REAR SEAT OCCUPANT PROTECTION IN FAR SIDE CRASHES

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ABSTRACT

The risk of being injured in side impact crashes is very high. Accident statistics show that numbers of vehicle occupants severely injured or killed of non-struck side occupants is approximately 30 percent. Based on accident data from the National Automotive Sampling System/Crash Data Study (NASS/CDS) an investigation concerning injuries and their levels of non-struck side occupants in side impact crashes was carried out. From the accident data, covering the years from 1998 to 2007, the injured body parts, their injury levels and the vehicle parts causing these injuries were analysed. The study showed that hard contacts between the occupants and the rigid vehicle parts cause most severe injuries. As a result of the accident analysis an occupant protection concept for non-struck side occupants on vehicle rear seat was designed. A numerical simulation model representing a non-struck side occupant, its vehicle environment and the airbag based protection system was set up to investigate different parameters, such as airbag shape and position, different dummy types and seating positions. Prototypes of the airbag concept were built and validated in sled tests. The study showed that this occupant protection concept is able to reduce the severity of head and chest injuries of non-struck side occupants in side impact accidents. Furthermore, a positive effect on the interaction between rear seated occupants in side impact crashes was observed.

Keywords: Side crash, airbag, rear seated passengers

INTRODUCTION

Today, research in side impact, side impact regulations and safety systems is mainly carried out in order to protect vehicle occupants seated on struck side of the car. However, far-side occupants, those located on the side opposite the lateral impact are also of risk of injuries during a side impact crash (Digges and Dalmotars, 2001). The protection of occupants seated on non-struck side of the passenger vehicle is not considered yet.

The objective of this study was to examine injury patterns of non-struck side passengers seated on the rear row of the car during collision. From accident analysis, a crash test scenario was derived and extensive numerical simulations were conducted to better understand the occupant kinematics that causes the most frequent injuries. Based on this work a protection system was proposed and its performance to protect the occupants was investigated.

ACCIDENT INVESTIGATION

The United States National Highway Traffic Safety Administration (NHTSA) investigates 4,000 to 5,000 crashes each year and provides the data in the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) database. The accident analysis presented in this paper was based on the examination of NASS/CDS data extracted from the files of the years 1998 to 2007.

The analysis which follows focuses on occupants of passenger vehicles subjected to far side impact. The investigation was limited to passenger cars as well as light and heavy trucks. Only occupants that were restraint by a three-point safety belt were included in the study. Children younger than six years and smaller than 120 cm were excluded from the study.

When reviewing NASS/CDS data according to the selected parameters, 2264 cases of belted passengers seated in the front row, and 190 cases of belted passengers seated on rear row injured according to MAIS1+ were found. Of these 517 front passengers and only a small number of rear passengers, 28 cases, were injured according to MAIS3+. In the following Figure 1 the ratio of serious injured occupants to all injured occupants (MAIS3+/MAIS1+) in far side crashes is shown for front and rear passengers.

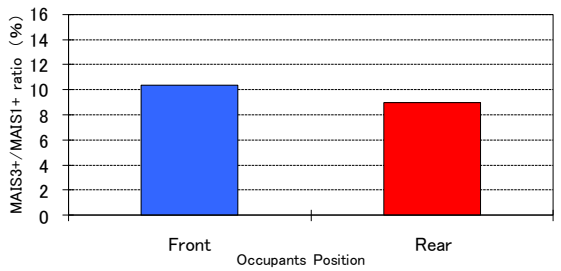


Figure 1: Accident ratio of far side impact accident seated in front and rear row

Far side struck occupants have a significant risk of injury. The fraction of all occupants who experienced serious injuries in a far side impact account for 11.7% on front row and 9.0% on rear row.

Based on the data obtained from the NASS/CDS database the sources causing MAIS3+ injuries were also derived. Figure 2 depicts the distribution of far side injuries, sorted by region, that were found for 517 cases of front seated passengers.

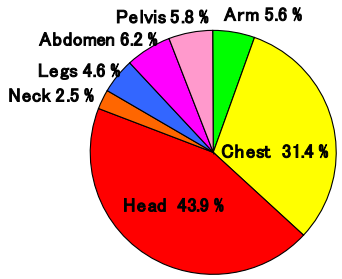


Figure 2: Injured body regions of front seated passengers suffered in far side impact

Head injuries account for more than forty percent of all MAIS3+ injuries, the largest fraction of all. The chest incurred about one-third of all injuries. Abdomen and pelvis are less injured body regions during the vehicle accident.

In the database 28 cases were recorded for rear seated passengers injured on MAIS3+ level. Here, head injuries account for more than one-third of injuries caused by a far side impact, which is shown in Figure 3. The risk of being injured in the chest area is about one-third and abdomen 10% of all.

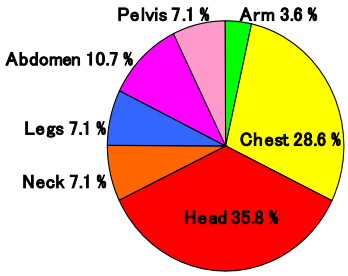


Figure 3: Injured body regions of rear seated passengers suffered from in side impact

As it was shown in Figure 2 and Figure 3, the distribution of far side impact by body region is very similar for both front and the rear seated occupants. Head and chest are most at risk followed by abdominal injuries. Overall, these injuries account for approximately three-third of all injuries reported in the NASS/CDS database.

Sources causing MAIS3+ injuries were analysed next and subdivided into near side interior, belt & buckle, other occupant, seat back and floor & console or roof. It appears that a hard contact of the human body part with the near side interior, the vehicle side facing the impact, is the main source of injuries front seated passengers suffer from (Figure 4). This was found for one-third of the injuries.

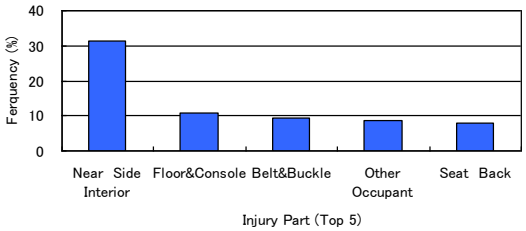


Figure 4: Vehicle parts causing far side impact injuries of front seated passengers

When evaluating the accident data for front seated passenger it can be stated that beside of a hard contact with the near side interior (one-quarter of all), the contact between the occupant and the belt & buckle as well as the contact with the seat back plays a major roll in suffering injuries at MAIS3+ level. Injuries caused by a hard contact with the vehicle

roof or caused by the interaction between the occupants are less frequent as shown in Figure 5.

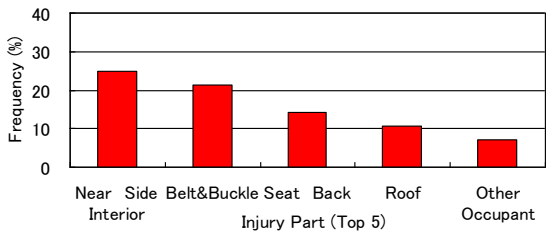


Figure 5: Vehicle parts causing far side impact injuries of rear seated passengers

The analysis presented in Figure 6 depicts the distribution of far side injuries as a function of the striking vehicle. The evaluation of the data shows that passengers seated in the front row of the car are mostly injured when the striking vehicle is a mid size or compact/mini car. This account for about one-quarter each. The striking vehicle for over more than 45% of the side struck occupants seated in the rear row was a mid size car. The vehicle group of van and light tucks accounts for one-third of all MAIS3+ injuries of rear occupants.

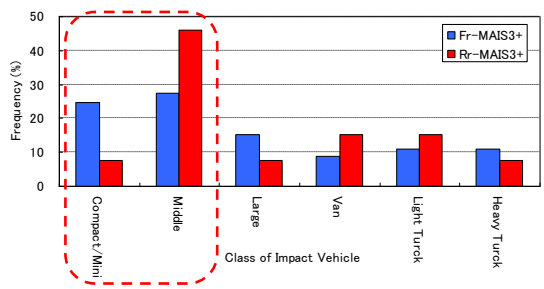


Figure 6: Frequency of injured passengers at MAIS3+ level related to vehicle class

NASS/CDS data base also provides information about the principal direction of force (PDOF). Zero degree is the front, 90 degree is normal to the side and 180 degree is the rear of the struck car. When evaluating the data related to MAIS3+ injuries, the most likely principle direction of force in far side accidents was 60 degrees which account for about 70% of serious injured passengers. Less injury was observed for a principle direction of force at 90 degrees or at 120 degrees as depict in Figure 7.

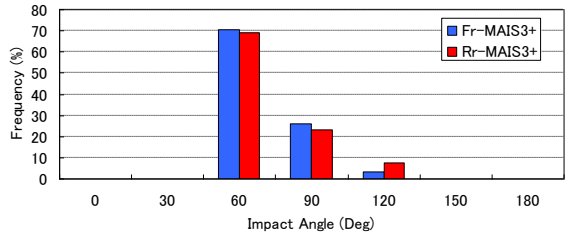


Figure 7: Distribution of far side impact injuries at MAIS3+ level by impact direction

A further evaluation was made according to the impact region of the stuck car. The impact to the occupant compartment is categorized by the NASS as follow: The Y (front 2/3 of the car side), P (centre 1/3 of the car side), Z (rear 2/3 of the car side) and D (distributed) and depict in Figure 8. (The University of Michigan, 2007)

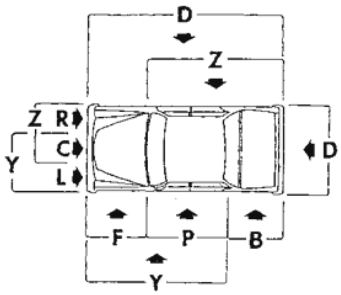


Figure 8: Definition of the vehicle impact area by The University of Michigan (2007)

The impact at front 2/3 of the vehicle was the most likely damage location for the vehicles investigated as shown in Figure 9. Impacts to this region also accounted for about 40% impacts in the region of rear 2/3 account for 18% of serious injured front seated passengers. The impact at 2/3 rear and centre 1/3 (each 30%) followed by impact on front 2/3 (23%) caused serious injuries for rear passengers.

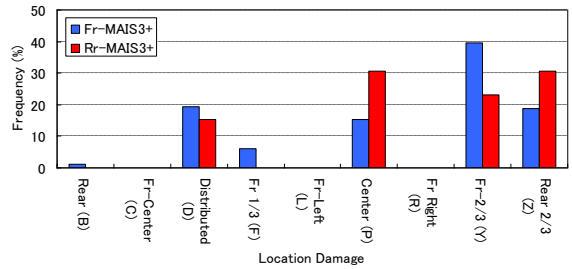


Figure 9: Distribution of far side impact injuries at MAIS3+ level by impact direction

Figure 10 presents the distribution of far side injuries by rigid barrier conversion velocity. The calculation was made according to Sukegawa et al (2007) by applying the energy absorption distribution map for the lateral stuck vehicle. As depict, the median barrier conversion velocity for all far side struck occupants with a MAIS3+ injury level was 31 to 40 km/h.

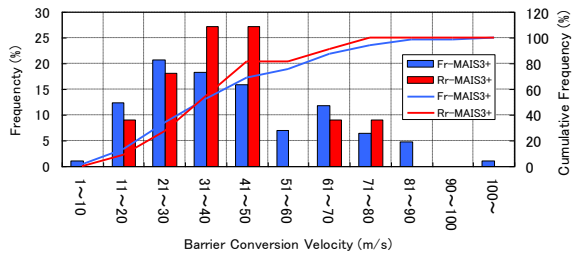


Figure 10: Distribution of far side injuries by barrier conversion velocity

The goal of this accident analysis was to establish priorities for injury countermeasure development for passengers seated in fare side struck vehicles. Two trends can be found.

The injury pattern. – The database exposed that the injury ratio of MAIS3+ to MAIS1+ is nearly the same for vehicle passenger seated on front or rear row during a far side impact. It can be stated that the occupants head and chest account for more than 2/3 of all injuries evoked by fare side impacts. The vehicle's side interior of the impact adverted vehicle side, the belt and the buckle as well as the seat back are the major injury sources. The interaction between the occupants plays a minor roll.

The accident scenario. – The occupants seated in the car classified as compact/mid size vehicles are mainly involved in far side impact crashes. The principle direction of force is at 60 degree and with a converted barrier velocity of 31 to 40 km/h fifty percent of the accidents are covered.

Protection of the head, chest and abdomen have priorities for countermeasure development. These three body regions accounted for approximately three-quarter attributed to far side impact of front and rear passengers.

PROTECTION CONCEPT

A new protection device was considered to enhance the protection of passengers seated on non-struck rear row position. An airbag was proposed to support the occupant kinematics during the event of crash and absorb impact energy and thus, mitigate the injury level. This airbag was installed in the centre console between the two passengers on the rear seat of an upper class car and it is supposed to enhance the protection capabilities in combination with a seatbelt system. The protection device also was designed to meet specific demands concerning side effects such as out-of-position scenarios.

The occupant protection device is integrated into the rear centre consol and shown in a full deployed position in Figure 11.

Figure 11: Rear centre console airbag front view left and side view right

The main design parameters of the rear centre console airbag are described in the following Table 1.

Table 1: Design parameter of the rear centre console airbag

Parameter	Value
Protection area	Thorax and head as depict in Figure 12
Airbag width	330 mm at head area and 230 mm at shoulder area
Airbag type	2D type with 100 mm tether
Airbag volume	66 litre
Inflator output	190 kPa in 60 litre tank (pyro inflator)
Vent hole size	2 holes with a diameter of 20 mm each
Cushion	Silicon coated
Time to fire	t = 9 ms

The airbag module with the cushion and the inflator is located in the upper part of the rear centre console. Once it is deployed it covers the whole thorax and head area of the seated occupants in the most forward and most rearward seating position. In order to position the airbag stable the airbag height was selected for a tight contact to the roof and the arm rest of the rear centre console. Two tethers form the width of the bag to 330 mm in the head area and to 230 mm in the shoulder area. In the following Figure 12, the geometry of the airbag and its location related to the side impact dummy ES2 is depict.

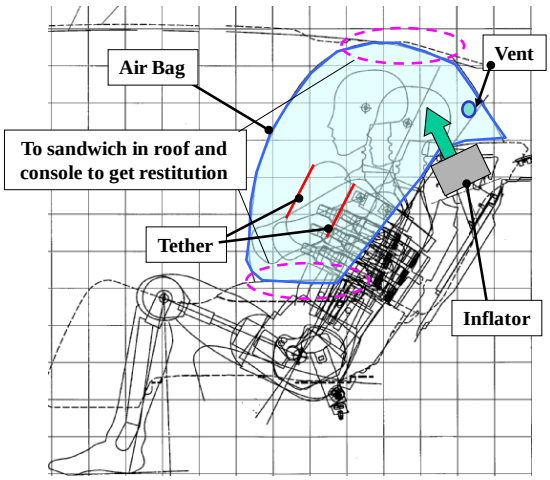


Figure 12: Protection area of the rear centre console airbag

As derived from NASS/CDS data investigations the rigid barrier conversion velocity in far side impacts is 31 to 40 km/h. Intensive numerical simulations were carried out to define a equivalent crash test setup using a AE-MDB (Advanced European Movable Deformation Barrier).

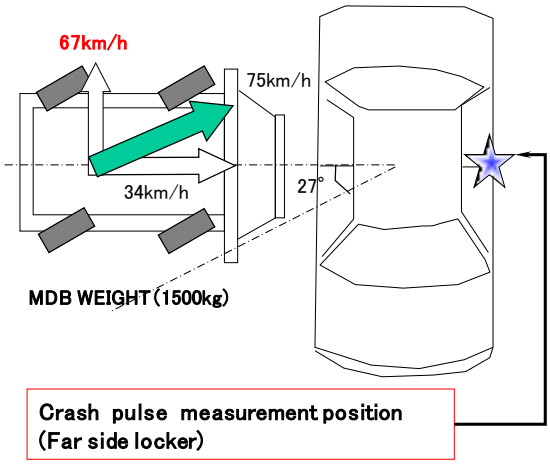


Figure 13: Crash test set up of far side impact

The Figure 13 depicts the crash test set up. The total delta-v of 75 km/h is the resultant change in velocity and includes both the lateral, of 34 km/h, and longitudinal, of 67 km/h, components. The AE-MDB with its mass of 1,500 kg hits the upper class car between the front and rear wheel with an impact angle of 27°. The car was equipped with two ES2 dummies on front row and one ES2 dummy on struck side on the rear seat. The crash pulse was measured on the B-pillar/rocker and the acceleration and velocity history are shown in the following Figure 14.

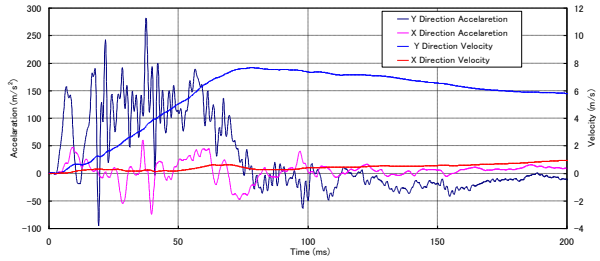
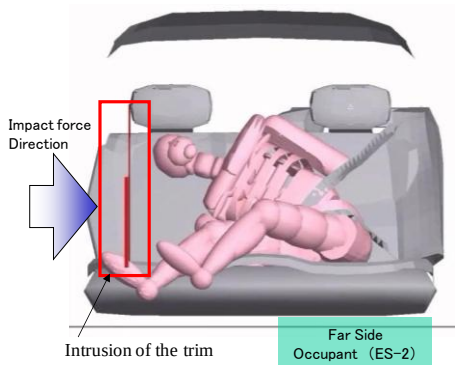


Figure 14: Acceleration and velocity history of the far side impact crash test

The acceleration signal was filtered with CFC180 and achieved a maximal value of 28 g during the intrusion of the movable barrier. Here, the struck vehicle was moved in y-direction up to a velocity of 7.6 m/s.

CONCEPT EVALUATION

Three steps were considered to evaluate the protection concept. As a start the injury severity as base line conditions was studied. Numerical simulations with the multi body software Madymo (Madymo, 2006) were performed placing one and two ES2 dummies on the rear row. As a second step the occupant protection concepts should be installed and the protection performance should be investigated under the same conditions as baseline. The derived output of the numerical simulations should be confirmed with a fare side impact sled test. This represents the third step of the concept evaluation.



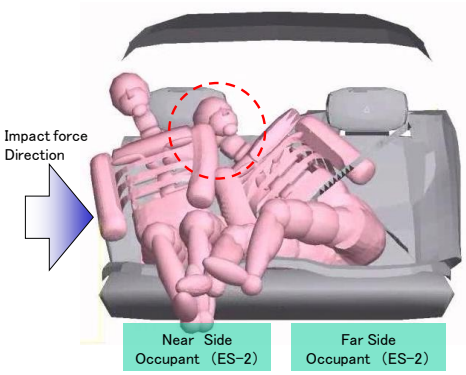


Figure 15: Numerical simulation sled model with far side dummy only (top) and with far side and near side dummy (bottom)

The results of the numerical simulation are presented in the following Figure 16.

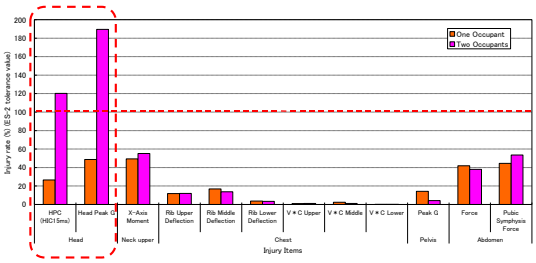


Figure 16: Injury results of the base line simulation with one and two occupants

It can be stated that the head performance criteria (HPC) is 20% higher as the maximal biomechanics limit of HPC 1,000. The head acceleration even exceeds the limit by more then 90%. The high head loads can be attributed to the hard contact between the far side seated dummy head and the near side seated dummy shoulder as can be seen in the bottom figure of Figure 15.

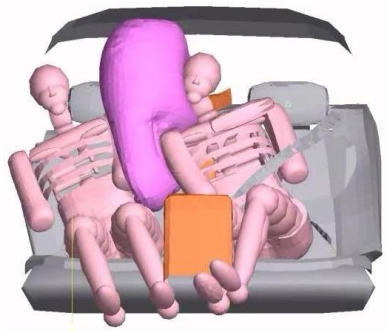


Figure 17: Numerical simulation sled model with rear centre console (top) and with rear centre console and rear centre airbag (bottom)

The Figure 17 above show the dummy kinematics at 110 ms during the far side impact with the Madymo simulations. The rear centre console prevents the dummy seated at the far side from intense lateral movement of the pelvis. The support of the dummy in pelvis area results in reduced head loads. Although there is no contact between the two dummies, the head acceleration can be lowered to just below the load limit and the HPC can be reduced to an acceptable load level of less then 20% of the respective load limit.

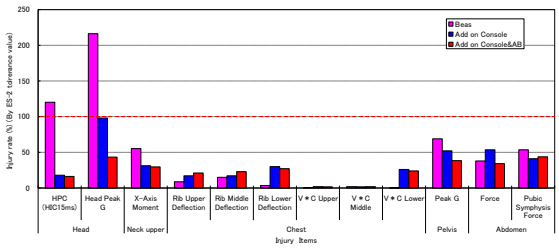


Figure 18: Injury results of simulation with far sine impact protection concept for rear seated passengers

As by the simulation results in Figure 18 shown, there is an increased protection performance when applying the rear centre airbag. An interaction between the two dummies is prevented. The head acceleration can be further mitigated to a level of 40% of the load limit. By introducing this protection concept for rear seated passengers, a slight increase of the chest deformation has to be taken into account, but the loads are still on a low level.

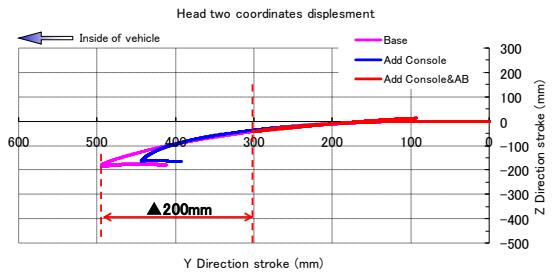


Figure 19: Head trajectory

The dummy kinematic were analysed for different body parts. In Figure 19 the trajectory of the head during the far side impact is plotted. The application of the rear centre console significantly reduces the head movement in y-direction by 50 mm. The combination of rear centre console and rear centre airbag is able to limit the head displacement in y-direction to 300 mm.

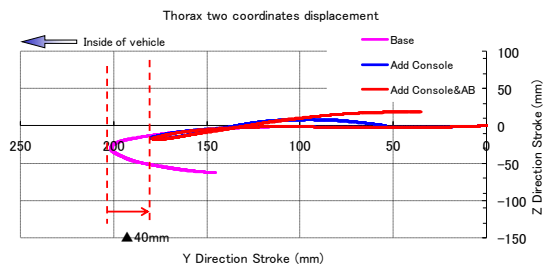


Figure 20: Thorax trajectory

A change of the thorax kinematic was also observed. The main effect was evoked by the application of the rear centre console. A reduction of 40 mm was observed. The rear centre airbag has only a minor effect of chest displacement as can be seen in the above Figure 20.

Based on the multi body simulations with the protection concept two sled test were performed to confirm the simulation results (Figure 21). A rear centre airbag prototype was built to equip a test set-up with rear centre console and two belted ES2 dummies. The vehicle side intrusion derived from the base line crash test was pre-set.

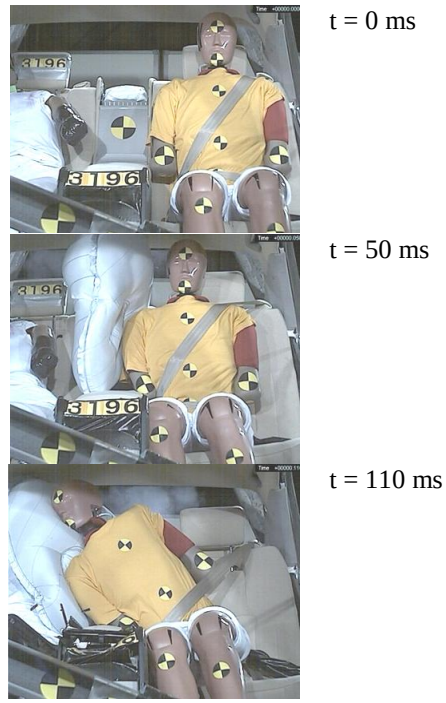


Figure 21: High speed video frames of sled test with rear centre console and rear centre airbag

In Figure 22 the results of numerical simulation and sled tests are compared. There is the same trend of the injury level of the different injury values. The average of the injury values obtained from two sled tests are below the injury values derived form the numerical simulation with Modymo.

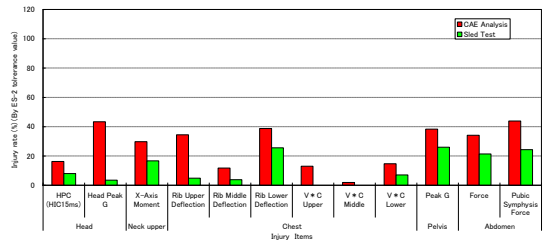


Figure 22: Comparison of numerical simulation and sled test results with the protection concept

When designing a new airbag system its side effects have to be considered too. Different dummy sizes are available to investigate a variety of different out-of-position scenarios. In order to confirm the potential side effects of a rear centre airbag the following scenarios, presented in Table 2, were investigated in deployment tests. The test results are shown in Appendix 1.

Table 2: Overview of the different out-of-position scenarios investigated

Dummy	Dummy position	
3YO	Turn backwards and half overlap of the airbag module	
3YO	Turn backwards and full overlap of the airbag module	
3YO	Face front	
3YO	Turn sideways	
6YO	Face front	
6YO	Turn sideways	
SID2-S	Position 1	
SID2-S	Position 2	

Three year old dummy (3YO), six year old dummy (6YO) and SID2-S dummy were used for out-of-position testing. It can be stated for all tested scenarios that the loads of the dummy were well below its regulated limits.

CONCLUSION

Within this study an accident investigation based on NASS/CDS data was carried out to analyse the accident characteristics and injury pattern in far side accidents. It can be stated that far side struck occupants are at significant risk of serious injury.

The median lateral barrier conversion velocity for occupants exposed to far side impact was 31 to 40 km/h. A test procedure applying a AE-MDB was developed to investigate future countermeasures.

A new protection concept was introduced for passenger seated on the rear row of the vehicle. An airbag deploys between the rear centre console and the vehicle roof in order to prevent the far side seated passenger form hard contact with the passenger seated on the impact side of the car. Intensive numerical simulations were carried out to optimise the rear centre airbag design parameters. It could be demonstrated that the protection concept with rear centre console and rear centre airbag is able to support the lateral dummy movement and thus to mitigate the occupant loads in the case of a far side impact significantly.

Side impact sled tests with prototypes of the new airbag concept were performed in order to confirm the multi body simulation results. It was shown that all injury criteria were far below its regulated limits and the trend which was observed in the simulation could be confirmed.

In addition to sled tests, deployment tests were performed to evaluate the injury risk of the protection device in out-of-position scenarios. It could be demonstrated in all test conditions with different dummy sizes in different positions to the rear centre airbag module, that the risk of suffering injuries is low.

The performed study was limited to the protection of belted rear seated passengers. Further work should continue the investigation of the protection principle for unbelted occupants in this position. The proposal and the investigation of a protection concept aiming to restraint passengers seated in the front row of the car during far side impact is additional future work. The experiences gained during this study will help to create a protection concept. Furthermore, the

application of human body model simulations in order to analyse the local loads of the occupant during far side impact and the protection effect of the restraint system proposed in this study will be future work. By this means the protection pattern can be understood in a wider sense.

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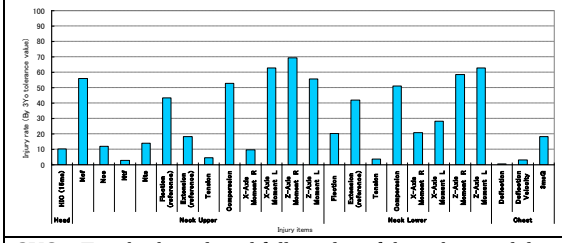
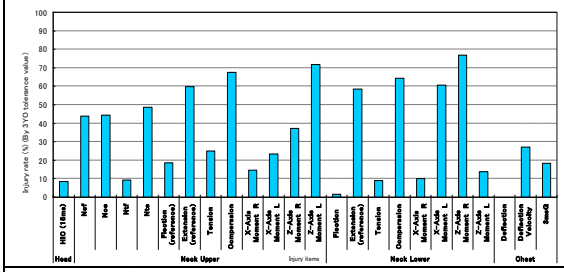
APPENDIX 1

Table 3: Results of out-of-position tests

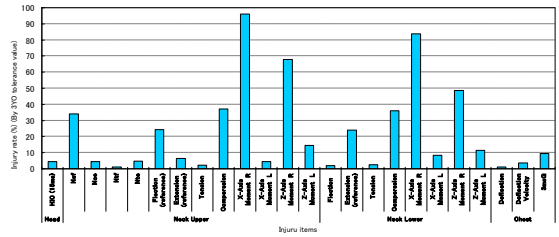
3YO – Turn backwards and half overlap of the airbag module



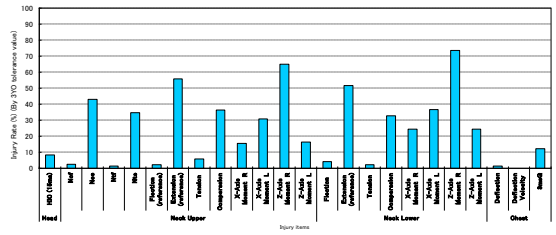
3YO – Turn backwards and full overlap of the airbag module



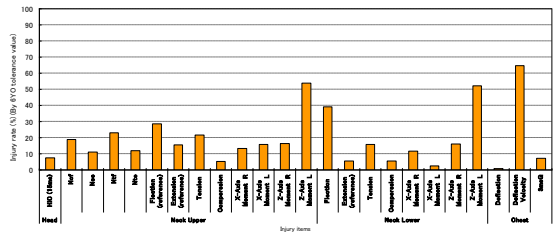
3YO – Face front



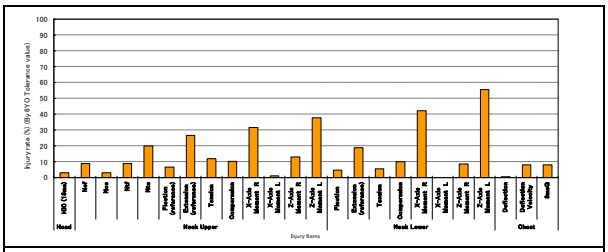
3YO – Turn sideways



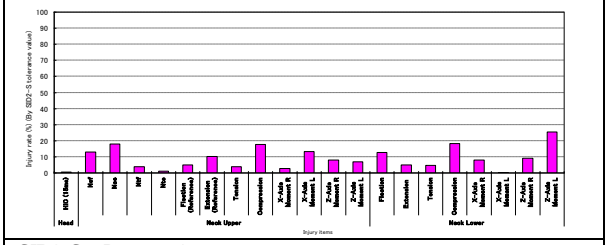
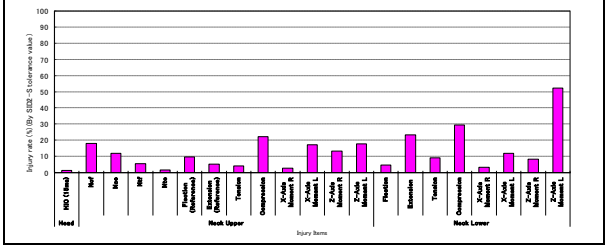
6YO – Face front



6YO – Turn sideways



SID2-S – Position 1



SID2-S – Position 2