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Parametric study of anchored earth wall by finite difference method

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ABSTRACT: This parametric study was undertaken to investigate the behavior of a new type of anchored earth wall system using a three dimensional explicit finite difference program, FLAC 3D. A 5m high and 4m wide anchored earth wall supporting a simultaneously constructed roadway was considered as standard wall and modeled using FLAC 3D. The wall system consists of reinforced soil and retained soil, four layer of reinforcing steel in both horizontal and vertical direction as cable element and concrete block as anchor. The parameters studied were (i) cable spacing (ii) fill soil property. Emphasis was placed to investigate the variation of (i) mid section deflection of the wall (ii) stress in the cable (iii) pull in the anchor with the above mentioned parameter. The study revealed that deflection of the wall, stress in cable and pull in the anchor depend, to a large extent, on cable spacing and soil stiffness. It was evident from the study that soil with elastic modulus of 20 MPa and cohesion of 40 kPa, provide better economy and serviceability.

1 GENERAL INSTRUCTIONS

In the recent years many geotechnical construction like roadways and bridge abutments use retaining walls especially mechanically stabilized earth (MSE) walls. Among the MSE wall systems, Anchored Earth Wall is another type reinforced soil system, where the mode of stress transfer from backfill to reinforcement is by passive resistance in addition to friction, was patented by the Transport and Road Research Laboratory of United Kingdom in1981(Ali et al., 2008a). Anchored earth systems are a combination of the techniques used in the reinforced soil and the soil anchoring (Yoo and Lee, 2003).

Although the design, analysis and construction techniques or approaches in the field of reinforced soil wall systems have been developed over the years (Bathurst and Simac, 1994; Collin, 1997; Elias and Christopher, 1997; Leshchinsky, 1993), the basic design methodology remains the same which is the limit equilibrium method. In design and analysis of reinforced earth wall, the limited equilibrium technique has been used from the first time while the reinforced earth was commercially constructed (Vidal, 1978).

Recent days have observed an increasing trend of construction of anchored earth wall system over other conventional systems in many countries of the world. Recently, a 13 m high wall is constructed in Malaysia (Lee and Oh, 1997). Anchored soil wall may be an alternative to conventional retaining walls with height above 3.5 m in Bangladesh. But the use of anchored walls in Bangladesh is impeded by various unavoidable reasons such as cost incurred by the unavailability of suitable backfill as well as lack of quality control of constructions etc. Therefore, the paper aims to formulate the parametric study of anchored earth wall supporting moderately compacted local soil using elasto – perfectly plastic Mohr-Coulomb model.

2 MODEL GENERATION

In the generation of the proposed model FLAC 3D a three explicit finite difference programme is used. The software able to simulate the behavior of structures built of soil, rock or other materials that undergo plastic flow when their yield limits are reached. The explicit, Lagrangian calculation scheme and the mixed discretization zoning technique used in FLAC 3D ensures that plastic collapse and flow are modeled very accurately.

2.1 *Standard wall geometry*

A 5 m high and 4 m wide earth wall supporting a simultaneously constructed roadway is modeled as standard wall (Fig. 1). Horizontal and vertical spacing of cables is kept to 1 m and cable length is taken to be equal to the height of the wall. The length of the wall is taken as twice the length of the cable in the model and the concrete block having cross section 0.90 m x 0.90 m is used as anchor. It is assumed that Fill soil fills the space between the wall front and anchor and natural soil is considered behind the anchor. Reinforcing steel having diameter 32.26×10^{-3} m is used as cable. Table 1, and Table 2 describes the properties of the materials used in the modeled wall.

Two types of structural elements – cable element and shell element are used in the model generation. Cable elements (reinforcing steel) have a deformable connection to the FLAC 3D grid along their length. Cable elements start from the face of the wall extending up to the anchor face. Frictions developed throughout the length of the cable retain the soil. To ensure this cable is extended beyond the potential failure plane. In the model shell element (concrete block) is used at the interface of fill soil and retained soil.

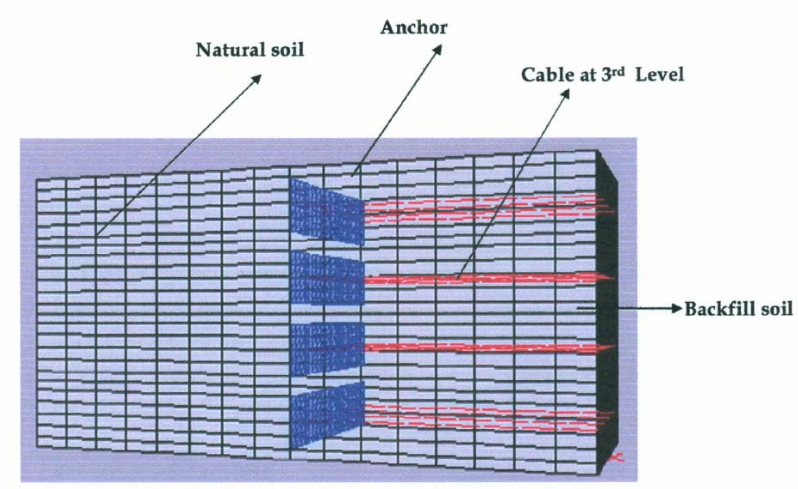

Figure 1. Geometry of the designed standard anchored earth wall system

Table 1. Material properties of concrete and soil for the designed standard wall system

Properties	Unit	Concrete	Fill soil	Natural soil
Young's Modulus	MPa	24900	20	20
Poisson's ratio	-	0.25	0.45	0.45
Cohesion (c)	kPa	-	40	40
Friction angle (φ)	Degree	-	14.5	14.5
Dilatancy angle (ψ)	Degree	-	0	0
Density	kg/m3	2500	-	-

Table 2. Material properties of cable (reinforcing steel)

Density (kg/m3)	78.5 x 103
Young's Modulus (MPa)	199 x 103
Cohesive strength (N/m)	2 x 105
Friction Angle (Degree)	14.5
Stiffness (N/m)	1.75 x 107
Exposed perimeter (m)	0.1
Cross sectional area (m2)	819.4 x 10-6
Compressive yield strength (N)	161 x 103
Tensile yield strength (N)	338 x 103

3 PARAMETRIC STUDY

A parametric study have been carried to examine the effect of variation of parameters such as cable spacing, fill soil properties, anchor size and cable diameter with and without surcharge on the behavior of the standard wall system to find out the optimum performance. Variations of these parameters are delineated in Table 3 - Table 6.

Table 3. Variation of cable spacing in parametric study

	1	2	3	4
Cable spacing (m)	1	1.25	1.5	1.75

Table 4. Variation of soil properties

Properties	Unit	E05	E10	E20	E30	E40
Young's Modulus	MPa	5	10	20	30	40
Poisson's ratio	-	0.45	0.45	0.45	0.45	0.45
Cohesion (c)	kPa	10	20	40	60	80
Friction angle (φ)	Degree	14.5	14.5	14.5	14.5	14.5
Dilatancy angle (ψ)	Degree	0	0	0	0	0

Table 5. Variation of anchor size in parametric study

	1	2	3	4	5
Anchor size (m2)	0.50 x 0.50	0.60 x 0.60	0.70 x 0.70	0.80 x 0.80	0.90 x 0.90

Table 6. Variation of cable diameter in parametric study

	1	2	3	4	5
Cable diameter (mm)	25.4	28.65	32.26	35.81	43.00

4 RESULTS & DISCUSS

4.1 *Effect of variation of cable spacing*

Figure 2 and Figure 3 shows the variation of midsection deflection of the wall with height for variable cable spacing considering two cases without surcharge and with surcharge respectively. From Figure 2 and Figure 3, it is observed that midsection deflection of wall front increases with increased height and cable spacing regardless of surcharge. It is also evident from the figures that maximum deflection occurs at mid height of the wall in both the cases. Comparison of Figure 2 and Figure 3 reveals that deflection increases with the application surcharge and it is prominent at the top of the wall.

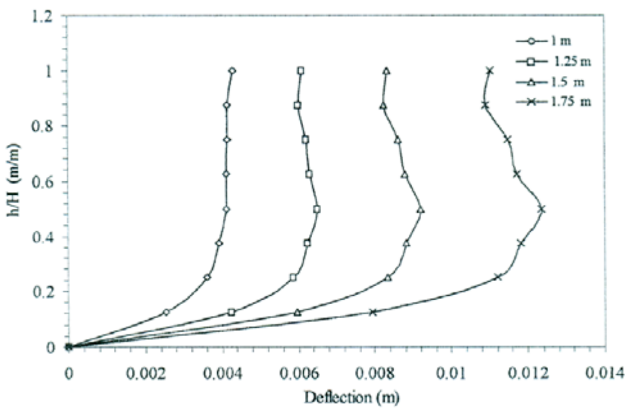

Figure 2. Variation of horizontal midsection deflection of wall front with height without surcharge (Parameter: cable spacing)

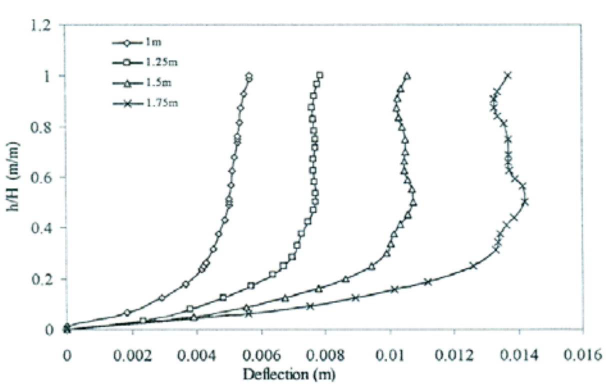

Figure 3. Variation of horizontal midsection deflection of wall front with height with surcharge (Parameter: cable spacing)

In the analysis variation of cable stress along the length of the cable at third level of reinforcement is studied for variation of cable spacing (Fig.4 and Fig.5). From the analysis it is clear that cable stress is very low near the face of the wall which gradually reaches maximum at mid length of the cable irrespective of application of surcharge. This is attributed to the fact that mid length of the cable falls beyond the assumed failure surface.

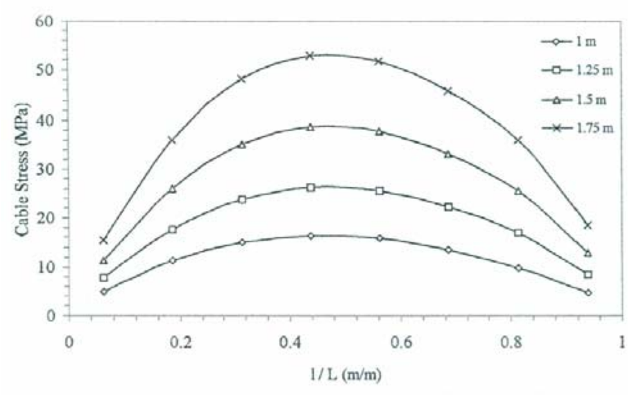

Figure 4. Variation of cable stress at 3rd level of reinforcement with length without surcharge (Parameter: cable spacing)

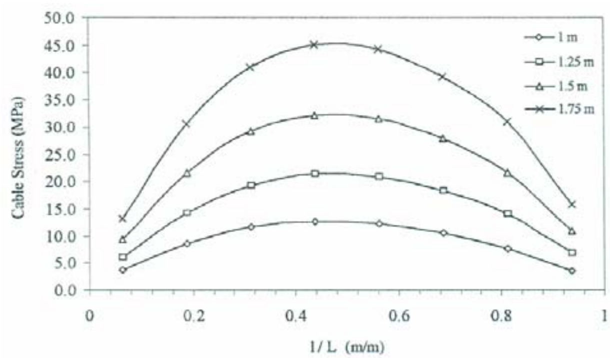

Figure 5. Variation of cable stress at 3rd level of reinforcement with length with surcharge (Parameter: cable spacing)

Due to self weight of soil, the anchor force should increase linearly with depth which is observed for (Fig.7) 60% of the depth from the top. Beyond this depth, pull in anchor reduces linearly. For a given cable spacing pull at the top & bottom anchor is more or less same.

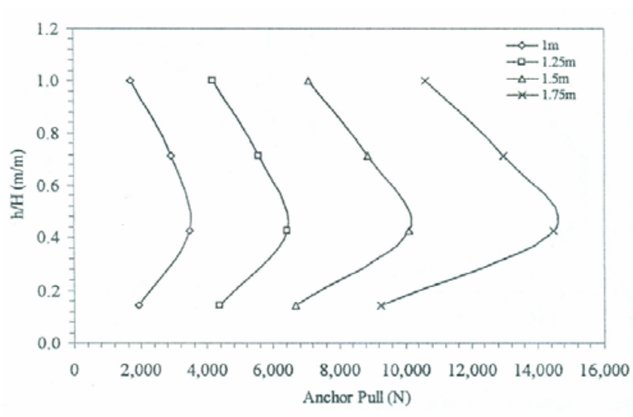

Figure 6. Variation of anchor pull with height without surcharge (Parameter: cable spacing)

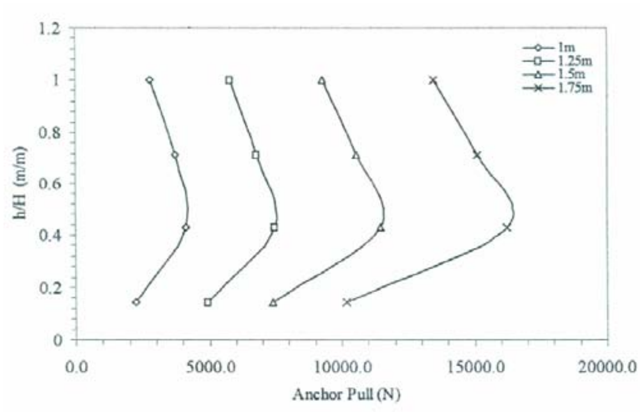

Figure 7. Variation of anchor pull with height without surcharge (Parameter: cable spacing)

4.2 *Effect of variation of fill soil properties*

Figure 8 & Figure 9 show the effect of fill soil properties (Table. 4) on the midsection deflection of wall with height, with and without surcharge. It is observed that elastic modulus should be greater than or equal 20 MPa and cohesion should be 40 kPa to have less deflection for both the cases (surcharges & without surcharge).

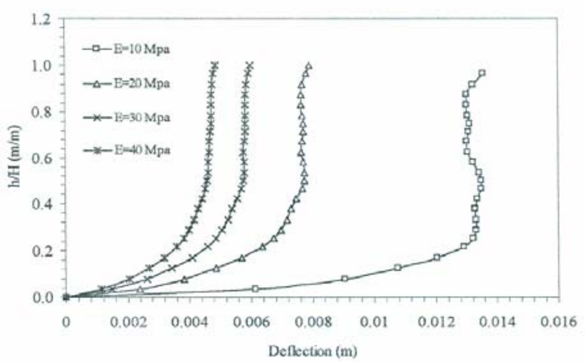

Figure 8. Variation of horizontal midsection deflection of wall front with height without surcharge (Parameter: fill soil property)

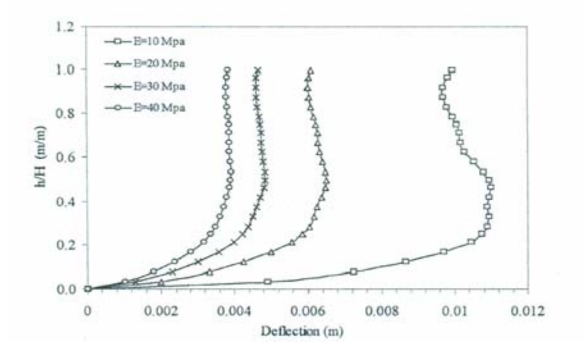

Figure 9. Variation of horizontal midsection deflection of wall front with height with surcharge (Parameter: fill soil property)

Cable stress decreases (Fig. 10 & Fig. 11) with an increase in the stiffness and cohesion of soil and become constant beyond elastic modulus of 40 Mpa. So for better performance elastic modulus should be greater than or equal to 40 MPa and cohesion should be 40 kPa. Maximum stress occurs at mid length of the cable from the wall face.

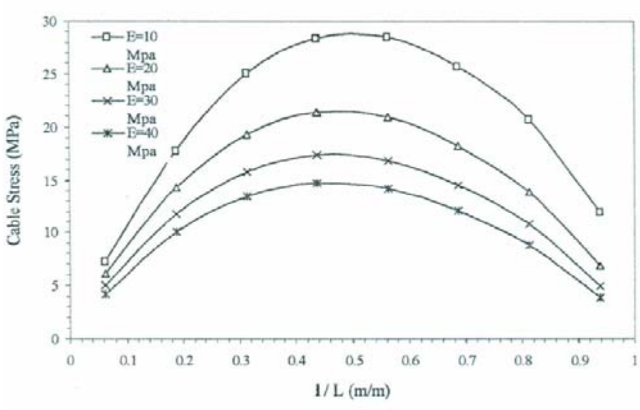

Figure 10. Variation of cable stress at 3rd level of reinforcement with length, without surcharge (Parameter: fill soil property)

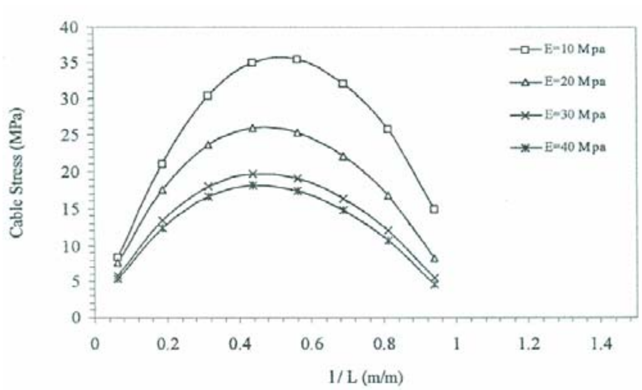

Figure 11. Variation of cable stress at 3rd level of reinforcement with length, with surcharge (Parameter: fill soil property)

An analysis regarding anchor pull reveals that maximum pull in the anchor occurs for minimum stiffness & cohesion value of fill soil (Fig. 12 & Fig. 13), which is about 10 kN when no surcharge load is considered. The maximum stress at the anchor for least stiffness of 10 MPa & cohesion of 20 kPa is about 12350 MPa whereas the yield stress for concrete anchor is 24900 MPa. So as the stiffness & cohesion of soil increases, stress in anchor decreases which eventually results in increase in factor of safety. Application of surcharge increases the anchor stress leading to less factor of safety.

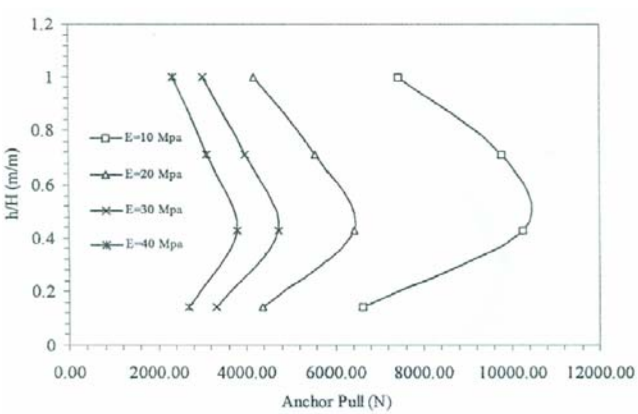

Figure 12. Variation of anchor pull with weight without surcharge (Parameter: fill soil property)

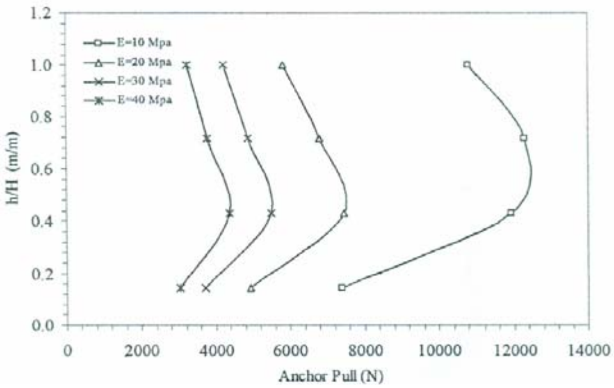

Figure 13. Variation of anchor pull with weight with surcharge (Parameter: fill soil property)

5 CONCLUSION

In this study the behavior of anchored earth wall system is analyzed through parametric study using a three dimensional explicit finite difference program. The emphasis of the parametric study is placed on the effects of various components of proposed wall system on deflection patterns, cable stress & pull in the anchor. The study revealed that deflection of the wall, stress in cable and pull in the anchor depend, to a large extent, on cable spacing and soil stiffness. It was evident from the study that soil with elastic modulus of 20 MPa and cohesion of 40 kPa, provide better economy and serviceability. For future study in line with the present observation, the following developments are envisaged:

(i) Instead of static and uniform surcharge dynamic and repetitive load should be incorporated to visualized its effects and to closely represent the condition that prevails in the road way.
(ii) A comparative economic study may be performed to compare costs between proposed wall system and other alternatives.

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