EVALUATION OF HEAVY EQUIPMENT OPERATORS' SAFETY BELT RESTRAINT SYSTEM.
PHASE II.

Joseph B. Benson
John W. Melvin
Richard G. Snyder

Transportation Research Institute
The University of Michigan
Ann Arbor, Michigan 48109

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U. S. Steel Corporation
600 Grant Street, Room 720
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**Abstract**

A proposed innovative restraint harness developed by U. S. Steel for the protection of heavy equipment operators was dynamically tested as Phase II of the restraint evaluation program. An impact sled was used for frontal and lateral testing, and a shaker platform was used to produce vertical jolts. An instrumented 50th percentile male Part 572 dummy simulated the equipment operator. The harness performance under these three test conditions was compared to the results obtained with a conventional lap belt. This report presents the data from the impact testing and makes recommendations for additional improvements to the harness system.

**Key Words**

- Restraint system
- Heavy Equipment
- Lap belt
- Dynamic tests

**Distribution Statement**

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I. Summary

This second phase of the study evaluated the proposed heavy equipment operator's safety belt restraint system under simulated dynamic conditions. Frontal, lateral, and vertical impacts were produced using the UMTRI impact sled and the shaker platform facilities. The performance of the proposed restraint was compared to the results obtained with conventional two-inch-wide lap belt webbing under identical conditions. This proposed harness offers a unique and promising approach to increasing restraint usage by heavy equipment operators, as detailed in the Phase I report. Further development to eliminate the problems found in Phase II impact testing is recommended.

The findings are summarized as follows:

- In frontal impacts, the proposed U. S. Steel restraints allowed greater pelvis and hip excursions than a conventional lap belt, but there was no difference in maximum head excursions.
- In lateral impacts, the proposed U. S. Steel restraint provided lesser pelvis and greater head excursions than a conventional lap belt.
- In vertical jolt impacts, there was no significant difference in performance between the proposed U. S. Steel restraint and a conventional lap belt.
II. Test Procedures and Results

A total of ten dynamic impact tests were conducted to evaluate the U. S. Steel restraint harness, six on the UMTRI impact sled and four on a vertical shaker platform. A conventional two-inch wide lap belt installation was used for comparison purposes.

The sled tests consisted of four frontal and two lateral impacts. The test platform consisted of a forklift seat attached to a fabricated frame. This assembly was rigidly fastened to the impact sled to simulate a typical operator seating configuration. Side and overhead high-speed movies were taken using Photosonics 1-B cameras operating at 1000 frames per second. A Polaroid Graph-Check sequence camera provided a "quick-look" at the restraint performance immediately after each test.

The shaker platform tests consisted of a single vertical jolt produced by a hydraulic servo system. This facility became available for use during the test program, and provided a more realistic simulation of vertical impacts experienced by equipment operators than could be produced on the sled. A fork lift seat attached to a frame was rigidly fastened to the shaker platform, similar to the impact sled setup.

A side view of the jolt test was recorded using a Photosonics 1-B camera operating at 1000 frames per second. A 50th percentile male Part 572 dummy instrumented with a triaxial accelerometer array mounted in its head and chest was used in these tests. GSE belt load cells were used to monitor belt webbing forces. These acceleration and force signals were recorded during each impact test on a Honeywell Model 7600 recorder.

Table 1 summarizes the impact sled testing of the proposed restraint system. Frontal tests were conducted at two different severity levels of approximately 18 mph at 30 g and 21 mph at 20 g. The higher velocity produced larger peak excursions of the knees and pelvis with either restraint system. The proposed restraint system gave a 75% greater pelvis excursion than the lap belt at 18 mph, and 120% greater excursions at 21 mph. Peak head excursions showed very little sensitivity to either restraint system or impact severity. The significantly higher peak head
accelerations and HIC in tests 82S005 and 82S006 resulted from the dummy head's striking the legs. Head/leg interaction also occurred during test 82S002, but the lower test velocity lessened the effect.

Lateral tests were conducted at a severity level of 12 mph at 18 g. The proposed restraint system gave a 4% lower peak head excursion and a 9% greater peak pelvis excursion than the conventional two-inch lap belt, an insignificant difference.

Table II summarizes the vertical jolt testing on the shaker platform. The proposed restraint system and the conventional lap belt both provided the same degree of restraint on peak vertical excursions of the head and shoulders. Also, both restraint systems provided lesser peak vertical excursions than those produced when simulating an unrestrained operator.
<table>
<thead>
<tr>
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<th>82S001</th>
<th>82S002</th>
<th>82S003</th>
<th>82S004</th>
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<th>82S006</th>
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<td>U.S. Steel</td>
<td>2&quot; lap belt</td>
<td>U.S. Steel</td>
<td>2&quot; lap belt</td>
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<td>Deceleration: (g)</td>
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<td>18.4</td>
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<td>Frontal</td>
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<td>Maximum Excursions (inches)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HEAD:</td>
<td>33.2</td>
<td>33.7</td>
<td>36.1</td>
<td>37.6</td>
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<td>32.6</td>
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<td>7.9</td>
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<td>32</td>
<td>357</td>
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<td>13</td>
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<td>21</td>
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<td>652</td>
<td>30</td>
<td>135</td>
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<td>Peak Platform Deceleration (g)</td>
<td>Maximum Vertical Excursions (inches)</td>
<td>Peak Belt Loads (pounds)</td>
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<td>Shoulder</td>
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<td>Lt</td>
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<td>2.8</td>
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<td>86</td>
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III. Discussion

From the test results, the proposed restraint system appears to offer comparable protection to a conventional lap belt during lateral and vertical impacts, but allows excessive pelvic excursions during a frontal impact. Analysis of the frontal test high-speed movies suggests the higher excursions result from the ability of the short side belts to move fore-and-aft along the main belt loop. While this provides adjustability so the restraint will fit a wide range of operators, it also appears to feed in additional effective belt length during frontal impact.

To eliminate this condition, it may be necessary to eliminate or modify the adjustability feature of the short side belts along the main belt loop. Either stitching the side belts to the main loop or providing several shorter adjustment ranges should reduce the forward excursion of the occupant.

Another consideration is the proper length or tension adjustment of the short side belts. For all the impact tests, these were pretensioned between 12 to 15 pounds to provide consistent initial conditions. However, the short belts are not as easy to tension as a conventional lap belt, increasing the probability of misuse or non-use. A simplified tightening method for the side belts that could be easily performed by a restrained, seated operator should improve usage rates as well as impact performance.

For the vertical jolt tests, the proposed severity level of 7 mph at 6 g was not attained. The low excursion of the unrestrained operator would suggest retesting at the higher severity to obtain a better comparison of the two restraint systems.

A suspension-type seat could not be obtained in time for inclusion in the Phase II test program. However, this type of seat was recently evaluated on the UMTRI impact sled using a similar restraint harness. In a frontal impact the entire suspension-type seat rotated forward and remained permanently deformed in this position. This motion allowed the dummy to slide off the end of the seat cushion and submarine under the restraint. Because of the greater pelvis excursions produced by the pro-
posed restraint system, the interaction with a suspension-type seat and the high potential for submarining should be investigated.
IV. Recommendations

To improve the impact performance of the proposed restraint system, emphasis should be placed on factors that reduce the pelvis and knee excursions during frontal impacts.

These include the following:

- Ensuring that installation of the harness attaching anchors will provide the recommended 50° ± 5° belt angle. Vertical attachments will significantly increase forward motion during impact.
- Provide an easily performed length adjustment for the short side belts to encourage operators to use the restraint in a correctly tensioned manner.
- Minimize or eliminate the fore-aft travel of the short side belts along the main loop. This adjustability feature unfortunately degrades frontal impact performance.

Additional testing should also be considered to evaluate the following:

- The effect of higher severity vertical impacts on restraint performance.
- The interaction of a suspension-type seat with the proposed restraint system to check for potential seat cushion override by the operator, resulting in submarining.
- The effectiveness of any alternative modifications to the proposed restraint system design.
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
Test Setup

Test Facility: UMTRI Impact Sled

Impact Parameters

Velocity: 18.2 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 = -12 g max = 9 g
R-L (Right-Left): min = -11 g max = 6 g
I-S (Inferior-Superior): min = -1 g max = 41 g
Resultant 42 g
HIC (Head Injury Criteria) 309 from 118 to 256 ms

Peak chest accelerations

P-A (Posterior-Anterior) min = -13 g max = 9 g
R-L (Right-Left): min = -3 g max = 5 g
I-S (Inferior-Superior): min = -1 g max = 18 g
Resultant 20 g

Peak belt loads

Right side: 1386 pounds
Left side: 1547 pounds

Maximum Excursions (from H. S. film analysis)

Head: 33.2 inches
Knees: 11.8 inches
Pelvis: 10.9 inches

Observations:
File # 43
256.00 ms = 2048 Pts / 8000 Hz
04:00:33 - 04:10:50

02
1000
x 24

HEAD P-A ACC
16 G

03
1000
x 24

HEAD R-L ACC
80 G

04
1000
x 24

HEAD I-S ACC
25 G

0 50 100 150 200 250 msec

H7: 178 ← A/D → SEAT-1 11/12/82 82S 001
Test Setup

Test Facility: UMTRI Impact Sled

Impact Parameters

- Velocity: 18.5 mph
- Deceleration: 30.0 g, with trapezoidal waveform
- Direction: Frontal
- Restraint System: 2" lap belt webbing

Test Results

Peak head accelerations

P-A (Posterior-Anterior): \( \text{min} = -138 \text{ g} \quad \text{max} = 12 \text{ g} \)
R-L (Right-Left): \( \text{min} = -44 \text{ g} \quad \text{max} = 85 \text{ g} \)
I-S (Inferior-Superior): \( \text{min} = -20 \text{ g} \quad \text{max} = 93 \text{ g} \)
Resultant \( 185 \) g
HIC (Head Injury Criteria) \( 652 \) from \( 149 \) to \( 216 \) ms

Peak chest accelerations

P-A (Posterior-Anterior): \( \text{min} = -35 \text{ g} \quad \text{max} = 6 \text{ g} \)
R-L (Right-Left): \( \text{min} = -3 \text{ g} \quad \text{max} = 4 \text{ g} \)
I-S (Inferior-Superior): \( \text{min} = -3 \text{ g} \quad \text{max} = 20 \text{ g} \)
Resultant \( 35 \) g

Peak belt loads

- Right side: 1631 pounds
- Left side: 1628 pounds

Maximum Excursions (from H. S. film analysis)

- Head: 33.7 inches
- Knees: 7.9 inches
- Pelvis: 6.2 inches

Observations:
Test Setup

Test Facility: UMTRI Impact Sled

Impact Parameters

Velocity: 11.9 mph
Deceleration: 18.8 g, with trapezoidal waveform
Direction: Lateral

Restraint System: U. S. Steel

Test Results

Peak head accelerations

P-A (Posterior-Anterior): min = -2 g max = 4 g
R-L (Right-Left): min = -8 g max = 10 g
I-S (Inferior-Superior): min = -12 g max = 1 g
Resultant 13 g
HIC (Head Injury Criteria) 30 from 150 to 408 ms

Peak chest accelerations

P-A (Posterior-Anterior): min = -2 g max = 1 g
R-L (Right-Left): min = -1 g max = 5 g
I-S (Inferior-Superior): min = -21 g max = 2 g
Resultant 21 g

Peak belt loads

Right side: 601 pounds
Left side: 32 pounds

Maximum Excursions (from H. S. film analysis)

Head: 36.1 inches
Knees: NA inches
Pelvis: 9.7 inches

Observations:
Test Setup

Test Facility: UMTRI Impact Sled

Impact Parameters

- Velocity: 12.0 mph
- Deceleration: 18.4 g, with trapezoidal waveform
- Direction: Lateral
- Restraint System: 2" lap belt webbing

Test Results

Peak head accelerations

- P-A (Posterior-Anterior): min = 0 g, max = 1 g
- R-L (Right-Left): min = 6 g, max = 7 g
- I-S (Inferior-Superior): min = -23 g, max = 2 g
- Resultant: 23 g
- HIC (Head Injury Criteria): 135 from 147 to 376 ms

Peak chest accelerations

- P-A (Posterior-Anterior): min = 3 g, max = 3 g
- R-L (Right-Left): min = -5 g, max = 1 g
- I-S (Inferior-Superior): min = -11 g, max = 1 g
- Resultant: 12 g

Peak belt loads

- Right side: 578 pounds
- Left side: 357 pounds

Maximum Excursions (from H. S. film analysis)

- Head: 37.6 inches
- Knees: NA inches
- Pelvis: 8.9 inches

Observations:
Test Setup

Test Facility: UMTRI Impact Sled

Impact Parameters

Velocity: 21.2 mph
Deceleration: 20.3 g, with trapezoidal waveform
Direction: Frontal
Restraint System: U. S. Steel

Test Results

Peak head accelerations

P-A (Posterior-Anterior): \( \text{min} = -50 \text{ g} \) \( \text{max} = 6 \text{ g} \)
R-L (Right-Left): \( \text{min} = -9 \text{ g} \) \( \text{max} = 42 \text{ g} \)
I-S (Inferior-Superior): \( \text{min} = -57 \text{ g} \) \( \text{max} = 0 \text{ g} \)
Resultant: 73 g
HIC (Head Injury Criteria): 976 from 118 to 228 ms

Peak chest accelerations

P-A (Posterior-Anterior): \( \text{min} = -27 \text{ g} \) \( \text{max} = 1 \text{ g} \)
R-L (Right-Left): \( \text{min} = -7 \text{ g} \) \( \text{max} = 23 \text{ g} \)
I-S (Inferior-Superior): \( \text{min} = -25 \text{ g} \) \( \text{max} = 3 \text{ g} \)
Resultant: 32 g

Peak belt loads

Right side: 1425 pounds
Left side: 1558 pounds

Maximum Excursions (from H. S. film analysis)

Head: 33.9 inches
Knees: 15.6 inches
Pelvis: 15.2 inches

Observations:
FILE # 61
256.00 ms = 2048 Pts / 8000 Hz

LEFT LAP LOAD
800 LB

RIGHT LAP LOAD
800 LB

SLFD DECEL
16 C

H7: 178  A/D  SEAT-1  11/23/82  82S 005
FILE # 61
256.00 ms = 2048 Pts / 8000 Hz
14:03:35-14:07:45

02
1650
x 24

HEAD P-A ACC
32 G

03
1650
x 24

HEAD A-L ACC
32 G

04
1650
x 24

HEAD I-S ACC
32 G

0 50 100 150 200 250 msec

H7: 178  A/D  SEAT-1  11/23/82  825 005
Test Summary

Test Setup

Test Facility: UMTRI Impact Sled

Impact Parameters

Velocity: 21.1 mph
Deceleration: 20.9 g, with trapezoidal waveform
Direction: Frontal
Restraint System: 2" lap belt webbing

Test Results

Peak head accelerations

P-A (Posterior-Anterior): min = -97 g max = 11 g
R-L (Right-Left): min = -139 g max = 14 g
I-S (Inferior-Superior): min = -95 g max = 7 g
Resultant: 194 g
HIC (Head Injury Criteria): 1439 from 119 to 226 ms

Peak chest accelerations

P-A (Posterior-Anterior): min = -66 g max = 12 g
R-L (Right-Left): min = -11 g max = 17 g
I-S (Inferior-Superior): min = -33 g max = 45 g
Resultant: 71 g

Peak belt loads

Right side: 1922 pounds
Left side: 1632 pounds

Maximum Excursions (from H. S. film analysis)

Head: 32.6 inches
Knees: 8.4 inches
Pelvis: 6.9 inches

Observations:
FILE # 60
256.00 ms = 2048 Pts / 8000 Hz

LEFT LAP LOAD
1000 LB

RIGHT LAP LOAD
1000 LB

SLFD DFCFL
16 G

H7: 178 → A/D → SEAT-1
11/23/82
825 006
Test Setup

Test Facility: Vertical Shaker Platform

Impact Parameters

Platform Motion: Upward jolt and return
Pulse Shape: Triangular displacement waveform
Peak Platform Acceleration: 2.2 g

Restraint System: U. S. Steel Restraint Harness

Test Results

Peak head accelerations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
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<tbody>
<tr>
<td>P-A (Posterior-Anterior)</td>
<td>-2 g</td>
<td>1 g</td>
</tr>
<tr>
<td>R-L (Right-Left)</td>
<td>-2 g</td>
<td>1 g</td>
</tr>
<tr>
<td>I-S (Inferior-Superior)</td>
<td>-3 g</td>
<td>6 g</td>
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<tr>
<td>Resultant</td>
<td>6 g</td>
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HIC (Head Injury Criteria) 1 from 97 to 614 ms

Peak chest accelerations

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<td>1 g</td>
</tr>
<tr>
<td>R-L (Right-Left)</td>
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<td>0 g</td>
</tr>
<tr>
<td>I-S (Inferior-Superior)</td>
<td>-3 g</td>
<td>7 g</td>
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<tr>
<td>Resultant</td>
<td>7 g</td>
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Peak belt loads

<table>
<thead>
<tr>
<th>Side</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>66</td>
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<tr>
<td>Left</td>
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Maximum Excursions (from H. S. film analysis)

<table>
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<td>Head</td>
<td>.9</td>
</tr>
<tr>
<td>Shoulder</td>
<td>1.7</td>
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</tbody>
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Observations:
Test Summary

Test Setup

Test Facility: Vertical Shaker Platform

Impact Parameters

Platform Motion: Upward jolt and return
Pulse Shape: Triangular displacement waveform
Peak Platform Acceleration: 1.6 g

Restraint System: U. S. Steel Restraint Harness

Test Results

Peak head accelerations

P-A (Posterior-Anterior): min = -2 g max = 1 g
R-L (Right-Left): min = -2 g max = 1 g
I-S (Inferior-Superior): min = -3 g max = 5 g
Resultant 5 g
HIC (Head Injury Criteria) 1 from 133 to 575 ms

Peak chest accelerations

P-A (Posterior-Anterior) min = -2 g max = 1 g
R-L (Right-Left): min = -1 g max = 0 g
I-S (Inferior-Superior): min = -3 g max = 6 g
Resultant 6 g

Peak belt loads

Right side: 65 pounds
Left side: 64 pounds

Maximum Excursions (from H. S. film analysis)

Head: 1.0 inches
Shoulde: 2.0 inches

Observations:
Test Setup

Test Facility: Vertical Shaker Platform

Impact Parameters:

Platform Motion: Upward jolt of 5.7 inches and return in 370 ms
Pulse Shape: Triangular displacement waveform
Peak Platform Acceleration: 2.5 g

Restraint System: None

Test Results

Peak head accelerations

P-A (Posterior-Anterior): \( \text{min} = -4 \text{ g} \) \( \text{max} = 1 \text{ g} \)
R-L (Right-Left): \( \text{min} = -2 \text{ g} \) \( \text{max} = 1 \text{ g} \)
I-S (Inferior-Superior): \( \text{min} = -7 \text{ g} \) \( \text{max} = 2 \text{ g} \)
Resultant: \( 7 \text{ g} \)
HIC (Head Injury Criteria): \( 1 \text{ from 442 to 482 ms} \)

Peak chest accelerations

P-A (Posterior-Anterior): \( \text{min} = -2 \text{ g} \) \( \text{max} = 1 \text{ g} \)
R-L (Right-Left): \( \text{min} = 0 \text{ g} \) \( \text{max} = 1 \text{ g} \)
I-S (Inferior-Superior): \( \text{min} = 8 \text{ g} \) \( \text{max} = 3 \text{ g} \)
Resultant: \( 8 \text{ g} \)

Peak belt loads

Right side: \( \text{pounds} \)
Left side: \( \text{pounds} \)

Maximum Excursions (from H. S. film analysis)

Head: \( 1.9 \text{ inches} \)
Shoulder: \( 2.6 \text{ inches} \)

Observations:
Test Summary

Test Setup

Test Facility: Vertical Shaker Platform

Impact Parameters

Platform Motion: Upward jolt of 5.7 inches and return in 370 ms
Pulse Shape: Triangular displacement waveform
Peak Platform Acceleration: 2.8 g

Restraint System: 2 inch wide lap belt webbing

Test Results

Peak head accelerations

P-A (Posterior-Anterior): min = -2 g max = 1 g
R-L (Right-Left): min = -2 g max = 1 g
I-S (Inferior-Superior): min = -3 g max = 4 g
Resultant 4 g
HIC (Head Injury Criteria) 1 from 44 to 543 ms

Peak chest accelerations

P-A (Posterior-Anterior) min = -2 g max = 1 g
R-L (Right-Left): min = 0 g max = 1 g
I-S (Inferior-Superior): min = -4 g max = 4 g
Resultant 5 g

Peak belt loads

Right side: 86 pounds
Left side: 75 pounds

Maximum Excursions (from H. S. film analysis)

Head: 1.3 inches
Shoulder: 1.8 inches

Observations: