Update on Investigation of New Side Impact Test Procedures in Japan

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ABSTRACT

The safety of cars in side impact accidents has been improved since regulations requiring improved performance in a side impact test (for example, ECE/R95 or FMVSS 214) have come into effect in many countries. However, many people continue to be injured in side impact accidents; and, as a consequence, further improvements in a car's performance in side impact crashes are desired. This paper has been written to provide an update on what future improvements may be required, and presents a study of recent side impact accident data collected in Japan and the effectiveness of the curtain side air bag in side impact crashes.

In evaluating the improvements of a car's safety performance in side impact accidents, the National Transportation Safety and Environment Laboratory (NTSEL) previously has conducted research and published papers about various full car side impact tests, for example, the regulatory ECE/R95 tests, moving deformable barrier (MDB) tests, and car-to-car tests. However, NTSEL considers that it is necessary to gain increased knowledge regarding the injured body regions of occupants involved in a side impact accident in order to evaluate the effectiveness of safety equipment in future side impact accidents.

In this study, we first investigated the recent side impact accident environment from accident data in Japan. In this review, we examined trends regarding collision partners, injured body regions, injury levels, and the curb mass of both the struck and striking vehicles. The results indicate the following two findings: Firstly, the head and chest are the main injured body regions in the fatal and serious injury side impact accidents. Secondly, the percentage of lighter vehicles is relatively large for the struck vehicles, and the percentage of heavier vehicles is relatively large for the striking vehicle in these fatal and serious injury side impact accidents.

Secondly, we investigated the occupants' seating postures in cars running on Japan's roads. The results show that 56% of the drivers' heads were in line or overlapped with the vehicles' B-pillars. A more detailed study about the seating postures of the driver also was conducted.

Thirdly, we conducted MDB-to-car side impact tests according to the Regulation ECE/R95 specification with the exception of the seating positioning of the dummy. The target vehicles were two same model K-cars, which are categorized in Japan as a very small size vehicle, and the seating positions were adjusted so that the dummy's head overlapped the B-pillar. One K-car had a Curtain Side Air Bag (CSA) and a Side Air Bag (SAB) installed; while, in the other K-car, the CSA and SAB were not installed. We compared these test data, previous test data collected for small vehicles, and the Japan New Car Assessment Program test data for the same model K-cars as well as other small cars. The compared data included the injury measures and kinematic behavior of the ES-2 dummies in the front seats of the struck vehicles. It was demonstrated that the CSA and SAB were effective for reducing the number of head and chest injuries in car-to-car crashes; however, it was also demonstrated that the degree of effectiveness was influenced by their design.

INTRODUCTION

Though the number of vehicle accidents has been decreasing recently in Japan, in 2010 it was greater than 720,000, and the number of injuries was greater than 890,000. Considering this traffic accident situation, regulations for occupant protection including the side impact protection [1] have been introduced in Japan. Additionally, The Japan New Car Assessment Program (JNCAP) conducts safety evaluation of new cars.

From the accident data analysis, it was shown that the contacts with the head and chest during side crashes are a major cause of serious injuries and death. In order to prevent the occupant's serious injuries during side impact accident, manufacturers have installed curtain side air bags (CSAs) and thorax side air bags (SABs) as supplemental restraint systems. In general, the CSA protects the occupant from head, face, and neck injuries; and the SAB protects the occupant from thoracic and abdominal injuries.

There are many studies published about the effectiveness of the CSA and the SAB. For example, the Insurance Institute for Highway Safety (IIHS) estimated that the side air bags with head protection reduce driver deaths in cars struck on the near side by 37% [2]. Otte et al. conducted research to analyze side impact accident data to confirm the effectiveness of the SAB [3]. The National Agency for Automotive Safety and Victim's Aid (NASVA) conducted pole side impact tests on vehicles with and without CSAs and compared the resulting head injury measures.

But for the case of a side impact accident in which the striking object is a passenger vehicle, the effectiveness of the CSA has not been studied as extensively. This may be due to the fact that the dummy head injury measures are not so large for the tests based on the ECE/R95 test procedure and consequently the CSAs are not needed. For example, most of the head injury criteria (HIC) data measured in the Japan New Car Assessment Program (J-NCAP) have been less than 500.

In this study, building on the bases of our past studies [4-[8], we hypothesized that the reason why the dummy head injury measures obtained from the ECE/R95 tests were not so large was due to the seating posture of the dummy. In almost all cases, the dummy head did not overlap the B-pillar under the ECE/R95 regulation. We conducted research on the side impact accidents in Japan and on the occupant seating postures in vehicles on the roads, and conducted full car side impact test series. Some of these results already have been published [8]. In this study, first we investigated the recent side impact accident data in Japan by injury levels and confirmed the macro trend. Next, we researched the occupant seating postures in vehicles on the roads and confirmed that 56% of drivers and 78% of passengers were seated such that their head overlapped the B-pillar (from a side view). And from our research sample study, we confirmed that the trend that, when the driver's height was large, the overlap of the head and B-pillar was large. We also found that the individual variability also had a large influence on the position as well as the height. Third, tests were conducted based on the specifications of Regulation ECE/R95 with the exception that the dummy was positioned so as the head would make contact with the B-pillar. To investigate the effectiveness of the CSA for head protection in car-to-car crashes, these tests were conducted for struck cars with and without a CSA for two types of vehicles. It was demonstrated that the CSA was effective for reducing the number of head injuries in car-to-car crashes.

STUDY ON SIDE IMPACT ACCIDENT IN JAPAN

In this study, the accident analyses in Japan were examined based on the Institute for Traffic Accident Research and Data Analysis (ITARDA) global accident data for 3 years (2005-2007). The side impact accident data were filtered to contain only belted occupants and crashes without multiple impacts. Figure 1 shows the percentage of striking vehicles and object types by the injured level (fatal, serious, and minor). The narrow objects (e.g., signals, telephone poles, and road signs) were defined as "poles." The injury level was defined by the days that the victim visited the hospital. The cases for which the visit to the hospital was over 30 days were defined as "serious" injuries, and the cases where the visits were under 30 days were defined as "minor" injuries. The cases that the occupants died within 24 hours of the accidents were defined as "fatal" accidents. In fatal accidents, 47% of the striking objects were a "passenger vehicle," 21% were "other object (without pole)," 19% were "pole," and 13% were "large vehicle, truck." In serious injury accidents, 81% of the striking objects were "passenger vehicle," 10% were "other object (without pole)," 5% were "large vehicle, truck," and 4% were "pole." In minor injury accidents, 97% of the striking objects were "passenger vehicle," 2% were "other object (without pole)," 1% were "large vehicle, truck," and 0.3% were "pole." The "passenger vehicle" was the largest source of striking objects for all the accidents though the percentage was relatively smaller in the fatal accidents and larger in the minor accidents. The "Large vehicle, truck," "pole," and "other object (without pole)" were large sources of striking objects in the fatal accidents, but very small in the minor injury accidents.

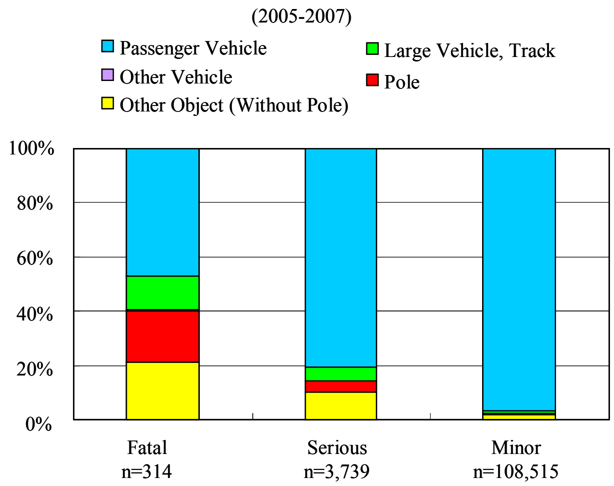


Figure 1 - Type of striking vehicle and object involved in side impact accidents (fatal, serious and minor injuries).

Figure 2 shows the injured body regions of the occupants by injured level. In the fatal accidents, 43%

of the injured body regions were the “head, face” and 28 % were the “thorax, back.” In the serious injury accidents, 32% of the injured body regions were the “thorax, back,” 21% were the “neck,” 19% were the “pelvis, lower extremities,” and 13% were the “head, face.” In minor injury accidents, 69% of the injured body regions were the “neck.” The “head, face” was the largest source in fatal accidents and not a small source in the serious injury accidents. The “thorax, back” was the next largest source in the fatal accidents and the largest source in the serious injury accidents. Thus, it has been determined that protecting the head and thorax of the occupant is important for reducing the fatal and serious side impact accidents.

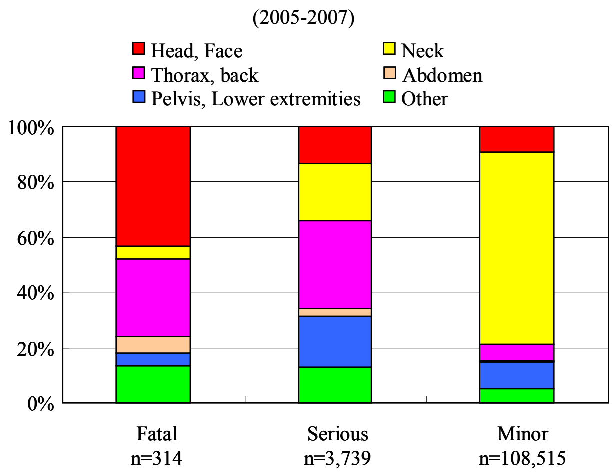


Figure 2 - Injured body regions in side impact accidents by injury level.

Figure 3 shows the injured body regions of the Figure 3, 4, and 5 show the injured body regions of the occupants by striking objects in the fatal, serious injury, and minor injury accidents. As for the fatal accidents, when struck by “passenger vehicles,” 36% of the injured body regions were the “thorax, back” and 34% were the “head, face.” When struck by “large vehicles, trucks,” 43% of the injured body regions were the “head, face” and 40% were the “thorax, back.” When struck by a “pole,” 60% of the injured body regions were the “head, face” and 13% were the “thorax, back.” When struck by “other object (without pole),” 50% of the injured body regions were the “head, face” and 15% were the “thorax, back.” In the side impact fatal accidents where the vehicle was struck by another vehicle, the number of occupants injured at the “head, face” and “thorax, back” was similar and larger than that for the other body regions. In the side impact fatal accidents where the vehicle was struck by “other object,” the number of the occupants injured at the “head, face” was larger than that for all of the other body regions.

As for the serious injury accidents, when struck by “passenger vehicles,” 33% of the injured body regions were the “thorax, back” and 24% were the “neck.” When struck by “large vehicle, truck,” 47% of the injured body regions were the “thorax, back” and 24% were the “head, face.” When struck by “pole,” 27% of the injured body regions were “pelvis, lower extremities,” 25% were the “head, face,” and 22% were the “thorax, back.” When struck by “other object (without pole),” 27% of the injured body regions were the “pelvis, lower extremities” and 22% were the “thorax, back.” In the side impact serious accident of the vehicle struck by a “passenger vehicle,” the number of occupants that injured the “neck” was larger probably because the serious injury had been judged during the days that the victim visited the hospital. And in Japan, generally, the neck-injured occupants in a traffic accident visit the hospital for a longer time even though the injury may have had an AIS value of 1. In all cases, the percentage of occupants that injured the “thorax, back” was larger than 20%, especially for the case involving being struck by a “large vehicle, truck,” which was 47% and was larger than any other case. In the side impact fatal accidents involving a vehicle being struck by a “large vehicle, truck” and a “pole,” the percentage of occupants that injured the “head, face” was larger than 20% and was larger than that for the other cases. In the side impact fatal accidents involving vehicles being struck by objects, the percentage of occupant that injured the “pelvis, lower extremities” was 27% and was the largest body injured region for this case.

As for the minor injury accidents of a vehicle being struck by “passenger vehicles,” 70% of the injured body regions were the “neck.” As shown in Figure 1, 97% of the striking objects were “passenger vehicle” in minor injury accidents. That is, almost all of the injured body regions in minor accidents were the “neck.”

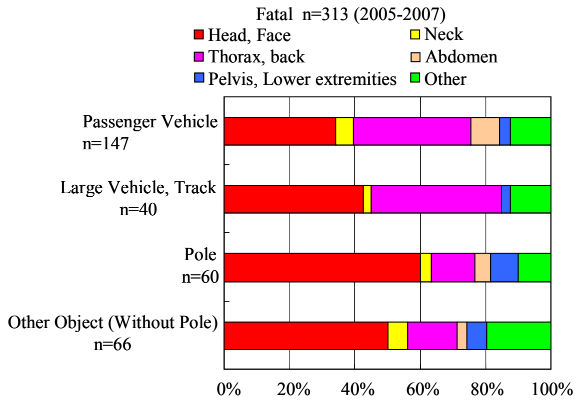


Figure 3 - Injured body regions for fatal in side impact accidents by striking object.

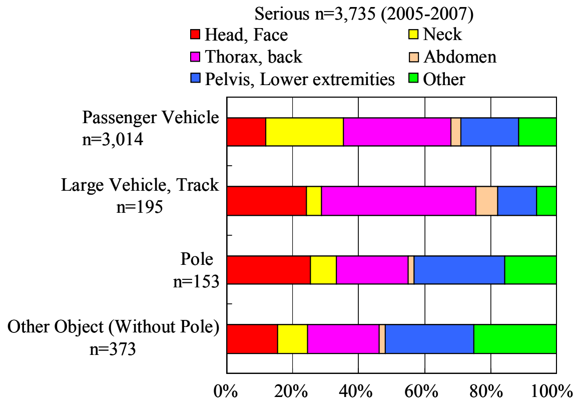


Figure 4 - Injured body regions for serious injuries in side impact accidents by striking object.

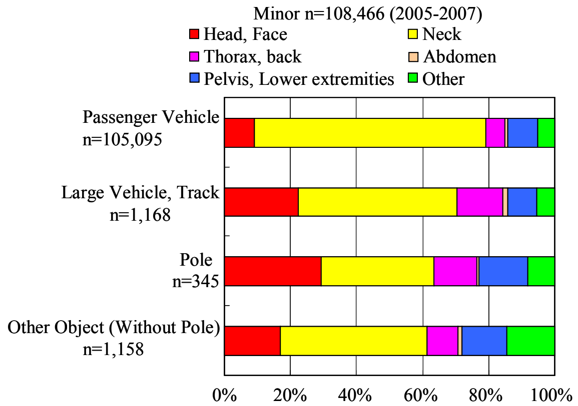


Figure 5 - Injured body regions for minor injuries in side impact accidents by striking object.

Figures 6, 7, and 8 show the curb mass of the striking vehicles and struck vehicles in the fatal accidents, serious accidents, and minor accidents, respectively. As for the fatal accidents, the percentage for which the curb mass of the striking vehicles was larger than 1500 kg was about 57%; while, in contrast,, the percentage for which the curb mass of the struck vehicles was smaller than 1250 kg was about 76%. The percentage rate of the heavier vehicles was large for the striking vehicle, and the percentage rate of the lighter vehicles was large for the struck vehicle.

As for the serious accidents, the percentage of the striking vehicles that the curb mass was larger than 1500 kg was about 31%; while, the percentage of the struck vehicles that the curb mass was smaller than 1250 kg was about 76%. The percentage rate of lighter vehicles was relatively large for the struck vehicle. The percentage rate of heavier vehicles was relatively large for the striking vehicle in the serious accidents but smaller than that in the fatal accidents.

As for the minor accidents, the percentage rates of the curb mass of the striking vehicles and that of the struck vehicles were similar. In the serious injury and fatal side impact accidents, the percentage rate of light weight vehicles was large for the struck vehicles.

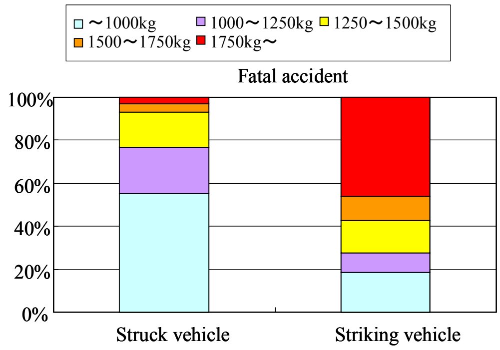


Figure 6 - Curb mass of the struck vehicles and striking vehicles for fatal in side impact accidents.

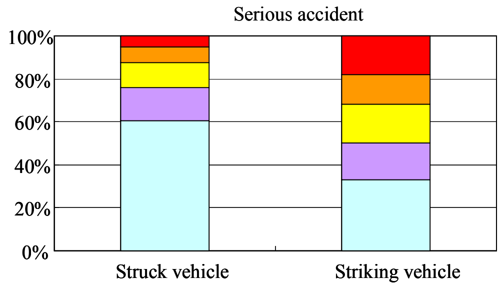


Figure 7 - Curb mass of the struck vehicles and striking vehicles for serious in side impact accidents.

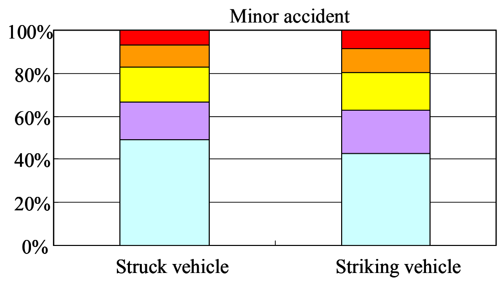


Figure 8 - Curb mass of the struck vehicles and striking vehicles for minor in side impact accidents.

INVESTIGATION OF RIDING POSTURE POSITION

VIDEO ANALYSIS

The seating postures of the driver and front passenger occupants in real-world driving conditions were surveyed in order to provide a basis for predicting injuries caused by the car interior in side impact accidents. The pictures of the position of a front seat occupant were recorded by a video camera from a side view of the vehicle, and the occupant's head position was observed. From the accident analyses, the head was determined to be a frequently injured body region in side impact accidents. Therefore, the percentage of occupants whose head location overlapped with the vehicle's B-pillar was examined. By analyzing the results, the conditions for which occupant protection devices effectively work (i.e., the area to be covered by the occupant protection device) also could be estimated.

Side views of vehicles traveling in both directions on a road near an intersection were filmed with a video recorder. Using the side view of the filmed occupants, the percentage of the occupants whose head overlapped with the B-pillar was examined. The head positions of the drivers (right side) and the front passengers (left side) were surveyed. The surveyed vehicles were limited to the passenger cars (sedans, wagons, K-cars and 1BOXs). That is, large vehicles (such as trucks and buses) and 2-door cars were excluded from the survey. In total, 565 cars were surveyed from the driver side, and 1,290 cars were surveyed from the front passenger side. However, note that only 165 front passengers were examined since the front passenger seating frequency was observed to be only 13%. Figure 9 shows the criterion used to evaluate whether the head overlapped the B-pillar. Note that, even if only a portion of the head overlapped with the B-pillar, it was defined as head/B-pillar overlap.

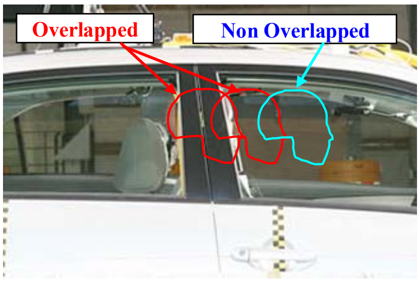


Figure 9 - The criterion of judgment for the head overlapping the B-pillar.

Figure 10 shows the percentage of vehicles that have passengers in the cars in this research. As already mentioned above, the number of vehicles that contained an occupant seated in the passenger seat was 165 during this research.

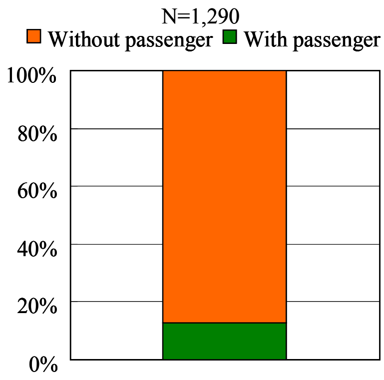


Figure 10 - The percentage of vehicles containing a front seat passenger occupant.

Figure 11 shows the percentages of head/B-pillar overlap for the driver and front passenger. Fifty-six percent of drivers and 78% of front passengers were determined to have head/B-pillar overlap. The percentage of front passengers was large probably because front passengers have the freedom to change their seat positions, whereas the driver must adjust the seat to accommodate reaching the steering wheel and floor pedals in order to drive the vehicle.

Based on the survey, it was found that 56% of the driver heads overlapped the B-pillar. Accordingly, it is predicted that the head is likely to contact the B-pillar during side crashes, and thereby lead to head injuries.

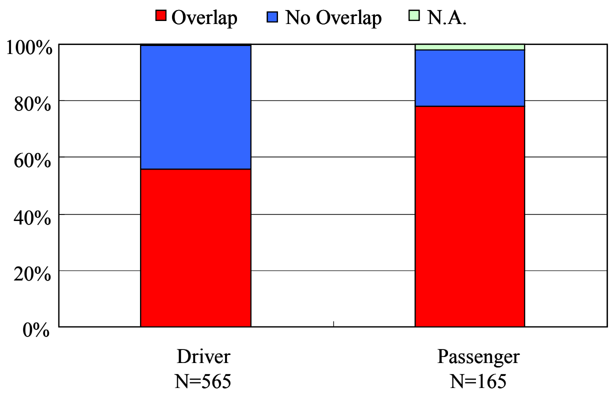


Figure 11 - Percentages with head and B-pillar overlap by front seat seating position.

SAMPLE ANALYSIS

A more detailed study about the seating postures of the driver was conducted. Pictures of the position of a front seat occupant were recorded with a vehicle that was the same as that tested. The examinees seated on the vehicle were members of the NTSEL staff. The pictures of the position of a driver were recorded by a camera from a side view of the vehicle. The distance from the B-pillar to the individual's head was measured. Also the height and sex of the examinees were recorded. The number of examinees was 38, with the number of males being 30 and the number of females being 8. Figure 12 shows the vehicle and the camera position used in this study. Figure 13 shows an example case of this study. Figure 14 shows the measurements of the distance from the B-pillar to the head. The distance was measured from the center of the ear to the front edge of the B-pillar.

Figure 15 shows the heights of the examinees. The average height of the examinees was 169 cm, with that of the males being 172 cm and that of the female being 157 cm. In this study, the height of the 50th percentile Japanese male was 170 cm and that of the 50th percentile Japanese female was 158cm.

Figure 16 shows the different measurements made for locating the head position in this research. L is defined at the horizontal distance from the center of the ear hole to the front edge of the B-pillar. H is defined as the vertical distance from the Seat Reference Point (SRP) to the center of the ear hole. The zero point of L is defined to be the front edge of the B-pillar, and the positive direction is defined as the direction heading from the rear of the vehicle to the front of the vehicle. So when the parameter L measurement was large, the distance from the B-pillar to the head was large. And when the parameter L measurement was negative, the B-pillar and the ear hole were overlapped. The zero point of H is the SRP location, and the positive direction is in the direction from the seat bottom up to the roof of the vehicle.

Figure 12 - The vehicle and the camera position in this study.

Figure 13 - A sample picture in this study.

Figure 14 - The measurement of the distance from B-pillar to the head.

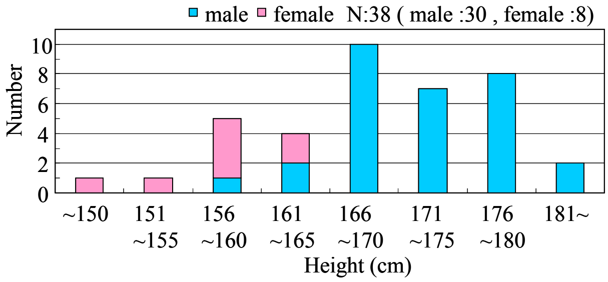


Figure 15 - The height of the examinees by the sex.

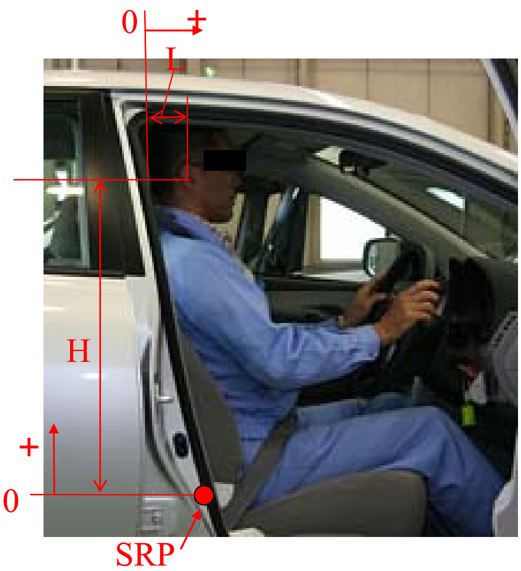


Figure 16 - The definition of the measurements.

Figure 17 shows the head positions of the examinees by the height in this research. The 50th percentile of the Japanese head length from the forehead to the rear of the head is about 180 mm. If the center of the ear hole is assumed to be the center of the head, an L measurement smaller than 90 mm indicates that the head and B-pillar were overlapped. The yellow area of Figure 17 depicts the measurements in which the L measurements were smaller than 90 mm. The number of measurements in the yellow area was 26 and represented 68% of the examinees. From the pictures, the number that overlapped the head and B-pillar was 30 and near to the number from the judgment from Figure 17. It seemed to be a tendency that, when the height was large, the L was small and the distance from B-pillar to the center of the head was small. But, there were some cases that, even though the height was large, the L was large. For example, the maximum L of the height in the range “151~155” was larger than the minimum L of the height in the range of “171~175”. This was most likely due to that individual variability was larger than the influence of the height.

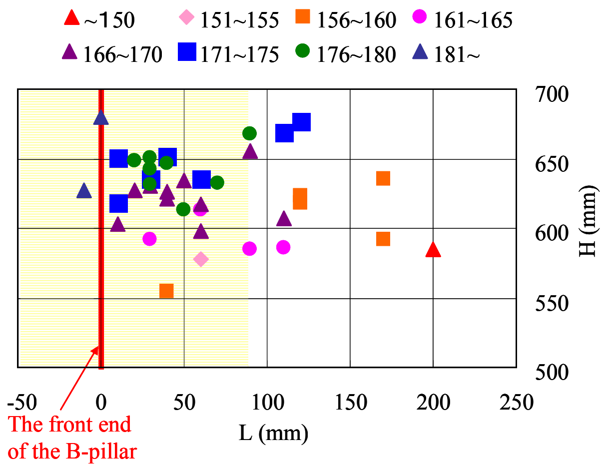


Figure 17 - The head positions of the research by the height.

FULL-SCALE SIDE IMPACT TEST

TEST METHOD

In order to understand the effectiveness of the CSA, a series of crash tests were carried out using two types of vehicles as a struck vehicle. Vehicle 1 was a sedan type small passenger vehicle that is popular in Japan. Vehicle 2 was a K-car that is categorized in Japan as a very small size vehicle. Vehicle 2 also is a popular K-car in Japan. Figure 18 shows Vehicle 1 and Figure 19 shows Vehicle 2. Table 1 presents the test vehicles’ specifications. The Vehicle 1 was 220 mm larger in width and 310 kg heavier in curb weight than Vehicle 2. Tests 1, 2, 4, and 5 were conducted based on the specifications of Regulation ECE/R95 other than the aspect for the positioning of the dummy as previously stated. The dummy position was defined such that the dummy head overlapped the B-pillar. Figure 20 shows the ECE/R95 mobile deformable barrier (MDB) used in this test series.

Figures 21 and 23 show the dummy seating postures in the Vehicle 1 and 2 before the tests 1, 2, 4 and 5. As shown, it is seen that the dummy head and B-pillar overlapped. Tests 3 and 6 were the JNCAP tests conducted of Vehicle 1 and Vehicle 2, from which data was used for reference, though the impact velocity of the MDB was 55 km/h. Figures 22 and 24 show the dummy seating postures in the Vehicle 1 and 2 before the Tests 3 and 6 as the Regulation ECE/R95 dummy position.

Figure 18 - The photo of the Vehicle 1 that was the small passenger vehicle tested in this study.

Figure 19 - Photo of Vehicle 2 that was the K-car tested in this study.

Table 1 – Specifications of tested vehicles.

	unit	Vehicle 1	Vehicle 2
Length	mm	4410	3395
Width	mm	1695	1475
Height	mm	1460	1610
Curb mass	kg	1130	820
Engine displacement	cc	1496	658

Figure 20 - Photo of the ECE/R95 MDB used in this study.

Figure 21 - The photos of dummy seating position in Vehicle 1 before tests 1 and 2.

Figure 22 - Photo of dummy seating position in Vehicle 1 before test 3.

Figure 23 - Photos of dummy seating position in Vehicle 2 before tests 4 and 5.

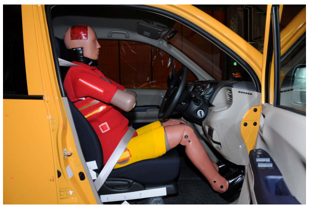


Figure 24 - Photo of dummy seating position in Vehicle 2 before test 6.

Figure 25 and Table 2 show the test configuration and specifications of Vehicle 1. Figure 26 and Table 3 show the test configuration and specifications of Vehicle 2. For these tests, ES-2 dummies were seated in the front driver seats of the struck vehicle. In addition, a front facing child restraint system (CRS) was installed in the rear right seat (near side) and a Q3s dummy was placed in the CRS in Tests 1, 2, 4, and 5. Additionally, in Test 2, a rear facing CRS was installed in the rear left seat and a CRABI 6-month dummy was placed in the CRS. In this study, the injury measures and kinematic behavior of the ES-2 dummies in the front seats of the struck vehicles are compared.

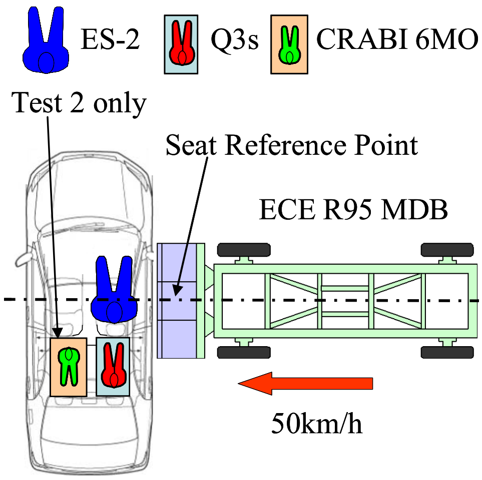


Figure 25 - Test configuration of Vehicle 1.

Table 2 – Test specifications of Vehicle 1.

Test No.		Test 1	Test 2	Test 3
Striking vehicle	Type	ECE/R95 MDB	ECE/R95 MDB	ECE/R95 MDB
	Mass	948 kg	948 kg	950 kg
	Velocity	50 km/h	50 km/h	55 km/h
Struck vehicle	Type	Vehicle 1	Vehicle 1	Vehicle 1
	Mass	1253 kg	1279 kg	1192 kg
	Front dummy	ES-2	ES-2	ES-2
	Rear dummy (near side)	Q3s with CRS	Q3s with CRS	-
	Rear dummy (far side)	-	CRABI 6MO with CRS	-
	Curtain side air bag	Without	With CSA	Without

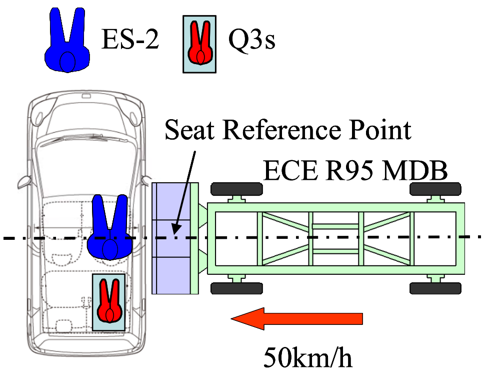


Figure 26 - Test configuration of Vehicle 2.

Table 3 – Test specifications of Vehicle 2.

Test No.		Test 4	Test 5	Test 6
Striking vehicle	Type	ECE/R95 MDB	ECE/R95 MDB	ECE/R95 MDB
	Mass	948 kg	948 kg	948 kg
	Velocity	50 km/h	50 km/h	50 km/h
Struck vehicle	Type	Vehicle 2	Vehicle 2	Vehicle 2
	Mass	958 kg	969 kg	894 kg
	Front dummy	ES-2	ES-2	ES-2
	Rear dummy (near side)	Q3s with CRS	Q3s with CRS	-
	Curtain side air bag	Without	With CSA	Without

Uni-axial accelerometers were attached to the B-pillar inner panel and to the opposite side sill at the center of the front door of the struck vehicles; and tri-axial accelerometers were attached to the center of gravity (C.G.) of both the striking MDB and struck vehicles. The locations where the accelerometers were attached are shown in Figures 27 and 28.

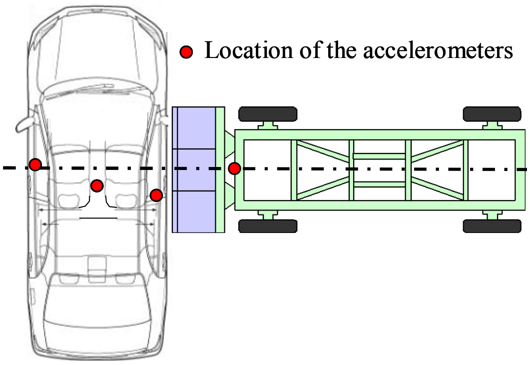


Figure 27 - Locations of accelerometers in Vehicle 1.

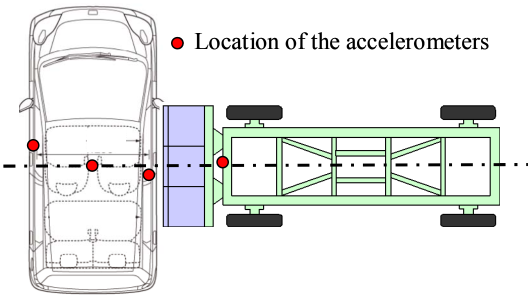


Figure 28 - Locations of accelerometers in Vehicle 2.

TEST RESULTS

Photographs of the vehicles taken after the Tests 1, 2, 4 and 5 were conducted are shown in Table 4. The deformations of Vehicle 1 for both tests and those of Vehicle 2 for both tests were very similar. Vehicle 2 in Test 4 rolled over a quarter turn during the impact test; but in Test 5, the vehicle did not roll over during the impact test.

Table 4 – The vehicles after crash test

Test 1	
Test 2	
Test 4	
Test 5	

Photographs of the vehicles interior conditions and dummy taken after Tests 1 and 2 were conducted are shown in Table 5, and those after Tests 4 and 5 were conducted are shown in Table 6. The contact points of the dummy head with the vehicle interior are marked with the red circles. As for the vehicle without a CSA (Tests 1 and 4), the contact points of the vehicle interior to the dummy head were the B-pillar. In Test 2, the paint mark of the dummy head was at the CSA inflated area. In Test 5, the paint mark from the head contact was at a section of the CSA where it did not inflate, but as can be seen in the photograph was very near to the inflated area.

Table 5 – The interior and dummy in Vehicle 1 after the crash test

Test 1	Vehicle interior	
	Dummy	
Test 2	Vehicle interior	
	Dummy	

Table 6 – The interior and dummy in Vehicle 2 after the crash test

Test 4	Vehicle interior	
	Dummy	
Test 5	Vehicle interior	
	Dummy	

The dummy kinematic behavior in Vehicle 1 as seen from a front view is shown in Table 7 and that from a side view is shown in Table 8. The dummy kinematic behavior in Vehicle 2 as seen from a front view is shown in Table 9 and that from a side view is shown in Table 10. The CSAs in Tests 2 and 5 started inflating between 10ms and 20ms. The time that the dummy head contacted the B-pillar in Tests 1 and 4 was between 40ms and 50ms. In Test 2, the center of the dummy head contacted the area of the CSA that was inflated. In Test 5, the center of the dummy head did not contact the area of the CSA that was inflated.

Table 7 – The dummy kinematic behavior in Vehicle 1 as seen from a front view

	Test 1 (without CSA)	Test 2 (with CSA)
0ms		
10ms		
20ms		
30ms		
40ms		
50ms		
60ms		
70ms		
80ms		

Table 8 – The dummy kinematic behavior in Vehicle 1 as seen from a side view

	Test 1 (without CSA)	Test 2 (with CSA)
0ms		
10ms		
20ms		
30ms		
40ms		
50ms		
60ms		
70ms		
80ms		

Table 9 – The dummy kinematic behavior in Vehicle 2 as seen from a front view

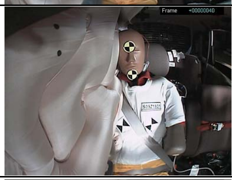
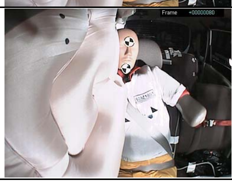
	Test 4 (without CSA)	Test 5 (with CSA)
0ms		
10ms		
20ms		
30ms		
40ms		
50ms		
60ms		
70ms		
80ms		

Table 10 – The dummy kinematic behavior in Vehicle 2 as seen from a side view

	Test 4 (without CSA)	Test 5 (with CSA)
0ms		
10ms		
20ms		
30ms		
40ms		
50ms		
60ms		
70ms		
80ms		

The exterior deformations of the struck vehicles at the belt line level and the Hip-point level after tests 1, 2, 4 and 5 are shown in Figure 29. At the belt line level of the SRP (i.e., at about -126 mm), the deformations of the struck vehicles measured in all tests were almost the same (about 140 mm). At the Hip-point level of the SRP, the deformations of the struck vehicles in all tests were almost the same (about 210 mm).

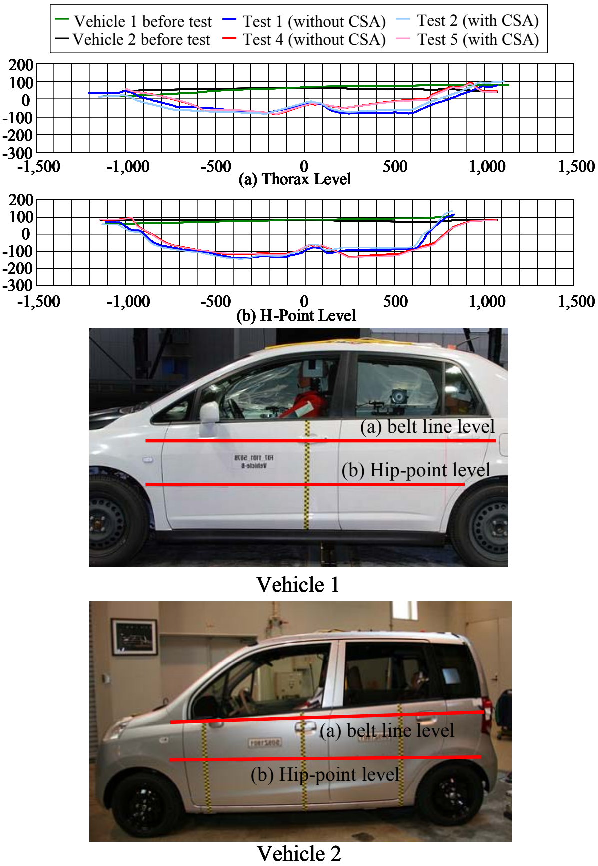


Figure 29 - Exterior deformation of struck vehicles.

of the dummies during these tests are shown in Figures 30 and 31. In all tests, the initial rise time of the head resultant acceleration occurred at about 20 ms. Sharp rises occurred at about 45 ms in Tests 1 and 3 and at about 50 ms in Tests 4 and 5. In Tests 2 and 6, a sharp rise did not occur. The reason why the sharp rise did not occurred in Test 6 was that the head did not make contact to the vehicle interior during the test. As for the maximum resultant acceleration, Test 4 had the largest magnitude at 1207 m/s². The magnitude of the acceleration in Test 1 was the next largest at 996 m/s². The magnitude in Test 5 was next to Test 1 at 808 m/s². The magnitude in Test 6 was next to Test 5 at 556 m/s². The magnitude in Test 3 was next to Test 6 at 543 m/s². The magnitude in Test 2 was the smallest at 351 m/s².

Regarding a comparison between the same vehicle type, the dummy maximum head resultant acceleration in a vehicle with a CSA was smaller than that in a vehicle without a CSA. Also, the dummy maximum head resultant acceleration in a vehicle without a CSA when the dummy head was not overlapped with the B-pillar was smaller than that when the dummy head was overlapped with the B-pillar (though the MDB impact speed was 5 km/h higher when the dummy head was not overlapped). As for the difference between the maximum head resultant accelerations of the dummies in a vehicle with and without a CSA, Vehicle 1 had a larger difference than Vehicle 2. The reason of the difference was probably due to the difference of the design of the inflated area of CSA , specifically the CSA equipped in Vehicle 1 restrained the dummy head before the dummy head made contact to B-pillar; whereas the CSA equipped in Vehicle 2 did not restrain the head before the contact occurred.

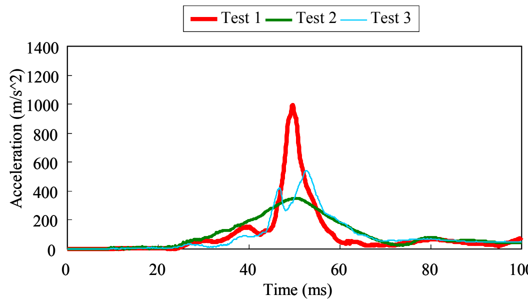


Figure 30 - Head resultant accelerations time histories in Vehicle 1.

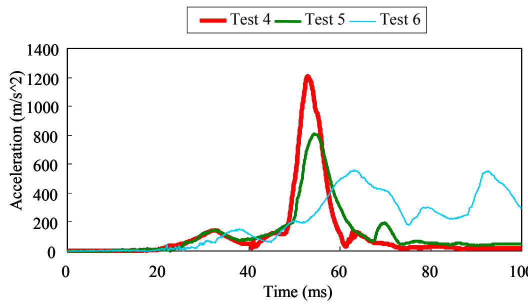


Figure 31 - Head resultant accelerations time histories in Vehicle 2.

The time histories of the thoracic rib deflections of the dummies are shown in Figures 32 and 33. As for the initial rise time of the thoracic rib deflection, the rise time in Test 2 occurred at about 15 ms and that in Test 5 occurred at about 16 ms. Both initial rise times occurred earlier in these tests than in the other tests. The initial rise time in Test 6 occurred at about 20 ms and was next in time after that for Tests 2 and 5. The initial rise time in Test 4 occurred at about 24 ms and was next in time after that for Test 6. The rise time in Test 1 occurred at about 29 ms and was next in time after that for Test 1. The rise time in Test 3 occurred at about 38 ms and was the latest in time of all of the tests. As seen in these figures, the initial rise times of the thoracic rib deflection in the vehicles with a CSA and SAB were earlier than those in the vehicles without a CSA and SAB.

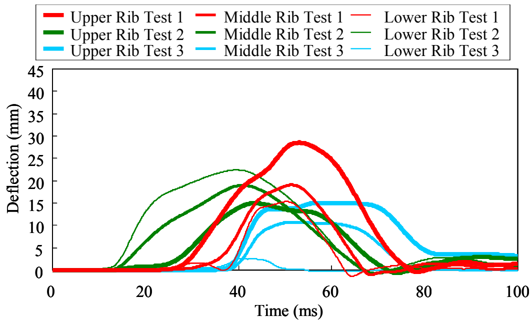


Figure 32- Thoracic rib deflections time histories in Vehicle 1.

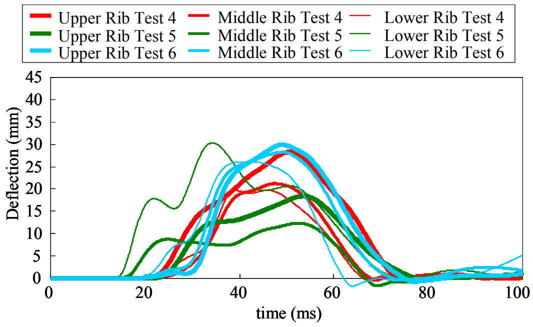


Figure 33- Thoracic rib deflections time histories in Vehicle 2.

The time histories of the abdominal forces of the dummies are shown in Figures 34 and 35. As for the initial rise time of the abdominal forces, the rise time in Test 5 occurred at about 16 ms and was the earliest occurring in all of the tests. The rise time in Test 2 occurred at about 20 ms and was the next earliest occurring. The rise time in Tests 3 and 6 occurred at about 22 ms and were next in time after Test 2. The rise time in Test 4 occurred at about 25 ms and was next in time after Tests 3 and 6. The rise time in Test 1 occurred at about 35 ms and was the latest occurring in all of the tests. Regarding the comparison between the same vehicle type, the initial rise times of the abdominal force in the vehicles with a CSA were the earliest and those in the vehicle of J-NCAP test conditions were the next earliest. Those in the vehicles without the SAB were the latest. This may be due to the fact that the SAB covered the abdominal area.

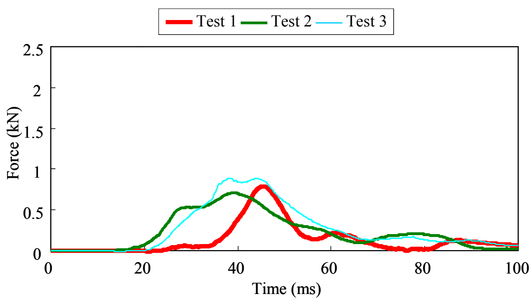


Figure 34- Abdominal force time histories in Vehicle 1.

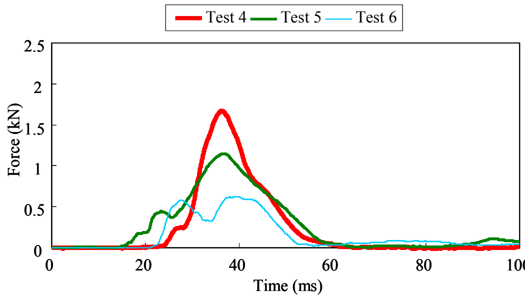


Figure 35- Abdominal force time histories in Vehicle 2.

The time histories of the pubic forces of the dummies are shown in Figures 36 and 37. The initial rise times of the pubic forces occurred at about 21 ms and were very similar in all tests. This may be due to the fact that the SAB did not cover the pelvic area.

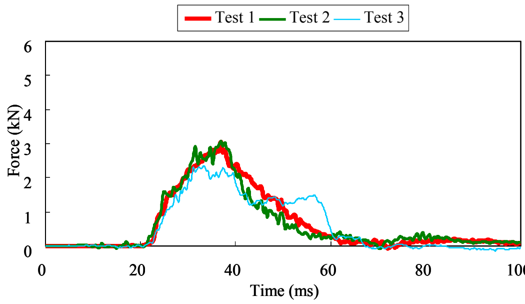


Figure 36 - Pubic force time histories in Vehicle 1.

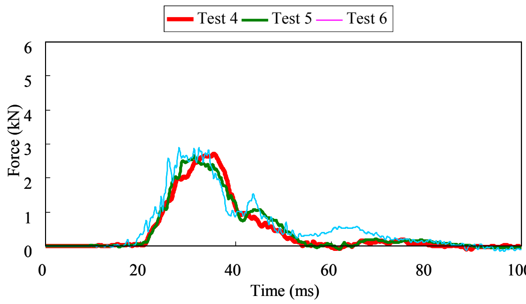


Figure 37 - Pubic force time histories in Vehicle 2.

The maximum injury measures of the ES-2 dummy and the corresponding IARVs for the dummy as specified by ECE R95 are shown in Tables 11 and 12. The ratios of the injury measures to the IARVs are shown in Figure 38. As can be observed, all of the injury measures were less than the corresponding IARVs.

As for the head performance criterion (HPC), more specifically the Head Injury Criterion (HIC), Test 4 was calculated to be 588 and was the largest of all the tests. Test 6 was calculated to be 411 and was the next largest, but the dummy head did not make contact to an object as seen from the video. (This is the reason why the shape of the head resultant acceleration time history of Test 6 was different from those of the other tests as shown Figure 31). HPC is used for the case when the head makes contact to an object. So the HPC of Test 6 was the reference. Test 5 was calculated to be 274 and was the next to Test 6. Test 1 was calculated to be 255 and was next to Test 4; however, it was similar to that in Test 4. Test 3 was calculated to be 113 and was the next to Test 1. Test 2 was calculated to be 86 and was the smallest of all the tests.

As for the 3 ms maximum head resultant acceleration, Test 4 was 983 m/s^2 and was the largest of all the tests, Test 5 was 726 m/s^2 and was the next largest. Test 1 was 667 m/s^2 and was next to Test 5; however, it was similar to Test 5. Test 6 was 525 m/s^2 and was next to Test 1. Test 3 was 451 m/s^2 and was next to Test 6. Test 2 was 343 m/s^2 and was the smallest of all the tests.

Comparing the head injury measures with the same vehicle type, those for a vehicle with a CSA were smaller than those for a vehicle without a CSA. So, these may be due to the fact that the CSAs have a likely effectiveness in decreasing the head injuries. In making a comparison of the head injury measures between the Vehicle 1 and Vehicle 2, those for Vehicle 2 were larger than those for Vehicle 1. In making a comparison of the head injury measures between the difference of the dummy postures, those for the case when the dummy head was overlapped with the B-pillar were larger than those for the case when the dummy head was not overlapped with the B-pillar.

As for maximum thorax rib deflection, Test 5 was 30.7 mm and was the largest of all the tests, Test 6 was 29.9 mm and was the next largest; however, it was very similar to Test 5. Test 1 was 28.5 mm and was the next to Test 6. Test 3 was 28.3 mm and was next to Test 1; however, it was very similar to Test 1. Test 2 was 22.4 mm and was next to Test 3. Test 3 was 15.0 mm and was the smallest of all the tests.

As for the maximum thorax rib V*C, Test 5 was 0.51 m/s and was the largest of all the tests, while Test 6 was 0.39 m/s and was the next largest. That in Test 4 was 0.29 m/s and was next to Test 6. That in Test 1 was 0.24 m/s and was next to Test 4. That in Test 2 was 0.15 m/s and was next to Test 1. Test 3 was 0.14 and was the smallest of all the tests; however, it was very similar to Test 2.

Comparing the thoracic injury measures with that in the same vehicle type, those of the Vehicle 1 with a CSA and SAB were smaller than those of Vehicle 1 without a CSA and SAB; however, those of Vehicle 2 with a CSA and SAB were larger than those for Vehicle 2 without a CSA and SAB. This was most probably due to the judgment that the influence of an SAB on the thoracic injury measures is dependent on the designs of the SAB and vehicle, which have several parameters. For example, the SAB design parameters are the pressure, the size, the position, etcetera. The vehicle design parameters are the sensing time, the position of the sensors, the space of the SAB deployed, etcetera. In making a comparison of the thoracic injury measures between the Vehicle 1 and Vehicle 2, those for Vehicle 2 were larger than those for Vehicle 1.

As for the abdominal force, Test 4 was 1.7 kN and was the largest of all the tests; Test 5 was 1.1 kN and was the next largest. Test 3 was 0.9 kN and was next to Test 5. Test 1 was 0.8 kN and was next to Test 3. Test 2 was 0.7 kN and was next to Test 1. Test 6 was 0.6 kN and was the smallest of all the tests. However, the maximum abdominal forces of Tests 1, 2, 3 and 6 were almost similar. The measured abdominal force of Vehicle 2 with a CSA and SAB was smaller than that of the Vehicle 2 without a CSA and SAB; however, that of Vehicle 1 with a CSA and SAB was very similar to that of Vehicle 1 without a CSA and SAB. Therefore, it was determined that the influence of SAB on the abdominal force was also dependent on the design of SAB and vehicle.

As for the pubic force, the pubic forces for Tests 1 and 2 were the same value at 3.1 kN and were the largest of all the tests. Test 6 was 2.9 kN and was the next largest. Test 4 was 2.7 kN and was next to Test 6. Test 5 was 2.6 kN and was next to Test 4. However, the maximum pubic forces of Tests 4, 5 and 6 were similar. Test 3 was 2.3 kN and was the smallest of all the tests. The force measures for the same vehicle type when the dummy seating postures were the same case were the same in each of the vehicles. Hence, the influence of a CSA and SAB on the pubic force was determined to be minimal in this study. The pubic force measures for the Vehicle 1 when the dummy seating postures were not the same case were different, though those for the Vehicle 2 when the dummy seating postures were not the same case were very similar. So this is most probably due to the judgment that the influence of dummy seating postures to the pubic force was dependent on the designs of vehicle.

Table 11 Maximum injury measures in Vehicle 1

	unit	Test 1	Test 2	Test 3	IARV
HPC		255	86	113	1000
Head resultant maximum acceleraion (3ms)	m/s2	667	343	451	-
Thorax upper rib deflection	mm	28.5	15.0	15.0	42.0
Thorax middle rib deflection	mm	19.1	18.9	10.6	42.0
Thorax Lower rib deflection	mm	15.3	22.4	2.6	42.0
Thorax upper rib V*C	m/s	0.24	0.07	0.14	1.0
Thorax middle rib V*C	m/s	0.16	0.08	0.07	1.0
Thorax Lower rib V*C	m/s	0.18	0.15	0.01	1.0
Abdominal force	kN	0.8	0.7	0.9	2.5
Pubic force	kN	3.1	3.1	2.3	6.0

Table 12 Maximum injury measures in Vehicle 2

	unit	Test 4	Test 5	Test 6	IARV
HPC		588	274	411	1000
Head resultant maximum acceleraion (3ms)	m/s2	983	726	525	-
Thorax upper rib deflection	mm	28.3	18.4	29.9	42.0
Thorax middle rib deflection	mm	21.2	12.3	28.2	42.0
Thorax Lower rib deflection	mm	19.7	30.4	25.9	42.0
Thorax upper rib V*C	m/s	0.23	0.11	0.38	1.0
Thorax middle rib V*C	m/s	0.21	0.06	0.39	1.0
Thorax Lower rib V*C	m/s	0.29	0.51	0.38	1.0
Abdominal force	kN	1.7	1.1	0.6	2.5
Pubic force	kN	2.7	2.6	2.9	6.0

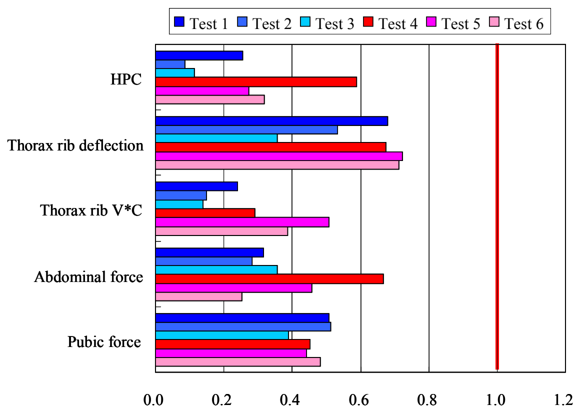


Figure 38 - Ratios of injury measures to IARVs.

DISCUSSION

In comparing the head injury measures within the same vehicle type, it was observed that those of the vehicle with a CSA were smaller than those for the vehicle without a CSA. As a result, it was determined that the CSA is effective in decreasing head injuries. However, the head injury measure ratio of Vehicle 1 with a CSA to that without a CSA was 0.33, and that of Vehicle 2 was 0.47; so the head injury measure ratio for Vehicle 1 was smaller than that of Vehicle 2 (refer to Tables 11 and 12 and to Figure 38). This is probably because the center of the dummy's head in Vehicle 2 did not make contact with the inflated area of the CSA (refer to Table 6). As a result, the center of the dummy's head had a more severe contact with the B-pillar though the vehicle was equipped with a CSA; and the dummy's head acceleration rose sharply and was the same as the dummy's head acceleration in the vehicle without a CSA (refer to Figure 31). But the front area of the dummy head had contact with the CSA (refer to Table 10), so the HPC and head maximum resultant acceleration of the dummy in Vehicle 2 with a CSA were smaller than those in Vehicle 2 without a CSA. As for Vehicle 1, the center of the dummy head contacted the inflated area of the CSA (refer to Table 5), and the dummy head acceleration rose gently (refer to Figure 30). So this was most likely due to the judgment that the effectiveness of the CSA of Vehicle 2 would have been larger if the inflated area of the CSA of Vehicle 2 had been large enough to have had contact with the center of the dummy's head.

In comparing the thoracic injury measures for the same vehicle, it was observed that those of Vehicle 1 with the CSA and SAB were smaller than those for Vehicle 1 without the CSA and SAB. However, the thoracic injury measures for Vehicle 2 with the CSA and SAB were larger than the measures for Vehicle 2 without the CSA and SAB. As can be observed from Tables 7 and 9, the SAB inflated between 10 ms and 20 ms. And as can be observed from the thorax deflection time histories (refer to Figures 32 and 33), the thoracic deflections of the dummies in the vehicle with the SAB rose earlier in time than those in the vehicle without the SAB, and the lower rib and middle rib deflections rose at about 15ms. From this observation, it is concluded that the SAB overlapped the dummy thorax middle rib and lower rib area in the vehicles used in this study. The maximum thoracic rib deflection of Vehicle 1 with the SAB was smaller than that without the SAB. However, the lower rib deflection of the dummy in Vehicle 2 with the SAB was the largest of all the rib deflections. It was determined a possibility that the pressure of the SAB of Vehicle 2 was high enough to induce the large rib deflection. This was most probably due to the judgment that the SAB could be effective in decreasing the maximum thorax rib deflection if the SAB had been designed for optimal performance.

Comparing the injury measures with the same vehicle but for the dummy seating postures were different, the cases when the dummy head was overlapped with the B-pillar were larger or very similar than the case when the dummy head was not overlapped with the B-pillar. Note that since the dummy head was not overlapped with the B-pillar under the ECE/R95 test condition, the ECE/R95 test condition probably was not the most severe condition.

The injury measures of the dummies in the Vehicle 2 were larger than those in the Vehicle 1 except for the thorax rib deflections and the pubic force. The thorax rib deflections of the dummies in Vehicles 1 and 2 without the CSA and SAB were very similar, and those in the Vehicle 1 with the CSA and SAB were smaller than those in the Vehicle 2 with the CSA and SAB. The pubic force of the dummy in Vehicle 2 was a little smaller than that in Vehicle 1. However, the difference was small. As stated previously, Vehicle 2 was a K-car, and so the weight of Vehicle 2 was about 300 kg lighter than of Vehicle 1. It is a possibility that the weight and width had a large influence on the injury measures.

SUMMARY/CONCLUSIONS

In order to discuss potential side impact test procedures for the future and to identify the issues in side collisions; accident analyses, a field survey of occupant posture, and crash tests were carried out. The results are summarized as follows:

1. In the recent side impact accident data collected in Japan, it was found that the number of accidents that a vehicle was struck by a "passenger vehicle" was the largest for all the accidents.

2. The cases that the occupant injured "head, face" and "thorax, back" were larger than for the other body regions were observed in the fatal accidents, and the cases that the occupant injured "thorax, back" was larger than for the other body regions were observed in the serious accidents. Thus, it is a possibility that improving the restraint system to protect occupants from head and thorax injuries would be effective for reducing the fatal and serious injury accidents.

3. In the fatal accidents, 57% of the striking vehicle's curb mass were larger than 1500 kg; while, in contrast, 76% of the struck vehicle's curb mass were smaller than 1250 kg. In the serious accidents, 50% of the striking vehicle's curb mass were larger than 1250 kg; however, 76% of the struck vehicle's curb mass were smaller than 1250 kg. So in the serious and fatal side impact accidents, the percentage rate of light weight vehicles was large for the struck vehicles and the percentage rate of heavy weight vehicles was large for the striking vehicles. This may be due to the fact that the light weight vehicles were less protective than the heavy vehicles.

4. From using video to the study of seating postures of the driver and front passenger in the real-world, it was observed that 56% of drivers and 78% of passengers had head/B-pillar overlap. As a result, it was determined to be possible that in side impact accidents head injuries would occur frequently due to contact with the B-pillar. From the more detailed study about the seating postures of the driver, the tendency was observed that, when the occupant's height was large, the distance from B-pillar to the center of the head was small. However, the individual variability was observed to be larger than the influence of the height.

5. The head injury measures of the dummies in the vehicles with curtain side air bags (CSAs) were smaller than those in vehicles without the CSAs. So, it was determined that the CSAs can be effective in decreasing the head injuries in the car-to-car side impact accidents. However, the effectiveness of the CSAs depends on their design, especially the relation of the CSA inflated area position and vehicle pillar position.

6. The thoracic injury measures of the dummy in Vehicle 1 with the side air bag (SABs) were smaller than those without the SAB. Also, the thoracic injury measures of the dummy in Vehicle 2 with the SAB were larger than those in Vehicle 2 without the SAB. The abdominal injury measure of the dummy in Vehicle 1 with the SAB was very similar to that without the SAB. The abdominal injury measure of the dummy in Vehicle 2 with the SAB was smaller than that without the SAB. So, the SABs would be effective in decreasing the thoracic and abdominal injury measures for the car-to-car side impact accidents; however, the effectiveness of the SABs depends on their designs.

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