DISCRETE ELEMENT MODELLING OF MOISTURE-LIMITED AEOLIAN SEDIMENT TRANSPORT

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INTRODUCTION

The presence of surface moisture on sandy beaches has long been acknowledged as a complicating factor in the process of aeolian sediment transport, reported by Belly (1964), Neuman and Scott (1998) and Davidson-Arnott et al. (2008). Many studies have been conducted on this subject, each offering a wind initiation threshold formula that incorporates the moisture effect differently, found in Belly (1964), Chepil (1956), Fécan et al. (1998), Wang (2006) and Haehnel et al. (2014). However, the impact dynamics in the transport process, regarded as the dominant mechanism for particle entrainment, was neglected in the derivation phase of these existing formulations. Therefore, to gain some insights into the physical mechanism where moisture plays a role in the aeolian process, as well as its impact on various other transport characteristics, this study employs a numerical model on the grain scale.

METHODOLOGY

To study how moisture-induced cohesion affects the grain behavior, we use Discrete Element Method (DEM). To model the moisture, this method incorporates a liquid model that combines the liquid migration law established by Mani et al. (2012), along with a capillary force calculation rule described by Willett et al. (2000), and a viscous lubrication force to simulate the dynamic behavior of the moisture between particles. The influence of wind is taken into account by using a one-dimensional flow model, similar to the one in Campmans and Wijnberg (2022). This flow model interacts with the DEM model in two directions, allowing for the exchange of momentum between the solid phase and the air phase. This entire transport model, illustrated in Figure 1 and Figure 2, is implemented in the open-source software package MercuryDPM (described by Weinhart et al. (2020)). To include the evaporation process on the saltating particles, we assume that the particles lose the liquid volume immediately as soon as they enter the saltation layer.

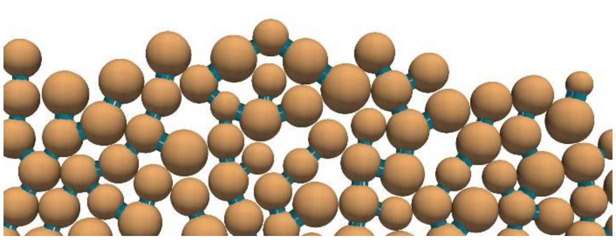

Figure 1 – A 2D particle bed with liquid bridges in between (liquid content=1%, D_{50}=0.25mm)

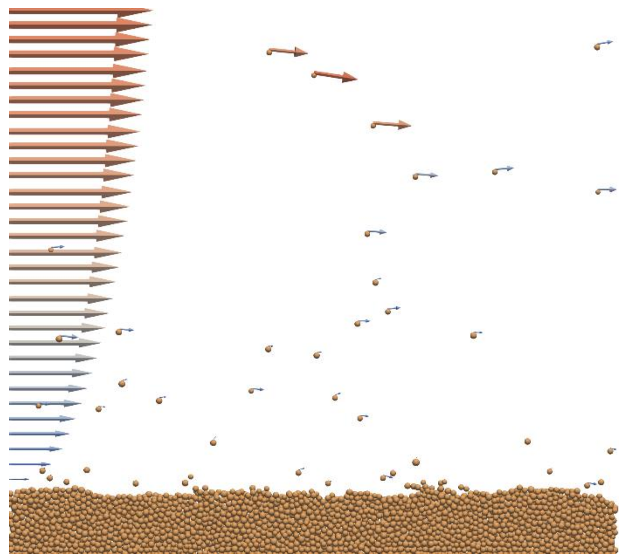

Figure 2 – Sand particles being transported by wind from a 3D bed (the arrows indicate the velocities of both phases, the Shields number=0.5, liquid content=0, D_{50}=0.25mm)

RESULTS

Through a particle-wall collision test, we first demonstrated the versatility of the liquid model in replicating the collision dynamics in wet conditions. By performing the CFD-DEM simulations, we have validated the steady-state transport rate obtained from this numerical model in the dry limit. When involving the moisture, the transport always ends up with a static bed with a new cohesive structure. However, by incorporating the evaporation process on the saltating particles, we can ultimately achieve a dynamic equilibrium. Moreover, the erodibility of a moist bed is lower than that of a dry bed and decreases as the bed's liquid content increases.

CONCLUSIONS

Moisture makes the aeolian sediment transport fundamentally different from that in dry conditions by restricting the particle entrainment through the liquid-induced cohesion. Additionally, the evaporation process plays an important role in sustaining the transport.

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