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Interaction analysis of back-to-back mechanically stabilized earth walls

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ABSTRACT

Back-to-back mechanically stabilized earth walls (BBMSEWs) are encountered in bridge approaches, ramp ways, rockfall protection systems, earth dams, levees and noise barriers. However, available design guidelines for BBMSEWs are limited and not applicable to numerical modeling when back-to-back walls interact with each other. The objective of this paper is to investigate, using PLAXIS code, the effects of the reduction in the distance between BBMSEW, the reinforcement length, the quality of backfill material and the connection of reinforcements in the middle, when the back-to-back walls are close. The results indicate that each of the BBMSEWs behaves independently if the width of the embankment between mechanically stabilized earth walls is greater than that of the active zone. This is in good agreement with the result of FHWA design guideline. However, the results show that the FHWA design guideline underestimates the lateral earth pressure when back-to-back walls interact with each other. Moreover, for closer BBMSEWs, FHWA design guideline strongly overestimates the maximum tensile force in the reinforcement. The investigation of the quality of backfill material shows that the minor increase in embankment cohesion can lead to significant reductions in both the lateral earth pressure and the maximum tensile force in geosynthetic. When the distance between the two earth walls is close to zero, the connection of reinforcement between back-to-back walls significantly improves the factor of safety.

1. Introduction

Mechanically stabilized earth (MSE) walls are well-recognized alternatives to conventional retaining walls due to many advantages such as ease of construction, economy, and aesthetics. For this, limit equilibrium and numerical methods were basically used to evaluate the stability of MSE walls (Leshchinsky and Han, 2004; Han and Leshchinsky, 2006, 2007, 2010). In recent years, back-to-back MSE walls (BBMSEWs) have been increasingly used for bridge approaches, ramp ways, rockfall protection systems, earth dams, levees and noise barriers. However, there are insufficient studies and guidelines concerning the behavior of BBMSEWs. FHWA design guideline (Berg et al., 2009) addressed the design of back-to-back walls, as illustrated in Fig. 1. Berg et al. (2009) divided back-to-back walls into two cases:

(1) Case 1: When the distance between the MSE walls, D, is greater than $H_1 \tan(45^\circ - \varphi/2)$, where H_1 is the height of the higher wall and φ is the friction angle of the backfill, the width of the ramp or embankment allows for construction of two separate walls with sufficient spacing between them to ensure that each wall can act independently. Hence each wall can be designed individually.
(2) Case 2: When $D = 0$ and the overlap length exceeds $0.3H_2$, where H_2 is the height of the lower wall, two walls are still designed independently for internal stability but no active thrust to the reinforced zone is assumed from the backfill. In other words, no active earth thrust from the backfill needs to be considered for external stability analysis. In this case, the two walls are assumed to act as a whole, without backfill to exert an external destabilizing thrust.

For intermediate geometries between Cases 1 and 2, when $0 < D < H_1 \tan(45^\circ - \varphi/2)$, Berg et al. (2009) suggested to interpolate linearly the earth pressure between full active earth pressure in Case 1 and zero earth pressure in Case 2. However, no justification was provided for this suggestion. Using numerical modeling

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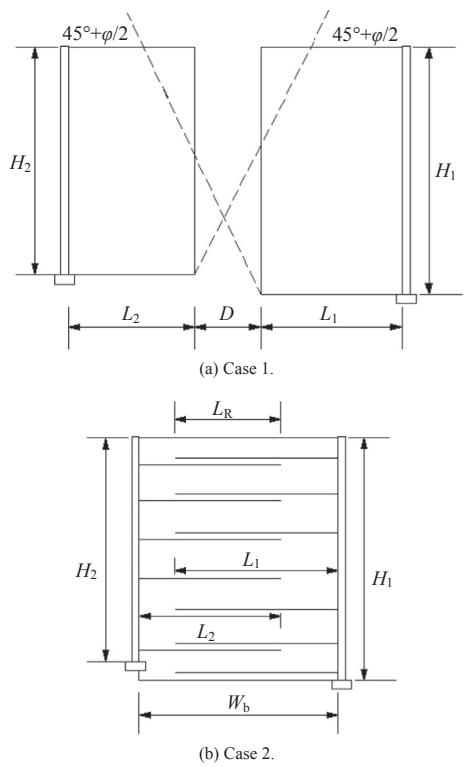

Fig. 1. Back-to-back mechanically stabilized earth walls (after Berg et al., 2009).

for the case of limit equilibrium state (i.e. the factor of safety $F_S = 1$), Han and Leshchinsky (2010) indicated that the FHWA design guideline underestimates the interaction distance, and for W/H_1 (W is the distance between two opposing wall facings) ranging from 2 to 3, the back-to-back walls still interact with each other. Recently, El-Sherbiny et al. (2013) analyzed different wall width to height ratios of BBMSEW using the finite element modeling. The numerical model was validated against an instrumented large-scale test wall (Won and Kim, 2007). It was indicated that when $D/H_1 < 1$, the two MSE walls interact with each other and the earth pressure behind the wall decreases because the failure wedge behind the wall is not fully developed.

In the above-mentioned studies, the interaction distance was identified when the critical failure surfaces in two opposing walls did not intercept each other. This seems to be not identical to that defined by the FHWA design guideline as shown in Fig. 1. In other words, a single failure surface may occur in one wall.

2. Numerical modeling

In this study, the PLAXIS software was utilized to perform the two-dimensional (2D) numerical analysis in the condition of plane strain. The geometry of the baseline model of BBMSEW (Fig. 2) considered in this study has the same configuration as that reported by Han and Leshchinsky (2010). The height of the walls is kept constant, equal to 6 m; and the soil foundation depth is equal to 2 m. The distance between the walls varies from $3H$ to $0.8H$ (large to narrow backfill width). Two soils are distinguished: backfill and base soils. The backfill material used for reinforced soil walls is assumed to be granular fill. A stiff soil like rock is chosen as the base soil to minimize its influence on the behavior of reinforced soil. The constitutive relation used for both soil types is the Mohr–Coulomb model. The properties of the two soils are shown in Table 1. The Tensar UX-1400 uniaxial geogrid was adopted to reinforce the BBMSEWs. The soils were simulated using 15-node triangular elements and the geogrid was modeled using an elastic-perfectly plastic model defined by the stiffness and tensile strength of geogrid. The vertical spacing of each layer of geogrid is 0.75 m. The length of reinforcement, $L = 4.2$ m, was selected to give $L/H = 0.7$. This ratio is the minimum value recommended by the FHWA design guideline for static design (Berg et al., 2009), except for Case 2 where $L/H = 0.6$ for the geometry with the overlap length, L_R, greater than $0.3H$. The geogrid properties used in modeling are summarized in Table 2. The well-known segmental precast concrete panels were considered in the current study to simulate the wall. Each wall contains 4 segmental concrete panels of 1.5 m in width and height and 0.14 m in thickness. The panels are modeled as a linear elastic material. For the panels, the Young's modulus $E = 25$ GPa, the Poisson's ratio $\nu = 0.2$, and the unit weight $\gamma = 23.5$ kN/m^3 Table 3 summarizes the panel properties as inputs to PLAXIS. The base of the wall is set to be hinged (i.e. the displacement of the wall is limited in vertical direction, but it is free to rotate and move in the horizontal direction).

In the numerical modeling, the geostatic stresses are firstly generated for the base soil. Secondly, the walls are constructed in stages, simulating the real construction process of these structures. The working stresses, strains, deformations, and tensile forces in the reinforcement are also evaluated in this phase. Then, reductions in φ and c (Brinkgreve et al., 2008) are conducted in models to determine the factor of safety. Finally, the methodology described above is validated by simulating the well-instrumented Founders/Meadow segmental bridge abutment reported by Abu-Hejleh et al. (2002).

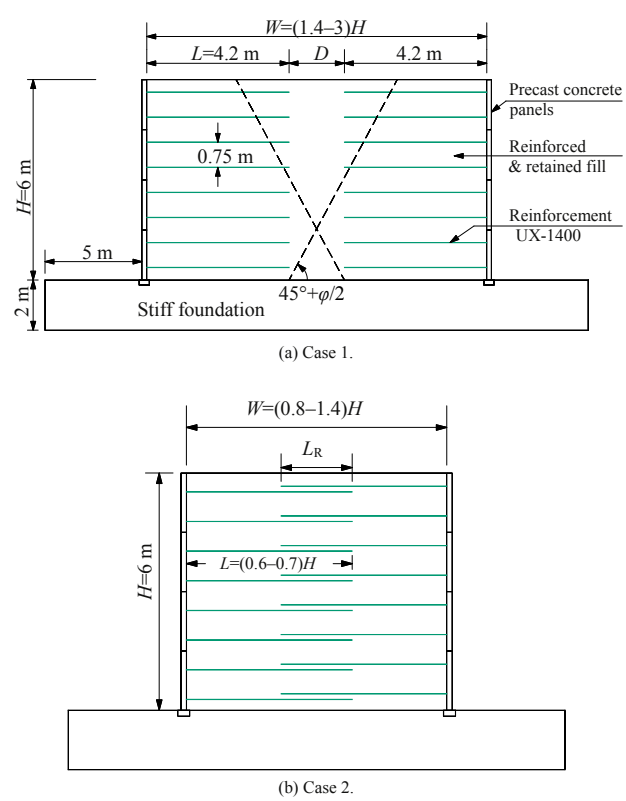

Fig. 2. Dimensions and parameters of the models.