

# Design and Calculation of JDS14/135X4 Skip Suspension Plate and Bucket Box Rotation Shaft

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**Abstract:** As a commonly used lifting equipment in metal mine shaft, bottom-dump skip is very important for its safety and reliability. A metal mine decided to design a bottom-dump skip as the lifting container of metal ore, with a designed load of 14t. The design and strength calculation of the skip suspension plate and the rotating shaft of the bucket box are particularly important. This paper mainly calculated and checked the design and strength of the skip suspension plate and the rotating shaft of the bucket box according to the technical parameters of the lifting container and the vehicle handling equipment to ensure the service performance of the designed skip.

**Keywords:** metal mine; bottom-dump skip; structural design; strength calculation

## 1. Introduction

With the development of social economy, especially the development of new energy vehicles, the demand for various mineral resources is increasing. China is a country with a large amount of mineral resources and a large demand for mineral resources. Therefore, the demand for mine mining lifting equipment will continue to increase. In order to realize the mining and application of mineral resources safely and effectively, the design and development of mine hoisting container is essential. The mine hoisting container with a well depth of less than 800m is a shallow or medium-deep lifting vessel, the lifting vessel with a well depth of more than 800m is called a deep lifting vessel, and the lifting vessel with a well depth of 1500m or more is called an ultra-deep lifting vessel<sup>[1-4]</sup>. The safety and reliability of mine hoisting container is directly related to the mine production efficiency and the life safety of workers, especially in the deep and ultra-deep well hoisting system, which has complex stress and harsh operating environment, and requires stricter structural strength of skip and reliability of connecting parts<sup>[5]</sup>. Therefore, it is necessary to accurately calculate and check the key components to ensure their safety and durability under long-term high load operation, taking into account the factors such as dynamic load, impact load and fatigue strength.

## 2. Lifting container and related parameters

The main shaft of a metallic iron mine has a diameter of 6m, and two sets of hoisting systems are arranged in the shaft, one is a double skip hoisting system, and the other is a cage with counter weight hoisting system. The cross section of the skip body is 1696mm×1346mm, and the height is 14188 mm. The shaft layout is shown in Figure 1. The effective volume of the skip is 6.3 m, the maximum load mass is 14 t, its own mass is 11.199t, the total load of the tail rope is 50.7kN, and the terminal load of the skip is 246.95kN.

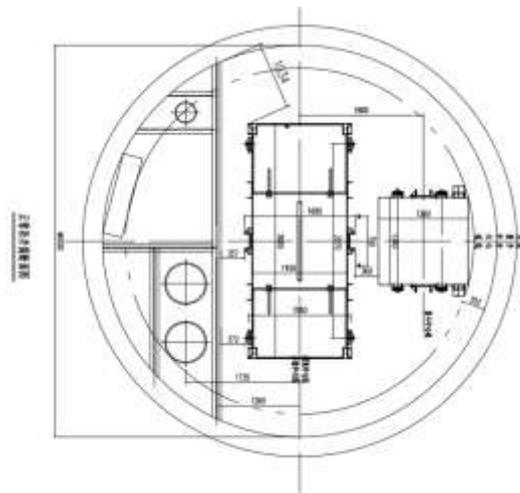


Fig. 1 Cross section of main shaft

## 3. Structure analysis and strength calculation of skip

### 3.1 Suspension plate (No.45 steel)

The suspension plate is a component of the suspension beam, and the suspension beam is connected with the upper chord plate and the side plate by welding. The suspension plate is directly connected with four head rope suspension devices through four pin holes.

Unit stress of hole wall of each pin hole (70 holes):

$$q = \frac{Q}{d \times \delta} = \frac{7593 \times 9.8}{0.07 \times 0.045} = 23.62 \text{ Mpa} < [\sigma] = \frac{[\sigma_b]_{II}}{K_{II}} = \frac{1150}{1.95} \times 0.098 = 57.8 \text{ Mpa}$$

Where:

Q- the load on a single pin hole,  $Q = \frac{Q_d}{4}$ , where is the terminal load and the total weight of the tail rope  
 $Q_d = (25199 + 5173) \times 9.8 = 297.65 \text{ KN}$  ;

D- the diameter of the pin hole;

δ-plate thickness;

The allowable stress  $[\sigma_b]_{II}$  under Class II load can be obtained by querying the allowable stress table of mining equipment components [3].

$$K_{II} = 0.65K_{III} + 0.35 = 0.65 \times K_1 K_2 K_3 + 0.35 = 0.65 \times 1.2 \times 1.71 \times 1.2 + 0.35 = 2.46$$

The designed suspension plate structure is shown in Figure 2. The suspension plate is simplified into a simply supported beam for stress analysis. The stress diagram is shown in Figure 3, and the equilibrium equations are juxtaposed:

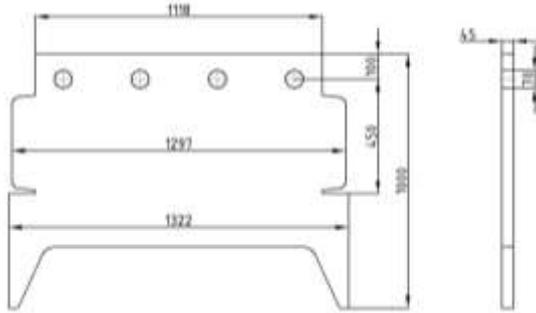


Fig. 2 Structure diagram of suspension plate

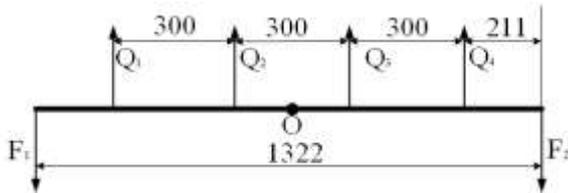


Fig. 3 Stress diagram of suspension plate

$$\begin{cases} \sum M_{F_1} = 0 \\ \sum M_{F_2} = 0 \end{cases} \quad (1)$$

$$\begin{cases} 1.322 \times F_2 - 211 \times Q_1 - 0.511 \times Q_2 - 0.811 \times Q_3 - 1.111 \times Q_4 = 0 \\ 1.322 \times F_1 - 1.111 \times Q_1 - 0.811 \times Q_2 - 0.511 \times Q_3 - 0.211 \times Q_4 = 0 \end{cases} \quad (2)$$

Where:  $Q_1 = Q_2 = Q_3 = Q_4 = 74.41KN$ , obtain:

$$\begin{cases} F_1 = 148.82KN \\ F_2 = 148.82KN \end{cases}$$

Shear force and bending moment diagram are shown in Figure 4:

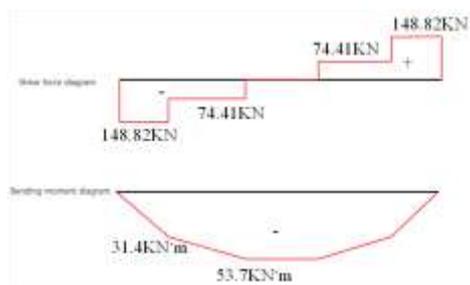


Fig. 4 Shear force and bending moment diagram of suspension plate

Solving bending stress according to shear force and bending moment diagram of suspension plate;

$$\sigma = \frac{Mx}{J_z} = 19.04Mpa$$

Where:

$$J_z = \frac{bh^3}{12} = 1.65 \times 10^{-3} m^4, x = 0.585m.$$

The safety factor is:

$$n = \frac{\sigma_b}{\sigma} = \frac{345Mpa}{19.04Mpa} = 18.12 > 13$$

Therefore, the suspension plate meets the strength requirements.

### 3.2 rotating shaft of hopper (No.45 steel)

#### 3.2.1 Force calculation of skip bottom

At the beginning of unloading, before the movable bucket bottom has moved, the force analysis of the movable bucket bottom is carried out, and the force analysis diagram is shown in Figure 5:

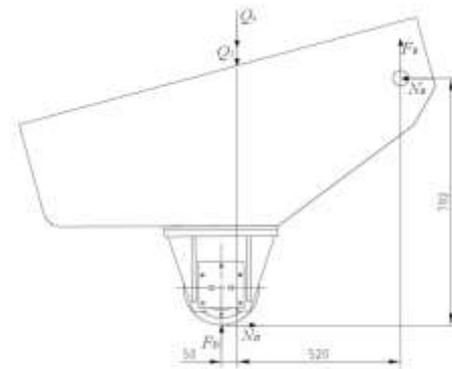


Fig. 5 Force analysis diagram of skip bottom (at the beginning of unloading)

In which:  $H_1 = 0.792m$ ,  $L_1 = 0.05m$ ,  $L_2 = 0.52m$ . Inclusion angle of horizontal section of supporting roller curve track  $\gamma = 1^\circ 54' 2''$ , the curved rail slope,  $i = \tan \gamma = \tan 1^\circ 54' 2'' = 0.033$ .

According to the stress analysis diagram of skip bottom, the balance equation is listed:

$$N_D - N_B = 0 \quad (3)$$

$$F_B + F_D - Q_s - Q_1 = 0 \quad (4)$$

$$F_D(L_2 - L_1) - (Q_s + Q_1)L_2 - N_D H_1 = 0 \quad (5)$$

Where:

$Q_1$  - Dead weight of bucket bottom,  $Q_1 = 840kg$

$Q_2$  - Self-weight of hopper,  $Q_2 = 5142kg$

$N_D$  - The total resistance of the roller when rolling on the curved track

$F_B, N_B$  - Bucket box articulated bearing reaction force

$F_D$  - The supporting reaction of the curved rail on the frame to the idler

Since the inclination angle  $\gamma$  of the horizontal segment of the curved track is small, the total frictional resistance  $N_D$  can be approximated as horizontal, which leads to:

$$N_D = F_D(\omega_n + i) \quad (6)$$

Where:

$\omega_n$  -The total friction resistance coefficient of the roller when rolling is 0.015 when starting and 0.01 when moving.

According to formulas (3), (4), (5) and (6), we obtain:

$$N_D = 6.82KN$$

$$F_D = 142.08KN$$

$$N_B = N_D = 6.82KN$$

$$F_B = Q_s + Q_1 - F_D = 3.352KN$$

### 3.2.2 Bucket box stress calculation

When the hopper has not moved, the position coordinate information of each hinge point and center of gravity is as follows:

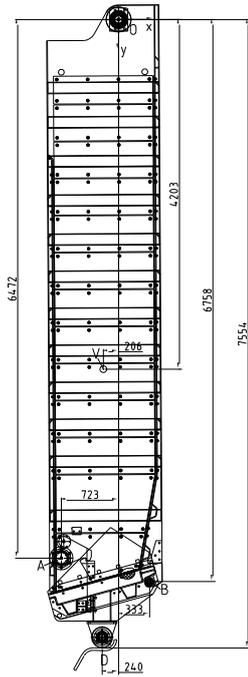


Fig. 6 Initial state of skip

Point A :

$$x_A = -0.723m, \quad y_A = 6.472m, \quad L_{OA} = \sqrt{x_A^2 + y_A^2} = 6.512m$$

$$\theta_{OA} = \tan^{-1} \frac{x_A}{y_A} = -6^\circ 22' 26''$$

Point B :

$$x_B = 0.333m, \quad y_B = 6.758m, \quad L_{OB} = \sqrt{x_B^2 + y_B^2} = 6.766m$$

$$\theta_{OB} = \tan^{-1} \frac{x_B}{y_B} = 2^\circ 49' 15''$$

Point D :

$$x_D = -0.24m, \quad y_D = 7.554m, \quad L_{OD} = \sqrt{x_D^2 + y_D^2} = 7.558m$$

$$\theta_{OD} = \tan^{-1} \frac{x_D}{y_D} = -1^\circ 49' 10''$$

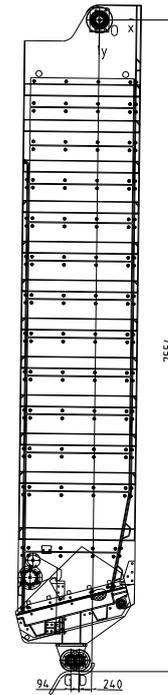


Fig. 7 Maximum stress position of bucket box pulling point Point V :

$$x_V = -0.206m, \quad y_V = 4.203m, \quad L_{OV} = \sqrt{x_V^2 + y_V^2} = 4.208m$$

$$\theta_{OV} = \tan^{-1} \frac{x_V}{y_V} = -2^\circ 48' 21''$$

In the whole skip unloading process, the maximum stress on the guide wheel hook shaft that pulls the bucket box to unload should be that the bucket box is pulled to the point where the riding wheel is at the arc tangent point where the end of the horizontal section of the curved rail meets the unloading section, that is, the bucket box is in the position shown in Figure 6.

After the bucket box is pulled, before the idler will enter the unloading section of the curved track (that is, the idler moves from point D to point G in Figure 5), the distance that the idler moves is  $S=0.094m$ , with the center of the rotating shaft of the bucket box as the origin O, the horizontal direction as the X axis, and the center line of the bucket box as the Y axis when the bucket box has not moved, the coordinates of point G are as follows:

$$x_G = x_D - 0.094 = -0.24 - 0.094 = -0.334m$$

$$y_G \approx y_D = 7.554m$$

The included angles between OD and OG and Y axis are respectively:

$$\theta_{OD} = \tan^{-1} \frac{x_D}{y_D} = \tan^{-1} \frac{-0.24}{7.554} = -1^\circ 49'$$

$$\theta_{OG} = \tan^{-1} \frac{x_G}{y_G} = \tan^{-1} \frac{-0.334}{7.554} = -2^\circ 31'$$

When the roller rolls from point D to point G, the angle of the segment OD is:

$$\theta_{GD} = \theta_{OG} - \theta_{OD} = -2^\circ 31' + 1^\circ 49' = -0^\circ 42'$$

There are:



$$\begin{cases} 1.253 \times F_2 - 0.0725 \times Q_1 - 1.1805 \times Q_2 = 0 \\ 1.253 \times F_1 - 1.1805 \times Q_1 - 0.0725 \times Q_2 = 0 \end{cases} \quad (14)$$

Where:  $Q_1 = Q_2 = \frac{P'_0}{2} = 30.682KN$ , obtain:

$$\begin{cases} F_1 = 30.682KN \\ F_2 = 30.682KN \end{cases}$$

Shear force and bending moment diagram are shown in Figure 11:

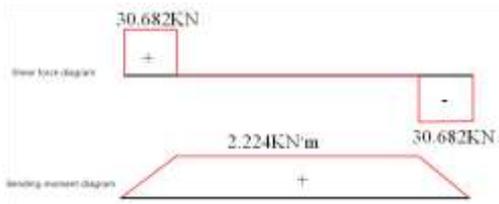


Fig. 11 Shear force and bending moment diagram of bucket rotating shaft

Bending stress:

$$\sigma = \frac{Mx}{J_z} = 45.388MPa, \quad \text{in} \quad \text{which:}$$

$$J_z = \frac{\pi d^4}{64} = 4.91 \times 10^{-6} m^4, \quad x = 0.1m.$$

Allowable stress:

$$[\sigma] = \frac{[\sigma_b]_{III}}{K_{II}} = \frac{1150}{1.95} \times 0.098 = 57.8MPa$$

In the formula, the allowable stress  $[\sigma_b]_{III}$  under Class II load is obtained by querying the allowable stress table of mining equipment components, and the durability reduction factor is:

$$K_{II} = 0.65K_{III} + 0.35 = 0.65 \times K_1 K_2 K_3 + 0.35 = 0.65 \times 1.2 \times 1.71 \times 1.2 + 0.35 = 2.46,$$

$$\sigma < [\sigma]$$

Therefore, the rotating shaft of the bucket box meets the strength requirements.

#### 4. Conclusion

Taking a metal mine as an example, the structural design and strength calculation of bottom-dump skip are carried out, and the stress analysis of the hanging plate and the rotating shaft of the skip box is carried out, which successfully verifies that the strength of the two key components meets the design requirements, which provides important reference and guidance for the transformation of shaft hoisting system and the design and application of metallurgical skip.

#### 5. References

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