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Research on the development of xanthan gum and clay mixture ground improvement materials.

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ABSTRACT

Erosion of the foundation due to scouring in the water is a severe problem that can lead to cracks or even collapse in critical parts of the bridges. The foundation structure should be reinforced to mitigate the structural failure that occurred by the scouring. However, it is not appropriate to use a massive amount of concrete on the foundation because the recent environmental issues cannot be ignored. Nowadays, biopolymer has been widely used in geotechnical engineering to stabilize soils without environmental damage. In this study, the erosion resistance of Xanthan gum biopolymer treated soil was evaluated by a combination of erosion function apparatus(EFA) and a P-wave reflection monitoring device. In addition, erosion resistance of silica sand contained specimen was evaluated. The addition of Xanthan gum improved the erosion resistance of the silica sand by enhancing its cohesion. Furthermore, Xanthan gum electrically bonds soil particles and showed a significant increase in erosion resistance. The results of this study showed the potential of Xanthan gum-treated kaolinite as a soil stabilization material to resist the shear force induced by flowing water.

1. INTRODUCTION

Bridge scouring refers to the erosion of the soil surrounding the foundation of bridge piers in rivers. 60% of bridge failures are caused by scouring underwater(Shirole and Holt, 1991). Several solutions have been presented to prevent the scouring of fundamentals underwater. Solutions nowadays include bed armoring(Lauchlan & Melville, 2004; Dey & Raikar, 2007), flow alteration(Zarrati et al., 2006; Deng & Cai, 2010; Heidarpour et al., 2010), and chemical soil stabilization(Bahar et al., 2004; Cheng & Cord-Ruwisch, 2012). Among them, the most preferred method is bed armoring. Most of the bed armoring operation uses concrete made of cement. However, in large-scale construction, using many artificial materials such as concrete causes serious damage to the environment. Portland cement produces approximately 126 kg of CO_2 during the production process.

Recently, biopolymers occurred by the metabolism of microorganisms have been

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used as ground-enhancing materials. It has been reported that when biopolymers are treated with soil, the compressive and shear strengths increase, and the hydraulic conductivity decreases (Chang & Cho, 2012; Chang et al., 2015). When biopolymers are applied in massive works such as bridge foundations, the cost aspect should be considered. Among various biopolymers, Xanthan gum has an advantage in microbial productivity (Chang et al., 2016). Not only the productivity, but Xanthan gum has an advantage on the environment. Xanthan gum produces less CO_2 than conventional construction material such as cement. The market price of the Portland cement is more economical than the Xanthan gum, but considering the environmental treatment cost, Xanthan gum is expected to be a more economical material.

This study used apparatus called EFA (Erosion Function Apparatus, Briaud 200) in combination with P-wave reflection monitoring to evaluate the erosion rate of the biopolymer treated soils. An accurate assessment of erosion rate can be made using the P-wave observation. In this study, both P-wave observation and bare-eye observation were conducted and compared.

2. Erosion rate($\dot{z}$) and shear stress(τ)

EFA method analyzes the erosion behavior of soils based on the erosion rate $\dot{z}$ and shear stress τ. The erosion rate ($\dot{z}$) is described as terms of flow duration, which can be shown as Eq. (1)(Kwon et al., 2021).

$$\dot{z} = \frac{1}{t} \times 3600 \qquad (1)$$

The τ(in Pa) is calculated in Eq. (2) based on the mean flow velocity *v*(in m/s) measured by the flow velocity meter(Kwon et al., 2021). The term *v* is the flow rate acting on the sample;

$$\tau = \frac{1}{8} \times f\rho v^2 \qquad (2)$$

where *f* is the friction factor obtained from Moody’s chart which varies by the Reynolds number of flowing water, and ρ is the density of water.

3. Experimental set-up

3.1 Sample preparation

This study considered two types of samples: Kaolinite(K) mixture of 80% silica sand with 20% kaolinite(SK). The dried soils and Xanthan gum solutions were thoroughly mixed with controlled water content to obtain uniform biopolymer treated soil (BPTS) samples with intended biopolymer content. Details of sample preparation conditions are summarized in Table 2.

Table 2 Sample information

Soil type	BP Type	m_b/m_s: %	Target water content [%]	Symbol
Kaolinite	XG	0	25	K-00
		0.5	25	K-05
		1.0	25	K-10
		2.0	25	K-20
Kaolinite + Silica Sand		0	25	SK-00
		0.5	25	SK-05
		1.0	25	SK-10
		2.0	25	SK-20

3.2 Erosion Function Apparatus(EFA) set-up

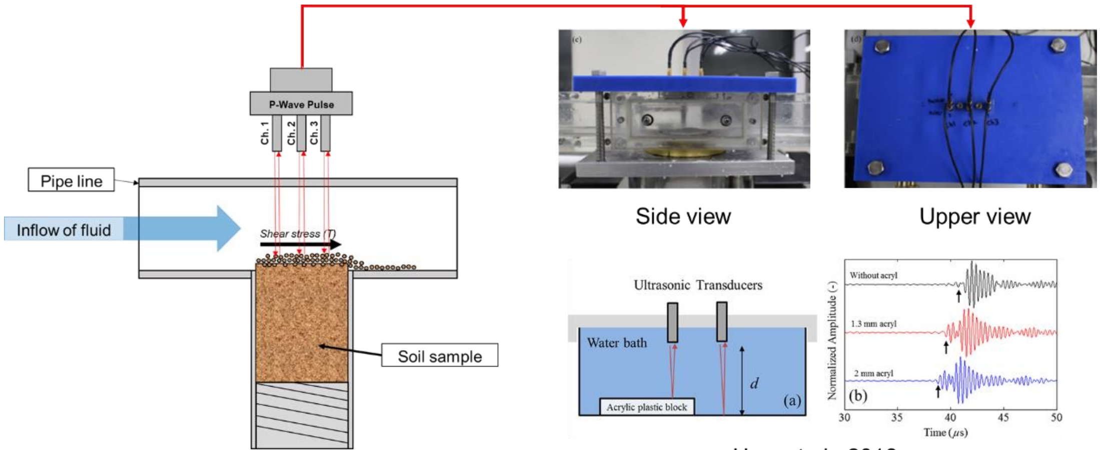
The Erosion Function Apparatus(EFA) is a device that evaluates erosion resistance. Water flow through the pipe erodes the soil sample. The EFA protruded 1 mm above the bottom of the pipe(Briaud et al., 2001), as shown in Fig. 1. Then the soil specimen was pushed into the water channel by a standard Shelby tube with a 76.2 mm outside diameter(ASTM 1999). The procedure of the EFA test is as follows.

1. Place the sample in the EFA, fill the pipe with water, and wait for one hour to uniformly saturate the soil specimen.
2. Set the target water velocity.
3. Protrude the soil sample 1 mm into the channel, then start the test.
4. Record the duration for the 1 mm of a soil sample to get eroded.
5. At the same time, the P-wave device also records the erosion every 3 seconds.

Three pairs of P-wave measuring devices are located right below the upper water channel(Ch. 1~3) has a generator and a receiver. After the P-wave is released from the generator, it travels to the packed medium(water) then makes contact with the sample. The P-wave is reflected from the soil surface then returns to the receiver. The sensor then records the travel time of the P-wave. The distance(L) from the P-wave apparatus to the sample can be calculated as Eq. (3);

$$L = \frac{1}{2} \times t \times V_p \ (m) \tag{3}$$

Where t is the travel time of the P-wave, V_p is the average velocity of the P-wave underwater, which was 1480 m/s(Prasad et al., 2004). During the experiment, travel time (round trip) of P-wave signals were recorded and half of the travel time(t) was determined as *t*.



<Ham et al., 2016>

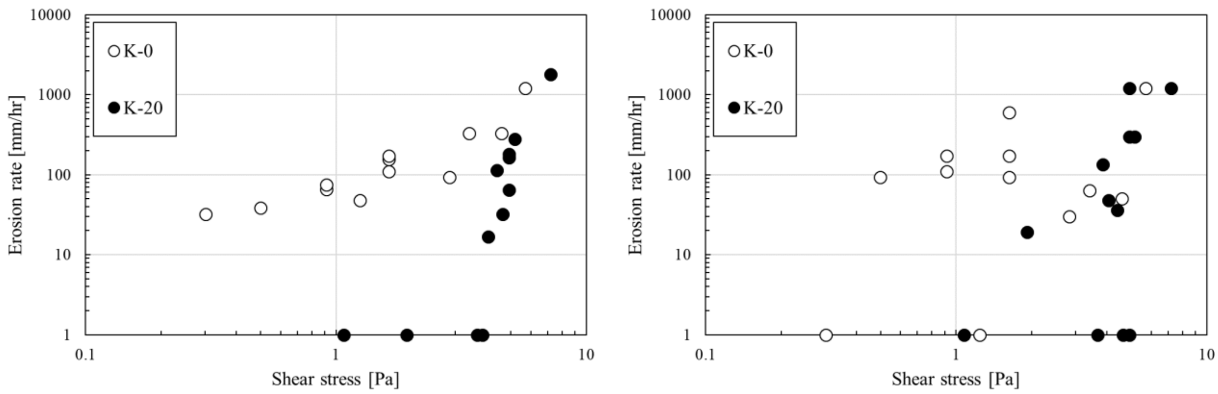
Fig. 1 EFA set-up

4. Results

4.1 Evaluation of P-wave measurement

A comparison analysis was performed between bare eye observation and P-wave observation for K-0 and K-20 samples to verify the accuracy of the method (Fig. 2). The horizontal axis represents a flowing water velocity which is expressed as shear stress based on Eq. (2).

Fig.2(a) and Fig.2(b) show the variation of erosion rate observed by bare-eye and P-wave observations. The P-wave observation and bare-eye observation showed a similar tendency, while P-wave observation showed a higher erosion rate at the same shear stress. The resolution of bare-eye observations may cause the difference in P-wave and bare-eye measurements because this study determines the erosion rate based on the 1 mm erosion. Furthermore, a higher xanthan gum treatment showed a smaller erosion rate at similar shear stress.

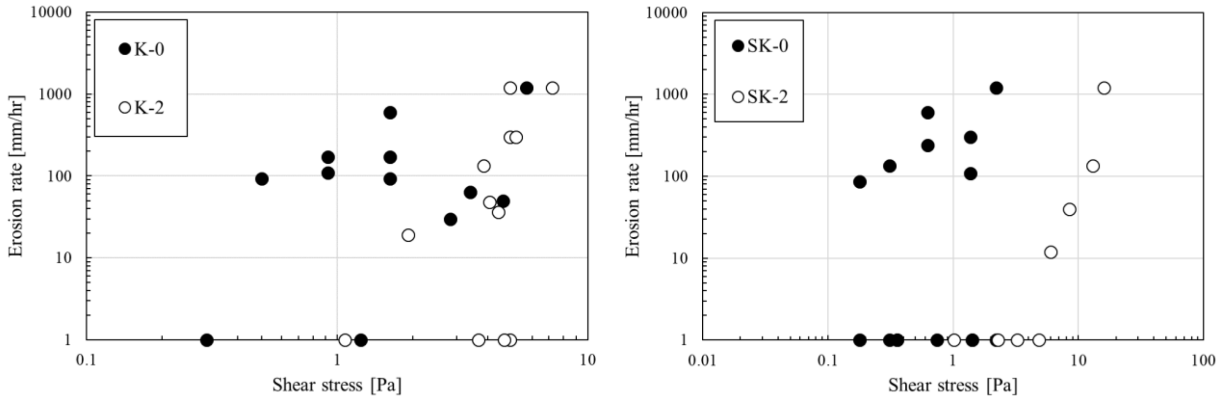


(a) Bare-eye observation (b) P-wave observation

Fig.2 The erosion curves observed by different methods

4.2 Effect of Xanthan gum content

Fig.3 shows the variation in erosion rate according to the shear stress. Fig.3(a) and Fig.3(b) are the samples Kaolinite(100%), and Kaolinite(20%)-Silica sand(80%), respectively. Both results show the more Xanthan gum contained, the more resistive to water flow.

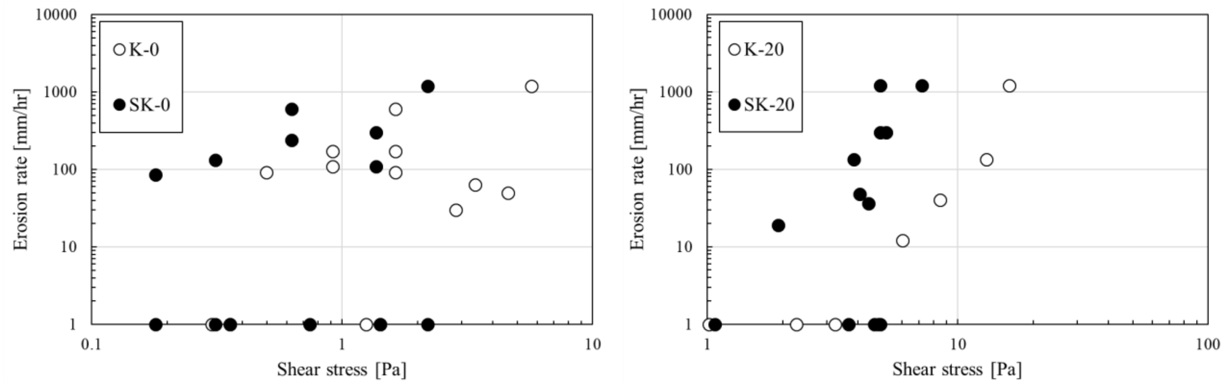


(a) Kaolinite (b) Silica sand mixed with kaolinite

Fig.3 Effect of Xanthan gum content on the erosion resistance of different soils.

4.3 Effect of clay proportions

Fig.4 shows also shows the erosion rate according to the shear stress. Fig.4(a) and Fig.4(b) are samples containing 0% and 2% of Xanthan gum, respectively. Both results show that samples with more clay components are more resistant to erosion.



(a) Xanthan gum 0% (b) Xanthan gum 2%

Fig.4 Effect of clay proportions

5. Discussions

The bonding caused by Xanthan gum between the soil particles leads the samples to be more resistant to water flow. Xanthan gum-treated soils mainly depend on four factors: (1) type of soil, (2) dehydration (e.g., moisture content), (3) Xanthan gum content, and (4) mixing method. The strength increases with an increase of Xanthan gum had a dramatic increase in erosion resistance. But it it should not be assumed that a high proportion of biopolymer will improve strength.Therefore, a further step of this study is to verify the effect of various Xanthan gum contents on the surface erosion of a wide range of soil classifications.

6. Conclusion

In this study, the erosion resistance of Xanthan gum treated and non-treated samples were compared and analyzed by EFA. The key findings are the following:

- The erosion resistance of Xanthan gum-treated soils was significantly improved by forming bonding between particles. However, additional research on the mixing ratio of kaolinite and Xanthan gum needs to be conducted.
- The sThe soil containing more clay (kaolinite) showed higher resistance to erosion due to its higher cohesion than sand.
- Xanthan gum biopolymer treated with clay soil has shown its potential as a soil stabilization material resisting flowing water.

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