ASSESSMENT OF THE FLEXIBLE PEDESTRIAN LEGFORM IMPACTOR (FLEX PLI-G) AS A TEST TOOL FOR LEGISLATION ON PEDESTRIAN PROTECTION

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ABSTRACT

A new pedestrian legform impactor with biofidelic characteristics (Flex PLI) showed first good test results on real cars in its version 2004. Aim of a research study at the Federal Highway Research Institute (BASt) was to give an assessment of the latest version of this impactor (Flex PLI-G) as a potential instrument for legislation. A series of tests was made on real cars with pedestrian-friendly bumper according to the EEVC test conditions and limits. Furthermore, a comparison with the EEVC Working Group 17 legform impactor was made within a series of tests under idealised test conditions.

Keywords: Biofidelity, Component tests, Flex PLI, Impactors, Pedestrians, Repeatability

A PEDESTRIAN LEGFORM IMPACTOR WITH BIOFIDELIC CHARACTERISTICS (Flex PLI) has been developed by the Japanese Automobile Research Institute (JARI) (Konosu et al, 2003). The impactor which is considered being introduced as a legislation tool within a global technical regulation on pedestrian protection (GTR, 2005) showed first good test results on real cars in its version 2004 (Konosu et al, 2005).

The Flex PLI in its G-Level was assessed at BASt regarding its handling and durability as well as the repeatability and reproducibility of test results. The certification procedure was analysed and tests on real cars with pedestrian-friendly bumpers according to the test conditions and limits of EEVC (2002) were performed. Furthermore, a comparison between the Flex-G and the legform impactor according to EEVC Working Group 17 ("Pedestrian Protection") was made within tests under idealised test conditions.

CERTIFICATION

The Flex-G impactor is foreseen being certified using a pendulum test: the impactor is suspended without flesh and skin over a pin joint from a fixed pendulum frame, lifted until it is 15 degrees above the horizontal and then released. A cross beam, originally covered with one neoprene and one rubber sheet, is fixed at a height such that it is hit by the knee joint of the released legform when reaching the vertical (Fig. 1), causing bending of the bones and shearing and bending of the knee.

Fig. 1 - Certification procedure

Five certification tests were performed. All ligament extensions of the Flex-G (medial collateral ligament MCL, anterior cruciate ligament ACL and posterior cruciate ligament PCL) were within the measurement range. The standard deviation S of the certification results was assessed according to the dummy requirements ($S \leq 3\%$ - good, $3\% < S < 7\%$ - acceptable, $7\% < S < 10\%$ - marginal, $S > 10\%$ - not acceptable). The leg showed good results for the elongation and good to acceptable results for the bending moments of femur and tibia.

As the impact was considered being too severe it was decided later on to add another neoprene and other two rubber sheets to the cross beam. Test results confirmed only slightly lower values. It has to be stated, that the impactor certification procedure is not compliant to its loadings during the legform tests.

REAL CAR TESTS

FLEX-G: Two cars with pedestrian friendly bumpers according to the EEVC test procedure and limits, a Mercedes A-Class with a Euro NCAP rated green lower leg test area, and a VW Golf V with borderline results to green bumper area, were to be tested with the Flex-G. Reference values from the Euro NCAP test programme revealed a possible comparability to the EEVC WG 17 impactor results.

Originally it was planned to perform first some tests with reduced impact speeds on each vehicle before testing under the conditions according to EEVC WG 17 with a full impact speed of 40 km/h. However, as the results of the tests on the series-production cars with an impact speed of 24 km/h already exceeded partially the measuring range for the bending moment as well as for the elongation of the leg, it was decided to modify the cars by removing the bumper padding and adding a padding at the lower outer contour of the car front (Fig. 2).

Fig. 2 - Car modifications

With those modifications, tests were conducted at impact speeds between 24 and 40 km/h. An impact height of 50 mm above ground level was chosen due to feasibility reasons. During the test programme, the impact speed was raised subsequently until 40 km/h were reached.

As it could be expected, in general the loads on the leg and knee got higher with an increased impact speed. The first and the second Golf test indeed showed a contrary behaviour, i.e. that the values of the test with the lower impact speed (6,64 m/s) were in most cases higher than those of the test with higher speed (8,16 m/s). The results of the tests conducted at 40 km/h are given in figure 3:

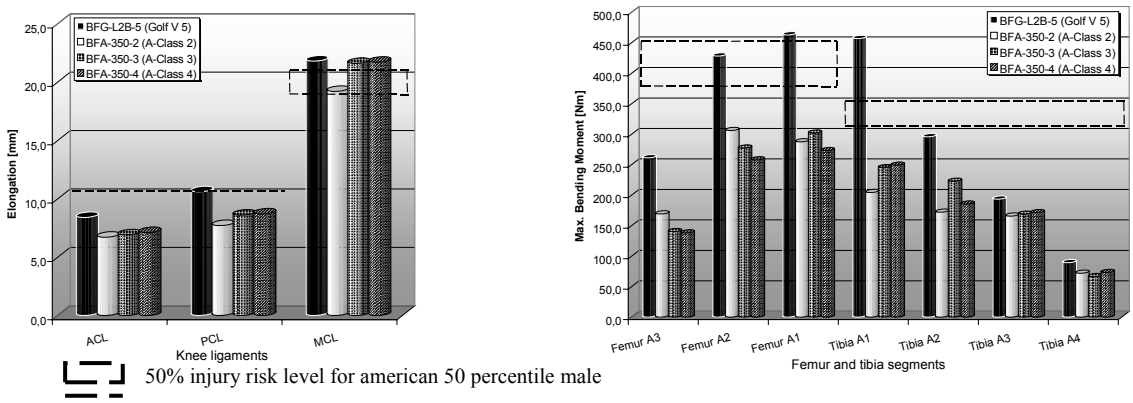

Fig. 3 - Test results of modified cars (40 km/h): knee, femur and tibia loads

Here, the test results for the modified Mercedes A-Class fulfilled the proposed requirements according to the 50% injury risk level for the 50 percentile american male (Konosu et al, 2005) for the bending moments of femur and tibia as well as for the ACL and PCL elongation. The MCL elongation shows a high injury risk for the knee. The Golf V test resulted in high loads for two ligaments as well as for two femur and one tibia segments which means a high risk for bone fractures and knee injuries.

Altogether, it can be stated that none of the cars could fulfil all Flex-G requirements with our without additional bumper padding at 40 km/h.

EEVC WG 17 PLI: Both cars were then tested on identical impact locations and at 40 km/h with the WG 17 legform impactor according to the EEVC test procedure, initially on the series-production cars and subsequently on the modified cars, last-mentioned ones due to comparability reasons once again at an impact height of 50 mm above ground level. Both car models passed the EEVC limits with and without modifications clearly (13-77 % below the EEVC limits), whereas the additional bumper

padding contributed in both cases to a further decrease of the knee bending angle.

INVERSE TESTS

REPEATABILITY: The Flex-G impactor was tested under idealised test conditions with a linearly guided aluminium honeycomb impactor at an impact speed of 40 km/h (Zander et al, 2005). In a first series of tests the honeycomb impactor was located with its centre at mid knee height in order to obtain test results within the measurement range of the impactor. As high knee loads especially for the medial collateral ligament were expected after some pre-tests at reduced impact speed, the final test speed was defined at 30,5 km/h. The results are shown in figure 4:

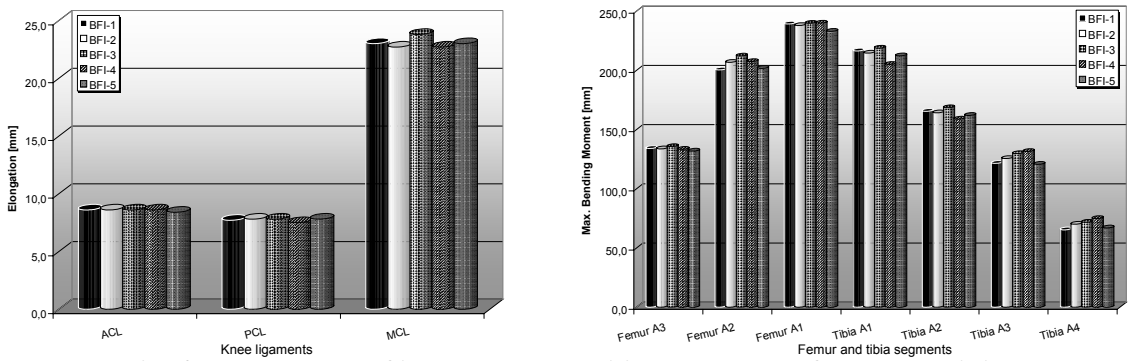

Fig. 4 - Test results of inverse repeatability tests: knee, femur and tibia loads

All five inverse tests showed loads beyond the proposed 50% injury risk level for the 50 percentile american male only for the MCL elongation. There, the proposed limits for the Flex PLI were exceeded clearly.

Based on the requirements for dummies the standard deviation was good for the ligament elongation and between good and acceptable for the bending moments:

Table 1: Repeatability of test results

	Max. Bending Moment [Nm]							Elongation [mm]		
	Femur A3	**Femur A2**	**Femur A1**	**Tibia A1**	**Tibia A2**	**Tibia A3**	**Tibia A4**	**ACL**	**PCL**	**MCL**
Standard deviation	1,37	4,73	2,88	5,25	3,62	4,83	3,78	0,09	0,13	0,45
in %	**1,02**	**2,30**	**1,21**	**2,46**	**2,21**	**3,84**	**5,43**	**1,04**	**1,69**	**1,96**
Assessment	**GOOD**	**GOOD**	**GOOD**	**GOOD**	**GOOD**	**ACC.**	**ACC.**	**GOOD**	**GOOD**	**GOOD**

REPRODUCIBILITY: In the next step, inverse tests under idealised test conditions were performed on two different Flex-G impactors. As the MCL loads were too high in the repeatability tests, the impact speed was reduced again and finally defined at 21 km/h in order to achieve results within the measurement range. For the impact height 40 mm was chosen, i.e. that the honeycomb impactor was set with its centre 40 mm above the mid knee height.

A good reproducibility of test results with the Flex-G can be confirmed by the standard deviation and the coefficient of variation according to the requirements for dummies (Mertz, 2004) which show continuously good to acceptable results for the maximum bending moments as well as for the elongation. Only the maximum bending moment results for the tibia A4 segment exceeded slightly the CV limit.

VARIATION OF IMPACT HEIGHT AND IMPACT LOCATION: In the last step, the influence of impact height and impact location on the test results were analysed. Therefore, the impact points were located on, 40 mm above, 40 mm below and 80 mm below the knee joint. Furthermore, two tests were performed with the honeycomb divided horizontally into two equal parts and impacting the femur and tibia at the height of their centres of gravity. In total, 14 tests were performed at 21 km/h.

No direct correlation could be observed between the impact height and knee loads on ACL and PCL. The MCL loads got higher the closer the impact location got to the knee joint.

As for the tibia section (knee joint and below, but still above all tibia strain gauges), the lower the impact location, the higher the maximum bending moment, the opposite trend could be observed for the femur section (knee joint and below). Here, the lower the impact location, the lower the maximum bending moment. An example of the femur and tibia results is given in figure 5:

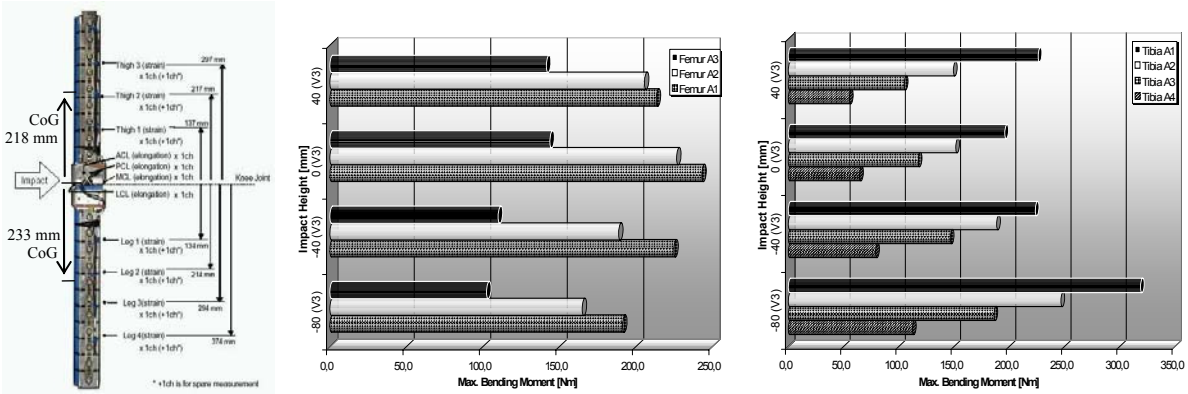

Fig. 5 - Influence of impact height and impact location: femur and tibia loads

As expected, the horizontally divided honeycomb reduced the knee loads because the impact points were located on the centres of gravity of femur and tibia. For those parts, the highest loads were on the segments close to the centres of gravity, i.e. the femur A2 and the tibia A2 strain gauges.

DISCUSSION

A good handling of the Flex-G can be stated. The certification procedure is easily applicable, but as the impactor is certified without flesh and skin, its usability requires a revision. The proposed calibration procedure for the strain gauges is influenced by mechanical aspects and needs to be re-defined. Besides, the calibration of the sensors and bones is currently not addressed. The durability of the knee bands and knee pads need further improvement. For the testing, no expendables as ligaments or foam are necessary.

A pedestrian-friendly bumper according to the EEVC WG 17 test procedure and limits seems to be too hard to be tested with the Flex-G without additional bumper modifications at 40 km/h. Even at a reduced impact speed of 24 km/h the tested cars could marginally meet the protection criteria currently proposed for the Flex PLI. On the other hand, good test results with the Flex-G on modified cars were confirmed by tests with the WG 17 legform impactor. Besides, the tests on modified cars as well as the inverse tests allowed a first assessment of the obviously good repeatability and reproducibility.

The variation of impact height and impact location under idealised test conditions gave first information about possible design changes of pedestrian-friendly bumpers according to the current Flex PLI criteria. This study also revealed that minor modifications between the Flex-G 01 and the following prototypes led to variations in the test results. It has to be mentioned that the Honda Civic fulfilled the requirements for the Flex2004 but exceeded the proposed Flex-G limits clearly (Imaizumi, 2005).

CONCLUSIONS

The study shows that the results obtained by tests with the EEVC WG 17 and Flex PLI-G legform impactor are not comparable. It reveals both a good repeatability and reproducibility of test results with the biofidelic legform impactor under idealised test conditions and lower impact speeds on the one hand but a need for further modification on the other hand. At this time, the impactor itself is not ready for legislation. The biofidelity of the knee joint has to be revised and the measurement range of the knee has to be expanded. Furthermore, the robustness, the durability and the certification method need further improvement. Subsequently, the usability under the legal test conditions has to be proved.

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