PELVIS HUMAN RESPONSE TO LATERAL IMPACT

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ABSTRACT

This paper gives a further approach to provide information on the human pelvis tolerance against lateral impacts with unembalmed cadavers. The aim of this work was to verify the influence of impactor parameters as velocity and weight on the criteria measured on pelvis as force, acceleration and deflection.

A previous study, presented in 1994 at the ESV Conference, concerned the establishment of behaviour laws for the pelvis response by a 23.4 kg impactor. The analysis of crash tests showed that the impacting masses are lower and the impact velocities are higher. It was essential to know the pelvis behaviour in new impact conditions.

A series of 11 new tests were conducted with a guided horizontal impactor at several speeds. The impactor was flat and rigid. It weight was 12 kg or 16 kg.

From the 31 tests it is possible to propose a deflection limit value of 46 mm at a 50% AIS ≥ 2 probability

We propose 2 'force / deflection' corridors for impacts energies of 800 and 1100 joules.

From these study results we propose :

A EUROSID-1 pelvis performance criteria of 3.93 kN with a 50% AIS ≥ 2 probability.

A EUROSID-1 pelvis performance criteria of 6.16 kN for a 50% AIS ≥ 3 probability.

1. INTRODUCTION

An experimental programme was set-up to determine the influence of the impactor's mass and velocity on the pelvis response to lateral impact. The experimental phase evaluation concerned 11 tests on human pelvis (1 impact per pelvis) and 20 tests on the same EUROSID-1 pelvis.

The impacting device used is a linear impactor guided and propulsed by a 6 or 9 Sandow series depending on the velocity to be reached. Its mass is about 12 or 16 kg and the impact surface used for all the pelvis impacts is a 200 x 200 mm square. This surface comprises two trapezoids in such a way as to be able to dissociate the bearing on the hip (iliac) crest from that on the trochanter : this is achieved by using three accelerometers fixed on the back of each of the 2 plates.

The cadavers used are unembalmed, kept in a sitting position and impacted laterally on the right side of the pelvis.

The triaxis accelerometer are attached to T1, T8, and T12 thoracic vertebrae and one on the sacrum.
Double targets were attached to the occipital, T1, T4, T8, T12 vertebrae and similar targets were attached to third lumber vertebrae and to the sacrum.
High speed camera (1000 frames/second) were used to analyze movements and deformations.
The same tests were carried out on the EUROSID pelvis.

For the human pelvis study, anthropometric measurements were made before each test on PMHS. The main data on the 11 cadavers are shown table 1 below.

Table 1 : Characteristics of PMHS solicited at the pelvis

Test N°	Sex	Age	Height (m)	Weight (Kg)	Pelvis Width (mm)
LCB 01	M	65	1.76	54.5	311
LCB 02	F	53	1.64	78.0	341
LCB 03	F	80	1.57	30.0	286
LCB 04	F	93	1.57	43.0	280
LCB 05	M	84	1.60	42.0	315
LCB 06	M	77	1.75	67.5	350
LCB 07	M	72	1.81	82.0	325
LCB 08	M	66	1.73	59.0	320
LCB 09	M	65	1.65	66.0	245
LCB 10	M	69	1.80	56.0	265
LCB 11	M	71	1.69	71.0	315

An autopsy is carried out after each test to assess the extent of injuries observed (see table 2).

Test conditions on the EUROSID-1 pelvis are given in table 3 below.

Various measurements made during the tests will be analyzed according to the following plan.

Analysis of sacrum acceleration caused by the impactor (chapter 2).

Analysis of the sacrum's angular velocity caused by the impactor (chapter 3).

Analysis of the impact force applied at the pelvis by the impactor (chapter 4).

Analysis of the impact force measured on the impactor (chapter 5).

Analysis of the load measured at the pubis of the EUROSID-1 dummy (chapter 6).

Pelvis deflection analysis during impact (chapter (7).

Load / deflection behaviour of the pelvis (chapter 8).

Human tolerance and performance criteria (chapter9)

Table 2 : Test conditions on PMHS pelvis and autopsy results.

Test N°	Mass (Kg) Impactor	Velocity (M/S) Impactor	Energy (J)	AIS	Autopsy Results
LCB 01	12.0	11.4	774	2	Ilio pubic branch fracture
LCB 02	16.0	9.91	786	3	Ilio + ischio pubic branch fract + sacro-illiac art.
LCB 03	16.0	10.0	803	3	Ilio + ischio pubic branch fract + illiac wing + femur.
LCB 04	12.0	10.0	600	3	Ilio/ischio pub branch fract + sacro-illiac art. + femur
LCB 05	12.0	13.4	1077	3	Illiac wing fracture + femur. Ilio/ischio pub branch fract
LCB 06	12.0	13.7	1120	3	+ illiac wing + cotyle Ischio pubic branch fracture
LCB 07	16.2	11.5	1073	3	+ femur Ilio/ischio pub branch fract
LCB 08	16.2	11.8	1118	3	+ sacro-iliac + femur Ischio pubic branch fracture
LCB 09	16.2	9.47	725	2	No injury
LCB 10	12.0	10.4	645	0	Ilio + ischio pubic branch fract. + cotyle
LCB 11	12.0	11.8	834	3	

Table 3 : Test conditions on the EUROSID-1 pelvis

Test N°	Mass (kg) Impactor	Velocity (M/S) Impactor	Energy (J)
LMB 01	12.0	6.00	216
LMB 02	12.0	11.4	778
LMB 03	12.0	11.4	778
LMB 04	12.0	13.4	1077
LMB 05	12.0	13.7	1120
LMB 06	12.0	13.1	1025
LMB 07	16.1	10.0	803
LMB 08	16.1	9.95	794
LMB 09	16.1	13.4	1430
LMB 10	16.1	13.2	1396
LMB 11	12.0	8.67	451
LMB 12	12.0	8.62	446
LMB 13	12.0	12.7	962
LMB 14	12.0	12.5	935
LMB 15	12.0	13.4	1081
LMB 16	11.4	10.3	600
LMB 17	11.4	9.56	521
LMB 18	11.4	10.4	611
LMB 19	16.2	11.4	1028
LMB 20	16.2	12.2	1201

Table 4 : Correspondence between tests carried out at constant energy

Objective selected for pelvic impact energy (joules)	Name of tests on dummy	Energy measured (joules)	Name of tests on PMHS	Energy measured (joules)
12 kg Impactor				
600 j	LMB 16	600	LCB 04	600
	LMB 17	520	LCB 10	645
	LMB 18	611		
1094 j	LMB 06	1025	LCB 05	1077
	LMB 04	1077	LCB 06	1120
	LMB 15	1081		
800 j	LMB 02	786	LCB 01	774
	LMB 03	803	LCB 11	834
16 kg Impactor				
800 j	LMB 08	794	LCB 02	786
	LMB 07	803	LCB 03	803
			LCB 09	725
1094 j	LMB 19	1028	LCB 07	1073
	LMB 20	1201	LCB 08	1118

2. Analysis of sacrum acceleration caused by the impactor

2.1 Analysis of resultant accelerations during impacts.

Four situations are selected to superpose curves recorded under the same tests conditions :

a) 12 kg impactor with a kinetic energy of about 800 j

b) 12 kg impactor with a kinetic energy of about 1100 j

c) 16 kg impactor with a kinetic energy of about 800 j

d) 16 kg impactor with a kinetic energy of about 1100 j.

The four figures (fig. 1 a, b, c, d) are shown using the same scale and on a single page in order to have an overall view for a qualitative analysis.

The curves representing resultant accelerations of the sacrum for both the PMHS and the EUROSID-1 dummy, have the same general form. However the maximum values obtained with EUROSID-1 are always higher than those obtained with PMHS.

The tests with EUROSID-1 show good reproducibility no matter what the configuration is. This is not always the case with PMHS.

At identical energy levels, the 16 kg impactor (fig. 1 c and d) gives resultant pelvic accelerations (for both EUROSID-1 and PMHS) slightly lower than those given by the 12 kg impactor (fig. 1 a and b) except for one 16 kg test on PMHS. This observation on the few curves selected to produce figure 1 cannot be generalized. Specifics are formulated in chapter 3 by analyzing the total data obtained from all the tests.

PMHS pelvic deflection and statistical Analysis

Pelvic deflection of the EUROSID-1 dummy.

The impactor's kinetic energy at the moment of impact, is an important parameter in several analysis foreseen and mentioned previously. In table 1 we have also established correspondences between the tests carried out on EUROSID-1 and PMHS for each impact zone and each energy level selected in the test programme.

These test references can be found in the various graphical representations of the results.

2.2. Analysis of the maximum resultant acceleration values of the sacrum as a function of impact energy.

These values are shown together in tables 5 & 6 in the annex.

All the tests (LCB and LMB) made during the last two years were used to analyze the maximum acceleration values of the sacrum under various loading conditions.

Graph (fig. 3) was produced by taking the following four groups into account :

a) Tests on PMHS with 16 kg impactor

b) Tests on PMHS with 12 kg impactor

c) Tests on EUROSID-1 with 16 kg impactor

d) Tests on EUROSID-1 with 12 kg impactor.

Straight regression lines are plotted for each group. In addition, two straight regression lines representing all the results for all the tests made on EUROSID-1 and on PMHS were superposed on the same graph with the equations and correlation values (R^2).

It is not possible from the tests made on the PMHS to differentiate between the results obtained with the 12 kg impactor from those with the 16 kg one. The straight regression lines are virtually superposed. Test results obtained with EUROSID-1 however indicate that sacrum accelerations obtained with the 12 kg impactor are slightly higher than those with the 16 kg one. At identical energy levels therefore, velocity does have a slight influence : An increase in impactor velocity results in an increase in sacrum acceleration.

The comparison of EUROSID-1 and PMHS in figure 3 **shows that the slope of the line representing the mean response of all the dummy tests is double that of the PMHS tests.** On the contrary, if we extrapolate this PMHS curve, it would seem that the dummy could be biofailthful between 200 to 400 j. but that above 500 j. the dummy's pelvis no longer absorbs the impact sufficiently to have a behaviour identical to PMHS.

3. Analysis of the sacrum's angular velocity caused by an impactor.

A sensor for measuring angular velocity around the X axis was attached to the sacrum in order to assess the rotational velocity and rotational angle of the pelvis during a lateral impact. The main aim was to confirm the values obtained during the film analysis. This analysis should make it possible to reconstitute the kinetic of the vertebral column during impacts on both the thorax and pelvis. This information is vital for validating the digital models of the human body.

a) 12 kg impactor with a kinetic energy of about 800 j

b) 12 kg impactor with a kinetic energy of about 1100 j

c) 16 kg impactor with a kinetic energy of about 800 j
d) 16 kg impactor with a kinetic energy of about 1100 j.

The four figures (fig. 4 a, b, c, d) are shown using the same scale and on a single page in order to have an overall view for a qualitative analysis

The same sensor for measuring angular velocity was also used on EUROSID-1 and on PMHS.

The EUROSID-1 tests show very good reproducibility, no matter what the configuration used. Looking at all the curves in figure 4 we observe that in all cases both on the dummy and on PMHS and no matter what impact energy was used, two very similar amplitude peaks with a time lag of about 12 milliseconds. After a very brief (about 10 ms) and positive rotation, the pelvis stops rotating and even oscillates in the opposite direction before rotating again in a positive direction. The behaviour of the dummy and the PMHS are very similar in the first phase; but in the second phase EUROSID-1 is much shorter.

What are the factors which could explain this behaviour ?

The first phase corresponds to a very small rotation, it is thus a question of a slight adjustment of the various bony or metallic elements making up the pelvic girdle. The second phase enables the complete pelvis to be rotated which is confirmed by the analysis of the movement using the films. Apart from this qualitative aspect of the movements, it would be difficult to analyze the values obtained due to the small number of tests available.

In the current database availability situation, the angular velocity measurement at the sacrum cannot be accepted as a usable parameter.

4. Analysis of the impact force applied on the pelvis by the impactor.

4.1 Comparison of maximum load values

We have consolidated on the same graph (figure 5) the maximum load values applied to the pelvis of either the EUROSID-1 dummy or the PMHS by the impactor, as a function of the kinetic energy levels available on the impactor at the moment of impact.

For the impacts on EUROSID-1 the tests were carried out with 2 impacting masses of 12 and 16 kg, whereas for the PMHS, we have the results obtained with the 12 and 16 kg impactors as well as results obtained with a 23.4 kg impactor used for a previous test programme carried out between 1992 and 1994. The characteristics of the PMHS tested in this previous programme are given in table 7. All the load values of the impactor tests (12, 16, and 23.4 kg impactors) have been consolidated in table 8. The straight regression lines were calculated by consolidating all the test results on the dummy and on the PMHS.

At low energy levels, the dummy gives the same impact load values as PMHS, but as soon as the impact energy increases, the loads recorded on the dummy are clearly higher than those measured on the PMHS. At 1100 j, the loads transmitted to the dummy are on average twice those transmitted to the PMHS.

In the graphical representation, we have used a different sign to mark the different impactor masses. Thus, we can see that the points are well distributed around the straight regression lines, from which we can conclude **that the impactor's mass is a parameter which relative to the applied load, has an unaccessible influence with these results. The dispersion of measurements due to the subjects characteristics makes this differentiation unusable.**

4.2 Comparison of curves representing loads on the PMHS pelvis.

The PMHS response curves were superposed on figures (6 a, b, c) by on the one hand separating them by taking account of the impact energy and on the other hand by marking the type of impactor used.

At 800 joules, the two tests made with a light impactor (12 kg) give higher force values than those obtained with a slightly heavier impactor (16 kg) : this result however was not confirmed during tests at 1100 joules. With such a small number of tests, no orientation can be considered for the conclusion. Other tests will be necessary to better understand this divergence in behaviour.

4.3 Comparison of load curves on the EUROSID-1 pelvis

PMHS response curves were superposed on figures (figure 7, a, b, c, d, e, f, g), by on the one hand, by separating them, by taking account of the impactor energy and on the other hand marking the type of impactor used. At 800 and 1100 j, the tests were made with two impactor devices (12 and 16 kg). At 800 joules the two tests made with a light impactor (12 kg), gave higher force values than those obtained with a slightly heavier impactor

(16 kg) : this result however was not so clear when the tests carried out between 1000 and 1100 joules were superposed. These results confirm the conclusion of paragraph 1 above.

5. Analysis of the impact force measured on the impactor.

In previous studies, load measurements taken in the contact zone were always a global measurement. When the zone is large, it takes into account all the forces transmitted by both the support on the trochanter and the support on the iliac wing. When the zone is small it only takes the impacted element into account (e.g. the trochanter) : however in this case we are distancing ourselves from the reality of automobile type impacts. An originality of this study is having envisaged dividing the support face into two in order to differentiate the loads passing through the iliac crest from those passing through the trochanter.

The support face of the impactor was split into two parts, each one resting on three load cells : because of this, there is a lower plate in correspondence with the trochanter and an upper plate in correspondence with the iliac wing.

From tables 5 and 6 showing the maximum values recorded by each load cell, the following figures have been plotted :

a) Distribution of loads during PMHS pelvis impacts (fig. 10).

b) Distribution of loads during EUROSID-1 pelvis impacts (fig. 9).

c) Superposing load distributions during PMHS and EUROSID-1 impacts (fig. 10).

In these three figures, the distributions were made as a function of the summation of loads measured and the same representation scales were kept.

5.1 Analysis of load distributions during PMHS pelvis impacts (fig. 10).

In the graph, the results obtained on each plate and impactor type used were marked differently. On the contrary, each straight regression line corresponds to all the results obtained on each of the support plates. When examining these straight regression lines it seems that the force measured on the upper plate corresponds to the support on the iliac wing, levelling out between 350 and 400 daN whereas the total load develops from 900 to 1500 daN.

The iliac wing is more flexible than the zone of the pelvis behind the trochanter. Under these conditions, the main load automatically passes via the most rigid point and the pelvis deflection thus corresponds to that of the trochanter. The iliac wing is involved in the transmission of the loads, but its deflection is primarily imposed by the capacities of the trochanter.

The differentiation between tests on different impactor masses was not shown on figure 10 because the straight regression lines are almost superposed.

The results of the 11 PMHS tests were too close to permit any conclusions to be drawn on the effect of the impactor's mass in relation to the load transmitted to the pelvis.

5.2 Analysis of load distributions during EUROSID-1 pelvis impacts (fig. 9).

The results obtained with the EUROSID-1 dummy show that, the load distribution between the lower and upper plates is about 75% (trochanter) and 25% (iliac crest) when all the results are taken into account (table 6) :

However, when we separate the results concerning the impactor masses, the distribution seems to develop differently. **A heavier impactor mass tends to increase the load supported by the trochanter.**

We have no explanation for this phenomena, all the more so since it does not appear on the PMHS figure (fig. 10).

5.3 Superposing load distributions during PMHS and EUROSID-1 impacts (fig. 10).

On this figure, only straight regression lines relative to the two plates have been represented for a global analysis. The lines representing the dummy results pass very close to zero, which is quite logical. On the contrary, the lines representing the PMHS results pass quite a long way from the origin of the coordinates, which tends to indicate that the line does not correctly represent the PMHS behaviour. This is especially valid for the load transmitted at the iliac crest.

In summary, we see that on the dummy (table 6), 75% of the loads pass by the trochanter and 25% by the iliac crest; whereas on the human body (table 5), although the average distribution is 68% by the trochanter and 32% by the iliac crest, we see a levelling off at 400 daN of the loads supported by the iliac wing.

6. Analysis of the load measured at the pubis of the EUROSID-1 dummy.

We have superposed on the same graph (fig. 11) the maximum total load values applied to the pelvis by the impactor (F app. MAX.), and the maximum values measured at the pubis of the dummy (F pubis MAX.). This latter measurement cannot be obtained on human bodies. On the contrary the load at the pubis is a value measured and recorded on the lateral impacted dummy; it makes it possible to evaluate the orthogonal load applied to the whole EUROSID-1 pelvis during the impact and of which we could not know the characteristics as in a vehicle environment.

To complete table 9, we have used the values obtained during the previous test series made at LBSU in 1992 and 1993. These tests were chosen because the impactor mass is different. All the values are consolidated in table 9 in annex.

The ratio (F pubis Max./ F app. Max.) of values obtained on each test enables us to pinpoint the load passing through the pubis at about 21 to 30% of the total load applied externally to the pelvis.

It nevertheless seems that the impactor's mass has an influence because when its mass increases, the ratio (F pubis Max. / F app. Max.), corresponding to the load transfer at the pubis reduces : The ratio of 29.8% for the 12 kg impactor falls to 21.7% for the 23.4 kg impactor. The use of a transfer coefficient of about 25% can be envisaged providing it is specified that a significant difference is implied.

7. Analysis of pelvis deflection during impact

Pelvis deflection can only be obtained by analyzing films made during the impact.

The camera is set to provide about 1000 frames / second.

With the help of "Photospot" follow-up sights, the coordinates of several points, attached to rigid elements of the body or dummy were recorded to be able to calculate the displacement of these points and the deflection of the demi-pelvis. To eliminate the effect of camera vibrations, the information is smoothed out compared to a fixed point of the picture (sight attached to the wall).

The deflection is obtained by studying the variation of distance between a fixed target on the impactor and one of the sights fixed on the sacrum.

To evaluate the basic difference, the starting image is tagged the moment the flash occurs. A check with a known distance is made to confirm the value of the enlargement scale used.

An initial deflection curve as a function of time can be established and the maximum value selected and shown in table 10.

The viscosity criteria 'V*C' makes it possible to take account of the compression and deflection velocity of a material or a set when this element is likely to have a more or less fluid plastic behaviour in accordance with the penetration velocity. This type of criteria is currently used a lot for evaluating the behaviour of the thorax.

Although the pelvis girdle is stiffer than the thoracic cage, it can nevertheless be subjected to significant deflections (in the order of 90 mm maximum in this experiment). It was thus worthwhile evaluating the effect of penetration speed and checking that the 'V*C' calculation can give a usable criteria value.

To estimate the influence of velocity on pelvic behaviour we have therefore calculated 'V*C' which represents the product of the demi pelvis compression that multiplies the compression velocity of this pelvis. The following steps are necessary to calculate the maximum 'V*C' value :

The demi-pelvis compression calculation C = D/L

D = deflection (mm); this is a 6 order polynomial of the measured deflection (study over about 60 ms with one point per ms)

L is the demi-width (mm) of the pelvis measured at the trochanter

The instantaneous velocity calculation (m/s) V = dD/dt; it is the derivative of the polynomial curve corresponding to the deflection.

Calculation of the 'V*C' product and extraction of the maximum value (given in table 10).

7.1 Deflection of PMHS pelvis and associated viscosity criteria ('V*C')

To complete the database, the results of the previous tests (1992 to 1994) at LBSU were incorporated with the results of the 11 tests of this experimental programme. All the data associating energy, deflection and viscosity criteria were consolidated in table 9 with the level of injuries obtained for each PMHS test.

We chose to represent maximum deflection as a function of the impactor's kinetic energy (fig. 12a) and also the injuries expressed in AIS severity (fig. 12b).

At identical energy levels, the impactor's velocity does not appear to be a determining factor. The points obtained overlap too much to evaluate any behavioural differences.

It seems ***that above 600 j, the available energy only serves to accelerate the body and not to crush it because the deflection no longer increases.***

The representation of the injury severity measured by AIS as a function of deflection, clearly shows that there is a relationship between penetration and the severity of pelvic injury.

Below 50 mm of penetration very few fractures occur, from 40 to 60 mm penetration a few simple fractures are seen and it is as of 60 mm penetration that serious injuries occur (AIS = 3).

We decided to represent the maximum viscosity criteria value as a function of both the impactor's kinetic energy (fig. 12c) and the AIS injury severity, (fig. 12d). The figures obtained are very close to the previously treated 12a and 12b figures.

Due to the overlapping of the points representing the results with the 12 kg and 16 kg impactors no behavioural differences could be established.

However, we can see that the dispersion is a little greater and thus that this complementary 'V*C' calculation does not provide any additional information in relation to the deflection.

7.2 Statistical analysis

A statistical analysis was carried out on all the results expressed in terms of AIS injury severity, as a function of either maximum deflection or 'V*C', in order to determine the critical values acceptable for the human pelvis.

For this, we calculated the injury probability using logistic regression and giving the value 0 for non fractured pelvis (AIS = 0) and the value 1 for all other pelvis ($AIS \geq 2$). Each logistic regression is shown graphically in figures (13 a and b).

The limit values proposed for protecting the human pelvis, corresponding to a 50% $AIS \geq 2$ probability, are 46 mm for pelvis deflection and 0.62 m/s for the 'V*C' criteria.

7.3 Pelvis deflection of the EUROSID-1 dummy

We selected 5 tests made under different impact conditions on the EUROSID-1 pelvis. the films taken during the impacts were analyzed to obtain deflections as a function of time. The results are given in table 10 and show that for **impact energies between 600 and 1100 joules, the deflection level is about 50 mm,** which corresponds to the maximum penetration of the foam covering of the pelvis.

The maximum deflection is thus reached at a very **low impact energy and is therefore not a very representative indicator of the severity of the impact.**

8. Pelvis « Load/Deflection » behaviour

8.1 Conception of corridors representing human bodies

The graphic presentation of the pelvic behaviour of the human body is made by using the measurement of the total force applied to the pelvis as a function of the deflection of this pelvis.

The deflection is a parameter obtained from the film analysis (see § VII above). The data was obtained at 1000 hz because of the camera speed. The force applied to the pelvis is calculated (see § IV) from values measure on 6 load sensors. This data was obtained at 10 Khz. To obtain the correspondence between load and deflection, we can only keep 1 point in 10 for the curve representing the load. As a function of available data enabling several results to be superposed, it was possible to give two graphs (figures 14 a and b), one for 800 joules impact energy and the other for 1100 joules. the corridors surrounding these curves are consolidated in figures (fig. 14 a and b) with the values of the coordinates.

8.2 EUROSID-1 Behaviour

The results obtained with the EUROSID-1 dummy, under the same test conditions were superposed in the corridors representing the human bodies (figures 16 a & b)

The EUROSID-1 response curves do not correspond at all to the human body corridor. Even though using the same conditions, EUROSID-1 has loads which are too high.

9 Human tolerance and performance criteria in terms of applied force.

9.1 History of the "pelvis" criteria in lateral impact

In 1982, D. Césari showed, with a test series made with a 17.3 kg hemispherical impactor, that there was a correlation between the impact force and the mass of the human subject (correlation R = 0.75). From the straight correlation line, he proposed an impact force limit of

10 kN for the tolerance of a human body weighing 75 kg (26th STAPP 82 1159). In this analysis, the impact force value selected corresponded to a duration equal to 3 ms and the injury severity corresponded to AIS ≥ 3.

The first EUROSID dummy, for which a performance criteria was envisaged, had a pelvis made of cast aluminium iliac wings. In March 1987 the Ad-Hoc CEVE group proposed performance criteria to use with this lateral impact dummy. The value of 10 kN was suggested for the maximum force measured at the pubic symphysis. ISO groups 5 and 6 (tc 22 / sc 12 / wg 6 N° 268 and wg 5 N° 312) have taken up the values proposed by CEVE.

The dummy has an impact response which revealed much higher loads than on the human body; on the contrary the measurement at the pubis is about one third of the external force. It was accepted that the one compensated the other, and an acceptable force at the pubis could be 10 kN.

From 1990, the EUROSID-1 dummy was commercialized. A few improvements were made, especially to the pelvis by making the iliac wings in plastic material. This made the complete unit more flexible and enabled an impact response to be obtained closer to that of the human body. Since then a redefinition of the measurable criteria value on the dummy proved to be essential. In 1991, CEVE duplicated some tests with EUROSID-1 and concluded that the pelvis performance criteria should be 6 kN measured at the pubiic symphysis.

The European parliamentary directive dated 20/05/96, concerning the protection of occupants in vehicles in lateral shock specifies a pelvic performance criteria which is : the maximum force recorded on the pubic symphysis must be less than or equal to 6 kN.

9.2 Establishing human tolerance as a function of applied force

In figure (fig. 13c) we have plotted the results in terms of AIS ≥ 2 as a function of the applied force and calculated and plotted the logistic regression curves for both AIS ≥ 2 and AIS ≥ 3. This analysis was based on 30 tests carried out with the same impactor using different masses and energies. AIS ≥ 2 was reached 8 times and AIS ≥ 3. was also reached 8 times with these tests.

For a 50% AIS ≥ 2 probability we have a 7.6 kN tolerance limit for the applied force. For a 50% AIS ≥ 3 probability, we have a 11.4 kN tolerance limit of the applied force. These results are of the same order as those published by D. Césari. A slight correction of the performance criteria will nevertheless be required no matter what protection level is wanted : AIS ≥ 2, AIS ≥ 3.

9.3 Performance criteria for the EUROSID-1 dummy pelvis

The performance criteria of the EUROSID-1 dummy pelvis can be defined as the value of the measurable load at the pubic symphysis, which corresponds to the human tolerance value for an acceptable injury severity. In the scope of this study, two situations can be considered, because by consolidating the data corresponding to the last two test series, (Test LCB and MRB) we have 8 tests causing AIS = 2 injuries and 8 tests causing AIS = 3 injuries. As a function of the new results available we are going to define two criteria, one associated to AIS = 2 and the other to AIS = 3.

We saw previously that :

EUROSID-1 was not completely biofaithful; at a given energy level, the applied force is higher for the dummy than for PMHS.

The load measured at the pubis moved with the test conditions.

Further, in order to pass from the impact force corresponding to the human tolerance to the force limit acceptable at the EUROSID-1 pubis, a double correction is necessary.

In table 11, we have consolidated the PMHS data corresponding to the tests of the two selected categories (AIS = 2 and AIS = 3). We recorded the impact energies corresponding to those tests in order to select out of the EUROSID-1 test series all the tests carried out under the same load conditions.

In the energy zone concerned, we took the middle point, (we obtained 629 joules for zone AIS = 2 and 860 joules for zone AIS = 3) and we plotted these values in figure 5; Using straight regression line equations of the PMHS and dummy responses, we obtained average theoretical values of the forces corresponding to AIS = 2 and AIS = 3 injury severities.

To reach AIS = 2, the ratio of forces gives :

F (EUROSID-1) = 1.82 F (PMHS)

To reach AIS = 3, the ratio of forces gives :

F (EUROSID-1 = 2.04 F (PMHS).

For the tests made with EUROSID-1, the ratio of the load measured at the pubis compared to the force applied at the pelvis, develops as a function of impact energy (see figure 17). As we did before, we used the straight regression line equation to calculate the theoretical ratio of forces at the middle points of the zones likely to result in an injury.

For the energy zone giving an AIS = 2,
the ratio is : **F (pubis) / F (applied) = 28.4%**
For the energy zone giving an AIS = 3,
the ratio is : **F (pubis) / F (applied) = 26.5%.**

The new performance criteria can be evaluated from the human tolerance values defined in the previous paragraph :

The 50% AIS ≥ 2 probability : the tolerance limit of the applied force is **7.6 kN.**

The 50% AIS ≥ 3 probability : the tolerance limit of the applied force is **11.4 kN.**

Performance criteria for the EUROSID-1 dummy pelvis : Performance criteria proposal for an
AIS ≥ 2 : 7.6 x 1.82 x 28.4% = 3.93 kN.
Performance criteria proposal for an
AIS ≥ 3 : 11.4 x 2.04 x 26.5% = 6.16 kN.

10 Conclusions

11 human pelvis were impacted laterally using an horizontal impactor fitted with a 200 x 200 mm impacting plate. The test programme had been developed to try to reveal a dominant parameter by varying the mass and velocity of the impactor. It emerges from the analysis of the various measurements taken during the impacts that, for a given impactor energy neither its mass nor velocity seemed to be dominant.

The impact force is transfered via the two support points namely the trochanter and iliac wing. As far as the load transfers are concerned, we see that for the dummy, 75% of the load passes via the trochanter and 25% via the iliac wing, whereas on the human body we note that even though the average load distribution is 68% via the trochanter and 32% via the iliac wing, there is a levelling out of the loads supported by the iliac wing at 400 daN.

Concerning the transfer of loads inside the dummy pelvis, the load sensor attached at the pubis enables us to locate the load passing via the pubis to about 21 to 30% of the total applied load. A transfer coefficient of about 25% can be considered.

The 20 impact tests previously carried out on the 10 human pelvis enabled the data base to be completed in order to obtain a human tolerance value. The analysis carried out using logistic regressions gave the following results. The limit values suggested for the protection of the human body corresponding to a 50% AIS ≥ 2 probability are 46 mm for maximum pelvis deflection and 0.62 m/s for the V*C viscosity criteria.

Two 'Force / Deflection' corridors are published, corresponding to impact energies of 800 and 1100 joules. The EUROSID-1 response curves do not correspond at all to the human body corridor. Although carried out under similar conditions to those applied to human bodies, the EUROSID-1 pelvis gives loads which are too high.

In terms of applied force, the human pelvis tolerance is based on the analysis of 30 tests made with the same impactor but with different impact masses and energies.

In these tests, AIS = 2 was reached 8 times and AIS = 3 was also reached 8 times. The analysis carried out using logistic regressions gave the following results : for a 50% AIS ≥ 2 probability, we have a 7.6 kN applied force tolerance limit and for a 50% AIS ≥ 3 probability we have an 11.4 kN applied tolerance limit.

The latter result is near the same force as that published by D. Césari.

By taking into account : the ratio of the forces sustained by the dummy and the PMHS impacted to the same load conditions, and the ratio between the force recorded at the pubis and the force applied to the EUROSID-1 pelvis, it was possible to calculate the value of new pelvis performance criteria.

With the results obtained in this study, we are able to propose : With a 50% AIS ≥ 2 probability that the pelvis performance criteria of EUROSID-1 is 3.93 kN. With a 50% AIS ≥ 3 probability, the pelvic performance criteria of EUROSID-1 is 6.16 kN.

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Table 5 : PMHS Pelvis impacts : Maximal measurements

Test N°	Impactor mass (kg)	Impactor speed (m/s)	Impact Energy (joule)	Max Result. accelerat (g)	Fs (N)	Fi (N)	Σ F (N)	Ratio Fs/ Σ F %	Ratio Fi/ Σ F %	(1) Measured Result. Force (N)	(2) Applied Force (N)
LCB 01	12.0	11.4	774		3 920	8 170	12 090	68	32	11 850	13 940
LCB 02	16.0	9.91	786	84	2 910	5 210	8 120	64	36	7 920	8 930
LCB 03	16.0	10.0	803	105	2 770	4 090	6 870	60	40	6 850	7 720
LCB 04	12.0	10.0	600	82	1 630	5 310	6 940	77	23	7 060	8 300
LCB 05	12.0	13.4	1077	107	3 560	6 170	9 730	63	37	10 020	11 790
LCB 06	12.0	13.7	1120	115	3 510	10 090	13 600	74	26	12 820	15 090
LCB 07	16.2	11.5	1073	86	3 290	11 660	14 950	78	22	14 310	16 120
LCB 08	16.2	11.8	1118	136	3 890	7 600	11 500	66	34	11 500	13 520
LCB 09	16.2	9.47	725	79	3 670	5 690	9 360	61	39	9 400	10 590
LCB 10	12.0	10.4	645	72	-	-	-	-	-	-	-
LCB 11	12.0	11.8	834	97	3 670	8 950	12 620	71	29	10 230	12 040
							Mean	68%	32%		

'Fs' = Maximum value of the summation of the three loads measured on the upper plate
'Fi' = Maximum value of the summation of the three loads measured on the lower plate
Σ 'F' = Summation of 'Fs' and Fi'
'(1) Measured Resultant Force = Maximum from the 6 filtered load measurements.
'(2) Applied Resultant Force = 'Measured Resultant Force totale (1)' **x** (Impacteur Mass) / (Impacteur Mass - Plates Masses)

Table 6 : EUROSID-1 Pelvis impacts : Maximal measurements -

Test N°	Impactor mass (kg)	Impactor speed (m/s)	Impact Energy (joule)	max résult. accelerat (g)	Fs (N)	Fi (N)	Σ F (N)	Ratio Fs/ Σ F %	Ratio Fi/ Σ F %	Applied Force (N)
LMB 01	12.0	6.00	216	55.	1 390	4 160	5 550	75	25	6 530
LMB 02	12.0	11.4	778	115	5 630	14 530	20 160	72	28	23 720
LMB 03	12.0	11.4	778	141	6 230	14 960	21 190	71	29	24 930
LMB 04	12.0	13.4	1077	186	10 750	18 760	29 510	64	36	34 720
LMB 05	12.0	13.7	1120	192	10 210	18 760	28 970	65	35	34 080
LMB 06	12.0	13.1	1025	184	10 450	18 500	28 940	64	36	34 050
LMB 07	16.1	10.0	803	114	3 820	14 370	18 190	79	21	20 500
LMB 08	16.1	9.95	794	115	3 100	15 050	18 150	83	17	20 450
LMB 09	16.1	13.4	1430	199	5 460	25 360	30 830	82	18	34 730
LMB 10	16.1	13.2	1396	202	6 990	29 720	36 710	81	19	41 360
LMB 11	12.0	8.67	451	68	2 410	5 580	7 990	70	30	9 400
LMB 12	12.0	8.62	446	73	1 990	8 110	10 090	80	20	11 870
LMB 13	12.0	12.7	962	162	5 270	15 390	20 660	74	26	24 310
LMB 14	12.0	12.5	935	164	5 180	16 120	21 300	76	24	25 060
LMB 15	12.0	13.4	1081	190	6 320	20 540	26 860	76	24	31 600
LMB 16	11.4	10.3	600	106		10 390				
LMB 17	11.4	9.56	521	89	2 190	8 160	10 350	79	21	12 180
LMB 18	11.4	10.4	611	114	2 980	10 420	13 400	78	22	15 770
LMB 19	16.2	11.4	1028	178	5 990	23 460	29 440	80	20	33 170
LMB 20	16.2	12.2	1201	190	5 100	24 600	29 700	83	17	33 470
							Mean	75 %	25%	

'Applied Resultant Force' = Measured Resultant Force totale **x** (Impacteur Mass) / (Impacteur Mass - Plates Masses)

Table 7 : Corps qualities and tests conditions (INRETS 1992/94)

Impactor mass = 23.4 kg
Each PMHS is impacted 2 times. First at lower speed (no injury), second at higher speed (juxta injury)

Tests N°	Sex	Age	Height (m)	Weight (Kg)	1/2 pelvis width (mm)	Speed (m/s)	Energy (joule)	Applied force (N)
MRB 01	M	76	1.73	82.0	165	3.50	143	5 640
MRB 03	M	57	1.74	76.0	165	3.40	135	6 220
MRB 05	M	66	1.72	69.0	170	3.41	136	3 670
MRB 07	M	69	1.64	52.0	155	3.43	138	4 160
MRB 09	M	78	1.62	54.0	160	3.29	127	4 010
MRB 11	M	38	1.81	86.0	155	3.34	131	4 270
MRB 13	M	63	1.70	60.0	150	3.35	131	3 000
MRB 15	F	69	1.69	59.5	165	3.26	124	3 210
MRB 17	M	81	1.67	82.0	170	3.22	121	4 310
MRB 19	M	70	1.90	70.0	165	3.26	124	4 920
Mean		**66.7**	**1.72**	**69.1**	**162**	**3.35**	**131**	
MRB 02	M	76	1.73	82.0	165	6.74	532	8 400
MRB 04	M	57	1.74	76.0	165	6.50	494	10 550
MRB 06	M	66	1.72	69.0	170	6.77	536	9 120
MRB 08	M	69	1.64	52.0	155	6.46	488	6 520
MRB 10	M	78	1.62	54.0	160	6.50	494	8 150
MRB 12	M	38	1.81	86.0	155	6.64	516	9 840
MRB 14	M	63	1.70	60.0	150	6.44	485	5 840
MRB 16	F	69	1.69	59.5	165	6.57	505	6 540
MRB 18	M	81	1.67	82.0	170	6.57	505	10 040
MRB 20	M	70	1.90	70.0	165	6.43	484	10 180
Mean		**66.7**	**1.72**	**69.1**	**162**	**6.56**	**504**	

Table 9 : EUROSID-1 Pelvic impact tests, maximal values of applied forces on pelvis and pubic symphysis.

Test N°	Impact energy (joule)	Applied Force (N)	Mesured Pubic Force (daN)	Fmes / F app %
Impactor	**200x200**	**12 kg**		
LMB 11	451	9 400	3 280	34.9
LMB 12	446	11 870	3 530	29.7
LMB 13	962	24 310	6 870	28.3
LMB 14	935	25 060	7 180	28.6
LMB 15	1081	31 600	8 120	25.7
LMB 16	600		4 310	
LMB 17	521	12 180	3 790	31.2
LMB 18	611	15 770	4 760	30.2
Mean				**29.8**
Impactor	**200x200**	**16 kg**		
LMB 07	803	20 500	5 880	28.7
LMB 08	794	20 450	5 680	27.8
LMB 09	1430	34 730	7 900	22.7
LMB 10	1396	41 360	8 450	20.4
LMB 19	1028	33 170	7 980	24.0
LMB 20	1201	33 470	7 890	23.6
Mean				**26.35**

Test N°	Impact energy (joule)	Applied Force (N)	Mesured Pubic Force (N)	Fmes / F app %
Impactor	**Φ 120mm**	**17.3 kg**		
IBE 27	294	7 260	2 000	27.5
IBE 28	662	13 040	3 580	27.5
IBE 29	300	7 550	2 190	29.0
IBE 30	671	13 320	4 050	30.4
Mean				**28.6**
Impactor	**100x200**	**23.4 kg**		
MRE 01	139	3 160	700	22.1
MRE 02	134	3 170	720	22.9
MRE 03	137	3 110	650	20.9
MRE 04	505	10 230	2 170	21.2
MRE 05	521	10 120	2 240	22.2
MRE 06	525	10 640	2 250	21.2
Mean				**21.7**

Impactors (12 and 16 kg) are squared plates (200x200mm); Impactor (23.4kg) is rectangular (100x200mm); Impactor 17.3kg) is an hemispherical plate (Φ 120 mm)

Table 10 : PMHS and EUROSID-1 pelvics impact tests : Maximum values of deflection and V*C.

PMHS Tests					EUROSID-1 Tests				PMHS Tests				
Test N°	Impact Energy (joule)	Deflection Max. (mm)	V*C Max (m/s)	AIS	Test N°	Impact Energy (joule)	Deflection Max. (mm)	V*C Max (m/s)	Test N°	Impact Energy (joule)	Deflection Max. (mm)	V*C Max (m/s)	AIS
LCB 01	774	50	1.12	2	LMB 01	216	-	-	MRB 01	143	31.8	0.26	0
LCB 02	786	89	1.78	3	LMB 02	778	63.0	226	MRB 03	135	28.0	0.23	0
LCB 03	803	67	1.54	3	LMB 03	778	66.9	2.38	MRB 05	136	32.7	0.20	0
LCB 04	600	75	1.55	3	LMB 04	1077			MRB 07	138	21.2	0.18	0
LCB 05	1077	61	1.53	3	LMB 05	1120	-	-	MRB 09	127	28.8	0.21	0
LCB 06	1120	71	1.80	3	LMB 06	1025	62.9	2.45	MRB 11	131			0
LCB 07	1073	66	1.04	3	LMB 07	803	67.9	2.23	MRB 13	131	24.5	0.16	0
LCB 08	1118	68	1.22	3	LMB 08	794	70.0	2.34	MRB 15	124	32.4	0.27	0
LCB 09	725	56	1.64	2	LMB 09	1430	63.4	2.64	MRB 17	121	36.4	0.26	0
LCB 10	645	67		0	LMB 10	1396	58.7	2.30	MRB 19	124	28.3	0.23	0
LCB 11	834	65	1.77	3	LMB 11	451	48.6	1.23	MRB 02	532	60.6	0.75	2
					LMB 12	446	44.9	1.12	MRB 04	494	38.8	0.65	2
					LMB 13	962	-	-	MRB 06	536	54.6	0.56	2
					LMB 14	935	49.6	1.73	MRB 08	488	56.7	0.95	2
					LMB 15	1081	62.1	2.50	MRB 10	494	56.9	0.86	2
					LMB 16	600	65.6	2.09	MRB 12	516			0
					LMB 17	521	45.3	1.21	MRB 14	485	54.0	0.66	2
					LMB 18	611	-	-	MRB 16	505	50.8	0.80	0
					LMB 19	1028	62.5	2.29	MRB 18	505	46.7	0.63	0
					LMB 20	1201	57.3	2.00	MRB 20	484	38.2	0.52	0

Table 11 : Impact tests used on EUROSID-1 and PMHS for evaluate a pelvic force criterion

a) Impact tests on EUROSID-1 used at a level of impact energy corresponding to AIS = 2 on PMHS.

EUROSID-1 Tests	Impact Energy (joule)	Applied Force (N)	Fpubic/Fapp %
LMB 12	446	11 870	29.7
LMB 11	451	9 400	34.9
LMB 17	521	12 180	31.2
LMB 16	600		
LMB 18	611	15 770	30.2
LMB 02	778	23 720	27.3
LMB 03	778	24 930	24.5
LMB 08	794	20 450	27.8
LMB 07	803	20 500	28.7

PMHS Tests	Impact Energy (joule)	Appied Force (N)	Injury AIS
LCB 01	774	13 940	2
LCB 09	725	10 590	2
MRB 02	532	8 400	2
MRB 04	494	10 550	2
MRB 06	536	9 120	2
MRB 08	488	6 520	2
MRB 10	494	8 150	2
MRB 14	485	5 840	2
Middle point	**629**		

(485 + 774) / 2 = 629

b) Impact tests on EUROSID-1 used at a level of impact energy corresponding to AIS = 3 on PMHS.

EUROSID-1 Tests	Impact Energy (joule)	Applied Force (N)	Fpubic/Fapp %
LMB 02	778	23 720	27.3
LMB 03	778	24 930	24.5
LMB 08	794	20 450	27.8
LMB 07	803	20 500	28.7
LMB 14	935	25 060	28.6
LMB 13	962	24 310	28.3
LMB 06	1025	34 050	22.2
LMB 19	1028	33 170	24.0
LMB 04	1077	34 720	23.0
LMB 15	1081	31 600	25.7
LMB 05	1120	34 080	22.7

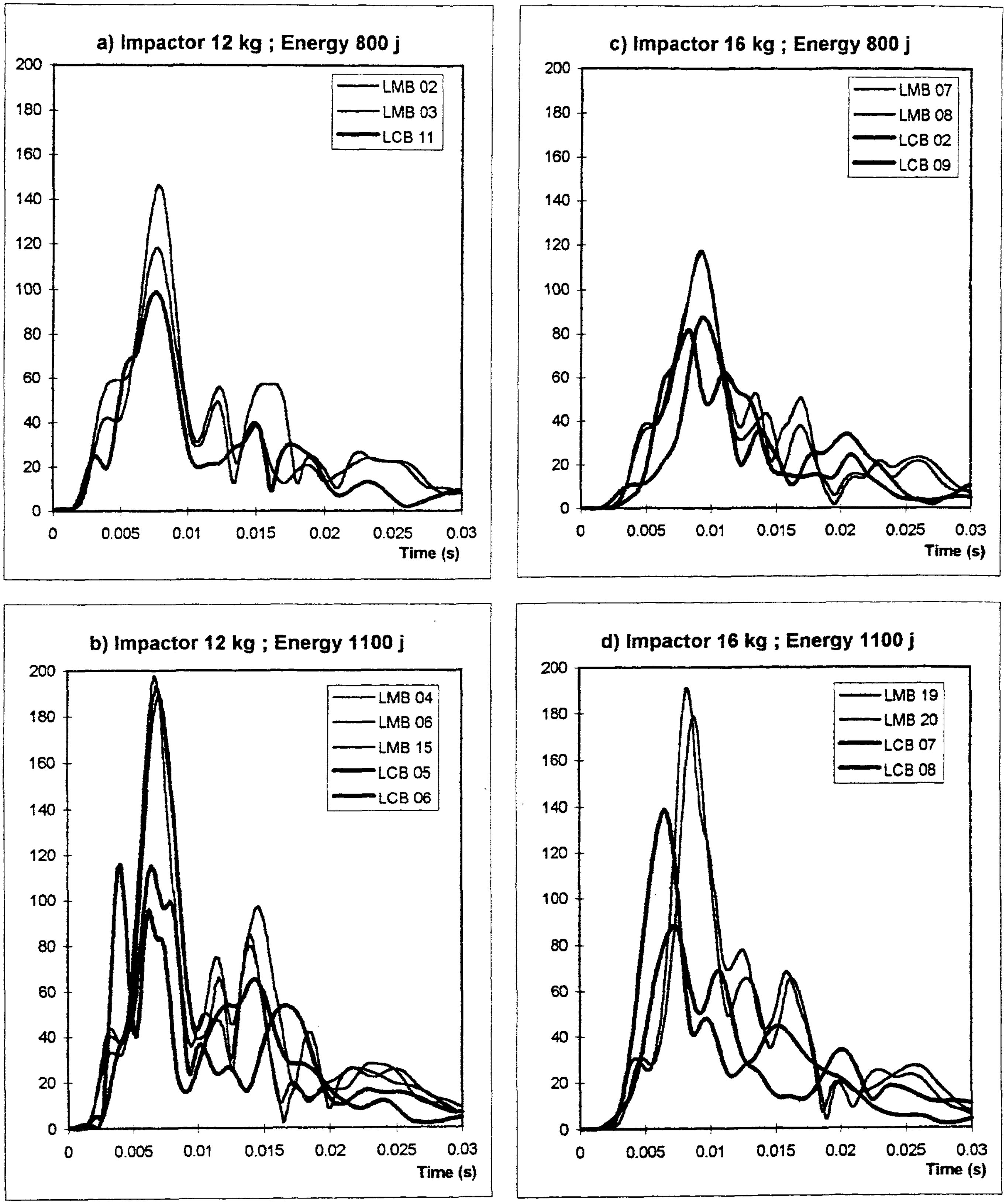
PMHS Tests	Impact Energy (joule)	Appied Force (N)	Injury AIS
LCB 02	786	8 930	3
LCB 03	803	7 720	3
LCB 04	600	8 300	3
LCB 05	1077	11 790	3
LCB 06	1120	15 090	3
LCB 07	1073	16 120	3
LCB 08	1118	13 520	3
LCB 11	834	12 040	3
Middle point	**860**		

(600+ 1120) / 2 = 860

In the energy zone concerned, we took the middle point, (we obtained 629 joules for zone AIS = 2 and 860 joules for zone AIS = 3) and we plotted these values in figure 5 and 17. Using straight regression line equations of the PMHS and dummy responses, we obtained

1) average theoretical values of the forces corresponding to AIS = 2 and AIS = 3 injury severities.
   To reach AIS = 2, the ratio of forces gives : **F (EUROSID-1) = 1.82 F (PMHS)**
   To reach AIS = 3, the ratio of forces gives : **F (EUROSID-1 = 2.04 F (PMHS).**
2) theoretical ratio of forces.
   For the energy zone giving an AIS = 2,,the ratio is : **F (pubis) / F (applied) = 28.4%**
   For the energy zone giving an AIS = 3, the ratio is : **F (pubis) / F (applied) = 26.5%.**

Figure 1 : Pubic resultant acceleration versus history



LMB tests = EUROSID-1 tests
LCB tests = PMHS tests

Figure 3 : Peak of pelvic resultant acceleration versus impact energy

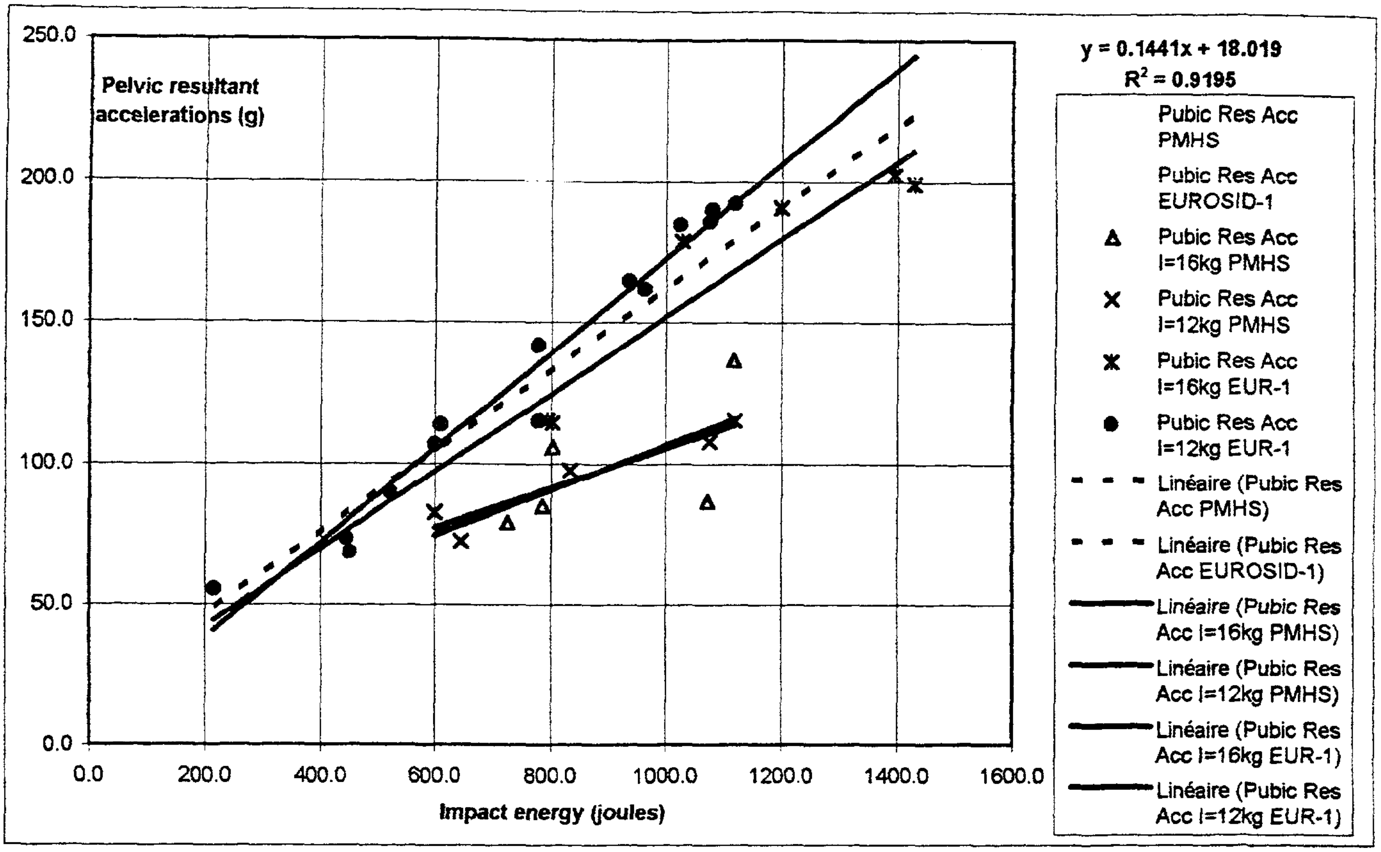


Figure 5 : Total applied force on pelvis versus impact energy. Comparison between EUROSID-1 and PMHS.

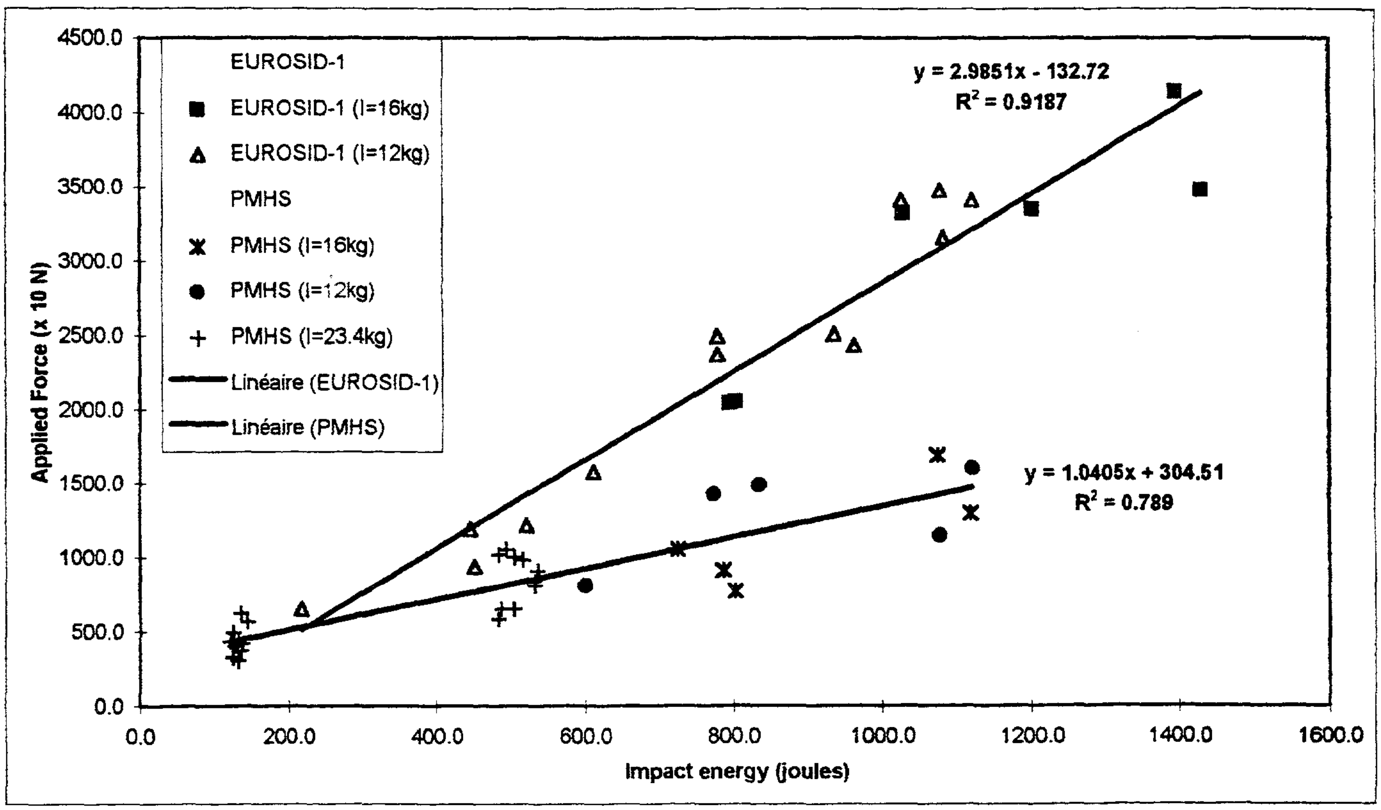
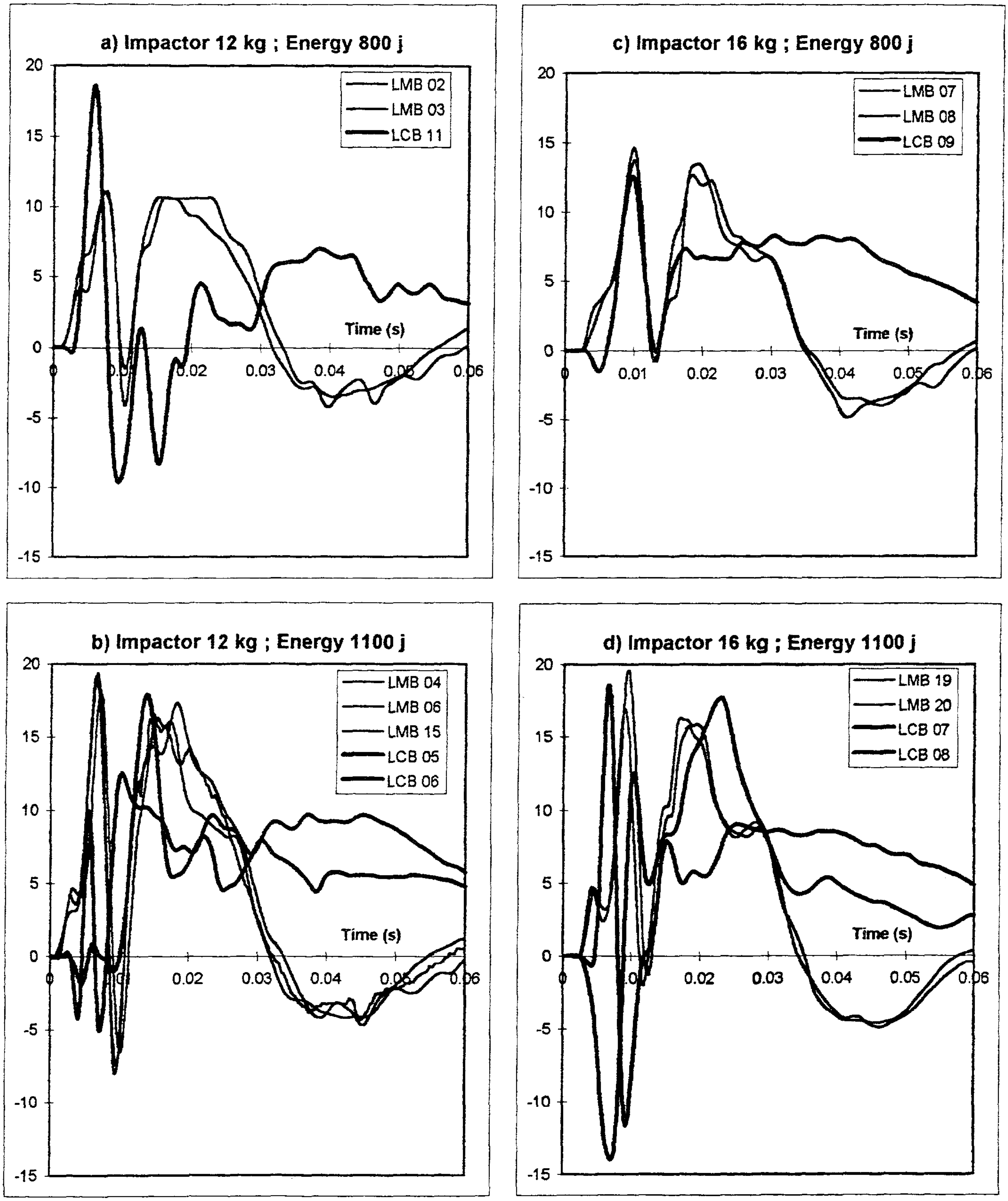
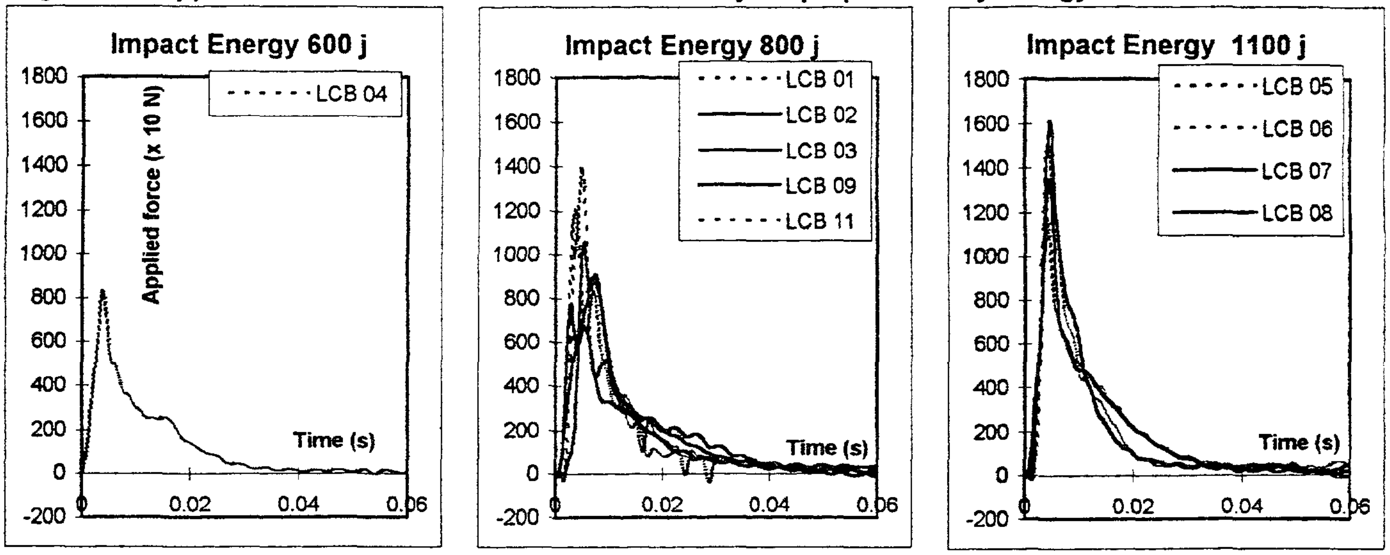


Figure 4 : **Pubic angular speed versus history**



LMB tests = EUROSID-1 tests
LCB tests = PMHS tests

Figure 6 : Applied Force on PMHS Pelvis versus History. Superposition by Energy



Dotted line : 12 kg impactor tests *Solid line : 16 kg impactor tests*

Figure 7 : Applied Force on EUROSID-1 pelvis

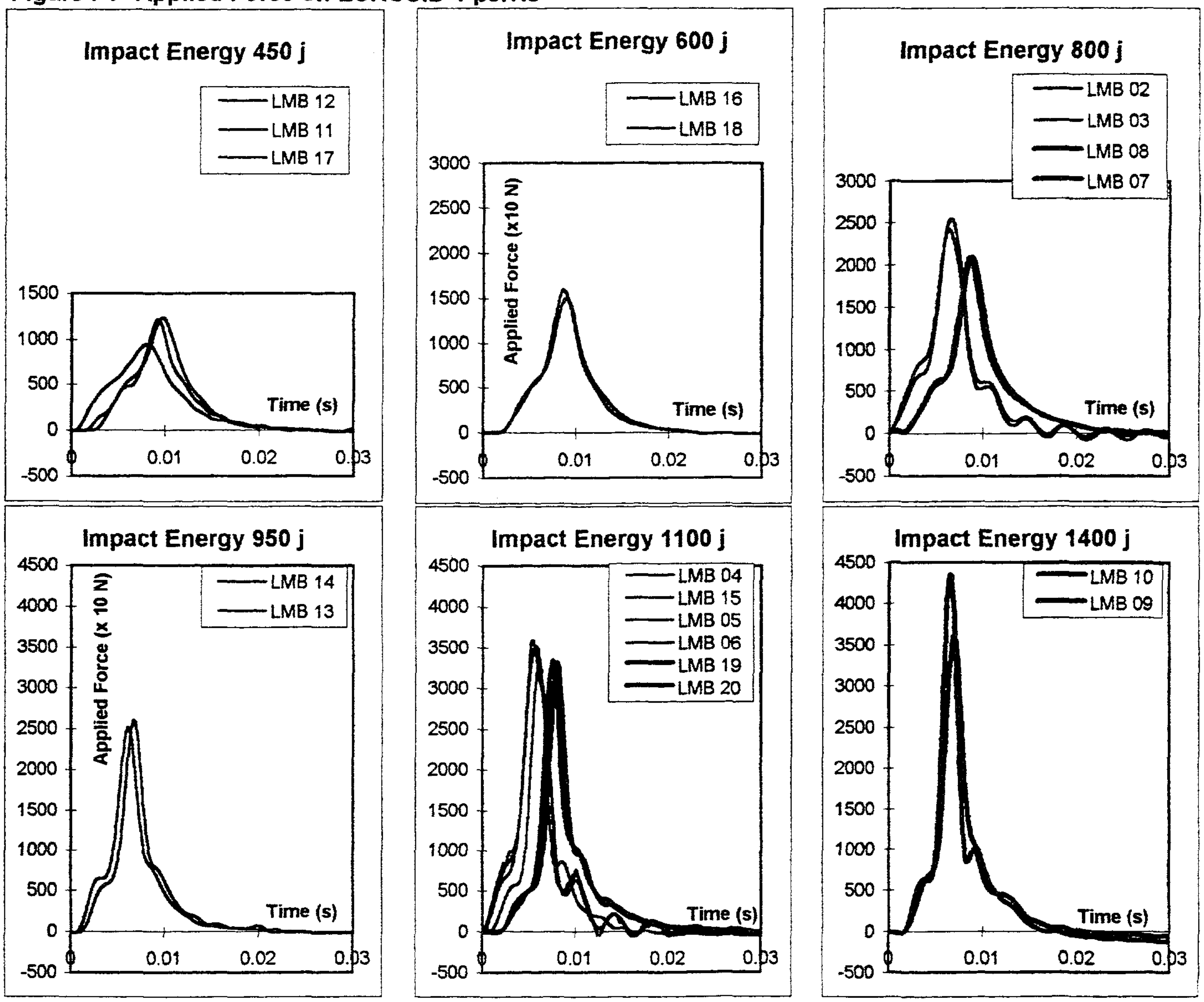


Figure 9 : EUROSID-1 pelvis tests. Forces distribution on 'Trochanter' plate (Troc pl) and iliac plate (Iliac pl).

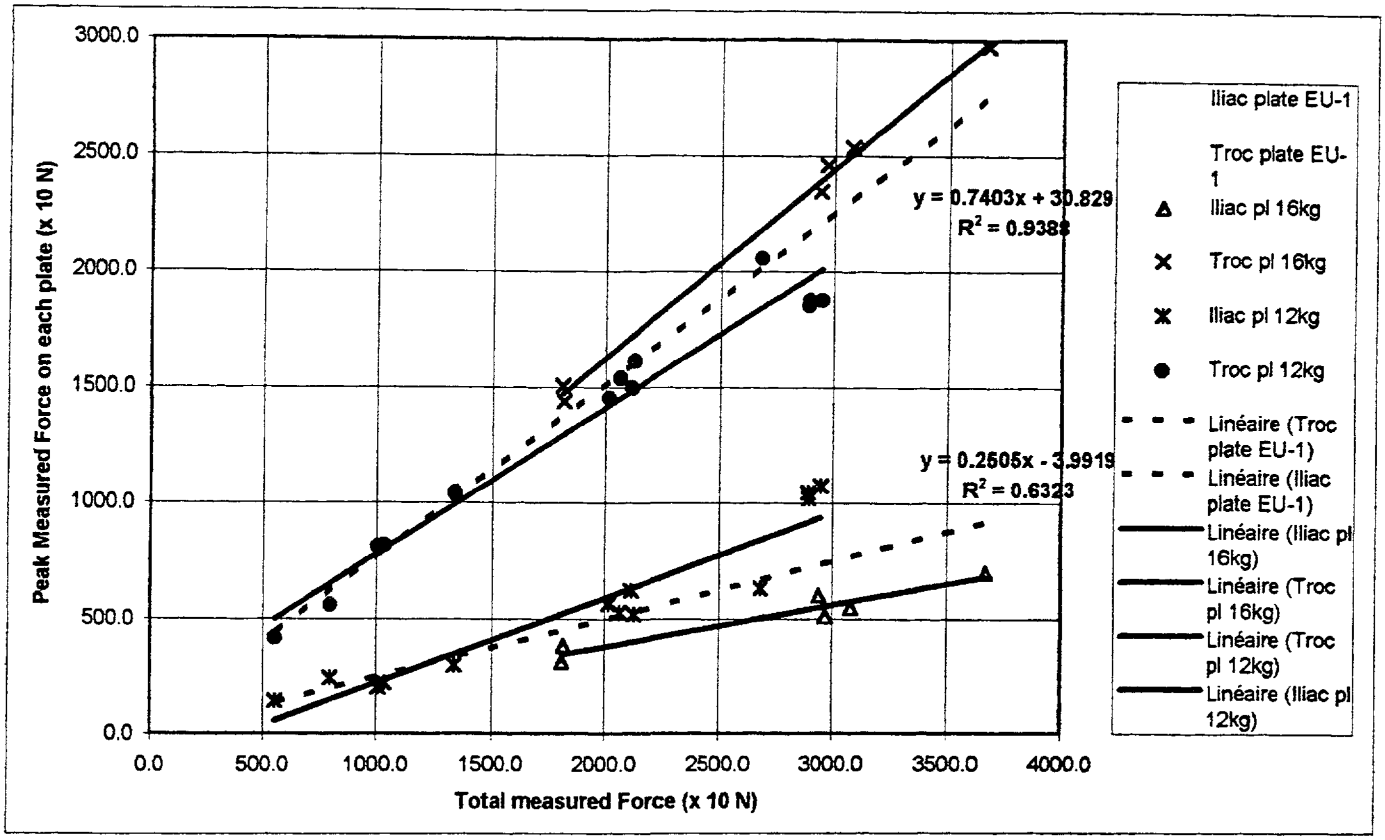


Figure 10 : PMHS and EUROSID-1 pelvis tests. Force distribution on trochanter plate (Troc pl) and iliac plate (Iliac pl)

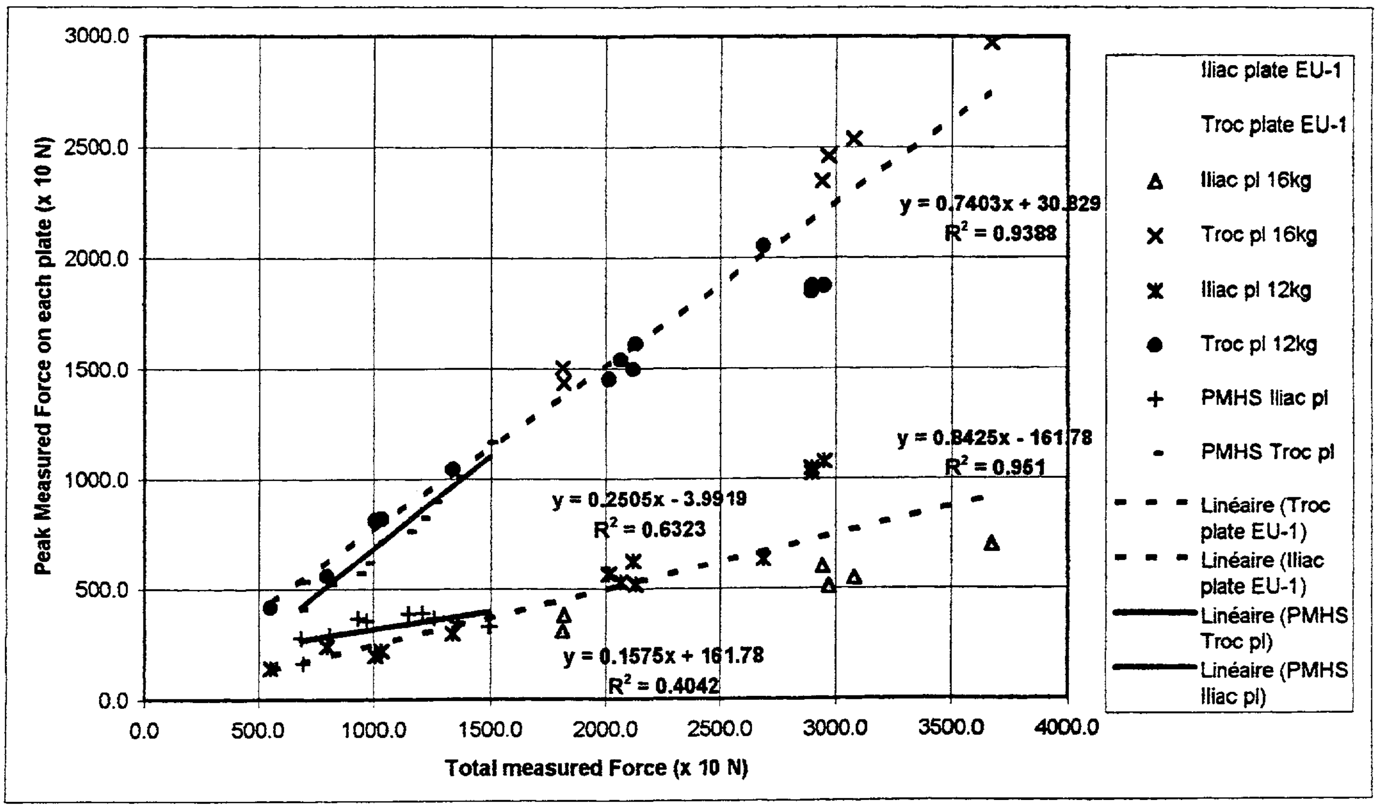


Figure 11 : Measured force on pubic symphysis and total applied force on EUROSID-1 pelvis

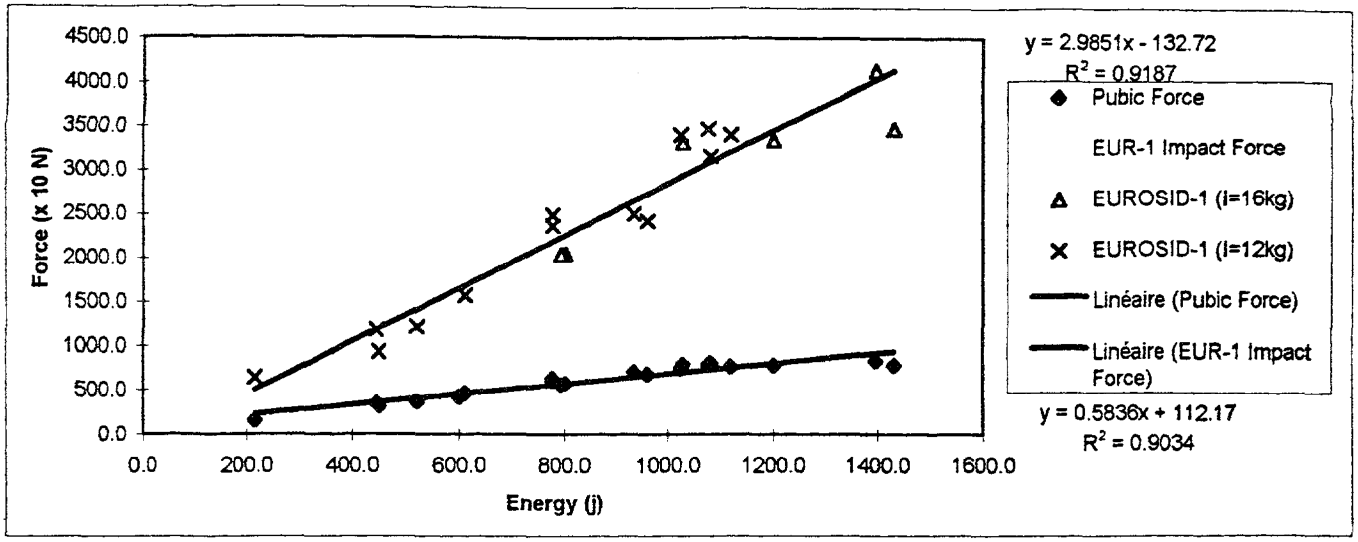


Figure 12 a & b : Maximum deflection analysis of each PMHS pelvis

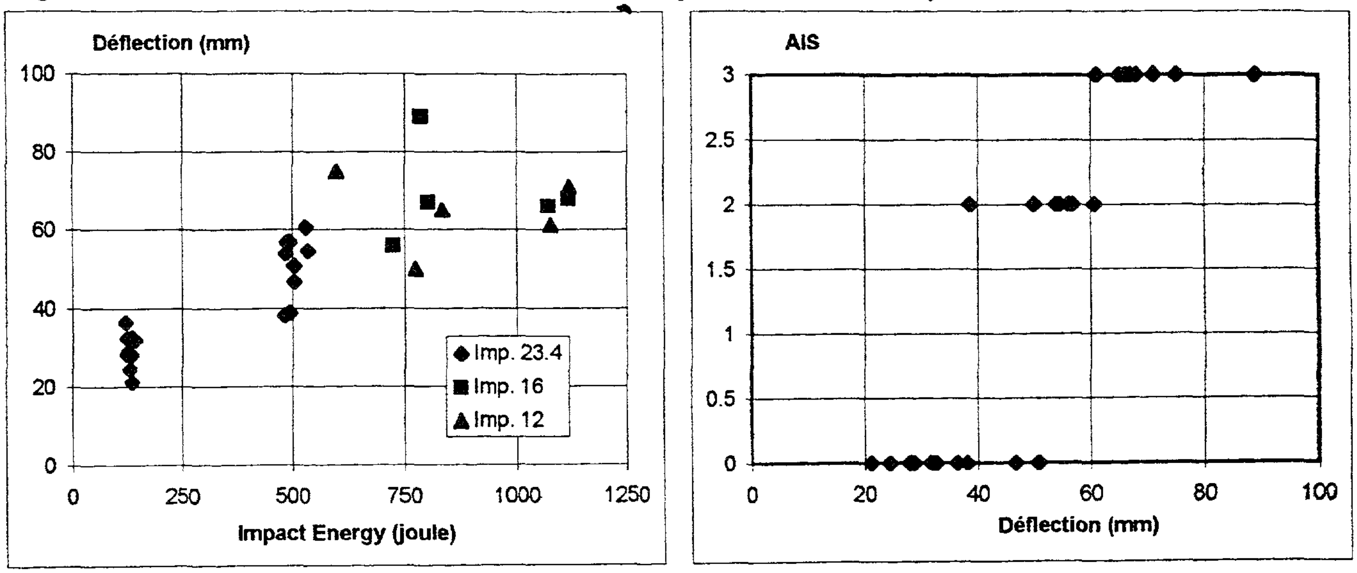


Figure 12 c & d : V*C analysis of each PMHS pelvis

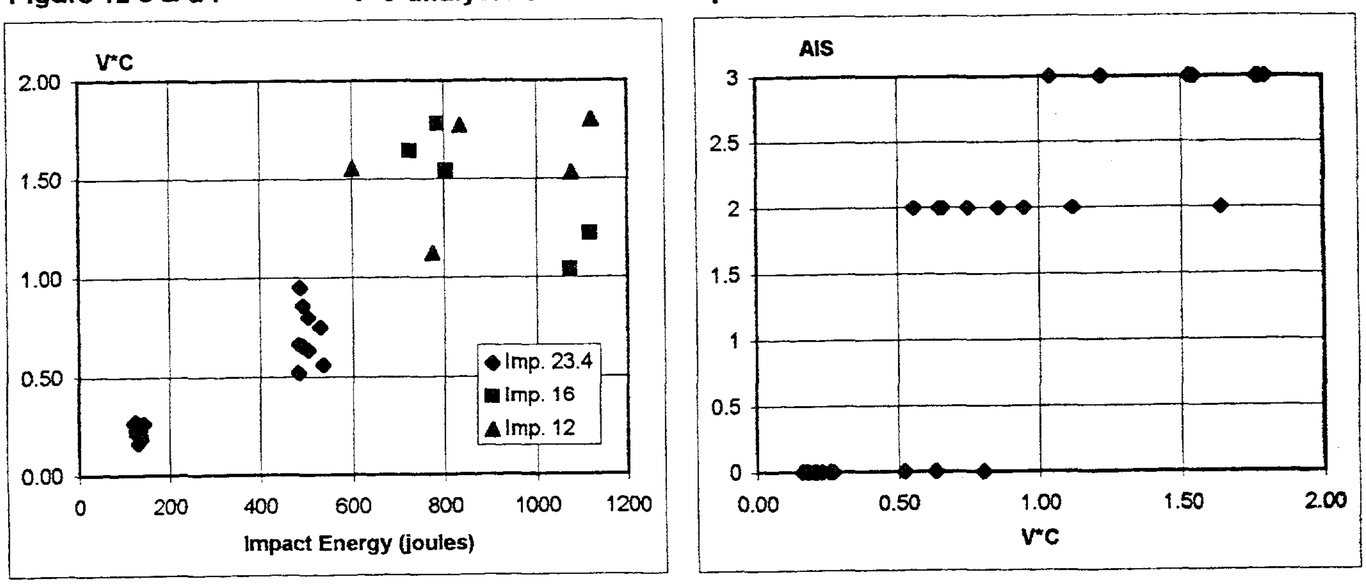
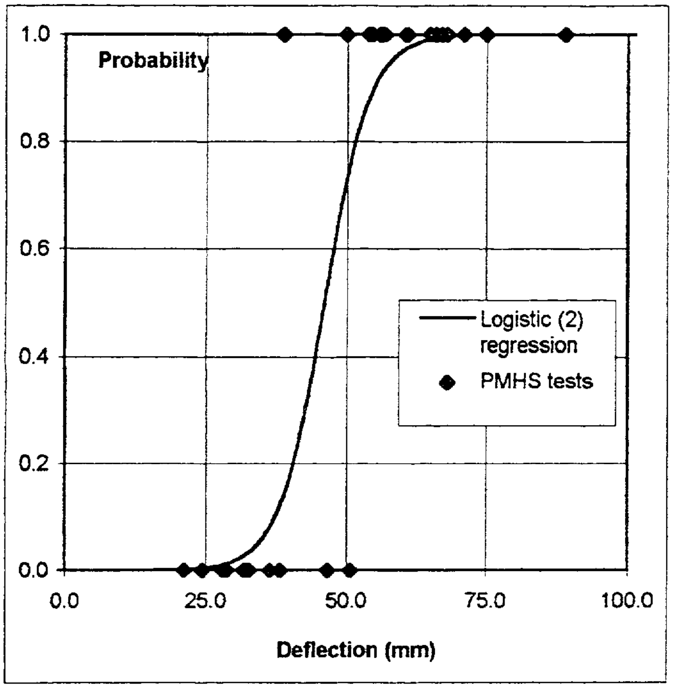
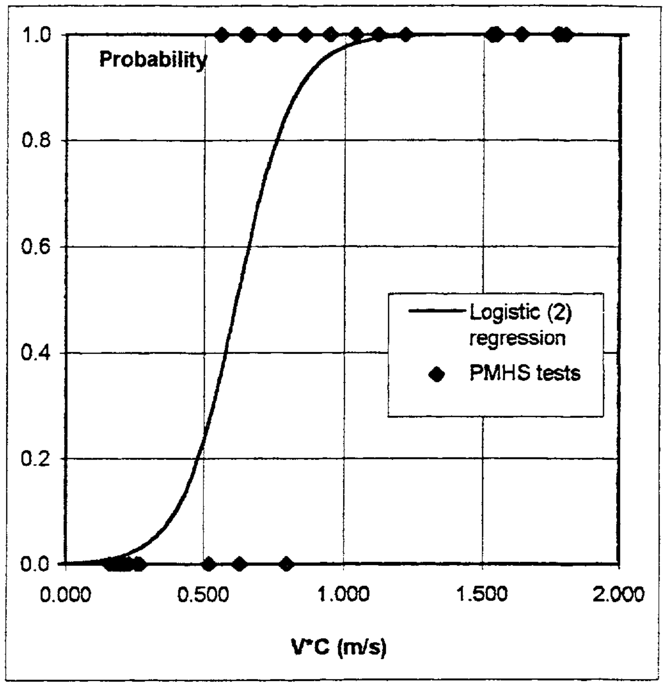


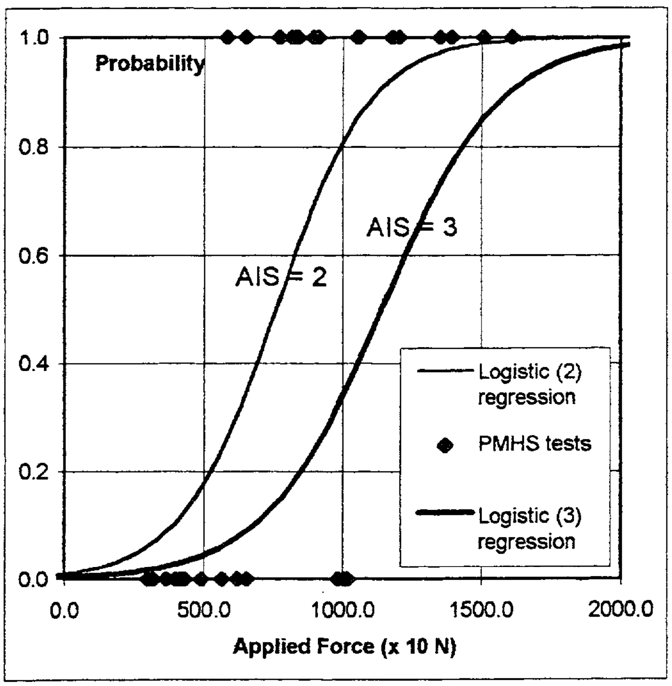
Figure 13 : Criterion assessment with logistic regressions



a) Deflection criterion of the human pelvis



b) Viscous criterion of the human pelvis



c) Human Pelvic Force Criterion

Criterion values of Human pelvis

Probability = 50% AIS ≥ 2

Deflection criterion= 46 mm

Viscous criterion (V*C) = 0.62

Applied Force criterion = 7600 N

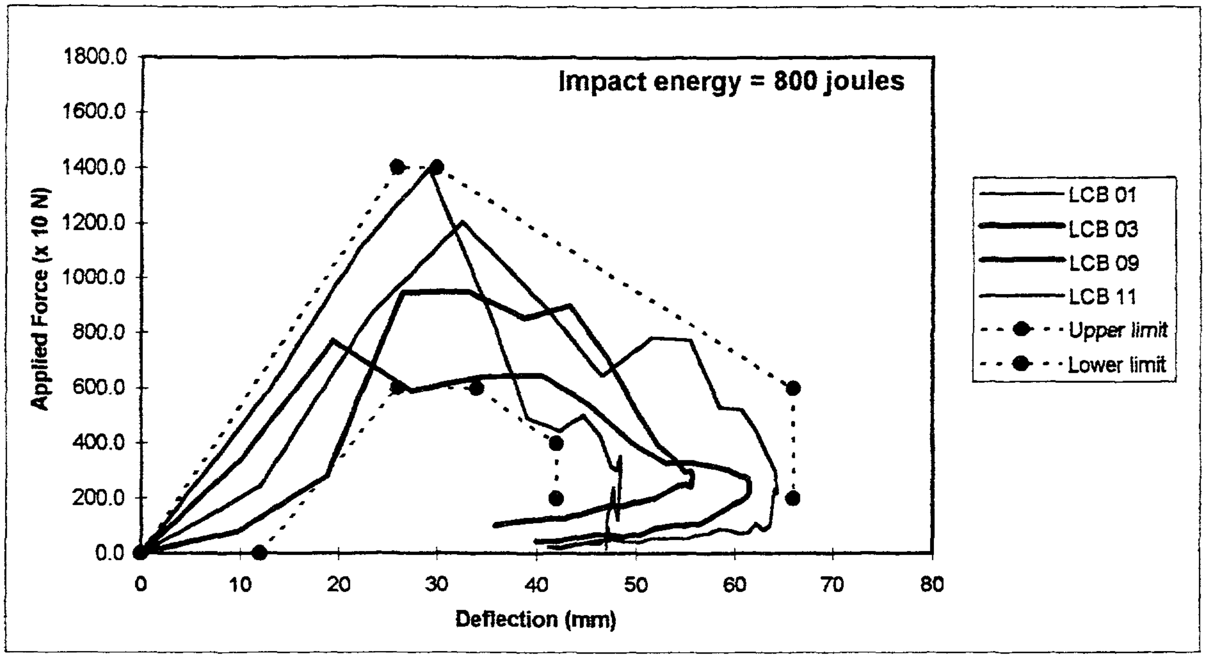
Probability = 50% AIS ≥ 3

Applied Force criterion = 11400 N

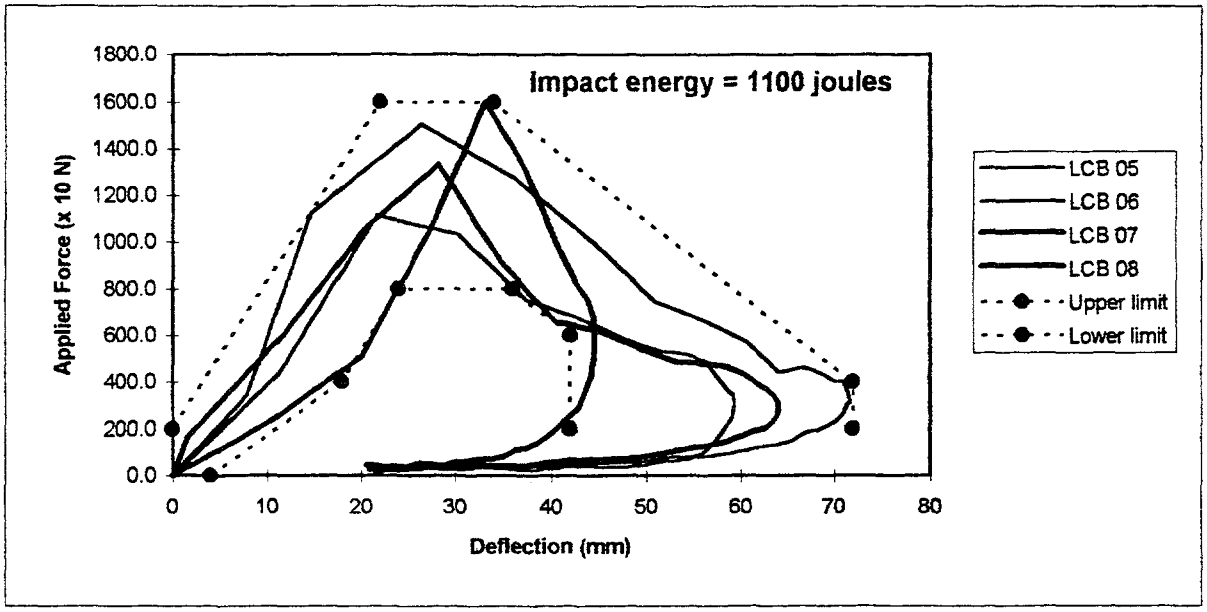
On the 3 graphs (a, b, c) the tests distribution is made with :

when AIS = 0 the probability is 0
when AIS =2 or 3 the propability is 1

Figure 14 : Corridors of human pelvis 'Force/Deflection' curves



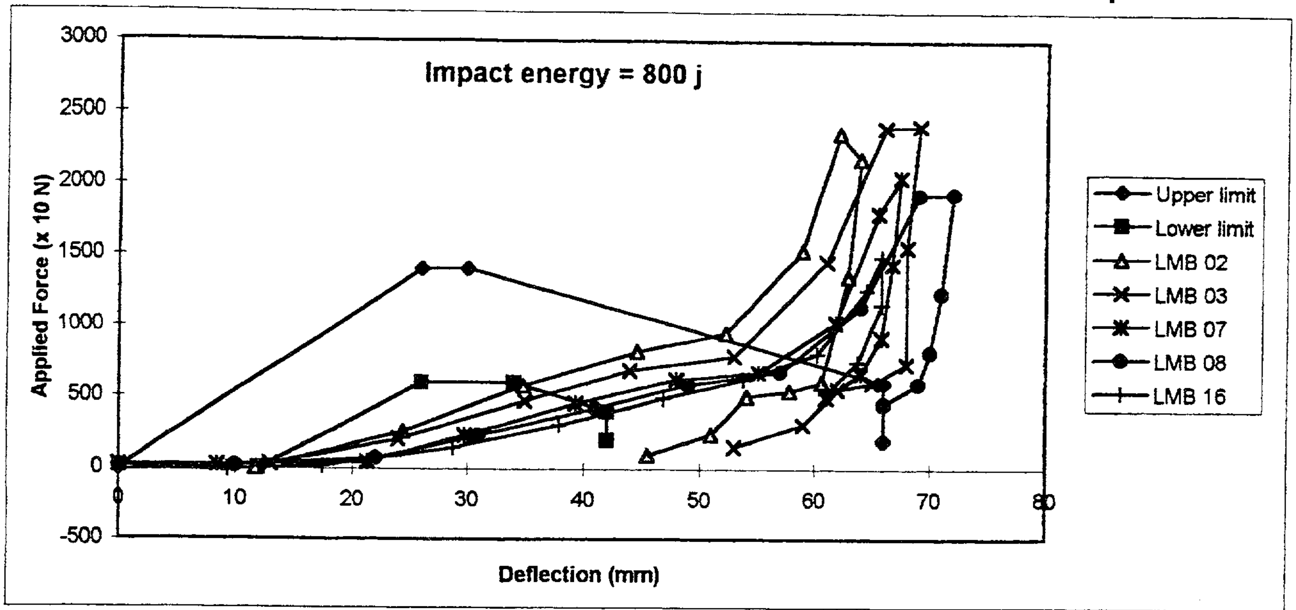
Dotted line = Impactor mass : 12 kg Solid line = Impactor mass : 16 kg



a) Corridor = 800 joules **b) Corridor = 1100 joules**

Deflection mm	Force N	Deflection mm	Force N	Deflection mm	Force N	Deflection mm	Force N
	Upper limit		Lower limit		Upper limit		Lower limit
0	0	12	0	0	2 000	4	0
26	14 000	26	6 000	22	16 000	18	4 000
30	14 000	34	6 000	34	16 000	24	8 000
66	6 000	42	4 000	72	4 000	36	8 000
66	2 000	42	2 000	72	2 000	42	6 000
						42	2 000

Figure 16 : Corridors of human pelvis 'Force/Deflection' curves and EUROSID-1 responses



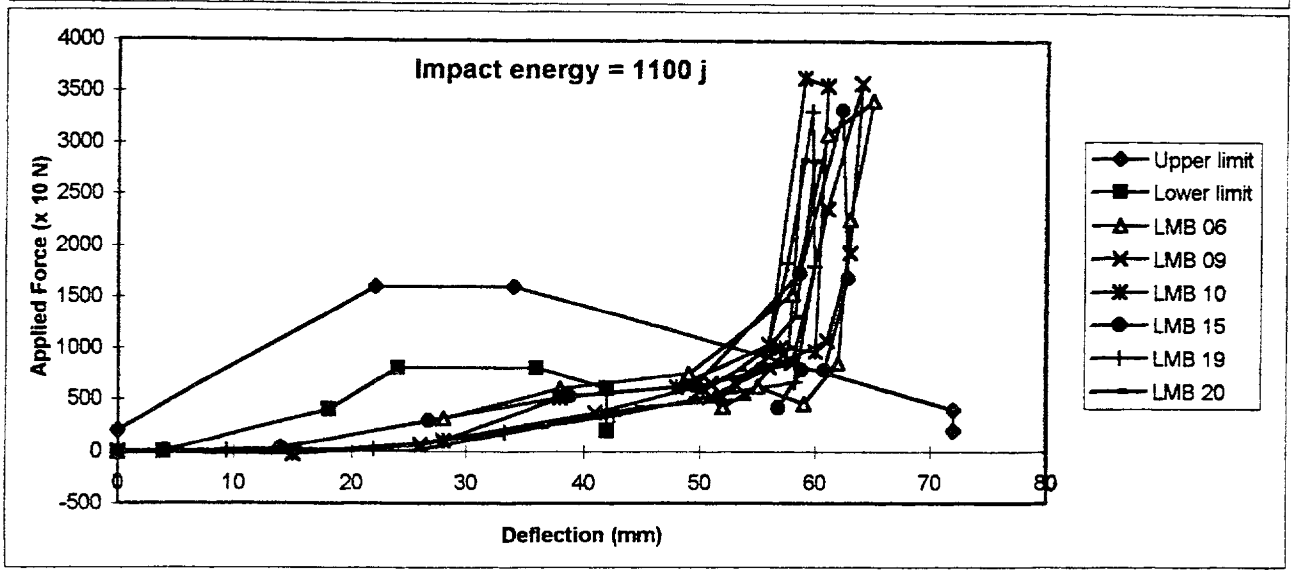


Figure 17 : EUROSID-1 Pelvic impact tests