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FINITE ELEMENT ANALYSIS OF AN ANCHORED REINFORCED EARTH WALL UNDER SLOPE SURCHARGE

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ABSTRACT
A parametric study was conducted using a finite element method to investigate the performance of an instrumented reinforced anchored earth wall. The performances was characterized herein under two criteria namely stress and deformation criteria. This study revealed that the increase in slope height and gradient of surcharge significantly enhance the summation of maximum axial stress in the reinforcing bars. However, the influence of surcharge becomes negligible when the surcharge height goes beyond 1.5 times the height of the wall. The influence of slope setback decreases with increase in setback but beyond 1.5 times the block width becomes insignificant.

***Key words*:** *Anchored blocks; reinforced earth; Finite Element; Parametric study*

INTRODUCTION
Nowadays retaining walls especially mechanically stabilized earth (MSE) types are frequently used in many geotechnical applications mostly on road construction and bridge abutments. Among the MSE wall systems, Anchored Earth Wall is another type reinforced soil system which was patented by the Transport and Road Research Laboratory of United Kingdom in1981 [1]. Anchored earth systems are a combination of the techniques used in the reinforced soil and the soil anchoring [2]. Nehemiah wall is similar to Anchored earth wall system has been widely used all over the Malaysia since it was introduced and developed [3].

In spite of successive developments [4-7] in the field of reinforced soil wall systems on the design, analysis and construction techniques or approaches, still the basic design methodology remains the same which is the limit equilibrium method. In design and analysis of reinforced earth wall, the limited equilibrium technique has been used from the first time while the reinforced earth was commercially constructed [8].

The present design guidelines or manuals (based on equilibrium techniques) are unable to evaluate the performance of reinforced earth wall under different boundary circumstances i.e. slope surcharge, lateral yielding of facing as well as vertical yielding at foundation soil. Although, Ali [1] reported the effect of facing yielding and vertical yielding on the behavior of Anchored wall but effect of slope surcharge was not included.

The use of numerical techniques, such as the finite element procedure is effectual for evaluating the performance of reinforced soil structures. It allows the amalgamation of complex geometrical and boundary conditions as well as material models. Lee [9] reported that most of the finite element models are carried out to analyze the behavior of the reinforced earth in 70's. At that time, two techniques were used to model reinforced soil walls namely the composite representation and the discrete representation of the constituents. In the composite representation, the reinforced mass is treated as an anisotropic, homogeneous material. Whereas in the discrete representation, each individual component of the reinforced soil wall system is independently represented by discrete finite elements. With the advent of powerful and high speed computers at affordable prices, the choice between composite and discrete representation is no longer an issue. Discrete representation has becomes the obvious choice due to the large computing resource available nowadays.

In this paper an extensive parametric study was carried out by finite element method to investigate the influence of several parameters on the behavior of anchored earth wall under slope surcharge (Figure 1). The studied parameters are effect of slope height, effect of slope gradient, and effect of slope set back, under two performance criteria that are stress and deformation criteria. The horizontal displacement at the facing was used as the deformation criteria and the following criterions were used as the stress criteria:

- Tension distribution along the reinforcing bars
- Summation of maximum tension developed in all the reinforcing bars Z_t
- Summation of tensile forces developed at the connection to the facing panels Z_c

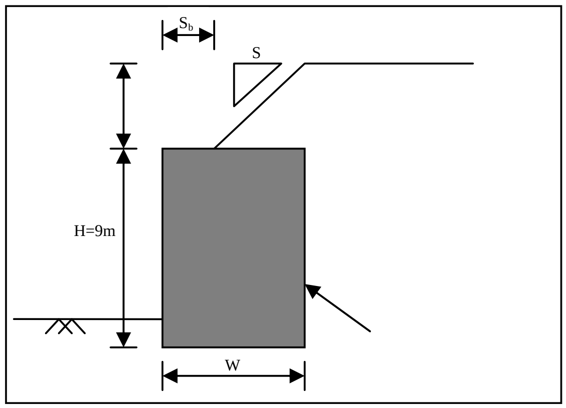


Figure 1: The geometry of a typical 9 m wall with slope surcharge

NUMERICAL MODEL AND PARAMETERS

A 9 m high Nehemiah wall was chosen as the standard case for the parametric studies by finite element method which was designed as per British Code [10]. According to the design, the length of the reinforcing bars was 10.9 m long and the vertical spacing of the reinforcing bars was a constant at 0.75 m. The boundaries were sufficiently far away so that they have no significant influence on the behavior of the wall.

The finite element mesh (Figure 2) of the Nehemiah wall system was generated by finite element software, PLAXIS [11]. In this finite element procedure a discrete model [9] was used in compare to the composite model. Using the discrete model, the components of the numerical model consists of foundation soil, pad footing, facing panels, backfill material, retained fill, reinforcing bars, and the anchor blocks were modeled distinctly and separately.

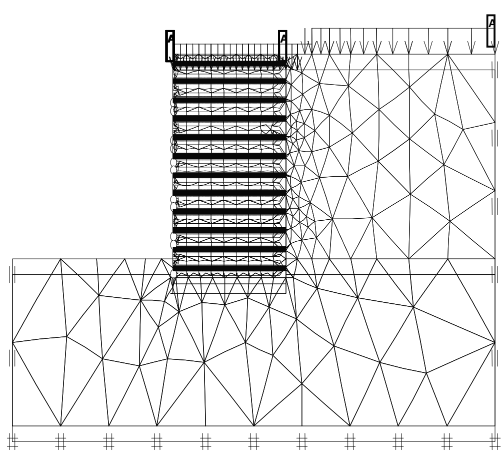


Figure 2: Generated finite element mesh for the 9 m high Nehemiah wall

For 2 D plane strain analysis, the 6 node triangular elements were selected to model the soils. It provides a second order interpolation for displacements. The element stiffness matrix was evaluated by numerical integration using a total of three Gauss points (stress points).

The soil-structure interaction between the reinforcing bars and the backfill material was modeled by the interface elements. Likewise the interaction between the facing panels and the backfill material was also modeled by interface elements. The stiffness matrix for interface elements was obtained using Newton-Coates integration points.

RESULT AND DISCUSSION

Effects of slope height

To investigate the effects of slope height H_s on the wall behavior, the slope gradient S was kept at a constant value of 2 (two) while slope setback S_b is kept at zero. The slope height was increased from 3 m high till 18 m high in increments of 3 m.

As determined by stress criteria, Figure 3 shows the tension distribution along the reinforcing bars for the wall with slope surcharge height of 6 m and gradient of 1v: 2h with zero set back. The maximum tension occurs at the connection for all levels of reinforcing bars except the bottom three levels. For the bottom three levels, the maximum tension occurs at or near the anchor block. This pattern of tension distribution is representative of all the slope heights. However, the summation of maximum tension Z_t increases with the slope height. In Figure 4 shows the increase in Z_t with the surcharge height. It is seen that Z_t increases only marginally when Hs exceeds 1.5 H. In other words, beyond 1.5 H, further increase in slope height has little effect on the internal stability of the wall.

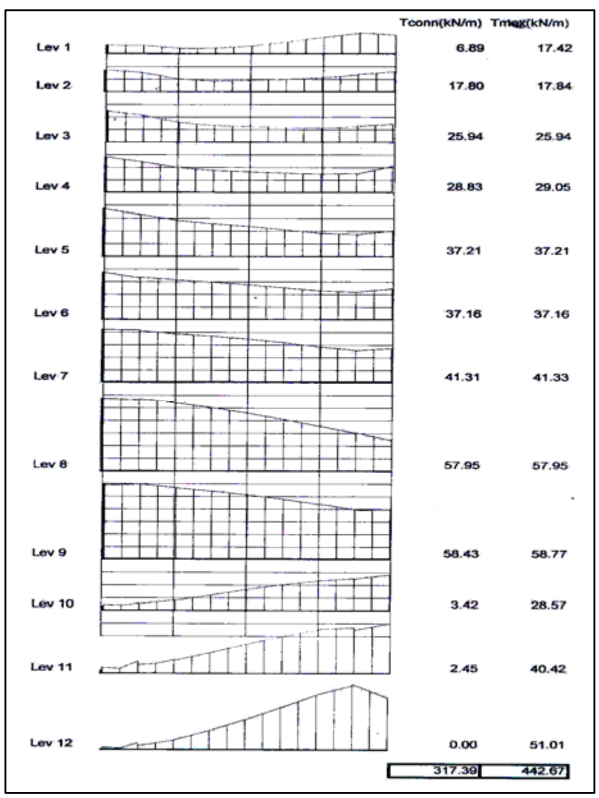
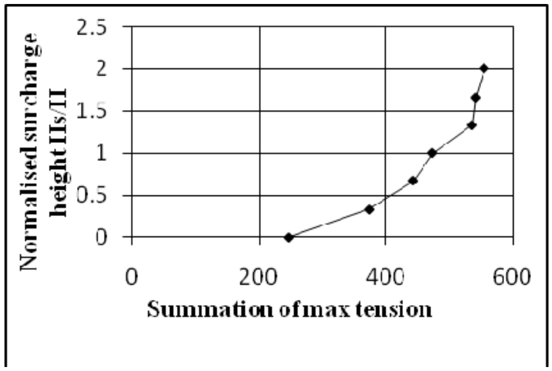


Figure 3: Tension distribution along the reinforcing bars of 9m high wall with 6m high slope surcharge



Fiure.4: Effect of slope surcharge on the summation of maximum tension

Related to deformation criteria, Figure 5 shows the horizontal displacement wall facing of a standard 9 m high wall with 6 m high slope surcharge at gradient of 1v: 2h with zero set back. It is seen that the maximum horizontal displacement of 172 mm occurs near the top of the wall. The acceptance criteria for the displacement depend on the serviceability requirements of the completed structure. The maximum horizontal displacement at the wall facing for each surcharge height was plotted as shown in Figure 6. It is seen that again, the effect of surcharge is only significant for surcharge height less than 1.5 H as observed same as stress criteria.

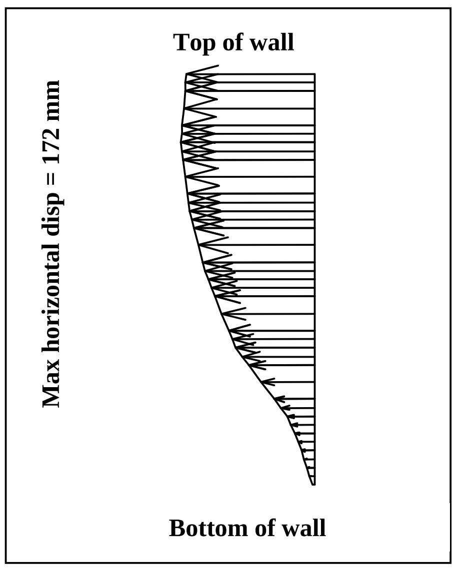


Figure 5: Horizontal displacement of wall facing

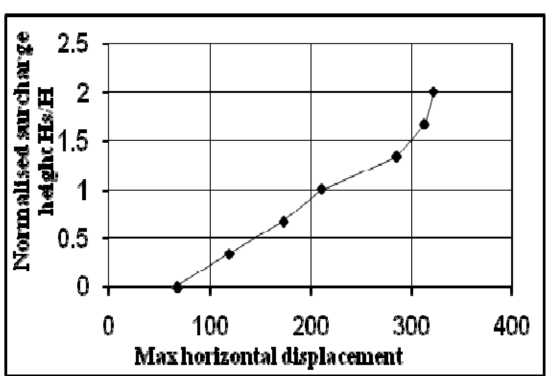


Figure 6: Effect of surcharge on maximum horizontal displacement at wall facing

Effects of slope gradient

Three slope gradients were considered for the study of their effects on the behavior of the wall. The slope gradient was denoted by the ratio of 1: S whereby S was the horizontal distance versus unit height. For the present study, three numerical values of S were considered and the values were 1.5, 2.0 and 2.5.

According to Stress criteria, for each slope gradient, the summation of the maximum tension Z_t developed in the reinforcing bars was computed. The plot of slope gradient versus Z_t is shown in Figure 7. It is seen that as the slope gradient gets steeper, Z_t increases correspondingly almost linearly. Similar trend was observed by Zornberg and Mitchell [12].

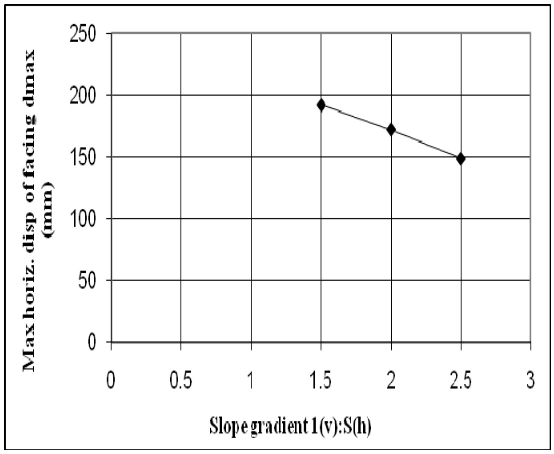


Figure 7: Plot of slope gradient S versus Z_t

Corresponding to deformation criteria, as seen in Figure 5, the maximum horizontal displacement d_{max} occurs near the top of the wall. The plot of slope gradient versus d_{max} is shown in Figure 8. The horizontal displacement increases as the slope gradient get steeper. As in the case of Z_t, the value of d_{max} varies with the slope gradient more or less linearly.

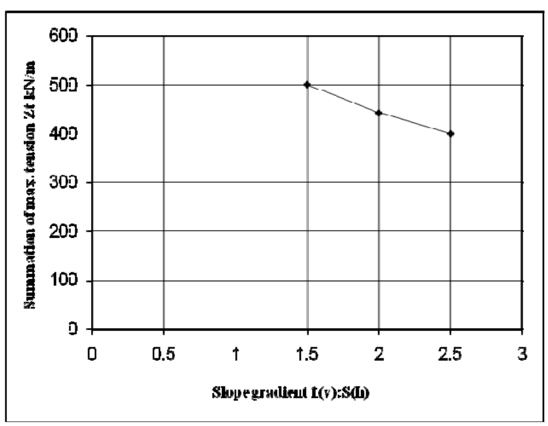


Figure 8: Plot of slope gradient versus maximum horizontal displacement of wall facing

Effects of slope set back

To study the effects of slope set back, surcharge height and slope gradient were kept 6 m and 1v: 2h respectively as a standard case. The slope set back S_b (Figure 1) were set at 0, 3, 6, and 12 m away from the wall face respectively for each parametric study. The effect of the setback on the summation of maximum tension developed in the reinforcing bars is shown in Figure 9. The setback was normalized by dividing S_b by the width (W) of the reinforced block. It is seen that when the setback exceeds 1.5 times the block width, the decrease in Z_t becomes no longer significant.

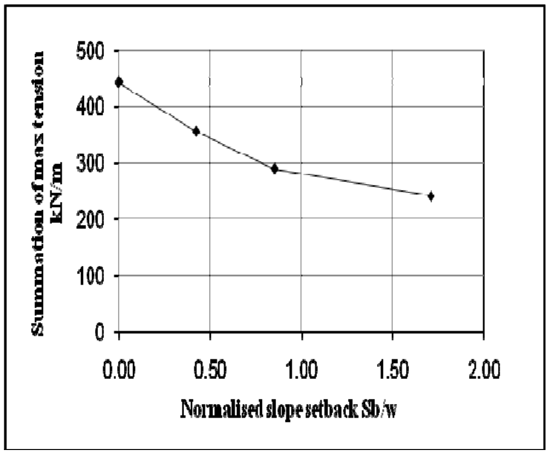


Figure 9: Effect of slope setback on summation of maximum tension

CONCLUSION

This paper reports the results of 2D finite element analysis on a 9 m high Anchored earth wall to investigate the effect of slope surcharge (with various geometrical configurations). The following conclusions can be drawn based on the finding of study.

1. As the surcharge height increases, the summation of maximum tension increases correspondingly until the surcharge height reaches 1.5 times the height of wall whereby any further increase in the surcharge height does not result in significant further increase in the summation of maximum tension.

2. As the surcharge height increases, the maximum horizontal displacement of the wall facing increases correspondingly until the height reaches 1.5 times the height of the wall whereby any further increase in the surcharge height does not result in significant further increase in the maximum horizontal displacement.

3. As the gradient of the slope surcharge gets steeper, the summation of maximum tension and maximum horizontal displacement of the wall facing increases correspondingly.

4. As slope setback increases, the summation of maximum tension decreases until the setback reaches 1.5 times the width of wall block whereby any further increase in setback does not result in significant further reduction of summation of maximum tension.

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NOMENCLATURE

H_s height of slope surcharge (m)
H height of wall (m)
S_b slope set back (m)
S slope gradient
W width of wall (m)