Factor causing scatter in dynamic certification test results for compliance with EEVC WG17 legform impactor standard

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Abstract: A pedestrian legform impactor is a tool for the evaluation of car front bumper aggressiveness when simulating a pedestrian leg hit by a car. The Transport Research Laboratory (TRL) developed a legform impactor in compliance with the European Enhanced Vehicle-safety Committee (EEVC)/WG17 specifications. The Commission of the European Communities (EC) proposed a dynamic certification test for a legform impactor, however, the test results using the TRL legform impactors manufactured to date have indicated an extremely wide scatter, especially in the maximum lower leg acceleration. Thus, the objectives of the present research are to clarify the factor possibly causing this scatter in the lower leg acceleration of the TRL legform impactor in the setup of the dynamic certification test, and to propose a way to adjust lower leg acceleration so as to comply with the corridor proposed by the EC.

The repeatability and reproducibility of the legform impactor products and different impact points of the ram in the setup for the dynamic certification test were thus investigated. High repeatability and reproducibility of the legform impactor products were observed. No difference was observed in the effect of different ram points of impact against a stationary legform impactor on the maximum lower leg acceleration. On the other hand, the lower leg acceleration was found to be greatly affected by humidity in the test apparatus. Therefore, the effect of humidity on the dynamic certification test setup was also investigated. The results indicated that the maximum lower leg acceleration increased drastically with higher humidity. Next, the relation between humidity and acceleration measured by a ram impacting a piece of confor^{TM} foam was investigated using a simplified test rig, since such foam sheathes the metal part of the legform impactor in a dynamic certification test setup. A strong relation between the humidity and acceleration was found. Thus concluded that humidity is a key factor affecting lower leg acceleration, and that adjusting it will be one of the many ways the lower leg acceleration can be made to comply with the proposed EC corridor in the dynamic certification test.

Key words: EEVC/WG17 Dynamic Certification Test, TRL legform impactor, Lower leg acceleration, Humidity, Scatter, Confor^{TM} Foam

INTRODUCTION

Pedestrian protection is one of the critical issues for vehicle safety legislation in Europe and Japan. As leg injuries are the most common injuries in nonfatal pedestrian accidents [1], the European Enhanced Vehicle-safety Committee (EEVC)/WG17 [2] proposed a test method to evaluate bumper aggressiveness by means of a legform impactor. This test procedure proposal introduces a subsystem test method in which the legform impactor is propelled into a stationary vehicle. Presently, only the legform impactor with a rigid leg and thigh designed by the Transport Research Laboratory (TRL) in 2000 [3] is approved by the EEVC/WG17. The legform impactor consists of an upper leg section, a lower leg section, a pair of steel knees covered by foam and a skin as shown in Figure 1. The length of the legform impactor is 926 mm and the mass is 13.4 ± 0.2 kg. The foam used is 25 mm thick confor foam^{TM} type CF-45, while the skin is made of 6 mm thick neoprene. An uniaxial accelerometer is mounted on the non-impacted side of the lower leg section, 66 mm below the knee joint centre (Figure 1), to measure the lower leg acceleration typically shown in Figure 2. The

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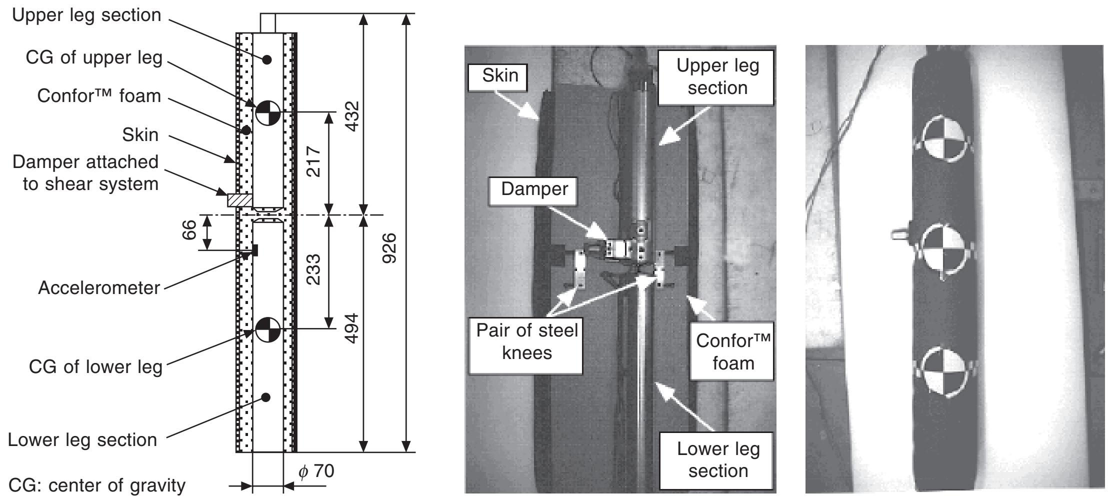


(a) Dimensions (b) Disassembled view (c) Assembled view

Figure 1 TRL legform impactor compliance with EEVC/WG17 specifications.

legform impactor is equipped to measure the shear displacement and bending angle between the upper and lower leg at the knee joint level. The lower leg acceleration is used to evaluate tibia fracture risk, and the shear displacement and bending angle are used to evaluate cruciate and collateral ligaments injury risks, respectively. The EEVC/WG17 proposed injury reference values for those criteria under the assumption that the impactor responses exactly represent the human ones. However, Matsui [4] reported that the impact responses of the legform impactor appreciably differ from those of the human lower extremity. Therefore, in his report [4], cruciate ligament injury risk curves for the legform impactor shearing displacement were found using the injury tolerances of post mortem human subjects (PMHSs) taking into account the difference between the PMHS and the legform impactor responses. Furthermore, Matsui [5] reported that the collateral ligament injury risk curves and tibia fracture risk curves for the legform impactor were determined based on the experimental results in which pedestrian lower extremities of car–pedestrian accidents were reconstructed by means of the legform impactor.

Since it is important to make test tools repeatable in order to achieve uniform standards, the EEVC/WG17 proposed a dynamic certification test simulating high–speed impact between the legform impactor lower leg and a bumper. In the dynamic certification test setup (Figure 3), the assembled legform impactor (Figure 1 (3)) is impacted by a linearly guided ram at 7.5 ± 0.1 m/s. The EEVC/WG17 initially proposed the mass of the ram to be 16 kg, but this caused excessive crushing of the confor™

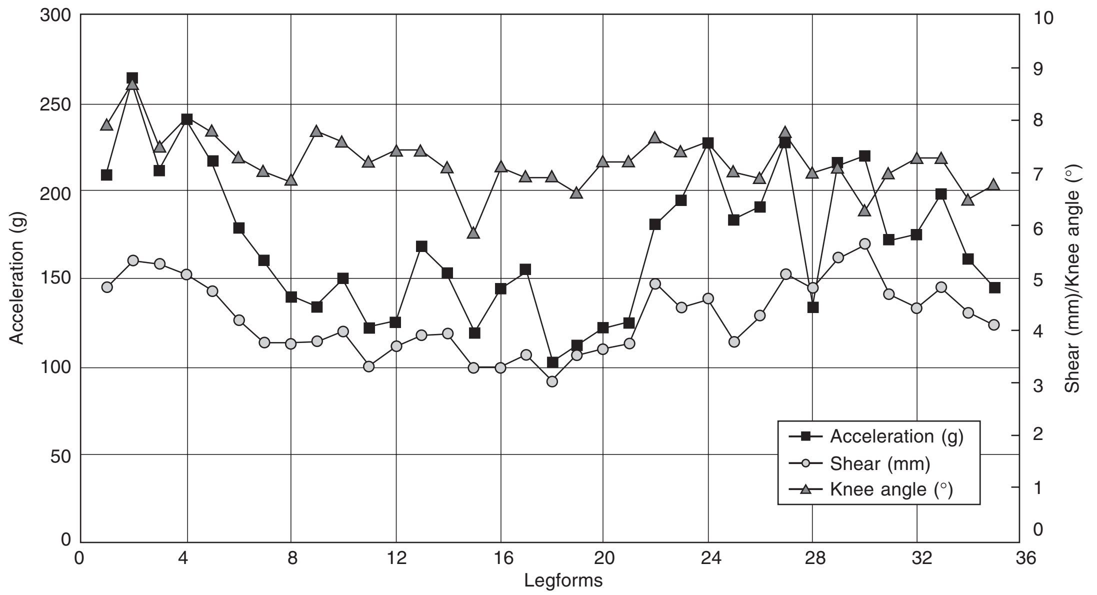


Figure 2 Dynamic certification results of the 35 TRL legform impactors produced between September 2000 and May 2002, obtained using modified EEVC/WG17 method but with reduced mass of ram (9 kg) [4].

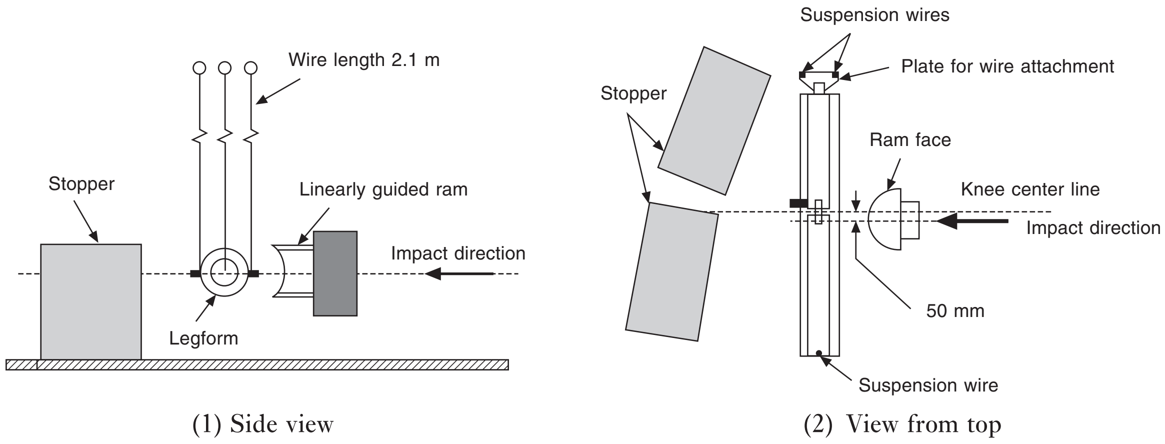


Figure 3 Test setup for dynamic certification.

foam [6]. Therefore, Lawrence and Hardy went to propose a ram mass of 9 kg [6], that was approved by the Commission of the European Communities (EC) for dynamic certification test [7].

The EC also approved a corridor in terms of maximum lower leg acceleration to be between 120 G and 250 G. In addition, the maximum shear displacement was specified to be between 3.5 mm to 6 mm, while maximum bending angle to be between 6.2° and 8.2° [7]. However, the dynamic certification test results of the 35 TRL legform impactors produced between September 2000 and May 2002 indicated extremely wide scatter, especially in the maximum lower leg acceleration as shown in Figure 2, where the mean and Standard Deviation of the acceleration were 170 G and 41 G, respectively [6]. Some of the legform impactors did not comply with the proposed EC corridor. In bumper evaluation testing, a grave problem arose where the use of legform impactors did not comply with the specified corridor for dynamic certification.

Thus, the objectives of the present research are to clarify the factor causing the wide scatter in lower leg acceleration of the TRL legform impactor in the dynamic certification test setup, and to propose a way to adjust lower leg acceleration so as to comply with the corridor proposed by the EC.

METHOD AND TEST SETUP

Verification of factors affecting lower leg acceleration for dynamic certification test

Factors causing the scatter in lower leg acceleration in a dynamic certification test are considered to be repeatability, reproducibility, and impact position. In this Section, investigations are carried out in determining the influence of this scatter caused by the above factors in actual dynamic certification tests. In addition the effect of humidity on test measuring equipment was also monitored by keeping the temperature to 20 ± 1°C, which is within the specified test temperature of 20 ± 2°C.

Repeatability of lower leg acceleration for dynamic certification tests

The assembled legform impactor, including the foam covering and skin, was suspended horizontally by three wire ropes 2.1 m in length as shown in Figures 3 and 4. The legform impactor was suspended with its longitudinal axis horizontal and perpendicular to the direction of the ram motion. The mass of the ram was 9.0 kg and was made of aluminum. To propel the ram, a guidance system was utilized to prevent out of plane motions. The ram was propelled horizontally at a velocity of 7.5 ± 0.1 m/s into the stationary legform impactor and was arranged so as to impact a position 50 mm from the knee centre toward the lower leg side (Figure 3 (2)) within a tolerance of 0.5 mm. Foam and pairs of steel knees were replaced for each test. Lower leg accelerations were measured and data processing was done using filter class SAE 180. These repeatability investigations of the lower leg acceleration measurements were performed three times per one calendar month over two different months.

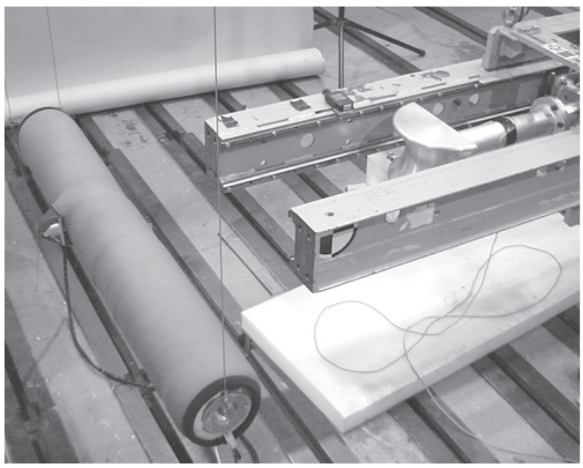


Figure 4 Test setup for dynamic certification.

Reproducibility of lower leg acceleration for dynamic certification tests

During the period between September 2000 and 2002, TRL sold approximately 35 legform impactors. Four of these were used in the reproducibility investigations. Each legform impactor was impacted three times using the same setup mentioned in Section 1.1, and lower leg acceleration was measured.

Effect of different impact points in vertical direction on lower leg acceleration

In the dynamic certification test procedure proposed by the EC, the propelling direction of the ram was arranged so that the centre of the ram would align with a position 50 mm from the knee centre-line, that has a tolerance of ±3 mm laterally and ±3 mm vertically. Since the shape of the ram contact area is elliptical as shown in Figure 5, when the ram centre impact position is not in line with the cross section of the legform impactor direction, the direction of the force exerted by the ram on the legform impactor will not be uni-directionally applied in the horizontal plane. Therefore, the impactor position was arranged so as to impact the legform impactor at zero, 3 mm and 10 mm (Figure 6). To check repeatability, the tests were carried out three times in all the three cases and acceleration data recorded for analysis.

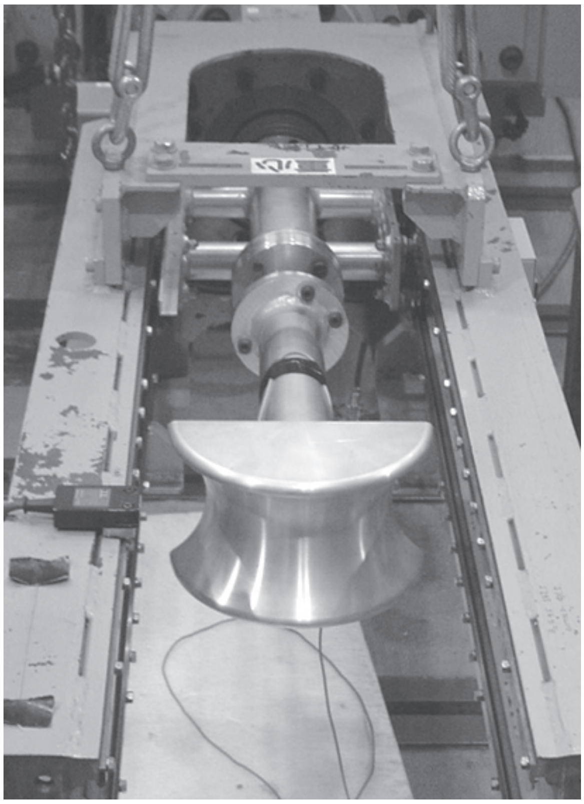


Figure 5 View of ram from front.

Effect of relative humidity on lower leg acceleration in dynamic certification test

Based on the results obtained through preliminary investigations in Section 1.1, the maximum lower leg acceleration varied with the time of the month in which the test was conducted. In Japan, the relative humidity varies widely throughout the year. Therefore, the present investigators focused on a further possibility that the relative humidity could affect the results of maximum lower leg acceleration in the dynamic certification test. In this Section, the dynamic certification tests were conducted under 4 different relative humidity conditions; 18%, 31%, 46% and 63%. The temperature was controlled at 20 ± 1°C. In a given relative humidity condition, dynamic certification tests were performed three times, and the lower leg acceleration was then measured.

Effect of relative humidity on ram acceleration in impact against confor™ foam

Based on the results obtained through preliminary investigations in Section 2, the lower leg acceleration was strongly affected by humidity. Since confor™ foam was utilized to sheathe the metal part of the legform impactor, in this Section investigations are carried out in determining the relationship of relative humidity and acceleration measured by a ram impacting a piece of foam using a simplified test rig (hereafter referred to as the drop test setup). To perform the test, it is necessary to pre–soak a specimen of confor™ foam to a given relative humidity. The volume of water in the test foam depends on the soak time. To investigate a suitable soak time for the test foam using a drop test setup, first, the relation of the mass of the test piece and soak time was determined at a given relative humidity (RH).

Relation of mass of confor™ foam specimen and soak time

The relation of the mass of the foam specimen and soak time at a given relative humidity (RH) was investigated using the setup shown in Figure 7. A piece of the confor™ foam specimen measured 300 × 300 × 25 mm using a digital scale with an accuracy of 0.01 g. The specimen mass was 212.55 g in the initial condition at RH35.7%. The foam specimen soaked at RH35.7% was placed within the enclosed micro-climate chamber, in which the humidity was kept at the following three virtually uniform levels: RH42%, RH60% and RH87%. The mass of the specimen and the RH were measured every minute for 50 minutes in the setup. The temperature was also controlled at 20 ± 1°C.

Relation of relative humidity and maximum ram acceleration in impact against confor™ foam specimen soaked at different humidity

The drop test was performed within the enclosed micro-climate chamber, in which the humidity can be controlled at stable temperatures (Figure 8). The spherical core part of the JAMA-JARI child headform impactor [8] was utilized as a ram (hereafter referred to as the ram) in the drop test setup. Near the geometric centre of this sphere

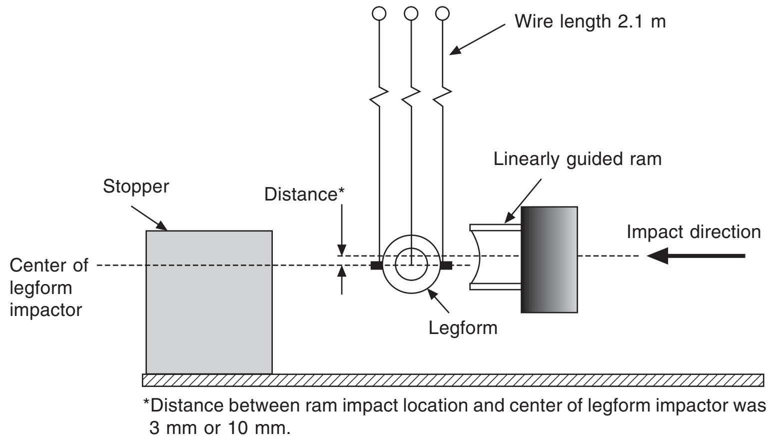


Figure 6 Test setup of dynamic certification to investigate effect of impact location on lower leg acceleration (side view).

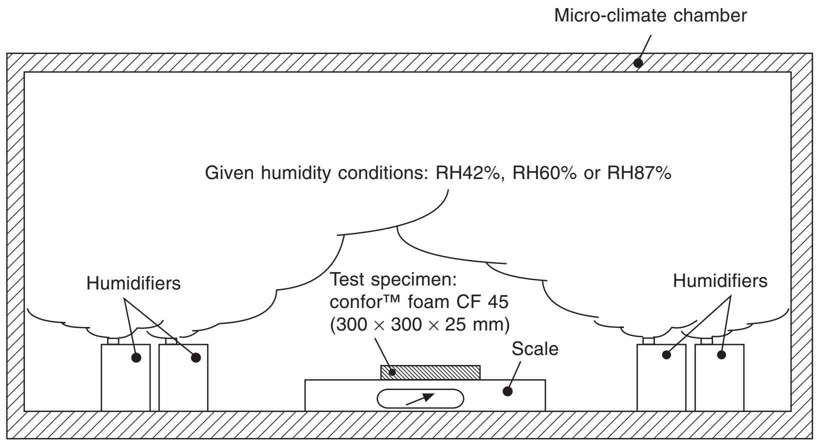


Figure 7 Schematic setup to investigate the relation of mass of the test specimen and soak time at given relative humidities.

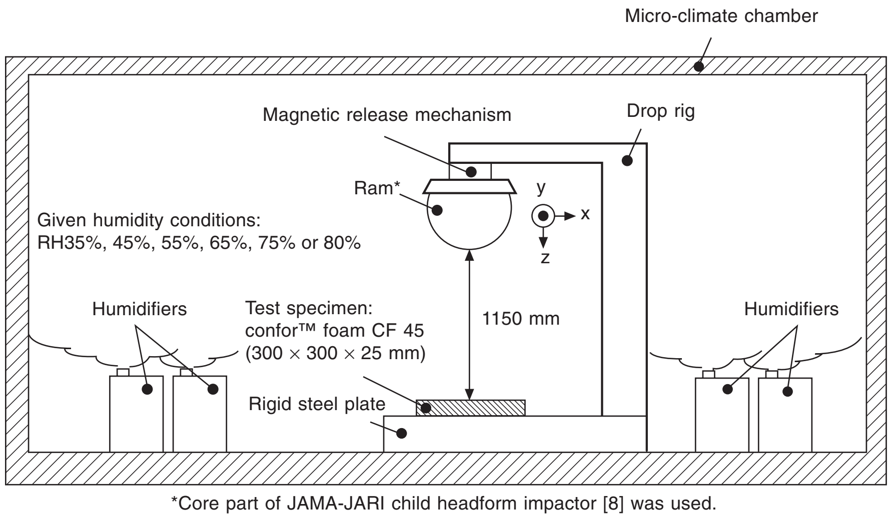


Figure 8 Impact drop test against confor™ foam specimen at various humidities.

ram, three accelerometers were installed to measure acceleration in the respective direction of the ram's three cartesian axes [8]. The mass of the ram was 2.724 kg and was dropped from a height of 1150 mm in such a way as to ensure instant release onto the confor™ foam specimen placed on the rigid supporting flat horizontal steel plate (50 mm thick and 600 mm × 600 mm square), Figure 9. The impact location of the centre of the ram was arranged

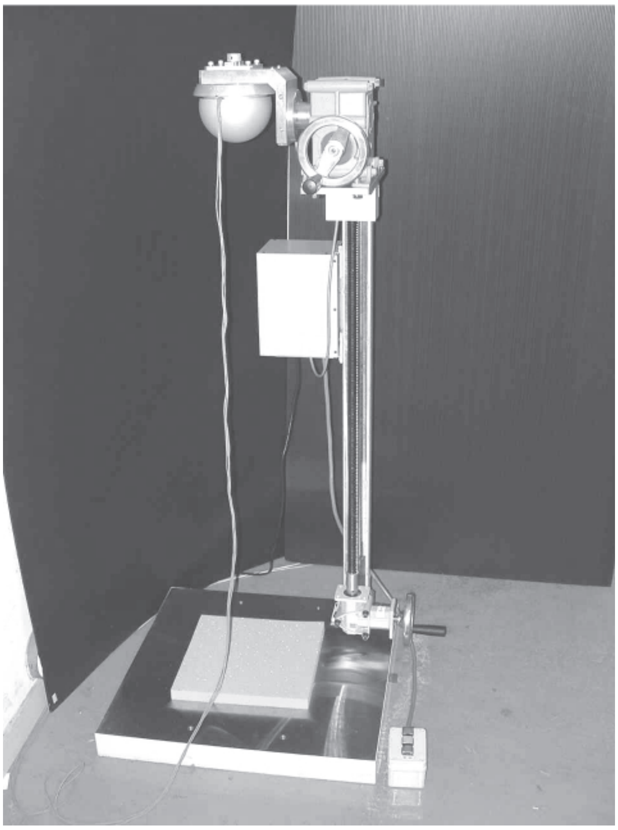


Figure 9 Drop test rig for impact against confor^{TM} foam specimen.

to be in line with the centre of the confor^{TM} foam specimen (Figure 10). The temperature was controlled at 20 ± 1°C and the impact drop test was conducted once in each of the following six humidity conditions; around RH35%, RH45%, RH55%, RH65%, RH75%, and RH80%. Resultant acceleration (hereafter referred to as the acceleration) of the ram was measured. The data processing was done using filter class SAE 1000.

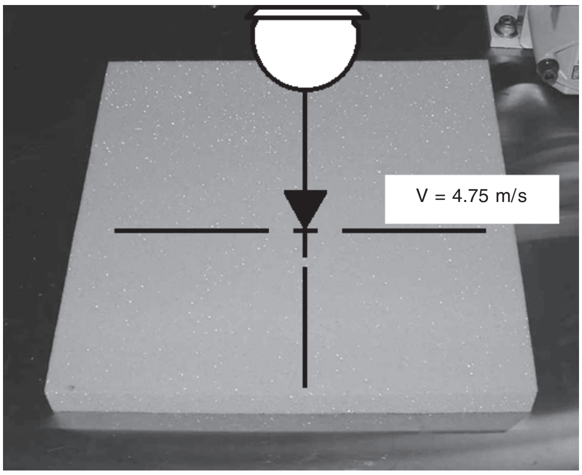


Figure 10 Center impact location on confor^{TM} foam specimen.

RESULTS

Verification of factors affecting lower leg acceleration for dynamic certification test

Repeatability of lower leg acceleration for dynamic certification tests

Table 1 lists the maximum lower leg acceleration for dynamic certification tests, in which the tests were conducted in two different months. The scatter was the focus of attention. The standard deviation in Month a and b was 7.2 G and 5.9 G, respectively, while the coefficient of variance was 2.0% and 2.8%, respectively. Thus, there was good repeatability.

Table 1 **Repeatability of maximum lower leg acceleration for dynamic certification tests**

	Maximum lower leg acceleration (G)	
	Month a n = 3	Month b n = 3
1st	282	208
2nd	286	210
3rd	272	219
Mean	280	212
SD	7.2	5.9
CV(%)	2.6	2.8

Next, the mean value was determined. The mean lower leg acceleration for Month a was 280 G, not in conformity with the EC corridor (120–250 G), whereas that for Month b showed compliance at 212 G. The same impactor was used in both tests, and the results differed with the mean 68 G, depending on the month. For uniform, non–controlled test conditions in both tests, it was decided to investigate the effect of humidity on lower leg acceleration in dynamic certification testing in Section 2.

Reproducibility of maximum lower leg acceleration for dynamic certification tests

Table 2 lists the lower leg acceleration measured by the four legform impactors manufactured for the dynamic certification tests. The test results were the same as those obtained from tests on the same day as for month b in Section 1.1. The mean lower leg acceleration measured with the four leg impactors ranged from 212 to 219 G, thus complying with the EC corridor. The standard deviation of each of the impactors' lower leg acceleration ranged between 4.0 to 12.0 G, while the coefficient of variance was from 1.9 to 5.6%. Thus, reproducibility of the four impactors was good.

Effect of different impact points in vertical direction on maximum lower leg acceleration

Table 3 shows the effects of different impact points on maximum lower leg acceleration on the vertical at zero,

Table 2 **Reproducibility of maximum lower leg acceleration for dynamic certification tests**

	Maximum lower leg acceleration (G)			
	Legform 1	Legform 2	Legform 3	Legform 4
1st	208	202	226	210
2nd	210	226	210	217
3rd	219	214	220	217
Number	3	3	3	3
Mean	212	214	219	215
SD	5.9	12.0	8.1	4.0
CV (%)	2.8	5.6	3.7	1.9
Overall mean (n = 12)	215			
Overall SD	7.3			
Overall CV (%)	3.4			

3 mm and 10 mm in relation to the ram height. At 3 and 10 mm, the mean lower leg acceleration was a low 14 and 4 G. The mean Standard Deviation (6.1 G, 7.1 G, 7.8 G) was 7.0 G for zero, 3 mm and 10 mm. At a 3 mm interval, the value obtained of 14 G was low in comparison to the standard setup, but it was comparable to two Standard deviations. Thus, even with the variation in ram centre height, there was no observable variance on the obtained value.

Effect of relative humidity on maximum lower leg acceleration for dynamic certification test

The lower leg acceleration obtained by dynamic certification test setups under 4 different relative humidity conditions of 18%, 31%, 46% and 63% is shown in Figure 11. As the humidity increased, so did the lower leg acceleration.

Table 3 **Effect of different impact points on maximum lower leg acceleration in vertical direction**

	Maximum lower leg acceleration (G)		
Distance in vertical*	0 mm n = 3	3 mm n = 2	10 mm n = 2
1st	177	165	175
2nd	167	155	164
3rd	178		
Mean	174	160	170
SD	6.1	7.1	7.8
CV (%)	3.5	4.4	4.6

*Distance between impact location of ram and center of legform impactor in vertical direction

With humidity conditions of RH18%, 31% and 46%, the lower leg acceleration fell within the EC corridor, but not at RH63%.

Effect of humidity on ram acceleration in impact against confor™ foam

Relation of mass of confor™ foam specimen and soak time

The relation of the mass of the confor™ foam specimen and soak time in given relative humidity (RH) conditions (RH42%, RH60% and RH87%) was shown in Figure 12. The results indicated that the increase in the mass of the foam specimen became stable when the RH35.7% test specimen was soaked for 50 minutes under the RH42% and RH60% conditions, respectively. Thus, the amount of water soaked up by the confor™ foam specimen reached saturation. On the other hand, when the RH35.7% test specimen was soaked for 50 minutes under RH87% conditions, its mass tended to increase.

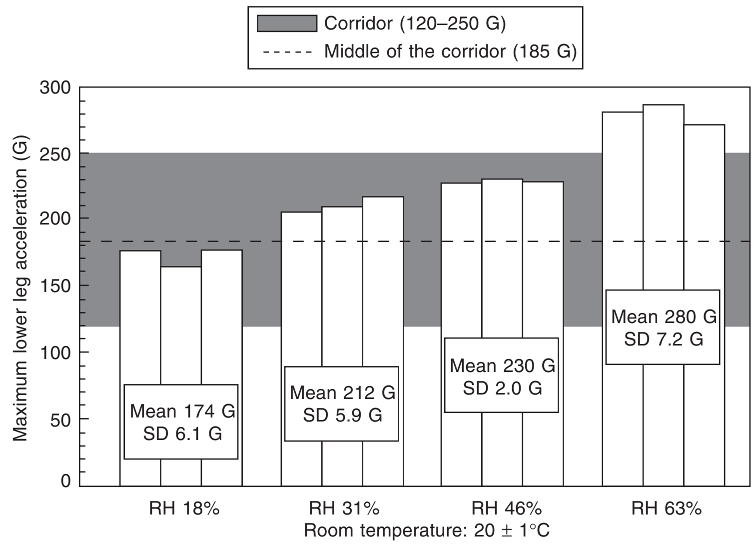
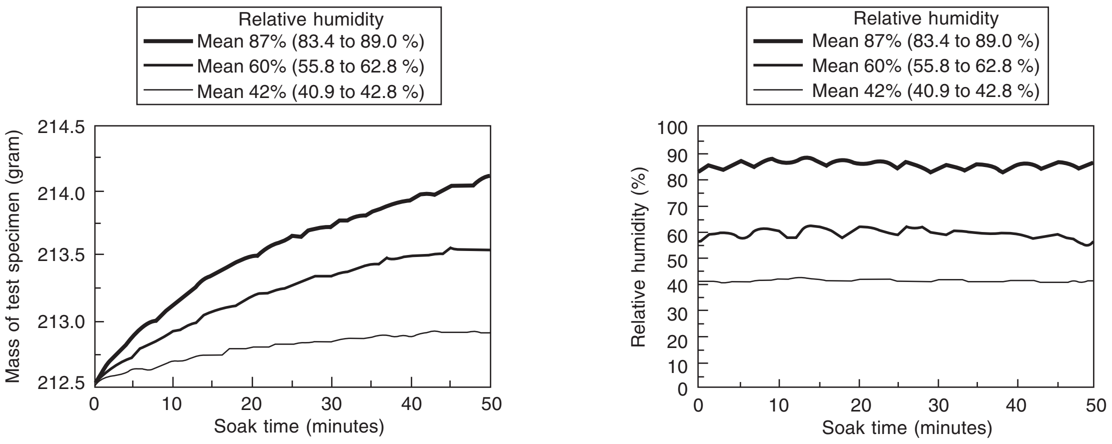


Figure 11 Maximum lower leg acceleration from dynamic certification test results at different relative humidity levels.



(1) Relation of specimen mass and soak time

(2) Relation of relative humidity and soak time

Figure 12 Relation of mass specimen and soak time.

Relation of relative humidity and maximum ram acceleration in impact against confor™ foam soaked at different humidities

Figure 13 shows the maximum acceleration when confor™ foam specimens soaked for 50 minutes at various humidities were impacted. Together with the increase in the relative humidity, the maximum acceleration increased. The maximum acceleration obtained at RH80.0% (209 G) was twice that (105 G) at RH35.7%. It was thus clear that humidity exerted a great influence on the confor™ foam impact results.

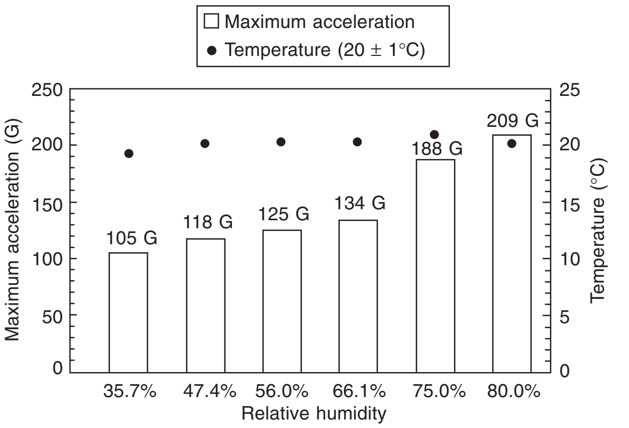


Figure 13 Maximum acceleration when confor™ foam specimens soaked for 50 minutes were impacted at various humidities.

DISCUSSION

Based on the results obtained by the present studies, the humidity was found to be the key factor affecting the result of the lower leg acceleration in dynamic certification tests of the legform impactor. In the conventional test procedure, only the temperature was prescribed. The present results made it clear that the humidity procedure must also be regulated. The upper limit of the humidity that will fall within the EC corridor would appear to be between RH46% and 63% (Figure 11). The boundary condition must be investigated in more detail in future.

In Japan, the relative humidity exceeds 80% during the monsoon months of June and July. It is virtually impossible during this time to pass a dynamic certification test in a non-humidity controlled test lab during that season.

Next, in discussing pre-soak time, it was found in Section 3.1 that saturation was reached when the foam specimen was soaked for 50 minutes at a relative humidity of less than 60% (Figure 12(1)), whereas it was not reached at 87%. When pre-soak time is more than one hour, the acceleration measured from the ram would exceed the levels obtained in the present study.

At present, the crush performance of the confor™ foam used to sheathe the legform impactor is indeed affected by both temperature and humidity. Ideally, one way to overcome this would be to develop a foam material with a characteristic impervious to temperature or humidity to be used for the legform impactor. In the certification test, it would be sufficient to streamline the testing equipment so as to confirm only the foam crush performance. As a tentative measure until such new foams were developed, one way would be to use the foamless static shearing certification test [7] prescribed by the EU.

CONCLUSIONS

In the dynamic certification test procedure proposed by the EC, the propelling direction of the ram was arranged so that the centre of the ram would align with a position 50 mm from the knee centre-line, with a tolerance of ±3 mm vertically. Results indicated that even with the variation in ram centre height, there was no observable effect on the obtained value. On the other hand, results obtained show the lower leg acceleration to be strongly affected by humidity in the test apparatus. The results of the impact test against the confor™ foam indicated that the measured acceleration increased drastically with higher humidity. Therefore, it is concluded that humidity is also a key factor affecting the result of the lower leg acceleration in a dynamic certification test of a legform impactor. Adjustment of the humidity within the test apparatus is thus one way to obtain the compliance of lower leg acceleration with the proposed EC corridor.

REFERENCES

1. Institute for Traffic Accident Research and Data Analysis of Japan (ITARDA), 'Annual Traffic Accident Report in 2002', Tokyo, 2003 (in Japanese).
2. European Enhanced Vehicle-safety Committee, *Improved Test Methods to Evaluate Pedestrian Protection Afforded by Passenger Cars*, EEVC Working Group 17 Draft Report, 1998.
3. Transport Research Laboratory, *TRL Pedestrian Legform Impactor User Manual. Version 2.0*, 2000.
4. Matsui, Y. 'Biofidelity of TRL Legform Impactor and Injury Tolerance of Human Leg in Lateral Impact', *Stapp Car Crash Journal*, 2001 Vol. 45, pp. 495-510.
5. Matsui, Y. 'New injury reference values determined for TRL legform impactor from accident reconstruction test', *International Journal of CRASHWORTHINESS*, 2003 Vol. 8 No. 2, pp. 179–188.
6. Lawrence, G. and Hardy, B. 'Reconsideration of the dynamic certification test for the EEVC WG17 legform impactor', TRL project report PR/SE/520/02, 2002.
7. Commission of the European Communities, 'Pedestrian Protection: Technical Prescriptions Concerning Test Provisions for Pedestrian Protection', DG Enterprise Working Document, 2003.
8. Matsui, Y and Tanahashi, M. 'Development of JAMA-JARI Pedestrian Headform Impactor in Compliance with ISO and IHRA Standards', *International Journal of CRASHWORTHINESS* (submitted).