REINFORCEMENT TENSILE FORCES IN BACK-TO-BACK RETAINING WALLS

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ABSTRACT: Back-to-back reinforced retaining walls are mostly used in approach embankments of bridges and flyovers. In the internal stability check for mechanically stabilized earth (MSE) walls, earth pressure theory is used to obtain the tensile forces in the reinforcement. However, tensile forces calculated from this method are found to be very conservative (by a factor of two) in comparison to the actual field measurements. The objective of this study is to examine the mobilization of reinforcement tensile forces at different levels within back-to-back MSE wall at working stress condition. Tensile forces in the reinforcements with reinforcement connected in the middle (*i.e.*, reinforcement extending from one wall to the other) are also obtained. Parametric study is carried out with the stiffness of reinforcement varying from 500 kN/m to 50000 kN/m and the ratio of spacing between two walls to wall height (*W/H*) varying from 1.4 to 2.0 to investigate their effect on tensile forces at every level of the reinforcement. Charts are also proposed showing the variation of the maximum tensile forces along the height of the wall.

1 INTRODUCTION

Back-to-back retaining walls are retaining walls that are relatively close to one another. Back-to-back walls are used in construction of railroad bridge embankments or 2-to-4 lane highway bridge approach embankments. Fig.1 shows the schematic cross-section of back-to-back walls. The behaviour of single reinforced walls is well understood, however studies on back-to-back walls are very limited. Anubhav and Basudhar (2012) studied the behaviour of back-to-back walls using experimental setup. Numerical analysis was carried by Han and Leshchinsky (2010); Hardianto and Turong (2010); Mouli and Umashankar (2014); Sherbiny et al. (2014); and Mouli et al. (2015). Katkar and Viswanadham (2012) performed centrifugal studies on back-to-back walls.

Tensions mobilized in single MSE wall was analysed experimentally by Yang et al. (2010); Bathrust et al. (2009); etc. Numerical modelling of MSE wall for studying tensile loads was also done (e.g. Hatami and Bathurst 2005; Guler et al. 2007; etc.). The stiffness of reinforcement plays an important role in the calculation of reinforcement loads under working stress condition. In the present study, the effect of stiffness of reinforcement in back-to-back walls is analysed.

2 PROBLEM DEFINITION

The objective of the present work is to study the effects of reinforcement stiffness (*J*) and ratio of the wall spacing to height of the wall (*W/H)* on the tensile forces mobilized in the reinforcement. Effect of connecting the reinforcement at the middle of the wall is also analysed.

A finite-difference based numerical analysis was conducted to perform the analysis of mechanically stabilized back-to-back walls.

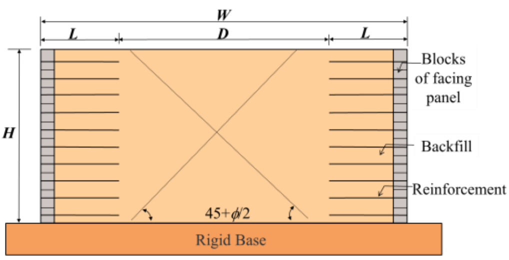

Fig. 1 Schematic of back-to-back MSE walls

3 NUMERICAL MODELLING

The Finite difference program, FLAC (Fast Lagrangian Analysis of Continua), was used for the analysis (Itasca, 2011). Back-to-back walls of height 6m was considered, and the length of reinforcements for both the walls was fixed as 4.2m (i.e., equal to 0.7 times the height of wall). The distance between the ends of the reinforcements extending from the two walls was varied from 0 to 0.6*H* so that *W/H* ratio ranges from 1.4 to 2.0. The vertical spacing between the reinforcement layers was taken as 0.6m.

Bottom of the foundation soil was fixed in both horizontal and vertical directions. Mesh convergence was done and the size of the grid was taken as approximately 0.1m. Large-strain mode was activated so that the coordinates of the grid points are updated at every step. This ensures accuracy in the numerical model, especially when high strains are developed in the material.

The foundation soil was assumed to be rigid. Reinforced soil was simulated as homogenous, isotropic, elastic-perfectly plastic using Mohr-Coulomb failure criterion. Table 1 provides the properties of reinforced soil, foundation soil, and facing panel.

Elastic modulus of the soil was dependent on the confining stress (Duncan et al., 1980). It was updated at every stage using the procedure given in Hatami and Bathurst (2005). Equation given by Duncan et al. (1980) was used [Eq. (1)].

$$E_{\mathrm{t}} = \left[1 - \frac{R_{\mathrm{f}}(1-sin\phi)(\sigma_1-\sigma_3)}{2c.cos\phi+2\sigma_3.sin\phi}\right]^2 . K_{\mathrm{e}} . P_{\mathrm{atm}}. \left(\frac{\sigma_3}{P_{\mathrm{atm}}}\right)^n \qquad (1)$$

where, E_t is the tangent elastic modulus, R_f is the failure ratio, K_e is the elastic modulus number, n is the elastic modulus exponent, P_{atm} is the atmospheric pressure, ϕ is the angle of shearing resistance of soil, c is the cohesion intercept of soil, σ_1 is the effective vertical pressure (overburden), and σ_3 is the effective lateral confining pressure.

The wall facing was modelled as modular blocks of size 0.3 x 0.2m. Material properties of modular blocks were assumed to be equal to that of concrete material (Table 1).

Table 1 Properties of the foundation soil, reinforced and retained backfills

Properties	Reinforced soil	Foundation soil	Modular blocks
Material type	Mohr-Coulomb	Mohr-Coulomb	Elastic
Cohesion (kPa)	0	1000	-
Angle of shearing resistance (ϕ) in deg.	34	35	-
Dilation angle in deg.	10	0	-
Shear Modulus (kPa)	3.846e4	3.846e4	8.70e6
Bulk Modulus (kPa)	8.333e4	8.332e4	9.52e6
Density (kg/m^3)	1800	1800	2400

Table 2 Constants used in the equation for stress dependent modulus of backfill soil

Properties	Reinforced soil
Elastic modulus number (K_e)	1150
Bulk modulus number (K_b)	575
Elastic modulus exponent (n)	0.5
Bulk modulus exponent (m)	0.5
Failure ratio (R_f)	0.86

Table 3 Reinforcement properties

Properties	Cable element
Stiffness (J) (kN/m)	500, 50000
Poisson's ratio (υ)	0.3

Reinforcement was simulated as cable element. Cable element in FLAC is a two-noded, one-dimensional element with high tensile stiffness and negligible compressive stiffness. Reinforcement was assumed to be rigidly fixed at the left end of the cable element to nodes of the wall facing to simulate the rigid connection that exists in the field.

Table 3 provides the reinforcement properties.

The model wall was constructed in stages. Each lift of 0.3m height was first placed, and the model solved for equilibrium. The elastic modulus was then updated using Eq. (1) (using the constants mentioned in table 2), and again solved for equilibrium. The next layer of soil was now placed on the deformed grid of the previous layer. At every stage, the maximum unbalanced force ratio was maintained to be less than 1e-3.

4 RESULTS

4.1 Connected and Unconnected case with *W/H*=1.40

Tensile forces mobilized in the reinforcement are a function of the stiffness of the reinforcement. Hence, the variations of tensile forces are provided for different stiffness values of the reinforcement. Tensile forces in reinforcements were given in back-to-back walls with *W/H*=1.40 and 2.00 (Fig.2). Tensile forces in reinforcements were calculated in back-to-back walls with *W/H*=1.40 and 2.00 (Fig. 2). The maximum tensile load profiles were also drawn. Comparison was made between connected and unconnected reinforcement cases. Figure 2 shows the tensile force profile for reinforcements at different heights of wall (reinforcements near the top of the wall (5.7m), near to the middle of the wall (3.3m) and near the bottom of the wall 0.9m) for *W/H*=1.40. It can be observed that for J=500 kN/m, the location of maximum tensile force in the reinforcement near the top of the wall and for the reinforcement near the bottom of the wall were at a distance of about 3.5m (A') and 0.9m (B') from the facing respectively. There was no clear peak tensile force observed in the reinforcement near the middle height. In the case of reinforcement near the bottom of the wall, position of peak tensile force had shifted towards the facing of the wall. The location of maximum tensile force can be justified from Fig. 3. Figure 3 plots the maximum shear strain increment contours for the case of J=500kN/m and reinforcement unconnected in the middle. Lines were drawn along the maximum of maximum shear strain increments. This line intersected the top and bottom reinforcements of the wall at point A and B, respectively. The horizontal distances from the facing to point A and B were around 3.5m and 0.9m which coincide with that of A' and B' (Fig. 2). It can be concluded that the maximum tensile force occurred at along the plane of maximum shear strain.

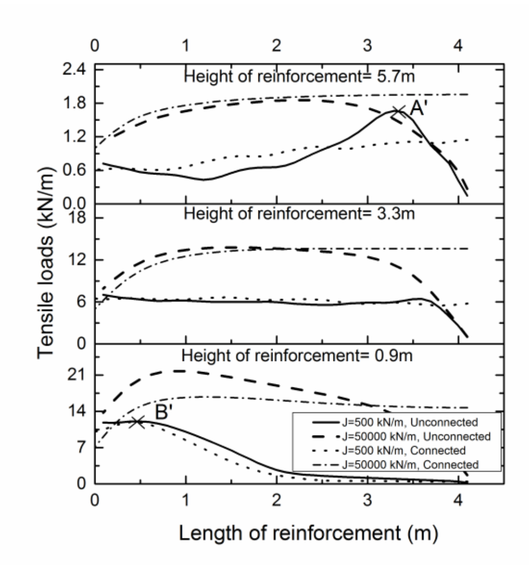

Fig. 2 Tensile force profile along the reinforcement length at different heights for connected and unconnected case (*W/H*=1.40)

For the case of J=50000 kN/m, unconnected reinforcement, there was no clear peak observed along the reinforcement length. As the wall was analysed in working stress condition, the displacements due to gravity loads (which are much lesser in case of stiffer reinforcement) were not sufficient enough to mobilize the critical slip surface. Near the bottom of the wall, the tension values in reinforcement with J= 50000kN/m case were much higher when compared to that of J=500 kN/m case, which is expected. The tensile forces for both connected and unconnected cases had almost equal values in J=500kN/m case. In the case of J=50000 kN/m, reinforcement near the bottom of the wall, the tensile forces were higher in the unconnected case than that of connected case.

In most of the cases, the tensile forces in the unconnected cases were tending towards zero value at the end of the reinforcement, but there was significant tension value in the cases of connected reinforcement at that location as the reinforcement was extending up to the adjacent wall. The distribution of maximum tension in each layer along the height of the wall is plotted in Fig. 4. It can be observed that for the case of reinforcement with low stiffness (i.e. J=500 kN/m),

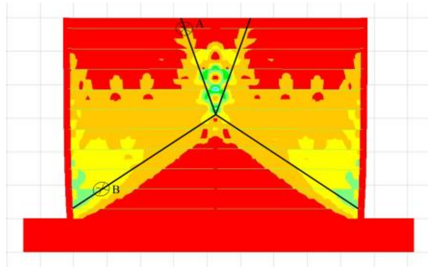

Fig. 3 Maximum shear strain increment contour for the case J=500 kN/m and *W/H*=1.40 unconnected reinforcement

difference between the connected case and unconnected case was insignificant. But when stiffness of reinforcement was increased to 50000 kN/m, unconnected reinforcement case showed higher maximum tension than that of the connected case. In the case of connected and stiffer reinforcement case, the interaction of other wall was much higher than the unconnected case.

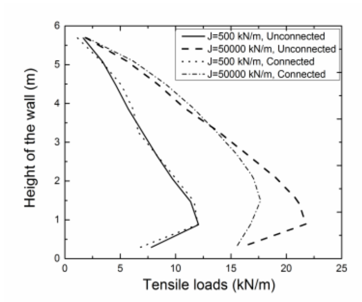

Fig. 4 Maximum tensile forces profile for connected and unconnected reinforcement cases (*W/H*=1.40)

4.2 Unconnected case with *W/H*=2.0

Figure 5 represents the tensile profiles of the reinforcement at different heights of the walls for *W/H* =2.0. As the distance between the two walls was considerable large, the walls were behaving as independent walls (Berg et al. 2011). Higher tension values were mobilized in the stiffer reinforcement. It can be observed that, except for the reinforcement near the top of the wall, the reinforcements had the maximum tension near the facing. Figure 6 shows the maximum tension distribution along the height of the wall. It was observed that the magnitude of tensions were almost the same for both *W/H*=1.4 and *W/H*=2.0 unconnected cases. But the tension profiles along the reinforcement length were different. In the latter case, the maximum tensile forces along the reinforcement occurred at the connection in all reinforcement except in the reinforcement at the top of the wall.

5 CONCLUSIONS

Tension profiles along the length of the reinforcement were plotted for both *W/H* ratios 1.4 and 2.0. Maximum tension distribution along the height of the wall was also plotted. Following conclusions can be drawn from the present study:

- Maximum of maximum tension occurred at 0.9m height from the bottom of the wall.
- Maximum of maximum tension in connected case is lesser than that of the unconnected case, when the reinforcement stiffness is large (J=50000 kN/m). But for the case of reinforcement with low stiffness value (J=500 kN/m), both connected and unconnected cases showed insignificant difference.
- *W/H* ratio has no significant effect with respect to the magnitude of maximum tension profile. But the location of maximum tension along the reinforcement length changes when the distance between the two walls increases.

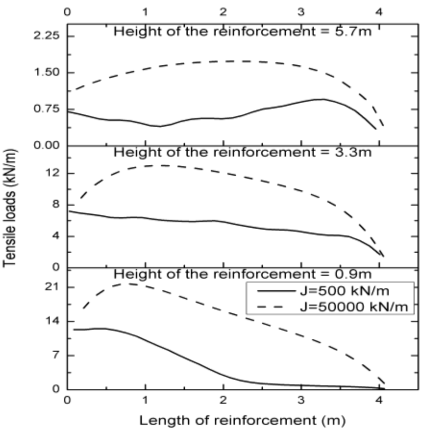

Fig. 5 Tensile force profile along the reinforcement length at different heights for unconnected case (*W/H*=2.0)

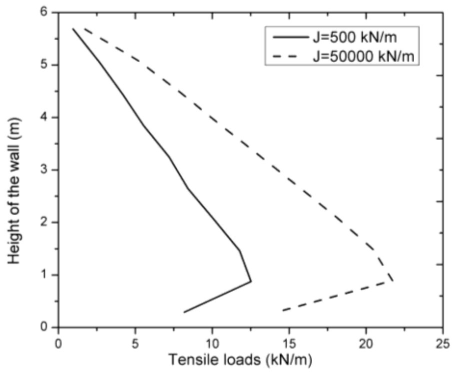

Fig. 6 Maximum tensile forces profile for unconnected case (*W/H*=2.0)

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