EXPERIMENTAL AND DEM INVESTIGATION ON SHEAR STRENGTH CHARACTERISTICS OF INHERENTLY ANISOTROPIC ELONGATED SAND

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Introduction

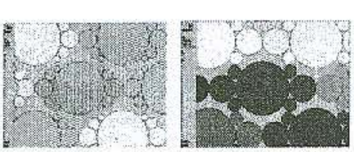
Inherent fabric anisotropy is known to develop in sands when deposited in air or water, aligning their faces normal to the direction of deposition resulting in an anisotropic mechanical behaviour. Thus, the inherent anisotropy was defined by Casagrande and Carillo (1944) as 'a physical characteristic inherent in the material and entirely independent of the applied strains'. Therefore, it is logical to expect sand to behave anisotropically with regard to its mechanical behaviour (Oda, 1972). In this context, it would also be prudent to know how profound the anisotropic behaviour would be due to the influence of degree of particle elongation which is conveniently defined by the aspect ratio.

In this study, two series of triaxial tests are carried out on inherently anisotropic dry sand having distinctly different aspect ratios. Further, a numerical investigation is carried out on an inherently anisotropic sand under biaxial stress conditions using a 2D discrete element method (DEM) utilizing the software PFC^{2D}.

Methodology

Two sand samples (Gs=2.66) categorised as 'moderately elongated' and 'highly elongated' were prepared manually to carry out triaxial tests (internal diameter 37 mm and height 75 mm) so that the plane of deposition makes an angle of $(90-\theta)°$ to the direction of major principal stress. The value of θ was selected to be 0°, 30°, 45°, 60° and 90°. The preparation of the sample was facilitated by a wooden rod whose one end has been cut at an angle of $\theta°$ to its longitudinal axis (Figure 1). The triaxial drained compression tests were carried out on the above inherently anisotropic sand samples (void ratio=0.70) under a cell pressure of 100 kPa.

Figure 1. Preparation of inherently anisotropic sand sample



(a) (b)

Figure 2. Modeling of a sand particle for aspect ratio (a) 1.7 (b) 2

The numerical analyses to simulate the laboratory triaxial tests were carried out using DEM utilizing the software PFC^{2D} (Itasca, 2004). The elongated shape of a sand particle was modelled by a number of circular particles clumped together to represent a predefined aspect ratio. In this analysis, aspect ratios of 1.7 and 2 were selected (Figure 2). Inherently anisotropic specimens of cross-sectional dimensions 38 mm x 76 mm and length 1000 mm were prepared for biaxial loading tests by arranging the clumped particles to have an orientation of 0°, 15°, 30°, 45°, 60°, 75° or 90° (Figure 3).

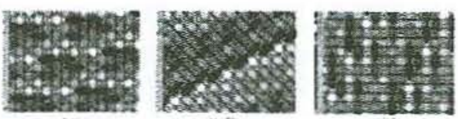
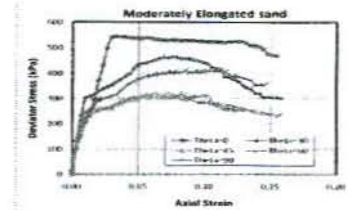


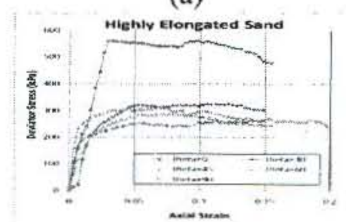
Figure 3. Orientation of particles for θ = 0°, 45° and 90°

Results

The deviator stress-axial strain relationships obtained from triaxial tests are shown in Figure 4 and the relationship of stress ratio at failure with inclination angle is shown in Figure 5 for moderately and highly elongated sand. The stress ratio-inclination angle relations obtained in the DEM analyses are shown in Figure 6. Figure 7 shows the variation of peak mobilised friction angle obtained experimentally and from the DEM analyses.



(a)



(b)

Figure 4. Relations of deviator stress and axial strain for (a)moderately (b) highly elongated sand

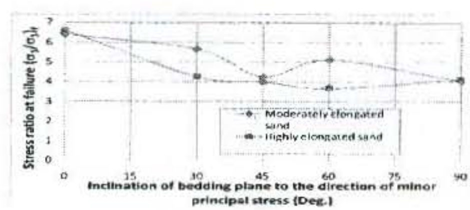


Figure 5. Relations between stress ratio at failure with inclination angle

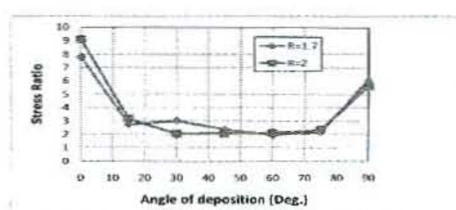
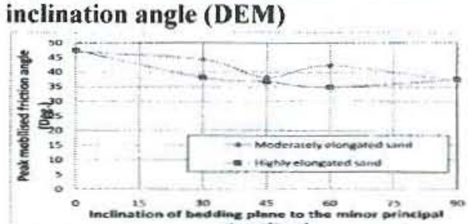
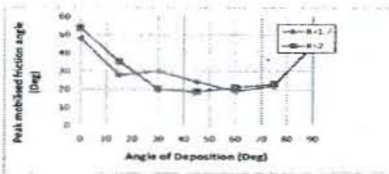


Figure 6. Variation of stress ratio with inclination angle (DEM)



(a) Experimental



(b) DEM simulation

Figure 7. Variation of peak mobilized friction angle with inclination angle

Discussion

The DEM simulation was carried out using particles of uniform size and constant aspect ratio aligned in a truly inherently anisotropic orientation. However, the sand samples prepared for the laboratory tests did not conform to such an idealisation. Nevertheless, the influence of inherent anisotropy on the shear strength is quite similar in both laboratory as well as numerical analyses. In both cases, the maximum stress ratio at failure occurs when the major principal stress is normal to the longitudinal axis of the particles. This can be expected as such an initial orientation is the most stable. The minimum strength occurs when the plane of deposition is inclined at an angle of about 45° to the direction of major principal stress. In this orientation, the shear plane gets more or less parallel to the bedding plane and therefore, shows the minimum strength. Although, it is possible to expect the particles to be of low strength when the major principal stress is applied along the plane of long axis, it appears that the particles realign and lock into voids within the particle assembly which inhibits further particle rotation thereby showing a higher strength. Further, it is observed that the assembly consisting of particles having the higher aspect ratio shows the lower strength. This can be attributed, to the fact that the higher aspect ratio facilitates the formation of shear bands at a lower axial strain. However, such a phenomenon is not operative for more stable particle orientations ($\theta=0°$) where the effect of aspect ratio is insignificant.

Conclusions

(1) The lowest value of shear strength is obtained when the direction of longitudinal axis of sand particles is inclined at an angle between 30°- 45° to the direction of major principal stress. Increase of aspect ratio further reduces this shear strength.

(2) The influence of inherent anisotropy is more profound for particles with higher aspect ratio.

(3) The effect of aspect ratio on the shear strength is insignificant when the longitudinal axis of particles is aligned either parallel or normal to the direction of major principal stress.

References

Casagrande, A. and Carillo. N. (1944). Shear failure of anisotropic materials. Proc. Boston Soc. *Civ.* Engrs. 31, 74-87.

Itasca Consulting Group Inc., PFC^{2D}(Particle Flow Code in Two Dimensions), version 3.1, 2004 (ICG:Minneapolis,MN, USA).

Oda, M. (1972). Initial fabrics and their relations to the mechanical properties of granular material. *Soils and Foundations,* 12(1): 17-36.