Steep sloped reinforced soil embankments under repeated loading

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ABSTRACT: Geosynthetic reinforcement is often adopted in steep sloped embankments to reduce the land take. The behaviour of traffic supporting steep sloped reinforced soil embankments subjected to repeated loading were investigated through non linear finite element analysis. Application of locally available low friction fill soil is explored. Attempt was made to improve the frictional properties of the geosynthetic-soil interface through the provision of a thin layer of sand on either sides of the reinforcement (sandwich technique). The effects of reinforcement layers on the behaviour of embankments having various side slopes were simulated. The sandwich technique was found to enhance the performance of the geosynthetic reinforced soil embankment under monotonic and repeated loading. In the case of embankments employing the sandwich technique, the incremental deformations reduced to a greater degree with increasing number of cycles. Better reinforcement forces were mobilised due to the provision of the sand layer. The technique can be successfully employed to construct steep sloped embankments to support repeated loading.

1 INTRODUCTION

Construction of conventional earth embankments requires considerable land take to accommodate the base width. Reinforced soil technique can be used to construct embankments with much steeper side slopes. Reinforced soil derives its strength from the frictional load transfer at the soil-reinforcement interface. This requires the use of only well graded frictional soils in the construction of reinforced soil structures. However, at many locations, frictional soils may not be available readily leading to heavy expenditure on transporting granular soils from long distances.

In the present investigation, an innovative attempt has been made to utilise locally available poor quality soil in reinforced soil construction. The technique involves in placing thin layers of highly frictional soil around the reinforcement and locally available soil as the bulk fill. This technique, termed as sandwich technique, helps in mobilising larger tensile forces in the reinforcement layers leading to increased stability (Unnikrishnan & Sreekantiah 1992).

The reinforced soil embankments acting as traffic support structures are subjected to repeated loading. The repeated loads may lead to failure of embankments even if the magnitudes are lower than the maximum load carrying capacity under static loading (Luo, 1973, Satyavanija & Nelson 1971). Strength of soil under cyclic loading depends on the number of load cycles (Seed & Lee 1966). Several cases of embankment failures at loads much lower than the design capacities under cyclic loading were reported in the past. In the investigation reported herein, the effect of repeated loading on such steep sloped embankments and the relative merits of using soil reinforcements are studied. The advantage of using sandwich technique in combination with geosynthetics under repeated loading was particularly explored. Finite element analyses were conducted to investigate the performance of sandwich system under both monotonic and repeated loading.

2 NUMERICAL MODELLING

Behaviour of the steep sloped embankment was simulated through non linear finite element simulations. Soil was modeled using Hierarchical Single Surface constitutive model (Wathugala & Desai 1993). The model is ideally suited for simulating the behaviour of soil structures under monotonic and cyclic loading (Desai et al. 1993). Loading, unloading and reloading up to the point of unloading are treated separately. A reference surface passing through the stress state corresponding to the point of unloading is used to differentiate between virgin loading and non-virgin loading. Phase change line differentiates the contractive and dilative behaviour of materials. Nine material parameters associated with this model can be determined from simple laboratory tests.

The model was modified to account for cohesive strength of clay soils. To reduce the numerical complexity, a total stress analysis was adopted by neglecting the pore pressures. Nonlinear, total stress analysis can be effectively used to fully understand the behaviour of reinforced soil embankments (Chalaturnyk et al. 1990, Zou et al. 1995).

3 FINITE ELEMENT MODELLING

The soil was simulated using three node isoparametric triangular elements with four per rectangle. The element matrices were evaluated using one point integration. The embankment fill was assumed to be cohesive soil. Hierarchical Single Surface Constitutive Model was used to model the soil. The foundation soil was assumed to be very stiff and to behave elastically under embankment loading. The reinforcement was modelled using two node isoparametric prismatic elements. The order of variation of displacements over this element is compatible to that in 3-node triangular elements. The stiffness of these elements is expressed in kN/m and these elements are used with a unit cross-sectional area. As the geosynthetic reinforcements are flexible and cannot sustain compressive loads, the compressive forces were not allowed to develop within the reinforcement elements.

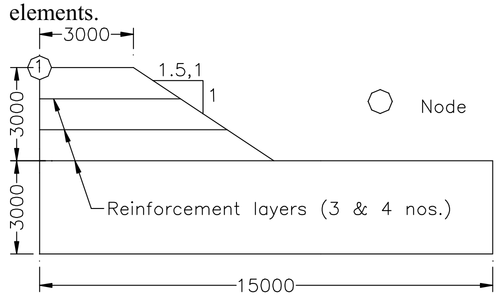

Figure 1. Configurations analysed (dimensions in mm).

The interfaces between reinforcement and soil were modelled using four node joint elements of the type developed by Ghaboussi et al. 1973. The order of variation of displacements along these elements is compatible with that in 3-node triangular elements used to represent the soil elements. The stresses in these elements were computed as a function of the relative displacements between the two surfaces on each side of the interface. Failure of interface was modeled using Mohr Coulomb failure criterion. The frictional strength of the interfaces was assumed to be equal to the friction angle of the surrounding soil. In their finite element analysis of embankments on peat, Rowe et al. 1984 also made similar assumption. For the interface with cohesive soil, the interface was assumed to have the same cohesive strength as the foundation soil with no frictional strength.

4 ANALYSIS DETAILS

Embankments with two side slopes 1.5:1 (H:V) and 1:1 (H:V) were considered (Figure 1). The number of reinforcement layers was varied between 3 and 4. The typical mesh used for the analysis is shown in Figure 2. A sand layer thickness of 100 mm was used in most of the analyses. Analyses were also conducted with other thickness values to study its influence.

To simulate monotonic loading, surcharge loading of 800 kPa was applied in 400 load steps on the crest. Cyclic pressure load 350 kPa was used. The ratio of this cyclic load to the ultimate capacity of an unreinforced embankment of 500 kPa was 0.7. Displacements were monitored at the crest of the embankment at the point 1(Figure 1). For convenience of comparison, the horizontal and vertical deformations are normalised with respect to the base width of embankment (W) and the height of the embankment (H) respectively.

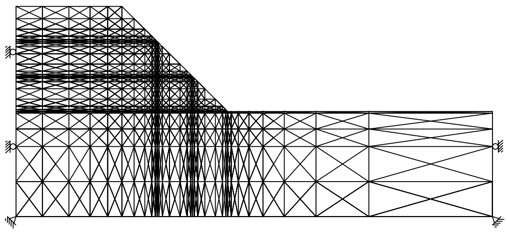

Figure 2. Typical FE mesh for the analysis.

5 RESULTS AND DISCUSSIONS

5.1 *Influence of Number of Reinforcement Layers*

Embankments with two and three layers of reinforcements within the fill were analysed. Figure 3 shows the displacement vectors at the end of loading of a reinforced embankment on competent foundation having a side slope of 1:1 (H:V) and having three reinforcement layers included in the fill. Figure 4 shows the displacement vectors of the same embbankment when sand layers are provided on either sides of the embankment. It can be seen that the deformations are substantially reduced due to the use of sandwich technique.

high. Such embankments undergo larger number of cycles before stabilising.

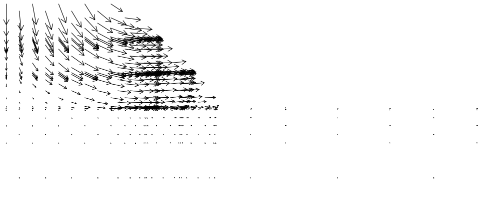

Figure 3. Displacement vectors for reinforced embankments on competent foundation (without sand layer).

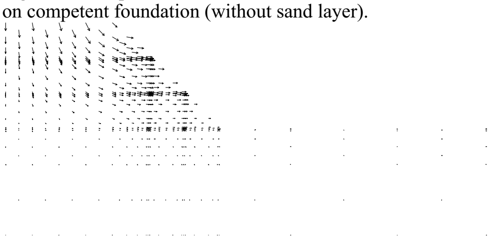

Figure 4. Displacement vectors for reinforced embankments on competent foundation (with sand layer).

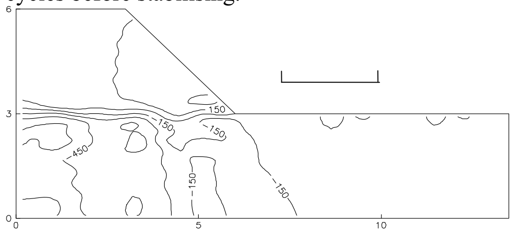

Figure 5. Vertical stress contours reinforced embankments on competent foundation having three reinforcement layers (without sand layer).

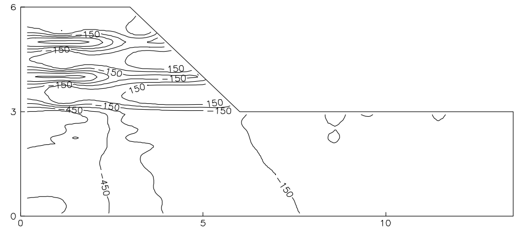

Figure 6. Vertical stress contours reinforced embankments on competent foundation having three reinforcement layers (with sand layer).

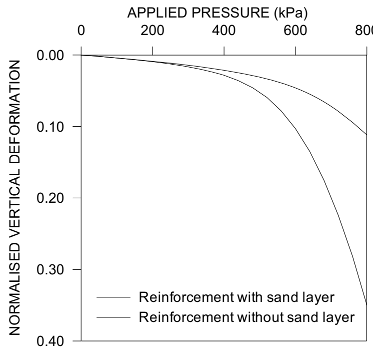

Figure 7. Vertical deformation of Node 1 (reinforced embankments on competent foundation having three layers of reinforcement, side slope 1(H):1(V)).

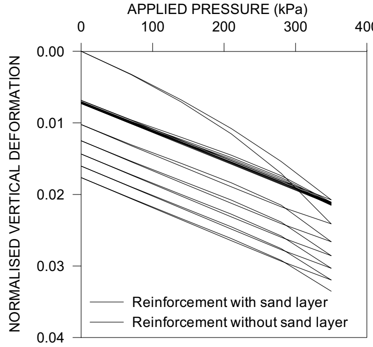

Figure 8. Vertical deformation of Node 1 under cyclic load (reinforced embankments on competent foundation having three layers of reinforcement, side slope 1(H):1(V)).

In the case of embankments on competent foundations, the horizontal deformations are more in comparison with vertical deformations. With the provision of sand layer, the strength of reinforcement is utilised to a larger extent which resulted in smaller lateral deformations. This enhances the stability of the embankment. The vertical stress contours shown in Figure 5 corresponds to the reinforced embankment without sandwich technique. Similar pattern was obtained for the unreinforced embankment also. Failure of interface results in the under utilisation of reinforcement and hence the stress field is not affected. In the case of embankments with sandwich technique, a concentration of vertical stress is noticed near the reinforcement zone (Figure 6). The sand layer and the reinforcement under tension acts like a rigid support which produces this concentration of vertical stress. In the case of embankments on soft foundation with a single layer of basal reinforcement, only one such mechanism develops (Unnikrishnan, 1997). When additional layers were provided as in the present case, more than one such mechanism develops, which is a major factor responsible for the substantial improvement in stability.

Comparison of the normalised vertical deformation of Node 1 under monotonic loading is given in Figure 7. Similar plot under repeated loading is given in Figure 8. Under repeated loading, the embankments employing sandwich technique almost stabilised to zero incremental deformations in the second cycle. This is highlighted in Figure 8. With the sandwich technique, the incremental deformations were very small in the first cycle itself and reduced to a minimum in the second cycle. However, in the case of embankments which did not use sandwich technique, the incremental deformations were

Analyses were carried out with more number of reinforcement layers. Closer spacing of reinforcement reduced the overall deformations.

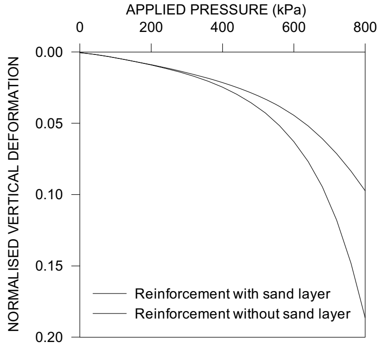

Figure 9. Vertical deformation of Node 1 (reinforced embankments on competent foundation having three layers of reinforcement, side slope 1.5(H):1(V)).

5.2 *Influence of Side Slope Angle*

Analyses were also conducted to study the behaviour of embankments on competent foundation having a flatter side slope of 1.5:1 (H:V). Figure 10 shows the vertical deformation of the Node 1 of such an embankment having three layers of reinforcement. The Figure shows that in the case of embankments with flatter side slopes also, the benefit of application of sandwich technique is considerable. However, embankments having flat side slopes are relatively more stable. Hence the overall deformations will be less under the same magnitude of applied load. As the deformations are less, the advantage due to the introduction of sandwich technique also reduces. This is evident from the comparison of the Figures 7 and 9. Similar observations were made in the case of cyclic loading also. Table 1 shows the reduction in the incremental and accumulated deformations of Node 1. It can be seen that though the reduction of accumulated deformations are comparatively less in the case of embankments with flatter slopes, the reduction in incremental deformations at the end of five cycles does not differ much. This has a cumulative effect after a number of cycles.

Table 1. Percentage reduction in vertical deformations of Node 1 due to the introduction of sand layer after five cycles of 350 kPa surcharge load.

Side Slope (H:V)	No. of layers	Percentage reduction in vertical deformations	
		Incremental	Accumulated
1:1	3	92	36
1:1	4	95	37
1.5:1	3	89	23

6 CONCLUSIONS

Application of sandwich technique improves the load carrying capacity of the reinforced soil structures by enhancing the frictional properties at the soil – reinforcement interface. Due to better bond, reinforcement forces are mobilised to a larger degree. The technique was found to improve the behaviour of steep sloped reinforced soil embankments on firm foundations. The improvement was considerable when the embankments were subjected to repeated loading as in the case of traffic loads. The incremental deformations of sandwich technique enabled embankments almost reduced to zero and the embankments stabilised within the first few cycles of load itself. The success of the technique in reducing the incremental deformations under cyclic loading holds good irrespective of the side slope angle. Under monotonic loading, sandwich technique produces pronounced results in the case of steep sloped embankments in comparison to embankments with relatively flatter side slopes.

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