Influence of the Connection Characteristics between Subsections of Car on Safety in Side Impact

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Abstract: Based on the analysis of the mechanical characteristics of car in side impact, a new method to improve the safety performance is proposed. In this method, the lateral characteristics of the connections between the passenger compartment and the front structure as well as the rear structure of car were modified. In order to investigate the effect of this method, the finite element model of a car was developed and validated. The safety performance of car in side impact was investigated by reducing the number and failure criteria of weld points and the thickness of plates in connection area. The injury related parameters of passenger were calculated by using multi-body Prescribed Structural Motion (PSM) method. The results show that lowering the lateral strength and stiffness of the connections between the passenger compartment and the front structure as well as the rear structure of car can significantly reduce the intrusion of door. Therefore, the values of injury related parameters of chest, abdomen, and pelvic decreased.

Key words: Side impact; Connection characteristics between subsections; Passenger injury

1 INTRODUCTION

In the side collisions, due to low level of the strength and stiffness of vehicle side components and small crash buffer area, the door and side panel can intrude the passenger compartment and generate serious passenger injuries. In such collisions, the head, chest, pelvis, spine, abdomen and lower extremity are commonly injured (TCRTC, 2006). Over the years, many studies about investigating the improvement of safety in this type of collisions were conducted and different protective systems were proposed.

At present, the measures to improve the safety in side impact of car mainly include increasing the stiffness of the side panel and door (You and Chen, 2006), selecting the structure and material of interior trim reasonably (Di Leo, 1998), adopting the side impact airbag (Haland and Pipkorn, 1993; White, 1998) and designing the structure of passenger compartment reasonably to get better force transfer (Viano,1990). However, the increase of stiffness and the improvement of design of side structures are limited due to characteristics of these structures. Therefore, the protection of the passengers by this approach is also limited and a better method to improve the safety performance is needed.

In the current paper, a new method to improve the safety performance in side impact of car is proposed. The car is simplified to three subsections and the influence of the connection characteristics between these subsections of car on safety is investigated.

2 METHOD

2.1 Principle of Theoretical Model

According to the studies about safety in side impact, the intrusion of door is the main factor that influence the severity of passenger injuries. This intrusion is directly related to the magnitude of contact force developed at impact (Chen, 2003). Therefore, the reduction of this force can decrease the door intrusion, and then the severity of passenger injuries can also decreased.

With this viewpoint, we can make the following analysis: suppose that the car is divided into three subsections (Figure 1) such as the front structure, the passenger compartment and the rear structure. When the ground friction is ignored, the force during side impact can be simplified as:

$$F = M_1 a_1 + M_2 a_2 + M_3 a_3 \quad (1)$$

where a_1, a_2 and a_3 are the lateral acceleration of the passenger compartment, the front structure and the rear structure respectively, and M_1, M_2 and M_3 are the corresponding mass of these structures.

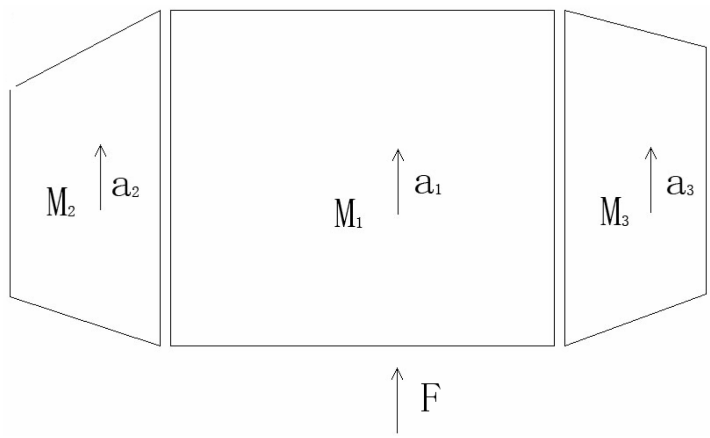


Figure 1 Theoretical model

The reduction of the lateral strength and stiffness of the connections between the passenger compartment and the front structure as well as the rear structure can generate relative movement between this compartment and other subsections of the car if the impact force reaches a certain value. As a result of that, the a_2 and a_3 and the impact force can be decreased. Then the door intrusion can be reduced and the severity of passenger injuries also decreased.

To validate this idea, a FE model and a multi-body model of a car were developed. With the FE model, we investigated the influence of modifications of connection characteristics between subsections, especially the reduction of the number and failure criteria of weld points and the thickness of plates in connection area, on the safety. The intrusion of side structures of the car was considered. Multi-body model was used to validate the effect of these modifications on injury risks. That was investigated by comparison of injury related parameters computed with dummy model from MADYMO.

2.2 Side Impact FE Model

Hypermesh was used to mesh the car model based on its geometry from the CAD drawing. The size of elements in the area where the impact contact happens is between 10 mm and 20 mm; while in the transition area is about 30 mm and away from the deformation area is above 50 mm. The whole FE model includes 332 278 nodes and 330 591 elements. The model also includes 4 006 spot-weld elements. The completed FE model has 358 components, including front rail, rear rail, floor, sub-frame, front and rear door, wheel assembly, suspension, engine, gear-box, oil tank, etc. In the original CAD drawing, the interior trim of front door and driver seat were not included so these structures were added.

The full-car FE model is shown in Figure 2. This model was validated with the results from crash test performed at the laboratory of Jeely Holding Group. To validate this model, the following parameters were considered: the time-history of velocity, acceleration and displacement in side direction (y) of the middle and bottom area of B pillar and the center of gravity (CG).

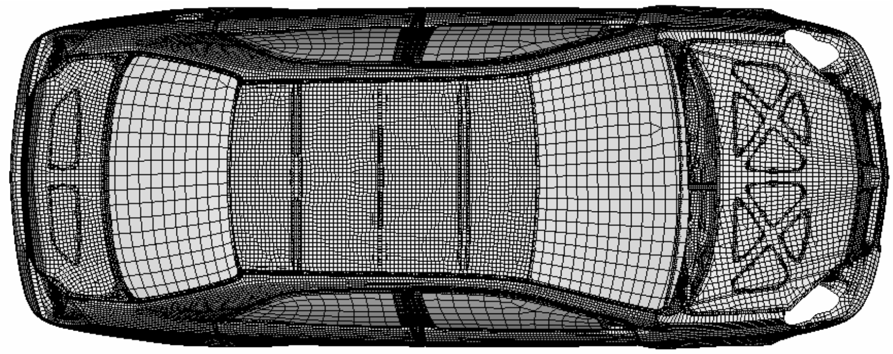


Figure 2 Full-car FE model

To simulate a side crash according to the conditions of regulation of Occupant Protection in Side Impact used in China, a sled FE model, which is shown in Figure 3, was adopted. The development and validation of this model was done by Cao et al. (2006).

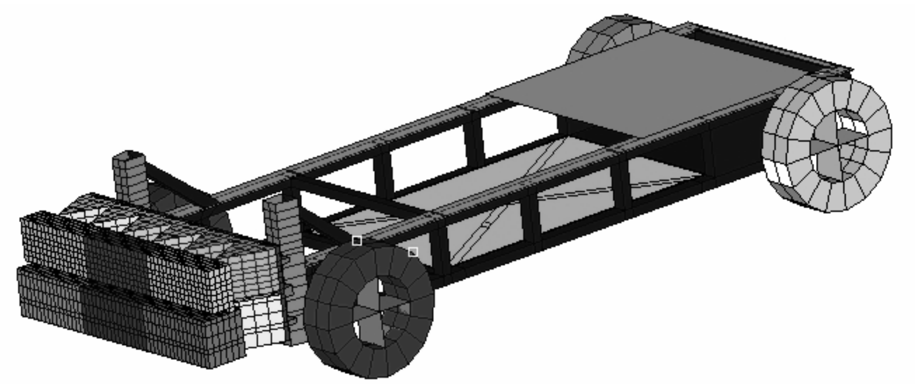


Figure 3 MDB FE model

The strength and stiffness of connections between subsections were changed by modifications of the number and failure criteria of weld points and the thickness of plates in connection area. The weld points in the full-car FE model were defined based on the quality criteria of the resistance spot-weld and seam-weld when HB5282-84 structural steel and stainless steel is used. Then the shear capacity S_s and the compression capacity S_n were readjusted. The failure criterion of weld points, which connect the subsections, was reduced to 30% and the number of weld points was decreased to 40% as a result of several simulations. The thickness of plates in the connection area was also reduced. The side collision was simulated with the modified model using the same set-up as for original model.

To investigate the influence of the connection characteristics between these subsections on safety, the maximum deformation of whole vehicle model before and after modification were compared and the intrusion of vehicle side structures of passenger compartment relative to vehicle central surface was calculated. The following parameters were considered: intrusions of the front of door, the outer panel and the upside, middle and underside parts of B pillar. The upside, middle and underside parts of B pillar were the connection area between B pillar and top crossbeam, the area of B pillar paralleled with the anchorage point of lap belt and the lower B pillar at threshold respectively. To reflect the severity of deformation of passenger compartment, the angle between the longitudinal center lines of front structure and passenger compartment was calculated. The velocities of middle B pillar and CG were also calculated to investigate the influence of the modifications on safety.

2.3 Multi-body Model

In the FE simulation, the maximum deformation of whole vehicle model and the intrusion of door can be calculated. However, the reliable and direct method to evaluate the safety in side impact should be based on the injury related parameters recorded from dummy during side impact. Therefore, to investigate the effect of the modifications on injury risks, PSM method in MADYMO was used to develop the side impact multi-body model of the car. The ES-II dummy model was adopted as the passenger model.

The multi-body model developed by PSM method is shown in Figure 4. The model includes: the seat, the outer and inner door panel, the bar fender, the inner panel of B pillar, the middle reinforcing plate of B pillar, etc. In the definition of the contact between dummy and corresponding bodies of the vehicle, the ellipsoids of dummy was defined as the master contact surface and the characteristic of contact was determined by the yield characteristic of dummy. The friction coefficients of all contacts were defined as 0.3. All the nodes of outer front door panel, outer rear door panel, side body, floor and bar fender were loaded with the displacement time-history measured from the FE side impact simulation during the whole crash time. The boundary nodes of other components of door were also loaded same way.

To investigate the effect of the modifications on injury risks, the maximum deformation of vehicle components and the injury related parameters before and after modification were compared. The following parameters were considered: the Head Injury Criterion (HIC), the Rib Deflection Criterion (RDC) and Viscous Criterion (VC) on upper, middle and lower rib level, the Abdominal Peak Force (APF) and the Pubic Symphysis Peak Force (PSPF).

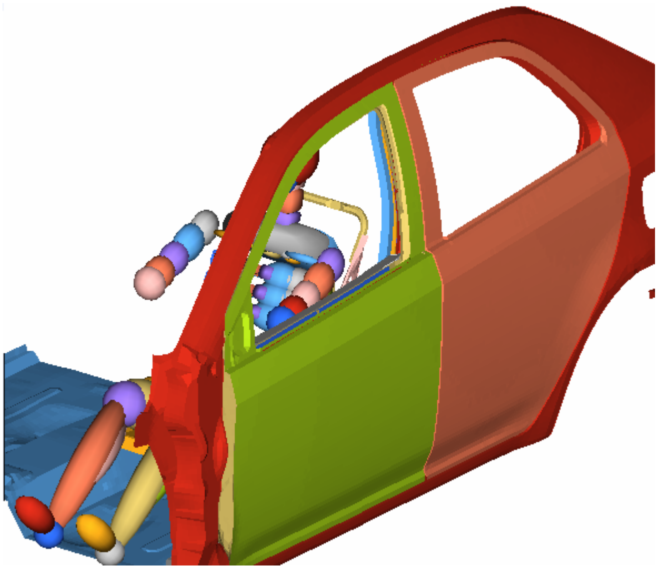
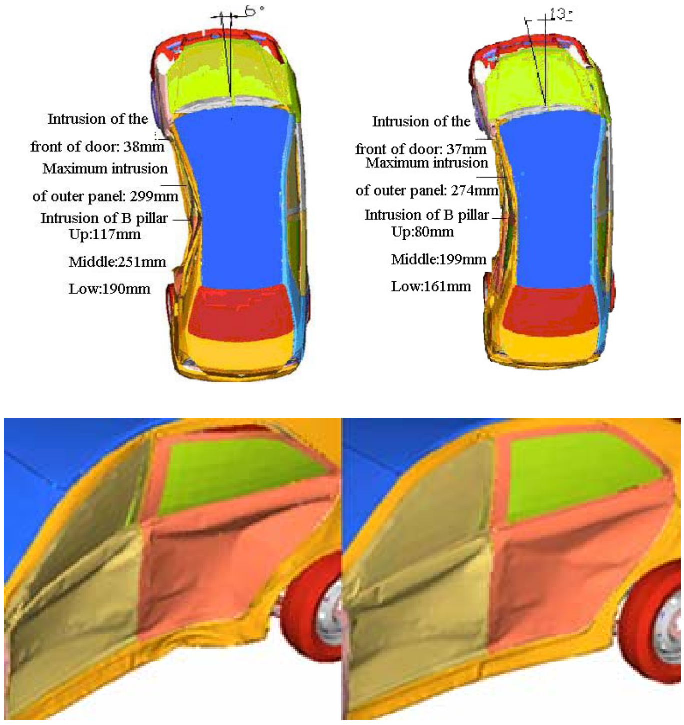


Figure 4 PSM model for side impact

3 RESULTS

3.1 Analysis of Connection Characteristics

The simulation results with the FE model are shown in Figure 5. It can be seen that the relative deformations between subsections increased significantly, especially between the front structure and the passenger compartment. The angle between the longitudinal center lines of front structure and passenger compartment increased from 6^0 to 13^0. The deformation of vehicle side structures of passenger compartment decreased significantly after the modification of the connection characteristics. The intrusion of upside, middle and underside parts of B pillar decreased 37 mm, 52 mm and 29 mm, respectively. The maximum intrusion of outer front door panel decreased 25 mm.



before modification after modification

Figure 5 Deformation patterns in FEM simulations

The comparison of the velocities of middle part of B pillar and CG are shown in Figure 6 and Figure 7 respectively. Although the velocity of CG after the modification is higher than before, especially in time window 0 to 80 ms, the velocity of middle part of B pillar is lower than the value of original model in time window 0 to 55 ms. Therefore, it can be concluded that the modification may slightly increase the acceleration of passenger compartment during the early stage of crash, however, the intrusion of the impacted door decreased significantly. The results coincide with the analysis results of the theoretical model.

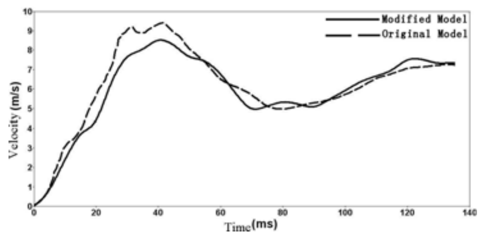


Figure 6 Velocities of the middle part of B pillar of original model and modified model

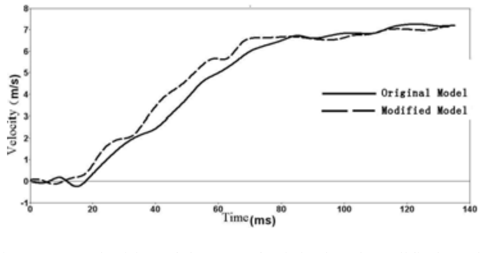
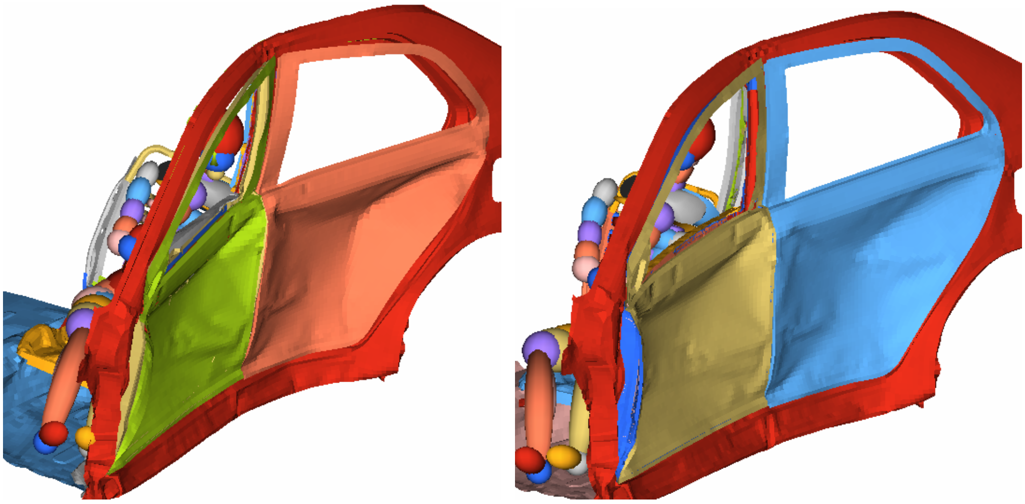


Figure 7 Velocities of the CG of original and modified model

3.2 Analysis of Multi-body Model

The results of the model before and after modification are shown in Figure 8. It can be seen that the deformation of door and B pillar of the model before modification are much bigger than after.



before modification after modification

Figure 8 Deformation patterns of the door and B-pillar

The injury related parameters calculated for dummy model before and after modification are listed in Table 1. It can be seen that while the characteristics of connections between subsections of the car are reduced, the injury related parameters of chest, abdomen and pelvis decrease significantly although the HIC increases slightly. However, HIC level is clear below that used as side impact criterion in China.

The time-history of the force on abdomen before and after modification are shown in Figure 9. The time-histories of the deflection of ribs are shown in Figure 10 and 11. Same effect of reducing the injury related parameters can be observed from these three figures.

Based on these results, it can be confirmed that the reduction of lateral characteristics of the connections between subsections of the car can have a positive effect on safety in side impacts.

Table1. Injury related parameters before and after modification

Parameter	Before modification	After modification	Side impact criterion in China
HIC_{36}	275	334	≤1000
RDC upper rib VC upper rib	47.9 mm 1.32 m/s	38.7 mm 0.85 m/s	
RDC middle rib VC middle rib	39.8 mm 0.72 m/s	37.8 mm 0.63 m/s	≤42 mm ≤1m/s
RDC lower rib VC lower rib	31.4 mm 0.41 m/s	28.1 mm 0.34 m/s	
APF	1.63 kN	1.19 kN	≤2.5 kN
PSPF	5.36 kN	3.88 kN	≤6 kN

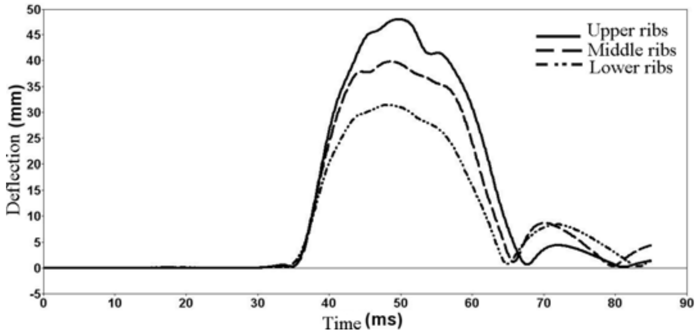


Figure 10 Deflection of ribs of original model

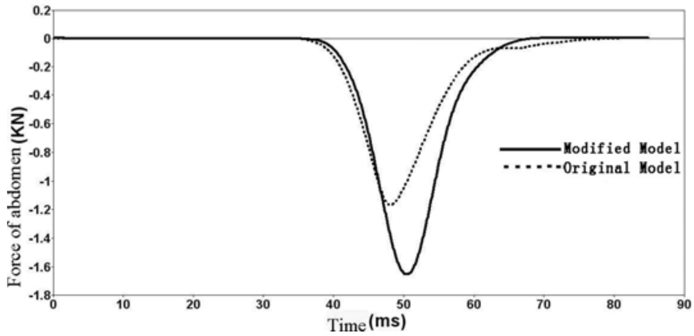


Figure 9 Force on abdomen before and after modification

4 CONCLUSION

A method that can improve the side impact safety by reducing the lateral strength and stiffness of the connections between the passenger compartment and the front structure as well as the rear structure is proposed. To validate this method, the FE model and the multi-body model are developed by LS-DYNA and MADYMO software respectively. The results show that designing the connection characteristics reasonably can reduce the intrusion of door and the risks of injury effectively. Only the characteristics of weld points and the thickness of plates in the connection area were considered, however, not the change of structure of the chassis. To design the structure of the car reasonably, the performance of frontal and rear crash should also be considered in the future studies.

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