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Rear Seated Occupants in Near-side Impacts Study Based on Chinese Accident Aatabases

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Abstract: The objective of this study was to describe the current situation of near-side impact accident in China, and to estimate the representativeness of C-NCAP side impact test.

The Chinese traffic accident field databases, CIDAS (2011-2016) and SHUFO (2005-2015), were used in this study. Simulation tests on acompact sedan model were calculated according to C-NCAP 2018 side impact test protocol.

Head and thorax were the most commonly injured body regions in near-side impacts. The deformation on passenger car's rear seat area was 13 cm, which covered 50% of CIDAS side impact cases; the lateral delta-v was 29 km/h, which covered 57% of SHUFO severe side impact cases. Thorax side-airbag reduced AIS3+ thorax injury risk from 29% to 11%.

The study showed that rear seat safety in near-side impacts needs to be addressed also in China. C-NCAP 2018 side impact protocol is representative for the real life situation. Thorax side-airbags on rear seats can reduce thorax injury risk substantially.

Keywords: Passenger car, Rear seat, side impact, thorax airbag

1 Introduction

CIDAS and SHUFO are accident research organizations in China, both collecting traffic accidents in different cities in China and building their own accident databases. In the latest updated database, CIDAS (2011-2016) had included 2898 cases and SHUFO (2005-2015) had included 1513 cases.

Recently, C-NCAP working group have published its test protocol for next update in 2018. Compare to its 2015 version, side impact test protocol is more rigorous. The moving deformation barrier will be changed from EEVC-2000 to AEMDB v3.9. The weight of deformation barrier will be increased from 950 to 1400kg, and the height will also be increased by 50mm. Dummy in first row, which was ES2, will be replaced by WorldSid 50 percentile male. The dummy on 2nd row, SID-IIs, will not be changed. The future scoring system was showed in **Table 1**, two points will be added on rear seat, for injury assessment on thorax and abdomen.

Table 1 Injury criteria and reference values for rear seated dummy in C-NCAP side impact test.

Region	Injury criterion	Higher performance	Lower performance	Point
Head	HIC15	500	700	1
Thorax	Rib deflection	31mm	41mm	1
	Rib VC	If >1m/s, 0 point get		
Abdomen	Rib deflection	45mm	59mm	1
	Rib VC	If >1m/s, 0 point get		
Pelvis	Sum of ilia and acetabulum force	3.5kN	5.5kN	1

In U.S. NCAP, the injury criteria were developed based on data from cadaveric sled tests and pendulum tests along with corresponding tests with the SID-IIs FRG dummies [1]. From the study result of NTHSA, AIS3+ thorax injury and pelvis injury risk can be estimated based on the maximum rib deflection, which is the maximum of the three SID-IIs FRG thoracic rib deflections.

The pelvic injury criterion was developed using the pelvic impact test data from Bouquet et al. [2]. It is based on the sum of acetabular and iliac force measured in the SID-IIs FRG [2].

Based on NASS-CDS database, Bohman et al. [3] described typical near side impacts with severely injured rear seat occupants. Injury risk reduction was evaluated when adding a thoracic side-airbag in the rear seat, at two different side impact speeds [3].

The objective of this study was to describe the current situation of near-side impact accident in China, and to estimate the representativeness of C-NCAP test protocol, and also to understand the potential effectiveness of thorax side airbag (SAB)for rear seat occupant protection.

2 Method

This study was consisted of two parts, a descriptive accident data study based on Chinese accident database, and simulation tests with and without SAB according to C-NCAP 2018 side impact test protocol.

2.1 Field accident data

Both CIDAS and SHUFO are field accident database in China. CIDAS investigated 6 cities in China from south (Foshan) to north (Changchun), and it records 4 wheeler vehicle involved accidents with at least one injured person. SHUFO investigate accidents happened in Shanghai Jiading district, and it records passenger car involved accidents with injury or high economy loss. Severe accidents have higher priority to be recorded in both databases.

Several sampling steps were used to extract sample data from CIDAS (2011-2016) and SHUFO (2005-2015). The selection criteria was passenger car in near-side impacts, with damage on its left or right side, and the crash direction was from clock wise 2,3,4,8,9,10 and the occupant sitting on the struck side of the vehicle. Passenger cars include SUV, MPV in this study. All ages of occupants were included, restrained or unrestrained.

Completely ejected rear seat occupants were excluded, due to the different injury mechanism. Also some special accident types were excluded, like VRU involved accident, multi-vehicle accident, rollover, falling accident, accident on fire and accident without enough information.

In following statistic, the sampling criterion were fully or partly used for different analysis purpose. To enlarge the sample size, all crash direction was included for the study of rear seat occupant's character. For other analysis related to impact direction, only side impact situation was included.

There are no available weight factors for the databases.

2.2 Simulation test

In order to evaluate effectiveness of rear seat SAB, side impact simulation was conducted using software MADYMO.

The 2nd row CAE system model was used in simulation, which included the rear door trim and some part of the seat model. The material and property of this model were given by experience. Inflator and diffuser were also included in the model as rigid parts. Soft cover and inert fabric were not taken into consideration. The airbag model was folded without any intersection through primer checking before test. The element size of model was uniformed as 4-5cm. All layers of fabric were included in the model, and were meshed directly from iges files. Seam line was represented by shell mesh. Vent holes were meshed to actual dimensions. Control Volume (CV) method was used for inflating cushion. The inflator energy loss was 20% at the beginning.

The impact condition was based on C-NCAP 2018 test procedure. According to the test procedure, a 1400 kg high bumper moving deformable barrier (AE-MDB) impacts the side of the vehicle perpendicularly at 50 km/h. SID-IIs dummy was used in this test on rear seat, and was restrained by a lap and shoulder belt. No pretensioner or load limiter was activated.

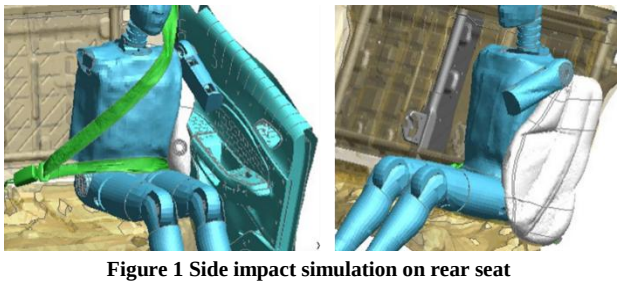

Figure 1 Side impact simulation on rear seat

The intrusion of rear seat model was from experiment test on a compact sedan. And the rib deflection of SID-IIs dummy in simulation had been benchmarked with the test result. To evaluate thoracic protection for the rear seat occupant, tests were performed with and without a thorax side airbag of 15.5l.

In this study, only rear seat occupant protection was considered, and dummy injury measures were according to

C-NCAP scoring criterion, and risk curves for SID-IIs developed by NHTSA [1].

3 Results

3.1 Field data analysis

When combining CIDAS and SHUFO, there were in total 4611 persons in passenger car when all crash directions and all injury severity levels were included, in which 13% (n=611) were rear seat occupants.

From accident investigation, seat belt usage condition of 517 rear seat occupant were recorded. Among them, only 3.7% (n=19) were belted.

Injury severity description was different in CIDAS and SHUFO. To increase sample size, the definition of injury severity in two databases were synchronized (Table 2).

Table 2. Injury severity synchronization

Injury severity	CIDAS	SHUFO
0_No injury	MAIS0	0-uninjury
1_Slight	MAIS1&unfatal	1_slight
2_Severe	MAIS2+&unfatal	2_serious,3_severe
3_Fatal	Fatal	4_fatal
Unknown injury excluded		

Using general variable of injury severity, 513 severe or fatal injury in-car occupant were selected, in which 27% (n=137) were rear seat occupants.

Table 3. Number of person in selection

Injury severity	All direction		Side impact	
	Front	Rear	Front	Rear
0_No injury	3119	307	145	9
1_Slight	515	140	88	5
2_Severe	251	99	50	7
3_Fatal	125	38	24	7

The age distribution was different between front seat and rear seat occupants. Among the rear seat occupants, 7% were under the age of 12 years and 6% were older than 60 years, while the relative proportion on front seat were 1% and 2% retrospectively.

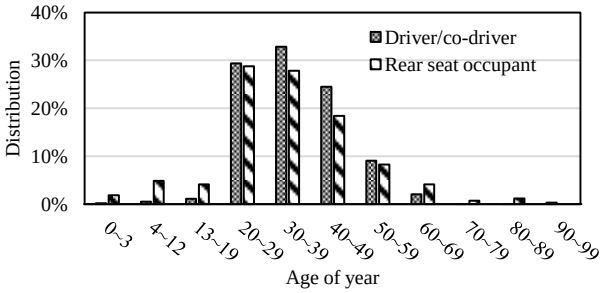

Figure 2. Age distribution of front and rear seat occupants

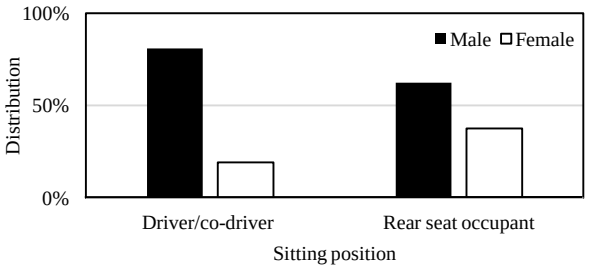

Figure 3Gender distribution of front and rear seat occupants

Gender distribution of in-car occupants on front seat and rear seat also showed the difference (Figure 3). Among occupants on front seat, 19% of them were female, while the proportion of female on rear seat was 38%.

In side impact accident, deformation between B-pillar and C-pillar on left or right side of passenger car may cause the injury of rear seat occupant. The intrusion depth in these areas was investigated. SHUFO database was not available for this deformation data, 76 side impact accidents in CIDAS were included for calculation. Figure 4 shows the cumulative curve of intrusion depth distribution.

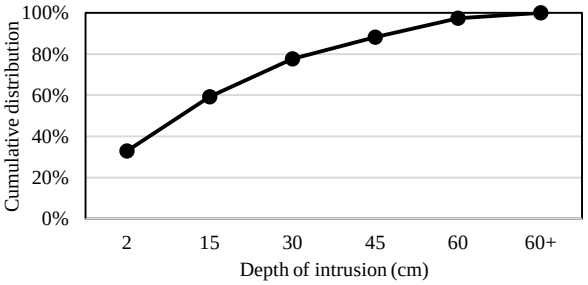

Figure 4Intrusion depth cumulative curve

Delta-V in lateral direction of struck vehicle was used to indicate the severity of side impact accident. In SHUFO database, all the selected side impact accidents had been reconstructed based on PC-crash software. Max lateral delta-V in first impact of each SHUFO case was calculated from the reconstruction process. Totally 74 SHUFO cases were included for calculation, in which 24 cases resulted in severe injury in the struck vehicle. Figure 5 shows the cumulative curve of lateral delta-v, and separated by max injury severity. The sample data were not limited to side impact between B and C pillar, but included all the side impact cases, to understand the severity of side impact in China.

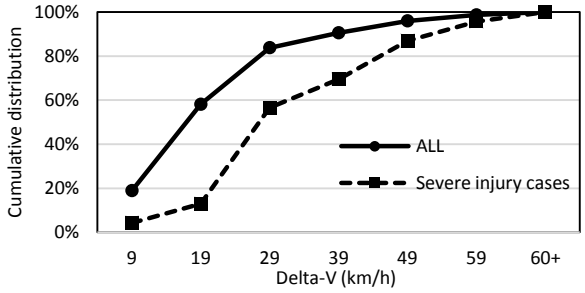

Figure 5 Lateral delta-v cumulative curve

In the next step, the sampling criterion was restricted by side impact on left or right side of car between B and C pillar. Combining CIDAS and SHUFO cases, totally 15 person were selected, in which 9 person got MAIS2+ or fatal injury. Further observation of injured body regions was made on this 9 person, to understand the injury situation. Table 4 shows the number of person who got AIS2+ or AIS3+ injury on different body regions. Note that, only one injury per body region per case occupant was included in the table. From Table 4, it can be found that, most of the severe injury (AIS3+) occurred to the head and thorax.

Table 4 Injured body regions of rear seat occupants

Injury level	Head/face	Thorax	Other regions
AIS2+	4	3	4
AIS3+	3	3	1

3.2 Simulation tests

Full car test according to C-NCAP 50AEMDB side impact protocol was made by Autoliv China, which was based on a compact car model. To indicate the severity of this test, intrusion at the H-point of rear seated SID IIs and max lateral delta-V were measured from this test, which were 13cm and 29kph. Compared to the field data, the intrusion was deeper than 50% of the CIDAS side impact cases and the max delta-V was higher in 57% of severe side impact cases in SHUFO.

Simulation results without SAB was compared with corresponding vehicle test results (Figure 6). The rib deflection were similar in timing and maximum deflection, while shoulder deflection was somewhat lower in simulations and abdominal rib deflection was to some extent higher in the simulations, compared to the vehicle test. For comparison, the simulation results with SAB were shown in the same figure in green. Comparing simulations results

with and without SAB showed that the rib deflection was reduced between 19% to 41%.

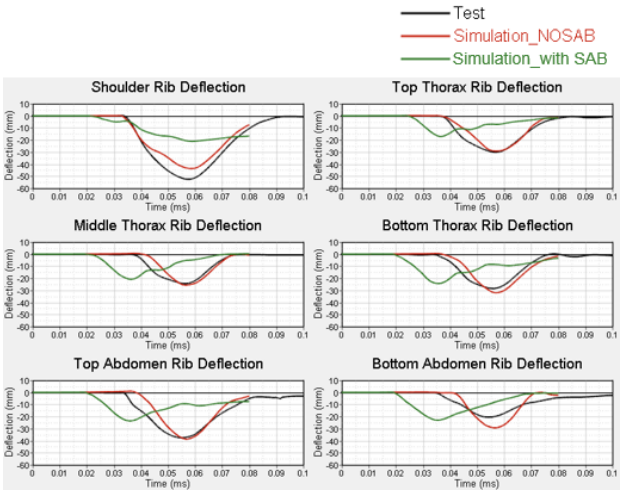

Figure 6 **Rib deflection from test and simulations**

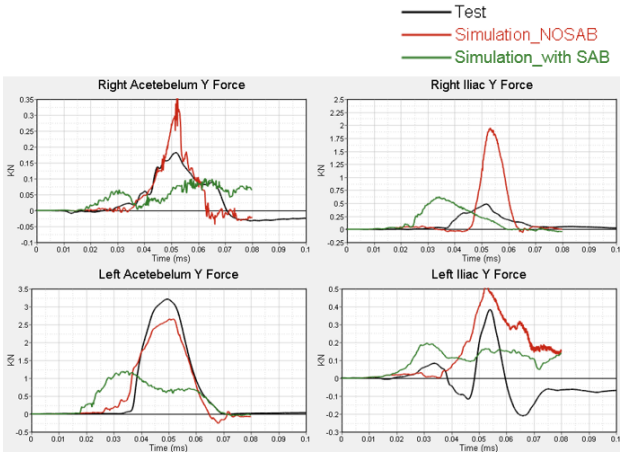

Figure 7 Force on pelvis from test and simulation

shows the force curve on acetebelum and iliac. The comparison also shows peak of the force have been reduced by the SAB.

Simulation result showed, the maximum thorax rib deflection and maximum abdomen rib deflection without SAB were 32mm and 39mm. With the protection of SAB, the deflection wereboth reduced to 24mm.

The maximumVC were all kept below 0.4m/s with or without SAB. By the protection of SAB, the thorax max VC was reduced from 0.29 to 0.25m/s, and the abdomen max VC was reduced from 0.40 to 0.19m/s.

In addition, based on risk curves published by NHTSA [1], the maximum rib deflection corresponded to a risk reduction of severe thoracic injuries (AIS3+) from 29% to 11%.

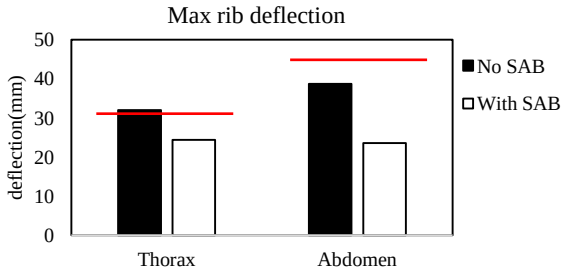

Figure 8 Max rib deflection from simulations with and without SAB. Red line refers to C-NCAP IARV.

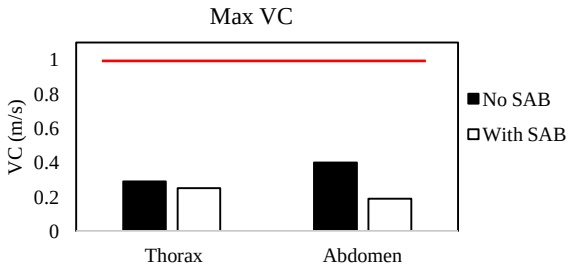

Figure 9 Max VC from simulation. Red line refers to C-NCAP IARV.

The sum of iliac and acetabulum force was considered as injury criterion for pelvis injury assessment on SID IIs dummy. The SAB performance was showed in Figure 10, sum of iliac and acetabulum force was reduced from 3.15 to 1.78kN, which corresponded to reduction of injury risk of severe pelvis injury (AIS2+) from 4% to 1%.

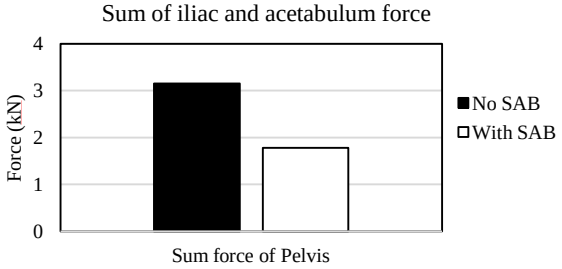

Figure 10 **Pelvis force from simulation**

4 Discussions

The field data showed that, among all the passenger occupants involved in crashes of all impact directions, 13% were rear seat occupants, which is similar level as US [4]. Among severely injured occupants, 27% were rear seat occupants. The seat belt usage on rear seat was 3.7%, comparing the seat belt usage of all occupant was 39%. Compared to front seat, the proportion of child, senior and female occupants was higher on rear seat. For the near-side impact cases, almost all the AIS3+ injuries were on the head and thorax.

Similar statistic was made on NASS-CDS data [3]. The study selected accidents occurring in US between 1994 and 2007. It found that, in the near-side impact accident with severe injury rear seat occupant, the belt usage ratio was 37%. Among the rear seat occupants, about 23% of them were children between 4 and 12 years old. It was found that of all MAIS3+ injured restrained occupants, 13 years and older, 59% had AIS3+ thoracic injuries and 38% had AIS3+ head injuries. For MAIS3+ injured children, age 4-12, 51% had AIS3+ thoracic injuries and 54% had AIS3+ head injuries.

Both Chinese and US data showed, in side impact accident, head and thorax was the most frequently severely injured body region to the rear seat occupants. The US data also showed, in the group of child occupants, the AIS3+ head injury risk was higher for occupants older than 12 years old. The difference in injury pattern between adults and children, are partly explained by different sitting height.

In the Chinese data, the proportion of 4-12 years old child occupant on rear seat in China was 7% (n=21), which

was much lower than US data. The reason for this situation could be explained by birth control policy and the lack of safety awareness, resulting in children seated in the front seat instead of the rear seat. Present study also found 18 children in the age of 4-12 seated on front seat in Chinese accidents. Since the birth control policy had been canceled recently and that the public's safety awareness has been increasing in recent years, it can be predicted that, the proportion of child on rear seat will also increase in the near future. Besides, Chinese data also showed, more female occupant seated on rear seat than front seat, which indicate the shorter stature of rear seat occupant. The high risk of head and thorax injury should be both highlighted in side impact accident. Accordingly, SID IIs dummy on the height of 5^{th} female will be used in C-NCAP test.

According to the field data, the intrusion was deeper than 50% of the CIDAS side impact cases and the maximum delta-V was higher than in 57% of severe side impact cases in SHUFO, which indicates that C-NCAP near-side impact test cover a majority of real Chinese accidents.

In this study, the simulations showed the risk of severe thoracic injuries (AIS3+) was reduced from 29% to 11% by the protection of SAB, meaning that this vehicle would be rated as good performance in C-NCAP if the SAB was included. The loading to the pelvis was already at a good performance level without SAB. When the SAB was included, the risk of pelvis injury was reduced further, from 4% to 1%. Bohman et al. [3] also showed injury risk reduction on thorax when a SAB was included, and the result was more significant in severe crash situation [3].

SHUFO and CIDAS do not have a weight factor system, meaning that the results do not reflect the whole country situation. The result was biased, because the two Chinese field databases are more focused on severe injury accident and limited in several investigation cities.

Only 9 person got MAIS2+ or fatal injury in nearside impact accident in Chinese database. The sample size was not large enough to analyze the common injury mechanism in these databases. The limited case by case review found the trend, that head and thorax were the most frequently severely injured body regions.

5 Conclusions

Field data analysis found, in China, rear seat occupant accounted for 13% of all in car occupant, while they accounted for 27% of all severe injured occupant, which indicated the relative high risk on rear seat. More child, senior and female occupant were seated in rear seat than the front seat. Due to change in population characteristics, more children will sit in the rear seat in the near future. Therefore, rear seat occupant safety should be highlighted in China, and pay attention to the injury mechanism of short stature occupants.

Head and thorax were the common severe injury body region on rear seat occupant in side impact accident. Simulation test on a compact sedan model showed the SAB reduced AIS3+ thorax injury risk from 29% to 11%, and reduced AIS2+ Pelvis injury risk from 4% to 1%. The test severity could cover more than 50% of the real world side impact accident situation, and SAB showed good protection in the test.

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