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Significant Analysis of Microscopic Parameters of Granite Model

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Abstract

Based on discrete element model of Hertz-Mindlin with Bonding (HMB), a trial error method is used to establish a numerical model of granite granite. PB test design method is used to significant analysis of meso-parameters, which affects the macro mechanical properties of rocks such as uniaxial compression strength (σ_c) and elastic modulus (E_c). The results showed that bonding tensile strength (σ^b), bonding normal stiffness (k_n^b) , particle elastic modulus (E_p) effect uniaxial compression strength significantly, bonding normal stiffness, stiffness ratio (R_k), particle elastic modulus effect elastic modulus significantly.

Keywords

Discrete element; granite granite; numerical simulation; significant analysis; meso-parameters.

1. Introduction

In rock construction such as tunnel construction, petroleum mining and mining, hard rocks are easy to break, which has a safety hazard on construction personnel and construction equipment, so it is of great significance for the mechanical properties of rocks. Numerical methods with a fast and low-cost advantage over real physical experiments have become an important method of simulating rock mechanics and studying rock rupture mechanism.

After continuous development, EDEM becomes a mature software suitable for discrete element, which can be used in combination with various software to coupling calculate, such as a large amount of application on particle multiple phase flows by coupling with CFD. EDEM is often used in rock mechanics. Cai[1] establishes a tungsten ore model by means of EDEM discrete element software, and studies the axial pressure crushing process of the ore model. Li[2] Based on EDEM uses a total-topical experimental design to study part of the meso-parameters of BPM, and quantitatively analyzes some of the microscopic factors and macro performance.

To meet the numerical coupling analysis of various rocks, the rock model required to build the discrete element software is the premise of completing these researches. It is determined that the significance of the microscopic factors affecting the performance of the rock mechanics is conducive to the rapid calibration of meso-parameters to establish the required rock discrete element model.

2. Establishment of granite model

2.1. Macro mechanical properties selection

There are a number of important mechanical parameters in rock materials. Text uses the uniaxial compression strength (σ_c) and elastic modulus (E_c) of rock under uniaxial compression as a characteristic value, σ_c is the maximum strength of the compression, calculation method of E_c is shown as

$$E_c = \frac{0.5\sigma_c}{\varepsilon_{0.75} - \varepsilon_{0.25}} \tag{1}$$

where $\varepsilon_{0.25}$ and $\varepsilon_{0.75}$ is the strain value of $0.25\sigma_c$ and $0.75\sigma_c$ on the stress-strain curve.

2.2. Meso-parameters selection

Hertz-mindlin with Bonding model for simulation calculation, as show in Figure 1, is built on the basis of Hertz, Potyondy et al[3]. The meso-parameters involved have particle density (ρ_p), particle Poisson's ratio (v_p), particle elastic model (E_p), recovery coefficient (e), static friction coefficient (μ_s), bonding normal stiffness (k_n^b), bonding stiffness ratio (R_k), tensile strength (σ^b), shear strength (τ^b), bonding radius (R_B) total 10 parameters.

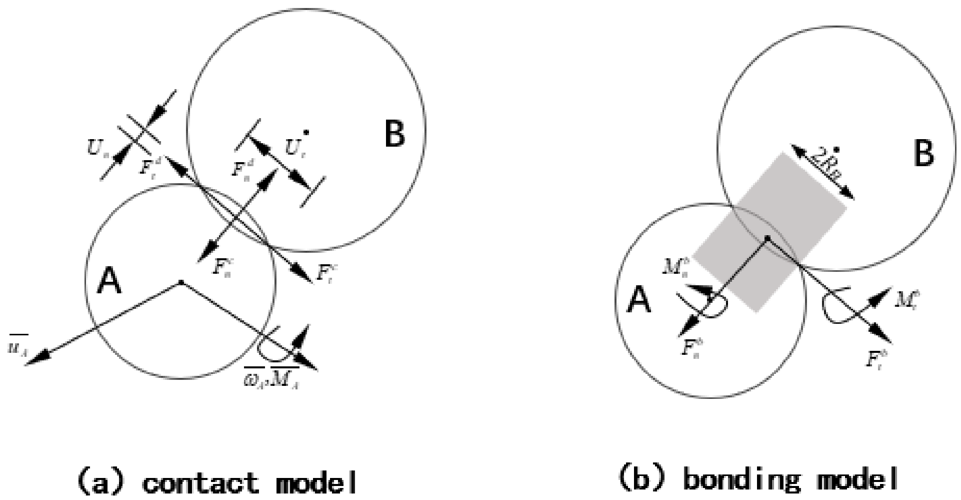

Figure 1 Theoretical model

Due to the difference in real granites and three-dimensional model, ρ_p cannot reflect the true density of granite, so it is selected by ensuring the total quality of the model and the quality of granite. Selected calculation formula is

$$\rho_p = \frac{M_r}{V_{sum,p}} \tag{2}$$

Where M_r is the quality of granite samples, $V_{sum,p}$ is the total volume of all particles and obtained by program statistics.

When the collision of the particles, e affect the size of the damping force. The damping force allows the particles to dissipate energy, mainly acting on the contact effect of the particles after bonding broken. The e is single-factor test, and it is found that σ_c and E_c has no effect, so take e is 0.2.

According to Potyondy[6], the ratio of τ^b and σ^b affects the destruction of rocks, and the adhesive shear destruction is reduced as the ratio increases. The tensile destruction and shear destruction should be present during the axial pressure crushing of the rock. In subsequent studies, the ratio of both is taken by 1, and τ^b changes with σ^b.

Since rocks are generally composed of tiny particles of different sizes, the particle size should also be analyzed as a microscopic parameter. The smallest radius (r_{min}) among all particles is chosen as the microscopic parameter. Note that when changing the particle size to generate the model, the total volume is kept unchanged, and the bonding radius (R_B) is taken as the average radius of the particles.

Finally, v_p, E_p, μ_s, k_n^b, R_k, σ^b, r_{min} a total of 7 meso-parameters were determined as experimental factors for analysis.

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2.3. Numerical model establishment

A standard rock model with a size of 50mm in diameter and 100mm in height was established, as show in Figure 2. Referring to the analysis and research on the mineral composition of granite by previous scholars, the proportion of feldspar, quartz and mica particles in granite is set to 12:7:1, the ratio of the maximum particle size to the minimum particle size is 1.66, and the particle size distribution is normal distributed ($\sigma^2 = 0.1$). According to the total volume of the particles, the particle density was determined to be 4274 kg/m^3.

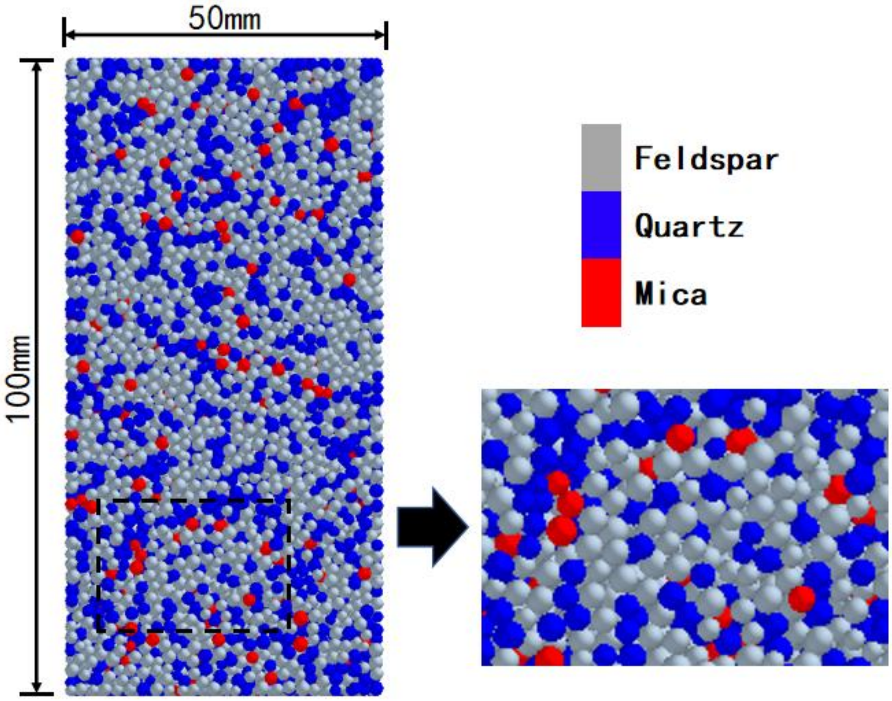

Figure 2 Granite model

Granite is composed of different minerals, and the mechanical properties of different minerals are different, so different particle meso-parameters are used to reflect this difference. Referring to the research of previous scholars[7], the relative hardness of minerals is considered to determine the elastic modulus and bonding parameter ratio of different particles. Take the elastic modulus of feldspar and the bonding parameter of feldspar-feldspar as the basic values, the elastic modulus of quartz and the bonding parameter of quartz-quartz are 1.2 times the basic value. the elastic modulus of mica and the bonding parameter of mica-mica are 0.4 times the basic value. The bonding parameters between different particles are taken as the average value of the two.

2.4. Numerical model validation

The mechanical properties of a granite standard sample were obtained through physical experiments ($\sigma_c^0 = 166.5$MPa、$E_c^0 = 17.9$GPa). The meso-parameters ($r_{min} = 0.75$mm, $v_p = 0.22$, $E_p = 20$GPa, $\mu_s = 0.5$, $k_n^b = 30$ GPa/mm, $R_k = 2$, $\sigma^b = 450$MPa) were selected by trial-and-error method for uniaxial compression, and the stress-strain curve was obtained as shown in Figure 3. According to the mechanical properties of the obtained granite model ($\sigma_c = 166.99$MPa、$E_c = 18.01$GPa), it can be seen that its stress-strain curve is consistent with the stress-strain curve of real granite under uniaxial compression.

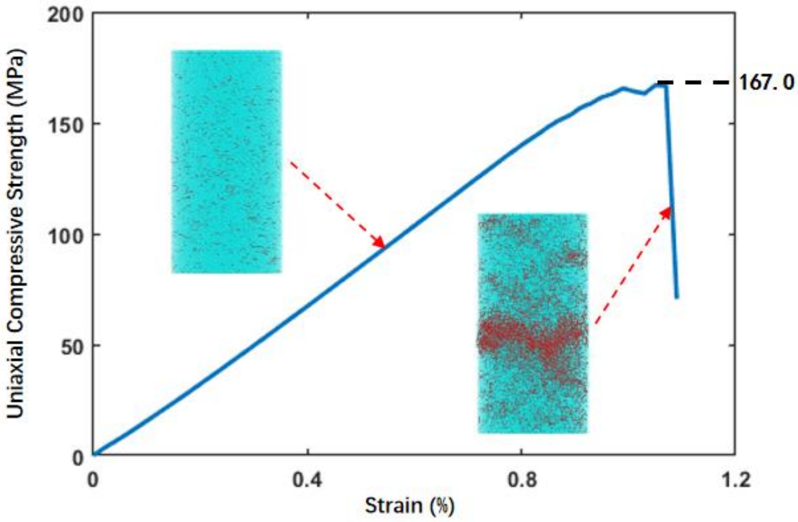

Figure 3 Stress-strain curve and model bonding state of the granite model

3. PB test

PB test is an effective method to detect the significance of test factors. The seven-factor PB test was carried out to study the significance of each meso-parameters on the uniaxial compressive strength and elastic modulus.

3.1. PB experimental design table

According to the results of the trial and error method, the selection range of the test factors is determined, which r_{min} is 0.75~1.05mm, v_p is 0.15~0.3, E_p is 20~50GPa, μ_s is 0.2~0.8, k_n^b is 30~90GPa/mm, R_k is 0.5~2.5, σ^b is 300 ~900MPa.

According to the value range of the experimental factors, the high and low levels in the PB design can be determined, as shown in Table 1.

Table 1 Test factor level

Test factor	Values for each level		
	-1	0	1
r_{min}/mm	0.75	0.9	1.05
v_p	0.15	0.225	0.3
E_p/GPa	20	35	50
μ_s	0.2	0.5	0.8
k_n^b/GPa	3×104	6×104	9×104
R_k	0.5	1.5	2.5
σ^b/MPa	300	600	900

Select the PB design table with 12 trials and add 2 center points. The trial table is shown in Table 2.

Table 2 PB experimental design table

Num	r_{min}	v_p	E_p	μ_s	k_n^b	R_k	σ^b
1	1	-1	1	1	-1	1	-1
2	1	-1	-1	-1	1	1	1
3	-1	1	1	-1	1	-1	-1
4	-1	-1	1	1	1	-1	1

5	1	1	-1	1	1	-1	1
6	-1	1	-1	-1	-1	1	1
7	-1	-1	-1	1	1	1	-1
8	1	1	1	-1	1	1	-1
9	1	-1	1	-1	-1	-1	1
10	0	0	0	0	0	0	0
11	1	1	-1	1	-1	-1	-1
12	-1	1	1	1	-1	1	1
13	0	0	0	0	0	0	0
14	-1	-1	-1	-1	-1	-1	-1

3.2. Analysis of test results

Uniaxial compression was performed on granite models with different meso-parameters according to the design of experiments table. The results of the mechanical properties of the granite are shown in Figure 4.

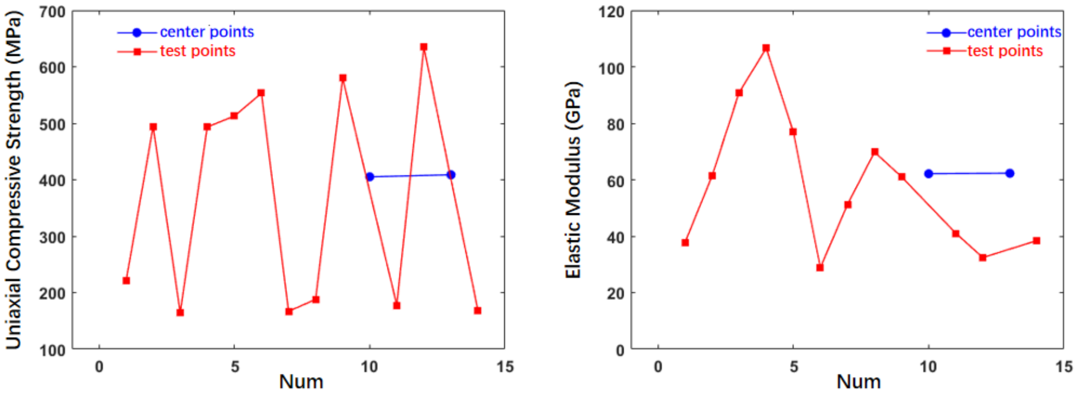

Figure 4 PB test results

The t-test with a significance level of 0.05 was used to judge the significance of the influence of each factor on the mechanical properties, and the Pareto effect diagram was established as shown in Figure 5.

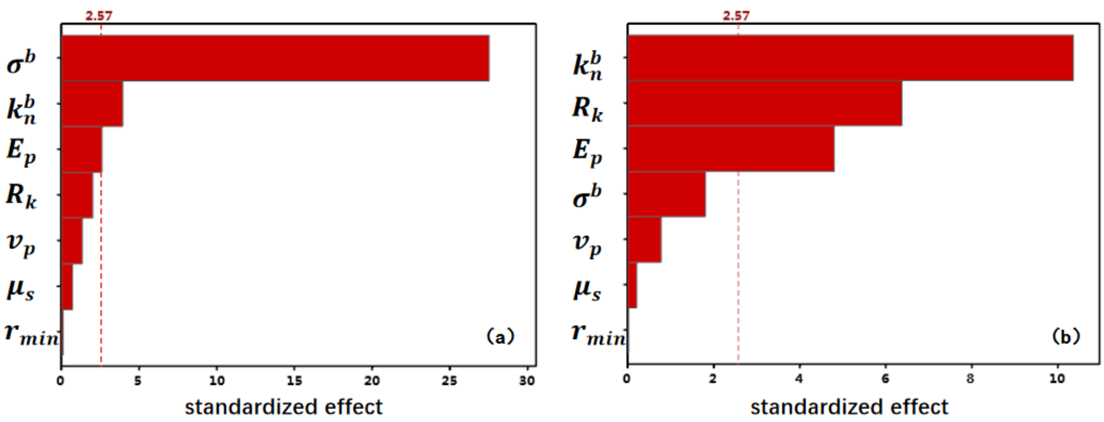

Figure 5 Pareto effect plot for meso-parameters: (a) Uniaxial compressive strength (b) Elastic modulus

It can be seen that σ^b, k_n^b, and E_p have significant effects on uniaxial compressive strength, and k_n^b, R_k, and E_p have significant effects on the elastic modulus. After removing the insignificant factors, a multiple linear regression equation was established for the remaining factors. The fitting results are shown as

$$\sigma_c = 10.8 + 1.159E_p - 0.000872k_n^b + 0.6063\sigma^b(R^2 = 0.986) \tag{3}$$

$$E_c = 18.96 + 0.559\mathrm{E_p} + 0.000603\mathrm{k_n^b} - 11.13\mathrm{k_n^b}/\mathrm{k_t^b}(\mathrm{R}^2 = 0.951) \tag{4}$$

The fitted formula is only used as a reference for meso-parameters selection due to the small number of data points. However, it can reflect part of the relationship between macroscopic mechanical properties (σ_c, E_c) and meso-parameters.

4. Conclusion

Based on the HMB model of EDEM, the meso-parameters of the granite model were studied and analyzed by numerical simulation. The following results are obtained:

(1) The granite model can be effectively constructed based on the HMB model. The stress-strain curve under uniaxial compression and the fracture shape of the rock model are consistent with the general granite physical test results. The mechanical properties and crushing morphology of the two are similar.

(2) The PB test method in the experimental design is used to study and analyze the meso-parameters that affect the mechanical properties of the rock model. Among the meso-parameters determined, σ^b, k_n^b, and E_p have significant effects on uniaxial compressive strength, and k_n^b, R_k, and E_p have significant effects on the elastic modulus. The regression formulas 3 and 4 obtained by fitting have certain reference significance.

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