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Intensification of Shear Strength in Black Cotton Soil

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***Abstract*—In India most of the land is covered with black cotton soil which don't have enough strength because of its swelling and shrinkage nature. For increasing the strength of black cotton soil, sand is mixed with soil in different proportions and tests are conducted on various specimens for each proportions. Comparatively best results are obtained at 20% addition of sand.**

Index Terms—Angle of internal friction, Black cotton soil, CBR value, Cohesion, Sand

I. Introduction

Shear strength is a term used in soil mechanics to describe the magnitude of the shear stress that a soil can sustain. The shear resistance of soil is a result of friction and interlocking of particles, and possibly cementation or bonding at particle contacts. Due to interlocking, particulate material may expand or contract in volume as it is subject to shear strains. If soil expands its volume, the density of particles will decrease and the strength will decrease; in this case, the peak strength would be followed by a reduction of shear stress. The stress-strain relationship levels off when the material stops expanding or contracting, and when inter-particle bonds are broken. The theoretical state at which the shear stress and density remain constant while the shear strain increases may be called the critical state, steady state, or residual strength.

The volume change behavior and inter-particle friction depend on the density of the particles, the inter-granular contact forces, and to a somewhat lesser extent, other factors such as the rate of shearing and the direction of the shear stress. The average normal inter-granular contact force per unit area is called the effective stress. The shear strength of soil depends on the effective stress, the drainage conditions, the density of the particles, the rate of strain, and the direction of the strain depending upon Soil composition (basic soil material),State (initial), Structure, Loading conditions.

II. Material

A) Black cotton soil:

Black soil, also known as regur, is formed from the disintegration of lava rocks, according to the Department of General Education, Government of Kerala website. Black soil is mostly found in the Deccan Plateau of India, specifically in the Coimbatore and Ramanathapuram districts. It is rich in calcium, potassium and magnesium, making the soil suitable for growing crops such as cotton, tobacco, juwar and maize.

Properties of Black Cotton Soil:

Rich proportion of montmorillonite is found in Black cotton soil from mineralogical analysis. High percentage of montmorillonite renders high degree of expansiveness. These property results cracks in soil without any warning.

As plasticity index and linear shrinkage decreased with the increase of lime content, a mixture of both lime and cement is necessary for adequate stabilization of road bases for heavy wheel loads on the black cotton soils.

Black cotton soils occur mostly in the central and western parts and covers approximately 20% of the total area of India. Highway and construction of structures on Black cotton soils has been a challenge to the respective engineers and designers because of its high swelling and shrinkage characteristics. This major group of soil consists of inorganic clays of medium to high compressibility. The Black cotton soil is very hard when dry, but loses its strength completely when in wet condition.

Black cotton soils of this particular region have liquid limit values ranging from 50 to 100%, plasticity index ranging from 20 to 65% and shrinkage limit from 9 to 17%. The amount of swell generally increases with increase in the plasticity index. The swelling potential depends on the type of clay mineral, crystal lattice structure, cations exchange capacity, ability of water absorption, density and water content.

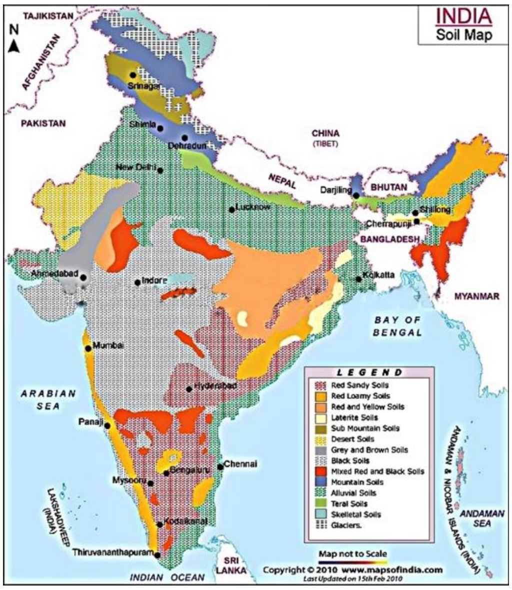

Fig. 1. Availability of Black Cotton Soil in India

Swell in the vertical direction is called heave. Among the illite, kaolinite and montmorillonite clay minerals, the montmorillonite possesses the greatest ability to swell by illite. The Kaolinite does not swell. Black cotton soils are very hard in dry state and possess high bearing capacity. In summer, it is very common to see shrinkage cracks with hexagonal columnar structure, with vertical cracks as wide as 10mm extending up to a depth of 3m or more. Soils containing expansive clays become very sticky when wet and usually are characterized by surface cracks or a "popcorn" texture when dry. Therefore, the presence of surface cracks is usually an indication of an expansive soil. The availability of the black cotton soil in India is shown in Fig. 1.

B) Sand:

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt. Sand can also refer to a textural class of soil or soil type; i.e., a soil containing more than 85 percent sand-sized particles by mass [1].

The composition of sand varies, depending on the local rock sources and conditions, but the most common constituent of sand in inland continental settings and non-tropical coastal settings is silica (silicon dioxide, or SiO_2), usually in the form of quartz. The second most common type of sand is calcium carbonate, for example, aragonite, which has mostly been created, over the past half billion years, by various forms of life, like coral and shellfish. For example, it is the primary form of sand apparent in areas where reefs have dominated the ecosystem for millions of years like the Caribbean.

ISO 14688 grades sands as fine, medium, and coarse with ranges 0.063 mm to 0.2 mm to 0.63 mm to 2.0 mm. In the United States, sand is commonly divided into five sub-categories based on size: very fine sand ($1/16$ – $1/8$ mm diameter), fine sand ($1/8$ mm – $1/4$ mm), medium sand ($1/4$ mm – $1/2$ mm), coarse sand ($1/2$ mm – 1 mm), and very coarse sand (1 mm – 2 mm). These sizes are based on the Krumbein phi scale, where size in $\Phi = -\log_2 D$; D being the particle size in mm. On this scale, for sand the value of Φ varies from −1 to +4, with the divisions between sub-categories at whole numbers.

III. Methodology

A) Tri-Axial Test:

After taking the soil from the site (IIST), it has been oven dried. Then the dried sample is weighted. Now, the weighted sample is allowed to fall freely in the mould and the soil sample is compacted by the tamping rod without any rupturing the mould. After this the required amount of sand in mixed with the soil sample. The load of 5 N/cm^2 is exerted and waited till the failure of specimen and repeatedly the pressure is increased by the difference of 5 N/cm2 at the same interval of .25mm.

B) California bearing ratio test:

Mainly C.B.R. method is measure of resistance of material for penetration of a plunger, pressure up to a penetration of 10mm used. The test is performed by measuring the pressure required to penetrate a soil sample. Measure pressure is then divided by the pressure required to achieve an equal penetration on a standard crushed rock material, the harder the surface the higher the C.B.R. rating.

IV. Results and Discussion

A) Tri-Axial Test:

When the black cotton soil is taken as the sample the value of C= 0.098N/mm^2 and Φ=4°. When the black cotton soil is mixed with 10% of sand the value of C=0.089N/mm^2 and Φ=6.5°. Similarly for Black Cotton when mixed with 20% of Sand the value of C=0.074N/mm^2 and Φ=12.5°. The data sheet is shown in Table-2.

B) California bearing ratio:

The C.B.R. Value of black cotton soil at 2.5mm penetration is 9.970% and C.B.R. Value at 5.0mm penetration is 8.879% is shown in data sheet Table-3 and graph in figure 2. Now, when the black cotton soil is mixed with 10% of the sand the C.B.R. Value at 2.5mm penetration is 10.737% and C.B.R. Value at 5.0mm penetration is 9.226% is shown in data sheet table 4 and graph in figure 3. Similarly, when the black cotton soil is mixed with 20 % of the sand the C.B.R. Value at 2.5mm penetration is 11.578% and C.B.R. Value at 5.0mm penetration is 10.298% is shown in data sheet Table-5 and graph in Fig. 4.

TABLE I
Properties of black Cotton Soil

S. No.	Description of properties	Value
1	Shear strength	soaked CBR of only 1.5%,
2.	Residual strength parameter Φ_r	12°
3.	Permeability	10^{-10} cm/sec
4.	Liquid limit (Indian subcontinent)	40% ~ 100%.
5.	Free Swell index	> 50%
An increase in lime content of 0 to 9% results in plasticity index to decreases from 47% to 5% and linear shrinkage to decreases from 11 to 3.6% respectively.		

TABLE II
Result Data Sheet for the Tri-Axial Test

Data sheet for Tri-axial Test (Black Cotton Soil)			
c=0.098 N/mm^2 , φ=4°			
	σ_1	σ_3	σ_1-σ_3
A	0.32	0.0981	0.2219
B	0.3778	0.14715	0.23065
C	0.4344	0.1962	0.2382
Tri-axial Test (Black Cotton Soil + 10%Sand)			
c=0.089 N/mm^2 , φ=6.5°			
	σ_1	σ_3	σ_1-σ_3
A	0.3222	0.0981	0.2241
B	0.3889	0.14715	0.24175
C	0.4667	0.1962	0.2705
Tri-axial Test (Black Cotton Soil + 20%Sand)			
c=0.074 N/mm^2 , φ=12.5°			
	σ_1	σ_3	σ_1-σ_3
A	0.3433	0.0981	0.2452
B	0.4222	0.14715	0.27505
C	0.4977	0.1962	0.3015

σ_1 = Axial Stress (N/mm^2)
σ_3 = Confining Stress (N/mm^2)
σ_1-σ_3 = Deviator Stress (N/mm^2)
c = Cohesion (N/mm^2)
φ = Angle of internal resistance

TABLE II
RESULT DATA SHEET FOR CBR TEST OF BLACK COTTON SOIL

Data Sheet for C.B.R. Test (Black Cotton Soil)					
Sample			Black Cotton		
Least Count of Dial gauge			0.01		
Least Count of Proving Ring			0.002		
S.No.	Dial gauge	Penetration in mm	Load in division	Load in kN	Load in kg
1	0	0.0	0	0	0
2	50	0.5	17	0.2125	21.662
3	100	1.0	39	0.4875	49.694
4	150	1.5	68	0.85	86.646
5	200	2.0	91	1.13	115.189
6	250	2.5	107	1.34	136.595
7	300	3.0	118	1.48	150.866
8	350	3.5	126	1.58	161.060
9	400	4.0	131	1.64	167.176
10	450	4.5	136	1.7	173.293
11	500	5.0	143	1.79	182.467
12	550	5.5	148	1.86	189.602
13	600	6.0	153	1.92	195.719
14	650	6.5	158	1.98	201.835
15	700	7.0	160	2.01	204.893
16	750	7.5	161	2.02	205.912
C.B.R. Value at 2.5mm penetration =			9.970%	Sr=83% (24hrs soaking)	
C.B.R. Value at 5.0mm penetration =			8.879%		
Soaked Weight			12630		
Un soaked Weight			12590		
Weight of soaked water			40		
Weight of water added			1200		
Total Water in soil			1240		

TABLE III
RESULT DATA SHEET FOR CBR TEST OF BLACK COTTON SOIL+10% SAND

Data Sheet for C.B.R. Test (Black Cotton + 10%Sand)					
Sample			Black Cotton + 10% Sand		
Least Count of Dial gauge			0.01		
Least Count of Proving Ring			0.002		
S.No.	Dial gauge	Penetration in mm	Load in divisio n	Load in kN	Load in kg
1	0	0.0	0	0	0
2	50	0.5	24	0.3	30.581
3	100	1.0	57	0.7	71.356
4	150	1.5	83	1.037	105.708
5	200	2.0	100	1.25	127.421
6	250	2.5	115	1.443	147.095
7	300	3.0	130	1.633	166.463
8	350	3.5	140	1.76	179.409
9	400	4.0	146	1.835	187.054
10	450	4.5	147	1.85	188.583
11	500	5.0	148	1.86	189.602
12	550	5.5	150	1.88	191.641
13	600	6.0	153	1.92	195.719
14	650	6.5	155	1.95	198.777
15	700	7.0	158	1.99	202.854
16	750	7.5	160	2.01	204.893
C.B.R. Value at 2.5mm penetration=			10.737 %	Sr=84% (48hrs soaking)	
C.B.R. Value at 5.0mm penetration=			9.226%		
Soaked Weight			12840		
Un soaked Weight			12720		
Weight of soaked water			120		
Weight of water added			750		
Total Water in soil			870		

TABLE IV
RESULT DATA SHEET FOR CBR TEST OF BLACK COTTON SOIL+20% SAND

Data Sheet for C.B.R. Test (Black Cotton + 20%Sand)					
Sample			Black Cotton + 20% Sand		
Least Count of Dial gauge			0.01		
Least Count of Proving Ring			0.002		
S.No.	Dial gauge	Penetration in mm	Load in divisio n	Load in kN	Load in kg
1	0	0.0	0	0	0
2	50	0.5	32	0.4	40.775
3	100	1.0	72	0.9	91.743
4	150	1.5	91	1.139	116.106
5	200	2.0	108	1.354	138.022
6	250	2.5	124	1.556	158.614
7	300	3.0	138	1.734	176.758
8	350	3.5	148	1.86	189.602
9	400	4.0	155	1.962	200
10	450	4.5	160	2.012	205.097
11	500	5.0	165	2.076	211.621
12	550	5.5	169	2.122	216.310
13	600	6.0	172	2.159	220.082
14	650	6.5	175	2.196	223.853
15	700	7.0	177	2.221	226.402
16	750	7.5	179	2.245	228.848
C.B.R. Value at 2.5mm penetration=			11.578 %	Sr=86% (24hrs soaking)	
C.B.R. Value at 5.0mm penetration=			10.298 %		
Soaked Weight			12880		
Un soaked Weight			12540		
Weight of soaked water			340		
Weight of water added			660		
Total Water in soil			1000		

TABLE V
RESULT COMPARISON DATA SHEET

Black Cotton Soil		Sr=83% (24hrs soaking)
C.B.R. Value at 2.5mm penetration=	9.970%	
C.B.R. Value at 5.0mm penetration=	8.879%	
Black Cotton + 10% Sand		Sr=84% (48hrs soaking)
C.B.R. Value at 2.5mm penetration=	10.737%	
C.B.R. Value at 5.0mm penetration=	9.226%	
Black Cotton + 20% Sand		Sr=86% (24hrs soaking)
C.B.R. Value at 2.5mm penetration=	11.578%	
C.B.R. Value at 5.0mm penetration=	10.298%	

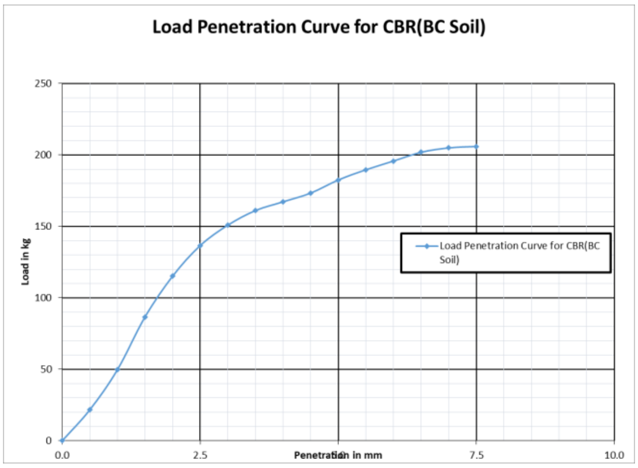

Fig. 2. Load penetration curve for CBR black cotton soil

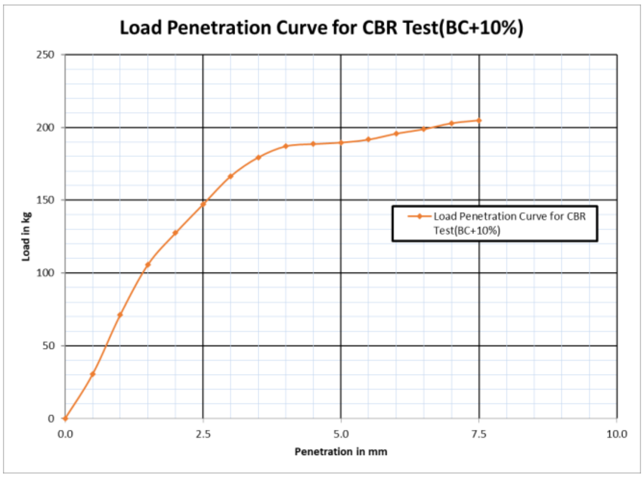

Fig. 3. Load Penetration curve for CBR test black cotton soil+10% sand

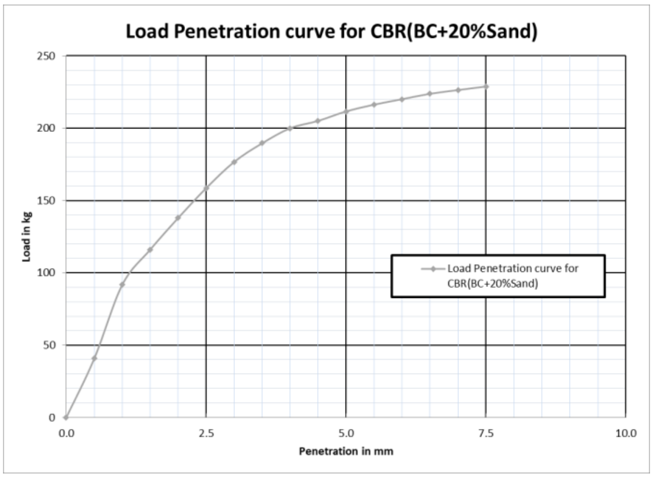

Fig. 4. Load Penetration curve for CBR test black cotton soil+20% sand

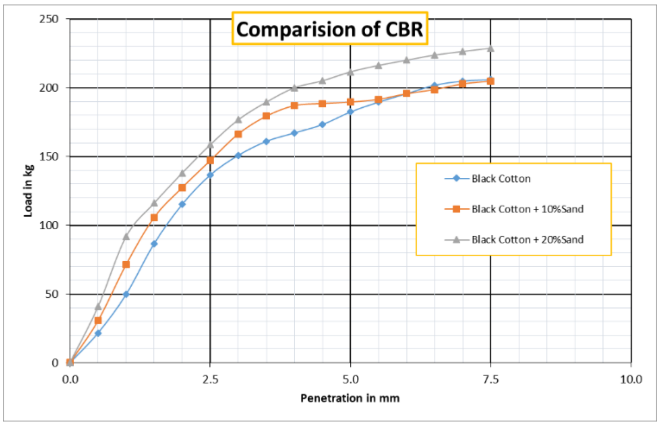

Fig. 5. Load penetration curve for comparison of CBR test

V. Conclusion

By the above research it shows that the bearing capacity of the soil increases and the thickness of the pavement decreases and eventually the cost of constructing the project decreases. Future maintenance works can also be reduced by improving the strength of sub grade soil. Construction speed increases. By increasing the speed of project, accidental rate and damage to nearby agriculture can be controlled and the environment and materials can be preserved for future generations. A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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