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Lateral Earth Pressure Coefficient and Lateral Earth Pressure against Retaining Walls

Jose Medina, Nicolas Sau and Qutberto Acuña

Department of Civil and Mining Engineering, University of Sonora, Hermosillo, Sonora 83000, México

Abstract: According the Coulomb earth pressure theory, it is obtained that, for normally consolidated soils, the lateral pressure coefficient of a soil at rest is equal to 1, and it is independent of the soil type, either granular or cohesive; or that the material is in a loose or compact state; hard or a soft cohesive soil. Also, a methodology to calculate the earth pressure for intermediate states between at rest condition and the active pressure is presented. In addition, a methodology to calculate the earth pressure for intermediate states between at rest condition and the passive pressure is presented. Two practical examples are presented: one for a frictionless wall; and another for a coarse wall. Practical recommendations are given for the use of the lateral earth pressure coefficient for different applications.

Key words: Lateral earth pressure at rest, retaining wall, active thrust, passive thrust, Rankine, Coulomb, lateral earth pressure coefficient, lateral earth pressure coefficient at rest.

1. Introduction

The coefficient of lateral earth pressure at rest is defined as the ratio of the effective horizontal stress and the vertical effective stress, as presented in Eq. (1):

$$ko = \frac{\sigma' oh}{\sigma' oz} \quad (1)$$

where σ′oh is the initial horizontal effective stress and σ′oz is the initial vertical effective stress.

The lateral earth pressure coefficient at rest is required to: (1) calculate the lateral thrust against a retaining wall at rest condition [1]; (2) determine the modulus of soil deformation in the triaxial chamber [2]; (3) study expansive soils [3]; (4) study collapsible soils [4]; (5) calculate lateral friction in piles foundation [5].

Fig. 1 shows a vertical retaining wall, with granular backfill and a horizontal surface.

Applying Eq. (1) on both sides of the wall, the horizontal diagram of earth pressure at rest, shown in Fig. 1, is obtained. The earth thrust at rest is the area of the horizontal earth pressure at rest diagram.

Corresponding author: José Medina, M. Eng./professor, research field: foundation and geotechnical engineering, jose.medina@prolas.com.mx.

On the active side of the wall:

$$Eo = \frac{1}{2} ko\, \gamma_m H^2 \quad (2)$$

On the passive side of the wall:

$$Eo = \frac{1}{2} ko\, \gamma_m {D_F}^2 \quad (3)$$

Eo is the earth thrust at rest condition (null displacement of the retaining wall).

2. Physical Aspect of the Problem

The physical aspect of the problem will be explained both for the active case as well as for the passive case. In both cases a failure wedge will be considered according to Coulomb earth pressure theory [1]:

The active case will be explained based on Fig. 2, where the earth pressure diagram against a retaining wall (for a granular soil) is shown. At first, the earth pressure at rest is obtained; and as the retaining wall moves, the soil shear force along the failure surface moves and the initial condition of earth pressure at rest is gradually passed to the active earth pressure. *δh* is the retaining wall lateral displacement, *Ts* is the shear force that develops on the failure plane, E_A is the active earth thrust, *Eia* is an intermediate thrust between *Eo* and E_A,

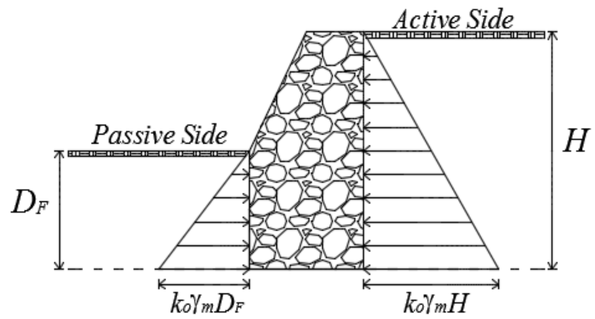

Fig. 1 Horizontal earth pressure at rest diagram.

H is the height of the wall and D_F is the depth of footing.

The passive case will be explained using Fig. 3. Fig. 3 shows the earth pressure diagram against a retaining wall (for a granular soil). Initially, the earth pressure at rest is obtained; and as the retaining wall yields, the shear force of the soil along the failure surface is mobilized, and the initial condition of earth pressure at rest gradually passes to the passive earth pressure, in which E_P is the passive earth thrust, *Eip* is an intermediate thrust between *Eo* and E_P.

The retaining wall lateral displacement can be calculated according to Medina et al. [6].

3. Calculation of *ko*

3.1 From the Active State

Fig. 4 shows the free body diagram for the failure wedge corresponding to the active case. From the balance of forces of the *t* axis, we have:

$$Ea = \frac{W \sin\beta - Ts}{\cos(\beta - \delta)} \quad (4)$$

$$Ts = N \tan\varphi \quad (5)$$

Ea is the active side earth thrust, *W* is the weight of the wedge, *Ts* is the force due to the soil shear strength, *N* is the normal force on the failure plane, φ is the soil internal friction angle, β is the angle that the failure surface forms with the horizontal and δ is the friction angle between the retaining wall and the backfill.

To develop the shear force *Ts* on the failure plane it is necessary that the wall moves. The condition of earth pressure at rest is obtained when *Ts* and δ are equal to zero, so that from Eq. (4):

$$Eo = W \tan\beta \quad (6)$$

So that that *W* is equal to:

$$W = \frac{\gamma_m H^2}{2 \tan\beta} \quad (7)$$

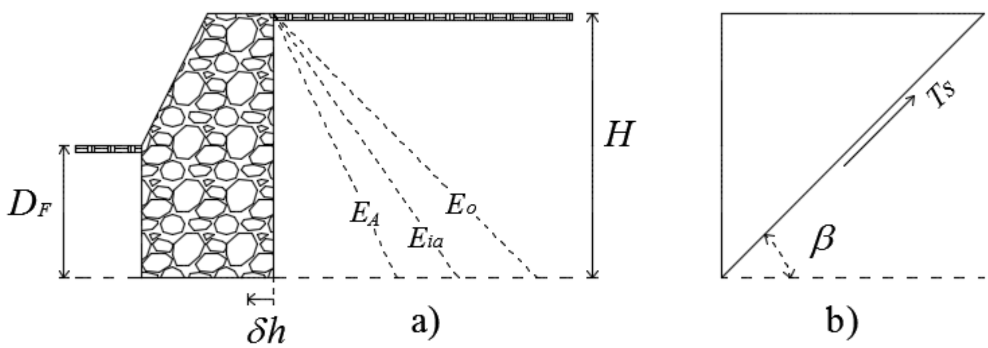

Fig. 2 Earth thrust at the active side: a) variation of earth pressure for a granular soil; b) failure wedge.

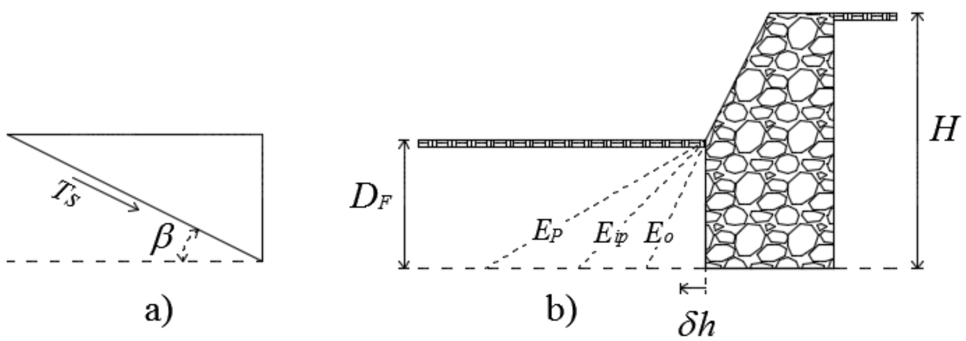

Fig. 3 Earth thrust at the passive side: a) failure wedge; b) variation of earth pressure for a granular soil.

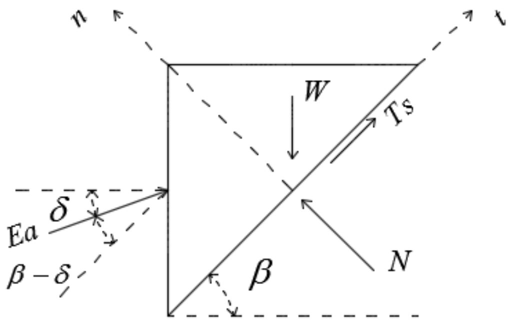

Fig. 4 Wedge free body diagram, active case.

γ_m is unit weigh of the soil.

Substituting Eqs. (7) in Eq. (6):

$$Eo = \frac{1}{2}\gamma_m H^2 \quad (8)$$

From Eqs. (2) and (8) we obtained:

$$ko = 1$$

The earth thrust, for an intermediate state between the earth pressure at rest and the active pressure, is obtained from Eq. (4):

$$Eia = \frac{W \sin\beta - f\,Ts}{\cos(\beta - f\delta)} \quad (9)$$

where *f* is a dimensionless number that varies from 0 to 1. For *f* = 0, *Eo* is obtained; while for *f* = 1, the active thrust, E_A, is obtained.

By definition of lateral earth pressure coefficient:

$$Ehia = \frac{1}{2}\, kla\, \gamma_m H^2 \quad (10)$$

Ehia is the horizontal component of the earth thrust on the active side of the wall; *kla* is the lateral earth pressure coefficient of the active side:

$$kla = \frac{2\,Ehia}{\gamma_m H^2} \quad (11)$$

$$Ehia = Eia\cos(f\delta) \quad (12)$$

$$\sigma'\text{ha} = kla\,\sigma'\text{z} \quad (13)$$

σ′ha is the horizontal effective earth pressure on the active side of the wall and σ′z is the vertical effective stress.

From Eq. (5) it is observed that, to calculate the force *Ts*, it is necessary to obtain the normal force *N* on the failure wedge and, therefore, it is required to know the active earth thrust, E_A.

From the balance of forces on the "*t*" and "*n*" directions (Fig. 4):

$$Ea = \frac{W\sin\beta - W\cos\beta\tan\varphi}{\cos(\beta-\delta) + \sin(\beta-\delta)\tan\varphi} \quad (14)$$

$$N = W\cos\beta + Ea\sin(\beta - \delta) \quad (15)$$

3.2 From the Passive State

Fig. 5 shows the free body diagram for the failure wedge corresponding to the passive side.

With a similar procedure performed in the active case:

$$ko = 1$$

$$Eip = \frac{W\sin\beta + f\,Fs}{\cos(\beta + f\delta)} \quad (16)$$

$$klp = \frac{2\,Ehip}{\gamma_m H^2} \quad (17)$$

$$Ehip = Eip\cos(f\delta) \quad (18)$$

$$\sigma'\text{hp} = klp\,\sigma'\text{z} \quad (19)$$

$$E_P = \frac{W\sin\beta + W\cos\beta\tan\varphi}{\cos(\beta+\delta) - \sin(\beta+\delta)\tan\varphi} \quad (20)$$

$$N = W\cos\beta + E_P\sin(\beta + \delta) \quad (21)$$

Eip is the earth thrust on the passive side of the wall, σ′hp is the horizontal effective earth pressure on the passive side, *kpl* is the earth lateral pressure coefficient on the passive side, and *Ehip* is the earth thrust horizontal component on the passive side.

4. Example 1: Frictionless Wall

4.1 Problem Statement

For the retaining wall shown in Fig. 6, it is required:

(1) Earth thrust at rest condition on the active side.

(2) Active earth thrust and shear force on the failure plane.

(3) The variation of *Eia* and *kla* with the coefficient *f*.

(4) Horizontal earth pressure distribution for the active side.

(5) Earth thrust at rest condition on the passive side.

(6) Passive thrust and shear force on the failure plane.

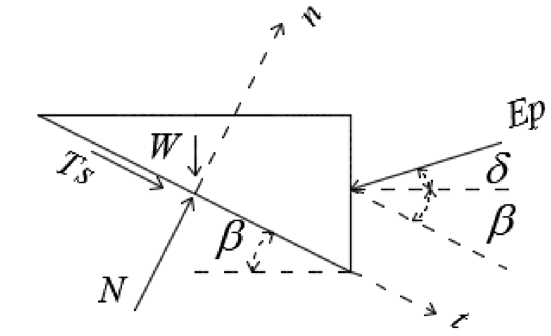

Fig. 5 Wedge free body diagram, passive case.

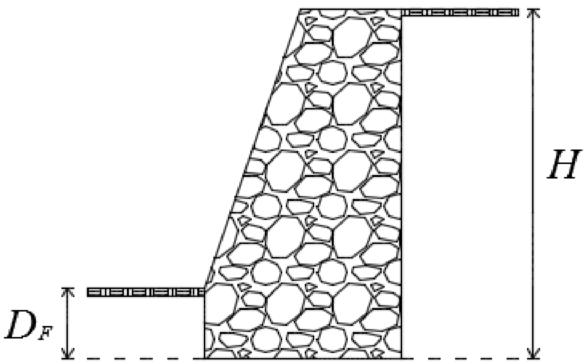

Fig. 6 Retaining wall on examples 1 and 2.

(7) The variation of *Eip* and *klp* with the coefficient *f*.

(8) Horizontal earth pressure distribution for the passive side.

Considering the following:

- H = 6.00 m, D_F = 1.50 m.
- Unit weight of backfill, γm = 19.0 kN/m^3.
- Retaining wall and backfill internal friction angle, δ = 0°.
- Soil internal friction angle, φ = 30°.
- Soil cohesion, C = 0 kN/m^2.

4.2 Solution

4.2.1 Earth Thrust at Rest Condition on the Active Side

From Eq. (8):

Eo = 342.000 kN/m

4.2.2 Active Thrust and Shear Force on the Failure Plane

Since is a frictionless wall, the active thrust is obtained on a plane β = 60º, and from Eqs. (14) and (15):

$E_A = 114.000$ kN/m; $N = 197.454$ kN/m

From Eq. (5):

T_S = 114.000 kN/m

4.2.3 Variation of *Eia* and *kla* with the Coefficient *f*

Table 1 shows the calculation of *Eia* and *kla* with the coefficient *f*. The variation of *Eia* and *kla* with *f*, is shown in Figs. 7 and 8, respectively.

Table 1 Variation of *Eia* and *kla* with *f* (frictionless wall).

f	*f Ts*	*Eia* (kN/m)	*kla*
0.000	0.0000	342.0000	1.0000
0.001	0.1140	341.7720	0.9993
0.250	28.5000	285.0000	0.8333
0.500	57.0000	228.0000	0.6667
0.750	85.5000	171.0000	0.5000
1.000	114.000	114.0000	0.3333

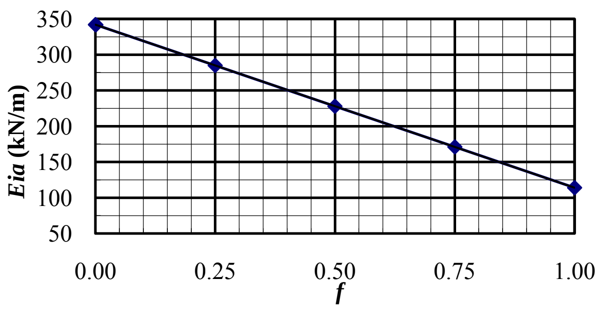

Fig. 7 Variation of *Eia* with *f*, active side, δ = 0°.

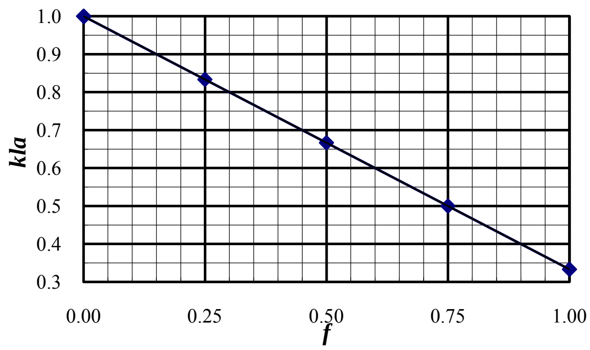

Fig. 8 Variation of *kla* with *f*, active side, δ = 0°.

4.2.4 Distribution of Horizontal Earth Pressure for the Active Side

Table 2 shows the calculation of horizontal earth pressure for the active side. The distribution of the horizontal earth pressure against the wall is shown in Fig. 9.

4.2.5 Distribution of Horizontal Earth Pressure for the Passive Side

From Eq. (8), changing H for D_F:

Eo = 21.375 kN/m.

4.2.6 Passive Thrust and Shear Force on the Failure Plane

Since is a frictionless wall, the passive thrust is obtained on a plane β = 30º, and from Eqs. (20) and (21):

$$E_P = 64.125 \text{ kN/m}, N = 64.125 \text{ kN/m}$$

From Eq. (5):

$$T_S = 37.023 \text{ kN/m}$$

4.2.7 Variation of *Eip* and *klp* with Coefficient *f*

Table 3 shows the calculation of *Eip* and *kpl* with coefficient *f*. The variation of *Eip* and *kpl* with *f*, is shown in Fig. 10 and 11, respectively.

4.2.8 Distribution of the Horizontal Earth Pressure on the Passive Side

Table 4 shows the calculation of the horizontal earth pressure on the passive side. Fig. 12 shows the distribution of the horizontal earth pressure against the wall.

5. Example 2: Coarse Wall

5.1 Problem Statement

Solve the retaining wall on example 1, considering δ = 10º.

5.2 Solution

5.2.1 Active Thrust and Shear Force on the Failure Plane

Table 5 shows the calculation of the active thrust and the normal force on the failure plane.

Table 2 Lateral pressure distribution, active side, δ = 0º.

f	0.00	0.25	0.50	0.75	1.00
kla	1.000	0.833	0.667	0.500	0.333
Depth	σ′ho	σ′h25	σ′h50	σ′h75	σ′h100
(m)	(kN/m^2)	(kN/m^2)	(kN/m^2)	(kN/m^2)	(kN/m^2)
0.00	0.00	0.00	0.00	0.00	0.00
1.00	19.00	15.83	12.67	9.50	6.33
2.00	38.00	31.67	25.33	19.00	12.67
3.00	57.00	47.50	38.00	28.50	19.00
4.00	76.00	63.33	50.67	38.00	25.33
5.00	95.00	79.17	63.33	47.50	31.67
6.00	114.0	95.00	76.00	57.00	38.00

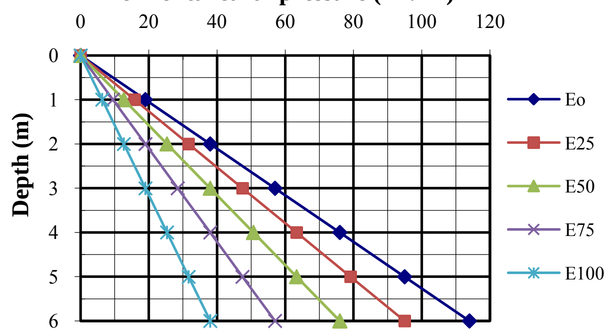

Fig. 9 Horizontal earth pressure, active side, δ = 0º.

Table 3 Variation of *Eip* and *klp* with *f* (frictionless wall).

f	*f Ts*	*Eip* (kN/m)	*klp*
0.000	0.0000	21.3750	1.0000
0.001	0.0370	21.4178	1.0020
0.250	9.2556	32.0625	1.5000
0.500	18.5113	42.7500	2.0000
0.750	27.7669	53.4375	2.5000
1.000	37.0226	64.1250	3.0000

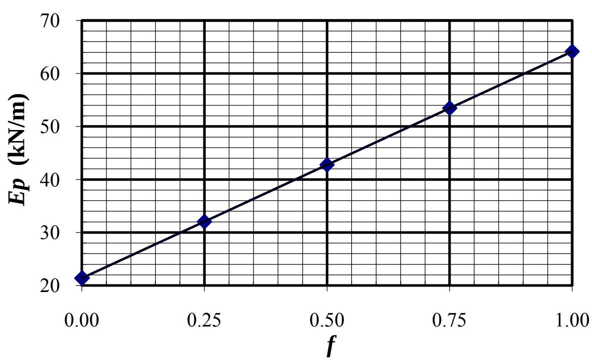

Fig. 10 Variation of *Eip* and *f*, passive side, δ = 0º.

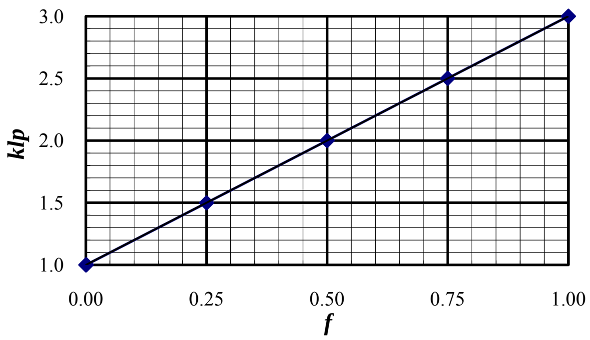

Fig. 11 Variation of *klp* with *f*, passive side, $\delta = 0^o$.

Table 4 Lateral pressure distribution, passive side, $\delta = 0^o$.

f	0.00	0.25	0.50	0.75	1.00
klp	1.000	1.500	2.000	2.500	3.000
Depth	σ′ho	σ′h25	σ′h50	σ′h75	σ′h100
(m)	(kN/m^2)	(kN/m^2)	(kN/m^2)	(kN/m^2)	(kN/m^2)
0.00	0.00	0.00	0.00	0.00	0.00
0.25	4.75	7.13	9.50	11.88	14.25
0.50	9.50	14.25	19.00	23.75	28.50
0.75	14.25	21.38	28.50	35.63	42.75
1.00	19.00	28.50	38.00	47.50	57.00
1.25	23.75	35.63	47.50	59.38	71.25
1.50	28.50	42.75	57.00	71.25	85.50

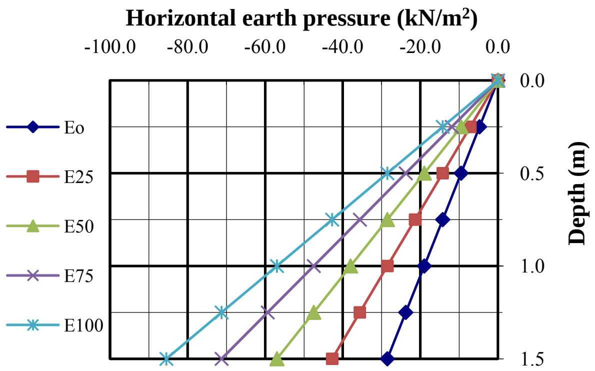

Fig. 12 Lateral pressure distribution, passive side, $\delta = 0^o$.

Table 5 Calculation of the active thrust (coarse wall).

β (°)	$\beta - \delta$ (Rad.)	*W* (kN/m)	*Ea* (kN/m)	*N* (kN/m)
57.5	0.8290	217.8780	105.4871	194.8391
57.6	0.8308	217.0398	105.4917	194.1966
57.7	0.8325	216.2034	105.4944	193.5557
57.8	0.8343	215.3689	105.4953	192.9164
57.9	0.8360	214.5362	105.4944	192.2785
58.0	0.8378	213.7053	105.4917	191.6422
58.1	0.8395	212.8763	105.4872	191.0073

From Table 5, the active and the normal force to the failure plane, $\beta = 57.8^o$:

$E_A = 105.4953$ kN/m; $N = 192.9164$ kN/m

From Eq. (5):

$Ts = 111.3803$ kN/m

5.2.2 Variation of *Eia*, and *kla* with the Coefficient *f*

Table 6 shows the calculation of *Eia* and *kla* with *f*. Figs. 13 and 14 show the variation of *Eia* and *kla* with *f*, respectively.

5.2.3 Horizontal Earth Pressure Distribution for the Active Side

Table 7 shows the calculation of the horizontal earth pressure for the active side. Fig. 15 shows the horizontal earth pressure distribution against the wall.

5.2.4 Passive Thrust and Shear Force on the Failure Plane

Table 8 shows the calculation of the passive thrust and the normal force to the failure plane.

From Table 8, the passive thrust and the normal force to the failure plane are obtained for $\beta = 23.4^o$:

$E_P = 88.5631$ kN/m, $N = 94.0845$ kN/m

From Eq. (5):

Table 6 Variation of *Eia* and *kla* with *f* (Example 2, $\delta = 10^o$).

f	*f Ts*	*Eia* (kN/m)	*Ehia* (kN/m)	*kla*
0.000	0.0000	342.0000	342.0000	1.0000
0.001	0.1114	341.6963	341.6963	0.9991
0.250	27.8451	271.2176	270.9594	0.7923
0.500	55.6902	209.3181	208.5216	0.6097
0.750	83.5352	154.5295	153.2074	0.4480
1.000	111.3803	105.4953	103.8926	0.3038

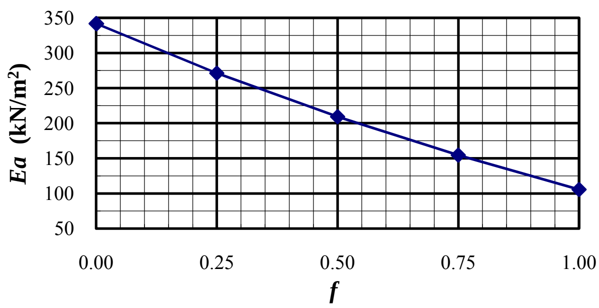

Fig. 13 Variation of *Eia* with *f*, active side, $\delta = 10^o$.

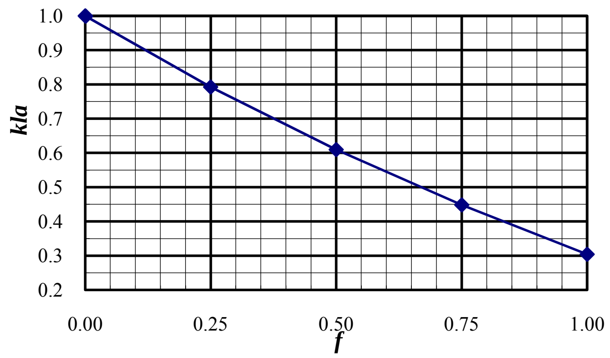

Fig. 14 Variation of *kla* with *f*, active side, $\delta = 10^o$.

Table 7 Horizontal pressure distribution, active side.

f	0.00	0.25	0.50	0.75	1.00
kla	1.000	0.7923	0.6097	0.4488	0.3038
Depth	σ′ho	σ′h25	σ′h50	σ′h75	σ′h100
(m)	(kN/m^2)	(kN/m^2)	(kN/m^2)	(kN/m^2)	(kN/m^2)
0.00	0.00	0.00	0.00	0.00	0.00
1.00	19.00	15.05	11.58	8.51	5.77
2.00	38.00	30.11	23.17	17.02	11.54
3.00	57.00	45.16	34.75	25.53	17.32
4.00	76.00	60.21	46.34	34.05	23.09
5.00	95.00	75.27	57.92	42.56	28.86
6.00	114.00	90.32	69.51	51.07	34.63

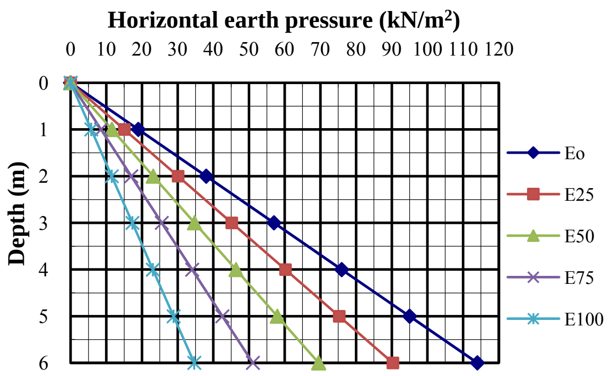

Fig. 15 Lateral pressure distribution, active side, $\delta = 10^o$.

Table 8 Calculation of the passive thrust. Example 2.

β	β+δ	*W*	*Ep*	*N*
(^{o})	(Rad.)	(kN/m)	(kN/M)	(kN/m)
23.1	0.5777	50.1130	88.5754	94.4662
23.2	0.5794	49.8716	88.5690	94.3359
23.3	0.5812	49.6322	88.5649	94.2087
23.4	0.5829	49.3947	88.5631	94.0845
23.5	0.5847	49.1591	88.5637	93.9634
23.6	0.5864	48.9254	88.5665	93.8454
23.7	0.5882	48.6936	88.5717	93.7304

Ts = 54.3197 kN/m

5.2.5 Variation of *Eip* and *klp* with the Coefficient *f*

Table 9 shows the calculation of the variation of *Eip* and *klp* with the coefficient *f*. Figs. 16 and 17 show the variation of *Eip* and *klp* with *f*, respectively.

5.2.6 Horizontal Earth Pressure Distribution for the Passive Side

Table 10 shows the calculation of horizontal earth pressure for the passive side. Fig. 18 shows the horizontal earth pressure distribution against the wall.

Table 9 Variation of *Eip* and *klp* with *f* (Example 2, $\delta = 10^o$).

f	*fTs*	*Eip* (kN/m)	*Ehip* (kN/m)	*klp*
0.000	0.0000	21.3750	21.3750	1.0000
0.001	0.0543	21.4358	21.4358	1.0028
0.250	13.5799	36.9036	36.8685	1.7248
0.500	27.1599	53.1768	52.9744	2.4783
0.750	40.7398	70.3406	69.7388	3.2626
1.000	54.3197	88.5631	87.2176	4.0804

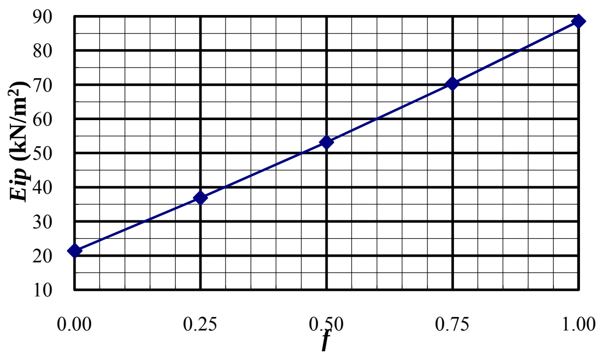

Fig. 16 Variation of *Eip* with *f*, passive side, $\delta = 10^o$.

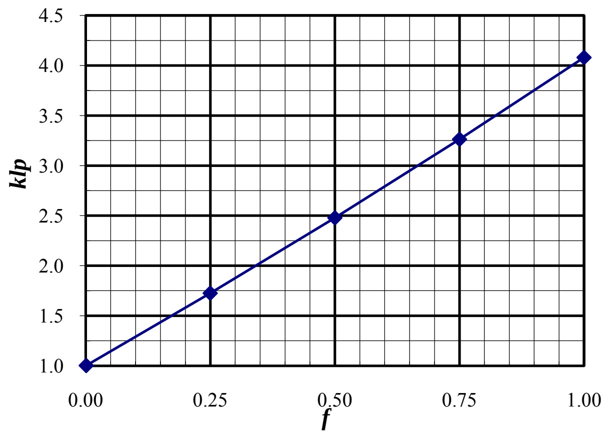

Fig. 17 Variation of *klp* with *f*, passive side, $\delta = 10^o$.

Table 10 Horizontal pressure distribution, passive side.

f	0.00	0.25	0.50	0.75	1.00
klp	1.000	1.725	2.478	3.263	4.080
Depth	σ'ho	σ'h25	σ'h50	σ'h75	σ'h100
(m)	(kN/m^2)	(kN/m^2)	(kN/m^2)	(kN/m^2)	(kN/m^2)
0.00	0.00	0.00	0.00	0.00	0.00
0.25	4.75	8.19	11.77	15.50	19.38
0.50	9.50	16.39	23.54	31.00	38.76
0.75	14.25	24.58	35.32	46.49	58.15
1.00	19.00	32.77	47.09	61.99	77.53
1.25	23.75	40.96	58.86	77.49	96.91
1.50	28.50	49.16	70.63	92.99	116.29

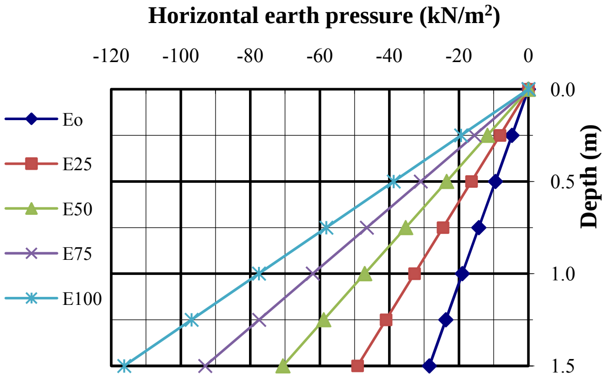

Fig. 18 Horizontal earth pressure, passive side, δ = 10º.

6. Discussion of Results

Results obtained in both examples agree with the statement problem physical aspect, so that we have:

On the active side of the wall:

- $E_A < Ehia < Eo$
- *Eo* is obtained when *Ts* = 0 (*f* = 0).
- E_A is obtained when *Ts* is equal to the shear strength of the soil on the failure plane (*f* = 1).
- *Ehia* is obtained with 0 < *f* < 1.
- The lateral earth pressure coefficient starts at 1 and is reduced when the wall moves laterally, and reaches a minimum value equal to the active earth pressure coefficient.
- In Tables 1 and 6, *Eia* and *kla* were calculated for a small coefficient value *f* (equal to 0.001), which resulted in a value of *Eia* slightly lower than *Eo* and *kla* slightly less than 1.

On the passive side of the wall:

- $Eo < Ehip < E_P$
- *Eo* is obtained when *Ts* = 0 (*f* = 0).
- E_P occurs when *Ts* is equal to the shear strength of the soil on the failure plane (*f* = 1).
- *Ehip* is obtained when 0 < *f* < 1.
- The coefficient of lateral earth pressure starts at 1 and is increased as the wall moves, and reaches a maximum value equal to the passive earth pressure coefficient.
- In Tables 3 and 9, *Eip* and *klp* were calculated for a small coefficient value *f* (equal to 0.001), which resulted in an *Eip* value slightly greater than *Eo* and *klp* slightly greater than 1.

Note that *kla* decreases with the retaining wall roughness, while *klp* increases.

6.1 Discussion of Results. Example 1. Frictionless Wall

According to the Rankine theory for a frictionless wall [1], the active and passive earth pressure coefficients are:

$$k_A = 1/N_\varphi \quad (22)$$

$$k_P = N_\varphi \quad (23)$$

$$N_\varphi = \tan^2(45^o + \varphi/2) \quad (24)$$

k_A is the active earth pressure coefficient and k_P is the passive coefficient.

For $\varphi = 30^o$ we have:

$k_A = 1/3$ and $k_P = 3$

which are the same values obtained with the lateral earth pressure coefficients with the factor "*f*" equal to 1.

The following equation proposed by Jaky [7] is widely used to estimate *ko*:

$$ko = 1 - \text{sen}\varphi \quad (25)$$

From the above equation with $\varphi = 30º$, *ko* = 0.50 is obtained.

From Table 1, for a lateral pressure coefficient equal to 0.50, 75% of the soil shear force needs to be developed on the failure surface, which is a contradiction for a null displacement of the wall.

6.2 Discussion of Results. Example 2. Coarse Wall

According to Juárez-Badillo and Rico-Rodríguez [8], the active earth pressure coefficient for a vertical wall and a horizontal backfill is:

$$k_A = \frac{\cos^2\varphi}{\cos\delta\left[1+\sqrt{\frac{\sin(\varphi+\delta)\sin\varphi}{\cos\delta}}\right]^2} \quad (26)$$

For $\varphi = 30^\circ$ and $\delta = 10^\circ$:

$k_A = 0.3085$

So that the active thrust is equal:

$$E_A = \frac{1}{2} k_A \gamma_m H^2 \quad (27)$$

Substituting data in Eq. (27):

$E_A = 105.50$ kN/m

Therefore, the active horizontal component force is:

$Eha = E_A \cos\delta = 103.8926$ kN/m

and, the active horizontal coefficient:

$kla = k_A \cos\delta = 0.3038$

Previous values of E_A, *Eha* and *kla* are the same as those obtained in example 2.

According to Juárez-Badillo and Rico-Rodríguez [8], the passive earth pressure coefficient for a vertical wall and a horizontal backfill is:

$$k_P = \frac{\cos^2\varphi}{\cos(-\delta)\left[1-\sqrt{\frac{\sin(\varphi+\delta)\sin\varphi}{\cos(-\delta)}}\right]^2} \quad (28)$$

For $\varphi = 30^\circ$ and $\delta = 10^\circ$:

$k_P = 4.1433$

So that:

$E_P = 88.5630$ kN/m, $Ehp = 87.2176$ kN/m and

$klp = 4.0804$

Previous values of E_P, *Ehp* and *klp* are the same as those obtained in example 2.

From Fig. 14, for a lateral pressure coefficient equal to 0.5, 67% of the soil shear force needs to be developed on the failure surface, which is a contradiction for a null displacement of the wall.

7. Conclusions

Based on Coulomb's earth pressure theory, it is concluded that, for normally consolidated soils, the lateral earth pressure coefficient at rest is equal to 1. This value was obtained from both, the earth pressure of the active side of the wall, as on the passive side.

By definition of the lateral earth pressure coefficient at rest, the displacement of the wall must be zero, and therefore, no soil shear force on the failure surface is developed. From this, it is concluded that the lateral earth pressure coefficient at rest is independent of the soil type, whether it is granular or cohesive soil, or the material is in a loose or compact state, a hard or soft cohesive soil.

On the active side of the wall, it starts with the earth pressure at rest, and as the wall moves, the earth pressure decreases, and the at-rest earth condition gradually passes to the active state.

On the passive side of the wall, it starts with the earth pressure at rest, and as the wall moves, the earth pressure increases, and the at-rest earth condition gradually passes to the passive state.

It can be concluded that, from Eqs. (9) and (16), the greater the soil shear strength and the greater the wall roughness, implies a greater reduction of the coefficient *kla* and a greater increase of the coefficient *klp*.

For retaining wall design, for the earth condition at rest (null displacement of the wall), *ko* must be equal to 1, in order to avoid cracking of structures resting on the wall or on the wall filling. In granular soil, when a small displacement of the wall is tolerated, *kla* approximately to 0.80 could be used to calculate the earth pressure on the active side of the wall; while for the passive side a *klp* of 1.20 could be used. When a greater displacement is admitted, the earth lateral thrust must be calculated using Rankine or Coulomb theories.

In the determination of the soil deformation modulus, the study of expansive and collapsible soils in the triaxial chamber, it is appropriate to use a value of *kla* of 0.70.

In percussion driven piles, *kpl* in the range of 1.15 to 1.60 should be used, depending on the displaced soil volume. The value of 1.15 corresponds to a coefficient $f = 0.05$ and 1.60 to a value of $f = 0.20$.

Cast on site piles (without casing), immediately after the excavation is completed, *kla* from 0.60 to 0.75 could to be used. The more time elapses between the pile drilling and the pile pouring, *kla* may reach much lower values.

In piles where the casing is placed as the excavation progresses, use *kla* from 0.70 to 0.80.

A methodology for calculating the earth pressure have been presented for:

- An intermediate state between at rest earth condition and the active case.
- An intermediate state between at rest earth condition and the passive case.

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