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Research on Shock Mechanism for Flying Gangue in Steeply Dipping Seam Mining

Ming Liu*[,1] and Yongping Wu[2]

[1]*College of Sciences, Xi'an University of Science and Technology, Xi'an, 710054, P.R. China*

[2]*School of Energy, Xi'an University of Science and Technology, Xi'an, 710054, P.R. China*

Abstract: Aim at the random problems of flying gangue movement in steeply dipping seam mining, based on the spherical flying gangue movement model, computational formula of collision restitution coefficient was established when flying gangue shocks bottom plate of working face according to the theory of Hertz classical elastic collision; Considering the influences of the randomness such as the density, radius size, impact velocity of flying gangue, the elastic modulus, Poisson's ratio of contact bottom plate of working face, the motion model of flying gangue with stochastic parameter was constructed by applying the random factor method; and the mean value and the variance of the collision restitution coefficient were derived by using the algebra synthesis method and moments method. The numerical examples show that the randomness of parameters has a rather large influence on the collision restitution coefficient of flying gangue in steeply dipping seam mining.

Keywords: Collision restitution coefficient, flying gangue, stochastic parameter, steeply dipping seam mining.

1. INTRODUCTION

Due to the environment of steeply dipping seam mining is complex, and there are many random factors exist in the process of mining, and the flying gangue is very easy to slide. The shock of flying gangue is so large that it is easy to hurt people, and is also easy to damage the brackets and smash the equipments. At present, few scholars engaged in the study of the flying gangue movement in steeply dipping seam mining from the literature published at home and abroad. Jiang Li-guo [1] who relates the motion of coal gangue with the motion of collapse and rockfall. The theory methods to solve impact force mainly are based on Hertz contact theory and the conservation of energy [2, 3]. Because the theoretical calculation of rockfall impact force is difficult, some scholars established empirical formulae of computing the impact force by experiment [4]. such as Japan road association, Yang Qi-xin [4], Pichler [5], Labiouse [6] established different empirical formulae of computing the rockfall impact force through many experiments. Although the motion of flying gangue can be linked with the motion of collapse and rockfall, but the definite empirical formulae were used in the research of rockfall movement, and the influence of the randomness of the parameters was not considered in the past. In reality, the law of motion of flying gangue in steeply dipping seam mining is very complicated, so it is difficult to have an accurate calculation for impact movement of flying gangue, the real collision between flying gangue and working face floor has highly randomness. Therefore the paper use the flying gangue in steeply dipping seam mining as a analysis model, considering all parameters are random, such as the size of flying gangue, and the elastic modulus, Poisson's ratio of contact bottom plate of working face, the digital features of normal collision restitution coefficient of flying gangue in steeply dipping seam mining were analyzed by applying the random factor method.

2. CALCULATION MODEL OF COLLISION IMPACT FORCE OF FLYING GANGUE

The shock response of flying gangue in steeply dipping seam mining is simplified into the shock of free fall of a rigid sphere on the semi-infinite elastic plastic body, assuming that the flying gangue free fall from a height, and it impact the rock mass of slope surface. The collision of the flying gangue on slope surface as shown in Fig. (**1**), we can do the following assumptions in order to research the problem conveniently:

1. The shape of slope surface is made of linear slope surface, the material of slope surface is homogeneous and isotropic elastoplastic;
2. Flying gangue was simplified as a sphere, the quality is uniform distribution and isotropic ideal elastoplastic, there is a certain angle between the impact velocity of flying gangue and the slope surface.

The impact velocity will be break up into two parts that along the normal and tangential

$$V_n = V\sin\alpha\ ;\ V_t = V\cos\alpha \tag{1}$$

where V_n and V_t are the tangential impact velocity and the normal impact velocity of flying gangue impact on the slope surface respectively; V is the impact velocity of flying

*Address correspondence to this author at the College of Sciences, Xi'an University of Science and Technology, Xi'an, Shaanxi, 710054, P.R. China; Tel: 13679202499; E-mail: liuming1075@163.com

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gangue; α is the angel between impact velocity of flying gangue and the slope surface.

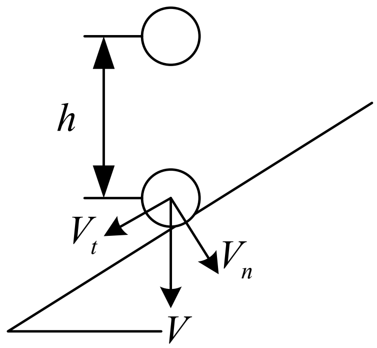

Fig. (1). Move model of flying gangue on slope.

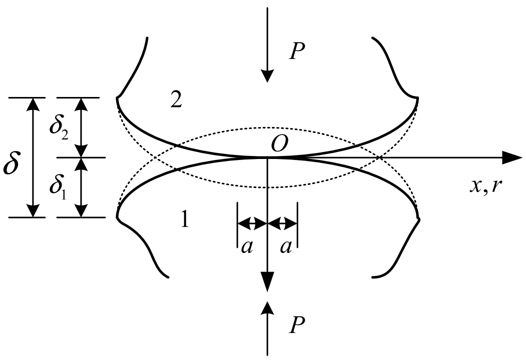

Fig. (2). Hertz contact problem.

The Hertz [7-9] gives an accurate non-linear model for the elastic contact problem of two different bodies as shown in Fig. (**2**). Calling P the contact force between two spheres of radius R_i, calling E_i the elastic modulus, calling ν_i the Poisson coefficient, the Hertz pressure distribution over the circular contact area of radius a is semi-elliptical

$$p(r)=\frac{3P}{2\pi a^2}\left[1-\left(\frac{r}{a}\right)^2\right]^{\frac{1}{2}} \tag{2}$$

The radius of contact area is

$$a=\left(\frac{3PR}{4E}\right)^{\frac{1}{3}} \tag{3}$$

The maximum value of the contact pressure [10-14] is

$$P_{\max}=\frac{3P}{2\pi a^2} \tag{4}$$

The deformation of contact and contact area has the following relationship

$$a^2=R\delta \tag{5}$$

where R is equivalent radius, and $\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}$

where R_1 and R_2 are the radius of the rock formations and flying gangue respectively. Under the condition of rock formations as a plane, $R_1\to\infty$, so there is $R=R_2$.

3. ANALYSIS OF RANDOM CHARACTERISTIC OF THE COLLISION RESTITUTION COEFFICIENT

In fact, the slope of rock mass is elastic-plastic material, when the maximum contact stress exceeds the yield strength of the rock mass slope; the next is to generate the plastically deforming area in the contact area. The relationship between the yield stress of slope and initial yield contact radius was given by formula (2) and formula (3) as follow

$$a_y=\frac{\pi R p_y}{2E} \tag{6}$$

where p_y is yield stress of contact material, it can be determined by experiment.

If the relative impact velocity is just large enough to initiate yield in one of the sphere then we can get [15]

$$\frac{1}{2}mV_y^2=\int_0^{a_y}P\,\mathrm{d}\delta=\frac{8Ea_y^5}{15R^2} \tag{7}$$

where V_y is defined as the yield velocity, it is the relative impact velocity below which the interaction behavior is assumed to be elastic, a_y is the contact radius when yield occurs.

Substituting formula (6) into formula (7) , we obtain

$$\begin{aligned}V_y&=\left(\frac{\pi}{2E}\right)^2\left(\frac{8\pi R^3}{15m}\right)^{\frac{1}{2}}\left(p_y\right)^{\frac{5}{2}}\\&=\frac{\pi}{\sqrt{30}}\frac{R^{\frac{3}{2}}}{E^2m^{\frac{1}{2}}}\left(p_y\right)^{\frac{5}{2}}=\frac{\sqrt{10\pi}}{20}\frac{\left(1-\nu_1^2\right)^2}{E_1^2\rho_2^{\frac{1}{2}}}\left(p_y\right)^{\frac{5}{2}}\end{aligned} \tag{8}$$

Assumption that the material meets the ideal elastic-plastic characteristics, Thornton deduced the computational formula of collision restitution coefficient of sphere based on Hertz contact theory

$$\begin{aligned}e_n=&\left\{\left(\frac{6\sqrt{3}}{5}\right)\left[1-\frac{1}{6}\left(\frac{V_y}{V_n}\right)^2\right]\right\}^{\frac{1}{2}}\cdot\\&\left\{\left(\frac{V_y}{V_n}\right)\left[\left(\frac{V_y}{V_n}\right)+2\sqrt{\frac{6}{5}-\frac{1}{5}\left(\frac{V_y}{V_n}\right)^2}\right]^{-1}\right\}^{\frac{1}{4}}\end{aligned} \tag{9}$$

where e_n is collision restitution coefficient of flying gangue; V_n is the normal impact velocity of flying gangue.

Letting $Z=\frac{V_y}{V_n}=\frac{\sqrt{10\pi}}{20}\frac{\left(1-v_1^2\right)^2}{E_1^2\rho_2^{\frac{1}{2}}V\sin\alpha}\left(p_y\right)^{\frac{5}{2}}$

The following formula can be obtained by using random factor method [16-18]

$$Z=\frac{V_y}{V_n}=\frac{\sqrt{10\pi}}{20\sin\alpha}\frac{\left(p_y\right)^{\frac{5}{2}}}{\bar{E}_1^2\bar{\rho}_2^{\frac{1}{2}}\bar{V}}\frac{\left(1-\bar{v}_1^2\tilde{v}_1^2\right)^2}{\tilde{E}_1^2\tilde{\rho}_2^{\frac{1}{2}}\tilde{V}}=c\frac{z^2}{\tilde{E}_1^2\tilde{\rho}_2^{\frac{1}{2}}\tilde{V}} \tag{10}$$

where $c=\frac{\sqrt{10\pi}}{20\sin\alpha}\frac{\left(p_y\right)^{\frac{5}{2}}}{\bar{E}_1^2\bar{\rho}_2^{\frac{1}{2}}\bar{V}}$ is the constant term.

The mean value and the variance were derived by using the algebra synthesis method

$$\mu_Z=c\left(\mu_{z/\tilde{E}_1}^2+\sigma_{z/\tilde{E}_1}^2\right)\left(1-\frac{\gamma_{\rho_2}^2}{2}\right)^{-\frac{3}{4}}\left(1+\gamma_V^2\right) \tag{11}$$

$$\begin{aligned}\sigma_Z^2=c^2\{&(1-\frac{\gamma_{\rho_2}^2}{2})^{-\frac{1}{2}}(2\mu_{z/\tilde{E}}^2\sigma_{z/\tilde{E}_1}^2+\sigma_{z/\tilde{E}_1}^4-\mu_{z/\tilde{E}_1}^4)\\&+(\mu_{z/\tilde{E}_1}^2+\sigma_{z/\tilde{E}_1}^2)^2[(1-\frac{\gamma_{\rho_2}^2}{2})^{-1}+\gamma_V^2(1-\frac{\gamma_{\rho_2}^2}{2})^{-\frac{3}{2}}]\}\end{aligned} \tag{12}$$

where $\mu_{z/\tilde{E}_1}=\left(1+\gamma_{E_1}^2\right)\left[1-\bar{v}_1^2\left(1+\gamma_{v_1}^2\right)\right]-6^{\frac{1}{2}}C_{\tilde{E}_1z}\bar{v}_1^2\gamma_{E_1}\gamma_{v_1}$

$$\sigma_{z/\tilde{E}_1}^2=\left[1-\bar{v}_1^2\left(1+\gamma_{v_1}^2\right)\right]^2\left(\gamma_{E_1}^2+6\bar{v}_1^4\gamma_{v_1}^2\right)-2\cdot 6^{\frac{1}{2}}\bar{v}_1^2C_{\tilde{E}_1z}\gamma_{E_1}\gamma_{v_1}\left[1-\bar{v}_1^2\left(1+\gamma_{v_1}^2\right)\right]$$

$$\mu_{(z/\tilde{E})^2}=\mu_{z/\tilde{E}}^2+\sigma_{z/\tilde{E}}^2,\sigma_{(z/\tilde{E})^2}^2=4\mu_{z/\tilde{E}}^2\sigma_{z/\tilde{E}}^2+2\sigma_{z/\tilde{E}}^4$$

$$\mu_{\rho_2^{\frac{1}{2}}}=\left(\frac{1}{2}\sqrt{4-2\gamma_{\rho_2}^2}\right)^{\frac{1}{2}},\sigma_{\rho_2^{\frac{1}{2}}}^2=1-\frac{1}{2}\sqrt{4-2\gamma_{\rho_2}^2}$$

$$\mu_{(z/\tilde{E})^2/\tilde{\rho}_2^{\frac{1}{2}}}=\frac{\mu_{(z/\tilde{E})^2}}{\mu_{\rho_2^{\frac{1}{2}}}^3}=\frac{\mu_{z/\tilde{E}}^2+\sigma_{z/\tilde{E}}^2}{\mu_{\rho_2^{\frac{1}{2}}}^3}=\left(\mu_{z/\tilde{E}}^2+\sigma_{z/\tilde{E}}^2\right)\left(1-\frac{\gamma_{\rho_2}^2}{2}\right)^{-\frac{3}{4}}$$

$$\sigma_{(z/\tilde{E})^2/\tilde{\rho}_2^{\frac{1}{2}}}^2=\left(1-\frac{\gamma_{\rho_2}^2}{2}\right)^{-\frac{1}{2}}\left(2\mu_{z/\tilde{E}}^2\sigma_{z/\tilde{E}}^2+\sigma_{z/\tilde{E}}^4-\mu_{z/\tilde{E}}^4\right)+\left(1-\frac{\gamma_{\rho_2}^2}{2}\right)^{-1}\left(\mu_{z/\tilde{E}}^2+\sigma_{z/\tilde{E}}^2\right)^2$$

The mean value and the variance of the collision restitution coefficient of flying gangue were derived by using the moments method that solving the random variable digital characteristics.

$$\mu_{e_n}=\left[\left(\frac{6\sqrt{3}}{5}\right)\left(1-\frac{1}{6}\mu_Z^2\right)\right]^{\frac{1}{2}}\cdot\left[\mu_Z\left(\mu_Z+2\sqrt{\frac{6}{5}-\frac{1}{5}\mu_Z^2}\right)^{-1}\right]^{\frac{1}{4}} \tag{13}$$

$$\sigma_{e_n}^2=(\frac{6\sqrt{3}}{5})^{\frac{1}{2}}\{\frac{[\mu_Z^{-\frac{3}{4}}\sqrt{1-\frac{1}{6}\mu_Z^2}-\frac{1}{6}\mu_Z^{\frac{5}{4}}(1-\frac{1}{6}\mu_Z^2)]}{\mu_Z+2\sqrt{\frac{6}{5}-\frac{1}{5}\mu_Z^2}}-\frac{\mu_Z^{\frac{1}{4}}\sqrt{1-\frac{1}{6}\mu_Z^2}[1-\frac{2}{5}\mu_Z(\frac{6}{5}-\frac{1}{5}\mu_Z^2)^{-\frac{1}{2}}]}{\left(\mu_Z+2\sqrt{\frac{6}{5}-\frac{1}{5}\mu_Z^2}\right)^2}\}\sigma_Z^2 \tag{14}$$

4. RESULTS

The analysis program for calculating the normal collision restitution coefficient of flying gangue in steeply dipping seam mining was completed according to the above calculation formula and calculation method for solving random variable digital features. The lithology of working face floor is sandstone, considering elastic modulus of the floor materials E_1, Poisson's ratio v_1, the density of flying gangue ρ_2, radius R_2 and impact velocity V are all random variable, their averages are: $\mu_{E_1}=2.5\times10^4MPa$, $\mu_{\rho_2}=2580kg/m^3$, $\mu_{v_1}=0.2$, $\mu_{R_2}=0.2m$, $\mu_V=8m/s$; seam inclination $\theta=45^\circ$, the yield stress of contact surface $p_y=35MPa$, due to the strong correlation of the same material, correlation coefficient $C_{\tilde{E}_1z}=0.6$. In order to study the influence of random parameters on the collision restitution coefficient for flying gangue, considering one and all of the modulus of elasticity E_1, density of mass ρ_2, Poisson's ratio v_1, radius R_2 and impact velocity V as random variables in the calculation model respectively.

The numerical simulation results of the mean and variance of the collision restitution coefficient when the coefficient of variation $\gamma=0.1$ are shown in Table **1**. Where $\gamma\left(all\right)$ express the normal collision restitution coefficient for flying gangue when all the parameters are random, and $\gamma\left(v_1\right)$, $\gamma\left(E_1\right)$, $\gamma\left(\rho_2\right)$, $\gamma\left(V\right)$ express the normal collision restitution coefficient for flying gangue when one of the parameters is random.

Figs. (**3, 4**) show the curve of the mean and the variance that the different random parameters on normal collision

Table 1. The mean and variance of the collision restitution coefficient in normal.

Variable Coefficient	*all*=0.1	v_1=0.1	E_1=0.1	ρ_2=0.1	*V*=0.1
μ_{e_n}	0.1030	0.1019	0.1027	0.1021	0.1022
$\sigma^2_{e_n}$	1.713E-8	1.365E-10	1.427E-8	8.924E-10	3.531E-9

restitution coefficient for flying gangue. We can see that from Fig. (**3**): the mean curves of the normal collision restitution coefficient are rise with the increase of coefficient of variation. Fig. (**3**) illustrates: the randomness of the elastic modulus of the floor materials and the impact velocity has larger influence on normal collision restitution coefficient of flying gangue. By contrast, the randomness of the mass density and the Poisson's ratio has smaller influence on normal collision restitution coefficient of flying gangue. We can see that from Fig. (**4**): the randomness of the elastic modulus of the floor materials has largest influence on the dispersion of normal collision restitution coefficient, then the randomness of the impact velocity and the mass density of flying gangue, the randomness of the Poisson's ratio of the floor materials has smallest influence on the dispersion of normal collision restitution coefficient.

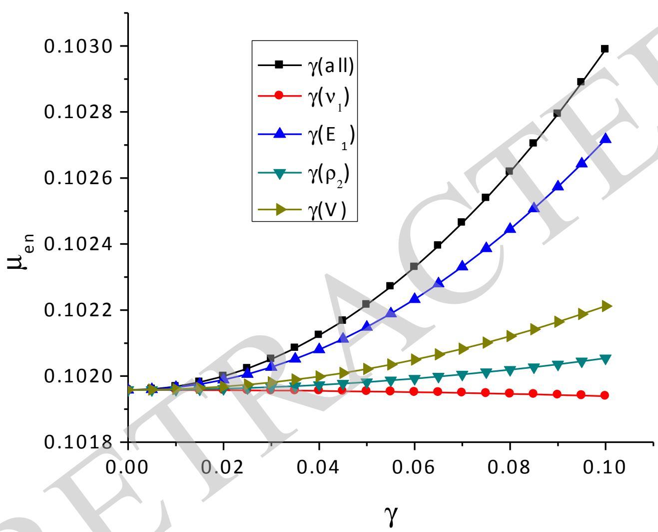

Fig. (3). The mean of the collision restitution coefficient in normal.

CONCLUSION

This paper derived the mean value and the variance of the normal collision restitution coefficient of flying gangue with stochastic parameter. The influence of the random parameters on the mean of the normal collision restitution coefficient of flying gangue is analyzed through program. The results show that the randomness of parameters has a rather large influence on the randomness of the normal collision restitution coefficient of flying gangue in steeply dipping seam mining. The randomness of the elastic modulus of the floor materials and the impact velocity has larger influence on normal collision restitution coefficient of flying gangue. The mass density and the Poisson's ratio has smaller influence on normal collision restitution coefficient of flying gangue.

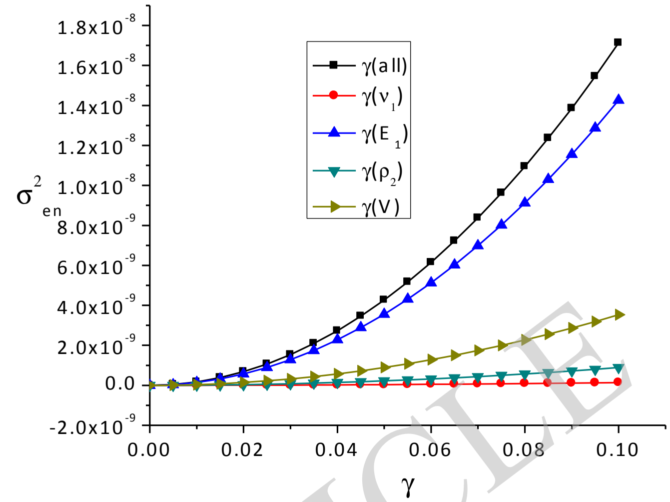

Fig. (4). The variance of the collision restitution coefficient in normal.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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