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Effect of bedding direction of oval particles on the behavior of dense granular assemblies under simple shear

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Key words:

Initial fabric anisotropy, Particle orientation, Simple shear, Non-coaxiality, Discrete element method

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Introduction

- The bedding plane effect induced by particle orientation is one of the main fabric factors leading to inherent anisotropy of granular assemblies.
- It is hard to experimentally examine the effect of bedding direction of particles on the shear behavior of particulate materials, such as sand.
- The Discrete Element Method (DEM) has been proved to be a powerful tool to study the micro mechanics of granular materials.
- In this work, the effect of particle orientation on the macroscopic behavior and non-coaxiality under simple shear was numerically investigated using DEM.

Methodology

- **Five samples with bedding angles $\theta = 0°, 30°, 45°, 60°$ and $90°$ were generated by prescribing the long axes of the oval clumped particles along with the desired bedding angles in PFC2D.**

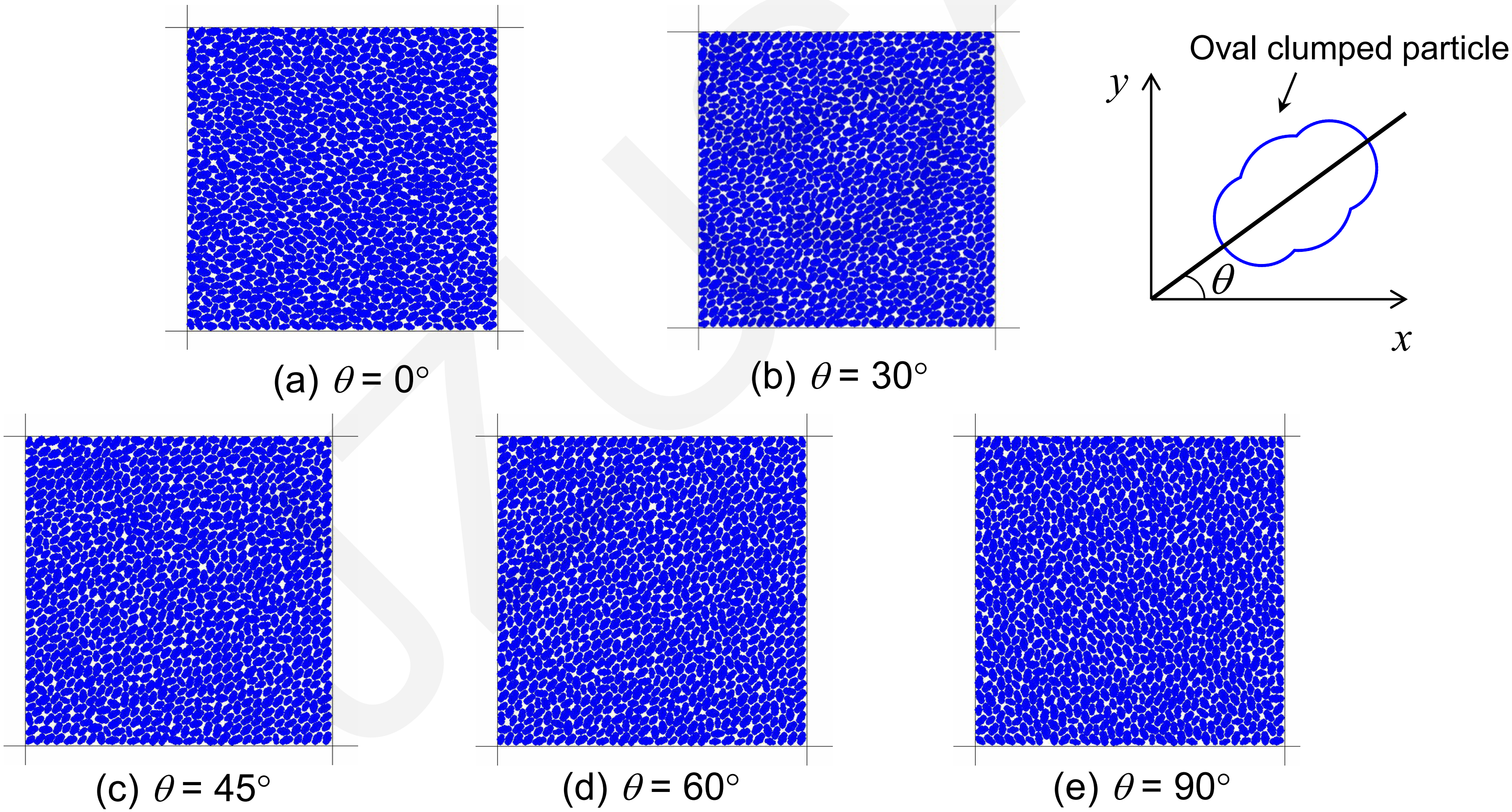
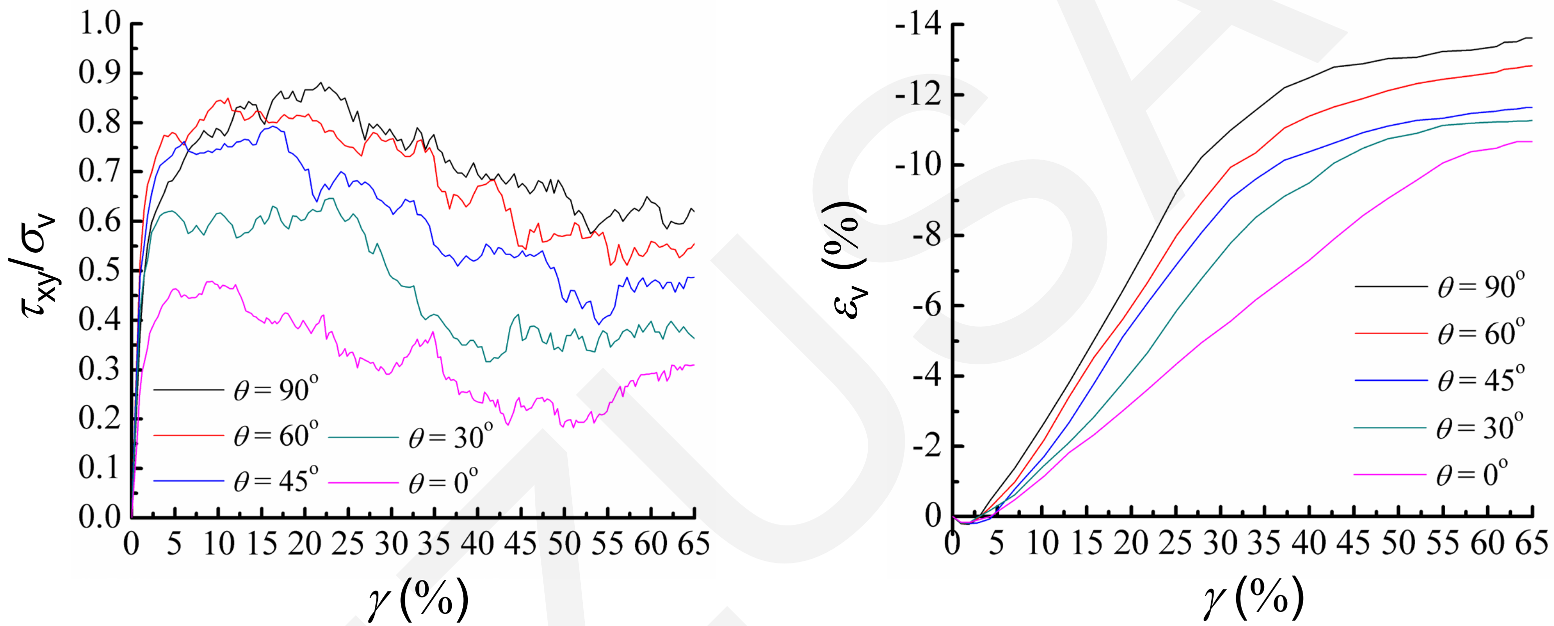


Fig. 1 DEM samples with various bedding angles

Results and discussions

■ Macroscopic responses to simple shear



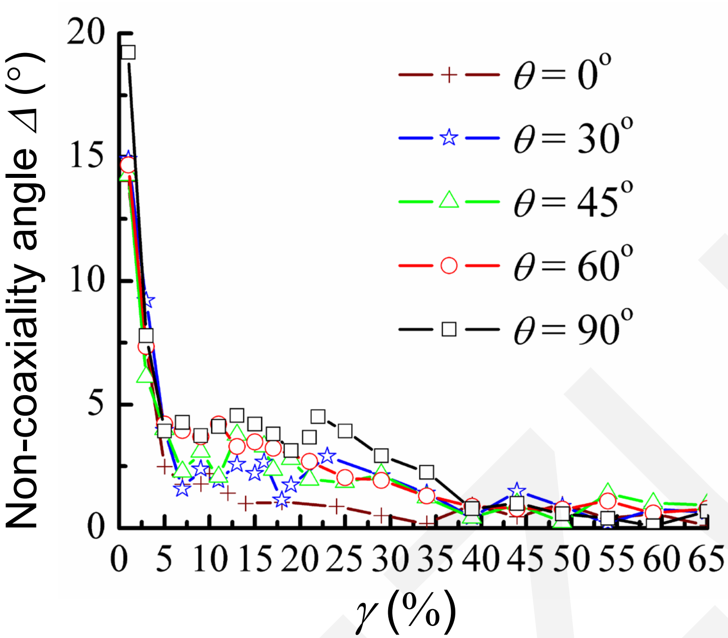
(a) Shear stress ratio τ_{xy}/σ_v - shear strain γ (b) Volumetric strain ε_v - shear strain γ

Fig. 2 Macroscopic behavior of DEM samples with different θ

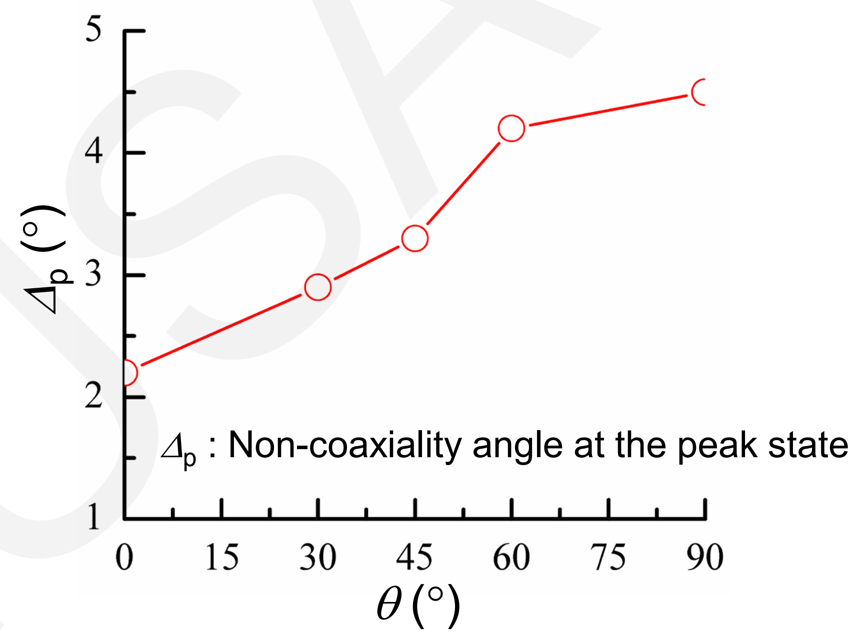
The peak shear stress ratio and peak dilation ratio both increase as the bedding angle increases from 0° to 90 °, and the numerical results agree with the reported experimental observations on granular soils.

Results and discussions

■ Effect of bedding angle on non-coaxiality



(a) Δ - γ



(a) Δ_p - θ

Fig. 3 Effect of bedding angle θ on con-coaxiality

It can be seen that in general, at $\gamma \leq 40\%$, the larger the bedding angle, the greater the non-coaxiality, and the non-coaxiality angle at the peak state Δ_p increases monotonically from 2.2° to 4.5° as θ varies from 0° to 90°.

Results and discussions

■ Stress-dilatancy relationship

Shi *et al*. (2015) extended the Rowe-Davis framework to study the stress-dilatancy relationship incorporating non-coaxiality:

(Shi, D. D., Xue J. F., Zhao, Z. Y., *et al*., 2015, A DEM investigation on simple shear behavior of dense granular assemlies. *Journal of Central South University*, 22(12): 4844-4855.)

$$\tan(\phi_{ss})_p = \frac{\tan(\phi_{ss})_r + \sin(\psi_p - 2\Delta_p)}{\cos(\psi_p - 2\Delta_p)}. \quad (1)$$

$(\phi_{ss})_p$: the peak simple shear friction angle

$(\phi_{ss})_r$: the residual simple shear friction angle

ψ_p: the peak dilation angle

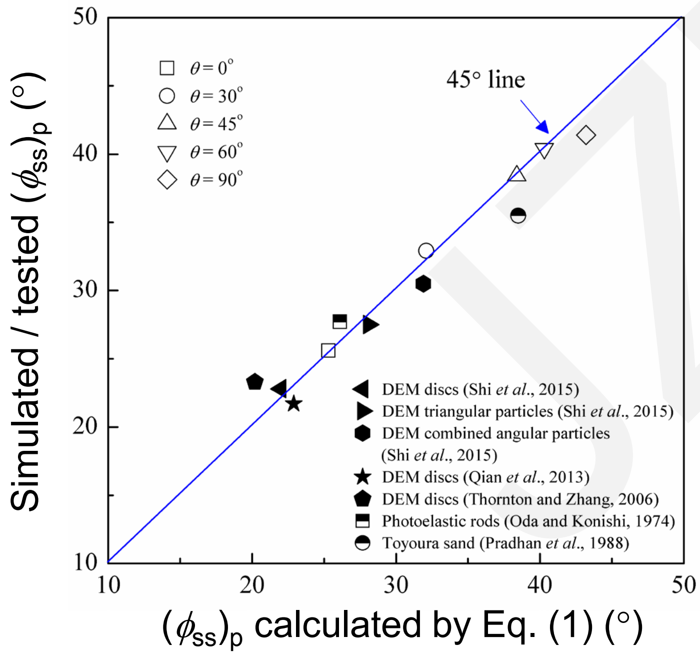


Fig. 4 Validation of Eq. (1)

The proposed stress-dilatancy relationship in Eq. (1) can effectively describe the non-coaxiality effect of granular materials under simple shear, independent of particle shape and initial fabric.

Results and discussions

■ Stress-force-fabric relationship

A new stress-force-fabric relationship based on Rothenburg- Bathurst equation is proposed to consider the effect of particle orientation:

$$\sin\phi_{\mathrm{ps}} = \frac{1}{2}\left(a + a_{\mathrm{n}} + a_{\mathrm{t}}\right) + \left(1 - a_{\mathrm{p}}\right)\sin\left(\theta_{\mathrm{p}} - \theta_{\mathrm{p}}^{45^\circ}\right). \quad (2)$$

ϕ_{ps} : the mobilized shear strength

a_p, a, a_n a_t : the anisotropic coefficients of particle orientation, contact normal, normal contact force and tangential contact force, respectively

θ_p: the principal direction of particle orientation anisotropy

$\theta_p^{45^\circ}$: the θ_p value of $\theta = 45^\circ$ sample

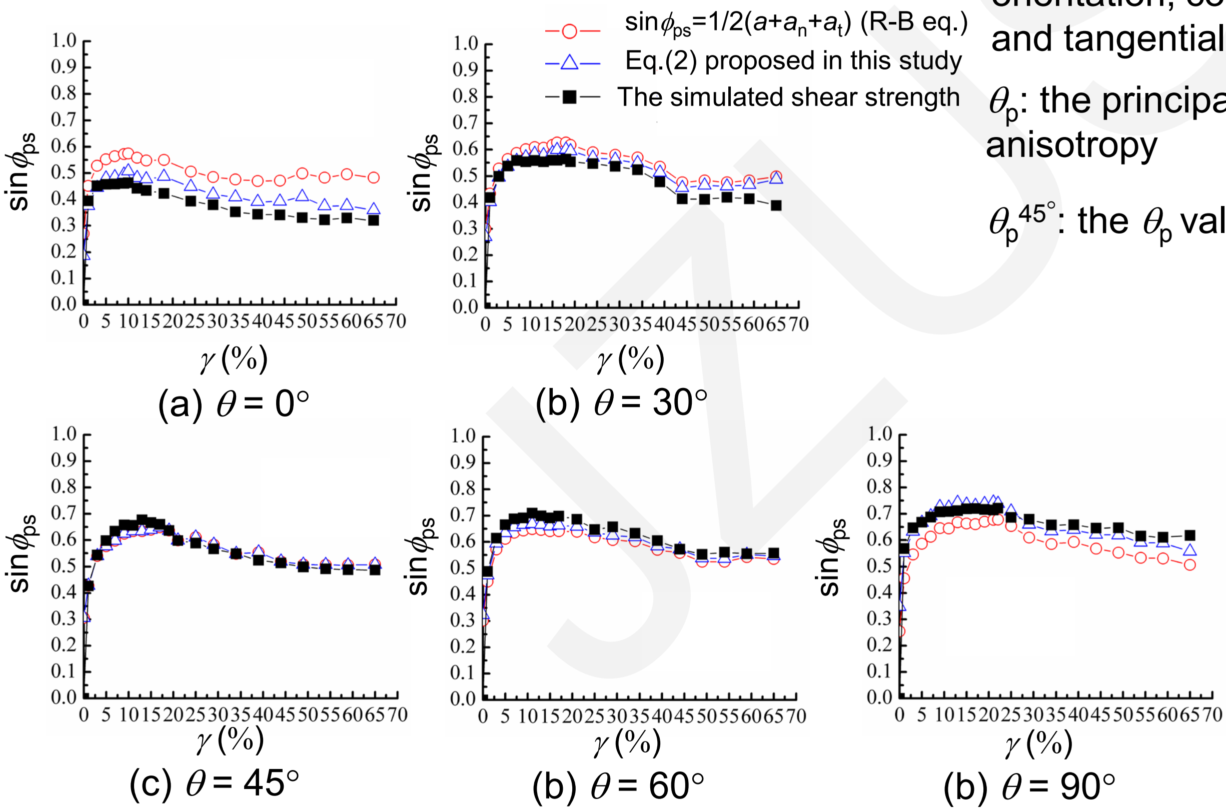


Fig. 5 Validation of Eq. (2)

The proposed stress-force-fabric relationship in Eq. (2) is better than the traditional R-B equation, when the initial different bedding angles of samples are considered.

Conclusions

- Bedding angle has significant influence on the strength and dilatancy behaviors of DEM samples under simple shear.
- Considerable difference in the non-coaxility angle can be observed within the shear strain range of $\gamma \leq 40\%$, and the larger the bedding angle, the greater the non-coaxiality.
- For samples with different bedding angles, the major directions of particle orientation have a tendency to approach the directions of major principal stress plane under simple shear loading.
- The proposed equations (Eqs. 1 and 2) can well reflect the stress-dilatancy and stress-force-fabric relationships incorporating the bedding plane effect.