Sandwich connection design for shored reinforced earth walls

Concept amorce sandwich pour les murs terre armée etayés

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ABSTRACT

This paper presents three design cases modeled by a geotechnical finite difference program used to study behavior and overall performance of narrow Shored Reinforced Earth Walls (SREW). SREW is a technology that combines the relative flexibility of a Mechanically Stabilized Earth (MSE) design in close proximity to an anchored or otherwise stabilized wall face with limited lateral space between. The design cases were selected based upon (1) a stand alone conventional MSE design for the narrow wall section, (2) a direct attachment design with anchors from new wall fascia to an existing stabilized face and (3) a “Sandwich Connection” design concept using overlapping reinforcements between the new wall fascia and existing stabilized face. By this study, the Sandwich Connection concept is a preferable design alternative for construction of a narrow wall section when space is available between new and existing wall facings.

RÉSUMÉ

Cet article présente trois cas d'étude sur le comportement et la performance générale des murs Terre Armée étroits, appelés Murs Terre Armée Etayés (MTAE). Pour cette étude, trois modèles ont été crées avec un logiciel différence finie. MTAE est une technologie qui combine la flexibilité relative d'un mur-remblai Terre Armée, à être situé au-devant d'un mur existant étayé ou du même genre, et l'espace étroit entre eux. Ci suivants sont les trois cas d'étude sélectionnés 1) un nouveau mur Terre Armée indépendant du mur existant 2) le nouveau mur est ancré directement au mur existant 3) le concept d'une amorce sandwich où les armatures provenant des deux murs sont superposées. Cette étude révèle que l'amorce sandwich est la solution de préférence dans le cas d'un espace très limité entre le mur nouveau et l'existant.

Keywords : mechanically stabilized earth, shored reinforcement, numerical modeling

1 INTRODUCTION

There is a growing trend in the United States highway industry for the construction of narrow-width walls that front either steep slopes or existing retaining walls with limited lateral space between. The resulting expanded structure is commonly referred to as a Shored Reinforced Earth Wall (SREW). One aspect of SREW technology is the widening of existing traffic lanes supported on top of Mechanically Stabilized Earth (MSE) walls, whether at bridge abutment locations or for thru-highway alignments, as shown in Figure 1. The purpose of this paper is to show, by way of numerical modeling, how SREW structures perform when combined with MSE walls in three types of settings.

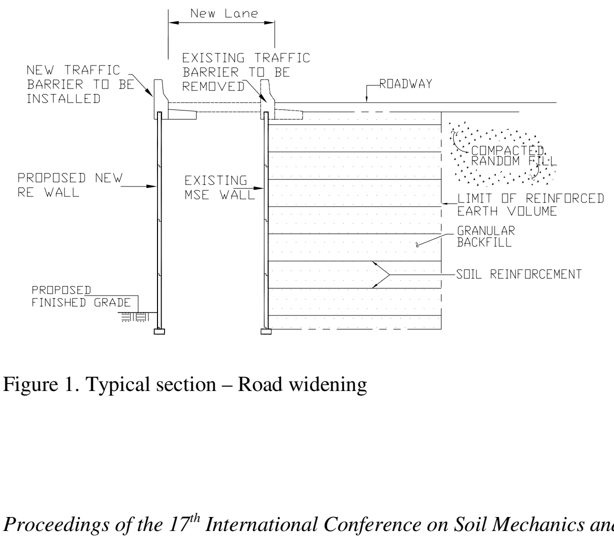

Figure 1. Typical section – Road widening

2 DESIGN MODELS

Three SREW design cases were modeled using the two-dimensional finite difference program known as FLAC (Itasca 2005). Common model geometry was developed first as a point of reference for the existing MSE wall to allow direct comparisons of performance and behavior in each design case where the SREW section was added. The MSE wall, as illustrated in Fig. 2, was modeled using four (4) high adherence ribbed steel reinforcing strips with a length of 4.25m and cross-section of 50 mm wide by 4 mm thick. The tributary wall design length was considered 3 meters or equivalent to the length of 2 adjacent facing panels.

Following layout of the initial MSE wall, SREW design cases were developed for this study consisting of: (1) conventional MSE design for a narrow wall section using discrete high adherence steel reinforcements, (2) direct mechanical connection of steel reinforcing strips from the back of the new facing to the front of existing wall face and (3) an overlapping reinforcement concept known as the sandwich connection system. The sandwich connection consists of attaching short lengths of steel reinforcements anchored into the existing wall face and overlapping these within the narrow annular space with short steel reinforcements attached to the new precast panel facing. The three design cases are each represented in Figure 3.

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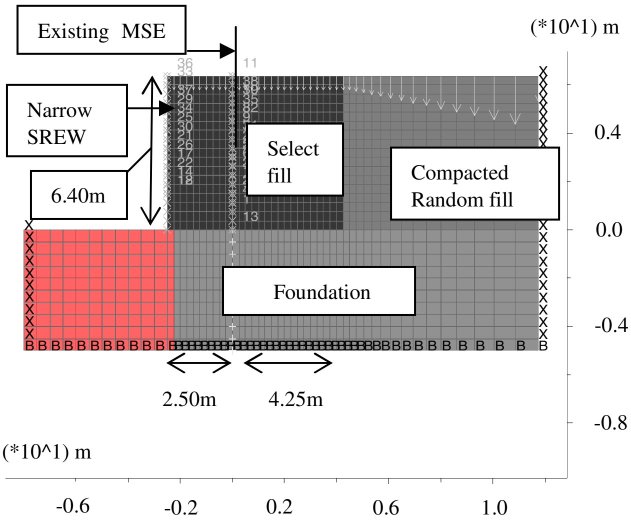
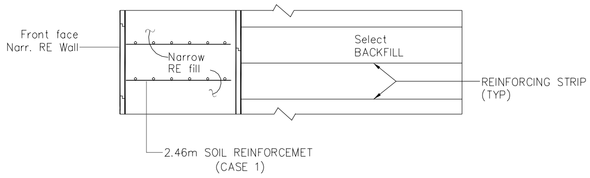
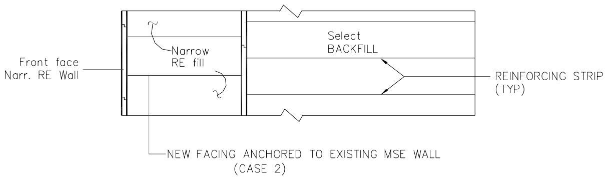


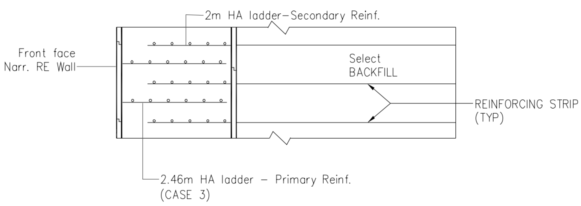
Figure 2. a) Typical FLAC and geometry model



(a) Case 1



(b) Case 2



(c) Case 3

Figure 3. Design models: a) Case 1, conventional MSE reinforcement, b) Case 2, direct and positive attachment of new facing to the existing wall and c) Case 3, sandwich connection concept

Upon adding the SREW section for each design case, the evaluations focus primarily on the induced stress and strain of soil reinforcements, which in turn results in horizontal displacements at the front face of the narrow SREW section. Further study was conducted to analyze the response of the existing MSE wall (0.7 aspect B/H ratio); mainly by way of changes analyzed in the initial state of the stress and strain of already-mobilized soil reinforcements with the addition of the new SREW section. Soil reinforcements considered in the SREW section for the design cases consisted of high adherence ladders described later in this paper.

The following steps were considered for construction of the FLAC models developed for the design cases:

- Standard MSE wall construction procedures were considered, i.e., backfill placed in 0.75m thick lifts to simulate the actual MSE wall construction sequence and consequently obtain more relevant results.
- At each lift the initial vertical and horizontal stresses were defined to simulate the compaction loading effects.
- The same interface properties defined between precast concrete panels (back face) and select fill were used to define the interface properties between narrow fill and front face of the original MSE wall.
- A uniform vehicular live load of 12 kPa was applied on top of the existing MSE wall as per “AASHTO Bridge Design Manual Specifications” prior to construction of the narrow SREW in front. (AASHTO 1996).

3 MATERIAL PARAMETRES USED FOR FLAC MODELS

The soil parameters used to construct the models are tabulated in Table (1). The reinforced backfill properties in particular are consistent with those addressed under design practice in accordance with AASHTO.

Table 1. Soil Properties and Parameters

	Reinforced backfill	Random backfill	Foundation mat’l
Soil model type	Mohr-Coulomb	Mohr-Coulomb	Elastic
Elastic modulus (kPa)	60,000	40,000	20,000
Poisson’s ratio	0.333	0.333	0.333
Unit weight (Mg/m^3)	1.9	1.9	1.9
Cohesion (kPa)	0	0	0
Effective soil friction angle	34	30	30
Dilation angle (degree)	4	0	0

The material properties for the concrete fascia units and steel reinforcing strips are represented in Tables 2 and 3, respectively. These properties were modified from their standard unit values to those on per meter basis to accommodate the input requirements of the two-dimensional analysis in FLAC. The fascia units were modeled using the structural beam element in FLAC to account for both flexural and axial stiffness of the precast concrete panels. The strip module on the other hand was used to model the inextensible steel reinforcements.

Table 2. Precast Concrete Panel Properties

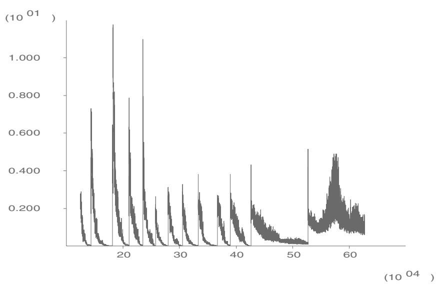
Area m^2/m	Moment of Inertia (I) m^4/m	Young’s Modulus (E) kPa/m
0.14	2.3E-04	1.00E10

Table 3. Steel Reinforcements Input Data

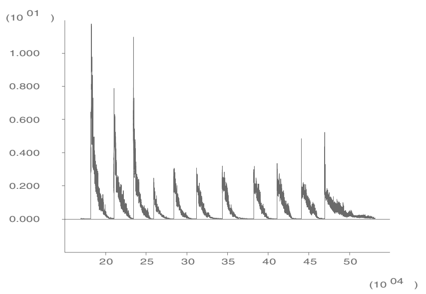
Soil Reinforcement Type	HA Strip (50x4mm)	HA Ladder (Cases 1 & 3)
Soil reinforcement width (mm)	50	100 (Equivalent width)
Tributary wall design length (m)	3	3
Steel elastic modulus (GPa)	210	210
Tensile strain (kN)	52	52
Initial coefficient of friction (f*)	2	2
Min. coefficient of friction (f*) @ transition depth	0.67	0.67
Confining pressure @ transition depth (kPa)	120	120

4 RESULTS

Case 1 was initially constructed using reinforcing strips followed by replacement with high adherence ladders. The model did not reach equilibrium condition and failed when reinforcing strips were initially considered (Figure 4a). The model for Case 1 was then modified to incorporate soil reinforcements with higher adherence properties, i.e. high adherence ladders. The higher adherence of the ladders is attributed to an equivalent width that is double that of a reinforcing strip. Thus, the ladder demonstrates higher pullout capacity in bond. Even with the use of ladder reinforcements, however, the performance of the constructed model was unsatisfactory (Figure 4b). The wall still demonstrated large horizontal displacement and mobilized an active wedge within the SREW section that resulted in high stresses and strains in the reinforcements.



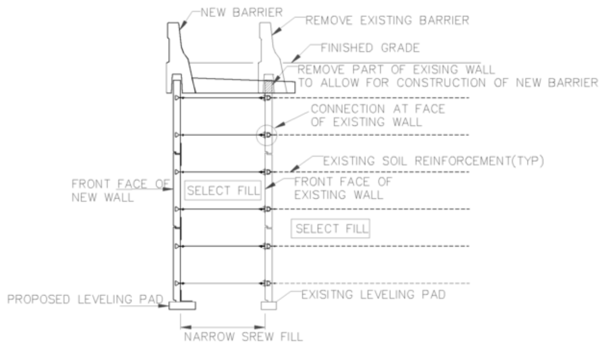
(a)



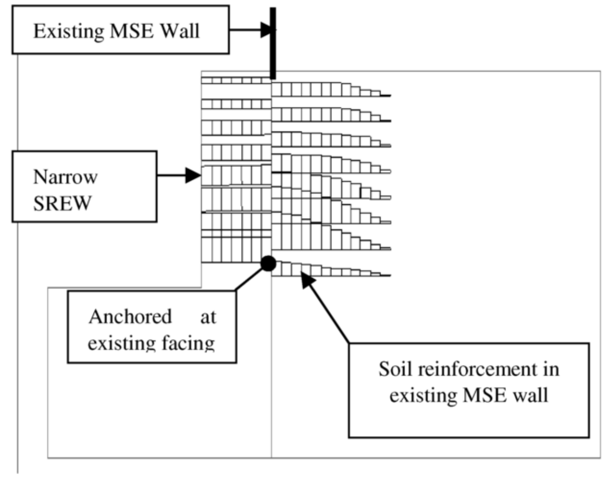
(b)

Figure 4. Unbalanced force diagram- Case 1: a) Using HA strip and b) Using HA ladder – (X axis: number of steps and Y axis: unbalanced forces)

For Case 2, the SREW section was modeled based on the traditional positive mechanical connection, and each panel was anchored to the existing wall facing (see Figure 5). As initially predicted, the model was stable and reached its equilibrium in a relatively more satisfying spectrum compared to Case 1 (Figure 6a) and similarly Figure 6b illustrates the unbalanced forces for Case 3.



(a)



(b)

Figure 5. Case 2: a) Typical section and b) Distribution of tensile force in soil reinforcing elements in FLAC model

The FLAC model conducted for Case 3 was based on the “Sandwich Connection” concept instead of the direct positive connection presented in Case 2. The Sandwich Connection consists of attaching short lengths of secondary reinforcement to the shored wall (in this case the existing MSE wall) that alternate horizontally with the primary reinforcements attached to the precast panels. The primary and secondary reinforcements are not directly connected to one another.

FLAC analyses show that the secondary reinforcements reduce the amount of stress and strain; hence the tensile force in the primary reinforcements is also reduced as a result of interaction between the two reinforcement elements (Figure 7). The interaction between primary and secondary reinforcements also leads to significantly less horizontal displacement at the wall face. In other words, the secondary reinforcements redistribute the induced tensile forces so that the required resistance force can be developed along the actual available lengths of the primary reinforcements.

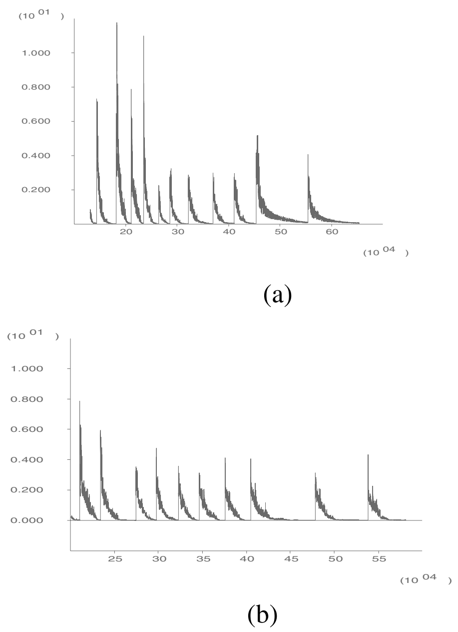


Figure 6. Unbalanced force diagrams: a) Case 2, and b) Case 3 (X axis: number of steps and Y axis: unbalanced forces)

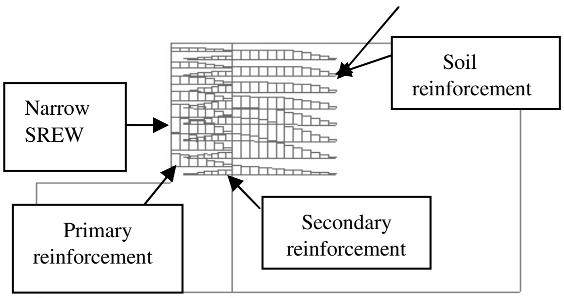


Figure 7. Case 3 - Distribution of tensile force in soil reinforcing elements based on "Sandwich Connection " concept

Figure 8 shows the relative lateral displacement at the front face of the SREW sections for Case 1 versus Case 2 and Case 3 versus Case 2. As shown, the displacement ratio for Case 3 versus Case 2 approaches unity, which means that the Sandwich Connection should provide resistance to displacements and result in a uniform appearance similar to conventional anchoring methods.

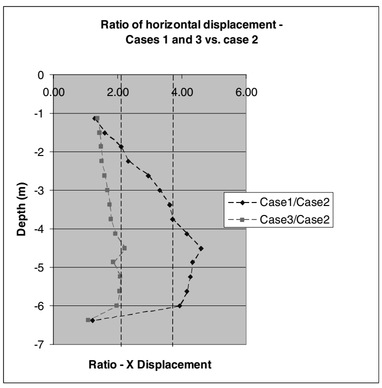


Figure 8. Ratio of horizontal displacement at front face of SREW panel between Cases 1 and 3 vs. Case 2

In a similar way, Figure 9 illustrates the ratio between developed tensile force in soil reinforcement in SREW sections for Case 1 versus Case 2 and Case 3 versus Case 2. The FLAC model comparisons show that the induced tensile loads in primary reinforcements for Case 3 are in good agreement with of that value Case 2, whereas the reinforcing elements in Case 1 experience significantly more stress compared to the other models.

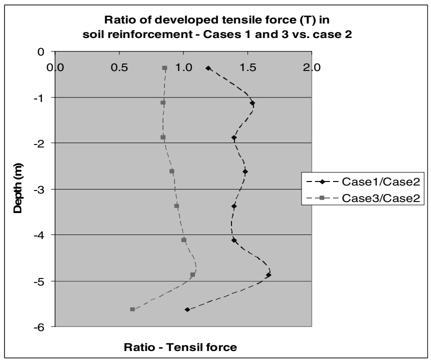


Figure 9. Ratio of developed tensile force developed in soil reinforcements between Cases 1 and 3 vs. Case 2

5 CONCLUSIONS

This paper has demonstrated that the "Sandwich Connection" is a viable design approach for narrow wall sections, where stability of the failure wedge is difficult to achieve or the end result would be a significant increase in number of reinforcements. The introduction of overlapping secondary reinforcements from the original MSE wall face in the "Sandwich Connection" substantially reduces the horizontal stress and resulting tensile force in primary reinforcements connected to the new fascia. The contribution of the secondary reinforcements is influenced by several factors, including the distance between the two walls, overlap length between primary and secondary reinforcements, vertical and horizontal spacing between reinforcements, depth of reinforcement, type of reinforcement and geometry of the original retaining wall section. It is noted that although the design cases in this paper were modeled for an original MSE wall face, it is possible to consider a similar connection type for other stable retaining wall or anchored facings.

From the results of FLAC modeling, it was found that the Sandwich Connection minimizes changes in the initial state of stress of already-mobilized existing reinforcements (in the case of this paper, the existing MSE wall). Furthermore the combined wall system represented by the Sandwich Connection preserves the inherent flexibility that is commonly associated with MSE technology against post-construction settlement conditions.

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