# THE ROLE OF WATER ON THE PRESSURE DIP IN SAND PILES

Tong Shan* & Jidong Zhao*a)
*Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology, Clearwater Bay, Kowloon, Hong Kong

*Summary* Pressure dip under the apex of conical sand pile has been an interesting phenomenon interesting to researchers from many branches of engineering and science. How the presence of water affects the formation of sand pile and the pressure dip characteristics, however, remains less explored. This paper presents a micromechanical study of the influence of water on the phenomenon by using a coupled Discrete Element Method (DEM) and Computational Fluid Dynamics (CFD) approach. Quantitative numerical results show the pressure dip appears to be moderately reduced in the case of water presence, as compared to the dry case (DEM simulation only). Characteristics of force chain network and local void ratio in the former case appears to be less heterogeneous than the latter case. The study paves the way for future work on debris flow and soil erosion research where soil-water interaction is important.

## INTRODUCTION

Experimental tests on granular media reveal a local minimum in the normal stress profile under the apex of conical sand pile. This phenomenon is commonly referred to as the pressure dip in sand pile. It is recognized that whether or not a pressure dip occurs depends on the construction methods. For example, appreciable pressure dip is observed in a sand pile prepared by hopper flow, while using raining sieve will produce a sand pile with a central peak normal stress. Various theories have been developed to explain the underlying mechanisms of pressure dip (see, e.g., [1-2]). Numerical simulations by Discrete Element Method have also been attempted. There, however, have been very scarce studies on the influence of water to the formation of sand pile and the characteristics of pressure dip. Indeed, the problem has a far wider engineering background that is closely related to such issues as dredging and land reclamation, mining production handling, soil erosion and debris flow wherein the interaction between soil and water is important. The present work attempts to investigate the pressure dip problem in the presence of water by a numerical micromechanical approach as entailed below.

## METHODOLOGY AND BENCHMARKING

A coupled Computational Fluid Dynamics and Discrete Element Method (CFD-DEM) will be employed for the study. Te motion and contact of soil particles in the Discrete Element Method (DEM) are governed by the Newton's laws of motion in conjunction with the Hertzian contact law and Coulomb's friction law. The flow of continuum fluid is assumed to be described by the locally averaged Navier–Stokes equations in the Computational Fluid Dynamics (CFD) method. The interactions between the fluid phase and the soil particles are modelled by exchange of drag force and buoyancy force added to the governing equation of each phase. Uniform particles have been used in the DEM.
The CFD-DEM code has been verified and benchmarked by two simple problems with analytical solutions available. The first one is the single particle settling from the air into the water, and the other the one-dimensional consolidation problem. The settling velocity of the particle as shown in Fig. 1 (the red-solid curve) compares well with the analytical solution summarised in [3] (the flow is assumed to be a Stokes flow). While for the classical 1-dimenstional consolidation, the dissipation of excess pore water pressure predicted by our CFD-DEM method is also in reasonable accordance with the Terzaghi's analytical solution, as shown in Fig.2. Benchmarking of the numerical code with both problems appears to be good.

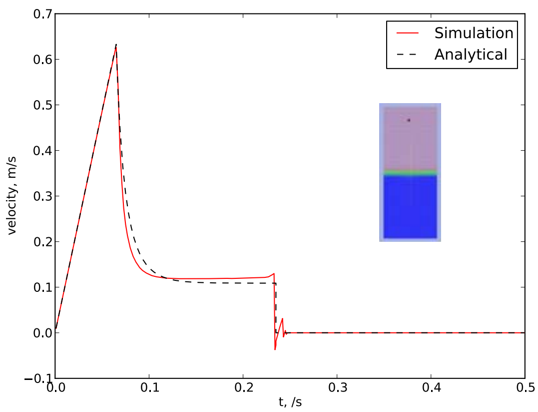


**Figure 1.** Comparison of the CFD-DEM prediction and analytical solution for the settling velocity of particle into water

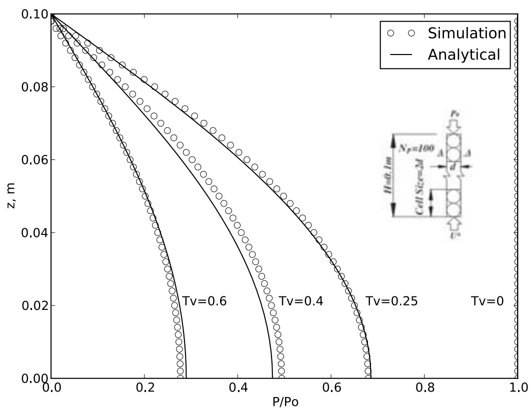


**Figure 2.** Benchmarking of the CFD-DEM simulation of dissipation of excess pore water for the 1D consolidation problem with Terzaghi's analytical solution

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a) Corresponding author. Email: jzhao@ust.hk. This work was supported by *Research Grants Council of Hong Kong* (***623609***).

## SIMULATIONS OF CONICAL SAND PILE FORMATION: RESUTLS AND DISCUSSION

Conical sand piles are formed by pouring particles from a hopper through a container filled with water onto a circular flat panel (see Fig. 3). Tests have also been conducted by forming piles without considering water (dry case, using the DEM only). While particle shape has been found having impact on the characteristics of pressure dip in a sand pile [4-5], it is considered (approximately) by introducing a rolling resistance model into the DEM code where an important parameter is the coefficient of the rolling resistance $\mu_r$. $\mu_r = 0$ and 0.1 have been selected to represent sphere and irregular particles, respectively. The obtained results are presented in Figs. 4-5. As can be seen from Fig. 4, the pressure dip is slightly reduced in the presence of water, while higher rolling resistance appears to lead to greater pressure dip. Shown in Fig. 5 is the local void ratio distribution in the sand pile which can be described by a Gamma distribution. The local void ratio is obtained by constructing the Voronoi tessellation cells. Apparently, consideration of irregular particle shape leads to a sand pile looser than otherwise. The presence of water, however, does not affect significantly the overall distribution of local void ratio as compared to the dry case.

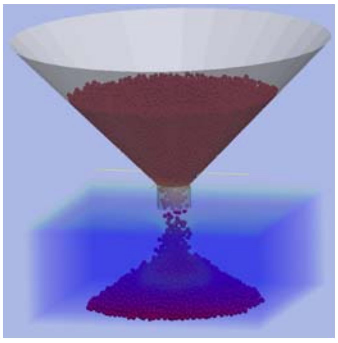

**Figure 3.** Illustration of forming a sand pile in water

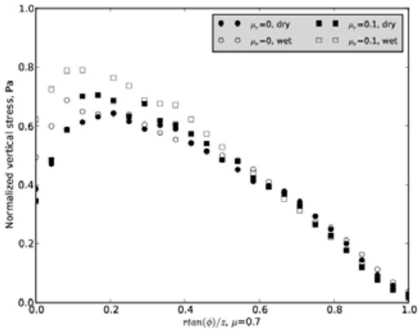


**Figure 4.** Comparison of vertical pressure profile at the base of sand pile for different cases.

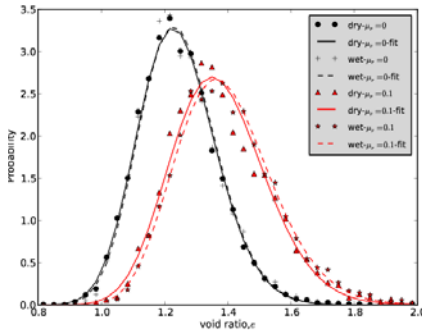


**Figure 5.** Comparison of the local void ratio distribution for different cases.

More indicative information on the pressure dip can be revealed by visualization of the internal structure in the sand pile. In doing so, the contact force network and local void ratio contour in a vertical cross section across the axis of the sand pile have been visualized and illustrated in Fig. 6 and Fig. 7, respectively. In the dry case, appreciable inclined orientated strong force chains are observed to form an arch at the centre part (upper figure in Fig. 6), while in the wet case the force chains are more vertically oriented (bottom figure in Fig. 6) which prevents the formation of an strong arch to shield the bottom centre particles. Evidently the latter case will lead to less pressure dip. Observations from the local void ratio contour in Fig. 7 further confirm the finding. The presence of water appears to lead to more or less more homogeneous distribution of void in the wet case than the dry case. Two obvious denser spots are found at some distance away from the centre along the base which may be the "toes of arch poles" that cause pressure dip.

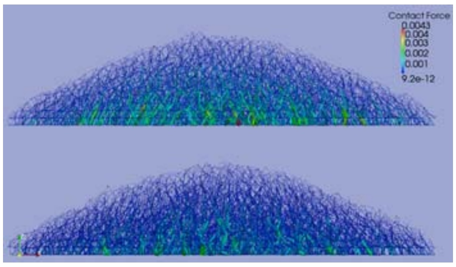


**Figure 6.** Comparison of contact force network in the sand pile for the dry case (upper) and the wet case (lower) ($\mu_r = 0$).

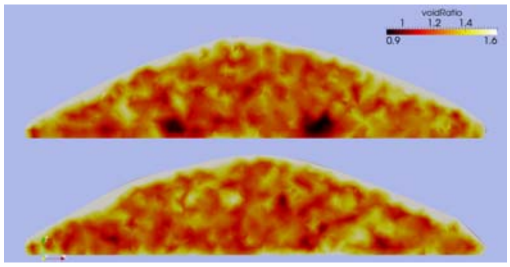


**Figure 7.** Comparison of the local void ratio contour for the dry case (upper) and the wet case (lower) ($\mu_r = 0$).

## CONCLUSION

A coupled CFD-DEM study has shown that the presence of water can reduce the pressure dip in a conical sand pile, and make the contact force network and local void ratio more homogeneous than the dry case. Consideration of irregular particle shape may have more significant impact on the characteristics of pressure dip in the sand pile.

## References

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