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An analytical approach to compute design loads of reinforced earth embankments

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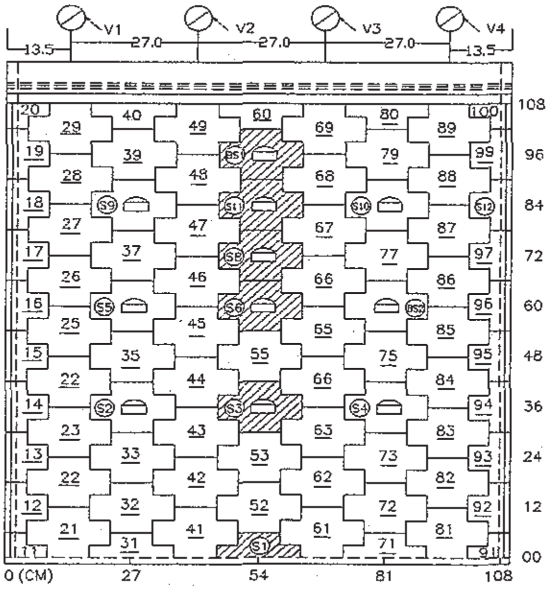
ABSTRACT: This paper presents the details of a large scale fully instrumented reinforced earth (RE) model wall (provided with teak wood facing panels and hand cut metallic strips for reinforcement) tested to failure under surface area (rectangular) load with varying edge distances. All the instrumentation used in this study, such as strain gauges, lateral and vertical earth pressure cells, an eighty six point light emitting diode (LED) tell tale system for sequential record of strip breakages etc.(designed, fabricated, calibrated and tested by the authors) was used to measure various values including lateral pressure on facing elements and tensile stress variation along reinforcing strips. For correlation studies, these values are compared with the corresponding values computed from classical earth pressure theories modified to simulate the test conditions. The load intensity causing first strip breakage is taken as the ultimate load on the wall and this value divided by a factor of safety 3 considered appropriate in view of the various constraints affecting field construction procedures and quality assurance, is taken as the allowable load.

1 INTRODUCTION

Reinforced earth walls with galvanized steel strips for reinforcement and R.C.C. cruciform shaped facing panels have come to stay as a credible innovative construction technique for approach embankments of flyovers, abutments etc. Considerable research and performance studies on laboratory model and field prototypes have resulted in better analysis, design methods and construction techniques as well as specifications for materials to be used with its attendant improved performance and quality assurance. Nevertheless, correlation studies between lateral earth pressures actually measured in tests and those obtained from classical earth pressure theories duly modified to simulate test conditions have been scarce. This paper details an attempt to modify the expressions (based upon classical theories) to evaluate the load intensity that causes the first strip breakage and the variation in lateral pressures on facing elements to obtain reasonable correlation with those actually measured in laboratory tests.

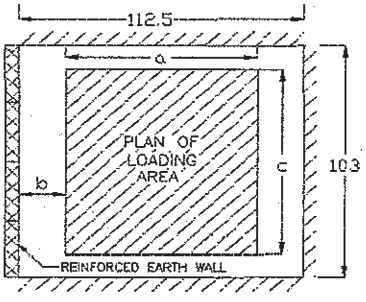
2 DESCRIPTION OF THE MODEL

The assembly of the RE wall model was built in a model box that fits into a self straining loading steel frame fitted with an appropriate loading mechanism and load measuring device comprising of a hydraulic jack and a proving ring each of 100 tons capacity. The model box of size 1.03 x 1.12 x 1.08 m has three sides made up of wooden planks stiffened with steel sections and the fourth side is open and kept free from the adjacent sides to facilitate fabrication of RE wall comprising of hand cut steel strips 800 x 10 x 0.137 mm for reinforcing elements provided with a hole at either end to receive a 3mm steel bolt with washers to facilitate connection to the skin element at the facing end and LED circuit connection at either end. The horizontal and vertical spacing of these strips are 27 cm and 6 cm respectively. The skin elements (86 nos.) of teak wood, cruciform in shape and 180 x 120 x 20mm in size are made up of two pieces 13 mm and 7 mm thick laid one over the other and nailed such that edge projections are available for necessary interlocking. The facing end of each strip is connected to the facing element at its center through an aluminium T bracket connector of size 20 x 18 x 18 mm screwed into the panel at its center. Soil used for the back fill is a medium sized sand (sw - sp) obtained from a nearby river source. The soil is compacted in layers such that the finished thickness of each layer equals the vertical spacing of strips. The strips are laid horizontally on the surface of the compacted layer and properly positioned and the next layer of soil is spread uniformly to needed thickness and compacted. This process is repeated till the model is completed. All the relevant properties of the materials used for facing elements, joints, reinforcing strips and the soil used, are determined and checked to satisfy the specifications and for use in the design. The arrangement of facing elements,



V1,V2.V3.V4: SURFACE SETTLEMENT GAUGES, (S6) : STAINLESS STEEL EARTH PRESSURECELL EMBEDDED IN FACING PANEL, 52: FACING PANEL NUMBER. – : LOCATION OF REINFORCING STRIP ATTACHED TO PANEL, ⌓ :DIAL GUAGE TO RECORD LATERAL DEFORMATION OF PANEL, ▨ :PANEL WITH STRAIN GAUAGED STRIP

Figure 1. Arrangement of facing panels, and location details of instrumentation.



TEST	a (cm)	b (cm)	c (cm)
1.	102.5	3.5	100.5
2.	96.0	10.8	99.0
3.	80.0	17.0	100.0
4.	58.0	27.0	100.0
5.	102.5	3.5	100.5

DETAILS OF LOADED AREA FOR DIFFERENT TESTS

LOADED AREA : a X c

EDGE DISTANCE : b

Figure 2. Plan of loaded surface area for different tests showing edge distance from r.e.wall.

and the details of instrumentation provided, common to all tests, are presented in Figure 1. Each strip is connected to the LED assembly that is provided with a bulb projecting out at the center of each skin element which blows out when the strip breaks and thus breaks the circuit. The actual lay out of loaded surface area and edge distances adopted for all the tests conducted are shown in Figure 2. The circuit details of the LED assembly are shown in Figure 3.

3 INSTRUMENTATION USED

a) Multi-channel switching and balancing units for measurement of strain gauged bridge output simultaneously from about 60 locations. b) 50mm diameter stainless steel diaphragm type strain gauged earth pressure cells to record lateral pressure on skin elements. c) 100 mm diameter brass diaphragm type pressure cells to record i) toe pressures at either end and center of RE wall, ii) lateral pressure along the height of one rigid vertical side of the model box, iii) vertical pressure in the compacted soil fill at three different depths vertically below the center of the loaded area, d) strain gauged (half bridge) reinforcing strips to record the tensile stress variation along their length. These are located at the relevant and vulnerable positions (usually along the central section of the loaded area) to obtain the peak values of various parameters. Also, included is the apparatus to conduct pull out test on the dummy additional strips provided, equipment for calibration of pressure cells, dial gauges and datum bars to measure lateral deflection of RE wall, and dial gauges to measure surface settlement at the four corners of the loaded surface area in all the tests conducted up to failure.

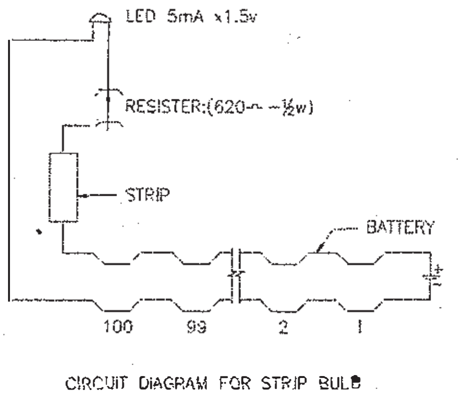


Figure 3. Layout of instrumentation – L.E.D. display unit (common to all tests).

4 TEST PROCEDURE

The construction of model is completed after ensuring that the instrumentation has been duly installed at each stage as planned and ensuring its satisfactory working. The plates one over the other decreasing in size from bottom to top plate for transfer of load applied, are arranged over which the load application device and measuring device are properly positioned. All initial readings from the instrumentation are also recorded. The load is applied gradually in increments of 50 kN/m^2. After each load increment, all the instruments are checked, read properly and the values recorded. This is repeated till the first strip breakage occurred, as indicated by the blow out of the glowing bulb at the center of the skin element connected to the broken strip, and the test is continued till failure, as indicated by either excessive lateral deformation of the wall leading to considerable gap between adjacent skin elements with attendant leakage of soil fill or by breaking of reinforcing strips accompanied by noise and excessive outward movement of skin elements or a possible combination of both. Later, the set up is carefully dismantled, and the sand filling is carefully removed in stages to facilitate complete and correct record of location and mode of breakage of all torn strips. Quite a few strips failed at the bolt hole connection with the facing elements. The same procedure is repeated for all tests conducted.

5 COMPUTATION OF RESULTS

5.1 *Load intensity causing first strip breakage*

5.1.1 *Experimental approach*

For any test, the load intensity corresponding to the first breakage of strip(s) is obtained from the LED display board. The total load applied as indicated by the proving ring divided by the loading area gives the value.

5.1.2 *Analytical approach*

After a discreet study of the various classical theories, Modified Spangler's (1982) approach is found to give values closest to the experimental values in respect of the surface area load intensity causing the first strip breakage. The approach to derive the expression is described below briefly. For a point load P, Boussinesq's formula for the lateral pressure s_{xx} on a flexible wall imagined to be a simple vertical plane in an elastic half space is given by

$$s_{xx} = (3P.x^2z) / (2\pi R^5) \qquad (1)$$

taking poisson's ratio μ for back fill as 0.5 and $R = (x^2 + y^2 + z^2)^{1/2}$. The Spangler's formula, a modification of Boussinesq's point load formula for a rigid retaining wall, considered by Terzaghi (1943) and Spangler (1982) etc. is given by

$$s_{xx} = 2\,(3P.x^2z) / (2\pi R^5) \qquad (2)$$

Spangler's modified formula intuitively arrived at for computing the lateral pressure on a RE wall facing having partial rigidity is given by the expression

$$s_{xx} = (2 - R^*)(3P.x^2z) / (2\pi R^5) \qquad (3)$$

where R* is a reduction factor explained below. This equation is integrated for a rectangular surcharge load intensity q (t/m²), shown in Figure 4, and the lateral pressure on the wall facing due to superimposed area load is given by

$$s_{xx} = (2 - R^*)(2)\,q\,(A-B-C+D) / 2\pi \qquad (4)$$

Where $A = \tan^{-1}(x_2 y_1 / z R_{x2})$,

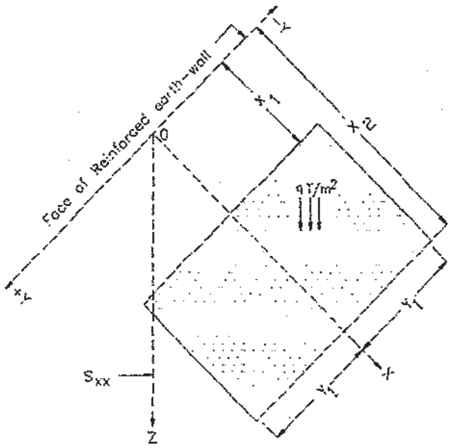


Figure 4. Boussinesq's approach (for area loading).

$B = x_2y_1z / (x_2^2+z^2)R_{x2}$, $C = \tan^{-1}(x_1y_1 / zR_{x1})$,

$D = (x_1y_1z)/(x_1^2+z^2)R_{x1}$, $R_{x1} = (x_1^2 + y_1^2 + z^2)^{1/2}$

and $R_{x2} = (x_2^2 + y_1^2 + z^2)^{1/2}$

Lateral pressure distribution on the RE wall facing elements due to an area surcharge will be maximum on the central vertical section of the loaded area. The values for each symbol used in the equations are obtained for each test conducted. The value of the reduction factor R* is evaluated from the relationship

$$R^* = 1 / (1 + k^*) \qquad (5)$$

Where k* is the relative stiffness factor (Relative flexural rigidity) of the facing or skin of a RE structure.

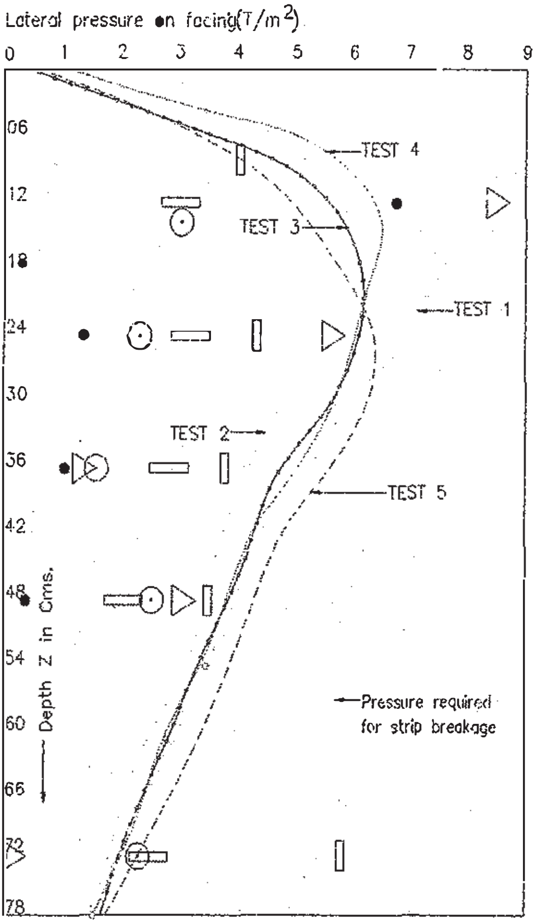
For a perfectly rigid facing, $k^* \rightarrow \infty$ while

for a perfectly flexible facing, $k^* \rightarrow 0$.
If $k^* = 0$ then

$R^* = 1$ and if $k^* = \infty$, then $R^* = 0$.

$$K^* = \frac{(39-\mu_s^2)E_p\{t\}^3}{(12-\mu_p^2)E_s\{0.5H\}^3} \qquad (6)$$

where μ_s and μ_p are the Poisson's ratios of the reinforced soil (assumed as 0.35) and wall facing material (taken as 0.25 for teak wood) respectively. For steel and reinforced concrete these values are 0.3 and 0.15 respectively. E_p and E_s are the stress-strain moduli for facing material and reinforced soil. The latter is taken approximately equal to that of unreinforced back fill soil, which depends upon a number of factors such as in-situ density, rate of loading, vertical stress, confining pressure, stress history etc.



TEST NO.	Lateral Pressure (a)	(b)	Strip Breaking LoadT/m² (a)	(b)
1.	· · · ··	▭	12.30	18.60
2.	· · · ·	⊙	15.90	15.80
3.	——	▷	19.40	20.00
4.	…………	▯	15.70	16.40
5.	-- -- --	●	27.60	30.00

a. As per modified Spangler theory
b. Recorded

Figure 5. Lateral pressures (recorded and computed).

This is to be determined from the slope of the tangent drawn at the relevant point on the stress strain curve obtained from triaxial compression test conducted in the laboratory on back fill sample (CD test). Alternatively this may be obtained as E_t (Tangent modulus for the backfill) as proposed by Kondener and Zelasko (1963) and modified by Duncan and Chang (1970) from the equation:

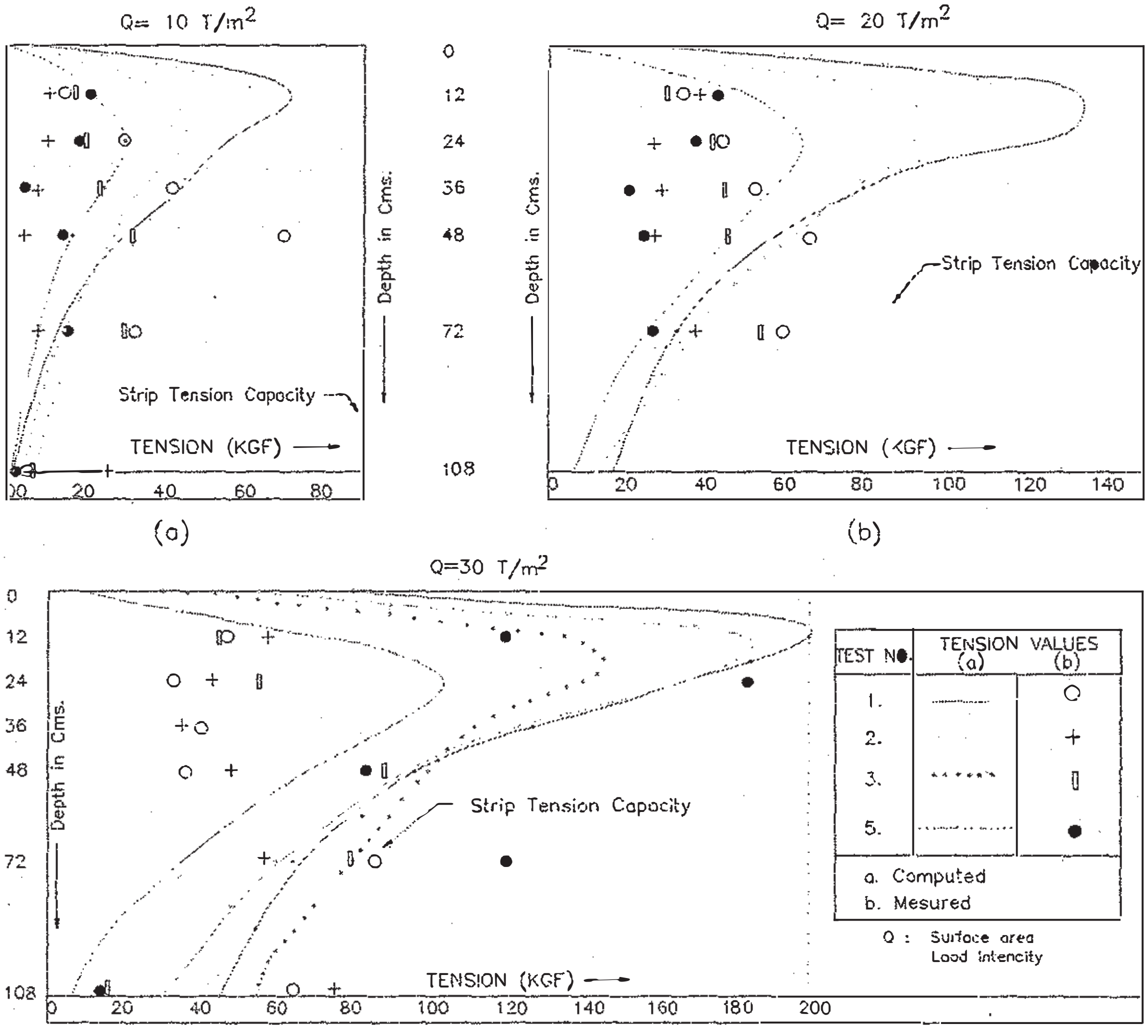
$$E_t = \{1 - M\}^2 k \sigma_a (\sigma_h / \sigma_a)^n \quad (7)$$

where $M = R_f (1-\sin\phi)(\sigma_v - \sigma_h)(2c\cos\phi+2\sigma_h \sin\phi)$ and R_f is a failure ratio equal to $(\sigma_v - \sigma_h)$ at failure divided by the asymptotic value of $(S_v - S_h)$, k is a modulus number, n is an exponent determining the rate of variation of initial tangent modulus with σ_h, σ_a is atmospheric pressure (10.13 t/m²), c is cohesion and ϕ is angle of internal friction of the backfill E_t is taken as zero i the value of $M \geq 1$. Values of R_f, k, n, c, and ϕ are to be determined experimentally. However, in the absence of tests the following values can be assumed in respect of a cohesion less soil fill. R_f=00.70, k=400, n=0.5, c=0 and $\phi=36^0$. The major principal stress $\sigma_v = (\sigma_1)$ is due to the self weight of backfill and the surface load above. The vertical stress component due to the surcharge is assumed to disperse uniformly on an area bounded by 2:1 dispersion. This assumption is justified as shown by Bowles (1982) that there is insignificant difference between the vertical pressure under a rectangular area load predicted by Boussenesq's theory and that derived from 2 to 1 stress distribution at critical depth equal to or greater than the width of the area load. The lateral pressure on the RE wall facing σ_{xx} can be computed as the sum of the lateral pressures caused due to compacted soil fill and the surcharge load applied on the surface.

6 CORRELATION OF DATA AND DESIGN

6.1 *Lateral earth pressure on RE wall facing*

Figure 5 presents the correlation study in respect of latcral pressure variation along the height of RE wall facing for its full height as obtained from (a) modified Spangler's approach and (b) the recorded values from instrumentation installed in the model for the surface area load intensity causing first strip breakage. The results are presented for four of the tests conducted with varying edge distance and size of loaded area as detailed in Figure 2. The analytical values fall within a small band width while the measured values show wide variation. A notable factor is the edge distance variation from test to test. In some tests it is less than minimum value usually specified. This could not be monitored because of limitations imposed by the model dimensions chosen. However, the edge distance is taken as the minimum specified or the actual value (whenever it is higher) for computation purpose. The analytical values are slightly on the higher side of observed values, thus ensuring safety. A factor of safety 3 is recommended to make good for the constraints that affect the quality assurance on the field. As such it is recommended that for any given RE wall either built or to be built, the area load intensity that causes the first strip breakage can be computed as the ultimate load. The permissible load can be arrived at with a factor of safety subject to a minimum edge distance of 1 m or one tenth height of wall (higher of the two



(a) (b) (c)

Figure 6 (a), (b), (c). Measured values of tension compared with computed values.

values). The design of the reinforcing strip against tension mode of failure is as follows:

$$T = \sigma_{xx}\ \Delta H\ \Delta S = \sigma_{yy}\, b\, t\ /\ F.S._{y} \qquad (8)$$

where b and t are the breadth and thickness of the strip and ΔH and ΔS are the vertical and horizontal spacing of the strips, and σ_{xx} and σ_{yy} are the stresses. Against pull out mode of failure.

$$T = \sigma_{xx}\ \Delta H\ \Delta S = \sigma_{zz}(\max) 2b \tan\varphi L_e\ /\ F.S\mu \qquad (9)$$

where $F.S._y$ and $F.S._\mu$ are factors of safety against tension and pull out modes of failure of strips, $\sigma_{zz}(\max)$ for a given load intensity q, taken as the maximum of all the values computed for different depths up to the bottom of the wall, is adopted in the design. L_e is the effective grip length of the strip.

6.2 *Maximum tension occurring in the strips*

The model wall is subjected to incremental load intensity over the total loading area in each of the tests. Figure 6 presents the values of maximum tension occurring in each of the strain gauged strips extending for the full height, at the center section of the loaded area for the load intensities of 10, 20 and 30 tons per square meter, marked (a), (b) and (c) in the figure, in respect of 4 tests conducted. The measured values shown are the corresponding maxi-mum tensions measured in each of the strips strain gauged at five locations along the length. As can be seen, the computed values as per modified Spangler's approach, form a band width and nearly envelop the recorded maximum tensions. This again indicates the validity of the use of modified Spangler's analytical approach.

7 CONCLUSIONS

(a) A light emitting diode tell tale system that can be connected to an innumerable number of reinforcing strips, has been designed and its satisfying performance has been established, for obtaining a record of surface area loading intensity that causes the first strip breakage, followed by a record of sequential strip breakages that occur upto the total failure of the RE wall.

(b) The analytical approach using modified Spangler's theoretical equation, so far as the limited data available from this study, holds promise to predict the ultimate load as well as design load intensity for any proposed or built up RE wall for which the data in respect of all the materials either used or proposed to be used is made available.

(c) It is considered prudent to recommend a factor of safety 3 for the load that causes the first trip breakage, to compute the safe design load for any given RE wall with details of design load, construction materials and construction technique as well as site characteristics.

(d) The limited data available from this analytical approach, tallies reasonably with the criteria for internal stability against tension failure and pull out failure usually adopted in the design of RE walls.

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