Discrete element method study of hysteretic behavior and deformation characteristics of rockfill material under cyclic loading

Keywords:
Granular material, Discrete element method (DEM), Plastic deformation, Cyclic loading, Hysteretic behavior

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Research background and objective

Primary concerns

The hysteretic behavior and accompanied strain accumulation

Most study concerns

Dynamic responses of geomaterials and liquefication of sandy soils

Rare study cases

Deformation characteristics of geomaterials under low-frequency cyclic loading (such as reservoir storage and discharge)

Research objective

- deformation characteristics of rockfill material under cyclic loading
- hysteretic behavior from a macro and microscale perspective

DEM cyclic loading tests

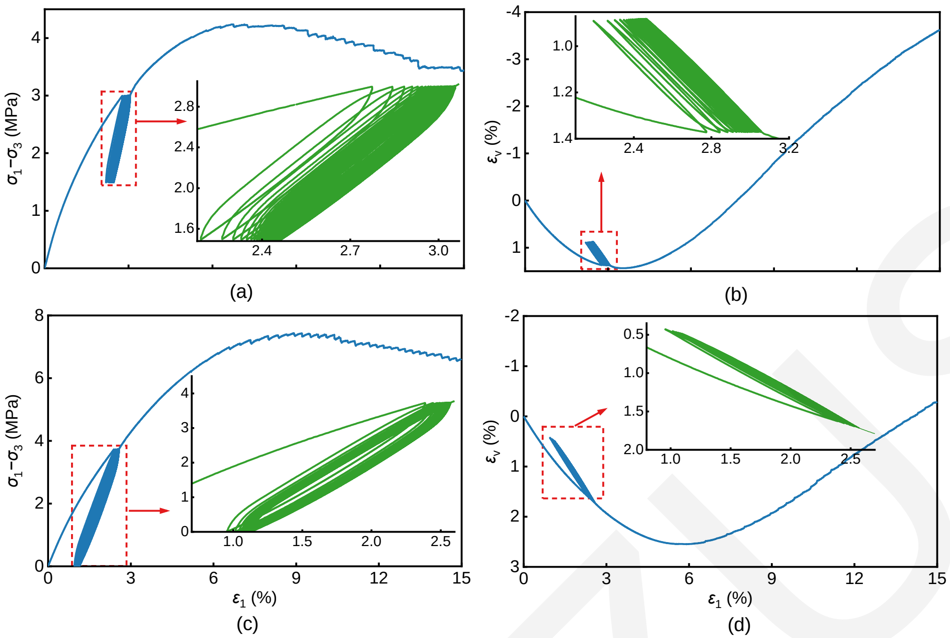

Fig. 1 Evolution of shear stresses (a and c) and volumetric strains (b and d) for crushable granular materials under different cyclic loading conditions: (a and b) P=1.0 MPa, S_L=0.7, and U_a=0.5; (c and d) P=2.0 MPa, S_L=0.5, and U_a=1.0

Table 1 Simulation groups design

Loading condition	Value
Confining pressure, P (MPa)	0.5, 1.0, 1.5, 2.0
Stress level, S_L	0.25, 0.5, 0.7, 0.9
Amplitude of cyclic loading, U_a	0.25, 0.5, 0.75, 1.0
Number of cycles, N	50

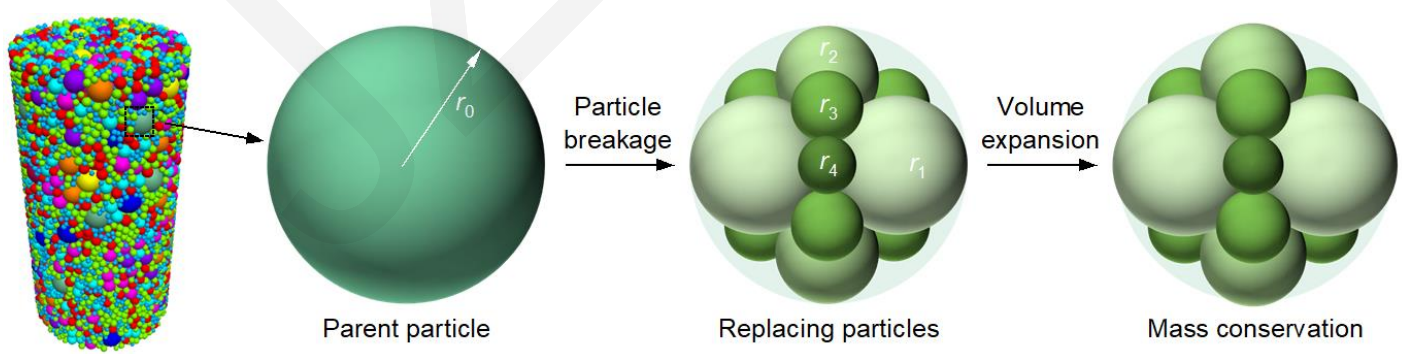

Fig. 2 Illustration of particle breakage modeling using fragment replacement method

Hysteretic behavior from a microscale perspective

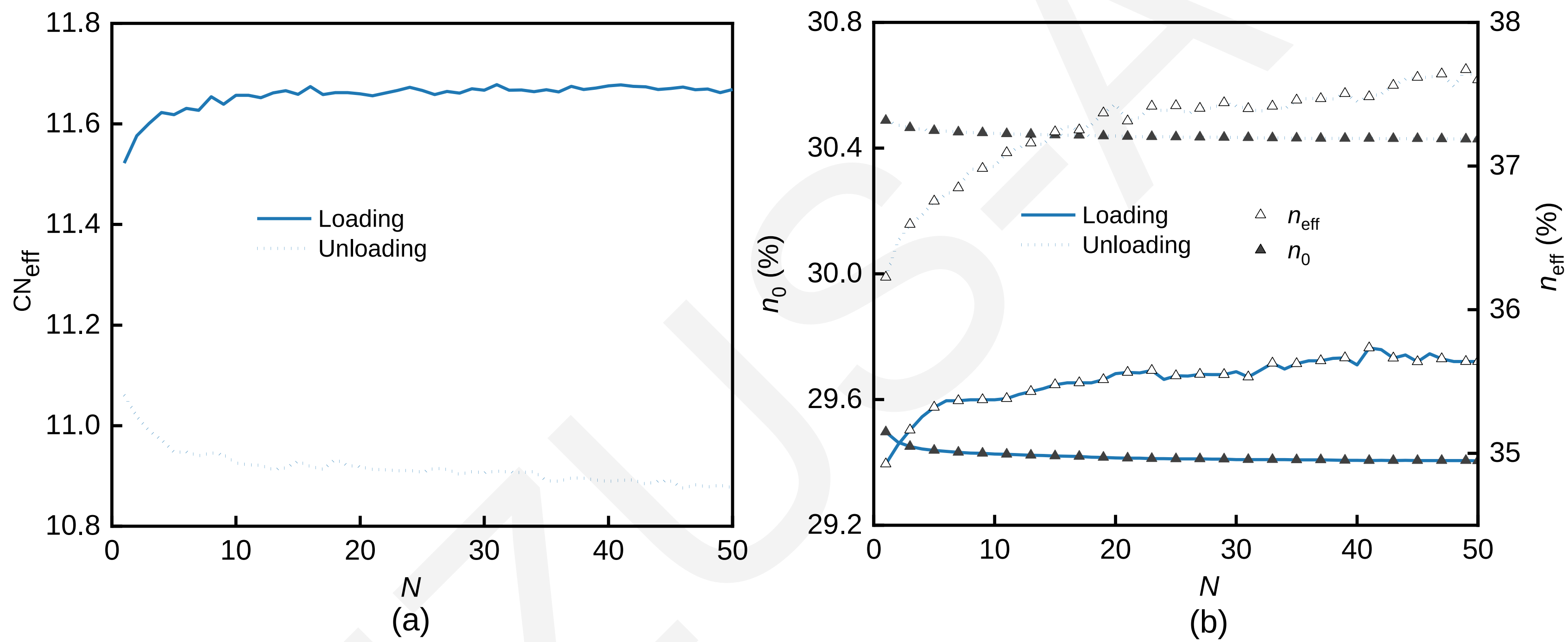

Fig. 3 Coordination number (a) and porosity evolution (b) of the specimen under different numbers of cycles N (P=1.5 MPa, SL=0.7, Ua=1.0)

- **According to the evolution of effective coordination number, the number of effective particles changing into rattlers is more than that of rattlers turning into effective particles, which probably produces the residual strain**
- **The change rate of porosity reduces after a certain number of cycles, suggesting the volumetric deformation become less and the hysteresis loops coincide**

Evolution of resilient modulus

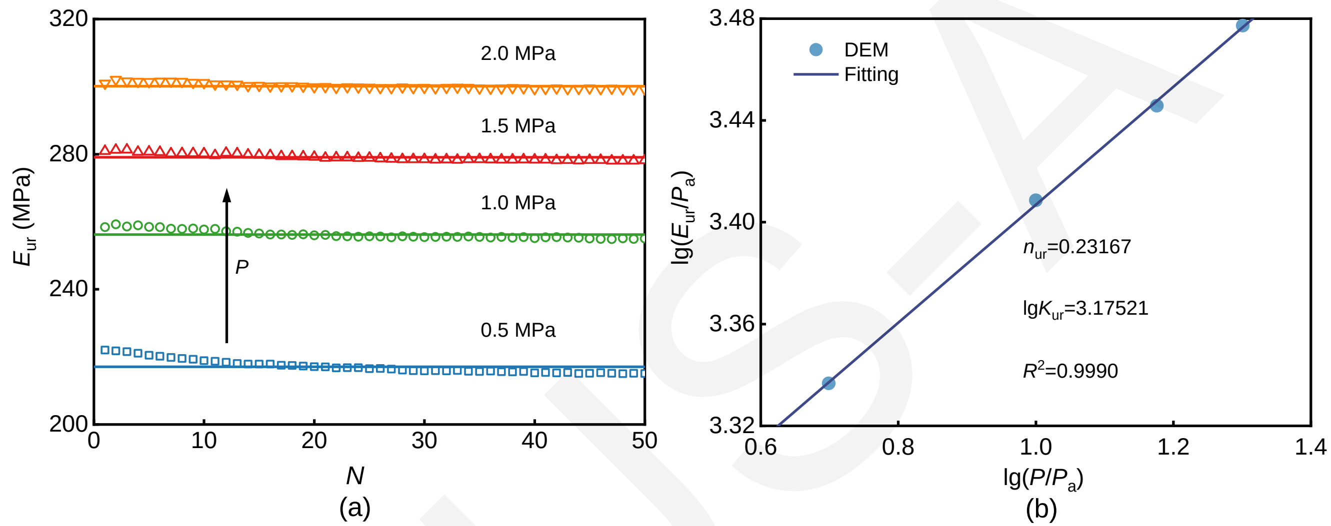

Fig. 4 Evolution of resilient modulus under different confining pressures (S_L=0.7, U_a=0.5): (a) E_{ur} evolve with N; (b) E_{ur} evolve with P

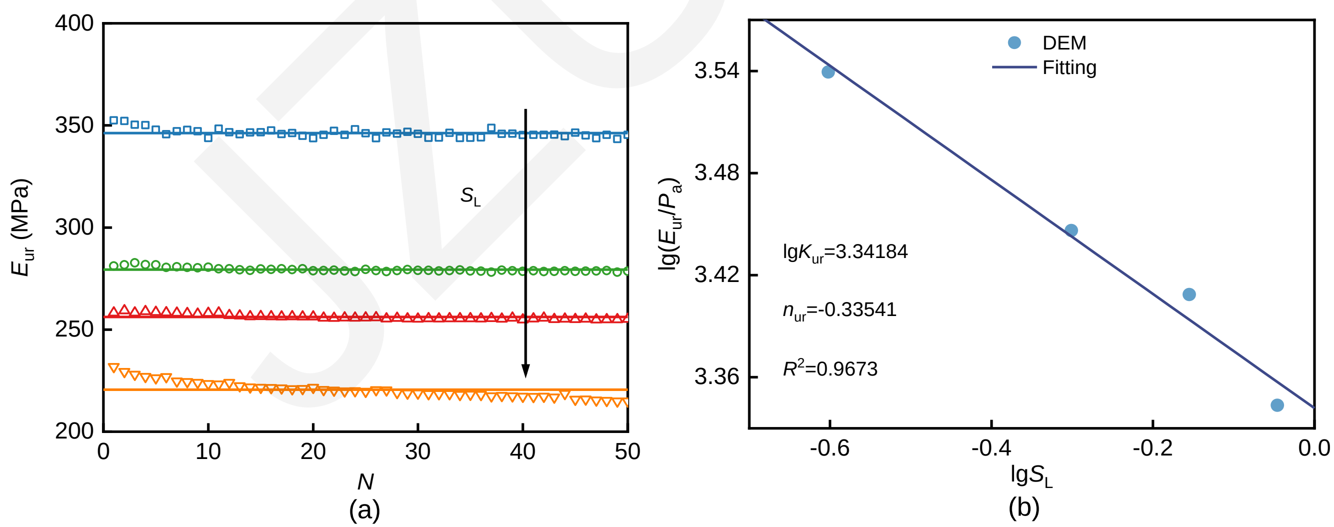

Fig. 5 Evolution of resilient modulus under different stress levels (P=1.0 MPa, U_a=0.5): (a) E_{ur} evolve with N; (b) E_{ur} evolve with S_L

Evolution of resilient modulus

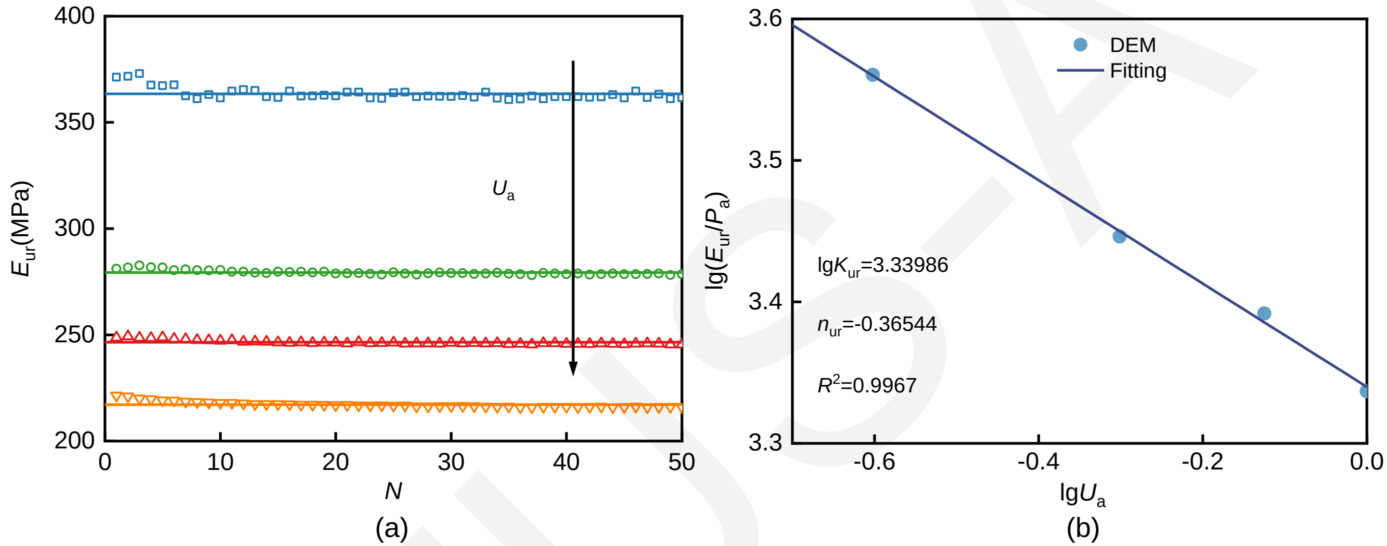

Fig. 6 Evolution of resilient modulus under different amplitudes of cyclic loadings (P=1.0 MPa, S_L=0.5): (a) E_{ur} evolve with N; (b) E_{ur} evolve with U_a

Considering the effects of confining pressure, stress level, and the amplitude of unloading, a reasonable evolution function of resilient modulus is proposed:

$$E_{ur} = \alpha_1 P_a \left(\frac{P}{P_a} \right)^{\alpha_2} S_L^{\alpha_3} U_a^{\alpha_4},$$

where P_a is the atmospheric pressure; α_1, α_2, α_3, and α_4 are fitting parameters

Conclusions

- **The hysteretic behavior of cyclic loading is analyzed from a microscale view**

  Rattlers accumulated during each cyclic loading can cause the generation of a residual strain

  The slowing down change in porosity during cyclic loading results in coincidence after a large number of cycles

- **The deformation characteristics under different cyclic loading conditions are discussed**

  A function considering the effect of confining pressure, stress level, and the amplitude of unloading is proposed to describe the resilient modulus

Prospectives

Programming and Verifying proposed resilient modulus

Investigating evolution of particle size distribution

Studying the effect of particle shapes under cyclic loading