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Geotechnical Properties of Marine Clay Treated with Foundry Sand and Lime for Pavement Subgrade Improvement

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Abstract - *Marine clay deposition in India is a significant geological phenomenon, particularly along the country's extensive coastline. These deposits are formed through the transportation and settling of fine-grained sediments, often brought by rivers and influenced by tidal and wave actions. which poses significant challenges for pavement construction due to their high compressibility, low shear strength, and poor California Bearing Ratio (CBR). The weak subgrade conditions lead to excessive settlement, loss of bearing capacity, and early deterioration of flexible pavements. Moreover, seasonal fluctuations in moisture content further aggravate shrink–swell behaviour, reducing long-term durability. In the present study the Geotechnical properties of marine clay such as Atterberg limits, Optimum Moisture Content (OMC), Maximum Dry Density (MDD), California Bearing Ratio (CBR) and strength characteristics were determined. Also, the industrial by product Foundry Sand is utilised for stabilization. The other additive used in this study is lime. This study demonstrates that the combined use of foundry sand and lime can effectively transform weak marine clay into a competent pavement sub grade material. These findings contribute to the development of durable and resilient road infrastructure in coastal regions while supporting sustainable construction practices through industrial by-product utilization. Together, they provide a cost-effective and eco-friendly stabilization technique, reducing reliance on conventional materials and provide a valuable insight for design and construction of pavements in marine clay dominated coastal regions of India.*

Key word: **Marine Clay (MC), Foundry Sand (F.S) Lime, Maximum Dry Density (MDD), Optimum Moisture Content (OMC), California Bearing Ratio (CBR).**

1.INTRODUCTION

Pavements in coastal regions are of great importance as they form the backbone of transportation infrastructure, connecting ports, cities, and towns along the coastline. These pavements facilitate the movement of services and people, supporting economic growth, trade, and tourism. Well-designed and well-maintained coastal pavements are essential for ensuring the safe and efficient. Transportation of goods and commodities, particularly for industries like shipping, and offshore energy. Flexible pavements are the most commonly adopted pavement system in highway construction due to their cost-effectiveness, ease of construction, and ability to withstand repeated traffic loads through a multi-layered structural arrangement. The overall performance and durability of flexible pavements are greatly influenced by the strength of the subgrade soil, which acts as the foundation for distributing stresses imposed by vehicular loads. By supporting transportation infrastructure, coastal pavements contribute significantly to the economic and social development of coastal regions.

This soil exhibits high natural moisture content and low bearing capacity, which make it unsuitable for use as a stable subgrade. When flexible pavements are constructed over untreated marine clay, the weak foundation leads to several structural distresses. These include rutting under traffic loads, longitudinal and alligator cracking due to differential settlement, edge failure caused by lateral movement, and pumping or heaving from moisture variations. Therefore, it becomes essential to adopt soil stabilization techniques such as the use of lime or industrial by-products like foundry sand to enhance the strength, reduce plasticity, and improve the load-bearing capacity of marine clay subgrades.

1.1 Stabilization Techniques for Marin e Clay

Marine clay requires stabilization before being used as a subgrade in flexible pavement construction because of its weak engineering properties. The main stabilization techniques include:

1. Mechanical Stabilization – Improvement of soil strength by compaction, blending marine clay with sand, gravel, or quarry dust to increase density and bearing capacity.

2. Chemical Stabilization – Addition of stabilizing agents such as lime. Lime reduces plasticity and improves workability, while cement and pozzolanic materials increase strength and durability.

3. Geosynthetic Reinforcement – Application of geotextiles, geogrids, or geocells between pavement layers to improve

load distribution, control settlement, and prevent soil movement.

1.2 The Effectiveness of Foundry sand and Lime on Marine Clay Stabilization

The Combined Effect of Lime and Foundry Sand, Lime chemically stabilizes clay, while foundry sand improves particle structure and reinforces strength.

The formation of C-S-H and C-A-H gels binds soil particles, leading to a denser, more compact structure. Cation exchange and flocculation reduce the plasticity index and inhibit the soil's ability to swell and shrink with changes in moisture content. The immediate flocculation of clay particles makes the soil more granular and easier to handle and compact during construction. The cementitious compounds fill the soil's pore spaces, decreasing its permeability and making it more resistant to water penetration.

2. RIVIEW OF LITERATURE

2.1 A Study on the Influence of Lime on Fly ash Treated Marine Clay- by Dr. D. Koteswara Rao et.al., (2011), The author was noticed that the liquid limit of the untreated marine clay has been decreased by 11% with the addition of 20% fly ash as an optimum. Further it was also observed that the liquid limit of the 80%M.C + 20% F.A mix has been decreased by 9% on the addition of 6.5% lime as an optimum. It was observed from the laboratory test results that the C.B.R. Value of the untreated marine clay has been increased 361% on addition of 20% Fly ash as an optimum and further the CBR value of the 80%M.C + 20% F.A mix has been increased by 87% with the addition of 6.5% Lime as an optimum.

2.2 Assessing the Application of Lime and Foundry Sand in Soil Stabilization – by M. Naveen prasad et.al., (2023), In this study shows the ideal moisture content increases from 22% to 27% when 10% foundry sand and 5% lime are used, and it then declines when foundry sand and lime volume are added over the course of the following 0,7,14 days. Maximum dry density decreases when 10% foundry sand and 5% lime are combined, but increases when 20% foundry sand and 10% lime are added later in the alternate days. When 10% lime and 20% foundry sand were added during the experiments, the CBR values significantly rose from 9.56% to 12.62%.

2.3 Improvement in CBR of Marine Clay Subgrade Stabilized with Lime and Rock Dust – by D. Prudhvi Raju (2018), It was observed the addition of lime decreases the Liquid limit, Plasticity index and increases the Plastic limit of the marine soil**.** Liquid limit, Plasticity index goes on decreasing and plastic limit goes on increasing with increase in percentage of RD in lime treated. The soaked CBR value of lime treated marine clay is goes on increasing with addition of RD content. At 25% Rock dust content, the CBR value increase from 0.9% at 100% marine clay to 16.2 % at 75% of lime treated marine Clay + 25% Rock dust.

2.4 Manali D. Patel et.al., (2020), The author was investigated by "Stabilization of soil by Foundry Sand Waste". In this study shows the effect of stabilizing the soil with foundry sand waste at different water content.

- Addition of 0 % of foundry sand waste –1.57 g /cc of Maximum Dry Density (MDD).
- Addition of 10% of foundry sand waste – 1.61 g /cc of MDD.
- Addition of 15 % of foundry sand waste – 1.73 g/cc of MDD.
- Addition of 20% of foundry sand waste – 1.89 g/cc of MDD.

2.5 Dr. D. KoteswaraRao et.al., (2011), Carried out the "Laboratory studies on the properties of stabilized marine clay from Kakinada Sea coast India" In this study explains the knowledge about the soft clay in connection with its Engineering characteristics. It was observed that the liquid limit, plastic limit and the plasticity index were significantly high and the optimum moisture content was below the plastic limit. It is noticed that swell pressure is $160KN/m^2$, cohesion is $0.12kN/m^2$ & angle of internal friction is 3.5 degrees. The time required for 90% consolidation is 311.6 days. It is observed from the chemical analysis, the marine clay was found to possess significant proportion of carbonate content, organic matter content, cat ion exchange capacity and marginally alkaline.

3. OBJECTIVES OF THE STUDY

1. To Determine the index and Engineering properties of the marine clay.
2. To determine the properties of foundry sand.
3. To evaluate the performance of marine clay on addition of different percentages of Foundry sand as an admixture.
4. To Evaluate the performance of the treated Marine Clay on addition of various percentages of Lime and its suitability as subgrade for Flexible pavements.

4. MATERIALS & PROPERTIES

The following materials used in this study

- Marine Clay (MC)
- Foundry Sand (F.S)
- Lime (Ca (OH_2))

4.1 Marine Clay

Marine clay is soil deposited in a marine or oceanic environment, characterized by its microcrystalline nature, high organic matter content, and a composition of both clay minerals (like Illite, kaolinite, and chlorite) and non-clay minerals (such as quartz and feldspar), often containing other components like mica, calcite, and iron oxides. This fine-grained soil is known for being soft, compressible, and having low permeability, which presents settlement challenges for structures built upon it.

Fig-1: Marine Clay

In this investigation, marine clay was sampled from a dredging site at a depth of 1m to 2m below the sea-bed level within the Kakinada deep water port premises.

4.2 Foundry Sand (F.S)

Foundry sand is silica sand used to make Molds for metal casting. It is high-quality, uniformly sized silica sand that forms Molds for casting ferrous (iron) and nonferrous (aluminium, copper) metals. Binders (like bentonite clay or resins) and other additives are used to improve its Moulding properties. After repeated use, foundry sand loses its quality, becoming unusable for casting and thus considered waste.In this study foundry sand was collected from SRI BHAVANI CASTINGS Ltd., Kakinada, Andhra Pradesh, India.

Fig-2: Foundry Sand

Table -1: Visual Properties of Foundry Sand (F.S)

S.NO	PROPERTY	DESCRIPTION
1	Grain shape	Sub Angular to Rounded
2	Texture	Fine-grained
3	Colour	Black
4	Plastic Limit /Plasticity index	Non-Plastic

Foundry sand is added to marine clay to improve its geotechnical properties through physical mixing in various proportions, followed by laboratory tests to determine theoptimal amount and verify improvements in strength, density, and bearing capacity.

Table -2: Physical properties of Foundry Sand (F.S)

S. No	PROPERTY	SYMBOL	VALUE
1	Particle Size Distribution		
	Gravel (%)	-	0
	Sand (%)	-	92.4
	Silt & Clay (%)	-	7.6
2	Specific Gravity	G	2.58
3	Differential free swell (%)	DFS	0
4	Atterberg Limits		
	Liquid Limit (%)	W_L	23.54
	Plastic Limit (%)	W_P	NP
	Plasticity Index (%)	I_P	-
5	Compaction Properties		
	Optimum Moisture Content (%)	OMC	21.24
	Maximum Dry Density(gm/cc)	MDD	1.734
6	Soaked C.B.R (%)	CBR	13.23
7	Cohesion(kg/cm^2)	(C)	0
8	Angle of internal friction(Φ)	(^{0})	34

Table -3: Chemical Composition of Foundry Sand (F.S)

S.NO	CONSTITUENT	PERCENTAGE (%)
1	SIO_2	80.14
2	Al_2O_3	4.3
3	Fe_2O_3	5.15
4	CaO	1.9
5	MgO	2.49
6	SO_3	0.05
7	Na_2O	0.1
8	K_2O	0.6
9	TiO_2	0.2
10	Mn_2O_3	0.02
11	SrO	0.03
12	Loss on ignition	5.02

Courtesy to Sri Bhavani Casting Ltd., Kakinada.

4.3 Lime (Ca (OH_2))

Calcium Hydroxide is defined as a white, powdery substance composed of calcium, hydrogen, and oxygen atoms. Its chemical composition is represented by the formula Ca $(OH)_2$, indicating that each molecule contains one calcium atom bonded to two hydroxide groups. This structure makes it a strong base, capable of neutralizing acids and participating in various chemical reactions.

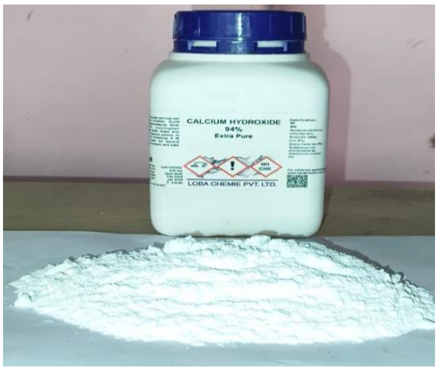

Fig -3: Lime (Ca (OH_2))

When lime is added to marine clay, it dissolves to form calcium hydroxide (Ca $(OH)_2$), which releases calcium ions (Ca^{2+}) and hydroxide ions (OH^-). The calcium ions then replace other absorbed cations (like sodium, Na^+, or hydrogen, H^+) attached to the clay surfaces, a process called cation exchange. To form new, non-crystalline cementitious products, such as calcium silicate hydrate (C-S-H) and calcium aluminum silicate hydrate (C-A-H). These products act as a binder, strengthening the soil.

Table -4: Chemical Composition of Lime (Ca (OH_2))

S. No	Constituents	Percentage (%)
1	SIO_2	6.31
2	Al_2O_3	2.18
3	Fe_2O_3	3.57
4	CaO	59.47
5	MgO	3.91
6	SO_3	0.60
7	Na_2O	0.61
8	K_2O	0.80
9	P_2O_5	0.30
10	MnO	0.30
11	Loss on ignition	17.00
12	others	4.95
	Total	**100.00**

Courtesy to LOBA CHEMIE Pvt. Ltd.

In this study the quantity of Lime was varied from 4% to 8% by dry weight of soil.

5. LABORATORY INVESTIGATION

The Laboratory investigations are carried out on the Untreated marine clay and marine clay treated with various percentages of Foundry Sand (F.S) and Lime (Ca (OH_2)). The Foundry Sand with proportions 8%,10%12%,14% and 16%. Lime with proportions 4%,5%,6%,7% and 8% are used in present study.

5.1 Liquid Limit (W_L)

The Liquid Limit test, defined by Indian standard IS 2720 (Part 5) – 1985, determines the moisture content at which a soil passes from a plastic to a liquid state. This test involves making a soil paste, placing it in a Casagrande device's cup, cutting a groove, and repeatedly dropping the cup until the groove closes 12 mm. The number of drops and corresponding water content are recorded for at least four trials to plot a curve and find the liquid limit corresponding to 25 blows. Liquid limit test was conducted on untreated marine clay and foundry sand treated marine clay and foundry sand treated marine clay treated with Lime

5.2 Plastic Limit (W_P)

In this test standardized under the Indian Standard code IS: 2720 (Part 5) - 1985. The test determines the moisture content at which a soil, when rolled into a thread by hand, crumbles when its diameter is reduced to 3 mm. Plastic limit test was conducted on untreated marine clay and foundry sand treated marine clay and foundry sand treated marine clay treated with Lime.

5.3 Differential Free Swell (DFS)

In this Differential Free Swell (DFS) test is a geotechnical test to determine the volume change of expansive soils. The test is performed according to IS 2720-(Part-40)-1977, which specifies using a soil sample passed through a 425-micron sieve. The formula for DFS is:

$$DFS (\%) = [(Vd – Vk) / Vk] \times 100$$

where Vd is the settled volume of the soil in water and Vk is the settled volume of the same soil in kerosene.

5.4 Modified Proctor Test (MPT)

The procedure given by Indian Standard (IS) code for the Modified Proctor Test (heavy compaction) is IS-2720-PART 8 - 1983, which specifies the laboratory method for determining the water content-dry density relationship of soils using heavy compaction. This test was conducted on untreated marine clay and foundry sand treated marine clay and foundry sand treated marine clay treated with Lime.

5.5 Specific Gravity(G)

This test conducted as per is 2720- (part3/sec1)-1980. Specific gravity of soil is the ratio of the density of soil solids to the density of water at a specified temperature.

5.6 California Bearing Ratio (CBR)

The soaked CBR (California Bearing Ratio) test is conducted to determine the soil's load-bearing capacity under saturated conditions, simulating worst-case scenarios like flooding, which are critical for designing durable flexible pavements. The relevant code for conducting the CBR test is IS:2720-Part 16, a standard from the Bureau of Indian Standards (BIS) for soil testing. CBR test was conducted on untreated marine clay and foundry sand treated marine clay and foundry sand treated marine clay treated with Lime.

5.7 Triaxial Compression Test

The Indian Standard (IS) code that governs this test is IS 2720-Part 11: 1993, which specifies the methodology for conducting the unconsolidated undrained triaxial compression test without pore pressure measurement. To determining the shear strength, cohesion (c), and angle of internal friction (Φ) of soil.

6. RESULTS

6.1 Index and & Engineering properties of untreated marine clay. Table-5 Present the properties of untreated marine clay obtained during this study.

Table-5: Index & Engineering Properties of Untreated Marine Clay

Particle size Distribution	Gravel (%)	0
	Sand (%)	13.9
	Silt (%)	22.89
	Clay (%)	63.21

SI.NO	PROPERTY	UNITS	UNTREATED MARINE CLAY
1	Natural Moisture Content (NMC)	%	82.462
2	Liquid Limit (W_L)	%	76.237
3	Plastic Limit (W_P)	%	30.608
4	Plastic Limit (I_P)	%	45.629
5	Soil Classification	__	CH
6	Specific Gravity(G)	__	2.37
7	Differential Free Swell (DFS)	%	90
8	Maximum Dry Density (MDD)	gm/cc	1.389
9	Optimum Moisture Content (OMC)	%	32.026
10	California Bearing Ratio (CBR)	%	1.479
11	Cohesion (C)	kN/m²	127.48
12	Angle of Internal Friction (Φ)	(^{0})	2.57

6.2 Marine Clay (MC) with percentage variation of Foundry Sand (F.S).

6.2.1 Differential Free Swell (DFS) Test Results

Table-6: Differential free swell values for MC + F.S

SI.NO	MIX PROPORTION	DFS (%)
1	100% MC+ 0% FS	90
2	92%MC + 8% FS	64
3	90%MC + 10% FS	59
4	**88%MC + 12% FS**	**55**
5	86%MC + 14% FS	49
6	84%MC + 16% FS	45

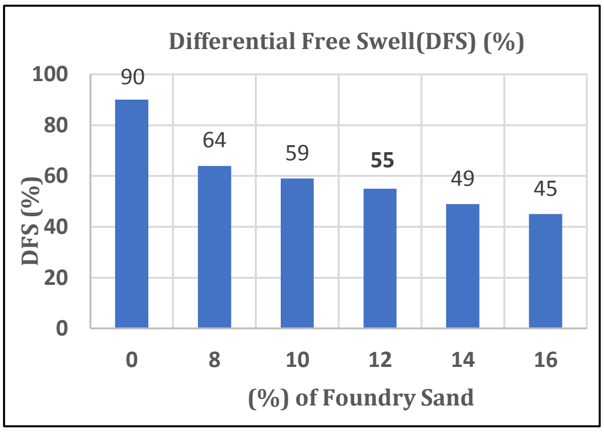

Chart -1: DFS values of marine clay treated with different percentages of Foundry Sand (F.S)

6.2.2 Atterberg limits test Results (W_L), (W_P)(I_P)

Table -7: Atterberg limits values for MC+F.S

SI. NO	MIX PROPORTION	W_L (%)	W_P (%)	I_P (%)
1	100% MC+0%FS	76.237	30.603	45.634
2	92%MC + 8% FS	67.517	32.753	34.764
3	90%MC+10% FS	65.592	33.217	32.375
4	**88%MC + 12% FS**	**63.551**	**33.770**	**29.781**
5	86%MC + 14% FS	61.155	34.372	26.783
6	84%MC + 16% FS	59.040	34.965	24.075

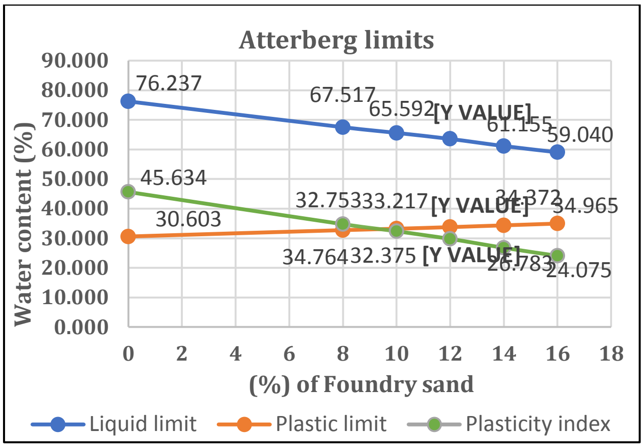

Chart -2: Atterberg limits values of marine clay treated with different percentages of Foundry Sand (F.S)

6.2.3 Modified Proctor Test (MPT) Results

Table -8: Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) values for MC+F.S

SI.NO	MIX PROPORTION	MDD (gm/cc)	OMC (%)
1	100% MC +0% FS	1.389	32.026
2	92%MC + 8% FS	1.589	25.460
3	90%MC+10% FS	1.611	24.720
4	**88%MC + 12% FS**	**1.632**	**23.967**
5	86%MC +14% FS	1.619	23.160
6	84%MC +16% FS	1.586	22.296

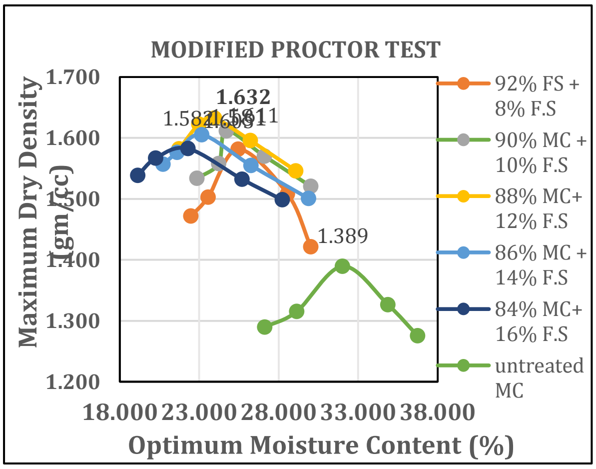

Chart -3: Modified Proctor test results of marine claytreated with different percentages of Foundry Sand(F.S)

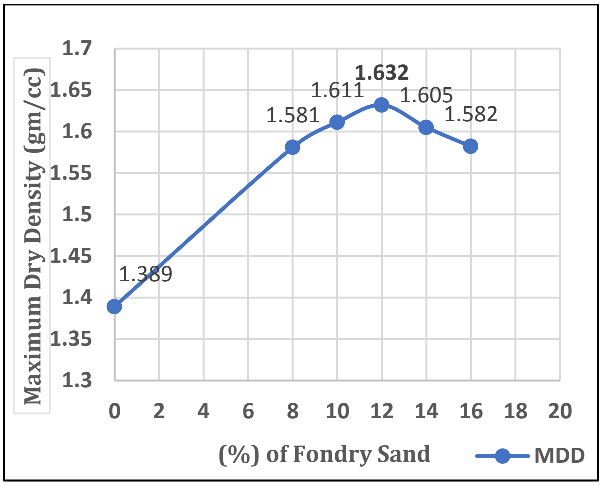

Chart -4: Maximum Dry Density (MDD) values of marine clay treated with different percentages of Foundry (F.S)

6.2.4 Soaked California Bearing Ratio (CBR) test Results

Table -9: Soaked CBR values for MC+F.S

SI.NO	MIX PROPORTION	CBR (%)
1	100% MC + 0% FS	1.479
2	92%MC + 8% FS	3.585
3	90%MC + 10% FS	4.482
4	**88%MC + 12% FS**	**5.378**
5	86%MC + 14% FS	4.706
6	84%MC + 16% FS	3.809

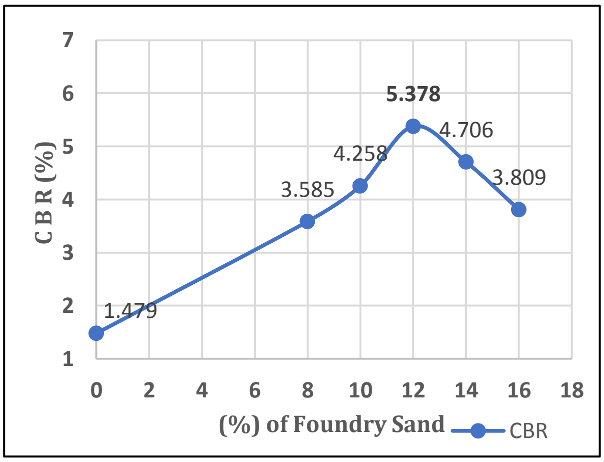

Chart -5: Socked CBR values of marine clay treated with different percentages of Foundry sand (F.S)

6.2.5 Triaxial Compression Test (cohesion (c) and Angle of internal friction(Φ)), Results

Table -10: C and **Φ** values for MC+F.S

SI.NO	MIX PROPORTION	(c)	(Φ)
1	100% MC+ 0 %FS	127.48	2.57
2	92%MC + 8% FS	106.89	3.86
3	90%MC + 10% FS	98.06	4.53
4	**88%MC +12% FS**	**89.24**	**5.71**
5	86%MC + 14% FS	81.39	4.73
6	84%MC + 16% FS	73.54	4.12

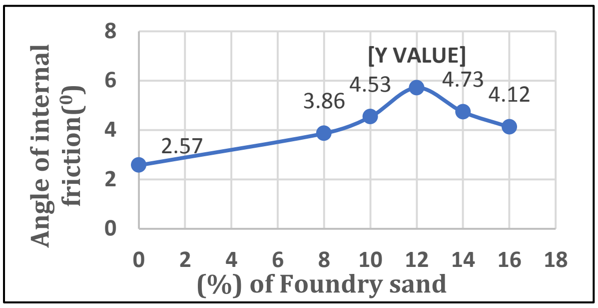

Chart -6 Angle of Internal friction (Φ) values of marine clay treated with different percentages of Foundry sand.

Table-11: Present Geotechnical properties of Untreated and Treated marine clay with an Optimum of 12% Foundry Sand (F. S)

PROPERTY	UNITS	UNTREATED MARINE CLAY	88%MC + 12%FS
Liquid Limit (W_L)	%	76.237	63.551
Plastic Limit (W_P)	%	30.608	33.770
Plastic Limit (I_P)	%	45.629	29.781
Soil Classification	_	CH	CH
Specific Gravity(G)	_	2.37	2.46
Differential Free Swell (DFS)	%	90	55
Maximum Dry Density (MDD)	gm/cc	1.389	1.632
Optimum Moisture Content (OMC)	%	32.026	23.967
Soaked CBR	%	1.479	5.378
Cohesion (C)	kN/m²	127.48	89.24
Angle of Internal Friction(Φ)	(⁰)	2.57	5.71

Discussion -1: In the present study, marine clay treated with an optimum of 12% foundry sand has exhibited a CBR value of 5.378 %.

The soil can be used as subgrade for flexible pavement should possess the minimum CBR value of 8% as per the IRC 37-2012.Hence this treated marine clay is not suitable as subgrade for flexible pavements as per the IRC 37-2012 code of practices. Present investigation has been continued by using Lime ($Ca(OH)_2$) with various percentages of 4%,5%,6%,7% and 8%. to improve CBR value of foundry sand treated marine clay.

6.3 Marine Clay with optimum percentage of Foundry Sand and percentage variation of Lime

6.3.1 Atterberg Limits Test Results

Table -12: Liquid Limit (W_L), Plastic Limit (W_P), Plasticity Index (I_p) Values for MC+12%F. S + Lime

SI. NO	MIX PROPORTION	W_L (%)	W_P (%)	I_P (%)
1	88%MC+12%FS + 0% Lime	63.551	33.770	29.781
2	84%MC+12% FS+4% Lime	53.056	34.664	18.392
3	83%MC+12% FS+5%Lime	51.112	34.994	16.118
4	**82%MC+12% FS+ 6% Lime**	**48.665**	**35.012**	**13.653**
5	81%MC+12% FS + 7%Lime	47.074	35.514	11.560
6	80%MC+12% FS+ 8%Lime	45.213	36.056	9.157

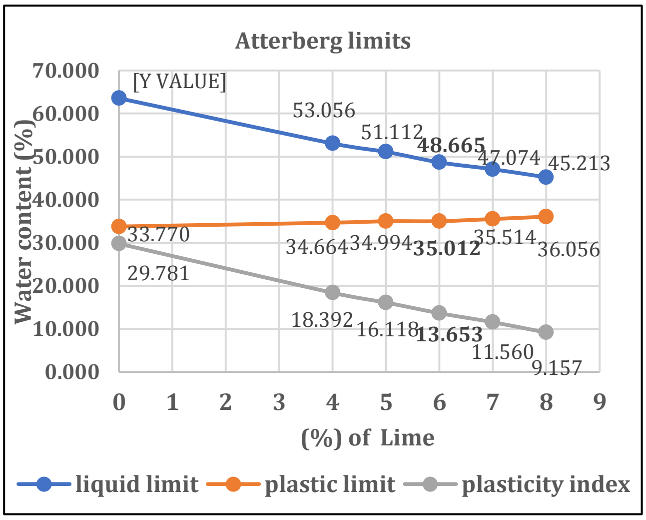

Chart -7: Atterberg Limits values of Marine Clay treated with an 12% Foundry Sand on addition of different percentages of Lime.

6.3.2 Modified Proctor Test (MPT) Results

Table -13: OMC and MDD values for MC+12%F. S+ Lime

SI.NO	MIX PROPORTION	MDD gm/cc	OMC (%)
1	88%MC+12%FS+0%Lime	1.632	23.967
2	84%MC + 12%FS+4%Lime	1.545	20.759
3	83%MC + 12%FS+5%Lime	1.567	22.293
4	**82%MC+12%FS+6%Lime**	**1.586**	**24.771**
5	81%MC + 12%FS+7%Lime	1.553	25.424
6	80%MC + 12%FS+8%Lime	1.527	26.358

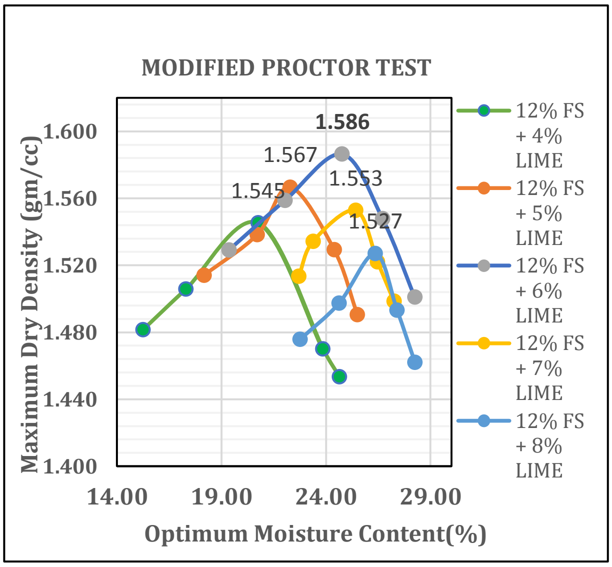

Chart -8: Modified Proctor Test (MPT) results of marine clay treated with an 12% of Foundry Sand on addition of different percentages of Lime.

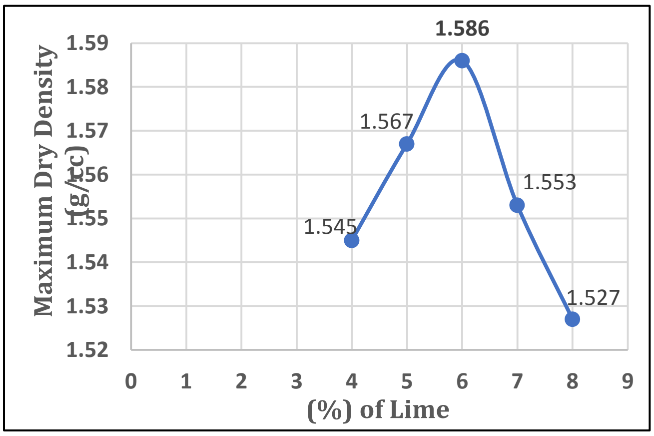

Chart -9: MDD values of marine clay treated with an 12% of Foundry Sand on addition of different percentage of Lime.

6.3.3 Soaked CBR Test Results

Table -14: Soaked CBR values for MC+12%F. S + Lime

SI.NO	MIX PROPORTION	CBR (%)
1	88%MC + 12% FS+0%Lime	5.378
2	84%MC + 12% FS+4%Lime	7.619
3	83%MC + 12% FS+5%Lime	9.412
4	**82%MC+12% FS+6%Lime**	**11.653**
5	81%MC + 12% FS+7%Lime	10.308
6	80%MC + 12% FS+8%Lime	8.964

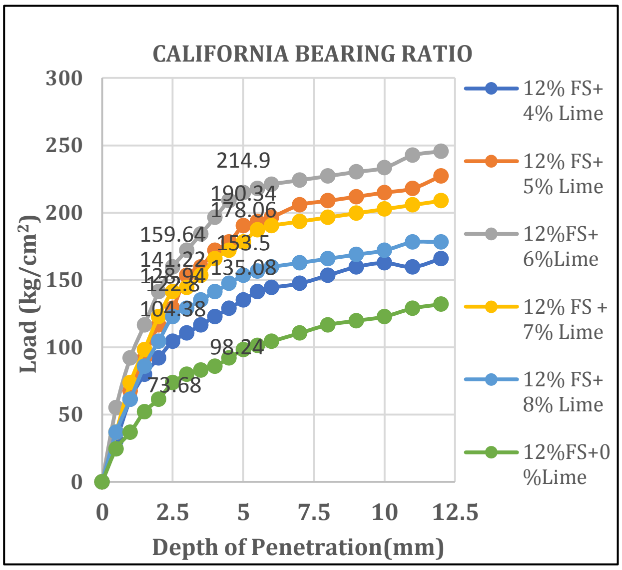

Chart -10: Soaked California Bearing Ratio (CBR) test results of marine clay treated with an 12% of Foundry Sand on addition of different percentage of Lime.

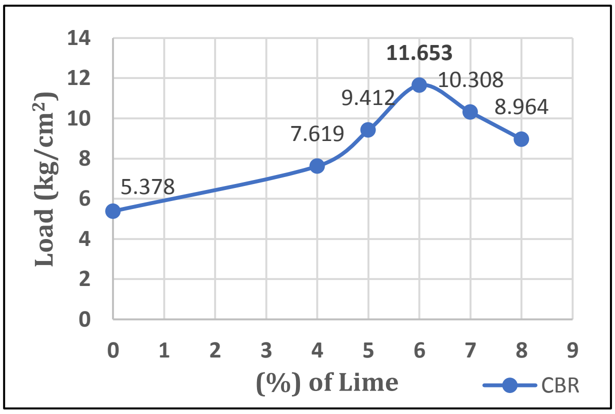

Chart -11: Soaked CBR values of marine clay treated with an 12% of Foundry Sand on addition of different percentages of Lime.

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6.3.4 Triaxial Compression Test (cohesion (c) and Angle of internal friction(Φ)), Results

Table -15: Present C and **Φ** values for MC+12%F. S+ Lime

SI. NO	MIX PROPORTION	(c)	(Φ)
1	88% MC+12%FS+0%Lime	89.240	5.71
2	84%MC +12% FS+4% Lime	80.543	6.81
3	83%MC + 12% FS+5%Lime	75.678	7.36
4	**82%MC+12% FS+6%Lime**	**72.569**	**7.80**
5	81%MC + 12% FS+7%Lime	68.430	7.23
6	80%MC + 12% FS+8%Lime	64.560	6.77

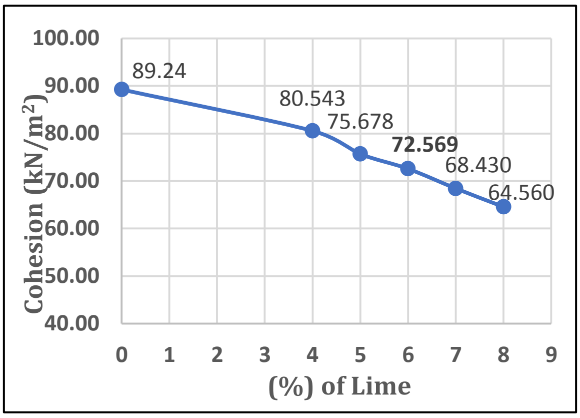

Chart -12: Cohesion (C) values of marine clay treated with an 12% of Foundry Sand on addition of different percentage of lime.

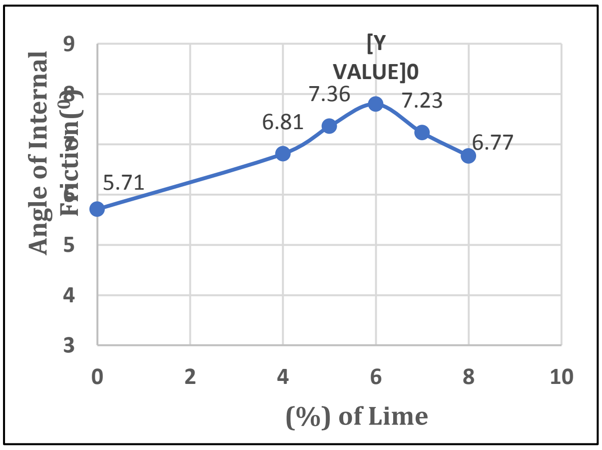

Chart -13: Angle of Internal Friction(Φ) values of marine clay treated with an 12% foundry Sand on addition of different percentages of lime.

Also conducted the Specific gravity(G), Differential Free Swell (DFS) tests on the marine clay treated with optimum percentages of foundry sand and Lime.

Discussion -2:

In the present study, the marine clay is treated with 12%Foundry Sand + 6% Lime has exhibited the CBR value of 11.65%. which is suitable as per IRC 37-2012 codes of practice. Hence, the marine clay treated with the optimum percentages of Foundry Sand and Lime can be used as subgrade for Flexible pavement.

Table -16: Laboratory test results of untreated Marine clay and marine clay treated with an Optimum percentage of Foundry sand and Lime.

PROPERTY	UNTREATED MARINE CLAY	88%MC + 12%F. S	82%MC + 12%F. S + 6%Lime
Liquid Limit (%)	76.237	63.551	48.665
Plastic Limit (%)	30.608	33.770	35.012
PlasticityIndex (%)	45.629	29.781	13.653
Soil Classification	CH	CH	CI
Specific Gravity (G)	2.37	2.46	2.54
Differential Free Swell (%)	90	55	10
Maximum Dry Density (gm/cc))	1.389	1.632	1.581
Optimum Moisture Content (%)	32.026	23.967	24.771
California Bearing Ratio (%)	1.479	5.378	11.653
Cohesion (kN/m²)	127.48	89.240	72.569
Angle of Internal Friction (⁰)	2.57	5.71	7.80

7. CONCLUSIONS

The Following conclusions are drawn based on the laboratory tests:

- It is observed from the laboratory test results that the liquid limit of marine clay has been decreased by 16.64% on the addition of 12% foundry sand and further it has been decreased by 36.16% on addition of 6% lime. when compared with untreated marine clay.

- It is noticed from the laboratory test results that the plastic limit of marine clay has been improved by 10.33% on the addition of 12% foundry sand and further, it has been improved by 14.38% on addition of 6% lime. when compared with untreated marine clay.

- It is observed that the plasticity index of marine clay has been decreased by 34.73% on the addition of 12% foundry sand and further it has been decreased by 70.07% on addition of 6% lime. when compared with untreated marine clay.

- It is observed that the specific gravity of marine clay has been increased by 3.79% on the addition of 12% foundry sand and further it has been increased by 7.17% on addition of 6% lime. When compared with untreated marine clay.

- It is noticed from the laboratory test results that the differential free swell of marine clay has been decreased by 38.88% on the addition of 12% foundry sand and further it has been decreased by 88.88% on addition of 6% lime. When compared with untreated marine clay.

- It is observed from the laboratory test results that the MDD of marine clay has been improved by 17.49% on the addition of 12% foundry sand and further it has been decreased by 13.82 % with addition of 6% lime. When compared with untreated marine clay.

- It is observed from the laboratory test results that the OMC of marine clay has been decreased by 25.16% on the addition of 12% foundry sand and further it has been increased by 22.65 % on addition of 6% lime. When compared with untreated marine clay.

- It is observed that the CBR of marine clay has been increased by 263.62% on the addition of 12% foundry sand. Further it has been increased by 687.89% on addition of 6% lime. When compared with untreated marine clay.

- It is observed that the cohesion (C) of marine clay has been decreased by 29.99% on the addition of 12% foundry sand. Further it has been decreased by 43.07 % on addition of 6% lime. When compared with untreated marine clay.
- It is observed that the Angle of internal friction (Φ)of marine clay has been increased by 122.17% on the addition of 12% foundry sand and further it has been increased by 203.50 % with addition of 6% lime. When compared with untreated marine clay.

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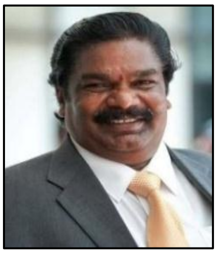

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