EVALUATION OF USEFULNESS AND REPEATABILITY FOR PEDESTRIAN PROTECTION FLEX-PLI

Yong-Won YOON
Gyu-Hyun KIM
Korea Automobile Testing and Research Institute
Korea
Jae-Moon LIM
Department of CAD & Graphics, Daeduk University
Korea
Gyung-Jin PARK
Department of Mechanical Engineering, Hanyang University
Korea
Paper Number 11-0425

ABSTRACT

Pedestrian-vehicle traffic accidents are a globally recognized safety concern. UN/ECE/WP29 established the Global Technical Regulation (GTR) for pedestrian safety on 12 November 2008. GTR is expected to significantly reduce the injuries of pedestrians in the event of frontal impacts. Recently, a new pedestrian lower legform named Flex-PLi has been developed for the body model of the human lower leg. Flex-PLi is introduced, and the characteristics of the model are identified through a comparison study with an existing lower legform. Usability, durability and repeatability are evaluated by using real vehicle impact tests. Moreover, the model is examined by considering the possibility of its application to pedestrian safety GTR phase 2.

INTRODUCTION

Of the various types of traffic accidents, the pedestrian-vehicle accident shows a very high death rate, 36% (as of 2008).1) Accordingly, studies to protect pedestrians have actively been conducted around the world.[2-3)] These studies led to the establishment of a global standard for the protection of pedestrians, GTR (Global Technical Regulation), which was established and declared in November 2008.4) Member countries that signed the agreement, including Korea, are planning to introduce GTR to protect their own pedestrians. In Korea, a new safety standard for automobiles based on GTR was adopted in December 2008. 5) The standard for protecting pedestrians will be applied to new vehicles from 2013, and to existing vehicles from 2018.

The assessment of the degree of pedestrian protection offered by an automobile is performed by calculating the body injury rate, which is obtained from the impact of headform or legform hitting a real vehicle. Unfortunately, the lower legform currently used (European Enhanced Vehicle Committee Working Group 17 Lower legform) has been criticized for its lack of duplicability of body. 6)

A newer legform, Flex-PLi (Flexible-Pedestrian Legform impactor), which is an improved model of the existing lower legform, was first developed in Japan in 2000. In 2005, the European Union (EU) organized the Flex-Technical Evaluation Group. The major focus for the group was evaluating the technical aspects of Flex-PLi for legal application.

European countries, the USA, and Japan have been leading the Round Robin Test of Flex-PLi. Korea also has participated in the test, and played a key role in the global society. In this paper, Flex-PLi was first introduced and used for the evaluation test for protecting pedestrians in Korea. Its differences from the existing legforms were confirmed, and procedures and methods of evaluation in the real car test were then established using Flex-PLi. Finally, with the car test, the validity of legal application was examined by analyzing characteristics of usefulness, durability and repeatability of Flex-PLi.

Flex-PLi

As seen in Fig. 1, Flex-PLi offers an improvement compared to the existing lower legforms by having structure and characteristics similar to that of a human body. It is an advanced legform model having full flexibility over the whole legform. 8)

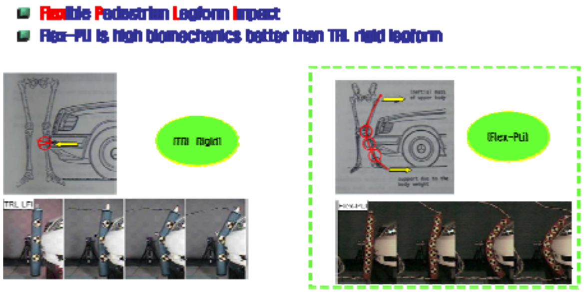

Fig. 1 Flex-PLi

2.1 Trend in Flex-PLi development

Fig. 2 provides a stepwise illustration of the development trend of Flex-PLi. Flex-PLi has been developed in Japan since 2000. Its design was established in 2002, and has been evolved with the change of its name from Flex-G in 2005 to Flex-GT in 2006. [9)]

However, the development led by Japan Automobile Manufacturers Association and Japan Automobile Research Institute faced realistic problems, such as difficulties in full-scale production and verification of durability. FTSS, a well known American dummy manufacturer, eventually acquired the development department of Flex-PLi in 2007, and the final version of the Flex PLi GTR model is about to be released. [10)]

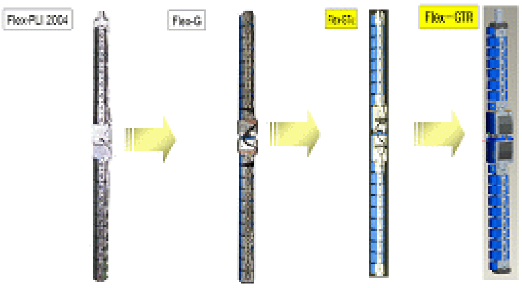

Fig. 2 Trend in development of Flex-PLi

2.1 Movement of Flex-TEG

The EU is now conducting active research in cooperation with Flex-TEG, a technical assessment group carrying out the second stage of GTR research for pedestrian protection. Flex-TEG was established in 2005 and has held 10 conferences as of December 2009. Since the first conference was opened by the World Automobile Manufacturers Association in France, BASt in Germany has held the following conferences thus far.

3. Vehicle test for Flex-PLi

3.1 Preparation of Flex-PLi for the test

The procedure of the car test for Flex-PLi is shown in Fig. 3. [11)] In brief, the procedure was as follows: basic preparation for Flex-PLi was conducted; a correction test using pendulum was conducted before the car test was executed; the condition of Flex-PLi was checked; rubber parts and skins were assembled on it; and finally, the car impact test was conducted. After the test was completed, the same procedure was repeated.

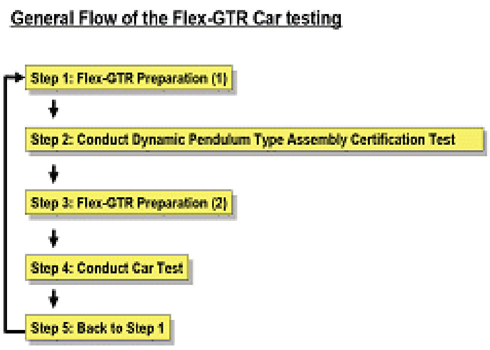

Fig. 3 The procedure diagram of the car test for Flex-PLi

The check points for fastening conditions during test preparation of Flex-PLi are shown in Fig. 4. [12)] Joint bolts were tightened with pre-determined torque (8 Nm), and clearance existence was checked. It was checked to determine whether the bolts were connected inside the central knee part, and whether any nuts and washers were protruded out of the surface level.

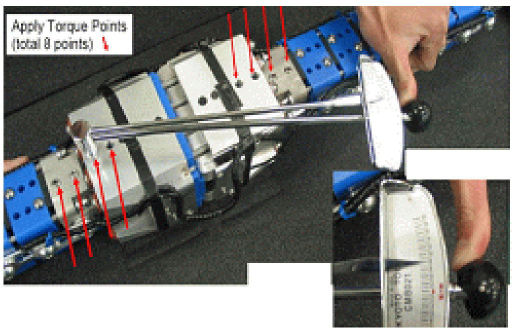

Fig. 4 Preparation and check for fastening condition of Flex-PLi

Fig. 5 illustrates a clearance check in the test preparation of Flex-PLi. 12) A thickness measuring gauge that is specially manufactured was used. Thickness of internal wires in the parts of femur and tibia were measured for their clearance. For femur, the clearance was maintained at 8 mm of thickness, and 9 mm for tibia.

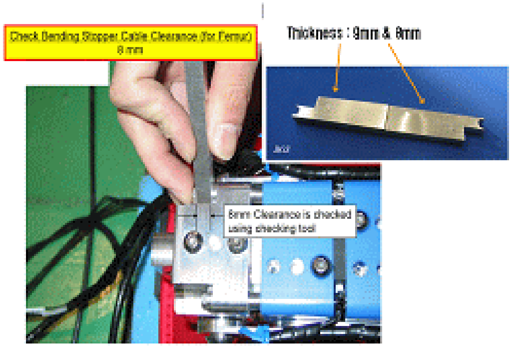

Fig. 5 Preparation of Flex-PLi - check for clearance

3.2 Correction test for Flex-PLi

The correction test for Flex-PLi can be roughly divided into the static correction test and the dynamic correction test. The dynamic correction test is further broken down into pendulum type and impact type. A pendulum type dynamic correction test for Flex-PLi was carried out by fixating the tibia part of Flex-PLi on the correction device, lifting it up to 15° above the horizontal (15° hanging angle), and releasing it to freely swing down. Data obtained from this activity were checked for correction if they were located between the maximum and minimum level. Fig. 6 below shows the dynamic correction test. [12)]

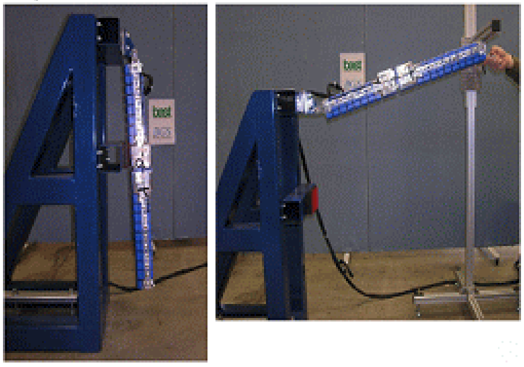

Fig. 6 Dynamic correction of Flex-PLi

Fig. 7 shows how to assemble Flex-PLi. [12)] On completion of the correction test, rubber parts and outer skin were put on Flex-PLi. The femur and tibia parts were covered with absorption material made from rubber, and the outer skin was mounted to complete the assembly. All preparation for the test was completed by assembling Flex-PLi. When disassembly was required after the test, the procedure above was carried out in reverse order.

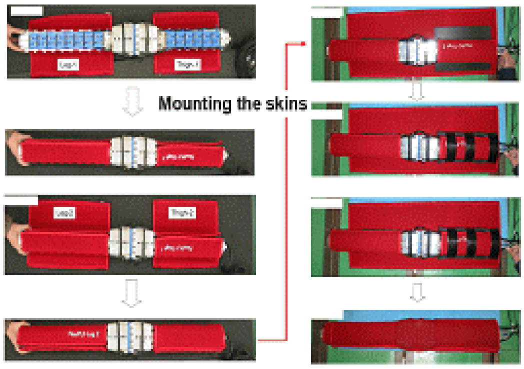

Fig. 7 How to mount skins on Flex-PLi

3.3 Test method for Flex-PLi

The test for Flex-PLi was conducted by creating impact to the impact zone on the vehicle with Flex-PLi. The impact velocity is 11.1±0.2 m/s. Fig. 8 shows the system configuration for the car test. The configuration consists of a stationary back plate for Flex-PLi, a power supply, a PC for downloading data after the impact test, and its specific application for analyzing data. The system configuration is relatively simple, because the system for data measurement is installed inside Flex-PLi. The car test started by installing Flex-PLi on the projectile. Power was provided from a cable linked to the power supply until discharging started, and the cable was set to be automatically separated. From that moment, Flex-PLi freely fell down to the test car without having any external cable linked to it. The difference between Flex-PLi and the existing lower legform was that Flex-PLi could eliminate the concern of data loss resulting from disconnection of measuring cable.

Fig. 8 Test method for Flex-PLi – System configuration

3.4 Car Test for Flex-PLi

The car test was done using Flex-PLi. The test car was chosen from among Korean cars that satisfy GTR requirements to protect pedestrians when tested with the existing lower legform.

The purpose of the assessment test was as follows: checking the fulfillment of GTR by Flex-PLi when an existing model meets the criteria; evaluating the repeatability of Flex-PLi when the test repeats on the same impact zone; and finally, identifying the durability and user-friendly characteristics of Flex-PLi during the test.

In Fig. 9, the purpose and method of the test are summarized with pictures. The main goals of the test were to evaluate repeatability and to check fulfillment of the regulation. The explanation includes impactor type, impact velocity, impact zone, impact point, impact times, and impact height.

Purpose of assessment test

(1) Check the fulfilment of GTR by Flex-PLi when existing model meets the criteria

(2) Evaluate repeatability of Flex-PLi when the test repeats on the same impact zone

Test Method

impactor type	Flex-PLi
impact velocity	11.1±0.2m/s
impact zone	EEVC WG17 Lower legform (Green zone)
impact point	2 Same cars (Same point)
impact times	3 Impact per 1 Car
impact height	75mm (From ground level)

Fig. 9 Car test for Flex-PLi – purposes and method

The zones on which the existing lower legform satisfied the impact test were selected as impact zones. The repetitive test was conducted by testing 2 identical cars without exchanging test material, such as a bumper, and alternating the turn to test. 3 impacts were provided to a car, and 2 cars were tested, which means the test was conducted 6 times in total. Fig. 10 shows pictures before and after the car test using Flex-PLi.

Fig. 10 Pictures before and after the car test for Flex-PLi

Data measurement for Flex-PLi basically consists of 7 bending moments, 3 of which are in the femur and 4 in the tibia, and 4 knee elongations and 1 knee acceleration, which totals 12 channels. Fig. 11 illustrates the data from the test by dividing it into bending moments in the femur and tibia, elongation in the knee, and knee acceleration.

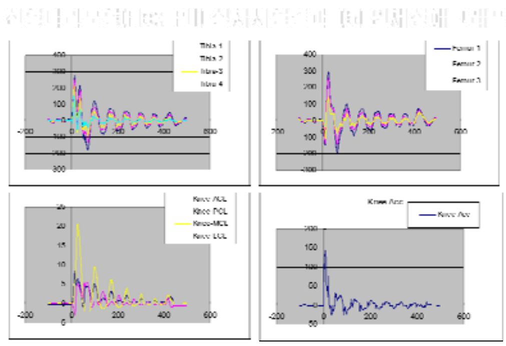

Fig. 11 Car test for Flex-PLi - Test data

In the basic data channel measured from Flex-PLi, tibia bending moment (criteria for Tibia: 340 Nm) and knee elongation (Knee-MCL: 22 mm) are regulated by the second amendment of GTR. Table 1 highlights the two weakest points for protection of pedestrians from the impact test of the 6 total tests.

Flex-PLi test results were proven to meet criteria value for body injury on the whole. The maximum value of bending moment for tibia 1 was 285.4 Nm, and for knee elongation was 20.7 mm, both of which can be analyzed to satisfy body injury criteria for Flex-PLi.

	unit	Max.	Min.		unit	Max.	Min.
Femur-3	(Nm)	154.0	-106.8	Femur-3	(Nm)	143.1	-103.5
Femur-2	(Nm)	270.1	-145.3	Femur-2	(Nm)	260.1	-141.9
Femur-1	(Nm)	307.4	-195.2	Femur-1	(Nm)	298.0	-194.5
Tibia-1	(Nm)	285.4	-173.7	Tibia-1	(Nm)	282.6	-177.9
Tibia-2	(Nm)	251.1	-133.5	Tibia-2	(Nm)	256.4	-136.7
Tibia-3	(Nm)	214.3	-87.4	Tibia-3	(Nm)	219.4	-90.3
Tibia-4	(Nm)	153.4	-50.6	Tibia-4	(Nm)	159.7	-55.9
Knee-ACL	(mm)	8.1	-1.4	Knee-ACL	(mm)	8.4	-0.8
Knee-PCL	(mm)	6.3	-2.3	Knee-PCL	(mm)	5.7	-2.8
Knee-MCL	(mm)	20.2	-2.1	Knee-MCL	(mm)	20.7	-2.1

Table 1. Body injury assessments from car test for Flex-PLi.

The test result of Flex-PLi was also compared with that of the existing lower legform. The purpose of this comparison is to judge the legal validity of Flex-PLi and lower legform for the same impact zones. Fig. 12 shows the number calculated from the result of Flex-PLi and existing lower legform tests.

Body injury level for the existing lower legform was measured for knee bending angle, shear displacement, and tibia acceleration. The criteria base is converted to 100% for each measurement. The test result is assumed to meet the criteria when it does not exceed this value. The car used for this test showed around 78%, 38%, and 74% for bending angle, shear displacement and acceleration, respectively. This proves that not only does the existing lower legform meets the criteria, but also that significant room can be secured when compared to the criteria.

Meanwhile, body injury level for Flex-PLi test was calculated with criteria base of 100 for knee elongation and tibia bending moment. Knee elongation was about 78% and tibia bending moment about 89%, both of which meet the criteria. However, the differences from the criteria base shown by the lower legforms were likely to reduce.

The comparative result between Flex-PLi and the existing lower legform should not be uniformly applied to unspecified cars. It may well be limited to the unique characteristics of the car used in this test.

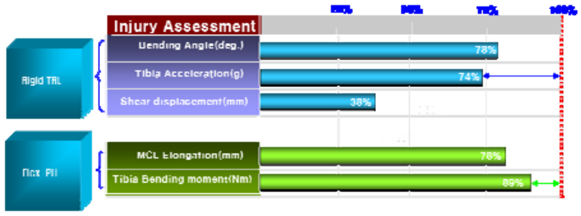

Fig. 12 Comparison between EEV WG17 Lower Legform and Flex-PLi

Repeatability of Flex-PLi was confirmed. On the whole, it was proven to be excellent. Fig. 13 shows the test result of repetitive impact for tibia 1 bending moment and knee elongation at the L1 zone out of 3 impact zones. The result from repetitive tests showed almost identical characteristics in the graphs.

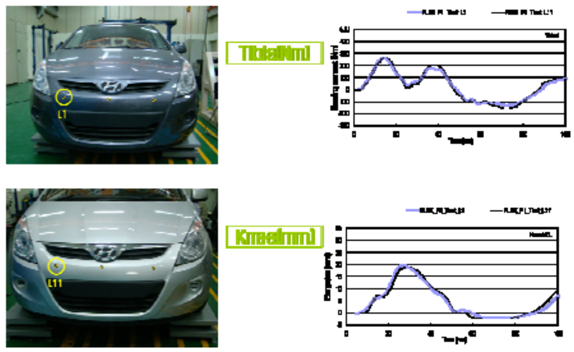

Fig. 13 Car test for Flex-PLi – Repeatability

Excellent repeatability appeared on tibia bending and MCL (Medial Collateral Ligament), injury assessment items for Flex-PLi. However, ACL (Anterior Cruciate Ligament) and PCL (Posterior Cruciate Ligament), which are now being discussed globally for monitoring, showed relatively low-toned repeatability.

The results of the Flex-PLi test with mean value and standard deviation are shown in Table 2.

		TIBIA 1	TIBIA 2	TIBIA 3	TIBIA 4	MCL	ACL	PCL
L1	TEST-1	261.4	234.9	194.1	150.5	19.7	8.5	10.1
	TEST-2	266.7	237	204.7	156.9	18.9	8.9	7.6
	MEAN	264.1	236	199.4	153.7	19.3	8.7	8.85
	ST.DEV	3.748	1.485	7.495	4.525	0.566	0.283	1.768
	C.V	0.014	0.006	0.038	0.029	0.029	0.033	0.2
	C.V(%)	1.42	0.63	3.76	2.94	2.93	3.25	19.97
L2		TIBIA 1	TIBIA 2	TIBIA 3	TIBIA 4	MCL	ACL	PCL
	TEST-1	253.6	242.7	188.1	175.9	18.4	7.8	6.4
	TEST-2	239	228.8	187.9	170.2	19.4	7.5	8
	MEAN	246.3	235.8	188	173.1	18.9	7.65	7.2
	ST.DEV	10.32	9.829	0.141	4.031	0.707	0.212	1.131
	C.V	0.042	0.042	8E-04	0.023	0.037	0.028	0.157
	C.V(%)	4.19	4.17	0.08	2.33	3.74	2.77	15.71
L3		TIBIA 1	TIBIA 2	TIBIA 3	TIBIA 4	MCL	ACL	PCL
	TEST-1	282.6	256.4	219.4	159.7	20.7	8.4	5.7
	TEST-2	285.4	251.1	214.3	153.4	20.2	8.1	6.3
	MEAN	284	253.8	216.9	156.6	20.45	8.25	6
	ST.DEV	1.98	3.748	3.606	4.455	0.354	0.212	0.424
	C.V	0.007	0.015	0.017	0.028	0.017	0.026	0.071
	C.V(%)	0.70	1.48	1.66	2.85	1.73	2.57	7.07

Table.2 Car test for Flex-PLi – Reliability

62% of all results were given as "Good," which means a Coefficient of Variation of less than 3%, and 24% belong to "Acceptable," which means a Coefficient of Variation in the range of 3~7%.

MCL, a criteria for injury assessment of Flex-PLi, was generally located in the range of 3~7% of Coefficient of Variation, "Acceptable." However, in the case of PCL, it was assessed as "Marginal," which falls in the range of 7~10%, and "Not Acceptable," which has a higher coefficient than 10%.

PCL has not been selected as a base criteria for injury level assessment of Flex-PLi. However, all PCL values were classed as "Marginal" and "Not Acceptable" in the test for analysis. Thus, improvement of the vulnerable repeatability of PCL is demanded.

4. Conclusion

In this paper, a car test using Flex-PLi was conducted to assess the protection of pedestrians by automobiles, and the following conclusions were obtained:

1) Consumable parts required by EEVC WG17 lower legforms, such as bending ligament and flash form, are not needed for usability of Flex-PLi. Without the concern of data loss and damage to the cable after impact test, convenience and efficiency for users are confirmed to be improved.
2) Around 62% of all results were "Good," meaning a Coefficient of Variation of less than 3%, and 24% were "Acceptable," meaning a Coefficient of Variation in the range of 3~7%. Generally, repeatability appeared to be excellent, but in the case of PCL, further investigation and supplementation is required for its vulnerable repeatability.
3) In terms of the durability of Flex-PLi, problems like destruction of device and failure did not occur during the test. Nevertheless, evaluation for durability is reserved because of the relatively short assessment period.
4) Automobiles that meet the criteria for EEVC WG17 lower legform also seemed to satisfy the criteria for Flex-PLi. However, Flex-PLi showed a decreased margin (in case of tibia bending moment), while EEVC WG17 lower legform secured a significant margin to the criteria level. It is believed that this comparative result between Flex-PLi and the existing lower legform should not be uniformly interpreted and applied to unspecified cars, because it may well be limited to the unique characteristics of the car used in this test.
5) More countries and automobile-related organizations are required to take part in the limitative round robin tests that are performed by the EU, the USA, Japan, and Korea. This will promote benefits to those participating countries based on exchange of opinions and the identification of global trends.
6) Ongoing supplementation should be explored to develop a user-friendly control program and provide measures for unpredictable rebound situations due to the use of a flexible device.

Acknowledgements

This research was undertaken as part of the "Coordination Project for Global Safety Standard" of Ministry of Land, Transport and Marine Affairs (MLTM), and the "Technology Innovation Project" of the Ministry of Knowledge and Economy in Korea.

References

1) Korea National Police Agency "2009 Traffic Accident Statistics," Issue No 11-1320000-000011-10, 2009. 07
2) J. W. Lee, "Introduction of Pedestrian Head Protection Test Method in Korea-NCAP," Spring Conference of KSAE, 2006.
3) Peter J. Schuster, "Current Trends in Bumper Design for Pedestrian Impacts," SAE, 2006-01-0464.
4) "Global Technical Regulation No.9 Pedestrian Safety" online at http://unece.org/trans/wp29/180a92.
5) Order. 75 from MLTM "Standard for Automobile Safety. Sec. 102-2 Protection of Pedestrians", issued in 2008. 12. 08
6) "EEVC Working Group 17 Report" online at http://uncec.org/trans/wp29grsp/pedestrian_10.
7) "Agenda for the first meeting of Flex-PLi Technical Evaluation Group" online at http://unece.org/trans/doc/2006/wp29grsp/teg-001e .
8) Atsuhiro Konosu, "Evaluation Tests for Pedestrian Legform Impactors," 19th International Technical Conference on the Enhanced Safety of Vehicles, 2005
9) "Flex-G and Flex-GT: a Comparison of Test Results" online at http://unece.org/trans/doc/2007/wp29grsp/teg-036e .
10) "Flex-PLi GTR Development Prototypes" online at http://unece.org/trans/doc/2009/wp29grsp/teg-071e .
11) "Phase 2 of the Global Technical Regulation-Flex PLi" ECE/TRANS/WP29/GRSP/2009/21, 24 September 2009.
12) "Flex-GT Handling and Usage" online at http://unece.org/trans/doc/2007/wp29grsp/teg-037e .