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Finite Element Analysis of a Reinforced Earth Wall

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Introduction

Reinforced earth is comparatively a newer construction material used extensively in civil engineering works. The concept of reinforced earth lies in mobilizing the friction between the soil and reinforcement. Normally soils possess very low tensile strength which can be improved by providing reinforcement in the direction of strains. On account of internal friction of forces, which develop within the reinforced soil mass, are absorbed by the reinforcement. The single largest application of reinforcement earth technology has been made in the construction of earth retaining structures. Hundreds of reinforced earth retaining walls have been built all over the world. These walls may yield about 50% economy over conventional retaining structures.

Statement of the Problem

Conventional brick masonary retaining wall forming one of the two side walls of a drain in the CBRI campus collapsed during rainy season in the year 1985. It was replaced by a reinforced earth wall of height 1.59 m. The wall, 33 m in length, was designed by Tiebreak Wedge Method for the following data :

Dry density of the fill	= 1.65 gm/cc
Angle of internal friction of backfill soil	= 32°
Coefficient of soil-reinforced friction	= 0.625

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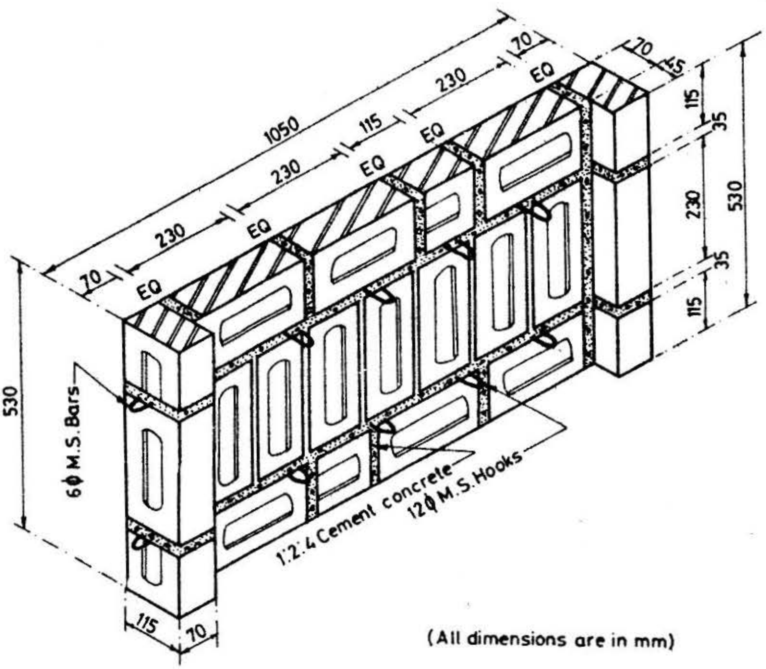

FIGURE 1 : Dimensional Sketch of the Brick Panel Used as Wall Facing

External surcharge loading at the surface of backfill	$= 4\ T/m^2$
Allowable range of ground bearing pressure	$= 0$ to $20\ T/m^2$
Factor of safety against sliding and overturning	$= 2.0$

Precast reinforced brick panels (Fig. 1), 75 mm in thickness, with proper arrangement of fixing the reinforcing strips were used as wall facing. Three such panels placed one above the other in vertical direction made the full height of the wall. GI strips 4 cm wide and 120 cm long were used as reinforcing elements and were positioned on the hooks provided in the brick panels through the hole punched in each strip (Fig. 2). The horizontal and vertical spacing of the strips were kept as 26.25 cm and 26.50 cm respectively. The local soil, classified as poorly graded sand, (SP), was used as backfill of the wall. The reinforcing strips were incremented to provide the variation of the tension along the length of a strip. Wall facing panels were incremented to monitor the lateral mevement of the wall. Distance observations between the side walls were taken with tape extensometer and deformeter. At the full height of the backfill, a lateral movement of 1.65 mm

FIGURE 2 : View of Reinforced Earth Wall Showing Laying of Reinforcing Strips in Position

of the retaining wall was recorded. Subsequent to that the strain gauges did not register any additional tension/compression. The vertical settlement of the backfill was recorded at the full height. The performance of the wall (Fig. 3), built in September 1985, was monitored at regular interval of time for about 20 months. Details of the field study were reported earlier (Bhandari et al., 1990).

2-D Finite Element Analysis of the same reinforced earth wall was carried out to obtain the deformation behaviour of the reinforced earth retaining structure. These theoratical values are compared with observed values. The cross-section of the reinforced earth wall, analysed by Finite Element Method, is shown in Fig. 4.

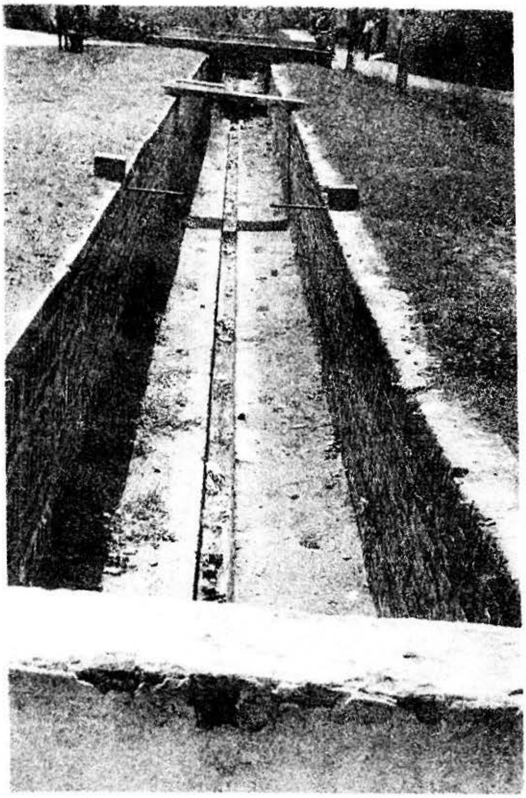

FIGURE 3 : View of Finished Reinforced Earth Wall

Method of Analysis

The reinforced earth retaining wall basically consists of :

1. Precast reinforced brick panels which constitute the wall facing.
2. Reinforcement, i.e., GI strips 4 cm wide and 120 cm long.
3. Backfilled sandy soil in between the reinforcing elements.
4. Backfill of the reinforced earth retaining wall which it is supporting.

The retaining wall facing (Precast reinforced brick panels) and the backfill soil have been discretized using 2-D four node isoparametric plane strain quadrilateral element. The geometry nodal point locations, loading and the coordinate system for this element are shown in Fig. 5. The element is defined by 4 nodal points having two degrees of freedom at each

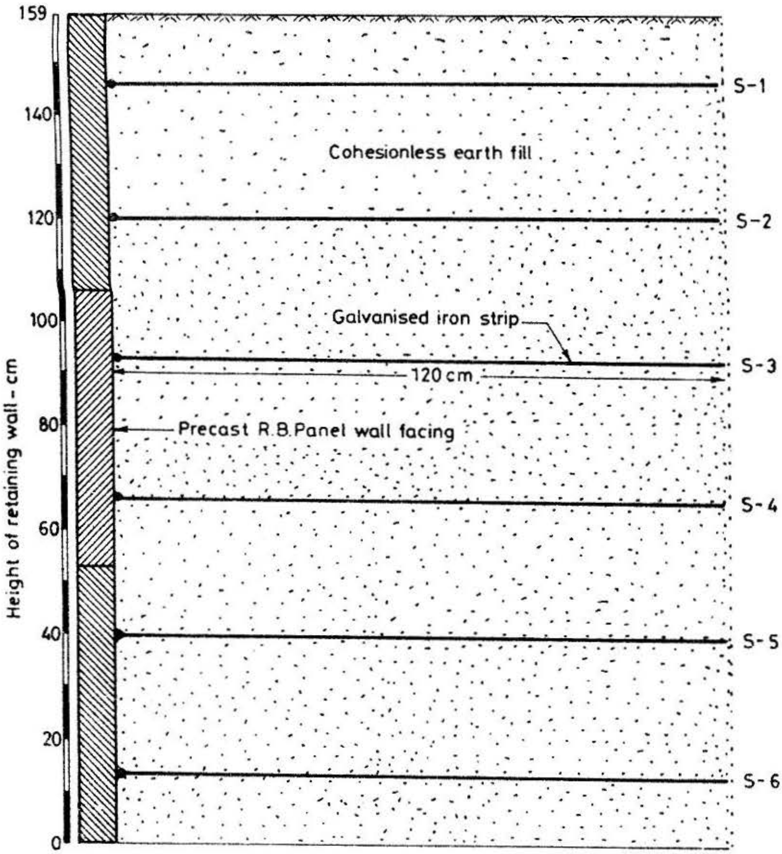

FIGURE 4 : Cross-Section of the Analyzed Reinforced Earth Wall

node : translation in the nodal X and Y directions. A unit thickness is assumed for this element. The state of stress for this element is characterised by four emponents : principal stress along X, Y, Z directions and shear stress in X-Y plane. The material properties to be input for this element for isotropic elastic case are Young's Modulus E, Poisson's ratio μ, Density γ.

The reinforcing elements have been modelled as two-dimensional line element (SPAR). It is uniaxial tension/compression element with two degree of freedom at each node. Translation in nodal X and Y directions. No bending of element is considered. The geometry, nodal locations, loading and the coordinate system for this element is shown in Fig. 6. The element is defined by two nodal points, the cross sectional area, an initial strain and the material properties (E and γ). The displacement direction for the SPAR element is assumed to be linear.

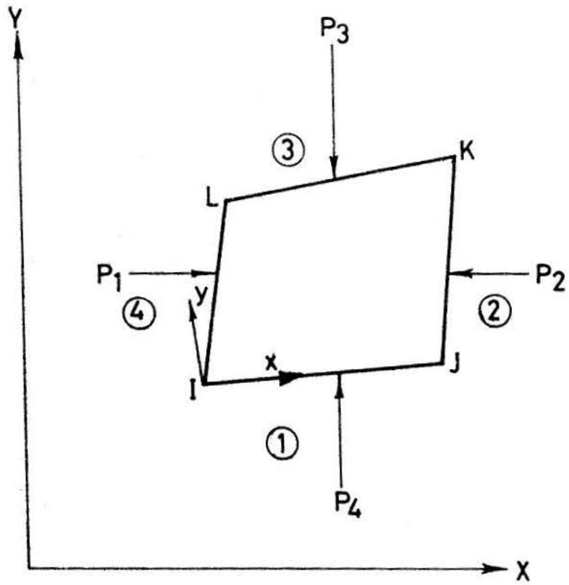

FIGURE 5 : Two-Dimensional Plane Strain Element

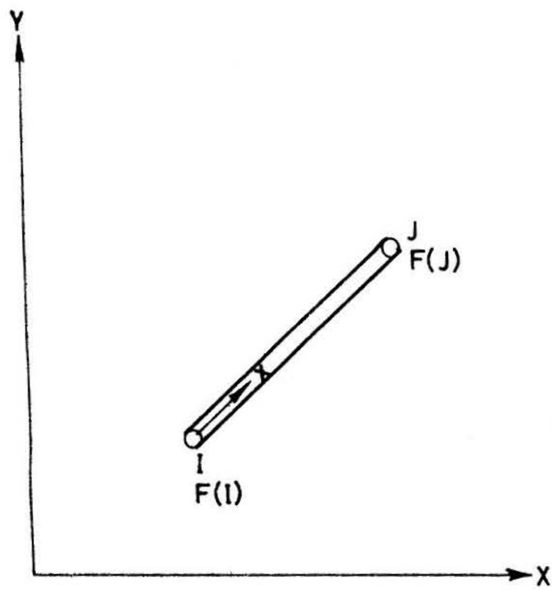

FIGURE 6 : Two-Dimensional SPAR Element

The interference between the reinforcing strips and the soil material has been modeled by two dimensional interface element. It represents two surfaces which may maintain or break physical contact and may slide relative to each other. The element is capable of supporting only ocmpression in the direction normal to the surface and shear (Coulomb friction) in the tangential direction. The element is non-linear and may have an open or closed status. The element has two degree of freedom at each node; translation in nodal X and Y directions. The geometry, nodal point locations and coordinate system of the element is shown in Fig. 7. The element is defined by two nodal points, an angle to define the interface, stiffness K, an initial displacement interference and an initial element status. The stiffness (K) of the surfaces in contact should be input. For the problems where local surface deformation is not of importance, then K value may be estimated as an order of magnitude one or two greater than the adjacent element stiffness (AE/L). The material property of the element to be input is the coefficient of friction. The element is represented by a pair of coupled non-linear orthogonal springs in normal and tangential directions to the interface and requires an iterative solution for static convergence procedure. The element is assumed to have converged when its status doesn't change between two successive iterations. However in cases of frictional contact, the element oscillates between sliding and sticking status, then the convergence criteria on the shear force has to be satisfied.

The following assumptions are made for the analysis :

1. Rigid boundaries are assumed at a considerable distance from the

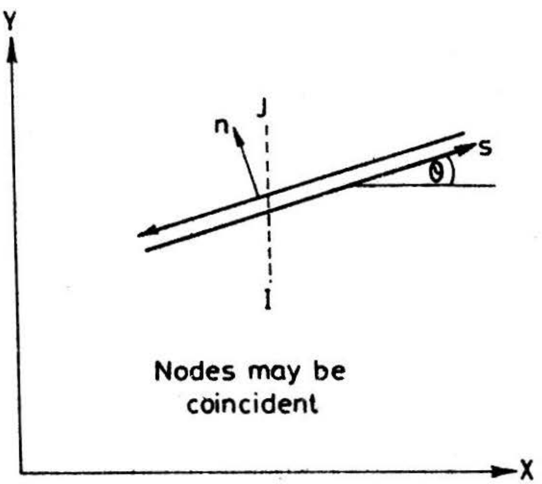

FIGURE 7 : Two-Dimensional Interface Element

retaining wall, so their existance has minimum effect on the stresses in the retaining wall.

2. The interface is assumed to be closed and sliding.

3. Orthotopic material directions correspond to the element coordinates directions.

4. The retaining wall and the reinforcing strips are treated as one continuum i.e., the displacement is together.

The FEM analysis has been carried out for the self weight of the retaining wall system, i.e., wall facing + reinforcing elements + backfill earth. The stress field and displacement is determined by using the non-linear static analysis. The non-linearity considered in the analysis is geometric non-linearity introduced by the interface element in the form of boundary non-linearity. All the other elements remain linear elastic throughout the analysis. In the case of geometric non-linearity the classical theory of infinitesimal strains does not hold and the strains are obtained from the displacements via a nonlinear operator. This type of nonlinearity may involve large displacements, large rotations and finite strains. The equilibrium and energy balance equations are written for the deformed configuration of interface elements. For solving these nonlinear equilibrium equations modified Newton Raphson method is used. The incremental solution is performed in a step by step manner and in each step the iterative scheme is performed until convergence. Since geometric non-linearity is considered the force convergence criterion is used. This assumes a step as converged when the ratio of the Euclidean norm of the residual force vector to the Euclidean norm of the incremental force vector is less than specified values of tolerance.

The stiffness K of the interface element is assumed to be two times the magnitude of AE/L of the reinforcement i.e., 1.5×10^4 kN/m. However, the stiffness K has been varied to determine the effect on the whole model. The "E" value of the backfill material, which is classified as poorly graded sand (SP), has been varied from the lowest value 2.11×10^4 kN/m^2 to maximum value of 5.25×10^4 kN/m^2. The lateral vartical displacement of the entire model has been determined by the analysis. The properties of the materials comprising the model are taken as follows :

For reinforced brick panels

$E = 8 \times 10^6$ kN/m^2

$\gamma = 20$ kN/m^3

$\mu = 0.15$

For backfilled earth

$E = 2.11 \times 10^4\ kN/m^2$ to $5.25 \times 10^4\ kN/m^2$

$\gamma = 16\ kN/m^3$

$\mu = 0.3$

For reinforcement

$E = 21 \times 10^4\ kN/m^2$

The coefficient of soil-reinforcement friction for the interface element is taken as 0.625.

Results and Discussion

The lateral displacement and vertical settlement of the retaining wall system have been determined for different stiffness values and also by varying the "E" value of the soil. The stress field of the retaining wall system has also been determined but the results are not presented in the paper as only field observations of displacement are available for comparison. For $E = 5.25 \times 10^4\ kN/m^2$ and stiffness $K = 1.5 \times 10^4\ kN/m^2$, the following results have been obtained :

1. The displacement profile of the retaining wall system i.e., wall facing panels, reinforcing strips and backfill (Fig. 8).

2. The displacement profile of the wall facing the Panels (Fig. 9). The magnitude of lateral maximum displacement obtained by FEM is 0.2203 cm which is on the slightly higher side with that of the observed maximum displacement of the wall in the field. The maximum lateral displacement of the wall facing obtained by FEM as well as that observed in the field is near top edge of wall.

3. The vertical settlement profile of the topmost surface of the earth backfill obtained by FEM analysis (Fig. 10) has a good correspondence with the observed settlement profile shown in the same figure.

4. The displacement profile of the wall facing and the reinforcement strips shown in (Fig. 11).

The maximum deflection of the retaining wall system and the settlement of the backfill have also been found out by varying the K values from $0.1\ kN/m$ to $1 \times 10^6\ kN/m$ and the E value of the backfill from $2.11 \times 10^4\ kN/m^2$ to $5.25 \times 10^4\ kN/m^2$. These have been plotted graphically in the Figs. 12 and 13 respectively. The maximum lateral displacement of

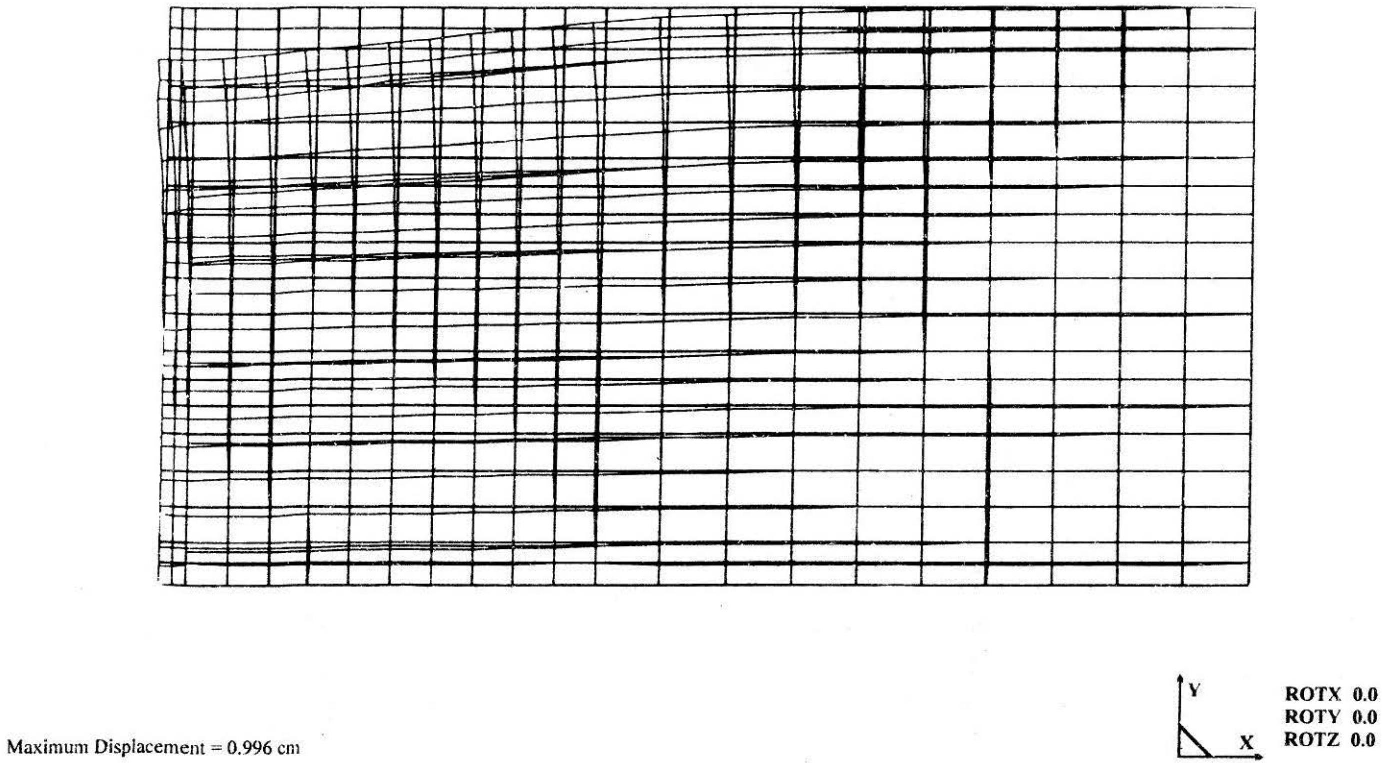

FIGURE 8 : Displacement Profile of the Reinforced Earth Retaining Wall System

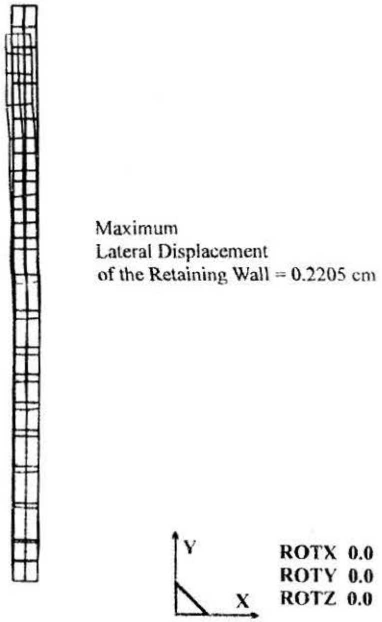

FIGURE 9 : Lateral Displacement Profile of Reinforced Earth Wall

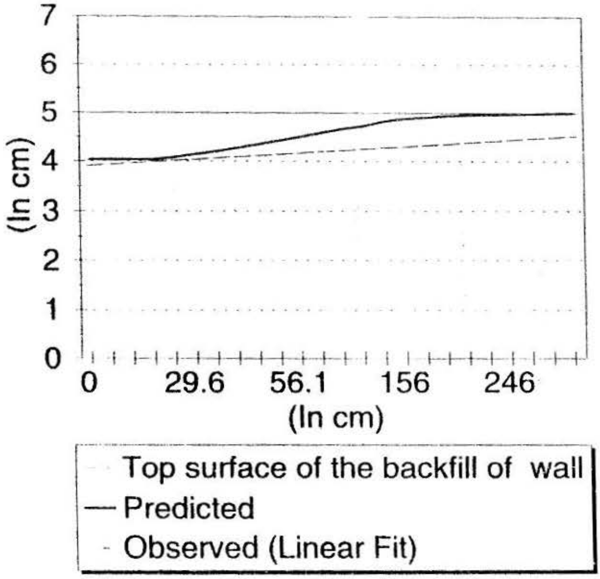

FIGURE 10 : Vertical Settlement Profile of the Topmost Surface of the Earth Backfill of the Wall

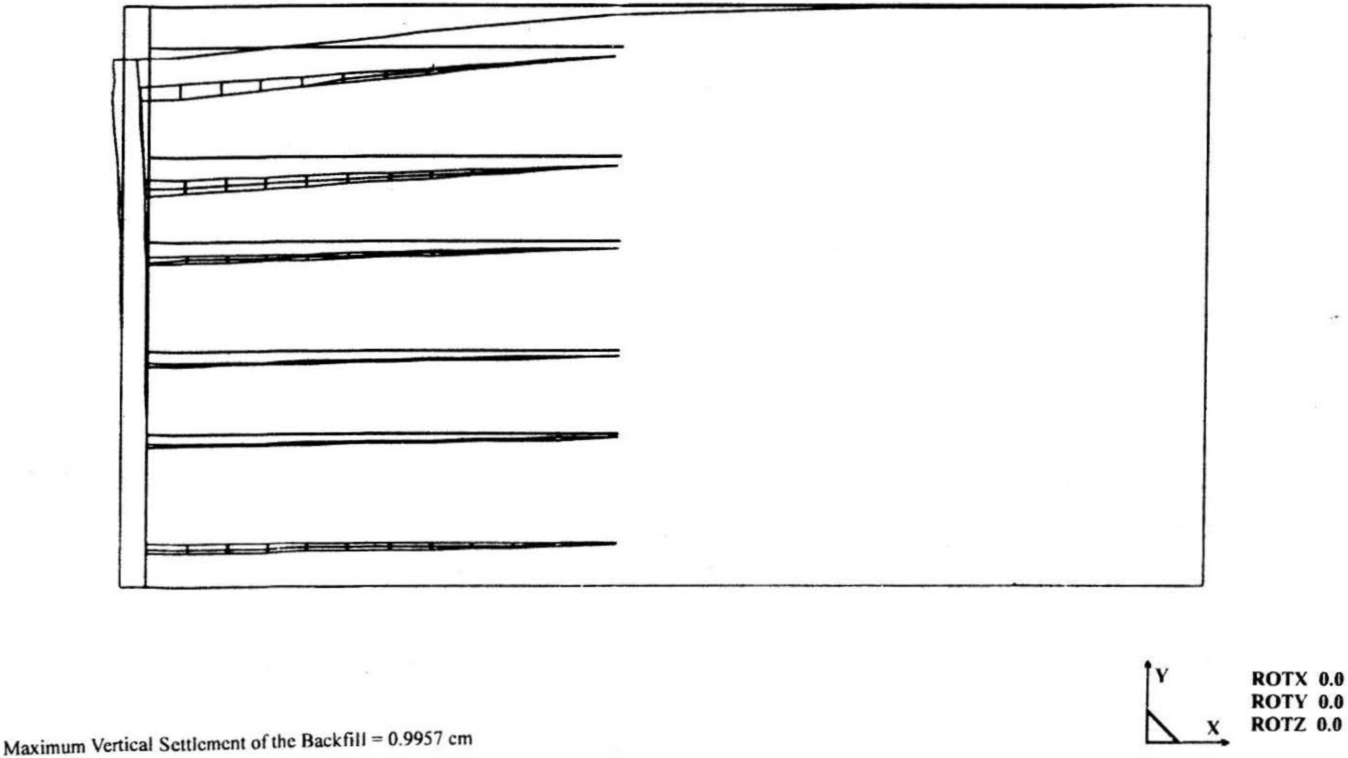

FIGURE 11 : Displacement Profile of the Wall Facing and the Reinforcement Strips

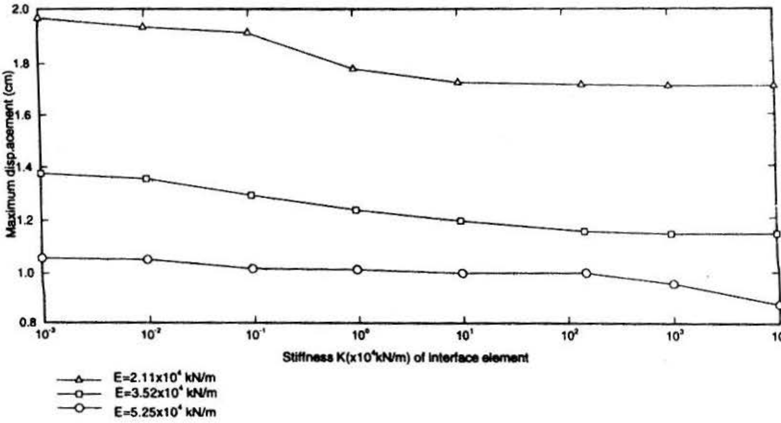

FIGURE 12 : Maximum Deflection of the Retaining Wall System for Different E Values of the Backfill

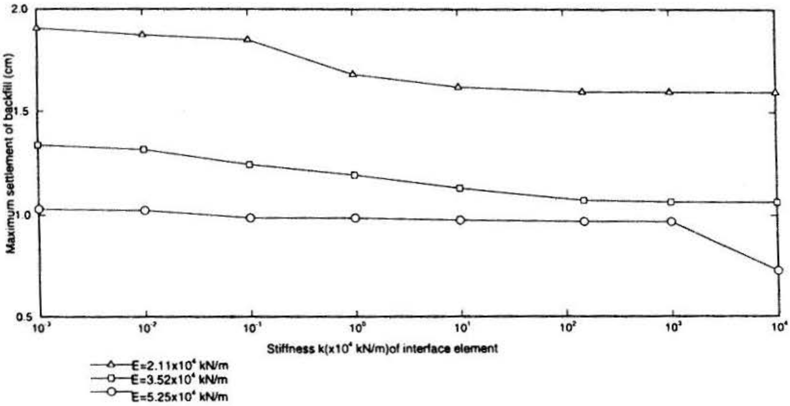

FIGURE 13 : Maximum Settlement of the Backfill Vs. Stiffness (K) for Different E Values of the Backfill

the retaining wall facing remains more or less constant with varying stiffness as shown in Fig. 14. The lateral displacement of the retaining wall facing and the settlement of the backfill have been plotted for different E values in Fig. 15 for one value of the stiffness (K) 1.5×10^4 kN/m.

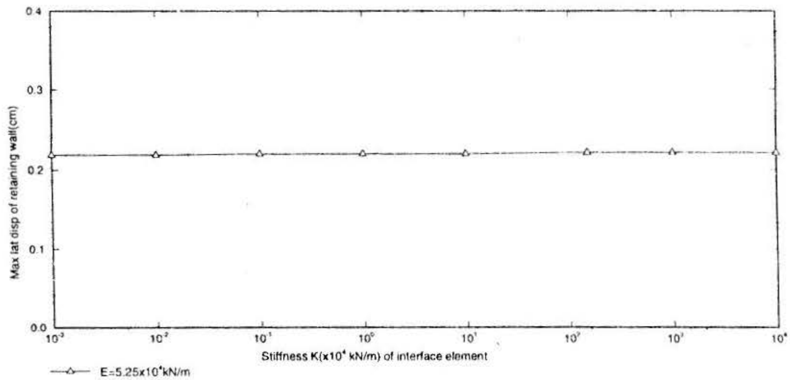

FIGURE 14 : Maximum Lateral Deflection vs. Stiffness

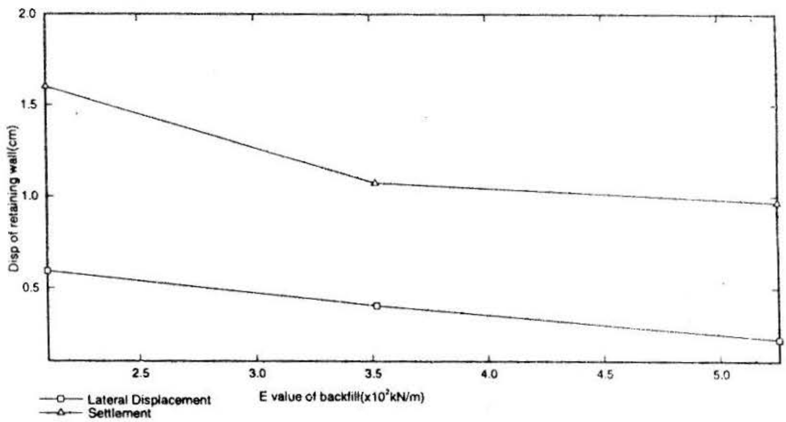

FIGURE 15 : Lateral Displacement of the Retaining Wall and the Settlement of Backfill

Conclusions

The finite element analysis of the reinforced earth wall system leads to the following conclusions :

1. The maximum lateral displacement of the retaining wall facing panels is near the top edge of the wall and is slightly higher than the observed value in the field.

2. The maximum vertical settlement of the retaining wall system obtained

by the FEM analysis as well as in the field is very close to the wall facing.

3. From the results it can be concluded that the settlement of the backfill decreases with increasing stiffness (K) and finally becomes constant for values of K greater than 1×10^6 kN/m.

4. The lateral displacement of the retaining wall facing remains the same as the stiffness increases.

5. From Fig. 15 it can be inferred that the lateral displacement of the retaining wall facing and the settlement of backfill decreases as "E" of the backfill increases.

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