TECHNICAL REPORT

ISO TR 9790-5

First edition
1989-05-01

Road vehicles — Anthropomorphic side impact dummy —

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

Véhicules routiers — Mannequin anthropomorphe pour essai de choc latéral —

Partie 5 : Caractéristiques de réponse de l'abdomen à un choc latéral permettant d'évaluer la biofidélité d'un mannequin

Reference number
ISO/TR 9790-5 : 1989 (E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 Technical reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.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 9790-5, 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 5 : Lateral abdominal 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.

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 abdominal 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.

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 9790-6 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Pelvis Impact Response Requirements to Assess the Biofidelity of the Dummy.

4.0 REQUIREMENT

4.1 Original Data

Researchers of the Association Peugeot-Renault subjected 11 unembalmed cadavers to lateral free falls onto simulated armrests (1)*. The cadavers were instrumented to monitor accelerations of their 12th thoracic vertebrae and the lateral aspects of their 9th ribs. The simulated armrests were secured to load cells, providing measurements of the force applied to the impacted surface. The actual data traces for these tests were provided by APR (2) and are presented in the Appendix.

4.2 Response Requirements

The original impact response curves, the peak thoracic spine accelerations and peak impacted rib accelerations of the cadaver subjects were normalized using the technique suggested by Mertz (3). (See the Appendix for a description of the normalization process.) The normalized force-time curves of the cadaver subjects and proposed response corridors are shown in Figures 1 and 2 for the 1 and 2 meter free falls onto 4.1 cm rigid armrest, respectively. The normalized force-time curves of the dummy should lie within these corridors when subjected to the 1 and 2 meter impacts described under Test Setup. The normalized peak acceleration of T12 should lie between 29 and 35 G for the 1 meter impact and between 75 and 91 G for the 2 meter impact. The normalized peak impacted rib acceleration should lie between 100 and 125 G for the 1 meter impact and between 160 and 200 G for the 2 meter impact. For both the 1 and 2 meter impacts, the abdominal penetration should be at least 4.1 cm which is the height of the rigid simulated armrest.

*Numbers in parentheses denote papers listed in References, Section 5.0.

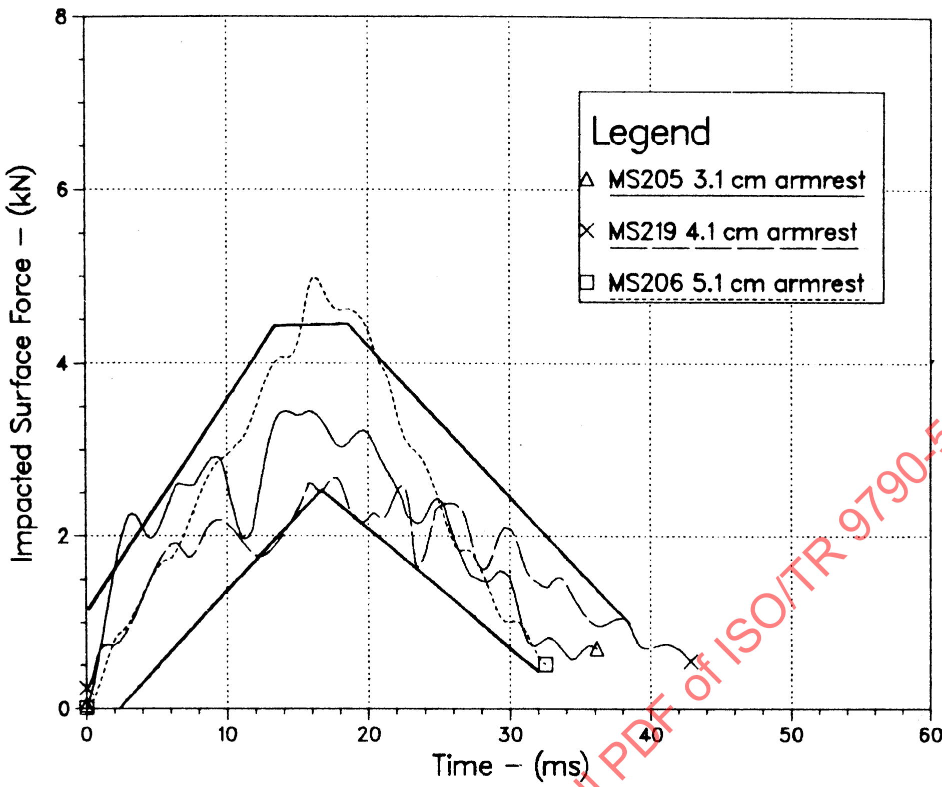

FIGURE 1. NORMALIZED LATERAL ABDOMINAL FORCE-TIME CURVES AND PROPOSED CORRIDOR FOR A 1 METER DROP ONTO A 4.1 CM RIGID ARMREST.

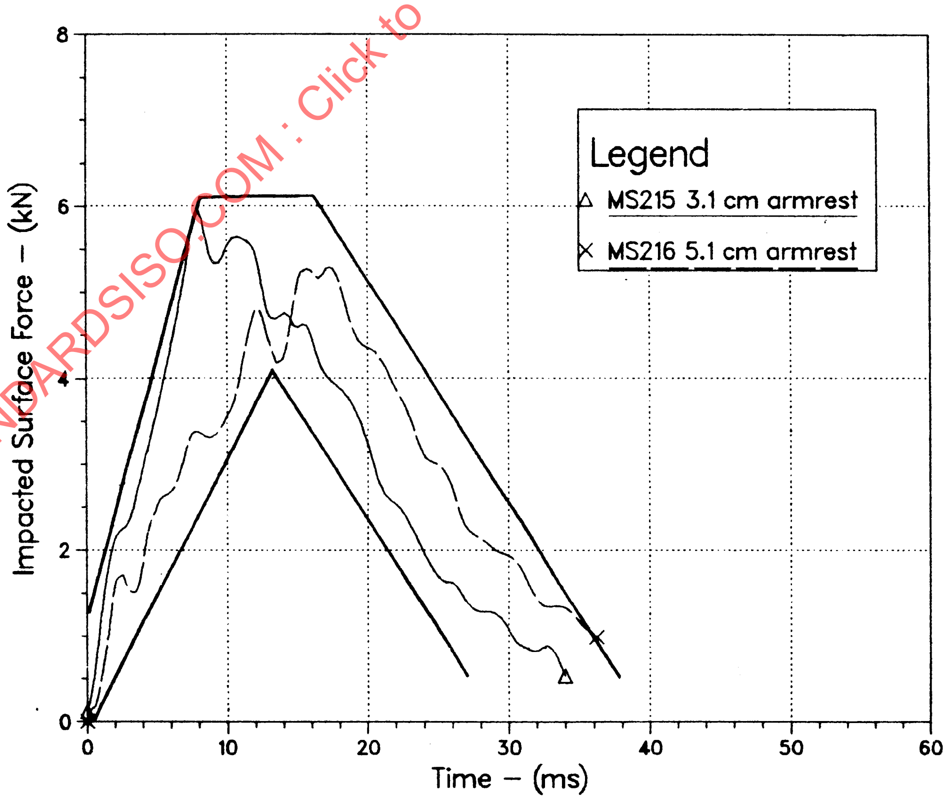

FIGURE 2. NORMALIZED LATERAL ABDOMINAL FORCE-TIME CURVES AND PROPOSED CORRIDOR FOR A 2 METER DROP ONTO A 4.1 CM RIGID ARMREST.

4.3 Test Setup

The simulated armrest is constructed of rigid hardwood. The armrest is 7 cm in width and of sufficient height to protrude 4.1 cm above the surrounding surface. The length must be sufficient to prevent the dummy from striking the ends. The top edges are rounded with a 1 cm radius. The dummy is to be suspended above the impact surface with its midsagittal plane horizontal and its abdominal region including the "area of the 9th rib" in line with the top surface of the simulated armrest. A quick-release mechanism is to be used to drop the dummy the prescribed distance (1 or 2 meters).

4.4 Instrumentation

The dummy should be instrumented to monitor the acceleration of the spine at the level of the 12th thoracic vertebral body and the acceleration of the impacted side rib at the level of the 9th rib. The simulated armrest is to be mounted on a load cell. Load and acceleration measurements are to meet SAE Channel Class 180 filter requirements. High speed camera coverage is required to determine abdominal penetration.

4.5 Normalization Procedure

Determine the impulse and change in velocity by integrating the force-time curve and the T12 acceleration-time curve, respectively. Calculate the effective mass from the following equation.

$$M_e = [\int_0^T F dt] / (Tg + \Delta V) \qquad (1$$

The mass ratio is calculated from the following equation,

$$R_m = 16.4 \text{ kg}/M_e \qquad (2$$

It is assumed that the lateral impact dummy has the same abdominal stiffness as the standard subject, and the stiffness ratio, R_k, is equal to 1.

The normalizing factors for force, time, and acceleration are given by,

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

$$R_t = (R_m)^{\frac{1}{2}} (R_k)^{-\frac{1}{2}} \quad (4$$

$$R_a = (R_k)^{\frac{1}{2}} (R_m)^{-\frac{1}{2}} \quad (5$$

Normalize the force-time curve by multiplying each force value by its normalizing factor and each time value by its normalizing value. Normalize the peak spinal acceleration and peak impacted side rib acceleration by multiplying the peak values by the acceleration normalizing factor. Compare the normalized responses to their respective requirements.

Abdominal penetration is defined as the vertical displacement of the thoracic spine relative to the armrest measured from the time of first contact of the abdominal surface with the armrest.

5.0 REFERENCES

1. Walfisch, G., Fayon, A., Tarriere, C., Rosey, J., Guillon, F., Got, C., Patel, A., and Stalnaker, R., "Designing of a Dummy's Abdomen for Detecting Injuries in Side Impact Collisions", Fifth International Conference on the Biomechanics of Impacts, September, 1980.

2. Bendjellal, F., Walfisch, G., Fayon, A., and Tarriere, C., "APR Biomechanical Data," Nanterre, France, Jan., 1984.

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

APPENDIX

ANALYSIS OF ASSOCIATION PEUGEOT - RENAULT LATERAL ABDOMINAL IMPACT DATA

This appendix describes the application of the normalization techniques of Mertz (3) to the lateral abdominal impact data provided by the Association Peugeot-Renault (2).

A.1 ORIGINAL DATA

Researchers of the Association Peugeot-Renault subjected eleven unembalmed cadavers to lateral free falls onto simulated armrests (1). The cadavers were perfused and accelerometers were attached to the 12th thoracic vertebral body and the 9th rib on the left and right sides. The cadavers were at room temperature during the test. The simulated armrest consisted of a rigid hardwood impact surface secured to a supporting material. The hardwood section was 7 cm wide and 2.5 cm thick, with rounded edges. The supporting material was either rigid hardwood, polystyrene, or phenespan. The thickness of the supporting material ranged from .6 cm to 3.0 cm. The armrest was secured to a piezoelectric load cell. Initially, the cadavers were suspended 1 or 2 meters above the top surface of the armrest, as shown in Figure 1. The cadavers were positioned such that their right sides would impact the armrest at the level of their 9th ribs ensuring involvement of their livers. Their right arms were raised so as not to impact the armrest. Following each test, the cadaver was autopsied for rib fractures and injuries to the liver.

Table 1 provides a summary of the weights of the cadavers and their abdominal widths measured at the level of the 9th rib. Also given are the total armrest height and type of supporting material used for each test. The force-time plots for the load applied to the cadavers' abdomens by the simulated armrest are shown in Figures 2 through 5. The acceleration-time plots for the spine at the level of T12 are

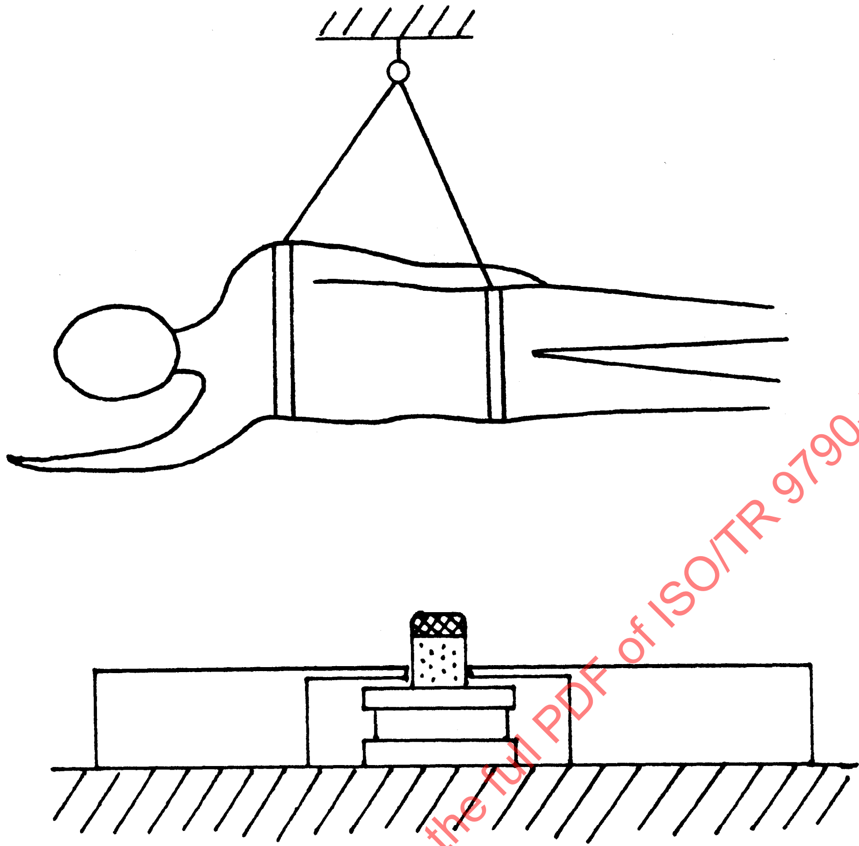

FIGURE 1. LATERAL ABDOMINAL IMPACT TEST CONFIGURATION.

Table 1 - Cadaver Characteristics and Test Conditions for the Lateral Abdominal Impact Tests Performed by the Association Peugeot-Renault (2) and Normalization Factors for the Abdominal Force-Time Data.

Cadaver Data			Test Conditions			Test Results		Effective Mass		Characteristic Ratios			Normalizing Factors	
Test No.	Body Mass (kg)	Abdominal Depth (cm)	Drop Height (m)	Supporting Material	Armrest Height (cm)	Impulse Ns	Change in Velocity (m/s)	M_e (kg)	Percent of Body Mass (%)	Mass R_m	Stiffness R_x	Time R_t	Force R_f	Acceleration R_a
205	32	13.5	1	hardwood	3.1	29.9	4.7	6.36	19.9	2.58	1.85	1.18	2.18	.85
219	52	18.5	1	hardwood	4.1	52.3	4.4	11.89	22.9	1.38	1.35	1.01	1.36	.99
206	82	24	1	hardwood	5.1	107.4	5.1	21.02	25.6	.78	1.04	.87	.90	1.15
215	53	20.5	2	hardwood	3.1	98.9	6.4	15.55	29.3	1.05	1.22	.93	1.13	1.08
216	49	20.7	2	hardwood	5.1	77.6	6.6	11.82	24.1	1.39	1.21	1.07	1.30	.93
210	71	26.3	1	polystyrene	5.1	77.2	5.0	15.56	21.9	1.05	.95	1.05	1.00	.95
211	43	18.5	1	phenespan	5.3	52.3	6.3	8.30	19.3	1.98	1.35	1.21	1.63	.83
212	45	21	1	polystyrene	5.5	41.4	5.4	7.70	17.1	2.13	1.19	1.34	1.59	.75
213	77	24.5	2	polystyrene	5.5	91.3	8.5	10.75	14.0	1.53	1.02	1.22	1.25	.82

Note: Average Percent Body Mass = 21.6%

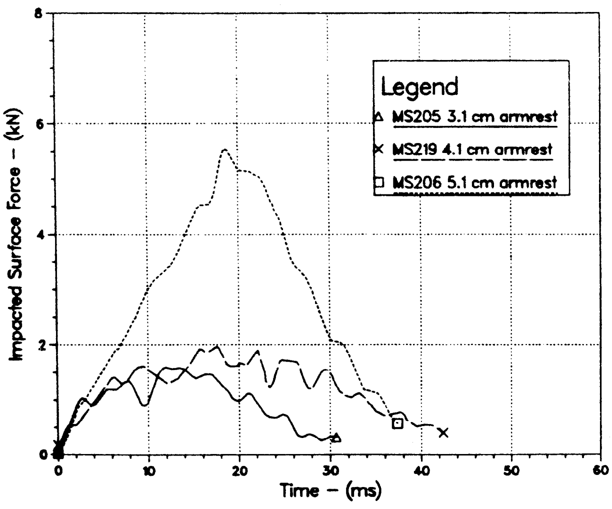

FIGURE 2. LATERAL ABDOMINAL FORCE-TIME CURVES FOR CADAVERS SUBJECTED TO 1 METER DROPS ONTO RIGID IMPACT SURFACES (2).

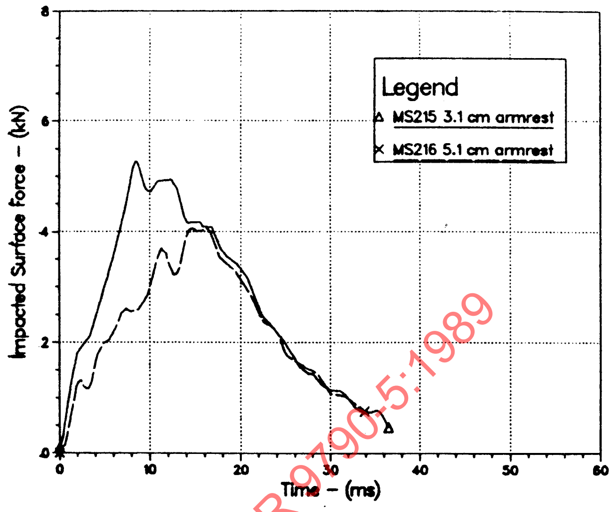

FIGURE 3. LATERAL ABDOMINAL FORCE-TIME CURVES FOR CADAVERS SUBJECTED TO 2 METER DROPS ONTO RIGID IMPACT SURFACES (2).

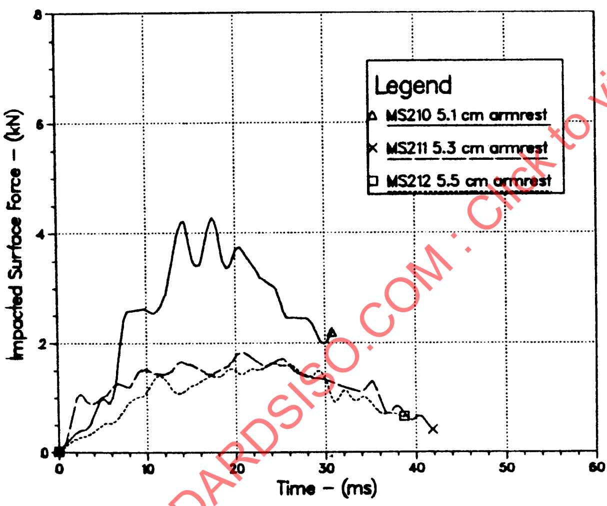

FIGURE 4. LATERAL ABDOMINAL FORCE-TIME CURVES FOR CADAVERS SUBJECTED TO 1 METER DROPS ONTO CRUSHABLE IMPACT SURFACES (2).

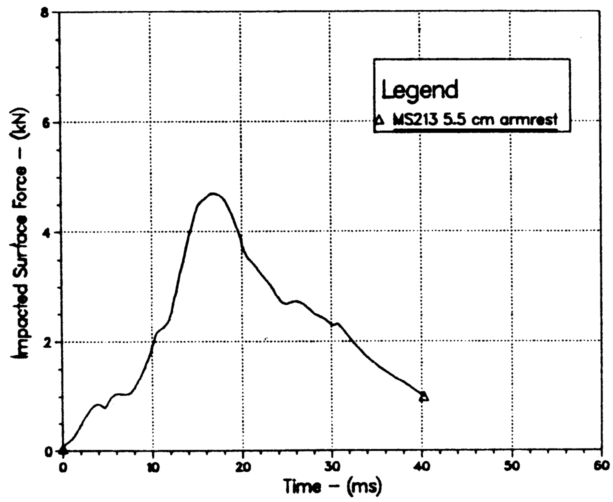

FIGURE 5. LATERAL ABDOMINAL FORCE-TIME CURVE FOR A CADAVER SUBJECTED TO A 2 METER DROP ONTO A CRUSHABLE IMPACT SURFACE (2).

shown in Figures 6 through 9. The acceleration-time plots for the 9th rib on the impacted side are shown in Figures 10 through 13. Note that complete data necessary for the calculation of normalizing factors were available for only 9 of the 11 cadavers that were tested. The acceleration plots for the 9th rib were available for eight of these cadavers.

A.2 NORMALIZED DATA

The force-time curve of the armrest load and the lateral acceleration-time curve of the 12th thoracic vertebral body were digitized for nine subjects. (Plots for the remaining two subjects were not available.) The eight available lateral acceleration-time curves for the near side 9th rib were also digitized. The characteristic features of each curve were represented by 50 to 100 points.

The effective mass, as defined by Mertz (3), was calculated by,

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

where $\int Fdt$ is the area under the force-time plot, T is the pulse duration, g is the acceleration of gravity and ΔV is the change in velocity during the impact which was obtained by integrating the lateral spine acceleration-time plot. The areas under the curves were calculated using the trapezoidal method of integration and the results are given in Table 1 under the headings of Impulse and Change in Velocity. The effective mass and percent of body mass for each cadaver are also given in Table 1. The average percent of body mass was 21.6%.

The effective mass of a 50th percentile adult male was obtained by multiplying its body mass of 76 kg by 21.6% giving an effective mass of 16.4 kg.

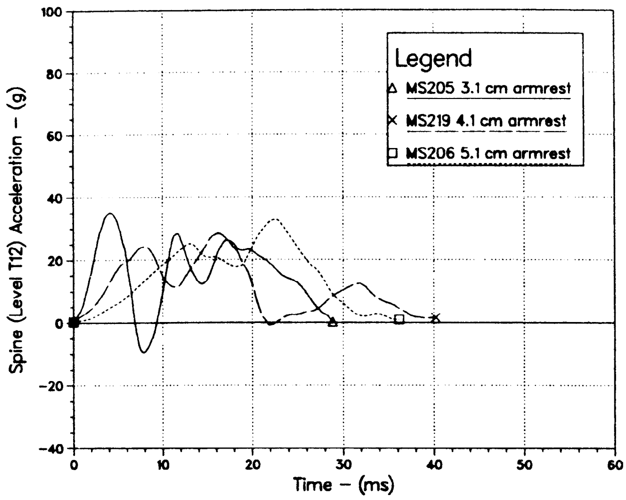

FIGURE 6. LATERAL SPINAL (LEVEL T12) ACCELERATION-TIME CURVES FOR CADAVERS SUBJECTED TO 1 METER DROPS ONTO RIGID IMPACT SURFACES (2).

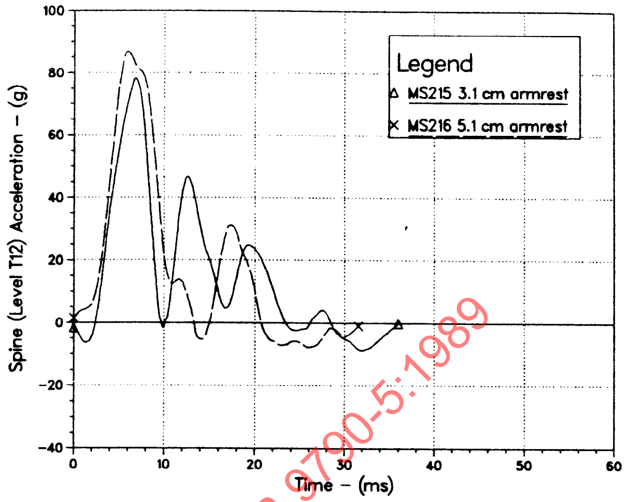

FIGURE 7. LATERAL SPINAL (LEVEL T12) ACCELERATION-TIME CURVES FOR CADAVERS SUBJECTED TO 2 METER DROPS ONTO RIGID IMPACT SURFACES (2).

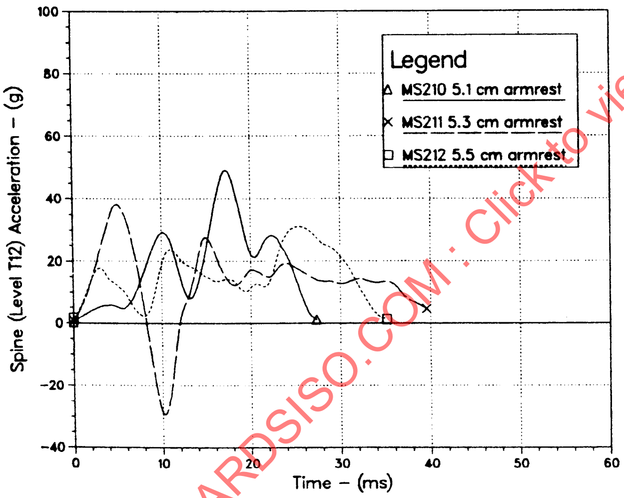

FIGURE 8. LATERAL SPINAL (LEVEL T12) ACCELERATION-TIME CURVES FOR CADAVERS SUBJECTED TO 1 METER DROPS ONTO CRUSHABLE IMPACT SURFACES (2).

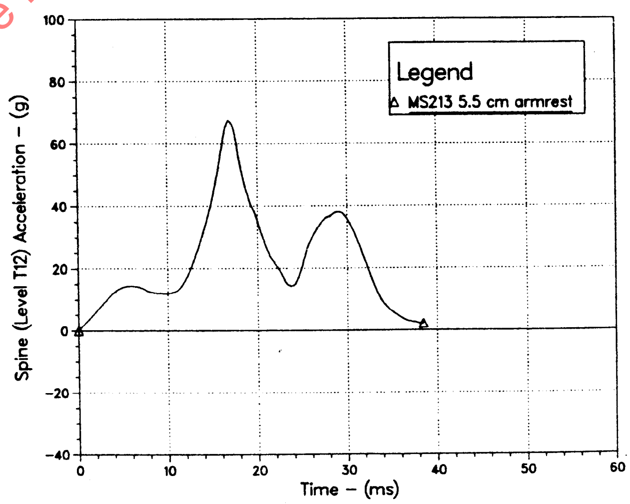

FIGURE 9. LATERAL SPINAL (LEVEL T12) ACCELERATION-TIME CURVES FOR A CADAVER SUBJECTED TO A 2 METER DROP ONTO A CRUSHABLE IMPACT SURFACES (2).

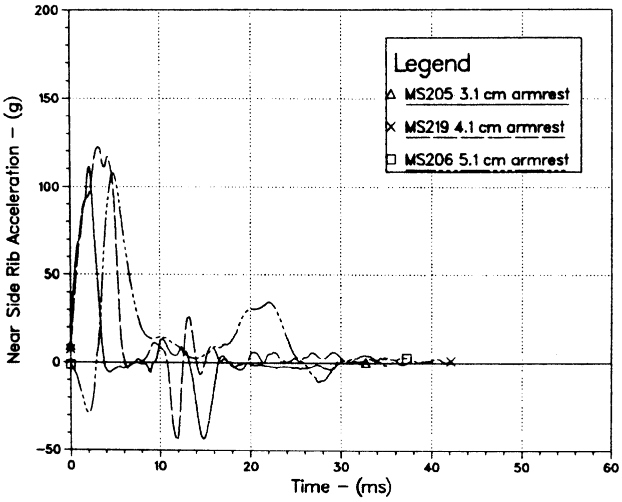

FIGURE 10. LATERAL NEAR SIDE RIB ACCELERATION-TIME CURVES FOR CADAVERS SUBJECTED TO 1 METER DROPS ONTO RIGID IMPACT SURFACES (2).

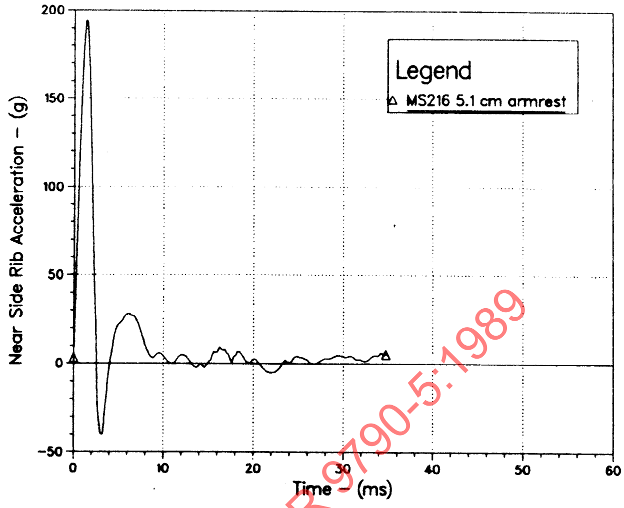

FIGURE 11. LATERAL NEAR SIDE RIB ACCELERATION-TIME CURVE FOR A CADAVER SUBJECTED TO A 2 METER DROP ONTO A RIGID IMPACT SURFACE (2).

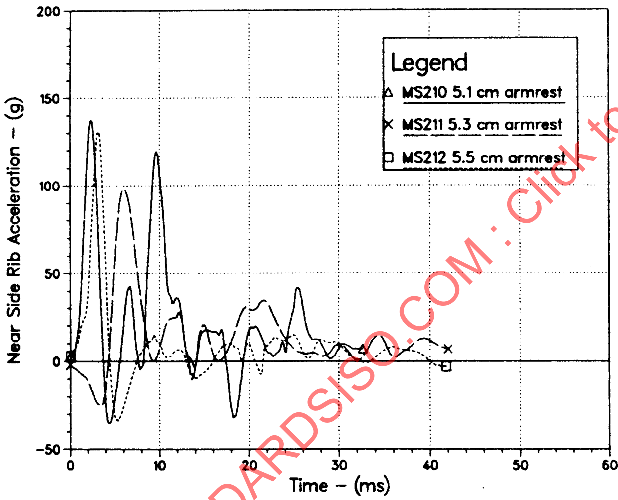

FIGURE 12. LATERAL NEAR SIDE RIB ACCELERATION-TIME CURVES FOR CADAVERS SUBJECTED TO 1 METER DROPS ONTO CRUSHABLE IMPACT SURFACES (2).

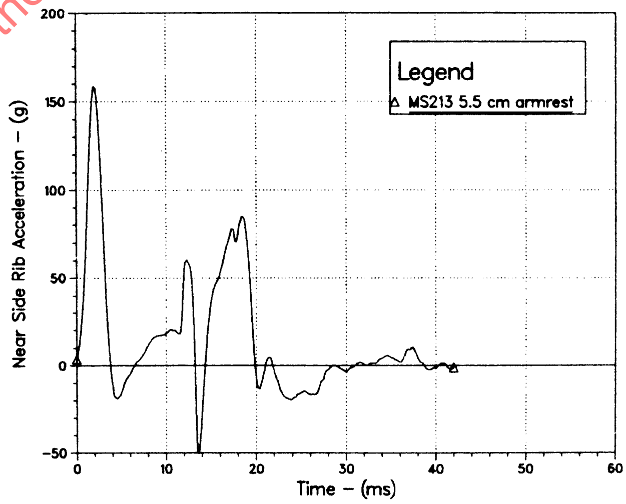

FIGURE 13. LATERAL NEAR SIDE RIB ACCELERATION-TIME CURVES FOR A CADAVER SUBJECTED TO A 2 METER DROP ONTO A CRUSHABLE IMPACT SURFACE (2).

The mass ratio, R_m, is defined as,

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

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,

$$R_m = 16.4 \text{ kg}/M_e \quad (3$$

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 (3) has shown that for geometrically similar structures with the same elastic modulus the stiffness is proportional to a characteristic length. This implies that the stiffness ratio can be expressed in terms of characteristic lengths, or,

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

The characteristic length for the abdomen was chosen as the abdominal depth at the level of the 9th rib. This measurement, for each test subject, is listed in Table 1. The abdominal depth of a 50th percentile adult male was not available. A linear relationship was assumed between the body mass and the abdominal depth for the cadaver subjects. The computed relationship, with a sample correlation of .84, is given by,

$$L = 9.8 + .20 \text{ M} \quad (6$$

where L is abdominal depth and M is the total body mass. For a 76 kg, 50th percentile adult male, the calculated depth is 25 cm. This value is used as the characteristic length L_s in Equation 5, or,

$$R_k = 25\ \text{cm}/L_i \qquad (7$$

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

The normalizing factors for time, force, and acceleration are defined by Mertz (3) as,

$$R_t = (R_m)^{\frac{1}{2}}(R_k)^{-\frac{1}{2}} \qquad (8$$

$$R_f = (R_m R_k)^{\frac{1}{2}} \qquad (9$$

and

$$R_a = (R_k)^{\frac{1}{2}}\ (R_m)^{-\frac{1}{2}} \qquad (10$$

The time, force, and acceleration normalizing factors for each cadaver impact are listed in Table 1. These factors were used to normalize the force-time curves shown in Figures 2 through 5 and the acceleration-time curves shown in Figures 6 through 13. For a given impact, the normalized force-time curve was obtained by multiplying each force value by its force normalizing factor and each time value by its time normalizing factor. The normalized acceleration-time curves were obtained by multiplying each acceleration value by its acceleration normalizing factor and each time value by its time normalizing factor. The resulting normalized force-time curves are shown in Figures 14 through 17. The resulting normalized acceleration-time curves for the spine at the level of T12 are shown in Figures 18 through 21. The resulting normalized acceleration-time curves for the 9th rib on the impacted side are shown in Figures 22 through 25.

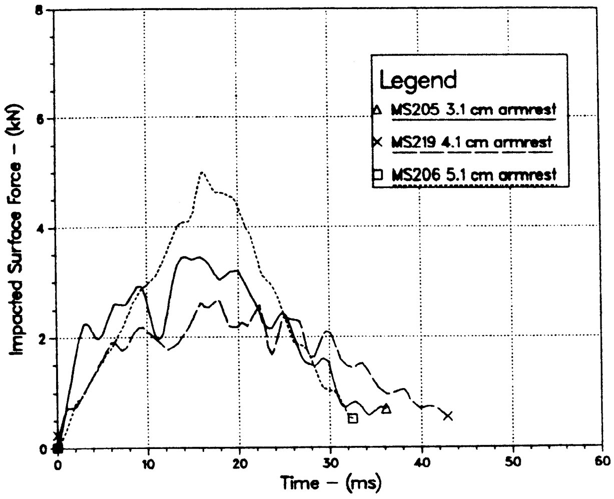

FIGURE 14. NORMALIZED LATERAL ADBOMINAL FORCE-TIME CURVES FOR CADAVERS SUBJECTED TO 1 METER DROPS ONTO RIGID IMPACT SURFACES.

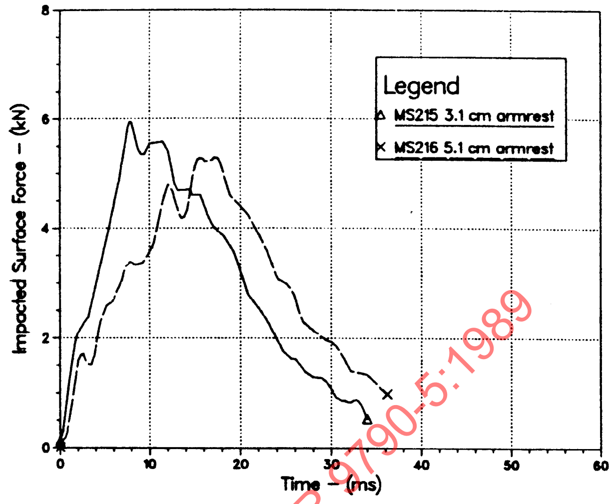

FIGURE 15. NORMALIZED LATERAL ABDOMINAL FORCE-TIME CURVES FOR CADAVERS SUBJECTED TO 2 METER DROPS ONTO RIGID IMPACT SURFACES.

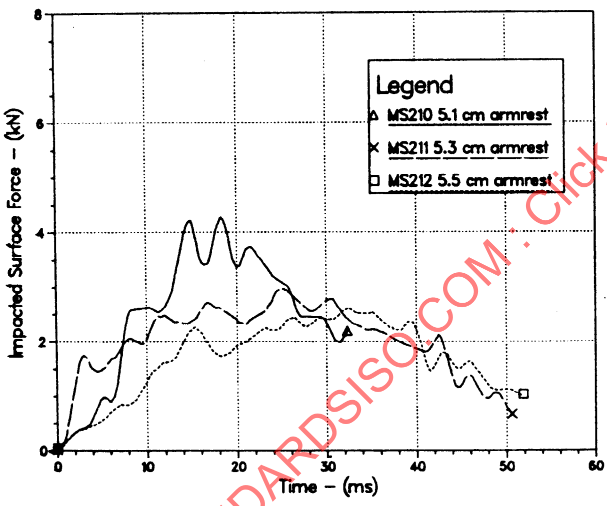

FIGURE 16. NORMALIZED LATERAL ABDOMINAL FORCE-TIME CURVES FOR CADAVERS SUBJECTED TO 1 METER DROPS ONTO CRUSHABLE IMPACT SURFACES.

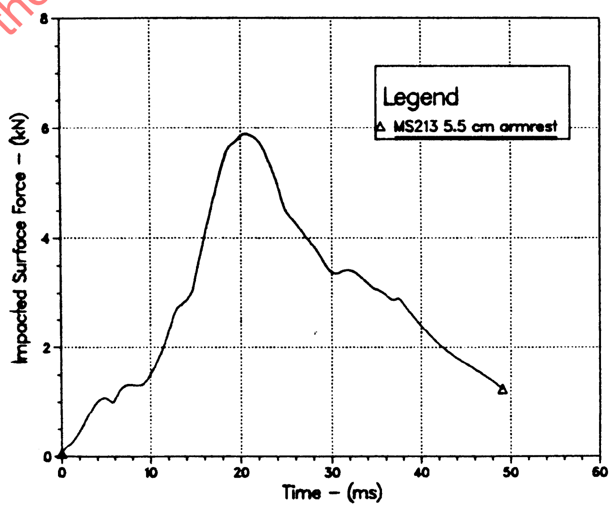

FIGURE 17. NORMALIZED LATERAL ABDOMINAL FORCE-TIME CURVE FOR A CADAVER SUBJECTED TO A 2 METER DROP ONTO A CRUSHABLE IMPACT SURFACE.

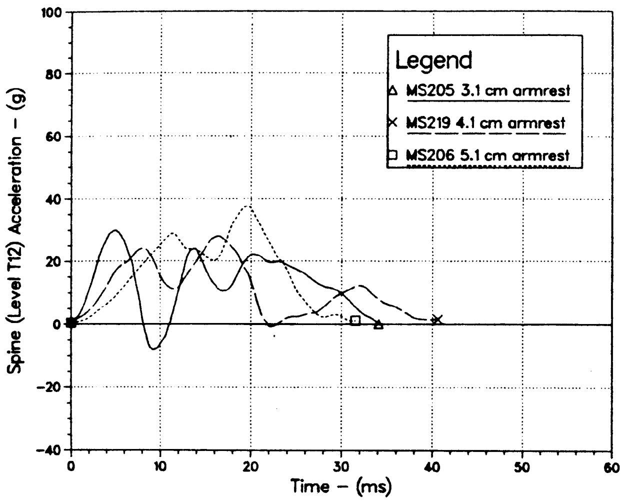

FIGURE 18. NORMALIZED LATERAL SPINAL (LEVEL T12) ACCELERATION-TIME CURVES FOR CADAVERS SUBJECTED TO 1 METER DROPS ONTO RIGID IMPACT SURFACES.

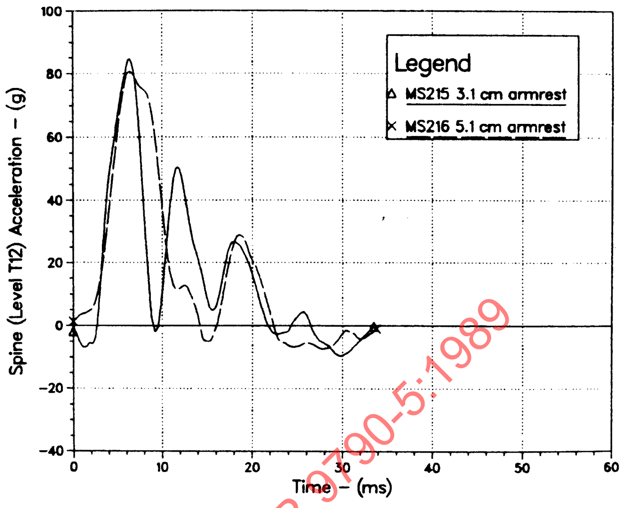

FIGURE 19. NORMALIZED LATERAL SPINAL (LEVEL T12) ACCELERATION-TIME CURVES FOR CADAVERS SUBJECTED TO 2 METER DROPS ONTO RIGID IMPACT SURFACES.

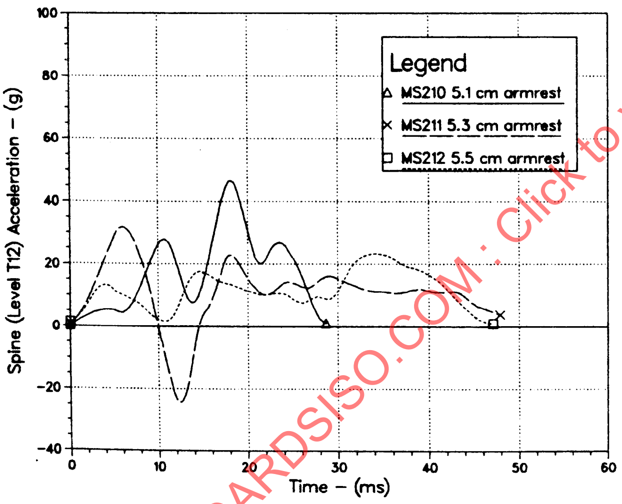

FIGURE 20. NORMALIZED LATERAL SPINAL (LEVEL T12) ACCELERATION-TIME CURVES FOR CADAVERS SUBJECTED TO 1 METER DROPS ONTO CRUSHABLE IMPACT SURFACES.

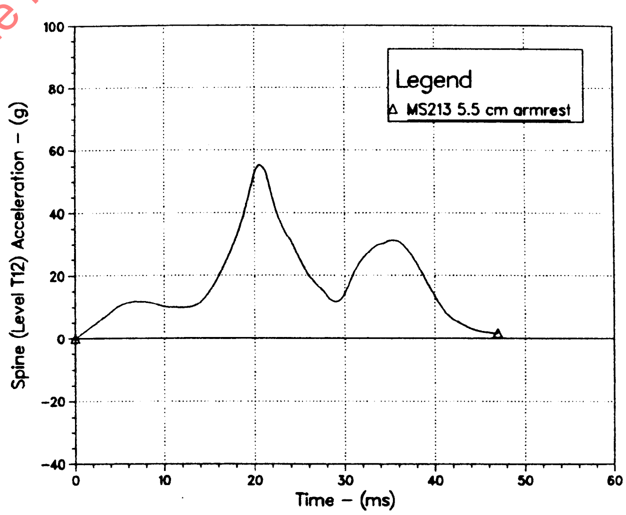

FIGURE 21. NORMALIZED LATERAL SPINAL (LEVEL T12) ACCELERATION-TIME CURVES FOR A CADAVER SUBJECTED TO A 2 METER DROP ONTO A CRUSHABLE IMPACT SURFACE.

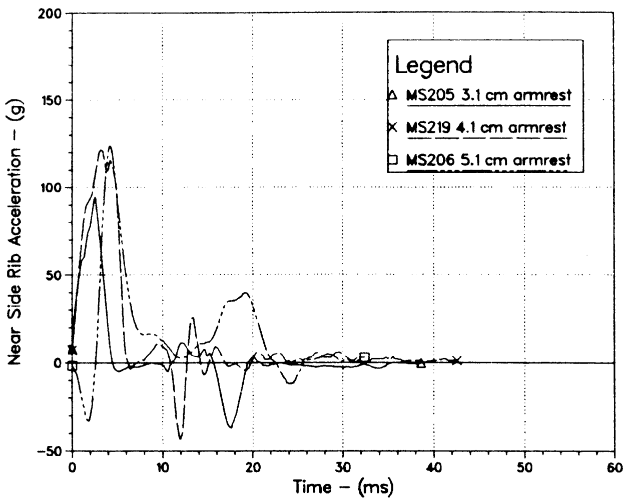

FIGURE 22. NORMALIZED LATERAL NEAR SIDE RIB ACCELERATION-TIME CURVES FOR CADAVERS SUBJECTED TO 1 METER DROPS ONTO RIGID IMPACT SURFACES.

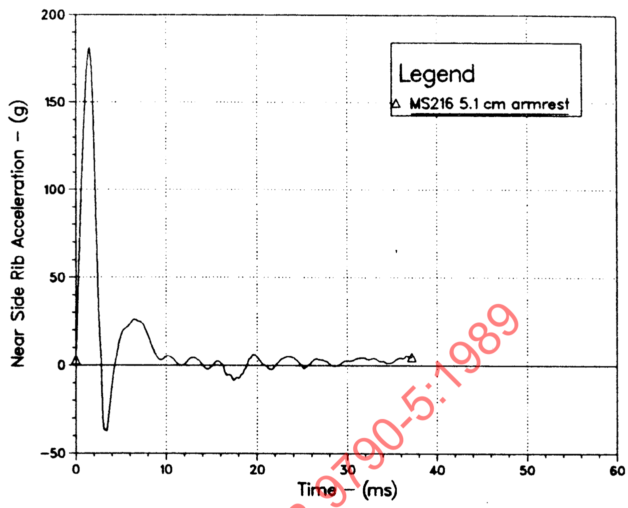

FIGURE 23. NORMALIZED LATERAL NEAR SIDE RIB ACCELERATION-TIME CURVE FOR A CADAVER SUBJECTED TO A 2 METER DROP ONTO A RIGID IMPACT SURFACE.

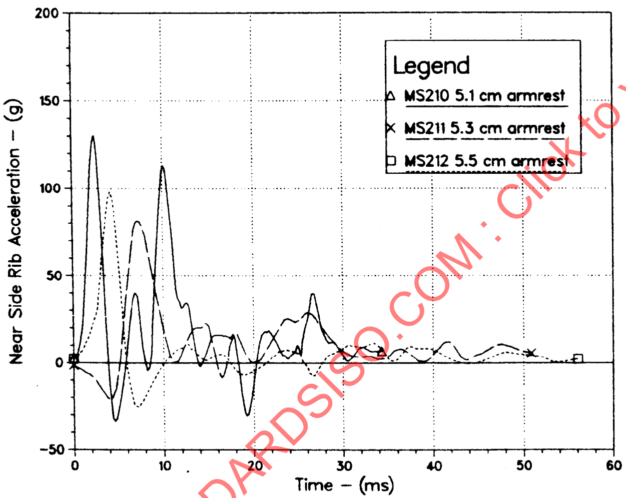

FIGURE 24. NORMALIZED LATERAL NEAR SIDE RIB ACCELERATION-TIME CURVES FOR CADAVERS SUBJECTED TO A 1 METER DROP ONTO CRUSHABLE SURFACES.

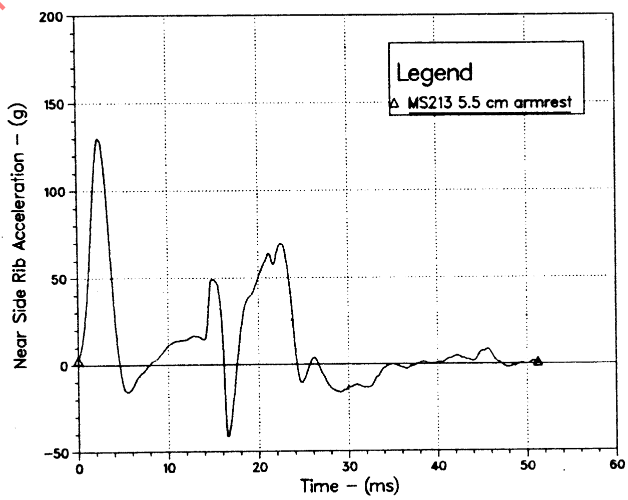

FIGURE 25. NORMALIZED LATERAL NEAR SIDE RIB ACCELERATION-TIME CURVE FOR A CADAVER SUBJECTED TO A 2 METER DROP ONTO A CRUSHABLE IMPACT SURFACE.