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Research on the risk of child occupant injury based on offset impact

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Abstract：

Background**:** World Health Organization study found that frontal impact was 34% of the total number of accidents which resulted in the death of children. In 2013, compared the total number of accidents in America, the sum of frontal collision about passenger car was up to 61%. In China, the percentage reached to 39.77%. In addition to vehicle linear acceleration, the occupant kinematics can be influenced by vehicle yawing and pitching. In 2006, domestic scholars began research on child restraint systems about frontal crash simulation and test methods. But for the study of offset collision impacted on children injury, it is temporarily unable to access to the relevant literature; it's also unable to access to the relevant literature which don't involve the research of influence of yawing motion and pitching motion of vehicle on the children injury, Woitsch、(2013）and CHEN（2014）respectively studied the effect of yawing motion and pitching motion on the adult injury. Compared the vehicle collision, sled impact lack the rotation, which has a difference between the vehicle collision and the sled impact. Therefore, the research of the influence of sled offset crash on the children kinematics and injury risk has great theoretical value and economic significance.

Objective: This paper is aimed to analyze the movement and damage risk of the children in the vehicle offset impact.

Method and Material: The paper adopts Q3 dummy and two kinds of child restraint system (5-point harness type，impact-shield type CRS) FE model. Based on the acceleration and angel from the crash conditions about frontal impact in 25%、40% and full overlap，the numerical analysis sled crash models are established.

Results: The results show that in the above 3 cases, there are obvious differences between the kinematic response and the injury of the children. In offset impact conditions, the X axial displacement of children is above 523mm, In offset impact conditions, the X axial displacement of children is above 523mm, the X axial displacement of children in the positive 100% overlap rigid barrier impact condition are 513mm and 478mm.The displacement of Y and Z in offset impact conditions were higher than that of 100% overlap rigid barrier impact condition; Under three conditions, the upper neck injury of child occupant who under the protection of two types CRS are exceeding the specified value 2120N; under the protection of 5-point-harness CRS, the influence of the offset impact on the child occupant injury is greater than that of front 100% overlap rigid barrier impact, under the protection of front impact shield CRS, the result is vice versa.

Conclusions**:** In order to deal with the complex traffic accidents, the design of CRS should consider the influence of offset impact, and also provide a reference for the development of CRS regulation and the research of CRS in the future.

Keyword*s*: offset crash, child occupant, finite element theory, child restraint system, sled cras

1 Introduction

World Health Organization study found that frontal impact was 34% of the total number of accidents which resulted in the death of children [1-3]. In 2013, compared the total number of accidents in America, the sum of frontal collision about passenger car was up to 61% [4]. In China, the percentage reached to 39.77% [5]. In addition to vehicle linear acceleration, the occupant kinematics can be influenced by vehicle yawing and pitching. In 2006, domestic scholars began research on child restraint systems about frontal crash simulation and test methods [6, 7]. But for the study of offset collision impacted on children injury, it is temporarily unable to access to the relevant literature; it's also unable to access to the relevant literature which don't involve the research of influence of yawing motion and pitching motion of vehicle on the children injury, Woitsch、(2013) and CHEN (2014) respectively studied the effect of yawing motion and pitching motion on the adult injury[9, 10]. Compared the vehicle collision, sled impact lack the rotation, which has a difference between the vehicle collision and the sled impact. Therefore, the research of the influence of sled offset crash on the children kinematics and injury risk has great theoretical value and economic significance.

In the paper, based the theory of finite element, using the verified finite element model established respectively frontal 25% overlap rigid barrier impact model (25%) 、 frontal 40% overlap deformable barrier impact model (40%) and frontal 100% rigid barrier impact model, which can acquire the acceleration of B pillar and the vehicle body rotation angel-time curves. And finally, studying children occupants' kinematic response and injury protection was based on the sled impact models that consisted of two kinds of CRS and Q series dummy.

2 The simulation model of CRS's offset impact

2.1 Introduction of CRS's sled model

In the paper, sled model of CRS (5-point harness type, impact-shield type CRS) 、Q3 dummy and ECE seat (Figure 1) have been developed and verified[11].

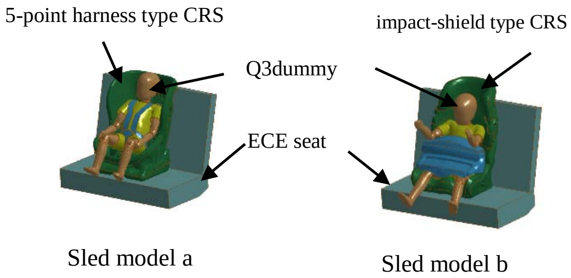
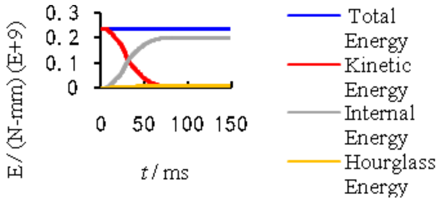


Figure 1 sled model

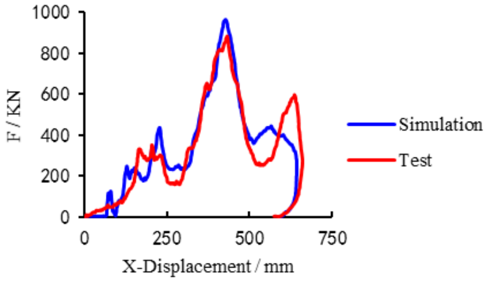
2.2 Boundary condition

Figure 2 and 3 shows the validation results of the Toyota camry car FE model. Test and simulation's curves fitted well, Therefore the finite element model could be used to do further research.

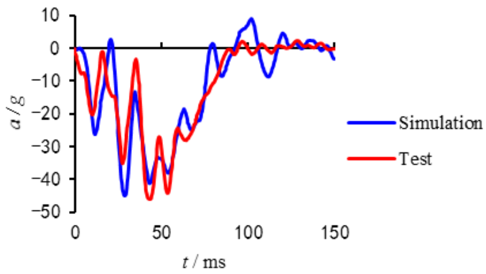
Figure 2 the comparison of collision animation



（a）Energy Statistics



（b）Rigid barrier force – displacement

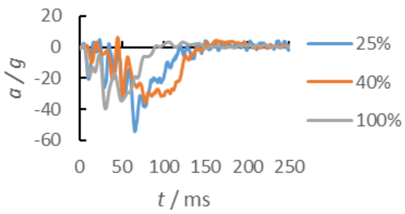


（c）Left floor acceleration

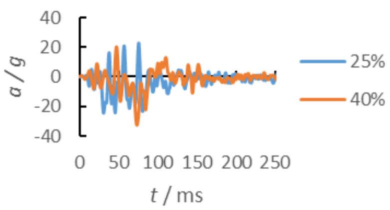
Figure 3 FE model validation

According to the requirements of the IIHS[12], 25% overlap rigid barrier impact model、frontal 40% overlap deformable barrier impact model and frontal 100% rigid barrier impact model were used to get the boundary data.

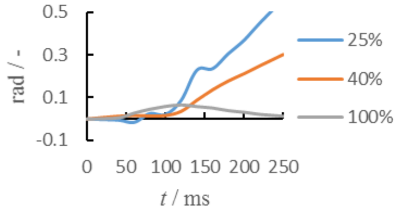
As can be seen from figures 4, picture a and b represent X-direction acceleration and Y-direction acceleration under 3 kinds of conditions, picture c represent vehicle yawing of offset impact and pitching of full overlap impact.



（a）X-acceleration



（b）Y-acceleration



（c）vehicle rotation

Figure 4 the boundary conditions of the sled

3 The analysis of CRS

Sled models consisted of verified sub-models and boundary conditions, which were used for the research of children occupants' injury risk.

3.1 Children occupants kinematic response

Figures 5 and 6 were the children occupants postures constrained by 5-point harness type CRS and impact-shield type CRS, which was respectively under the frontal 25% overlap rigid barrier impact model、frontal 40% overlap deformable barrier impact model and frontal 100% rigid barrier impact model.

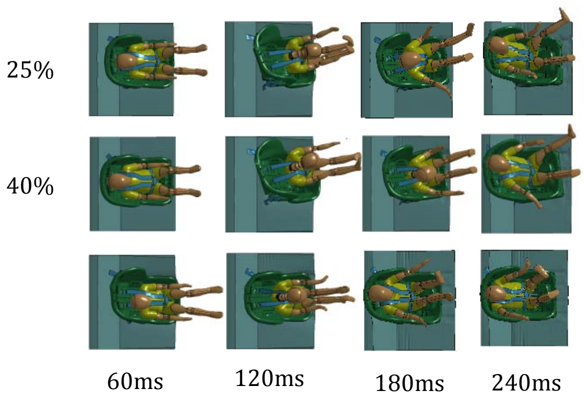


Figure 5 the postures of children occupants constrained by 5-point harness type CRS

As can be seen from the figures 6 and 7, children occupants started to move forward, and because of the belt and shield, children occupants rebounded and began to move backward, finally, children impacted the back of CRS. Under the offset impact conditions, constrained by the same CRS, children occupants' displacement of offset movement to the side under 25% condition was larger than children occupants' displacement of offset movement to the same side under 40% condition. The displacement of offset movement is from the symmetry plane of CRS to the child occupant left limb. Without turning out rebound motion of the children occupants, constrained by the 5-point harness type CRS. The offset displacement under 25% and 40% condition was respectively 357mm and 329mm. When constrained by impact-shield type CRS, the offset displacement under 25% and 40% condition was respectively 328mm and 287mm.

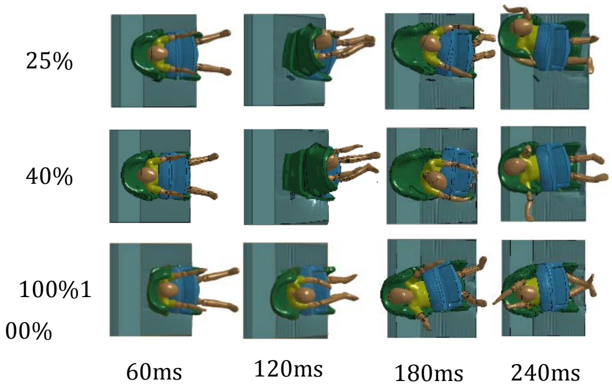


Figure 6 the postures of children occupants constrained by impact-shield type CRS

When children occupants started to rebound, constrained by the 5-point harness type CRS, the offset displacement under 25% and 40% condition was respectively 529mm and 357mm. constrained by impact-shield type CRS, the offset displacement under 25% and 40% condition was respectively 556mm and 299mm.

Figure 7、8 and 9 respectively were acceleration of head、chest and pelvis constrained by 2 CRS under 3 conditions. As can be seen from these curves, time interval was 0-0.15s before children occupants rebounded, and rebound time interval was 0.15-0.25s. Children occupants' injury mainly came from collision with seatbelt or shield without rebound, the large displacement of children occupants mainly caused by rebounded. Constrained by the same CRS, roughly, the acceleration of head、chest and pelvis under 25% condition were large than the other two conditions', and compared to the 25% and 100% conditions, the acceleration of head、chest and pelvis under 40% condition was smaller.

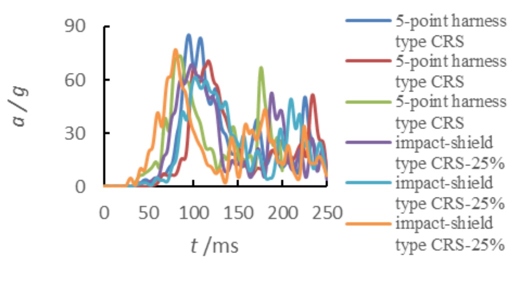


Figure 7 the acceleration of head centroid

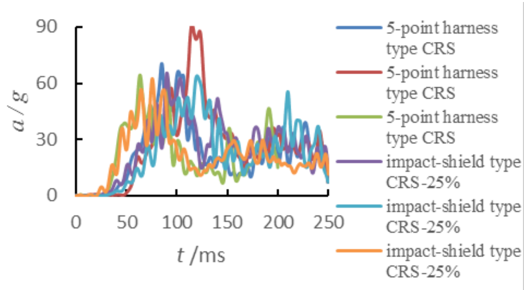


Figure 8 the acceleration of chest centroid

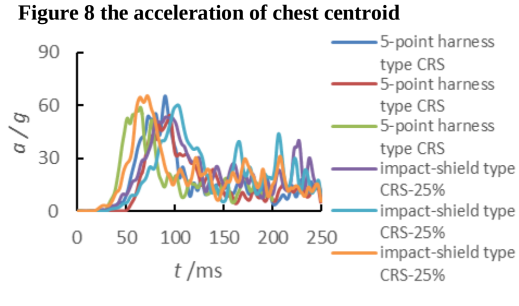


Figure 9 the acceleration of pelvis

3.2 Child occupants injury evaluation According to ECE R129 regulation, the acceleration of head centroid、the acceleration of chest centroid and the displacement of head were requested, child occupant neck injury did not specify the injury index and just be a monitoring item[13], but National Highway Traffic Safety Administration（NHTSA）research showed, children chest and neck were vulnerable, and definite the limitation of chest deflection、upper neck tension force and upper neck flexion moment[14]. Table 1 was children occupants injury under 3 conditions, M-dis represented the max of displacement, ah represented the acceleration of head, a_c represented the acceleration of chest, D represented chest deflection, $F_{neck-upper}$ represented upper neck tension force, $M_{neck-upper}$ represented upper neck flexion moment.

Table 1 children occupants' injury under three conditions

Conditions	CRS	M-dis（mm）		HIC15	a_h(g)	a_c(g)	D（mm）	$F_{neck-upper}$（N）
		X	Z					
Regulation value		550	800	800	80	55	53	1705
25%	5-point harness type	558	780	761	85	62	30.7	2400
	impact-shield type	533	733	506	68	64	55.2	2280
40%	5-point harness type	523	766	530	70	88	23.6	2560
	impact-shield type	540	749	391	60	62	57.1	2240
100%	5-point harness type	513	741	594	72	63	31.7	2390
	impact-shield type	478	739	566	76	60	58.4	2830

Constrained by 5-point harness type CRS, the Max-X、Z direction displacement of children occupants reduced in turn under frontal impact in 25%、40% and full overlap, and the Max-X direction displacement of child occupant exceeded 550mm that was the regulation value, the displacement was 558mm. For the acceleration of head and HIC15, under 25% impact condition, head acceleration of child occupant exceeded the regulation value and HIC15 passed the regulation value. For the chest of children occupants, under 3 impact conditions, the acceleration of chest of children occupants exceeded the regulation value, chest deflections were less than 34mm. For the neck of children, under 3 impact conditions, the tension force of upper neck of children occupants exceeded the regulation value, and upper neck flexion moment passed the regulation value.

Constrained by impact-shield type CRS, the Max-X、Z direction displacement of children occupants were within the regulation value, and the Max-X、Z direction displacement of children occupants children occupants was clearly larger than the other two impact conditions'. For the acceleration and HIC15 of head, the acceleration and HIC15 of head passed the regulation value. For the chest and upper neck of child, compared the same injury ,the value of chest acceleration、chest deflection、upper neck tension force and upper neck flexion moment were similar, and except upper neck flexion moment, other injury indicators exceeded the regulation value.

Compared the same condition, the displacement of head、HIC15 and the acceleration of head of children occupants constrained by impact-shield type CRS respectively were smaller than the displacement of head、HIC15 and the acceleration of head of children occupants constrained by 5-point harness type CRS. For the injury of chest, the acceleration of chest of children occupants constrained by 2 CRS were similar roughly. For the chest deflection, children occupants' deflection constrained by impact-shield type CRS were twice children occupants' deflection constrained by 5-point harness type CRS. For the upper neck injury, children occupants' neck injury were similar constrained by 2 CRS.

4 Conclusion

1）The offset displacement of children occupants reduced successively under frontal impact in 25%、40% and full overlap. For the displacement of X direction and Z direction, displacement caused by offset impact conditions was larger than displacement caused by full overlap impact conditions, and head and limbs might be caused by the secondary impact with vehicle interior when children occupants were placed in the side of impact under offset impact condition.

2）Compared to the influence of children occupants on 3 impact conditions, the 5-point harness type CRS is good for protecting chest of 3-year-old child occupant, the impact-shield type CRS is beneficial to protect head of 3-year-old child occupant, but for the upper neck, the 2 CRS cannot provide good protection. This will also be one of the potential problem of child occupant injury.

3）Constrained by the 5-point harness type CRS, children occupants injury reduced successively under frontal impact in 25%、40% and full overlap. For the impact-shield type CRS, children occupants injury caused by full overlap impact condition was more serious than children occupants injury caused by offset impact conditions.

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