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Dynamic properties of Gellan treated sands using resonant column tests

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ABSTRACT

Due to the numerous environmental concerns in recent years, the search and development of sustainable technologies have been pursued. As a result environmentally friendly methods of soil improvement, such as the potential use of biopolymers, has been researched. Previous studies on biopolymers uses in soil improvement have shown that the strengthening efficiencies of biopolymer are substantial (Chang and Cho 2012). However, in order to fully understand the applicability of biopolymer treated soils, various properties such as the dynamic properties of these soils must be considered. In this study, the dynamic properties of biopolymer treated soils were observed through the use of resonant column tests. Gellan gum was the target biopolymer used in this study, and the target soil for this study was Jumunjin sand, the standard sand of Korea. Through this study it was seen that the use of biopolymers were capable of enhancing the dynamic properties of the soil, and that its use had possibilities of being used to reduce earthquake related soil failures.

1. INTRODUCTION

Due to the numerous environmental concerns in recent years, the search and development of sustainable technologies have been pursued. Among geotechnical engineering methods, one area that has remained fairly stagnate has been the field of soil improvement and treatment. The most widely used and accepted method of soil improvement has been the use of cement. This is because cement is an extremely versatile substance that provides exceptional strength improvements for low costs. However, the use of cement has been widely accepted as an environmentally hazardous material.

Among sustainable practices, one method of a sustainable soil improvement method has been the use of biopolymers within the soil. Biopolymer researches and

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applications have been increasing in recent years, and the development of various biopolymer enhancements to soils has been studied (Awad et al. 2012; Chang and Cho 2012; Chang et al. 2015a; Khatami and O'Kelly 2013). These studies have shown that the use of biopolymers have interesting and recognizable improvements to the engineering properties of soils. However, the majority of these studies focus on the static conditions of these biopolymer treated soils. Therefore, for the focus of this study the dynamic conditions of biopolymer treated sand will be determined using a resonant column test.

One major area of concern for soil stability is with earthquake loadings and the liquefaction of soils as a result of these loadings. Since liquefaction occurs mainly on sandy soils, the target soil for this study was set a Jumunjin sand, the standard sand for S. Korea. In this study the biopolymer gellan gum was thermally treated to improve the engineering characteristics of these sands, and the dynamic properties were observed using a resonant column apparatus.

2. MATERIALS AND PROCEDURE

2.1 Materials

Jumunjin Sand

Jumunjin sand is the standard sand in S. Korea, and it has been used in numerous studies and researched in the field of geotechnical and environmental engineering. It is classified as a poorly graded sand with a D_{60} and D_{10} of 0.6 mm and 0.31 mm respectively. It has a specific gravity (G_s) of 2.65 and a uniformity coefficient (C_u) and a coefficient of gradation (C_c) of 1.94 and 1.09 respectively. The particle size distribution of Jumunjin sand is shown in *Fig. 1*.

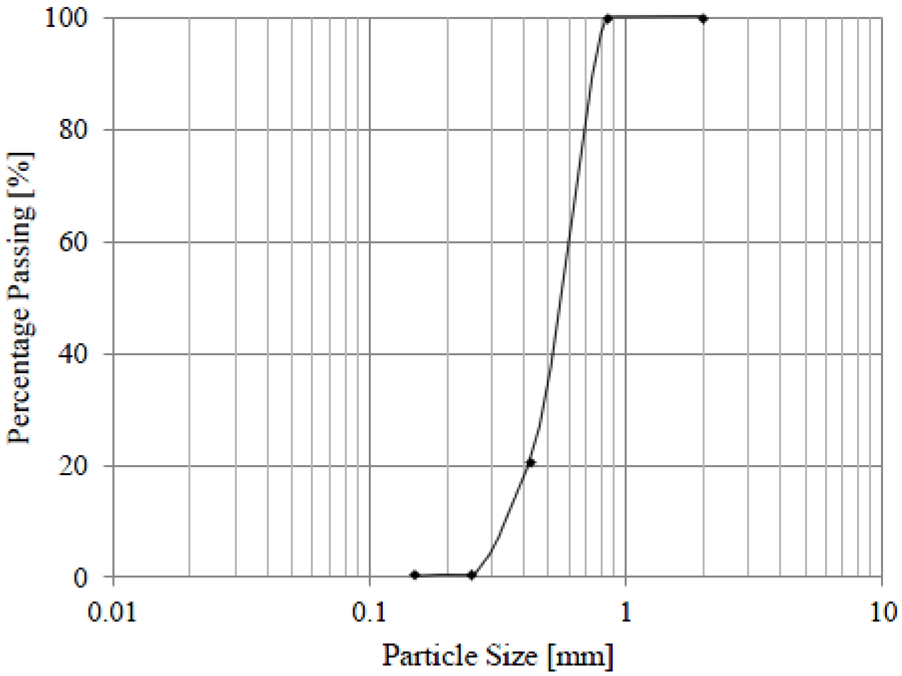

Fig. 1 Particle size distribution of Jumunjin sand

Gellan Gum Biopolymer

Gellan gum is a polysaccharide biopolymer with a high molecular weight that is fermented from the microbe *Sphingomonas elodea* (Bajaj et al. 2007*)*. The gellan gum biopolymer used in this study was purchased from Sigma Aldrich with a CAS No: 71010-52-1. One major property of gellan gum is its thermos-gelation characteristic. At normal room temperature, gellan gum is only partially hydrated in deionized water, however, when the water is heated to temperatures above 90°C, the gellan particles are easily dispersed. After the solution is heated, when it cools back down to room temperature the gellan particles reform with suitable cations that allow for a stronger link between the particles, which results in the formation of a stiff hydrogel (Huang et al. 2007).

2.2 Procedure

Sample Preparation

In order to maximize the use of the hydro-gelation property of gellan gum, the specimens were prepared under the influence of heat. First a solution was prepared with the gellan gum biopolymer. Using deionized water heated to 90°C, the gellan gum was added and allowed to fully dissolve. To initiate homogenous mixing, a magnetic stirrer was used. After the solution was prepared, it was mixed directly into the sand. The mixing was performed so that the water content of the specimens were set at 30% and the gellan to sand concentrations were set at 1.0 and 2.0%. When the mixture was evenly mixed, the mixture was set into cylindrical molds with a diameter of 5 cm and a height of 10 cm.

The molds were then set to cool back down to room temperature for 1 day, and a thin plastic film was used to ensure that no moisture was lost during this process. After cooling, the mixture was then removed from the mold. The condition of the soils immediately after being removed from the mold was called the initial condition. Once removed from the mold, half the specimens were left to air dry at room temperature (20±1°C) for 13 days, called the dry condition, while the remaining half were tested at the initial condition.

Experimental Procedure

For the resonant column tests, the testing apparatus was connected to a computer for detailed measurements and automated calculations. The specimens were attached to the testing pedestal on the top and bottom caps through the use of gypsum. Confining pressures were applied to the specimens at confinements of 25, 50, 100, 200, and 400 kPa. After applying the confining pressures, the specimens were then left to fully consolidate before shearing was applied. The testing apparatus of the resonant column test can be seen in *Fig 2*.

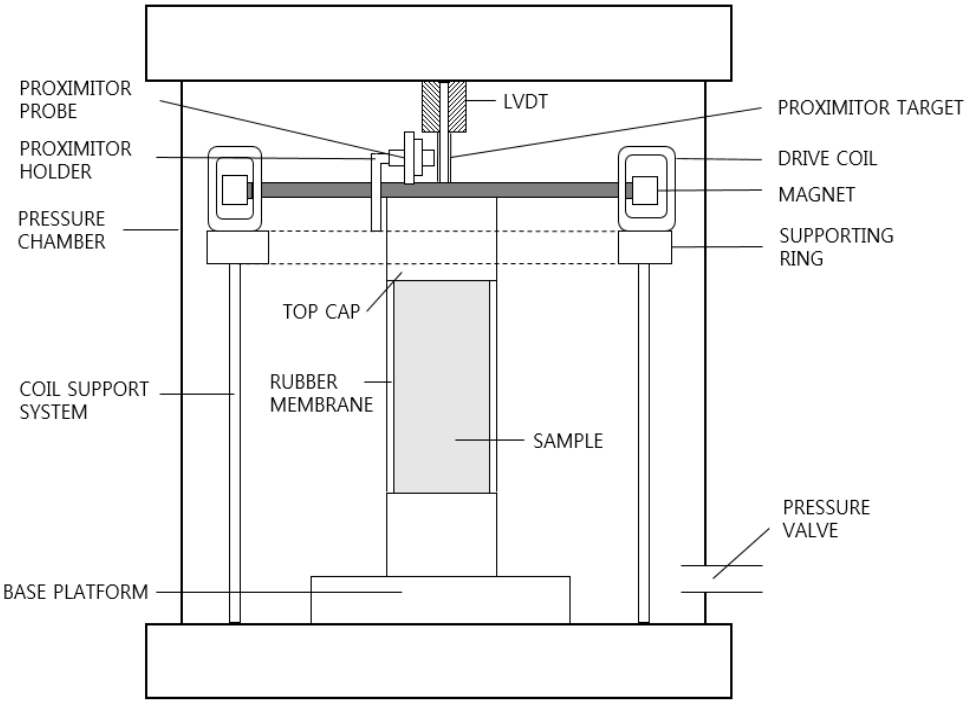

Fig. 2 Resonant column testing apparatus

3. RESULTS AND ANALYSIS

The shear modulus of the gellan gum treated and untreated sands are shown in Table 1. As it can be seen, as the confinement increases the shear stiffness of the soils increase. However, it can be seen that the increase in stiffness with confinement for the gellan gum treated sands is significantly lower than that of untreated soils. This results in a lower shear stiffness value at higher confinements. On the other hand, at lower confinements it can be seen that with gellan gum treatment the shear stiffness is higher than the untreated sands.

Table 1. Shear modulus of gellan gum treated and untreated soils with confinement

Confinement (kPa)	Untreated (MPa)	Gellan Dry (MPa)		Gellan Initial (MPa)	
		1%	2%	1%	2%
25	50.1	53.1	60.5	43.6	47.6
50	68.5	54.7	67.5	48.8	49.3
100	94.9	59.0	75.2	57.0	44.7
200	127.2	80.5	116.0	64.2	70.8
400	166.2	103.5	203.4	76.2	86.2

From this we can see that since the samples were prepared and set in the unconfined condition, due to the increased initial stiffness of the soil with gellan gum treatment, subsequent increases in confinement have a limited effect on the shear modulus. This behavior is expected as gellan treatment creates a rigid structure within the soil matrix that provides addition strength and cohesive forces.

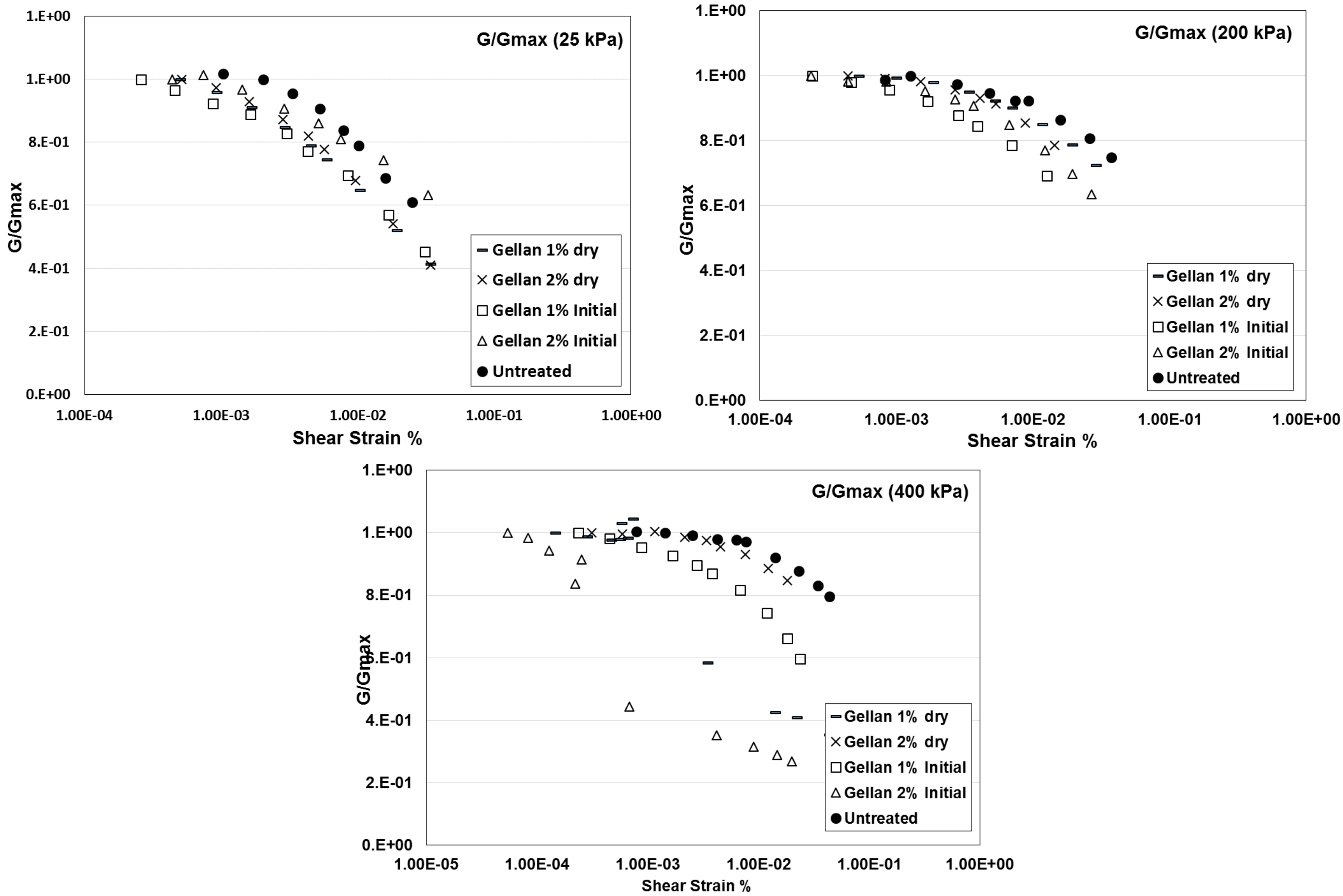

Fig.3 G/G_{max} curves of untreated and gellan treated soils

From the G/G_{max} curves shown in *Fig. 3* the normalized deterioration of the shear modulus of the various conditions can be seen with an increasing shear strain. Overall the gellan treated samples show a faster stiffness deterioration with an increased shear strain. This is most likely because as the gellan structures in the soil are strained, the majority of the stress will be held by the gellan structures and not the sand particles. With all the stress being allocated in the gellan structures, it will approach the plastic condition at a faster rate than the untreated sand samples.

The damping ratios of the gellan gum treated and untreated sand are shown in *Fig. 4*. As the figures shows gellan treated sands follow the general trend of increased damping with increased shear strain. However, it can be seen the gellan treated soils have a significantly larger damping ratio than the untreated soils. Although the addition of gellan structures in the sand particles allow for increased strength and cohesion, the damping of these gellan treated soils are shown to be larger. It is believed that this is due to the structure of the gellan constructs within the pore spaces of the sand particles. Previous studies have shown that the use of gellan in sands create a fibrous gellan structure that enhances the particle interactions thereby increasing the strength of the soils (Chang et al. 2015b). It is because of these fibrous gellan constructs that the damping of the specimens are larger than that of the untreated sands. As the energy is transferred along the gellan fibers the energy can be significantly reduced due to the strain along these gellan fibers, which are a lot more ductile than sand particles.

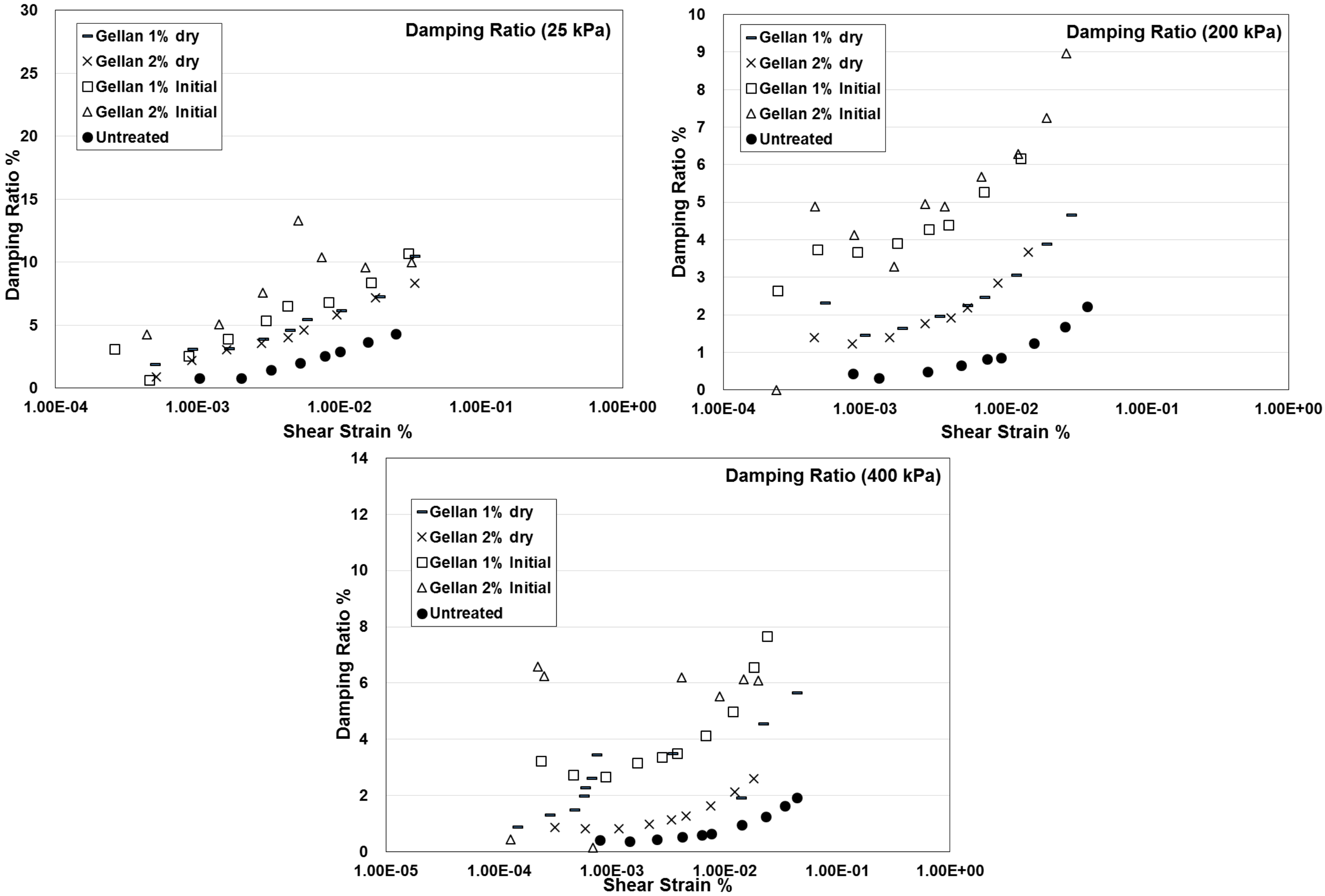

Fig. 4 Damping ratios of gellan treated and untreated sands

4. CONCLUSION

In conclusion it was seen that gellan gum treatment of sand allowed for an increase in the shear modulus at low confinement. However, at higher confinements the effect of confinement on the shear modulus is greatly reduced with gellan treatment. Additionally, it was seen that due to the gellan fibrous structures within the sand pores, the energy dissipation was greatly enhanced allowing for a larger damping ratio than the untreated sands. From these results, although its effects may be limited to shallow depths, the use of gellan gum biopolymers for soil treatment may be effective in the prevention of liquefaction in sandy soils.

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