TRL Limited

PUBLISHED PROJECT REPORT PPR048

THE EFFECT OF HUMIDITY ON LEGFORM IMPACTOR CERTIFICATION RESULTS

Version: Final

by G J L Lawrence, B J Hardy and W M S Donaldson (TRL Limited)

Prepared for:	**Project Record:**	**S222C/VF – Pedestrian Protection Procedures**
	Client:	**Vehicle Technology and Standards Division, Department for Transport (Ian Knowles)**

	Approvals
Project Manager	
Quality Reviewed	B. Hardy

This report has been produced by TRL Limited, under/as part of a Contract placed by the Department for Transport. Any views expressed are not necessarily those of the Department for Transport.

TRL is committed to optimising energy efficiency, reducing waste and promoting recycling and re-use. In support of these environmental goals, this report has been printed on recycled paper, comprising 100% post-consumer waste, manufactured using a TCF (totally chlorine free) process.

CONTENTS

Executive summary

A European collaborative group, under the auspices of the European Enhanced Vehicle-safety Committee (EEVC), has produced test methods and performance criteria. An adoption of these test methods has been used in the European Union's Directive for pedestrians and other vulnerable road users (2003/102/EC). The EEVC test methods consist of three test procedures where the car is impacted to assess its performance. These represent the three main phases of a pedestrian impact: the bumper impact at about knee height, the bonnet leading edge impact at upper leg or pelvis height and the head impact with the bonnet top.

For any formal vehicle assessment, whether for regulatory or non-regulatory (e.g. consumer information) purposes, it is important to make vehicle test methods and test tools repeatable in order to achieve constant standards. In order to achieve consistent test tools, EEVC specifies both the physical and dynamic requirements. TRL have developed a legform impactor to meet the EEVC's requirements. This impactor was developed in several stages, and in December 1999 the damped legform impactor was shown to fulfil the EEVC specification and was therefore accepted as an approved EEVC impactor.

In parallel with the development of the legform impactor, dynamic certification methods for the legform impactor were devised and refined with the aim of producing a repeatable certification test that approximately reproduced the loading on the legform impactor produced by a car with a pedestrian friendly bumper. The current version of the legform dynamic certification method is described in the updated version of the EEVC Working Group 17 report. The tibia acceleration and knee shear tolerance bands for this certification method are wider than those normally used because the certification test was found to be unduly sensitive to variations in the Confor™ foam (used to represent human flesh) during the bottoming-out phase.

Lawrence and Hardy reported results using the legform impactor and considered the philosophy of certification tests. They concluded that ideally a dynamic certification test should use as an impacting partner a representation of a vehicle which could crush or deform. Nevertheless, the current certification method uses a rigid impact partner as the inclusion of crush produced with disposable material would have created more problems, of trying to make that material repeatable. The use of a rigid impact partner in the current certification method is thought to be the fundamental cause of the high variability in the acceleration and shear results, the cause is not a problem with the impactor itself. TRL impactor sales have developed ways of reducing certification variation mainly by developing methods of selecting 'good' flesh i.e. foam that is more likely to yield a pass in the certification test.

Another factor that has been shown to affect the certification results is the relative humidity of the Confor foam flesh. Matsui and Takabayashi showed that the acceleration achieved in legform certification tests ranged from 170 to 280 g for a range of relative humidity of 18 to 63 percent respectively. As part of a feasibility study for the European Commission, Lawrence *et al.* reviewed the work of Matsui & Takabayashi, and proposed provisional humidity tolerances for testing vehicles and certifying the legform impactor, but also recommended that a further study be carried out to confirm or adjust these proposed tolerances.

The main objective of this current study was to further investigate the effects of humidity on the legform impactor certification results.

The conclusions from this study were:

- TRL's results confirm the sensitivity to relative humidity that was first reported by Matsui and Takabayashi. The greatest sensitivity is in tibia acceleration; however, TRL's results show a much lower rate of acceleration change against relative humidity.
- The tolerances previously proposed for relative humidity (35 ±10 percent in certification tests and 35 ±15 percent in vehicle tests) are supported by this study, although it would be preferable to have more data.

- The relationship of relative humidity to tibia acceleration is the end cause of two relationships, the relationship between relative humidity and Confor foam stiffness, and the relationship between Confor foam stiffness and tibia acceleration. Both relationships are or may be non-linear. Confor foam stiffness to tibia acceleration is normally inverse (lower stiffness gives a higher peak acceleration) and non-linear due to ‘bottoming out’.
- Differences in the tibia acceleration’s sensitivity to relative humidity may be caused by different characteristics of Confor foam used by TRL and by Matsui & Takabayashi (such as a different stiffness at a given relative humidity) or a slightly different thickness of foam.
- The use of a separate humidity controlled cabinet to condition the legform and the use of a humidity-tight box to transfer the legform from the chamber to the test laboratory worked well.
- Because of the cost and technical difficulty of controlling relative humidity in a large test laboratory it is recommended that the option of using a chamber to condition only the legform be permitted. The use of a humidity-tight transfer box could also be permitted.
- It would be useful to study the issue of soak times further, so that recommendations on the time required to condition the legform could be made with greater confidence.

Abstract

A European collaborative group, under the auspices of the European Enhanced Vehicle-safety Committee (EEVC), has produced test methods and performance criteria for pedestrian protection. An adaptation of these test methods has been used in the European Union's Directive for pedestrians and other vulnerable road users (2003/102/EC).

EEVC specifies both the physical and dynamic requirements of their impactors. TRL have developed a legform impactor to meet the EEVC requirements.

The dynamic performance of the legform impactor is difficult to determine in a simple dynamic certification test because it has three very different injury modes which all need to be activated in the one test. The current version of the legform dynamic certification method has tolerance bands that are wider than normal because the certification test was found to be unduly sensitive to variations in the properties of the Confor™ foam used to represent human flesh.

Another factor that has been shown, by Matsui and Takabayashi, to affect the acceleration achieved in legform certification results is the relative humidity, which influences the behaviour of the foam flesh.

The main objective of this current study was to further investigate the effects of humidity on the legform impactor certification results.

1 Introduction

A European collaborative group has produced test methods and performance criteria suitable for use in regulations to require pedestrian protection in cars. This work was carried out under the auspices of the European Enhanced Vehicle-safety Committee in their Working Group 10 followed by their Working Group 17. The test methods consist of three test procedures where the car is impacted to assess its performance. These represent the three main phases of a pedestrian impact: the bumper impact at about knee height, the bonnet leading edge impact at upper leg or pelvis height and the head impact with the bonnet top. The European Union Directive for pedestrians and other vulnerable road users (2003/102/EC) was approved in late 2003 and it makes use of the EEVC test methods.

For any formal vehicle assessment, whether for regulatory or non-regulatory (e.g. consumer information) purposes, it is important to make vehicle test methods and test tools repeatable in order to achieve constant standards. In order to achieve consistent test tools, EEVC specifies both the physical and dynamic requirements. At the start of this work there was no dynamic certification test method available for specifying the dynamic response of the legform impactor, so a method had to be developed. The approach of the EEVC Working Groups 10 and 17 was firstly to produce a specification for the impactor that was based on human anthropomorphic and biomechanical data and on the required injury mechanism outputs. Secondly, the EEVC developed an impactor to meet this specification with suitable robustness and outputs. Thirdly, the EEVC developed a suitable dynamic certification test method for the impactor. Finally, using the results of dynamic certification tests with a conforming impactor, the dynamic certification pass requirements were set to approve that impactor when the impactor is working as intended. Following on from earlier work, TRL developed a legform impactor to meet the working group's requirements. This impactor was developed in several stages, and in December 1999 the damped legform impactor was shown to fulfil the EEVC specification (European Enhanced Vehicle-safety Committee, 1998). Therefore, the EEVC WG17 accepted it as an approved EEVC impactor.

In parallel with the development of the legform impactor, dynamic certification methods for the legform impactor were devised and refined with the aim of producing a repeatable certification test that approximately reproduced the loading on the legform impactor produced by a car with a pedestrian friendly bumper. The current version of the legform dynamic certification method is described in the updated version of the EEVC Working Group 17 report (European Enhanced Vehicle-safety Committee, 2002). The tibia acceleration and knee shear tolerance bands for this certification method are wider than those normally used because the certification test was found to be unduly sensitive to variations in the Confor™ foam (used to represent human flesh) during the bottoming-out phase (Lawrence and Hardy, 2002).

Lawrence and Hardy reported results using the legform impactor and considered the philosophy of certification tests. They concluded that ideally a dynamic certification test should use as an impacting partner a representation of a vehicle which could crush or deform (Lawrence and Hardy, 2002). Nevertheless, the current certification method uses a rigid impact partner as the inclusion of crush produced with disposable material would have created more problems, of trying to make that material repeatable. The use of a rigid impact partner in the current certification method is thought to be the fundamental cause of the high variability in the acceleration and shear results, the cause is not a problem with the impactor itself. TRL impactor sales have developed ways of reducing certification variation mainly by developing methods of selecting ‘good’ flesh i.e. foam that is more likely to yield a pass in the certification test.

Another factor that has been shown to affect the certification results is the relative humidity of the Confor foam flesh. Matsui and Takabayashi (2004) showed that the acceleration achieved in legform certification tests ranged from 170 to 280 g for a range of relative humidity of 18 to 63 percent respectively. As part of a feasibility study for the European Commission, Lawrence *et al.* (2004) reviewed the work of Matsui & Takabayashi, and proposed provisional humidity tolerances for testing vehicles and certifying the legform impactor, but also recommended that a further study be carried out to confirm or adjust these proposed tolerances.

The main objective of this current study was to further investigate the effects of humidity on the legform impactor certification results.

2 Methodology

As well as showing a relationship between relative humidity and legform certification results, Matsui and Takabayashi (2004) also conducted separate impact tests on samples of Confor™ foam in a humidity controlled chamber. These tests showed that the Confor foam was sensitive to the humidity level. TRL discussed these findings with the experts of E-A-R, the company who make Confor foam. The E-A-R experts confirmed the material is sensitive to relative humidity with the water acting within the matrix of the foam, as if a lubricant, making it effectively softer and more likely to bottom out. Lawrence and Hardy (2002) had concluded that the tibia acceleration and knee shear outputs are unduly sensitive to variations in the Confor™ foam (used to represent human flesh) during the bottoming-out phase of the certification test. It was therefore decided to carry out a series of certification tests at different relative humidity levels, to determine the sensitivity of the foam in this situation, whilst minimising other variables. Therefore, the tests were conducted using foam flesh and ligaments from the same batch and minimising, as far as possible, variations in impact speed and ambient temperature. Two legform impactors were used for this study so that the humidity in one impactor and flesh could be stabilising whilst the other was being tested; thus reducing the time necessary for the test programme. This would also have the advantage of identifying any variability due to differences between impactors.

2.1 Legform certification at a range of relative humidity

The legform certification rig was set up on the TRL sled and the height of the suspended legform adjusted so that the impact was within the height tolerance set by the current EEVC WG17 test procedures. The test set up is shown in Figure 2.1 below.

The relative humidity range selected in this study was from 15 to 65 percent at a temperature of 20°C, which was similar to that used by Matsui and Takabayashi (2004) in their study. The TRL sled facility has no system to control the ambient humidity. Therefore a separate chamber was used to condition the legforms themselves; however, this was some distance away. In order to transport the legforms while maintaining them at the selected humidity, two humidity-tight boxes (one for each legform used) were made with quick-close sealed lids. The boxes were designed so that a legform, complete with ligaments and flesh, could be supported at each end by the metal at the hip joint and foot plate respectively. This arrangement was chosen so that the skin and foam would not be compressed by the impactor's weight and to allow a better flow of conditioned air around the impactor. For each test the legforms were fitted with new ligaments, dressed with a new piece of flesh and then placed in the box with the zip open (just the ends of the zip were engaged). The box was then placed into the humidity chamber with the lid off for one hour after which the skin was fully zipped up. The legform was then left for a further 20 minutes and then the lid was sealed on the box, with the instrumentation cables passing trough the rubber seal of the lid. The leg, in its sealed box, was then transported to the test rig. To minimise the time that the legform was exposed to the ambient room conditions the instrumentation cables were connected to the data recording system with the legform still in its sealed box. The box was then removed just before the certification test. For the first test the wire ropes required for the certification test were attached to the legform before it was placed in the humidity chamber. However, for subsequent tests the ropes were left attached to the certification facility as it was found to be quicker to attach them to the legform after removing it from the box. The temperature within the test facility was closely monitored and regulated to minimise this unwanted additional variability. The ambient temperature and ambient relative humidity were recorded just before the test using a digital thermometer / hygrometer. The majority of the tests were filmed using a digital video camera, to check the impact height of the certification impactor. The transfer of a small dot of wet paint from the centre-line of the certification face to the skin of the impactor was used to obtain an indication of the longitudinal position of the contact with the legform.

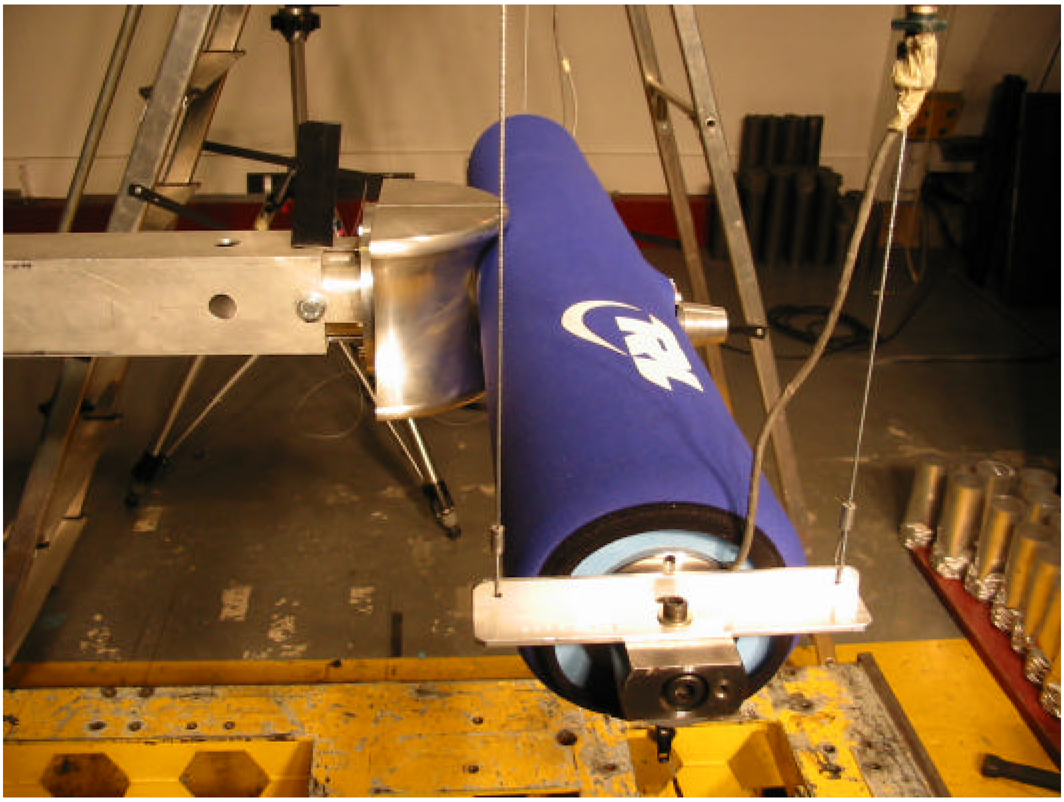


Figure 2.1. Legform impactor certification rig

3 Results

The videos show that the impactor height was consistent for each test and that the impact was within the 3 mm tolerance set within the EEVC WG17 protocol.

The full results of the testing are shown in Table 4.1 and include the times that the leg was in the controlled environment, the test velocities, the ambient temperature, the ambient relative humidity and a rough indication of the horizontal impact location (measured from the transferred paint spot to the foot plate of the legform).

A summary of the results from this test program and the results obtained by Matsui and Takabayashi (2004) are shown for comparison in Table 4.2. The TRL results in Table 4.2 are the average of the two tests at the same humidity, with one exception. This was for the results of the two tests at 45 percent relative humidity, where one acceleration result was discarded, as it was found after the test that the tibia had been inadvertently attached to the femur the wrong way round. As this resulted in the certification face impacting directly over the tibia accelerometer the result, which did not follow the pattern of the rest of the tests, was regarded as suspect and ignored.

4 Discussion

The main aim of this study was to investigate the effect of relative humidity on the dynamic legform certification results. The results show that there is a definite sensitivity to humidity, over the range examined of 15 to 65 percent relative humidity. All three measured outputs show an increasing trend with relative humidity as shown in Figure 4.1 below, but tibia acceleration has the greatest sensitivity. In the case of all three outputs it can be assumed that the higher outputs are caused because the impact has generated a higher contact force; due to humidity changing the performance of the Confor foam. This higher force directly causes a higher tibia acceleration, and the higher force / acceleration will in turn drive higher shearing velocities and rotational bending velocities and hence lead to a higher peak shear displacement and bending angle. In the discussion following, for simplicity, only the strongest and most direct of these relationships will be mentioned, that between tibia acceleration and relative humidity.

It can also be seen from Figure 4.1 that the two TRL impactors gave very similar results; however, it can be seen that impactor LG25/9 gave slightly lower shear displacements and its acceleration results, with one exception, are slightly higher than those of impactor LG44.

The results in Figure 4.1 demonstrate a relationship between relative humidity and the certification results. As these tests are carried out within tight temperature tolerances it would not matter if this relationship were actually stronger with *absolute* humidity than with *relative* humidity. A relationship with humidity has been demonstrated and, as measurements have been made of relative humidity, it has been assumed that the relationship is primarily of *relative* humidity against the certification results.

It seems reasonable to conclude that this relationship is due to the effect of relative humidity on the stiffness of the Confor foam. The manufacturers of the foam have stated that the foam is least sensitive in the range 20 to 60 percent relative humidity and it can be seen from Figure 4.1 that the results appear to be reasonably consistent between 25 to 55 percent, with the greatest effect on the results, especially acceleration, at the extremes of the humidity range. There is a significant increase in acceleration between 55 percent and 65 percent relative humidity.

The trend in tibia acceleration results with humidity is thought to be cause by two relationships:

- Effect of *Humidity* on Confor foam *Stiffness*
- Effect of Confor foam *Stiffness* on Tibia *Acceleration*

However the exact combined effect of these relationships is unknown as both are non-linear. The effect of Confor foam stiffness on peak tibia acceleration is normally inverse, i.e. lower stiffness foam gives a higher peak acceleration. This is because a lower stiffness foam in the early part of the impact gives a lower *initial* acceleration. As a result there will be a greater velocity differential, between legform and certification impactor, to be overcome in the latter part of the impact. The foam is highly compressed anyway in this late stage of the impact, and the stiffness increases rapidly as the foam becomes further compressed. This process can be seen in the tibia acceleration time histories in Figures 4.2 and 4.3 (showing filtered and unfiltered data respectively). The process can be described as ‘bottoming out’, as the foam begins to run out of compression. Foam that was initially less stiff (i.e. at moderate compression) will therefore bottom out more severely in the latter part of the impact,

Table 4.1: Legform certification results and time in controlled environment

Test No.	**1***	**2#**	**3**	**4**	**5**	**6**	**7 ♦**	**8**	**9**	**10**	**11**	**12**
Leg no.	L25/9	LG44	L25/9	LG44	L25/9	LG44	L25/9	LG44	L25/9	LG44	L25/9	LG44
Foam (TRL ref, sheet and piece no.)	B67-3-4	B67-3-5	B67-3-6	B67-2-6	B67-3-1	B67-2-4	B67-3-2	B67-2-2	B67-3-3	B67-2-3	B67-2-5	B67-2-1
Chamber humidity (%)	15	15	25	25	35	35	45	45	55	55	65	65
Chamber temp. (degrees C)	20	20	20	20	20	20	20	20	20	20	20	20
Soak time (hrs:mins)	01:48	01:25	01:24	01:28	01:23	01:24	16:09	17:26	02:02	01:33	01:24	01:24
Time out of box (mins)	13	9	10	9	8	8	8	15	7	7	7	7
Ambient humidity (%)	50.5	53.0	53.8	53.8	54.8	52.5	36.7	38.8	36.5	36.4	35.3	31.2
Ambient temp. (degrees C)	20.0	18.6	19.9	19.7	19.0	19.5	19.0	18.2	19.9	19.5	19.2	20.6
Impactor velocity (m/s)	7.25 *	N/A #	7.58	7.57	7.55	7.55	7.62	7.61	7.46	7.50	7.45	7.50
Tibia acceleration (g)	175	171	189	186	194	191	222	196	194	190	210	218
Knee shear displacement (mm)	4.38	4.50	4.55	4.73	4.45	4.74	4.82	4.86	4.68	4.77	4.82	5.07
Knee bending angle (degrees)	6.74	7.05	7.14	7.20	7.42	7.23	7.39	7.47	7.08	7.27	7.41	7.66
Distance of impact from foot plate (mm)	446	442	443	442	443	446	441	445	446	442	442	445

* The speed measurement overlapped with the impact instead of being completed just before impact; hence it is believed that the true speed was within tolerance as the setup had not changed since the pre-test speed runs.

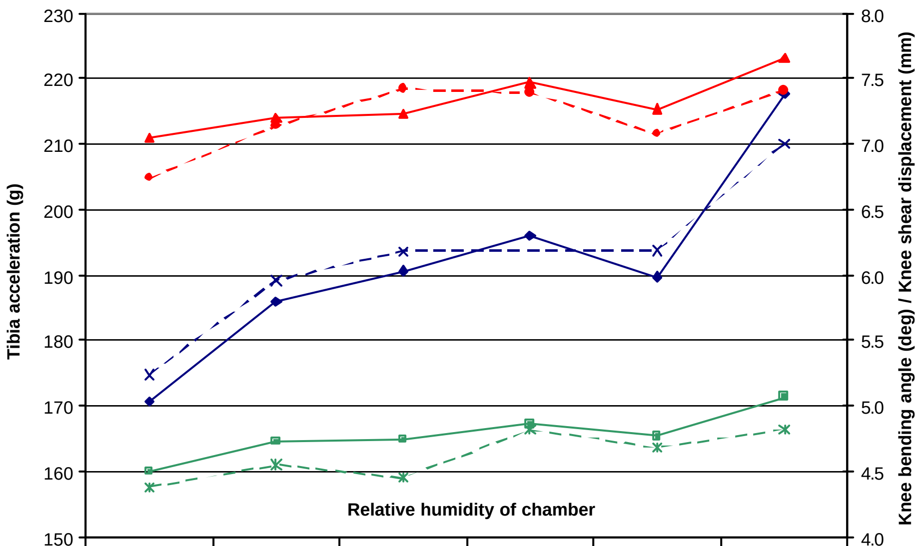
The timer on the speed measurement was triggered before testing; it is believed that the speed was within tolerance as the setup had not changed since the pre-test speed runs.

♦ Test 7 had the Tibia section installed the wrong way round, so that the impact occurred directly over the accelerometer.

resulting in a higher peak acceleration. This process is highly non-linear, as foam that is somewhat less stiff than normal could produce a very significant increase in the peak tibia acceleration, in the latter stages of the impact.

Table 4.2: Comparison of TRL's and Matsui & Takabayashi's certification results

TRL				Matsui and Takabayashi (2004)	
Relative humidity	**Tibia acceleration (g)**	**Knee shear displacement (mm)**	**Knee bending angle (degrees)**	**Relative humidity**	**Tibia acceleration (g)**
15%	173	4.44	6.90	18%	174
25%	188	4.64	7.17	-	-
35%	192	4.60	7.33	31%	212
45%	196	4.84	7.43	46%	230
55%	192	4.73	7.18	-	-
65%	214	4.95	7.54	63%	280



	15%	25%	35%	45%	55%	65%
Tibia Acceleration LG44 (g)	171	186	191	196	190	218
Tibia Acceleration L25/9 (g)	175	189	194	N/A	194	210
Knee Shear Displacement LG44 (mm)	4.50	4.73	4.74	4.86	4.77	5.07
Knee Shear Displacement L25/9 (mm)	4.38	4.55	4.45	4.82	4.68	4.82
Knee bending angle LG44 (degrees)	7.05	7.20	7.23	7.47	7.27	7.66
Knee bending angle L25/9 (degrees)	6.74	7.14	7.42	7.39	7.08	7.41

Figure 4.1. Legform certification results

The relatively large increase in acceleration between 55 and 65 percent relative humidity could be due to the fact that the softening effect on the flesh of humidity has reached a point where the certification impactor face is bottoming out much more violently on the metal tibia towards the end of the impact. This conclusion is supported by comparing the acceleration time histories of the 25 and 65 percent relative humidity tests as shown in Figure 4.2. It can be seen that during the first 3½ ms the acceleration is lower in the test with the higher relative humidity, indicating that the foam was less stiff. It can be seen that in both cases the acceleration then increases markedly, which is presumably because the foam is highly compressed and is in a 'bottoming out' phase, as described earlier. Confor foam does not bottom out as suddenly as do some foam materials, the process is more gradual. Nevertheless, the acceleration rapidly increases. The filtering specified in the test procedures actually masks much of this increase. Figure 4.3 shows a similar comparison with unfiltered data (strictly speaking, the data has had only the anti-aliasing filter at about 3½ kHz applied). It can be seen that as well as the unfiltered peak values being significantly larger, the proportional effect of the relative humidity is greater on the unfiltered peak values (the unfiltered peak values show a 37 percent increase from 25 to 65 percent relative humidity compared with a 17 percent increase with the CFC 180 peak values).

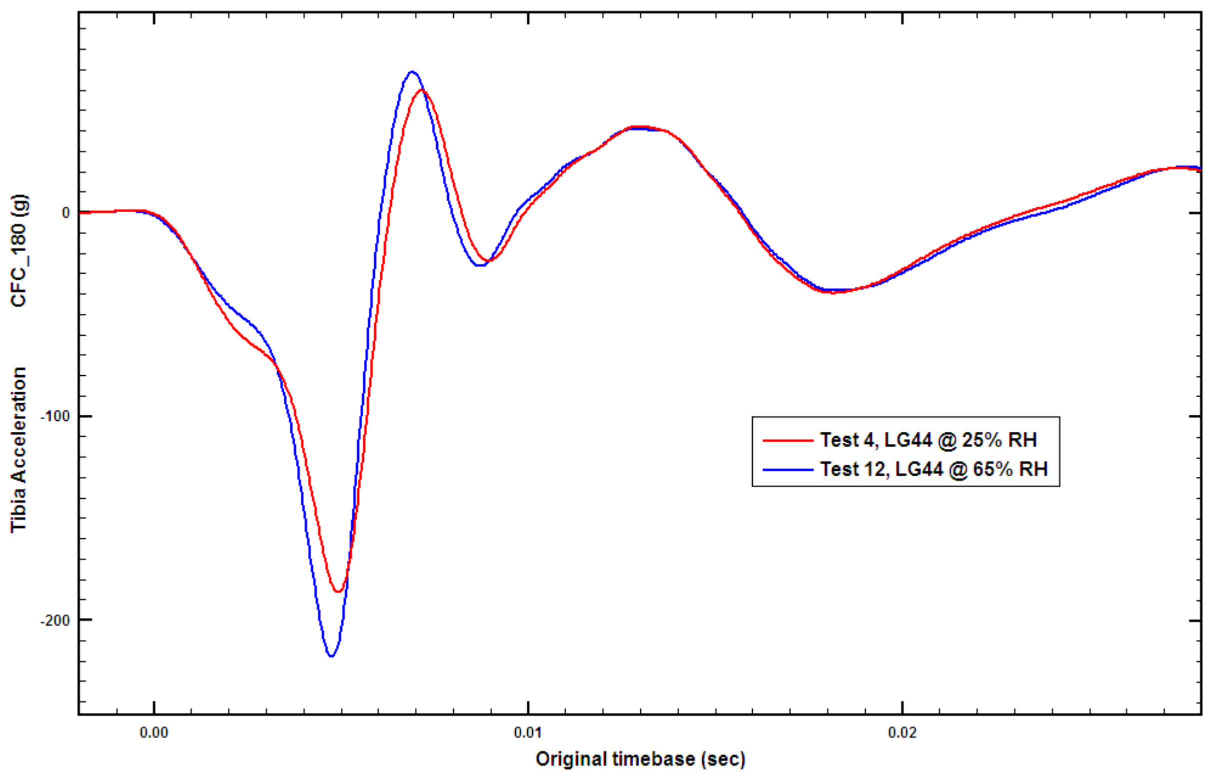


Figure 4.2. Comparison of tibia accelerations obtained in tests at 25 percent and 65 percent relative humidity, filtered at CFC 180

The relatively large increase in acceleration between 55 and 65 percent relative humidity could be due to the fact that the softening effect on the flesh of humidity has reached a point where the certification impactor face is bottoming out much more violently on the metal tibia towards the end of the impact. This conclusion is supported by comparing the acceleration time histories of the 25 and 65 percent relative humidity tests as shown in Figure 4.2. It can be seen that during the first 3½ ms the acceleration is lower in the test with the higher relative humidity, indicating that the foam was less stiff. It can be seen that in both cases the acceleration then increases markedly, which is presumably because the foam is highly compressed and is in a 'bottoming out' phase, as described earlier. Confor foam does not bottom out as suddenly as do some foam materials, the process is more gradual. Nevertheless, the acceleration rapidly increases. The filtering specified in the test procedures actually masks much of this increase. Figure 4.3 shows a similar comparison with unfiltered data (strictly speaking, the data has had only the anti-aliasing filter at about 3½ kHz applied). It can be seen that as well as the unfiltered peak values being significantly larger, the proportional effect of the relative humidity is greater on the unfiltered peak values (the unfiltered peak values show a 37 percent increase from 25 to 65 percent relative humidity compared with a 17 percent increase with the CFC 180 peak values).

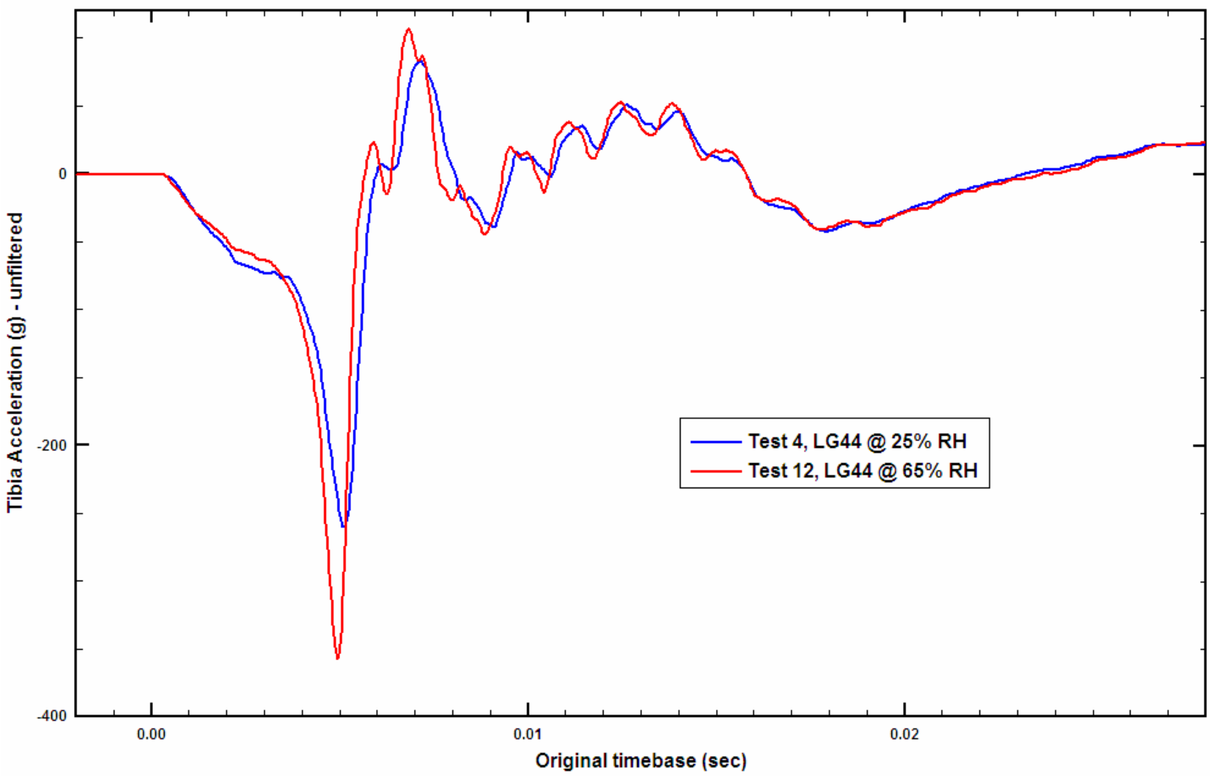


Figure 4.3. Comparison of tibia accelerations obtained in tests at 25 percent and 65 percent relative humidity, unfiltered

It is effectively a requirement of the legform certification test that some degree of bottoming out occurs, as without it the acceleration would not reach the lower limit of 120 g, and the lower acceleration would not excite the desired degree of knee bending. Because the acceleration is initially lower in the test with the higher relative humidity the certification impactor velocity and the Confor foam compression will be greater at any given time. When after 3½ ms the acceleration becomes greater at the higher relative humidity it is presumably only because the effect of the greater compression outweighs the softening effect of the higher relative humidity. At any given compression factor the foam at the higher relative humidity would presumably have the lower stiffness.

Perhaps inevitably the results shown in Figure 4.1 are not totally consistent. The differences between the 45 and 55 percent relative humidity results go against the overall trend. The longer soak times before the 45 percent relative humidity tests may have increased those values. However, the 55 percent relative humidity test results seem to be the ones that diverge further from the overall trend. Part of the explanation may be that the tests at 45 percent relative humidity were at slightly higher speeds than the 55 percent relative humidity tests. Many other factors can also cause variation between tests, such as piece-to-piece variation in the properties of the Confor foam.

In summary, the effect of relative humidity on Confor foam stiffness appears to be great at the extremes, but between 25 percent and 55 percent relative humidity the TRL results show that there is little variation in the accelerations observed. The tolerances previously proposed (Lawrence *et al.*, 2004) for relative humidity (35 ±10 percent in certification tests and 35 ±15 percent in vehicle tests) are supported by this study. It would of course be preferable to have more data, particularly of tests involving Confor foam from a number of different batches.

The soak time in TRL's tests (1 hour with the skin unzipped + 20 minutes zipped up) was selected based on the 50 minutes that Matsui and Takabayashi (2004) used before their drop tests. However, they also weighed a sample over a series of 50 minute soak periods. A sample increasing from 36 to 42 percent relative humidity (+6 percent) stabilised in about 40 minutes. A sample increasing from 36 to 60 percent relative humidity (+24 percent) seemed to have just about stabilised in the 50 minute period, but it would have been preferable to have seen results over a longer period. A sample increasing from 36 to 87 percent relative humidity (+51 percent) was still increasing in weight quite quickly at the end of the 50 minutes; however this is an extreme change in relative humidity. It isn't clear whether humidity could enter the underside of the foam in their tests; if it could the soak period would then need to be longer with the foam on the legform for a given humidity change, because then humidity could only enter from the outer surface. It may be that the circulation of air around a legform has a significant effect on the rapidity of moisture exchange. Matsui & Takabayashi's weight results were all for an increase in the relative humidity; however it might be the case that more time is required for a decrease in relative humidity. It was effectively taken for granted that the effect of humidity within the foam on the foam stiffness occurs relatively quickly, compared with the time for the moisture to be absorbed or given up, but it is possible that the effect takes longer in which case a longer soak period would be required. For these reasons, it is possible that the soak times used by TRL were not adequate; however there is nothing to indicate that this was the case. It would be useful to study the issue of soak times further, so that recommendations on them could be made with greater confidence.

The phenomenon of a range of relative humidity over which the tibia acceleration is relatively insensitive to relative humidity is not however shown in the results obtained by Matsui and Takabayashi (2004), although the results of this current study confirm their findings that tibia acceleration increases with humidity. Figure 4.4 compares the TRL results with the results of Matsui and Takabayashi and shows the large differences in tibia accelerations. These differences may have been caused by the following factors:

- Different characteristics of the Confor foam used by TRL and by Matsui & Takabayashi, in particular the stiffness may be different at a given relative humidity
- Slightly different thickness of foam
- Differences in the soak times and methods

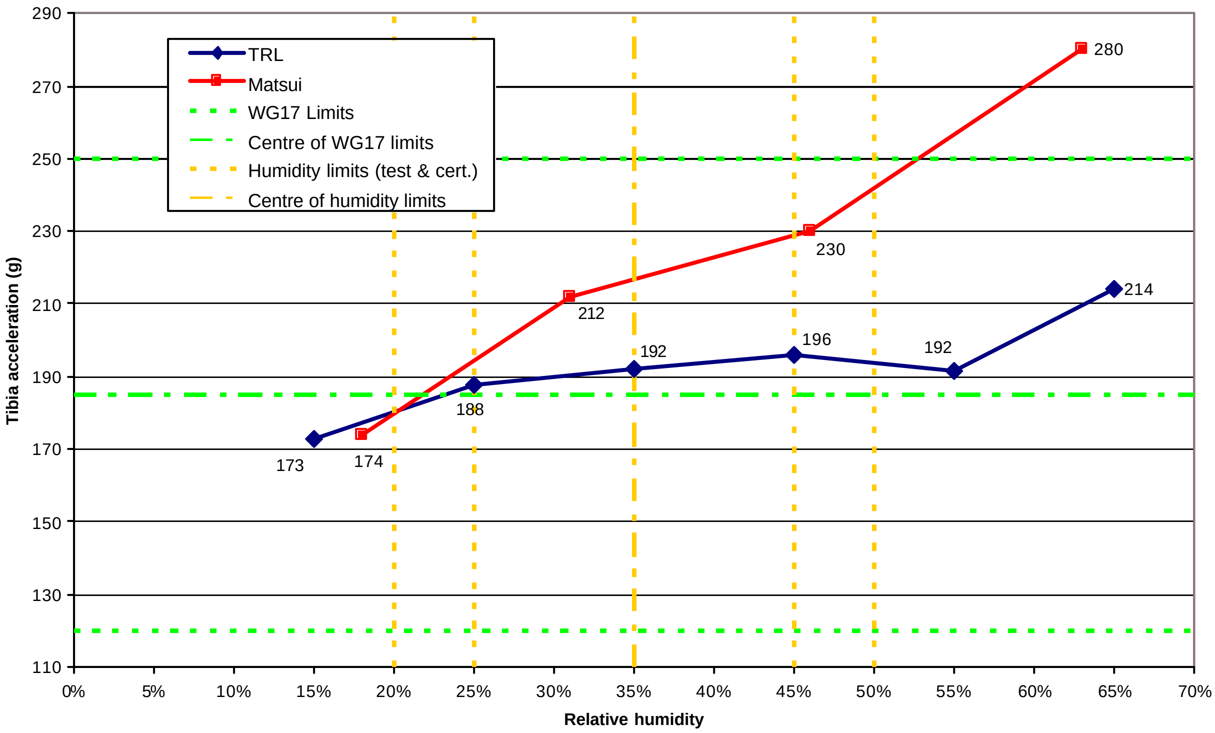


Figure 4.4. TRL and Matsui & Takabayashi results and proposed humidity limits

As are shown in Figure 4.4, the Matsui and Takabayashi results are generally much higher than those obtained by TRL and this may be due to the foam being softer much earlier on and hence the impactor bottoming out more severely. It had therefore been concluded that the high Matsui and Takabayashi acceleration results suggest that their Confor foam was less stiff and possibly slightly thinner.

Despite these differences the results can still be used to set relative humidity limits for the EEVC WG17 dynamic certification test. These limits should reduce the variability of the results obtained and may lead to a tightening of the output limits for the certification test, particularly that for tibia acceleration which is currently very wide. The data currently available are not sufficient to allow a tighter pass corridor to be proposed at this time. Further work to reduce the width of the corridor should use Confor foam from as many different batches as possible, as different batches are likely to vary in the way that changes in relative humidity translate into peak tibia acceleration. Also, it would be preferable to base revised limits on data from as many test houses as possible, from certification tests that have been carried out within the proposed relative humidity limits. To get more information and hence set the output limits at sensible values, EEVC WG17 members have been requested to supply legform certification results along with temperature and humidity readings and also if known Confor foam batch numbers, ILD or IFD values (Indentation Load / Force Deflection) and thicknesses.

As can be seen in Table 4.1, it was found that by making appropriate preparations the set-up-time, with the legform removed from the humidity-tight transfer box was very short, typically less than 10 minutes. With the outer neoprene skin zipped-up it is thought unlikely that there would have been a significant change in the humidity of the legform flesh in so short a time. Therefore it can be concluded that the use of a separate humidity controlled cabinet and a humidity-tight box to transfer the legform from the chamber to the test laboratory worked well. Although many test laboratories have temperature control few have humidity control. One car manufacturer has expressed concerns to TRL about the feasibility of controlling the humidity of a typical test laboratory due to the large volume involved, leakage and air flows. Because of the cost and technical difficulty of controlling humidity in a large test laboratory it is recommended that the option be permitted of using a humidity chamber to control the humidity of the impactor only, including the foam. The use of a humidity-tight transfer box could also be permitted, although it would be preferable to have the humidity chamber close by, within the test laboratory. A time limit of say 10 minutes is suggested between removing the legform from the humidity chamber (or transfer box) and completing the vehicle or certification test. However, it could also be argued that the time allowed should be inversely related to the degree to which the ambient relative humidity was outside the proposed limits. As with soak times, it would be useful to investigate this issue further.

It should be remembered that the legform dynamic certification test is particularly sensitive to small changes in the Confor foam properties, such as those due to changing relative humidity, because the Confor foam ‘flesh’ and the neoprene skin are the only parts preventing metal-to-metal contact between the rigid certification face and the rigid tibia section. This is compounded by the need to have a severe impact in order to achieve an adequate knee bending angle despite the relatively low test velocity. However, in a test of a vehicle that has been designed to pass the test requirements the legform’s collision partner, the bumper, will be deforming as well as the foam ‘flesh’ and the skin. Also the contact forces into the legform may be distributed over a larger area. The peak tibia accelerations obtained in the legform to vehicle test will therefore be much less sensitive to the properties of the Confor foam. However, it is still important to control relative humidity in legform to vehicle tests because test-to-test variability needs to be kept as low as possible, to permit vehicle designs that meet the requirements efficiently (i.e. with the minimum crush depth).

5 Conclusions

1) TRL’s results confirm the sensitivity to relative humidity that was first reported by Matsui and Takabayashi.

2) The greatest sensitivity is in tibia acceleration; however, TRL's results show a much lower rate of acceleration change against relative humidity.
3) The tolerances previously proposed for relative humidity (35 ±10 percent in certification tests and 35 ±15 percent in vehicle tests) are supported by this study, although it would be preferable to have more data.
4) The relationship of relative humidity to tibia acceleration is the end cause of two relationships, the relationship between relative humidity and Confor foam stiffness, and the relationship between Confor foam stiffness and tibia acceleration.
5) Both relationships are or may be non-linear. Confor foam stiffness to tibia acceleration is normally inverse (lower stiffness gives a higher peak acceleration) and non-linear due to 'bottoming out'.
6) Differences in the tibia acceleration's sensitivity to relative humidity may be caused by different characteristics of Confor foam used by TRL and by Matsui & Takabayashi (such as a different stiffness at a given relative humidity) or a slightly different thickness of foam.
7) The use of a separate humidity controlled cabinet to condition the legform and the use of a humidity-tight box to transfer the legform from the chamber to the test laboratory worked well.
8) Because of the cost and technical difficulty of controlling relative humidity in a large test laboratory it is recommended that the option of using a chamber to condition only the legform be permitted. The use of a humidity-tight transfer box could also be permitted.
9) It would be useful to study the issue of soak times further, so that recommendations on the time required to condition the legform could be made with greater confidence.

Acknowledgements

The work described in this report was carried out in the Vehicle Safety and Engineering Department of TRL Limited.

The information and assistance provided by Dan Renninger of E-A-R Speciality Composites is gratefully acknowledged.

References

European Enhanced Vehicle-safety Committee (1998). *EEVC Working Group 17 report. Improved test methods to evaluate pedestrian protection afforded by passenger cars.* Delft, The Netherlands: TNO Crash-Safety Research Centre.

European Enhanced Vehicle-safety Committee (2002). *EEVC Working Group 17 report. Improved test methods to evaluate pedestrian protection afforded by passenger cars (December 1998 with September 2002 updates).* Crowthorne, UK: TRL Limited. (Document available at www.eevc.org)

Lawrence G J L, Hardy B J, Carroll J A, Donaldson W M S, Visvikis C and Peel D A (2004). *A study on the feasibility of measures relating to the protection of pedestrians and other vulnerable road users – Final report.* TRL Project Report available from the European Commission: http://europa.eu.int/comm/enterprise/automotive/pagesbackground/pedestrianprotection/pedestrian_protection_study.pdf.

Lawrence G J L and Hardy B J (2002). *Reconsideration of the dynamic certification test for the EEVC WG17 legform impactor.* Project Report PR/SE/520/02. Crowthorne, UK: TRL Limited.

Matsui Y and Takabayashi M (2004). *Factor causing scatter in dynamic certification test results for compliance with EEVC WG17 legform impactor standard.* International Journal of Crashworthiness, 2004, Vol. 9, No. 1, pp5-13.