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Microscopic Study of Factors Affecting Liquefaction Strength during Anisotropic Consolidation

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1. Introduction

Conventional triaxial tests have been extensively conducted to elucidate the mechanisms of liquefaction. During earthquakes, vertically propagating shear waves rotate the axes of principal stress in soil elements, resulting in different stress states from those in triaxial tests. To address the limitations of traditional experiments, alternative testing methods, including hollow torsional shear tests [1] were utilized to study liquefaction. This study proposed a novel approach for simulating undrained hollow torsional tests using the discrete element method (DEM). It offered a microscopic perspective on how initial anisotropy influences the liquefaction strength.

2. Methodology

The initial boundary conditions, as shown in Fig. 1, involve two rigid cylinders with an inner diameter of 6 cm and an outer diameter of 10 cm. The upper and lower boundaries are located 10 cm apart. Additionally, 6 blades designed for applying shear forces are positioned on the two ends of the apparatus

To obtain anisotropically consolidated specimens, triaxial compression ($K_0 < 1.0$) and extension ($K_0 > 1.0$) shear tests were conducted on isotropic specimens under constant-p' condition. 10 cases of anisotropically consolidated specimens with K_0 values ranging from 0.3 to 3.33 were obtained. As indicated by Eq. (1), the variation of the outer and inner radii R and r was controlled proportionally to ensure a constant volume of the specimen, and t denotes time. Specimens with initial K_0 values ranging from 0.33 to 3.33 were subjected to shear forces with 7 different stress ratios (CSR) τ_{max}/p'_0 ranging from 0.225 to 0.375 until liquefaction occurred.

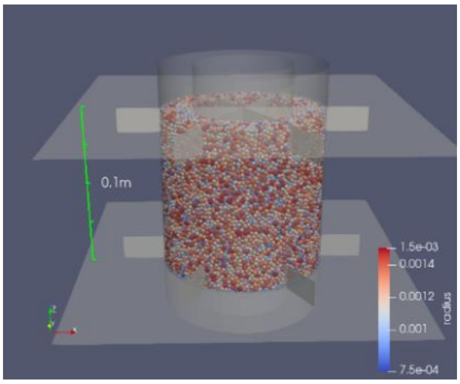


Fig. 1. Specimen and apparatus in simulation

$$\frac{dR}{dt}=\frac{r}{R}\frac{dr}{dt} \tag{1}$$

3. Results and discussion

Fig. 2 depicts the relationship between deviatoric stress σ_{vM} and mean principal stress p' during the liquefaction process, and a typical stress evolution in laboratory tests has been replicated in DEM simulations, providing evidence for the effectiveness of the method proposed. Fig. 3 shows that an increasing initial stress anisotropy induced lower liquefaction resistance strength.

The coordination number (Z) serves as an indicator reflecting the microscopic density of granular materials. Fig. 4 shows the evolution of Z under different initial stress states during the liquefaction process, and the the relationship between Z and the number of cycles required to trigger liquefaction (N_L). The result indicates that initial Z contributes to the liquefaction resistance strength, and the preliminary triaxial shear produces a lower Z, thus reducing the liquefaction strength.

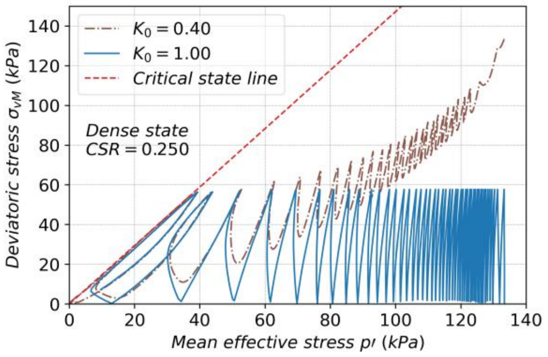


Fig. 2. Relationship between σ_{vM} and p'

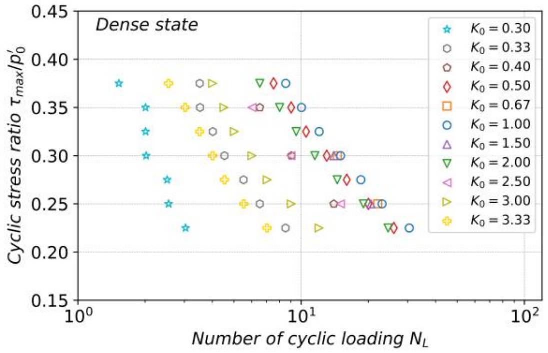


Fig. 3. Liquefaction resistance strength

Contact density is defined as the mathematical expectation of the average number of contacts per unit surface area in all orientations for one particle. Fig. 5(a) represents the state with initial K_0=0.5, exhibiting a elongated morphology extending toward the axial direction, whereas Fig. 5(b) depicts the contact density of the extension state with initial K_0=2.0, characterized by a dimpled disk oriented toward the axis. As cyclic shear proceeds, the direction of maximum contact density continuously varies following the rotating major principal stress axis, and the overall contact density gradually decreases. The post-liquefaction distribution of contact density is almost independent of the initial state, shifting between two columnar distributions in different directions.

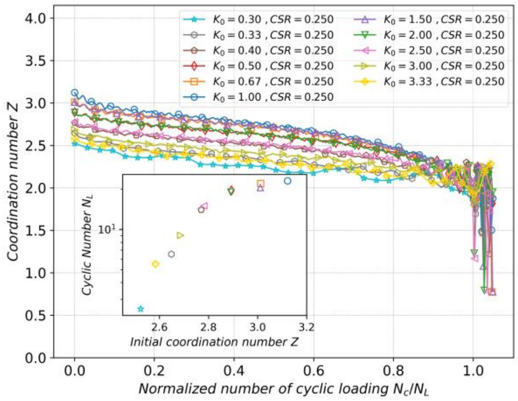
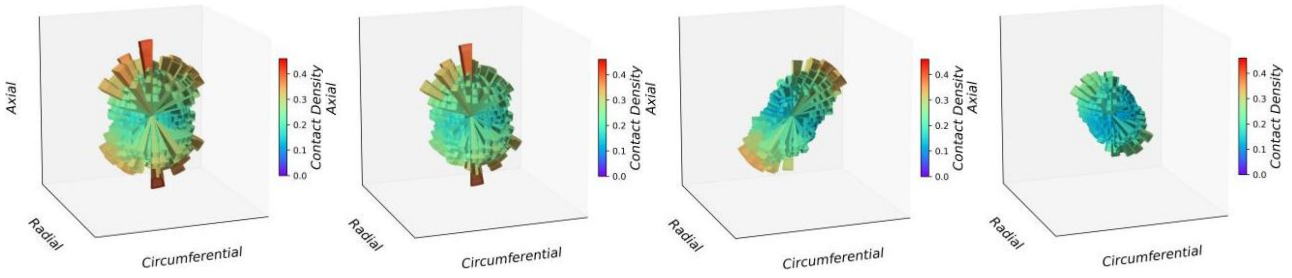


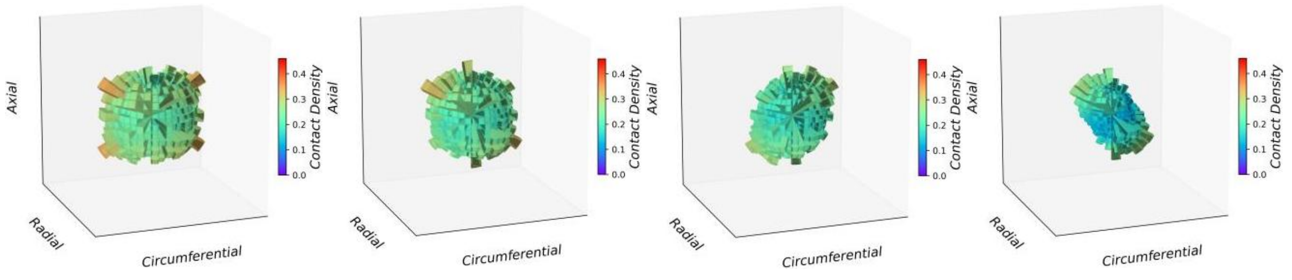
Fig. 4. Evolution of Z and relationship between Z and N_L

4. References

[1]Vargas, R. et al.(2020). Soil Dynamics and Earthquake Engineering, 133, 106111.



(a) Anisotropic state with K_0 = 0.5



(b) Anisotropic state with K_0 = 2.0

Fig. 5. Comparison of contact density evolution in liquefaction process with different initial K_0