Finite element analysis of ROPS for mechanical driving dump truck cab

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Abstract. For roll-over protective structures (ROPS) in a mechanical driving dump truck cab, it simulates the lateral, vertical and longitudinal loads of ROPS. It obtains stress and deformation of the cab that occurs to roll. For the relative weak position of ROPS in the cab, the structure of the cab is improved and verified according to the ISO 3164:1995. The results show that the established finite element model can effectively predict the deformation and stress distribution of ROPS, and optimize the weak structure of the cab, which has important guiding significance for structural design of the cab and ROPS optimization of the mechanical driving dump truck cab.

1. Introduction

With the increasing demand for mining resources, the competition of large mining and special dump truck supporting equipment is increasingly fierce [1, 2]. Special mining dump truck plays an important role in mining because of some advantages, which contains large carrying capacity, strong adaptability to environment, high efficiency and so on. At the same time, the driver's comfort and safety are also important. In addition to the intelligent dashboard, steering wheel, AB column position and other humanization design, the cab ROPS has also made great development [3].

In recent years, many experts have carried out a large number of cab ROPS intensity simulation analysis and test. The United States Construction and Industrial Machinery Technical Committee (CIMTC) established a repeatable method to detect the safety performance of the driver's safety structure in 1972 [4]. Therefore, in the static test, the deflection-limiting volume (DLV) is proposed as the limit deformation standard of the driver's safety protection structure. Shimoda adopted the nonlinear finite element method to analyze the ROPS energy absorption of D60 bulldozer cab in 1983, but did not form a system [5]. Stockton of the British Silsoe Research Institute studied various vehicle ROPS standards to analyze comprehensively the differences between the various standards, and gave 51 common ROPS standards in 2001 [6]. Clark, Queensland University of technology, uses ABAQUS to simulate the lateral, vertical and vertical loads of the ROPS. The half-size model is used to replace the prototype of 170t mining dump truck, and the cab ROPS is verified [7]. Wang Guoqiang, Jilin University, carried out a lot of destructive tests on various types of ROPS. He obtained various deformation
forms and failure mechanisms of ROPS, and used genetic algorithm to optimize the global design of ROPS.

With the continuous improvement of simulation and optimization algorithm, ROPS simulation analysis has gradually matured, but the structural optimization design for different cabs are very different. The skeleton of the cab needs to keep enough space as a safe area after certain damage and deformation. In this study, the mechanical mining truck is as the research object. It simulates the lateral, vertical and longitudinal loading process of ROPS test by the finite element method, and obtains stress and deformation distribution of the cab that occurs to roll. It optimizes the weak structure of the cab, and verifies the ROPS test.

2. Establishment of finite element model

2.1. The geometry model of the cab.
The geometry model of the cab is simplified in the keyhole, chamfer, groove, and so on. Delete dashboard, steering wheel, small interiors, and so on, which impact hardly on structural strength and stiffness of the cab. The geometric model of the cab is shown in figure 1. According to the ISO 3164: 1995, the vertical projection distance from the seat plane to the top of the helmet is 1020 mm. On the basis of no human body model, the vertical distance between the top of the cab and the seat plane determines whether there is danger in the vertical direction. To reduce the degree of the cab freedom, the cab is simplified as shell-element. According to the ISO 3164: 1995, the top cover plate is used as the solid-element. The cab model is meshed. The number of units is 253 thousand, and the number of nodes is 242 thousand.

![Figure 1. The geometry model of the cab](image)

2.2. Establishment of material parameters.
The material of the cab framework is Q345. Assuming that the material is uniform, continuous, fully elastic and isotropic, it obtains mechanical properties of Q345 steel by the experiment and JMATPRO. The mechanical properties vary with temperature as shown in figure 2.

![Figure 2. Relationship between mechanical parameters and temperature of Q345](image)
2.3. Loads.
The bolted connections in the cab are simplified for bonding contact together. The weight of mine truck is 67 tons, and the quality of cargo is 14 tons. According to ISO 3164: 1995, the whole frame structure in ROPS analysis does not include the quality of the cargo box and the loading. When the quality is in the range of 58960 kg and 22540 kg, it calculates of the loading and lateral load energy of the ROPS cab, according to the formula (1), (2), (3), (4).

\[ F_S = 10M \quad (1) \]
\[ U_S = 1.84M \quad (2) \]
\[ F_V = 19.61M \quad (3) \]
\[ F_L = 8M \quad (4) \]

Definite loads. The lateral load that is 530 KN applies to the driver side near the upper crossbeam interval. The vertical load that is 1039.33 KN applies to the top beam of the cab. The longitudinal load that is 424 KN applies to the middle of the beam in the rear of the cab. At the same time, the energy absorption of the lateral load needs more than 97520 J. The cab skeleton has the deflection-limiting volume, and it is not allowed to invade the driver’s space.

3. Simulation result analysis and discussion

3.1. Simulation results analysis of the longitudinal load.
Through the longitudinal load of the cab, the displacement and stress distributions of the cab are simulated and analyzed, as shown in Figure 3.

![Displacement and stress counters of the longitudinal load](image)

Figure 3. Displacement and stress counters of the longitudinal load

From figure 3(a), when the maximum longitudinal load reached 424kN, the maximum displacement is 3.84 mm on the longitudinal side of the cab. The maximum displacement is at the top center of the cab contact with the longitudinal load distributor. It is far less than the safe distance between DLV and ROPS, so guarantee the driver’s safety.

From Figure 3(b), the maximum stress appears on the top and bottom of the front and rear columns, as well as the cross of the front and rear columns and the middle-beam. The peak value of stress is 294.1 MPa, and does not reach the yield strength, so the longitudinal load of the mining dump truck meets the ROPS standard requirements. Considering lightweight design, there is still a margin for further optimization in longitudinal load. It is suggested that further optimize structure to reduce material waste and maximize utilization the performance of materials.
3.2. Simulation results analysis of the lateral load.

Referring to the ISO 3164: 1995, the lateral load is applied to the model to obtain the displacement and stress results of the cab under the condition as shown in Figure 4.

From figure 4(a), the maximum displacement is near the front of the cab. The maximum displacement is 11.57 mm. It is less than the safe distance between DLV and ROPS. Therefore, the cab can ensure the driver’s safety.

From Figure 4(b), the maximum stress is 315.5 MPa, which is mainly concentrated in the top and bottom of the front and rear columns, and does not reach the yield strength, so the lateral load of the mining dump truck meets the ROPS standard requirements. From the maximum utilization of materials to consider, the material utilization rate of the lateral load has reached highly, so it is not recommended for optimization design. At the same time, from the safety factor, it has met the performance not to increase the structure that uses to strengthen the structure and stiffness of the cab.

3.3. Simulation results analysis of the vertical load.

As the ISO 3164: 1995, the vertical load is applied to the model to obtain the displacement and stress results of the cab under the condition as shown in Figure 5.

From figure 5(a), the maximum displacement is in the top center of the cab contact with the vertical load distributor. The maximum displacement is 136.9 mm. The vertical projection distance between the seat plane and the top of the helmet is 1016.1 mm that is larger than the safe distance. The ROPS has intruded into the DLV, so the cab cannot ensure the driver’s safety.
From Figure 5(b), the maximum stress occurs at the cross of the column and the top, and the peak value of stress is 415.3MPa. The plastic deformation has occurred, basically reaching the strength limit of Q345 steel. The vertical load of the cab ROPS cannot meet the requirements of the ISO 3164: 1995. Therefore, structural optimization is needed.

4. Structure improvement and test verification

4.1. Structure improvement of the cab.
The ROPS skeleton of the mechanical drive mine dump truck cab consists of the steel and the plate. Based on the simulation analysis, under the vertical load condition, in figure 5 (a) deformation has relatively large on the right and left sides of the cab roof, and the deformation is mainly released along the transverse direction, so it is necessary to increase the restraint at this location. The column is added, and the column material is Q345. The cross section is 90mm x 40mm, and the thickness is 2mm.

In Figure 4 (b), stress in the column and bottom position is concentrated, and the steel is added to strengthen the stiffness. It is suggested that the steel pipe is added in the lower position between the pillar and the post column. The steel pipe material is Q345. The cross section is 40mm x 40mm, and the thickness is 2mm. At the same time, the steel pipe with connection between the post columns is added, and the material is Q345. The cross section is 110mm x 110mm, and the thickness is 5mm. The improvement structure of the cab is as shown in Figure 6. Because the structural strength has been improved, it is necessary to ensure that the vertical load meet the ROPS requirements. No further simulation analysis is carried out, and ROPS test is carried out directly.

![Figure 6. Sketch of the improved cab](image)

4.2. Test verification of the ROPS cab.
The ROPS skeleton of the mechanical drive mine dump truck cab consists of the steel and the plate. The ROPS test is verified by static load. As the ISO 3164: 1995, the lateral, vertical and longitudinal loads on the upper of the cab are applied to verify the strength and stiffness of the cab. In the trial stage of the prototype, the ROPS test is carried out on the test bed. The equipment of ROPS test is shown in Figure 7. The object is the cab of a mechanical drive mine dump truck.
When the loads and energy are required, the constant load does not continue a period of time until it does not occur to deform. The test is stopped. Under the lateral, vertical and longitudinal loads, there is the DLV. The cab cannot invade the DLV after loading. Under the lateral load, ensure enough strength and keep enough performance against rollover impact. Therefore, the driver cannot be crushed on the following prerequisites, such as driving on the hard clay pavement, the maximum gradient is 30 degrees, the initial advance speed from 0 to 16 km/h, and the vertical turning over 360 degrees, and always keeping contact with the slope [8]. The test proves that the finite element model is effective, and can provide reference for the design of the ROPS and the laboratory test.

5. Conclusions
As a mechanical driving dump truck, adopt the nonlinear finite element method of the cab ROPS. At the prototype design and development stage, the finite element model of the cab ROPS is effective, and effectively predict the dump truck cab safety strength. According to the ISO 3164: 1995, under the vertical load, the cab occurs plastic deformation. The maximum stress reaches the strength limit, and the ROPS invades the DLV. By improvement structure, the cab stiffness is increased, and the cab influencing vertical load is optimized. The test proves that the ROPS of the improved cab is qualified. However, in the actual production, the quality of the process needs to be ensured. The location of stress concentration usually occurs in the welding joint. Considering the welding residual stress, it is beneficial for the stress distribution to be closer to the reality. Further research is needed.

Acknowledgments
This work was financially supported by National High-tech Research and Development Program (2011AA060404), and National Science and Technology Support Program (2015BAF07B02).

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