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Experimental study on cyclic shear behavior of biopolymer treated soils

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ABSTRACT

Biopolymer is a kind of material produced from the secretions of microorganisms that exist in nature. It is eco-friendly and does not emit carbon dioxide during the production process. Humans have used biopolymers in various fields, such as cosmetics and food. In addition, recent attempts have been made to utilize biopolymers as a ground improvement material, and uniaxial compressive strength and shear strength are increased with a smaller amount than cement (Chang et al. 2015). In the ground improvement method, shear strength is an indicator of the stability of the ground. The types of shear strength include static state shear strength and dynamic state shear strength. Dynamic state shear strength indicates how stable the ground is from disasters such as liquefaction and earthquakes. Im et al., 2017 reported that biopolymer-treated soil had a higher damping ratio than untreated soil, indicating that energy dissipation was more likely to occur. In this study, biopolymer-treated soil's dynamic shear behavior was tested and analyzed.

1. INTRODUCTION

Biopolymer-treated soil, an eco-friendly ground improvement material, has been found to improve the strength of the underlying ground through previous studies (Cabalar et al., 2017). The bearing capacity and strength of the foundation ground are critical indicators of the stability of the structure. Various studies to increase the foundation's strength have been conducted through numerous studies. Still, most are studies to improve strength in static loading conditions, and studies on dynamic loading conditions such as earthquakes and liquefaction are insufficient. Dynamic loading conditions can indicate strength against various repetitive loads such as artificial

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explosive vibration and ocean wave loading, as well as vibration caused by earthquake or liquefaction and these kinds of threats are increasing (Ardeshiri-Lajimi et al. 2016, USGS 2016). A representative machine that simulates such dynamic shear loading is a cyclic simple shear test apparatus (CSS) modified with a direct shear test apparatus. After performing sufficient consolidation under confinement stress conditions, CSS measures various properties by applying a set cyclic stress ratio. This study conducted a cyclic simple shear test using biopolymer-treated soil according to different cyclic shear stress. As a result, shear strength under dynamic loading conditions was studied. Thus, biopolymer-treated soil's potential as a liquefaction mitigation material was confirmed.

2. CYCLIC SIMPLE SHEAR TEST

2.1 Materials

2.1.1 Sand: Jumunjin standard sand

Jumunjin sand is used to be the target cohesionless sand in this study. Jumunjin sand is a standard sand in Korea classified as *SP* due to the particle size distribution is shown in Fig. 1. Detail representative basic soil properties of Jumunjin sand are summarized in Table 1.

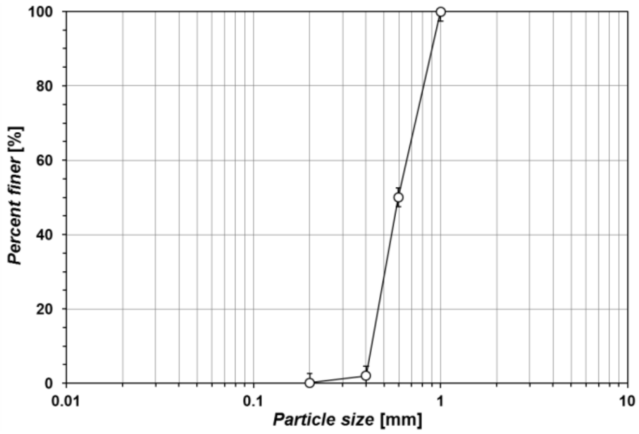


Fig. 1 Particle size distribution of Jumunjin sand.

Table.1 Basic geotechnical engineering properties of Jumunjin sand.

C_u	C_c	e_{max}	e_{min}	G_s	*USCS*
1.94	1.09	0.89	0.64	2.65	SP

2.1.2 Biopolymer: Crosslinked Xanthan Gum

When an aqueous solution of cations such as Cr^{3+}, Ca^{2+}, Fe^{3+} is added to xanthan gum hydrogel, which has an anion on the surface, the ions on the surface crosslinking and hardening (Fig. 2). In other words, if the existing xanthan gum-treated soil showed strength through the drying process (Chang et al., 2015), xanthan gum cation crosslinking showed strength over time. In this study, Cr^{3+} ion was used among various cations. The xanthan gum-crosslinked soil used in this study is defined as XGCr treated sand.

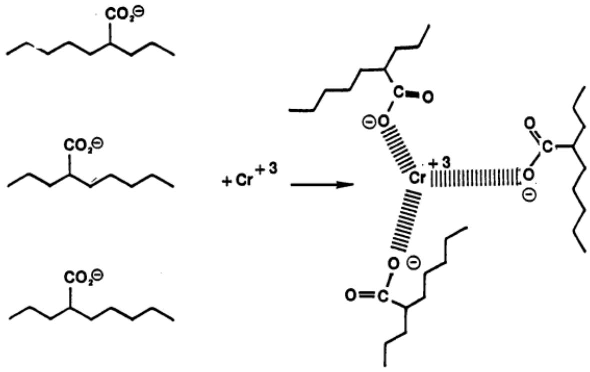


Figure. 2 Crosslinking of xanthan gum and Cr^{3+} ion

2.1.3 Biopolymer: Gellan Gum

Gellan gum, like xanthan gum, is a polysaccharide-based biopolymer and is known to be produced by a microorganism called Sphingomonas elodea (Bajaj et al., 2007). The gellan gum biopolymer used in this study was purchased from Sigma Aldrich with CAS No: 71010-52-1. Gellan gum is a linear anionic polymer with a molecular weight of 0.5-2 × 10^6 Da (Imeson 2010). Gellan gum can be maintained as a complete aqueous solution at temperatures above 90 degrees Celsius. If continuous heat is not applied, the curing action occurs immediately, gradually changing to a gel state.

A previous study confirmed that the damping ratio and shear modulus values, which are essential parameters of dynamic loading resistance, were high due to the gel form characteristics of gellan gum. In particular, the damping ratio at a very small strain (0.001%) is about five times higher than that of untreated sand (Im et al., 2017).

2.2 Experimental methods

2.2.1 Cyclic stress ratio (CSR) & Cyclic resistance ratio (CRR)

Accurate prediction of residual pore water pressure in sandy soil due to seismic loads is a critical factor in the performance-based design of geotechnical structures, including tunnels. To this end, various experimental and theoretical pore-water pressure models have been developed and applied. One of the most critical factors in predicting residual pore water pressure is identifying the empirical relationship between cyclic loading and the number of loadings that induce liquefaction, which is also related to the evaluation of resistance to seismic loads. The cyclic load is typically normalized to the initial confinement stress, called the cyclic stress ratio, CSR (1). The CSR at the number of loads N causes liquefaction is called cyclic strength, or cyclic resistance ratio (CRR). A curve showing the relationship between various CRRs, cyclic numbers, and N is called a repetition resistance curve.

$$CSR = \frac{\tau_{cyc}}{\sigma'_{vc}} \quad (1)$$

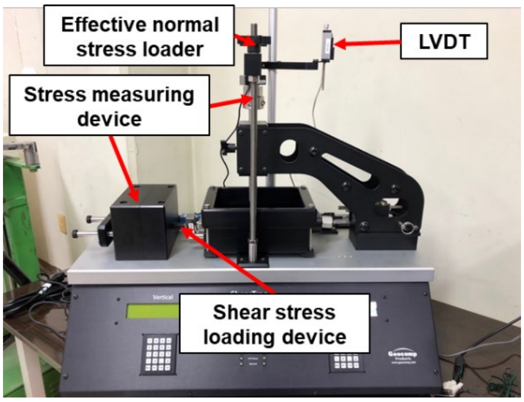
2.2.2 Specimen preparation

The cyclic simple shear test used gellan gum-treated sand, and XGCr treated sand. In the previous direct shear test results, XGCr treated sand had high shear strength at a curing time of 24 hours or more. Therefore, resistance to dynamic loading was also confirmed in the cyclic simple shear test at a curing time of 24 hours or more. The water content of the sample specimen was 20% of the soil mass, and the size was 20 mm in height and 63 mm in diameter. The composition of both xanthan gum and gellan gum was set to 1% of the soil mass. The specimen was stored in a thermostat during the curing process to prevent water evaporation. Since the resistance of dynamic loading depends on the degree of compaction of the specimen, the degree of compaction was uniformly 'dense.'

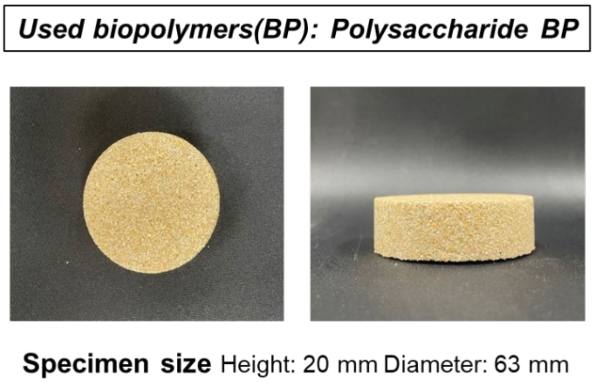
2.2.3 Cyclic simple shear testing

The cyclic simple shear test equipment used in this study is a Shear Trac II-DSS equipment developed by GEOCOMP, and both static shear test and cyclic simple shear test can be implemented. The test apparatus is divided into a consolidation phase and a shear phase. In the consolidation phase, the initial set confinement pressure is continuously applied. The degree of consolidation is measured. When a constant value is maintained, the cyclic shear test starts by moving to the shear phase. The confinement pressure in this study is 100 kPa.

This apparatus measures about 500 shear strain, shear stress, axial strain, and excess pressure per cycle. Shear strain amplitude, shear stress amplitude, peak pressure ratio, shear modulus, and damping ratio are measured for each cycle. The experimental setting in this study was set to stop when the shear strain amplitude reached 10% of the specimen diameter. The experiment was conducted by changing the CSR value for each case.



(a) Direct shear apparatus



(b) Specimen description

Figure. 3 Outline of cyclic direct shear test

3. RESULTS

The number of cycles in Figure 4 is a graph showing at what cycle the sample peak-to-peak strain value exceeds 10% at a specific cyclic stress ratio when the cyclic shear test is performed. This study described resistance curves for gellan gum treated soil, XGCr treated soil and dry-state Jumunjin. Both gellan gum-treated sand and XGCr-treated sand, which are biopolymer-treated sands, have a cyclic stress ratio of 0.3 or higher. The cyclic resistance ratio is when the peak-to-peak strain value is above 10% and when the cyclic liquefaction number is ten. Based on the trend line, the CRR value of the gellan gum treated soil is The CRR value of 0.320, XGCr treated soil was 0.319, and the shear resistance to dynamic loading of biopolymer treated soil was high.

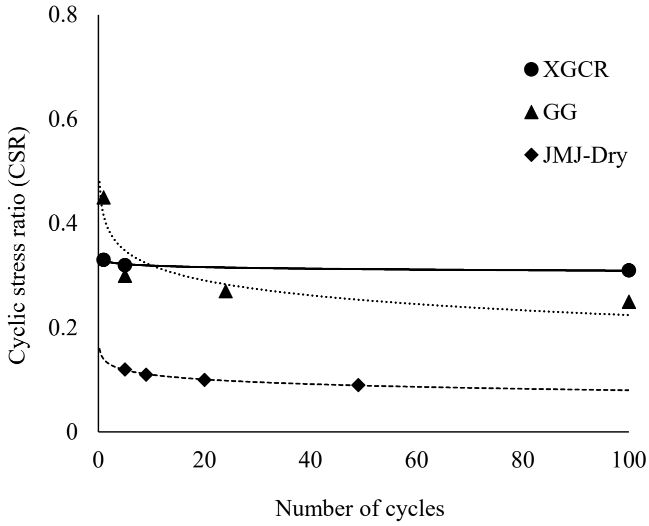


Figure 4. Cyclic resistance ratio (Jumunjin sand, Gellan gum, Xanthan gum)

Table 2. Cyclic Resistance Ratio comparison

Soil type	State	Cyclic Resistance Ratio (CRR)
Gellan Gum	Wet	0.320
XGCr	Wet	0.319
Jumunjin	Dry	0.109

4. CONCLUSIONS

In this study, cyclic simple shear test was conducted on various types of biopolymer-treated soil samples. Depending on the thermo-gelation characteristics of gellan gum, thermal treatment was applied to gellan gum-treated soil during the specimen preparation process. Also, time-gelation characteristics of cation crosslinked xanthan gum, time curing treatment was also applied to xanthan gum-treated soil too. It is concluded that the existence of a biopolymer within sand pores affected the dynamic properties of the sand. When dynamic loading is applied due to gelation, energy dissipation occurs (Im et al., 2017), making biopolymer-treated soil resistant to a higher cyclic stress ratio. This study confirmed that biopolymer-treated soil had sufficiently higher resistance to dynamic loading than untreated soil. In addition, the experiment performed in this study is a basic study to evaluate whether biopolymer-treated soil has resistance to dynamic loading. Further experiments should be conducted for various conditions in the future.

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