**Misan Journal of Engineering Sciences** ISSN: 2957-4242
Vol. 4, No. 1, June 2025 ISSN-E: 2957-4250

# Feasibility of Biopolymer in Enhancing the Load Capacity and Deformation of the Granular Pile

Alaa H. J. Al-Rkaby [*1]

[1]*Department of Civil Engineering, College of Engineering, University of Thi Qar, Nasiryah, 64001, Iraq*
**Corresponding author E-mail*: alaa.al-rakaby@utq.edu.iq ; *alaa.astm@gmail.com*

(Received 31 Dec 2024, Revised 5 Jan 2025, Accepted 7 Jan 2025 )

**Abstract:** This paper presents an innovative concept to improve the load carrying capacity, settlement, and the lateral deformation characteristics of the granular-pile by incorporating biopolymer as a binder to the fill materials of the granular pile. This natural biopolymer is sustainable and eco-friendly substitute binder to the conventional binder ( cement, lime), which have sever impacts on the environment. A series of loading tests using large scale models was performed considering different biopolymer contents, various ratio of footing diameter to pile diameter *df/Dp*, and fiber content. Results revealed that the incorporating biopolymerresulted in stiffening granular pile and eliminate the common bulging failure. Therefore, load carrying capacityincreased significantly, corresponding with clear restraint against the lateral deformation. For ground reinforced with ordinary granular pile considering *df/Dp* of 1.5, 1.25, 1.0, 0.75 and 0.5, the bearing pressure increased from 60 kN/m2 for the native ground to 65, 110, 157, 185 and 230 kN/m2 respectively. Compared with 230 kN/m2 for the ordinary granular pile with *df/Dp* = 0.5, bearing pressure increased to 245, 304, 525, 638 and 649 kN/m2 when 1, 2, 4, 6 and 8% of biopolymer was incorporated with the granular material of the pile, respectively. However, with increasing *df/Dp* to 1.5, the capacity increased from 65 kN/m2 for the ordinary granular pile to 74, 107, 144, 442, and 495 kN/m2 for *biopolymer-granular pile* considering the aforementioned contents of the biopolymer respectively.

**Keywords:** Biopolymer, Granular pile, Soft Clay, Bearing Capacity, Settlement, Lateral Deformation.

## 1. Introduction

On soft cohesive soil, buildings, infrastructure, and earth dams may experience excessive settlement and low bearing-capacity. Soil enhancement concepts have garnered significant interest in recent decades to strengthen the weak subsoil to support traditional shallow foundations In many cases, the suggested constructions on enhanced or stabilized soft soils are deemed economically feasible owing to the substantial expense of undeveloped property and the environmental requirements to locate infrastructure away from urbanized regions. Chemical improvements are used commonly by mixing traditional chemical-agents, such as cement and lime, to improve the strength-deformation characteristics of the soil clay[1-7].

The granular pile or stone column is an efficientway to enhance the strength- deformation characteristics of the soft clayey layers. The granular pile's ability to support the stresses depends on both the materials of the pile itself at which the stress is applied and the confinement that the surrounding earth provides.

Numerous studies examining the behavior of stone column treated grounds have been published in the literature over the last few decades. These studies are based on large-scale field load experiments and laboratory model tests. Bergado et al. (1984) showed that the granular-piles enhanced the bearing-capacity by approximately three to four times compared to untreated ground[8]. Additionally, with pile separation was two times the pile width, the neighboring heaps behaved independently. Bergado and Lam (1987) found that the columns made of pure gravel has a larger final pile capacity compared with columns made of sand, which rises with the granular materials' density and friction angle[9]. Triaxial model experiments were used to examine the interactions between granular pile and the adjacent soil and results demonstrated that the confining pressure had a crucial impact on the modules and strength of fill-material.

DOI: https:// doi.org/10.61263/mjes.v4i1.131

This work is licensed under a Creative Commons Attribution 4.0 International License.

Furthermore, lateral contact between the pile and the surrounding material is brought about by the dilatency of the gravel[10]. Loading tests and unit cell consolidation tests were also employed to investigate the failure concepts and different factors affecting the behavior of endbearing granular piles. Even for low area replacement ratios, sand columns greatly increased the undrained strength while also increasing Young's modulus and reducing the induced of pore-pressure under shearing[11]. With the exception of completely penetrating columns with large area replacement ratios, it was discovered that the sand column reinforcement had no effect on the drained shear strength values[12].

For granular-piles in layered soils, the strength, bearing pressure, and expansionresponse of granular piles are significantly impacted by the top weak layer. As the thickness of the top weak layer increases, the stiffness and load capability of the layered ground treated with granular piles diminish. The upper weak layer zone was where the most of the bulging was seen[13]. It is well known that the lateral confining caused by the adjacent ground provides the granular pile with its load capability [14]. Due to limited lateral confinement, stone columns may not have a considerable load-bearing capability when placed in very soft clays. With a lower constraint in the range of 5–15 $kN/m^2$, the undrained shear strength of the adjacent clay is often employed as the criteria to determine the improvement's viability [15]. When the soft clay around the stone column failed to hold it in place, causing extremeexpansion and the soft clay to push into the particles spaces. In these circumstances, more confinement may be necessary for the granular pile itself for enhancing its performance.

The adjacent confinement provided by the surrounding-clay may not be enough to support the granular piles when they are placed in soft layers. As a result, the stone columns will bulge more and cause larger surface settlements, which will reduce their effectiveness to a very low level. This is a significant drawback of the stone column method, particularly in very pliable soils. Mixing the granular materials of the stone with chemical additives is an innovative way to enhance the capability of the granular piles placed in these types of soils. This kind of treatment gives the stone columns more lateral confinement and increases their strength and stiffness. Gegrids are used as encasement to improve the lateral confinement of the granular pile. Moreover, Portland cement and lime, have long been employed to improve the engineering qualities of stones of the granular pile. In other words, These materials can be used as binder to the columns materials.

Despite the fact that the cement and lime has been used extensively for ground improvements, over reliance on and usage of cement has lately raised several environmental issues. The cement business contributes up to 8% of global $CO_2$ emissions yearly, making it the third largest source of carbon dioxide emissions behind the coal and oil and gas industries[1-7]. This emphasizes how important it is for civil and geotechnical engineering processes to use sustainable approaches.

The use of biopolymers as eco-friendly agents in the geostructures has recently been attempted. Organic-polymers made from natural resources are defined as biopolymers. Plant-based, animal-based, and microorganism-produced biopolymers are the three primary categories into which biopolymers may be divided according to their origin [2]. Plant-based-biopolymers such as guar, lignin, agar, beta-glycan, and alginate have been used in geotechnical engineering[16-20]. The fermentation process yields microorganism-based biopolymers such dextran, gellan gums, and xanthan gum. Previous investigations have revealed their capacity to enhance soil characteristics [16-20]. Several researchers have found that the use of biopolymer addition agents , such as xanthan gum, beta-glucens, guar gum, chitosan, algenate sugarcane and paper mills, resulted in increased soil strength [17, 19-20]. Although xanthan gums have been examined to improve shear/compressive strengths, prior studies have mostly focused on examining the unconfined compressive strength and confirming viability. Specifically, the use of the biopolymer in the geotechnical applications have not been sufficiently taken into account.

The novelty of this work stems from the utilization of newly developed engineered biopolymer in improving the performance of the granular-pile. Despite the potential improvements arising from the combination of the biopolymer with stones and fibers to create stiffening columns, no research on this subject was found in the available literature. Therefore, this work intends to fill up the aforementioned gaps by examining the feasibility of using xanthan biopolymer as binder to improve the performance of the gran-

ular pile throughout conducting extensive tests on large scale models of untreated and biopolymer-granular pile.

## 3. Materials

In this study, the *soft clayey soil* was chosen to investigate its improvement using the biopolymer-granular pile. It classified as highly plastic soil group with 55% and 35% of liquid limit and plasticityin-dex.Moreover, itsundrained cohesion is 15 kN/m2. The physical properties are illustrated in *Table 1a*. The material used in modelling the granular pile was the *gravel,* which is uniformly-graded gravel with particles sizes in the range of 15-25 mm.

The biopolymer xanthan gum, which is a natural anionic polysaccharide, was utilized as binders to the gravel fill of the granular pile. Even at minimal concentrations, this biopolymer exhibits significant vis-cosity and pseudo-plastic performance.*Table 1b*. summarize some of its properties.Moreover, commer-cially available fiberglass wasused in this study (*Table 1c*.).

Table 1a. Some properties of soft clay

| Passing sieve No. 200, % | Liquid limit, % | Plastic limit, % |  |
|---|---|---|---|
| 63 | 58 | 17 | |
| Specific Gravity | Maximum dry density, gm/cm$^3$ | Undrained co-hesion, kN/m2 | |
| 2.76 | 1.81 | 15 | |

Table 1b. Some properties of the Biopolymer.

| Color | State | Viscosity | pH |  |
|---|---|---|---|---|
| Yellow-like | Powder | 1400 | 7 | |
| Passing No.200, % | Ethanol | As | Hg | |
| 91 | 388ppm | <1.8ppm | <0.9ppm | |

Table 1c. Some properties of the used fiber.

| Color | Length (mm) | Diameter (μm) | Strength (MPa) |  |
|---|---|---|---|---|
| White | 7.5 | 12.4 | 570 | |

## 4. Methods

In this study, large scale test was consisted with a single granular pile with and without *biopolymer* and fiber under different *diameter ratiodf/Dp*, which refer to the ratio of footing diameter to the pile diameter. Therefore, large container size 2115 mm x 2115 mm x 2115 mm in length, width and depth respectively was used.

Air-Driedsoil was mixed with 37% water using a larger mixer for 15 minutes for each batch. Then, the mixed soil was poured into thelarge container in layers, and compacted using a vibratory plate to reach the field moist unit weight of 16.1 kN/m$^3$. Before pouring the next soil fill layer, the plane of soil was grooved, in order to provide good interlocking for the next layer. The moisture content and the unit

weight were checked for each layer, and the variation was less than 2%. Moreover, selected samples were taken from the prepared soil and their average undrained shear strength was14.8kN/m2. This strength simulated the real field case where the soil was in soft consistency.
Pre-drilled hole was used to construct the single granular pile by pushinga plastic pipe, which hasdiameter of 100and sharp edges, vertically into the soft soil bed. Then the pipe was extruded from the soft bed gently. Thegranular materials was then poured into the predrilled borehole to model the granular pile. For cemented granular pile, the gravel was mixed with different content of the *biopolymer* and/or fiber in advanced (based on *Table 2*) then poured into the hole.

Table 2. Testing program of testing the granular pile conceding different parameters

| Series | Description | Biopolymer, % | Ratio of Footing diameter to the Pile diameter, *df/Dp* | Fiber, % |
|---|---|---|---|---|
| Series-1 | Soil without *Granular Pile* | – | – | None |
| Series-2 | Soil with ordinary *Granular Pile* | 0 | 0.5, 0.75, 1.0, 1.25 and 1.5 | None |
| Series-3 | Soil with *Biopolymer-Granular Pile* | 1 | 0.5, 0.75, 1.0, 1.25 and 1.5 | None |
| | | 2 | | |
| | | 4 | | |
| | | 6 | | |
| | | 8 | | |
| Series-4 | Soil with *Fiber-Biopolymer-Granular Pile* | 8 | 0.5, 0.75, 1.0, 1.25 and 1.5 | 0.5 |
| | | | | 1.0 |

## 5. Results and Discussions

### *5.1 Effect Biopolymer on the Load Capacity Granular pile*

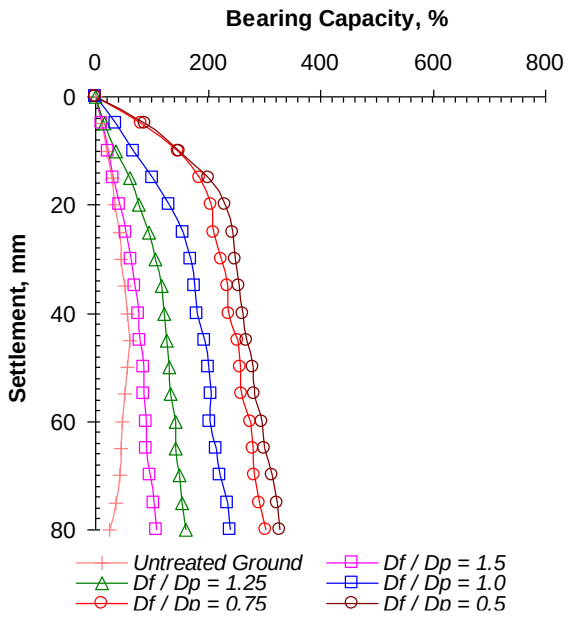
In this part, the behaviour of granular pile containing up to 8% biopolymer was presented. The load-settlementcurves of granular pile with variousbiopolymerpercentages, with various *diameter ratiodf/Dp*, are plotted in Figures 2.
The results exhibited that biopolymerpercentage*BP* clearly affects the load-settlementproperties of granular pile. Generally, the addition of biopolymerin granular pile increases theload capacity, based on *diameter ratiodf/Dp*.
Under *diameter ratio df/Dp*= 0.5–1.0, adding biopolymermodified the measuredload-settlementvalues,wherethe slope was not steep compared to that plotted for ordinarygranular pile . The plottedload-settlementcurves for variousbiopolymerpercentages almost merged until near the peaks, at whichsubstantial differences happened where ultimate load increased with increasing biopolymerpercentage, but not for biopolymer= 1%. For instances, with*diameter ratio df/Dp*= 0.5, load capacityincreased from 200kN/m2 for ordinary granular pile to 215kN/m2 for 1% biopolymerpercentageand to 288kN/m2 for 2% biopolymercontentbefore increasing significantly to 400, 579 and 662kN/m2 for biopolymer= 4, 6 and 8%, respectively. Accordingly, the maximum increasing in the bearing pressure (231%) occurred at *BP* = 8%. A similar trend was reported for *diameter ratio df/Dp*= 0.75, where the improvement due to adding biopolymercontentwas 7.0% when *biopolymer*= 1%, while the it was 110% when *biopolymer*= 8%.
However, the trend for the range *diameter ratio df/Dp*= 1.25–1.5 was different. Models with a *biopolymer*percentageof 3% showed little increase in the bearing-pressure in comparison with the ordinary gran-

ular pile , while significant increase in the bearing-pressure was reported forgranular pile prepared with other *biopolymer*percentage. For instances, an increase in $q_p$ of 3 and 5% was achieved for granular pile *df/Dp*= 1.25 and 1.5, respectively, when adding 1% *biopolymer*content, while 8% *biopolymer*resulted in about 74.0 and 48.5%increase in the capacity for granular pile *df/Dp*= 1.25 and 1.5, respectively.

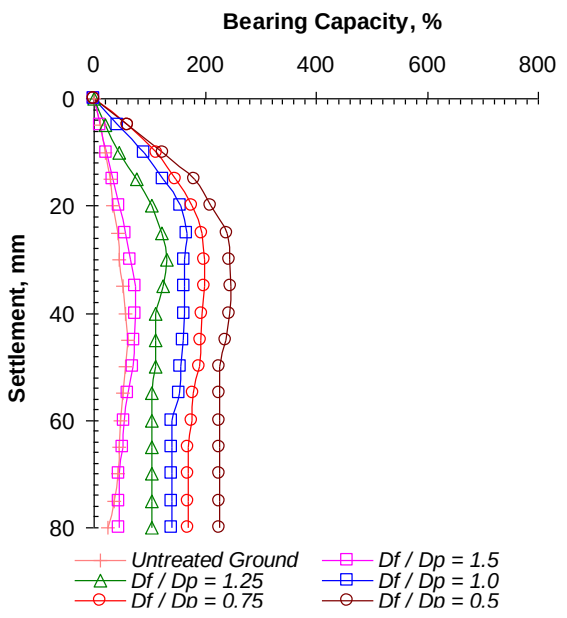
Figure 3 shows the variation in bearing capacity versus *biopolymer*percentage. This changingmay discussed in term of both the insignificant change in *bearing capacity*for3-6% *biopolymer*and the significant improvement in *bearing capacity*accompanied with a 4-8% *biopolymer*percentage. The insignificant improvement that occurred in granular pile when *BP* = 3-6% is due to the small percentageof*biopolymer*-acting as cement material for the pile fill material. As the friction and bonding of the fill materials constitute theshear strength of the granular pile, the incorporating of small amount of *biopolymer* (1-2%) would not be sufficient to be as inter-particle materialsto increase the bonding and consequentlystrength. The applied load can result in moving and sliding fill-particles easily under shearing; and thereby, lead tolow*bearing capacity*. For *biopolymer* = 9-8%,the substantial improvementis returned back to that these percentagescan fills the voids and coated thefill material, which leads to a significantbonding to the composite particles. For many geotechnical applications, the strength of the soil should be not less than 500 kN/m2. This means that *biopolymer*= 6-8% is likely the optimum *biopolymer*. Indeed, both of *biopolymer* content and *diameter ratio df/Dp* affectthe behaviour of granular pile and it is better to take them into consideration.

Figure 4 demonstrated the variation of the load capacity along the *diameter ratio df/Dp*. Increasing the *biopolymer* percentages caused clear drop in the *df/Dp* effect, especially for *biopolymer*≥ 6%, despite some difference was kept between the *bearing capacities* obtained at *diameter ratio df/Dp*= 0.5and those at *diameter ratio df/Dp*= 0.75–1.5. For instances, for 8% *biopolymer*content, the ultimate load keptunchanged at 549kN/m2 with increases *diameter ratio df/Dp*from 0.5 to 0.75, before decreasing to 565, 521 and 495kN/m2for*diameter ratio df/Dp*= 1.0, 1.25 and 1.5 respectively. This means that the reduction in the strength corresponding to increasing the *diameter ratio df/Dp* to 0.75, 1.0, 1.25 and 1.5 were 0.5, 12.4, 19.2 and 23.2% respectively. For the other *biopolymer* contents of 1, 2, 4 and 6%, the reduction in theload capacity*associated with increasing thedf/Dp from 0.5 to1.5* were 70.0, 65.1, 71.0 % and 30.7%, respectively. These reductions in ultimate bearing capacities were less than that with ordinarygranular pile (21.8%).

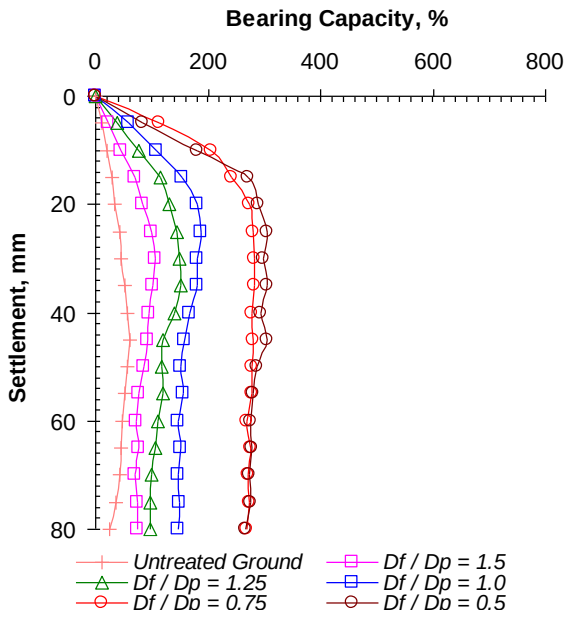
This drop in the variationof theultimate bearing capacityis returned back to the influnce of the *biopolymer*in the composite, and may be discussed from two points. Firstly, *biopolymer*can come into voidsand coatthe particles of granular pile to form stiff mixtureand inhance the poor-interlocking. The added *biopolymer* provide cemented composite matrix which characterised by high strength compared with ordinary granular pile, and thereby decreases what likely occurs in the ordinary granular pile models in regard to the easy sliding-rotation of the gravels in the pile. However, the addition of *biopolymer*cannot totally prevent the drop in the load capacity due to the effect of *diameter ratio df/Dp*. To examine the effect of fiber on the properties of *biopolymer-granular pile*, *biopolymer* content of 15% was adopted for such part.



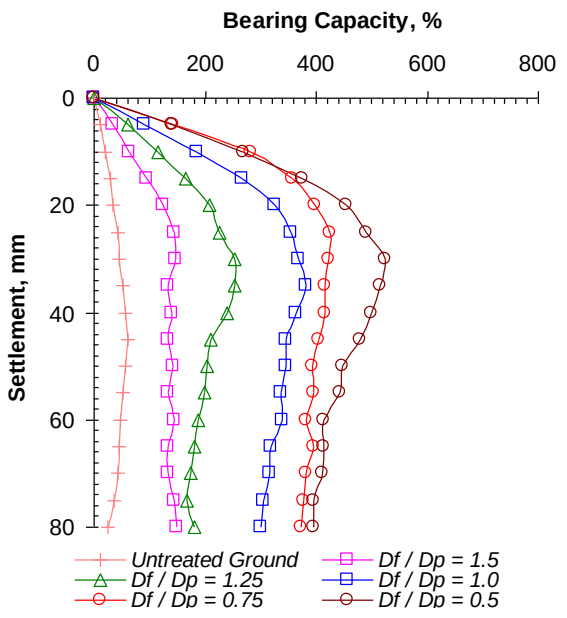

**(a) Biopolymer = 0%**




**(b) Biopolymer = 1%**

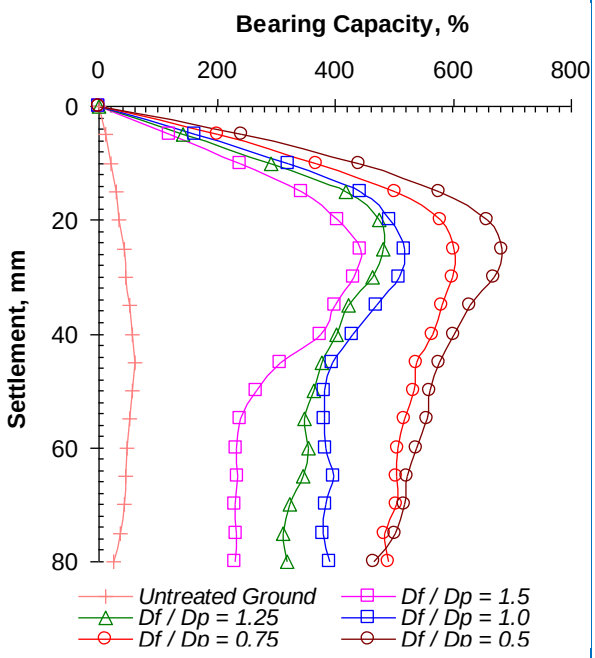



**(c) Biopolymer = 2%**

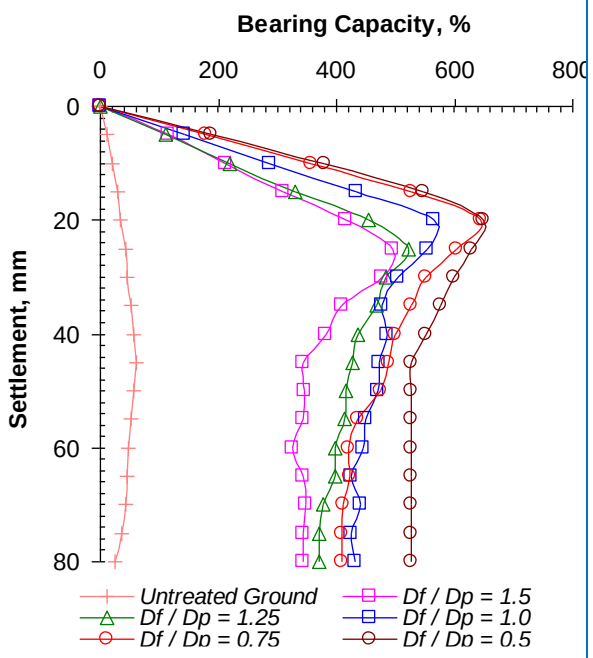



**(d) Biopolymer = 4%**

Fig. 2. Bearing capacity – Settlement of Granular Pile Considering Different Biopolymer Content and Diameter Ratio $d_f$ / $D_p$ (continued)




**(e) Biopolymer = 6%**




**(f) Biopolymer = 8%**

Fig. 2. Bearing capacity – Settlement of Granular Pile Considering Different Biopolymer Content and Diameter Ratio $d_f / D_p$

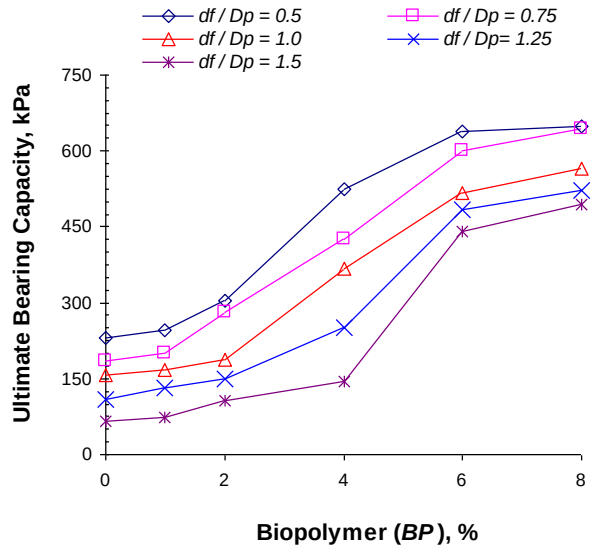



Fig. 3. Ultimate Bearing Capacities Considering Different Biopolymer Percentages

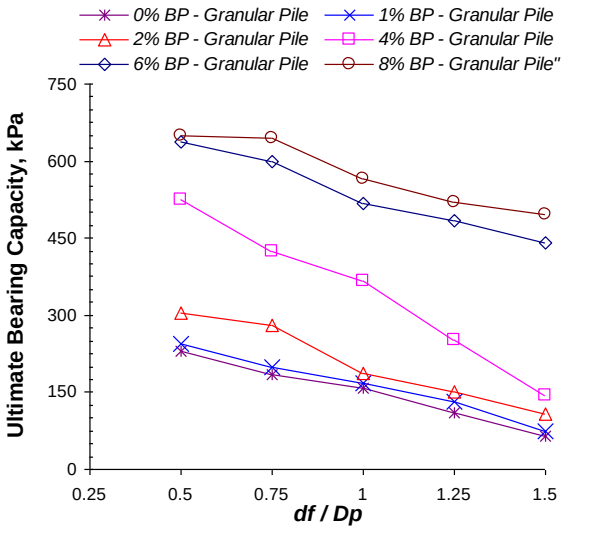



Fig. 4. Ultimate Bearing Capacities Considering Different $d_f / D_p$

### *5.2 Effect of Fiber on the bearing capacity of Biopolymer-Granular pile*

In this part, 0.5 and 1% of fiber were utilizedfor reinforcing the selected *biopolymer-granular pile*, i.e. *biopolymer*= 8%. This content was adopted as it provided the ultimate strength and the minimum variation due to the effect of the *diameter ratio df/Dp*. The prepared models of *fiber-biopolymer- granular pile* were tested considering different *diameter ratio df/Dp*= 0.5, 0.75, 1.0, 1.25 and 1.5.

Figure 5 summarises the variation in load capacity of *fiber-biopolymer-granular pile* along the *diameter ratio*, and compares it with *biopolymer-granular pile* and ordinary *granular pile*. This variation can be classified into two groups, *diameter ratio df/Dp*= 0.5 -1.0; and *diameter ratio df/Dp*= 1.25 and 1.5. For *biopolymer-granular pile*reinforced with 0.5% of fiber, the ultimate load capacity for *diameter ratio df/Dp*= 1.25 and 1.5 were very close to each other, and much less than those of *diameter ratio df/Dp*= 0.5 and 0.75, (although they have the same biopolymer content) where the load capacity $q_p$was 850, 800, 757, 603 and590kN/m2 for *diameter ratio df/Dp*= 0.5, 0.75, 1.0, 1.25 and 1.5, respectively. This means that the improvementof models, due to the 0.5% of fiber inclusion, relative to the *biopolymer-granular pile*, were31.0, 26.0, 24.1, 16.1 and 14.8% for *diameter ratio df/Dp*= 0.5, 0.75, 1.0, 1.25 and 1.5, respectively.

Similar trend can be seen for *biopolymer-granular pile*reinforced with 1.0% of fiber, as thecapacitydecreased slightly from 890 to 871 and 794 as *diameter ratio df/Dp* increased from from 0.5 to 0.75 and 1.0, followed by clear drop to 628 and 608kN/m2 as *diameter ratio df/Dp*increased to 1.25 and 1.5, respectively, consisting very significant improvement, at 39.0, 36.0, 35.5, 23.1 and 20% respectively.Therefore, it can be reported that although the effect of *diameter ratio df/Dp* on the reinforced granular pile is clear due to the soft clay adjacent to the pile, the capacities of the *fiber- biopolymer-granular pile* significantly higher than that of ordinary granular pile. The difference in the bearing capacity of *biopolymer-granular* with 1.0% fiber due to variation in *diameter ratio df/Dp* decreased to 2.1–29.6%, compared with 19.5–71.7% for the ordinary granular pile.

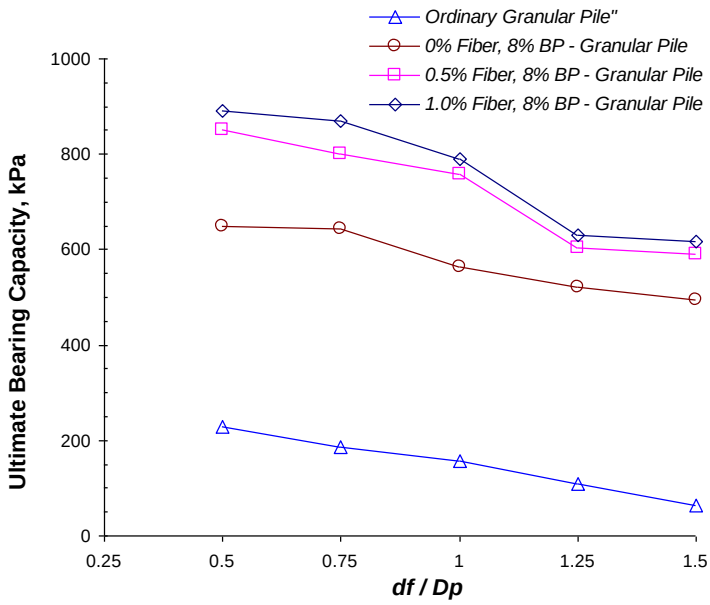



Fig. 5. Variation of The Ultimate Bearing Capacity With $d_f$ / $D_p$ of 8%Biopolymer-Granular Pile Considering 0.5 and 1% of Fiber

The improvement in the *fiber-biopolymer-granular* models can be returned back to the roles of the *fiber* and the *biopolymer*. The fiber has clear role in confining the granular particles, while 8% *biopolymer* substantially enhances binding between the fiber and *granular pile* particles, that create stiffening composite piles. This consequently enhance the behaviour of fiber, even with large *diameter ratios df/Dp*. In

other words,*biopolymer* can act as a cementation material by occupying the inter-granular voids and bonding the particles and the added fiber to form a single mass, and thereby eliminate the possible sliding and rotation of granular particles

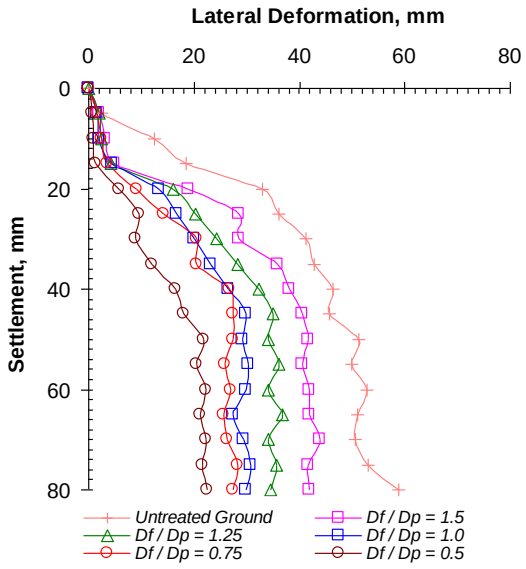
### *5.3 Deformation of the Fiber - Biopolymer-Granular pile*

This section details the deformation accompanied with ultimate load that was discussed in the above sections. It is worth to note that the lateral deformation was measured at depth of 30cm below the top surface of the ground, i.e. at about (length of *granular pile*/4).

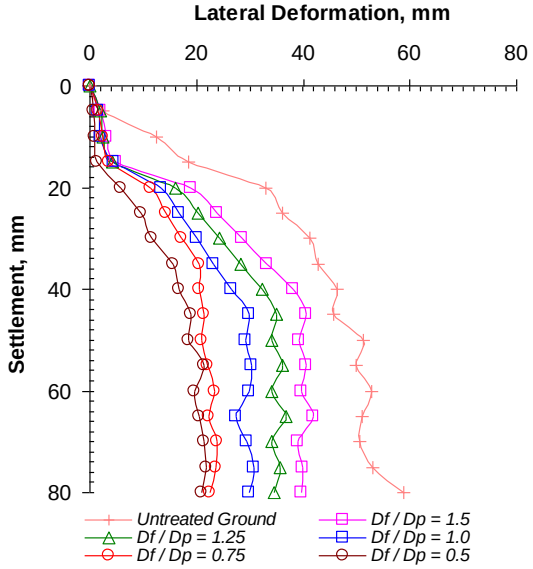
Compared with ordinary granular pile, contractionmode was dominant in the models until highsettlement and/or applied load was achieved. For example, insignificantlateral deformation was induced from the beginning of loading until the settlementachieved 12-17mm (for granular pile with 0, 1 and 2% of *biopolymer*), and until 17-24mm (for *granular pile* with 4-8% of *biopolymer*) (Figures 6). However, ordinary *granular pile* exhibited a significant amount of lateral deformation, particularly under *diameter ratio df/Dp*= 1.25-1.5. For example, the lateral deformation of the *granular pile* was 18, 21, 29, 34mm and 39mm for *diameter ratio df/Dp*= 0.5, 0.75, 1.0, 1.25 and 1.5, respectively.

Regardless of the *biopolymer*percentages, the stiffening granular pileshowed decreases in lateral deformation under all *diameter ratios df/Dp*. Moreover, as the *biopolymer*percentageincreased, less tendency for the granular pile to deform laterally (Figures 6). This tendency is attributedmainly to the properties of *biopolymer*, that has high bondingin comparison with theordinary granular pile, and therebywill cause low deformation. For example, the lateral deformation under *diameter ratio df/Dp*= 0.5 reached 20mm with 1% *biopolymer*, while with increasing *biopolymer*contents to2, 4, 6 and 8%, lateral deformationdecreased to 17, 15, 9mm and 6mm, respectively. The induced lateral deformation varied depending on *diameter ratio df/Dp* where, for example, the lateral deformationof *granular pile*was 22, 27, 29, 34mm and 41mm with *diameter ratio df/Dp*= 0, 0.5, 0.75, 1.0, 1.25 and 1.5, respectively. However,with *BP* = 8%, the lateral deformationwas 6, 11, 12, 17mm and 18mm with *diameter ratio df/Dp*= 0, 0.5, 0.75, 1.0, 1.25 and 1.5, respectively. Compared with ordinary granular pile, the low values of the lateral deformationand the less effect of the *diameter ratio df/Dp* is attributed to the bondinginfluenceachieved by *biopolymer*occupying the inter-granular voids, which resulted inbetter interlocking, high stabilityand less tendency of the particles in the *granular pile* to move and slide. Moreover, the using both the highest *biopolymer* content and less *diameter ratio df/Dp* resulted in the lowest lateral displacement.

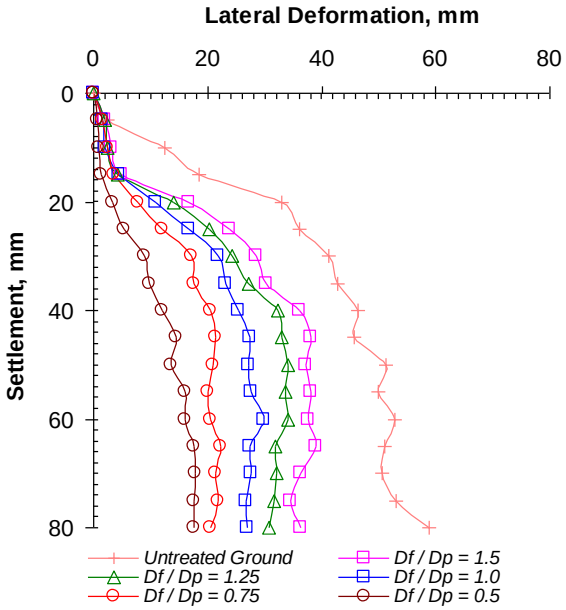
However, the lateral deformation of *8%biopolymer-granular pile*reinforced with 0.5 and 1.0% of fiber and loaded under different *diameter ratio df/Dp* of0.5, 0.75, 1.0, 1.25 and 1.5 are illustrated in Figures 7.Similar to the trends for *8%biopolymer-granular pile*, the initial lateral deformation occurs, depends on the *diameter ratio df/Dp*. For example, *granular pile* reinforced with 1.0%fiber deformed laterally when *settlement* reached 24mm for *diameter ratio df/Dp* of 0.5-1.0. As *diameter ratio df/Dp* increased to 1.25-1.5, the settlementrequired to start lateral deformationdecreased to 17mm. Moreover, the induced lateral deformation of *fiber-biopolymer-granular pile* also varies depending on the *diameter ratio df/Dp.* For the *biopolymer-granular pile* with 1.0% fiber, for example, it was a minimum of 4mm under *diameter ratio df/Dp*= 0.5 and increased to 5, 6, 8 and 10mm for *diameter ratio df/Dp*= 0.75, 1.0, 1.25 and 1.5 respectively. As expected, these values are less than those of ordinary granular pile due to the restraining nature of the *biopolymer* and fiber.



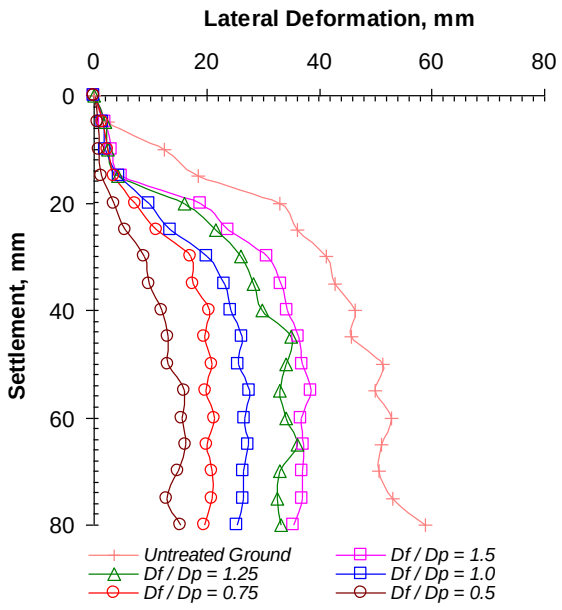

**(a) Biopolymer = 0%**




**(b) Biopolymer = 1%**

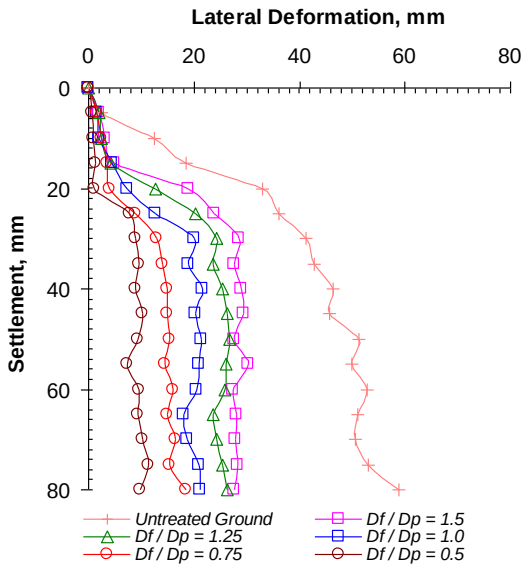



**(c) Biopolymer = 2%**

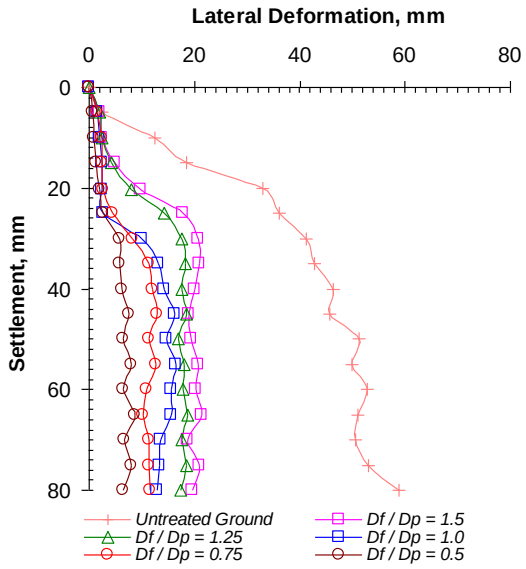



**(d) Biopolymer = 4%**

Fig. 6. Lateral Deformation – Settlement of Granular Pile Considering Different Biopolymer Content and Diameter Ratio $d_f / D_p$ (continued)

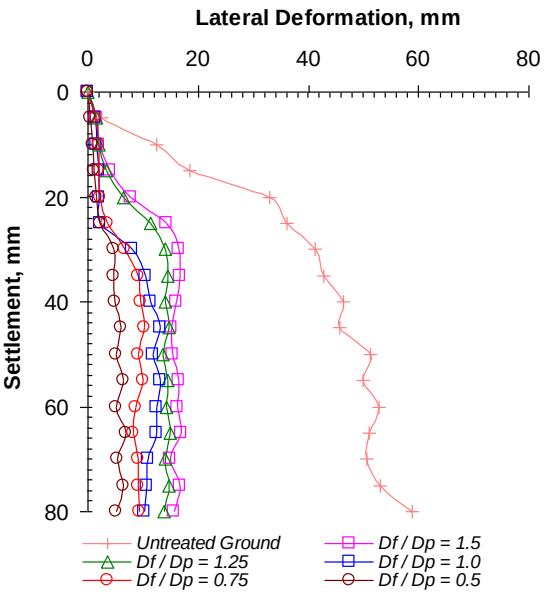



**(e) Biopolymer = 6%**

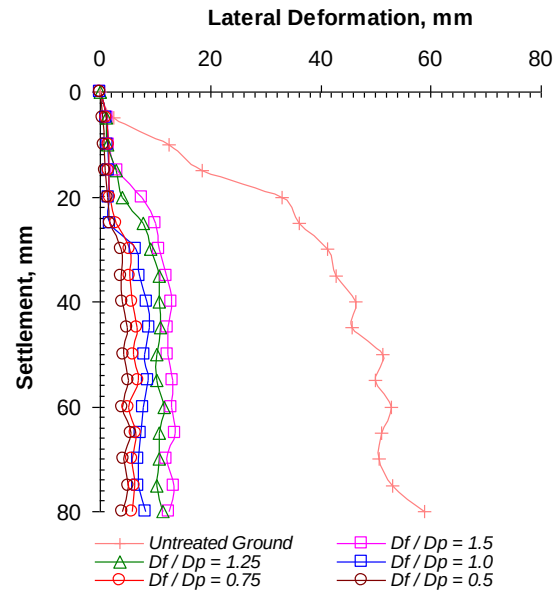



**(f) Biopolymer = 8%**

Fig. 6. Lateral Deformation – Settlement of Granular Pile Considering Different Biopolymer Content and Diameter Ratio $d_f / D_p$




**(a) Biopolymer = 8%, Fiber = 0.5%**




**(b) Biopolymer = 8%, Fiber = 1.0%**

Fig. 7. Lateral Deformation – Settlement of of 8%Biopolymer-Granular Pile Considering 0.5 and 1% of Fiber

## 6. Conclusions

The work aims to examine the performance of the granular pile incorporated with natural biopolymer as substitute to the conventional cements, which have sever impacts on the environment. The biopolymer was evaluated based on its ability to eliminate the bulging failure of the granular pile under loading.

In light of the obtainedoutcomes, the following points have been concluded:

- Incorporating the biopolymer resulted in improving the performance of the ordinary granular pile in respect of higher bearing capacity and less settlement. This improvement became significant with >4% biopolymer, as the bearing capacity of the ordinary granular pile with df / Dp = 0.5 (230.0 kN/m2) increased by 6.5, 32.1, 128.2 and 182.1% for biopolymer content of1, 2, 4, 6 and 8%, respectively.
- Although all biopolymer percentage resulted in increasing the load carrying-capacity of the granular pile, this improvement was affected by the diameter ratio df / Dp. Increasing df / Dp showed clear reduction in the bearing capacity. For 4% biopolymer, for example, the bearing capacity decreased from 525 kN/m2 to 425, 367, 252 and 144 kN/m2 as the df / Dp increased from 0.5 to 0.75, 1.0, 1.25 and 1.5 respectively. This reflects the effect of the adjacent soft layer.
- Experiments exhibited elimination to the bulging of the granular pile due to the role of the biopolymer in turning such pile to stiffening member. This improvement was accompanied with decreasing the lateral deformation significantly from 22.4 – 42.0 mm for the ordinary granular pile to about 6.4 – 18.7 mm for the 8%biopolymer-granular pile.
- Adding fiber provided more improvement as it act as reinforcements between the granular fill and the biopolymer.

**Author Contributions**: All parts of the current study have been prepared by the single author Prof. Alaa Al-Rkaby.

**Funding**: This study received no external funding.

**Conflicts of Interest**: The authors declare no conflict of interest.

## References

[1] Odeh, N. A., & Al-Rkaby, A. H. (2022). “Strength, Durability, and Microstructures characterization of sustainable geopolymer improved clayey soil”, *Case Studies in Construction Materials*, *16*, e00988.
[2] Al-Rkaby, A. H. (2019). “Strength and deformation of sand-tire rubber mixtures (STRM): an experimental study”, *Studia Geotechnica et Mechanica*, *41*(2), 74-80.
[3] Al-Rkaby, A. H., Chegenizadeh, A., & Nikraz, H. R. (2019). “An experimental study on the cyclic settlement of sand and cemented sand under different inclinations of the bedding angle and loading amplitudes”, *European Journal of Environmental and Civil Engineering*, *23*(8), 971-986.
[4] Dawood, A. O., Sangoor, A. J., & Al-Rkaby, A. H. (2020). “Behavior of tall masonry chimneys under wind loadings using CFD technique”, *Case Studies in Construction Materials*, *13*, e00451.
[5] Al-Rkaby, A. H., Nikraz, H. R., & Chegenizadeh, A. (2017). “Stress and deformation characteristics of nonwoven geotextile reinforced sand under different directions of principal stress”, *International Journal of Geosynthetics and Ground Engineering*, *3*, 1-11.
[6] Al-Rkaby, A., Chegenizadeh, A., & Nikraz, H. (2017). “Effect of anisotropy on the bearing capacity and deformation of sand”, *Australian Geomechanics Journal*, *52*(3), 53-63.
[7] Al-Rkaby, A. H., Chegenizadeh, A., & Nikraz, H. R. (2017). “Cyclic behavior of reinforced sand under principal stress rotation”, *Journal of Rock Mechanics and Geotechnical Engineering*, *9*(4), 585-598.

[8] Bergado, D. T., Rantucci, G., & Widodo, S. (1984). "Full scale load tests of granular piles and sand drains in the soft of Bangkok clay", In *Renforcement en place des sols et des roches. Colloque international* (pp. 111-118).
[9] Bergado, D. T., & Lam, F. L. (1987). "Full scale load test of granular piles with different densities and different proportions of gravel and sand on soft Bangkok clay", *Soils and foundations*, *27*(1), 86-93.
[10] Li, G. X., Huang, W. F., & Ugai, K. (2000). "Interactions between column inclusion and surrounding soil in composite ground", Lowland technology international: the official journal of the International Association of Lowland Technology (IALT)/Institute of Lowland Technology, Saga University, 2(1), 23-34.
[11] Bae, W. S., Shin, B. W., An, B. C., & Kim, J. S. (2002, May). "Behaviors of foundation system improved with stone columns", In ISOPE International Ocean and Polar Engineering Conference (pp. ISOPE-I). ISOPE.
[12] Najjar, S. S., Sadek, S., & Maakaroun, T. (2010). "Effect of sand columns on the undrained load response of soft clays", Journal of Geotechnical and Geoenvironmental Engineering, 136(9), 1263-1277.
[13] Shivashankar, R., Dheerendra Babu, M. R., Nayak, S., & Rajathkumar, V. (2011). "Experimental studies on behaviour of stone columns in layered soils", Geotechnical and Geological Engineering, 29, 749-757.
[14] Greenwood, D. A. (1970, June). Mechanical improvement of soils below ground surface. In *Inst Civil Engineers Proc, London/UK/*.
[15] Wehr, J. (2006). "The undrained cohesion of the soil as criterion for the column installation with a depth vibrator", In *Proceedings of the international symposium on vibratory pile driving and deep soil Vibratory compaction. TRANSVIB, Paris* (pp. 157-162).
[16] Niaounakis, M. (2015). Biopolymers: applications and trends. William Andrew.
[17] Soldo, A., Miletić, M., & Auad, M. L. (2020). "Biopolymers as a sustainable solution for the enhancement of soil mechanical properties", Scientific Reports, 10(1), 267.
[18] Chang, I., Im, J., Lee, S. W., & Cho, G. C. (2017). "Strength durability of gellan gum biopolymer-treated Korean sand with cyclic wetting and drying", Construction and Building Materials, 143, 210-221.
[19]Ta'negonbadi, B., & Noorzad, R. (2018). "Physical and geotechnical long-term properties of lignosulfonate-stabilized clay: An experimental investigation", Transportation Geotechnics, 17, 41-50.
[20] Zhang, T., Liu, S., Zhan, H., Ma, C., & Cai, G. (2020). "Durability of silty soil stabilized with recycled lignin for sustainable engineering materials", Journal of Cleaner Production, 248, 119293.