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A Parametric Study of Anchored Earth Wall by Finite Element Method

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Abstract

A parametric study using finite element method of analysis was undertaken to investigate the behavior of an anchored earth wall system supporting clay backfill. In this paper the effects of stiffness of reinforcing tendon, elastic modulus of backfill soil, elastic modulus of retained soil and anchor size on the behavior of the wall system are presented. It was observed that deformation of wall decreases with increasing stiffness of reinforcement and above certain value of stiffness it has no effect on deformation. Most important finding was that coefficient of lateral earth pressure depends on the stiffness of reinforcement. For extensible reinforcements (axial strain > 1%), coefficient of lateral earth pressure is less than that of an active pressure condition. Deformation decreases with increasing stiffness of backfill and retained soil. Anchor force also decreases with increasing stiffness of backfill but remains constant with the variation of stiffness of the retained soil. It was also concluded that anchor block may be designed for a factor of safety of 2 or more.

Keywords: *anchored earth wall, coefficient of lateral earth pressure, stiffness of reinforcment, pullout capacity of anchor*

1. Introduction

In Bangladesh, retaining wall means conventional retaining wall (Gravity type, Reinforced Cement Concrete (RCC) cantilever type or RCC counterfort type). Conventional retaining walls may be constructed economically only up to a height of 3 to 4 m. Reinforced soil wall may be a good alternative beyond this height. Construction of road embankment confined by reinforced soil wall and extension of existing road width without acquiring adjacent lands are two good examples of application of reinforced soil wall. But construction of reinforced soil wall in countries like Bangladesh would be difficult due to the following reasons: (i) Coarse sand for backfill material is expensive, as it is available only in some selected areas of Bangladesh. Therefore it is necessary to use the local soil in reinforced zone as well as in the retained soil mass for road construction which will be very cost effective. (ii) Compaction of reinforced soil and retained soil of roadway is also costly, as it requires heavy equipment like compaction rollers. Not only that quality control of such compaction works may not be done properly due to various unavoidable circumstances. Therefore it was envisaged to use moderately compacted fill. (iii) Having the poor strength properties and low stiffness of such moderately compacted local indigenous soil, geosynthetic (sheet type) reinforced earth wall would require large pull out length which may be costlier or may not be feasible due to space limitation. Therefore, in this paper, anchored soil wall supporting moderately compacted soft indigenous fill is investigated for future use.

Based on the results of finite element analyses, Rowe and Ho (1995 and 1996) reported the effects of intermediate reinforcing layers, the effect of interface shear, the effect of panel continuity and location of panel connections, backfill soil stiffness and foundation stiffness on the behavior of reinforced earth wall. They put forward following important conclusions about the stiffness of backfill soil (a) modulus of elasticity of backfill does not have significant effect on the forces required for either external rigid body equilibrium or internal equilibrium of the reinforced soil wall system except for very low values of modulus and (b) a change in backfill modulus only affects the horizontal deformation behind the reinforced soil block and consequently the horizontal deformation at wall face. Rajagopal and Hari (1996) worked on the prediction of anchor capacities in anchored retaining walls based on finite element analysis and laboratory model tests. They proposed simple design method for these walls.

The effects of compaction reported by Ingold (1979) have good lessons for using uncompacted backfill though uncompacted backfill has other limitations. Tatsuoka *et al*. (1986) showed that steep side slopes of embankments made of sensitive Kanto loam can be effectively stabilized by using nonwoven geotextile. Ling and Tatsuoka (1992) reported the numerical procedure employed to predict the performance of two geosynthetic-reinforced walls, one backfilled with granular soil and the other with cohesive soil.

Mechanically stabilized backfill structure where the mode of

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stress transfer from the backfill to the reinforcement is by passive resistance in addition to friction, is not a new concept. Andre Coyne (1929) invented one of the earliest versions of this system in 1929. After that, the Transport and Road Research Laboratory in the UK came up with their version of anchored earth in 1981. The application of such system was reported by Jones *et al.* (1985). In this paper, a parametric study of an anchored earth wall system was carried out. The proposed anchored earth wall system is economic and easy to construct using local soil and reinforcing tendons. In the proposed wall system, the new concept was the use of clay backfill entirely and thin vertical layer of granular backfill where the mode of stress transfer from the backfill to the reinforcement is mainly by passive resistance.

2. Principle of Anchored Earth Wall

Investigation of the basic reinforcing mechanism reveals that the retained soil comprises two distinct zones. These are shown in Fig. 1 as the active zone and the resistant zone. Without reinforcement the active zone is unstable and tends to move outwards and downwards with respect to the resistant zone. If anchor block is installed beyond the active zone with a tie bar across the active and resistant zones it can serve to stabilize the active zone. Due to self-weight of soil and surcharge on the structure, lateral deformation of soil induce lateral thrust on back face of facing, which eventually lead to development of tensile force in reinforcing tendon. Bearing pressure developed in soil resists this pull out force of reinforcing tendon on anchor block. Fig. 1 shows a single layer of reinforcement. A practical reinforcement layout would contain multiple layers of reinforcement; however, the single layer shown in Fig. 1 is adequate to illustrate the basic mechanism involved. Destabilizing forces in active zone is transferred to resistant zone through reinforcement. Most of the resistance comes from anchor blocks and some from soil-reinforcement friction in resistant zone.

3. Pullout Capacity of Vertical Anchor

Numerous research works have been carried out on pull out capacity of horizontally loaded vertical anchors. Some of the examples are Wang and Wu (1982), Das (1975), Das and Seely (1975), Akinmusuru (1978), Neely *et al.* (1973), Rowe and Davis (1982a, 1982b), Rajagopal and Hari (1996). BS 8006 (1995) also proposes a simple formula for pull out capacity of

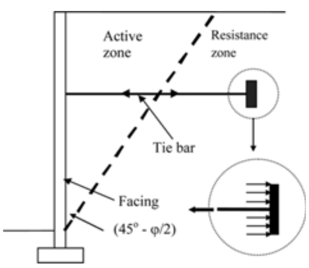

Fig. 1. Reinforcing Mechanism in Anchored Earth Wall

vertical anchors. This is the simplest method of estimating pull-out resistance of anchor. However, it does not consider the B_a/t_a ratio, where B_a is width and t_a is thickness of anchor. Rowe and Davis (1982a, 1982b) considered the anchor capacity as function of orientation, embedment ratio, friction angle of soil, dilatancy, initial stress state and anchor roughness. This method also does not consider the B_a/t_a ratio.

Rajagopal and Hari (1996) used data generated by laboratory experiments and finite element simulations in developing an equation to relate a number of important parameters such as the size and shape of anchors (B_a/t_a ratio), friction angle of soil, normal pressure acting at the mid-depth of anchor. The equation is given as:

$$\frac{P}{B_a} = S_a C\left[1+\frac{t_a}{B_a}\right]^m \gamma t_a^2 \left(\frac{\sigma_V}{\gamma t_a}\right)^n K_p^q \quad (1)$$

where,

B_a = Long term width of anchor
C = Non-dimensional constant = 1.42
K_p = Coefficient of passive earth pressure
m = Exponent = 1.36
n = Exponent = 1.46 for shallow embedment depths for which $\sigma_v/\gamma H$ less than 15
= 1.03 for higher embedment depths
q = Exponent = 1.09
S_a = Shape factor = 0.8 for circular anchors
=1.0 for square and rectangular anchors
t_a = Long term height of anchor

4. Finite Element Model for Parametric Study

A 4.5 m high vertically faced anchored earth wall supporting soft backfill was designed as per BS 8006 (1995). Anchor size was designed according to Rajagopal and Hari (1996) with a factor of safety of about 1, 2 and 6 for a surcharge loading of 100 kN/m^2 on the roadway. Due to surcharge loading, embedment ratio of all anchors ($\sigma_v/\gamma t_a$) were so high that they satisfied the criteria to be deep anchors in all methods. Horizontal and vertical spacing of reinforcement was 1.0 m. Dimension of anchor block was 1 m × 0.12 m (for FS = 6) so that the wall system become a plane strain problem in the finite element model. Though in consideration of ease of construction and efficiency in pull-out resistance, square shaped anchor is the best, to make finite element model of the proposed wall system a plane strain model, plane strain anchors were adopted. Large factor of safety (F.S. = 6) for anchors was used for standard wall configuration to minimize the effect of anchor size during study of other parameters. RCC wall was used as rigid facing to reduce lateral deformation of wall and hence vertical deformation of top surface of roadway. Material properties used in designing this standard wall are shown in Tables 1 and 2.

4.1 Numerical Model of Proposed Wall

The finite element mesh, as shown in Fig. 2, of the proposed

Table 1. Material Properties of Concrete and Soils for the Designed Standard Wall

	Unit	Concrete	Sand-1	Sand-2	Clay-1	Clay-2	Clay-3
Young's modulus	MPa	20,000	40	40	20	20	50
Poisson's ratio (ν)	-	0.15	0.25	0.25	0.45	0.45	0.40
Drained Cohesion (c_d)	kPa	400	0	0	40	40	100
Friction angle (ϕ)	Degree	40°	40°	40°	14.5°	14.5°	14.5°
Dilatancy angle (ψ)	Degree	2.3°	13°	13°	0°	0°	0°
K_o (=1-Sinϕ)	-	0.36	0.36	0.36	0.75	0.75	0.75

Table 2. Variation of Stiffness of Reinforcement in the Parametric Study

	1	2	3	4 (design value)	5	6	7
Spring constant (N/m)	1v10^6	2×10^6	5×10^6	1×10^7	1×10^8	1×10^9	1×10^{11}

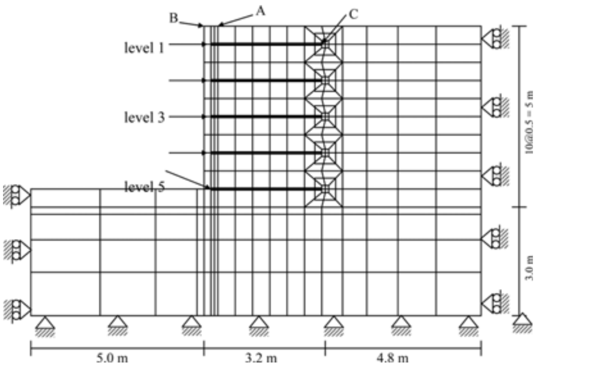

Fig. 2. Finite Element Meshes Showing the Position of Reinforcements and Points A, B and C

wall system was created using finite element software DIANA (1998). In the FEM model, 8 node quadrilateral plane strain element was used to represent soil and concrete (anchor blocks and facing wall). No interface element was used considering a perfect bonding between the soil and anchor blocks and back face of facing wall under the working load. Anchor blocks and facing wall were connected by 2 node spring elements to represent the reinforcement/tie bars. As a result no contribution of soil-reinforcement friction was considered in the numerical model.

Although the elasto-plastic strain hardening softening constitutive models are more appropriate for soil, but for simplicity elasto-perfectly plastic Mohr-Coulomb constitutive model was used in this study. The embedment depth of anchored earth wall was recommended by BS 8006 (1995) to protect the wall from future wash out of soil from in front of wall. But to observe positive effect of embedment depth just after construction of wall system, soil in front of wall was kept in the model.

The outer boundaries of finite element mesh should be placed sufficiently far away from the region subjected to the greatest load changes so as not to influence the results. If the boundaries were placed beyond the regions where stress changes were less than 5%, then results would be within sufficient accuracy. For retaining wall, as a general rule, the vertical boundaries should be placed at a distance of at least 4H to 5H from the wall (H = Height of wall). In this study vertical boundary after clay-3 is considered as centerline of a roadway. That is why, effect of this boundary location was not considered. The bottom boundary of the mesh should be at depth of at least 4H or at hard stratum, whichever is nearer. In the current study, the base soil was assumed to be sufficiently stiff. Due to stiff base soil bottom boundary was located nearer to bottom of wall.

4.2 Parameters

Although to apply this type of structure in the field, it is necessary to consider the consolidation settlement of backfill soil and ground with clay, uneven settlement, external stability, drainage problem of the whole structure, in this study only following parameters and elastic settlements are considered. The parameters studied are: (1) stiffness of reinforcement, (2) elastic modulus of soft backfill (clay-1), (3) elastic modulus of retained soil (clay-2), (4) elastic modulus of granular soil (sand-2) in between backfill and retained soil, (5) rigidity of facing (6) anchor size and (7) anchor position. Zoning of finite element mesh indicating different materials are shown in Fig. 3. In this paper the effect of stiffness of reinforcing tendon, elastic modulus of backfill soil, elastic modulus of retained soil and anchor size on the behavior of the wall system is presented. Variation of these parameters is tabulated in Tables 2, 3 and 4.

4.3 Stiffness of Reinforcement

This is the spring constant of spring element connecting facing

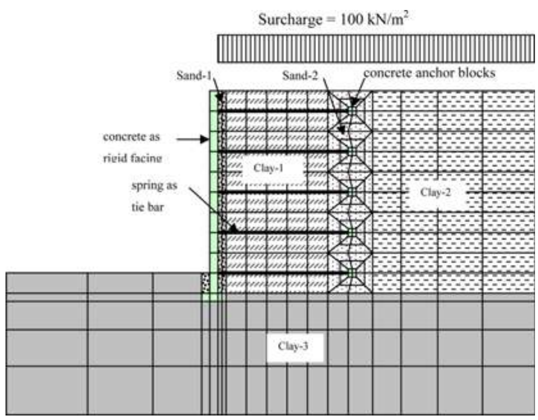

Fig. 3. Zoning of Finite Element Mesh Showing Different Materials

Table 3. Variation of Material Properties of Clay-1 and Clay-2 in the Parametric Study

	Unit	E05	E10	E20 (design value)	E30	E40	E50
Young's modulus	MPa	5	10	20	30	40	50
Poisson's ratio (ν)	-	0.45	0.45	0.45	0.45	0.45	0.45
Drained Cohesion (c_d)	kPa	40	40	40	40	40	40
Friction angle (ϕ)	Degree	14.5°	14.5°	14.5°	14.5°	14.5°	14.5°
Dilatancy angle (ψ)	Degree	0°	0°	0°	0°	0°	0°
K_o (=1-sinϕ)	-	0.75	0.75	0.75	0.75	0.75	0.75

Table 4. Variation of Anchor Size (1.0 m×t_a) in the Parametric Study

	1	2	3
t_a	0.02 m	0.04 m	0.12 m
Factor of Safety	1	2	6

to anchor. Stiffness is the combined effect of Modulus of Elasticity (E) of reinforcement, length and cross-sectional area for metallic reinforcement, and thickness for sheet reinforcement. Stiffness is calculated from:

$k_s = AE/L$ for flat and round bar
$k_s = tE/L$ for sheet reinforcement where, $A = t \times 1 = t$

The design value of stiffness of reinforcement was 1×10^7 N/m which is approximately stiffness of a 16 mm diameter round bar. In the FEM model, the reinforcement is simply a spring of equivalent stiffness, which does not hamper the plane strain condition of the model. This parameter was varied from 1×10^6 to 1×10^{11} N/m. Variation of spring constant in the parametric study is shown in Table 2.

4.4 Stiffness and Strength Properties of Backfill Soil (Clay-1)

Silty clay fill in between anchors and facing and surrounded by sand is termed as clay-1. Clay-1 is considered as cohesive frictional (φ = 14.5°) soil. A Young’s modulus of 20 MPa, cohesion of 40 kPa and friction angle of 14.5° was the design values of stiffness and strength properties of backfill soil clay-1. Young’s modulus was varied from 5 to 50 MPa and cohesion was varied from 10 to 100 kPa respectively. Angle of internal friction was kept constant. Variation of material properties of clay-1 as cohesive frictional soil in the parametric study is shown in Table 3. To simulate undrained condition of clay-1 Poisson's ratio of clay-1 is assumed as 0.45. Young's modulus E is estimated from the empirical relation E = (100 to 500) S_u (Bowles, 1997) for silt and clays. E = 500 S_u was adopted in this study. To estimate K_o, Jaki's (Jaky, 1944) formula (1-sinϕ) was used.

4.5 Stiffness and Strength Properties of Retained Soil (Clay-2)

The silty clay fill of roadway, which is retained by the wall system, is termed as clay-2. A Young’s modulus of 20 MPa, cohesion of 40 kPa and friction angle of 14.5° was the design values of stiffness and strength properties of clay-2. Young’s modulus was varied from 5 to 50 MPa and cohesion was varied from 10 to 100 kPa respectively. Angle of internal friction was kept constant. Variation of material properties of clay-2 is same as variation of clay-1, which is shown in Table 3.

4.6 Anchor Size

Using formula given by Rajagopal and Hari (1996), the anchor size was designed for factor of safety of 1, 2 and 6 (Table 4). Although factor of safety 1 should not be used in the practical design, here it was used to verify the ultimate anchor capacity given by the formula. Heights of plane strain anchors are 0.02 m, 0.04 m and 0.12 m respectively. Since Rajagopal and Hari (1996) have performed pull-out test on anchors in an anchored earth wall arrangement and considered the B_a/t_a ratio in Eq. (1), their formula might be suitable for anchors used in anchored earth wall. Comparison of ultimate pull-out capacity of horizontally loaded vertical anchors is made among three methods and shown in Table 5. It is observed that pull-out capacity of anchor estimated by using equation given by Rajagopal and Hari (1996) is less than that estimated by other two methods. Because, only Eq. (1) given by Rajagopal and Hari (1996) considered the B_a/t_a ratio

Table 5. Comparison of Ultimate Pull-Out Capacity of Anchors at Different Levels of the Proposed Wall System Calculated using 3 Methods for 3 Anchor Sizes

			Anchor size = 0.02 m²			Anchor size = 0.04 m²			Anchor size = 0.12 m²		
	Method	Rankin's Theory (K_a=0.22)	BS 8006 (1995)	Rajagopal and Hari (1996)	Rowe and Davis (1982)	BS 8006 (1995)	Rajagopal and Hari (1996)	Rowe and Davis (1982)	BS 8006(1995)	Rajagopal and Hari (1996)	Rowe and Davis (1982)
Depth (m)	σ_v (kPa)	P_{req} (kN)	P_u (kN)	P_u (kN)	P_u (kN)	P_u (kN)	P_u (kN)	P_u (kN)	P_u (kN)	P_u (kN)	P_u (kN)
0.5	108	24	40	20	28	79	40	55	238	128	166
1.5	124	27	46	23	32	91	46	64	274	147	191
2.5	140	31	52	26	36	103	52	72	309	167	216
3.5	156	34	57	29	40	115	58	80	344	187	240
4.5	172	38	63	32	44	127	64	88	380	206	265

of anchor and the B_a/t_a ratios (50, 25 and 8) of anchors used in this study are very high which was necessary to make the problem as plane strain.

5. Results and Discussion

For convenience of presentation of results Fig. 2 shows the finite element mesh indicating the position of reinforcements and points A, B and C in the mesh. Results of the parametric study are presented in the following subsections.

5.1 Effect of Stiffness of Reinforcement

Figure 4 shows the deformation of top surface of roadway with respect to distance from tip of wall at different stiffness of reinforcement. Fig. 5 shows the lateral displacement of the wall face with respect to depth. Fig. 6 is the graphical plot of anchor force with depth. In Fig. 7, vertical displacements of point A, horizontal displacements of point B and C (Fig. 2) is plotted against stiffness of tie bar in logarithmic scale to show the rate of variation clearly. In Fig. 8, anchor force at level 3 is also plotted against stiffness of tie bar in logarithmic scale.

Stiffness of reinforcement or tie bar is a very important parameter among the parameters to be considered in designing anchored earth wall. It was observed from Fig. 4 that stiffness of tie bar has less effect on deformation of top surface of retained soil and has more effect on deformation of top surface of backfill soil. The stiffness of reinforcement should be equal to or greater than 5.0 $\times 10^6$ N/m so that settlement of backfill and retained soil would be uniform. In case of metallic reinforcement, its yield strength governs the design. As a result stiffness of reinforcement becomes greater than this requirement automatically. But if geogrid or any other type of reinforcement were used for the proposed wall system, it had must been ensured that stiffness was greater than 5.0×10^6 N/m. Similar conclusions may be drawn from Fig. 5. Lateral deformation of wall may be kept within 0.4% of height of wall if stiffness of reinforcement is greater than or equal to 5.0×10^6 N/m. The combined effect of embedment depth and small

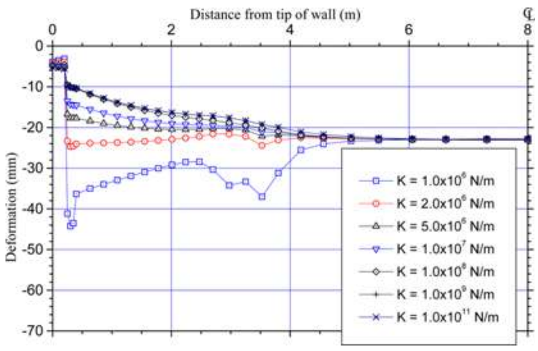

Fig. 4. Deformed Shape of Top Surface of Roadway after 100 kPa Uniform Static Loading on Roadway with Different Stiffness of Tie Bar

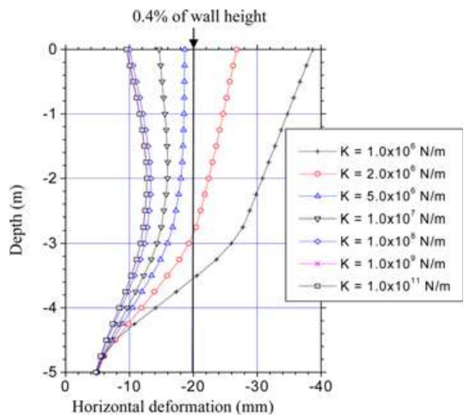

Fig. 5. Deformed Shape of Facing Wall after 100 kPa Uniform Static Loading on Roadway with Different Stiffness of Tie Bar

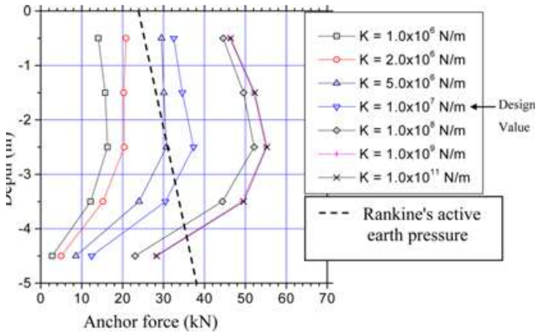

Fig. 6. Variation of Anchor Force with Depth at Different Stiffness of Tie Bar

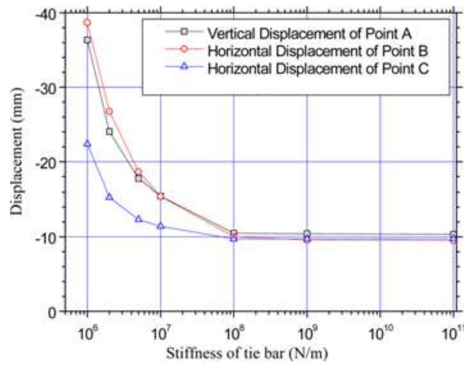

Fig. 7. Displacement Variation with Stiffness of Tie Bar: Points A, B and C are Shown in Fig. 2

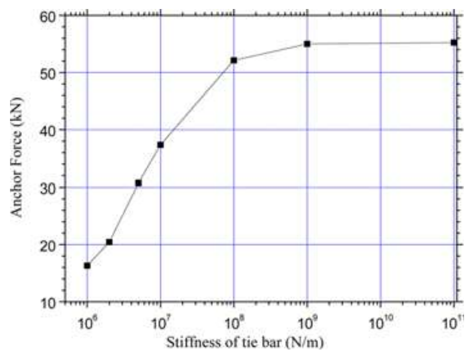

Fig. 8. Variation of Anchor Force at Level 3 with Stiffness of Tie Bar

foundation under continuous rigid facing is clearly observed in Fig. 5. Lateral displacement of bottom of wall is only about 5 mm and this value is independent of stiffness of reinforcement.

Due to self weight of soil, the anchor force should increase linearly with depth. Due to surcharge loading anchor force should decrease with depth. So combined effect of self weight of soil and surcharge load anchor force is almost constant (Fig. 6) with depth up to 3 m. Beyond this depth anchor force decreases due to passive resistance of soil in front of wall.

Vertical deformation of top surface and lateral deformation of wall decreases exponentially (Fig. 7) with increasing stiffness of reinforcement and become constant beyond stiffness 1×10^8 N/m. Lateral displacement of points B and C are equal beyond stiffness 1×10^8 N/m indicating that beyond this stiffness total wall system works as a rigid body and the rigid body movement of about 10 mm is due to lateral deformation of retained soil only. Anchor force increases with increasing stiffness of tie bar and beyond the stiffness of 1.0×10^8 N/m the anchor force become constant (Fig. 8). No relative movement of facing and anchor blocks occur at higher stiffness of tie bar. For better performance of designed wall, lower limit of stiffness of reinforcement is 5.0×10^6 N/m. That implies that in the proposed wall system extensible reinforcement (axial strain > 1.0%) should not be used.

Most important finding was that coefficient of lateral earth pressure depends on the stiffness of reinforcement. For extensible reinforcements (axial strain > 1.0%), K value is less than that for active condition. From the anchor forces of level 1 to 3, coefficient of lateral earth pressure (K) is calculated and plotted against logarithm of stiffness of tie bar in Fig. 9. It was observed that when $K = K_a$ at stiffness of reinforcement 1×10^6 N/m, when the wall deformations were so large that it exceeded the serviceability limits. Therefore, for this type of retaining wall, required anchor forces or tensile forces in reinforcements should be estimated from K_o condition of backfill soil. Active earth pressure condition may be used for extensible (axial strain > 1.0%) reinforcement like geotextile. With the increase of stiffness of reinforcement, coefficient of lateral earth pressure should be increased to calculate lateral forces acting on wall face. This finding is similar to findings of Transportation Research Board (1995) of Washington, D.C. They recommended $K = K_a$ for geotextile reinforced soil, for stiffer reinforcements $K > K_a$.

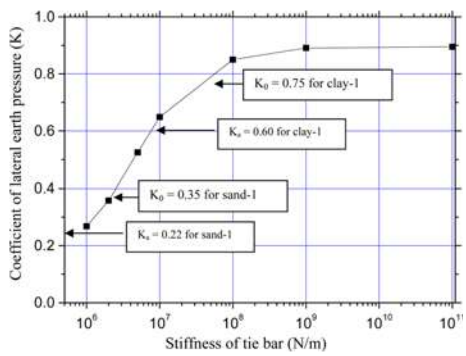

Fig. 9. Variation of Coefficient of Lateral Earth Pressure with Stiffness of Tie Bar

5.2 Effect of Stiffness of Backfill Soil (Clay-1)

Settlement of top surface of roadway against distance from tip of wall is plotted in Fig. 10 at different elastic modulus of clay-1 (ϕ = 14.5°). Fig. 11 is the plot of lateral deformation of facing against depth of wall. From these figures it was observed that elastic modulus of clay-1 (ϕ = 14.5°) should be greater than or equal to 10 MPa and cohesion should be greater than 20 kPa. Fig. 12 shows the anchor force variation with depth. Anchor forces are almost constant with depth up to 3m and decreases beyond this, because of embedment depth. In Fig. 13, vertical

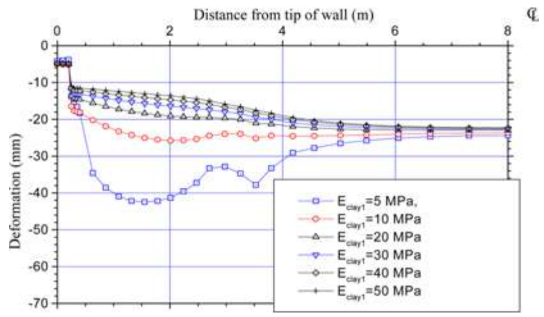

Fig. 10. Deformed Shape of Top Surface of Roadway after 100 kPa Uniform Static Loading on Roadway with Different Elastic Modulus of Backfill Soil (Clay-1)

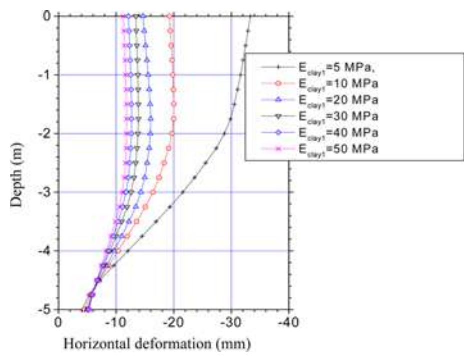

Fig. 11. Deformed Shape of Facing Wall after 100 kPa Uniform Static Loading on Roadway with Different Elastic Modulus of Backfill Soil (Clay-1)

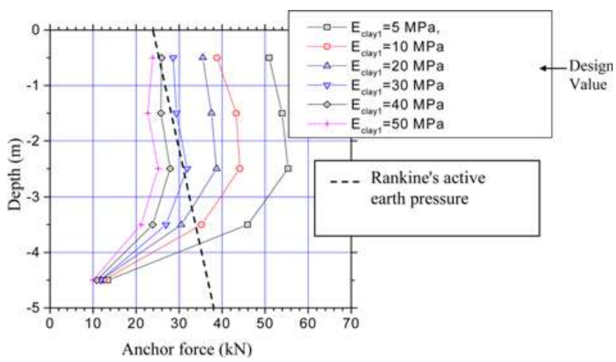

Fig. 12. Variation of Anchor Force with Depth at Different Elastic Modulus of Backfill Soil (Clay-1)

displacements of a point on top surface at a distance of 1.55 m from tip of wall, horizontal displacements of point B and C is plotted against elastic modulus of clay-1 to show the rate of variation. In Fig. 14, anchor force at level 3 is also plotted against elastic modulus of clay-1.

Maximum displacement of top surface and lateral displacement of wall facing decreases rapidly with increasing stiffness of backfill soil and displacement became constant beyond stiffness 30 MPa. For better performance of designed wall, lower limit of stiffness of clay-1 is 10 MPa. Clay-1 with stiffness 10 MPa has cohesion c = 20 kPa which is in the range of soft consistency. It is also clear that design value of elastic modulus and cohesion of clay-1 is the optimum value considering deformations and anchor forces.

From the anchor forces of level 1 to 3, coefficient of lateral earth pressure (K) is calculated and plotted against elastic modulus of clay-1 in Fig. 15. It is seen that anchor forces decreases with increasing stiffness of clay-1. This means that well compacted backfill soil reduces the requirement of reinforcement and hence the size of anchors.

5.3 Effect of Stiffness of Retained Soil (Clay-2)

Settlement of top surface of roadway against distance from tip of wall is plotted in Fig. 16 at different elastic modulus of retained soil clay-2 (ϕ= 14.5º). Fig. 17 is the plot of lateral deformation of facing against depth of wall. From these figures it is observed that elastic modulus of clay-2 (ϕ = 14.5º) should be greater than or equal to 20 MPa and cohesion should be greater than 40 kPa. Fig. 18 shows the anchor force variation with depth. Anchor forces are almost constant with depth up to 3m and decreases beyond this, because of embedment depth. In Fig. 19, vertical displacements of a point on top surface at center of roadway, horizontal displacements of point B and C is plotted against elastic modulus of clay-2 to show the rate of variation.

Maximum displacement of top surface and lateral displacement of wall facing decreases rapidly with increasing stiffness of retained soil and displacement become constant beyond stiffness

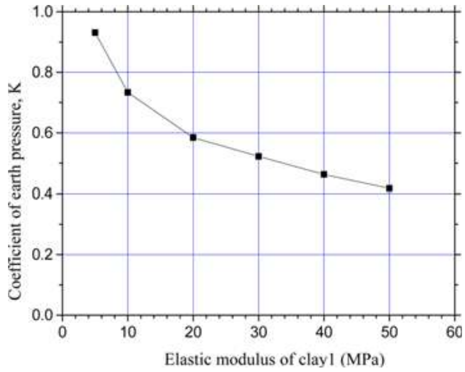

Fig. 15. Variation of Coefficient of Earth Pressure, K with Elastic Modulus of Backfill Soil (Clay-1)

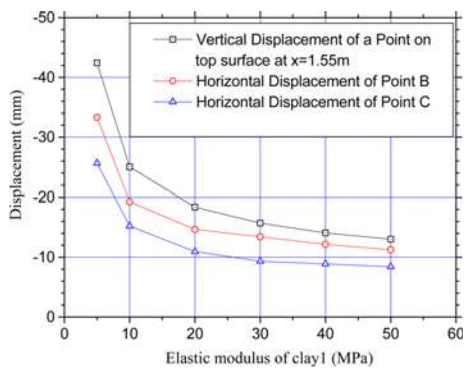

Fig. 13. Displacement Variation with Elastic Modulus of Backfill Soil (Clay-1): Points A, B and C are shown in Fig. 2

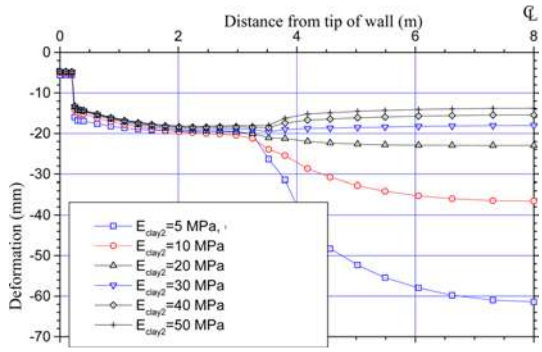

Fig. 16. Deformed Shape of Top Surface of Roadway after 100 kPa Uniform Static Loading on Roadway for Different Elastic Modulus of Retained Soil (clay-2)

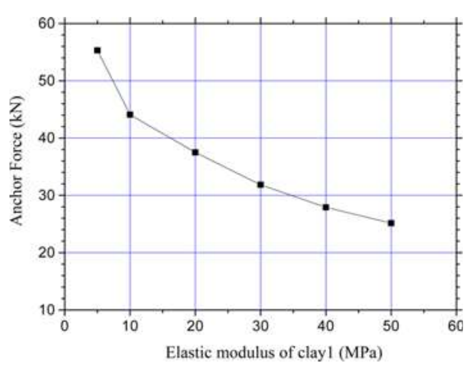

Fig. 14. Variation of Anchor Force at Level 3 with Elastic Modulus of Backfill Soil (Clay-1)

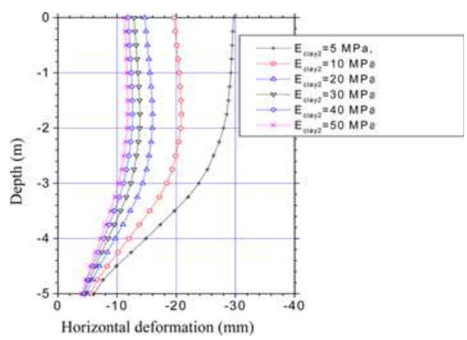

Fig. 17. Deformed Shape of Facing Wall after 100 kPa Uniform Static Loading on Roadway for Different Elastic Modulus of Retained Soil (Clay-2)

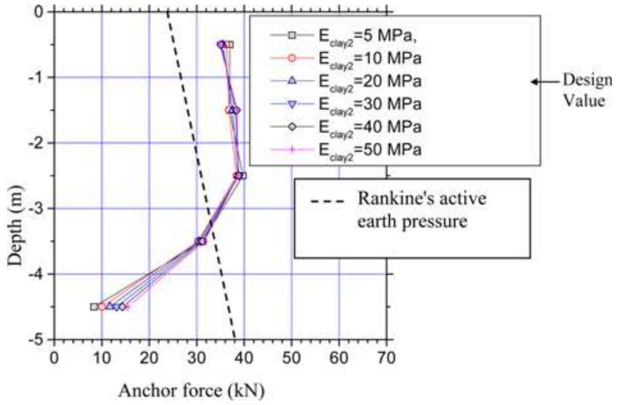

Fig. 18. Variation of Anchor Force with Depth for Different Elastic Modulus of Retained Soil (Clay-2)

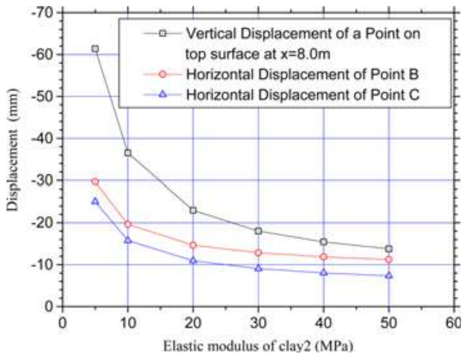

Fig. 19. Displacement Variation with Elastic Modulus of Retained Soil (Clay-2): Points A, B and C are Shown in Fig. 2

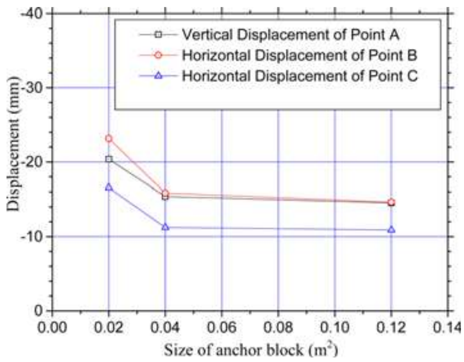

Fig. 20. Variation of Displacement at Points A, B and C with Size of Anchor Block: Points A, B and C are Shown in Fig. 2

30 MPa. For better performance of designed wall, lower limit of stiffness of clay-2 should be 20 MPa. It is also clear that design value of elastic modulus and cohesion of clay-2 is the lower limit considering deformations.

From the anchor forces of level 1 to 3, coefficient of lateral earth pressure (K) is calculated as 0.65. It is seen that anchor force remains constant with increasing stiffness of clay-2. This indicates that relative movement of anchor and facing wall produces the pull-out tensile forces in reinforcements. Stiffness of retained soil affects the rigid body movement of total retaining system. Displacement difference of point B and C seen in Fig. 19 is constant

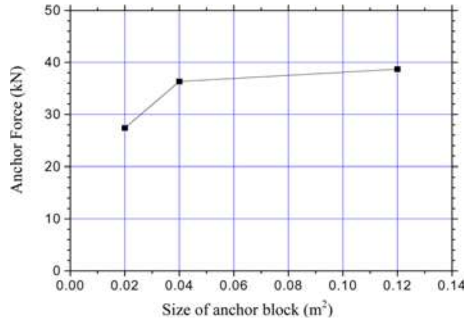

Fig. 21. Variation of Anchor Force at Level 3 with Size of Anchor Block

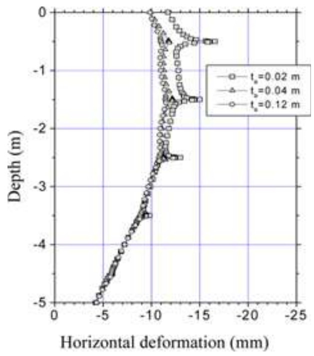

Fig. 22. Deformed Shape of Anchor Front of Wall after 100 kPa Uniform Static Loading on Roadway with Different Anchor Sizes

with variation of stiffness of clay-2, this also proves the rigid body movement of total retaining system due to deformation of retained soil.

5.4 Effect of Anchor Size

In Fig. 20, vertical displacements of point A, horizontal displacements of point B and C are plotted against size of anchor to show the rate of variation. In Fig. 21, anchor force at level 3 is also plotted against size of anchor. Deformed shape of a vertical line at anchor position is shown in Fig. 22.

The anchors were designed using a formula given by Rajagopal and Hari (1996). Deformation of anchor front at $t_a = 0.02$ m (FS = 1) in Fig. 22 proves local shear failure of anchors at ultimate pull-out load. Local shear failure were absent for anchor sizes which were designed using FS=2 and 6. This means Eq. (3) of anchor pullout capacity given by Rajagopal and Hari (1996) can be used to design anchored earth wall with factor of safety 2 or more. This also indirectly proved that for high B_a/t_a ratio, pullout capacity of anchor using Eq. (3) given by Rajagopal and Hari (1996) gives better accuracy than others. If anchors are designed for a Factor of Safety equals to 2 or greater, anchor size has very negligible effect on wall deformations and anchor force.

6. Conclusions

A parametric study using finite element method of analysis was undertaken to investigate the behavior of an anchored earth wall system supporting soft backfill. In this paper the effect of stiffness of reinforcing tendon, elastic modulus of backfill soil, elastic modulus of retained soil and anchor size on the behavior of the wall system is presented. The following conclusions were drawn from the parametric study.

1. Deformation of wall decreases with increasing stiffness of reinforcement and above certain value of stiffness it has no effect on deformation.
2. Anchor force increases with increasing stiffness of reinforcement and above certain value of stiffness it has no effect on anchor force.
3. Deformation decreases with increasing stiffness of backfill and retained soil. Anchor force also decreases with increasing stiffness of backfill but remain constant with variation of stiffness of retained soil.
4. To avoid differential settlement of roadway, reinforced soil and retained soil should have same stiffness and strength properties.
5. Formula given by Rajagopal and Hari (1996) was found to be valid to estimate ultimate pull out capacity of vertical anchor used in anchored earth wall.

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