Parametric Study of Reinforced and Unreinforced Embankment on Soft Soil

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ABSTRACT

Parametric studies of reinforced and unreinforced embankment were conducted using Finite Element Sage Crisp program. Construction sequence and consolidation during construction were modeled. Several factors such as stiffness of reinforcement, stage construction, permeability of the foundation soil were systematically investigated to determine its effect on the foundation embankment system. Horizontal and vertical displacement of the ground surface, excess pore water pressure dissipation, and mobilize reinforcement force are among the aspects presented and discussed. Large displacement analysis based on updated Lagrangian and Modified Newton Raphson iterative scheme available in Sage Crisp program was used to account for large deformation associated with soft soils.

Key words: *reinforced soil, embankment, stress, finite eleme*nt

1. INTRODUCTION

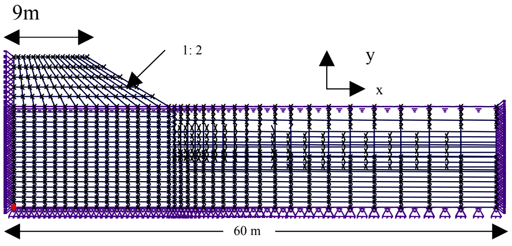
Conventional limit equilibrium and finite element is the two most common analysis method used by geotechnical engineers for designing and predicting the mechanical behavior of reinforced and unreinforced embankment. The main advantage of finite element analysis over the conventional method is that complete interaction of the embankment foundation system can be simulated. In the case of limit equilibrium method, the maximum tensile force developed in the reinforcement due to the embankment loading need to be determined beforehand. This raises the question of how to assign the magnitude of the stabilizing force used to represent the geotextile. In this regard, finite element analysis can be used to determine the magnitude of the stabilizing force and limit equilibrium analysis can then be carried out to determine the overall safety factor. Another disadvantage of limit equilibrium method is that the mode of failure probably encounter has to be pre determine [1].

2. SCOPE

The scope of study in this paper is to conduct parametric study on a typical embankment commonly use in highway construction by using Finite Element Sage Crisp program. No verification of the results with field trial embankment or case studies were conducted. The main aim is to investigate how several important parameters affect the mechanical behaviour of the reinforced embankment system. This will provide insight and better understanding into how the physical mechanisms control the behaviour of embankment.

3. FINITE ELEMENT MODELLING OF THE REINFORCED EMBANKMENT

A typical road embankment of 18m crest width and 1:2 side slopes has been chosen for this parametric study. The depth of the soft foundation soil is 10m underlain by a rigid bed rock. Finite element discretization of the problem is as shown in Fig 1. Due to symmetry along the centre line only half of the geometry was simulate. The finite element mesh consists of 775 numbers of 8-node quadrilateral elements to model both the foundation and embankment soil and 15 numbers of 3-node bar elements to model the reinforcement (geotextile). The bottom of the geometry is fixed in both direction and both vertical ends are allowed to move vertically and restraint in the horizontal direction. The ground water table is assumed to be located at the ground surface and the bottom boundary was idealized as impermeable. A single layer of geotextile reinforcement is placed at the interface of the soft foundation and embankment. The interface between the soil and reinforcement was not simulated. This assumption is sufficient provided that the shear stresses developed at the interface of the soil and reinforcement during the loading process are less than the interface shear strength itself. If this is not the case special interface element should be used to realistically model the interaction of the reinforcement with the surrounding soil. Conventional element can also be used as interface provided that the aspect ratio of the element is within certain range.[2]. The interface element for two dimensional analysis available in Sage Crisp program is based on [3]. It consists of 4 nodes or 6 node quadrilateral element with zero thickness. However its use in simulating interface for reinforced embankment problem has not been well tested.



Bottom boundary fixed in both directions

Fig 1 Finite element discretization of embankment and subsoils

4. MATERIAL MODELS AND PARAMETERS

4.1 Foundation Soil Properties

The foundation soil is model as a Modified Cam Clay material [4]. Muar soft clay commonly found along the west coast of Johore, Malaysia is used in this paper to represent the soft soil. Eight material parameters were needed to characterize the modified cam clay model for the soft foundation soil as shown in Table 1. The material parameters were taken from the published literature.

Table 1 Material properties for foundation soils

Λ	K	e_{cs}	M	G KN/m^2	Bulk KN/m^3	k_y m/day	k_x m/day
0.25	0.05	2.44	0.9	3.2E3	15.5	1.728E-4	1.728E-4

4.2 Embankment Soil Properties

The embankment fill soil was modeled as anisotropic elastic material. This is considered adequate since major settlement arises from the soft foundation soil.

4.3 Reinforcement Properties

Two nodes or three nodes bar element available in Sage Crisp program can be used to model geotextile reinforcement. These types of elements can only sustain axial forces along its longitudinal axis. The number of nodes for the bar element and the side of soil element where the bar is positioned need to have similar numbers of nodes to ensure displacement compatibility is maintained. Therefore 3 nodes bar element is utilized in this paper to simulate the geotextile reinforcement. The reinforcement behaviour is modeled as a linear elastic response. The only material properties required for the analysis are the stiffness and cross sectional area of the geotextile. In practice these properties depend on the type of geosynthetic material used and usually the properties are available from the product manufacturer catalogue.

4.4 Insitu stresses

It is important to establish the initial yield surfaces when using the MCC soil model. For MCC model the insitu stresses are defined in terms of effective stresses. Table 2 shows the value of the insitu stresses for the foundation soil.

Table 2 Insitu Stresses

Height M	σ'_{xx} KN/m^2	σ'_{yy} KN/m^2	σ'_{zz} KN/m^2	τ_{xy} KN/m^2	PWP KN/m^2	P_c KN/m^2
10	0	0	0	0	0	0
0	56.9	56.9	56.9	0	98.1	40

4.5 Stage Construction

In finite element analysis of embankment problem it is very important to be able to model correctly the construction process. For all the analysis performed in this paper, the construction of the embankment consists of 5 lifts. The height of embankment fill for each lifts is one meter. Between each lifts there is a waiting period to allow for dissipation of pore water pressure to take place. Table 3 shows the full construction process adopted for the parametric studies.

Table 3 Construction Stage

Stage	**Time (days)**	**Load increments**
Lift 1	2	10
Consolidation for lift 1	100	10
Lift 2	2	10
Consolidation for lift 2	100	10
Lift 3	2	10
Consolidation for lift 3	100	10
Lift 4	2	10
Consolidation for lift 4	100	10
Lift 5	2	10
Consolidation for lift 5	100	10

5. DETAILS AND RESULTS OF ANALYSES

5.1 Effect of reinforcement stiffness

Four different analyses were conducted on the typical embankment with reinforcement modulus ranging from 0 to 6.0E6. A conventional embankment with the control parameters and no reinforcement (zero modulus) was modeled as case 1. Analyses of case 2 to case 4 represent reinforced embankment with modulus of reinforcement (geotextile) ranging from 2.0 E6 to 6.0E6. In each of the analyses the vertical and horizontal movement along the ground surface from the centre line was compared. (Fig.2 and Fig 3). generally the horizontal displacement profile for all the cases is quite similar. The horizontal displacement along the ground surface for all the cases increases gradually from the left boundary of the embankment and reach maximum value near the toe. Thereafter, the horizontal displacement decreases gradually and reaches a value of zero at a distance of about 40 m from the centre line. The maximum horizontal displacement is 523 mm, which occurred for the unreinforced case. With the inclusion of reinforcement with modulus of 2.0E6, the horizontal displacement reduces to 400 mm. This represents about 23% reduction. When the reinforcement modulus was increase twice, the maximum horizontal displacement reduced by 31%. With another increase of twice the modulus the reduction in displacement was about 36%. This shows that an increase in reinforcement modulus from 4.0E6 to 6.0E6 do not contribute much to the reduction in horizontal displacement. This also means that there is a limit to the reinforcement stiffness, which can be mobilized.

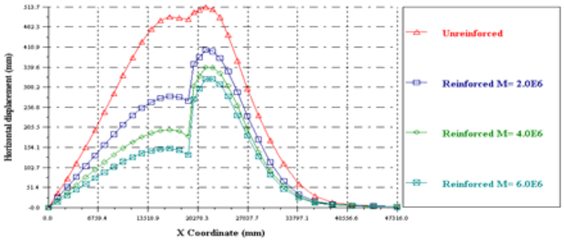


Fig 2 Horizontal displacement against X direction along ground surface

The pattern of vertical displacement (Fig 3) along the ground surface for all the cases was also similar with small base heave occurring immediately beyond the toe of the embankment. It is interesting to note that the maximum vertical displacement do not occur beneath the center of the embankment but at a lateral distance of about 6.7 m from the centre line. This is due to the zone of lower effective horizontal stresses. Maximum vertical displacement was 580 mm for the unreinforced embankment. The maximum vertical displacement decreases by about 17 % when the reinforcement modulus increases from 0 to 6.0E6. In comparison to the total reduction of about 36 % for the maximum horizontal displacement, proves that the inclusion of reinforcement has significant effect in reducing horizontal displacement. The inclusion of reinforcement also helps to reduce slightly the base heave as can be seen from Fig 3.

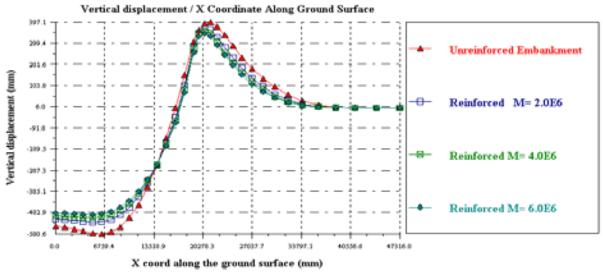


Fig 3 Vertical displacement against X direction along ground surface

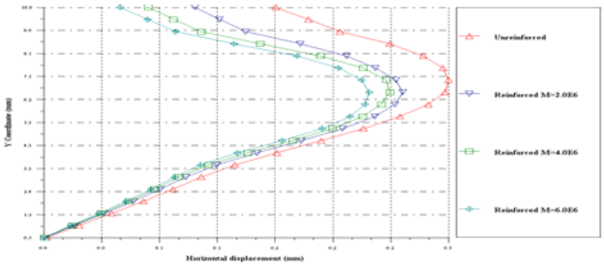


Fig 4 Horizontal displacement against Y direction at the toe of the embankment

The horizontal displacement against vertical depth at the toe of the embankment is shown in Fig. 4 It can be seen that with the inclusion of reinforcement, the horizontal displacement reduce quite significantly. This shows that the main aim of the reinforcement is to reduce the lateral shear stress developed in the foundation soil due to the weight of the fill embankment.

5.2 Effect of pore water permeability coefficient

Coefficient of permeability in the horizontal and vertical direction is required when performing consolidation analysis. Permeability is not a soil constant and in situation in which large loads are applied and significant consolidation takes place, changes in void ratio can lead to changes in the coefficient of permeability. Research conducted by [5] shows that using variation of permeability coefficient with respect to changes in void ratio, provide better prediction of pore water dissipation. However, Sage Crisp used constant pore water permeability throughout the analyses.

Fig 5 shows the excess pore-water pressure changes with time at several locations beneath the embankment. The pore water pressure rises immediately after the construction of a lift and then falls until the next lift is placed. After the final lift has been placed, the pore water pressure at the specified location drops from a high of 90 KN/m^2 to about 55 KN/m^2. Significant excess pore water pressure remains at the end of construction indicating that additional long term settlement will occur. Fig 6 shows the contour of excess pore water pressure beneath the embankment at the end of consolidation for lift 5. It can be seen that the maximum excess pore water pressure occurred at the center line beneath the embankment and at a distance of about 5 m from the ground surface. The excess pore water pressure decreases gradually from the center line to a zero value at a distance slightly further from the toe of the embankment.

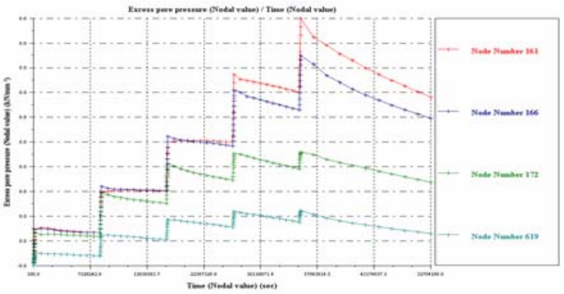


Fig 5 Excess Pore Pressure Against Time at Several Locations Beneath the Embankment

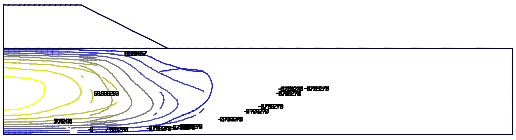


Fig 6 Contour of excess pore water pressure at the end of consolidation for lift 5

Fig 7 shows the displacement vector at the end of consolidation for lift 5. The pattern of the displacement vector indicates that the mode of failure will occur in the form of circular shape with base heave occurring near the toe of the embankment.

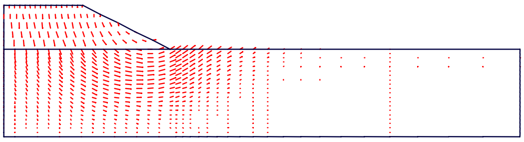


Fig 7 Displacement vectors at the end of consolidation for Lift 5

6. CONCLUSIONS

The response of an embankment on soft clay was investigated by a series of finite element analyses using SAGE CRISP program. Construction sequence, reinforcement and consolidation of soft clay were simulated. The soft soil and fill materials were respectively modelled by Modified Cam Clay material and linear elastic model available in the program. The influence of geotextile reinforcement was investigated. The following conclusion can be drawn from this study:

(1) Maximum pore pressure occur beneath the centre of the embankment

(2) The mode of embankment failure occurred in the form of circular shape with base heave occurring near the toe of the embankment.

(3) Increasing the reinforcement stiffness does not contribute much to the reduction in vertical displacement compared to horizontal displacement.

(4) Maximum vertical displacement does not occur beneath the centre of the embankment but at a lateral distance of about 6.7m from the centre line.

(5) There is a limit to the reinforcement stiffness, which can be mobilized

(6) Sage Crisp has successfully analysed reinforced embankment problem.

7.0 REFERENCES

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