

AN EXPERIMENTAL ANALYSIS OF MARINE CLAY STABILIZED WITH FOUNDRY SAND AND ZYCOBOND

Dr. D. Koteswara Rao¹, G. Sathish²

¹Professor, Department of Civil Engineering and OSD to Hon'ble Vice Chancellor, JNTUK, Kakinada, Andhra Pradesh, India,

²Post graduation Student, Department of Civil Engineering, University College of Engineering Kakinada(A), JNTUK, Kakinada, Andhra Pradesh, India.

Abstract - The Marine clay is available in and around the off-shore areas abundantly. It becomes a challenge for civil engineers to construct pavements on marine clays due to its low shear strength and high deformation characteristics. The marine clay are generally found in the coastal region of West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Maharashtra and some parts of Gujarat. Marine clay that exists in these regions are weak and deformative in nature. The present study deals with the strength characteristics of the marine clay collected from Special Economic Zone (SEZ), Kakinada, Andhra Pradesh, India. In the present study, an attempt has been taken to improve the Index and Engineering properties of the marine clay by using foundry sand as admixture and zycobond as a chemical. Laboratory tests were conducted to analyze the influence of varying percentages of foundry sand on percentage variation of Zycobond. Differential free swell Test, Modified Proctor Compaction Test, Atterberg Limits, and California Bearing Ratio (CBR) tests were performed. The Atterberg Limits, Dry Density and CBR of the marine clay has been improved on addition of 10% foundry sand and 1.5% zycobond as an optimum percentages. The present study demonstrates that the combination of industrial waste and chemical additives can be an effective, economical, and sustainable technique for the stabilization of marine clay.

Key Words: Marine Clay (MC), Foundry Sand (FS), Zycobond (ZB), Soil Stabilization, CBR.

1. INTRODUCTION

Marine clay is a soft, fine-grained soil formed in coastal regions due to sediment deposition under marine conditions. It is characterized by high water content, high compressibility, and very low bearing capacity, making it unsuitable for direct use in foundations or pavement construction. The excessive settlement and instability of marine clay pose challenges in geotechnical engineering, particularly in coastal infrastructure projects. Conventional stabilization techniques often involve lime, cement, or other binders, but these may not always be cost-effective or environmentally sustainable.

1.1 Foundry Sand

Foundry sand is a by-product obtained from the metal casting industry. After several cycles of reuse, the foundry sand loses its binding capacity and is discarded as a byproduct. This discarded material, known as foundry sand waste, primarily consists of silica sand contaminated with ferrous and non-ferrous residues from the casting process, along with various binders.

1.2 Zycobond

Zycobond is a commercially available chemical, used to enhance the bonding system of fine-grained soils. It works on modifying the soil microstructure, reducing plasticity, and improving strength characteristics. When combined with industrial by-products such as foundry sand, Zycobond as a chemical, resulting in improving load-bearing capacity and reducing the compressibility of problematic soils like marine clay.

2. OBJECTIVE OF THIS PRESENT STUDY

- To determine the properties of Marine Clay.
- To access the influence of varying dosage of foundry sand (8%, 9%, 10% and 11% by dry weight of soil) on the strength characteristics of marine clay and finalizing the optimum percentage addition of foundry sand.
- To access the effect of varying dosage of Zycobond (0.5%, 1%, 1.5% and 2% by dry weight of soil) on the strength properties of the marine clay treated with an optimum percentage of foundry sand and finalizing the optimum percentage addition of zycobond to the treated marine clay.
- To perform the cyclic plate load tests on both the treated and untreated marine clay subgrade model flexible pavements in the laboratory.

3. LITERATURE REVIEW

Dr. D. Koteswara Rao et al. (2011)⁽¹⁾, observed from laboratory investigations that the liquid limit and the plasticity index were significantly high and the optimum moisture content was below the plastic limit. It is also

noticed that the swell pressure was 160kN/m^2 , cohesion was 0.12kN/m^2 and angle of internal friction was 3.5° .

Dr. D. Koteswara Rao et al. (2011)⁽²⁾, investigated that the M.D.D and CBR values of the untreated marine clay has been improved with percentages variation of GBFS, and further, the treated marine clay has been improved on percentages variation lime at OMC of the marine clay.

Izabel K J et al. (2016)⁽³⁾, observed Liquid limit and plastic limit decreased in addition to Jerofix when compared with marine clay. Maximum dry density increased whereas the OMC showed a decreasing trend with the addition of Jerofix. Unconfined compression strength increased with addition of Jerofix and a maximum value of 106kPa was obtained with the addition of 40% of Jerofix. The CBR value of uncontaminated marine clay which was 3.85 increased to 6.04 with the addition of 30% of Jerofix. Thus, it is suitable for construction of road embankments.

Manali D. Patel et al. (2020)⁽⁴⁾, intent is to determine the foundry sand mix in order to ascertain the proportionate quantity added for greater strength. Maximum dry density and optimum moisture content both rise with the addition of WFS. The test results indicate that 20% of the soil's weight should be the recommended dosage of foundry sand.

Kuldeep Grower et al. (2019)⁽⁵⁾, they used marble dust and foundry sand in dosages ranging from 13% to 22% to stabilize the soil. It is clear from the experimental results that foundry sand stabilizes soil more effectively than marble dust. Because foundry sand has a high silica content, it can better bond with soil particles, enhancing the soil's bearing ability.

Nandan A. Patel et al. (2015)⁽⁶⁾, examine Terrasil and Zycobond impact on the soil index proportion of untreated soil. According to their test results, the soil's liquid limit improved, the plastic limit dropped, the Free swell index decreased, and the soaked CBR also improved. From an economic standpoint, improving soil qualities with the use of terrasil (0.041%) and zycobond (0.020%) is feasible.

Rakshitha G. S. et al. (2022)⁽⁷⁾, From that study they concluded that Free swell index decreases from 40% to 20% with an increase in dosage of Terrasil and Zycobond along with of varying dosage of Terrasil and Zycobond (0.06%, 0.08%, 0.1% and 0.12% by dry weight of soil) on the strength properties and to find out the optimum dosage of Terrasil and Zycobond with addition of waste foundry sand to achieve optimum content of waste foundry sand. Maximum dry density is achieved at 0.1% of Terrasil and Zycobond is 1.84g/cc and optimum moisture content of 16.2%.

Brajesh Mishra (2014)⁽⁸⁾, based on this study and experimental investigation It was observed that with the addition of foundry sand in and y clayey soil the Maximum Dry Density (MDD) and California Bearing Ratio (CBR) Values of the soil foundry sand mixture initially increased up to a certain value but on further addition of foundry sand in sandy clayey soil the values of Maximum Dry Density (MDD) and California Bearing Ratio (CBR) showed a decreasing trend. Hence it can be concluded that there exists an optimum percentage of foundry sand which was responsible for increased strength of soil.

4. METHODOLOGY

The experimental program was carried out at several stages to evaluate the performance of foundry sand and zycobond on improving the strength characteristics of the marine clay. The overall procedure included viz., soil collection, material preparation, proportioning of mixes, laboratory testing, and analysis of results.

4.1 Soil Collection

The marine clay required for the present investigation was collected from the special economic zone (SEZ) in Uppada region at a depth of 1.0–1.5 m below the ground level to avoid the marine clay mix with impurities at ground level. The soil samples were carefully excavated, transported to the laboratory, and then air-dried. The air-dried marine clay was pulverized thoroughly lumps and then sieved through a 4.75 mm IS sieve to obtain a uniform soil sample for testing.

- **Marine Clay:** The collected soil was used as the base material for stabilization. Its index and engineering properties of the marine clay were determined as per IS 1498, IS 2720 and IS 1888 codes of practice.
- **Foundry Sand:** The Foundry sand used in the present investigation was procured from the Bhavani Metal Casting Industry, Kakinada, Kakinada district, Andhra Pradesh State, India. It typically contains around 85–95% silica (SiO_2) along with small amounts of binders such as bentonite clay, carbonaceous materials, and residual metals.
- **Zycobond:** The Zycobond was collected from the ZYDEX Industries and it is available as a liquid chemical stabilizer. Zycobond acts as a bonding agent, it enhances the quality of soil layer, controls soil disintegration, quick drying of soil layers, reduces undulations and low maintenance costs.

4.2 Mix Proportions

The stabilization process involved preparing marine clay samples with different proportions of foundry sand and Zycobond. Four mix ratios of foundry sand were considered, viz., 8%, 9%, 10%, and 11% and then the marine clay treated with an optimum of foundry sand was stabilized on percentages (0.5%, 1%, 1.5%, and 2%) of Zycobond.

Table -1: Mix Proportions for testing Soil

S.NO	Stabilizing Agent	% content
1	Foundry Sand	8,9,10,11
2	Zycobond	0.5,1,1.5,2

4.3 Laboratory Testing

To evaluate the influence of foundry sand and Zycobond on improving the properties of marine clay, a series of laboratory tests were carried out in accordance with relevant IS codes of practice. The tests were conducted are as follows:

- **Differential Free Swell (DFS) Test (IS 2720 – Part 40):** The free swell behavior of the untreated and treated marine clay was studied to evaluate the reduction in expansiveness after stabilization. The DFS value was obtained by immersing oven-dried soil samples in kerosene and distilled water separately, and calculating the difference in swell percentage. This test was particularly important in determining the effectiveness of stabilization in controlling volumetric changes of marine clay.
- **Specific Gravity Test (IS: 2720 Part 3 – 1980):** The specific gravity of soil solids was determined using a pycnometer method as per IS: 2720 (Part 3). Oven-dried soil passing through a 4.75 mm sieve was used. The soil sample was mixed with distilled water in the pycnometer, and weights were recorded for different stages. The specific gravity was calculated based on the ratio of the weight of soil solids to the weight of an equal volume of water. This property helps assess soil composition and its suitability for stabilization.
- **Atterberg Limits Test (IS 2720 – Part 5):** This test was performed to determine the liquid limit, plastic limit, and plasticity index of both untreated and stabilized soil samples. The variation in plasticity characteristics helped in assessing the reduction in swelling tendency and workability of the soil.

- **Standard Proctor Compaction Test (IS 2720 – Part 7):** Compaction tests were conducted to establish the maximum dry density (MDD) and optimum moisture content (OMC) for each mix proportion. The effect of foundry sand and Zycobond on soil densification and water requirement was examined.
- **California Bearing Ratio (CBR) Test (IS 2720 – Part 16):** Both soaked and unsoaked CBR tests were conducted to determine the load-bearing capacity of the stabilized soil. The results provided a measure of the potential application of the stabilized marine clay in pavement subgrade construction.

Table -2: Properties of Marine clay

S.NO	Soil type	Marine Clay
1	Particle size distribution	
	Sand, (%)	12.25
	Silt, (%)	18.21
	Clay, (%)	69.54
2	Atterberg's limit	
	Liquid limit, (%)	70.18
	Plastic limit, (%)	32.90
	Plasticity index, (%)	37.28
3	Modified compaction results	
	Optimum moisture content, (%)	32.17
	Maximum dry density, (g/cc)	1.46
4	Differential free swell, (%)	90
5	Specific Gravity,	2.43
6	IS Classification	CH
7	California bearing ratio, C.B.R (%)	1.45
8	Cohesion, C (kN/m ²)	114.18
9	Angle of internal friction, ϕ (0°)	2.61

5. RESULTS AND DISCUSSION

5.1 Differential free swell

Table -3: Results of Free swell index test

S.NO	MIX PROPORTIONS	DFS (%)
1	90%MC + 10%FS + 0%ZB	62
2	89.5%MC + 10%FS + 0.5%ZB	44
3	89%MC + 10%FS + 1%ZB	28
4	88.5%MC + 10%FS + 1.5%ZB	15
5	88%MC + 10%FS + 2%ZB	09

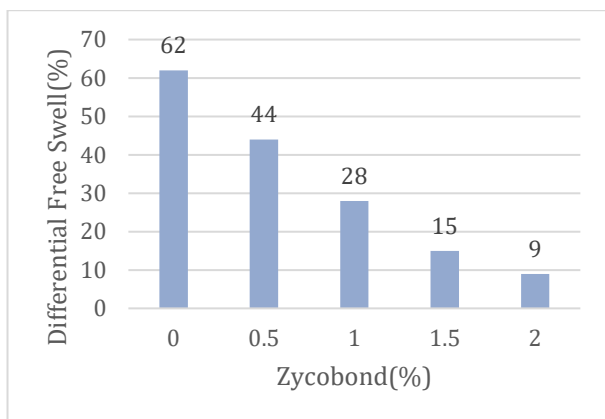


Fig -1: Variation in DFS of Marine Clay and Foundry Sand treated with percentage of Zycobond

5.2 Atterberg's Limit Test

Table -4: Results of Atterberg's limit test

S.NO	MIX PROPORTIONS	LL, (%)	PL, (%)	PI, (%)
1	90%MC + 10%FS + 0%ZB	62.17	40.07	22.10
2	89.5%MC + 10%FS + 0.5%ZB	60.67	41.11	19.56
3	89%MC + 10%FS + 1%ZB	58.34	42.90	15.44

4	88.5%MC + 10%FS + 1.5%ZB	56.65	43.54	13.11
5	88%MC + 10%FS + 2%ZB	54.27	44.20	10.07

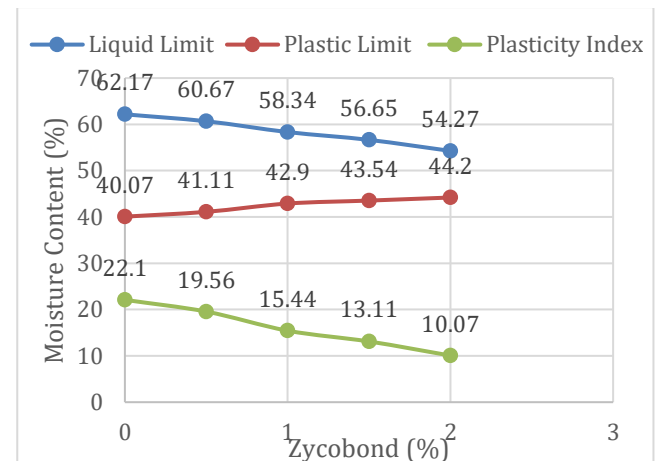


Fig -2: Variation in LL, PL & PI of Marine Clay and Foundry Sand treated with percentage of Zycobond

5.3 Standard Proctor Compaction Test

Table -5: Results of Modified compaction test

S.NO	MIX PROPORTIONS	OMC, (%)	MDD, (g/cc)
1	90%MC + 10%FS + 0%ZB	26.71	1.61
2	89.5%MC + 10%FS + 0.5%ZB	25.14	1.64
3	89%MC + 10%FS + 1%ZB	23.55	1.66
4	88.5%MC + 10%FS + 1.5%ZB	21.68	1.69
5	88%MC + 10%FS + 2%ZB	20.59	1.68

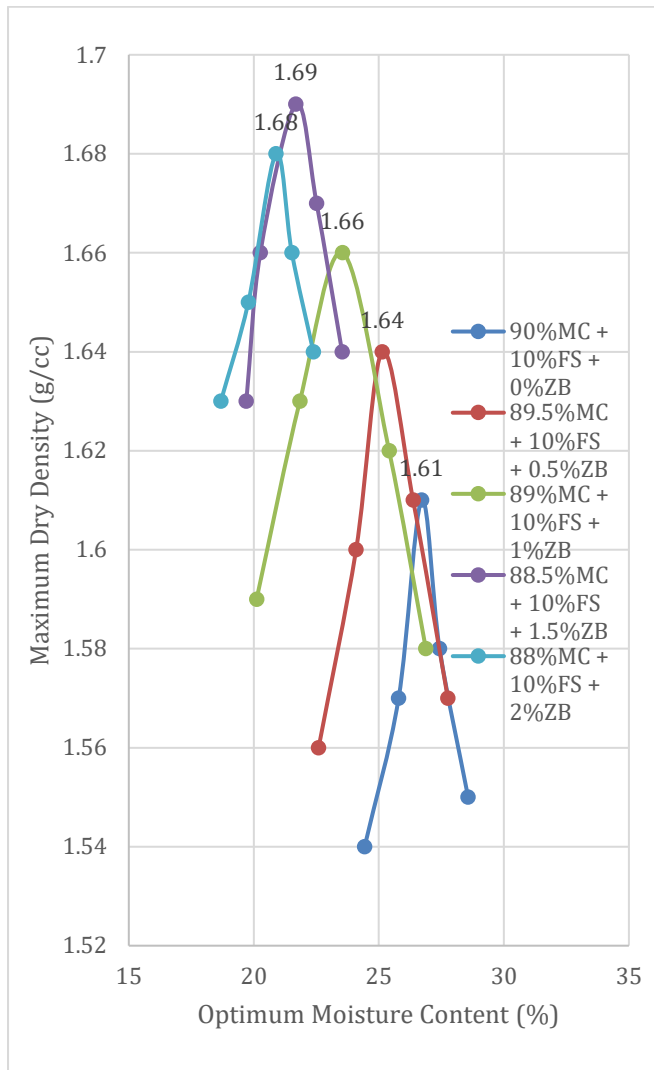


Fig -3: Variation in OMC & MDD of Marine Clay and Foundry Sand treated with percentage of Zycobond

5.4 California Bearing Ratio (CBR) Test

Table -6: Results of CBR test

S.NO	MIX PROPORTIONS	CBR, (%)
1	90%MC + 10%FS + 0%ZB	5.65
2	89.5%MC + 10%FS + 0.5%ZB	6.50
3	89%MC + 10%FS + 1%ZB	7.71
4	88.5%MC + 10%FS + 1.5%ZB	9.19
5	88%MC + 10%FS + 2%ZB	8.34

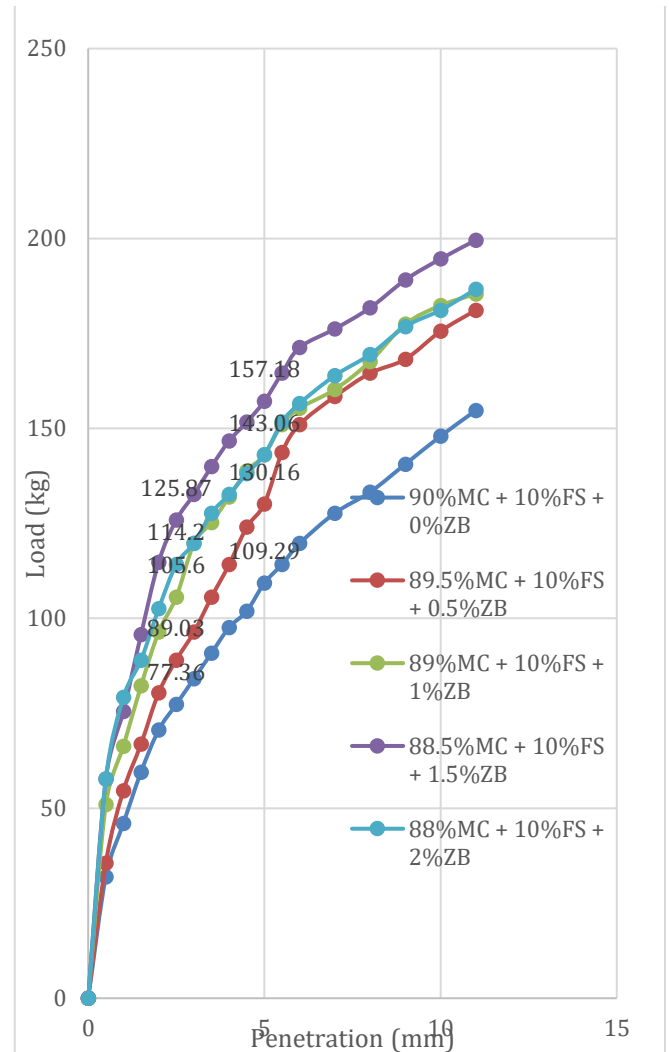


Fig -4: Variation in Compaction curves of Marine Clay and Foundry Sand treated with percentage of Zycobond

Table -7: Properties of untreated and treated Marine clay

Soil type	Untreated marine clay	90%MC + 10% FS	90%MC + 10% FS + 1.5% ZB
Liquid limit, (%)	70.18	62.17	56.65
Plastic limit, (%)	32.91	40.07	43.99
Plasticity index, (%)	37.27	22.10	12.66
Differential free swell, (%)	90	62	15

Optimum moisture content, (%)	32.17	26.71	21.67
Maximum dry density, (g/cc)	1.46	1.61	1.69
California bearing ratio, C.B.R (%)	1.45	5.65	9.19
Cohesion, C (kN/m ²)	114.18	85.96	69.78
Angle of internal friction, ϕ (°)	2.61	4.21	5.97

6. CONCLUSIONS

The following conclusions were drawn based on the laboratory studies carried out for stabilizing the marine clay with an optimum of 10% foundry sand and further, the foundry sand treated marine clay was stabilized further with an optimum of 1.5% Zycobond.

Table -8: Optimum Percentages of FS and ZB, observed the laboratory investigations

S.NO	ADDITIVE	OPTIMUM PERCENTAGES OF ADDITIVES
1	Foundry Sand	10%
2	Zycobond	1.5%

- It is noticed from the laboratory test results that the Differential Free Swell of the Marine Clay has been reduced 45.16% on the addition of 10% FS and it has been further reduced 500% with an addition of 1.5% Zycobond when compared with untreated Marine Clay.
- It is observed from the laboratory test results that the Liquid limit of Marine Clay has been decreased 12.88% on the addition of 10% FS and it has been further decreased 23.88% with an addition of 1.5% Zycobond.
- It is observed from the laboratory test results that the Plastic limit has been increased 21.76% in addition to 10% FS and it has been further increased 16.82% with an addition of 1.5% Zycobond.

- It is noticed that the Plasticity Index has been decreased 68.64% in addition to 10% FS and it has been further decreased 184.29% with addition of 1.5% Zycobond.
- It is observed from the laboratory tests that the OMC of the Marine Clay has been decreased 20.44% on the addition of 10% FS and it has been further decreased 48.45% with addition of 1.5% Zycobond.
- It is observed from the laboratory tests that the MDD of the Marine Clay has been increased 10.27% on the addition of 10% FS and it has been further increased 15.75% with addition of 1.5% Zycobond.
- It is observed that the CBR of the Marine Clay has been increased 289.66% on the addition of 10% FS and it has been further increased 533.79% with addition of 1.5% Zycobond.
- It is observed that the Cohesion of the Marine Clay has been decreased 61.30% on the addition of 10% FS and it has been further decreased 63.63% with addition of 1.5% Zycobond.
- It is observed that the Angle of Internal Friction of the Marine Clay has been increased 32.83% on addition of 10% FS and it has been further increased 128.74% with addition of 1.5% Zycobond.

APPLICABILITY:

The treated marine clay can be used as a sub grade for flexible pavements as it exhibited this CBR value of 9.19% and this CBR value is suitable as IRC 37-2018.

As per IRC 37-2018 codes of practice, any sub grade material should possess a minimum CBR value of 8%.

In the present study the treated marine clay as exhibited a CBR value of 9.19%. Hence this treated marine clay is suitable to use as sub grade for flexible pavement.

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BIOGRAPHIES

Author-1: Dr. D. KOTESWARA RAO



Professor, Department of Civil Engineering and OSD to Hon'ble Vice Chancellor, JNTUK, Kakinada, Andhra Pradesh, India. He has received best teacher awards several times viz., national level, state level, University level and also he has received the best teacher awards several times at the college level from the students feedback.

Author-2: G.SATHISH



Post graduation Student, Department of Civil Engineering, University College of Engineering Kakinada(A), JNTUK, Kakinada, Andhra Pradesh, India.