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IMPROVEMENT OF THE SHORT-TERM STABILITY OF EMBANKMENT ON SOFT SOIL BY USING A GEOSYNTHETIC FABRIC WITH INSTALLED STONE COLUMNS

Dr. Saad Faik Abbas Al-Wakel

Lecturer, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq.

Abstract: In this study, the short term stability of an embankment on soft has been improved by reinforced the embankment with a geosynthitic fabric and reinforced the foundation by stone columns. The behavior of the embankment is numerically modelled, the finite element analysis for the reinforced embankment on soft clay (with and without stone columns) is presented. The principle of this improvement is that the geotextile as geosynthitic fabric is used to increase the factor of safety for the short term stability of the embankment, then the stone columns are used to maintain the side slope stability with a minimum factor of safety.

Keywords: *Finite element, embankment, geosynthitic fabric, stone columns.*

تحسين الاستقرار القصير الأمد للسد الترابي على تربة طينية رخوة باستخدام النسيج الصناعي وتثبيت الأعمدة الركامية

الخلاصة: في هذا البحث، تم دراسة استخدام طريقة التركيب من التسليح لقاعدةِ السد الترابي باستعمال النسيج وتسليح الأسس بأعمدةِ الركام وبيان مدى تأثيرها على تَحسين الاستقرار قصير الأمد للسدود الترابية المنشأة على تربةِ طينية رخوةِ باستخدام طريقة العناصرِ المحدودة. أن التسليح بالنسيج أستعمل لزيَاْدَة عاملِ الأمانِ للاستقرار قصير الأمد للسد الترابي. ومن ثم، أعمدة الحجارةَ أبقت استقرار المنحدرِ الجانبي للسد الترابي ضمن الحد الأدنى لعامل الأمانِ.

1. Introduction

The design of reinforced embankment takes into account the consideration of stability with reinforcement providing an additional resistance which is required to provide a confidence in the stability of embankment as in Rowe and Taechakumthorn [1]. Rowe and Soderman [2] stated that even though an embankment may be stable, there will often be significant local shear failure within the underlying soft soil.

One of the method to improve the stability of the embankment is construct stone columns in soft clay under the embankment to increase the shear strength of the foundation. The installation of stone columns changes the stress state and the structure in the ground dramatically as in Weber et al. [3].

The geosynthetic materials are used to reinforce embankments to be constructed over soft soils, where one or more layers of geotextiles or geogrids are placed between the soil and the embankment to provide the reinforcement. Mwasha [4] mentioned that, the concept of the geotextiles refers to the ability of the geotextile in providing additional stability to an embankment erected on soft ground until the foundation soil achieves the desired shear strength over time.

To assess the stability, the limit equilibrium methods of slices such as Bishop's simplified method have been widely used. In this method, the factor of safety which is defined as the ratio of the available shear strength to the shear stress required to maintain equilibrium is computed as in Low and Tang [5].

2. Stability of an Embankment on Soft Soil

The failure of embankments constructed over relatively deep deposits of soft soils have shown that when failure occurs the adjacent ground rises and the failure is that of rotation along cylindrical slip surface as shown in Fig.1.

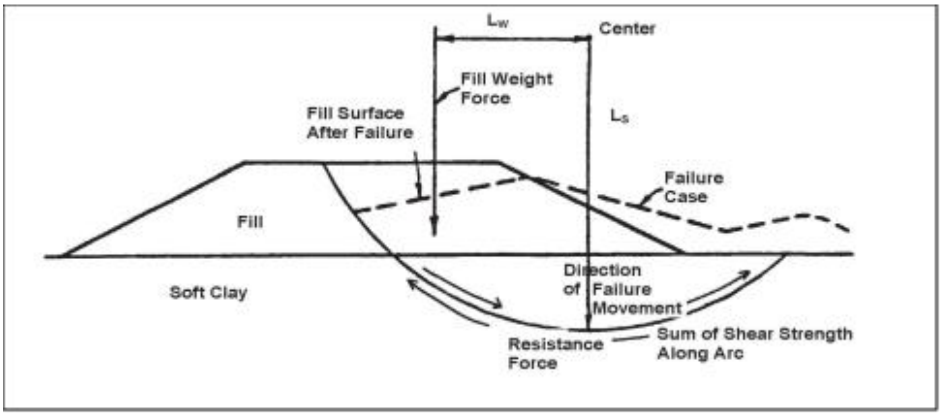

Figure 1. Typical circular arc failure mechanism of embankment.

In some cases when the soil is fully saturated, the increase in absorbed moisture of clayey soil is the major factor in decrease in the strength of soil, where the water absorbed by the clay minerals causes an increased in the water contents that decrease the cohesion of clayey soils.

3. The Safety Factor Analysis in Finite Element Method

A basic assumption in the limit equilibrium analysis is that the method treats the soil as a rigid plastic material, where the soil does not deform as long as the driving shear stress is less than the soil strength. Once the driving shear stress exceeds the soil strength, the soil will deform excessively and reach failure. The method assumes that the shear stress along the potential failure are mobilized simultaneously, which is not true for most cases as in Duncan [6]

According to Figure (1) above, the factor of safety verses slope instability is equal to the ratio of the resisting moment to driving moment; therefore,

$$\text{Factor of Safety} = \frac{\text{Total Shear Strength} \times L_s}{\text{Weight Force} \times L_w} \tag{1}$$

In other words, the factor of safety is equal the resisting moment to the driving moment. The failure will take place if the safety factor is less than 1 (the driving moment is greater than resisting moment).

In the present study, a robust method which is proposed by Brinkgreve and Bakker [7], is adopted to determine the safety factor against shear failure. The method is based on the reduction of the strength parameters of the soil, which are the friction angle of internal friction, ϕ and the cohesion of the soil, c. The principle of ϕ/c reduction is that the strength of the soil will be gradually reduced, and the factor of strength reduction is considered a factor of safety on soil strength when the failure is occurred. Therefore, the factor of safety is

$$\text{Factor of Safety} = \frac{c + \sigma'_n \tan\phi}{c_c + \sigma'_n \tan\phi_c} \tag{2}$$

where c_c is the critical cohesion, ϕ_c is the critical of friction angle and σ'_n is the effective normal stress at the plane considered. Both c and ϕ are effective strength parameters.

For $c = c_c$ and $\phi = \phi_c$ the factor of safety becomes equal to unity. According to this method the above definition of the factor of safety coincides with the definition as used in slip circle analysis on the condition that is define:

$$\frac{c_c}{\tan\phi_c} = \alpha \frac{c}{\tan\phi} \tag{3}$$

In this method, the proportionality with $\alpha = 1$ it is retained in order to remain compatible to the traditional slip circle analysis. The method concentrates on the computation of the above factor of safety by use an elasto-plastic finite element method. Instead of the usual increasing of loads, the strength parameters will be reduced. This technique was first proposed by Zienkiewicz et al. [8], but the procedure in this method robust by adding an arc-length technique. The procedure was implemented into the Plaxis finite element package.

4. Improvement the Short-Term Stability of an Embankment

In the present study, a typical embankment is presented with a cross-section as shown in Fig. 2. The symmetry of the embankment about its centerline has been considered.

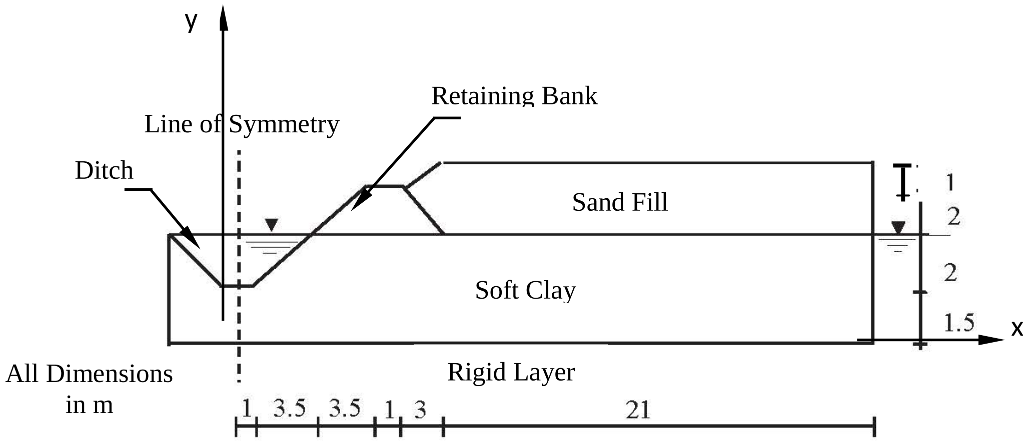

Figure 2. Cross-section of the typical embankment.

The material properties of the embankment and the soil foundation are shown in Table 1.

Table (1): Soil Parameters of the embankment and soil foundation

Parameter	Clay	Retaining bank	Hydraulic fill
Dry unit weight (γ_{dry}), kN/m^3	-	13.5	18
Saturated unit weight ($\gamma_{sat.}$), kN/m^3	13.5	-	-
Permeability (k), m/sec.	1.157×10^{-8}	-	-
Modulus of elasticity (E), kN/m^2	2667	2667	4000
Poisson's ratio (υ)	0.333	0.333	0.333
Cohesion (c), kN/m^2	8	8	3
Angle of internal friction (ϕ), deg.	20	20	30

In the case of limited construction time available for the construct, it is necessary to design the embankment to have a satisfactory factor of safety during embankment construction which has the minimum holding periods between loading stages.

The major point in used the geotextiles are their porous to liquid flow across their manufactured plane and also within their thickness. In addition, the fabric always performs at least one of four discrete functions; separations, reinforcement, filtration and/or drainage. The behavior of geotextile element is defined by the elastic axial stiffness, EA. The stiffness is based on the material tension stiffness and the cross-section area. Thus, the geotextile elements cannot sustain compression forces. The axial stiffness is the ratio of the axial force per unit width and the axial strain, $\Delta L/L$ (where ΔL is the elongation and L is the length).

For the numerical modelling, the geotextiles are composed of geotextile elements (bar elements) with two translational degrees of freedom in each node. Since the soil elements used with 15 nodes; therefore, each geotextile is defined by five nodes, and the geotextile with a stiffness in extension 2500 kN/m has been used.

In the present study, the method of converted the axisymmetric of unit cell of stone column into an equivalent plane strain column as shown in Fig. 3 is used.

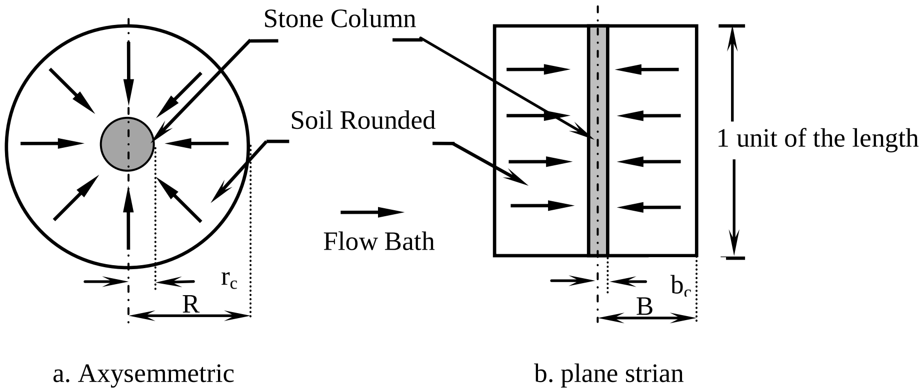

Figure 3. Cross-section of unit cell stone column and plane strain conversions.

The width of the plane strain column will be given by the following relationship which is based on the equivalence of the area replacement ratio:

$$b_c = B\ r^2 / R^2 \qquad (4)$$

And the relationship between R and B given by the following equation based on the equivalence of total area for a square pattern of columns:

$$R = 1.13B \qquad (5)$$

For simplicity, the permeability of the soil in the plane strain will be taken as an equal to the permeability of the axisymmetric cross-section. The material parameters for the stone column model is shown in Table 2.

Table 2. Material parameters of stone columns

Parameter	Value
unit weight, kN/m^3	20.0
Permeability (k), m/sec.	1.16×10^{-4}
Modulus of elasticity (E), kN/m^2	30000
Poisson's ratio (υ)	0.3
Cohesion (c), kN/m^2	5
Angle of internal friction (ϕ), deg.	40

The plane strain model of stone column is modelled numerically by using 15-node triangular elements. The width of stone columns in the plane strain model is 0.20 m, and the space between the columns is 2.4 m. The material of the soil is modeled as Mohr-Coulomb model. The geometry of the embankment reinforced with geotextile and supported on stone columns is shown in Fig. 4.

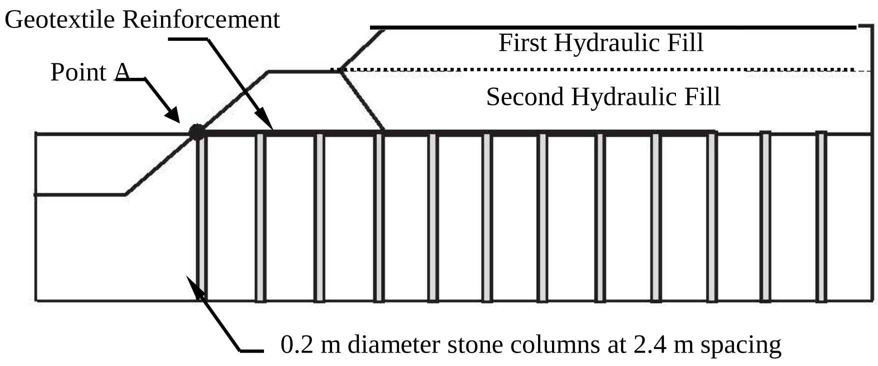

Figure 4. Geometry of the embankment with geotextile and supported on stone columns

5. Numerical Analysis of the Short-Term Stability of the Embankment

The plane strain finite element analysis is performed using Plaxis 2D (version 8.6). The construction of the embankment on soft soil with a high groundwater level which leads to an increase in pore pressure is considered. Therefore, the analysis consists of two alternatives for the construction of the embankment; the undrained and consolidation behavior.

5.1. The fully undrained construction of the embankment

The construction of the embankment is performed in two successive layers, where the second layer is constructed immediately after the first layer of the embankment.

The curve of the factor of safety for non-reinforced and reinforced embankment for the undrained behavior is shown in Figs 5 and 6, respectively.

For the undrained behavior, where a limited construction time available for the construct, the safety factor for the non-reinforced embankment and the reinforcement embankment with a geotextile and reinforcement the foundation by stone columns are 1.09 and 1.6, respectively. This behavior of an increase in the factor of safety for the reinforced embankment can be attributed to the resist of the lateral forces in the embankment and the lateral deformation of the soil by the tension induced in the geotextile which is used in the case of the factor of safety for the short term stability of the embankment is less than 1.3 In consequence the stone columns have been maintain the side slope stability with a minimum factor of safety greater than 1.3 for the short term stability.

5.2. The consolidated construction of the embankment

In this section the influence of consolidation which occurred during the construction stages on the factor of safety has been assessed. The construction of the ditch and retaining bank is assumed to be taking 3 days, where during this time interval the construction will be take place, as well as consolidation. The first layer of the hydraulic fill will take 7 days, and the second hydraulic fill will take 3 days. The curve of the factor of safety for non-reinforced and reinforced embankment for the consolidated behavior is shown in Figs. 7 and 8, respectively.

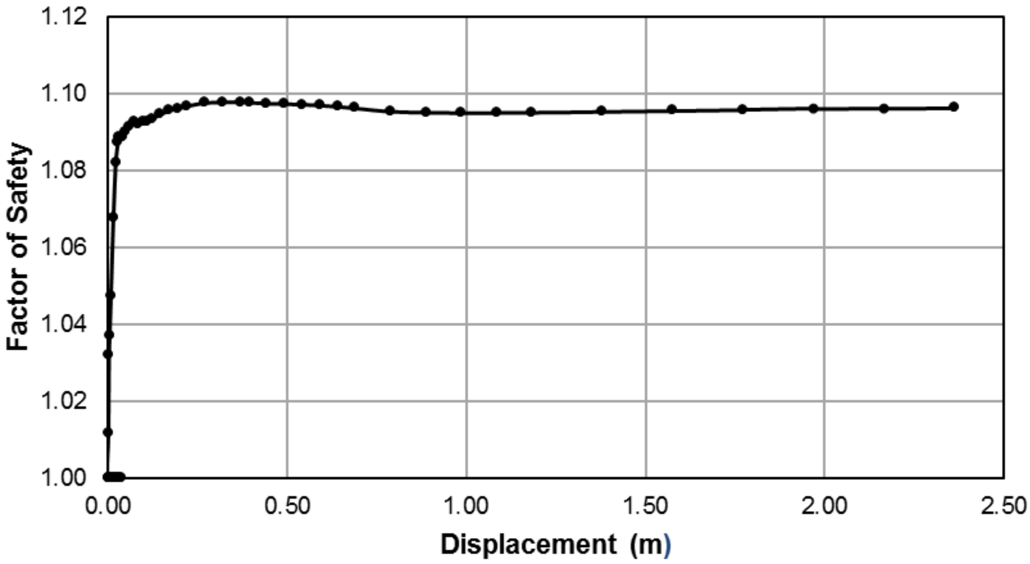

Figure 5. Safety factor analysis at point A, undrained behavior for non-reinforced embankment.

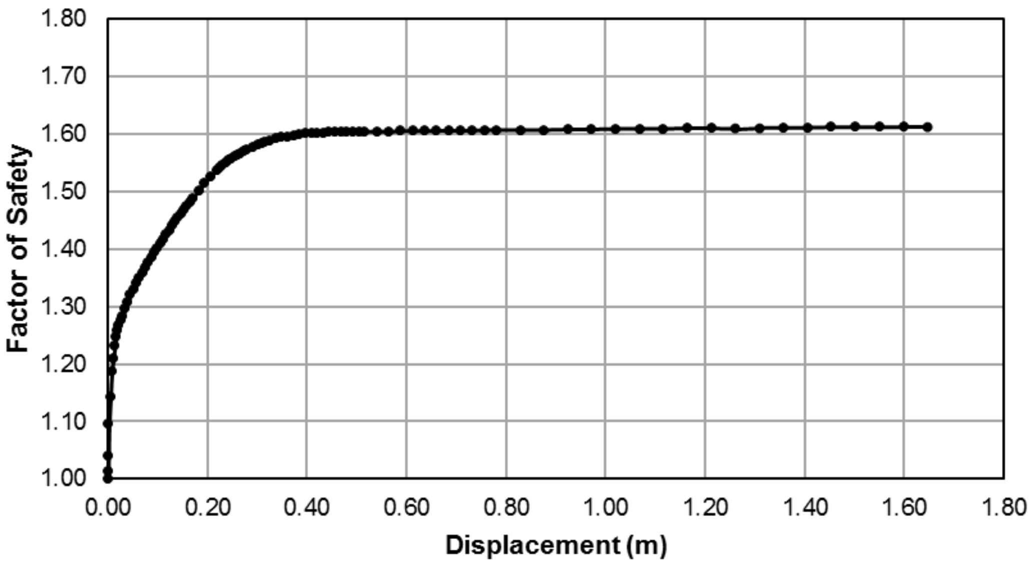

Figure 6. Safety factor analysis at point A, undrained behavior for reinforced embankment.

For the consolidated behavior, the time interval of the construction is considered, the factor of safety is increased compared with that for the undrained behavior from 1.09 to 1.45 for the non-reinforced embankment, and from 1.61 to 2.30 for the reinforced embankment. This behavior is due to the contribution of the stone column in accelerating the primary consolidation of foundation soil.

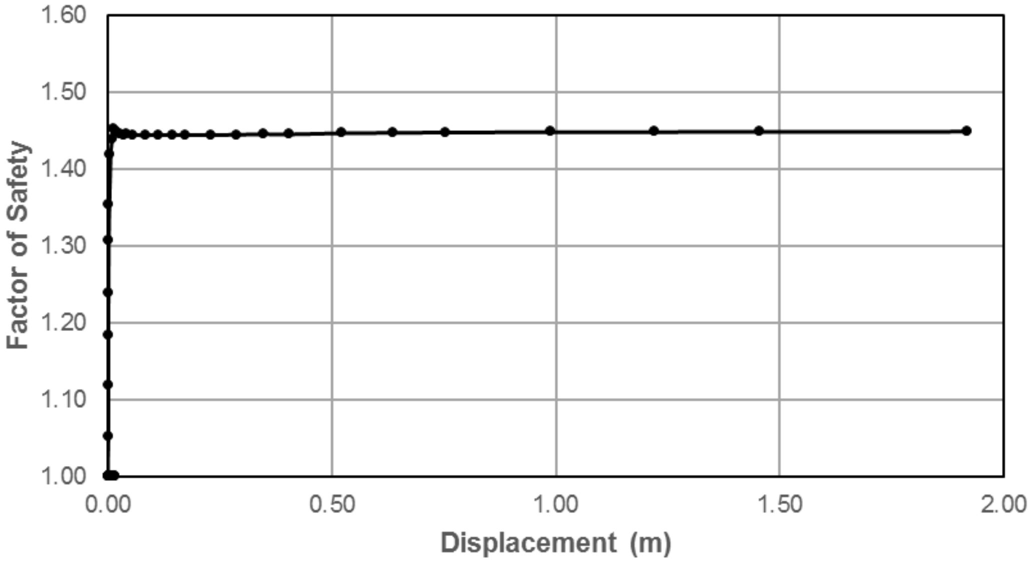

Figure 7. Safety factor analysis at point A, consolidated behavior for non-reinforced embankment.

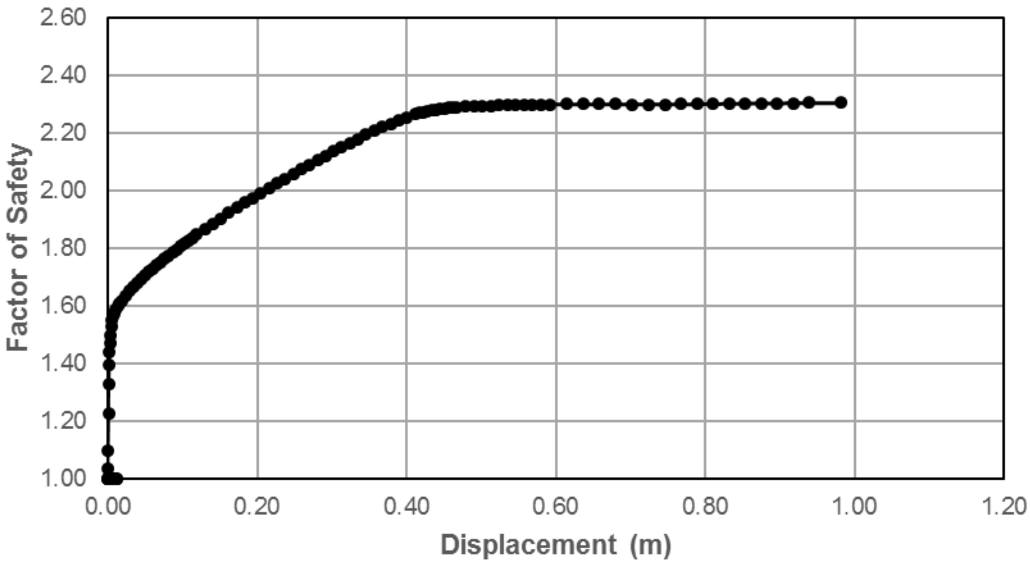

Figure 8. Safety factor analysis at point A, consolidated behavior for reinforced embankment.

In addition, by comparing the values of safety factor for the undrained and consolidated behavior for non-reinforced embankment, it can be noticed that the factor of safety for the consolidated behavior is more than that for the undrained behavior.
This behavior can be attribute to the dissipate of the excess pore pressure which occurred afire 13 days of the embankment construction as shown in Fig. 9. The displacement after that time will be reached to asymptotic values (see, Fig 10).

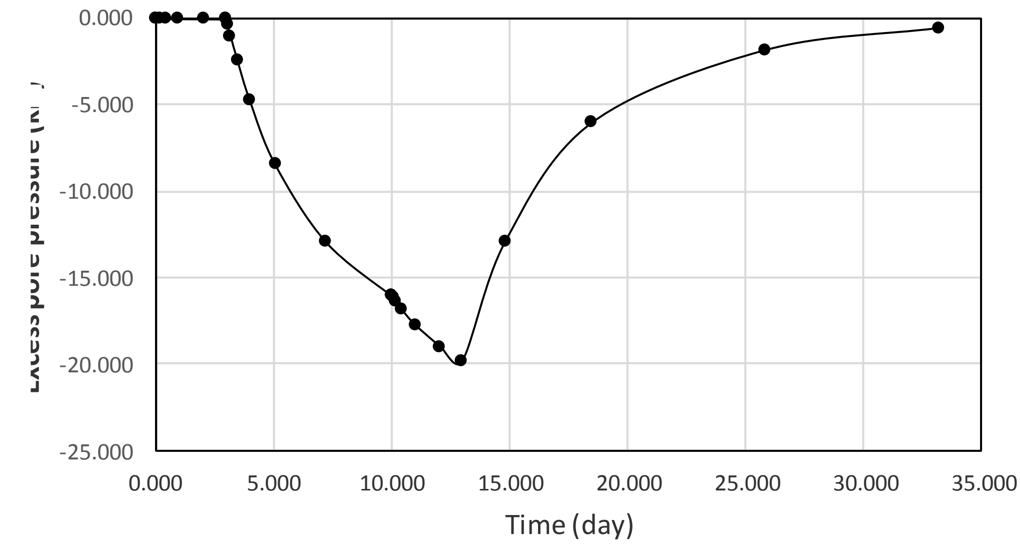

Figure 9 Consolidated, non-reinforced embankment, excess pore pressure at geometry point (32.900, 1.75)

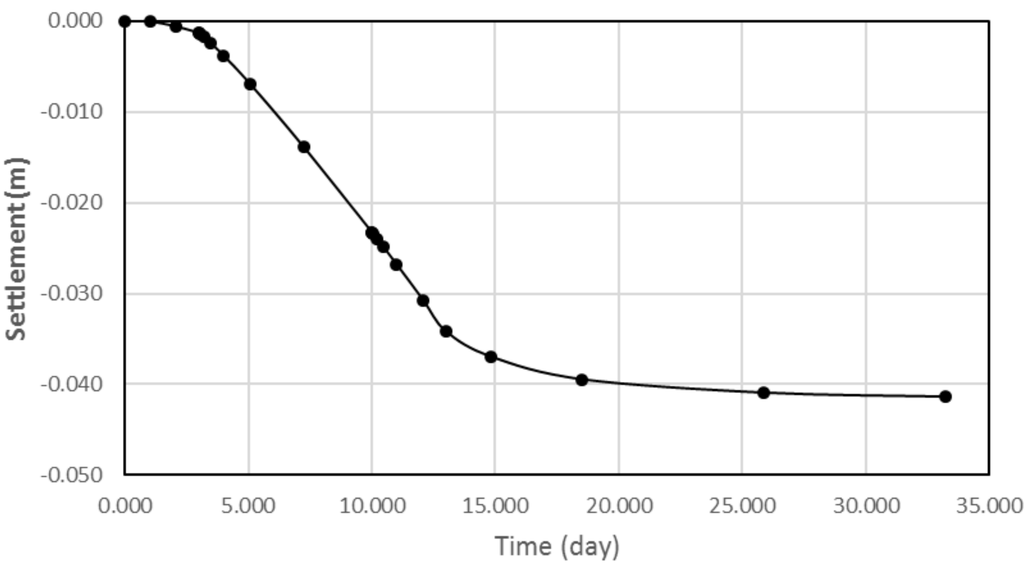

Figure 10 Consolidated, non-reinforced embankment, displacement at geometry point (32.900, 1.75)

6. Conclusions

1. For the undrained behavior, the case of limited construction time available for the construct of the embankment, the factor of safety can be increased to a limit satisfies a minimum factor of safety by reinforcement the embankment with a geotextile and reinforcement the foundation by stone columns.
2. For the consolidated behavior, when the time interval of the construction is considered, the factor of safety is increased compared with that for the undrained behavior from a value of 1.09 to 1.45 for the non-reinforced embankment, and from 1.61 to 2.30 for the reinforced embankment. This behavior is due to the

contribution of the stone column in accelerating the primary consolidation of foundation soil.

3. The installed of stone columns in soft clay has been improved the stability of the embankment on the soft clay during the period of construction of the embankment.
4. The factor of safety for the consolidated behavior is more than that for the undrained behavior. This behavior can be attribute to the dissipate of the excess pore pressure which occurred afire 13 days of the embankment construction

4. References

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