Development and validation of a reference vehicle for future research in passive safety

Thorsten, Adolph
Federal Highway Research Institute, BASt (1)
Germany
Richard, Damm
Ministry of Transport, Building and Urban Development (2)
Germany
Nimoy Kanjuparambil, Ulrich Langer
University of Applied Sciences Cologne (3)
Germany
Arno Meyna
University of Wuppertal (4)
Germany
Daniel Huster
University of Applied Sciences Dortmund (5)
Germany

Paper Number 13-0446

ABSTRACT
The objective was to develop and validate a crash trolley (reference vehicle) equipped with a compartment and a full restraint system for driver and front seat passenger which can be used in full scale crash testing. Furthermore, the crash trolley should have a suspension to show rotation and nick effects similar to real vehicles.

Within the development phase the reference vehicle was build based on a European family car. Special attention was needed to provide appropriate strength to the trolley and its suspension. The reference vehicle is equipped with a restraint system consisting of airbags, pedals, seats, dashboard, and windshield. On the front of the vehicle different crash barriers can be installed to provide miscellaneous deceleration pulses.

For the validation phase a series of low and high speed crash tests with HIII dummies were conducted and compared with full scale tests. For the comparison deceleration pulse, dummy numbers and vehicle movement were analyzed.

Validation tests with velocities up to 60 km/h showed promising results. The compartment and the suspension systems stayed stable. Rotation effects were comparable with full scale car crash tests. The airbags and seat belt system worked reasonable. The acceleration pulse compared to an Euro NCAP test had a similar characteristic but was in general slightly lower.

After the successful validation the reference vehicle is already in use in different studies in the field of vehicle safety research at BASt.

INTRODUCTION

For crash tests usually two types of methods are used. The most realistic procedure is to use the whole vehicle, also called a full scale crash test. This kind of testing requires the full equipped vehicle including dummies. In contrast sled test are used for component development und dummy research. Sled tests are much cheaper and faster to perform, but have certain limitations in terms of rotational and pitching movement during the impact. In addition to this intrusions are difficult to apply.

For different research questions a test method would be useful which has the advantages of both methods, sled tests (cheap and repeatable usage) and reacting more like a real car including a chassis with suspension and a full restraint system. This was achieved by the modification of components of an existing real car which is durable enough for repeating crash tests. Therefore a crash trolley was developed which has a chassis with suspension and damper systems, in the following called reference vehicle. On the crash trolley a compartment of a European middle class vehicle is installed so a full restraint system can be integrated.

This reference vehicle could be for example applied in the field of dummy development, compatibility research and testing of road side barriers.

Accident analyses have identified improvements in regard to frontal impact and compatibility (1). However, it is difficult to describe the compatibility of a
A mobile deformable barrier has different advantages particular with regard of the assessment of frontal stiffness to match deformation force levels between the colliding vehicles (5). The final test procedure for the MPDB (mobile progressive deformable barrier) is described in (6) and (7). The reference vehicle is in addition to this able to evaluate the frontend stiffness of the opponent car due to the assessment of the dummy loading.

Further research is planned for the testing and assessment of road side barriers. Often older cars will be used and no dummies are installed in the vehicle. The evaluation of the performance of the restraint system can be helpful to assess the acceleration level from the road side barrier in particular for small and stiff vehicles (8) and (9).

The objective of this paper was to describe the development and validation of a crash trolley (reference vehicle) equipped with a compartment and a full restraint system for driver and front seat passenger which can be used frequently for crash testing. Furthermore, the crash trolley should have a suspension to show rotation and pitch effects similar to real vehicles.

For the validation crash test data of the reference vehicle were compared to an Euro NCAP crash tested vehicle. Differences were analyzed to determine the advantages and disadvantages and to understand the boundary conditions of the reference vehicle for future investigations.

MATERIALS

Based on German registration statistics in 2006 the three most represented vehicles in road traffic with a test weight of about 1.500 kg were identified by their market share (10). The typical weight for a medium vehicle is about 1.500 kg (11) and also the test weight which was chosen for the MPDB crash test procedure within the FIMCAR project (3).

Three models were identified which had the largest market share: Volkswagen Golf/Jetta, Opel Astra and Audi A3. After comparing technical details and the effort to recreate them in a reference vehicle the Opel Astra was chosen. The Opel Astra had a relatively simple 3-point “Mc-Pherson” wheel suspension which makes it easier to recreate and stabilize.

To simulate the Astra the shortened passenger compartment was mounted and stiffened on a steel frame. The construction was designed to obtain the same mass distribution and inertia torque as the original Opel Astra. With the adjustable suspension the reference vehicle is able to simulate the rolling- and pitch-motions as they were observed at the real vehicle. Furthermore the height adjustments allow the adaptation of the ride heights of the reference vehicle to analyze the influence of different masses on the spring deflection.

The main framework is made of steel including the chassis. The compartment was integrated and reinforced. Special attention was needed to provide appropriate strength to the trolley and its suspension. The additionally reinforcement was chosen in such a way that the mass and the centre of gravity is still comparable to the original vehicle. Thus, a realistic behavior is given in car-to-car crash tests (10).

The chassis of the middle class vehicle was changed in a way that crash test pulses do not damage or bend the structure. Particular focus was laid on the suspension system, because the flexible parts need to be durable enough for repeating crash tests.

In order to provide miscellaneous deceleration pulses different types of crash test barriers can be attached to the front of the vehicle. The PDB (Progressive Deformable Barrier, (12)) was a good candidate because the stiffness is quite similar to a real front end of this type of car (13). The frontend of the vehicle needed strengthening and a flat stiff plate for the attachment of the barriers. The Figure 1 shows the reference vehicle positioned in front of the crash block with Hybrid III dummies installed.
The reference vehicle is equipped with a restraint system consisting of airbags, pedals, seats, dashboard, and windscreen. The wind shield is made out of plastic which is durable enough for the crash tests. The front seat passenger airbag is supported by the wind shield as it does in a real vehicle.

In the back of the reference vehicle the installation of the trigger box for airbags and seatbelts, the emergency brake system, the data acquisition box and further systems can be installed for the tests.

METHODS

For the validation a series of low and high speed crash tests with HIII dummies was conducted and compared with full scale tests (14). For the comparison deceleration pulse, dummy numbers and vehicle movement were analyzed.

First a couple of low speed crash tests were performed at lower speeds to check the straight running, durability and the emergency brake systems. Inspections and static measurements were conducted before and afterwards to check the stability of the reference vehicle and to ensure the vehicle’s crash resistance.

A high speed crash test was performed and compared with a Euro NCAP crash test using an equivalent Opel Astra. The full scale crash test with the Opel Astra was conducted according to the Euro NCAP frontal impact test protocol with 64 km/h, 40 % overlap against the ODB and with two Hybrid III Dummies. For the reference vehicle the test speed, overlap and barrier types were selected accordingly. The reference vehicle had a PDB barrier attached, version 8 XT (extended). On the crash test block an ODB (15) barrier was installed with a LCW behind. The following Figure 2 gives an overview of the final test procedure.

RESULTS

The measurements of the dummies and the vehicle of two similar crash tests were compared and the differences discussed. For the comparison deceleration pulse, dummy numbers and movements as well as the vehicle movement were analyzed.

Crash Data Reference Vehicle

Vehicle values

In Figure 3 the accelerations measured at the a-pillar for both sides are shown for the reference vehicle and the Opel Astra Euro NCAP test configuration. The maximum accelerations measured in the passenger compartment show a similar characteristic with slightly lower accelerations in the reference vehicle. In the beginning the acceleration of the reference vehicle is a little bit higher due to the stiffness of the
PDB element. The real Opel Astra is softer in the first part of the crash due to the bumper region.

Figure 3  Comparison of the acceleration measured at the a-pillar

In the following Figure 4 the measured maximum accelerations in the vehicle are compared (tunnel, a-pillar and b-pillar). It turns out, that the measurements of the sensors placed in the vehicles are similar but in general slightly lower for the reference vehicle. Accelerations measured at the tunnel (Centre of Gravity) in z direction are lower for the reference vehicle which could indicate a lower pitch moment. This is comprehensible because the reference vehicle has less elastic parts compared to the Opel Astra.

Figure 4  Comparison of maximum vehicle accelerations

**Dummy values**

Also the effects on the upper parts of the dummy bodies from head to pelvis can be simulated very well with the reference vehicle. Figure 5 shows the resulting chest-acceleration of all four involved dummies as an example. It is recognizable that the characteristic of the graphs is very similar. However there is a displacement of the points in time with the maximum accelerations. In the reference vehicle the dummy loadings occur earlier due to the used barrier which has a different structure compared with the front of the Astra.

Figure 5  Comparison of the resulting chest acceleration

Figure 6 and Figure 7 show a comparison of the dummy values in relation to the ECE-R 94 limits (15). The limits for the different body regions as described in the regulatory frontal impact configuration are listed in Table 2.

<table>
<thead>
<tr>
<th>Body region</th>
<th>Criterion</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>HIC&lt;sub&gt;36&lt;/sub&gt;</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>a&lt;sub&gt;3ms&lt;/sub&gt;</td>
<td>80 g</td>
</tr>
<tr>
<td>Neck</td>
<td>My</td>
<td>57 Nm</td>
</tr>
<tr>
<td>Chest</td>
<td>ThCC</td>
<td>50 mm</td>
</tr>
<tr>
<td></td>
<td>VC</td>
<td>1 m/s</td>
</tr>
<tr>
<td>Femur</td>
<td>Fz</td>
<td>7,58 kN (&gt; 10 ms)</td>
</tr>
<tr>
<td>Knee</td>
<td>DS</td>
<td>15 mm</td>
</tr>
<tr>
<td>Tibia</td>
<td>Tibia-Index</td>
<td>1,3</td>
</tr>
<tr>
<td></td>
<td>TCFC</td>
<td>8 kN</td>
</tr>
</tbody>
</table>

The dummy values for the driver side show similar numbers as for the dummy in the Opel Astra Euro NCAP test (see Figure 6). However, the head impact and the loading of the chest were in the reference vehicle higher. This can be explained by the higher pulse in the beginning of the crash due to the PDB element attached to the reference vehicle. In addition the dummy is loaded from the steering wheel airbag which should have been fired a few milliseconds earlier to substitute the increase of the deceleration pulse. The numbers for the lower extremities are in a comparable range. Due to the stiffened passenger compartment the footwell of the reference vehicle stays stable in a crash. For this reason the loadings on the lower extremities of the occupants differ from those recorded in the Opel Astra.
The validation tests show that the reference vehicle is in principal suitable for crash testing. However, several limitations need to be considered. The test was driven with a velocity of 60 km/h and therefore 4 km/h slower than the Opel Astra Euro NCAP test. Nevertheless the loadings on the Hybrid III Dummies were at a higher level in the reference vehicle. The higher loadings are caused due to the stiffness of the PDB element which is different compared to the frontend of the Opel Astra. Additionally in the Opel Astra has a certain amount of elasticity which is higher compared to the reference vehicle.

The barrier element is difficult to modify but the overlap and the test speed can be changed easily which has a direct influence on the deceleration gradient. It needs to be considered that the first part (e.g. bumper) of the Opel Astra is very soft while the PDB element is not.

The analyses of the dummy values indicated that the occupant loading of the upper body regions are realistic. The characteristics of the curve linearity are comparable to the Opel Astra. However, differences are present in the maximum values and can be explained with the higher pulse in the beginning of the crash. This should be considered for the selection of the fire times for the restraint systems in future investigations. The analyses of the firing times show that the trigger times should be reduced of approximately 5 ms for future tests with similar deceleration pulses.

Comparative analyses of the high-speed movies showed that the rotational effects due to the offset in the impact configuration are very similar to the real car. Pitch effects were present but less because elasticity of the suspension and the frame are different compared to the Opel Astra.

In general the results showed that the reference vehicle can be used for different kind of crash testing studies. However, there are some limitations due to the design which need to be considered for further investigations. The restraint system has to be triggered manually which has advantages in repeatability studies. The crash pulse is dependent of the barrier used and the overlap.

CONCLUSIONS

A reference vehicle equipped with a compartment and a restraint system for driver and front seat passenger dummies was developed and validated successfully. A variation of the deceleration pulses can be achieved due to the attachment of different deformable barriers. The reference vehicle was able to cope with accelerations up to 35 g.

DISCUSSIONS
The reference vehicle is a useful tool to answer further questions in different fields of passive automotive safety and road network. Compared to a traditional crash trolley dummies can be used as well as rotational and nick moments are present. Future applications are planned in the field of dummy development, compatibility investigations and impacts with road side barriers.

ACKNOWLEDGEMENTS

The authors thank Kai Nebel for preliminary work conducted during his diploma theses. In particular the authors thank the Opel AG for the support during this project with the allocation of parts and knowledge during the development.

REFERENCES