VEHICLE COMPATIBILITY IN CAR -TO-CAR FRONTAL OFFSET CRASH

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Abstract Number 156

ABSTRACT

A series of full-scaled car-to-car frontal offset crash tests within passenger car category were conducted to research the current incompatible situations using Hyundai Autonomous Crash Vehicle System. The first test using two midsize cars with 50% overlap and 50km/h each was conducted to compare the injury levels and deformations with the offset regulation case, and check the test results within two same vehicles for test repeatability. The second test using midsize and minisize car with mass ratio of 1.58 :1 was done. The last test with MPV and small car at closing speeds of 120kph was followed. Mass, stiffness and geometry effects are investigated. Simulation results of car-to-car frontal offset and side impacts in case of MPV-to-small and small-to-MPV are included for better understanding. Finally a few design recommendations are also suggested.

INTRODUCTION

Up to the middle of ’90, the enhancement of vehicle crashworthiness performance for its own occupants according to the current FMVSS and other safety standards is main purpose to all vehicles. However the published accident and injury statistics show that the small passenger cars have more occupant’s death ratio than any other vehicle category in frontal and side collisions. This means that the previous optimal crashworthiness process without regard to the crashworthiness performance of the collision partners can lead to serious incompatible and aggressive vehicle designs.

The reason for the higher injury risk for occupants of small cars can be found in the lower mass and stiffness that result in a higher change of velocity in comparison with heavier cars. Furthermore, the structural and restraint system designs are still being optimized for a frontal impact on rigid barrier, and not against the statistically most probable counterpart.

Vehicle compatibility in case of two-vehicle’s real field accident is defined as the ability of a car to help protect, not only its own occupants, but also partner car’s occupants as well.

Figure 1. Vehicle compatibility subject.

Recently in USA, light trucks and vans (LTVs) currently account for over one-third of registered passenger vehicles. Yet, collisions between cars and LTVs account for over one half of all fatalities in light vehicle-to-vehicle crashes. In these crashes, 81% of the injured were occupants of the car. These statistics suggest that LTVs and passenger cars are incompatible in traffic crashes, and LTVs are more aggressive than passenger cars.

Also same situations between mid/large and mini/small cars are expected. Different mass, stiffness and geometry of both vehicles affect the incompatible problems. Impact modes, driver’s age and occupant restraint conditions are also important factors.

In this paper three times of full-scaled car-to-car frontal offset crash tests at closing speeds of 100km/h and 120km/h were conducted to investigate current incompatible situation within passenger vehicle category using Hyundai Autonomous Crash Vehicle System.

The first test using two midsize cars was conducted with the velocity of 50km/h, mass ratio 1 : 1 and 50% overlap each to check out the reconstruction of the EEVC offset regulation test and the repeatability of injury levels and deformation amounts in two same cars.

The second test with midsize car and minisize car was done to research current incompatible situations. The mass ratio was 1.58 : 1 and 50% overlap in minisize car base. Injury levels and structural deformations are compared between two cars.

The last test with MPV and small car with the mass ratio 1.36 : 1 and closing speeds of 120km/h was followed using HACV system. Injury levels and structural deformations are also compared.

Simulation results of side impacts in case of MPV-to-small and small-to-MPV are included for better understanding. Finally a few design recommendations are also suggested.

DEFINITION OF COMPATIBILITY

Vehicle compatibility is defined as the ability of a car to protect both its own occupants and partner car's occupants. If two vehicles in car-to-car crash accident have the same death ratio and lower number of fatalities at the time, then the compatibility of these vehicles is good. The vehicle compatibility is composed of self-protection having meaning of crashworthiness and partner-protection. The lower partner-protection a car has, the higher aggressivity has it.

Aggressivity Metric by Vehicle Category

NHTSA developed aggressivity metric to rank order all passenger vehicles and LTVs by their relative aggressivity using 1991-94 FARS and GES. Aggressivity metric(AM) is defined as driver fatalities in collision partner divided by number of crashes of subject vehicle. Full-sized vans were found to be the most aggressive vehicle category with an AM=2.47. And the AM of passenger car was significantly lower and ranged form AM=0.45 for subcompact cars to AM=1.15 for large cars.

The aggressivity metric is a strong function of vehicle weight. But vehicle weight is not always proportional to the aggressivity metric. The geometry and stiffness are also main factors in vehicle compatibility.

Aggressivity by Crash Accident Type

Another crash accident statistics from FARS (Fatality Analysis Reporting System) is a good clue to investigate what is aggressivity according to the crash accident type – mainly frontal to frontal and frontal to side. Table 1 shows the ratio of fatally-injured drivers in LTVs-to-cars frontal and side collisions. The driver's death ratio of full size vans-to-cars frontal collisions is 1 : 6. And this ratio is higher than that of cars-to-cars frontal collisions. In case of vans-to-cars side collisions the driver's death ratio is about 1 : 23.

Table 1.
Ratio of fatally-injured drivers in LTVs-to-Car frontal and side collisions. (FARS 1992-96)

LTVs (a:Front) *(c:Side)*	Drivers Death Ratio		CARs (b:Front) *(d:Side)*
	FRONT (a : b)	*SIDE (c : d)*	
Full-Size Vans	1 : 6.0	*1 : 23*	Cars
Full-Size Pickups	1 : 5.3	*1 : 17*	Cars
SUVs	1 : 4.1	*1 : 20*	Cars
Minivans	1 : 3.3	*1 : 16*	Cars
Small Pickups	1 : 1.6	*1 : 11*	Cars
Cars	1 : 1.0	*1 : 6*	Cars

Factors for Vehicle Compatibility

There are generally main factors for vehicle incompatible problems – vehicle mass, stiffness and geometry. Each of them affects vehicle incompatibility independently or dependently. And the incompatible effects could be changed according to the vehicle crash types, frontal-to-frontal and frontal-to-side, due to the different stiffness and geometry of collapsed areas. The occupant restraint systems, driver's ages and driving characteristics are also important factors.

Mass Effect Several accident data are reported that the death ratio of small and light cars is higher than that of large and heavy ones in car-to-car frontal accidents. It is obvious that the vehicle mass has the largest effects on the vehicle compatibility.

A small and light car will always experience higher velocity changes that can be calculated with the law of conservation of momentum.

$$\Delta v_1 = \frac{m_2}{(m_1 + m_2)}(v_1 + v_2) \qquad (1)$$

$$\Delta v_2 = \frac{m_1}{(m_1 + m_2)}(v_1 + v_2) \qquad (2)$$

It is well known that there is a strong relationship between delta ν and occupant injury risks, and small and light cats have larger delta ν and higher injury risk.

Fatalities per crash accident are minimized when two vehicles have the same vehicle weight. Therefore two vehicles in same weight have the best compatibility conditions due to the same death ratio and minimum fatalities.

The small and light cars nearly under 1000 kg are needed to enhance self-protection capability, and the large and heavy cars roughly over 1500 kg are needed to enhance partner-protection capability. The vehicle mass is obviously one of dominant incompatible factors but the control of vehicle mass is hardly possible.

Stiffness Effect The small and light cars have a tendency of lower stiffness and small crush space, and large deformations in case of crash accident with heavier vehicle. Due to the large deformations in cabin areas the passengers in small cars might experience higher injury levels especially in lower extremities which are not properly protected by safety devices; a/bag, s/belt, and k/bolster, etc. A small and light car should enhance the self-protection capability in terms of structural designs and restraint systems to improve compatibility. But the higher deceleration magnitude resulted in the strong structure should be controlled with best safety restraint systems.

Geometry Effect The different geometry, higher center of gravity and bumper can cause partial intrusion, under-run and override in LTVs-to-cars frontal and rear crashes. More dangerous situation can be occurred in case of LTVs front-to-cars side crashes due to the unbalanced height of side sill, front and rear bumper.

CAR-TO-CAR OFFSET CRASH TEST

Hyundai Autonomous Crash Vehicle System

To reconstruct car-to-car crash accidents in the real field, the Autonomous Crash Vehicle System was developed. This system consists of communicating, sensing, accelerating, braking, steering and data recording subsystems. All these are designed to be compact, light and collapsible, so that the crash characteristics of test vehicle are not affected.

The velocity performance of the system covers from 10km/h to 100km/h within ± 0.5km/h, and the lateral deviation is constrained within ± 20mm. With this system several frontal offset and side crash tests were carried out successfully. Deformations, injury level, deceleration signals and dynamic behaviors during crash tests were typically investigated. And the effects on the compatibility were also investigated. Main subsystems are briefly explained as follows.

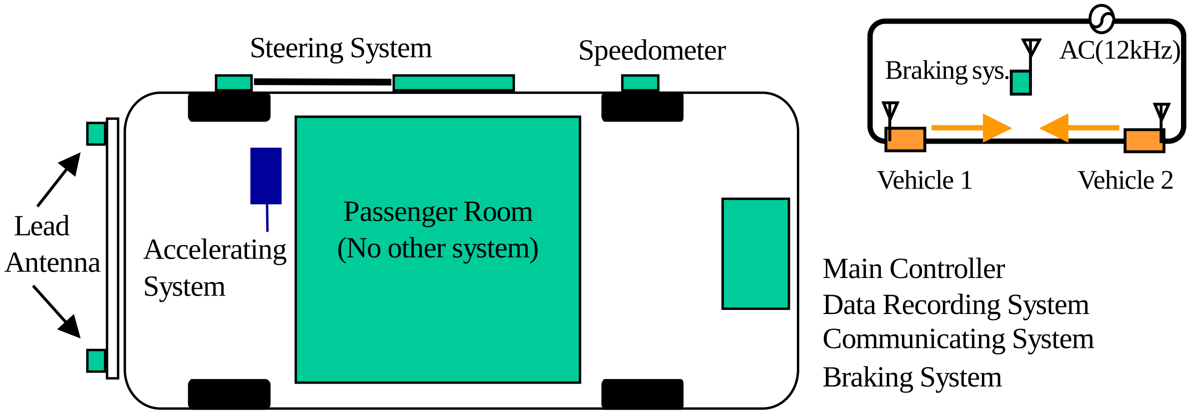


Figure 2. The schematic diagram of HACV system for car-to-car crash test.

Sensing System This system consists of lateral data input module that receives lateral variation of test vehicle, and longitudinal data input module that collects current velocity of test vehicle.

For a car crash test, the operator makes closed loop with electric wire in the test ground, and makes the designed loop course of autonomous driving history, and supplies the closed lead cable with a certain level of electric current. The lead antennas set up in the test vehicle are aligned to the electric-magnetic field frequency in the lead cable. By principle that the voltage from the lead antenna varies proportional to the distance between lead cable and lead antenna, we can find out the lateral deviation distance of test vehicle from the target courses. These antennas are mounted at the lower bumper to avoid noise problems from the test vehicle, and are modified to the modules so that various crash tests can be executed just by moving the lead antenna modules.

Verified encoders are used to measure the velocity of the autonomous test vehicle. By the principle that pulse frequencies from the wheel encoder are proportional to the speed of test vehicle, we can calculate the current velocity, and can process the later algorithm routines at the main central processing unit.

Acceleration System When the autonomous vehicle drives along the path, velocity data is received to the control unit, and the variation between target and current velocity is processed into the minimum error, the longitudinal velocity is controlled for the accurate target velocity within allowed limitations of the crash test regulations. In this system, a PID control method is used and the numerical formula is

$$\varphi(t) = \varphi(t - \Delta t) + K_P(\upsilon_S - \upsilon) + K_d\dot{\upsilon} + K_I\int \upsilon dt \qquad (3)$$

$\varphi(t), \varphi(t-\Delta t)$: Accel. value needed at time t and t-Δt

υ_S, υ : Target velocity and current velocity at time t

K_P, K_d, K_I : Proportional, derivative, integral coefficients

As well as pre-defined velocity in the regulations, arbitrary velocities can be executed by changing target velocity in the main control program. Thus this system has a wide flexibility to the reconstruction of the real accidents.

Braking System As commented in the acceleration system, no other systems can be mounted within the passenger room of the vehicle due to the dummy loading. Mounting the wire braking system in the trunk room of test vehicle satisfies test specification. Remote controller for emergencies in the main control unit is connected to the hydraulic braking system, so the autonomous vehicle can stop by wireless remote controller.

Steering System Hardware of steering system to control the lateral behavior of test vehicle can't be mounted at the front or indoor of test vehicle due to the dummy loading. This system is installed, and can control the lateral behavior. The contact switch sensor that can perceive the impact moment is adapted to the vehicle, and steering system can be moved freely just after crash.

Lateral variation data from the lead antenna is sent to the main control unit, result data after processing is ordered to the steering system. The vehicle can be operated to follow along the target path without separation from the defined courses. In this system, the PID control method is used and the formula is

$$\phi(t) = r_S + f_1(\upsilon)r + f_2(\upsilon)\dot{r} + f_3(\upsilon)\int r dt \qquad (4)$$

$\phi(t)$: Steering value needed at time t

r_S, r : Steering zero point and the lateral deviation

$f_1(\upsilon), f_2(\upsilon), f_3(\upsilon)$: Coefficients (function of velocity)

Data Recording System Various data collected during autonomous driving and impact moment are recorded in the data recording system on the test vehicle. These data are used for adjusting autonomous systems and they can be a basic database for later tests.

Car-to-Car Frontal Offset Crash Test Between Mid-size Cars

Test Condition For a car-to-car frontal offset crash test the impact point must be determined. The longitudinal distances and the lateral deviations are fixed before crash for the accurate test specifications. In this test, offset percentage is 50%, and the needed longitudinal distances are about 372m and 350m each to get the stable target impact velocity. The detail test condition is shown in Table 2. The slightly different test weight is due to the dummy on passenger seat in midsize No.2. Seat belt is changed later from ELR 5% to P/T & L/L as standard safety device. PPD (Passenger Presence Detection) system is adapted in passenger a/bag.

Figure 3 shows car-to-car frontal 50% offset crash test using two midsize passenger cars.

Table 2.
Mid. and mid. car-to-car test condition.

Vehicle	Midsize (No.1)	Midsize (No.2)
Engine Type	V6 2.5D A/T Full Option	V6 2.5D A/T Full Option
Mass Ratio (1 : 1.04)	Vehicle : 1450 kg Device : 30 kg Dummy : 78 kg	Vehicle : 1441 kg Device : 30 kg Dummy : 78 x 2EA
	Total : 1558 kg	Total : 1627 kg
Dummy	H-III 50%ile Male (Drv only)	H-III 50%ile Male (Drv + Pas)
Velocity	49.36 kph	50.02 kph
Overlap (885mm)	50%	50%
Distance (time)	372 m (40.0 sec)	350 m (40.0 sec)
Restraint System	- DAB + PAB(PPD) - Belt (ELR 5%)	- DAB + PAB(PPD) - Belt (ELR 5%)

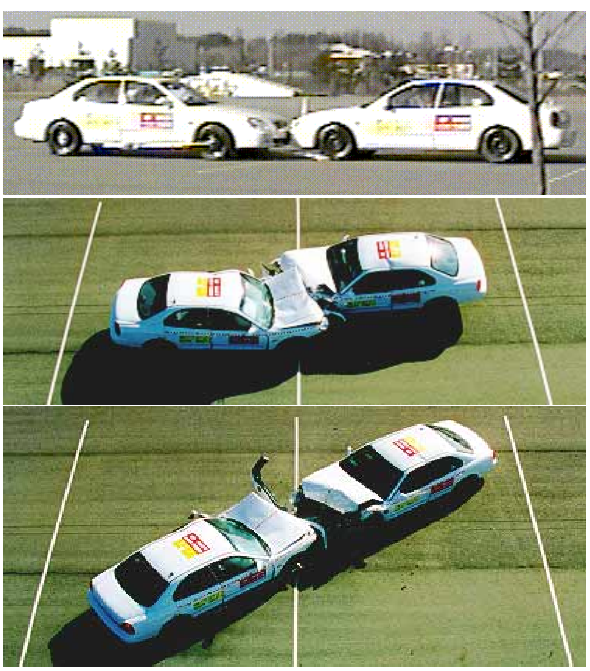


Figure 3. Car-to-car 50% overlap offset crash test. (midsize vs. midsize, 50km/h each)

Test Results Table 3 shows drive's occupant injuries, and main structural deformations are compared according to the IIHS reference in Table 4.

Table 3.
Injury results of car-to-car offset crash test.

INJURY		C-T-C No.1	C-T-C No.2	Offset Reg.(3)	*Criteria*
Head	HIC	445.3	432.8	380.2	*1000*
	3ms G	53	58	48	*80*
Neck	Tension (kN)	1.99	1.98	1.28	*3.3*
Chest	3ms G	42.7	42.2	31.8	*60*
	DISP. (mm)	35.9	28.1	28	*50*
Femur	LH(kN)	2.16	4.19	0.54	*10*
	RH(kN)	7.29	5.37	2.5	*10*

Table 4.
Body 'G' and structural deformations.

Displacement(mm)		C-T-C No.1	C-T-C No.2	Offset Reg.(3)
Body 'G'	LH(G)	28.8	30.3	26.7
	RH(G)	32.8	34.4	21
S/whl	RR Disp.	45	45	73.3
Deform (IIHS)	LH Lwr I/P	60	65	74
	RH Lwr I/P	65	45	75
	B/Pedal	220	220	195
	Dash - LH	132	132	130
	Dash-CTR	140	130	155
	Dash - RH	116	120	139
	Foot Rest	65	80	54
	Door Open'g	20	40	68

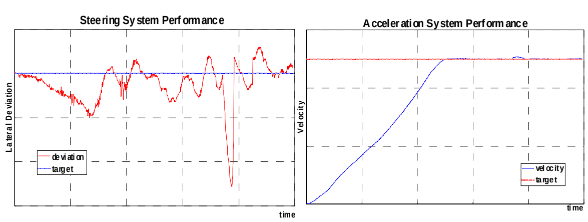
In comparison with test results between car-to-car crash test at velocity 50km/h each and 40% offset crash test (EU regulation at velocity 56km/h, and average test results of 3 times), occupant injury level of car-to-car crash test is slightly higher than that of 40% offset crash test. And the deformation of body structure is somewhat lower than that of offset regulation test. Injury results of car-to-car test using two midsize passenger cars are roughly a half level of required criteria. And these results show good similarity and test repeatability.

Car-to-Car Frontal Offset Crash Test between Midsize Car and Minisize Car

<u>Test Condition and Driving Records</u> The same HACV system is applied for car-to-car crash test with midsize and minisize cars to check the incompatible problems. Test condition is listed in Table 5, and driving records of minisize car are in Figure 4.

Table 5.
Mid and mini car-to-car test Condition.

Vehicle	Midsize Car	Minisize Car
Engine Type	V6 2.5D A/T Full Option	I4 1.0S A/T Standard
Mass Ratio (1.58 : 1)	Vehicle : 1486 kg Device : 30 kg Dummy : 78 kg	Vehicle : 898 kg Device : 30 kg Dummy : 78 kg
	Total : 1594 kg	Total : 1006 kg
Dummy	H-III 50%ile Male (Drv only)	H-III 50%ile Male (Drv only)
Velocity	50.05 km/h	50.1 km/h
Overlap (750mm)	42.38%	50.18%
Driving Distance	250 m (24.8 sec)	300 m (24.8 sec)
Restraint System	- DAB + PAB(PPD) - P/T & L/L	- DAB - P/T



(a) Str'g response **(b) Velocity response**

Figure 4. Driving records of minisize car.

<u>Test Results</u> The comparison of injury results from midsize versus minisize car crash test is described in Table 6 and structural deformations in Table 7. From the theoretical equation (1) & (2), delta v of midsize car is 39km/h and that of minisize car is 61km/h. After examination about crash test results between minisize car and midsize car, we found the small (minisize) car has low self-protection and large (midsize) car has high aggressivity. Most of occupant injuries of mini car are higher than that of midsize car. Especially driver's HIC value in minisize car is about 3.6 times higher due to the higher velocity change. That's because of large deceleration and deformation of minisize car due to small weight, low stiffness and relatively high center of gravity. Large deceleration makes occupants absorb more impact energy.

Table 6.
The injury results from mid and mini car crash test.

Injury	Car	Mid.	Mini.	Injury Criteria	Injury Ratio (Mid:Mini)
	delta v	*39km/h*	*61km/h*		
Head	HIC	148	537	1000	1 : 3.6
	3ms G	31	59	80	1 : 1.9
Neck	Tens.(kN)	1	2.4	3.3	1 : 2.4
Chest	Disp.(mm)	20	31.4	50	1 : 1.6
Femur	LH (kN)	3.3	4.1	10	1 : 1.2
	RH (kN)	5.8	2.8	10	1 : 0.5

Table 7.
The deformations from mid and mini car crash test.

Body 'G' Disp.(mm)	Car	Mid.	Mini.	Ratio (Mid:Mini)
	delta v	*39km/h*	*61km/h*	
Body 'G'	LH (G)	24.3	ND	-
	RH (G)	20.6	37.2	1 : 1.8
String Wheel	Rear (mm)	28	35	1 : 1.3
	Upr (mm)	37	82	1 : 2.2
Disp.(mm)	I/P (LH)	43	13	1 : 0.3
	I/P (RH)	46	30	1 : 0.7
	B/Pedal	86	60	1 : 0.7
	Dash	117	155	1 : 1.3
	Foot Rest	31	89	1 : 2.9
	Dr Open'g	25	47	1 : 1.9

Initial kinetic energy and total deformation energy by computer simulation are presented in Table 8. As initial kinetic energy of midsize car is partially transferred into minisize car, deformation of midsize car is decreased so much. On the contrary, structural deformation and the occupant injuries of minisize car are increased. Figure 5 shows vehicle deformations and dynamic behaviors after crash.

Table 8.
The energy comparison before & after crash.

CAE Result	Initial Kinetic Energy (tonf.mm)	Total Internal Energy (200ms)
Midsize	12500	10533
Minisize	8700	11926

SITE MAP	Midsize Car			Minisize Car		
	Before	After	Disp.	Before	After	Disp.
W/B(LH) mm	2700	2545	-155	2380	2110	-270
W/B(RH) mm	2700	2715	+ 15	2380	2435	+155
Rotation	-59°			-202°		
Final Position	1303 mm Forward (X : 948, Y : 894)			3075 mm Backward (X : 1702, Y : -2561)		

Figure 5. Vehicle deformations and dynamic behaviors after crash.

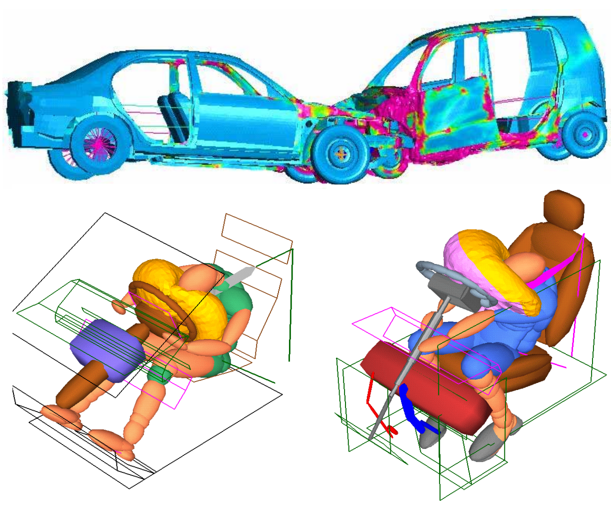


Figure 6. Analysis results of car-to-car crash

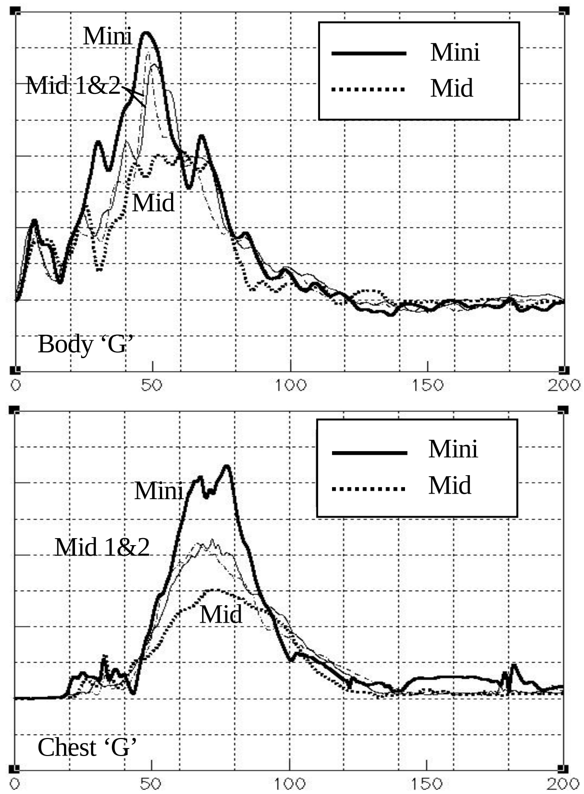


Figure 7. Body 'G' and chest 3ms 'G'.

Car-to-Car Frontal Offset Crash Test between MPV and Small Car

<u>**Test Condition**</u> The test condition is in Table 9.

Table 9.
MPV and small car-to-car test condition.

Vehicle	MPV	Small Car
Engine	I4 2.0D A/T	I4 1.5D A/T
Mass Ratio (1.36 : 1)	Vehicle : 1746 kg Device : 30 kg Dummy : 78 kg	Vehicle : 1258 kg Device : 30 kg Dummy : 78 kg
	Total : 1854 kg	Total : 1366 kg
Dummy	H-III 50%ile Male (Drv only)	H-III 50%ile Male (Drv only)
Velocity	59.94 kph	59.88 kph
Overlap	47.3% (870mm)	50.6% (870mm)
Time	17.4 sec	17.4 sec
Restraint System	- DAB + PAB - P/T & L/L	- DAB - P/T & L/L

<u>Test Results</u> The comparison of injury results from MPV versus small car crash test is described in Table 10 and structural deformations in Table 11.

Table 10.
The injury results from MPV and small car crash test.

Injury	Car	MPV	Small	Injury	Injury Ratio
	delta v	*51km/h*	*69km/h*	Criteria	(MPV:Small)
Head	HIC	176	525	1000	1 : 3.0
	3ms G	38	55	80	1 : 1.4
	Res.(G)	40	57	80	1 : 1.5
Chest	3ms G	38	58	60	1 : 1.5
	Disp.(mm)	21	34	50	1 : 1.6
Femur	LH (kN)	3.7	2.6	10	1 : 0.7
	RH (kN)	3.1	21.0	10	1 : 6.9

Table 11.
The displacements from MPV and small car crash test.

Body 'G' Disp.(mm)	Car	MPV	Small	Ratio
	delta v	*51km/h*	*69km/h*	(MPV:Small)
Body 'G'	LH (G)	29.7	46.6	1 : 1.6
	RH (G)	30.1	43.0	1 : 1.4
String Wheel	Rear (mm)	18	111	1 : 6.1
	Upr (mm)	45	-38	1 : 0.8
Disp.(mm)	I/P (LH)	34	93	1 : 2.7
	I/P (RH)	41	106	1 : 2.6
	B/Pedal	84	168	1 : 2.0
	Dash	154	261	1 : 1.7
	Foot Rest	87	243	1 : 2.8
	Dr Open'g	45	125	1 : 2.8

DISCUSSION

Compatibility for Frontal Crash

<u>Relationship between Compatibility</u> It is important to consider self-protection of small vehicle and partner-protection of large vehicle when we only take compatibility of vehicle into account, and in the aspect of vehicle stiffness, we must also consider the higher stiffness of small vehicle and vise versa. But the promotion of vehicle stiffness is limited because higher vehicle stiffness may cause the decelerations of vehicle cabin to increase especially in case of individual accidents. In the other hand, lower stiffness can bring about a decrease of vehicle safety of its own vehicle. We can find the small vehicle in the car market that improved the vehicle compatibility in crash against large vehicle through higher structural stiffness and lower structure deformation by adjusting Engine L/out. It is comfortable enough to prepare for the crash against large vehicle, but, it weighs about 1,000kg and more, we must investigate its own aggressivity.

<u>Harmonization with Regulations</u> To satisfy the regulation of frontal and offset crash test currently carried out all over the world, it is necessary to increase the vehicle weight and make it stiffer. Keeping in mind the balance between them, it is very difficult to make the safety standard about vehicle compatibility. It is an issue what grade vehicle can be representative for vehicle compatibility. It is proper to choose the largest registered and average size vehicle as the standard one among the candidates of representative vehicle, self-protection must be reinforced in the smaller one, partner-protection must be focused in the larger one for the global vehicle compatibility.

<u>Recommendations for Compatibility</u> With stiffness increase vehicle decelerations can be worse. The possibility of occupant injuries is decreased by optimal restraint systems against high vehicle deceleration in crashes. It is possible by stiffness decrease of large vehicle. Vehicle decelerations and structural deformation of small partner vehicle can be decreased simultaneously and the possibility of occupant injuries can also be reduced. Inspection dimensions between small and large vehicle, it can be a substitute to adjust vehicle size in large vehicle. Figure 8 shows incompatible front and rear end geometry between SUV and small cars.

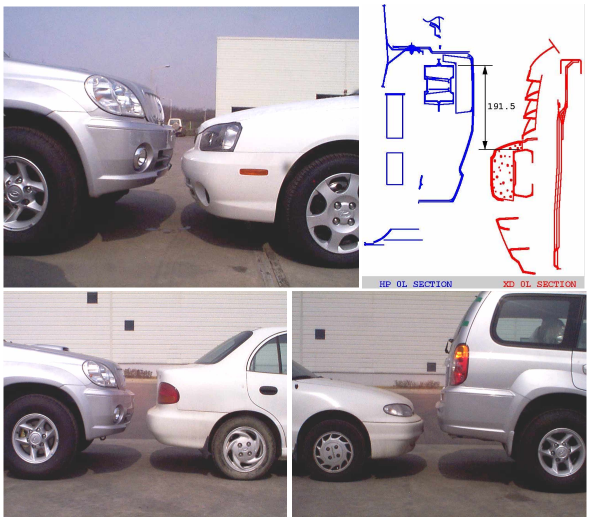


Figure 8. The incompatible front and rear end geometry between SUV and small cars.

Automakers Design Changes Several vehicle specialists with the statistical real field accident data have consistently shown the negative responses about SUV's aggressive designs which the current SUV's are three times as likely as cars to kill the other drivers. Recently automakers attempted to modify the designs of vehicle such as lowering the steel rail, design change of front-end geometry, adding the energy absorbing hollow bar under bumper, strengthen bumper for the energy dispersion, and in addition, moving hard, heavy and dangerous components down, and so on.

Compatibility for Side Crash

From the Table 1, incompatible problem in side crash case is severer than in frontal crash case even within passenger car category. Without regard to the vehicle mass, the different geometry and stiffness between striking and struck vehicle in side crash are main factors Side stiffness and front-end stiffness have a ratio of at least 1 : 2~3. A car must be designed with self-protection. And energy must be absorbed in a very small displacement. Side a/bag is essential safety device for protection. The moving deformable barriers that are using in side impact regulation tests should be modified if real field accident is considered.

The different mass and geometry in case of SUV-to-car side crash are shown in Figure 9 and analysis results by PAM_CRASH S/W are shown in Figure 10 and Table 12. From the analysis results in Table 12, the injury level of MPV-to-CAR side crash is much higher than that of CAR-to-MPV side crash. CAE approach will be virtually very efficient to demonstrate and better understand the nature of the vehicle compatibility problems. After model correlation works with frontal and side car-to-car crash tests several other case study could be possible within computer simulation technology.

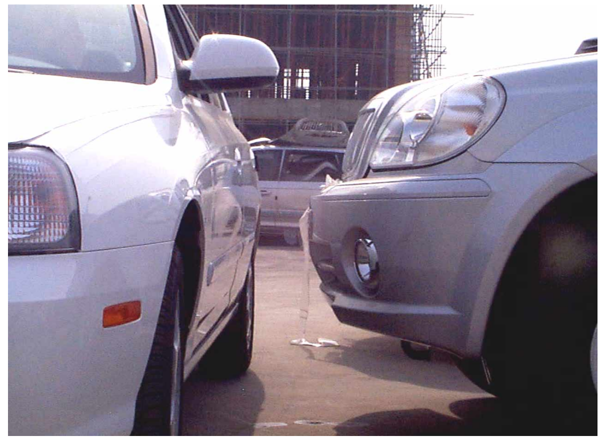


Figure 9. The incompatible front and side geometry between SUV and small car.

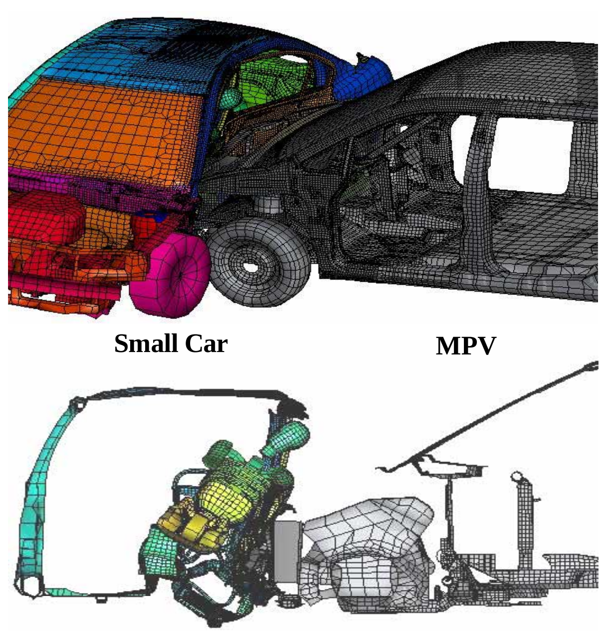


Figure 10. The crash simulation of MPV-to-car side impact including HMC-EUROSID dummy model.

Table 12.
The injury ratio between MPV-to-car side and car-to-MPV side.

96/27/EC Conditions	(a) MPV-to-Car Side	(b) Car-to-MPV Side	Ratio (a : b)
Upper RDC(mm) / VC(m/s)	42.3 / 1.09	7.1 / 0.05	6.0 / 21.8 : 1
Mid RDC(mm) / VC(m/s)	37.1 / 1.22	7.7 / 0.18	4.8 / 6.8 : 1
Lower RDC(mm) / VC(m/s)	34.2 / 1.03	15.1 / 0.18	2.3 / 5.7 : 1
Abdominal Peak Force(kN)	2.9	3.7	0.8 : 1
PSPF(kN)	9.3	1.8	5.2 : 1
B-Pillar max. Disp.(mm)	457	256	1.8 : 1

CONCLUSIONS

Vehicle compatibility under the current complex vehicle categories is basically difficult subject to solve. Unfortunately the design of the car structure and the restraint systems are somewhat still being optimized only for rigid wall and deformable barrier collision according to the current standards and regulations. Moreover the offset crash tests in EURO-NCAP, IIHS and ANCAP drive automakers to produce vehicles more aggressive and stiffer. The reasonable test methods and procedures for compatibility will be essentially anticipated.

The crash test speed in safety standard is just same regardless of the vehicle mass, stiffness and geometry. The mass dependent crash test speed could be quite reasonable and acceptable. The control of vehicle mass is originally limited due to the product planning and purpose. Design modifications regarding stiffness and geometry are strongly recommended to reduce incompatible real field situation. A small and light car should be enhanced self-protection capability in terms of structural designs and restraint systems to improve compatibility.

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