COEFFICIENTS OF ACTIVE AND PASSIVE EARTH PRESSURE ON RETAINING WALLS UNDER SEISMIC CONDITIONS

by

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SYNOPSIS

On the basis of Coulomb's theory prerequisities the formulas for determining a slip surface and an active earth pressure coefficient for the case of an arbitrary uneven loading of a horizontal backfill surface are suggested. The solution is derived for the case of a rough inclined wall. Dimensionless coefficients of the active and passive earth pressures upon inclined rough walls under uniformly distributed load acting on an inclined earth surface were found on the basis of a safe stress state theory developed by V.V. Sokolovsky and S.S. Golushkevich.

INTRODUCTION

Our knowledge about the dynamic behaviour of retaining walls and backfills is not adequate to become the basis of a precise calculation taking into account seismic activity . That is why the engineers very often resort to a static theory of seismic resistance in order to determine the earth pressures. Under complex loading of a backfill, as it is the case with quays, it is necessary to start at plain slip surfaces [illegible]. However, for many practically important cases it is possible to receive a more exact and simple solution using the engineering theory of a safe stress state [illegible].

COULOMB'S THEORY-BASED CALCULATION METHOD

Considering a calculation diagram (Fig.1), it is possible to receive an expression for the resultant of a seismic active earth pressure acting on an arbitrary

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surface of failure inclined at an angle β to vertical line:

$$E=\frac{\gamma h^2}{2}\lambda_c+qh_o\lambda_c;\ \lambda_c=\frac{(tg\alpha+tg\beta)[1+K_c tg(\beta+\varphi)]}{Cos(\alpha+\delta)[tg(\beta+\varphi)+tg(\alpha+\delta)]},$$

where, $K_c=j/g=tg\omega$ - seismic factor; j - seismic acceleration; ω - angle of deviation of the resultant gravity force and horizontal seismic force from the vertical line; γ - bulk density of earth; φ - angle of internal friction; λ_c - active earth pressure coefficient. Having taken the derivative, $dE/d\beta$, and assumed it be equal to zero, we receive an expression for the calculation of the angle β corresponding to maximum of E :

$$tg\beta=-m\pm\sqrt{m^2+\frac{m[K_c+ctg\varphi-(tg\alpha-S)(1-K_c ctg\varphi)]-(tg\alpha-S)(K_c+ctg\varphi)}{1-K_c ctg\varphi}},\quad (1)$$

where, $S=2aq/h(\gamma h+2q)$ - a dimensionless coefficient for the diagram of loading shown in Fig.1; $m=tg(\alpha+\delta+\varphi)$. In case $\alpha+\delta+\varphi<90^\circ$, plus sign is chosen before the root and, if $\alpha+\delta+\varphi>90^\circ$, minus sign is used. Practically, it is more convenient to draw epures of horizontal pressure components (Fig.1):

$$a_\gamma=\gamma h\lambda_{cx};\ a_q=q\lambda_{cx};\ E_{x\gamma}=\frac{\gamma h^2}{2}\lambda_{cx};\ E_{xq}=qh_o\lambda_{cx};\ E_{y\gamma}=E_{x\gamma}tg(\alpha+\delta);$$

$$E_{yq}=E_{xq}tg(\alpha+\delta);\ \lambda_{cx}=\frac{(tg\alpha+tg\beta)[1+K_c tg(\beta+\varphi)]}{tg(\beta+\varphi)+tg(\alpha+\delta)}.\quad (2)$$

The expressions for $tg\beta$ and λ_{cx} are correct for any kind of a loading pattern; the formula for S depends on a loading pattern. Thus, for the most general case (Fig.2):

$$S=-\frac{2[b_1(q_1-q_5)+b_2(q_2-q_5)+b_3(q_3-q_5)+b_4(q_4-q_5)]}{h(\gamma h+2q_5)};$$

$$a_\gamma=\gamma h\lambda_{cx};\ a_{q_1}=q_1\lambda_{cx};\ \cdots\cdots;\ a_{q_5}=q_5\lambda_{cx};\ E_{x\gamma}=\frac{a_\gamma h}{2};\ E_{y\gamma}=E_{x\gamma}tg(\alpha+\delta);$$

$$E_{1x}=a_{q_1}h_1;\ E_{1y}=E_{1x}tg(\alpha+\delta);\cdots\cdots;\ E_{5x}=a_{q_5}h_5;\ E_{5y}=E_{5x}tg(\alpha+\delta).$$

The expression for δ can be written in a general form for any kind of a loading pattern. The coefficient, δ, represents the ratio of the weight of lacking or excessive loading within the boundaries of the prism of failure (comparing with the weight of the uniform loading, having the intensity, q_0, acting on the same prism) to the weight of an earth prism which surface width is equal to h, taking into account the weight of a uniform loading, q_0, on the prism:

$$\delta = \frac{\sum_{0}^{i} b_i(q_0 - q_i)}{\frac{\gamma h^2}{2} + q_0 h} = \frac{2\sum_{0}^{i} b_i(q_0 - q_i)}{h(\gamma h + 2q_0)}, \qquad (3)$$

where, q_0 - intensity of loading at the point of wedge intersection with a slip surface of a backfill; q_i and b_i - intensity and width of loading in the regions where $q_i \neq q_0$. It is easy to notice that the general function[3] helps to obtain previously mentioned formulas for δ. At the beginning of calculation the section of loading, within the boundaries of which the wedging of a failure plane is supposed to take place, is defined. Designating the intensity of loading on this section by q_0, the δ and $tg\beta$ values are defined which prove that the failure plane wedges out within the boundaries of the same section. Otherwise, the calculation is carried out until the coincedence takes place. In case of absence of seismic action expressions in all the formulas, $K_c = \omega = 0$ should be assumed. The numerical values of β and λ_{cx} are calculated by means of a computer for all practically encountered combinations of φ, δ, K_c and δ.

SAFE STRESS STATE THEORY-BASED CALCULATION METHOD

In order to construct the slip surfaces without taking into account the volumetric forces, the following formulas are obtained (the upper signs correspond to an active pressure case (Fig.3) while the lower signs correspond to a passive pressure case (Fig.4):

$$\theta_1=\frac{1}{2}\left\{\rho+\arccos\left[\pm\frac{\sin(\rho\pm\omega)}{\sin\varphi}\right]\mp\varphi\mp\omega\right\}; \qquad (4)$$

$$\varepsilon=\frac{1}{2}\left(\frac{\pi}{2}-\arcsin\frac{\sin\delta}{\sin\varphi}\pm\delta\mp\varphi\right); \quad \theta=\theta_1-\alpha-\varepsilon, \qquad (5)$$

where, ρ - angle of backfill surface slope to the horizontal line (assumed positive for rising slopes and negative - for lowering slopes); α - angle of back side of the wall inclination to the vertical line (assumed positive for outwardly inclined walls and negative - for inwardly inclined walls). Considering in succession the equilibrium conditions of different earth zones at various stress conditions, we may obtain the calculation formulas:

$$E=E_G+E_P=\frac{\gamma h^2}{2}\lambda_\gamma+qh\lambda_q; \quad a_\gamma=\frac{2E_G}{h}\cos(\alpha\pm\delta); \quad a_q=\frac{E_P}{h}\cos(\alpha\pm\delta); \qquad (6)$$

$$\lambda_\gamma=2S_\gamma\left[b(n+1)+d+i\right]; \quad \lambda_q=S_q a_0(n+1), \qquad (7)$$

where, E_G and E_P - the resultant backfill and load pressures; q - the intensity of a vertical uniformly-distributed loading on a backfill (t/m^2, horizontal projection). The coefficients and angles present in the formulas are derived:

$$\eta=\varepsilon\pm\varphi; \quad a_0=\frac{\cos\rho\cos\eta\exp(\mp\theta\,tg\,\varphi)}{\cos\omega\cos\alpha\sin(\theta_1-\rho\pm\varphi)}; \quad b=\frac{\exp(\mp2\theta\,tg\,\varphi)\cos(\theta_1-\rho)\cos^2\eta}{2\cos\omega\cos^2\alpha\cos\varphi\sin(\theta_1-\beta\pm\varphi)};$$

$$i=\frac{\sin\varepsilon\cos\eta}{2\cos^2\alpha\cos\varphi\cos\omega}; \quad d=\frac{\left[\pm1\mp\exp(\mp2\theta\,tg\,\varphi)\right]\cos^2\eta}{2\cos\omega\cos^2\alpha\sin2\varphi}; \quad \mu_q=\frac{\pi}{2}-\alpha-\eta\mp\omega; \ (180^\circ>\mu_q>0^\circ);$$

$$\psi=\eta+\operatorname{arctg}\left[\frac{\exp(\mp\theta\,tg\,\varphi)-\cos\theta}{\sin\theta}\right]; \quad n=\frac{\sin(\theta_1-\psi-\alpha)\cos(\theta_1\pm\varphi\pm\omega)}{\cos\varphi\sin(\psi+\alpha\pm\omega)};$$

$$\mu_\gamma=\operatorname{arctg}\left\{\frac{\left[b(n+1)+d+i\right]tg(\alpha+\eta\pm\omega)+i\,ctg(\psi+\alpha\pm\omega)}{b(n+1)+d}\right\}; \ (180^\circ>\mu_\gamma>0^\circ);$$

$$S_\gamma=\frac{\sin(\psi+\alpha\pm\omega)\sin(\mu_\gamma+\alpha+\varepsilon\pm\omega)}{\sin(\psi+\alpha+\mu_\gamma\pm\omega)\cos(\varepsilon\mp\delta)}; \quad S_q=\frac{\sin(\psi+\alpha\pm\omega)\sin(\mu_q+\alpha+\varepsilon\pm\omega)}{\sin(\psi+\alpha+\mu_q\pm\omega)\cos(\varepsilon\mp\delta)}.$$

The coefficients of active and passive pressures caused by the earth and the loads λ_γ and λ_q are dimensionless values depending exclusively on the angles ω, φ, δ, α and ρ.

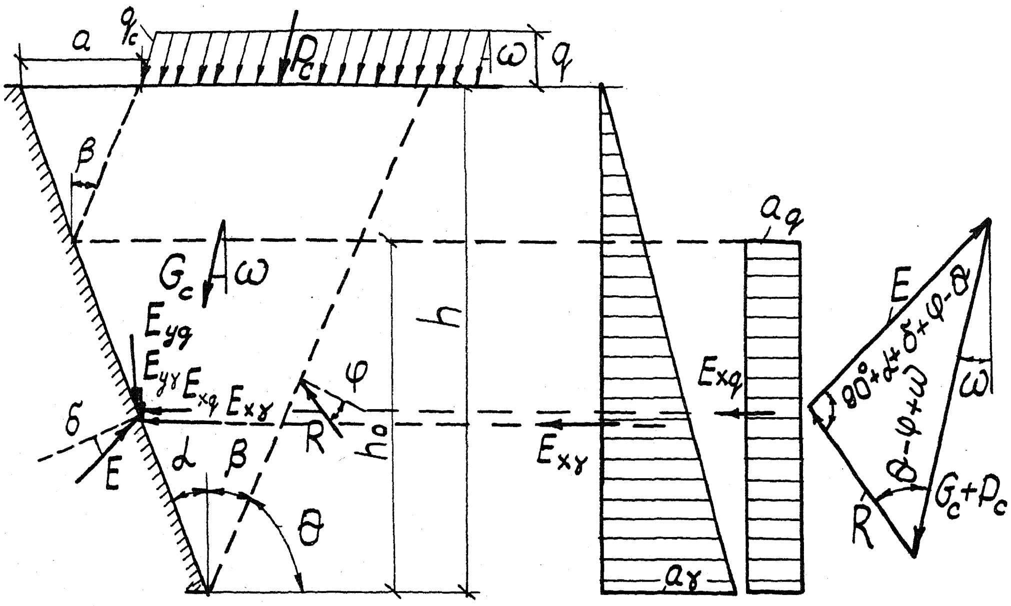

Fig. 1. Calculation diagram

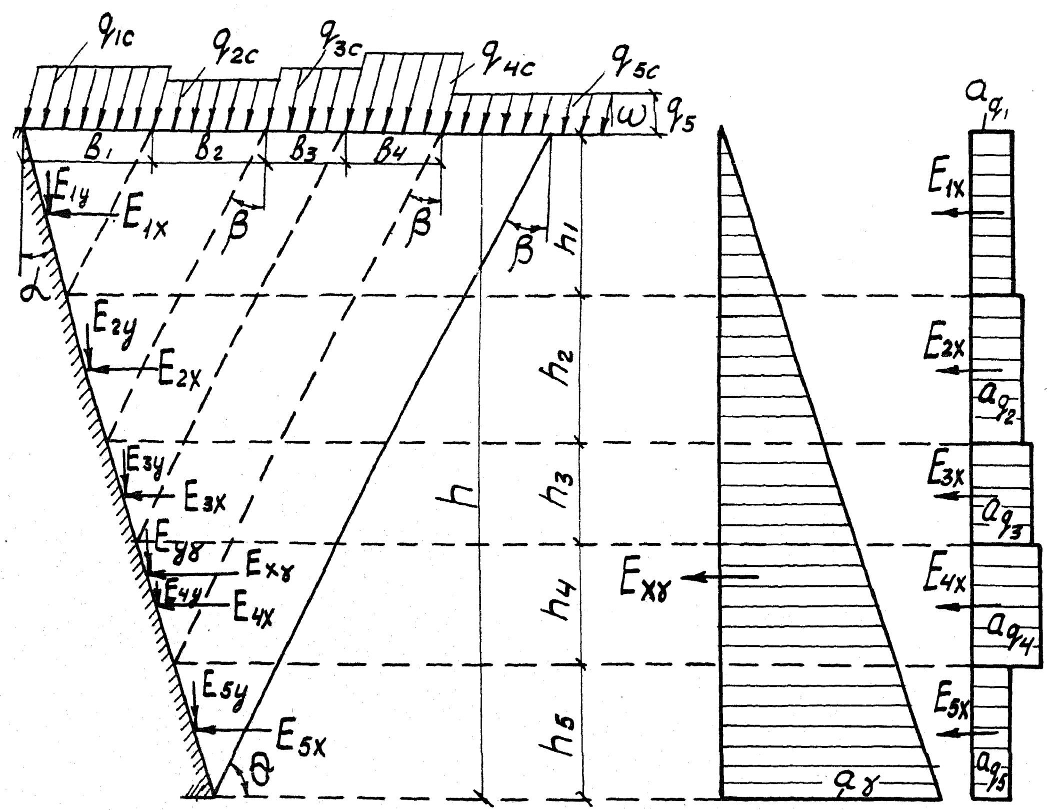

Fig. 2. Construction of a pressure epure for the cases of complex loading

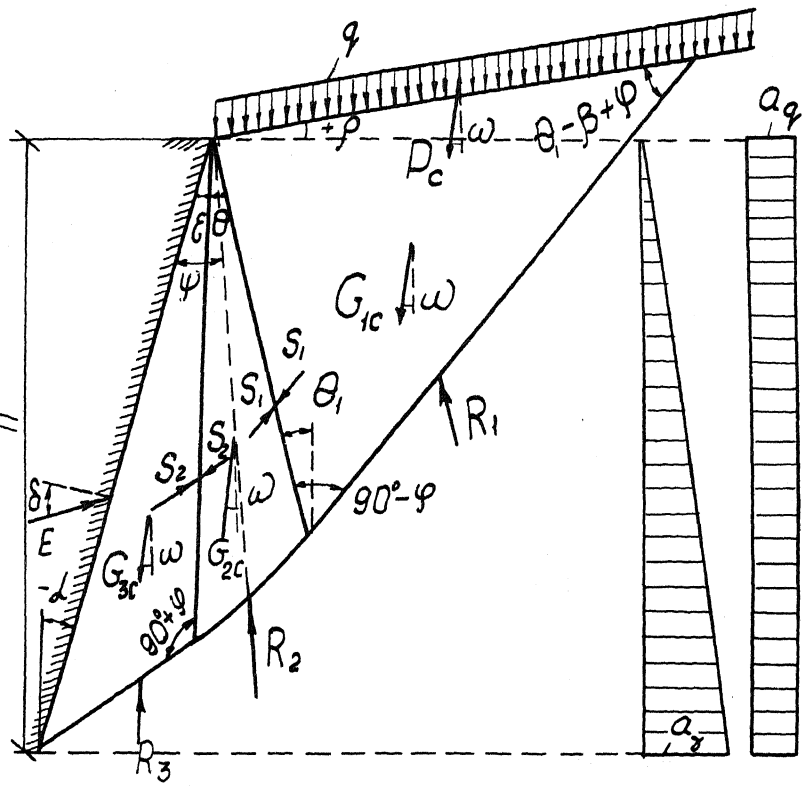

Fig.3. Slip surfaces for the case of active pressure

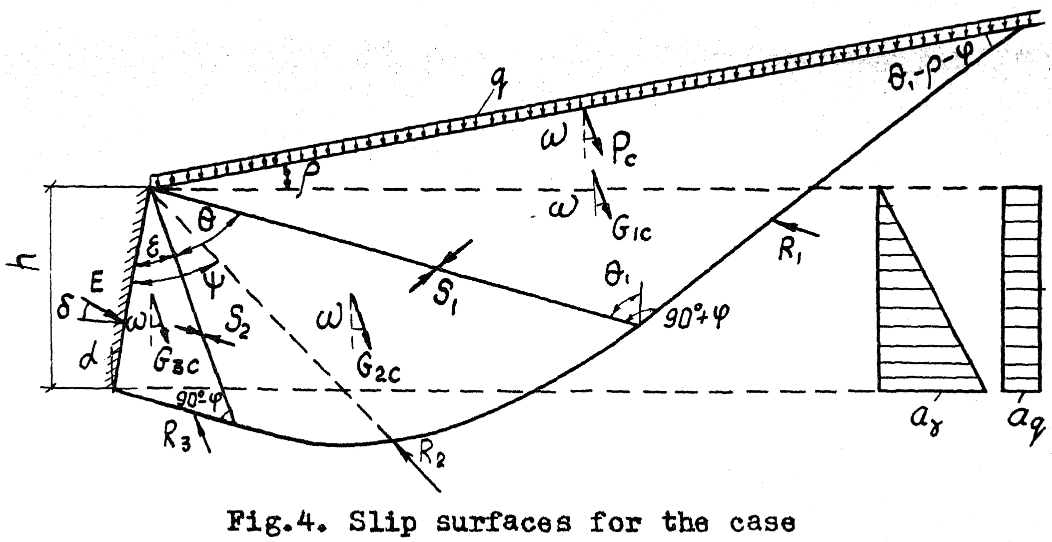

Fig.4. Slip surfaces for the case of passive pressure

DISCUSSION

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1. We had made the derivations for computing dynamic earth pressure behind retaining walls subjected to earthquake forces in 1966 on the same basis as presented in this paper. The work presented by us was more comprehensive as we considered.

a) c - ∅ soil
b) Effect of tension cracks

In addition to other papers, this work was published in Earthquake Symposium 'held at Roorkee in 1966'.

2. In this type of approach, an assumption has to be made for the point of application of the earth pressure for the complete design of retaining wall and its foundation. Any arbitrary assumption violates the condition of equilibrium.

3. We had suggested two alternative procedures for getting pressure distribution:

(a) One is already published in 'European Symposium on Earthquake Engineering' which was held at Bulgaria in 1974.

(b) Another approach is presented here in this Symposium in paper No. 6-39. This approach is based on Dubrova's method. These two approaches give total earth pressure as well as point of application.

Author's Closure

Not received.