BIW Safety Performance Research Based on Vehicle Frontal Crash

Zhida Shen, Xin Qiao and Haishu Chen

Abstract This paper introduces the research course of vehicle crash safety performance. A vehicle frontal crash FEA model is established according to CMVDR294. Vehicle frontal crash simulation calculation is conducted by LS-DYNA. Energy absorption area and transmission route of impact force in frontal crash are introduced in details. Affects of longitudinal beams deformation on vehicle crashworthiness are discussed deeply through simulation of the longitudinal beams design plan. Finally, tests are made to verify feasibility of the longitudinal beams design plan and reliability of the vehicle frontal crash model. As result, references are provided for vehicle longitudinal beams design and improvement for the future.

Keywords FEA · Frontal crash · Longitudinal beam · Vehicle crashworthiness

1 Preface

With the development of the society and the progress of human culture, automobile has become necessary means of transport in people's life. Along with increased automobile ownership and rapid development of high grade

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expressways, road traffic accidents have increased year by year. In all types of crash accidents, frontal crashes cover about 30 % of the total number of accidents. The injury rate and lethality rate are also very high [1]. Therefore, how to improve vehicle passive safety performance in crash and how to avoid or alleviate injury and death of passengers in crash to the maximum have become an important subject of vehicle passive safety performance research in our country.

Even though vehicle crash tests are indispensable for final authentication and evaluation of vehicle type and passive protective device, yet the preparatory expenses and test costs are extremely expensive. Furthermore, the test results are not stable enough and the repeatability is poor due to some random factors. As shown by related studies home and abroad, computer simulation of vehicle crash course with a dummy can not only predict the crashworthiness of the vehicle structure itself, but also the response and injury degrees of the passenger during the crash more accurately. So it may give better prediction of passive safety performance of the vehicle being developed and accelerate the development pace of new vehicle types.

FEA theory and its application were born in early 1960s. At that time computer simulation research on vehicle crash had been carried out in foreign countries. However, the research was restricted by the development of computer hardware technology and algorithm theory, actual breakthrough started in 1986 when LS-DYNA succeeded in simulating vehicle large deformation for the first time [2]. Ever since then, computer simulation technique based on dynamic explicit non-linear finite element technology has seen its widespread applications abroad. Their researches are mainly concentrated on the following aspects:

(1) Computer simulation of 100 % frontal crashes. Frontal crash of vehicle is the most common traffic accidents, in which casualties and property damages are more serious, therefore, the contents of this aspect were the first focus when crash simulation analyses were made and passive safety statutes were drafted in America and some European countries. In 1993, British Transport Research Laboratory conducted simulation calculation of the frontal crash of a car by using a giant computer and dynamic nonlinear FEA software. The vehicle model was composed of 25,000 deformed elements and 100 ms response course of vehicle crash was calculated, in which acceleration curve and vehicle deformation, etc. during the crash were acquired [2]. It showed that the passenger had serious injuries mainly in the head, chest and legs in the frontal crash. In view of the seriousness of passenger's injury in vehicle frontal crash, corresponding statutes related to vehicle frontal crash have been formulated in America and Europe. Therefore, simulation analysis of vehicle frontal crash is very significant to improve vehicle crashworthiness in frontal crash (Fig. 1).
(2) In 40 % ODB crashes, the obstacles may be rigid walls or deformable objects. This is because when compared with frontal crash, the front end structure of the vehicle body intrudes into the passenger's space more seriously in side crashes, which may easily injure the passenger on the intruded side of the structure. The method for the research is basically similar to the method used

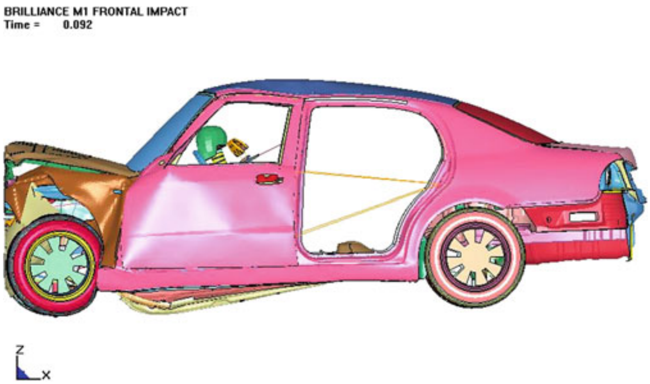


Fig. 1 The 100 % frontal crash simulation

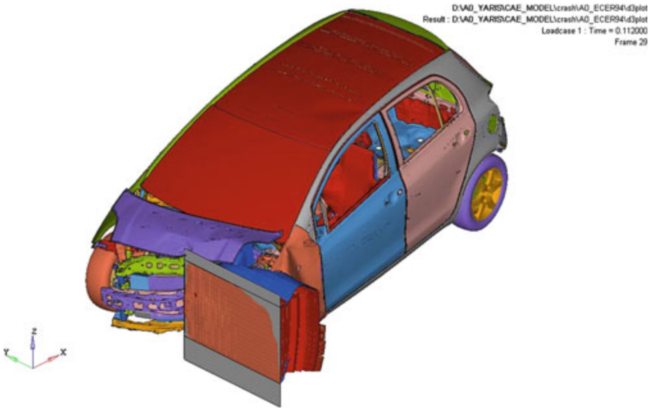


Fig. 2 The 40 % ODB crash simulation

for computer simulation research of vehicle frontal crash, except that the key objects to be considered in the vehicle simulation are not totally the same as those in front crash. Besides front longitudinal beams and dash panel, the front tyre, the front door frame, the steering wheel and the pillar on the side crash side are also the key objects for consideration and research (Fig. 2).

(3) The side impact simulation. The key point to be considered in side crash simulation is the peripheral structure, including side door, door frame, pillar, roof and floor on the crashed side, passenger seat and so on. The expected objective is that the deformations of the pillar and the door are small. Therefore, The side impact simulation is equally important for the research of vehicle crashworthiness (Fig. 3).

Since crash accidents endanger human safety, definite and stringent requirements for vehicle crashworthiness are specified in automobile codes or standards

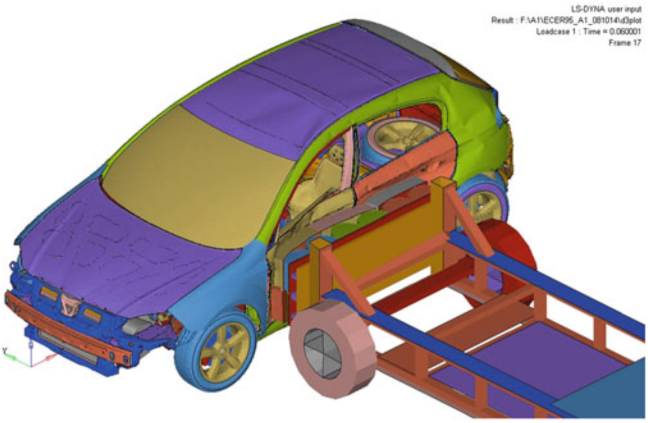


Fig. 3 The side impact simulation

both home and abroad. In foreign countries, safety performance must be evaluated before a vehicle is finalized for production and sales of vehicles that fail to meet the crashworthiness specified by the statute shall not be permitted. On Jan. 1, 2000, the Chinese Government also implemented Regulations for Protective Design of Passengers in Frontal Crash (CMVDR294), which specifies that vehicles to be newly listed in China later than October, 1999 must meet the above Regulations, that the import licensing of imported vehicles that had been sold in China before implementation of the above Regulations must be cancelled if they had not meet the Regulations. As for the vehicles that had been produced and listed but failed to meet the Regulations, they must satisfy the Regulations through structural modification before July 1, 2002, otherwise the production must be stopped.

2 Establishment of Finite Element Model

In modeling thought, the finite element model of vehicle frontal crash is generally the same as those similar crash models. What is different lies only in different concerns for vehicle body components due to differences in the purpose of analysis. The grid of energy absorption components in the front end of vehicle body: front bumper beam, crash box, upper longitudinal beams and lower longitudinal beams must be detailed appropriately, and the connecting relations between components must be simulated as much as possible. The components and structures inside the engine compartment must be detailed as much as possible; the engine and the gearbox may be simplified properly, but accuracy of the overall dimensions must be ensured. Generally speaking, the quality of the simulation model analyzed may affect the precision of the calculation results directly, so it is critically important for the analysis [3]. Therefore, for any complicated crash simulation model, a set of standardized modeling flow is necessary for accuracy of the simulation model.

A finished automobile has many complicated components, so the establishment of vehicle simulation model is a gigantic work that requires large quantities of manpower and vigor. In establishing the vehicle finite element model, the first thing is to check the 3D dig fax and 3D welding points of the real vehicle structure provided by design section, and show critical concerns about all the structural components affecting the crash analysis. After that, CATIA 3D models of all the vehicle parts and components shall be saved in MODEL format files, geometric contours of parts shall be input via the formatted data conversion interface in Hypermesh software so as to make the grid by using the lines and planes, in which the main characteristic lines must be reserved and the grid must be fitted properly with the geometry.

The modeling method for each subsystem and its parts and components depends upon the structural characteristics and the response features during the crash. Generally, in modeling of frontal crash, the model is established in three categories of components. The first category is body sheet metal parts such as front bumper beam, crash box, upper longitudinal beams and lower longitudinal beams, which are the main components for deformation energy absorption and force transmission, because they are the main objects to express the deformation of the crashed body. The second category is the chassis and power assembly system, whose mass and rigidity are great relative to the vehicle body structure, so the inertia should not be neglected. The third category is body accessories, whose deformation energy absorption ability is very low, but the mass occupies a larger proportion, so they have greater impact on vehicle body response. The elasticity and damping characteristics of front and rear suspensions are particularly important in frontal crash modeling, because rigidity characteristics of rubber suspension and other factors shall affect the response to movement such as body pitching and side deflection in the course of crash, which is just one of the features in modeling of frontal crash [4].

Vehicle model shall be assembled according to automobile manufacturing process (Fig. 4). First thing is the relations between all the small assemblies, then all the subassemblies shall be assembled, and finally the vehicle model shall be assembled [5]. Assembling of vehicle model shall be realized through addition of connecting units (welding points hinged to short beams) or restrictions (e.g. rigid restriction) on the connecting positions. Finally boundary conditions shall be defined and all the contact problems between components during the crash shall be resolved.

Vehicle frontal crash model has large quantities of nodes and units, so it has certain high requirements for software and hardware. This modeling is completed on DELL/T3500 work station by using Hypermesh, which is a common preprocessing software in automobile industry. For more accurate and more effective modeling, a LS-DYNA file [6] may be set up for each crash respectively according to the subsystems of the vehicle, the suffix of the file is key. Subsystems of the model include: BIW system, four doors and two hoods system, chassis system,

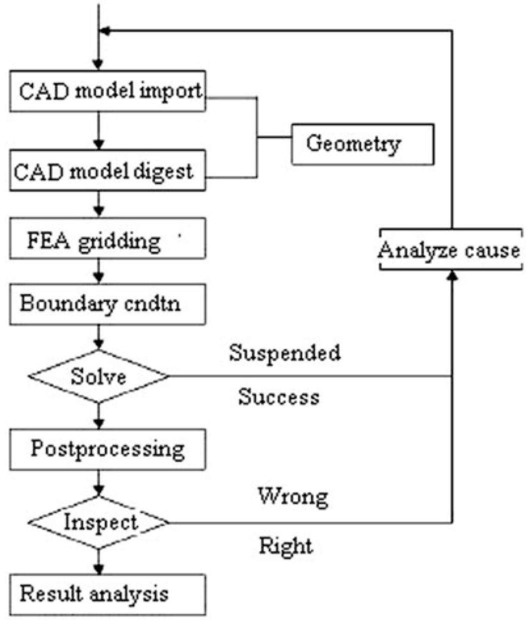


Fig. 4 The FEA modeling process configuration

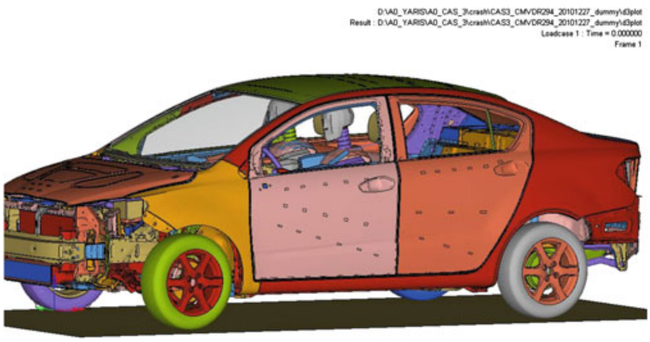


Fig. 5 The total vehicle frontal crash FEA model configuration

steering system, power transmission system, interior and exterior decoration system and safety system. Finally, all the subsystems are assembled together by means of an associated file. Through statistics, the model is composed of 1,183,754 nodes, 1,291,149 units, 3,698 body welding points, and the mass of the finished vehicle is 1,145 kg. Penetration and interference of parts and components must be avoided in the model so as to ensure that the calculation results of the crash model are accurate.

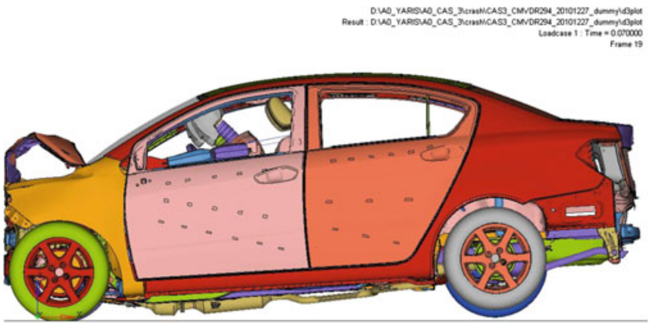


Fig. 6 The vehicle frontal crash simulation result

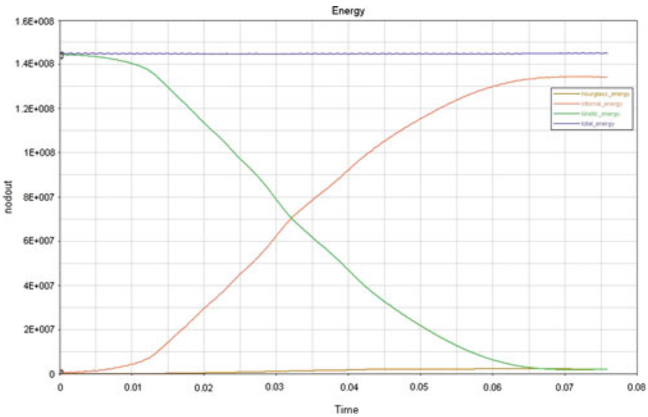


Fig. 7 The system energy curves

Crash simulation was carried out for this type of vehicle according to Regulations for Protective Design of Passengers in Frontal Crash (CMVDR294), which is officially promulgated for execution in our country. The model was stricken against a rigid barrier (as shown in Fig. 5) at a speed of 50 km/h. The bode deformation after the crash is as shown in Fig. 6.

Through simulation calculation, the total energy variation tendency of frontal crash model is shown in Fig. 7. After the crash is performed, the general system deformation energy (internal energy) and dynamic energy are about 47 % respectively, the remaining 6 % of energy are crash interfacial energy and hourglass energy in value calculation, of which the hourglass energy only covers 2.5 % of the total energy. Therefore, it can be seen from the figure and the data that this simulation is believable. The response characteristics of the total energy may be used to evaluate the general crashworthiness of the body structure.

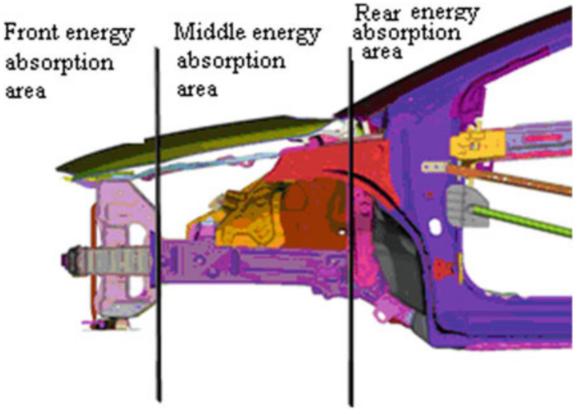


Fig. 8 Division of crash energy absorption areas

3 Energy Absorption Area of Vehicle Body and Force Transmission Route in Frontal Crash

At present, the method popularly adopted for vehicle body design is to divide the body into three areas: front, middle and rear energy absorption areas [7], as shown in Fig. 8. in which, the front energy absorption area is mainly made up of front bumper beam, bumper beam buffer block, engine hood front end and crash box. Such components are made of high performance plates, which can absorb the energy produced in the impact as much as possible through their deformation, and also continue to split the energy to the left and the right by using the force borne by the structure and transfer the energy rearward. The middle energy absorption area is mainly composed of upper and lower longitudinal beams of the body, fender, engine hood rear part and auxiliary frame. Such structures absorb most energy produced in the crash through reasonable bending deformation. The rear energy absorption area is composed mainly of the driver's cab that is both strong and rigid. In design of rear energy absorption area, deformation that may cause injury to the passengers must be avoided as much as possible so as to guarantee the passengers' safety by reducing the intrusion into the front floor and the crash speed as well as the acceleration of frontal crash.

Crash force transmission routes: The front, middle and rear energy absorption areas are the basis of multiply force transmission routes in frontal crash. Setting of multiply force transmission routes in frontal crash for frontal crash may effectively absorb energy and transmit crash force. Multiply force transmission routes in frontal crash are generally divided into three layers as shown in Fig. 9, which are typical force transmission routes in the course of frontal crash.

It can be seen from the above figure that the upper layer of frontal crash force transmission routes is composed of such components as engine compartment, upper longitudinal beams and front damper mounting hood, which absorb some of the crash energy from the front area, and disperse the rest of energy to Pillar A, front wall and reinforcing beam.

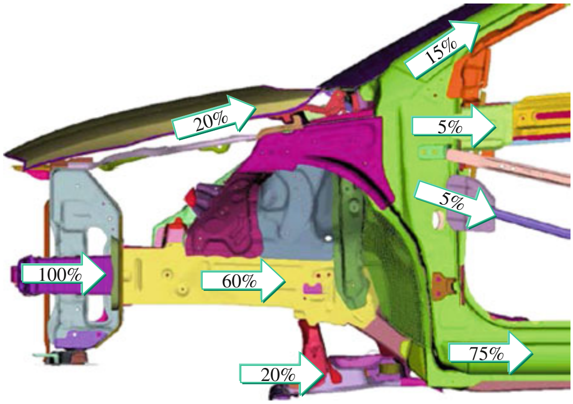


Fig. 9 Division of crash force transmission

The middle layer mainly consists of bumper beam, crash box and lower longitudinal beams, which is the major force transmission route in the course of crash. The bumper beam and the crash box split the energy produced in the crash leftward and rightward and absorb the energy initially, and then through the above components, transmit the energy to such areas as lower longitudinal beams, front floor, middle channel and threshold. The lower layer is mainly made up of the auxiliary frame, which absorbs part of the crash energy from the engine and the gearbox, and transmit the rest of energy to the front floor longitudinal beams, the threshold and other areas.

4 Influence of Longitudinal Beams on the Crash

It is known from the above discussion that the longitudinal beams of the body plays a vital role in frontal crash. Since one of the engines mounted in this type of vehicle has a large volume, the shape of the right longitudinal beams has to be amended according to the proposal of the general arrangement. The most direct scheme is to reduce Y section in the middle of the right longitudinal beams. Design plan (1) is as shown in Fig. 10.

Through simulation calculation, it is discovered that the middle part of the right longitudinal beams has seriously bent before the energy absorption box is entirely squashed. As shown in Fig. 11, this type of state is not favorable to energy absorption in the early stage, which may cause more serious injury to the passenger.

On the basis of Plan 1, Plan 2 is a transition design by using a smooth curve in the variable cross section, which is bound to affect the rigidity of the middle part of the right longitudinal beams.

Therefore, a semi-enclosed reinforcing part is added in the middle part to reinforce the rigidity at this place, as shown in Fig. 12. Through simulation calculation, the right crash box is squashed completely, but the middle part of the

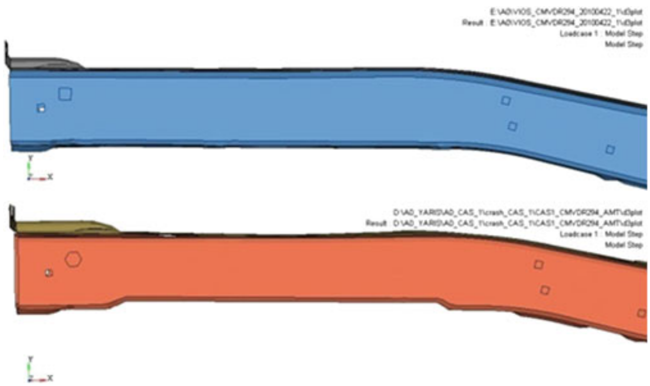
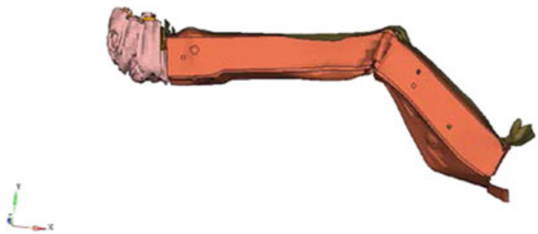


Fig. 10 The right longitudinal beams design plan 1 (The above is the original plan of the longitudinal beams)

Fig. 11 Plan 1 the right longitudinal beams deformation



longitudinal beams is not bent. This state will make the energy transmit directly to the root of the right longitudinal beams and the front floor, and the intrusion of the right fire bulkhead is increased obviously, as shown in Fig. 13.

Plan 3 is made on the basis of Plan 2, in which the semi-enclosed reinforcing part in the middle of the right longitudinal beams is cancelled. In order to reinforce the bending rigidity at this position, two 20 mm stiffeners are added in the weak position in the middle of the right longitudinal beams, as shown in Fig. 14.

Through simulation calculation, the middle of the right longitudinal beams is bent seriously after the crash box at the front end of the right longitudinal beams is completely squashed. This type of design can ensure the bending rigidity of the right longitudinal beams and also most energy produced in the crash is consumed in the area in front of the cab. So this type of deformation is relatively idealistic in frontal crash, as shown in Fig. 15.

5 Design Verification

In order to verify the design feasibility, the design of Plan 3 is used in a real vehicle crash test. Seen from the crash result as shown in Fig. 16, the front energy absorption area and the middle energy absorption area of the vehicle have suffered

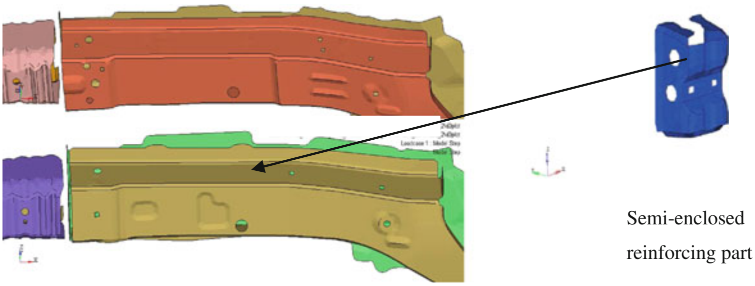


Fig. 12 The right longitudinal beams design plan 2 (the above is plan 1)

Fig. 13 The right longitudinal beams deformation of plan 2

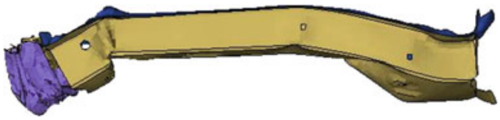


Fig. 14 The right longitudinal beams design plan.3 (the above is plan 2)

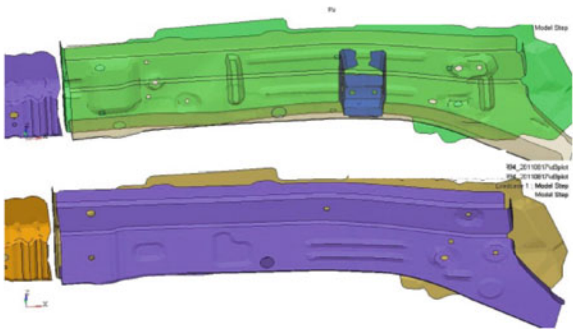
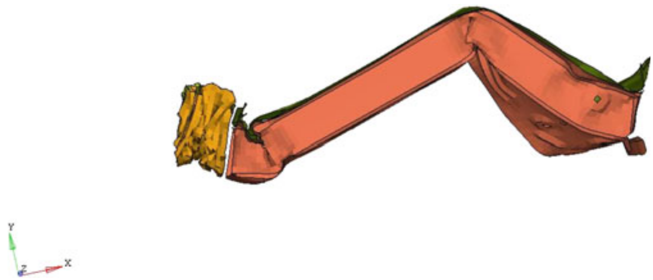


Fig. 15 The right longitudinal beams deformation of plan 3



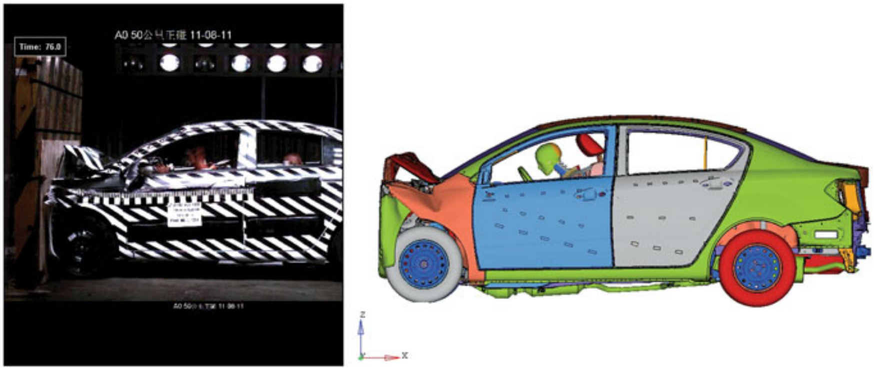


Fig. 16 Comparison between test result and simulation result

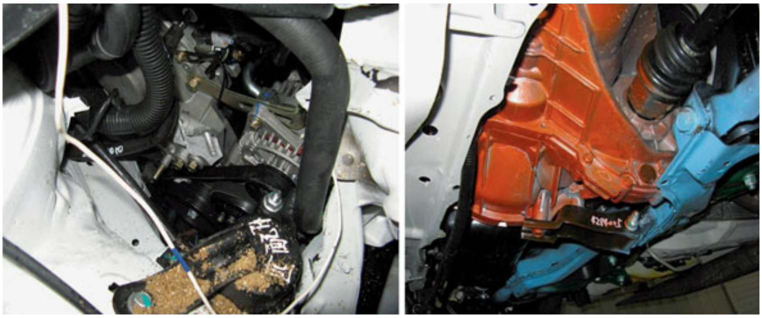


Fig. 17 The failure parts after testing

from more serious deformation, which absorbs most of the energy. Behind Pillar A, the area deformation is smaller, the intrusion of the fire bulkhead is smaller, the front floor does not have essential deformation, the door can be opened normally, the fuel tank does not have any leakage. In this test, only the crashworthiness of the vehicle body is verified, so no safety airbag is installed in the test vehicle.

After the real vehicle crash, two places are found to have obvious fractures, one is the connecting position of the engine suspension to the engine body, the other is the lower housing of the gearbox, where serious cracks occur as shown in Fig. 17.

However, the higher simulation result may be because of the different contact mode algorithm, the higher contact rigidity used as well as one-directional mass point instead of the mass of vehicle body accessories and interior decorations. As a whole, the fitness of the wave forms and peak values of the simulation curve and the test curve is higher.

After the failure mode of the corresponding fracture position is adjusted in the crash model, the simulation calculation is carried out for the second time. An acceleration curve corresponding to the time course is output and compared with the acceleration signal collected in the test, as shown in Fig. 18. It can be seen that

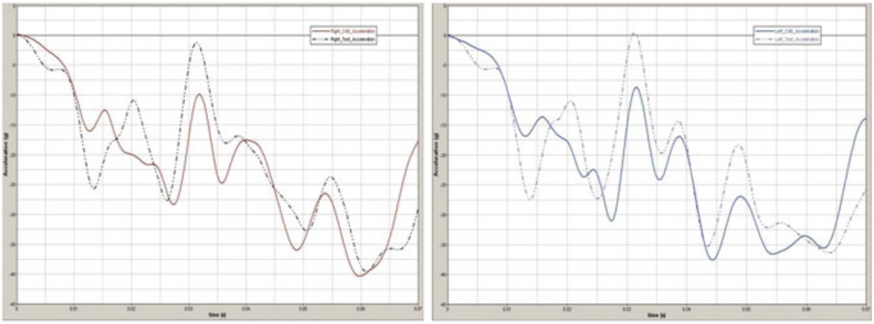


Fig. 18 Comparison between acceleration curves of left and right B pillars (*solid line* is simulation value, *dotted line* is test value)

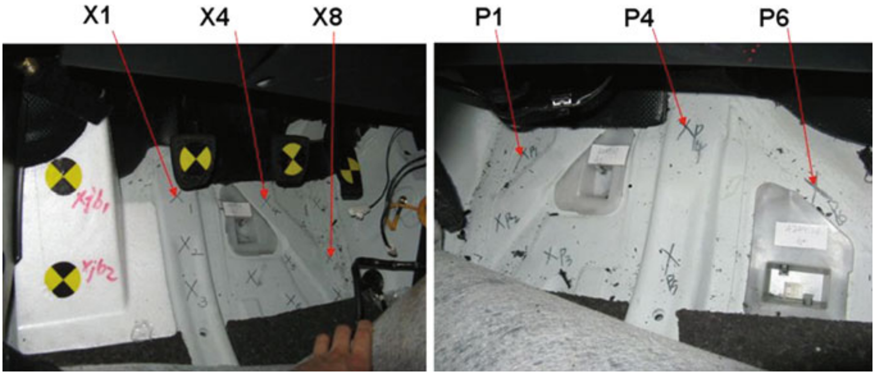


Fig. 19 The measuring points of floor intrusion

the left side acceleration peak appears near 45 ms while the right side acceleration peak appears near 60 ms. It is measured that the variations of the two acceleration curves are basically the same, but there are certain differences between the peak value and the corresponding time when it appears, the simulation value is a bit higher than the test result. According to the modeling experience, the difference between the test and the simulation time is caused by the instable factors existing in the model, e.g. negative value of contact energy and contact failure.

Similarly, when floor deformation value is acquired from the front floor of the cab, the size of the deformation may directly affect the leg injury value of the passenger, so to control the intrusion of this area is utterly important, as shown in Fig. 19.

The accelerations of simulation value and test value are controlled within 2 g. The intrusion difference at corresponding positions is controlled within 4 mm, which are used to verify the reliability of this simulation and the feasibility of body design. See Table 1 for specific values.

Table 1 Summary of acceleration and intrusion

	B Pillar lower acceleration		Left side front floor intrusion(mm)			Right side front floor intrusion(mm)		
	Left	Right	Point × 1	Point × 4	Point × 8	Point P1	Point P4	Point P6
CAE value	37.29	40.31	10.11	13.1	13.56	15.16	13.54	12.15
Test value	36.41	39.56	8.69	9.02	9.63	13.31	11.33	10.01

6 Conclusion and Prospect

In this paper, with a Class A vehicle of a certain type as the research object, the situation of vehicle crash safety research and development both home and abroad has been introduced, the frontal crash FEA model of this type of vehicle has been established, simulation calculation of the model has been made, frontal crash energy absorption areas have been divided, transmission routes of frontal crash force have been analyzed. Through simulation calculation of vehicle body right longitudinal beams design plan, the longitudinal beams deformation influence on the whole vehicle in the course of crash has been deeply discussed. The optimum design plan of the right longitudinal beams has been used for real vehicle frontal crash test to verify the feasibility of this longitudinal beams design and the reliability of the frontal crash model.

The research method and the simulation results in this paper have provided certain examples for body longitudinal beams design in future and certain references for optimization of related frontal crash structures.

References

1. (2005) Automobile crash and safety. Qinghua University Press
2. Weigang Z, Zhihua Z et al (2007) Research on application of computer simulation technology on improvement of automobile frontal crash safety performance. Mech Eng J
3. Zhihua Z (2008) FEA method for automobile crashworthiness analysis. Autom Eng
4. Watanabe K, Tachibana M, Wiemann M, Frankenberg D (2008) Vehicle side structure. Strength steel and roll forming technology. SAE paper No.01-1403
5. Xichan Z (2007) Research on automobile crash safety performance by application of computer simulation technology. People's Transportation Press, Beijng, pp 16–21
6. ls-dyna_970_manual (user's manual). 165–203
7. Chunyu W, Bing W (2007) Research on car frame structure crashworthiness by application of FEA method. Autom Eng 04:41–46

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