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Stability analysis of back-to-back MSE walls

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ABSTRACT: Back-to-back MSE walls are commonly used for embankments approaching bridges. However, available design guidelines are limited. The distance between the two opposing walls is a major parameter used for determining the analysis methods in FHWA/AASHTO Guidelines. Two extreme cases are identified: (1) reinforcements from both sides overlap, and (2) the walls are far apart, independent of each other. However, existing design methodologies do not provide a clear answer how the required tensile strength of reinforcement changes with respect to the distance of the back-to-back walls. The focus of this paper is to investigate the effect of back-to-back distance on stability of MSE walls under static conditions. Finite difference method incorporated in FLAC software and limit equilibrium method (i.e., the modified Bishop method) in ReSSA software were used for this analysis. Parametric studies were carried out by varying two important elements, the wall back-to-back distance and the quality of backfill material, to investigate their effects on the critical failure surface and the required tensile strength of reinforcement. The results of the parametric studies imply that the back-to-back distance of MSE walls influences the required reinforcement tensile strength when the walls are relatively close.

1 INTRODUCTION

Design of back-to-back MSE walls is considered as a special situation having a complex geometry in FHWA Demonstration Project 82 (Elias and Christopher, 1997). In this FHWA design guideline, two cases are considered based on the distance of two opposing walls, D, as illustrated in Figure 1. When D is greater than Htan $(45° - \phi/2)$, full active thrust can be mobilized. For this case, the typical design method for MSE walls can be used. When D is equal to 0, two walls are still designed independently for internal stability but no active thrust is assumed from the backfill. The guideline indicates that when D is less than H tan $(45° - \phi/2)$, active thrust cannot be fully mobilized so that the active thrust is reduced. However, the guidelines do not provide any method how to consider the reduction of the active thrust, thus, no method is provided to calculate the required tensile strength for reinforcement.

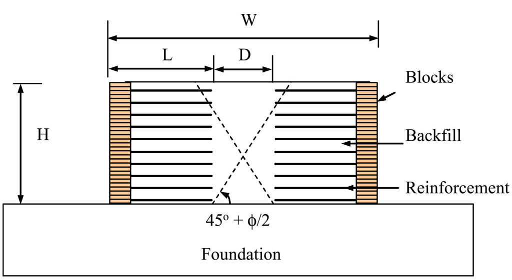


Figure 1. Back-to-back MSE wall and definitions.

Limit equilibrium and numerical methods have been successfully used to evaluate the stability of MSE walls (for example, Leshchinsky and Han, 2004; Han and Leshchinsky, 2006; Han and Leshchinsky, 2007) and yield close results in terms of factors of safety and critical failure surfaces. In this study, these two methods were also adopted to investigate the effect of the wall back-to-back distance and the quality of backfill material on the required tensile strength of reinforcement.

2 METHODS OF ANALYSES

2.1 *Limit equilibrium method*

Bishop's simplified method, utilizing a circular arc slip surface, is probably the most popular limit equilibrium method. Although Bishop's method is not rigorous in a sense that it does not satisfy horizontal force limit equilibrium, it is simple to apply and, in many practical problems, it yields results close to rigorous limit equilibrium methods. In this study, Bishop's simplified method was modified to include reinforcement as a horizontal force intersecting the slip circle, which is incorporated in ReSSA(2.0) software, developed by ADAMA Engineering (2002). This modified formulation is consistent with the original formulation by Bishop (1955). The mobilized reinforcement strength at its intersection with the slip circle depends on its long-term strength, its rear-end pullout capacity (or connection strength), and the soil strength. The analysis assumes that when the soil strength is reduced by a factor, a limit equilibrium state is achieved (i.e., the system is at the verge of failure). The slip circle for which the lowest factor (i.e., the largest mobilized soil strength) exists is the critical slip surface for which the factor of safety is rendered. Under this state, when the factor of safety is a unit, the soil and reinforcement mobilize their respective strengths simultaneously.

2.2 *Numerical method*

The finite difference program (FLAC 2D Version 5.0, developed by the Itasca Consulting Group, Inc.) was adopted in this study. A shear strength reduction technique was adopted in this program to solve for a factor of safety of stability. In this technique, a series of trial factors of safety are used to adjust the cohesion, c and the friction angle, ϕ, of soil. Adjusted cohesion and friction angle of soil layers are re-inputted in the model for limit equilibrium analysis. The factor of safety is sought when the specific adjusted cohesion and friction angle make the slope become instability from a verge stable condition (i.e., limit equilibrium). The critical slip surface often can be identified based on the contours of the maximum shear strain rate.

3 MODELING

3.1 *Baseline case*

The geometry and material properties of the baseline model used in this study are shown in Figure 2. Since the factor of safety is determined based on a state of yield, or verge of failure, it is insensitive to the selected elastic parameters: Young's modulus (E) and Poisson's ratio (ν) when using FLAC. If the system contains soils with largely different elastic parameters, it will take longer time to solve for the factor of safety; however, the effects on this factor would be small since it depends mainly on Mohr-Coulomb strength parameters. Hence, constant values of $E = 100$MPa and $\nu = 0.3$ were used in FLAC. The effect of wall facing cohesion on the required tensile strength of reinforcement in the numerical analysis will be discussed in the next section. Mohr-Coulomb failure criteria were used for strength between stacked blocks, the

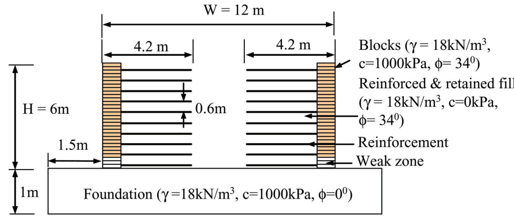


Figure 2. Dimensions and parameters of the baseline case.

reinforced and retained fill, and the foundation soil. Reinforcement is modeled as a cable with grouted interface properties between cable and soil. The bond strength between reinforcement and reinforced fill was assumed equal to 80% the fill strength, same as in the limit equilibrium analysis when considering pullout resistance. A weak zone at the toe of the MSE wall with a dimension of 0.3m wide and 0.4m high having cohesion equal to 0 but the same friction angle as the fill was assumed to ensure the critical failure surface of passing through the toe of the MSE wall.

In this baseline case, the back-to-back wall width (W) /height (H) ratio is equal to 2.0 and the distance at back of two walls, D is equal to 3.6m, which is slightly greater than $H \tan(45° - \phi/2) = 3.2$m. Based on the FHWA design guideline, a typical design method for a single wall can be adopted. The reinforcement length, $L = 4.2$m, was selected based on the typical reinforcement length/wall height ratio of 0.7 recommended by the FHWA design guideline.

Two important parameters, the back-to-back wall width and the quality of backfill material, were selected in this study to investigate their influence on the critical failure surface and the required tensile strength of reinforcement. In addition to $W/H = 2.0$ for the baseline case, two other W/H ratios (1.4 and 3.0) were used. One parameter in the baseline was changed at a time while all others were unchanged. The same models were used in numerical and limit equilibrium analyses. The required tensile strength of reinforcement was determined to ensure the factor of safety of the MSE wall equal to 1.0.

3.2 *Effect of wall facing cohesion*

The effect of wall facing cohesion was examined in this study. As shown in Figure 3, the factor of safety of the back-to-back MSE wall increases with an increase of the wall facing cohesion. However, it becomes constant after the cohesion is greater than 100 kPa. In this case, the potential failure of the MSE wall would only pass through the toe of the MSE wall. In all analyses discussed below, the cohesion of the wall facing was assumed to be 100kPa except a weak zone close to the toe. Figure 3 also shows that the effect of the wall facing cohesion for the case with low-quality

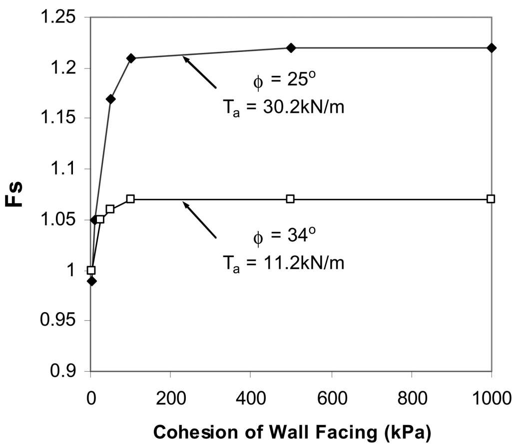


Figure 3. Effect of wall facing cohesion.

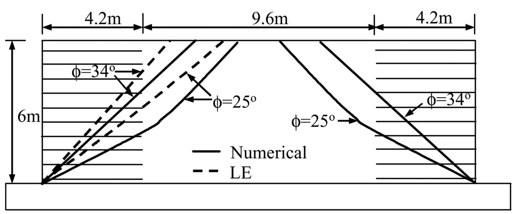


Figure 4. Critical failure surfaces within walls at W/H = 3.

backfill ($\phi = 25°$) is more significant than that with high-quality backfill ($\phi = 34°$).

4 RESULTS

4.1 *Critical failure surfaces*

The locations and shapes of critical failure surfaces of the back-to-back walls at different wall width/height ratios (W/H) were determined based on the contours of shear strain rate in the numerical analysis and presented in Figures 4, 5, and 6. Figure 4 shows that the critical failure surfaces in two opposing walls do not intercept each other, therefore, they behave independently. The critical failure surfaces by the LE method are also shown in Figure 4 and have slightly steeper angles than those by the numerical method.

Figure 5 shows the critical failure surfaces within back-to-back walls at W/H = 2, which intercept each other from two sides. More interactions occur for the case with a low-quality backfill. (i.e., $\phi = 25°$). For both cases, the critical failure surfaces do not enter the reinforced zone on the opposing side. In other words, the potential failure surface is constrained by the reinforced zone on the opposing side. Based on the FHWA formula (D > 3.2m) using $\phi = 34°$, there should be

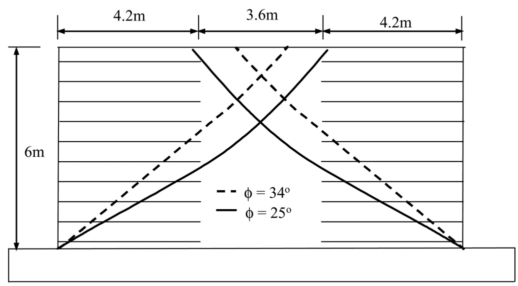


Figure 5. Critical failure surfaces within walls at W/H = 2.0.

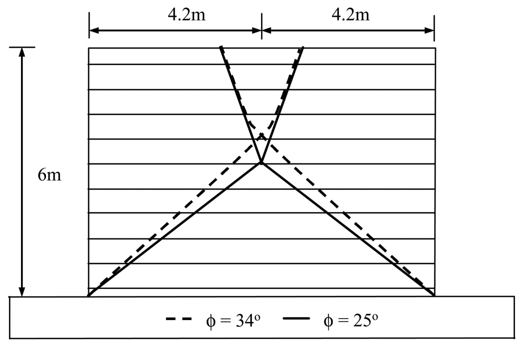


Figure 6. Critical failure surfaces within walls at W/H = 1.4.

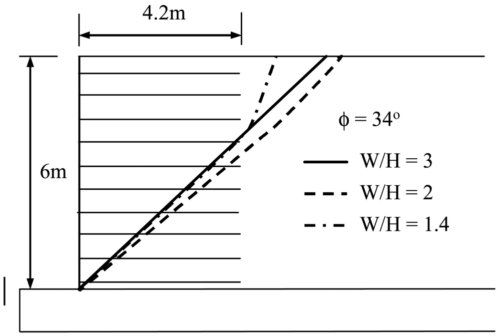
no interaction between these two walls. Apparently, this assumption is not supported by the numerical result. However, the FHWA assumption leads to more conservative results.

Figure 6 shows critical failure surfaces developed within the back-to-back walls when there is no retained fill between these two walls (i.e., D = 0m). In both cases, reinforcement layers are not connected at the back of two walls. The numerical results show the interactions of critical failure surfaces in two opposing walls. In both cases, the failure surfaces enter the reinforced zone from another side.

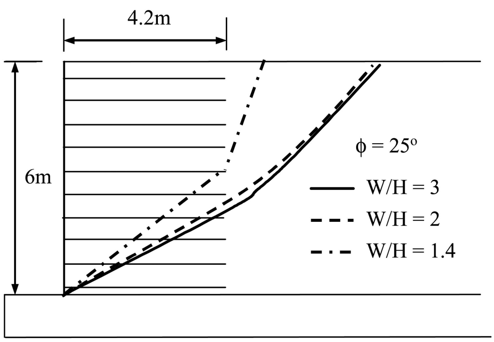
The comparisons of locations and shapes of critical failure surfaces at different W/H ratios but the same quality of fill are presented in Figure 7. Figure 7 shows that the locations and shapes of the critical failures are almost same for W/H = 3 and 2. This result can be explained as the failure surfaces not entering the reinforced zone on the opposing side. For W/H = 1.4, however, the locations and shapes of the critical failure surfaces deviate from others as the failure surfaces enter the reinforced zone on the opposing side.

4.2 *Required tensile strength*

The required maximum tensile strengths of reinforcement for all the cases discussed above are presented



(a) φ=34°



(b) φ=25°

Figure 7. Critical failure surfaces at different W/H ratios.

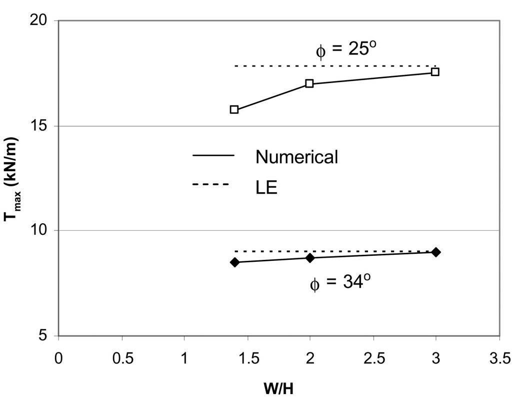


Figure 8. Required maximum tensile strength of reinforcement.

in Figure 8. The results from the LE method were based on the analyses of one side wall, therefore, no interaction of two opposing walls was considered. In other words, the required tensile strengths do not change with the W/H ratios. Figure 8 clearly shows that a decrease of W/H ratio from 3 to 1.4 reduce the required maximum tensile strength of reinforcement. The LE method without considering the interaction of the opposing walls would provide conservative design of back-to-back MSE walls. The difference in the maximum tensile strength of reinforcement with and without considering the interaction is within 12% based on the cases investigated in this study. The required maximum tensile strengths can be used for the selection of geosynthetics in the back-to-back MSE walls.

5 CONCLUSIONS

The study using the numerical and limit equilibrium methods shows that two back-to-back walls interact when they are close. This interaction will change the location and shape of critical failure surface. When the distance of the walls gets closer, the required maximum tensile strength decreases.

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