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Geotechnical Investigation on Lithomargic Clay Blended with Quarry Dust and Lime and its Application to Slope Stability Problems

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ABSTRACT

The coastal area of Andhra Pradesh has a hard crust on the top. These top layers of the laterite formations are highly porous but hard and strong. In between this top low level laterites and bottom high level laterites some of the beds are having size distribution between JEDI (clay) and GODI (silt) soils, but do not show the behaviour of the clay nor silt, called shedi soil (lithomargic clay). Shedi soil is the name given to the locally available whitish, pinkish/ yellowish lithomargic soil with high silt content and low bearing strength. When the shedi soil become saturated as a result of rain, it loses its strength and possess the same problems as that of dispersive soil. Usually the low lying areas of Andhra Pradesh state are usually filled up with these problematic soils. Construction on these type of soil possess problem of excessive settlement and low bearing capacity. In this paper, an attempt is made to stabilize the shedi soil of Baptla Guntur Dist Andhra Pradesh state using the quarry dust obtained from the Trident infrastructure, Bajpe and lime procured from the local market. The shedi soil was replaced by quarry dust in different proportion of 10, 20, 30, 40 and 50% by dry weight of soil whereas lime was added to soil in proportion of 2.5, 5 and 7.5% by dry weight. A series of laboratory experiments were conducted on the un stabilised bas well as stabilized specimens. All the specimens were prepared at OMC and MDD.

Introduction

1.1. General

The word soil is derived from the latin word '***Solium***' which means the upper layer of Earth that may be dug or plowed. Soil is nothing but an unconsolidated material composed of solid particles produced by the disintegration of rocks.

Soil formation, or pedogenesis, is the combined effect of physical, chemical, biological and anthropogenic processes working on soil parent material. When a rock surface gets exposed to atmosphere for appreciable time, it disintegrates or decomposes into small particles and thus soils are formed.

The use of soil as a construction material dates back to ancient times. Soil was used as a construction material for building huge earth mound for religious purposes, burial places and dwellings in ancient times. These poor sites are characterized by low bearing capacities and large settlements.

Soil particles can be classified by their chemical composition (mineralogy) as well as their size. The particle size distribution of a soil, its texture, determines many of the properties of that soil, but the mineralogy of those particles can strongly modify those properties.

With increase in construction activity both onshore and off shore, it has become imperative to solve geotechnical problems concerned with soft and compressibile soil.

Shedi Soil

The coastal area of Andhra Pradesh has a hard crust on the top, these top layers of the laterite formations are highly porous but hard and strong.

In between this top low level laterites and bottom high level laterites some of the beds are having size distribution between JEDI (clay) and GODI (silt) soils, but do not show the behaviour of the clay nor silt. These soils dissolve and flow like water when water gushes through this layer during monsoon and many times washes–off the fine soil, creates cavities and at time causes heavy settlement and sliding of the top layers after the application of load. This bed soil is termed as lithomargic clay (shedi soil).

These soils are whitish, pinkish or yellowish silty sand and represent an important group of residual soils existing under lateritic soils (Achari and Shivshankar 2005). This soil is present in between weathered laterite and hard granite gneiss and is present at a depth of 1–3 m below the top lateritic outcrop (throughout the Sarkar belt of India).As long as the soil is confined and in dry state,it possess good strength, whereas significant reduction of strength takes place when it comes in contact with water.

1.3. Soil Stabilisation

Soil stabilization is the process of improving the engineering properties of the soil and thus making it more stable. The prime objective of soil stabilization is to improve the California Bearing Ratio of in-situ soils by 4 to 6 times. The other prime objective of soil stabilization is to improve on-site materials to create a solid and strong sub-base and base courses.

In the past, soil stabilization was done by utilizing the binding properties of clay soils, cement-based products, and/or utilizing the "rammed earth" technique and lime.

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Now new types of soil stabilization techniques classified as "green technologies" have emerged and some of them are: enzymes, surfactants, biopolymers, synthetic polymers, co-polymer based products, cross-linking styrene acrylic polymers, tree resins, ionic stabilizers, fiber reinforcement, calcium chloride, sodium chloride and more..

Traditionally and widely accepted types of soil stabilization techniques use products such as bitumen emulsion which can be used as a binding agents for producing Dust (CKD), Tree resin and Ionic stabilizers are all commonly used stabilizing agents.

Four groups of ground modification techniques are distinguished:

- Mechanical stabilization

In this method the soil density is increased by the application of short term external mechanical forces, including compaction of surface layers by static, vibratory or impact rollers and plate vibrators and deep compaction by heavy tamping at the surface or vibration at a depth.

Compaction is the most common method of ground modification.

- Shallow surface compaction which can be achieved by either the static pressure or by dynanmic pressure caused by impact or vibration. It includes use of smooth wheel rollers, sheep foot rollers , tampers, rammers etc.
- In deep compaction the densification of the deep soil deposit can be achieved. The methods of deep compaction includes pre-compression, compction by explosion, by heavy tamping etc.

- Hydraulic modification

It is the process of forcing out free pore water out of the soil via drains or wells i.e. in simple words dewatering. In coarse grained soil this achieved by gravity drainage into sump i.e. by lowering the groundwater level through pumping from boreholes or trenches.

The traditional dewatering techniques includes:

- Open sumps and wells
- gravity flow wells
- Vaccum dewatering wells
- Dewatering by pre fsbricsted drains

- Physical and chemical modification

Physical treatment of soil implies the change in the physical structure of the soil by the application of thermal energy. It is also called thermal modification. Due to the consumption of large quantity of fuel for the heat production, this method has become obsolete these days.

Chemical modification is done by the addition of certain chemicals like lime, cement, calcium chloride, sodium silicate, sodium chloride, bitumen tar, etc to the soil.

- Modification by inclusion and confinement.

Reinforcement in the form of fibres, strips, bars, meshes and fabrics are added to soil to impart tensile strength to the soil. Retaining structures are made stable by confing the soil using concrete, steel or fabric elements which includes crib and bin walls and sand bags.

The primary purpose of reinforcing the soil mass is to improve its durability, to impart tensile strength, to increase the bearing capacity and to reduce the settlement.

1.3.1. Stabilisation using lime and quarry dust

1.3.1.1. Lime stabilisation

The addition of lime to improve the properties like strength of soil is not a new technology. It dates back to the Roman times, when lime was used to construct the Appian way in 312BC.

Lime can modify almost all type of fine grained soils, but most dramatic improvement occurs in the case of moderate to high plastic clayey soil.

Thus the clay mineralogy is altered providing the following benefits:

- Plasticity reduction
- Reduction in moisture holding capacity
- Swell reduction
- Improved stability

Quick lime is delivered in the form of a coarse grained powder with a bulk density of 0.85 to 1.05 t/m^3. It react quickly with water, producing hydrated or slaked lime, considerable heat, causing a volume increase. The transition from quick lime to hydrated lime is characterized by the following index properties:

Table 1.1. Properties of quick lime and hydrated lime

	Quick lime	Water	Hydrated lime
Molecular weight	56	18	78
Specific Gravity	3.3	1	2.2
Relative weight	1	0.32	1.32
Relative Volume	1		1.99

The quick lime has several advantages over hydrated lime:

1. Quicklime has a higher available lime content per unit mass than hydrated lime. 3% quick lime is normally equivalent to 4% hydrated lime.
2. Quick lime is denser than hydrated lime requiring less storage and transport space.
3. Quick lime is considerably less dusty than hydrated lime.
4. Quicklime produces a large reduction in moisture content due to hydration and evaporation. It is particularly beneficial with wet soils.

Mechanism of lime stabilization

The addition of lime to soil comprises of short term reaction which include hydration and flocculation (ion exchange). Longer term reactions are cementation and carbonation.

Hydration

Quick lime will immediately react with the water in the soil. This drying action is particularly beneficial in the treatment of moist clays. The actual moisture content of the soil is, therefore reduced in addition to the apparent drying out caused by the increase in plastic limit.

Flocculation

When lime is mixed with soil containing clay minerals in the presence of water, the sodium and other cations adsorbed by the soil mineral surfaces are exchanged with calcium.

Cementation

In the second stage of clay lime reaction removes silica from the clay lattice to form products not unlike those of cement hydration.

The clay minerals are natural pozzolonas and have the ability to react with lime added to the soil to produce cementitious products.

Lime is not suitable for stabilizing clean sands or gravels.

Carbonation

Reaction of lime with carbon dioxide in the open air or in voids of the ground forms a relatively weak cementing agent. This is beneficial in situation where lime is available in plenty.

1.3.1.2. Quarry dust

Due to the increased demand of aggregates for the construction purposes, a large number of stone quarries and aggregate crushers units have been established. These aggregate crusher units produce enormous amount of quarry dust, a waste product produced during the crushing of rubbles. The only way in which quarry dust can be utilized economically and eco friendly is by using them for the highway construction purposes thereby reducing the cost of construction as well as providing a solution to the environmental problem.

The physical properties, chemical composition and mineralogy of quarry dust vary with the aggregate type and producer source, but are relatively consistent at each location of quarries. Quarry dust has proved to be a successful substitute for sand, can be used to improve the engineering properties of weak soils.

1.3.2. Application of stabilisation

The application of soil stabilization are:

- Increase the shear strength of the soil
- increase the bearing capacity of foundation soil
- reduce compressibility and there by settlement
- Reduce permeability
- control swelling and shrinkage

○ **MATERIALS USED**

▪ **Shedi soil**

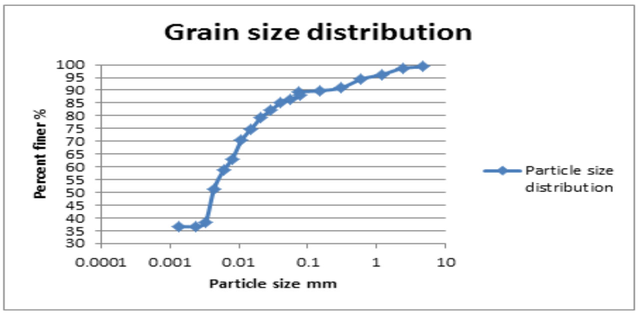
Shedi soil is the name given to the locally available whitish, pinkish silty sand, which is considered as a problematic soil of the Eastren coastal areas of India extending from Nellore To Srikakulam. In the present study, the soil samples were collected from a site near Baptala, Guntur District of Andhra Pradesh state. The geotechnical properties of shedi soil alone and for soil blended with quarry dust and lime were analysed. The soil was replaced by quarry dust in different proportion by weight of soil i.e. 0, 10, 20, 30, 40, 50% and lime was added in different percentages of 2.5, 5, and 7.5% by weight of soil.

The soil was kept in oven for about 24 hours for drying. Then these oven dried samples were mixed in different proportion by dry weight as per study. For each trial uniform mixing has to be ensured to study the geotechnical properties of soil. Various geotechnical tests were conducted on the samples to obtain the general characteristics of soil. The testing of stabilized soil for was being done only after ensuring that the soil has developed sufficient stabilization reaction with the admixture so added.

3.1.1. Quarry dust

3.1.2. Lime

Result and Discussions

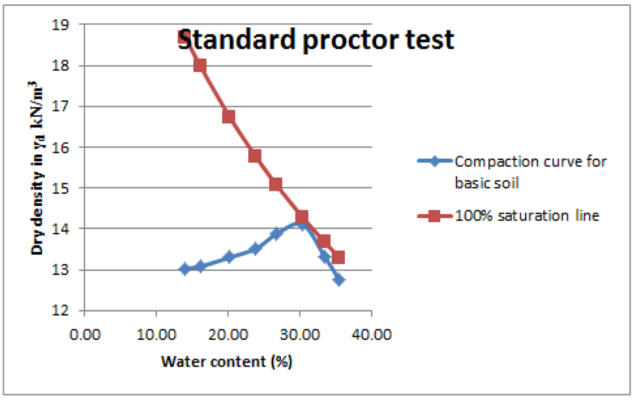


Geotechnical properties of lithomargic clay.

Sl No.	Properties	Particulars
1	Specific Gravity	2.56
2	Grain Size Analysis Gravel size, % Sand size, % Silt size% Clay size, %	 1.0 10.0 49.0 40.0
3	Atterberg's limit Liquid Limit (%) Plastic Limit (%) Plasticity Index (%) IS classification	 49.0 34.0 15.0 MI
4	Standard Proctor Test OMC (%) Max dry unit weight kN/m^3	30.2 14.13
5	Unconfined Compressive Strength (kPa)	152
6	Triaxial compression Test (UU) Angle of internal friction ϕ, (Degrees) Cohesion (kPa)	20 22
7	CBR soaked (%)	2

Tests Conducted

- Atterberg's limit (IS 2720-1985 Part 5 and 6)
- Hydrometer analysis (IS 2720-1985 Part 4)
- Specific gravity analysis (IS 2720-1980 Part 3)
- Proctor compaction test (IS 2720-1980 Part 7)
- Unconfined compression test (IS 2720-1973 Part 10)
- California bearing ratio (IS 2720-1987 Part 16)
- Triaxial test (IS 2720-1993 Part 11)



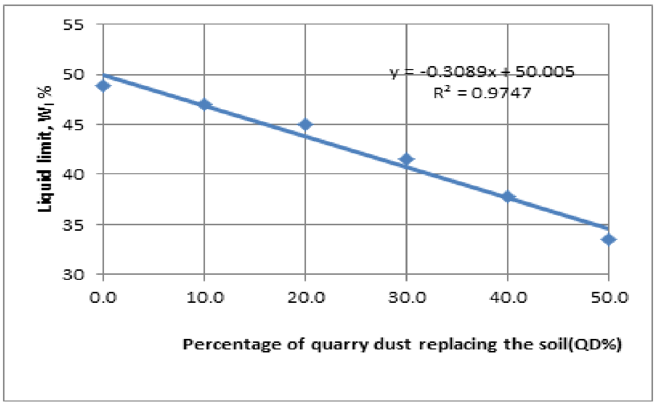
Geotechnical Properties and Correlations for Shedi Soil Blended With Quarry Dust

In the present study, quarry dust was used as a stabilizer. The soil was replaced with quarry dust in different proportion of 10, 20, 30, 40 and 50% by dry weight of soil. The summary of the test results of shedi soil before and after quarry dust stabilization are presented in Table 4.2.

Variation of liquid limit with the percentage of quarry dust replacing the soil.

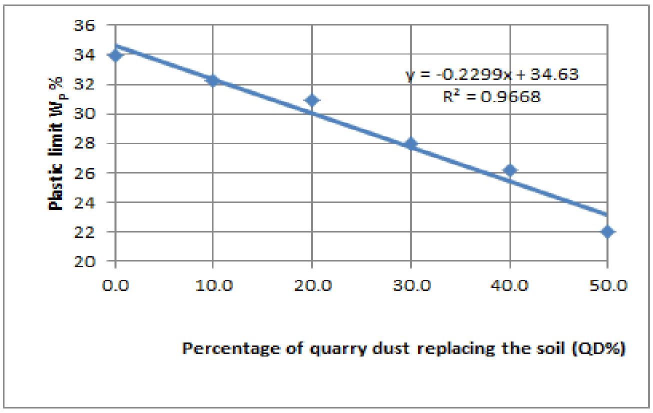
Sl No.	Properties	Percentage of Quarry Dust Replacing soil (%)					
		0%	10%	20%	30%	40%	50%
1	Max dry unit weight (kN/m^3)	14.4	15.1	15.5	16.4	17	18.1
2	OMC (%)	30.2	25.5	23.6	19	18	14.8
3	Specific Gravity	2.56	2.58	2.60	2.60	2.61	2.62
4	Unconfined Compressive Strength (kPa)	152	177	299	176	71	52
5	UU angle of internal friction	20	23.5	30	33.5	37	39
6	UU Cohesion (kPa)	22	21	20.1	19.2	18	17.1
7	CBR soaked (%)	2.2	3.9	4.7	6.4	7.0	8.3
8	Liquid Limit (%)	49.0	47.0	45.0	41.5	37.8	33.5
9	Plastic Limit (%)	34.0	32.2	30.9	28.0	26.2	22.0
10	Plasticity Index (%)	15.0	14.8	14.1	13.5	11.6	11.5

$w_l = -0.3089 * (QD\%) + 50.005$



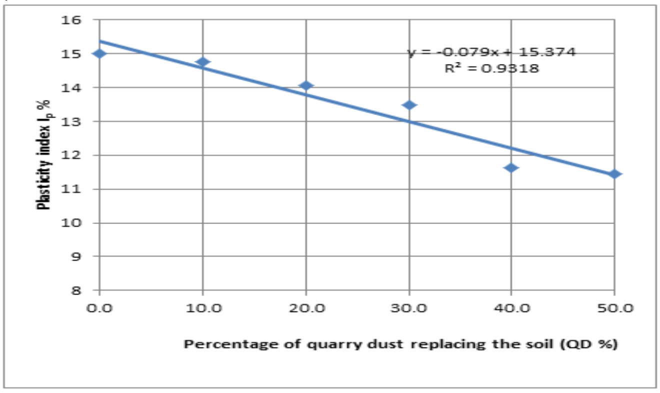
Variation of plastic limit with the percentage of quarry dust replacing the soil

w_p = -0.2299* (QD%) + 34.63



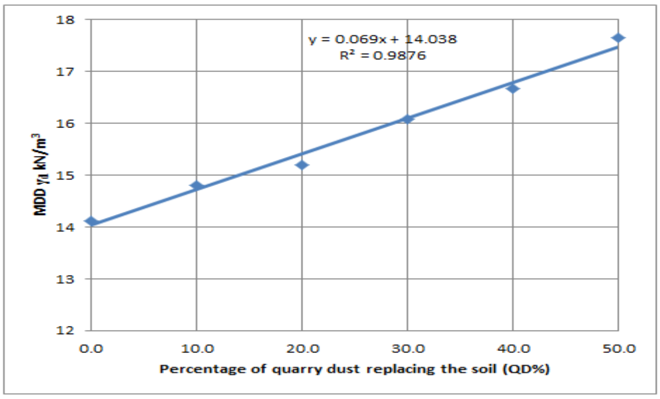
Variation of plasticity index with the percentage of quarry dust replacing the soil

I_p = -0.079 * (QD%) + 15.37



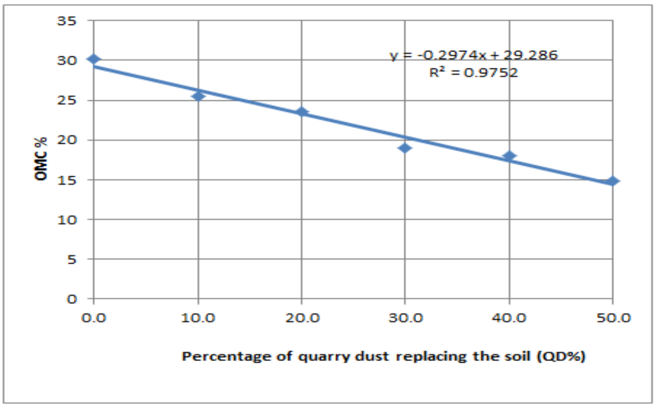
Variation of maximum dry density with the percentage of quarry dust replacing the soil

MDD (kN/m^3) = 0.069 * (QD%) + 14.038

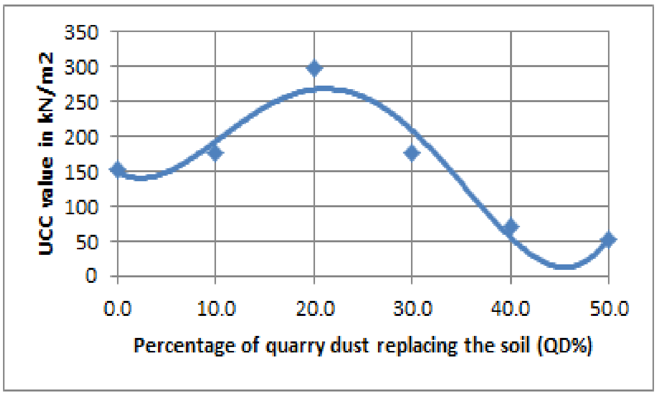


Variation of optimum moisture content with the percentage of quarry dust replacing the soil

OMC % = -0.2974 * (QD%) + 29.286

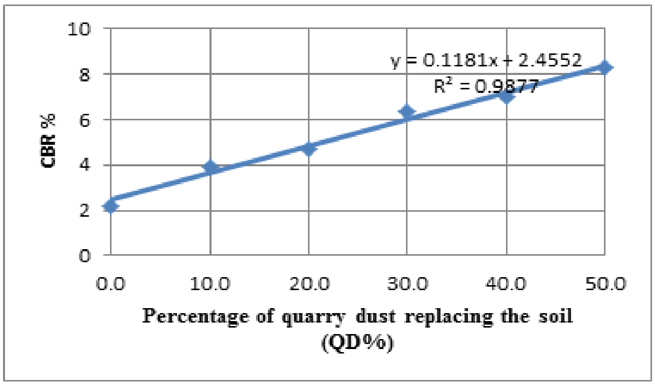


Variation of unconfined compressive strength with the percentage of quarry dust replacing the soil



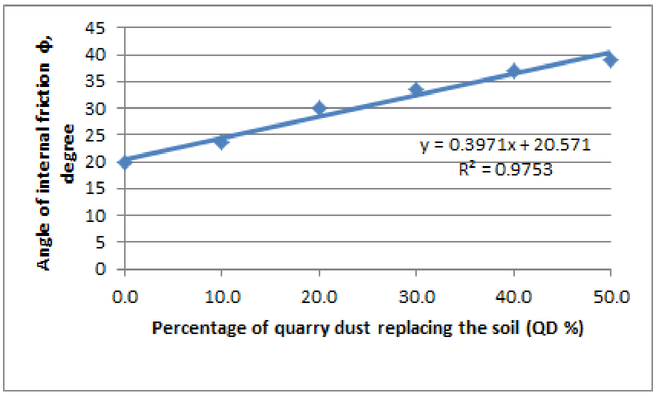
Variation of California bearing ratio with the percentage of quarry dust replacing the soil

CBR % = 0.1181 * (QD%) + 2.4552



Variation of angle of internal friction with the percentage of quarry dust replacing the soil

ϕ = 0.3971* (QD%) + 20.571



Variation of cohesion with the percentage of quarry dust replacing the soil

C (kPa) = -0.0983 * (QD%) + 22.024

Geotechnical properties of shedi soil blended with lime

Sl No.	Properties	Percentage of Lime added to soil (L%)			
		0%	**2.5%**	**5%**	**7.5%**
1	Liquid limit W_l (%)	48.9	47.3	46.4	44.6
2	Plastic Limit W_p(%)	34	35.6	37.4	38.1
3	Plasticity Index I_p (%)	15	11.7	9	6.5
4	Max dry unit weight γ_d kN/m^3	14.1	14.0	13.9	13.8
5	OMC (%)	30.2	30.57	31.1	31.54
6	Unconfined Compressive Strength (kPa)	152	205	272	358
7	UU angle of internal friction ϕ (degrees)	20	27.5	31.5	35
8	UU Cohesion (kPa)	22	36	48	60
9	CBR soaked (%)	2	5	8	12

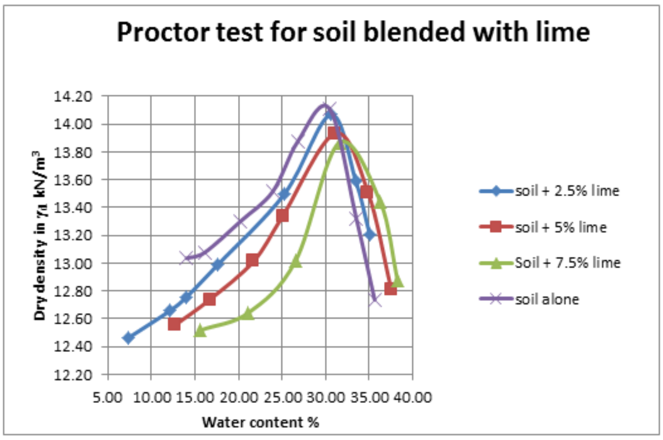


Figure 4.12. Standard Proctor test results for soil blended with lime

Application of Lime Stabilized Soil to Slope Stability Problems

5.1 General

Stability of slopes is one of the important area in geotechnical engineering. A previously stable slope can become unstable due to a lot of reasons. Climate plays a major role in destabilizing the slopes and causing mass movement by increasing the shear stress acting on the soil mass.

Table 5.1. Different methods of slope stability analysis and their assumption.

METHOD	ASSUMPTION
Ordinary method	Interslice forces are neglected
Bishop's simplified/modified	Resultant interslice forces are horizontal. There are no interslice shear forces.
Janbu's simplified	Resultant interslice forces are horizontal. An empirical correction factor is used to account for interslice shear force
Janbu's generalized	An assumed line of thrust is used to define the location of the interslice normal force
Spencer	The resultant interslice forces have constant slope throughout the sliding mass.
Lowe and Karafiath	The direction of the resultant interslice force is equal to the average of the ground surface and the slope of the base of each slice
Corps of Engineers	The resultant interslice force is either parallel to the ground surface or equal to the average slope from the beginning to the end of the slip surface..
Morgenstern-Price	The direction of the resultant interslice forces is defined using an arbitrary function. The fractions of the function value needed for force and moment balance is computed.

Table 5.2. Properties of basic soil and lime stabilized soil considered for analyzing various slopes.

Particulars	soil alone	soil + 2.5% lime	soil + 5% lime	soil + 7.5% lime
Dry density, γ_d (kN/m^3)	14.12	14.04	13.93	13.83
OMC (%)	30.2	30.6	31.1	31.5
Bulk density γ (kN/m^3)	18.39	18.33	18.26	18.19
Cohesion (kN/m^2)	22	36	48	60
ϕ, degree	20	27.5	31.5	35

Table 5.3. Factor of Safety (FOS) for i=26.57^o considering lithomargic clay only, for various heights of the slope.

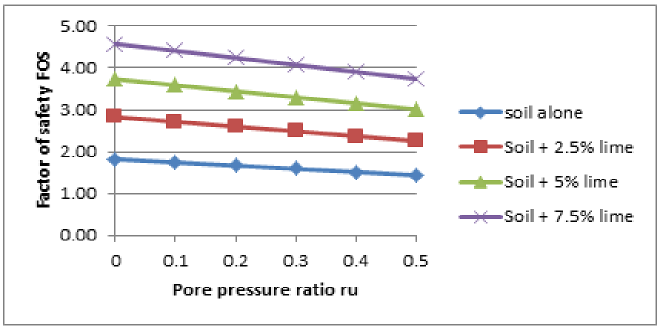
Height h (m)	c/ϒh	m'	n'	Factor of safety F_s					
				r_u = 0	r_u = 0.1	r_u = 0.2	r_u = 0.3	r_u = 0.4	r_u = 0.5
2	0.598	5.279	1.434	5.28	5.14	4.99	4.85	4.70	4.56
4	0.299	3.18	1.24	3.18	3.06	2.93	2.81	2.68	2.56
6	0.199	2.473	1.155	2.47	2.36	2.24	2.13	2.01	1.90
8	0.150	2.122	1.114	2.12	2.01	1.90	1.79	1.68	1.56
10	0.120	1.908	1.089	1.91	1.8	1.69	1.58	1.47	1.36

Table 5.4 Factor of Safety (FOS) for i=26.57^{o}considering lithomargic clay + 2.5% lime, for various heights of the slope

Height h (m)	c/ϒh	m'	n'	Factor of safety F_s					
				r_u = 0	r_u = 0.1	r_u = 0.2	r_u = 0.3	r_u = 0.4	r_u = 0.5
2	0.982	8.402	2.096	8.40	8.19	7.98	7.77	7.56	7.35
4	0.491	5.069	1.900	5.07	4.88	4.69	4.50	4.31	4.12
6	0.327	3.798	1.698	3.80	3.63	3.46	3.29	3.12	2.95
8	0.245	3.240	1.609	3.24	3.08	2.92	2.76	2.60	2.44
10	0.196	2.876	1.551	2.88	2.72	2.57	2.41	2.26	2.10

Discussion on Variation in Factor of Safety

Pore Pressure Ratio,r_u	Combination of soil and lime			
	Soil only	Soil + 2.5% lime	Soil + 5% lime	Soil + 7.5% lime
0	1.82	2.83	3.73	4.58
0.1	1.75	2.72	3.59	4.41
0.2	1.67	2.60	3.45	4.24
0.3	1.59	2.49	3.3	4.08
0.4	1.52	2.37	3.16	3.91
0.5	1.44	2.26	3.02	3.74



Concluding Remarks

This thesis work is carried out to study the stabilization of shedi soil using quarry dust and lime in various proportions. The shedi soil was stabilized using quarry dust by replacing the soil with quarry dust in 10%, 20%, 30%, 40% and 50% by dry weight. The lime stabilization was conducted by the addition of lime to soil in 2.5%, 5% and 7.5% by dry weight.

The following are the conclusions drawn from the study

6.1.1 Conclusions drawn from study after stabilization using quarry dust

- After stabilization the liquid limit has reduced from 49% to 33.5%, plastic limit from 34% to 22% and hence plasticity index from 15% to 11.5%. A reduction in liquid limit by 69% is observed when quarry dust replaces the soil by 50%. Plasticity index reduced by 77% for quarry dust replacing the soil by 50%.
- The MDD of the soil increase from 14.1kN/m^3 to 18.1kN/m^3 upon increasing the percentage of quarry dust replacing the soil. This can be due to the replacement of soil by quarry dust of high specific gravity.

The OMC of the soil blended with quarry dust decreases with dust percentage. Reduction in the clay content of the soil as the percentage of quarry dust increase can be the cause.

- The replacement of soil with quarry dust by 20% saw an improvement in UCC strength by 97%.
- The angle of internal friction showed a considerable improvement from 20^0 to 39^0 for 50% quarry dust replacing the soil. The cohesion value on the other hand is found to decrease with increasing percentage of quarry dust. A 77% decrease in cohesion occurred for 50% quarry dust replacing soil.
- The CBR value showed a sharp improvement for 50% quarry dust replacing soil. The increase in CBR value was computed to be about 277% (CBR from 2.2% to 8.3%)

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