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Implementation of WorldSID and AE-MDB to Side Crash Tests for the Occupant Protections in KNCAP

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Abstract:

Background**:** In Korea, the side impact type traffic accident is one of the major sever accidents in terms of numbers of accidents and fatality. Since 2003, 50kph 90 degree side crash test has been initiated as a safety regulation with ES-1 at the first stage and also same time 55 kph impact speed test has been conducted as a part of KNCAP program. Currently only ES2 is accepted as a regulatory tool for vehicle certification and KNCAP.

Objective**:** The occupants in passenger cars are more likely to sustain severe injuries when the striking vehicle is a pickup truck or sport utility vehicle (SUV) than in a passenger car-to-car crash. In side impact collisions with vehicle mismatch, this study has examined injury outcomes for each vehicle. Whereas a majority of the light truck vehicles (LTV) occupants sustained no injury or minor injury, the most of the passenger car occupants sustained major or fatal injuries.

Method and Material**:** In this study, the influences of MDB barrier face characteristics, mass of MDB, impact speeds and dummies were examined to further enhancing KNCAP to better protect occupants of passenger cars. The series of crash tests were conducted to assess the effects of theses variables with helps of computer simulations.

Results**:** Increasing the weight of MDB, the safety of smaller passenger cars may be affected. Larger passenger cars did not shown in degradation of injury risks due to compatible with the increased of MDB weights. The higher impact speed increased injury values in both two dummies. But the difference is not significant for WS50 dummy. For the 50 kph case, the maximum rib deflection was 23.46 mm at the upper rib. Increasing impact speed to 55 kph, the maximum rib deflection is increased 19.6%, 28.06 mm.

Conclusions: Side impact accident is one of the most frequent and highest fatality cause traffic accidents. It is due that the most road traffic accident occurs in the city areas near the intersection. From the new technologies such as forward collision warning system, AEBS devices can prevent or mitigate frontal crash type accident. However, the elder driver and female driver or passengers are vulnerable against side impacts. It is time to consider the safety of far side occupants from the side crash accidents as well as near side vulnerable drivers such as elderly driver or small size females.

Keywords: AE-MDB, WorldSID, Side Impact, Injury Risks, Simulations

1 Introduction

Side impacts protections have always been somewhat of an engineering design challenge in terms of provision of good protection to vehicle occupants as well as government regulatory bodies to establish good countermeasures from the real world side collision accidents. In the main, this is because there is generally so little space between the occupant and the striking object which gives little scope for providing crash energy management unlike the situation in frontal impacts. Therefore in many cases, the occupants can be subjected to a very severe impact to the side of the vehicle. The seat belt can offer only reduced protective benefits compared to frontal impacts simply because of the lack of ride-down space.

Occupants can also slip easily out of the seat belt in side impacts. Additionally, because of the seated position of the occupants, there is potential for ejection of the head through the side window aperture and consequent exterior head contacts or with the front passenger occupants.

Furthermore, occupants in passenger cars are more likely to sustain severe injuries when the striking vehicle is a pickup truck or sport utility vehicle (SUV) than in a car-to-car crash. In side impact collisions with vehicle mismatch, this study has examined injury outcomes for each vehicle. Whereas a majority of the light truck vehicles (LTV) occupants sustained no injury or minor injury, the most of the passenger car occupants sustained major or fatal injuries.

Near-side occupants are at higher risk than far-side occupants and account for more than 70 percent of all side impact injuries [1]. The risk of severe or fatal injuries is more than twice as high for a near-side occupant than for a far-side. Recently, occupant-to-occupant interaction has been identified as a risk factor. It has shown that a driver with a front seat passenger present has a higher risk than a driver without a passenger. It is also known from previous studies that both age and gender influence the risk of being fatally injured in a car crash [2]. In particular, age and fatality risk are strongly correlated with each other [3][4]. In side impact crashes senior drivers are more than three times as likely as non-senior to be severely injured. Sunnevång et al [5] have shown that senior drivers are killed at lower crash severity than non-senior in side impact. Furthermore, it is well known that senior drivers are overrepresented in intersection.

In Korea, the side impact type traffic accident is one of the major sever accidents in terms of numbers of accidents and fatality. Since 2003, 50kph 90 degree side crash test has been initiated as a safety regulation with ES-1 at the first stage and also same time 55 kph impact speed test has been conducted as a part of KNCAP program. Currently only ES2 is accepted as a regulatory tool for vehicle certification and KNCAP. In 2009, for further enhancing the protection of side collision, the perpendicular 29 kph pole side impact test with ES-2 dummy has been introduced as an optional test in KNCAP. The main objective of the optional pole side impact test was to promote installation of side curtain airbag in the vehicle fleet as a standard option.

In this study, the influences of MDB barrier face characteristics, mass of MDB, impact speeds and WorldSID and ES-2 dummies were examined to further enhancing KNCAP to better protect occupants of passenger cars. The series of crash tests were conducted to assess the effects of theses variables with helps of computer simulations.

2 Global side impact protection activities

The worldwide activities to improve passive safety in side impacts were started in the 1980’s with research work at the NHTSA. A static side intrusion test was developed. This became the FMVSS 214. In 1990 FMVSS 214 was extended to include the dynamic crabbed barrier test. In 1997 NHTSA included a lateral impact consumer test known as SINCAP. This was an additional test to the frontal NCAP. Instead of the FMVSS214 speed of 53 km/h, the rating test is completed with a velocity of 61 km/h.

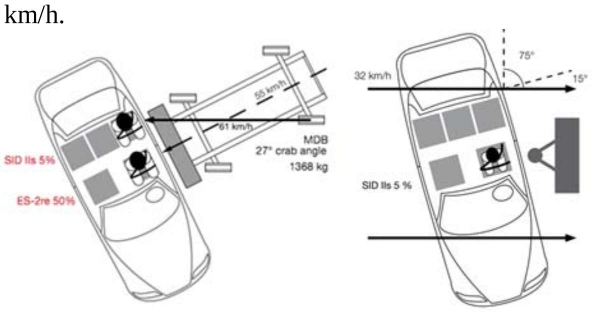

Fig.1. Current US-NCAP test procedures

Parallel in Europe the EEVC WG13 started their research activities to create a UN ECE R95 regulation. This included a new European barrier and a new generation of dummy, EuroSID1. In 1997, Euro NCAP decided to implement the research work of the EEVC WG13 into their program. The more stringent targets at Euro NCAP, especially rib intrusion and abdominal forces, were set at a higher level than current European legislation.

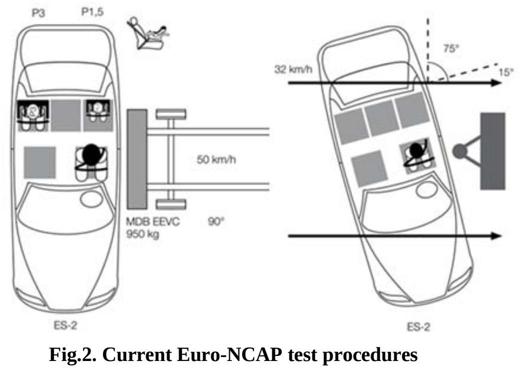

Fig.2. Current Euro-NCAP test procedures

In 2004, NHTSA proposed the update of the existing regulation with replacement of the dummy: ES2 modified with a rib extension kit (ES2re) and a new dummy SID IIs modified with a floating rib guide (SIDIIsFRG). Both will be used in the barrier test and in a newly developed 75° pole impact which later became a global standard. In Europe the EEVC WG13 is working closely together with the Japanese authorities to develop an Advanced European – Mobile Deformable Barrier (AE-MDB). The target for the barrier is to better represent the current fleet of European vehicles. Since 1997 the “ISO World Side Impact Dummy Task Group” has being developing a new dummy (WorldSID). The WorldSID heralds a significant improvement in the ability of crash dummies to duplicate human motions and responses in side impact tests. The use of this dummy should lead to improved vehicle designs and occupant protection.

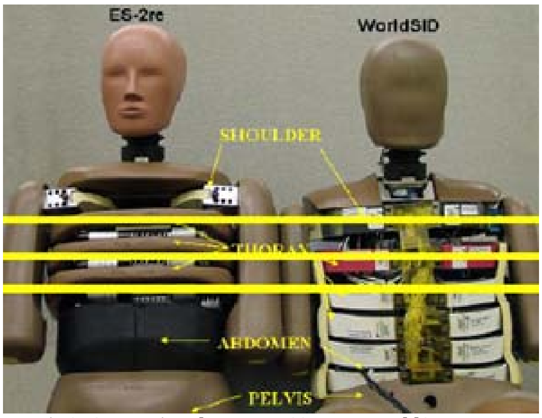

Fig.3. Comparison between ES2 re vs. WorldSID

3 KNCAP side impact protection activities

In spite of the introduction of stringent regulation and KNCAP procedures for the protection in lateral collisions during the last 10 years, injuries in this accident type still constitute a significant category of road traffic injuries. The fatality from side impact accidents has not been successfully decreased as anticipated. While the head injury scores of KNCAP tested vehicles reached almost perfect scores, the head injury is major sources of fatality in side impact crash accidents in Korea. In In 2009, for further enhancing the protection of side collision, the perpendicular 29 kph pole side impact test with ES-2 dummy has been introduced as an optional test in KNCAP. The main objective of the optional pole side impact test was to promote installation of side curtain airbag in the vehicle fleet as a standard option

From police reports, in 2014, car-to-car type accidents, total fatality was 1,914. While the fatality of the frontal crash accidents was 259, the side crash fatality was 555 which is the most frequent and severity accident. In terms of injured occupants, the total 272,147 occupants were either hospitalized or reported to police as injured from the 2014 traffic accident police statistics. The injured occupant from the side impact accident was about 34% of all injured accidents.

During the last 10 years, the popularity of SUV or larger size passenger vehicle are significantly impacted in the domestic automotive market as well as traffic patterns. After reviewing of nation vehicle registration data, it was found that the portion of the curb weight more than 1400kg of passenger vehicles such as SUV exceed lighter vehicles since 2010. Therefore 6 out of 10 passenger vehicle on the road is heavier vehicle mass is more than 1400 kg.

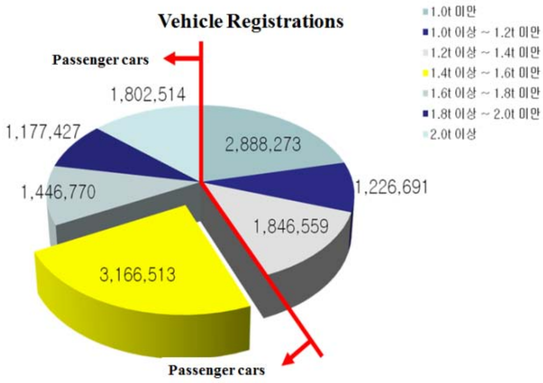

Fig.4. Statistics of vehicle registration

Also, the designs of front ends of current vehicles are more similar to AE-MDB rather than the current MDB. The overall shapes from the compact size vehicle to larger family vehicle are much similar to AE-MDB than current MDB. The height is same in both AE-MDB and current MDB compared with average height of vehicle. But in widthwise, AE-MDB is 1700 mm long which is represent medium size vehicle. The current 1500mm MDB may represents compact size vehicle width.

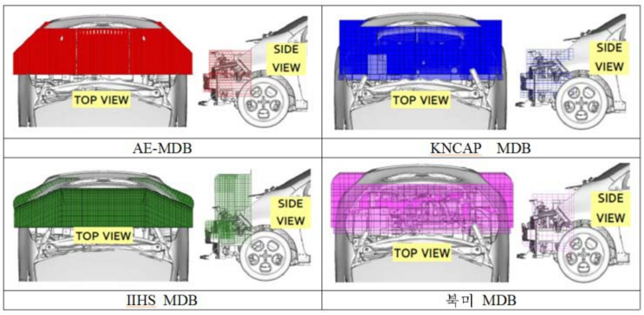

Fig.5. Front end shape of a typical compact car with AE-MDB

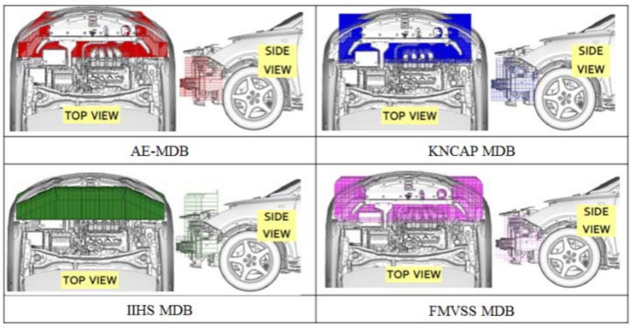

Fig.6. Front end shape of a typical SUV with AE-MDB.

3.1 Increase of bullet mass with AE-MDB face

In order to evaluate the frontal structure and of current trends of passenger vehicle, the new test were compared with the current existing MDB face with 950 kg mass of striking barrier. The new test method was conducted with AE-MDB face with 55 kph impact speed in both 1,300kg and 1,500 kg mass of moving barrier. The impact position of the struck vehicle was moved 250 mm to the backward longitudinal direction based on the R-point of the driver's seat according to the center line of the AEMDB.

Table 1. Compact, mid-size and large cars test results and star ratings

Body	Injury	Weight of MDB		
		950kg	1,300kg	1,500kg
Head	HIC36	74	238	461
Chest	Compression (mm)	15.2	21.1	23.0
	V/C (m/s)	0.12	0.19	0.26
Abdomen	Forces (kN)	0.54	0.79	0.82
Pelvis	Forces (kN)	1.55	1.62	1.69
Star Rating (Sum of points)		★★★★★ (16.0)	★★★★★ (16.0)	★★★★★ (15.8)

Body	Injury	Weight of MDB		
		950kg	1,300kg	1,500kg
Head	HIC36	43	74	92
Chest	Compression (mm)	23.0	21.4	17.7
	V/C (m/s)	0.19	0.17	0.12
Abdomen	Forces (kN)	0.69	0.94	0.97
Pelvis	Forces (kN)	1.31	2.03	2.01
Star Rating (Sum of points)		★★★★★ (15.8)	★★★★★ (16.0)	★★★★★ (16.0)

Body	Injury	Weight of MDB		
		950kg	1,300kg	1,500kg
Head	HIC36	41	74	81
Chest	Compression (mm)	11.0	14.0	14.0
	V/C (m/s)	0.08	0.09	0.09
Abdomen	Forces (kN)	0.73	0.73	0.65
Pelvis	Forces (kN)	2.66	1.97	2.04
Star Rating (Sum of points)		★★★★★ (16.0)	★★★★★ (16.0)	★★★★★ (16.0)

The test vehicles were selected as typical compact, mid-size and large passenger cars to evaluate the injury risks. The test results and the star ratings according to KNCAP were listed in Table 1, 2 and 3. The side airbags and curtain airbags were mounted in all vehicles. The head injury (HIC36) increased depending on the weight of MDB. In the case of compact car, the chest compression increased depending on the weight of MDB. The trends of rib compression for the midsized car and large-sized car were not similar to the compact car. Increasing the weight of MDB, the safety of smaller passenger cars may be affected. Larger passenger cars did not shown in degradation of injury risks due to compatible with the increased of MDB weights. As shown in Table, all tested cars achieved five stars ratings.

3.2 Comparison two dummies with AE-MDB

Regardless of MDB weight increased, the good ratings reflected the effect of the side airbag and curtain airbag under the current side crashes test protocol and injury assessments except compact size cars. The side airbags and the curtain airbags could be dominantly reduced the ES-2 dummy injuries if vehicle interior has enough room to interaction with these airbags.

In other hand, the total 4 vehicles were tested according to EuroNCAP test method with 2 different dummies, WorldSID 50%tile and ES-2 with 1300kg MDB mass to evaluate effectiveness of new dummy as well as harmonization of test method between KNCAP and EuroNCAP. In the test, two different types of vehicles were selected as mid-size and small compact size vehicle to evaluate structural performances. AE-MDB was used in the test with 50kph impact speed. The test specification was shown in shown figure 7. The Both cars were equipped with thorax and curtain airbags.

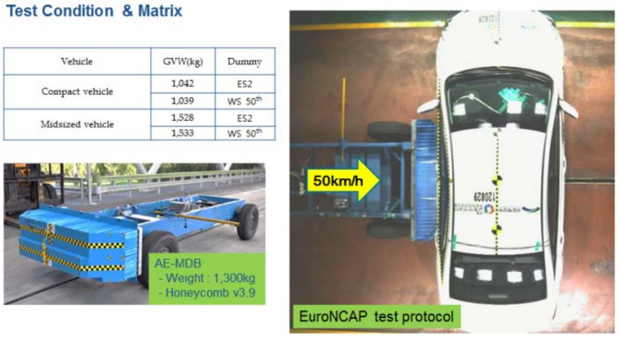

Fig. 7. AE-MDB side impact test

In this test, each of dummy was seated in the driver to evaluate dummy kinematics and injury patterns especially thoracic and pelvic parts. The dummies seated in the cars shown in figures 8 and 9.

Figure 8. Dummy seated in the compact size car

Figure 9. Dummy seated in the mid-size car

The test results are shown in Table 2. In the compact car, the rib defections of WorldSID are significantly lower than those of ES-2 dummies. It may be caused by more rotational behavior in WorldSID than ES-2. In the ES-2 dummy, while the upper rib deflection was the maximum value, the lower rib had a largest deflection in the WorldSID. But reversely, mid-size care case, WorldSID rib deflection is larger than ES-2. The public forces from the WorldSID are lower than ES-2 in both vehicles. The thorax rib deflections and pubic forces are shown in figures 4 and 5.

Table 2. Injury outcomes from side impact tests

			Compact vehicle		Midsized vehicle	
			ES2	WS 50th	ES2	WS 50th
Head	HIC 36	-	84.03	62.93	63.15	96.2
	Peak resultant Acceleration	g	37.33	27.79	26.23	29.33
	3ms	g	29	23.09	25.41	27.05
Shoulder	Shoulder Rib Deflection(1)	mm	-	20.12	-	38.7
Thorax	Upper Rib Deflection(2)	mm	32.4	7.09	12.3	6.13
	Middle Rib Deflection(3)	mm	22.1	7.57	10.0	9.6
	Lower Rib Deflection(4)	mm	22.5	11.89	15.7	18.3
Abdominal & Pelvis	Abdomen Rib1 Deflection(5)	mm	-	16.66	-	20.6
	Abdomen Rib2 Deflection(6)	mm	-	31.03	-	21.9
	Pubic Symphysis Force(Fy)	kN	2.11	1.2	2.48	1.37

Since the injury criteria for the WorldSID 50%tile dummy is not finalized yet, the relative injury risks were examined by IARV's criteria in steads of direct comparison. In these comparisons, the injury risk rations were simple calculated by the linear relationships instead of logistic regression equations.

Table 3. Injury ratios between two dummies in the compact car

Compact Car Injury Performances

ES-2	Injury	Unit	Injury value	IARV's	Ratio
Thorax Ribs	Deflection	mm	32.4	44	73.6%
Pubic	Force	kN	2.11	6.0	35.2%

WorldSID	Injury	Unit	Injury value	IARV's	Ratio
Thorax Ribs	Deflection	mm	11.89	[55.4]	21.5%
Pubic	Force	kN	1.2	[3.365]	35.7%

As shown in Table 3 and 4, the pelvis injury performance, pubic force, are similar in the both dummies. The thorax injury risk ratios for the WorldSID is relatively lower than ES-2 for compact cars. For the mid-size car, the both thorax and pelvis injury ratios are similar.

Table 4. Injury ratios between two dummies in the mid-size car

Mid-size Car Injury Performances

ES-2	Injury	Unit	Injury value	IARV's	Ratio
Thorax Ribs	Deflection	mm	15.7	44	35.7%
Pubic	Force	kN	2.48	6.0	41.3%

WorldSID	Injury	Unit	Injury value	IARV's	Ratio
Thorax Ribs	Deflection	mm	18.3	[55.4]	33.0%
Pubic	Force	kN	1.37	[3.365]	40.7%

3.3 Simulation of 55kph impact speed with WS

Traditionally KNCAP test speed is always sever than regulation test conditions. The series of the computer simulation were conducted to evaluate two dummies with the different impact speeds and side structural integrities. In the simulation, LS-Dyna with FE WorldSID and ES-2 dummy models were used. Due to the limit resources of vehicle safety device design information, the generic mid-size vehicle was modeled without airbags to eliminate effects of airbags.

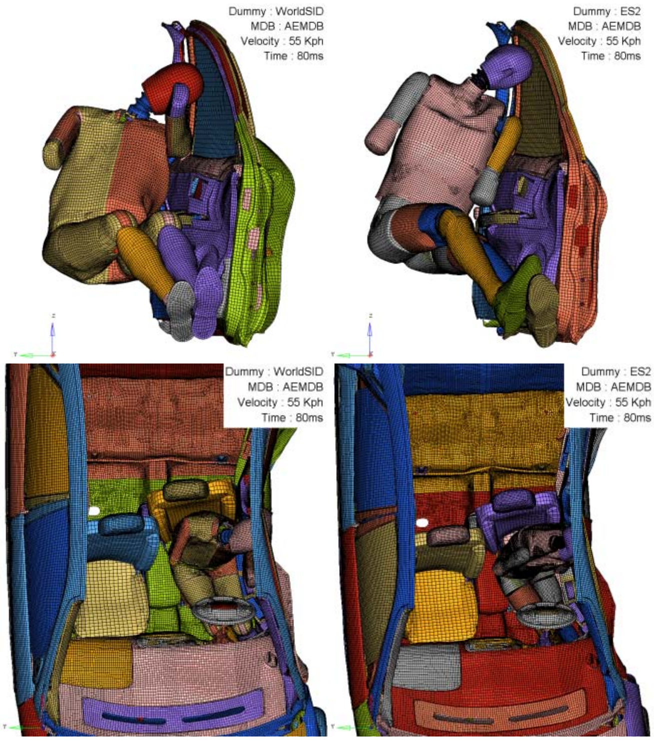

Figure 10. WS and ES-2 kinematics

As a first analysis model, injury outcomes of two dummies were compared with 55 kph impact speed with 1,300 kg mass of AE-MDB. The dummies kinematics and injury results were shown in figure 10 and Table 5.

Table 5. Injuries of two dummies in the mid-size car simulations

WorldSID				ES2			
Shoulder (KN)		-1.29		Clavicle (KN)		-0.46	
Rib acc. (g) def. (mm)	U	Ax	107.6	Rib acc. (g) def. (mm)	U	Ay	172.0
		Ay	274.5				
		Az	111.2			def.	-45.2
		def.	-28.1				
	M	Ax	108.9		M	Ay	183.3
		Ay	192.7				
		Az	60.6			def.	-49.7
		def.	-23.6				
	L	Ax	54.8		L	Ay	110.9
		Ay	149.7				
		Az.	56.8			def.	-53.7
		def.	-13.6				
T12 (G)		Ay	68.6	Lower spine acc. (G)		Ay	6.64
		AR	69.1				
Pubic symphysis Shear-s (KN)		1.68		Pubic symphysis Shear-s (KN)		3.25	
Abdominal def. (mm)		Upper	-12.1				
		Lower	-59.2				

As shown in figures and Table, the rib deflections of WorldSID are lower than ES-2. It can be due to the rotation of dummy during the impact. In the ES-2 dummy, x, z directions rib acceleration sensors are not available. However, x, y directional acceleration values are significant in WorldSID dummy. It means that the deformation of rib cage is influenced by x, z directional forces and generating acceleration in these directions. In figure 11, it displays the rotation of rib cage. Each individual rib can be deformed and rotated independently. But in the ES-2, whole rib cage is moved as one whole part.

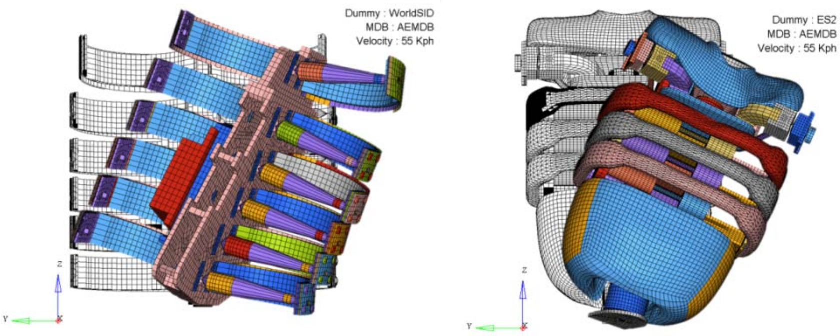

Figure 11. Deformation shape of WorldSID and ES-2

4 Discussions and Conclusions

Increasing the weight of MDB, the safety of smaller passenger cars may be affected. Larger passenger cars did not shown in degradation of injury risks due to compatible with the increased of MDB weights

The higher impact speed increased injury values in both two dummies. But the difference is not significant for WS50 dummy. For the 50 kph case, the maximum rib deflection was 23.46 mm at the upper rib. Increasing impact speed to 55 kph, the maximum rib deflection is increased 19.6%, 28.06 mm.

For the ES-2 dummy, increasing impact speed to 55 kph, the maximum rib deflection is increased only 6.7%, 53.67 mm. With impact tests and computer simulations, two different side impact dummies, WS50 and ES-2 have been evaluated in terms of dummy kinematic and injury outcomes. In general, WS50 dummy shows lower thorax rib deflection than ES-2. It may be caused by rotational behaviors in WS50 dummy. Since WS50 dummy is designed for ability to be used in side impacts up to ±30° from the pure lateral impact direction. Also, the way of construction of rib cage which more flexible and independently movable each rib part. Therefore, the resultant deflection of WS rib and abdomen should be counted in steads of only y directional deflection to consider rotational behavior of dummy.

Since injury criteria for WS50 is not established yet, IARV's values of each dummy were compared. In general, injury risk curves can be expressed by the logistic regression equations. But in these comparisons, the injury risk rations were simple calculated by the linear relationships. The pelvis injury performances, pubic force, are similar in the both dummies. The thorax injury risk ratios for the WorldSID is relatively lower than ES-2.

Side impact accident is one of the most frequent and highest fatality cause traffic accidents. It is due that the most road traffic accident occurs in the city areas near the intersection. From the new technologies such as forward collision warning system, AEBS devices can prevent or mitigate frontal crash type accident. However, the elder driver and female driver or passengers are vulnerable against side impacts. It is time to consider the safety of far side occupants from the side crash accidents as well as near side vulnerable drivers such as elderly driver or small size females.

Acknowledgements

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