INVESTIGATION OF REAR SEAT OCCUPANT POTENTIAL INJURY RISK BASE ON SEAT BELT CONFIGURATIONS

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Paper Number 15-0443

ABSTRACT

The occupants of all ages and sizes can be seated in the rear seats. But legal requirements regarding the qualification of the second seat row restraint system with anthropomorphic test devices (ATDs) currently do not exist. The protection of frontal seat passengers in both driver and front seated occupant has been more focused from the auto industries as well as regulatory bodies more than 40 years. Fortunately, their interests have been extended to rear seat occupants especially children and female occupants in recent years. However, the current available safety devices for the rear seat occupants are standard seat belt system only. Also, the majority of the rear seat occupant studies were focused to evaluate and protect child either CRS or using seat belt restrained in rear seat. The rear seat seemed to offer the greatest protection to children 0–12 years. Children seated in the rear seat had a lower risk of death compared with front seat passengers whether or not they were restrained. However, among adolescent and adult passengers, the rear seat offered less protection with increasing age and when restraints were used.

As a pilot project in Korea, total 452 accident cases have been collected and numbers of injured occupants (in patient) were 698. Drivers were 383 (54.9%), front passengers were 164, 2nd row left side seat were 47 (6.7%), 2nd row right side seat were 82 (11.6%), 2nd row middle seat were 15 (2.1%), and the remains are 3rd and 4th row seat occupants. Results from ISS injury severity analysis, the occupant of driver seating position has the highest ISS scores, 7.8±10.3, while front passenger (7.7±12.9), 2nd middle seat (6.3±7.7), 2nd left seat (6.1±9.3), 2nd right seat 6±11.7), 3rd left seat (6±0.0), 3rd middle seat (5±0.0), and 3rd left seat (2.8±1.7). Although the analysis was based on the limited numbers of data set, the safety of the rear seat adult occupants can't be ignored. Especially, the majority of rear seat potential occupants may be vulnerable occupants such as child, female with children, pregnant woman, and elderly.

In this study, the rear seat belts anchorage locations of the current domestic passenger vehicles were investigated to evaluate the influence of rear seat belt anchorage geometrical configurations in terms of the rear seat passenger safety. The sled type simulation models are developed with three point belts are fitted on the HybridⅢ 5th percentile dummy and HybridⅢ 50th percentile dummy. The injury value, particularly HIC15 and Chest deflection were examined to evaluate the contribution of rear seat belt anchorage locations.

INTRODUCTION

Accident statistics over the last decades have shown a continuous reduction of killed and severely injured in the road traffic accidents. Historically the driver and front seat occupant have been the highest priority because these positions are occupied most often and therefore account for the greatest numbers of casualties. The introduction of airbags, seat belts and other advanced safety systems in front seating positions, along with vehicle structural improvements, has led to a significant reduction in the number of casualties and fatalities among vehicle occupants. This development was driven forward by new legislative requirements and the introduction and continuous progress on worldwide consumer test programs like the Euro-NCAP. The user's consciousness on safety is continually increasing due to publications and public discussion of road safety issues. Car manufacturers, in cooperation with suppliers, have taken massive action in order to achieve a top rating in consumer tests. The equipment rate of active and passive elements is steadily increasing and allows predicting further positive effect on road safety for the future. In newer model vehicles, occupant protection is achieved through the utilisation of a 'system'; a combination of vehicle crush characteristics, enhanced seat and seat belt technologies, such as seat belt pretensioners and load limiters, and airbags. This has largely been a result of consumer and regulatory assessments evaluating the performance of the system, rather than regulating the presence of any single component. Since these assessment

programs evaluate the protection provided in the front seat only, there has been less motivation for vehicle manufacturers to develop and implement these technologies in the rear seat, and the extent to which such technologies are available in the rear seat is not documented. Less attention has been paid to the rear seat. It was due to the rear seat has been considered safer than the front seat. Recently, however, a number of recent studies have been conducted showing instances of lower levels of protection for rear seat occupants compared to front seat occupants in the frontal crash test.

On the rear seat, the occupants of all ages and sizes can be seated. But the legal requirements regarding the vehicle safety issues of the second seat row restraint system with anthropomorphic test devices (ATDs) currently do not exist. Only consumer tests such as EuroNCAP, JNCAP and C-NCAP with respect to rear occupant protection systems have been adopted as a part of safety performance evaluations. Several recent publications discuss the passenger safety of the second row. Kuppa et al. indicates higher mechanical loads on rear seat passengers during a crash and deduce a higher injury risk compared to drivers and passengers in the first row. Restraint components like inflatable cushions (airbags) in order to protect the head and thorax or the lower extremities as well as pyrotechnical pre-tensioners partly with multi-stage load limiters for belt retractors are standard equipment in the front seat row. The next generation of advanced restraints system for first row occupants is already under development. Individualized restraint systems, like those providing adaptive pressure control of the airbag pressure and multi-stage belt force limitation concepts, are pending market introduction. These systems enable tailored restraint performance depending on crash severity and occupant size. In contrast to this, a 3-point belt retractor without pretension and force limitation is still the standard for the back seat passengers.

Consumer protection organizations incorporated adult passengers on the rear seat in their frontal test programs. The Hybrid III ATD with the 5th percentile is already an element of a test configuration for China-NCAP and Japan-NCAP. Euro-NCAP has been announced a follow up in 2015.

From 2014 national survey of seat belt usages, the wearing rate of dirver and front passenger was 78%, but only 22% of rear occupant was belted. It is significant improved from 2011's 5% rate of the belted rear seat occupant. To further promote usage of rear seat belts, the traffic regulation for wearing all seated passenger is effected in 2015. According to the survey, the one of main reason for unbelted was inconvenience of fitting and geometrical diffculty of buckle-up in the rear seat.To protect the rear seated occupants, MLIT granted a research project as a part of ASV program. This research program is part of a project intended to understand the optimal rear seat environment for rear seated adults and old child passengers who use the vehicle belt for primary restraint. Therefore, the objectives of this study were development of test protocols for rear seat occupant protection in future KNCAP plan. The total domestic 39 passenger vehicles including SUVs of the second rows seat's belt-anchorage geometrical configuration are investigated and compared with the KMVSS 102 (similar to FMVSS 210) criteria. To estimate injury risk of rear seat occupant, the sled type frontal crash simulations has been conducted with 5th female H3 and 50th male H3 dummies based on KNCAP crash pulse.

ACCIDNT DATA ANALYSIS

A numerous researchers have been studied to focus on the relationships between the safety of the front and rear seat passengers. The most of these studies were limited to evaluate and protect child either CRS or adult seat belt restrained in rear seat. On the basis of the analysis of injuries of the road accident victims (injured and killed), it has been estimated that the risk of death of a rear seat passenger was smaller by 26–41% compared to a front seat one, even without the seat belts. On the average, the risk of death was 21% lower among passengers in the rear seat compared with front seat passengers. This apparent protection varied with age, restraint use, and airbag presence. The rear seat seemed to offer the greatest protection to children 0–12 years. Children seated in the rear seat had a lower risk of death compared with front seat passengers whether or not they were restrained. Among adolescent and adult passengers, the rear seat offered less protection with increasing age and when restraints were used. Restraints offered more protection to both front and rear seat passengers in vehicles with a front passenger airbag. In addition, restraints offered greater protection to front seat passengers compared with rear seat passengers.

Improving road safety, the first step in the process is identifying significant safety enhancement areas and the mechanisms of accidents and/or injuries that govern the problem. As a pilot project, total 452 accident cases have been collected from 3 different regional hospitals during last 11months period of traffic accident investigations. The sizes of 3 cities are from 210,000 to 450,000 populations which are typical medium size city. The total collected numbers of injured occupants (in patient) were 698. Drivers were 383 (54.9%), front passengers were 164, 2nd row left side seat were 47 (6.7%), 2nd row right side seat were 82 (11.6%), 2nd row middle seat were 15 (2.1%), and the remains are 3rd and 4th row seat occupants. Results from ISS injury severity analysis, the occupant of driver seating position has the highest ISS scores, 7.8±10.3, while front passenger (7.7±12.9), 2nd middle seat (6.3±7.7), 2nd left

seat (6.1±9.3), 2nd right seat 6±11.7), 3rd left seat (6±0.0), 3rd middle seat (5±0.0), and 3rd left seat (2.8±1.7) as shown in Table 1. In this analysis, un-belted occupants were not discriminated. Although the analysis was based on the limited data set, safety of the rear seat occupants can't be ignored. Therefore, the safety of rear seat occupant is equally important and must be seriously considered in terms of overall vehicle safety concepts from all related stock holders such as government body, auto makers, insurance agencies, and NGO. Especially, the majority of rear seat potential occupant may be vulnerable occupants such as child, female with children, pregnant woman, and elderly.

Table 1 ISS injury severity by the different occupant seating positions

(n, %)/Seating position	Driver	F. Pass	2nd row Left	2nd row Right	2nd row Middle	3rd row Left	3rd row Right	3rd row Middle	4th row Left
Total (698, 100)	383 (54.9)	164 (23.5)	47 (6.7)	81 (11.6)	15 (2.1)	1 (0.1)	4 (0.6)	1 (0.1)	2 (0.3)
ISS (mean±std)	7.8 ±10.3	7.7 ±12.9	6 ±11.7	6.1 ±9.3	6.3 ±7.7	6 ±0.0	2.8 ±1.7	5 ±0.0	1.5 ±0.7
ISS (median)	4	3	3	2	5	11	-	-	-
ISS (interquartile range)	2-9.8	2-12.3	2-10.3	1-3	2-11	3-22.8	-	-	-

LEGAL REQUIREMENTS FOR REAR SEAT BELT ANCHORAGES

Recent work at the University of Michigan Transportation Research Institute (UMTRI) has demonstrated that belt anchorage locations have a strong effect on occupant kinematics. More-rearward or higher lower anchorages (flatter lap belt angles) tend to reduce lower-body excursion, except when submarining occurs due to the belt slipping off the pelvis and into the abdomen. More-forward and higher upper anchorage locations tend to increase head excursion, except when submarining occurs.

In Korea, the locations of the anchorages of seat belt systems are regulated by Korea Motor Vehicle Safety Standard (KMVSS) 102 which is similar to FMVSS 210. Anchorage locations are referenced to the seating reference point (SgRP), which is measured using the SAE J826 H-point manikin. Lap belt anchorages must be positioned such that a vector from the anchorage to the SgRP in side view forms an angle of between 30 and 75 degrees with the horizontal. Upper anchorages must be located within a side-view zone defined with respect to the SAE J826 two-dimensional template with the template H-point aligned with the SgRP.

SHOULDER BELT ANCHORAGES:

SEAT	SEATING POSITION	SPECIFIED ANGLE RANGE ABOVE OR BELOW HORIZONTAL	MEASURED ANGLE
FRONT	Left	0 - 80 degrees above	
		0 - 40 degrees below	
	Right	0 - 80 degrees above	
		0 - 40 degrees below	
REAR	Left	0 - 80 degrees above	
		0 - 40 degrees below	
	Right	0 - 80 degrees above	
		0 - 40 degrees below	

LAP BELT ANCHORAGES:

SEAT	SEATING POSITION	SPECIFIED ANGLE RANGE ABOVE HORIZONTAL	MEASURED ANGLE		DOES BELT SECURELY FIT ON PELVIS?
			I/B	O/B	
FRONT	Left	30 to 75 degrees			
	Center	30 to 75 degrees			
	Right	30 to 75 degrees			
REAR	Left	30 to 75 degrees			
	Center	30 to 75 degrees			
	Right	30 to 75 degrees			
THIRD	Left	30 to 75 degrees			
	Center	30 to 75 degrees			
	Right	30 to 75 degrees			
SIDE FACING	Left Side	30 to 75 degrees			
	Right Side	30 to 75 degrees			

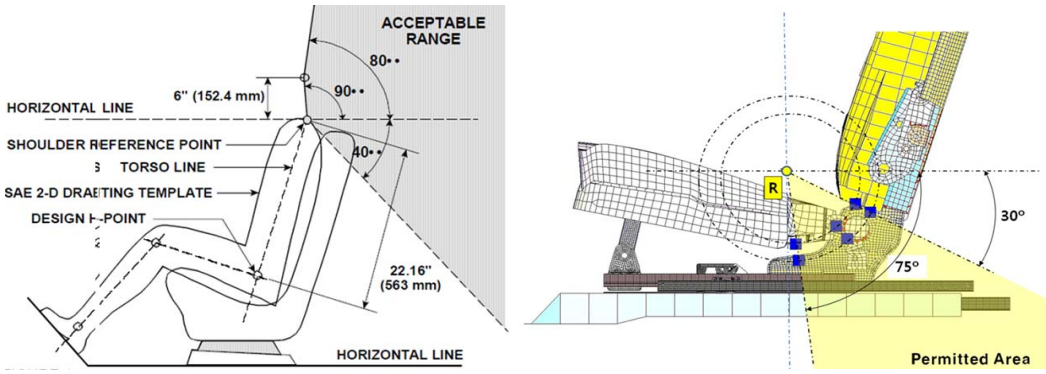

Fig. 1 KMVSS 102 requirements for rear seat belt anchorage points

SIMULATION MODEL FOR REAR SEAT OCCUPANT

To assess safety of rear seat occupants, sled type simulation was conducted with calculated average value of 2010 - 2012 KNCAP 33 tested vehicles crash pulses to normalize crash severity as shown in Fig 4. The physical rear seat of each vehicle was manufactured differently due to different vehicle configuration as well as characteristic of vehicle model.

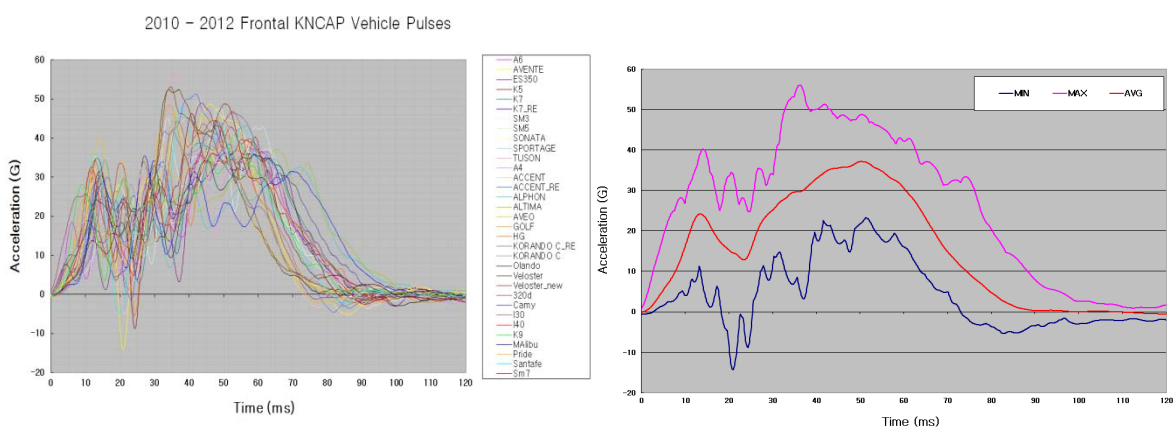

Fig. 4 Vehicle pulses of 2010-2012 KNCAP test and average pulse

In this simulation, the rear seat was modeled according to UN R44 as a standard seat model in order to eliminate seat variation, only focus to observe influence of seat belt anchorage configurations. The standard rear seat and polyurethane foam were modeled as shown in Fig 5. The webbing of seat belt was modeled as having 7% elongation material property. The pre-tensioner and load limiter of rear seat belt were not available for most of current production vehicle. These devices were not modeled.

Also, in the simulation model, to examine kinematics of occupants and injury levels of the different types of dummies during the crash event, the front seat was modeled as shown in Fig 6. Injuries of 5th H3 and 50th H3 dummies were compared with different seat belt anchorage locations.

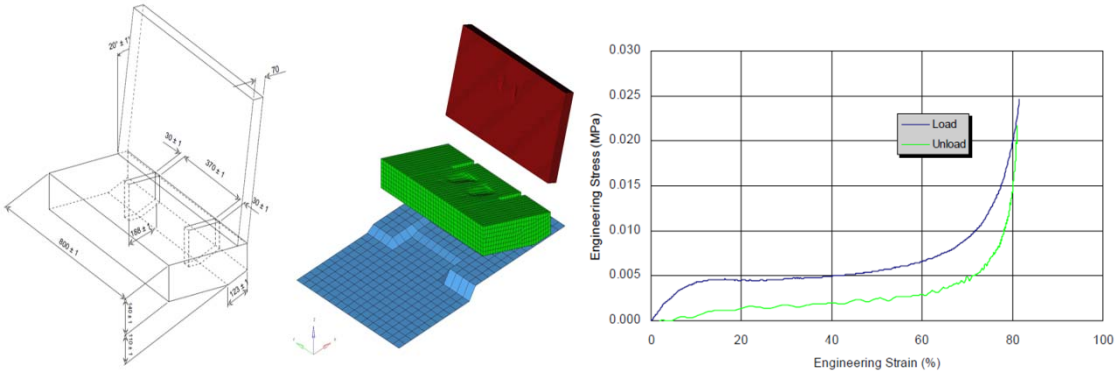

Fig. 5 Standard rear seat model and seat cushion characteristics

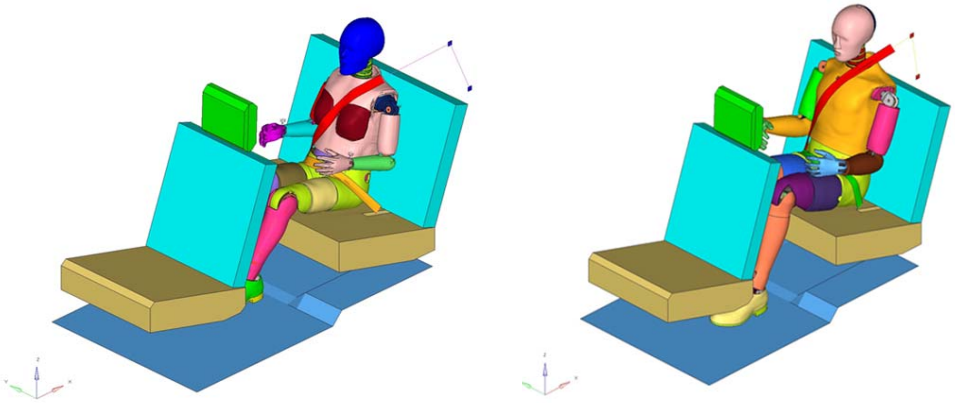

Fig. 6 Rear seat frontal impact simulation model for 5%tile and 50%tile dummies

RESULTS

In this study, the total 39 passenger vehicles (sedan and SUV) from the 5 domestic car manufactures were examined. These vehicles were consisted in 3 sub-compacts, 3 compacts, 11 mediums, 9 large vehicles, and 12 SUV vehicles. In geometric data collection process, the coordinate of upper and lower anchorages were calculated from CAD data without any physical measurements due to availability of all vehicles. Fig. 1 shows the current KMVSS 102 requirements for the rear seat belt anchorages.

Table 2 and Fig 2 and 3 show the calculated seat belt anchorage locations relative to SgRP according to KMVSS 102 allowable zones. The red dots were average locations of examined vehicles. The lower anchorage locations scattered the entire allowable range of side-view angles. Upper anchorage locations also spanned a wide range, reflecting the wide variety of upper belt anchorage configurations, including those mounted in the C-pillar, package shelf, and integrated into the seat. But, the distributions of Z directional range were relatedly narrowed due to accommodate from 5th H3 to 95th H3 dummies. Inboard, buckle-side lower anchorages had slightly steeper (higher) lap belt angles, and the inboard anchorage was generally closer to the occupant centerline than the outboard anchorage. Since the distributions of all 39 vehicle's anchorages location were calculated only based on the CAD geometric data, it is not intended to verify fulfillment of requirements of regulation for out-ranged vehicle's anchorage locations.

Table 2 Relative coordinates of rear seat belt anchorage points (reference point: SgRP in mm)

	vehicle Type	D-ring Coordinate			Lower Outboard			Lower Inboard			Seat Angle
		X	Y	Z	X	Y	Z	X	Y	Z	
01	Small	-679.4	-216.5	471.1	-48.3	-354.4	-156.2	-122.4	177.3	-142.6	27

02	Medium	-675.9	-206.4	509.3	-64.1	-263.1	-174.8	-157.5	170.0	-135.5	25
03	Large	-675.9	-206.4	509.3	-64.1	-263.1	-174.8	-171.3	195.5	-125.1	28
04	SUV	-251.3	-276.0	654.8	-132.1	-338.0	-173.9	-210.5	159.5	-222.5	25
05	Mini	-442.1	-275.3	549.3	-52.5	-300.5	-92.8	-117.6	141.5	-147.8	26
06	Compact	-504.7	-293.2	599.0	-101.7	-221.3	-146.9	-75.3	162.0	-157.1	25
07	Small	-539.0	-230.0	519.0	-62.0	-336.5	-141.9	-137.0	200.4	-129.3	27
08	Medium	-450.7	-255.5	471.8	-50.0	-340.3	-125.0	-129.5	125.3	-143.8	27
09	Large	-460.6	-225.4	452.8	-60.0	-310.3	-144.0	-139.5	155.3	-162.8	25
10	SUV	-412.4	-312.3	580.5	-249.9	-318.0	-230.2	-196.3	181.4	-160.9	25
11	SUV	-306.6	-304.2	638.2	-109.3	-270.4	-217.2	-196.3	181.4	-162.8	25
12	SUV	-482.3	-296.6	567.4	-85.7	-254.5	-184.2	-84.4	183.3	-204.6	25
13	Large	-520.4	-309.6	592.3	-127.6	-308.7	-135.7	-105.5	233.6	-112.4	27
14	Large	-382.4	-261.5	561.1	-2.5	-275.0	-147.3	-53.3	208.4	-202.3	27
15	SUV	-444.1	-192.8	542.6	-375.0	-236.6	-287.4	-67.0	191.4	-118.2	15
16	SUV	-393.4	-265.1	618.4	-130.3	-315.0	-62.3	-82.2	240.9	-97.1	15
17	SUV	-405.9	-271.4	615.6	-47.4	-331.0	-133.1	-138.9	120.0	-202.9	15
18	Compact	-392.5	-201.0	577.5	-103.5	-250.2	-106.4	-127.1	156.0	-114.1	26
19	Small	-522.7	-243.0	496.9	-72.7	-286.5	-72.7	-128.5	187.4	-87.4	26
20	Small	-471.5	-271.1	501.6	-86.7	-275.1	-112.2	-152.1	152.9	-125.6	26
21	Small	-419.5	-212.8	541.1	-112.4	-275.1	-87.1	-150.9	184.0	-116.0	27
22	Medium	-410.0	-226.0	545.0	-54.5	-368.2	-112.8	-51.7	130.1	-154.3	27
23	Medium	-457.2	-279.5	524.3	-98.8	-355.8	-107.7	-124.9	201.2	-135.3	26
24	Large	-413.4	-220.4	538.6	-66.6	-359.2	-107.9	-63.6	139.5	-152.0	27
25	Large	-438.7	-210.7	534.4	-49.2	-256.7	-78.5	-70.1	215.2	-109.7	26
26	Large	-494.1	-195.0	540.3	-88.5	-256.1	-89.9	-108.2	219.5	-126.2	27
27	SUV	-261.7	-263.7	631.1	-88.7	-254.4	-146.6	-53.5	171.9	-145.0	25
28	SUV	-221.7	-263.7	631.1	-48.7	-254.4	-146.6	-13.5	171.9	-145.0	25
29	SUV	-246.8	-256.9	633.6	-130.9	-197.9	-170.0	-142.5	171.4	-157.3	23
30	Mini	-332.7	-249.8	584.5	-78.0	-215.0	-118.7	-139.8	108.7	-110.9	24.5
31	Mini	-350.8	-267.8	598.5	-198.0	-207.0	-119.0	-70.4	186.8	-119.7	21
32	Compact	-409.2	-234.2	625.0	-105.5	-249.3	-97.4	-94.2	164.1	-135.7	26
33	Small	-443.3	-208.2	561.6	-108.3	-272.6	-87.1	-157.1	185.1	-124.3	27
34	Medium	-415.7	-226.6	537.7	-56.8	-363.0	-111.4	-51.7	130.2	-153.4	27
35	Large	-436.2	-220.2	543.8	-61.6	-359.2	-107.9	-58.7	139.7	-151.4	27
36	Large	-436.7	-195.0	533.0	-59.6	-242.5	-88.3	-80.0	225.5	-116.6	27
37	SUV	-315.4	-270.2	618.0	-94.9	-255.7	-168.6	-84.7	187.6	-162.8	25
38	SUV	-353.0	-244.4	607.4	-157.4	-298.8	-187.5	-93.0	183.0	-88.8	23
39	SUV	-410.7	-252.4	612.8	-130.9	-197.9	-170.0	-142.5	171.4	-157.3	23

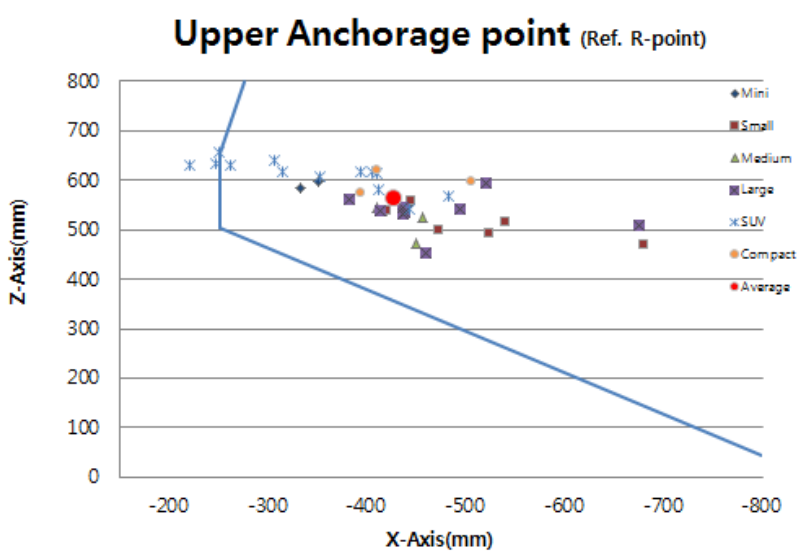

Fig. 2 Side views (y direction) of rear seat belt upper anchorage locations

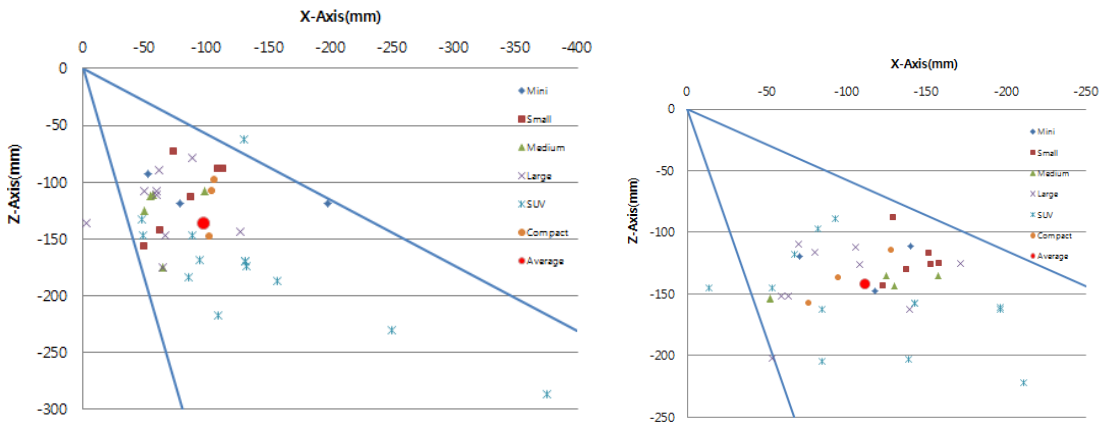

Fig. 3 Side views (y direction) of rear seat belt lower outboard and inboard anchorage locations

DISCUSSIONS

Geometrical distribution of seat belt anchorages

Normally, the belt geometry in rear seats is less favorable than in front seats. This is due on the one hand to vehicle geometry, which does not permit optimal belt-anchoring points, for example, the rear wheel house restricts the possibilities of fastening the anchor fitting. On the other hand, the rear seat running all the way through results in restrictions in fastening buckles. The seat position of the occupant in the rear seat is also different from in the front seat. Due to the restricted foot space extending to the front seat, the knees bend further causing the pelvis to tilt further backwards. The geometry of belts and the seat position result in the angle between the lap belt and the pelvis normally becoming comparatively small. As a consequence, the risk in a head-on collision of the lap belt slipping over the wings of ilium is evident, i.e., submarining can occur. The upper fastening point of the shoulder belt, which has frequently been positioned far to the rear, also promotes submarining.

In this study, the second-row belt anchorage locations for 39 domestic passenger vehicles using CAD geometric data were examined. The results indicate that seat belt anchorage locations in second rows vary widely. The range of upper anchorage locations were relatively widely spread in X direction compared with Y and Z directions as shown in Fig 7. In Z direction, the most of SUV type vehicles were in higher location of upper anchorage points. Due to absence of separated trunk wall in SUVs, the upper anchorage points were attached to the C-pillar. In general, upper anchorage locations may affect the risk of torso rollout in frontal crashes and also can contribute to discomfort due to contact between the belt and the occupant's neck if the anchorage is too high or too far from inboard. The fore-aft location of the anchorage can also affect head excursion and chest loading in frontal crashes.

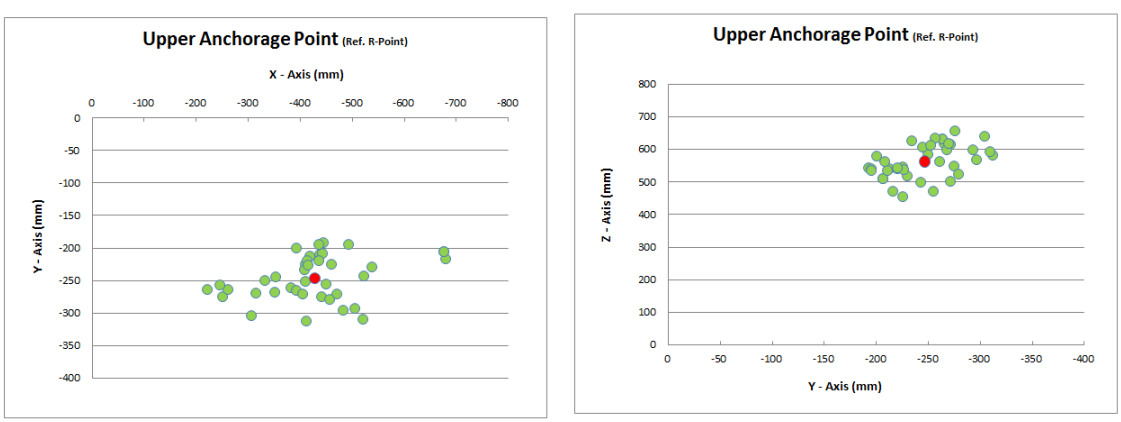

Fig. 7 Distribution of upper anchorage points in y-x and z-y planes

Fig 8 shows the range of lower anchorages, which spans the allowable range, is of particular concern for belt performance in frontal impact. In general, flatter belt angles are associated with better pelvis restraint but a higher likelihood of submarining, although submarining is influenced by many other factors. Steeper lap belt angles are needed to prevent submarining for smaller occupants, particularly children seated on vehicle seats with long seat cushions that produce slouched postures.

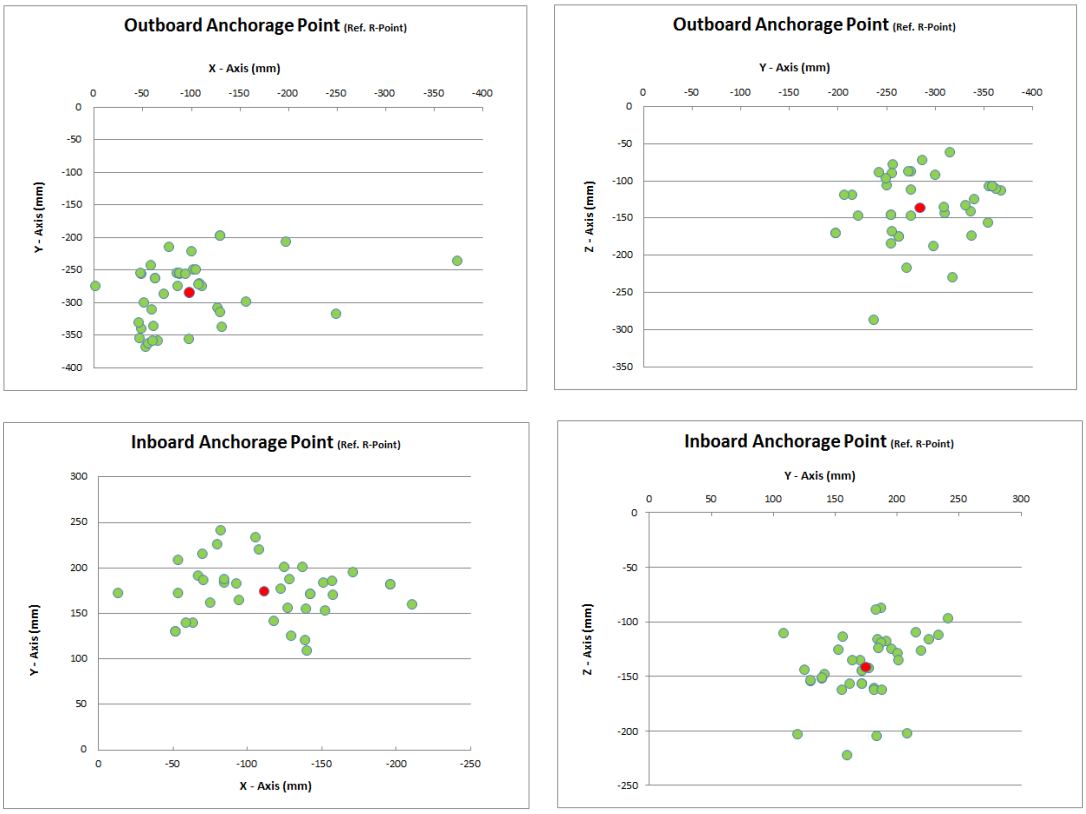

Fig. 8 Distribution of lower anchorages points in x-y and z-y planes

Dummy seating position with different seat belt fitting

As shown in Fig. 9 and 10, the seated position of 5%tile and 50%tile dummies were based on case 28 configuration which is foremost X direction of upper anchorage. The shoulder belt can't hold firmly upper torso of female dummy compared with same upper anchorage for 50%tile male dummy.

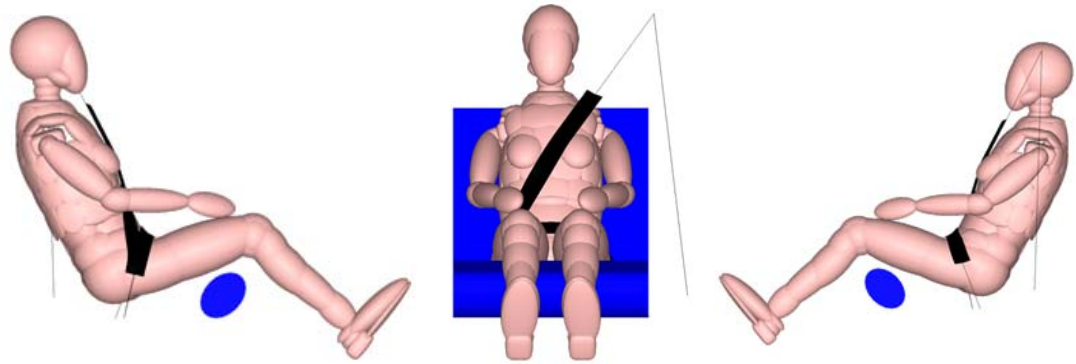

Fig. 9 5%tile female dummy Seated configuration of case 28

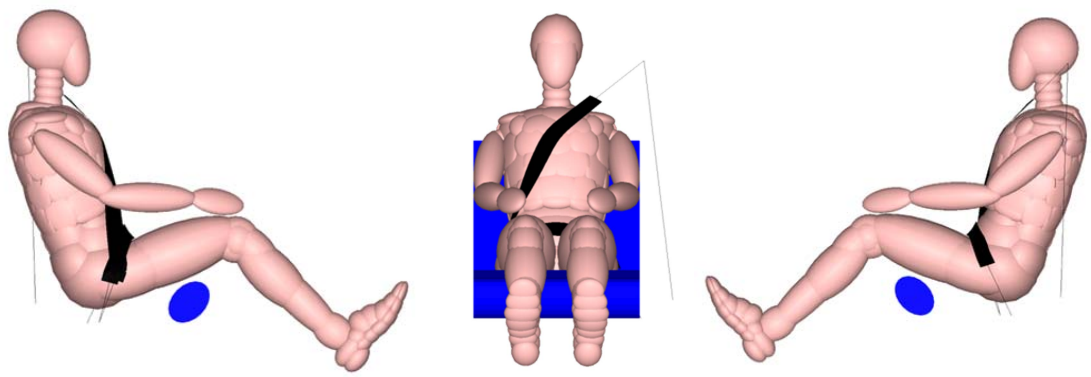

Fig. 10 50%tile male dummy Seated configuration of case 28

Injury assessment for rear seat belt anchorage location

Results from the sled simulation, injury values reveal that the most dominate factor is x directional location of upper anchorage point both in 5th H3 and 50th as shown in Table 3, Fig. 9 and 10. The more rearward locates upper anchorage point shows the less HIC values. Since regulation required at least suitable for 5th female dummy, less affecting coordinate in HIC is z directional point. For the chest deflection, also x coordinate of upper anchorage is influencing factor.

Table 3 Injury assessment for different rear seat belt anchorage points

	Type	Hybrid Ⅲ 5%tile Female Dummy					Hybrid Ⅲ 50%tile Male Dummy				
		Head	Chest	Neck			Head	Chest	Neck		
		HIC_{15}	Deflection (mm)	Tension (kN)	Compression (kN)	N_{ij}	HIC_{15}	Deflection (mm)	Tension (kN)	Compression (kN)	N_{ij}
01	Small	600.8	35.5	2.8	1.6	1.2	694.6	22.4	3.1	2.6	0.7
02	Medium	607.9	35.8	2.6	1.6	1.2	748.3	30.2	3.6	2.6	0.8
03	Large	556.4	39.8	2.4	1.6	1.1	725.2	51.5	2.9	2.6	0.7
04	SUV	1132.0	44.4	3.1	1.4	1.3	1358.6	44.4	4.4	2.2	1.0
05	Mini	987.4	40.4	2.7	1.7	1.5	1060.7	58.5	3.6	2.8	0.8
06	Compact	988.8	46.1	3.1	1.6	1.0	1061.8	53.0	3.5	2.4	0.9
07	Small	511.3	39.1	2.5	1.5	1.1	861.4	59.1	3.4	2.6	0.8
08	Medium	709.3	54.2	2.6	1.7	1.0	1029.9	64.7	3.4	2.4	0.9
09	Large	724.0	42.9	2.5	1.5	1.2	924.2	55.1	3.5	2.8	0.8
10	SUV	931.3	54.7	2.8	1.6	1.2	981.1	52.3	3.4	2.7	0.8
11	SUV	991.4	56.1	2.9	1.4	1.1	1167.4	64.6	3.7	2.5	0.8
12	SUV	823.8	53.0	2.4	1.4	1.1	836.0	50.7	3.0	2.4	0.9
13	Large	932.1	47.0	2.7	1.7	1.3	929.9	44.7	3.3	2.7	0.8
14	Large	933.4	53.5	2.9	1.5	1.2	924.5	53.7	3.1	2.5	0.8
15	SUV	737.7	40.6	2.4	1.6	1.2	907.0	45.3	3.2	2.6	0.9
16	SUV	916.9	46.4	2.7	1.5	1.5	975.6	45.5	3.4	2.6	0.7
17	SUV	1082.5	52.9	3.0	1.6	1.4	1090.2	63.6	3.7	2.7	0.8
18	Compact	687.7	37.7	2.5	1.4	1.3	898.6	56.6	3.3	2.6	0.8
19	Small	527.8	47.3	2.5	1.7	1.2	756.5	47.1	3.6	2.6	0.8
20	Small	765.6	43.8	2.6	1.6	1.4	921.0	57.2	3.5	2.6	0.9
21	Small	783.6	44.9	2.5	1.7	1.2	811.5	52.2	3.2	2.5	0.8
22	Medium	1023.0	51.5	2.7	1.7	1.3	1097.4	64.1	3.6	2.4	0.8
23	Medium	667.0	52.3	2.4	1.6	1.0	927.7	51.8	3.3	2.6	0.9
24	Large	966.6	51.0	2.8	1.6	1.3	966.5	62.0	3.6	2.5	0.9
25	Large	644.1	43.2	2.5	1.5	1.3	809.0	45.5	3.1	2.6	0.7
26	Large	524.2	38.8	2.3	1.4	1.0	728.2	43.8	2.9	2.6	0.7
27	SUV	1162.4	53.8	3.3	1.5	1.2	1171.8	52.7	3.6	2.3	0.9
28	SUV	1204.5	56.6	3.2	1.4	1.0	1156.4	65.1	3.6	2.3	0.9
29	SUV	1176.8	52.1	3.1	1.5	1.2	1218.5	48.6	3.8	2.5	0.9
30	Mini	1087.8	49.2	3.1	1.6	1.5	1065.7	61.9	3.7	2.4	0.9

31	Mini	947.3	53.6	2.7	1.4	1.1	1144.5	48.9	3.7	2.6	0.8
32	Compact	1015.2	46.6	2.9	1.6	1.4	1027.8	50.6	3.5	2.6	0.8
33	Small	706.0	41.4	2.5	1.7	1.2	706.0	41.4	3.2	2.7	0.8
34	Medium	929.6	55.2	2.6	1.8	1.0	1081.9	60.8	3.5	2.5	0.8
35	Large	991.5	49.7	2.7	1.7	1.3	1072.1	60.1	3.6	2.6	0.8
36	Large	628.5	42.1	2.3	1.5	1.1	772.3	43.5	3.0	2.6	0.8
37	SUV	1005.6	52.0	3.2	1.4	1.2	1144.1	50.1	3.6	2.5	0.9
38	SUV	880.7	47.8	2.8	1.5	1.3	957.1	52.0	3.3	2.6	0.8
39	SUV	952.5	44.7	2.9	1.6	1.3	969.2	57.7	3.4	2.5	0.8

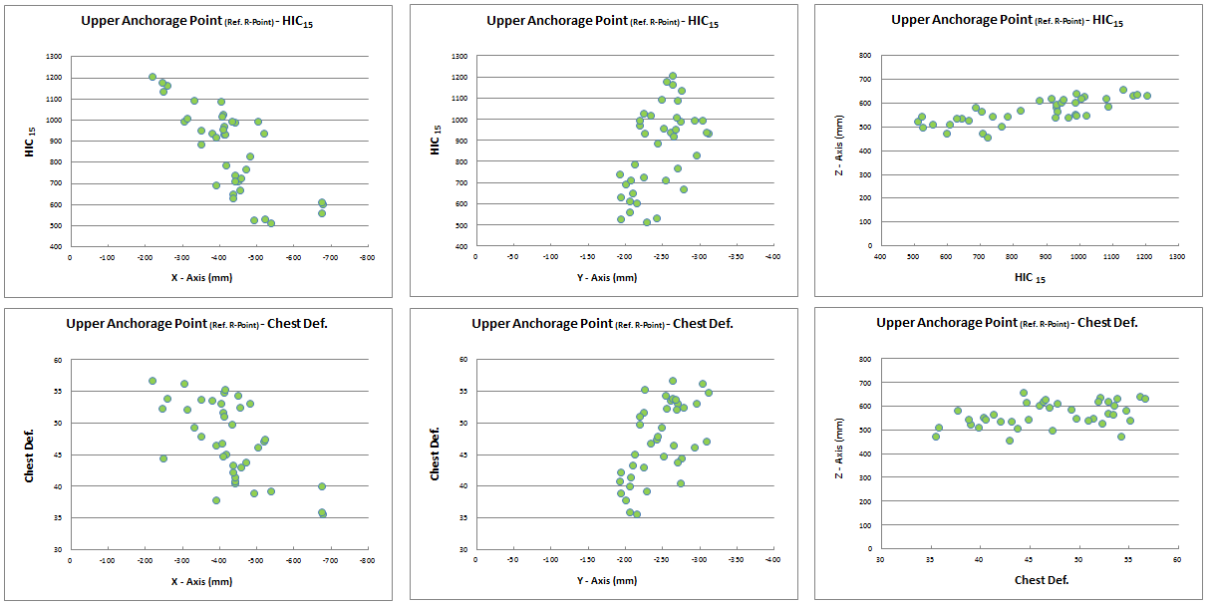

Fig.9 Injury severity of 5%tile female dummy based on distribution of upper anchorage locations

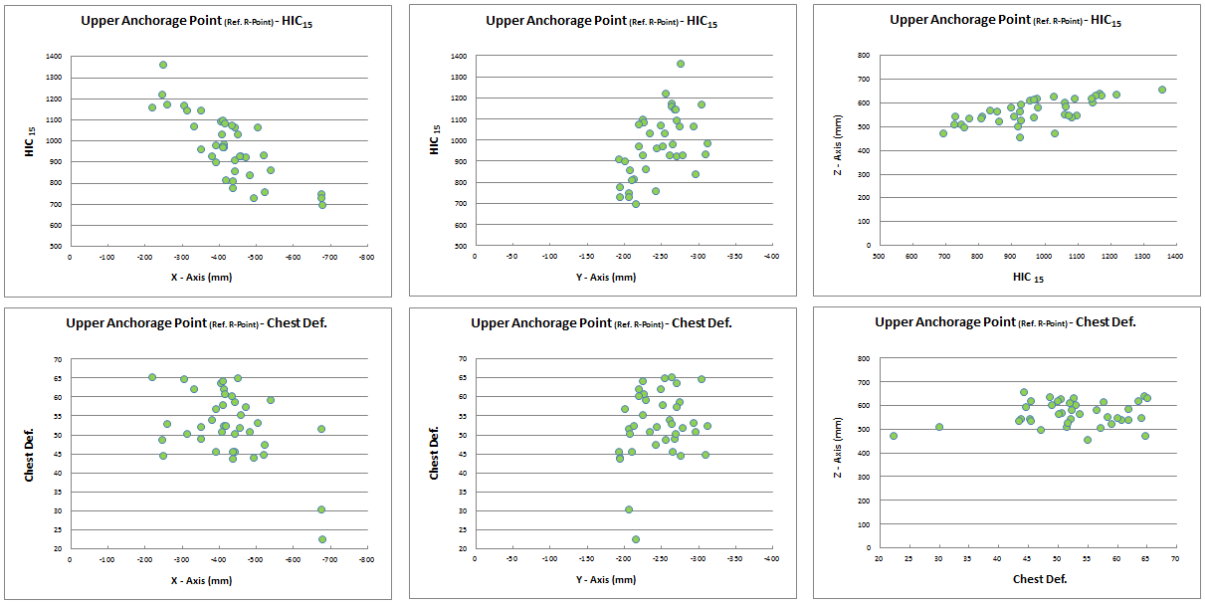

Fig. 10 Injury severity of 50%tile male dummy based on distribution of upper anchorage locations

CONCLUSIONS

A significant increase has been observed in the number of installed restraint technologies available to front seat occupants as compared to rear seat technologies over the last couple of decades. With current research suggesting that the front seat is becoming relatively more effective at mitigating injuries [6-9], there is scope to improve the rear seat occupant protection system. The implementation of already available supplemental restraints available in the front seat and/or novel technologies, are potentially effective methods of improving safety in the rear seat.

In this study, the second-row belt anchorage geometric data were examined. Based on the geometric locations of rear seat belt anchorage, a standard frontal impact simulation was conducted to assess the influence of these belt anchorage points in rear seat occupant between 5%tile female H3 dummy and 50%tile H3 male dummy. From results from geometric calculation, the rear seat belt anchorages were widely scattered especially in X directional upper anchorage point. Some of vehicles were even out ranges of regulation requirements. The results indicate that seat belt anchorage locations in second rows vary widely. The range of upper anchorage locations were relatively wider spread in x direction compared with y and z directions. In injury assessments, the upper anchorage point strongly influences the motion of upper body. Results from the sled simulations, injury values reveal that the most dominate factor for HIC is x directional location of upper anchorage point both in 5th H3 and 50th. The more rearward location of upper anchorage point shows the lower HIC values. Since regulation required at least suitable for 5th female dummy, less affecting coordinate in HIC is z directional point. For the chest deflection, also x coordinate of upper anchorage is influencing factor.

ACKNOWLEDGEMENTS

This research has been supported by a grant from MLIT and KAIA(11PTSI-C54118-03) of Korean government

REFERENCES

[1] Schönebeck S., Schepers A., Pöppel-Decker M., Leipnitz C., Fitschen A. Voraussichtliche Entwicklung von Unfallanzahlen und Jahresfahrleistungen in Deutschland, Ergebnisse 2011 Bundesanstalt für Straßenwesen

[2] Kuppa S., Saunders J., Fessahaie O. Rear Seat Occupant Protection in Frontal Crashes International Technical Conference of the Enhanced Safety of Vehicles, 2005

[3] Forman J., Michelson J., Kent R.; Kuppa S., Bostrom O. Occupant Restraint in the Rear Seat: ATD Responses to Standard and Pre-Tensioning, Force –Limiting Belt Restraints 52nd AAAM Conference, 2008

[4] Stegmeier M., Bausch H. Rear Seat Protection for Occupants Sizes from Q6 to HIII 95%ile in Frontal Crashes 9th International Conference Protection of Children in Cars, 2011

[5] Klinich, K.D., Reed, M.P., Orton, N.R., Manary, M.A., and Rupp, J.D. (2011). Optimizing Protection for Rear Seat Occupants: Assessing Booster Performance with Realistic Belt Geometry using the Hybrid-III 6YO ATD. Technical Report 2011-40. University of Michigan Transportation Research Institute, Ann Arbor, MI.

[6] Website China-NCAP http://www.c-ncap.org.cn/C-NCAP/index.htm

[7] Website Japan-NCAP http://www.nasva.go.jp/mamoru/en/index.html

[8] Website EuroNCAP http://www.euroncap.com/home.aspx

[9] Smith, K. M., Cummings, P., Passenger seating position and the risk of passenger death in traffic crashes: a matched cohort study, Injury Prevention No. 12, pp. 83–86, USA 2006

[10] R. Kent*, et al.*, "The feasibility and effectiveness of belt pretensioning and load limiting for adults in the rear seat," *International Journal of Vehicle Safety,* vol. 2, pp. 378-403, 2007.

[11] Klinich, K.D., Reed, M.P., Orton, N.R., Manary, M.A., and Rupp, J.D. (2011). Optimizing Protection for Rear Seat Occupants: Assessing Booster Performance with Realistic Belt Geometry using the Hybrid-III 6YO ATD. Technical Report 2011-40. University of Michigan Transportation Research Institute, Ann Arbor, MI.