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Effective Placement of Reinforcement to Reduce Lateral Earth Pressure

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Introduction

Reinforced earth is a composite material wherein soil is reinforced with elements that can take tension. The reinforcing elements may be in the form of strips, sheets, nets or mats of metal, synthetic fabrics or fabric-reinforced plastics. The friction between the earth and the reinforcement is the essential phenomenon in the reinforced earth, and the stresses, built up in the soil mass, are transmitted to the reinforcement through this friction.

Since the first commercial use of Reinforced Earth, a variety of structures have been built in other countries. But single largest use of reinforced earth has been made in the construction of earth retaining walls. In this type of retaining walls, the reinforcement is tied to the wall and the lateral earth pressure on the wall is almost counterbalanced by the development of soil-reinforcement interface friction.

Though the concept of earth reinforcement is gaining popularity in developed countries of the world, it will take some more time in India for it to be accepted by the civil engineers as an economical alternative to routine construction technique. This may be due to limited awareness about the new technique and also due to high cost of reinforcing materials. Situations call be met in practice where reinforced earth walls may not prove to be an ideal solution. This can be true for locations with limited space behind the wall or for narrow hill roads on unstable slopes which may not permit the use of designed length of reinforcement. In such circumstances a rigid wall with

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reinforced backfill may prove to be more appropriate. Backfill earth is reinforced with strips that are not tied to the wall and are laid horizontally and perpendicular to the wall back.

Based on model test findings reduction of about 40 percent in overturning moment, due to active earth pressure on the rigid model wall, was reported by Hausman and Lee (1978). The wall was retaining cohesionless fill reinforced with strips that were not attached to the wall. An increase of three times in the length of reinforcing strips did not result in further reduction in the overturning moment on the wall.

Talwar (1981) worked out non-dimensional design curves for computing resultant lateral earth pressure and height of its point of application above base of rigid wall retaining cohesionless fill reinforced with unattached strips. Reinforcement characteristics were taken into account in terms of non-dimensional factors

(a) $D_p = \left(w\, f^* H\right) / S_x \cdot S_z$, and

(b) L/H

where w = width of strip,

f^* = coefficient of apparent soil-strip friction,

S_x = horizontal spacing of strips,

S_z = vertical spacing of strips,

L = length of the reinforcing strips and

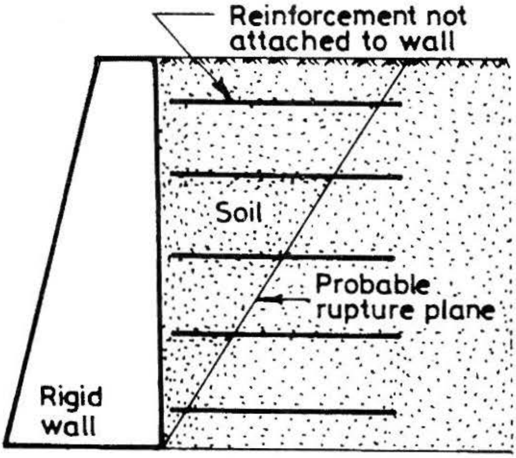
H = height of wall.

Optimum length of reinforcing strips was reported around 0.6 times height of wall.

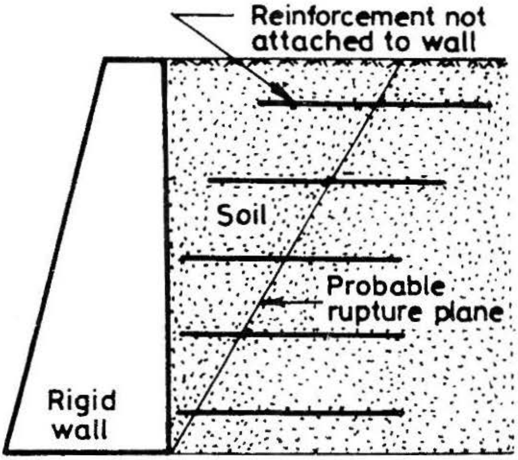
Saran et al. (1992) extended the work of Talwar for analysing the wall with reinforced backfill having uniformly distributed surcharge load at the top of backfill. Similar type of non-dimensional design curves were given by them for evaluating the resultant earth pressure and its point of application.

The investigations reported so far have considered their laying of reinforcement from the backface of the wall (Fig. 1a) and the reinforcing strips, lying totally within the moving wedge of retained soil, will not provide any relief in the lateral earth pressure on the wall. Therefore it was considered to place the reinforcement in such a way that it is effective, in reducing the active earth pressure on the wall, right from its top most layer.

In this paper a novel method (Fig. 1b), termed as effective placement of reinforcement (EPR), has been suggested for laying the reinforcement to



(a) Normal placement of reinforcement (NPR)



(b) Effective placement of reinforcement (EPR)

FIGURE 1 : Sections of Rigid Wall with Reinforced Backfill

give most economical results. The reinforcing strips are considered to be laid across the hypothetical rupture surface, extending half of its total length on either side of the rupture surface. An example has been included to illustrate the design lucidity and remarks have been made on relative economy with respect to conventional method. Here for the sake of clarity, the methodology discussed by Saran et al. (1992) has been termed as normal placement of reinforcement (NPR) in the backfill (Fig. 1a).

Theoretical Analysis

The assumptions and procedure of stability analysis are the same as discussed in the case of normal placement of reinforcement by Saran et al. (1992). In this (EPR) case the effective length of reinforcement, for the height of wall in which $(H-y)\tan\theta \geq L/2$, will be $L/2$, where H. y, θ and L are as shown in Fig 2.

Unlike the case of normal placement of reinforcement in the backfill, in which the stability analysis of failure Wedge of soil was carried out for three different cases

case 1 : $(H-y)\tan\theta \geq L/2$;
case 2 : $L/2 \leq H\tan\theta \leq L$, and
case 3 : $H\tan\theta > L$,

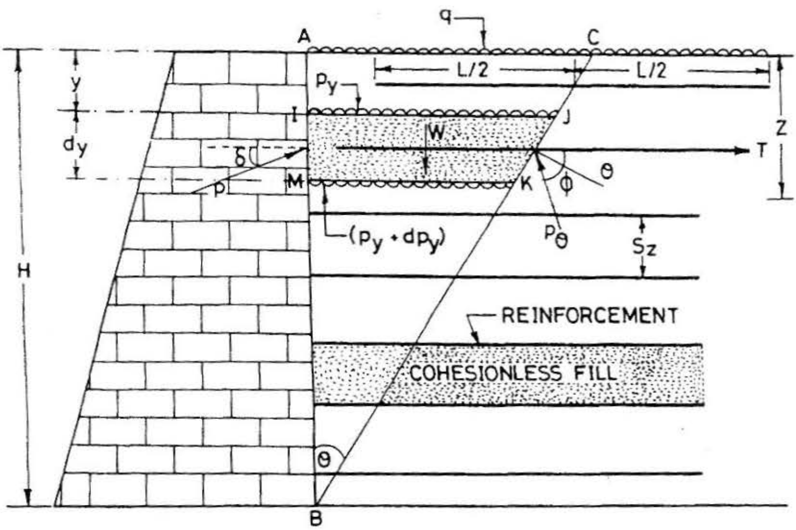


FIGURE 2 : Failure Wedge and Various Intensities of Forces keeping Element IJKM in Equilibrium

the effective placement of reinforcement involves only one case for which $(H-y)\tan\theta \geq L/2$

The stability of the horizontal element IJKM of the failure wedge ABC (Fig. 2) has been considered under the following intensities of forces :

p_y = pressure intensity, acting uniformly orl IJ in the vertical direction, due to self weight of backfill lying above IJ and uniform surcharge q.

$p_y + dp_y$ = uniform reaction intensity acting on KM in the vertically upward direction.

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

p = pressure intensity on IM acting at an angle δ with the normal to IM, δ being the angle of wall friction.

W = weight of an element IJKM acting downward

$$= 1/2 \cdot \gamma \cdot dy \cdot \left[(H-y)\tan\theta + (H-y-dy)\tan\theta\right] \qquad (1)$$

T = tensile force in the reinforcing strip (assumed transmitted uniformly to soil layers of thickness S_z encompassing the strip

$$= t \cdot S_z, \text{ where "t" is intensity of tension} \qquad (2)$$

The static equilibrium $(\sum H = 0, \sum V = 0 \text{ and } \sum M = 0)$ of an element IJKM (Fig. 2) yields :

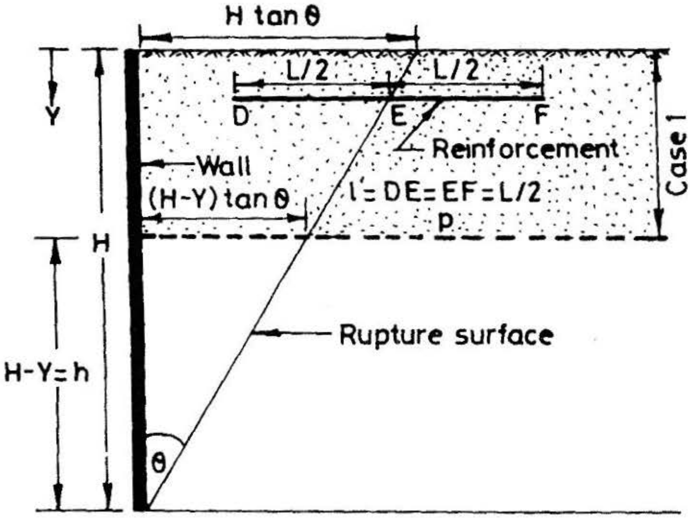
$$\frac{dp}{dy} = -C_1 \frac{p}{H-y} + C_2\gamma - C_3 \frac{dt}{dy} \qquad (3)$$

where

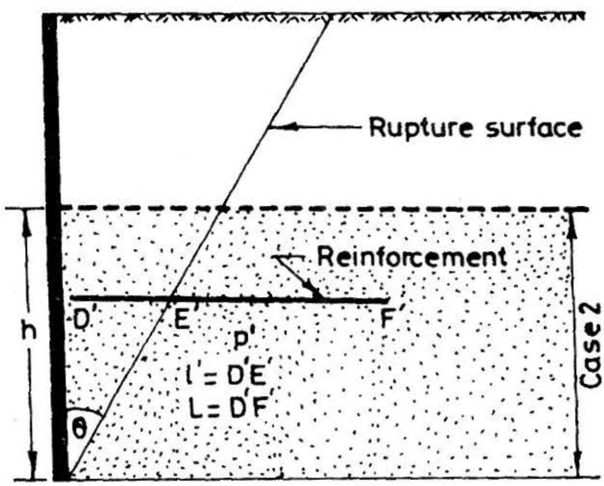
$$C_1 = \frac{2\sin\delta\cos(\theta+\delta)}{\sin(\theta+\phi-\delta)} \qquad (4a)$$

$$C_2 = \frac{\sin\theta\cos(\theta+\phi)}{\cos\theta\sin(\theta+\phi-\delta)} \qquad (4b)$$

$$C_3 = \frac{\sin(\theta+\phi)}{\sin(\theta+\phi-\delta)} \qquad (4c)$$



(a) Case 1 : (H-Y) tan θ ≥ L/2



(b) Case 2 : (H-Y) tan θ < L/2

FIGURE 3 : Effective Length Criteria of Reinforcement

The Eqn. 3 and the values of constants (C_1, C_2 and C_3) remain the same as reported earlier by Saran et.al. (1992).

At limiting equilibrium :

$$T = \frac{2wf^*[y + (dy/2)\gamma + q]l'}{S_x} \tag{5}$$

where l' = effective length of strip,

q = uniformly distributed external loading on the surface of the retained soil, l' will vary for each reinforcing strip beyond depth z, depending on the wedge angle e and the length L of the Strip as shown in Fig. 3.

Case 1 : $y < z$; $l' = L/2$

$$t = \frac{2wf^*\gamma\tan\theta}{S_x S_z}\left[\left(y + \frac{dy}{2}\right) + \frac{q}{\gamma}\right](L/2\tan\theta) \tag{6}$$

On differentiating Eqn. 6 and neglecting quantities of second order,

$$\frac{dt}{dy} = K(L/2\tan\theta) \tag{7}$$

where

$$K = \frac{2wf^*\gamma\tan\theta}{S_x S_z} \tag{8}$$

at $y = 0$

$$t_{q0} = K(q/\gamma)(L/2\tan\theta) \tag{9}$$

Equation (3) can be expressed as follows :

$$\frac{dp}{dy} = -C_1\frac{p}{H-y} + C_2\gamma - C_4(L/2\tan\theta) \tag{10}$$

The solution of the differential equation (10) for the boundary condition, $p_y = q$ at $y = 0$, provides the following :

$$p = -\frac{C_2\gamma}{1-C_1}\left[(1-y/H)-(1-y/H)^{C_1}\right] + \frac{C_4H(L/H)}{2(1-C_1)\tan\theta}\left[(1-y/H)-(1-y/H)^{C_1}\right] + \frac{q\tan\theta - t_{q0}(\theta+\phi)}{\cos\delta\tan(\theta+\phi)-\sin\delta}(1-y/H)^{C_1} \quad (11)$$

Lateral earth pressure p consists of the following :

1. lateral earth pressure due to backfill earth p_γ, and
2. lateral earth pressure due to surcharge load p_q, i.e.

$$p = p_\gamma + p_q \quad (12)$$

$$p_\gamma = -\frac{C_2\gamma H}{1-C_1}\left[(1-y/H)-(1-y/H)^{C_1}\right] + \frac{C_4 H(L/H)}{2(1-C_1)\tan\theta}\left[(1-y/H)-(1-y/H)^{C_1}\right] \quad (13)$$

$$P_q = \frac{q\tan\theta - t_{q0}\tan(\theta+\phi)}{\cos\delta\tan(\theta+\phi)-\sin\delta}(1-y/H)^{C_1} \quad (14)$$

Case 1 : $y > z$; $l' = (H-y)\tan\theta$

Solution of Eqn. (3) for the relevant boundary condition, i.e., $p' = (p)_{y=z}$ at $y = z$, yields :

$$
\begin{aligned}
p' = & -\frac{C_2 \gamma H}{(1-C_1)}(1-y/H) - \frac{C_4 H^2}{(1-C_1)}(1-y/H) \\
& + \frac{2C_4 H^2}{(2-C_1)}(1-y/H)^2 - \frac{C_4 q H}{\gamma(1-C_1)}(1-y/H) \\
& + \frac{C_2 \gamma H}{(1-C_1)}(1-y/H)^{C_1} + \frac{C_4 H^2}{(1-C_1)} Q^{(2-C_1)}(1-y/H)^{C_1} \\
& + \frac{C_4 H^2}{(1-C_1)} Q\,(1-y/H)^{C_1} + \frac{C_4 H^2}{(1-C_1)} Q^{(1-C_1)}(1-y/H)^{C_1} \\
& - \frac{2C_4 H^2}{(2-C_1)} Q^{(2-C_1)}(1-y/H)^{C_1} + \frac{C_4 q H}{\gamma(1-C_1)} Q^{(1-C_1)}(1-y/H)^{C_1} \\
& + \frac{q \tan\theta - t_{q0} \tan(\theta+\phi)}{\cos\delta \tan(\theta+\phi) - \sin\delta}(1-y/H)^{C_1}
\end{aligned}
$$

..........(15)

where $Q = (L/2H \tan\theta)$

Here again

$$p' = p'_\gamma + p'_q \tag{16}$$

where

$$
\begin{aligned}
p'_\gamma = & -\frac{C_2 \gamma H}{(1-C_1)}(1-y/H) - \frac{C_4 H^2}{(1-C_1)}(1-y/H) \\
& + \frac{2C_4 H^2}{(2-C_1)}(1-y/H)^2 + \frac{C_4 \gamma H}{(1-C_1)}(1-y/H)^{C_1} \\
& + \frac{C_4 H^2}{(1-C_1)} Q^{(2-C_1)}(1-y/H)^{C_1} + \frac{C_4 H^2}{(1-C_1)} Q\,(1-y/H)^{C_1} \\
& + \frac{C_4 H^2}{(1-C_1)} Q^{(1-C_1)}(1-y/H)^{C_1} - \frac{2C_4 H^2}{(2-C_1)} Q^{(2-C_1)}(1-y/H)^{C_1}
\end{aligned}
$$

..........(17)

and

$$p'_q = -\frac{C_4 q H}{\gamma(1-C_1)}(1-y/H) + \frac{C_4 q H}{\gamma(1-C_1)} Q^{(1-C_1)}(1-y/H)^{C_1} + \frac{q\tan\theta - t_{q0}\tan(\theta+\phi)}{\cos\delta\tan(\theta+\phi) - \sin\delta}(1-y/H)^{C_1} \quad \text{.........(18)}$$

The procedure, discussed by Saran et al. (1992), is followed, for obtaining expressions for resultant earth pressure and height of its point of application above the base of wall and is expressed in nondimensional form as follows :

$$K_\gamma = \frac{P_\gamma}{(1/2)\gamma H^2} = \frac{\int_0^z p_\gamma\, dy + \int_z^H p'_\gamma\, dy}{(1/2)\gamma H^2} \tag{19}$$

$$\frac{\overline{H}_\gamma}{H} = 1 - \frac{\int_0^z p_\gamma y\, dy + \int_z^H p'_\gamma y\, dy}{H\left[\int_0^z p_\gamma\, dy + \int_z^H p'_\gamma\, dy\right]} \tag{20}$$

$$K_q = \frac{P_q}{qH} = \frac{\int_0^z p_q\, dy + \int_z^H p'_q\, dy}{qH} \tag{21}$$

$$\frac{\overline{H}_q}{H} = 1 - \frac{\int_0^z p_q y\, dy + \int_z^H p'_q y\, dy}{H\left[\int_0^z p_q\, dy + \int_z^H p'_q\, dy\right]} \tag{22}$$

where P_γ = resultant earth pressure due to reinforced earth backfill only,

P_q = resultant earth pressure due to surcharge load only,

$\overline{H}_\gamma$ = height of point of application of P_γ from base of retaining wall,

$\overline{H}_q$ = height of point of application of P_q from base of retaining wall,

K_γ = coefficient of active earth pressure for reinforced earth backfill,

K_q = coefficient of active earth pressure for surcharge on reinforced backfill.

The detailed derivations along with the closed form solutions of the above equations are available elsewhere (Garg, 1988).

Solutions of the Eqn.s (19) to (22) were obtained for following parameters :

Parameter	Range	Interval	Notes
ϕ	30° – 40°	5°	$\delta = \frac{2}{3}\phi$
D_p	0.2 – 2.0	Variable	$D_p = \frac{w f^{*} H}{S_x S_z}$
L/H	0 – 1.0	0.2	

The closed form solutions have yielded negative pressure intensity zone in the top portion of wall in case of soil with higher angle of internal friction (ϕ) and/or with more amount of reinforcement in the fill. Figure 4 illustrates the point for a typical case.

The positive earth pressure diagrams of p_γ and p_q are integrated separately and then maximised with respect to their corresponding wedge angles, θ_γ and θ_q, to yield the resultant earth pressure. θ_γ and θ_q are the wedge angles at which resultant pressures P_γ and P_q are maximum. Values of θ_γ and θ_q are used in Eqn.s 19 to 22 to evaluate resultant active earth pressure coefficients and the corresponding points of application (Fig.s 5 to 7).

It is evident from these figures that optimum length of reinforcement ranges between 0.4 to 0.6 times height (H) of wall depending on the values of D_p and ϕ; and increasing thee amount of reinforcement beyond a certain limit ($D_p > 1.5$) is not advantageous in further minimising the earth pressure on the wall for all practical values of θ.

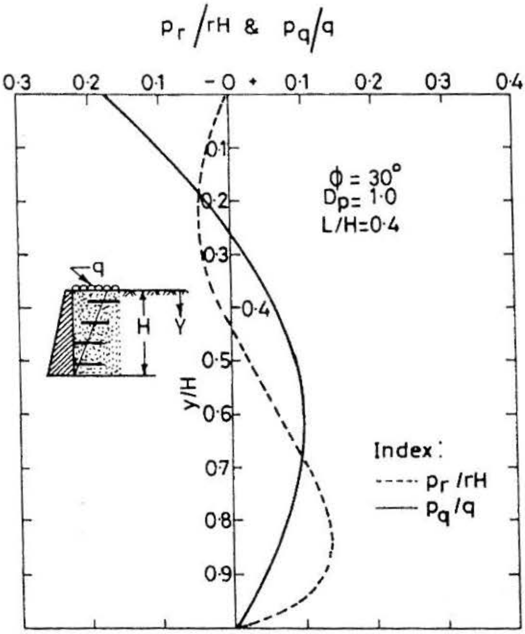


FIGURE 4 : Variation of $p_{\gamma}/\gamma H$ and p_q/q along the Depth of the Wall

The designer need to know in advance the critical rupture surface to decide about the placement of reinforcing elements in the fill at appropriate locations. That is possible with the knowledge of critical rupture wedge angle, θ_{cr}.

Series of curves are presented in Fig. 8, which provide relationship between wedge angles (θ_{γ} and θ_q) and L/H ratio for different values of ϕ and D_p. Normally there is not much difference in the values of θ_{γ} and θ_q, and therefore it is suggested that an average value (θ_{γ} and θ_q) should be taken as the critical rupture wedge angle, θ_{cr}.

Guidelines For Practical Applications

1. Get the data for which the wall is to be designed.

2. Choose an appropriate reinforcing material and get its frictional characteristics f^* and allowable tensile Stress σ_t.

3. Assume suitable values of L/H and D_p. For economical design, it is recommended to adopt L/H between 0.4 to 0.6 and D_p between 0.5 to 1.0.

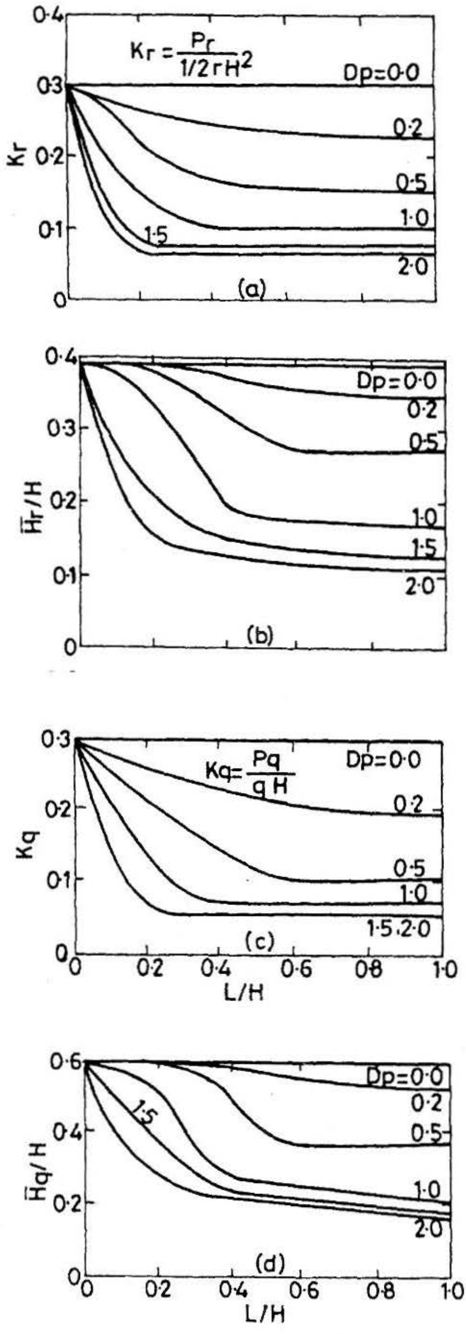


FIGURE 5 : Non-dimensional Charts for Resultant Pressure and Height of Point of Application : (i) a and b due to Backfill; (ii) c and d due to Surcharge Loading (ϕ = 30°)

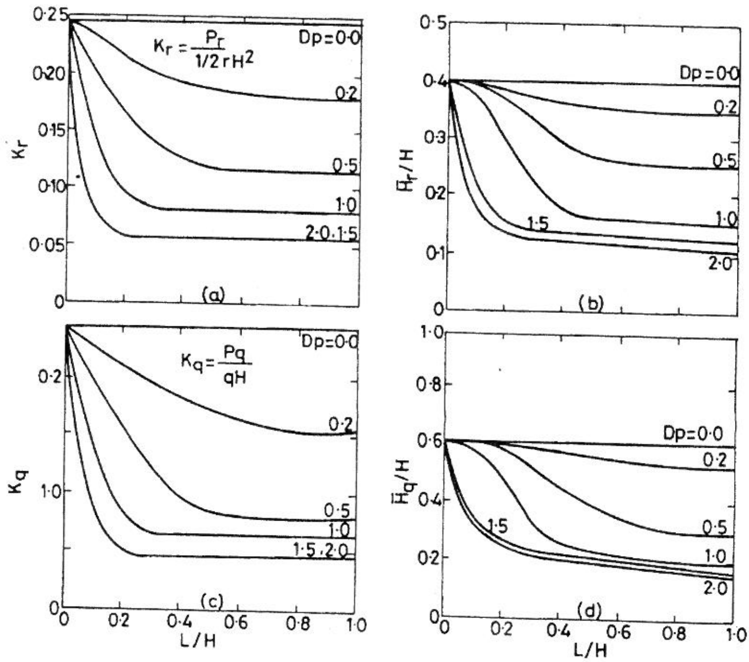


FIGURE 6 : Non-dimensional Charts for Resultant Pressure and Height of Point of Application : (i) a and b due to Backfill; (ii) c and d due to Surcharge Loading (ϕ = 35°)

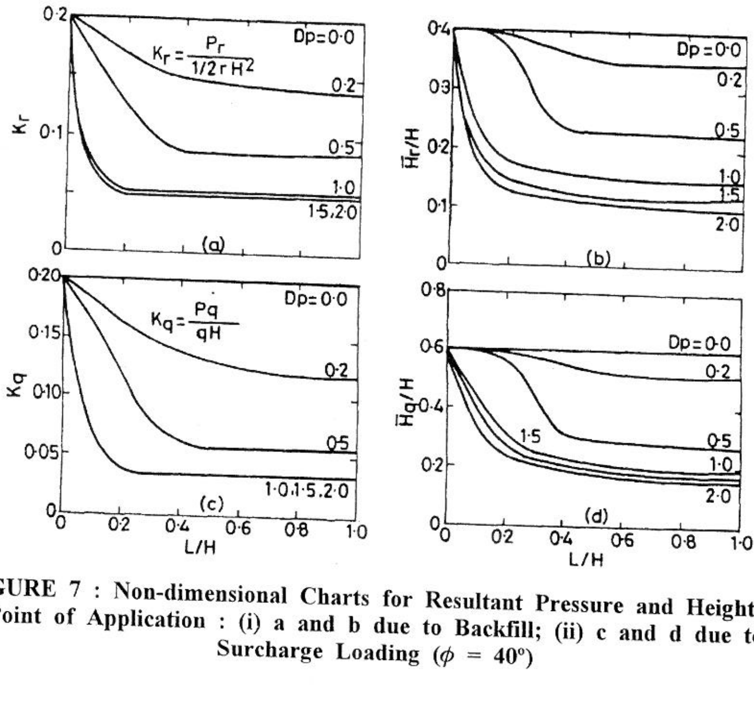


FIGURE 7 : Non-dimensional Charts for Resultant Pressure and Height of Point of Application : (i) a and b due to Backfill; (ii) c and d due to Surcharge Loading (ϕ = 40°)

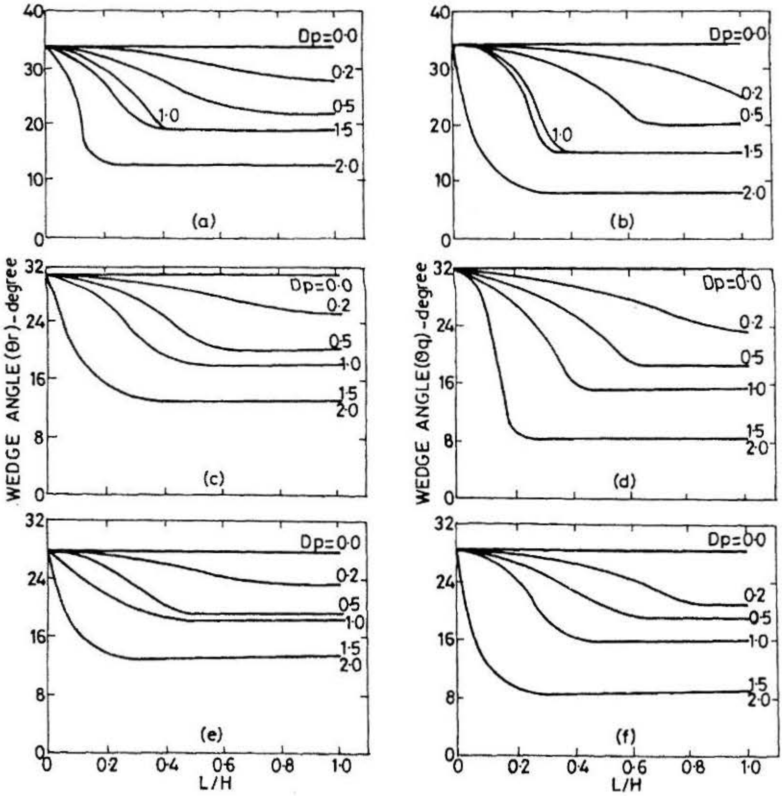


FIGURE 8 : Rupture Wedge Angles θ_γ and θ_q with L/H ration : (i) a and b for ϕ = 30°; (ii) c and d for ϕ = 35°; (iii) e and f for ϕ = 30°

4. Get values of K_γ, $\overline{H}_\gamma/H$, K_q and $\overline{H}_q/H$ for the given value of ϕ and the assumed values of L/H and D_p from Fig. 5, 6 or 7.

5. Adopt appropriate dimensions (b and w) of the reinforcing strip where b is the thickness of the reinforcing strip. The horizontal (S_x) and vertical (S_z) spacings of the reinforcing strips may be kept equal and can be worked out as given below :

$$S_x \cdot S_z = \frac{f^* \cdot w \cdot H}{D_p} \tag{23}$$

6. The bottom most strip will be subjected to maximum tension (T_B) and

that is given by

$$T_B = \left[\gamma H\left(K_{\gamma 0} - K_\gamma\right) + q\left(K_{q0} - K_q\right)\right] S_x \cdot S_z \tag{24}$$

where $K_{\gamma 0} = K_{q0}$ (Coulomb's active earth pressure coefficient for unreinforced backfill and is obtained from Fig. 5, 6 or 7 for $L/H = 0.0$.

The maximum tension TB is less than or equal to the allowable tensile strength of the reinforcing strip, i.e.,

$$T_B \le \sigma_t \cdot b \cdot w$$

7. Check the stability of the section of the wall against sliding, overturning, and bearing failure for the resultant earth-pressure values (P_γ and P_q) and their corresponding points of application ($\overline{H}_\gamma$ and $\overline{H}_q$).

   This method can also be used for mat-type reinforcement with some modification as given below :

$$D_p = f^*(H/S_z) \tag{25}$$

and

$$T_B = \left[\gamma H\left(K_{\gamma 0} - K_\gamma\right) + q\left(K_{q0} - K_q\right)\right] \cdot S_z \tag{26}$$

   In case of mat type reinforcement the value of D_p will usually be more than 2.0 and therefore values of earth-pressure coefficients may by obtained from Fig.s 5, 6 or 7 for $D_p = 2.0$. Values of D_p higher than 2.0 have no significant effect on the earth-pressure coefficients.

8. To get the probable location of theoretical failure surface, obtain value of θ_{cr} for the given value of ϕ and assumed values of L/H and D_p. Compute the height (h) from bottom of wall to the point, along the height of wall, at which half-length of reinforcing strip equals the distance of failure wedge from the wall, i.e., $h \tan\theta = L/2$ and $h = H - y$, where y is measured from top of the wall (Fig. 9).

9. Place the reinforcing strips in the fill upto tine height, h, from bottom as shown in Fig. 1b.

10. Between height h and H along the wall, the reinforcing strips are laid across the failure surface by extending half of its length on either side of the rupture surface (Fig. 1b).

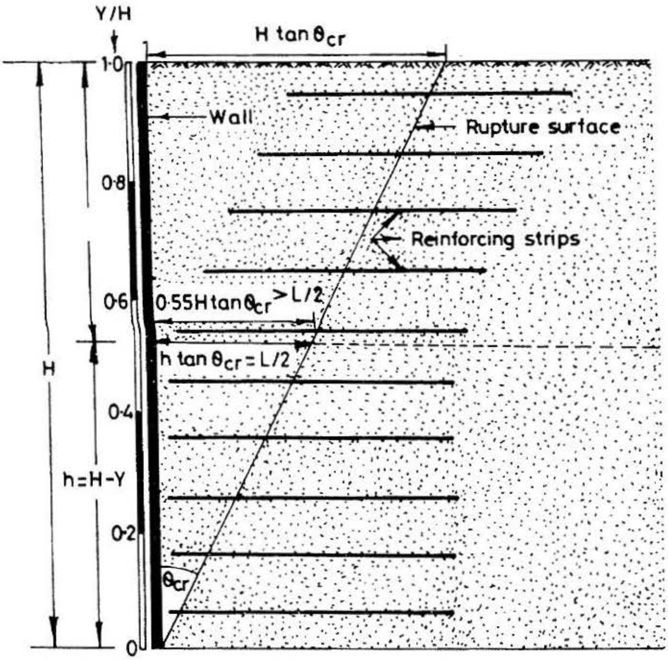


FIGURE 9 : Process of Locating Reinforcement Location on Ground at the Back of Retaining Wall

Design Example

1. Take the following data as given :

$$H = 8 \text{ m},$$
$$\gamma = 16 \text{ kN/m}^3,$$
$$\phi = 30°,$$
$$\mu = 0.5,$$
$$q_a = 300 \text{ kN/m}^2, \text{ and}$$
$$q = 30 \text{ kN/m}^2.$$

Using galvanised iron (GI) strips with $f^* = 0.75$ and $\sigma_t = 140{,}000$ kN/m^2, as reinforcement.

2. Assume $L/H = 0.4$ ($L = 3.20$ m) and $D_p = 1.0$

3. From Fig. 5, for $\phi = 30°$, $D_p = 1.0$ and $L/H = 0.4$;

$$K_\gamma = 0.10,$$

$$
\begin{aligned}
K_{\gamma 0} &= 0.30, \\
\overline{H}_\gamma / H &= 0.195, \\
\overline{H}_\gamma &= 1.56 \text{ m}, \\
K_q &= 0.070, \\
K_{q0} &= 0.30, \\
\overline{H}_q / H &= 0.27, \text{ and} \\
\overline{H}_q &= 2.16 \text{ m}.
\end{aligned}
$$

4. Selecting 3 mm thick and 100 mm wide reinforcing strips of galvanised iron and taking

$$
\begin{aligned}
S_x &= S_z \\
D_p &= 1.0 - \frac{w \cdot f^* \cdot H}{S_x\, S_z} = \frac{0.10 \times 0.75 \times 8}{S_z^2} \\
S_z &= 0.775\,\text{m}
\end{aligned}
$$

Adopt $S_x = S_z = 0.75$ m.

5. $$T_B = \left[\gamma H\left(K_{\gamma 0} - K_\gamma\right) + q\left(K_{q0} - K_q\right)\right] S_x \cdot S_z$$

$$= [16 \times 8\,(0.30 - 0.10) + 30\,(0.30 - 0.07)]\; 0.75 \times 0.75$$

$$= 18.3 \text{ kN/m}$$

The allowable tensile strength $= 140000 \times 0.10 \times 0.003 = 42$ kN. Since $T_B < 42$ kN, it is therefore safe.

6. A trial reinforced cement concrete wall section, as shown in Fig. 10, was chosen for checking its stability for pressures,

$$
\begin{aligned}
P_\gamma &= (1/2)\,\gamma\, H^2\, K_\gamma \\
&= (1/2) \times 16 \times 8^2 \times 0.10 \\
&= 51.2 \text{ kN/m}
\end{aligned}
$$

acting at 1.56 m from the base; and

$$
\begin{aligned}
P_q &= q \cdot H \cdot K_q \\
&= 30 \times 8 \times 0.07 \\
&= 16.8 \text{ kN/m}
\end{aligned}
$$

acting at 2.16 m above the base.

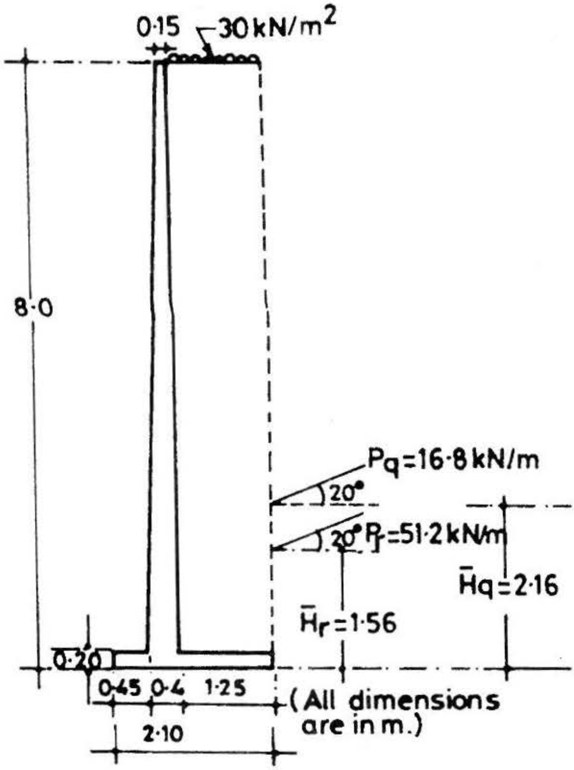


FIGURE 10 : Trial Section of Reinforcement Cement Concrete Wall Retaining (G.I. strips/geogrid) Reinforcement Fill

By checking the stability of the wall in the conventional way, we obtained a factor of safety against sliding = 1.90, a factor of safety against overturning = 3.0 and maximum base pressure = 166 kN/m^2.

7. Taking $\theta_{cr} = \left(\theta_\gamma + \theta_q\right)/2$ from Fig.s 8a and 8b, θ_{cr} = 18.5° (for locating the failure surface for laying the reinforcement).

The same problem has also been solved without using any reinforcement in the backfill. Trial reinforced cement concrete section of the wall, shown in Fig. 11, was checked for its stability and yielded a factol of safety against sliding of 1.50, a factor of safety against overturning = 3.2, and maximum base pressure = 174 kN/m^2. A comparison of cost of the two cases has been given in Table 1 using two types of reinforcing materials, separately, in the backfill earth.

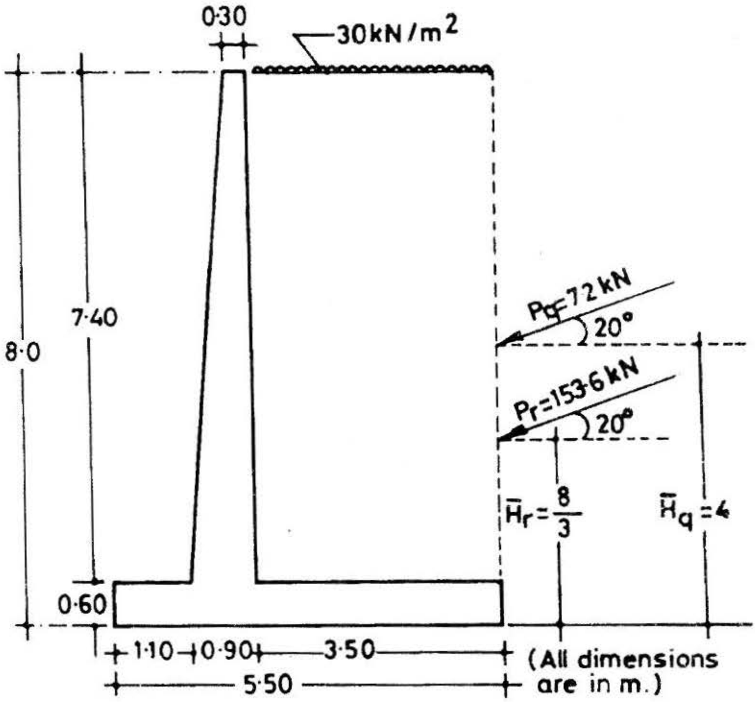


FIGURE 11 : Trial Section of Reinforcement Cement Concrete Wall with Unreinforced Backfill

It is evident from Table 1, that in case galvanised strips are used as reinforcing material, the saving is around 61 percent whereas use of Tenax geogrids in place of galvanised iron strips results in about 50 percent saving in the cost of construction of a 8 m high retaining wall.

It can be inferred from Table 1 that substantial economy can be achieved if the reinforcement is placed in the backfill as per the procedure illustrated in this paper.

Conclusions

Based on the findings of this study :

(a) This mode of placement of reinforcement in the backfill yields significantly reduced earth pressures on the wall. To illustrate the point, let us take a case of reinforced fill for D_p = 1.O; L/H = 0.4 and ϕ = 30°, the reduction with respect to unreinforced earth backfill is of the order of 67 percent in earth pressure due to backfill earth and

Table 1
Cost Estimates per Meter Length of Wall Retaining Unreinforced and Reinforced Backfill Separately

Item	Unit	Rate (Rs.)	Retaining Wall with Unreinforced Backfill		Wall retaining backfill reinforced with			
			Quantity	Amount (Rs.)	Galvanised Iron Strip		Tenax Geogrid	
					Quantity	Amount (Rs.)	Quantity	Amount (Rs.)
Reinforced Cement Concrete	m^3	1457	7.74	11277.18	2.57	3744.49	2.57	3744.49
Steel	Kg	16.75	585	9798.75	212.60	3561.05	212.60	3561.06
Normal earth filling including compaction	m^3	10.20	26	265.20	20.00	204.00	20.00	204.00
Galvanised Iron Strips	m^3	250	—	—	3.40	850.00	—	—
Tenax Geogrid (TT-301)	m^2	260	—	—	—	—	12.4	3224.00
Total				21341.13		8359.54		10733.54
Saving						61%		50%

Note : Rates are as per Delhi Schedule of rate of 1993

75 percent in earth pressure due to surcharge loading. Further the reduction with respect to normal placement of reinforcement (Saran et al., 1992), keeping same D_p and L/H, is of the order of 44 percent in earth pressure due to backfill and 23 percent in earth pressure due to surcharge loading.

(b) The height of point of application of resultant earth pressure reduces with increased value of D_p and L/H ratio.

(c) Optimum length of reinforcement, for most of the practical cases, lies between 0.4 to 0.6 times height (H) of wall.

(d) Substantial economy can be achieved in the construction of a high retaining wall by reinforcing the backfill.

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Notation

b	=	thickness of reinforcing element;
C_1, C_2, C_3	=	coefficients depending upon ϕ, δ and θ;
C_4	=	$K\,C_3$;
D_p	=	spacing coefficient;
f^*	=	coefficient of apparent soil – reinforcement friction;
H	=	height of wall;

$\overline{H}_q$ = height of point of application of earth pressure due to surcharge load above base;

$\overline{H}_\gamma$ = height of point of application of earth pressure due to backfill above base;

$$K = \frac{2 w f^* \gamma \tan\theta}{S_x S_z}$$

K_q = coefficient of active earth pressure for surcharge load in case of reinforced backfill;

K_{qo} = coefficient of active earth pressure for surcharge load in case of unreinforced backfill;

K_γ = coefficient of active earth pressure for reinforced backfill;

$K_{\gamma o}$ = coefficient of active earth pressure for unreinforced backfill;

L = total length of reinforcing strip;

l' = effective length of reinforcing strip;

P_q = resultant active earth pressure due to surcharge loading;

P_γ = resultant active earth pressure due to backfill;

p, p′ = lateral earth pressure intensity on wall;

p = $p_\gamma + p_q$;

p = $p'_\gamma + p'_q$;

p_q, p'_q = lateral earth pressure intensity on wall due to surcharge load;

p_γ, p'_γ = lateral earth pressure intensity on wall due to backfill;

p_y = pressure acting on an element of soil in vertical direction;

p_θ = intensity of reaction on failure surface;

q = intensity of surcharge loading;

q_a = allowable soil pressure;

S_x = horizontal spacing of reinforcing strips;

S_z = vertical spacing of reinforcing strips;

T = total tension in the reinforcing strip;

T_B = total tension in the bottom-most strip;

t = uniformly distributed tensile stress;

W = weight of slice or element of soil;

w = width of reinforcing strip;

y = distance along wall from top;

Z = depth from top;

γ = unit weight;

δ = angle of wall friction;

θ = wedge angle with vertical;

θ_{cr} = critical wedge angle with vertical;

θ_q = wedge angle with vertical due to surcharge loading;

θ_γ = wedge angle with vertical due to backfill;

μ = coefficient of friction;

σ_t = permissible tensile stress in reinforcing strip;

σ_v = vertical stress in soil;

ϕ = angle of internal friction of soil.