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Analysis of Inclined Retaining Wall Having Reinforced Cohesionless Backfill with uniformly Distributed Surcharge

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Introduction

The technique of reinforcing the soil has been widely accepted as an economical alternative construction technique for earth retaining structures and improving the poor ground. The usefulness of the patented reinforced earth retaining wall of Vidal has been proved economical by thousands of such structures constructed all over the world. But situations can be met where reinforced earth walls may not provide ideal solution. This can be true for location with limited space behind wall or for narrow hill roads on unstable slopes which may not permit use of designed length of reinforcement. In such circumstances a rigid wall with reinforced backfill may appear more appropriate. Backfill is reinforced with unattached horizontal strips/mats/nets laid normal to the wall.

Broms (1977, 1987), Hausmann and Lee (1970) performed model tests and reported considerable reduction in moments at the base of wall. Talwar (1981) developed non dimensional curves for obtaining earth pressure and its point of application in vertical wall with horizontal reinforced backfill. Garg (1988) extended the work of Talwar (1981) for the surcharge on the backfill.

These studies illustrate the effectiveness of unattached reinforcement in reducing the lateral earth pressure on a vertical rigid wall. However, the effect of inclination of wall back with vertical has not been considered. In practice, the back of retaining wall is kept inclined. Thus there is a need to

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develop an analysis for the inclined retaining wall having reinforced backfill with uniformly distributed surcharge load. An attempt has been made to develop an analysis applicable to both strip and mat type reinforcements.

Theoretical Analysis

The following assumptions were made to develop the analysis of inclined retaining wall having reinforced backfill with uniformly distributed surcharge load.

1) The backfill is homogeneous, isotropic and non-cohesive.

2) The failure surface is a plane passing through the heel of retaining wall.

3) The coefficient of friction between soil and reinforcement is independent of the overburden pressure and the length of reinforcement.

4) The failure plane divides the length of reinforcing strip in two zones, one that lies within failure wedge another out side. Only that part of strip which experiences movement of soil relative to itself is assumed to be contributing frictional resistance.

5) The frictional resistance to the lateral movement of wedge of backfill behind the retaining wall contributed by a reinforcing strip is assumed to be uniformly distributed over a fill height equal to vertical spacing of reinforcement encompassing that reinforcement strip.

6) The retaining wall undergoes an outward movement or rotation about the base which is sufficient to cause mobilisation of full frictional resistance in the soil as well as reinforcing strips.

Analysis

Consider a retaining wall of height H with inclined back making angle β° with vertical, retaining a horizontal cohesionless backfill of dry unit weight γ and angle of internal friction ϕ° supporting uniformly distributed load of intensity of q (Fig.1) . It is reinforced with unattached horizontally laid strips of length L and width w at vertical spacing S_V and horizontal spacing S_H. A failure plane BC making an angle θ with the vertical passes through the heel of retaining wall. The frictional resistance to the lateral movement of the wedge ABC contributed by a reinforcing strip is computed from its effective length. Effective length is the portion of the strip which experiences movement of soil relative to itself. Reinforcing strip located completely with in the moving wedge will not contribute any frictional resistance to the movement of wedge.

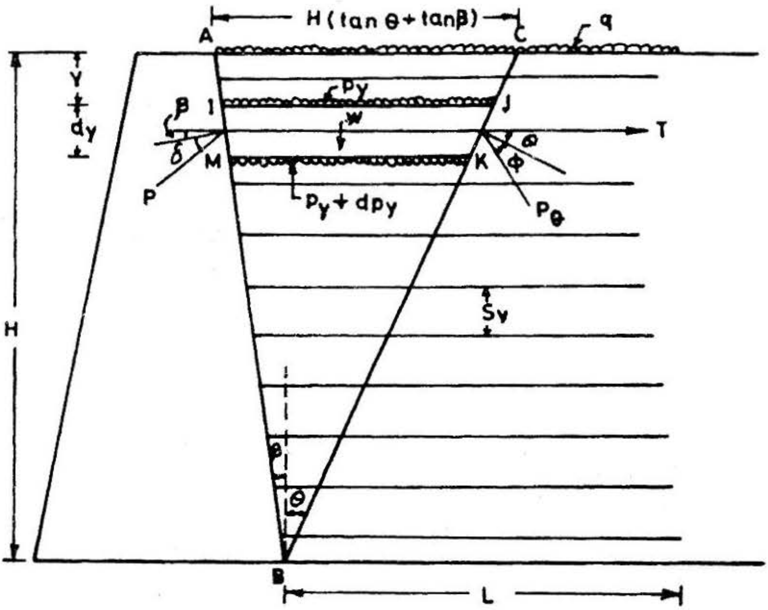

FIGURE 1 : Wall Details with Reinforcement

Considering equilibrium of an element IJKM of thickness dy of failure wedge ABC; located at a depth y from the top of the wedge (Fig.1). Following forces per unit length of the wall act on the element of the wedge ABC.

p_y = pressure intensity acting on IJ in the vertical direction

$(p_y + dp_y)$ = pressure intensity acting on KM in the vertical direction

p_q = reaction intensity on JK acting at an angle ϕ to the normal to JK.

p = pressure intensity on IM acting at an angle δ with the normal to IM

W = weight of slice IJKM acting downwards

T = tensile force in the strip assumed transmitted uniformly to soil layer of thickness S_V encompassing the strip,

$$t = \frac{T}{S_V} = \frac{2 \cdot w \cdot f^* L_e \sigma_v}{S_H S_V}$$

b = inclination of wall back with vertical

(i) Considering static equilibrium of the element of wedge under the action of all the forces in the horizontal direction:

$$t \cdot dy + p\cos(\delta+\beta)\sec\beta = p_\theta \cos(\theta+\phi)\, dy \sec\theta \text{ , or}$$

$$p'_\theta = \frac{t' + p'\cos(\delta+\beta)\sec\beta}{\sec\theta\cos(\theta+\phi)} \tag{1}$$

where $p'_\theta = \dfrac{p_\theta}{\gamma H}$, $t' = \dfrac{t}{\gamma H}$, $p' = \dfrac{p}{\gamma H}$

(ii) Considering static equilibrium of the element under the action of all the forces in the vertical direction

$$\begin{aligned} p_y (H-Y)(\tan\theta - \tan\beta) &- (p + dp_y)(H - Y - dy)(\tan\theta + \tan\theta) \\ &+ \gamma\, dy \frac{(H-Y)(\tan\theta - \tan\beta) - (H-Y-dy)(\tan\theta + \tan\theta)}{2} \\ &- p\sin(\delta+\beta)\, dy \sec\beta - p\theta \sin(\theta+\phi)(\tan\theta + \tan\beta) = 0 \end{aligned}$$

Neglecting small quantities of second order the expression reduces to

$$\begin{aligned} \frac{dp'_y}{dy'} = \frac{p'_y}{(1-y')} + 1 - \frac{p'}{(1-y')} \frac{\sin(\delta+\beta)\sec\beta}{(\tan\theta + \tan\beta)} \\ - \frac{p'_\theta}{(1-y')} \frac{\sin(\theta+\phi)\sec\theta}{(\tan\theta+\tan\beta)} \end{aligned} \tag{2}$$

where $dy' = \dfrac{dy}{H}$, $y' = \dfrac{y}{H}$

(iii) Taking moments of all the forces about the mid point of slice between J and K

$$p_y\,(H-Y)(\tan\theta+\tan\beta)\left\{\frac{(H-Y)(\tan\theta+\tan\beta)}{2}-\frac{dy}{2}\tan\theta\right\}$$

$$-(p_y+dp_y)(H-Y-dy)(\tan\theta+\tan\beta)\left\{\begin{array}{l}\dfrac{(H-Y-dy)(\tan\theta+\tan\beta)}{2}\\[2ex] -\dfrac{dy}{2}\tan\theta\end{array}\right\}$$

$$-p\sin(\delta+\beta)\,dy\sec\beta\left(H-Y-\frac{dy}{2}\right)(\tan\theta+\tan\beta)$$

$$+\gamma\,dy\,\frac{\left(H-Y-\dfrac{dy}{2}\right)^2(\tan\theta+\tan\beta)^2}{2}=0$$

Simplifying and neglecting small quantities of higher order yields

$$\frac{dp'_y}{dp'}=1-\frac{2p'}{(1-y')}\frac{\sin(\delta+\beta)\sec\beta}{(\tan\theta+\tan\beta)}-\frac{2p'}{(1-y')}\left\{\frac{\tan\theta}{(\tan\theta+\tan\beta)}-1\right\} \quad (3)$$

Substituting the value of p_θ from Eqn. (1), Eqn. (2) reduces to

$$\frac{dp'_y}{dy'}=1+\frac{p'_y}{(1-y')}-\frac{p'}{(1-y')}\frac{\sin(\delta+\beta)\sec\beta}{(\tan\theta+\tan\beta)}$$
$$-\frac{\{t'+p'\cos(\delta+\beta)\sec\beta\}}{(1-y')}\frac{\tan(\theta+\phi)}{(\tan\theta+\tan\beta)} \quad (4)$$

Solving Eqns. (3) and (4), one gets

$$p'=C_1\,p'_y-C_1\frac{\tan(\theta+\phi)}{\tan\theta-\tan\beta}t' \quad (5)$$

where $$C_1=\frac{\tan\theta-\tan\beta}{\cos(\delta+\beta)\sec\beta\tan(\theta+\phi)-\sin(\delta+\beta)\sec\beta}$$

On differentiating Eqn. (5) with respect to y'

$$\frac{dp'}{dy'} = C_1 \frac{dp'_y}{dy'} - C_1 \frac{\tan(\theta+\phi)}{\tan\theta - \tan\beta} \frac{dt'}{dy'}$$

Substituting the value of $\frac{dp'}{dy'}$ from Eqn. (3) into the above expression

$$\frac{dp'}{dy'} = C_1 - \frac{2\,p' C_1 \sin(\delta+\beta)\sec\beta}{(1-y')(\tan\theta+\tan\beta)} - \frac{2p'_y}{(1-y')}\left(\frac{\tan\theta}{\tan\theta+\tan\beta} - 1\right)$$
$$- C_1 \frac{\tan(\theta+\phi)}{\tan\theta-\tan\beta} \cdot \frac{dt'}{dy'}$$

Solving the above expression after substituting the value of p'_y from Eqn. (5), one gets

$$\frac{dp'}{dy'} = -C_2 \frac{p'}{(1-y')} + C_1 - C_3 \frac{dt'}{dy'} - C_4 \frac{t'}{(1-y')} \tag{6}$$

where

$$C_2 = \frac{2\{C_1 \sin(\delta+\beta)\sec\beta - \tan\beta\}}{\tan\theta+\tan\beta}$$

$$C_3 = \frac{C_1 \tan(\theta+\phi)}{\tan\theta - \tan\beta}$$

$$C_4 = -\frac{2\,C_1 \tan\beta \tan(\theta+\phi)}{\tan^2\theta - \tan^2\beta} \tag{7}$$

Neglecting C_4 being very small for small values of β, one gets

$$\frac{dp'}{dy'} = -C_2 \frac{p'}{(1-y')} + C_1 - C_3 \frac{dt'}{dy'} \tag{6a}$$

At the limiting equilibrium, the value of t can be taken as

$$\frac{2\,w\,f^*\sigma_v\,L_e}{S_H\,S_V} \tag{8}$$

where w = width of reinforcing strip

f^* = apparent coefficient of friction between backfill soil and reinforcement

σ_v = vertical stress on strip

L_e = effective length of strip

$$t = \frac{2\,w\,f^*\left[\gamma\left(y+dy/2\right)+q\right]L_e}{S_H\,S_V} \tag{9}$$

The values of L_e will vary from strip to strip and will depend on wedge angle θ and length L of the strip. There may be three cases:

Case 1 : $H\left(\tan\theta+\tan\beta\right) \le L/2$

$$L_e = \left(H-Y-\frac{dy}{2}\right)\left(\tan\beta+\tan\beta\right) \tag{10}$$

for all reinforcing elements

Case 2 : $L/2 \le H\left(\tan\theta+\tan\beta\right) \le L$

$$L_e = L-\left(H-Y-\frac{dy}{2}\right)\left(\tan\beta+\tan\beta\right),\ \text{for } Y \le Z1 \tag{11}$$

$$= \left(H-Y-\frac{dy}{2}\right)\left(\tan\beta+\tan\beta\right),\ \text{for } Y > Z1 \tag{12}$$

Case 3 : $H\left(\tan\theta+\tan\beta\right) \ge L$

$$L_e = 0,\ \text{for } Y \le Z2 \tag{13}$$

$$= L-\left(H-Y-\frac{dy}{2}\right)\left(\tan\beta+\tan\beta\right),\ \text{for } Z2 \le Y \le Z3 \tag{14}$$

$$= \left(H-Y-\frac{dy}{2}\right)\left(\tan\beta+\tan\beta\right),\ Y > Z3 \tag{15}$$

For Z_1, Z_2 and Z_3 refer to Fig.2

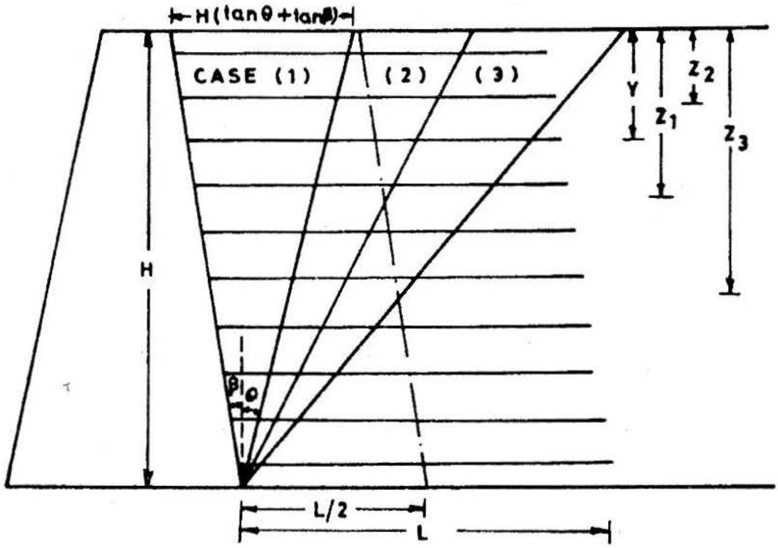

FIGURE 2 : Schematic Representation of Three Cases of Analysis

Examination of Eqns. (10) to (15) reveals that if $L_e > 0$, the effective length L_e is equal to either $(H-Y-dy/2)(\tan\theta+\tan\beta)$ or $L-(H-Y-dy/2)(\tan\theta+\tan\beta)$

(i) If $L_e = \left(H-Y-\frac{dy}{2}\right)(\tan\beta+\tan\beta)$

$$t = t_1$$

from Eqn. (9)

$$t_1 = \frac{2\,w\,f^*\left[\gamma\left(y+dy/2\right)+q\right](H-Y-dy/2)(\tan\theta+\tan\beta)}{S_H\,S_V}$$

or

$$t_1' = 2\,D_p\,(\tan\theta-\tan\beta)\left[\left(y'-y'^2\right)+q'(1-y')\right]$$

where $$t_1' = t_1/\gamma H$$

$$q' = q/\gamma H$$

$$D_p = \frac{w f^* H}{S_H S_V}$$

$$y' = y/H$$

dy/2 H and its second order term have been ignored.

$$\therefore \frac{dt_1'}{dy'} = 2 D_p (\tan\theta + \tan\beta)[(1-2y') - q'] \tag{18}$$

$$\frac{d^2 t_1'}{dy'^2} = -4 D_p (\tan\theta + \tan\beta) \tag{19}$$

(ii) If $L_e = L - \left(H - Y - \dfrac{dy}{2}\right)(\tan\beta + \tan\beta)$

$$t = t_2$$

from Eqn. (9)

$$t_2 = \frac{2 w f^* (\gamma(Y + dy/2) + q)\{L - (H - Y - dy/2)(\tan\theta + \tan\beta)\}}{S_H S_V} \tag{20}$$

$$t_2' = 2 D_p \begin{bmatrix} \{L'y' - (y' - y'^2)(\tan\theta + \tan\beta)\} \\ + q'\{L' - (1-y')(\tan\theta + \tan\beta)\} \end{bmatrix}$$

where $$L' = L/H$$

$$t_2' = t_2/\gamma H$$

$$\frac{dt_2'}{dy'} = 2 D_p [\{L' - (1-2y)(\tan\theta + \tan\beta)\} + q'(\tan\theta + \tan\beta)] \tag{22}$$

$$\frac{d^2t_2'}{dy'^2} = 4D_p(\tan\theta + \tan\beta) \tag{23}$$

Equation for pressure distribution along the height of wall may be obtained by solving differential equation (6a)

$$\frac{p'}{(1-y')^{C_2}} = \left[\int C_1(1-y')^{-C_2} - \int C_3(1-y')^{-C_2}\frac{dt'}{dy'}\right]dy' \tag{24}$$

or

$$\frac{p'}{(1-y')^{C_2}} = I_1 - I_2 + K \tag{25}$$

where K = coefficient of integration

$$I_1 = -\frac{C_1(1-y')^{1-C_2}}{(1-C_2)} \tag{26}$$

$$I_2 = -\frac{C_3}{(1-C_2)}\left[\frac{dt'}{dy'}(1-y')^{1-C_2} + \frac{d^2t'}{dy'^2}\frac{(1-y')^{2-C_2}}{(2-C_2)}\right] \tag{27}$$

Pressure Intensity on the Wall

Case 1 : $H(\tan\theta + \tan\beta) \leq L/2$

Equation (25) can be further solved for boundary conditions at $y' = 0$

$$p'_{1(y'=0)} = C_1 q' - \frac{C_1 \tan(\theta+\phi)}{(\tan\theta - \tan\beta)} t'_{1(y'=0)} \tag{28}$$

$$p_1' = \left[I_1 - I_2 + p'_{1(y=0)} - I_{1(y=0)} + I_{2(y=0)}\right](1-y')^{C_2} \tag{29}$$

Corresponding values of I_1, I_2 and $p'_{1(y=0)}$ are to be taken from Eqns. (26, 27 and 28) and corresponding values of t', dt'/dy', d^2t'/dy'^2 from Eqns. (17, 18 and 19).

Case 2 : $L/2 \leq H(\tan\theta + \tan\beta) \leq L$

For $y < Z_1$, the effective length of reinforcing element will be

$$L_e = L - (H - Y - dy/2)(\tan\theta + \tan\beta)$$

$$t' = t'_2$$

Equation (25) can be further solved for boundary conditions at $y' = 0$

$$p'_{2(y=0)} = C_1 q' - \frac{C_1 \tan(\theta + \phi)}{(\tan\theta - \tan\beta)} t'_{2(y=0)} \tag{30}$$

one gets

$$p'_{2a} = \left[I_2 - I_2 + p'_{2(y=0)} - I_{1(y=0)} + I_{2(y=0)}\right](1 - y')^{C_2} \tag{31}$$

Values of I_1, I_2 and $p'_{2(y=0)}$ are given in Eqns. (26, 27 and 30), corresponding values of t', dt'/dy' and d^2t'/dy'^2 are to be taken from Eqns. (21, 22 and 23).

For $Y > Z_1$, the effective length will be $(H - Y)\tan\theta$ and pressure intensity at any depth $Z_1 < Y < H$, can be obtained by solving the Eqn. (25) for the limits $y = Z_1$ to $y = H$ for the boundary condition that at $y = Z_1$,

$$p'_{2b} = (p'_{2a})_{y'=Z'_1}.$$

where $Z'_1 = Z_1/H$

$$p'_{2b} = \left[\begin{array}{c} I_1 - I_2 + \dfrac{p'_{2a(y'=Z'_1)}}{(1 - Z'_1)^{C_1}} \\ - I_{1(y'=Z'_1)} + I_{2(y'=Z'_1)} \end{array}\right](1 - y')^{C_2} \tag{32}$$

The value of $\left[\left\{p'_{2a(y'=Z'_1)}\right\}/\left(1-Z'_1\right)^{C_2}\right]$ is to be taken from Eqn. (31), values of I_1 and I_2 for Eqn. (32) are to be adopted from Eqns. (26 and 27) and the corresponding values of t', dt'/dy' and d^2t'/dy'^2 and from Eqns. (17, 18 and 19).

Case 3 : $H(\tan\theta + \tan\beta) \geq L$

For the domain y = 0 to y = Z_2, the failure surface is not cut by any reinforcing element and passes through soil alone. Therefore no part of strip will experience movement of soil relative to itself and the value of t will be equal to zero. The differential equation (6a) will become

$$\frac{dp'}{dy'} = -\frac{C_2\, p'}{(1-y')} + C_1 \tag{33}$$

Solution of the differential Eqn. (33) for the boundary condition that at $y' = 0,\ p'_{(y=0)} = C_1 q'$

$$\frac{p'}{(1-y')^{C_1}} = I_1 + K$$

$$p'_{3a} = \left[I_1 + C_1 q' - I_{1(y'=0)}\right](1-y')^{C_2} \tag{34}$$

Values of I_1 and $I_{1(y'=0)}$ are to be accepted from Eqn. (26).

For the domain y = Z_2 to y = Z_3, the equation for pressure intensity p'_3 can be evaluated by solving the Eqn. (25) with the boundary condition that at $y' = Z'_2$,

$$p'_{3b} = p'_{3a(y'=Z'_2)}$$

where $Z'_2 = Z_2/H$

$$p'_{3b} = \left[\begin{matrix} I_1 - I_2 + \dfrac{p'_{3a(y'=Z'_2)}}{(1-Z'_2)^{C_2}} \\ -I_{1(y'=Z'_2)} + I_{2(y'=Z'_2)} \end{matrix}\right](1-y')^{C_2} \tag{35}$$

Values of I_1 and I_2 can be taken from Eqns. (26 and 27) and the corresponding values of t', dt'/dy' and d^2t'/dy'^2 from Eqns. (21, 22 and 23).

Finally for the domain $y = Z_3$ to $y = H$, the pressure intensity p'_{3c} can be obtained by solving Eqn. (25) with the boundary condition that at $y = Z_3$

$$p'_{3c} = p'_{3c(y'=Z'_3)}$$

where $\quad Z'_3 = Z_3/H$

$$p'_{3c} = \left[\begin{array}{c} I_1 - I_2 + \dfrac{p'_{3b(y'=Z'_3)}}{\left(1-Z'_3\right)^{C_2}} \\ -I_{1(y'=Z'_3)} + I_{2(y'=Z'_3)} \end{array} \right] \left(1-y'\right)^{C_2} \tag{36}$$

Values of $p'_{3b(y'=Z'_3)}$ are to be calculated using Eqn. (35). Values of I_1 and I_2 can be taken from Eqns. (26 and 27) and corresponding values of t', dt'/dy' and d^2t'/dy'^2 from Eqns. (17, 18 and 19).

Method of Computation

For few typical cases, the pressure distribution along the height of wall obtained by using Eqns. 29, 31, 32, 34, 35 and 36 are shown in Fig. 3. It is evident that the pressure intensities become negative in some of the portion of the wall.

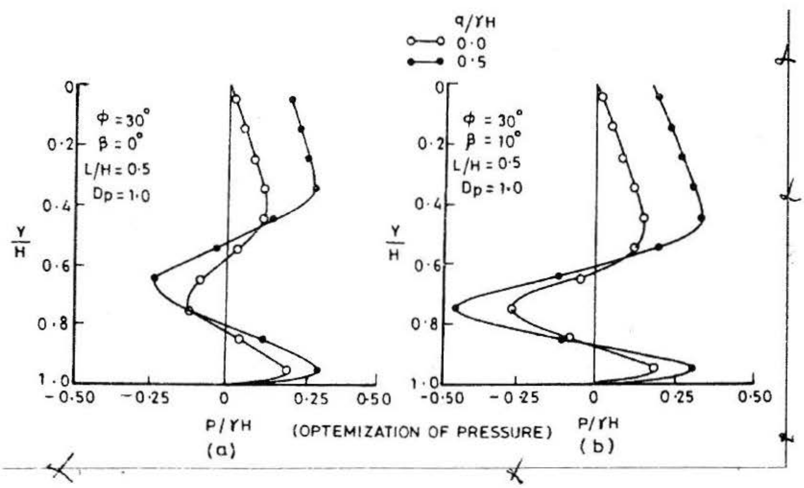

FIGURE 3 : Pressure Intensity along Height of Wall

The value of the total pressure is obtained by numerical integration neglecting the negative pressure. The design of wall needs to check its stability against sliding and overturning. The former needs the value of maximum resultant earth pressure which is obtained by optimising it with respect to wedge angle θ. Similarly the moments of the positive pressure intensities were taken about the heel of the wall and the same is optimized with respect to wedge angle θ to obtain its maximum value. The optimised values of resultant earth pressure and moment are denoted by P and M respectively and are presented in the charts in non-dimensional form as $P/\left(1/2\right)\gamma H^2$ and $M/\left(1/6\right)\gamma H^3$ respectively.

Parametric Study

Ranges of design parameters D_p, angle of internal friction ϕ, L/H ratio and $q/\gamma H$, likely to be used in the practice, have been considered and are given in Table 1.

Values of non-dimensional resultant pressure $P/\left(1/2\right)\gamma H^2$ are presented in Fig.4, and values of non-dimensional moments $M/\left(1/6\right)\gamma H^3$ in Fig. 5 for illustration.

Interpretation and Discussion

Justification of Assumptions

Assumptions 1, 4 and 6, reported earlier, are normally made in such analysis. The anisotropy caused by the inclusion of reinforcement, has been considered in an indirect way by taking the frictional strength of strip in the direction of reinforcement. Assumptions 2, 3 and 5 are being justified in the following paragraphs.

TABLE 1 : Parameters Considered In Present Study

Parameter	Range	Interval
ϕ	25° - 40°	5°
δ	$\frac{2}{3}\phi$ for all cases	
D_p	0.25 - 2.0	Variable
L/H	0.0 - 1.0	0.1
$q/\gamma H$	0.0 - 1.0	0.5

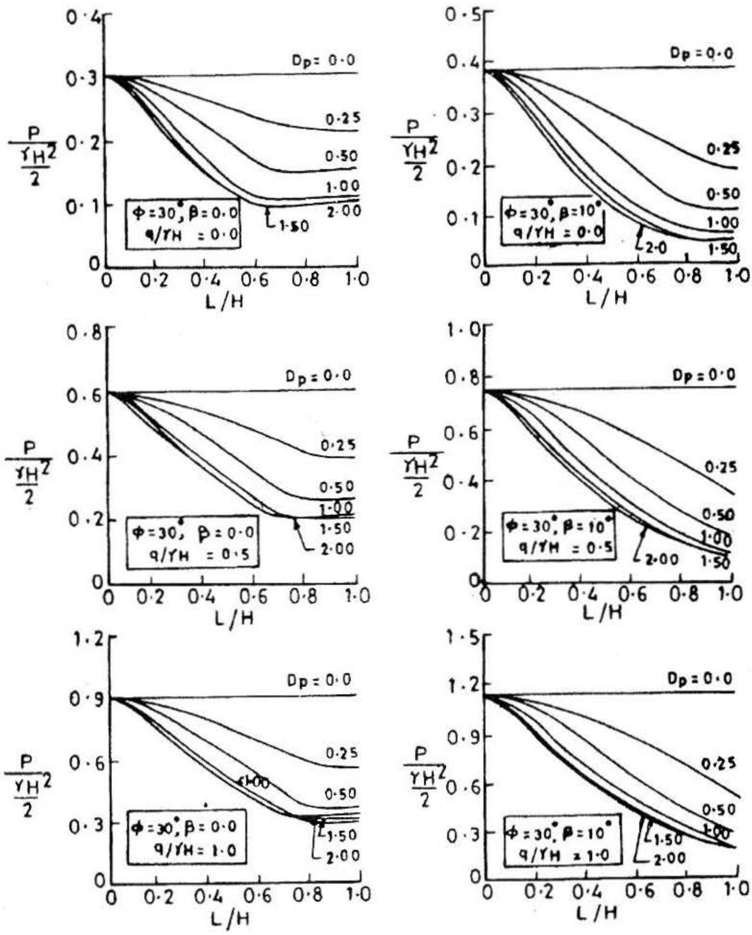

FIGURE 4 : Resultant Earth Pressure Vs. L/H (Stability against Sliding)

It is well established (Terzaghi, 1943; Terzaghi and Peck, 1967 and Tschebotarioff, 1973) that the error in resultant pressure due to the assumption of planer surface in active condition is very small (less than 5 percent).

The work of earlier investigators (Bacot et al., 1978; Schlosser et al., 1978; Talwar, 1981; Garg, 1988; Saran and Khan, 1989; Khan and Saran, 1990; Saran and Khan, 1991) indicate that the apparent coefficient of friction between soil and reinforcement increases with increase in the length of reinforcement and decreases with increase in overburden pressure. However, the findings include that this trend was observed for low range of overburden

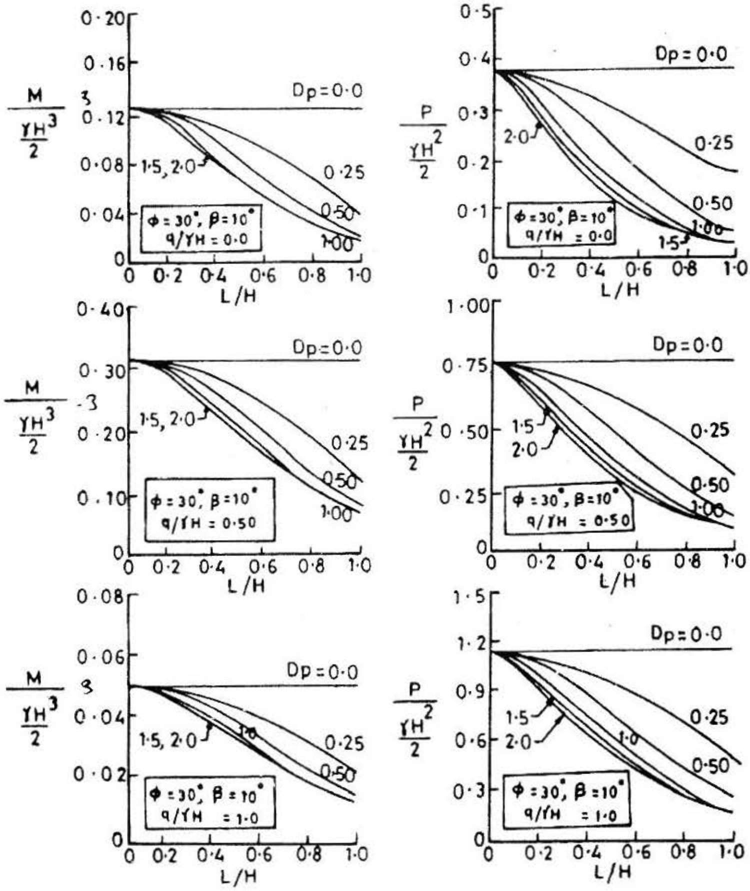

FIGURE 5 : (a) Resultant Moment Vs. L/H; (b) Resultant Earth Pressure Vs. L/H (Stability against Overturning)

pressure and for smaller lengths of reinforcement. Khan (1991) reported that the value of apparent coefficient of friction did not vary with overburden pressure greater than 10 t/m^2 (100 kN/m^2) and length of reinforcement more than 3.0 m.

In case of retaining wall higher than seven metres, for which reinforced backfill will provide an economical solution, taking average range of height of overburden and the length of reinforcement will fall in a range for which the apparent coefficient of friction f* is fairly constant. Keeping the above fact in view, the Assumption 3 was made.

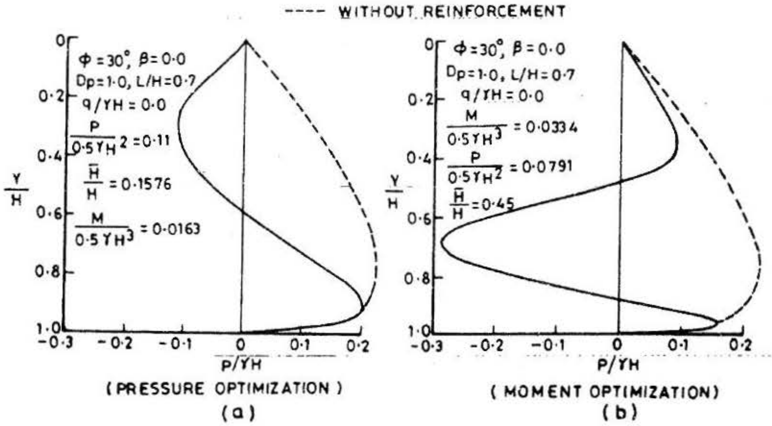

FIGURE 6 : Pressure Distribution along Height of Wall

Model tests have been performed for different vertical spacings. The test data on each pressure compares well with the predicted values from the proposed theory. From this it may be said that if the spacing between the reinforcement assumed is reasonable then the assumption of uniform distribution of frictional resistance imparted by a reinforcement over a fill height equal to its vertical spacing, may be considered valid.

Pressure Distributions

Typical plots of pressure distribution for $\phi = 30°$, $\beta = 0°$ and $10°$, $L/H = 0.5$, $q/\gamma H = 0.0$ and 0.5 and $D_p = 1.0$ are given in Figs. 3 (a and b) and for $\phi = 30°$, $\beta = 0°$ and $10°$, $L/H = 0.7$, $q/\gamma H = 0.0$ and $D_p = 1.0$ in Figs. 6 (a and b). It is evident from these figures that pressure may be negative in some portion of retaining wall. The location of portion of wall in which the intensity is negative depends on the value of angle of shearing resistance of fill, L/H ratio and D_p.

Resultant Earth Pressure for Checking Stability Against Sliding

As mentioned earlier, the resultant earth pressure for checking the stability of the wall against sliding was obtained by integrating the positive pressure zones of pressure intensity diagrams and then optimising it with respect to wedge angle θ. Figure 4 shows the plots of resultant pressure $P/(1/2)\gamma H^2$ for various values of angle of internal friction ϕ, wall inclination β, $q/\gamma H$, L/H and D_p factor. It may be seen from these plots that the value of resultant earth pressure decreases with (i) increase in the value of ϕ;

(ii) decrease in the value of β; (iii) decrease in $q/\gamma H$ value; (iv) increase in L/H ratio and (v) increase in D_p factor.

The effect of reinforcement is expressed in terms of L/H and D_p factor. The rate of decrease in resultant earth pressure is very high for smaller range of L/H and D_p ($L/H < 0.4$ and $D_p < 0.5$), The resultant earth pressure gets reduced to about 1/3rd for $L/H > 0.6$ and $D_p > 1.0$. Further increase in L/H and D_p did not affect significantly the resultant earth pressure.

Keeping the above facts in view an engineer may adopt $L/H = 0.6$ and $Dp = 1.0$ for design.

Resultant Moment and Corresponding Earth Pressure for Checking Stability Against Overturning and Bearing Failure

As mentioned earlier, the resultant moment for checking stability against overturning and bearing failure was obtained by taking the moments of the positive pressures about the heel of the wall, and after integrating the same, optimised with respect to wedge angle θ. Figure 5 represents the plots of $M/(1/6)\gamma H^3$ and corresponding $P/(1/2)\gamma H^2$. It is evident from these plots that resultant moment and earth pressure follow the same trend with respect to ϕ, β, $q/\gamma H$, L/H and D_p factor as described in the previous section for resultant earth pressure in sliding case.

These figures also suggest that a value of $L/H = 0.6$ and $D_p = 1.0$ is adequate for adoption in design.

Comparison of Proposed Theory with Experimental Results

The details of experimental investigations, setup used, observation etc. are given elsewhere (Khan, 1991).

Figure 7(a) shows a plot between moments computed by the proposed theory and experimental findings of Talwar (1981), Garg (1988) and the studies conducted under this investigation (without any surcharge). The observed moments were less than the corresponding theoretical moments. It may be due to side wall frictions which seem to have prevented the full development of failure wedge. The difference was less than 20% except in few tests.

Figure 7(a) shows the comparison between the observed moments and theoretical moments (backfill supporting u.d.l.), out of the four tests conducted (Garg, 1988), three showed the variation of 5 to 10 percent from theoretical.

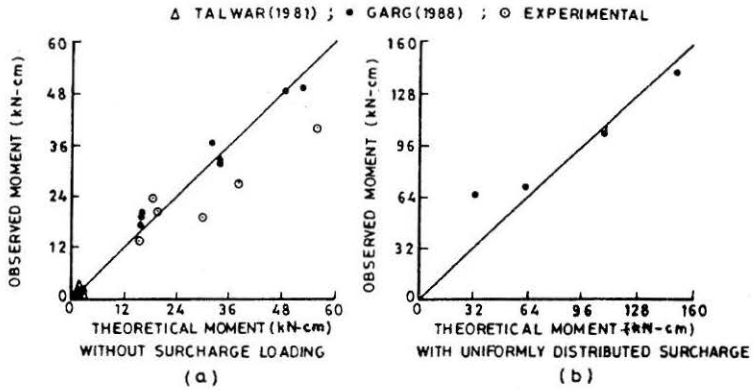

FIGURE 7 : Comparison between Theoretical and Observed Moments

Conclusions

(i) Unattached reinforcing strips considerably reduce the lateral pressure intensity on the wall.

(ii) The resultant earth pressure and the resultant overturning moments are function of the length of reinforcement and non-dimensional parameter D_p (@) and they reduce as the latter two increase. It is found that the decrease in earth pressure becomes insignificant when $L/H > 0.6$ and $D_p > 1.0$.

(iii) The value of $L/H = 0.6$ and $D_p = 1.0$ can be adopted for economic design of retaining wall with reinforced backfill.

(@) $$D_p = \frac{w f^* H}{S_H S_V}$$

where
w = width of reinforcement
f* = apparent coefficient of friction
H = height of retaining wall
SH = horizontal spacing between reinforcing strips
SV = vertical spacing between reinforcing strips

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