Improvement on Crash Worthiness of Steel Energy Absorbing Structures in Coach-to-car Frontal Impact

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Abstract — **In order to study the issues of the main energy-absorbing position configuration in coach-to-car frontal crashes, and using a numerical simulation model of sedan Taurus and medium-sized coach, we evaluate configuration performance by choosing the intrusion deformation and speed of the steering wheel as the parameters. Coach-to-Car frontal crash simulations were developed by three-dimensional explicit finite element analysis software LS-DYNA3D. Through the analysis of the simulation results, we found that configuration performance of the two vehicles could be improved by adding a secondary, 'deputy', energy-absorbing beam (DEB) with type of No20 steel. Then we contrasted and analyzed the test results. The results show that: DEB has a significant impact on solving the frontal crash configuration issues, and also improves the crashworthiness of coach frontal steel energy-absorbing structure.**

Keywords - ***crashworthiness; crash compatibility*; *deputy energy-absorbing beam (DEB); coach-to-car impact.***

I. BACKGROUND

Crash compatibility has become the latest research in the field of passive safety [1]. Many studies have shown that the frontal crash is the main type of car to car collision accident, safety design of vehicle should pay attention not only to protect car occupants, also to protect another passenger vehicle involved in the collision accidents. Crash compatibility is defined by optimizing the body design and decreasing the damage of passenger vehicles involved in the collision in this two sides[2]. Crash compatibility research has obtained the attention of governments and car manufacturers. In 20th Century 90 times' meta-phase, USA National Highway Safety Administration (NHTSA) started the research project of the vehicle violating the properties and compatibility [3-5]. In 1996, the EU Auto Safety Promotion Council (EEVC) established crash compatibility working group of WG15, in 2003 started to carry the vehicle crash compatibility research project AC-COMPACT, to assess the crash test method and the evaluation system[6]. Compatibility test in a vehicle collision, researches and developments are focused on experimental barrier, have put forward three kinds of experimental barrier schemes, namely the mobile barrier (Moving Deformable Barrier, the variability of MDB) [7], the full width of the deformable barrier wall (Full width Deformable Barrier, FDB) [8-9] and progressive deformable barrier (Progressive Deformable Barrier PDB test[10-11]).

The present study of relevant laws and regulations and test evaluation method are still in progress. In the improvement of vehicle collision compatibility studies, also has great progress. A new kind of vehicle body front structure of Honda Corporation Masuhiro proposed by reference [12] (Advanced Compatibility Engineering Body, ACE body), which can effectively improve the compatibility of the frontal collision, and has been widely used in various models in many companies. Safety Cage structure of Volvo, Lars Forsman proposed by reference [13], has been applied to the company's SUV models, it effectively reduced the invasion of passenger cars. Domestic research institutions have carried out the research work of the crash compatibility, reference [14] studied the effect of compatibility factors, and reference [15] studied the Collision Regulations Implementing Effect on compatibility. In 2006 in Changchun, Guangzhou Honda did two car collision test at domestic, for the first model of Honda Odyssey and Honda Accord. The Great-wall Automobile as a domestic independent brand automobile company also did the two car collision test between Jiayu and Spirit for the first time in 2008.

In recently years, along with the passenger cars' ownership and quantity continuing to grow, safety problem has been widely concerned. Due to the high coach chassis and collision energy, the small car has high aggression, and the small car occupants have high casualty rate when involving a collision with coach. Compatibility issues of the two models are an important factor of the collision of high casualty rate. According to the occupant injury accident type statistics in automotive industry developed countries, frontal collision accidents accounted for fifty percents or more in the various serious injuries and death caused by traffic accidents. Therefore, the theme of this paper is to improve the frontal crash compatibility between coaches and cars.

This paper chooses a medium-sized coach and a car model, then let the coach hit the wall barrier and the car in turn by the finite element method, through the analysis of simulation results, that designing a deputy energy-absorbing beam in the front of coach, then from the simulation analysis, it could improve the frontal crash compatibility between coaches and cars without compromising their own safety.

II. COMPATIBILITY ANALYSIS

Vehicle compatibility include vehicle itself, protecting the safety of the vehicle occupants, on the other side, protecting the attack vehicle and its occupants' injury. Mainly collision form includes the car to car or the car to other objects in traffic accidents. In the collision, it shows that two cars have good compatibility when passengers and property loss less. As the collision regulations improvement and increasing public attention to the safety of cars, car crash compatibility will be more and more attracted people's attention.

Factors influencing the compatibility of the collision mainly have the following three aspects: the quality of cars, stiffness ratio and longitudinal beam height difference.

It can be found from the road accidents, servicing quality has very important effects on the collision, the greater the quality of the other vehicles in collision, the greater our vehicle occupants injury. In the collision process, assuming that the quality of the two collided cars respectively is m_1 and m_2 ($m_1<m_2$), the speed v_1 and v_2 are chosen when the instantaneous collision occurred, according to the law of conservation of energy, they can be calculated:

$$\Delta v_1 = \frac{m_2}{m_1 + m_2}(v_1 + v_2) \qquad (2\text{-}1)$$

$$\Delta v_2 = \frac{m_1}{m_1 + m_2}(v_1 + v_2) \qquad (2\text{-}2)$$

It can be seen from the type, the quality of small car takes more speed change than a massive car, so as to take more risks. For the design principle of stiffness on front, generally the collision load level is that the both sides of the vehicle body acceleration should be controlled in no more than 40g to 50g benchmark. After satisfying these requirements, then coupled with the vehicle occupant restraint system, accident casualties can reach a minimum.

Assuming that the stiffness of vehicle front as K, the quality as m, collision speed as V, the biggest dynamic collision deformation as X. Then there is the following relation:

$$K = \frac{(mV^2)}{X^2} \qquad (2\text{-}3)$$

As can be seen from the above equation, the speed of a certain vehicle collision and the vehicle's front structure stiffness is inversely proportional to the amount of deformation, As a result, people want to buy body frame stiffness of vehicles, so once vehicle collided, the vehicle has a relatively small deformation, that can be well protect the safety of the vehicle occupants. In the process of body design, considering the stiffness influence on collision compatibility, the small quality of the front of the vehicle should be appropriately increase stiffness to effectively improve the car crash compatibility. The larger quality vehicles should be appropriate to reduce the front of the stiffness, reducing the damage of other vehicles in collision accident.

Car stringer height difference also have a great impact on collision compatibility , in order to reduce collisions resulting in deformation of the cab and other injuries, car will be designed with the front bumper, absorbing energy-absorbing boxes and rails and other components, but due to different front of the car stringer with different categories of height , crash parts exist when there is height difference, resulting in energy-absorbing crumple cannot occur when the collision takes place, the more serious will happen drill collision phenomenon. Such as cars and coaches collide, cars are often drilling impact to the lower part of coach bumper, causing serious injury to car occupants. Table 1 lists some of the cars and coaches stringer height, the height difference can be seen in large coaches and cars, it is prone to drill touch. The focus of this study is to install the front passenger vice-class energy-absorbing mechanism to adjust the height difference collision to prevent cars and coaches hitting drills and other phenomena occur, so as to improve the car and the front passenger crash compatibility.

TABLE I. RESULT OF EXPERIMENTS AND THEORY

Vehicle Model	**The Lowest Point**	**The Highest Point**	**The Average Height**
Taurus	392	530	461
Yaris	412	510	461
Camry	421	533	477
Mini-bus	457	553	505
Medium-sized coach	777	970	874

III. ESTABLISHMENT AND VERIFICATION OF FINITE ELEMENT MODEL

A. Finite Element Model of Vehicle

It chooses the finite element model of car which came from Ford listed vehicles, finite element model of coach came from a company's medium-sized coach XMQ6900Y, the finite element model of two cars structure are based on the original vehicle geometry structure of building, as shown in Figure 1, the model connection properties and material properties of the components are defined in accordance with the design requirements of vehicles, two cars with finite element models have higher accuracy.

Fig.1 The finite element model.

Table II lists the finite element model of related parameters and two cars information.

TABLE II. COMPARISON OF PARAMETERS OF VEHICLE MODEL

Vehicle Type	Mass (kg)	Mass Ratio	Mean Front Rail Height (mm)	Deference (mm)
Medium-size coach	8803	5	874	413
Taurus	1758	1	461	0

B. Vehicle Finite Element Model Validation

The frontal crash simulation model is set up based on the national front collision regulations and the software LS-DYNA, the model calculated results are based on computer simulation. The first need is to validate the stability of the model, it is generally believed that when the hourglass energy percentage within 5% then the model has stability. And verify the validity of the finite element model by comparing the deformation of model and the related curve of the experiment with simulation. Sedan model of the George Washington University collision simulation model is used, there is no need to verify its stability, passenger front crash simulation model results are shown in Figure 2, the hourglass energy is less than 5%, sum of kinetic energy, internal energy and hourglass energy remained unchanged, the total energy remained unchanged, following the law of conservation of energy.

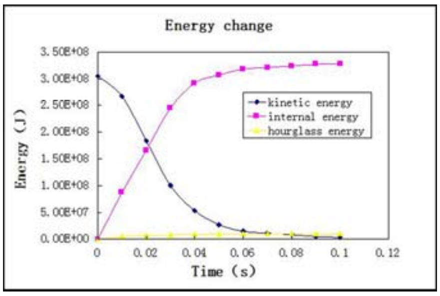

Fig.2 Frontal impact energy diagram.

IV. SIMULATION OF FRONTAL CRASH COMPATIBILITY

This paper use computer simulation method to study the front crash compatibility between passenger car and coach. Whether there is the installation of deputy energy-absorbing structure for the front body of coach or not, it was simulated and comparative analyzed results.

A. Frontal Crash Compatibility Simulation

As can be seen from crash simulation, the main energy-absorbing parts of the two vehicles did not happen crumple deformation, there was a clear drill as figure 3 showed. Get the quantity of car steering wheel in direction of X, Z, the amount of car steering wheel invade and the car steering wheel speed. Analysis data can be seen, the quantity of intrusion volume of the car steering wheel in z axis is nearly 300 mm, it more than doubled in the x direction, indicating that the occurrence of significant drilling car collision and this kind of circumstance is harmful to the car driver. Also intrusion of steering speed has reached 7000 mm/s, it will also have a very large impact on the driver even if there is the airbag protection. So in this case the front cars and coaches collision is not compatible.

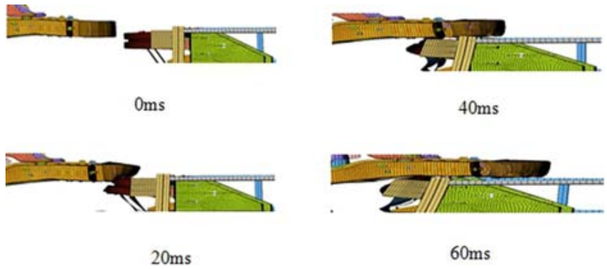

Fig.3 crash simulation.

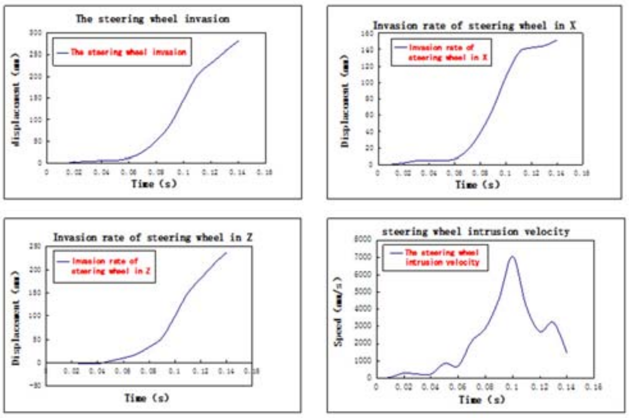

Fig.4 Pre-improvement crash simulation curve.

B. Coach Design Energy-absorbing front of the deputy-level institutions

Deputy energy-absorbing beam designed as in Figure 6, set a single beam below the bumper, the height of an ordinary sedan based on the height of the front rail, when the coach collided with a car that body can play its role, on the one hand to prevent the car drill, on the other hand to absorb energy by plastic deformation, thereby, it can reducing the amount of deformation of the cab and the driver's injuries.

Fig.5 Deputy energy-absorbing beam.

Due to restricted by the characteristics of deformation of the structure, the energy single beam absorption is limited, so the single beam and car body bearing can set a suction box directly, using suction box crumple deformation to absorb a lot of energy. And it can be found that the hexagonal and octagonal box absorbing cartridge in suction effect are quite higher than the other section of the suction box from the sectional shape of the selected energy absorbing cartridge, but first collision force of octagon box is larger and more complex processing than hexagon box, so, for the choice of the energy absorption box, we choose a hexagon box. This will maximize energy absorption, and control the cost in a reasonable range.

C. Comparison of Simulation

Did the frontal crash simulation of the car again after installing a primary energy absorbing mechanism on the front side coach, the simulation results are shown as below. Analysis of data can be seen, the steering wheel intrusion volume decreased from 157mm to 136mm in the X direction, its a decrease of 13.4% after the installing energy-absorbing body vice-class to the car, indicating that the front of the car stringers occurred more effective crumple deformation to absorb more energy due to the installation of the institution , thus reducing the deformation of the cab; Invasion rate of car steering wheel in the direction of Z decreased from 238mm to 194mm, its a decrease of 18.5%, indicating that the device is effective to reduce the front car’s extent of the collision to avoid drilling; And the steering wheel intrusion velocity reduced from 7140mm/s to 5700mm/s, its a decrease of 20.2%, which greatly reduced the impact on the driver's steering wheel and the damage to the driver. In summary, the design of the front passenger deputy energy absorption level institutions to improve the frontal collision compatibility to a car is positive and effective.

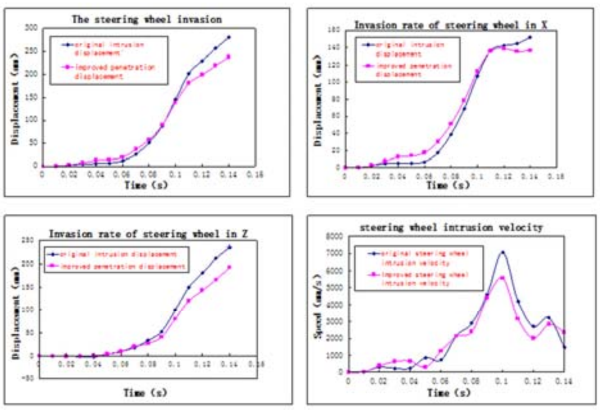

Fig.6 Intrusion velocity curve of post-improvement.

V.COACH CRASH SAFETY ANALYSIS ITSELF

Due to the structure of the vehicle improved can not affect the security of the collision regulations, according to the following frontal crash regulations for passenger cars, the original model and improved model were respectively used in frontal impact simulation analysis, compared of improved coach before and after the simulation by model cab deformation and acceleration of the crew, simply validate the collision safety of improved vehicle. This is a feedback on compatibility improvement, if compatibility is improved after the serious impact on passenger car of their own safety, so secondary coach front energy absorbing mechanism will be of no practical significance, they need to redesign; if the improved compatibility had little effect on the vehicle of their own safety, or improve their safety, the compatibility improved structure were accepted.

Contrast analysis of the door on the both sides collision simulation deformation, the cab floor around the lateral deformation, the integrity of the bridge and the changes of the position of the head acceleration of the in front occupant , as shown in figure 8. Measurement results were shown in Table 3 and Table 4.

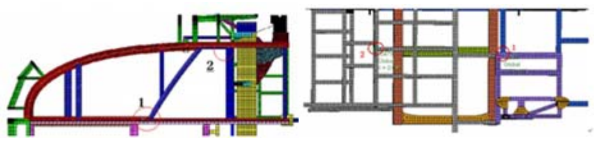

Fig.7 measure location.

TABLE III. MEASUREMENTS BEFORE AND AFTER THE COLLISION(MM)

Location	**Deformation before Improvement**	**Deformation after Improvement**
Z_{12}	234	195
Y_{12}	218	170
D_1	206	150
D_2	181	109

TABLE IV. CREW ACCELERATION MEASUREMENT RESULTS（G）

Location	Z_1	Z_2	Z_3	Y_1	Y_2	Y_3
Acceleration before Improvement	37	30	28	31	30	28

Acceleration after Improvement	24	24	25	33	25	24

From the above results, we can see, cab door deformation was reduced by 16.7~22%, the floor deformation was reduced by 26.7~39.7%, while the occupant head position of acceleration reduce overall, which left the location of maximum drop 35.1%. The deputy energy absorption beam in the front of coach improved the impact on its structure, so the structure is positive and effective to the car and coach crash compatibility.

VI.CONCLUSIONS

Vehicle crash compatibility is an important indicator for evaluating crashworthiness of the steel structure of a vehicle in real traffic accident and the occupant protection of a vehicle. Numerical simulation of finite element model and collision model in this paper, Taurus and medium-sized coach were established by using the Hyperworks and LS-DYNA software, the invasive capacity of wheel and speed are as the evaluation index of coaches' and cars' compatibility analysis.

Frontal crash cars and coaches do exist incompatibility problem, car steering wheel intrusion in the direction of Z reaches 238mm, invasive capacity is far greater than that in the X direction, so it's easy to get drilling collision phenomenon.

Invasion of the car steering wheel reaches 7140mm/s, it's a great impact on the driver.

With the installation of the deputy two-stage steel mechanism, car steering wheel in the X and Z directions' intrusion value decreased by 13.4% and 18.5%, and 20.2% reduced in intrusion speed, which can effectively avoid drilling collision accidents.

Cab door deformation was maximum reduced by 22%, the floor deformation was maximum reduced by 40%, and the position of whole crew head acceleration are decreased, which left the position of the maximum decrease of 35.1%, which improved anti-collision of their structure .

The next step will be to study the collision of two positive models' compatibility with different overlapping rates. In addition, the current domestic regulations mainly related compatibility are GB 1l567.2-2001 and GB 11567.1-2001. The two are for the side impact protection and rear underrun protection device. There is no clear regulations for coach frontal crash compatibility, so this will provide advice and reference for the formulation of laws and regulations.

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