A TECHNICAL EVALUATION OF THE EEVC PROPOSAL ON PEDESTRIAN PROTECTION TEST METHODOLOGY

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ABSTRACT

Following the publication in November 1994 of the EEVC WG10 proposal for methods to evaluate pedestrian protection for passenger cars and the subsequent adoption of those recommendations into a European Commission draft proposal, ACEA (European Automotive Manufacturers Association) initiated a project to perform a technical evaluation of those test methodologies. The proposed methodology consists of sub-system tests of a child and an adult headform to the bonnet surface, an upper leg impact to the bonnet leading edge, and a leg impact to the bumper and front structure of the vehicle.

The programme of work undertaken by ACEA was performed at two European test laboratories and consisted of 269 tests with the four impactors. The tests were performed on seven vehicles selected to represent the variety of vehicles currently on the European roads. Subsequent additional testing has also been performed to add to the experience gained in this initial test programme.

This paper reports the work performed within this test programme plus the subsequent test work performed to date. It details the test results of typical vehicles on the road today, evaluates the test methodology in terms of repeatability and reproducibility. The experience gained in performing the tests is reported and conclusions are drawn relating to the practicality of performing these tests and the technical feasibility of applying the proposed requirements to future vehicles.

INTRODUCTION

An ACEA project was set up in 1995 to perform a technical evaluation of the proposed pedestrian protection test procedure which had been developed by EEVC WG10, and to assess the practicality of the procedures in a vehicle development environment. The objectives of this programme were to evaluate the test methods, to establish the performance of current vehicles and to assess the technical feasibility of the proposed legislation for European vehicles.

The ACEA programme consisted of a total of 269 tests with the four pedestrian impactors and at two laboratories, with seven different vehicles. The seven vehicles which were initially selected for this programme, were chosen to represent the European vehicle parc, as regards mainly their size, design and engine configuration. An eighth vehicle, on which an additional 18 tests were performed, was later added to obtain improved repeatability data for the upper leg and leg impactors. The vehicles selected were the Citroën XM, Fiat Punto, Range Rover, Renault Twingo, Renault Espace, Rover 100, Volvo 940, and VW Golf.

For each of the four subsystems, the test programme consisted of:

- An evaluation of each of the vehicles according to the proposed test procedure;
- A study of the repeatability of the test procedure;
- A study of the reproducibility of the test procedure;

OVERVIEW OF TEST METHOD AND PROGRAMME

The programme of vehicle tests was performed according to the EEVC WG 10 pedestrian protection test procedure which was adopted as a draft proposal by the EC DG III. The test proposal consists of a series of sub-system impact tests to the front end structure of a vehicle with instrumented impactors designed to represent the adult head, child head, upper leg, and leg of a pedestrian.

According to the proposal, the vehicle bonnet is struck by a child or an adult headform depending on the impact position on the bonnet. Both headforms strike the vehicle at 40 km/h (11.1 m/s) and are in free flight before contacting the bonnet. The child headform, weighing 2.5 kg, is fired at 40 degrees to the vertical, whilst the adult headform, weighing 4.8 kg, is fired at 25 degrees to the vertical. A triaxial accelerometer mounted at the centre of the headform measures accelerations from which a Head Injury Criteria can be calculated. Where the impact zones permitted, twelve head impact tests were performed on each vehicle split equally between child headforms and adult headforms, and between those locations expected to give better results and those expected to give worse results. On vehicles with shorter bonnets some adult headform tests were omitted. Further, one vehicle was selected on which repeatability tests were performed.

The bonnet leading edge of the vehicle is struck by a linearly guided upper legform impactor. The impact conditions (energy, velocity, and angle) are dependent on each vehicles' geometry and, for any vehicle, can vary from the centre of a vehicle to its edges. The impact energy for a vehicle could theoretically be between 200 J and just under 1000 J, the velocity between 20 km/h and 40 km/h, and the impact angle between 10 and 47 degrees to the horizontal. Values for the tested vehicles were in the ranges: 312-949 J, 22.7-40 km/h, and 19.1-43.3 degrees, which represents a good spread acroos the range of test conditions. The impactor is instrumented to measure impact force on each end of the impactor front member, and the bending moment near the centre of the front member of the impactor. Three upper leg impact tests were performed on each vehicle at different positions. Again, one vehicle was selected for repeatability tests.

The bumper and front structure of the vehicle are struck by a legform impactor which has an articulated knee joint. The impactor, weighing 13.4 kg, strikes the vehicle front at 40 km/h and is in free flight on contact. The leg is instrumented to measure accelerations in the tibia, shear displacement in the knee joint and the bending angle in the knee joint. Three leg impact tests were performed on each vehicle at different positions followed by repeatability tests on one selected vehicle.

Once these tests were completed additional tests were performed at a second test laboratory on the vehicles selected at the first laboratory for repeatability tests. Three head impact tests were performed at 6 bonnet positions and three upper leg and three leg impact tests were performed at each of the three impact positions used previously. This gave both repeatability data from two test laboratories and permitted the reproducibility between the test laboratories using different test rigs to be calculated. An eighth vehicle was also later tested at the second laboratory with three upper leg and three leg impact tests at each of three locations on the bonnet leading edge and bumper to more appropriate repeatability data.

The upper leg impactor was also tested against a flat rigid plate at reduced impact speeds in order to investigate the bending moment which can be induced purely by the uniform compression of the Confor™ foam.

ANALYSIS OF RESULTS

Headform Tests

The cars were tested with the child and adult headform impactors, insofar as the impact area for adults on the bonnet was large enough. This was not the case with two cars, for which no adult point could be tested, and, to a certain extent, with a third car, for which only four adult impact points could be tested instead of six. Impact points were carefully selcted to get both good and bad results for both the child and the adult headforms.

The results of the tests are illustrated in Figure 1 for all the vehicles and all the impact locations. Despite 50 % of the locations being chosen with the expectation of being better locations, only 22.9 % of all the points tested could meet the requirement of a HIC less than 1000; this corresponds to 16 points out of a total of 70 points tested (9 for the child headform out of 42 tests and 7 for the adult headform out of 28 tests). As a whole, the results showed that none of the tested vehicles is able to meet the required HIC value for all of the impact locations.

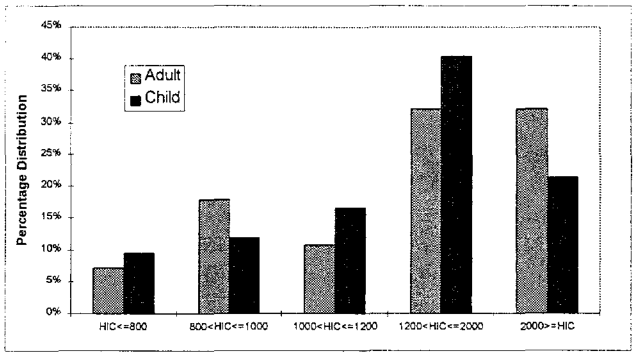

Figure 1. Percentage Distribution of Head HIC levels for Adult and Child Headforms.

One vehicle was selected in order to investigate the repeatability of the procedure. Two additional tests were performed on six of the original twelve locations. On examination of these results it was observed that the repeatability improved as the HIC level reduced (Figure 2). This was assumed to be due to the absence of contact with underbonnet hard points which increases the test sensitivity. As a result, the repeatability is reported only for those three impact locations giving results around the EEVC limits.

The repeatability* of the tests at LAB 1 ranged from -4.9 % to 4.7 %, whilst at LAB 2 the repeatability was from -4.3 % to 3.7 %.

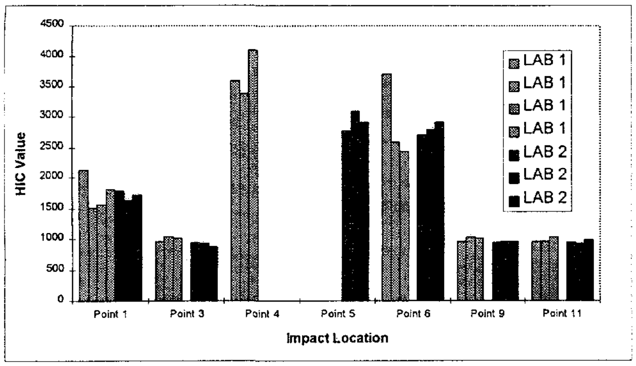

Figure 2. Repeatability and Reproducibility results for Head Impact Tests.

The reproducibility** between the two laboratories, where the results were around the EEVC limits, was ± 4.9 %. This gives a total scatter of all comparable tests in the range of -9.0 % to 9.1 %.

Upper Legform Tests

The vehicles were tested along their bonnet leading edge (BLE). In each third of the BLE one target point is associated to two geometric distances (bonnet leading edge height and bumper lead) which define the test conditions (velocity, energy and impact angle) of the upper legform impactor, in accordance with the requirements of the EEVC proposal. Each vehicle was tested at:

- the centre line
- the centre of the left-hand headlight
- the inside corner of the right-hand headlight

A new piece of Confor™ foam was used for each test because it was believed that the properties of the foam would degrade with each impact. The tests were conducted using Confor™ foam cut according to the new dimensions specified by TRL which avoids a load path to the back of the impactor through the foam.

* Repeatability is calculated as the percentage of deviation of a single test from the average of the tests for an impact location at a single laboratory.

** Reproducibility is calculated as the percentage of deviation of the test lab average from the mean value of both test lab averages.

The results of these tests are given in Figure 3 for all vehicles. No vehicle met the requirements either for the total load or for the bending moment in any of the 21 tests. The measured values were up to three times higher than the proposed EEVC limits (4 kN - total load, 220 Nm - bending moment).

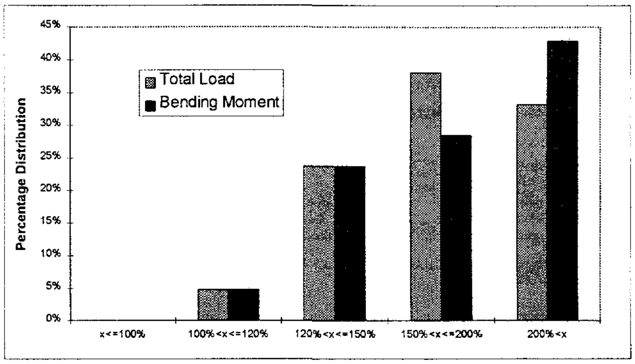

Figure 3. Percentage Distribution of Upper Leg Load and Bending Moment Relative to the Proposed Limits.

One vehicle was chosen for two additional tests to show the accuracy of repeatability. The values measured for the total loads scattered in the range of -11.9 % to 16.2 % and for maximum bending moments in the range of -11.1 % to 14.1 % at LAB 1. For LAB 2, the values measured for the total loads were scattered in the range of -10.3 % to 7.2 % and for the maximum bending moments in the range of -10.3 % to 7.8 %.

Having found that with the head impact the repeatability alters as the limits are approached, additional tests were performed with an eighth vehicle which was believed to have a better performance. Tests on the eighth vehicle at LAB 2 resulted in total load being scattered in the range of -4.4% to 7.7% and bending moments in the range of -4.3% to 4.5%.

The reproducibility (Figure 4) between LAB 1 and LAB 2 was up to ± 7.8 % for both loads and moments. The total scattering for comparable test results from LAB 1 and LAB 2 was in the range of -16.5 % to 15.3 % for both, loads and moments.

Legform Tests

The tests were performed at three points across the front of the car. In accordance with the prescribed procedure, these were selected to provide the most severe conditions, and the centreline. Typically the bumper mounting, towing bracket, or front longitudinal provided the 'worst case' targets.

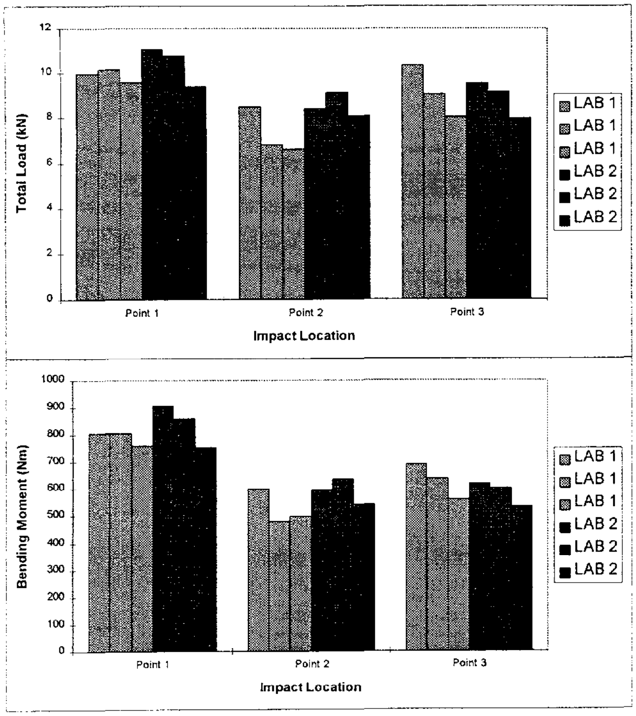

Figure 4. Repeatability and Reproducibility Results for Total Load in Upper Leg Impacts.

The summarised results for all vehicles are presented in Figure 5. It was seen that no vehicle met the EEVC Criteria for the legform completely. The tibia acceleration values exceeded the 150 g limit in 17 of the 21 cases. The peak bending angle limit of 15° was exceeded in all but two cases, one recording 14.8° at a location bolt, and another 11.3° at the corner of the mounting. 15 of the 21 tests had a bending angle peak value above 28.5°; the design maximum mechanical limit of the knee joint is around 30°, and all these results probably involve physical limits of the knee being reached; values could be higher if more articulation was possible.

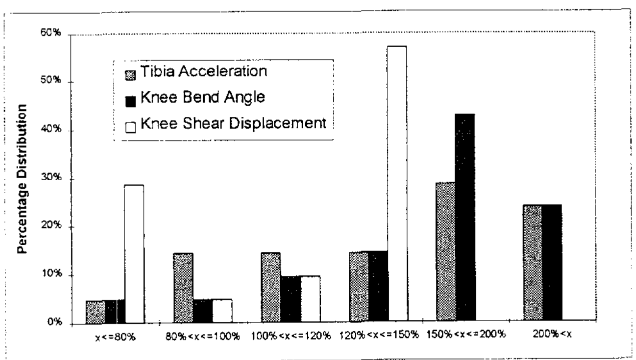

Figure 5. Percentage Distribution of Leg Injury Parameters Relative to the Proposed Limits.

In contrast, the peak shear displacement was satisfied in 6 cases, three on one vehicle, two on another. However, the highest twleve results all exceeded 7 mm displacement and were all most likely affected by the mechanical limit.

The result for any vehicle is dependent on shape, stiffness, and height of the major bumper elements and of the nearby structure above the bumper. The ligaments absorb little of the initial kinetic energy by bending meaning that both sections of the legform must be physically stopped by the vehicle structure in a controlled manner.

At LAB 1, a vehicle was selected for repeat tests at a reduced impact speed of 35 km/h in the expectation that the results would be less affected by the mechanical shear and bend limits. Even at these reduced speeds the bending mechanical limit was reached on each test and therefore repeatability data for knee bending cannot be calculated.

Repeatability tests at LAB 1 (based on two tests per point) gave ± 3.5 % for tibia acceleration and ± 12.7 % for knee shear. The same vehicle was used for repeatability tests (based on three tests per point) at LAB 2 and gave a range of 12.3 % to - 12.6 % for tibia acceleration and a range of 50 % to - 26 % for knee shear.

Similar to the upper leg testing, an eighth vehicle, which was believed to have a better performance, was tested at LAB 2. In all the tests on this vehicle the mechanical limits were not reached. For the tibia acceleration the repeatability was -11.1% to 10.8%, for knee bend it was -21.4% to 12.3%, and for knee shear it was -10.5% to 7.5%. Though these results are better, they are far from the level of repeatability one would expect from a legislative test requirement.

Reproducibility between the two laboratories (Figure 6.) is up to 15.7 % for tibia acceleration and up to 42 % for knee shear displacement. The overall range of scatter is 25.6 % to - 19.4 % for tibia acceleration and 79.8 % to - 46.1 % for knee shear displacement.

Additional Testing

Upper legform impact tests against a rigid plate at 4, 5, and 6 m/s gave an apparently linear relationship between impact speed and measured impact force. The relationship indicated that an impact generating the proposed force limit of 4 kN would require an impact speed of 4.48 m/s, and that the bending moment created due to compression of the foam would be 205 Nm. Though the impactor was created to encourage designs with greater radii of curvature, even with an infinite radius the inherent design of the impactor creates a bending moment close to the proposed criteria of 220 Nm, unless there is significant deformation.

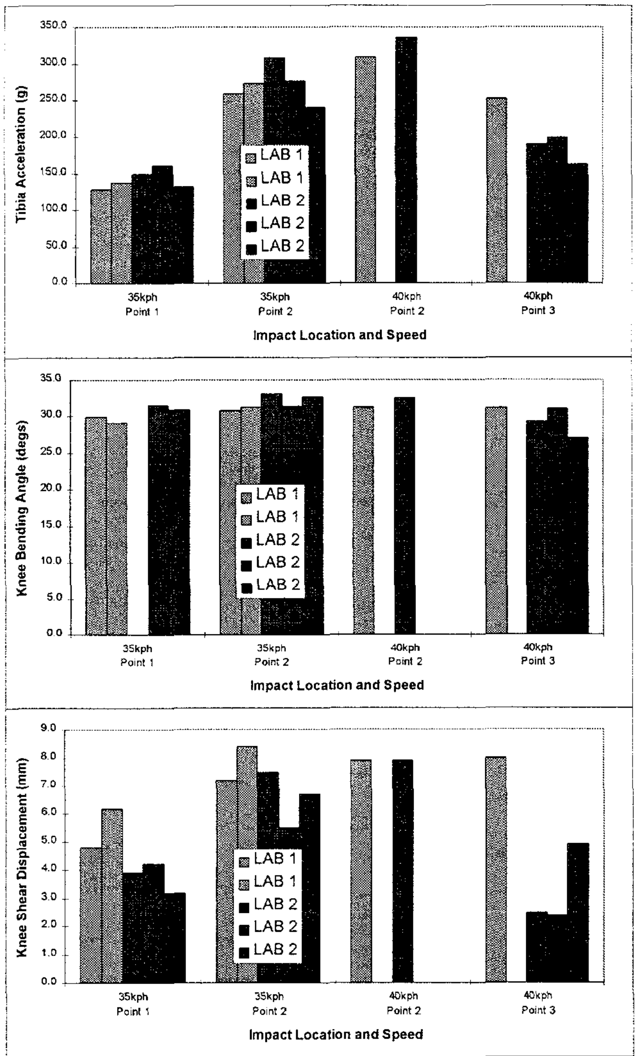

Figure 6. Repeatability and Reproducibility Results for Lower Leg Impact Tests

The geometry of some vehicles, particularly off-road vehicles, necessitates performing an upper legform impact and a child head impact at the same location. A mock-up vehicle front end was constructed using layers of foam with a covering of a single sheet of 0.7 mm thick steel such as would be able to achieve the upper legform criteria. An impact test with the upper legform was performed at the conditions typical of an off-road vehicle which has the maximum impact energy. The mock-up was very close to achieving upper legform compliance. But, when a child headform impact was performed a HIC of 1863 was calculated indicating that the two impact test requirements could be incompatible.

TEST EXPERIENCE AND COMMENTS

Headform Tests

The calibration corridor of 225 to 275 g for adult headform and 210 to 260 g for the child headform could cause large deviations on HIC. On the other hand, the measured deceleration of the headform appeared to be quite sensitive to the fixation of the skin and a variation in decelerations of 100 g were measured during the calibration procedure in one test house.

A minimum time between impacts, including the certification tests, should be established to ensure that the skin has fully recovered before the next test.

The impact velocity required is 11.1 m/s ± 0.5 m/s; the 0.5 m/s tolerance (equivalent to ± 9 % of energy) could cause large deviations in the HIC values; this will increase the amount of scattering in repeatability tests. It is proposed that this tolerance should be reduced.

Upper Legform Tests

A main problem was the abnormal bending of the main body of the impactor after only 50 impacts although the load cells never exceeded their maximum load limit of 18 kN.

The shape of some vehicle front ends caused the impactor to contact another point on the bonnet before contacting the target point. This caused the impactor to rotate upwards or downwards. The proposal does not ensure that the first point struck is always the target point.

The allowed velocity deviation of about ± 5 % could cause increased scattering in repeatability tests and should be reduced.

Pre-loading of the Confor™ foam caused by fitting the rubber skin could influence the results of the impactor. Further investigation of this phenomenon is required.

Legform Tests

Examination of traces showed that a vibration at about 80 Hz was present, and this is noticeable in the acceleration and shear outputs at about 5-10 g and 1 mm amplitude respectively. Relative to the proposed criteria this vibration would limit confidence in the repeatability of test results, and could change 'passes' into 'fails', or vice versa. Further modifications to the legform are being investigated at TRL to damp out the shear vibration, and so the results and any conclusions for this impactor have to be regarded as provisional.

Detailed analysis of the results is hampered by nearly all tests reaching the mechanical stops at an angle around 30° or a shear around 7.5 mm. Such tests will provide very little in terms of design guidance, as it changes the kinematics of the leg, and could render the acceleration result meaningless. The legform needs to be designed such that there is an increased overload capability without influencing the kinematics, particularly for the knee shear displacement, in order to be a valid vehicle development tool.

One repeatability test at 40 km/h suffered from breakage of the ligament retaining bolts after the maximum possible angle had been reached and excess energy remained, but this was late enough not to affect tibia 'g' values. The bolt problem has been encountered at TRL too, however in a vehicle which complies with the proposed requirements this problem should not reoccur.

In the repeat tests, the maximum shear displacements were sometimes positive, sometimes negative. The shape of the trace always followed a set pattern and the highest absolute value is used in the analysis of the results. There is still a very large variation in the absolute values for nominally identical tests. For shear displacements, the unpredictable change of peak time and direction between impacts indicates a potentially unrepeatable situation which is not a satisfactory basis for a legislative proposal.

The tibia accelerations can vary by 20 % for nominally identical conditions. It was noted later that there was a 10 mm difference in some bumper reference line positions between the two laboratories. If this was due to damage not apparent on visual inspection, it is likely that the performance could also be affected. A further study of repair/replacement conditions is required; visual inspection may not be adequate.

The legform was calibrated to the quasistatic procedures specified but not to the dynamic calibration requirements specified in the draft proposal as these were known to be invalid. The necessity for a dynamic test which recreates the vehicles impact conditions without reaching the mechanical limits is clear. Further, the requirements for re-calibration in the proposal also need clarification.

CONCLUSIONS

This extensive series of testing of vehicles representative of the European vehicle parc has indicated that most, if not all, vehicles would be severely affected by the introduction of the proposed pedestrian requirements. Though about a quarter of head impact locations achieved compliance there would be significant challenges in meeting the requirements for all impact locations. Upper leg and leg impact performance was far from achieving the proposed requirements and would involve major redesign and repackaging of vehicle front ends. It may be that conflicts will exist between the front end requirements to protect pedestrians and the other crashworthiness requirements for vehicle front ends.

The head impact test appears to be the most robust with acceptable repeatability and reproducibility in testing compliant locations. This is not the case for the upper leg impact test where the repeatability and reproducibility can be slightly larger than would be recommended as regulatory tool. Significant concerns must be expressed regarding the leg impact test where even tests that give acceptable results experienced unacceptably poor repeatability.

Some details of the proposed requirements need clarification or amendment, and some further investigation of the impactors is required. In particular, the impact speed tolerance should be reduced and the calibration requirements and methods reviewed. The legform impactor suffers from oscillations in it's shear displacement measurement which need to be damped. It is further limited as a development tool by the lack of overload designed into the knee shear with the mechanical limit being only around 1.5mm greater than the proposed requirement.

Designing vehicles to provide pedestrian protection is a further step towards reducing the fatalities and injuries on the road, however the tools and requirements used to guide the design of vehicles must be robust and repeatable to be used in a development environment.

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REFERENCES

EEVC WG10, "Proposals for methods to evaluate pedestrian protection for passenger cars". Final Report. November 1994

EC DG III, "Draft proposal for a European Parliament and Council Directive relating to the protection of pedestrians and other road users in the event of a collision with a motor vehicle and amending Directive 70/156/EEC". February 1996