Influence of Biopolymer Treatment on Suction Characteristics of Bhavnagar Expansive Soil

Jahnavi Parmar[1], Vikas Yadav[2] and Saloni Pandya[3]

[1] Former, Undergraduate student, Civil Engineering, Navrachana University, Vadodara, Gujarat-391410
[2] Former, Undergraduate student, Civil Engineering, Navrachana University, Vadodara, Gujarat-391410
[3] Assistant Professor, Civil Engineering, Navrachana University, Vadodara, Gujarat-391410

Abstract. Unsaturated expansive soils are recognized as one of the most problematic soils owing to its swelling-shrinkage characteristics. Expansive soils in the unsaturated state are part of vadose zone and encountered in several arid and semi-arid parts of the world. The presence of such soils in highway/railway embankments, slopes and earthen dam sites manifests various critical issues during and after the construction of structures. Presence of suction in unsaturated state of soil influences the geometric arrangement of soil fabric, which induces the volume change behaviour in expansive soil. Bhavnagar region of Gujarat (India) is a coastal city which consists of salt rich expansive soils of Basaltic origin. The present study aims to evaluate the influence of biopolymer stabilization on the suction characteristics of saline Bhavnagar black cotton soil. A series of non-contact and in-contact filter paper tests were conducted on the biopolymer treated and non-treated soil to evaluate total, matric and osmotic suction of the soil. Biopolymer treatment of black cotton soil was executed employing three different biopolymers namely Xanthan gum, Guar gum and Chitosan. Biopolymers were mixed in different proportions to obtained optimum percentage of treatment from filter paper tests. The tests indicated significant influence of the biopolymer treatment on the suction (Total, Matric and Osmotic) characteristics of treated expansive soil. The optimum percentage of Xanthan gum, Guar gum and Chitosan obtained from the present study were 0.5%, 1.5% and 0.12% respectively. Influence of biopolymer treatment on swelling, strength and salinity characteristics was also assessed to obtain the most effective biopolymer treatment for Bhavnagar salt rich expansive soil. Potential methodology of application of the treatment to the soil in field also discussed in the present research.

Keywords: Saline black cotton soil, Suction, Biopolymer, Unsaturated, Filter paper test.

1 Introduction

Long term stability attributes of black cotton soils (expansive soils) depends upon the tendency of the soil to swell (increase in volume) and shrink (decrease in volume). Black cotton soil in partially saturated condition (S_r < 100%) experiences acute shrinkage and swelling on account of timely change in the water content (w) of soil mass due to climatic variations. Approximately 20% of continental crust in India comprises of shrinkage-swelling (expansive) soils. Expansive soils are encountered in numerous parts of Gujarat, Andhra Pradesh, Uttar Pradesh, Karnataka, western Madhya Pradesh and Maharashtra [Verma and Maru, 2013]. The vital problem related to expansive soils was noticed to be related to induced volumetric deformation, which causes terrible upheaving and enormous cracks in pavements &embankments; damage to the floor slabs; concrete and steel plinths failure; basement buckling due to increased lateral stresses; damages to retaining walls; deterioration of water pipelines etc.

Several different methods have been adopted for stabilization of expansive soils which include physical, chemical and polymers methods. Physical methods comprise of compaction methods and drainage provision, however, this method is found to be less popular [Naveena and Reddy, 2015] owing to meagre agreement between effectiveness of method and cost. Stability treatment by physical method was found to decrease over time and would provide impermanent stabilization. Chemical soil stabilization using lime, fly ash and cement are harmful, add toxicity and are not degradable [Swain, 2015, Naveena and Reddy, 2015]. Both, physical and chemical treatments were reported to unsustainable [Swain, 2015; Naveena and Reddy, 2015]. Biopolymer treatment has gained popularity as sustainable method for expansive soil stabilization. Biopolymer stabilization treatment was reported as efficient sustainable, and durable alternative to conventional techniques [Latifi et al., 2017; Naveena and Reddy, 2015; Swain, 2015; Chang et al., 2016; Hataf et al., 2018; Joga et al., 2019]

Geological spread of such soils are found in the active zone/ vadose zone of hyper arid, arid and semi-arid regions of the world [Pandya and Sachan, 2018] and hence, are under unsaturated condition. Formation of expansive soils is attributed to the leaching and chemical weathering of basaltic rocks due to lower degree of precipitation, high evaporation owing to high temperature and fluctuating wetting & drying cycles. Detrimental volumetric changes caused by the swelling-shrinkage phenomena of expansive soils would be governed by soil-water chemistry (Suction); salinity of soil; clay mineralogy & plasticity, extent of ground water table, extent of water content variation over space and time, vegetation cover, permeability, temperature, soil profile etc. [Nelson and Miller, 1997; Houston et al. 2011]. The degree of expansiveness of the unsaturated soil was found to be crucially governed by amount of negative pore water pressure (suction) present in the unsaturated expansive soils [Pandya and Sachan, 2018]. Amount of suction governs the macro and micro soil fabric arrangement of the expansive soil. Matric suction and Osmotic suctions governs the crystalline and osmotic swelling in the expansive soils [Likos, 2004; Rao et.al., 2013]. Hence, it is imperative to evaluate the influence of biopolymer stabilization treatment on the suction characteristics of treated shrinkage-swelling soils. Available literature on stabilization of expansive soil remains concentrated on the strength and swelling characteristics of expansive soils. Influence of biopolymer treatment on the suction characteristics of expansive soils remains unexplored. In the present study, an attempt has been made to evaluate the influence of bio-polymer treatment on suction (Total, Matric and Osmotic), strength, swelling and salinity characteristics of salt enriched Bhavnagar black cotton soil

2 Material Properties and Sample Collection

The soil for the present study was collected from the village Madhya, Bhavnagar district, Gujarat, India. The site was located near the Salt production works (Latitude – 21° 51’ 6’’and Longitude - 72° 6’ 2’’). The topographical map showing the soil collection site is shown in Fig 1. Soil was collected at a depth of 0.5 m below the ground level. There were no construction works in and around the area and was purely dedicated for salt production works. Bhavnagar is located along the coast line of Gulf of Khambhat or Gulf of Cambay in the Arabian Sea. The geological origin of Bhavnagar soil was reported to have volcanic origin [Mehta and Sachan, 2017]. The volcanic outpourings and distribution of lava led to denudation which led to formation of a basaltic topography. Salinity in the soil has been developed due to gradual withdrawal of sea from the surrounding areas of Bhavnagar city near Gulf of Khambhat. The Gulf encompasses an area of high tides and is portrayed by the command of strong tidal currents.

The geotechnical properties and grain size distribution of Bhavnagar expansive soil are listed in Table 1. The soil has been classified as CH as per Indian Standard classification system [IS 2720-Part 4, 1985]. Bhavnagar expansive soil exhibited high electrical conductivity indicating the extreme salinity of the soil (Table 1).

Table 1. Geotechnical Properties of Bhavnagar soil

Test	Bhavnagar soil
Gravel (%)	0.01
Sand (%)	0.33
Silt (%)	49.53
Clay (%)	50.13
OMC (%)	21.42
MDD (g/cc)	1.66
Free swell index (FSI) (%)	110
Liquid limit (%)	66.87
Plastic limit (%)	62.5
Shrinkage limit (%)	9.33
Specific gravity (%)	2.64
Electrical conductivity (µS/cm)	10900
Organic content (%)	12.63

Fig. 1. Topographical map of Gujarat showing the Bhavnagar expansive soil collection site

2.1 Biopolymers

Biopolymers are natural polymers produced by living organisms. They are polymeric biomolecules derived from plant matter. Biopolymers contain monomeric units that form larger structures. Each monomeric unit is chemically bonded with each other. Properties such as renewability, sustainability, non-toxic, degradable, carbon neutral etc. emboldens to be used in stabilization and treatment of expansive soil [Latifi et al., 2017; Hataf et al., 2018; Naveena and Reddy, 2015; Swain, 2015].

2.1.1 Xanthan Gum

Xanthan gum is a microbial polysaccharide produced by the bacteria Xanthitalics Campestris by the process of fermenting glucose, sucrose, or any other carbohydrate sources. It is polysaccharide which has strong sorption characteristics and creates microstructural interactions with clay forming a viscous hydrocolloid when added to water [Naveena and Reddy, 2015].

This biopolymer is used widely in various applications such as in the cosmetic industry, food industry, agriculture, civil engineering, pharmaceutical and petrochemical industries and in other sectors as a thickening agent, stabilizer, or emulsifier and combined with other gums it can act as a gelling agent [Swain, 2015]. In the current study, the Xanthan gum procured from National Chemicals (Cost: 1265 per 100 gm) was employed.

2.1.2 Guar gum

In semi-arid regions guar has been used to replenish the soil. Guar gum or cluster bean is a polysaccharide composed mainly of the sugars galactose and mannose. Guar gums made from guar beans have thickening and stabilizing properties [Swain, 2015]. In the current study, the Guar gum procured from National Chemicals (Cost: Rs.250 per 100g) was used.

2.1.3 Chitosan

A polysaccharide obtained from Chitin. It is the second most abundant polysaccharide in the world. Chitosan has been used in medical applications such as antimicrobial and therapeutic biomaterials as it is biocompatible and non-toxic [Chang et al., 2016]. It has also been used as chelating agent as it possesses ability to bind with fats cholesterol, proteins and metal ions. Chitosan is obtained from waste of shrimp shells [Hataf et al., 2018]. In the current study, the Chitosan procured from National Chemicals (Cost: Rs.9840 per 100g) was used.

3 Experimental Program

3.1 Total, matric and osmotic suction

For evaluating suction characteristics of Bhavnagar expansive soil in-contact and non-contact filter paper test [ASTM D5298-10 2010] was employed. The filter paper method covers large range of suction (10 kPa to 100 MPa) and has been described as the most efficient, quick, accurate and reliable method for suction measurements [Chandler and Gutierrez, 1986; Bulut, 2001; Bulut and Leong, 2008; Sawangsuriya et al., 2008; Mabirizi and Bulut, 2009; Stenke et al., 2006; Shen et al., 2013; Pandya and Sachan, 2017].

For evaluating total suction (ψ) of expansive soil non-contact filter paper method was used and for evaluating matric suction (ψ_m) in-contact filter paper method was used. Osmotic suction (ψ_ϕ) is obtained by accessing difference in total suction and matric suction values. Whatman 42 filter paper was used during the experimental program. The oven dried soil was passed from 4.75 mm sieve. Suction evaluation of untreated soil was carried out of 1.58 g/cc (95% of MDD) and varying water contents (10%, 15%, 20% and 25%). For treated soil, amount of biopolymer by weight was calculated and was added to the soil. Biopolymer treated soil specimens were prepared at 1.58g/cc dry density and 10% water content. For biopolymer treatment, percentage by weight of Xanthan Gum and Guar Gum used were 0.5%, 1% & 1.5% and percentage by weight of Chitosan used was 0.12% & 0.16%. Percentage variation range was selected based on optimum percentage of biopolymer treatment report by several researchers [Latifi et al, 2017; Naveena and Reddy, 2015; Swain, 2015; Chang et.al., 2016; Hataf et al., 2018]. Specimen treated with Guar gum, Xanthan gum and Chitosan were kept under curing for 7 days, 7 days and 1 day respectively [Latifi et al., 2017; Joga, et al., 2019; Swain, 2015].

Moist tamping method [Pandya and Sachan, 2017] was chosen as the sample preparation technique for both untreated and non-treated soil. The sequential sample preparation procedure and filter paper test methodology adopted for the present study has been shown in Fig 2. After the completion of curing period two identical soil cakes were prepared. Whatman 42 filter paper of diameter 55mm was sandwiched between two Whatman filter of diameter 65mm and these three filter papers were placed between the prepared two soil cakes to measure the matric suction (In-contact filter paper method). The cakes were covered with insulating tape to prevent for any loss of moisture and then were kept in glass jar, which was also insulated using electrical tape. Whatman filter paper of diameter 55mm was suspended above the soil cakes to measure total suction (non-contact filter paper method). The jar was sealed and kept for equilibrium process for 7 days in biological incubator. After the 7-day equilibration process, weight of wet filter paper was measured and then dry weight of filter paper was measured after oven drying for 24 hours. Table 2 represents the obtained values of suction (Total, Matric and Osmotic) for different percentage of three biopolymers.

Fig. 2. Sequential sample preparation and filter paper test methodology.

Table 2. Suction values at different percentages of bio-polymer treated

	Biopolymer (%)	Ψ (kPa)	Ψ_m (kPa)	Ψ_ϕ (kPa)
Without treatment	0	2866.81	2483.59	383.22
Chitosan	0.12	2528.541	2353.47	175.071
	0.16	2483.59	2439.439	44.151
	0.20	2815.853	2765.795	50.058
Xanthan Gum	0.5	2353.512	2190.53	162.94
	1	2971.52	2620.89	350.63
Guar Gum	0.5	3888.92	3369.06	519.86
	1	2918.7	2866.81	51.89
	1.5	2716.62	2620.89	95.73

3.1.1 Need of curing

Curing would enable biopolymer to build bond with the soil particles and assimilate alterations in the structural alignment of soil fabric. Curing would induce ductility amongst soil particles leading to higher strength and resistance to collapse. From the literature the curing period was found to be different for different biopolymers. Guar gum and Xanthan gum required minimum of 7 days of curing, while Chitosan needed only 1 day [Latifi et al., 2017; Joga, et al., 2019; Swain, 2015]. In the present study, curing was done in an isolated place where the change in temperature was observed to be negligible.

3.2 Swell Pressure

Swell pressure test was conducted of untreated soil and bio-polymer treated soil at the obtained optimum percentage of each biopolymer. The test was performed using conventional oedometer set up in accordance to IS 2720 Part-XLI (1977). In this test, the as-compacted specimen prepared in the oedometer ring was placed in the consolidation set up and water was allowed to penetrate the soil specimen. Under seating load of 5 kPa, specimen was allowed to swell until the volume change became constant. Subsequently, the specimen was loaded sequentially from 10 kPa, 20 kPa, 50 kPa, 100 kPa, 200 kPa, 400 kPa and 800 kPa. The pressure increment, at which soil specimen reached its initial void ratio (e_0), was determined as swelling pressure of soil from e vs log σ_v'. The values acquired of swell pressure for untreated and treated Bhavnagar expansive soil are given in Table 3.

3.3 Electrical Conductivity

Qualification of the salinity in the soil was obtained by evaluating electrical conductivity of the Bhavnagar saline expansive soil. Electrical conductivity of untreated and bio-polymer treated soil was evaluated at optimum percentages by conductivity meter as per IS 14767 (2000). The values obtained for electrical conductivity of soil are shown in Table 3. In this test, 20g of oven dried soil was added to 40ml distilled water in a closed beaker and was placed horizontally in shaking machine for 30 minutes to obtain a homogeneous solution. Electrode of conductivity meter was placed in the soil water solution to measure the electrical conductivity until the reading reached a constant value. The values obtained for electrical conductivity of soil are shown in Table 3.

3.4 Unconfined compressive strength

Unconfined compressive strength was conducted on untreated and biopolymer treated soil at optimum percentages of each biopolymer as per IS 2720 Part-10 (2011). The unconfined compression strength values obtained for the expansive soil are presented in Table 3.

Table 3. Values for swell pressure, electrical conductivity and unconfined compressive strength at optimum percentages of bio-polymer treated soil.

	Optimum polymer percentage obtained (%)	Swell Pressure (kPa)	Electrical Conductivity (µs/cm)	Unconfined compressive strength (kPa)
Without treatment	0	53	10900	185
Chitosan	0.12	37	819	148
Xanthan gum	0.5	40	524	218
Guar gum	1.5	58	1605	279

4 Results and Discussions

4.1 Suction characteristics of Bhavnagar Expansive soil

Suction or water potential designates the propensity of water to transport from one place to other owing to surface tension, capillary action and osmosis phenomena. Suction is the measurable indication of the potential energy amongst pore water within the soil skeleton and the free water (hydraulic datum). It changes with the alteration in solute concentration termed as osmotic potential (osmotic suction) and due to alteration in cohesive/adhesive forces imbibing the water molecules to the solid surfaces designated as matric potential (matric suction).

The total suction, matric suction and osmotic suction of the untreated expansive soil at different gravimetric water contents (10%, 15%, 20% and 25%) are presented in Fig 3. It was observed that value of total suction, matric suction and osmotic suction reduced with increase in water content and degree of saturation. As depicted from Fig. 3, the total suction, matric suction and osmotic suction of the Bhavnagar saline expansive soil was found to be decreasing with the increase in water content. Increment in the as-compacted water content / degree of saturation would lead to enhanced bulk water proportion within the soil particles of unsaturated expansive soil [Pandya and Sachan, 2017]. Increase in the bulk water proportion would lead to progressive dilution of the solute concentration and gradual dissolution of the air-water interface causing reduction in osmotic potential and matric potential of the soil respectively. Hence, overall the total suction of the soil would reduce with increase in the as-compacted water content.

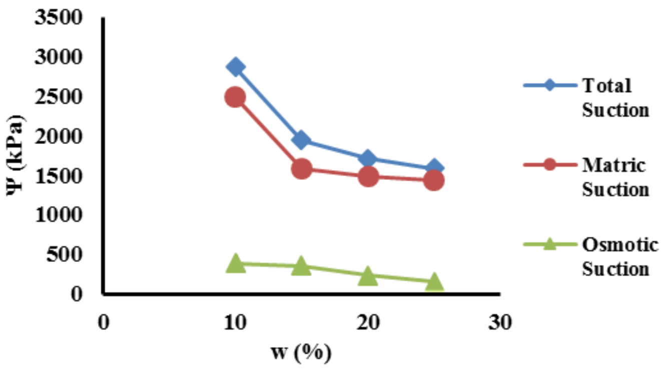


Fig. 3. Variation of Total suction, Matric suction and Osmotic suction at different water content of untreated Bhavnagar expansive soil**.**

4.2 Influence of biopolymer treatment on Suction, Swelling and Strength characteristics of Saline Bhavnagar Expansive Soil

4.2.1 Treatment by addition of Chitosan

Biopolymer treatment by Chitosan was carried out by adding varying percentage of Chitosan by weight to the Bhavnagar expansive soil. The percentage variation of Chitosan ranged from 0.12, 0.14 and 0.16%. The Total suction, Matric suction and Osmotic suction characteristics at different percentage of Chitosan has been presented in Table 2. It was observed that the optimum percentage of Chitosan was obtained to be 0.12%. As compared to untreated soil, reduction in the total suction, matric suction and osmotic suction at optimum percentage of Chitosan biopolymer treatment were obtained to be 338 kPa, 130kPa and 208 kPa respectively (Table 4). Chitosan treatment would lead to formation of a sol-gel around soil particles [Hataf et al., 2018]. It results in the development of an inorganic colloidal suspension (sol) and gelation of the sol in a continuous liquid phase (gel) to form a three-dimensional network structure. This would cause generation of thick gel around clay particles. The formation of thick sol-gel could lead to development of enhanced true cohesion between the soil particles. As a result, soil particles would be held together by enhanced attraction which would lead to restricted development of air-water interface at lower water content in unsaturated soil. Considering the Toroidal approximation [Lui and Likos, 2004] the matric suction of soil would depend upon the surface tension, filling angle (θ) and spherical radii (r_1 and r_2) of the air-water interface. The creation of sol-gel could led to increase in the filling angle (θ), which would in turn lead to increase in the spherical radii (r_1 and r_2). This would lead to the restricted development of the air-water interface and hence, would cause reduction in the matric suction of the soil. Osmotic suction was observed to reduce drastically by 208.15 kPa as compared to untreated soil (Table 2). It has been reported that Chitosan enhances the plant growth by reducing osmotic potential in saline conditions [Sen and Mandal, 2016]. It was found to be analogous to the electrical conductivity results of the Chitosan treated Bhavnagar expansive soil (Table 3). Creation of sol-gel could restrict the osmosis process within the soil skeleton due to solidification of the salt solutes, which could have led to decrease the electrical conductivity leading to significant decrease in the osmotic suction of the soil.

Swelling pressure of Bhavnagar expansive soil was evaluated for untreated and Chitosan treated expansive soil at obtained optimum Chitosan percentage (Table 3). It was observed that the addition of Chitosan led to decrease in the swelling pressure of treated soil. Reduction in the total suction due to chitosan treatment led to decreased capillary force between the soil particles [Pandya and Sachan, 2018] and hence, the unbalanced negative charge would reduce, causing reduction in the affinity for water to create equilibrium. This, might cause reduction in the swelling pressure of soil. However, Chitosan treatment led to decrease in the unconfined compressive strength of the soil.

Table 4. Comparison of **s**uction values at optimum percentages for different bio-polymer treatment of Bhavnagar saline Expansive soil.

	Optimumpolymer percentage obtained (%)	Ψ (kPa)	Ψ_m (kPa)	Ψ_ϕ (kPa)
Without treatment	0	2866.81	2483.59	383.22
Chitosan	0.12	2528.541	2353.47	175.07
Xanthan gum	0.5	2353.47	2190.53	162.94
Guar gum	1.5	2716.2	2620.89	95.72

4.2.2 Treatment by addition of Xanthan Gum

Xanthan Gum treatment by was carried out by adding varying percentage of Xanthan Gum by weight to the Bhavnagar black cotton soil. The percentage deviation of Xanthan Gum was varied from 0.5% to 1 %. The Total suction, Matric suction and Osmotic suction characteristics at different percentage of Xanthan Gum has been presented in Table 2. It was observed that the optimum percentage of Xanthan Gum was obtained to be 0.5%. As compared to untreated soil, reduction in the total suction, matric suction and osmotic suction at optimum percentage of Xanthan Gum biopolymer treatment were obtained to be 513kPa, 293kPa and 220kPa respectively (Table 4).

Inclusion of Xanthan gum in the black cotton soil could lead to sorptive and microstructural changes within the soil skeleton. Xanthan gum monomers would form hydrogen or electrostatic bonding with clay particles. Xanthan monomers tends to link with clayey particles owing to hydrogen bonding and cation bridging between the carboxyl group (–COOH) and the hydroxyl (–OH) groups of xanthan gum and negatively charged soil surfaces [Latifi et. al, 2017]. As a result, a cementitious product forms between the Xanthan gum and clay particles which causes flocculation of particles which induces reduction in the surface area [Latifi et. al, 2017]. According to Cho and Santamarina (2001), matric suction of soil was found to be function of surface area of soil. Increase in the surface area due to filled up of the pore spaces of the black cotton soil owing to hydrogen bonding and cation bridging caused significant reduction in the matric suction of the unsaturated expansive soil (Table 4). Addition of Xanthan gum would increase the viscosity of the pore fluid as a result, the solute concentration might imbibe in the primarily viscous and conclusively hard cementitious bond. This would harp the osmosis action within the pore spaces, resulting into extensive decline of the osmotic suction values of Bhavnagar saline black cotton soil. Similar response of the Xanthan gum treatment was observed from the electrical conductivity test on black cotton soil treated at optimum percentage of Xanthan gum as shown in the Table 3.

From the present study it was observed that swelling pressure of Xanthan gum treated soil was observed to decrease with Xanthan gum treatment as compared to untreated black cotton soil as presented in Table 3. Development of hydrogen bond between Xanthan gum monomers and soil particles would decrease the micro pore spacing and satisfy the unbalanced negative charge on the individual clay particle. Hence, affinity for water to create neutral equilibrium and interlayer spacing between the structural units of swelling mineral would also reduce, which would ultimately result in the lower swelling pressure of black cotton soil.

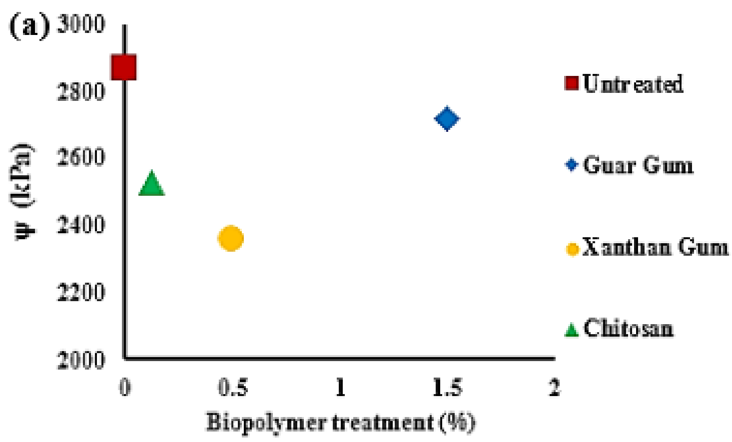
Significant improvement in the unconfined compressive strength of the Xanthan gum treated black cotton soil was observed from the present study (Table 3). Growth of Xanthan gum bridges within soil fabric [Chang et. al, 2015] would lead to reduction in micro pore spaces of the soil. This would induce enhanced contact area and interlocking amongst the soil particles, which would cause increase in the strength of the soil mass macroscopically.

4.2.3 Treatment by addition of Guar Gum

Influence of Guar Gum treatment by was evaluated by adding varying percentage of Guar Gum by weight to the Bhavnagar black cotton soil. The percentage variation of Guar Gum was varied from 0.5, 1 and 1.5%. The Total suction, Matric suction and Osmotic suction characteristics at different percentage of Guar Gum has been presented in Table 2. From the present study it was observed that sample preparation using Guar gum was found to be very difficult due to the tendency of Guar gum to form lumps when mixed with soil. Decrease in the suction value was observed with increase in the percentage of Guar Gum. It was observed that the optimum percentage of Guar Gum was obtained to be 1.5% (Table 4). With addition of 1.5% of Guar gum, total suction and osmotic suction was reduced by 150kPa and 287 kPa respectively but reduction in matric suction values was not observed. Guar gum tends to possess high specific surface area and forms hydrogel with the soil particles. It has tendency to hydrate and introduces an additional adhesive force due to creation of strong hydrogen bonds which tends to hold soil particles together reducing the micro pore spaces between the particles [Sujatha and Saisree, 2019]. Formed hydrogel has acute affinity to absorb water. Matric suction would originate in an unsaturated soil due to adhesive -cohesive force between the soil particles. Guar gum treatment intensified the adhesive force within the soil particles and hydrogel. Specific surface area of the soil would also increase due to addition of Guar gum. The matric suction of unsaturated soil depends upon the specific surface area of the soil particles [Cho and Santamarina, 2001]. Hence, due to intensified adhesive force and increased specific surface area of the soil, the matric suction component of the Bhavnagar black cotton soil remained unaffected by Guar gum treatment. However, generation of hydrogel could restrict the osmosis process within the soil skeleton due to coagulation of the salt solutes owing to development of hydro-gel, which could have led to decrease the osmotic suction leading to considerable decrease in the electrical conductivity of the Bhavnagar saline black cotton soil.

The swelling pressure of Guar gum treated soil was observed to increase as compared to untreated black cotton soil as presented in Table 3. Development of hydrogel introduced enhanced affinity for water as compared to untreated state of unsaturated expansive soil. Enhanced adhesive force between particles due to development of enhanced forces of attraction, which would lead to reduced interlayer spacing between structural units. This would lead to generation of severe affinity to imbibe water amongst clay particles to reach equilibrium and neutralization and hence leading to higher swelling pressures in treated Bhavnagar expansive soil.

Significant improvement in the unconfined compressive strength of the Guar gum treated black cotton soil was observed from the present study (Table 3). Growth of viscous hydrogel develops additional cohesive force due to formation of hydrogen bond between soil particles [Sujatha and Saisree, 2019]. Improved cohesive attraction contributes to increase in the unconfined compressive strength of the Guar gum treated Bhavnagar expansive soil.



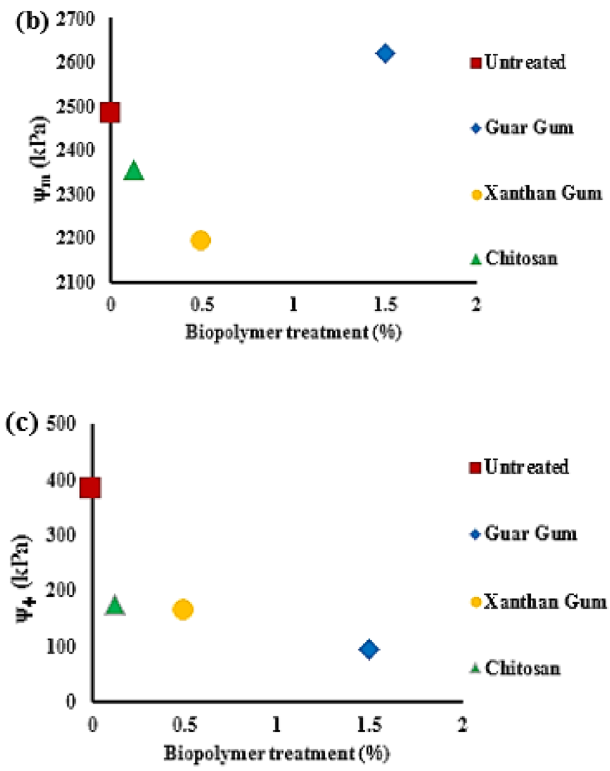


Fig. 4. Variation of suction with optimum percentage of biopolymer treatment. (a) Total suction, (b) Matric suction, (c) Osmotic suction.

4.3 Comparison of biopolymer treatment on Bhavnagar saline expansive soil

In the current study, influence of biopolymer treatment on suction, unconfined compressive strength, swelling and electrical conductivity characteristics of Bhavnagar saline expansive soil was evaluated. Chitosan, Xanthan gum and Guar gum were added to soil by weight and cured as a part of biopolymer treatment. Comparison of total suction, matric suction and osmotic suction of biopolymer treated soil by Chitosan, Xanthan gum and Guar gum has been presented in Fig 4 (a), (b) and (c) respectively. It could be identified that, soil treated by Xanthan gum showed best treatment response by exhibiting the lowest total and matric suction values as compared to Chitosan and Guar gum. However, Guar gum exhibited lower osmotic suction values as compared to Chitosan and Xanthan gum.

Comparison of the swelling pressure, unconfined compressive strength and electrical conductivity of the biopolymer treated expansive soil has been presented in Fig 5(a), 5(b) and 5(c) respectively. It could be identified from Fig 5(a) that specimen treated with Chitosan exhibited lowest swelling pressure, however, not much difference (7 kPa) in the swell pressure values were obtained for specimen treated with Xanthan gum. Unconfined compression test values were found to be highest for the specimen treated with Guar Gum, however substantial improvement in the unconfined compression strength was observed for specimen treated with Xanthan gum (Fig 5(b)). The difference between unconfined compression strength value of specimen treated with Guar gum and Xanthan gum was found to be 61 kPa.

Electrical conductivity test results (Fig 5(c)) revealed that the specimen treated by Xanthan Gum exhibited least electrical conductivity as compared to specimen treated by Chitosan and Guar gum. Water present within the hydrogel formed by Guar gum treatment would al allow free diffusion of some solute molecules, as a result electrical conductivity of Guar gum was found to be considerably higher as compared to Chitosan and Xanthan gum treated specimens

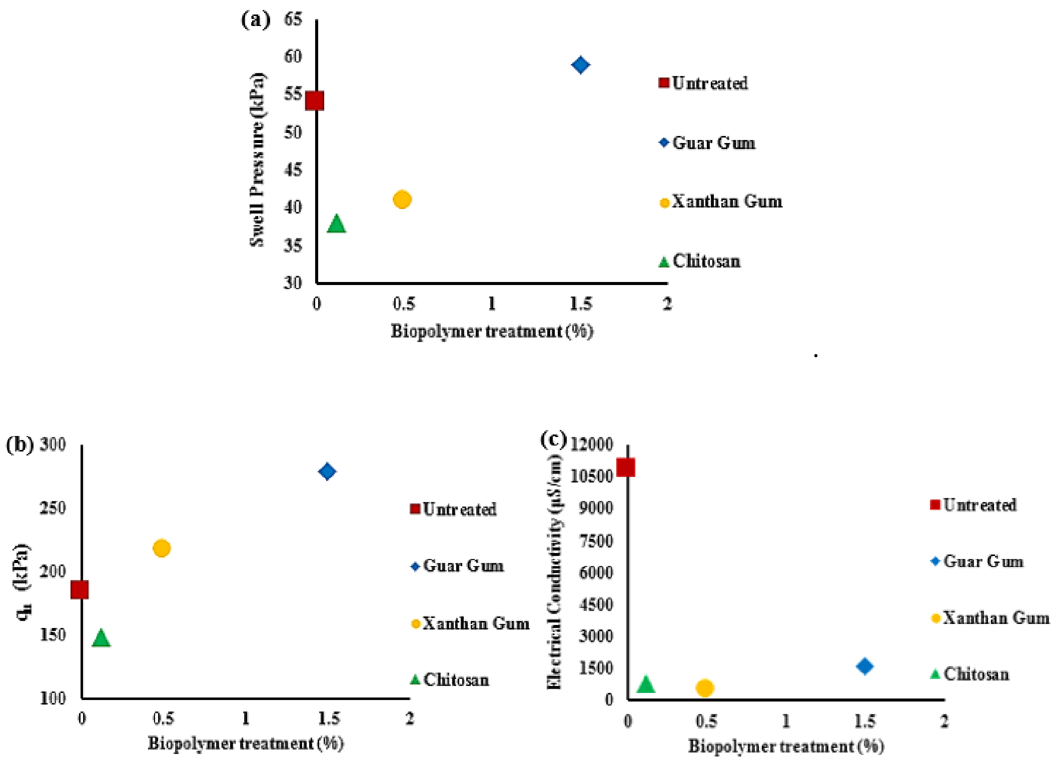


Fig. 5. Variation of swelling, strength and salinity characteristics of untreated and different biopolymer treated Bhavnagar expansive soil. (a) Swell pressure, (b) Unconfined compression strength (q_u), (c) Electrical conductivity

5 Methodology of Application of Biopolymer as Soil Stabilizer In Field

The biopolymer inclusions in the field can be made exactly in the similar manner as conventional lime treatment (McDowell, 1959). For the biopolymer treatment same methodology could be followed with some modifications distinctive to the biopolymer treatment employed. The available expansive soil which has to be stabilized would be pulverized by suitable equipment. In-place mixing should be performed with required amount of biopolymer upto appropriate depth. Effective pulverization and mixing should be ensured, so that thorough amalgamation of biopolymer and expansive soil would be achieved. Amount of water equivalent to required water content should be sprayed biopolymer mixed soil mass and then should be left for characteristic curing process depending upon the biopolymer employed for treatment. Proper curing should be assured to enable development of proper bond between expansive soil matrix and biopolymers. Soil should be sprinkled with water from time to time or covered with subsequent impermeable material to ensure negligible evaporation of water during curing process. Light compaction could be applied if required, during curing period to keep the soil matrix and biopolymers bonded together. After the completion of curing duration final thorough mixing should be executed. Field tests should be conducted to check water content and maximum dry density of compacted soil.

6 Conclusions

Biopolymer treatment significantly reduces the Total, Matric and osmotic suction of Bhavnagar saline expansive soil. From, the present studies following conclusions are made:

1. The optimum percentages for reducing suction (Total, Matric and Osmotic) of xanthan gum and chitosan are 0.5% and 0.12% respectively.
2. Biopolymer treatment by Xanthan gum and Chitosan led to substantial reduction in the suction (total, matric and osmotic) of Bhavnagar saline expansive soil.
3. Guar gum treatment was found to be ineffective in reducing matric suction and swell pressure of expansive soil. However, osmotic suction and electrical conductivity were found to decrease by Guar gum treatment.
4. Xanthan gum and Chitosan biopolymer treatment led to reduction in the electrical conductivity and swelling characteristics of the expansive soil.
5. Significant improvement in the unconfined compressive strength of biopolymer treated expansive soil was observed for Xanthan gum and Guar gum treatment. However, unconfined compressive strength of specimen treated with Chitosan reduced due to induced brittleness owing to sol-gel development within soil matrix.
6. Xanthan gum biopolymer treatment was found to be most effective in treating Bhavnagar expansive soil as it improved salinity, suction, and swelling and strength characteristics of the soil. Easy availability of Xanthan gum and

efficacious treatment makes it the best biopolymer stabilization technique for Bhavnagar saline expansive soil.

References

1. ASTM D5298-10. Standard test method for measurement of soil potential (suction) using filter paper, West Conshohocken, Pennsylvania, USA (2013).
2. Bulut, R., and Leong, E. C.: Indirect measurement of suction. Geotechnical and Geological Engineering 26(6), 633-644 (2008).
3. Bulut, R., Lytton, R. L., & Wray, W. K.: Soil suction measurements by filter paper. In Expansive clay soils and vegetative influence on shallow foundations, ASCE, 115 (1), 243-261 (2001).
4. Chandler, R. J., and Gutierrez, C. I.: The filter-paper method of suction measurement. Geotechnique 36(2), 265-268 (1986).
5. Chang, I., Im, J., & Cho, G. C.: Introduction of microbial biopolymers in soil treatment for future environmentally-friendly and sustainable geotechnical engineering. Sustainability 8(3), 251-274 (2016).
6. Chang, I., Im, J., Prasidhi, A. K., & Cho, G. C.: Effects of Xanthan gum biopolymer on soil strengthening. Construction and Building Materials 74, 65-72 (2015).
7. Cho, G. C., and Santamarina, J. C.: Unsaturated particulate materials-particle-level studies. Journal of geotechnical and geoenvironmental engineering 127(1), 84-96 (2001).
8. Hataf, N., Ghadir, P., & Ranjbar, N.: Investigation of soil stabilization using chitosan biopolymer. Journal of Cleaner Production 170(1), 1493-1500 (2018).
9. Houston, S. L., Dye, H. B., Zapata, C. E., Walsh, K. D., and Houston, W. N.: Study of expansive soils and residential foundations on expansive soils in Arizona. Journal of performance of constructed facilities 25 (1), 31-44 (2011).
10. IS 14767: Methods of test for soils- Determination of the Specific Electrical Conductivity of Soils, Bureau of Indian Standards, New Delhi (2000).
11. IS 2720-Part 10: Methods of test for soils- Determination of unconfined compressive strength, Bureau of Indian Standards, New Delhi (2011).
12. IS 2720-Part 4: Methods of test for soils: Part 4 Grain Size Analysis, Bureau of Indian Standards, New Delhi (1985).
13. IS 2720-Part XLI: Measurement of Swelling Pressure of Soils, Bureau of Indian Standards, New Delhi (1977).
14. Joga, J. R., & Varaprasad, B. J. S.: Sustainable improvement of expansive clays using xanthan gum as a biopolymer. Civil Engineering Journal 5(9), 1893-1903 (2019).
15. Latifi, N., Horpibulsuk, S., Meehan, C. L., Abd Majid, M. Z., Tahir, M. M., & Mohamad, E. T.: Improvement of problematic soils with biopolymer—an environmentally friendly soil stabilizer. Journal of Materials in Civil Engineering 29(2), 04016204 (1) - 04016204 (11) (2017).
16. Likos, W. J., & Lu, N.: Hysteresis of capillary stress in unsaturated granular soil. Journal of Engineering mechanics 130(6), 646-655 (2004).
17. Mabirizi, D. and Bulut, R.: A comparison of total suction measurements with thermocouple psychrometer, filter paper technique, and chilled-mirror device, GeoHunan International Conference: Challenges and Recent Advances in Pavement Technologies and Transportation Geotechnics. Geotechnical Special Publication, ASCE, 189 (1), 1–6 (2009).

18. McDowell, C.: Stabilization of soils with lime, lime-fly ash and other lime reactive materials. Highway Research Board Bulletin 231(1), 60-66 (1959).
19. Mehta, B., & Sachan, A.: Effect of mineralogical properties of expansive soil on its mechanical behavior. Geotechnical and Geological Engineering 35(6), 2923-2934 (2017).
20. Naveena, S., & Reddy, G. S.: Strength Characteristics of Expansive Soils Using Eco-Friendly Xanthan Gum. International Journal of Science and Research 6(6), 2439-2442 (2015).
21. Nelson, J., and Miller, D. J. Expansive soils: Problems and practice in foundation and pavement engineering, 1st edn. John Wiley and Sons, Canada, (1997).
22. Pandya, S. & Sachan, A.: Matric suction, swelling and collapsible characteristics of unsaturated expansive soils. Journal of Geotechnical and Transportation Engineering 4(1), 1-9 (2018).
23. Pandya, S., & Sachan, A.: Effect of matric suction and initial static loading on dynamic behaviour of unsaturated cohesive soil. International Journal of Geotechnical Engineering 12(5), 438-448 (2017).
24. Rao, S. M., Thyagaraj, T., & Rao, P. R.: Crystalline and osmotic swelling of an expansive clay inundated with sodium chloride solutions. Geotechnical and Geological Engineering, 31(4), 1399-1404 (2013).
25. Sawangsuriya, A., Edil, T. B., and Bosscher, P. J.: Modulus-suction-moisture relationship for compacted soils. Canadian Geotechnical Journal 45(7), 973-983 (2008).
26. Sen, S. K., & Mandal, P.: Solid matrix priming with chitosan enhances seed germination and seedling invigoration in mung bean under salinity stress. Journal of Central European Agriculture 17(3), 749-762 (2016).
27. Shen, M. F., Tan, X. H., Xin, Z. Y., Xie, Y., & Xu, Q.: Laboratory research of soil water characteristic curve by osmotic method and filter paper method. Electronic Journal of Geotechnical Engineering, 18 (1), 5421-5434 (2013).
28. Stenke, F., Toll, D. G. & Gallipoli, D.: Comparison of water retention curves for clayey soils using different measurement techniques, Unsaturated soils, Geotechnical Special Publication, ASCE, 147 (1), 1451–1461 (2006).
29. Sujatha, E. R., & Saisree, S.: Geotechnical behaviour of guar gum-treated soil. Soils and Foundations, 59(6), 2155-2166 (2019).
30. Swain, K.: Stabilization of soil using geopolymer and biopolymer -Doctoral dissertation. National Institute Of Technology, Rourkela (2015).
31. Verma, S. K., and Maru, S.: Behaviourial study of expansive soils and its effect on structures–A review. International Journal of Innovations in Engineering and Technology 2(2), 228-238 (2013).

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