

Cite this as: Wei XIONG, Qi-min ZHANG, Jian-feng WANG, 2023. Effect of morphological gene mutation and decay on energy dissipation behaviour of granular soils. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 24(4):303-318.

<https://doi.org/10.1631/jzus.A2200226>

Effect of morphological gene mutation and decay on energy dissipation behaviour of granular soils

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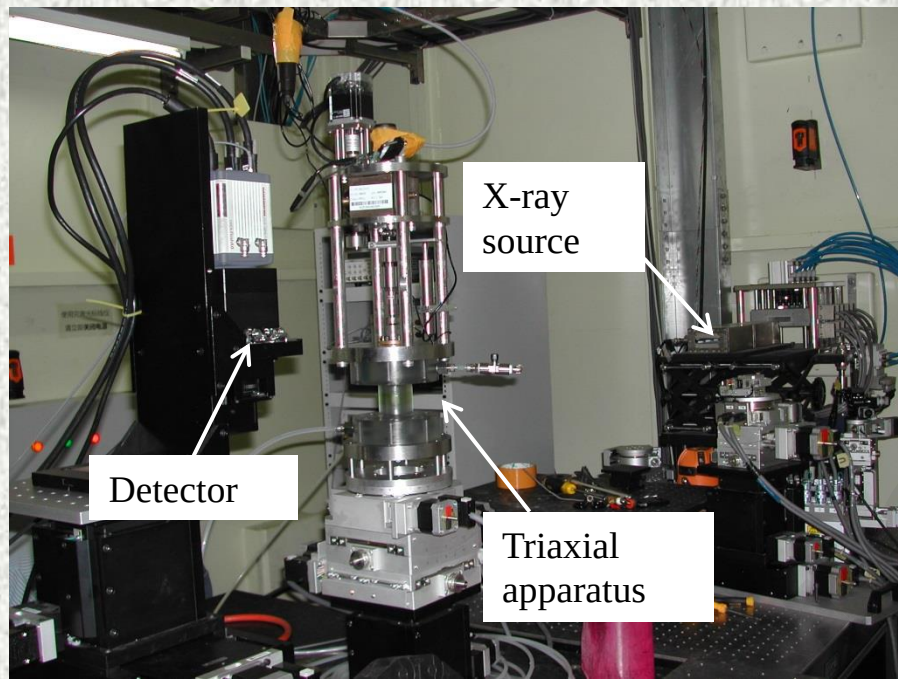
Key words:

X-ray micro-computed tomography (X-ray μ CT); Spherical harmonic analysis (SHA); Discrete element method (DEM); Morphological gene mutation; Energy dissipation



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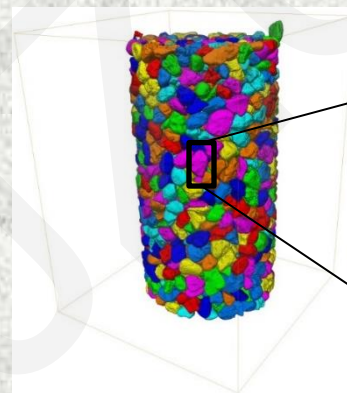
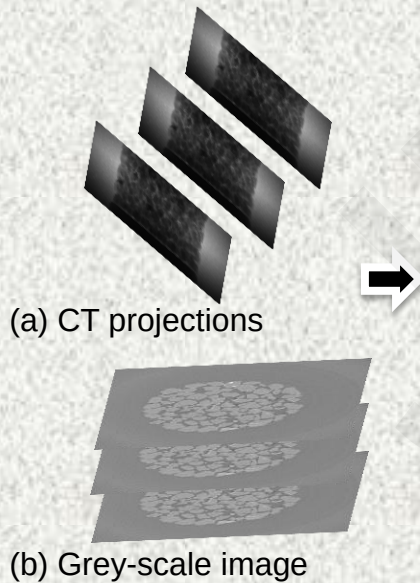


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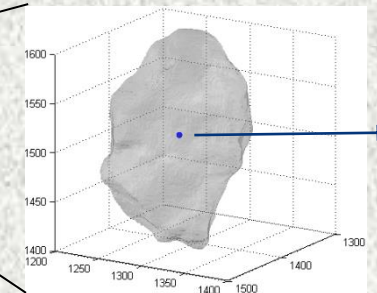


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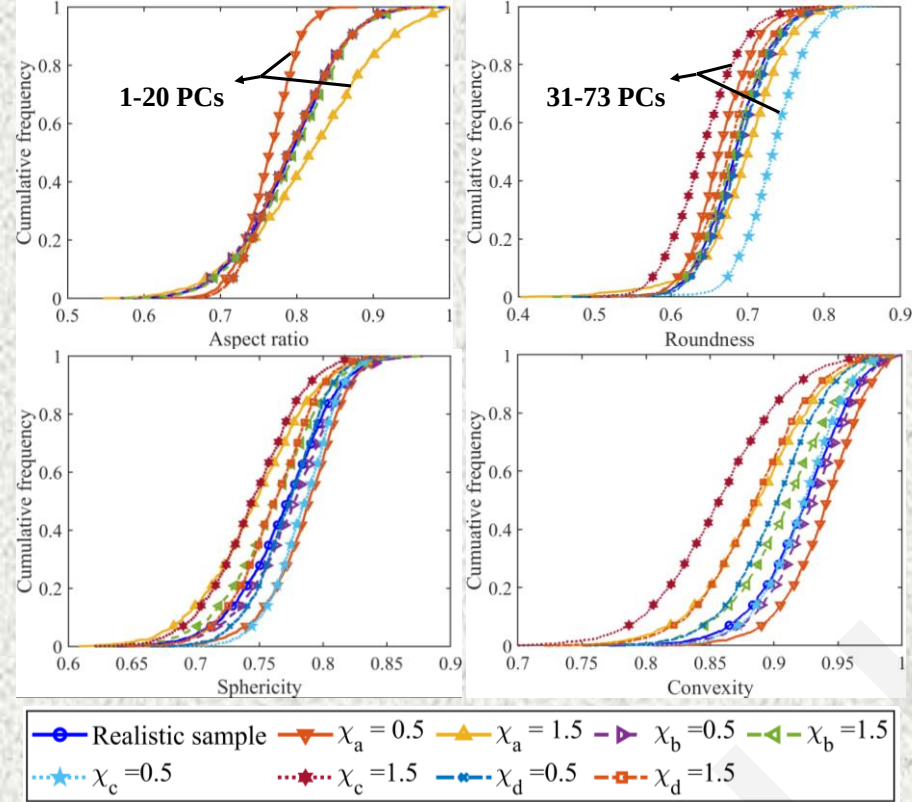
(c) Labelled image



(d) Individual particle

Centroid coordinate
(1401.0, 1281.9, 1506.8)
Volume:
 $387,414.9 \text{ mm}^3$
Surface area:
 $25,093.1 \text{ mm}^2$

Particle morphology extraction by X-ray micro-tomography



It is found that the **1-20 PCs** are mainly for general form (GF), **31-73 PCs** for local roundness (LR).

$$b_{nj} = u_{\mathbf{B}} + \chi_a \sum_{t=1}^{20} b_t + \chi_b \sum_{t=21}^{30} b_t + \chi_c \sum_{t=31}^{73} b_t + \dots, \quad (8)$$

The morphological gene mutation that adds variance to particle morphology at different length scales can be readily implemented

Spherical harmonic analysis

$$r(\theta, \varphi) = \sum_{n=0}^{\infty} \sum_{m=-n}^n C_n^m Y_n^m(\theta, \varphi), \quad (1)$$

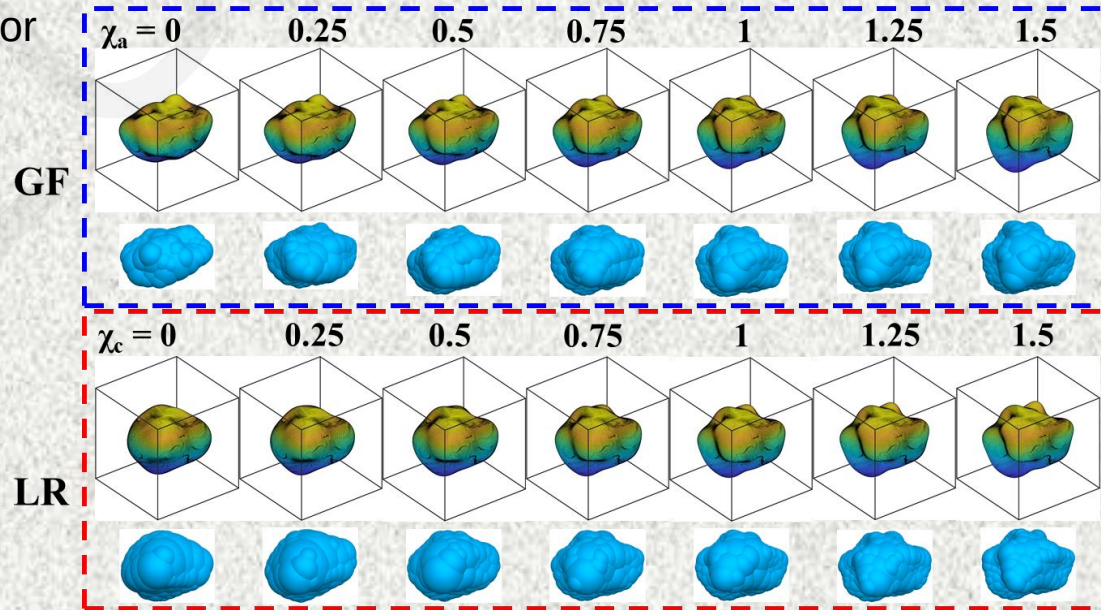
$$Y_n^m(\theta, \varphi) = \sqrt{\frac{(2n+1)(n-m)!}{4\pi(n+m)!}} P_n^m(\cos\theta) e^{-i\omega\varphi}, \quad (2)$$

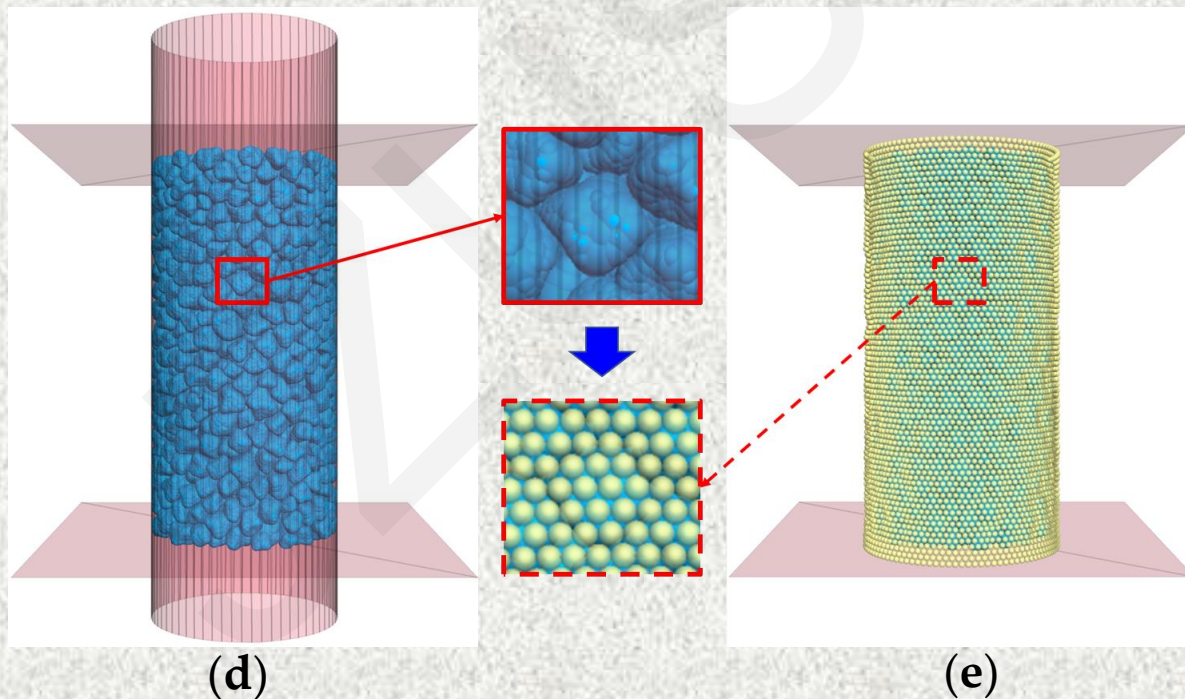
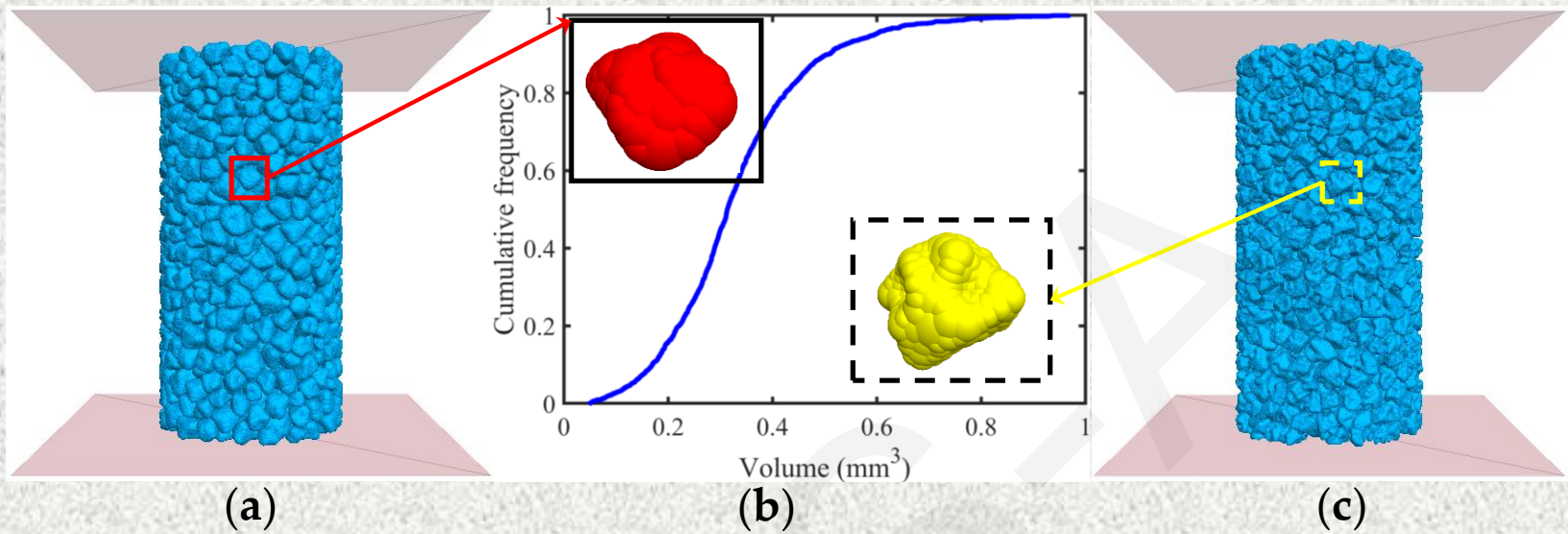
$$P_n^m(x) = \frac{(-1)^m}{2^n n!} (1-x^2)^{m/2} \frac{d^{n+m}}{dx^{n+m}} (x^2-1)^n. \quad (3)$$

Any particle within the given sample can be expressed as:

$$(C_{nj}^m)^T = u_{\mathbf{B}} + \sigma_{\mathbf{B}}^2 y, \quad (5)$$

$u_{\mathbf{B}}$ and $\sigma_{\mathbf{B}}^2$ reflect the average particle surface and the overall variation from the average one for a given sample





DEM modelling technique with morphological gene mutation (a) LR-GM $\chi_c = 0$ (b) real volume distribution (c) LR-GM $\chi_c = 1.5$ (d) rigid servo-wall (e) membrane servo-wall

Concluding remarks:

In this study, the X-ray μ CT, SH-PCA and DEM were incorporated to generate morphological gene-mutated virtual samples at different length scales. The obtained 27 DEM samples were categorized into three groups, and the effects of particle morphology at different length scales on the stress-strain and energy storage/dissipation behaviours are carefully investigated. The main contributions and findings of this study are summarized as follow:

(1) The comparison of the simulation results from RDPS and RLPS indicates that the effects of particle morphology on the stress-strain, volumetric strain and energy storage/dissipation responses are more pronounced for looser samples than for denser samples. Among different length scales, the particle morphological features at LR-level outperforms those at GF-level in dictating the initial stiffness, peak state stress ratio, volumetric strain and frictional energy dissipation behaviours.

(2) The frictional energy dissipation curves are consistent with the corresponding stress ratio curves for both RDPS and RLPS, reflecting the significant role of interparticle friction in dissipating the input boundary work throughout the majority of the shearing process. Besides, the peak incremental frictional energy dissipation is a result of the competition between particle morphology and initial void ratio. It is found that the incremental frictional energy dissipation increases with decreasing roundness while shows an increasing trend with increasing initial void ratio at small initial void ratios but an opposite trend at larger initial void ratios.

香港城市大学 王剑锋 课题组现面向海内外招收博士研究生，团队将提供良好的科研环境，巨大的发展空间和极富竞争力的待遇，欢迎优秀的师弟师妹踊跃报名。

主要研究方向

1. 图像处理：X射线CT对饱和/非饱和颗粒土壤的表征；用于细粒土壤混合物的体积数字图像相关（DIC）方法。
2. 数值模拟：基于X射线CT扫描的大尺度DEM建模；联合断裂网络（DFN）模拟节理岩体；耦合CFD-DEM建模。
3. 机器学习：机器学习在颗粒材料中的应用。

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Dr. Jianfeng Wang received his BSc and MSc degrees from Tongji University, China, in 1999 and 2002, respectively, and his PhD degree from Virginia Tech, USA, in 2006. Dr. Wang is currently an Associate Professor at the Department of Architecture and Civil Engineering at City University of Hong Kong. Dr. Wang is an internationally recognized expert in the field of micromechanical characterization and modelling of granular soils. His research aims to explore the multiscale physics and mechanics underlying the macroscopic soil behaviour using the discrete element method (DEM) simulation and X-ray computed tomography (CT). His works over the past 20 years include the X-ray CT characterization of micro-structures and micro-morphologies of geomaterials, and the DEM modelling and analysis of fundamental soil behaviours of crushable sands and their applications in various kinds of geotechnical engineering problems such as pile foundation, slope stability and retaining structures, etc. Dr. Wang has received a number of prestigious international research awards including VEBLEO fellow 2022, International Association of Advanced Materials (IAAM) award 2022, Geotechnical Research Medal (UK Institution of Civil Engineers) 2011 and Higher Education Institutions Outstanding Research Award – Natural Science Award (the Ministry of Education of China) 2010. Dr. Wang currently serves as an Associate Editor of *Géotechnique*, and Editorial Board Member of *Computers and Geotechnics*, *Journal of Rock Mechanics and Geotechnical Engineering*, and *Soils and Foundations*. So far Dr.