Special Vehicle Collision Safety Analysis

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Abstract: Special vehicles have the characteristics of large volume, high center of gravity, and high quality. At the same time, the driver 's field of vision is low, making special vehicles prone to collision safety accidents. In order to improve the collision safety of special vehicles, based on the finite element method of numerical simulation, this paper innovatively establishes the finite element model of the whole vehicle including the front windshield of the vehicle simulated by the element deletion method and the tire of the vehicle simulated by the particle method. According to the collision regulation C-NCAP, two collision conditions of 50 km/h frontal 100% collision with rigid wall and 50 km/h frontal 40% offset collision with rigid wall are built. The collision process simulation is realized by explicit dynamic algorithm, and the collision safety of special vehicles is studied. The results show that the basic shape of the cab of the vehicle model remains unchanged in the two collision conditions, which can meet the needs of occupant living space. Further research results show that the front windshield of the vehicle will not break or break away from the window, and only small cracks will occur in some positions.

1 INTRODUCTION

Special vehicles are special purpose vehicles that exceed the design limits of general vehicles in terms of shape and size. They are equipped with special equipment and special tasks. Common special vehicles include oil tanker cars, aerial work vehicles, radar vehicles, etc. Special vehicles have the characteristics of difficult driving, large vehicle volume, high center of gravity, high quality, precise internal structure, equipped with special equipment dedicated to the implementation of a task, while the driver 's field of vision is low, making special vehicles prone to collision safety accidents. However, due to the small number of special vehicles, the safety research of special vehicles lags behind that of normal passenger vehicles. Therefore, it is particularly important to study the collision phenomenon and provide theoretical basis for improving the collision safety of special vehicles.

In the evaluation of vehicle collision safety, in addition to the safety regulations issued by the government, there is a more stringent standard based on social organizations, namely the star standard NCAP for vehicles. The C-NCAP standard applicable to China has made the standard requirements for collisions in accident scenarios such as frontal collision, frontal offset collision, side collision and heavy hammer impact.

In C-NCAP, frontal collision refers to the collision speed of 50 km/h, and four Hybrid III dummy are placed on the four seats of the vehicle. The front dummy is used to test the collision injury of the front occupant, and the rear dummy is used to detect the protection performance of the restraint system.

Frontal offset collision is a collision with a front-end collision surface overlap rate of 40% of the vehicle width, which is used to simulate the collision between the vehicle and the frontal vehicle or frontal obstacle.

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Figure 1: Vehicle frontal collision diagram.

Figure 2: Vehicle frontal offset collision diagram.

For the study of vehicle collision safety, there are three main methods: empirical method, real vehicle test method and numerical simulation method. The empirical method is the initial use of the method, based on the results of previous vehicle collisions, the structure and components of the vehicle redesign to improve vehicle collision safety. (Lei, 2004) The real vehicle test method is a method to test the completed vehicle products according to the standard experimental regulations, but the real vehicle test method has the disadvantages of long time, high cost and poor repeatability (Li, 2015). With the development of computer numerical simulation technology, the finite element method is now used to study the collision of vehicles. The research on vehicle simulation collision at home and abroad started earlier and developed more comprehensively. In this field, domestic and foreign scholars have developed computer simulation of vehicle collision test conditions and simulation methods with the help of computer simulation software.

In 1987, D. V. Lugt et al. used the explicit finite element program to simulate on the CRAY X-MP supercomputer, studied the results of 30 miles per hour bus in frontal barrier collision, and compared the deformation shapes in simulation and experiment (Lugt, 1987). In 1993, Jesse S. Ruan et al. first established a three-dimensional head model to study the dynamic response of the human head when the human head is impacted by a vehicle collision (Ruan, 1993). In 1998, Lu Bin of Chongqing University wrote the first domestic red flag car collision simulation process carried out by Changchun Automobile Institute (Lu, 2008). In 2001, Gao Weimin of Tongji University used PAM.CRASH to build a full-width frontal collision platform of a car and carried out a collision computer simulation (Gao, 2001). In 2011, Liu Qi simulated the establishment of a three-layer structure of the vehicle front glass, and simulated the contact between the occupant 's head and the front glass during the collision, which verified the rationality of the three-layer structure glass simulation (Liu, 2011). In 2015, KA Danelson et al. used the dummy model to evaluate the effects of different safety restraint systems on chest injuries, including three-point seat belts, frontal airbags, and buckle pretensioners (Kerry, 2015).

In summary, the previous finite element simulation of vehicle collision began earlier. However, with the development of computer technology, new theories and methods have been applied to the field of finite element simulation. However, there are few studies on the application of these new methods to the field of vehicle collision. This paper uses new research methods such as CPM particle method to simulate vehicle collision, which can provide a theoretical basis for improving vehicle safety.

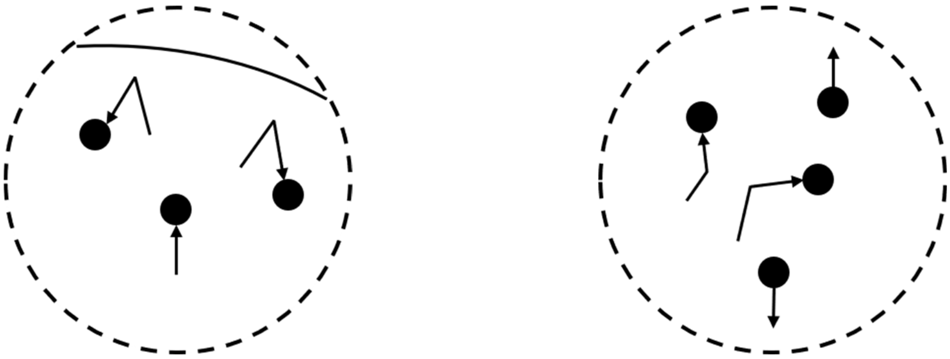
2 NUMERICAL SIMULATION METHOD

In 2007, Lars Olovsson et al. proposed the particle method based on molecular dynamics theory. The particle method discretizes the gas into particles. The gas molecule cluster containing multiple gas molecules is simplified as a rigid particle. The macroscopic physical quantities such as temperature and pressure of the gas are calculated by counting the collisions between the rigid particles and the wall and the collisions between the particles. According to the molecular dynamic theory, the pressure is the function of the molecular specific kinetic energy, and the gas static pressure in the particle method is calculated by counting the average kinetic energy of the particles. At the inlet of the flexible cylinder, the particle method injects a large number of particles into the flexible cylinder according to the mass flow rate curve. The particle direction is arbitrary. The average velocity of the newly created particles is determined by its temperature and mass. The particle rate obeys the Maxwell-Boltzmann rate distribution and enters the flexible cylinder (Yang, 2022).

The element deletion method means that when the elements in the model meet the preset failure criteria, the program will automatically delete the corresponding elements and nodes. When a series of elements and nodes are deleted and connected to each other, a visual crack path is formed. Among them, the most commonly used method is to add failure criteria such as maximum principal stress, maximum principal strain or maximum tensile stress. If any preset failure criterion is satisfied during the loading process, the material is destroyed; another way is to use the material model with failure criterion in the finite element software, and embed the failure criterion into the corresponding material constitutive without adding additional failure criterion. The element deletion method is simple in theory and efficient in calculation. It is often used to calculate the damage of glass materials. The deleted elements can be regarded as cracks (Wang, 2022).

3 ESTABLISHMENT OF VEHICLE FINITE ELEMENT MODEL

The vehicle model is shown in Figure 4. It is a two-axle special vehicle with a bucket. The length of the vehicle is 8.06 m, the width of the vehicle is 2.46 m, the height of the vehicle is 2.88 m, and the length of the head is 1.95 m. The 3D model of the vehicle consists of 128 components, and the head model consists of 48 components.



(a) particle-to-wall collision (b) particle-to-particle collision

Figure 3: Principle schematic diagram of particle method.

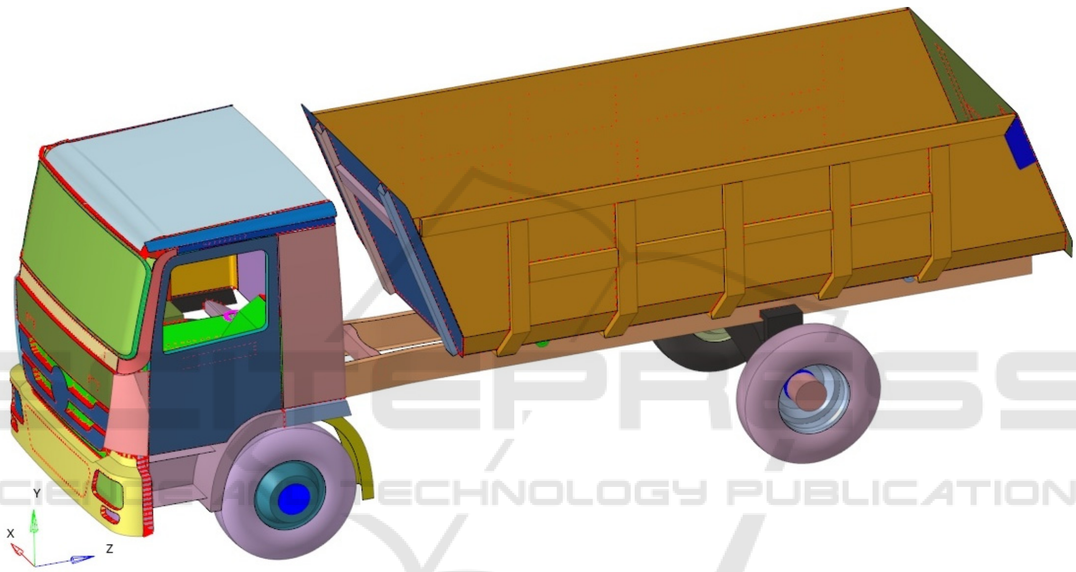


Figure 4: Special vehicle model.

The materials used in the finite element simulation of vehicles can be divided into metal materials and non-metallic materials. Non-metallic materials such as rubber, plastics, etc., metal materials are used more in vehicles, such as low carbon steel, composite aluminum, etc. For the front panel of the vehicle, some sheet metal parts, etc. will produce large deformation of the material, the use of linear elastic material (PIECEWISE_LINEAR_PLASTICITY) simulation, and according to the actual situation to give aluminum, steel and other material data. For rigid bodies that are not easily deformed in vehicles, such as engines, vehicle reducers, etc., rigid materials (RIGID) are used for simulation, giving material data to Q235 steel with great stiffness. For rubber materials such as tires in vehicles, elastic material (ELASTIC) simulation is used. For brittle materials such as vehicle front windshield, the piecewise elastic-plastic (MODIFIED_PIECEWISE_LINEAR_PLASTICITY) material is used for simulation, and the unit is deleted after failure. The material parameters of the main components of the vehicle are shown in Table 1.

The particle method is used to simulate the vehicle tires to see the movement and deformation of the head and body parts during the collision. Set the initial environmental conditions and tire internal conditions, and set the particle number to 200,000. The data setting of the tire control panel is shown in Table 2.

Table 1: Material parameters of vehicle main parts.

	Rho (density)	E (young's modulus)	PR (poisson ratio)	SIGY (yield strength)	ETAN (tangent modulus)	FAIL (maximum strain failure)
Q235 steel	7.86e3 kg/m^3	2.1e5 MPa	0.3	235 MPa	6100 MPa	/
Aluminium	2.7e3 kg/m^3	7.2e4 MPa	0.3	200 MPa	1130 MPa	/
Rubber	6.88e3 kg/m^3	2.61e4 MPa	0.3	/	/	/
Glass	2573 kg/m^3	7e3 MPa	0.22	30 MPa	1000 MPa	0.025

Table 2: Tire parameter control.

Parameter	Ambient atmosphere	Tire
TATM (temperature)	293 K	293 K
RPATM (pressure)	101325 Pa	8e6 Pa
XMAIR (molar mass of gas)	29 g/mol	29 g/mol
AAIR (constant heat capacity)	/	25 J/(mol·K)
BAIR (linear heat capacity)	/	4.2e-3 J/(mol·K)
CAIR (quadratic heat capacity)	/	0

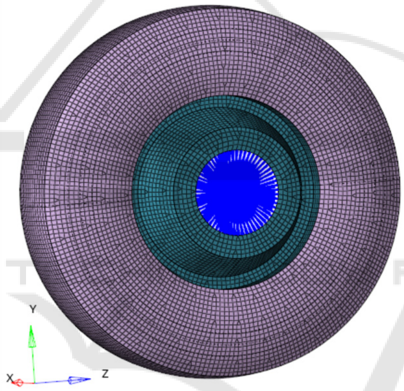


Figure 5: Tire simulation diagram.

The finite element model of the tire simulated by the airbag is shown in Figure 5. The blue radial line segment is a schematic diagram of the revolute pair of the wheel.

The previous simulation of glass mostly used the PVB multi-layer glass structure similar to the actual vehicle front windshield. The PVB film simulated by the hyperelastic material was added between several layers of glass simulated by the piecewise elastic-plastic material, and the maximum failure principal strain of the piecewise elastic-plastic material was set. When the principal strain of the element exceeds the limit value, it is judged as the element failure, which is manifested as the element deletion.

This paper mainly studies the deformation results of the car body itself in the collision process, so the simulation of glass is simplified, using piecewise elastic-plastic material to simulate single-layer glass. The maximum principal strain failure criterion is set to 2.5% in the control panel of the glass. When the principal strain of the grid reaches 2.5%, the grid failure is determined, which is shown as the removal of the grid from the model. A simple simulation of the rupture of the glass is performed. The parameter settings of the front windshield are shown in Table 1.

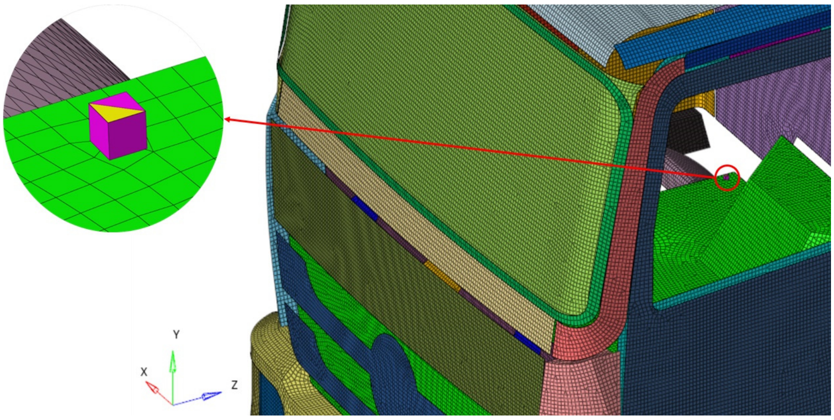


Figure 6: Acceleration sensor diagram.

In the real vehicle collision test, the acceleration sensor needs to be installed and placed at the B-pillar on both sides of the vehicle. This is because the stiffness of the vehicle at this location is larger and the deformation is smaller. It is more reasonable to represent the acceleration of the vehicle with the acceleration at this location. At the same time, it is close to the driver's seat, which can reflect the driver 's acceleration overload feeling in the collision as much as possible. Therefore, the acceleration sensor is placed inside the B-pillar of the vehicle in the simulation. The acceleration sensor at the B-pillar of the vehicle is shown in Figure 6.

4 VEHICLE COLLISION SAFETY ANALYSIS

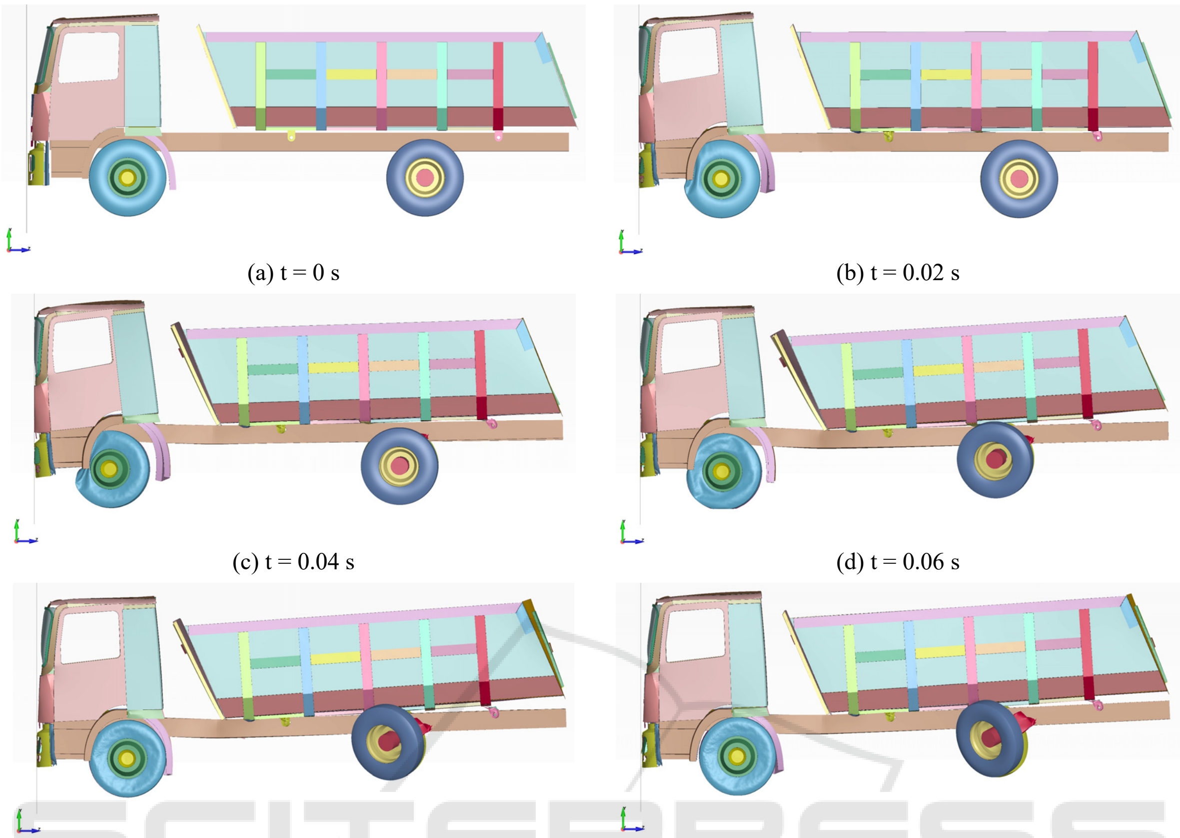
Based on a special vehicle model, the finite element model of vehicle collision with rigid wall is established, and the frontal 100% collision and frontal 40% offset collision simulation of vehicle are realized. The collision safety of vehicle is analyzed based on the results of vehicle energy change and vehicle body deformation.

4.1 Vehicle 100% Frontal Collision

This part simulates the vehicle's 100% frontal impact on the rigid wall at a speed of 50 km/h, and views the data of vehicle deformation, overall energy change, and acceleration change during the collision.

Figure 7 shows the deformation of the vehicle at different times during the 100% frontal collision from 0 to 0.1 s. Because the front end of the vehicle energy absorption deformation part is less, so the deformation of the vehicle in the collision process is not obvious, the basic shape of the cab is not destroyed, the collision deformation time mainly occurs in the first 20 ms. In addition to the vehicle longitudinal beam has a slight bending, bucket before and after the panel has a small bending deformation, the basic framework of the vehicle little change. At the same time, the deformation of the tire was observed. At 40 ms, the deformation of the vehicle tire basically reached the maximum, and then rebounded.

Vehicle collision is a process involving the collision of multiple objects in contact with each other, with momentum and energy exchange. Figure 8 is the curve of vehicle energy changing with time during the collision process. The energy change of the whole process is coherent, the curve is smooth and smooth, and the simulation process is reasonable. The decrease in total energy is due to the fact that the rigid wall still retains part of the contact energy during the collision, which is dissipated to the outside in the form of thermal energy, and that the deleted element also consumes part of the energy due to the use of the element deletion method to simulate the deformation of the glass. Vehicle energy change for kinetic energy becomes smaller, internal energy becomes larger, in line with the objective law of kinetic energy to internal energy conversion. It can be seen from the diagram that the kinetic energy and internal energy are basically stable at 0.04 s, and the increase or decrease is not large. It can be considered that the collision is basically over, and basically at 0.04 s, the internal energy of the vehicle basically reaches the final value, and the deformation degree basically reaches the maximum.



(a) t = 0 s

(b) t = 0.02 s

(c) t = 0.04 s

(d) t = 0.06 s

(e) t = 0.08 s

(f) t = 0.1 s

Figure 7: Vehicle frontal collision deformation diagram at different times.

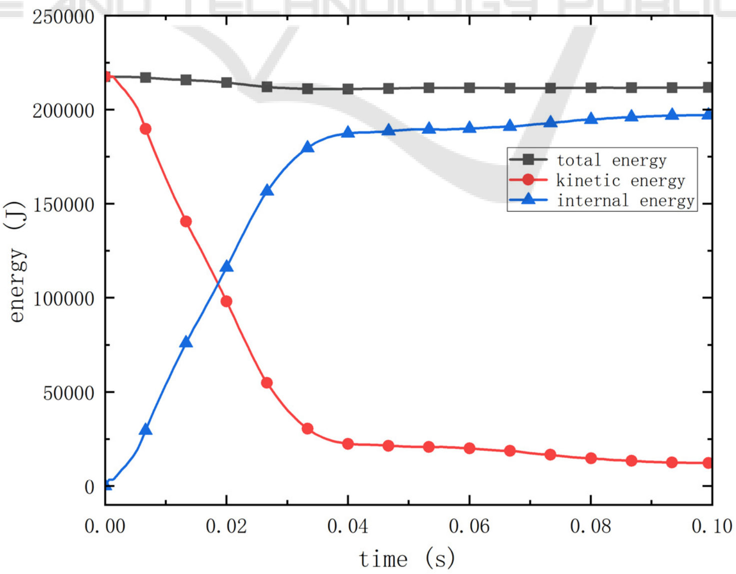


Figure 8: Energy change in collision process.

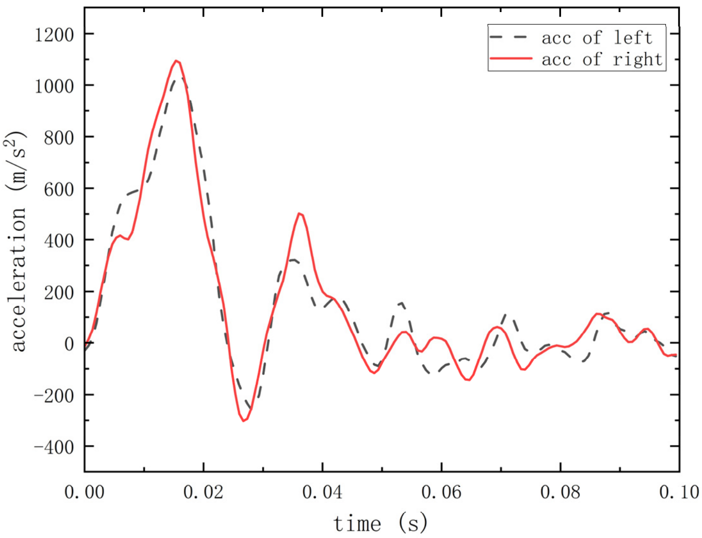


Figure 9: Vehicle acceleration curve.

Figure 10: Deformation of vehicle front windshield at 0.04 s.

Acceleration curve is obtained by deriving the speed of vehicle acceleration sensor unit to study the change of vehicle acceleration during collision. The acceleration curve obtained by the acceleration sensor units on both sides of the vehicle B-pillar is shown in Figure 9.

Due to the asymmetry of the established vehicle cab model, the acceleration of the B-pillars on both sides is not exactly the same. It can be seen that the acceleration increases from negative to about 1038 m/s^2, then decreases to about-233 m/s^2, and then oscillates near zero. The maximum acceleration is about 105g and the acceleration is about 13g at 0.04 s after the collision.

Figures 10 show the deformation of the vehicle's front windshield and window frame at 0.04 s. It can be seen that the vehicle 's front windshield and window frame are still connected at 0.04 s, and there is no glass falling off the window. And the failure unit mainly occurs at the connection, and there will be no splash of glass debris; therefore, it can be judged that the deformation of the front windshield of the vehicle during the collision does not threaten the safety of the occupants.

After the collision of the vehicle, whether the door can open normally without external force plays an important role in the timely escape and treatment of the occupants after the accident. However, it is difficult to directly judge whether it can be opened, and it can be indirectly judged by observing the deformation of the door. The deformation of the left door is shown in Figure 11.

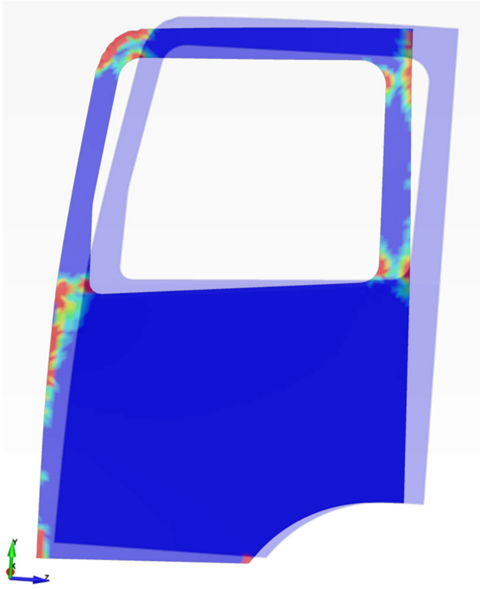


Figure 11: Car door deformation diagram.

Table 3: Coordinate change of y-axis and z-axis at four corners of door.

node	z-axis coordinates	y-axis coordinates	z-axis coordinates (0.04 s)	y-axis coordinates (0.04 s)
Upper left corner	674.278	2723.523	403.548	2740.413
Bottom left corner	1548.325	1306.621	1440.063	1423.892
Upper right corner	1548.858	2768.338	1268.210	2874.717
Lower right corner	470.285	1104.993	389.409	1110.424

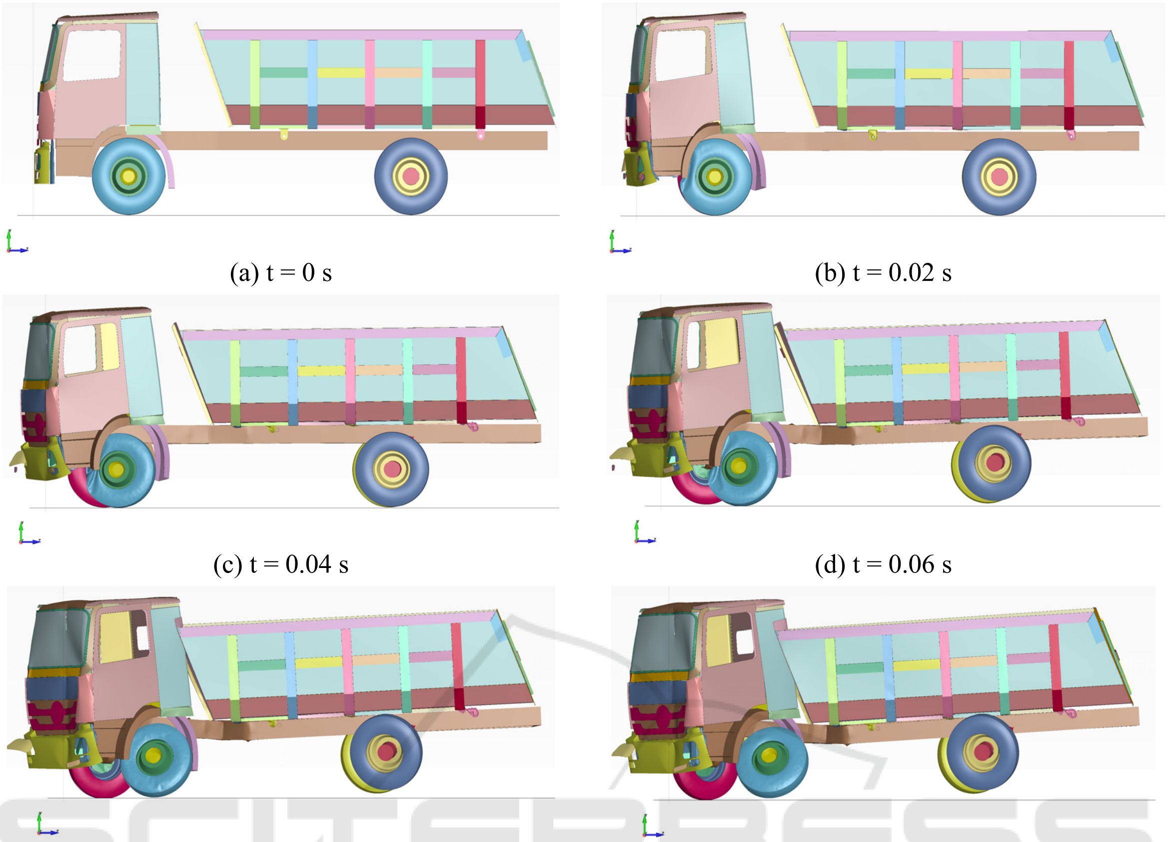
Figure 11 shows the deformation of the door at 0 s and 0.04 s. It can be seen that the basic shape of the door has not changed. In order to measure the deformation of the door, the output point is set at the four corner nodes of the door, and the change of the diagonal length of the door at 0s and 0.04 s is calculated.

According to Table 3, the two diagonal lines of the door do not change much at 0 s and 0.04 s, and basically only change by 11 mm. Therefore, it can be considered that the door does not deform much during the collision.

4.2 Vehicle 40% Frontal Offset Collision

This part simulates the vehicle hitting the offset rigid wall at a speed of 50 km/h. The simulation time is 0.1 s. In the post-processing, the vehicle deformation, the overall energy change and the deformation energy absorption of each component are viewed. Since the vehicle tire is more crushed during the offset collision, an analysis of the tire is added to the offset collision.

Figure 12 shows the deformation of the vehicle in the period of 0 to 0.1 s. It can be seen that the front of the vehicle began to turn to the offset side from 0.02 s, and the front beam began to bend at 0.04 s, which lasted until 0.1 s at the end of the simulation. At the same time, it can be seen that the rear panel of the vehicle cab collided with the front of the vehicle at 0.06 s, and the rear of the vehicle began to rise at 0.06 s and continued until the end of the simulation. The deformation of the tire is more obvious on the left side, and the maximum deformation of the left tire occurs at about 0.4 s, and then the tire rebounds.



(a) t = 0 s (b) t = 0.02 s

(c) t = 0.04 s (d) t = 0.06 s

(e) t = 0.08 s (f) t = 0.1 s

Figure 12: Vehicle frontal offset collision deformation diagram at different times.

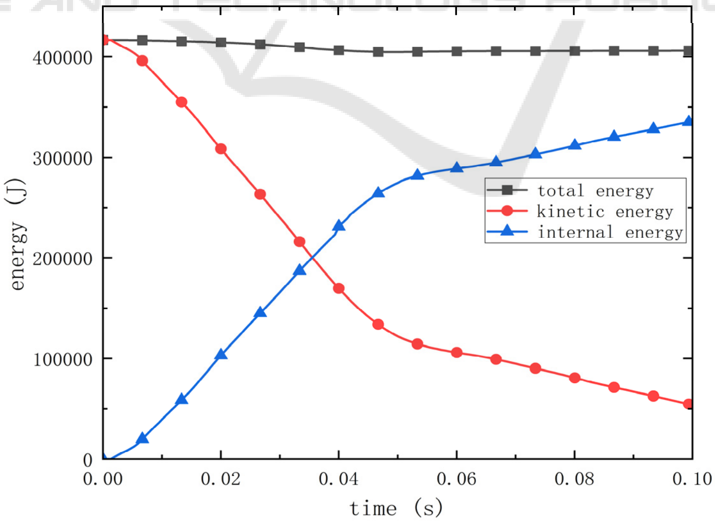


Figure 13: Frontal offset collision energy change.

Figure 13 reflects the overall energy change in the offset collision. The curves are coherent and smooth, and the simulation calculation is reasonable. The decrease of the total energy curve is due to the contact energy between the vehicle and the rigid wall and the energy consumption after the element removal is not included.

It can be seen that the kinetic energy of the vehicle decreases and the internal energy increases. The kinetic energy and internal energy of the vehicle change at a faster rate in the first 0.05 s, and still increase or decrease after 0.05 s, but the change rate decreases. The deformation of the vehicle before 0.05 s is mainly compressive deformation along the speed direction; the deformation of the vehicle after 0.05 s is mainly due to the slow increase of the internal energy of the beam bending caused by the compression of the offset rigid wall and the slow decrease of the kinetic energy of the head deflection.

The deformation of the front windshield of the vehicle at 0.1 s is shown in Figure 14. It can be seen that under the extrusion of the offset rigid wall, the glass produces an indentation at the edge of the rigid wall and the position where the glass contacts, and there is a partial unit failure at the indentation. There are a small number of unit failures at the connection between the window and the glass, and it is judged that the front windshield of the vehicle will not be detached from the window in the collision simulation.

The particle method is used to simulate the tire. By counting the collisions between a large number of particles and the collisions between particles and the wall, the macroscopic physical quantities of the gas inside the tire are calculated. The curves of tire pressure and volume with time are shown in Figure 14 and Figure 15.

From Figure 15, it can be seen that the pressure of the left front wheel squeezed by the collision increases first and then decreases, from the initial

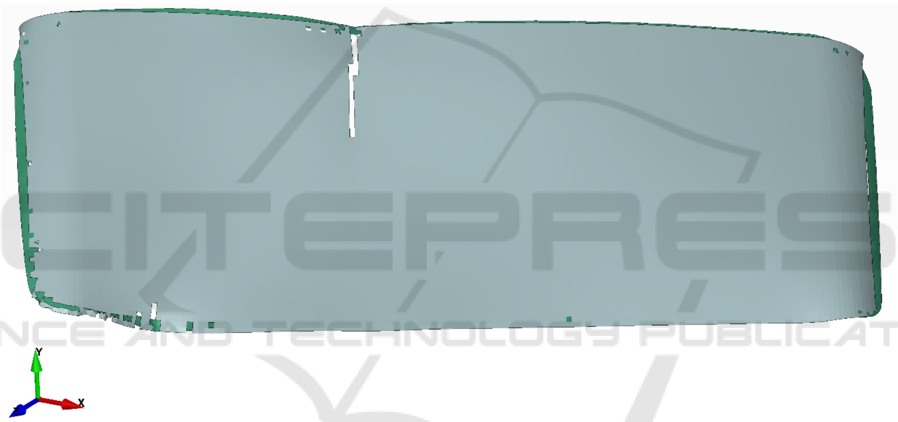


Figure 14: Deformation of vehicle front windshield at 0.1 s.

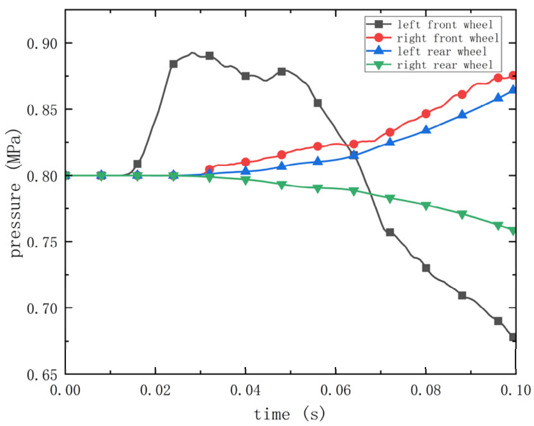


Figure 15: Tire pressure time curve.

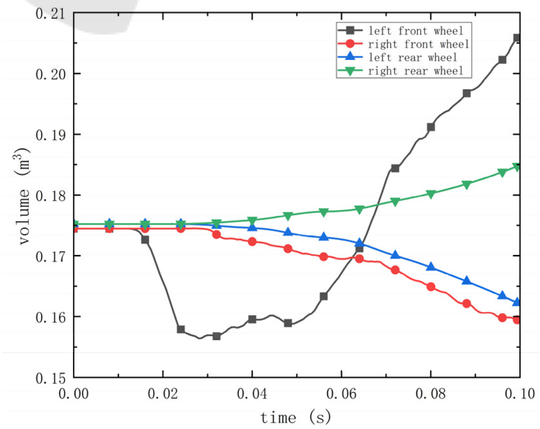


Figure 16: Tire volume time curve.

0.8 MPa to about 0.89 MPa, and the pressure continues to decrease to 0.68 MPa after fluctuation. As the volume of the airbag inside the tire increases gradually during the collision, the gas pressure inside the tire decreases. The pressure of right rear wheel decreases from 0.8 MPa to 0.76 MPa, and the pressure of right front wheel and left rear wheel increases from 0.8 MPa to 0.87 MPa and 0.86 MPa respectively. The volume curve of the tire basically shows a trend opposite to the pressure curve.

5 CONCLUSION

In this paper, the finite element method is used to simulate the vehicle collision process. The vehicle front windshield simulated by element deletion method and the vehicle tire simulated by particle method are applied to the collision of the vehicle model to improve vehicle safety. It is found that the basic shape of the cab remains unchanged under two collision conditions, and the vehicle safety is high. And the cab deformation occurs mainly in 50 ms, deformation time is short. The front windshield of the vehicle will only crack in some parts, and there will be no large area out of the window. The tire of the vehicle will produce large deformation in the offset collision, and the pressure in the tire will also change to a certain extent, but the pressure change is small, and the vehicle is safer.

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