Effect of Sugar-Cane Bagasse Ash on Engineering Properties of Low Plastic DGK Soils

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Abstract

Soft cohesive soils that contain the significant percentage of montmorillonite, illite and mica in their mineralogical composition may undergo volume changes upon interaction with water. Pavements and building foundations constructed on such soils may fail due to change in volume with variation in the seasonal moisture content. If encountered, treatment is essential to improve the shearing strength and enhance the load carrying capacity of such foundation/subgrade soils. Numerous studies have been done to improve such soils by adding various materials such as cement, lime, bitumen, rubber and plastic etc., or by chemical, thermal and electrical stabilization. In chemical stabilization, soil stabilization is achieved by chemical reaction of stabilizer (cementitious material) and soil minerals (pozzolanic material). The use of bagasse ash created by sugar cane industries is ideal for chemical stabilization of soft soils as it is economical & environment friendly and offers a potent solution for weak soil particle bonding. This study has been carried out to examine the stabilization potential of the subgrade soil of D. G. Khan. Bagasse Ash is a by-product of sugar-cane industry, where bagasse is burnt to produce electricity. Bagasse ash contains high silica and alumina contents and is therefore a pozzolanic material, that reacts with calcium to form cementitious calcium silicate and aluminate hydrates. This study shows an increase of almost 30 times in soaked unconfined compressive strength of stabilized soil and a significant increase in CBR values of subgrade soils. One dimensional swell potential of treated soil also found to decrease from 2.5 percent to almost zero.

Keywords: Low Plastic Soil, Sugarcane Bagasse Ash (SCBA), CBR, MDD, OMC, Atterberg's Limits, Minerals

1. INTRODUCTION

Engineering properties of subgrade and embankment soils are always a major consideration from engineering point of view. The current practice in Pakistan is to use in situ soil as a subgrade or embankment material where possible. In general, soft clays are considered unsuitable as foundation material because of their unpredictable and dramatic behavior all over the world significant problems have been faced during the construction of railway tracks, runways, taxiways, highways and embankments because of dramatic change in soil behavior. The most renowned problems associated with clay are swell-shrink and large variation in the properties such as field moisture content, degree of compaction and shear strength with the fluctuating index properties like liquid limit, plastic limit and plasticity index. Change in volume of clays is associated with the change in insitu, moisture content of soil. This change in volume results in reduction in shearing strength of soils eventually results in several pavement distresses. (Mowafy et al., 1990). It is estimated that damage caused due to expansion of clays is more than twice the cumulative damage caused by other natural hazards, i.e., floods, hurricanes, earthquakes and tornados (Jones and Holtz, 1973). Being a citizen of Pakistan, we are concerned with its transportation system. According to Ministry of Industries and Production (2003), transportation sector accounts for 12% of the total GDP. Roads in Pakistan almost carry 92% of passenger and freight traffic. According to NHA, freight growth rate is 3% and passenger's growth rate is 4.5%. Total road network in Pakistan is approximately 260,000km. In which national roads consist of 140726km and farm to market roads consist of 117233km. Only 13000km of roads are managed and taken care by NHA, which comes equal to only 4% of the total road network existing in Pakistan. This 4 % of the total road network caters for almost 80% of the total road traffic in Pakistan. Almost 5000km roads are classified as fair to poor in Pakistan by NHA. As mentioned earlier, enormous growth rate of traffic is causing deterioration and failure of pavement structures. Pavement deterioration is inevitable because the roads are not designed for the traffic load that usually plies on them. To avoid pavement deterioration, high strength construction materials, modern design procedures and versatile construction techniques must be used. The first and foremost thing to keep in mind is the limited resources available for pavement structures. So, there is a stringent need to use the high strength materials and develop the modern building techniques suitable for the concerned conditions

2. LITERATURE REVIEW

Clayey Soils

Based on mechanical analysis, plastic soils having particle size less than 0.002 mm (2μm) are commonly known as clayey soils. These soils contain minerals like montmorillonite, illite, kaolinite and mica etc. Plasticity and undrained shear strength are the primary characteristics of clayey soils. Clayey soils are mostly made up of minerals, ranging from microscopic to submicroscopic particles derived from weathering of rocks. Plasticity of soil varies from low to very high with moderate to wide range of in-situ water content. Permeability of these soils is very low. While at higher water content, these soils are considerably sticky. (Terzaghi et al 1996). Individual grains of clay can't be seen with naked eye. (Holtz et al 1981). Clayey soils tend to have more swelling potential then other types of soil. Classification of clayey soils based on swell potential and cation exchange capacity is tabulated as:

Table 1: Soil Classification Based on Swell Potential (Seed et al., 1962)

Soil Type	Very High	High	Medium	Low
Swell Potential	> 25	5 – 25	5 – 1.5	< 1.5

Table 2: Soil Classification Based on Cation Exchange Capacity (Yilmaz, I. (2004)

Soil Type	Very High	High	Medium	Low
Swell Potential	> 55	37 – 55	27 – 37	< 27

Table 3: Typical Values of CEC for Various Clay Minerals (Mitchell 1993)

Colloid Type	CEC (meq/100gm)
Kaolinite	2-15
Montmorillonite	80-150
Chlorite	10-40
Hydrous Mica (Illite)	10 – 40

Table 4: Rating of Expansive Soil on the basis of Liquid Limit (Day, 2006)

Liquid Limit	Expansion Potential
0-20	Very Low
20-35	Low
35-50	Medium or moderate
50-70	High
70-90	Very High
>90	Extra High

Table 5: Subgrade Classification Based on CBR (TRH4, 1996)

Material Quality	CBR (%)
Good	>15
Moderate	7 – 15
Fair	3 – 7
Poor	< 3

3. SOIL STABILIZATION

Soil stabilization is an improvement in the soil properties such as shearing strength and compressibility by performing physical, chemical, biological or a combination of these techniques to meet the engineering requirements. Soil Stabilization results in reducing compressibility of soil, reducing plasticity, increasing bearing capacity and increasing shear strength.

Mechanical stabilization involves techniques like compaction, pre loading, drainage, etc. Chemical stabilization of soil consists of a process in which different chemical substances are mixed with the soil to improve its engineering properties. The chemicals directly react with soil particles. These reactions are either cementitious or pozzolanic in nature.

4. BAGASSE ASH

According to ASTM bagasse ash is classified as pozzolanic material. As per ASTM definition, pozzolans are

"*A siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value, but will, when in finely divided form and in the presence of moisture, chemically reacts with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties*." ASTM, C618, (2005). Pozzolanic activity is defined as the measure of Pozzolanic reaction over time in presence of water. The reaction rate is dependent upon particle properties i.e. definite surface area of pozzolan, chemical composition of pozzolan and reaction conditions. Bagasse is an industrial waste produced in sugar industry, that is used as fuel and the ashes produced from combustion of sugarcane bagasse are known as sugarcane bagasse ash (SCBA) which contain high amounts of unburnt matter, oxides of silica and aluminum are most important components of these ashes (Díaz-Pinzon, L., & Ordonez, L. M. ,2002). Sugarcane bagasse ash does have excellent pozzolanic characteristics and is widely used as the pozzolanic material.

5. **Potential Uses of Bagasse Ash**

The pozzolanic nature of SCBA and its availability, makes it an attractive material for utilization in engineering applications. Major engineering applications of bagasse ash includes soil stabilization in conjunction with lime or cement, partial replacement of cement in concrete mixes and manufacturing of low-cost mud blocks for building construction.

6. Effect of Bagasse Ash on Engineering Characteristics of Clayey Soils

Gandhi, K. S, (2012) successfully used bagasse ash to reduce plasticity index of expansive clays. Gandhi.*et.al.,* reported that addition of 10% bagasse ash results in decrease in liquid limit from 72% to 52%, PI from 42% to 27% and shrinkage limit reduced from 21% to 15%. Ashish et al, (2015) used bagasse ash to stabilize locally available medium plastic clay and reported that for addition of 10% bagasse ash, liquid limit of soil reduced from 35% to 26% and PI reduced from 13% to mere 9%.

Chhacchia & Mittal, (2015) utilized bagasse ash for the stabilization of clayey soils. They used up to 28 percent of bagasse ash in soil. They reported an increase in OMC from 22.42% to 27.9% and a reduction in MDD from 1.82 g/cm^3 to 1.34 g/cm^3. Ashish et al, (2015) investigated the effect of sugarcane bagasse ash on the engineering properties of locally available medium plastic clay. With addition of 10% bagasse ash, an increase in OMC from 15.3% to 18% and a decrease in MDD from 1.793 g/cm^3 to 1.692 g/cm^3 was observed.

Bagasse ash can produce a significant improvement in CBR and swell properties of soil. Ahmed et al, (2015) reported that addition of bagasse ash none, 1%, 3%, 5%, 7% and 9% to the soil samples caused an increase in CBR value at the rate of 6.47%, 8.63%, 10.97%, 12.05%, 13.5%, 13.85% respectively and at the addition of 11% bagasse ash, CBR value decreased to 13.28%. So, 9% was selected as optimum percentage of bagasse ash. Chhacchia & Mittal, (2015) observed that untreated medium plastic clay had a CBR of 2.1%. It increased to 9.8% with the addition of 24% SCBA. But further addition of bagasse ash up to 28% reduced the CBR value to 6.7%. So, they selected 24% bagasse ash as optimum percentage for the soil under study. Gandhi, K. S, (2012) reported a reduction of free swell index from 150% to 80% with the addition of 10% bagasse ash.

MATERIALS AND METHODOLOGY

Soil was collected from a town named Shadan Lond of Dera Ghazi Khan Division, Punjab, Pakistan. Location of soil sample's soource is shown in Figure 1. While bagasse ash was collected from Sheikhoo Sugar Mills Limited Sanawan, (figure 2). Muzaffargarh, Punjab, Pakistan. Location of this site is shown in Figure 2. Independent laboratory testing was carried out at geotechnical laboratory, CED, KFUEIT, RYK, Pakistan. Laboratory testing was carried out in two phases as listed below

Phase: 1- Characterization of Untreated Soil

Phase: 2- Characterization of soil treated with Sugarcane Bagasse Ash

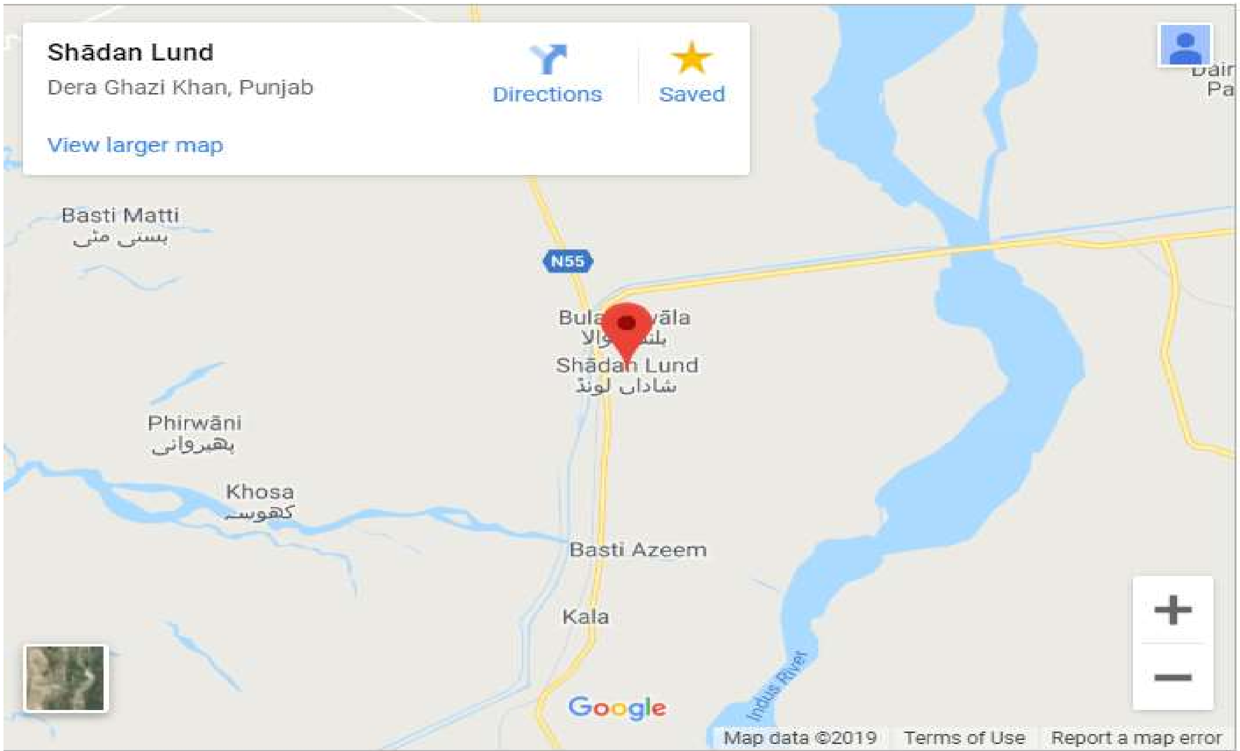

Figure 1: Location of Site (From where soil sample was collected

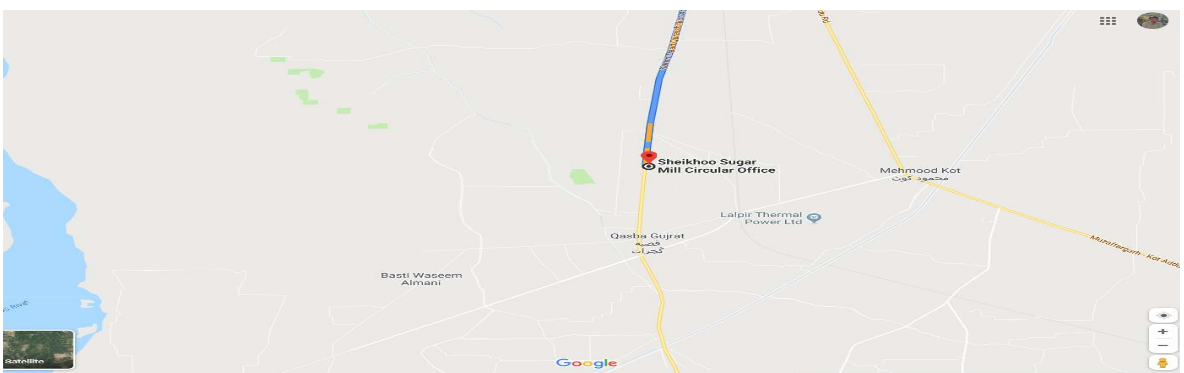

Figure 2: Location of Sheikhoo Sugar Mills Limited (From where SCBA was collected)

Phase 1: Characterization of untreated soil
The first phase of this study consisted of characterizing the untreated soil. In this phase, following properties of untreated soil were examined.

- LL, PL and PI
- MDD and OMC
- UCS
- CBR
- Swell potential

Phase 2: Characterization of soil treated with SCBA
Second phase of this study was aimed to analyze the impact of SCBA on engineering

properties of soil.

- LL, PL and PI
- MDD and OMC
- UCS
- CBR.
- Swell Potential

After the analysis of results, optimum dosage/content of SCBA was finalized.

Soil Sample Preparation

ASTM Standards were adopted to prepare the soil samples for each test. Mixing was carried out by weight. Soil sample was kept in oven for 24 hours to eradicate the field moisture. Dried soil was used for each sample preparation. ASTM standards adopted in this study are as followed

Laboratory tests were performed according to the following ASTM standards,

- Sieve Analysis ASTM D6913-17
- Hydrometer Analysis ASTM D7928-17
- Atterberg's limits of soil ASTM D4318-17
- Specific gravity of the soil ASTM D854-14
- Modified Proctor Test ASTM D1557-12
- California Bearing Ratio (CBR) ASTM D1883-16
- Unconfined Compressive Strength (UCS) ASTM D2166M-16.
- Cation Exchange Capacity (CEC) $e^{(2.63 + 0.002 LL)}$ Yilmaz (2004)

RESULTS AND DISCUSSIONS

Characterization of Untreated Soil

All the laboratory tests of untreated soil were conducted according to the ASTM standards. Table 4.1 represents the summary of results of untreated soil characterization.

Table 6 Summary of Untreated Soil Characterization

Soil Property		Values
Soil Type (USCS)		CL
% Passing Through Sieve #200		91.4
LL (Liquid Limit)		49
PL (Plastic Limit)		24
PI (Plasticity Index)		25
Soil pH		8.02
Maximum Dry Density (MDD) g/cm^3		1.93
Optimum Moisture Content (OMC) %		13.73
Specific Gravity (G_s)		2.65
Clay Minerals (Using XRD)	Predominant Montmorillonite, Mica, illite	
Clay Content %		79
UCS, (Unconfined Compressive Strength) psi		27
CBR %	Un-Soaked	3.69
	Soaked	2.14

One Dimensional Swell Potential, %	4.19

Effects of Bagasse Ash on Atterberg's Limits of Soil

Atterberg's limits of soil reduced with the increase in Bagasse ash content. Table 4.2 demonstrates the effect of sugar-cane bagasse ash on index properties.

Table 7: Effect of SCBA on Atterberg Limits of Soil

Sr. No.	Soil Sample	DGK Soil	
		Liquid Limit (%)	Plasticity Index
01	Soil Only	49	24
02	Soil + 5% BA	47.3	27.6
03	Soil + 7% BA	42.8	24.3
04	Soil + 9% BA	41.3	22.8
05	Soil + 11% BA	38.7	18.9

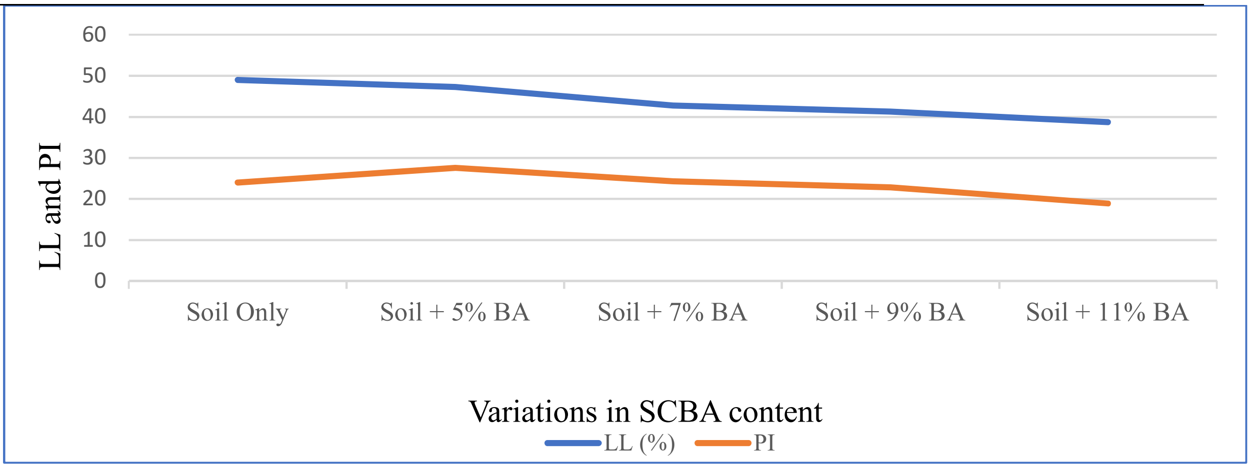

Figure 3: Effect of varying SCBA content on LL and PI of Soil

Effects of Sugar-Cane Bagasse Ash on OMC and MDD of Soil

Modified proctor test was conducted to analyze the impact of SCBA on OMC and MDD of soil. Addition of Bagasse ash with soil showed considerable change in OMC and MDD of soil. Bagasse ash being a conventional soil stabilizer tend to increase the MC and reduce the density of soil. On the contrary, non-conventional soil stabilizer tend to increase the density by reducing the moisture content. Casagrande apparatus was used to analyze the index properties of soil. Table 4.3 depicts the real changes in OMC and MDD of DGK soil.

Table 7: Variations in MDD and OMC of Soil

Sr. No	Description	OMC (%)	MDD (g/cm^3)
01	Soil Only	13.73	1.93
02	Soil+ 5% SCBA	15.1	1.81
03	Soil+ 7% SCBA	16.7	1.75
04	Soil+ 9% SCBA	18.6	1.71

05	Soil+ 11% SCBA	17.2	1.79

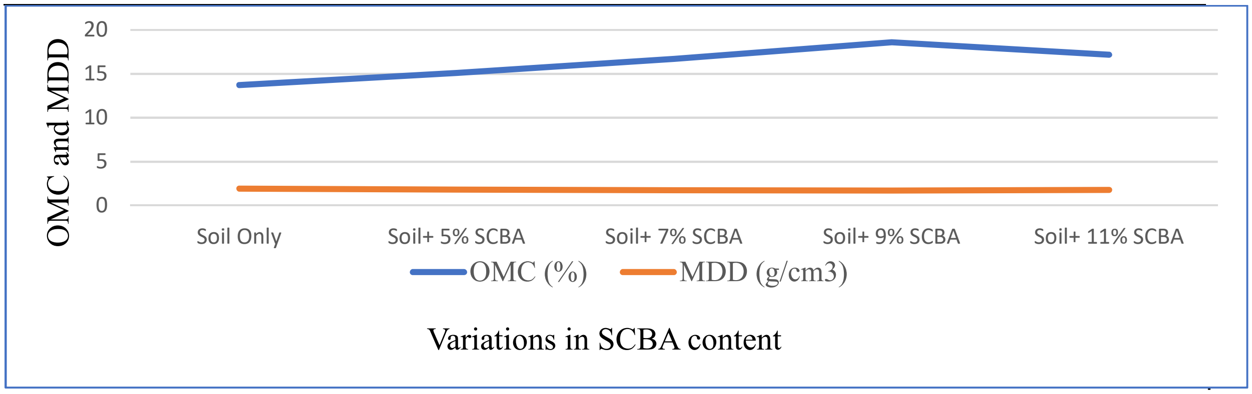

Figure 4: Effect of varying SCBA content on OC and MDD of soil

Effect of Sugar-Cane Bagasse Ash on CBR of Soil

Samples of CBR were prepared using the MDD and OMC of soil. Un-soaked CBR was conducted to check the behavior of treated soil under dry conditions. While soaked CBR was conducted to assess the CBR under worst conditions i.e. soil exposed to fully moist conditions. For soaked CBR, samples were kept in moist environment for 96 hours. Table 4.4 shows the impact of bagasse ash on CBR of soil.

Table 8: Variations in CBR of Treated Soil

Sr. No	Sample Description	CBR Un-soaked (%)	CBR Soaked (%)
01	Soil Only	3.69	2.14
02	Soil+5 % BA	7.18	2.91
03	Soil+7 % BA	7.93	3.38
04	Soil+9 % BA	9.26	5.18
05	Soil+11 % BA	8.87	4.09

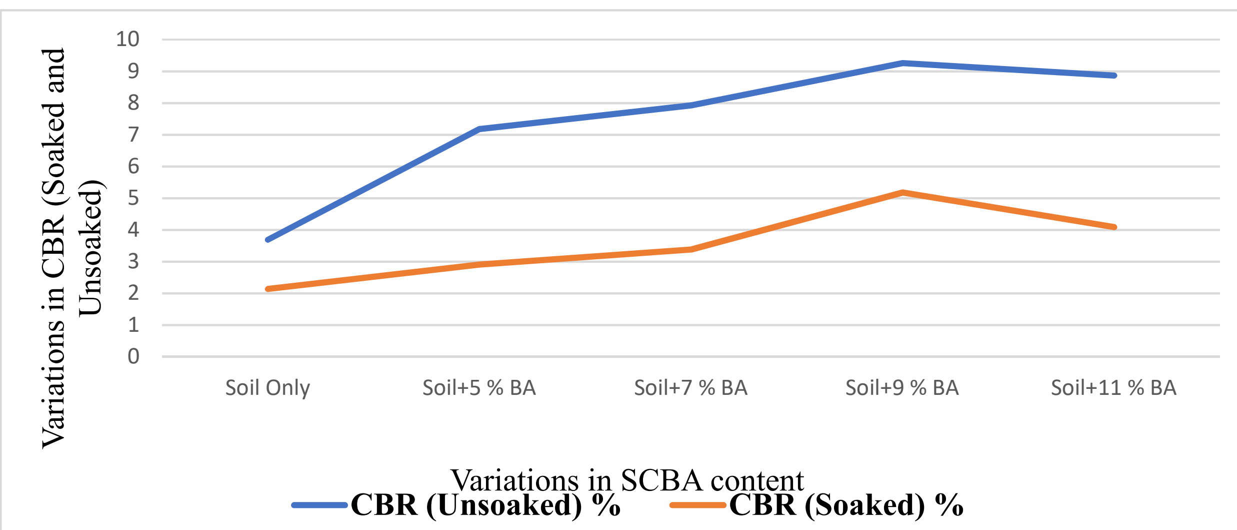

Figure 5: Effect of varying SCBA content on CBR (Un-soaked and Soaked) of soil

CONCLUSIONS AND RECOMMENDATIONS

Following conclusions are drawn on the basis of independent laboratory testing conducted on DGK soil (classified as CL).

- Addition of bagasse ash caused the significant reduction in LL and PI of treated soil
- Maximum Dry Density (MDD) of treated soil decreased with the increase in bagasse ash content. After the addition of 9% bagasse ash, MDD started increasing. Which means 9% of bagasse ash content is the optimum quantity which can be used to treat the soil of this class.
- Optimum Moisture Content (OMC) increased with increase in SCBA content. After 9% of bagasse ash, it started decreasing. Change in OMC and MDD can be attributed to the pozzolanic nature of bagasse ash.
- Soil treated with bagasse ash showed considerable increase in CBR under soaked conditions, while under un-soaked conditions improvement in CBR of treated soil was more significant.
- Swell potential of soil decreased to 0.83% from 4.19%, which lies in the limits described by International Building Code (2006).
- On the basis of conclusions, it is recommended that bagasse ash provides an efficient solution for the low plastic soil.

RECOMMENDATIONS

- Effect of bagasse ash on engineering characteristics of collapsible soil can be studied
- Shear strength and modulus of resilience of high plastic soil treated with bagasse ash should be extensively examined
- In this study, one dimensional swell potential was taken into account, overall free swell of soil should be examined
- Effect of bagasse ash imported from different places should be studied to standardize its use as a technically potential soil stabilizer
- Bagasse ash can be used in engineering projects as a potential soil stabilizer, as this is abundantly available in Pakistan
- Comparative analysis on impacts of bagasse ash and any other non-conventional (biological) soil stabilizer should be studied to further endorse its usage as a competent soil additive.

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