STABILITY ANALYSIS OF REINFORCED SLOPED EMBANKMENTS

Elsayed M. Ibrahim,
Civil Engineering Department, Faculty of Engineering, University of Alexandria, Egypt.

Mohamed E. El-Naggar and John B. Kennedy
University Distinguished Professor of Civil and Environmental Engineering, University of Windsor, Windsor, Ontario, Canada N9B 3P4.

ABSTRACT

This paper is concerned with the stability of reinforced sloped embankments. Effects of both vertical and horizontal loads are considered. Different embankments geometry such as: spacing between reinforcements in the vertical, horizontal and transverse directions; embankment height; degree of slope; and, reinforcing elements length are studied. The tensile force distribution in the reinforcing elements, displacements of the slope facing elements, displacements at the foundation-embankment interface and the change in stresses within the soil mass are also investigated. A total of five models including fifty experiments are tested to failure. The results from these tests are used to investigate the improvements in the load-carrying capacity of the embankment due to the presence of reinforcement and to verify the finite element modelling used in the parametric study. An extensive parametric study is conducted to examine the behaviour of the structure. A design equation for predicting the maximum tensile force within the embankment is proposed.

Keywords: Reinforced soil, Side slope, Embankment, Displacements.

Notations

A	cross sectional area;
B	width of loading strip;
C	cohesion of unreinforced soil;
C_c	coefficient of gradation;
C_u	uniformity coefficient;
D	foundation depth;
D_{10}	effective size;
D_{50}	mean grain size;
F	horizontal load;
f_a	allowable stresses;
f_x	horizontal stresses;
f_y	vertical stresses;
H	height of the embankment;
h_i	vertical distance from the foundation and reinforcing layer i;
L_r	length of the reinforcing strips;
m	degree of slope;
n	rate of variation between δ and Log (T_{max});
q	strip load intensity;
S_h	horizontal spacing between reinforcing strips;
S_t	spacing between the reinforcing layers in the transverse direction;
S_v	spacing between the reinforcing layers in the vertical direction;
T_{HB}	maximum tensile force due to different loading strips;
T_m	maximum tensile force due to different slopes;
T_{max}	maximum tensile force;
T^*	maximum tensile force when H/S_v=8;
$(A.E)_{reinf}$	axial stiffness of the reinforcing material;
$(A.E_{\sigma 3})_{soil}$	axial stiffness of embankment soil for a confining pressure = σ_3;
H/B	loading strip ratio;
H/S_h	horizontal spacing ratio;
H/S_v	vertical spacing ratio;
L_r/H	reinforcing length ratio;
δ	ratio of relative stiffness;
ϕ	angle of internal friction for unreinforced soil;
ϕ_R	angle of internal friction for reinforced soil;
ψ	rate of variation of H/B and Log T_{HB}; and,
ω	rate of variation of m and T_m.

INTRODUCTION

Since Vidal (1969) developed the concept of reinforced soil, the use of this technique to increase the stability of various soil-related structures has spread rapidly. Reinforced soil has been used efficiently to improve the stability of embankments and slopes, retaining walls, foundations, bridge abutments etc. Vidal (1972) showed that reinforcing the soil material increases the cohesion of the soil, thus increasing the stability of the structure as well as resisting the tensile forces in the soil mass. Investigators on the analysis and design of reinforced-soil have concentrated on retaining structures, as for example: Mossaad, (1977); Chang et. al., (1977a); Andrawes et.al., (1980); Hafez, et. al., (1983); Brown et.al., (1984); Kennedy et.al., (1980, 1986); Laba et al., (1984); and, Brown and Poulos, (1984) and not on embankments and slopes. Therefore, the present paper focuses on the analysis and design of multi-layered reinforced sloped embankments under both vertical and horizontal loadings. Models studies were conducted to determine the behaviour and failure loads of reinforced soil embankments. An extensive parametric study was carried out to investigate the influence of several parameters on the load response of reinforced soil embankments. The finite element modelling adopted in the parametric study was verified and substantiated by the results on the tested models. The parameters varied included: embankment height, vertical spacing between reinforcing elements, degree of slope, and reinforcing element length.

EXPERIMENTAL STUDY

The experimental work in the current investigation was conducted to investigate the behaviour of straight embankments under strip loads. The study was performed on five models, including fifty experiments, tested to failure. The following parameters were varied: (i) Height of the embankment, H in terms of H/B where B is the width of the loading strip; (ii) Degree of the slope facing elements, m; (iii) Length of the reinforcing strips, L_r, in terms of L_r/H; (iv) Spacings between the reinforcing layers in the vertical direction, S_v in terms of H/S_v; and in the horizontal direction, S_h in terms of H/S_h; and, (v) Cases of loading in the vertical and horizontal directions. Figure (1) shows the various variables used in the analysis.

Description of the Experimental Model: The main elements of the experimental model, shown in Figure (2), are: steel angles forming the main frame of the container; four plywood sheets forming the base and three sides of the container; a plexiglass plate forming the front of the model; aluminum strips; backfill soil; concrete panels to support the slope; and two pieces of rubber to fill the clearance between the inner sides of the container and the reinforced concrete panel ends. The backfill material used in this study was Lake Erie coarse sand. The angle of internal friction, ϕ, obtained from direct shear tests was 39^o with a uniformity coefficient, C_u, of 2.35 and a coefficient of gradation, C_c, of 0.97. The mean grain size, D_{50}, and the effective size, D_{10}, were found to be about 0.36 and 0.17 mm, respectively. The sand's dry density was 18.1 kN/m^3. Concrete panels with thickness of about 20.00 mm were used to construct the slope facing element. These panels were constructed over a reinforced concrete foundation at the toe of the slope. The thickness of this foundation was 40.00 mm and its width was 60.0 mm. Aluminum reinforcing strips were used in all the tests. The strips were 0.50 mm thick and 15.0 mm wide. The yield stress of the aluminum strip was approximated at 250.0 MPa, ultimate stress 315.0 MPa and its modules of elasticity at $7.1*10^5$ MPa. The strips length was chosen according to the height of the embankment and to achieve the required length for the design value of factor of safety against tie pullout using the design procedure developed by Laba et al. (1984). To increase the frictional capacity of these strips, Aluminum wires of 2.40 mm diameter and 15.00 mm length were glued to the top and bottom surfaces of the reinforcing strips. Electrical resistance strain gages and mechanical dial gauges were used to measure the strain and the deflection, respectively. Load cells were used to measure the load increments.

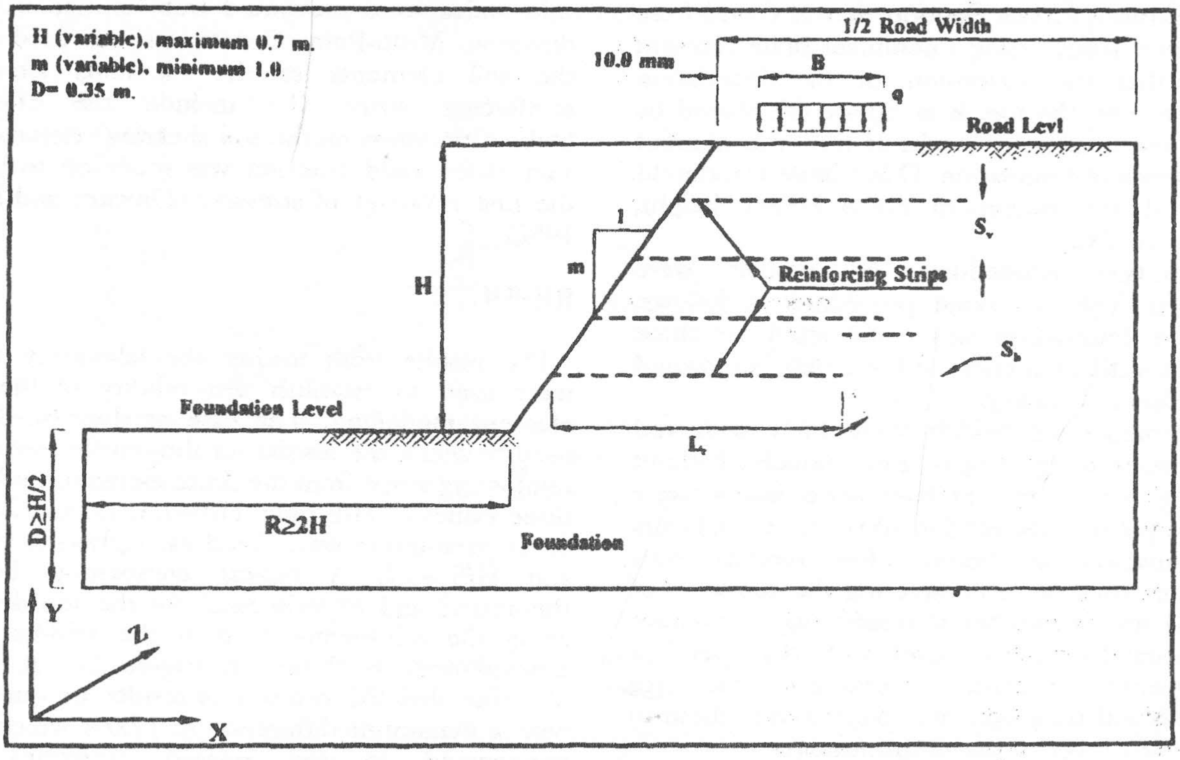

Figure 1. Variable of reinforced soil embankment used in the analysis.

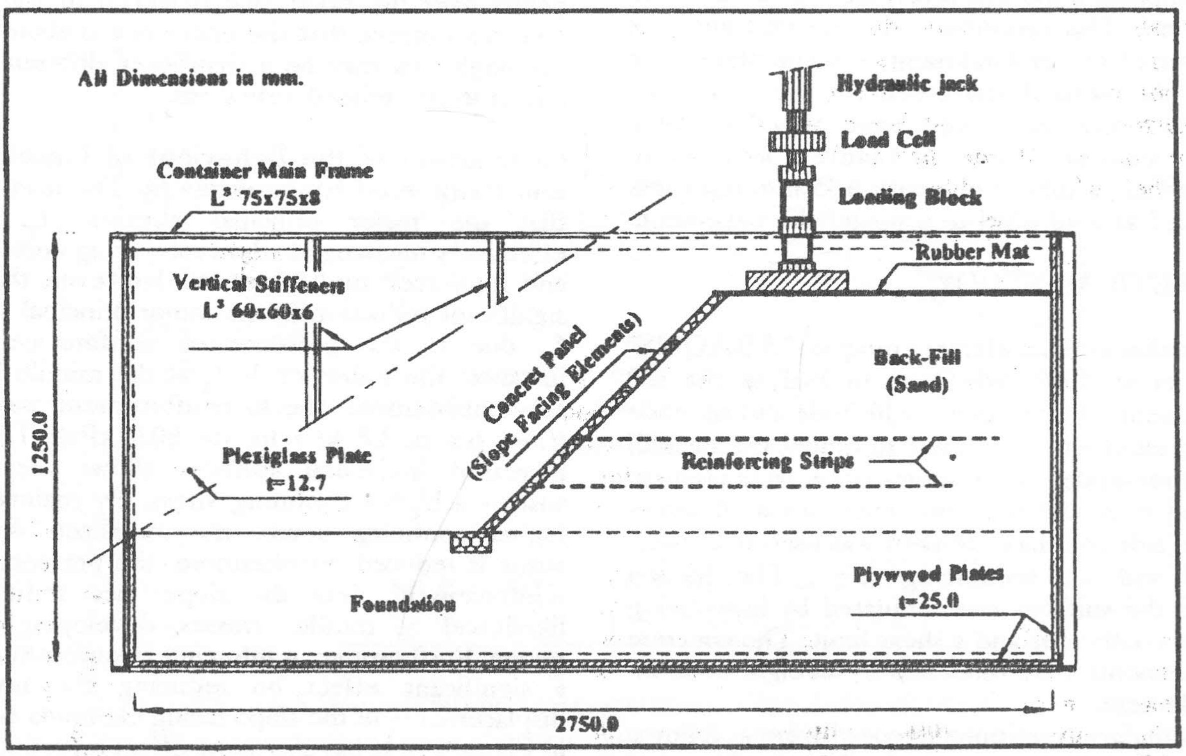

Figure 2. Main elements of the experimental model.

Embankment Cross Section: It was found from a preliminary study, using a nonlinear finite element analysis, that the extension of the foundation material beyond the toe, R in Figure (1), should be ≥ twice the maximum height of the embankment and the depth of foundation, D in Figure (1), should be ≥ half the maximum embankment height, Mashhour (1979).

Construction procedure: All models were constructed with the same procedure as follows: First, the foundation was constructed on three layers each with a thickness of 116.7 mm, compacted with an electric checker.

The embankment models were built with and without reinforcing strips. For models without reinforcing strips, the embankment layers were formed by pouring the sand in 100.0 mm thick layers and compacted as before. For models with reinforcing strips, after completing the top level of the foundation, a number of reinforcing strips were laid horizontally at this level with the specified spacing centre to centre according to the case considered and then sand was poured over them to form the first layer of the embankment.

Simultaneously the first reinforced concrete facing panel was built with the same thickness as this layer. After compacting the first layer, the second layer was constructed. This procedure was repeated until the final layer of the embankment was completed. To monitor the vertical movement of the sand, thin horizontal white sand layers were placed between the compacted sand layers. To prevent local failure at the surface, a rubber mat with 6.35 mm thickness was placed at road level to simulate the pavement.

THEORETICAL STUDY

The nonlinear finite element program "ABAQUS" (Hibbit et al. 1989) was used to analyze the soil embankments. Plane-strain eight-node and six-node bi-linear elements were used to model the backfill soil. A three-node, linear interpolation truss element was used to model the reinforcing strips. A three-node per side interface element was used to connect the soil and the reinforcing strips. The friction between the surfaces was simulated by introducing a friction coefficient and a shear limit. The concrete facing elements were modelled by an eight-node bi-linear element.

The boundary conditions imposed were as follows; (i) The base nodes were restrained in the X and Y directions; and, (ii) The left-hand and right-hand side nodes were prevented from motion in the X direction. Multi-Point Constraints was used to join the soil elements to the elements along the reinforcing strips. To include the effect of hydrostatic stress on the soil shearing resistance, the Von Mises yield criterion was modified to include the first invariant of stresses, (Drucker and Prager, 1952).

RESULTS

The results from testing the laboratory models were used to establish the validity of the finite element modelling. The case of slope m=3.0 was used to check the results for the tensile force in the reinforcing strips from the finite element model with three values of H/B ratio: H/B=1.3, 1.8 and 2.5. The other parameters were fixed as: $L_r/H=1.2$; $H/S_v=4$; and $H/S_h=3.7$. A typical comparison between theoretical and experimental for the tensile forces along the reinforcing strip at the middle of the embankment is shown in Figure (3). It can be observed that the two sets of results are quite close with a maximum difference of 17.0% which is not unexpected in soil related structures. The comparison between the experimental and theoretical for the horizontal displacements at some points over the slope face is shown in Figure (4). One can observe that the difference is about 43.0%. Although this may be a significant difference, it is not so in soil related structures.

Comparison of the Behaviour of Unreinforced and Reinforced Embankments: The results show that the major principal stresses, f_y, remain effectively unchanged when comparing unreinforced and reinforced embankments. However, there is a significant reduction in the minor principal stresses, f_x, due to the presence of reinforcement. For instance, the reduction in f_x at the middle level of the embankment due to reinforcement was 41.0% (from 6.5 to 3.8 kPa for q= 50.0 kPa). Thus, the increased horizontal stiffness allows the soil to sustain a higher confining stress. By maintaining a higher confining stress, the mobilized deviator's stress is reduced. Furthermore, the presence of the reinforcement near the slope face reduces the likelihood of tensile stresses developing in this region. Furthermore, reinforcing an embankment has a significant effect on reducing the horizontal displacements of the slope facing elements as shown in Figure (5). It has also some effect on reducing the horizontal and vertical displacements at the embankment-foundation interface.

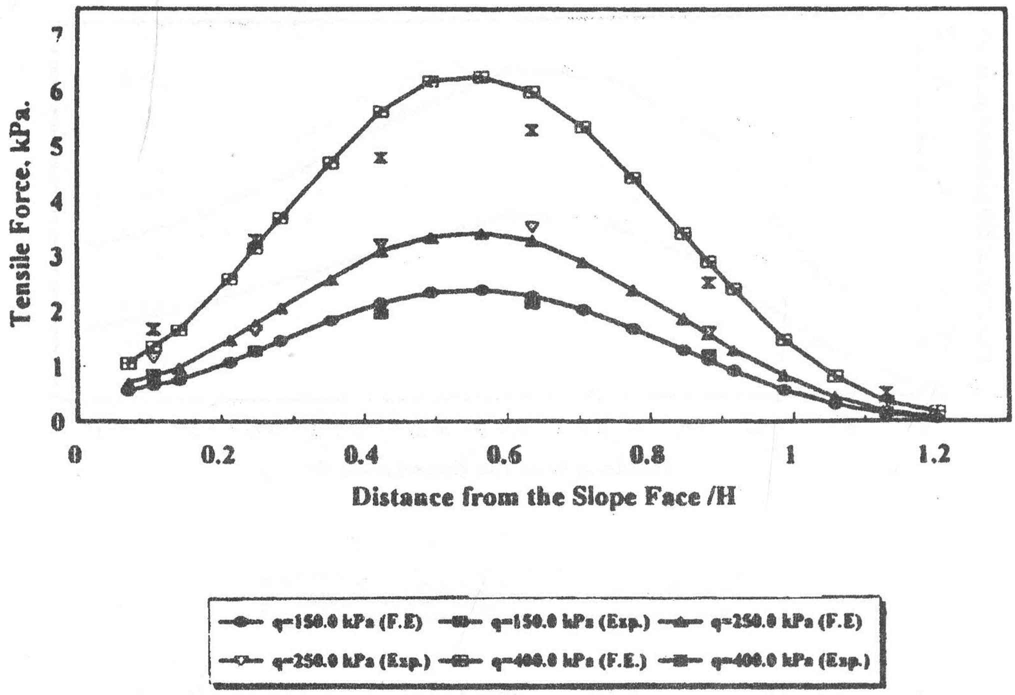

Figure 3. Tensile force distribution along the reinforcing strip at level H/2 from the foundation
(Comparison between experimental and finite element results)
($H/S_v=4$, $L_r/H=1.2$, $H/S_h=3.7$, $m=3.0$, $H/B=2.5$).

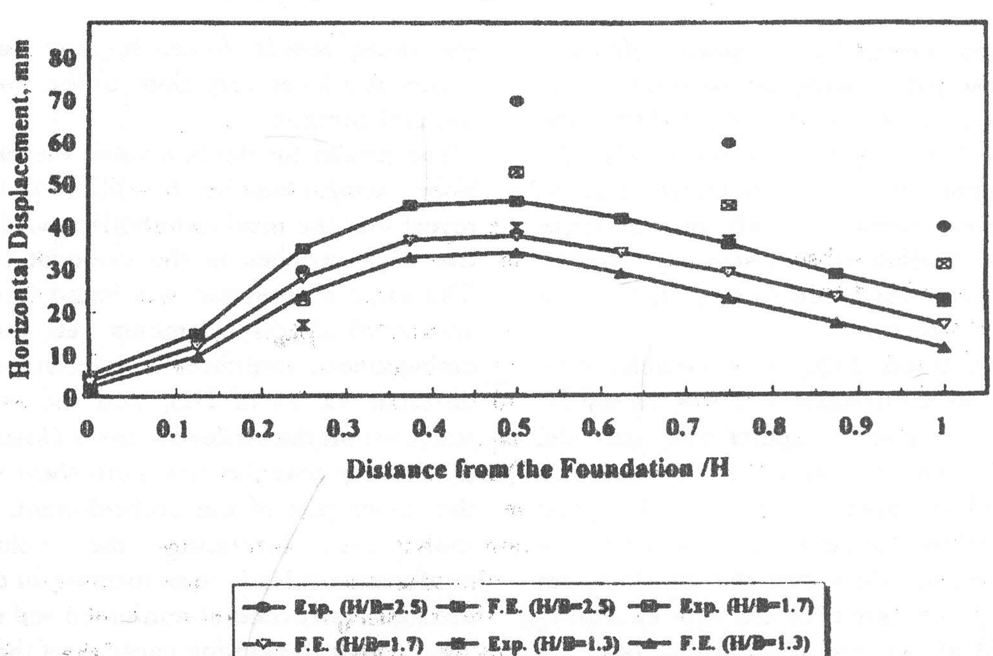

Figure 4. Horizontal displacement of the slope facing elments
(Comparison between experimental and finite element results)
($H/S_v=4$, $L_r/H=1.2$, $H/S_h=3.7$, $m=3.0$, $H/B=2.5$).

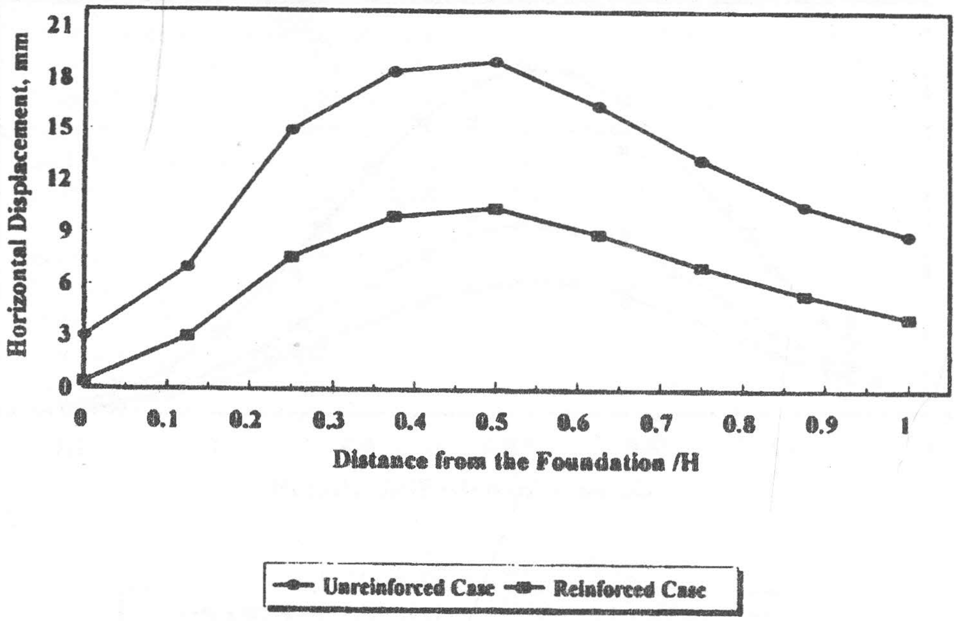

Figure 5. Horizontal displacement of the slope facing elments
(Comparison between reinforced and unreinforced embankments)
(Vertical applied load q, = 50,0 kPa).

Parametric Study: The parametric study conducted herein involves the following design parameters: the loading strip width, B, in terms of H/B, the reinforcing vertical spacing, S_v, in terms of H/S_v; the reinforcing element length, L_r, in terms of L_r/H; and, the slope of the facing elements, m. The finite element models, verified and substantiated by the experimental results, were used to study the effects of these design parameters.

Vertical Spacing Ratio, H/S_v, as a variable: Five variables of H/S_v were considered: 2, 4, 8, 16 and 24. The following parameters pertaining to the reinforced embankment were kept constant: H/B=2.5; S_h=0.33 m; m=3.0; and, L_r/H=1.0. The comparisons were conducted for a vertical load q= 100.0 kPa. The results show that the tensile forces in the reinforcing elements decrease with increasing H/S_v. Figure (6) shows the relationship between T_i/T_{max} and h_i/H, where T_i is the maximum tensile force in the reinforcing element at vertical level h_i from the foundation. It is observed that the maximum tensile force, for any values of H/S_v, occurs at a level very close to the middle height of the embankment.

The results for the horizontal displacement of the slope facing elements for different values of H/S_v reveal that the maximum horizontal displacement of the slope reduces as the value of H/S_v increases. The same observation was noted for the horizontal and vertical displacements at the foundation-embankment interface. The relationship between different values of H/S_v and the maximum shear strain within the embankment is illustrated in Figure (7) showing that the maximum shear strain occurs in the upper part of the embankment. These results show that increasing the volume of the reinforcement leads to an increase in the friction and the shear resistance of reinforced soil embankments. Thus, the load-carrying capacity of the embankment increases with smaller deformation in the soil mass as well as in the tensile forces in the reinforcing strips.

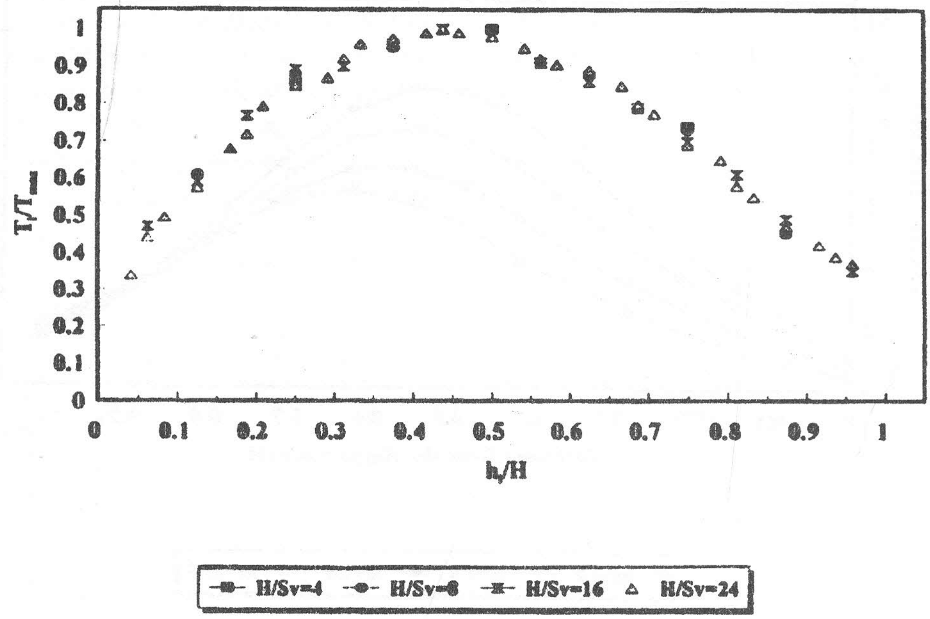

Figure 6. Effect of fifferent values of H/S_v on the maximum force at different levels (L_r/H=1.0, H/B=2.5, q=100.0 kPa).

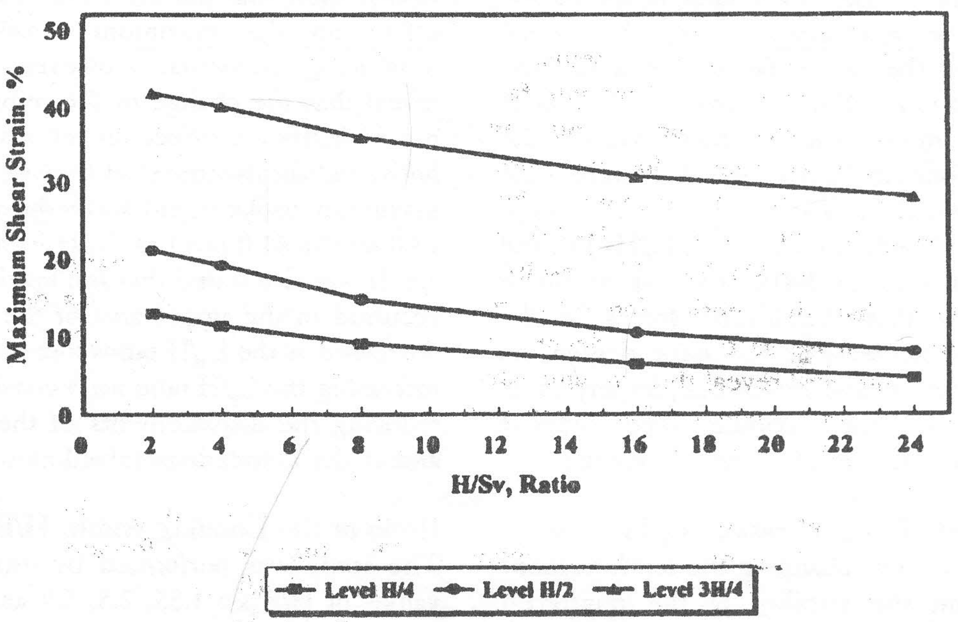

Figure 7. Effect of fifferent values of H/S_v on the maximum shear strain within the embankment (L_r/H=1.0, H/B=2.5, m=100.0 kPa).

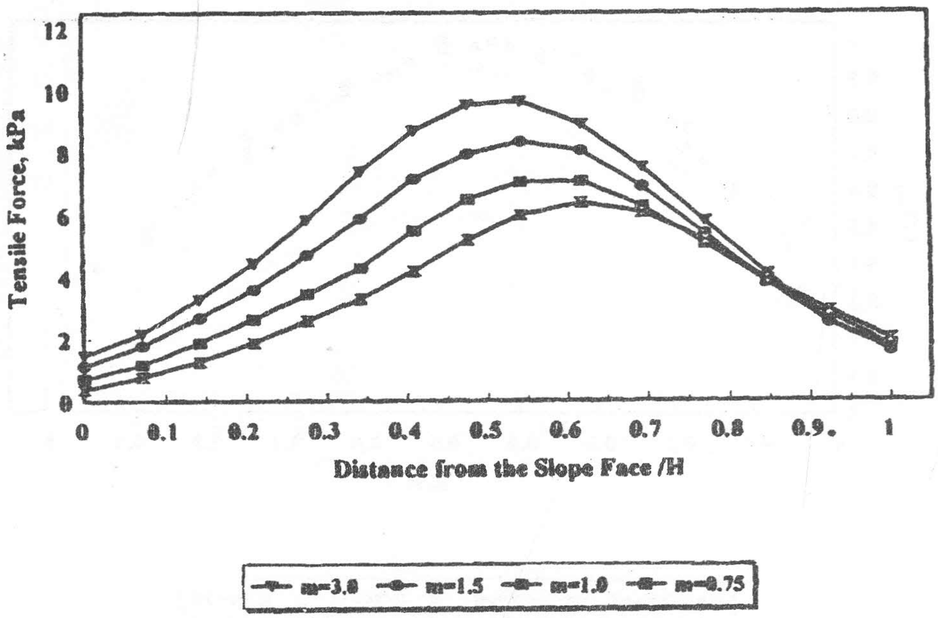

Figure 8. Effect of slope degree m, on the distribution of the tensile force level H/2 from the foundation (L_r/H=1.0, H/B=2.5, H/S_v=8, q=100.0 kPa).

Slope of the Facing Elements, m, as a variable: The purpose here is to determine the effect of the slope degree, m, on the: distribution of the tensile forces along the reinforcing strips; the lateral displacement of the slope facing elements; the settlement at the foundation-embankment interface; and, the maximum shear strain within the embankment. Four different slope values were used: m= 0.75, 1.0, 1.5 and 3.0. The other parameters kept constant were: H/S_v=8; H/B=2.5; and, L_r/H=1.0; and a vertical applied load, q= 100.0 kPa. The results in Figure (8) show that the tensile forces in the reinforcing strips decrease as the slope degree, m, decreases. The results also reveal that, for any value of m, the location of the maximum force occurs at approximately the middle of the embankment.

Reinforcement Length ratio, L_r/H, as a variable: The effect of changing the reinforcement length, L_r/H, on the stability of the reinforced embankment was studied for different values. These values were: 0.8; 1.0; 1.2; 1.4; and, 1.6. The other parameters kept constant were: H/B=2.5; m=3; and, H/S_v=8 and a vertical applied load, q= 100.0 kPa. The response of using different reinforcement lengths on the maximum tensile force in the reinforcing elements is illustrated in Figure (9). The results show that the L_r/H ratio has an insignificant effect on the maximum tensile force in the reinforcing elements. However, the results also reveal that the change in the reinforcement length has a significant effect on reducing the maximum horizontal displacement of the slope elements. The maximum displacement was reduced by 44.0% (from 73.0 mm to 41.0 mm) as L_r/H increased from 0.8 to 1.6. It was also found that the maximum shear strain occurred in the upper area of the embankment. It decreased as the L_r/H ratios increased. Furthermore, increasing the L_r/H ratio has a considerable effect on reducing the displacements of the facing elements and at the foundation-embankment interface.

Ratio of the Loading width, H/B, as a variable: The study was performed by using four different values of H/B as: 1.25, 2.5, 5.0 and 7.5. The other parameters kept constant were: H/S_v=8, m=3.0 and L_r/H=1.0. A vertical applied load of 150.0 kN was chosen for all the values of H/B, and the embankment height was kept constant. Figure (10) presents the distribution of the tensile force along the reinforcing elements at level H/2 from the foundation. It is observed that the maximum tensile force decreases as the H/B ratio decreases and with its position shifting away from the slope face as the H/B is reduced. However, the horizontal displacement of the slope facing elements increases when H/B is increased. Similar trends were found for the vertical and horizontal displacements at the embankment-foundation interface and for the maximum shear strain within the embankment. Generally, decreasing the H/B ratio improves the embankment performance since an increase in the loading width means increasing the distribution area of stresses within the embankment.

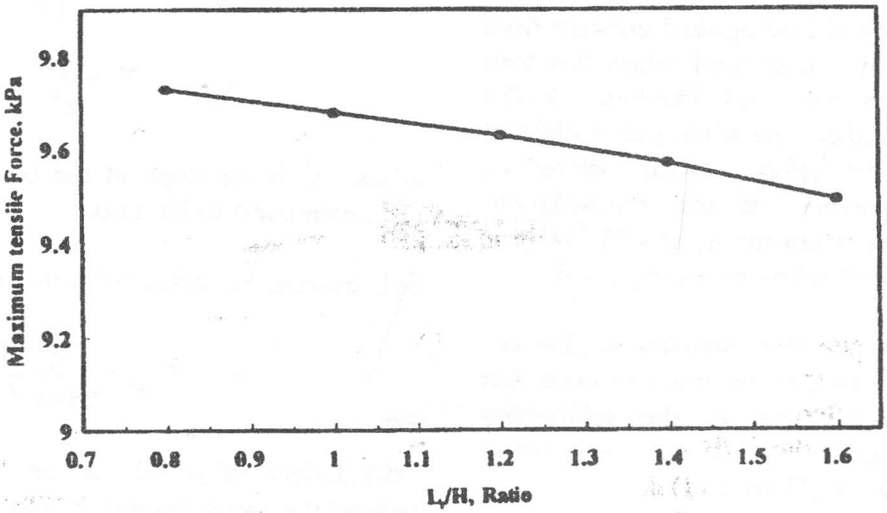

Figure 9. Effect of Different values of L_r/H on the maximum force within the embankment (H/S_v=8, H/B=2.5, m = 3.0, q=100.0 kPa).

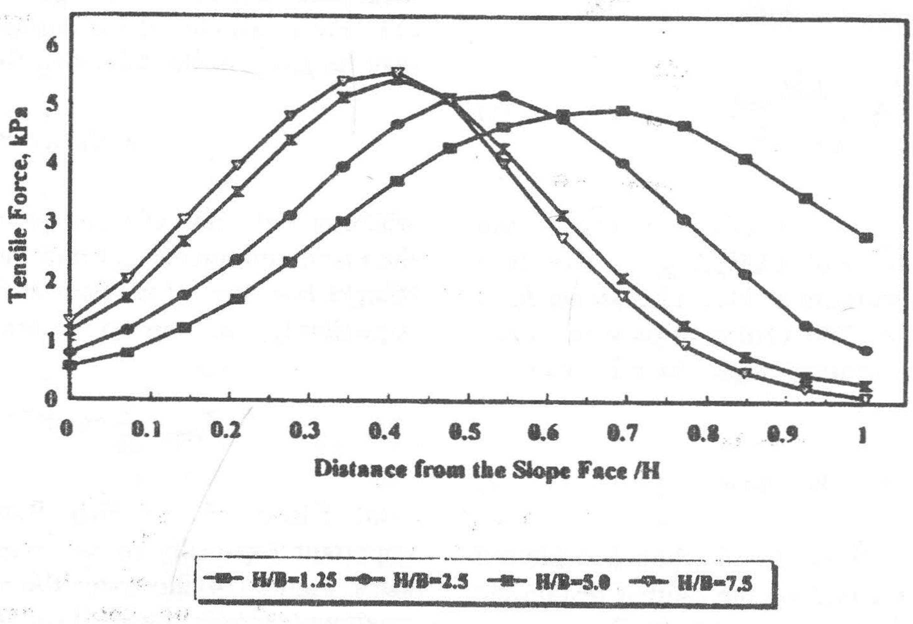

Figure 10. Effect of loading strip ratio, H/B, on the distribution of the tnsile force at level H/2 from the foundation
(H/S_v=8, H/B=2.5, m = 3.0, q=100.0 kPa).

Horizontal Load as a Variable: The effect of horizontal load on the behaviour of the reinforced soil embankments was also considered. The parameters pertaining to the reinforced embankment were taken as: $H/S_v=8$, $m=3$, $H/B=2.5$ and $L_r/H=1.0$. Horizontal loads toward and outward from the embankment were studied. The results show that the maximum tensile force in the reinforcement increased for a horizontal load applied outward from the embankment and it decreased when this load was applied toward the embankment. Similar findings were observed for the maximum horizontal displacement of the slope facing elements. Generally, the resistance of the embankment significantly improves when the horizontal load was applied toward the embankment, as expected.

Design Formula for the Maximum Tensile Force: The forgoing parametric study showed that the maximum tensile force in the reinforcing elements is influenced by all the parameters considered except the L_r/H ratio.

(i)Effect of H/S_v: Figure (11) illustrates the relation between the maximum tensile force T_{max}, and the ratio of the relative axial stiffness δ, for different cases of H/S_v, where δ is defined as:

$$\delta=\frac{(A.E)_{reinf}}{(A.E_{\sigma_3})_{soil}} \qquad (1)$$

in which $(A.E)_{reinf}$ is the axial stiffness of the reinforcing material and $(A.E_{\sigma 3})_{soil}$ is the axial stiffness of the embankment backfill material for a confining pressure σ_3. The confining pressure at any point within the embankment backfill can be calculated as:

$$\sigma_3=\gamma.h(1-\sin\phi) \qquad (2)$$

The results show a linear trend when δ is plotted versus Log (T_{max}). Based on the plotted results the maximum tensile force can be expressed as:

$$T_{max}=\frac{2.0T^*}{e^{n.\delta}} \qquad (3)$$

in which n is the slope of the linear relation in Figure (11) with a value equal to: 0.05, 0.1 and 0.13, for confining pressure equal 10.0, 30.0 and 50.0 kPa, respectively. T^* is the maximum tensile force when $H/S_v=8$. From Figure (12) the relation between T^* and the vertical applied load q, is determined. From such a plot, one can assume that T^* may be taken in the following form:

$$T^*=\frac{q}{n^*} \qquad (4)$$

where: n^* is the slope of the best-fit line in Figure (12), estimated to be 11.0.

Substituting Equation (4) into Equation (3) yields:

$$T_{max}=\frac{q}{5.5*e^{n.\delta}} \qquad (5)$$

(ii) Effect of Slope degree, m: As mentioned before, the slope degree m, has a significant effect on the stability of reinforced soil embankment. The variation between the slope degree, m, and the maximum tensile force, T_m, is plotted in Figure (13). From this plot, the maximum tensile force, T_m, may be given in the following form:

$$T_m=0.6T^*e^{(\omega.m)} \qquad (6)$$

where ω is the rate of variation of the slope, m, and the maximum force, T_m. From the slope of the fitted straight line, the value of ω was found equal to 0.18. Equation (5) can now be written as:

$$T_{max}=\frac{3}{28}*q*e^{(\omega.m-n.\delta)} \qquad (7)$$

(iii) Effect of the H/B Ratio: This effect is important especially in the case of heavy applied loads. Figure (14) illustrates the relation between the maximum tensile force, T_{HB}, and the ratio H/B. Based on the plotted results shown in Figure (14), the maximum tensile force may be expressed as:

$$T_{HB}=0.93*T^*+(\frac{H}{B}).\psi \qquad (8)$$

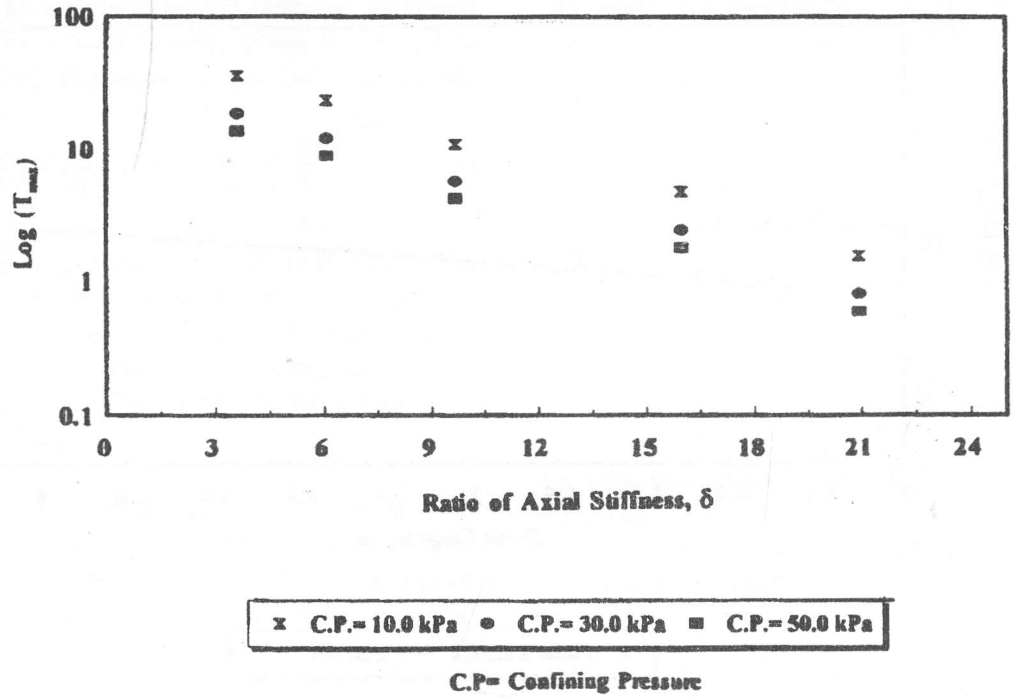

Figure 11. Relation between log (T_{max}) and ratio of axial stiffness, δ ($m=3.0$, $L_r/H=1.0$, $H/B=2.5$, $q=100.0$ kPa).

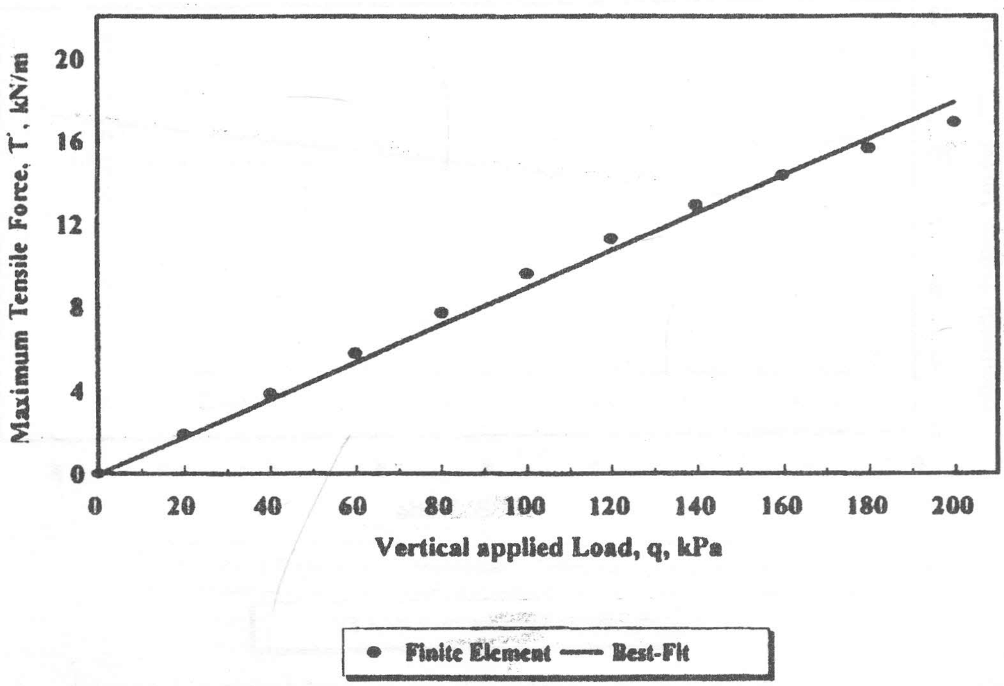

Figure 12. Relation between maximum tensile force, T^* and vertical applied load, q ($m=3.0$, $L_r/H=1.0$, $H/B=2.5$, $H/S_v=8$).

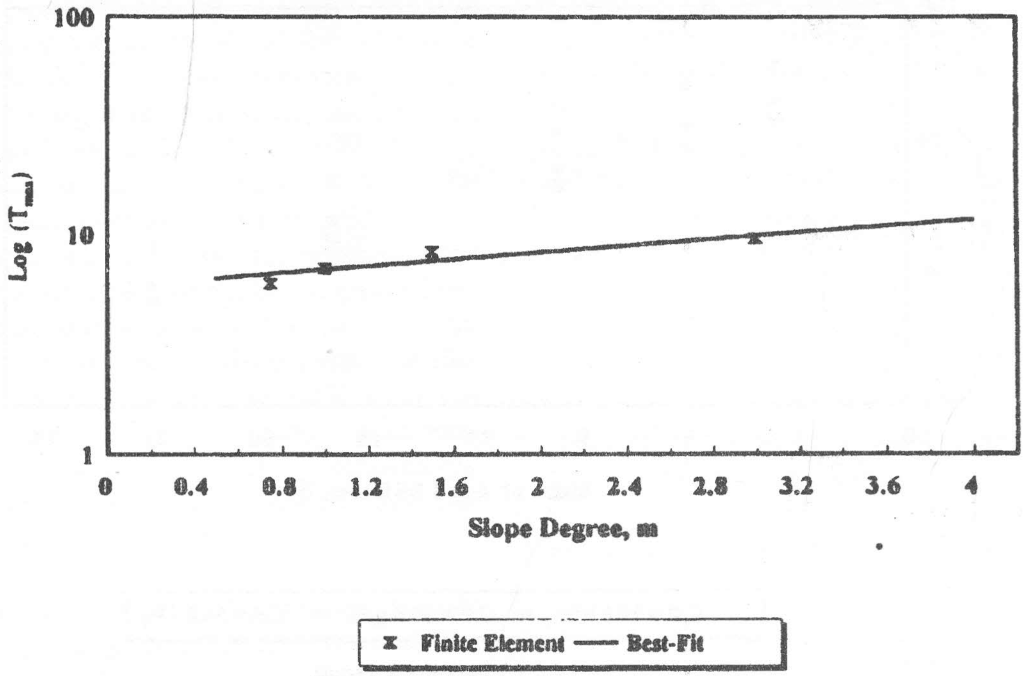

Figure 13. Relation between log (T_{max}) and slope degree, m
(H/S_v=8, L_r/H=1.0, H/B=2.5, q=100.0 kPa).

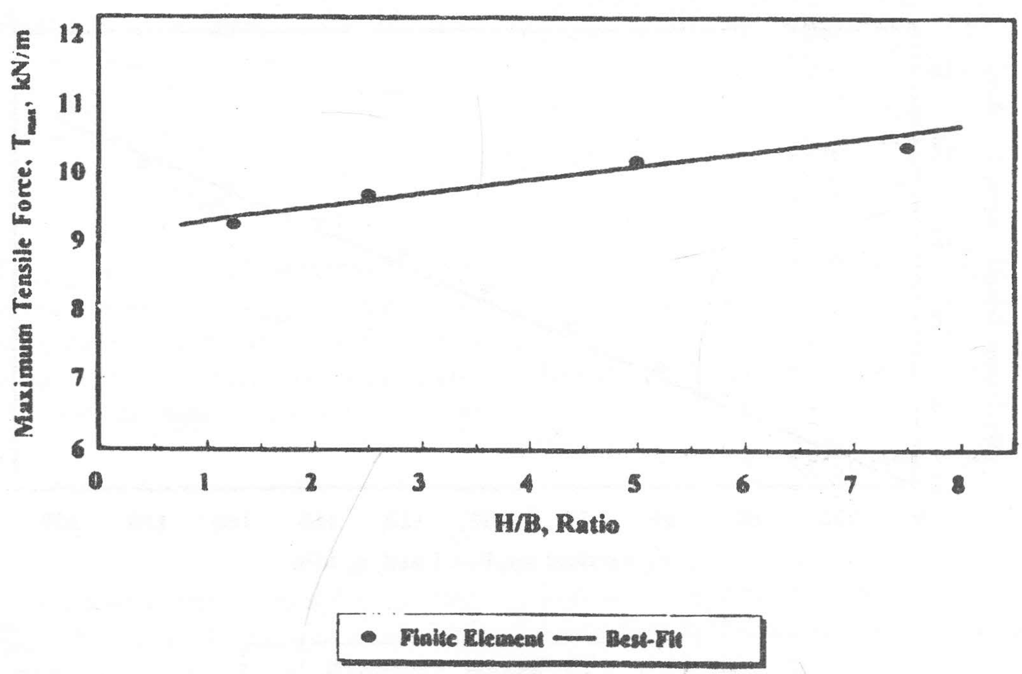

Figure 14. Relation between T_{max} and loading strip ratio, H/B
(m=3.0, L_r/H=1.0, H/S_v=8, q = 100.0 kPa).

in which ψ is the rate of variation between H/B and Log (T_{HB}). From a best-fit line, ψ was estimated to be 0.2. Therefore, Equation (7) can be rewritten as:

$$T_{max}=\frac{q}{10.5}*e^{(\omega.m-n.\delta)}+\frac{H}{B}.\psi \tag{9}$$

Equation (9) is a general formula to evaluate the maximum tensile force within the embankment under vertical loading with different parameters. Comparing the results based on this equation with the results given from Terzaghi's Equation showed a difference of 8.0%.

(vi) Effect of a horizontal Load: Figure (15) illustrates the effect of horizontal load on the maximum tensile force. The results from this figure show that the maximum tensile force can be expressed as follows:

In case of a horizontal load, F, applied outward from the embankment:

$$T_F=1.1T^{*}e^{(0.9*\frac{F}{q})} \tag{10}$$

In case of a horizontal load, F, applied toward the embankment:

$$T_F=\frac{0.98T^{*}}{e^{(0.95*\frac{F}{q})}} \tag{11}$$

To take the effect of horizontal load into account, Equation (9) is rewritten as:

In case of a horizontal load, F, applied outward from the embankment:

$$T_{max}=\frac{q}{10.3}*e^{(\omega.m-n.\delta+0.9*F/q)}+\frac{H}{B}.\Psi \tag{12}$$

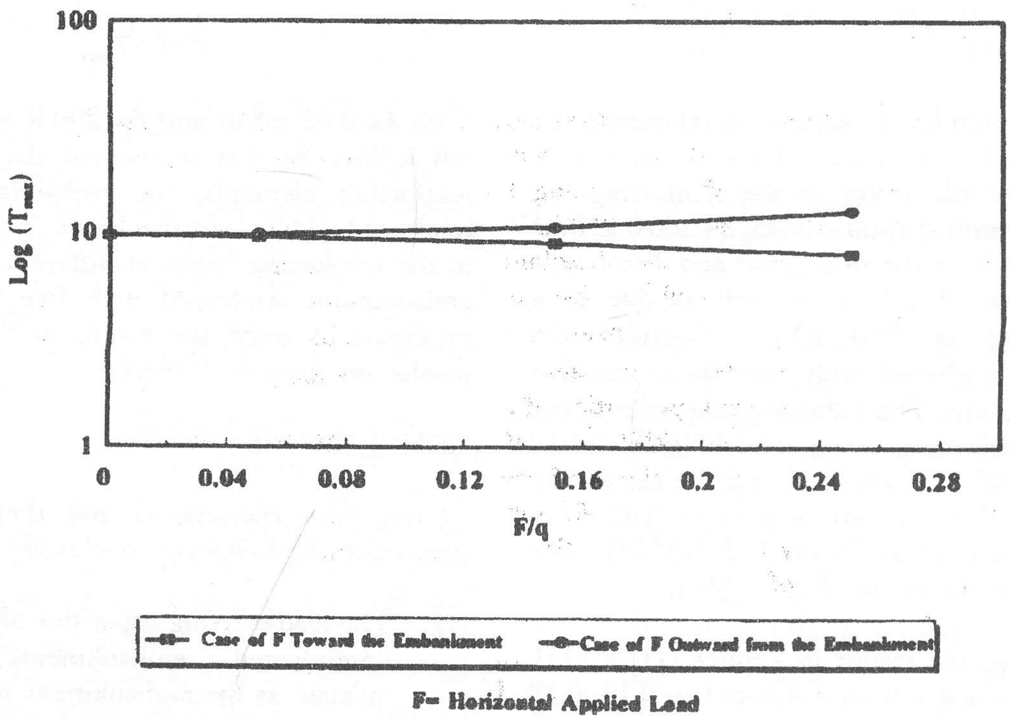

Figure 15. Effect of horizontal load. F, on the maximum tensile force within the embankment (L_r/H=8, H/S_v=8, H/Bm=2.5, m=3.0, q=100.0 kPa).

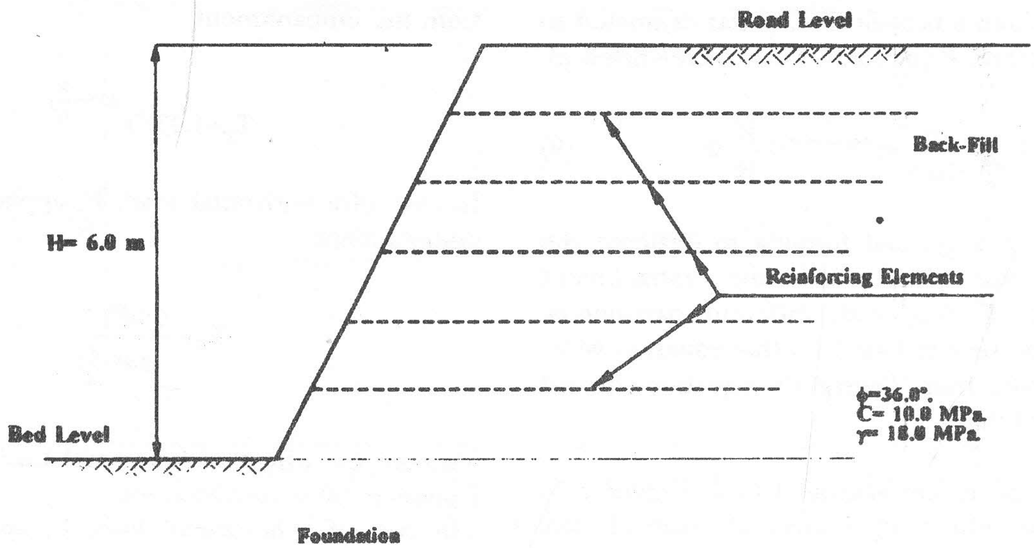

Figure 16. Embankment cross-section for illustrated design example.

In case of a horizontal load, F, applied toward the embankment:

$$T_{max} = \frac{q}{10.7} * e^{(\omega.m - n.\delta - 0.95 * F/q)} + \frac{H}{B}.\Psi \qquad (13)$$

Illustrated Design Example: For the reinforced-soil embankment shown in Figure (16), it is required to estimate the tensile forces in the reinforcing flat bars, due to a vertical applied load, q= 100.0 kN/m^2 acting at 1.0 m from the slope crest and distributed over a distance of 3.0 m, as well as due to a horizontal load of 10.0 kN/m. Consider the embankment reinforced with one, three and five layers, respectively. The following properties of the unreinforced soil are given: γ=18.0 kN/m^3, C=10.0 kPa and ϕ=36.0°. It is assumed that the reinforcing flat bar material has a cross section of 0.02 m^2/m with a modulus of elasticity of (3.15)*10^4 MPa and an allowable tensile stress of 200.0 MPa.

Solution: Using the results in Figures (11) to (15), the constants n, ω and Ψ are estimated as: 0.13, 0.18 and 0.2, respectively. Using these constants in Equation (12) yields T_{max}=12.6, 6.0 and 3.1 kN/m, for embankment reinforced with one, three and five layers, respectively.

Check the Reinforcing Element Area: the reinforcing area must be strong enough to prevent failure in tension where the resisting tensile force is:

$$A * f_a \geq T_{max} \qquad (14)$$

With A= 0.02 m^2/m and f_a= 200.0 MPa, $(A)*(f_a)$ = 4.0 kN/m. So that to prevent the failure in the reinforcing elements, the embankment must be reinforced with at least five layers. The tensile forces in the reinforcing layers at different levels, for the embankment reinforced with five layers, can be estimated by using the results in Figure (6). The results are given in Table (1).

CONCLUSIONS

From the experimental and theoretical results presented, the following conclusions can be made:

(1) The load-carrying capacities of reinforced and unreinforced embankments significantly increase as the embankment slope degree m, decreases. Furthermore, the maximum tensile force in the reinforcing strips diminish as m decreases;

(2) The height of the embankment has a great influence on its load-carrying capacity. The

load resistance of the embankment increases as the embankment height decreases;

Table 1. Tensile Forces in Reinforcing Elements. at Different Levels within the Embankment with Five Layers of Reinforcing.

Level of Reinforcing Layer from the Foundation	Tensile Force kN/m
H/6	0.62*3.1=1.9
H/3	0.93*3.1=2.9
H/2	1.00*3.1=3.1
2H/3	0.77*3.1=2.4
5H/6	0.46*3.1=1.5

(3) Increasing the horizontal reinforcement ratio, H/S_h, and hence the volume of reinforcement increases the resistance of the embankment significantly in as far as the maximum tensile force in the reinforcement as well as the lateral displacements of the slope facing elements; (4) The contribution of the reinforcing layer at the embankment-foundation interface, on the performance of the structure, is not significant and therefore that layer can be neglected;

(5) The vertical reinforcement ratio, H/S_v, has a significant effect in improving the resistance of the embankment and in reducing the maximum tensile force within the reinforcing elements as well as in minimizing the horizontal displacement of the embankment slope facing elements;

(6) The location of the maximum tensile force in the reinforcing strips invariably occurs in the strips at the middle of the embankment;

(7) Increasing the reinforcement length ratio, L_r/H, leads to increasing the load-carrying capacity of the embankment. However, while it has no significant effect on the maximum tensile force in the reinforcing strips, it has a significant effect on reducing the horizontal displacement of the embankment slope facing elements;

(8) Decreasing the loading strip ratio, H/B, helps to improve the resistance of both unreinforced and reinforced embankments, as well as to minimize the maximum tensile force along the reinforcing elements;

(9) The presence of the reinforcement reduces the horizontal stresses significantly while the reduction in the vertical stresses is only marginal; and,

(10) The load resistance of the embankment is significantly improves when the horizontal load is applied toward the embankment since this load helps to reduce the tensile loads within the reinforcing elements.

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