UMTRI-83-51

EVALUATION OF THE UPGRADED HEAVY EQUIPMENT OPERATORS' SAFETY BELT RESTRAINT SYSTEM

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16. Abstract

A proposed innovative restraint harness developed by U. S. Steel for the protection of heavy equipment operators was dynamically tested to evaluate design changes made as a result of prior testing. Five frontal impacts were conducted on the UMTRI sled facility. An instrumented 50th percentile male Part 572 dummy simulated the equipment operator. Fixed forklift and suspension-type seating surfaces were used. The upgraded harness performance was compared to previous results obtained with a conventional lap belt. This report presents the data from the sled testing and makes further recommendations for improving the restraint system.

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I. Summary

A revised heavy equipment operator's safety belt restraint system with fixed instead of floating side tether straps was evaluated for frontal impact protection on both fixed and suspension-type seats using the UMTRI sled facility. Five tests were run and the results compared to a previous test using a conventional 2" lap belt.

The finding are summarized as follows:

- When tested on a fixed forklift seat, the revised U. S. Steel restraint system produced slightly lower head and knee excursions, and slightly higher pelvis excursions than obtained with a 2" lap belt.
- The flexing of the suspension-type seat during impact increased dummy excursions by up to four inches over excursions obtained with a fixed seat.
- Metal edges along the sides of a seat cushion can cut the restraint tether straps if contact is made during impact.

II. Test Procedures and Results

Five dynamic tests were conducted on the UMTRI impact sled to evaluate the revised U. S. Steel restraint harness. All five tests simulated a frontal impact.

Two test platforms were used. For the first three tests, the dummy was seated in a fixed forklift seat attached to a fabricated frame structure which was bolted to the sled. The last two tests utilized a heavy equipment suspension-type seat bolted directly to the sled platform.

Photographic coverage consisted of two Photosonics 1-B movie cameras operating at 1000 frames per second providing side and overhead views of the test. A Polaroid Graph-Check sequence camera provided a "quick-look" at the restraint performance immediately after each test. Black and white 35 mm setup and post-test photos were taken for each test setup.

A 50th percentile male Part 572 anthropomorphic dummy instrumented with a triaxial accelerometer array mounted in its head and chest was used in these tests. The double webbing thickness of the harness tethers prevented the monitoring of belt forces. Test data signals were recorded during each impact on a Honeywell Model 96 recorder and then digitized, analyzed, and plotted using a NOVA/4 laboratory computer.

Table I summarizes the test results obtained with the revised harness design. Table II compares the performance of the U. S. Steel restraint system on both a fixed forklift seat and a suspension seat to previous results obtained with a 2-inch lap belt on a forklift seat.

Table I. Summary of Sled Test Results

Test Number:	83S001	83S002	83S003	83S004	83S005
Restraint System:	U. S. Steel	U. S. Steel	U. S. Steel	U. S. Steel	U. S. Steel
Seating:	Forklift	Forklift	Forklift	Suspension	Suspension
Velocity (mph):	17.5	16.9	30.7	18.4	17.8
Deceleration (g):	33.5	31.9	22.7	29.8	29.8
Impact Direction:	Frontal	Frontal	Frontal	Frontal	Frontal
Max. Excursion (in.)					
HEAD:	NA	32.5	35.2	NA	36.5
KNEES:	NA	7.7	9.2	NA	11.5
PELVIS:	NA	6.5	7.9	NA	9.4
Peak Resultant Accelerations (g)					
HEAD:	34.7	97	307	25.7	183
CHEST:	16.6	23.9	67	24.7	29.4
Head Injury Criteria (HIC):	72	330	2603	127	686

Table II. Performance Comparison

Test Number:	82S002	83S002	83S005
Restraint System:	2" lap belt	U. S. Steel	U. S. Steel
Seating:	Forklift	Forklift	Suspension
Velocity (mph):	18.5	16.9	17.8
Deceleration (g):	30.0	31.9	29.8
Impact Direction:	Frontal	Frontal	Frontal
Max. Excursions (in.)			
HEAD:	33.7	32.5	36.5
KNEES:	7.9	7.7	11.5
PELVIS:	6.2	6.5	9.4
Peak Resultant Acceleration (g)			
HEAD:	185	97	183
CHEST:	35	23.9	29.4
Head Injury Criteria (HIC):	652	330	686

III. Discussion

The revised belt harness as first received had the side tethers stitched to the main belt at 90 degrees, eliminating the previous fore-aft motion but not providing an optimum loading angle. Pull-type adjusters were provided on the tethers, which greatly simplified belt tensioning, but they required an awkward, downward pull by the operator.

In the first test, 83S001, the stitching which held the side tethers to the main belt failed. The following improvements were decided upon:

- The use of a lock-stitch to increase the strength of the side tether attachment.
- Angling the side tethers rearward to reduce belt slack and prevent the stitching from being loaded unevenly.
- Changing the adjustment configuration of the side tethers to permit an upwards pull by the operator for belt tensioning.

All these improvements were incorporated in a second set of revised harnesses, with the side tethers angled rearward at 25°. The upward-pull tether tensioners worked very well and should make it much easier for an operator to properly adjust his restraint harness.

Four additional sled tests were then conducted on these upgraded harnesses, as indicated below:

Test 83S002 was run at 16.9 mph and 31.9 g on the forklift seat. The U. S. Steel harness restrained the dummy with equivalent or better excursions, peak accelerations, and HIC than a conventional 2" lap belt. (See Table II). A slight puckering was observed in the belt fabric at the side tether stitching after the impact, but seemed to relax with time. No degradation of the restraint webbing or hardware was observed.

Test 83S003 was run at 30.7 mph and 27.7 g on the forklift seat. This higher-velocity impact was used to evaluate the U. S. Steel restraint under typical automotive compliance conditions. The excursions were only slightly increased from those obtained in the previous test. Belt puckering occurred at the side tether stitching, but no degradation of the restraint was observed. The significantly higher head accelerations and

HIC resulted from the dummy head's striking the legs during impact, and cannot be meaningfully compared to the other test results.

Test 83S004 was run at 18.4 mph and 29.8 g on a suspension-type seat. The restraint tethers could not be shortened adequately to utilize the belt attachment points on the seat side-frames, so additional bracketry was fabricated below the side-frames with anchor points that maintained the 45° tether angle. The right side tether strap failed as it pulled across the upper edge of the seat side-frame. The left tether also displayed signs of similar abrasion, although these edges were not abnormally sharp. The edges on both sides of the seat were rounded with a file and covered with several layers of duct tape before further testing.

Test 83S005 was run at 17.8 mph and 29.8 g on a suspension-type seat. This duplicated the conditions of the previous test, but with the seat side-frame edges rounded and taped to protect the restraint. Despite the forward tipping of the suspension seat, which increased excursion values somewhat, the restraint kept the dummy well positioned on the seat cushion during impact. The duct tape on the seat side-frames was abraded by the restraint tethers. (See post-test photos in the appendix).

The U. S. Steel restraint system, as redesigned with fixed instead of floating side tether straps, offers equivalent or better protection than a conventional 2" lap belt in frontal impacts. While the program budget did not permit retesting the restraint's side impact performance, the initial floating tether design had performed reasonably well in previous lateral tests. The fixed tethers of the redesigned restraint should provide equivalent or better protection from their elimination of potential belt slack.

A functional problem noted during testing was a tendency for the main 3" belt to frequently slip adjustment and loosen. An improved means of maintaining belt tension is needed to eliminate this annoyance, such as improved adjustment hardware or velcro securements for the loose belt ends.

IV. Recommendations

The following changes are suggested to further improve the U. S. Steel restraint system:

- Increase the angle of the tether straps to the main belt to 45° rearward.
- Allow the tether straps to be adjustable to a shorter length than the present design, to accommodate seat-mounted belt anchors.
- Provide abrasion protection such as a strip of nylon or plastic sheeting on the inboard faces of the tether strap to prevent cutting on seat frames.
- Provide a better means of maintaining the tension in the main belt, such as a velcro securement or improved belt adjustment hardware.

V. Appendix

1. Test Data

   Data are arranged in the following sequence for each impact test:

   - Test Summary
   - Data Plots
   - Setup Photograph
   - Graph-Check Photograph
   - Post-Test Photograph(s)

Test Summary TEST 83S001

Test Setup

Test Facility: UMTRI Impact Sled

Impact Parameters

Velocity: 17.5 mph

Deceleration: 33.5 g, peak, with half-sine waveform

Direction: Frontal

Restraint System: U. S. Steel

Test Results

Peak head accelerations

P-A (Posterior-Anterior):	min = - 7 g	max = 32 g
R-L (Right-Left):	min = - 5 g	max = 4 g
I-S (Inferior-Superior):	min = -22 g	max = 9 g
Resultant	34.7 g	
HIC (Head Injury Criteria)	72 from 88 to 248 ms	

Peak chest accelerations

P-A (Posterior-Anterior)	min = -10 g	max = 1 g
R-L (Right-Left)	min = - 3 g	max = 4 g
I-S (Inferior-Superior)	min = -15 g	max = 12 g
Resultant	16.6 g	

Peak belt loads

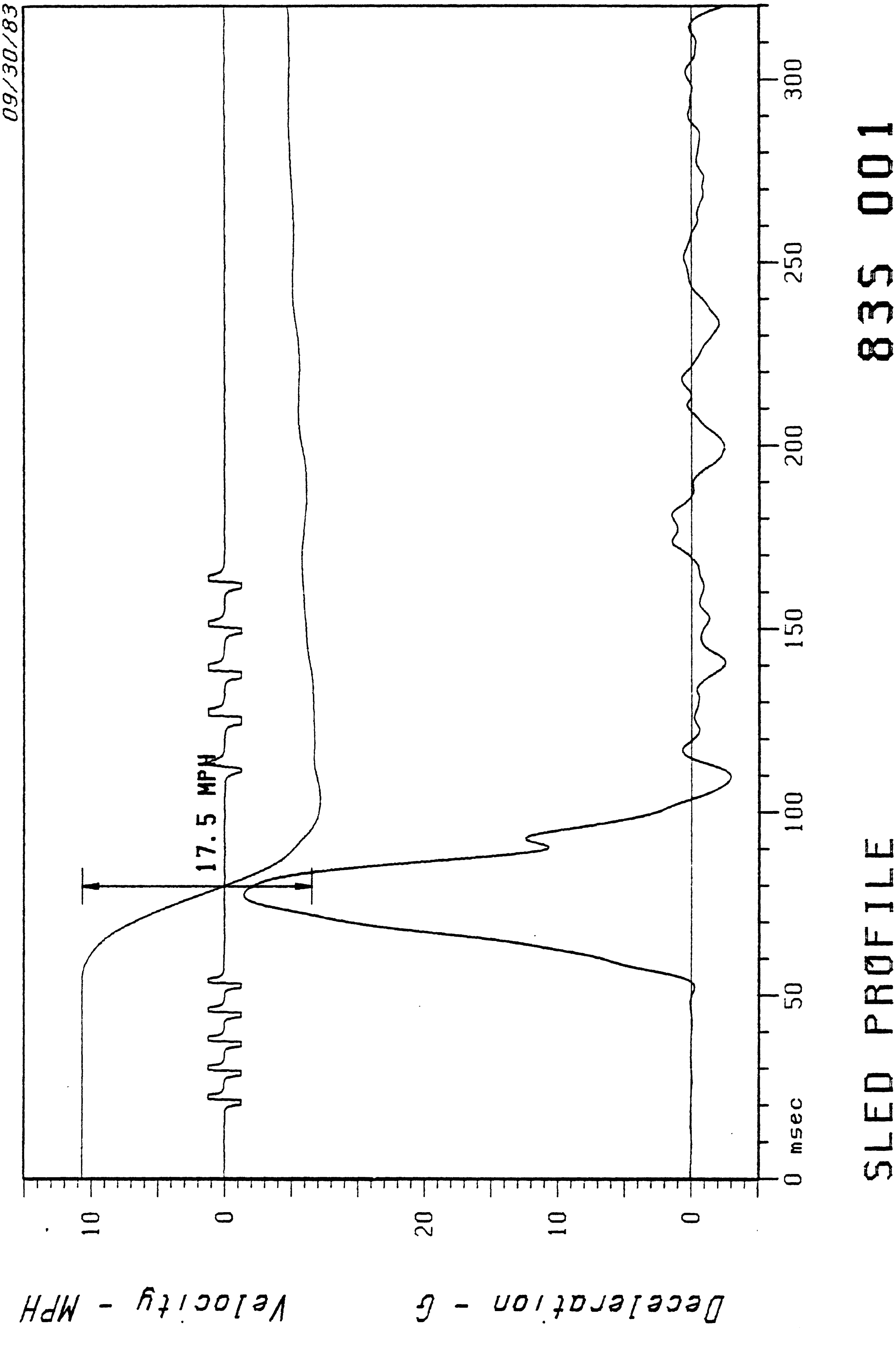
Right side:	N.A. pounds
Left side:	N.A. pounds

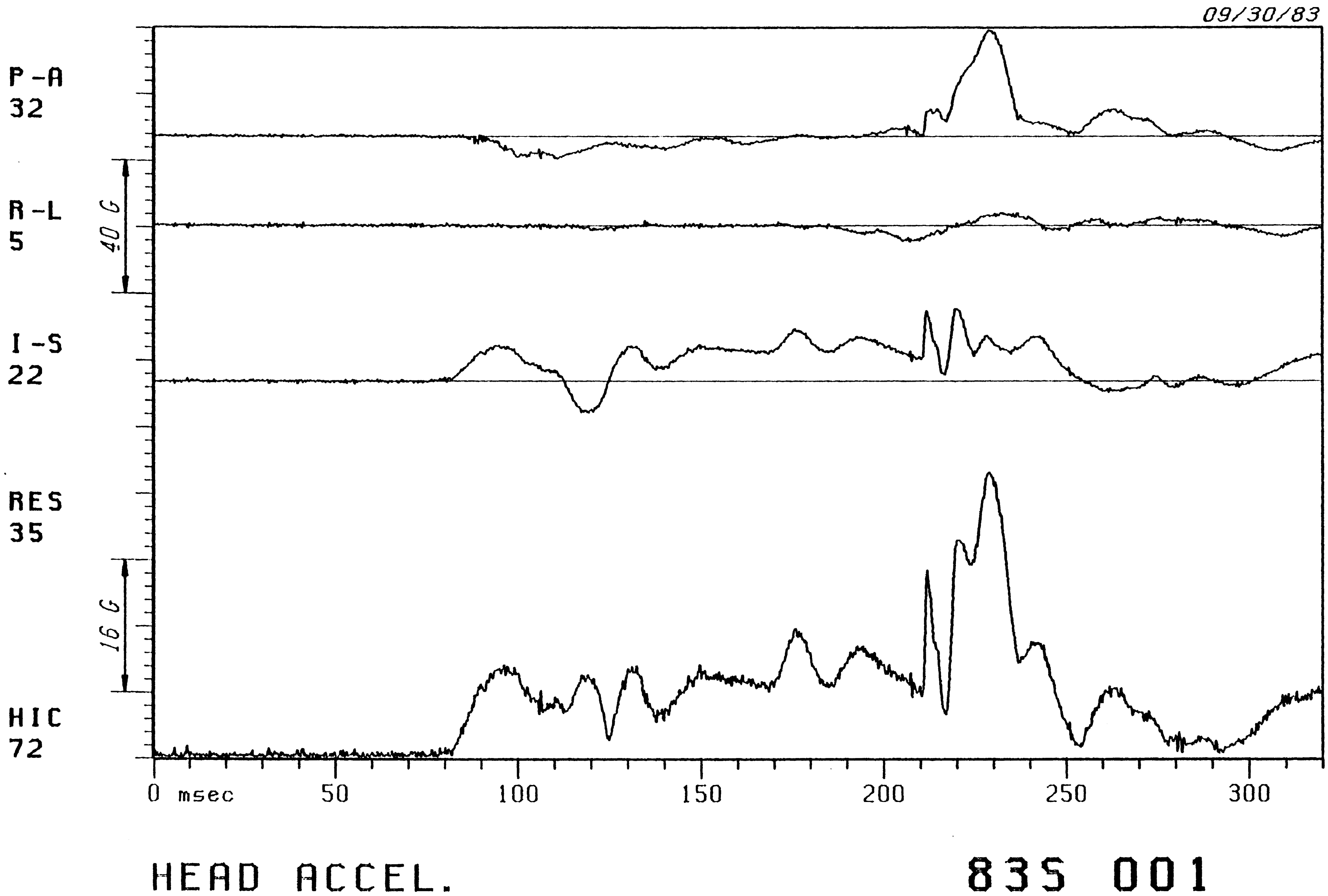
Maximum Excursions (from H. S. film analysis)

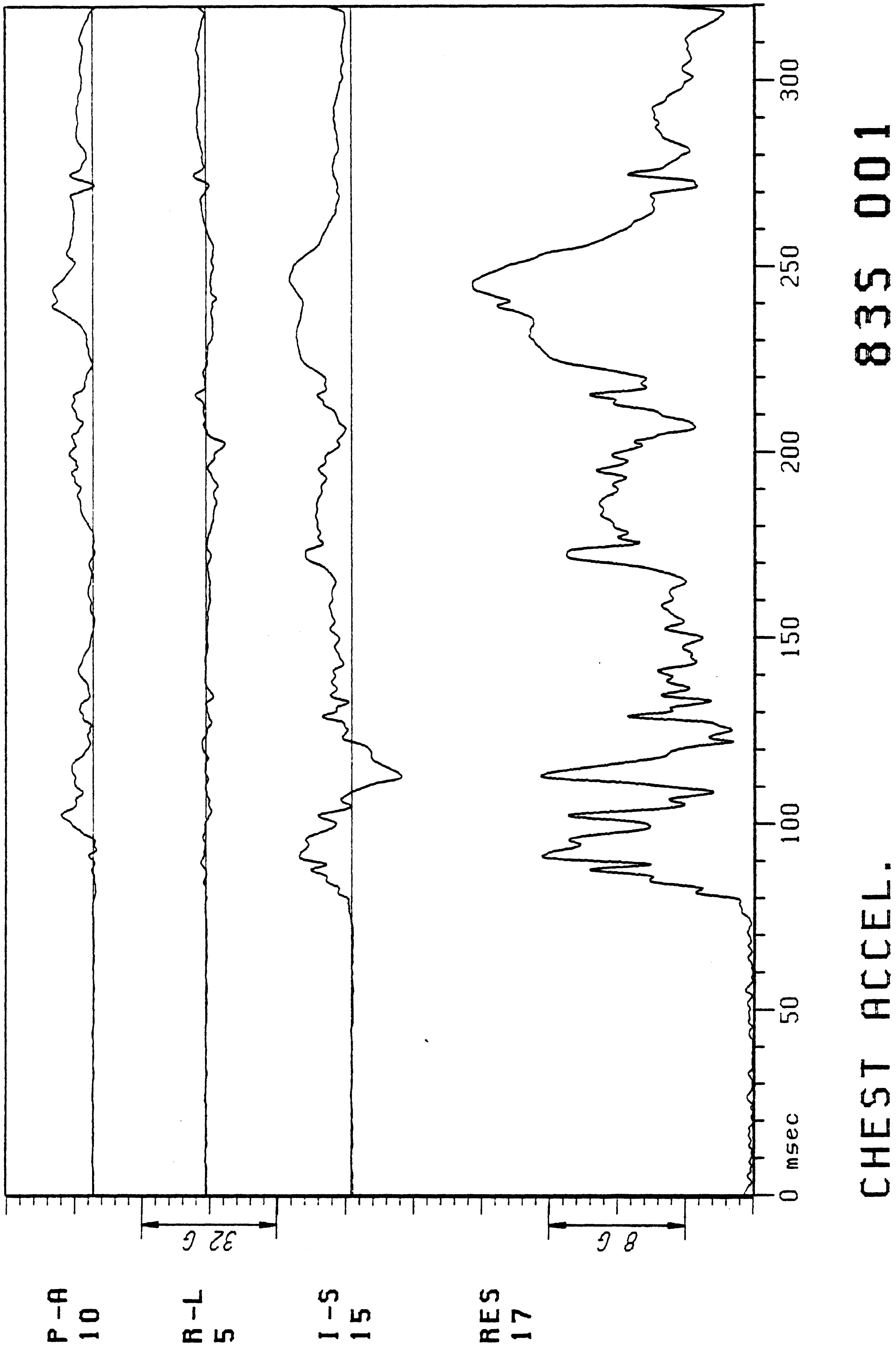
Head:	N.A. inches
Knees:	N.A. inches
Pelvis:	N.A. inches

Observations:

Tether strap stitching failed, dummy was not restrained during test.

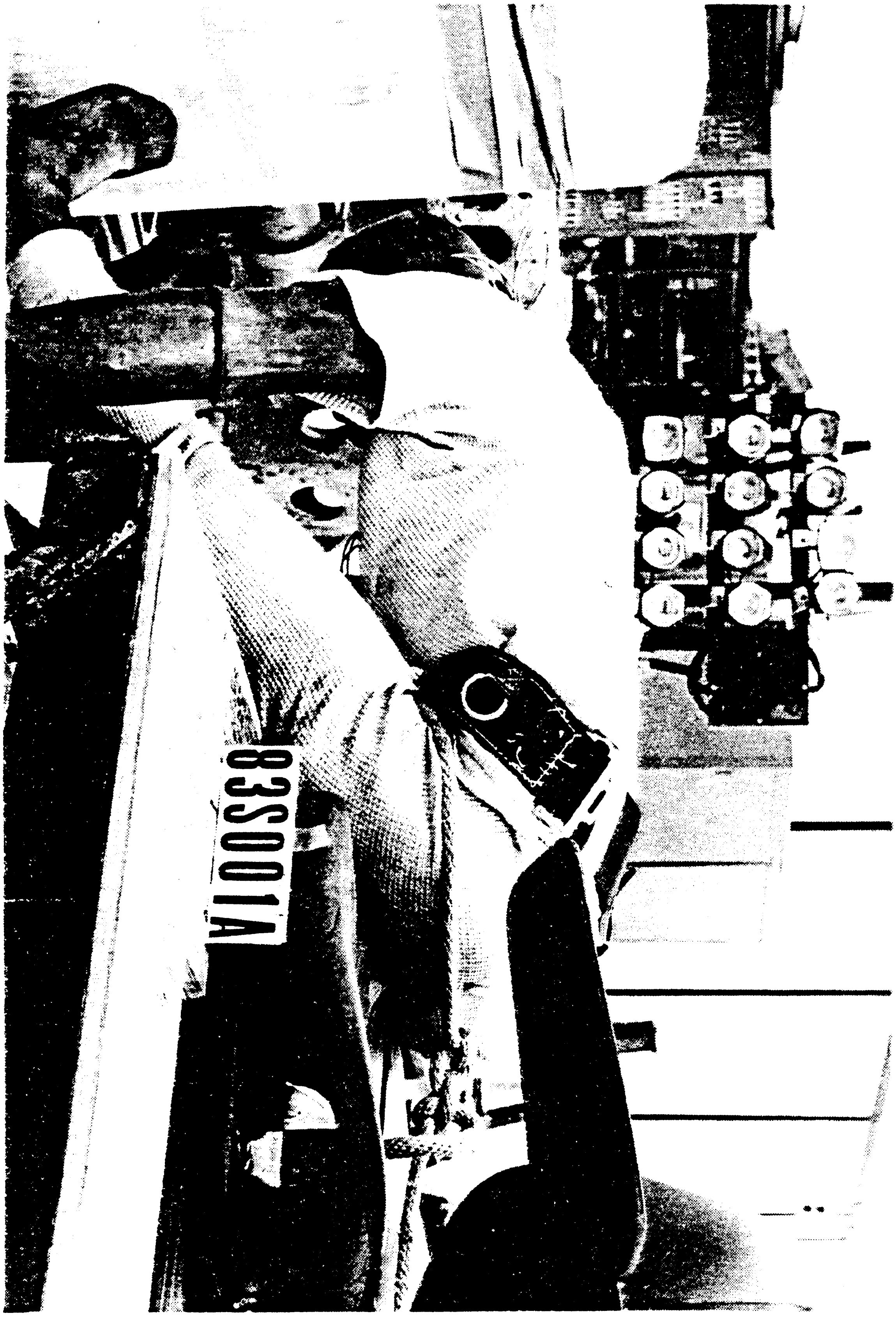

09/30/83
17.5 MPH
Velocity - MPH
Deceleration - G
msec
SLED PROFILE
835 001


09/30/83
P-A
32
R-L
5
I-S
22
RES
35
HIC
72
40 G
16 G
0 msec
50
100
150
200
250
300
HEAD ACCEL.
835 001


CHEST ACCEL.
835 001
09/30/83
P-A 10
R-L 5
I-S 15
RES 17
32 G
8 G
0 msec
50
100
150
200
250
300


83S001
83S001

83S001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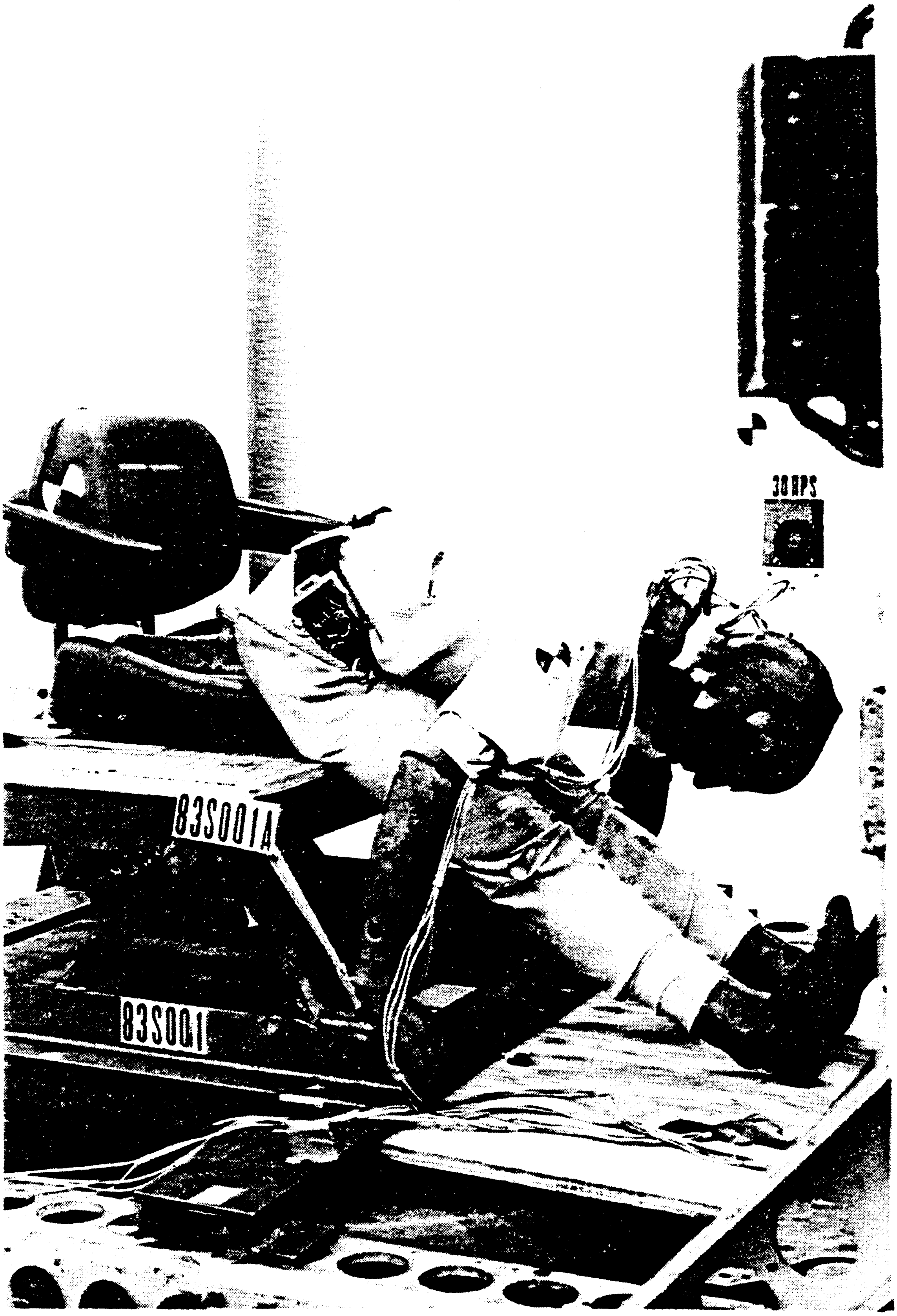
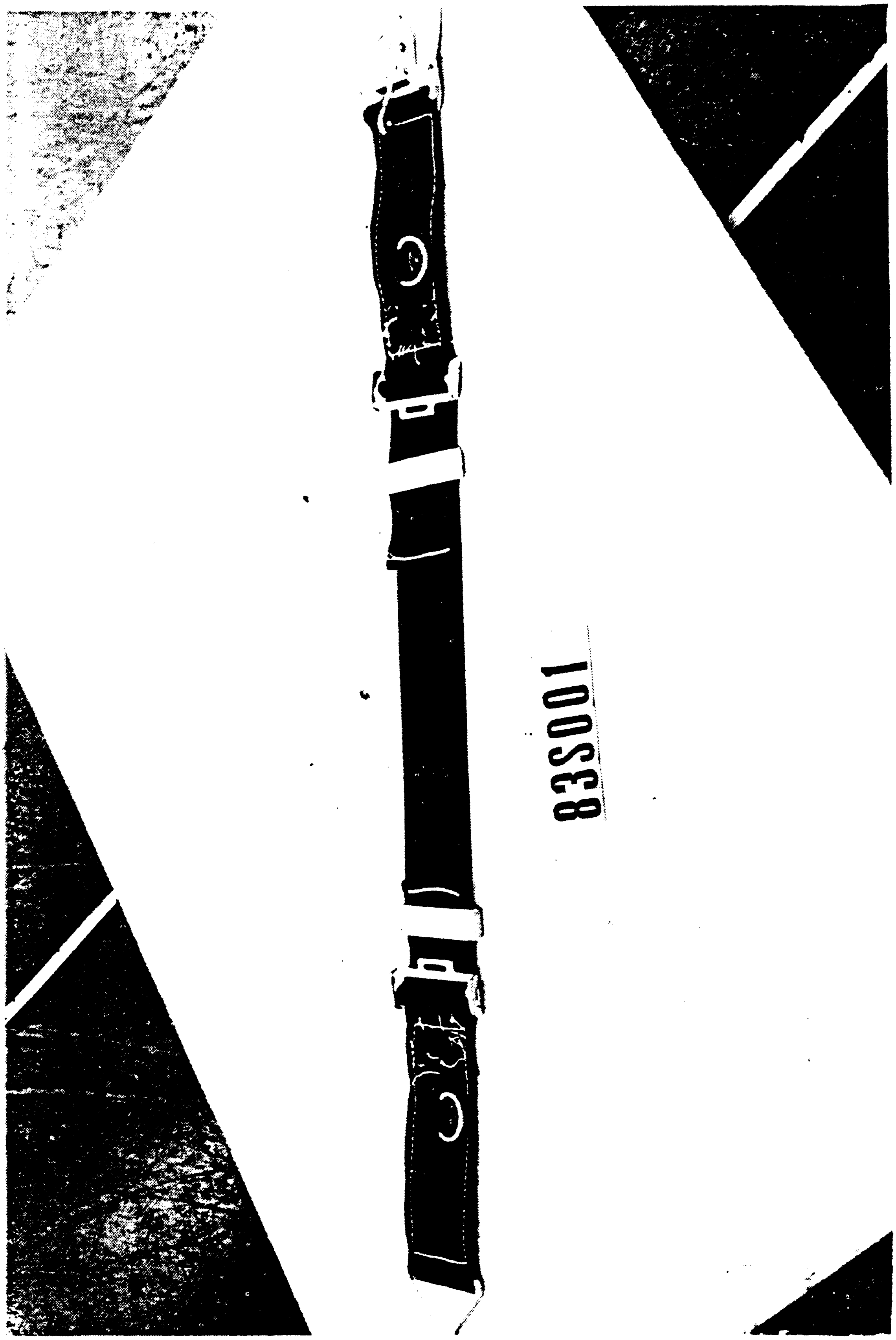

83S001A
83S001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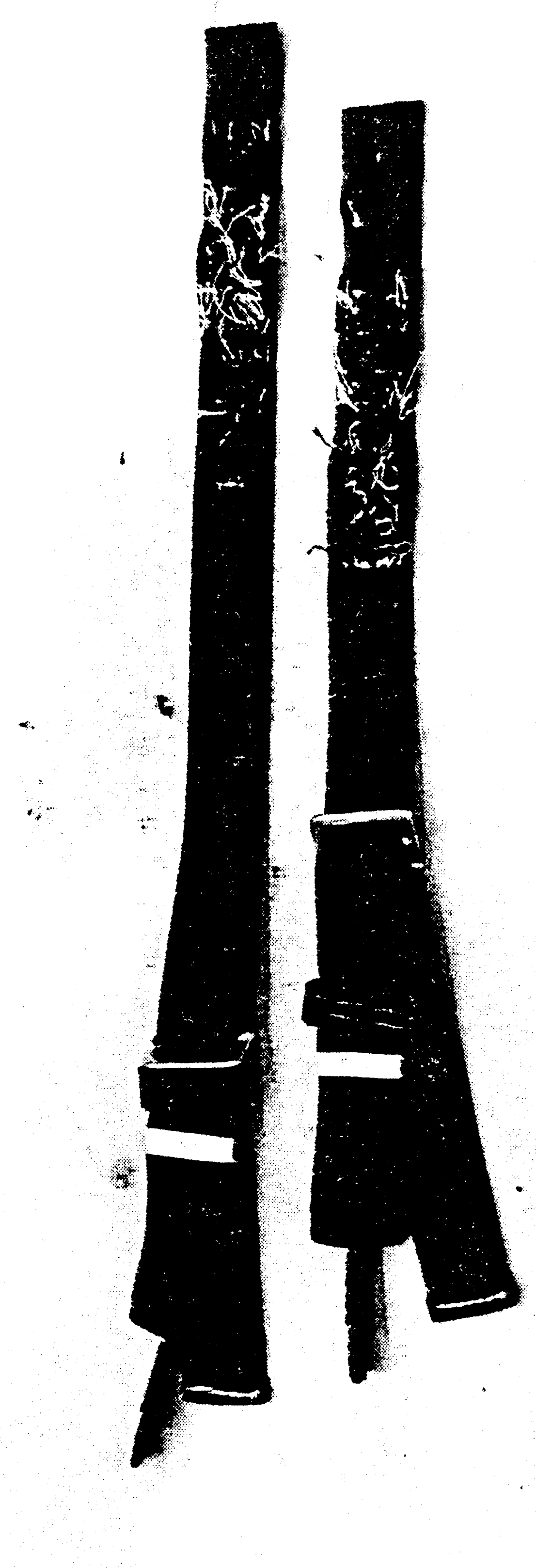


Test Summary TEST 83S002

Test Setup

Test Facility: UMTRI Impact Sled

Impact Parameters

Velocity:	16.9 mph
Deceleration:	31.9 g, peak with half-sine waveform
Direction:	Frontal

Restraint System: U. S. Steel

Test Results

Peak head accelerations

P-A (Posterior-Anterior):	min = -13 g	max = 79 g		
R-L (Right-Left):	min = -28 g	max = 28 g		
I-S (Inferior-Superior):	min = -13 g	max = 56 g		
Resultant	97 g			
HIC (Head Injury Criteria)	330	from 93	to 204	ms

Peak chest accelerations

P-A (Posterior-Anterior)	min = - 8 g	max = 23 g
R-L (Right-Left)	min = - 3 g	max = 4 g
I-S (Inferior-Superior)	min = -12 g	max = 23 g
Resultant	23.9 g	

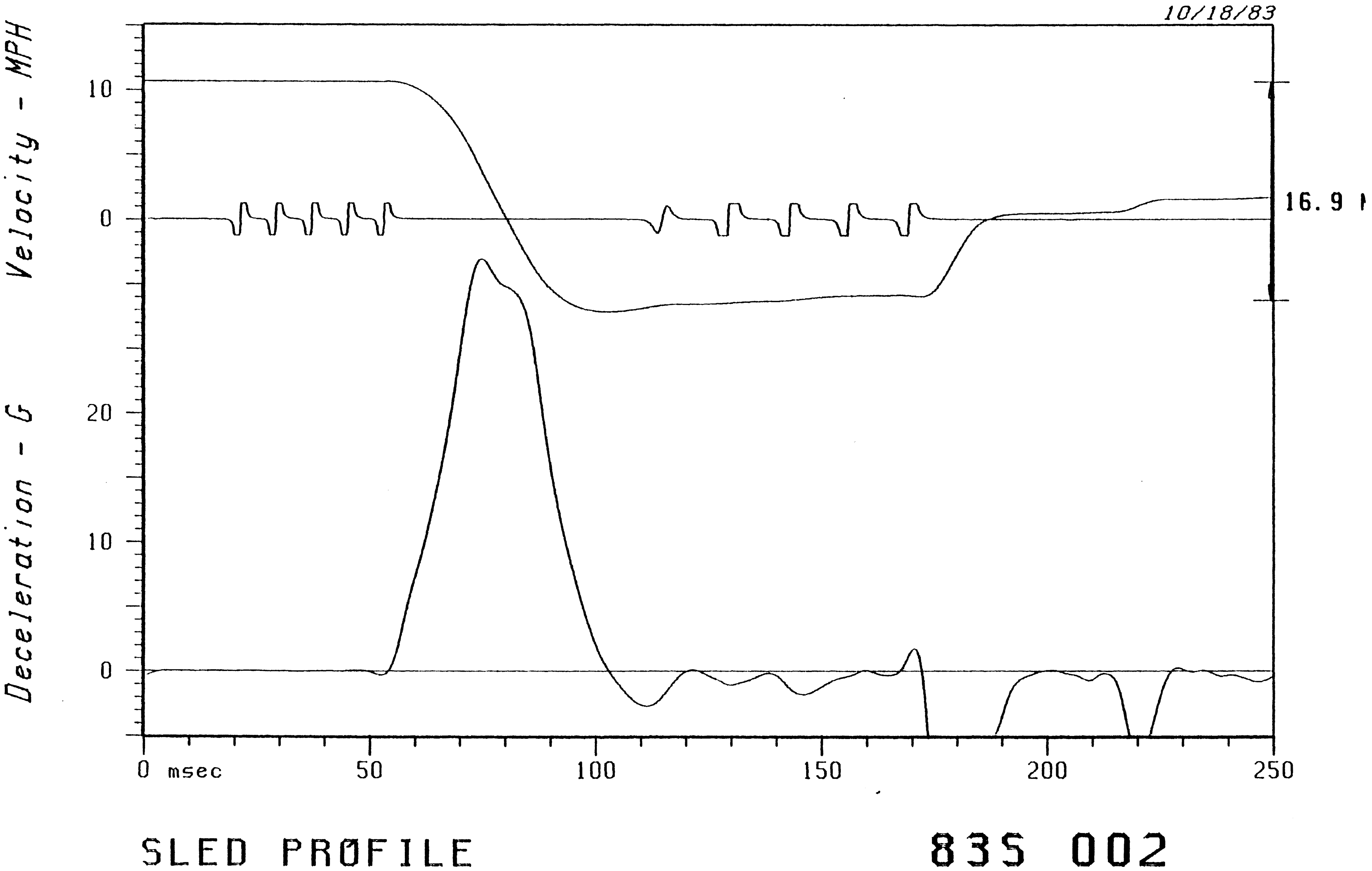
Peak belt loads

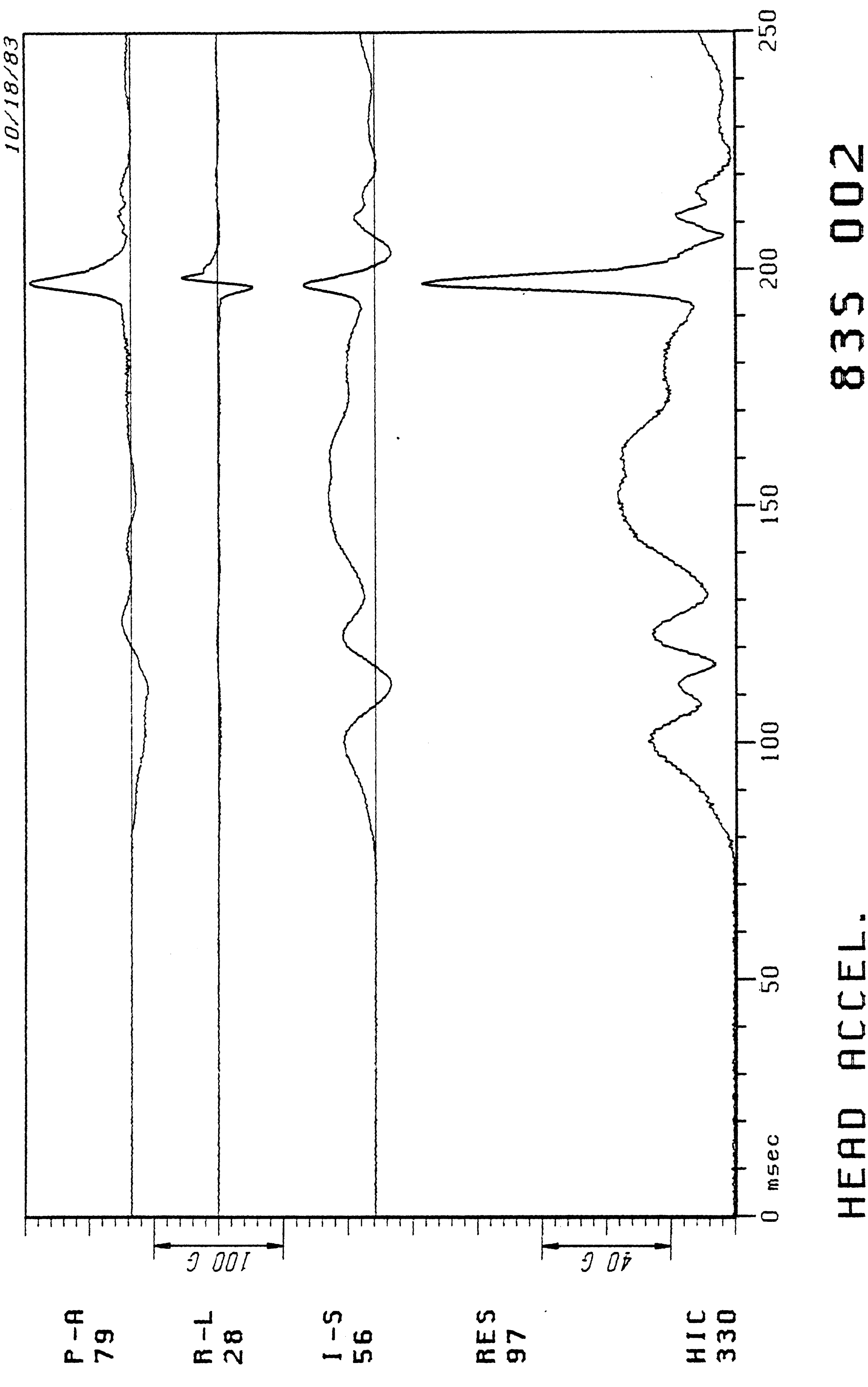
Right side:	N.A. pounds
Left side:	N.A. pounds

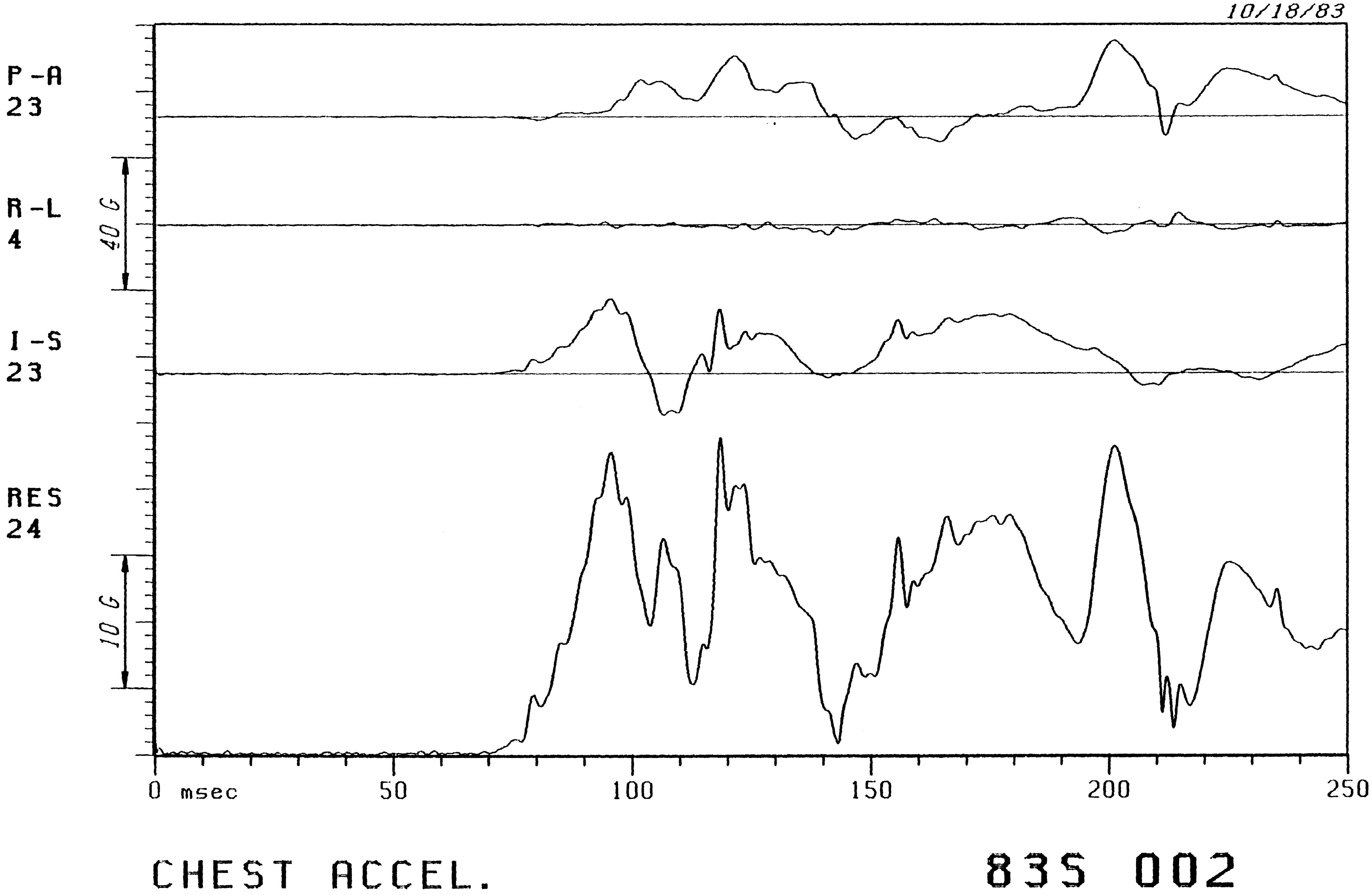
Maximum Excursions (from H. S. film analysis)

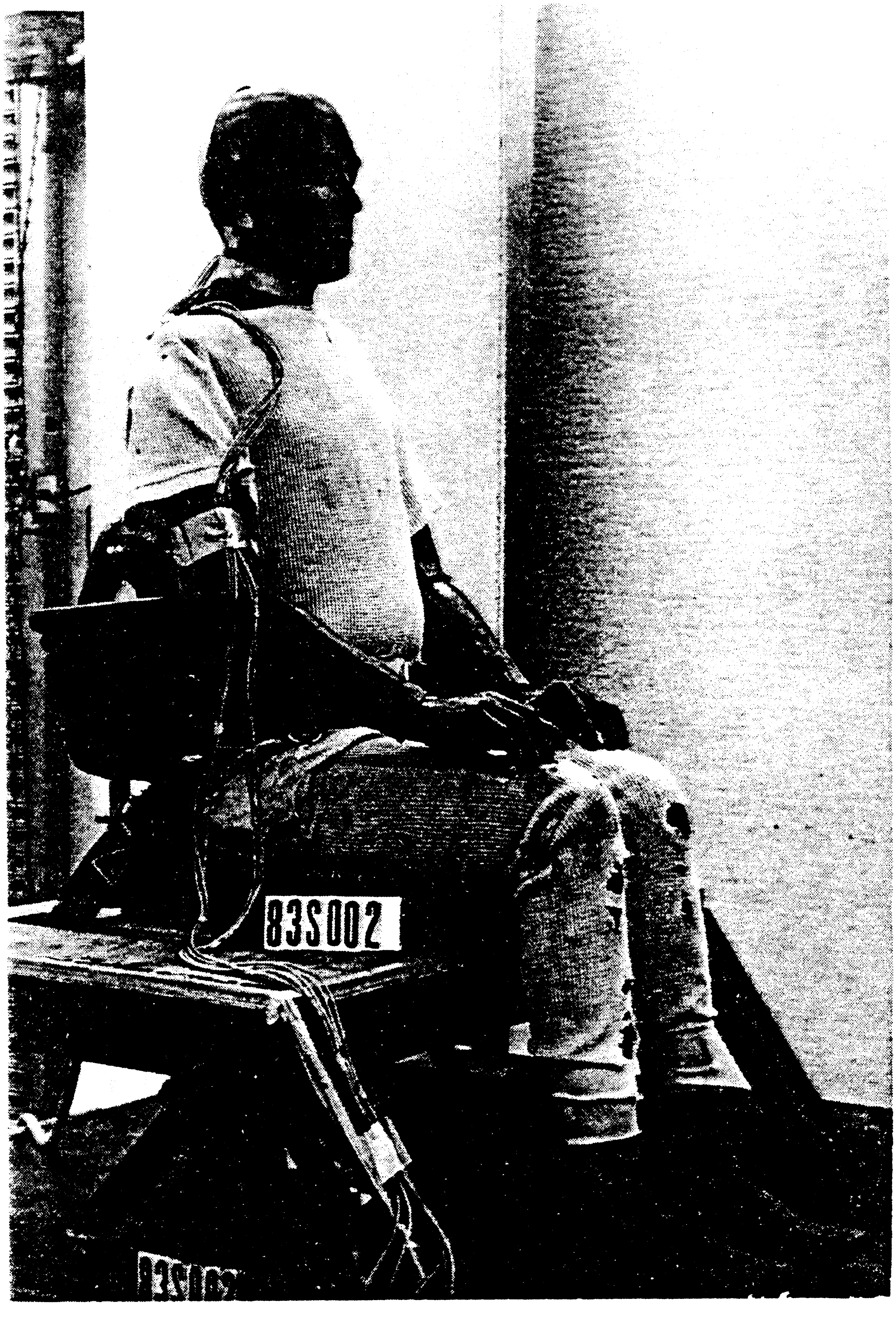
Head:	32.5 inches
Knees:	7.7 inches
Pelvis:	6.5 inches

Observations:


10/18/83
Velocity - MPH
Deceleration - G
10
0
20
10
0
16.9 M
0 msec
50
100
150
200
250
SLED PRØFILE
83S 002


10/18/83
HEAD ACCEL.
835 002
0 msec
50
100
150
200
250
100 G
40 G
P-A 79
R-L 28
I-S 56
RES 97
HIC 330


10/18/83
P-A
23
R-L
4
I-S
23
RES
24
40 G
10 G
0 msec
50
100
150
200
250
CHEST ACCEL.
83S 002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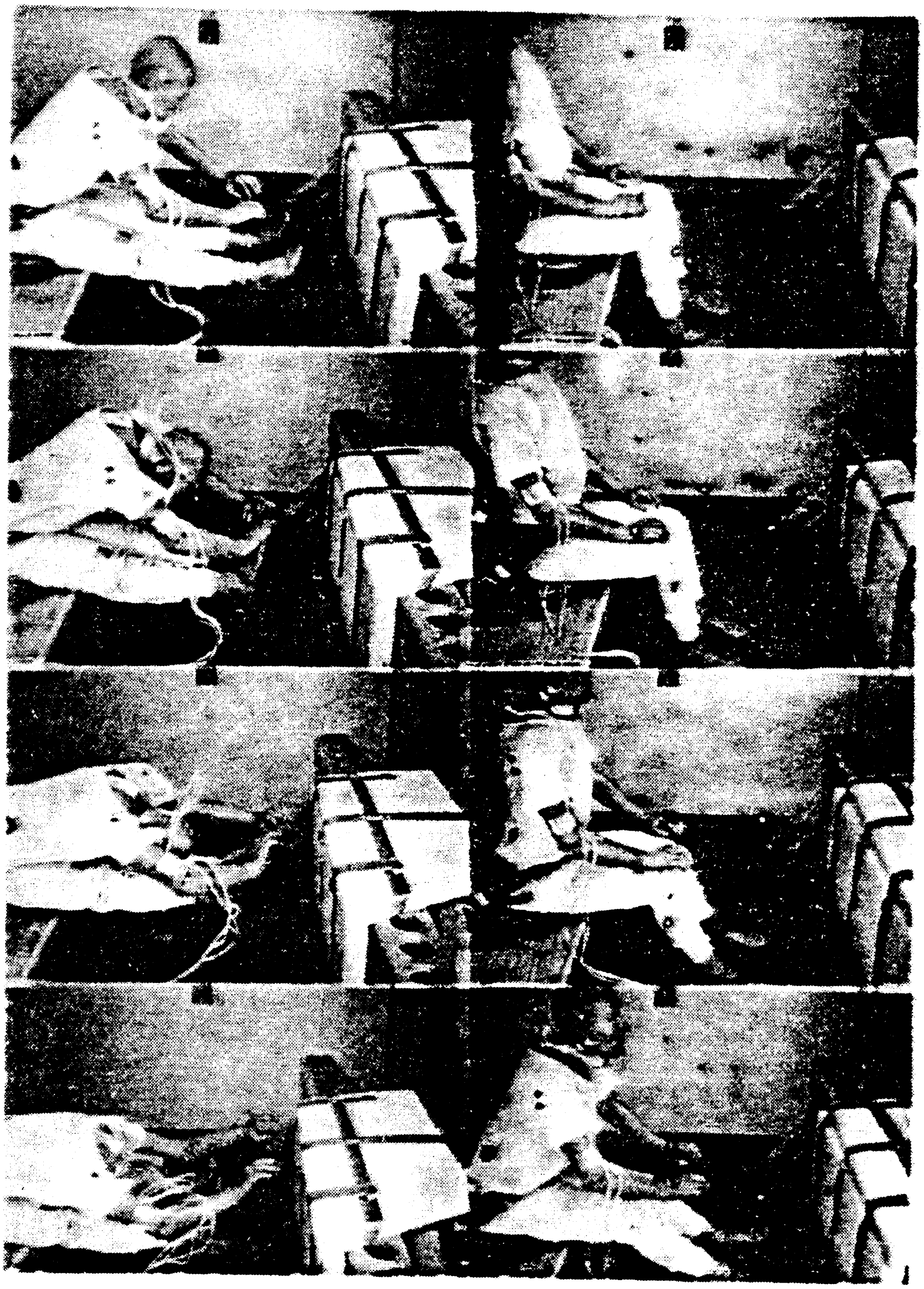


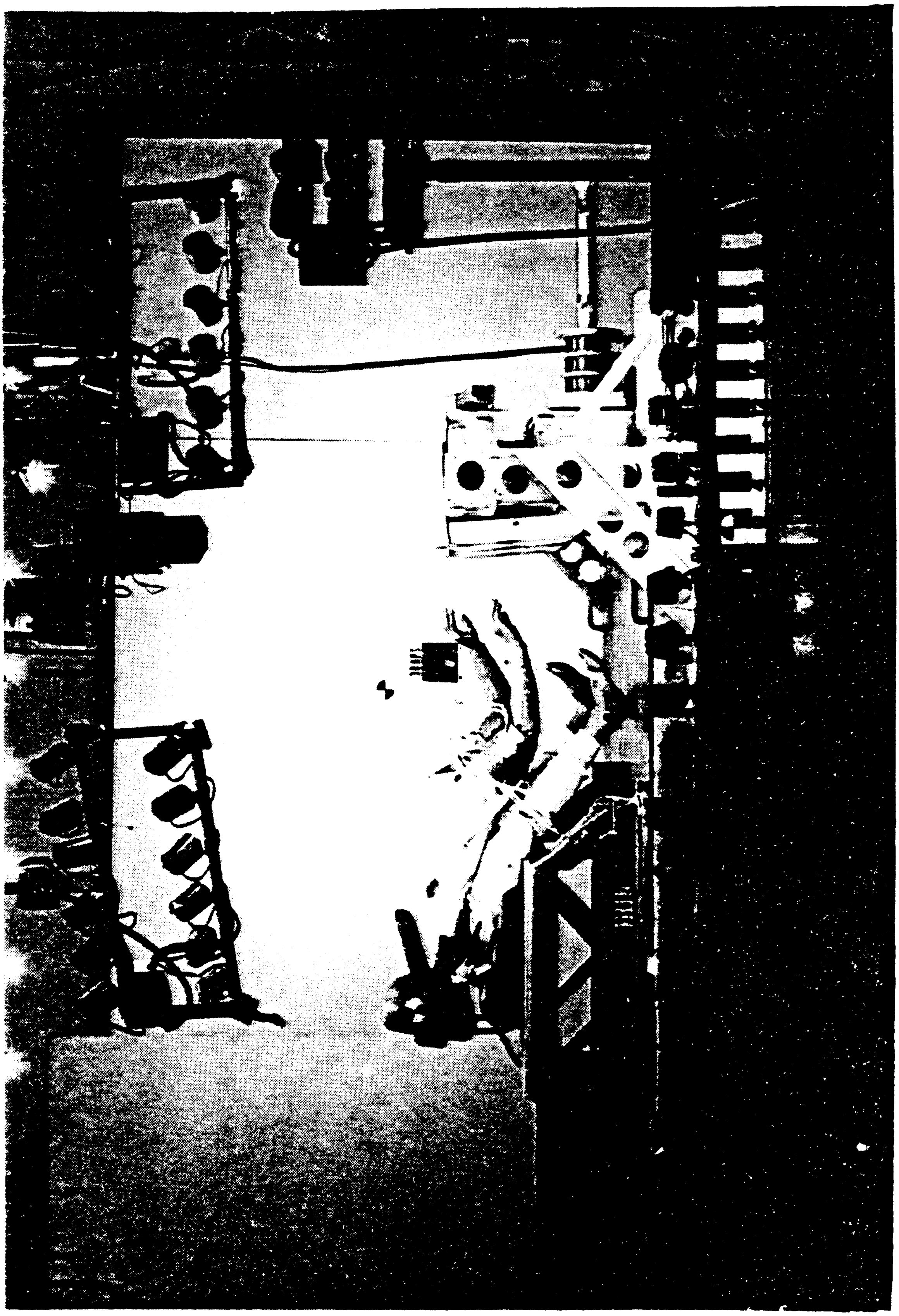
5 1

6 2

7 3

8 4

83S002




83S002A
83S002

Test Summary TEST 83S003

Test Setup

Test Facility: UMTRI Impact Sled

Impact Parameters

- Velocity: 30.7 mph
- Deceleration: 22.7 g, with trapezoidal waveform
- Direction: Frontal

Restraint System: U. S. Steel

Test Results

Peak head accelerations

P-A (Posterior-Anterior):	min = - 22 g	max = 177 g
R-L (Right-Left):	min = -205 g	max = 122 g
I-S (Inferior-Superior):	min = - 1 g	max = 147 g
Resultant	307 g	
HIC (Head Injury Criteria)	2603 from 110 to 144 ms	

Peak chest accelerations

P-A (Posterior-Anterior)	min = -51 g	max = 57 g
R-L (Right-Left)	min = -15 g	max = 14 g
I-S (Inferior-Superior)	min = - 9 g	max = 66 g
Resultant	67 g	

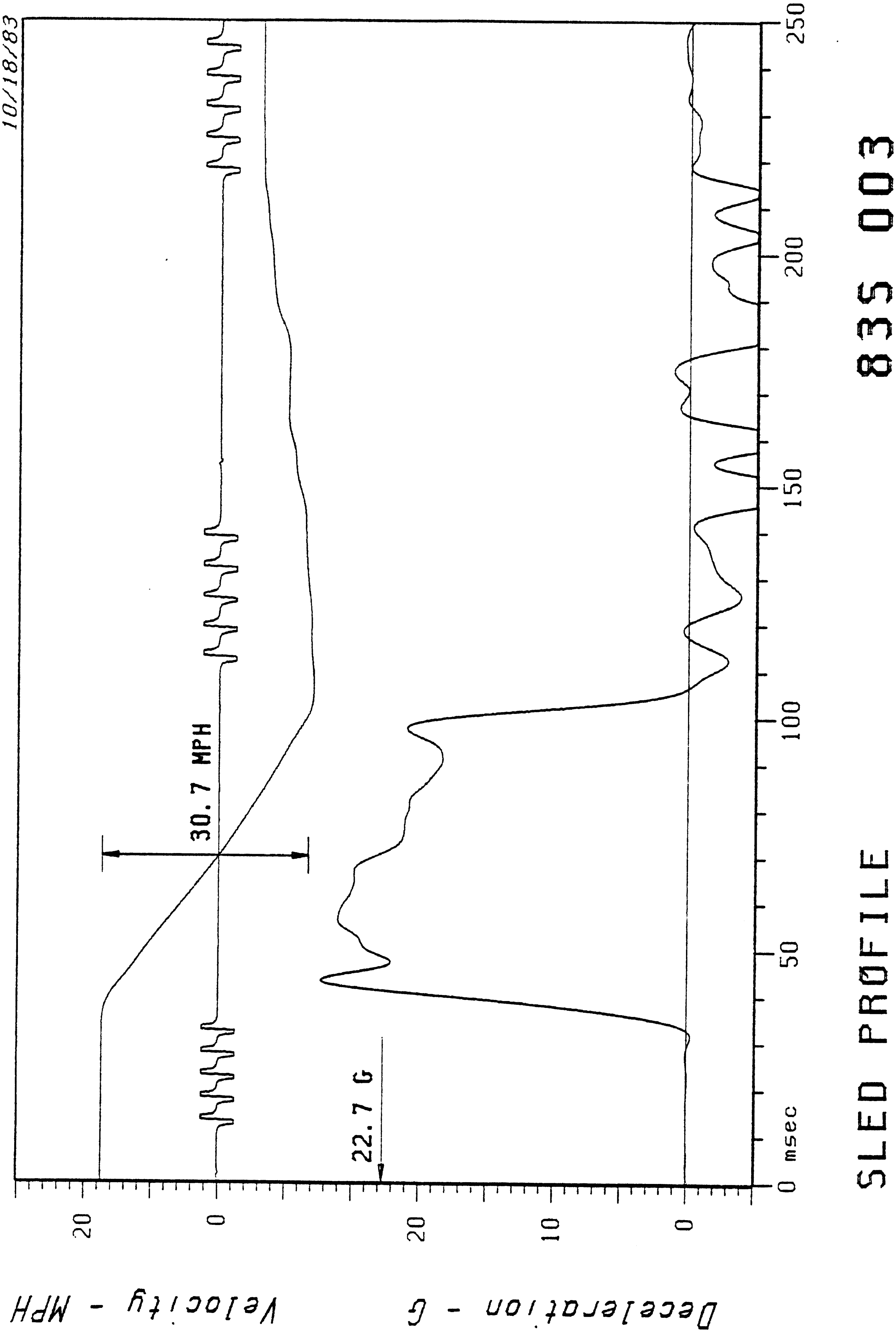
Peak belt loads

- Right side: N.A. pounds
- Left side: N.A. pounds

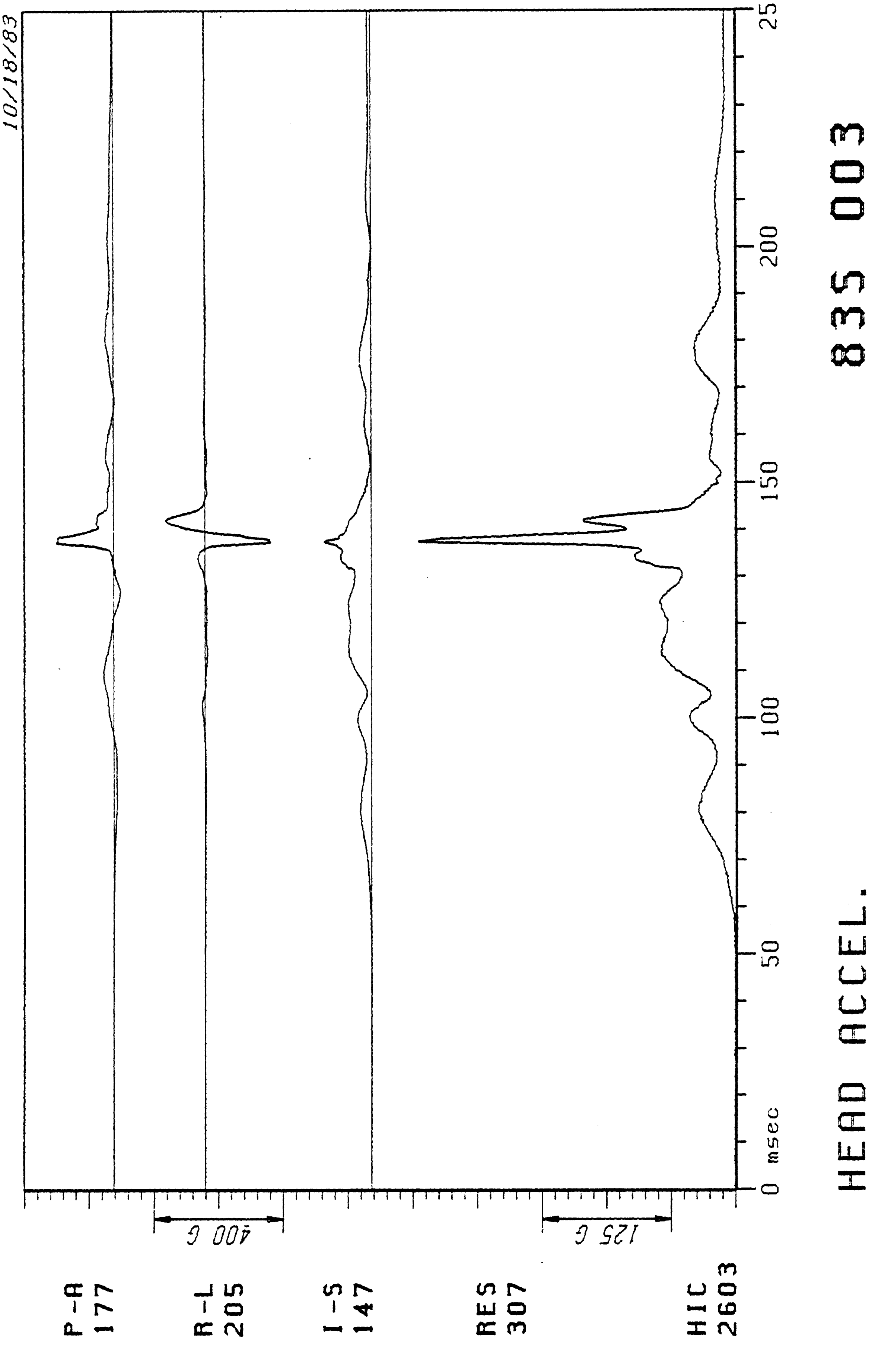
Maximum Excursions (from H. S. film analysis)

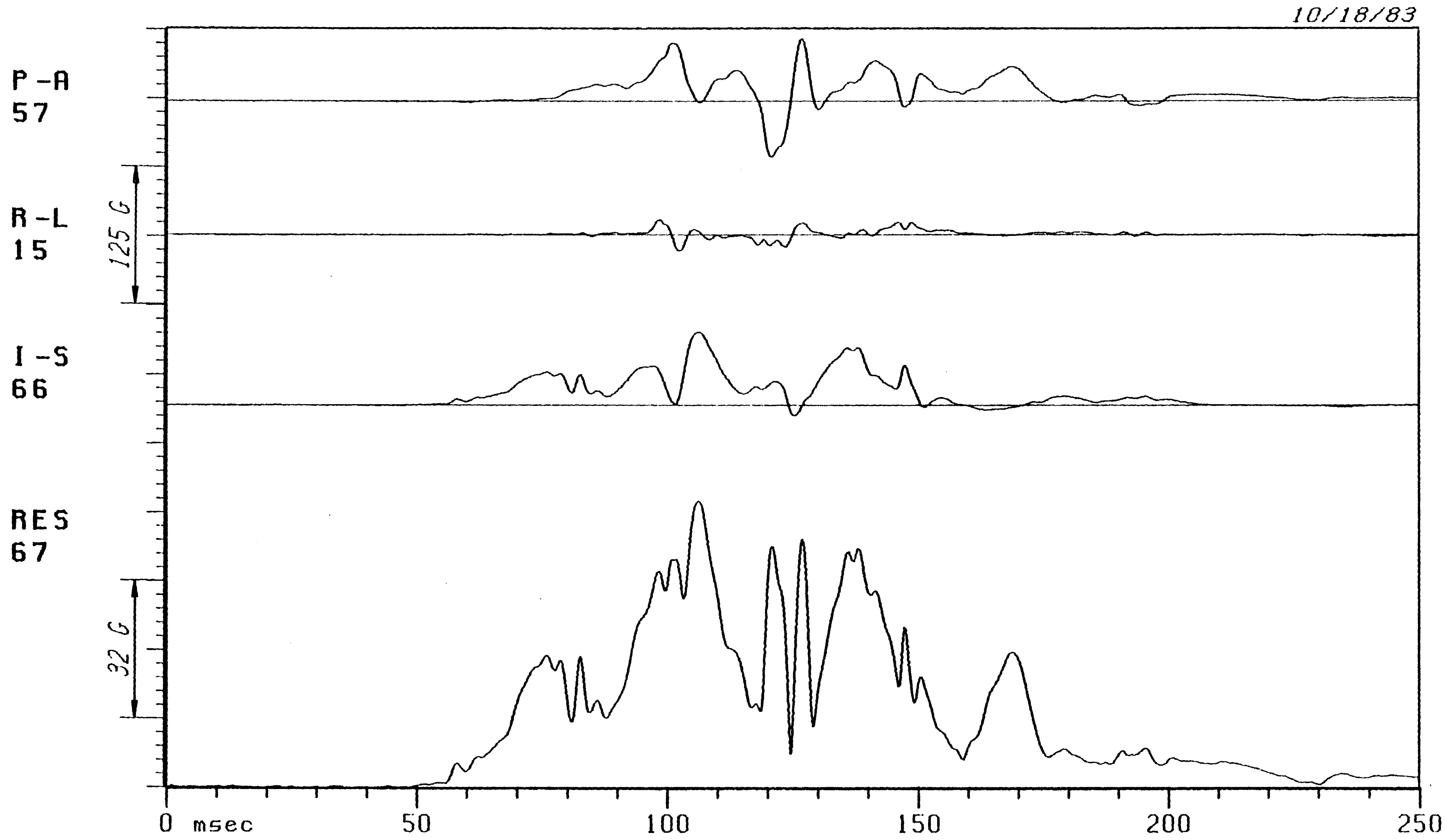
- Head: 35.2 inches
- Knees: 9.2 inches
- Pelvis: 7.9 inches

Observations:



SLED PROFILE
835 003
10/18/83
30.7 MPH
22.7 G
0 msec
50
100
150
200
250
20
0
20
10
0
Velocity - MPH
Deceleration - G

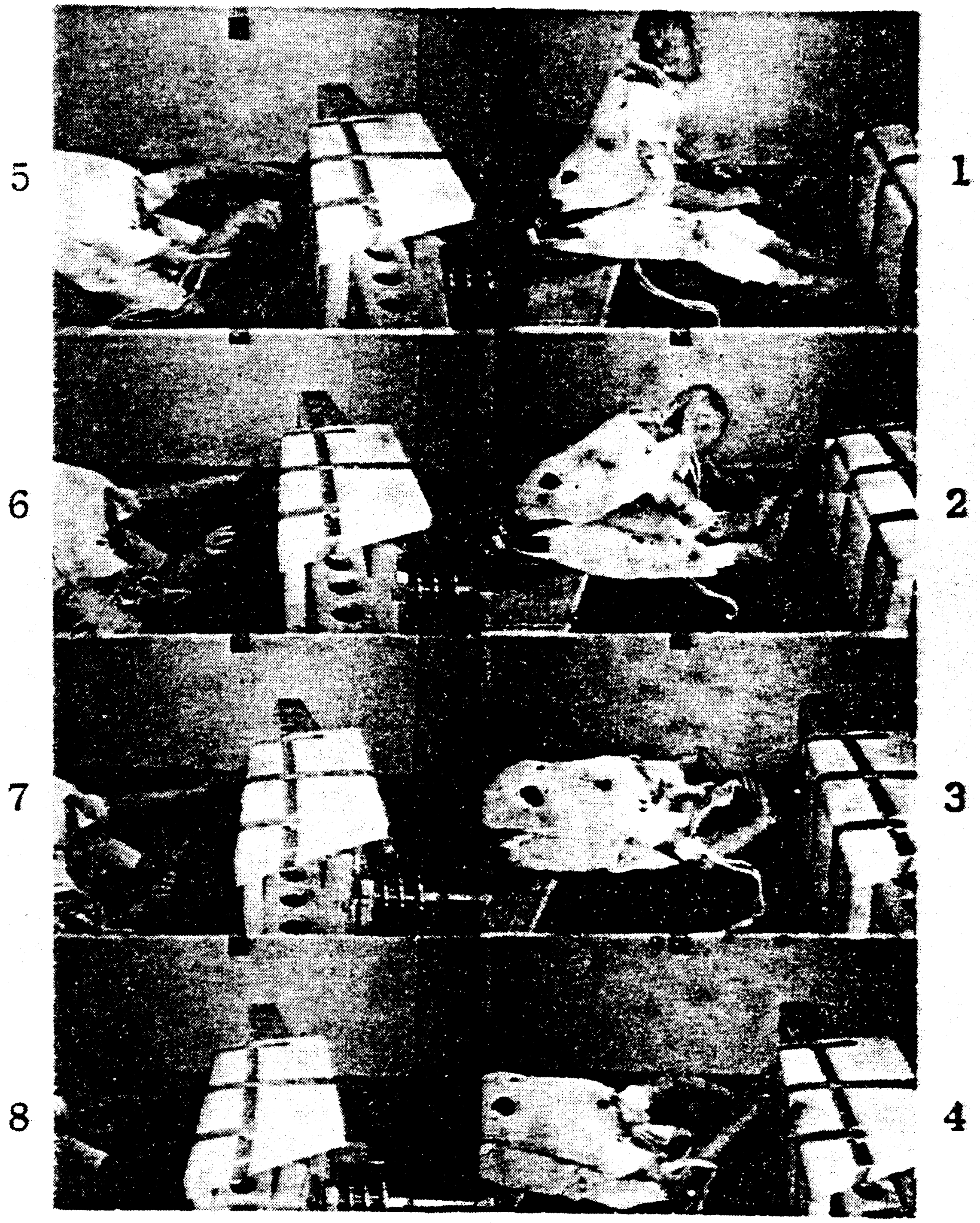

10/18/83
P-A
177
R-L
205
I-S
147
RES
307
HIC
2603
400 G
125 G
0 msec
50
100
150
200
250
HEAD ACCEL.
835 003



CHEST ACCEL.

83S 003


83S003
83S003



83S003


83S003A
83S003

Test Summary TEST 83S004

Test Setup

Test Facility: UMTRI Impact Sled

Impact Parameters

Velocity: 18.4 mph
Deceleration: 29.8 g, with trapezoidal waveform
Direction: Frontal

Restraint System: U. S. Steel

Test Results

Peak head accelerations

P-A (Posterior-Anterior):	min = -11 g	max = 8 g
R-L (Right-Left):	min = - 8 g	max = 4 g
I-S (Inferior-Superior):	min = -25 g	max = 25 g
Resultant	25.7 g	
HIC (Head Injury Criteria)	127 from 103 to 218 ms	

Peak chest accelerations

P-A (Posterior-Anterior)	min = - 4 g	max = 13 g
R-L (Right-Left)	min = - 6 g	max = 6 g
I-S (Inferior-Superior)	min = -21 g	max = 25 g
Resultant	24.7 g	

Peak belt loads

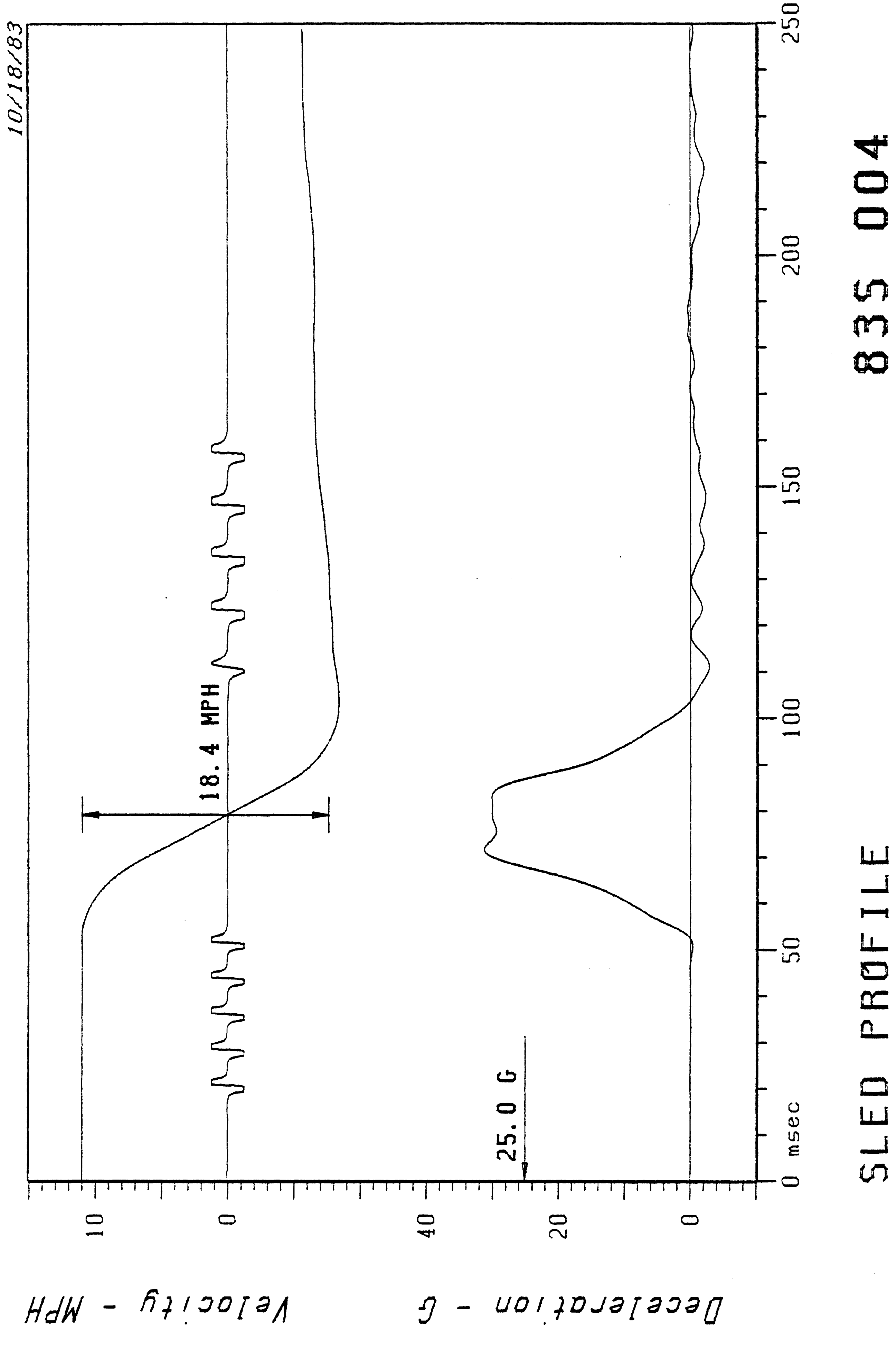
Right side:	N.A. pounds
Left side:	N.A. pounds

Maximum Excursions (from H. S. film analysis)

Head:	N.A. inches
Knees:	N.A. inches
Pelvis:	N.A. inches

Observations:

Tether webbing was cut by side-rails of suspension seat. Right side tether strap failed and dummy was not restrained during test.


10/18/83
835 004
SLED PROFILE
18.4 MPH
25.0 G
0 msec
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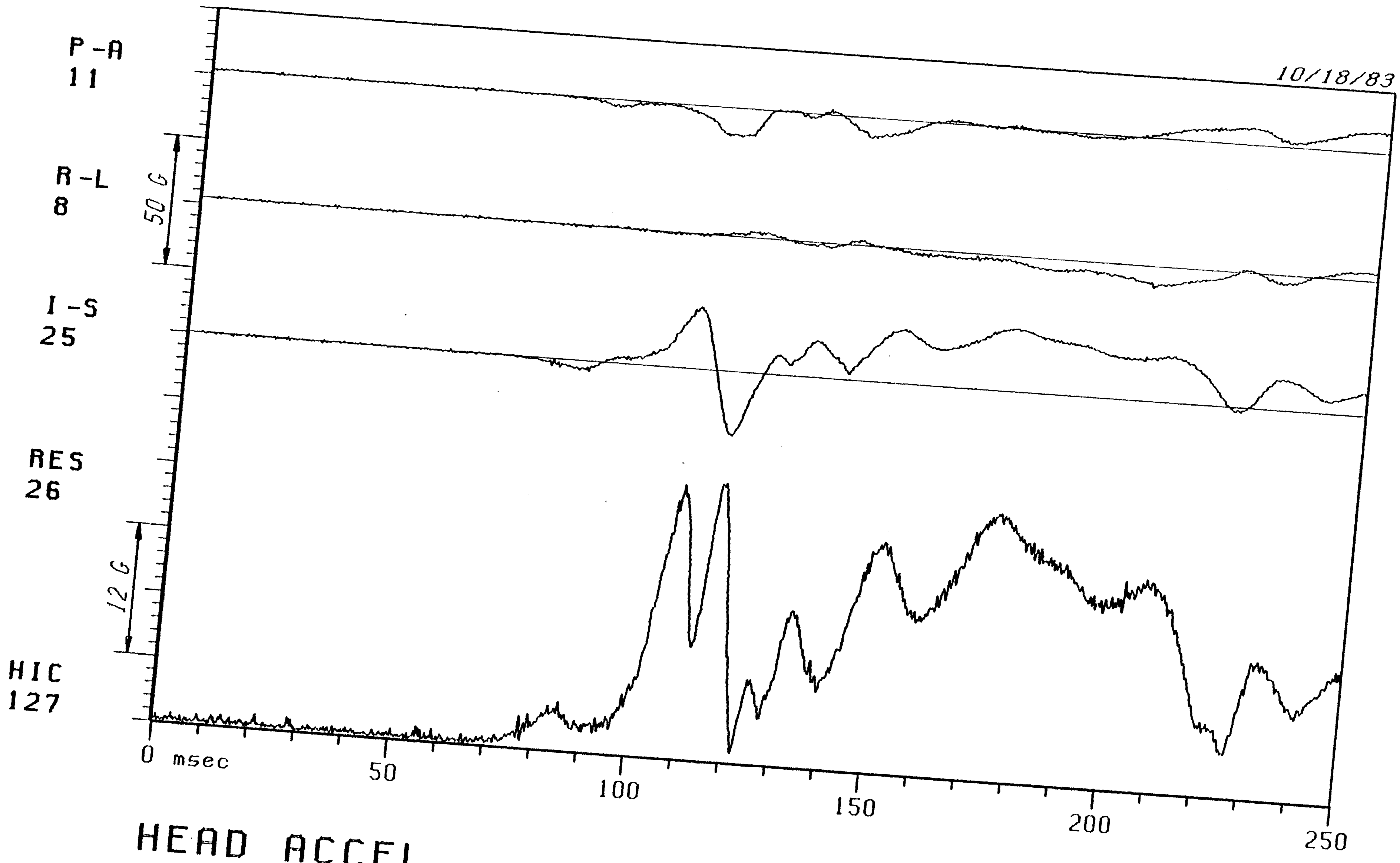
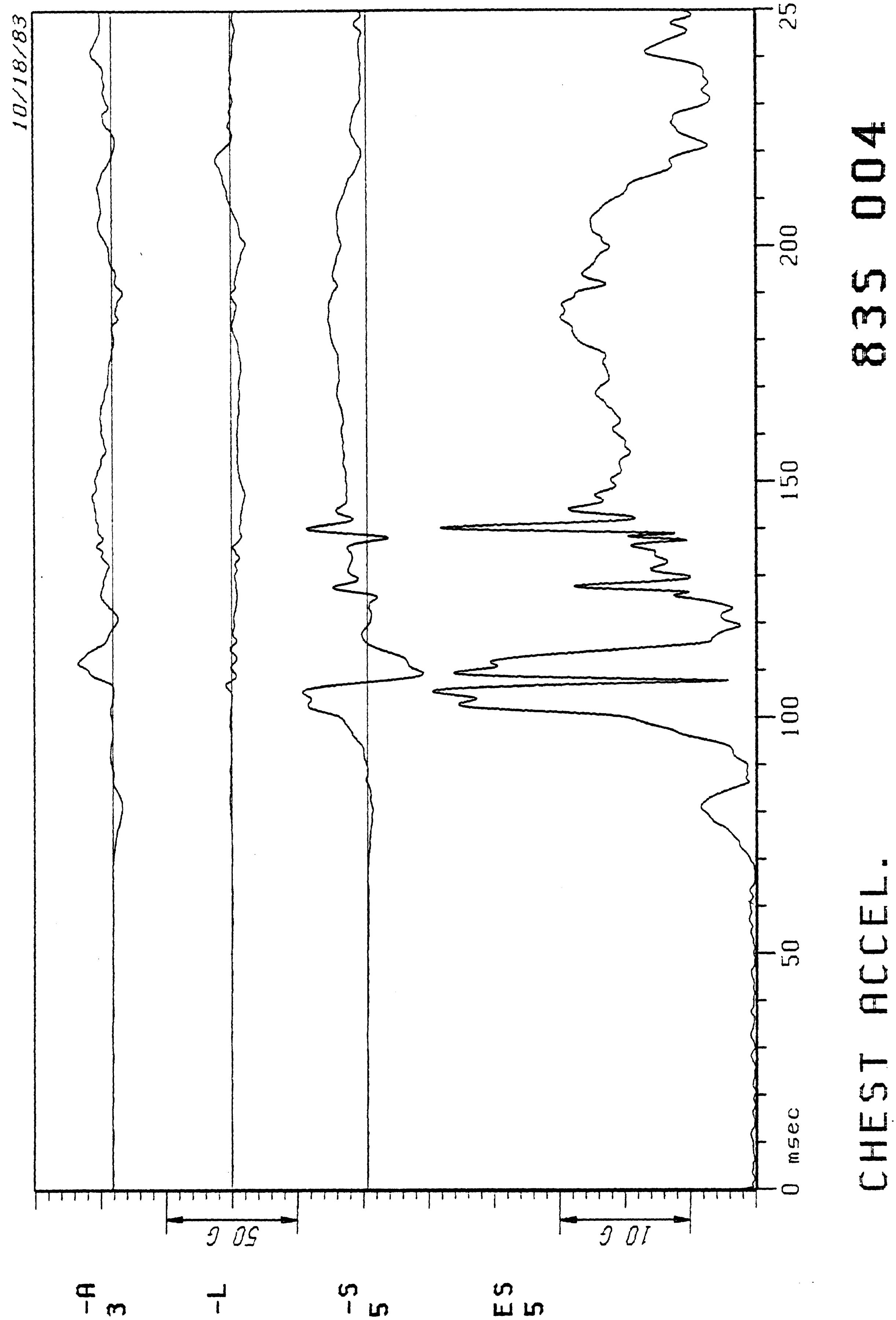
100
150
200
250
10
0
40
20
0
Velocity - MPH
Deceleration - G



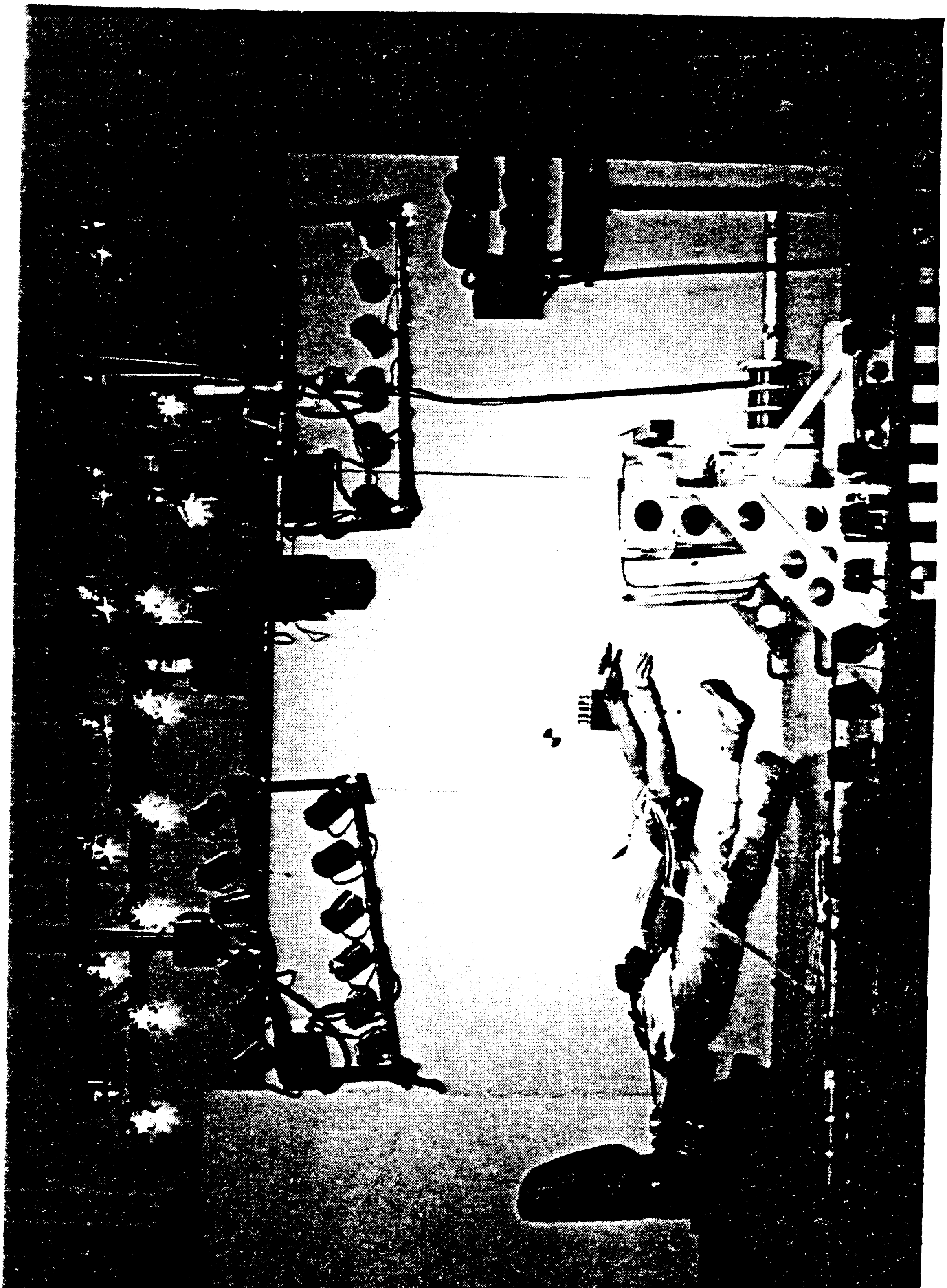
HEAD ACCEL.

835 004


10/18/83
P-A
13
R-L
6
I-S
25
RES
25
50 G
10 G
0 msec
50
100
150
200
250
CHEST ACCEL.
835 004


83S004

83S004




83S004
83S004A


83S004A

Test Summary TEST 83W005

Test Setup

Test Facility: UMTRI Impact Sled

Impact Parameters

- Velocity: 17.8 mph
- Deceleration: 29.8 g, with trapezoidal waveform
- Direction: Frontal

Restraint System: U. S. Steel

Test Results

Peak head accelerations

P-A (Posterior-Anterior):	min = -15 g	max = 98 g
R-L (Right-Left):	min = -113 g	max = 94 g
I-S (Inferior-Superior):	min = -19 g	max = 108 g
Resultant	183 g	
HIC (Head Injury Criteria)	686 from 193 to 201 ms	

Peak chest accelerations

P-A (Posterior-Anterior)	min = - 9 g	max = 24 g
R-L (Right-Left)	min = - 3 g	max = 5 g
I-S (Inferior-Superior)	min = - 6 g	max = 29 g
Resultant	29.4 g	

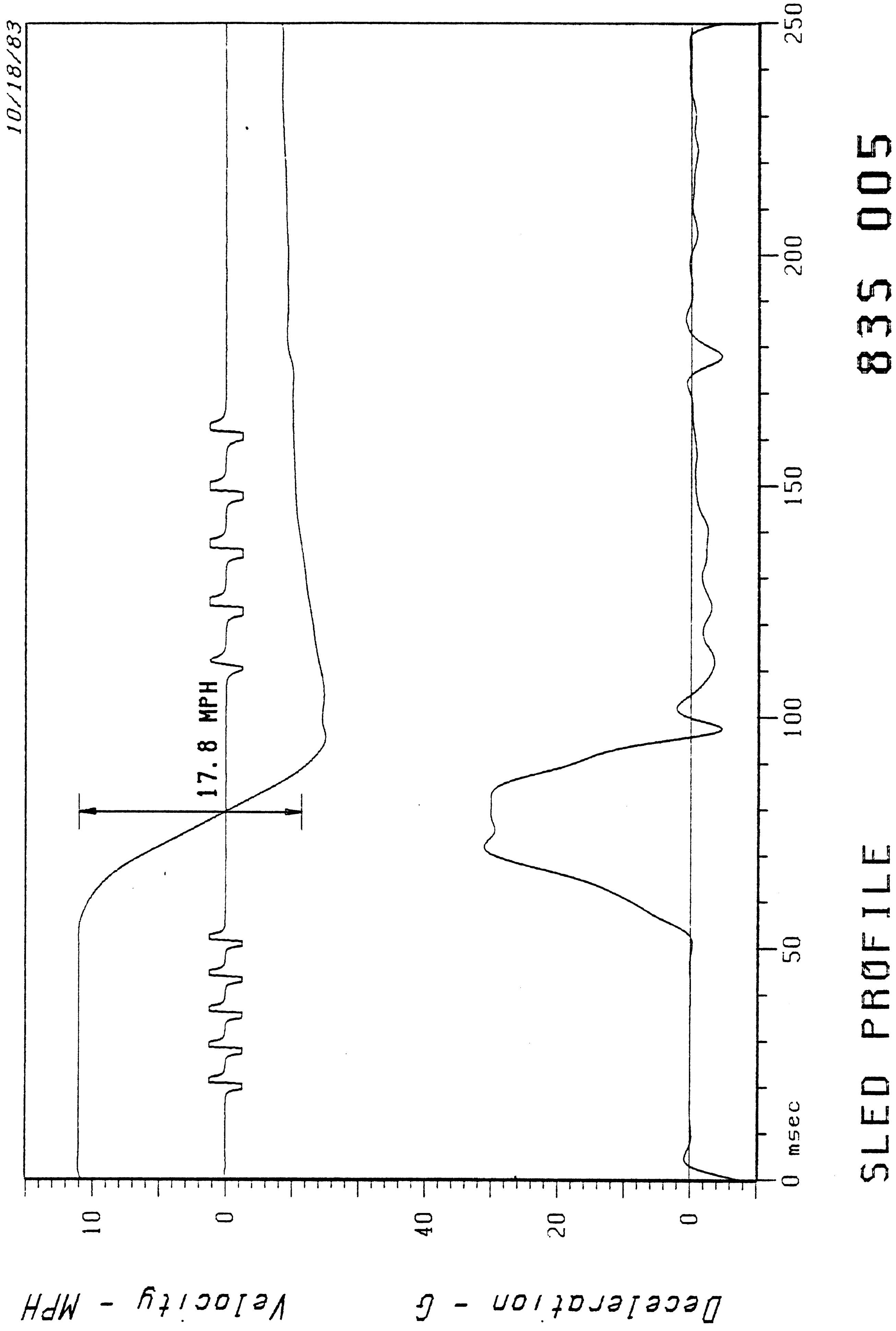
Peak belt loads

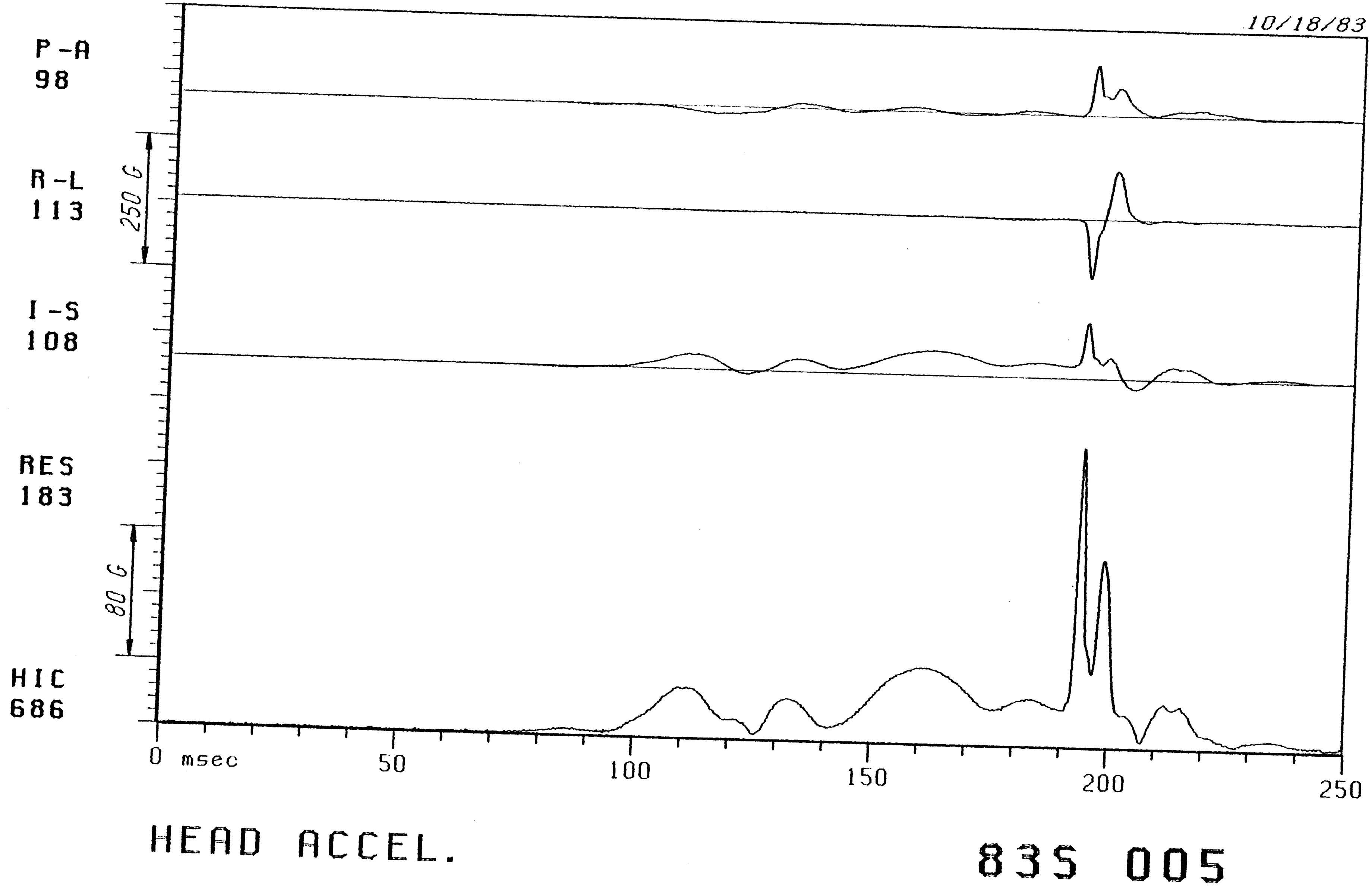
Right side:	N.A. pounds
Left side:	N.A. pounds

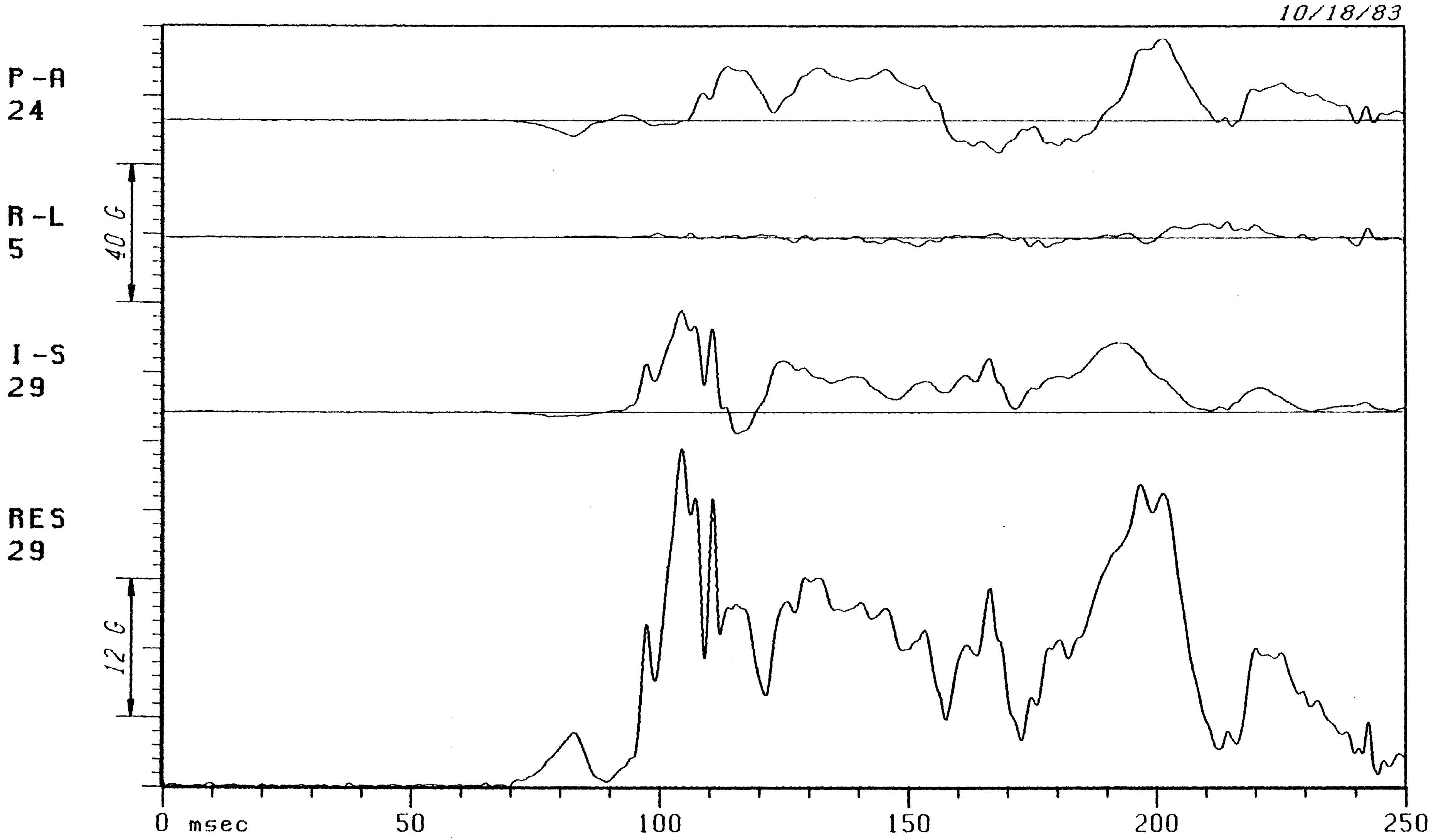
Maximum Excursions (from H. S. film analysis)

Head:	36.5 inches
Knees:	11.5 inches
Pelvis:	9.4 inches

Observations:


10/18/83
835 005
SLED PROFILE
17.8 MPH
0 msec
50
100
150
200
250
10
0
40
20
0
Velocity - MPH
Deceleration - G

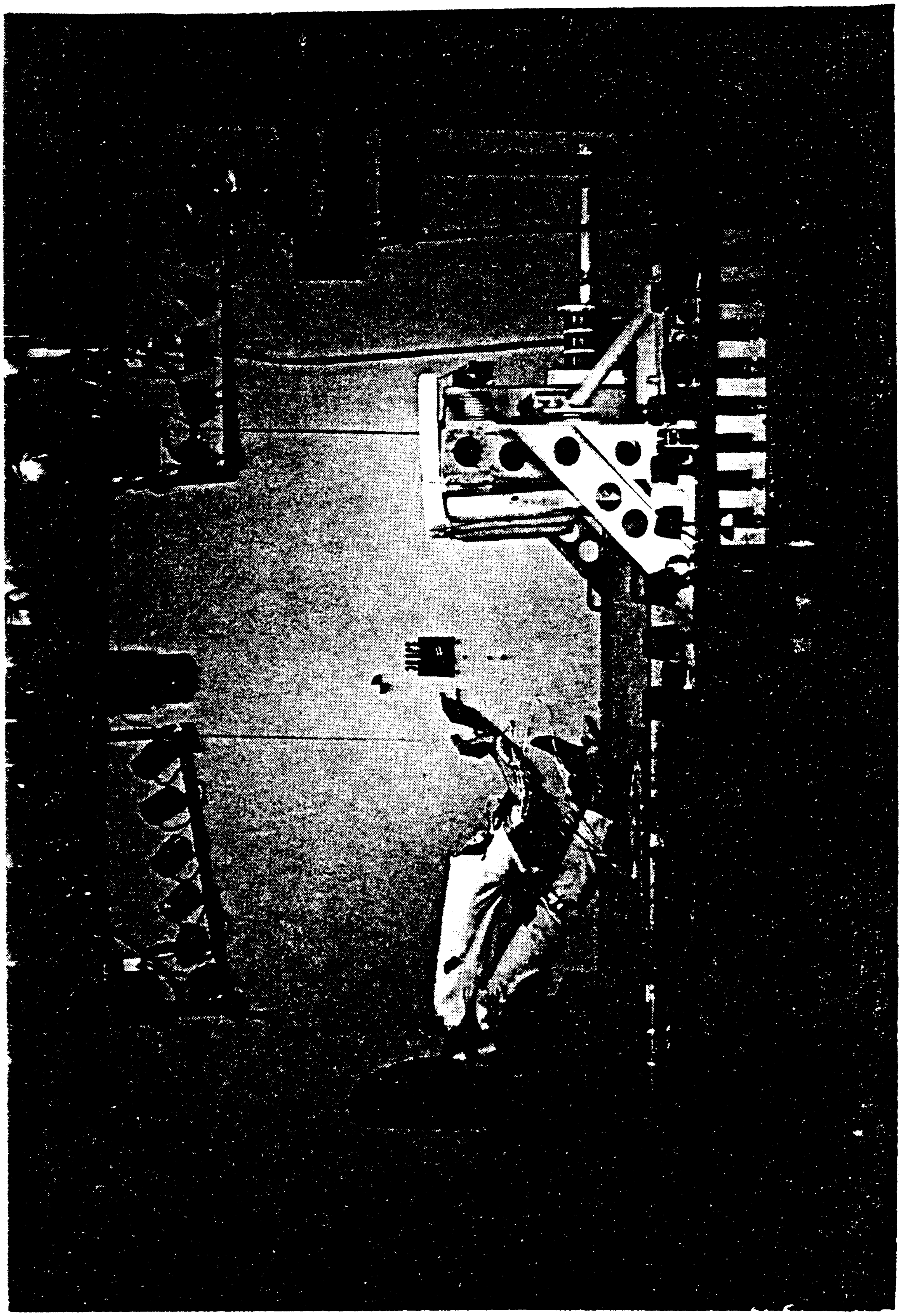

10/18/83
P-A
98
R-L
113
I-S
108
RES
183
HIC
686
250 G
80 G
0 msec
50
100
150
200
250
HEAD ACCEL.
835 005

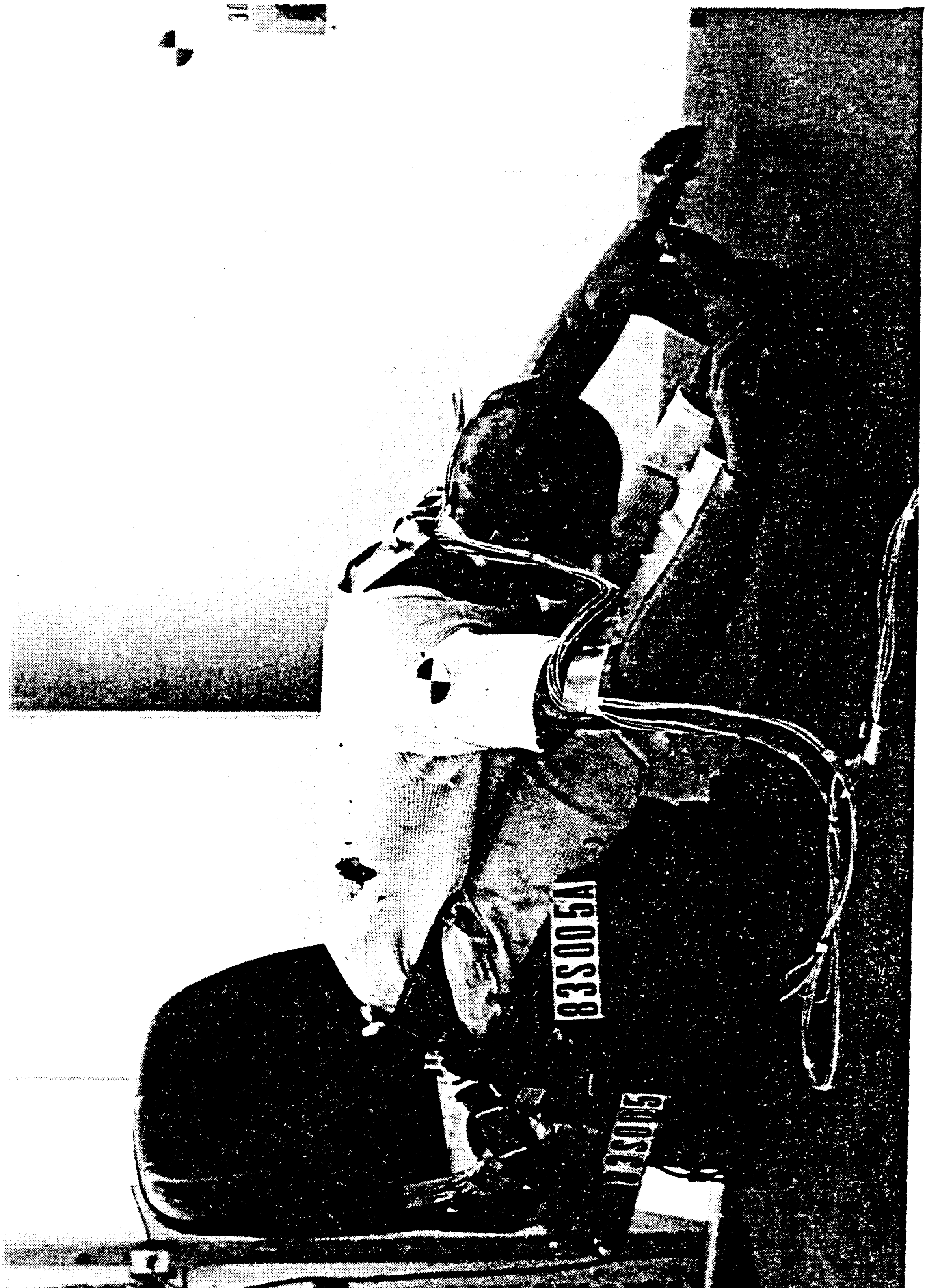


CHEST ACCEL. 83S 005


83S005
83S005

83S005

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