Collision Simulation and Optimization Analysis of Vehicle Thin-Walled Components Based on Trolley Test

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Abstract. Based on the response data of the frontal impact test of the trolley, the frontal impact simulation and analysis of the double-tube model of the trolley were carried out using finite element software. Starting from the thin-wall deformation mode, acceleration and energy curve changes as response indicators, the error between simulation and experiment is studied. With the goal of improving the simulation accuracy of the model, the influence of strain rate effect on the collision response is studied, and the deformation mode and acceleration curve are compared with those without strain rate and actual vehicle test. The final result shows that considering the strain rate effect is obviously better than not considering the strain rate in terms of the acceleration peak and the number of thin-wall deformation folding.

1. Introduction
Car frontal collision accidents account for about 66.9% of all collision accidents. When a car has a frontal collision, the car collision in passive safety is mainly through the deformation of the front rail to alleviate and absorb the impact kinetic energy. In the experiment, the car test is often used to simulate the whole vehicle. It is one of the main methods to test the energy absorption effect of important parts such as the frame and the front rail.

With the development of computer technology, simulation has become an important means of scientific research on various structures. In the simulation process of the trolley simulation test, the method of combining the trolley test and the finite element model simulation is adopted. Based on a certain precision finite element model, it starts with noise reduction filtering and considering the strain rate effect to improve The simulation accuracy of trolley collision takes the speed of trolley test as input to study the deformation mode, acceleration, total absorbed energy and other responses of important parts such as the end of the front rail. Through the CAE computer simulation analysis of vehicle crash safety, taking into account the cost of the vehicle crash test, a supplement and optimization method for the trolley test is carried out.

2. Trolley Double Cylinder Test and Finite Element Model Establishment
For cars, the end of the front rail is the main energy-absorbing component, which affects the energy-absorbing characteristics of the vehicle. In order to facilitate and accurately simulate the deformation of the end of the front longitudinal beam, the front longitudinal beam is simplified into an energy-absorbing tube with a thin-walled beam structure. The total mass of the test vehicle is 536kg, and its front end is
welded with a 410×80×80mm energy absorbing tube, and the solder joint spacing is 40mm. Because the low-strength high-strength steel material has low average acceleration and excellent deformation mode, it can give occupants better protection. Therefore, three materials of B340/590DP, B380/590TR, and B400/780DP are used for testing, and the thickness is maintained at about 1.4mm. The double-beam collision test adopts double-beam welding, and hits the rigid wall at a speed of 38Km/h. Finally, the obtained test data is analyzed and compared. When creating the finite element model, the design of the test piece adopts the same design size as the real test piece. At the same time, in order to ensure the accuracy of the simulation, the real trolley model shown in Figure 1 is selected for collision in the collision simulation study. A double energy absorption tube is connected to the front end of the trolley to evaluate the response of the trolley simulation model.

![Figure 1. Finite element model of trolley double tube.](image)

3. Acceleration Curve Processing

A signal that meets certain conditions can be regarded as a superposition of infinite sine waves. Volatile acceleration data acquired by the acceleration sensor, in order to filter out high frequency components in the waveform using the frequency of CFC 60 on data path in SAE J211 grade predetermined "collision experiment test instrument" in the filtering process, the value of CFC represents its maximum flat frequency in the amplitude frequency domain, and its related parameters are shown in Table 1. The comparison before and after filtering is shown in Figure 2. The noise signal generated in the collision process is well processed through filtering, so as to obtain a good real-time and accurate acceleration curve.

| Number | CFC (Hz) | 60-60 | CFC (Hz) | 60-60 |
|--------|----------|-------|----------|-------|
| 1      | f1       | 0.1   | fn       | 100   |
| 2      | a(db)    | +0.5-0.5 | c dB    | +0.5-4.0 |
| 3      | f0 (Hz)  | 60    | d dB/oct | -9.0 |
| 4      | b(db)    | +0.5-0.5 | e dB/oct | -24  |
| 5      | g(db)    | -30   | f dB/oct | ∞     |

![Figure 2. Comparison of deceleration curve before and after filtering.](image)
4. Simulation Verification and Analysis of Trolley Collision

4.1. Strain Rate Effect
One of the main differences between the dynamic constitutive relationship of materials and the static constitutive relationship is that the former should include the strain rate effect, while the static constitutive relationship does not consider the strain rate effect. Compared with static load, the constitutive relationship of elastic-plastic materials under dynamic load has a series of different mechanical properties. One of the most important characteristics is that under fast loading conditions, the yield limit of many metal materials has obvious increase, but the appearance of yielding has a hysteresis phenomenon. [6] Therefore, the strain rate effect has a certain influence on the accuracy of the simulation results under high-speed collision conditions. It can be seen from Figure 3 that the ideal axial progressive telescopic deformation occurs when the strain rate is considered. It can be seen from Figure 4 that there is a significant difference between whether the strain rate is considered or not, considering that the strain rate has a lower acceleration. At the same time, from the comparison of Fig. 4 with the test results, it can be seen that the strain rate and the test are in good agreement under high-speed collision conditions. Therefore, considering the strain rate can improve the accuracy of the analysis and simulate the real situation of the test more accurately.

Figure 3. Axial progressive telescoping deformation considering strain rate.

Figure 4. Whether the strain rate is considered consistent with the test.
4.2. Comparison of Simulation Results

The deformation mode, acceleration curve and energy absorption curve of the three materials of B340/590DP, B380/590TR and B400/780DP are compared.

4.2.1. Acceleration. At the same time, it can be seen from the comparison of acceleration curves in Figure 5 that the simulated acceleration curve is roughly consistent with the experimental acceleration curve trend and range, and there is some deviation in response time, but the consistency in the number of acceleration peaks is strong, and the formation of each acceleration peak represents a thin The collapse of the wall structure, that is, the number of folds after the collision is basically the same. Lower acceleration can give passengers better protection. [7] Table 2 further quantifies and compares the average acceleration of simulation and test. It can be seen that there is a certain error in the average acceleration of simulation and test. Simulation can basically simulate the acceleration of the test, but there is still a lot of room for improvement. This also provides design space for further optimization of the material constitutive model parameters.

![Figure 5](image)

**Figure 5.** Comparison of simulated acceleration curves and experimental acceleration curves of different materials.

| Material          | Simulation value | Test value | Error |
|-------------------|------------------|------------|-------|
| B340/590DP        | 19.94            | 18.58      | 7.3%  |
| B380/590TR        | 17.53            | 18.24      | 3.9%  |
| B400/780DP        | 23.56            | 20.77      | 13.4% |
| B410/780DP+Z      | 18.1             | 17.09      | 5.9%  |

**Table 2.** Average acceleration of four materials.
4.2.2. Energy. As the collision occurs, the kinetic energy of the system is gradually transformed into internal energy, and it can be seen from the energy change curve in Figure 6 that the curve trend is consistent and the energy change law is similar. The comparison curve shows that the end time of the energy collision between the simulation and the test is very consistent, but due to the influence of the hourglass energy, slip energy and other factors in the simulation, the total energy obtained by the simulation is less than the test, but the energy error of each is far less than 5%. Therefore, it can be considered that the simulation model is reasonable. At the same time, the hourglass energy and slip energy are both positive, which can also prove that the model is correct from the side. Therefore, it can be considered that the simulation can better simulate the energy change of the test.

![Energy curve of different materials.](image)

**Figure 6.** Energy curve of different materials.

5. Conclusions
In this paper, the frontal collision test and finite element simulation analysis of the trolley double-tube are carried out, combined with the experiment and the finite element simulation hybrid numerical algorithm, the simulation accuracy of various high-strength steels in the frontal collision experiment is studied, and the corresponding optimization strategy is proposed. The study found that there is a big difference between considering the strain rate effect and not considering the strain rate effect on the simulation acceleration response results. From the point of view of acceleration peak, the value of strain rate effect is considered to be consistent with the test value. On the contrary, the acceleration curve without strain rate effect is generally higher than the test value in the early stage of thin-wall crushing. From the perspective of the law of energy change, the simulation and experiment changes are similar and the hourglass energy is less than 5%, indicating that the model is correct.

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