value and MDD values.

Dr. Kalpana V. Maheshwari et al., (2016) observed that Marine Clay when treated with different percentages of murrum soil the settlements and swelling reduced as the percentage of morrum increased.

DSV Prasad et al., (2016) reported that Marine Clay when treated with various percentages of Quarry dust as an admixture and Ferric chloride as additive the deformation and load carrying capacity of treated Marine Clay increased greatly.

Mohammed Ali Mohammed Al-Bared and AmanatonMarto (2017) Presented A review on the geotechnical and engineering characteristics of marine clay and the modern methods Viz., Cement grouting, Chemical Additive and Environmental friendly additive are used for improving the properties of marine clay. Among the above three, the authors have presented cement stabilization is the best method for improving the properties of marine clay, (MJFAS).

Dr.D. Koteswara Rao and Y. SaiEswar (2018) presented the efficiency of Calcium Carbide and other chemicals for improving the consolidation characteristics of marine clay.

Dr. D. Koteswara Rao and Ch. Ajay Kumar (2018) presented a laboratory investigation on the efficiency of lime and silica fume on improving the properties of the expansive soil for flexible pavements subgrades.

Dr. D. Koteswara Rao and K. Pradeep (2018), presented the importance of using Phosphogypsum and lime for improving the properties of Kakinada marine clay to suite it as a subgrade for flexible pavements.

II. OBJECTIVES OF THE STUDY

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 Silica Fume as an admixture and Calcium Chloride as an additive.
- To study the performance of un-treated and treated marine clay as sub grade for flexible pavements under cyclic pressures.

III. MATERIALS USED

3.1 Marine Clay

The Marine clay used in this study is obtained at a depth of 0.5m to 1m in Kakinada Sea Ports Limited, Kakinada which is located on east coast of India at a latitude of 16° 56' North and longitude of 82° 15' East.

3.2 Silica Fume

The Silica Fume used in this study is collected from GRR ASSOCIATES, Visakhapatnam, Andhra Pradesh, India.

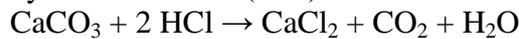
Table 3.1 Physical Properties of Silica Fume Table 3.2 Chemical Composition of Silica Fume

PROPERTY	VALUE
Particle size(typical)	<1m
Bulk density As Produced Slurry Densified	130-430kg/m ³ 1320-1440kg/m ³ 480-720kg/m ³
Specific Gravity	2.5
Surface Area	13,000- 30,000m ² /kg

Constituents	Composition (%)
SiO ₂	93.68
K ₂ O	0.27
Na ₂ O	0.36
Fe ₂ O ₃	0.88
MOISTURE	0.79
+45 MICRON	2.42
Al ₂ O ₃	0.70

Courtesy to GRR Associates, Vizag 3.2.1 Calcium Chloride (CaCl₂) Commercial grade calcium chloride (consisting of 58% calcium chloride +42% magnesium chloride) was used in this investigation. The quantity of calcium chloride was varied from 0% to 1.5% by dry weight of soil.

Preparation: Calcium chloride is mainly produced by reacting limestone (CaCO₃) with hydrochloric acid (HCl).



It is also produced as a major by-product during manufacture of soda ash (Na₂CO₃) by the Solvay process, in which limestone is reacted with NaCl solution.

Physical properties: Calcium chloride is found as an odorless white powder, granules or laves. It has a density of 2.15 g/ml, melting point of 782 °C and a high boiling point over 1600 °C.

Chemical properties: CaCl₂ is highly water soluble, hygroscopic (absorbs moisture from air) and deliquescent (absorbs enough water to turn into liquid). Calcium chloride dissolves in water in a very exothermic manner (releasing a large amount of heat). Calcium chloride fully dissociates in water to give calcium cations and chloride anions. In aqueous solutions, the calcium ions can displace other ions in exchange reactions, such as the conversion of potassium phosphate into calcium phosphate:



Uses: Calcium chloride has several similar uses as sodium chloride, and it is used as a food additive, food preservative, for de-icing roads in winter, and as brine in refrigeration plants. It is also used as a swimming pool chemical, in water treatment plants, and for desiccating purposes. It also has applications in metallurgy, oil-well drilling, and rubber, paper, dye and paint industries.

Geotextile

The geotextile used in this study is PP woven geotextile-GWF-40-220, manufactured by GARWARE –WALL ROPES LTD, Pune, India. The tensile strength of woven Geotextile is 62.00kN/m for warp and 46.00kN/m for weft.

Aggregates

The size of Road aggregate used in this study is inbetween 40-20 mm, confirming WBM-III standards was used for the preparation of the base course in the investigation of the modal flexible pavements.

Gravel

The Gravel used in this study is collected from Surampalem, East Godavari District, Andhra Pradesh, India. The gravel is well graded gravel and used as sub-base course in all model flexible pavements.

Table 3.3 Properties of Gravel

Sl.No	Property	Values
1	Specific gravity	2.65
2	Grain size Distribution	
	Gravel (%)	63
	Sand (%)	28
	Silt & soil (%)	9
3	Compaction properties	
	Maximum dry density (g/cc)	19.96
	OMC (%)	11.48
4	Atterberg limits	
	Liquid limit (%)	28
	Plastic limit (%)	16
	Plasticity index (%)	6
5	Soaked CBR (%)	16

IV. LABORATORY TEST RESULTS

PROPERTIES OF MARINE CLAY (MC)

Visual characteristics of soil

The following properties were observed from visual classification in dry condition.

Colour -- Black in colour

Odour -- Odour of decaying vegetation

Texture -- Fine grained

Table 4.1 Properties of Untreated Marine clay

S.No	Property	Symbol	MC Value
1	Gravel (%)		0
2	Sand (%)		6
3	Fines (%)	Silt	27.4
		Clay	66.6
4	Liquid Limit (%)	WL	73
5	Plastic Limit (%)	WP	40.65
6	Plasticity Index (%)	IP	32.35
7	Soil Classification	----	CH
8	Specific Gravity	G	2.63
9	Free Swell (%)	FS	120
10	Optimum Moisture Content (%)	O.M.C	34.81
11	Maximum Dry Density (g/cc)	M.D.D	1.398
12	CBR (%)	----	0.827

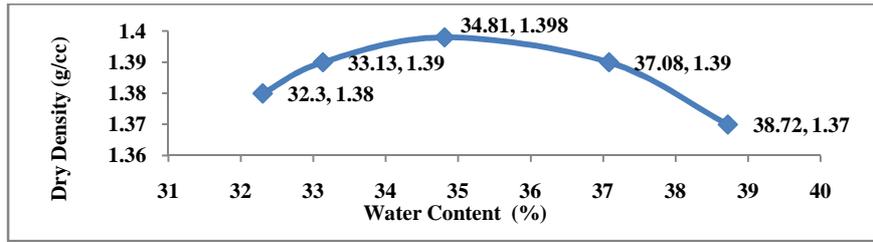


Figure 4.1 OMC & MDD Values of Untreated Marine clay

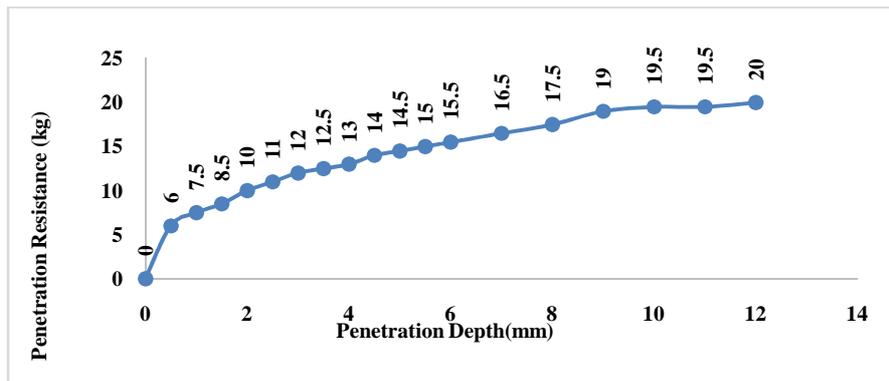


Figure 4.2 CBR Values of Untreated Marine Clay

Table 4.2 OMC and MDD values of Marine Clay treated with % variation of Silica Fume

S.No	MIX PROPORTION	MOISTURE CONTENT (%)	DRY DENSITY (g/cc)
1	100% SOIL	34.81	1.398
2	84% SOIL+16% SILICA FUME	29.5	1.426
3	83% SOIL+17% SILICA FUME	33.3	1.437
4	82% SOIL+18% SILICA FUME	30.3	1.453
5	81% SOIL+19% SILICA FUME	30.1	1.432
6	80% SOIL+20% SILICA FUME	28.3	1.426

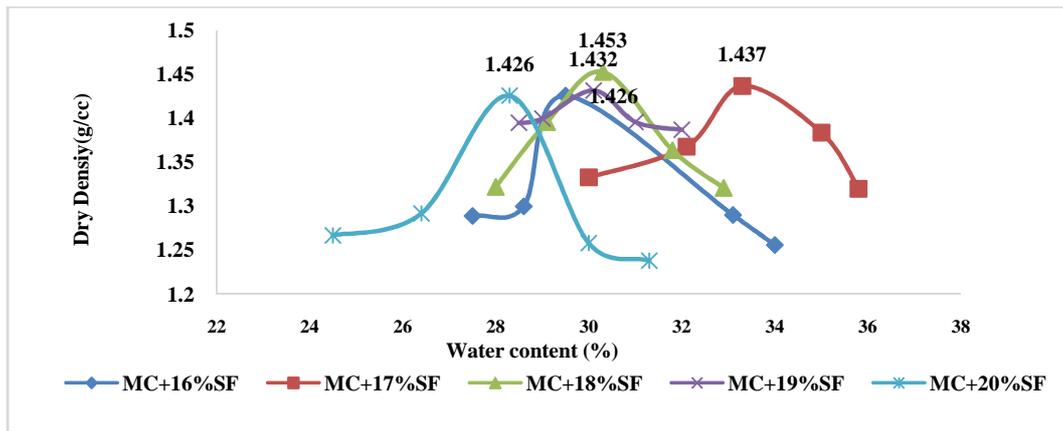


Figure 4.3 OMC and MDD Values of Marine Clay Treated with % Variation of Silica Fume

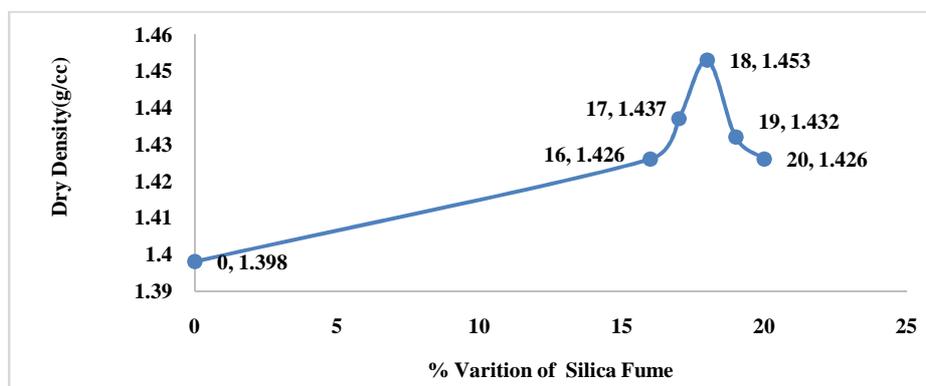


Figure 4.4 MDD Values of Marine Clay Treated with % variation of Silica Fume

Table 4.3: CBR Values of Marine Clay Treated with % Variation of Silica Fume

S.No	MIX PROPORTION	SOAKED CBR (%)
1	100%SOIL	0.827
2	84%SOIL+16% Silica Fume	3.72
3	83%SOIL+17% Silica Fume	4.23
4	82%SOIL+18% Silica Fume	4.81
5	81%SOIL+19% Silica Fume	4.67
6	80%SOIL+20% Silica Fume	4.01

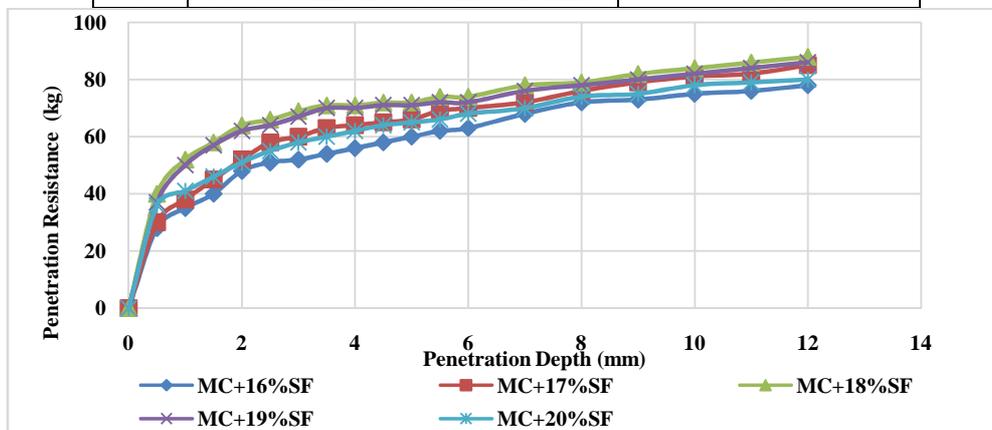


Figure 4.5 CBR Values of Marine Clay Treated with % Variation of Silica Fume

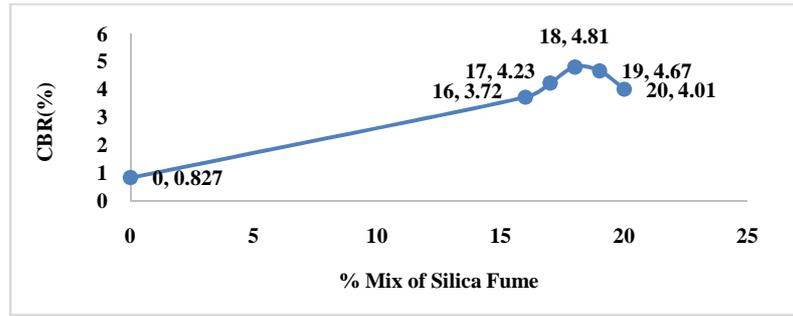


Figure 4.6 Variation in CBR values with % variation of Silica Fume

Discussion-1

As per IRC 37- 2012 the subgrade soil should exhibit the minimum CBR value of 8%. In the present study silica fume treated marine clay has exhibited the CBR value of 4.81% which is less as per the codes of practice. To achieve required CBR value as per codes of practice, an attempt has been taken to improve the CBR value of the silica fume treated marine clay with the percentage variation of Calcium Chloride to suite it as subgrade for flexible pavements.

Table 4.4 OMC and M.D.D values of Marine Clay treated with an optimum of 18% Silica Fume on addition of % variation of Calcium Chloride

S.No	MIX PROPORTION	WATER CONTENT(%)	DRY DENSITY (g/cc)
1	MC+18%SF+6%CaCl ₂	31.6	1.443
2	MC+18%SF+7%CaCl ₂	30.2	1.484
3	MC+18%SF+8%CaCl ₂	32.0	1.513
4	MC+18%SF+9%CaCl ₂	31.8	1.493
5	MC+18%SF+10%CaCl ₂	31.3	1.482

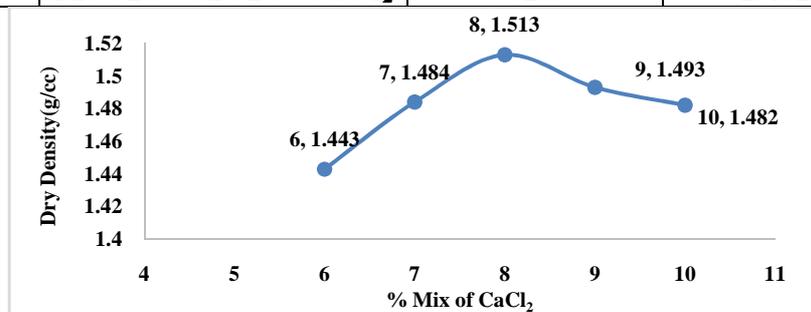


Figure 4.7 MDD values of treated Marine Clay with % variation of CaCl₂

Table 4.4 CBR values of the Marine Clay Treated with an optimum of 18% S.F on % Variation of Calcium Chloride

S.No	MIX PROPORTION	SOAKED CBR (%)
1	MC+18%SF+0.5% Calcium Chloride	8.00
2	MC+18%SF+1% Calcium Chloride	8.64
3	MC+18%SF+1.5% Calcium Chloride	9.39

	Chloride	
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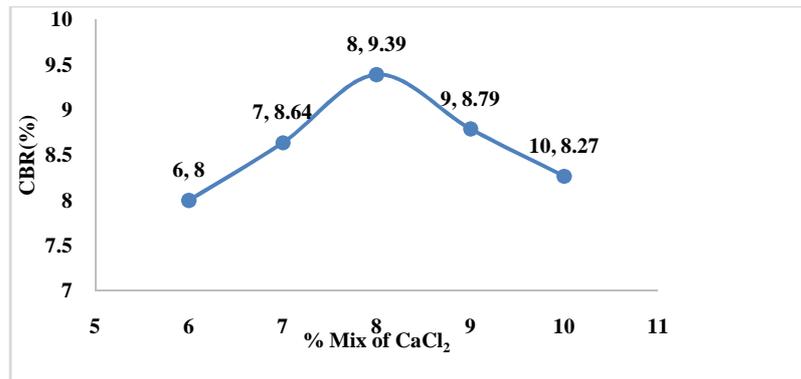


Figure 4.8 CBR Values the Treated Marine Clay with % Variation of CaCl₂

Discussion-2

From the above study, the marine clay treated with an optimum of 18% silica fume and 1.5% CaCl₂ has exhibited the CBR value of 9.39%. Therefore, this treated marine clay is suitable as subgrade for flexible pavements as per IRC 37-2012 codes of practice.

Table 4.5 Properties of Treated and Untreated Marine Clay

S.No	PROPERTY	MC	MC+18% S.F	MC+18% S.F+8% 1.5% CaCl ₂
1	Liquid Limit (%)	73.00	66.39	42.8
2	Plastic Limit (%)	40.65	41.4	24.25
3	Plasticity Index (%)	32.35	24.99	18.55
4	Soil Classification	CH	CH	CH
5	Specific Gravity	2.63	2.72	2.75
6	Optimum Moisture Content (%)	34.81	30	32
7	Maximum Dry Density (g/cc)	1.398	1.453	1.513
8	CBR (%)	0.827	4.81	9.39

V. CYCLIC PLATE LOAD TEST

Cyclic plate load tests are more significant for determining the ultimate load carrying capacity of the pavements. These tests were conducted in the laboratory on untreated and treated marine clay as subgrade for flexible pavements using model tanks.

MODEL TANK

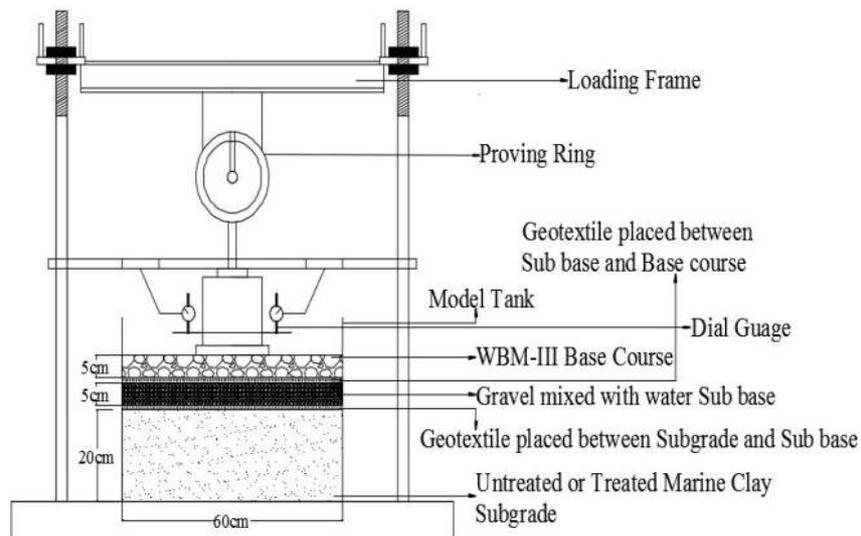


Plate 1 Experimental set up for conducting cyclic plate load test

A circular model tank made of steel with a diameter of 60cm and height of 50 cm is used in this study. In this study a model flexible pavement is prepared with treated and untreated marine clay as subgrade of 20cm thickness over which 5cm thick gravel sub base and 5 cm WBM-III is provided as base course with suitable degree of compaction.

5.1 Test Procedure

A model flexible pavement is prepared in the model tank by providing 3 layers viz. subgrade, sub base, and base course for untreated and treated marine clay flexible pavement conditions.

5.1.1 Preparation of Subgrade

The marine clay passing through 4.75 mm IS Sieve was used and compacted in layers of 2cm thickness at O.M.C to a total compacted thickness of 20cm for untreated and treated marine clay as subgrade for model flexible pavement. For the untreated marine clay, water was mixed directly with the soil corresponding to the OMC of the natural marine clay. For the silica fume treated marine clay the weight of the dry mixes were taken corresponding to the M.D.D of marine clay and marine clay is compacted at O.M.C without any lumps. For further treatments, the required quantity of silica fume was spread on the pulverized soil and mixed thoroughly, until there was uniform mix of silica fume with the soil without any lumps. Further, the required quantity of Calcium Chloride was mixed thoroughly with already mixed soil-silica fume mix at OMC corresponding to the untreated marine clay.

5.1.2 Preparation of Sub Base

On the prepared marine clay subgrade, the gravel mixed with water at OMC was laid in layers of 2.5 cm compacted thickness to a total thickness of 5cm. The sub base layer was compacted to MDD and OMC of the gravel.

5.1.3 Preparation of Base Course

On the prepared sub base, two layers of WBM-III each of 2.5 cm compacted thickness, was laid to a total thickness of 5 cm and the gravel was used as a binding material, the spreading of WBM-III as base course for the model flexible pavement. Prepared Flexible pavement is placed at the center of the loading frame of compression testing machine. A metal plate of 10 cm diameter is placed on the Model flexible pavement through which

loading is done. Two dial gauges of least count 0.01mm were arranged to obtain deformations. A hydraulic jack of 5 tonne capacity is placed on the metal plate. In singly reinforced system a woven geotextile is used as reinforcement and separator between subgrade and sub base course. In case of doubly reinforced flexible pavement first layer is provided as reinforcement and separator between sub grade and sub base and the second layer was provided as separator & reinforcement in between the subbase and base course for offering more pressures on the reinforcement flexible pavement system. Cyclic plate load was carried out on untreated and treated marine clay model flexible pavements corresponding to tire pressures of, 500kPa, 560kPa, 630kPa, 700kPa, 1000kPa at O.M.C as per IRC codes of practice. Each pressure increment was applied until there is no further change in deformations in between the consecutive cycles. The test is continued until the failure to record the ultimate pressure of untreated and treated flexible pavement.



Plate 2. Authors are Conducting Cyclic Plate Load Tests

5.2 Cyclic Plate load Test results

a). Table 5 and Fig 5.1 Present the load carrying capacity of the untreated marine clay under cyclic pressures. The untreated marine clay has exhibited the load carrying capacity of 70kPa at 2.98mm settlement.

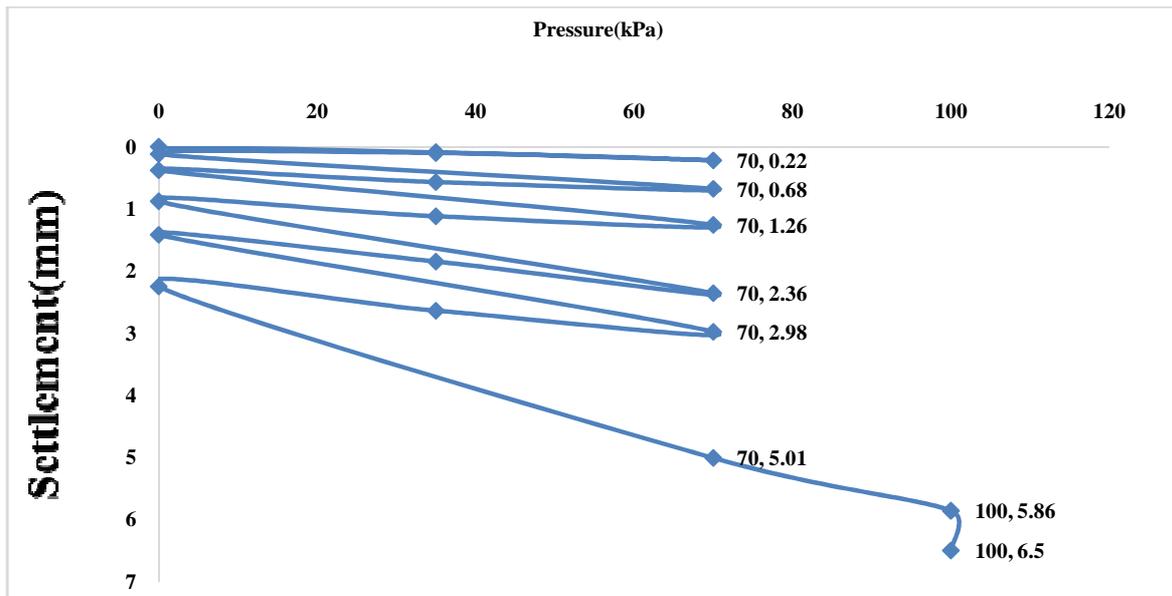


Figure 5.1 Cyclic Plate Load test results of the Untreated Marine Clay

b). Table 5 and Fig 5.2 Present the load carrying capacity of the untreated marine clay subgrade flexible pavement under cyclic pressures. The untreated marine clay subgrade flexible pavement has exhibited the load carrying capacity of 630kPa at 2.5mm settlement.

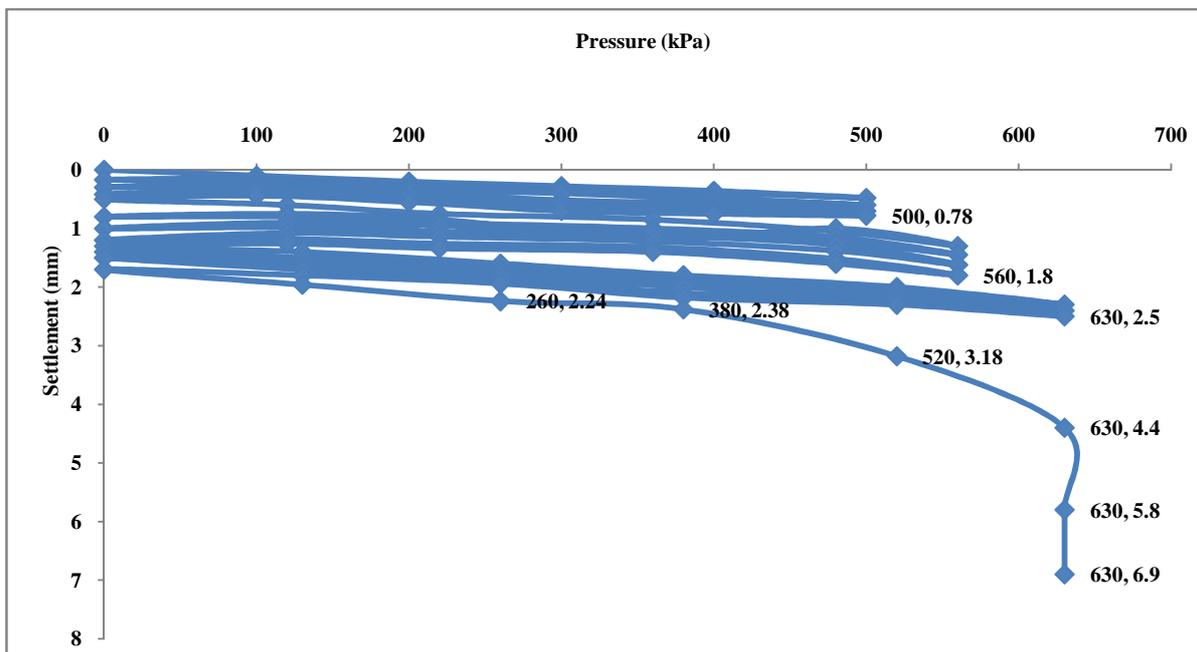


Figure 5.2 Cyclic Plate Load test results of Un-treated Marine Clay subgrade flexible pavement

c). Table 5 and Fig 5.3 present the load carrying capacity of the treated marine clay subgrade flexible pavement under cyclic pressures. The treated marine clay subgrade flexible pavement has exhibited the load carrying capacity of 1000kPa at 2.3mm settlement

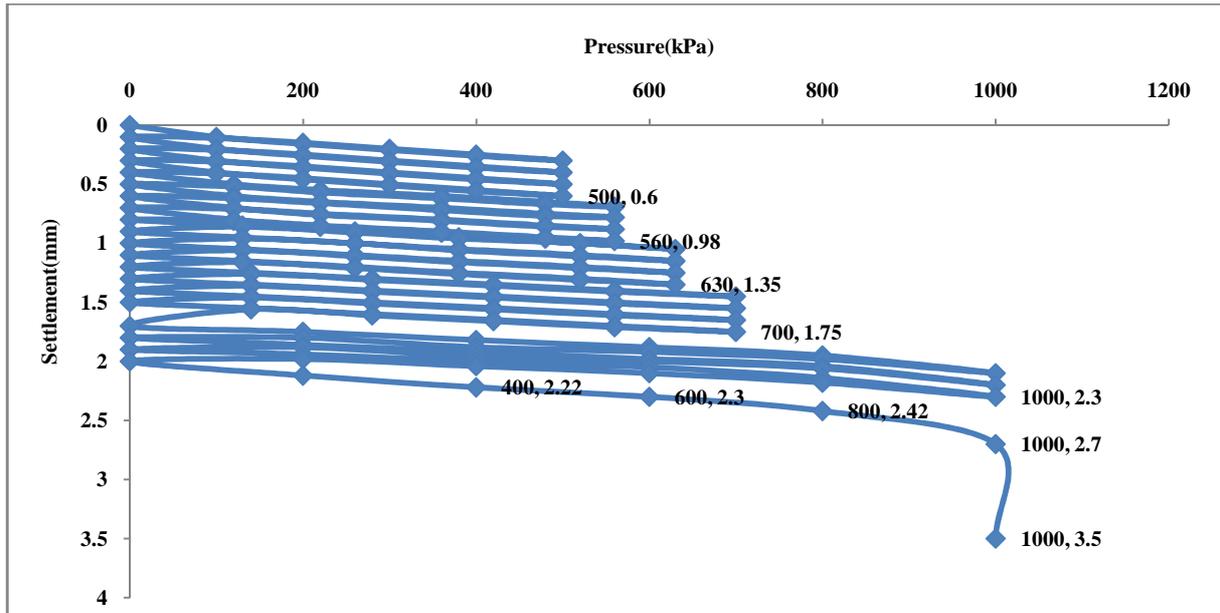


Figure 5.3 Cyclic plate load test results of Treated Marine Clay subgrade flexible pavement

d). Table 5 and Fig 5.4 show the result of singly (geotextile) reinforced treated marine clay subgrade flexible pavement, exhibited the ultimate cyclic pressure of 1400kPa at 2.1mm settlement.

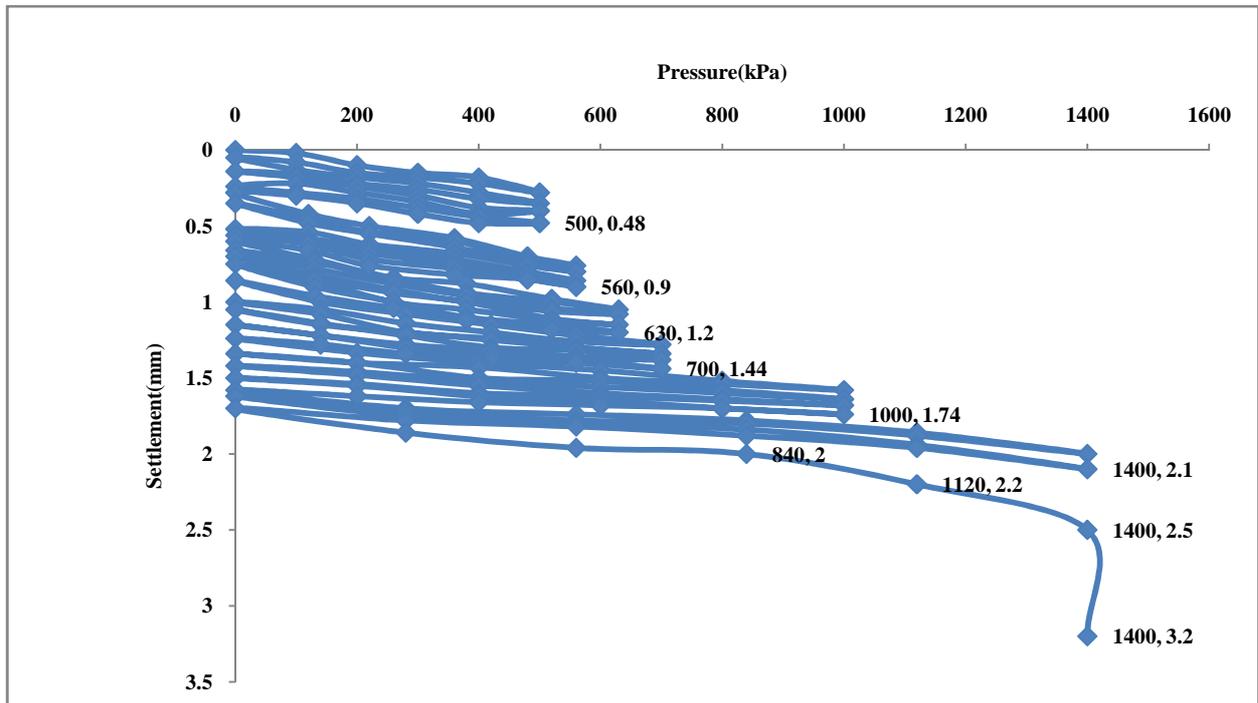


Figure 5.4 Cyclic plate load test results of Treated Marine Clay subgrade flexible pavement reinforced with single layer of geotextile

e). Table 5 and Fig 5.5 show the result of doubly reinforced treated marine clay subgrade flexible pavement, exhibited the ultimate cyclic pressure of 2200kPa at 1.6mm settlement. In this experiment two layers of geotextile has been provided viz. the first layer

was provided in between the subgrade & the sub base and also the second is provided in between the sub base and the base course.

Table 5 Results of Cyclic Plate Load Test results of Un-treated and treated Marine Clay Subgrade Flexible Pavements under cyclic pressures

S.No	Type of Subgrade	Sub-Base	Basecourse	Pressure(kPa)	Settlement(mm)
1	Untreated Marine Clay	-----	-----	70	2.98
2	Untreated marine clay subgrade flexible pavement	Gravel	WBM-III	630	2.5
3	18% silica fume and 1.5% CaCl ₂ treated marine clay subgrade flexible pavement	Gravel	WBM-III	1000	2.3
4	Treated Marine Clay subgrade flexible pavement with geotextile as reinforcement (singly reinforced) & separator in between subgrade and sub base	Gravel	WBM-III	1400	2.1
5	Double geotextile reinforced Treated Marine Clay subgrade flexible pavement.	Gravel	WBM-III	2200	1.6

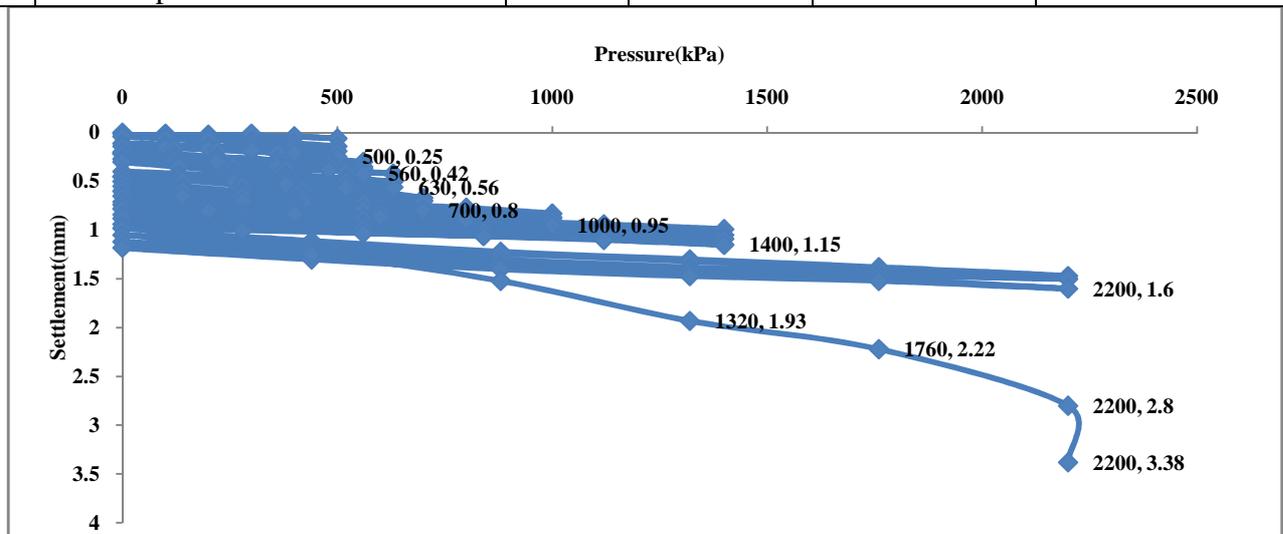


Figure 5.5 Cyclic plate load test results of doubly reinforced Treated Marine Clay subgrade flexible pavement

5.3 Discussion 3

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

VI. CONCLUSIONS

- It is noticed from the laboratory test results that the liquid limit of the marine clay has been decreased by 9.05% on addition of 18% silica fume and further liquid limit of

silica fume treated marine clay has been decreased by 41.36% with an optimum of 1.5% CaCl_2 addition when compared with untreated marine clay.

- It is observed from the laboratory test results that the plasticity index of the marine clay has been improved by 22.75% on addition of 18% silica fume and further plasticity index of silica fume treated marine clay has been improved by 42.65% with the addition of 1.5% CaCl_2 as an optimum when compared with untreated marine clay.
- It is found from the laboratory test results that the Maximum Dry Density of the marine clay has been improved by 3.93% on addition of 18% silica fume and further maximum dry density of silica fume treated marine clay has been improved by 8.22% when 1.5% CaCl_2 is added with respect to untreated marine clay.
- It is observed from the laboratory test results that the C.B.R. value of the marine clay has been improved by 481.62% on addition of 18% silica fume as an optimum and further C.B.R. value has been improved by 1035.42% when 1.5% CaCl_2 is added with respect to untreated marine clay.
- It is noticed from the laboratory cyclic plate load test results that the ultimate pressure of treated (silica fume, CaCl_2 and doubly reinforced) marine clay subgrade flexible pavement has been increased by 249.20% with respect to untreated marine clay subgrade flexible pavements.
- It is noticed from the laboratory cyclic plate load test results that the total deformations of treated (silica fume, CaCl_2 and doubly reinforced) marine clay subgrade flexible pavement has been improved by 36% with respect to untreated marine clay subgrade flexible pavements.

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