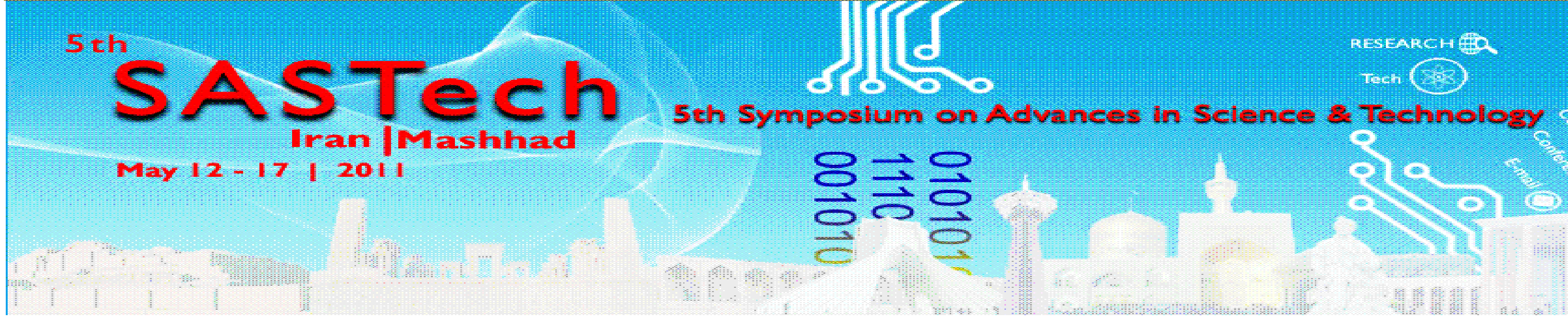

Lateral Earth Pressure Based on Experimental Slip Surface

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Abstract

The shape of slip surface of the wedge creating lateral thrust on retaining wall plays an important role in the magnitude, distribution, and height of point of application of lateral force. Considering the shape of slip surface as linear, circular, logarithmic spiral, or a combination of them is various conventional assumptions made in the literature review. It is know that the Coulomb method assumes a linear distribution of soil pressure on retaining walls, thus the point of application of total thrust is placed in one third height of the wall supporting granular backfill. However, some experimental studies have revealed non-linear distribution of earth pressures. In addition, the point of application of resultant thrust is placed somewhere upper than one third height of the wall. In the present study, plasticity equations are used and governing equations are derived on the basis of limit equilibrium approach to determine the nonlinear failure surface. For this purpose, a new analytical solution for determining total resultant thrust on the wall is introduced and the distribution of pressures and the point of application of thrust are computed with no simplifying assumptions. The results are compared with data from earlier available research work data. The results obtained from the developed method will be presented in tabular and graph forms for better understanding of the problem of earth pressure theorem.

Key words: Retaining wall, Slip surface, Plasticity, Limit equilibrium method, Distribution of earth pressure

1. Introduction

The problem of retaining soil is one of the oldest in geotechnical engineering and some of the earliest and most fundamental principles of soil mechanics were developed to allow rational design of earth retaining structures. Earth retaining structures take many different forms supporting slopes, bridge abutments, quay walls, and excavations. As such, they are frequently key elements of ports and harbors, transportation systems, lifelines, and other constructed facilities. Therefore, their design for static and seismic loading has always been an important subject in geotechnical engineering.

In some cases such as analysis of lateral earth pressure, the calculation of bearing capacity of shallow foundations, and stability analysis of slopes, the entire or a part the failure surface in the soil is assumed to be linear, circular, logarithmic spiral, or a combination of them

Also for a rough wall, the shape of the slip surface and the distribution of the active earth pressure depend on the yielding mode of the wall (Terzaghi, 1943; Fang and Ishibashi, 1986).

If the wall yields by tilting around its lower edge, the slip surface is curved near the base of the wall and planar near the top, with a roughly triangular distribution of active earth pressure exerted on the wall (Terzaghi, 1943). If the surface of the backfill is horizontal and the rigid wall rotates around its upper edge, the slip surface with curved shape which intersects the horizontal surface of the backfill at right angles. For this case, according to Terzaghi (1943), a roughly parabolic distribution of active earth pressure is applied on the yielding wall. Finally, if the wall yields by horizontal translation, the slip surface will have a more complex shape.

Currently, for practical applications, in the analysis of retaining walls, the failure surface is assumed to be planar, however, in order to accurately calculate of the total resultant thrust, relatively correct shape of the slip surface is essential to determine.

Many experimental results show that the distribution of active pressure on the face of a rough wall depends on the mode of wall movement and the distribution of active earth pressure against a rigid wall is nonlinear [4, 11, 13].

Tsagareli (1965) investigated the lateral pressure of wall backfill made of loose medium sand on large installation retaining wall model with a vertical back face and horizontal backfill surface and determined the amount, distribution and height of point of application of active earth pressure. This research shows the slip prism has a curvilinear boundary. Also the normal earth pressure obtained in these experiments is close to that calculated by Coulomb's formula.

In this study an analytical solution for determination of total resultant thrust and point of application of thrust has been developed without any simplifying assumptions. A nonlinear failure surface is assumed at soil-soil surface using a shape observed in experiment of Tsagareli (1965), and comparison was made with existing test results.

2.Data and Material

Definition of Problem

Tsagareli (1965) performed a series of large installation retaining wall model with a vertical back face and horizontal backfill with cohesionless soil in active conditions. He observed that the shape of slip surface in active condition can be well approximate with exponential function. Eq. 1 expresses the shape of slip surface in cartesian coordinates in plane.

$$y = (0.5 + 3.6\,\varphi)^{x} - 1 \tag{1}$$

where φ is the soil internal friction angle, and x and y are coordinate of slip surface in plane

Determination of pressure on the failure surface

Considering experimental shape for the failure surface in the backfill as is shown in Eq.1, the Kotter's equation based on the plastic theory is used to compute the reaction of the stable soil on the failed wedge. This equation is expressed as:

$$\frac{dp}{ds} - 2p.\tan\varphi\,\frac{d\alpha}{ds} = \gamma\sin(\alpha - \varphi) \qquad)2($$

where γ is the soil unit weight, α is the angle between the horizontal direction and tangential line at a given point on the failure surface, s is the arc starting from point A (Fig. 2). Fig. 1 shows pressure applied on failure surface for cohesionless soil in active and passive conditions.

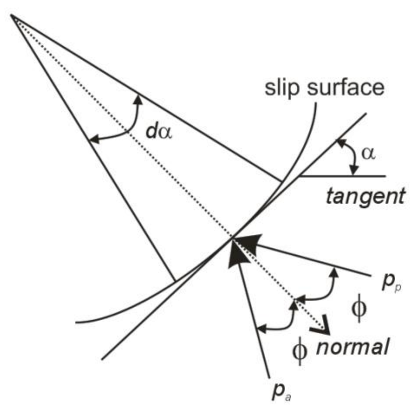

Fig. 1. Pressure applied on failure surface for cohesionless soil in active and passive conditions

The total length of the arc from A to a given point on the failure is determined using:

$$S = \int ds \tag{3}$$

where

$$ds = \sqrt{(dx)^2 + (dy)^2} = \sqrt{1 + (dy)^2} \tag{4}$$

Differentiation from Eq. (1) gives:

$$dy = (0.5 + 3.6\varphi)^{x}\log(0.5 + 3.6\,\varphi)^{x} \tag{5}$$

According to the Fig. 1, α can be obtained from:

$$\tan\alpha = (0.5 + 3.6\varphi)^{x}\log(0.5 + 3.6\varphi) \tag{6}$$

Eq. (6) may be converted to:

$$\alpha = \tan^{-1}[(0.5 + 3.6\varphi)^{x} \log(0.5 + 3.6\varphi)] \tag{7}$$

Differentiation from Eq. (7) results in:

$$d\alpha = \frac{(0.5 + 3.6\varphi)^{x} \log(0.5 + 3.6\varphi)^{2}}{1 + (0.5 + 3.6\varphi)^{2x} \log(0.5 + 3.6\varphi)^{2}} dx \tag{8}$$

As observed in Fig. 3, assuming zero pressure at point B as a boundary condition and substituting Eqs. (4), (7), and (8) into Eq. (2), the differential equation of pressure is solved to give the distribution of reaction of the stable soil on the failed wedge, p, along AB surface. Fig. 3. shows reaction pressure on slip surface behind the retaining walls.

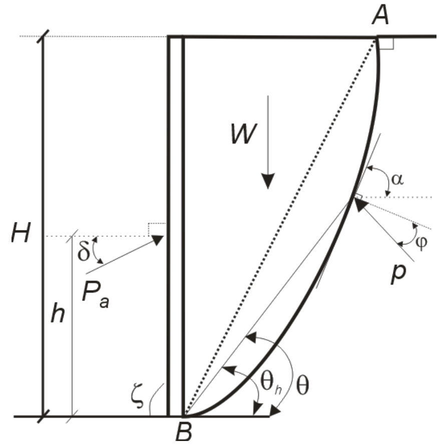

Fig. 2. Reaction pressure on slip surface behind the retaining walls

Due to shape of slip surface and exponential function this equation should solve with numerical methods

Distribution of Earth Pressure on Retaining Wall

To determine the distribution of lateral earth pressure on retaining wall, Fig. 6a is considered in which a horizontal element of the backfill soil at depth y from the wall top is shown. Fig. 7a illustrates the forces and stresses on the soil element.

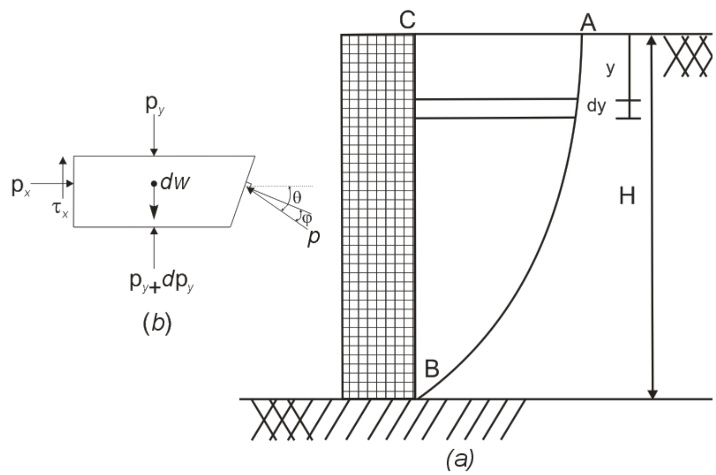

Fig. 3. Retaining wall and backfill soil element for analysis of horizontal earth pressure distribution on wall

According to Fig. 3a, the equilibrium of the horizontal forces on the backfill soil element results in:

$$p_x \times dy - p \times \cos\theta \times \frac{dy}{\sin\alpha} = 0 \quad (9)$$

which can be re-written as:

$$p_x = p \times \frac{\cos\theta}{\cos(\theta - \varphi)} \quad (24b)$$

Fig. 4 shows the distribution of the earth pressure on the retaining wall. As seen, the distribution of earth pressure is nonlinear and its maximum does not occur at the toe of the wall. This distribution is of similar shape as obtained by Fang (1986).

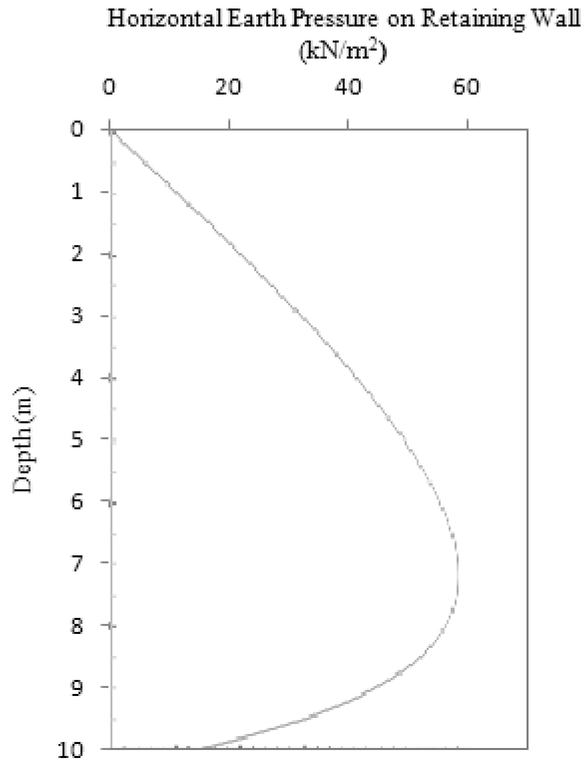

Fig. 4. Distribution of horizontal earth pressure on retaining wall for

$$\varphi = 35^{\circ}, \delta = \frac{\varphi}{2}, H = 10 \text{ m}, \beta = 0, \xi = 90^{\circ}, \gamma = 18\,\frac{\text{kN}}{\text{m}^3}$$

Determination of total thrust

Total thrust can be determined by integrating by earth pressure behind wall. Fig. 5 shows the variation of total active thrust on the wall with friction angle of backfill. As observed, for friction angles greater than 23^o, the planar slip surface estimate estimates greater total thrust than computed using the experimental surface. With increasing the backfill friction angle, the rate of increasing the lateral thrust increases.

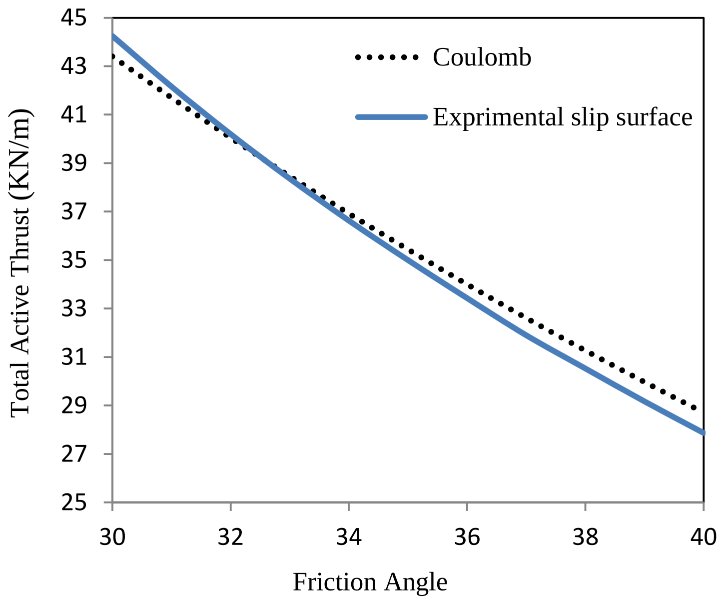

Fig. 5. Variation of total active thrust with friction angle of backfill for

$$\delta = \frac{\varphi}{2}, H = 4\ m\ , \beta = 0, \xi = 90^{\circ}, \gamma = 18\ \frac{kN}{m^3}$$

Also the point of application of the total thrust can be calculated from moment equilibrium of earth pressure. Due to nonlinear distribution of earth pressure and that the maximum earth pressure does not occur at the toe of the wall, the point of application of total thrust place somewhere upper than one-third from the wall bottom.

5. Conclusions

An analytical solution has been presented in this paper in which the experimental failure surface is assumed to occur in granular backfill behind a rigid retaining wall. The solution the Kotter's plasticity theory has been used to determine the reaction of the stable backfill soil on the failure wedge. The solution can be used to compute the total active thrust and the lateral earth pressure distribution on the wall. The analysis data have been compared with available data reported from earlier researches, resulting in satisfactory agreement. The results show that the distribution of the horizontal earth pressure on the retaining wall is nonlinear and the height of point of application of the total thrust is estimated upper than one-third from the wall bottom.

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