

# IMPROVEMENTS TO PEDESTRIAN PROTECTION AS EXEMPLIFIED ON A STANDARD-SIZED CAR

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## SUMMARY

Despite the steadily declining number of pedestrian fatalities and injuries in most European countries during the recent decades, pedestrian protection is still of great importance in the European Union as well as in Germany. This is because they still constitute a large proportion of road user casualties and are more likely to suffer serious and fatal injuries than most other road users. In 1999 only car occupants suffered more fatal injuries than pedestrians in Germany. In December 1998, EEVC WG 17 completed their review and updating of the EEVC WG10 pedestrian test procedure that made it possible to evaluate the protection afforded to pedestrians by the front of passenger cars in an accident. Within the scope of this procedure four different impactors are used representing those parts of the body, which are injured very often and/or very seriously in vehicle-pedestrian-collisions.

In a project executed by ika and BASt a small family car was tested according to the EEVC WG 17 test procedure. Afterwards modifications to the car were carried out in order to improve the pedestrian protection provided by the vehicle design. There were certain restrictions placed on the level of modifications undertaken, e.g. only minor modifications to vehicle styling and to the vehicle structures, which provide passenger protection. The redesigned vehicle was tested again using the WG17 test procedure. The test results of the modified vehicle were compared with those of the standard vehicle and evaluated. The results show that considered measures for pedestrian protection in many areas of the vehicle front structure and the use of innovative techniques can lead to a significant reduction of the loads of pedestrians at an acceptable expense.

## INTRODUCTION

### Accident Data

In 1999 there were about 1.3 million traffic accidents with personal injury in the European Union, resulting in 42,000 fatalities. Among the fatally injured road users were more than 6,000 pedestrians and about 2,300 cyclists [2].

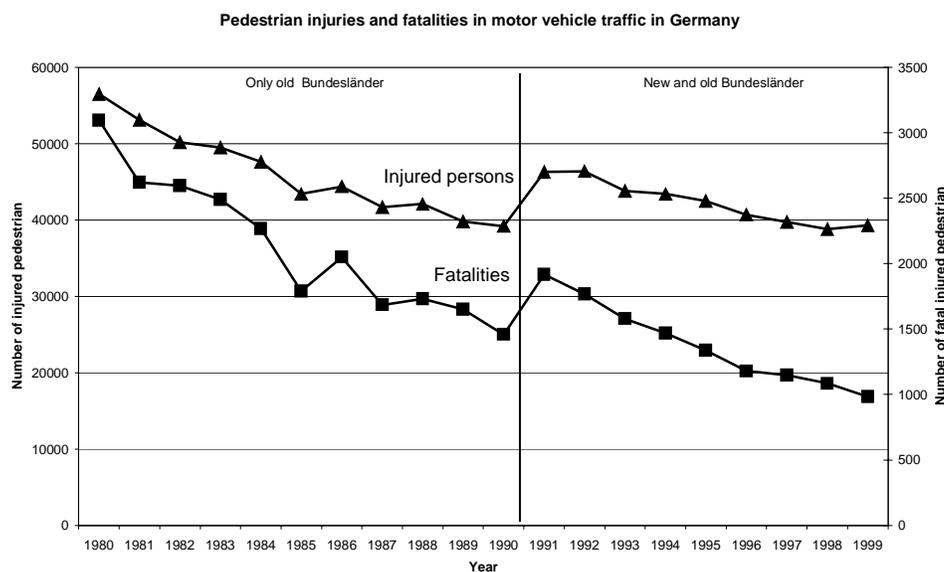
In the same year 395,689 accidents with personal injury were registered in Germany, with 521,127 people injured and 7,772 people killed. Pedestrians account for 7.5 % (in absolute figures: 39,312) of all injured road users including 12,805 seriously and 26,507 slightly injured pedestrians. Cyclists and their passengers account for 14.3 % (in absolute figures: 74,397) of injured road users. 16,621 cyclists were seriously injured and 57,758 only suffered slight injury.

Of the 7,772 persons who were killed in traffic accidents in 1999, 12.6 % were pedestrians, (absolute: 983) and 8.5 % cyclists (absolute: 662).

The number of cyclists involved in accidents was almost twice the number of pedestrians. However, cyclists were mostly only slightly injured, while pedestrians suffered fatal injury more frequently.

Considering road accidents with two involved traffic participants 23,982 occurred with pedestrians. Thereby in 76 % (in absolute figures: 18.230) of all cases the pedestrian was struck by a single vehicle. If these accidents are analysed in more detail, it can be seen that of the 490 pedestrians killed in accidents with two road users involved, 362 were killed in collision with a passenger car (73.9 %). For these single vehicle to pedestrian accidents the proportion involving passenger cars was 76.8 % [3] for the slightly and seriously injured pedestrians.

If the accident trend in Germany is followed over a longer period, it can be seen that the number of people killed and injured in accidents has decreased considerably (see Figure 1). Despite the overall decrease of European accident rates in the last few

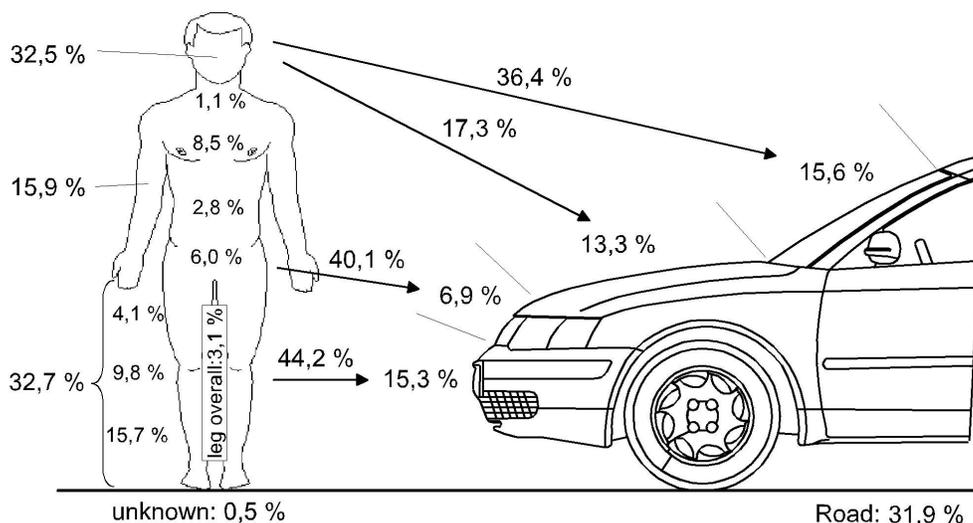


**Figure 1 Injured and fatally injured pedestrians in road traffic accidents in Germany (1980-1999)**

years further measures for the prevention and reduction of accident consequences are necessary, if the aim of the European Union to reduce the number of road fatalities from 44,000 in 1997 to 25,000 in 2010 [4], is to be met.

Since 1985 the Medical University of Hanover has been carrying out accident investigations at the sites of the accident in accordance with a statistical

random sampling plan, commissioned and funded by BAST directly. Estimates of the frequency distribution of injuries to individual parts of the body of pedestrians caused by a collision with a motor vehicle for the period between 1985 and 1998 were made based on these data. In addition, the vehicle components that frequently cause injury were determined (see Figure 2).



**Figure 2 Frequency of injury to different parts of the body of pedestrians and portions of the vehicle causing injury in collisions between vehicles and pedestrians (n=783)**

Figure 2 shows that the lower extremities are the most frequently injured body parts of pedestrians (32.7 %). For the lower extremities knee injuries are considered the most serious injuries because of their

long-term disablement consequences. Head injuries (32.5 %), which can result in fatalities, and injuries to the upper extremities (15.9 %) are often observed.

Examination of different areas of the vehicle front with regard to their influence on injuries shows that 15.6 % of the injuries were caused by the windscreen and its frame, 13.3 % by the top of the bonnet or wing , 6.9 % by the bonnet leading edge and 15.3 % by the bumpers. This comes to 83 % altogether. The remaining share up to 100 % comprises unknown cases and injuries caused by other car parts.

Allocation of the individual injuries to the part of the vehicle where they occurred shows that 36.4 % of the head injuries were caused by the windscreen and its frame, 17.3 % of head injuries were due to the bonnet, 40.1 % of hip injuries were caused by the bonnet leading edge and 44.2 % of leg injuries can be ascribed to the bumper.

If serious injuries to pedestrians during collisions with vehicles are analysed (AIS2+), it can be seen that the head and lower extremities are seriously injured most frequently, followed by the upper extremities. It is the case that the serious injuries are mainly caused by the impact with the vehicle and not the ground.

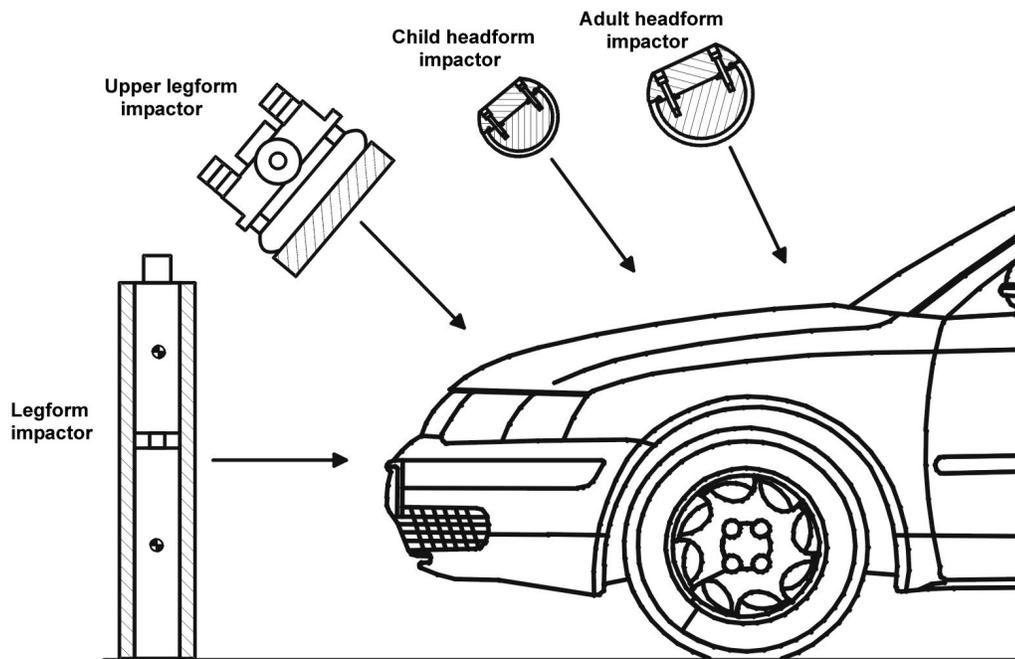
As Figure 1 illustrates, at the beginning of the 80s many pedestrian fatalities and injuries occurred in Germany and even today it is a serious problem. For this reason the EEVC has been considering the subject of pedestrian protection in various working groups since the beginning of the 80s. After

comprehensive investigations, partly financed also by the European Commission, the EEVC Working Group 17 submitted its final report "Pedestrian Safety" whose Annex includes a test procedure for investigating the pedestrian protection afforded by motor vehicles. This test procedure is described in the following section of this paper.

**TEST PROCEDURE FOR INVESTIGATING THE PEDESTRIAN PROTECTION AFFORDED BY MOTOR VEHICLES IN ACCORDANCE WITH EEVC**

The test procedure according to EEVC WG17 [1] is based on sub-systems tests, in other words, no tests are carried out using complete pedestrian dummies. Instead of this, individual test pieces, so called impactors, are used, which represent individual parts of the pedestrian body which are most frequently and seriously injured. There are three main types of impactors and altogether four impactors (see Figure 3):

- Headform Impactors,
  - Adult Headform Impactor,
  - Child Headform Impactor,
- Upper Legform Impactor,
- Legform Impactor.



**Figure 3 Overview of EEVC component test procedure for investigating pedestrian protection afforded by motor vehicles**

The impactors represent the head of an adult, the head of a child, the thigh or hip and the leg of an adult pedestrian. The test procedure aims to investigate the vehicle structures which most seriously influences the pedestrian kinematics and injury in a collision with a motor vehicle. The test conditions correspond to an accident where a pedestrian is hit by a vehicle travelling at a speed of

40 km/h at impact.

The impactors described above, the test methods and the load criteria to be applied are presented in Table 1. The most recent version of the test procedure in accordance with the EEVC Working Group 17 is shown (WG17 have revised and updated the test methods originally developed by EEVC WG10).

**Table 1 EEVC Pedestrian Protection Test Procedure (Version: EEVC WG17)**

Test procedure	Contents	EEVC Proposal
Child headform to bonnet test	Test procedure	Impactor mass Impact speed Impact angle
	Criteria	HPC
Adult headform to bonnet test	Test procedure	Impactor mass Impact speed Impact angle
	Criteria	HPC
Legform to bumper test (Height of lower bumper reference line < 500 mm)	Test procedure	Impactor mass Impact speed Impact angle
	Criteria	Acceleration Bending angle Shear
Optional upper legform to bumper test (Height of lower bumper reference line -LBRL > 500 mm)	Test procedure	Impactor mass Impact speed Impact angle
	Criteria	Total force Bending moment
Upper legform to bonnet leading edge test	Test procedure	Impactor mass Impact speed Impact angle
	Criteria	Total force Bending moment

### OPTIMISATION OF A MOTOR VEHICLE IN ACCORDANCE WITH EEVC WG17

At the Institut für Kraftfahrwesen Aachen (ika) of RWTH Aachen a vehicle was modified in consideration of the test procedure of EEVC WG10/WG17 within the framework of the research project entitled "Optimised vehicle front with regard to pedestrian protection". The test methods and the load criteria of EEVC WG17 were considered. As the revised headform impactors and the lower leg impactor of EEVC WG17 were not available at that time, impactors according to EEVC WG10 were used for the test programme. The use of the older versions

of these impactors is thought to have had little effect on the test results.

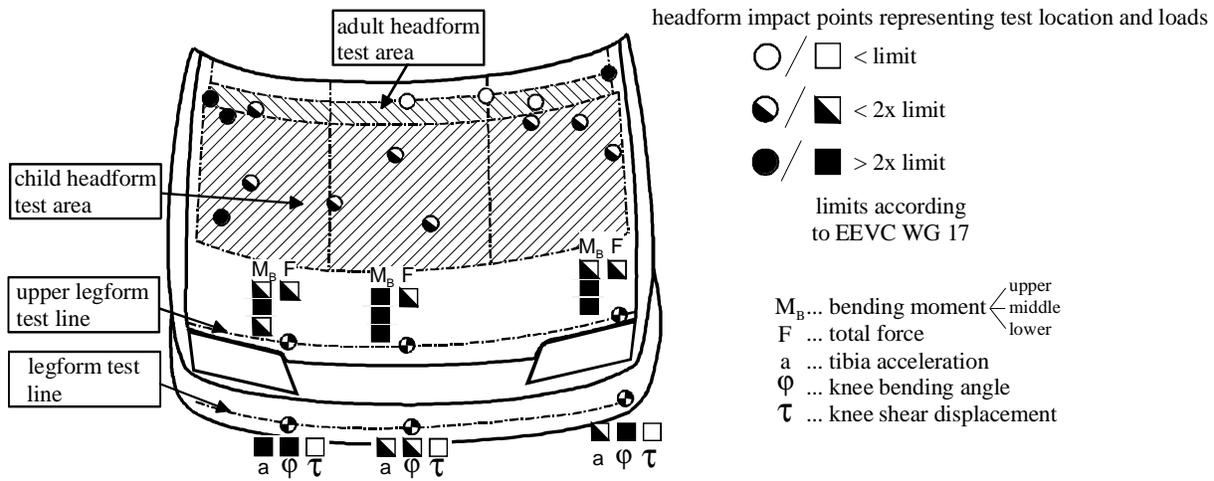
A representative small family car was selected for the investigations. First, the standard production vehicle was tested for pedestrian protection in accordance with the EEVC WG17 test procedure. Based on the results of the investigation, modification were made to the vehicle aiming to improve the test results. The modified model was tested again according to the EEVC WG17 procedure. From these tests the effectiveness of the design and construction changes was investigated and evaluated. The research project was commissioned by the Federal Highway Research Institute (BAST). The EEVC WG17 tests within the framework of the project were carried out at the BAST

in Bergisch Gladbach, Germany. The most important results of this research project are described as follows.

### Test results with a standard vehicle

For the tests with the head impactors, impact locations at which under-bonnet components were close to the underside of the bonnet as well as areas where the bonnet was thought to be very stiff were selected, see Figure 4. These stiff areas specifically include the connecting points of the bonnet hinges or

the ribs of the bonnet inner panel. The top edge of the wings were also considered very stiff, however, they were such a shape as to deflect the head of a pedestrian and did not lie within the area prescribed for the EEVC WG17 headform tests. As the EEVC WG17 headform test method specifies minimum distances between the test locations as the test area for the adult headform was small only six adult headform impact tests were carried out instead of the full nine tests required by the test procedure.



**Figure 4 Test results with standard vehicle**

The test locations selected for the upper legform to bonnet leading edge tests were the mounting of the left headlight, the bonnet latch and the end of the upper frame longitudinal member.

The legform tests were to the right-hand third of the bumper onto the area at which the bumper is connected with the frame longitudinal member; to the vehicle centre and to the outer end of the bumper. The bumper end was thought to have a high injury potential, since the curvature of the plastic cover at this point has a stiffening effect.

The test results achieved with the small family car are shown in Figure 4. With the adult headform impactor the limit value  $HIC=1000$  is fulfilled at three points in the centre of the bonnet and included locations at which beads of adhesions existed between the inner and outer panel of the bonnet or hood. At the outside right- and left-hand test locations the  $HIC$  amounts approximately 4000, since the bonnet hinge was impacted or the deformation travel was limited by the upper frame longitudinal member.

In the child head area no impact point tested was found to comply with the limit value of  $HIC=1000$ . At the impact locations with an  $HIC$  between 1000 and 2000 it was concluded that the stiffness and/or

the moment of inertia of the steel bonnet was too high. The  $HIC$  values above 2000 were attributed to the contact of the bonnet with underlying structures. There was a particular need for improving the front edge of the hood in the area of the hip impact test as both the total force and the bending moments exceed the given limit values at all three test locations. This was particularly so at the middle impact location where very high loads were registered because of the stiffening effect of the bonnet latch.

In the case of the legform to bumper tests the shearing displacement was within the limit value at the three test locations. The impactor was supported each side of the knee after slight deformation of the bumper cover. Limit values for tibia acceleration and knee bending were nevertheless exceeded with the knee bending angle recorded being restricted by the mechanical bending stops of the impactor.

### Modifications of the small family car

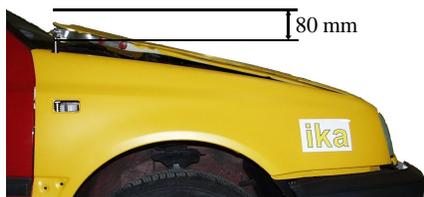
Modification of the motor vehicle, were restricted so as not to change components relevant to the safety of

the vehicle occupants. Furthermore it was decided that the modifications should be done in a way neutral to the styling of the vehicle.

**Modification of the headform to bonnet test areas**

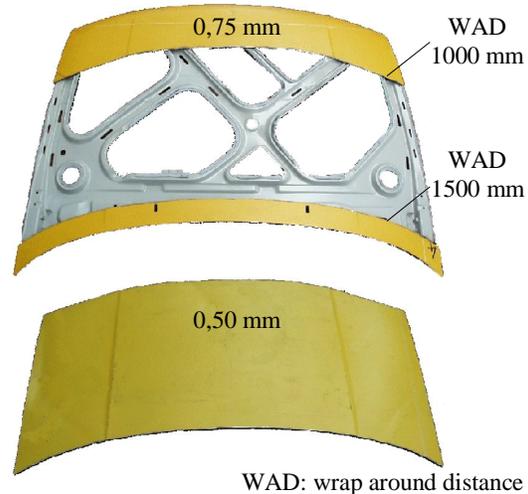
The EEVC test requirements can only be fulfilled if there is enough space between the bonnet surface and immovable objects underneath the bonnet (eg. engine and suspension towers) to allow the energy of the headform impactor to be converted into deflection. In order to fulfil the limit value of HIC=1000, the theoretical deformation distance for the child headform to bonnet test amounts to about 53 mm and for the adult headform to bonnet test to about 63 mm. In order to achieve these deformation distances, the stiffness of the bonnet must be reduced in the child and adult headform impact areas. In the area in which the two zones border each other, the bonnet must be designed in accordance to the requirements of the lighter child headform. For the adult headform to bonnet test a practical deformation distance of up to 100 mm may be required if typical efficiencies of absorbing energy are used.

Since it was decided that the frame longitudinal members should not basically be affected by the modifications and that the styling of the vehicle should not be changed, the necessary deformation distance was created by raising the bonnet during impact. A mechanism was developed by means of which the rear edge of the bonnet was actively raised by 80 mm if an accident occurs, see Figure 5. The mechanism is based on pretensioned spiral springs and the bonnet can be returned to its original position without repair work being necessary. The time needed for the raising of the bonnet for this design was about 100 ms. The bonnet was held in the raised position by means of residual tension in the springs. Since the bonnet in the area of the hinges can be pushed downwards when in its raised position, the raising mechanism is also intended to make impact on the bonnet hinges less serious. In future production triggering could be realised by means of pre-crash sensors that are currently at the development stage, or suitable contact sensors or mechanical devices activated under pedestrian impact load.



**Figure 5 Raising of bonnet**

In order to reduce stiffness and moment of inertia of the bonnet, in the child headform test area the 0.75 mm metal outer panel currently in use was replaced by sheet of 0.50 mm thickness, Figure 6. The hood stiffening structure was not changed.

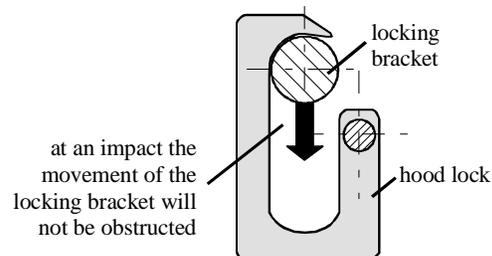


WAD: wrap around distance  
**Figure 6 Thinner outer panel in the child headform test area**

**Modification of the upper legform to bonnet leading edge test area**

The impact conditions for this test are dependent on the shape of the car under test. The EEVC WG17 look-up graphs specifies a 12.6 kg impactor with an impact energy of 533 J for the small family car tested for the upper legform test to the middle of the vehicle. If the maximum impact force of 5 kN is not to be exceeded, a minimum deformation distance of about 110 mm is necessary assuming typical energy absorbing efficiencies. In order not to exceed the permissible bending moment of 300 Nm, the impact force must be introduced into the impactor over an area as large as possible.

Within the framework of vehicle optimisation, a modified bonnet latch was used that does not prevent downwards movement of the locking bracket in the case of impact, see Figure 7.



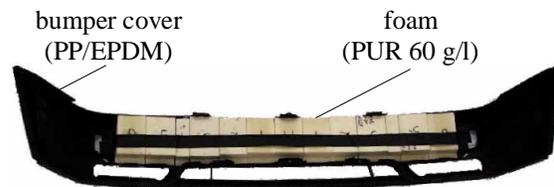
**Figure 7 Modified bonnet lock**

For the tests with the upper legform impactor to the right and left hand thirds of the standard production vehicle, the headlamps were found to have a significant effect on the results exceeding the limit values. The lenses and the housing are so stiff that they do not allow any significant deformation of the bonnet leading edge. Even if the headlamp mounting points were to fail, there was no additional deformation distance available. In order to improve impact behaviour with the upper legform impactor, the headlamps were modified to make them more flexible with lenses made of plastic. In addition, the front-end of the car was weakened at several places. The upper frame longitudinal members were provided with a 70 mm long notch at their ends in order to reduce their vertical stiffness. Considering the fact that 70 % of the energy released in a crash is taken up by the lower frame longitudinal members [5] and that the upper frame longitudinal members were only weakened in the front area, only very slight worsening of safety for the vehicle occupants is to be expected due to this modification.

#### Modification of legform to bonnet test area

With a limit value for tibia acceleration of 150 g a theoretical deformation distance of about 42 mm is necessary, if the impactor neither bends at the knee nor rotates about the bumper nor absorbs any energy in its knee or flesh. The free space between bumper cover and front cross members is 40 mm in the case of the standard production vehicle. Within the framework of vehicle optimisation with regard to the legform to bumper test, the bumper cover was moved forward 20 mm, in order to increase the deformation distance to 60 mm. The standard production plastic bumper cover was made more elastic and a foam-core of PUR 60 g/l inserted between cover and cross members, see Figure 8. This was intended to reduce the tibia acceleration and the bending of the legform impactor, as after sufficient deformation of the bumper, the legform impactor can be supported on the bonnet leading edge which will prevent further lateral bending of the knee.

When increasing the deformation distance of the bumper, the lower edge of the cover was brought forward 10 mm further than the upper edge, in order to displace downwards the first contact of the vehicle with the legform impactor compared with the original situation. This was also intended to reduce lateral knee bending.



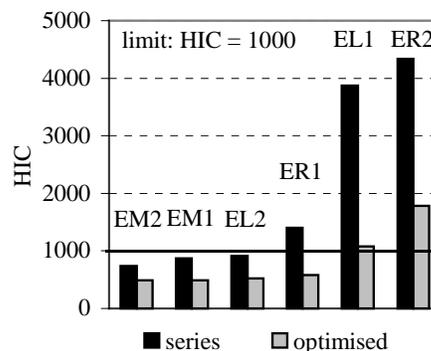
**Figure 8 Bumper system with foam**

#### **Test results with the modified vehicle**

In order to investigate and evaluate these modifications the tests originally carried out on the standard vehicle were repeated on the improved vehicle.

#### Headform to bonnet tests

The results of the adult head impact tests with the modified vehicle and the standard production vehicle are shown in Figure 9.



**Figure 9 HIC for adult headform to bonnet tests with the small family car**

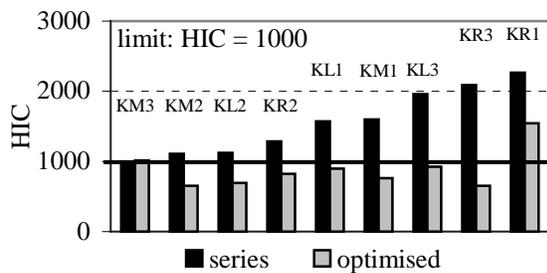
The modifications have clearly improve the test results in the case of the adult headform to bonnet test. At test locations EM2, EM1, EL2 and ER1 the HIC value was now well below the limit value of HIC=1000. In the case of the locations EL1 and ER2 the HIC values are improved by more than 58 %, but they still exceed the limit value.

Locations EL1 and ER2 are situated right above the upper frame longitudinal members. The deformation distance with raised bonnet is more than 80 mm. This means that sufficient travel distance was available to transform the kinetic energy of the impactor into deformation energy and therefore to fulfil the limit value. When the impactor hit the bonnet, the connecting rods of the bonnet raising mechanism retracted. During this process the deceleration of the headform impactor dropped to less than 20 g, so that during this period only a small amount of impact energy was absorbed. When the connecting rods were

in their final position there was still so much energy in the headform impactor, that the upper frame longitudinal member was impacted. The performance can be further improved by optimising the spring stiffness or by using springs or energy absorbing struts with a progressive characteristic curve.

The results of the child headform to bonnet tests with the modified and standard production vehicles are shown in Figure 10.

Clear improvements as regards HIC values were achieved at all test locations. HIC values were reduced by about 30 % at point KR1 and up to 70 % at location KR3. The improvement were particularly notable at test points KL1, KR3 and KL3, which were situated above the upper frame longitudinal members and the suspension-strut dome, with HIC values under 1000 being achieved with the modified vehicle. This improvement is due to the bot raising of the bonnet and reducing its stiffness, which considerably increases the available deformation distance.



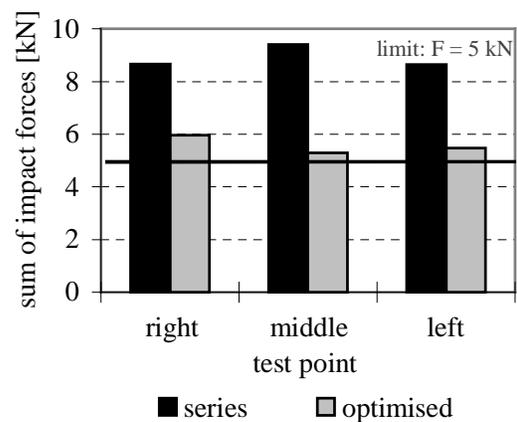
**Figure 10** HIC in child headform to bonnet tests with the small family car

**Upper legform to bonnet leading edge tests**

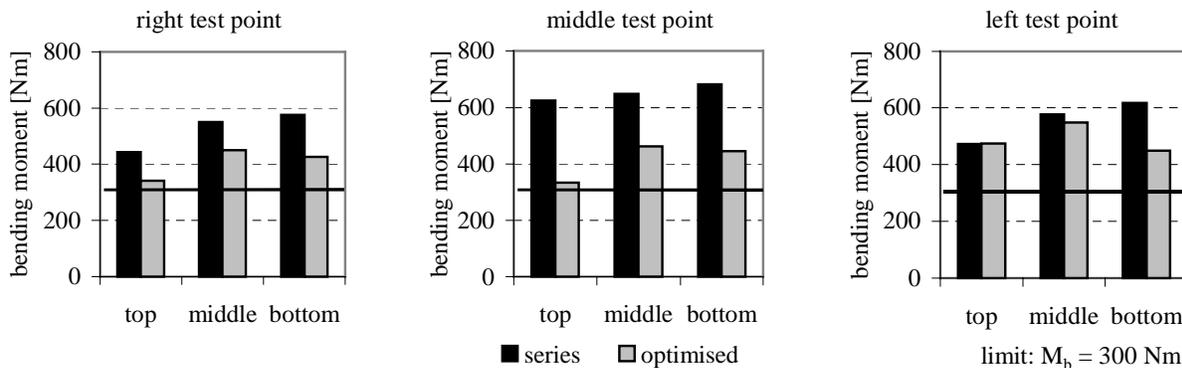
The results of the upper legform to bonnet leading edge tests comparing the modified vehicle and the standard production vehicle are shown in Figure 11 and Figure 12.

The modification measures lead to clear improvements in the vehicle performance at the middle and right-hand test locations. The values for the bending moments were reduced by about 30 % to 50 %, the impact forces were almost halved. Nevertheless, all the values still exceed the limit values proposed by EEVC WG17.

In the case of the left-hand impact point, the upper longitudinal member has a decisive influence on the test results. The values for the upper and middle bending moment are 27 % lower than with the standard production vehicle. Also, the total impactor force is considerably lower, particularly because of the decreased force at the lower end of the impactor.



**Figure 11** Total forces in upper legform to bonnet leading edge tests with the small family car

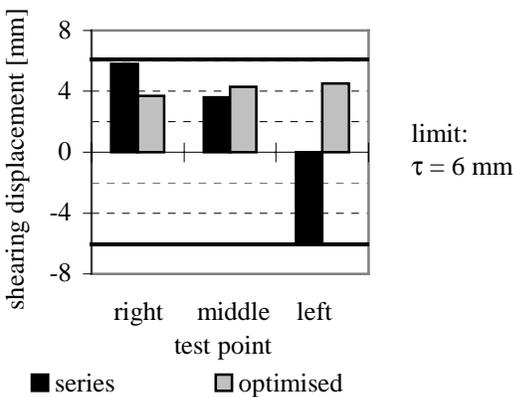


**Figure 12** Bending moments in upper legform to bonnet leading edge tests with the small family car

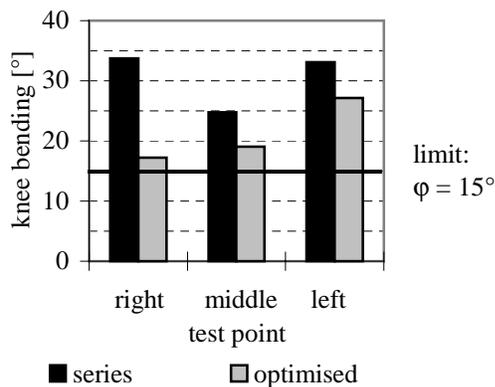
### Legform to bumper test tests

The results of the legform to bumper tests with the improved vehicle and the standard production vehicle are shown in Figure 13 to Figure 15.

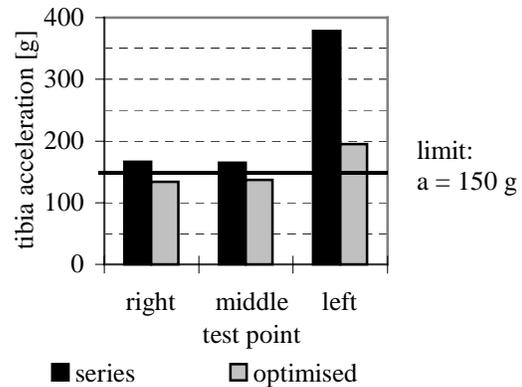
The shearing displacement of the knee at the three test locations was about 4 mm for the improved vehicle and is therefore well inside the allowed limit value of 6 mm (Figure 13). Knee bending angle was also improved by means of the modifications, but still lies above the permitted value of 15 degrees (Figure 14). Again in the case of tibia acceleration, clear improvements were achieved, despite the limit value being slightly exceeded at the left-hand test location, where the modifications lead to much more favourable test result with acceleration being reduced by about 50 % (Figure 15).



**Figure 13** Shearing displacement in legform to bumper tests with the small family car



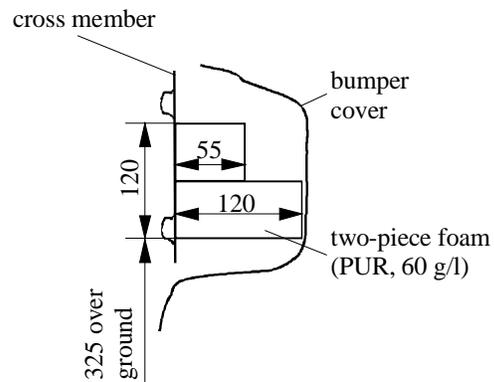
**Figure 14** Knee bending in legform to bumper tests with the small family car



**Figure 15** Tibia acceleration in legform to bumper tests with the small family car

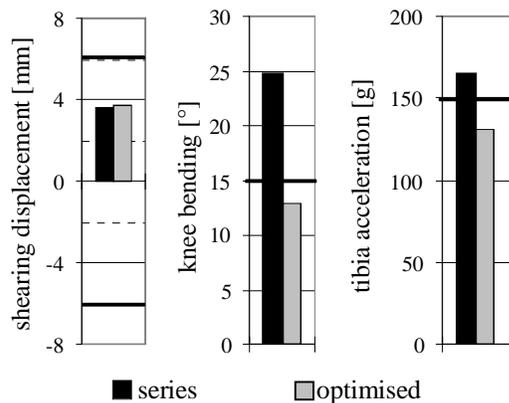
A further modification was made for the legform to bumper test. A bumper was produced which allowed a longer deformation distance between the cover and the crossmember, Figure 16.

The foam core was produced in two pieces, so that the point where the bumper force acts upon the legform impactor is as low as possible. This result in the impactor rotating so that the upper part of the impactor will be supported on the front edge of the bonnet early during impact reducing knee bending.



**Figure 16** Bumper with longer deformation distance and two-piece foam core

The three specified limit values were found to be fulfilled with these further revisions of the bumper design, see Figure 17. The investigation shows that if the deformation distance was now long enough and the point of application of force was now low down on the impactor, that all the limit values could be observed. It is also thought conceivable that a bumper with a foam core that changes density over the height of the bumper can have similar impact properties whilst taking up less space.



**Figure 17 Test results of the legform to bumper test with the use of two-piece foam core**

## CONCLUSION

Despite the fact that accident figures for pedestrians in Germany have been decreasing for years, pedestrians are still very frequently injured and killed, particularly in collision with passenger cars. For this reason, pedestrian protection is of great importance both in the European Union and in Germany.

Against this background the EEVC WG 17 presented a test procedure in December 1998 which makes it possible to determine the loads on pedestrians during a collision with a passenger car. The test procedure requires the use of four different impactors which represent those parts of the human body that are injured most frequently or seriously in pedestrian-car collisions.

Using the EEVC WG 17 test procedure a small family car was tested in a joint project of BASt and ika. After implementation of modifications to improve pedestrian protection, the vehicle was retested. The considerations of the requirements to improve pedestrian protection to meet the criteria proposed by WG17 and the test results can be summarised as follows:

It is only possible to achieve measure values below the required limit for the headform impact test if enough deformation distance is available. Within this project the bonnet was raised to achieve the required deformation for the headform impact tests. For production cars this measure can be achieved using active systems in a way that neither the styling nor the aerodynamics of the vehicle are affected. If the bonnet raising mechanism, activated during the impact, is suitably designed, the effects of impact both in the area of the hinges and above the frame longitudinal members can be rendered less serious. However, before active systems can be used, suitable

sensors and activating systems must be developed. For the child headform to bonnet test, the stiffness of the bonnet must also be reduced.

With regard to the upper legform to bonnet leading edge test, modifications which could be carried out to current production vehicles have been shown to considerably reduce the impactor loads. In the case of the vehicle which was analysed, however, such modifications did not result in observance of the EEVC WG17 limit values. The investigations show that in order to observe the limit values, new concepts are necessary in the area of the bonnet leading edge. These will have to be taken into consideration at an early stage of vehicle development, as modifications to the frame longitudinal members as well as to the design of the bonnet and its connection to the front end are thought to be necessary.

The test results with the EEVC legform impactor can be considerably improved if a bumper system with foam core is used and a deformation distance of 60 mm to 70 mm is provided, tibia acceleration can be reduced to less than 150 g. Knee shearing displacement does not cause problems with smooth and even bumper covers, if the contact between impactor and bumper occurs exactly at knee height. In order to fulfil the limit value of 15 degrees, there must be precise adjustment of the bumper and the front edge of the bonnet. If the upper leg section can be supported on the front edge of the bonnet, it is not necessary to provide a spoiler lip that extends far forward which would limit the ground clearance of the vehicle.

## LITERATURE

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