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ORIGINAL PAPER

Effect of Cement and Quarry Dust on Shear Strength and Hydraulic Characteristics of Lithomargic Clay

Sitaram Nayak · Purushotham G. Sarvade

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Abstract The lithomargic clay constitutes an important group of residual soils existing under lateritic soils. This soil is found on the western and eastern coasts of India over large areas. This soil is a problematic one and is very sensitive to water and loses a greater part of its strength when becomes saturated. These high silt deposits have invited many problems such as slope failures, foundation failures, embankment failures, uneven settlements etc. In this investigation an attempt is made to study the effect of cement and quarry dust on shear strength and hydraulic characteristics of the lithomargic clay after the stabilization. Microfabric and mineralogical studies were carried out to find out the reason for the strength development of the stabilized soil using SEM and XRD analysis. The results indicated that there is an improvement in the properties of the lithomargic clay with the addition of cement and quarry dust. The XRD results indicated the formation of CSH and CAH, which are responsible for strength development in the stabilized soil.

S. Nayak
Department of Civil Engineering, NITK, Surathkal,
Karnataka, India
e-mail: snayak65@yahoo.co.in

P. G. Sarvade (✉)
Department of Civil Engineering, MIT,
Manipal University, Manipal, Karnataka, India
e-mail: pgsarvade@gmail.com

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1 Introduction

The infrastructural developmental activities due to rapid urbanization and fast growing industries such as Mangalore Refineries & Petrochemicals Ltd., Mangalore Chemicals & Fertilizers, New Mangalore Port Trust etc. in Dakshina Kannada, Udupi districts and adjacent districts of Karnataka, India are forcing the civil engineers to put to the best use of even the poorest sites available and discarded by our ancestors. These poor sites are characterized by low bearing capacities and large settlements. Also low lying agricultural and marshy lands in and around Mangalore and Udupi are being converted into estates with locally available lithomargic clay. Large hills are cut for these purposes. These filled up areas pose problems of low bearing capacity as well as excessive settlements because of improper compaction and poor drainage. The design and construction of the embankments and foundation structures on such soft or problematic soil is a challenging task for a civil engineer, particularly for a foundation engineer. Hence it has become imperative to solve the geotechnical problems concerned with soft and compressible soils.

The lithomargic clay (shedi soil) constitutes an important group of residual soils existing under lateritic soils. These soils are whitish, pinkish or yellowish silty sand. These soils are mainly composed of hydrated alumina and kaolinite powder (Achari and Shivshankar 2005). This soil is present at a depth of 1–3 m below the top lateritic outcrop (throughout the konkan belt of India). These soils are the product of tropical or subtropical weathering. Their strength is high in dry conditions, whereas significant reduction of strength takes place when there is an increase in moisture content. These types of dispersive soils are highly susceptible to erosion (Ramesh and Nanda 2007). Leaching of this soil takes place primarily due to heavy rainfall (Fig. 1). Engineers have to be extremely careful in handling these types of soil. As long as this soil is confined and dry, there is a very little or no problem, but on the exposure in a cutting or when it comes in contact with water, it loses its strength drastically. Slope failures, landslides etc., are quite common in this type of soil (Ravishankar et al. 2006). Hence the construction works in this type of soil is challenging.

2 Modification by Admixtures

Modification by admixtures is a method of modifying the natural soil by the mechanical addition of granular materials or chemical compounds to improve certain properties and make it to serve adequately for an intended engineering purpose. The different uses of soil pose different requirements of mechanical strength and a resistance to environmental forces, controlling method to be used for the stabilization. The purpose of mixing these additives with the ground is to: increase strength, reduce deformability, provide volume stability, reduce permeability and reduce erodibility (Hausmann 1990).

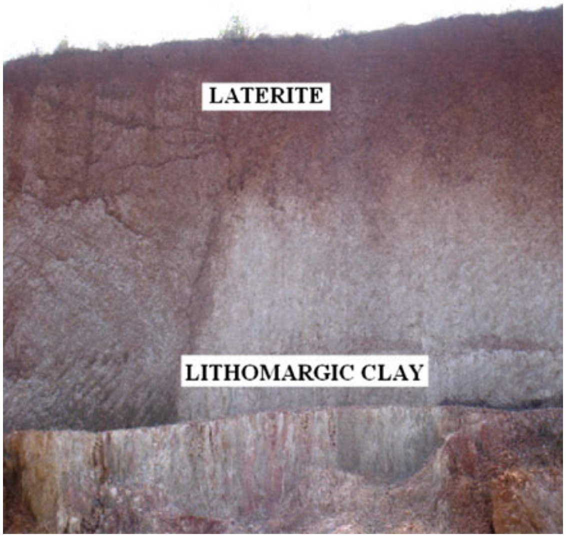


Fig. 1 Lithomargic clay

2.1 Stabilization with Ordinary Portland Cement

Ordinary Portland Cement (OPC) is one of the commonly used admixtures to improve the properties of soil. Cement stabilization is extensively used for road construction purposes resulting in increased bearing capacity of soil subgrade, enabling a reduction of the base course thickness. Layers of cement stabilized clays, with their high strength and high modulus, can also function as a rigid crust which is useful in spreading the applied loads to the subsoil.

2.2 Stabilization with Quarry Dust

Quarry dust is produced mainly during crushing operations. It constitutes 20–25% of the output of each rubble crusher unit. By a rough estimate about 200 million tonnes of quarry by-products are being generated each year in India. Normally this waste product is left in huge heaps in the neighborhood of the quarry causing serious health hazards. Further, the space required for waste disposal is another problem faced by the industry. Quarry dust consists mainly of excess fines generated from crushing, washing and screening operations at quarries. The material properties of this waste vary with the source, but are relatively constant at a particular site. Problems associated with the construction of highways over clayey subgrade can be reduced significantly by mixing with quarry dust (Soosan et al. 2005).

3 Experimental Programme

3.1 Soil

The Lithomargic clay used in the present study was obtained from a site near Kavoor of Dakshina Kannada district (Karnataka State, India). The soil was encountered at a depth of about 1.5 m from the ground level. The disturbed soil was placed in plastic bags and carried to the laboratory for investigation along with undisturbed sample in a core cutter for

Table 1 Geotechnical and chemical properties of untreated lithomargic clay of Kavoor

Sl. no.	Characteristics	Values and descriptions
1	Color	Pinkish
2	Depth	1.5 m
3	Field water content (%)	37
4	Field unit weight (kN/m^3)	19
5	Field dry unit weight (kN/m^3)	13.8
6	Specific gravity	2.58
7	Liquid limit (%)	62
8	Plasticity index (%)	23.2
9	Clay size (%)	12
10	Silt size (%)	56.2
11	Sand size (%)	31.8
12	Soil classification	MH
13	Maximum dry unit weight (kN/m^3)	15.7
14	Optimum moisture content (%)	22.5
15	Unconfined compressive strength (kPa)	152
16	Cohesion (kpa)	29.4
17	Angle of internal friction (degrees)	21
18	California bearing ratio	3.9
19	Coefficient of permeability (m/day)	0.00321
20	pH	4.16
21	Electrical conductivity (µs)	30.79
22	Cation exchange capacity (meq/100 g)	12.92

determining the field density. The geotechnical and chemical properties of the untreated lithomargic clay are presented in Table 1.

3.2 Stabilization

3.2.1 Stabilization of Lithomargic Clay with Cement

In the present study, Ordinary Portland Cement (OPC), 43 grade was used for the stabilization of lithomargic clay obtained from Kavoor of Dakshina Kannada District. The lithomargic clay was first air dried and then oven dried at a temperature of 105°C. Then the soil was crushed, pulverized and sieved in 425 μ sieve. The pulverized soil was then mixed with different percentages of cement (2.5, 5, 7.5 and 10%) by weight for stabilization. After thorough mixing, soil specimens were prepared at OMC and the samples were kept in air tight bags in desiccators for 7 days (curing period) (Fig. 2). After curing, soil samples were tested to get various geotechnical and chemical properties as per IS. For the determination of shear strength parameters, cylindrical samples were prepared at OMC and compacted in three layers at maximum dry density. Then the samples were kept in desiccators for curing of 7 days. After the curing period, the samples were tested in a triaxial compression testing apparatus under unconsolidated undrained condition. Typical mohr circles for the soil sample stabilized with 5% cement is shown in Fig. 3. The summary of results for basic geotechnical properties are presented in Table 2.

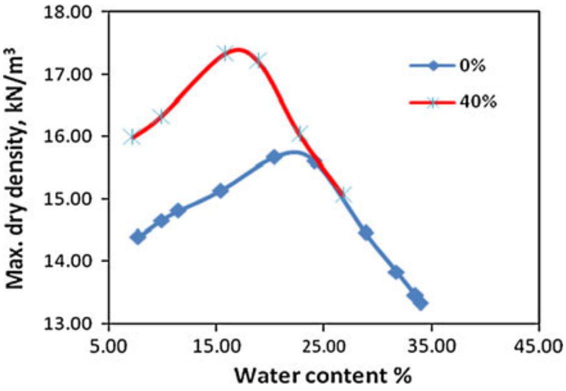


Fig. 2 Moisture-density curve for soil stabilized with 40% quarry dust

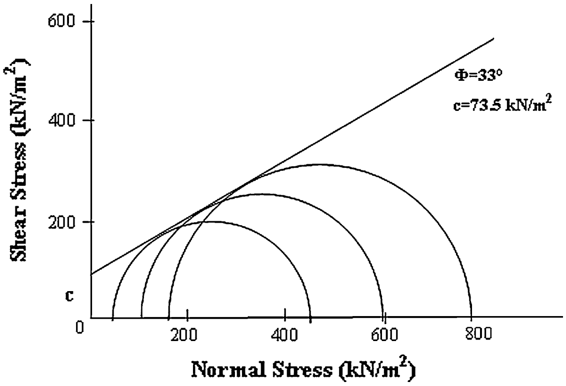


Fig. 3 Mohr circles for undrained tests for soil sample stabilized with 5% cement

The following correlations for lithomargic clay stabilized with cement are obtained:

Figure 4 shows the plot between liquid limit (w_L) and percentage of cement (C%) added. It is clear from the graph that as the cement content increases, the liquid limit decreases. The prediction model is developed for the change in the liquid limit with the cement content, and it resulted $R^2 = 0.907$.

Table 2 Geotechnical properties of lithomargic clay stabilized with cement

Sl. no.	Parameter	Percentage of cement added				
		0%	2.5%	5%	7.5%	10%
1	Specific gravity	2.58	2.6	2.62	2.63	2.65
2	Liquid limit (%)	62	55	52.8	51.8	48
3	Plastic limit (%)	38.8	39.7	40.3	41.2	43.8
4	Shrinkage limit (%)	31.8	40.1	41.2	45.4	46.1
5	Plasticity index (%)	23.2	15.3	12.5	10.6	4.2
6	Maximum dry density (before curing) (kN/m^3)	15.7	15.7	15.7	15.7	15.9
7	Optimum moisture content (%)	22.5	21	20.5	22	22
8	Maximum dry density (after curing) (kN/m^3)	15.7	15.2	15.4	14.9	14.7
9	Optimum moisture content (%)	22.5	22	22.9	25	25
10	Unconfined compressive strength (kPa)	152	248	397	496	676
11	Angle of internal friction (degrees)	21	31	33	40	45
12	Cohesion (kPa)	29.4	58.8	73.5	88.3	93.2
13	Coefficient of permeability (m/day)	0.00321	0.00172	0.00022	0.00017	0.00010

The prediction equation is obtained as given below:

$$w_L(\%) = -1.248\ C\% + 60.16 \quad (1)$$

Figure 4 represents the plot between the plasticity index (I_P) and the percentage of cement added. It is clear from the graph that the plasticity index reduces as the cement content increases. The prediction model is developed for the change in the plasticity index with the cement content, it resulted $R^2 = 0.946$. The prediction equation is obtained as given below:

$$I_P(\%) = -1.708\ C\% + 21.7 \quad (2)$$

The variation of cohesion (c) with percentage of cement added is plotted in Fig. 4. It is clear from the graph that the cohesion value is showing an increasing trend with the increase in the percentage of cement added. The prediction model is developed for the change in cohesion value with cement content, it resulted $R^2 = 0.931$. The prediction equation is obtained as given below:

$$c(\text{kPa}) = 6.284\ C\% + 37.22 \quad (3)$$

Figure 4 represents the variation of the angle of internal friction (Φ) with the percentage of cement added. It is clear from the graph that the friction angle value has increased with the percentage of cement added. The prediction model is also developed for the change in the friction angle with the cement content, it resulted $R^2 = 0.967$. The prediction equation is developed, and is given below:

$$\Phi = 2.28\ C\% + 22.6 \quad (4)$$

The variation of the coefficient of permeability (k) with the percentage of cement added is shown in Fig. 4. It is clear from the graph that the coefficient of permeability is decreasing with the percentage of cement added.

3.2.2 *Stabilization of Lithomargic Clay with Quarry Dust*

In the present study, the quarry dust has been used as a stabilizer and added in different proportions to the lithomargic clay from Kavoor of Dakshina Kannada District. The quarry dust has been collected from a nearby quarry at Athrady of Udupi District. The various percentages of the quarry dust used for stabilization are 10, 20, 30, 40 and 50%. The method of sample preparation, curing etc., for conducting various experimental investigations is similar to lithomargic clay stabilized with cement. The summary of results for basic geotechnical properties are presented in Table 3. The unconfined compressive tests on stabilized soil samples revealed that the unconfined compressive strength increased up to 20% addition of quarry dust and then decreased as the percentage of quarry dust increased. This decrease in unconfined compressive strength at higher percentage of quarry dust (>20%), is due to no confinement. A typical

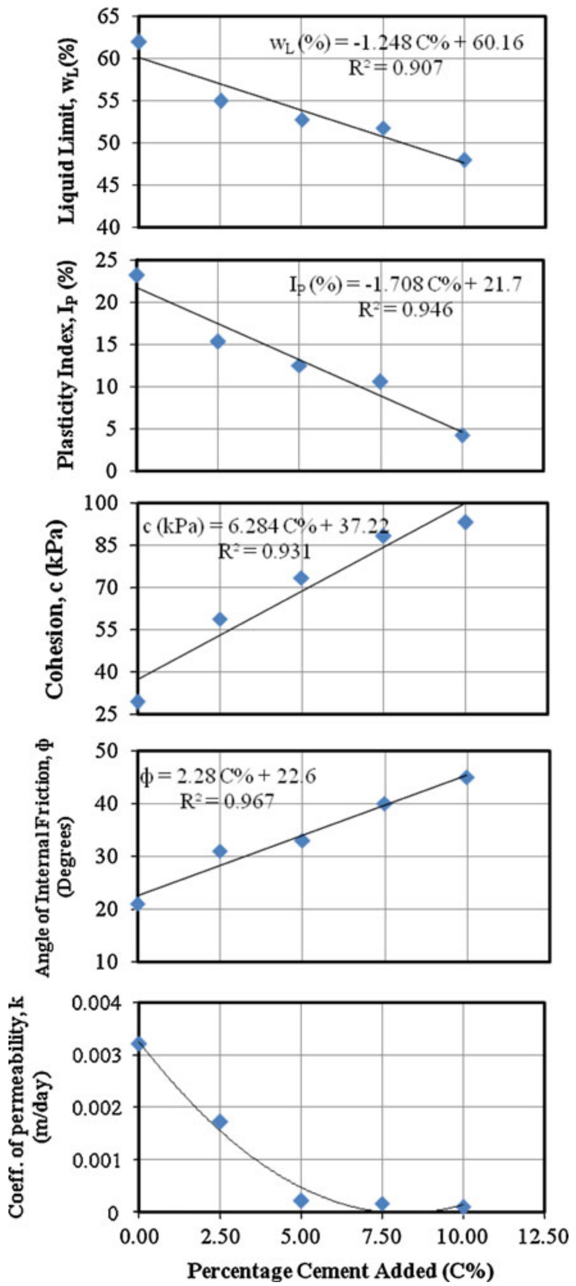


Fig. 4 Variation of geotechnical properties (index and strength) with percentage of cement added

moisture density compaction curve for the soil stabilized with 40% quarry dust is shown in Fig. 2.

The following correlations for lithomargic clay stabilized with quarry dust are obtained:

Fig. 5 represents the plot between the liquid limit (w_L) and the percentage of the quarry dust (QD%) added. It is clear from the graph that the liquid limit is showing a reverse trend. i.e., for increased quarry dust content, liquid limit decreases. The prediction model is developed for the change in liquid limit with quarry dust content, and it resulted $R^2 = 0.960$. The prediction equation generated is as given below:

$$w_L(\%) = -0.576\ \text{QD}\% + 60.25 \tag{5}$$

Figure 5 represents the plot between the plasticity index (I_P) and the percentage of the quarry dust added. It is clear from the graph that the plasticity index decreases with the increased quarry dust content. The prediction model is developed for the change in the plasticity index with the quarry dust content, and it resulted $R^2 = 0.984$. The prediction equation generated is as given below:

$$I_P(\%) = -0.330\ \text{QD}\% + 22.35 \tag{6}$$

Figure 5 represents the plot between the cohesion value (c) and the percentage of the quarry dust added. It is clear from the graph that the cohesion value showing a decreasing trend with the increase in percentage of quarry dust added. The prediction model is developed for the change in the cohesion with the quarry dust content, and it resulted $R^2 = 0.936$. The prediction equation generated is as given below:

$$c(\text{kPa}) = -0.316\ \text{QD}\% + 34.22 \tag{7}$$

Figure 5 represents the plot between the angle of internal friction (Φ) and the percentage of the quarry dust added. It is clear from the graph that the friction angle increases with the increase in the percentage of the quarry dust added. The prediction model is developed for the change in the angle of internal friction with the quarry dust content, that results $R^2 = 0.929$. The prediction equation generated is as given below:

$$\Phi = 0.168\ \text{QD}\% + 22.28 \tag{8}$$

Figure 5 represents the plot between the maximum dry density (γ_{dmax}) and the percentage of the quarry dust added. The maximum dry density increased with the increase in the percentage of the quarry dust. The prediction model is developed for the increase in the γ_{dmax} value with the quarry dust content, and it resulted $R^2 = 0.967$. The prediction equation generated is as given below:

$$\gamma_{dmax}(\text{kN/m}^3) = 0.052\ \text{QD}\% + 15.53 \tag{9}$$

Figure 5 represents the plot between the coefficient of permeability (k) and the percentage of the quarry

Table 3 Geotechnical properties of lithomargic clay stabilized with quarry dust

Sl. no.	Parameter	Percentage of quarry dust added					
		0%	10%	20%	30%	40%	50%
1	Clay size (%)	12	11	9	8	5	3
2	Silt size (%)	56	49	46	43	42	38
3	Sand size (%)	32	40	45	49	53	59
4	Liquid limit (%)	62	54.3	45.5	42.3	40.3	30.7
5	Plastic limit (%)	38.8	36.5	30	29.1	31.1	25.0
6	Shrinkage limit (%)	31.8	30.4	28.5	27.3	26.1	23.6
7	Plasticity index (%)	23.2	17.8	15.5	13.2	9.2	5.7
8	Max. dry density (kN/m^3)	15.7	16.0	16.5	17.0	17.4	18.4
9	Optimum moisture content (%)	22.5	22.0	20.0	17.6	16.6	15.4
10	Unconfined compressive strength (kPa)	152	354	598	353	141	103
11	Angle of internal friction (degrees)	21°	25°	26°	28°	29°	30°
12	Cohesion (kPa)	33.34	32.36	29.42	22.56	20.59	19.61
	Coefficient of permeability (m/day)	0.00321	0.01313	0.02432	0.0355	0.0467	0.05789

dust added. The coefficient of permeability increased with the increase in the percentage of the quarry dust. The prediction model is developed for the increase in the coefficient of permeability with the quarry dust content, and it resulted $R^2 = 0.999$. The prediction equation generated is as given below:

$$k(\mathrm{m/day}) = 0.001\ \mathrm{QD}\% + 0.002 \qquad (10)$$

3.2.3 Stabilization of Lithomargic Clay with Quarry Dust + Cement

An experimental study have been undertaken to investigate the effect of cement on the quarry dust stabilized soil. The lithomargic clay selected for stabilization was from the same site (Kavoor of Dakshina Kannada district) mixed with different percentages of cement and the quarry dust and have been tested in the laboratory to get various geotechnical properties. The sample preparation, curing, testing etc., is similar to the lithomargic clay stabilized with cement and quarry dust. The laboratory test results are presented in Table 4.

From the Table 4, it is clear that as the percentage of the quarry dust and cement increases, the liquid limit decreases. But with the increase in the percentage of cement on different percentages of quarry dust there is increase in the plastic limit. The plasticity index decreases with the increase in the percentage of the quarry dust and cement. The angle of internal friction increases with the addition of cement and the quarry dust to the lithomargic clay. The value of cohesion increases with the addition of cement to the lithomargic clay stabilized with quarry dust.

4 Microfabric and Mineralogical Studies Using SEM and XRD on the Lithomargic Clay Stabilized with Cement and Quarry Dust

Soil stabilization has been widely used all over the world to improve the soil behavior. Most of the research works have concentrated only on the study of the properties of the stabilized soil. However, more research works have to be done in order to study how soil properties have been improved. The microfabric (geometric arrangement of platelets) and mineralogical aspects of the lithomargic clay treated with cement and quarry dust was studied using Scanning Electron Microscope (SEM) and X-ray Diffractometer (XRD). The main objective of the investigation is to find out reason for the strength development of the stabilized soil.

The Scanning Electron Microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity.

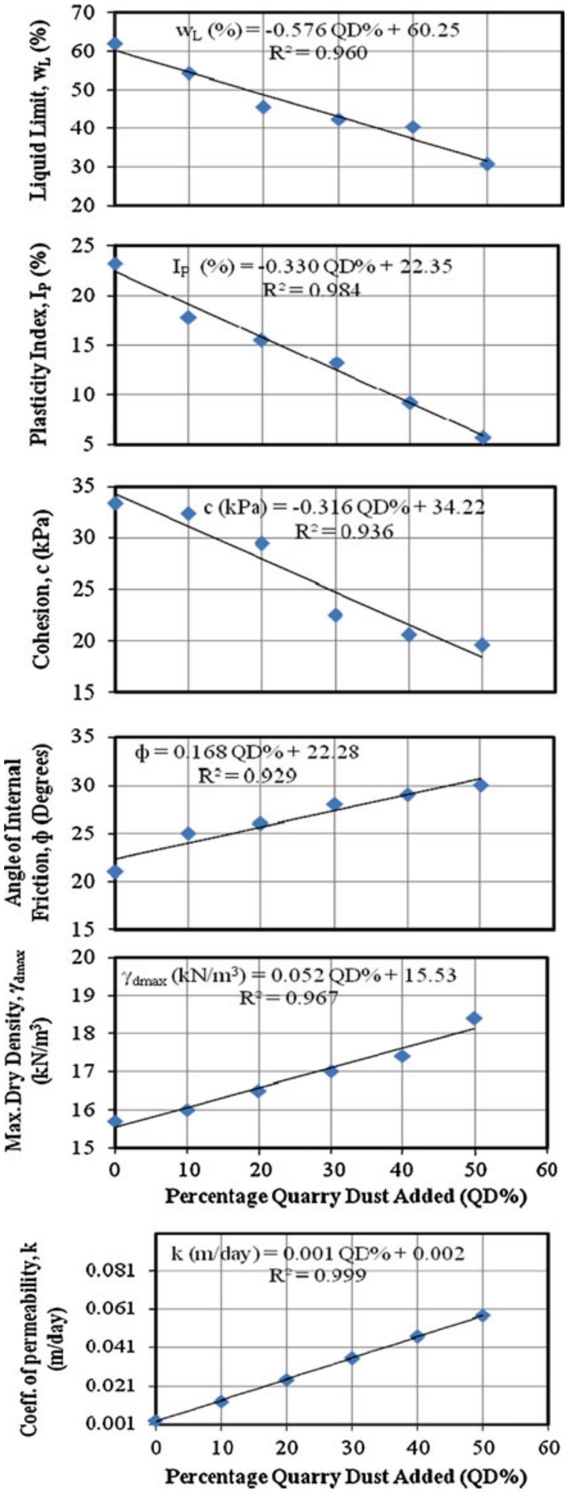


Fig. 5 Variation of geotechnical properties (index and strength) with percentage of quarry dust added

The X-ray Diffraction (XRD) is a versatile, non-destructive technique that reveals detailed information about the chemical composition and crystallographic structure of natural and manufactured materials. XRD is the most direct and accurate method for determining the presence of absolute amounts of mineral species in a sample.

4.1 SEM Analysis of Stabilized Lithomargic Clay

The scanning electron microscope used in present study is of the type JEOL JSM—6380 LA (Fig. 6). The secondary electron imaging (SEI) is used as mode of imaging. In this case the secondary electrons are reflected only from the surface of the sample. Thus, SEM can identify the microfabric of only topmost surface of the sample. First the entire surface is scanned under low magnification and then, the chosen areas are magnified to get the clear picture of the micro fabric arrangement. Seven days cured samples are taken for this study so that there is reasonable time for the development of the cementitious bonds. Sample preparation included mounting samples on carbon double-stick tape on aluminum stubs. The samples were coated with gold sputter coater (Fig. 7).

4.1.1 SEM Analysis of Lithomargic Clay Stabilized with Cement

This study focuses on understanding the microstructure development with cement content for particular water content (OMC). Figures 8, 9 and 10 shows some of the typical SEM images of lithomargic clay, lithomargic clay mixed with 5% of cement and lithomargic clay mixed with 10% of cement, respectively.

When the soil is stabilized with 5% cement, hydration products are clearly seen surrounding the soil particles. As the cement content increased, hydration products are clearly seen in the pores (Fig. 7) and the cementitious products significantly increase. The cementitious products not only enhance the inter-cluster bonding strength but also fill the pore space, as shown in Fig. 10. The volume of pores is significantly reduced with cement, thus, the reduction in total pore volume. The effect of cation exchange and attraction causes clay particles to become close to

Table 4 Geotechnical properties of lithomargic clay stabilized with quarry dust + cement

Sl. no.	Parameter	Lithomargic clay	Percentage of quarry dust + cement added					
			10 + 2.5	30 + 2.5	50 + 2.5	10 + 5	30 + 5	50 + 5
1	Clay size (%)	12	1	0.5	0.5	1	0.5	0.5
2	Silt size (%)	56.2	55.2	53.6	50.5	53.9	52.6	51.5
3	Sand size (%)	31.8	43.8	45.9	49.0	45.1	46.7	48.0
4	Liquid limit (%)	62	45.2	40.1	34.4	43.3	36.8	33.2
5	Plastic limit (%)	38.8	37.4	33.1	31.5	38.2	34.2	32.6
6	Shrinkage limit (%)	31.8	32.2	30.8	24.0	34.3	34.0	28.2
7	Plasticity index (%)	23.2	7.8	7.0	2.9	5.1	2.6	0.6
8	Maximum dry density (before curing) (kN/m^3)	15.7	16.4	16.0	16.8	16.7	18.04	17.9
9	Optimum moisture content (%)	22.5	20.5	21.5	19.5	18.0	15.5	15.5
10	Maximum dry density (after curing) (kN/m^3)	15.7	15.2	14.8	15.7	14.8	17.5	16.2
11	Optimum moisture content (%)	22.5	24.5	26.0	23.5	22.0	20.0	21.5
12	Unconfined compressive strength (kPa)	152	208	230	245	366	375	390
13	Angle of internal friction (degrees)	21	29	30	34	37	39.5	41
14	Cohesion (kPa)	29.4	34.3	24.5	26.5	39.2	49	29.4
15	Coefficient of permeability (m/day)	0.00321	0.01581	0.09072	0.16563	0.01432	0.08923	0.16414

each other (Al-Rawas et al. 2005). As a result, the strength significantly increases with cement. In Fig. 10, when lithomargic clay is stabilized with 10% cement, inter cluster bonding with cementitious products are clearly visible.

4.1.2 SEM Analysis of Lithomargic Clay Stabilized with Quarry Dust

This study focuses on understanding the microstructure development with quarry dust stabilization. The Fig. 11 shows the SEM images of lithomargic clay mixed 50% of quarry dust.

The micro structure of the lithomargic clay stabilized with quarry dust clearly differs from that of unstabilized lithomargic clay. From Fig. 11, it is clear that, when the soil is stabilized with 50% quarry dust; there is no cementation between the particles but the structure of the soil becomes denser. And the denseness increases as the percentage of quarry dust increases. Hence a higher densification of soil mass is achieved eliminating all the voids. This increases the strength of the soil.

Fig. 6 JEOL JSM – 6380LA Analytical scanning electron microscope

Fig. 7 JEOL JFC-1600 Auto fine coater

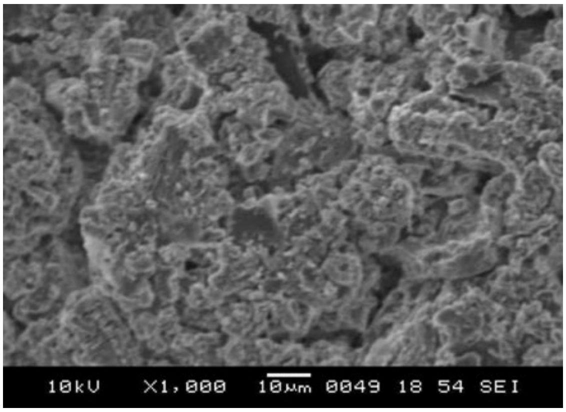


Fig. 8 SEM image of Lithomargic clay

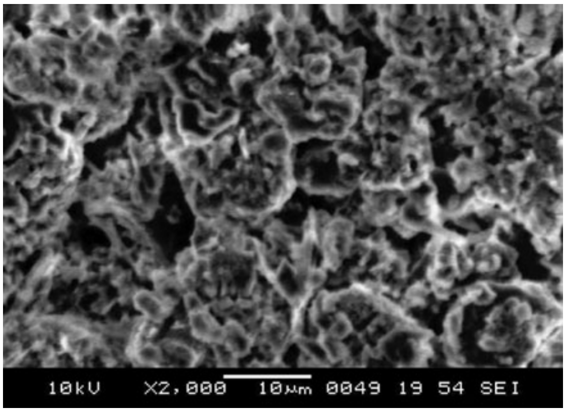


Fig. 9 SEM image of Lithomargic clay + 5% cement

4.1.3 SEM Analysis of Lithomargic Clay Stabilized with Quarry Dust + Cement

This study focuses on understanding the microstructure development with quarry dust + cement stabilization.

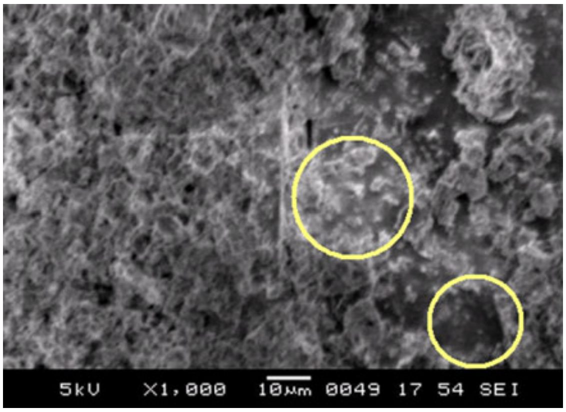


Fig. 10 SEM image of Lithomargic clay + 10% cement

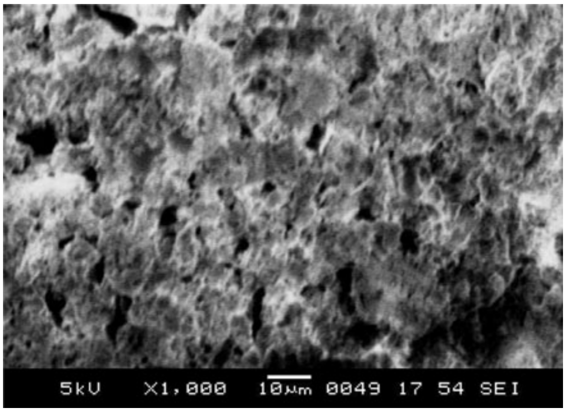


Fig. 11 SEM image of lithomargic clay + 50% quarry dust

Fig. 12 shows the typical SEM image of lithomargic clay mixed with 50% of quarry dust +5% cement. The cementation which is absent in lithomargic clay soil blended with only quarry dust is seen when the lithomargic clay soil is stabilized with selected percentage of quarry dust and cement. As the cement content increased, hydration products are clearly seen in the pores and the cementitious products significantly increase.

4.2 XRD Analysis of Stabilized Lithomargic Clay

The X-ray diffractometer used in the present study is of type JEOL-Model DX-GE-2P (Fig. 13). In this method the material was exposed to a filtered X-ray beam. The X-ray passes into the material and causes the electrons in the atoms of the minerals to vibrate and reflect the beam through the successive planes. The method involves increasing of incidence angle

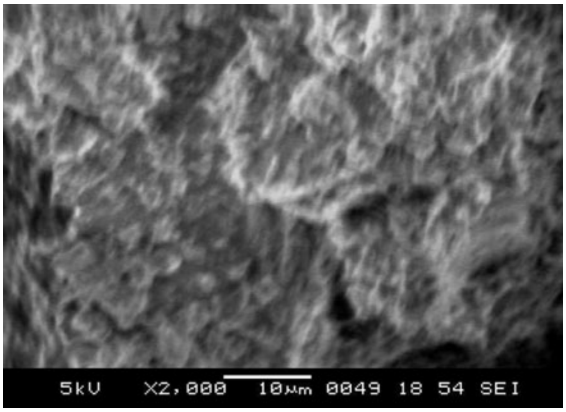


Fig. 12 SEM image of lithomargic clay + 50% quarry dust + 5% cement

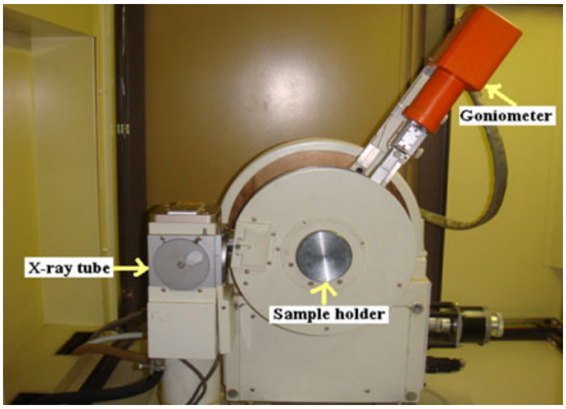


Fig. 13 X - ray Diffractometer – JEOL- Model DX-GE-2P

and monitoring the intensity of the diffracted X-radiation until a maximum value of the diffracted intensity is achieved. Qualitative study by using XRD was carried out to investigate the reaction products of the stabilized soil during the stabilization process. The stabilized soil samples after 7 days curing were used in this investigation.

4.2.1 XRD Analysis of Lithomargic Clay Stabilized with Cement

XRD analysis of lithomargic clay and lithomargic clay stabilized with 5% cement are shown in Figs. 14 and 15.

The improvement of clay soils with cement involves cation exchange, flocculation and agglomeration, cementitious hydration and pozzolanic reaction (Prusinski and Bhattacharja 1999; Puppala et al. 2004). Ordinary Portland Cement (OPC) is composed of calcium-silicates and calcium-aluminates that, when combined with water, hydrate to form the cementing compounds of Calcium-Silicate-Hydrate (CSH) and Calcium-Aluminate-Hydrate (CAH), as well as excess calcium hydroxide. A pozzolanic reaction occurs between the calcium hydroxide released during hydration and soil alumina and soil silica present in lithomargic clay soil. This is an important aspect in the stabilization of this soil. The resulting stabilized soil is a moisture-resistant soil that is highly durable and resistant to leaching over the long

Fig. 14 XRD pattern of lithomargic clay

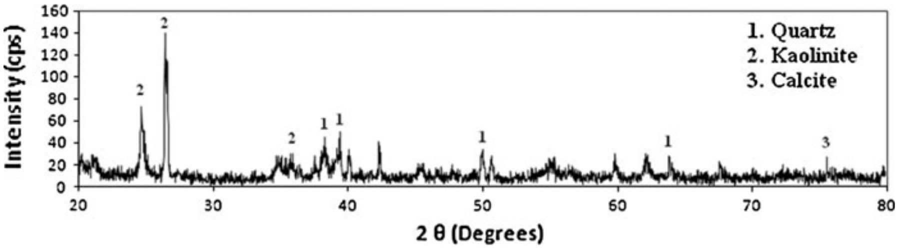
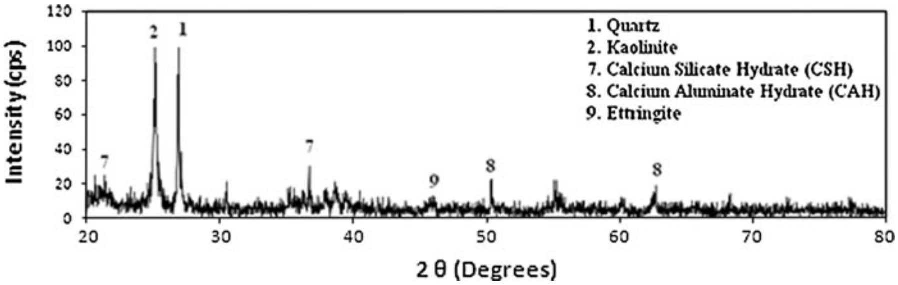


Fig. 15 XRD pattern of lithomargic clay + 5% cement



term. The XRD pattern of the untreated soil, as shown in Fig. 14, indicated that the soil is composed of silica in the form of quartz, calcite and kaolinite as dominant minerals. Identification revealed that the untreated soil initially contained no cementing materials. After the stabilization with cement, formation of CSH and CAH was observed. Ettringite is also found in all the stabilized samples. Ettringite is a calcium aluminum sulfate hydrate (CASH) type mineral which is responsible for the early strength gain Khoury et al. (2004).

4.2.2 *XRD Analysis of Lithomargic Clay Stabilized with Quarry Dust*

XRD analysis of quarry dust and lithomargic clay stabilized with 30% quarry dust are shown in Figs. 16 and 17. The XRD pattern of lithomargic clay stabilized with of quarry dust revealed the existence of the following minerals—Quartz, Kaolinite, Magnetite, Zircon and Garnet.

4.2.3 *XRD Analysis of Lithomargic Clay Stabilized with Quarry Dust + Cement*

XRD analysis of lithomargic clay stabilized with 50% quarry dust + 2.5% cement is shown in Fig. 18. The XRD pattern of lithomargic clay stabilized with quarry dust + cement revealed the existence of the following minerals—Quartz, kaolinite, Calcite, Magnetite, Zircon and Garnet. The formation of hydration product (CSH) is also observed.

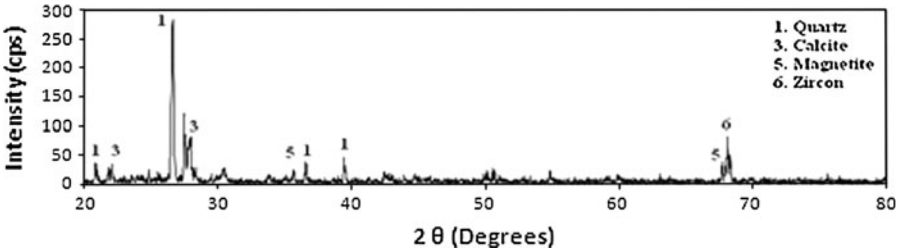


Fig. 16 XRD pattern of quarry dust

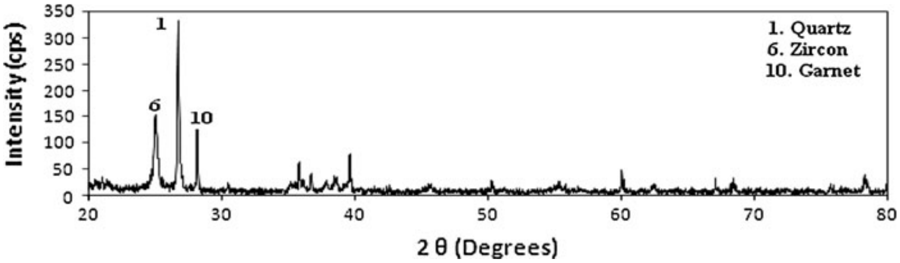


Fig. 17 XRD pattern of lithomargic clay + 30% quarry dust

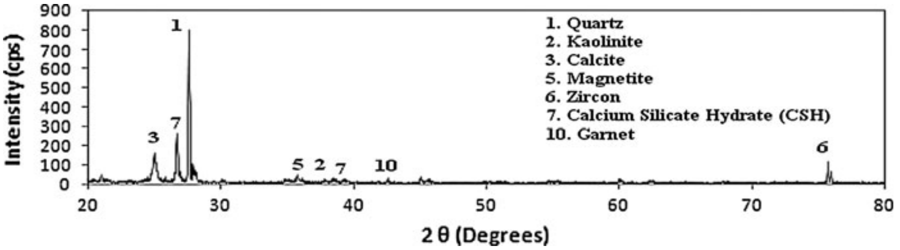


Fig. 18 XRD pattern of lithomargic clay + 50% quarry dust + 2.5% cement

5 Conclusions

A study was undertaken to see the effect of admixtures (cement, quarry dust and quarry dust +cement) on the strength of the lithomargic clay during stabilization. The microfabric and mineralogical study was made on unstabilized and stabilized soil using Scanning Electron Microscope (SEM) and X Ray Diffraction (XRD) respectively. The following conclusions are drawn from the above investigations:

1. The percentage reduction in liquid limit is about 22.6% when 10% of cement was added. Plasticity index has reduced by about 81.9% for 10% cement addition.
2. There is a sharp improvement in shear strength parameters with the addition of cement. Angle of internal friction has witnessed an improvement of about 114% for 10% cement addition. Cohesion value has an improvement of about 217% for 10% cement addition.
3. After stabilization of lithomargic clay soil using quarry dust, the percentage reduction in liquid limit is about 50.5% when 50 percentage of quarry dust was added. Plasticity index has reduced by about 75.4% for 50 percentage quarry dust addition.
4. There is an increase of 18% in max. dry density values for the addition of 50% quarry dust. This increase in max. dry density value is because of the increase in percentage of sand. There is 32% decrease in the values of optimum moisture content.
5. For 50% quarry dust addition, angle of internal friction has witnessed an improvement of 43%.
6. For 50% quarry dust addition, coefficient of permeability showed an improvement from 0.00321 m/day to 0.05789 m/day.
7. After stabilization, it is found that the liquid limit, plastic limit and shrinkage limit has reduced with quarry dust + cement addition. Plasticity index has reduced by about 97.4% for 50% quarry dust + 5% cement addition.
8. With the addition of quarry dust, angle of internal friction has witnessed an improvement and cohesion value has decreased. But when the soil is stabilized using both quarry dust and cement, there is increase in cohesion as well as angle of internal friction.
9. XRD analysis of lithomargic clay soil stabilized with cement resulted in the formation of new mineral namely, ettringite which is responsible for early strength gain. Due to hydration of cement, it is found from XRD analysis that there is formation of Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH) which is responsible for strength development in stabilized soil.
10. SEM analysis revealed change in the soil structure due to the addition of cement and quarry dust.

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