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Whether the Spherical Fines with Rolling Resistance Can Replace the Real-Shaped Fines in Granular Mixtures

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Abstract: Taking particle shapes into consideration is an inevitable trend in simulating geotechnical granular matters. However, the computational costs involving irregular shapes are considerable, especially for granular mixtures with abundant particles. To improve computational efficiency, the shapes of some particles, e.g., fine particles, are simplified, yet the simplification may distort simulation results. This short communication investigates the substitution effect of simplified particles with rolling resistance on real-shaped fine particles. This is achieved by simulating confined compaction tests of mixture models with different fine particles. The contact parameters in models were calibrated and the reliabilities of models were verified by a series of physical tests. The results show that the macroscopic deformation and mesoscopic particle motions in simplified models with rolling resistance are perfectly close to those in the models with real-shaped fines, especially when the size ratio exceeds 8. Due to the different sources of rolling resistance, however, applying rolling resistance inevitably causes a difference in kinetic energy.

Keywords: ***Granular mixture, Discrete element method, Shape simplification, Rolling resistance, Compaction deformation.***

Introduction

Geotechnical granular mixtures, such as sand-gravel mixtures, are common filling materials in many large-scale construction projects like earth dams, road embankments, railway ballasts, and mountainous airports. The mechanical behaviors of granular mixtures are affected by numerous factors, such as fine content, particle size gradation, particle shape, etc.

Although many studies have paid attention to these factors, there are still some deficiencies in the modeling of mixtures, such as concentration of particle sizes, arbitrariness of contact parameters, and over-simplification of particle shapes. Specifically, some studies set *SR* (the size ratio between coarse and fine particles) to be small, resulting in the concentration of sizes and not conforming to the actual gradation (Zhu et al., 2020; Liu et al., 2022). Additionally, contact parameters in DEM models are often casually selected without systematic evidence. Despite recent advances in computing power, the simulation capability is limited if realistic particle shapes are to be considered. Therefore, the shape of fine particles is often simplified into spheres and only the shape of coarse particles is considered in some studies (Chakrabarty et al., 2022; Wu et al.,2023). This simplification is based on the belief that the shape effect of fine particles can be ignored compared with coarse particles. However, this belief has not been demonstrated before. It is not clear how simplification influences the simulation accuracy and what condition is suitable for the simplification.

Many studies (e.g., Wensrich et al., 2012; Phan et al., 2021) indicated that taking rolling resistance into account can reflect the shape effect of spherical particles without additional computational cost. Whether the spherical fine particles with rolling resistance can replace the real-shaped fine particles in mixture models? If feasible, what size ratios are suitable for the replacement? What are the advantages of a mixture model with rolling resistance versus one without rolling resistance? To solve the above series of questions, this study was organized as follows.

Methodology

Three sand-gravel mixture models were established through DEM-based software. Coarse particles in all models were generated based on six gravel templates with aspect ratios of 0.45 to 0.95 (Figure 1a). Fine particles in the first model (denoted as M_{real}) were irregular-shaped, which were generated based on the representative sand template in Figure 1b. Fine particles in the second model (denoted as M_{simp}) and the third model (denoted as M_{roll}) both were simplified into spheres, with the difference that the former does not consider rolling resistance, while the latter does.

The selection of the above particle templates can refer to the previous study. The average size of coarse particles was 20 mm, and that of fine particles was determined by the size ratio, which was varied from 2 to 13 with a step of 1. Given that the deformation is most sensitive to the change in size ratio when fine content is nearly 30%, the mass content of fine particles was set as 30% in all models. Taking *SR* = 5 as an example, three mixtures were shown in Figure 1c.

Results and discussion

The differences in permanent deformation, rebound deformation, particle motion and particle contact between the two models (M_{real} and M_{simp}) under different *SR*s were quantified and analyzed (Figure 2). Under the condition of $SR \geq 10$, the permanent deformation evolution of the two models is basically the same. However, no matter how *SR* changes, M_{simp} cannot reproduce the rebound deformation behavior of M_{real}, and the degree of difference in particle motion between the two models increases with the increasing *SR*. As a mesoscopic manifestation of macroscopic mechanical behavior, the differences in particle motion may be the internal cause of deformation differences. Therefore, to reduce the differences between models, it is necessary to lower the difference degree in particle motions.

The application of rolling resistance to spherical particles can reflect the irregular shape effect, change the particle movement volume, and does not increase additional computational costs. This study added the rolling resistance of fine particles based on the simplified model. When considering rolling resistance, under the condition of $SR \geq 8$, the permanent deformation, springback deformation and particle motion of the simplified model are basically the same as those of the real model. However, due to the influence of the source of rolling resistance, the rotational kinetic energy dissipation of the simplified model when considering rolling resistance is much greater than that of the real model.

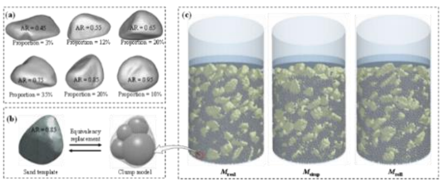

Figure 1, (a) Gravel templates and (b) sand template for generating coarse and fine particles in (c) three models.

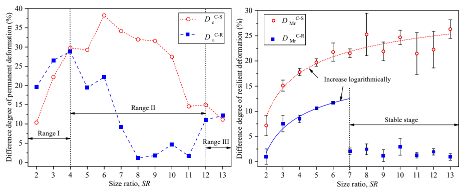

Figure 2, Differences in compaction deformation among three types of models.

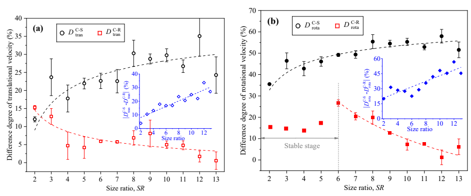

Figure 3, Differences in particle motions among three types of models

Using a sand–gravel mixture with an average coarse particle size of 30 mm and an average fine particle size of 1 mm as an example, the optimized model is expected to be at least hundreds of times more computationally efficient than the mixture model in which the fine particle shape is not simplified (each fine particle represented by a four-sub-sphere clump).

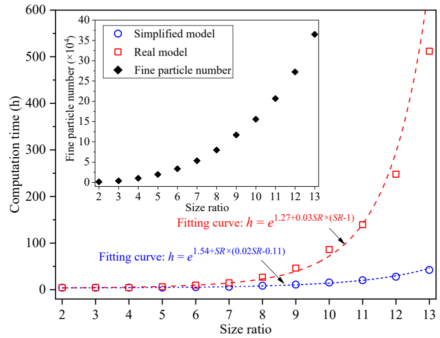

Figure 4, Calculation time of simplified models and real models with different size ratios

For computational efficiency and adequate accuracy, fine particle shapes may be simplified when SR ≥ 8 with suitable rolling resistance, providing a quantitative basis for DEM modeling of soil–rock and sand–gravel mixtures.

References

Chakrabarty, A., Biswas, R., Basu, S., and Nag, S. (2022). Characterisation of binary mixtures of pellets and sinter for DEM simulations. Advanced Powder Technology, 33, 103358. https://doi.org/10.1016/j.apt.2021.11.010

Liu, S., Hu, W., Gong, J., and Nie, Z. (2022). An improved index of mixing degree and its effect on the strength of binary geotechnical mixtures. Granular Matter, 24, 1–19. https://doi.org/10.1007/s10035-021-01168-5

Phan, Q. T., Bui, H. H., Nguyen, G. D., and Bouazza, A. (2021). Effect of particle rolling resistance on drained and undrained behaviour of silty sand. Acta Geotechnica, 16, 2657–2682. https://doi.org/10.1007/s11440-020-01128-y

Wensrich, C. M., and Katterfeld, A. (2012). Rolling friction as a technique for modelling particle shape in DEM. Powder Technology, 217, 409–417. https://doi.org/10.1016/j.powtec.2011.10.057

Wu, M., Zhou, F., and Wang, J. (2023). DEM modeling of mini-triaxial test on soil–rock mixture considering particle shape effect. Computers and Geotechnics, 153, 105110. https://doi.org/10.1016/j.compgeo.2022.105110

Zhu, Y., Nie, Z., Gong, J., Zou, J., Zhao, L., and Li, L. (2020). An analysis of the effects of the size ratio and fines content on the shear behaviors of binary mixtures using DEM. Computers and Geotechnics, 118, 1–16. https://doi.org/10.1016/j.compgeo.2019.103353