SIMULATION TEST STUDY ON COMPACTION CHARACTER OF GROUTING BACKFILL IN CAVING AREA

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ABSTRACT

Based on discrete element theory, the particle flow model of backfill body in caving area is built, and the relation of particle mesomechanical character, such as contact stiffness, contact character, and macrocosm character is analyzed. By particle flow numerical simulation, dynamic process of grouting backfill in caving area, including coal mining, roof collapse and backfill, are realized. The influence of filling ratio, cementation character and elasticity modulus of backfill material to the compaction character of grouting backfill in caving area is studied. It is found that filling ratio, if more than 15%, compaction curve of the model changes sharply, is the most sensitive factor influencing compaction character of backfill body; in the same filling ratio, yield point of cementation strength of backfill body, controlled by cementation strength of backfill material, is critical factor influencing the quantity of compaction subsidence, but not influencing the limit quantity; the smaller the backfill ratio is, the influence of elasticity modulus on compaction character of backfill body is more evident.

Key words: Mining Engineering, Grouting Backfill in Caving Area, Compaction Character, PFC^{2D} particle flow code.

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INTRODUCTION

Coal-mining subsidence badly destroys environment[1]. Grouting backfill in caving area refers to any mineral waste material or sand that is placed into roof fall rocks in order to reinforce the roof fall broken rock[2-4]. Grouting backfill is performed to resist to roof fall and reduce surface subsidence. The grouting backfill method of fall rocks has been used in Poland for many years. The method is based on longwall with caving, and surface deformation value decreased 30~40%. The configuration of the roof fall rocks and grouting materials mixture is call to backfill; The backfill will be compacted after strata cracks; so the compaction character is a key factor influencing coal-mining subsidence; but the study on compaction character is lack.

So far, study means of compaction character of grouting backfill in caving area is still lack because of two reasons: first, the dynamic process of grouting backfill in caving area, including coal mining, roof collapsing, filling and compacting, are complicated, and the material contact constitutive relationships is variational in the process; so the dynamic process can’t be theoretically analyzed and tested in the laboratory. Secondly, the geological condition in the coal is intricate; so it is difficult to survey the compaction character in the field. There exists complicated structure and stress field in backfill, as enduring various complicated geological process during its formation history, which results in different properties of backfill. Such structures of backfill can be regarded as spatial structure system, which consists of single particle (assemblies and block). The way of force impressing and the deformation properties of backfill are determined by the form of the backfill cell such as single particle of mineral (assemblies and block). The structural strength of the backfill is determined by the bond type of the particles (point contact or plane contact), and the stability of the soil is determined by the particles arrangement. Such properties of backfill can be investigated from the viewpoint of meso-mechanics. Generally,the properties of backfill mainly depend upon its meso-composition an d structures either for fall rocks or for grouting materials mixtureIt is known that the backfill properties should be studied in the micro point of view,but it is too difficult to constitute quantity relation between macro and micro levels. The backfill properties can be simulated with meso-mechanics by particle flow code(PFC) and the macro-response of backfill can be an analyzed by investigating its meso-parameters.

The theory of particle flow is introduced in the paper, and the hypothesis of macro-continuity in traditional continuum mechanics has been removed. Based on the theory, the dynamic process of grouting backfill in caving area and compaction character are simulated, and the relations between meso-structure and macro-response are constituted. It has been understood more thoroughly on the compaction properties of backfill, such as critical filling ration and limit the limit quantity of compaction of backfill.

THEORETICAL BACKGROUND OF PFC^{2D}

PFC2D (Particle Flow Code in 2Dimensions) models the movement and interaction of circular particles by the distinct element method (DEM)[5]. It uses a two-dimensional code to model physical phenomena which are three dimensional in nature. *PFC2D* may be used to model static or dynamic problems, but the full dynamic equations of motion are solved even when static solutions are required. This is done in order to follow such phenomena as failure and “flow” of material in a realistic manner; it is not necessary to invoke some nonphysical algorithm, as done in some implicit methods. Modeling with *PFC2D* involves the execution of many thousands of timesteps. At each step, Newton’s second law is integrated twice for each particle to provide updated velocities and new positions, given a set of contact forces acting on the particle. Based on these new particle positions, contact forces are derived from the relative displacements of pairs of particles; a linear or nonlinear force/displacement law at contacts may be used. *PFC2D* is also able to model a brittle solid, by bonding every particle to its neighbor; the resulting assembly can be regarded as a “solid” that has elastic properties and is capable of “fracturing” when bonds break in a progressive manner. *PFC2D* contains extensive logic to facilitate the modeling of solids as close packed assemblies of bonded particles.The steps for performing an analysis with PFC2D include: (1) particle generation. (2) boundary and initial conditions. (3) choice of contact model and material properties. (4) loading, solution and sequential modeling. (5) interpretation of results.

PFC SIMULATION OF BACKFILL COMPACTION PROPERTIES

Assumptions

Based on discrete element theory and Particle Flow Code in 2Dimensions, assumptions follow as:

(1) The roof fall rocks and grouting materials mixture are treated as rigid circular Particles.

(2) Bonds can exist at contacts between grouting materials mixture particles, and grouting materials mixture particles are treated as the contact-bond model; the roof fall rocks are treated as the slip model.

PFC2D allows particles to be bonded together at contacts. Two bonding models are supported, a contact-bond model and a parallel-bond mode1. Both bonds can be envisioned as a kind of glue joining the two particles. The contact-bond glue is of a vanishingly small size that acts only at the contact point, while the parallel-bond glue is of a finite size that acts over either a circular or rectangular cross-section lying between the particles. The contact bond can only transmit a force, while the parallel bond can transmit both a force and a moment. The model is suitable to be used for the cohesive materials such as grouting materials.

The slip model is an intrinsic property of the two entities (ball-ball or ball-wall) in contact. It provides no normal strength in tension and allows slip to occur by limiting the shear force. The model describes the constitutive behavior for particle contact occurring at a point. And it is suitable to be used for the disseminate materials such as fall rocks.

(3) The stiffness are treated as elasticity modulus in the model of backfill.

PFC2D allows model to represent given individual particle, such as broken rocks, and to represent bonded together particles, such as concrete. The stiffness between particles can be visualize as elasticity modulus of the material.

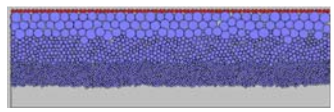
Numerial modeling of PFC^{2D}

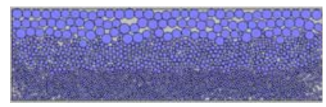
To analyse grouting Backfill in long wall Caving Area of a coal mine mining in china , the particle flow model of backfill body in caving area is built as Figure 2., and the model is 40×12 m. Firstly, the boundary of the model was defined; it constitute three walls, the bottom boundary wall simulate the seam floor ,and another two walls simulate the pillars which are not mined; second, the parallel joint particles simulate the hard strata above the immediate roof as the loaded plate; last, 3m coal particle was built, including 48620 particles,9m immediate roof sandstone particle, including 71862 particles. The immediate roof is divide into 3m layers; the particles in every layer are stochastic in appointed area; the radii of the particles from the bottom up is increasing; particle radius are distributing averagely. The contact model between the particle and the wall is the linear elastic model.

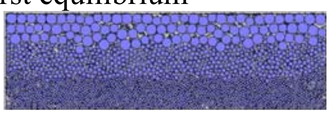
Process of the simulation

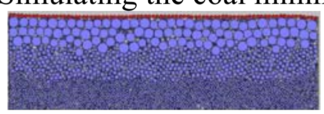
The simulation of dynamic process can be divided into 6 steps (figure 1.).


a. first equilibrium


b. Simulating the coal mining


c. falling of roof


d. grouting backfill


e. compaction process

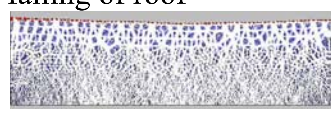

f. compaction

Figure 1.: The simulation of dynamic process of coal mining and backfill.

Disposing measure place after first equilibrium (Figure 1a.). the model should reach balance by itself gravitation, then load it to initial rock stress state, all the measure place's Y-coordinate are 12m, which are tracking the vertical movement of the particle and note the vertical displacement of each measure place. Simulation of the coal mining. The particles was deleted ranging from 0 to 3m in the model to simulate the coal mining, as Figure 1b. shown simulation of the immediate roof caving (Fig.1c-). The model was unloaded; because of the gravity, by calculating ,the immediate roof is full caved and the model shows a lot of voids. Simulation of grouting backfill (Figure 1d.). The particles of grouting materials mixture were filled into voids in the model. According to r, which refers to filling ration in the model, the number of the particles of grouting materials mixture can be calculated. The formula of backfill ratio is as follwing

$$r = \frac{v_1}{v} = \frac{n_1}{n} \qquad (1)$$

Where; v1 denote volume of grouting materials mixture; v denote volume of mining coal; n1 denote the number of the particles of grouting materials mixture; n denote the number of the particles of coal. Compaction process (Figure 1e.). According the model, the load σ was placed on hard strata; Y-coordinate was recorded as mean value of displace, and then start to calculate last compaction (Figure 2f.). Y-displace should be recorded according to the calculation.

$$\varepsilon\ \Delta h/h=(\Delta s+h-12)/h \qquad (2)$$

where ε is the vertical strain of the backfill, □s is the vertical placement of the particle, □h is the compress subsidence of the backfill, h is the compress subsidence of the backfill creat backfill particle in the voids of the model directly, Basic parameters of backfill model are as table 1., based on the backfill ratio in the simulation project, use formula (1) to work out the amount of the backfill particle, the contect stiffness between backfill particles is cementation strength.

Choice of the parameters in the PFC model

In the PFC model, the parameters of backfill model are based on the result of mechanics text and the size of the model. The parameters of the PFC model were Modulated time after time to ensure the based parameters of coal and sandstone, till the vertical placement in the result of the numerical simulation is similar with the immediate roof subsidence of practical long wall mining backfill ratio =0

Table 1.: Basic parameters of backfill model

Particle name	Density/ (kg.m-3)	radius /m	Contact modulus/GPa	Friction coeff.
Coal	1.15	0.05	6	0.7
Sand rock	1.6	0.08 ~ 0.45	0.95	0.7
Grouting material	1.25	0.05	2	60

Making Plans of Simulation Test on Compaction

There are many factors influencing the characteristic of backfill, such as the load above the immediate roof, the cementation strength, elasticity modulus of the backfill model and filling ratio. Based on the influence factor, the particle flow model of backfill body in caving area were build as following:

(1) To study the connection between the backfill ratio and compaction curve of the backfill body, the amount of the particles in the model of backfill body was changed.

(2) The cementation strength of backfill material was changed in order to study the relation between the cementation strength of backfill body and compaction curve of the backfill body.

(3) To study relation between elasticity modulus and compaction curve of the backfill body, Contact modulus in the model of backfill body was changed.

ANALYSIS OF SIMULATION TEST

The connection between the backfill ratio and compaction curve of the backfill body

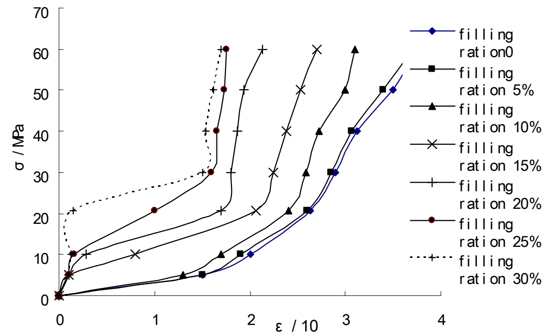


Figure 2.: The relation of backfill ratio and compaction curve

Figure 2. shows the connection between the backfill ratio and compaction curve under the condition that the cementation strength is 2MPa.

Figure 2. indicates the backfill ratio is the key factor compaction character of backfill body; if more than 15%, compaction curve of the model become smaller sharply with the increase of the backfill ratio: when the backfill ratio is 5%, compaction curve of the model is nearly the same with that of backfill ratio is 0;the three compaction curve which filling ratio is less than15% are similar, they are increasing curve, but when the backfill ratio is more than 15%, the form of the compaction curve changes a lot. So we can call 15% a critical backfill ratio, the engineering meanings is: it is meaningless to try to use backfill to control the subsidence of roof and the ground surface when the backfill ratio is less than 15%.

The relation between the cementation strength and compaction curve

Figure 3. reflects the relation of cementation strength and compaction.

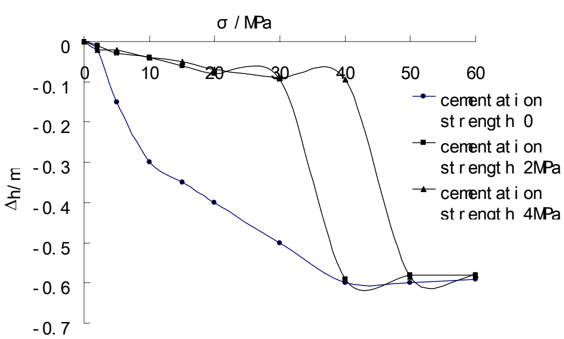


Figure 4.: The relation of cementation strength and compaction.

Figure 3. indicates yield point of cementation strength of backfill body with filling ration of 30% is 22 MPa; it is very evident that compaction curve in the cementation filling model

has inflexion. If the load value is less than 22 MPa, compaction value is very small. If the load value is more than 22 MPa, compaction value goes up sharply.

Relation between elasticity modulus and compaction curve

Figure 4. shows that compaction curve of the backfill body of filling ration of 30, resemble the one of filling ration of 25, tow curve is smooth. Compaction curve of the backfill body of filling ration of 10 and 20% resemble the one of filling ration of 0, three curve is sharper than 25. It is concluded that the smaller the backfill ratio is, the influence of elasticity modulus to compaction character of backfill body is more evident.

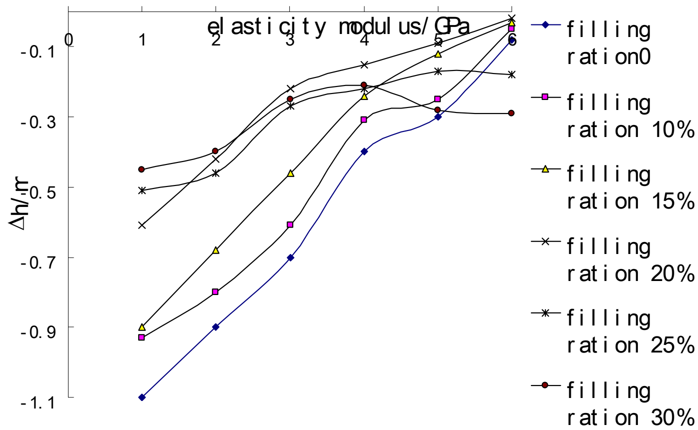


Figure 4.: The relation of stiffness and subsidence quantity.

CONCLUSION

(1) PFC^{2D} can add or delete particle at any time, and the contact constitutive relationships can be formed automatically, and dynamic process of grouting backfill in caving area, including coal mining, roof collapse and backfill, are simulated effectively. It’s very easy to simulate the compaction character of grouting backfill body by changing micro parameter, which meaning of the corresponding character is clear in the PFC model. The result of the numerical simulation can direct the physics model experiment.

(2)The PFC simulation indicates that the filling ratio is the key factor influencing the compaction character, filling ration of 15% is the critical value, when filling ration is more than 15%, compaction curve of the model changes sharply, but when less than 15% compaction curve of the model changes slowly, nearly as the curve on condition of filling ratio of 0.

(3) Compaction curve in the cementation filling model has inflexion; If the load value is less than inflexion, compaction value is very small; If the load value is inflexion, compaction value goes up sharply;

(4) With the increasing of the backfill ratio, the influence of elasticity modulus on compaction curve is less evident.

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