International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 08, August-2018

IMPROVING THE PROPERTIES OF THE MARINE CLAY USING PHOSPHOGYPSUM AND LIME AS SUBGRADE FOR FLEXIBLE PAVEMENTS

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Abstract: Vast areas particularly the coastal regions are covered with thick soft marine clay deposits. India has a large coastline exceeding 6000kms. In general; Soft Marine Clays are generally weak and possesses high deformation values in nature. Soft soils are generally labeled as 'problematic' because of their poor resistance to deformation, low permeability and limited bearing capacity natures. Its properties differ significantly in moist and dry conditions. Due to the poor engineering characteristics of these deposits, they pose several foundation problems to various coastal structures. Keeping in view the research findings outlined above, in the present work, experimentation was carried out to investigate the efficacy of different additives viz., phosphogypsum and lime, in stabilizing the marine clay thereby improving its strength, swell characteristics. Systematic and methodological process was followed involving experimentation in the laboratory under controlled condition.

Keywords: - Marine Clay, MDD, OMC, Load carrying capacity, Phosphogypsum, Lime.

I. INTRODUCTION

Marine clay can be found widely in the ocean bed and onshore as well. This situation differ the properties of marine clay from moist soil and dry soil. Marine clay is microcrystalline in nature and clay minerals like chlorite, kaolinite and illite and non-clay minerals like quartz and feldspar are present in the soil. Kakinada onshore are covered by large areas of marine clay, it is one of the problematic soft soils and should be pretreated to enhance the usability and serviceability of the constructed highway. Marine clay is characterised by low permeability and has the capability in attenuation of inorganic contaminant. These deposits generally need a pre-treatment before application of 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 to improve that the method is well suited for a particular system. The common method in soft soil improvement process is to remove the soft soil, and replace it with a stronger and good material. However the high cost of replacement incurred alerted highway agencies to explore an alternative method of highway construction on soft subgrades. One considered economical soft soil stabilization method is chemical stabilized method.

In this work, Phosphogypsum and lime is added to marine clay and the strength characteristics are evaluated. Laboratory tests conducted are Atterberg's limits, standard proctor test, and California bearing ratio test.

II. REVIEW OF LITERATURE

A substantial literature has concluded the severity and extent of damage inflicted by soil deposits of selling nature, to various structures, throughout the world (Ganapathy, 1977; Jones and Jones, 1995; Abdul jauwad, 1995; Osama and Ahmed, 2002; Zhan, 2007). The loss caused due to damaged structures proved the need for more reliable investigation, of such soils and necessary methods to eliminate or reduce the effect of soil volume change. Improving the strength of soil by stabilization technique was performed by Supakji Nontananandh et.al (2004) and Can Burak Sisman and Erhan Gezer (2011). The effect of electrolytes on soft Soils were explained by Sivanna, G.S (1976);Anandakrishnan et.al(1966); Saha et.al (1991); Rao, M.S et.al(1992); Sivapullaiah,P.V. et al (1994); Bansal et.al(1996); S. NarasimhaRaoet.al(1996); Appamma.P(1998); Chandrashekar et.al (1999); G.Rajasekaran et.al (2000); J. Chu et.al (2002);MatchalaSuneelet.al (2008). The effect of steel industrial wastes on soft soils were presented by Ashwani Kumar et.al (1998); Bhadra, T. Ket.al (2002); Dr.D.D.Higgins (2005).

Fig.1 Phosphogypsum

Fig.2 Lime

III.OBJECTIVES OF STUDY

The objectives of present experimental study are as follows.

- 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 pavement sub grade.

IV. MATERIALS USED

A. Marine clay (MC)

Marine clay sample was collected from a dredging site, where dredging was carried out at a depth of 2-4 m below the sea water level near Kakinada, sea port ltd. The collected samples were black in colour and undesirable odour was noted. The presence of sea shells indicated the presence of organic content. The hydrometer analysis conducted on marine clay shows 65.33% of clay content and 24.65% of silt content.

TABLE I
GEOTECHNICAL PROPERTIES OF THE UNTREATED MARINE CLAY

SI.No	Property		Marine Clay
1	Soil classification	Gravel (%)	0
		Sand (%)	10.02
		Silt (%)	24.65
		Clay (%)	65.33
2	Liquid Limit, (%)		76.00
3	Plastic Limit, (%)		34.33
4	Plasticity Index,(%)		41.67
5	Soil classification		CH
6	Specific Gravity		2.42
7	Free Swell, (%)		110
8	Optimum Moisture Content, (%)		37.32
9	Maximum Dry Density,(g/cc)		1.47
10	CBR (%)		1.792
11	Cohesion (kg/cm^2)		0.7
12	Angle of shear resistance (ϕ) (^{0})		3.71^0

B. *Phosphogypsum (PG)*

Phosphogypsum (PG) is a waste by-product from the processing of phosphate rock by wet acid method in fertilizer production, which currently accounts for over 90% of phosphoric acid production. In this study, PG finer than 75 micron, Indian Standards sieve, was used as an admixture. Also, the grain size distribution of this fraction was analyzed on this fraction in accordance with Bureau of Indian Standards (BIS) code. This analysis revealed 88.3 % silt size fractions and 11.7 % clay size fractions. The specific gravity of PG was determined as 2.48, in accordance with BIS code, which lies in the range of 2.3 to 2.6 for PG.

TABLE II

CHEMICAL COMPOSITION OF PHOSPHOGYPSUM

SI.No	Parameter	Composition (%)
1	H_2O	18.0
2	SO_2	43.6
3	CaO	32.0
4	MgO	0.40
5	Al_2O_3+ Fe_2O_3	1.82
6	Sio_2	1.64
7	P_2O_5	1.03
8	F	0.76
9	Organic matter	0.26
10	Na_2O_5	0.36

Courtesy to Jijo James, P. Kasinatha PandianAnna University Tagore Engineering College Department of Civil Engineering Chennai, India

B. Lime

Lime chemically known as, Calcium oxide (CaO), commonly known as quick lime or burnt lime, is widely used chemical compound. It is a white, caustic, alkaline crystal solid at room temperature. It is useful for stabilization of clayey soil compound.

properties of lime

1. Lime is a white amorphous solid.
2. It has a high melting point of 2600^0C.
3. It is highly stable and even fusion cannot decompose it.

Chemical Properties

On hydration, quick lime forms slaked lime or lime water. When water is added to lime it becomes hot and cracks to form a white powder. This is called slaking of lime.

$$CaO + H_2O \longrightarrow \underset{\text{Slaked lime}}{Ca(OH)_2}$$

Calcium oxide is a basic oxide. It can react with acids to give calcium salts.

$$CaO + \underset{\text{Sulphuric acid}}{H_2SO_4} \longrightarrow \underset{\text{Calcium sulphate}}{CaSO_4} + H_2O$$

With acidic oxides like silicon dioxide and phosphorus pentoxide, it forms silicates and phosphates. This property makes lime useful as a flux in metallurgy to remove impurities.

$$Cao + SiO_2 \longrightarrow \underset{\text{Calcium silicate}}{CaSiO_3}$$

$$3CaO + P_2O_5 \longrightarrow \underset{\text{Calcium phosphate}}{Ca_3(PO_4)_2}$$

When quick lime is added to the untreated marine clay it reacts with sufficient water to form a white powder. This process is referred to as slaking. Lime treated clay exhibit decreased plasticity, improved workability and reduced volume change characteristics.

TABLE III

COMPOSITION OF LIME

SI.No	Component	Component (%)
1	Assay	95
2	Chloride	0.01
3	Sulphate	0.2
4	Arsenic	0.0004
5	Lead	0.001
6	Insoluble matter	1

Courtesy to Andhra laboratory chemicals

IV. LABORATORY STUDIES

The laboratory studies were carried out on the samples of Marine clay, Marine clay with percentage variation of phosphogypsum, and marine clay with optimum of PG and percentage variation of Lime for obtaining the optimum mix.

1. Liquid limit

Liquid limit test was conducted on Marine clay, Marine clay with percentage variation of phosphogypsum and Marine clay with optimum of PG and percentage variation of Lime mixes using Casagrande's liquid limit apparatus as per the procedures laid down in IS: 2720 part 4 (1970).

2. Plastic limit

Similarly Plastic limit test was conducted on Marine clay, Marine clay with optimum of phosphogypsum and Marine clay with optimum of PG and percentage variation of Lime, as per the specifications laid down in IS: 2720 part 4 (1970).

3. Differential Free Swell

Differential Free Swell (DFS) is a parameter used for the identification of the expansiveness of the soil.
To determine the free swell of a soil, 20g of oven dry soil passing through 425µ size sieve is taken. One sample of l0g is taken into a l00cc capacity graduated cylinder containing water, and the other sample of 10g is taken into a l00cc capacity graduated cylinder containing kerosene oil.

Differential Free Swell (%) = $\frac{vd-vk}{vk} * 100$

Where,
V_d= volume of soil specimen read from the graduated cylinder containing distilled water.
V_k = volume of soil specimen read from the graduated cylinder containing kerosene.
Because kerosene is a non-polar liquid, it does not cause any swell of the soil IS: 2720 (Part III- l980) gives degree of expansion of a soil depending upon its differential free swell as under.

TABLE IV
RANGE OF DIFFERENTIAL FREE SWELL

S. No	Differential Free Swell	DFS
1	Low	<20%
2	Moderate	20-35%
3	High	35-50%
4	Very High	>50%

Courtesy to New Age International Publishers, text book of Basic and Applied Soil Mechanics by GopalRanjan & A.S.R. Rao

4. Proctor Modified compaction Test

The optimum moisture content and maximum dry density have an important role in changing the strength properties of clay. Preparation of soil sample for proctor's compaction test was done as per IS: 2720 part-6 (1974).

5. Specific Gravity Test

Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. The specific gravity of a soil is used in the phase relationship of air, water, and solids in a given volume of the soil. Specific gravity test was carried out by Pycnometer as per IS 2720 Part 3 (1980).

6. California Bearing Ratio Test

The California bearing ratio tests are conducted on Marine Clay, Marine Clay treated with phosphogypsum, and Marine clay with optimum of phosphogypsum and percentage variation of lime mixtures as per IS 2720 part 16 (1979). The test was conducted under a constant strain rate of 1.25mm/min. The proving ring reading is noted for 50 divisions, and loading was continued until 3 (or) more readings are decreasing (or) constant. The test was conducted at Optimum moisture content. The samples were tested in soaked condition. The tests were conducted at time interval of curing for 4 days.

V. RESULTS AND DISCUSSIONS

Compaction and CBR values of the treated expansive soil

(i) ***Compaction test results***

The marine clay was treated with different percentages of admixture i.e., the sea Phosphogypsum. Phosphogypsum was replaced with the marine clay in different percentages varying from 2% to 8% to improve the properties of the soil. Table 5 and figure 3 & 4 present the OMC and MDD values of untreated marine clay and also treated marine clay with percentage variation of phosphogypsum.

TABLE V
OMC & MDD VALUES OF TREATED & UNTREATED MARINE CLAY WITH % VARIATION OF PHOSPHOGYPSUM

Marine clay treated with percentage variation of phosphogypsum	MDD	OMC
Soil	1.47	37.32
Soil + 2%PG	1.522	34.88
Soil + 4%PG	1.528	34.76
Soil + 6%PG	1.541	33.98
Soil + 8%PG	1.512	35.78

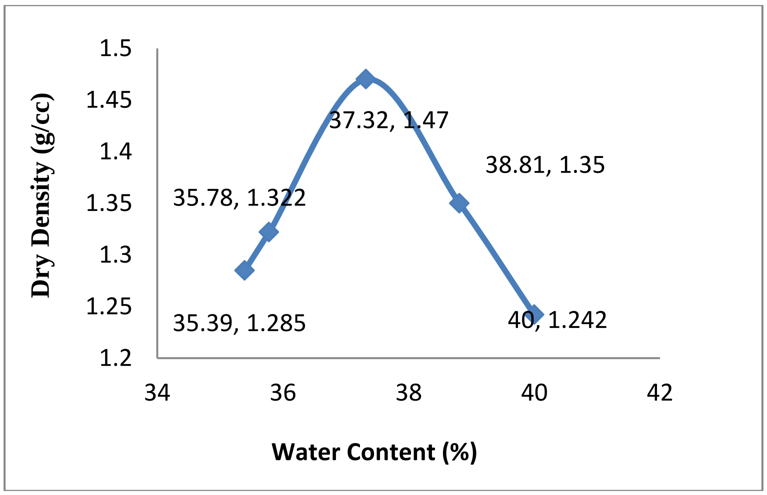

Fig. 3 OMC and MDD values of untreated marine clay soil

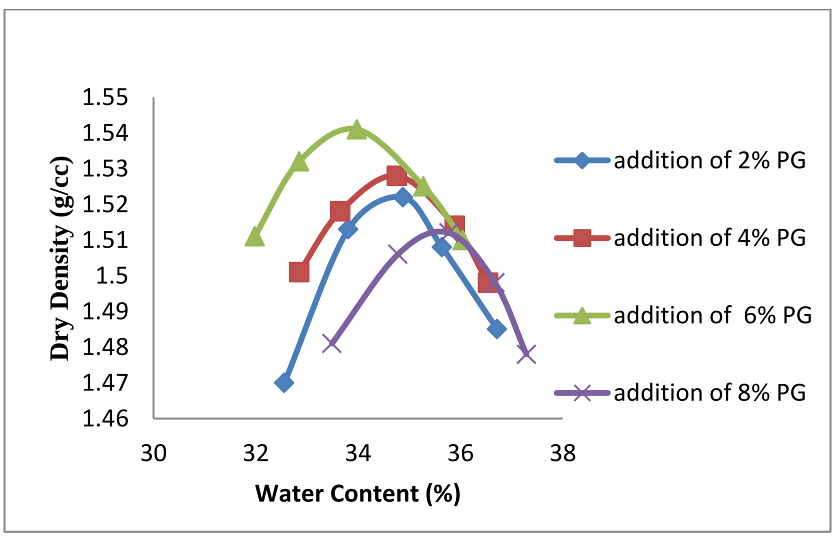

Fig. 4 OMC and MDD values of MC treated with percentage variation of phosphogypsum

(ii) ***CBR test results***

CBR values of various mixes of marine clay and Phosphogypsum using OMC obtained from compaction are determined. The soaked CBR after immersing in water for four days, that is when full saturation is likely to occur, is also determined The CBR test was carried out as per the IS code 2720 part 16, 1987. Table 6 and fig. 6& 7 present the CBR values of untreated marine clay and also marine clay treated with the percentage variation of phosphogypsum.

TABLE VI
CBR VALUES OF MARINE CLAY TREATED WITH PHOSPHOGYPSUM

SI.No	Marine clay treated with percentage variation of phosphogypsum	CBR Value
1	Soil	1.792
2	Soil+2%PG	1.915
3	Soil+4%PG	2.24
4	Soil + 6%PG	3.137
5	Soil+8%PG	2.835

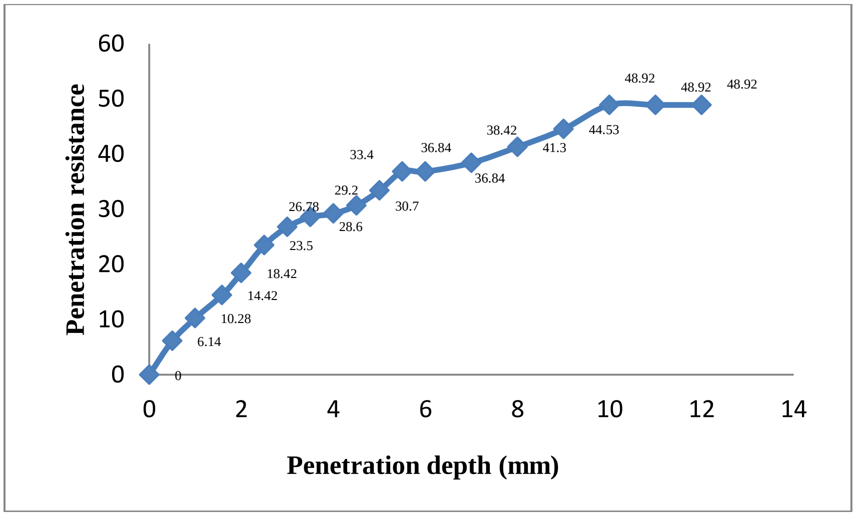

Fig. 5 CBR values of untreated marine clay soil

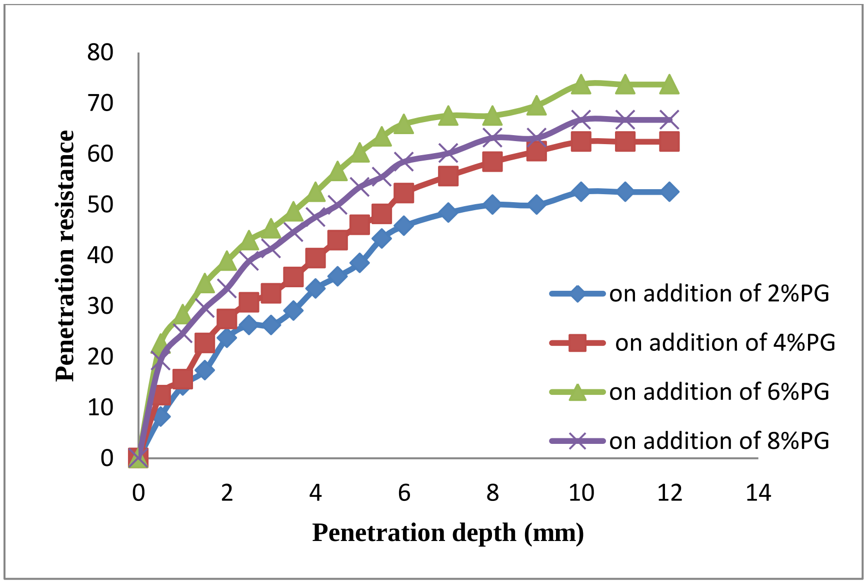

Fig. 6 CBR values of MC treated with percentage variation of phosphogypsum

DISCUSSION-1

It can be observed that 6% phosphogypsum treated with marine clay has effectively improved the laboratory CBR value. However, beyond the addition of 6% PG required improvement in CBR values of the marine clay was not observed. As per IRC Codes 37-2001& 2012 the minimum CBR value of sub grade is 6%. In this present study an attempt has been made to improve the CBR value of the PG treated Marine Clay with percentage variation of Lime as an admixture to suit it as subgrade for flexible pavements as per IRC 37-2001.

Initially, the OMC, MDD and CBR values were determined for the treated marine clay with percentage variation of lime and the results were shown in tables 7 & 8 respectively.

I. OMC & MDD values

TABLE VII

OMC & MDD VALUES OF MC TREATED WITH AN OPTIMUM OF 6% PG UPON ADDING PERCENTAGE VARIATION OF LIME

Phosphogypsum treated marine clay with percentage variation of lime	OMC	MDD
5%	32.45	1.567
6%	31.41	1.591
7%	31.21	1.621
8%	31.29	1.597

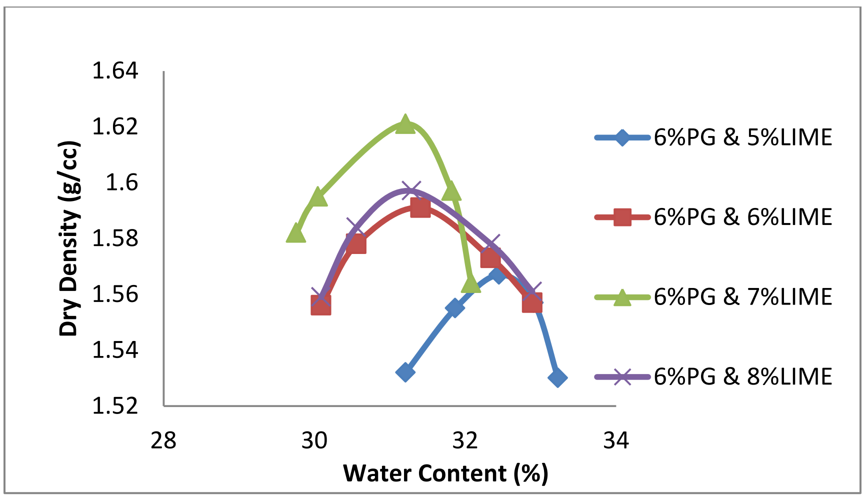

Fig. 7 OMC & MDD values of marine clay treated with an optimum of 6% PG upon adding percentage variation of lime

(b*) **CBR test results***

TABLE VIII

CBR VALUES OF MARINE CLAY TREATED WITH AN OPTIMUMOF 6% PG UPON ADDING PERCENTAGE VARIATION OF LIME

SI.No	Phosphogypsum treated marine clay with % variation of lime	CBR value
1	5%	5.37
2	6%	6.2
3	7%	8.17
4	8%	6.78

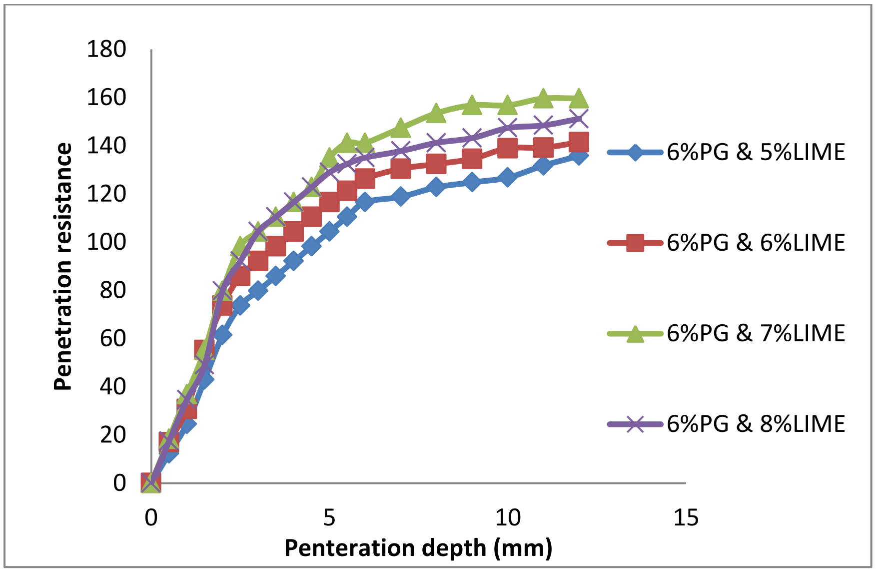

Fig.8 CBR test results of marine clay treated with an optimum of PG upon adding percentage variation of lime

DISCUSSION-2

It was observed that 6% PG treated as individually and with the combination of 7% lime with marine clay has effectively improved the laboratory CBR value. In this present study, the marine clay treated with 6% PG and 7% Lime has exhibited the CBR value of 8.17%, which is suitable value for using this material as sub grade for flexible pavements as per IRC 37-2001 & 2012.Hence the laboratory tests results of Liquid limit, Plastic limit, Plasticity Index, Compaction, CBR, Specific gravity, Differential Free Swell, Cohesion, angle of shear resistance were conducted on the expansive soil treated with the optimum percentage of PG and Lime are as follows:

TABLE IX

LABORATORY TEST RESULTS OF THE UNTREATED AND TREATED MARINE CLAY

SI.No	Property	Symbol	Untreated marine clay	Marine clay with 6% phosphogypsum	Marine clay treated with an optimum of 6% PG & 7% Lime
1	Liquid limit (%)	W_L	76	61.4	42.4
2	Plastic limit (%)	W_P	34.33	36.67	40.23
3	Plasticity index (%)	I_P	41.69	32.03	21.86
4	Specific gravity	G	2.42	2.61	2.69
5	Optimum moisture content (%)	OMC	37.32	33.98	31.21
6	Maximum dry density (g/cc)	MDD	1.47	1.541	1.621
7	Cohesion (kg/cm^2)	C	0.74	0.61	0.42
8	Angle of shear resistance (^{o})	Φ	3.71^0	8^0	17^0
9	CBR (%)		1.792	3.137	8.17
10	Differential free swell	DFS	110	60	35

VI. CONCLUSIONS

1) It is noticed that the liquid limit of the marine clay has been decreased by 19.21% on addition of 6% phosphogypsum and it has been further decreased by 44.2% when 7% lime is added.
2) It is observed that the plastic limit of the marine clay has been improved by 6.3% on addition of 6% phosphogypsum and it has been further improved by 14.6 % when 7% lime is added.
3) It is observed that the plasticity index of the marine clay has been decreased by 23.1% on addition of 6% phosphogypsum and it has been further decreased by 47.5% when 7% lime is added.
4) It is found that O.M.C of the marine clay has been decreased by 8.94% on addition of 6% phosphogypsum and it has been further decreased by 16.3% when 7% lime is added.
5) It is found that M.D.D of the marine clay has been improved by 4.6% on addition of 6% phosphogypsum and it has been further improved by 9.3% when 7% lime is added.
6) It is observed that the C.B.R. value of the marine clay has been increased by 42.8% on addition of 6% phosphogypsum and it has been further improved by 61.6% when 7% lime is added.
7) It is observed that the DFS value of the marine clay has been decreased by 45.4% on addition of 6% phosphogypsum and it has been further decreased by 66.3% when 7% lime is added.

The soaked CBR of the soil on stabilizing is found to be 8.17% and it is satisfying standard specifications as per IS-2720 (Part-16) and IRC: 37-2012, pp:10. So finally it is concluded from the above test results that the stabilized marine clay is suitable to use as subgrade material for the pavement construction and also for various foundations of buildings.

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