

Lecture Notes in Civil Engineering

Kasinathan Muthukkumaran
Rajesh Sathiyamoorthy
Arif Ali Baig Moghal
S. P. Jeyapriya *Editors*

Ground Improvement Techniques

Proceedings of the Indian Geotechnical
Conference 2021 Volume 3

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Preface

The Indian Geotechnical Society, Trichy (IGS-Trichy) Chapter, and National Institute of Technology (NIT) Tiruchirappalli, India, organized the Indian Geotechnical Conference (IGC-2021) at Trichy during 16–18 December 2021. The main theme of the conference was **“GEO-INDIA”—GEOTECHNICS FOR INFRASTRUCTURE DEVELOPMENT AND INNOVATIVE APPLICATIONS**.

The sub-themes of the conference included:

1. Soil Behaviour and Characterization of Geomaterials
2. Geotechnical, Geological and Geophysical Investigation
3. Foundation Engineering
4. Ground Improvement Techniques
5. Geo-environmental Engineering
6. Soil Dynamics and Earthquake Geotechnical Engineering
7. Earth Retaining Structures, Dams and Embankments
8. Slope Stability and Landslides
9. Transportation Geotechnics
10. Geosynthetics Application
11. Computational, Analytical and Numerical Modelling
12. Rock Engineering, Tunnelling, Deep Excavations and Underground Constructions
13. Forensic Geotechnical Engineering and Case Studies
14. Others: Behaviour of Unsaturated Soils, Offshore & Marine Geotechnics, Remote Sensing & GIS, Instrumentation & Monitoring, Retrofitting of Geotechnical Structures, Reliability in Geotechnical Engineering, Geotechnical Education, Codes & Standards, & any other relevant topic.

The proceedings of this conference consists of selected papers presented at the conference. The proceedings is divided into six volumes. A special issue on IGC-2021 keynote and theme lecture presentations were published by Indian Geotechnical Journal.

We sincerely thank all the authors who have contributed their papers to the conference proceedings. We also thank all the theme editors and reviewers who have been

instrumental in giving their valuable inputs for improving the quality of the final papers. We greatly appreciate and thank all the student volunteers for their unwavering support that was instrumental in preparation of this proceedings. Finally, thanks to Springer team for their support and full cooperation for publishing six volumes of this IGC-2021 proceedings.

Trichy, India
2021

Kasinathan Muthukkumaran
Chairman, IGC

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Chapter 1

Enhancement of Soil Properties by Using Red Mud and Lime



Sujit Kumar Rout, Rupashree Ragini Sahoo, Soumya Ranjan Satapathy,
and Barada Prasad Sethy

Introduction

The term red mud (RM) is used synonym of bauxite tailing. Annually over 150 million tons of RM produced internationally out of which India is producing 9 million tons per year (Ministry of Mines, Government of India, 2019). Red mud is produced from the refining process of bauxite in to alumina followed by Bayer's process, which is not disposed satisfactorily. According to Yang and Xiao [1] the RM is highly alkaline in nature and stored either in a red mud pond with low solid content about 15–40% by volume or in dry form more than 65% [2]; either way, it uses large amount of land. The properties of RM like chemical composition typically depend on the extraction of alumina from bauxite which influences the overall properties of RM. The primary composition of RM is Fe_2O_3 (48–54%), Al_2O_3 (17–20%), SiO_2 (4–6%), Na_2O (3–5%), TiO_2 (3–4%), and CaO (1–2%) [3]. Various methods have been adopted to find out the properties and its utilization [4–6] but, due to very less utilization rate, huge quantity of RM leftovers in ponds. Numerous methods have been implemented by the different organizations to utilize the RM in an effective way. Due to its cohesive property, the RM is considered as an effective material to improve the engineering properties of the soil. Many methods have been implemented by the different organizations to dispose the waste material which will cause benefits to the society. Due to the cohesive property, RM is the efficient material for enhancing the engineering properties of soil. Parekh [7, 8], studied the behavior of RM and suggested that it is highly alkaline in nature and have clay fraction (20–30%). Also,

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he reported that major particles are silt (CaCo_3 , goethite, hematite, sodalite, and gibbsite. Vick [9] found out its low plasticity property and found out LL to be 45% and PL to be 10% with high specific gravity ranging from 2.8 to 3.3. Kalkan [10] had explained stabilization of expansive clay with red mud and cement-RM. He observed that strength is increasing and permeability and swelling pressure are decreasing. Sundaram [11] studied the behavior of RM and suggested that it can be used as foundation material in in situ condition itself. He also found that the RM is highly alkaline in nature ranging from 9.3 to 10.2. The Atterberg limits range from 39 to 45%, 27 to 29%, and 19 to 22% as liquid limit, plastic limit, and shrinkage limit, respectively. Rout et al. [12] used RM for the road embankment design based on its geotechnical properties. They observed that specific gravity, MDD, and soil friction angle values are more compared to soil without addition of RM. Satyanarayana et al. [13] studied the characterization of lime stabilized red mud mix for feasibility in road construction. RM was stabilized with 2–12% of lime at an increase rate 2%, and tests like UCS, split tensile strength, and CBR were conducted at 1, 3, 7, and 28 days curing periods, respectively. It has been detected that 10% of lime shows higher values when compared with other percentage. Singh et al. [14] stabilized the RM using cement kiln dust (CKD). The percentage of CKD varies from 2 to 12% with an increment of 2%. The strength criteria like MDD and UCS values have been checked. The optimum percentage of CKD is 8%. After the optimum value, further addition of CKD has no effect on strength criteria. Deelwal et al. [15] did the characterization of RM (both index and engineering properties). They concluded that RM is suitable for base and subbase course of road where the traffic is less. They also suggested that it is suitable for some geotechnical work. Pandey and Jawaid [16] did the stabilization of disturbed soil by adding fly ash and RM. The optimum value of RM is found to be 30% with 3% of fly ash which shows the higher CBR values. Lakshmi et al. [17] had stabilized red mud with cement in different proportions and obtained increase in OMC and UCS and decrease in MDD value with increased dosage of cement. Cement and RM mixture changed the dispersed structure of RM to flocculated structure; hence, it increased the strength of cement-RM mixture. Aswathy et al. [18] studied the behavior of clay by adding RM and found that addition of 20% RM with 2% of lime gives more strength compared to only addition of RM (15%).

This study involves the utilization RM, which can be used for stabilization of weak clay soil which has been collected from NALCO, Odisha. The strength criteria (i.e., compaction, UCS, direct shear tests, CBR) of have been studied for the maximum utilization of RM. The RM and soil mix are then treated with lime to obtain the optimum utilization of RM with lime treatment. All the tests have been executed confirming to IS 2720.

Table 1.1 Different properties of RM and soil

Properties		Soil	Red mud
Maximum dry density (g/cc)		1.66	1.73
Optimum moisture content (%)		19	24
Specific gravity		2.36	3.27
Grain size Distribution (%)	(a) Sand	5	12
	(b) Silt	72	36
	(c) Clay	23	52
Liquid limit (%)		48.72	33
Plastic limit (%)		26.12	24
Plasticity index		22.6	9
Classification		CI	ML
Cohesion (kN/m ²)		29.42	20.59
Soil friction angle (in degree)		19	36.5

Materials and Research Methodology

Soil

The soil is collected from Godavaga village, Sambalpur. To make the soil free from vegetation, pebbles, gravel, etc., a depth of 0.3 m from ground level is chosen for sample collection. After collection, the soil lumps are broken into small pieces and passed through 4.75 mm IS sieve. Based on the index properties, the soil is called CI conferring to IS classification system. The geotechnical properties are mentioned in Table 1.1.

Red Mud

Red mud is collected from NALCO which is located in the district of Odisha called. RM is a multifaceted material that varies due to the dissimilar types of bauxites rummage sale and has diverse parameters. Test results are shown in Table 1.1; it shows that RM is subjugated by silt elements and also high plasticity features. The basic geotechnical characteristics of RM are stated in the Table 1.1. Table 1.2 shows the chemical elements. The chemical compositions and metal content of the red mud were determined using energy dispersive spectroscopy (EDS) in Fig. 1.1.

Table 1.2 Chemical elements of RM and lime

Red mud		Lime	
Element	Weight (%)	Element	Weight (%)
CaCO ₃	0.72	CaCO ₃	3.12
SiO ₂	31.95	SiO ₂	36.12
Al ₂ O ₃	7.10	Al ₂ O ₃	0.12
Fe	45.38	Fe	0.26
Ti	2.33	Ca	52.52
Na	6.24	MgO	0.71
Ca	1.34	YbF ₃	6.21
P	0.17	–	–
K	0.13	–	–

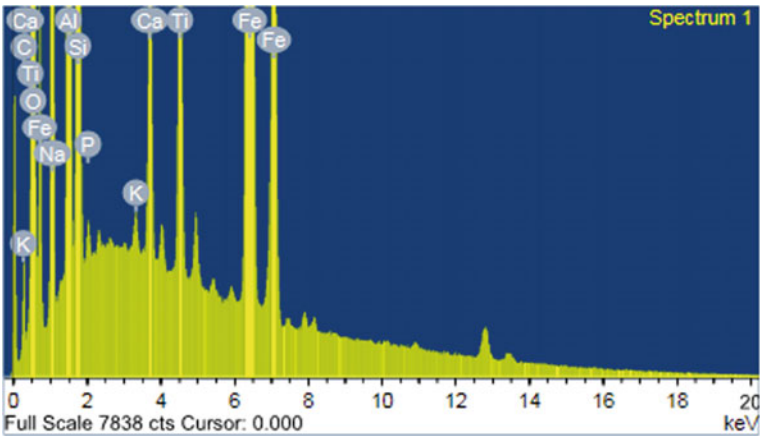


Fig. 1.1 EDS breakdown of RM

Lime

Lime is collected from nearby market in Sambalpur. The chemical composition (elements) is mentioned in Table 1.2, and chemical compounds present in lime are shown in Fig. 1.2 using EDS test.

Sample Preparation

The soil used in this study is clay. It is oven dried at 105 °C approximately and grounded before use to get uniform mixture. First, the desired proportion of clayey

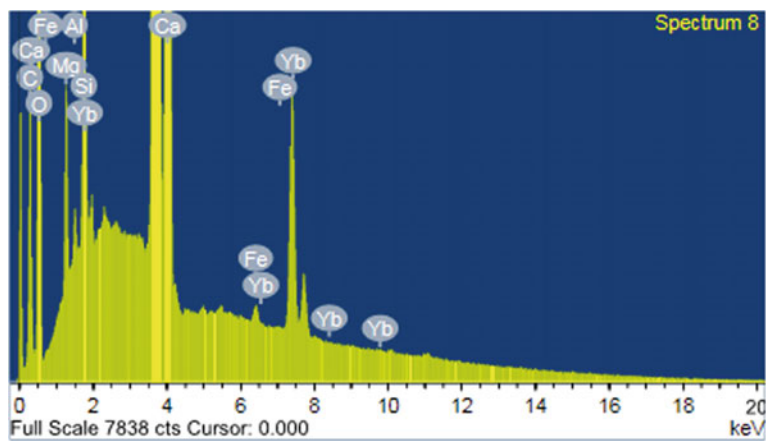


Fig. 1.2 EDS breakdown of lime

Table 1.3 Experimental program for different proportions of soil with dissimilar proportion of RM and lime

Sl. No.	Symbol	Soil (%)	Red mud (%)	Lime (%)
1	R1	100	0	0
2	R2	70	30	0
3	R3	60	40	0
4	R4	50	50	0
5	RL1	60	40	2
6	RL2	60	40	3
7	RL3	60	40	4
8	RL4	60	40	5

soil, red mud, and lime has been blended together under dry condition. The percentages of red mud are 30, 40, and 50% of the total weight of soil. Lime was taken as 2, 3, 4, and 5% by weight of total volume of mixture (soil and RM) (Table 1.3).

Results and Discussion

Compaction Characteristics

Proctor test (standard) has been conducted to determine the compaction characteristics of the red mud and soil and RM stabilized soil through lime with reference IS:

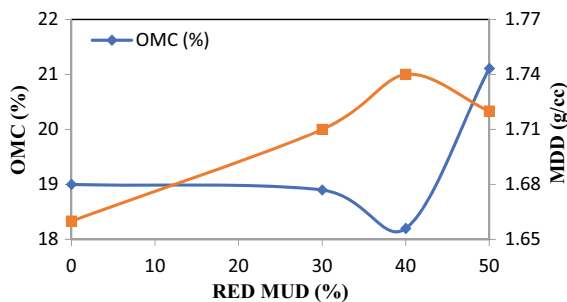


Fig. 1.3 OMC and MDD values for soil with red mud

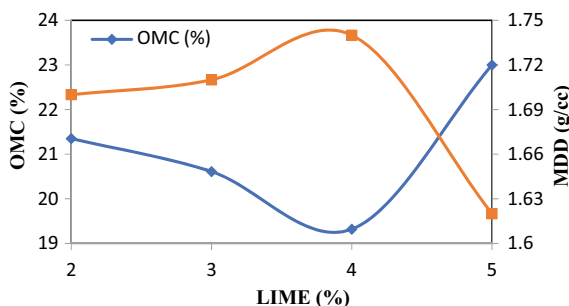


Fig. 1.4 OMC and MDD of RM stabilized soil with lime

2720 (Part 7). The variations of diverse combinations of OMC and MDD are plotted in Figs. 1.3 and 1.4.

The test result in Fig. 1.3 shows that, OMC of soil reduces significantly with the intensification of red mud percentage up to 40 after which the OMC value increases with increase in RM content. Simultaneously, the MDD of red mud mix soil increases significantly with red mud content (increase) up to a certain percentage after which there is decrease in MDD value. Originally, the OMC value and MDD value of virgin soil were 19% and 1.66 g/cc, respectively. But after adding red mud in different proportions, the optimal value of MDD and OMC was 18.2% and 1.74 g/cc, respectively.

Figure 1.4 shows that the optimum red mud mixed soil was again treated with different proportions of lime in order to get the best result. It has been observed that, the addition of $\text{Ca}(\text{OH})_2$, the OMC decreases about 4% then it is increasing and the vice versa pattern is observed in case of MDD. The OMC and MDD values obtained in addition with 4% lime were 19.32% and 1.74 g/cc.

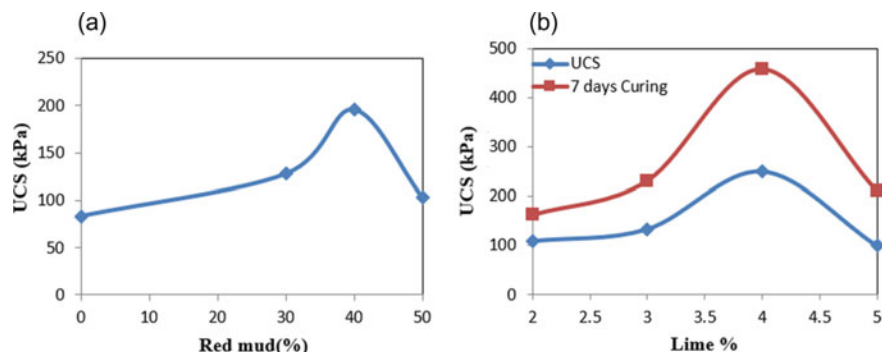


Fig. 1.5 Variation of UCS **a** with red mud, **b** with lime

Uniaxial Compression Test

The uniaxial compression test was conducted with strain rate of 1.25 mm/min as per IS: 2720 (Part 10), and static compaction method has been used to reach MDD and OMC. Figure 1.5 shows that the UCS is improved by 1.5 times in comparison with the soil without reinforcement and occurred at RM content of 40%. In addition, the lime has considerable effect on UCS when stabilized with RM. The UCS of soil increased to 249.58 kN/m² from 195.83 kN/m² when lime was added to RM stabilized clayey soil. The accumulation of lime more than 4% decreases the value (UCS) to 99.63 kN/m². The UCS value hits the peak with addition of 4% lime and 40%, or RM attains the maximum value when the lime is 4%. The UCS values of the virgin soil increases three times by the combined effect of RM and Ca (OH)₂. The cause of this consequence is the pozzolanic reactions of Ca (OH)₂ with soil and red mud. After addition of 5% lime, the strength decreases because of the availability of extra lime.

California Bearing Ratio (CBR)

The CBR test is used to evaluate the strength of sub-grade of road embankment. This test has been conducted as per IS: 2720 (Part 16).

The CBR value of RM mixed soil rises significantly through increasing the RM content up to 40% after which there is a decreasing trend. The CBR of RM stabilized soil increases to 4% from 2.8% of virgin soil in unsoaked condition and 2.69% from 1.7% of virgin soil in soaked condition.

By adding different percentages of lime show significant properties on the CBR (soaked and unsoaked) of the RM alleviated soil. Adding different percentage of lime, the unsoaked CBR values of RM stabilized soil increased to 19.43% from 6.32%, at 4% lime, by an increasing factor of 1.75; further the addition of lime decreases

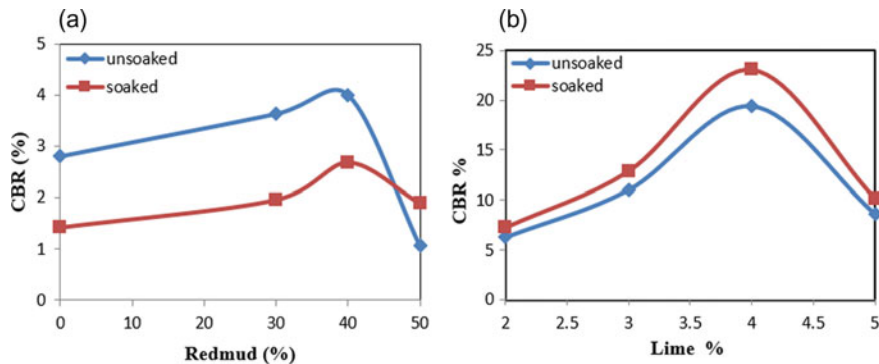


Fig. 1.6 Variation of CBR **a** with red mud, **b** with lime

the CBR value (soaked) of soil. Likewise, the CBR value (soaked) of RM stabilized soil increased to 23.07% from 7.27%, when 4% lime was added, by an increasing factor of 1.78 and further decreases (Fig. 1.6).

Shear Strength Parameters

Soil shear strength properties include the cohesion (c) and the soil friction angle. The test is conducted by putting the sample at OMC and MDD inside the shear box. The sample has been compacted in the box (shear) of $(60 \times 60 \times 60)$ by tamping at MDD to obtain the specimens. The samplings were tested at stresses of 50 kN/m^2 , 100 kN/m^2 , and 150 kN/m^2 in UU conditions confirming to IS code 2720 (Part 13) 1986. The load is applied at a strain rate 0.002 mm/s . The readings were noted down at a fixed interval of horizontal dial gauge readings to study the displacement performance of soil RM mix and soil–RM–lime mix.

The observed shear parameters are c and ϕ in the Fig. 1.7 specifies that the stabilized soil shows an increase in the cohesion (c) and the soil friction angle (ϕ) up to 40% of RM content then decreases. The soil friction angle is increased considerably from 19° to 30° , and the cohesion increases from 29.42 to 49.03 KN/m^2 .

Figure 1.8 illustrates that there is a rise in the cohesion (c) and soil friction angle (ϕ) up to 4% of lime content. The soil friction angle increased significantly from 19° to 40° at 4% of lime and then decreased. Similarly, cohesion increased from 33.33 to 58.82 KN/m^2 and after that it decreased.

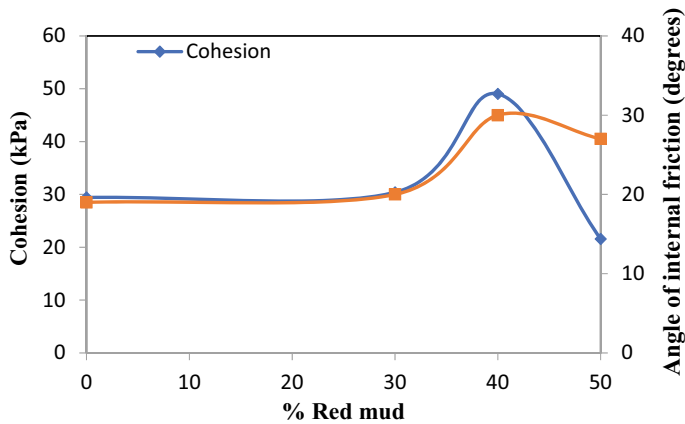


Fig. 1.7 Effect of red mud on shear strength parameters

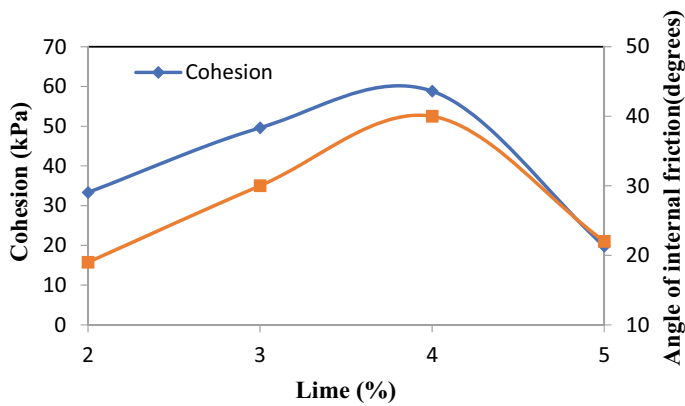


Fig. 1.8 Effect of lime on shear strength parameters

Analysis of EDS

The EDS analysis of particles is shown in Figs. 1.9 and 1.10 for RM stabilized soil and RM-soil mix with lime. The Ca content was increased with addition of lime that is 1.55%–5.78%. The iron content decreases from 45.38 to 29.0% in RM stabilized soil and 26.57% in lime stabilized red mud-soil mix.

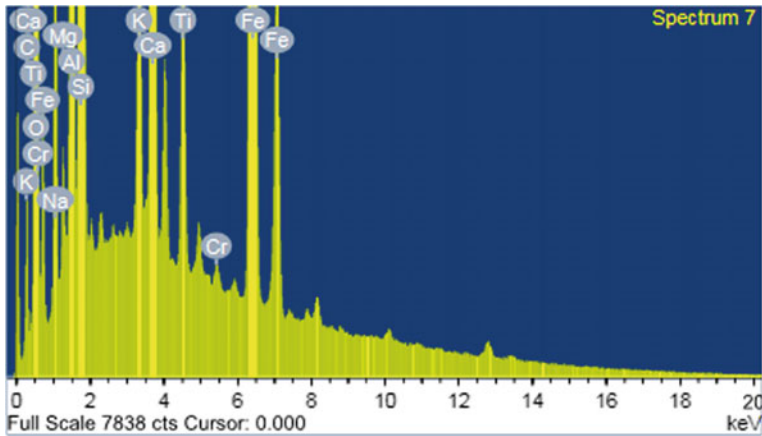


Fig. 1.9 EDS analysis of sample (red mud 60% + soil 40%)

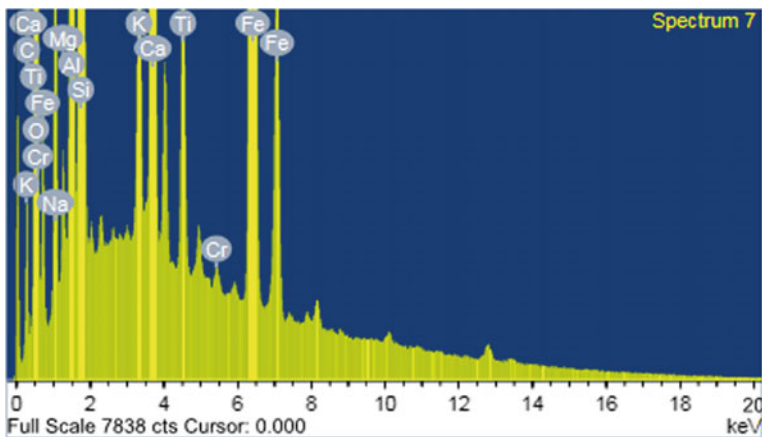


Fig. 1.10 EDS analysis of sample (red mud 60% + soil 40% + lime 4%)

Conclusion

Based on shear strength parameter, UCS results, and CBR results, the optimum proportion of soil to RM was 60:40 by weight. Addition of lime (up to 4%) to the stabilized clayey soil with optimal ratio of RM, the OMC value decreased with intensification in MDD. Further addition of lime results in decreasing in MDD and increasing in OMC. The soaked CBR of RM stabilized soil added with lime increased by a factor of 1.78 at 4% lime and further decreased. In unsoaked condition, the CBR value of RM stabilized soil added with lime increased by a factor of 1.75 at 4% lime and then decreased. The UCS achieves the maximum value when 4% of lime is added

with RM stabilized soil. The UCS value of the virgin soil increases 3 times by the combined effect of RM and lime. After curing, the maximum value of UCS was found at 4% Lime. So, the optimum percentage of Soil: Red mud: Lime was found to be 60:40:4. The red mud is utilized with lime to enhance the behavior of soil strata for better results. Hence, it may be concluded from this study that the RM may be used in soil enhancement of poor clayey soil in its place of simply being predisposed on the land.

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Chapter 2

Ground Improvement for Open Foundation on Soft Clays Using Stone Columns and PVD Drains for Retaining Walls and Approaches of a Cable Stayed ROB



Anurag Goyal and Anjali Gupta 

Introduction

During the design of any embankment, the designer mainly emphasizes on checking of the bearing pressure, settlement, and overall stability. In case of embankment over soft soil, it is necessary to improve the sub-soil to increase the required bearing capacity and other related parameters. There are many ground improvement methods available nowadays, however, the engineering properties of the soft sub-soil can be improved considerably using preloading with prefabricated vertical drains (PVD) [1].

For design of retaining walls ground, improvement by provision of granular piles/stone columns is an effective method to strengthen the soft clays and control settlements within acceptable limits. Therefore, to optimize the cost and find a technically viable solution, combination of two ground improvement techniques has been proposed using stone columns beneath the retaining wall footings and using PVDs beneath the intermediate soil fill. The paper presents the case study of ground improvement carried out for the approaches to a cable stayed bridge—an ROB at Chandmari, West Bengal. Figures 2.1 and 2.2 show the typical cross section of approach ramps and elevation of ROB including approach ramps.

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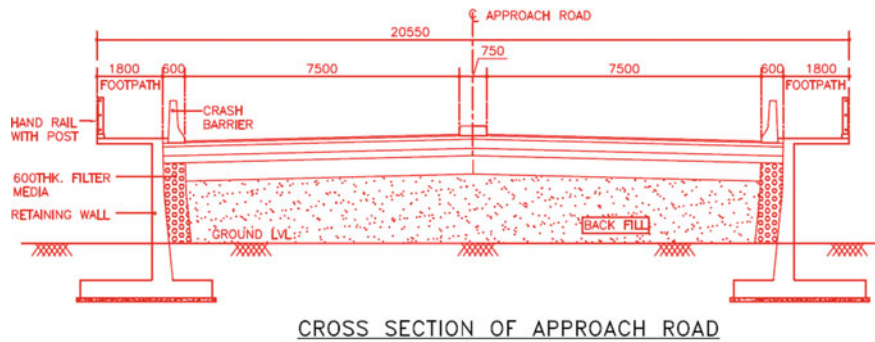


Fig. 2.1 Typical cross section of approach ramp

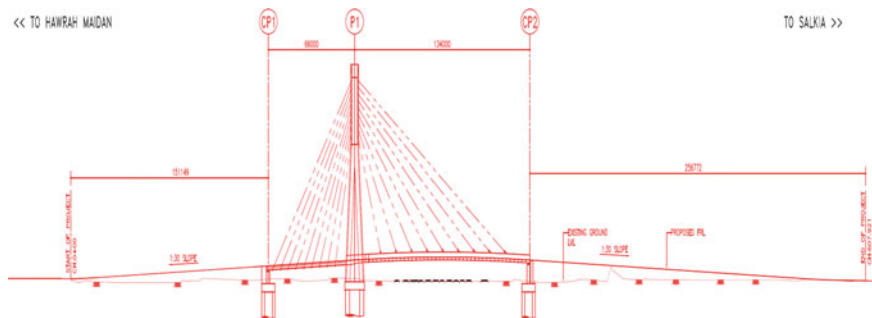


Fig. 2.2 Elevation of ROB and approaches

Sub-Soil Characteristics

Soil investigation report indicated that the top soil was observed to be filled up with overburden loose soil underlain by clayey soil. The clayey soil was found to be soft to medium till a depth of around 15.0 m. However, below this soil, a layer of stiff to very stiff clayey soil was also observed till the 30.0 m depth. This layer was followed by a hard clay layer till 50.0 m depth and further underlain by very dense sand.

Based on soil investigation report, the soil properties reported in Table 2.1 are recommended by considering total four layers and were utilized for the calculations of safe bearing capacity in shear and settlement. It is essential to note that in all three boreholes, slight variation in the depth of layer is observed. The depth of filled up soil was varying from 1.2 m to 5.7 m. Similarly, the depth of different layers was also found to be variable to some extent.

Table 2.1 Sub-soil strength parameters

Layer No.	Depth. M	Strength parameters	
		C (kPa)	Ø (Degrees)
1	00.00–15.00	35	0
2	15.00–30.45	70	0
3	30.45–50.00	200	0
4	50.00–75.00	34	34

Recommendations Within Soil Investigation Report

As per soil investigation report, well foundation was suggested for the main span of ROB. For the approaches and retaining walls, the optimum solution had to be worked out. Hence, in order to optimize, it was essential to identify the alternative solution which can be adopted for the approach portion and side retaining walls. Hence, looking at the present condition, this exercise was undertaken where the existing capacity of ground was evaluated, and the same was compared with the required capacity of ground.

Safe Bearing Capacity of Ground

Looking at the ground model suggested in the soil investigation report, the ground has clayey stratum from the depth 0.0–15.0 m. Considering the approach requirements, a raft of width 6.0 m was assumed for calculating ultimate bearing capacity and allowable bearing pressure.

Ultimate bearing capacity for clayey soil, $q_{ult} = C \times N_c = 35 \times 5.14 = 179.9$ kPa.

Hence, allowable bearing pressure in shear criteria, $q_{ult}/FOS = 179.9/2.5 = 71.96$ kPa = 7.2 T/sqm.

Consolidation settlement at 71.96 kPa for a 12 m depth of clay layer ($2 \times B$),

Using $C_c = 0.405$ (As per Bowels, $C_c = 0.009 \times (w_l - 10)$).

$e_o = 1.167$ (As per soil report).

$H = 12.0$ m ($2 \times B$).

and equation [2],

$$\Delta H = \frac{C_c H}{1 + e_o} \log \frac{p'_o + \Delta p}{p_o} \quad (2.1)$$

Settlement = 300 mm (approximately).

Therefore, for a 7.2 T/m² allowable bearing pressure, a settlement of approximately 300 mm is expected which exceeds the permissible value of 100 mm for a plastic clay.

Expected Loading and Expected Pressure on the Ground

Looking at the approaches of ROB, the maximum height of retention above ground is approximately 8.0–9.0 m. This would require approximately $9 \times 2 + 2.4 = 20.4 \text{ T/m}^2$ including live load surcharge of 2.4 T/sqm. Moreover, for retaining walls, it is essential to restrict the settlements within permissible limits.

Hence, on comparison of existing ground capacity with the expected pressure on the ground, it can be concluded that the ground is not suitable for the open foundation. Hence, the other option was to provide deep foundation, i.e., pile foundation or well foundation. However, the cost and time required for completion of these solutions are very high. This necessitates considering alternative solutions such as ground improvement techniques which can help in increasing the allowable bearing capacity by controlling shear failure and reducing settlement.

Ground Improvement Techniques

With the aim of improving bearing capacity and reducing settlement, mainly two ground improvement schemes are adopted for this project as stated below:

- (I) Ground improvement using stone columns for side retaining walls.
- (II) Ground improvement using PVDs for approach embankments.

Design of Ground Improvement Using Stone Columns for Retaining Walls

Stone columns are considered as one of the most versatile and cost-effective techniques and extensively used over the past few decades in numerous ground improvement and foundation projects. It has gained acceptance due to applicability to an array of soil conditions and soil strengths. The overall performance of stone columns is controlled by the lateral support provided by the surrounding soils, which typically increases with depth. Stone column is laid by drilling holes in the soft soil (clay in present case) and subsequently filling it up with granular material compacted in stages so as to improve the strength and consolidation properties of soft soil (clays).

Typically, stone column helps in improving safe load carrying capacity due to three mechanisms:

- (a) By increasing load bearing capacity as the stones have higher modulus which results in higher load carrying capacity within the unit cell (area where stone column provides resistance).
- (b) By densifying the surrounding soil which results in increased lateral confinement and improvement of shearing strength of soil.