Behavior of Narrow Mechanically Stabilized Earth Walls

Comportement des murs étroits de sol mécaniquement stabilisé

Gihan Abdelrahman

Civil Engineering Department, Professor, Fayoum University, Egypt, gsa00@fayoum.edu.eg

Youssef Gomaa

Civil Engineering Department, Assistant Professor, Fayoum University, Egypt

Mohamed Kamel,

Construction Engineering Department, Demonstrator, Misr University for Science & Technology, Egypt

ABSTRACT: Previous studies defined narrow mechanically stabilized earth walls as a retaining wall with aspect ratio (ratio of wall width to wall height), L/H, less than 0.70 as in conventional walls. Some studies investigated its behavior and its failure planes compared to those of conventional walls. In this paper, parametric study using finite element program PLAXIS, 8.2, and limit equilibrium using Geo-Studio 2007 program (Slope/W Design) had been introduced to discuss the behavior of narrow MSE wall as a function of aspect ratio, L/H, reinforcing elements spacing, S. Also, this paper presents the effect of varying aspect ratio, L/H, of narrow MSE wall on location and shape of failure surface. The results indicated that increasing aspect ratio, increases the factor of safety, and maximum tensile force. While increasing reinforcing elements spacing decreases the factor of safety, and increases maximum tensile force. In addition, inclination angle of the failure surface increases with increasing of aspect ratio from 0.2 to 0.7. The limit equilibrium results are verified the results reported from finite element.

RÉSUMÉ: Des études antérieures ont défini des murs étroits de sol mécaniquement stabilisés comme un mur de soutènement avec un rapport d'élancement (L/H) inférieur à 0,70 considéré pour les murs classiques. Certaines études ont étudié son comportement et ses plans de rupture par rapport à ceux des murs conventionnels. Dans cet article, une étude paramétrique utilisant le programme d'éléments finis PLAXIS, 8.2, et le programme d'équilibre limite Geo-Studio 2007 (Slope /W Design) ont été introduits pour discuter du comportement de la paroi étroite de MSE en fonction du rapport d'élancement, L/H, L'espacement des éléments de renforcement, S, et l'angle de frottement du sol, φ. En outre, cet article présente l'effet du rapport d'élancement variable, L/H, de la paroi étroite de MSE sur l'emplacement et la forme de la surface de la rupture. Les résultats indiquent qu'en augmentant le rapport d'élancement et l'angle de frottement, le coefficient de sécurité et la force de traction maximale augmentent. L'augmentation de l'espacement des éléments de renforcement diminue le coefficient de sécurité et augmente la force de traction maximale. En plus, l'angle d'inclinaison de la surface de rupture augmente avec l'augmentation du rapport d'élancement de 0,2 à 0,7. Les résultats d'équilibre limite vérifient les résultats rapportés à partir des analyses en éléments finis.

KEYWORDS: Narrow Mechanically Stabilized Earth wall, Finite element, Limit equilibrium, Failure surface.

1 INTRODUCTION.

FHWA design guidelines for shored mechanically stabilized earth wall systems are suggested for the design of MSE walls with aspect ratios from 0.3 to 0.7. However, several important characteristics of narrow MSE walls are not considered in these guidelines. The stability of narrow MSE walls was addressed by many researchers such as (Frydman and Kelssar 1987, Take and Valsangker, 2001, Woodraff, 2003, Leshchinskg and Hu, 2003, Lawson and Yee, 2005) for at rest conditions. They all concluded that, due to arching effect, the earth pressure coefficient decreased as wall aspect ratio, (ratio of wall width to wall height), L/H, decreased.

2 FINITE ELEMENT MODELING.

In the current study, the analysis was performed using the finite element program Plaxis software package (Bringkgreve and vermeer, 1998). Plaxis is capable of handling a wide range of geotechnical problems such as slopes, and earth structures such as retaining walls. Two dimensional plain strain model was used in the analysis.

2 .1 *Geometry and boundary conditions*

A narrow MSE wall system is referred to as a MSE wall with an aspect ratio, L/H, less than 0.7, that is placed in front of a stabe face. Shtamtic diagram of a narrow MSE wall with its dimensions is illustrated in Figure 1.

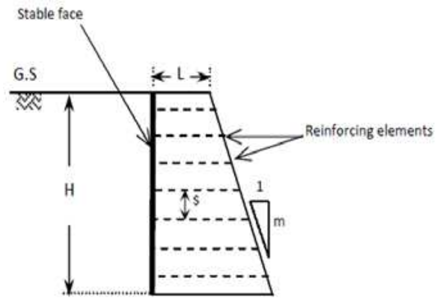

Figure 1. Narrow MSE wall in front of a stable face

The finite element mesh is composed of 15-node isoparametric triangular elements. The mesh coarseness was set as “Very fine”. Horizontal fixities (rollers) were applied to the stable face.Total fixities were placed at bottom of the foundation. Plane strain was assumed to solve the three-dimensional problem with a two-dimensional analysis. To simulate the real construction process of narrow MSE Walls, the wall was constructed with a stage construction procedure in this analysis.

2.2 *Backfill soil properties*

Hardening Soil model was selected to simulate nonlinear plastic response of soil. The Hardening Soil model is stress-dependent hyperbolic model based on the flow rule and plasticity theory. The adapted hyperbolic model parameters for the backfill soil are shown in Table 1. These parameters were selected to simulate the properties of compacted clean medium to coarse sand which often used in construction of MSE walls.

Table 1: Hyperbolic Model Parameters for the Backfill Soil

Parameter	Value
Unit Weight γ, (kN/m^3)	17.00
Peak Friction Angle, φ (deg.)	35
Cohesion, c , (kPa)	5
Angle of Dilatancy, Ψ (deg.)	5
Secant Stiffness, E_{50ref}, (kPa)	35000

2.3 *Reinforcement and facing element properties*

The reinforcements were modelled as line elements with a normal stiffness but with no bending stiffness. An elasto-plastic model was selected to model the breakage of reinforcement. The reinforcement properties used in the modelling is assumed according to typical values of geo-grid elements used in reinforcement of narrow MSE walls. These parameters were summarized in Table 2. Plate elements were used to represent the stabilized and narrow MSE wall faces. The facing parameters are listed in Table 3 and 4.

Table 2: Reinforcement properties

Parameter	Value
Axial Stiffness, EA, (kN/m)	1800
Maximum Axial Tension Force, Np, (kN/m)	120

Table 3: Wall face properties

Parameter	Value
Axial Stiffness, EA, (kN/m)	8.4x10^6
Bending Stiffness, EI, (kNm^2/m)	11.2 x10^4

Table 4: stable face properties

Parameter	Value
Axial Stiffness, EA, (kN/m)	10^9
Bending Stiffness, EI, (kNm^2/m)	10^{11}

3 LIMIT EQUILIBRIUM MODELING

The commercial limit equilibrium program GeoStudio 2007 (Slope/W Design) was used to perform the limit equilibrium in this study. This program is a limit equilibrium program specifically intended for the slope stability analysis in geotechnical engineering projects.

3.1 *Backfill Soil and reinforcement properties*

In this study, Mohr-Coulomb soil model was selected. The soil parameters in limit equilibrium study are similar to that in the corresponding finite element study. The adapted hyperbolic model parameters for the backfill soil are shown in Table 5. The reinforcement properties used in modeling is summarized in Table 6.

Table 5: Hyperbolic Model Parameters for the Backfill Soil

Parameter	Value
Unit Weight γ, (kN/m3)	17.00
Peak Friction Angle, φ (deg.)	35
Cohesion, c , (kPa)	5

Table 6: Reinforcement properties

Parameter	Value
Contact cohesion (kPa)	5
Contact Phi (deg.)	35
Interface factor	2
Bond safety factor	1
Fabric capacity, Np. (kN)	120
Fabric safety	1
Load orientation	0

4 RESULTS AND DISCUSSION

The constant and variable wall parameters in each case in limit equilibrium study are similar to that in the correspon ding finite element study, so that the developed limit equil ibrium model is verified by comparing its results with that reported in finite element.

4.1 *Parameters affecting factor of safety, F.S.*

The factor of safety is defined as the ratio of available soil strength to strength at failure which can be used to evaluate the stability of narrow MSE walls. Results demonstrate that the factor of safety increases significantly with increasing the aspect ratio, L/H, from 0.2 to 0.7 in nonlinear relationship. For walls with aspect ratio less than 0.20, the wall become unsafe (i.e. safety factor is less than 1). This result is consistent with (Woodruff, 2003) observation that the wall become unstable when the wall aspect ratio decreased below 0.3. Also, factor of safety decreases significantly with increasing the spacing between reinforcing elements in linear relationship.

4.1.1 *Effect of aspect ratio, L/H*

As shown in Figure 2, the limit equilibrium and the finite element results agreed favorably for aspect ratio from 0.3 to 0.7 (i.e. the factor of safety increases significantly with increasing the aspect ratio). The increase in factor of safety will be about 27.5% when aspect ratio increased from 0.6 to 0.7 in both studies. For walls with aspect ratio less than 0.20, the wall become unsafe (i.e. safety factor is less than 1). The increase in factor of safety is attributed to reinforcement mechanism which derived from the friction resistance in both faces along length of reinforcing elements. Thus, increasing the aspect ratio, L/H, increases the reinforcing elements length which leads to increase the friction resistance.

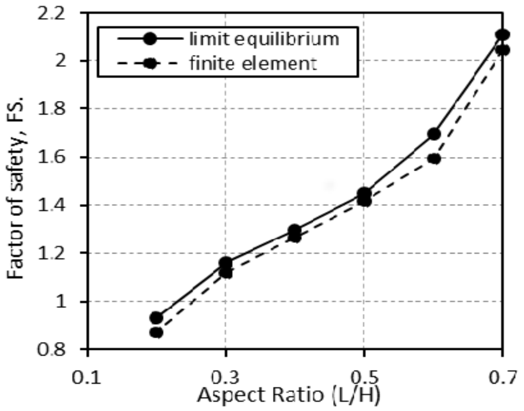

Figure 2: Relationship between aspect ratio, and Safety Factor

4 .1. 2 *Effect of spacing between reinforcing elements, s*

As shown in Figure 3, the factor of safety decreases significantly with increasing the spacing between reinforcing elements. The decrease in factor of safety will be about 19% in finite element and 22.65% in limit equilibrium when spacing between reinforcing elements increased from 0.3m to 1.0m. This decrease is due to the number of reinforcing elements decreases with increasing the spacing between reinforcing elements.

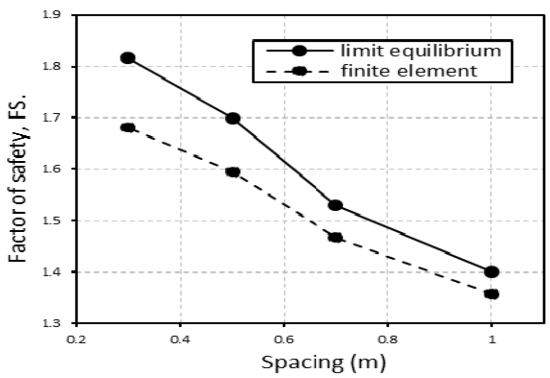

Figure 3: Relationship between reinforcing spacing, and Safety Factor

4 .2 Parameters affecting maximum tension force in reinforcing elements, Tmax

Effect of wall aspect ratio, and spacing between reinforcing elements, on maximum tension force in reinforcing elements of narrow MSE wall were investigated. Results demonstrate that relationship between maximum tension forces and aspect ratio is linear. The maximum tension force increases significantly with increasing the reinforcing elements spacing.

4 .2. 1 *Effect of aspect ratio, L/H*

Figure 4, shows that maximum tension force in reinforcing elements increases significantly with increasing the aspect ratio. The increase in maximum tension force will be about 25.9% in finite element and 23.3% in limit equilibrium when wall aspect ratio changes from 0.2 to 0.7. The increase in maximum tension force may be attributed to increase of lateral earth pressure force. Lateral earth pressure increases with increasing the aspect ratio.

4 .2. 2 *Effect of spacing between reinforcing elements, s*

It was found that, the maximum tension force increases significantly with increasing the spacing between reinforcing elements. The increase in maximum tension force will be about 55.4% in finite element and 65% in limit equilibrium when spacing between reinforcing elements increases from 0.5 to 1 m as shown in Figure 5

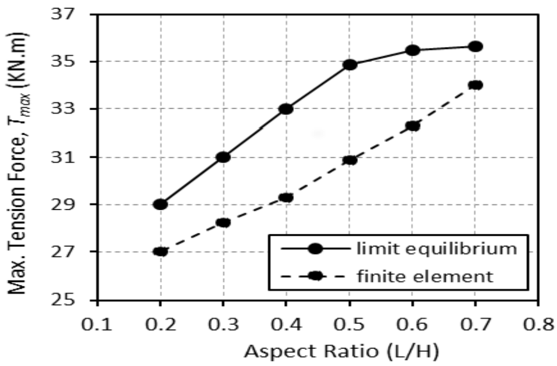

Figure 4: Relationship between aspect ratio and max tension force

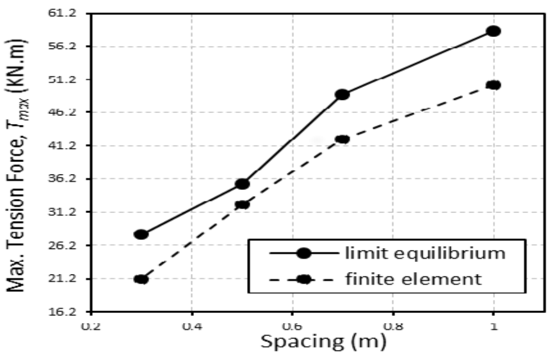

Figure 5: Relationship between spacing and max tension force

4 .3 *Location of the failure surface*

In reinforced soil structures such as narrow MSE walls, The portion of the reinforcement that extends beyond the failure surface provides resistance against pullout. Therefore, location of failure surface is important to determine the pullout resistance of the reinforcement and eventually for the design of these structures. In order to study the effect of varying the aspect ratio, L/H, of narrow MSE walls on location of failure surface, coordinates (0, 0) of narrow MSE wall are shown in Figure 6.

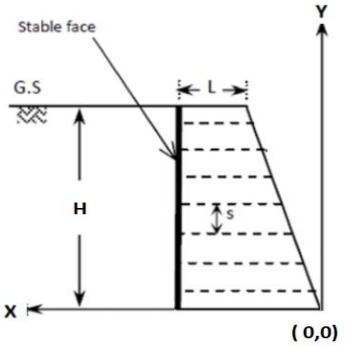

Figure 6: Coordinates for location of failure surface

Figure 7 shows a comparison between the locations of the failure surface obtained by limit equilibrium for different aspect ratio. All predicted results show the failure surface goes partially through the reinforced soil and partially along the interface between the reinforced soil and stable face. Good agreement can be observed between finite element and limit equilibrium results. In addition, both the numerical and limit equilibrium results show that the inclination angle of the failure surface increases with increasing of aspect ratio from 0.2 to 0.7.

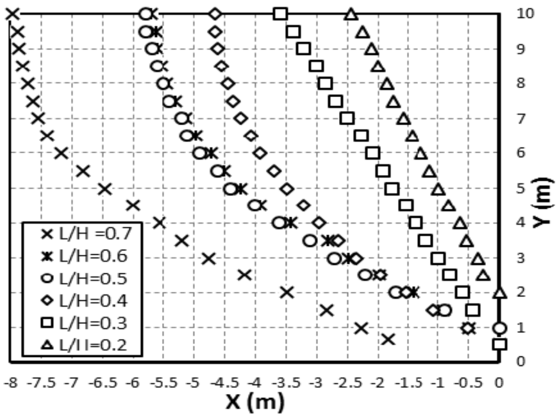

Figure 7: Locations of failure surface for different aspect ratio

Figures 8 and 9 show the comparison among the locations of the failure surface obtained numerically from finite element, limit equilibrium and Rankine failure surface. The result of analysis demonstrates that the inclination angle of the failure surface at any aspect ratio obtained from finite element is less than the theoretical value defined by the Rankine failure surface criteria. This conclusion is essintial for design of narrow MSE wall which may be used to calculate the factor of safety against pullout. In addition, results indicated that critical failure plane was bilinear for low aspect ratios and for higher aspect ratios the critical failure plane was linear. Also, the inclination angle of the critical failure plane decreased slightly with a increase in wall aspect ratio.

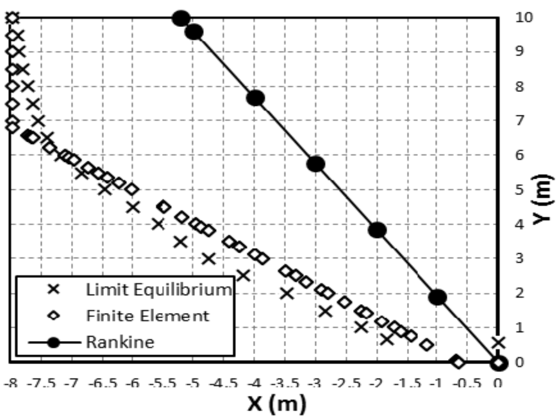

Figure 8: Locations of failure surface for aspect ratio equal 0.7

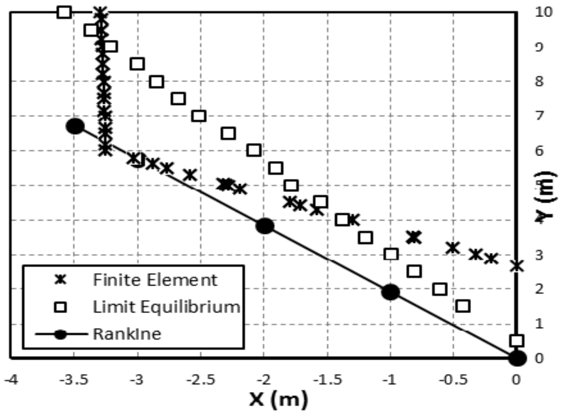

Figure 9: Locations of failure surface for aspect ratio equal 0.3

5 CONCLUSION.

Limit equilibrium and finite element analyses were carried out to model narrow MSE wall behavior in active state. Limit equilibrium results agreed to greet extent with finite element results. Factor of safety and maximum tension force increase with increasing the aspect ratio. Increasing reinforcement element spacing increases maximum tension force, and decreases safety factor. Finite element and limit equilibrium results show that the failure surface goes partially through the reinforced soil and partially along the interface between the reinforced soil and stable face. In additional to, the inclination angle of failure surface increases with decreasing of aspect ratio from 0.2 to 0.7. Finally, the results of analysis demonstrates that the inclination angle of the failure surface at any aspect ratio is less than the theoretical value defined by the Rankine failure surface.

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