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Earth pressure of layered soil on retaining structures

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ABSTRACT

Earth pressure evaluation of retaining structure is not a new thing in geotechnical engineering. Up to date, many analytical and numerical approaches have been developed, but limitations of these available approaches are obvious for the application in some situations. The main objective of this paper is to develop a method to predict the earthquake pressure of retaining structures based on wedge method with as few limitations as possible. The developed method is suitable for retaining structures in the case of layered backfill with zero slope angle from horizontal level and with curved failure surface. To generate a curved failure surface, the sliding wedge is divided into many thin-layer micro-elements and the equilibrium equations of each micro-element are established. In the case of seismic analysis, the seismic actions are considered as static inertia forces on layered micro-elements. The shape of failure surface is determined by using available optimization method. Effects of the friction angle between wall and backfill soil on the distribution of earth pressure and the shape of failure surface were investigated, and earth pressures estimated based on curved and linear failure surfaces were compared. Analysis results indicate that the potential failure surface in the backfill soil depends on the friction angle between wall and backfill soil. For small friction angle, the failure surface tends to be planar. The active earth pressures corresponding to curved and planar failure surfaces are almost identical, but the discrepancies between the results of the two failure surface are large and increase with the increase of wall friction. Comparisons between results of the proposed method and those of the available methods as well as experimental results were conducted. Comparison result indicates that the merits of the proposed method are obvious.

1. Introduction

Retaining wall is a kind of structure that prevents soil from collapsing and sliding by withstanding the active earth pressure generated by soil, and has been widely used in railways, bridges, buildings, hydraulic and harbor engineering. For the safety design of retaining wall under service load and seismic load, earth pressure on retaining wall needs to be predicted. But, reliable prediction of earth pressure is difficult due to the soil-structure interaction which is seriously influenced by backfill material properties, wall rigidity, wall displacement and so on. Rankine's theory [1] and Coulomb's theory [2] are two main classical theories for predicting earth pressure, and have been broadly used in routine design process.

Both Rankine's and Coulomb's earth pressure theories are developed based on limit-state analyses. The former is based on the stress state in half space; and the latter focuses on the equilibrium of forces acting upon the whole soil wedge, regardless of the stress state within soil mass. Rankine's theory can deal with the earth pressure problem of layered soil, but scarcely be used for providing dynamic solution. In contract, Coulomb's theory is not applicable to layered soil, and can provide pseudostatic solution by incorporating the effect of earthquake through the use of constant horizontal and vertical accelerations on the soil mass of wedge. Additionally, Coulomb's theory is based on the assumption that the wedge slips along a linear surface passing through the heel of the wall, which is inconsistent with engineering practices and usually results in overestimation for passive earth pressure when the interface friction angle is larger than one-third of soil friction angle. Terzaghi [3] provided the relative exact solution of passive earth pressure by assuming the shape of failure surface as a logarithmic spiral on the bottom part of retaining wall and a

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straight line on the upper part. Subsequent to Terzaghi's work, valuable experimental work associated with passive earth pressure has been conducted [4–12]. Experimental investigation conducted by Mackey and Kirk [6] reported that for loose backfill, the passive earth pressures observed in experiment agreed well with those predicted based on Coulomb's theory; but for dense backfill, Coulomb's solution was approximately 100% higher than experimental results. Experimental results of Narain et al. [7] indicated that the passive pressure coefficient calculated with Coulomb's theory was 127% higher than experimental values. Another unreasonable assumption of Coulomb's theory is the linear distribution of earth pressure along the height of the retaining structure. Extensive experimental observations have clearly indicated a curve distribution of earth pressure. Каган [13] and Wang [14] extended Coulomb's theory by dividing the sliding wedge into many micro-elements. Based on the force equilibrium of each thin-layer micro-element, earth pressure stress with a nonlinear distribution was obtained by solving differential equation when considering surcharge on the ground surface as boundary conditions. Although a nonlinear distribution of earth pressure solution can be obtained, this approach was developed based on the assumption of planar failure surface.

Okabe [15] and Mononobe and Matsuo [16] extended Coulomb's theory for seismic design practice by considering seismic force as inertia force in the equilibrium equation of sliding wedge. Thereafter, extensive research has been conducted to develop the calculation method of seismic earth pressure. Pseudo-static analysis is the most commonly used approach. Representatives of this analysis approach are limit equilibrium method [17–27], characteristics method [28–30], and limit analysis method [31–39]. Since Horizontal Slice Method (HSM) was proposed based on limit equilibrium method by Lo and Xu [40], many researchers have utilized it to solve dynamic active earth pressure problem. Nouri et al. [20,21] adopted HSM in the investigation of active pressure distribution along the height of retaining wall, and predicted the angle of failure wedge in active state. Ahmadabadi and Ghanbari [22] and Ghanbari and Ahmadabadi [23–25] used HSM to predict the active pressure on reinforced fill walls with cohesive-frictional backfills. But, in the above-mentioned studies, there have been few investigations focusing their attention on predicting the seismic earth pressure of layered soil and applying HSM to passive earth pressure solutions. Extensive research, both analytical and experimental, has revealed that the pseudo-static analysis has overestimated passive earth pressures due to the assumption of planar failure surface.

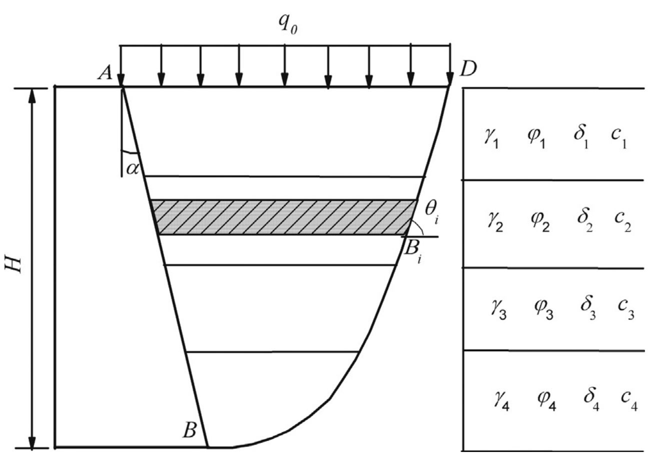

Fig. 1. Active wedge of retaining structure.

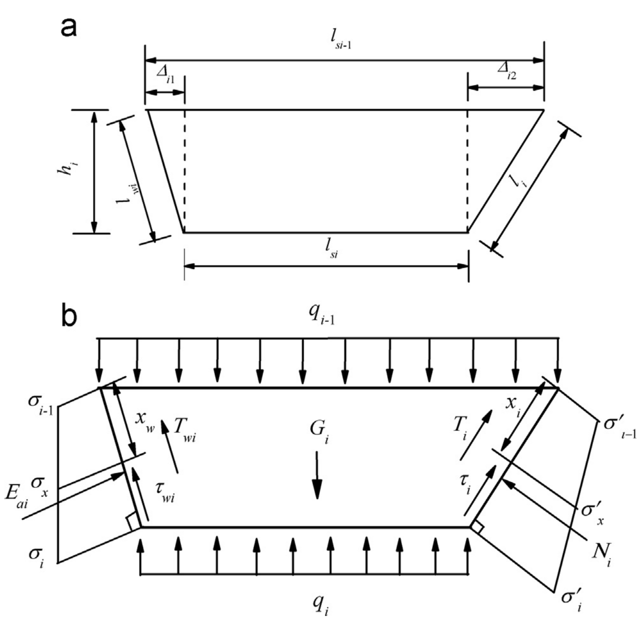

Fig. 2. Micro-element of active wedge. (a) Geometric dimensioning, and (b) force diagram.

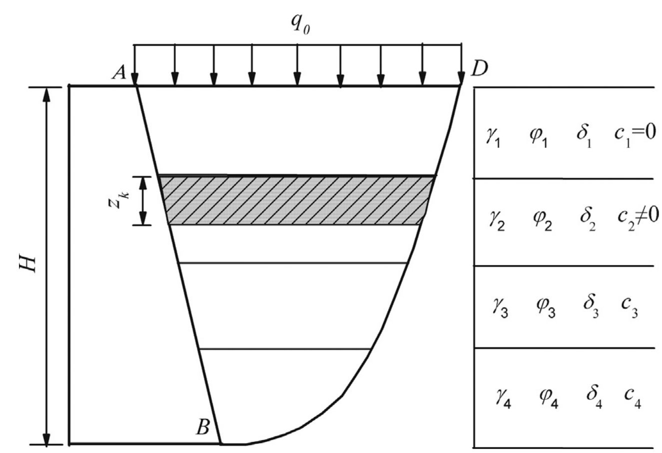

Fig. 3. Gap height in coherent soil layer.

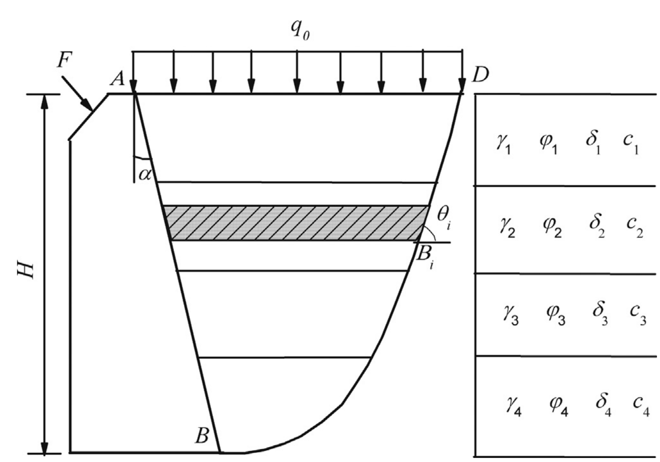

Fig. 4. Passive wedge of retaining structure.