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AGRICULTURAL APPLICATIONS OF THE DISCRETE ELEMENT METHOD

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Abstract: The global population has been steadily increasing, putting pressure on available resources, including agricultural land. The decrease of available agricultural land has made it difficult to sustainably produce enough food to feed the growing population. Global warming and water issues have also made it challenging to grow crops, with changing weather patterns and water scarcity affecting yields. To address these challenges, there is a need to modernize agricultural technologies. One of the available possibilities is the improvement of post-harvest technologies. By gaining more knowledge on the mechanical behavior of particulate materials using discrete element modeling, it may be possible to optimize post-harvest technologies for food processing and storage. This could lead to improvements in the quality and safety of food products while reducing waste and increasing efficiency. This paper reviews the key literature concerned with the agricultural applications and DEM parameters calibration of agricultural particles, which generally are corn, rice, wheat, soybean, sunflower seed and soil particles.

Keywords: agricultural particles, discrete element method, calibration

1. Introduction

The discrete element method (DEM) proposed by Cundall and Strack in 1979 [1] is a numerical analysis method for describing the motion and interactions of particles based on Newton's second law [2]. With the development of hardware and software, the computational power of DEM simulation has increased significantly, and the application of DEM in modeling the mechanical behavior of agricultural particulate materials is becoming more and more widespread. Finding the micromechanical properties of these (the so-called calibration procedure) is a time- and computational resource-intensive process. The calibration of DEM is particularly important.

Our goal is to demonstrate the applicability of the DEM method in agricultural engineering-related problems and to introduce the reader to the calibration problem. Through advancements in agricultural technology, it may be possible to increase food production while minimizing the negative impact on the environment, ultimately contributing to the sustainability of our planet. Many of the technological processes involved in agricultural mechanical engineering can be interpreted as the interaction of a granular material assembly with a body in contact with or moving in it. Such is the interaction between the soil-tillage tool, the soil wheel, the grain-silo, and the grain-material handling machine. In the technical design of these processes, the most difficult problem is the correct interpretation and accurate modeling of the phenomena occurring at the interface of the granular material assembly and the body.

2. Materials and Methods

Many studies regarding agricultural granular materials have used DEM modeling to validate the interaction of contacted particles and reproduce the dynamic behavior of agricultural particles based on the calibrated micromechanical parameters. The micromechanical parameters are almost difficult to measure directly, and their values need to be systematically modified according to the modeled macro behavior until the particle assembly is the same as the real behavior of the particle [3], [4], this is so-called calibration. The calibration is the most time- and resource-consuming part of the DEM modeling, and it would be a really good thing from application point of view to have an available database of pre-calibrated data for the different agricultural crop particles DEM simulations. The micromechanical parameters of static and dynamic friction coefficients, and rolling and sliding friction coefficients of wheat particles were calibrated in their research works [5], [6], [7] to determine the interaction of contacted particles and particle-wall. Validation of corn flow in a commercial screw auger was conducted by [8] to get a better understanding of the interaction between corn particles and particle-wall based on the DEM modeling. To determine the impact of the number of paddles and the filling configuration on the mixing rate of a single-shaft paddle mixer, [9] performed DEM simulations on corn particles.

2.1 Agricultural applications of DEM

DEM simulation is considered as a powerful method to numerically simulate interactions between the contacting areas for the agricultural particles. Effect of tool vibration has been investigated by DEM [10] (Fig. 1). Predicting the discharge rate from a rectangular hopper, simulating the compression tests, loading in silos and gravity flowing in silos using the DEM [11], [12], [13]. The DEM has been used to simulate the interactions between fruits to predict the dynamic behavior of apples and grapes [14], [15], [16], and maize stalk, cotton stalk, and citrus fruit stalk [17], [18], [19]. DEM simulations are also widely used for the flow of agricultural granular materials in chutes, the shear cell shown in Fig. 2, and dryers shown in Fig. 3 [20], [21], [22], [23]. The vane shear testing experiments were also conducted with DEM shown in Fig. 4 [24]. The agricultural particle screening during the combine harvester [25] and high capacity vibrating screening for non-spherical particles [26] are studied based on the DEM simulations. Many cases apply the DEM simulations in food processing, such as the food grains drying process [27], [28] and the collision of amorphous food particles during spray drying for particle-wall [29]. This paragraph talked about the agricultural products relating to the DEM simulation.

This paragraph collects agricultural applications of soil and fertilizer particles with DEM. [30], [31], [32] studied the bulk residual soil strength, the mapping relationship of soil stress-stain, constitutive response prediction of both dense and loose soils and the dynamic interactions that happen during the soil tillage process with DEM simulations. Fertilizer granular materials play a very important role in agricultural production activities. Calibration of micromechanical parameters of fertilizer particles, the study of the interaction between fertilizer granules and agricultural machinery and equipment, the dual-band application of fertilizer particles, and the application of broken solid organic fertilizers in cultivated land [4], [33], [34], [35], [36] are examples of DEM used in fertilizer simulations.

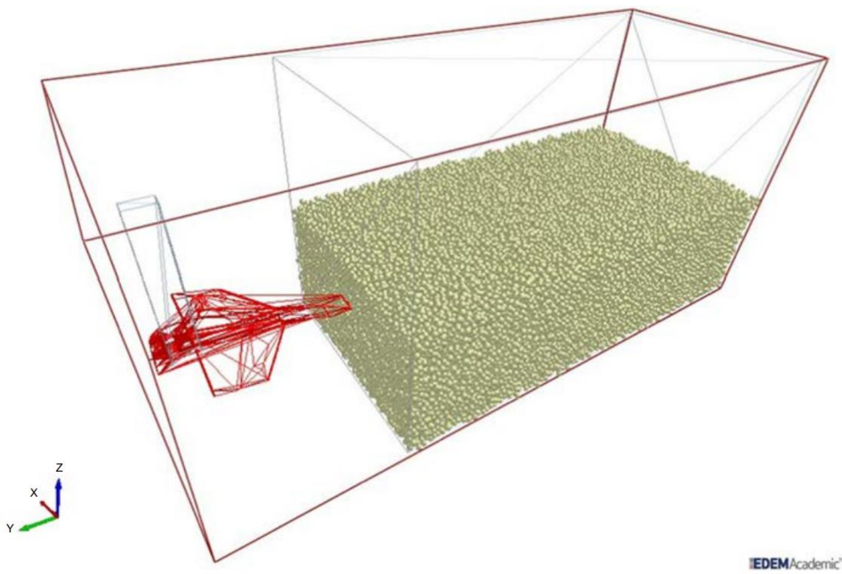

Figure 1. Effect of tool vibration has been investigated by DEM [10]

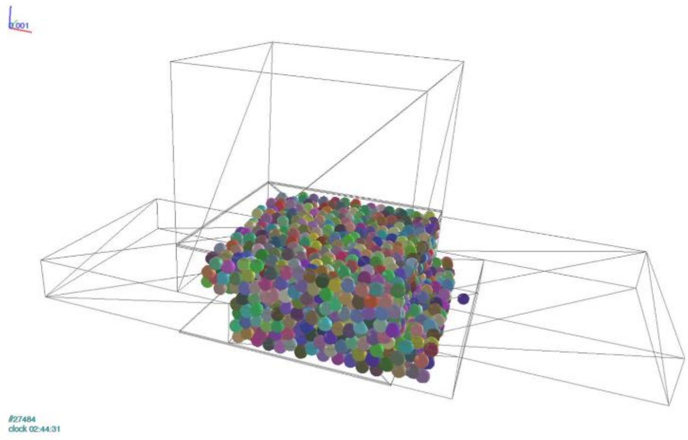

Figure 2. DEM modeling of the shear cell [37]

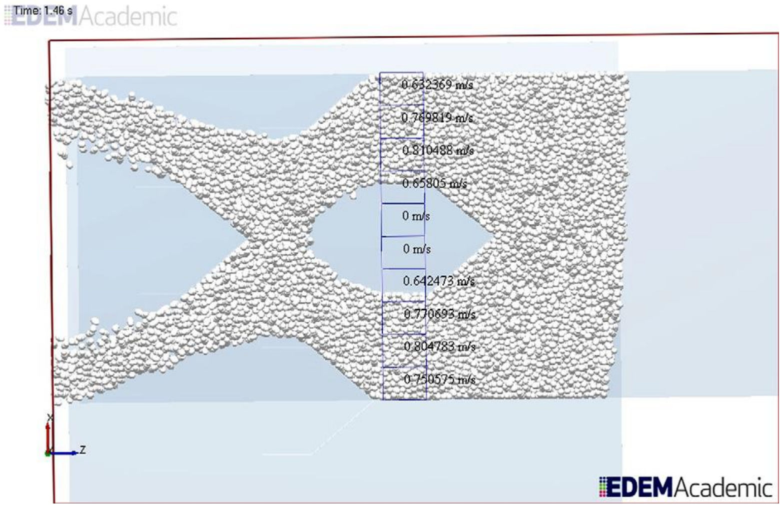

Figure 3. Binning of the dryer section [20]

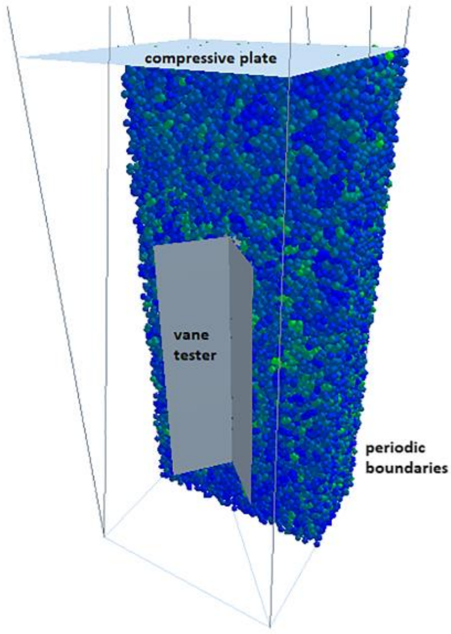

Figure 4. DEM model of vane shear testing apparatus [24]

2.2 The calibration problems

DEM simulations need to consider several factors such as the shape, size, surface properties and material characteristics of the particles. The complexity of these factors makes it necessary to involve many parameters in the simulation, some of which may be difficult to measure and estimate. The transportation of agricultural particles from the original place to the measurement laboratory may cause changes in some micromechanical parameters due to the change in particle moisture content, thereby, [24] developed the in-situ calibration method to avoid these problems. [37] applied the rectangular lid instead of a circular shear lid shown in Fig. 5, so it is a shear box, followed by a detailed sensitivity analysis using shear testing experiments. The internal friction angle of corn and the friction angle of corn-steel and corn-glass were determined by direct shear testing with a shear box [38]. The experimental results show that inconsistent with each other. The calibration is extremely difficult since the differences in calibration environment and calibration methods can lead to very different results. The relative error (RE) of the bulk angle of repose was 0.39% [13] using the particle scaled-up method in the DEM parameters calibration for rice grains. [3] used a two-spherical clump as the simulated shape of corn granules and calibrated the angle of repose of corn particles with the help of a cylinder shown in Fig. 6.

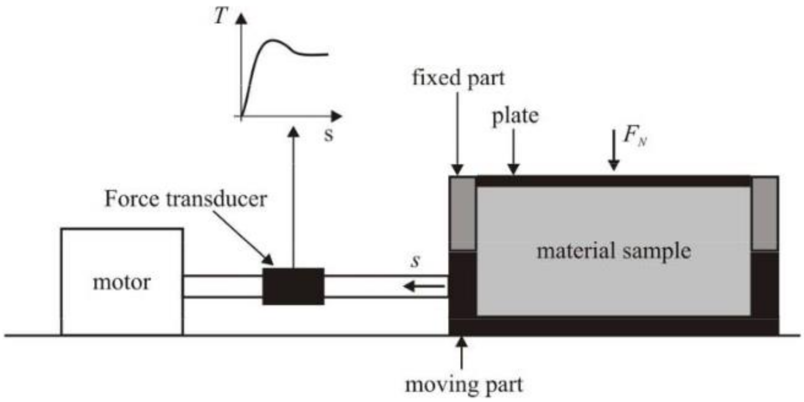

Figure 5. Shear box [37]

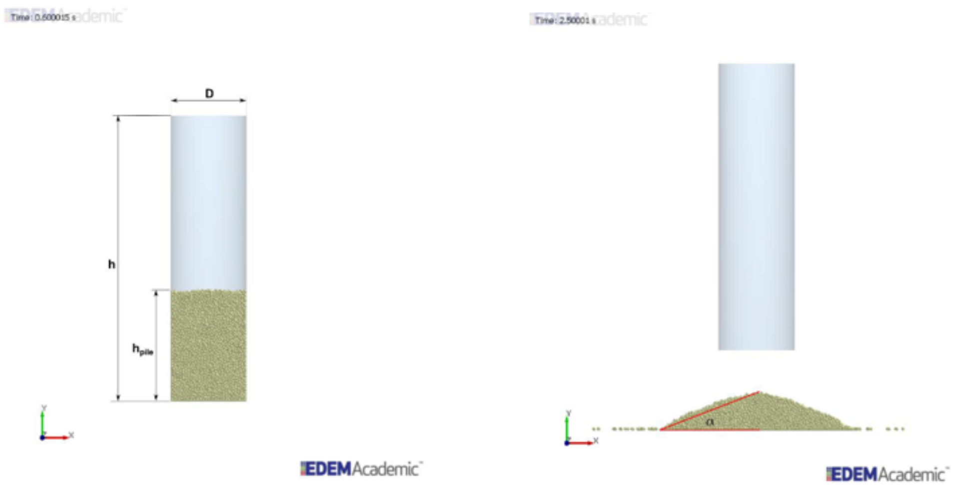

Figure 6. The measurement process of the angle of repose [3]

3. Conclusions

This literature review is about the numerical simulation of agricultural granular materials based on DEM. It mainly reviews the agricultural application possibilities of the discrete element method (DEM) simulating and calibrating the micromechanical parameters of granular materials and understanding the interactions between particles and particle-wall, so that the DEM simulation can reproduce the dynamic behavior of the agricultural particles.

The calibration of microparameters is a fundamental and ongoing challenge in DEM simulation, and it plays a critical role in the DEM simulation for agricultural application purposes. As the field continues to advance, new methods and techniques for calibration are likely to emerge, enabling even more powerful and accurate simulations of complex systems. DEM modeling can be used more widely in agricultural applications. The aim of our research is to provide practicing engineers with a database that they can use to focus directly on the field of engineering problem they are solving, without having to spend time on calibration.

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