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Strength characteristics of soilbags under inclined loads

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A B S T R A C T

The application of soilbags in permanent or semi-permanent projects is becoming increasingly wider. When used in some projects like retaining walls, soilbags are usually undertaken loads that are not perpendicular to their long axis direction, i.e. under inclined loads. In this study, a 2D strength formula of soilbags under inclined loads is derived, expressed as the apparent cohesion c_T resulting from the tensile force of the bags. A way of modeling flexible bags in DEM simulation is proposed. The soilbags stacked at different inclination under biaxial compression is numerically simulated by DEM to verify the derived strength formula of soilbags. The results indicate that under inclined loads, the developed tensile forces of the bags and thus the corresponding apparent cohesion c_T of soilbags decrease with the increasing inclination of soilbags.

1. Introduction

Soilbag, with soil contained in a bag, is familiar to everyone. For a long time, soilbags have been used to prevent a flow of soils from floodwater and build temporary structures in case of emergency (Kim et al., 2004). It is probably because of no knowledge on the features of soilbags and the deterioration of soilbags after a long exposure to sunlight, especially for such polyethylene-made soilbags that are very sensitive to ultraviolet rays. As a result of the studies by Matsuoka et al. (1999, 2000b, 2003, 2006), many advantages of soilbags, such as improving bearing capacity of soft ground, being friendly to our environment, reducing traffic-induced vibration, preventing frost heave and so on, have been elucidated. It has been found that the polythene (PE) or polypropylene (PP)-made bag is stable against both acids and alkali, and is durable if the bag is protected from the exposure to sunlight by embedding it into ground. Recently, the use of soilbags has been extended to permanent or semi-permanent projects, such as soft soil foundation reinforcement (Matsuoka and Liu, 2006; Liu and Matsuoka, 2007; Xu et al., 2008; Li et al., 2013), expansive soil treatment (Liu et al., 2012, 2015; Wang et al., 2015), base vibration isolation (Liu et al., 2014), retaining wall construction (Liu and Matsuoka, 2007; Lee et al., 2013; Wen et al., 2016), coastal protection projects (Martinelli et al., 2011; Hornsey et al., 2011; Kim et al., 2015; Moreira et al., 2016), soil railway embankment reinforcement (Matsuoka and Liu, 2006; Indraratna et al., 2014; Liu et al., 2017) and so on.

In the case of reinforcing soft building foundation, soilbags are mainly subjected to vertical loads from the upper structure weight (parallel to the short axis of soilbags); while in the case of constructing retaining walls, soilbags bear backfill earth pressures that are inclined to the vertical direction (not parallel to the short axis of soilbags), as indicated in Fig. 1. In this study, we define the angle between the direction of the major principal stress σ_1 and the short axis of soilbag as δ. Thus, in the case of reinforcing soft building foundation, the angle $\delta = 0$.

So far, many researches on the compressive strength of the soilbag in the case of $\delta = 0$ have been conducted. Matsuoka et al. (2000a, 2003, 2006) derived a strength formula of the soilbag in two dimensional stress states (2D) and verified it through a series of unconfined and biaxial compression tests, in which the high compressive strength of the soilbag was interpreted as the contribution of an apparent cohesion c resulting from the tension of the bag. Based on the generalized Mises and the Lade-Duncan failure criteria, Bai et al. (2010) suggested two compressive strength formulas of the soilbag in three-dimensional stress states, which can predict the compressive strength of soilbags under vertical loads

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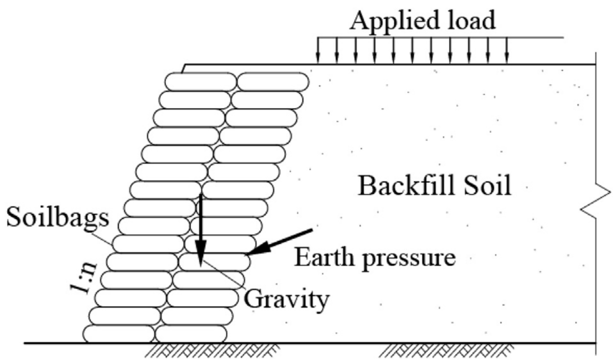

Fig. 1. Construction of retaining wall with soilbags.

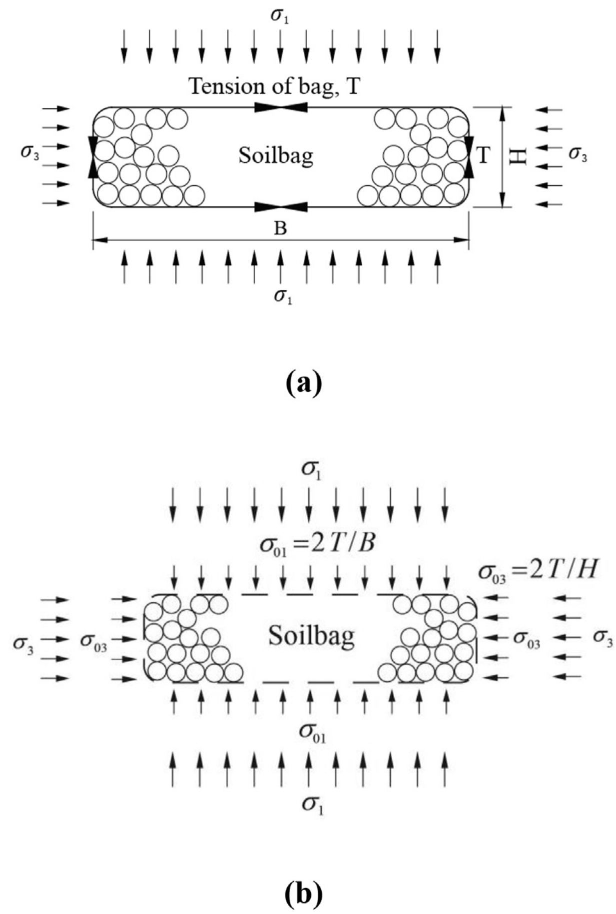

Fig. 2. Stresses acting on two-dimensional model soilbag and on particles inside the soilbag: (a) Stresses acting on soilbag; (b) Stresses acting on particles inside soilbag.

more accurately. On the other hand, some numerical analyses have also been carried out on soilbags in the case of $\delta = 0$. The effectiveness of the ground improvement with soilbags has been validated as the result of the finite element analysis (Muramatsu et al., 2007; Tantono and Bauer, 2008; Ansari et al., 2011). The FEM simulation conducted by Ye et al. (2011) showed that soilbags could greatly reduce the ground vibration propagated from a point vibration source. And some numerical modeling of geosynthetics has been conducted using the DEM and proper coupling between the DEM and other methods (Bhandari and Han, 2010, 2015; Ahmed et al., 2015; Ngo et al., 2015; Chen et al., 2015; Cheng et al., 2017). By using the distinct element method (DEM), Cheng et al. (2016) numerically investigated the stress states and fabric anisotropies in the wrapped soil under unconfined compression and simple shear. The performance and mechanisms of the soilbag earth reinforcement method, i.e., confinement and interlocking, can be better understood from the perspectives of stress state, volumetric change and anisotropies.

When soilbags are used to construct permanent structures like retaining walls, they may be subjected to external loads not parallel to the short axis of soilbag, i.e. $\delta \neq 0$. In this paper, we present a 2D strength formula of the soilbag in the case of $\delta \neq 0$ and the verification through the numerical simulation using distinct element method (DEM).

2. Strength of soilbags in the case of $\delta = 0$

First, we review the 2D strength formula of the soilbag derived by Matsuoka et al. (2000a, 2003, 2006). Fig. 2 (a) shows a soilbag subjected to external principal stresses σ_1 and σ_3 in a two-dimensional manner. Under the actions of σ_1 and σ_3, the soilbag usually tends to be flat, accompanied by the extension of the total perimeter of the bag. As a result, a tensile force T is produced along the bag, which in turn produces an additional stress on the soil particles inside the bag. The components of the additional stress are expressed as

$$\sigma_{01} = 2T/(B \times 1); \quad \sigma_{03} = 2T/(H \times 1) \tag{1}$$

where B and H are the width and height of the soilbag, respectively. Thus, the stresses acting on the soil wrapped in the bag are the combined result of the externally applied stresses and the apparently produced stresses by the bag tensile force T, as shown in Fig. 2 (b). At failure, the following equation holds:

$$\sigma_1 + \frac{2T}{B} = K_p\left(\sigma_3 + \frac{2T}{H}\right) \tag{2}$$

where $K_p = (1 + \sin\varphi)/(1 - \sin\varphi)$ and φ is the internal angle of friction of the wrapped soil. As the width B is usually greater than the height H for soilbag, it is known from Eq. (1) that the tensile force T induced along the bag causes stronger confinement to the wrapped soil in the σ_3 direction than in the σ_1 direction. Thus, the larger the ratio of B/H of the soilbag is, the more the reinforcement effect is.

By comparing Eq. (2) with the strength expression of $\sigma_1 = \sigma_3 K_p + 2c\sqrt{K_p}$ for a cohesive-frictional material, the following expression of the apparent cohesion, c, of the soilbag resulting from the bag tension T is obtained.

$$c_T(\delta = 0) = \frac{T}{B\sqrt{K_p}}\left(\frac{B}{H}K_p - 1\right) \tag{3}$$

Thus, soilbag can be taken as a cohesive-frictional material with an apparent cohesion c as expressed in Eq. (3) and the same internal friction angle φ as that of the material contained in the bag. That is to say, the high compressive strength of the soilbag can be interpreted as the contribution of an apparent cohesion c resulting from the tension of the bag.

3. Strength of soilbags in the case of $\delta \neq 0$

Fig. 3 shows a two-dimensional soilbag that is inclined to the horizontal direction with an angle of δ, but subjected to the vertical major principal stress σ_1 and the horizontal minor principal stress σ_3. For the case of $\delta \neq 0$, through a series of biaxial compression tests on the wrapped aluminum rod assemblies, Matsuoka and Liu