TECHNICAL REPORT

ISO TR 9790-6

First edition
1989-05-01

Road vehicles — Anthropomorphic side impact dummy —

Part 6 :
Lateral pelvic impact response requirements to assess biofidelity of dummy

Véhicules routiers — Mannequin anthropomorphe pour essai de choc latéral —

Partie 6 : Caractéristiques de réponse du bassin à un choc latéral permettant d'évaluer la biofidélité d'un mannequin

Reference number
ISO/TR 9790-6 : 1989 (E)

Foreword

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The main task of ISO technical committees is to prepare International Standards. In exceptional circumstances a technical committee may propose the publication of a technical report of one of the following types:

— type 1, when the necessary support within the technical committee cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development requiring wider exposure;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical reports are accepted for publication directly by ISO Council. Technical reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 9790-6, which is a technical report of type 3, was prepared by Technical Committee ISO/TC 22, *Road vehicles*.

ISO/TR 9790 consists of the following parts, under the general title *Road vehicles — Anthropomorphic side impact dummy*:

— *Part 1: Lateral head impact response requirements to assess biofidelity of dummy*

— *Part 2: Lateral neck impact response requirements to assess biofidelity of dummy*

— *Part 3: Lateral thoracic impact response requirements to assess biofidelity of dummy*

— *Part 4: Lateral shoulder impact response requirements to assess biofidelity of dummy*

— *Part 5: Lateral abdominal impact response requirements to assess biofidelity of dummy*

— *Part 6: Lateral pelvic impact response requirements to assess biofidelity of dummy*

Road vehicles — Anthropomorphic side impact dummy — Part 6 : Lateral pelvic impact response requirements to assess biofidelity of dummy

1.0 INTRODUCTION

The impact response requirements presented in this Technical Report are the result of a critical evaluation of data selected from experiments agreed to by experts as being the best and most up-to-date information available.

Three sets of lateral pelvic impact response requirements are defined. The first requirement is based on impactor tests of ONSER (1, 2, 3)*, the second is based on free fall cadaver tests of Association Peugeot-Renault (4) and the third set is based on cadaver sled tests of the University of Heidelberg (5). All cadaver data were normalized to be representative of the responses of the 50th percentile adult male using the method described by Mertz (6).

2.0 SCOPE AND FIELD OF APPLICATION

This Technical Report is one of six reports that describe laboratory test procedures and impact response requirements suitable for assessing the impact biofidelity of side impact dummies. This Technical Report provides information to assess the biofidelity of lateral pelvic impact response.

3.0 ISO REFERENCES

ISO DP 9790-1 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Head Impact Response Requirements to Assess the Biofidelity of the Dummy.

*Numbers in parentheses denote papers in References, Section 7.0.

ISO DP 9790-2 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Neck Impact Response Requirements to Assess the Biofidelity of the Dummy.

ISO DP 9790-3 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Thoracic Impact Response Requirements to Assess the Biofidelity of the Dummy.

ISO DP 9790-4 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Shoulder Impact Response Requirements to Assess the Biofidelity of the Dummy.

ISO DP 9790-5 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Abdominal Impact Response Requirements to Assess the Biofidelity of the Dummy.

4.0 REQUIREMENT NO. 1

4.1 Original Data

Researchers of ONSER studied the response of 22 unembalmed cadavers to lateral impacts delivered to the greater trochanter (1, 2, 3)*. Pelvic acceleration was measured by an accelerometer attached to the posterior of the sacrum. The unbelted cadavers were seated without lateral support and impacts were delivered at various speeds by either a rigid or padded impactor. Forces and accelerations of the impactor were measured. Data from these tests are summarized in Appendix A.

4.2 Peak Impactor Force Requirements

The peak impactor forces were normalized (see Appendix A) using the technique suggested by Mertz (6). The normalized peak forces are plotted against their impact velocities in Figure 1. Also shown is the proposed response corridor for a 17.3 kg rigid impactor striking the greater trochanter region. For dummy impacts between 6 m/s and 10 m/s, the normalized peak impactor force should lie within the corridor.

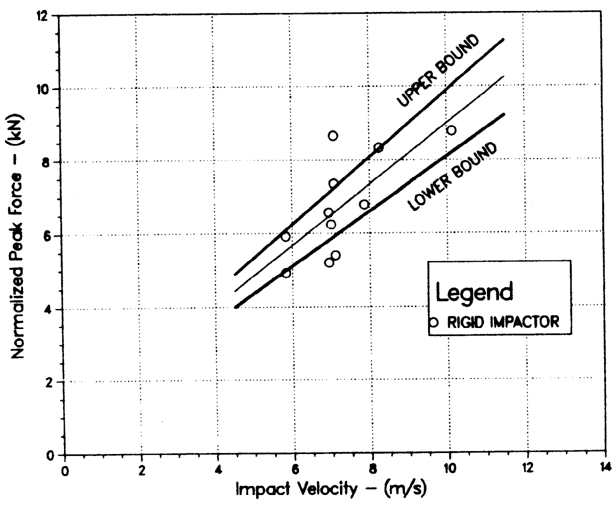

FIGURE 1. SCATTER PLOT OF IMPACT VELOCITY VERSUS NORMALIZED PEAK FORCE, LINEAR RELATIONSHIP BETWEEN IMPACT VELOCITY AND NORMALIZED PEAK FORCE, AND PROPOSED CORRIDOR FOR A 17.3 KG RIGID IMPACTOR STRIKING THE GREATER TROCHANTER REGION.

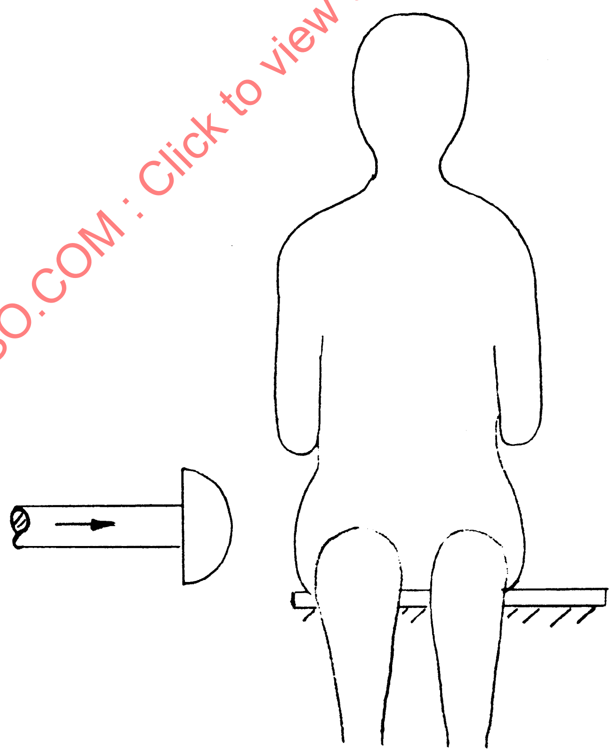

FIGURE 2. LATERAL PELVIC IMPACT TEST CONFIGURATION.

4.3 Test Setup

A 17.3 kg impactor with a rigid spherical segment impact face (R = 600 mm, r = 175 mm) is required. Seat the side impact dummy as shown in Figure 2 and adjust the impactor to strike the greater trochanter region at velocities between 6 m/s and 10 m/s.

4.4 Instrumentation

Instrument the side impact dummy to monitor acceleration of the pelvis. Provide force measurement capabilities for the impactor. Forces and accelerations are to be filtered using SAE Channel Class 1000.

4.5 Normalization Procedure

Determine the impulse by integrating the force-time curve.

The effective mass is defined by,

$$M_e = [\int_0^T F dt] / (V_o) \qquad (1$$

where $\int_0^T F dt$ is the impulse and V_o is the initial impact velocity. The mass ratio is defined by,

$$R_m = 14.5 \text{ kg}/M_e \qquad (2$$

Calculate the effective mass and mass ratio for each test.

It is assumed that the dummy has the same pelvic stiffness as the standard subject. Thus, the stiffness ratio, R_k, is equal to 1.

The normalizing factor for force is given by,

$$R_f = (R_m R_k)^{\frac{1}{2}} \qquad (3$$

Normalize the peak force by multiplying it by its normalizing factor.

A dummy with reasonable response characteristics will have a normalized peak force that lies within the proposed response corridor.

5.0 REQUIREMENT NO. 2

5.1 Original Data

Researchers of the Association Peugeot-Renault studied the response of 26 unembalmed cadavers to lateral free falls onto either rigid or padded impact surfaces (4). Pelvic acceleration was measured by an accelerometer attached to the sacrum. The impact surfaces were positioned to impact with the pelvis and thorax. The cadavers were dropped from heights ranging from 0.5 to 3.0 meters. Data for these tests are summarized in Appendix B.

5.2 Peak Pelvic Acceleration Requirements

The peak pelvic acceleration values were normalized (see Appendix B) using the technique suggested by Mertz (6). Upper and lower bounds for peak normalized pelvic accelerations defined for each combination of drop height and impact surface stiffness are given in Table 1. Normalized peak pelvis acceleration of the dummy should lie within these bounds.

5.3 Test Setup

Suspend the dummy the required height above the impact targets with its sagittal plane horizontal. Use a "Quick Release" device to ensure that the dummy drops freely. Conduct the tests indicated in Table 1.

TABLE 1 - RESPONSE BOUNDS FOR PEAK NORMALIZED PELVIC ACCELERATION

Drop Height (m)	Impact Surface*	Average Normalized Peak Pelvic Acceleration (G)	Peak Normalized Acceleration Bounds Lower (G)	Peak Normalized Acceleration Bounds Upper (G)
0.5	Rigid	41	37	45
1.0	Rigid	70	63	77
2	APR Pad	43	39	47
3	APR Pad	53	48	58

* Characteristics of the APR Pad are given in Appendix D.

5.4 Instrumentation

Instrument the dummy to monitor acceleration of the sacrum. Provide force measurement capabilities for the pelvic impact surface. Forces and accelerations are to be filtered using SAE Channel Class 180.

5.5 Normalization Procedure

The mass ratio, R_m, is calculated using the following equation:

$$R_m = 76 \text{ kg}/M_i \qquad (1$$

where M_i is the total body mass of the dummy. This is the same relationship that was used to analyze the cadaver data given in Appendix B.

It is assumed that the dummy has the same pelvic stiffness as the standard subject. Thus the stiffness ratio, R_k, is equal to 1.

The normalizing factor for acceleration is given by,

$$R_a = (R_k)^{\frac{1}{2}}(R_m)^{-\frac{1}{2}} \qquad (2$$

Normalize the peak acceleration value by multiplying it by its normalizing factor.

A dummy with reasonable response characteristics will have a normalized peak pelvic acceleration that lies within the proposed bounds given in Table 1.

6.0 REQUIREMENT NO. 3

6.1 Original Data

Researchers at the University of Heidelberg conducted two sled test series using unembalmed cadaver subjects (5). Rigid surface impacts were conducted at 23 km/h, 24 km/h and 32 km/h. Padded surface impacts were conducted at 32 km/h. Pelvic acceleration was measured in both test series. Impact force was measured only in the second test series. Data for both test series were provided by NHTSA who funded the studies. A summary of the data is given in Appendix C.

6.2 Peak Response Requirements

The peak acceleration and force data were normalized (see Appendix C). Data from tests with similar impact velocity and impact surface stiffness were grouped and average values of normalized peak pelvic acceleration and normalized peak impact force were calculated. These averages were used to define reasonable upper and lower bounds for these parameters. These response requirements are given in Table 2 along with their respective test conditions.

TABLE 2 - RESPONSE REQUIREMENTS FOR PEAK NORMALIZED PELVIC ACCELERATION AND PEAK NORMALIZED IMPACT FORCE

Impact Velocity (km/h)	Impact Surface	Normalized Peak Pelvic Acceleration Average (G)	Lower (G)	Upper (G)	Normalized Peak Impact Force Average (kN)	Lower (kN)	Upper (kN)
23.5	Rigid	70	63	77	7.1	6.4	7.8
32	Rigid	106	96	116	24.4	22.4	26.4
32	APR Pad	68	61	75	12.6	11.6	13.6

6.3 Test Setup

A seat with a force sensing side panel is to be secured to an impact sled, sideways to the direction of travel. The top edge of the side board is to be 540 mm above the seat plane. The surface of the seat is to have a low coefficient of friction to assure that the dummy will translate relative to the seat without rotating. The dummy is to be placed on the seat at a sufficient distance from the side board to assure that the sled is completely stopped prior to impact. For padding tests, 140 mm x 140 mm blocks of APR open cell urethane foam are to be fastened to the thorax and pelvis impact surfaces. Characteristics of APR padding are given in Appendix D.

6.4 Instrumentation

The dummy is to be instrumented to measure pelvis acceleration. An inertia compensated load transducer is to be attached to the side board to measure pelvic force. Force and acceleration measurements are to meet SAE Channel Class 1000 filter requirements. For comparison to the biomechanical response requirements of Table 2, the data must be filtered using a 100 Hz FIR filter (5).

6.5 Normalization Procedure

The mass ratio, R_m, is calculated using the following Equation:

$$R_m = 76 \text{ kg}/M_i \quad (1$$

where M_i is the total body mass of the dummy. This is the same relationship that was used to analyze the cadaver data given in Appendix C.

It is assumed that the dummy has the same pelvic stiffness as the standard subject. Thus, the stiffness ratio, R_k, is equal to 1.

The normalizing factors for force and acceleration are given by,

$$R_f = (R_m R_k)^{\frac{1}{2}} \quad (2$$

$$R_a = (R_k)^{\frac{1}{2}}(R_m)^{-\frac{1}{2}} \quad (3$$

Normalize the peak force value by multiplying it by its normalizing factor. Normalize the peak acceleration value by multiplying it by its normalizing factor.

A dummy with reasonable response characteristics will have normalized peak force and normalized peak acceleration values that lie within the proposed response bounds defined in Table 2.

7.0 REFERENCES

1. Cesari, D., Ramet, M., and Clair, P., "Evaluation of Pelvic Fracture Tolerance in Side Impact", SAE 801306, Twenty-Fourth Stapp Car Crash Conference, Oct. 1980.

2. Cesari, D. and Ramet, M., "Pelvic Tolerance and Protection Criteria in Side Impact", SAE 821159, Twenty-Sixth Stapp Car Crash Conference, Oct. 1982.

3. Cesari, D., Ramet, M., and Bouquet, R., "Tolerance of Human Pelvis to Fracture and Proposed Pelvic Protection Criterion to be Measured on Side Impact Dummies", Ninth International Technical Conference on Experimental Safety Vehicles, Nov. 1982.

4. Tarriere, C., Walfisch, G., Fayon, A., Rosey, J., Got, C., Patel, A., Delmas, A., "Synthesis of Human Tolerances Obtained from Lateral Impact Simulations", Seventh International Technical Conference on Experimental Safety Vehicles, June 1979.

5. Kallieris, D., Mattern, R., Schmidt, G., and Eppinger, R., "Quantification of Side Impact Responses and Injuries", SAE 811008, Twenty-Fifth Stapp Car Crash Conference, Sept. 1981.

6. Mertz, H. J., "A Procedure for Normalizing Impact Response Data", SAE 840884, Warrendale, PA, May 1984.

APPENDIX A

ANALYSIS OF ONSER LATERAL PELVIC IMPACT DATA

This appendix describes the application of the normalization techniques of Mertz (6) to the lateral pelvic impact data provided by ONSER (1, 2, 3).

A.1 Original Data

Researchers of ONSER studied the response of 22 unembalmed cadavers to lateral impacts delivered to the greater trochanter. Pelvic strains were measured by 3 strain gages on the internal face of the ileal wing and 1 strain gage on the ileo-pubic ramus (3). Pelvic acceleration was measured by an accelerometer attached to the posterior of the sacrum. The unbelted cadavers were seated without lateral support, as shown in Figure 1. Lateral impacts were delivered at known speeds by a 17.3 kg rigid or padded impactor. The impact surface of the rigid impactor was a segment of a sphere (R = 600 mm, r = 175 mm). The padded surface was a polyurethane block. Forces and accelerations of the impactor were measured. Each cadaver was impacted at increasing speeds until pelvic fracture was diagnosed by X-ray or external examination (2).

The mass and height of cadavers struck by the rigid impactor are summarized in Table 1. The impact velocity, peak force, and impulse of the first impact to each cadaver are also given. Only results where data for the first impact were given and the cadavers had acceptable bone condition were analyzed.

FIGURE 1. LATERAL PELVIC IMPACT TEST CONFIGURATION (2).

Table 1 - Cadaver Characteristics, Test Conditions and Test Results of ONSER Lateral Pelvic Impacts Tests (1, 2, 3); and Characteristic Ratios, Normalizing Factors, and the Normalized Test Results.

	Cadaver Data		Test Conditions		Test Results		Effective Mass		Characteristic Ratios		Normalizing Factors	Normalized Test Results
Test No.	Body Mass (kg)	Height (cm)	Impact Velocity (m/s)	Impact Surface	Peak Force (kN)	Impulse (Ns)	M_e (kg)	Percent of Body Mass (%)	Mass R_m	Stiffness R_k	Force R_f	Peak Force (kN)
A1	58	167	5.83	Rigid	4.17	63	10.8	18.6	1.34	1.04	1.18	4.92
B1	70	154	5.83	Rigid	5.1	71	12.2	17.4	1.19	1.13	1.16	5.92
C1	78	173	7.11	Rigid	5.62	113	15.9	20.4	.91	1.01	.96	5.40
D1	52	160	6.94	Rigid	4.41	88	11.3	24.4	1.28	1.09	1.18	5.20
E1	60	156	7.00	Rigid	5.52	88	12.6	21.0	1.15	1.12	1.13	6.24
F1	55	152	7.86	Rigid	5.61	89	11.3	20.5	1.28	1.14	1.21	6.79
H1	86	175	7.08	Rigid	6.62	82	11.6	13.5	1.25	.99	1.11	7.35
I1	63	181	7.08	Rigid	10.21	77	10.9	17.3	1.33	.96	1.13	11.54
J1	63	177	7.08	Rigid	7.73	79	11.2	17.8	1.29	.98	1.12	8.66
K1	55	171	6.94	Rigid	5.52	73	10.5	19.1	1.38	1.02	1.19	6.57
L1	85	175	8.25	Rigid	8.33	118	14.3	16.8	1.01	.99	1.00	8.33
R1	82	180	10.14	Rigid	9.44	163	16.1	19.6	.90	.97	.93	8.78
Z1	58	167	12.64	Padded	7.36	158	12.5	21.6	1.16	1.04	1.10	8.10

Note: Average Percent of Body Mass = 19.1%

A.2 Normalized Data

For the case where the impulse direction is horizontal, Mertz (6) defines the effective mass as,

$$M_e = [\int_0^T Fdt] / (\Delta V) \quad (1$$

where $\int_0^T Fdt$ is the impulse and ΔV is the change in velocity. The impact velocity was used as an estimate of the change in velocity since data were not available to calculate it. The effective mass and percent of body mass for the first impact of each cadaver are given in Table 1. The average percent of body mass is 19.1%.

The effective mass of a 50th percentile adult male was obtained by multiplying its body mass of 76 kg by 19.1% giving an effective mass of 14.5 kg.

The mass ratio, R_m, as defined by Mertz (6) is,

$$R_m = M_s M_i^{-1} \quad (2$$

where M_s is the effective mass of the standard subject and M_i is the effective mass of the i-th subject. For the data discussed here, Equation 2 becomes,

$$R_m = 14.5\ kg/M_i \quad (3$$

The mass ratios for the cadavers are given in Table 1.

The stiffness ratio, R_k, is defined as,

$$R_k = K_s K_i^{-1} \quad (4$$

where K_s is the stiffness of the standard subject and K_i is the stiffness of the i-th subject. Mertz (6) has shown that for geometrically similar structures with the same elastic modulus the stiffness is proportional to the characteristic length. For such structures the stiffness ratio can be expressed as,

$$R_k = L_s L_i^{-1} \qquad (5$$

where L_s and L_i are characteristic lengths of the standard and i-th subjects, respectively.

A characteristic length of the pelvis was not available. The standing height was used as the characteristic length. The standing height of each cadaver is given in Table 1. This measurement is 174 cm for the 50th percentile adult male. Using this value Equation 5 can be written as,

$$R_k = 174 \text{ cm}/L_i \qquad (6$$

The stiffness ratios for the cadavers are given in Table 1.

The normalizing factor for force as defined by Mertz (6) is,

$$R_f = (R_m R_k)^{\frac{1}{2}} \qquad (7$$

The force normalizing factors for the cadaver impacts are given in Table 1. The normalized peak forces were obtained by multiplying the measured peak forces by their force normalizing factors. The resulting normalized peak forces are given in Table 1. A plot of normalized peak force versus impact velocity is shown in Figure 2.

A.3 Peak Impactor Force Requirements

The force normalizing factors map the peak impact forces of the cadaver subjects onto the peak forces of a 50th percentile adult male. The normalizing factors do not correct for the variability of impact surface material. Test Number I1 appears to be an outlier and was not used in the selection of a response corridor.

Linear regression analysis was performed to determine the relationship between impact velocity and normalized peak force for the rigid impactor data given in Table 1. The computed relationship, with a sample correlation of .71, is given by,

$$F = .71 + .83V \quad (8$$

where F is the normalized peak force and V is the impact velocity. A response corridor was drawn to allow reasonable deviation from the impact velocity and peak force relationship. Figure 3 shows the scatter plot of impact velocity versus the normalized peak force, the curve given by Equation 8, and the response corridor for impacts delivered by a 17.3 kg rigid impactor. For dummy impacts between 6 m/s and 10 m/s, the normalized peak impactor force should lie within the corridor shown in Figure 3.

Response requirements are not proposed for tests with a padded impactor because the results of the first impact were available for only one cadaver subject.

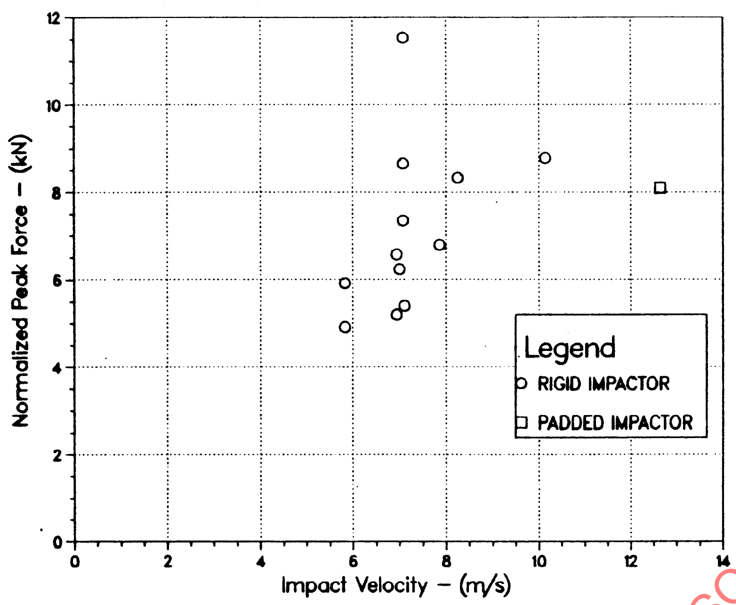

FIGURE 2. SCATTER PLOT OF IMPACT VELOCITY VERSUS NORMALIZED PEAK FORCE FOR A 17.3 KG RIGID IMPACTOR STRIKING THE GREATER TROCHANTER OF SEATED CADAVERS.

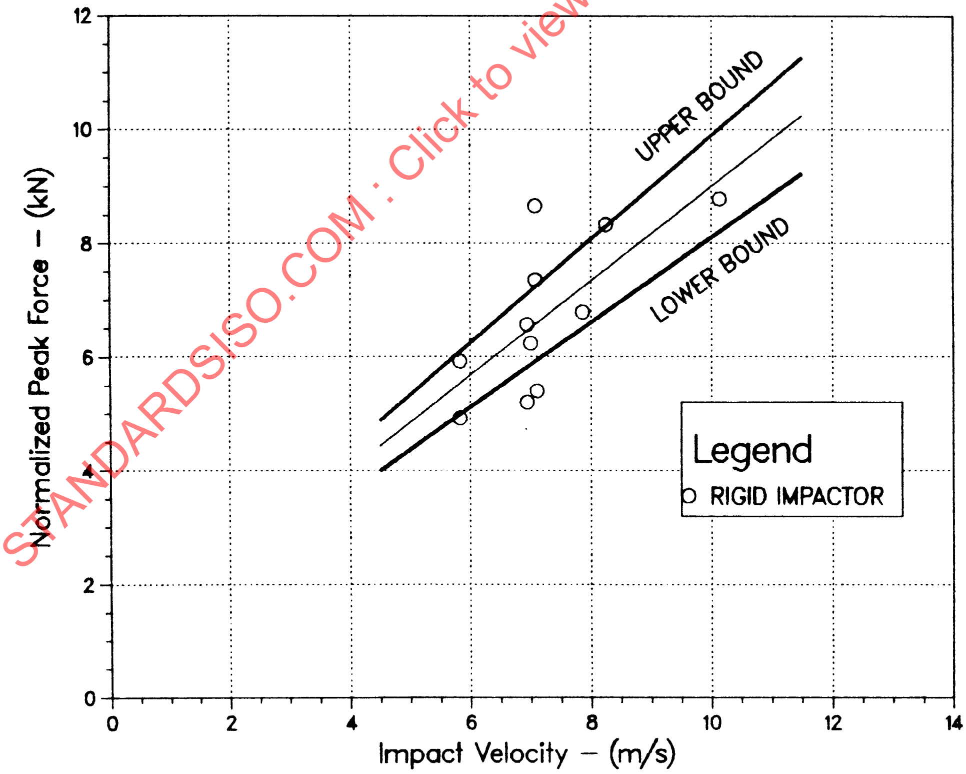

FIGURE 3. SCATTER PLOT OF IMPACT VELOCITY VERSUS NORMALIZED PEAK FORCE, LINEAR RELATIONSHIP BETWEEN IMPACT VELOCITY AND NORMALIZED PEAK FORCE, AND PROPOSED CORRIDOR FOR A 17.3 KG RIGID IMPACTOR STRIKING THE GREATER TROCHANTER REGION.

APPENDIX B

ANALYSIS OF ASSOCIATION PEUGEOT-RENAULT LATERAL PELVIC IMPACT DATA

This appendix describes the application of the normalization techniques of Mertz (6) to the lateral pelvic impact data collected by researchers of the Association Peugeot-Renault (4).

B.1 Original Data

Researchers of the Association Peugeot-Renault subjected 26 unembalmed cadavers to lateral free falls onto either rigid or padded impact surfaces. Accelerometers were attached to the 4th thoracic vertebra and the sacrum. The impact surfaces were positioned to impact with the thorax and pelvis, as shown in Figure 1. The padded, pelvic impact surfaces were polyurethane foam. The cadavers were dropped from heights ranging from 0.5 to 3.0 meters. Following each test, the cadaver was autopsied for thoracic and pelvic fractures.

Tables 1 and 2 summarize the body mass and thoracic depths of the cadavers for the rigid and padded impacts, respectively. The drop height, impact surface configuration as defined in Figure 1, and pelvic accelerations are also given for each test.

B.2 Normalized Data

The force-time and acceleration-time histories were not available for the APR data. Consequently, the mass ratio, R_m, was calculated using total body mass or,

$$R_m = 76 \text{ kg}/M_i \qquad (1$$

where 76 kg is the total body mass of the 50th percentile adult male and M_i is the total body mass of the i-th subject. The mass ratios for the

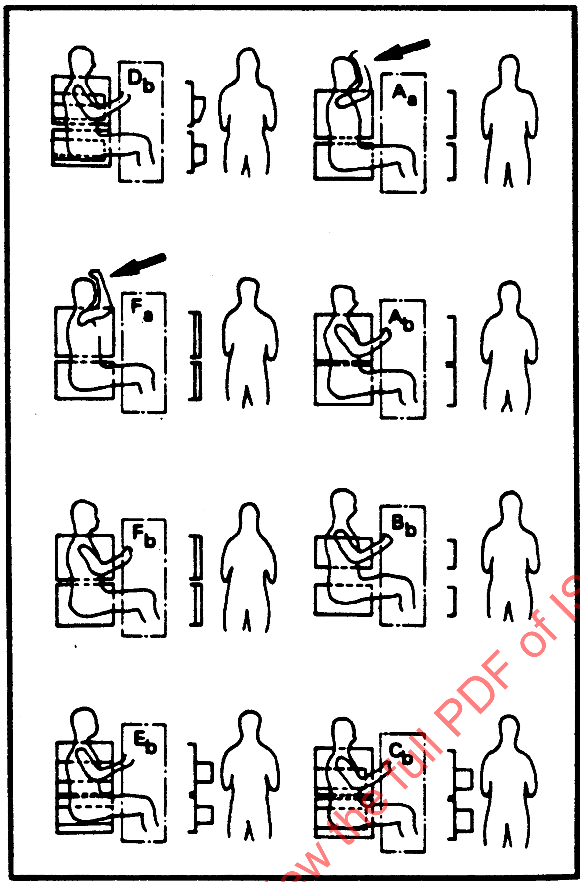

FIGURE 1. LATERAL PELVIC IMPACT TEST CONFIGURATIONS (4).

Table 1. Cadaver Data, Test Conditions, and Test Results for the Rigid Lateral Pelvic Impact Tests Performed by the Association Peugeot-Renault (4); and Characteristic Ratios, Normalizing Factors, and Normalized Test Results for the Pelvic Acceleration Data.

Test No.	Cadaver Data		Test Conditions		Test Results	Characteristic Ratios		Normalizing Factors	Normalized Test Results
	Body Mass (kg)	Thoracic Depth (cm)	Drop Height (m)	Configuration	Peak Pelvic Acceleration (G)	Mass R_m	Stiffness R_k	Acceleration R_a	Peak Pelvic Acceleration (G)
118	49	20	.5	Bb	62	1.55	1.18	.87	54
119	41	20	.5	Bb	34	1.85	1.18	.80	27
104	59	20	1	Aa	55	1.29	1.18	.96	53
105	54	20	1	Aa	153	1.41	1.18	.91	139
111	53	21	1	Ab	89	1.43	1.12	.88	78
155	69	20	1	Ab	75	1.10	1.18	1.04	78
156	57	17	1	Ab	69	1.33	1.39	1.02	70

Table 2. Cadaver Data, Test Conditions, and Test Results for the Padded Lateral Pelvic Impact Tests Performed by the Association Peugeot-Renault (4); and Characteristic Ratios, Normalizing Factors, and Normalized Test Results for the Pelvic Acceleration Data.

	Cadaver Data		Test Conditions			Test Results	Characteristic Ratios		Normalizing Factors	Normalized Results
Test No.	Body Mass (kg)	Thoracic Depth (cm)	Drop Height (m)	Configuration	Impact Surface Material	Peak Pelvic Acceleration (G)	Mass R_m	Stiffness R_k	Acceleration R_a	Peak Pelvic Acceleration (G)
100	56	18	2	Fb	firm padding	44	1.36	1.31	.98	43
101	52	20	2	Fb	firm padding	110	1.46	1.18	.90	99
102	53	21	3	Eb	firm padding	62	1.43	.87	.78	48
107	42	17	3	Eb	firm padding	77	1.81	.91	.71	55
108	50	19	3	Eb	firm padding	74	1.52	.87	.76	56
120	70	23	2	Cb	improved padding	37	1.09	1.03	.97	36
121	75	23	2	Cb	improved padding	32	1.01	1.03	1.01	32
122	45	16	2	Cb	improved padding	34	1.69	1.48	.94	32
128	50	20	2	Db	improved padding	48	1.52	1.18	.88	42
129	44	21	2	Db	improved padding	48	1.73	1.12	.80	38
131	45	21	2	Db	improved padding	50	1.69	1.12	.81	41
132	44	20	2	Db	improved padding	60	1.73	1.18	.83	50
133	61	23	2	Db	improved padding	84	1.25	1.03	.91	76

cadavers are given in Tables 1 and 2, for the rigid and padded impacts, respectively.

As was noted in Appendix A, the stiffness ratio can be defined in terms of characteristic lengths for geometrically similar structures with the same elastic modulus, or,

$$R_k = L_s L_i^{-1} \qquad (2$$

Using thoracic depth as the characteristic length, Equation 2 becomes,

$$R_k = 23.6 \text{ cm}/L_i \qquad (3$$

where 23.6 cm is the thoracic depth for a 50th percentile adult male. The stiffness ratios for the cadavers are given in Tables 1 and 2, for the rigid and padded impacts, respectively.

The normalizing factor for acceleration is defined as,

$$R_a = (R_k)^{\frac{1}{2}}(R_m)^{-\frac{1}{2}} \qquad (4$$

The acceleration normalizing factors for the cadaver impacts are listed in Tables 1 and 2. For each test, the peak pelvic acceleration was multiplied by its normalizing factor. The normalized peak pelvic accelerations are given in Tables 1 and 2 for the rigid and padded impacts, respectively.

B.3 Peak Acceleration Response Requirements

The acceleration normalizing factors adjust the peak pelvic acceleration values of the available subjects to a standard cadaver subject. The data in Tables 1 and 2 were grouped by impact surface stiffness and drop height. Average normalized peak accelerations were calculated and are given in Table 3. Tests 101 and 105 were not included in the analysis since these peak pelvic accelerations appear to be outliers. Upper and lower bounds for the peak normalized dummy pelvis accelerations for each impact configuration are given in the Table 3 as well.

TABLE 3 - RESPONSE BOUNDS FOR PEAK NORMALIZED PELVIC ACCELERATION

Drop Height (m)	Impact Surface	Average Normalized Peak Pelvic Acceleration (G)	Peak Normalized Acceleration Bounds Lower (G)	Upper (G)
0.5	Rigid	41	37	45
1.0	Rigid	70	63	77
2	Firm Pad	43*	39	47
3	Firm Pad	53	48	58
2	Improved Pad	43	39	47

* Single Test

A description of the characteristics of the "Firm Pad" is given in Appendix D. A description of the "Improved Pad" is not available. These data will not be used in defining performance requirements.

APPENDIX C

ANALYSIS OF UNIVERSITY OF HEIDELBERG LATERAL PELVIC IMPACT DATA

This appendix describes the application of the normalization techniques of Mertz (6) to the lateral pelvic impact data collected in two studies at the University of Heidelberg (5). Data from these tests were provided by NHTSA who funded the studies.

C.1 Original Data

In the first study, researchers of the University of Heidelberg subjected 10 unembalmed cadavers to lateral impacts at either 24 km/h into a rigid surface, or 32 km/h into either a rigid or padded surface. Each cadaver was instrumented with 24 accelerometers, three of which provided triaxial acceleration measurements of the pelvis. Following each test, the cadaver was autopsied for injuries.

Each cadaver was seated on a low-friction bench that was mounted sideways on an impact test sled. The cadavers were located 61 to 91 cm from a vertical side board that was attached to the seat, and slid into the board upon rapid deceleration of the sled. In all tests, the side board was stopped prior to the cadaver striking it. For the 24 km/h rigid surface impact tests, the side board was of sufficient height to allow the cadavers' heads to strike it. For the 32 km/h tests, the impact surface was 54 cm high, measured from the seat pan. Each padded impact surface consisted of a 14 cm high padded block at the level of the seat pan and a similar block at the top of the impact surface. Two of the padded impact tests used 14 cm thick blocks of open cell urethane and two tests used 8.9 cm thick blocks of fiberglass matrix pad. Table 1 summarizes the mass and standing heights of the cadavers for these tests. The impact velocity, impact surface material, and peak pelvic acceleration are also given for each cadaver subject.

In the second study, eight cadavers were subjected to either 23 km/h impacts into a rigid wall, or 32 km/h impacts into either a rigid or padded wall. The results of one cadaver were not used in this study because the cadaver's body mass was not reported. In addition to pelvic acceleration, the pelvic impact surface force was also recorded. The cadaver data, test conditions, peak pelvic accelerations and peak forces are given in Table 2 for this test series.

In both studies, the data were filtered using a 100 Hz FIR filter (5). Similar filtering must be done to the dummy data since the FIR filter may have significantly distorted the amplitude and phase of the cadaver data.

C.2 Normalized Data

The force-time and acceleration-time histories were not available for the Heidelberg data. Consequently the mass ratio, R_m, was calculated using total body mass or,

$$R_m = 76 \text{ kg}/M_i \qquad (1$$

where 76 kg is the total body mass of the 50th percentile adult male and M_i is the total body mass of the i-th cadaver subject. The mass ratios are listed in Tables 1 and 2.

The characteristic dimension used to calculate the stiffness ratios was standing height since Kallieris et al (5) did not report any pelvic dimensions. Stiffness ratios were calculated using the following equation,

$$R_k = 174 \text{ mm}/L_i \qquad (2$$

where 174 mm is the standing height of the 50th percentile adult male and L_i is the standing height of the i-th cadaver subject. The stiffness ratios for the cadavers are given in Tables 1 and 2.

Table 1. Cadaver Data, Test Conditions, and Test Results for the Lateral Pelvic Im by the University of Heidelberg (5); and Characteristic Ratios, Norma Normalized Test Results for the Pelvic Acceleration Data.

Test No.	Cadaver Data		Test Conditions		Test Results	Characteristic Ratios		No
	Body Mass (kg)	Standing Height (cm)	Impact Velocity (km/h)	Impact Surface	Peak Pelvic Acceleration (G)	Mass R_m	Stiffness R_k	Ac
H80 011	89	180	24	rigid	49	.85	.97	
H80 014	84	169	24	rigid	63	.90	1.03	
H80 017	70	175	24	rigid	58	1.09	.99	
H80 024	65	176	32	rigid	108	1.17	.99	
H80 002	65	165	32	rigid	88	1.17	1.05	
H80 004	80	165	32	rigid	95	.95	1.05	
H80 018	61	166	32	APR padding	72	1.25	1.05	
H80 020	67	167	32	APR padding	54	1.13	1.04	
H80 021	63	180	32	fiberglass	34	1.21	.97	
H80 023	82	159	32	fiberglass	69	.93	1.09	

Table 2. Cadaver Data, Test Conditions, and Test Results for the Lateral Pelvic Impact Tests Performed by the University of Heidelberg (5); and Characteristic Ratios, Normalizing Factors, and Normalized Test Results for the Pelvic Acceleration Data.

Test No.	Cadaver Data: Body Mass (kg)	Cadaver Data: Standing Height (mm)	Test Conditions: Impact Surface	Test Conditions: Impact Velocity (km/h)	Test Results: Peak Force (kN)	Test Results: Peak Accel. (G)	Characteristic Ratios: Mass R_m	Characteristic Ratios: Stiffness R_k	Normalizing Factors: Force R_f	Normalizing Factors: Accel. R_a	Normalized Test Results: Peak Force (kN)	Normalized Test Results: Peak Pelvic Acceleration (G)
H82015	69	190	rigid	23	4.5	83	1.10	1.24	1.17	1.06	5.3	88
H82018	85	240	rigid	23	10.2	110	.89	.98	.93	1.05	9.5	116
H82019	67	210	rigid	23	5.8	44	1.13	1.12	1.12	1.00	6.5	44
H82014	61	200	rigid	32	22.0	154	1.25	1.18	1.21	.97	26.6	149
H82016	50	200	rigid	32	16.6	114	1.52	1.18	1.34	.88	22.2	100
H82021	99	260	APR padding	32	15.3	136	.77	.91	.84	1.09	12.9	148
H82022	77	220	APR padding	32	11.9	86	.99	1.07	1.03	1.04	12.3	85