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Geotechnical Characteristics of Fiber Cemented Collapsible Soil

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Abstract: This research is focusing on the investigation of the capability of using materials such as biopolymer (it is considered to be non harmful material to the environment) to improve the strength of the mechanical characterizations of the problematic soil including the collapsible ones. There are two different types of biopolymers which is used in this study (xanthan gum and guar gum) because of the most stable behaviour according to sever situations and their obtainable and economical cost. The program which is used in this paper is stand on three main soil characterizations, which are; densification properties, collapsible prospect and shear factors, those previous soil characterizations are indispensable in any soil enhancement project. Many of biopolymer condensations are included in this research and the investigational program work is proceeded at two treatment phases (first stage subsequent to blending the soil by the biopolymer, second stage after seven days treatment time). Shear factors are measured for the cured samples in both drenched and sundrenched conditions. On the other hand the collapsible prospective test is performed under several of mixing conjuncture (before and after wet mix). A numerical module is established to prophesy the behavior of the cured problematic soil with and without inundation. The analysis of the output point to that the capability of the both xanthan and guar gum are available as one of successful soil enhancement objects for the collapsible soil improvement. The collapsible prospective is decreased significantly starting at 9% to 1% the mixture of soil with 2% biopolymer concentration in the saturated phase. In the case of oneweek treatment period, the cohesion stress climbed beginning of 8.5 to 105 kPa by raising the xanthan gum condensation from 0.00 percent to two percent, reaching the needed total enhancement in the soil shear strength. Also, it proved that the superiority of guar gum over xanthan gum in improving the shear strength is about 30% more than xanthan gum at the same conditions and reduces the collapsible potential by about 20% more than xanthan gum at the same conditions.
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Keywords: Collapsing problematic soil; xanthan gum; guar gum; collapsing prospective; shear strength; compaction and arithmetical model.

1. Introduction

Collapsing (weak) soils are any unsuitable soils directly used for construction or their behavior can change with the change in environmental conditions. Collapsible soil is a metastable soil, one of wide spread problematic soils all over the world in arid and semi-arid areas, which can be known by its unexpected quick volumetric failure when it exposed to moisture. The collapsible mechanism of such soils is depending on variety of parameters for example; density, void ratio, soil formation and water content [1], [2]. Most of the collapsible soils are originally came from wind deposited silt or sand. Loess are considered to be wind deposited collapsible soil which cover 15-20% of European continent, large parts of China and United States [3]. The reason behind the collapsible soil cohesion is the existing of the clay particles which increase the bond between the soil particles which gives a stiff and firm appearance to the soil in its waterless condition. a few other solvable contents might be the reason for making ostensibly cohesion among the soil particles for instance; gypsum and calcium chloride. Collapsing soil is steady in its dry case which has higher ostensibly shear stress, but at an inundation situation, the water breaks down the bond between the particles give rise to large volumetric reduction [4], [5].

Variety of procedures area unit out there in several references to boost the collapsible soil behavior, whereas the choice of the acceptable technique is sometimes more difficult in respect with varied parameters such as; collapsibility degree, financial aspects and construction characteristics. Wet compaction are often efficient to enhance the shallow stratums of collapsible soil that may be appropriate for lightweight structures, whereas inoculation will effectively be good for the higher enhancement of significant or subversive structures. Chemical steadiness is wide victimization to cure Collapsing soil by victimization many helpful materials for instance;

cement, sulfur, acrylate, and glass. Deep foundations like piles are often used in collapsible soil by transferring the structures load to constant stratums underneath the collapsible one. Nevertheless, the induced negative friction ought to be believed in that condition[6]–[11].

In spite of the good achievement of chemical stability materials in up improving the performance of collapsible soil, it know how to not be thought of ecological green materials, because it will be toxic, modify the PH scale of soil, pollute ground water and infect the soil. Moreover, cement production are accountable for five-hitter of world CO_2 emanations.

Wherever manufacturing of one ton cement is amid emotional one ton of CO_2[12]. Several environmental factors – like the large quantity of energy consumed for production, gross water used, the contribution in international temperature change and dioxide emissions – created it essential to looking up for brand new environmental friendly material which might cover these aspects and be sustainable in addition. Biopolymeris a sustainable carbon neutral and is often classed as a renewable material as a reason of it is made from agricultural non-food crops which might be out there indefinitely. Hence, the usage of biopolymer in soil engineering could produce a sustainable industry[13].

Despite there are several of potential uses of biopolymers in geotechnical engineering, nowadays, the shows potential applications are only focused on bio-clogging. Bio-clogging seeks to decrease the hydraulic connectivity of soil and porous rocks, that might be useful in the following (a) decrease the erosion of drain channel, (b) shape grout barrier to decrease the transfer of intense metals and natural contaminants and (c) stop the piping of earth dams [14]. Other applications are studied by the United States Authority of Engineering in the respect with the use of biopolymers to enhance the incline steadiness on bermranges and decrease the failure of sediment in ground water runoff [15]. Lots of researches have investigated the capability of increasing the shear strength of soil by start using bio-polymer. Other types of biopolymers (such as xanthan gum, guar gum, customized starches, agar and glucan) recently used to enhance the performance of normal soil (sand, silt and clay)[16]–[22]. Biopolymer illustrate a spectacular achievement in amelioration the soil strength, although the enhancement percentage varies in line with biopolymer type, soil types and formation, biopolymer amount and curing conditions. plummeting the soil permeability by biopolymer is studied formerly, when biopolymer showed another success[20], [23], [24]. However the success of biopolymer in improving the properties of typical soils, the research in using biopolymer to cure the weak soil is almost nonexistent. permanence of biopolymer and its financial viability as soil enhancement material are investigated before in detail in previous paper [20]. despite of the stability of xanthan and guar gum which are documented in the writing in several of brutal circumstances and after treatment period equal to 25 months [16], more researches have to be done by using some suitable biopolymer such as lignin sporopollenin which has higher durability. The molder of biopolymer after many periods and with the contact to hydrated and dehydrated sequences also should be studied as well.

The present research seeks to realize and valuation the behavior of two types of biopolymers on the properties of the problematic soil. Varieties of condensation were used in the study with both with and without water mixing. Compaction properties, shear factors and the weak soil are the focused factors in this study. Also, a numerical model is done to evaluate the settlement vs. load curves for the cured soil with many biopolymer concentrations with and without inundation.

2. Materials and experimental procedures

2.1. Soils characterizations

For a better understand the behaviour of biopolymer on the mechanical soil properties, a normal problematic soil is obtained from New Borg-Alarab City, Egypt. The values of the soil physical indices are shown in Table 1, whereas the grain size curve is presented in Figure 1.

Table 1. Physical properties of the collapsible soil

Properties	
LL (%)	34.60
PL (%)	19.20
PI (%)	15.40
G_s	2.64
Maximum dry density, γ_{max} (kN/m^3)	19.15
Optimum water content, *o.w.c.* (%)	12.40

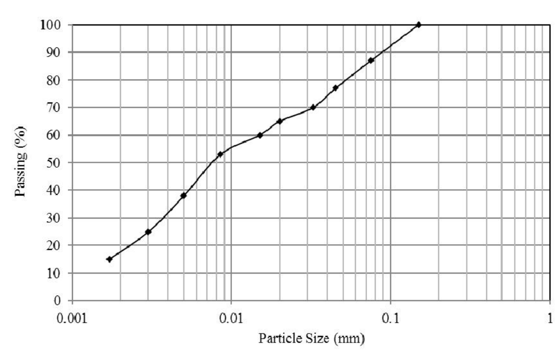

Fig. 1. Particle size distribution curves for the used soils

2.2. Biopolymers

Both different kinds of biopolymers; xanthan gum and guar gum are used in this study. These biopolymers were chosen because of their availability with reasonable prices compared to other biopolymers, moreover the used two biopolymers have unique functional properties. These properties include excellent cold water dissolving, *pH* stability, storage stability, ionic salt compatibility and pseudo plastic flow characteristics[20].

2.3. Samples preparation

To equip the cured soil sample, the naturalistic collapsible soil is shredded by hands, dried by air source for seven days and after that filtered by U.S. sieve girth #50. The water content in the soil is almost three percent after getting dried by air and ahead of mixture the soil with the biopolymer. Both ways are used for mixing up the soil and biopolymer; with and without water mixing. The moisture mixing is the major technique in the research and is for equipping the specimen for all required experiments. For this technique, the biopolymer sol is arranged already by a particular condensation then it will be blended by the air-dried soil sample to get the standard moisture ratio of 8%±0.1 in soil sample. The sol condensation is determined as a proportion between the mass of the used biopolymer powder and the total mass of the sol in rate. The crushed biopolymer is placed in the water slowly to eschew cluttering, after that the sol is mixed until a matching explanation is gained. Biopolymer condensation of different percentage in range of 0.25, to 4% are investigated in this search.

It is considered to be hard to get a confirmed density for all the samples with different concentrations and with variety of types of biopolymer as the difference in the sol viscosities effect be on consedreation on the soil densities in addition to, mounting the condensation direct to a decrease in the density, that is going to be exegsis in the compaction output afterward. Consequently, every one of samples are equipped at 75% of its utmost dried out density in respect with the compaction specification as the naturalistic density is almost around 75% of the utmost dried out density.

On the other hand the dried out mixing way for equipping specimens which are included in the collapsible potential experiment, to aid in studying the influence of the mixture technique on the collapsible performance. In this manner, the weight of the required biopolymer for a specific condensation is figured as same as the wet mixing technique and mixed with the air-dried sample until the needed homogeneity. The mix is equipping the needed oedometer sample, where the moisture increasing in the samples through the experiment. every single one of the samples are stayed in air following being poured in the drier at thirty degree Celsius pending tested, to make sure the similar treatment condition for all samples.

2.4. experiment process

The adjusted Proctor experiment is carried out under the specification of the ASTM D1557-12 standard. The experiment is important to obtain the max dry density for the soil under investigation and the optimal matching water ration with two different kinds of biopolymer at variety condensation.

Group of direct shear tests are performed with 6 x 6 Cm shear box with and without curing the soil biopolymer by the moisture mixing method. The test is held in respect with the ASTM D3080-04 standard.

An oedometer single test is accomplished according to the ASTM D 5333 to evaluate the collapsible potential. The vertical stress is gradually raised till a vertical stress equal to 200 kPa, while the specimens is mixed with water for 24 hours. The collapsible soil potential is equal to the dissimilarity in the vertical strain (%) at a confining stress of 200 kPa with and without the inundation consistent with the required standards.

3. Outputs

3.1. Compaction Characterization

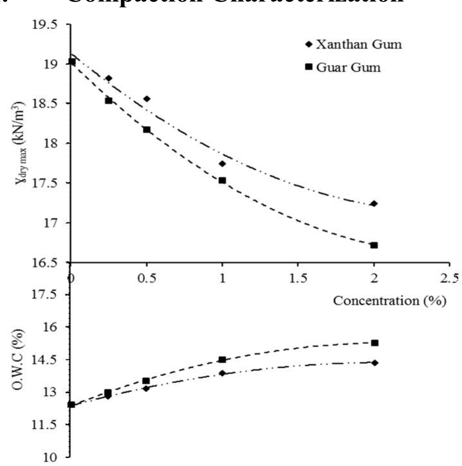

Fig. 2. Compaction Characterizations for soil biopolymer mixtures

Compaction is an essential soil improving method which mainly used in increasing the upper ground soil stratums characterization, when the soil is compressed to a specific density subsequent to mixing with a stabilization material. The required density subsequent to the compaction process would directly effect on the mechanical properties of the soil for instance; settlement, shear strength, and soil bearing capacity. Consequently, it is important to investigate the compaction of the collapsible soil mixture with dissimilar condensation of biopolymer. The optimum dry density decreased with the rising of the biopolymer condensation for both xanthan and guar gum as illustrated in Figure 2. For xanthan gum samples, density decreased at start by 19 to 17.2 kN/m^3 by increasing the condensation starting from 0.00 to 2%. The decreased in dry density is more in the condition of guar gum than xanthan gum, where the density is 16.7 kN/m^3 at a guar gum condensation of 2%.

The remarkable behavior be able to be explained owing to the physical properties of the biopolymer sol and the soil sample mass. The sprightly mass of the soil particles provide them to shift far from each other because of the sol viscidity, which leads to an overall decreased in the density (Figure 3). In addition to, increasing the sol condensation will raise the viscidity, which will make extra lessening in the soil intensity. The more viscidity of guar gum sol than xanthan gum for similar condensation, signifies the major result in favor of the advancement of guar gum in decreasing the density plus raising the moisture content than xanthan gum at similar condensation[20], [22].

The optimum water content is found to be raised by increasing the sol condensation. While, the optimum water content, *o.w.c.* jumped from 12.40% for 0.00 condensation, to 15.3% and 14.4% at a condensation of 2% for guar gum and xanthan gum correspondingly, which can be interpret due to raising the soaked up water is to soften the biopolymer by rising the condensation.

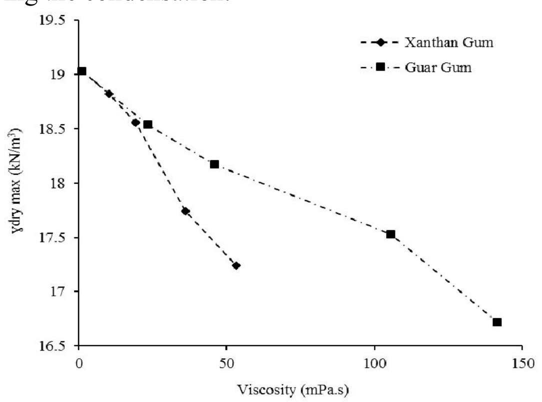

Fig. 3. Relationship between solution viscosity and soil maximum dry density

3.2. Collapse Potential

The collapsible soil conduct has a considerably alteration with changing the mixture way. The collapsible soil potential in the current research is calculated in three different cases; dry mix, wet mix instantly after mix (t= 0) and wet mix after 7 days treatment period (t= 1 week). Figure 4A shows the output of the collapsible soil potential tests for uncured collapsible soil in the three different cases, while Figure 4B shows the outcomes of collapsible potential for collapsible soil cured with 1% guar gum.

The most higher amount of collapsible potential for uncured soil is around 15.4% for dry mix, while it is 10.3% for the moistured mix (t= 0) and the least collapsible potential amount is almost 9% for the wet mix (t= 1week) as seen in Figure 4A.

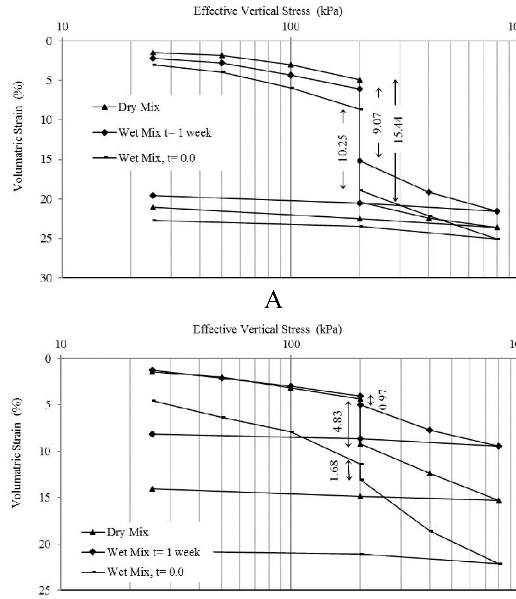

Fig. 4. Effects of mixing conditions and curing times on the collapse test result for:
(a) Uncured soil;
(b) Guar gum cured soil with a condensation of 1%

For guar gum cured soil, Figure 4B, the value of the collapsible soil potential is decreased in all three cases. However, the biopolymer efficiency in reducing the collapsible potential is varied according to the mixing case. For dry mix, the collapsible potential is decreased from 15.44% to 4.8% with efficacy proportion in decreasing the collapsible soil potential of 69%. On the other hand for moisture mixture, the efficacy proportion in reduction of the collapsible potential for the moisture mix is almost 83.6% and 89% for t = 0 week and t = 7 days on the relay. That is why, the efficacy of the mositured mixuture in decreasing the collapsible soil potential is much more than the dry mix, in addition to the maximum case in decreasing the collapsible soil potential is the moisture mixture case after the period of seven days of treatment. This can be assigned to the bulge conduct of polysaccharide in water. For dry mixing case, the swelling of the biopolymer particles in the outer stratums of the samples subsequent to moisture would decrease the permeability of the outer stratums. This lowering in the permeability handicap the water from flowing inside the samples, decreasing the efficacy of resolving the biopolymer particles inside the cured samples [29]. Moreover, the treatment period allows these links to win more strength thereby more resistance to collapse.

The influence of the guar gum condensation on a collapsible soil potential is shown in Figure 5 for moisture mixing case after seven days of curing. The guar gum concentration deeply affects the collapsible soil potential, even at minimum condensations. The collapsible soil potential dropped from 9 to 3.7% with adding 0.25% guar gum condensation, while raising the condensation from 0.25 to 1%, the collapsible soil potential decreased to about 1%. At a condensation of 4%, the collapsible soil potential almost disappear with a proportion fewer than 0.1%.

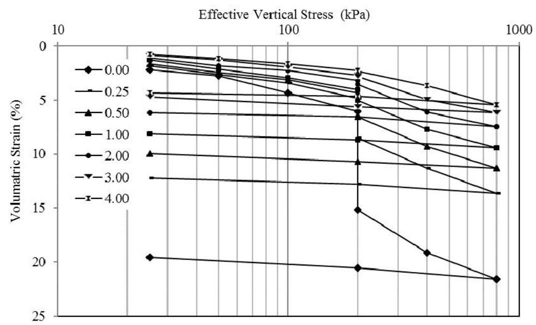

Fig. 5. Collapse test results for different guar gum concentrations of wet mixing soil after a one week curing period

Xanthan gum also has the similar influence on collapsible soil potentials. The efficacy of xanthan gum is fewer than guar gum as shown in Table 2 and Figure 6. For the moisture mixing case after seven days treatment time, about 1.5% condensation of guar gum is required to decrease the collapsible soil potential less than 1% to reach a "No Problem" condition, however, this might require a 2% xanthan gum condensation to have the ability of reaching the similar condition. For dry mixing, 1% guar gum condensation is required to get a 5% collapsible potential but it will take around 2% xanthan gum condensation for reaching the similar collapsible potential proportion. The superiority of guar gum over xanthan gum can be interpreted due to natural cohesion which created between the soils matrixes. Xanthan gum form an ionic cohesion between xanthan gum and particles of the soil accompanying by very high percentage of aggregation and big voids full of air or biopolymer gel, although guar gum structures are hydrogen cohesion with little aggregation and few voids. The minimum voids and stronger hydrogen bonding contribute to the high efficacy with the guar gum sol more than that with the xanthan gum sol [20], [22].

Table 2. Collapse Potential for biopolymer treated soil with different concentrations

Bio. Concentration	Collapse Potential (%)					
	Dry Mix		Wet Mix, t= 0 week		Wet Mix, t= 1 week	
	Xanthan	Guar	Xanthan	Guar	Xanthan	Guar
0.00	15.44	15.44	10.26	10.26	9.07	9.07
0.25	11.55	10.01	7.40	5.11	4.46	3.66
0.50	9.68	7.07	5.52	3.87	3.36	2.19
1.00	7.13	4.83	3.08	1.68	2.46	0.97
2.00	4.30	3.13	1.59	0.56	0.89	0.35
3.00	2.61	2.31	1.04	0.12	0.22	0.13
4.00	1.83	1.24	0.13	0.08	0.09	0.06

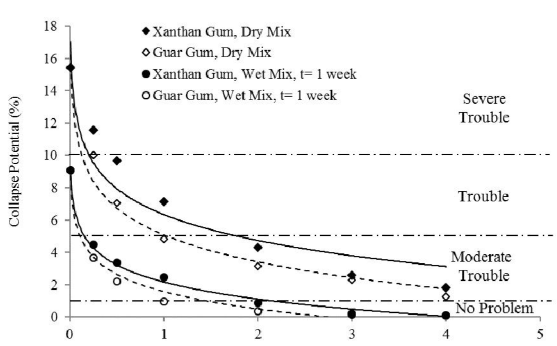

Fig. 6. Effects of mixing conditions and curing times on the collapse test results for guar gum treated soil

3.3. Shear strength

Shear strength is one of the main aims factors in soil enhancement. Improving the shear strength will automatically affect on soil improvement represented in bearing capacity, lateral earth pressure and settlement, but the main obstacle with collapsible soil depends on water content, therefore, it was important to calculate the shear strength in wet and dry samples. The dry samples are tested in the direct shear instrument without any change in its moisture content, while the wet samples are tested after exposing to moisture. The percentage of shearing is modified to be 0.02 mm/min for all tests to make sure of the dry conditions. The shear strength factors (including friction angle φ, and cohesion c) of the cured soil mixture is obtained from the direct shear test by showing the mode of failure for τ-σ diagram as seen in Figure 7. Samples are treated with variety condensations of xanthan gum of 2%, for the dry condition after 7 days treatment time. The failure envelopes for all conditions tend to be linear with correlation coefficients R^2 varies between 0.95 and 0.98. Generally, all biopolymer mix exhibited a great rising in shear strength by comparing it to the uncured samples.

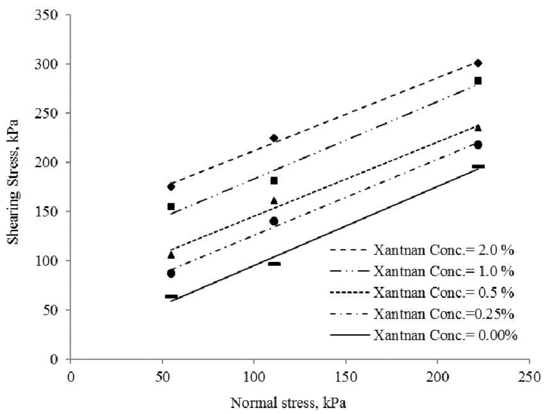

Fig. 7. Failure envelopes of xanthan soil mixtures after a one week curing period for soaked specimens

The friction angle of the sample following treatment changed from 37° to 38.2° whereas it is 38.4° previous to curing. It is illustrated that the casing influence of the biopolymer on the grain outsides polished the micro scale coarseness, that way decreasing the harshness superposition of sand grains which leads to a small decrease in the friction angle[20]. Coherence stress jumped from 14 to 137 kPa by raising the xanthan gum condensation from 0.00 to 2.00%.

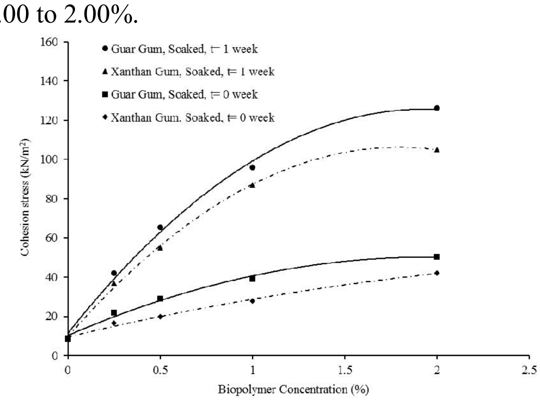

Fig. 8. Influence of biopolymer concentrations on cohesion stress for soaked specimens

Figure 8 illustrate the influence of the treatment period on the cohesion stress of the cured collapsing soil with many condensations of both xanthan gum and guar gum. The increasing in cohesion stress subsequent to seven days treatment period is shown in the figure, where the cohesion stress raised from 42kPa directly after the mixture to 105.0 kPa at xanthan gum condensation of 2% and from 51.0 to 126.0 kPa for guar gum samples at the same condensation. The induced interrelation stress enlarged after 7 days from 2 to about 3 times comparing to its value right after the mixture for the both guar gum and xanthan gum mixtures. Furthermore, Guar gum mixture specimens turned into more consistency strength than for xanthan gum cured specimens at similar condensation and treatment period.

The enhancement in the shear strength of the soil could be point out to the actuality that biopolymers have a variety of chemical practical groups, such as hydroxyl, ester or amines. Their long chain structure also prolong additional sites at which the attribute chemical reactions of a given functional group can occur. Chemical bonding coincide to the bonding agent forces, whose function is to grasp the soil particle and gel together at their surfaces [21]. On a microscopic scale, the effectiveness of bonding depends mainly on the type of forces present at the interface of the particle and the gel. The forces operating at such a phase interface include ionic/electrostatic or covalent bonds (chemisorption), hydrogen bonding (strong polar attraction) and van der Waals forces (physical absorption). Short range ionic/electrostatic and covalent bonds have the highest bond energy in terms of KJ/mol and therefore give the strongest bond. Van der Waals forces, which are the interaction between dipoles within the bulk material, develop the weakest bonds over a long range as shown in the SEM micrographs presented in Figure 9 after Ayeldeen (2016) [20],[30]. Conversely, solutions of thickness frequently enlarge as the biopolymer molecular mass raises, where the high percentage of the biopolymer molecular mass, gathers the possibility of sustaining the crystallization of its macromolecule chain that directs to increase in the quantity of cross connecting in the soil medium. Accordingly, as the guar gum has a much thickness sol than xanthan gum, the guar gum mix has a higher shearing confrontation than xanthan gum mix as stated before in [20].

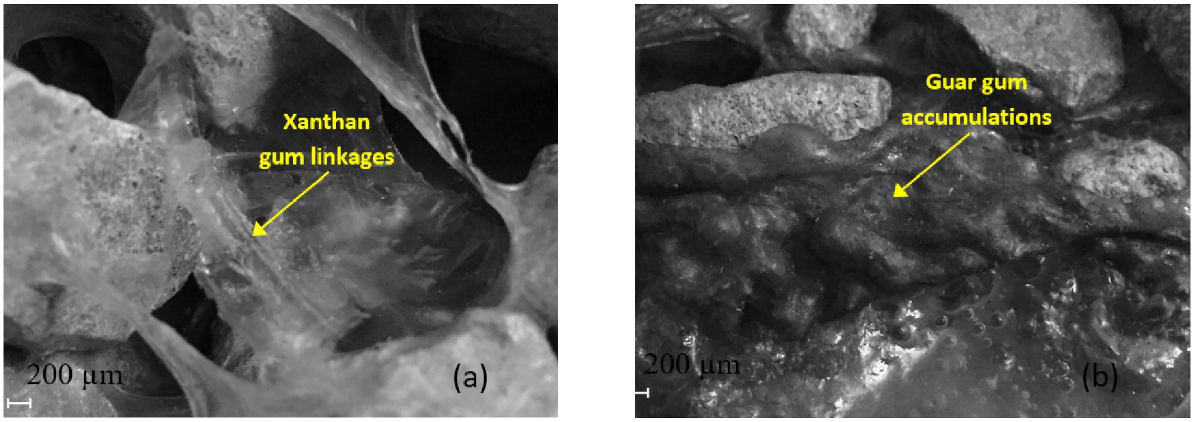

Fig. 9. Scanning electron micrographs of the interaction mechanism between biopolymer and soil particles for: (a) xanthan gum, and (b) guar gum, after Ayeldeen (2016).

For the investigation the influence of the wet trial on the performance of the cured collapsible soils, a direct shear experiment is completed two times (wet and dry) for each mixing situation. While the non-cured soil, saturated the soil with water will lessen the shear stress of the soil about 30% for compressed soil relying on moisture content and solidity [31]. xanthan gum mixed soil at a treatment period of zero, raising the biopolymer condensation raise the cohesion stress as illustrated before for both wet and dry conditions as shown in Figure 10A. The decrease parameter between the cohesion stress for wet and dry conditions (the ratio between cohesion stress in a wet case as divergent to that for dry case) tends to be slightly augmented with growing the biopolymer condensation, where the decrease factor is almost 10% at a condensation of 0.25% and up to 15% at 2% condensation. The influence of moisture on the cohesion stress becomes more obvious and perceptible after 7 days of treatment. The reduction factor in cohesion stress between wet and dry specimens begins at almost 20% at 0.25% condensation and jumped to 30% at 2% condensation.

Cohesion stress not the only parameter which controls the shear strength, escalating the biopolymer condensation, causes rising in the cohesion stress and a decrease in the friction angle. Consequently, to have a fair evaluation about the general shearing performance after the cured of the collapsible soil, the total shear strength of the soil is used to compare the behavior consistent with the next formula:

$\tau_f = c + (\sigma + \gamma\, h)\tan\phi$

Where τ_f is the shear strength at position situated at deepness h, c is the cohesion stress, ϕ is the friction angle, σ is the external stress, and $\gamma\ h$ is the over burden pressure.

The shear strength is evaluated via an over burden pressure at a depth, h of 1.50m from the surface as seen in Figure 10B. The difference in the whole shear strength for the both cohesion stress and angle of internal friction though, leading to a decrease in the this angle and it has effect on the entire shear strength particularly at small condensation.

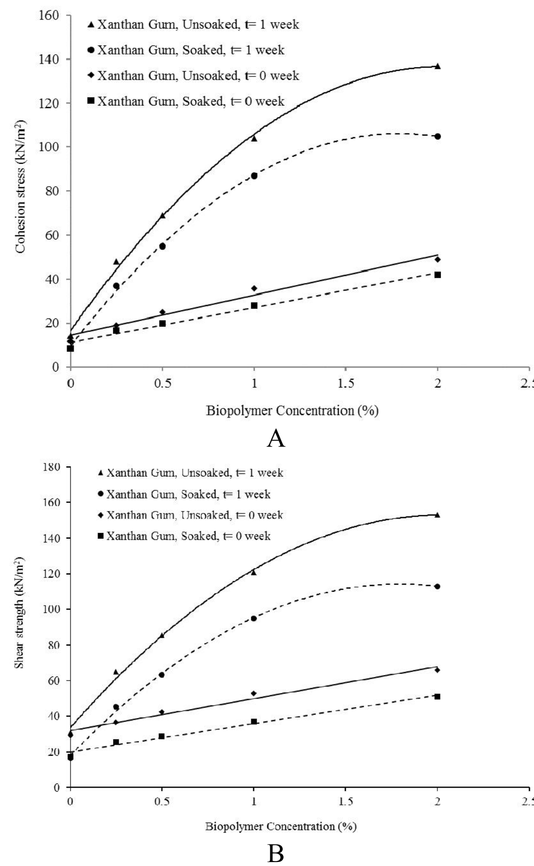

Fig. 10. Influence of soaking conditions for xanthan gum treated soil on both:
(a) Cohesion stress.
(b) Shear resistance at a depth of 1.5 m.

The decrease in the parameter of the shear stress (the ratio between shear stress in wet case than that for dry case) for zero treatment period started at 50%, at a biopolymer condensation of 0.00; then it was decreased in straight line to 30% at 2% condensation, after 1 week of curing, the reduction factor in shear stress decreased starting with 50% at zero condensation to 30% at 1% condensation, though, the decrease parameter begun to amplify another time following 1% condensation to achieve 35% at a condensation of 2%.

4. Finite element analysis

4.1. Modeling definition

The numerical model is done by *Plaxis 2D* version of *8.2*. The model under investigation consists of a concrete base with 2 m width and 0.50 m in depth over 10 m stratum of collapsible soil. The soil restrictions are stretched straightly for 10 m far away of the foundation at the both sides, with an overall horizontal extent of 22 m and also reaches 10 m beneath the foundation. The horizontal boundary is reserved in both horizontal and vertical direction, yet; the perpendicular boundary is kept just in the horizontal path and 15 node elements are included for both the soil model and the concrete footings elements. The model mesh is produced as a fine roughness and then sophisticated to be very small to enlarge the nodes numbers around the footing in the influenced area which increase the accuracy of the results as seen in Figure 11.

The concrete base is simulated as a linear elastic non-porous material, which is defined by the unit weight (γ_{unsat}), modulus of elasticity (E_{ref}) and Poisson ratios (υ). The soil is modeled using the Moher-Coulomb method by defining the soil unit weight (γ), Young`s modulus (E), Poisson ratio (υ), cohesion stress (C), friction angle (ϕ) and dilatancy angle (ψ). The soil parameters that are needed for the Moher-Coulomb *MC* model are acquired from the direct shear results which are completed formerly in this search - section 3.3 - before and after deluge conditions. Young`s modulus ($E$) is evaluated following findding $E_{oed}$-one dimensional compression modulus of elasticity- from the oedometer experiment with and without immersion as stated in section 3.2, for both $E_{oed}$ and $E$ could be evaluated in respect with Hooke`s law as follows:

$$E_{oed} = \frac{\partial \sigma`_y}{\partial \varepsilon_y}$$

$$E = \frac{(1-2\upsilon)(1+\upsilon)}{(1-\upsilon)} E_{oed}$$

Where $E$is Young`s modulus, E_{oed} is the oedometer modulus of elasticity and $\upsilon$is Poisson ratio. The numerical model parameters are shown in table 3.

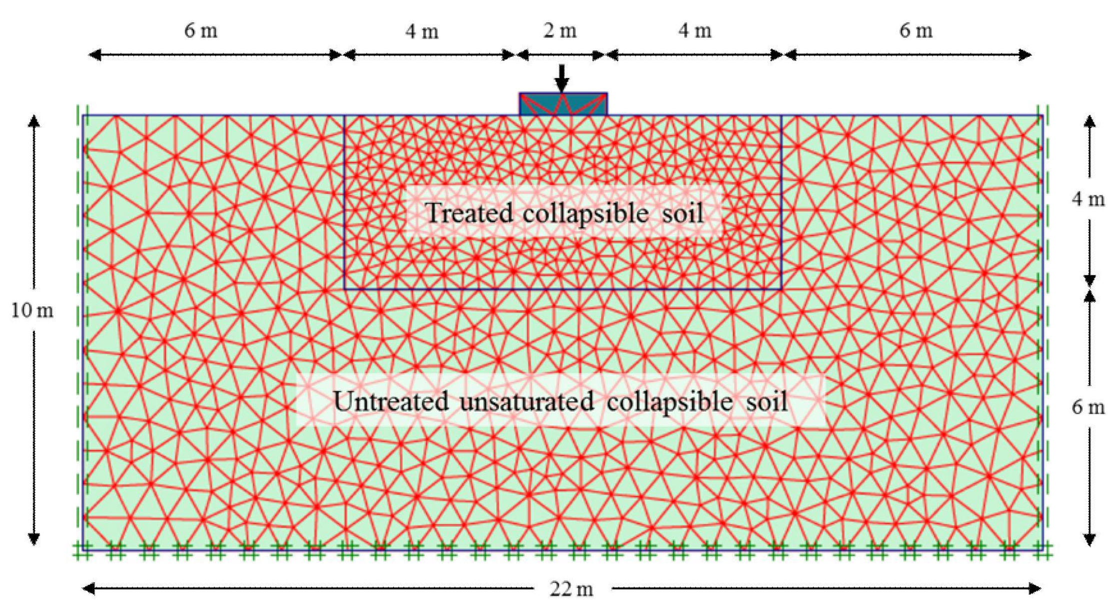

Fig. 11. Finite element model

Table 3. The model parameters which used in the research with and without inundation.

Case	Bio. Con (%)	Before Inundation (unsaturated case)					At Inundation				After Inundation (saturated case)				
		γ, kN/m^3	E_{oed}, kN/m^2	E, kN/m^2	C, kN/m^2	φ, °	C_p,%	σ_{mid}	ε_c	ε_v	γ, kN/m^3	E_{oed}, kN/m^2	E, kN/m^2	C, kN/m^2	φ, °
Pure Soil, t= 0 week	0.1	14.82	10000	7428.57	11.7	38	10.26	288.02	14.78	1.48	17.76	3000	2228.57	8.5	37.31
Xanthan, t = 0 week	0.25	15.1	6340	4709.71	19	37.95	7.40	291.10	10.77	1.08	17.85	2800	2080.00	16.5	36.87
	0.5	15.15	5130	3810.86	25	37.52	5.52	291.65	8.05	0.80	17.91	2570	1909.14	20	36.65
	1	15.2	4622	3433.49	35.75	36.76	3.08	292.20	4.50	0.45	18.03	2240	1664.00	28	36.2
	2	15.25	4134	3070.97	49	36.43	1.59	292.75	2.33	0.23	18.13	2020	1500.57	42	36.2
Guar, t = 0 week	0.25	15.13	8300	6165.71	26	36.87	5.11	291.43	7.45	0.74	18.1	3300	2451.43	22	36.65
	0.5	15.18	7700	5720.00	36	36.2	3.87	291.98	5.65	0.56	18.13	3000	2228.57	29	36.2
	1	15.23	6300	4680.00	41	35.98	1.68	292.53	2.46	0.25	18.15	2650	1968.57	39	35.75
	2	15.26	6100	4531.43	52	35.53	0.56	292.86	0.82	0.08	18.17	2400	1782.86	50.5	35.3
Pure Soil, t = 7 dayes	0.1	14.14	9000	6685.71	14.20	38.44	9.07	280.54	12.72	1.27	17.19	4400	3268.57	8.50	37.52
Xanthan, t = 1 week	0.25	14.20	9600	7131.43	48.00	38.17	4.46	281.20	6.27	0.63	17.20	4780	3550.86	37.00	37.10
	0.5	14.23	9800	7280.00	69.00	37.74	3.36	281.53	4.73	0.47	17.23	6000	4457.14	55.00	36.87
	1	14.31	10400	7725.71	104.00	37.52	2.46	282.41	3.47	0.35	17.31	7000	5200.00	87.00	36.20
	2	14.36	11500	8542.86	137.00	37.10	0.89	282.96	1.26	0.13	17.36	8000	5942.86	105.00	35.80
Guar, t = 1 week	0.25	14.21	11600	8617.14	67.50	37.90	3.66	281.31	5.15	0.51	17.36	6000	4457.14	42.00	37.10
	0.5	14.25	12300	9137.14	76.00	37.52	2.19	281.75	3.09	0.31	17.41	6600	4902.86	65.50	36.90
	1	14.29	13000	9657.14	123.00	36.87	0.97	282.19	1.37	0.14	17.45	7500	5571.43	96.00	36.20
	2	14.34	14200	10548.57	161.50	36.20	0.35	282.74	0.49	0.05	17.62	8700	6462.86	126.00	35.75

4.1. The model stages

The model is used to verify the stress/displacement curves for the cured soils after and before deluge, which is necessary to calculate the bearing capacity of the cured soil. It is also used to evaluate the settlement for a loaded footing lying over a cured soil subsequent to saturation. As a result, 3 stages are included in this search as seen in Figure 12. The soil is alienated into 2 regions; uncured not submersible collapsible soil that would still unsaturated for the period of the 3 stages and the cured collapsible soil that might modify from not submersible to submersible consistent with the stage. *Phase I* is the unsaturated condition while all desirable factors for the *MC* model are intended in the not submersible condition and is used to study the performance of the cured soil with no deluge (in the dry case) as performed by line *AF*. *Phase II* is the submersible condition where the wanted factors are evaluated after inundating the soil by water. This phase is accustomed to recognize the performance of the cured soil subsequent to immersion (in the soaked condition) as represented by line *AE*. *Phase III* is a particular condition for collapsing soil, while the soil is becoming full of moisture after it was loaded, which is the case in a collapsible settlement, this collapsible settlement is caused by lots of problems in the constructed structures on collapsible soil[32]. The performance of this phase is shown in Figure 12 by following the line *ABCD*. *AB* shows the dry region, while the soil is loaded previous to the inundation. The performance in this area is similar as the initial phase as in the dry condition (*line AF*), it is illustrated that the *AB* and *AF* lines. The next region is *BC*, that shows the soil volumetric contraction after failure because of immersion. The third region is *CD*, that shows the soaked area. This area shows the soil performance after inundation, where it illustrates similar behavior as the subsequent soaked stage (*line AE*). To replicate areas *AB* and *CD*, the data is used from the first unsaturated zone and the second saturated zone, in that order. On the other hand, the volumetric reduction after failure is because of deluge (*line BC*) and is practical in the model as the negative volumetric strains (ε_v). The volumetric strains are evaluated from the strain at collapse (ε_c) which relates to the volumetric strain by the celebration factor *C*[33]as follows:

$$\varepsilon_v = C \times \varepsilon_c$$

where ε_v is the volumetric strain, ε_c is the collapsible strain and *C* is the celebration factor which was found to be 0.1[33].

ε_c could be obtained from the collapsible potential (C_P) after bigger than burden pressure modification at the center of the collapsible startum [34] as shown in the following equation:

$$\varepsilon_c = \frac{C_P}{200} \times (\sigma + \gamma h_{mid})$$

Where C_P is the collapsible potential from a sole oedometer experiment (%), σ is the outer stress from the base (kPa), and γh_{mid} is the over burden pressure at the middle of the treated collapsible layer (kPa).

The model is confirmed by the comparison of the numerical outputs with two different institute test outcomes determined through plate load test on collapsible soils after Ali (2015) and Shalaby (2014) and it is found a fine agreement between the field results and the numerical model, that verifies the capability of the model to calculate the performance of collapsible soils [35], [36].

4.2. Influence of deluge on stress deformation curves

The influence of immersion on both uncured and cured collapsible soil can be shown in Figure 13, where the stress deformation/settlement is plotted for uncured collapsing soil and xanthan gum treated soil with a condenastion of 2% treated for seven days with and without water mixing. The maximum bearing capacity (q_{ult}) is evaluated from the intersection among the primary line or tangent and the steeper tangent for every curve[37]. It is noticed from the following figure that, q_{ult} for uncured soil is decreased by 67% because of the influence of the immersion (from 158 to 106 kPa). nevertheless, curing of the soil with xanthan gum raised q_{ult} by 700% (from 158.0 to 1116.0 kPa).

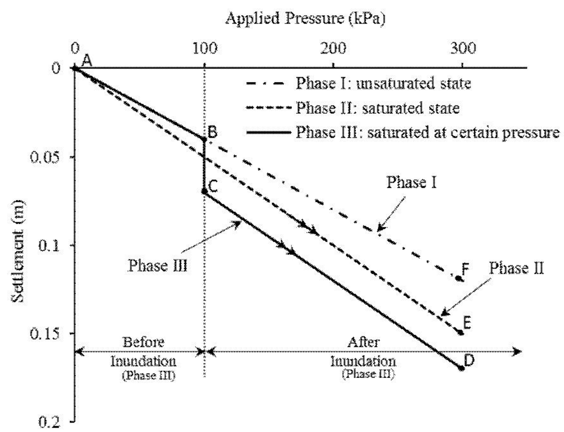

Fig. 12. Schematic diagram of the used phases in the analysis

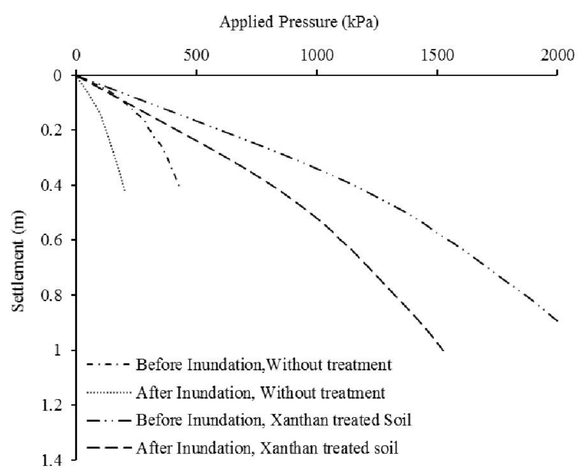

Fig. 13. influence of immersion on pressure settlement curves for uncured soil and xanthan gum treated soil with a concentration of 2% after 1week of curing time.

The decrease in bearing capacity owing to water inundation on the treated soil is fewer than for uncured soil, where q_{ult} for treated soil is decreased by 81% after immersion (from 1116 to 900 kPa). That canbe expound because of the decrease in permeability subsequent to curing the soil with biopolymer, which prevent the water flow in the soil pore cracks in that way decreasing the influence of immersion. The crosslink in the soil holes which shaped by the biopolymer could also enhance the bearing capacity later than immersion. Nonetheless, the enhancement in shear stress factors is mostly accountable for the enhancement in ultimate capacity with and without cure.

4.3. Influence of condensation on the settlement due to collapse (Phase III)

Figure 14 shows the amplitude of deformation curves for collapsing soil cured with guar gum through deluge after seven days of treatment time. The outputs are acquired from the finite element model by *Phase III* to investigate the influence of biopolymer condensations on the load settlement curve. It illustrated that the rise in the condensation uncommonly decreases the displacement during and after immersion, on the other hand guar gum condensation of 2% decreased settlement at immersion from 0.22m to 0.05m.

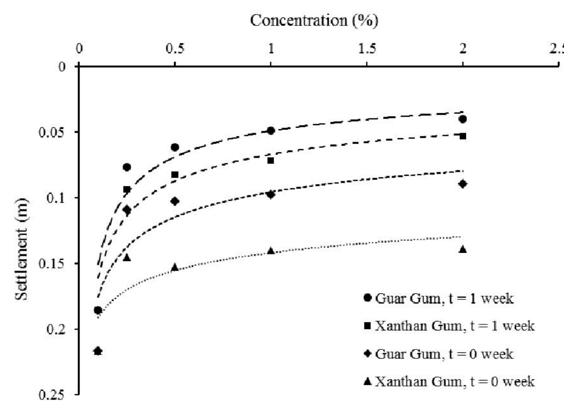

Fig. 15. Variation in settlement under footings with different biopolymer concentrations.

To have a good accepting of the influence of immersion on settlement beneath the base, Figure 15 present the influence of both guar gum and xanthan gum on a settlement of a 2m width base loaded with a condensation load of 250 kN as obtained from *phase III* in the finite element model. From the figure, it is shown that the efficacy of biopolymer rose significantly by rising the biopolymer condensation, where increasing the concentration reflected directly to a decrease in settlement. Yet, this drop in settlement became not as much effectual following rising the condensation from 1 to 2%. This could be clarifyed because of the influence of biopolymer on the soil shear stress, while raising the biopolymer condensation will help in growing the soil cohesion, the soil flexibility will be abridged as a consequence of increasing the condensation.

The efficacy of guar gum is obviously bigger than xanthan gum in resisting settlement throughout inundation in spite of the treatment period. This could be explained because of the high molecular mass of guar gum matched up to xanthan gum, where raising the molecular mass reflects directly to higher enlargement in the buildup of cross linking between particles, subsequently a higher decrease in permeability[20]. This drop in permeability will work on handicap the leakage in the soil, which will lessen the influence of inundation for guar gum rather than xanthan gum mix. The efficacy of biopolymer tends to be satisfactory in decreasing the settlement yet devoid of a treatment period, conversely, after seven days treatment time, the efficacy of by biopolymer turn out to be much helpful.

4.4. **Bearing capacity**

Ultimate bearing capacity (q_{ult}) is the highest stress which the soil could hold up earlier than the shear fails and by reducing q_{ult} by factor of safety, the permissible bearing capacity ($q_{all,shear}$) could be evaluated. On the other hand, in some kinds of soils which are predictable to hand out a huge settlement or in some different types of structures while it is necessary to control the settlement to a definite significance; in these conditions, the allowable bearing capacity ($q_{all,sett}$) could be believed consistent with the essential settlement. In general, the considered allowable bearing capacity ($q_{all,considered}$) is controlled by both soil collapse and allowable settlement -the least of $q_{all,shear}$, and $q_{all,sett}$-. Two ways are useful to predict the allowable bearing capacity from stress settlement plots; for the first way, the ultimate bearing pressure is evaluated from the intersection among the initial tangent and the steeper tangent, after that the allowable bearing pressure $q_{all,shear}$ is evaluated by a factor of safety and its value is 3.0 [37], whereas in the next way, the allowable stress $q_{all,sett}$ at 10 cm settlement is calculated, as seen in Figure 16 for the cured soil with and without inundation.

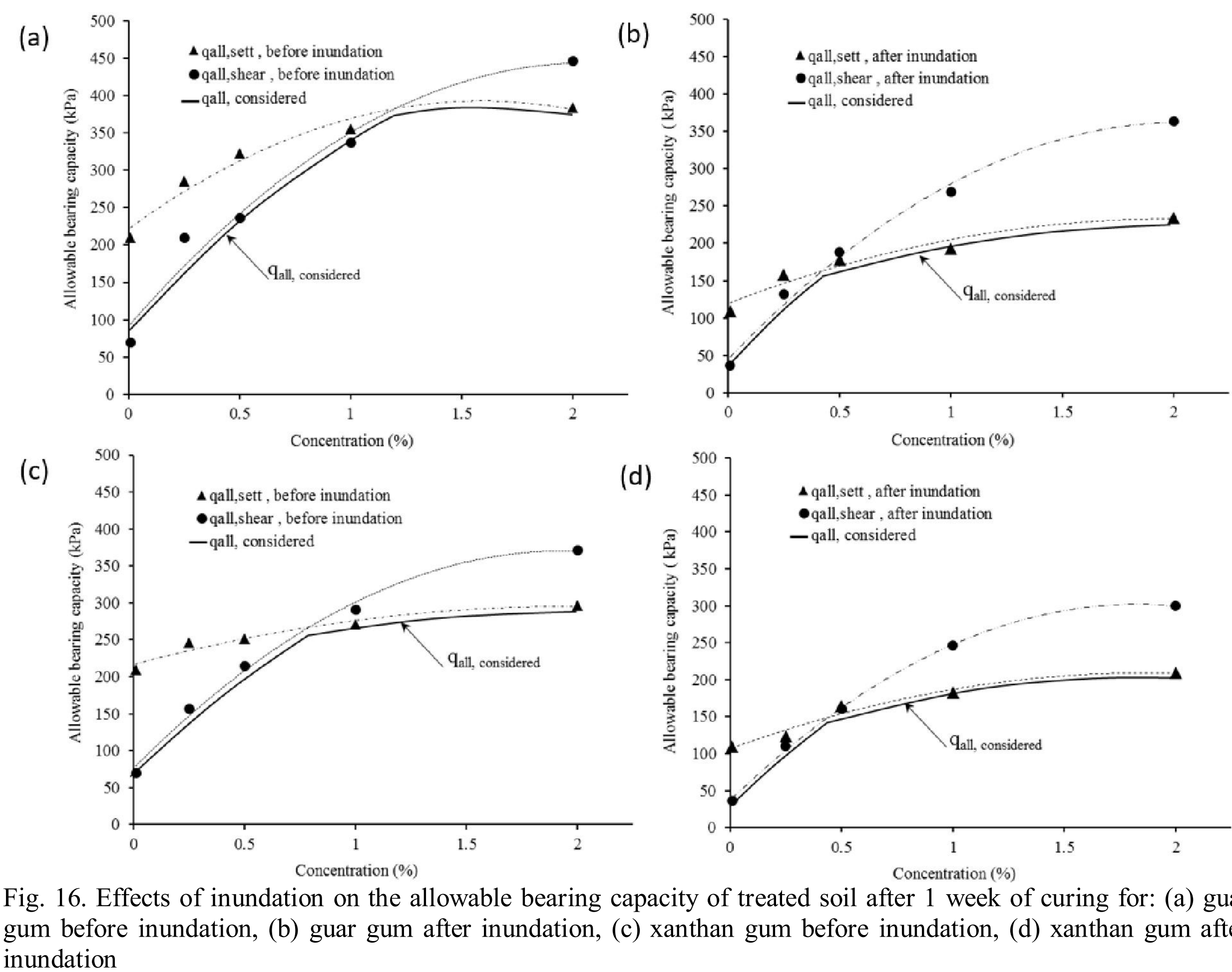

Fig. 16. Effects of inundation on the allowable bearing capacity of treated soil after 1 week of curing for: (a) guar gum before inundation, (b) guar gum after inundation, (c) xanthan gum before inundation, (d) xanthan gum after inundation

In the case of untreated soil with or without inundation, $q_{all,shear}$ is about 50% fewer than $q_{all,sett}$. hence, it is considered to be the allowable bearing capacity ($q_{all,considered}$). With raising the condensation, both $q_{all,shear}$, and $q_{all,\ sett}$ must be amplified, yet, the proportion of increase $q_{all,shear}$ is much higher than $q_{all,sett}$. $q_{all,shear}$ by about 600% by rising the condensation from 0 to about 2%, while $q_{all,sett}$ increased by a proportion of about 200%. This could be explained because of improving the shear factors by rising the condensation which will lead to an amplify in $q_{all,shear}$. simultaneously, escalating the biopolymer condensation may lead to a decrease in the soil stiffness in the form of elastic modulud of the cured soil[20], which might explain the advantage of increasing $q_{all,shear}$ than $q_{all,sett}$. The hole between $q_{all,shear}$ and $q_{all,sett}$ begun to get smaller with mounting the biopolymer condensation until a assured concentration amount is obtained, this amount varies in respect with the soil deluge state, where $q_{all,shear}$, and $q_{all,sett}$ becomes equivalent. afterward the value of $q_{all,shear}$ becomes higher than $q_{all,sett}$ at the same concentration. soaked cured soil (after inundation), $q_{all,considered}$ is mostly restricted by $q_{all,sett}$, apart from the condition of light condensations (less than 0.5%), where the inundation will enlarge the soil elasticity, increase the settlement and decrease the allowable bearing capacity. On the other hand, in the condition of unsoaked soil (before inundation), $q_{all,considered}$ is evenly effected by both $q_{all,shear}$ and $q_{all,sett}$ according to the concentration, as 1% concentration is the critical value where the performance differ before and after from $q_{all,shear}$, to $q_{all,sett}$ correspondingly. With varying the necessary settlement magnitude or the factor of safety, the significant point might be shifted. Consequently, it is important to ensure both $q_{all,shear}$ and $q_{all,sett}$ especially for condensations in the region of the critical point (almost in the range of 0.5 to 1.5%).

5. Conclusions

Based on the experimental range of this study, the following conclusions can be stated:

- The dry density reduces with increasing the solution concentrations for both guar gum and xanthan gumfrom 19.00 to about 17.00 kN/m^{3,} whereas the optimum moisture content raised from 12% to around 14.6%.
- Biopolymer proves highly efficiency in decreasing the collapsible potential for both wet and dry mixing cases. The efficacy of biopolymer for the wet mixing is almost 2-3 times over dry mixing. Consequently, the present research proposes the wet mix method to cure collapsible soils instead of dry mix.
- Mixing the soil with 2% biopolymer condensation directs to a decrease in the collapsible possible from 9% to about 1%.
- In spite of the decrease in density that is noticed with increasing the condensation the shear resistance of the cured soil has enhanced. The cohesion stress has increased by raising the condensation with alight decrease in the friction angle. Nevertheless, the total shear stress has amplified with mounting the condensations for both guar gum and xanthan gum.
- Guar gum showed superiority over xanthan gum for mounting the soil cohesion stress and dropping the collapsible potential with a percentage of about 20%.
- Based on the numerical model it can be concluded that:

a. Curing the soil with biopolymer can significantly improve the soil bearing capacity and decrease the effects of inundation.

b. The biopolymer condensation guides to dropping the collapsing settlement during and after inundation under the foundation.

c. For cured collapsing soil by such technique after inundation, $q_{all,sett}$ can be acted as the allowable bearing capacity, especially for biopolymer condensations > 0.5%. Nevertheless, for cured soil before submergence, it is recommended to compute both $q_{all,sett}$ and $q_{all,shear}$ before estimating the considered allowable bearing capacity.

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