Stabilization of Black Cotton Soil Using Red Mud, Phosphogypsum and Lime

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Abstract. Nowadays the availability of good land for construction has been reduced drastically due to increase in population. Previous soil scientists took extensive efforts to find out appropriate waste material which might be utilized for stabilizing the problematic soil like expansive black cotton soil (BCS) to make it suitable for construction. Expansive soil shows unusual volume change and undesirable engineering behaviour when it comes in contact with water. Hence, constructing a pavement over such soil is very vulnerable to damage, requiring high maintenance cost for its repair. In this present study, an attempt has been taken for utilizing the various combinations of phosphogypsum (PG), red mud and lime with black cotton soil to access and improve their geotechnical behaviour. The effects of phosphogypsum (PG), lime and red mud treatment on BCS have been investigated in laboratory by conducting various test such as california bearing ratio (CBR) test, standard proctor test (SPT) and unconfined compression stress (UCS) test. Considerable improvement has been noticed in the value of UCS and maximum dry density (MDD) when 2% of PG was added to mix of BCS and red mud in the ration of 3:2, whereas the CBR value was found to be maximum when 5% of lime was added to the mix.

Keywords: Expansive soil; Red mud; Lime; Phosphogypsum; Soil stabilisation

1 Introduction

Expansive soil with variation of water content shows undesirable behavior for construction. Expansive soil is present all around the globe. India also has large area of expansive soil known as black cotton soil (BCS). It covers around 0.8 million square kilometers which is 20% of total land area (Mehta et al., 2014). Around 4.71 million tons of red mud is produced every year in India which is 6.25% of world's total generation (Paramguru et al 2005; Parlikar et al 2011). In general, for minimizing the effect of swelling and shrinkage behavior of BCS, red mud along with some additives (lime, cement, fly ash and phosphogypsum) is added. Several investigations were conducted by many researchers all over the world to reduce the expansive behavior of the soil.

Mane and Rajashekhar (2017) studied the properties of BCS with addition of red mud and sodium silicate. They observed that 30% replacement of red mud along with Sodium silicate give better result in the values of California bearing ratio (CBR Value). Singh and Vasaikar (2013) found that the addition of lime with BCS increased the CBR value and decreased the maximum dry density (MDD). Anusha et al. (2021) conducted a study to stabilize BCS with phosphogypsum and lime. In their study, they noted a significant improvement in unconfined compressive strength (UCS). Sridevi et al. (2016) investigated on BCS to improve its properties with the addition of red mud and lime. They found that its UCS value as well as compaction characteristics increases significantly. Degirmenci et al. (2007) carried out several tests on expansive soil with additives like phosphogypsum, cement and fly ash. He observed that the optimum moisture content (OMC) decreases and maximum dry density increases with increase in phosphogypsum quantity. However, there is a dearth of study which investigated the use of phosphogypsum as an additive to stabilize the BCS along with the considerable quantity of red mud.

An effort has been made in the current study to utilize red mud a largely available industrial waste for stabilizing highly expansive black cotton soil. In addition, the study investigated the effectiveness of phosphogypsum and lime as the admixture to enhance various properties in different mixes of BCS and red mud. In this study, various laboratory tests have been conducted to measure their OMC, MDD, UCS and CBR value to explore the possibilities of improving various properties of black cotton soil.

2 Material and Methodology

2.1 Materials

In this present study, black cotton soil and red mud were used as the main soil materials whereas lime and phosphogypsum were considered as the admixture for investigating their effects on various geotechnical and engineering properties of different mixes. Black cotton soil was collected from Banapur of Khordha district located in state of Odisha. Red Mud was collected from NALCO located in Koraput district of Odisha. Phosphogypsum and lime ware procured from local market nearby the university where the study was carried out.

2.2 Basic characterizations

The geotechnical properties of black cotton soil and red mud were evaluated in the laboratory as per the guidelines mentioned in the corresponding parts of IS code: 2720. The results obtained is summarized in Table 1.

Table 1. Geotechnical properties of black cotton soil and red mud

Properties	Black cotton Soil	Red mud
Specific gravity	2.816	2.61
Liquid limit (%)	59.29	27.55
Plastic limit (%)	35.56	24.95
Plasticity index (%)	23.73	2.6
Shrinkage limit (%)	23.77	16.65
OMC (%)	23.6	22.7
MDD (g/cc)	1.62	1.97
Unconfined compressive strength (cohesion $kN.m^{-2}$)	48.78	98.013
Unsoaked CBR (%)	3.43	5.64
Free swell index (%)	27.7	NA
Percentage of finer fraction (less than 0.075 mm)	95.12	64.29

Note: NA – Not Applicable

2.3 Sample preparation

Total twelve different combinations of black cotton soil, red mud, phosphogypsum and lime were considered for the study. Three mixes were first prepared by blending 60%, 70% and 80% of black cotton soil with 40%, 30% and 20% of red mud respectively. Six samples were then prepared by adding 1% and 2% of phosphogypsum to each of the three mixes. This range of percentage of adding phosphogypsum was decided for its economic utilization in enhancing the soil strength based on previous studies Kumari et al. (2014). Similarly, another six samples were prepared by adding 2.5% and 5% of lime. Such range of percentage of lime was incorporated to the soil mixes for its utilization in improving suitable properties according to several past

researches (Kumari et. al 2014; Singh and Vasaikar 2013). Table 2 presents all of these twelve samples along with the designations indicating their various mix proportions. Test specimens were finally prepared for evaluating UCS and CBR values from all these sample mixes at their respective OMC (refer to Fig. 1) and MDD (refer to Fig. 2) by adding suitable quantity of water.

Table 2. Proportions of various sample mixes used in the study

Mix Designation	Percentage (%) of				Sample No.
	Black cotton soil	Red mud	Phosphogypsum	Lime	
B60R40	60	40	1	–	1
	60	40	2	–	2
	60	40	–	2.5	3
	60	40	–	5	4
B70R30	70	30	1	–	5
	70	30	2	–	6
	70	30	–	2.5	7
	70	30	–	5	8
B80R20	80	20	1	–	9
	80	20	2	–	10
	80	20	–	2.5	11
	80	20	–	5	12

3 Result and Discussion

This present study investigated the variation of optimum moisture content (OMC), maximum dry density (MDD), unconfined compressive strength (UCS) and California bearing ratio (CBR) in twelve different combinations of black cotton soil, red mud, phosphogypsum and lime.

3.1 Variation in optimum moisture content

Optimum moisture contents (OMCs) were determined in the laboratory by conducting standard proctor test on three various mixes of 60%, 70% and 80% of black cotton soil with 40%, 30% and 20% of red mud respectively. Four tests were performed on each mix twice by adding 1% and 2% of phosphogypsum and twice by adding 2.5% and 5% of lime. Figure 1 showcases all these test results of OMCs which ranges from 20.3% to 25.3 % in terms of bar charts. The figure shows the higher values of OMCs in case of lime addition than in case of addition of phosphogypsum. The least value of OMC was noted in mix of 70% black cotton soil and 30% red mud when 2% of phosphogypsum was added. Whereas the highest value of OMC was observed in the mix of 80% black cotton soil and 20% red mud when 5% of lime was added. For a specific mix, OMC increases with the increase in lime whereas it decreases with increase in percentage of phosphogypsum. Degirmenci et al. (2007) observed the similar trends in the results of OMC from their investigation.

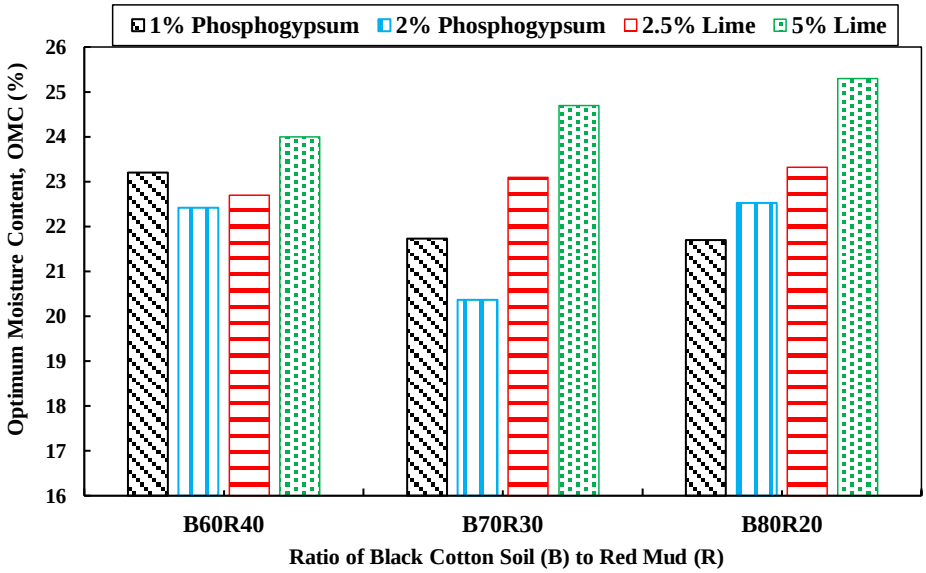

Fig. 1. Variation of optimum moisture content (OMC) in different combination of black cotton soil, red mud, phosphogypsum and lime

3.2 Variation in maximum dry density

The standard proctor test was performed in the laboratory for evaluating the maximum dry densities (MDDs) of twelve different combinations of black cotton soil, red mud, phosphogypsum and lime. Three mixes were first prepared by blending 60%, 70% and 80% of black cotton soil with 40%, 30% and 20% of red mud respectively. Total twelve samples were then prepared including six samples by incorporating 1% and 2% of phosphogypsum and six samples by adding 2.5% and 5% of lime to each of three mixes. Figure 2 illustrates the observed results of MDDs of all these samples with the help of bar diagrams. The figure indicates higher values of MDDs when phosphogypsum was added and lower values of MDDs when lime was incorporated. It also portrays that the values of MDDs remain in between 1.665 g/cc and 1.820 g/cc. The minimum MDD was found when 5% of lime was incorporated to the mix of 80% black cotton soil and 20% red mud. The maximum MDD was noticed when 1% of phosphogypsum was added to the mix of 70% black cotton soil and 30 % red mud. Similar observations were found in several previous studies (Degirmenci et al. 2007; Singh and Vasaikar 2015). However, the red mud was not considered as component material in their study.

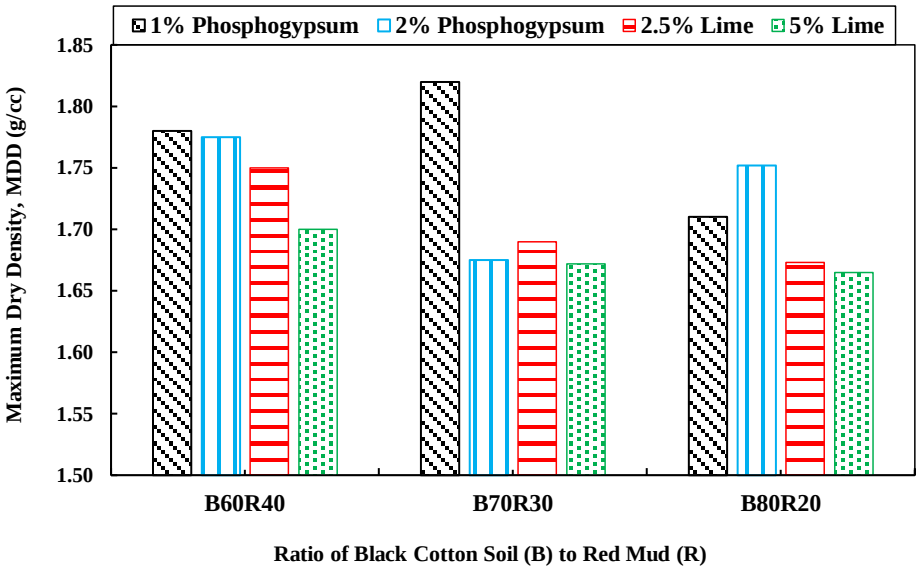

Fig. 2. Variation of maximum dry density (MDD) in different combination of black cotton soil, red mud, phosphogypsum and lime

3.3 Variation in unconfined compressive strength

Unconfined compressive strength tests were carried out in the laboratory on twelve disturbed and remolded cylindrical specimens which were prepared by following the way explained in the above section 4.1 or 4.2. Figure 3 demonstrates the experimental observations of unconfined compressive strengths (UCSs) for all the soil specimens in

terms of bar graphs. The UCS values varies in a range from 157.5 kPa to 223.5 kPa. The figure indicates the higher values of UCSs when both of phosphogypsum and lime were added in higher percentage whereas the lower values of UCSs were observed in case of lower percentage of both phosphogypsum and lime. In this study, the unconfined compressive strength reaches its peak when 5% of lime was added to the mix of 60% black cotton soil and 40% red mud. The UCS value was found to be the least when 1% phosphogypsum was incorporated to the mix of 80% black cotton soil and 20% red mud. Anusha et al. (2021) found the similar results in their research study where red mud was not utilized unlike the present study.

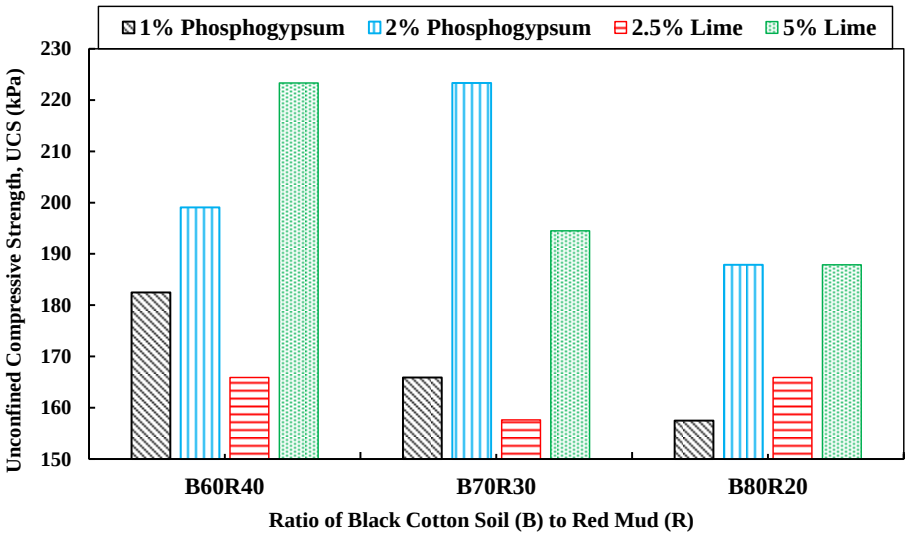

Fig. 3. Variation of unconfined compressive strength (UCS) in different combination of black cotton soil, red mud, phosphogypsum and lime

3.4 Variation in California bearing ratio

Values of California bearing ratios (CBRs) were determined in the laboratory by conducting CBR tests on twelve disturbed and remolded samples which were prepared based on the above procedures described in section 4.1 or 4.2. All the CBR values obtained from the experiment were depicted in forms of bar diagrams in Fig. 4. The figure clearly shows that the higher CBR values were observed when 60% black cotton soil was mixed with 40% red mud and lower CBR values were obtained when 80% black cotton soil and 20% red mud were mixed. For a particular addition of either phosphogypsum or lime to a particular mix, CBR value improves with the increase in red mud to the mix. In this study, the CBR value was found to be the maximum when 2% lime was added to the blend of 60% black cotton soil and 40% red mud. Minimum CBR vale was noted in case of mix of 80% black cotton soil and 20% red mud when 1% phosphogypsum was added. Singh and Vasaikar (2015) noticed the similar trends in their observations.

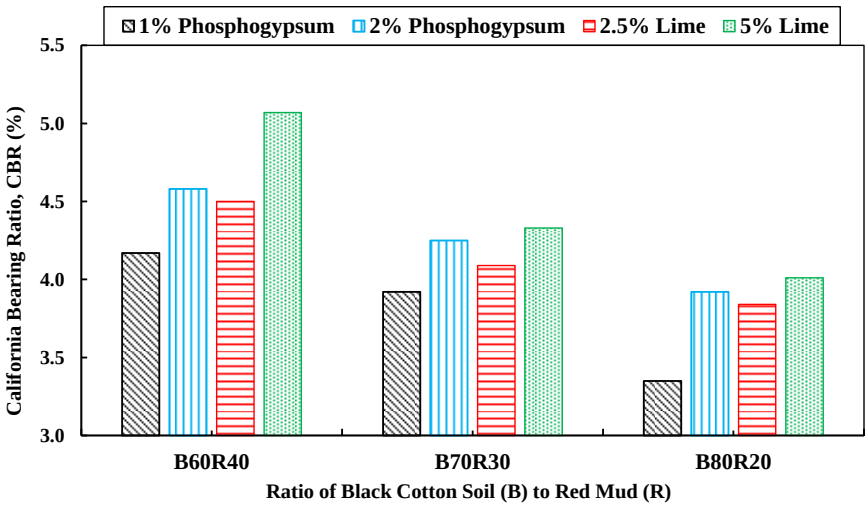

Fig. 4. Variation of California bearing ratio (CBR) in different combination of black cotton soil, red mud, phosphogypsum and lime

4 Conclusion

Following conclusions can be derived from this current study.

- Addition of lime influences the optimum moisture content of the mixtures of black cotton soil and red mud significantly than the addition of phosphogypsum. For a particular mix, the optimum moisture content rises with the increase in lime whereas it falls with the rise in percentage of phosphogypsum.
- Incorporation of phosphogypsum improves the maximum dry density of various blends of black cotton soil and red mud better than the addition of lime. The Maximum dry density was noticed to be highest when 1% of phosphogypsum was incorporated to the mix of 70% black cotton soil and 30 % red mud.
- Relatively higher amount of both lime and phosphogypsum improves unconfined compressive strength of various mixes of black cotton soil and red mud. The unconfined compressive strength was found to reach its peak when 5% of lime was added to the mix of 60% black cotton soil and 40% red mud.
- For a particular addition of either lime or phosphogypsum, enhancement in CBR value is found if the higher quantity of red mud is mixed with black cotton soil. The CBR value was noted to be the maximum when 2% lime was mixed to the blend of 60% black cotton soil and 40% red mud.
- The mixture of 60% black cotton soil and 40% red mud perform the best to enhance the soil properties in terms of UCS and CBR values.

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