Effects of Seat Structure Stiffness on Side Impact Safety

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Abstract: The current paper aims to study the effect of the stiffness of seat on occupant injuries in side impact. A side impact finite element model was developed and validated with LS-DYNA, and the values of occupant injuries were calculated with PSM method in MADYMO environment. Then, the stiffness of the seat was adjusted by adding reinforcement in the back of seat, increasing the thicknesses of seat parts, and changing the materials properties. The injury values, which obtained from simulations of original and modified seat were compared. The results show that our optimization could reduce the intrusion velocity of the B pillar and the front door, and the values of injury parameters such as Rib Deflection Criterion (RDC), Abdominal Peak Force (APF) and Pubic Symphysis Peak Force (PSPF). Therefore, the selection of a proper stiffness for the seat is very crucial when we are considering the risks of occupant injury.

Keywords: side impact; seat stiffness; PSM method; occupant injuries

1. Introduction

In China, side impact is most often represented in all accidents, 39.50% in relation to 26.43% for frontal one, and also in casualty cases, 37.36% in relation to 27.73% for frontal one[1]. It seems that the side structure of vehicle body is relatively weak in stiffness and strength compared to other structures. There are fewer components used to absorb energy and the space is not enough. Once the accident happens, the occupant contacts the B-pillar and trims directly, which may cause serious injuries[2].

There are a lot of researches about side impact in abroad. Some vehicle safety regulations were published in Europe and USA such as ECE R95[3] and the FMVSS-214[4], respectively. In China, in order to protect the occupants effectively, the government also published the regulation "Occupant Protection in Side Impact" GB 20071-2006 to enforce the automotive companies to improve the vehicle safety in this configuration. This indicates that also our country pays more attention to safety performance of vehicle.

Regarding various studies about seat properties, many researchers[5,6] have investigated these properties in frontal and rear collisions, but comparatively less in side collisions. It is because that the structural stiffness of seat is smaller than B-pillar, crash beams and door structures. However, the studies[7,8] show that structural stiffness of the seat is also an important factor influencing the load transfer, which is strongly influencing occupant injuries.

In the studies mentioned above the authors found that if the seat is designed close to the B-pillar, the B-pillar will impact the seat before the door inner contacts the occupant that usually cause serious injuries, especially in middle-size vehicles. If the seat is close to the B-pillar, and if the seat stiffness is large enough, it can distribute the impact load and avoid large impact force to the occupant. The intrusion velocity of the B-pillar is reduced, and the impacted vehicle is accelerating in lateral direction earlier, and the occupant injury value can also be reduced. Therefore, the optimization of the seat structure stiffness can effectively improve crashworthiness of the side impact.

Based on study above, in current research we established and validated a side impact finite element model. In simulations we changed the stiffness of the seat and analyzed the kinematics of B-pillar, front door and seat considering the intrusion velocity and deformation. The occupant injury parameters were also analyzed based on PSM method.

2. Method and Materials

2.1. The Idea of Optimization of Seat Structure Stiffness and Evaluation

Based in the suggestions from [7] the authors decided to study the influence of strengthening of the seat structure stiffness. The seat model based on a real-world medium-size vehicle in China was modified according to the visual collapse mode of the original seat. The model was modified as follows:

1) The connective reinforcements, made up of 24 mm diameter tubes with a wall thickness of 3 mm was added to the seat back;

2) The diameter of seat-back tube was increased to 32 mm;

3) All thicknesses of the seat parts were doubled;

4) Material properties for all parts were changed from low strength steel to higher strength steel;

5) The console of the seat was made rigid in order to provide a better load path to the non-struck side of the

National "863 Program" (2006AA110101), the MOE & SAFEA of the P.R. China "111 program" (111-2-11), the MOF "ZQ Project" (2007-237), Hunan University SKLVB (60870004).

vehicle.

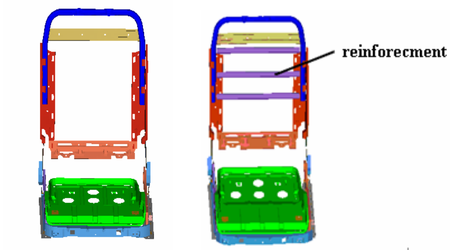

Figure1. Comparison of original and improved seat model

To evaluate the effectivenes of modifications the related variable parameter before and after optimization need to be analyzed. We selected the followings: intrusion velocity of the B-pillar, the velocity of the front door, the deformation of the seat, and the intrusion velocity of the seat back. Side structure velocities are calculated at the locations shown in Figure 2. The principle of choosing the points on B-pillar and front door is that these points should be as near as possible to the seat, to better reflect the changies of trends of velocity.

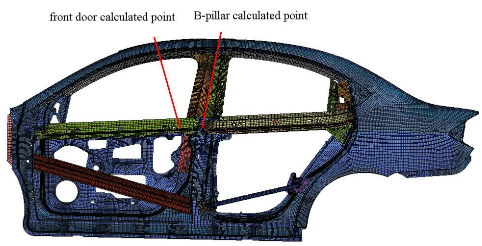

Figure 2. Locations of points to calculate velocity

In order to verify if the optimization method can effectively reduce the occupant injury values, PSM substructure method [9] was used in the study. The side impact PSM model of sub-structure was set up with MADYMO, as showed in Figure 3. The dummy model used in the study was ES2. The load conditions, parts connections and contact definitions were considered. The groups of pre-defined dummy elements were used as a master surface in contact interactions. These interactions were defined with the seat, the door trim, the roof rail and the vehicle outer side panel. The friction coefficient of all contact interactions was set to 0.3. The following injury criteria were selected: HIC, VC, Rib Deflection Criterion (RDC), Abdominal Peak Force (APF) and Pubic Symphysis Peak Force (PSPF). Because the PSM model was used for verification of the trends of injury related parameters we validated it regarding to pattern of deformation only.

2.2. Development and Validation of the Side Impact FE Model

The FE vehicle model was based on a real-world medium-size vehicle in China market. The side impact FE model was set according to the regulation "The Protection of Occupants in the Event of a Lateral Collision" [10] as shown in Figure 4. The FE model of MDB was positioned by aligning the longitudinal vertical median plane of MDB with a transverse vertical plane passing through the R point of the front seat near side of struck vehicle. The Euro SID II dummy that should be placed in the driver-side was replaced by a mass node.

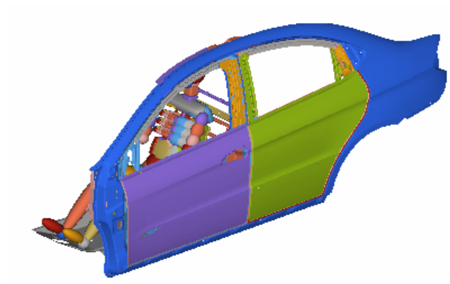

Figure 3. PSM model

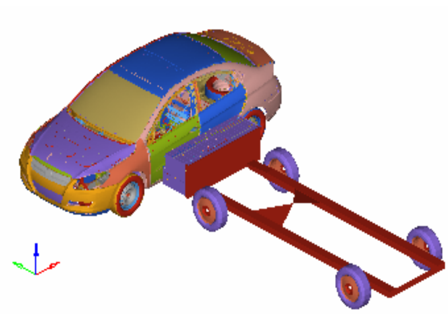

Figure 4. Side impact FE model

The FE model of side impact was validated through the comparison of acceleration and deformation of vehicle in the test and simulation. The comparison of the acceleration time histories at the bottom of the B-pillar between test and simulation is showed in Figure 5. It can be observed that the curve shapes and peak values show good correlation and consistency. The maximum values of acceleration from the tested and simulation is 16.4 g and 18.5 g, respectively. The difference of peak response from simulation and test is less than 5%.

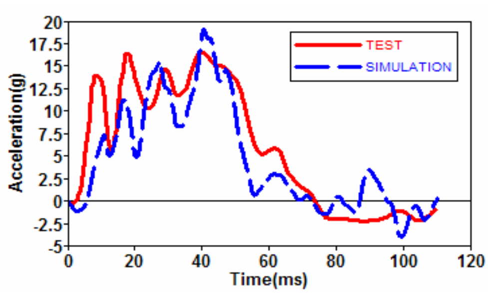

Figure 5. Comparison of vehicle acceleration

Table 1 shows the detailed front door deformation on the impacted side in both simulations and tests. The positions of points on the doors that were compared are shown in Figure 6. We can observe from Table 1: Firstly, the maximal deformation in simulation, which appeared on point No.5 differs from test only about 6%. Secondly, the deformation trends both in simulation and test are consistent. For example, the deformation values increase gradually from point No.1 to No.5 in simulation, which it also happened in test.

Table 1. The front door deformation [mm]

Position	Test	Simulation	Position	Test	Simulation
1	131	127	11	91	108
2	171	186	12	122	121
3	202	222	13	126	129
4	221	240	14	137	135
5	237	253	15	125	139
6	226	252	16	111	126
7	214	240	17	106	112
8	197	222	18	109	113
9	162	210	19	112	113
10	160	176	20	116	115

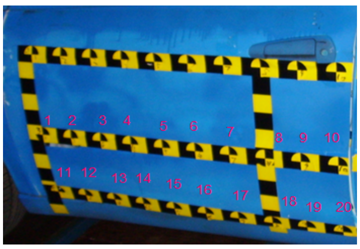

Figure 6. Positions of measured point on doors

Also the whole deformation profile shows a reasonable agreement between the test and simulation. The bottom of the front door and the back of rear door were stripped from the doorsill both in simulation and test as shown in Figure 7.

Figure 7. Comparison of deformation

Regarding the deformation of the impacting MDB we can figure out that in the test and simulation is also consistent as shown in Figure 8. As one can see the most extensive deformation in both cases is associated with contact with B-pillar.

Figure 8. MDB deformation

The agreement of acceleration pulses, door deformation, and deformation of the MDB showed that the FE model of side impact was assumed as validated and could be further used for the purpose of current study.

3. Results

The velocity calculated at point on B-pillar is shown in Figure 9. The shape of the velocity curves is similar in the original and improved model; however the peak value of this velocity could be lowered with about 1.5 m/s between the original model and improved model. Both peaks occur at about 35 msec. The biggest difference of 2.4 m/s between time history curves of original and improved model can be seen at about 50 msec.

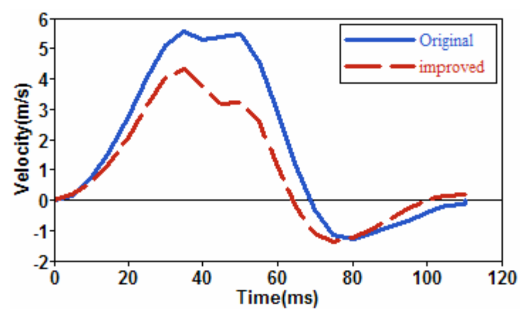

Figure 9. Calculated velocity at selected point on B-pillar

The velocity measured at the front door is displayed in Figure10. Both in original and improved model the peak velocity occurs approximately at 30 msec with value of 6 m/s for the former and 6.2 m/s for the latter. The difference of maximum velocity appears at 55 msec. The velocity in improved model is 3.5 m/s, while that in original one is 5.5 m/s.

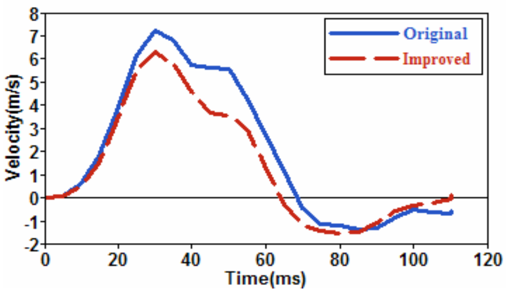

Figure 10. Calculated velocity at selected point on front door

Seat back velocity from the original and improved models is shown in Figure 11. The peak velocity is decreased obviously in improved model. The value of peak velocity is dropped form about 6.0 m/s to 3.0 m/s.

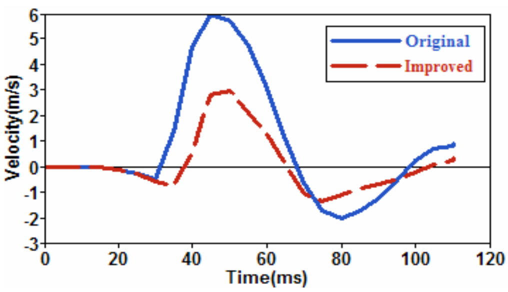

Figure11. Calculated velocity on the seat back

The comparison of seat deformation is shown in Figure 12. One can see that the deformation of original seat is larger than improved one; especially the deformation of the seat base has been reduced.

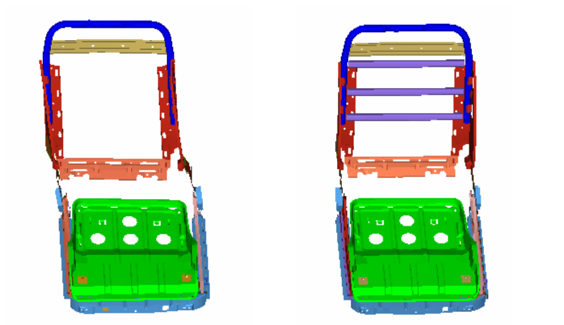

Figure 12. The deformation of original and improved seat structure

The example of deformation of vehicle structure in the PSM model is shown in Figure 13. The deformation in both models, original and modified was similar to deformations observed in comparable FE models. The injury values calculated from the dummy in PSM model are shown in Table 2.

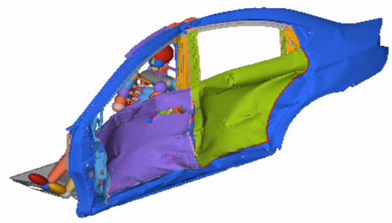

Figure 13. Deformation of the vehicle structure in PSM modified model

Table 2. Injury values calculated from ES2 dummy

Criterion	Original	Improved	Standard
RDC up	-25.9 mm	24.8 mm	
VC up	0.29	0.26	
RDC mid	34.3 mm	31.2 mm	
VC mid	0.53	0.42	RDC≤42 mm
RDC low	33.8 mm	31 mm	VC≤1 m/s
VC low	0.50	0.39	
APF	1.8 KN	1.7 KN	≤2.5 KN
PSPF	7.7 KN	5.5 KN	≤6 KN

As Table 2 shows, by optimizing the seat stiffness, the chest, abdomen and PSPF values are reduced. For example, the deformation of the RDC low is reduced from 33.8 mm to 31mm (corresponding VC values drop from 0.5 m/s to 0.39 m/s). Furthermore, the pelvis force is 7.7 KN in original PSM model. After optimization, the pelvis value reduced to 5.5 KN, also approximately 30%. The HIC values are not shown in the Table 2 because there was not contact between the ES2 dummy and vehicle structures. PSPF time history is shown in Figure 14. The peak value of the PSPF is reduced obviously by optimization.

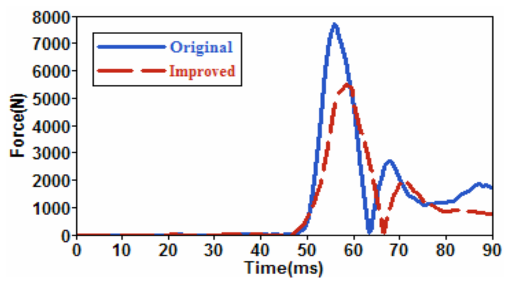

Figure 14. Comparison of the PSPF

4. Discussion

From the analysis of our simulations it could be found in simulations of original and improved seat model that when the impact was happened, the B-pillar contacted with the seat, and the seat started to resist the load while deforming. However in the improved seat model, the seat with increased stiffness could transfer high load to the chassis of the vehicle, therefore, the peak velocities of the B-pillar and front door could be reduced. Because the time duration of the velocity was similar in both simulations it is possible to assume that the intrusion these structures also could be reduced.

One of the selected injury related parameter was HIC to describe head injury risk in hard contact, however after all simulations we didn't found contact between the head and the side structure therefore finally this parameter was not considered.

The paper just evaluates the effect of seat structure stiffness for medium-size vehicle. However, the effect on vehicles of other sizes may be not the same as it was found in the study. Therefore, in future it could be recommended to evaluate the influence of stiffness of seat structure for other types of vehicles.

5. Conclusions

The structure stiffness of seat has an influence on the risk of occupant injuries in medium size car. Increase this stiffness of seat reasonably will reduce the intrusion velocity of the B pillar and the front door. This reduction of velocity of side structures will also lead to reduction of the intrusion that is a leading factor causing occupant injuries.

It is thought that the results of current study will be useful to provide reference for improving the crashworthiness of vehicles in side impact.

Acknowledgement

The study is sponsored by the Ministry of Science and Technology in National "863 Program" (2006AA110101), the Ministry of Education and State Administration of Foreign Expert Affairs of the P.R. China in "111 program" (111-2-11), the Ministry of Finance in "ZQ Project"(2007-237), Hunan University State Key Lab of Advanced Design and Manufacturing for Vehicle Body in "Autonomous Project" (60870004).

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