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Influence of biopolymer treatment on the dynamic properties of silty sand

S Smitha[1] and K Rangaswamy[2]

[1] Former Research Scholar, Department of Civil Engineering, National Institute of Technology, Calicut- 673601
[2] Associate Professor, Department of Civil Engineering, National Institute of Technology, Calicut- 673601
ranga@nitc.ac.in
smithasivadas123@gmail.com

Abstract. The silty sand obtained from Waynad, Kerala was found to be liquefaction susceptible under saturated condition when subjected to cyclic loading. The stabilization of the soil using agar biopolymer was found to impart significant resistance to liquefaction since a great reduction in excess pore pressure build-up was observed. In this study, the effect of biopolymer treatment on the secant shear modulus and damping behavior of the soil under varying biopolymer content, curing period and over-consolidation ratio (OCR) have been studied. A set of cyclic triaxial tests were performed on the untreated and biopolymer treated silty sand. It was observed that the shear modulus increased with increase in the biopolymer content, curing period and OCR. Furthermore, the biopolymer treated soil was found to exhibit a higher damping when compared to the untreated silty sand.

Keywords: silty sand; liquid limit; permeability; shear modulus; damping ratio; biopolymer; OCR

1 Introduction

In the present day, sustainable soil improvement techniques are gaining popularity since the use of conventional improvement methods cause harm to the soil and soil ecosystem in many ways. The traditional admixtures like cement, lime and chemical grouts interact with soil chemically and change the soil structure for betterment of its properties. But they release many by-products that prove to be harmful to the plants as well as the microbes in soil. Also, the production of these admixtures requires a high carbon footprint that affects the sustainability. Hence, vigorous studies are being carried out by researchers around all over the world to replace the traditional admixtures like cement and chemical additives completely from soil improvement realm. As a part of this objective, the soil improvement focussing on enhancement of dynamic properties of soil using environmental friendly methods are also to be analysed. Many new such methods for mitigation of liquefaction and improvement of dynamic properties of soil are imminent (Huang and Wen 2015, Towhata 2008). Some of the methods are partial desaturation of soil by use of nitrogen gas bubbles or biogas (He et al. 2013, Rebata-Landa and Santamarina 2012), calcium carbonate precipitation (Xiao et al. 2018) and use of non-traditional admixtures like biopolymers, nano-materials etc (Smitha and Rangaswamy 2020, Smitha and Rangaswamy 2021a, Rangaswamy et al. 2021).

In the present study the application of biopolymer for enhancing the properties of liquefaction prone silty sand is explored. Biopolymers are produced from living organisms like algae fungi etc. and are commonly used in food industry and pharmaceutical industry. A plant based biopolymer; agar was used to improve the properties silty sand. Special attention was given to explore the modifications imparted on the dynamic parameters of the soil by the addition of biopolymer. The changes in its permeability characteristics and plasticity indices were also analysed.

2 Materials and Methods

2.1 Materials

The silty sand attained from Kalpetta in Kerala was used. It had a coarse content of 75% and fine content of 25%. The fine content of the soil consisted of mainly silt and less than 3% of clay. Hence the soil was almost cohesionless and did not possess any plasticity characteristics. The properties of the soil that were determined by performing various laboratory tests are given in Smitha et al. (2019). The biopolymer chosen for the current study was agar biopolymer that was obtained from Urban Platter. It was of food grade quality and the properties are listed in Smitha and Rangaswamy (2020).

2.2 Experimental program

The silty sand was mixed with the biopolymer through the wet mixing process where the biopolymer was added to the soil after making it into a solution form. Soil was found to be fully saturated at water content of 40% and hence the biopolymer solution with respect to weight of dry soil was kept as 40%. The agar is insoluble in water below 80°C. Therefore agar-water mixture was heated to 90°C and then the viscous solution was added to the dry soil and mixed well. When the temperature of the mix drops to less than 40°C, the viscosity of the agar solution goes on increasing and at a temperature of about 35°C it sets to form a firm hydrogel. This agar solution would have completely wetted the soil during this temperature transition stage and hence the hydrogel would be formed within the soil pores, in between the soil particles and as a coating over individual soil grains.

Generally, the sandy soils do not possess any plasticity characteristics due to the absence of clay minerals. The silty sand from Kalpetta also did not show any plasticity behavior in wet condition. But since agar gel is sticky and binding in nature, it imparts some plastic properties to the soil. Hence, the plasticity characteristics of treated silty sand were attempted to be found out using Atterberg‘s limit tests. The treated soil after 7 days of curing was powdered and sieved through 425 micron sieve to carry out plasticity indices tests as per IS code. The treated soil samples were cured for 7 days and again crushed and filled in the permeability mould to determine the permeability property. A set of consolidated undrained cyclic triaxial tests were also carried out at varying agar dosages, curing periods and OCRs. For preparing the untreated soil samples, air pluviation method was employed. The treated soil specimens were prepared in a split mould. After adding the hot agar solution to the dry silty sand, the wetted soil was transferred to the split mould. Later once the gel formation has occurred the samples were extracted out of the moulds and kept for curing in a temperature-monitored environment. All the soil specimens were prepared at a skeletal relative density of 30%. The relative density was fixed as 30% so that a loose soil condition was replicated in laboratory. Soil specimens were saturated using a three step process of CO_2 saturation, water circulation and pressure saturation after which consolidation and shearing was carried out. The detailed steps for soil sample saturation and consolidation are elaborated in Smitha and Rangaswamy (2020). The specimens were subjected to strain controlled sinusoidal loading during which the pore pressure and deviatoric stress measurements were recorded.

3 Results and Discussions

The plastic limit and shrinkage limit tests did not yield any significant results. The soil was not much plastic to be rolled into threads or the shrinkage of agar gel was very less within the pore space of soil to cause any overall volume change. The liquid limit test was performed on silty sand treated with different dosages of agar (0.5%, 1% and 2%) using cone penetrometer (Fig. 1(a)) and the results are shown in Fig. 1(b). The liquid limit was taken as the water content corresponding to 20 mm penetration and it was obtained as 26, 33 and 37% for 0.5, 1 and 2% of agar treatment. The increase in liquid limit with increase in agar content shows that biopolymer in silty sand has imparted the plasticity in cohesionless silty sand. The water retention and water absorption property of the agar hydrogel due to its hydrophilic property is a justification for the increased liquid limit with increase in agar biopolymer content.

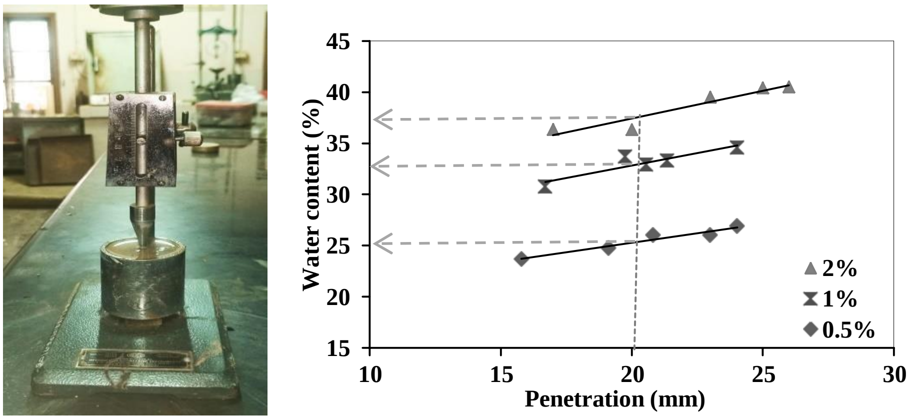

Fig. 1. (a) Cone penetrometer apparatus (b) Liquid limit of treated soil at different concentration of agar biopolymer using cone penetration test.

The constant head permeability test was carried out on both untreated and agar treated silty sand samples and the results of coefficient of permeability (k) of the same are tabulated in Table 1. The permeability of agar biopolymer treated soil was found to decrease and as the dosage of biopolymer increased permeability was found to be decreasing. This was because the agar biopolymer would fill up the pore spaces in soil that reduces the pathway to the flow of water and produce a clogging effect. Also, agar biopolymer was hydrophilic in nature that leads to absorption of water to some extent during the test, thereby causing a reduced permeability in treated soil. The coefficient of permeability had reduced by as much as 42% in 2% agar treated soil when compared to untreated silty sand. The results are comparable with previous permeability studies on biopolymer treated soil by Bouazza et al. (2009), Khachatoorian et al. (2003), Cabalar et al. (2018) and Ivanov and Chu (2008). The permeability reduction due to treatment with biopolymer suggest that there are lesser pore spaces for the passage of water and the availability of lesser pore spaces would result in lower pore pressure build-up during cyclic loading.

Table 1. Permeability characteristics of biopolymer treated and untreated silty sand

% Agar	k (mm/s)	Decrease in k (%)
0	0.013848	-
1	0.011456	17.27
2	0.007941	42.65

In order to analyse the effect of biopolymer dosage on dynamic properties of agar treated soil, the cyclic triaxial tests were done on untreated soil as well as agar treated soil at agar contents of 0.5%, 1%, 2% and 3%. The percentage of agar was calculated based on the dry weight of soil. The curing period was kept as 7 days for all the tests. Other test parameters such as loading frequency and strain amplitude were kept as 1 Hz and 0.8% respectively. The secant shear modulus (G) and damping ratio (D) at different loading cycles was analysed from hysteresis loops (Stress vs. strain curves) as and is plotted in Fig. 2. The 0% agar in the plots indicates the untreated silty sand. The G value was found to be decreasing with increase in number of cycles for both treated and untreated soil (Fig. 2a). But for treated soil this decrease was much less. Furthermore, it can be clearly perceived that with biopolymer treatment, the shear modulus had significantly increased. The agar biopolymer creates a three dimensional gel network within the soil and enhances the stiffness of the soil thereby increasing the shear modulus of the silty sand. It was seen that as the concentration of agar increased, the damping ratio also increased (Fig. 2b), which was ascribed to the increased amount of hydrogel in between the soil particles, which led to greater dissipation of energy.

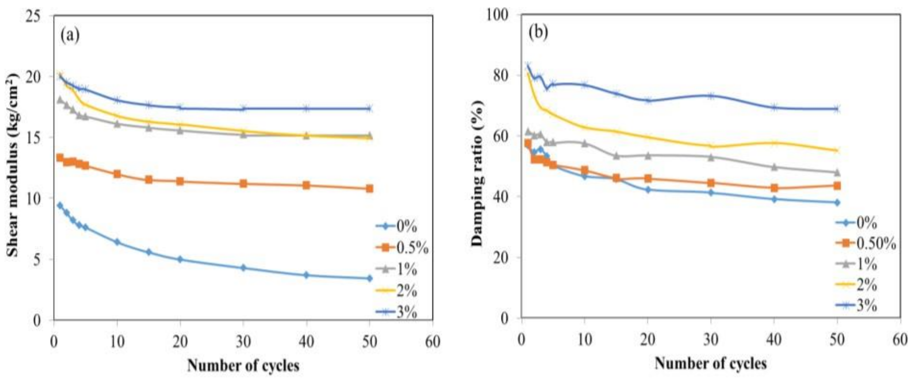

Fig. 2. Effect of biopolymer content on (a) secant shear modulus (b) damping ratio

Similarly, the variation in modulus and damping with curing of the treated soil samples were analysed by performing cyclic triaxial tests on agar treated soil after a curing period of 1, 3, 7, 28 days and 1 year. The G value was found to be increasing with an increase in curing up to 7 days after which it was almost constant (Fig. 3a). The shear modulus curves of 7 days, 28 days and 1 year cured soil samples are almost overlapping. This shows that after 7 days the strength gain of agar treated soils had almost stabilised. The decrease in G with the increase in cycles was not found for 1 day and 3 days cured soil samples; whereas it decreased with the number of cycles for higher curing times. This might be because at lower curing time the agar gel in the pore spaces would still be in a softer form with higher water content. Agar gel, being hydrophilic in nature has a tendency to absorb water during saturation of the soil sample. As per Clarke (1925) the water content of the agar gel before exposure to water determines the amount by which it swells back on exposure to water. When the soil specimen at lower curing times are saturated the amount by which the agar absorbs water and swells is much higher than the same for longer curing times. Hence the pore spaces in soil at lower curing period is lower that causes lesser stiffness degradation with increase in number of cycles. The damping was also found to increase with increase in curing period (Fig. 3b). With increase in curing the pore spaces in soil would be more as indicated from the pore pressure study by authors (Smitha and Rangaswamy 2021c). Hence the energy dissipation within the treated soil cured for longer curing times will also be higher

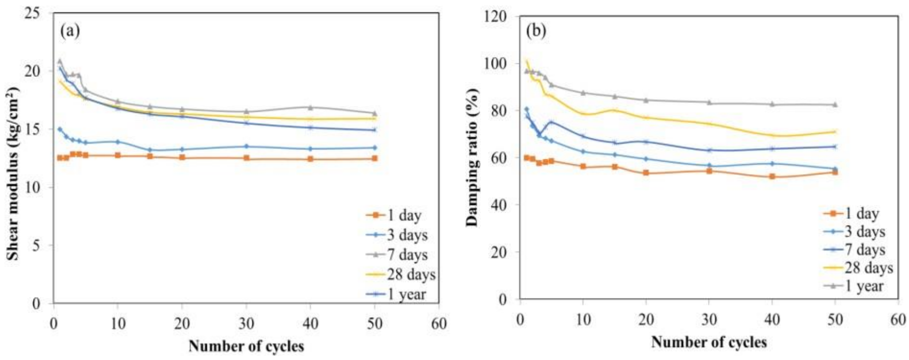

Fig. 3. Effect of curing period on (a) secant shear modulus (b) damping ratio

The cyclic tests were performed on the untreated and 7-day cured 2% agar treated soils at varying over-consolidation ratios. Other parameters of the test were kept constant. The strain amplitude for testing was maintained as 1%, frequency 1 Hz and effective cell pressure during shearing was fixed as 100 kPa. For the purpose of producing OCRs of 2, 3 and 4, the saturated soil samples were initially consolidated at effective confining pressures of 200 kPa, 300 kPa and 400 kPa respectively, after which the cell pressure was reduced to adjust the effective confining pressure to 100 kPa. Then the samples were consolidated and sheared following the procedure similar to any other test. The shear modulus and damping ratios, calculated for different cycles at OCR ranging from 1 to 4 are plotted in Fig. 4a and b respectively. For both untreated and treated soil similar pattern was observed for the effect of OCR on shear modulus. It was found that the shear modulus increased with an increase in OCR in both cases. This was similar to the behavior shown by any soil (Sun and Yuan 2006). The particles are in a closer contact with each other when the pressure applied The variation of OCR did not produce any significant effect on the damping characteristics of untreated soil, but for treated soil the damping ratio was found to increase with the increase in OCR (Fig.5a and b). This was because at high OCR, the closer contacts produced between the gel and soil at higher past pressure will be still present even upon decreasing the confining pressure. This would result in increased energy dissipation at gel-soil interphase that produced high damping.

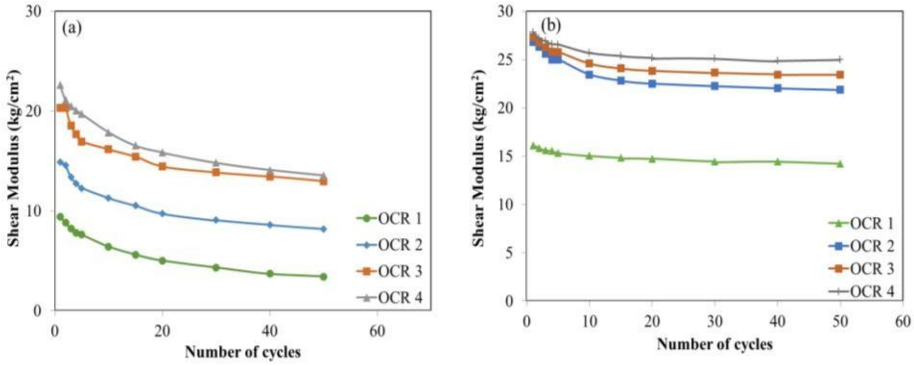

Fig. 4. Effect of OCR on secant shear modulus of (a) untreated soil and (b) 2% agar treated soil

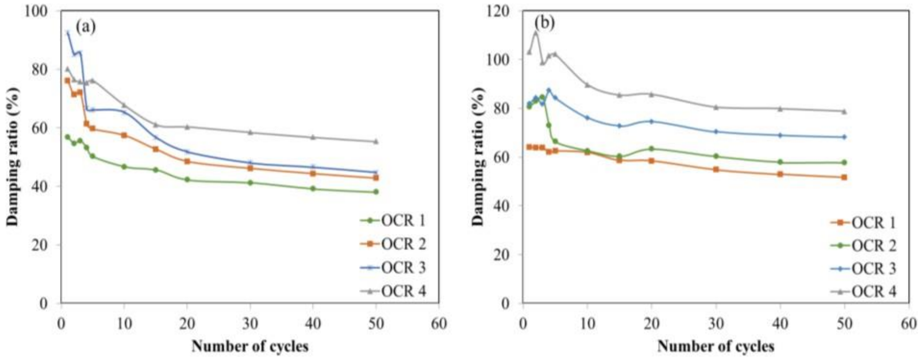

Fig. 5. Effect of OCR on damping ratio of (a) untreated soil and (b) 2% agar treated soil

4 Results and Discussions

Based on the experimental study of the use of biopolymer for improving the dynamic properties of silty sand from Wayanad, the following conclusions were drawn:-

a) The biopolymer treatment had induced plasticity characteristics in the silty sand as indicated by the liquid limit. With increase in agar dosage the liquid limit was found to be increasing
b) A decrease in permeability due to biopolymer treatment was observed in the silty sand showing that the pore spaces in the soil may be plugged with the biopolymer gel.
c) An increased damping ratio and shear modulus was exhibited in the agar treated soil.
d) The secant shear modulus increased with increase in agar content, curing period and OCR
e) The damping ratio was found to increase with agar content and curing period. But it did not show much variation at different OCRs.

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