Establishment of virtual vibrating sieve based on PFC3D

Weidong Liu¹, ², Xing Gong², * and Zhenwei Peng²

¹Key Laboratory of Road Structure & Material Ministry of Transport, Beijing, China
²School of Architecture and Transportation Engineering, Guilin University of Electronic Technology, Guilin, China

*Corresponding author e-mail: 453951916@qq.com

Abstract. The generation of virtual aggregate, close to realistic aggregate by numerical tool, is a key step in investigating the mechanical properties of asphalt mixture from the mesoscopic level. To verify the accuracy of assemblage of aggregate, this paper is based on the improved algorithm of random cutting technology previously proposed, using PFC3D editing program to establish a vibrating sieve, and the reliability of the improved algorithm was verified by sieving test. The results show that the improved algorithm of the irregular polyhedron random cutting technique proposed by the author can ensure that the gradation of the aggregate is consistent with the actual, and the sieving test can be used to evaluate the quality of the virtual aggregate based on PFC3D.

1. Introduction
The three-dimensional morphological characteristics of the aggregate have a profound impact on the mechanical response of the asphalt mixture or aggregate. Therefore, in the process of PFC3D simulation analysis, how to accurately characterize the morphological characteristics of the actual aggregate is undoubtedly an extremely important link. Tian et al. constructed the microstructure of asphalt mixture with single geometric shapes such as spheroid, ellipsoid and ellipse, which was far from the actual morphology of aggregate [1]. Wang et al. constructed two-dimensional or three-dimensional virtual specimens through a series of image processing technology based on the digital camera or X-ray CT equipment for digital image, which can truly reflect the characteristics of the aggregate shape. However, expensive equipment was required in this research [2, 3]. Lu et al. generated irregular polyhedral aggregate based on PFC3D program through random technology, which could not establish grading relation with actual aggregate [4]. Liu et al. generated the aggregate through assumed the aggregate as a specific polyhedron, which can well reflect the aggregate gradation, but the ideal assumption led to a big difference between the morphology of the aggregate and the actual situation [5]. Ferellec et al. created complex irregular particle shapes through overlapping spheres, which can well simulate the shape of aggregate, but it was no experimental verification and lacked reliability [6].

To solve the above problems, this paper established the PFC3D vibrating sieve and verified the reliability of the improved algorithm by sieving test based on the improved algorithm of random cutting technology [7]. The content of this paper provides a basis for the study of the compaction process and mechanical behavior of aggregate or asphalt mixture.
2. Discrete element virtual vibration sieving test verification
The size information of the actual aggregate can be obtained by the sieving test of the standard sieve. To further verify the accuracy of the aggregate size, the virtual vibration sieving test of the aggregate was achieved by using the sieving principle of the standard sieve based on PFC3D editing program, so that the passing rate of the corresponding mesh virtual aggregate can be calculated, and compare this passing rate with the target passing rate, the particle size of the virtual aggregate can be evaluated to some extent.

2.1. Establishment of discrete element vibrating sieve model
In the discrete element PFC3D program, the container is generally simulated by the wall. The assembly of the aggregate can only be in the area enclosed by the effective side, therefore, the effective side of the wall should be noted when generating the wall, otherwise the aggregate will escape. Considering the operating efficiency and actual situation of the discrete element, this paper uses the 9.5mm and 4.75mm sieves as an example to establish a three-dimensional discrete element virtual vibration sieving model. The other sieve sizes are similar. The container is consisted with the upper and lower walls and the cylindrical side wall, which can be achieved by using the wall command, as shown in Fig. 1. The friction coefficient of the wall is 0.3, the height of the side wall is 0.21m and the radius of the cylindrical is 0.075m. The sieve is simulated with a special wall (line3d), which is different from the wall representing the container. The sieve has a certain caliber.

![Figure 1. Discrete element vibrating sieve model.](image)

In the 4.75-19mm aggregate particles, the 4.75-9.5mm one account for 21%, while the 9.5-13.2mm one account for 55%. Assuming that the normal stiffness and tangential stiffness of the particles are 1.0^6 N/m, the aggregate density is 2700 kg/m³, and the friction coefficient of the aggregate is 0.5.

2.2. Application of discrete element vibrating sieve load
The sieving of the aggregate is actually under the action of gravity, the vibration excitation imposed by the outside forces the aggregate to have a complex movement in the horizontal and vertical directions to make it pass through the sieve size. The wall of PFC3D does not satisfy the force-displacement equation, that is, it cannot be loaded through the wall, but the velocity can be applied to the wall to make the particles collide and produce contact force, and the aggregate will have complex movement at the same time. To simulate the vibration load, sine velocity is applied to the wall, in which the amplitude is 0.0375m and the frequency is 5Hz. Through repeated tests, it is found that the passing rate of aggregate remains basically unchanged at running time 5s, so the sieve virtual test time is determined as 5s.
2.3. Selection of Discrete Element Vibrating Sieve Damping

The energy of particles can be released by sliding friction. However, sliding friction may not be activated in certain models, or even if activated, the particle system cannot reach equilibrium within a reasonable time. In PFC3D, local non-viscous damping is an effective way to dissipate the kinetic energy of particles, the setting of the specific damping is to set a coefficient by the corresponding command.

![Linear contact model and viscous damping at the contact.](image)

By default, the local damping coefficient of the system is 0.7. Simply dissipating the kinetic energy of the system by setting the coefficients has the following advantages [8]: (1) Damping is only effective for acceleration, and does not cause damping force for the particles of uniform motion. (2) The damping coefficient is constant, independent of the studied dimension. (3) Damping Independent of frequency, it has the same damping for regional particle systems with different natural periods. In addition, the value of damping coefficient is related to the type of system equilibrium. For the quasi-static or static equilibrium system, a large damping coefficient is usually adopted to make the system reach equilibrium within a reasonable period of time. However, for the dynamic system, a small and even zero damping coefficient is usually adopted to match the simulated object. This paper simulated the sieving process of the vibrating sieve, which was a dynamic problem, and the local damping coefficient was zero.

When the viscous damping is activated, the normal and tangential dampers act on each contact. Viscous damping and contact model can work together, as shown in Fig. 2, linear contact model and viscous damping act on the contact. The damping force $D_i$ ($i=n:normal, i=s:shear$ hereafter the same) incorporated into the contact force, the normal and tangential expressions are as follows:

$$D_i = C_i |V_i|$$  \hspace{1cm} (1)

Where, $C_i$ is the damping constant (coefficient) and $V_i$ is the relative velocity at the contact, and the direction of the damping force is opposite to the direction of motion. Generally, the damping coefficient is not directly specified, and the critical damping ratio $\beta_i$ is directly specified. The damping coefficient and the critical damping ratio can be calculated by the following formula:

$$C_i = \beta_i C_{i\text{crit}}$$  \hspace{1cm} (2)

Where, the critical damping coefficient is defined as follows:

$$C_{i\text{crit}} = 2m\omega_i = 2\sqrt{mk_i}$$  \hspace{1cm} (3)
Where, \( \omega_i \) is the natural frequency of the undamped system, \( k_i \) is the tangent stiffness of the contact, and \( m \) is the effective mass of the system. If it is a ball-wall contact, \( m \) is the mass of the ball. If it is a ball-ball contact, it is calculated according to the following formula:

\[
m = \frac{m_1 m_2}{m_1 + m_2}
\]

Where, the mass of the ball 1 and the ball 2, respectively.

In this paper, viscous damping is adopted to simulate the sieving process of the vibrating sieve. The ratio of normal to tangential critical damping is 0.1.

3. Discrete element vibrating screen virtual screening test results

According to the above steps, a discrete element vibrating sieve was established for sieving test, as shown in Fig. 3. In the sieving process, the position of the aggregate in the z-axis direction will be significantly changed, when the aggregate can pass the corresponding sieve size. Therefore, the passing rate of 9.5mm and 4.75mm aggregate was tracked by fish language programming with the position of the aggregate on the z-axis as the index.

Fig. 4 shows the aggregate passing rate of 9.5mm and 4.75mm. With the increase of time step, the aggregate passing rate gradually increases and finally reaches a stable value. Among them, the passing rate of the 9.5 mm aggregate is about 54%, and the passing rate of the 4.75 mm aggregate is 22%, which is basically same as the content of the aggregate formed in the initial stage of the test. Among them, the passing rate of the 9.5 mm aggregate is about 54%, and the passing rate of the 4.75 mm aggregate is 22%, which is basically the same as the content of the aggregate formed in the initial stage of the test. Therefore, the improved algorithm of the irregular polyhedron random cutting technique proposed by the author can ensure that the gradation of the aggregate is consistent with the actual, and the sieving test can be used to evaluate the quality of the virtual aggregate based on PFC3D.
4. Conclusion
This paper was based on the improved algorithm of random cutting technology previously proposed, in
order to further verify the accuracy of aggregate size, a discrete element vibration sieve virtual test model
was proposed, and the following conclusions were obtained:

The virtual test model of discrete element vibration sieve was proposed based on PFC3D, in which
a special wall was used to simulate the sieve, the wall was subjected to a sinusoidal velocity simulation
vibration excitation, and viscous damping was used to dissipate kinetic energy. The results of virtual
sieving test show that the improved irregular algorithm proposed by the author ensures the size
information of the aggregate, verifies the reliability of the improved algorithm, and provides a reference
for evaluating other particle generation algorithms.

Acknowledgments
This work was financially supported by Opening Funding Supported by the Key Laboratory of Road
Structure & Material Ministry of Transport, Beijing, PRC, and Guangxi Science and Technology fund
(AD18281043).

References
[1] L. Tian, Y. Liu, B.G. Wang, Three-dimensional discrete element model of asphalt mixture and its
reconstruction technology, Journal of Chang’an University (Natural Science Edition). 27 (2007) 23-27.
[2] L.B. Wang, J.D. Frost, J.S. Lai, Three-dimensional digital representation of granular material
microstructure from X-ray tomography imaging, J. Comput. Civ. Eng. 18 (2004) 28-35.
[3] Y.R. Fu, L. Wang, M.T. Tumay, Quantification and simulation of particle kinematics and local
strains in granular materials using X-ray tomography imaging and discrete element method, J.
Eng. Mech. 134 (2008) 143-154.
[4] M. Lu, G.R. McDowell, The importance of modelling ballast particle shape in the discrete element
method, Granu. Matter. 9 (2007) 69-80.
[5] Y. Liu, Q.L. Dai, Z.P. You, Visualization and simulation of asphalt concrete with randomly
generated three-dimensional models, J. Comput. Civ. Eng. 23 (2009) 340-347.
[6] J.F. Ferellec, G.R. McDowell, A method to model realistic particle shape and inertia in DEM,
Granu. Matter. 12 (2010) 459-467.
[7] W.D. Liu, Y. Gao, X.M. Huang, L.M. Li, Investigation of motion of coarse aggregates in asphalt
mixture based on virtual simulation of compaction test, Int. J. Pavement. Eng. available at
https://doi.org/10.1080/10298436.2018.1447109.
[8] J. Chen, X.M. Huang, Discrete element method was used to evaluate aggregate skeleton structure,
Journal of Southeast University (Natural Science Edition). 42 (2012) 761-765.

Figure 4. 9.5mm and 4.75mm aggregate passing rate.