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Discussion on "Evaluating the effect of slope angle on the distribution of the soil-pile pressure acting on stabilizing piles in sandy slopes"

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1. Introduction

To determine the soil-pile pressure acting on stabilizing piles in slopes, He et al. [1] improved Ito and Matsui's approach [2] for calculating the active lateral pressure by considering the effect of soil arching [3]. Reasonable assumptions allow for a meaningful investigation of the distribution of the soil-pile pressure acting on stabilizing piles in a slope. However, the study presented by He et al. [1] was based on unreasonable assumptions, particularly in the theoretical analysis. First, the soil elements were assumed to have the same stress state in the inclined wedge with the same Mohr's circle to describe the stress characteristics of a soil element adjacent to the centerline of the pile; second, the stress relation of a representative element in the slope was introduced without considering the influence of the inclined slope angle; third, to integrate the total force of the flat element, the upper limit of the integration interval was set equal to $\pi/2$ without considering the effect of the slope angle; finally, the equilibrium equation of the flat element derived from unrealistic assumptions mentioned above was also questionable. This discussion aims to correct the unrealistic assumptions to solve this boundary value problem in a rigorous way.

2. Theoretical analysis

2.1. Analysis of the stress state of a soil mass

Two types of stress states exist in an inclined soil mass of a slope at failure, as shown in Fig. 1. The first type of stress state exists in the soil element adjacent to the centerline of the pile (Element I in Fig. 2(a)), and the second type of stress state exists in the element in the soil-arching zone between the sliding surface and the pile (Element II in Fig. 2(b)). The Mohr circles of these two different stress states are shown in Fig. 2. However, He et al. [1] assumed that all soil elements have the same stress state in the thrust wedge and proposed a corresponding Mohr circle, which cannot accurately represent the real stress states of the soil elements along line A–B.

From the Mohr circle of the first stress state (Fig. 2(a)), the stress relation can be expressed as:

$$\left(\sigma - \frac{\sigma_1 + \sigma_3}{2}\right)^2 + \tau^2 = \left(\frac{\sigma_1 - \sigma_3}{2}\right)^2 \tag{1}$$

where σ_1 and σ_3 are the major and minor principal stresses, respectively, and σ and τ are the normal and shear stresses, respectively.

Line C–D in Fig. 2(a) can be expressed as:

$$\begin{aligned}\tau &= \tau_{hw} + (\sigma - \sigma_{hw})\tan\beta = \sigma_{hw}\tan\varphi + (\sigma - \sigma_{hw})\tan\beta \\ &= \sigma\tan\beta + \sigma_{hw}(\tan\varphi - \tan\beta)\end{aligned} \tag{2}$$

where τ_{hw} and σ_{hw} are the shear and normal stresses acting on the vertical plane A–B, respectively; β is the slope angle; and φ is the soil friction angle.

By setting $\Delta\tau = \sigma_{hw}(\tan\varphi - \tan\beta)$, the normal stress σ is determined using Eqs. (1) and (2) as follows:

$$\sigma = \frac{[(\sigma_1 + \sigma_3) - 2\Delta\tau\tan\beta] \pm \sqrt{[(\sigma_1 + \sigma_3) - 2\Delta\tau\tan\beta]^2 - 4(1 + \tan^2\beta)(\sigma_1\sigma_3 + \Delta\tau^2)}}{2(1 + \tan^2\beta)} \tag{3}$$

The normal stress (σ'_v) acting on plane d–c of Element I (Fig. 1(b)) can be expressed as:

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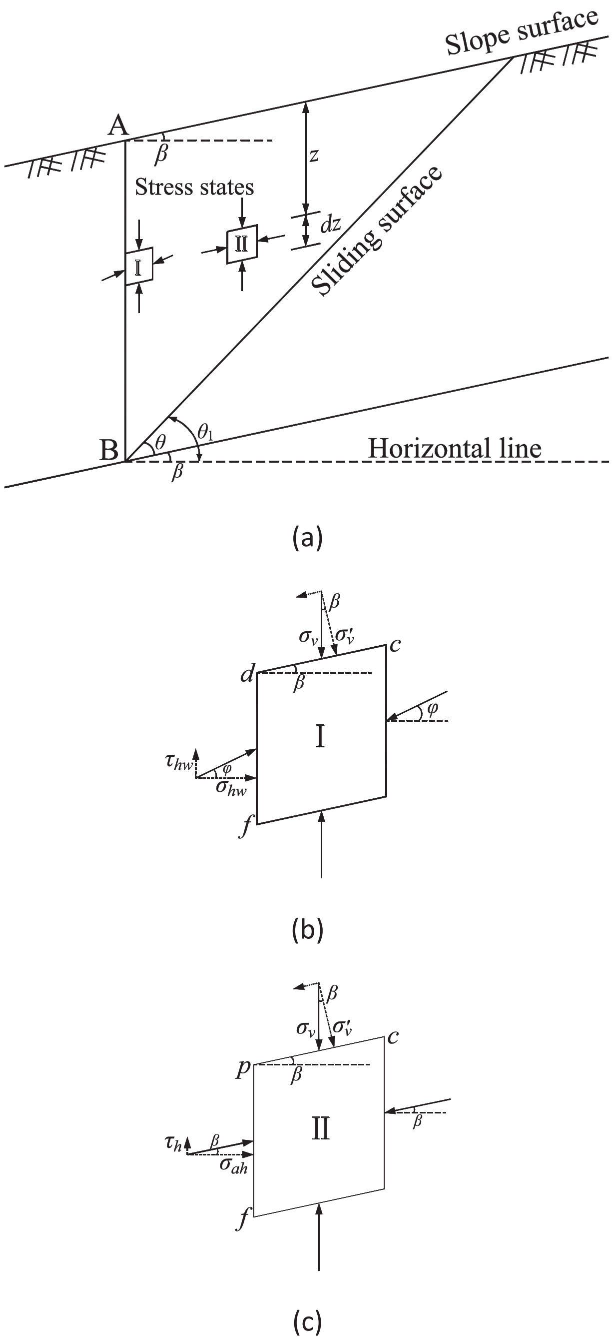

Fig. 1. Semi-infinite, cohesionless mass with an inclined surface: (a) schematic of positions of different stress states; (b) stress state of Element I; and (c) stress state of Element II.

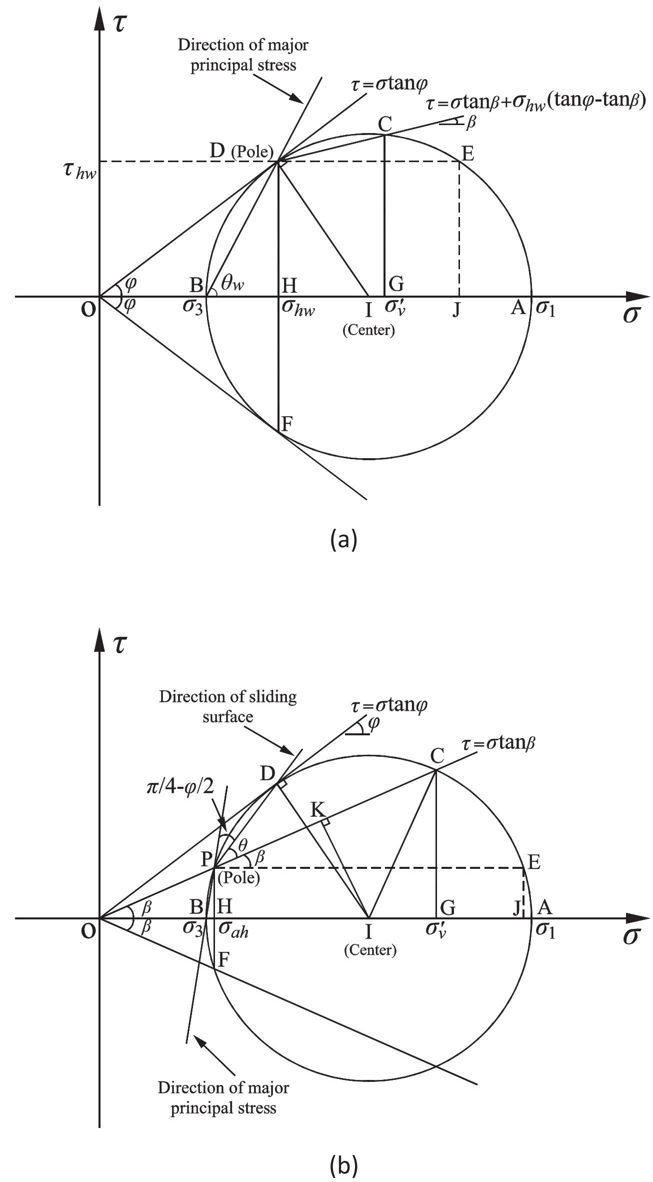

Fig. 2. Mohr's circle of the stress states at failure: (a) Element I and (b) Element II.

$$\sigma'_v = \sigma_v \cos\beta \tag{4}$$

where σ_v is the vertical stress acting on plane d–c.

Substituting Eq. (4) into Eq. (3), the stress relation can be simplified as:

$$\sigma_1 + \sigma_3 = \frac{\sigma_v}{\cos\beta} + \sigma_{hw}(1 - \tan^2\beta + 2\tan\beta\tan\varphi) \tag{5}$$

Similarly, the stress relation of the second state (Fig. 2(b)) can be formulated as:

$$\sigma_{ah} + \sigma_v \cos\beta = \cos^2\beta(\sigma_1 + \sigma_3) \tag{6}$$

where σ_{ah} is the horizontal stress acting on the vertical plane.

Eqs. (5) and (6) indicate that the stress relations are dependent on the slope angle; however, to analyze the rotation of the major and minor principal stress in the soil arching zone, He et al. [1] used the following stress relation without considering the effect of the slope angle:

$$\sigma_{ah} - \sigma_3 = \sigma_1 - \sigma_v \tag{7}$$

When the slope angle equals zero, Eqs. (5) and (6) become Eq. (7); therefore, using Eq. (7) to analyze slopes with non-zero slope angles is not appropriate.

The original paper by He et al. [1] focuses on the effect of the slope surface angle on the soil-pile pressure, which implies that the inclined angle β is an important parameter, and β equaling zero is a special case. However, using Eq. (7) directly without considering the inclined slope surface angle makes the results questionable. The use of the stress relation of different stress states given by Eqs. (5) and (6) is recommended to ensure accurate analysis results.

2.2. Rotation of the principal stress and the active lateral stress ratio

To investigate the rotation of the principal stresses of the inclined soil mass shown in Fig. 3, the trajectory of the minor principal stress proposed by Paik and Salgado [3] was used in the form