CONVERTER MAGAZINE
Volume 2021, No. 7

Research on Reconstruction of Frontal Collision Accidents of Two Cars Based on the Combination of PC-crash and Finite Element Method

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Abstract

In this paper, PC-crash and finite element method are combined to analyze a typical frontal collision accident of two cars, determine the relationship between the overlap rate of the two workshops and the damaged parts, so as to obtain the force transmission path in the collision; meanwhile, analyze the linear relationship between the difference between the absolute speeds of the two cars and the deformation of the anti-collision beam at the main energy-absorbing part. Through the comparison with the actual accident measurement, the original parameters before the collision in the PC-crash are determined, and the parameters are used as the boundary conditions of the finite element analysis. Through simulation and calculation, the changes of speed, acceleration, energy and force of the two vehicles at the moment of collision, as well as the deformation and damage of the main components of the vehicle, are of great significance for the analysis and investigation of traffic accidents.

Keywords: *Finite element method, Frontal collision, Accident reconstruction, Car, PC-crash.*

I. Introduction

As the number of cars in the country increases year by year, the frequency of collision accidents has also remained high. In 2017, there were more than 1,000 collision accidents in Harbin, of which the frontal collision of two vehicles accounted for nearly 30%[1]. In view of these collision accidents, PC-crash is mainly used at home and abroad to reproduce the accident process, which is used to study the driving process of the vehicle, and the accuracy of the result is more than 95%[2].The finite element method uses a display center difference algorithm with a small integration time step, and comprehensively considers the strain efficiency and elastoplastic characteristics of the material, and is widely used in vehicle development [3]. Due to its high calculation accuracy, many domestic and foreign experts and scholars have used the finite element method to analyze traffic accident cases in recent years [4]. Coon and Reid established a finite element model of the car and the guardrail, studied a case of a vehicle hitting the guardrail, and calculated the speed of the accident vehicle. S[5]. Potula et al. studied the influence of the five variables of the side airbag on the driver's head injury, and put forward relevant suggestions on the problems that should be paid attention to when designing the side airbag[6]. Ran Cao et al. used the finite element method to analyze the impact of heavy trucks on bridge piers and pointed out that the impact of the engine block usually produces the highest peak force, which is closely related to the impact speed[7]. It can be seen that applying the finite element method to a traffic accident can provide a more in-depth analysis of the degree of damage at this moment. At the same time, the combination with PC-CRASH can combine their respective advantages to study the full picture of the accident more comprehensively.

II. Accident Information Extraction

According to the vehicle body information of the two vehicles shown in Table 1, after completing the simulation of the collision between the Subaru and the Jetta in PC-crash [4], the parameters of the time when the two vehicles

ISSN: 0010-8189

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start to collide are extracted, as shown in Table 2.

Table 1 Vehicle body information of vehicles

Model	Jetta	Subaru
Body length	4475mm	4560mm
Body width	1674mm	1780mm
Body height	1415mm	1700mm
Total mass	1545kg	2015 kg
Front track	1429mm	1530mm
Rear track	1422mm	1530mm
Front overhang	890mm	——
Back overhang	1054mm	——
Wheelbase	2471mm	2615mm

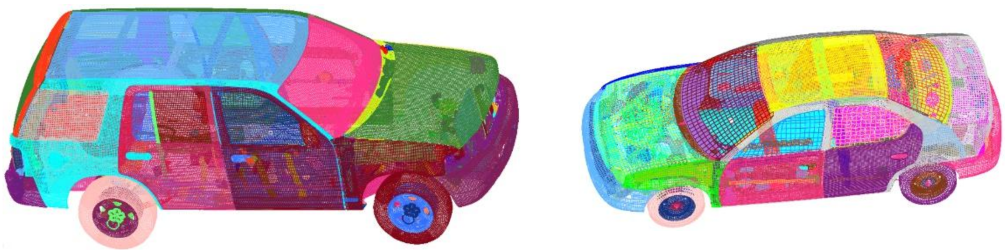
Table 2 PC-crash output data

parameter	Jetta	Subaru
Velocity before collision	83.54km/h	39.59km/h
Deflection angle at the time of collision	12.39°	-174.05°
Road adhesion coefficient	0.8	
Coefficient of friction between car bodies	0.5	

III. Etablishment of the Finite Element Model of the Accident Vehicle

3.1 Establishment of Vehicle Model

The sub-assembly modeling method is used to build the finite element model of the two vehicles, as shown in Fig. 1. Due to the frontal collision of the two vehicles, the front grids of the two cars are dense, and the middle and rear grids are larger. Subaru sedan has 616,521 grids and 624042 nodes; Jetta sedan has 273,617 grids, and 282026 nodes.



a）Subaru b）Jetta

Fig. 1 Accident vehicle model

3.2 Determination of the Relative Position of the Vehicle

The accident was caused by the Jetta sedan illegally occupying the opposite lane and collided with the oncoming Subaru sedan. According to the deformation position and depth of the accident vehicle, it can be judged that the main force position of the two vehicles in collision contact. Based on this, the relative position of the collision between the two vehicles as shown in Fig. 2 can be initially established.

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Fig. 2 Relative position map of the accident vehicle

3.3 Contact settings and Boundary Conditions

In order to prevent penetration between its own parts, the keyword CONTACT_AUTOMATIC_SINGLE_SRUFACED is used to define the whole vehicle [5]. At the same time, in order to prevent the two vehicles from penetrating and causing calculation errors, the contact between the two vehicles is defined using the keyword CONTACT_AUTOMATIC_SRUFACE_TO_SRUFACE. In the setting of boundary conditions, the initial speed of the vehicle model is set by the loading method of INITIAL_VELOCITY_GENERAT
ION.

IV. Adjustment and Optimization of the Finite Element Model of the Accident Vehicle

4.1 Overlap Rate

According to the information extracted in Table 2, it can be determined that the speed at the moment when the Subaru and the Jetta collide are 40km/h and 84km/h respectively.According to the information extracted in Table 2, it can be determined that the speed at the moment when the Subaru and the Jetta collide are 40km/h and 84km/h respectively. The angle between the two workshops can be calculated based on the deflection angle of the two cars when they collide. It is 186.5°, which can determine the initial parameters of the two vehicles and the relative position before the collision. However, due to the different overlap ratios in the collision of two vehicles, the corresponding force transmission paths are different, and the main deformation and energy absorption positions of the vehicles also change accordingly. Therefore, by setting different overlap ratios, the corresponding relationship between the energy-absorbing components and the overlap ratio is explored, so as to adjust and optimize the two vehicle models. The overlap rate is set here as shown in Table 3, as shown in Fig. 3 is the relative position of the two workshops when the overlap rate is 80%.

Table 3 Overlap rate settings

Serial number	1	2	3	4	5
Overlap rate	100%	80%	60%	40%	20%

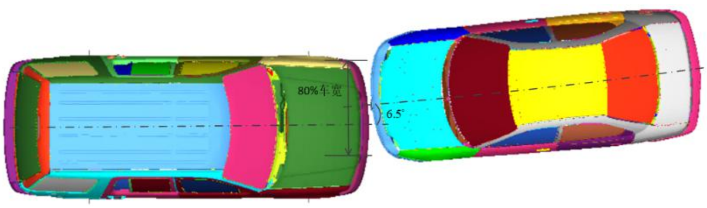

Fig.3 overlap rate80%

The simulation analysis shows that the overlap ratio has the following relationship with the load transfer path, as shown in Fig. 4. It can be seen from the figure that in the collision of each overlap rate, both the left side wall structure and the tire participate in the load transfer. With the increase of the overlap rate, different structures participate in the load transfer in turn. Since the Subaru body is slightly wider than the Jetta body and there is a certain angle between the two workshops, although the right tire and the right side wall structure are damaged, they are not involved in the load transfer process. In the accident, the right front side member of the Subaru did not deform. It can be determined that the overlap rate between the Subaru car and the Jetta car is about 60%.

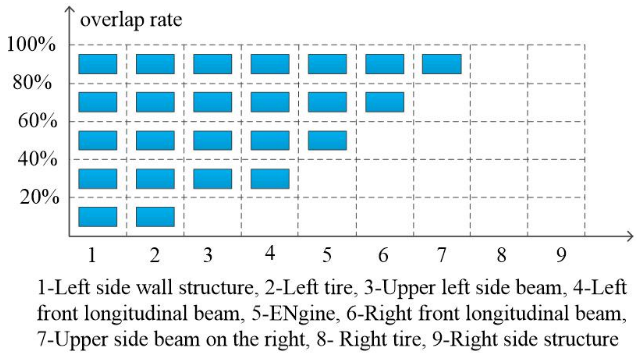

Fig.4 Relationship between overlap rate and load transfer

4.2 Optimization of Vehicle Speed

In a two-vehicle collision, the stiffness of the car is directly related to the deformation. The greater the stiffness, the smaller the deformation. Assuming that the two cars are in a collision, their fronts are linear, and the process is a plastic collision process, then the law of conservation of energy and the conservation of momentum are obtained by[15]:

$$F_{mid} = \frac{1}{2} \cdot \frac{m_1 m_2}{m_1 + m_2} \cdot \frac{\Delta v^2}{L_1 + L_2} \tag{1}$$

Where, F_{mid} is average collision force during collision； m_1 , m_2 is quality of two vehicle； Δv is the speed difference between the two vehicles before the collision; L_1 , L_2 is average deformation of two vehicles.

It can be seen from equation 3-1 that when two vehicles collide, the stiffness of the two vehicles is a fixed value, and the mass ratio and speed difference of the two vehicles will affect the average deformation of the two vehicles. Since the mass of the two vehicles in the frontal collision of Subaru and Jetta is a fixed value, the relationship between the average deformation of vehicle components and the speed difference between the two vehicles can be explored through simulation analysis.

Fig. 5 shows the deformation measurement when the speed difference between the two workshops is 45km/h.According to the three-dimensional space coordinate method, 6 points are selected at equal intervals on the front bumpers of the two vehicles, and the lengths before and after the collision are measured respectively, and the deformation amount at this point is calculated, as shown in Table 4.

Table 4 Deformation measurement at 45km/h speed difference

	Subaru Deformation	Jetta deformation
N1	419.34	740.54
N2	404.64	927.04
N3	441.62	916.88
N4	409.23	923.93
N5	242.66	973.08
N6	45.11	1027.14

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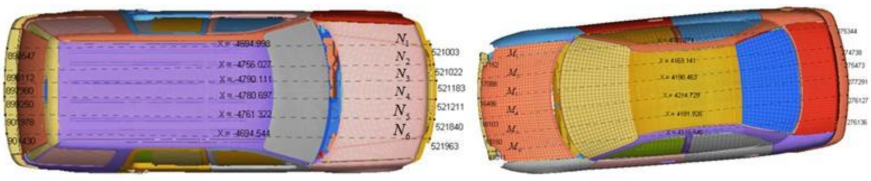

Fig.5 Three-dimensional space coordinate method

According to the CRASH criterion [17], substituting the deformation of the above six points into the formula (3-2), the average deformation of the front bumper of Subaru car (NV1)and the average deformation of front bumper of Jetta car (NV2)can be calculated：

$$N_V = \frac{1}{10}\left(N_1 + 2N_2 + 2N_3 + 2N_4 + 2N_5 + N_6\right) \tag{2}$$

Set the speed of Subaru to 40km/h, change the speed of Jetta, set different speed differences, and perform simulation calculations respectively to obtain the data of the relative deformation and speed difference between the two workshops as shown in Table 5.

Table 5 Relative deformation and speed difference

$v_2 - v_1$ （km/h）	30	35	40	45	50
$N_{V2} - N_{V1}$ （mm）	246	362	436	578	654

According to the data obtained in Table 5, the relationship curve between the average deformation difference of the front bumpers of the two workshops and the speed difference between the two workshops as shown in Fig. 6 is obtained after Origin fitting. The fitting polynomial of this curve is:

$$y = 1.32\times10^{-7}x^3 - 1.74\times10^{-4} + 0.12x + 8.98 \tag{3}$$

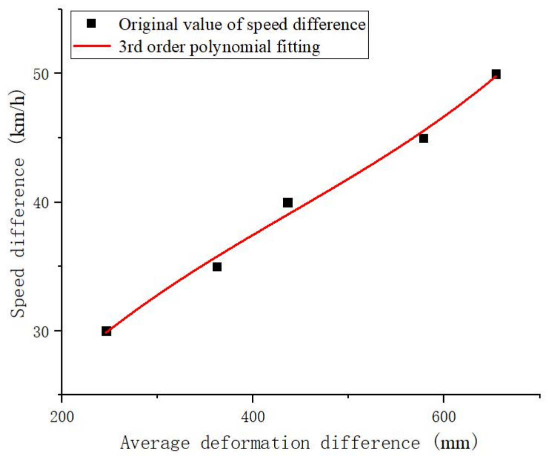

Fig.6 Relationship between average deformation difference and speed difference

The measurement method of the front bumper deformation of Subaru and Jetta is shown in Fig. 7, and the actual measurement values and the average value of deformation are shown in Table 6.

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Table 6 Measured values of deformation of two vehicles

point	Subaru	Jetta
1	430	696
2	410	885
3	465	873
4	425	900
5	234	936
6	40	985
average value	353.8	886.9

Fig.7 Front bumper measurement method

From Table 6, the difference between the average deformation of the two cars is 553mm, and substituting into Equation 3-3, the corresponding speed difference is 42km/h, which is close to the 44km/h extracted in Table 2. Since the Jetta had obvious braking marks in the frontal collision accident, the speed calculated by the mark method [4] was 85.62km/h, and the Subaru had no obvious braking marks, so the speed was 39.38km/h calculated according to the deformation method [4]. The speed difference is shown in Table 7.

Table 7 Speed difference comparison

Speed difference（km/h）	Speed difference（km/h）
Poor simulation speed in PC-crash	42
Polynomial fitting speed difference	44
Formula method speed difference	46.24

V. Analysis of Results of the Finite Element Model of the Accident Vehicle

5.1 Speed Analysis

The collision process between two vehicles can be divided into a deformation phase and a recovery phase.When the two vehicles begin to contact and compress and deform, due to the interaction between the two vehicles, the speed gradually decreases until the deformation of the two vehicles reaches the maximum. At this moment, the speeds of the two vehicles are equal, and the deformation phase is completed; from the moment of maximum deformation to the moment when the two vehicles have just separated, the process is the recovery phase.

Using the finite element method to simulate and analyze the collision accident of Subaru and Jetta , the speed

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changes of the two vehicles can be obtained as shown in Fig. 8. It can be seen from the figure that when approaching 0.01s, the speeds of the two vehicles begin to change.At about 0.045s, the speeds of the two vehicles are equal, about 5m/s. It can be explained that the period of 0.01s-0.045s is the stage of collision and deformation of the two vehicles. Due to the interaction between the two vehicles, the speed of the two vehicles drops sharply. After 0.06s, the speed of the two cars gradually stabilized and approached 0, indicating that 0.045s-0.06s is the recovery phase of the collision between the two cars.Due to the effect of inertia, the two vehicles still have a small speed after the collision recovery phase ends (ie 0.06s).

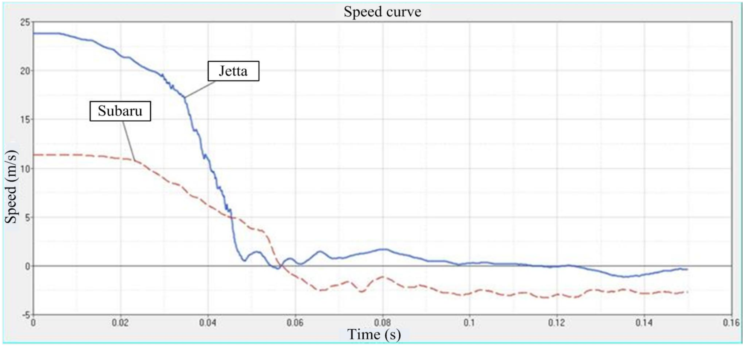

Fig.8 Two car speed changes

5.2 Acceleration Analysis

In a collision between two vehicles, there will be a great interaction force between the two vehicles, which will cause large acceleration fluctuations.As shown in Fig. 9, in a frontal collision between Jetta and Subaru, the interaction force between the two vehicles in the deformation phase gradually increases, resulting in greater acceleration, which reduces the speed of the two vehicles and the force value fluctuates largely at the same time. In the recovery phase, there is still an interaction force between the two vehicles, but the force is slightly smaller than the deformation phase, so the acceleration generated is slightly smaller, and its value fluctuates greatly; after the two vehicles are separated, the acceleration of the two vehicles gradually tends to zero.

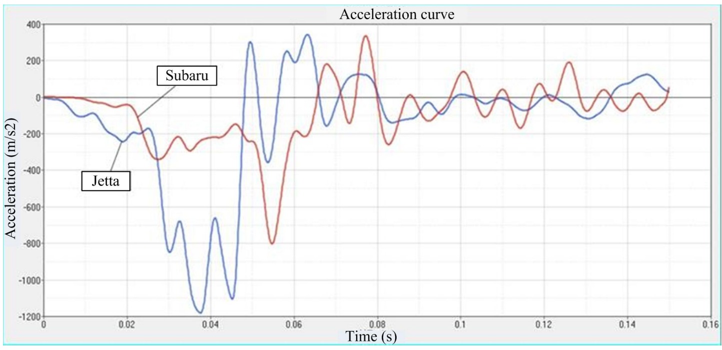

Fig. 9 Two-vehicle acceleration curve

5.3 Energy Analysis.

In a collision accident, the energy conversion between the two vehicles still conforms to the law of conservation of energy. The energy change curve of the accident process is shown in Fig. 10. The added value of the hourglass energy is about 23,400,000J, and the total energy is about 537,000,000J, which is about 4.36% of the total energy. Within 5% of the total energy, the increase in hourglass energy is reasonable. As the two cars collide and deform, the total kinetic energy of the two cars decreases and the internal energy increases. After 0.06s, the collision recovery phase of the two cars ends, and the total kinetic energy and total internal energy of the two cars tend to stabilize. Due to the influence of friction and other factors, Its energy sum is slightly lower than the total energy.

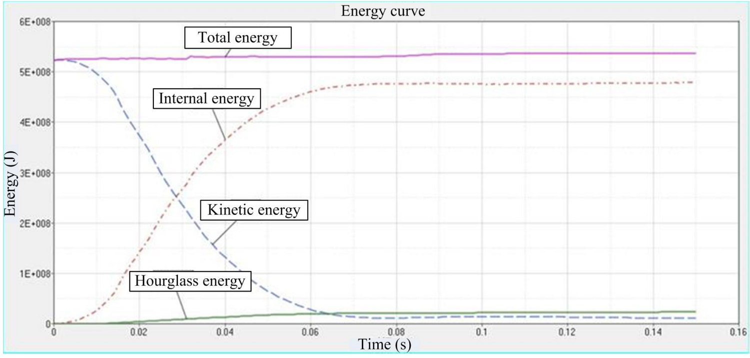

Fig.10 Energy curve

5.4 Force Analysis.

The force between the two vehicles will change as the collision progresses. In the frontal collision accident, the force change curve between the two vehicles is shown in Fig. 11. It can be seen from the figure during 0-0.025s, the interaction force between the two workshops basically increases linearly, reaching a peak value of about 750kN. After maintaining for a short period of time, the force dropped rapidly and the two vehicles gradually separated. At about 0.045s, the force of the two workshops decreased gradually, and as the two vehicles were completely separated, the force gradually tended to zero.

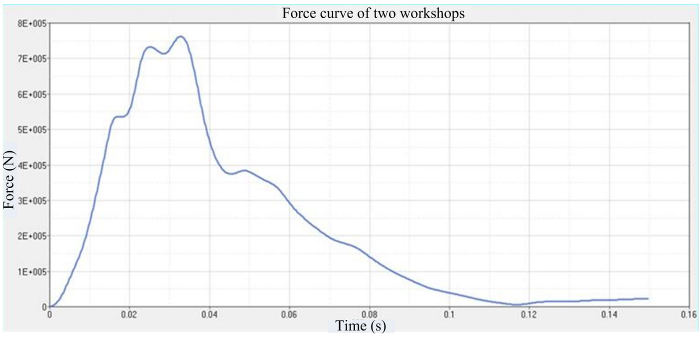

Fig.11 Changes in the force of the two workshops

Vi. Comparison of Accident Finite Element Analysis Results with Actual Accident Information

6.1 Comparison of Collision Deformation Between Two Vehicles.

Using the finite element method, the shape of the accident vehicle can be displayed intuitively.As shown in Fig. 12, the stressed part of the Subaru is the front part of the car body, where the left front part of the front has the largest deformation, the bumper, the energy absorption box, and the front rail are all compressed, and the left front fender deforms greatly;As shown in Fig. 13, the front end of the vehicle is moved back as a whole, and the internal left space is compressed more; As shown in Fig. 14, after the collision of the Jetta, the engine cover is compressed and protrudes upwards, the left and right fenders are all deformed, and the main energy-absorbing parts such as the front bumper, energy-absorbing box, and longitudinal beams are compressed inward. It can be seen that the

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deformation shape obtained by simulation is basically the same as the deformation shape of the actual accident vehicle.

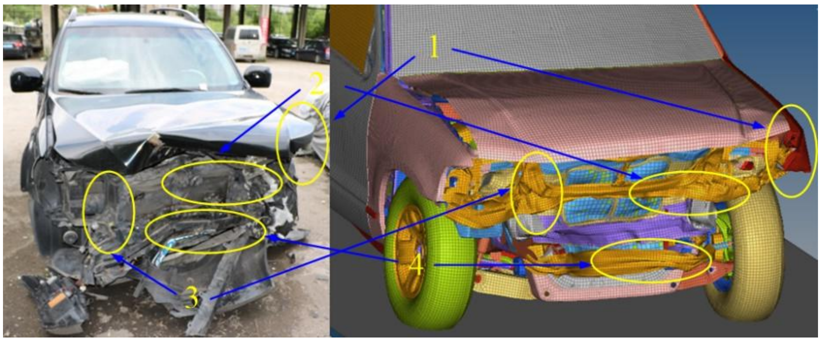


Fig.12 Comparison of deformation patterns of Subaru sedan

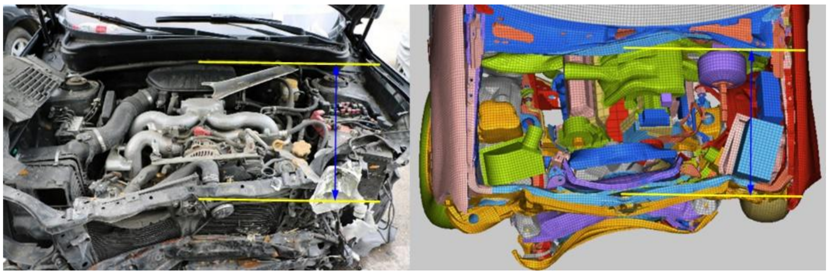


Fig.13 Comparison of front-end space compression of Subaru sedan

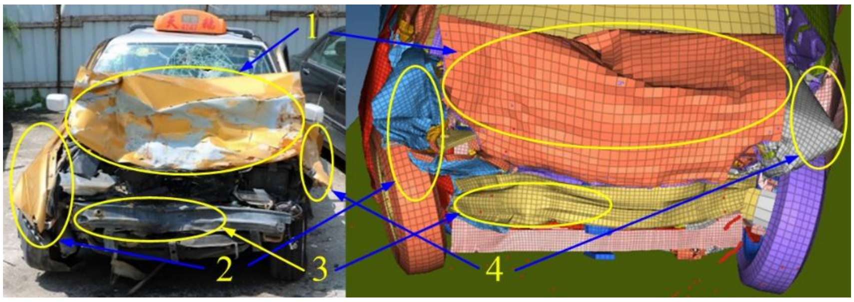
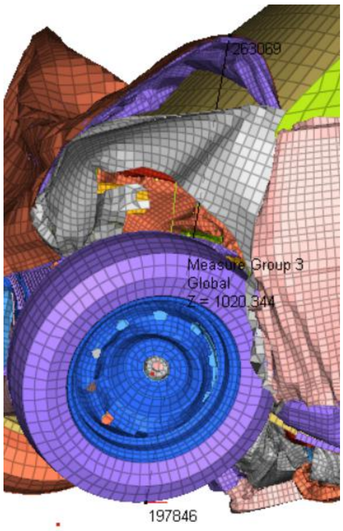


Fig.14 Comparison of deformation modes of Jetta seda

6.2 Comparison of the Size of Collision Deformation.

As there are many vehicle parts, the main deformable parts can be selected for measurement. Here select the engine cover of the Jetta car for deformation measurement. Fig. 15 shows the comparison between the deformation dimensions measured on the Jetta engine cover and the finite element simulation data.As shown in Fig. 15 a), taking the ground as the reference, the distance from the highest point of the left side of the engine cover to the ground is 1.10m; As shown in Fig 15 b), in the finite element simulation, the Z-direction distance from the highest point of the protrusion on the left side of the engine cover from the ground is 1.02m, and the error can be calculated to be 7.27%, which can be seen that the simulated deformation of Jetta is more consistent with the actual deformation.



a）On-site measurement of deformation size　　b）Finite element simulation deformation size

Fig.15 Engine cover deformation measurement

The largest inward deformation of the front part of the Subaru is selected for measurement. Fig. 16 is a comparison diagram of the maximum depth measured by the Subaru on-site and the maximum depth measured by finite element simulation.As shown in Fig. 16 a), the measured maximum depression depth is 465mm; the simulation result measurement method is shown in Fig. 16 b), taking the rear cover of the vehicle as the reference, and selecting the point of maximum deformation at the front of the vehicle. The measurement shows that the distance before the collision is 4454m and the distance after the collision is 4038mm. The deformation amount is 416mm, and the error is 10.54%. It can be seen that the simulation deformation results are basically consistent with the actual accident results.

a）Actual measurement　　b）Simulation measurement

Fig.16 Measurement of the maximum concave deformation at the front

VII. Conclusions

The overlap rate of the two collision workshops directly affects the transmission path of the force. As the overlap rate increases, the side structure, tires, side rails, front rails, and engines take part in the transmission of force, thereby affecting their energy absorption in a collision accident.

ISSN: 0010-8189

Through theoretical derivation and fitting analysis, it is found that there is a certain linear relationship between the absolute speed difference of the two vehicles and the average deformation difference of the two vehicles. As the average deformation difference of the two vehicles increases, the absolute speed difference is also larger.

Taking the original parameters before the collision in PC-crash as the boundary conditions of the finite element analysis, we can get the changes of the speed, acceleration, energy, mutual force between the two cars at the moment of collision, as well as the deformation and damage of the main parts of the vehicle, which is of great significance to the analysis and investigation of traffic accidents.

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