INJURY MECHANISM OF PEDESTRIANS IMPACT TEST WITH A SPORT-UTILITY VEHICLE AND MINI-VAN

Günter Schroeder
Hannover Medical School, Hannover, Germany

Keisuke Fukuyama, Kunio Yamazaki
Japan Automobile Research Institute, Tsukuba, Japan

Koichi Kamiji, Tsuyoshi Yasuki
Japan Automobile Manufacturers Association, Tokyo, Japan

ABSTRACT

Pedestrian accidents make up nearly 30% of traffic accidents in Japan; therefore, measures have been taken to abate the number of casualties. In recent years, it has been noticed that the type of injury depends on the car type, especially on the front car-body shape. In fact, various researches have been conducted based on accident data, experiments, simulations, etc. The author et al., who had studied the whole body behavior and injury of pedestrians in the case of accidents caused by Sedans, conducted a whole body impact experiment of pedestrians (Post Mortem Human Subjects - PMHS) in the cases of Sports Utility Vehicle (SUV) and Mini-Van using test specimens in order to examine the differences of injury that might be caused by the difference of the front car-body shape. As a result, not only the impact behaviors of the pedestrians when collided with a SUV or a Mini-Van but also the accelerated velocity that appeared on various parts of the body were identified. In addition, the results indicated that the trajectory of the head and the injuries were different from those in the past impact experiments of pedestrians using Sedans. Finally, basic data were collected that are necessary for the analysis of injury mechanism of pedestrian accidents caused by SUV and Mini-Van and for the injury-reproducing simulation using human models.

Keywords: pedestrian, safety, collision, accident, injury

INTRODUCTION

In Japan the number of deaths in motor vehicle accidents has recently been decreasing partly because of the improvement of safety technologies. On the other hand, the number of the injured has been increasing; in fact, the number surpasses one million every year. Therefore, it is now required to develop further safety measures for decreasing the injured as well as the dead in car accidents. In particular, not only because the number of pedestrian accidents occupies nearly 30% (Cabinet office of Japan, 2007) of the total number of car accidents but also because the type of injury is different according to the type of motor vehicles, especially to the front car-body shape, it is necessary to examine the type of injury in the car accidents involving pedestrians.

From the research in which the author et al. examined the injury in the accidents caused by Sedan-type cars, it has been learned that the lower limbs are relatively more susceptible than other parts of the victim's body, and that in the trajectory of pedestrians there exists no significant difference between old-type sedans and new-type sedans (G. Schroeder et al, 2000).

Nowadays, the application of automobiles has varied, and accordingly various types of cars have appeared in the market. Thus, it is important to capture the nature of the injury of the pedestrians involved in the accidents caused by SUV and Mini-Van (J. Kerrigan et al, 2008).

Therefore, in this study, in order to capture the nature of the injury and trajectory that are specific to the accidents caused by SUV and Mini-Van, the impact characteristic data when these types of automobiles collide with pedestrians were collected by using test specimens (whole human bodies).

In order to collect the data of whole-body behavior of the pedestrians, impact response (acceleration) of main body parts (head, chest, hip, and lower limbs), and types of injury, four impact experiments on the collision of a car and a pedestrian were conducted using whole-body test specimens. The car types were SUV and Mini-Van, and these cars collided at the speed of 40 km/h with the pedestrians who were standing in an upright position.

All the experiments in this study were conducted at Hannover Medical School in Germany under the examination and approval of the Medical Ethics Committee of Hannover Medical School.

METHODS

The experiments that each whole-body specimen (human body) collides with each SUV and each Mini-Van were conducted. Table 1 indicates the experimental conditions. Two experiments were conducted with each vehicle. The height of the specimens was measured by hand. As the index of the skeleton strength, the bone mineral density of each test specimen was also measured with Yokogawa GE Express-A1000, which is a bone mineral density measure device using ultrasonic sound waves. The test specimens were males, and their height ranged from 165 to 185 cm, their weight from 60 to 85 kg, their age from 70 to 84 years old, and the BMD stiffness index from 49 to 89. Since the standard stiffness index of young adults is 100 and the indexes of the test specimens in this study are all below 100, it can be considered that the skeleton strength of these test specimens were deteriorated.

Table 1 - Experimental conditions

Vehicle		SUV		Mini-Van	
Test No.		HJ1	HJ2	HJ3	HJ4
Collision speed	(km/h)	40	40	40	40
PMHS-height	(cm)	165	185	171	171
-weight	(kg)	60	85	80	61
-gender		Male	Male	Male	Male
-age	(years)	80	84	80	70
-bone mineral density	(BMD)	66	86	49	89

Table 2 indicates the sizes and weights of the SUV and the Mini-Van used in the experiment. Main sizes were as follows: the bumper height of the SUV was 658 mm, while that of the Mini-Van was 631 mm. Likewise; the hood leading edge of the SUV was 907 mm, while that of the Mini-Van was 888 mm. At the time of the experiment, the vehicle body mass of the SUV was 810 kg and that of the Mini-Van was 803 kg.

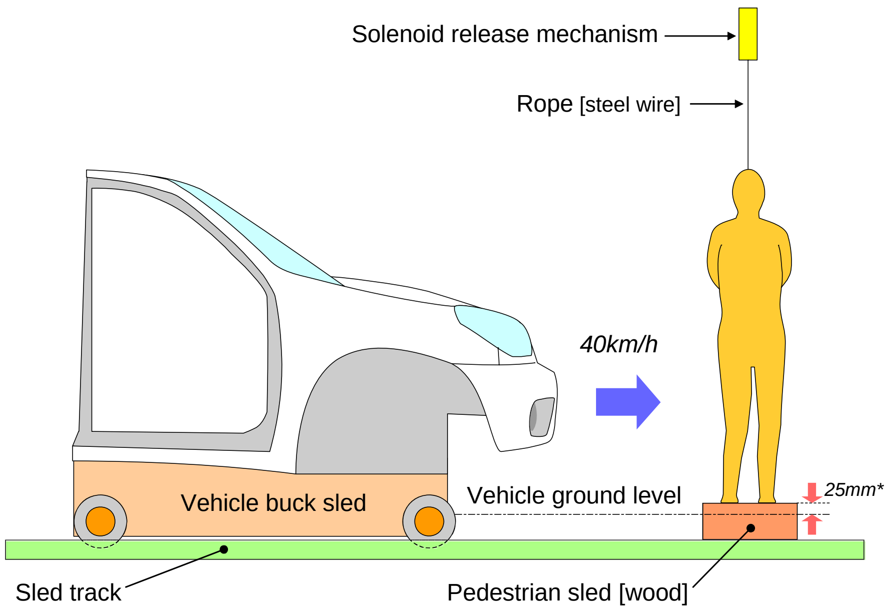
Table 2 - Vehicle size and vehicle weight

Vehicle		SUV (HJ1,HJ2)	Mini-Van (HJ3,HJ4)
Bumper height (Top) [EEVC,1998]	(mm)	658	631
Bumper protrusion	(mm)	163	121
Hood leading edge [EEVC,1998]	(mm)	907	888
Hood length	(mm)	861	493
Hood inclination	(degree)	9	14
Windshield inclination	(degree)	38	40
Vehicle body mass	(kg)	810	803

Fig 1 shows the setup of the experiment. In each experiment, the test specimen was set on the virtual ground made of wood and was impacted at the speed of 40 km/h. The left leg was set forward, while the right leg was set backward; especially, the left knee was set in a position that it could collide with the center of the bumper. The bare feet without socks were set 25 mm above the ground level, which was considered as the height of an ordinary shoe (Working Party on Passive Safety, 2006). A steel wire was fixed with the head. 60 ms before the beginning of the impact the steel wire was released with the solenoid release mechanism. In order to prevent the hands from entering between the car and the lower limbs, the hands were bound with medical tape with low adhesion and were set in front of the abdomen. Furthermore, in order to mitigate the impact of the test specimen when it falls down, cushioning material was set at and around the point of fall.

In order to identify the behavior of the test specimen during collision, this experiment employed MEMRECAM Ci, a high-speed video camera. The shooting speed was 1000 frames per second, and the target marks with the diameter of 80 mm were attached to the backside of the specimens. The images from the video camera were processed with Movias Pro Ver.1.60, the analysis software by Nac Image Technology Inc., and the lens distortion was corrected. Thus the trajectory of the target marks on the surface of the test specimen was calculated.

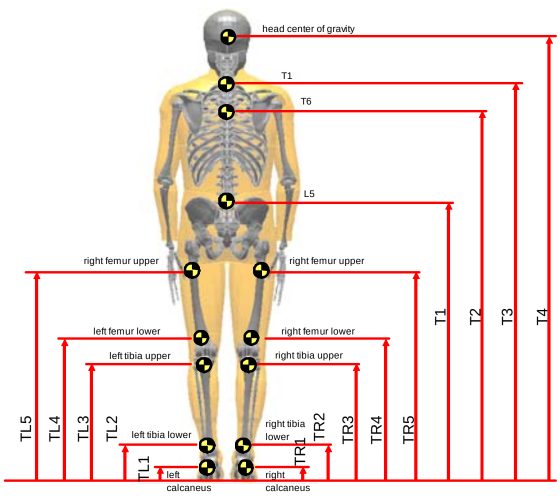
In addition, in order to examine to what extent the car-body was deformed after collision, the maximum permanent deformation at each deformed part were measured with a scale.



25mm: Corresponding to shoe height referred from GTR pedestrian legform to bumper test procedure.*

Fig. 1 - Setup of the experiment

The test specimen was set in a position that it could take a walking posture. Fig 2 indicates the locations of the target markers and the measured values. The values were calculated from the photographs.



Location	Value (m)			
	HJ1	HJ2	HJ3	HJ4
T1	0.99	1.18	1.06	0.99
T2	1.27	1.42	1.30	1.25
T3	1.43	1.62	1.51	1.43
T4	1.58	1.77	1.67	1.60
TR1	0.16	0.13	0.15	0.12
TR2	0.26	0.23	0.23	0.21
TR3	0.45	0.49	0.45	0.41
TR4	0.54	0.62	0.54	0.53
TR5	0.75	0.97	0.83	0.70
TL1	0.09	0.08	0.09	0.11
TL2	0.23	0.19	0.18	0.21
TL3	0.46	0.47	0.45	0.42
TL4	0.57	0.61	0.54	0.55
TL5	0.76	0.96	0.83	0.70

Fig. 2 - Locations of the target marks

Fig 3 shows the locations of acceleration meters on the test specimen. Three single axis acceleration meters were attached to the head, T6, and L5 respectively, while one single axis acceleration meter was attached to the thigh and the tibia. Table 3 indicates the applied filters. ASE-A-500 by Kyowa Inc., a damped acceleration meter, was used for the head, the femur, and the tibia, whereas undamped acceleration meter Endevco7264 was used for T6 and L5. The measured acceleration data were input into the personal computer, changed into physical quantities, and processed with filters. Thus, HIC (the head injury criterion) was calculated.

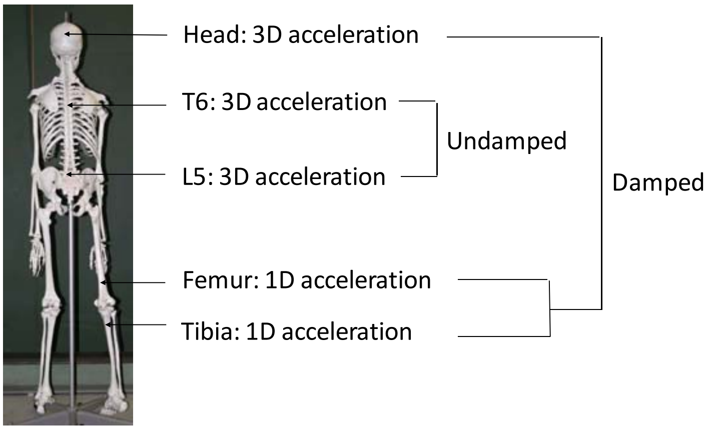


Fig. 3 - Locations of acceleration meters on the test specimen

Table 3 - Specifications of acceleration meters

Location	Model	Strain type	Filter
Head	Kyowa ASE-A-500 Oil damped	Foil strain gauge	CFC1000
T6	ENDEVCO 7264-200 Undamped	Semiconductor strain gauge	CFC180
L5	ENDEVCO 7264-200 Undamped	Semiconductor strain gauge	CFC180
Femur	Kyowa ASE-A-500 Oil damped	Foil strain gauge	CFC180
Tibia	Kyowa ASE-A-500 Oil damped	Foil strain gauge	CFC180

Table 4 indicates the head contact time of the specimens, the peak resultant acceleration time of the head, starting time of braking, and the deceleration. The head contact time, braking timing, and deceleration ratio were measured and calculated from video analysis. The peak resultant acceleration time of the head was identified from the electrical data.

Finally, the types of injury on the test specimens caused by the experiment were examined and specified by the post-experimental autopsy.

Table 4 - Head contact timing and car braking timing

Test	Pedestrian		Vehicle	
	Head contact time* (ms)	Peak head resultant acceleration time** (ms)	Starting time of braking* (ms)	Deceleration* (G)
HJ1	90	97.5	135	1.4
HJ2	116	121.8	130	1.8
HJ3	103	108.4	145	1.7
HJ4	92	-	145	1.4

* video analysis (sampling 1000 Hz)

**electrical data (sampling 20 kHz)

RESULTS

WHOLE BODY BEHAVIOR OF PEDESTRIANS: Fig 4 illustrates the whole-body behaviors of the test specimens (HJ1 - HJ4) from the time of the first collision with the vehicle (0 ms) to 140 ms later.

In the cases of specimens HJ1 and HJ2, which both collided with the SUV, they were very different in height, and thereby great difference was identified in the contact time of the upper bodies. To be concrete, at the time of 100 ms after the collision, the head of HJ1 is in contact with the vehicle, while the head of HJ2 is not in contact with the vehicle.

In the cases of specimens HJ3 and HJ4, both of which collided with the Mini-Van, their heights were not very different; however, at the time of 80 ms after the collision, difference is identified in the movement of the head and the neck, and at the time of 100 ms after the collision, the head of HJ3 is not in contact with the vehicle, while the head of HJ4 is in contact with the vehicle. It can be considered that this is because of the differences of the weight and the initial posture between HJ3 and HJ4. The weight of HJ3 is heavier than that of HJ4 by 19 kg, and the head movement of HJ3 is slower than that of HJ4 due to the fictitious force. In addition, the release timing of HJ4 is earlier than any other specimen, and thereby its torso falls onto the hood, revolving rightwards around the hip.

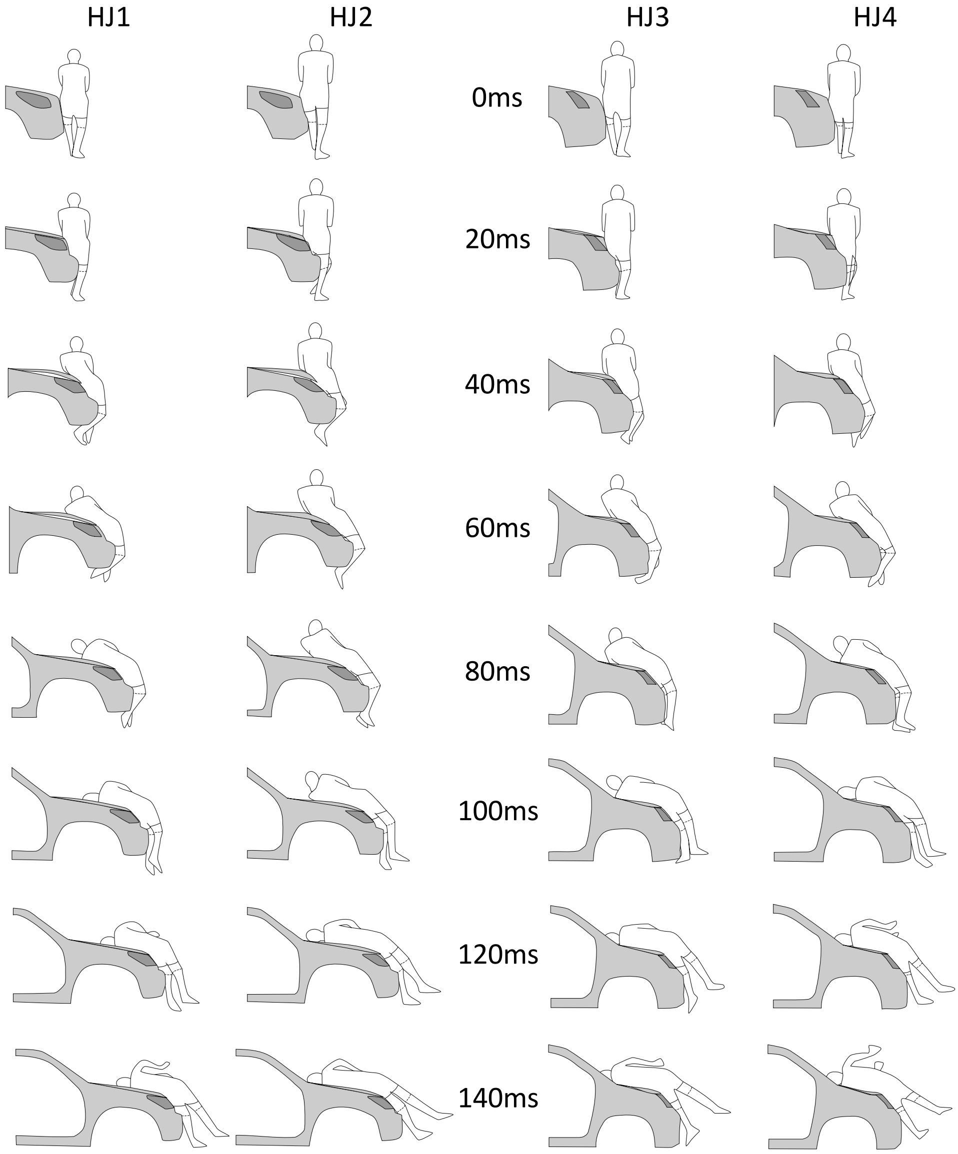
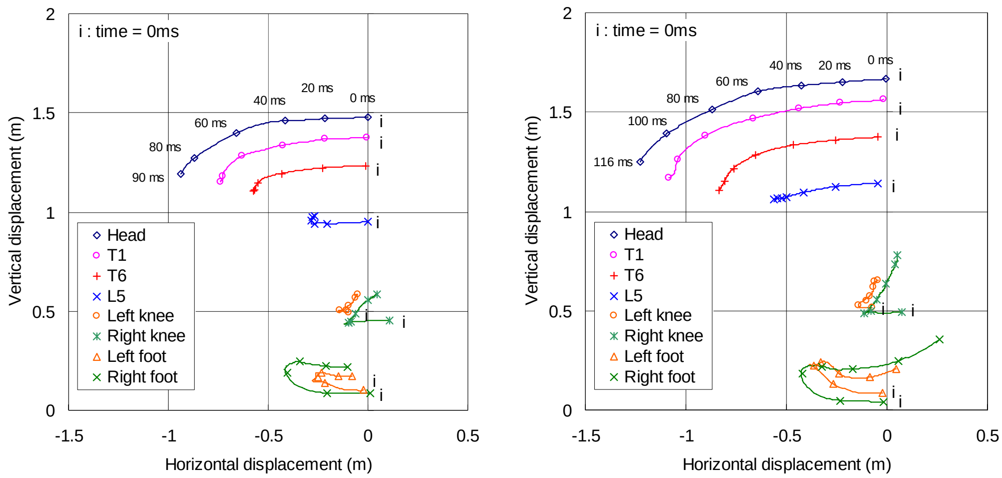


Fig. 4 - Behavior of PMHS

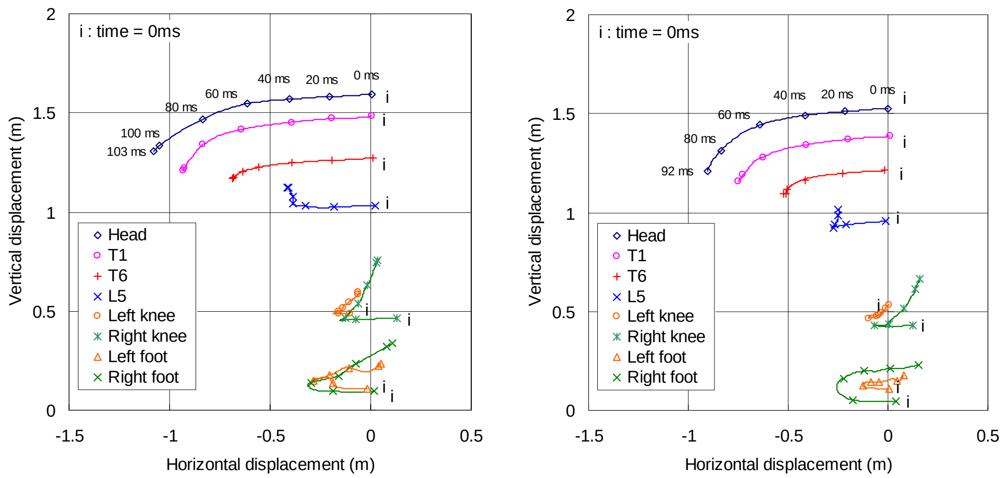
TRAJECTORY OF PEDESTRIANS ON THE VEHIACLE COORDINATE SYSTEM: Fig 5 indicates the trajectory of the main parts of the body of specimens HJ1 and HJ2, which both collided with the SUV. It can be identified that at the time of 0~116 ms the horizontal displacement of the main parts of the upper body (above L5) of HJ2, whose height is taller than that of HJ1, is larger than that of HJ1 at the time of 0~90 ms by around 0.3 m. The horizontal displacement of the knees of HJ2 (0~116 ms) is similar to that of HJ1 (0~90 ms). In addition, the horizontal displacement of the feet of HJ2 (0~116 ms) is larger than that of HJ1 (0~90 ms) by 0.3 m. On the other hand, on all the main body parts, the vertical displacement of HJ2 (0~119 ms) is larger than that of HJ1 (0~90 ms). It can be considered that these differences in displacement stem from the difference of the body type between HJ1 and HJ2. Since HJ2 is taller than HJ1, not only are the contact parts with the SUV different, but the behavior of the upper body is also different because the center of gravity of HJ2 is higher than that of HJ1.

Fig 6 indicates the trajectory of the main parts of the body of specimens HJ3 and HJ4, which both collided with the Mini-van. The heights of the specimens HJ3 and HJ4 are the same, but the horizontal displacement of the main parts of the upper body (above L5) of HJ3 is larger than that of HJ4 by around 0.2 m. The horizontal displacement of the knees of HJ4 is quite similar to that of HJ3. It can be considered that the difference of horizontal displacement between HJ3 and HJ4 stems from the fact that the release time of HJ4 is earlier than that of HJ3 and thereby the body of HJ4 revolves more greatly around the torso when falling down. Finally, no significant difference was identified in the vertical displacement between HJ3 and HJ4.



HJ1 HJ2

Fig. 5 - Trajectory in case of SUV

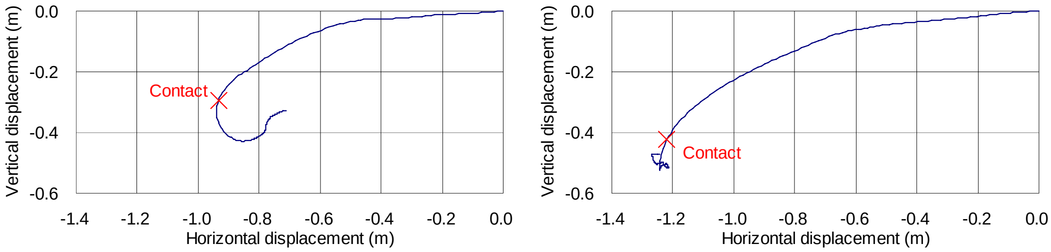


HJ3 HJ4

Fig. 6 - Trajectory in case of Mini-Van

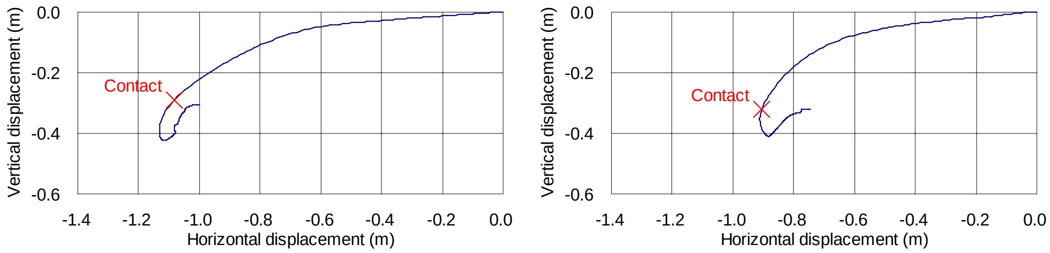
HEAD TRAJECTORY AND HEAD CONTACT DEGREE:

Fig 7 and Fig 8 indicate the head displacement trajectory and the head contact degree of HJ1 - HJ4. The tendency has been identified that the taller the body is, the larger the head displacement is and the smaller the contact degree against the vehicle is. The height of HJ4 is the same as that of HJ3; however, because the release time of HJ4 was earlier, its torso sank and revolved. As a result, the head displacement and the head contact degree differed between HJ3 and HJ4.



HJ1 **HJ2**

Fig. 7 - Head trajectory in collision (SUV)

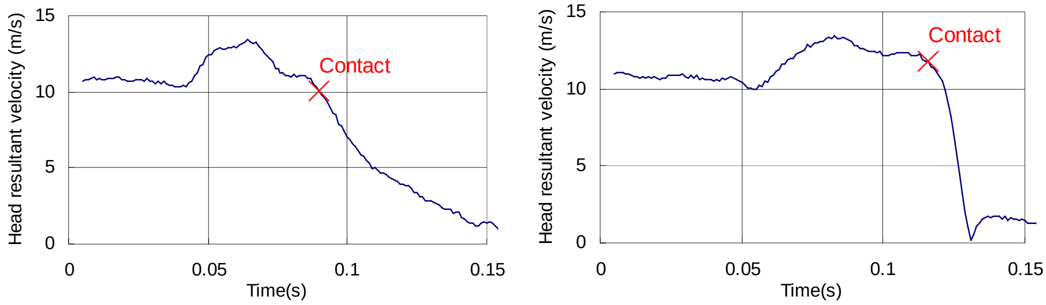


HJ3 **HJ4**

Fig. 8 - Head trajectory in collision (Mini-Van)

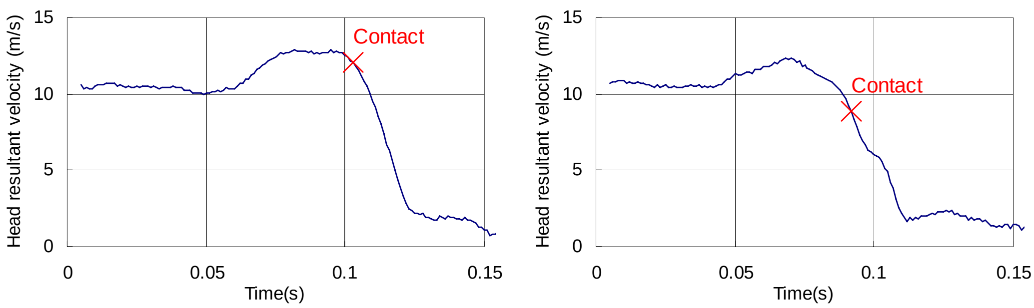
Fig 9 shows the time history of the resultant velocity of HJ1 and HJ2, which both collided with the SUV. Since HJ2 is taller than HJ1, its head contacts the SUV later than HJ1. The head contact timing and the resultant velocity at the time of head contact of HJ1 are around 10 m/s at around 0.09 s. On the other hand, the resultant velocity of HJ2 is around 12 m/s at around 0.12 s. This means that the taller HJ2 contacts the vehicle later than the shorter HJ1 and that the resultant velocity of the taller HJ2 is bigger than that of the shorter HJ1.

Fig 10 indicates the time history of the resultant velocity of HJ3 and HJ4, which both collided with the Mini-Van. Although the heights of HJ3 and HJ4 are the same, their head contact timing and the resultant velocities are different. The head contact timing of HJ4 is earlier than that of HJ3 by around 0.02 s, and the resultant velocity of HJ4 is lower than that of HJ3 by around 3 m/s. It can be considered that one reason for these differences in the contact timing and the resultant velocity between HJ3 and HJ4 is that the initial posture of the test specimen HJ4 revolved rightwards and thereby the side body of HJ4 did not collide with the Mini-Van. In all the four experiments, the head resultant velocity at the time of contact ranges from 9 m/s to 12 m/s.



HJ1 **HJ2**

Fig. 9 - Time history of the head resultant velocity (SUV)



HJ3 **HJ4**

Fig. 10 - Time history of the head resultant velocity (Mini-Van)

DATA OF ACCELERATION: Table 5 shows maximum resultant accelerations on main body parts. As for L5 and T6, 3 msG is also indicated, and as for head, HIC is also indicated. Due to the data communication trouble of the measuring device, it was impossible to conduct electrical measure of the tibia, the femur, and the head of HJ4. In all the test specimens, acceleration tends to be high at the lower limbs (tibia and femur) and the head. The reason for this is that the lower limbs directly contact the bumper and are raised up sharply as is indicated in Fig 4. Thus the acceleration becomes high. In the cases of HJ1 and HJ2, which both collided with the SUV, the accelerations of the lower limbs (tibia and femur) are high, whereas in the case of HJ3, which collided with the Mini-Van, SUV, the accelerations of the lower limbs is lower than that in the case of SUV. As for HIC, the HICs of HJ1, HJ2, and HJ3 were 443, 2228, and 1591 respectively. In particular, the HIC of HJ2 was high and that of HJ1 was low.

Table 5 - Maximum accelerations on main body parts

Test	Tibia	Femur	L5		T6		Head	
	MRA(G)	MRA(G)	MRA(G)	3msG	MRA(G)	3msG	MRA(G)	HIC
HJ1	194	200	116	63	46	38	167	443
HJ2	225	244	31	29	30	28	284	2228
HJ3	83	161	38	36	28	27	297	1591
HJ4	NA	NA	57	51	43	41	NA	

[MRA] : Maximum Resultant Acceleration, [NA] : Not Available

CONTACT PARTS AND INJURY SITUATIONS: Table 6 indicates the types of injury in case of the collision with the SUV, and Table 7 indicates those in case of Mini-Van collision.

HJ1 (SUV): The head of the test specimen HJ1 collided with the right side of the SUV from the center-rear of the hood, and the reentrant depth was 18 mm. From Fig 4 it is learned that the hips collided with the right side of the center of the vehicle on the hood leading edge designated by EEVC. And the reentrant depth was 27 mm. The left knee is in contact with the center of the bumper. The pelvis had an anterior pelvic ring fracture composed of superior & inferior pubic ramus fracture. The knee had an MCL-avulsion.

HJ2 (SUV): The head of HJ2 collided with the lowest edge of the windshield, and the reentrant depth was 51 mm. From Fig 4, it can be considered that the difference of the collision part between HJ1 and HJ2 stemmed from the difference of their heights. The hips were greatly deformed because they contacted near the hood leading edge. The left knee contacted near the center of the bumper (40 mm left from the center). As is indicated in Table 5, although the windshield was deformed due to the collision with the head, the bone did not fracture (the reentrant depth was 51 mm). Due to the contact with the upper arms of the specimen, ribs fractured. The pelvis had an anterior pelvic ring fracture of iliopubic eminence and an anterior pelvic ring fracture of inferior pubic ramus. The knees had an MCL-avulsion and an ACL-avulsion. The injury places of the hips and the knees of HJ2 were quite similar to those of HJ1.

Table 6 - Injuries in the case of SUV

<table>
<tr><th>Test</th><th>Part</th><th>Detail</th></tr>
<tr><td rowspan="5">HJ1</td><td rowspan="2">Left knee</td><td>MCL - avulsion of superficial layer of tibial insertion</td></tr>
<tr><td>Posterior medial capsule rupture</td></tr>
<tr><td>Pelvis
(left ring)</td><td>Anterior pelvic ring fracture composed of superior & inferior pubic ramus fractures</td></tr>
<tr><td>Left arm</td><td>Abrasion on the forearm</td></tr>
<tr><td>Head</td><td>Abrasion on the face</td></tr>
<tr><td rowspan="9">HJ2</td><td rowspan="3">Left knee</td><td>Rupture of deep part of MCL, which is connected to the medial meniscus</td></tr>
<tr><td>ACL - avulsion of femoral insertion</td></tr>
<tr><td>MCL - avulsion of tibial insertion</td></tr>
<tr><td rowspan="2">Pelvis
(left ring)</td><td>Anterior pelvic ring fracture of inferior pubic ramus</td></tr>
<tr><td>Anterior pelvic ring fracture of iliopubic eminence</td></tr>
<tr><td>Left hand</td><td>Abrasion on the hand</td></tr>
<tr><td>Left arm</td><td>Abrasion on the forearm</td></tr>
<tr><td>Rib</td><td>Fracture of 5th and 6th rib at the medio clavicular line; 120 mm from the center line of the sternum, 130 mm from the center line of the sternum</td></tr>
<tr><td>Head</td><td>・ Contusion</td></tr>
</table>

HJ3 (Mini-Van): The head of the test specimen HJ3 collided with the right-center of the windshield, and the reentrant depth was 68 mm. The hips were greatly deformed due to the contact with the hood leading edge. The left knee contacted near the center of the bumper (25 mm left from the center). As is indicated in Table 7, the head contacted near the center of the windshield and had a skull fracture with the length of 15 mm in vertical direction. Due to the contact with the upper arms of the specimen, ribs fractured. The hips had an anterior pelvic ring fracture composed of superior pubic rams multi fragmented fracture and an inferior pubic ramus fracture. Also, tibia wedge fracture and fibula transverse fracture below fibula head were identified.

HJ4 (Mini-Van): The head of the specimen HJ4 collided with the lowest edge of the right windshield, and the reentrant depth was 68 mm. The hips were greatly deformed due to the contact with the hood leading edge. The left knee contacted near the center of the bumper. As is indicated in Table 7, because the head contacted the windshield and the dashboard, it had a skull fracture with the length of 75 mm in vertical direction going to the skull base. The knees, which collided with the upper hood, the ribs were fractured with MCL-rupture.

Table 7 - Injuries in the case of Mini-Van

Test	Part	Detail
HJ3	Left tibia	Tibia wedge fracture
	Left fibula	Fibula transverse fracture
		Fibula transverse fracture below fibula head
	Pelvis (left ring)	Anterior pelvic ring fracture composed of superior pubic ramus multi fragmented fracture & inferior pubic ramus fracture
	Rib	・ Fracture of 5th rib at the medio clavicular line; 122 mm from the center line of the sternum
	Head	・ Skull fracture with length of 15 mm in vertical direction
HJ4	Right ankle	・ Elongation of calcaneofibular ligament
	Left knee	・ MCL - rupture of superficial layer
		・ MCL - avulsion of femoral insertion
	Rib	・ Fracture of 11th and 12th rib at the middle of scapula line
	Head	・ Skull fracture with length of 75 mm in vertical direction going to the skull base

DISCUSSION

COMPARISON OF INJURY

Comparison of injury between SUV and Mini-Van: Table 8 indicates the injuries of the test specimens HJ1, HJ2, HJ3, and HJ4. The bone mineral density (BMD) of HJ1, HJ2, and HJ4 were 66, 86, and 89 respectively. In the collision with the bumper, all these three specimens had MCL-avulsion. On the other hand, The BMD of HJ3 was 49, and HJ3 had no MCL-avulsion, but it had tibia and fibula fractures. It can be considered that this is because the load on the collateral ligament was light due to the fractures of the tibia and the fibula.

Due to the collision with the hood leading edge, three out of the four experiments had a pelvis fracture. In the case of HJ4, the ribs fractured due to the collision with the upper part of the hood. In the cases of HJ2 and HJ3, the ribs fractured due to the contact of the upper arms of the specimens. In the case of head contact, since HJ1 is rather short with the height of 165 cm, this specimen collided with the upper part of the hood and its head had an abrasion. The head of HJ2, rather tall with the height of 185 cm, collided with the lower part of the windshield and had contusion. The head of HJ3 collided with the windshield, and its skull fractured, probably due to its low BMD (49). The head of HJ4 collided with the lowest edge of the windshield, and its skull fractured. Finally, the HIC of HJ1 was 443, which was much lower than that of HJ2 (2228). It can be considered that the reason of this low HIC of HJ1 is that the height of HJ1 is much lower than that of any other specimen and thereby the contact parts were different from that of other specimens.

Table 8 - Injuries in all the experiments

<table>
<tr><th rowspan="3">PMHS body parts</th><th rowspan="3">Vehicle body parts impacted</th><th colspan="2">SUV</th><th colspan="2">Mini-Van</th></tr>
<tr><th>HJ1</th><th>HJ2</th><th>HJ3</th><th>HJ4</th></tr>
<tr><th>BMD : 66
80 years</th><th>BMD : 86
84 years</th><th>BMD : 49
80 years</th><th>BMD : 89
70 years</th></tr>
<tr><td>Lower leg</td><td rowspan="2">Bumper</td><td>-</td><td>-</td><td>Tibia & fibula fracture</td><td>-</td></tr>
<tr><td>Knee</td><td>MCL avulsion</td><td>MCL & ACL avulsion</td><td>-</td><td>MCL avulsion</td></tr>
<tr><td>Pelvis</td><td>Bonnet leading edge</td><td>Pelvic ring fracture</td><td>Pelvic ring fracture</td><td>Pelvic ring fracture</td><td>-</td></tr>
<tr><td>Rib</td><td>(A) PMHS arm
(B) Bonnet top</td><td>-</td><td>5th & 6th rib fracture
(A)</td><td>5th rib fracture
(A)</td><td>11th & 12th rib fracture
(B)</td></tr>
<tr><td>Head</td><td>(B) Bonnet top
(P) Glass
+ in. panel
(G) Glass</td><td>Abrasion
(B)
HIC : 443</td><td>Contusion**
(P)
HIC : 2228</td><td>Skull fracture
(G)
HIC : 1591</td><td>Skull fracture
(P)
HIC : NA</td></tr>
</table>

** possibility in brain injury: We could not investigated it in present study.

Comparison of injury with sedan: Table 9 shows the pedestrian injuries in the case of collision with SUV and Mini-Van, Sedan. Compared with the injuries in the case of collision against Sedans that have been examined so far, several differences can be identified in the cases of pedestrian collisions with SUV and Mini-Van. For example, in the experiments in this study with SUV and Mini-Van, all the three specimens aged 80 or above (HJ1: 80, HJ2: 84, and HJ3: 80) had pelvic ring fractures, but it is known that in the case of pedestrian collision with a Sedan, no pelvic fracture have been identified. It can be assumed that one of the factors of this difference is the fact that the pelvis directly collided with the hood leading edge in the cases of SUV and Mini-Van. Another difference is that in the case of collision with a Sedan, L1 and C6 fractured, but such injuries did not happen in this study with SUV and Mini-Van.

Table 9 - Injuries in the case of SUV and Mini-Van, Sedan

Type	Test	Part	Detail
SUV	HJ1	Left knee	MCL - avulsion of superficial layer of tibial insertion
			Posterior medial capsule rupture
		Pelvis (left ring)	Anterior pelvic ring fracture composed of superior & inferior pubic ramus fractures
		Left arm	Abrasion on the forearm
		Head	Abrasion on the face
	HJ2	Left knee	Rupture of deep part of MCL, which is connected to the medial meniscus
			ACL - avulsion of femoral insertion
			MCL - avulsion of tibial insertion
		Pelvis (left ring)	Anterior pelvic ring fracture of inferior pubic ramus
			Anterior pelvic ring fracture of iliopubic eminance
		Left hand	Abrasion on the hand
		Left arm	Abrasion on the forearm
		Rib	Fracture of 5th and 6th rib at the medio clavicular line; 120 mm from the center line of the sternum, 130 mm from the center line of the sternum
		Head	Contusion
Mini-Van	HJ3	Left tibia	Tibia wedge fracture
		Left fibula	Fibula transverse fracture
			Fibula transverse fracture below fibula head
		Pelvis (left ring)	Anterior pelvic ring fracture composed of superior pubic ramus multi fragmented fracture & inferior pubic ramus fracture
		Rib	Fracture of 5th rib at the medio clavicular line; 122 mm from the center line of the sternum
		Head	Skull fracture with length of 15 mm in vertical direction
	HJ4	Right ankle	Elongation of calcaneofibular ligament
		Left knee	MCL - rupture of superficial layer
			MCL - avulsion of femoral insertion
		Rib	Fracture of 11th and 12th rib at the middle of scapula line
		Head	Skull fracture with length of 75 mm in vertical direction going to the skull base
Sedan	Y1	Left tibia	Metaphysial transversal fracture of left tibia (420 mm above ground)
			Diaphyseal transversal fracture of left tibia (290 mm above ground)
		Left fibula	Metaphysial transversal fracture of left fibula (410 mm above ground)
		Vertebra	Fracture L1 vertebra-body
		Head	Abrasion and haematoma temporal left
	Y2	Left knee	Subcutan haematoma left knee
			Avulsion of tibia collateral ligament left knee
			Elongation of postterior cruclate ligament left knee
		Vertebra	Fracture C6 vertebra-body
		Head	Contused-lacerated wound (~ 3cm length) temporal left
	Y3	Left tibia	Crush fracture left tibia (300 - 420 mm above ground)
		Left fibula	Metaphysial transversal fracture of left fibula (450 mm above ground)
		Left arm	Contused-lacerated would (~ 3cm) left elbow

COMPARISON OF ACCELERATION DATA

Comparison of acceleration between SUV and Mini-Van: Table 10 indicates the acceleration data of the test specimen HJ1 - HJ4. In the comparison of HJ1 with HJ2 in the case of collision with the SUV, the head of the HJ1 collided with the upper part of the hood due to its low height; the acceleration of the head of HJ1 is lower than that of HJ2. In the comparison of HJ3 with HJ4 in the case of collision with the Mini-Van, the accelerations of L5 and T6 of HJ3 are lower than those of HJ4. One reason for this difference can be considered that the BMD of HJ3 was much lower that that of other specimens and thus HJ3 had the tibia and fibula fractures; that is, the fractures of tibia and fibula reduced acceleration. Therefore, it is possible to consider that if HJ3 had not had these fractures, the acceleration of its lower limbs would have been similar to those of HJ1 and HJ2.

Finally, due to the collision with the hood leading edge, at L5 of HJ2, HJ3, and HJ4, the accelerations of 31 G - 57 G were generated. On the other hand, since the height of HJ3 was short, HJ3 collided with the grill of the Mini-Van, and the acceleration of 116 G was generated at its L5. One reason for this difference can be considered that the pelvis of HJ1 hit from a side direction, but the pelvis of HJ2 - HJ4 hit from an oblique direction. Therefore, it can be assumed that body height can affect on the test results.

Table 10 - Acceleration data of all the four experiments

PMHS body parts	Vehicle body parts impacted	SUV		Mini-Van	
		HJ1	HJ2	HJ3	HJ4
		BMD : 66 165 cm	BMD : 86 185 cm	BMD : 49 171 cm	BMD : 89 171 cm
Tibia	Bumper	194 G	225 G	83 G	NA
Femur		200 G	244 G	161 G	
L5	Bonnet leading edge	116 G (Grill)	31 G	38 G	57 G
T6		46 G	30 G	28 G	43 G
Head	(B) Bonnet top (P) Glass + in. panel (G) Glass	167 G HIC : 443 (B)	284 G HIC : 2228 (P)	297 G HIC : 1591 (G)	NA (P)

Comparison of acceleration with sedan: Table 11 indicates the HIC of Sedan, SUV, and Mini-Van, and Table 12 indicates the shapes of the front of the vehicles in this study and in our previous research with Sedans. In this section, the HIC and the head acceleration of the Sedan and SUV are compared (because only the HIC and the head acceleration of HJ3 in the case of Mini-Van were able to be obtained, these figures are mentioned here as reference).

The test specimen Y1 in the case of collision with a Sedan and the test specimen HJ1 in the case of SUV are both short (167 cm and 165 cm respectively) and their weights were both within the range of 60 kg to 69 kg. Thus it can be assumed that the height and the weight of Y1 are similar to those of HJ1. The head of Y1 is in contact with "Glass+ in. panel," whereas the head of HJ1 is in contact with "Glass." In the contact of Y1 with "Glass+ in. panel," it is estimated that its HIC became high because its head was thrust against the instrument panel with the top was in touch with the glass. Moreover, as for the location of the hood leading edge, the hood leading edge of a Sedan is lower than that of a

SUV. In fact, the difference of the height of reaches around 250 mm. The test specimen Y1 collided with the hood leading edge of the Sedan at the thigh, and the head revolved around the thigh. On the other hand, the test specimen HJ1 collided with the hood leading edge at the hips, and the head revolved around the hips. Therefore, it can be considered that the difference of the supporting points generated different accelerations on the heads of Y1 and HJ1.

Next, in comparison of the acceleration between specimens Y2 and HJ2, both of which are tall (around 180 cm) but the weight of HJ2 is heavier than that of Y2 by 22 kg, the head of Y2 is in contact with the "Glass", while the head of HJ2 is in contact with "Glass+ in. panel" (Glass and instrument panel). In the contact of HJ2 with “Glass+ in. panel”, the HIC of HJ2 can be esteemed higher than that of Y2 because its head is thrust against the instrument panel with the top was in touch with the glass. Moreover, as for the location of the hood leading edge, Y2 is in contact with the hood leading edge at its thigh, and its head revolves around the thigh. On the other hand, HJ2 is in contact with the hood leading edge at its hips, and its head revolves around the hips. In other words, the location of the supporting point of the tall specimen is not different from that of the short specimen. However, since the weight of HJ2 is heavier than that of Y2 by 22 kg, it is estimated that the head acceleration of HJ2 at the time of collision was higher than that of Y2 due to the fictitious force.

Table 11 - HIC and head acceleration

Vehicle type	Sedan		SUV		Mini-Van	
Test No.	Y1	Y2	HJ1	HJ2	HJ3	HJ4
PMHS hight (cm)	167	182	165	185	171	171
PMHS weight (kg)	68	63	60	85	80	61
HIC	1600	650	443	2228	1591	NA
Head acceleration (G)	134	71	167	284	297	NA

Table 12 - Shapes of the front of the vehicles

Vehicle		Sedan (Y1,Y2)	SUV (HJ1,HJ2)	Mini-Van (HJ3,HJ4)
Bumper hight (Top) [EEVC,1998]	(mm)	446	658	631
Bumper protrusion	(mm)	141	163	121
Hood leading edge [EEVC,1998]	(mm)	643	907	888
Hood length	(mm)	1110	861	493
Hood inclination	(degree)	10	9	14
Windshield inclination	(degree)	35	38	40

CONCLUSION

From this impact experiment of pedestrians using test specimens, whole-body behaviors of pedestrians in colliding with a SUV or a Mini-Van were identified. It was also determined that the type of injury is different between in the collision with a Sedan and in the collision with a SUV and Mini-Van.

The bone mineral density (BMD) of HJ1, HJ2, and HJ4 were 66, 86, and 89 respectively. In the collision with the bumper, all these three specimens had MCL-avulsion. On the other hand, The BMD of HJ3 was 49, and HJ3 had no MCL-avulsion, but it had tibia and fibula fractures. It can be considered that this is because the load on the collateral ligament was light due to the fractures of the tibia and the fibula.

In the case of head contact, since HJ1 is rather short with the height of 165 cm, this specimen collided with the upper part of the hood and its head had an abrasion. The head of HJ2, rather tall with the height of 185 cm, collided with the lower part of the windshield and had contusion. The head of HJ3 collided with the windshield, and its skull fractured, probably due to its low BMD (49). The head of HJ4 collided with the lowest edge of the windshield, and its skull fractured. Finally, the HIC of HJ1 was 443, which was much lower than that of HJ2 (2228). It can be considered that the reason of this low HIC of HJ1 is that the height of HJ1 is much lower than that of any other specimen and thereby the contact parts were different from that of other specimens.

For example, in the experiments in this study with SUV and Mini-Van, all the three specimens aged 80 or above (HJ1: 80, HJ2: 84, and HJ3: 80) had pelvic ring fractures, but it is known that in the case of pedestrian collision with a Sedan, no pelvic fracture have been identified. It can be assumed that one of the factors of this difference is the fact that the pelvis directly collided with the hood leading edge in the cases of SUV and Mini-Van. Another difference is that in the case of collision with a Sedan, L1 and C6 fractured, but such injuries did not happen in this study with SUV and Mini-Van.

However, it is possible that the type of injury and behavior vary according to the bone mineral density of the test specimen. Therefore, further more detailed research would be necessary.

REFERENCES

Cabinet office of Japan, White paper on traffic safety in Japan 2006, Government of Japan, p11, 2007.6.

J. Kerrigan, D. Subit, C. Unataroiu, J. Crandall, Pedestrian lower extremity response and injury: A small sedan vs. a large sport utility vehicle, Paper Number 2008-01-1245, Society of Automotive Engineers, Warrendale, PA.

G. Schroeder, A. Konosu, H. Ishikawa, J. Kajzer, Injury Mechanism of Pedestrians during a Front-End Collision with a Late Model Car, Forum of Pedestrian Safety in Japan, JSAE, 2000.

European Enhanced Vehicle Safety Committee, Improved test method to evaluate pedestrian protection afforded by passenger cars, EEVC Working Group 17 Report, 1998.

Working Party on Passive Safety (GRSP), Proposal for a global technical regulation on uniform provisions concerning the approval of vehicles with regard to their construction in order to improve the protection and mitigate the severity of Injuries to pedestrians and other vulnerable road users in the event of a collision, 2006.3.