Strength Enhancement of Expansive Soil using Unconventional Material

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ABSTRACT

Expansive soils are widely spread across the world and result in loss of life and property due to moisture variations within the soil. Conventional materials used for stabilization of such soils are not only expensive but result in hazardous waste generation causing negative impacts on environment. This study is focused on utilization of unconventional material, i.e., biochar, as an economical, efficient and environment friendly material for strength enhancement of expansive soil. As per AASHTO classification, A-6 soil was selected and improved with biochar percentages of 3%, 6%, 9%, 12% and 15%. Effect of biochar was studied on soil plasticity, compaction characteristics, hydraulic conductivity, and strength enhancement. The liquid limit, plastic limit, plasticity index, optimum moisture content, CBR value and hydraulic conductivity values were increased from 34.61% to 54.33%, 17.98% to 21.50%, 16.63% to 32.83%, 10.6% to 17%, 5.4% to 10.8%, and 9.7×10^{-7} cm/s 3.2×10^{-6} cm/s, respectively. Whereas maximum dry density was dropped from 2043 kg/m^3 to 1518 kg/m^3. Results have shown that use of biochar increases the strength and hydraulic conductivity of A6 soil considerably, making it an environment friendly non-conventional admixture.

Keywords: Expansive soil, Biochar, California Bearing Ratio, Hydraulic Conductivity, Compaction Characteristics

1. INTRODUCTION

Stabilization of soil is most widely used in the projects involving the construction of embankments, foundations and most particularly pavement works such as roads. Adopting soil stabilization techniques to a natural soil improves the confinement of soil particles that enhances its physical and mechanical properties meeting the requirements for the engineering purposes. These properties mainly include strength, volume, stability as well as durability. It also helps in reducing the overall cost of the project since economy is a major factor deciding the speed and quality of work.

In most of the projects involving construction of pavements, problematic soil becomes a major hindrance in the progress of the construction. Such a soil, due to its composition, particles shape and size distribution can cause additional problems from engineering point of view that are essential to be treated. AASHTO cover this type of soil in its classification categories ranging from A-4 to A-7. Soil stabilization becomes essential in any construction project since soil is the main foundation material upon which whole of the structure rests. Therefore, for any structure, it is necessary that the material upon which whole of the structure is to be built is strong enough to bear its load. The key purpose of soil stabilization is to improve the bearing capacity of soil.

The extent of damage of the problematic can be reduced by adopting certain stabilization measures. Different additives such as compost, sewage sludge and fiber are added to the soil Vinot [1]to increase the vegetation on embankments which is found to be very effective in bringing stability to the soil. Such additives may be effective for the stability of the soil but are hazardous for the environment since they produce harmful greenhouse gases upon microbial decomposition Seidl [2] such as CH_4 and CO_2.

Addition of Biochar to soil is also considered to be one of the most effective, environmentally friendly and economical way to stabilize a soil. Biochar is a carbon rich product obtained from the incineration of biomass. Its production sources include agricultural waste, wood production waste as well as other biological sources. Biochar obtained from these sources composes of varying carbon, and volatile components Mwangi [3] that also effect the soil properties. Since it is purely a natural product it has no side effect on the environment. It is a microbial non-biodegradable material that is best suited for the agricultural as well as engineering purposes. Biochar also enhances the agricultural productivity of soil Bordoloi [4], therefore it has also been used in agricultural and environmental remediation projects as a type of carbon capture technology.

However, biochar has also found its application in civil engineering projects as a soil enhancing agent. Addition of biochar with percentages ranging from 5%, 10% and 15% by weight enhances the hydraulic conductivity and shear strength of landfill cover soil with a reduction in compressibility. Due to its high porosity, it improves the water retaining capacity of sandy soils with a reduction in its density and specific gravity. The improved water holding capacity also increases the vegetation growth suitable for slope stability other soil engineering properties such as resistance to soil erosion [5] and liquefaction [6]. It also reduces pore-water pressure and gas permeability due to high water holding capacity in sandy soils Zong [5]. It was discussed by M Ahmad [6] that natural soil when embedded with different types of biochar has an increased angle of internal friction (ϕ) and a decreased cohesion value (c). The effect of biochar on the subgrade comprising of expansive clay has also been studied by GuhaRay [7] in which he found improvement in California bearing Ratio (CBR) value. This means that the load bearing capability of soil also improves upon addition of biochar. The present study also focuses on the effect of addition of biochar with different percentages upon the load bearing capability of the soil which would be measured in terms of the California bearing ratio (CBR) value.

2. MATERIALS AND METHODOLOGY

2.1 Materials:

Following are the materials used for this study:

2.1.1 Soil

In this study A-6 Soil (as per AASHTO classification) was used. The soil was collected from Chakwal District in the province of Punjab, Pakistan. The soil of this region is mainly A-6 as per AASHTO classification. The soil collected was over dried, sieved and tested for consistency limits (plasticity index, liquid limit), specific gravity, hydrometric analysis according to the standard procedure as mentioned in ASTM standards (ASTM C128-15, 2015; ASTM D422–63, 2007; ASTM D698-12, 2012; ASTM D854, 2010; ASTM D4318-10, 2010; ASTM D4972, 2018). in order to verify it as A-6 soil. The soil sample (A-6 soil) consists of about 29% of sand and 60 % of fines (silt and clay).

Table 1: Properties of Soil

Soil Properties	Specifications
AASTHO Classification	A-6
Liquid Limit (%)	34.61
Plastic Limit (%)	17.98
Plasticity Index	16.63
OMC (%)	10.6

Max. Dry Density (kg/m^3)	2041

2.1.2 Biochar

In this study biochar (Cow dung) was used as stabilizing agent for the stabilization of soil. Cow dung is the waste product of animal species. Cow dung was sun dried and brought into powdered form prior to the use.

2.2 Methods

First soil sample was classified (as per AASTHO classification of soils) as A-6. For this purpose, the wet sieving and Atterberg's limits tests were performed on oven dried soil. For Atterberg's limit soil passing through sieve #40 was used to perform the tests. The tests were conducted for particle size distribution, liquid limit, plastic limit, specific gravity according to the standard procedure as mentioned in the ASTM C136, D4318, D854 respectively. For soil passing sieve no. 200, hydrometer analysis was performed according to ASTM D7928 in order to measure the particle sizes smaller than 0.075mm and respective percentage passing. The Modified Proctor Test was performed according to ASTM D1557 in order to find the Optimum Moisture Content and Maximum Dry Density for each proportion of biochar i.e., 0%, 3%, 6%, 9%, 12% and 15%. Oven dried soil passing through sieve 5mm was used to perform Modified Proctor Test. In order to find out the hydraulic conductivity of soil, falling head permeability test was also performed on bare and each proportion of biochar amended soil according to the standard procedure as mentioned in ASTM D5084. The samples for permeability tests were made at 90% Maximum Dry Density as determined earlier. Soaked California Bearing Ratio test was performed on the bare and biochar-amended soil samples according to the standard procedure as mentioned in ASTM D1883-16, 2016. The soil passing 5mm sieve was used in this test. The sample molds for CBR for bare and biochar amended soil were then prepared at their respective optimum moisture content as determined earlier. Following the standard procedure, all samples were prepared and then placed in the water tank for 96h with a load and deflection measuring assembly to measure the swell index. Samples were then taken out of the water and were allowed to drain completely for 15 minutes. Each sample was then placed in the test assembly in which 50mm diameter plunger was allowed to penetrate on the surface of samples at a deformation rate of 1.25mm/min. Load versus penetration readings were noted.

3. RESUTLS AND DISCUSSION

This section describes the geotechnical properties of pure soil and soil treated with varying percentages of biochar (3%, 6%, 9%, 12% and 15%). The soil sample consists of about 75.92% of fine particles passing through sieve No. 200 (0.075mm). The specific gravity of soil is about 2.65.

3.1 Modified Compaction Test:

Modified compaction test was conducted on A-6 soil with different percentages of biochar (0%, 3%, 6%, 9%, 12%, 15%) in accordance with the standard procedure as described in ASTM: D1557-07 to study the relationship between the optimum moisture content and dry density. Soil sample passing through sieve size 5mm was used for testing. From the test results it is noted that with an increase in biochar percentage, optimum moisture content increased while maximum dry density decreased. The test results indicate that the optimum moisture content of biochar amended soil increased with an increase in biochar percentage than that of pure soil due to the more water holding capacity than that of soil and porous structure of biochar. The maximum dry density of soil decreased with an increase of biochar percentage due to light particles (lower specific gravity) of biochar than soil. The test results are represented below in figures 1 and 2. Similar results were reported by U B Smrithi, Soorya S R [8].

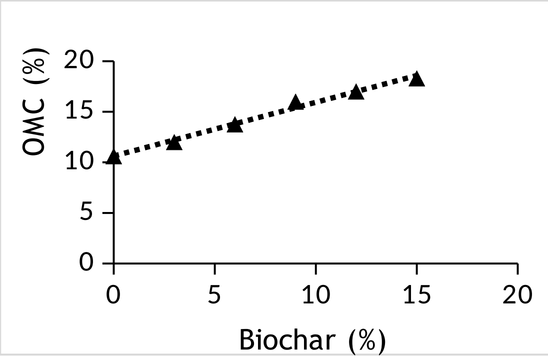

Figure 1: Biochar (%) vs OMC (%)

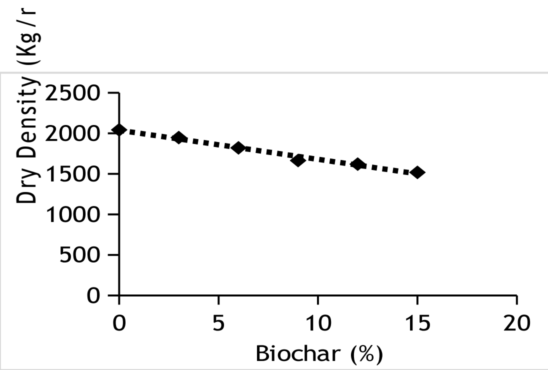

Figure 2: Biochar (%) vs Dry Density (kg/m^3)

3.2 Atterberg's Limits:

Atterberg's limits (Liquid limit, Plastic limit and Plasticity Index) test is performed according to standard ASTM: D 4318 on pure soil for AASTHO Classification of soil and on biochar amended soil with varying percentages of biochar (3%, 6%, 9%, 12%, 15%) to study the variation of Atterberg's limit with the varying biochar content. It is observed that the liquid and plastic limits of soil are increased with an increase in biochar concentrations. Soil sample passing through 5 mm sieve was used to determine liquid limit, plastic limit and plasticity index.

The test results show an increase in liquid limit with increase in biochar content. The variation of liquid limit is shown in figure 3.

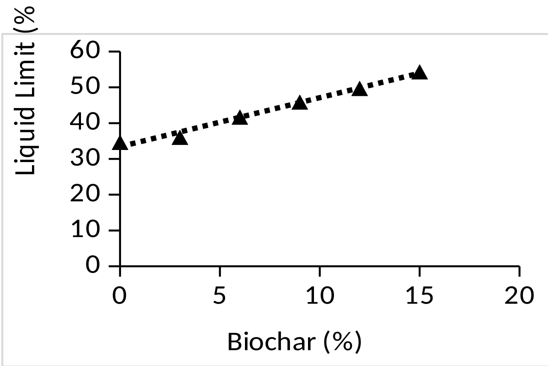

Figure 3: Biochar (%) vs Liquid Limit (%)

With an increase in biochar content in soil, the plastic limit of soil also increased. The results are shown in figure 4.

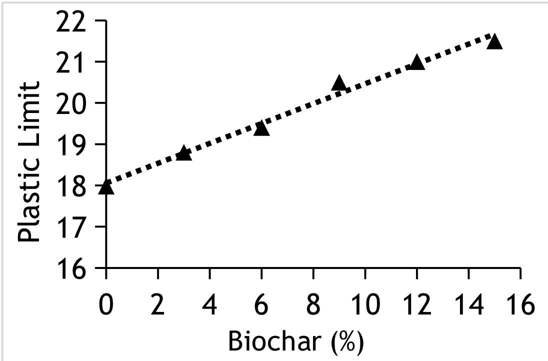

Figure 4: Biochar vs Plastic Limit (%)

3.3 Hydraulic Conductivity:

Falling head permeability test is performed on pure soil and biochar treated soil to determine the hydraulic conductivity coefficient or coefficient of permeability according to standard procedure as per ASTM D: 5084-10 (Method B-Falling Head, constant tailwater elevation). Soil was amended with different concentrations of biochar such as 0%, 3%, 6%, 9%, 12% and 15%. Soil sample passing through sieve size 5mm was used to determine hydraulic conductivity. The test specimen was remolded at 90% relative max. dry density of soil using optimum moisture content of corresponding soil sample. It is observed that the hydraulic conductivity of soil is increased with an increase in biochar percentage. The variation of hydraulic conductivity is shown in fig. The increase in the hydraulic conductivity of soil is due to the porous structure of biochar than that of soil.

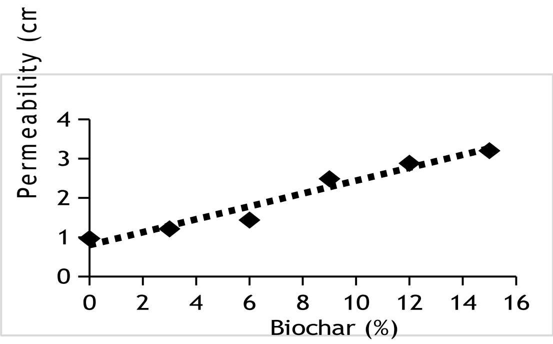

Figure 5: Biochar (%) vs Permeability (cm/s)

3.4 California Bearing Ratio:

Soaked California bearing ratio tests were performed on pure and biochar treated soil with varying percentages (3%, 6%, 9%, 12%, 15%) as per standard procedure prescribed in ASTM D1883-16. Three CBR molds were prepared against each biochar proportion, filled in five layers with 10, 30 and 65 blows on each layer respectively. Samples were soaked in water for 96 hours with a surcharge weight of 2.5 lbs. A constant strain rate of 1.25 mm/min is applied through a plunger of diameter 50mm and load values are noted. The test results show an increase in CBR value with the gradual increase in biochar percentage. The soaked CBR value was increased 2 times on 15% biochar concentration. The increase in CBR value may be due to formation of bond between charged surfaces of biochar and soil. Similar results were reported by Arijit Sarkar [9].

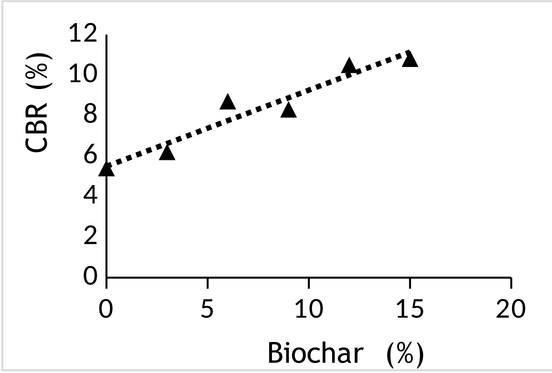

Figure 6: Biochar (%) vs CBR (%)

4. CONCLUSIONS

Biochar is an economical, efficient and environment friendly material for strength enhancement of expansive soil. Following conclusions are made from this study:

- The liquid and plastic limits of the soil were increased about 56% and 20%, respectively with the increase in biochar concentration from 0% to 15%. This shows water holding capacity of soil was increased.
- Addition of biochar (from 0% to 15%) results in a decrease in the maximum dry density (from 2043 kg/m^3 to 1518 kg/m^3) and increase in the optimum moisture content of soil (from 10.6% to 18.3%). This is due to more water holding capacity and lower specific gravity of biochar.
- Due to high porous structure of biochar the addition of biochar has a significant effect on the Hydraulic Conductivity of soil. Hydraulic conductivity of soil was increased (from $9.7E^{-07}$ cm/s to $3.2E^{-06}$ cm/s) with the addition of biochar percentage (from 0% to 15%).
- The California Bearing Ratio (CBR) value of soil was increased about two times (from 5.4 to 10.8) with the increase in biochar concentration from 0% to 15%.

5. REFERENCES

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