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15. Supplementary Notes

Evaluation of Vest Restraint System (VRS). Phase I. Interim Report. November 30, 1982. Richard G. Snyder and John W. Melvin

16. Abstract

Seven tests of the Bureau of Mines proposed vest restraint system were conducted at UMTRI as the phase II or development program. The factors that were found to provide good performance of the vest restraint were the elimination of sliding motion between belt webbing in the vest, common slots in the anchor hardware for the two tether belts on each side, and anchors positioned rearward to provide a 45-degree tether angle. It was recommended that the vest restraints be sized to the torso height of the wearer to preclude abdominal intrusion by the lap belt segment and that upper torso restraint be added to protect against frontal impact, significantly reducing head excursions and associated injuries.

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Restraint System Vest restraint Driver protection Off-highway trucks Dynamic tests	

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified		105	

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CONTENTS

I. INTRODUCTION

Phase I of this program consisted of a limited literature review of harness restraint systems, an overview of heavy equipment accidents, a multidisciplinary evaluation of the heavy equipment operator's environment, a review of potential functional problems with the proposed vest restraint system, and one sled impact test of a vest restraint. The vest restraint approach was seen as a viable method of increasing restraint usage by heavy equipment operators, but vest failure during the impact test indicated further development was needed.

Phase II, the subject of this report, consisted of dynamic sled impact testing at UMTRI to assist in evaluating subsequent upgraded versions of the vest restraint. In all, seven impact tests were conducted using both a rigid forklift seat and a suspension seat. The results of this testing are presented in Section V.

II. TEST METHODS

All tests were conducted on the UMTRI impact sled. The sled operates on the rebound principle, achieving a desired velocity by reversing its direction of motion during the impact event. The sled crash pulse is trapezoidal in shape and it is reported as a total velocity change and an average deceleration level in g's. The sled velocity is monitored immediately before and after the impact.

GSE seat belt load cells were placed on the harness belt webbing to measure the restraint forces. One triaxial accelerometer was mounted in the head and one in the chest of the test dummy to record the severity of the head and chest motion during the impact. The data generated during the test were multiplexed using an EMR Signal Conditioner and recorded on a Honeywell Model 96 magnetic tape recorder. The signals were subsequently de-multiplexed and time-expanded for digitizing, filtering, and analysis on a NOVA/4 computer. All test signals were filtered to the requirements of SAE J-211.

The photoinstrumentation consisted of two high-speed (1000 frame/sec) 16mm motion picture cameras (Photosonics 1B) for side and overhead views and a quick-look sequenced Polaroid Graphcheck camera. The transducer data and the motion picture test films were simultaneously marked by a timing pulse generator at 10 millisecond intervals. A strobe flash recorded the onset of impact.

III. DISCUSSION

In phase 1 of this project, a prototype version of the vest restraint system was evaluated using the UMTRI impact sled. In that test, 82M001, both the stitching and vest fabric failed, and the dummy was not restrained. The harness was effectively elongated by the stitching failure, allowing the dummy to submarine and slide well off the forward end of both the seat and seating platform. The remaining harness belts were pulled up into the dummy's ribcage, in a manner that would indicate severe abdominal intrusion.

A vest restraint with improved stitching was then provided and evaluated in 82M002, the first test of this program's second phase. During impact, the left side tether strap "D"-ring weld failed, and the "D"-ring pulled open and released the tether belts. The dummy was not restrained and impacted against the front of the sled.

To reduce fabrication time for revised vest restraints, the next three tests were conducted using only the belt webbing portion and eliminating the vest fabric. In test 82M003, this bare harness was anchored to the test platform using conventional seat belt hardware for attaching the tether belt ends. Both the front and rear tethers on each side were routed through the same belt anchor. This configuration withstood the impact forces and restrained the dummy on the seat, although the dummy's forward excursion was excessive and almost allowed the dummy to ride over the front edge of the seat. Although abdominal intrusion was not indicated, the lap belt portion of the harness could still be slightly lower to obtain good pelvic retention and preclude submarining.

The next test, 82M004, used a similar belt harness as the previous test, but a suspension-type seat was substituted for the rigid forklift seat. Locking-loop tether end clips were used to facilitate attachment to the eyelets supplied on the seat frame. During impact, the right side eyelet pulled out of the seat frame because of insufficient thread engagement with its retaining nut, and the dummy was not restrained.

Test 82M005 was then conducted as a rerun of the conditions of the previous test, but with the tether eyelets securely installed in the seat frame. During impact, the harness did not fail, but the suspension seat pitched forward and the dummy slid off the forward edge. As in previous tests when the dummy ramped off of the seat, very severe abdominal intrusion by the harness was observed, and this condition is quite obvious in the post-test photos.

Test 82M006 was conducted to evaluate a revised vest restraint system with new tether anchors and revised belt routing and securement in the harness. A flat-plate tether anchor with separate feed-through slots for the front and rear tether was used on each side. However, it provided too large an angle between the front and rear sets of slots, and it proved very difficult to adjust. The belts of the harness had been stitched together at all intersections to prevent any available belt slack from being pulled into the tether straps and increasing the dummy's excursion. During impact, the belt slots in the tether anchor distorted badly and cut the belt on the left side, releasing the dummy. A similar belt-cutting failure had also been initiated at the right side anchor plate.

An identical vest restraint was evaluated in 82M007, with heavier gauge tether anchor plates. In addition, the anchor points for the tethers were moved rearward on the seating platform to provide a more rearward initial pull, approximately a 45 degree angle for the front tethers. Although the tether anchor plate still deformed at the belt loops and began to abrade the tether webbing, the vest system provided good restraint for the dummy. The elimination of belt slippage within the harness worked well, and the tether belts did not pull slack from the harness, reducing the dummy excursion as intended. The high HIC value of 1380 resulted from the dummy head striking the lower legs during maximum excursion and demonstrates the desirability of providing upper torso restraint.

The last test, 83M001, was a repetition of the previous configuration vest restraint and anchoring, but using improved feed-through tether anchor plates to replace the seat belt anchors that had been improvised for the last test. However, during the impact, the stitching tore at several junctions in the harness, and the vest fabric was also torn as the belt webbing shifted. Subsequently, it was reported that an incorrect thread had been used in the harness fabrication. Further testing was discontinued at this point at the request of the sponsor.

IV. RECOMMENDATIONS

Based on the test program to date, the following recommendations are made:

* The vest harness should be based on the most recent design tested that restricts relative motion of the belts and has a common attachment for the tether belts on each side.

* The tether belt anchor points should be selected to provide the most forward tether straps with an angle of approximately 45 degrees to horizontal to minimize forward excursion.

* The vest restraint should be sized to the torso height of the wearer to prevent abdominal intrusion by the lap-belt portion of the harness during an impact.

* Upper torso restraint to protect against frontal impact would significantly reduce operator head excursion and exposure to injury and should be seriously considered as a future upgrade to the vest restraint system.

V. RESULTS

The impact tests being reported are as follows:

For each sled impact test, information is presented in the following sequence:

* Test Summary Sheet
* Test Setup Photos
* Graphcheck Time Sequence Photo
* Post-Test Photos
* Data Plots

TEST SUMMARY

TEST NUMBER: 82M002

IMPACT VELOCITY: 20.5 mph

DECELERATION: 27.0 g

TEST RESULTS:

PEAK HEAD ACCELERATIONS

P-A: 30.0 g

R-L: 8.9 g

I-S: 90.3 g

PEAK RESULTANT: 92.0 g

HIC: 1028

PEAK CHEST ACCELERATIONS

P-A: 22.3 g

R-L: 11.7 g

I-S: 30.7 g

PEAK RESULTANT: 39.2 g

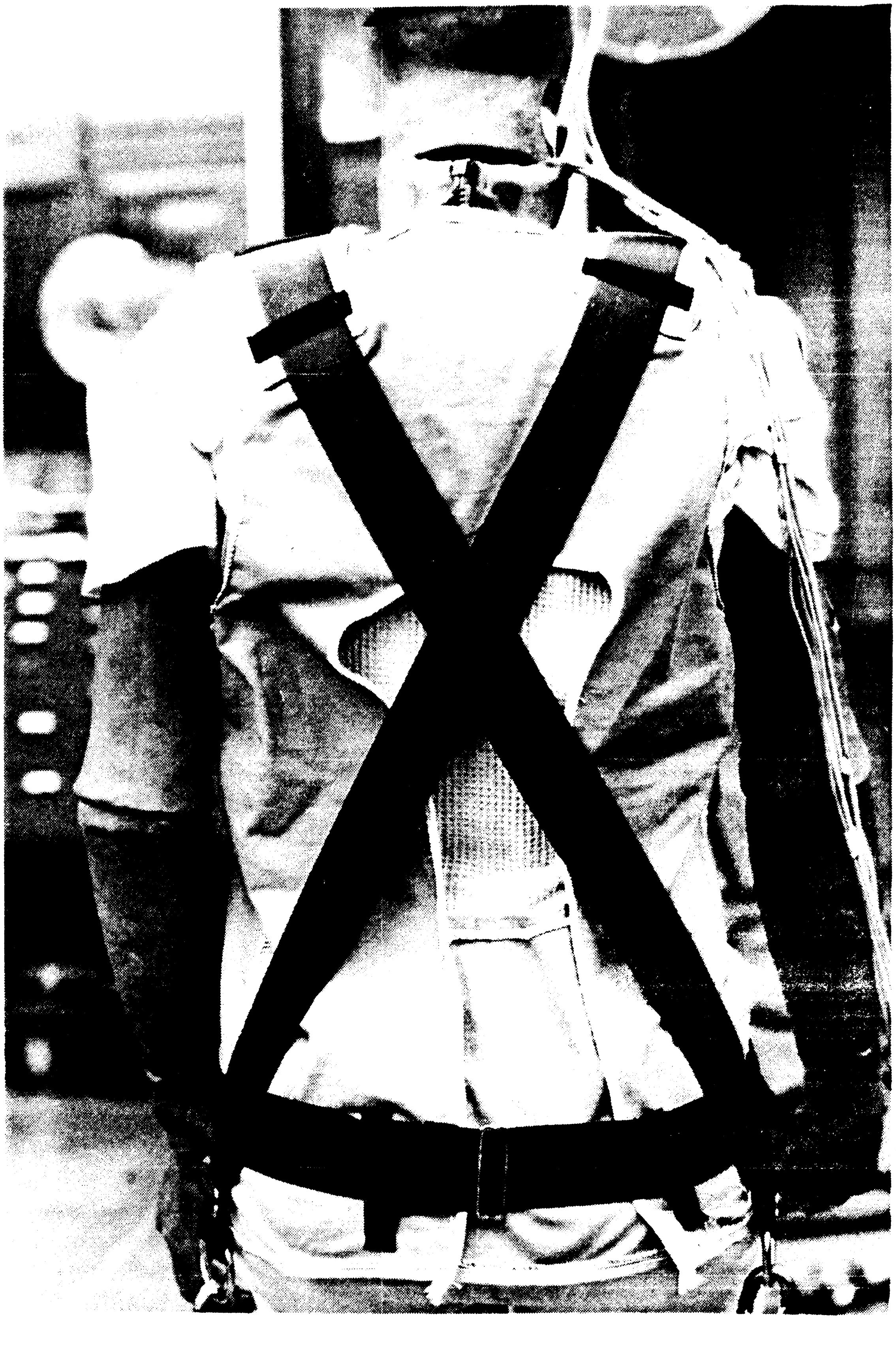
BELT LOADS

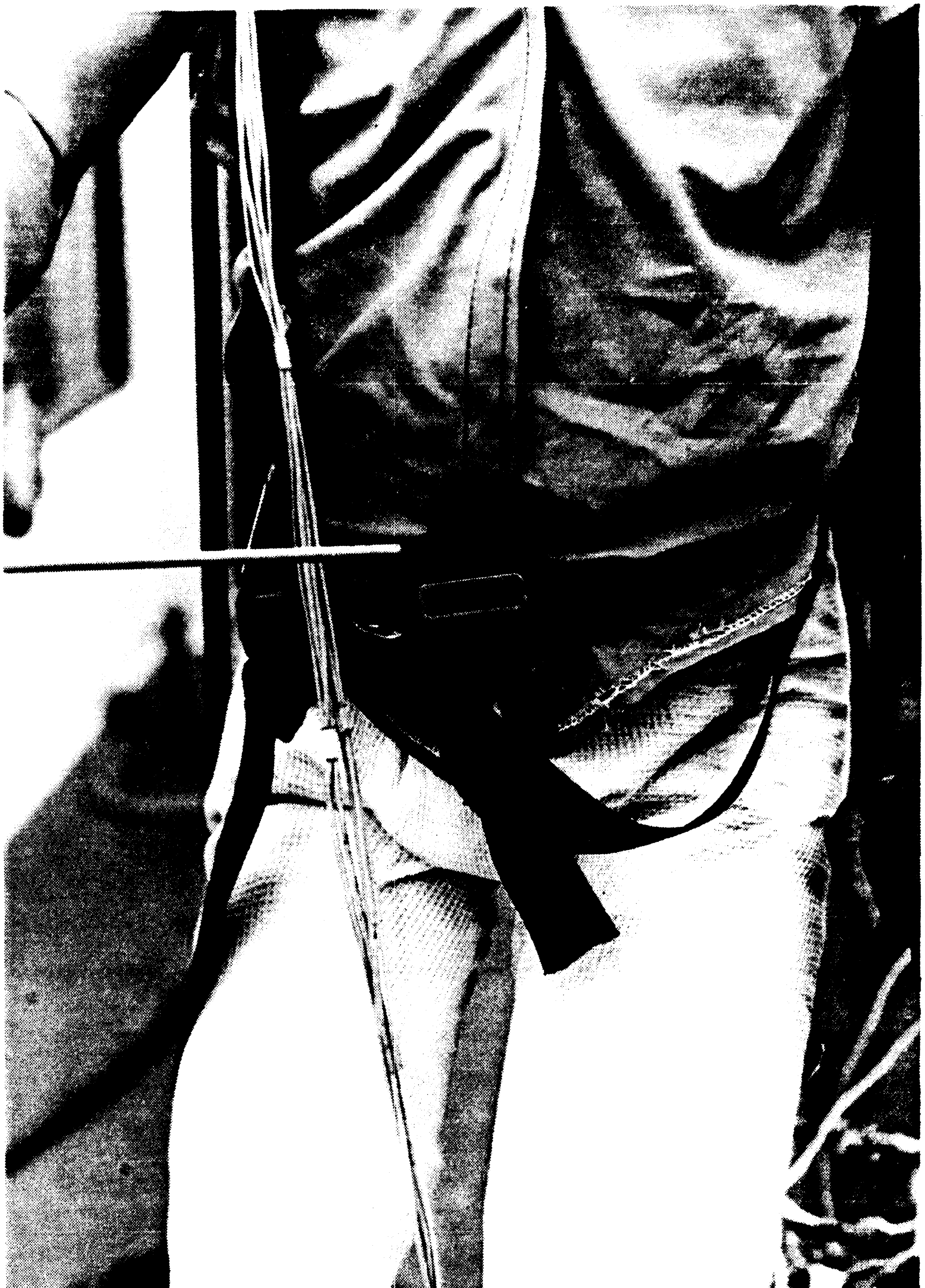
RIGHT SHOULDER STRAP: 459 lbs

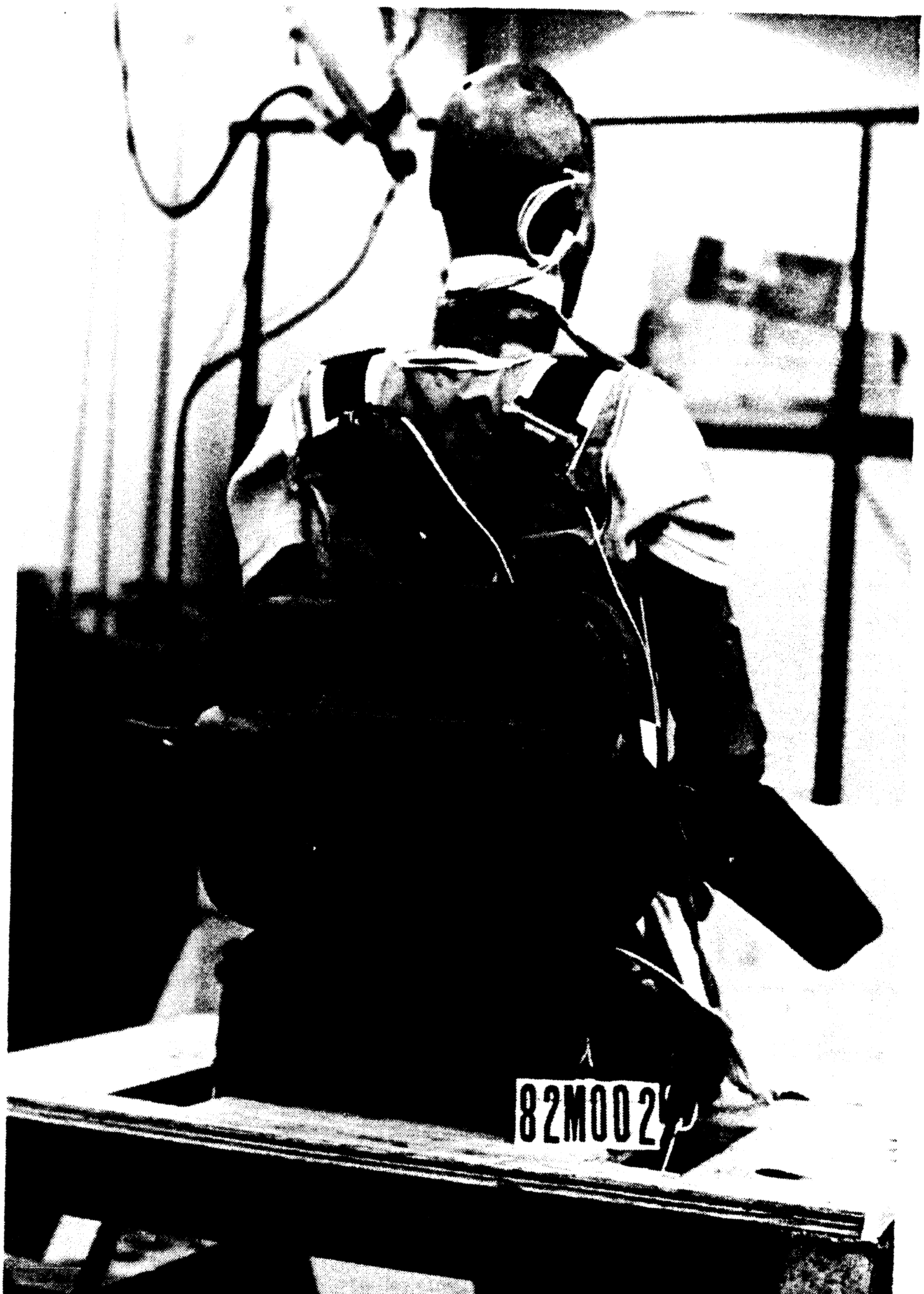
LEFT SHOULDER STRAP: 102 lbs

OBSERVATIONS: Left side tether "D"-ring failed, releasing dummy during impact.


82M002
82M002



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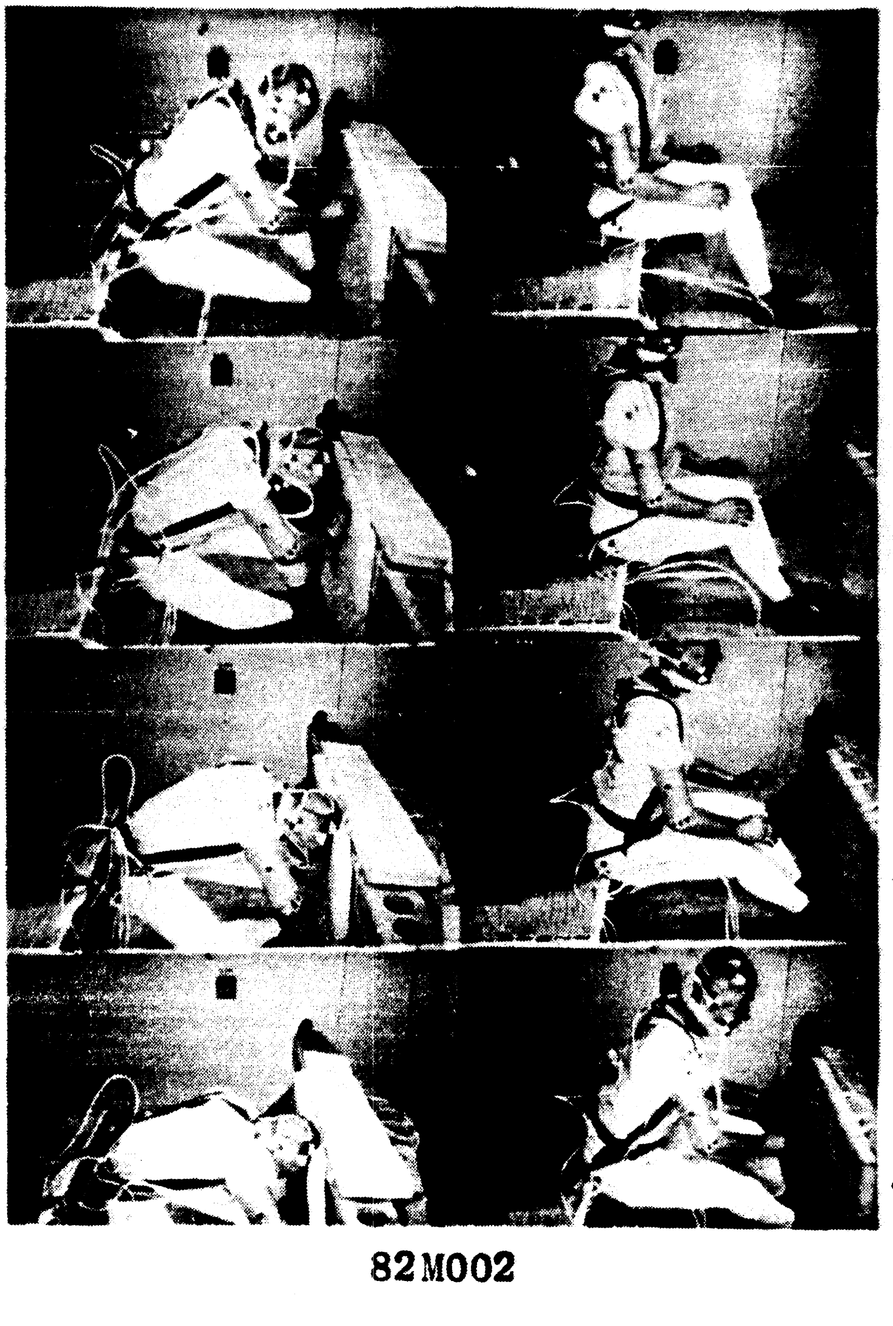
R2M002



82M002


82MC02A

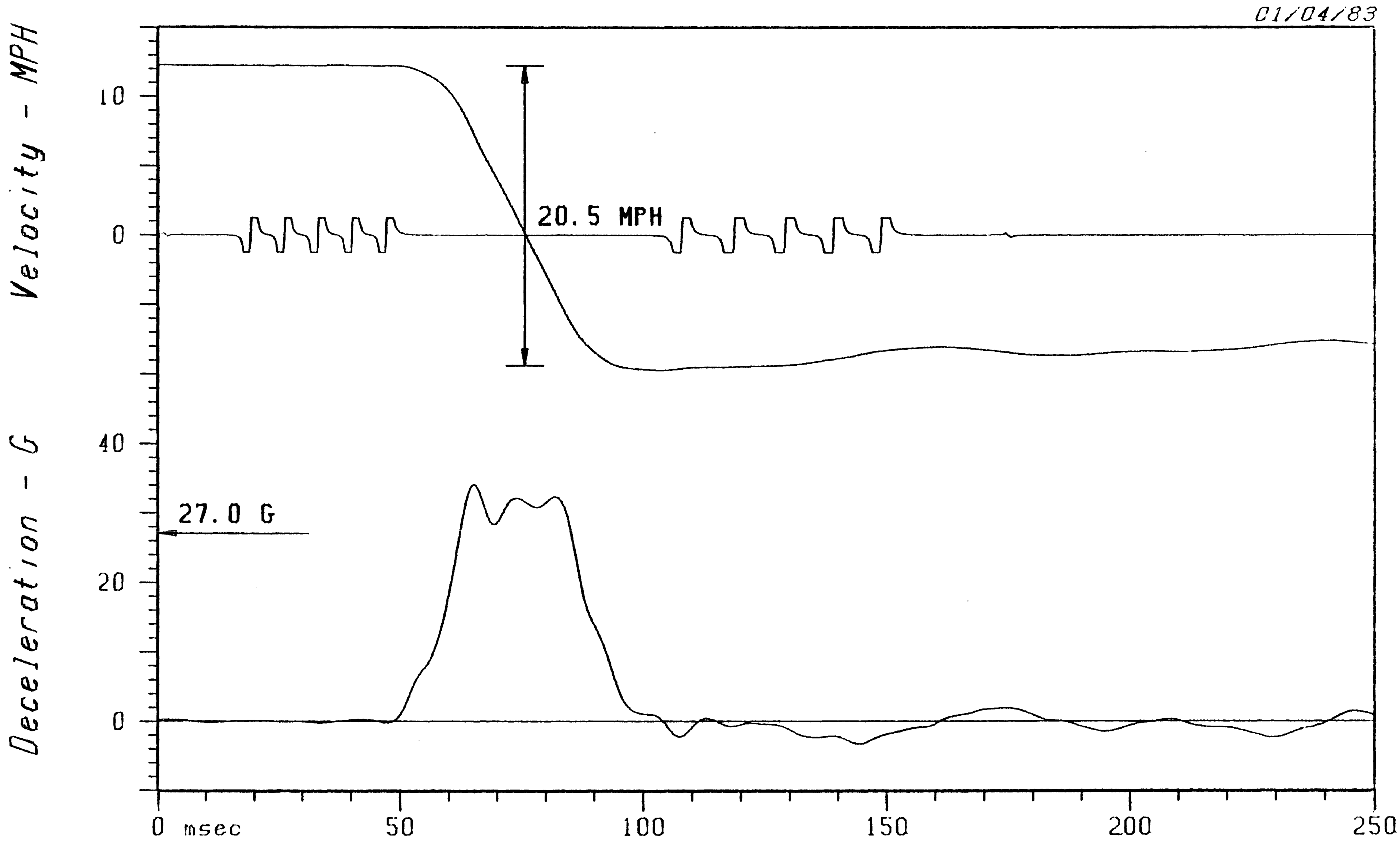

82M002


82M002A


82M002A

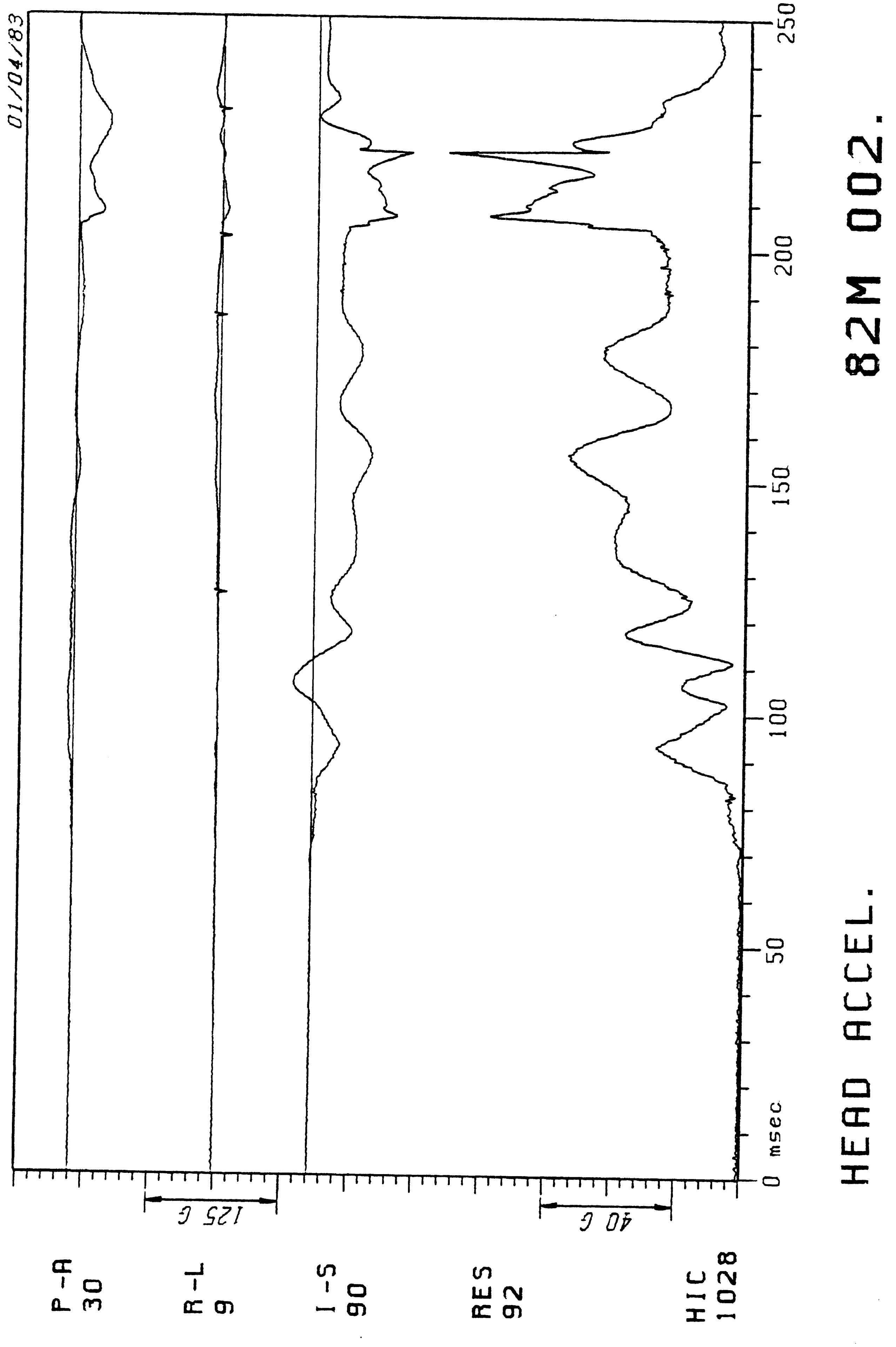

82M002
82M002A

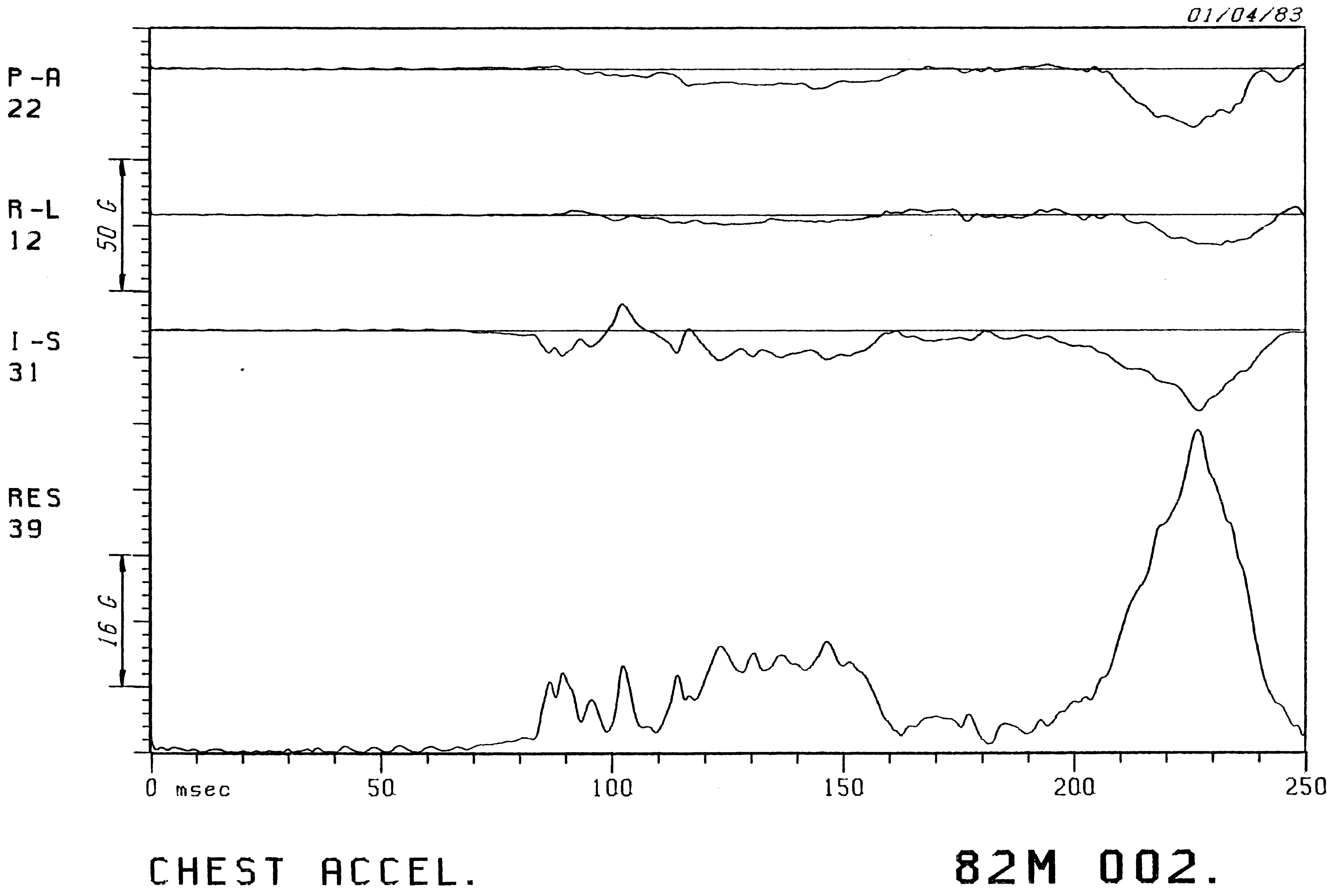

82M02A

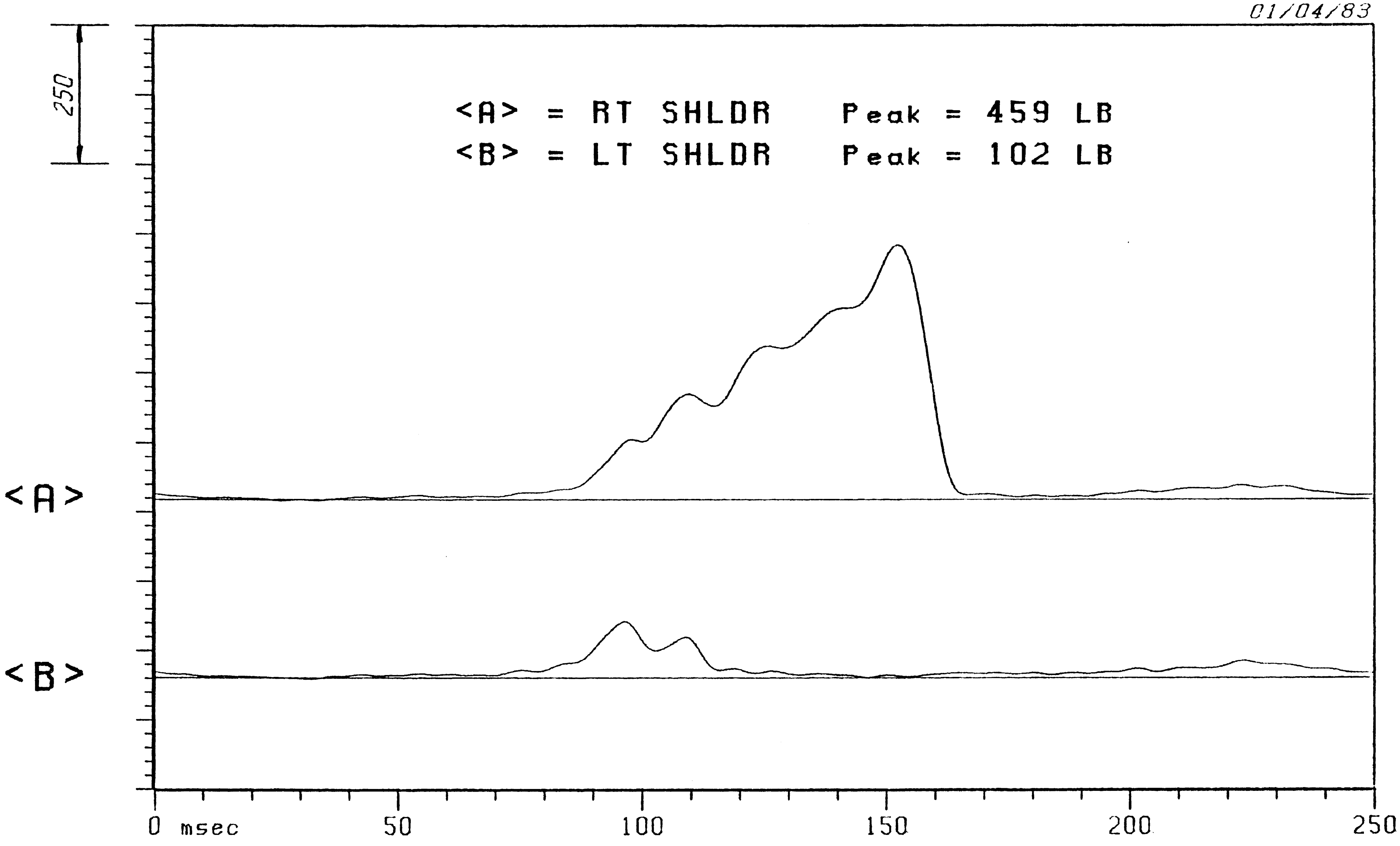


SLED PRØFILE

82M 002.


HEAD ACCEL.
82M 002.
01/04/83
P-A 30
R-L 9
I-S 90
RES 92
HIC 1028
125 G
40 G
0 msec
50
100
150
200
250


01/04/83
P-A
22
R-L
12
I-S
31
RES
39
50 G
16 G
0 msec
50
100
150
200
250
CHEST ACCEL.
82M 002.



BELT LØADS

82M 002.

TEST SUMMARY

TEST NUMBER: 82M003

IMPACT VELOCITY: 20.0 mph

DECELERATION: 27.4 g

TEST RESULTS:

PEAK HEAD ACCELERATIONS

P-A: 118.5 g

R-L: 64.1 g

I-S: 82.8 g

PEAK RESULTANT: 158.2 g

HIC: 673

PEAK CHEST ACCELERATIONS

P-A: 17.3 g

R-L: 5.4 g

I-S: 30.2 g

PEAK RESULTANT: 31.6 g

BELT LOADS

RIGHT REAR TETHER STRAP: 609 lbs

LEFT REAR TETHER STRAP: 461 lbs

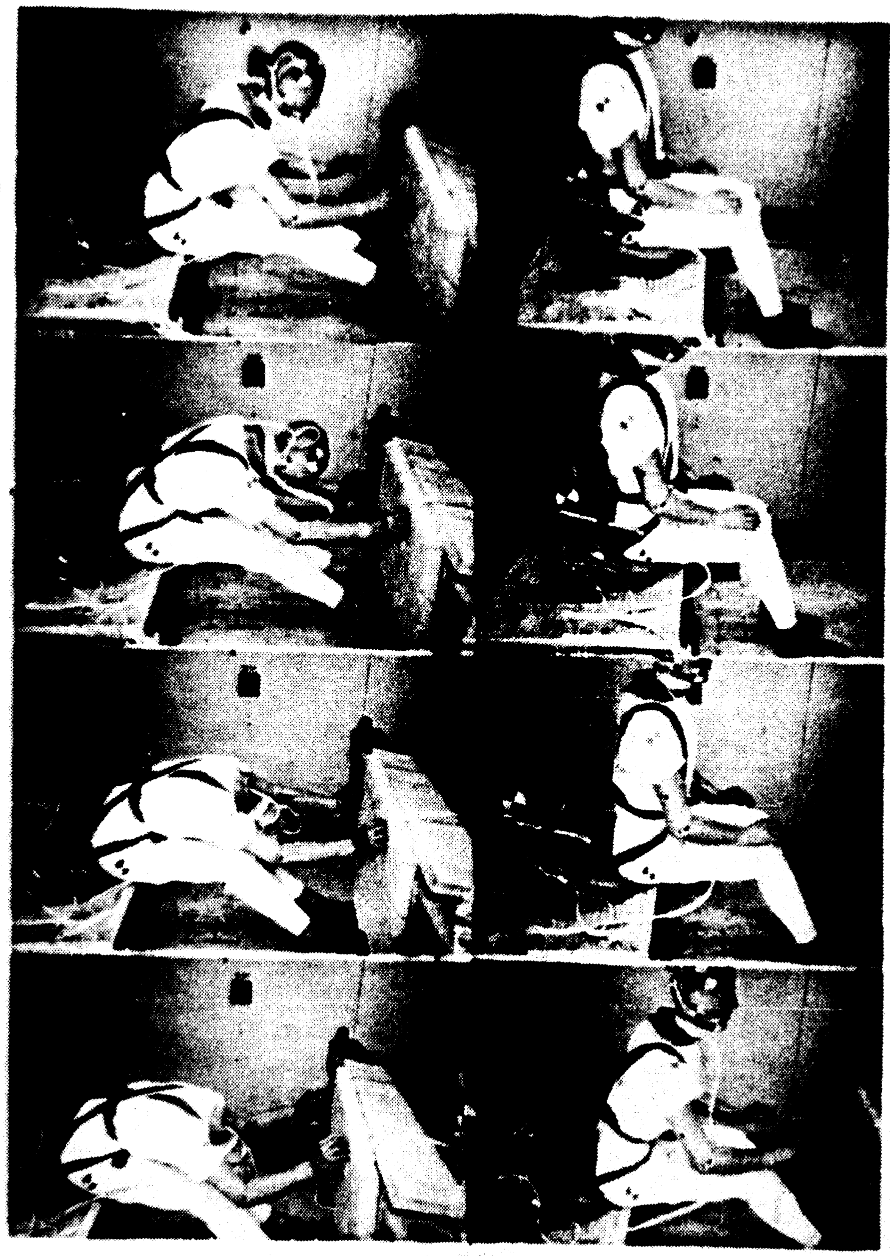
OBSERVATIONS: Belt harness did not fail, but dummy experienced excessive excursion to the forward edge of the seat as well as possible abdominal intrusion from the lap belt portion of the harness.


82M003
82M003


82M003


82M003
82M003

5 1
6 2
7 3
8 4

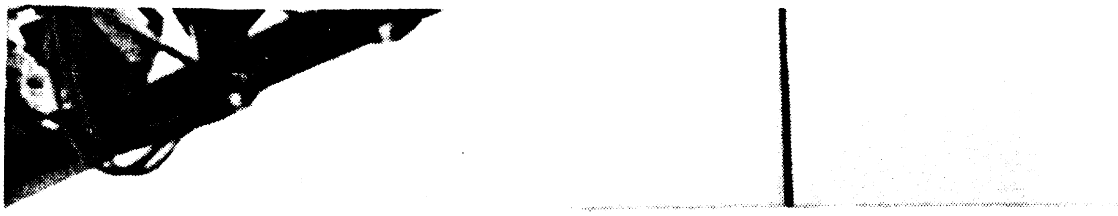


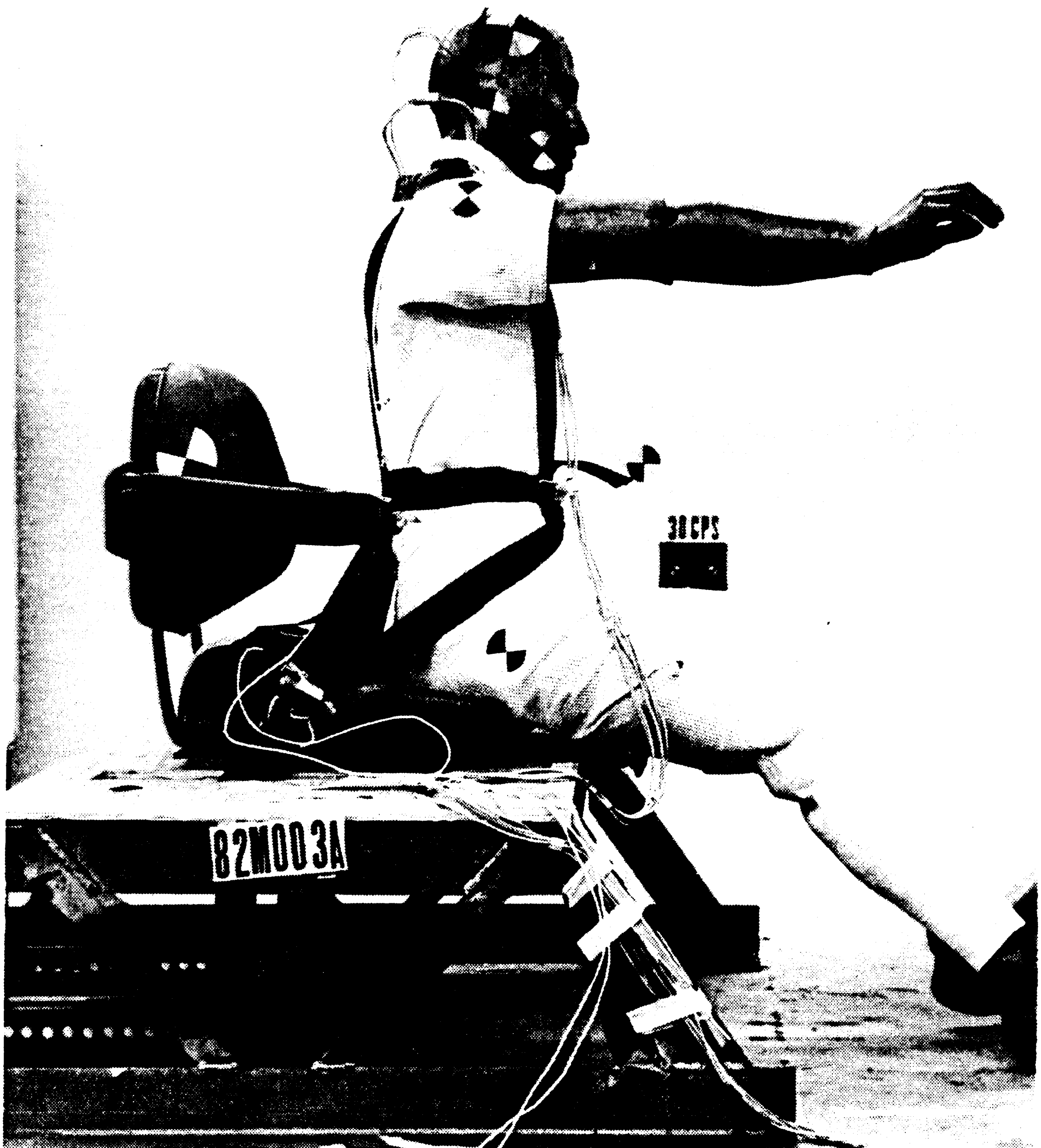
82M003


82M0003A


82M003A


82M003A

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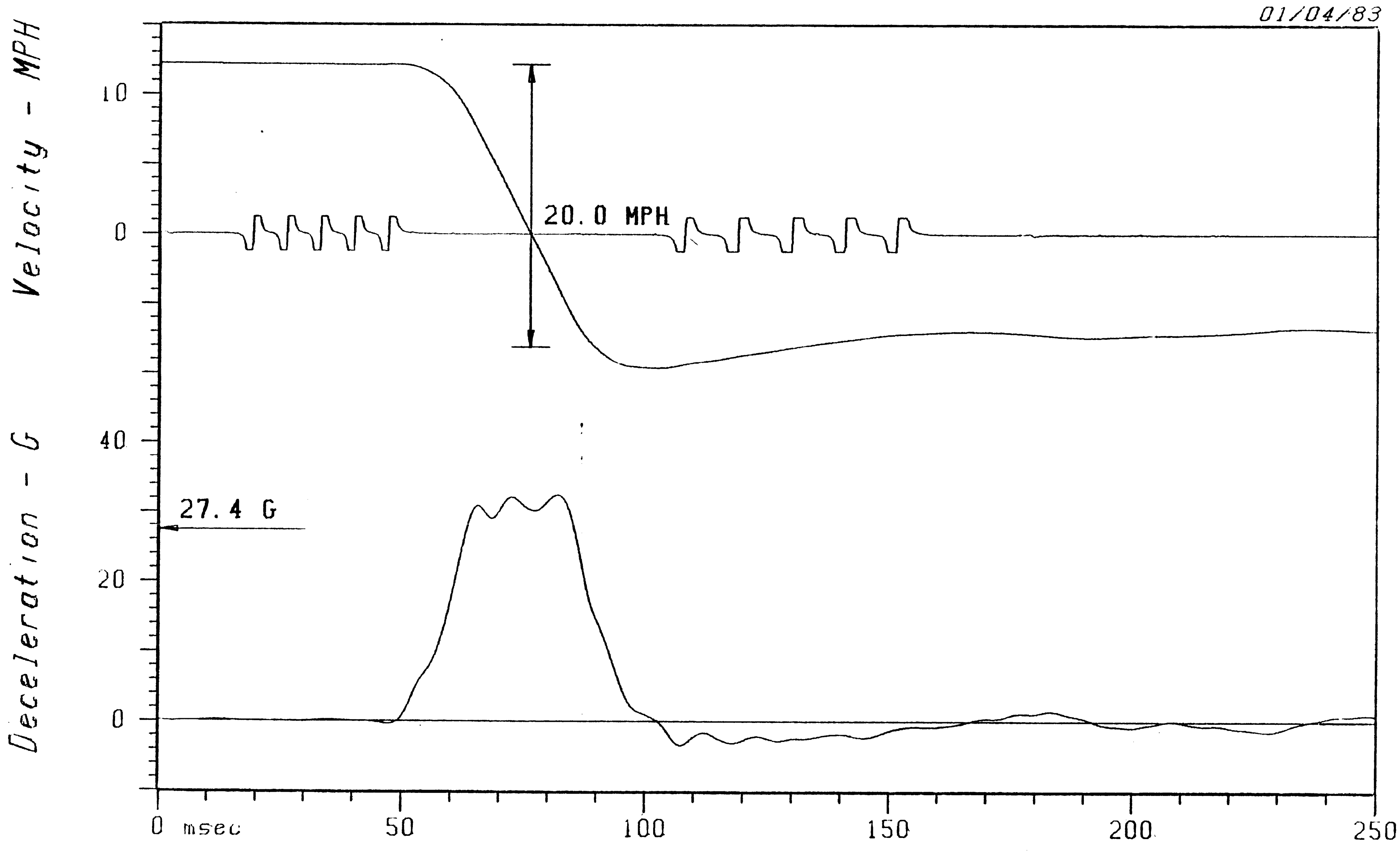
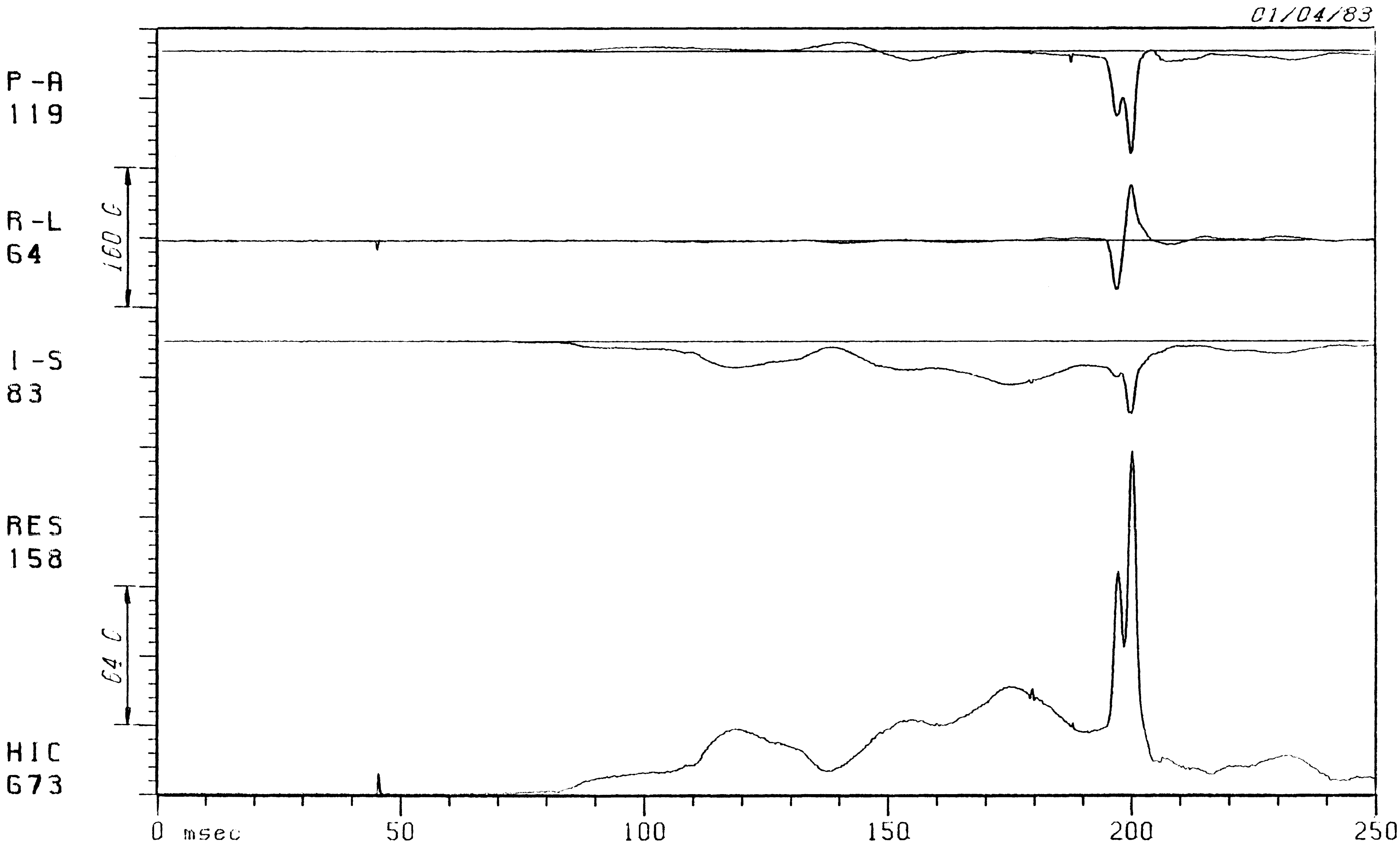


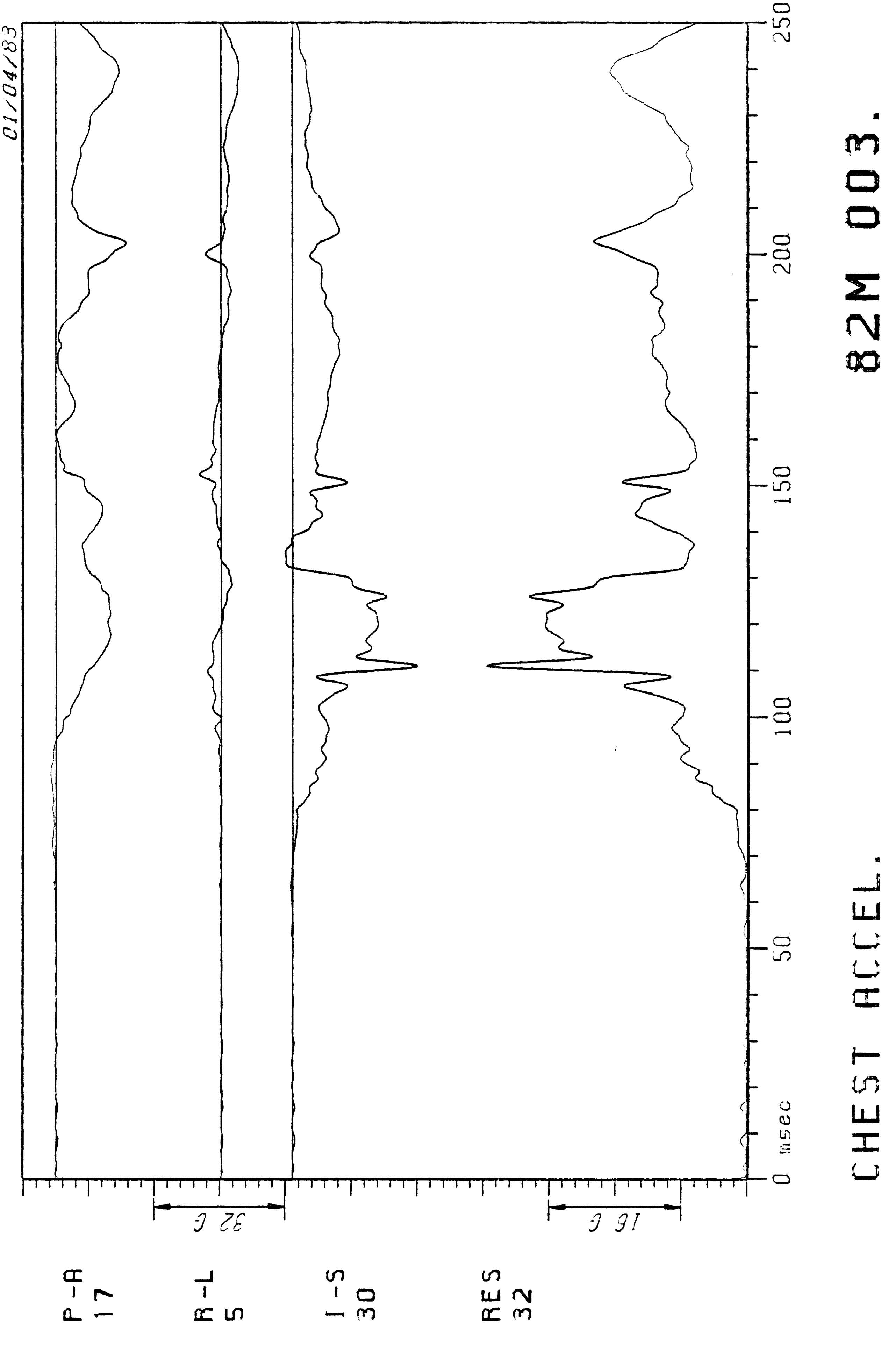
SLED PROFILE

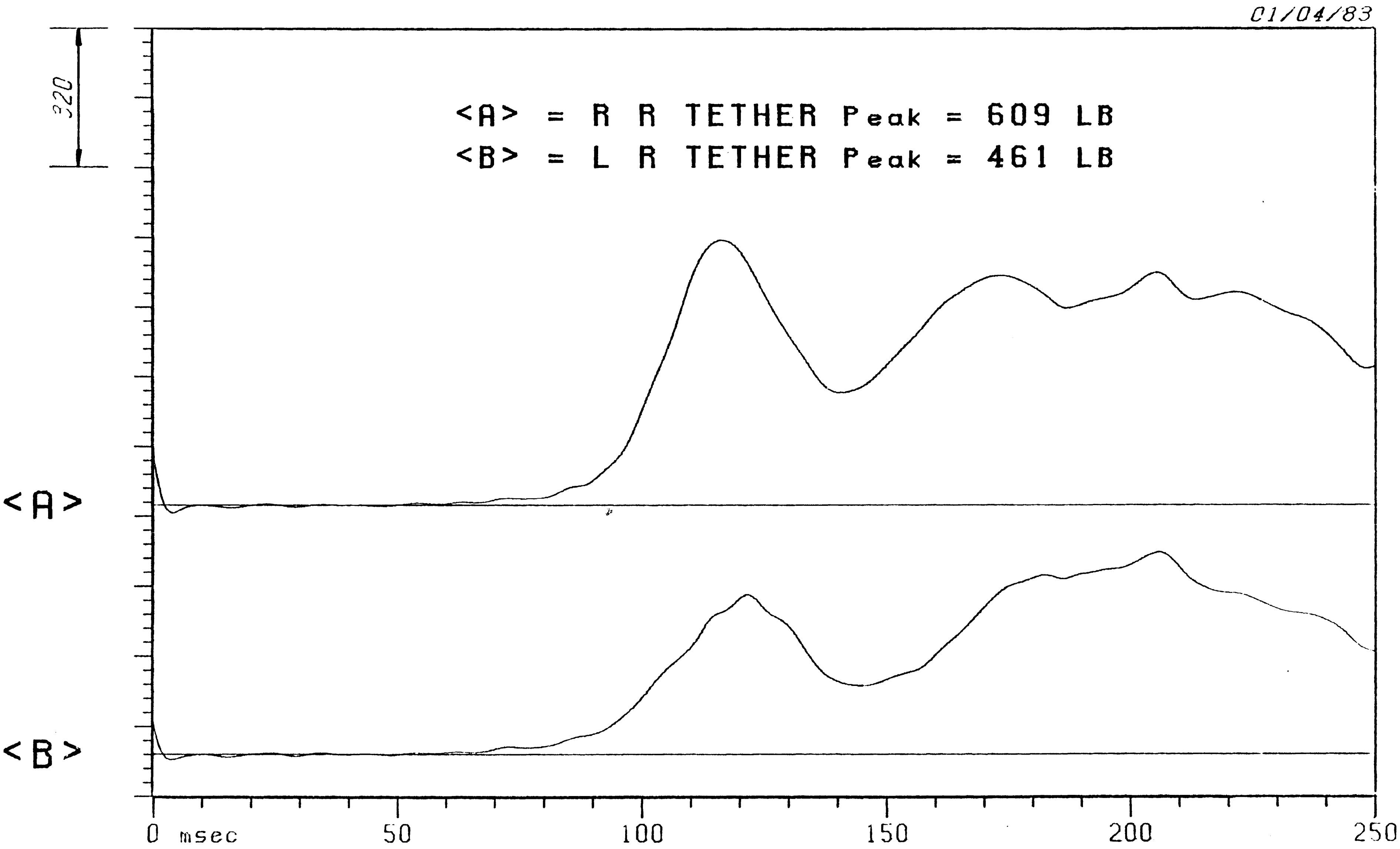
82M 003.



HEAD ACCEL.

82M 003.


CHEST ACCEL.
82M 003.
01/04/83
P-A 17
R-L 5
I-S 30
RES 32
32 G
16 G
0 msec
50
100
150
200
250



BELT LØADS

82M 003.

TEST SUMMARY

TEST NUMBER: 82M004

IMPACT VELOCITY: 20.2 mph

DECELERATION: 27.9 g

TEST RESULTS:

PEAK HEAD ACCELERATIONS

P-A: 8.9 g

R-L: 12.0 g

I-S: 21.9 g

PEAK RESULTANT: 22.3 g

HIC: 97

CHEST ACCELERATIONS

P-A: 8.5 g

R-L: 4.2 g

I-S: 34.6 g

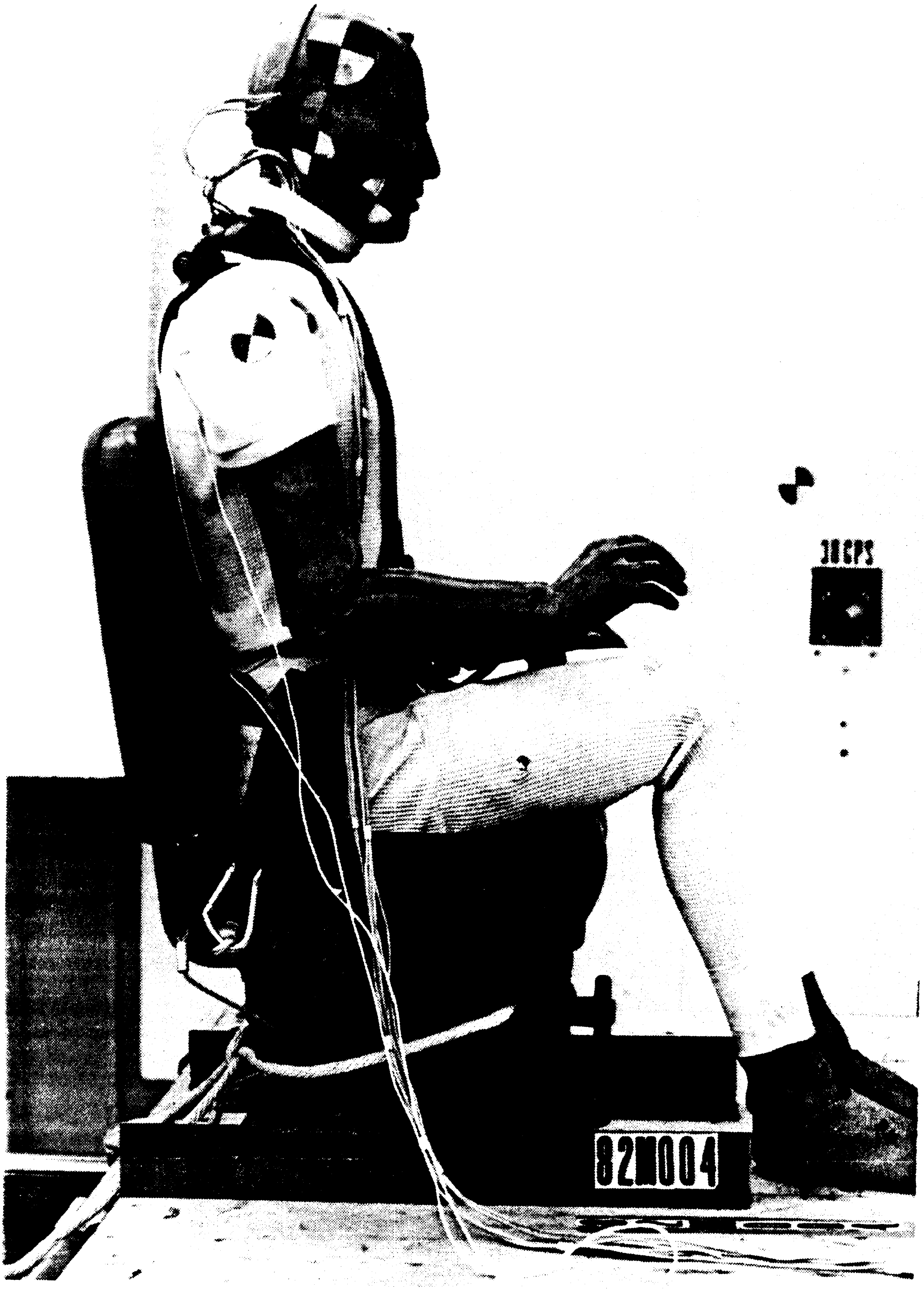
PEAK RESULTANT: 34.6 g

BELT LOADS

RIGHT SHOULDER STRAP: 132 lbs

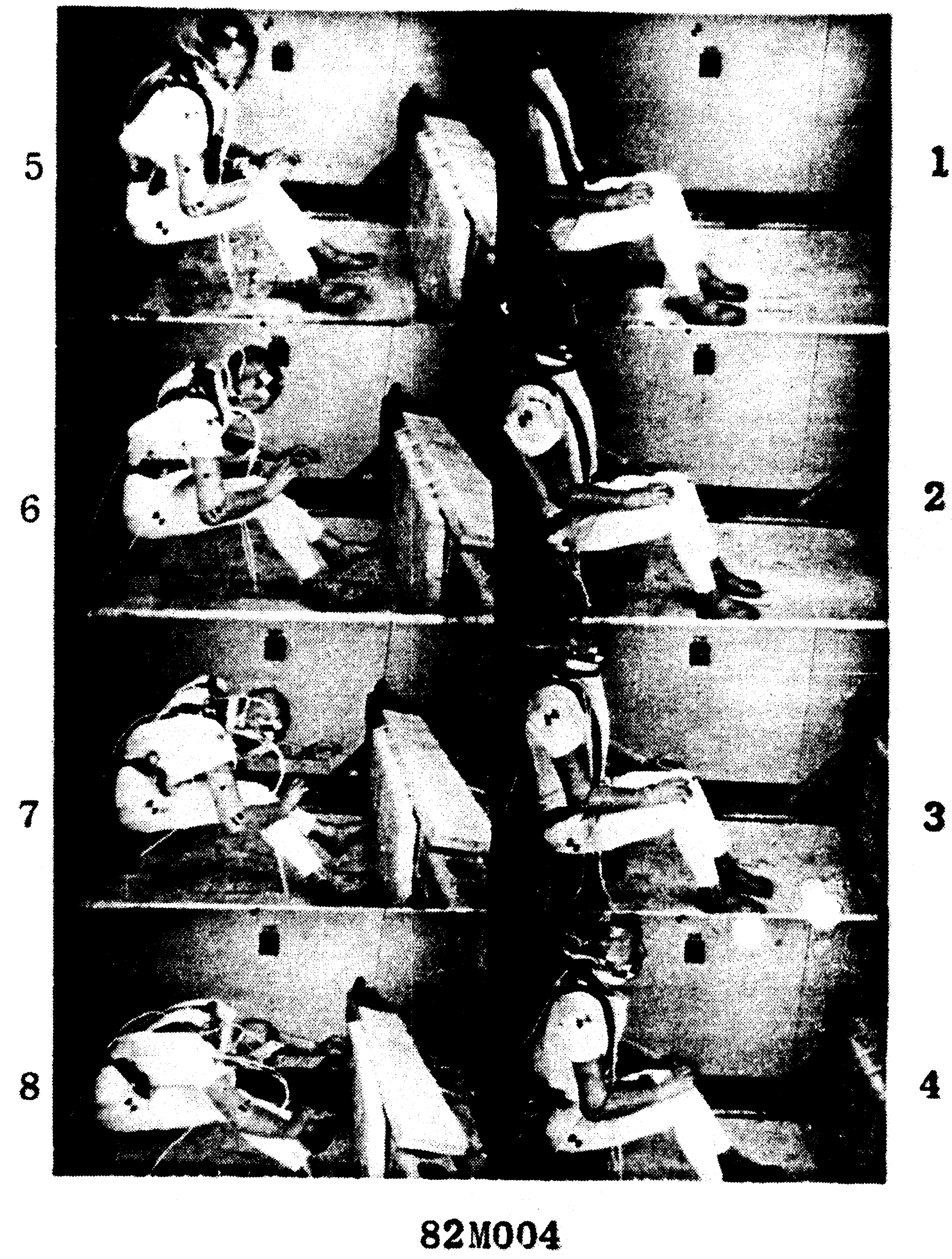
LEFT SHOULDER STRAP: 24 lbs

OBSERVATIONS: Right tether anchor pulled out, releasing the dummy during impact.


30CPS
82M004


82M004

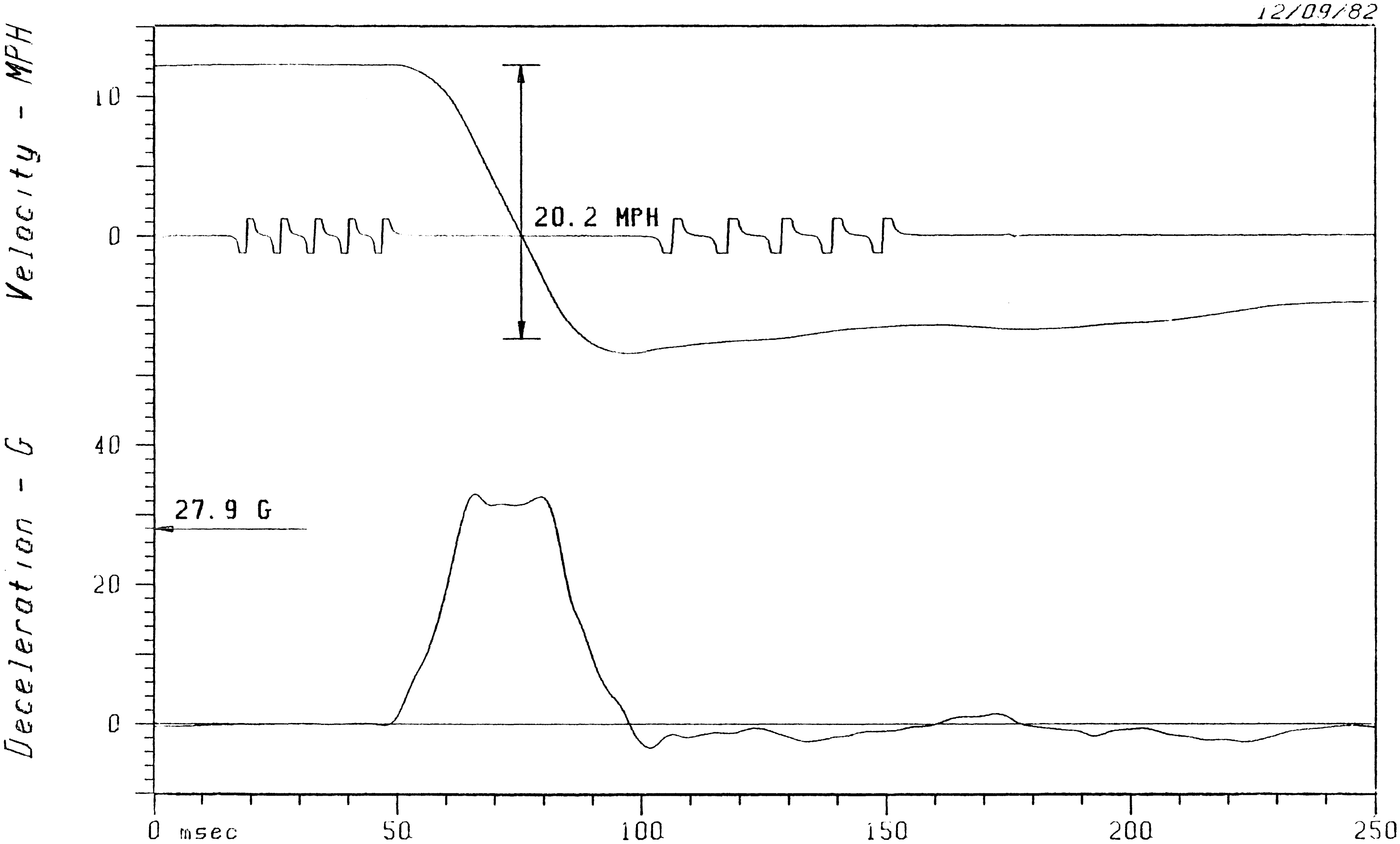

82M004



82M004


82M004A


82M004A



SLED PRØFILE

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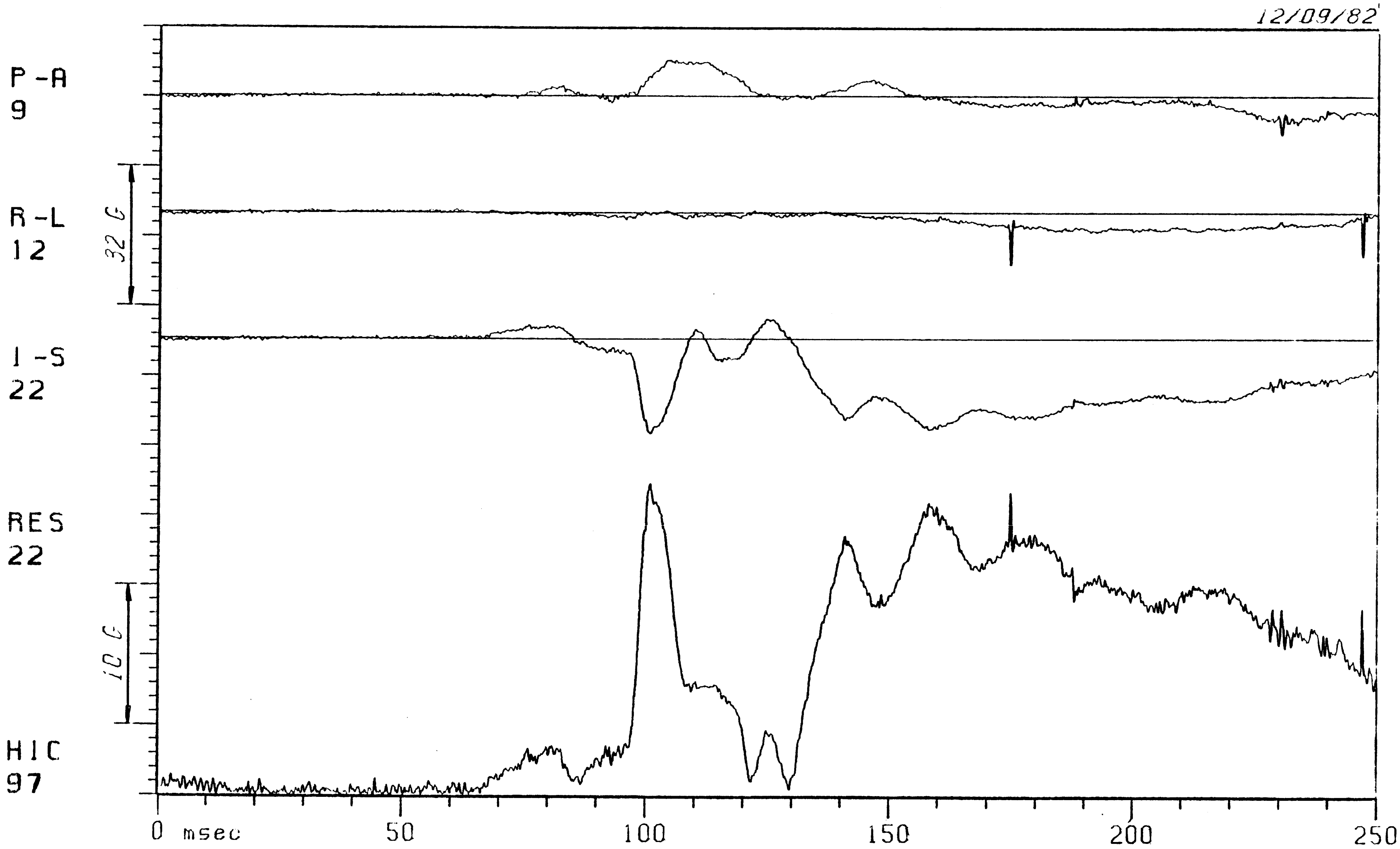
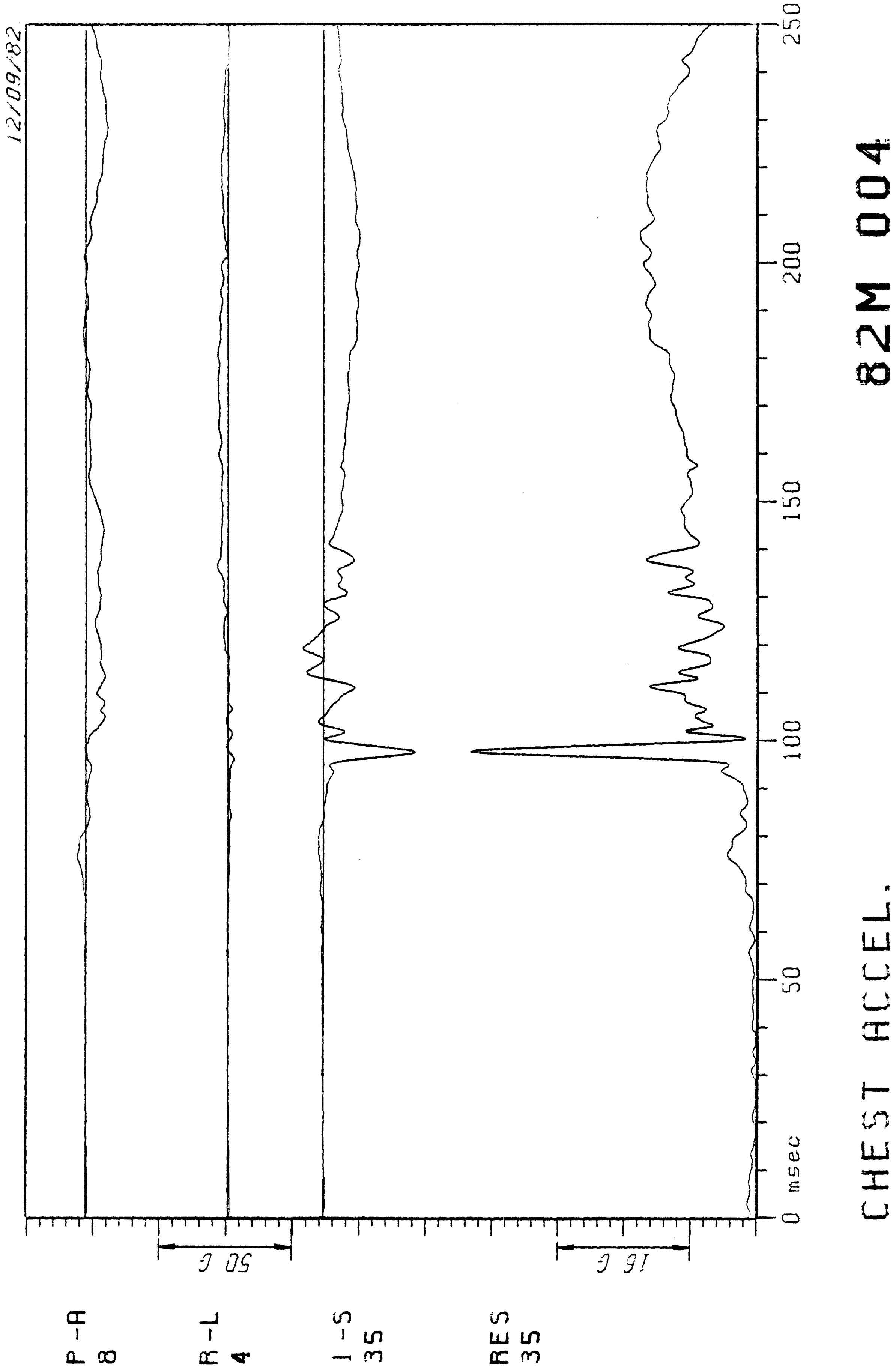
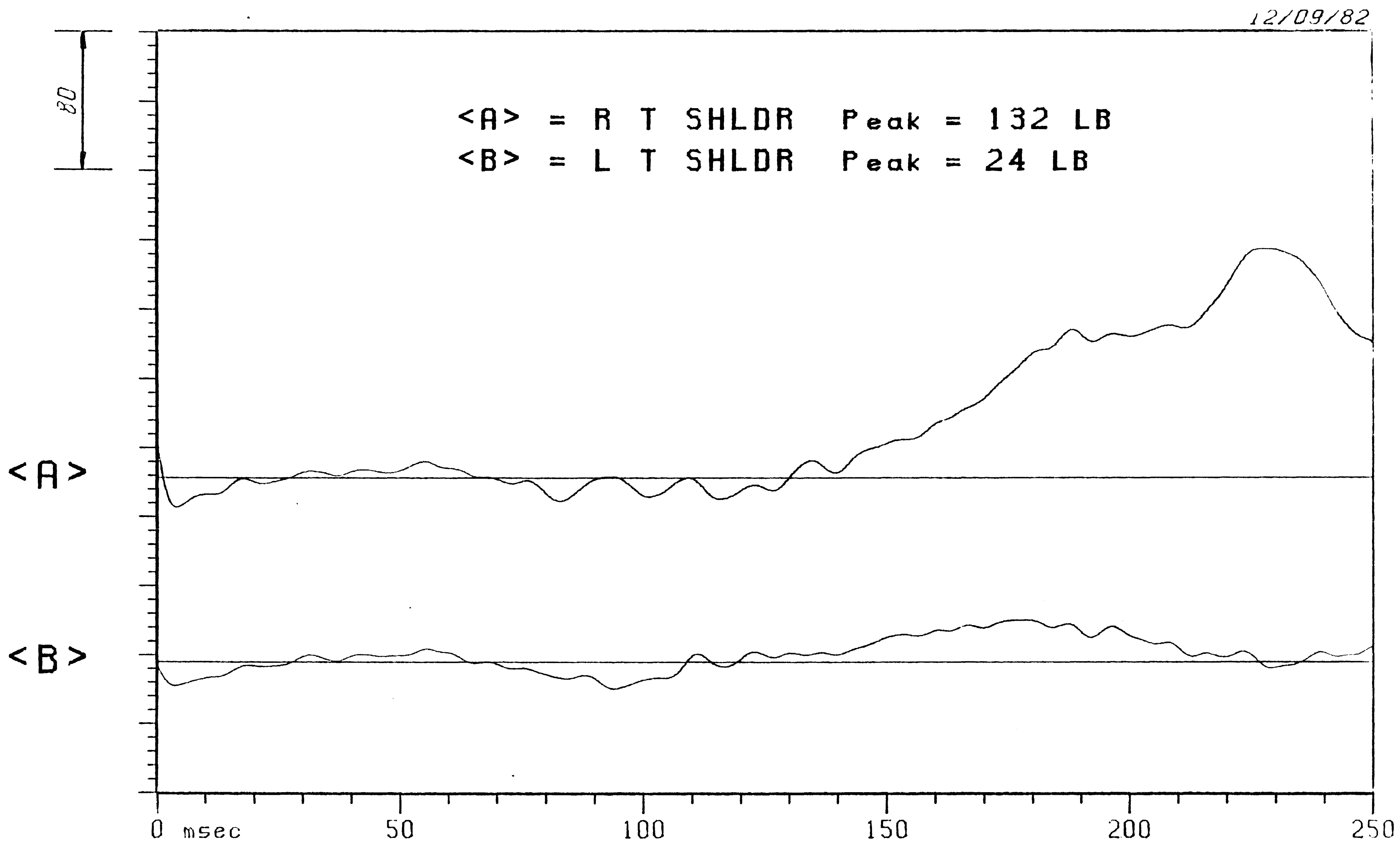


HEAD ACCEL.

82M 004


12/09/82
P-A
8
R-L
4
I-S
35
RES
35
50 G
16 G
0 msec
50
100
150
200
250
CHEST ACCEL.
82M 004



BELT LØADS

82M 004

TEST SUMMARY

TEST NUMBER: 82M005

IMPACT VELOCITY: 20.4 mph

DECELERATION: 27.9 g

TEST RESULTS:

PEAK HEAD ACCELERATIONS

P-A: 163.4 g

R-L: 25.5 g

I-S: 104.3 g

PEAK RESULTANT: 194.2

HIC: 775

PEAK CHEST ACCELERATIONS

P-A: 22.5 g

R-L: 5.4 g

I-S: 35.2 g

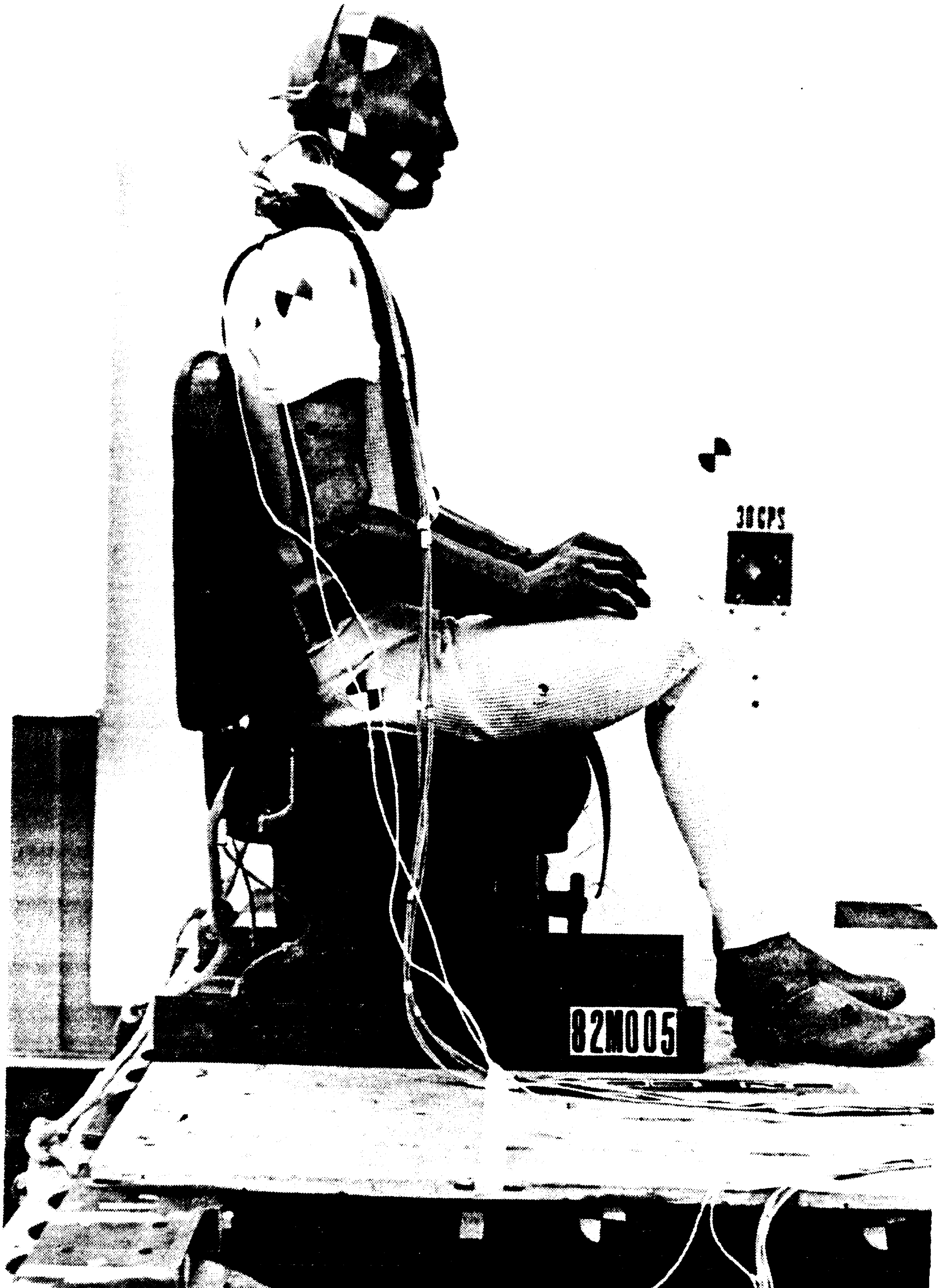
PEAK RESULTANT: 35.2 g

BELT LOADS

RIGHT SHOULDER STRAP: 77 lbs

LEFT SHOULDER STRAP: 34 lbs

OBSERVATIONS: Suspension seat pitched forward, ramping the dummy off the forward edge and producing severe abdominal belt intrusion.


30 CPS
82M005


82M005


82M00.5

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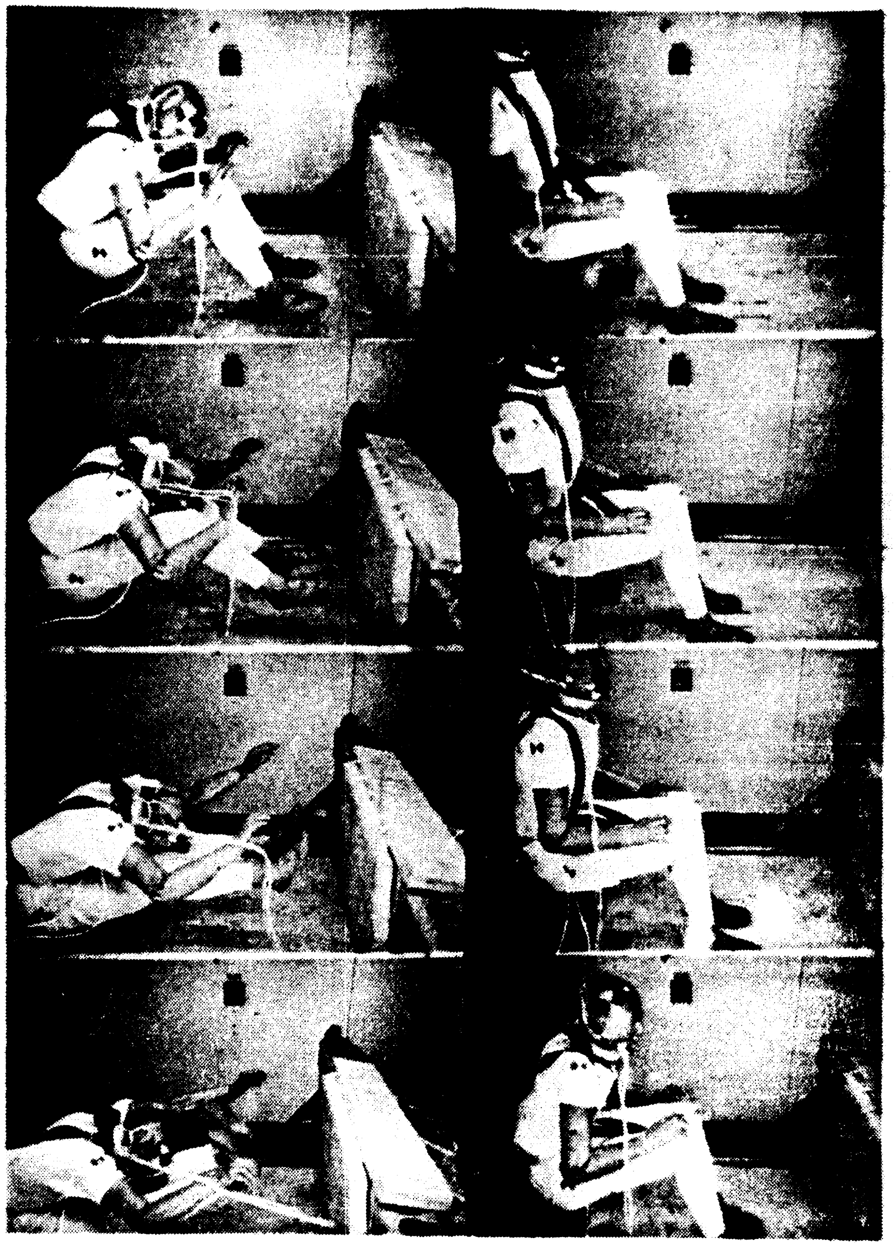
7 3

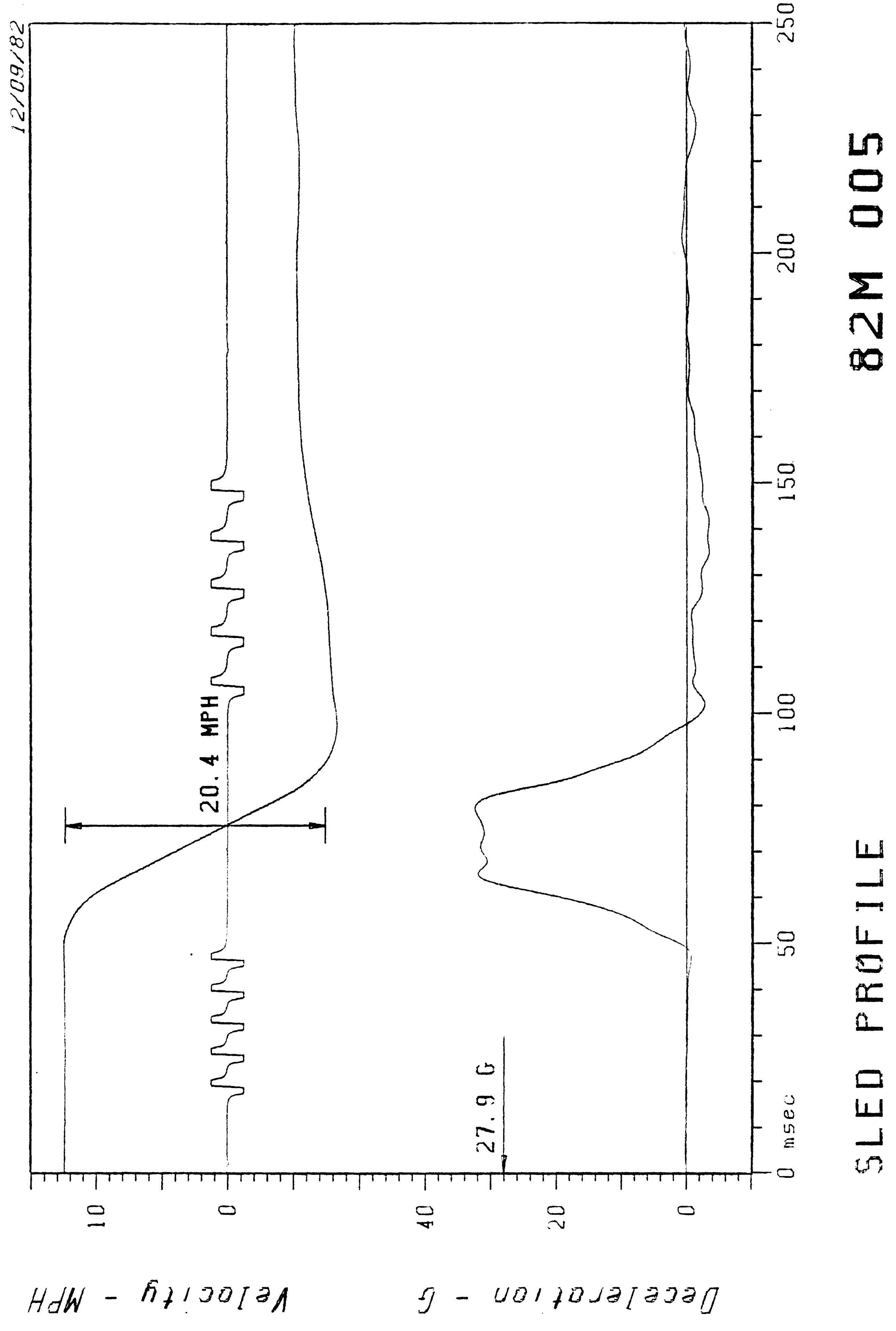
8 4

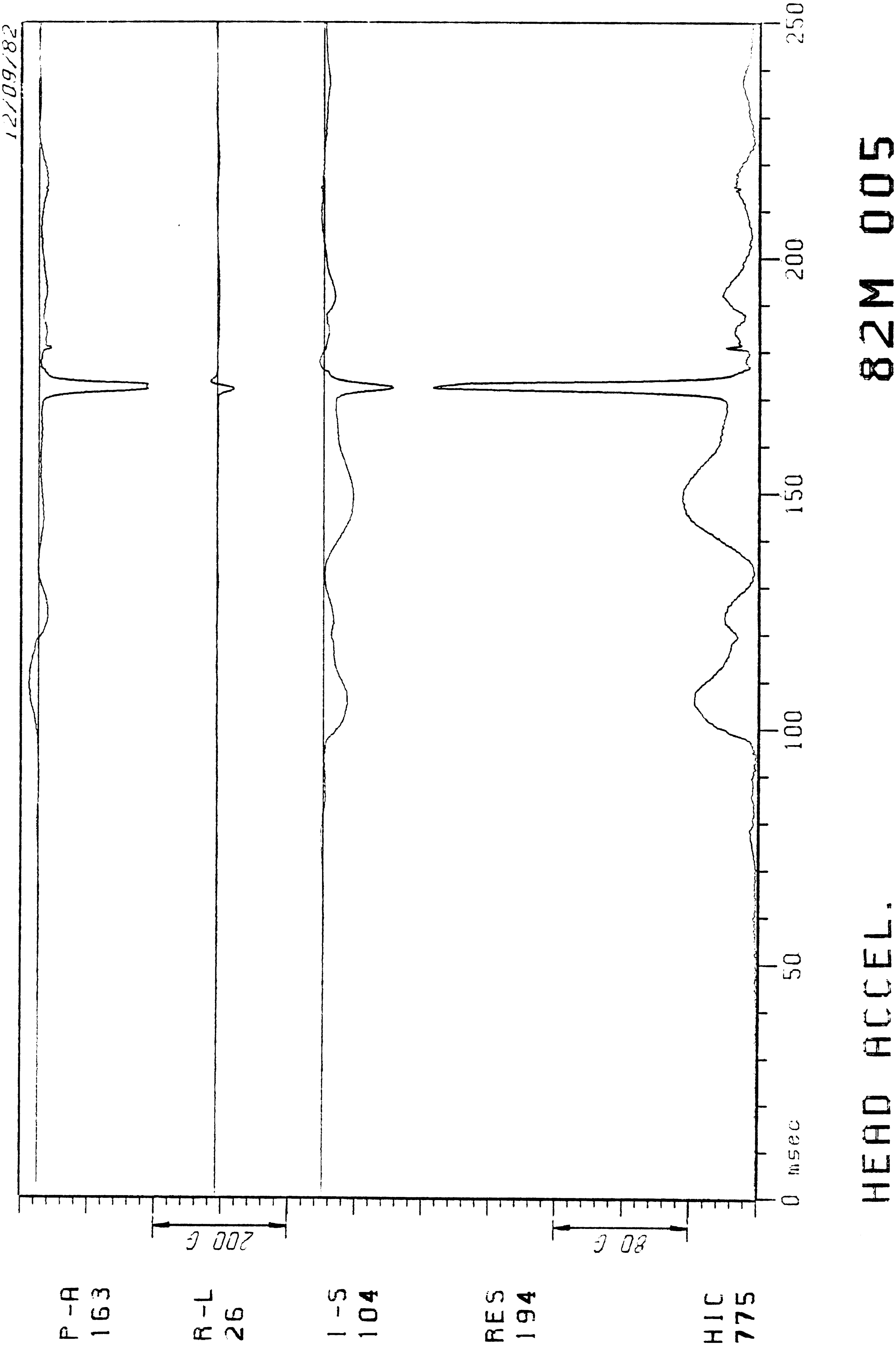


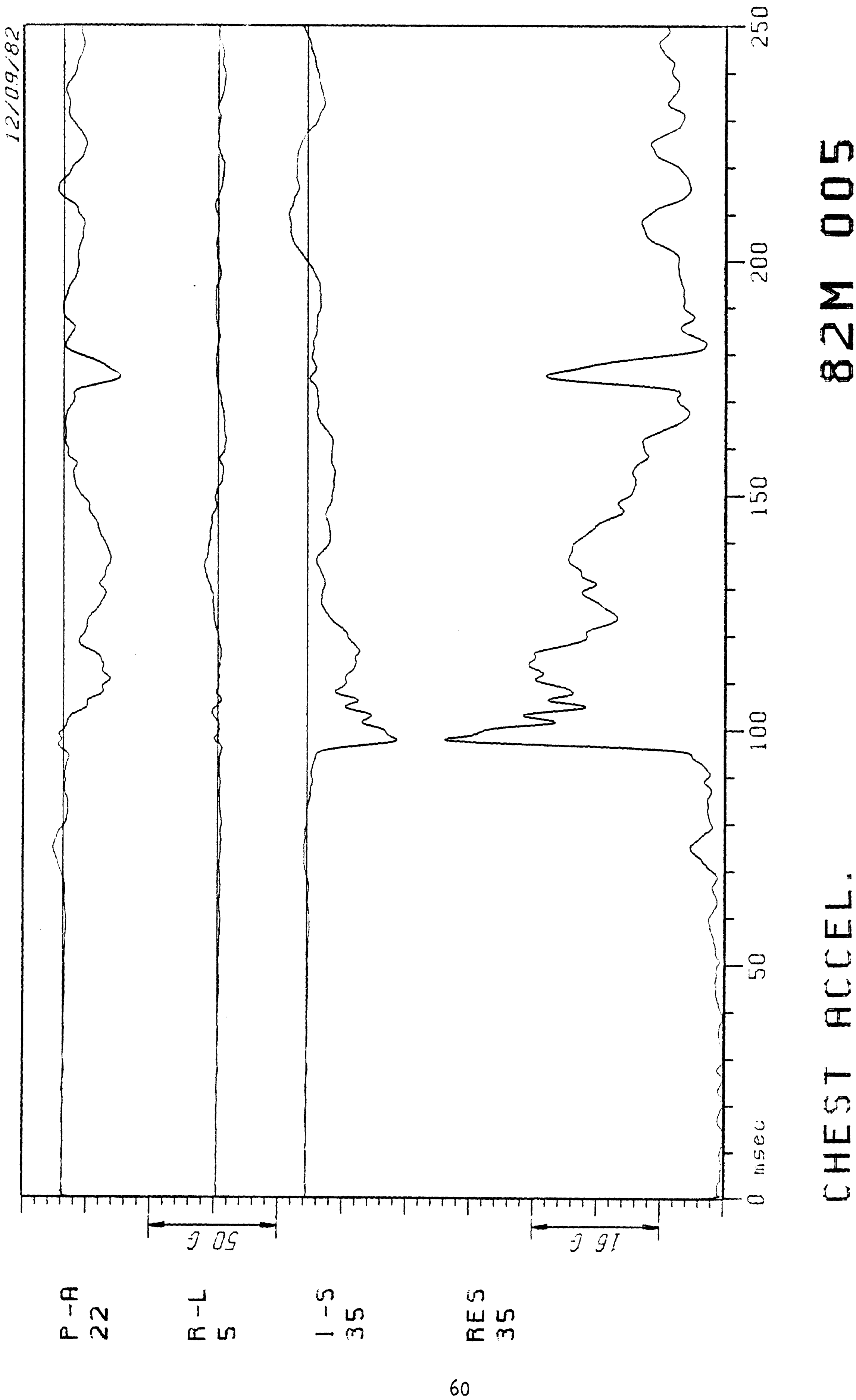
82M005


82M005A


82M005A


SLED PROFILE
82M 005
12/09/82
20.4 MPH
27.9 G
0 msec
50
100
150
200
250
10
0
40
20
0
Velocity - MPH
Deceleration - G


12/09/82
82M 005
HEAD ACCEL.
0 msec
50
100
150
200
250
200 G
80 G
P-A 163
R-L 26
I-S 104
RES 194
HIC 775



12/09/82
82M 005
CHEST ACCEL.
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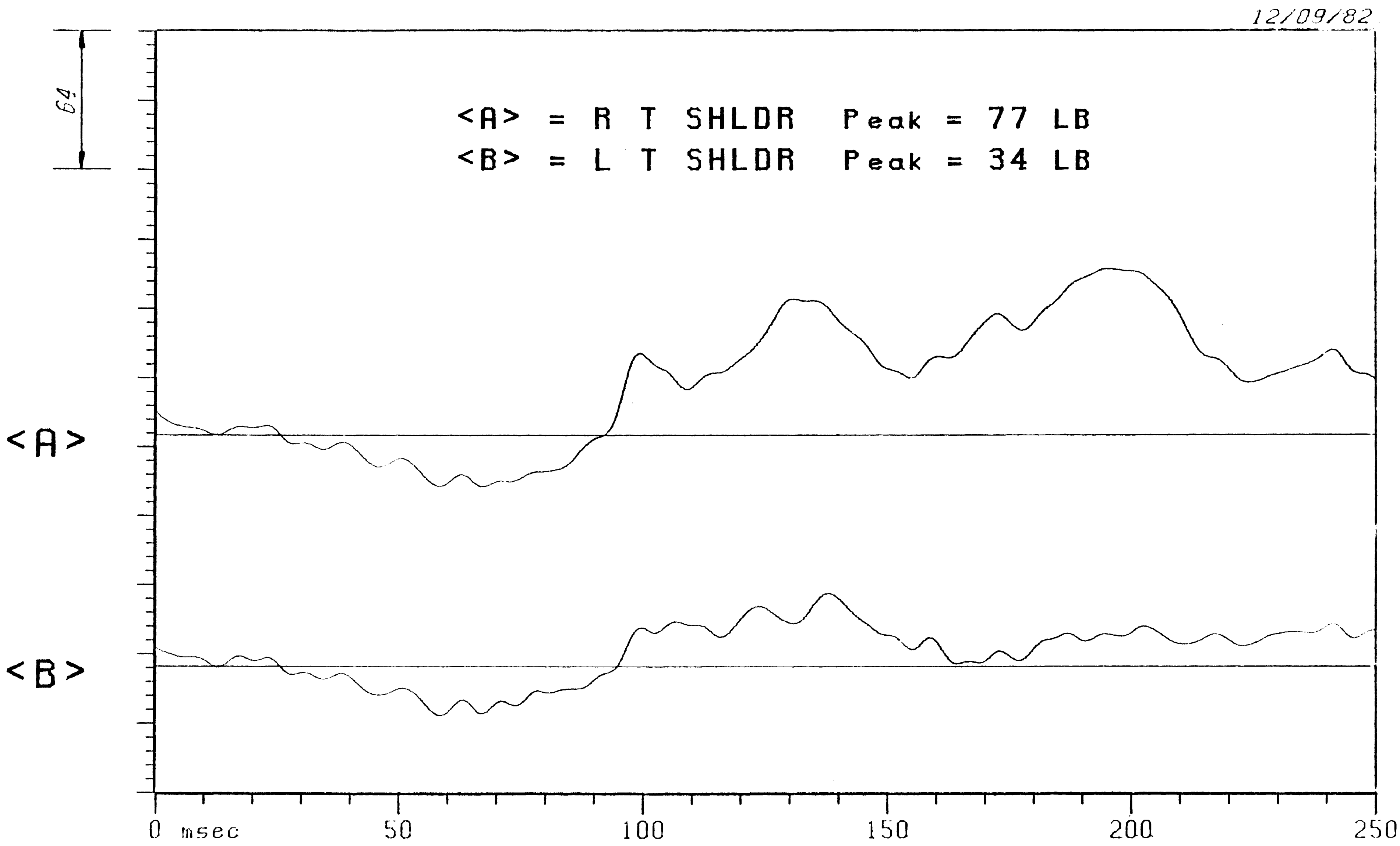
100
150
200
250
50 G
16 G
P-A 22
R-L 5
I-S 35
RES 35



BELT LØADS

82M 005

TEST SUMMARY

TEST NUMBER: 82M006

IMPACT VELOCITY: 20.2 mph

DECELERATION: 28.2 g

TEST RESULTS:

PEAK HEAD ACCELERATIONS

- P-A: 66.5 g
- R-L: 77.4 g
- I-S: 40.8 g
- PEAK RESULTANT: 104.2 g
- HIC: 334

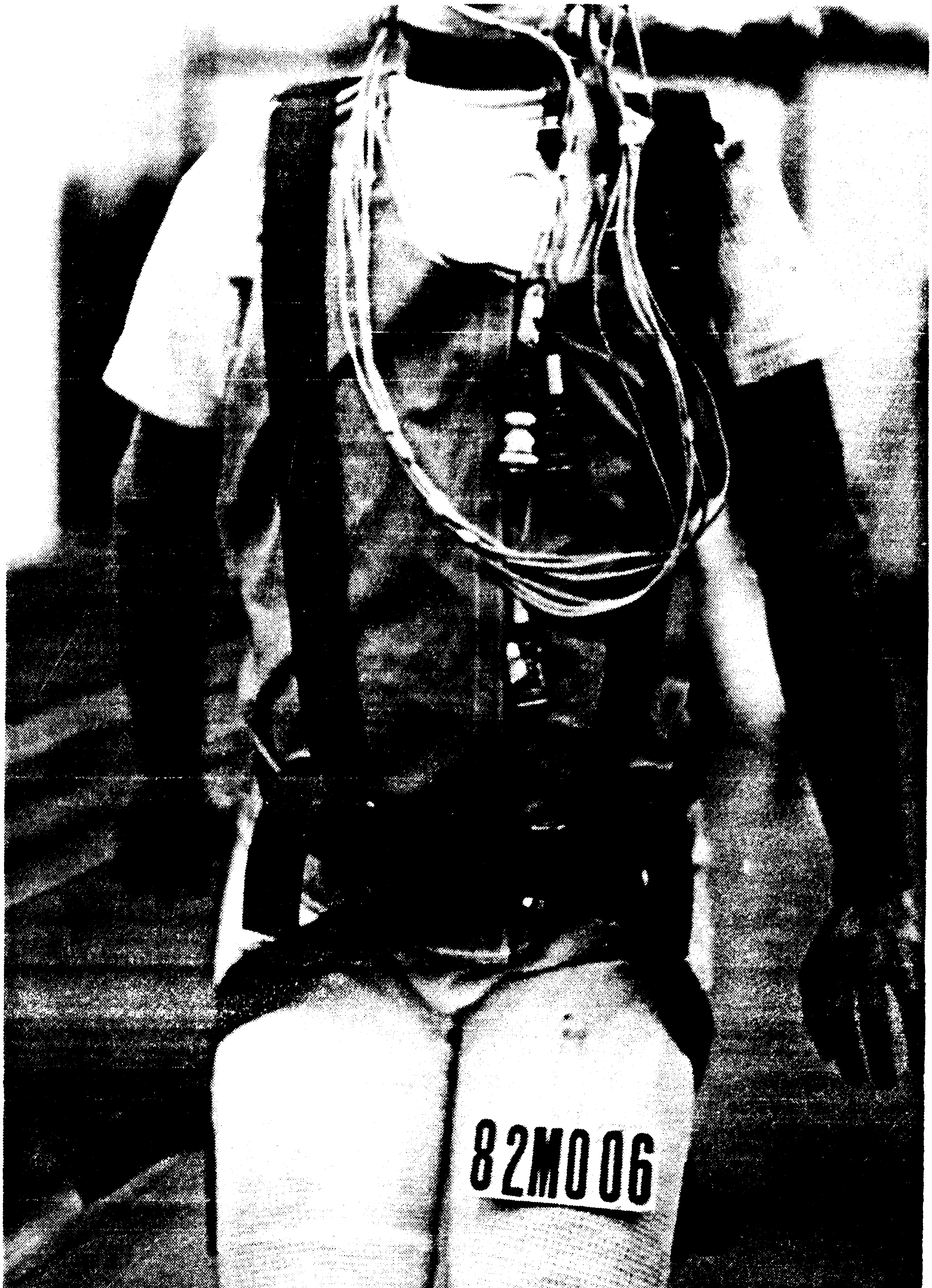
PEAK CHEST ACCELERATIONS

- P-A: 15.7 g
- R-L: 17.0 g
- I-S: 23.2 g
- PEAK RESULTANT: 24.5 g

BELT LOADS

- RIGHT LAP: 1490 lbs
- LEFT LAP: 1346 lbs
- RIGHT SHOULDER STRAP: 440 lbs
- LEFT SHOULDER STRAP: 369 lbs

OBSERVATIONS: Left tether anchor bracket distorted and tore the belt webbing, releasing the dummy during impact.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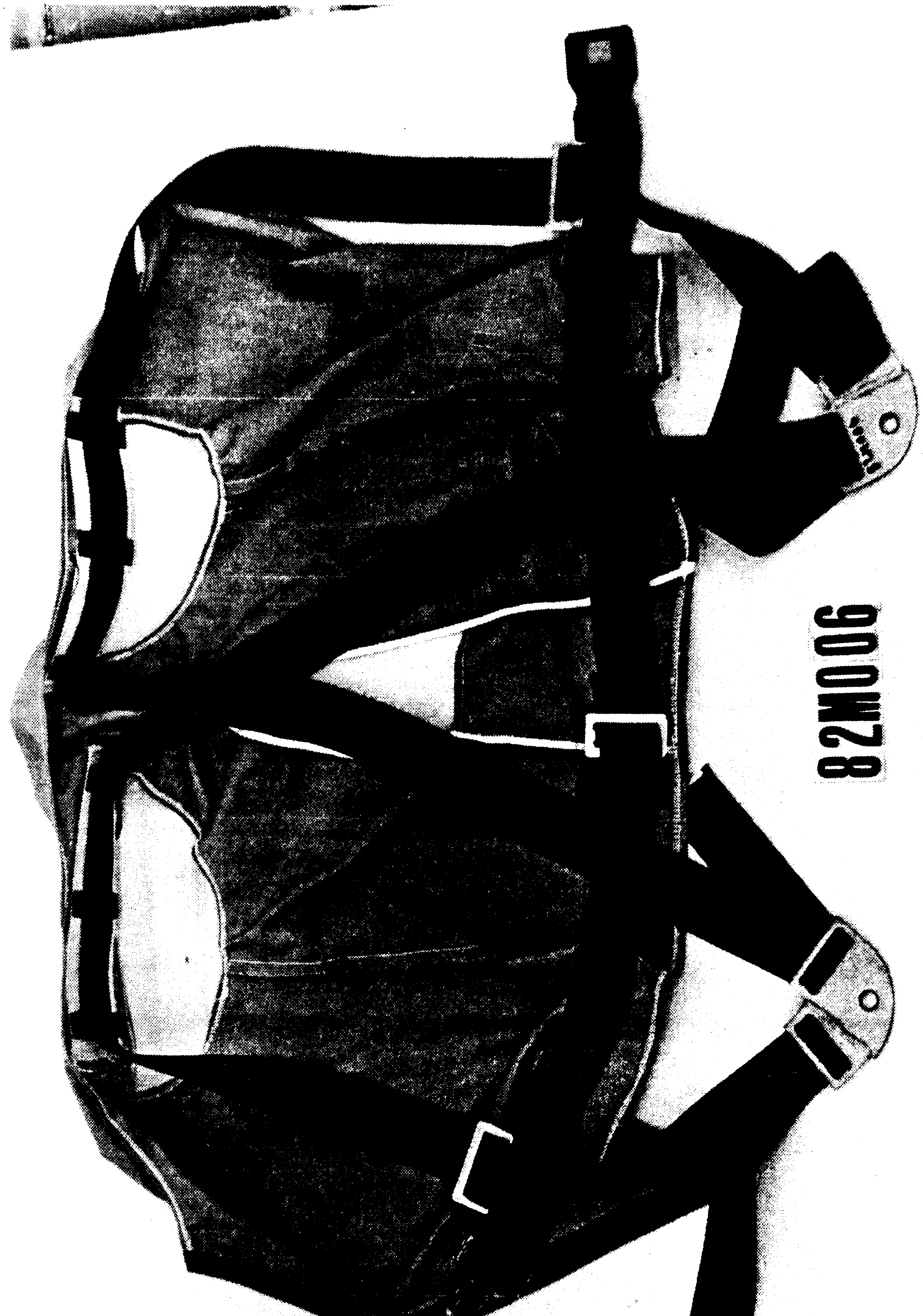

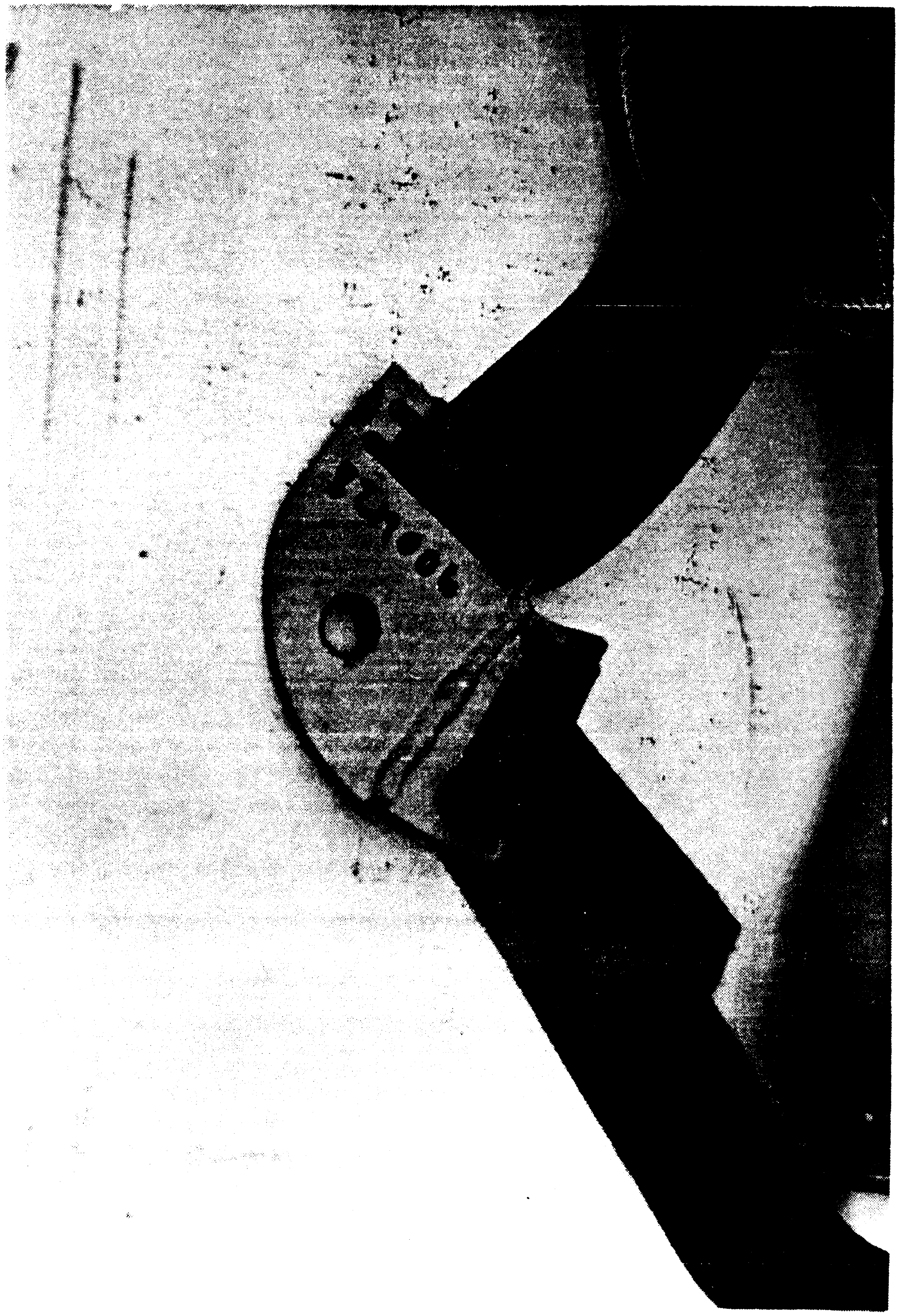


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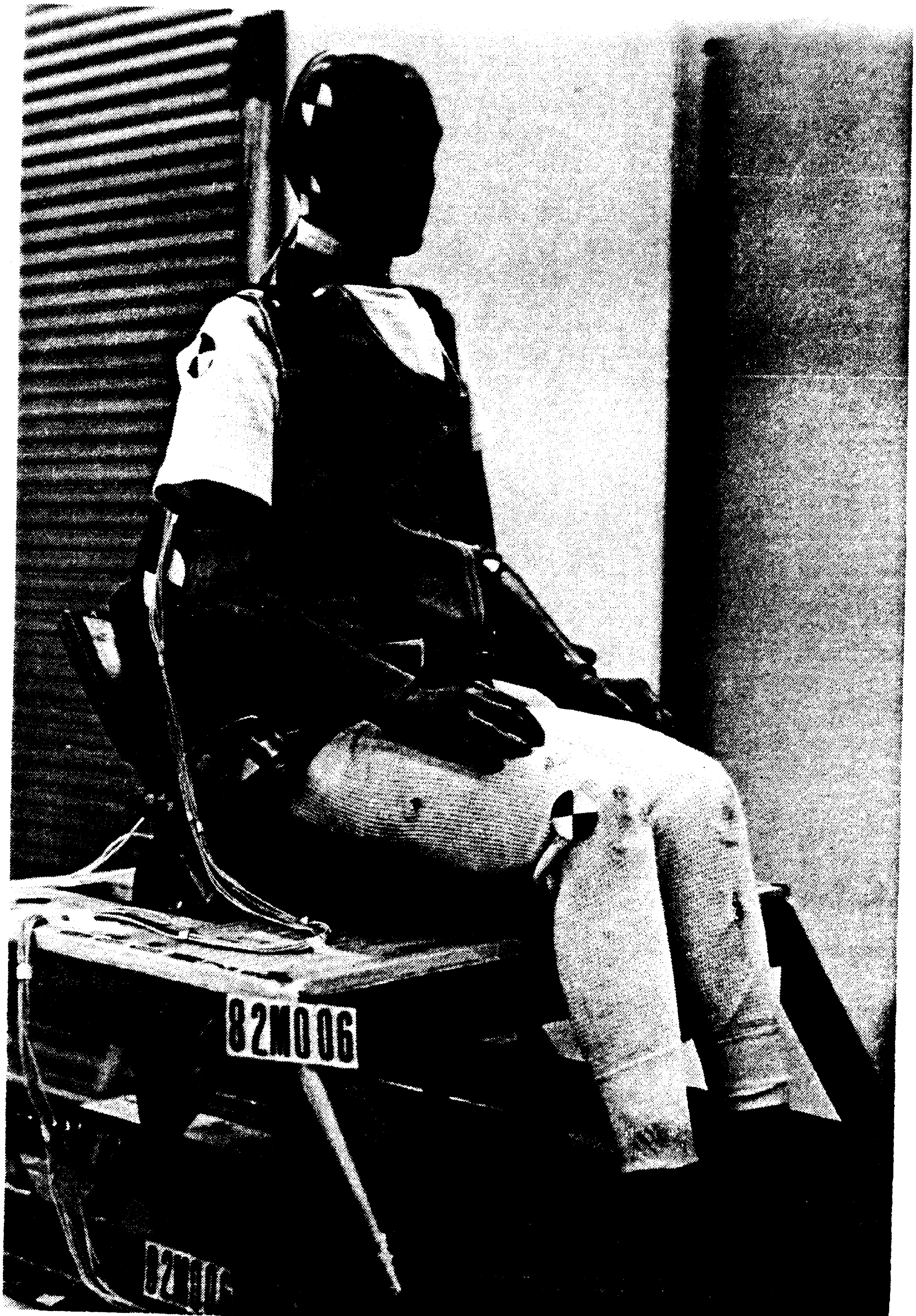
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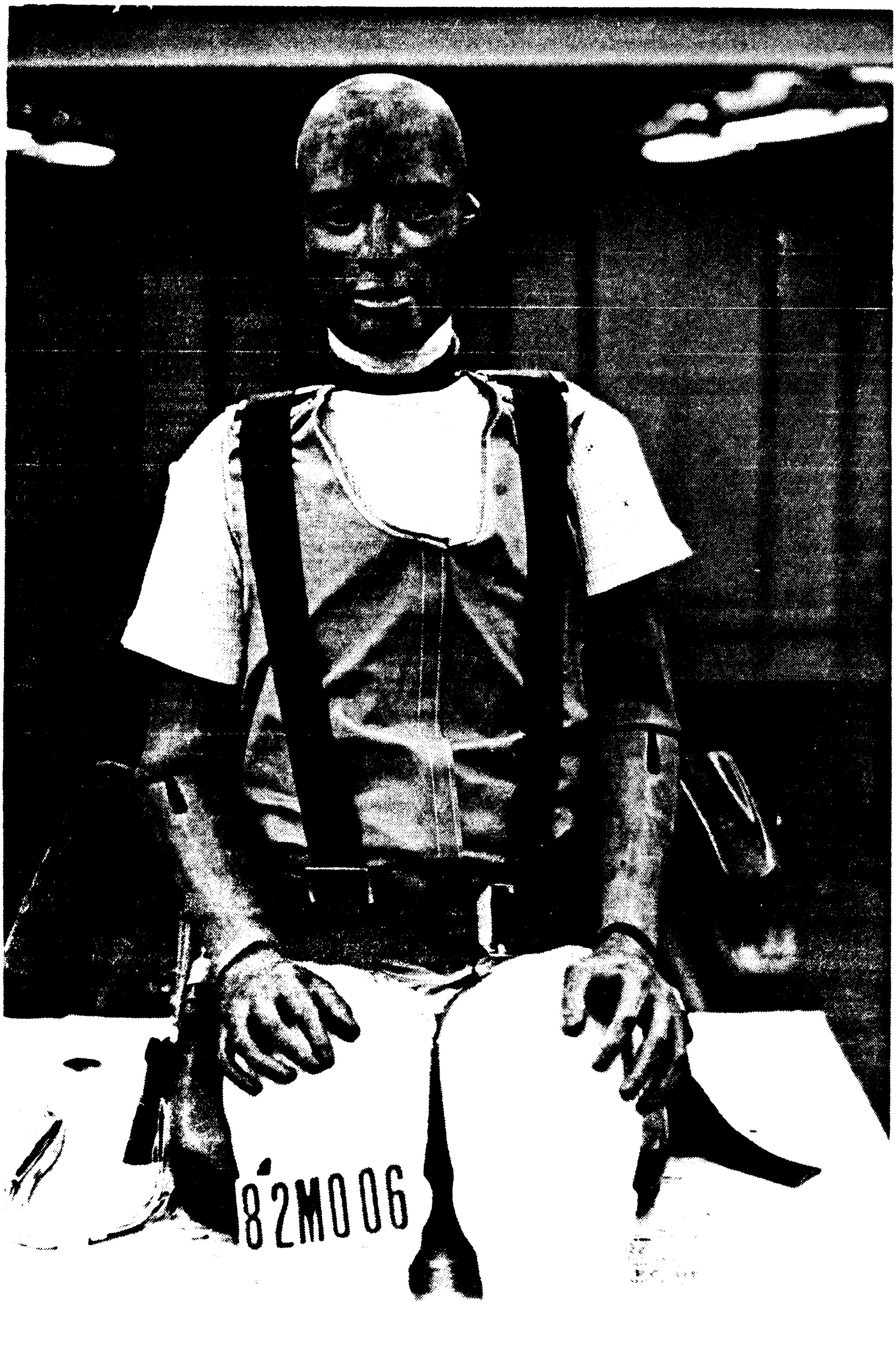
82M006

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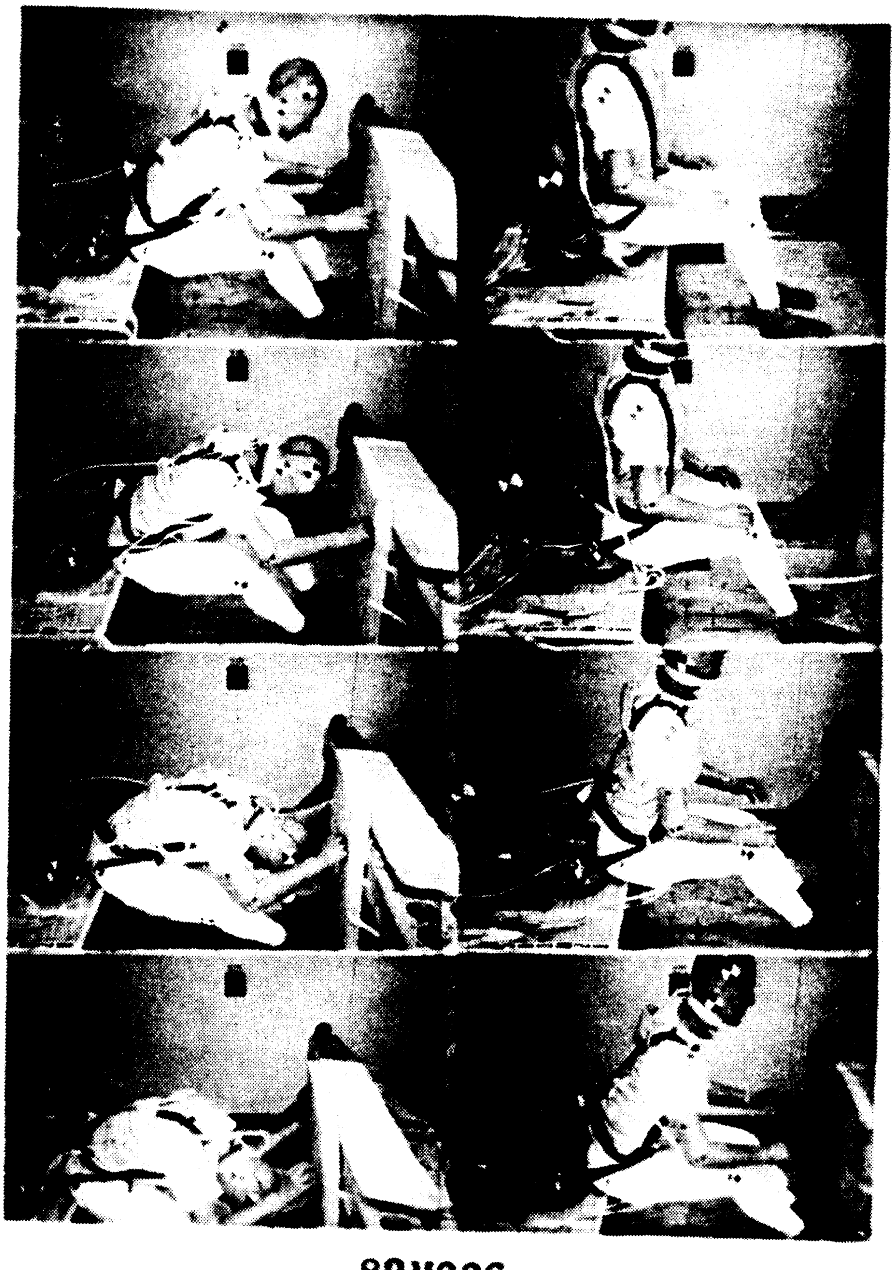
6 2
7 3
8 4



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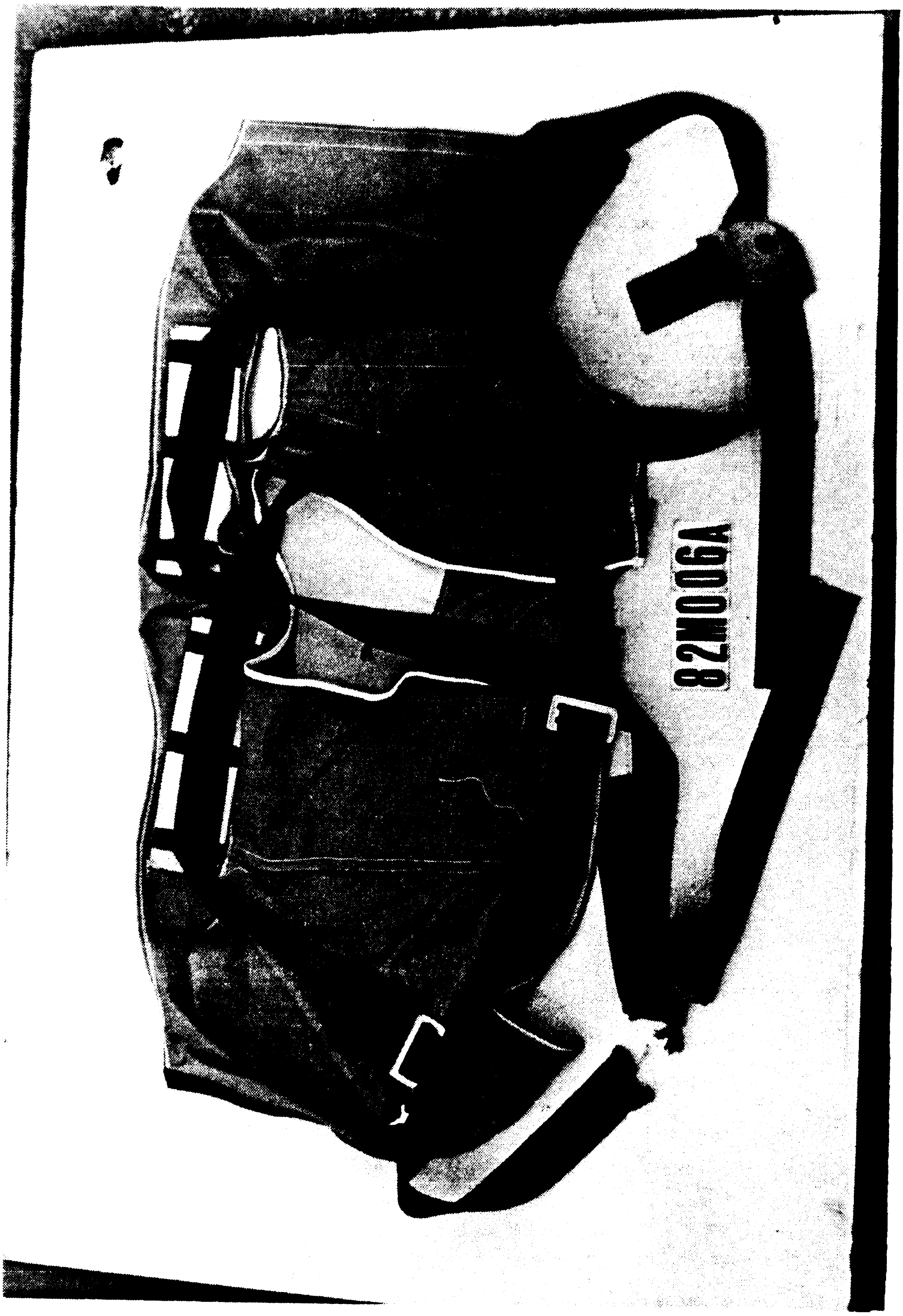
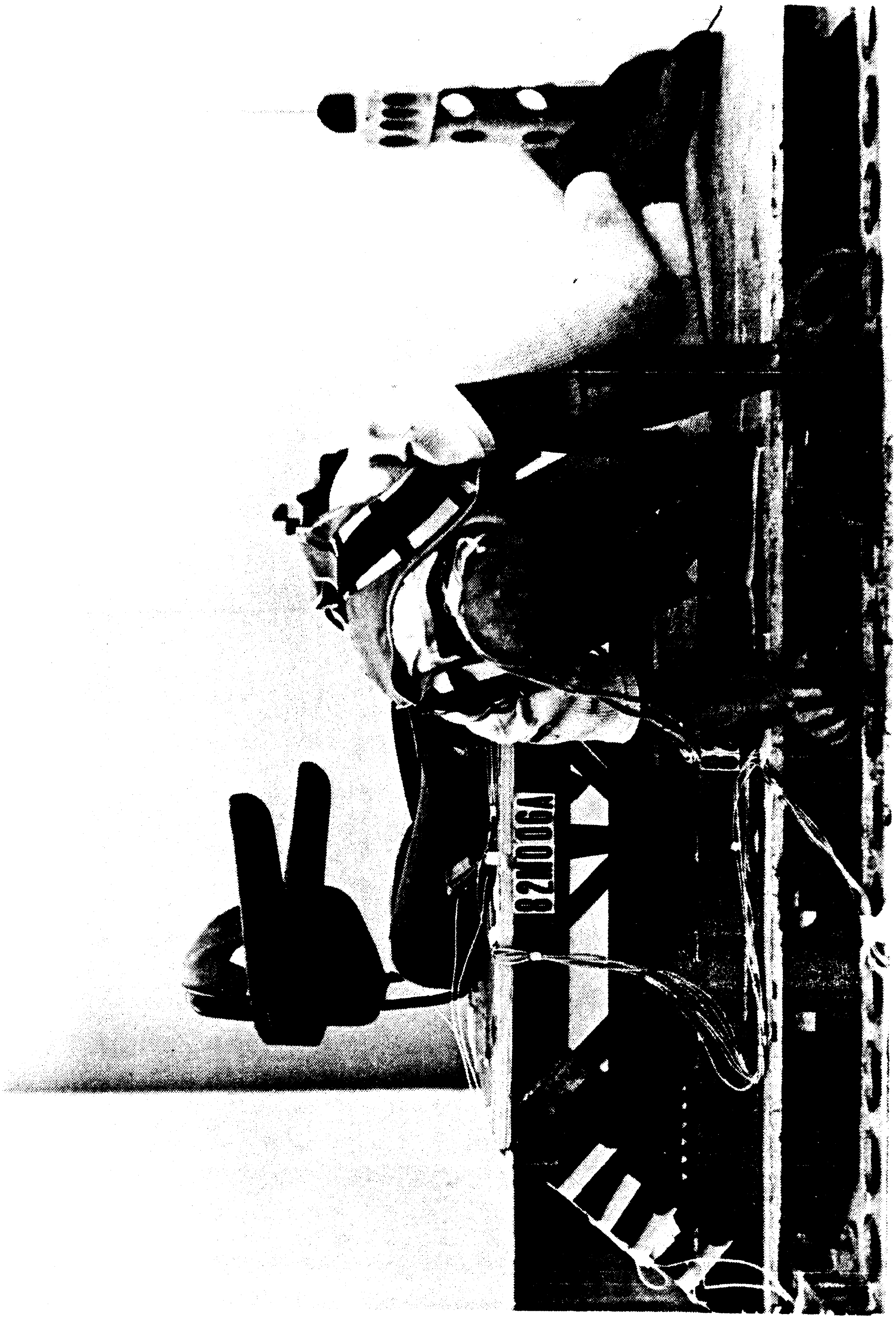
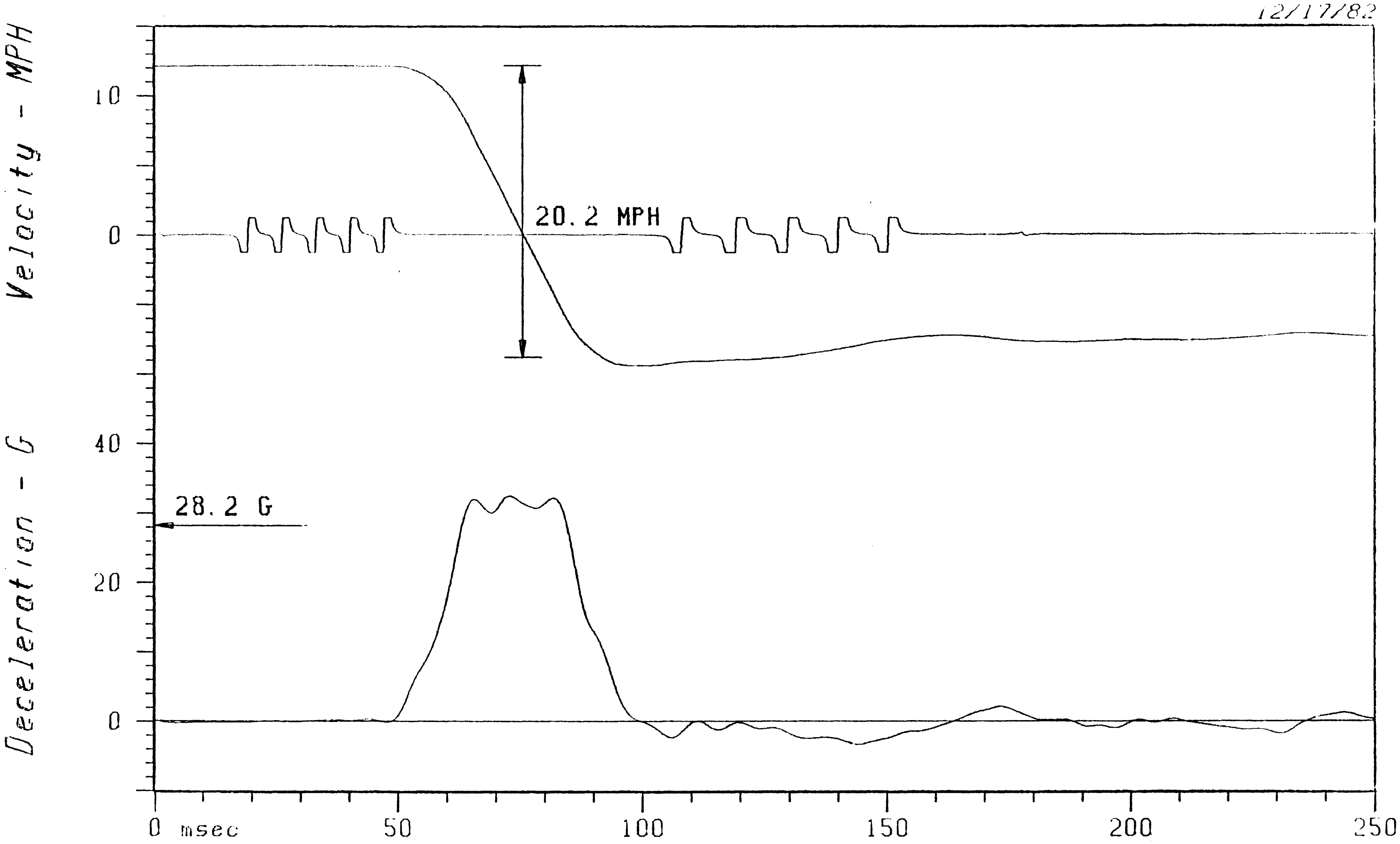



82M006A

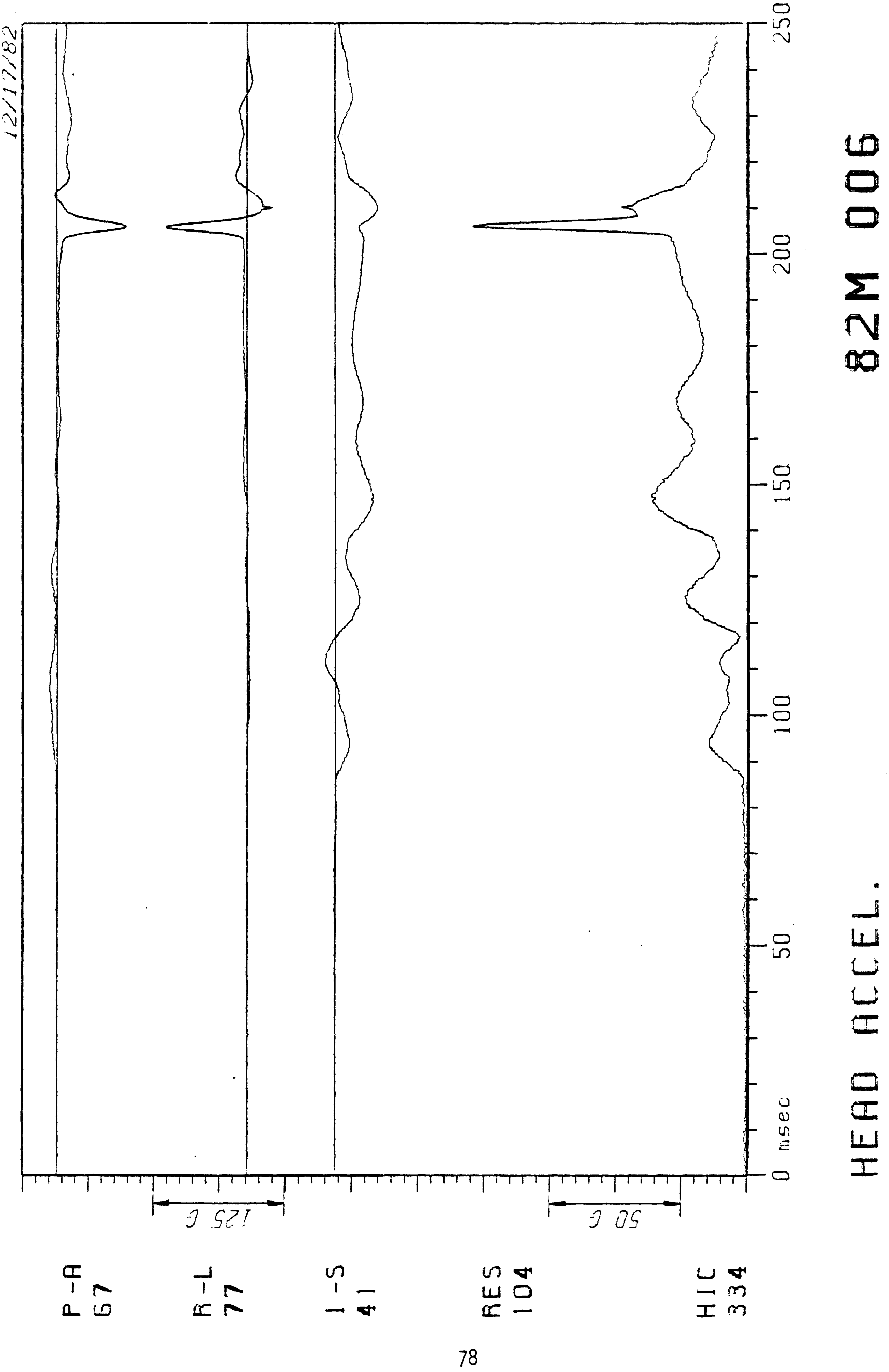

82MD06A

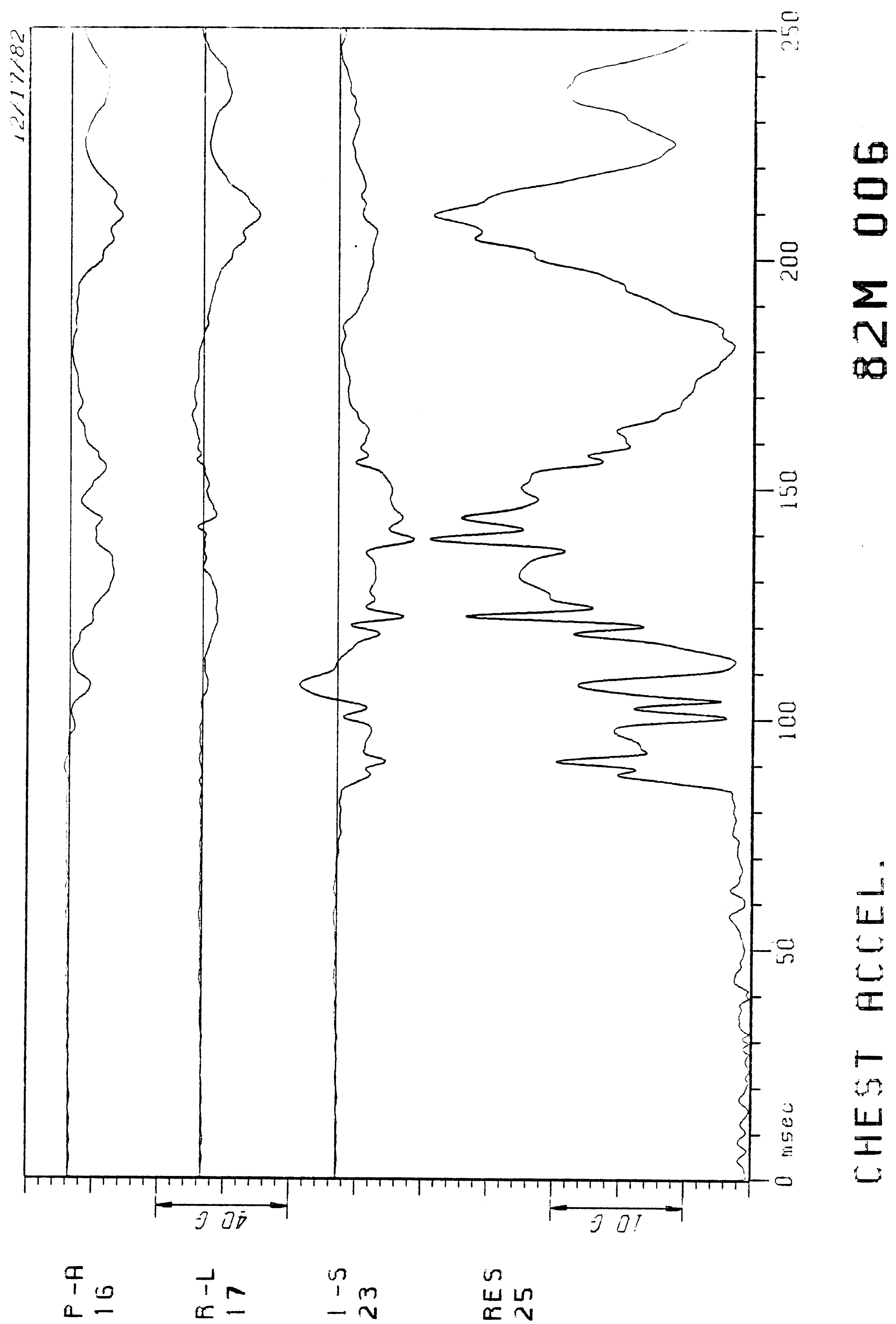


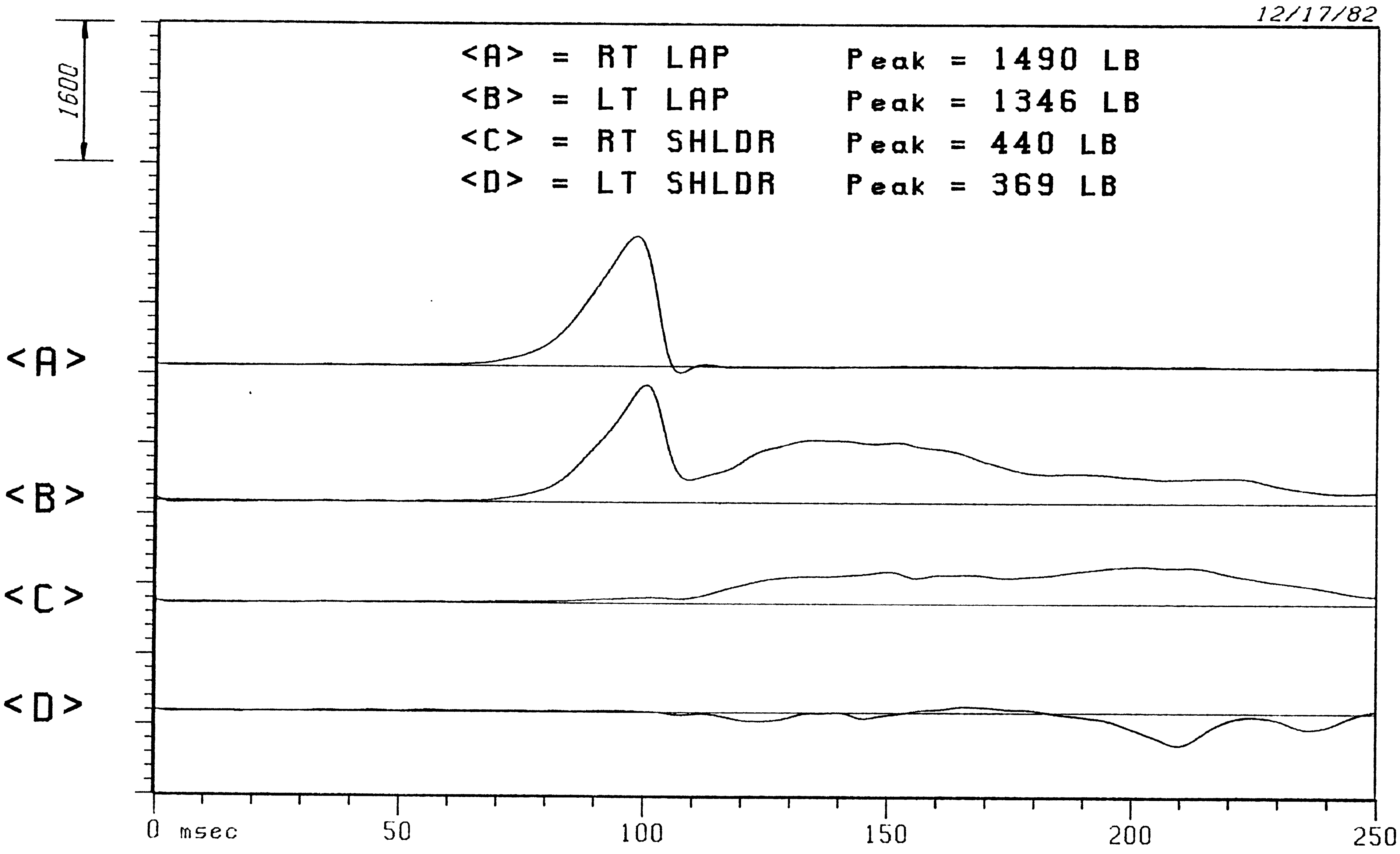


SLED PRØFILE

82M 006


12/17/82
82M 006
HEAD ACCEL.
0 msec
50
100
150
200
250
125 G
50 G
P-A 67
R-L 77
I-S 41
RES 104
HIC 334


12/17/82
P-A
16
R-L
17
I-S
23
RES
25
40 G
10 G
0 msec
50
100
150
200
250
CHEST ACCEL.
82M 006



BELT LOADS 82M 006

TEST SUMMARY

TEST NUMBER: 82M007

IMPACT VELOCITY: 19.2 mph

DECELERATION: 27.7 g

TEST RESULTS:

PEAK HEAD ACCELERATIONS

P-A: 154.9 g

R-L: 89.7 g

I-S: 118.7 g

PEAK RESULTANT: 211.3 g

HIC: 1380

PEAK CHEST ACCELERATIONS

P-A: 33.8 g

R-L: 5.9 g

I-S: 34.4 g

PEAK RESULTANT: 36.8 g

BELT LOADS

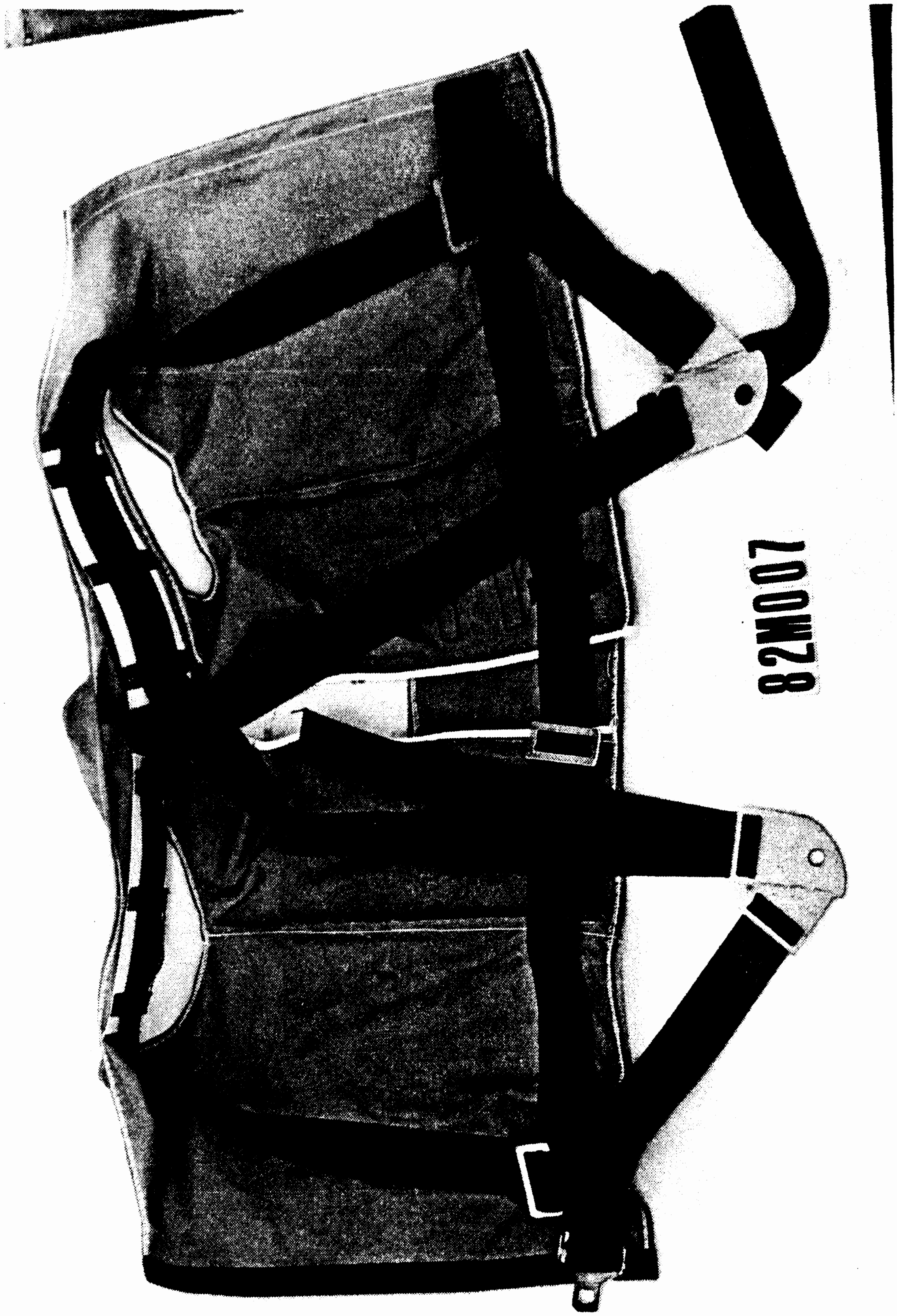
RIGHT LAP: 1895 lbs

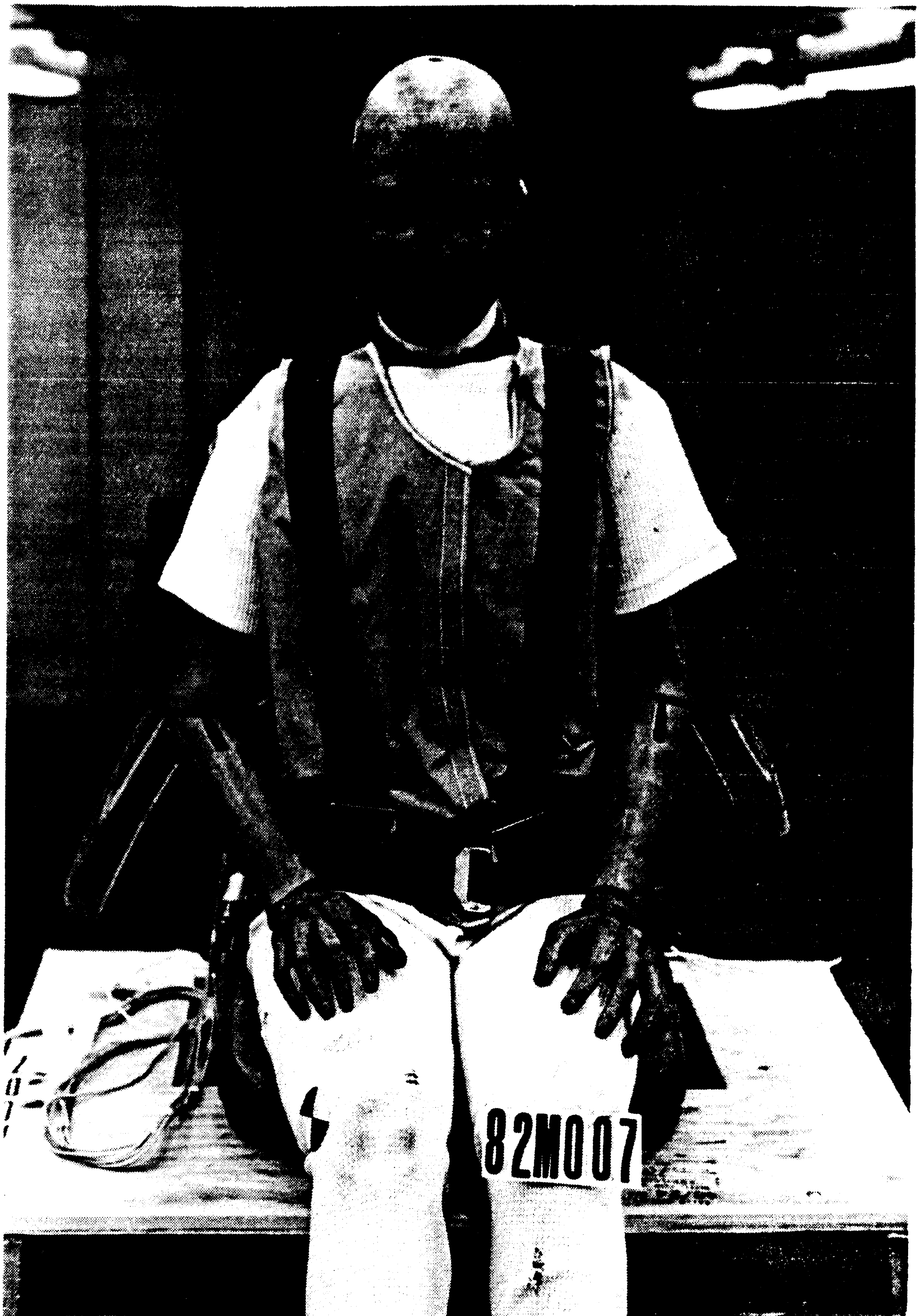
LEFT LAP: 1655 lbs

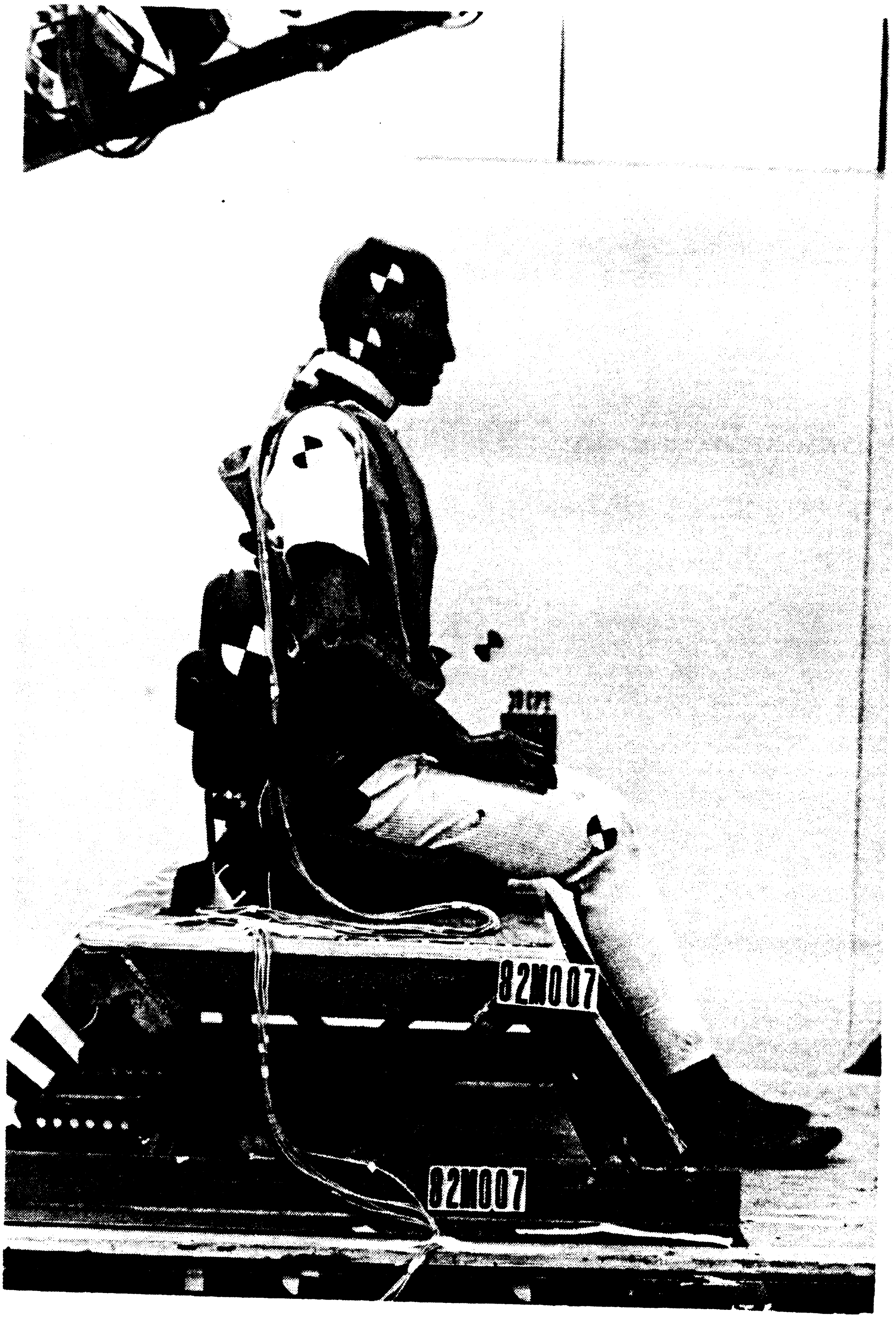
RIGHT REAR TETHER STRAP: 270 lbs

LEFT REAR TETHER STRAP: 115 lbs

OBSERVATIONS: Harness system performed well. The dummy was restrained on the seat with acceptable excursion, and the lap belt portion of the harness appeared to remain low on the pelvis. The high HIC value of 1380 resulted from the dummy's head striking its lower legs at maximum excursion.


82MW07


82M007


82M007
82M007

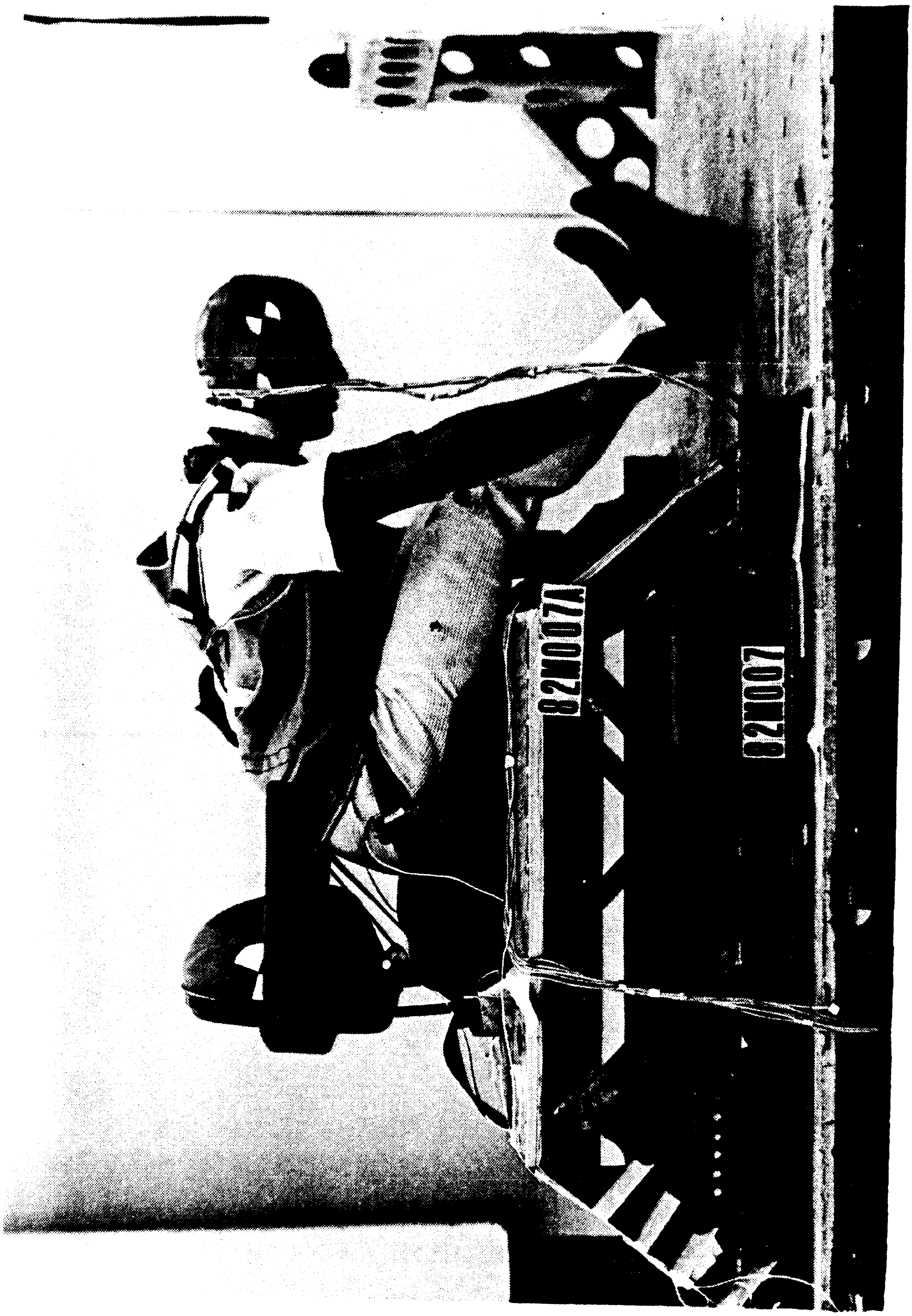
5 1

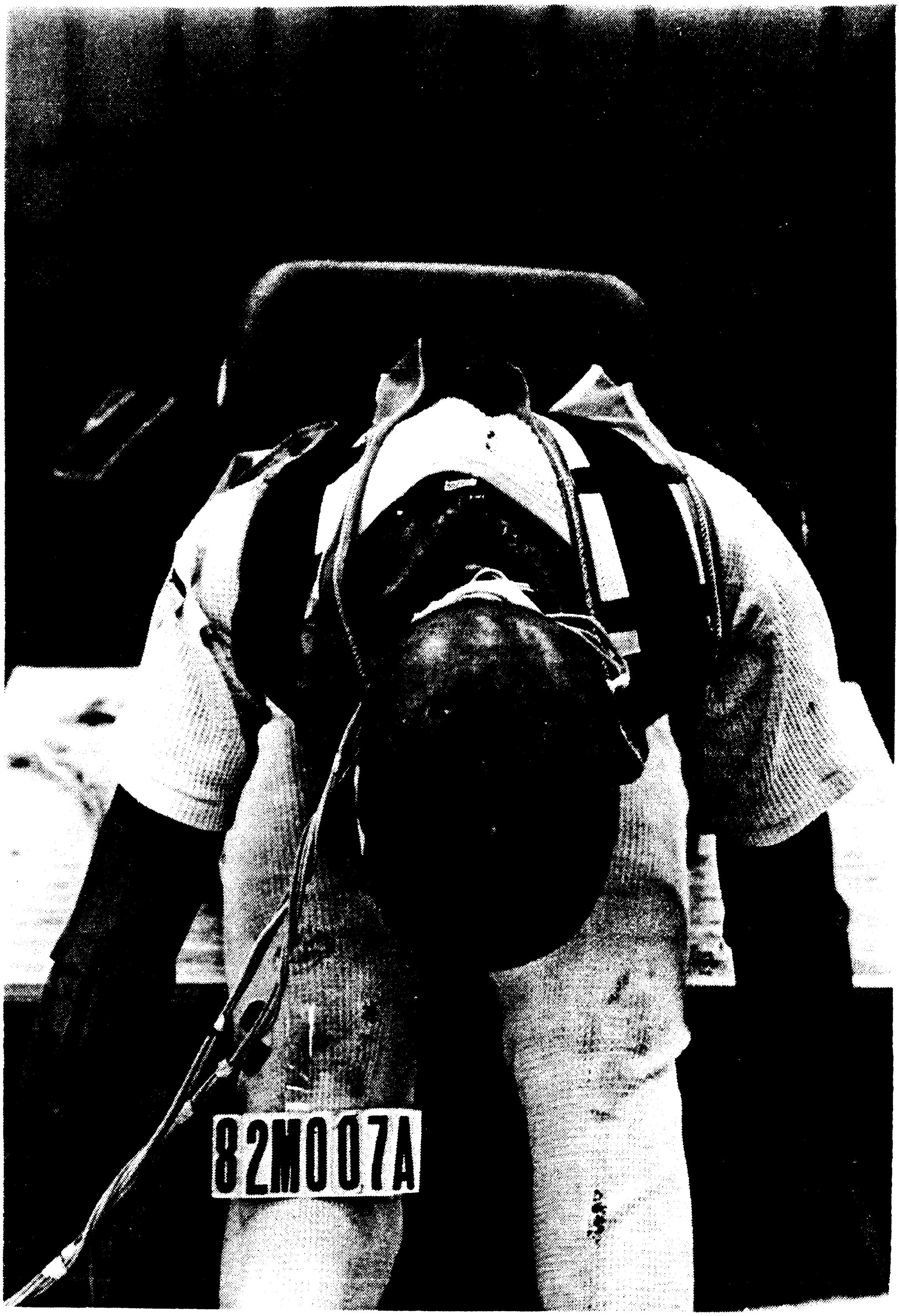
6 2

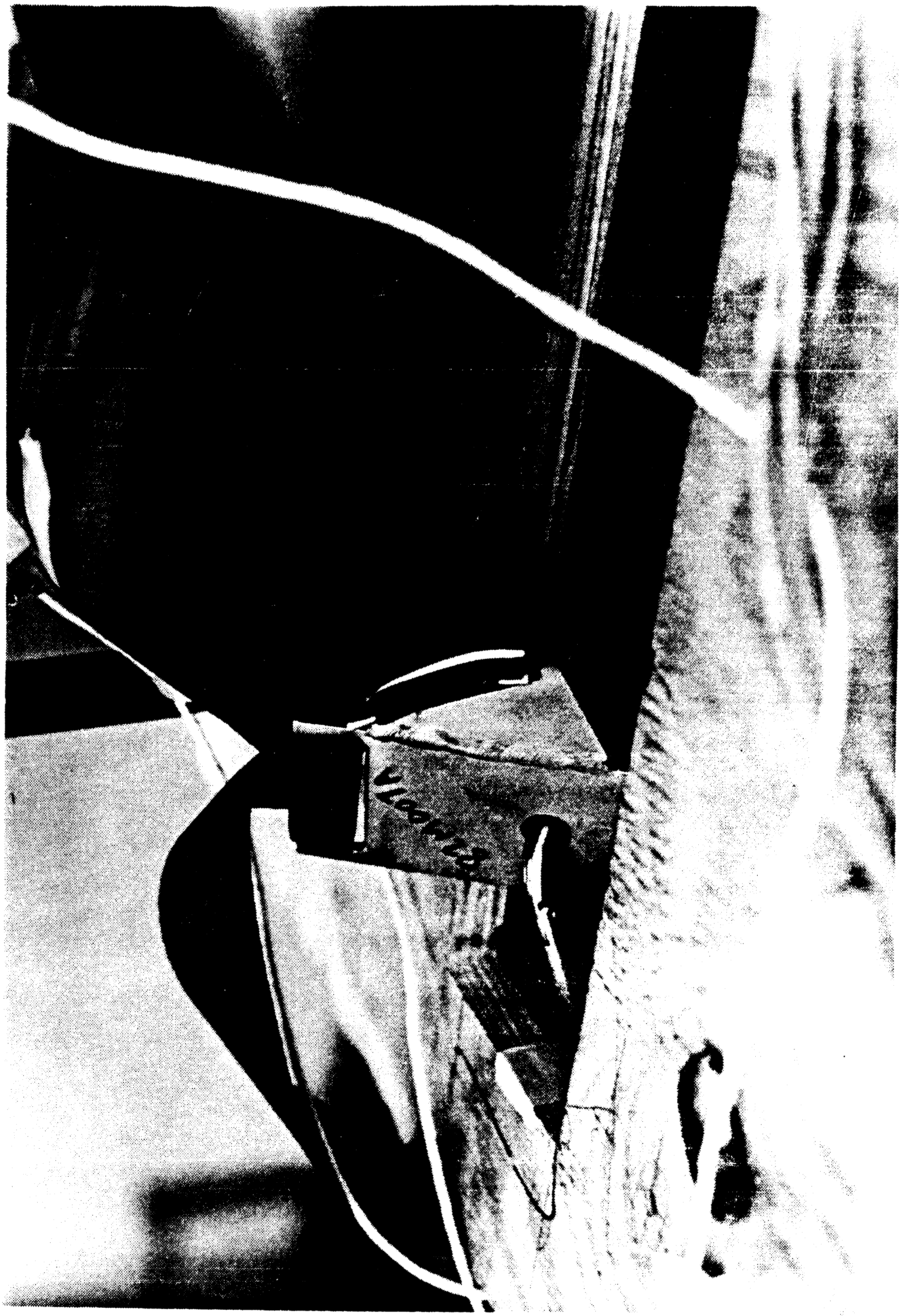
7 3

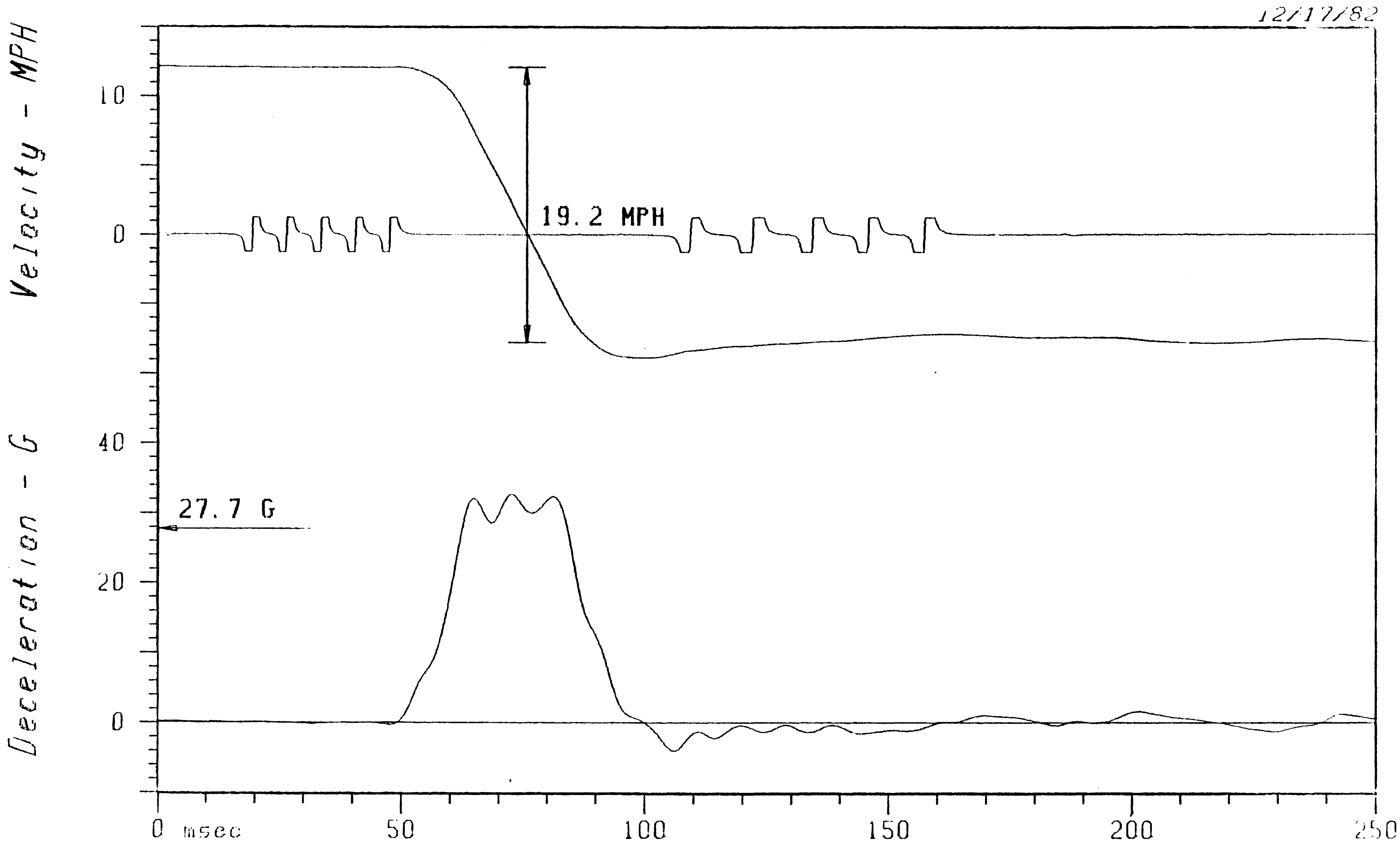
8 4

82M007



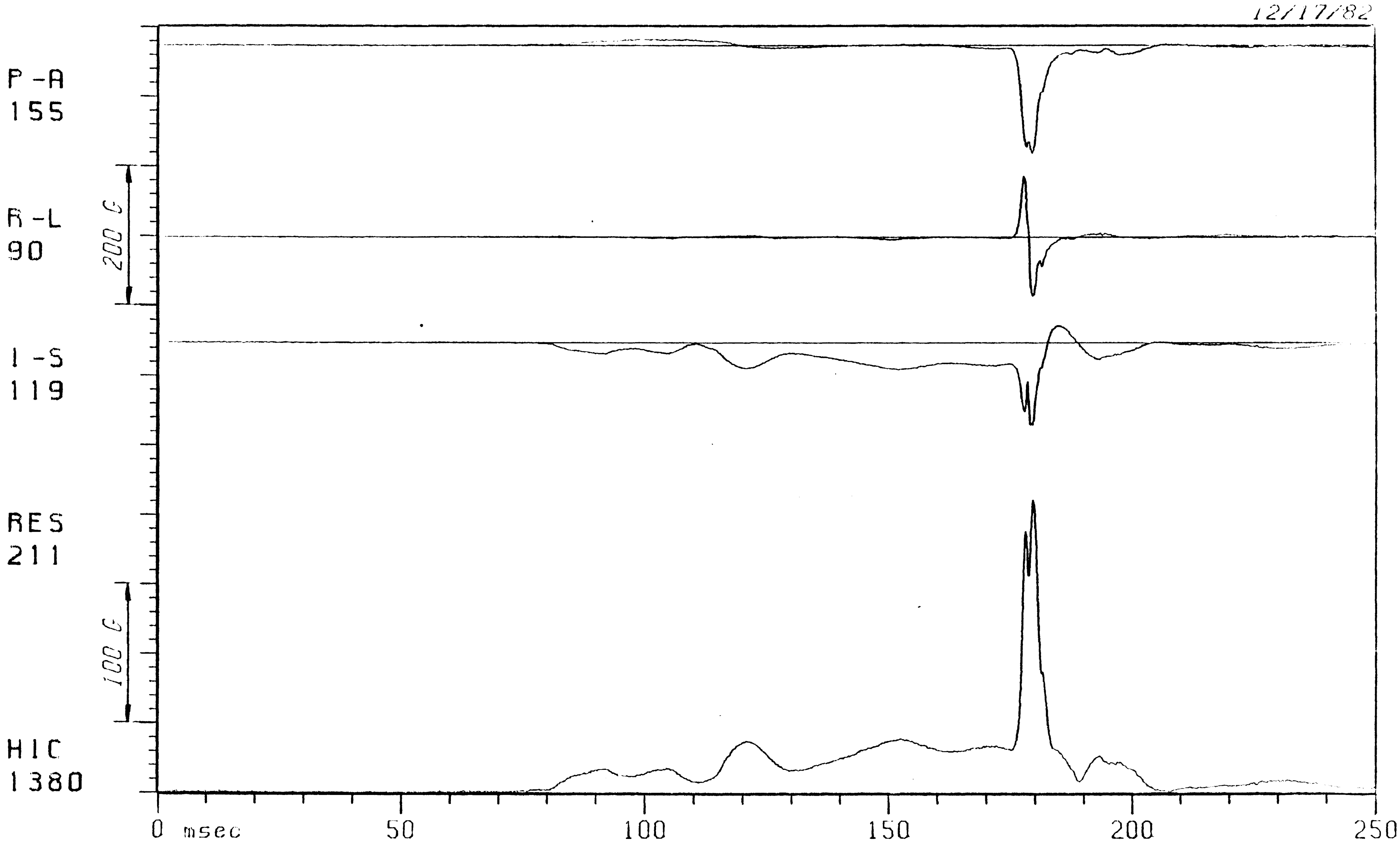

82M007A





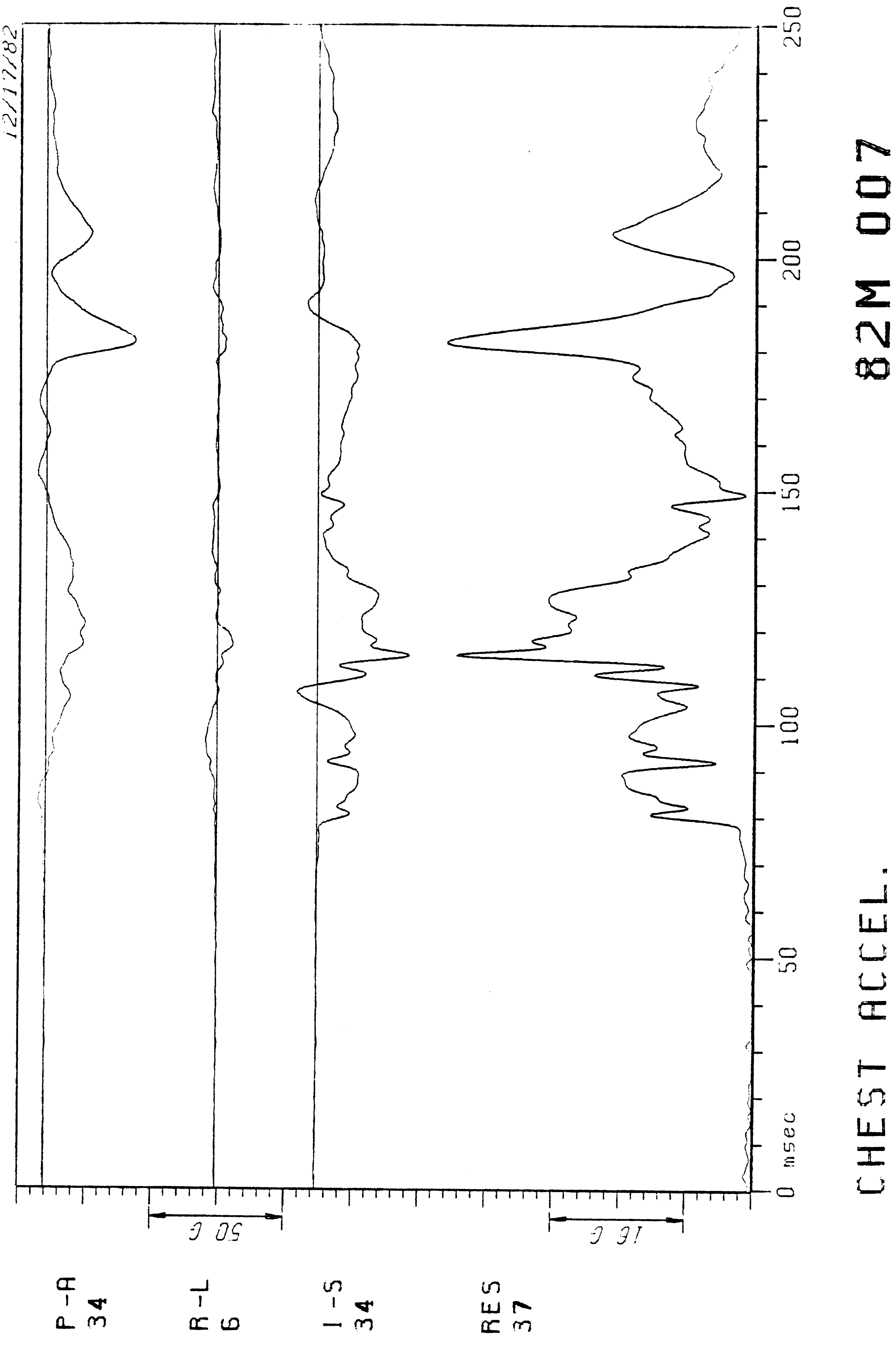
SLED PROFILE

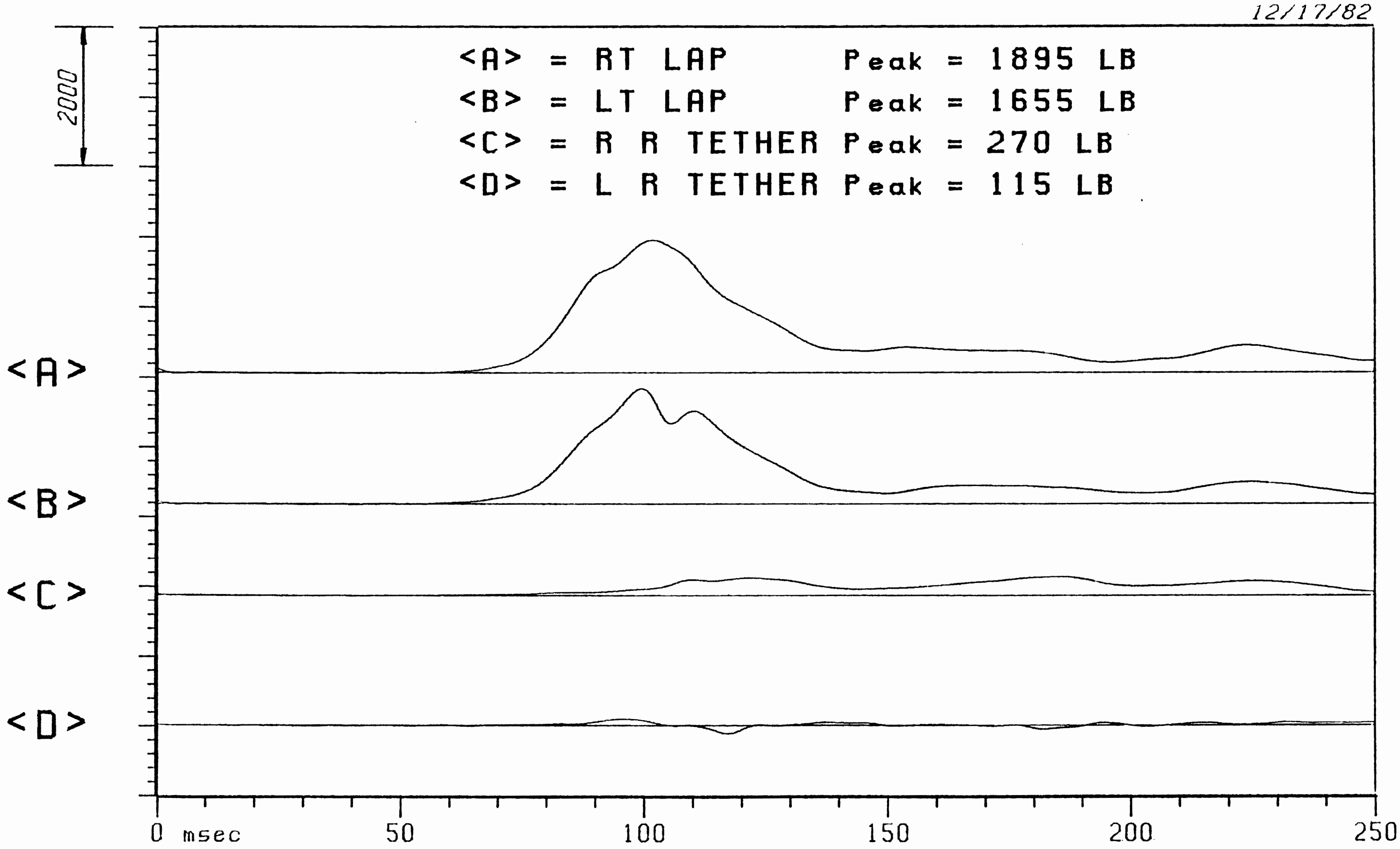
82M 007



HEAD ACCEL.

82M 007


CHEST ACCEL.
82M 007
12/17/82
P-A 34
R-L 6
I-S 34
RES 37
50 G
0 msec
50
100
150
200
250



BELT LØADS

82M 007

TEST SUMMARY

TEST NUMBER: 83M001

IMPACT VELOCITY: 19.4 mph

DECELERATION: 28.5 g

TEST RESULTS:

PEAK HEAD ACCELERATIONS

P-A: 20.6 g

R-L: 4.9 g

I-S: 40.1 g

PEAK RESULTANT: 40.8 g

HIC: 287

PEAK CHEST ACCELERATIONS

P-A: 31.0

R-L: 4.6

I-S: 35.5

PEAK RESULTANT: 42.3 g

BELT LOADS

RIGHT FRONT TETHER STRAP: 1227 lbs

RIGHT REAR TETHER STRAP: 822 lbs

LEFT REAR TETHER STRAP: 671 lbs

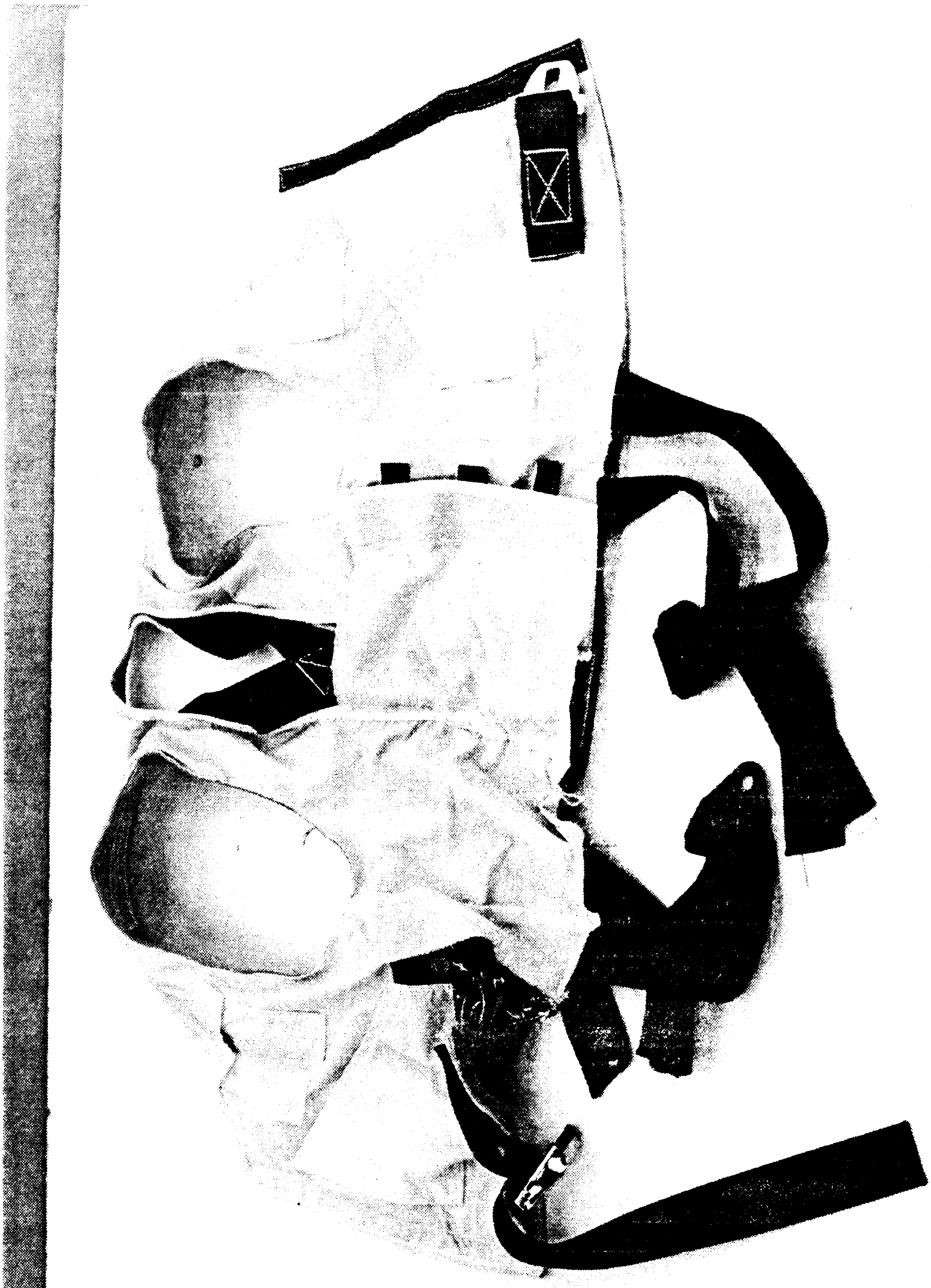
LEFT FRONT TETHER STRAP: 1110 lbs

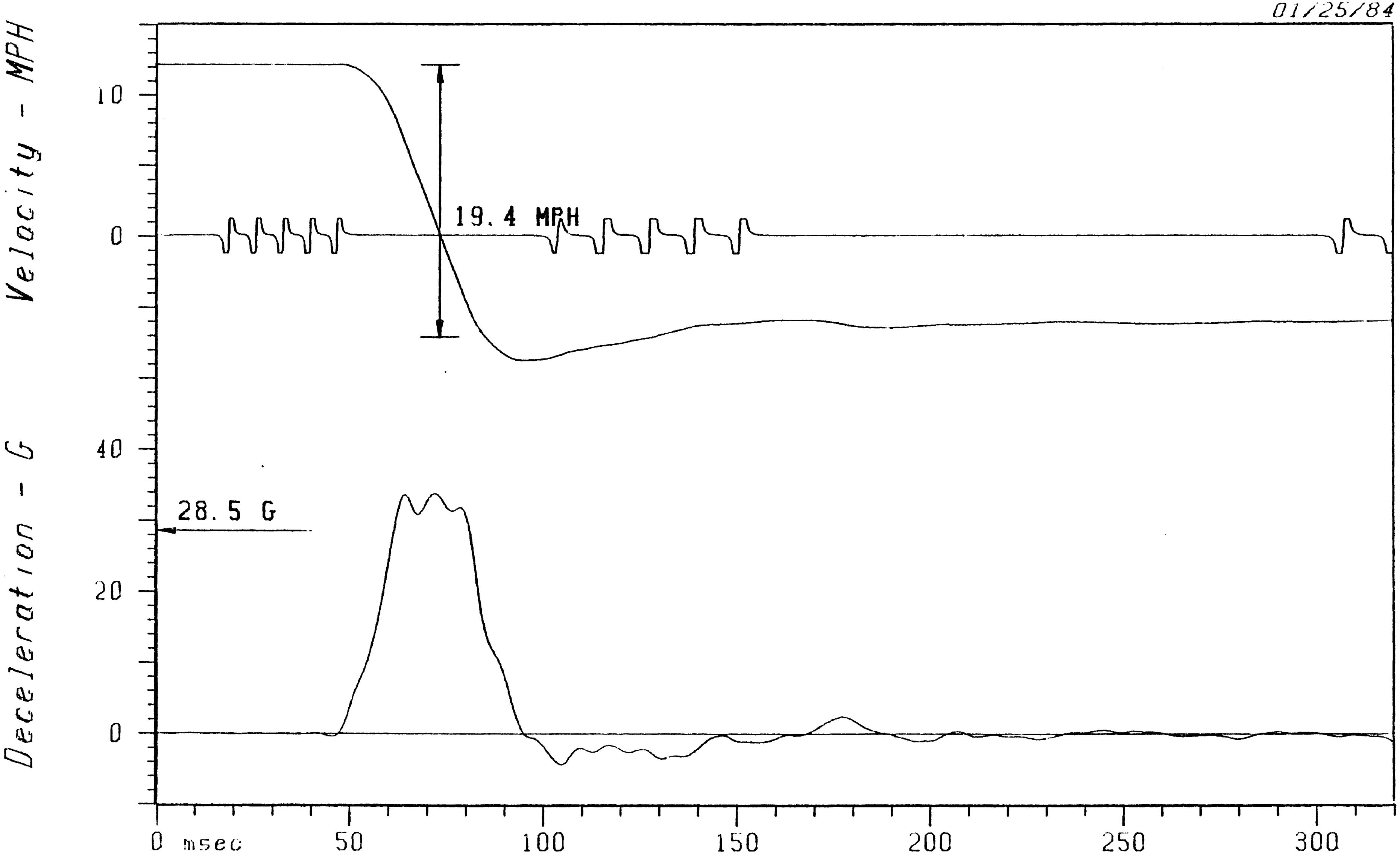
OBSERVATIONS: Harness stitching failed, allowing the dummy to slide off the front edge of the seat and producing abdominal belt intrusion.


83M001
83M001


30 RPS
83M001A
83M001

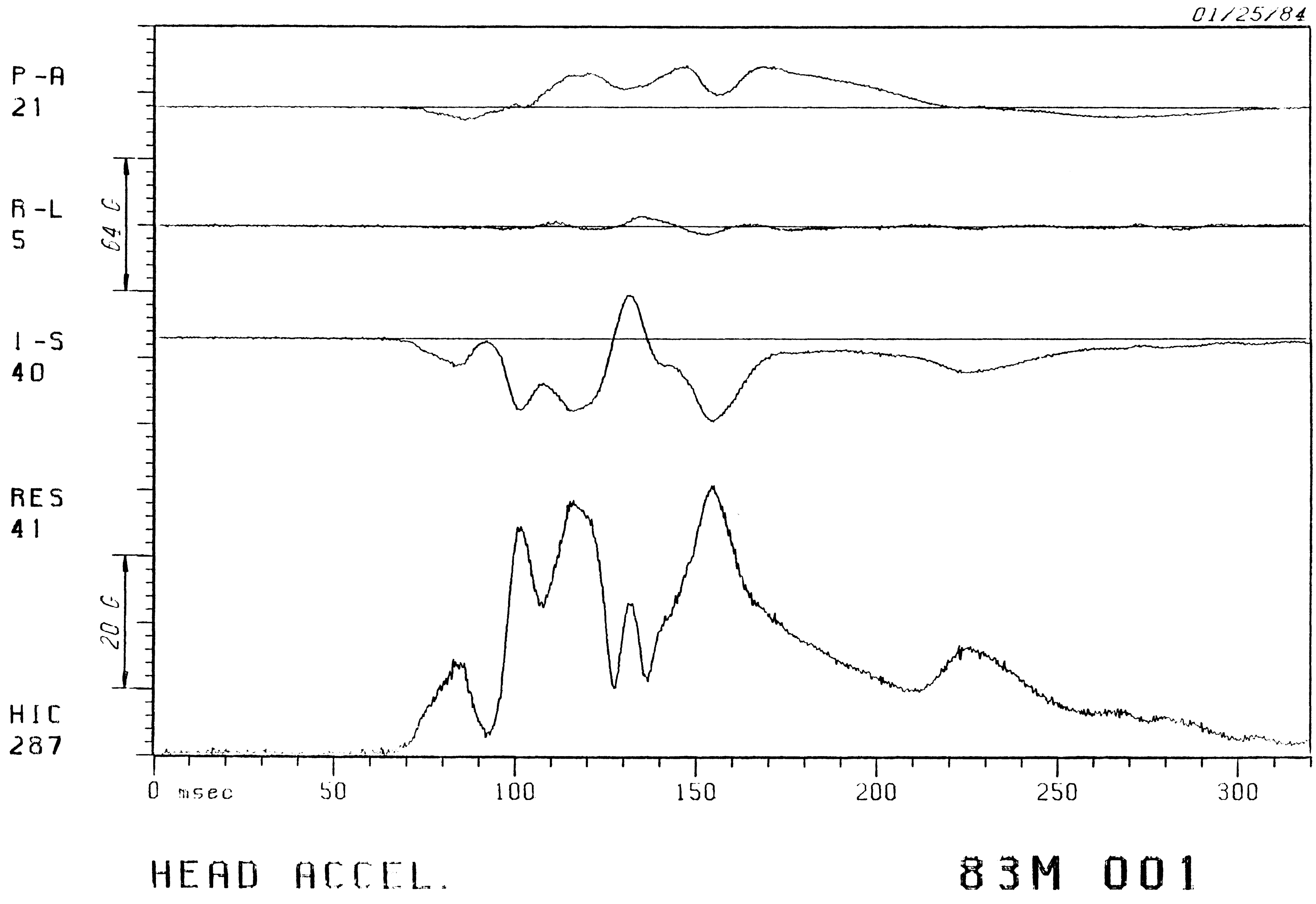

83M001A
83M001

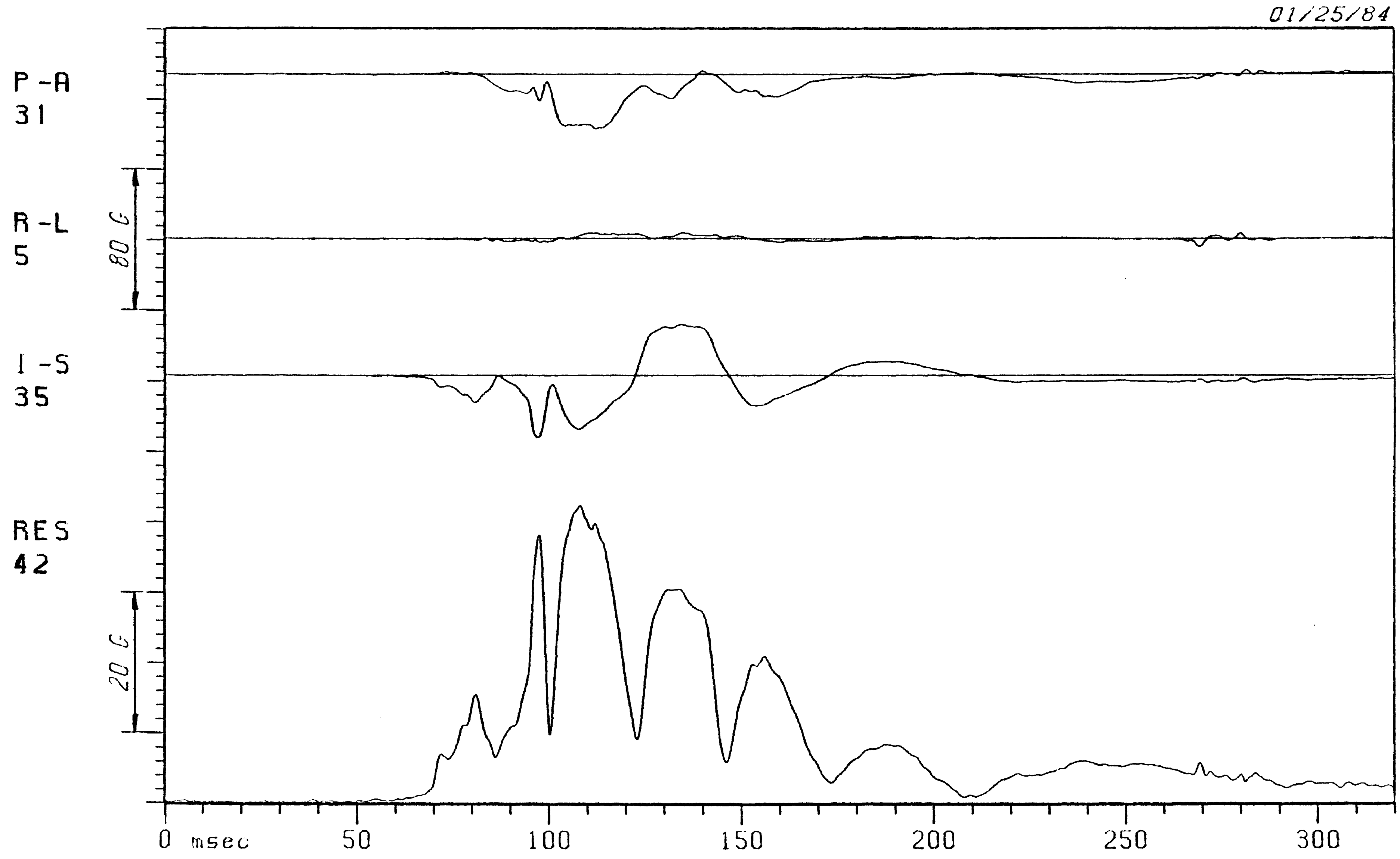




SLED PROFILE

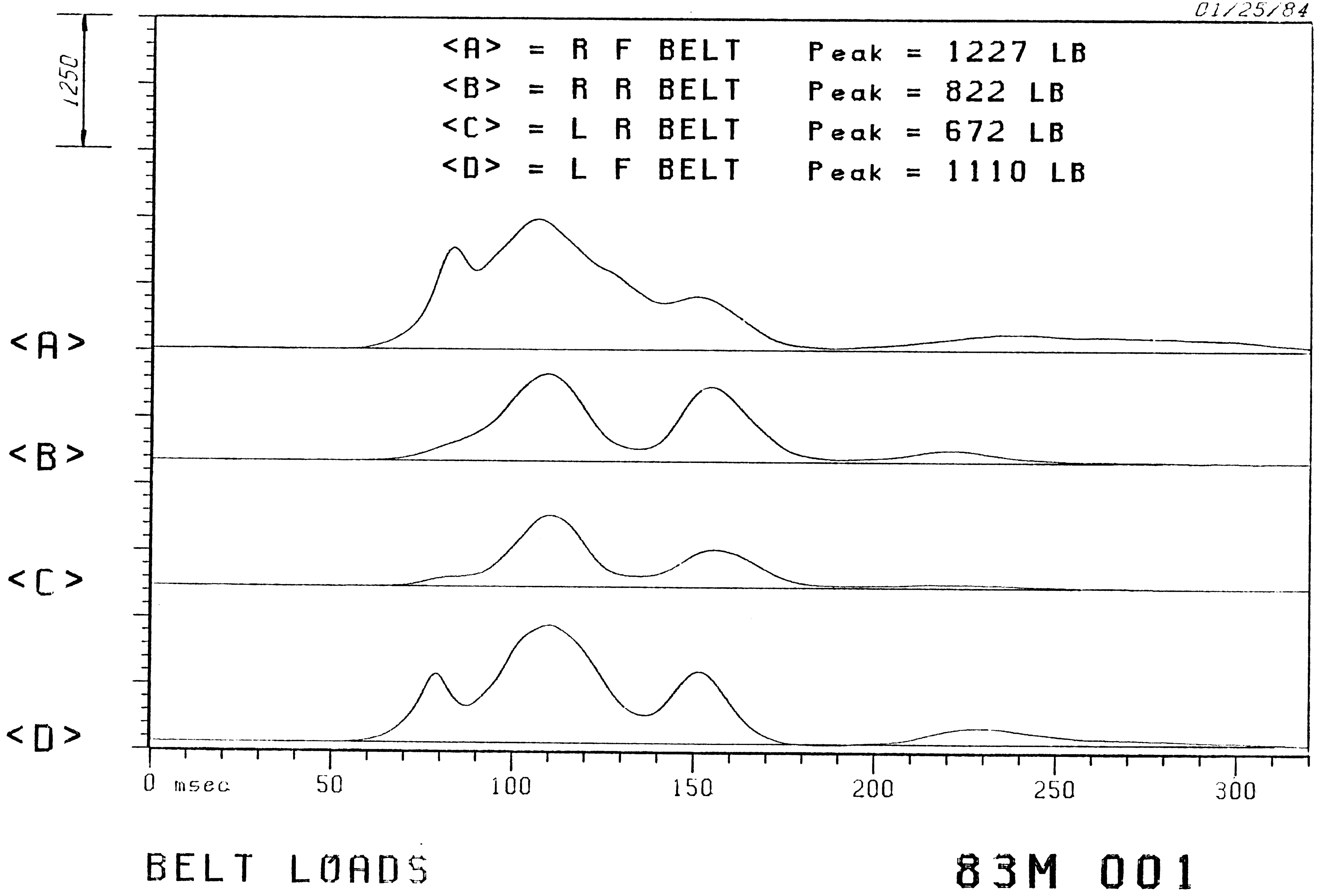
83M 001


01/25/84
P-A
21
R-L
5
I-S
40
RES
41
HIC
287
64 G
20 G
0 msec
50
100
150
200
250
300
HEAD ACCEL.
83M 001



CHEST ACCEL.

83M 001


01/25/84
1250
<A> = R F BELT Peak = 1227 LB
<B> = R R BELT Peak = 822 LB
<C> = L R BELT Peak = 672 LB
<D> = L F BELT Peak = 1110 LB
<A>
<B>
<C>
<D>
0 msec
50
100
150
200
250
300
BELT LØADS
83M 001