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Coupled DEM-FDM centrifuge model of piles in soft rocks

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Background

- Continuum based numerical methods such as the finite difference method (FDM) are computationally efficient but usually unable to deal with large deformations and computational efficiency in boundary value problems respectively.
- The discrete element method (DEM) is particularly well suited to model large deformation problems, but impractical to use to model large scale boundary value problems (BVPs) as computational costs are very high
- Imposing the initial density and stress distribution using DEM through traditional numerical “pluviation” methods is extremely time-consuming (Fig. 1).
- Foundation design in soft rocks like chalk is very conservative because of the complex behaviour of the material and the limited understanding of its interaction with rigid foundation.

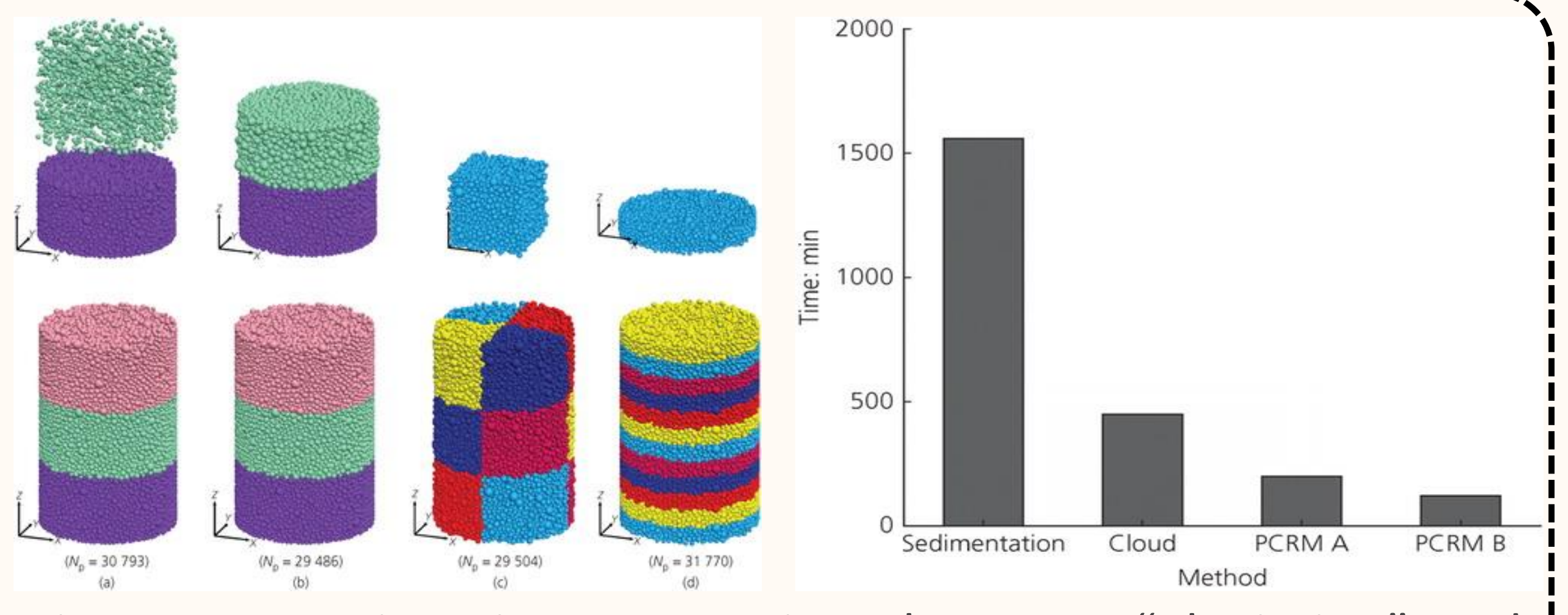

Fig.1 Generation time comparison between “pluviation” and other methods proposed by Ciantia et al. (2018).

Objectives

- To create a virtual centrifugal environment based on coupled FDM-DEM to exploit the advantages of both numerical methods.
- To develop a fast-generation method for cemented materials considering the stress distribution of self-weight within a DM-DEM coupled environment.
- To investigate the micromechanics of large deformation pile penetration in soft rocks under different gravity levels.

A fast generation technique of FDM-DEM coupled models

Create a representative element volume (REV) of bonded particles and confine it to a prescribed stress and porosity using periodic boundaries. Replicate this REV in *x*, *y* and *z* directions to fill the desired volume. Generate the FDM elements and couple them with the DEM using coupling walls. Scale the contact forces of the DEM model to be consistent with the gravitational field imposed.

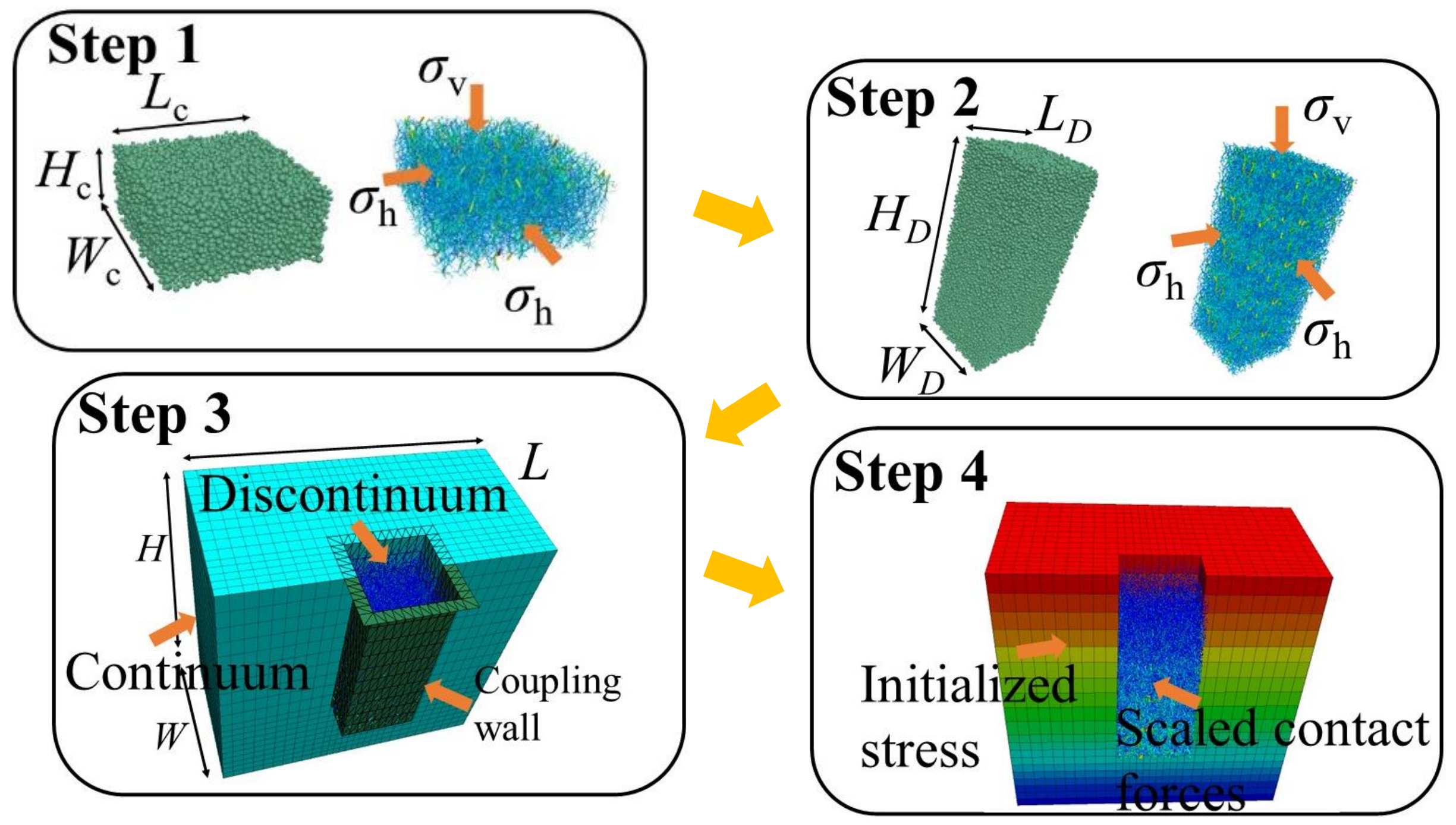

Fig.2 Flow chart of the fast-generation technique.

Fig.3 compares numerical and theoretical stresses (vertical and horizontal) at the end of the generation phase. The good agreement suggests that the generation technique proposed is successful. As for Ciantia et al. (2018) the computational costs are greatly reduced. To decrease the number of discrete elements in the model, decreasing further the computational load, particle upscaling (Coetzee, 2019) can also be used. Fig.4 shows that if used appropriately scaling does not change the predicted macroscopic response of the material.

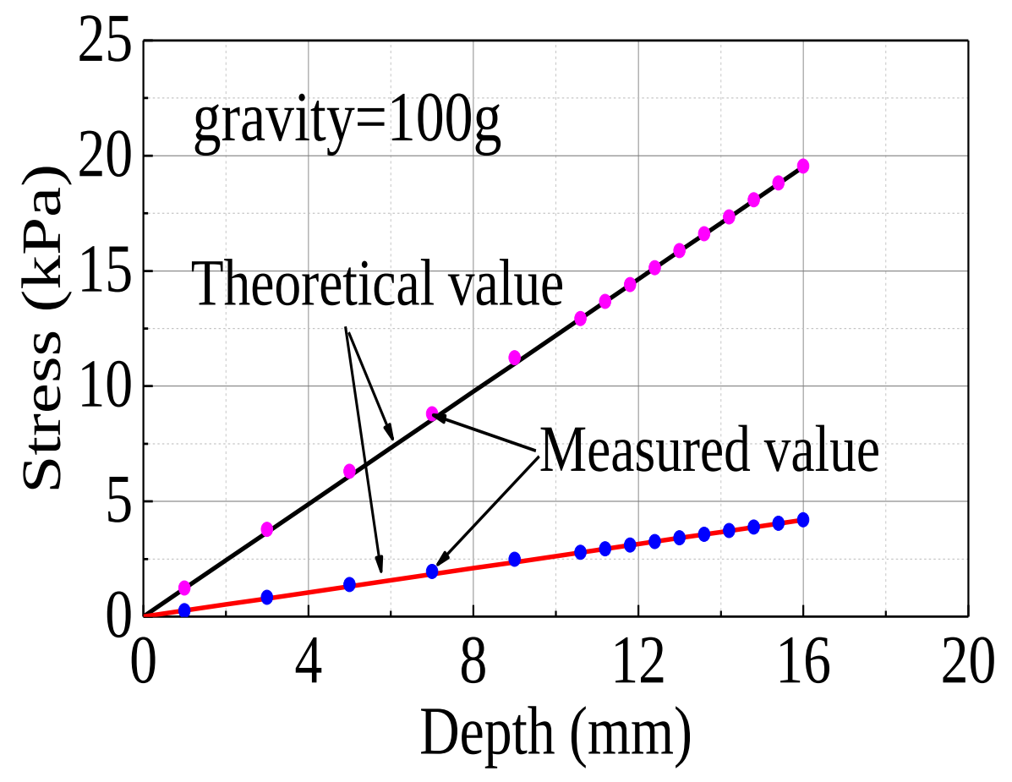

Fig.3 Vertical and horizontal stress distribution of the FDM-DEM coupled model.

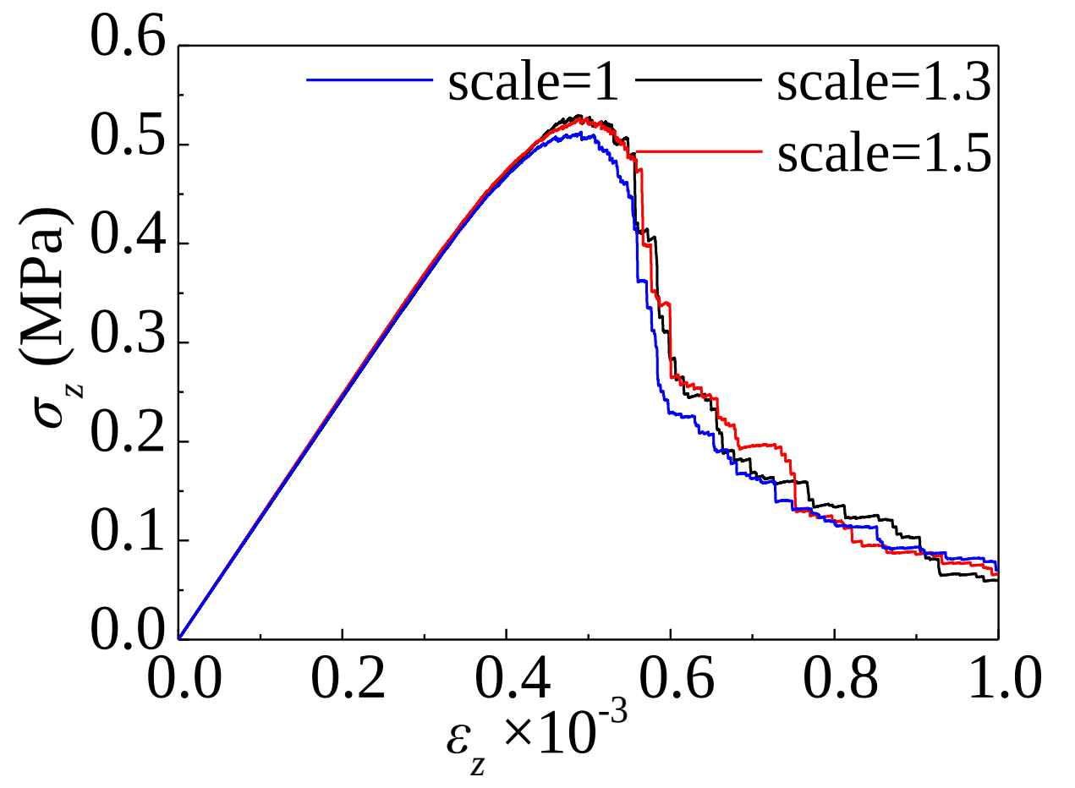

Fig.4 Axial stress vs strain for uniaxial compression test of DEM models of various particle scaling.

Pile penetration in soft rocks

A model pile penetration in centrifuge is simulated using the FDM-DEM coupled approach presented. To simulate a soft rock behaviour, the soft bond model (SBM) is used to govern contact interaction of the DEM portion of the model. Using the contact model parameter in Table 2 a UCS of 500 kPa is obtained.

Table 2 Contact parameters of soft bonded model (SBM).

Parameters	Value
Effective modulus	2.8GPa
Normal to shear stiffness ratio	2.4
Cohesion	0.45MPa
Tensile strength	0.45MPa
Friction angle	32°
Bond softening factor	100
Bond softening strength factor	0.05

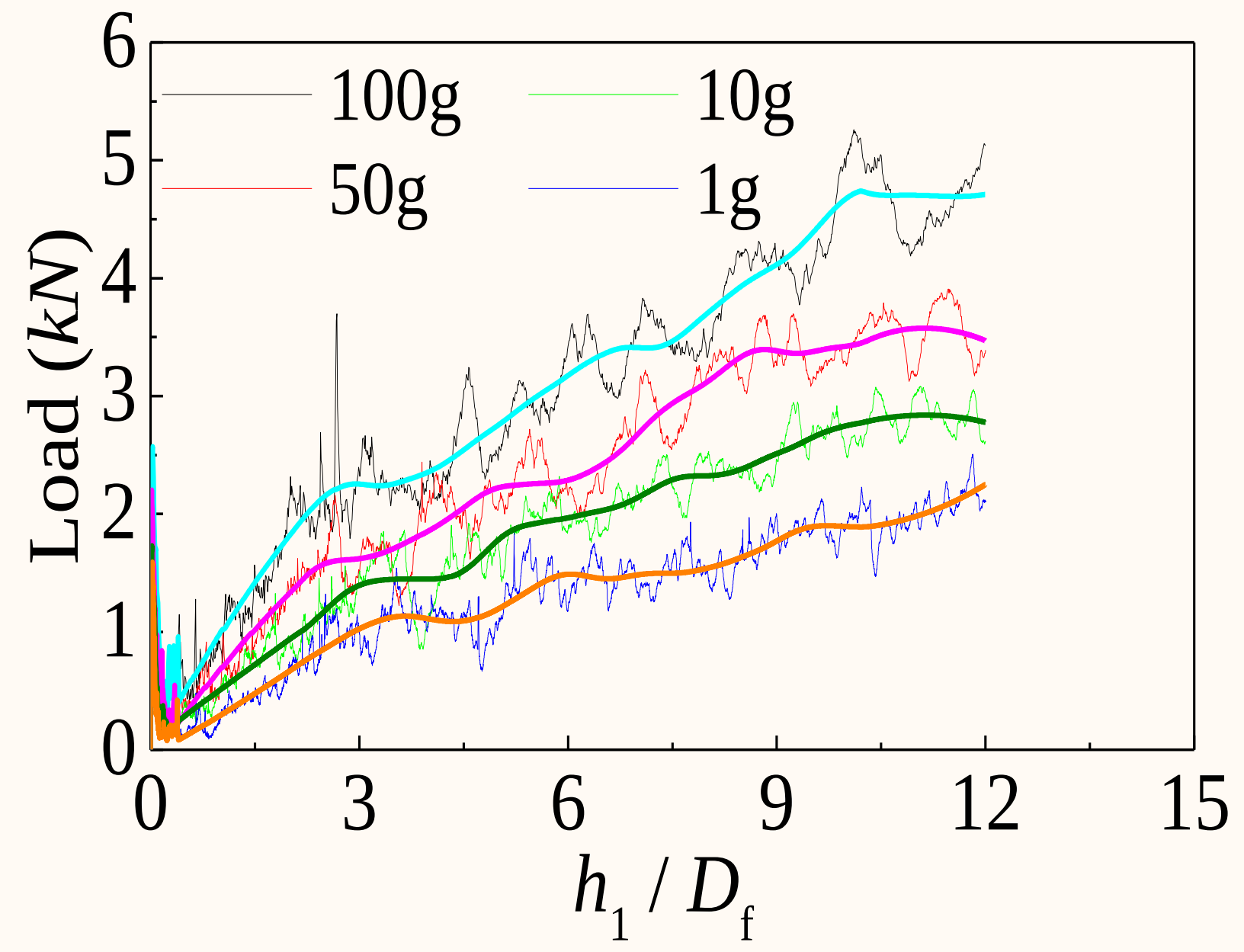

Fig.5 Load – displacement curves.

The penetration curves of model piles installed at different g levels are reported in Fig.5. Looking at the initial stages of the curves (Fig.6), after an initial elastic response, a collapse of the porous rock below the pile tip causes a softening like behaviour. h_1 and D_f are the penetration depth and foundation diameter, respectively.

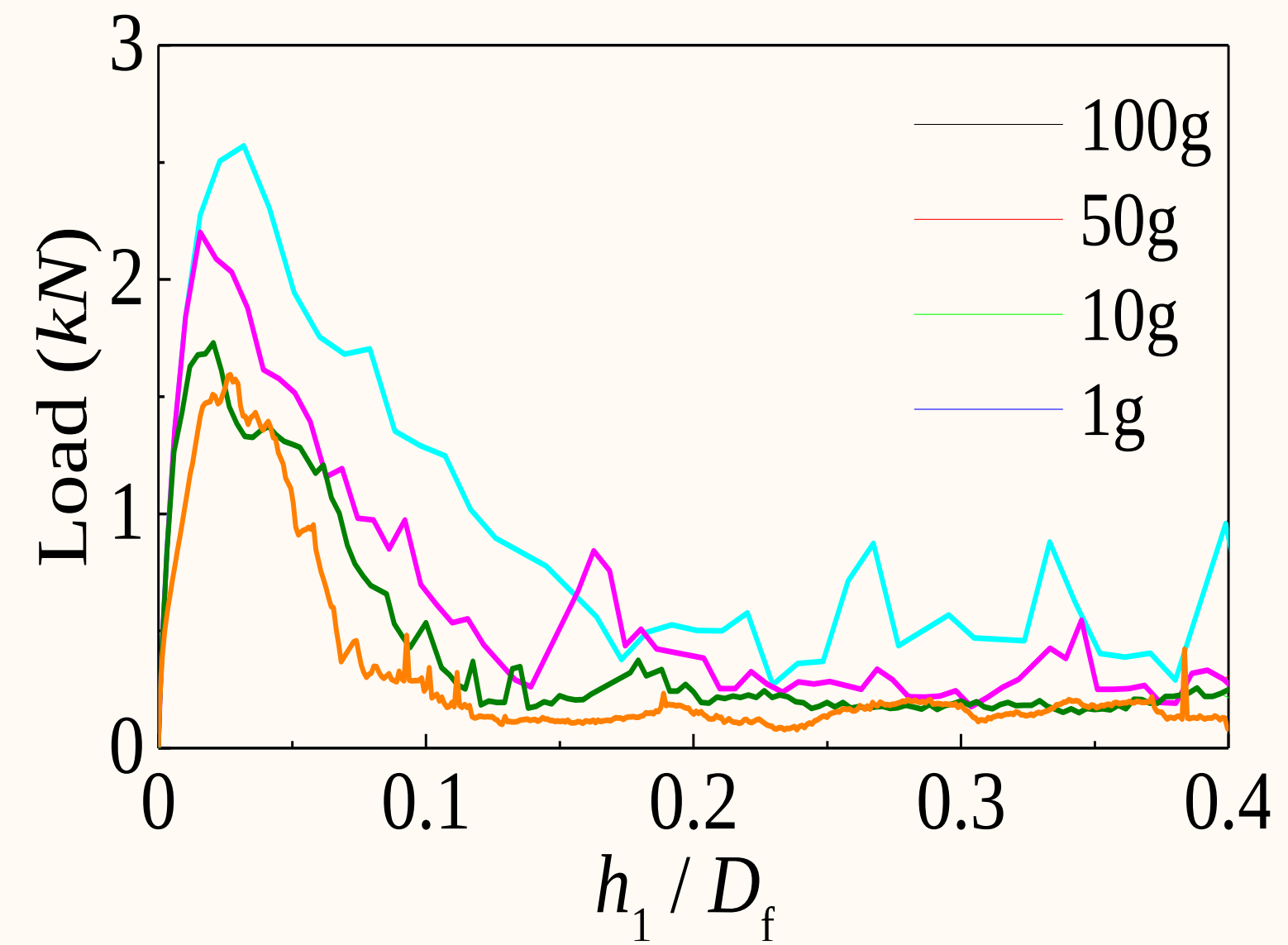

Fig.6 Load – displacement curves in the initial stage.

Conclusions

- Model pile penetration in virtual centrifuge was simulated using a FDM-DEM coupled model.
- A fast sample generation technique was developed to allow the creation of the model in reasonable time
- The combination of fast generation technique, domain reduction through FDM coupling and particle upscaling method significantly reduces the computational burden inherent to large scale DEM models.
- The contact model used to replicate the soft rock was found to be inadequate as the collapse in the post-peak stage of pile penetration was deemed not very realistic. In fact, the SBM does not consider bond failing in compression, assumes a softening behaviour only for bonds breaking in tension while the bonds yielding in shear have an abrupt brittle failure (Fig.7).
- The particle scaling effects and other parameters like penetration velocity can be investigated numerically in advance, to assist the design of centrifuge model tests.

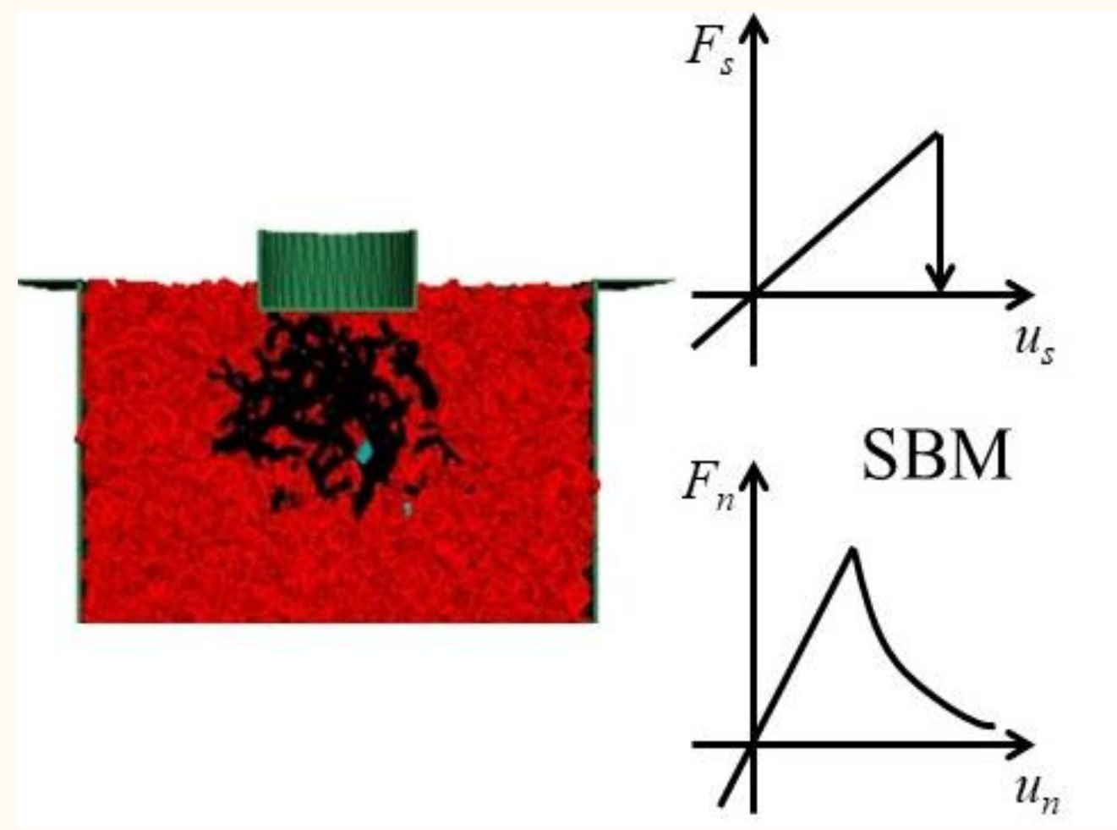

Fig.7 Bonds state during penetration. In black bonds that fail in shear, in blue the ones that fail in tension. In red the intact bonds.

References

- Ciantia, M. O. et al. (2018) ‘Numerical techniques for fast generation of large discrete-element models’, Proceedings of the Institution of Civil Engineers: Engineering and Computational Mechanics, 171(4), 147–161.
- Coetzee, C. J. (2019). Particle upscaling: Calibration and validation of the discrete element method. Powder technology, 344, 487-503.