Packing effect of particles on mechanical behaviours under biaxial compression by DEM

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INTRODUCTION

Developing countries often lack reliable and safe transportation infrastructure, especially in remote rural areas where resources are limited. This is due to a shortage of skilled workers, frequent maintenance needs, and high costs. To address this issue, a Japanese technology called Donou is being promoted worldwide (Fukubayashi and Kimura, 2014). Donou uses recycled rice bags or similar materials to increase the bearing capacity of weak soil in roadbeds. The bags are filled with soil and manually compacted, resulting in higher bearing capacity than soil alone. While previous research (e.g. Matsuoka and Liu, 2003) has explained the mechanism, the specific behaviours of soil materials inside the bag and the bag itself have not been fully investigated. This study aims to investigate how soil bags enhance soil strength properties by conducting DEM simulations of biaxial loading with and without a bag and examining particle kinematics.

METHODOLOGY AND SIMULATION CONDITIONS

The DEM simulations were conducted in PFC2D (Particle Flow Code 2D by Itasca). Bags and geomembranes in DEM have been modelled by previous researchers (Hongyang et al., 2016; Liu et al., 2018) as a chain of bonded circles.

The model setup is based on Ali et al., 2023, validated DEM model without Donou bag. The specimen is 35 cm x 35 cm in size, the packing is done with circular particles of 2 diameter sizes, 6mm and 10mm, in a 3:2 mass ratio, respectively. The total number of generated particles is 2662, which represents the aluminium rods applied in the biaxial compression test. For the model including a bag element, an additional 364 particles of 1 mm diameter size are generated, representing a bag made of, for example, Japanese paper. Since rigid boundaries are applied in the simulation the bag is placed at the central part of the specimen for maximum effect on the shear band formation, this is because for rigid boundaries a shear localization at the diagonals can be observed (Ali et al., 2023). 2 contact models are applied: "Hertz model" (no tension) for the aluminium rod particles and wall elements, and a "Linear Parallel Bond model" at the bag particles to model tension.

There are a total of 4 simulation cases, divided as: without bag and with a bag; and both conducted at 39.2 kPa and 58.8 kPa of confining pressure. The simulation is conducted in 2 steps: 1st) isotropic compression ($\sigma_1 = \sigma_3$) and 2nd) biaxial compression ($\sigma_1 > \sigma_3$) with displacement control at a rate of 0.5 mm/s. During these steps, the bottom wall is fixed while the others are free to move perpendicularly, wall rotation is not allowed.

Table 1. Model parameters.

	Particles	Wall	Bag
Shear modulus, G [kPa]		2.6×10^7	
Poisson's ratio, v	0.3		0.4
Friction coefficient	0.2		0.4
Damping coefficient	0.2		0.1
Tensile strength, σ_c [kPa]	-		1.4×10^3
Normal pbond stiffness, *pb_kn*	-		1.0×10^7
Shear pbond stiffness, *pb_ks*	-		1.4×10^2
Pbond cohesion	-		1.4×10^3
Density [kg/m^3]	2.71×10^3	-	0.01×10^3
Initial porosity of the model		0.174	

Table 2. Simulation Cases

Cases	Bag	Displacement Rate	Confining Pressure σ_3
Case 1	×	0.5 mm/s	39.2 kPa
Case 2	○		
Case 3	×		58.8 kPa
Case 4	○		

RESULTS AND DISCUSSIONS

Figure 1 shows average vertical stress-axial strain relationship and volumetric strain-axial strain relationship. **Figure 2** shows tension force-axial strain relationship for pre-selected bag particles. The average vertical stress corresponds to the stress of the wall element at top side of each specimen. The stress strain curves show that the cases with bag (case 2 and 4) exhibit higher vertical stress than the cases without bag at the initial stages of loading. At around 3% axial strain both cases, with bag and without bag, exhibit similar vertical stress and this might be because this point is where initial breakage of the bond between bag particles occurs at the bottom part of the bag. As shearing continues, the broken bag still provides

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some reinforcement and higher vertical stress can be seen again for the cases with bag at around 6% axial strain, after that more bond breakages occur and from then the curves follow a similar path. **Figure 3** shows particle rotation at 2.5% and 5% axial strain. At 2.5% we see higher rotation on the bottom corners and on the left side wall for the cases without bag. While with the bag the rotations are less and seem to concentrate on the corners of the bag, and there's also a band developed at the lower right corner that's starting from the bag.

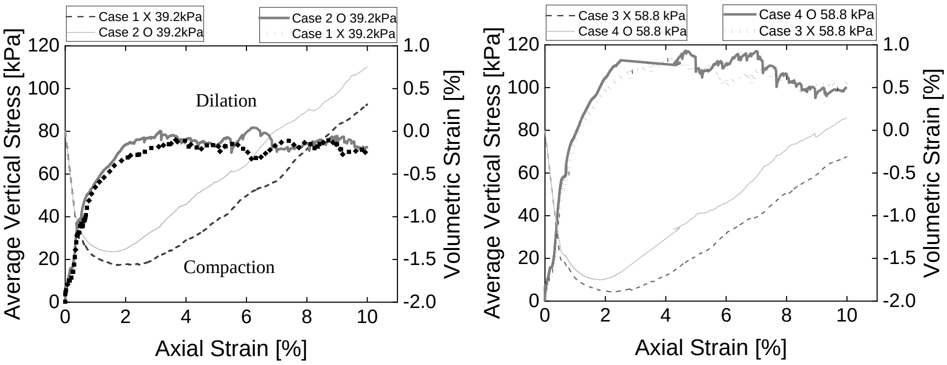


Fig. 1 – Stress, and volumetric strain - axial strain relationship.

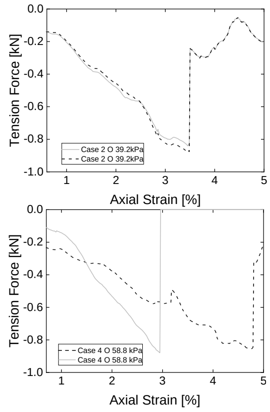
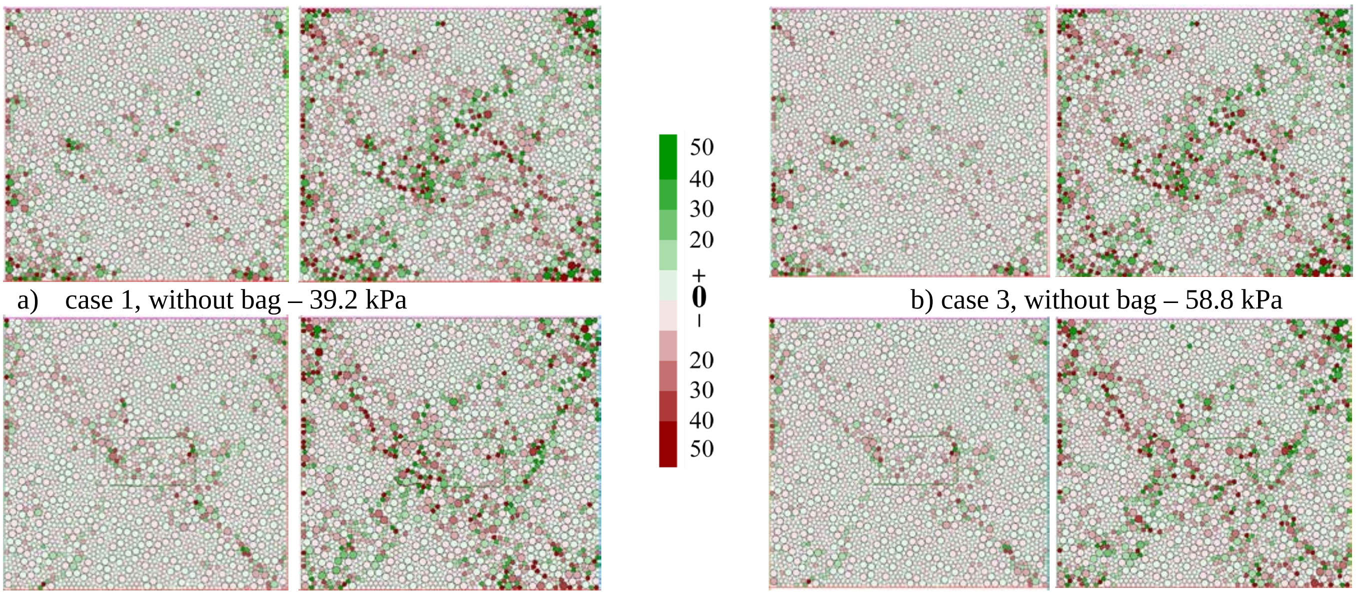


Fig. 2 – Tension force.



a) case 1, without bag – 39.2 kPa

b) case 3, without bag – 58.8 kPa

c) case 2, with bag – 39.2 kPa

d) case 4, with bag – 58.8 kPa

Fig. 3– Particle rotation at 2.5% and at 5% axial strain.

CONCLUSIONS

Adding particles inside a bag can clearly affect the mechanical behaviour of soil. With DEM it was possible to model the bag material as a chain of bonded circles and observe an increase in initial strength of the specimen. A subsequent cycle of loss and gain of strength was observed and it is believed to be due to the breakage of bond between bag particles, which initially tends to occur at the bottom part of the bag. There seems to be an effect on the shear band formation, the particle rotation is limited inside the bag, the shear band tends to happen at the edges of the bag and, more narrow, straight, and defined shear paths can also be observed. The effect on shear band needs to be further studied under a no breakage condition for the bag.

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