

Influence of Circular Plate's Local Geometric Feature on The Sinking Performance in Soft Soil

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Abstract: To study the influence of local geometric feature on circular plate's sinking performance in the soil, radial and circumferential grooves are added at the bottom of circular plate separately. Smoothed particle hydrodynamics and finite element method (SPH/FEM) are used to simulate the sinking process. The results show that the maximum effective stress of soil and the sinkage of plate with circumferential groove are smaller than those of plate with radial groove. While comparing the sink simulating result of circumferential groove with depth of 1cm and 2cm, it is found that the sinkage of circular plate and the soil's maximum Von Mises stress is smaller when groove's depth is 1cm. The research provides benefit references to the design of mechanical part working in soft soil.

Introduction

The load-bearing capacity of soil directly affects the traffic ability of the vehicles working on soil, it is necessary to carry out test and analysis on the sinking process in order to analyze the vehicle's performance. At present, the analysis methods of the soil sinking process can be generally classified into empirical method and semi-empirical method based on the Bekker's sinking theory, and the numerical simulate [1-4]. Of the experiment method, the plate sinking test is used widely. Based on plate experiments, M.G. Bekker [1] had derived the relationship between the shear displacement and shear stress, and put forward Bekker's sinking formula in soil. Considering the influence of rigid wheel size, Gareth [4] propose the modified static sinkage model with semi-empirical method. However, numerical simulation method is more efficient than experiment method, and has been used increasingly in recent years. Finite element analysis and discrete element method are used to simulate tire-soil interaction by Li [2,3] and Shmulevich [5] to study tire's in soil separately, and ideal results of simulation are obtained.

There are many researches on sinking in soil, but few researches are concentrating on the influence of geometric shape of the part on sinking performance, especially the researches of local geometric feature's influence has seldom been reported. In this paper, SPH/FEM method are used to analyze the influence of local detailed shape feature on the circular plate's sinking process in soil.

Simulation method

The principle of SPH. SPH is a meshless modeling method, which uses a series of particles to simulate fluid, soft body and soil problems [6]. It has obvious advantages on dealing problems with the moving boundary and large deformation. The core idea of SPH method is to smoothly approximate the basic functions and particle attributes. The approximation of the basic functions is defined as following [6]:

$$f(x) = \int_D f(x') W(x-x', h) dx' \quad (1)$$

Where x is an arbitrary spatial variables, and D is the integration interval of x . Function

$W(x-x',h)$ is called as interpolation kernel function. The approximation of the particles is applied in numerical calculations. The detailed derivation process of the particles' approximation can be found in [6]. The function is given as:

$$r_i(x) = \sum_{j=1}^N m_j f_j(x') W(x-x',h) \quad (2)$$

Where r and m are material's density and mass separately.

Soil's constitutive models. The soil is described with LS-DYNA's MAT147 soil model [7]. It is an isotropic material model with damage, which modifies Mohr-Coulomb surface and define the pressure dependent shear strength. MAT147 also consider the moisture content of soil, which can be used to calculate the amount of air voids. MAT147 soil model's yield surface is defined as [7]:

$$F = -p \sin j + \sqrt{J_2 k(q)^2 + a^2 \sin^2 j} - c \cos j = 0 \quad (3)$$

where r , j and c denote pressure, soil's cohesion and internal friction angle, J_2 and $K(q)$ express second invariant of the stress deviator and the function of the angle in the deviator plane. The coefficient is the parameter which defines the closeness degree between the modified yield surface and the standard Mohr-Coulomb yield surface. When $a = 0$, the original Mohr-Coulomb surface is obtained. Fig.1 shows the shear stress and the pressure curve in the modified yield surface and the standard Mohr-Coulomb yield surface.

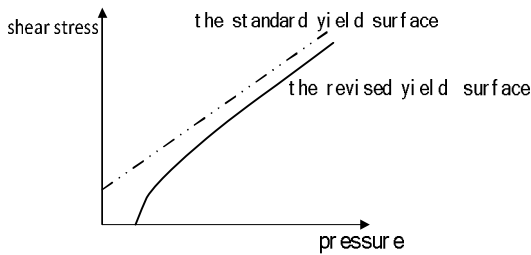
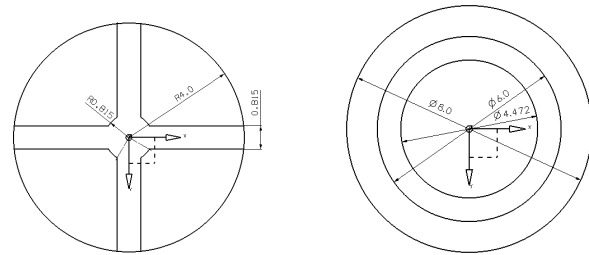


Figure 1. Shear stress and pressure curve in Mohr-Coulomb groove



(a) Radial groove (b) Circumferential groove
Figure 2. Section shape of the yield surface and modified yield surface

Simulation method

Figure 2(a) and 2(b) show the shape of two plates with radial groove and circumferential groove separately, of which the area of them are the same and the depth of them are 1cm. The dimension of soil used in this simulation is $20\text{cm} \times 20\text{cm} \times 10\text{cm}$. In order to get accurate result in reasonable time, the simulation uses SPH method combining with FEM method. According to the deformation degree of soil, the soil under the plate is modeled as SPH particles and other soil far from the plate is modeled with FEM method. The dimension of soil modeled as SPH particles is $10\text{cm} \times 10\text{cm} \times 5\text{cm}$.

The density of plate is 7.23 g/cm^3 . The density, poisson ratio, friction angle, elastic module volume module and shear module are 1.88 g/cm^3 , 0.35, 22° , 1.17MPa, 4.5MPa and 2.7MPa separately. The plate and soil are described as 3D Tet-Solid 168 and 3D Solid 164 element respectively. The vertical forces applying on the plate is 450N and the simulation time is 26ms.

Numerical simulation result

The stress distribution of soil. The simulation results show that the sinkage of plate with circumferential groove is 1.508cm, and the sinkage of plate with radial groove is 1.554. Both can reach convergence finally. It can be concluded that the former behaves better than the latter in reducing the sinkage.

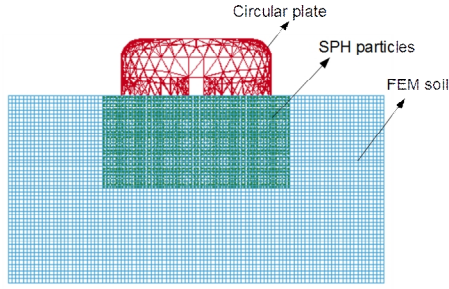
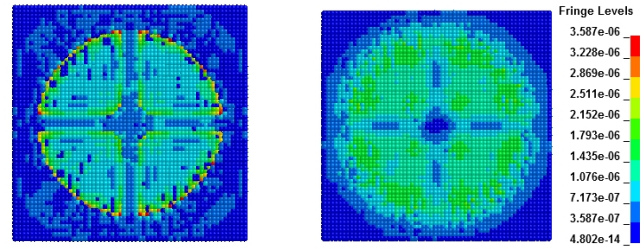


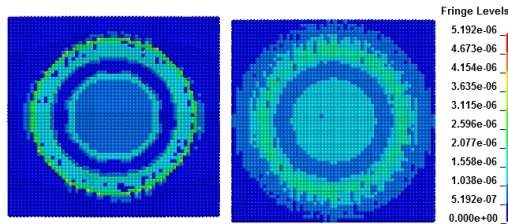
Figure 3. The plate-soil interaction model



(a) $z=0$

(b) $z=-1\text{cm}$

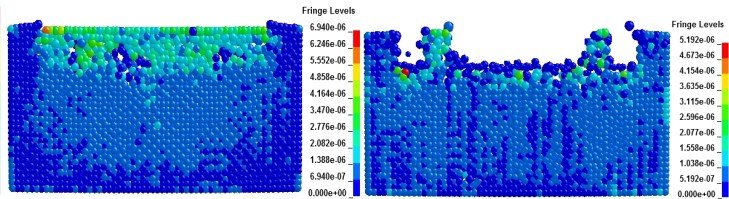
Figure 4. The Von Mises stress of SPH soil particle under the plate with radial groove($T=5\text{ms}$)



(a) $z=0$

(b) $z=-1\text{cm}$

Figure 5. Von Mises stress of SPH soil particle under plate with circumferential groove($T=5\text{ms}$)

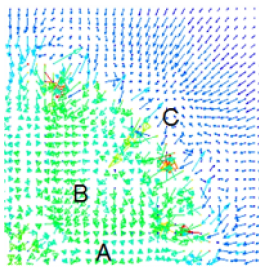


(a) Radial groove

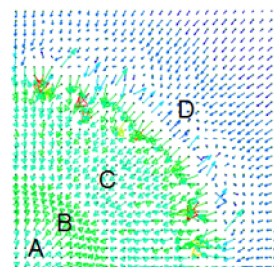
(b) Circumferential groove

Figure 6. Von Mises stress of SPH soil particle at vertical section($T=26\text{ms}$)

Fig.4(a) shows the Von Mises stress distribution of surface soil under the circular plate with radial groove at 5ms. The soil near the edge of plate's reach the maximum Von Mises stress of 0.0359Mpa at the depth of 5.5cm. Figure 5(a) shows the Von Mises stress distribution of surface soil under the circular plate with circumferential groove at 5ms. The maximum effective stress is 0.0519MPa at the depth of 5.1cm. Figure 4(b) and Fig.5(b) show the effective stress distributions of SPH soil particles at the depth of 1cm at time 5ms. Fig.6 shows the effective stress distributions of SPH soil particles at vertical section. It is found that with the increase of soil's depth, the influence of local shape feature on soil's stress distribution is decreasing.



(a) Radial groove



(b) Circumferential groove

Figure 7 The velocity vector of SPH soil particle under the bottom of circular plate ($T=5\text{ms}$, $z=0$)

The flowing trend of soil particles. The velocity vectors of the surface soil SPH particle under the two circular plate with radial and circumferential groove at 5ms are shown in Fig. 7(a) and Fig. 7(b) separately. With radial groove at the bottom of circular plate, SPH soil particles in Fig 7(a) can be divided into A, B and C three part. Since the existence of the groove the density of soil particle in part A is relatively smaller than the soil nearby. The soil particles in part B have the flowing trend towards part A. While the particles in part C move to the center of soil under the plate. At this point, the particle reaches the maximum speed 2.704m/s, and the velocity of the SPH particles which directly contact with the edge of the bottom of circular plate is larger. As Fig 7(b) shown, Soil SPH particles under plate with circumferential groove can be divided into A, B, C and D four parts. Due to the existence of circumferential groove, the soil particle in part B have a relatively small density; When the plate press the soil, the soil particles in A and C parts are made flow towards Part B, and

the soil particle is made flow towards the center point of the plate along the radial direction. At this point, the particles reach the maximum velocity 1.647 m/s, the velocity of the SPH particles which directly contact with inner ring of groove and the bottom center of circular plate is more larger.

The velocity vectors of SPH particles in vertical section under the circular plate with radial and circumferential groove are shown in Fig. 8 and Fig. 9 separately, which shows that the squeezed particles have a tendency to move downward or around.

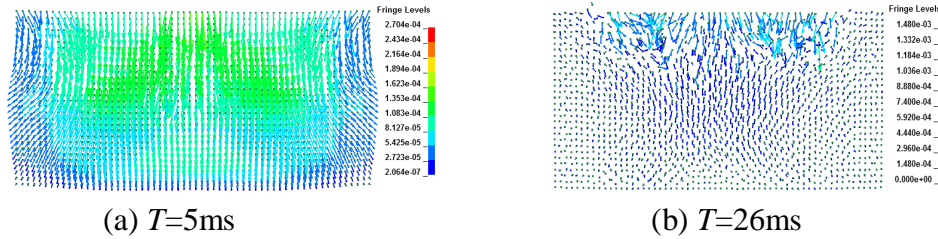


Figure 8. Velocity vectors of SPH soil particle under the circular plate with radial groove

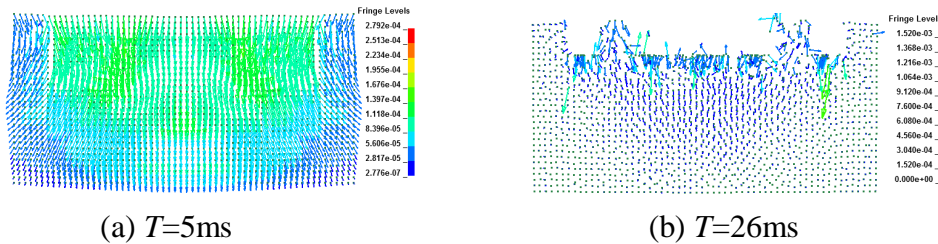


Figure 9 Soil particle's velocity vectors under the circular plate with circumferential groove

The influence of groove's depth on plate's sinkage. It has been concluded that the sinkage of plate and the maximum stress of soil become smaller with the circumferential groove. In order to find the optimal configuration of groove, the influence of circumferential groove's depth on the sinkage is analyzed. The shape and area of plate with circumferential groove are set the same as previous except the depths are set as 1cm and 2cm separately. The simulation results show that the sinkage of plate with 1cm depth's groove is 2.060cm, and the sinkage of plate with 2cm depth's groove is 2.508cm. Both can get converge result finally. When comparing the difference of the plate's sinking results, it can be found that the sinkage of rigid body with 2cm deep groove is larger, so the circular plate with 1cm depth's groove is better in reducing the sinkage.

The analysis of soil stress

Fig.11 and Fig.12 show Von Mises stress of SPH soil particle under the circular plate with 1cm and 2cm deep groove separately, and their overall effective stress distributions are similar. At the beginning of the sinking, the stress of soil particles which directly contact with circular plate is larger than the soil around. As the circular plate pressing the soil completely, the stress distribution is more homogeneous. The maximum effective stress of soil particles under the circular plate with 1cm deep groove is larger than plate with 2cm deep groove at the same time.

The sinking process in soil has a significant influence on the vertical stress distribution. Fig.12 and Fig.12 show the vertical stress distribution of SPH soil particle under the circular plate with 1cm and 2cm deep groove separately. It can be found that in Fig.12 and Fig.13 with the soil particles squeezed by circular plate, particles move and get downwards vertical stress. As soil particles squeeze continuously, the magnitude of forces between particles increases, and the particles move upward trend and get a downwards vertical stress.

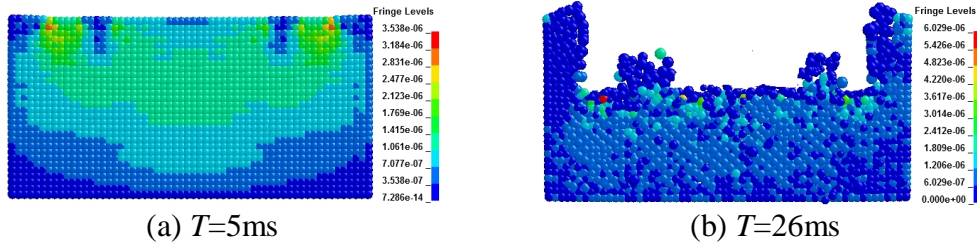


Figure 10. Von Mises stress of SPH soil particle (h=1cm)

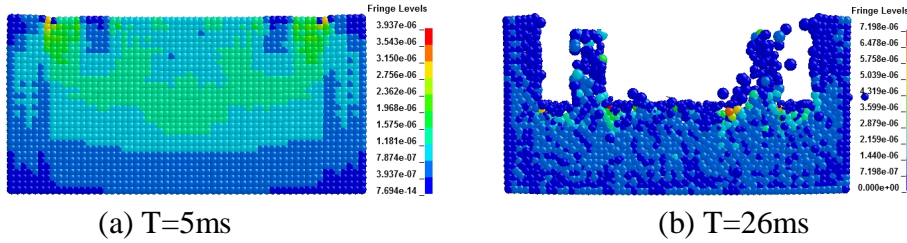


Figure 11 Von Mises stress of SPH soil particle (h=2cm)

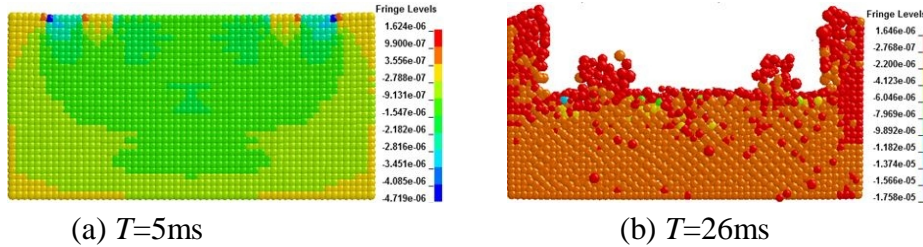


Figure 12 The vertical stress distribution of SPH soil particle (h=1cm)

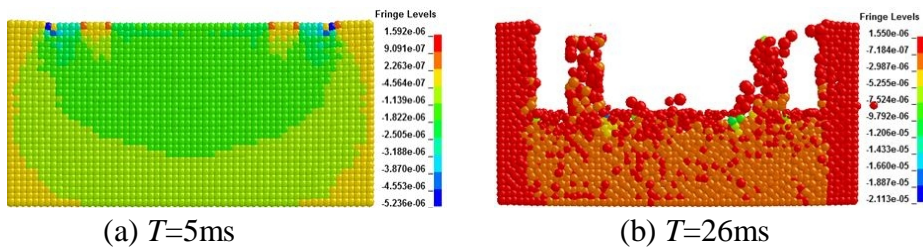


Figure 13 The vertical stress distribution of SPH soil particle (h=2cm)

Conclusion

In order to analyze the influence of local geometric feature on the sinking performance of circular plate in the soil, radial and circumferential grooves are added on the bottom of circular plate, then the sinking process is simulated and analyzed. The results show that with the circumferential groove, the sinkage of plate and the stress of soil are smaller, so the circumferential groove is more ideal. Through analyzing the influence of circumferential groove's depth on the sinkage performance, it is found that 1cm deep circumferential groove is helpful to reduce the sinkage but get a relatively large Von Mises stress in the soil.

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