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EFFECT OF STIFFNESS OF REINFORCING TENDON ON THE BEHAVIOR OF ANCHORED EARTH WALL SUPPORTING SOFT BACKFILL

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Abstract: A parametric study using a finite element method of analysis is undertaken to investigate the behavior of a new type of anchored earth wall system supporting simultaneously constructed roadway. In this paper the effect of stiffness of reinforcing tendon and backfill soil on the behavior of the wall system is presented. It is observed that deformation of wall decreases with increasing stiffness of reinforcement and after certain value of stiffness it has no effect on deformation. On the other hand, anchor force increases with increasing stiffness of reinforcement and after certain value of stiffness it has no effect on anchor force. 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. Moderately compacted fill of which elastic modulus is greater than or equal to 10 MPa is sufficient for reinforced zone, provided that stiffness of reinforcement is greater than $5.0 x 10^6$ N/m.

Key Words: Pavement Design, Reinforcement, Backfill, Finite Element, Parametric study.

1. INTRODUCTION

Although the elasto-plastic strain hardening softening constitutive models are more appropriate for soil, but for simplicity elasto-perfectly plastic Mohr-Coulomb constitutive model is used in this study. The parameters studied are (1) stiffness of reinforcement, (2) elastic modulus of soft backfill, (3) elastic modulus of retained soil, (4) elastic modulus of granular soil in between backfill and retained soil, (5) rigidity of facing (6) anchor size and (7) anchor position. In this paper the effect of stiffness of reinforcing tendon and backfill soil on the behavior of the wall system is presented.

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 drawn 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. Tatsuoka (1992) discussed the role of facing rigidity in the context of observations made in laboratory model tests and field tests, and has shown that facing rigidity is an important parameter to be considered. Numerical findings of Ho and Rowe (1996) also indicate the same.

2. PROPOSED WALL SYSTEM

The schematic diagram of the proposed wall system is shown in Fig. 1. In addition to reinforcing tendon, this will have, starting from facing to centerline of roadway, (i) facing wall, (ii) thin vertical layer of compacted coarse sand as filter and drainage, (iv) thick vertical layer of moderately compacted soft backfill, (v) thin vertical layer of compacted granular backfill (vi) anchor plates or blocks and (vii) retained soil of roadway. Here what is new is that use of soft backfill mostly and thin layer of granular backfill where the mode of stress transfer from the backfill to the reinforcement is mainly by passive resistance and the reinforcement will be stressed more after subsidence of soft backfill. The purpose of this wall system is to develop an easy to construct and economic anchored earth wall system supporting soft backfill and newly constructed roadway.

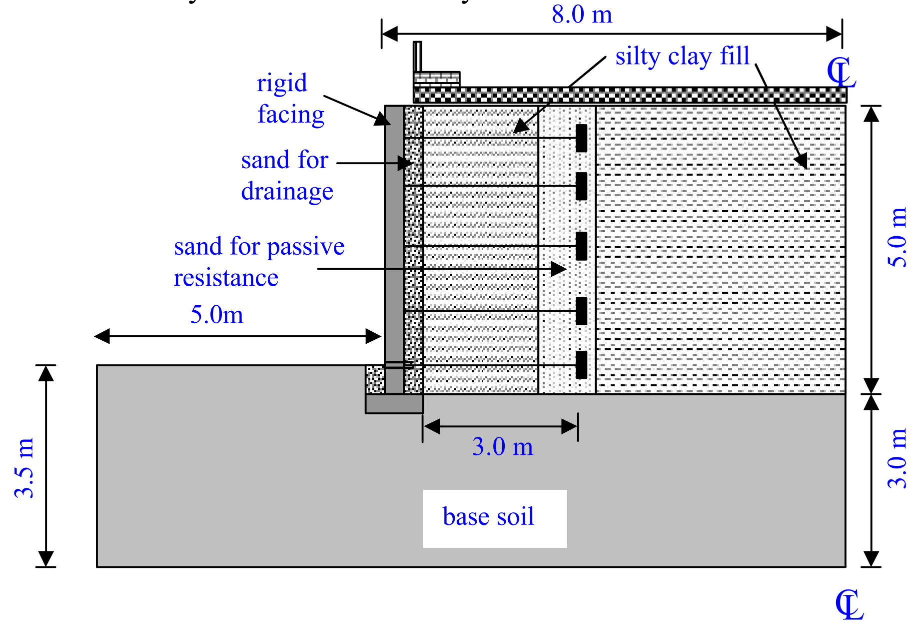

Fig. 1: Schematic diagram of the proposed wall system supporting a roadway.

2.1 Background of the Proposed Wall System

Outskirts of most of the cities in Bangladesh comprise low-lying areas. But land values of these low-lying areas are high due to continued development of model towns to accommodate large population of city areas. Construction of ring road or bypass road at periphery of city areas will require 4-5 m high road embankment. Vertically faced anchored earth wall supporting newly and simultaneously constructed roadway in these cases will save valuable lands. For a road of 5 m height land saving is 20 m^2 per meter length of road. This land saving reduces the land requirement to half of area required for two lane road embankment of slope 1:2. About the land value it is noteworthy that price of lands adjacent to roadway increases exponentially with time after construction of such roadway. Use of local silty clay soil for roadway and backfill may be an economic solution for the construction of such road embankment. The proposed wall system may also be used to increase the width of existing roads and highway without acquiring adjacent lands.

3. NUMERICAL MODEL

A 4.5m high vertically faced anchored earth wall supporting a simultaneously constructed roadway is designed as per BS 8006 (1995). Anchor sizes are designed according to Rajagopal and Hari (1996) for a surcharge loading of 100 kN/m^2 on the roadway. Horizontal spacing of reinforcement is 1.0 m and length of anchor is also taken as 1.0 m so that it become a plane strain anchor of length 1.0 m and height 0.12 m in the finite element model. Large factor of safety for anchors is used for standard wall configuration to minimize the effect of anchor size during study of other parameters. Lightly steel reinforced concrete wall with a small pad below wall is used as continuous rigid facing to reduce lateral deformation of wall and hence vertical deformation of top surface of roadway.

The finite element mesh (Fig. 2) of the proposed wall system is created using finite element software DIANA (1998). In the FEM model, 8 noded quadrilateral plane strain element (CQ16E) is used to represent soil and concrete (anchor blocks and facing wall). No interface element is 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 noded spring elements (SP2TR) to represent the reinforcing tendons. As a result no contribution of soil-reinforcement friction is considered in the numerical model.

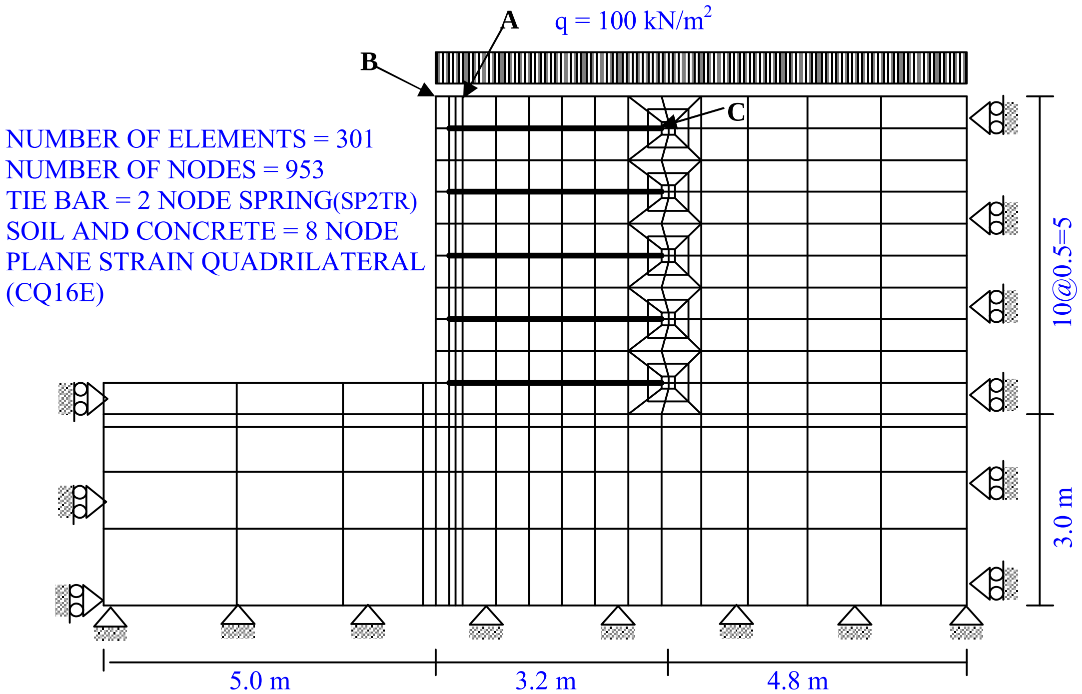

Fig. 2: Finite element mesh and boundary condition of proposed anchored earth wall

Table 1: Material properties of concrete and soils for the designed standard wall

	Unit	Concrete	sand1	sand2	clay1	clay2	clay3
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
Cohesion (c)	kPa	400	0	0	40	40	100
Friction angle (ϕ)	Degree	40^o	40^o	40^o	14.5^o	14.5^o	14.5^o
Dilatancy angle (ψ)	Degree	2.3^o	13^o	13^o	0^o	0^o	0^o
K_o (=1-Sinϕ)	-	0.36	0.36	0.36	0.75	0.75	0.75

Elasto-perfectly plastic Mohr-Coulomb constitutive model is used for sand, clay and concrete. Though a Cam-clay model is more suitable for in-situ clay soil than Mohr-Coulomb model, yet it is modeled by Mohr-Coulomb type yield surface for simplicity in calculation. The embedment depth of anchored earth wall is 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 is kept in the model. Material properties are shown in Table 1.

3.1 Stiffness of Reinforcement

This is the spring constant of spring element SP2TR connecting facing 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 metallic reinforcement

$k_s = tE/L$ for sheet reinforcement

The design value of stiffness of reinforcement was $1\text{x}10^7$ N/m. This parameter was varied from $1\text{x}10^6$ to $1\text{x}10^{11}$ N/m. Variation of spring constant in the parametric study is shown in Table 2.

Table 2: Variation of spring constant in Parametric Study: Case I

	1	2	3	4 (design value)	5	6	7
Spring constant (N/m)	$1\text{x}10^6$	$2\text{x}10^6$	$5\text{x}10^6$	$1\text{x}10^7$	$1\text{x}10^8$	$1\text{x}10^9$	$1\text{x}10^{11}$

3.2 Stiffness and Strength Properties of Backfill

The backfill was considered as silty clay fill in between anchors and facing and sandwiched by sand. This silty clay backfill was considered as cohesive frictional ($\varphi = 14.5^o$). A Young's modulus of 20 MPa, cohesion of 40 kPa and friction angle of 14.5^o were the design values of stiffness and strength properties of the backfill. 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 remained constant. Variation of material properties of backfill in the study is shown in Table 3. To simulate undrained condition of clay1 Poisson's ratio of clay1 is assumed as 0.45.

Young's modulus E is estimated from the empirical relation E = (100 to 500) S_u (Bowles, 1997, pp. 317) for silt and clays. E = 500 S_u is adopted in this study. To estimate K_o, Jaki's (Jaky, 1944) formula (1-Sinϕ) is used.

Table 3: Variation of material properties of clay1 and clay2 in Parametric Study: Case II and Case III (ϕ = 14.5^o) respectively

	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
Cohesion (c)	kPa	10	20	40	60	80	100
Friction angle (ϕ)	Degree	14.5^o	14.5^o	14.5^o	14.5^o	14.5^o	14.5^o
Dilatancy angle (ψ)	Degree	0^o	0^o	0^o	0^o	0^o	0^o
K_o (=1-Sinϕ)	-	0.75	0.75	0.75	0.75	0.75	0.75

4. RESULTS AND DISCUSSION

4.1 Effect Of Stiffness Of Reinforcement

Fig. 3 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. 4 shows the lateral displacement of the anchor front 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 is observed from Fig. 3 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 5.0x10^6 N/m. In case of metallic reinforcement, its yield strength governs the design. As a result stiffness of reinforcement become greater than the requirement. But if geogrid or any other type of reinforcement is used for the proposed wall system, it must be ensured that stiffness is greater than 5.0x10^6 N/m. Same conclusions may be drawn from Fig. 4 and 5. Lateral deformation of wall may be kept within 0.5% of height of wall if stiffness of reinforcement is greater than or equal to 5.0x10^6 N/m. The combined effect of embedment depth and small pad under continuous rigid facing is clearly observed in Fig. 4. Lateral displacement of bottom of wall is only about 5 mm and this value is independent of stiffness of reinforcement.

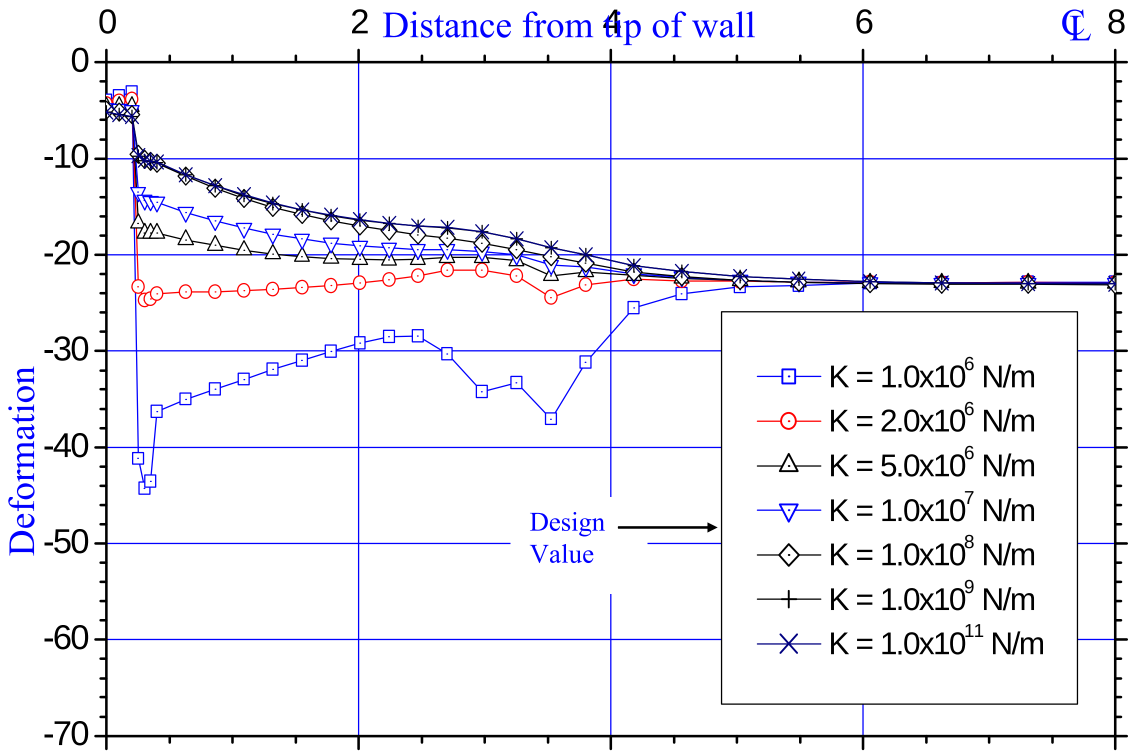

Fig. 3: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: stiffness of tie bar)

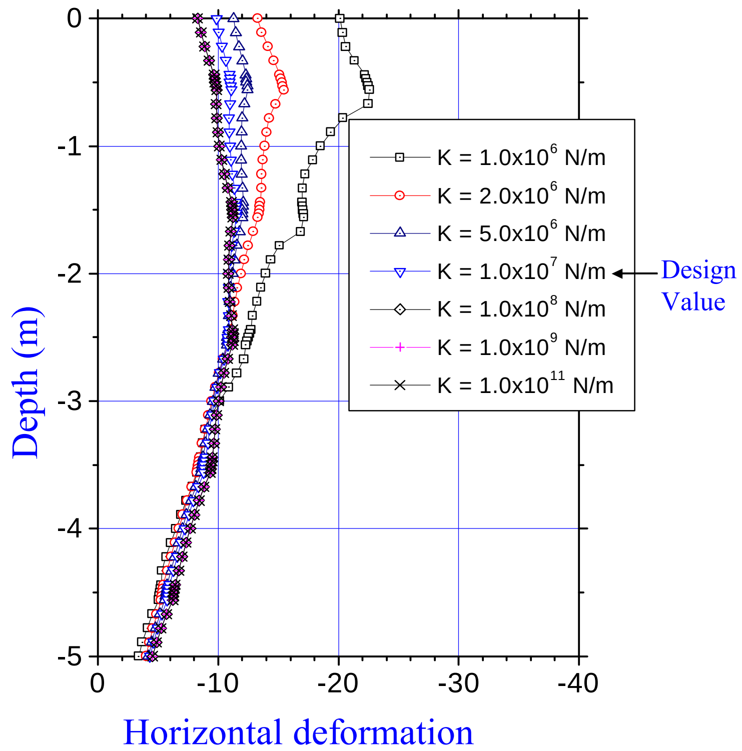

Fig. 4: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of tie bar)

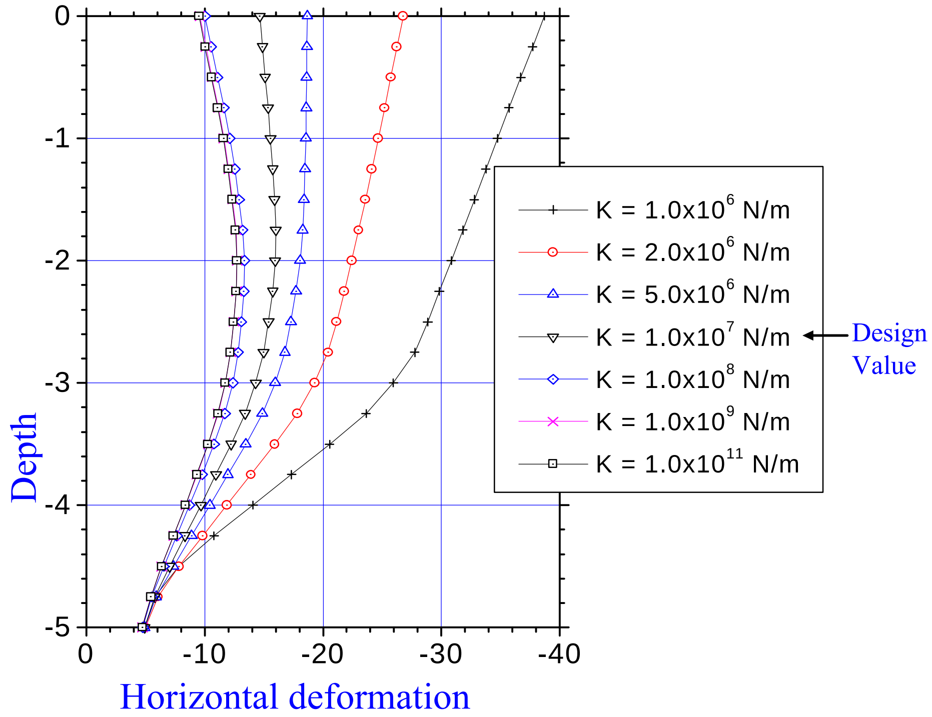

Fig. 5: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of tie bar)

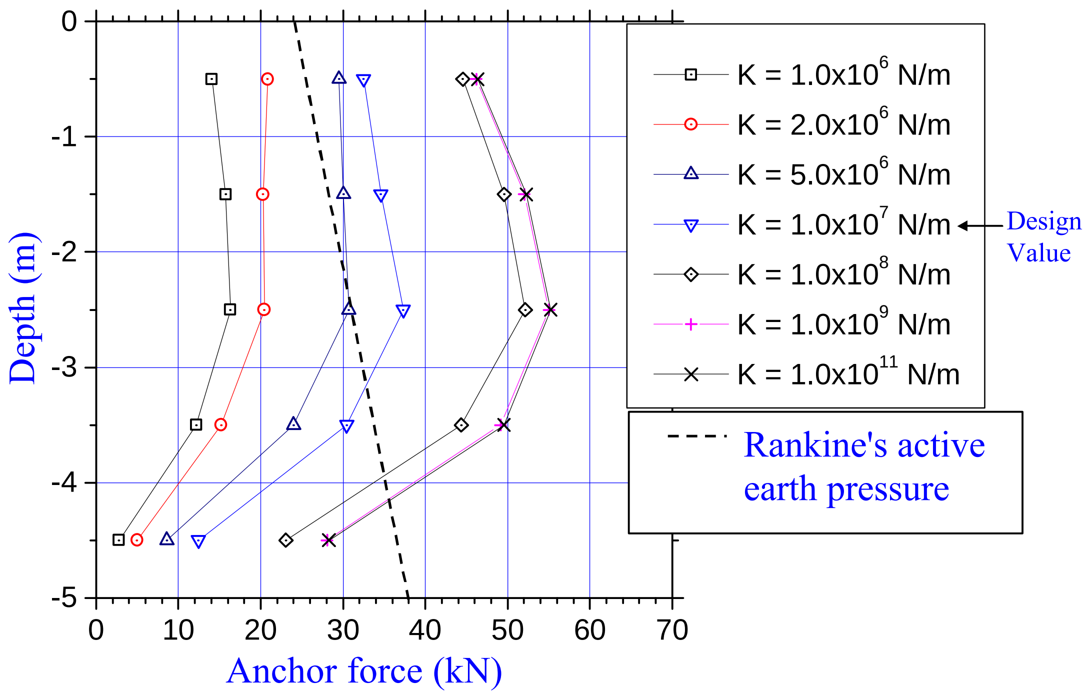

Fig. 6: Variation of Anchor Force with depth (Parameter: stiffness of tie bar)

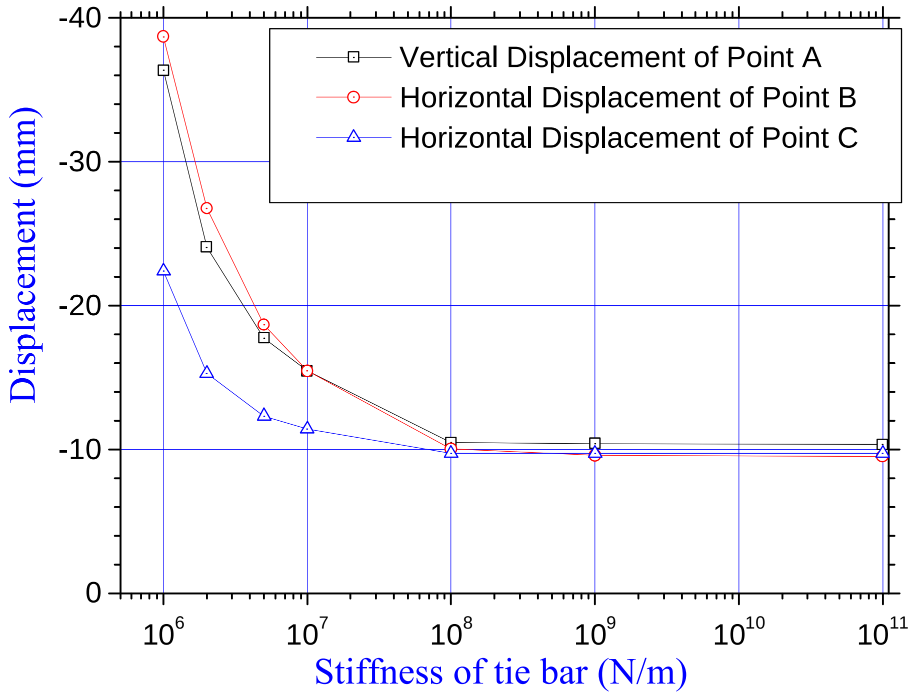

Fig. 7: Displacement variation with stiffness of tie bar

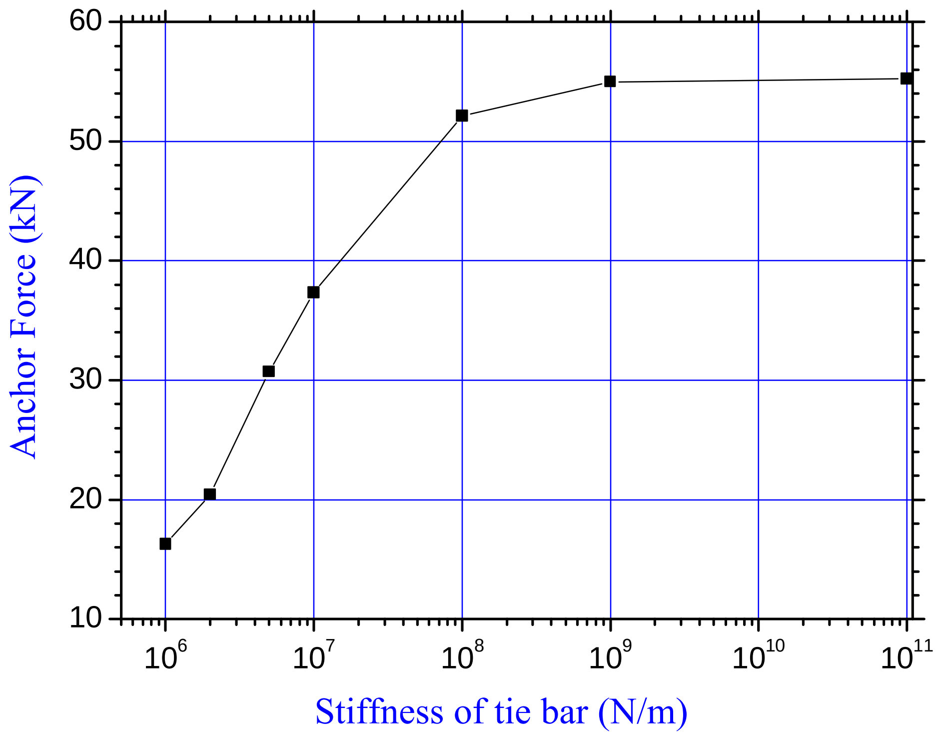

Fig. 8: Variation of anchor force at level 3 with stiffness of tie bar

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 upto 3m.

Beyond this depth anchor force decreases due to combined effect of embedment depth and small pad under facing.

Vertical deformation of top surface and lateral deformation of wall decreases exponentially (Fig. 7) with increasing stiffness of reinforcement and become constant beyond stiffness $1x10^8$ N/m. Lateral displacement of points B and C are equal beyond stiffness $1x10^8$ 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 $1.0x10^8$ N/m the curve becomes horizontal (Fig. 8). Because no relative movement of facing and anchor blocks occur at higher stiffness. For better performance of designed wall, lower limit of stiffness of reinforcement is $5.0x10^6$ N/m. That implies that in the proposed wall system extensible reinforcement (Axial strain > 1.0%) could not used.

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 is observed that when $K = K_a$ at stiffness of reinforcement $1x10^6$ N/m, the wall deformations are so large that exceed 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.

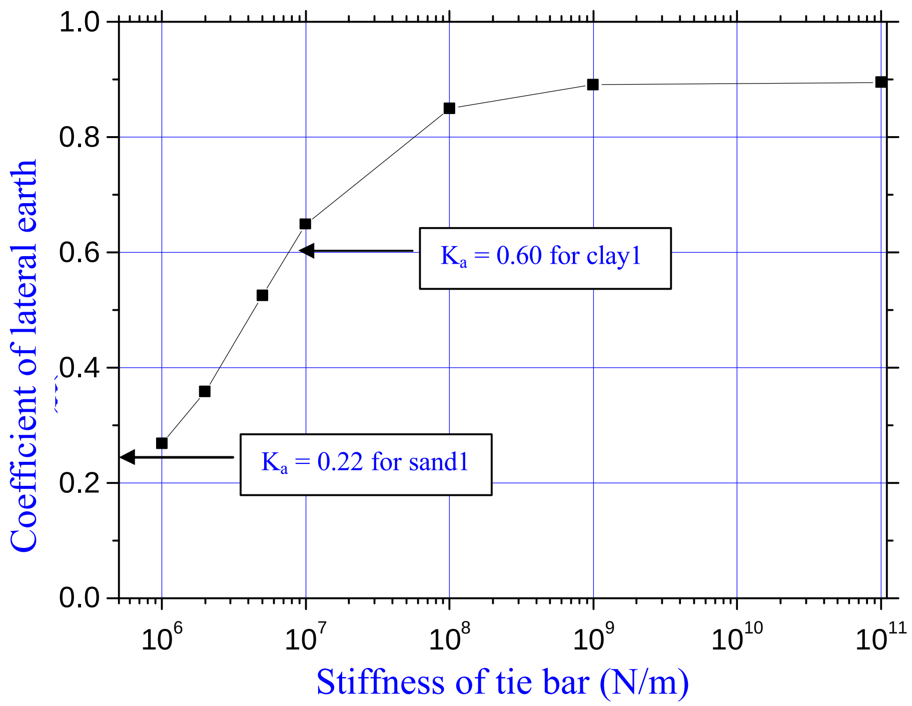

Fig. 9: Variation of coefficient of lateral earth pressure with stiffness of tie bar

4.2 Effect of Stiffness of Backfill Soil

Case II of the parametric study is divided by two parts; one is considering clay1 as cohesive frictional ($\varphi = 14.5^o$) and another is considering clay1 as purely cohesive ($\varphi = 0^o$). Settlement of top surface of roadway against distance from tip of wall is plotted in Fig. 10 at different elastic modulus of clay1 ($\phi = 14.5^o$). Fig. 11 is the plot of lateral deformation of facing against depth of wall and Fig. 12 is the plot of lateral deformation of anchor front against depth of wall. From these three figures it is observed that elastic modulus of clay1 ($\phi = 14.5^o$) should be greater than or equal to 10 MPa and cohesion should be greater than 20 kPa. Fig. 13 shows the anchor force variation with depth. Anchor forces are almost constant with depth upto 3m and decreases beyond this, because of embedment depth. In Fig. 14, vertical displacements of a point on top surface at a distance of 1.55m from tip of wall, horizontal displacements of point B and C (Fig. 2) is plotted against elastic modulus of clay1 to show the rate of variation. In Fig. 15, anchor force at level 3 is also plotted against elastic modulus of clay1.

Maximum displacement of top surface, lateral displacement of wall facing and lateral displacement of anchor front decreases rapidly (Fig. 14) with increasing stiffness of backfill soil and rate of decrease become constant beyond stiffness 30 MPa. For better performance of designed wall, lower limit of stiffness of clay1 is 10 MPa. Clay1 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 clay1 is the optimum value considering deformations and anchor forces.

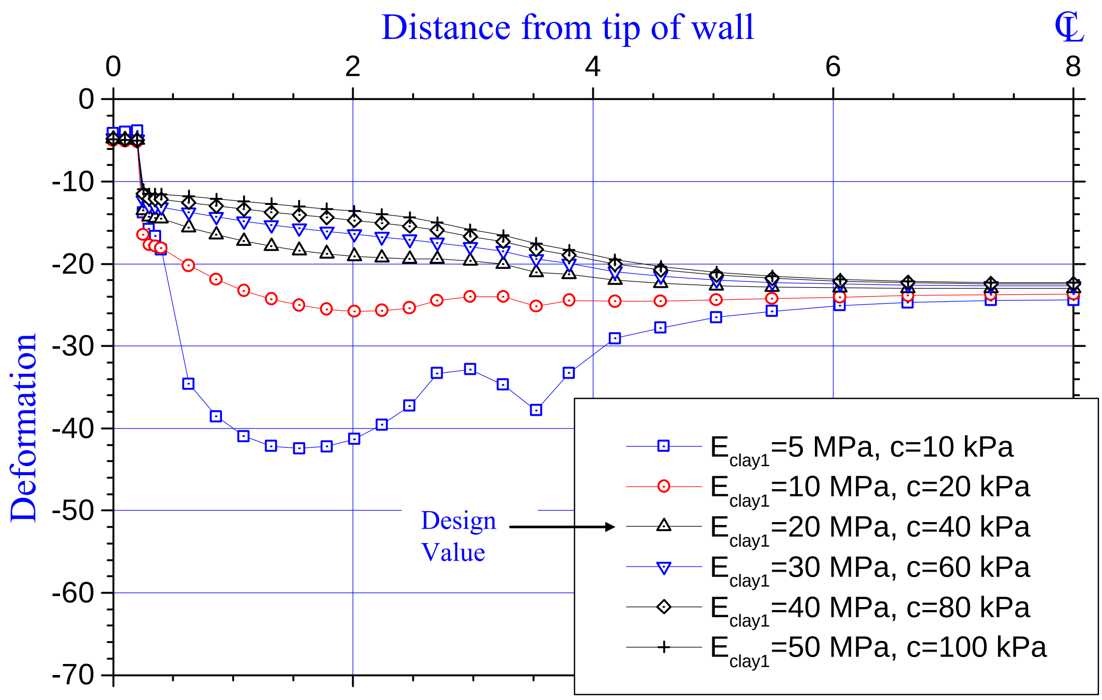

Fig. 10: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay1 ($\phi = 14.5^o$))

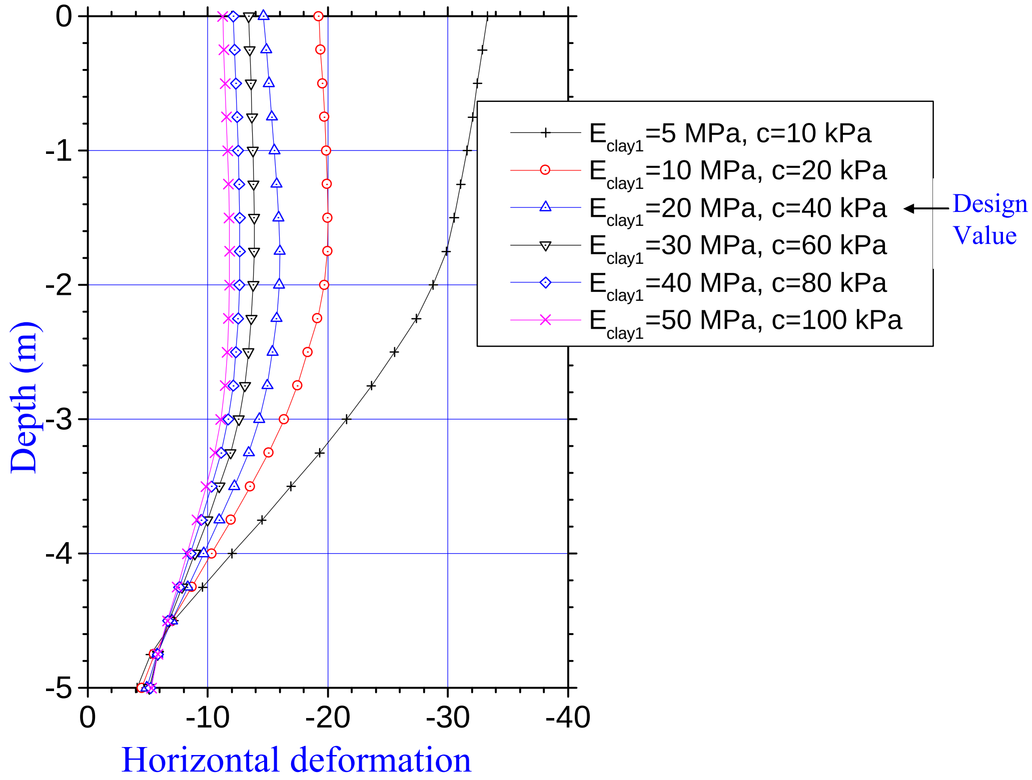

Fig. 11: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay1 ($\phi = 14.5^{o}$))

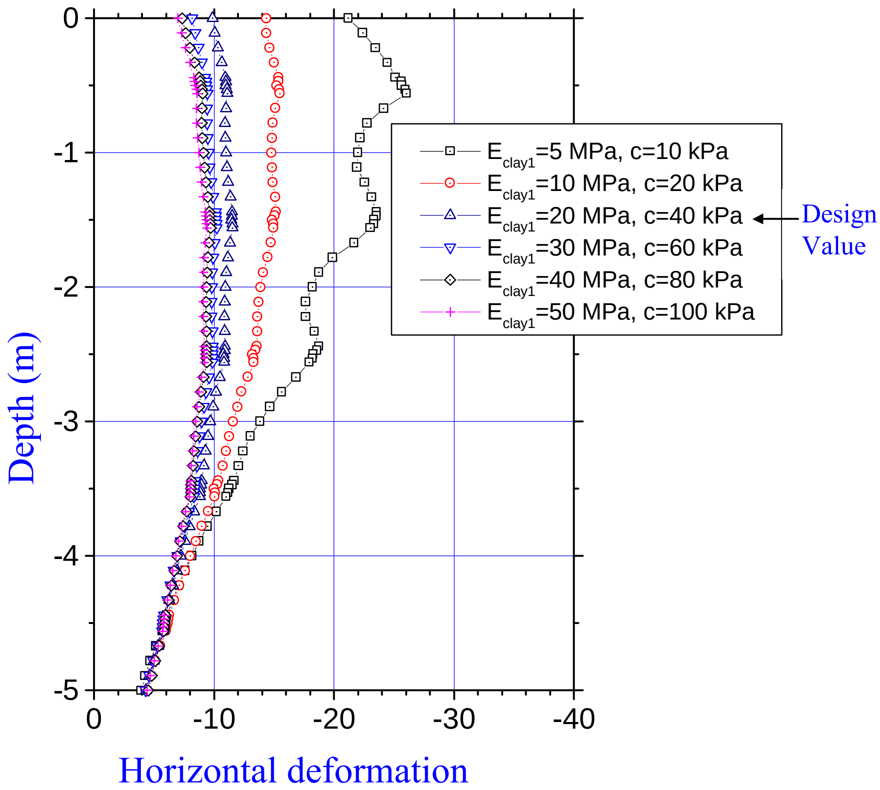

Fig. 12: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay1 ($\phi = 14.5^{o}$))

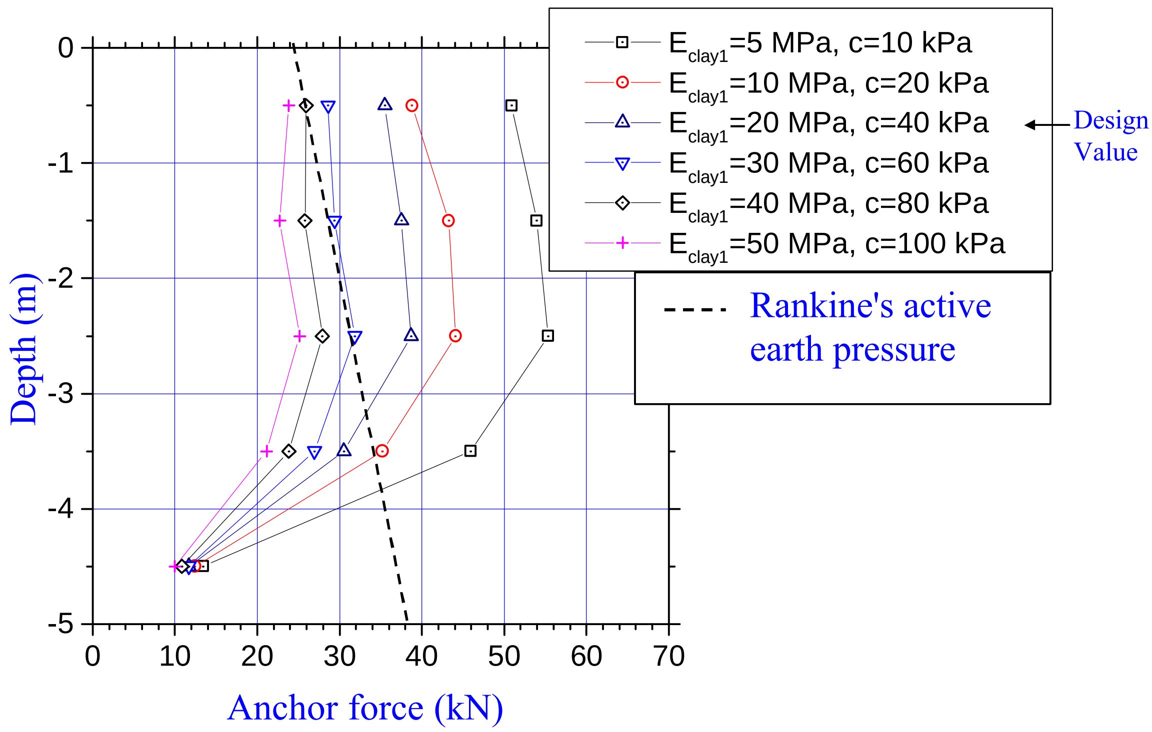

Fig. 13: Variation of anchor force with depth (Parameter: stiffness of clay1 (ϕ = 14.5^o))

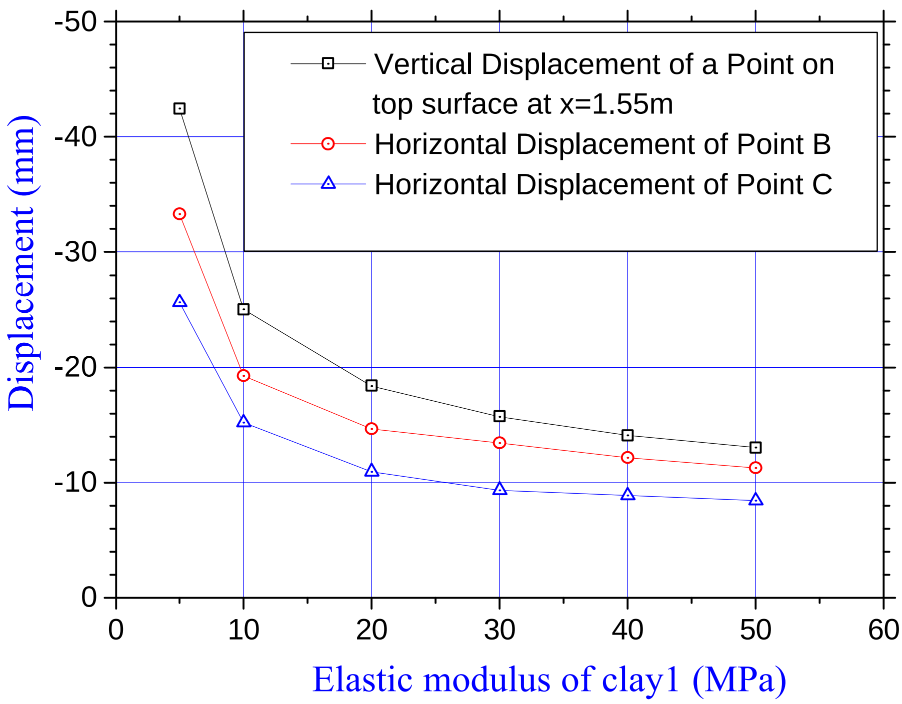

Fig. 14: Displacement variation with elastic modulus of clay1

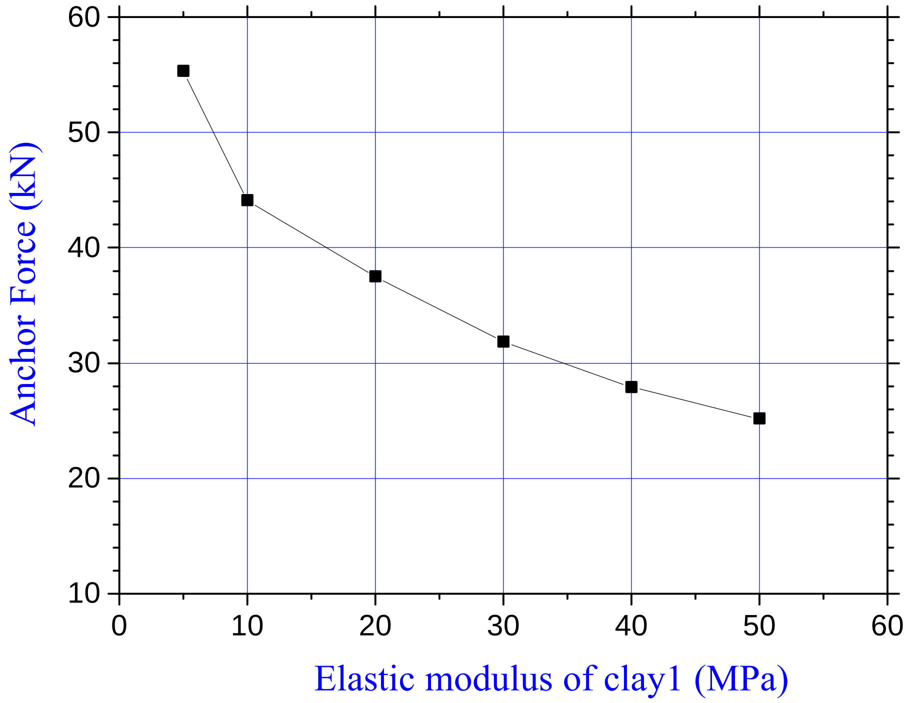

Fig. 15: Variation of anchor force at level 3 elastic modulus of clay1

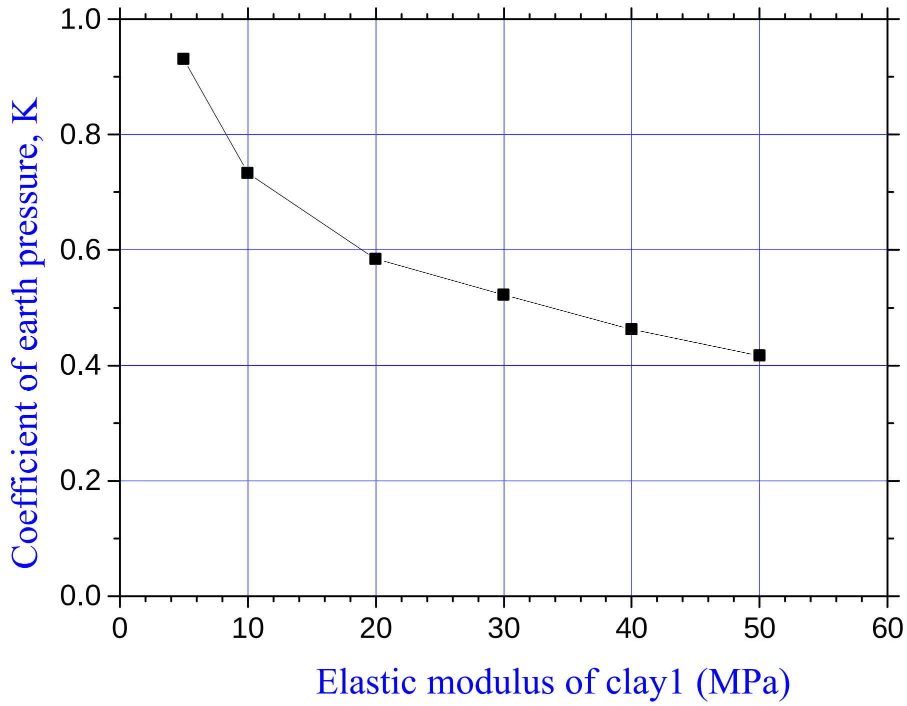

Fig. 16: Variation of coefficient of earth pressure, K with elastic modulus of clay1

From the anchor forces of level 1 to 3, coefficient of lateral earth pressure (K) is calculated and plotted against elastic modulus of clay1 in Fig. 16. It is seen that anchor forces decreases with increasing stiffness of clay1. This means that well compacted backfill soil reduces the requirement of reinforcement and hence the size of anchors.

5. CONCLUSION

It is observed that deformation of wall decreases with increasing stiffness of reinforcement and after certain value of stiffness it has no effect on deformation. On the other hand, anchor force increases with increasing stiffness of reinforcement and after certain value of stiffness it has no effect on anchor force. 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.

From the study it may be concluded that locally available silty clay soil may be used in the reinforced zone as well as in the retained soil mass of roadway. Moderately compacted fill of which elastic modulus is greater than or equal to 10 MPa is sufficient for reinforced zone, provided that stiffness of reinforcement is greater than 5.0×10^6 N/m.

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