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Studying On The Parameters Of Bond-model In DEM For Asphalt Mixture

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Abstract. The discrete element method used to simulate asphalt mixture’s performance can fully consider the effect of interaction between particles, but the key to use discrete element method is to select reasonable parameters of contact constitutive model. Using 2D and 3D discrete element method to establish asphalt mixture splitting test model which adopting contact-bond method between particles, the influence of particle stiffness and bond strength on the simulation results are analyzed. It is found that the straight slope of the load-deformation curve is mainly determined by the stiffness parameter and the peak load is determined by the bond strength. Asphalt mixture laboratory splitting test of AC-20 and AC-13 at -10℃, 0℃, 10℃ and 20℃ are accomplished, then according to the load-deformation curve’s initial slope and peak load, discrete element model parameters are determined. The relationship between load-deformation curve’s initial straight slope and stiffness, peak load and bond strength are concluded on the basis of splitting test results curve.

1. Introduction
The discrete element method proposed by American Cundul P.A in 1971, is mainly used to solve the mechanical analysis of the discontinuity or continuous medium that has defects. Many scholars have applied it to the performance analysis of asphalt mixture successfully. In 1992 Rothenburg used a series of plane particles to establish asphalt mixture model, the simulation results showed that the sixty percent of unconfined compressive strength was provided by the bonding effect between particles and the remaining forty percent was provided by the friction effect between particles [3]. In 2000, Butter. W and YOU Z established two-dimensional asphalt mixture micro fiber bundle model and found that the displacement results of uniaxial compression test was 40% larger than test results[4]. In 2006, YOU.Z establish the two-dimensional model of asphalt mixture based on discrete element method and the dynamic modulus was simulated[5].

At low temperature, the elastic properties of asphalt mixture are close to linear elasticity and the elastic bond model of discrete element can be used. The determination of the model parameters will affect the accuracy of the simulation results. In literatures [6] to [9], the parameters of discrete model are different distinctly. Because of different implications of parameters and parameter units, the values of contact-bond and parallel-bond are different. Considering the existing literatures unable to get reasonable value of contact model parameters of asphalt mixture, this paper will conduct a research on determining the parameters of discrete element model on the basis of splitting test.
2. Discrete element bond model

In the discrete element software PFC, there are two kinds of bond models, which are contact-bond model and parallel-bond model. The contact-bond model assumes that the contact between particles is only in a small range, as shown in figure 1, named point contact. The parallel-bond model assumes that there is a certain range of contact between particles, as shown in figure 2, particles can transfer force and moment at the same time.

![Contact-bond model](image)

![Parallel-bond model](image)

The contact-bond (shown in figure 1) can be regarded as a pair of springs with constant normal stiffness and tangential stiffness effect on particles contact point. The contact-bond model has four parameters, normal stiffness $k_n$, tangential stiffness $k_s$, normal bond strength $n_{-b}$, tangential bond strength $s_{-b}$. The parallel-bond model (shown in figure 2) assumes that there is an interlayer material between the particle’s limited range. The parallel-bond model is defined by five parameters, normal stiffness $p_{b\_k_n}$, tangential stiffness $p_{b\_k_s}$, normal strength $p_{b\_nstr}$, tangential strength $p_{b\_sstr}$ and bond radius $p_{b\_rad}$. Taking the AC-13 type asphalt mixture as an example, the geometric models of the two-dimensional and three-dimensional splitting test are shown in figure 3.

![Two-dimensional disk model](image)

![Three-dimensional model](image)

3. Analysis of influence factors of discrete element splitting test

3.1 Minimum particle size

The minimum particle size has a great influence on the simulation results of the splitting test. If the contact-bond model is used, with the minimum particle size decreasing, the peak strength of specimens increases significantly. When the minimum particle size change from 0.6 mm to 0.3 mm, 0.15 mm and 0.075 mm, the damage peak force will increase 81.9%, 209% and 379% respectively. However, the influence of the minimum particle size is relatively small when the parallel-bond model is used, as shown in figure 6 the slope and the peak stress have not clearly change. Under the condition that the minimum particle size is 0.6mm, 0.3mm and 0.15mm respectively, the peak stress is very close.

The reason for the difference results between two bond models is mainly determined by the assumptions. The contact-bond model assumes point contact between particles and all particles contact stiffness and bond strength are independent of particle size. If the particle size is smaller, particles will have more contact points, so the deformation stiffness and the failure strength of specimens will increase. While the parallel-bond model considers that contact between particles has a limited range and this range of contact is related to the particle size meaning that point contact force is distributed in a limited area, therefore, parallel-bond model calculation considers the effect of particle size.
3.2 Influence of contact-bond model parameters

In order to find out the influence of parameters on the mechanical properties of specimens, the particle stiffness and the bond strength are changed in the analysis process. As can be seen from figure 6(a), with the stiffness increasing, the slope of load-deformation curve increase gradually and the peak stress increase as well. The results tell us that at certain bond strength the materials with bigger contact stiffness have a higher modulus and higher strength. As can be seen from figure 6(b), when the particle stiffness is constant, the peak stress is affected by the bond strength significantly and the peak load increases with the bond strength increases. The straight line’s initial slopes of loading-deformation curve are close, so the results can be got that the loading-deformation line’s initial slope is mainly determined by the stiffness parameters and the peak load is determined by the bond strength.

From the above discussion, contact-bond model parameters can be fitted by test data. Firstly, determining the stiffness value by the straight line’s initial slope of loading-deformation curve, then according to the destructive peak force to get the parameter of contact-bond strength.

3.3 Influence of parallel-bond model parameters

Fig.9 shows the influence of parallel-bond model parameters on simulation results. When analyzing the effect of stiffness, the bond strength is fixed $1.5 \times 10^7 \text{ Pa}$ and in the analysis of bond strength, contact stiffness is fixed $1 \times 10^{11} \text{ Pa/m}$. It can be seen from figure 7(a), with the stiffness of parallel-bond model increasing, the initial slope of loading-deformation curve will increase. This is consistent with the effect of the stiffness to the contact-bond model, however, with the contact stiffness increasing, the peak value will decrease, which is opposite to the contact-bond model. In figure 7(b), the peak value increases with bond strength increasing, however, the line’s initial slope of loading curve is very close. The rule is similar to contact-bond model. In summary, the straight line’s initial slope of
parallel-bond model is determined by contact stiffness and the peak load of certain contact stiffness is mainly affected by bond strength parameters.

![Figure 7. Influence of parallel-bond model parameters](image)

(a) Stiffness effect (b) Bond strength effect

4. Parameters determination method of discrete element bond model based on splitting test

4.1 Splitting test
This experiment adopts 70# asphalt and the aggregates and fillers are all limestone in the area of Shandong Province in China. Two types of asphalt mixtures AC-13 and AC-20 are made respectively. The splitting tests are conducted at four temperature: -10°C, 0°C, 10°C and 20°C. The loading speed is set to 1 mm/min at the temperature -10°C and 0°C and adopts 50 mm/min at the temperature 10°C and 20°C. The optimization asphalt content of AC-20 and AC-13 is 4.3% and 5% and the splitting test results are shown in figure 8.

![Figure 8. Splitting test results of AC-20](image)

(a) -10°C and 0°C loading-displacement curve (b) 10°C and 20°C loading-displacement curve

4.2 Comparison of laboratory splitting test and discrete element method
Taking the AC-20 type asphalt mixture as an example, the secant slope of loading-deformation curve' at zero degree is 23.1 kN/mm and peak load is 29.4 kN. The parameters of discrete element bond model are fitted and the results are listed in table 1.

|                  | stiffness | bond strength |
|------------------|-----------|---------------|
| two-dimensional  | contact-bond model | $1.5 \times 10^{12}$ Pa·m$^{-1}$ | $2 \times 10^7$ N |
|                  | parallel-bond model | $1 \times 10^{12}$ Pa·m$^{-1}$ | $2 \times 10^7$ Pa |
| three-dimensional| contact-bond model | $9 \times 10^6$ N·m$^{-1}$ | 52 N |
|                  | parallel-bond model | $2.7 \times 10^{12}$ Pa·m$^{-1}$ | $7.5 \times 10^7$ Pa |

Using the parameters in table 2, discrete model simulating results and laboratory test results are plotted in figure 9 and figure 10 for examination. As can be seen that the two-dimensional and three-dimensional discrete element simulating results are close to the initial slope and peak load of actual laboratory test. But deformation values corresponding to peak load are different with laboratory test.
except three-dimensional parallel-bond model. Deformation values corresponding to peak load of two-dimensional contact-bond model, two-dimensional parallel-bond model and three-dimensional contact-bond model are larger than laboratory test results 44%, 25.8% and 55.8% respectively. So parallel-bond model is more suitable to simulate mechanical performance of asphalt mixture than contact-bond model.

5. Main conclusions

Minimum particle size in discrete element model has a great influence on calculation results when the contact-bond model is used. The minimum particle size is smaller and the peak load is larger. However, when parallel-bond model is used, minimum particle size has little effect on calculation results.

The parameters of stiffness in contact-bond model and parallel-bond model are determined by initial slope of loading-deformation curve. The larger initial slope is, the greater stiffness is. Bond strength parameters have a great influence on peak load and corresponding deformation values. The greater bond strength is, the greater peak load and corresponding deformation are.

The relationship between line’s initial slope of splitting test loading-deformation curve, the relationship between peak load and bond strength can be drawn. According to the relation graph and splitting test loading-deformation curve, the parameters of bond-model in discrete element can be regressed.

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