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Comparison of Numerical Modeling Methods for Soil Vibration Cutting

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Abstract. In this paper, we studied the appropriate numerical simulation method for vibration soil cutting. Three numerical simulation methods, commonly used for uniform speed soil cutting, Lagrange, ALE and DEM, are analyzed. Three models of vibration soil cutting simulation model are established by using ls-dyna.The applicability of the three methods to this problem is analyzed in combination with the model mechanism and simulation results. Both the Lagrange method and the DEM method can show the force oscillation of the tool and the large deformation of the soil in the vibration cutting. Lagrange method shows better effect of soil debris breaking. Because of the poor stability of ALE method, it is not suitable to use soil vibration cutting problem.

1. Introduction

In the field of uniform speed soil cutting, the research of numerical simulation has a solid foundation. Shen Jianqi (2009) using LS-DYNA software to establish ALE model of shield cutter digging soil. The experiment results show that ALE model can reflect soil cutting [1]. Su Cuixia (2011) built Lagrange simulation model of shield cutter driving in Abaqus software [2]. Xu Zijun (2012) established the mesoscopic structure model of rock mass by using discrete element software PFC3D [3]. The mechanism of rock breaking and crack generation was revealed by simulation and experiment. Liu Xiucheng (2015) also established the ALE model for harrow soil cutting process, and confirmed the advantage of ALE method in soil cutting [4].

Vibration cutting is different from the traditional uniform speed cutting, and it is an advanced processing and production method. Related study shows that the application of vibration excitation in rock and soil excavation will have benefits of drag reduction and energy reduction [5]. This paper analyzes and discusses the advantages and disadvantages of three numerical modeling methods, Lagrange, ALE and DEM, in the simulation of soil vibration cutting.

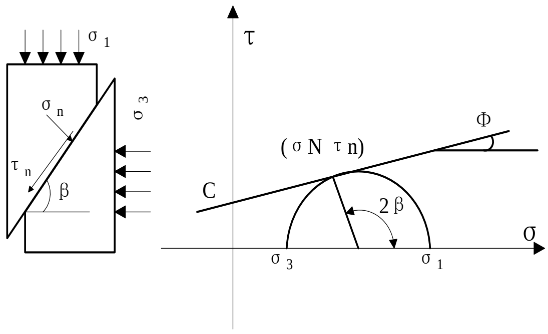
2. Mechanism Analysis of Numerical Modeling Methods for Lagrange, ALE and DEM

Mohr Coulomb law is the core of the governing equation of the soil continuum [6]. It comes from the compression failure test of a cylindrical soil mass (fig.1 a). The parameters (like C,Φ,σ,τ)in soil materials obtained by experiments is as follows:

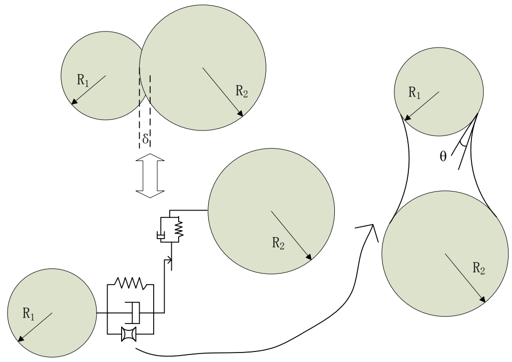
$$\tau=C+\sigma\tan(\Phi). \qquad (1)$$

Where: τ: shear ; σ: normal stress ;C: soil cohesion; Φ: the internal friction angle of soil.

Obviously, the soil formed by this method is considered as a whole material, and it cannot deal with the microscopic action of particles in the soil. The soil material of Lagrange, ALE and SPH is applied to this principle.



(a) Schematic diagram of soil three axial compression test



(b) Definition of particle material in DEM

Figure 1. Definition of continuum and discrete soil

The modeling idea of DEM is the opposite [7]. It takes the microscopic characteristics of particles between soils as the kinetic equations (fig.1 b). Only the properties of the particles and the interaction of particles are defined in the material. This method is called Mesoscopic model. Because the model considers the scale between macroscopic continuum and microscopic molecule.

The above is the basic introduction of the two ways of macro and micro in numerical modeling. Between the Lagrange and ALE methods, the difference is the flow of the material grid.

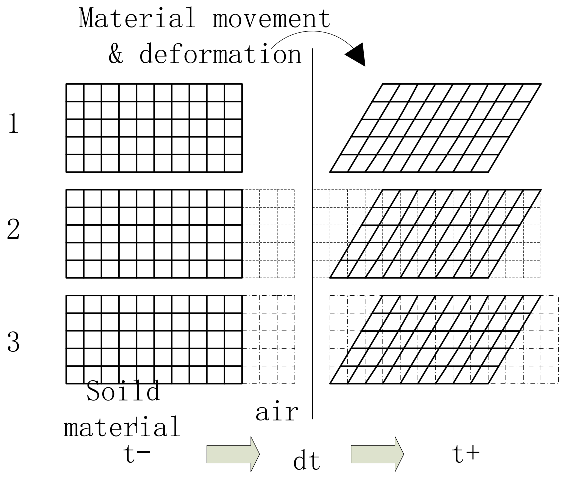


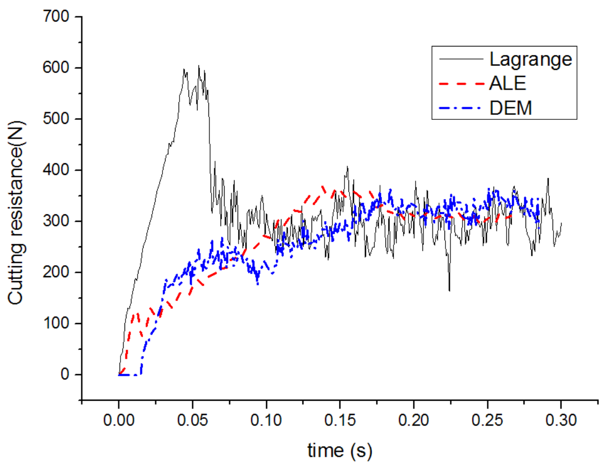
Figure 2. Lagrange, Euler, ALE three kinds of grid introduction

Fig.2 1 is Lagrange, and the mesh is directly divided into the material when modeling. In the calculation, the element mesh will deform with the moving and deforming of the material. 2 is the Euler method, and the space of the grid is fixed. The solid part of the material mesh can move and deform in space in the divided space grid. The 3 is the ALE method, which combines the last two properties. The bottom line is a ALE space grid, which can be moved or exchanged. ALE bulk material can also move in the space grid.

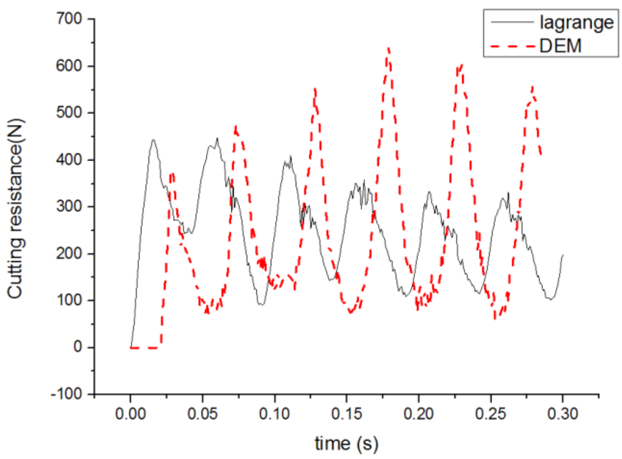
3. The Model of Soil Vibration Cutting

In LS-DYNA software, the Lagrange, DEM, ALE cutting models are established respectively (fig.4). The modified Mohr Coulomb model (Mat147) is used for the soil material in Lagrange and ALE methods [8]. The definition of DEM depends on empirical estimation [7]. By adjusting the relevant parameters in the simulation, the simulation of the three methods can be approached.

Fig.3 is the time history diagram of cutting resistance under three kinds of simulation modeling methods. Under the Lagrange method, the cutting resistance begins to have an overshoot. Subsequently, the cutting resistance of the three is close to each other under uniform cutting (a). They all can reflect the cutting tool loading in the process of cutting. (b) is the cutting resistance while cutter is under the cosine excitation of the frequency 20Hz and the amplitude is 8mm in the direction of the tool advancing. The force acting on the cutter is close between DEM and Lagrange under the vibration. The ALE model (use mat147 material) is unstable after applying vibration; several attempts were unsuccessful during the study period. As a result, this part of the data is missing.



(a) uniform cutting



(b) cutting applied vibration

Figure 3. resistance time history diagram of cutting tools

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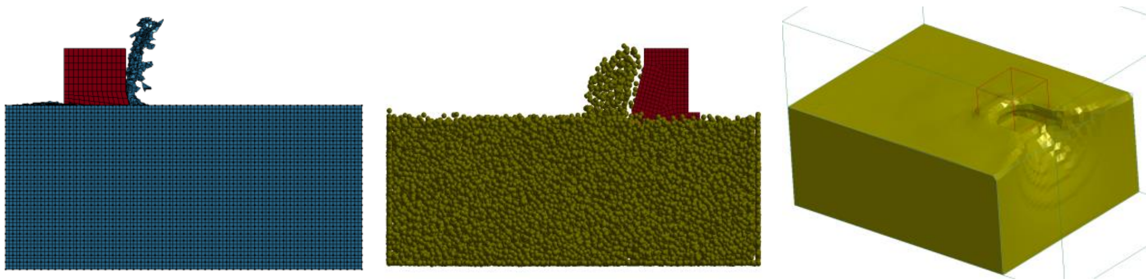
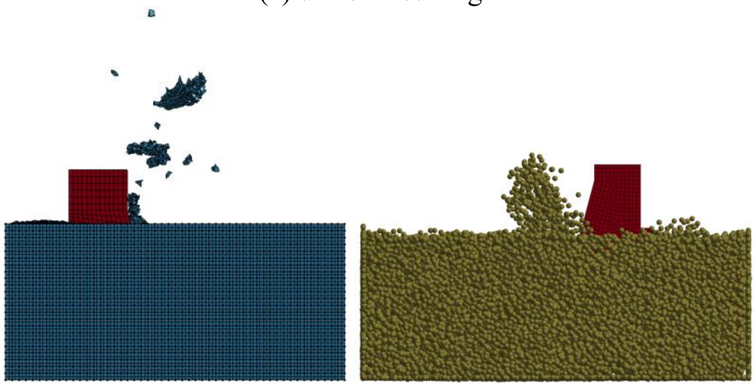


(a) uniform cutting



(b) cutting applied vibration

Figure 4. 3 kinds of numerical model before and after the vibration of soil morphology change

Fig.4 is the process of soil cutting in simulation. It can be seen from (a) that the three numerical methods all can reflect the force, deformation, failure and flow of the soil. The flow of soil in ALE is close to mud, a kind of soil that contains a large portion of water; however, the effect of DEM is closer to that of granular soil. Because of the absence of the ALE method, here are only the DEM and Lagrange methods (b). It can be seen that soil fracture is flying out under Lagrange method. In the DEM method, the soil particles are bent forward under the action of vibration and separated from the rake face.

4. Summary

From the three simulation methods in theory, Lagrange and ALE methods are the reflection of macro soil overall characteristics. DEM is based on the interaction of Meso-scale particles. In the Lagrange method, the material and the mesh are the same, and the deformed mesh will deform correspondingly with the deformation of the material. In the ALE method, the material is separated from the mesh and the material can flow in the mesh. The DEM method has no mesh constraint.

Three cutting vibration models of Lagrange, ALE and DEM are established by using LS-DYNA software. In the uniform speed cutting, the lagrange method has an overshoot in the process of entering the soil. Under vibration excitation, the resistance trend of Lagrange method and DEM method are close. ALE method failed to achieve stable state under vibration cutting.

The Lagrange method is more suitable for the study of soil fragmentation and crack propagation, based on the soil morphology in the simulation results. Because of the instability of ALE method in vibration cutting, it is suitable as a vibration cutting simulation of soil. If only the shape of soil is not considered and the stress condition of cutting tool is emphasized, the DEM method will have the advantages of fast calculation and good stability.

Table 1. Summary of three numerical methods in vibration cutting

Method Property	lagrange	ALE	DEM
Clay	Solid	fluid	particles
Material scale	Macro	Macro	Meso-scale
Material sources	Accuracy	Accuracy	Rough
calculation speed	Slow	Medium	Fast
Stability calculation	Medium	Bed	Good

5. Acknowledgment
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