Study on Material Model and Pressure Distribution Characteristics of Off-highway Mining Dump Truck Bucket

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Abstract: In view of the existing problems in the calculation method of the external contour of the material accumulation of the off-highway mining dump truck bucket, the reverse engineering technology and the 3D laser scanning method are proposed to accurately obtain the 3D model of the material distribution in the truck bucket. Based on the three-dimensional solid model of the material, the pressure formulas of the front plate, the side plate and the bottom plate of the bucket are derived by the force analysis method based on the thin-layer element method. References for the structure design and performance analysis of dump truck bucket are provided.

1. Introduction

An important basis for the structural design and performance analysis of the body of heavy mining dump truck is the distribution characteristics of the bulk pressure in the body. The study of pressure distribution characteristics can not only realize the lightweight design of the body, but also play an important role in the failure analysis and improvement of the body under complex loads. In order to study the characteristics of calculated pressure distribution, two problems need to be solved. One is the calculation of the material block model of the heavy dump truck, the other is the calculation of the body pressure based on the determined material block model.

There are three kinds of calculation methods given by researchers at home and abroad for the material distribution profile in the body of off highway mining dump truck: ISO standard 6483 [1] in 1980, SAE standard J1365 [2] in 1995 and Philip hagenbuch's "a light mining dump truck body" patent founder profile curve fitting Law. According to the research of the first two methods, it is found that the center of mass position of the material contour shape predicted by this standard is deviated from that of the field investigation [3]. The third method only selects 15 discrete points for approximate fitting, and the data is not accurate enough. In this paper, three-dimensional laser scanning technology is used to obtain the three-dimensional simulation model of material distribution in the body [4]. At present, most of the pressure calculation methods are for the rectangular body of the road dump truck. The calculation methods mainly include the classical Rankine theory and Coulomb theory, AAR standard of American Railway Society, and many scholars such as Hong Yuanshan, Wang Shouchang, Liu Dawei[5-7], have improved or explored the classical Rankine and Coulomb theory, all of which
have greatly improved the calculation accuracy and are closer to the measured value.

2. Implementation process of 3D scanning technology for body material distribution shape

2.1 Scheme introduction
This scanning scheme is mainly based on the equivalent principle. Through the new 930E body model with a load of 290 tons, which is manufactured in 100:1 ratio, 3D laser scanning is carried out according to the body loading material model obtained in the free loading state. Scanning is carried out in the front and rear directions of the body respectively. The auxiliary equipment adopts spherical reflection target. The scanning time point spacing is set to 5cm, and the accuracy is 1cm. After scanning, the point cloud registration is carried out with Trimble Real Works [5], and the registration accuracy meets the requirements according to the point cloud registration quality evaluation table. The scanning results of the registered dump truck are shown in Figure 1.

![Three dimensional scanning diagram of dump truck loading materials](image1)

![Material 3D solid model](image2)

2.2 Calculation of 3D solid model
According to the 3D coordinates output by 3D scanning technology, after data screening and filtering, the material distribution function in the body is obtained as follows:

\[
Y = 6742.3\left[1 - \left(\frac{X}{7218.6}\right)^2\right]\left[1 - \left(\frac{Z - 3265.5}{8345.5}\right)^2\right]
\]

In Formula 1, X = 0 represents the middle plane; Y = 0 represents the horizontal plane passing through the boundary line of the base plate and the front plate; Z = 0 represents the vertical plane passing through the boundary line of the base plate and the front plate.

In MATLAB, the material contour surface inside the hopper is generated, which is combined with each side of the body to get a three-dimensional solid model, as shown in Figure 2. By comparing the total volume of the model with the volume of the stacking model given by SAE standard, the relative error is less than 5%, so the 3D CAD model obtained by 3D scanning technology is reliable.

3. Force analysis based on thin layer element method
According to Liu Dawei’s research[7] on rectangular carriage, and based on the assumption of plane slip surface of Coulomb theory and considering the complex situation of cohesive force, internal friction angle and so on of bulk material, the pressure calculation formula of each plate of V-type bucket of heavy dump truck is derived by using thin layer element method.
3.1 Calculation of body bottom plate pressure

Figure 3. Stress analysis of body bottom plate, sliding wedge and thin layer element

Here BJ: Slip surface of bulk material; $a$: Angle between front plate and horizontal plane; $\beta$: Angle between base plate and horizontal plane; $R_1$: Front plate force; $R_2$: Slip surface force; $\phi$: Internal friction angle of bulk material; $\epsilon$: Angle between sliding surface and vertical surface; $c$: Bulk cohesion; $C_w$: Adhesion between bulk material and front plate; $dw$: Unit gravity; $P$: Top vertical force; $P+dp$: Bottom vertical reaction; $\delta$: Friction angle between bulk material and front plate of body.

Figure 3 shows the longitudinal section of the body filled with materials. The coal material acting on the bottom plate of the body is divided into two parts: CBJ and AEBJ, and AE and BJ are parallel to the sliding surface. The pressure of the bulk material on the bottom plate in the area aebj acts on the AJ area of the bottom plate, and the pressure of the bulk material on the bottom plate in the area BJC acts on the JC area of the bottom plate.

3.1.1 Take a thin layer of bulk unit PQUT in the coal material CBJ area.

According to the equilibrium conditions of the horizontal and vertical forces acting on the element, the following results can be obtained:

$$
- P \cos(\epsilon + \phi) + c \cos \epsilon \bigg|_{PT} - \bigg[ R \sin(\delta + \beta) + c w \cos \beta \bigg|_{TU} +

\left[ (p + dp) \cos(\phi + \epsilon) - c \sin \epsilon \right]_{QU} = 0
$$

(2)

$$
[ P \sin(\epsilon + \phi) + c \cos \epsilon \bigg|_{PT} + \bigg[ c w \sin \beta - R \cos(\delta + \beta) \bigg|_{TU} -

\left[ (p + dp) \sin(\phi + \epsilon) + c \cos \epsilon \right]_{QU} + dw = 0
$$

(3)

According to geometric relationship: $BC = L$; $Bp = l$; $PQ = dl$ so

$$
QU = (L - l - dl) \frac{\sin(\alpha + \beta)}{\cos(\beta - \epsilon)}; \quad PT = (L - l) \frac{\sin(\alpha + \beta)}{\cos(\beta - \epsilon)}; \quad TU = \frac{dl \cos(\alpha + \epsilon)}{\cos(\beta - \epsilon)};
$$

Thus, the area $S$ of the bulk unit PQUT can be obtained.

According to the dead weight of bulk unit

$$
dw = \gamma \cdot S = \frac{2 \left( 2L - 2l - dl \right) \sin(\alpha + \beta) \cos(\alpha + \beta)}{\cos(\beta - \epsilon)}
$$

Bring it into equation (2) and equation (3), and the force $R$ of the bottom plate in the CBJ area of the body is adjusted, so

$$
R = \frac{\gamma L - c_u \left[ \sin \alpha \sin(\phi + \epsilon) + \cos \alpha \tan(\epsilon + \phi) \right]}{\tan(\epsilon + \phi) \sin(\delta + \beta) + \cos(\delta + \beta) \sin(\beta - \epsilon)}
$$

(4)

3.1.2 Similarly, FGNM of thin layer bulk unit in AEBJ area is taken.

According to the equilibrium conditions of horizontal and vertical forces acting on the element.

$$
- P \cos(\epsilon + \phi) + c \sin \epsilon \bigg|_{FM} - \bigg[ R \sin(\delta + \beta) + c w \cos \beta \bigg|_{MN} +

\left[ (p + dp) \cos(\phi + \epsilon) + c \sin \epsilon \right]_{GN} = 0
$$

(5)
The force $R$ in the AJ area of the body floor can be obtained, thus

$$R = \frac{c_{n_1} - c_{w} n_2 + \gamma L [\sin(\varphi + \varepsilon) + \cos \varepsilon]}{\cos(\varepsilon + \varphi) [\sin(\delta - \beta) \tan(\varepsilon + \varphi) + \cos(\delta + \beta)]}$$

In the formula:

$$n_1 = \sin \beta \tan(\varepsilon + \varphi) + \cos \varepsilon ; \quad n_2 = \cos(\delta + \beta) [\sin \alpha \tan(\varepsilon + \varphi) + \cos \alpha]$$

Figure 3 shows the longitudinal section of the body filled with material. The coal material acting on the bottom plate of the body is divided into CBJ and AEBJ. According to the horizontal and vertical equilibrium conditions of the thin coal unit, the bottom plate force $r$ in the CBJ area of the car body can be obtained

$$R = \frac{\gamma L - c_{w} n_2 + \gamma L [\sin(\varphi + \varepsilon) + \cos \varphi \tan(\varepsilon + \varphi)]}{\tan(\varepsilon + \varphi) \sin(\delta - \beta) \tan(\varepsilon + \varphi) + \cos(\delta + \beta) \sin(\beta - \varepsilon)}$$

Similarly, the FGNM of the thin layer bulk unit in the AEBJ area can be used to obtain the force $r$ of the bottom plate in the AEBJ area of the body, that is

$$R = \frac{c_{n_1} - c_{w} n_2 + \gamma L [\sin(\varphi + \varepsilon) + \cos \alpha \tan(\varepsilon + \varphi)]}{\cos(\varepsilon + \varphi) [\sin(\delta - \beta) \tan(\varepsilon + \varphi) + \cos(\delta + \beta)]}$$

### 3.2 Body front plate pressure calculation

![Stress Analysis of body front plate, sliding wedge and thin layer element](image)

The derivation of the front plate pressure is similar to that of the bottom plate pressure, and the front plate force $R$ of the body can be obtained (the second order differential above is omitted).

$$R = k_1 P + k_2 c_w + k_3 c$$

In formula (10), $k_1$, $k_2$, $k_3$ - earth pressure coefficient;

### 3.3 Calculation of body side plate pressure

![Stress analysis of body side plate, sliding wedge and thin layer element](image)

The derivation method of side plate pressure is similar to that of front plate pressure. The acting force on the side plate of the body is as follows:

$$R = K_1 P + K_2 c_w + K_3 c$$
4. Calculation results and analysis

According to the above calculation of the force of bulk material on the front plate, side plate and bottom plate of dump truck body, the change curve of the pressure on each plate is made, as shown in figure 6. In the figure 1 represents Coal, 2-Glutenite 3-Coarse sandstone 4-Fine sandstone 5-Sandstone.

![Material pressure distribution](image)

(a)Front plate pressure - height; (b)Base plate pressure - length; (c)Side panel pressure - height

Figure 6. Material pressure distribution

It can be seen from figure 6 that the pressure distribution characteristics of materials acting on each plate of dump truck are basically the same. The bulk pressure of side plate and front plate is nonlinear, and the maximum pressure is about 3/5 of the body depth. The pressure on the bottom of the body is also non-linear, and the pressure in the middle part is the largest, and the change trend of the pressure distribution curve is similar to the distribution shape of the material in the body.

5. Conclusion

(1) This paper introduces the simplified model of body load distribution in SAE-J1363 standard and the measurement method of the body load distribution model in Hagenbuch standard, and the problems of the two methods are analyzed.

(2) Based on the reverse engineering technology, the three-dimensional model of material distribution in the body is obtained by three-dimensional laser scanning technology, and the material distribution function in the body is obtained.

(3) Based on the assumption of plane slip surface of Coulomb theory, the calculation formula of the pressure acting on the front plate, side plate and bottom plate of dump truck is derived by using the thin layer element method.

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