EFFECT OF DIAMETER OF STIRRING RODS ON MIXING OF DIFFERENT-SIZED PARTICLES

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1. INTRODUCTION

Soil mechanics, sometimes, deals with the mixing of soil such as in deep mixing of soil and mixing of soil in tunnel boring machines, i.e., EPB-TBM machine. The geometry of mixing apparatus such as size, number, and position of stirring rods play an important role to achieve higher degree of mixing. Moreover, the effect of gap-graded particles being mixed on degree of mixture should also be evaluated.

This study intends to evaluate the effect of diameter of stirring rod on degree of mixture of two different size (i.e., gap-graded) particles mixed by the rotary action of these rods in a cylindrical soil specimen using discrete element method (DEM). The simulations are performed, and degree of mixture is evaluated as proposed in Naqi et al., 2022.

2. METHODOLOGY AND OBSERVATIONS

2.1. Material and Simulated Cases

The DEM simulations were performed using a modified version of LAMMPS (Plimpton 1995) and the model test simulation broadly follows Ali et al. (2020). Spherical particles were used (Young's modulus: 71.6 GPa; Poisson's ratio: 0.23, particle density: 2650 kg/m^3; diameters: 2 mm (uniformly graded) or mixture of 2 and 4 mm (Gap-graded); refer **Table 1**). The simplified Hertz-Mindlin contact model was used with an inter-particle friction coefficient of 0.05. The wall-particle friction was set to zero. **Table 1** shows the four test cases conducted in this study. The particles are mixed by rotation of stirring rods at 100 RPM.

In **Fig. 1**, two colors show that the particles are being mixed from different portions (i.e., left and right) of the specimen. While in Cases 2 and 4 (i.e., gap-graded cases), bigger particles (i.e., 4 mm dia.) were initially provided only in the left part and are mixed subsequently upon rotation of rods. **Fig. 3** compares the mixing conditions of these cases after 25 rotations.

2.2. Effect of rod diameter on degree of mixture

Fig. 2 explains the effect of rod diameter (φ) on mean degree of mixture, $\overline{d_m}$ of soil after 25 rotations. The bigger rods (i.e., φ = 3 cm) are more effective to achieve higher $\overline{d_m}$ for a given rotation number. Moreover, the $\overline{d_m}$ achieved by the same size stirring rods is comparable. The $\overline{d_m}$ of gap-graded particles cases are slightly lower as compared to that of uniformly graded particles. This effect is also illustrated in **Fig. 3**, where yellow color is dominant in bigger rods cases showing higher degree of mixing while smaller rods exhibit blue color indicating lower degree of mixing.

Table 1. Test cases and specifications.

Case	Dia. of particles	Dia. of stirring rod, (φ)	No. of particles
	mm	cm	
1	2	3	165,919
2	2&4	3	107,484
3	2	1	169,398
4	2&4	1	109,809

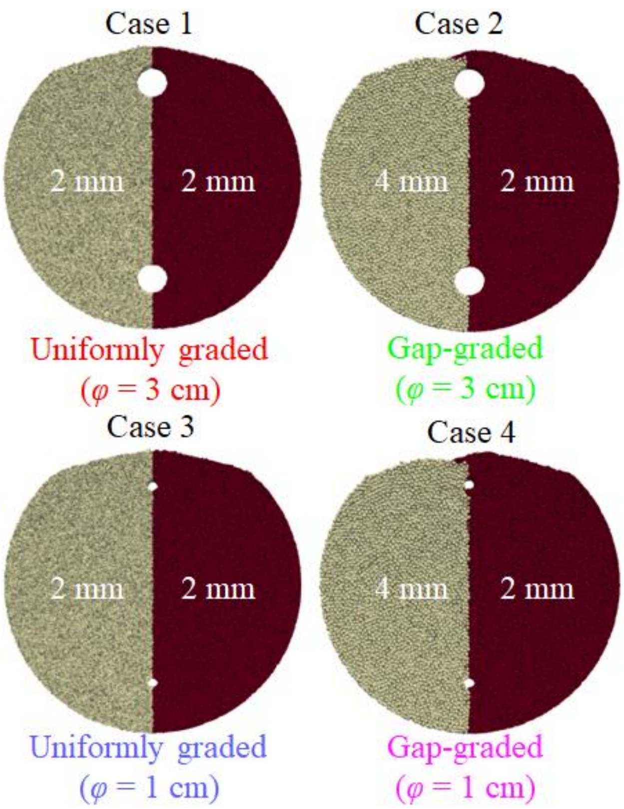

Fig. 1 Initial configuration of all cases.

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3. DISCUSSION

The $\overline{d_m}$ is calculated as the mean value of degree of mixing, *dm* (Naqi et al., 2022) defined below:

$$d_m = \left(1 - \frac{|n_1 - n_2|}{n_1 + n_2}\right) * 100 \qquad \text{(Eq. 1)}$$

Fig. 2 demonstrates bigger rods (i.e., φ = 3 cm) achieve higher $\overline{d_m}$ while smaller rods (i.e., φ = 1 cm) exhibits lower $\overline{d_m}$. The reason can probably be due to the less influenced zone generated by the motion of smaller rods during rotation. Such impact can lead to the generation of locally concentrated zones of unmixed particles. In **Fig. 3**, it can be seen as locally concentrated blue zones which demonstrate that the soil is not well-mixed in those regions while the opposite can be said about the yellow zones. Such locally concentrated blue zones are more dominant in Cases 3 and 4 having smaller rods (i.e., φ = 1 cm) explaining their lower influenced zone during mixing. The locally concentrated blue zone is also present in Case 2 which may explain lower degree of mixture as compared to Case 1.

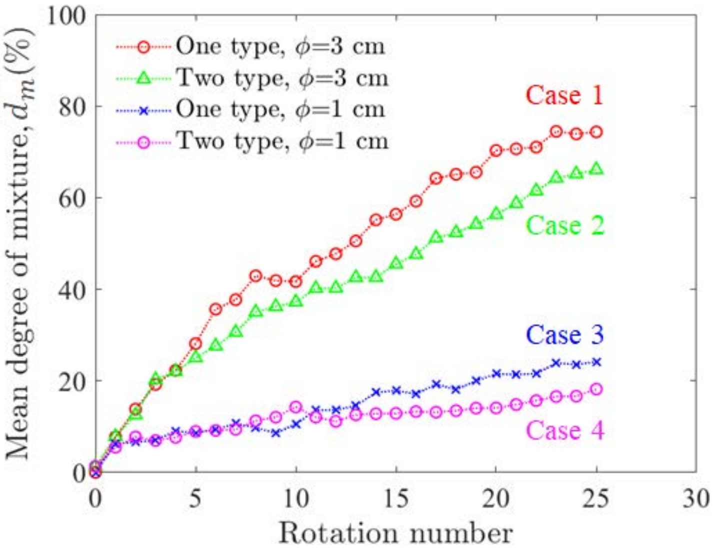

Fig. 2 Mean degree of mixing of different diameter stirring rods for uniformly and gap-graded particles.

4. CONCLUSION

Mean degree of mixture is more sensitive to the size of stirring rods rather than the size of the particles being mixed, probably due to the less influenced zone generated by the motion of smaller rods during rotation. Moreover, **Fig. 2** illustrates that as the number of rotations increase up to 25, the mean degree of mixture also increases. The mean degree of mixture achieved by the same size stirring rods is similar in presented cases with $\overline{d_m}$ of gap-graded particles cases slightly on the lower side as compared to that of uniformly graded particles.

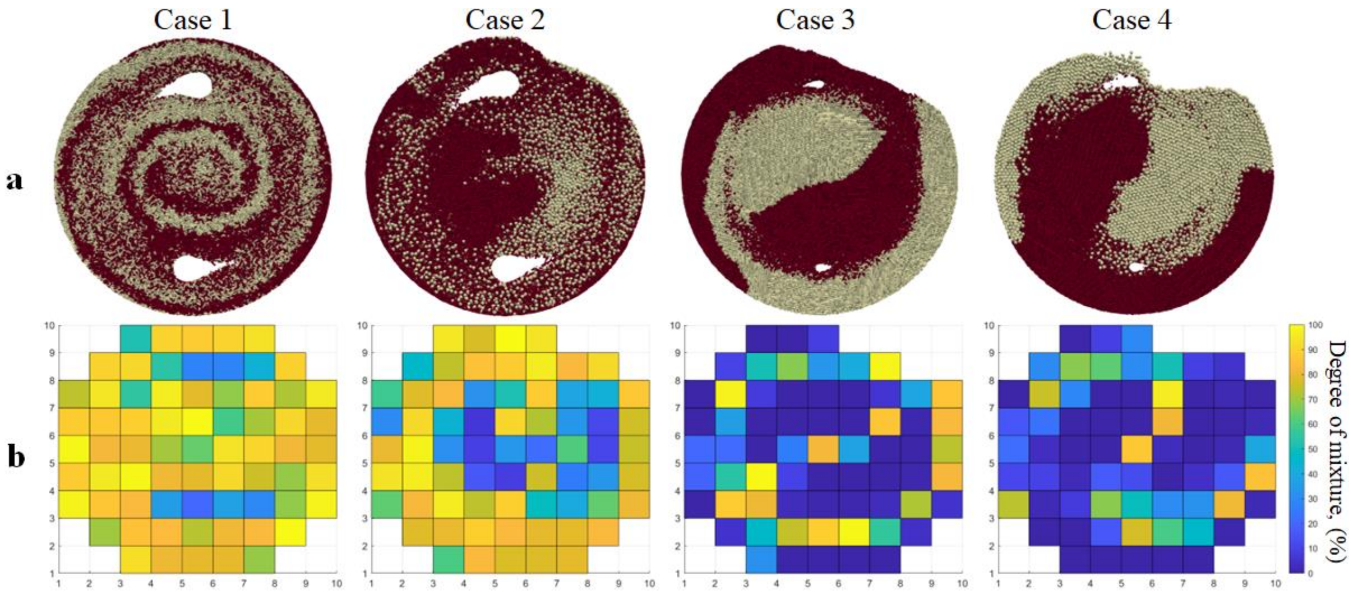

Fig. 3: a) Mixing condition **b)** Comparison of degree of mixture for all cases after 25 rotations.

REFERENCES

Naqi, A., Otsubo, M., Kuwano, R., Nagatani, H., Kawano, K., Liu, W. (2022). "Evaluating degree of mixture of soil particles using DEM analysis". *The 77th JSCE Annual Meeting Proceedings, CS2-42*.

Plimpton, S., (1995). "Fast parallel algorithms for short-range molecular dynamics". *J. Comput. Phys. 117 (1), 1–19. https://doi.org/10.1006/jcph.1995.1039.*

Ali, U., Otsubo, M. Ebizuka, H. & Kuwano, R. (2020). "Particle-scale insight into soil arching under trapdoor condition". *Soils and Foundations, 60(5), 1171-1188.*