Earth Pressures by the Method of Characteristics with Different Adhesion Ratio and Wall Friction Ratio

by

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Introduction

WALL friction ratio is one of the important factors that influence the earth pressure on retaining walls. The wall friction ratio is usually assumed as a fraction of angle of shearing resistance of the backfill soil. In the analysis presented herein, both active and passive earth pressures have been obtained using the method of characteristics and assuming adhesion ratio and wall friction ratio as different.

Figures 1 and 2 show the forces acting on the face of a retaining wall for the active and passive cases, respectively. The shear stress τ_{nt} acting along the face of retaining wall is usually taken as

$$\tau_{nr} = (\sigma_n + H) \tan \delta, \text{ for active case,} \qquad \ldots(1)$$

and

$$\tau_{nt} = -(\sigma_n + H) \tan \delta, \text{ for passive case} \qquad \ldots(2)$$

where,

σ_n = normal stress acting on the retaining wall,

δ = angle of wall friction,

$H = c \cot \varphi$

c = cohesion intercept of the soil, and

φ = angle of shearing resistance of the soil.

The angle δ is usually assumed as a fraction of angle of shearing resistance of the soil and is generally taken as φ, $\frac{1}{2}\varphi$, or $\frac{2}{3}\varphi$, Sometimes, tan δ is taken as a fraction of tan φ.

When the wall friction and adhesion ratios are different, Eqs 1 and 2 can be rewritten as

$$\tau_{nt} = \sigma_n \tan \delta_1 + c_a \qquad \ldots(3)$$

$$\tau_{nt} = -\sigma_n \tan \delta_1 - c_a \qquad \ldots(4)$$

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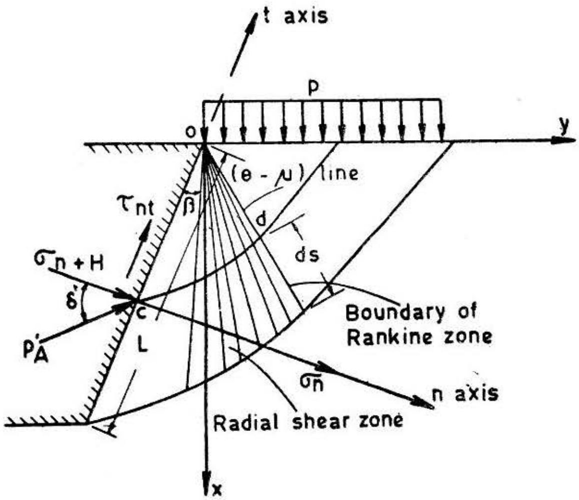

FIGURE 1 Active Earth Pressure on Retaining Wall

where,

σ_n and δ_1 = shear stress on the retaining wall due to wall friction, and

c_a = adhesion along the retaining wall.

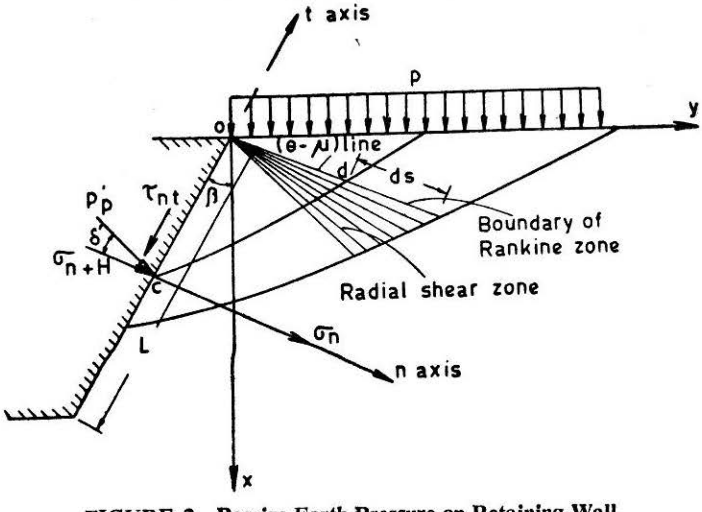

FIGURE 2 Passive Earth Pressure on Retaining Wall

For $c-\varphi$ soil, δ_1 could be a function of angle of shearing resistance of soil which may vary from φ to $\frac{1}{2}\varphi$, and c_a will be a fraction of cohesion c. The adhesion ratio, value of c_a/c, could be ranging from a small value of 0.25 to a maximum value of 1.0. Retained soil and retaining wall are of different materials. Hence, angle of wall friction will be different from angle of shearing resistance. Similarly adhesion will be different from cohesion intercept of retained soil. The cohesion intercept and angle of shearing resistance will have different values for different soil conditions such as void ratio, grain size, grain shape and interparticle forces.

Sokolovsky (1960) has arbitrarily taken $\frac{c_a}{c} = \frac{\tan \delta_1}{\tan \varphi}$, where δ_1 = angle of wall friction of soil. In actual practice $\frac{c_a}{c}$ will be different from this and hence in this analysis $\frac{c_a}{c}$ is taken to be equal to $\frac{\tan \delta_2}{\tan \varphi}$ where δ_2 could be different from δ_1. For convenience in the anaiysis, Equations 3 and 4 can be written in the form

$$\tau_{nt} = \sigma_n \tan \delta_1 + H \tan \delta_2 \qquad ...(5)$$

$$\tau_{nt} = -\sigma_n \tan \delta_1 - H \tan \delta_2 \qquad ...(6)$$

δ_2 can be called as an equivalent wall friction corresponding to adhesion ratio c_a/c. In the analysis presented herein, both for active and passive cases, for values of φ and δ_1, δ_2 is varied and earth pressures on the retaining walls are calculated. The influence of this assumption *i.e.* $\delta_2 \neq \delta_1$, on the slip lines is also presented.

Analysis

Active Earth Pressure

Referring to Fig. 1, with respect to x and y axes, the normal and shear stresses at a point are given by

$$\sigma_x = \sigma\,(1+\sin\varphi \cos 2\theta) - H \qquad ...(7)$$

$$\sigma_y = \sigma\,(1-\sin\varphi \cos 2\theta) - H \qquad ...(8)$$

$$\tau_{xy} = \sigma \sin\varphi \sin 2\theta \qquad ...(9)$$

where,

σ_x = normal stress in the x-direction,

σ_y = normal stress in the y-direction,

$\sigma = \frac{\sigma_x + \sigma_y}{2} + H$, and

θ = angle between the direction of major principal stress and x-axis.

With reference to the normal and tangential directions of the retaining wall, the stresses are given by

$$\sigma_n = \sigma\{1+\sin \varphi \cos 2[\theta-(90-\beta)]\} - H \qquad ...(10)$$

$$\tau_{nt} = \sigma \sin \varphi \sin 2[\theta-(90-\beta)] \qquad ...(11)$$

where,

σ_n = normal stress along n-axis,

τ_{nt} = tangential stress along t axis, and

β = inclination of retaining wall with x-axis.

Substituting for σ_n from Eqs. 10 into Eq. 5 and equating Eq. 11 and Eq. 5, the following expression is obtained

$$-\sigma \sin\varphi \sin 2(\theta+\beta) = \sigma \tan\delta_1 - \sigma \sin\varphi \cos 2(\theta+\beta) \tan\delta_1 - H\tan\delta_1 + H\tan\delta_2 \quad ...(12)$$

Multiplying Eq. 12 through out by $\frac{\cos\delta_1}{\sin\varphi}$, rearranging and simplifying, it reduces to

$$\sin[\delta_1-(2\theta+2\beta)] - \frac{\sin\delta_1}{\sin\varphi} = \frac{H}{\sigma}\,\frac{\sin(\delta_2-\delta_1)}{\cos\delta_2\,\sin\varphi} \quad ...(13)$$

The angle measured counterclockwise is taken as positive. With the negative sign for β, for $\delta_2=\delta_1$, the right hand side of Equation 13, reduces to the usual expression given by Sokolovsky (1960),

$$2\theta = \delta_1 + 2\beta - \sin^{-1}\left(\frac{\sin\delta_1}{\sin\varphi}\right) \quad ...(14)$$

Referring to Fig. 1, at point O, to the right of point O, the major principal stress is vertical and hence $\theta=0$ and $\sigma_x=p$. Introducing the following nondimensional quantities, $\sigma'=\sigma/c$, $x'=x/l$, $p'=p/c$, $y'=y/l$, l=characteristic length γ/c, and substituting for θ and σ_x in Equation 7, the expression for σ' on right hand side becomes,

$$\sigma'_{RO} = \frac{p'+\cot\varphi}{1+\sin\varphi} \quad ...(15)$$

At O, η = constant. Therefore, η on left hand side is equal to η on right hand side, *i.e.*

$$\frac{\cot\varphi}{2} \ln \sigma'_{RO} - \theta_{RO} = \frac{\cot\varphi}{2} \ln \sigma'_{LO} - \theta_{LO} \quad ...(16)$$

where,

$$\eta = \chi + \theta, \text{ and } \chi = \frac{\cot\varphi}{2} \ln \sigma'$$

$\theta_{RO} = 0$, and σ'_{RO} is given by Eq. 15. Substituting for θ_{RO} and σ'_{LO} in Eq. 16, the expression for σ'_{LO} is obtained as

$$\sigma'_{LO} = \frac{(p'+\cot\varphi)\, e^{2\theta_{LO}\tan\varphi}}{1+\sin\varphi} \quad ...(17)$$

Substituting for σ as $c\sigma'_{LO}$ in Eq. 13, Eq. 13 reduces to

$$\sin[\delta_1-(2\theta_{LO}+2\beta)] - \frac{\sin\delta_1}{\sin\varphi} = \frac{\cot\varphi\,(1+\sin\varphi)\sin(\delta_2-\delta_1)}{(p'+\cot\varphi)e^{2\theta_{LO}\tan\varphi}\cos\delta_2\sin\varphi} \quad ...(18)$$

In the above expression θ_{LO} is unknown, which can be obtained by trial. Substituting this θ_{LO} in Equation σ'_{LO} can be obtained. Equating τ_{nt} as given from Eqs. 5 and 11 the following relationship is obtained.

$$\sigma'_n = \frac{-\sigma'_{LO} \sin \varphi \sin (2\theta_{LO}+2\beta) - \cot \varphi \tan \delta_2}{\tan \delta_1} \quad ...(19)$$

At other points along the retaining wall, the quantities σ'_n and θ are arrived as follows.

Point such as c shown in Fig. 1 is on the retaining wall and is also on the $(\theta-\mu)$ characteristic line. If θ_c is the value of θ at c, σ'_c is the value of σ' at c, then

$$\frac{\cot \varphi}{2} \ln \sigma'_c = \eta_c + \theta_c \quad ...(20)$$

Therefore,

$$\sigma'_c = e^{2(\eta_c+\theta_c) \tan \varphi} \quad ...(21)$$

Equating σ'_c obtained from Eq. 21 and Eq. 13, the following relationship is obtained.

$$e^{2(\eta_c+\theta_c) \tan \varphi} = \frac{\cot \varphi \sin (\delta_2-\delta_1)}{\cos \delta_2 \sin \varphi \left\{\sin[\delta_1-(2\theta_c+2\beta)] - \dfrac{\sin \delta_1}{\sin \varphi}\right\}} \quad ...(22)$$

θ_c is obtained by trial from Eq. 22. Once θ_c is known, the quantities σ'_n and τ'_{nt} along the retaining wall can be obtained using Eqs. 10 and 11.

With the analysis presented as above, and using the equations along the characteristics (Sokolovsky, 1960), the slip lines and the stresses along the retaining wall are obtained.

Passive Earth Pressure

Referring to Fig. 2, for the passive case, equating τ_{nt} given by Eqs. 11 and 6, the following relation is obtained.

$$-\sigma_n \tan \delta_1 - H \tan \delta_2 = -\sigma \sin \varphi \sin 2(\theta+\beta) \quad ...(23)$$

Substituting for σ_n from Eq. 10 into Eq. 23,

$$\sigma_n\{[1-\sin \varphi \cos 2(\theta+\beta)]-H\} \tan \delta_1 - H \tan \delta_2 = \sigma \sin \varphi \sin 2(\theta+\beta) \quad ...(24)$$

Multiplying Eq. 24, through out by $\frac{\cos \delta_1}{\sin \varphi}$, rearranging and simplifying it reduces to

$$2\theta = \pi - \delta_1 - 2\beta - \sin^{-1}\left[\frac{\sin \delta_1}{\sin \varphi} + \frac{H \sin(\delta_2 - \delta_1)}{\sigma \sin \varphi \cos \delta_2}\right] \quad ...(25)$$

When $\delta_1 = \delta_2$, Eq. 25 reduces to the usual expression (Sokolovsky, 1960)

$$2\theta = \pi - \delta_1 + 2\beta - \sin^{-1}\left(\frac{\sin \delta_1}{\sin \varphi}\right) \quad ...(26)$$

Further analysis for the passive case is similar to the procedure explained for active case. The boundary conditions for the two cases differ and appropriate equations along the characteristics are to be used.

At O, ξ = constant. Therefore equating ξ on left hand side of O to ξ on right hand side,

$$\frac{\cot \varphi}{2} \ln \sigma'_{RO} + \theta_{RO} = \frac{\cot \varphi}{2} \ln \sigma'_{LO} + \theta_{LO} \quad ...(27)$$

where, $\xi = \chi + \theta$

$\theta_{RO} = \pi/2$ and σ'_{RO} is obtained by substituting $\theta = \pi/2$ and $\sigma_x = p$ in Eq. 7, which is

$$\sigma'_{RO} = \frac{p' + \cot \varphi}{1 - \sin \varphi} \quad ...(28)$$

Substituting for σ'_{RO} and θ_{RO} into Equation 27, the expression for σ'_{LO} is obtained as

$$\sigma'_{LO} = \frac{(p' + \cot \varphi)\, e^{(\pi - 2\theta_{LO})\tan \varphi}}{(1 - \sin \varphi)} \quad ...(29)$$

Substituting for σ'_{LO} from Eq. 29 into Eq. 25, the expression for θ_{LO} is obtained as

$$2\theta_{LO} = \pi - \delta_1 - 2\beta - \sin^{-1} \frac{\sin \delta_1}{\sin \varphi} + \frac{(\cot \varphi)(1 - \sin \varphi) \sin(\delta_2 - \delta_1)}{(p' + \cot \varphi)\, e^{(\pi - 2\theta_{LO})\tan \varphi} \sin \varphi \cos \delta_2} \quad ...(30)$$

θ_{LO} *in Eq.* 30 is to be obtained by trial. Once, θ_{LO} is known, σ'_{LO} can be obtained from Eq. 25. σ'_n and τ'_{nt} are obtained by Eqs. 10 and 11 respectively.

At other points along the retaining wall, the quantities σ'_n, θ and σ'_{nt} are arrived as follows, For a point such as c shown in Fig. 2, which is on the retaining wall on the $(\theta+\mu)$ characteristic line, if θ_c is the value of θ at c, and σ'_c is the value of σ' at c, then

$$\frac{\cot \varphi}{2} \; ln \; \sigma'_c = \xi_c - \theta_c \qquad \ldots(31)$$

$$\sigma'_c = e^{2(\zeta_c - \theta_c) \tan \varphi} \qquad \ldots(32)$$

Equating σ'_c obtained from Eqs. 32 and 25, the following relationship is obtained.

$$e^{2(\zeta_c - \theta_c) \tan \varphi} = \frac{\cot \varphi \sin (\delta_2 - \delta_1)}{\sin \varphi \cos \delta_2 \left\{ \sin [\pi - (\delta_1 + 2\theta_c + 2\beta)] - \frac{\sin \delta_1}{\sin \varphi} \right\}} \qquad \ldots(33)$$

In the above equation, θ_c is to be arrived by trail. Once θ_c is known, σ'_c ,and σ'_n at c and τ'_{nt} at c can be obtained using Eqs. 32, 10 and 11 respectively.

With the analysis presented as above, and using the equations along the characteristics, the slip lines and the stresses along the retaining wall are obtained.

Results and Discussion

Active Earth Pressure

Numerical results are obtained for $\varphi = 5$, 10 and 20 degrees. The values of δ_1 used are φ, $\frac{2}{3}\varphi$ and $\frac{1}{2}\,\varphi$ for $\varphi = 5$ and 10 degrees. For $\varphi = 20$ degrees, δ_1 values used are 20, 15 and 10 degrees. The values of adhesion ratio $H' \tan \delta_2$ (*i.e.* $\cot \varphi \tan \delta_2$) used are 0.25 to 1.0. When $\delta_1 = \delta_2$, *i.e.* $\cot \varphi \tan \delta_2 = \cot \varphi \tan \delta_1$, the case corresponds to the usual case. Results for $\beta = 0°$ case only are presented.

When $\delta_2 \neq \delta_1$, the value of θ_{LO} at O (Fig. 1) is obtained from Equation 18 and the normal stress σ'_n is to be obtained from Eq. 19 and thes hear stress along the retaining wall is obtained using Eq. 5. With the sign convention used in this analysis, the shear stress should be greater than zero and the inclination of major principal stress should be negative and the magnitude of the angle of inclination should not exceed 90 degrees.

Referring to Eq. 18, for some range of adhesion ratios and other parameters, unless the absolute value of θ is greater than 90°, Eq. 18 cannot be satisfied. In the present analysis, adhesion ratios of 0.25 or 0.95, are used in general for all the cases. When solution is not possible for either 0.25 or 0.95, solutions have been obtained for ratios of 0.50 and 0.75. p' has been assumed as zero throughout the analysis. H in non-dimensional form is denoted as $H' = \cot \varphi$. A sufficiently finer mesh is used for the numerical computation.

Referring to Fig. 1, if p'_A is the resultant pressure, its inclination with normal is denoted as δ'. δ' is given by

$$\delta' = \tan^{-1}\left[\frac{\sigma'_n \tan\delta_1 + \cot\varphi \tan\delta_2}{\sigma'_n + \cot\varphi}\right] \qquad \ldots(34)$$

Fig. 3 shows a plot of p'_A vs. nondimensional length L for $\varphi = 5°$, $\delta_1 = 5°$, $\beta = 0°$ and different adhesion ratios. The figure reveals that the plot is practically a straight line and the coefficient of active earth pressure can be taken as the slope of the straight line. Similar trend was observed for the range of other parameters considered in this analysis.

Table 1 shows the values of p'_A and δ' for different values of L along

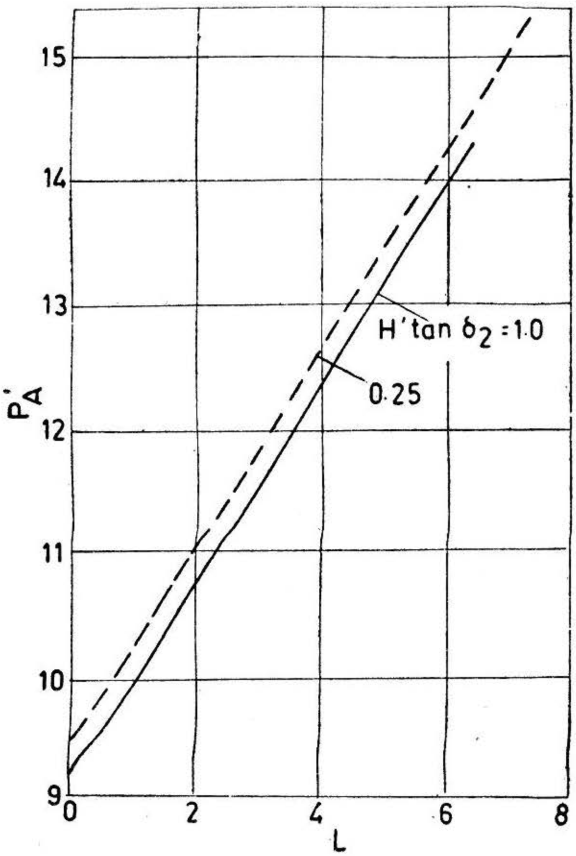

FIGURE 3 p'_A vs. L for $\varphi = 5°$, $\delta_1 = 5°$ and $\beta = 0°$

TABLE 1

Active Pressure p'_A Along Retaining Wall and its Inclination with Normal δ'

L	p'_A	δ_1 (deg)	L	p'_A	δ_1 (deg)	L	p'_A	δ' (deg)
$\varphi = 10°$, $\beta = 0°$ and $\delta_1 = 10°$								
	$H' \tan \delta_2 = 1.0$			$H' \tan \delta_2 = 0.95$			$H' \tan \delta_2 = 0.50$	
0.0	3.720	10.0	0.0	3.718	9.24	0.0	3.862	2.68
1.625	4.755	10.0	1.650	4.774	9.41	1.899	5.071	4.42
3.498	5.924	10.0	3.539	5.988	9.53	3.957	6.387	5.58
5.407	7.152	10.0	5.460	7.227	9.61	5.991	7.699	6.33
7.328	8.433	10.0	7.401	8.481	9.67	8.013	8.996	6.86
$\varphi = 10°$, $\beta = 0°$ and $\delta_1 = 6.66°$								
	$H' \tan \delta_2 = 0.75$			$H' \tan \delta_2 = 0.663$			$H' \tan \delta_2 = 0.25$	
0.0	3.726	8.00	0.0	3.746	6.66	0.0	3.053	0.71
1.707	4.834	7.69	1.755	4.891	6.66	2.028	5.271	2.20
3.699	6.121	7.48	3.752	6.199	6.66	4.210	6.698	3.16
5.670	7.426	7.33	5.777	7.527	6.66	6.358	8.104	3.77
7.694	8.758	7.24	7.820	8.867	6.66	8.489	9.503	4.119
$\varphi = 10°$, $\beta = 0°$ and $\delta_1 = 5°$								
	$H' \tan \delta_2 = 0.75$			$H' \tan \delta_2 = 0.496$			$H' \tan \delta_2 = 0.25$	
0.0	3.720	8.90	0.0	3.784	5.0	0.0	3.918	1.42
1.685	4.815	8.01	1.830	4.997	5.0	2.003	5.246	2.32
3.647	6.102	7.37	3.902	6.373	5.0	4.194	6.705	2.90
5.663	7.432	6.95	5.997	7.765	5.0	6.369	8.153	3.28
7.713	8.797	6.65	8.106	9:170	5.0	8.536	9.584	3.53

retaining wall, for $\delta = 5$ and 10 degrees and different values of other parameters. It can be seen from Table 1, that when $\delta_2 \neq \delta_1$, there is considerable change in the inclination of resultant pressure p'_A with the normal along the length L. Fig. 4 shows the variation of δ' along the length of retaining wall for $\varphi = 5°$ and $\beta = 0°$. As could be seen from Figs. 4 to 6 and Table 1, when $\delta_2 < \delta_1$, as L increases δ' increaes and when $\delta_2 > \delta_1$ δ' decreases with length L. At greater lengths, the effect of adhesion ratio to be different from wall friction ratio has not much influence on the value of δ'. This is evident due to the fact that as L increase, σ'_n increases and contribution of the term σ'_n tan δ_1 will be more compared to that of cot φ tan δ_2, in arriving at the shear stress along the retaining wall.

Table 2 shows the values of coefficients of active earth pressure. Since the plot of p'_A vs. L is nearly a straight line for the data considered in this analysis, the coefficient of active earth pressure can be taken as the slope of P'_A vs. L line.

TABLE 2

Active Earth Pressure Coefficient k_A for $\varphi = 5°$ and $10°$

$\phi = 5°, \beta = 0°$			$\phi = 10°, \beta = 0°$		
δ_1 (deg)	H' tanδ_2	k_A	δ_1 (deg)	H' tan δ_2	k_A
5.0	1.0	0.7930	10	1.0	0.6421
	0.95	0.7948		0.95	0.6436
	0.25	0.7909		0.50	0.6407
3.3	0.75	0.8058	6.66	0.75	0.6540
	0.666	0.8047		0.663	0.6549
	0.250	0.8061		0.25	0.6538
2.5	0.75	0.8079	5.00	0.75	0.6583
	0.499	0.8119		0.496	0.6645
	0.250	0.8124		0.55	0.6634

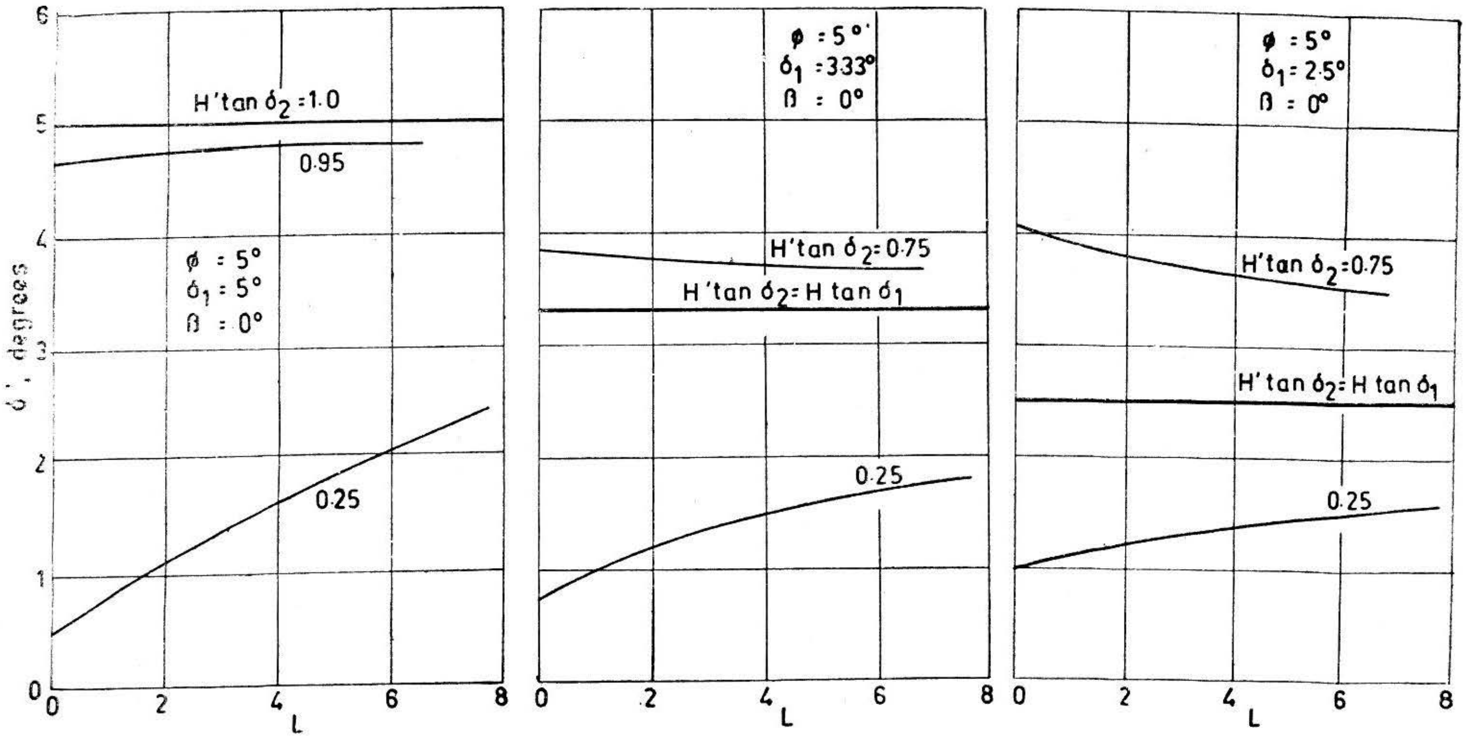

FIGURE 4 δ' versus L for Values of δ_1 (Active Case)

As could be seen from Table 2, the coefficient of earth pressure is practically the same for different adhesion ratios. In otherwords, effect of $\delta_2 \neq \delta_1$ is to change the inclination of the resultant pressure along the retaining wall and it does not influence the coefficient of earth pressure appreciably.

The values of δ' and p'_A obtained for $\varphi = 20$ degree are shown in Table 3. Since p'_A vs. L. plot is linear, only the maximum lenghts L_m obtained and corresponding values of p'_A and δ' are given. As could be seen from the values shown in Tables 1 and 3, as φ increases, the influence $\delta_2 \neq \delta_1$ is less.

In order to show the influence of δ_2 on the failure surface, failure surfaces for few typical cases are shown in Figs. 5 and 6. As could be seen from these figures, as δ_2 decreases, the failure surface becomes deeper.

Passive Earth Pressure

Using the values of θ_{LO}, σ'_n is to be obtained from Eq. 23 and τ'_n from Eq. 6. The shear stress τ'_{nt} for the passive case should be less than zero and O obtained using Equation 30 should be positive.

Referring to Fig. 2, δ', the inclination of resultant pressure p'_p with with normal is given by,

$$\delta' = \tan^{-1}\left(\frac{-\sigma'_n \tan \delta_1 - \cot \varphi \tan \delta_2}{\sigma'_n + \cot \varphi}\right) \qquad \ldots(35)$$

Figure 7 shows a plot of p'_p vs. L for $\varphi = 5°$, $\delta_1 = 5°$, $\beta = 0°$ and different adhesion ratios. The figure reveals that the plot is practically a straight line. Similar trend was observed for other range of parameters considered in this analysis.

Table 4 shows the values of p'_p and δ' for different values of L along retaining wall for $\varphi = 5°$ and $10°$ and different values of other parameters. As in the active case, it can be seen from Table 4, that when $\delta_2 \neq \delta_1$, there is considerable change in the inclination of resultant pressure p'_p with normal along the length. Fig. 8 shows the variation of δ' along the retaining wall for $\varphi = 5°$, $\delta_1 = 5°$ and $\beta = 0°$. The figures reveal that when $\delta_2 < \delta_1$, δ' increases with increase in length L and when $\delta_2 > \delta_1$, δ' decreases with increase in length L. As could be seen in the figures, at greater lengths, the values of δ' are not very much affected due to change in adhesion ratio.

TABLE 3

Active Earth Pressure p'_A Along Retaining Wall and its Inclination for $\varphi = 20°$

L	p'_A	δ' (deg)	L	p'_A	δ' (deg)	L	p'_A	δ' (deg)
$\beta = 0.0°$ and $\delta_1 = 20°$								
	$H' \tan \delta_2 = 1.0$			$H' \tan \delta_2 = 0.95$			$H' \tan \delta_2 = 0.25$	
0.0	1.233	20.0	0.0	1.224	1.780	0.0	1.246	9.13
9.256	5.276	20.0	9.316	5.301	19.49	9.558	5.413	17.49
$\beta = 0.0°$ and $\delta_1 = 13.33°$								
	$H' \tan \delta_2 = 0.75$			$H' \tan \delta_2 = 0.651$			$H' \tan \delta_2 = 0.5$	
0.0	1.225	17.88	0.0	1.227	13.33	0.0	1.264	6.65
9.618	5.455	14.33	9.752	13.33	13.33	9.959	5.664	11.85
$\beta = 0.0°$ and $\delta_1 = 10°$								
	$H' \tan \delta_2 = 0.65$			$H' \tan \delta_2 = 0{\cdot}484$			$H' \tan \delta_2 = 0.5$	
0.0	1.224	17.64	0.0	1.240	10.0	0.0	1.237	10.71
9.789	5.583	11.67	10.029	5.742	10.0	10.006	5.727	10.15

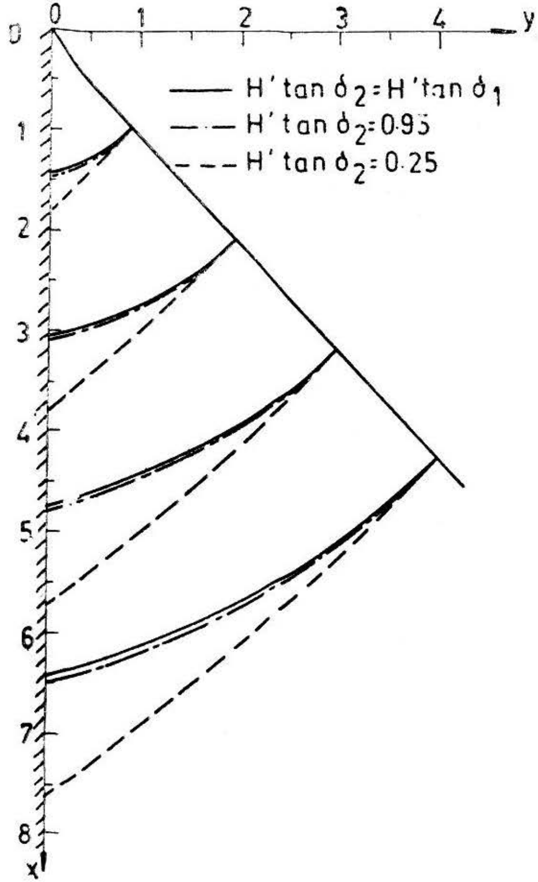

FIGURE 5 Failure Surface for $\varphi = 5°$, $\beta = 0°$ and $\delta_1 = 5°$ (Active Case)

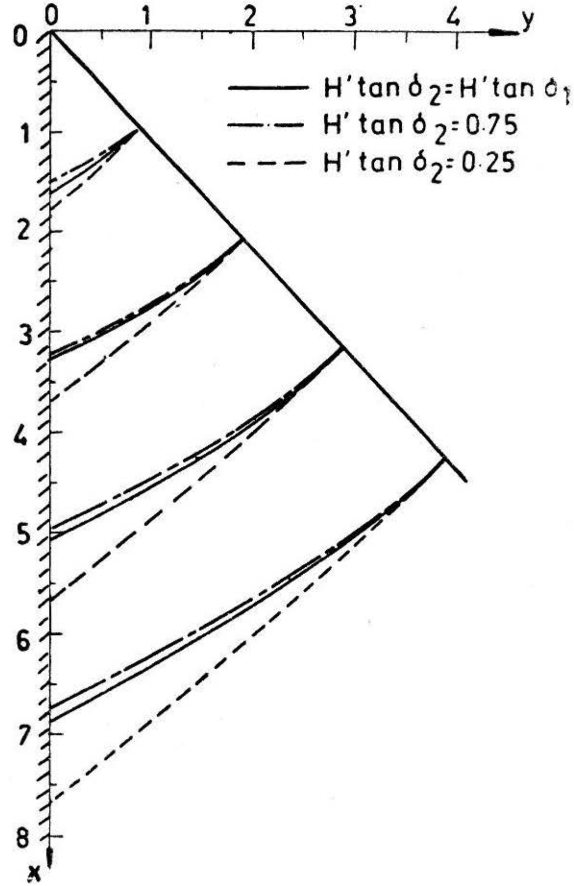

FIGURE 6 Failure Surface for $\varphi = 5°$, $\beta = 0°$ and $\delta_1 = 3.33°$ (Active Case)

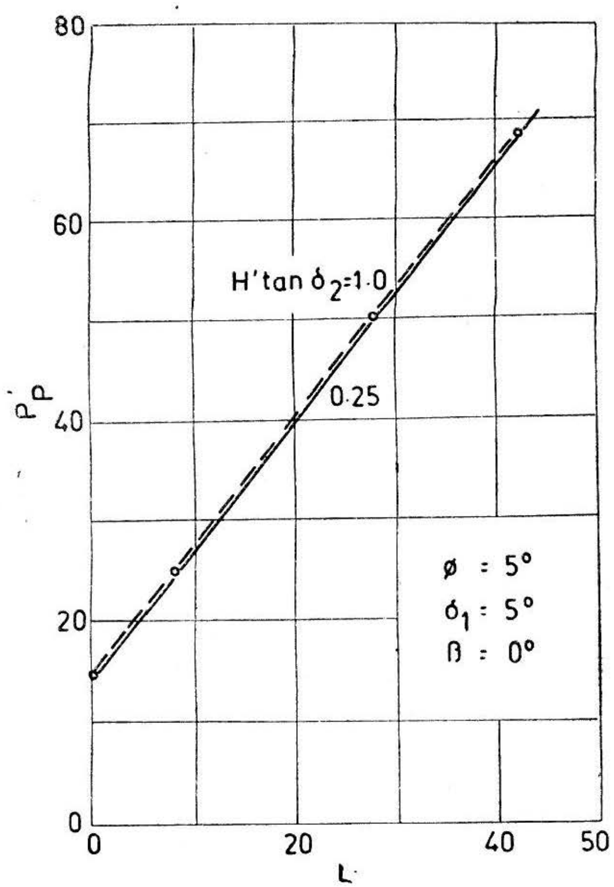

FIGURE 7 p'_p **vs.** L **for** $\varphi = 5°$, $\delta_1 = 5°$ **and** $\beta = 0°$ **(Passive Case)**

This is again due to fact that whereas σ'_n tan δ_1 increases with increase in L, the adhesion ratio remains constant and hence its influence decreases with increase in length L.

Table 5 shows the values of passive earth pressure coefficients. Since the plot of p'_p vs. L is practically a straight line, the coefficient of passive earth pressure is taken as the slope of p'_p vs. L line.

As could be seen from Table 5, the coefficients do not change much with change in δ_2. The effect of $\delta_2 \neq \delta_1$ is to change the inclination of

TABLE 4

Passive Earth Pressure p_p' Along Retaining Wall and its Inclination with Normal δ'

L	p_p'	δ' (deg)	L	p_p'	δ' (deg)	L	p_p'	δ' (deg)
$\varphi = 10°, \beta = 0.0$ and $\delta° = 10°$								
	$H' \tan \delta_2 = 1.0$			$H' \tan \delta_2 = 0.95$			$H' \tan \delta_2 = 0.25$	
0.0	9.194	10.0	0.0	9.182	9.69	0.0	8.78	5.18
2.343	13.151	10.0	2.356	13.158	9.78	2.605	13.129	6.77
12.473	29.999	10.0	12.450	30.024	9.90	13.067	30.045	8.61
25.438	51.494	10.0	25.476	51.538	9.94	26.169	52.206	9.18
38.480	73.106	10.0	38.522	73.171	9.96	39.271	73.936	9.43
$\varphi = 10°, \beta = 0.0$ and $\delta°$ 6.66								
	$H' \tan \delta_2 = 0.95$			$H' \tan \delta_2 = 0.663$			$H' \tan \delta_2 = 0.25$	
0.0	9.104	8.44	0.0	8.946	6.66	0.0	8.637	3.94
22.459	13.101	7.91	2.568	13.071	6.66	2.763	13.037	4.86
13.140	30.211	7.21	13.420	30.391	6.66	13.887	30.760	5.90
35.196	65.379	6.91	27.252	52.441	6.66	27.814	52.961	6.22
40.742	74.221	6.89	41.139	74.576	6.66	41.748	75.174	6.35
$\varphi = 10°, \beta = 0.0$ and $\delta_1 = 5°$								
	$H' \tan \varrho_2 = 0.95$			$H' \tan \delta_2 = 0.496$			$H' \tan \varrho_2 = 0.25$	
0.0	9.056	7.86	0.0	8.766	5.0	0.0	8.560	3.36
2.514	13.051	6.98	2.715	13.000	5.0	2.850	12.982	3.92
13.527	30.282	5.86	14.045	30.636	5.0	14.306	30.915	4.35
27.772	52.430	5.49	28.433	53.006	5.0	28.823	53.370	4.74
42.134	74.772	5.35	42.863	75.448	5.0	43.284	75.862	4.81

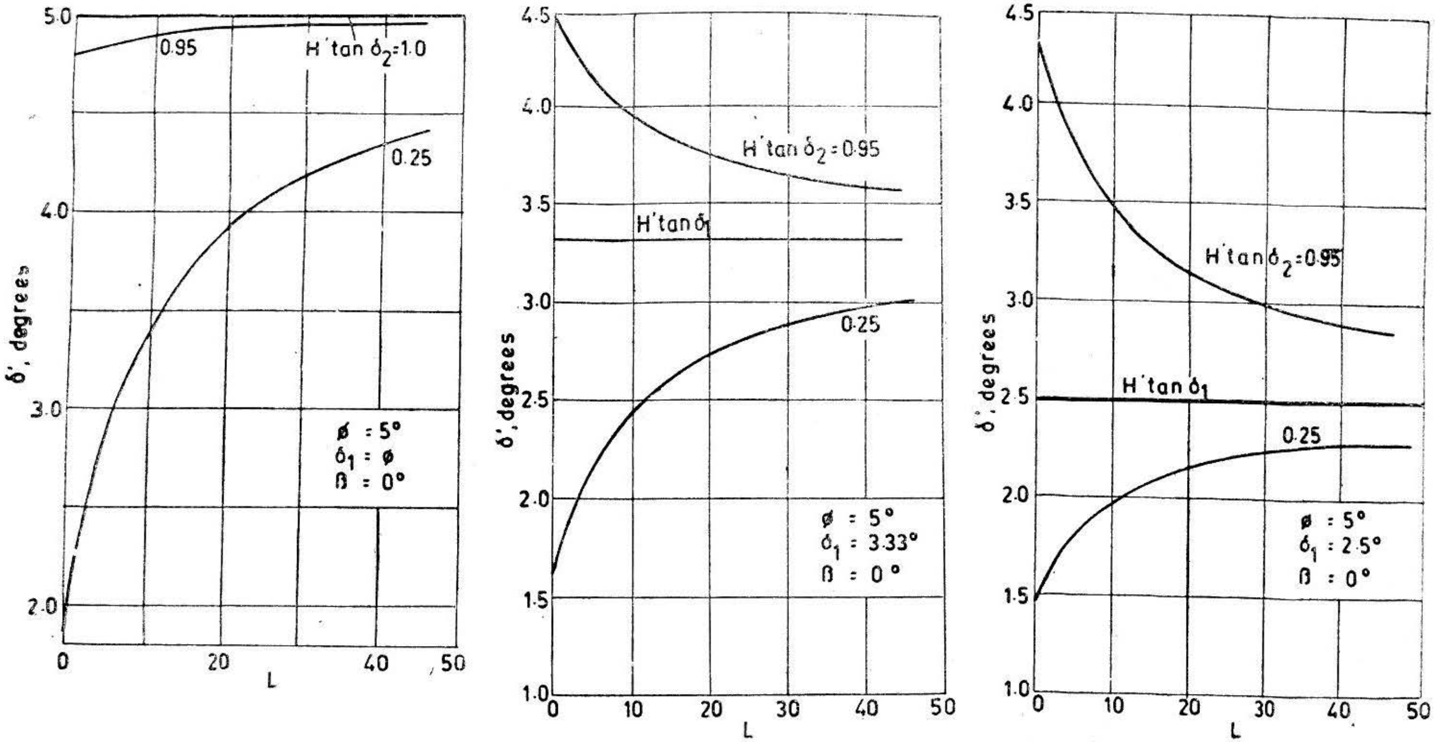

FIGURE 8 δ' versus L for Values of δ_1 (Passive Case)

TABLE 5

Passive Earth Pressure Coefficient k_p for $\varphi = 5°$ aad 10°

$\phi = 5°, \beta = 0°$			$\phi = 10°. \beta = 0°$		
δ_1 (deg)	$H' \tan \delta_2$	k_p	δ_1 (deg)	$H' \tan \delta_2$	k_p
5.00	1.000	1.2766	10.00	1.000	1.6609
	0.950	1.2771		0.950	1.6611
	0.250	1.2766		0.250	1.6589
3.00	0.950	1.2568	6.66	0.950	1.5983
	0.666	1.2544		0.663	1.5953
	0.250	1.2537		0.250	1.5938
2.50	0.950	1.2440	5.00	0.950	1.5597
	0.499	1.2406		0.496	1.5557
	0.250	1.2439		0.250	1.5549

resultant pressure p'_p with normal and the coefficients are not much influenced by the change in the value of δ_2.

Figs. 9 and 10 show the influence of δ_2 on the failure surfaces for a few typical cases. As could be seen from these figures, as δ_2 decreases, the failure surface becomes deeper,

Table 6 shows the values of p'_p and δ' for $\varphi = 20°$. Since p'_p vs. L plot is linear, only the maximum lengths L_m obtained and the corresponding values of p'_p and δ' are given.

If there is static pore water pressure under saturated condition of soil, the influence of the porewater pressure on pressures on retaining walls can be taken into account by assuming linear variation of porewater pressure on the retaining wall and taking submerged unit weight of soil while calculating the earth pressures from the approach presented in the paper. In that case the characteristic length $l = \frac{\gamma'}{c}$, where γ' = submerged unit weight of soil.

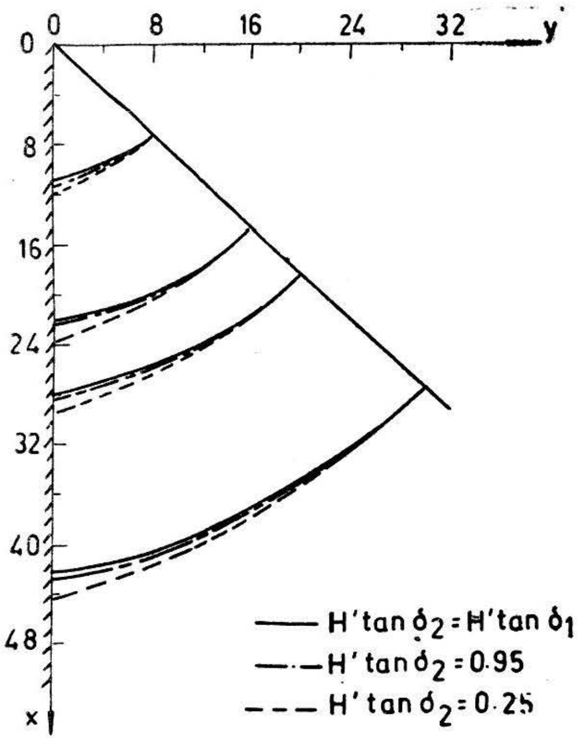

FIGURE 9 Failure Surfaces for $\varphi = 5°$, $\beta = 0°$ and $\delta_1 = 5°$ (Passive Case)

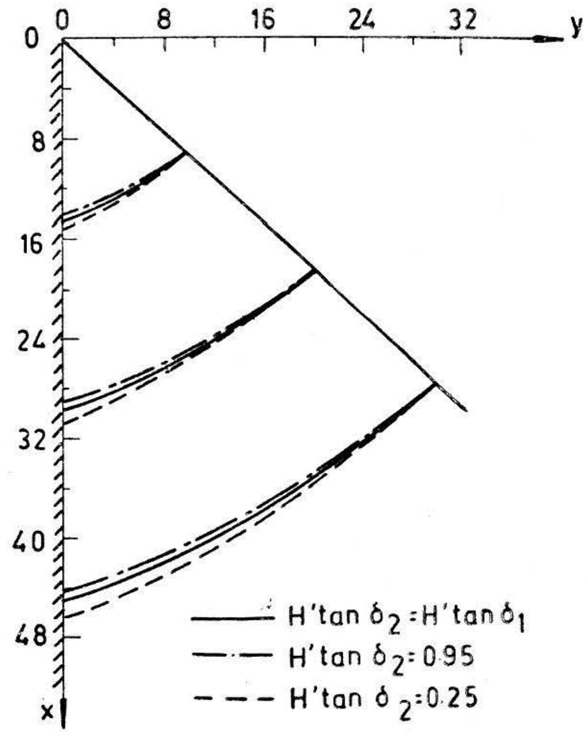

FIGURE 10 Failure Surfaces for $\varphi = 5°$, $\beta = 0°$ $\delta_1 = 3.33°$ (Passive Case)

TABLE 6

Passive earth pressure p_p' Along Retaining Wall and its Inclination with Normal for $\varphi = 20°$

L	p_p'	δ' (deg)	L	p_p'	δ' (deg)	L	p_p'	δ' (deg)
$\beta = 0.0°$ and $\delta_1 = 20°$								
	$H' \tan \delta_2 = 1.0$			$H' \tan \delta_2 = 0.95$			$H' \tan \delta_2 = 0.25$	
0.0	7.892	20.0	0.0	7.879	19.66	0.0	7.421	14.55
30.436	100.916	20.0	30.451	100.970	19.67	30.625	99.671	14.59
$\beta = 0.0°$ and $\delta_1 = 15°$								
	$H' \tan \delta_2 = 0.95$			$H' \tan \delta_2 = 0.736$			$H' \tan \delta_2 = 0.25$	
0.0	7.619	16.55	0.0	7.346	15.0	0.0	7.050	11.18
31.122	98.416	15.12	32.962	98.227	15.0	32.481	98.595	14.73
$\beta = 0.0°$ and $\delta_1 = 10°$								
	$H' \tan \delta_2 = 0.95$			$H' \tan \delta_2 = 0.484$			$H' \tan \delta_2 = 0.25$	
0.0	7.321	13.59	0.0	6.911	10.0	0.0	6.668	8.01
34.329	95.452	10.27	34.643	96.641	10.0	34.808	95.764	9.86

Conclusions

Based on the results and discussion presented, it can be concluded that the assumption that the coefficient of the wall friction and adhesion are dependent on φ only is satisfactory as far as the coefficients of earth pressures are concerned. But, when adhesion ratios are different from wall friction ratios, the adhesion ratio has considerable influence on the direction of resultant pressure.

Reference

SOKOLOVSKY, V.V., (1960), *'Statics of Soil Media'*, Butterworths Scientific Publications, London.