COMPUTATION OF ACTIVE EARTH PRESSURE OF COHESIVE BACKFILL ON RETAINING WALL CONSIDERING SEISMIC FORCE

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Abstract:

This paper based on having research conclusion, according to the Coulomb's earth pressure theory, from the condition of the equilibrium of the force when the slide wedge was in limit equilibrium, thinking about most infaust condition to retaining wall stability during earthquake, a formula was derivated for the calculation of active earth pressure of cohesive or non-cohesive backfill soils. This formula could be used in the calculation of earth pressure with superimposed load uniformly distributed on any location of ground surface behind retaining wall. Some suggestions were proposed to the calculation of earth pressure in gravity retaining wall design in high frequency seismic region considering seismic force.

Key words: Coulomb's theory; gravity retaining wall; seismic force; active earth pressure; uniformly distributed load

INTRODUCTION

Active earth pressure computation method about Gravity style retaining wall (CHEN Xizhe, 1998; QIAN Jiahuan, et al., 2000) is very much, but all this methods have default. There is little error used the Coulomb's earth pressure theory to cohesive-less soil; about active earth pressure of cohesive soil, reference (GB50007, 2002) fits for the situation that uniformly distributed load act from top of retaining wall, about the situation that uniformly distributed load act from a distance to top of retaining wall , reference (Feng Zhen, et al.,2008) gives a formula that was derivated for the calculation of active earth pressure of cohesive or non-cohesive backfill soils, but it can not completely consider seismic force. To the question of retaining wall earth pressure computation, reference (Matsuo,H, 1941; Mononobe,N and H. Matsuo, 1929; Prakash. S. and B.M.Basvanna, 1969; Prakash. S. and S. Saran, 1966) do some useful research; but the conclusion of reference (Matsuo,H, 1941; Mononobe,N and H. Matsuo, 1929) only can be used to cohesive-less soil; reference (Prakash. S. and B.M.Basvanna, 1969; Prakash. S. and S. Saran, 1966) do some research about cohesive soil, but only fit for uniformly distributed load act from top of retaining wall. About the situation that uniformly distributed load act from a distance to top of retaining wall considering seismic force (Figure 1), there is no precise simple computation to now. This paper based on reference (Feng Zhen, et al.,2008; Prakash. S., 1984) , give a formula of active earth pressure computation considering seismic force and uniformly distributed load q acting from a distance d to top of retaining wall, do some necessary expansion to researches done by Feng Zhen et al (2008).

EARTH PRESSURE ABOUT BACKFILL SURFACE

Suppose there is a retaining wall , the angle between wall back and vertical axis is r (Figure 1), the response of retaining wall to ground movement under seismic force is like figure 2. The backfill surface is level , from a distance d to top of retaining wall , there is uniformly distributed load q acting on the earth wedge ABC , the forces acting on earth wedge is like figure 1. Let backfill surface is x axis , and through wall heel vertical line to x axis is y axis.

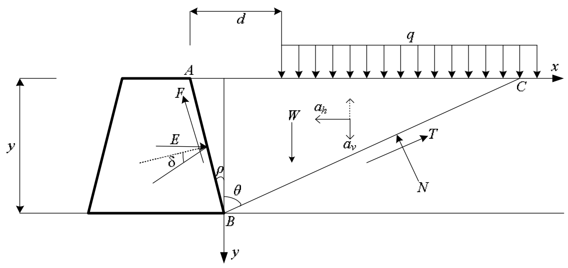

Figure 1. Force acting on the soil wedge

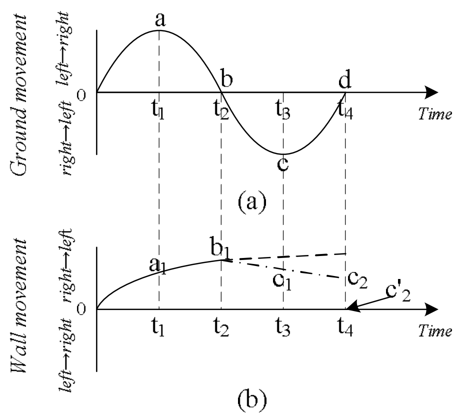

Figure 2. Response of Retaining wall to ground movement

Expression of earth wedge self-weight：

$$W = \frac{1}{2} g y^2 (\tan q + \tan r) \qquad (1)$$

in which: g -earth gravity density. If horizontal acceleration of earth wedge is a_h , vertical acceleration of earth wedge is a_v , then horizontal inertial force is Wa_h / g , vertical inertial force is Wa_v / g , in actual earthquake, the most infaust condition to active earth pressure is Wa_h / g act to wall direction, so choose the direction that can increase earth pressure in actual (Figure 1).

Now let： $\frac{a_h}{g} = a_h$, $\frac{a_v}{g} = a_v$

where a_h ——horizontal earthquake coefficient； a_v ——vertical earthquake coefficient.

When the earth wedge in limit equilibrium condition , resistance of retaining wall and static earth to earth wedge is:

$$F = \frac{1}{\cos r}(c'y + E\tan d) \qquad (2)$$

$$T = cl + N\tan j \qquad (3)$$

in which: d - friction angle of wall back to earth, j - inner friction angle of earth; c' - viscous force of wall back to earth, c - viscous force of earth. l - length of BC.

Resistance of retaining wall to wedge F is made of viscous resistance and friction resistance. Thinking about every kind of factor (for example: decline of wall back, coarseness), this paper let: $\tan d = h\tan j$, $c' = hc$, h - coefficient in 0~1. So, resistance of retaining wall back is:

$$F = \frac{h}{\cos r}(cy + E\tan j) \qquad (4)$$

According to situation of earth body standing force, x、y direction equilibrium formula of force is:

$$\sum y = Q + W - F\cos r - T\cos q - N\sin q - E\tan r \pm (W+Q)a_v = 0 \qquad (5)$$

$$\sum x = T\sin q - N\cos q - (W+Q)a_h + E - F\sin r = 0 \qquad (6)$$

in which: Q - sum of uniformly distributed load superimposed on wedge surface, *so*

$$Q = qy(\tan q + \tan r) - qd \qquad (7)$$

take formula （1）、（3）、（4）、（7） to equilibrium formula（5）、（6）, remove N , get:

$$\frac{qy(\tan q + \tan r) - qd + \frac{1}{2}ry^2(\tan q + \tan r) - cy - E\tan r - h(cy + E\tan j)}{E - h(cy + E\tan j)\tan r + cy\tan q} \rightarrow$$

$$\leftarrow \frac{\pm\left[\frac{1}{2}gy^2(\tan q + \tan r) + qy(\tan q + \tan r) - qd\right]a_v}{-\left[\frac{1}{2}gy^2(\tan q + \tan r) + qy(\tan q + \tan r) - qd\right]a_h} = \frac{\tan j + \tan q}{1 - \tan j\tan q}$$

clean up then get:

$$\begin{aligned}&(\frac{1}{2}gy^2 + qy)(\tan q + \tan r)\tan j\tan q - (\frac{1}{2}gy^2 + qy)(\tan q + \tan r) + \\ &qd(1 - \tan j\tan q) + cy[1 + h + \tan^2 q - h\tan j\tan q - h\tan r(\tan q + \tan j)] \\ &\pm\left[\frac{1}{2}gy^2(\tan q + \tan r) + qy(\tan q + \tan r) - qd\right]a_v(1 - \tan j\tan q) - \\ &\left[\frac{1}{2}gy^2(\tan q + \tan r) + qy(\tan q + \tan r) - qd\right]a_h(\tan q + \tan j) = \\ &[(h\tan^2 j - 1)(\tan q + \tan r) - (1 + h)(\tan j - \tan j\tan q\tan r)]E\end{aligned}$$

so, in limit equilibrium condition, we get the force acting on retaining wall in direction x is:

$$E = \frac{1}{2} wg\, y^2 + wqy - z\, qd - y\, cy \qquad (8)$$

where:

$$w = \frac{(\tan q + \tan r)[1 - \tan j \tan q + a_h(\tan q + \tan j) \pm a_v(1 - \tan j \tan q)]}{(1 - h \tan^2 j)(\tan q + \tan r) + (1 + h)(\tan j - \tan j \tan q \tan r)},$$

$$z = \frac{1 - \tan j \tan q + a_h(\tan q + \tan j) \pm a_v(1 - \tan j \tan q)}{(1 - h \tan^2 j)(\tan q + \tan r) + (1 + h)(\tan j - \tan j \tan q \tan r)},$$

$$y = \frac{1 + h + \tan^2 q - h \tan j \tan q - h(\tan q + \tan j)\tan r}{(1 - h \tan^2 j)(\tan q + \tan r) + (1 + h)(\tan j - \tan j \tan q \tan r)}。$$

Differentiate formula（8）to q , and let $\partial E / \partial q = 0$, because denominator can not be 0, numerator must be 0, can get slim craze angle corresponding to most active pressure . reader can derivate it referring to (Feng Zhen, et al.,2008.

Let the length of *AB* is *S*, then $y = S \cos r$, differentiate formula（8）to S , then we get

$$e = (wg\, y + wq - y\, c)\cos r \qquad (9)$$

Where: e ----positive pressure intension of x direction.
Formula （9）divide $\cos r$, then we get

$$s_3 = wg\, y + wq - y\, c \qquad (10)$$

Where: s_3 -----positive pressure intension of x direction through *y* axis.

when $s_3 = 0$, from formula（10）,we get the height of positive pressure intension equal zero is

$$y_0 = \frac{y\, c}{y\, y} - \frac{q}{g} \qquad (11)$$

when $y = 0$, get the most positive pressure intension is

$$s_3 = wq - y\, c \qquad (12)$$

So get the sum of tension is

$$E' = \int_0^{y_0} s_3 \, \mathrm{d}\, y = -\frac{1}{2wy}(wq - y\, c)^2 \qquad (13)$$

EARTH PRESSURE OF LEVEL BACKFILL CRACK ZONE THAT BE HOMOGENEOUS REPLACEMENT

The natural condition can give great effect to soil property, and can make fissure on soil surface. This paper use uniformly distributed load replacement referring to Feng Zhen, et al.(2008). Look the soil upper intension zero point as uniformly distributed load $q_0 = g y_0$, the force acting on soil is like figure 3.

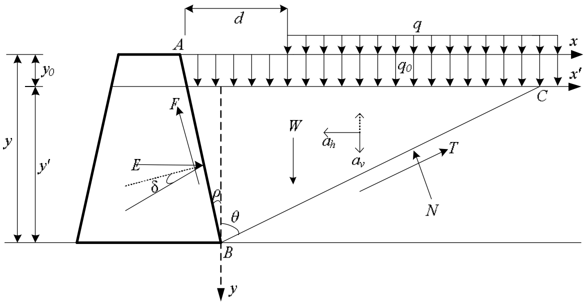

Figure 3 Forces acting on the soil with uniform load substituted

Move axis x to zero point of positive pressure intension, use x' to express, and let $q' = q + q_0$ as uniformly distributed load, $y' = y - y_0$, take to equilibrium formula（5)、（6）, then

$$E = \frac{1}{2} wg\, y'^2 + wq'y' - z\, qd - y\, cy' = \frac{1}{2} wg\, (y - y_0)^2 + wq'(y - y_0) - z\, qd - y\, c(y - y_0) \qquad (14)$$

where w、z、y same as formula（8）.

Look formula (14), if differentiate y, then we get:

$$s_3 = wg\, y' + wq' - y\, c \qquad (15)$$

Where: s_3-----positive pressure intension of x direction through y axis.

If $y' = 0$, $wq' = y\, c$; if $y' \neq 0$, formula（14)、(15) can change to

$$E = \frac{1}{2} wg\, y'^2 - z\, qd = \frac{1}{2} wg\, (y - y_0)^2 - z\, qd \qquad (16)$$

$$s_3 = wg(y - y_0) \qquad (17)$$

EARTH PRESSURE ABOUT DECLINING BACKFILL SURFACE

Suppose there is angle b between declining backfill surface to level(look figure 4), still let backfill surface is x axis, and through wall heel vertical line to x axis is y axis, according to the forces acting on earth wedge (look figure 4), x、y direction equilibrium formula of force is:

$$\sum y = (Q+W)\cos b - F\cos r - T\cos q - N\sin q - E\tan r - (W+Q)a_h \sin b \pm (Q+W)a_v \cos b = 0 \qquad (18)$$

$$\sum x = T\sin q - N\cos q + E - F\sin r - (Q+W)\sin b - (W+Q)a_h \cos b\ \mathbf{m}\ (Q+W)a_v \sin b = 0 \qquad (19)$$

where W、T、F、Q same as formula（1)、（3)、（4)、（7)。

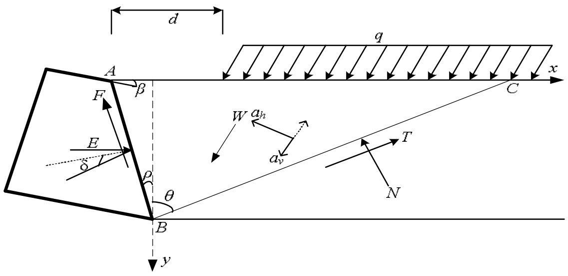

Figure 4. Forces acting on the soil wedge

so, in limit equilibrium condition, we get the force acting on retaining wall in direction x is:

$$E = \frac{1}{2} wg\, y^2 + wqy - z\, qd - y\, cy \qquad (20)$$

in which:

$$w = \frac{(\tan q + \tan r)[(1-\tan j\ \tan q \pm a_v(1-\tan j\ \tan q) + a_h(\tan q + \tan j))\cos b}{(1-h\ \tan^2 j)(\tan q + \tan r)+} \rightarrow$$
$$\leftarrow \frac{+(\tan j + \tan q - a_h(1-\tan q\ \tan j) \pm a_v(\tan j + \tan q))\sin b]}{(1+h)(\tan j - \tan j\ \tan q\ \tan r)},$$

$$z = \frac{(1-\tan j\ \tan q \pm a_v(1-\tan j\ \tan q) + a_h(\tan q + \tan j))\cos b +}{(1-h\ \tan^2 j)(\tan q + \tan r)+} \rightarrow$$
$$\leftarrow \frac{(\tan j + \tan q - a_h(1-\tan q\ \tan j) \pm a_v(\tan j + \tan q))\sin b}{(1+h)(\tan j - \tan j\ \tan q\ \tan r)},$$

$$y = \frac{1+h+\tan^2 q - h\ \tan j\ \tan q - h(\tan q + \tan j)\tan r}{(1-h\ \tan^2 j)(\tan q + \tan r) + (1+h)(\tan j - \tan j\ \tan q\ \tan r)} 。$$

If $b = 0$, formula（20）change to formula（8）. Let $\partial E/\partial q = 0$, people can get slim craze angle corresponding to most active earth pressure , reader can derivate it referring to Feng Zhen, et al.(2008).

The height upper positive intension zero point computing through (11), use above formula can solve earth pressure.

EARTH PRESSURE OF DECLINING SURFACE BACKFILL CRACK ZONE THAT BE HOMOGENEOUS REPLACEMENT

As above, The natural condition can give great effect to soil property, and can make fissure on soil surface. This paper use uniformly distributed load replacement referring to Feng Zhen, et al.(2008). Look the soil upper positive intension zero point as uniformly distributed load $q_0 = g\, y_0$, the force acting on soil is like figure 5.

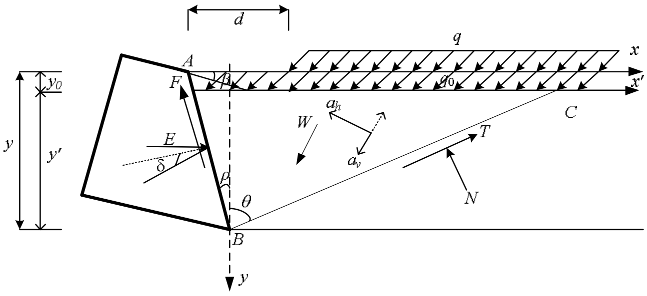

Figure 5. Forces acting on the soil with uniform load substituted

Move axis x to zero point of positive pressure intension, use x' to express, and let $q' = q + q_0$ as uniformly distributed load, $y' = y - y_0$, take to equilibrium formula（18）、（19）, then

$$E = \frac{1}{2} wg\, y'^2 + wq'y' - z\, qd - y\, cy' = \frac{1}{2} wg\,(y - y_0)^2 + wq'(y - y_0) - z\, qd - y\, c(y - y_0) \qquad (21)$$

where w 、z 、y same as formula（20）.

Look formula (21), if differentiate y, then we get:

$$s_3 = wg\, y' + wq' - y\, c \qquad (22)$$

Where: s_3-----positive pressure intension of x direction through *y* axis.

If $y' = 0$, $wq' = y\, c$; if $y' \neq 0$, formula（21）、(22) can change to

$$E = \frac{1}{2} wg\, y'^2 - z\, qd = \frac{1}{2} wg\,(y - y_0)^2 - z\, qd \qquad (23)$$

$$s_3 = wg(y - y_0) \qquad (24)$$

To non-cohesive soil, let $c = 0$, use above formula can solve. Reader can derivate it self.

CONCLUSIONS

Based on having research conclusion, according to the Coulomb's earth pressure theory, this paper gets the following results:

（1）Do some necessary expansion to computation formula of reference (Feng Zhen, et al.,2008; Prakash. S. 1984);

（2）The method of this paper mainly fit for cohesive soil, also fit for non-cohesive soil, especially to the situation that uniformly distributed load act from a distance to top of retaining wall considering seismic force, use this paper's method, can make computation of active earth pressure is feasible and simple;

（3）This paper only can supply a approximate method to computation of earth pressure, because the factor affecting soil property is very complex;

（4）About the question of earth pressure considering layer soil or ground water and inertial force, the author write another article to express it.

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