U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

www.nhtsa.gov

**DOT HS 811 335** **May 2010**

# NHTSA's Motorcoach Safety Research Crash, Sled, and Static Tests

# DISCLAIMER

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# EXECUTIVE SUMMARY

Motorcoach travel is a very safe mode of highway transportation in the United States. Over the ten year period between 1999 and 2008, on average, 16 fatalities have occurred annually to occupants of motorcoaches in crash and rollover events, with two of these fatalities being drivers and 14 being passengers. Among the 14 motorcoach passenger fatalities, 66 percent occurred in rollover events and 34 percent in roadside and multi-vehicle impacts. Ejection from motorcoaches accounts for 81 percent of passenger fatalities in motorcoach rollover events. [1].

Passenger ejections can be reduced by using a number of different technologies, such as reducing openings by using stronger window retention methods, improvements to the integrity of window and other glazing areas, use of seat belts, etc. For passenger ejection, incorporation of seat belts has been pursued as the most expedient way to mitigate ejection. Crash and sled tests to study the effects of using seat belts are described in the report.

The National Highway Traffic Safety Administration (NHTSA) conducted a crash test in December 2007 at the NHTSA Vehicle Research and Test Center (VRTC) in East Liberty, Ohio. The primary purpose of the crash test was to record the crash pulse from a severe frontal crash of a motorcoach. This pulse was used in a sled test program to evaluate restraint performance. Unbelted dummies and dummies with lap belts had high head accelerations and Nij values, while the dummies with lap/shoulder belts had low head and neck loads. All dummies had low chest accelerations, chest displacements, and femur loads. All belted dummies remained in their seats while the unbelted dummies ended up in the aisle or in the seats in front of them. There was no evidence of any “compartmentalization” in the unbelted seat configurations, as the unbelted dummies did not stay in their seats. All seat attachments (including baseline) remained intact. The seats did not separate from the floor or side-rail.

The crash pulse from the crash test (VRTC pulse) was used in sled tests to simulate such impacts and to study the dummy kinematics and injury assessment values under different seating and dummy size combinations. Some tests were also conducted using the Europe (ECE) Regulation 80 pulse. Like in the crash test, the higher dummy injury measures were mostly limited to HIC and Nij, although the unbelted 5th females often recorded high femur loads. When the VRTC pulse was used, no lap/shoulder belted dummy had a Nij which exceeded the IARV, and only one lap/shoulder belted dummy recorded a HIC response above the injury assessment reference values (IARV). Rear loading of the target seat by unbelted dummies often led to increased injury values for the lap/shoulder belted dummy, compared to tests that had no rear dummy loading. The ECE pulse produced higher HIC responses than the VRTC pulse. Several of the lap/shoulder belted dummies exceeded the IARV for HIC when tested with the ECE pulse. The ECE pulse has a shorter duration and higher peak acceleration than the VRTC pulse.

Static pull tests were developed to subject the seat belts, seat belt anchorages, seat structures, and seat anchors to forces observed in the sled tests. The static tests will ensure that the seat belt assemblies and the seat hardware in complying systems will withstand the forces generated in such crash environments.

# 1.0 BACKGROUND

Motorcoach travel is a very safe mode of highway transportation in the United States. Over the ten year period between 1999 and 2008, on average, 16 fatalities have occurred annually to occupants of motorcoaches in crash and rollover events, with two of these fatalities being drivers and 14 being passengers. Among the 14 motorcoach passenger fatalities, 66 percent occurred in rollover events and 34 percent in roadside and multi-vehicle impacts. Ejection from motorcoaches accounts for 81 percent of passenger fatalities in motorcoach rollover events. [1].

Passenger ejections can be reduced by using a number of different technologies, such as reducing openings by using stronger window retention methods, improvements to the integrity of window and other glazing areas, use of seat belts, etc. For passenger ejection, incorporation of seat belts has been pursued as the most expedient way to mitigate ejection [2]. Crash and sled tests to study the effects of using seat belts are described in the following sections.

# 2.0 CRASH TEST

## 2.1 Introduction

The National Highway Traffic Safety Administration (NHTSA) conducted a crash test in December 2007 at the NHTSA Vehicle Research and Test Center in East Liberty, Ohio (Test # 6294 in NHTSA Vehicle Crash Test Database). The primary purpose of the crash test was to record the crash pulse from a severe frontal crash of a motorcoach. This pulse was used in a sled test program to evaluate restraint performance (discussed in Chapter 3).

Figure 1 shows the motorcoach used in the test. It was a 2000 MCI 102EL3 Renaissance with a Detroit Diesel Series 60 diesel engine and B500 Allison Automatic transmission. The coach was 45 ft (1372 cm) long, 12 ft 6 inches (381 cm) tall, with 54 seats (34 inches apart longitudinally). The weight as tested (including dummies and equipment) was 42,720 lbs (19,378 kg).

**Figure 1 - Motorcoach Used for Crash Test**

The coach had unbelted seats from American Seating Company, seats with 2 and lap/shoulder belts from Amaya, and a seat with lap/shoulder belts from Freedman Seating Company.

The crash test speed was 30 mph (48.3 kph) into a fixed rigid barrier at zero degrees, full overlap condition. The test collected data from 355 dummy channels and 26 vehicle channels at 12,500 samples/sec.

## 2.2 Selection of the motorcoach

Motor Coach Industries (MCI) is one of the leading manufacturers of motorcoaches in use in the North American market. According to Polk, ABA estimates, in 2007, MCI, Prevost, ABC/Van Hool and Setra had market shares of 56%, 23%, 19% and 2% of the industry-wide fleet of 49,493 units, respectively. According to National Bus Trader estimates, MCI had 38% of the annual sales (1,794) in the private coach segment in 2007. For 2009, the annual sales market share for MCI, Prevost, ABC/Van Hool and Setra were 49%, 21%, 22% and 8% of annual sales.

The MCI E-series Renaissance bus was introduced in 1996 and is still sold as the top-of-the line tour bus model by MCI.

## 2.3 Seats used in the crash and sled tests

The motorcoach used in the crash test came with unbelted seats from the American Seating Company (see Figure 2).

**Figure 2 – Unbelted Seats from the American Seating Company**

At the time of the crash test (Fall 2007), there were no known suppliers of motorcoach seats with belts. Therefore, custom solutions from existing suppliers of seats were sought. Freedman Seating supplies belted seats for transit buses and small and mid-size coaches. Custom belted seats for the MCI motorcoach were purchased from Freedman Seating (see Figure 3).

**Figure 3 – Custom Lap/Shoulder Belted Seats from the Freedman Seating Company**

Additionally, custom seats made by Amaya and based on the European market for belted seats were purchased (see Figure 4). These seats were versions of seats, modified to fit in the MCI 102EL3 bus used in this program, designed to meet the following Economic Commission for Europe (ECE),bus definitions (as defined in Regulation 14, TRANS/WP.29/78/Rev.1/Amend2):

M3: Vehicles with more than eight seats (plus driver) and mass greater than five tonnes (11,023 lbs). This uses a load equivalent to 6.6 g. These seats are referred to as “7G seats” in this report.

M2: Vehicles with more than eight seats (plus driver) and mass less than five tonnes (11,023 lbs). This uses a load equivalent to 10 g. These seats are referred to as “10G seats” in this report.

**Figure 4 – European Lap/Shoulder Belted Seats from Amaya**

In order to study the effect of having lap belts, custom 7G seats with lap belts, made by Amaya were also purchased.

## 2.4 Crash test conditions

A full frontal crash into a fixed rigid barrier at a speed of 30 mph was selected, which represents a severe crash condition (pre-test set-up is shown in Figure 5). Since the deceleration pulse from this test was to be used for sled testing to evaluate restraints, it was judged that a severe crash was the most suitable. A crash that occurred in southern Kentucky in June 2007 would be an example of such a severe crash. A 1987 MCI motorcoach carrying 42 adult and 22 child passengers crashed into an overpass support about 75 miles north of Nashville on Interstate 65, at highway speed, (see Figure 6). The driver and one passenger were killed. Other crash conditions, including some European requirements, were simulated on the sled tests described later in the report.

**Figure 5 – Pre-Test Set-Up for Motorcoach Crash Test**

**Figure 6 – Kentucky Motorcoach Crash Scene**
(photograph by Associated Press)

2.5 Dummy and instrumentation placement

The crash test used 22 instrumented dummies at different seat locations throughout the bus. The types and numbers of dummies used were as follows:

Hybrid III 50th percentile male – 5 ft, 9 inches (175 cm) tall and 170 lb (77 kg) - 17 dummies

Hybrid III 5th percentile female – 5 ft (150 cm) tall and 110 lb (50 kg) - 3 dummies
Hybrid III 95th percentile male – 6 ft, 2 inches (188 cm) tall and 220 lb (100 kg) - 2 dummies

Each dummy had accelerometers in the head and chest, load cells in the upper neck and femurs, and a chest displacement potentiometer.

The locations of the dummies and vehicle-mounted accelerometers (3 axes at locations A, B, C, D, and E) are shown in Figure 7. Locating accelerometers at various locations, on the longitudinal structural beam of the coach, allowed for the measurement of the crash pulse in both the crush zone and the occupant area.

The belted dummies of different size combinations were seated on the right side of the aisle in Rows 9R, 11R, 13R in Amaya 7 g seats with lap/shoulder belts. The corresponding unbelted dummy size combinations were seated on the left of the aisle in baseline unbelted seats (American Seating Co.), in rows 8L, 10L, and 12L. This allowed for a direct comparison of dummy injury assessments and kinematics for belted and unbelted dummies (and the performance of the seat structures).

A single, lap belts only Amaya seat was installed in Row 5L. This was to study the performance of lap belts in restraining 50th percentile male and 5th percentile female dummies.

The effect of rear loading from unbelted dummies in the seats behind the belted seats was also examined. Mid-size male dummies were seated in lap/shoulder belted seats from Amaya and Freedman Seating in rows 4R and 6R, respectively. They were subject to rear loading from unbelted dummies in rows 5R and 7R. The belted seats in rows 4R and 6R were attached to the bus using reinforced structures, shown in Figure 8. The intent was to study the dummy injury assessments and kinematics without the seats getting detached from the bus. The rest of the nine occupied and 13 unoccupied rows were attached to the bus using OEM equipment (T-bolts) shown in Figure 9.

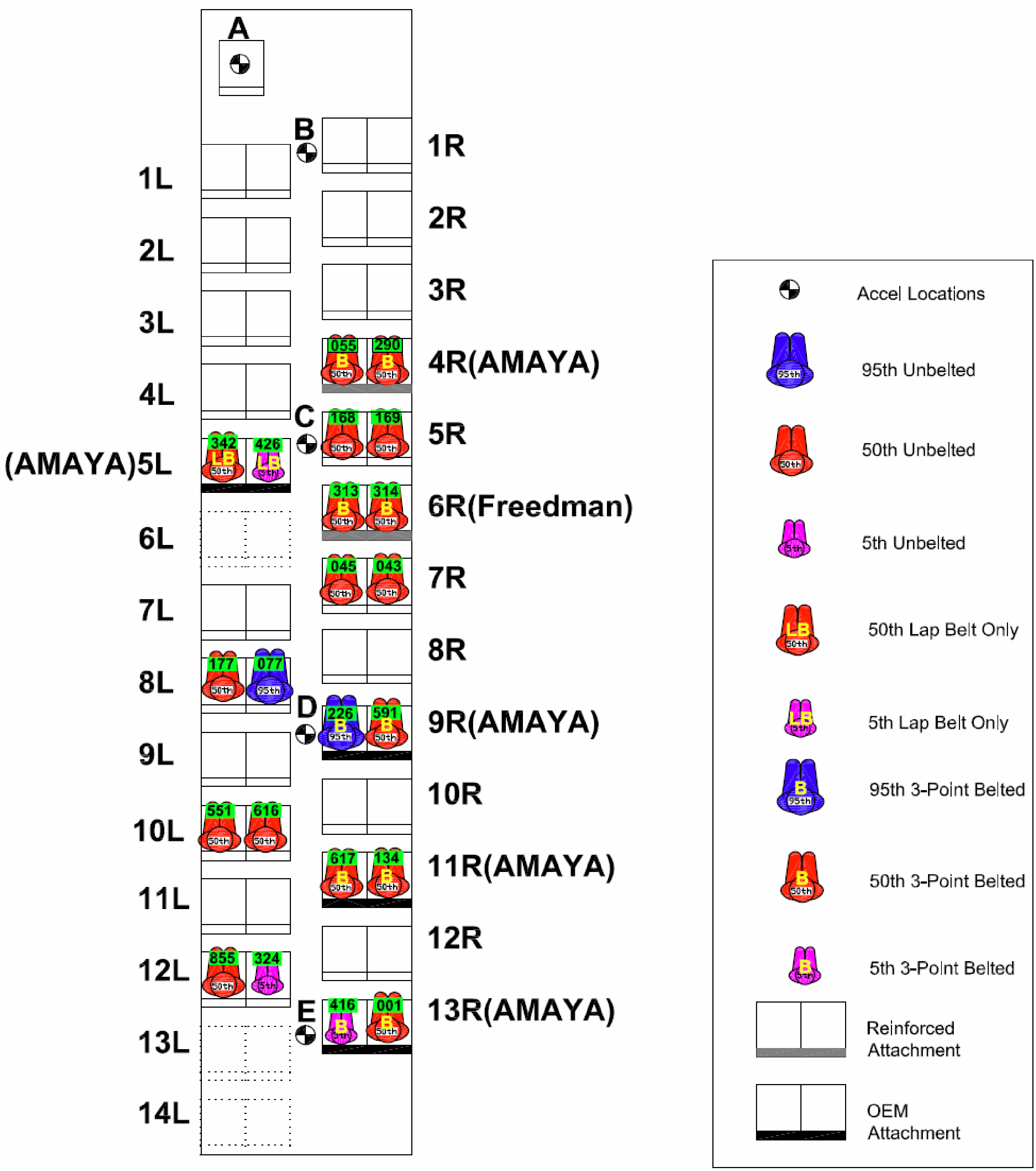


Figure 7 – Dummy Seating Locations and Vehicle-Mounted Accelerometer Placement

**Figure 8 – Reinforced Seat Mountings for Rows 4R and 6R**

**Figure 9 – OEM Seat-Mounting Attachments**

## 2.6 Photographic coverage

The crash test was extensively documented using ten on-board high-speed (1000 fps) cameras (three high resolution (1536 x 1024), seven standard resolution (752 x 752)), nine off-board high speed cameras, including overhead and underbody views (eight high resolution, one medium resolution (640 x 480)), two real-time panning views, and pre and post-test still photographs. The locations of the high-speed cameras are shown in Figure 10.

## 2.7 Summary of results

The measured speed of the crash test was 30.36 mph (48.86 kph). The peak deceleration was about 13 g at 125 milliseconds, obtained from accelerometer data filtered to SAE CFC 60 (shown in Figure 11). The velocity and displacement curves, obtained by integrating the accelerometer data, are shown in Figures 12 and 13, respectively.

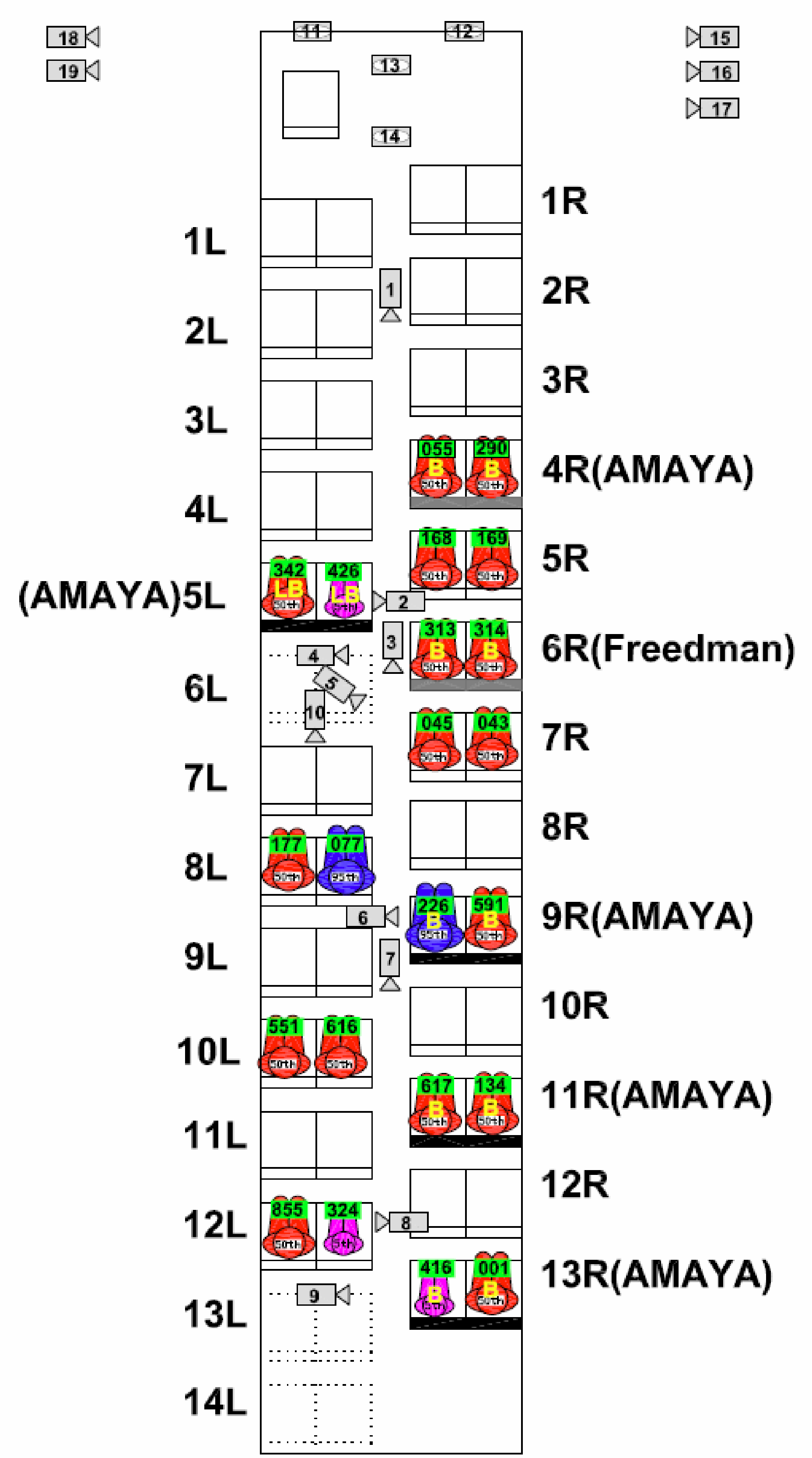


Figure 10 – Locations of High-Speed Cameras

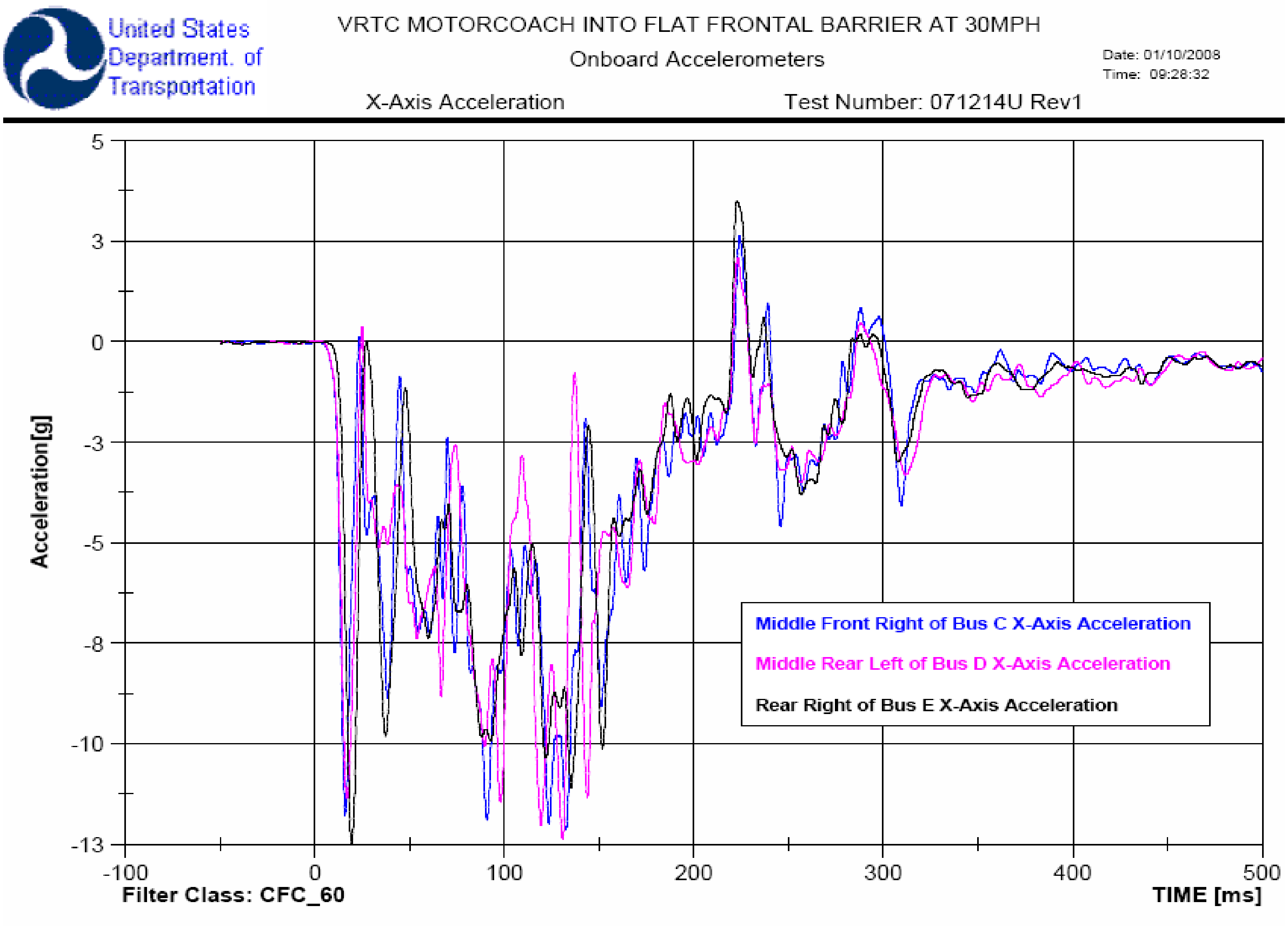


**Figure 11 – Vehicle Deceleration from Crash Test**

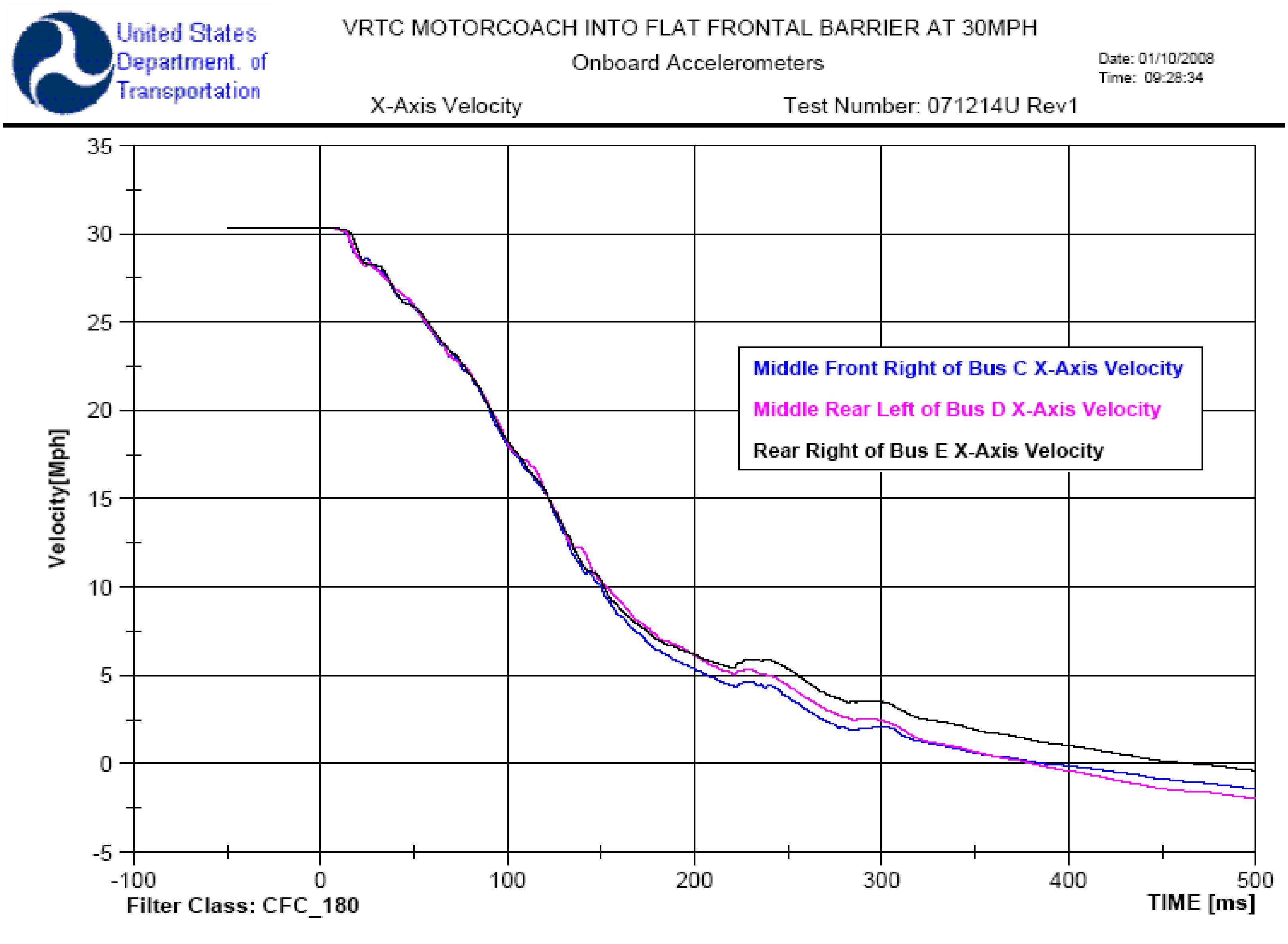


Figure 12 – Vehicle Velocity from Crash Test

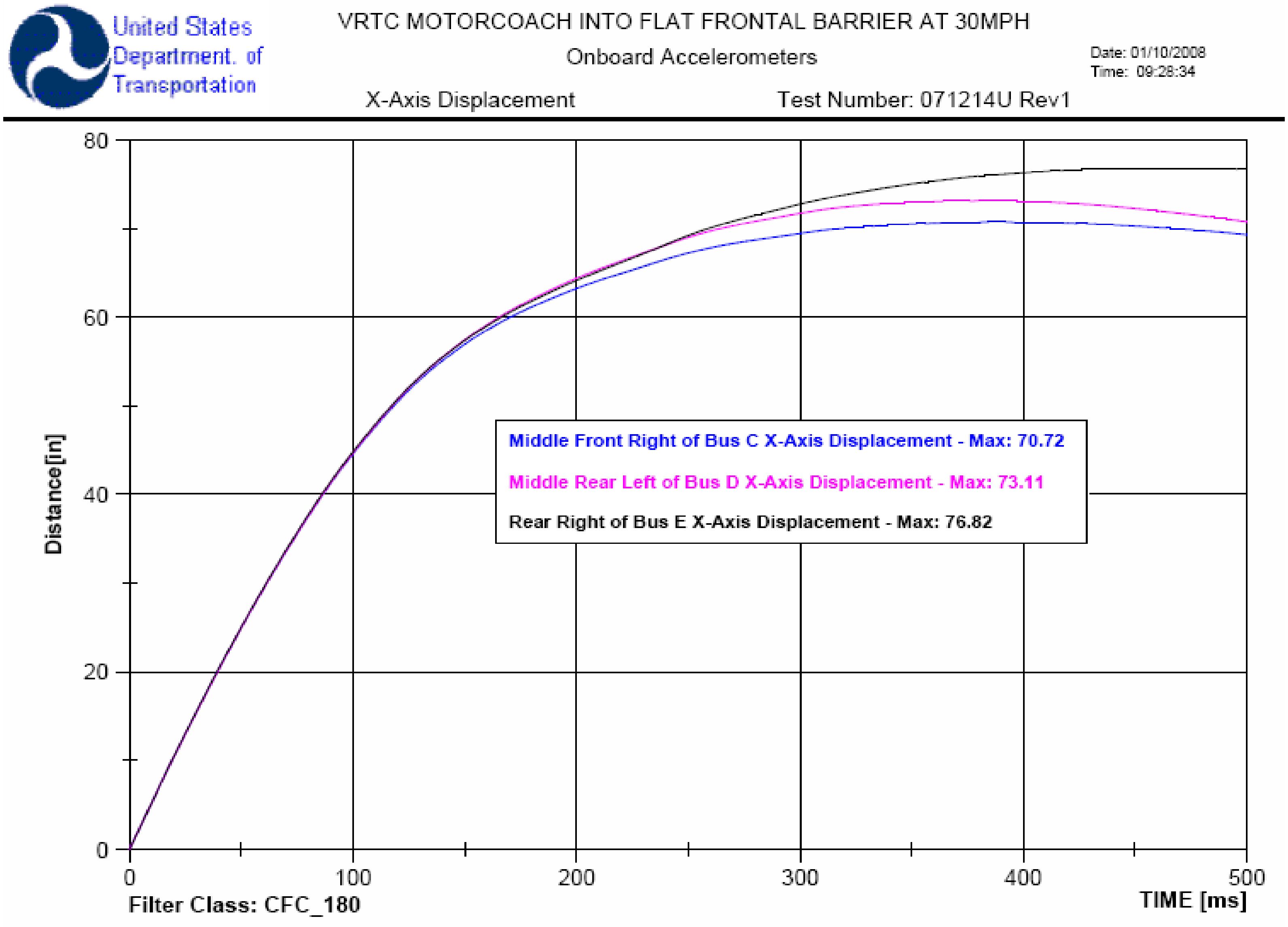


**Figure 13 – Vehicle Displacement from Crash Test**

The displacement plot shows a peak dynamic crush of approx 77 inches (196 cm). Post-test pictures of the damage are shown in Figures 14 and 15.

**Figure 14 – Frontal Views of Damage from Crash Test**

**Figure 15 – Side View of Damage from Crash Test**

## 2.8 Dummy injury assessments

The dummy injury assessment values from the crash test are listed in the Appendix. All dummies had chest and femur injury values less than 80 percent of the associated injury assessment reference values (IARV), so these are not shown in this section.

The head injury criteria (HIC) values for the dummies are shown in Figure 16. The values exceeding the IARV of 700 are shown in red, and the values below 80 percent of the IARV are shown in green. The resultant head accelerations of the dummies are shown in Figures 17 to 20. Figure 17 shows high head acceleration values for the unbelted 5th percentile female dummy and the dummy restrained by lap belts. Similarly, Figures 18 and 19 show that the unbelted 50th percentile male dummies (dotted line) had much higher head accelerations than belted dummies (solid line), especially when interacting with the seat in front of the dummy. Head accelerations in the 150 ms – 200 ms timeframe resulted from head of the dummy striking the seat in front of the dummy. The unbelted dummy #177 had a secondary impact at approx 350 ms into the fixture for video cameras two rows forward of the dummy.

The neck injury criteria (Nij) and the corresponding component of the maximum Nij (compression, tension, flexion, and extension) are shown in Figure 21.

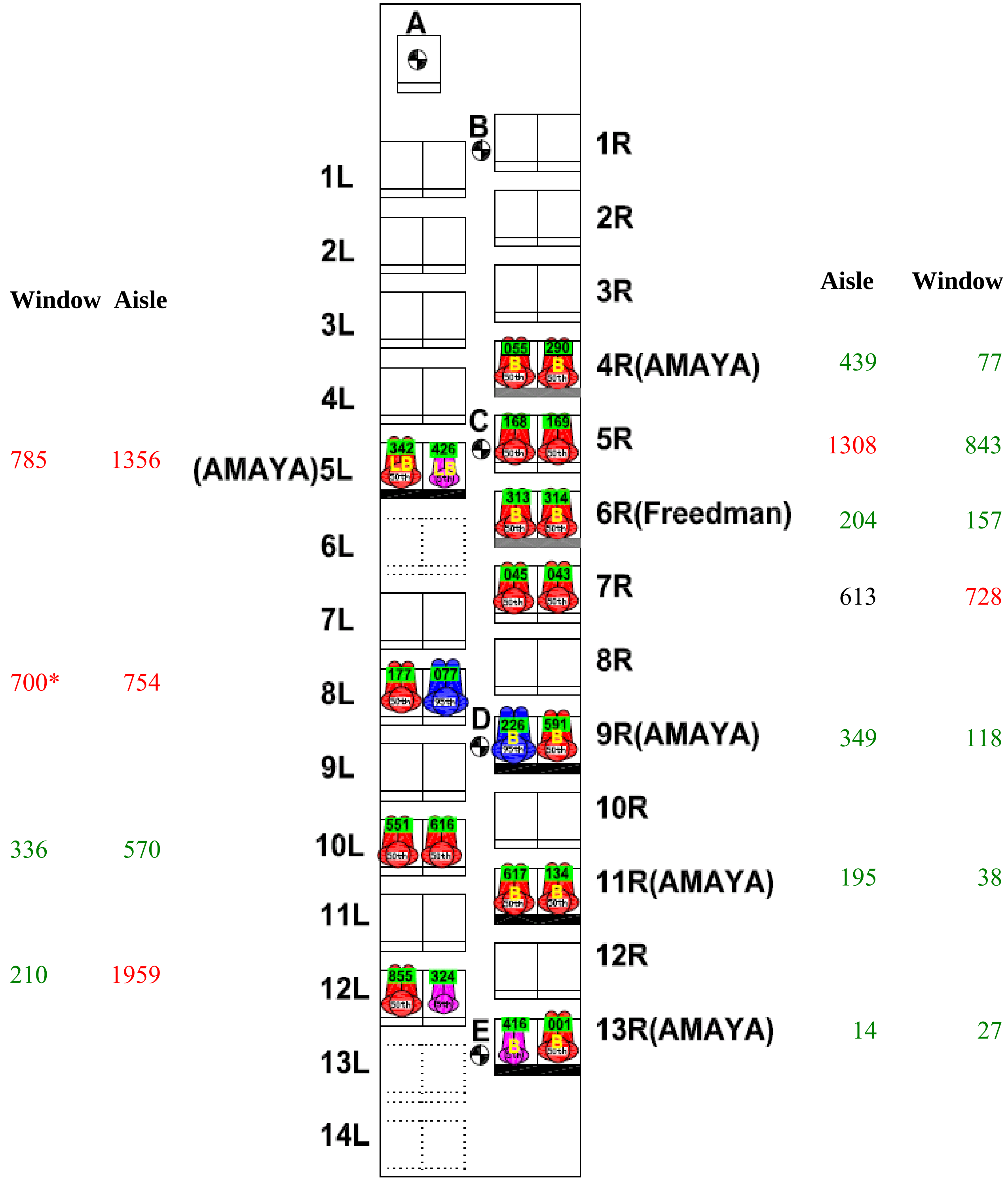
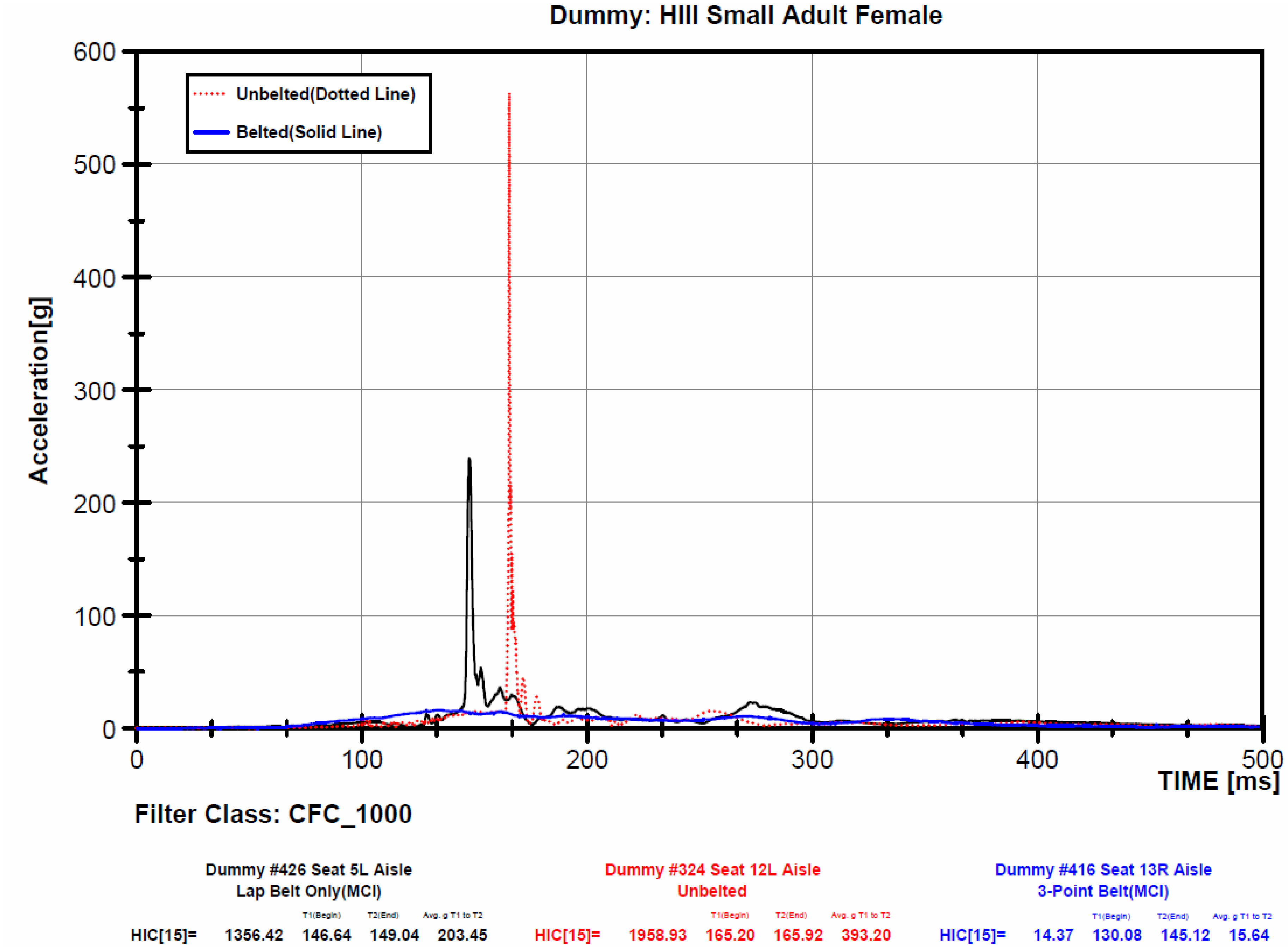


Figure 16 - HIC Values Obtained in Crash Test



Dummy #426 Seat 5L Aisle
Lap Belt Only(MCI)

| | | T1(Begin) | T2(End) | Avg. g T1 to T2 |
|---|---|---|---|---|
| HIC[15]= | 1356.42 | 146.64 | 149.04 | 203.45 |

Dummy #324 Seat 12L Aisle
Unbelted

| | | T1(Begin) | T2(End) | Avg. g T1 to T2 |
|---|---|---|---|---|
| HIC[15]= | 1958.93 | 165.20 | 165.92 | 393.20 |

Dummy #416 Seat 13R Aisle
3-Point Belt(MCI)

| | | T1(Begin) | T2(End) | Avg. g T1 to T2 |
|---|---|---|---|---|
| HIC[15]= | 14.37 | 130.08 | 145.12 | 15.64 |

**Figure 17 - Resultant Head Accelerations – 5th Female**

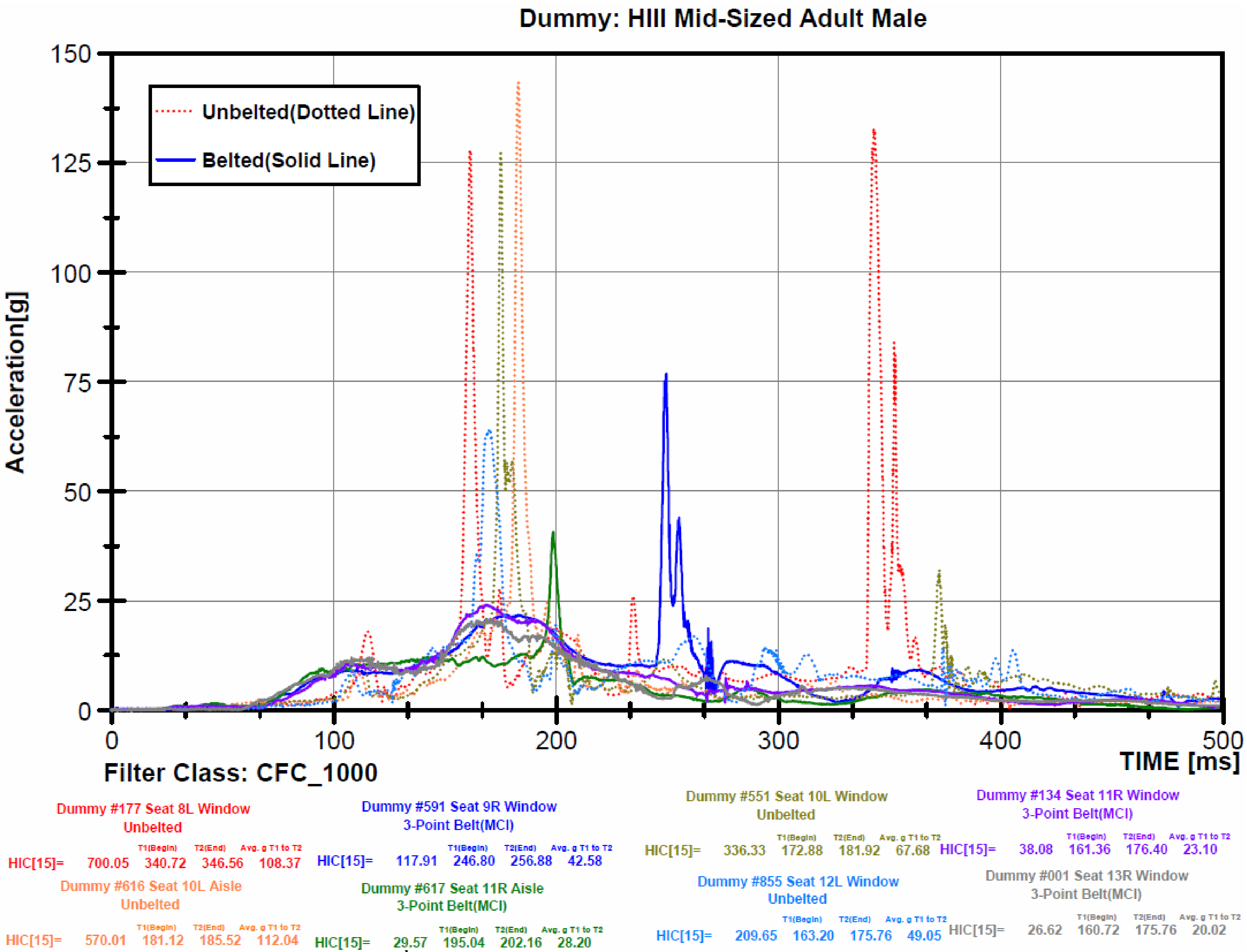


**Figure 18 - Resultant Head Accelerations – 50th Male - Rear**

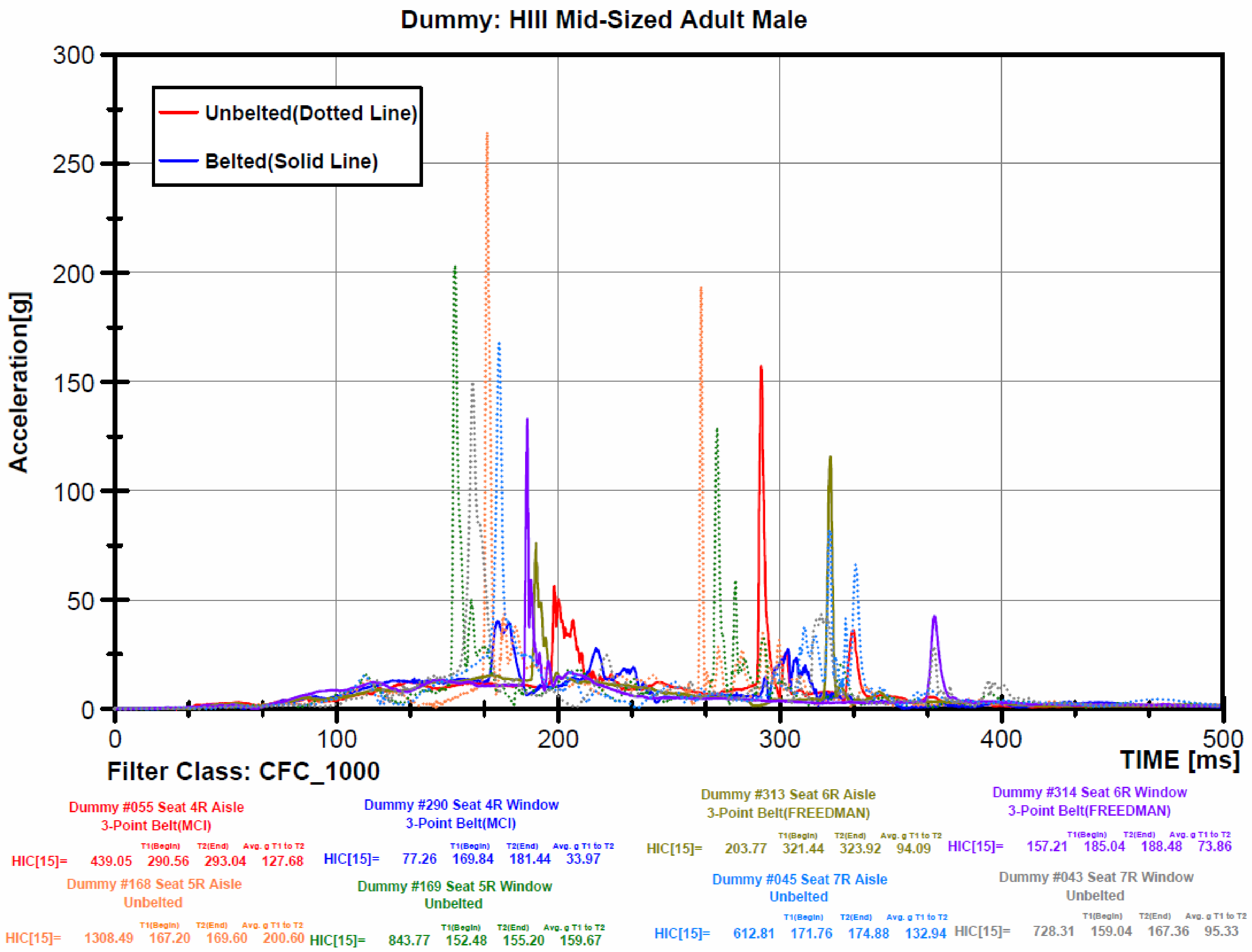


Figure 19 - Head Accelerations – 50th M - Front

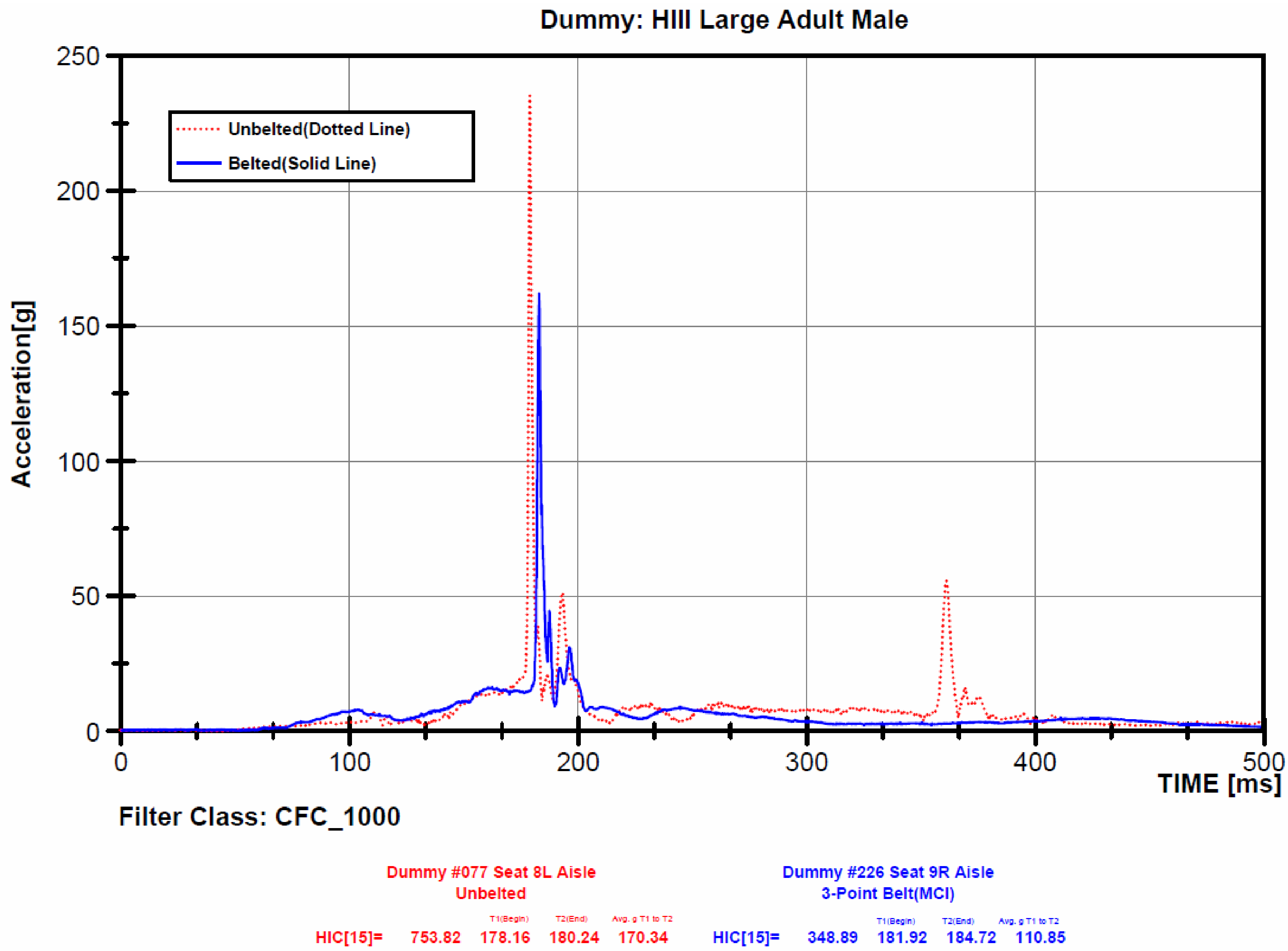


Figure 20 - Head Accelerations – 95th M

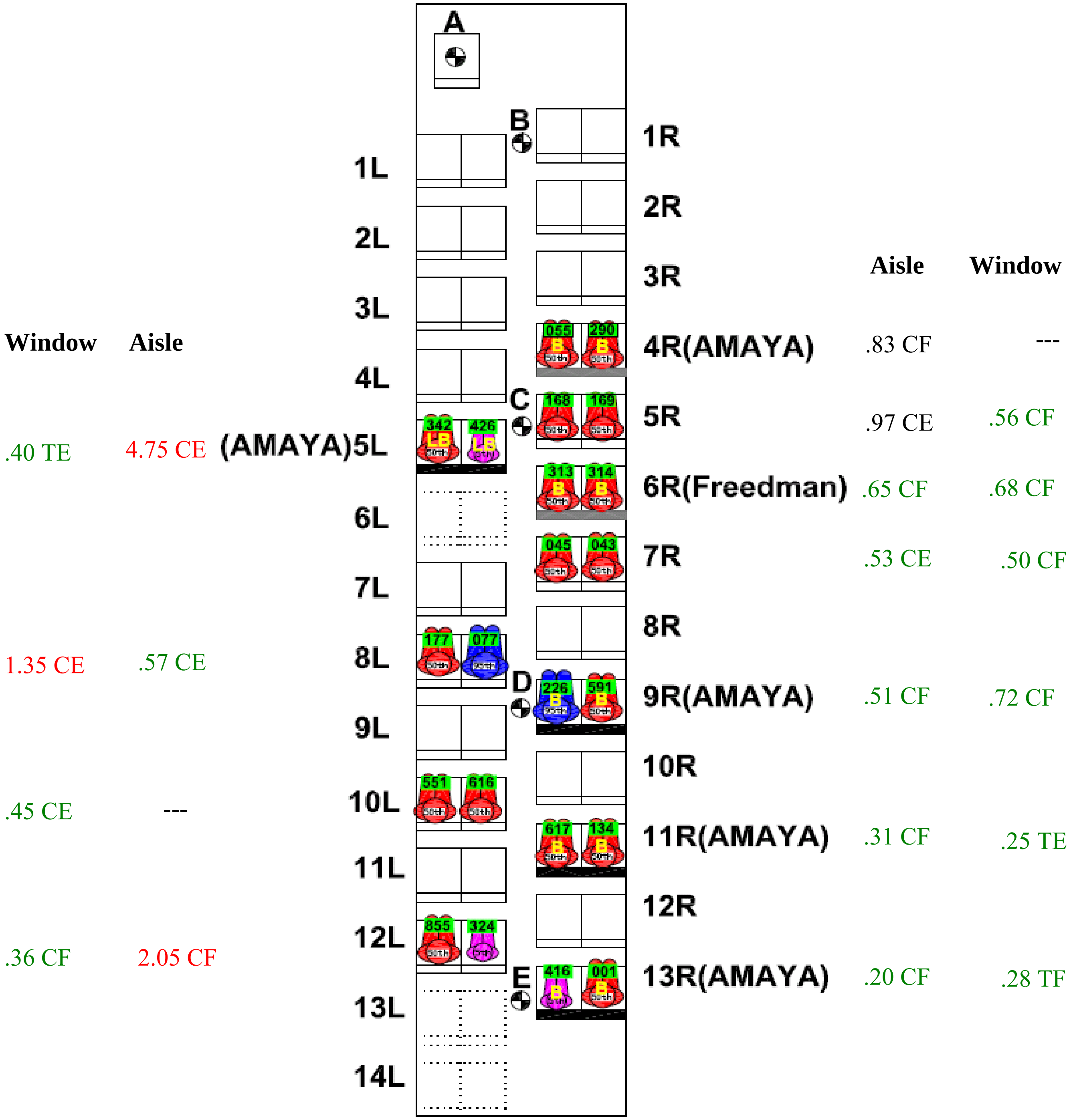


Figure 21 - Neck Injury Values (Nij)

## 2.9 Observations

Unbelted dummies and dummies with lap belts had high head accelerations and Nij values, while the dummies with lap/shoulder belts had low head and neck loads. All dummies had low chest accelerations, chest displacements, and femur loads.

The unbelted dummies typically made the first head contact with the back of the seat in front within 150 to 180 milliseconds. The belted dummies did not strike the seat in front in any significant way, except for the 95th male dummy in row 9R, which struck the seat in front with the knees and head.

The dummies in lap/shoulder belts had HIC values below 80 percent of the IARV, while the unbelted dummies and dummies in lap belts had HIC values exceeding the IARV. The high head acceleration of the unbelted dummy #177 in the 8L window seat at 350 milliseconds (relatively late in the event) was caused by the head striking a camera mount two rows in front of the seat.

All belted dummies remained in their seats (Figure 22), while the unbelted dummies ended up in the aisle or in the seats in front of them (Figures 23). There was no evidence of any "compartmentalization" in the unbelted seat configurations, as the unbelted dummies did not stay in their seats (Figure 24).

The dummies with high neck loads were either unbelted or in 2-pt belts.

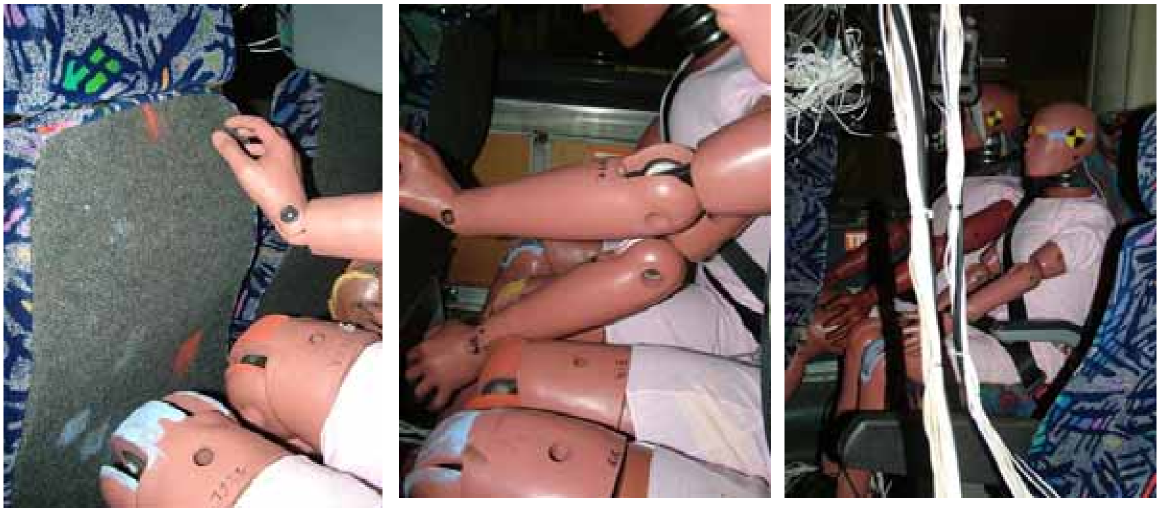


**Figure 22 – Post-test positions of belted dummies**

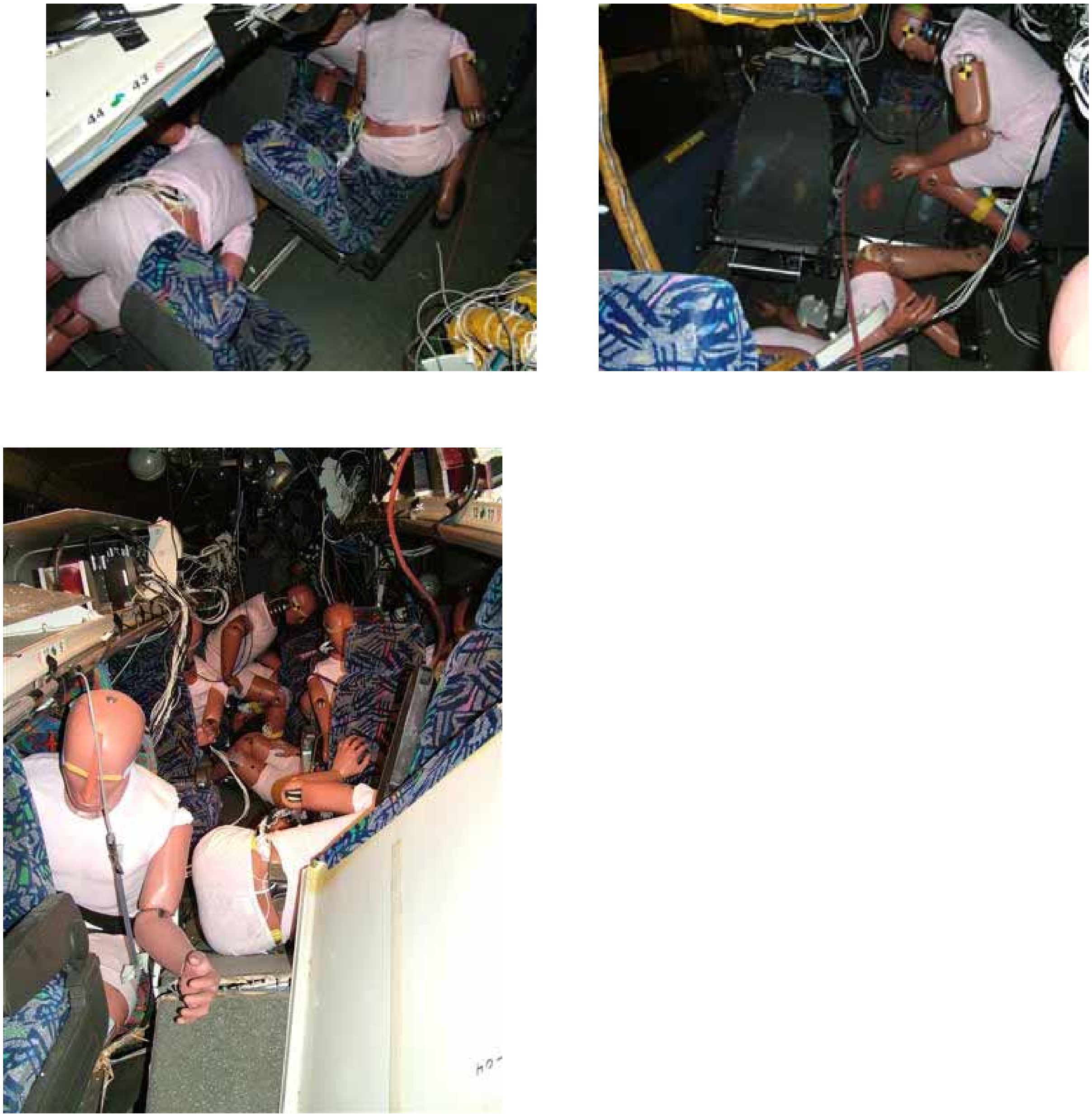


Figure 23 – Post-test positions of unbelted dummies

**Figure 24 - Lack of compartmentalization of unbelted dummies**

All seat attachments (including baseline) remained intact. The seats did not separate from the floor or side-rail. There was one failure of the seat frame at the floor attachment (Figure 25). This was a baseline seat (not designed for belts). This unoccupied seat had high forces exerted on it by unbelted 50th male and 95th male dummies in the row behind it.

**Figure 25 - Damage to the seat mounting hardware**

The baseline seats and the Freedman seat back were bent and/or broken when impacted by unbelted dummies in the seats behind them (Figure 26).

**Figure 26 - Dummy contact with seat in front**

The D-ring mount of the belted Amaya seat in row 11R failed (Figure 27). The D-ring is attached to the seat back using two bolts. The top bolt sheared, resulting in forward excursion of the D-ring. However, this did not result in dummy contact with the seats in front or high injury assessment values.

**Figure 27 - Damage to D-ring mount**

## 3.0 SLED TESTS

### 3.1 Introduction

The primary purpose of the crash test was to record the crash pulse from a severe frontal crash of a motorcoach. The crash pulse would be used in sled tests to simulate such impacts and to study the dummy kinematics and injury assessment values under different seating and dummy size combinations. This allows for an understanding on how the crash environment affects the outcome and the likelihood of severe injuries or fatalities in such crashes.

### 3.2 Sled pulse selection

Figure 28 shows the crash pulse (magenta) at the occupant compartment (away from the crush zone) from the crash test. The data in this plot has been filtered to SAE CFC 60. The sled pulse for most of the sled tests (referred to as the VRTC pulse in this document) is in black, while the sled pulse for the European ECE 80 conditions is in blue, and ECE 80 corridor is in red.

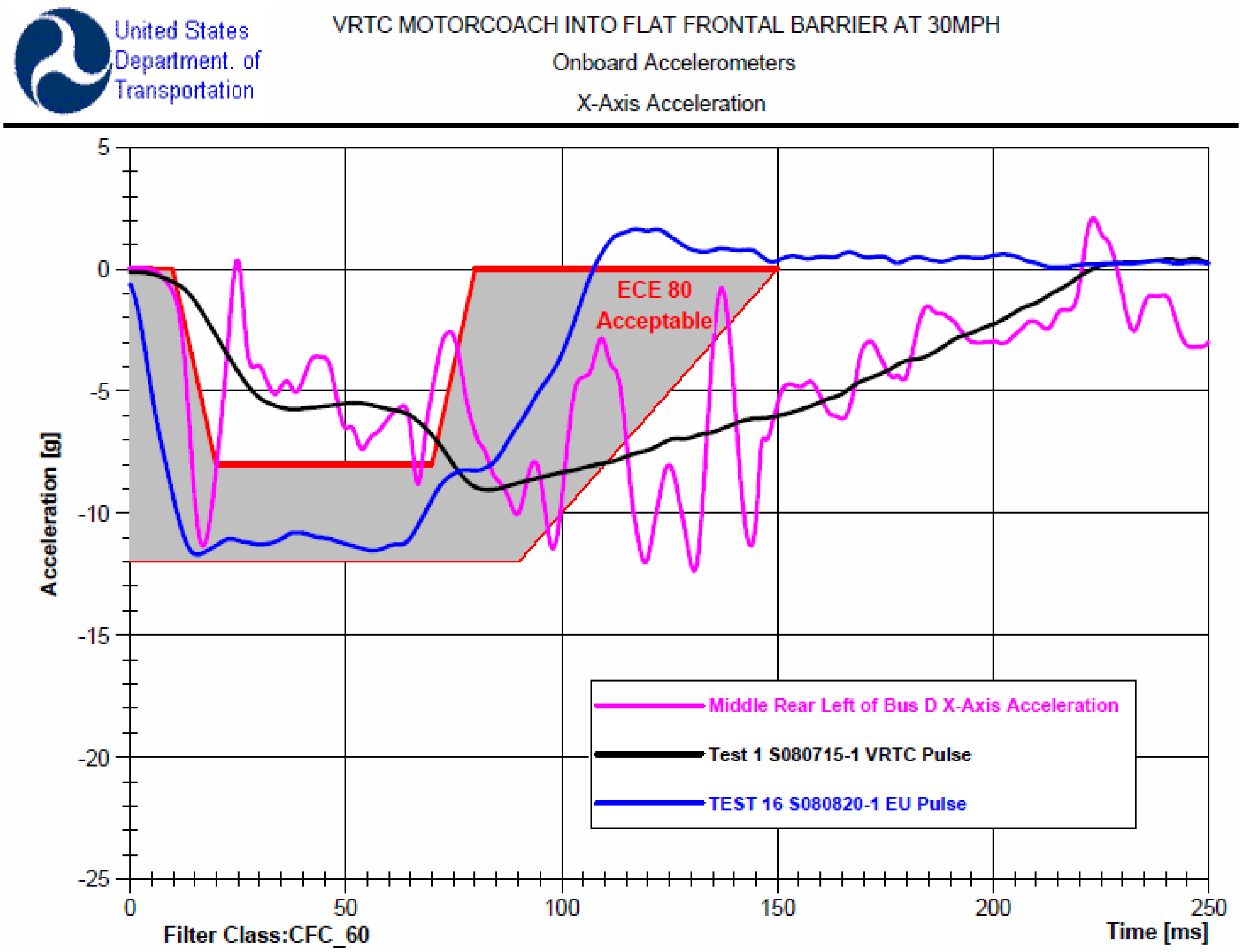


**Figure 28 - Crash and sled pulses used (SAE CFC 60)**

The HYGE sled produces sled pulses without any significant data above 30 Hz. This can be seen in Figure 29, which has the same data as in Figure 28, except that the crash test pulse is filtered to a 30 Hz cutoff frequency.

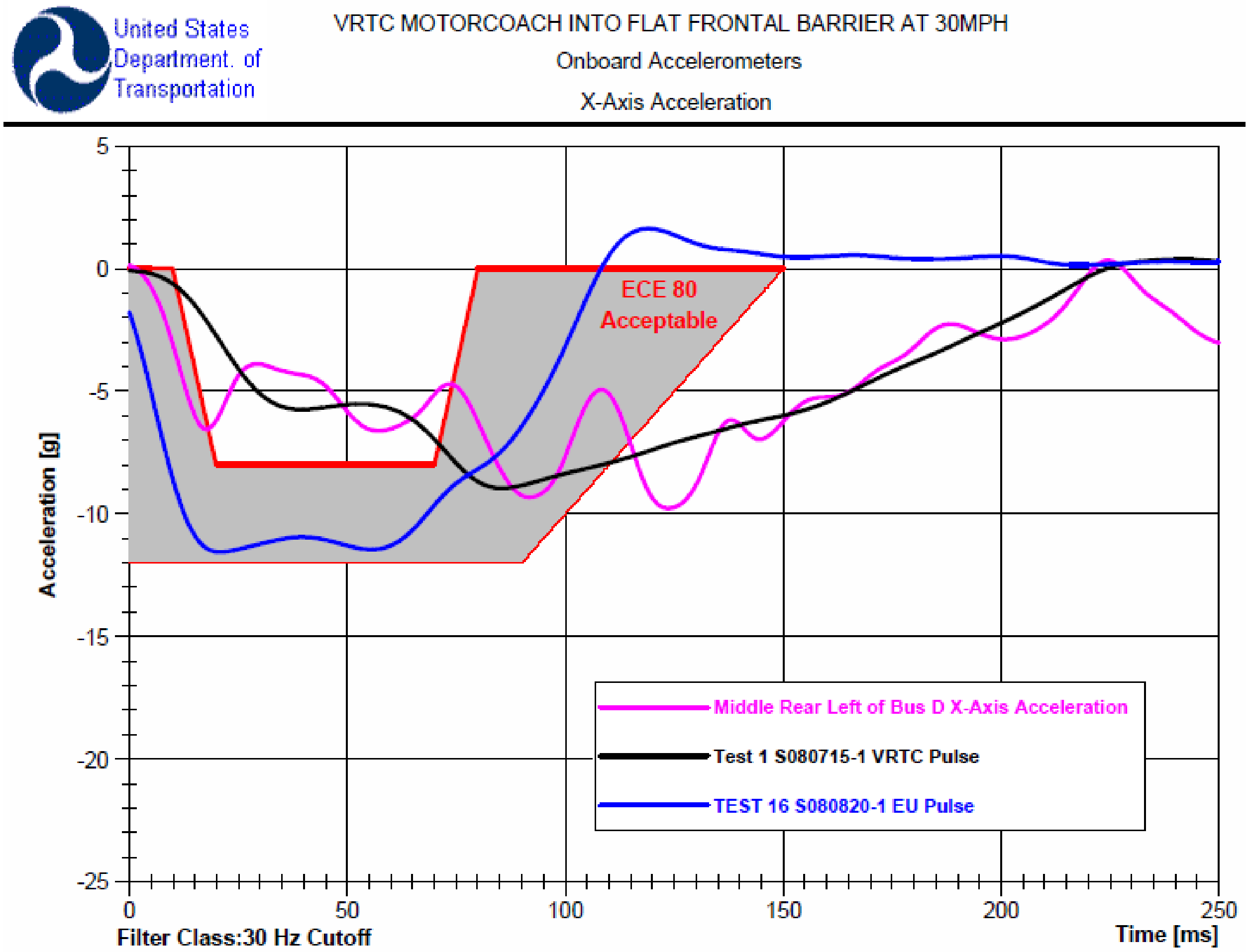


**Figure 29 - Crash and sled pulses used (30 Hz cutoff)**

Figure 30 shows the velocity from the crash test and the sled tests simulating the crash and ECE 80 sled pulse. The velocity time history and ΔV values from the crash test and the VRTC pulse are very similar.

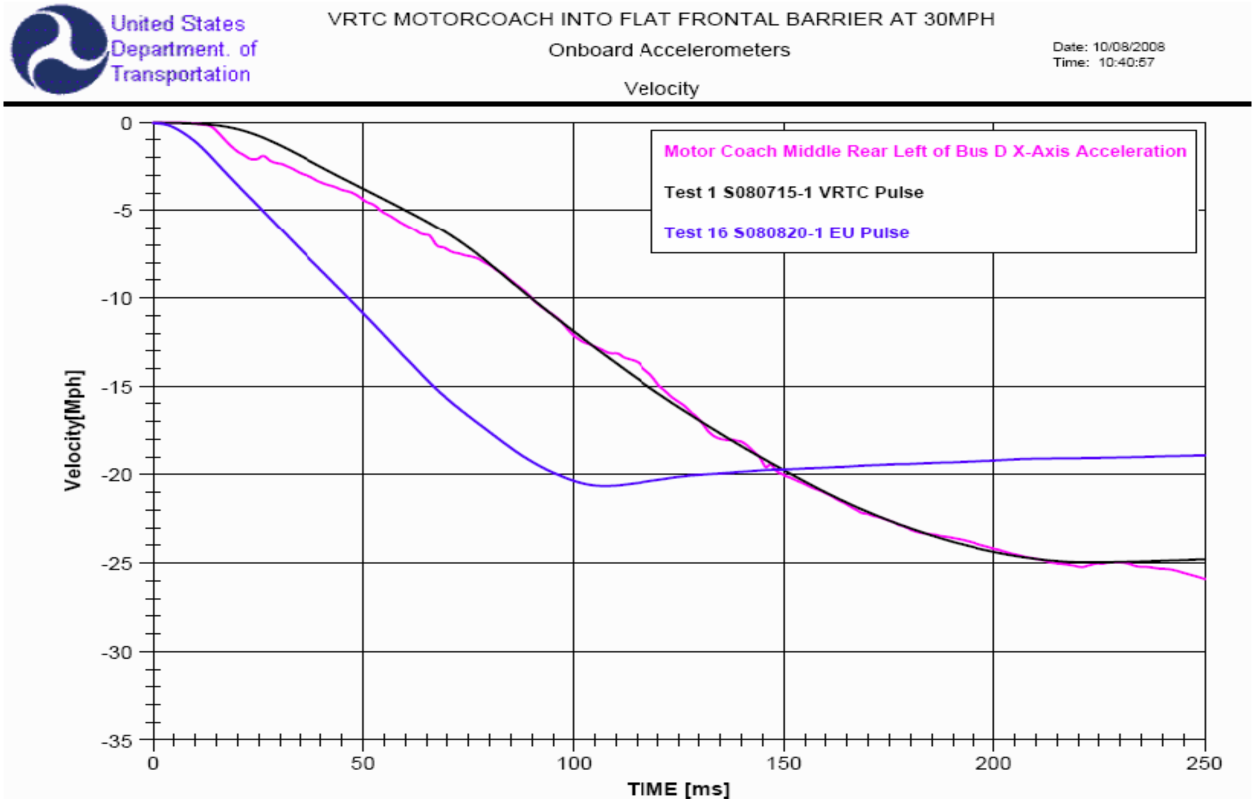


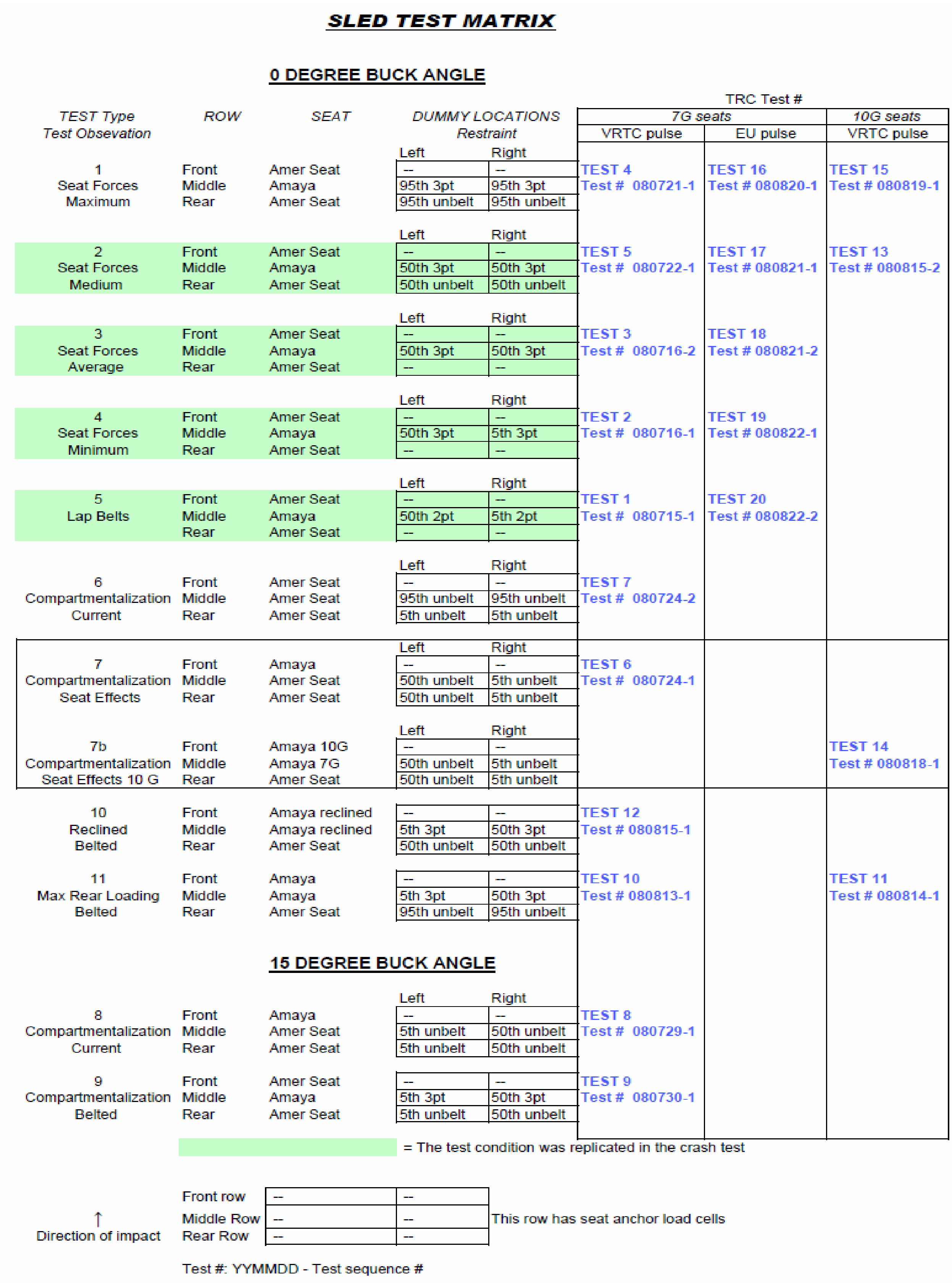
**Figure 30 - Crash and sled velocities**

3.3 Sled test setup

The sled test used baseline (unbelted) seats from American Seating, and M3 and M2 seats from Amaya, as described in section 2.3. These are referred to as “Amer Seat”, “Amaya” 7G and “Amaya” 10G, respectively in the test matrix (Figure 32).

The sled setup consisted of three rows of seats: front row, middle row, and rear row. The belted seat was located in the middle row, attached to the sled at the floor and side rail through three axis load cells (Figure 31). The front row was always unoccupied and provided surfaces for the dummies in the middle row to strike (with knees and head/neck). The rear row was used for unbelted dummies that loaded the middle row, or it was left unoccupied. The sled test matrix is shown in Figure 32.

**Figure 31 - Sled test setup with load cells at seat anchor of middle row seat**



**SLED TEST MATRIX**

**0 DEGREE BUCK ANGLE**

| *TEST Type*<br>*Test Obsevation* | *ROW* | *SEAT* | *DUMMY LOCATIONS*<br>*Restraint* | | TRC Test # | | |
|---|---|---|---|---|---|---|---|
| | | | | | *7G seats* | | *10G seats* |
| | | | Left | Right | VRTC pulse | EU pulse | VRTC pulse |
| 1 | Front | Amer Seat | -- | -- | TEST 4 | TEST 16 | TEST 15 |
| Seat Forces | Middle | Amaya | 95th 3pt | 95th 3pt | Test # 080721-1 | Test # 080820-1 | Test # 080819-1 |
| Maximum | Rear | Amer Seat | 95th unbelt | 95th unbelt | | | |
| 🟩 2 | Front | Amer Seat | -- | -- | TEST 5 | TEST 17 | TEST 13 |
| 🟩 Seat Forces | Middle | Amaya | 50th 3pt | 50th 3pt | Test # 080722-1 | Test # 080821-1 | Test # 080815-2 |
| 🟩 Medium | Rear | Amer Seat | 50th unbelt | 50th unbelt | | | |
| 🟩 3 | Front | Amer Seat | -- | -- | TEST 3 | TEST 18 | |
| 🟩 Seat Forces | Middle | Amaya | 50th 3pt | 50th 3pt | Test # 080716-2 | Test # 080821-2 | |
| 🟩 Average | Rear | Amer Seat | -- | -- | | | |
| 🟩 4 | Front | Amer Seat | -- | -- | TEST 2 | TEST 19 | |
| 🟩 Seat Forces | Middle | Amaya | 50th 3pt | 5th 3pt | Test # 080716-1 | Test # 080822-1 | |
| 🟩 Minimum | Rear | Amer Seat | -- | -- | | | |
| 🟩 5 | Front | Amer Seat | -- | -- | TEST 1 | TEST 20 | |
| 🟩 Lap Belts | Middle | Amaya | 50th 2pt | 5th 2pt | Test # 080715-1 | Test # 080822-2 | |
| 🟩 | Rear | Amer Seat | -- | -- | | | |
| 6 | Front | Amer Seat | -- | -- | TEST 7 | | |
| Compartmentalization | Middle | Amer Seat | 95th unbelt | 95th unbelt | Test # 080724-2 | | |
| Current | Rear | Amer Seat | 5th unbelt | 5th unbelt | | | |
| 7 | Front | Amaya | -- | -- | TEST 6 | | |
| Compartmentalization | Middle | Amer Seat | 50th unbelt | 5th unbelt | Test # 080724-1 | | |
| Seat Effects | Rear | Amer Seat | 50th unbelt | 5th unbelt | | | |
| 7b | Front | Amaya 10G | -- | -- | | | TEST 14 |
| Compartmentalization | Middle | Amaya 7G | 50th unbelt | 5th unbelt | | | Test # 080818-1 |
| Seat Effects 10 G | Rear | Amer Seat | 50th unbelt | 5th unbelt | | | |
| 10 | Front | Amaya reclined | -- | -- | TEST 12 | | |
| Reclined | Middle | Amaya reclined | 5th 3pt | 50th 3pt | Test # 080815-1 | | |
| Belted | Rear | Amer Seat | 50th unbelt | 50th unbelt | | | |
| 11 | Front | Amaya | -- | -- | TEST 10 | | TEST 11 |
| Max Rear Loading | Middle | Amaya | 5th 3pt | 50th 3pt | Test # 080813-1 | | Test # 080814-1 |
| Belted | Rear | Amer Seat | 95th unbelt | 95th unbelt | | | |

**15 DEGREE BUCK ANGLE**

| *TEST Type*<br>*Test Obsevation* | *ROW* | *SEAT* | *DUMMY LOCATIONS*<br>*Restraint* | | TRC Test # | | |
|---|---|---|---|---|---|---|---|
| | | | | | *7G seats* | | *10G seats* |
| | | | Left | Right | VRTC pulse | EU pulse | VRTC pulse |
| 8 | Front | Amaya | -- | -- | TEST 8 | | |
| Compartmentalization | Middle | Amer Seat | 5th unbelt | 50th unbelt | Test # 080729-1 | | |
| Current | Rear | Amer Seat | 5th unbelt | 50th unbelt | | | |
| 9 | Front | Amer Seat | -- | -- | TEST 9 | | |
| Compartmentalization | Middle | Amaya | 5th 3pt | 50th 3pt | Test # 080730-1 | | |
| Belted | Rear | Amer Seat | 5th unbelt | 50th unbelt | | | |

🟩 = The test condition was replicated in the crash test

| | | | | |
|---|---|---|---|---|
| | Front row | -- | -- | |
| ↑ | Middle Row | -- | -- | This row has seat anchor load cells |
| Direction of impact | Rear Row | -- | -- | |

Test #: YYMMDD - Test sequence #

Figure 32 - Sled test matrix

Test types 1 through 4 were intended to record varying amounts of force on the belted seat in the middle row. Test types 2 through 5 replicated seating conditions used in the crash test (rows 9R through 13R). Test type 5 had dummies in seats with lap belts (lap belts). Test types 6, 7, 8 and 9 examined the compartmentalization provided by baseline and belted seats (7G and 10G) for unbelted dummies. Test type 10 looked at the effect of having belted dummies in reclined seats and the corresponding difference in the spacing between the seat-backs on belted and unbelted occupants. Test type 11 studied the effect of maximum loading from unbelted 95th male dummies in the rear seat. The test # 11 of this type used the 10G seat in the middle row and 7G seat in the front row. Test types 8 and 9 replicated certain seating conditions for a 15 degree oblique impact by angling the sled (Figure 33).

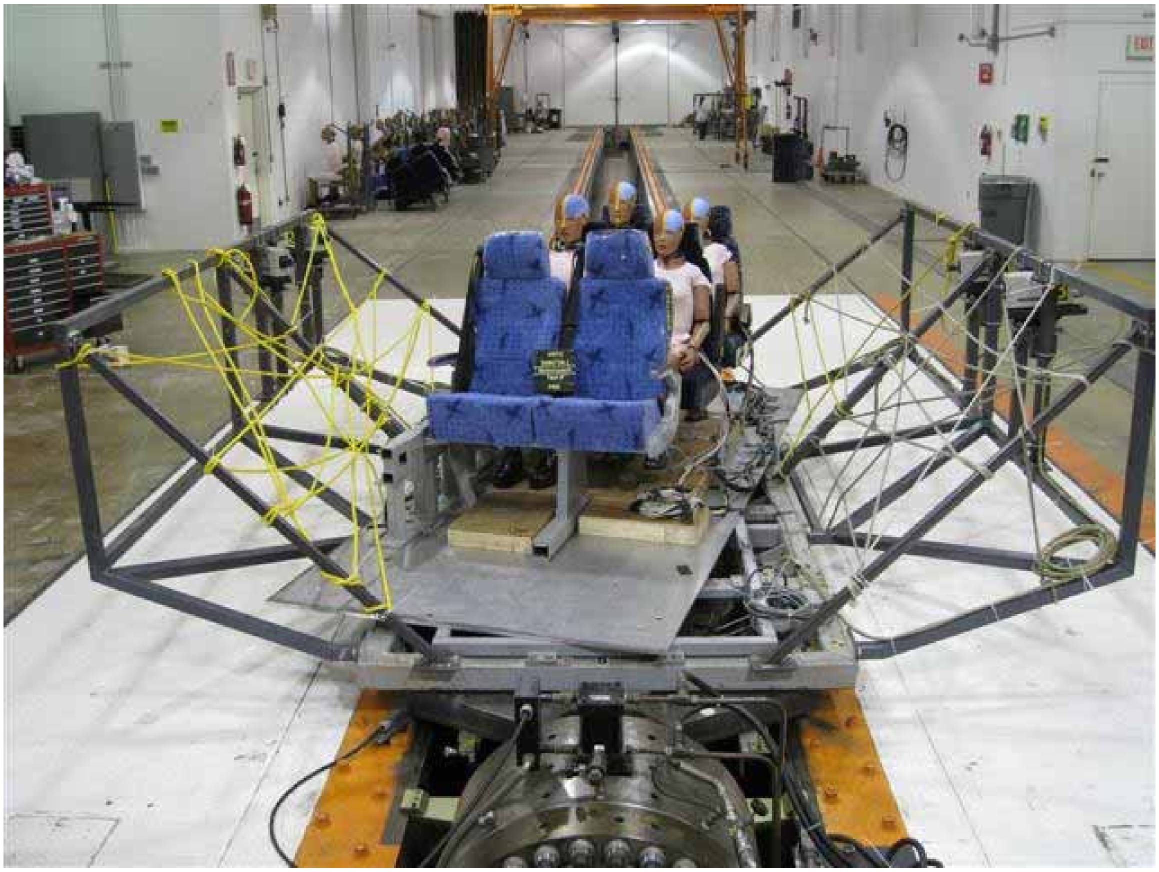


**Figure 33 - Angled sled test setup**

3.4 Sled test results.

The sled test results are in the Appendix. Like in the crash test, the higher dummy injury measures were mostly limited to HIC and Nij, although the unbelted 5th females often recorded high femur loads. When the VRTC pulse was used, no lap/shoulder belted dummy had an Nij which exceeded the IARV, and only one lap/shoulder belted dummy recorded a HIC response above the IARV (test 11). Rear loading of the target seat by unbelted dummies often lead to increased injury values for the lap/shoulder belted dummy, compared to tests that had no rear dummy loading. This was because rear loading caused the seat back of the belted seat to move forward, thereby increasing the likelihood of contact with the seat in front.

The ECE pulse produced higher HIC response than the VRTC pulse. Several of the lap/shoulder belted dummies exceeded the IARV for HIC when tested with the ECE pulse. The ECE pulse has a shorter duration and higher peak acceleration than the VRTC pulse.

Dummy injuries measures (HIC and Nij) were elevated (i.e. above 80 percent of the IARV) or exceeded the IARV in the lap belt tests, due to head contact with the seat in front. Nij values exceeded the IARV for all lap belted occupants and many unbelted ones. The 5th female consistently recorded higher injury numbers when compared to the larger occupants in lap and unbelted conditions.

Low injury numbers were recorded for 15 degree angled testing, however unbelted dummies were not contained between the seats and often fell into the aisle (Figure 34).

**Figure 34 - Angled sled test post test dummy positions**

When compared, the Amaya 7G and 10G seats injury values were relatively similar. In test type 11, the dummy in the middle row right side seat (10G) had high HIC because the head strike with the seat back of the front row seat. In the corresponding test (# 10) with 7G seats, the dummy head contacted the head restraint instead of the seat back, possibly encountering a more compliant surface. The unbelted 5th female dummy in the middle row right side of Test # 6 had high neck readings because of the chin contact with the upper part of the seat back of the front row seat.

## 4.0 STATIC SEAT PULL TESTS – TEST PROCEDURE

### 4.1 Introduction

The sled tests resulted in the belted seat (usually in the center row) being subjected to loads from dummies occupying the seat (pulling on the belts), and from the unbelted dummies in the rear seat. The reaction forces at the seat mounts were recorded using 3-axis load cells. The seat belt tensions were also recorded during the sled tests. These sled tests represented the crash environment from the severe crash test described in section 2.0 and the ECE pulse.

Static pull tests were developed to subject the seat belts, seat belt anchorages, seat structures, and seat anchors (to the floor and side of the coach) to forces observed in the sled tests. The static tests will ensure that the seat belt assemblies and the seat hardware in complying systems will withstand the forces generated in such crash environments.

### 4.2 Estimating forces on the belted seat

The intent of the static tests was to subject the belted seat to forces that were similar to the forces on the seat in certain representative sled tests. Two different methods were used to estimate the forces on the belted seat.

Method A: Estimate the forces on the seat from the following:

- loads on the seat belts (from the inertia of the belted dummy)
- loads on the lower seat back and frame from the knees/femur of the unbelted dummies in the rear seat
- loads on the upper seat back from the head and upper torso of the unbelted dummies in the rear seat

Method B: Estimate forces on the seat from the forces measured during the sled tests at the seat attachment points on the floor and the side-rail.

#### 4.2.1 Method A

This method used the five selected sled tests to examine the time-history of forces on the seat. These consisted of the following:

- Inertial forces from belted occupants in the seat determined from
  - Lap belts loads
  - Shoulder belt loads
- Forces from unbelted occupants in the rear seat determined from
  - Knee/femur loads into the lower seat frame
  - Head/upper torso loads into the upper seat back

The time-history of these forces were used to compute peak forces and longer sustained forces on the seat. The details are described in sections 4.2.1.1 through 4.2.1.3 below.

##### 4.2.1.1 Forces from seat belts

In the sled tests, the seat belts exerted force on the seat structure due to the inertial loading of the belted dummy occupying the seat on the seat belt. These seat belt forces were recorded by belt tension load cells (Figure 35). In static pull tests, loads were applied on the seat through body-blocks representing the torso and the pelvis of the dummies. The purpose of the static tests is to pull at the torso and pelvic body blocks (green arrows) so that belt forces (red arrows) similar to those recorded in sled tests are achieved. In order to do this, a static pull test (described in sec. 5.1.1) was conducted in which the shoulder and lap seat belt forces (red arrows) as well as the torso and pelvic block pulling forces (green arrows) were recorded.

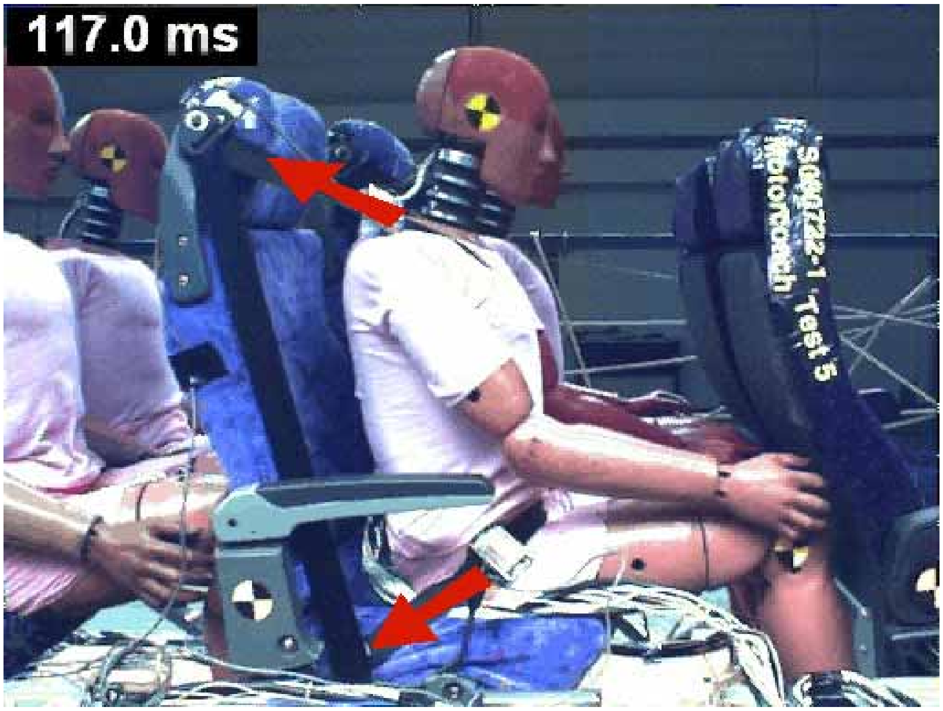


Figure 35 - Belt forces in sled test

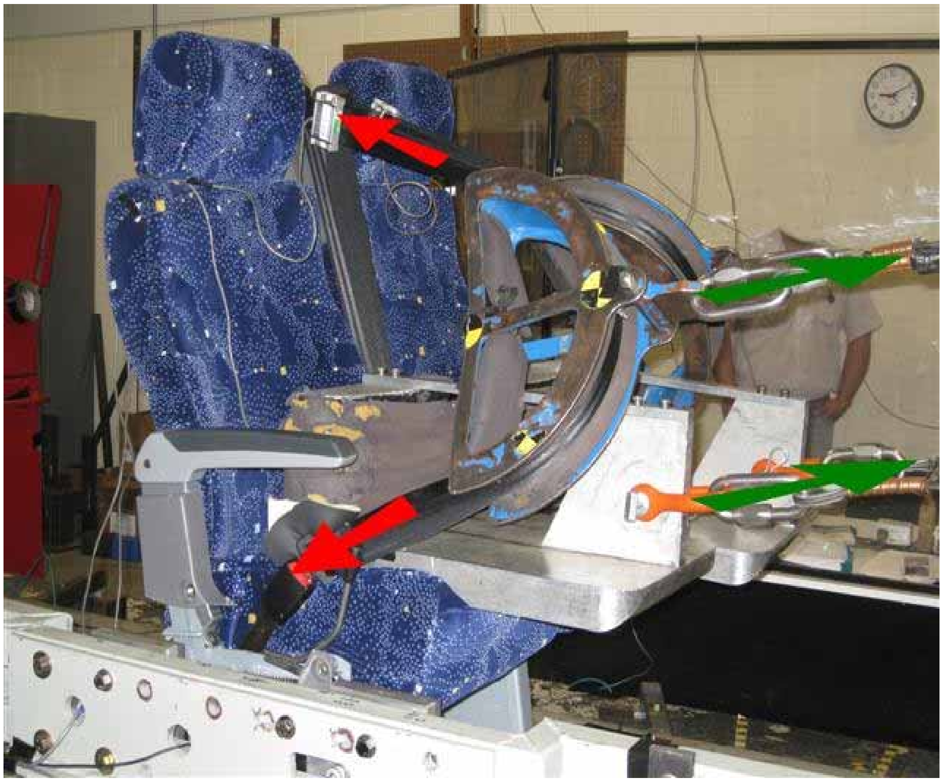


Figure 36 - Belt forces and body block pulling forces in static test

The seat belt forces generated in the test were recorded, along with the torso and pelvic block pulling forces, shown by red and green arrows, respectively in Figure 36.

The data collected was used to generate a “transfer function” between each pulling force and the resulting seat belt force. These transfer functions, shown in Figure 37A .. 37D, were implemented using a look-up table. The table consisted of a list of belt forces and corresponding body block pulling forces recorded in the static test. Thus, knowing the belt forces from sled tests, the corresponding body block pulling forces required to achieve those belt forces can be estimated using this transfer function lookup table.

#### 4.2.1.2 Forces from unbelted rear dummies

From the sled tests, the force on the lower seat back and the seat frame from the knee/femur of the rear dummy was estimated by adding the compressive forces on the dummy femurs, recorded by the femur load cells. The force from the head and upper torso striking the upper seat back was obtained by multiplying the resultant acceleration of the head and chest by the mass of the Hybrid III dummy head and upper torso, respectively. For the 50th percentile male, these values are 4.54 kg and 17.2 kg, respectively. The values for the 95th percentile male are 4.94 kg and 22.6 kg respectively.

#### 4.2.1.3 Example of Method A

An example of the Method A calculations for Test #5 (080722-1) is shown in Figure 38. The peak forces on the seat occur about 125 milliseconds into the event, with the rear dummy loading the seat through the knee/femur (dotted lines) and the seat belts pulling on the seat (solid line), as shown in Figure 39.

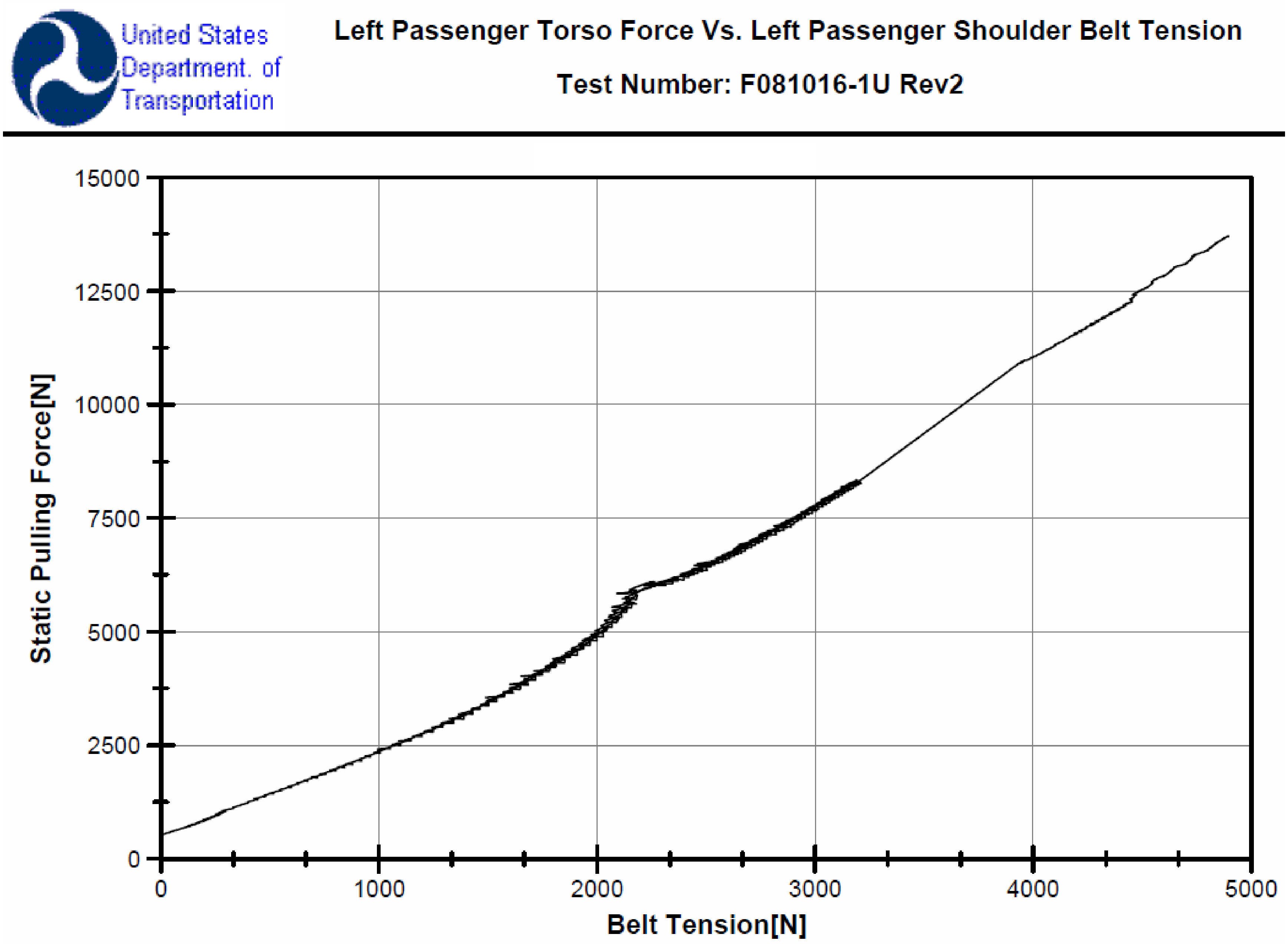


**Figure 37A – Left Passenger torso pulling force vs. belt tension transfer function**

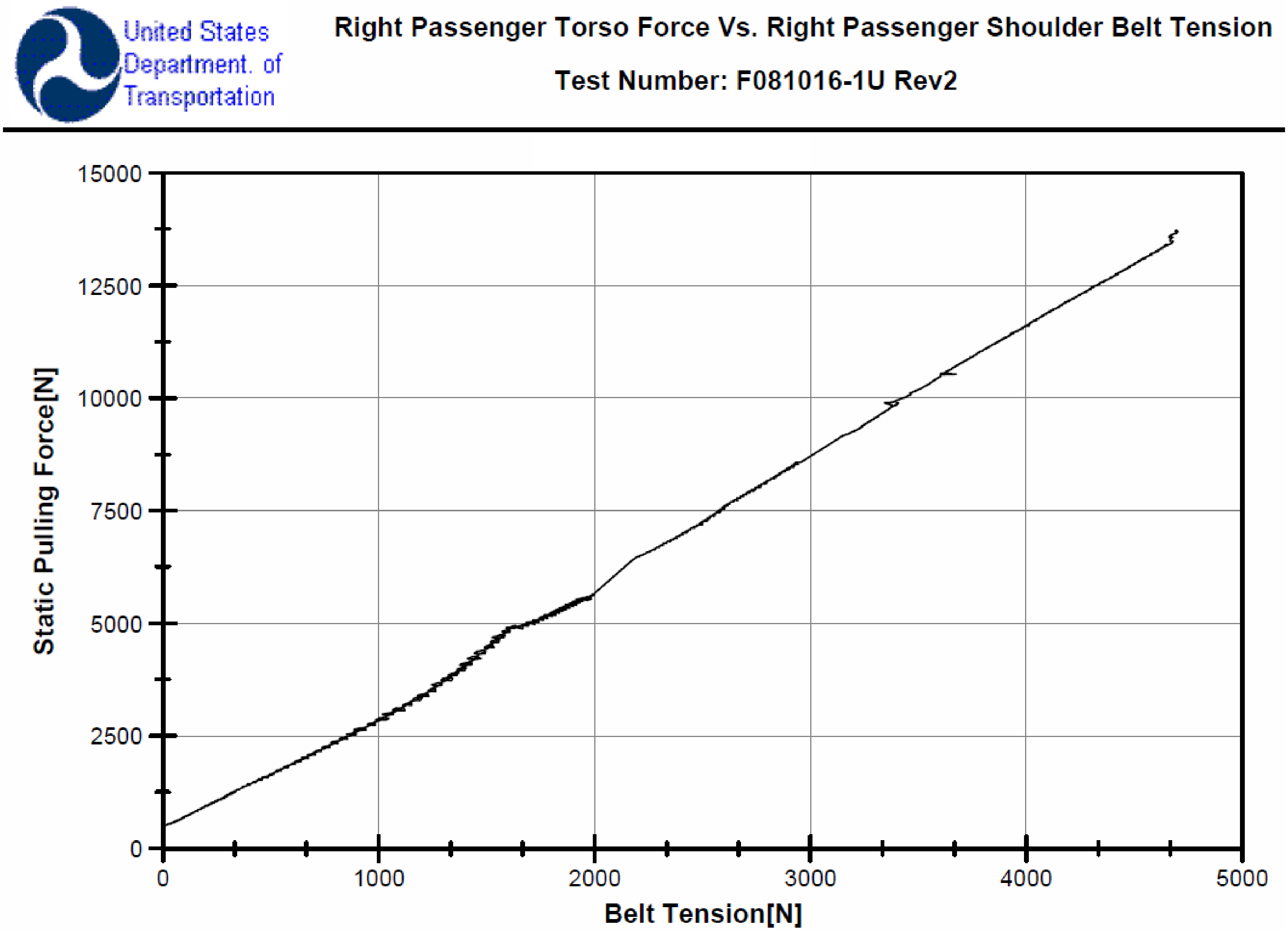


Figure 37B – Right Passenger torso pulling force vs. belt tension transfer function

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**Left Passenger Pelvis Force Vs. Left Passenger Lap Belt Tension**

**Test Number: F081016-1U Rev2**

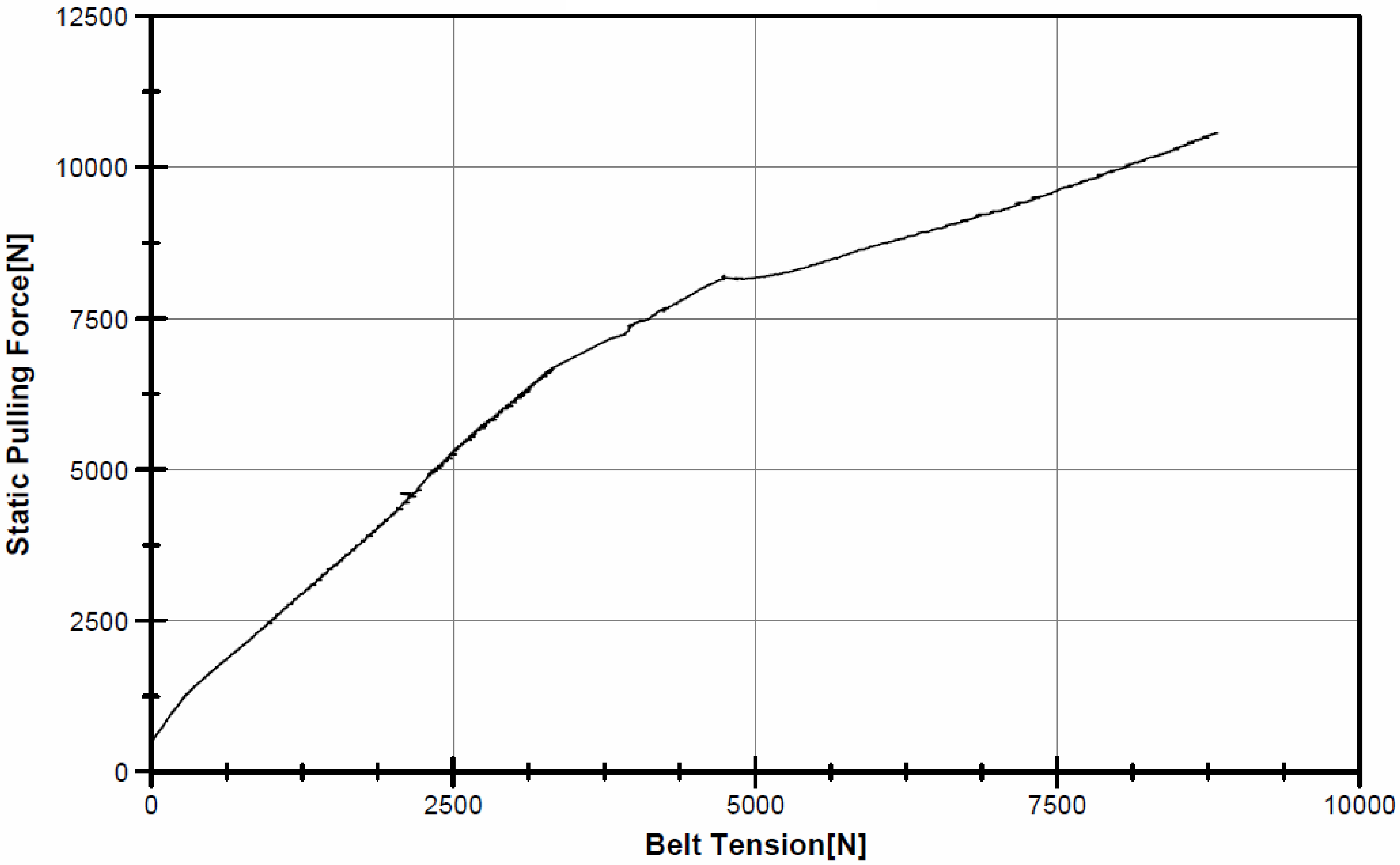


**Figure 37C – Left Passenger pelvis pulling force vs. belt tension transfer function**

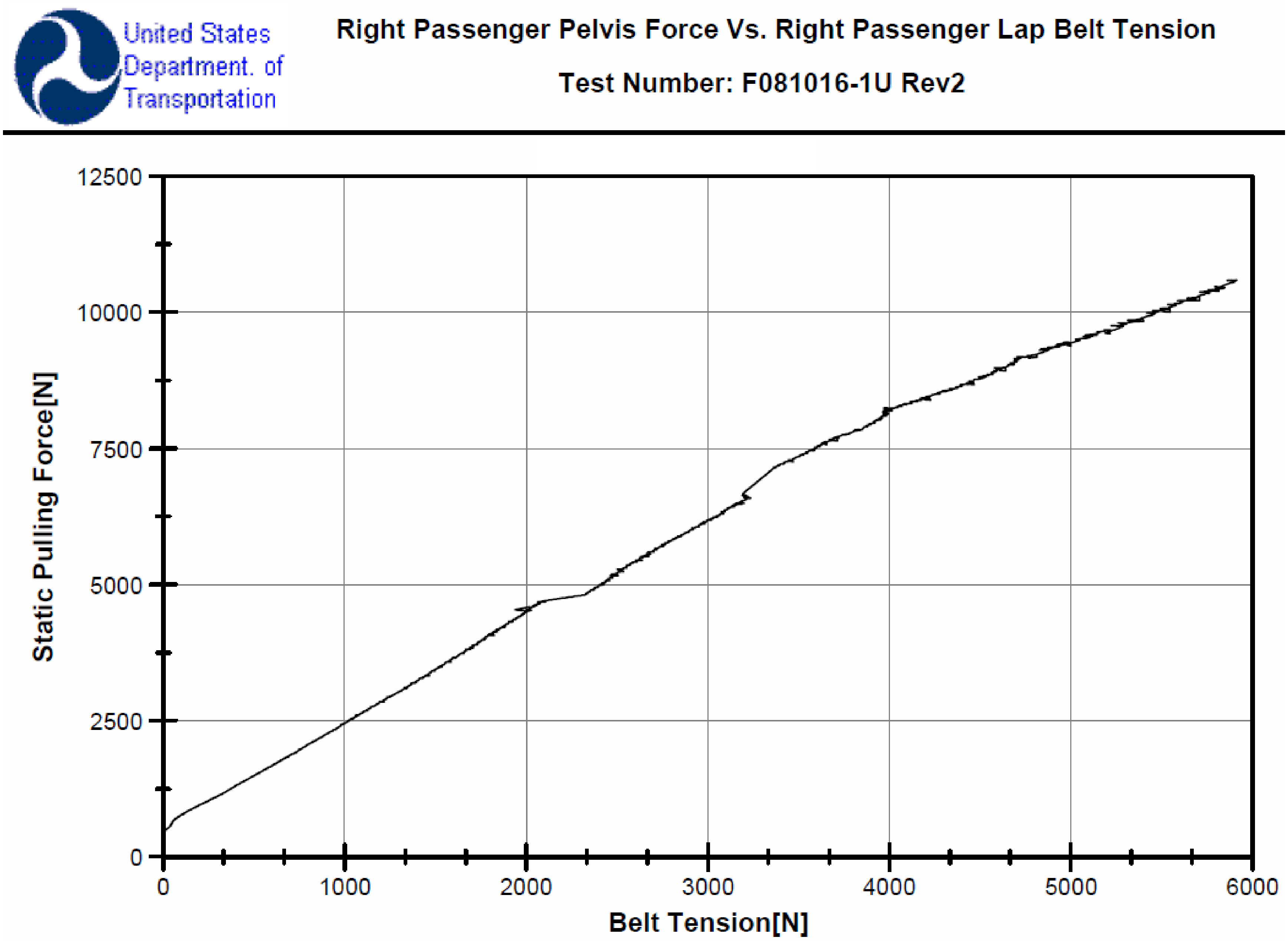


**Figure 37D – Right Passenger pelvis pulling force vs. belt tension transfer function**

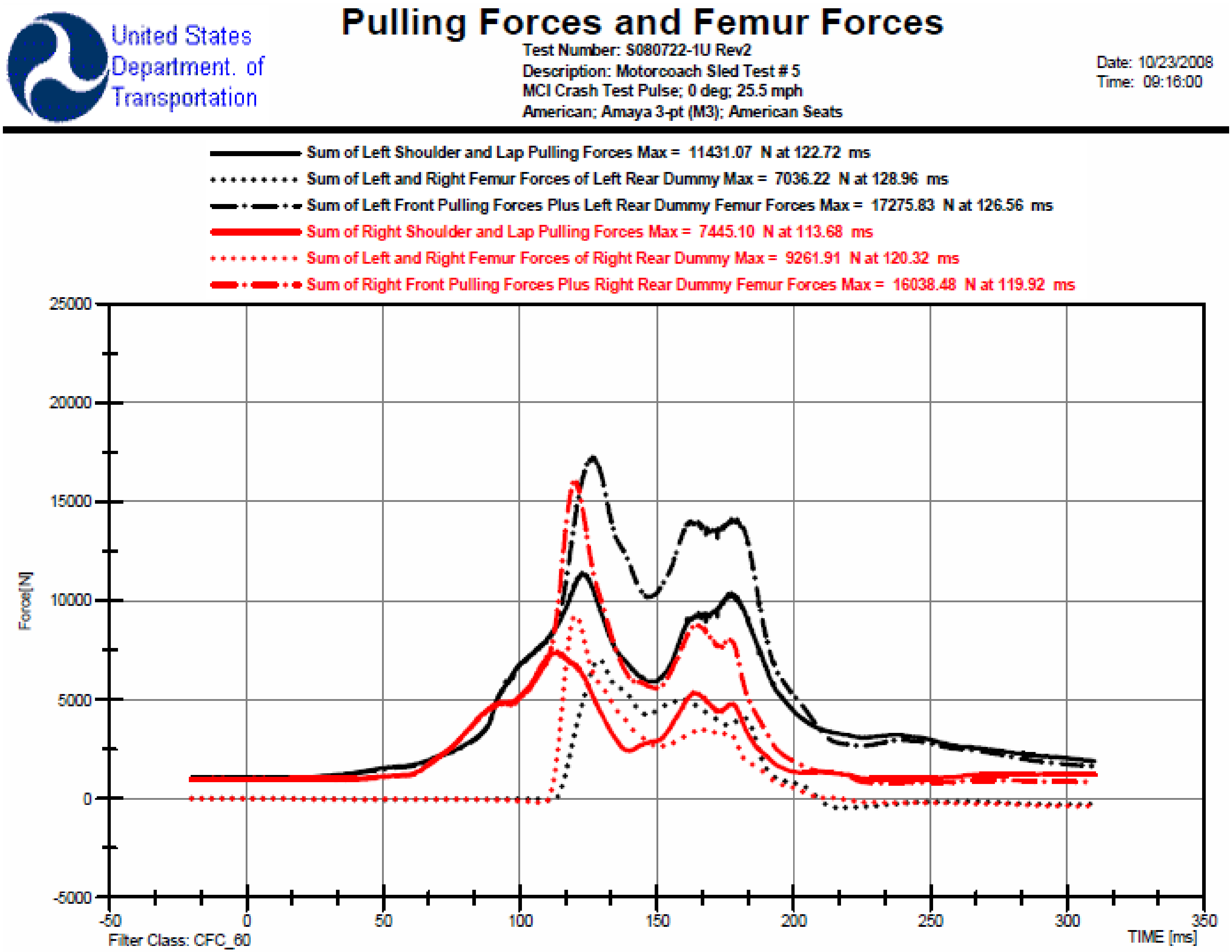


Figure 38 - Shoulder (torso), lap (pelvic) body block pulling forces and femur loads from rear dummies

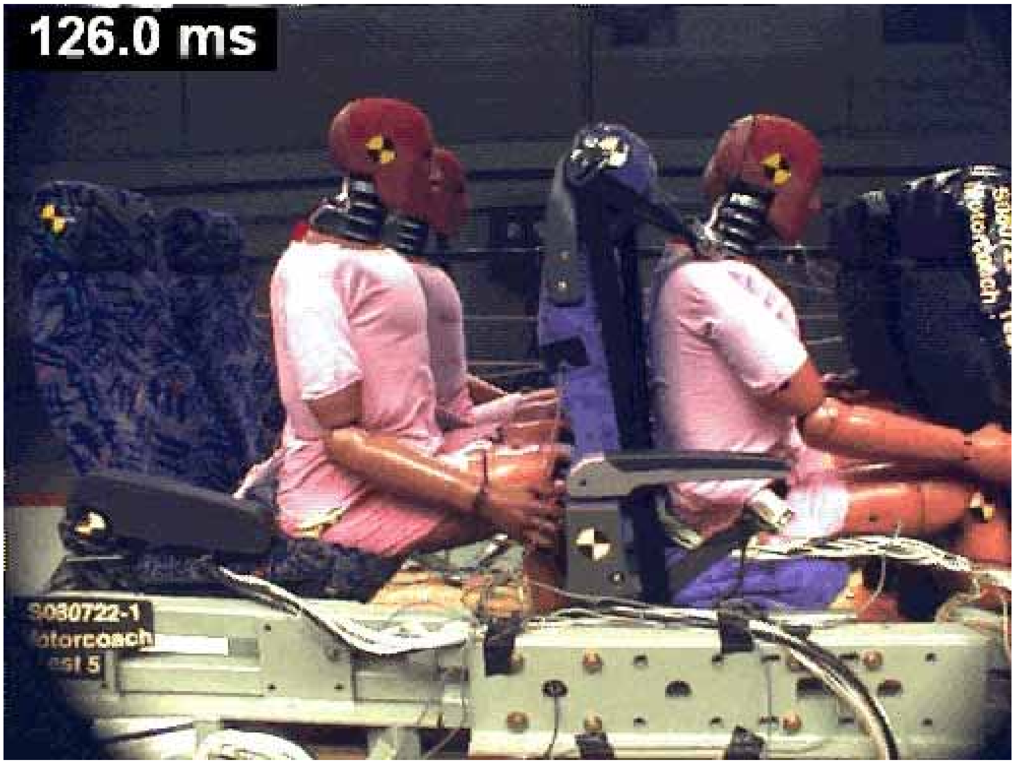


**Figure 39 - Maximum rear loading (from femur load cells)**

Later in the event, at approx 165 milliseconds, the forces on the seat reduce to a lower sustained force after the seat back deforms, as shown in Figure 40.

**Figure 40 - Maximum sustained force on the seat**

The forces from the rear dummy head and chest striking the seat back occurred late in the event (approximately 180 milliseconds) and is of much lower magnitude than those from the belts and the rear dummy knees (Figure 41).

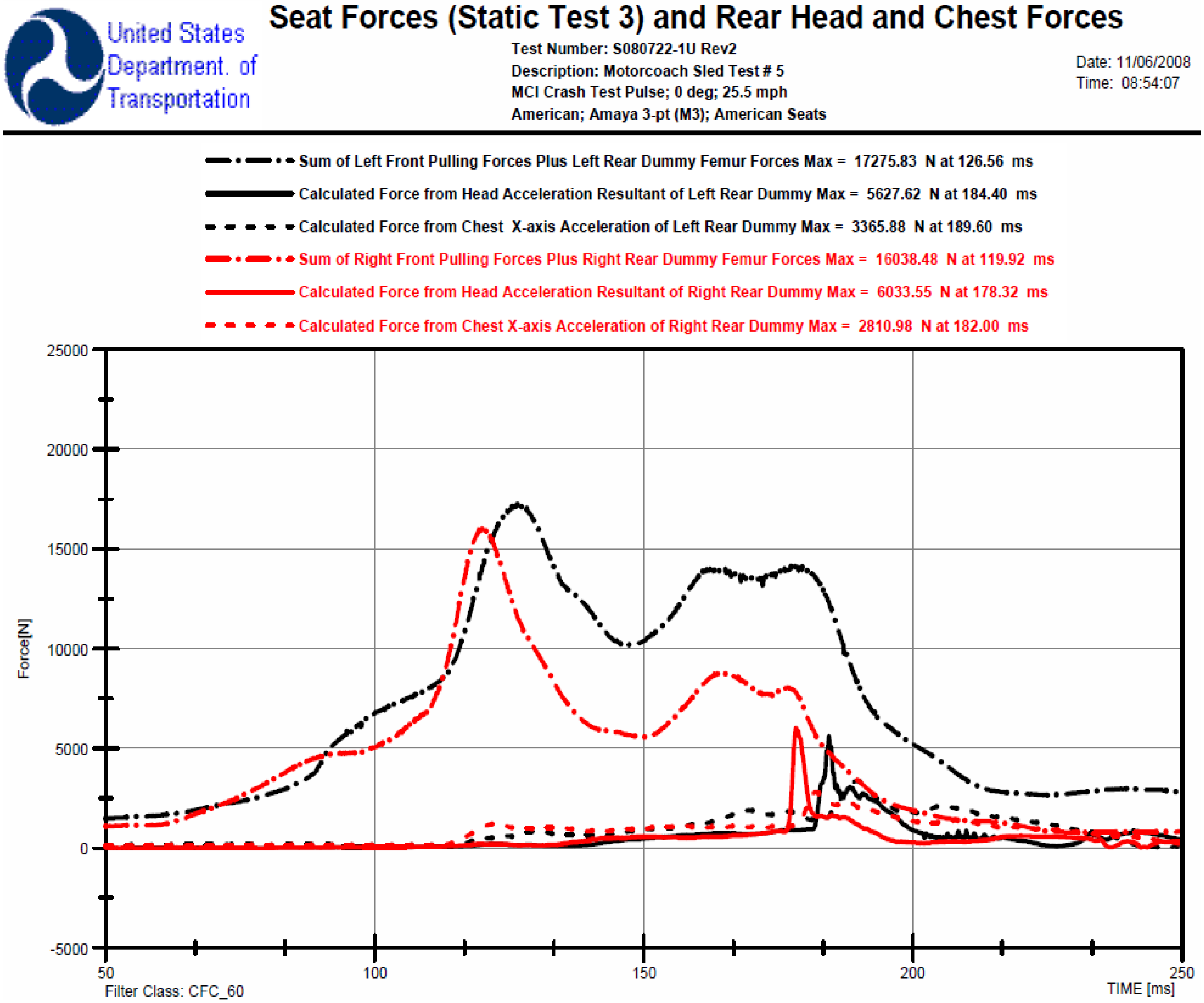


**Figure 41 - Forces from head and torso of the rear dummy**

This figure shows the total force on the seat (from the belts and rear dummy knees) from the two dummies, along with the forces from the head and the chest of the rear dummy striking the seat back. The forces on the upper seat back from the rear dummies are relatively small compared to the forces from the belts and rear dummy knees. Therefore, static tests were run on the seats with body blocks to pull on the torso and lap belts (Figure 36) and a lower rear loading bar 20 inches above the floor (Figure 42) to represent loading from the knees of the dummies in the rear seat. The seat belts and the rear bar were pulled to a pre-determined peak force (attained in 30 seconds), and then the forces were reduced (within 1 second) to a lower, pre-determined value (seen in Figure 38) and held for another 30 seconds. The method for determining the peak force and the lower force is described below. The timing for attaining the peak and hold forces, were based on FMVSS No. 222 final rule published in October 2008.

**Figure 42 - Rear loading bar setup**

To estimate the pulling forces needed for the body blocks and the lower rear loading bar in the static tests, Figure 38 was used to determine the time, $T_{max}$, at which the total force on the seat reached a maximum in the sled tests. Total femur loads from the rear dummy, $F_{max}$(rear), were recorded at $T_{max}$. Individual seat belt forces at $T_{max}$, $P_{max}$(lap) and $P_{max}$(sh), were obtained from the lap and shoulder belt force-time histories (Figure 43).

Similarly, $T_{hold}$ was defined as the time at which total force on seat reached a plateau. The total femur loads from rear dummy, $F_{hold}$(rear), and individual seat belt forces, $P_{hold}$(lap) and $P_{hold}$(sh), were recorded at $T_{hold}$.

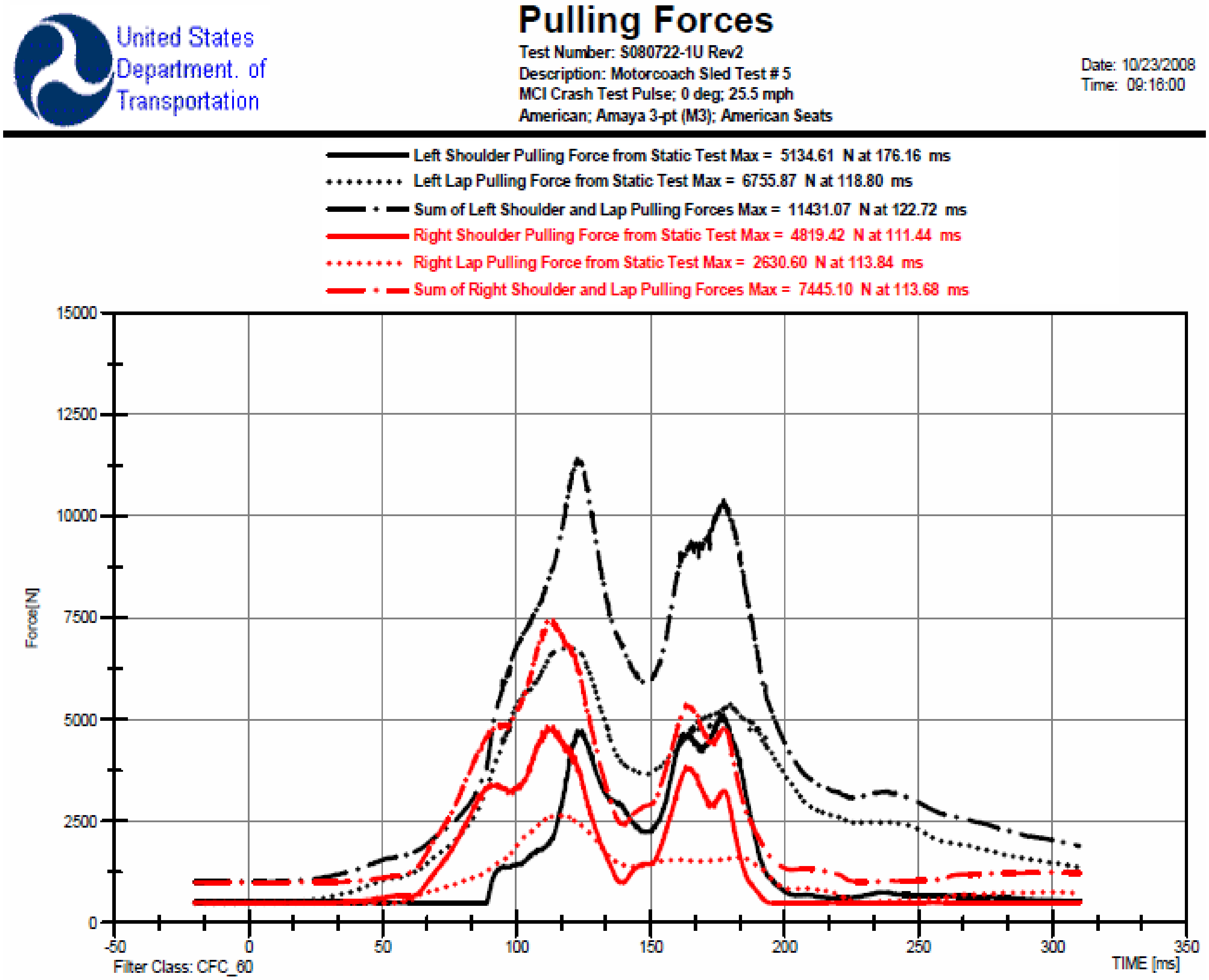


**Figure 43 - Pulling forces of individual body blocks**

4.2.1.4 Results of Method A

Forces on the belted seats were calculated for five sled tests (# 3, 5, 10, 11, 13). These cover the range of seating conditions, including 50th male dummies without rear loading, to 5th female and 50th male dummies with rear loading from unbelted 95th male dummies. The forces on the seats in these tests are shown in Table 1.

**Table 1 - Peak and sustained loads in selected sled tests (using Method A)**

| Test # | Position | Dummy size | Rear dummy | Seat type | $T_{max}$ msec | $F_{max}$ rear N | $P_{max}$ lap N | $P_{max}$ sh N | Thold msec | $F_{hold}$ rear N | $P_{hold}$ lap N | $P_{hold}$ sh N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | Left | 50th | NA | 7g | 123 | NA | 3829 | 6055 | 180 | NA | 1910 | 6492 |
| 3 | Right | 50th | NA | 7g | 118 | NA | 6750 | 5262 | 180 | NA | 3893 | 5540 |
| 5 | Left | 50th | 50th | 7g | 127 | 7036 | 6756 | 4654 | 170 | 4600 | 4681 | 4613 |
| 5 | Right | 50th | 50th | 7g | 120 | 9231 | 2620 | 4760 | 165 | 3450 | 1520 | 3764 |
| 10 | Left | 5th | 95th | 7g | 126 | 7041 | 5570 | 3700 | 165 | 5500 | 4600 | 3600 |
| 10 | Right | 50th | 95th | 7g | 118 | 7543 | 6455 | 5442 | 164 | 3809 | 2763 | 4328 |
| 13 | Left | 50th | 50th | 10g | 125 | 6450 | 5687 | 5149 | 150 | 4719 | 3774 | 5213 |
| 13 | Right | 50th | 50th | 10g | 124 | 9459 | 5916 | 5105 | 162 | 2854 | 2639 | 4506 |
| 11 | Left | 5th | 95th | 10g | 112 | 5892 | 3598 | 4154 | 164 | 5149 | 2698 | 4101 |
| 11 | Right | 50th | 95th | 10g | 121 | 8705 | 4082 | 10199 | 165 | 5009 | 2055 | 4909 |

Loads for use in the static tests were determined based on the average of the values listed in Table 1 for tests #5, 10, 11, and 13 (#3 did not have rear loading). For the rear loading bar, the sums of the left and right positions were used. For the torso and pelvis loads on the individual seating positions, the left and right forces were not summed. The resulting proposed load profile for Method A was as follows:

THE FOLLOWING ALL OCCURS SIMULTANEOUSLY
Attain the following loads within 30 seconds:
Rear bar Loading: Load up to 15,340 N
For each seating position:
Pelvic Body Block Loading: Load up to 5,085 N
Torso Body Block Loading: Load up to 5,400 N
Reduce to the following loads within 1 second of attaining the above peak loads:
Rear bar Loading: Reduce to 8,770 N
For each seating position:
Pelvic Body Block Loading: Reduce to 3,100 N
Torso Body Block Loading: Reduce to 4,380 N
Hold for 30 seconds

### 4.2.2 Method B

This method used the forces recorded at the seat anchors (on the floor and the side-rail) from the sled tests to determine a static load profile. All forces acting on the seat are transferred to the bus structure through the seat anchors. The longitudinal (X) component of the forces at the seat anchors are added together to determine the peak and sustained hold loads for the static test profile. As an example, the resulting total force from sled test #5 is plotted in Figure 44.

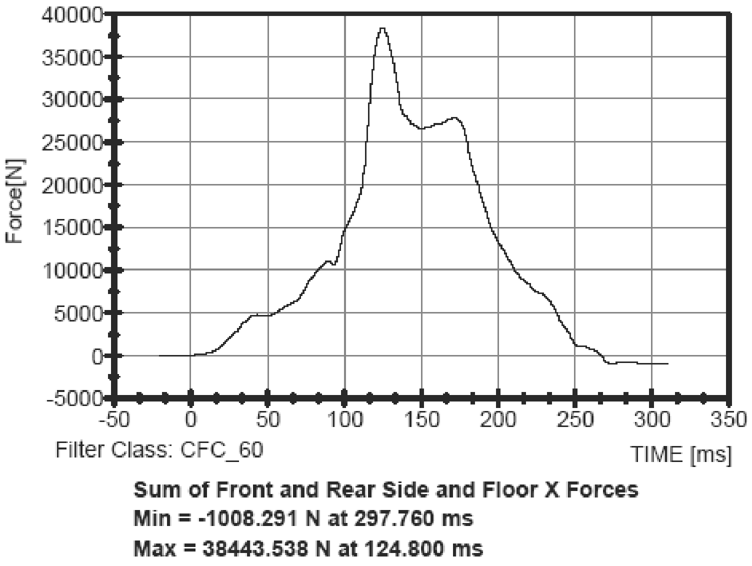


Figure 44 - Sum of Horizontal forces at seat attachment locations

A transfer function (in the form of a table) was obtained between the total body-block pulling forces (torso and pelvic) and the forces at the seat anchors from a static test. A graphical representation of the relationship between the total body block pulling forces and the X-component of the forces recorded at the seat anchors is shown in Figure 45.

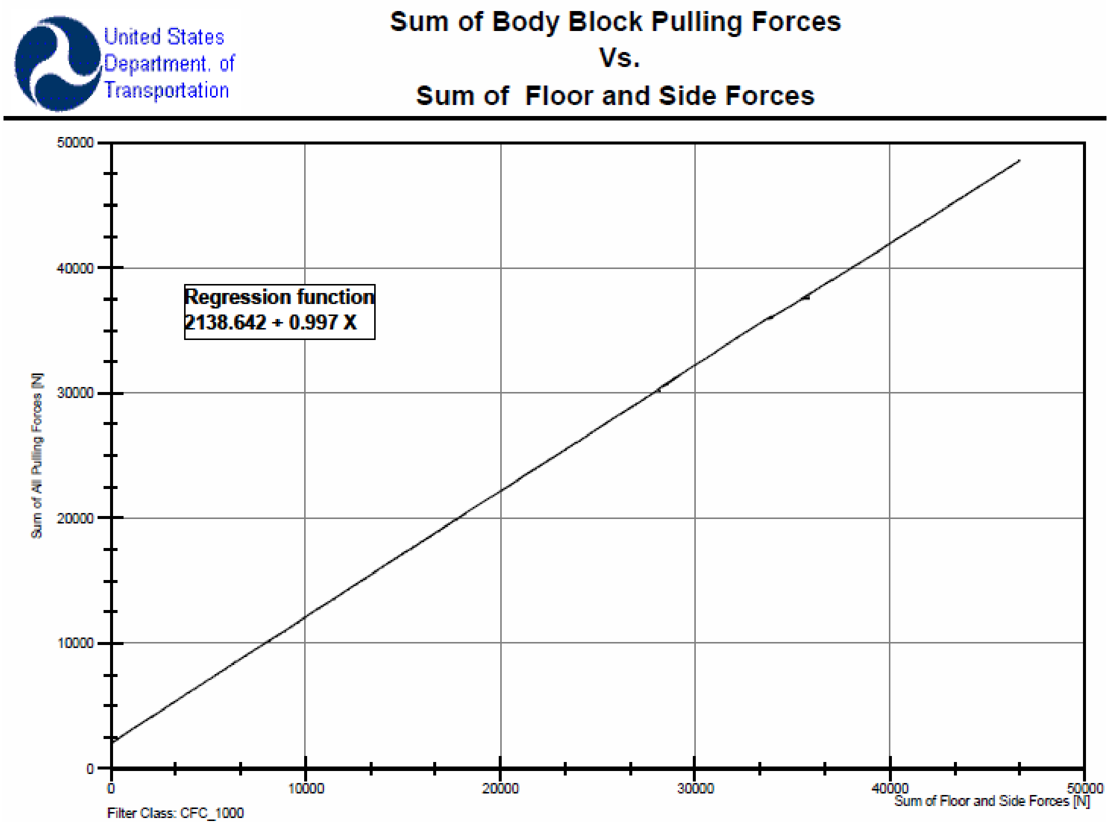


Figure 45 - Body block pulling forces vs. loads at seat attachments

The transfer function was used to create the pulling force-time history shown in Figure 46. This figure shows the sum of the pulling forces needed (at the four body blocks (left and right torso and pelvis blocks)) to produce the same total longitudinal forces at all the load cells at the seat attachments. Note that this method does not use any rear loading bar, as all forces at the seat anchors are attributed to loading through the body-blocks only.

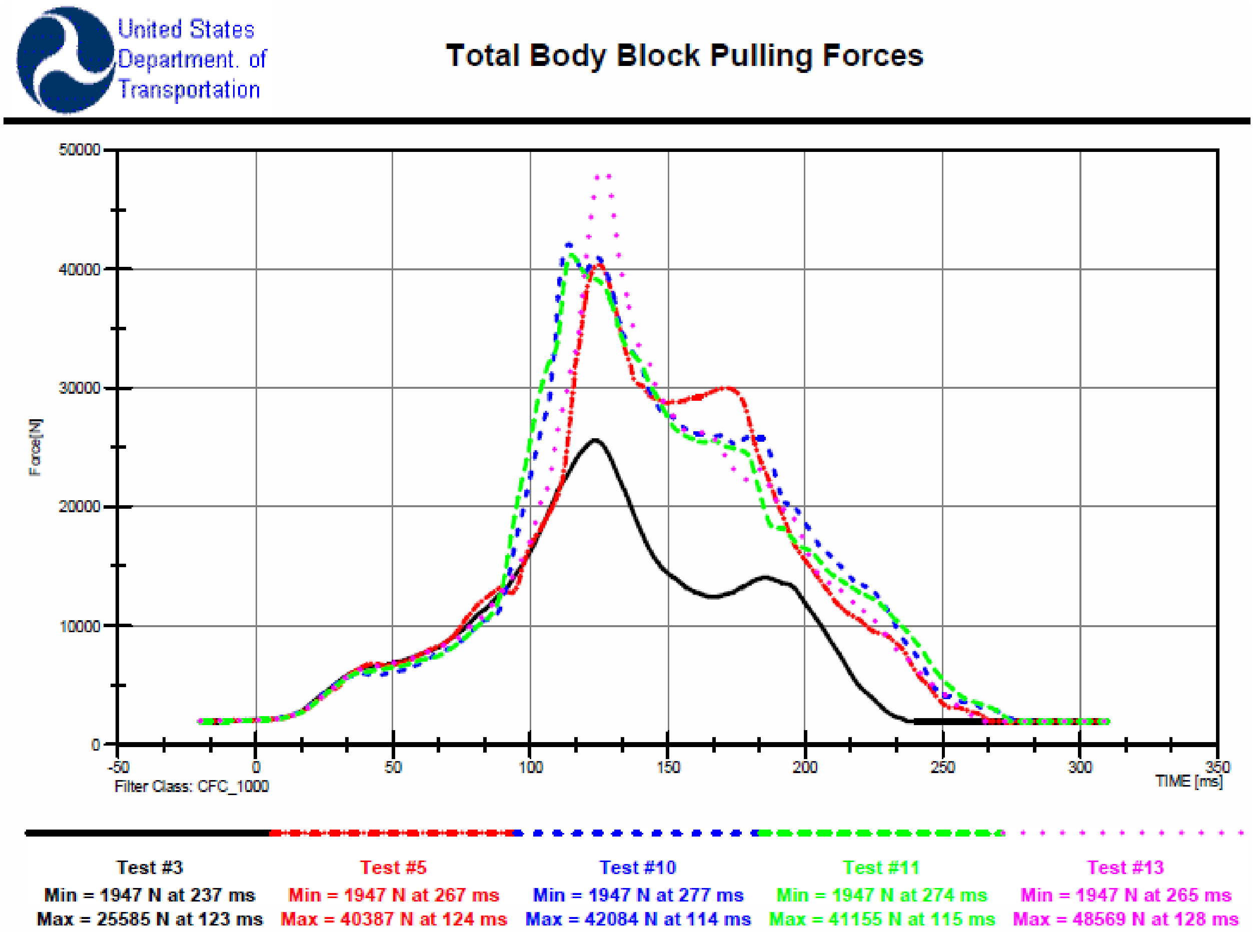


**Figure 46 -Total pulling forces on all body blocks for selected sled tests**

The peak and hold pulling forces thus obtained were divided equally between the four body blocks (two torso and two pelvic) for both occupants of the seat. This was because the seat anchor load cells record the total force on the seat, and cannot differentiate between the various pulling forces at the different belts. Using this method, the peak and hold values of pulling force were calculated for sled tests # 3, 5, 13, 10, and 11 (Table 2).

**Table 2 - Peak and sustained loads in selected sled tests (using Method B)**

| Test # | Subject Dummy (aisle) | Subject Dummy (rail) | Rear Dummy | Seat Type | Pmax Total | Phold Total | Pmax Body Block | Phold Body Block |
|---|---|---|---|---|---|---|---|---|
| | | | | | N | N | N | N |
| 3 | 50th | 50th | ---- | 7G | 25585 | 13000 | 6396 | 3250 |
| 5 | 50th | 50th | 50th | 7G | 40387 | 30000 | 10097 | 7500 |
| 13 | 50th | 50th | 50th | 10G | 48569 | 26000 | 12142 | 6500 |
| 10 | 5th | 50th | 95th | 7G | 42084 | 26000 | 10521 | 6500 |
| 11 | 5th | 50th | 95th | 10G | 41155 | 26000 | 10289 | 6500 |

Loads for use in the static tests were determined based on the average of the $P_{max}$ and $P_{hold}$ body block values listed in Table 2 for tests #5, 10, 11, and 13 (#3 did not have rear loading). The results were as follows:

For each seating position, simultaneously:

Attain the following loads within 30 seconds:

| | |
|---|---|
| Pelvic Loading: | Load up to 10,760 N |
| Torso Loading: | Load up to 10,760 N |

Reduce to the following loads within 1 second of attaining the above peak loads:

| | |
|---|---|
| Pelvic Loading: | Reduce to 6,750 N |
| Torso Loading: | Reduce to 6,750 N |

Hold for 30 seconds

In one instance (test 13), using 10G Amaya seats, the peak force on the seat indicated that each body block should be pulled at 12,124 N. This compares to the FMVSS No. 210 requirements (for passenger vehicles) of a pulling force of 13,345 N for each body block.

## 5.0 STATIC SEAT PULL TESTS – TEST RESULTS

Two types of static pull tests were conducted: with load cells at the seat attachment locations (rigid mounting) and with the seats attached using seat rails from a motorcoach (more realistic mounting and no load cells).

### 5.1 Tests with load cells at seat attachment locations

### 5.1.1 Amaya 7G seat – slow pull to failure

This test was conducted with the purpose of finding a transfer function between the forces recorded at the seat attachment points and the pulling forces on the body blocks. This allows the estimation of the pulling forces required to attain the same seat anchor loads observed in the sled tests (Method B in section 4.2.2). Seat belt tension forces were also recorded, which allowed the estimation of the body block pulling forces required to attain the belt tensions observed in the sled tests (Method A in section 4.2.1).

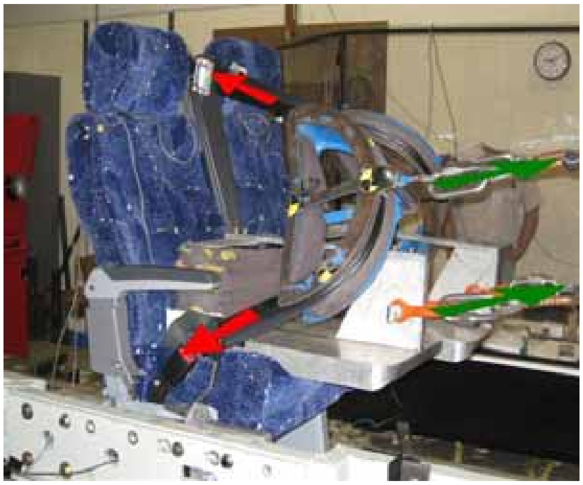
This test was run with the seat attached to a rigid aluminum plate using 3-axis load cells (Figure 47), which recorded forces in the following three directions:

X: Positive forward
Y: Positive to the right (when viewed as seated)
Z: Positive downwards

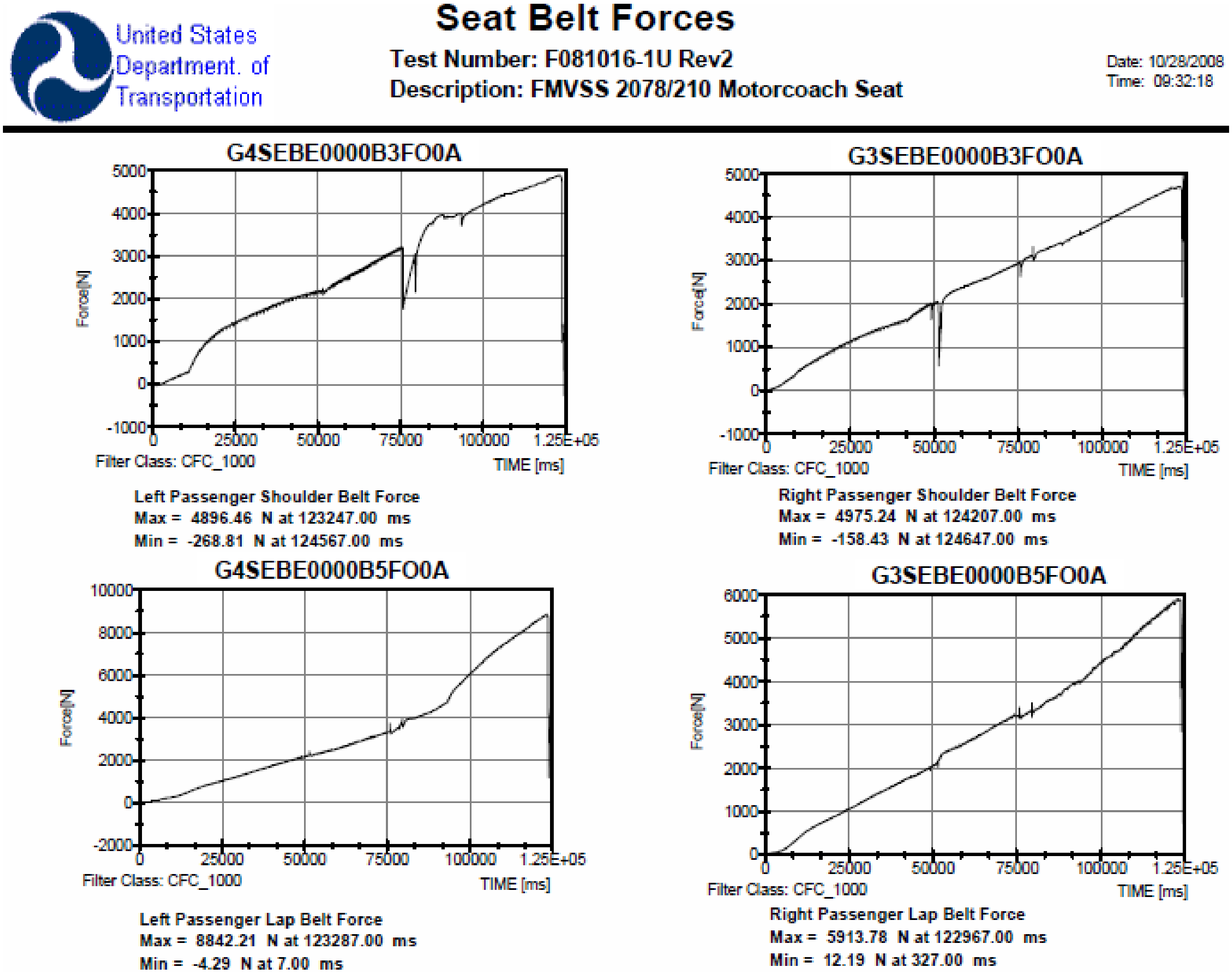
Forces were applied to the body blocks until the seat failed, as shown in Figure 48. The seat belt tensions recorded from this test are shown in Figure 49. The corresponding body block pulling forces are shown in Figure 50. These data were combined to get the transfer function between the body block pulling forces and the seat belt tension forces (discussed previously in section 4.2.1.1 and Figure 37A .. 37D, and repeated here in Figure 51).

**Figure 47 - Load cells at seat attachment points**

**Figure 48 - Static pull and seat failure**



Seat belt forces => **red arrows**



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**Seat Belt Forces**

**Test Number: F081016-1U Rev2**
**Description: FMVSS 2078/210 Motorcoach Seat**

Date: 10/28/2008
Time: 09:32:18

G4SEBE0000B3FO0A

Filter Class: CFC_1000

**Left Passenger Shoulder Belt Force**
**Max = 4896.46 N at 123247.00 ms**
**Min = -268.81 N at 124567.00 ms**

G3SEBE0000B3FO0A

Filter Class: CFC_1000

**Right Passenger Shoulder Belt Force**
**Max = 4975.24 N at 124207.00 ms**
**Min = -158.43 N at 124647.00 ms**

G4SEBE0000B5FO0A

Filter Class: CFC_1000

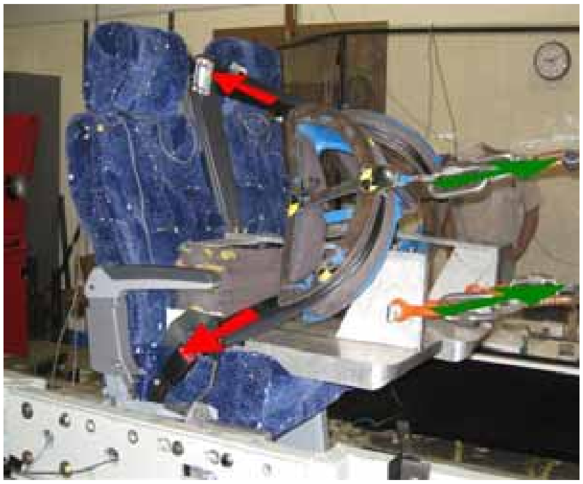
**Left Passenger Lap Belt Force**
**Max = 8842.21 N at 123287.00 ms**
**Min = -4.29 N at 7.00 ms**

G3SEBE0000B5FO0A

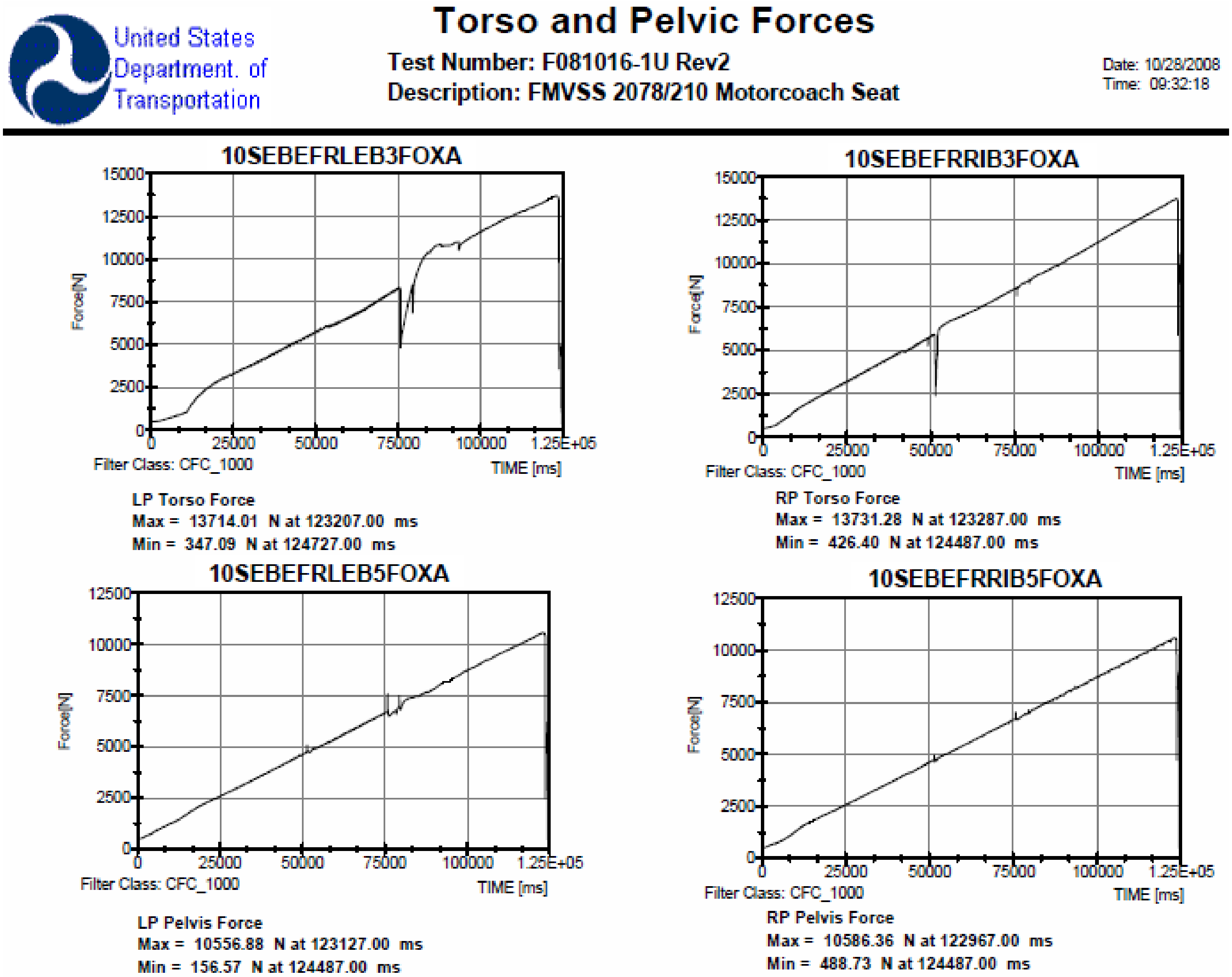
Filter Class: CFC_1000

**Right Passenger Lap Belt Force**
**Max = 5913.78 N at 122967.00 ms**
**Min = 12.19 N at 327.00 ms**

**Figure 49 - Seat belt forces in static test (red arrows)**



Torso and pelvic forces => **green arrows**



**Torso and Pelvic Forces**

**Test Number: F081016-1U Rev2**
**Description: FMVSS 2078/210 Motorcoach Seat**

Date: 10/28/2008
Time: 09:32:18

**10SEBEFRLEB3FOXA**

Filter Class: CFC_1000

**LP Torso Force**
**Max = 13714.01 N at 123207.00 ms**
**Min = 347.09 N at 124727.00 ms**

**10SEBEFRRIB3FOXA**

Filter Class: CFC_1000

**RP Torso Force**
**Max = 13731.28 N at 123287.00 ms**
**Min = 426.40 N at 124487.00 ms**

**10SEBEFRLEB5FOXA**

Filter Class: CFC_1000

**LP Pelvis Force**
**Max = 10556.88 N at 123127.00 ms**
**Min = 156.57 N at 124487.00 ms**

**10SEBEFRRIB5FOXA**

Filter Class: CFC_1000

**RP Pelvis Force**
**Max = 10586.36 N at 122967.00 ms**
**Min = 488.73 N at 124487.00 ms**

**Figure 50 - Body block pulling forces in static test (green arrows)**

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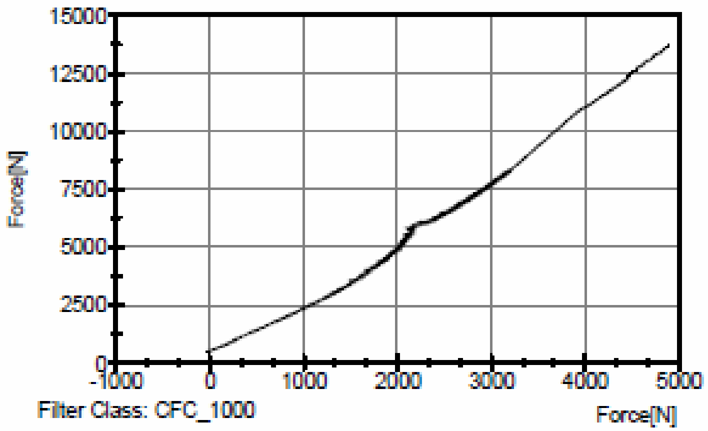
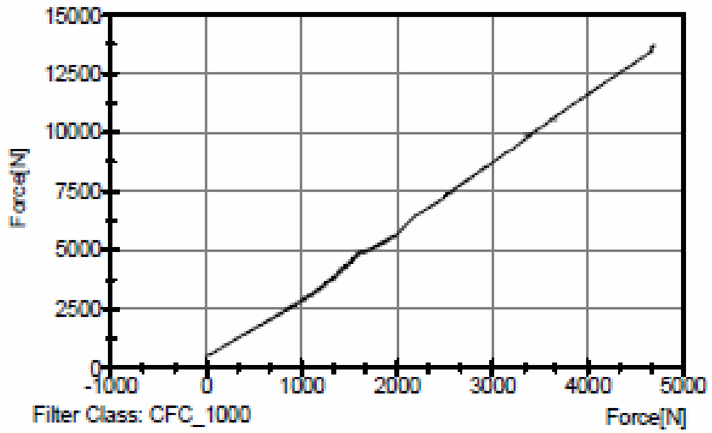
# Pulling force Vs Belt Tension

**Test Number: F081016-1U Rev2**
**Description: FMVSS 2078/210 Motorcoach Seat**

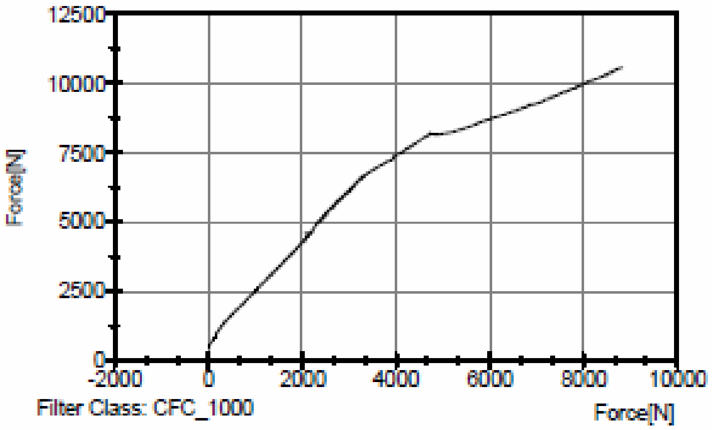
Date: 10/28/2008
Time: 09:32:18



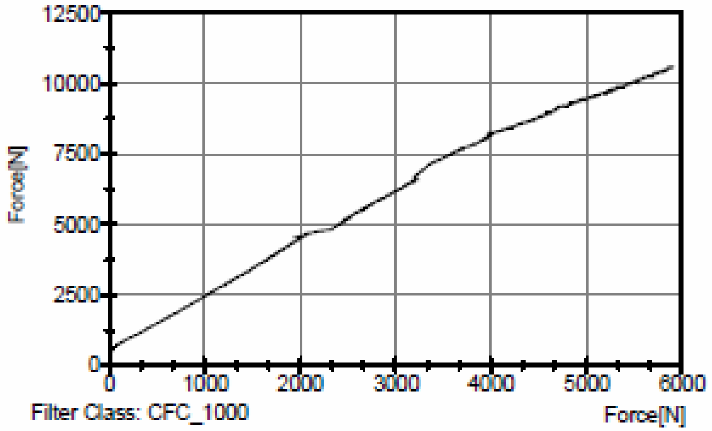
**LP Torso Force Vs. Left Passenger Shoulder Belt Force**
**Max = 13714.01 N at 4896.46 N**
**Min = 347.09 N at -138.55 N**



**RP Torso Force Vs. Right Passenger Shoulder Belt Force**
**Max = 13731.28 N at 4696.90 N**
**Min = 426.40 N at 3321.37 N**



**LP Pelvis Force Vs. Left Passenger Lap Belt Force**
**Max = 10556.88 N at 8816.97 N**
**Min = 156.57 N at 1174.64 N**



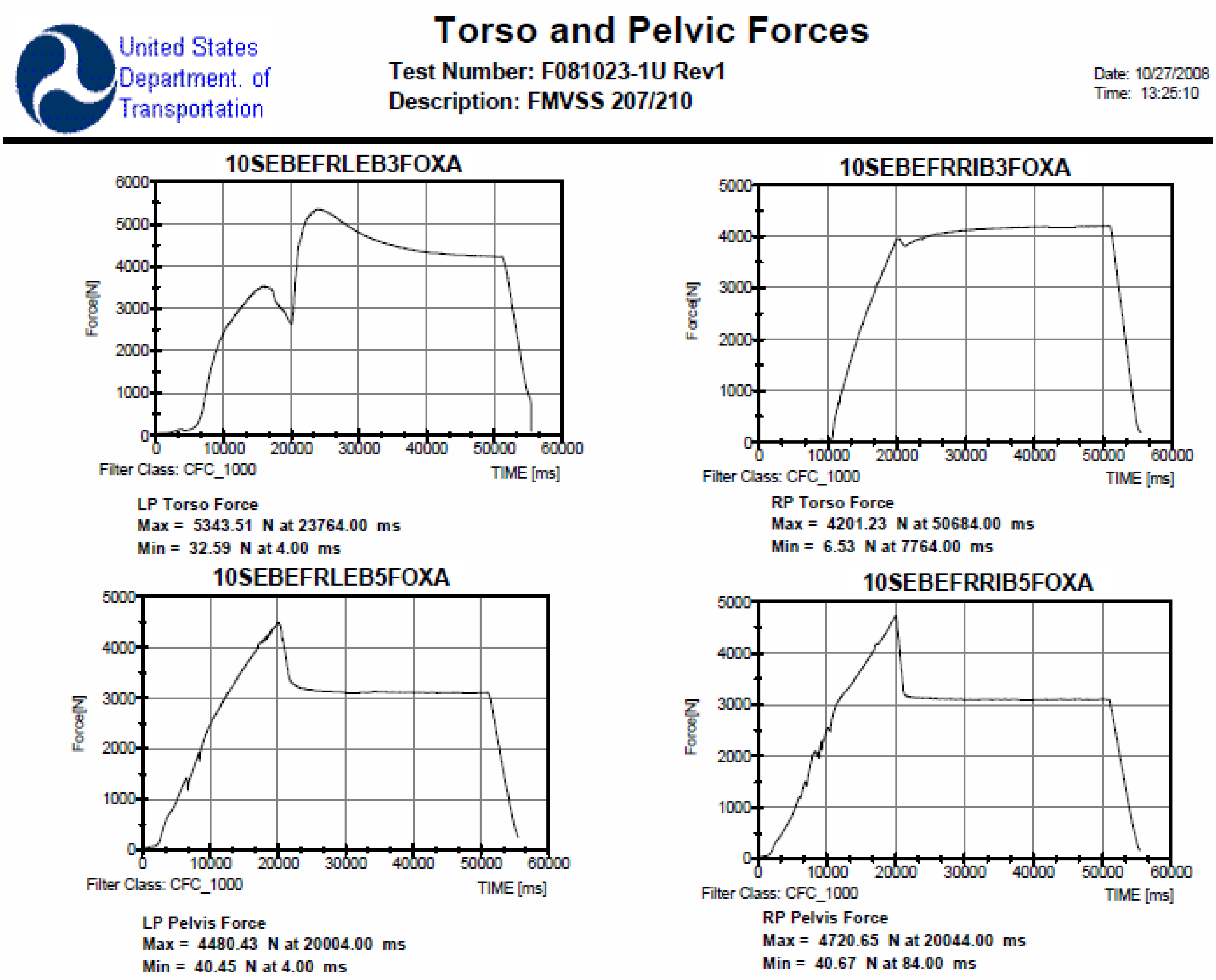
**RP Pelvis Force Vs. Right Passenger Lap Belt Force**
**Max = 10586.36 N at 5913.78 N**
**Min = 488.73 N at 2128.48 N**

**Figure 51 - Body block pulling forces vs. belt tension forces**

### 5.1.2 Amaya 7G seat using Method A

This test was run to observe the performance of the Amaya 7G seat (used in the crash test and most sled tests) using the procedure derived using Method A (in section 4.2.1.4). A rear loading bar was used (Figure 52). The pulling forces on the body block are shown in Figure 53.

**Figure 52 - Use of rear loading bar**



United States Department of Transportation

Torso and Pelvic Forces

Test Number: F081023-1U Rev1

Description: FMVSS 207/210

Date: 10/27/2008

Time: 13:25:10

10SEBEFRLEB3FOXA

Filter Class: CFC_1000

**LP Torso Force**
Max = 5343.51 N at 23764.00 ms
Min = 32.59 N at 4.00 ms

10SEBEFRRIB3FOXA

Filter Class: CFC_1000

**RP Torso Force**
Max = 4201.23 N at 50684.00 ms
Min = 6.53 N at 7764.00 ms

10SEBEFRLEB5FOXA

Filter Class: CFC_1000

**LP Pelvis Force**
Max = 4480.43 N at 20004.00 ms
Min = 40.45 N at 4.00 ms

10SEBEFRRIB5FOXA

Filter Class: CFC_1000

**RP Pelvis Force**
Max = 4720.65 N at 20044.00 ms
Min = 40.67 N at 84.00 ms

**Figure 53 - Body block pulling forces**

The test equipment could not apply the requirements as stated in Section 4.2.1.4. While the seat structure did not break, the test equipment could not accommodate the excessive deformation of the structure and did not attain the desired pulling forces (peak force of 5085 N and 5400 N in pelvic and torso body blocks, respectively) within 30 seconds. This was because the hydraulic cylinders attached to the body blocks were unable to dynamically adjust to the rapid and excessive seat deformation caused by the rear loading bar.

### 5.1.3 Amaya 10G seat using current FMVSS 210 pulling forces.

The Amaya 10G seat was tested per current FMVSS No. 210 conditions (achieving 13,345 N in each body block in 30 sec, holding for 10 seconds). This was to verify that the seat would meet the current FMVSS No. 210 requirements.

This test was conducted using load cells at the seat anchor locations and no rear loading bar. The post-test damage to the seat and attachment locations was minimal. There was some bending (but no fracture) at the side attachment tab and the seat lateral frame to the pedestal (Figure 54). The results of this test are shown in Figures 55 through 58, and as can be seen, this seat passed the FMVSS No. 210 requirements (sustained force of 13,345 N for each body block).

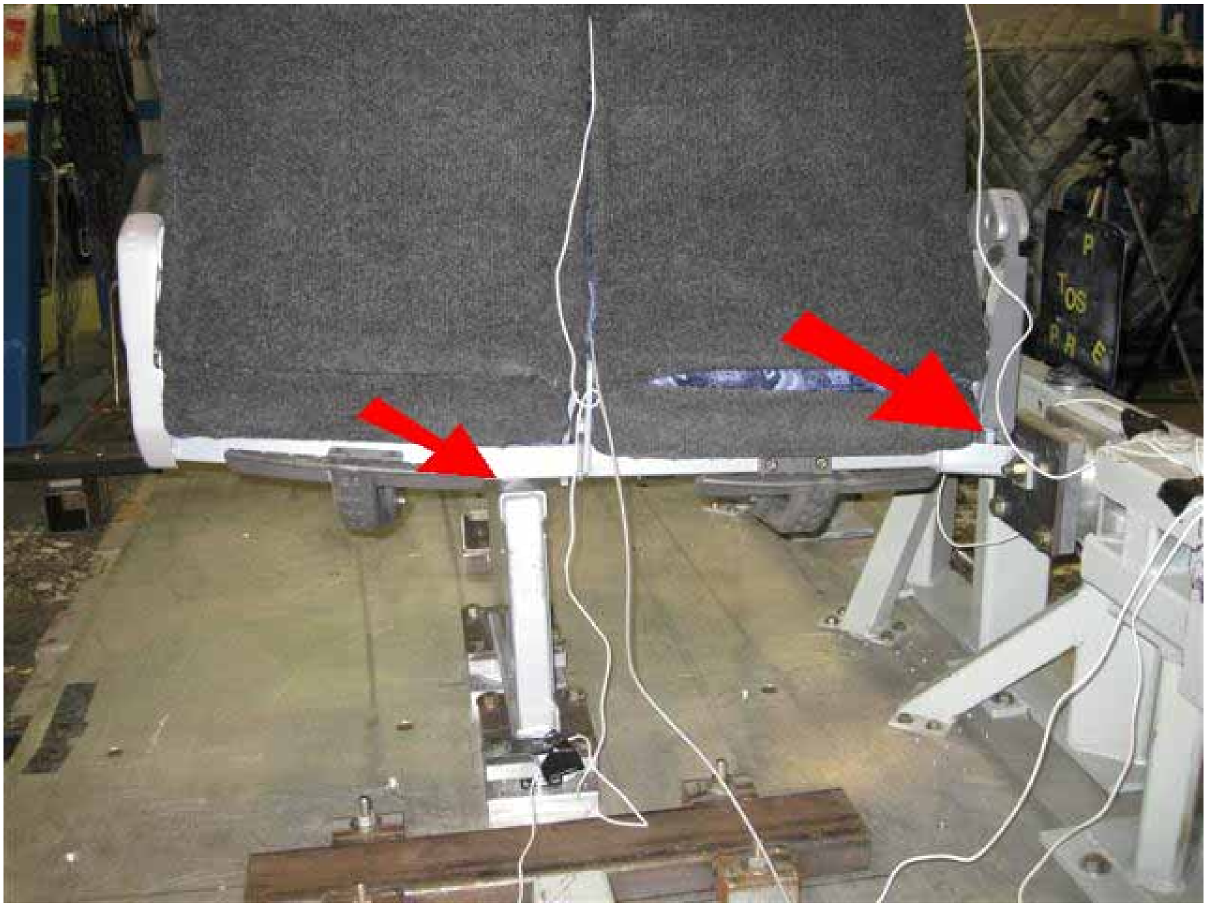


**Figure 54 - Post-test damage to the 10G seat**

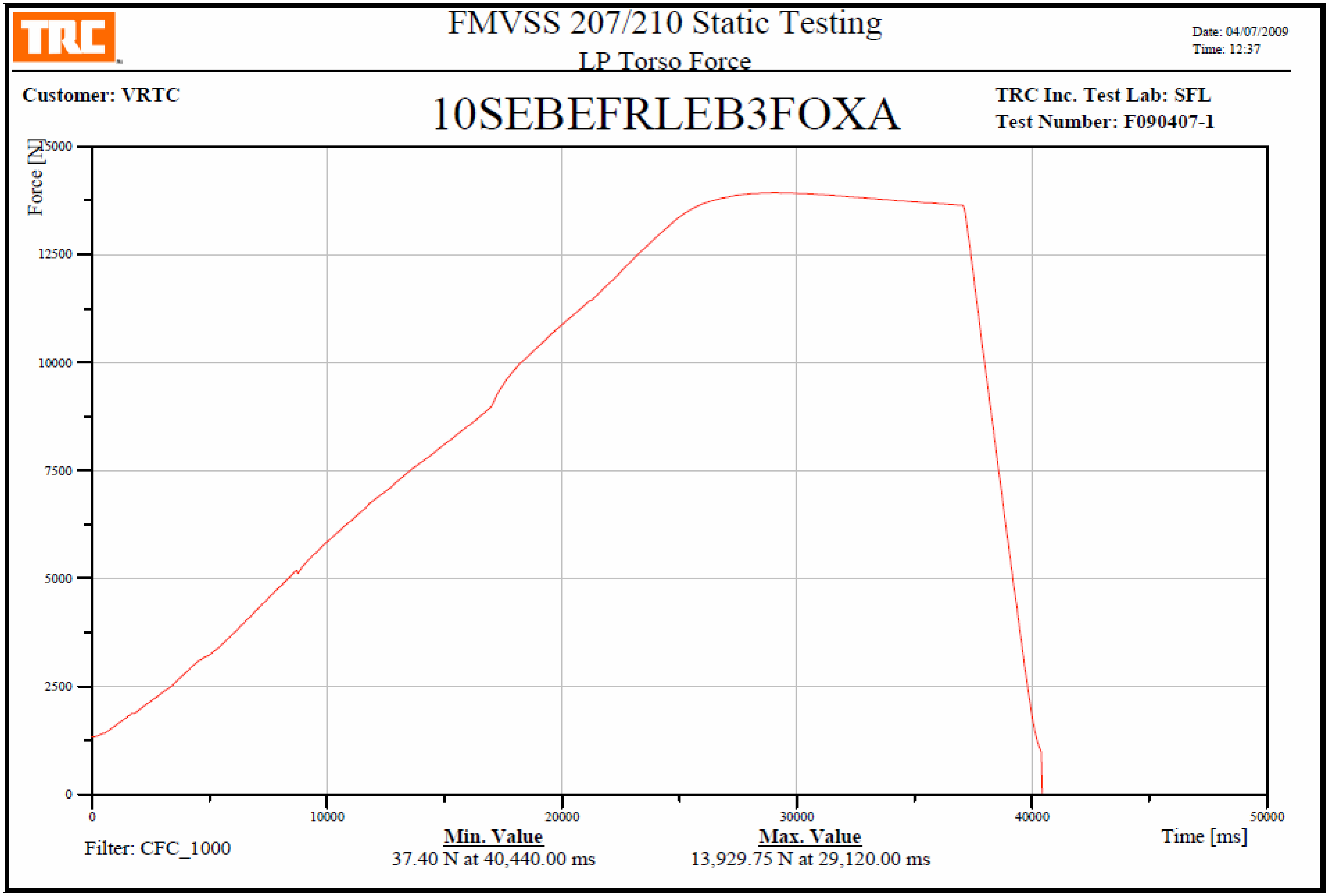


**Figure 55 - Left torso body block pulling force**

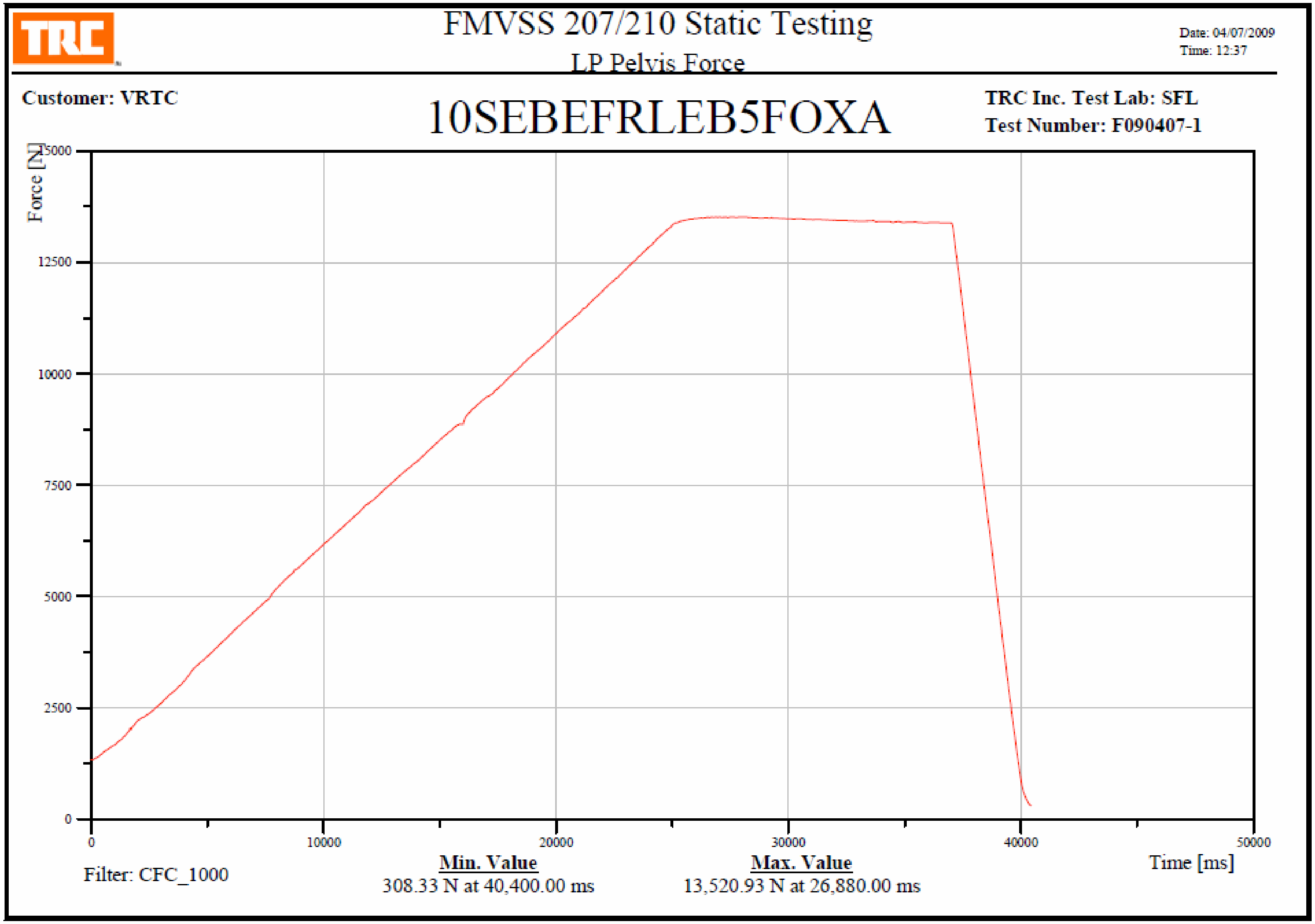


**Figure 56 - Left pelvis body block pulling force**

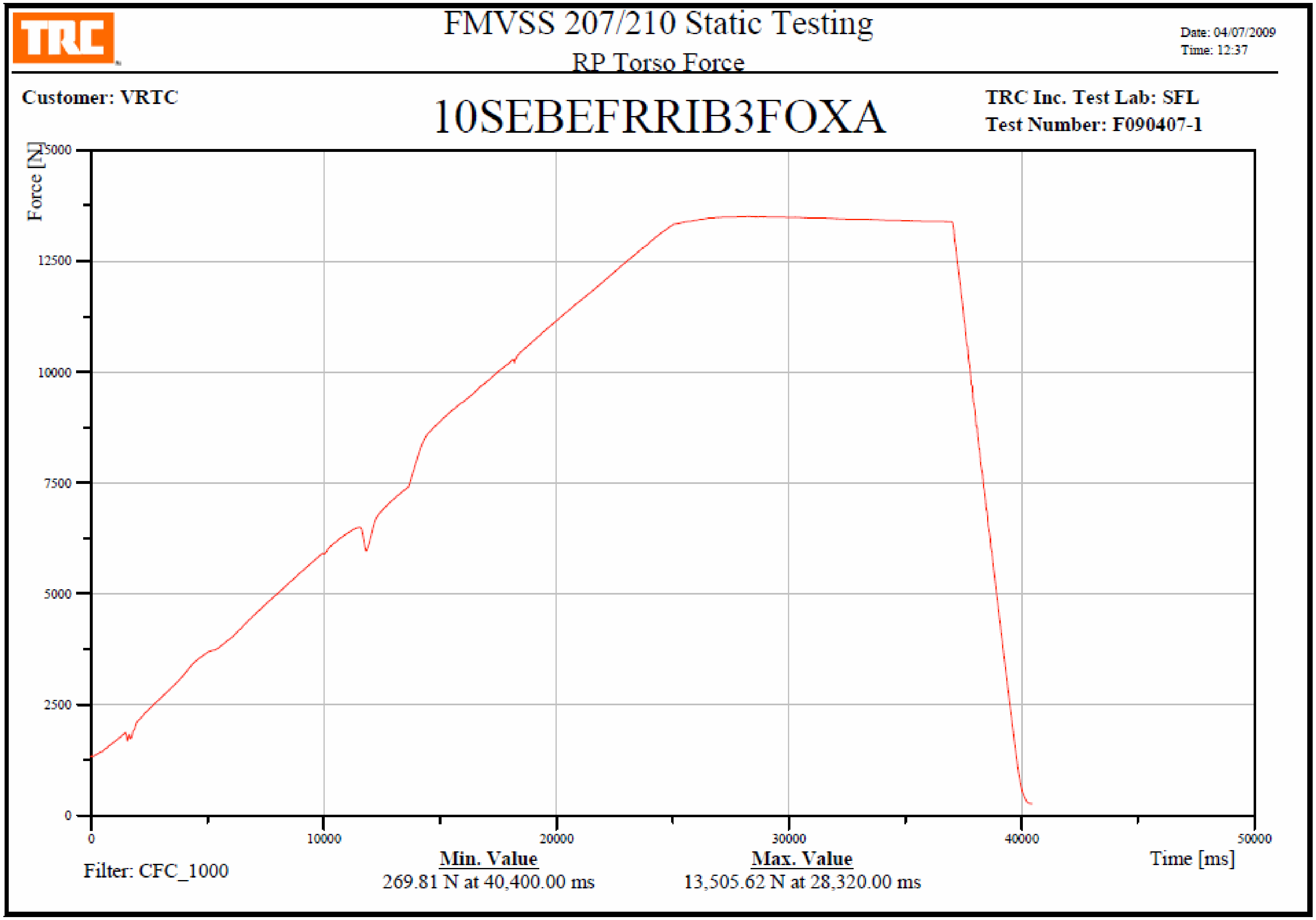
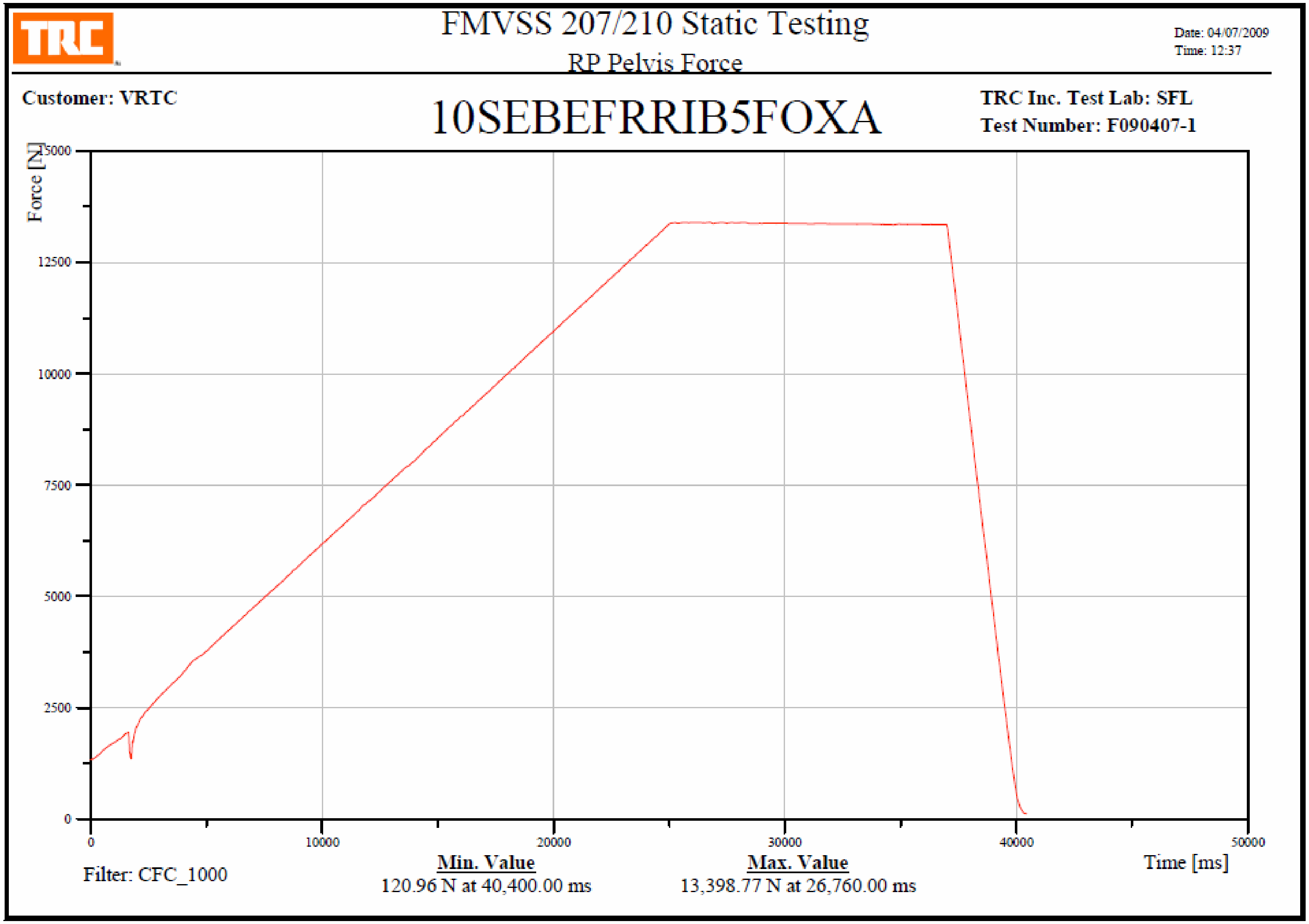


Figure 57 - Right torso body block pulling force



FMVSS 207/210 Static Testing

RP Pelvis Force

Date: 04/07/2009
Time: 12:37

Customer: VRTC

10SEBEFRRIB5FOXA

TRC Inc. Test Lab: SFL
Test Number: F090407-1

Filter: CFC_1000

**Min. Value**
120.96 N at 40,400.00 ms

**Max. Value**
13,398.77 N at 26,760.00 ms

Figure 58 - Right pelvis body block pulling force

## 5.2 Tests using seat rails

The purpose of these tests was to determine if the Amaya 7G and 10G seats would meet the current FMVSS No. 210 requirements when using hardware used in motorcoaches to attach the seats to the floor and sides.

The side rail was an actual section taken from the crashed bus and mounted to the static test fixture the same as it was in the coach (Figure 59). A floor rail from a motorcoach was welded onto a steel plate using the same weld pattern used in the bus (Figure 60). In the bus, the rails were welded onto the longitudinal frame rail running down the center of the bus under the floor (Figure 61). All tests were conducted to the current FMVSS No. 210 loads.

**Figure 59 - Coach side rail used in static test**

Figure 60 - Coach floor rail used in static test

Figure 61 - Coach longitudinal floor-rail used to attach the seats

### 5.2.1 Amaya 7G seat test

The Amaya 7G seat was attached to the floor rails and tested to 13,345 N on each of the four body blocks (Figure 62). This seat met the requirements on FMVSS No. 210, as shown in Figures 63 through 66.

**Figure 62 - Amaya 7G seat static test using floor and side rails**

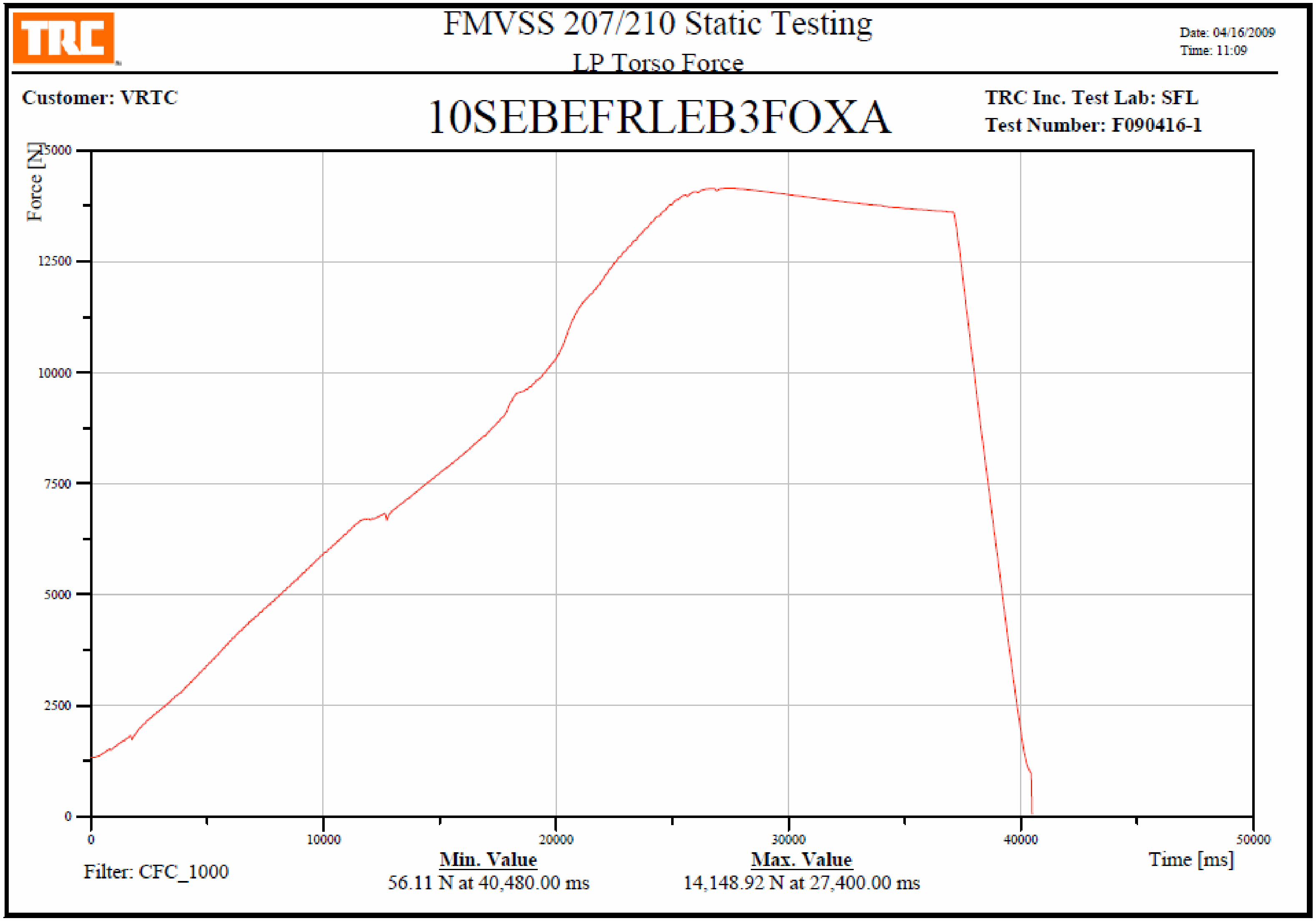


**Figure 63 - Left torso body block pulling force**

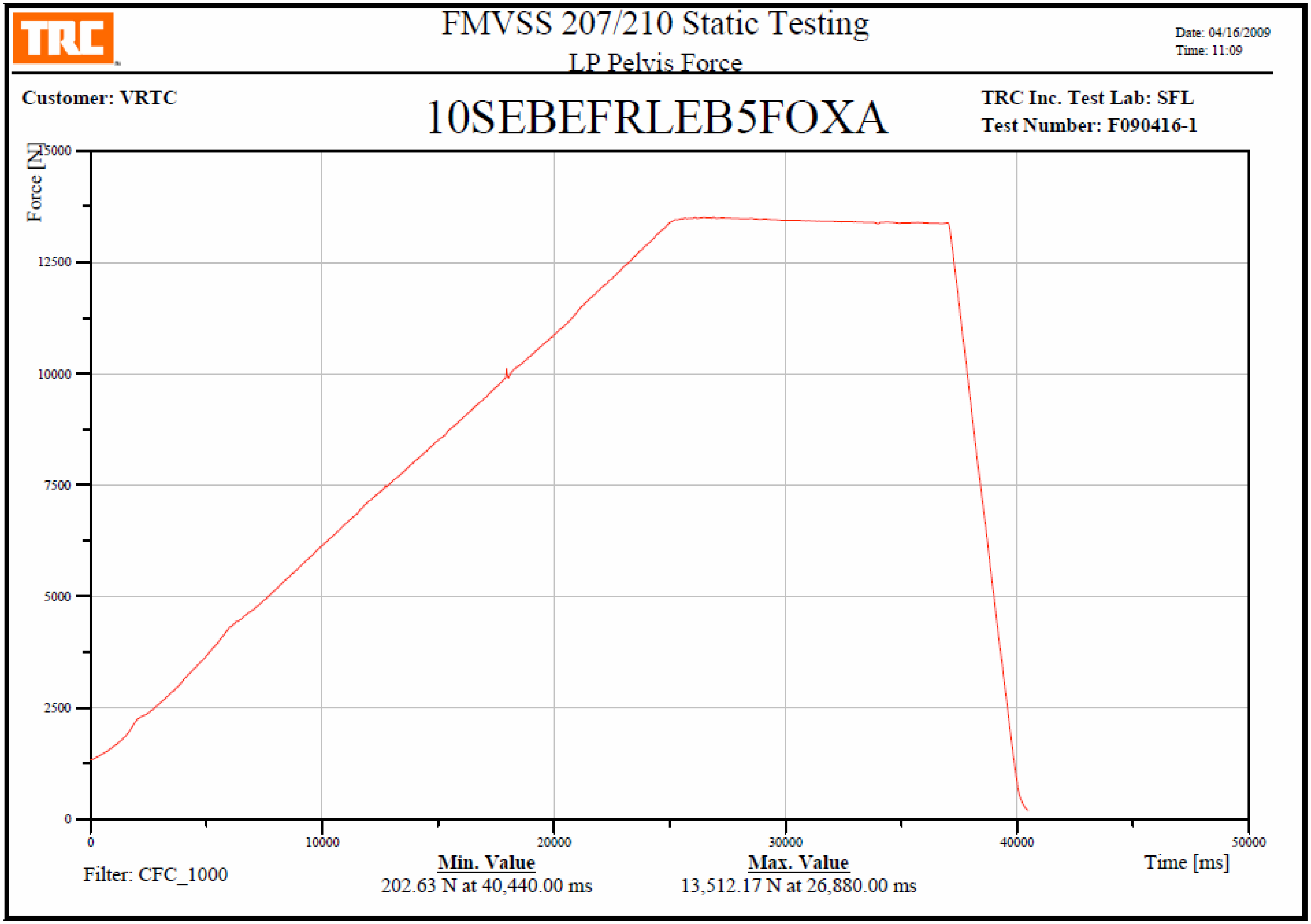


**Figure 64 - Left pelvis body block pulling force**

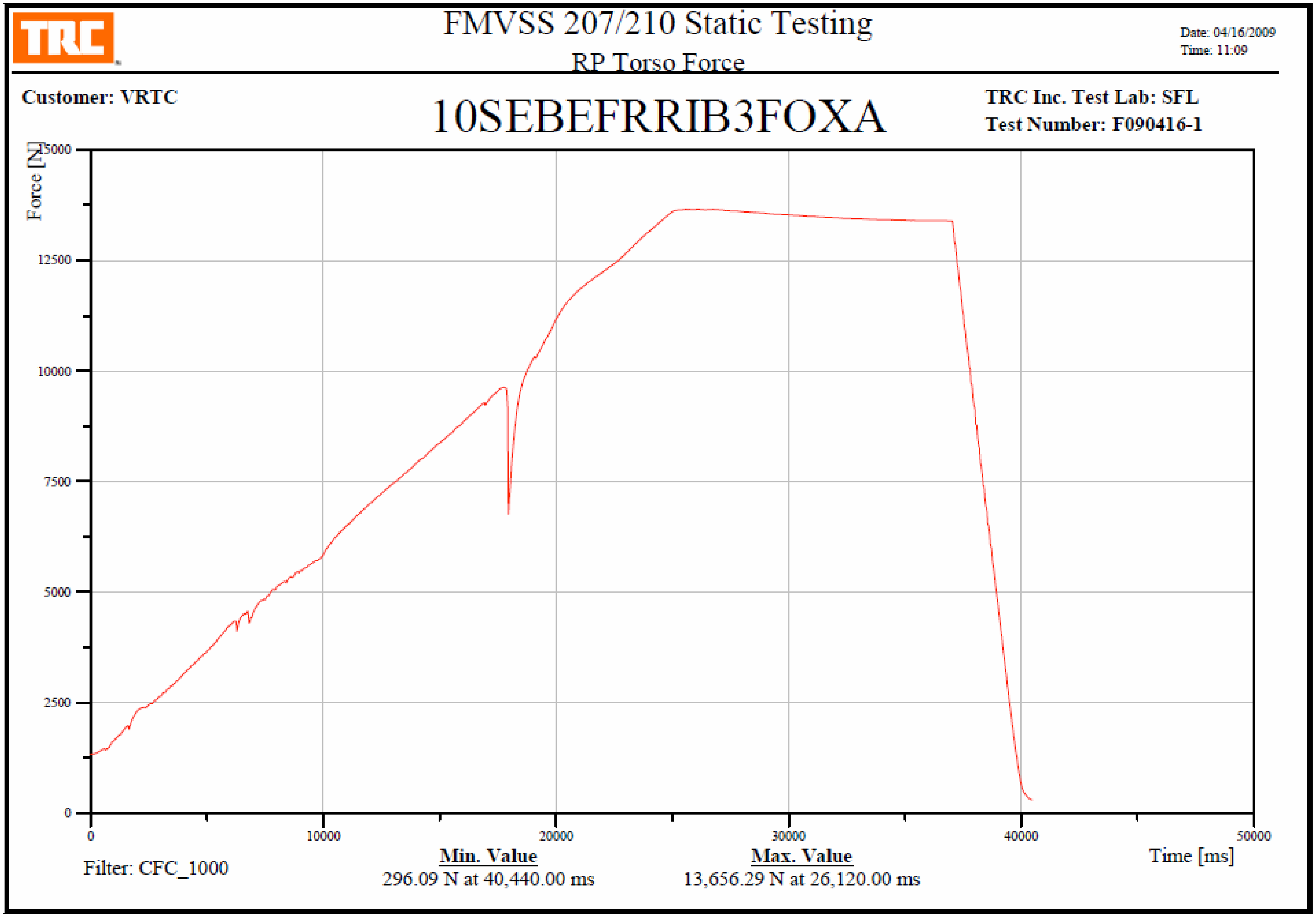


Figure 65 - Right torso body block pulling force

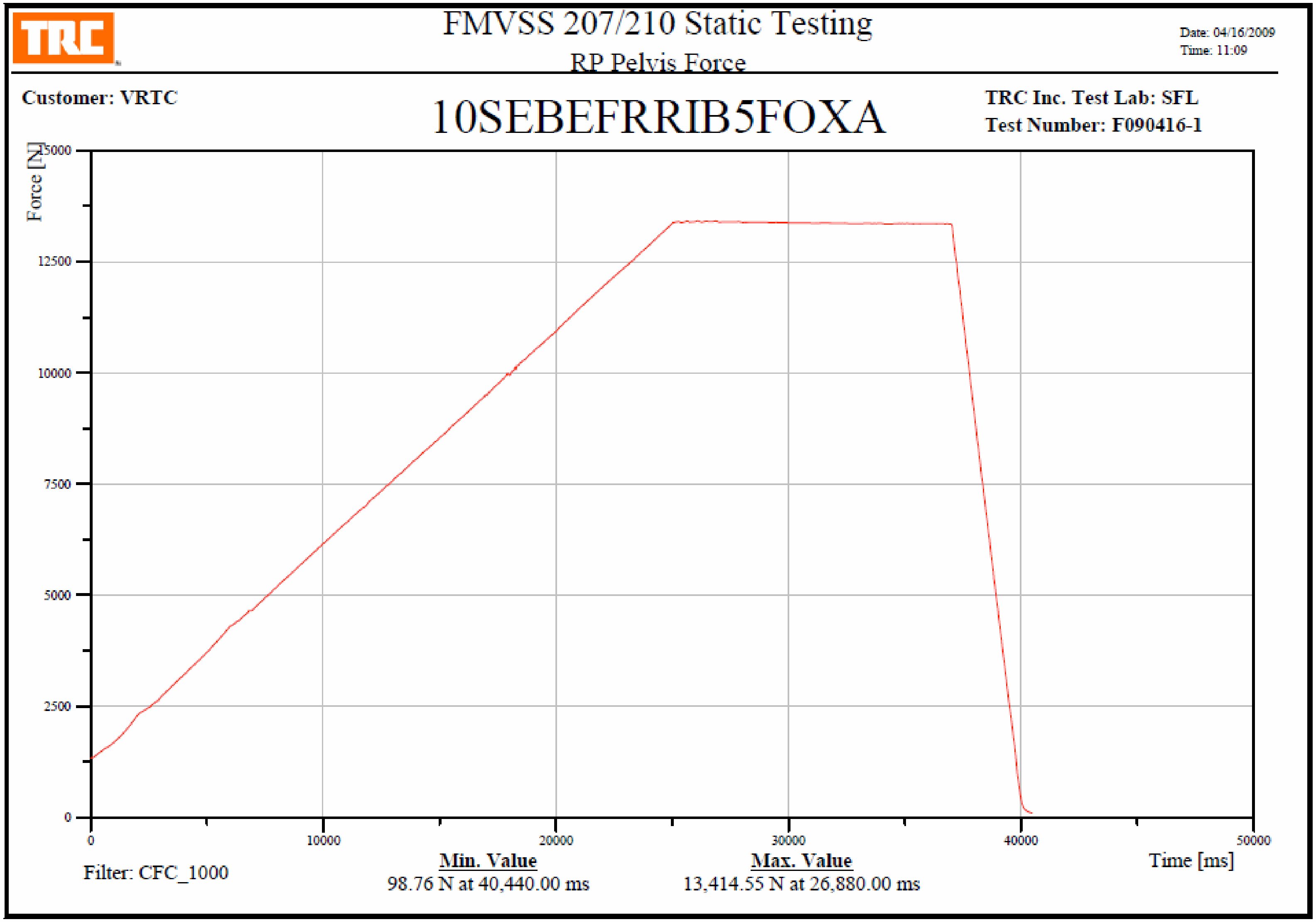


**Figure 66 - Right pelvis body block pulling force**

### 5.2.2 Amaya 10G seat test #1 with seat rails

An Amaya 10G seat was then tested using the same floor and side mounting rails used in the 7G seat test described in Section 5.2.1. The seat rails failed on the floor rear attachment bolt, resulting in the seat coming loose from the rails (Figure 67) and the FMVSS No. 210 requirements not being met, as shown in Figures 68 through 71.

**Figure 67 - Amaya 10G seat using floor and side rails used previously**

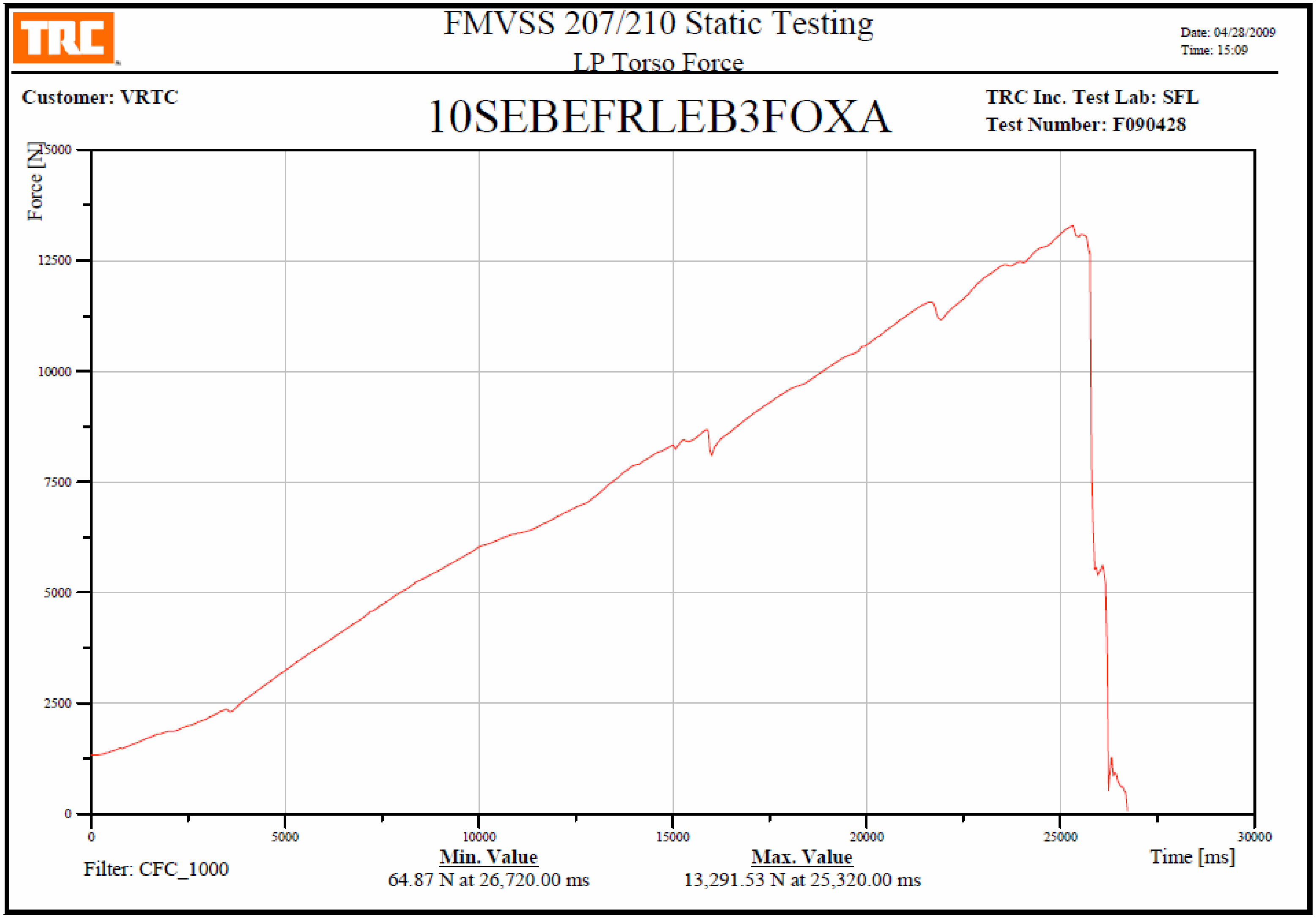


Figure 68 - Left torso body block pulling force

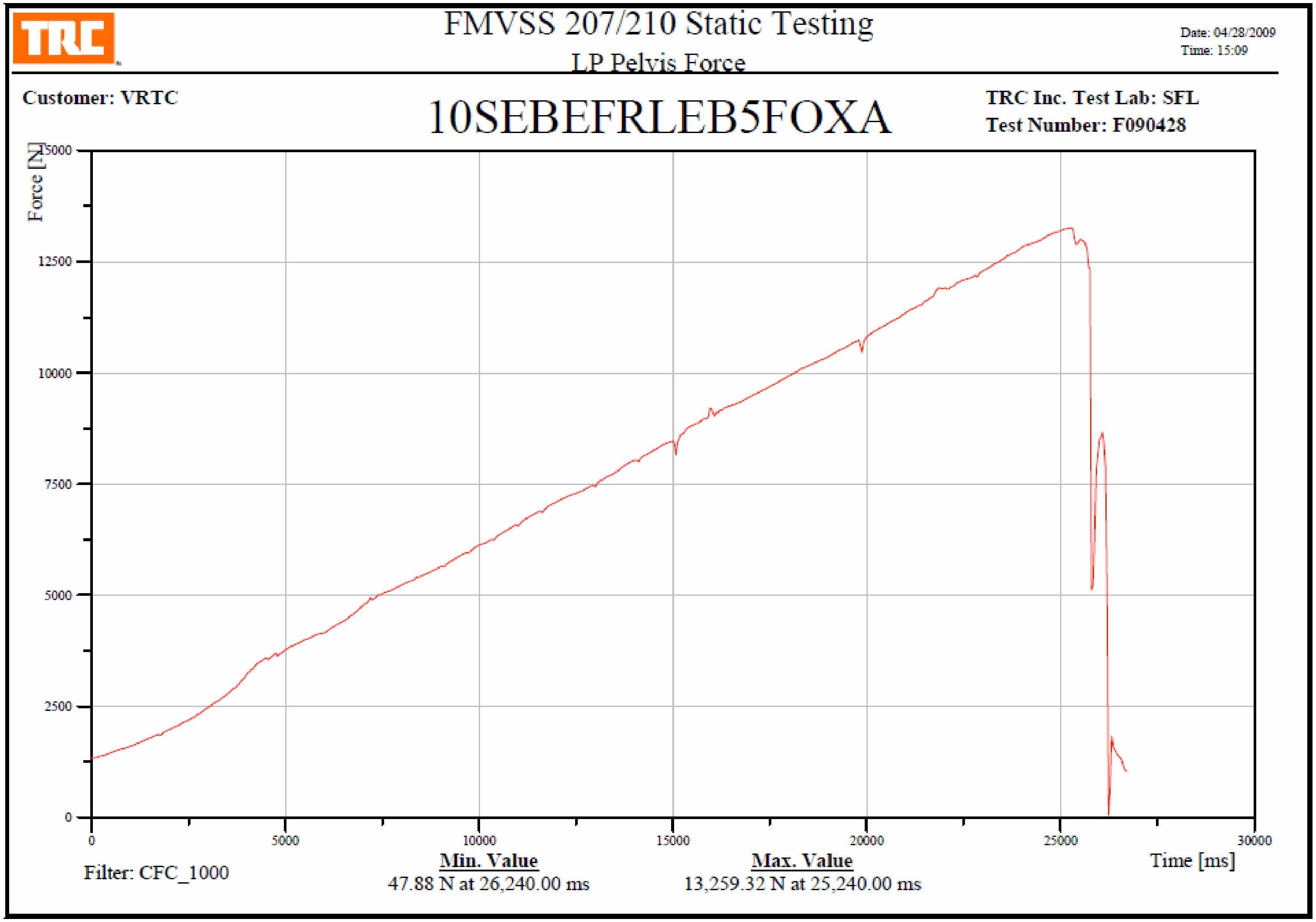


Figure 69 - Left pelvis body block pulling force

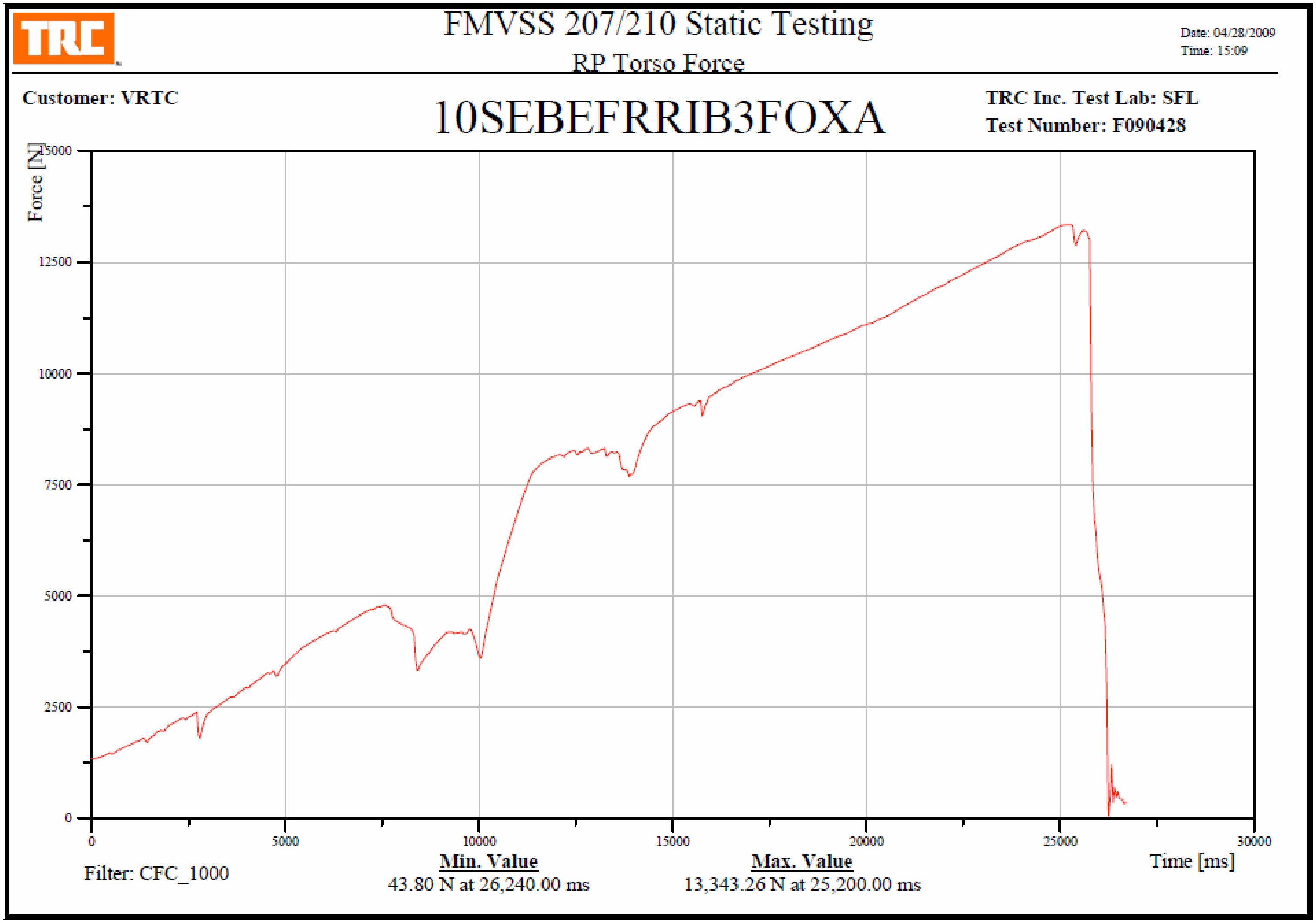


**Figure 70 - Right torso body block pulling force**

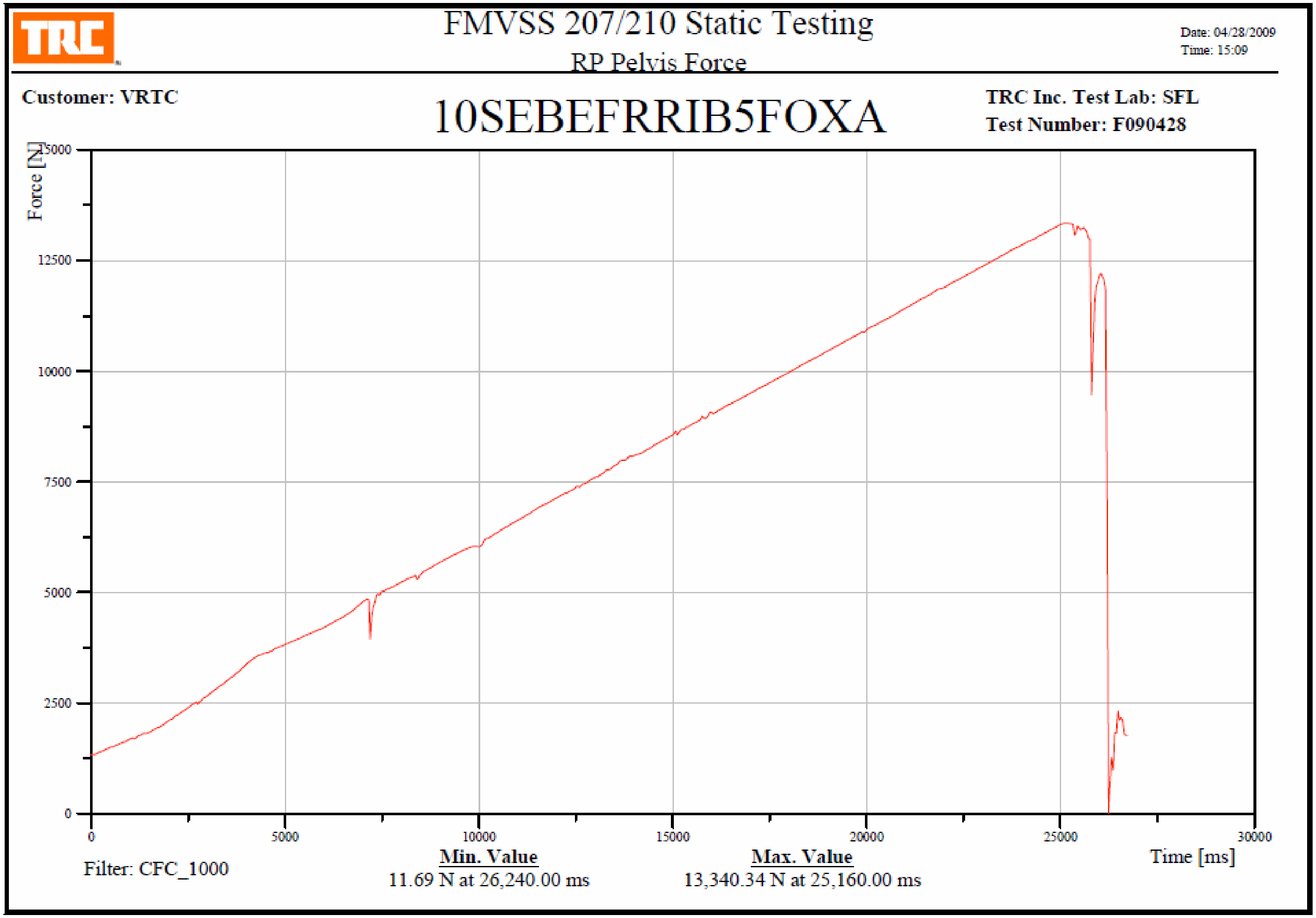


Figure 71 - Right pelvis body block pulling force

The floor rail was considered to have been weakened from its prior use in the 7G seat test. The floor and side rails from this test are shown in Figure 72, clearly showing the locations where the rail yielded under load.

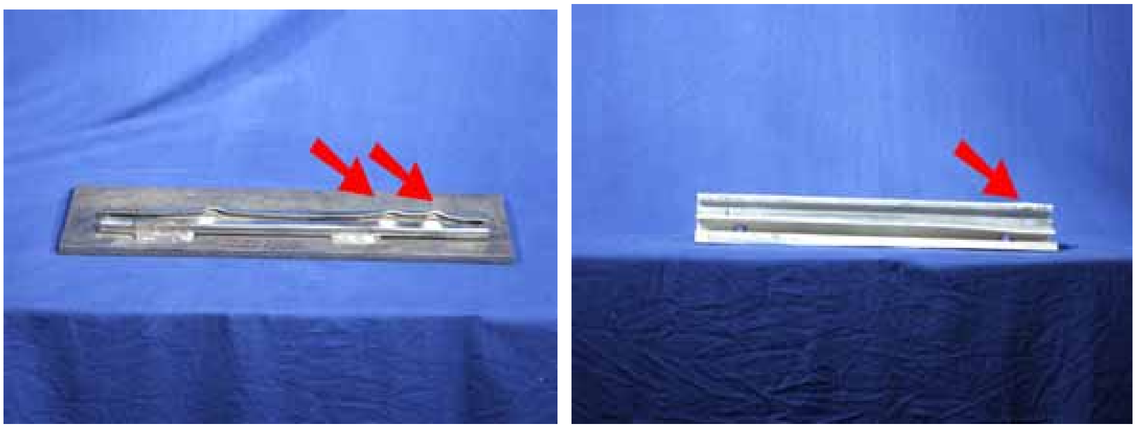


**Figure 72 - Damage to the floor and side rails**

### 5.2.3 Amaya 10G seat test #2 with seat rails

Another test with the 10G seat was conducted using pieces of the floor and side rail that had not been used in any previous tests (Figure 73). This time, the rails did not fail and the seat was able to sustain the pulling force of 13,345 N on each body block, as shown in Figures 74 through 77.

**Figure 73 - Amaya 10G seat using new floor and side rails**

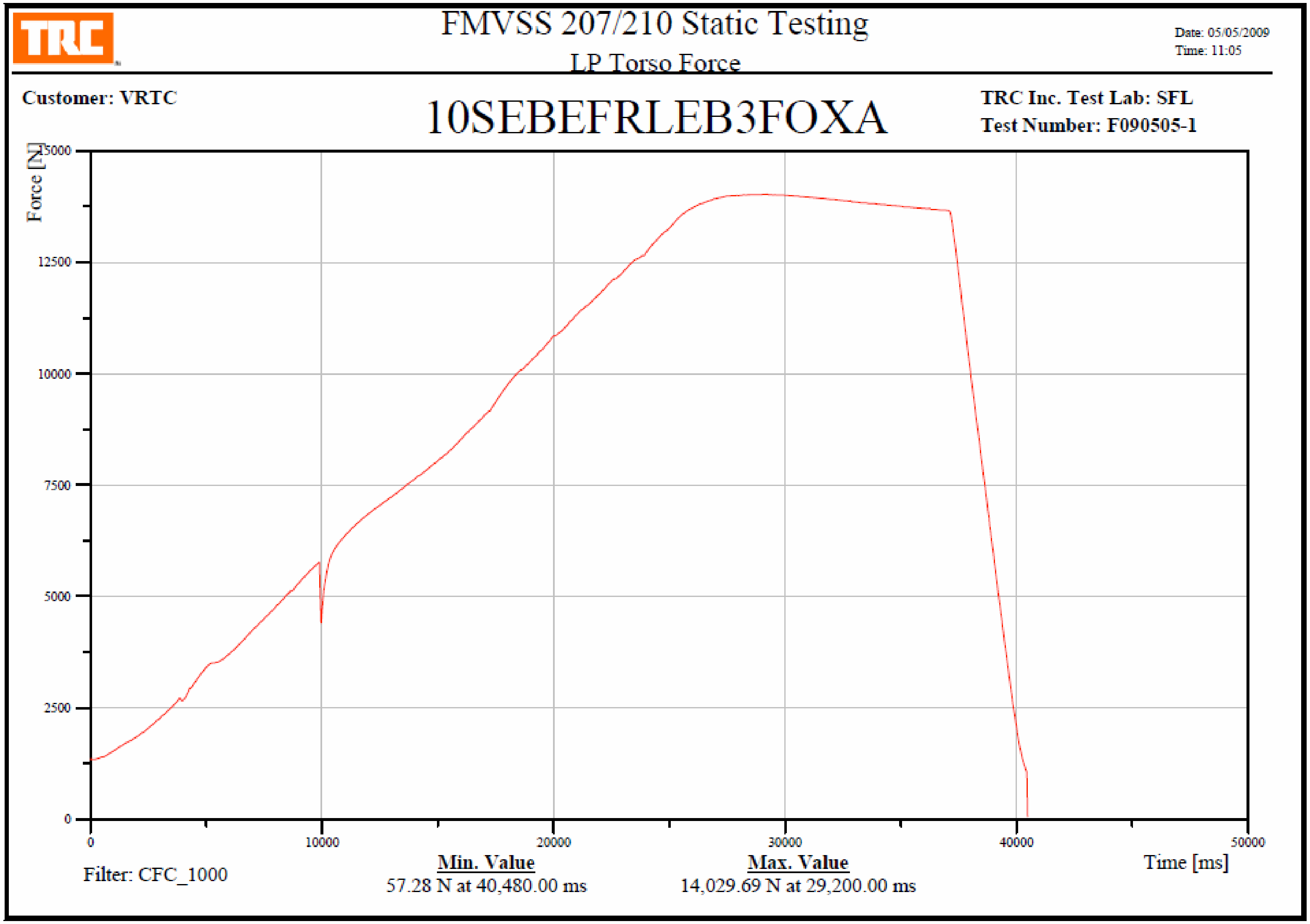


Figure 74 - Left torso body block pulling force

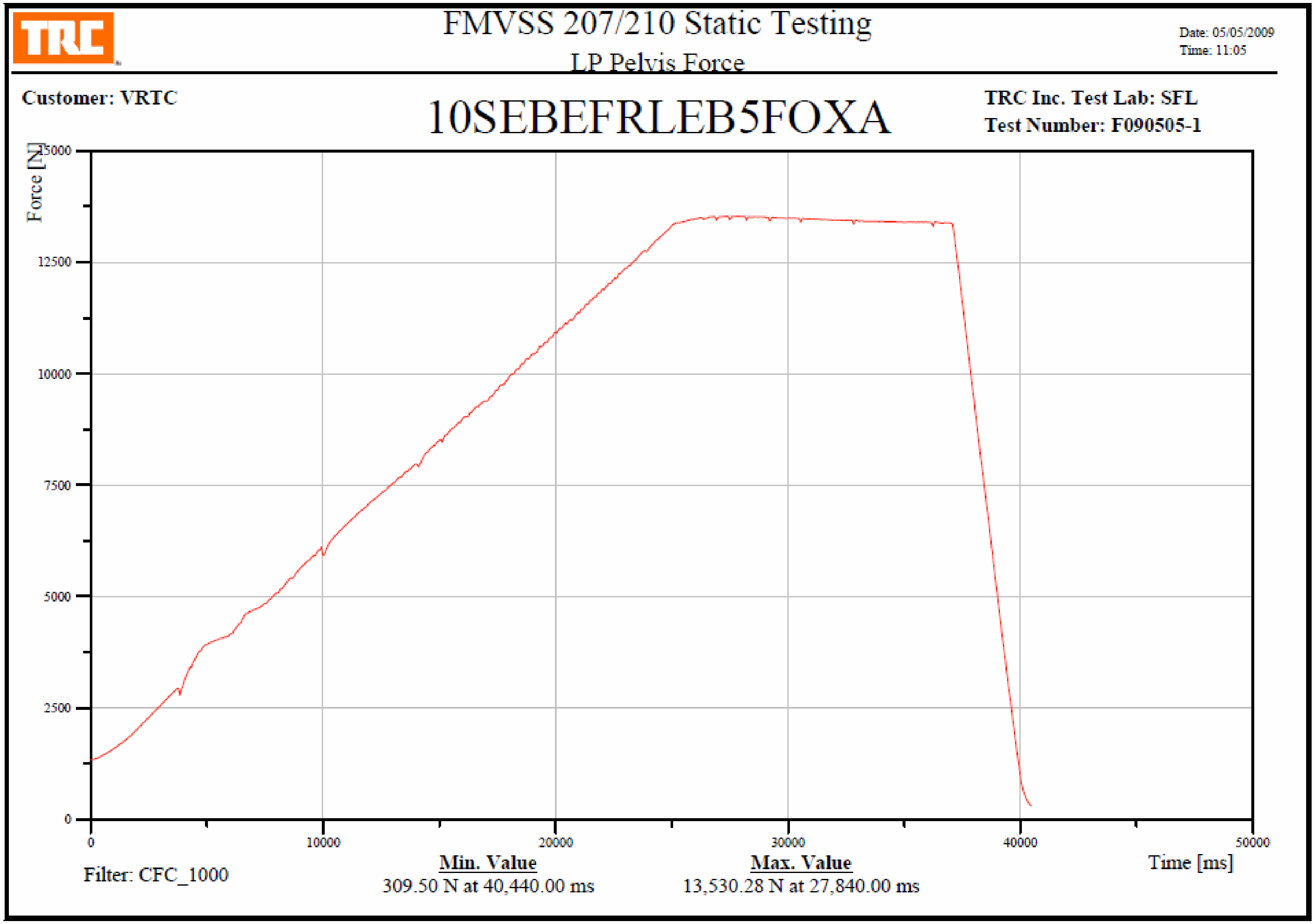
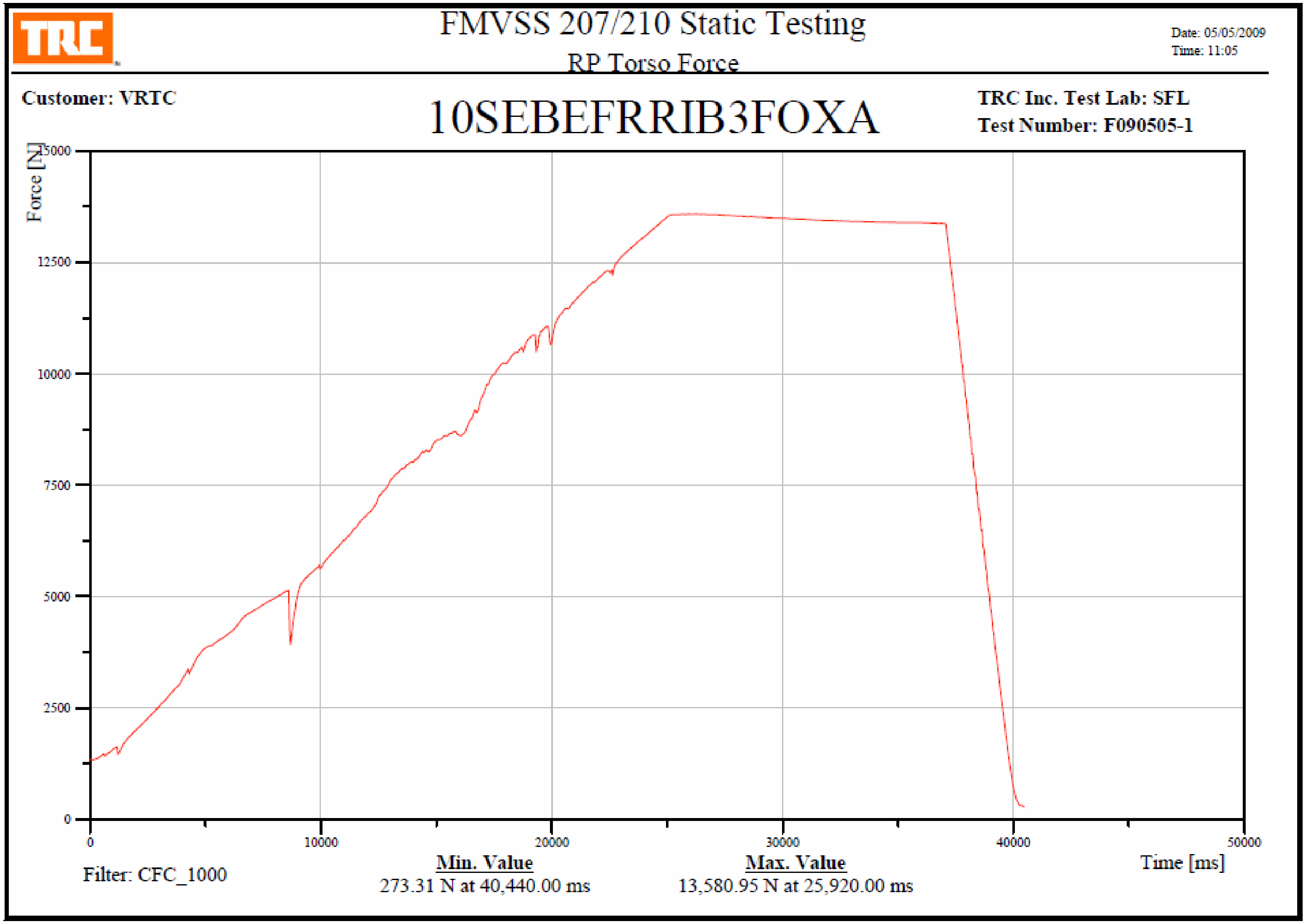


**Figure 75 - Left pelvis body block pulling force**



FMVSS 207/210 Static Testing

RP Torso Force

Date: 05/05/2009
Time: 11:05

Customer: VRTC

10SEBEFRRIB3FOXA

TRC Inc. Test Lab: SFL
Test Number: F090505-1

Filter: CFC_1000

Min. Value
273.31 N at 40,440.00 ms

Max. Value
13,580.95 N at 25,920.00 ms

**Figure 76 - Right torso body block pulling force**

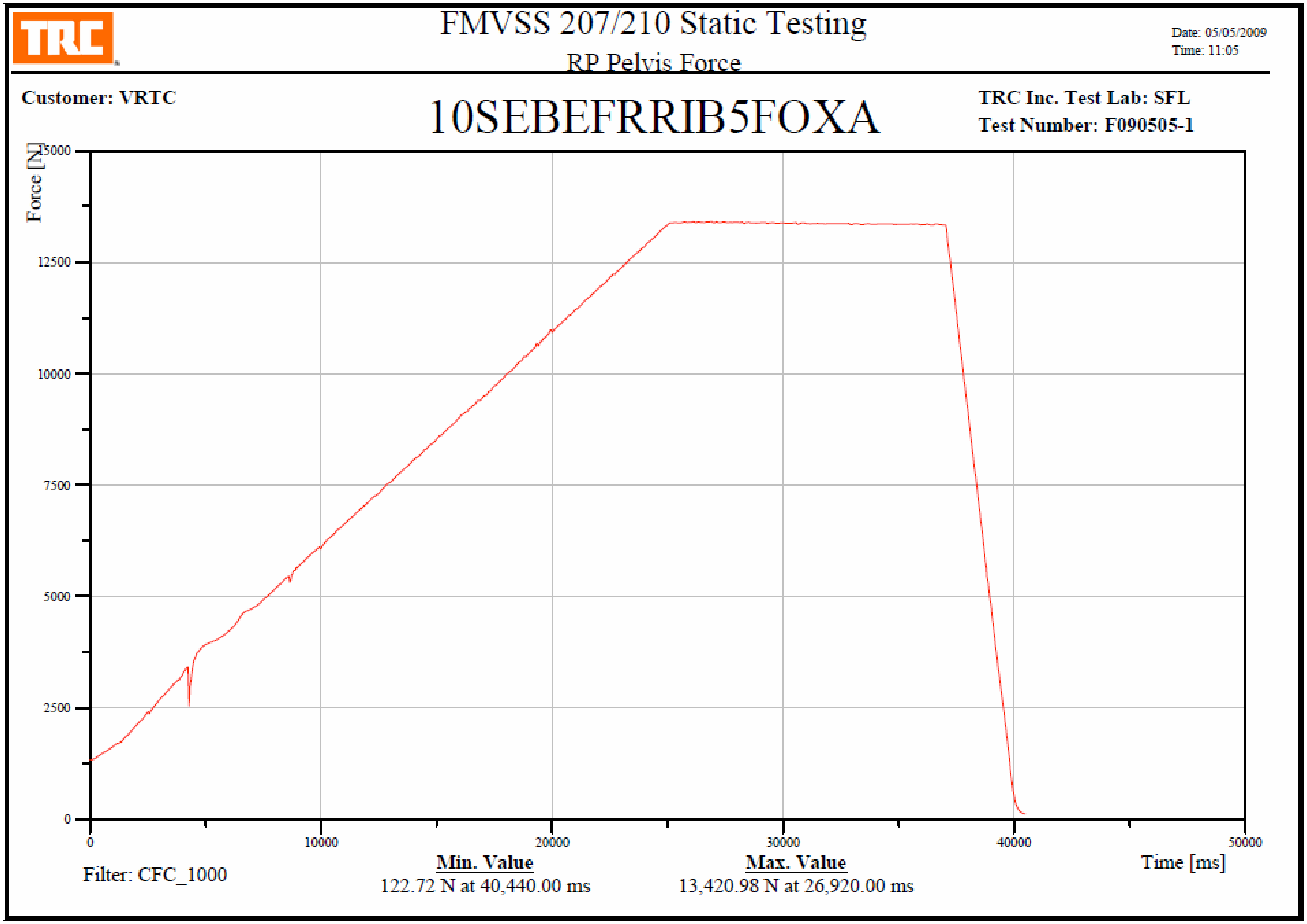


**Figure 77 - Right pelvis body block pulling force**

# 6.0 SUMMARY

The study of the feasibility and effectiveness of using seat belts on motorcoaches, described in this report, consisted of three distinct phases: crash testing, sled tests and static pull tests.

The motorcoach crash test (section 2.0) demonstrated the effectiveness of lap/shoulder seat belts in severe frontal crashes of motorcoaches. All belted dummies remained in the seats and generally had much lower injury assessment values than unbelted dummies. Lap belts alone (lap belts) were not effective in protecting the occupants in the frontal crash mode. All the seats stayed attached to the floor and side rails during the event. The crash pulse recorded had a peak value of approx 13 g and duration of about 300 milliseconds (although the vehicle continued to move forward for an additional 125 ms). The dynamic crush in the crash test was approximately 6.5 ft.

Sled tests were conducted to observe the dummy kinematics and the forces on the seats under various crash conditions. The crash pulses observed in the crash test, as well as that used by ECE regulations, were replicated in these tests. Two different belted seats meeting ECE requirements were used, along with baseline unbelted seats used in the USA fleets. Dummy injury assessment values and seat anchor forces were recorded for different dummy sizes, rear loading from unbelted dummies, and crash angles.

Static pull tests were conducted to replicate the seat anchor forces attained in selected sled tests. Two different methods were considered for estimating the pulling forces on the body blocks for the static pull tests: Method A used the seat belt tensions and knee/femur loads from unbelted dummies in the rear seat; Method B used forces recorded at the seat anchor load cells. Method B was the more direct method in that it used seat anchor load cell data from both sled and static tests. However, this method cannot differentiate between the loads on the belt anchors and the loads on the seat structures. It also averages the forces for the left and right seating positions. Even so, the belt anchor forces are still ultimately transferred through the seat anchors. Thus, Method B does replicate the combined loads on the seat anchors, including the inertial loads due to the mass of the seat.

Static test procedures were developed using both these methods. Method B, when applied to the most severe test (#13) indicated that the body blocks be pulled at 12,124 N each, which is close to the current FMVSS No. 210 requirement of 13,345 N.

Finally, static tests under the current FMVSS No. 210 conditions were conducted on the 7G and 10G seats, as installed on the floor and side rails mounting hardware of the bus. Both the seats passed the FMVSS No. 210 requirements.

## REFERENCES

1. U.S. Department of Transportation, Motorcoach Safety Action Plan, DOT HS 811 177, November 2009.
2. U.S. DOT/NHTSA - Memorandum: Approach to Motorcoach Safety, Docket ID: NHTSA-2007-28793, http://www.regulations.gov/search/Regs/home.html#docketDetail?R=NHTSA-2007-28793

# APPENDIX

## Injury Assessment Values

## A.1 - Crash Test

| | | | | | | | | | | | | | | Femur Load Compression (N) | | | | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dummy | | Seat | | | | HIC [15] | | 3ms Clip | | Chest Deflection (mm) | | NIJ | | Femur Right | | Femur Left | | |
| Size | ID # | Row | Position | Manu. | Restraint | Peak Value | Time (ms) | Peak Value | Time (ms) | Peak Value | Time (ms) | Peak Value | Time (ms) | Peak Value | Time (ms) | Peak Value | Time (ms) | |
| 50th | 55 | 4R | Aisle | MCI/Amaya | 3pt | 439.05 | 290.56 | 25.51 | 200.42 | 7.82 | 132.56 | 0.83 | 209.12 | 1142.4 | 135.36 | 1036.45 | 227.12 | DUMMY IN CRUSH ZONE |
| 50th | 290 | 4R | Window | MCI/Amaya | 3pt | 77.26 | 169.84 | 15.1 | 151.46 | 12.68 | 132.4 | OVER RANGED My | | 181.92 | 446.08 | 329.53 | 187.92 | DUMMY IN CRUSH ZONE |
| 50th | 168 | 5R | Aisle | American | Unbelted | 1308.49 | 167.2 | 19.7 | 195.92 | 2.23 | 346 | 0.97 | 283.52 | 1909.76 | 168.4 | 2936.75 | 189.76 | |
| 50th | 169 | 5R | Window | American | Unbelted | 842.77 | 152.48 | 21.35 | 174.96 | 1.38 | 283.44 | 0.56 | 186.08 | 1227.63 | 157.84 | 3386.83 | 193.6 | |
| 5th | 426 | 5L | Aisle | MCI/Amaya | Lap Belt | 1356.42 | 146.64 | 24.23 | 169.79 | 0.71 | 499.84 | OVER RANGED Fz | | 168.13 | 241.04 | 354.31 | 210.96 | DUMMY SLIDES FORWARD WITH SIGNIFICANT NECK EXTENSION |
| 50th | 342 | 5L | Window | MCI/Amaya | Lap Belt | 785.18 | 150.08 | 25.1 | 165.88 | 0.11 | 442.4 | 0.4 | 191.36 | 2569.26 | 121.28 | 630.85 | 120.32 | |
| 50th | 313 | 6R | Aisle | Freedman | 3pt | 203.77 | 321.44 | 15.94 | 189.61 | 14.49 | 174.88 | 0.65 | 190.56 | 21.7 | 440.72 | 9.3 | 296.88 | |
| 50th | 314 | 6R | Window | Freedman | 3pt | 157.21 | 185.04 | 19.78 | 185.82 | 7.1 | 217.36 | 0.68 | 186.32 | 65.7 | 320.56 | 38.86 | 298.32 | |
| 50th | 45 | 7R | Aisle | American | Unbelted | 612.81 | 171.76 | 18.68 | 296.03 | 3.72 | 202.24 | 0.53 | 324.32 | 1971.48 | 167.92 | 3652.27 | 192 | |
| 50th | 43 | 7R | Window | American | Unbelted | 728.31 | 159.04 | 28.32 | 170.47 | 16.2 | 189.28 | 0.5 | 242.88 | 2885.95 | 178.32 | 3829.49 | 181.52 | |
| 95th | 77 | 8L | Aisle | American | Unbelted | 753.82 | 178.16 | 13.49 | 195.87 | 20.31 | 202.4 | 0.57 | 364.32 | 4040.88 | 112 | 6608.95 | 112.24 | |
| 50th | 177 | 8L | Window | American | Unbelted | 700.05 | 340.72 | 17.55 | 157.69 | 1.84 | 220.56 | 1.35 | 363.28 | 3467.68 | 114.08 | 2683.03 | 179.68 | SUSPECT DUMMY HIT CAMERA STAND BEYOND 300ms |
| 95th | 226 | 9R | Aisle | MCI/Amaya | 3pt | 348.89 | 181.92 | 15.57 | 182.43 | 15.19 | 194.8 | 0.51 | 183.52 | 3123.96 | 110.08 | 1129.83 | 108.48 | |
| 50th | 591 | 9R | Window | MCI/Amaya | 3pt | 117.91 | 246.8 | 15.12 | 143.8 | 14.11 | 196.4 | 0.72 | 257.52 | 48.48 | 268.08 | 791.59 | 140 | |
| 50th | 616 | 10L | Aisle | American | Unbelted | 570.01 | 181.12 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | 3033.15 | 166.48 | |
| 50th | 551 | 10L | Window | American | Unbelted | 336.33 | 172.88 | 17.4 | 184.61 | NO DATA | NO DATA | 0.45 | 378.64 | 4254.01 | 111.28 | 5880.47 | 108.48 | |
| 50th | 617 | 11R | Aisle | MCI/Amaya | 3pt | 29.57 | 195.04 | 13.9 | 141.37 | 11.38 | 147.68 | 0.31 | 200.16 | 1029.47 | 150.64 | Questionable Data | | |
| 50th | 134 | 11R | Window | MCI/Amaya | 3pt | 38.08 | 161.36 | 15.32 | 132.57 | 16.97 | 181.2 | 0.25 | 181.76 | 1537.98 | 132.8 | 485.96 | 143.04 | |
| 5th | 324 | 12L | Aisle | American | Unbelted | 1958.93 | 162.2 | 22.31 | 172.03 | NO DATA | NO DATA | 2.05 | 325.36 | 2922.15 | 120.72 | 4148.77 | 126.32 | DUMMY FLEW OVER SEAT |
| 50th | 855 | 12L | Window | American | Unbelted | 209.65 | 163.2 | 14.8 | 171.84 | 1.78 | 363.68 | 0.36 | 337.6 | 4505.35 | 106.48 | 6229.63 | 104.48 | DUMMY FLEW OVER SEAT |
| 5th | 416 | 13R | Aisle | MCI/Amaya | 3pt | 14.37 | 130.08 | 12.29 | 142.87 | 13.54 | 146.08 | 0.2 | 282.8 | 195.08 | 138.16 | 34.01 | 200.64 | |
| 50th | 1 | 13R | Window | MCI/Amaya | 3pt | 26.62 | 160.72 | 13.37 | 128.21 | 16.3 | 179.2 | 0.28 | 173.2 | 1602.46 | 144.56 | NO DATA | NO DATA | |

NOTE:
DUMMIES TYPICALLY MAKE FIRST HEAD CONTACT WITH FORWARD SEATBACK WITHIN 150ms to 180ms

## A.2 - Sled Test HIC

### HEAD INJURY VALUES

**0 DEGREE BUCK ANGLE** | **HIC15**

| TEST Type | ROW | SEAT | DUMMY LOCATIONS | | 7G seats | | | | 10G seats | |
|---|---|---|---|---|---|---|---|---|---|---|
| Test Obsevation | | | Restraint | | VRTC pulse | | EU pulse | | VRTC pulse | |
| | | | Left | Right | TEST 4<br>Test # 080721-1 | | TEST 16<br>Test # 080820-1 | | TEST 15<br>Test # 080819-1 | |
| 1 | Front | Amer Seat | -- | -- | | | | | | |
| Seat Forces | Middle | Amaya | 95th 3pt | 95th 3pt | 🟩 77.68 | 🟩 232.08 | 🟥 755.08 | 🟨 638.03 | 🟩 147.56 | 🟩 171.14 |
| Maximum | Rear | Amer Seat | 95th unbelt | 95th unbelt | | | | | | |
| | | | Left | Right | TEST 5<br>Test # 080722-1 | | TEST 17<br>Test # 080821-1 | | TEST 13<br>Test # 080815-2 | |
| ▨ 2 | Front | Amer Seat | -- | -- | | | | | | |
| Seat Forces | Middle | Amaya | 50th 3pt | 50th 3pt | 🟩 384.47 | 🟩 442.73 | 🟥 1733.02 | 🟥 780.28 | 🟩 496.49 | 🟩 331.09 |
| Medium | Rear | Amer Seat | 50th unbelt | 50th unbelt | 🟩 448.78 | 🟩 347.96 | 🟨 601.78 | 🟩 418.8 | 🟩 415.02 | 🟩 455.26 |
| | | | Left | Right | TEST 3<br>Test # 080716-2 | | TEST 18<br>Test # 080821-2 | | | |
| ▨ 3 | Front | Amer Seat | -- | -- | | | | | | |
| Seat Forces | Middle | Amaya | 50th 3pt | 50th 3pt | 🟩 79.84 | 🟩 366.6 | 🟩 127.46 | 🟥 1526.41 | | |
| Average | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 2<br>Test # 080716-1 | | TEST 19<br>Test # 080822-1 | | | |
| ▨ 4 | Front | Amer Seat | -- | -- | | | | | | |
| Seat Forces | Middle | Amaya | 50th 3pt | 5th 3pt | 🟩 35.04 | 🟩 30.59 | 🟥 838.77 | 🟩 58.29 | | |
| Minimum | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 1<br>Test # 080715-1 | | TEST 20<br>Test # 080822-2 | | | |
| ▨ 5 | Front | Amer Seat | -- | -- | | | | | | |
| Lap Belts | Middle | Amaya | 50th 2pt | 5th 2pt | 🟨 695.58 | 🟥 1377.77 | 🟥 1687.16 | 🟥 786.23 | | |
| | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 7<br>Test # 080724-2 | | | | | |
| 6 | Front | Amer Seat | -- | -- | | | | | | |
| Compartmentalization | Middle | Amer Seat | 95th unbelt | 95th unbelt | 🟩 352.23 | 🟨 612.59 | | | | |
| Current | Rear | Amer Seat | 5th unbelt | 5th unbelt | 🟥 1045.74 | 🟥 933.79 | | | | |
| | | | Left | Right | TEST 6<br>Test # 080724-1 | | | | | |
| 7 | Front | Amaya | -- | -- | | | | | | |
| Compartmentalization | Middle | Amer Seat | 50th unbelt | 5th unbelt | 🟩 440.35 | 🟩 318.07 | | | | |
| Seat Effects | Rear | Amer Seat | 50th unbelt | 5th unbelt | 🟩 457.51 | 🟥 761.44 | | | | |
| | | | Left | Right | | | | | TEST 14<br>Test # 080818-1 | |
| 7b | Front | Amaya 10G | -- | -- | | | | | | |
| Compartmentalization | Middle | Amaya 7G | 50th unbelt | 5th unbelt | | | | | 🟩 214.25 | 🟩 318.03 |
| Seat Effects 10 G | Rear | Amer Seat | 50th unbelt | 5th unbelt | | | | | 🟩 456.53 | 🟩 385.19 |
| | | | | | TEST 12<br>Test # 080815-1 | | | | | |
| 10 | Front | Amaya r | -- | -- | | | | | | |
| Reclined | Middle | Amaya r | 5th 3pt | 50th 3pt | 🟩 246.82 | 🟩 305.25 | | | | |
| Belted | Rear | Amer Seat | 50th unbelt | 50th unbelt | 🟩 344.05 | 🟩 178.63 | | | | |
| | | | | | TEST 10<br>Test # 080813-1 | | | | TEST 11<br>Test # 080814-1 | |
| 11 | Front | Amaya | -- | -- | | | | | | |
| Max Rear Loading | Middle | Amaya | 5th 3pt | 50th 3pt | 🟨 675.58 | 🟩 465.74 | | | 🟩 156.32 | 🟥 880.7 |
| Belted | Rear | Amer Seat | 95th unbelt | 95th unbelt | 🟩 495.54 | 🟩 465.65 | | | 🟩 451.5 | 🟩 305.98 |
| | | **15 DEGREE BUCK ANGLE** | | | | | | | | |
| | | | Left | Right | TEST 8<br>Test # 080729-1 | | | | | |
| 8 | Front | Amaya | -- | -- | | | | | | |
| Compartmentalization | Middle | Amer Seat | 5th unbelt | 50th unbelt | 🟩 176.56 | 🟩 464.12 | | | | |
| Current | Rear | Amer Seat | 5th unbelt | 50th unbelt | 🟩 209.3 | 🟩 137.89 | | | | |
| | | | | | TEST 9<br>Test # 080730-1 | | | | | |
| 9 | Front | Amer Seat | -- | -- | | | | | | |
| Compartmentalization | Middle | Amaya | 5th 3pt | 50th 3pt | 🟩 83.31 | 🟩 54.87 | | | | |
| Belted | Rear | Amer Seat | 5th unbelt | 50th unbelt | 🟩 121.94 | 🟨 624.27 | | | | |

▨ = The test condition was replicated in the crash test

| Dummy size | Injury Assesment Reference Value (IARV) |
|---|---|
| 5th Female | 700 |
| 50th Male | 700 |
| 95th Male | 700 |

🟩 < 80% of IARV
🟨 > 80% and < 100 % of IARV
🟥 > 100 % of IARV

## A.3 - Sled Test Nij

### ***NECK INJURY VALUES***

0 DEGREE BUCK ANGLE

**Nij**

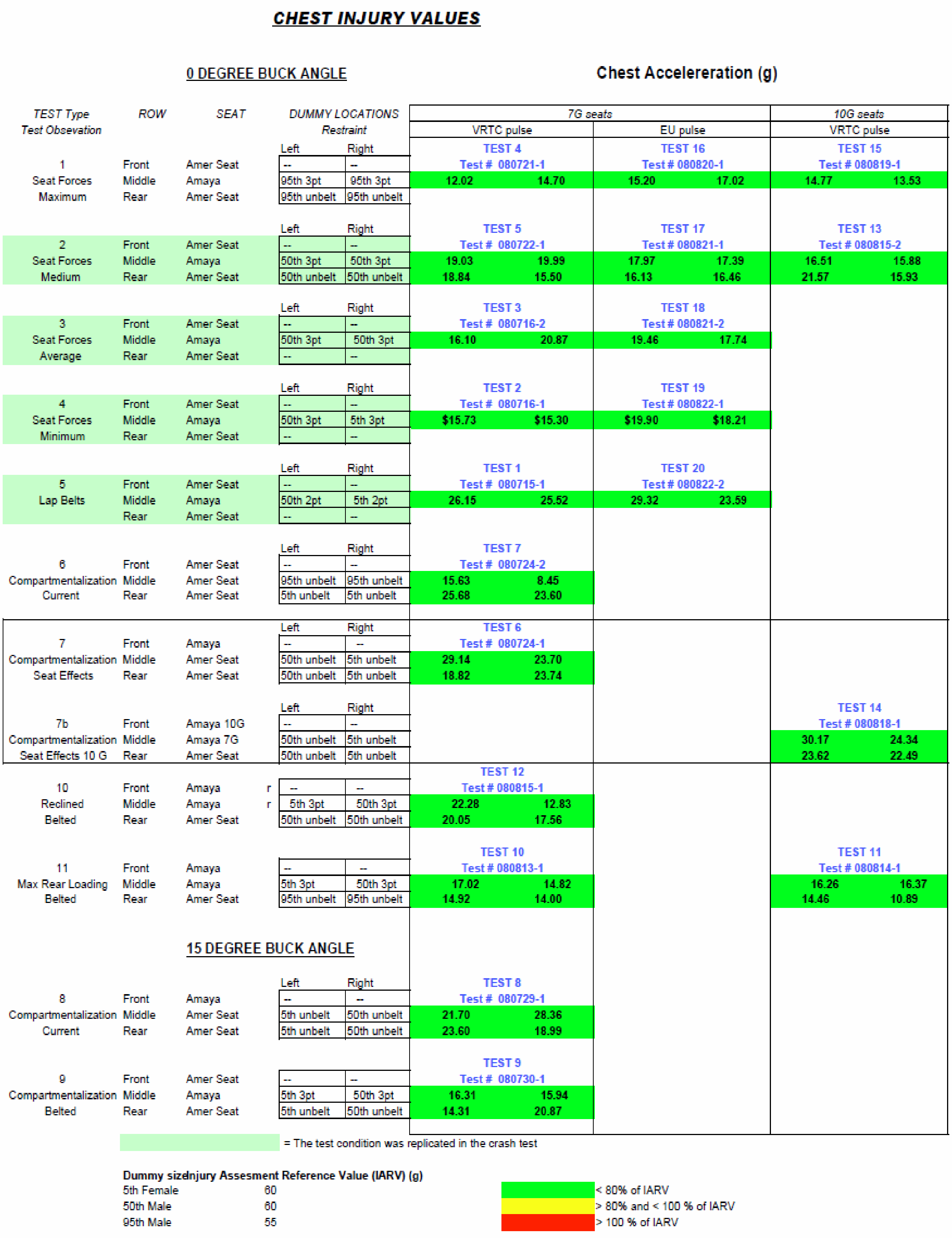
| *TEST Type* | *ROW* | *SEAT* | *DUMMY LOCATIONS* | | *7G seats* | | | | *10G seats* | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Test Obsevation* | | | *Restraint* | | VRTC pulse | | EU pulse | | VRTC pulse | |
| | | | Left | Right | TEST 4 | | TEST 16 | | TEST 15 | |
| 1 | Front | Amer Seat | -- | -- | Test # 080721-1 | | Test # 080820-1 | | Test # 080819-1 | |
| Seat Forces | Middle | Amaya | 95th 3pt | 95th 3pt | 🟩 0.20 | 🟩 0.27 | 🟩 0.51 | 🟩 0.57 | 🟩 0.32 | 🟩 0.30 |
| Maximum | Rear | Amer Seat | 95th unbelt | 95th unbelt | | | | | | |
| | | | Left | Right | TEST 5 | | TEST 17 | | TEST 13 | |
| 2 | Front | Amer Seat | -- | -- | Test # 080722-1 | | Test # 080821-1 | | Test # 080815-2 | |
| Seat Forces | Middle | Amaya | 50th 3pt | 50th 3pt | 🟩 0.39 | 🟩 0.37 | 🟩 0.58 | 🟩 0.53 | 🟩 0.63 | 🟩 0.50 |
| Medium | Rear | Amer Seat | 50th unbelt | 50th unbelt | 🟨 0.91 | 🟩 0.44 | 🟩 0.61 | 🟩 0.65 | 🟩 0.71 | 🟩 0.45 |
| | | | Left | Right | TEST 3 | | TEST 18 | | | |
| 3 | Front | Amer Seat | -- | -- | Test # 080716-2 | | Test # 080821-2 | | | |
| Seat Forces | Middle | Amaya | 50th 3pt | 50th 3pt | 🟩 0.26 | 🟩 0.49 | 🟩 0.27 | 🟩 0.70 | | |
| Average | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 2 | | TEST 19 | | | |
| 4 | Front | Amer Seat | -- | -- | Test # 080716-1 | | Test # 080822-1 | | | |
| Seat Forces | Middle | Amaya | 50th 3pt | 5th 3pt | 🟩 0.24 | 🟩 0.23 | 🟩 0.59 | 🟩 0.35 | | |
| Minimum | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 1 | | TEST 20 | | | |
| 5 | Front | Amer Seat | -- | -- | Test # 080715-1 | | Test # 080822-2 | | | |
| Lap Belts | Middle | Amaya | 50th 2pt | 5th 2pt | 🟥 1.56 | 🟥 1.13 | 🟥 2.45 | 🟥 1.60 | | |
| | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 7 | | | | | |
| 6 | Front | Amer Seat | -- | -- | Test # 080724-2 | | | | | |
| Compartmentalization | Middle | Amer Seat | 95th unbelt | 95th unbelt | 🟩 0.44 | 🟩 0.26 | | | | |
| Current | Rear | Amer Seat | 5th unbelt | 5th unbelt | 🟨 0.89 | 🟨 0.87 | | | | |
| | | | Left | Right | TEST 6 | | | | | |
| 7 | Front | Amaya | -- | -- | Test # 080724-1 | | | | | |
| Compartmentalization | Middle | Amer Seat | 50th unbelt | 5th unbelt | 🟨 0.85 | 🟥 1.05 | | | | |
| Seat Effects | Rear | Amer Seat | 50th unbelt | 5th unbelt | 🟩 0.56 | 🟨 0.81 | | | | |
| | | | Left | Right | | | | | TEST 14 | |
| 7b | Front | Amaya 10G | -- | -- | | | | | Test # 080818-1 | |
| Compartmentalization | Middle | Amaya 7G | 50th unbelt | 5th unbelt | | | | | 🟩 0.39 | 🟩 0.78 |
| Seat Effects 10 G | Rear | Amer Seat | 50th unbelt | 5th unbelt | | | | | 🟩 0.78 | 🟨 0.97 |
| | | | | | TEST 12 | | | | | |
| 10 | Front | Amaya r | -- | -- | Test # 080815-1 | | | | | |
| Reclined | Middle | Amaya r | 5th 3pt | 50th 3pt | 🟩 0.68 | 🟩 0.49 | | | | |
| Belted | Rear | Amer Seat | 50th unbelt | 50th unbelt | 🟩 0.46 | 🟩 0.40 | | | | |
| | | | | | TEST 10 | | | | TEST 11 | |
| 11 | Front | Amaya | -- | -- | Test # 080813-1 | | | | Test # 080814-1 | |
| Max Rear Loading | Middle | Amaya | 5th 3pt | 50th 3pt | 🟩 0.73 | 🟩 0.39 | | | 🟩 0.50 | 🟩 0.54 |
| Belted | Rear | Amer Seat | 95th unbelt | 95th unbelt | 🟩 0.40 | 🟩 0.49 | | | 🟩 0.70 | 🟩 0.48 |
| | | 15 DEGREE BUCK ANGLE | | | | | | | | |
| | | | Left | Right | TEST 8 | | | | | |
| 8 | Front | Amaya | -- | -- | Test # 080729-1 | | | | | |
| Compartmentalization | Middle | Amer Seat | 5th unbelt | 50th unbelt | 🟩 0.79 | 🟩 0.61 | | | | |
| Current | Rear | Amer Seat | 5th unbelt | 50th unbelt | 🟩 0.75 | 🟩 0.43 | | | | |
| | | | | | TEST 9 | | | | | |
| 9 | Front | Amer Seat | -- | -- | Test # 080730-1 | | | | | |
| Compartmentalization | Middle | Amaya | 5th 3pt | 50th 3pt | 🟩 0.63 | 🟩 0.24 | | | | |
| Belted | Rear | Amer Seat | 5th unbelt | 50th unbelt | 🟩 0.67 | 🟨 0.89 | | | | |

▨ = The test condition was replicated in the crash test

| **Dummy size** | **Injury Assesment Reference Value (IARV)** |
|---|---|
| 5th Female | 1.00 |
| 50th Male | 1.00 |
| 95th Male | 1.00 |

🟩 < 80% of IARV
🟨 > 80% and < 100 % of IARV
🟥 > 100 % of IARV

## A.4 - Sled Test Chest G's



**CHEST INJURY VALUES**

**0 DEGREE BUCK ANGLE**

**Chest Accelereration (g)**

| TEST Type<br>Test Obsevation | ROW | SEAT | DUMMY LOCATIONS<br>Restraint | | 7G seats | | | | 10G seats | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | VRTC pulse | | EU pulse | | VRTC pulse | |
| | | | Left | Right | TEST 4 | | TEST 16 | | TEST 15 | |
| 1 | Front | Amer Seat | -- | -- | Test # 080721-1 | | Test # 080820-1 | | Test # 080819-1 | |
| Seat Forces | Middle | Amaya | 95th 3pt | 95th 3pt | 12.02 | 14.70 | 15.20 | 17.02 | 14.77 | 13.53 |
| Maximum | Rear | Amer Seat | 95th unbelt | 95th unbelt | | | | | | |
| | | | Left | Right | TEST 5 | | TEST 17 | | TEST 13 | |
| 2 | Front | Amer Seat | -- | -- | Test # 080722-1 | | Test # 080821-1 | | Test # 080815-2 | |
| Seat Forces | Middle | Amaya | 50th 3pt | 50th 3pt | 19.03 | 19.99 | 17.97 | 17.39 | 16.51 | 15.88 |
| Medium | Rear | Amer Seat | 50th unbelt | 50th unbelt | 18.84 | 15.50 | 16.13 | 16.46 | 21.57 | 15.93 |
| | | | Left | Right | TEST 3 | | TEST 18 | | | |
| 3 | Front | Amer Seat | -- | -- | Test # 080716-2 | | Test # 080821-2 | | | |
| Seat Forces | Middle | Amaya | 50th 3pt | 50th 3pt | 16.10 | 20.87 | 19.46 | 17.74 | | |
| Average | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 2 | | TEST 19 | | | |
| 4 | Front | Amer Seat | -- | -- | Test # 080716-1 | | Test # 080822-1 | | | |
| Seat Forces | Middle | Amaya | 50th 3pt | 5th 3pt | $15.73 | $15.30 | $19.90 | $18.21 | | |
| Minimum | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 1 | | TEST 20 | | | |
| 5 | Front | Amer Seat | -- | -- | Test # 080715-1 | | Test # 080822-2 | | | |
| Lap Belts | Middle | Amaya | 50th 2pt | 5th 2pt | 26.15 | 25.52 | 29.32 | 23.59 | | |
| | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 7 | | | | | |
| 6 | Front | Amer Seat | -- | -- | Test # 080724-2 | | | | | |
| Compartmentalization | Middle | Amer Seat | 95th unbelt | 95th unbelt | 15.63 | 8.45 | | | | |
| Current | Rear | Amer Seat | 5th unbelt | 5th unbelt | 25.68 | 23.60 | | | | |
| | | | Left | Right | TEST 6 | | | | | |
| 7 | Front | Amaya | -- | -- | Test # 080724-1 | | | | | |
| Compartmentalization | Middle | Amer Seat | 50th unbelt | 5th unbelt | 29.14 | 23.70 | | | | |
| Seat Effects | Rear | Amer Seat | 50th unbelt | 5th unbelt | 18.82 | 23.74 | | | | |
| | | | Left | Right | | | | | TEST 14 | |
| 7b | Front | Amaya 10G | -- | -- | | | | | Test # 080818-1 | |
| Compartmentalization | Middle | Amaya 7G | 50th unbelt | 5th unbelt | | | | | 30.17 | 24.34 |
| Seat Effects 10 G | Rear | Amer Seat | 50th unbelt | 5th unbelt | | | | | 23.62 | 22.49 |
| | | | | | TEST 12 | | | | | |
| 10 | Front | Amaya r | -- | -- | Test # 080815-1 | | | | | |
| Reclined | Middle | Amaya r | 5th 3pt | 50th 3pt | 22.28 | 12.83 | | | | |
| Belted | Rear | Amer Seat | 50th unbelt | 50th unbelt | 20.05 | 17.56 | | | | |
| | | | | | TEST 10 | | | | TEST 11 | |
| 11 | Front | Amaya | -- | -- | Test # 080813-1 | | | | Test # 080814-1 | |
| Max Rear Loading | Middle | Amaya | 5th 3pt | 50th 3pt | 17.02 | 14.82 | | | 16.26 | 16.37 |
| Belted | Rear | Amer Seat | 95th unbelt | 95th unbelt | 14.92 | 14.00 | | | 14.46 | 10.89 |
| | | 15 DEGREE BUCK ANGLE | | | | | | | | |
| | | | Left | Right | TEST 8 | | | | | |
| 8 | Front | Amaya | -- | -- | Test # 080729-1 | | | | | |
| Compartmentalization | Middle | Amer Seat | 5th unbelt | 50th unbelt | 21.70 | 28.36 | | | | |
| Current | Rear | Amer Seat | 5th unbelt | 50th unbelt | 23.60 | 18.99 | | | | |
| | | | | | TEST 9 | | | | | |
| 9 | Front | Amer Seat | -- | -- | Test # 080730-1 | | | | | |
| Compartmentalization | Middle | Amaya | 5th 3pt | 50th 3pt | 16.31 | 15.94 | | | | |
| Belted | Rear | Amer Seat | 5th unbelt | 50th unbelt | 14.31 | 20.87 | | | | |

🟩 = The test condition was replicated in the crash test

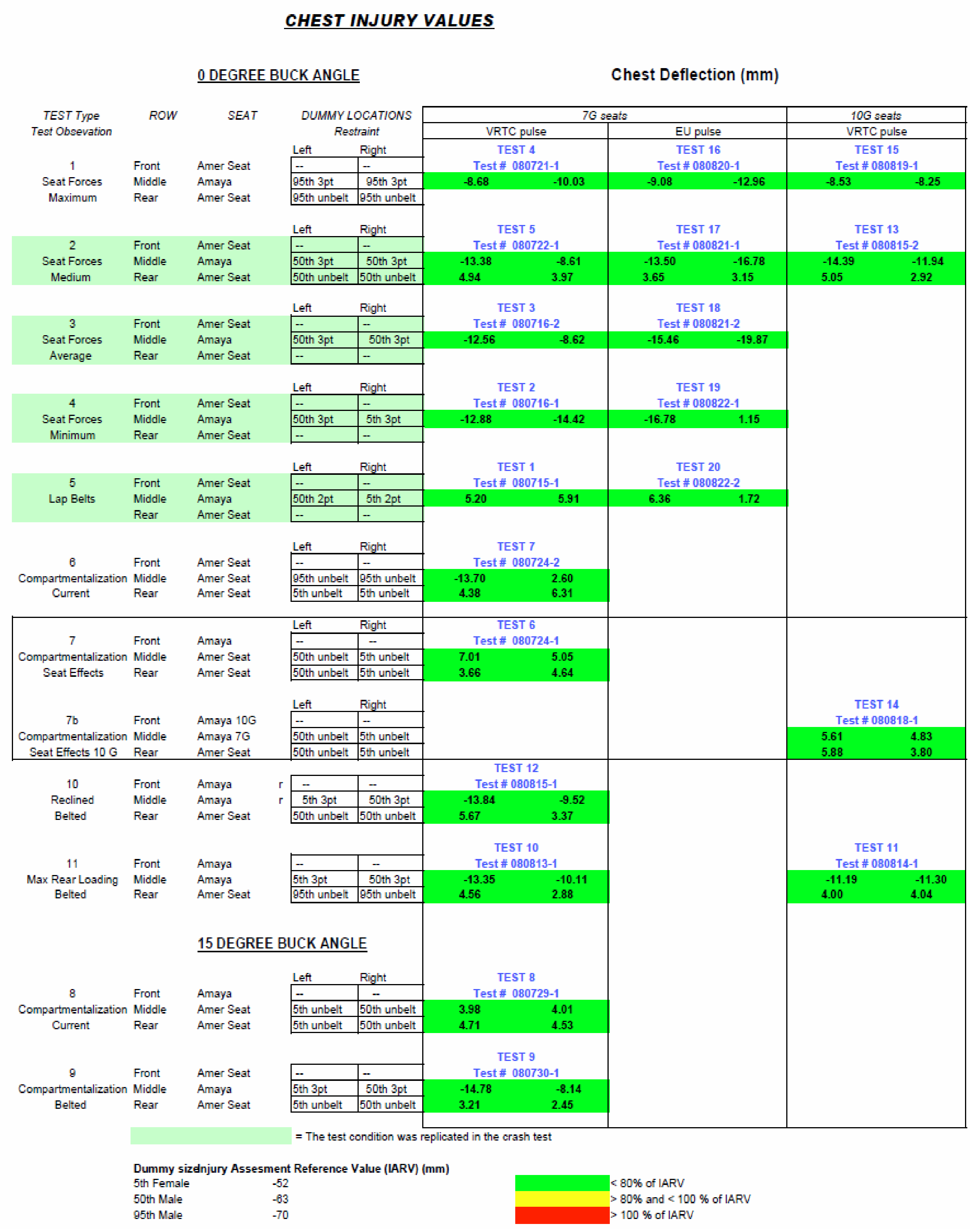
| Dummy sizdnjury Assesment Reference Value (IARV) (g) | |
|---|---|
| 5th Female | 60 |
| 50th Male | 60 |
| 95th Male | 55 |

🟩 < 80% of IARV

🟨 > 80% and < 100 % of IARV

🟥 > 100 % of IARV

# A.5 - Sled Test Chest Deflection



**CHEST INJURY VALUES**

**0 DEGREE BUCK ANGLE**

**Chest Deflection (mm)**

| TEST Type | ROW | SEAT | DUMMY LOCATIONS | | 7G seats | | | | 10G seats | |
|---|---|---|---|---|---|---|---|---|---|---|
| Test Obsevation | | | Restraint | | VRTC pulse | | EU pulse | | VRTC pulse | |
| | | | Left | Right | TEST 4 | | TEST 16 | | TEST 15 | |
| 1 | Front | Amer Seat | -- | -- | Test # 080721-1 | | Test # 080820-1 | | Test # 080819-1 | |
| Seat Forces | Middle | Amaya | 95th 3pt | 95th 3pt | -8.68 | -10.03 | -9.08 | -12.96 | -8.53 | -8.25 |
| Maximum | Rear | Amer Seat | 95th unbelt | 95th unbelt | | | | | | |
| | | | Left | Right | TEST 5 | | TEST 17 | | TEST 13 | |
| 2 | Front | Amer Seat | -- | -- | Test # 080722-1 | | Test # 080821-1 | | Test # 080815-2 | |
| Seat Forces | Middle | Amaya | 50th 3pt | 50th 3pt | -13.38 | -8.61 | -13.50 | -16.78 | -14.39 | -11.94 |
| Medium | Rear | Amer Seat | 50th unbelt | 50th unbelt | 4.94 | 3.97 | 3.65 | 3.15 | 5.05 | 2.92 |
| | | | Left | Right | TEST 3 | | TEST 18 | | | |
| 3 | Front | Amer Seat | -- | -- | Test # 080716-2 | | Test # 080821-2 | | | |
| Seat Forces | Middle | Amaya | 50th 3pt | 50th 3pt | -12.56 | -8.62 | -15.46 | -19.87 | | |
| Average | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 2 | | TEST 19 | | | |
| 4 | Front | Amer Seat | -- | -- | Test # 080716-1 | | Test # 080822-1 | | | |
| Seat Forces | Middle | Amaya | 50th 3pt | 5th 3pt | -12.88 | -14.42 | -16.78 | 1.15 | | |
| Minimum | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 1 | | TEST 20 | | | |
| 5 | Front | Amer Seat | -- | -- | Test # 080715-1 | | Test # 080822-2 | | | |
| Lap Belts | Middle | Amaya | 50th 2pt | 5th 2pt | 5.20 | 5.91 | 6.36 | 1.72 | | |
| | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 7 | | | | | |
| 6 | Front | Amer Seat | -- | -- | Test # 080724-2 | | | | | |
| Compartmentalization | Middle | Amer Seat | 95th unbelt | 95th unbelt | -13.70 | 2.60 | | | | |
| Current | Rear | Amer Seat | 5th unbelt | 5th unbelt | 4.38 | 6.31 | | | | |
| | | | Left | Right | TEST 6 | | | | | |
| 7 | Front | Amaya | -- | -- | Test # 080724-1 | | | | | |
| Compartmentalization | Middle | Amer Seat | 50th unbelt | 5th unbelt | 7.01 | 5.05 | | | | |
| Seat Effects | Rear | Amer Seat | 50th unbelt | 5th unbelt | 3.66 | 4.64 | | | | |
| | | | Left | Right | | | | | TEST 14 | |
| 7b | Front | Amaya 10G | -- | -- | | | | | Test # 080818-1 | |
| Compartmentalization | Middle | Amaya 7G | 50th unbelt | 5th unbelt | | | | | 5.61 | 4.83 |
| Seat Effects 10 G | Rear | Amer Seat | 50th unbelt | 5th unbelt | | | | | 5.88 | 3.80 |
| | | | | | TEST 12 | | | | | |
| 10 | Front | Amaya r | -- | -- | Test # 080815-1 | | | | | |
| Reclined | Middle | Amaya r | 5th 3pt | 50th 3pt | -13.84 | -9.52 | | | | |
| Belted | Rear | Amer Seat | 50th unbelt | 50th unbelt | 5.67 | 3.37 | | | | |
| | | | | | TEST 10 | | | | TEST 11 | |
| 11 | Front | Amaya | -- | -- | Test # 080813-1 | | | | Test # 080814-1 | |
| Max Rear Loading | Middle | Amaya | 5th 3pt | 50th 3pt | -13.35 | -10.11 | | | -11.19 | -11.30 |
| Belted | Rear | Amer Seat | 95th unbelt | 95th unbelt | 4.56 | 2.88 | | | 4.00 | 4.04 |

**15 DEGREE BUCK ANGLE**

| TEST Type | ROW | SEAT | DUMMY LOCATIONS | | 7G seats | | | | 10G seats | |
|---|---|---|---|---|---|---|---|---|---|---|
| Test Obsevation | | | Restraint | | VRTC pulse | | EU pulse | | VRTC pulse | |
| | | | Left | Right | TEST 8 | | | | | |
| 8 | Front | Amaya | -- | -- | Test # 080729-1 | | | | | |
| Compartmentalization | Middle | Amer Seat | 5th unbelt | 50th unbelt | 3.98 | 4.01 | | | | |
| Current | Rear | Amer Seat | 5th unbelt | 50th unbelt | 4.71 | 4.53 | | | | |
| | | | | | TEST 9 | | | | | |
| 9 | Front | Amer Seat | -- | -- | Test # 080730-1 | | | | | |
| Compartmentalization | Middle | Amaya | 5th 3pt | 50th 3pt | -14.78 | -8.14 | | | | |
| Belted | Rear | Amer Seat | 5th unbelt | 50th unbelt | 3.21 | 2.45 | | | | |

🟩 = The test condition was replicated in the crash test

**Dummy sizeInjury Assesment Reference Value (IARV) (mm)**

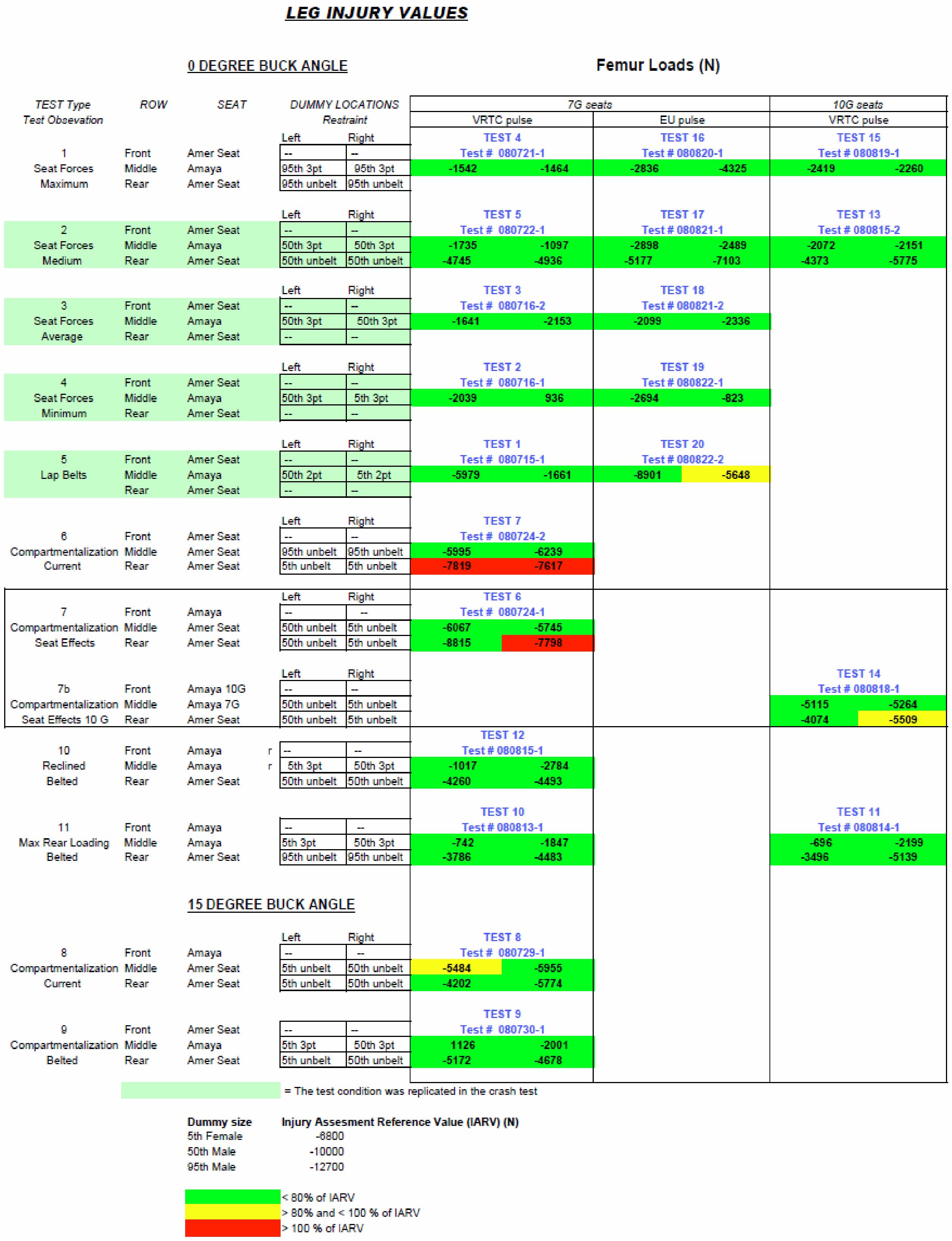
| | |
|---|---|
| 5th Female | -52 |
| 50th Male | -63 |
| 95th Male | -70 |

🟩 < 80% of IARV

🟨 > 80% and < 100 % of IARV

🟥 > 100 % of IARV

## A.6 - Sled Test Max Femur Loads



### LEG INJURY VALUES

0 DEGREE BUCK ANGLE

**Femur Loads (N)**

| TEST Type | ROW | SEAT | DUMMY LOCATIONS | | 7G seats | | | | 10G seats | |
|---|---|---|---|---|---|---|---|---|---|---|
| Test Obsevation | | | Restraint | | VRTC pulse | | EU pulse | | VRTC pulse | |
| | | | Left | Right | TEST 4 | | TEST 16 | | TEST 15 | |
| 1 | Front | Amer Seat | -- | -- | Test # 080721-1 | | Test # 080820-1 | | Test # 080819-1 | |
| Seat Forces | Middle | Amaya | 95th 3pt | 95th 3pt | -1542 | -1464 | -2836 | -4325 | -2419 | -2260 |
| Maximum | Rear | Amer Seat | 95th unbelt | 95th unbelt | | | | | | |
| | | | Left | Right | TEST 5 | | TEST 17 | | TEST 13 | |
| 2 | Front | Amer Seat | -- | -- | Test # 080722-1 | | Test # 080821-1 | | Test # 080815-2 | |
| Seat Forces | Middle | Amaya | 50th 3pt | 50th 3pt | -1735 | -1097 | -2898 | -2489 | -2072 | -2151 |
| Medium | Rear | Amer Seat | 50th unbelt | 50th unbelt | -4745 | -4936 | -5177 | -7103 | -4373 | -5775 |
| | | | Left | Right | TEST 3 | | TEST 18 | | | |
| 3 | Front | Amer Seat | -- | -- | Test # 080716-2 | | Test # 080821-2 | | | |
| Seat Forces | Middle | Amaya | 50th 3pt | 50th 3pt | -1641 | -2153 | -2099 | -2336 | | |
| Average | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 2 | | TEST 19 | | | |
| 4 | Front | Amer Seat | -- | -- | Test # 080716-1 | | Test # 080822-1 | | | |
| Seat Forces | Middle | Amaya | 50th 3pt | 5th 3pt | -2039 | 936 | -2694 | -823 | | |
| Minimum | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 1 | | TEST 20 | | | |
| 5 | Front | Amer Seat | -- | -- | Test # 080715-1 | | Test # 080822-2 | | | |
| Lap Belts | Middle | Amaya | 50th 2pt | 5th 2pt | -5979 | -1661 | -8901 | -5648 | | |
| | Rear | Amer Seat | -- | -- | | | | | | |
| | | | Left | Right | TEST 7 | | | | | |
| 6 | Front | Amer Seat | -- | -- | Test # 080724-2 | | | | | |
| Compartmentalization | Middle | Amer Seat | 95th unbelt | 95th unbelt | -5995 | -6239 | | | | |
| Current | Rear | Amer Seat | 5th unbelt | 5th unbelt | -7819 | -7617 | | | | |
| | | | Left | Right | TEST 6 | | | | | |
| 7 | Front | Amaya | -- | -- | Test # 080724-1 | | | | | |
| Compartmentalization | Middle | Amer Seat | 50th unbelt | 5th unbelt | -6067 | -5745 | | | | |
| Seat Effects | Rear | Amer Seat | 50th unbelt | 5th unbelt | -8815 | -7798 | | | | |
| | | | Left | Right | | | | | TEST 14 | |
| 7b | Front | Amaya 10G | -- | -- | | | | | Test # 080818-1 | |
| Compartmentalization | Middle | Amaya 7G | 50th unbelt | 5th unbelt | | | | | -5115 | -5264 |
| Seat Effects 10 G | Rear | Amer Seat | 50th unbelt | 5th unbelt | | | | | -4074 | -5509 |
| | | | | | TEST 12 | | | | | |
| 10 | Front | Amaya r | -- | -- | Test # 080815-1 | | | | | |
| Reclined | Middle | Amaya r | 5th 3pt | 50th 3pt | -1017 | -2784 | | | | |
| Belted | Rear | Amer Seat | 50th unbelt | 50th unbelt | -4260 | -4493 | | | | |
| | | | | | TEST 10 | | | | TEST 11 | |
| 11 | Front | Amaya | -- | -- | Test # 080813-1 | | | | Test # 080814-1 | |
| Max Rear Loading | Middle | Amaya | 5th 3pt | 50th 3pt | -742 | -1847 | | | -696 | -2199 |
| Belted | Rear | Amer Seat | 95th unbelt | 95th unbelt | -3786 | -4483 | | | -3496 | -5139 |
| | | 15 DEGREE BUCK ANGLE | | | | | | | | |
| | | | Left | Right | TEST 8 | | | | | |
| 8 | Front | Amaya | -- | -- | Test # 080729-1 | | | | | |
| Compartmentalization | Middle | Amer Seat | 5th unbelt | 50th unbelt | -5484 | -5955 | | | | |
| Current | Rear | Amer Seat | 5th unbelt | 50th unbelt | -4202 | -5774 | | | | |
| | | | | | TEST 9 | | | | | |
| 9 | Front | Amer Seat | -- | -- | Test # 080730-1 | | | | | |
| Compartmentalization | Middle | Amaya | 5th 3pt | 50th 3pt | 1126 | -2001 | | | | |
| Belted | Rear | Amer Seat | 5th unbelt | 50th unbelt | -5172 | -4678 | | | | |

▨ = The test condition was replicated in the crash test

| Dummy size | Injury Assesment Reference Value (IARV) (N) |
|---|---|
| 5th Female | -6800 |
| 50th Male | -10000 |
| 95th Male | -12700 |

🟩 < 80% of IARV

🟨 > 80% and < 100 % of IARV

🟥 > 100 % of IARV

## A.7 - Seat Anchor Load Cell Peak Loads

**Peak Force Values at Seat Anchor Locations (N)**

| | Seat-to-floor | | | | | | | | Seat to side | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Front | | | | Rear | | | | Front | | | | Rear | | | |
| Test # | X | Y | Z | Resultant | X | Y | Z | Resultant | X | Y | Z | Resultant | X | Y | Z | Resultant |
| 1 | 8096 | -675 | 8600 | 11806 | 3204 | 571 | -11099 | 11143 | 5038 | -1694 | -8835 | 10180 | 2571 | -2306 | -8311 | 8889 |
| 2 | 11375 | -1716 | 13397 | 17619 | 1830 | 1820 | -13354 | 13518 | 10681 | -6467 | -11856 | 16802 | -3661 | -6650 | -12078 | 13766 |
| 3 | 12877 | -2119 | 17280 | 21538 | 2420 | 1117 | -15762 | 15815 | -6929 | -7301 | -9341 | 12434 | 8774 | -7301 | -10044 | 13489 |
| 4 | 17339 | -1050 | 23490 | 29151 | 6451 | -1053 | -22789 | 23654 | 12113 | -7765 | -13558 | 19573 | 7321 | -9947 | -14687 | 17628 |
| 5 | 15663 | -1846 | 23278 | 27801 | 6859 | 890 | -21886 | 22902 | 9749 | -7066 | -13246 | 17213 | 10761 | -8525 | -13212 | 18744 |
| 6 | 15879 | -538 | 13258 | 20687 | -3257 | -1033 | -9691 | 9775 | 6531 | -6121 | -8677 | 11033 | 8146 | -5542 | -7386 | 11474 |
| 7 | 16288 | 369 | 12602 | 20587 | -2657 | -1897 | -7978 | 8154 | 6122 | -4853 | -7231 | 10088 | 7569 | -5145 | -7299 | 11241 |
| 8 | 7529 | 1967 | 11897 | 14161 | 4541 | -3395 | -9383 | 10747 | 3663 | -4071 | -5100 | 5838 | 4803 | -5815 | -6320 | 8998 |
| 9 | 7994 | -1871 | 32652 | 33622 | 14889 | 834 | -24967 | 29069 | 12006 | -6217 | -14403 | 17580 | 7682 | -8730 | -19277 | 22326 |
| 10 | 11794 | -1536 | 27957 | 29469 | 11933 | 876 | -24885 | 27600 | 17460 | -6717 | -15418 | 23222 | 3556 | -8057 | -14952 | 16463 |
| 11 | 15212 | -1376 | 25532 | 29662 | 6803 | 1655 | -22711 | 23549 | 13601 | -7660 | -13577 | 19729 | 11159 | -11596 | -13514 | 17350 |
| 12 | 15601 | -1870 | 22642 | 26454 | 3857 | 1188 | -17823 | 17909 | 8615 | -8029 | -15004 | 17234 | 12532 | -8263 | -15493 | 21248 |
| 13 | 19121 | -925 | 28026 | 33849 | 7472 | -1106 | -24740 | 25862 | 15764 | -6996 | -14124 | 21928 | 6933 | -10969 | -14412 | 18048 |
| 14 | 12409 | 1311 | 18614 | 22366 | 3563 | 2122 | -16492 | 16701 | 10594 | -3725 | -11191 | 14807 | 5228 | -5274 | -12348 | 13535 |
| 15 | 13768 | -7230 | 15241 | 21371 | 10927 | 9955 | -16106 | 18373 | 13681 | -1322 | -25965 | 29078 | 10511 | -2717 | -25164 | 27265 |
| 16 | 18657 | -8387 | 17680 | 25635 | 10716 | 12353 | -16305 | 20982 | 17760 | -1323 | -31432 | 34749 | 9209 | -2191 | -113500 | 113588 |
| 17 | 16667 | 1122 | 31005 | 35208 | 10249 | 1871 | -26105 | 27942 | 13156 | -7416 | -13608 | 19685 | 11705 | -9835 | -14072 | 18224 |
| 18 | 16461 | -2353 | 19408 | 24878 | -3345 | 1506 | -19005 | 19010 | -7946 | -7011 | -11329 | 14092 | 7458 | -7608 | -11696 | 15139 |
| 19 | 14883 | -2148 | 17664 | 23027 | -3242 | 1568 | -16684 | 16688 | -8962 | -6956 | -12346 | 14248 | 9950 | -6249 | -12538 | 15787 |
| 20 | 9334 | -970 | 7797 | 12140 | 2290 | 831 | -11460 | 11609 | 3925 | -2369 | -8625 | 9575 | 2452 | -2143 | -7321 | 7876 |
| | | | | | | | | | | | | | | | | |

**Polarities:**

| | |
|---|---|
| X | positive forward |
| Y | positive to the right |
| Z | positive downwards |

🟥 exceeded full-scale

All measurements in Newtons

**DOT HS 811 335**
**May 2010**

U.S. Department
of Transportation

**National Highway
Traffic Safety
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