Experimental Investigation On The Strength And Engineering Characteristics Of Marine Clay Stabilized With Fly Ash And Lime

P.Prudhvi Teja[1], P.D. Sasikala[2]
[1] Dept of Civil Engineering
[2]Assistant Professor, Dept of Civil Engineering
[1, 2] Lenora College of Engineering, Rampachodavaram

Abstract- *Marine soil refers to the deposits formed beneath the seabed and is also commonly found along coastal areas. The engineering behavior of fully saturated marine soil is considerably different from that of partially moist or dry soil. It generally contains a high percentage of organic matter and exhibits expansive characteristics, undergoing swelling and shrinkage as its moisture content changes. These volume variations can adversely affect the stability of foundations and other civil engineering structures, resulting in increased construction and maintenance costs in coastal regions. To overcome these challenges, ground improvement techniques are widely adopted to enhance the engineering properties of marine soil so that it satisfies foundation and infrastructure requirements. Maintaining a consistent moisture condition around and beneath foundations is considered one of the most effective methods for minimizing the harmful effects associated with expansive soils. For the present investigation, marine clay samples were collected from the coastal region of UPPADA village in Kakinada District, Andhra Pradesh.*

The primary reason for selecting marine clay from this location is the recent announcement by the Government of Andhra Pradesh regarding the construction of a fishing harbour in the area. Therefore, a preliminary investigation has been carried out to assess the engineering and strength characteristics of the locally available marine clay. At the same time, the disposal of industrial waste materials has become a significant environmental concern. Fly ash, a by-product generated from coal-fired thermal power plants, is one such material with considerable potential for reuse. Although fly ash possesses limited cementitious properties on its own, it reacts with moisture to produce cementitious compounds that improve the strength and compressibility behavior of soils. Accordingly, this experimental study aims to enhance the properties of marine clay while promoting the beneficial utilization of industrial waste. The research focuses on evaluating the influence of fly ash and lime on the strength characteristics of marine clay.

Keywords: FlyAsh, cementitious compounds, compressibility, Lime.

I. INTRODUCTION

GENERAL

Marine clay deposits are extensively distributed along coastal regions and exhibit varying characteristics depending on the geological formation, parent rock, and depositional environment. These soils are commonly found beneath coastal plains and offshore areas throughout the world. Marine clay is generally soft, highly compressible, and possesses low shear strength, making it one of the most challenging foundation soils for engineering applications. It mainly consists of fine-grained particles with moderate to high clay content and exhibits high plasticity. The thickness of marine clay deposits along coastlines generally ranges between 10 m and 30 m. These deposits often contain calcareous materials in the form of fragmented shells and marine organisms. Their engineering behavior is influenced by mineral composition, particle arrangement, and the microstructure developed during deposition.

MARINE CLAY

General

Soft marine clay is highly susceptible to variations in stress conditions, moisture levels, and the chemical characteristics of pore water. Because of these properties, geotechnical engineers often adopt suitable ground improvement techniques to enhance its engineering performance before constructing foundations and other civil engineering structures. Owing to its high compressibility, low stiffness, and limited shear strength, soft clay is prone to excessive settlement under structural loading. During drying, marine clay undergoes shrinkage that results in the formation of surface cracks. In severe conditions, these cracks may attain widths ranging from approximately 250 mm to 500 mm and can extend to depths of nearly 1.0 m below the ground surface. Extensive deposits of marine clay are distributed along the coastal regions of India, particularly in the states of West

Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Maharashtra, and parts of Gujarat. The marine and soft clays occurring in these areas are generally weak, highly compressible, and expansive, making them unsuitable for construction without appropriate stabilization or ground improvement measures.

II. REVIEW OFLITERATURE

Mohammed Ali Mohammed Al-Bared and Aminaton Marto (2012) published "A Review on the Geotechnical and Engineering Characteristics of Marine Clay and the Modern Methods of Improvements." Their review comprehensively discussed the geotechnical, mineralogical, microstructural, and engineering characteristics of marine clay. Marine clay was described as a soft, highly compressible soil commonly found in coastal and offshore regions, characterized by high moisture content, low shear strength, poor bearing capacity, and an unconfined compressive strength generally below 20 kPa. The review emphasized that even light structural loads may induce excessive settlement due to the weak nature of marine clay. Important engineering properties such as moisture content, particle size distribution, specific gravity, Atterberg limits, mineral composition, and shear strength were critically examined. The authors also reviewed various stabilization methods, including cement grouting, chemical additives, and environmentally sustainable stabilizers. Based on long-term performance, cement stabilization was identified as one of the most reliable methods for improving marine clay. The review serves as a valuable reference for engineers involved in the design and construction of structures on marine clay deposits.

Dr. D. Koteswara Rao, M. Anusha, P.R.T. Pranav, and G. Venkatesh (2013) carried out a laboratory investigation on the stabilization of marine clay using sawdust and lime. Their experimental results demonstrated that incorporating 15% sawdust reduced the liquid limit by 15.43%, while the addition of 4% lime further reduced it to 27.50%. The plastic limit increased by 4.08% with sawdust and by 11.50% after lime stabilization. Similarly, the plasticity index decreased by 26.47% with sawdust and by 49.57% when lime was added. The optimum moisture content decreased by 15.37% due to sawdust and by 17.91% with the addition of lime. The maximum dry density also showed improvement, increasing by 1.96% with sawdust treatment and by 1.10% following lime stabilization. The study concluded that the combined use of sawdust and lime effectively enhances the engineering characteristics of marine clay.

III. METHODOLOGY

Marineclay

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.

When clay is deposited in the ocean, the presence of excess ions in seawater causes a loose, open structure of the clay particles to form, a process known as flocculation. Once stranded and dried by ancient changing ocean levels, this open framework means that such clay is open to water infiltration. Construction in marine clays thus presents a geotechnical Engineering challenge.

The marine clay used in this study was typical soft clay. The marine clay was collected at a depth of 0.30m from ground level from Uppada area, Kakinada, Andhra Pradesh State, India. All the tests carried on the soil are as per IS specifications.

Fig 3.1 Marine Clay

Fly Ash

Investigations were made on fly ash procured from Thermal Power Plant, Dr. Narla Tatarao Thermal Power Station, Vijayawada. It was tested for chemical and physical properties per ASTM C 311.The chemical and physical properties of the fly ash used in the investigation.

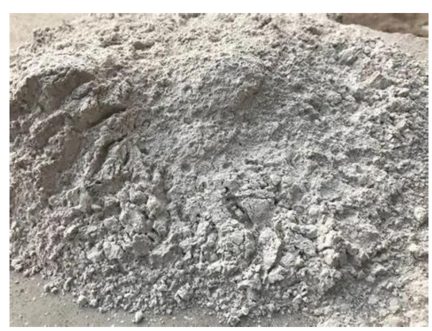

Fig 3.2 Fly Ash

Table 3.1: Chemical Composition of Fly Ash.

S. No	Particulars	Requirement ASTM C 618 (%)	Test Results (%)
1	($SiO_2+Al_2O_3+Fe_2O_3$), %	70 min	91.69
2	SiO_2, %	35.0 min	59.08
3	MgO	5.0 max	0.36
4	Sulphuric Anhydride, %	3.0 max	0.11
5	Total Alkali as Na_2O, %	1.5 max	0.62
6	Total Loss on Ignition, %	5.0 max	2.08

Table 3.1A: Physical Properties of Fly Ash

S. No	Particulars	Requirement ASTM C 618 (%)	Test Results (%)
1	Fineness Specific Surface (cm2/gm)	3200 min	3258
2	Residue on 45 micron (wet sieving)	34 max	30.17
3	Lime Reactivity (kg/cm2)	45 min	51.03
4	Compressive strength (kg/cm2), 28 days	Not less than 80% of strength of corresponding plain cement Mortar cubes	85.99
5	Dry shrinkage, %	0.15 max	0.04
6	Soundness expansion by auto clave, %	0.8 max	0.03

Lime

The commercial Surya lime took from the market for the purpose of stabilizing soil, which imparts cementing property to the soil mix.

Properties of lime

- Lime is a white amorphous solid.
- It has a high melting point of 2600ºC.
- It is highly stable and even fusion cannot decompose it.

Fig 3.3 Lime

IV. RESULTS AND ANALYSIS

GENERAL

In the laboratory various experiments were conducted by mixing different percentages of Fly Ash and lime. Compaction, California bearing ratio, Unconfined compression strength tests were conducted with a view to determine the optimum combination of Fly Ash and lime as a stabilizer.

The influence of the above said materials on the compaction and strength properties were discussed in the following sections. In the laboratory all the tests were conducted as per IS codes of practice.

S. No	Property	Value
1	Specific Gravity	2.65
2	Differential Free Swell Index	40
3	Atterberg's Limits	
	i) Liquid limit (%)	65.7
	ii) Plastic Limit (%)	32.6
	iii) Plasticity Index	33.1
4	Grain Size Distribution	
	i) Sand Size Particles	13
	ii)Silt & Clay Size Particles	87
5	Compaction Parameters	
	i)Maximum Dry Density (g/cc)	1.65
	ii)Optimum Moisture Content (%)	22.22
6	Penetration Parameters	
	California Bearing Ratio (%)	
	At 2.5 mm	1.04
	At 5 mm	0.89
7	Unconfined Compressive Strength Test	
	i)Unconfined Compression Strength (qu) (MPa)	0.359
	ii)Shear Strength (S=qu/2) (MPa)	0.179

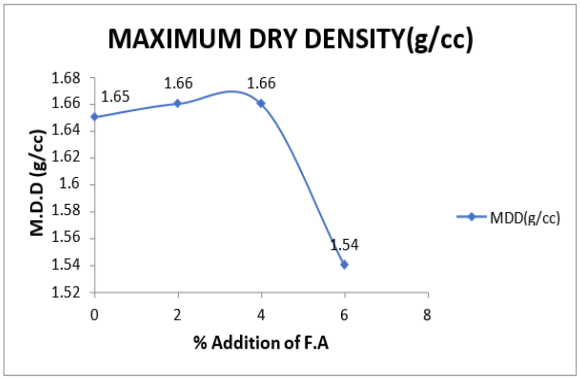

Fig 4.1 Plot showing the variation in MDD with different % of F.A

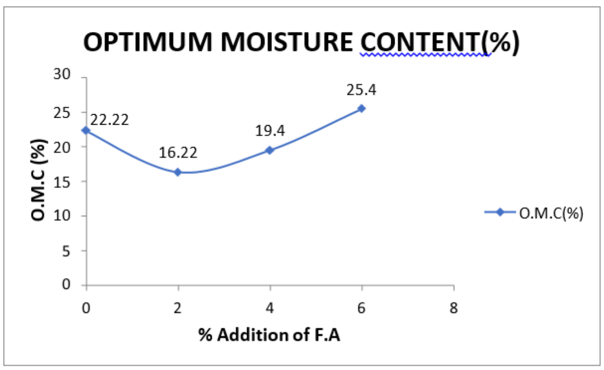

Fig 4.2 Plot showing variation in OMC with different % of F.A

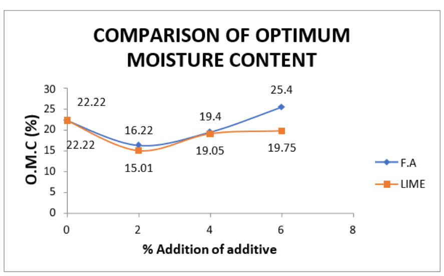

Fig 4.10 Plot showing comparison of O.M.C. values of Marine Clay treated with F.A and LIME

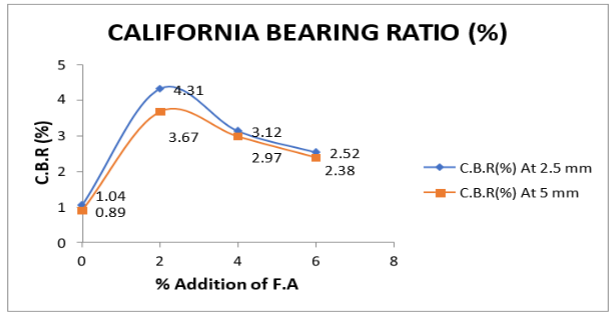

Fig 4.3 Plot showing variation in C.B.R with different % of F.A

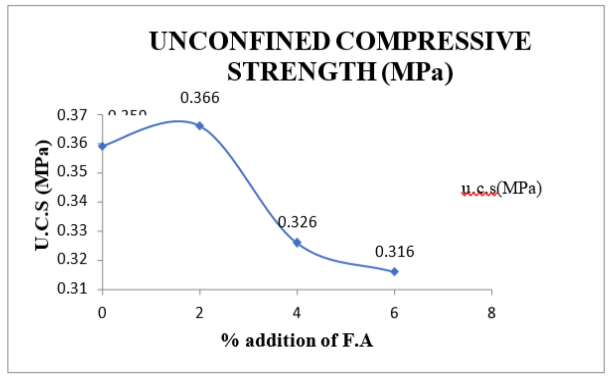

Fig 4.4 Plot showing the variation in U.C.S with different % of F.A

Table 4.4 Results of the tests conducted on marine clay blended with different percentages of lime

LIME(%)	MDD(g/cc)	O.M.C(%)	C.B.R(%)		U.C.S(MPa)
			At 2.5 mm	At 5 mm	
0	1.65	22.22	1.04	0.89	0.359
2	1.71	15.01	5.20	5.35	0.396
4	1.63	19.05	5.80	5.45	0.364
6	1.61	19.75	4.97	4.35	0.323

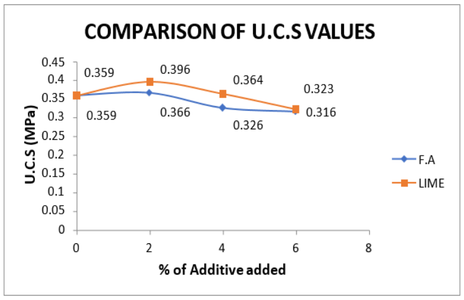

Fig 4.12 Plot showing comparison of U.C.S values of Marine Clay treated with F.A and LIME

V. CONCLUSIONS

Based on the laboratory investigations carried out on marine clay stabilized with fly ash and lime, the following conclusions have been drawn:

The Maximum Dry Density (MDD) of untreated marine clay increased from 1.65 g/cm³ to 1.66 g/cm³ with the addition of 2% fly ash. Further increase in fly ash content resulted in a reduction in MDD. The Optimum Moisture Content (OMC) decreased from 22.22% to 16.20% at 2% fly ash and subsequently increased with additional fly ash content. Similarly, the MDD increased from 1.65 g/cm³ to 1.71 g/cm³ with 2% lime, after which it gradually decreased. The OMC also reduced from 22.22% to 15.01% at the optimum lime content before increasing with further lime addition.

The California Bearing Ratio (CBR) of the untreated marine clay improved significantly with stabilization. The CBR value increased from 1.04% to 4.31% when 2% fly ash was added, but decreased with higher fly ash contents. In the case of lime stabilization, the CBR increased from 1.04% to 5.35% at 2% lime, indicating superior improvement compared to fly ash. Beyond the optimum dosage, the CBR value declined.

The Unconfined Compressive Strength (UCS) also showed noticeable enhancement after stabilization. With the addition of 2% fly ash, the UCS increased from 0.359 MPa to 0.366 MPa, whereas the incorporation of 2% lime increased the UCS from 0.359 MPa to 0.396 MPa. In both cases, the strength decreased when the stabilizer content exceeded the optimum percentage.

A comparative evaluation of the experimental results indicates that lime provides greater improvement in the engineering and strength characteristics of marine clay than fly ash. The stabilized soil treated with lime exhibited higher values of MDD, CBR, and UCS, demonstrating its superior performance as a stabilizing agent.

Overall, the experimental investigation confirms that lime is a more effective stabilizer thanfly ash for improving the engineering properties of marine clay. The optimum addition of 2% lime produced the best overall performance, making it a suitable and efficient stabilizing material for enhancing the load-bearing capacity and strength of marine clay used in pavement subgrades and foundation applications.

REFERENCES

[1] Al-Bared, M. A. M., & Marto, A. (2012). *A review on the geotechnical and engineering characteristics of marine clay and the modern methods of improvements*. **Malaysian Journal of Fundamental and Applied Sciences**, 8(1), 38–50.
[2] Chen, F. H. (1988). *Foundations on Expansive Soils* (2nd ed.). Elsevier Science Publishers.
[3] Das, B. M. (2018). *Principles of Geotechnical Engineering* (9th ed.). Cengage Learning.
[4] Bowles, J. E. (1996). *Foundation Analysis and Design* (5th ed.). McGraw-Hill.
[5] Ingles, O. G., & Metcalf, J. B. (1972). *Soil Stabilization: Principles and Practice*. Butterworths.
[6] Sherwood, P. T. (1993). *Soil Stabilization with Cement and Lime*. Transport Research Laboratory, HMSO.
[7] Katti, R. K. (1978). *Search for Solutions to Problems in Black Cotton Soils*. Indian Geotechnical Journal.
[8] Lay, M. G. (1986). *Handbook of Road Technology*. Gordon and Breach Science Publishers.
[9] Paige-Green, P. (1998). *The Use of Lime in Road Construction*. CSIR Transportek, South Africa.
[10] Watson, C. H. (1994). *Lime Stabilization of Road Pavements*. Transport Research Laboratory.
[11] Ramanjaneya Raju, E., Prudhvi Raju, D., & Krishnam Raju, G. L. V. K. (2013). *Improvement in CBR of Marine Clay Subgrade Stabilized with Lime and Rock Dust*. International Journal of Engineering Research.
[12] Nontananandh, S., Boonyong, S., Yoobanpot, T., & Chantawarangul, K. (2013). *Strength Development of Soft Marine Clay Stabilized with Cement and Fly Ash*. **Agriculture and Natural Resources**.
[13] Koteswara Rao, D., Rameswara Rao, G. V. V., & Pranav, P. R. T. (2013). *A Laboratory Study on the Effect of Fly Ash and Lime on the Properties of Marine Clay*. International Journal of Civil Engineering Research.
[14] Noohu, N. K. (2017). *Effect of Lime on Geotechnical Properties of Marine Clay*. International Journal of Engineering Science and Computing.