Numerical analysis of shored reinforced soils walls

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ABSTRACT: Reinforced soil walls (RSW) in confined spaces like steep mountainous slope or extended/widening highway approaches have always been a challenge for design, stability and economy. A practical solution to such situations is to construct a reinforced soil wall in front of existing stable embankment. Such walls are known as Shored Reinforced Soil Walls (SRSW) which requires shorter reinforcement lengths at bottom than conventional reinforced soil walls. In this paper an attempt has been made to analyze SRSW using a finite element program Plaxis 2D.The reinforced soil wall models are validated using sample reinforced soil wall. SRSW has been analyzed by varying the shoring wall inclination. The shoring wall inclination is varied by keeping the lower reinforcement length as 0.30 times the height of wall, while the top reinforcement length is varied from 0.30 times height to 0.70 times the height of wall. The maximum tensile force in the reinforcement is studied for variation of shoring wall inclination. A further analysis was carried out to obtain relationship between the percentage wall height and ratio of coefficient of active earth pressure from finite element analysis for varying shoring wall inclination. The finite element analysis reveals that SRSW walls with low wall aspect ratio as low as low as 0.30H times wall height can be used in field provided the top reinforcements (where the failure plane does not intersect the reinforcement) shall be connected with the shored wall.

Keywords: Shored reinforced soil wall, numerical analysis, reinforced soil, shoring wall

1 INTRODUCTION

In case of steep mountains valley, the sharp curves and narrow switchbacks, reduces turning radii for larger vehicles critically. This not only compromises safety of vehicles but also requires limited confinement and complicated design considerations with reduced geogrid length (less than 0.7H). Similarly the existing highway needs further expansion covering full right of way which is mostly having an expansion width less than 0.70H. Thus there arose a need for RSW design methodology which involves consideration of stable pre-existing rock/ retaining wall structure along with constrained low width space in front of stable face. Thus shored reinforced soil walls were introduced to overcome this shortcoming from conventional reinforced soil wall designs.

A Shored reinforced soil wall (SRSW) is a combination of stable wall face (mostly soil nail wall) and Reinforced Soil wall (RSW) constructed in front of the back slope. While conventional RSW are designed with minimum reinforcement length equaling 0.70H, Shored reinforced soil wall works with minimum wall aspect ratio of 0.30H till 0.70H and a basic mechanism: The shoring wall stabilises soil behind the RSW against external sliding/overturning forces. The behavior of SRSW varies from the conventional RSW wall mainly in terms of location of failure plane and lateral earth pressure exerted on RSWs. This causes variation in reinforcement tension and lateral earth pressure as that calculated from Tie-back wedge method.

Studies on SRSW include centrifuge modeling of SRSW (Woodruff, 2001) with varying wall aspect ratio and influence on displacements with locating the failure surface. A field study was carried out by Morrison (2006) based on the centrifuge models from Woodruff studies for SRSW. More detailed study was conducted using Limit equilibrium analysis by Yang (2011) to evaluate the failure surface developed in SRSW. A numerical analysis has been conducted using Plaxis program by Lee (2010) by changing the changing the soil and geogrid parameters. They all concluded that, due to different failure mechanism and earth pressure occurrence, the earth pressure coefficient decreased as wall aspect ratio, ratio of wall width to wall height (L/H), decreased. This implies that the traditional method using conventional earth pressure equations to calculate the factor of safety are not same for SRSW. The influence of shoring wall inclination and failure surface orientation with connected and unconnected configuration on earth pressure coefficient was not studied previously.

This paper presents FEM analysis of SRSW using a program PLAXIS 2D. A conventional RSW wall is analyzed to validate the model by comparing the total displacement of RSW with increasing wall surcharge. Then SRSW is modeled and results obtained were evaluated with Tie-back wedge method and field model results. The SRSW was studied for variation of shoring wall inclination, earth pressure coefficient with changing height.

2 STUDIES ON SRSW

2.1 *Centrifuge tests*

A set of centrifuge tests were performed by Woodruff in 2001 for SRSW with 24 different models to understand the behavior of such walls compared to conventional reinforced soil wall at University of Colorado. The parametric study involved RSW with stable back slope and varying wall aspect ratio from 0.17 to 0.90 with Woven and Nonwoven geotextile to determine the influence of reinforcement strength, and inclination of stable shoring face. Also, reinforcement configuration with reinforcement connected and unconnected with stable shoring face. The failure pattern observed in shored reinforced soil walls is with three failure modes: (a) Internal failure (a failure found through all reinforcement layers of the wall) (b) External failure (due to sliding, or overturning) (c) Compound failure with failure line passing through selected bottom layers and at shoring wall interface at top.

Model wall with wall aspect ratio above 0.60H failed due to internal failure matching with the Rankine failure plane. RSW with aspect ratio lower than 0.30H failed by overturning and ones between 0.30H to 0.60H failed with compound failure. Thus as wall aspect ratio increases, failure mode shifts from external to internal failure mode. A decrease in the aspect ratio still followed Rankine failure surface, but only till the intersection with stable wall.

2.2 *Field tests*

Morrison (2006) conducted field tests with model SRSW. The study was involved on reduction in lateral earth pressure due to presence of shoring face and effect of connecting the top reinforcements with the shoring face. The wall height was 5.5m with base width of 0.25H increasing to 0.40H at top. The wall contained 12 layers of geogrid reinforcement and facing with combination of welded wire mesh and a woven geotextile wrap around. The Shoring wall and SRSW wall had a facing batter of 1H:6V and 1H:24V respectively. Strip load was applied to the wall using footing of size 2.5m by 1.0m placed on the crest of the wall to a value of 356kPa.

The wall behaved stable at the maximum surcharge load. The maximum vertical footing settlement observed to be 17mm with maximum lateral movement of 8mm and lateral maximum strain was less than 1%. Maximum lateral movement in conventional RSW was observed at middle or top. The distribution of lateral earth pressure for the test wall is as shown in Figure 1. Maximum lateral earth pressure is noted at top & bottom of wall for connected reinforcement and unconnected wall system respectively.

2.3 *Numerical analysis*

A finite element model was carried out by Lee (2010) using FEM program Plaxis 2D. Geometrical dimensions for Shored reinforced soil wall model was used from one of the Centrifuge model CT6 (Woodruff, 2001) for FEM analysis. Reinforcement vertical spacing was varied from 0.20m, 0.40m and 0.60m and reinforcement stiffness varied from 2000kN/m, 4000kN/m and 6000kN/m. Backfill friction angle varied as 37°, 42° and 47°. The shoring wall face wall assumed to have negligible horizontal movements and consequently provided with horizontal fixity. Incremental load application was modelled similar to centrifuge model using footing of dimensions of 2.5m by 1.0m and load value was increased to a maximum value of 359kPa.

A parametric study on the SRSW wall revealed that the footing settlement decreased 18% as the friction angle increased from 37° to 42° at a footing pressure of 300 kPa. The footing settlement decreased 23% for the increase from 37° to 47°. The maximum facing lateral displacements showed reduction of 19% for φ=42° and of 37% for φ =47°. The vertical and horizontal displacements were found to have decreased by 32% and 42 % respectively by increasing the reinforcement stiffness from 2000kN/m to 4000kN/m and from 4000kN/m to 6000kN/m respectively. The lateral deflection reduced by 46% by reducing the reinforcement spacing from 0.40m to 0.20m while increased by 61% for 0.40m to 0.60m vertical spacing. The vertical settlement decreased by 26% for 0.40m to 0.20m and increased by 31% for 0.40m to 0.60m vertical spacing.

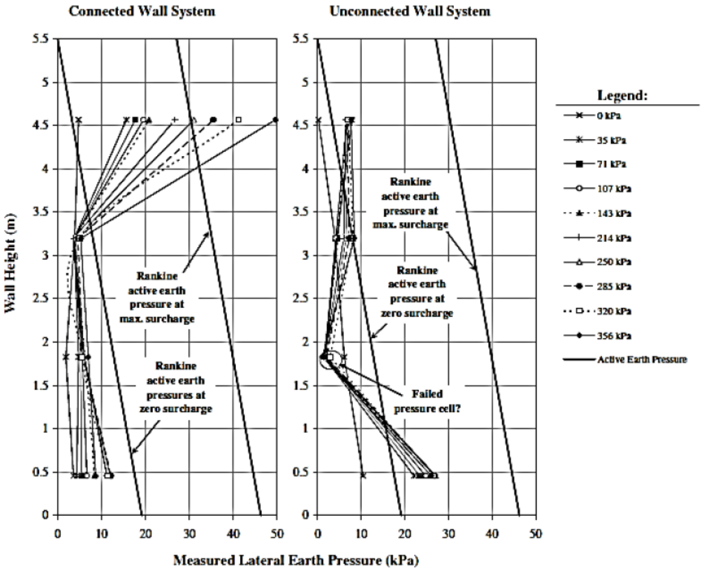

Figure 1. Distribution of lateral earth pressure for connected and unconnected configuration (Morrison 2006)

2.4 *Shored reinforced soil wall system behavior*

Some of the facts derived from the literature of SRSW showed that as compared to conventional reinforced soil wall, SRSW can be designed with low reinforcement length as low as 0.30H. External forces like sliding and overturning are minimized due to presence of stable shoring wall face at backside of RSW. Also rupture and pull-out calculations are required only for the bottom reinforcements where the Rankine failure plane intersects with the reinforcement at angle of 45+ φ/2.

3 NUMERICAL MODEL

The finite element two dimensional program Plaxis is used to conduct numerical analysis in this study. The program discretizes the soil element using 15-noded iso-parametric triangular elements. Plate elements used to model slender structures like RSW fascia. Reinforcements were modeled using geogrid elements. The procedure of stage construction was also modeled. Mohr-Coulomb model was chosen as the soil constitutive model.

Interaction between soil-geogrid and soil-RSW facing is represented by interface element. The interface element acts as an intermediate between smooth and fully rough surface of respective structural members. The roughness of the interaction is modelled by choosing a suitable value for strength reduction factor in the interface (Rinter). An elastic-plastic model was used to depict the behavior of interfaces. The Mohr-Coulomb criterion was used to distinguish between elastic behavior and plastic interface behavior when permanent slip may occur.

4 NUMERICAL ANALYSIS

A sample RSW was analysed to verify the FEM model prepared. The verification was done to ensure that the results obtained by program matches with previous studies done by Singhai et. al. 2008. The wall geometry includes wall height of 7.0m with a reinforcement spacing of 0.50m. Foundation soil assumed of dimensions 25.0m x 4.0m. Reinforcement length was kept to be 5.0m to be constant throughout the wall height. The wall is modeled using following material parameters.

Table 1. Soil parameters (After Singhai et.al. 2008)

Mohr-Coulomb Model	ϒ (kN/m3)	K_x (kN/m3)	K_y (kN/m3)	E_{ref} (kN/m3)	v	c (kN/m3)	φ	ψ	R_{int}
Type: Drained	18.9	1	1	40000	0.3	10	30	2	0.85

Table 2. Facing and Geogrid parameters (After Singhai et.al. 2008)

No.	Identification	EA kN/m	EI kNm^2/m	V	Mp kNm/m
1	Diaphragm wall	7.50E+06	1.00E+06	0	1.00E+15
2	Footing	5.00E+06	8500	0	1.00E+15
3	Geogrid	1500	-	-	-

The modeling was done with above parameters with boundary conditions like: total fixities for foundation and horizontal fixities for reinforced and retained soil mass. The finite element meshes are composed of 15-node isoparametric triangular elements. Stage construction was included by conducting layer-by layer construction in Plaxis. Output results were obtained for horizontal displacements and these were compared with results obtained by Singhai et. al. 2008 and results are comparable.

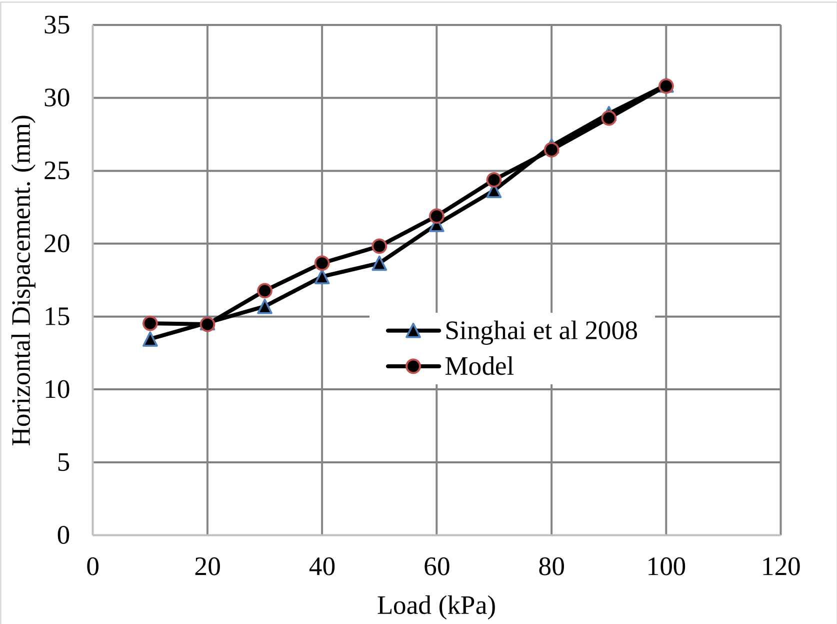

Figure 2. Comparison of horizontal displacements by Researcher with present analysis

The horizontal displacements were calculated using the material properties considered by Singhai et al. 2008. The displacements were found to be in agreement with the present analysis using similar FEM analysis code Plaxis.

5 ANALYSIS OF SHORED REINFORCED SOIL WALL

A SRSW was analyzed using finite element program Plaxis. The wall height was kept as 7m; reinforcement spacing of 0.50m, embedment depth of 1.5m was maintained. Variation of maximum reinforcement tension along with earth pressure was studied.

A parametric study was attempted to understand the behavior of the SRSW. Parametric study conducted varying parameters like: shoring wall inclination, surcharge, and connection of reinforcement with shoring wall, The shoring wall inclination was varied by keeping the bottom width of 0.30H and varying the top width of RS wall in increment of 0.1H (0.30H to 0.70H) where H is the height of SRSW.

Spangler and Handy developed Equation 2 by first assuming the weight of granular backfill placed between a retaining wall and existing stable face was supported in part by friction between the backfill and retaining wall and between the backfill and existing stable face. They then assumed that the weight of the backfill supported by the retaining wall and existing stable face was a function of the friction between the backfill and respective surfaces.

$$\sigma_h = \frac{\gamma W}{2 \tan(\delta)} * [1- \exp(-2K (\frac{z}{W}) \tan(\delta))] \quad (1)$$

where W is the width of the constrained space, z is the depth of the point of interest below the top of the wall, δ is the interface friction angle between the soil and wall, K is the horizontal earth pressure coefficient, and γ is the unit weight of the backfill. The value of the horizontal earth pressure coefficient, K, was not specified by Spangler and Handy, however, in subsequent analyses it was assumed that K was equal to the theoretical at-rest earth pressure coefficient (K0) as defined using Jaky's empirical formula (K0 = 1-sin(φ')), where φ' is the soil friction angle. This equation was used to estimate K value for various models.

6 RESULTS

Variation of maximum reinforcement tension along the wall height for no surcharge with a bottom width 0.30H is presented in Fig 4. It can be noted that maximum reinforcement tension value at mid height of the wall is similar for all models. The reinforcement tensions calculated by the tie-back wedge method appear to be much higher than the predicted reinforcement tensions, possible reasons for this are that the conventional method uses the lateral earth pressure distribution without modifications for soil-reinforcement interactions and toe restraint provided by the soil foundation in front of the wall. Similarly variation of earth pressure coefficient with height has been shown in in Fig. 3.

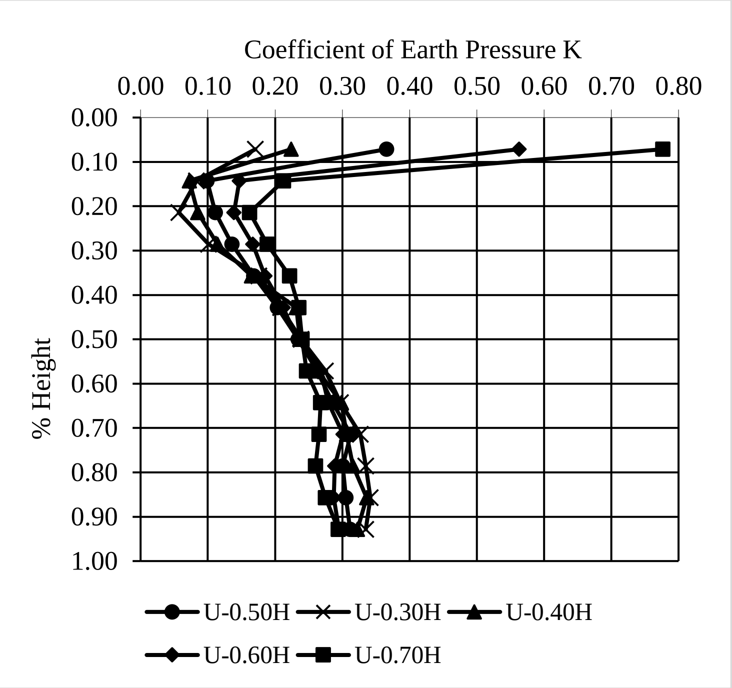

Figure 3. Variation of Coefficient of Earth pressure K with unconnected configuration with shoring wall

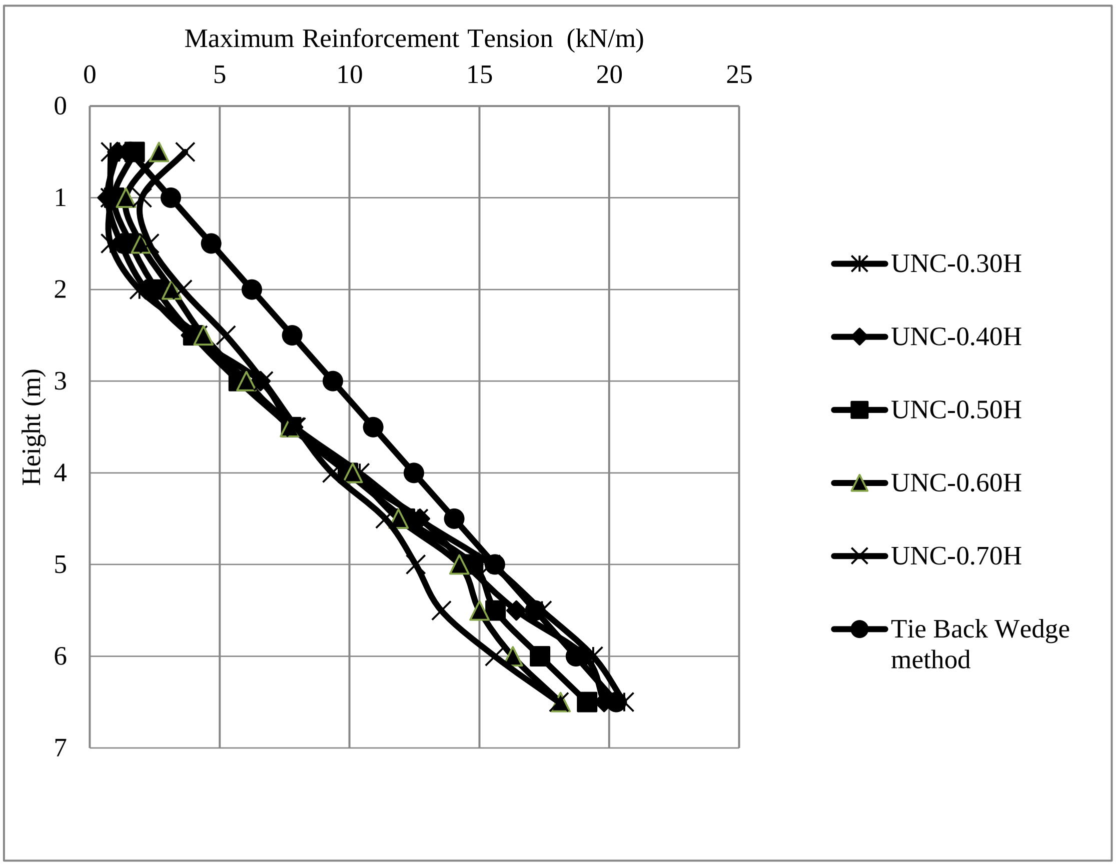

Figure 4. Variation of maximum reinforcement tension without surcharge condition without connection with shoring wall

Fig 5 presents variation of maximum reinforcement tension along the wall height without surcharge condition. The C-0.30H-0.30H, C-0.30H-0.40H, C-0.30H-0.50H line shows the variation of maximum reinforcement tension along wall height with 0.30H bottom width and top six, five, and two reinforcement layers respectively connected to stable wall (where failure plane do not intersect the reinforced mass). It can be noted that the maximum reinforcement tension values in the top portion of the reinforced soil wall are found to be higher than those calculated by Tie-back wedge method. Increase in tension is anticipated due to connection transferring tensile stresses generated in soil matrix completely to reinforcement which was otherwise getting converted into outcropping of the wall. Variation of earth pressure coefficient is presented in Fig. 6 shows very high values at top suggesting at rest condition getting developed due to connection of reinforcement with shoring wall.

7 CONCLUSIONS

For fully unconnected wall system, for both no surcharge and 12kPa surcharge condition, the maximum reinforcement tension values in top half portion of wall height increases with decrease in shoring wall inclination. While maximum reinforcement tension values in the bottom half portion of wall height decrease with decrease in the shoring wall inclination. This suggests that lower shoring wall inclination requires higher tensile strength at the top including greater reinforcement length in top region.

For low width confined walls, the lateral earth pressure is less than that calculated using Tie Back Wedge method in top reinforcement layers which are not intersected by failure plane.

After connecting reinforcement with shoring wall, the maximum Reinforcement Tension values at top increases to maximum value, while that in bottom decreases to minimum value. Partially Connected System allows full use of Reinforcement strength due to connection with stable face. The connection transfers tensile stresses generated in soil matrix completely to reinforcement which was otherwise getting converted into outcropping of wall.

For 0.30H fixed base width, Ka value is highest in the top layer while it decreases in the mid portion and reaches a constant value in the bottom portion. The occurrence of such nature of K is that in case of unconnected

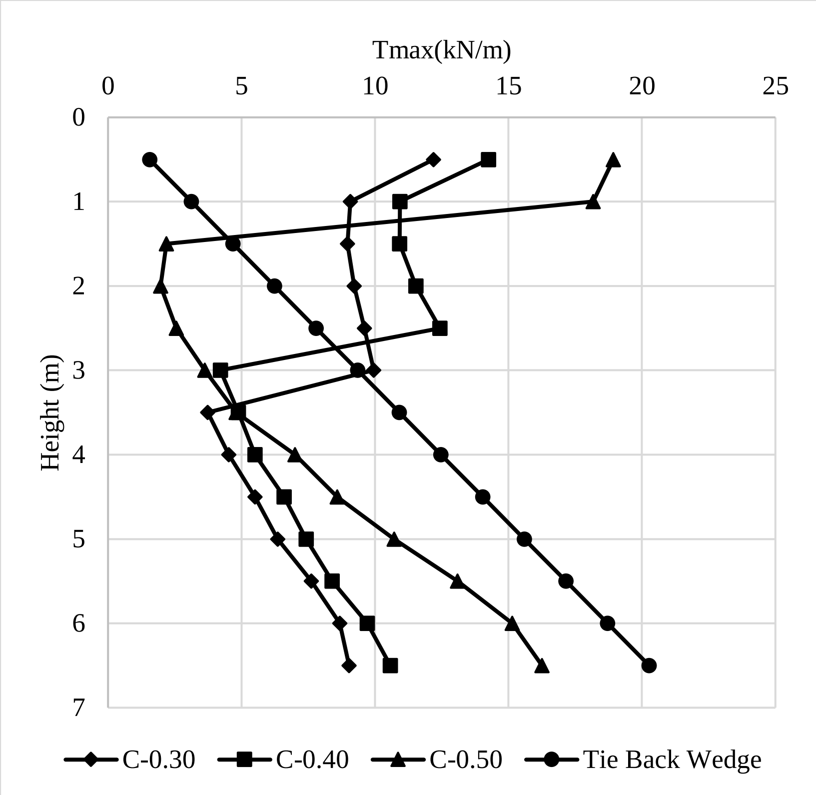

Figure 5. Variation Maximum reinforcement tension without surcharge condition with connection with shoring wall

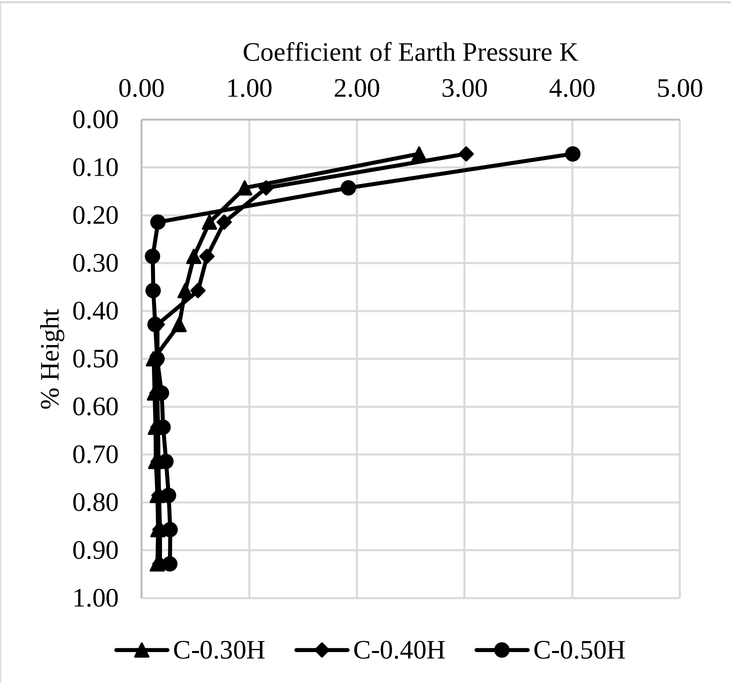

Figure 6. Variation of Coefficient of Earth pressure Ka variation with connected configuration with shoring wall

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REFERENCES

Bajantri M., (2013) “Analysis of fascia retaining wall”, M Tech Thesis, College of Engineering, Pune

Kniss K.T.,Yang K.H., Zornberg J.G, and Wright S.G. (2008) “ Finite Element Analyses for Centrifuge Modelling of Narrow MSE Walls” The First Pan American Geosynthetics Conference & Exhibition

Kniss K.T., Yang, K.H, Zornberg, J.G., and Wright S.G. (2007) “Design Considerations for RSW Retaining Walls Constructed in Confined Spaces” Report No. FHWA/TX-08/0-5506-1, Center for Transportation Research, Austin, Texas

Kniss K.T.,Yang K.H, Zornberg J.G, and Wright S.G. (2008) “Numerical Modeling of Narrow MSE Walls with Extensible Reinforcements ” Report No. FHWA/TX-08/0-5506-2 Center for Transportation Research, Austin, Texas

Lee Y.B., McCartney J. S. and Ko H.-Y. (2010) “Centrifuge Modeling of Shored Mechanically Stabilized Soil Walls” University of Colorado at Boulder, Boulder, CO, USA

Lee Y.B. (2010) “Deformation Behavior of Shored Mechanically Stabilized Soil (SMSE) Wall Systems” University of Colorado, Boulder, CO, USA

Lee Y.B., Ko H.-Y. and J. S. McCartney (2010) “Deformation response of shored MSE walls under surcharge loading in the centrifuge” Geosynthetics International, 17, No. 6, 389–402.

Mahmood T. (2009) “Failure analysis of a mechanically stabilized soil (MSE) wall using finite element program Plaxis” University of Texas at Arlington, USA

Morrison K. F., Harrison F. E., and Anderson S. A.(2008) “Evolution of Mechanically Stabilized Soil Wall Design to Incorporate Permanent Shoring” Geo-volution, ASCE, 149-157, 2006

Morrison, K., Harrison, F., Collin, J., Dodds, A. & Arndt, B.2006. Shored Mechanically Stabilized Earth (SMSE) Wall Systems. FHWA-CFL/TD-06-001. 212 pg

Singhai G. (2008) “Analysis of Reinforced Soil Wall”, M Tech Thesis, Delhi College of Engineering, Delhi University, Delhi.

Spangler, M. G. & Handy, R. L. (1984). “Soil engineering” , New York: Harper & Row

Woodruff R. (2001), “Centrifuge Modelling for MSE-Shoring Composite Walls” University of Coloradoat Boulder, Boulder, CO, USA

Yang K.H., Zornberg J.G., Hung W.Y., & Lawson C.R. (2011) “ Location of failure plane and design considerations for narrow GRS wall systems” Journal of Geoengineering ,6(1), 13-26