GELLAN GUM-MODIFIED BENTONITE AND ITS APPLICABILITY OF AS EMERGENT EXCAVATION SLURRY

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ABSTRACT

Biopolymer soil method has been considered the latest technological innovation in the field of soil improvement purposes. Biopolymers such as agar, xanthan, casein and so on have been commonly studied to improve strength, reduce the hydraulic conductivity and dust control of soils. In this study, the effect of gellan gum biopolymer on strengthening bentonite slurry was studied. In order to observe the effect of gellan gum on the bentonite strengthening effectiveness, the unconfined compression tests were conducted on gellan gum-modified bentonite with consideration of gellan gum concentration, thermal curing process. The experimental results were combined with studies conducted by Tran and Takeshi (2021) to extend the understanding of the strength properties of gellan gum-treated bentonite. Furthermore, the effect of gellan fum-bentonite slurry for emergent excavation stabilization was evaluated via 2D finite-difference program (FLAC2D), considering gellan gum concentration and thickness of the treatment area. The numerical results support the application of gellan gum biopolymer to excavation wall stabilization.

Keywords: gellan gum, bentonite slurry, excavation wall, FLAC2D, factor of safety.

1. INTRODUCTION

Bentonite slurry is one of the primary materials used for wall stabilization of an excavation. The slurry hydraulically shores the trench to prevent collapse and to reduce the groundwater flow into the excavation. In practice, bentonite slurry is made by thoroughly mixing and hydrating powder bentonite. The slurry is then left for a period of time to form a gel, stabilizing the quality of the slurry. However, the water pressure and earth pressure are essential factors since they impact the workability and stability of bentonite slurry [1]. This study is to introduce a modified bentonite slurry with higher stabilization compared to the conventional one.

Gellan gum biopolymer has been proved to have a significant improvement in pressurized hydraulic conductivity [2] and the strength of soils under wetting/drying cycles [3] via hydrogen bonding between gellan gum and kaolinite clay and coating of gellan gum on sand surface [4]. However, the effect of gellan gum on the strength of a high swelling clay (i.e., bentonite) has not been widely under study. Tran and Takeshi (2021) introduced gellan gum as a strengthening admixture for bentonite slurry, and emphasized the effects of thermal curing at 30° [5]. This study aims to extend the understanding on the effects of thermal curing time and degree on the strength of gellan gum-modified bentonite slurry.

In order to investigate the stability of the modified bentonite, a series of unconfined compression experiments was conducted on gellan gum-treated bentonite with consideration of thermal curing period (1 day and 3 days) and temperature (room temperature, 30° and 40°). The result of shear strength at room temperature was used to estimate the feasibility of the modified bentonite for excavation stabilization via the 2D finite-difference program. Based on the experimental and numerical analysis results, the applicability of gellan gum–treated bentonite for the stabilizing excavation wall can be observed.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

2.1. Materials

Bentonite

In this study, Betonite API, which is used as drilling mud in the construction of Barrette piles, diaphragm walls, etc., was used. The product is manufactured according to the standards of the American Petroleum Institute. The soil properties of PL = 32 %, LL = 350 %, Gs = 2.73 were obtained.

Gellan gum biopolymer

A thermo-gelation biopolymer, low-acyl gellan, a type of bacterial polysaccharide, is used in this study. Gellan gum is a water-soluble fermentation polysaccharide produced by the microorganism Sphingomonas elodea. Previous studies show the successful performance of gellan gum in biomedical and food industrial applications [6]. In addition, for geotechnical engineering, gellan gum is proved to be a highly durable additive for soil improvement and stabilization purposes [4].

Gellan gum-treated bentonite preparation

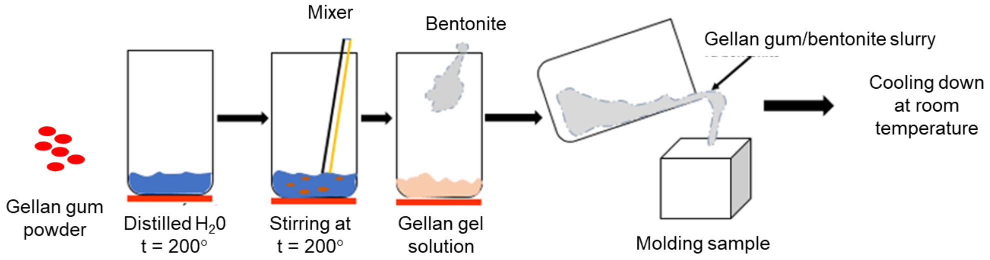

Figure 1. Gellan gum-bentonite specimen preparation process

Gellan gum powder was first dissolved and hydrated fully in distilled water heated up to 200 °C to obtain a uniform mixture [7] for varying gellan gum concentration to the mass of water (m_G/m_w) of 0, 3, and 7%. The gellan gum concentration was selected based on the results obtained by Tran and Takeshi (2021) [5]. 2% cannot show a positive effect on the strength of soil and even disturb the original stability of bentonite slurry itself [5]. The highest gellan concentration obtained in their study is 7% for a uniform bentonite and gellan gum slurry [5].

A dry bentonite powder and the hot gellan gum solution were thoroughly mixed at the water content of 500% to form a uniform gellan gum–bentonite slurry using hand mixer (Fig. 1). The mixtures were then immediately placed into cubic molds made of stainless steel having inner dimensions of 35 mm width, 35 mm length, and 35 mm depth for the Unconfined compression test. The average dry density of the specimens was 0.327 ± 0.03 g/cm^3.

2.2. Unconfined compression test

A series of unconfined compressive strength (UCS) tests were carried out on the prepared specimens based on ASTM D2166 [8]. The strength tests were conducted on the cubic specimens in two conditions: initial condition (i.e., after 6 hours of cooling down) and thermal curing conditions (40°C). Specimens were cured in the oven for 1 day and 3 days at 40°C. The axial strain was controlled at a medium rate of 1.7% strain/min [8-9]. The UCS is often taken as the peak of the axial stress versus strain curve; however, if any specimen did not show a peak value, the stress level recorded at 15% strain was taken as the UCS [8]. The maximum strength and the stress-strain behaviors were obtained by averaging three different measurements for a single condition.

In order to use the UCS as one of the parameters for numerical simulation of excavation stabilization, the UCS obtained was used to estimate the cohesion c_u as following equation [10]

$$c_u = \frac{UCS}{2} \tag{1}$$

3. ANALYSIS METHODS

3.1. Shear strength reduction method

The shear strength reduction method is a powerful tool for slope stability analysis. The factor of safety can be easily calculated by reducing effective cohesion and tangent of effective friction angle in equal proportion [11]. This "shear-strength reduction technique" can also be applied to geotechnical stability problems such as cantilever walls, braced excavations and retaining walls [12].

Based on Bishop's effective stress [13] the shear strength τ_{max} and the effective stress σ' are expressed as

$$\tau_{\max} = \sigma' \tan\phi' + c' \tag{2}$$

where ϕ' is the effective friction angle and c' is the effective cohesion of the soil.

To calculate the safety factor of an unsaturated slope using a shear strength reduction technique, a set of simulations is performed with the reduced shear strength parameters C_{trial} and ϕ_{trial} defined as follows:

$$C^{trial} = \frac{1}{F^{trial}} C \tag{3}$$

$$\phi^{trial} = \left(\arctan \frac{1}{F^{trial}} \tan\phi \right) \tag{4}$$

where F^{trial} is the trial factor of safety.

The initial shear strength reduction F^{trial} is set to be sufficiently small to ensure the stability of the slope. F^{trial} is then increased incrementally until a failure occurs and that value is considered to be the factor of safety of the slope. In this study, the shear strength method which is available in FLAC [14] was used.

3.2. Numerical analysis

The numerical study of excavation stabilization used the finite difference program FLAC2D. The numerical study aimed to investigate the effects of gellan gum-treated bentonite slurry on short-term and temporary stabilization of a fictitious excavation via the factor of safety (*FoS*) and shear stress distribution within the excavation sidewall.

A fictitious vertical one with 5m in thickness and 4m in height was introduced to present a severe case of a precarious excavation wall (Fig. 3). It consisted of 2 soil layers: weak soil and good soil. Properties of soil are shown in Table 1

Table 1. Properties of fictitious soils

Properties		Weak soil	Good soil	Gellan gum –bentonite slurry	
				3% gellan	7% gellan
Mass density	kg/m^3	1300*	1800*	1975**	1995**
Friction angle*	°	20	20	20	20
Cohesion	Pa	2000*	30000*	4580**	27615**

* Assumed values

** Referred to [5]

Figure 2 shows the overall algorithm of the simulation to assess the two main points of interest in this study:

- Effect of gellan gum concentration:

In order to estimate the effect of gellan gum concentration, 3% and 7% gellan gum-treated bentonite slurry at the initial condition were used to form a thickness of 5 cm. The properties of these soils are shown in Table 1.

- Effect of thickness of treatment wall

The thickness effect of the treatment layer on the stabilization of the excavation wall was emphasized by considering varying thicknesses with an increment of 5 cm until the *FoS* ≥ 1.2 for the case of 3% gellan gum treatment.

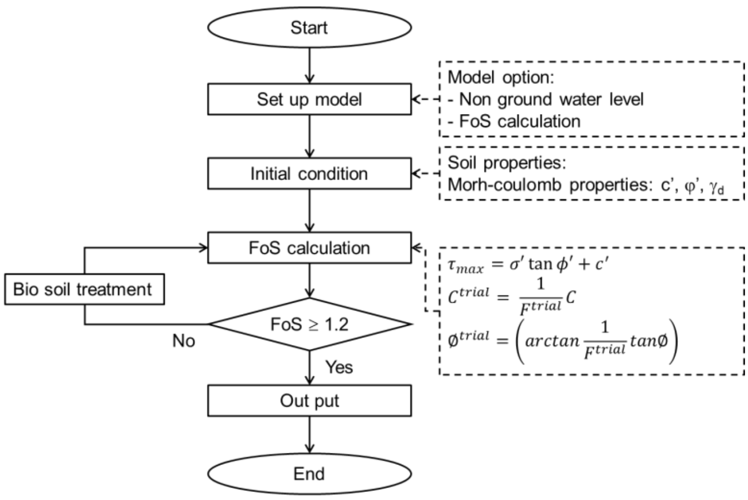

Figure 2. Algorithm of numerical analysis of excavation stabilization with biosoil treatment

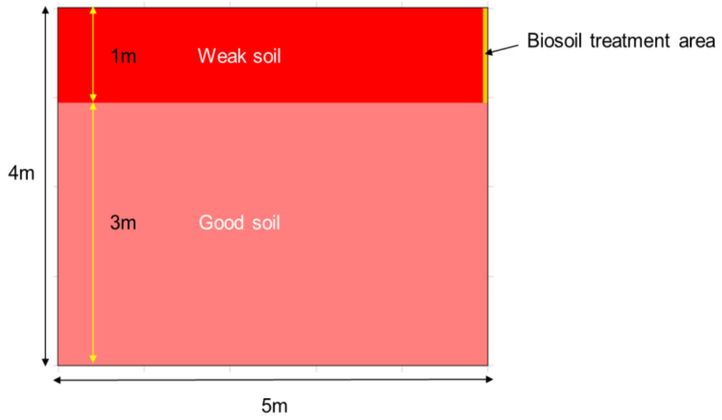

Figure 3. Geometry of fictitious excavation wall

4. RESULTS AND DISCUSSIONS

4.1. Effects of temperature on strength of bentonite-treated different gellan gum

The enhancement of the UCS of clay as treated with gellan gum was proved in some previous studies [4, 15]. Tran and Takeshi concluded that the gellan gum increased the strength of bentonite slurry right after the cooling process. Furthermore, the strengthening performance of gellan gum increased with its concentration and curing temperature (i.e., zero and 30°, Fig. 4a). In this study, as the modified soils were cured at a temperature of 40°, the similar effects of gellan gum concentration on the UCS could be obtained (Fig. 4b).

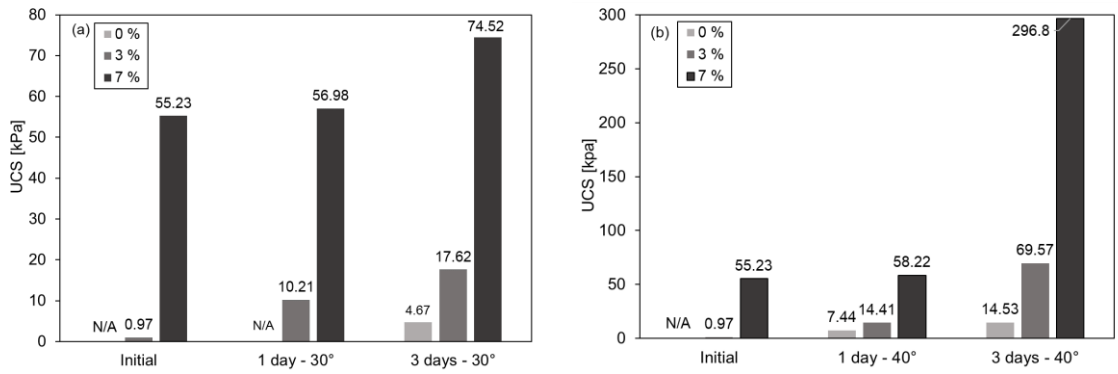

Figure 4. Unconfined compressive strength of (a) 30°C and (b) 40°C gellan gum-treated bentonite under varying thermal curing conditions

As seen in Figs. 4a and b, 7% gellan gum–treated bentonite shows the highest UCS, compared to 3% treatment and untreated conditions (i.e., 0%) for all cases of studied temperature. The higher UCS with gellan gum concentration was due to the greater inter-cohesion of soil formed by the amount of clay – gellan matrix [16-17] as the gellan gum concentration increased within clay [4].

Moreover, the effect of temperature on the UCS improvement could be observed, disregarding gellan gum concentration and curing time. Higher temperature caused a higher UCS for bentonite treated by the same gellan gum concentration (Figs. 4a and b). However, the increase rate of the UCS depended on heating time. Cured for 1 day, at 30° and 40°, the UCS of the bentonite treated 3% gellan gum increased by 953 % and 1386 %, respectively, the value of initial condition (i.e., 0.97 kPa). As the soils were cured for 3 days, the UCS raised up by 1716% and 7072% for bentonite cured at 30° and 40° (Fig. 4a), respectively. Similar soil strengthening tendency was observed for the case of 7% gellan gum. The UCS increased by 35% and 437% as the specimen under 3 days of thermal curing at 30° and 40°, respectively (Fig. 4b). The phenomenon happened due to the role of temperature on the loss of water within the gellan gum gel and bentonite [5]. Similar strengthening tendecny was reported by Soldo et al. (2020), where the compressive strength of silty sand treated with xanthan gum, guar gum and beta-glucan gum increased with thermal curing time [18].

However, the increase rate of strength was smaller for 7% gellan gum treated soil compared to 3% gellan gum treatment (Fig.5). Like other biopolymers with pseudoplastic behavior [19], the viscosity of gellan gum gel increases with gellan concentration, triggering higher viscosity for gellan gum - bentonite mixture [15]. In other words, the more gellan gum monomers within clay, the earlier the mixture reaches close to its stabilization state during the cooling process.

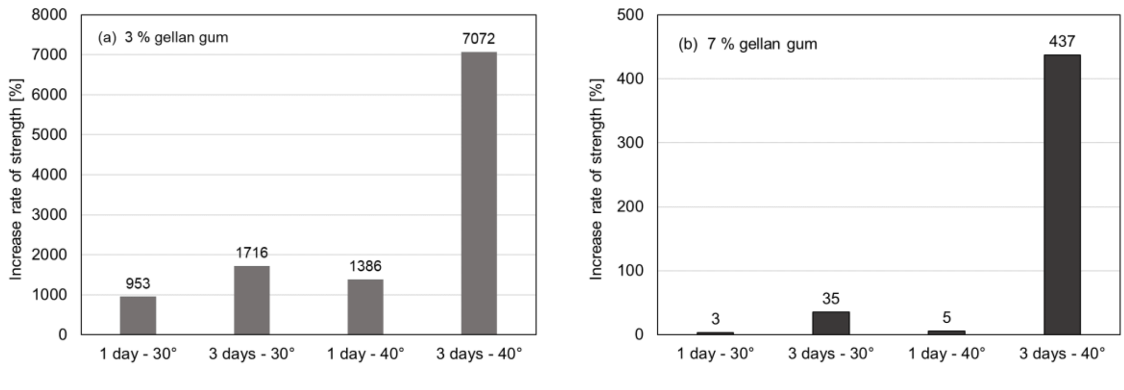

Figure 5. Increase rate of unconfined compressive strength of (a) 3% and (b) 7% gellan gum-treated bentonite under varying thermal curing conditions

4.2. Effect of gellan gum-modified bentonite on safety factor of excavation wall

With the initial excavating condition and given the engineering properties of the fictitious excavation, the FLAC 2D simulation shows that the excavation wall is not stable with the *FoS* of 0.83, and the failure occurred with the displacement of 0.08 m.

The shear strain distribution at the failure area is shown in Fig. 6a. The max shear strain distribution is where the failure curve is formed.

Fig. 6b and c, in turn, show the changes in displacement, failure area, and *FoS* as gellan gum - bentonite slurry is applied along the predicted failure surface. The use of gellan gum-modified bentonite increases cohesion of the soil, which boosts the shear strength τ via the relationship shown in Eq. 2. 3% gellan gum used can enhance the strength of the wall and the displacement go down to only 0.01 m. The area where the max shear strain distribution gets narrower (Fig. 6b). However, the *FoS* of 0.97 forecasts that the wall is still in an unstable state. A significant change can be seen for the case of 7% gellan gum. The *FoS* dramatically increases to 1.49, which meets the demand for excavation stabilization (*FoS* $\geq$ 1.2). The failure area disappears entirely on the given excavation (Fig. 6c).

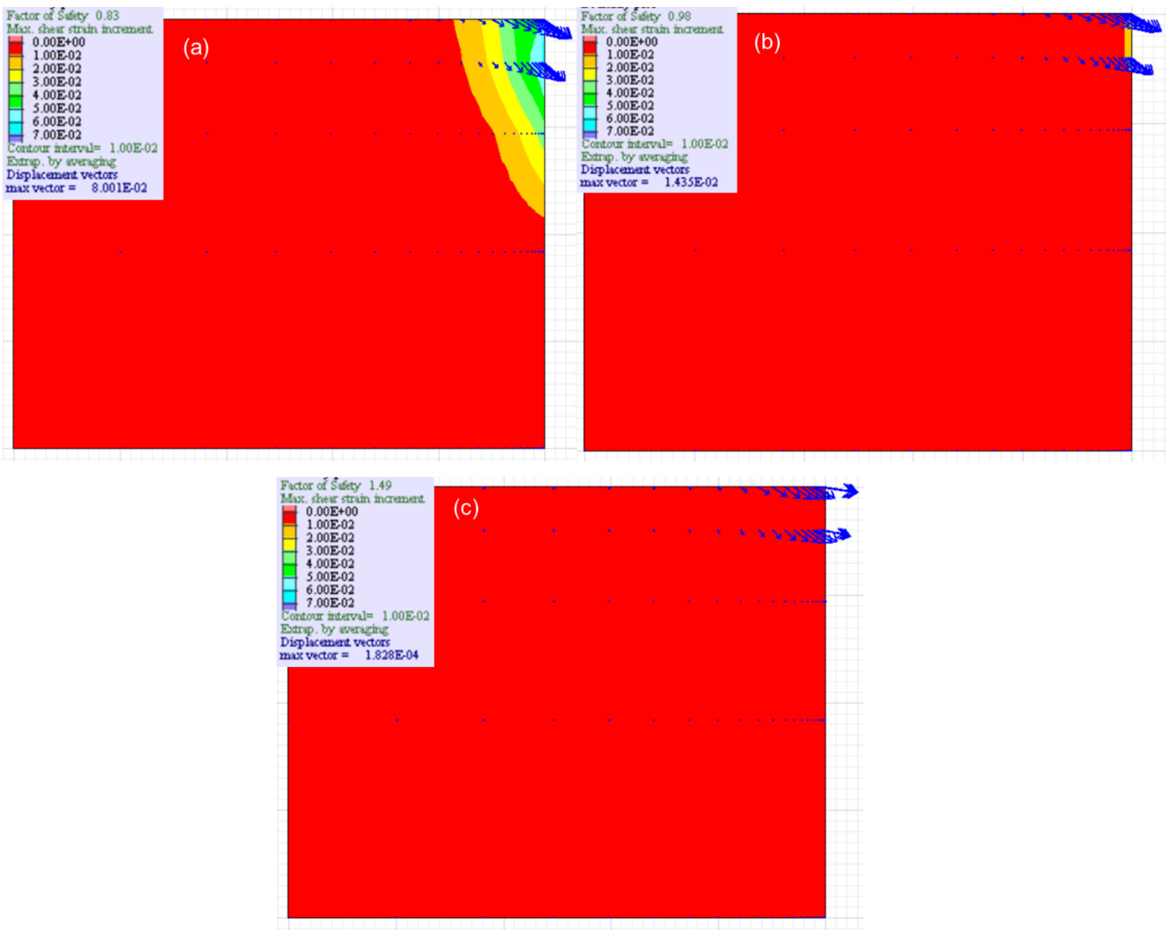

Figure 6. Shear strain distribution and failure area of excavation wall at failure for (a) untreated slope; (b) use of 3% gellan gum treatment and (c) use of 7% gellan gum treatment

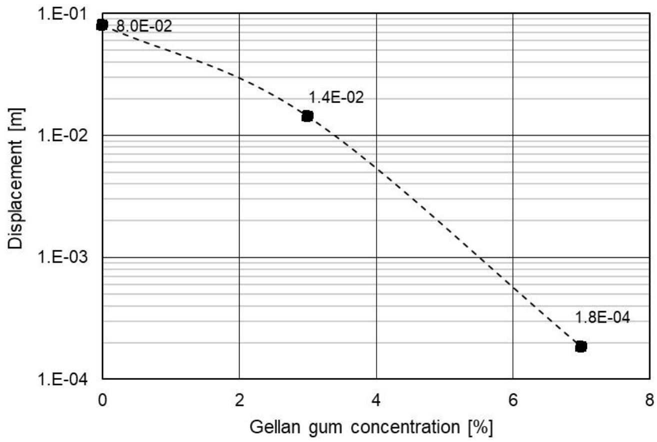

Figure 7. Changes in displacement of excavation wall at failure

The numerical simulation provides that as the failure area is amended by modified bentonite, suggested in this study, the displacement at failure reduces (Fig. 7) and the max shear strain distribution gets narrowed (Fig. 6a, b, c), and in turn increases the *FoS* of the excavation (Fig. 8). The improvement of these parameters depends on gellan gum concentration used to modify bentonite slurry.

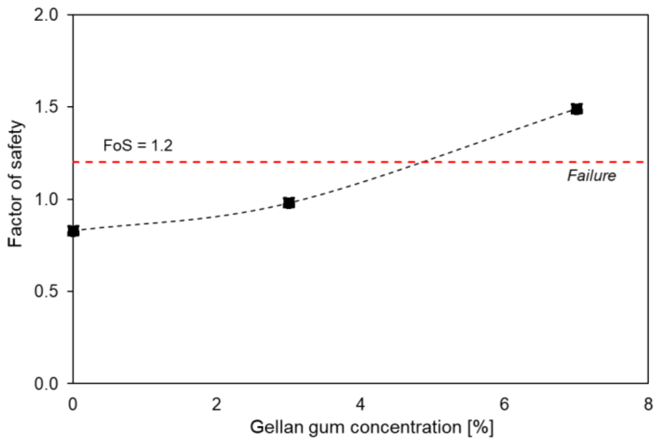

Figure 8. Effects of gellan gum concentration on factor of safety

Besides, the thickness of treatment area is another impact factor for the effectiveness of the slurry method using modified bentonite. Fig. 9 proves that the *FoS* increase with the thickness. For example, if 3% gellan gum-treated bentonite is used, the *FoS* will reach a value higher than 1.2 at 20 cm.

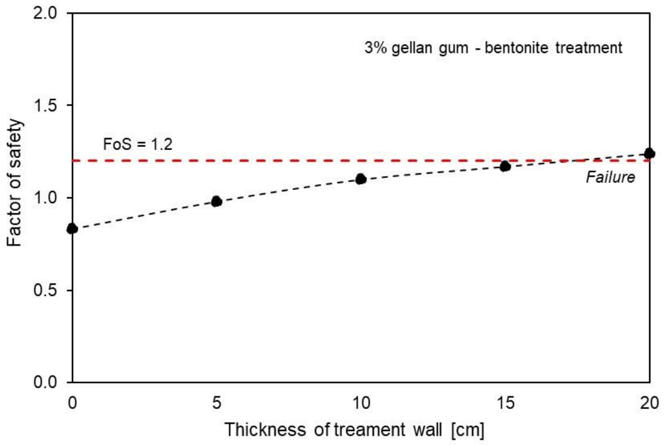

Figure 9. Effects of the thickness of treatment are on factor of safety for 3% gellan gum treatment

5. CONCLUSIONS

To extend the understanding of shear strength properties of gellan gum-treated bentonite and its applicability in geotechnical engineering practice, this study conducts the Unconfined compression test and numerical modeling using FLAC2D. The experimental and numerical results give the following conclusions:

1. Gellan gum concentration, thermal curing temperature and time are crucial affecting factors for the unconfined compressive strength of bentonite slurry treated with gellan gum. These factors impact the strength via improving inner interaction, controlling water loss and self-stabilization of soil mixture. The highest UCS of 296.8 kPa was obtained for 7% gellan gum – treated bentonite slurry cured at 40°C for 3 days.

2. The effectiveness of slurry trench method using gellan gum-modified bentonite considerably depends on gellan gum concentration and the thickness of the treatment area. The FLAC2D can fully estimate the effect of gellan gum on excavation stabilization. 5 cm of 7% gellan gum-treated bentonite raise the safety factor of excavation wall upto 1.49; while with 3% gellan gum the thickness is not less than 20 cm in order to void the instability of the wall.

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CẢI TẠO BENTONIT BẰNG GELLAN GUM VÀ KHẢ NĂNG ỨNG DỤNG LÀM DUNG DỊCH ỔN ĐỊNH TỨC THỜI THÀNH HỐ ĐÀO

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TÓM TẮT

Cải tạo đất sử dụng chất dẻo sinh học (biopolymer) được coi là cải tiến công nghệ mới nhất trong lĩnh vực cải tạo đất nền. Agar, xanthan, casein, v.v. là những biopolymer được sử dụng phổ biến trong nghiên cứu trong cải thiện độ bền và giảm tính thấm của đất. Trong nghiên cứu này, vai trò của chất dẻo sinh học gellan gum trong gia tăng cường độ của dung dịch bùn sét bentonite được nghiên cứu. Hiệu quả trong cải tạo cường độ dung dịch bùn sét bởi gellan gum được thể hiện qua kết quả độ bền kháng nén một trục nở hông xem xét ảnh hưởng của hàm lượng gellan gum và nhiệt độ sấy lên mẫu. Kết quả thí nghiệm thu được, kết hợp với kết quả từ nghiên cứu đã nghiên cuwusddoojh , mở rộng sự hiểu biết về độ bền của mẫu sét bentonite được xử lý bởi gellan gum. Thêm vào đó, hiệu quả của bùn gellan fum-bentonite đến độ ổn định tức thời thành hố đào cũng được đánh giá thông qua chương trình phần mềm dựa trên phương pháp sai phân hưu hạn FLAC2D để đánh giá ảnh hưởng của nồng độ gellan gum sử dụng và độ dày của khu vực được xử lý. Kết quả mô hình toán đã chứng minh được khả năng ứng dụng của gellan gum đến độ ổn định tường hố đào.

Từ khóa: gellan gum, dung dịch sét bentonit, tường khai đào, phần mềm FLAC2D, hế số ổn định bờ dốc.

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Lĩnh vực nghiên cứu: Địa chất, khoáng sản.