Recent Trends in Stabilization of Black Cotton Soil: A Comprehensive Review

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Abstract— **In this comprehensive review, comprising over past two decades from 2000 to 2020, a mechanistic literature of black cotton soil stabilization is presented here by reviewing 16 published research articles. Black cotton soils, Laterite, Compressible soils are problematic soils on which construction work should be avoided. Now a day due to growth in population land useful for construction is not available and so it becomes necessary to improve the ground by using stabilizers (additives) or by giving chemical treatment. Here total 16 papers are reviewed that consist experimental study on Black Cotton soils of India and in some cases abroad to improve its index as well as engineering properties. This work will help geotechnical engineers to opt for suitable stabilizers in the field. This paper will help the others to have idea about the varieties of additives to be used and its proportion and percentage improvement of its properties.**

Index Terms— **Geosynthetics, Free Swell Index, California bearing ratio, Unconfined compressive strength**

I. INTRODUCTION

In civil engineering structures many types of soils are used. Many types of natural soils are suitable in their natural condition for the construction purpose however some problematic soils are not suitable in their natural condition and they required replacement or treatment for stabilization. The best example of problematic soil is expansive soil or Black cotton soil. Black cotton soils expand when it comes in contact with the moisture content and shrinks in absence of the same. This property of swelling and shrinkage in presence or absence of moisture content is due to presence of Montmorrillonite mineral in the soil. Due to such characteristic of black cotton soil wide crack in walls, heaving of floor, unequal heaving of road, diagonal severe cracks in walls may occur when it is constructed on black cotton soil[1].

Prediction of the in situ volume change and movement of expansive soils over time can be categorized in three domains:

I. consolidation theory-based methods,
II. water content-based methods, and
III. suction-based methods.[2]

Due to the problematic nature of black cotton soil, geotechnical engineers are perpetually searching for various options to reduce its characteristics via soil stabilization technologies. In stabilization of expansive soil the engineers focus on improvement of strength properties by normalize the volume change and plasticity characteristics of black cotton soil. Finally, this paper discusses the stabilization results of addition of various stabilizers to expansive soils.

II. CLAY MINERALS

The swelling and shrinkage properties of expansive soils is due to presence of clay minerals – Montmorrillonite, Illite, Kaolinite. Mineralogical properties of these clay minerals are listed in table no.1 Montmorrillonite consist of alternating sheets of alumina octahedral sheets between two silica tetrahedrons sheets linked via weak Vander Wal's bond. Due to which Water molecules are attracted towards this mineral. Kaolinite is the least expansive among all the three clay minerals due to presence of very strong hydrogen bond between alternating sheets of silica tetrahedron and alumina octahedral sheets.[3]

III. DETRIMENTAL EFFECTS ON STURCTURES DUE TO SWELLING

Expansive soils are a worldwide problem, causing extensive damage to civil engineering structures. Greatest hazards in regions having pronounced wet and dry seasons may occur due to presence of expansive soils. The problems occur due to volume change on wetting and drying of expansive soils. Wetting of expansive soils may occur due to seasonal changes, garden watering, leakage of underground water pipelines, drainage systems etc. Expansive soils exert swelling pressure to the structures and may cause -

- Uplifting of tiles due to heaving of floor slabs,
- Heavy cracks in basement walls,
- Diagonal cracks on walls,
- Diagonal cracks above windows or doors may observed.
- Foundation heave can not be ignored due to swelling of soil.
- Non uniform heaving of roads
- Cracks on road surface

Grade beams, if not properly tied together with reinforcement, can result in cracks and movement due to swelling of soils. Expansive should not be used as backfill material until the wall is properly restraint at top and bottom. Expansive soil as backfill material should be loosely compacted. [4]

The losses due to extensive damage to structures founded on expansive soils are worth billions of dollars all over the world.

IV. IDENTIFICATION OF EXPANSIVE SOILS

Classification of expansive soils based on Atterberg's limits is given in Table 2 Classification of expansive soils based on Swelling is given in Table 3

Table No. 1: Properties of Clay Minerals:

CLAY MINERAL	MONTMORRILONITE	ILLITE	KAOLINITE
STRUCTURE	Alternating sheets of alumina octahedral sheets between two silica tetrahedrons sheets	Alternating sheets of alumina octahedral sheets between two silica tetrahedrons sheets	Alternating sheets of silica tetrahedron and alumina octahedral sheets
INTERLAYER BOND	Vander Val Bond	Potassium ion bond	Hydrogen ion bond
ISOMORPHOUS SUBSTITUTION	High	Moderate	Low
SHRINK-SWELL	Very High	low	Very low
LIQUID LIMIT	Up to 900%	60%-120%	30%-75%
PERMEABILITY(cm/s)	10^{-5}—10^{-7}	10^{-4}—10^{-6}	10^{-3}—10^{-5}

Table No. 2: Classification of Expansive soils on the basis of Atterberg's Limits:

Liquid limit %	Plasticity Index	Shrinkage Limit %	Shrinkage Index	Linear shrinkage %	Expansivity index
>60	>35	<10	>50	>18	Very High
45-60	25-35	10-12	35-50	13-18	High
35-45	18-25	12-14	25-35	8-13	Medium
<35	<18	<14	<25	< 8	Low

Table No 3: Classification of expansive soils on the basis of Swelling:

Swell Potential	Total Expansion	Swell pressure in kPa	Free Swell Ratio	Degree of Expansion
>25	> 35	>687	>4	Very High
5-25	20-35	392- 687	2-4	High
1.5-5	10-20	196-392	1.5-2	Medium
<1.5	<10	< 196	1.5-1	Low

5. Experimental Set up and Methodology Adopted:

The soil sample should be taken and determine Atterberg's limits, compaction parameters of the soil by using IS codes.. California Bearing Ratio , Unconfined compressive strength and swelling parameters can be determined by using IS code. Study of Table No-4 will give guidance to the researchers about the additives to be used for the stabilization of black cotton soil. Same testing should be done on the stabilized soil and comparison of the results will inform about how much the additives beneficial. Free Swell Index Test: IS 2720(Part 40)-1977 is used to perform FSI test. Take two flasks of 100 ml capacity. Put 10 grams of oven dried soil sample passed through 425 micron IS sieve in each flask. Now add kerosene in one flask containing 10 gram of sample up to 100ml mark. Add distilled water in to the other flask containing 10 grams of sample up to 100 ml mark. Kept both of the flasks for 24 hours to settle and swell the sample..

Free swell index= 100x[Vd- Vk]/ Vk

Vd= Volume of soil specimen read from the graduated cylinder containing distilled water

Vk= Volume of soil specimen read from the graduated cylinder containing kerosene

Take atleast three readings and average it

Swelling Pressure Test: IS 2720(Part 41)-1977 is used to perform swelling Pressure test. There are two methods of the test.

1) Consolidometer method
2) Constant Volume method

Table No:4 Details of Additives used and Improvement shown

Location	properties	additives	Percentage used (Optimum)	Improvement	References
Hyderabad city, India	L.L= 58% P.I = 29% OMC= 15% ODD= 1.71 kN/m^3 CBR = 3.74%	Granite dust(Railapur Villgae)	5%, 10%, 15% 15% optimum	L.L= 42% P.I = 7% OMC= 12% ODD= 2.14 kN/m^3 CBR = 6.08 %	N. Vijay Kumar, SS.Asadi, A.V.S. Prasad,2017 [5]
		Geotextiles	Placed at 50mm, 100mm, 150 mm from top- best 50mm from top	CBR= 7.92 %	
Shoraw site north of Kirkuk Iraq	L.L= 38.64% P.I = 20.96% OMC= 13% ODD= 1.89 kN/m^3 CBR = 2.7% Free swelling=4.35 % UCC= 49 kPa	Beverage cans: specific weight of 2.6 to 2.8 (g/cm3), and 0 % absorption	2%,4%,6%,8%,10% by dry mass of soil used. Best result in consideration with CBR= 6% aluminum	For 10 % aluminum OMC= 9% ODD= 1.94 kN/m^3 Free swell = 1.8 % CBR= 10%	Hanifi Canakcia,*, Fatih Celika, Mohammed O. A. Bizneb, Media O. A. Biznea, 2016 [6]
Komaragiripatnam , East Godavari District, India	L.L= 80 % P.I = 44 % OMC= 24 % ODD= 1.4kN/m^3 CBR = 2.1% Differential Free swell=160%	Vitrified polish waste (5%,10%,15%,20% and quick lime(1%, 2%)	Optimum combination=20%VPW+2 % Quick Lime	L.L= 58.3 % P.I = 18.3 % OMC= 51.4 % ODD= 1.59kN/m^3 CBR = 7.4% Differential Free swell= 70%	Adapa Kiran , B.Ganesh, 2017 [7]
Indore, India	L.L= 57 % P.I = 21 % OMC= 18 % ODD= 1.2 kN/m^3 CBR = 1.48% Swelling Pressure = 35	Fly Ash (FA) Coconut Coir Fiber (CCF) & Crushed Glass (CG) from Indore	optimum combination is 20% FA + 5% CG +1 % CCF With soil	CBR = 5.18% Swelling Pressure = 3.5	Amit Tiwari, H.K.Mahiyar,2014 [8]
Greensland, Australia.	L.L= 86 % P.I = 49 % OMC= 36.5 % ODD= 1.29 kN/m^3 CBRunsoaked = 7.1% CBR soaked= 3.2 % Swelling Pressure = 80	Hydrated lime	6.25 %	CBR Unsoaked=61.7%	Hayder Hasan , Liet Dang, Hadi Khabbaz, Behzad Fatahi, and Sergei Terzaghi [9]
		Hydrated Lime+Bagasse Ash (1:3)	L(6.25%)+BA(18.75%)	CBR Unsoaked=62.6%	
Jukhala, Himachal Pradesh, India	L.L= 55% P.I = 35% OMC= 16.5 % ODD= 1.71 kN/m^3 CBR soaked= 3.2 % UCS- 516kPa Differental Free Swell Index= 35%	waste foundry sands (WFS) and molasses (M) along with lime (L)	9% lime, 20% WFS and 10% molasses is found to be satisfactory	Diffrential Free swell Index=0% UCS =980 kPa	Avinash Bhardwaj and Ravi Kumar Sharma, 2019 [10]
Thatthamanji Village , Tamil Nadu, India	L.L= 68% P.I = 41% OMC= 25% ODD= 1.53 kN/m^3 UCS- 115.8 kPa	Photogypsum with Hydrated Lime	7% lime+ 1% Photogypsum	Free Swell Index- 7.1%	Jijo James and P. Kasinatha Pandian, 2016 [11]

Syria	L.L= 58.8 % P.I = 28.8 % OMC= 27% ODD= 1.48 kN/m3 UCS- 315 kPa CBR- 2.89 %	Calcined Clay with Hydrated Lime	6%L+ 20% CC	UCS- 569 kPa CBR=79.41 %	Dr. Ibrahim Hammoud Dr.Aref Alswidani Ayman Meziab, 2019 [12]
Nagpur, India	L.L= 48.5 % P.I = 14.21 % OMC= 22.65% ODD= 1.65 kN/m3 CBR- 3.64 %	Waste synthetic bags + Mix(50% BCS+50%FA+8% Lime)	Properties of mix L.L= 37.12 % P.I = 4.21 % OMC= 14.68 % ODD= 1.71 kN/m3 CBR- 16.63 %	CBR= 23.82 % when synthetic bag 2x2 cm^2 size in 0.1% proportion	Ajay Kumar Agarwal , Vaishali Rajurkar , Prerna Mokadam, 2015 [13]
North Cyprus, Turkey	L.L= 57 % P.I = 29% OMC= 24% ODD= 1.49 kN/m3 CBR- 3.64 %	Polypropylene Fiber	1% of dry weight of BC soil is blend.	Free swell decreses UCS Increses Cohesion=1.5 times unreinforced soil Tensile strength= 2.7 times unreinforced soil	Mona Malekzadeh , Huriye Bilsel, 2012[14]
south Damascus, Syria	L.L= 74.18% P.I = 40.7 % OMC= 27% ODD= 1.47kN/m3 CBR- 2.57 %	Crushed Glass	20 % By dry weight of Black cotton soil	MDD= 1.57 kN/m^3 OMC= 19.5% CBR= 9.46% P.I= 29.31 % L.L = 55%	Nazieh Aboud, Mousa Alkaseem, 2017 [15]
Harihara, Davanagere distict, Karnataka.	L.L= 62.13% P.I = 32.69 % OMC= 21.96% ODD= 15.16kN/m3 UCS- 84.92 kN/m^2 CBR- 2.11 % Soaked= 1.40	Bagasse Ash+ Cement	BA= 4%,8%,12% L= 2%,4%,6%,8%, C= 2%, 4%, 6%,8%	CBR=5.43(4%BA+8%C) UCS=174.91(8%BA+8%C)	Kiran R.G, Kiran L., 2013 [16]
		Bagasse Ash+ Lime		CBR=4.57(4%BA+4%L) UCS=153.05(4%BA+2%L)	

6. Additives Used

- CBR of black cotton soil was increased 62.5% by using Granite dust and 112% by using Geotextiles placed 50 mm from the top [5].
- Free swell of expansive soil was reduced from 4.35% to 1.8% by using Aluminum beverage cans 10% of the dry weight of the expansive soil.[6]
- Improvement in CBR value and reduction in Differential swell achieved by using Vitrified polish waste with hydrated lime [7]
- Coconut coir and crushed glass was used with fly ash to stabilize black cotton soil and 3.5 times improvement in CBR value and 10 times reduction in swelling pressure achieved.[8].
- CBR value can be increased up to 8.9 times by using hydrated lime only. Further improvement in CBR can be achieved by adding bagasse ash in hydrated lime.[9]
- Waste foundry sand and molasses with hydrated lime reduced the differential free swell and improved unconfined compressive strength values.[10]
- Strength parameters of weak soils can be improved and swelling properties of expansive soils can be reduced by using photo gypsum with hydrated lime or calcined clay with hydrated lime.[11],[12]
- Polypropelene fibers decrease Free swell and increases Unconfined compressive strength of black cotton soils.[14]
- Crushed glass improves the properties of black cotton soil considerably.[15]
- Combination of Bagasse ash with cement as well as Bagasse ash with lime improves properties of black cotton soil.[16]

CONCLUSION

- Locally available waste materials like granite dust, vitrified tiles ash, Photo Gypsum, Plastic waste, crushed glass, Bagasse ash, Rice husk ash ,fly ash, coconut coir, waste foundry sand etc. with or without hydrated lime can be used with precautions as additives to reduce swelling and shrinkage properties of Black Cotton soils. Environmental hazards also can be reduced by use of such waste materials.
- Geosynthetic materials give the best results as compared to the use of waste materials.

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