Performance study of a prototype reinforced earth embankment

L'étude du comportement d'un prototype de remblai en terre armée

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SYNOPSIS: This paper presents a study of a prototype reinforced earth embankment(75m long, 10.5m wide and 4.20m high) designed, constructed (including a fully instrumented test section) and subjected to a sustained surface area loading. The materials used for and size, shape and method of fabrication of skin elements and reinforcing strips are described. The construction procedure and instrumentation provided are explained. The details of loading applied and the performance data obtained (Lateral deformation, earth pressure on skin elements, Pressure distribution in the reinforced earth mass and tensile stress variation along strips) are briefly presented and analysed.

1 INTRODUCTION

The technique of reinforcing soils has been in vogue since ancient times in crude forms, until Henry Vidal (1966) Proposed certain design methods for reinforcing soil by embedment of metallic strips in a soil fill with almost vertical sides covered by skin elements suitably connected to one end of each strip, and keeping other ends free. This has resulted in a coherent composite material termed "Reinforced Earth". Various research workers (Lee et.al. 1973;,Kennedy et.al.1980) have attempted to overcome the problem of switching from models to prototype structures. However, such an embankment fully instrumented and subjected to surface area loading, has evaded their attention. The present day need of this country, to construct several road bridges over railway track (especially in developed areas) for grade separation to improve transportation needs, for which reinforced earth technique offers optimal solution for approaches, had prompted the authors to take up the performance study of a prototype. Perhaps, for the first time in India, prototype reinforced earthen embankment (constructed in the Regional Engineering College Campus, Warangal) with a fully instrumented test section, has been subjected to surface area loading.

2 MECHANISM OF REINFORCED EARTH

In this study the classical Rankine's approach, is considered valid to assume that (i) Rankine's active condition is realised both during construction and under applied loading and (ii) Pressure distribution on the vertical side face is linear with depth. As such,

$$\sigma_h = K_a\ (q + rh) \quad ..... \qquad (1)$$

Where K_a = coefficient of active earth pressure

q = surcharge pressure r = average unit weight of soil fill and σ_h is the lateral pressure at any depth 'h'. The tensile force(T_h) acting on a strip at a depth 'h' is given by

$$T_h = K_a\ (q + rh)\ X\ Z \quad ...... \qquad (2)$$

Where X and Z are respectively the horizontal and vertical spacing of the strips. Usually reinforced earth structures are designed for (a) internal stability and (b) external stability. The former in a given situation depends upon the dimensions, spacing and material used for the strips as well as the soil fill. For satisfactory performance, the strips should not fail either by tension or by pull out mode of failure. The dimensions of the strip are to be chosen to satisfy the condition that

$$F_y\ w\ t \;=\; F_{sy}\ T_{max} \quad ..... \qquad (3)$$

Where F_y = yield stress of strip material, w and t are the width and thickness of the strip, F_{sy} is the factor of safety against breaking of strip and T_{max} in the maximum tension force acting on any strip in the structure under design, given by eq. (2). The factor of safety with respect to pull out mode of failure F_{sq} is

$$F_{sf} = \frac{2\ l\ w\ \tan\phi_\mu}{K_a\ X\ Z} \quad ..... \qquad (4)$$

Where l = effective length of a strip at any height 'h', given by the expression L-(H-h)/tanθ where L = full length provided for all strips, θ = $(45^\circ + \phi/2)$ where ϕ = angle of internal friction of the soil fill as compacted. ϕ_μ = friction angle between the soil fill and the reinforcing strip used, and obtained from a direct shear box test under relevant conditions. For the external stability, the reinforced earth mass is checked for stability against (i) sliding at the base (ii) overturning about the toe (iii) bearing capacity failure and (iv) settlement that impairs its functionality.

3 METHODOLOGY FOR TESTING PROGRAMME

3.1 Earlier Studies

Earlier studies conducted by the authors, (Venkata Ratnam(1987),Bhalabadra Rao(1988), on instrumented laboratory model of 1.10m high and 1.20m long, using sand for earth fill and teak-wood cruciform shape skin element 20mm thick and (ii) a pilot model of reinforced earth retaining wall using RCC skin elements and earth fill, both identical to those used in the present studies have provided valuable data and a good insight for locating the instrumented portion in the proposed prototype for obtaining reliable performance data.

3.2 Details of Prototype embankment

The prototype embankment comprises of a 15.0m long level portion, 10.5m wide and 4.20m high connected to an existing road (elevation 0.20m) on one end, with an approach ramp 60m long and of slope 1:15, and a vertical reinforced earth face 4.20m high for the full width of 10.5m on the other end, referred to as the dead end.

3.3 Skin elements

The vertical side surfaces for the ramp portion are covered with galvanised iron(G.I.) sheet skin elements of semi-elliptical section with suitable overlaps and joints and of size 240 x 25 x 0.10 cm for an initial length of about 35.0m, and RCC cruciform panels 8 cm thick and of overall size 90 x 60 cm with a recess on the edges to facilitate snug fit, for the balance length of the sloping portion as well as the level portion of the embankment. The semi-elliptical G.I. skin elements are prepared from standard GI sheets by cutting followed by moulding to the desired shape and size, using a special moulding device. The RCC cruciform panels with nominal reinforcement are cast at site using appropriate moulds. During casting, a short length of strip element (Bent to a channel shape of size 30 cm x 15 cm) is embedded in the panel with its ends projecting out as stubs, on the inside face to facilitate joining the reinforcing strips to be placed in the embankment. Five different types (slightly modified) of concrete panels, A,B,C,D and E (Fig.1) to meet the needs for the bottom, intermediate and top layers, have been cast to the required number and used.

3.4 Reinforcing Strips

Two different materials are used for these (i) Aluminium strip of requisite strength of size 360 x 6.0 x 0.12 cm in the level portion including the instrumented test zone, cut from the commercially available standard size sheets, and (ii) Galvanised(GI) plane strip of size 240 x 6.0 x 0.10 cm for the approach ramp. Their respective yield tensile strength are 1450 and 3600 Mpa respectively.

3.5 Backfill

The portion of backfill from the innerface of skin elements upto the end of reinforcing strip length is referred to as select fill, which in this study is a murum soil with a uniform coefficient of 3.0 and having an angle of internal friction of 35° at a compacted density of 19.0 KN/m^3. In the other portion referred to as random fill, locally available black cotton soil has been used.

3.6 Sequence of Construction

The soil profile at site comprises of black cotton type soil for the top 1.8 to 2.0m depth underlain by poorly graded murum to gravelly murum. The site is fairly level and the soil is excavated upto a depth of 0.60m and a concrete bed of 1:3:6 mix and size 30 cm wide and 15 cm thick is laid for the full length of reinforced wall facing on both sides as well as the vertical dead end face. (Fig.1). The first course of skin elements consists of half full size (Type A) and full size (Type B) RCC skin elements with flat bottom edges and of size 90 x 30 cm and 90 x 60 cm respectively are placed alternately to ensure break of horizontal joints. These panels rest on the concrete bed to facilitate their plumb line. The soil fill dumped and evenly mixed with water at optimum moisture content, is spread uniformly and continuously for a depth arrived at by trial and error, so that after compaction to its maximum dry density, a finished thickness of 15 cm is achieved. The compaction is done by a 2.5 tonne roller operated manually. However, the compaction on the sides upto a distance of 0.30m from the inside face of panels, has been carried out by hand ramming. The reinforcing strips of the desired length are connected to the ends of the stubs projecting from the skin elements by means of two 6.3mm diameter bolts and nuts. It is ensured that the strips as far as practicable stay horizontal in the soil fill after the compaction is completed. The second course of

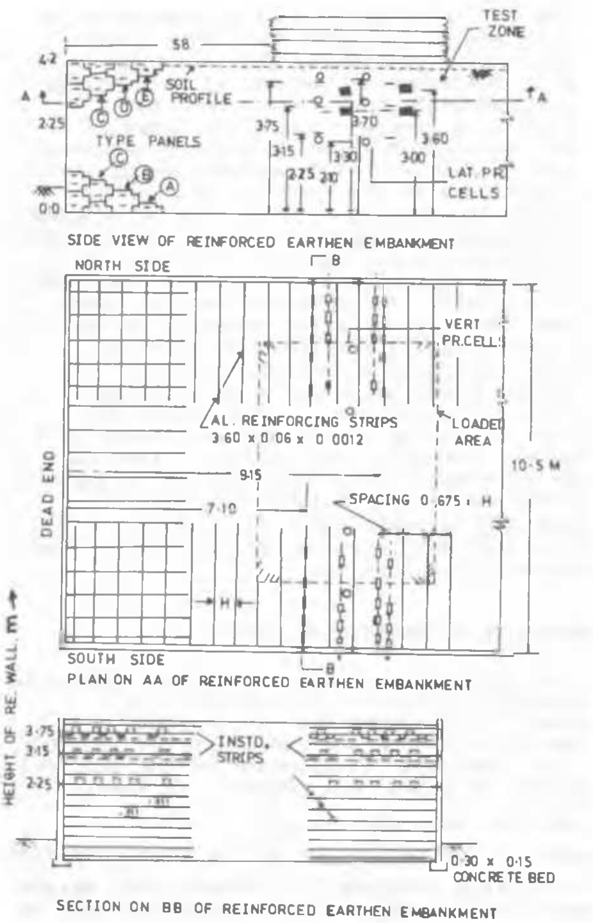

Fig.1 Prototype Reinforced Earth Embankment.

panels (Type C) is positioned on the top of the first course ensuring vertically by the smooth insertion of M.S. rods of 6.0 mm diar. into the dowel holes of 20.0mm/provided during ∠ dia. casting of the elements for the said purpose. The finished lift of each subsequent compacted layer of soil is 30 cm equal to the vertical spacing of the reinforcing strips. The above mentioned operation is repeated for each lift of the embankment till the final height is accomplished with no major variation. The top row of skin elements is made up of alternate half (Type D) and full (Type E) panels with their top edges flat and smooth for neat finish. Temporary struts are used to prop the outside face of the skin elements, to prevent possible excessive deflection during errection and compaction. The same have been subsequently removed as the construction has advanced. However, beyond the height of 2.5m these struts are not used. Similar procedure duly modified has been adopted for the errection of G.I. semi elliptical skin elements, for which special care has been taken to stagger vertical joints in successive layers. Suitable measures are taken to ensure quality control for the compacted fill and provide weep holes for drainage.

3.7 Instrumentation and Observations

The test section which is instrumented to measure various parameters both during construction and after application of surface area loading, is located centrally in level portion.

In this portion, the lateral deformation of the sides (vertical reinforced earth face) is measured with reference to guide posts fixed rigidly at base and vertically, 30cm away from the facing. In the test zone, two such guide posts on each of the two sides, connected by thin GI wire marked at every 0.30m have facilitated the measurement of lateral deformation at every strip location in a grid pattern for the full range of loading studied.

The lateral earth pressures on panels are measured by means of 100mm dia. brass earth pressure cells (Diaphragm type) designed, fabricated and calibrated by the authors, and placed on the inside face of skin elements and kept flush with the panel face (In a recess left while casting the skin elements). Six pressure cells are kept on each side at two locations distant 7.1 and 8.45m from the dead end and at elevations of 2.1, 3.30 and 3.90m. The vertical pressures in the composite soil mass are measured by means of eight numbers of 100 mm dia. brass pressure cells positioned horizontally and symmetrically from either side at distances of 1.80 and 3.60 and at elevations of 3.30 and 3.90 m at each location.

To study the variation in magnitude of tensile stress along selected reinforcing strips, five numbers of bakelite electrical resistance type gauges spaced uniformly along the length and attached to the strips, are used (Fig.1). All these are connected by means of four and two core lead wire to the switching and balancing unit which in turn is connected to a digital strain indicator read for recording readings as the construction progressed in stages followed by surface area loading thereafter.

3.8 Load Application

After the completion of construction to the desired height of 4.2m, surface area loading is applied symmetrical to the width of embankment and in stages. The plan of the loaded area is 8m (Across the embankment) x 5m such that it commences at a distance of 5.50m and extends upto 10.5m from the dead end. The load is applied by dead weight. (Empty gunny bags filled with dry sand). Each bag is filled to the required weight, then stitched and placed in position. Thus each layer of sand bags, weighs around 9 tonnes which is taken as the incremental load, and allowed for 24 hours to facilitate record of readings before the next increment is added. All readings are recorded before each load increment and at regular intervals whenever there is discernible difference under any specific load with lapse of time. This procedure is continued till the desired load of 105 tonnes is reached in eleven stages.

4 PRESENTATION OF RESULTS

For the properties of the materials used the computed factors of safety are 1.8 and 1.4 against failure of reinforcing strip in tension and pull out respectively.

4.1 Lateral Deformation

The bottom row of panels remained vertical upto the end of construction. However, the skin elements at a height of about 2.5m did deform upto about 0.5 to 0.7% of the height and the deformation increased to a maximum of 2.3% of the height after the full height of 4.2m is completed. The increase in lateral movement under increasing surface area loading is plotted in Fig.2. The outward tilt of about 2.0% has occured by the end of construction and a further tilt of 0.5% is observed under applied loading.

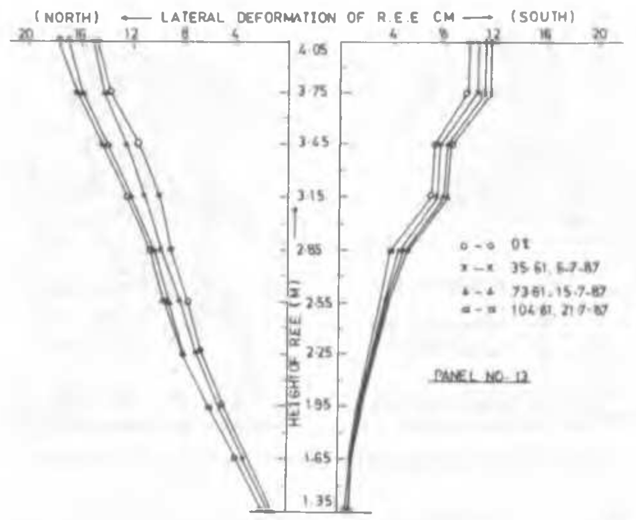

Fig. 2 LATERAL DEFORMATION OF R.E.E. BOTH DURING CONSTRUCTION AND UNDER APPLIED SURCHARGE.

4.2 Lateral Pressure

The lateral pressures recorded at the end of construction at 2.10, 3.30 and 3.90m height at a distance of 7.10m from the dead end, i.e. in panel no.11 are 45, 15 and 3.5 Kpa respectively on the Southern side. The variation of the pressure at the end of construction and under various loads are plotted in Fig.3. The load applied is converted to the equivalent height of fill. Under various equivalent heights of fill the pressures recorded are presented in Fig.3.

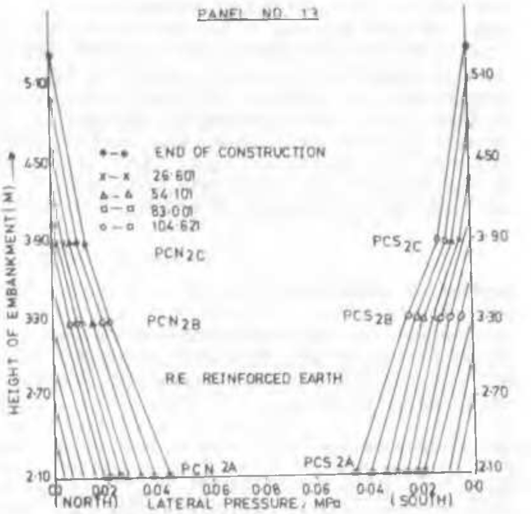

Fig 3 LATERAL PRESSURE OF R.E. WALL DUE TO SOIL AND SURCHARGE

4.3 Tensile Stress Distribution in Strips

At any stage of construction or loading later, the tensile stress in an instrumented strip is computed from the strain recorded at the corresponding section and the elastic modulus of the strip material. Fig.4 indicates the tensile stress variation along the length of instrumented strips for the range of loading studied.

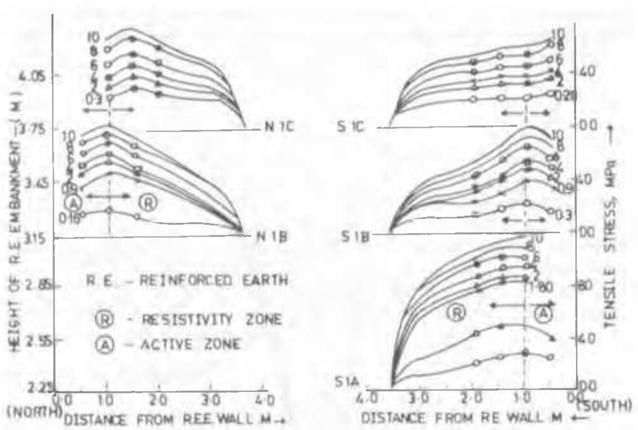

Fig.4 TENSILE STRESS DISTRIBUTION IN STRIPS DUE TO SOIL AND SURCHARGE

5.0 DISCUSSION OF RESULTS

The lateral deformations on average are of the order of 2.0% of the height during construction and 2.5% during surface area loading which are well within **reasonable** limits. This lateral movement is attributed to (i) non-snug fit of adjacent/skin elements and (ii) method of compaction which can be improved with experience. The lateral deformation is found to be more in respect of G.I. elliptical skin elements as compared to RCC skin elements under identical conditions.

The measured lateral pressures on the skin elements at the end of construction are about 1.2 to 1.4 times the predicated values. Considerable intermittent delays and inadequate attention during those periods may be some of the causes. However, under applied loads, the measured values range between 1.1 to 1.15 times the computed values.

The measured stresses in the reinforced earth mass, at the end of construction are about 10 to 12% in excess of computed values. The tensile stress in the reinforcing strips increases gradually from zero at free end to a maximum in its middle third portion, and then tends to decrease towards the panel end. The locus of the location of maximum tensile stress in the strips is nearly vertical upto mid depth which divides the reinforced earth fill into an active and a resistant zone. Effect of ambient conditions on the long term performance is under study. The limited data establishes that the reinforced earth construction technique is advantageous and could be considered as a cost effective alternative method. However, more studies of this nature are recommended to help the economic growth of the country.

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