Effect of Salts on Consistency Limit and Thickness of Double Layer in Clayey Soils

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Abstract - **Due to the shortage of land and the increase in population over the past decades, there has been a requirement of construction on soft and weak soil in India. Therefore, techniques to improve soil mechanical behaviour must be adopted. In the study, the influence of the addition of sodium chloride and calcium chloride on black cotton soil and sodium hexametaphosphate on bentonite soil in terms of consistency limits and swell behaviour was carried out. The concentrations of chloride salts and sodium hexametaphosphate were varied as 0N, 0.5N, 1N, 2N and 3N. The concentration of sodium hexametaphosphate was varied as 0N, 0.1N, 0.18N, 0.32N, 0.43N and 0.54N. The cations of the salts react with the negatively charged clay particles which reduce the thickness of the diffused double layer and forms strong cementatious matrix. The reduction in double layer and the mechanism of pozzolanic reactions on addition of salts in black cotton soil and bentonite soil for reducing plasticity and swelling has been elaborated.**

keywords - **Chloride salts, sodium hexametaphosphate, consistency limit, double layer thickness**

I. INTRODUCTION

Clayey soil is one of the major soils of India. The colour of the black cotton soil is mostly black due to the presence of iron and aluminium compounds. Bentonite and black cotton soil are types of clay with a very high proportion of clay mineral montmorillonite, resulting from the decomposition of volcanic ash. In the dry season, these soil develop deep cracks and in the wet season, show high water-absorbent behaviour leading to high shrinkage and swelling characteristics[1]. It has been the objective of researches in geotechnical engineering to look for an economical and efficient method of stabilization of black cotton soil and bentonite, occupying 2.85 lakh sq-km of the land of India[2]. Among several techniques adopted to overcome the problems posed by expansive soils, gypsum and lime have been used during the past few decades due to its abundance and adaptability[3,4]. The soft clayey soil stabilized with recycled gypsum, mixed with lime and cement, and other admixtures in a wet environment showed better performance stability and durability of soil[5]. One such alternative is to look for salts that can reduce the high plasticity of such soils. Efficacy of different chloride, carbonate and sulphate salts on highly plastic soil has been studied [6-11]. A study to control heaving in black cotton soil by adding salts of magnesium and potassium was carried out and it was noticed that swelling of soil reduced significantly[12].Chlorides of potassium, calcium and ferrous as electrolytic solutions were used for soil stabilization. Ferric chloride was found to most effective[13]. An embankment on black cotton soil having a slope of 1:2.5 gave the greatest factor of safety on the addition of 3% of calcium chloride[9].

The work in this paper elaborates the effect different concentrations of chloride salts in BCS and sodium hexametaphosphate on BS in terms of Atterberg's limits, activity and swelling behaviour with the reaction mechanism. The amount of chloride salts has been varied as 0N, 0.5N, 1N, 2N and 3N. The sodium hexametaphosphate amount has been varied as 0N, 0.1N, 0.18N, 0.32N, 0.43N and 0.54N.

II. MATERIALS AND METHODS

Materials

Soil. The black cotton soil and bentonite soil were collected from Malwa region of Indore, Madhya Pradesh from a depth of approximately 1 m and from market in Varanasi, respectively. The soils were dried and sieved through a 4.75 mm opening as it contained traced of fine gravel. The index properties-consistency limits and grain size distribution and engineering properties of the black cotton soil and bentonite soil are shown in Table1. Fig.1 shows the particle size distribution curve of the soil.

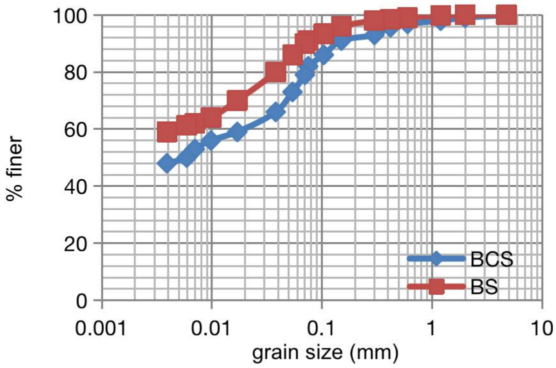

Fig.1.The particle size distribution curve of black cotton soil and bentonite soil

Table 1. Physical and Engineering properties of black cotton soil and Bentonite soil

Properties	BCS	BS
Specific gravity	2.31	2.63
Liquid limit %	44.06	328.89
Plastic limit %	24.67	72.68
Plasticity Index %	19.39	256.21
Shrinkage Limit %	14.13	11.8
Shrinkage Index %	10.54	60.88
OMC %	16.72	32.43
MDD (kN/m^3)	15.75	12.9
UCS (KPa)	82.93	54.21
Activity	0.44	4.93
% finer than 4.75mm	100	100
% finer than 2mm	99	100
%finer than 75µ	86	89
%finer than 2µ	44	52

SALTS. Chlorides of sodium and calcium for black cotton soil and sodium hexmetaphosphate for bentonite soil have been used in the study. The salts were collected from Chemistry Lab of the college. The chloride salts were available in crystal form and sodium hexametaphosphate was available in powdered form.

Methods

The salt solutions were prepared by dissolving the salts in distilled water. The concentration of chloride salts has been varied as 0.5N, 1N, 2N and 3N. The sodium hexametaphosphate amount has been varied as 0N, 0.1N, 0.18N, 0.32N, 0.43N and 0.54N.. The series of laboratory experiments to determine Liquid limit (LL), Plastic limit (PL), Plasticity index (PI), Shrinkage limit(SL), Shrinkage Index(SI) and Differential swell (DSV) test have been conducted on BCS and (BS) by IS Code 2720 Part 5. The activity of the soil has been calculated as the ratio of plasticity index to the percentage of clay fraction in the soil.

III. RESULTS AND DISCUSSION

The Atterberg's limits, differential swell index and activity of black cotton soil addeded with chloride salts and bentonite soil added with sodium hexametaphosphate have been shown in Fig. 2-7 and Fig.8-9, respectively.

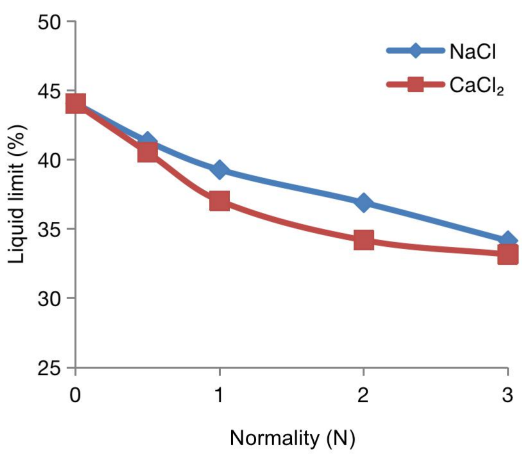

Fig.2. Effect of chloride salts on liquid limit of Black Cotton Soil

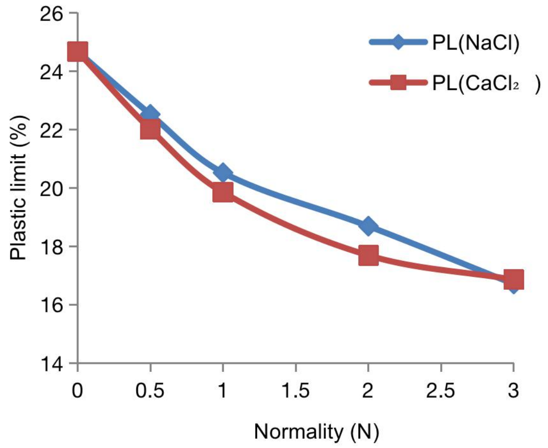

Fig.3. Effect of chloride salts on plastic limit of Black Cotton Soil

The liquid limit and plastic limit of the soil decreases with increase in concentration of salts. But the decrease in liquid limit is greater than decrease in plastic limit of soil (Fig.2 and Fig.3). Therefore, the plasticity index of the soil, the difference between liquid limit and plastic limit, decreases with concentration of salt (Fig.5). At concentration of 3N, the compressibility of black cotton soil changes from intermediate plasticity (CI) changes to low plasticity (CL).

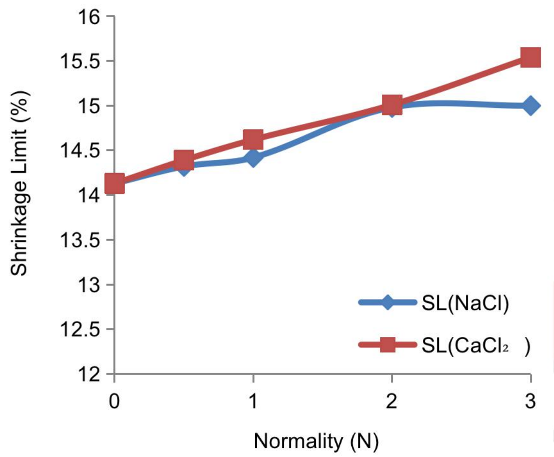

Fig.4. Effect of chloride salts on shrinkage limit of Black Cotton Soil

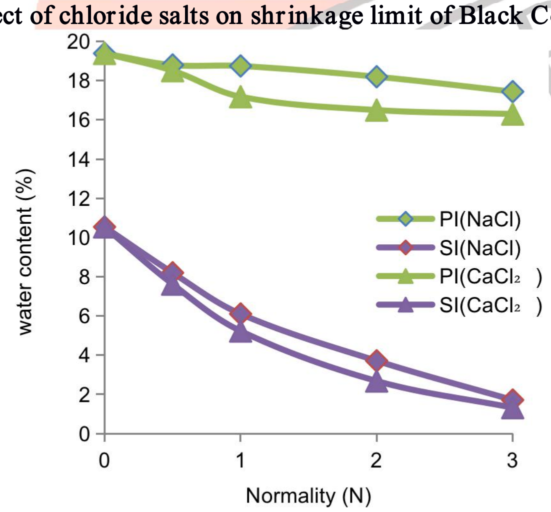

Fig.5. Effect of chloride salts on plasticity index and shrinkage index of BCS

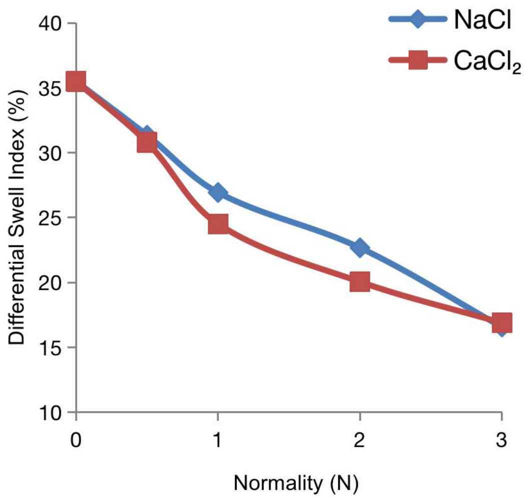

Fig.6. Effect of chloride salts on differential swell index of Black Cotton Soil

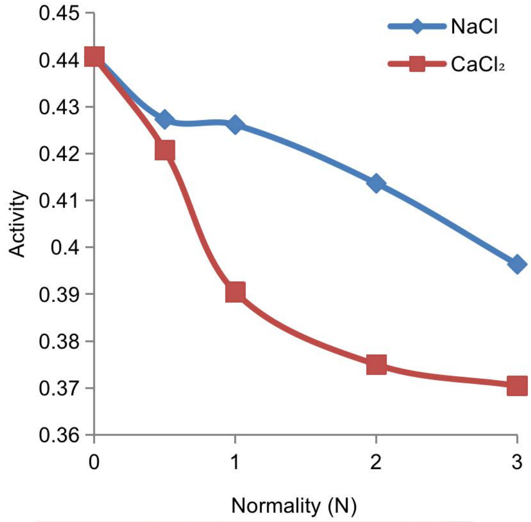

Fig.7. Effect of chloride salts on activity of Black Cotton Soil

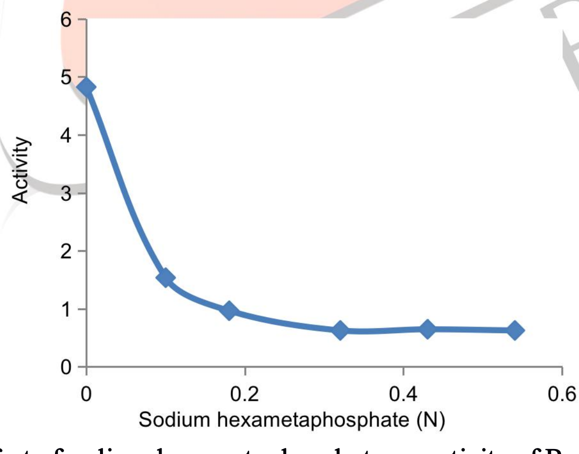

Fig.8. Effect of sodium hexametaphosphate on activity of Bentonite Soil

The clay particles are negatively charged due to isomorphous substitution and water is bipolar in nature. In the presence of water, the positive ions of water molecules are attracted by the clay particles forming a thin layer of water around each particle which is known as diffused double layer. Due to this, the black cotton soil and bentonite soil swells as water is imbibed into it. When NaCl and $CaCl_2$ salts are added in soil, the exchangeable ions- Na^+ and Ca^{2+} and mineral surface hydrate. The hydrated cations are too large to fit in the monoionic layer of the mineral particles. The exchangeable ions with their shell of water try to move to position of equilibrium and are also attracted to the negative clay particles leading to electrostatic force development between negative surface of clay and positive exchangeable ions. The actual position exchangeable ions occupy are compromised between these two types of forces. The electrostatic force depends on the soil mineral and valency of the exchangeable cations. The more is the concentration and valency, greater is the reduction in thickness of diffused double layer of soil as cations of the added salt replace dissimilar cations from the exchange complex of the soil and form cluster around the negatively charged clay particle. This leads to flocculation and aggregation of clay particles, thus, reducing plasticity and swelling behaviour of soil significantly. The flocculation of the clay particles increases with electrolytic concentration, valency of exchangeable ion and temperature.

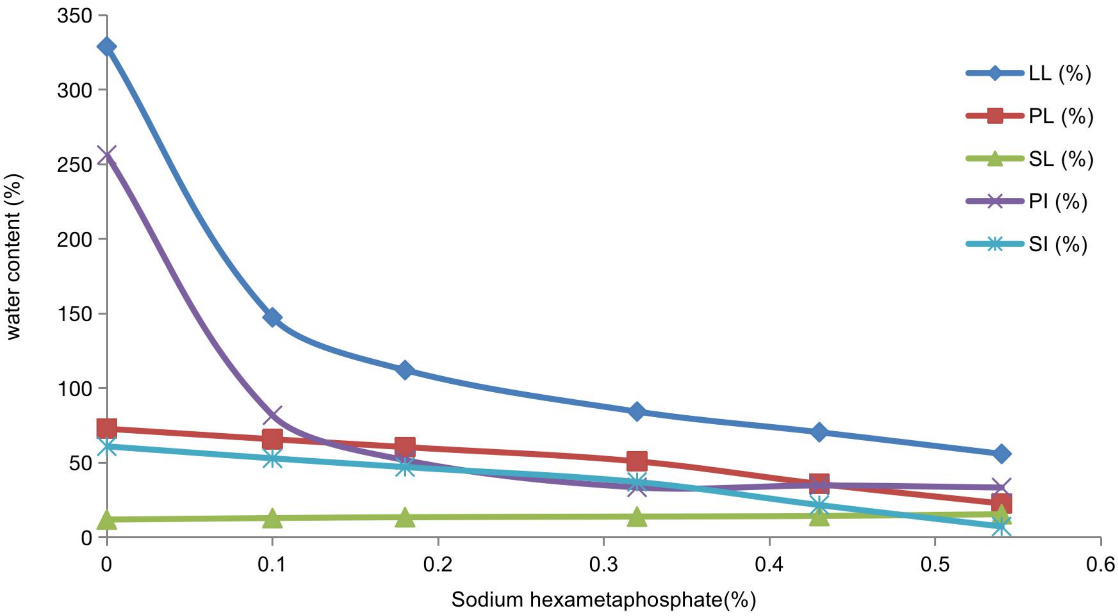

Fig.9. Effect of sodium hexametaphosphate on consistency limits of Bentonite Soil

The Gouy-Chapman theory gives the thickness of double-layer thickness (1/κ) as:

$$\frac{1}{\kappa} = \sqrt{\frac{\lambda K T}{8\pi n_0 e^2 \upsilon^2}} \ \text{(cm)} \qquad (1)$$

Where
λ = dielectric constant of the medium
K= Boltzmann's constant (1.38x 10^{-16}erg/K)
T = absolute temperature
e = unit electrostatic charge (4.8x 10^{-10} esu)
υ = ionic valences
n_0=concentration of positive and negative ions away from clay surface in equilibrium liquid

Table.2. Double layer thickness with concentration of chloride salts in BCS

Normality	Double layer thickness (Å)	
	NaCl	$CaCl_2$
0.5	4.28	2.14
1	3.03	1.51
2	2.14	1.07
3	1.75	0.87

Table.3. Double layer thickness on addition of sodium hexametaphosphate in BS

Normality	Double layer thickness (Å)
	$Na_6(PO_3)_6$
0.1	9.58
0.18	7.14
0.31	5.44
0.43	4.62
0.52	4.12

The clay particles experience repulsion being negatively charged and attraction due to Van der Waal's force in the presence of water. Van der Waal's force depends on the dielectric constant of the medium separating the mineral surfaces. Water has very high dielectric constant, therefore, when salt is added to it, it's dissociation occurs. The arrangement of polarised water molecules around the cation and anion decreases the attraction between the ions of the salt and repulsion between negative clay particles.

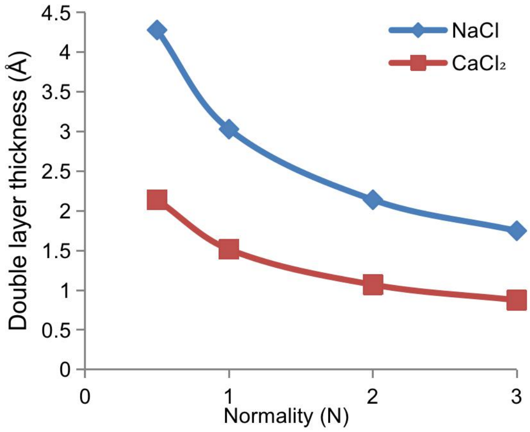

Fig.10.Variation of double layer thickness with concentration of chloride salts in BCS

From eq (1), it can be seen that with the decrease in dielectric constant of the medium and increase in valency of exchangeable cation, keeping all other parameters constant, the double-layer thickness reduces. By putting the value of λ =80, T=290K and n_0= M x 10^{-3} x 6.022x1$0^{23}$, where M is the molarity of the medium, the Eq (1) reduces to:

$$\frac{1}{\kappa} = \frac{3.03 \text{ X } 10^{-8}}{\upsilon\sqrt{M}} \quad (2)$$

Putting υ = 1 for NaCl and $Na_3(PO_3)_6$, and υ = 2 for $CaCl_2$, the thickness of double layer has been calculated at different normalities, shown in Table.3 and Table.4. (Fig.12).

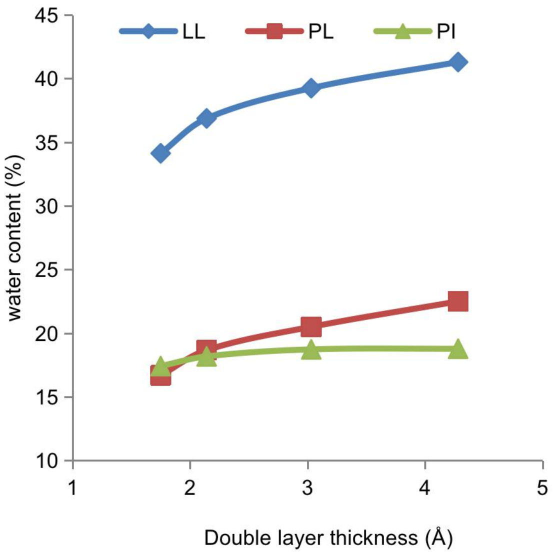

Fig.11.Double layer thickness with Atterberg's limit on addition of NaCl in BCS

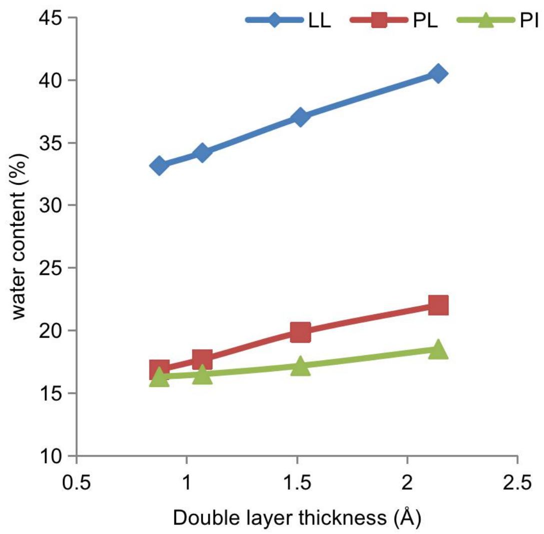

Fig.12. Double layer thickness with Atterberg's limit on addition of $CaCl_2$ in BCS

$$CaCl_2 + H_2O \rightarrow Ca^{2+} + 2Cl^- \quad (3)$$
$$Ca^{2+} + OH^- + \text{soluble clay silica} \rightarrow CSH \quad (4)$$
$$Ca^{2+} + OH^- + \text{soluble clay alumina} \rightarrow CAH \quad (5)$$
$$NaCl + H_2O \rightarrow Na^+ + Cl^- \quad (6)$$
$$Na^+ + OH^- + \text{soluble clay silica} \rightarrow NSH \quad (7)$$
$$Na^+ + OH^- + \text{soluble clay alumina} \rightarrow NAH \quad (8)$$

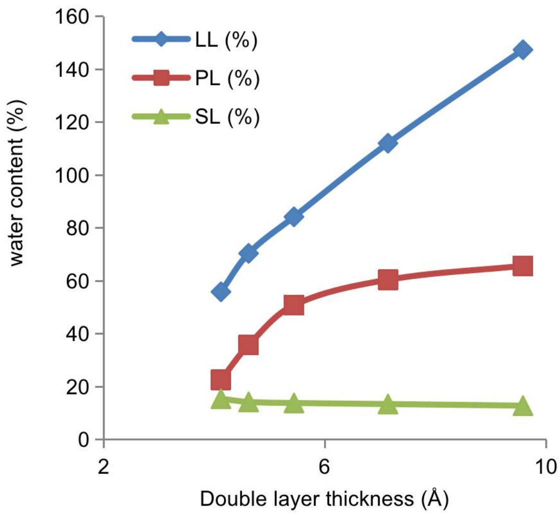

Fig.13. Double layer thickness with Atterberg's limit on addition of $Na_3(PO_3)_6$ in BS

Equations (3) and (6) show the dissolution of calcium and sodium salt when added in silica and alumina rich soil. After dissolution, precipitation of calcium and sodium leads to the formation of CSH (calcium silicate hydrate), CAH (calcium aluminate hydrate) gel (shown in Eqs. (4) and (5)) and NSH (sodium silicate hydrate), NAH (sodium aluminate hydrate) gel (shown in Eqs. (7) and (8))[14]. The cations act as a link between the clay particles. Sodium ions have a single positive charge, so their clay-binding ability is poor. Calcium ions have a double positive charge, so their clay-binding ability is better. Hence, the plasticity of soil (liquid limit and plastic limit) and differential swell index have greater reduction in values in presence of calcium chloride solution than in the presence of sodium chloride solution.

IV. CONCLUSION

In this study, the performance of the black cotton soil stabilised by sodium chloride and calcium chloride have been compared in terms of liquid limit, plasticity index, shrinkage limit and differential swell index. The liquid limit of the soil reduced from 44.06% to 34.15% and 33.16% when added with sodium chloride and calcium chloride of concentration 3N respectively. Calcium cation being of greater valency than sodium gets more strongly held to the negatively charged clay particles and thus reduce the thickness of diffused double layer to a greater extent. Similarly, when the sodium hexametaphosphate is added to bentonite soil, the cations of salt participated in reducing the liquid limit of soil, from

328.89% to 55.83% on addition of 33.33% salt, by making the soil particles undergo flocculation and agglomeration.

V. FUTURE SCOPE

The study for carried out to know the optimum amount amount of chemicals suitable for stabilization of highly plastic soil. Based on the outcome of this study, we have the following future plan and suggestions- study of stabilizing clayey soil by geopolymer, which is more environmental friendly and natural additive. Comparison of soil added with different additives can be made which will give wider view for selecting a more economical, optimum and sustainable additive to the soil.

Abbreviations

BCS, black cotton soil; BS, bentonite soil; LL, liquid limit; PL, plastic limit; PI, plasticity index; SL, shrinkage limit; SI, shrinkage index; DSV, differential swell value; OMC, optimum moisture content; MDD, maximum dry density; UCS, unconfined compressive strength.

VI. ACKNOWLEDGMENT

The authors are grateful to the faculty members of Geotechnical Engineering, DTU, Delhi and IIT BHU, Varanasi for their cooperation and moral support which helped in completing the research.

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