EVALUATION OF THE EFFECTS OF TEST PARAMETERS ON THE RESULTS OF THE LOWER LEGFORM IMPACTOR

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ABSTRACT

The PDB, BASt and Opel conducted two test series to evaluate possible effects on the results obtained using the EEVC WG17 Lower Legform Impactor as a test tool for the assessment of pedestrian safety.
The reproducibility and repeatability of the test results were assessed using six legform impactors while keeping the test parameters constant. In the second series one impactor was used and the test parameters were varied to assess the effects on the readings of the legform. The test parameters were velocity, temperature, relative humidity, the point of first contact regarding the deviation in z-direction and the deviations of the pitch, roll and yaw angle.
The tests were performed using an inverse setup, i.e. the legform was hit by a guided linear impactor equipped with a honeycomb deformation element. This setup was chosen to be able to vary each single parameter while avoiding variations of the other test parameters at the same time. The test parameters were varied stronger than allowed in regulatory use in order to determine possible dependencies between the parameters and the readings which were acceleration, bending angle and shear displacement.

INTRODUCTION

During the last years great progress was made in enhancing the pedestrian safety capabilities of passenger cars. To improve current and future vehicles even more it is necessary to have testing equipment which enables the engineers to assess improvements even in small steps.
Therefore it is essential to know in detail about the performance of the testing equipment and the parameters that influences the performance.
For this purpose PDB, BASt and Opel designed a series of tests to research the performance of the EEVC WG17 Lower Legform Impactor. The test series were split into two steps. In the first step the repeatability and the reproducibility were addressed. In the second step effects produced by the propulsion system, e.g. point of impact and deviations of the angular orientation as well as environmental influences, e.g. temperature and humidity were addressed.
All tests had in common an inverse setup. That means that the legform in contrary to regular testing was attached to a fixture and was hit by a linear guided impactor. To simulate the impact on a bumper of a vehicle, the face of the impactor was equipped with an aluminum honeycomb deformable element. This setup was chosen to be able to precisely control the variation of the test parameters. Thus the effect on the performance of the legform could be evaluated in detail.
The velocity at the time of impact was chosen according to the regulatory test procedure to achieve similar kinematics in order to avoid discrepancies due to dynamic effects.

TEST SETUP

As mentioned in the introduction the test setup was inverse as shown in Figure 1. The legform was attached to a frame using a hook, that was designed such that the legform releases itself when it starts to move due to the impact (Figure 2). In that way the influence of the fixture on the kinematics of the legform could be considered negligible.
The aluminum honeycomb had the dimension 250mm x 160mm x 60mm and a compressive strength of 75psi. The impact surface was covered with a layer of paper to prevent the neoprene skin of the legform from being cut by the honeycomb.
The impactor which was attached to a sled that runs on two tubes using linear ball bearings was accelerated by a hydraulic propulsion system. By using the guiding tubes the propulsion system did not affect the position and the orientation of the impactor. The Propulsion system was able to reproduce the speed within a close tolerance.

Figure 1. Propulsion system with linear guided impactor.

Figure 2. Support system for the legform with release spring (left) and position of impactor relative to point of impact (right).

The chosen point of impact was the midpoint of the cavity in the ligaments and the upper edge of the honeycomb on the impactor (Figure 2).
For this series of tests the ligaments, the foam and the honeycombs were taken from a single batch each to minimize the influence of a possible variation of the material properties.
The determination of the influence of varying material properties on the performance of the legform could be an objective of a subsequent test series.

PREPARATION AND CHECK OF THE LEGFORM IMPACTORS

For the assessment of the repeatability and reproducibility as well as for the parameter study all legform individuals used for the tests were inspected regarding

- no visible damages,
- weight,
- geometry,
- center of gravity (femur, tibia, assembly),
- passed static and dynamic certification test.

The center of gravity was corrected when needed as far as possible by adjusting the position of the weight in the tibia section.
This was done to ensure that the variation of the test results was not affected by readings of an impactor which could not be considered for regular testing due to failing a certification test or being out of the specification.
Before starting with the inverse impacts all legforms were certified by performing the static and dynamic tests as specified in [2]. Each legform was assigned to an individual set of foam and ligaments.

ASSESSMENT

The assessment was performed by statistically evaluating the particular maxima of the measured data for the bending angle, the shear displacement and the tibia acceleration considering the mean value, the standard deviation, the absolute minimum and maximum, the minimum and maximum deviation from mean and the CV (coefficient of variation, i.e. standard deviation divided by the mean value in percent). For “acceptable” repeatability and reproducibility, respectively, the threshold of the CV is defined to be less than 5% [3]. Test equipment causing a CV higher than 5% is considered to be “not acceptable” for testing.

TESTING

The testing was split into two steps. In the first step six legforms were used to assess the repeatability and the reproducibility of the lower legform while keeping the test parameters as constant as possible. In the second step only one legform was used to assess the influence of the different test parameters that could vary when performing regular tests on vehicles. The test parameters which are supposed to affect the test results were identified to be

- the velocity at the time of impact,
- the point of first contact with respect to the z-direction,
- the orientation of the legform at the time of first contact, regarding pitch, roll and yaw angle,
- the temperature of the foam and
- the relative humidity of the foam.

Repeatability and Reproducibility

The tests for assessing the repeatability and the reproducibility of the legform were performed using six individuals.
The test conditions were defined as follows:

- impactor velocity – 11.1m/s,
- point of impact – mid of ligaments,
- temperature – 21°C±1°C,
- rel. humidity – 30%-70% .

The series contained a total of 76 tests. The tests were distributed to the legforms according to Table 1.

Table 1.
Number of tests with the individual legforms

Legform #	L1	L2	L3	L4	L5	L7
Number of tests	10	10	15	10	15	16

Results – The first tests confirmed that the chosen setup was convenient to produce readings comparable to those obtained in tests with a vehicle. Figure 3 shows typical responses of the three sensors produced with the inverse setup for an impact velocity of 11.1m/s.

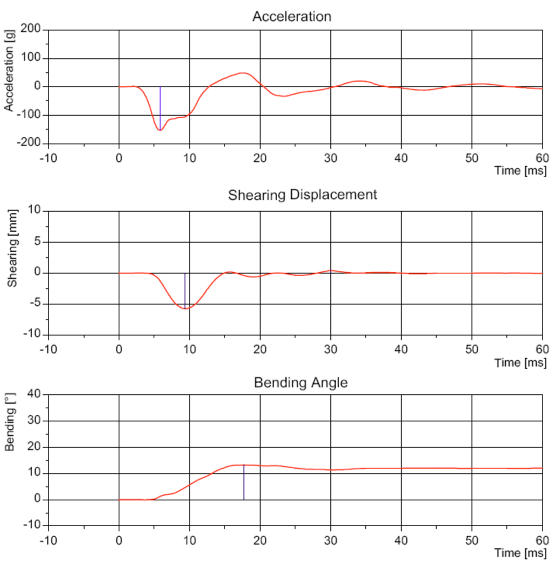

Figure 3. Typical readings of the legform sensors obtained with the inverse setup.

The bar graphs in Figure 4 give an image of the individual means for the three measurement locations of the legform whereas the graph in Figure 5 displays the three CV's for each legform.
The results of the statistical evaluation for the assessment of the reproducibility are listed in Table 2. The CV values from Table 2 are pictured in Figure 6.

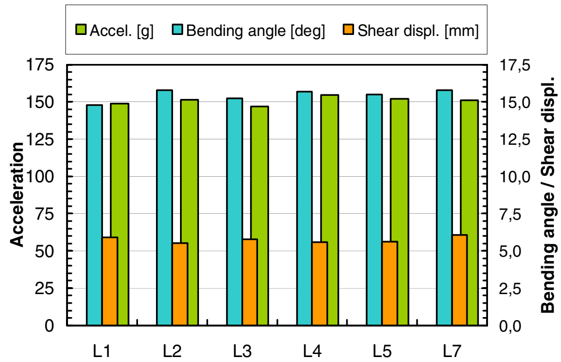

Figure 4. Mean values of bending angle, shear displacement and tibia acceleration of the legforms.

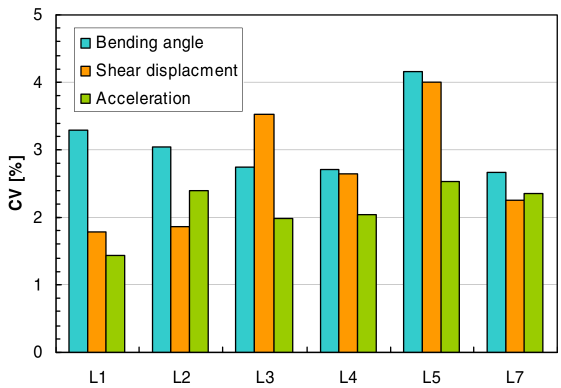

Figure 5. Coefficient of variation with respect to repeatability over all tests of each legform.

Table 2.
Results of the reproducibility study in engineering units (EU) and %.

		Bending angle	Shear displ.	Accel.
Mean	[EU]	15.47	5.76	150.64
Standard deviation	[EU]	0.58	0.26	3.98
	[%]	3.76	4.50	2.64
Minimum absolute	[EU]	14.00	5.20	140.90
Maximum absolute	[EU]	16.70	6.30	159.90
Max dev. from mean	[EU]	1.47	0.56	9.74
	[%]	9.47	9.70	6.47
CV	[%]	3.76	4.50	2.64

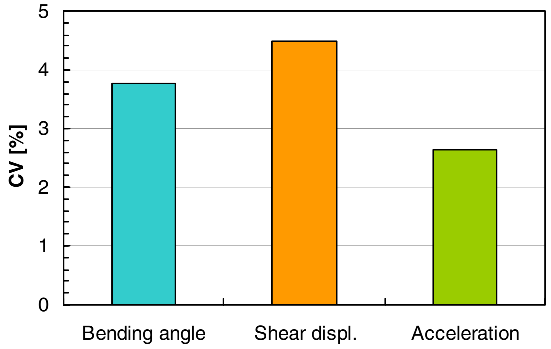

Figure 6. Coefficient of variation with respect to reproducibility over all tests.

Analysis – The analysis of the means shows no significant behavior of one of the legforms which can be covered by the measurements even if the standard deviations of the individuals differ considerably.

With regard to the mentioned CV threshold of 5% for an acceptable repeatability all legforms fulfilled this criterion. In this context it is important to keep in mind that the test parameters had to be within narrower than the regulated corridors. It can be observed that the legforms differ with respect to their overall performance. The wider spread readings of legform #5 in comparison to the other five legforms could not be explained by the influence of test parameters that were outside the defined limits or setup failures.

Looking at the three measures the tibia acceleration shows the best repeatability followed for the majority of the legforms by the shear displacement. The bending angle seems to be the least predictable measurement.

The result of the data evaluation regarding reproducibility with CV's below the threshold could be expected due to the fact that all individual CV's were acceptable and the means didn't differ that much. But it is also evident that deviations of almost ten percent from the overall mean are possible without any observable indication for the particular cause.

Parameter study

For a better understanding of the influence of the different test parameters on the performance of the legform this parameter study was conducted. The assessment was carried out using one single legform.

If not intentionally varied the values for the fix parameters were set to the same values and the same limits, respectively, as in the repeatability and reproducibility test series.

In detail the corridors for the variation of the test parameters were set as follows:

- impactor velocity – ±0.5m/s from 11.1m/s (6 tests),
- point of impact – ±5mm and ±10mm from mid of ligaments (6 tests each),
- orientation – pitch, roll and yaw angle ±5° (6 tests each)
- temperature – 16°C – 24°C (6 tests),
- rel. humidity – 10% – 70% (12 tests),
- time between subsequent tests – 0.5h, 1h, 2h, 4h and 12h (16 tests).

For the variation of the legform temperature and the relative humidity a climate chamber was used, that was capable to control both parameters at the same time.

Results – The following diagrams are the most significant from the complete matrix of results which contains the dependencies of the three measures from all the test parameters listed above. The dependencies were determined using a linear regression that was applied to the data. The data points are also shown as scatter plots to give an impression of their distribution.

The Figures 7, 8 and 9 show the influence of the impact velocity on the tibia acceleration, the bending angle and the shear displacement. The dependency of the tibia acceleration from the temperature is shown in Figure 10, and the dependency of the bending angle from the point of impact in the z-direction in Figure 11.

Table 3 summarizes the outcome for those parameters that were identified to have a considerable influence on the test results to be produced with the legform. The results are given as a gradient of the linear regression and as a percentage with respect to the threshold of the particular measurement.

The results of a statistical evaluation are listed in Table 4. The values were calculated only for that subset of the data which was produced with the test parameters within the allowed corridors. To emphasize the CV values they are additionally depicted in the bar graph of Figure 12.

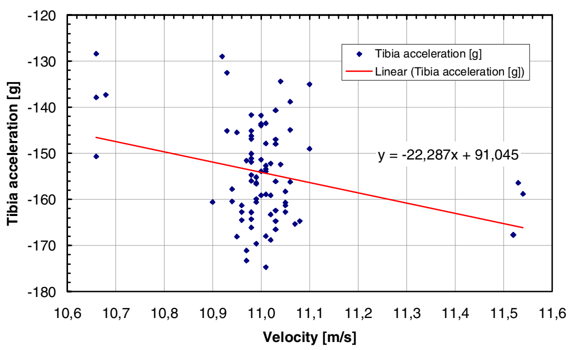

Figure 7. Dependency of the tibia acceleration from the impact velocity.

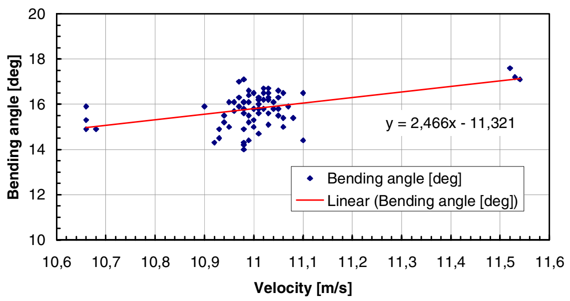

Figure 8. Dependency of the bending angle from the impact velocity.

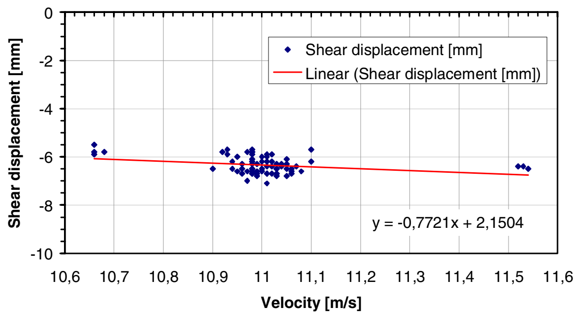

Figure 9. Dependency of the shear displacement from the impact velocity.

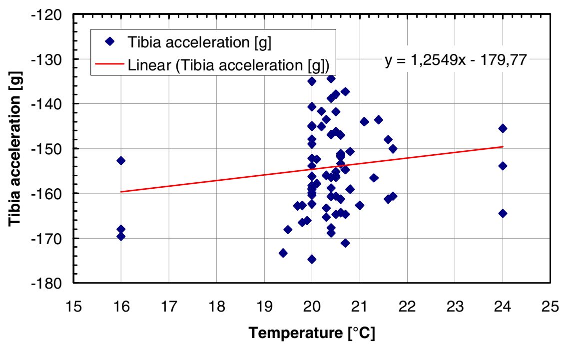

Figure 10. Dependency of the tibia acceleration from the temperature.

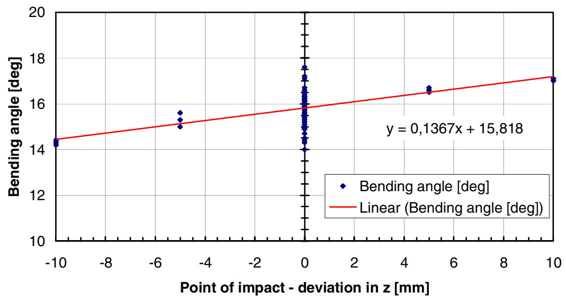

Figure 11. Dependency of the bending angle from the point of impact.

Table 3.
Dependency of the measurements from the test parameters.

Test parameter		Bending angle	Shear displ.	Accel.
Threshold [1]		15°	6mm	150g
Velocity	[EU/(m/s)]	2.47	0.77	22.30
	[%/(m/s)]	16.47	12.83	14.87
Temperature	[EU/°C]	0.06	0.03	1.25
	[%/°C]	0.38	0.43	0.83
Point of impact	[EU/mm]	0.14	0.03	0.03
	[%/mm]	2.28	0.45	0.02

Table 4.
Evaluation of the repeatability based only on tests parameters within the allowed limits.

		Bending angle	Shear displ.	Accel.
Mean	[EU]	15.70	6.41	152.94
Standard deviation	[EU]	0.82	0,37	10.54
	[%]	5.21	5.70	6.89
Minimum absolute	[EU]	14.00	5.70	129.00
Maximum absolute	EU]	17.1	7.10	174.70
Max. dev. from mean	[EU]	1.70	0.71	23.94
	[%]	10.85	11.06	15.65
CV	[%]	5.21	5.70	6.89

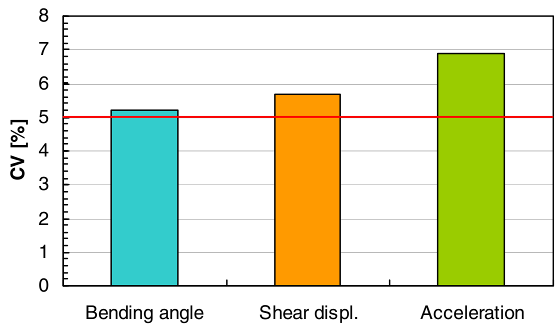

Figure 12. Coefficient of variation based only on tests parameters within the allowed limits.

Analysis – The comparison of all regressions showed that the impact velocity has the strongest effect on the performance of the legform. This influence could be expected and can be supposed to be even stronger for impacts on vehicles due to the quadratic dependency of the kinetic energy from the velocity.

There are small influences of the temperature on the tibia acceleration and of the point of impact on the bending angle. The variations of the pitch, roll and yaw angle had no significant effect on the performance just like the relative humidity.

The statistical evaluation of the data with respect to repeatability showed that the rating of the legform changed from "acceptable" to "not acceptable” as a consequence of varying the test parameters over the full width of the allowed corridors. It can be assumed that the repeatability may be reduced even more, if there are coincident effects of more than one parameter which may lead to an increase or a decrease, respectively, of the measured signal due to a superposition of the effects. The latter should be the scenario occurring in the field.

CONCLUSIONS

The repeatability and reproducibility study showed that there are systematic differences between the examined legforms regarding the individual performance. There are no considerable differences in the mean amplitudes but in the variation of the readings. A detailed inspection of all legforms didn’t reveal any particular cause.
According to the parameter study it is essential for testing with the legform to adjust first of all the impact velocity as close as possible to the nominal value in order to achieve a good repeatability. But also the sum of the minor influences can lead to an increase of the deviation.

REFERENCES

[1] DIRECTIVE 2003/102/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 November 2003 relating to the protection of pedestrians and other vulnerable road users before and in the event of a collision with a motor vehicle

[2] COMMISSION DECISION of 23 December 2003 on the technical prescriptions for the implementation of Article 3 of Directive 2003/102/EC of the European Parliament and of the Council relating to the protection of pedestrians and other vulnerable road users before and in the event of a collision with a motor vehicle (2004/90/EC)

[3] ISO/TC22/SC12/WG5 N751, Calculation Methods & Acceptance Levels for Assessing Repeatability and Reproducibility (R & R), H. Mertz, WG 5 Chairman, Dec. 6, 2004