

FRONT AND SIDE CAR-TO-CAR CAE BASED CRASH ANALYSIS OF DIFFERENT CLASS VEHICLES

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ABSTRACT

In recent years, rapid-increasing market share of compact cars and SUVs has brought for both consumer and automaker to pay more attention on crash compatibility between the compact passenger vehicles and the light trucks (i.e., Pickups and SUVs). Vehicle compatibility regarding both self and partner protection in frontal crash of different class vehicles is one of hot issues in vehicle safety. Furthermore, it is expected that the amendment of UNECE-Regulation 94 to implement compatibility issues in couple of coming years. This paper presents front and side car-to-car CAE based crash of different class vehicles which describes a car accident in real field. Structural engagement and energy balance of different class vehicles in front and side car-to-car crash are identified. In this study, conceptual design of compatibility compliant frontal vehicle structure which subjects to improve the distribution of frontal crash loading and structural engagement between vehicles is introduced. The effects of proposed vehicle structure on possible candidates (i.e. FWRB, FWDB and PDB) for a compatibility evaluation test procedure and car-to-car crash are also investigated.

INTRODUCTION

SUVs and light trucks have a bad reputation as being incompatible with smaller vehicles in frontal crash. Indeed, those vehicles' aggressivity or incompatibility has been a thorny issue for many years and has been the subject of research both in Europe and the US. As well as protecting the occupants of a vehicle from the effects of a crash (self protection – i.e., NCAP), the protection of occupants in the colliding vehicles (partner protection) is on the Euro-NCAP road map and has been voluntarily committed to in the North American market.

Historically the most important factor for car crash compatibility was the vehicle mass ratio. Recently various studies and research have paid more attention on geometric alignments of vehicle front structure in car-to-car crash. To identify structural interaction of

front structures and assess partner protection performance there is currently couple of test procedure candidates, which are expected to form the basis for future legislation and/or consumer testing to improve compatibility: proposed by EEVC WG15 [1] and NHTSA [2]. As well as evaluating the occupant injuries and compartmental deformation, the new compatibility metrics evaluate structural interaction and load distribution. For each of candidates a set of metrics has been proposed, defined and await finalization following the correlation between the proposed metrics and the added partner protection in the field.

This paper presents conceptual design of compatibility compliant frontal vehicle structure which subjects to improve the distribution of frontal crash loading and structural interactions between vehicles. The effects of proposed vehicle structure on possible candidates for a compatibility evaluation test procedure (i.e. FWRB, FWDB and PDB) are investigated by CAE simulation. In this study, Front and side car-to-car CAE based crash of different class vehicles which describes a car accident in real field has been conducted. The interactions of proposed frontal vehicle structure and energy balance in front and side car-to-car crash are also investigated.

COMPATIBILITY COMPLIANT VEHICLE STRUCTURE

Various studies show that frontal crash performance of a vehicle is significantly affected by interaction and stiffness of frontal structures [3]-[4]. In general the longitudinal members of large vehicles are inclined to higher than those of smaller vehicles. Additionally the horizontal misalignment of longitudinal members in frontal crash between different size vehicles can also occur because of their mismatch in design layout. When the crash members of vehicles miss each other, they fail to absorb enough crash load. Furthermore it could result in a severe deformation of passenger compartment or a penetration of smaller vehicle's cabin by missed longitudinal members [5].

Figure 1 shows baseline structure and concept design of

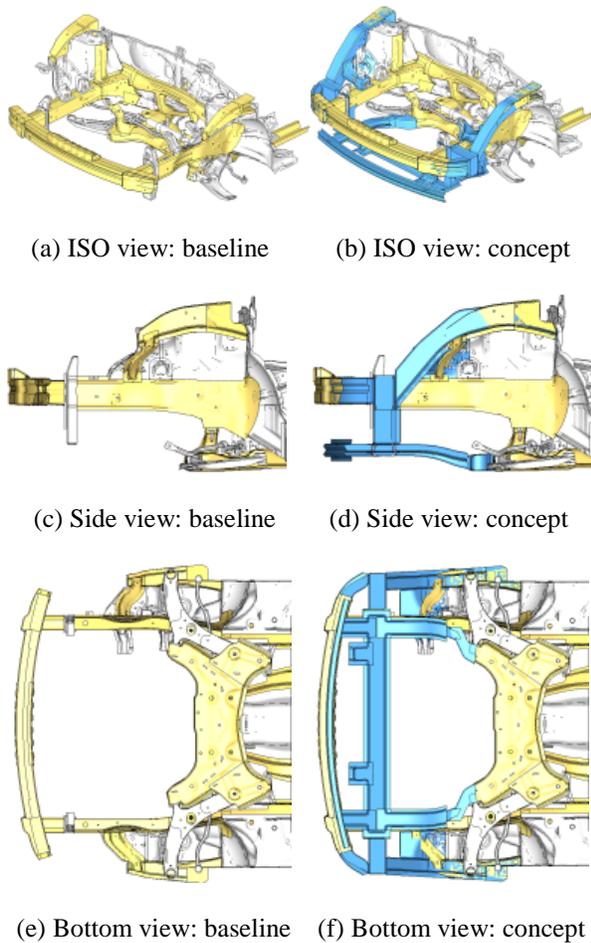


Figure 1. Baseline and concept design of compatibility compliant vehicle structure.

compatibility compliant vehicle structure. In concept structure, the connectivity of structure is improved as shown in the figure; lower members are added, front bumper rail is wider and coupled with fender. Lower members are elongated to front end as much as it can and also has its bumper rail to improve structural interactions at the initial crash stage.

In baseline, most of crash loadings are simply concentrated on the longitudinal members. By increasing loading path, the compatibility compliant vehicle structure has better uniform crash loading distribution characteristics than baseline vehicle structure which means the homogeneity of vehicle structure is improved. Another distinct feature of compatibility compliant vehicle structure is improving structural interactions between vehicles.

In order to clarify whether the presence of the lower member can be detected Full-Width Rigid Barrier test, Full-Width Deformable Barrier test and Progressive Deformable Barrier test have been conducted by CAE simulation [6]-[8].

Full-Width Rigid Barrier Test

In FWRB test, 125mm by 125mm high resolution load cells were used. The ground clearance of load cell barrier was 80mm as recommended by IHRA (International Harmonized Research Activities) Phase 1a [6]. The impact velocity of vehicles was set at 56km/h.

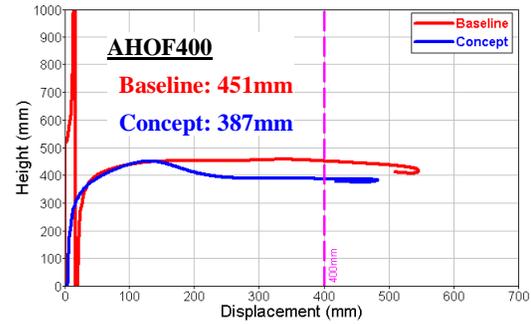


Figure 2. AHOF-displacement curves.

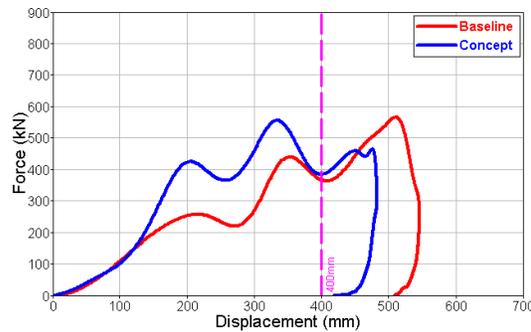


Figure 3. Total barrier force-displacement curves.

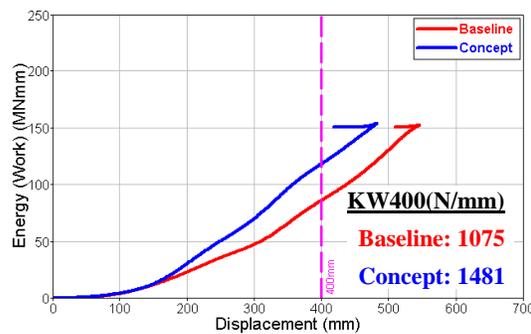


Figure 4. Energy-displacement curves.

Average Height of Force (AHOF)-displacement curve was shown in Figure 2. The AHOFs, which were calculated from displacement up to 400mm (AHOF400), was 451mm for baseline, and it decreased to 387mm for concept due to the presence of lower member. The coupling of bumper rail with fender apron

and elongated lower member which strengthen the stiffness of front end structure result in increasing of total barrier force up to 400mm and KW400 (Figure 3-4). This means better crash loading support at the early stage of impact.

Full-Width Deformable Barrier Test

The deformable barrier face used in FWDB test has two layers [7]. The first layer consists of a 0.34MPa aluminum honeycomb, and the second layer consists of a 1.71MPa element. The impact velocity was set at 56km/h.

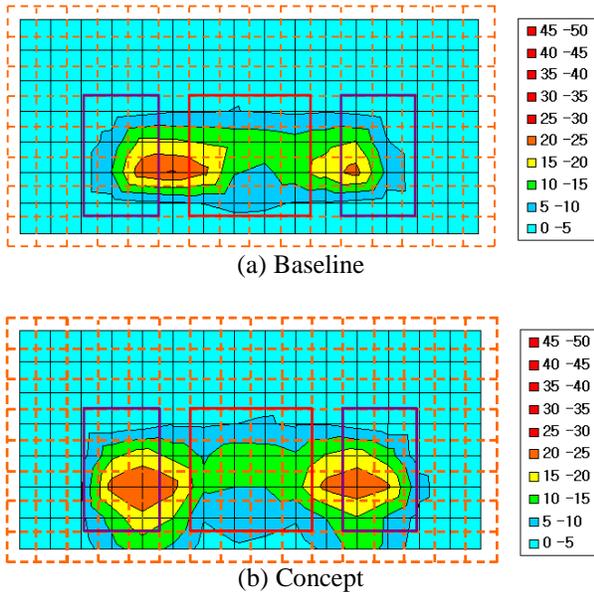


Figure 5. Peak load cell distributions.

Figure 5 shows peak load cell force distributions of baseline and concept vehicle structures. It was observed that the force on the area of longitudinal members was large for both cases. As shown in figure, peak cell force for concept has wider area than that for baseline. This means concept vehicle structure has better homogeneity. Besides, the forces of 1st and 2nd rows for concept vehicle structure were generated by the lower member, which were not shown for baseline.

The Horizontal Structural Interaction (HSI) and Vertical Structural Interaction (VSI) in the assessment area for rows 2 to rows 5 are shown in Table 1-2. As shown in Table 1, outer support parameters of row 3 and row 4 for concept vehicle structure were lowered. This means concept vehicle structure has better horizontal homogeneity than baseline as above mentioned. In Table 2, minimum support of row 2 was lowered to zero which implies the presence of lower member and the force generation by the lower member are identified.

Table 1.
Structural interaction criteria
: horizontal structural interaction

	Baseline		Concept	
	Center Support	Outer Support	Center Support	Outer Support
Row 5	0.0	0.5	0.0	0.8
Row 4	0.0	2.5	0.3	1.0
Row 3	1.4	2.4	3.0	0.4
Row 2	0.0	0.6	2.6	0.1

Table 2.
Structural interaction criteria
: vertical structural interaction

	Baseline		Concept	
	Minimum Support	Load Balance	Minimum Support	Load Balance
Row 5	49.5	0.5	58.8	0.4
Row 4	0.0		0.0	
Row 3	0.0		0.0	
Row 2	42.8		0.0	

Here again, the presence of lower member on proposed conceptual design of compatibility compliant vehicle structure was clearly detected in FWDB test. Better crash loading support by the lower member is also demonstrated.

Progressive Deformable Barrier Test

Test conditions for PDB (60km/h, 50%) are used in this study [8]. The points that differed from the current ODB test conditions were the barrier structure, impact speed and overlap ratio.

The deformed shapes of barrier caused by each test vehicle are shown in Figure 6. It only shows a slight difference on PDB deformations. It is shown the results in these figures that the most of barrier deformations are caused by the engine and the transmission in both cases. It means that even though a lower member does play a great role on the early stage of crash, the existence of lower member was not detected.

The test results obtained for each vehicle in terms of the ADOD, AHOD and maximum barrier deformation are given in Table 3. The results show that AHOD is slightly lowered. The presence of a lower loading path is considered as an important factor with respect to compatibility. However, no significant difference is seen in AHODs. These results imply that it is difficult to detect or identify the presence of a lower member by AHOD alone. ADOD values also show no significant difference. The results indicate the ADOD is

dominantly influenced by the mass of vehicles rather than the characteristic of vehicle structure. In PDB test, the effect of proposed conceptual vehicle structure is slightly shown. It is due to the final deformed shape of barrier is only considered in PDB test. It is required that other assessment parameters which can detect or identify the presence of member for improving structural interactions.

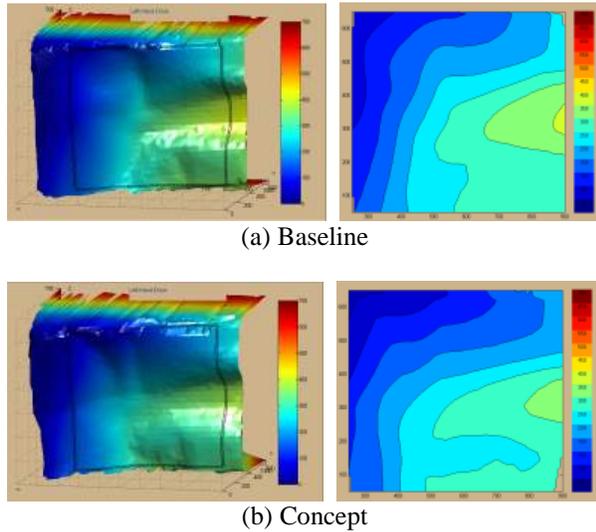


Figure 6. PDB deformations.

Table 3.
Partner protection parameters for PDB

	Baseline	Concept
ADOD(mm)	246	227
AHOD(mm)	322	310
Dmax(mm)	407	372

FRONTAL CAR-TO-CAR CRASH

Frontal offset car-to-car crash test was performed as shown in figure 7: one is a midsize sedan (1465kg) and the other is a subcompact car (1060kg). The impact velocity was 56km/h for both vehicles and the overlap ratio was 50% of the smaller car (subcompact).

Figure 8 shows the front structural components for baseline vehicles and concept vehicles for respectively. In case of baseline vehicles, both midsize and compact cars have longitudinal members and bumper rail to absorb crash energy. For concept vehicles, lower members are added, front bumper rail is widened and coupled with fender to improve structural interactions. In the crash test, there existed geometric misalignments of the longitudinal members in the horizontal and vertical directions between vehicles. Consequently, the longitudinal members are vertically and horizontally

missed each vehicles and the under ride of subcompact car was occurred in case of baseline vehicles (Figure 9-(a),(c),(e)). For concept vehicles, better structural interactions were shown than those of baseline vehicles. As shown in Figure 9-(b),(d),(f), vertical and horizontal mismatch of longitudinal members also exists. However, widened bumper rail and lower member result in better structural engagement in case of both lateral and vertical mismatch of longitudinal members. It is demonstrated that proposed concept vehicle structure is quite effective for structural interaction improvement at the early stage of car-to-car crash.

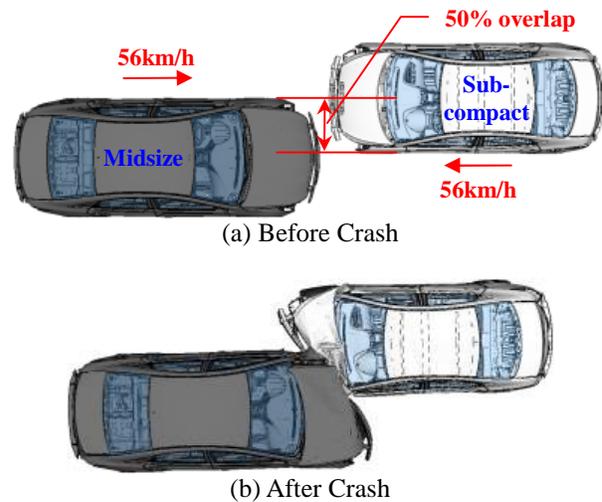


Figure 7. Frontal car-to-car crash (both vehicles at 56km/h with 50% overlap of subcompact car).

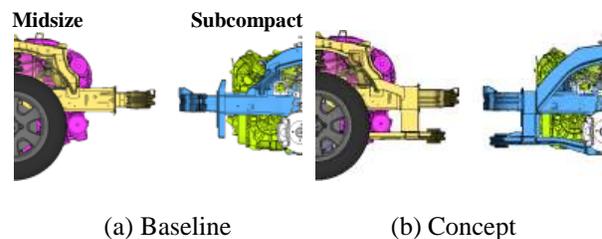


Figure 8. Geometric alignment of vehicles.

Figure 10 shows deformations of both vehicles in frontal car-to-car crash tests. For baseline vehicles, mismatch of longitudinal members results that lateral bending of member for midsize car occurred. In case of concept vehicles, the lower member and gusset of midsize car were engaged with the bumper rail of compact car which was vertically missed. The upper member of compact car which coupled with bumper rail was engaged with the bumper rail of midsize car as well. It is pointed that lower member of compact car was slightly deformed caused by the under ride of compact car.

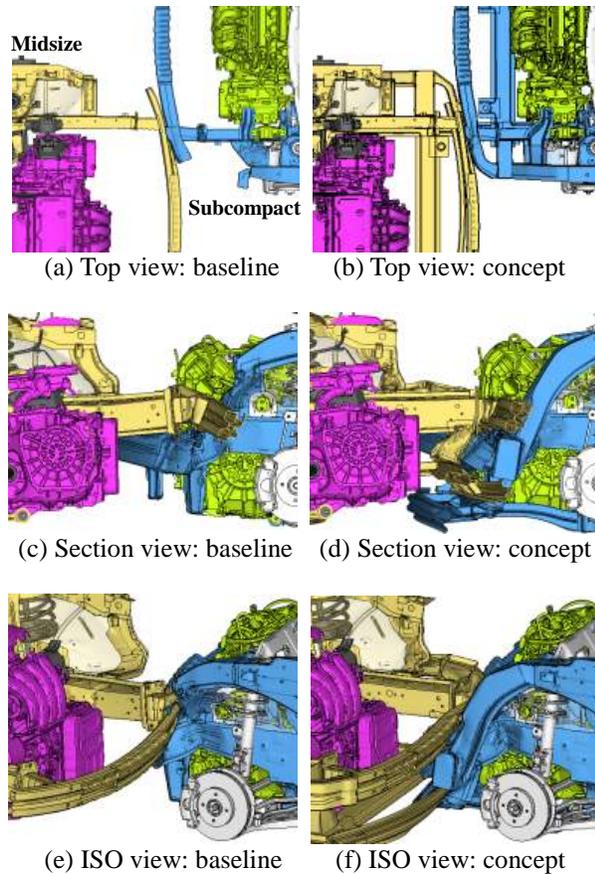


Figure 9. Structural engagements for frontal car-to-car crash.; (a)~(b): @10ms, and (c)~(f): @ 25ms

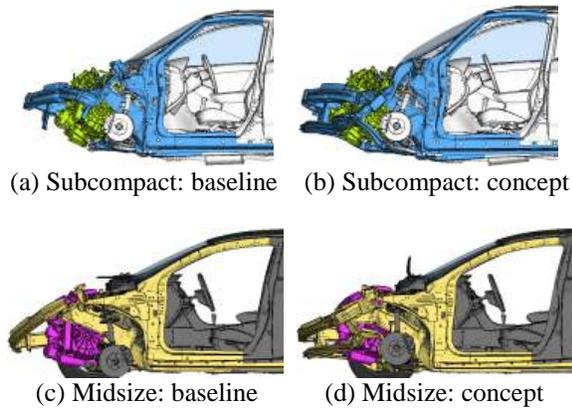


Figure 10. Deformations for frontal car-to-car crash.

Figure 11 shows deceleration curves for both midsize and compact cars. Due to the improvement of structural interactions at the early stage of crash for concept vehicles, not only initial deceleration values but also peak values were lowered for both midsize and compact cars.

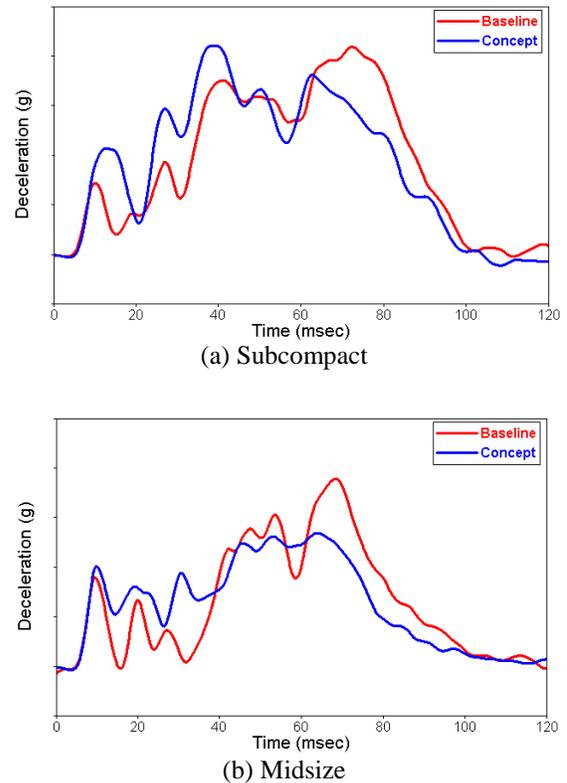


Figure 11. Deceleration curves for frontal car-to-car crash.

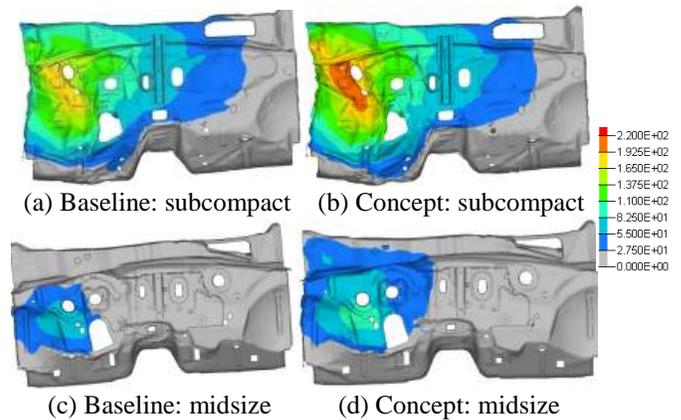


Figure 12. Dash intrusions for frontal car-to-car crash.

Figure 12-13 shows dash intrusions and vehicles deformations respectively. As shown in figure 12, dash local intrusions for both subcompact car and midsize car were slightly increased. The A-pillar deformation of the compact car was increased approximately 20mm caused by the under ride and increased stiffness of upper member. For midsize car, more intrusion at the brake pedal was occurred by the increased local intrusion of dash panel.

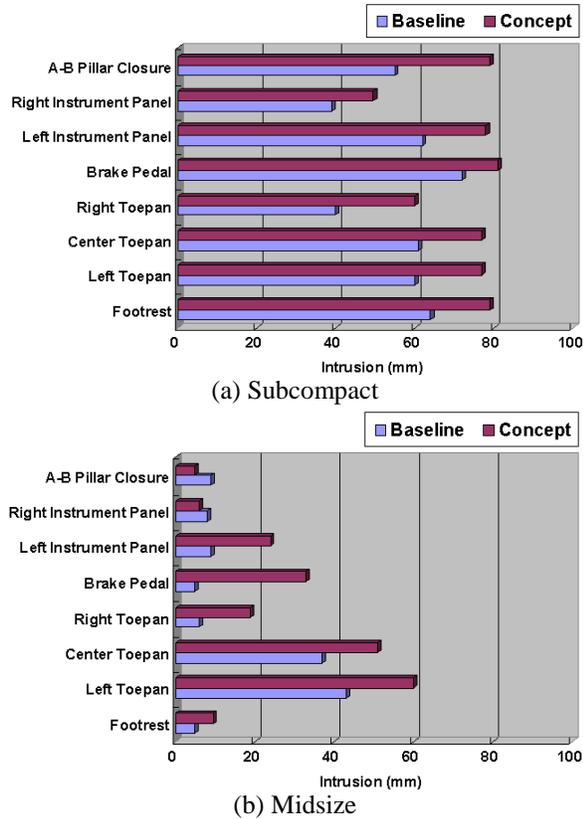


Figure 13. Vehicle deformations for frontal car-to-car crash.

The energy absorbed by both midsize car and subcompact car is distributed as shown in figure 14. For concept vehicles, added vehicle structures result that internal energy for each vehicles are increased. It is pointed that the ratio of absorbed energy was barely different. This means energy ratio is mainly influenced by mass ratio of vehicles even though both vehicles' stiffness is increased by concept vehicle structures.

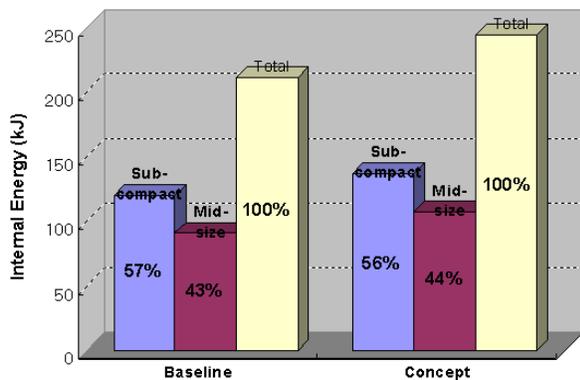


Figure 14. Internal energy distribution of frontal car-to-car crash.

SIDE CAR-TO-CAR CRASH

Side car-to-car crash test was performed as shown in figure 15: bullet (striking) vehicle is a midsize sedan (1465kg) and target (struck) vehicle is a subcompact car (1060kg). The velocity of target vehicle was 24km/h, and the bullet vehicle was travelling at 48km/h. The centerline of bullet vehicle was aimed at the R-point of target vehicle, with both vehicle centerlines perpendicular to each other. Test configuration is the same to that of the previous research performed by EVC WG-13 [9]. Two tests have been performed using baseline and concept bullet vehicles.

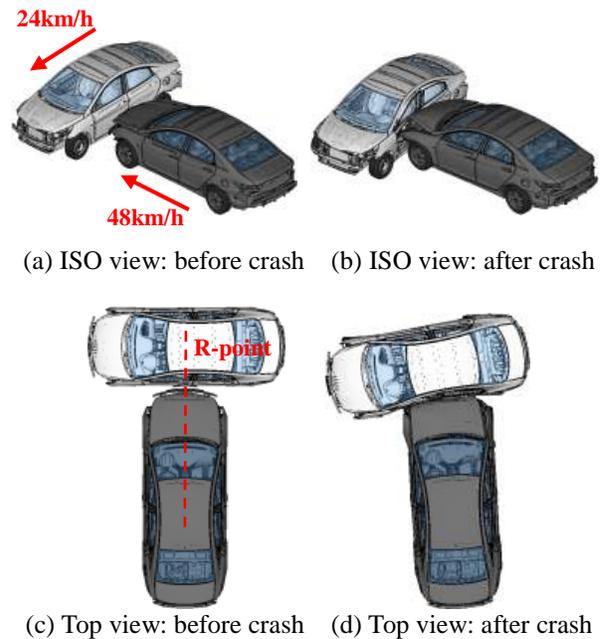
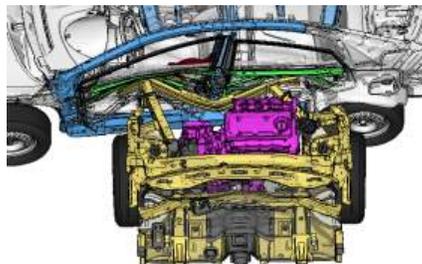


Figure 15. Side car-to-car crash (bullet vehicle at 48km/h vs. target vehicle at 24km/h).

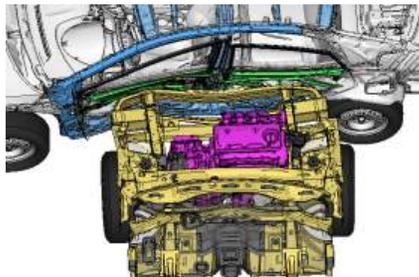
Figure 16 shows structural engagement between both bullet and target vehicles. In case of baseline vehicle, the structural engagement of longitudinal member of bullet vehicle with target vehicle's side impact beam was occurred at the early stage of crash. After that, the longitudinal member of bullet vehicle was laterally bent. As show in figure 16-17, it was observed that concentrated side intrusion of target vehicle at the area of passengers' femur by the longitudinal members of bullet vehicle. There was no structural engagement between the side-sill of target vehicle and the front structure of bullet vehicle due to the absence of lower member. For concept vehicle, front bumper rail of bullet vehicles was less bended. Less concentrated side intrusion occurred and the longitudinal members of bullet vehicle were slightly bent, because that homogeneity of bullet vehicle's frontal structure was

improved. It was clearly observed that structural engagement between the side-sill of target vehicle and the front structure of bullet vehicle by the presence of lower member.

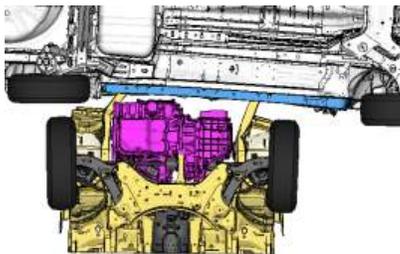
Figure 18 shows b-pillar intrusions of target vehicle. For concept vehicle, maximum b-pillar intrusion was increased about 70mm caused by structural engagement between the side-sill of target vehicle and the lower member of bullet vehicle.



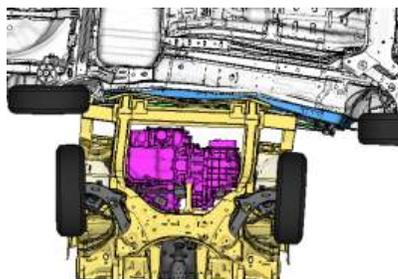
(a) Top view: baseline



(b) Top view: concept



(c) Bottom view: baseline



(d) Bottom view: concept

Figure 16. Structural engagements of side car-to-car crash. (@60ms)

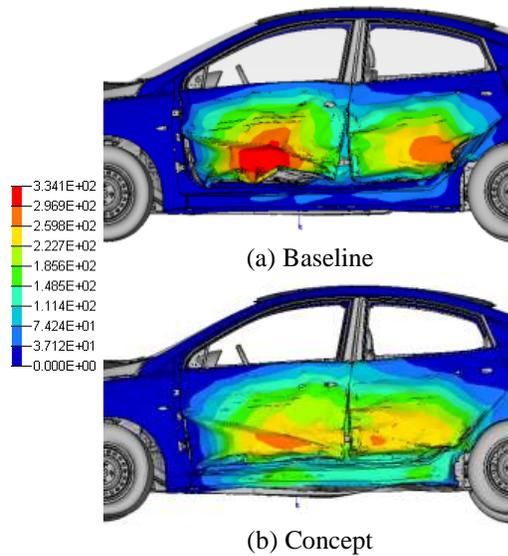


Figure 17. Side intrusions of target vehicle.

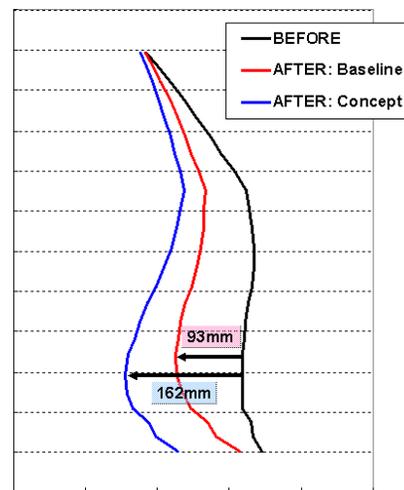


Figure 18. B-pillar intrusions of target vehicle.

The energy absorbed by both bullet vehicle and target vehicle is distributed as shown in figure 19. For concept vehicle structure the internal energy of target vehicle was highly increased 48% to 71% because of improved structural engagement of vehicles which results more increased deformation of target vehicle. On the contrary internal energy of bullet vehicle was decreased 52% to 23%. This means stiffness mismatch between the side structure of target vehicle and front structure of bullet vehicle.

In terms of side compatibility, it needs to be carefully examined that stiffness of front vehicle structure which subjects to improve structural interactions in frontal compatibility.

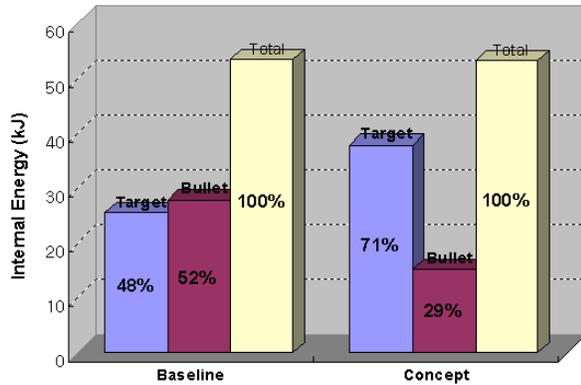


Figure 19. Internal energy distribution of side car-to-car crash.

CONCLUSIONS

For the improvement of structural interactions in front and side car-to-car crash a series of crash tests using midsize and subcompact vehicles was conducted. The results can be summarized as follows:

1. Conceptual design of compatibility compliant frontal vehicle structure which subjects to improve the distribution of frontal crash loading and structural interactions between vehicles is proposed.
2. In FWRB and FWDB test, the presence of lower member on proposed conceptual design of compatibility compliant vehicle structure was clearly detected. Better crash loading support by increased stiffness of front end structure is also demonstrated.
3. In PDB test, the effect of proposed conceptual vehicle structure is slightly shown. It is due to only the final deformation of barrier is measured in PDB test. It is required that other assessment parameters which can detect or identify the presence of member for improving structural interactions.
4. It is demonstrated that proposed concept vehicle structure results the improvement of structural interactions in front and side car-to-car crash. In terms of side compatibility, it needs to be carefully examined that the stiffness of front vehicle structure which subjects to improve structural interactions in frontal compatibility.

REFERENCES

- [1] "Car Crash Compatibility and Frontal Impact," EECWG15 Final Report, 2007
- [2] Patel, S., et al., "NHTSA's Recent Vehicle Crash

Test Program on Compatibility in Front-to-Front Impacts," 20th International Technical Conference on the Enhanced Safety of Vehicles, Paper No. 07-0231, 2007

[3] Wykes, N., et al., "Compatibility Requirements for Cars in Frontal and Side Impact," 16th International Conference on the Enhanced Safety of Vehicles, Paper No. 98-S3-O-04, 1998

[4] Edwards, M., et al., "The Essential Requirements for Compatible Cars in Frontal Collisions," 17th International Conference on the Enhanced Safety of Vehicles, Paper No. 158, 2001

[5] Kleinwagen gegen Geländewagen: Audi Q7 vs. Fiat500 Crash Test, <http://www.adac.de>, 2008

[6] O'Reilly, P., "Status Report of IHRA Compatibility Working Group," 19th International Conference on the Enhanced Safety of Vehicles, Paper No. 365, 2005

[7] FWDB Test Protocol v3.0, 2007

[8] PDB Test Protocol v2.3, 2006

[9] "Development and Evaluation of the Advanced European Mobile Deformable Barrier (AE-MDB) Test Procedure," APROSYS Development Report, AP-SP11-0083, 2006