Differential Method of Thin Layer for Retaining Wall Active Earth Pressure and Its Distribution under Seismic Condition

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Abstract. This paper studies the calculation of active earth pressure of retaining structure under the condition of earthquake. By comparing with the Rankine theory and Coulomb theory, we get a very good result. The analytical solutions of the previous works are for single homogeneous isotropic filling .but in this paper, the calculation formula and method are suitable for the calculating of active earth pressure of retaining wall which is for different multilayer nature filling. In this paper, the conclusion is the same with the conclusion of literature before, namely the point position of passive earth pressure is lower than the position of Rankine theory and Coulomb theory, which should also be noticed.

Introduction

Since 1920s, a lot of scholars at home and broad have carryed on a lot of research about Retaining wall active earth pressure and its distribution under seismic condition [1-5], which most about theory research and model test, put forward early and up to now still widely used is the Mononobe - Okabe theory, since then a number of seismic earth pressure calculation theory was developed based on the theory. M-O theory was based on Coulomb theory, which was see as the model of earth pressure calculation [2-9].This paper use the method of pseudo static and horizontal layer analysis method, get differential soil studies intensity distribution formula the point position of total earth pressure, rupture angle calculation formula of soil of homogeneous clayey soil retaining structure active earth pressure under seismic condition. [2, 3]

The Analysis Model

Pseudo-static Analysis

The calculation process, the basic assumptions and horizontal and vertical earthquake force of the pseudo-static analysis are the same to [3].

Analysis the Model

As shown in figure 1,the height of retaining wall H ,wall back Angle α, the filling wall surface behind wall i β. Cohesive force behind wall c_i, internal friction angle ϕ_i, cohesive force between soil wall c_i', external friction angle between soil wall ϕ_i', when the rigid wall behind retaining wall move deviate from the filling behind the wall and reaches a certain level, the filling behind the wall will move along $\overline{BC}$ which course the wall heel and cause θ to the vertical direction. We assume that the sliding surface $\overline{BC}$ is a plane. Then we see the soil pressure caused by the soil wedge $\overline{ABC}$.

The Theoretical Derivation

Basic Assumption

(1)The Filling wall is layered cohesive soils.

(2)The soil wedge Fracture surface $\overline{BC}$ is a plane.

(3)The soil wedge ABC's movement was seen as a whole rigid body.

(4)The infinitesimal body the front and bottom $\overline{ed}$ and $\overline{fg}$ respective by resultant force q_i and q_{i+1}, their direction is vertical.

(5) c_i and c'_i along $\overline{BC}$ and $\overline{AB}$ distributed uniformly.

The Basic Formula of the Layered Soil

The geometrical relationship and power relations of the infinitesimal body are the same to [3].

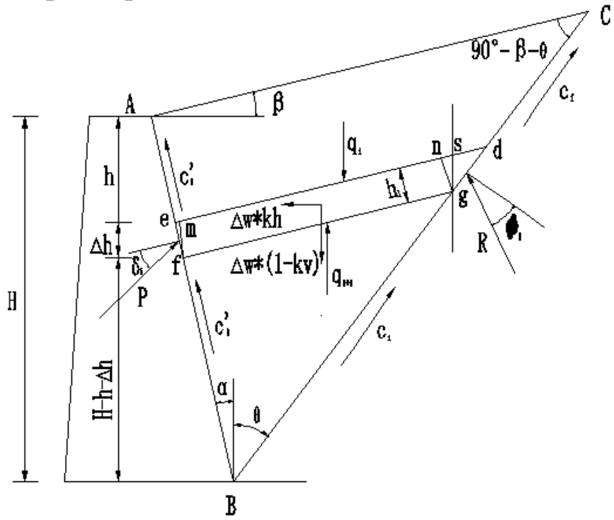

Fig. 1 A Layered Model of Active Earth Pressure

Equation of Forces

Equation of forces of horizontal direction:

$$P_a \cdot \overline{ef} \cdot \cos(\alpha+\delta_i) - K_h \cdot \Delta w - c'_i \cdot \overline{ef} \cdot \sin\alpha + c_i \cdot \overline{gd} \cdot \sin\theta - R \cdot \overline{gd} \cdot \cos(\theta+\phi_i) = 0$$

Equation of forces of vertical direction:

$$P_a \cdot \overline{ef} \cdot \sin(\alpha+\delta_i) - q_i + q_{i+1} - (1-K_v) \cdot \Delta w + c'_i \cdot \overline{ef} \cdot \cos\alpha + c_i \cdot \overline{gd} \cdot \cos\theta + R \cdot \overline{gd} \cdot \sin(\theta+\phi_i) = 0$$

Moment equilibrium equations:

$$-P_a \cdot \overline{ef} \cdot \cos(\alpha+\delta_i) \cdot \frac{\overline{ed}+\overline{fg}}{2} \cdot \sin\beta + P_a \cdot \overline{ef} \cdot \sin(\alpha+\delta_i) \cdot \frac{\overline{ed}+\overline{fg}}{2} \cdot \cos\beta$$

$$+c'_i \cdot \overline{ef} \cdot \sin\alpha \cdot \frac{\overline{ed}+\overline{fg}}{2} \cdot \sin\beta + c'_i \cdot \overline{ef} \cdot \cos\alpha \cdot \frac{\overline{ed}+\overline{fg}}{2} \cdot \cos\beta$$

Computation Process

Starting from the top, $q = q_0 = 10kp_a$, q_0 is in the midpoint of $\overline{AC}$, q_i and q_{i+1} are in the midpoint of $\overline{ed}$ and $\overline{fg}$.

We can get:

$$\mathrm{p_a} = -\frac{c'_i \cdot i_1}{i_2} - \frac{c_i \cdot i_3}{i_4} - q_i \cdot \frac{i_5}{i_2} - \Delta w \cdot K_h \frac{i_6}{i_2 \cdot \Delta h} - \Delta w \cdot (1-K_v) \cdot \frac{i_7}{i_2 \cdot \Delta h}$$

$$q_{i+1}=\frac{-p_a\cdot\Delta h\cdot\sin\left(\alpha+\delta_i+\theta+\varphi_i\right)-c_i'\cdot\Delta h\cdot\cos\left(\alpha+\theta+\varphi_i\right)}{\cos\alpha\cdot\cos\left(\theta+\varphi_i\right)}+q_i+\left(1-K_v\right)\cdot\Delta w_i$$

$$-\frac{c_i\cdot\Delta h\cdot\cos\left(\alpha-\beta\right)\cdot\cos\varphi_i}{\cos\alpha\cdot\cos\left(\theta+\beta\right)\cdot\cos\left(\theta+\varphi_i\right)}+\frac{\Delta w\cdot K_h\cdot\sin\left(\theta+\varphi_i\right)}{\cos\left(\theta+\varphi_i\right)}$$

$$i_1=(2H-2h-\Delta h)\cdot\sin(\theta+\alpha)\cdot\cos(\alpha-\beta)\cdot\cos(\theta+\varphi_i)$$
$$-(H-h-\Delta h)\cdot\sin(\theta+\alpha)\cdot\cos\beta\cdot\cos(\alpha+\theta+\varphi_i)-\Delta h\cdot\cos(\alpha-\beta)\cdot\sin\theta\cdot\cos(\alpha+\theta+\varphi_i)$$

$$i_2=(2H-2h-\Delta h)\cdot\sin(\theta+\alpha)\cdot\sin(\alpha+\delta_i-\beta)\cdot\cos(\theta+\varphi_i)$$
$$-(H-h-\Delta h)\cdot\sin(\theta+\alpha)\cdot\cos\beta\cdot\sin(\alpha+\delta_i+\theta+\varphi_i)-\Delta h\cdot\cos(\alpha-\beta)\cdot\sin\theta\cdot\sin(\alpha+\delta_i+\theta+\varphi_i)$$

$$i_3=\cos(\alpha-\beta)\cdot\cos\varphi_i\cdot[(H-h-\Delta h)\cdot\sin(\theta+\alpha)\cdot\cos\beta+\Delta h\cdot\cos(\alpha-\beta)\cdot\sin\theta]$$

$$i_4=(2H-2h-\Delta h)\cdot\sin(\theta+\alpha)\cdot\sin(\alpha+\delta_i-\beta)\cdot\cos(\theta+\varphi_i)\cdot\cos(\theta+\beta)-(H-h-\Delta h)$$
$$\cdot\sin(\theta+\alpha)\cdot\cos\beta\cdot\sin(\alpha+\delta_i+\theta+\varphi_i)\cdot\cos(\theta+\beta)-\Delta h\cdot\cos(\alpha-\beta)\cdot\sin\theta\cdot\sin(\alpha+\delta_i+\theta+\varphi_i)\cdot\cos(\theta+\beta);$$

$$i_5=\cos\alpha\cdot\cos(\theta+\varphi_i)\cdot[2\cdot\cos(\alpha-\beta)\cdot\sin\theta-\sin(\theta+\alpha)\cdot\cos\beta]$$

$$i_6=(H-h-\Delta h)\cdot\sin(\theta+\alpha)\cdot\cos\beta\cdot\sin(\theta+\varphi_i)\cdot\cos\alpha$$
$$+\Delta h\cdot\cos(\alpha-\beta)\cdot\sin\theta\cdot\sin(\theta+\alpha)\cdot\cos\alpha+2\cdot x\cdot\tan\beta\cdot\cos^2\alpha\cdot\cos(\theta+\beta)\cdot\cos(\theta+\varphi_i)$$

$$i_7=(H-h-\Delta h)\cdot\sin(\theta+\alpha)\cdot\cos\beta\cdot\cos(\theta+\varphi_i)\cdot\cos\alpha$$
$$+\Delta h\cdot\cos(\alpha-\beta)\cdot\sin\theta\cdot\cos\alpha\cdot\cos(\theta+\varphi_i)-2\cdot x\cdot\cos^2\alpha\cdot\cos(\theta+\beta)\cdot\cos(\theta+\varphi_i)$$

Compute Instance

Calculation example reference Chen Xizhe tsinghua university "soil mechanics and foundation" and "retaining wall calculation handbook", and we can get that the conclusion in this passage is the same with the conclusion of literature Rankine theory and Coulomb theory.

(1) The conclusion in this passage is the same with the conclusion of Rankine theory

[1] The question is $H=6.0$ m, $\alpha=0°$, $\beta=0°$, $\delta=0°$. $\gamma=18KN/m^3$, $\varphi=30°$, how to get the active earth pressure?

We let $c=0, c'=0, k_h=0, k_v=0, q_0=0$, $\Delta h=$ 0.25m,from the Rankine theory, we can get $\theta=45°-\frac{1}{2}\varphi=30°$, the Calculation results see the table below.

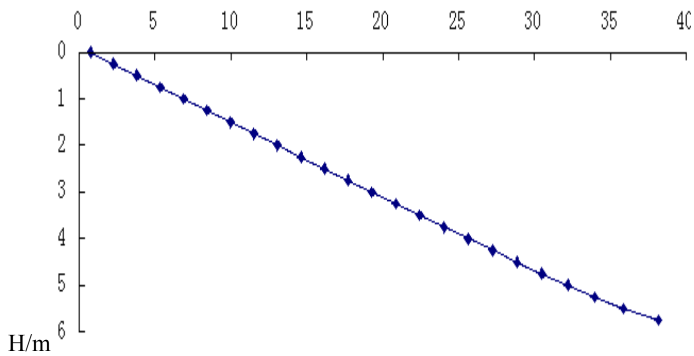

Fig.2 Active Soil Pressure Distribution of Different Clayey Soils under Seismic Condition

Tab.1 Calculation Results by Layers of Active Soil Pressure

i	$dw_i(KN)$	$p_{ai}(KN/m)/m$	$q_{i+1}(KN)$	$\Delta h(m)$	$h_i(m)$
1	15.5884	0.7553	15.2613	0.25	0.00
2	14.9389	2.2879	29.2095	0.25	0.25
3	14.2894	3.8220	41.8439	0.25	0.50
4	13.6399	5.3577	53.1638	0.25	0.75
5	12.9903	6.8952	63.1684	0.25	1.00
6	12.3408	8.4347	71.8569	0.25	1.25
7	11.6913	9.9763	79.2283	0.25	1.50
8	11.0418	11.5205	85.2815	0.25	1.75
9	10.3923	13.0673	90.0154	0.25	2.00
10	9.7427	14.6173	93.4286	0.25	2.25
11	9.0932	16.1709	95.5196	0.25	2.50
12	8.4437	17.7286	96.2865	0.25	2.75
13	7.7942	19.2912	95.7273	0.25	3.00
14	7.1447	20.8595	93.8401	0.25	3.25
15	6.4951	22.4346	90.6208	0.25	3.50
16	5.8456	24.0198	86.0727	0.25	3.75
17	5.1961	25.6137	80.1777	0.25	4.00
18	4.5466	27.2210	72.9372	0.25	4.25
19	3.8971	28.8462	64.3435	0.25	4.50
20	3.2475	30.4967	54.3856	0.25	4.75
21	2.5980	32.1852	43.0470	0.25	5.00
22	1.9485	33.9375	30.3001	0.25	5.25
23	1.2990	35.8208	16.0802	0.25	5.50
24	0.6495	38.1356	0.2165	0.25	5.75
total	--	449.4955	--	--	--

active soil pressure distribution(MPa)

We can get the active pressure from table 1:

$$\mathrm{P_{a1}} = 449.4955 \times 0.25 = 112.3737 KN/m,$$

We can get the active pressure from Rankine theory

$$\mathrm{P_{a2}} = \frac{1}{2}\cdot\gamma\cdot H^2\cdot k_a = \frac{1}{2}\cdot\gamma\cdot H^2\cdot\tan^2(45°-\frac{1}{2}\varphi) = \frac{1}{2}\times 18\times 6^2\times 0.34 = 110.16 KN/m$$

$$\frac{\mathrm{P_{a1}}-\mathrm{P_{a2}}}{\mathrm{P_{a2}}} = \frac{112.3737-110.16}{110.16} = 2.01\%,$$

The result of table 1 is agreed well with the Rankine theory.

As: $$Z_{0a} = \frac{\sum_{i=1}^{n} p_{ai}\cdot\frac{\Delta h_i}{\cos\alpha}\cdot[H-(\Delta h_1+\Delta h_2+\cdots+\Delta h_{i-1}+0.5\cdot\Delta h_i)]}{\sum_{i=1}^{n} p_{ai}}$$

Earth pressure resultant force point height $Z_{0a}\approx 0.3528H$,a little higher than $\frac{1}{3}H$.

(2)The conclusion in this passage is the same with the conclusion of Coulomb theory

[2]The question is $H = 6.0$ m, $\alpha = 10°$, $\beta = 10°$, $\delta = 20°$. $\gamma = 18KN/m^3$, $\varphi = 30°$,how to get the active earth pressure?

We let $c = 0, c' = 0, k_h = 0, k_v = 0, q_0 = 0$, $\Delta h =$ 0.25m, we can get $\theta = 45° - \frac{\phi}{2} = 45° - \frac{14°}{2} = 38°$, the Calculation results see the table below:

Tab. 2 Calculation Results by Layers of Active Soil Pressure

i	$dw_i(KN)$	$p_{ai}(KN/m)/m$	$q_{i+1}(KN)$	$\Delta h(m)$	$h_i(m)$
1	30.9188	0.8991	30.3154	0.25	0.00
2	29.6305	2.7207	58.1201	0.25	0.25
3	28.3422	4.5506	83.4086	0.25	0.50
4	27.0539	6.3894	106.1748	0.25	0.75
5	25.7657	8.2381	126.4121	0.25	1.00
6	24.4774	10.0978	144.1131	0.25	1.25
7	23.1891	11.9699	159.2696	0.25	1.50
8	21.9008	13.8557	171.8722	0.25	1.75
9	20.6125	15.7572	181.9106	0.25	2.00
0	19.3242	17.6764	189.3728	0.25	2.25
11	18.0359	19.6159	194.2451	0.25	2.50
12	16.7477	21.5792	196.5117	0.25	2.75
13	15.4594	23.5702	196.1539	0.25	3.00
14	14.1711	25.5942	193.1495	0.25	3.25
15	12.8828	27.6581	187.4718	0.25	3.50
16	11.5945	29.7711	179.0879	0.25	3.75
17	10.3062	31.9461	167.9561	0.25	4.00
18	9.0179	34.2015	154.0225	0.25	4.25
19	7.7297	36.5654	137.2143	0.25	4.50
20	6.4414	39.0832	117.4282	0.25	4.75
21	5.1531	41.8356	94.5068	0.25	5.00
22	3.8648	44.9882	68.1815	0.25	5.25
23	2.5765	48.9692	37.8964	0.25	5.50
24	1.2882	55.6666	1.8286	0.25	5.75
total	--	573.1994	--	--	--

active soil pressure distribution (MPa)

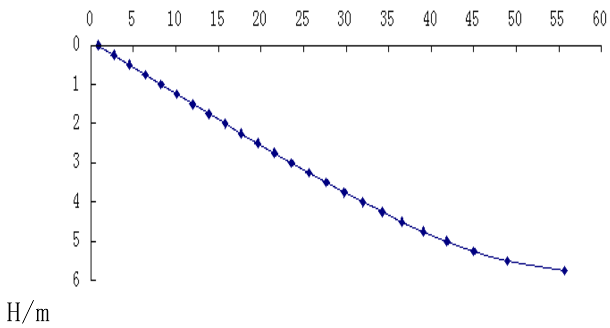

Fig.3 Active Soil Pressure Distribution of Different Clayey Soils under Seismic Condition

We can get the active pressure from table 2:

$$P_{a1} = 573.1944 \times 0.25 = 143.299kN/m$$

We can get the active pressure from Coulomb theory:

$$P_{a2} = \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_a = \frac{1}{2} \times 18 \times 6^2 \times 0.46 = 149.04 KN/m$$

$$\frac{\mathrm{P_{a2}} - \mathrm{P_{a1}}}{\mathrm{P_{a2}}} = \frac{149.04 - 143.299}{149.04} = 3.85\%,$$

The result of table 1 is agreed well with the Coulomb theory.

As: $$Z_{0a} = \frac{\sum_{i=1}^{n} p_{ai} \cdot \frac{\Delta h_i}{\cos\alpha} [H - (\Delta h_1 + \Delta h_2 + \cdots + \Delta h_{i-1} + 0.5 \Delta h_i)]}{\sum_{i=1}^{n} p_{ai}}$$

Earth pressure resultant force point height $Z_{0a} \approx 0.3475H$, a little higher than $\frac{1}{3}H$

Conclusion

(1)This paper studies the calculation of passive earth pressure of retaining structure under the condition of earthquake. Assume that every layer $\Delta \mathrm{h}_i$ only transfer force downward q_i,there is no friction between the layers,that is the horizontal seismic force fully borne by retaining wall.

(2)The calculation formula and method are suitable for the calculating of active earth pressure of retaining wall which is for different multilayer nature filling .

(3)The conclusion is the same with the conclusion of literature Rankine theory and Coulomb theory.

(4)The point position of active earth pressure is higher than the position of Rankine theory and Coulomb theory, which should also be noticed,because the rigidity of the retaining wall problem is beneficial.

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