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Evaluation of the WorldSID 50th Percentile Male Side Impact Dummy

Qualification and Sled Test Repeatability and Reproducibility

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16. Abstract

This report summarizes NHTSA's evaluation of repeatability and reproducibility of the Worldwide harmonized Side Impact Dummy (WorldSID) 50th percentile adult male dummy in qualification and sled test environments. Based on the results presented in this document, NHTSA finds that the WorldSID 50th male test dummy exhibits an acceptable level of repeatability and reproducibility for use in regulatory testing.

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1 Executive Summary

This report summarizes NHTSA's evaluation of repeatability and reproducibility (R&R) of the Worldwide harmonized Side Impact Dummy (WorldSID) 50th percentile adult male dummy in qualification and sled test environments.

Any anthropomorphic test device (ATD or dummy) that is to be used in regulatory testing or rating programs must first demonstrate an acceptable level of repeatability and reproducibility. For this study, NHTSA conducted a quantitative analysis of variations in the dummy responses to known, controlled inputs to assess the dummy's level of R&R.

Qualification tests were performed using the draft procedures specified in NHTSA's document, *WorldSID 50th Percentile Male Qualification Procedures Manual.* Multiple tests were performed by NHTSA Vehicle Research and Test Center (VRTC) on multiple dummies. NHTSA also contracted with several independent testing labs to perform additional qualification tests to assess lab-to-lab differences in dummy responses. The test conditions included: head drops, neck pendulum tests, shoulder impacts, thorax (with and without arm) impacts, abdomen impacts, and pelvis impacts. Select sled test conditions were also used for the R&R assessment. Average, standard deviation, and coefficient of variation (CV) were calculated for each required measurement parameter of each test condition.

The results of the qualification test statistical analysis generally showed CV values less than 5 percent for the parameters examined with a few exceptions noted. In cases when CV values exceeded 5 percent, the result could generally be attributed to one of the dummies exhibiting a response that, although repeatable, was marginally different than that displayed by the other dummies. Qualification test response corridors were generated based on the results observed in the qualification R&R assessment.

Sled tests, by nature, are more complex than qualification tests and they introduce more sources of test variation. Despite these additional sources of variation, the dummies generally exhibited CV values less than 5 percent in the sled test conditions. Measurements that exhibited CV values greater than 5 percent were examined further to understand the possible sources of variation.

Based on the results presented in this document, NHTSA finds that the WorldSID 50th percentile male ATD exhibits an acceptable level of R&R for use in regulatory testing.

2 Objective

The objective of this project is to evaluate the WorldSID 50th percentile male side impact dummy for potential use in NHTSA regulatory or rating programs initiatives. This report includes the results of evaluating the R&R of the WorldSID dummy using qualification test procedures and several sled test conditions.

3 Background

In 2005, in cooperation with the WorldSID 50th International Organization for Standardization (ISO) Task Group and using two dummies on loan from the Occupant Safety Research Partnership (OSRP), VRTC began an evaluation of the WorldSID 50th percentile male side impact dummy. VRTC was notified that both of the dummies had been previously used in a number of evaluation programs, but a detailed use history was not provided. Findings made during VRTC's initial series of tests resulted in the implementation of several design modifications.

One modification was made to the design of the rib damping material. The original ribs used a black damping material similar to that used for rib damping in HIII frontal dummies. This material proved to have inadequate durability as it developed cracks and began to delaminate from the metal rib bands after only a few impacts, as shown in Figure 3-1. Ribs with a new blue damping material were developed by First Technology Safety Systems (FTSS) and provided to VRTC for evaluation. The new rib damping material exhibited improved durability but still had a problem of developing cracks in the stepped area provided for the rib mounting clips at the end of the damping material, as shown in Figure 3-2. A modified design removed the stepped area and tapered the ends of the damping material, as shown in Figure 3-3. The blue rib damping material and configuration exhibited adequate durability and was used for all testing in this R&R evaluation.

Figure 3-1. Original rib damping material

Figure 3-2. Initial design with blue damping material

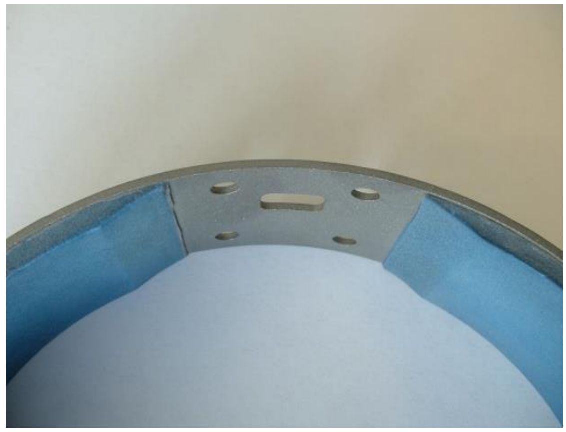

Figure 3-3. Modified blue damping material with tapered ends

A second design modification was in the pelvis data acquisition system (DAS) docking station. During the initial high-speed Heidelberg Rigid Wall sled test, it was discovered that the impact-side pelvis bone was deflecting far enough to make contact with the pelvis DAS docking station (see Figure 3-4). The pelvis DAS docking station was removed from the pelvis and replaced with a mass/structural replacement having a similar bolt pattern, but with recessed corners, providing more space for pelvis bone deflection (see Figure 3-5). If additional data channels are required for research purposes, beyond the 64 channels provided by the DAS located within the spine assembly, additional space for DAS is available in the left and right upper leg flesh. The revised pelvis design was used throughout the remainder of the sled tests and qualification tests cited in this report.

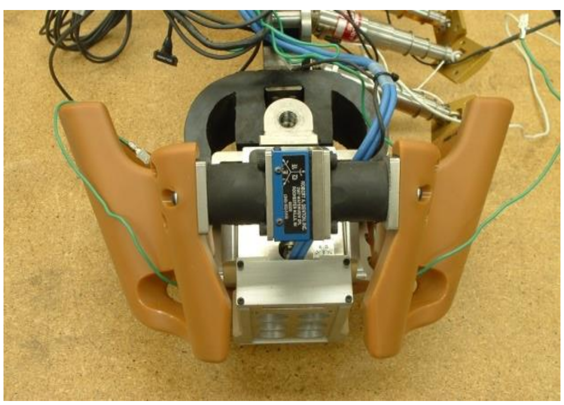

Figure 3-4. Original pelvis with DAS docking station

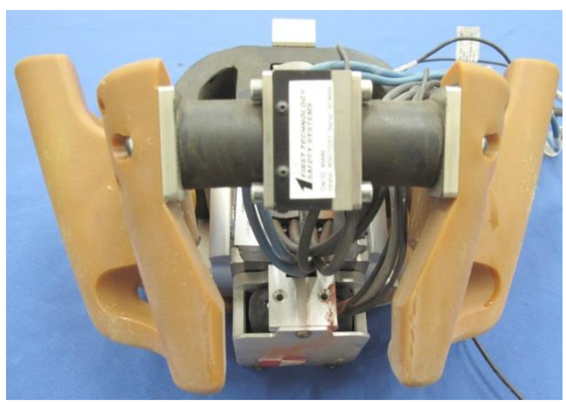

Figure 3-5. Modified pelvis with DAS mass/structural replacement

The original design for the WorldSID 50th male dummy measured upper torso rib displacements using a device known as the IR-TRACC (InfraRed -Telescoping Rod for Assessment of Chest Compression). During NHTSA's evaluation of the WorldSID it was determined that the IR-TRACC was adequate for measuring deflection at the point where it is attached to the rib. However, if the impact location is at some other point along the rib, then the IR-TRACC may not capture the full amount of rib deflection that occurs. Therefore, NHTSA initiated an extensive research and development project to assess the RibEye measurement system. RibEye is an optical system which can measure 3-dimensional (x-, y-, and z-coordinates) displacements at multiple, discrete locations on each rib. It provides an enhanced ability to determine the maximum rib compression toward the spine which is necessary for assessing injury potential. Details of the agency's efforts to evaluate and incorporate the system can be found in NHTSA's reports *Evaluation of RibEye Installed in the WorldSID 50th Percentile Dummy* and *Development of Optimal RibEye LED Locations in the WorldSID 50th Percentile Male Dummy* (Rhule et al., 2019).

The RibEye system was installed in dummies for the qualification testing discussed in this report, however the sled testing described herein was conducted prior to NHTSA's research on the RibEye system and therefore was conducted using IR-TRACC instrumentation. Sled tests were not repeated with the RibEye system since the loading imparted by the sled wall was primarily in the lateral direction and the IR-TRACCs should provide accurate responses for this loading path. However, subsequent crash testing conducted with the RibEye-equipped dummy led to another revision. Post-test dummy inspections revealed that the dummy's shoulder pad had become lodged into the shoulder rib cavity, effectively blocking the RibEye's shoulder-mounted sensors (see Figure 3-6). This observation led to the NHTSA's development of a new shoulder pad configuration designed to minimize the likelihood of the pads blocking the RibEye sensors (see Figure 3-7). The new shoulder pads feature internal stiffening elements designed to resist vertical forces. Additionally, the right- and left-side shoulder pads are connected via a Delrin segment that provides additional resistance to forces that could push the pad into the shoulder rib cavity. Shoulder impact qualification tests were conducted with the original and revised shoulder pad configurations to assess if the dummy's response had changed due to the new shoulder pad configuration. The changes in qualification responses attributed to the new shoulder pad were less than the test-to-test variations that were observed across multiple dummies at multiple labs in the R&R study. Therefore, it was determined that the effect of the new shoulder pad on the dummy's responses was not significant. The new shoulder pad configuration was used in the shoulder, thorax and abdomen qualification tests cited in this report; however, sled tests for this evaluation were conducted prior to development of the new shoulder pad and were therefore conducted with the original shoulder pad design.

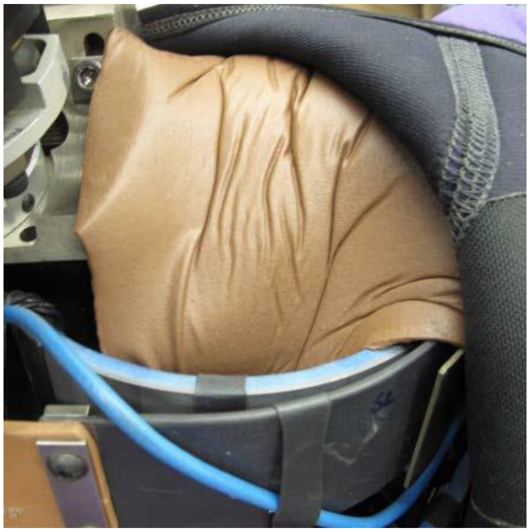

Figure 3-6. Shoulder Pad Lodged Into Shoulder Rib Cavity

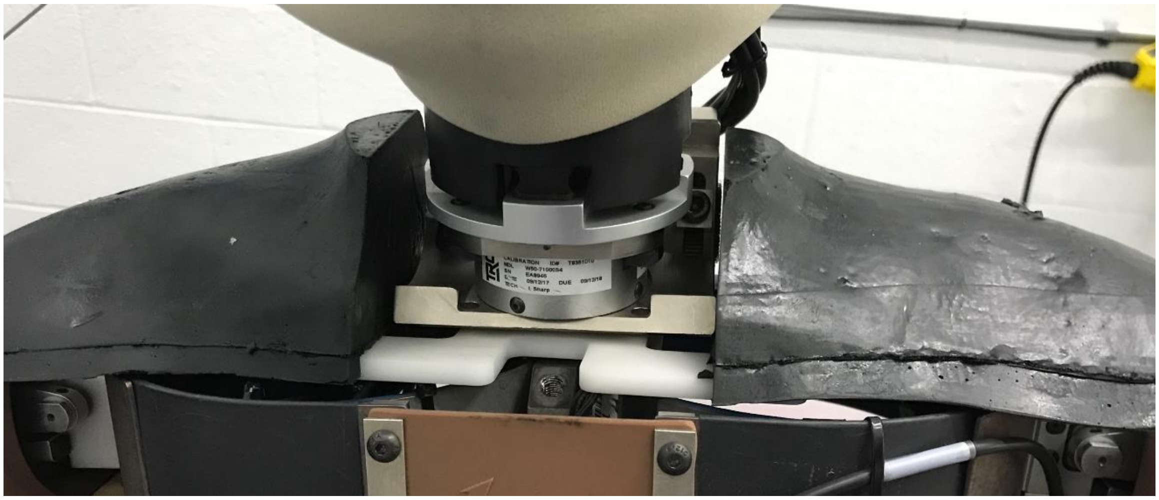

Figure 3-7. Revised Shoulder Pad Assembly

Another modification was required for the dummy's thorax pad. The original design utilized a one-piece thorax pad spanning the lateral aspect of the thorax from the top of thorax rib 1 to the bottom of abdomen rib 2. The one-piece thorax pad contained multiple holes to accommodate Velcro straps which connected the pad to the dummy's ribs (see Figure 3-8). Tears in the thorax pad were commonly observed either extending from the holes, between adjacent ribs, or along the edge of a rib, such as that illustrated in Figure 3-9.

Figure 3-8. Original One-Piece Thorax Pad

Figure 3-9. Typical Damage Observed in One-Piece Thorax Pad

As a result of these observations, a new thorax pad configuration was introduced which utilized individual pads corresponding to each individual rib (see Figure 3-10). The pads are attached to each rib by means of Velcro strips along the front and back of each pad (see Figure 3-11). The split pad configuration eliminates the sources of tear initiation that were present in the one-piece thorax pad. Thorax and abdomen qualification tests were conducted with both the one-piece and split thorax pad configurations to assess any changes in the dummy's response. The changes in qualification responses attributed to the split thorax pad were roughly equivalent to the test-to-test variations that were observed across multiple dummies at multiple labs in this R&R study. Therefore, it was determined that the effect of the split thorax pad on the dummy's responses was not significant. The split pad configuration was utilized in the qualification tests cited in this study; however, sled tests were performed prior to implementation of the split pad and therefore were conducted with the one-piece pad.

Figure 3-10. Split Thorax Pad Configuration

Figure 3-11. Velcro strips attach the individual pads to the corresponding ribs

The final design revision involved the dummy’s skinsuit. The original skinsuit included sleeves for the arms and contained a sizeable hole under the arm to facilitate arm motion (see Figure 3-12). In this configuration, the sleeve fabric could bunch together during shoulder flexion and the hole provided a path for external light to enter the thoracic cavity, potentially interfering with the RibEye functionality. Therefore, a sleeveless skinsuit design was adopted (Figure 3-13). The sleeveless suit provides improved freedom of arm motion without bunching and eliminates the potential light path under the arm. Qualification tests in this study utilized the sleeveless skinsuit while sled tests were performed prior to this development and were therefore conducted with the original skinsuit.

Figure 3-12. Sleeved Suit - hole under arm (left) and fabric bunching during shoulder flexion (right)

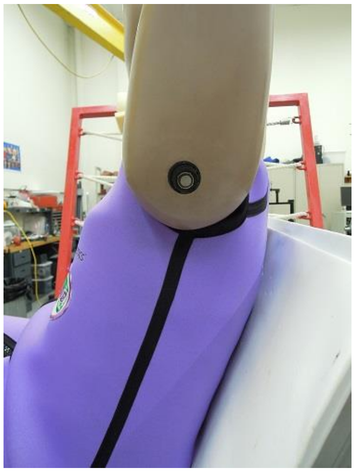

Figure 3-13. Sleeveless suit eliminates hole under arm

4 Methods

Repeatability is defined as the similarity of responses from a single dummy when subjected to multiple repeats of a given test condition. Reproducibility is defined as the similarity of test responses from multiple dummies when subjected to multiple repeats of a given test condition. A quantitative assessment of R&R is achieved by evaluating the coefficient of variation for each measured response. The coefficient of variation (CV) is a measure of variability expressed as a percentage of the mean. CV is calculated as follows:

$$CV(\%) = \frac{\sigma}{\overline{X}} \times 100$$

where σ = standard deviation of responses

$\overline{X}$ = mean of responses

CV results were assessed using the criteria shown in Table 4.1.1.

Table 4.1.1. CV Scores Assessment

Data Assessment	Action
$CV \leq 5$ AND all trials within ± 10% of mean	No further investigation
$5 < CV \leq 10$ OR Some trials outside ± 10% of mean	Sources of variability investigated
$CV > 10$	Test procedures thoroughly reviewed and dummies inspected

To make the interpretation of the results within this report easier, the summary tables that follow will use the color code convention as demonstrated in Table 4.1.1 for CV assessment: green for CVs less than 5, yellow for CVs between 5 and 10, and red for CVs greater than 10.

4.1 Qualification Corridors

Dummies used in NHTSA regulatory testing or rating programs are subjected to a series of qualification tests in order to ensure that their components are functioning properly. The qualification tests are typically conducted before and after a vehicle crash test to support the validity of the test results and generally evaluate the dummy's components that have important consequences in those crash tests.

Typically, by the time NHTSA begins to evaluate a dummy for use in a regulatory or rating program, a preliminary set of qualification tests and response requirements have been developed. For the WorldSID-50M, preliminary qualification test procedures and response corridors have been proposed by the ISO in its document *Design and Performance Specifications for the WorldSID 50th Percentile Male Side Impact Dummy* (ISO, 2018). Using the ISO document as a starting point, NHTSA has developed and documented its own set of procedures and response corridors in the *WorldSID 50th Percentile Male Qualification Procedures Manual.* In general, the ISO-proposed procedures and response corridors have been adopted. There are, however, a few exceptions where NHTSA either added requirements to assess additional measurements or adjusted the response corridors to reflect the results of the R&R testing.

The NHTSA response requirements were determined by analyzing the NHTSA R&R results as follows:

1) Determine the range of the NHTSA R&R testing as the smaller of two ranges:
    a. the mean plus or minus two standard deviations
    b. the mean plus or minus 10 percent of the mean
2) Compare the range of the NHTSA R&R data to the ISO-recommended corridors
    a. If the NHTSA range is within the ISO-recommended corridors, then the ISO corridors are adopted.
    b. If the NHTSA lower- or upper-boundary value exceeds the ISO-recommended corridors, the ISO corridors are adjusted accordingly while maintaining the magnitude of the ISO range.

NHTSA has also included a test procedure and response corridors for a new test (i.e., not included in the ISO-proposed procedures): the neck torsion test. NHTSA has observed in sled and crash tests that the dummy's neck rarely exhibits pure lateral bending, rather the motion is typically a combination of lateral bending and neck torsion (neck twist about the dummy's z-axis). Thus, we felt it necessary to assess the torsion response of the dummy's neck. Additionally, NHTSA has deviated from the ISO-proposed qualification requirements for lateral neck bending. ISO proposed criteria on the peak values and the time at which those peak values occurred for the forward and rearward potentiometers used in the lateral neck qualification test. However, typical responses in NHTSA tests contained multiple peaks of similar magnitude, making it difficult to achieve a repeatable response for the time of the peak response. NHTSA believes that the most important response in this test is the headform flexion angle and therefore has decided to eliminate the forward and rearward potentiometer criteria. Additionally, NHTSA has proposed a requirement on the headform's angular velocity response. NHTSA believes that there is a reasonable probability that a brain injury criterion, such as BrIC, could be a component of future crash test injury criteria and head angular velocity is a necessary component of many brain injury criteria.

Where NHTSA has introduced a new test condition or a new response criterion for an already existing test condition, we have chosen to set the response requirements using the mean +/- 10 percent of the mean from the NHTSA R&R testing. In all such cases, the mean +/-10 percent of the mean was greater than the mean plus or minus two standard deviations. Thus, this approach acknowledges that the NHTSA R&R data set is a relatively small sample size of data and that a wider response corridor is needed to better represent the larger population of dummies in use.

In Section 5, the ISO response corridors and NHTSA response requirements are both presented.

4.2 Qualification Test Repeatability and Reproducibility

Qualification tests were performed using the procedures specified in NHTSA's document, *WorldSID 50th Percentile Male Qualification Procedures Manual*. That document should be referenced for details about the test equipment, dummy configuration and positioning, required instrumentation, etc. In order to evaluate R&R of the WorldSID 50th, multiple qualification tests were performed on several dummies at multiple labs. For head drop tests, right- and left-side head drop tests, as well as frontal head drop tests, were conducted on five dummy heads. Lateral and torsion neck pendulum tests were conducted on right- and left-side configurations of four dummy neck assemblies. For the shoulder, thorax (with and without arm), and abdomen tests, three dummies were configured with a RibEye system, revised shoulder pads, split thorax pads, and the sleeveless suit. Due to time constraints, these tests were conducted only on the dummy's left side. Pelvis tests were conducted on four dummies.

Average, standard deviation, and coefficient of variation were calculated for each required measurement parameter of each qualification procedure. Qualification tests were conducted at the VRTC ATD calibration lab and four independent test labs.

4.3 Sled Test Repeatability and Reproducibility

The WorldSID dummy biofidelity evaluation required sled testing using several test protocols. More information on the biofidelity evaluation can be found in *Comparison of WorldSID and ES-2RE Biofidelity Using an Updated Biofidelity Ranking System* (Rhule, et al, 2009). Since several of the test configurations were repeated multiple times with two WorldSID dummies, this data is also being used for the R&R evaluation. Repeat tests were performed using the following protocols.

- NHTSA 6.7 m/s Rigid Flat Wall (Maltese et al., 2002)
- NHTSA 6.7 m/s Padded Flat Wall (Maltese et al., 2002)
- Heidelberg 6.8 m/s Rigid Flat Wall (ISO/TR 9790, 1999)
- Wayne State 6.8 m/s Rigid Wall (ISO/TR 9790, 1999)

All of the tests were performed using 2 WorldSID dummies simultaneously on VRTC's two-occupant side impact sled buck. The dummies were equipped with the updated ribs (blue damping material) and pelvis assemblies described in Section 3. However, the sled testing was conducted prior to NHTSA's research on the RibEye system and therefore torso rib deflections were measured using the IR-TRACC instrumentation. Since the dummy loading in these sled tests was primarily in the lateral direction, the IR-TRACCs should provide accurate responses for this loading path. Furthermore, the sled tests were conducted prior to the revisions made to the shoulder pad, thorax pads, and skinsuit. NHTSA component testing indicated that these changes did not produce significant differences in the dummy's responses. Finally, the shoulder IR-TRACCs were removed from the dummies to eliminate the possibility of damage to the instruments.

4.3.1 NHTSA 6.7 m/s Rigid and Padded Flat Wall

A drawing of the seat/load wall configuration for the NHTSA rigid and padded flat wall sled tests is shown in Figure 4-1. NHTSA sled buck load plate configuration. Photographs showing examples of the 6.7 m/s rigid and padded flat wall sled test set-ups are shown in Figure 4-2 and Figure 4-3, respectively. For the padded tests each load wall segment was covered with 4 inches of ETHAFOAM Select padding having a density of 28.8 kg/m^3 (also known as ETHAFOAM 180). Foam padding was replaced after every test with new padding for subsequent tests. Example sled pulses used for the NHTSA 6.7 m/s rigid and padded wall sled test are shown in Figure 4-4.

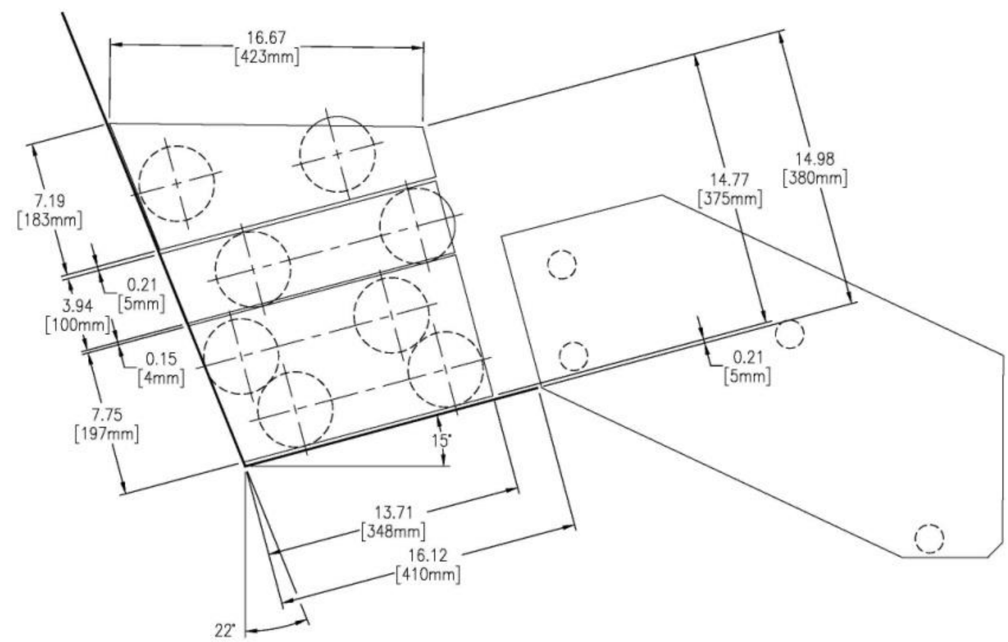

Figure 4-1. NHTSA sled buck load plate configuration

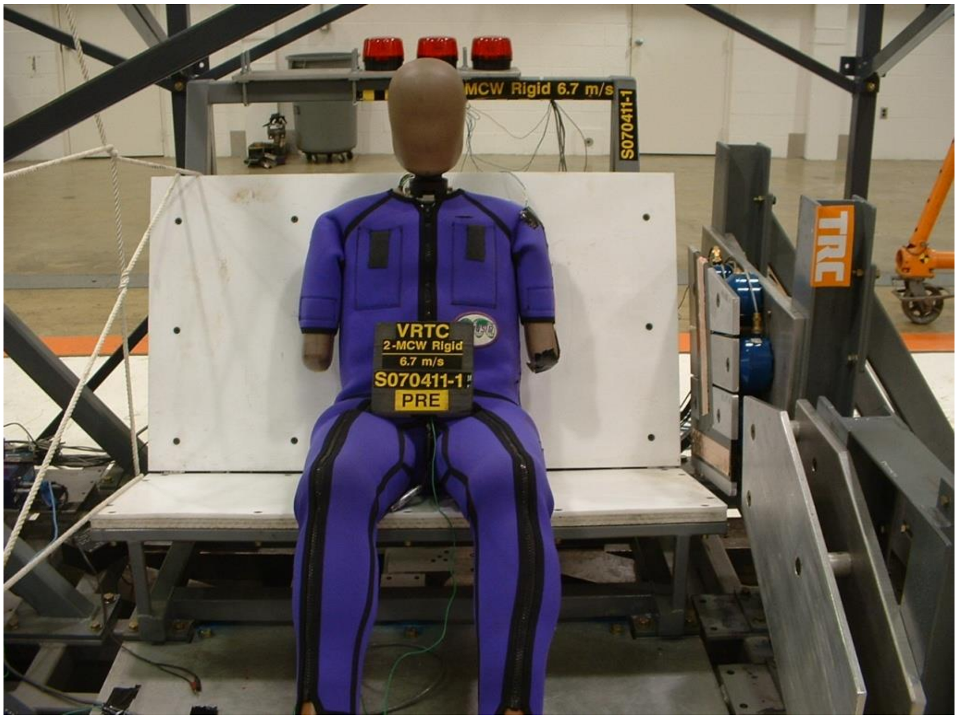

Figure 4-2. NHTSA 6.7 m/s rigid flat wall test

Figure 4-3. NHTSA 6.7 m/s padded flat wall test

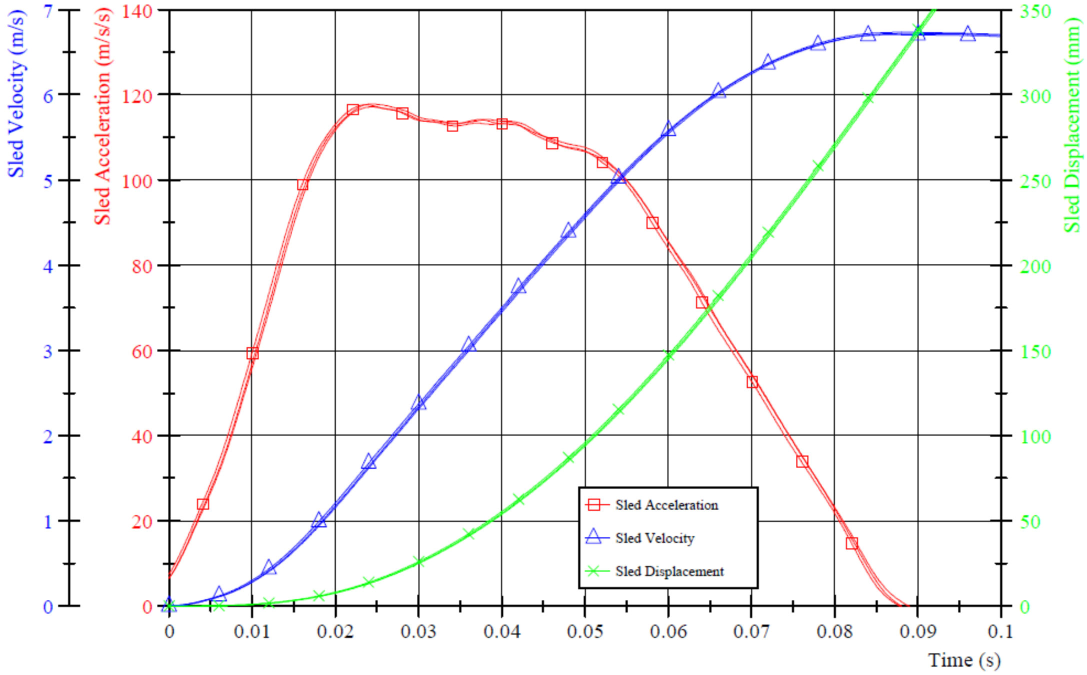

Figure 4-4. Example sled pulse from NHTSA 6.7 m/s flat wall tests

4.3.2 Heidelberg 6.8 m/s Rigid Wall

A drawing of the seat/load wall configuration for the Heidelberg rigid flat wall sled tests is shown in Figure 4-5. A photograph showing an example of the Heidelberg 6.8 m/s rigid flat wall sled test set-up is shown in Figure 4-6. The sled pulses for the Heidelberg tests are shown in Figure 4-7.

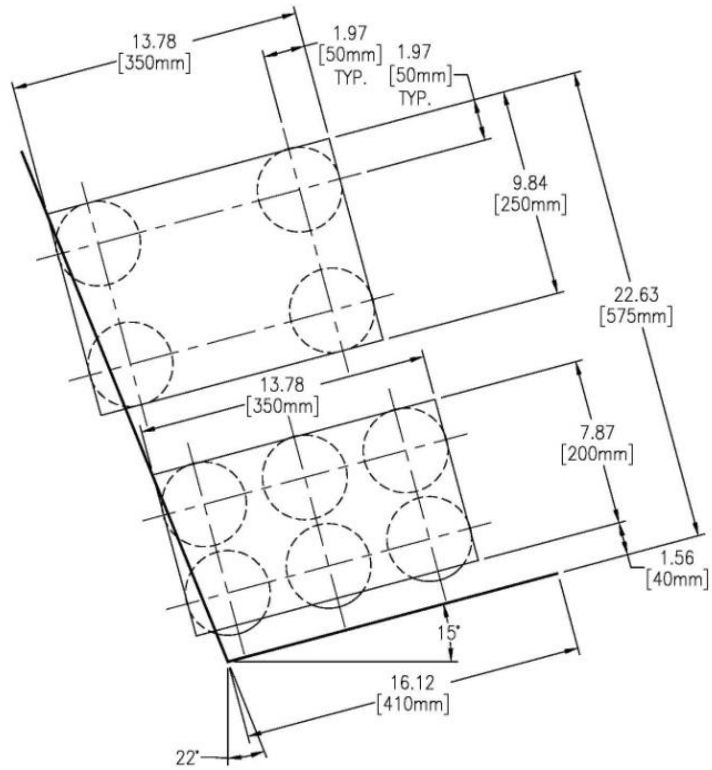

Figure 4-5. Heidelberg sled buck load plate configuration

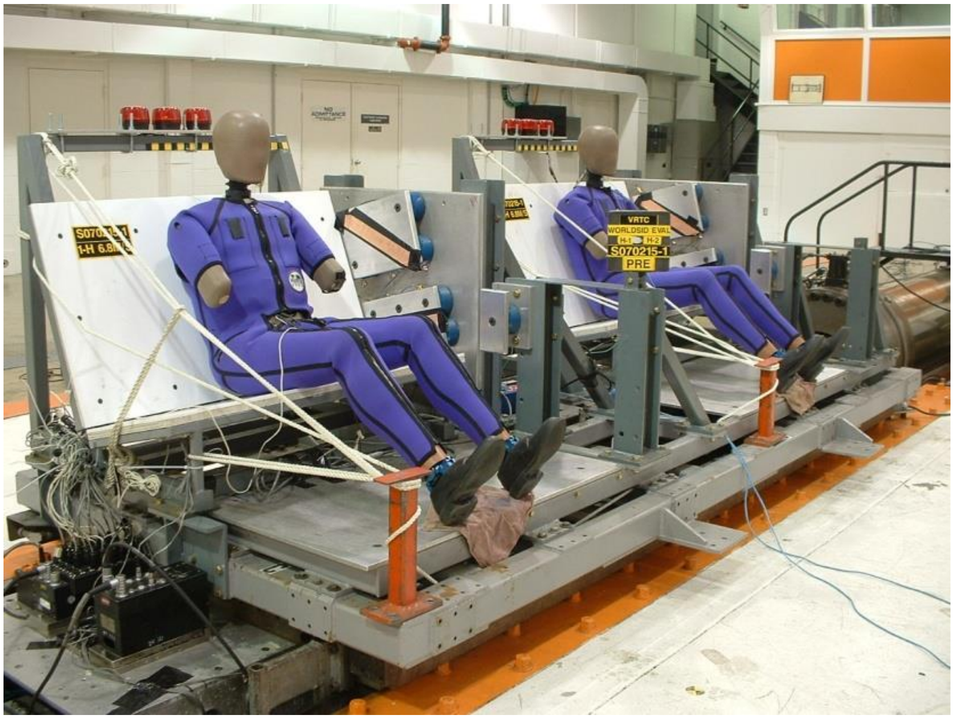

Figure 4-6. Heidelberg 6.8 m/s rigid wall test

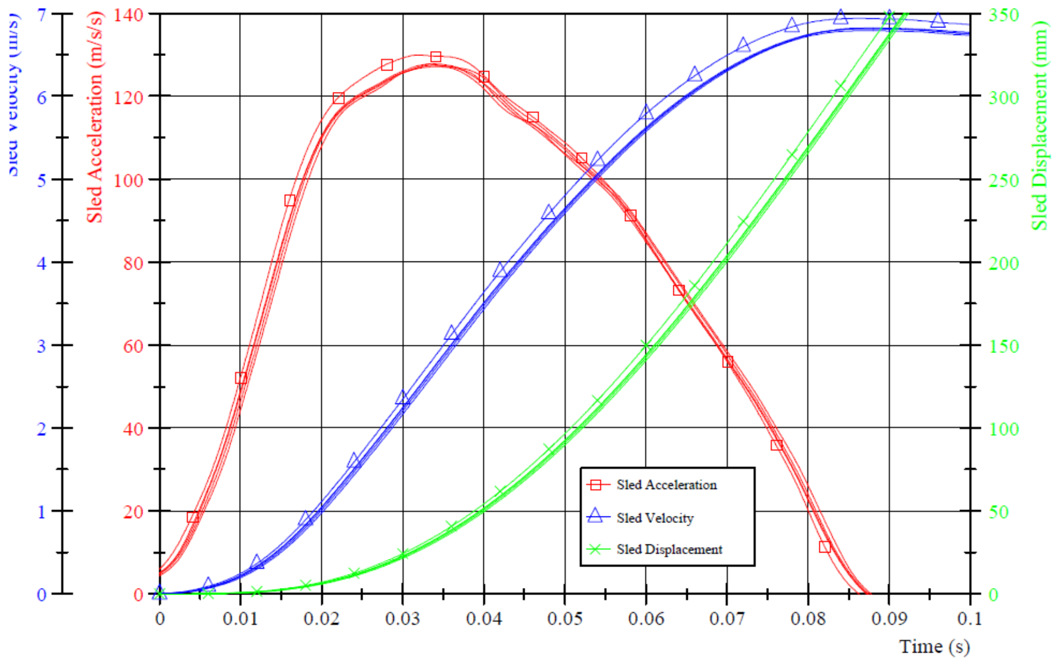

Figure 4-7. Sled pulse data from Heidelberg 6.8 m/s rigid wall tests

4.3.3 Wayne State Sled Tests

A drawing of the seat/load wall configuration for the Wayne State rigid wall sled tests is shown in Figure 4-8. An example of the rigid wall test configuration is shown in Figure 4-9. An example sled pulse for the 6.8 m/s rigid wall tests is shown in Figure 4-10.

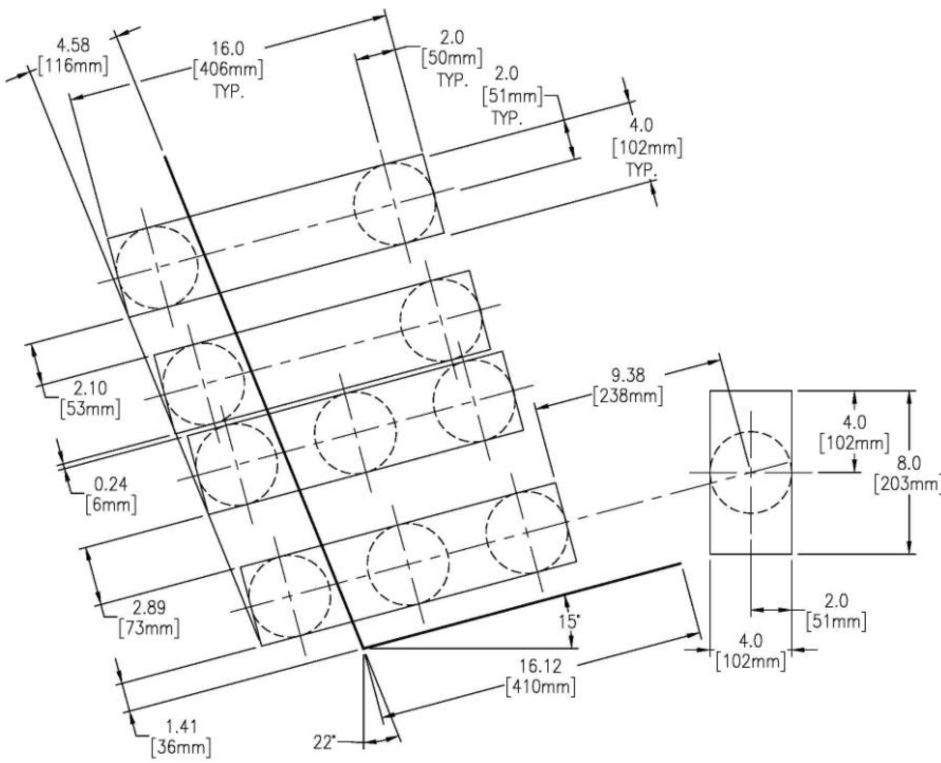

Figure 4-8. Wayne State sled buck load plate configuration

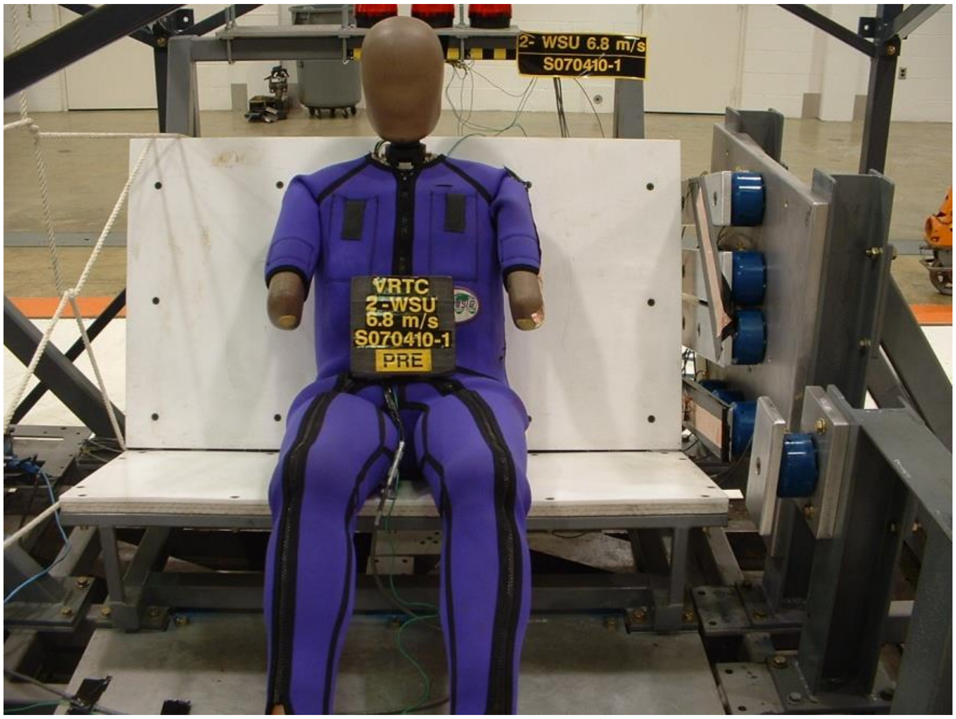

Figure 4-9. Wayne State 6.8 m/s rigid wall test

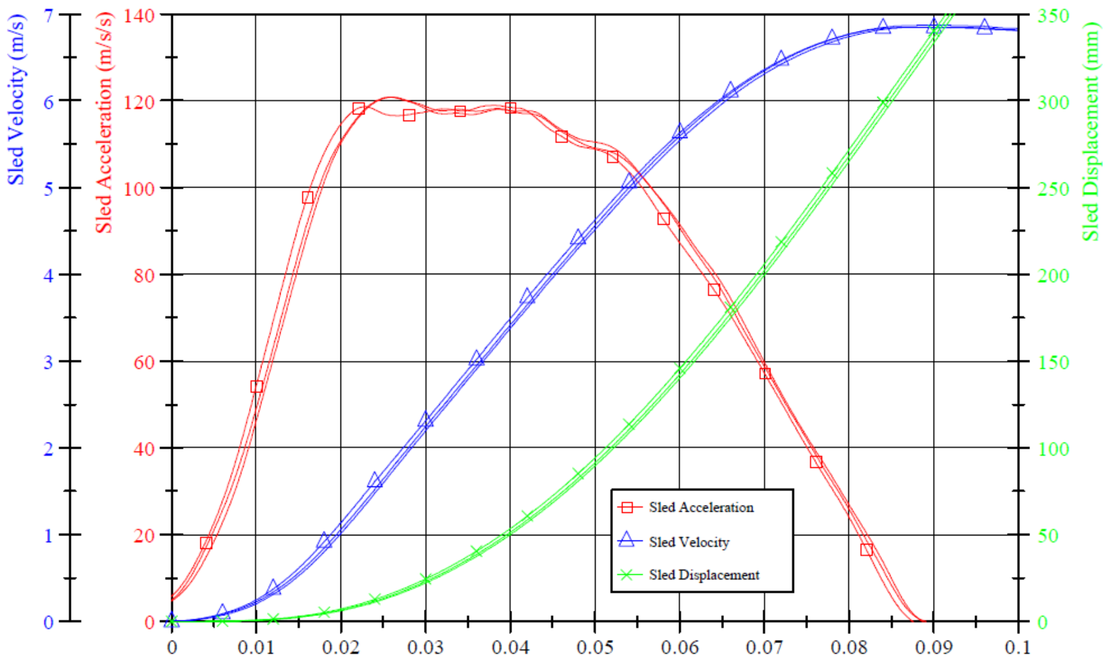

Figure 4-10. Example sled pulse data from Wayne State 6.8 m/s rigid wall tests

4.3.4 Dummy Positioning

Each dummy was positioned on a Teflon seating surface with its back and thighs flat against the seating surfaces. The feet were positioned at 90° relative to the lower legs. In earlier tests, cotton shop cloths were placed under the heels of the feet. The cotton cloths were later replaced with 2 sheets of Teflon. The distance between the dummy and the wall was set so that first dummy contact with the load wall occurred when the sled reached a constant (peak) velocity. This distance was determined by integrating the sled acceleration pulse to get velocity and double integrating to get sled displacement. The distance the sled had traveled when it reached constant (peak) velocity was determined from the data plots. Trial tests were performed using this distance and then the distance was adjusted as required so that first contact occurred at constant sled velocity. The dummy-to-load wall distances for each test configuration were as follows.

Heidelberg and Wayne State 6.8 m/s Tests	318 mm
NHTSA 6.7 m/s Tests	305 mm

5 Qualification Test Results

For all qualification tests discussed in Section 5, the individual test results and plots of the time histories can be found in Appendix A.

5.1 Head Drop Test

5.1.1 R&R Results

A summary of the R&R results is shown in Table 5.1.1. Note that left and right lateral head drop responses have been combined.

Table 5.1.1. Head Drop R&R Results

Lab/ Dummy			Peak Resultant Acceleration (g) frontal	Peak Resultant Acceleration (g) lateral
Repeatability	Lab A EA-7820	avg	250.3	121.8
		std dev	2.10	5.58
		%CV	0.8%	4.6%
	Lab B EA-7820	avg	238.9	121.3
		std dev	7.66	0.88
		%CV	3.2%	0.7%
	Lab C EA-7820	avg	255.3	120.4
		std dev	0.55	2.27
		%CV	0.2%	1.9%
	Lab D EA-7820	avg	251.3	117.7
		std dev	2.70	4.01
		%CV	1.1%	3.4%
	VRTC OSRP-1	avg	233.7	117.2
		std dev	4.38	1.30
		%CV	1.9%	1.1%
	VRTC OSRP-2	avg	235.1	117.6
		std dev	2.95	1.54
		%CV	1.3%	1.3%
	VRTC 014	avg	240.0	117.8
		std dev	1.49	0.87
		%CV	0.6%	0.7%
	VRTC 016	avg	236.1	111.9
		std dev	2.88	0.79
		%CV	1.2%	0.7%
All Tests Reproducibility		avg	242.3	117.7
		std dev	8.88	3.67
		%CV	3.7%	3.1%

5.1.2 Qualification Corridors

The NHTSA response requirements were determined by applying the methodology described in Section 4.1 and summarized in Table 5.1.2.

Table 5.1.2. Lateral and Frontal Head Drop Corridors

	Parameter	Units	NHTSA R&R Range		ISO 15830-5		NHTSA Response Requirements	
			Min	Max	Min	Max	Min	Max
Lateral	Peak Resultant Acceleration	g	110.4	125.1	104	123	107	126
Lateral	Peak Longitudinal Acceleration (Ax)	g		< 15		< 15		< 15
Lateral	Maximum % after main peak	%		<10		<10		<10
Frontal	Peak Resultant Acceleration	g	224.5	260.1	205	255	211	261
Frontal	Peak Lateral Acceleration (Ay)	g		< 15		< 15		< 15
Frontal	Maximum % after main peak	%		<10		<10		<10

5.1.3 Discussion

The CV values of the dummy's responses for the NHTSA R&R study were both below 5 percent for frontal and lateral head drop tests.

For lateral head drop tests, the maximum value of the NHTSA R&R range was slightly greater than the ISO maximum value and therefor the NHTSA response requirement is 107-126g. For frontal head drops, the NHTSA R&R range maximum value was also slightly higher than the ISO maximum and therefore the NHTSA response requirement is 211-261g.

5.2 Neck Pendulum Tests

5.2.1 Lateral Neck R&R Results

During the R&R neck testing, it became apparent that the various labs were employing different methods for determining time zero (T0), making comparisons of the pendulum pulse data meaningless. Therefore, NHTSA developed a new, definitive procedure for determining time zero (T0) (refer to the WorldSID 50th Percentile Male Qualification Procedures for details). All labs were made aware of the new T0 procedure, provided with preliminary target pendulum pulse corridors, and instructed to conduct five repeat tests. New pulse corridors were then developed using the mean plus/minus two standard deviations of all the results from all labs. Table 5.2.1 summarizes the pendulum pulse R&R results, and

Table 5.2.2 presents the new pulse corridors.

Table 5.2.1. Lateral Neck Pendulum Pulse Results

	Lab/ Dummy S/N	Side		Probe Velocity	Pendulum Pulse 4 msec	8 msec	12 msec
units				m/s	m/s	m/s	m/s
Repeatability	Lab A EA-7820	Left	mean	3.45	0.92	1.87	2.85
			Std.Dev.	0.00	0.03	0.07	0.06
			CV%	0.1%	3.8%	3.7%	2.1%
	Lab B EA-7820	Left	mean	3.41	0.94	1.84	2.87
			Std.Dev.	0.01	0.01	0.03	0.07
			CV%	0.4%	1.3%	1.8%	2.3%
	Lab C EA-7820	Left & Right	mean	3.38	0.94	1.80	2.71
			Std.Dev.	0.02	0.04	0.07	0.09
			CV%	0.7%	4.0%	3.6%	3.4%
	Lab D EA-7820	Left	mean	3.36	0.93	1.85	2.89
			Std.Dev.	0.00	0.01	0.01	0.05
			CV%	0.0%	1.5%	0.6%	1.8%
	VRTC EB9641	Left & Right	mean	3.38	1.01	1.96	2.96
			Std.Dev.	0.03	0.05	0.08	0.10
			CV%	0.8%	5.1%	4.0%	3.4%
	VRTC DW6607	Left & Right	mean	3.40	1.04	2.01	3.02
			Std.Dev.	0.00	0.03	0.06	0.11
			CV%	0.0%	3.2%	3.1%	3.8%
	VRTC EE9391	Left & Right	mean	3.39	0.99	1.94	2.95
			Std.Dev.	0.01	0.02	0.05	0.10
			CV%	0.2%	2.5%	2.8%	3.5%
All Tests Reproducibility			mean	3.39	0.98	1.91	2.90
			Std.Dev.	0.03	0.06	0.10	0.14
			CV%	0.80%	5.65%	4.99%	4.69%

Table 5.2.2. Lateral Neck Pendulum Pulse Corridors

Parameter	units	VRTC Preliminary Min	VRTC Preliminary Max	NHTSA Response Requirements Min	NHTSA Response Requirements Max
Impact Speed	m/s	3.3	3.5	3.3	3.5
Pulse @ 4 msec	m/s	0.77	1.04	0.87	1.09
Pulse @ 8 msec	m/s	1.60	1.90	1.72	2.10
Pulse @ 12 msec	m/s	2.43	3.29	2.63	3.17

Several of the lateral neck R&R tests did not meet the new pendulum pulse criteria and therefore those responses were eliminated from the analysis. The results for tests meeting the pulse requirements are summarized in Table 5.2.3. Note that, where applicable, left and right lateral pendulum test responses have been combined.

Additionally, it should be pointed out that the ISO response corridors placed limits on the peak rotation and time of peak rotation for both the forward and rearward potentiometers used on the headform test equipment for this test. The critical parameter, total rotation of the head, is determined by adding the response of the headform potentiometer to the forward potentiometer (a description of where the potentiometers are located is provided in the qualification manual.) ISO does place limits on the peak of the total rotation, but not the time of the peak.

The omission of a peak time for the total rotation is a practical consideration. The pulse generated by the pendulum, in combination with test set-up, results in a significant plateau in the rotation recorded by the headform potentiometer (over 30 ms in many cases). During this dwell time, there are slight fore/aft movements of the headform as the neck continues to bend and rebound, such that the time of peak rotation cannot be pinpointed objectively.

The forward and rearward potentiometers on the pendulum also display this behavior, but to a lesser extent (see Figure 5-1 and Figure 5-2). When the frontward and headform potentiometer signals are added to produce the total rotation, the resulting plot also exhibits multiple peaks of nearly identical magnitudes, thus providing inconsistent values for the time of peak rotation.

Therefore, NHTSA has eliminated limits on the time of peak rotation. Implementing such a requirement would necessitate a wide time interval to account for the plateau effect and would provide very little assurance that necks are uniform. NHTSA has also eliminated limits on maximum rotation for the forward and rearward potentiometers since the total head rotation is considered the critical parameter for rotation. In their place, NHTSA has added a new requirement, the maximum angular velocity of the headform (the time rate of change of total head rotation), which may be pinpointed objectively.

NHTSA’s lateral neck measurements listed in Table 5.2.3 are highly objective, and the limits are sufficient to assure that all necks put into service will be uniform.

Table 5.2.3. Lateral Neck Pendulum R&R Results

	Lab/ Dummy S/N	Side		D-Plane Peak Rotation (deg)	D-Plane time - Peak to 0 deg (msec)	Occipital Condyle Peak Moment (Nm)	Occipital Condyle time - Peak to 0 Nm (msec)	Peak Headform Angular Velocity (deg/s)
Repeatability	Lab A EA-7820	Left	mean	55.0	64.0	62.5	77.9	2331.6
			Std.Dev.	0.37	0.82	0.40	0.39	10.17
			CV%	0.7%	1.3%	0.6%	0.5%	0.4%
	Lab B EA-7820	Left	mean	55.6	63.8	61.8	76.8	2294.9
			Std.Dev.	0.57	1.73	0.25	0.18	16.37
			CV%	1.0%	2.7%	0.4%	0.2%	0.7%
	Lab C EA-7820	Left & Right	mean	53.1	62.0	61.4	77.1	2269.4
			Std.Dev.	0.37	1.60	1.15	0.39	27.50
			CV%	0.7%	2.6%	1.9%	0.5%	1.2%
	Lab D EA-7820	Left	mean	53.3	62.6	61.9	76.9	2284.3
			Std.Dev.	0.56	2.70	0.14	0.66	4.64
			CV%	1.1%	4.3%	0.2%	0.9%	0.2%
	VRTC EB9641	Left & Right	mean	55.6	66.9	56.2	75.5	2195.6
			Std.Dev.	0.43	0.48	3.76	0.52	27.04
			CV%	0.8%	0.7%	6.7%	0.7%	1.2%
	VRTC DW6607	Left & Right	mean	55.9	64.8	55.3	74.7	2234.0
			Std.Dev.	0.28	0.33	0.46	0.25	14.20
			CV%	0.5%	0.5%	0.8%	0.3%	0.6%
	VRTC EE9391	Left & Right	mean	57.5	65.7	64.5	76.7	2360.0
			Std.Dev.	0.84	1.30	1.36	1.66	36.61
			CV%	1.5%	2.0%	2.1%	2.2%	1.6%
All Test Reproducibility			mean	55.3	64.5	60.3	76.4	2278.7
			Std.Dev.	1.59	2.13	3.81	1.26	61.24
			CV%	2.9%	3.3%	6.3%	1.7%	2.7%

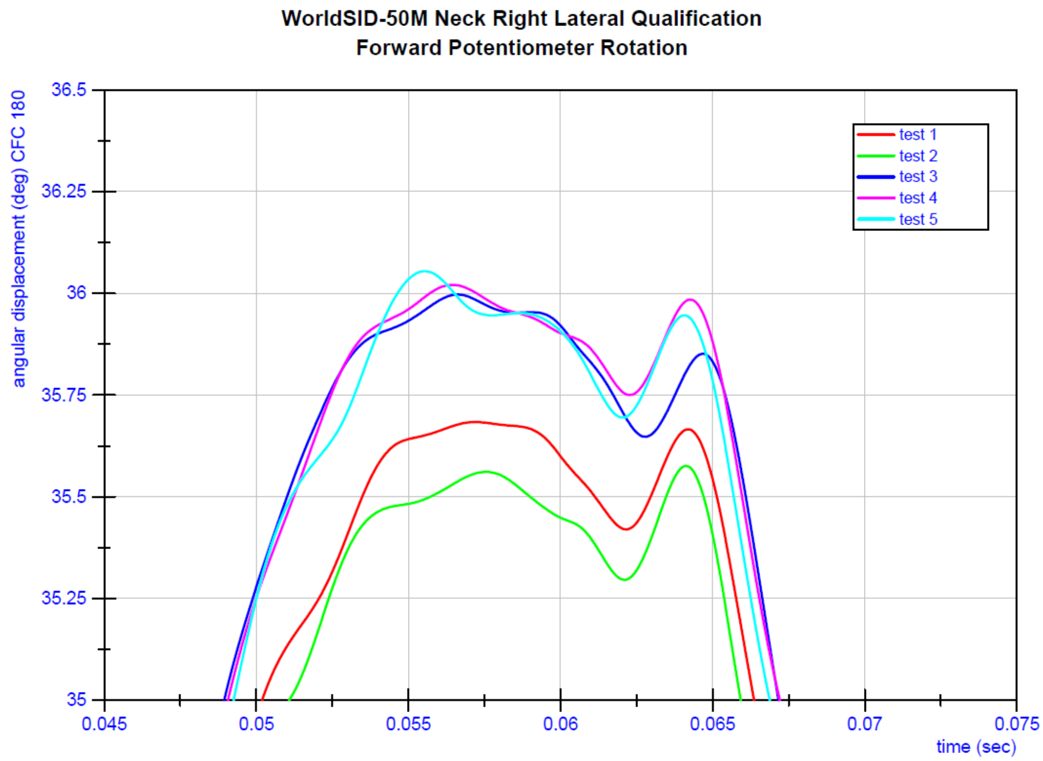

Figure 5-1. Multiple Peaks in the Forward Potentiometer Response

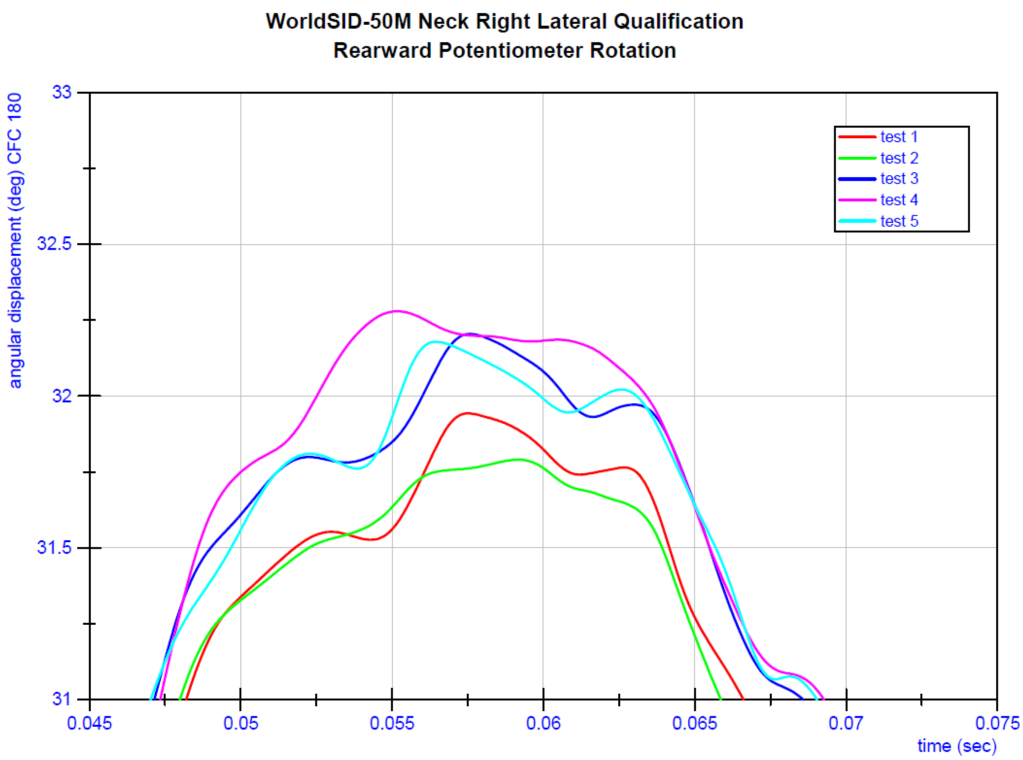

Figure 5-2. Multiple Peaks in the Rearward Potentiometer Response

5.2.2 Lateral Neck Qualification Corridors

The NHTSA response requirements for the lateral neck qualification were determined by applying the methodology described in Section 4.1 and summarized in Table 5.2.4.

Table 5.2.4. Lateral Neck Pendulum Response Corridors

		NHTSA R&R Range		ISO 15830-5		NHTSA Response Requirements	
Parameter	units	Min	Max	Min	Max	Min	Max
Headform Rotation	deg	52.1	58.4	50.0	61.0	50.0	61.0
Time of Peak Headform Rotation To 0 deg	msec	60.2	68.7	58.0	72.0	58.0	72.0
Peak OC Moment	Nm	54.1	66.1	55.0	68.0	54.0	67.0
Time of Peak OC Moment To 0 Nm	msec	73.7	78.9	71.0	87.0	71.0	87.0
Head X-angular rate	deg/s	2047.7	2502.7	n/a	n/a	2047.0	2503.0

5.2.3 Lateral Neck Discussion

All the CV values for the NHTSA R&R study were below 5 percent with two exceptions: (1) repeatability of peak moment for neck EB9641 and (2) the reproducibility of peak moment for all tests. Regarding repeatability of EB9641, the neck exhibited differences in response between left and right lateral tests as illustrated in Figure 5-3. The lateral left peak moment responses exhibited the lowest values of all tests conducted in this series. Upon inspection, neck EB9641 did not exhibit any unusual wear or damage, nor were there any significant differences in the pendulum pulses of left and right tests. With regard to the overall reproducibility of the neck moment response, the low values observed in the lateral left tests of EB9641 certainly contributed to the CV result greater than 5 percent. It should be noted that none of the lateral left neck moment responses of EB9641 would meet the NHTSA response requirements and thus this neck would likely be rejected.

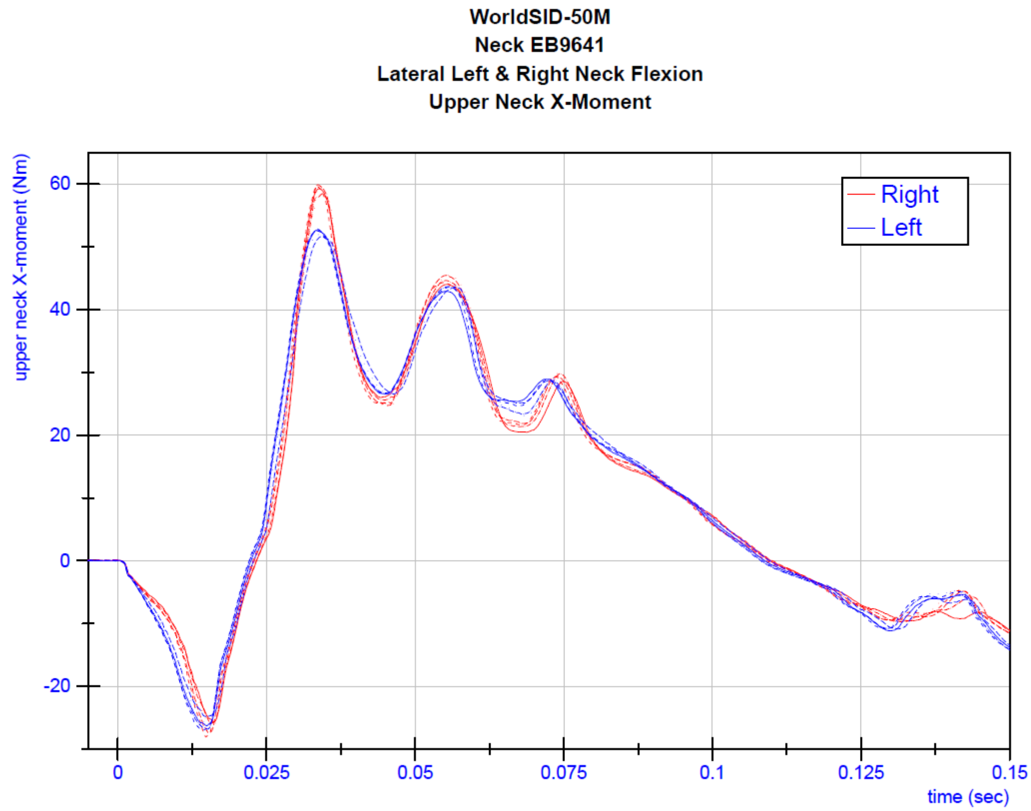

Figure 5-3. Left and Right Lateral Flexion Tests for Neck EB9641

The NHTSA R&R ranges were all within the preliminary ISO response corridors except for the peak OC moment, where the NHTSA R&R minimum value, 54.1 Nm, was slightly below the ISO value, 55 Nm. Therefore, the NHTSA response requirements were adjusted to 54-67 Nm. All other NHTSA response requirement values are consistent with the ISO values. Also, NHTSA introduced a new parameter, head Y-axis angular rate, necessary for assessing the ARS instrumentation needed to compute BrIC.

5.2.4 Neck Torsion R&R Results

Neck torsion tests were not included in the ISO qualification procedures. However, as discussed in Section 4.1, NHTSA believes that predictable neck torsion response is an important feature.

Because this represents an entirely new test, the R&R results were used to establish the pendulum pulse requirements as well as the response requirements. Table 5.2.5 summarizes the pendulum pulse R&R results, and Table 5.2.6 presents the new pulse corridors.

Table 5.2.5. Neck Torsion Pendulum Pulse Results

	Lab/ Neck S/N	Test No.	Impact Velocity (m/s)	Pendulum Pulse 10 ms (m/s)	Pendulum Pulse 15 ms (m/s)	Pendulum Pulse 20 ms (m/s)
Repeatability	Lab A EA-7820	avg	5.21	2.13	3.24	4.30
		std dev	0.01	0.03	0.07	0.10
		CV (%)	0.11%	1.52%	2.25%	2.41%
	Lab B EA-7820	avg	5.24	2.27	3.34	4.56
		std dev	0.03	0.04	0.05	0.10
		CV (%)	0.63%	1.93%	1.63%	2.10%
	Lab C EA-7820	avg	5.20	2.19	3.33	4.45
		std dev	0.01	0.03	0.06	0.07
		CV (%)	0.14%	1.29%	1.74%	1.55%
	Lab D EA-7820	avg	5.20	2.18	3.34	4.48
		std dev	0.01	0.04	0.05	0.07
		CV (%)	0.19%	1.66%	1.51%	1.48%
	VRTC EB9641	avg	5.20	2.23	3.43	4.58
		std dev	0.01	0.06	0.09	0.10
		CV (%)	0.16%	2.87%	2.59%	2.14%
	VRTC DW6607	avg	5.20	2.27	3.52	4.72
		std dev	0.01	0.06	0.09	0.11
		CV (%)	0.10%	2.63%	2.43%	2.33%
	VRTC EE9391	avg	5.22	2.30	3.49	4.68
		std dev	0.01	0.04	0.05	0.06
		CV (%)	0.10%	1.58%	1.45%	1.21%
All Tests Reproducibility		avg	5.21	2.23	3.41	4.57
		std dev	0.02	0.07	0.11	0.15
		CV (%)	0.3%	3.1%	3.2%	3.3%

Table 5.2.6. Neck Torsion Pendulum Pulse Corridors

		VRTC Preliminary		NHTSA Response Requirements	
Parameter	units	Min	Max	Min	Max
Impact Speed	m/s	5.1	5.3	5.1	5.3
Pulse @ 10 msec	m/s	2.04	2.28	2.09	2.37
Pulse @ 15 msec	m/s	3.20	3.57	3.19	3.63
Pulse @ 20 msec	m/s	4.32	4.83	4.27	4.87

The neck torsion R&R results are summarized in Table 5.2.7.

Table 5.2.7. Neck Torsion R&R Results

	Lab/ Neck S/N	Left/ Right	Test No.	Peak Lower Neck Z Moment (N-m)	Peak Neck Fixture Rotation (deg)	Decay Time to 0 deg from peak angle (ms)	Peak Head Angular Rate Wz (deg/sec)
Repeatability	Lab A	Left	avg	37.1	46.3	39.4	1483.0
			std dev	0.24	0.40	0.13	8.03
			CV (%)	0.64%	0.87%	0.32%	0.54%
	Lab B	Left	avg	39.3	45.3	39.5	1473.9
			std dev	0.40	0.65	0.31	29.12
			CV (%)	1.02%	1.43%	0.79%	1.98%
	Lab C	Left	avg	37.9	46.1	39.9	1498.8
			std dev	0.11	0.16	0.12	5.97
			CV (%)	0.29%	0.35%	0.30%	0.40%
	Lab D	Left & Right	avg	38.5	46.1	40.1	1503.8
			std dev	0.13	0.27	0.14	18.43
			CV (%)	0.33%	0.58%	0.34%	1.23%
	VRTC EB9641	Left & Right	avg	36.8	46.8	39.5	1499.0
			std dev	0.28	0.86	0.25	12.57
			CV (%)	0.75%	1.85%	0.62%	0.84%
	VRTC DW6607	Left & Right	avg	38.3	46.1	38.6	1502.9
			std dev	0.13	0.36	0.17	12.38
			CV (%)	0.34%	0.79%	0.44%	0.82%
	VRTC EE9391	Left & Right	avg	38.3	46.2	37.6	1543.3
			std dev	0.24	0.35	0.23	13.74
			CV (%)	0.62%	0.75%	0.62%	0.89%
All Tests Reproducibility			avg	38.0	46.2	39.1	1505.6
			std dev	0.79	0.62	0.91	25.11
			CV (%)	2.1%	1.3%	2.3%	1.7%

5.2.5 Neck Torsion Qualification Corridors

The NHTSA response requirements for neck torsion qualification were determined by applying the methodology described in Section 4.1 and summarized in Table 5.2.8.

Table 5.2.8. Neck Torsion Corridors

		NHTSA R&R Range		ISO 15830-5		NHTSA Response Requirements	
Parameter	units	Min	Max	Min	Max	Min	Max
Neck Z-moment	N-m	34.2	41.8	n/a	n/a	34	42
Neck Fixture Rotation	deg	41.6	50.8	n/a	n/a	41.5	51.0
Decay Time to 0 deg from Peak Rotation	msec	35.2	43.0	n/a	n/a	35	43
Head Z-angular rate	deg/s	1345.1	1655.0	n/a	n/a	1345	1655

5.2.6 Neck Torsion Discussion

All the CV values for the NHTSA R&R study were less than 5 percent for the neck torsion tests.

Since neck torsion is a new test procedure, ISO corridors did not exist. Thus, the NHTSA response requirements reflect the values obtained in the NHTSA R&R analysis.

5.3 Shoulder Impact Test

5.3.1 R&R Results

The shoulder impact test R&R results are summarized in Table 5.3.1. Note that for this test series, as well as for the thorax and abdomen impacts, the dummy was instrumented with the RibEye displacement measurement system, which includes three LED transmitters on each rib. For the purposes of this analysis, only the middle RibEye LED of the relevant rib is considered. In this section, as well as in subsequent sections, rib deflection is reported. The term “deflection” as used in this report can best be described as the change in length of an imaginary cord connecting the RibEye sensor (located on the dummy’s spine) and the LEDs (mounted on the interior lateral portion of the dummy’s ribs). Deflection takes into account the LED’s change of position in both the x- and y-coordinates. A detailed explanation for computing the rib deflections can be found in the *WorldSID 50th Percentile Male Qualification Procedures Manual*.

Table 5.3.1. Shoulder Impact R&R Results

	Lab/ Dummy No.	Test No.	Peak Pendulum Force (kN)	Peak Shoulder Deflection Mid LED (mm)	Peak Shoulder Force (kN)
Repeatability	Lab A EA-7820	Mean	3.10	42.25	1.64
		Std Dev	0.14	0.41	0.01
		CV (%)	4.52%	0.97%	0.84%
	Lab B EA-7820	Mean	2.96	41.38	1.64
		Std Dev	0.14	0.45	0.01
		CV (%)	4.68%	1.09%	0.80%
	Lab C EA-7820	Mean	2.96	41.90	1.59
		Std Dev	0.10	0.58	0.02
		CV (%)	3.39%	1.39%	1.19%
	VRTC EA-7820	Mean	2.99	40.56	1.67
		Std Dev	0.01	0.54	0.01
		CV (%)	0.44%	1.33%	0.89%
	VRTC EB-8888	Mean	2.93	45.71	1.60
		Std Dev	0.02	0.42	0.02
		CV (%)	0.59%	0.92%	1.20%
	VRTC EE-8800	Mean	2.77	39.03	1.67
		Std Dev	0.03	0.52	0.02
		CV (%)	0.94%	1.32%	0.91%
All Tests Reproducibility		Mean	2.95	41.80	1.64
		Std Dev	0.13	2.12	0.03
		CV (%)	4.4%	5.1%	2.0%

5.3.2 Qualification Corridors

The NHTSA response requirements for shoulder impact qualification were determined by applying the methodology described in Section 4.1 and summarized in Table 5.3.2.

Table 5.3.2. Shoulder Impact Qualification Corridors

		NHTSA R&R Range		ISO 15830-5		NHTSA Response Requirements	
parameter	units	Min	Max	Min	Max	Min	Max
Peak Probe Force	kN	2.7	3.2	2.6	3.3	2.6	3.3
Peak Shoulder Rib Deflection	mm	37.6	46.0	35	44	37.0	46.0
Peak Lateral Shoulder Force	kN	1.47	1.80	n/a	n/a	1.47	1.80

5.3.3 Discussion

All the CV values for the NHTSA R&R study of the shoulder impact tests were below 5 percent, with the lone exception being the reproducibility of peak shoulder deflection for all dummies, which was only marginally greater than 5 percent. While each individual dummy exhibited extremely low CV values (each individual dummy's repeatability CV was less than 1.39%), the peak shoulder deflection responses of dummy EB-8888 were near the upper boundary of the NHTSA response requirements and this result led to the reproducibility CV being greater than 5 percent.

The NHTSA R&R ranges were all within the ISO response corridors except for the peak shoulder rib deflection, where the NHTSA R&R maximum value, 46.0 mm, was greater than the ISO value, 44 mm. Therefore, the NHTSA response requirements were adjusted to 37.0-46.0 mm. All other NHTSA R&R response requirement values are consistent with the ISO values. Also, a new parameter was introduced, peak lateral shoulder force, as NHTSA believes that the proper shoulder response is important to insure appropriate loading of the thorax and head. Since no ISO corridors exist, the range established in the NHTSA R&R study are adopted as the NHTSA recommended corridors.

5.4 Thorax With Half-Arm Impact

5.4.1 R&R Results

R&R results for the thorax with half-arm impact tests are summarized in Table 5.4.1.

Table 5.4.1. Thorax With Half-Arm Impact R&R Results

	Lab/ Dummy No.	Test No.	Peak Pendulum Force (kN)	Peak T4 Y-Axis Accel (g)	Peak T12 Y-Axis Accel (g)	Peak Deflection Middle LED (mm)		
						Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
Repeatability	Lab A EA-7820	Mean	5.99	34.43	25.95	41.10	48.56	36.05
		Std Dev	0.09	1.31	0.21	1.27	1.03	1.11
		CV (%)	1.5%	3.8%	0.8%	3.1%	2.1%	3.1%
	Lab B EA-7820	Mean	5.97	33.96	24.64	40.46	48.63	36.32
		Std Dev	0.16	1.27	1.43	1.52	1.41	1.63
		CV (%)	2.6%	3.8%	5.8%	3.8%	2.9%	4.5%
	Lab C EA-7820	Mean	5.71	33.96	23.58	40.27	47.76	34.71
		Std Dev	0.05	0.76	0.82	1.26	0.95	0.71
		CV (%)	0.9%	2.2%	3.5%	3.1%	2.0%	2.0%
	VRTC EA-7820	Mean	6.02	33.40	24.28	40.63	47.11	34.86
		Std Dev	0.08	0.37	0.13	1.28	0.57	0.28
		CV (%)	1.4%	1.1%	0.6%	3.2%	1.2%	0.8%
	VRTC EB-8888	Mean	5.61	34.51	24.13	43.42	47.56	35.82
		Std Dev	0.07	0.90	0.39	0.56	0.88	0.56
		CV (%)	1.3%	2.6%	1.6%	1.3%	1.8%	1.6%
	VRTC EE-8800	Mean	5.74	34.65	24.57	42.52	48.28	35.65
		Std Dev	0.04	0.58	0.78	0.40	0.35	0.70
		CV (%)	0.64%	1.66%	3.19%	0.93%	0.73%	1.96%
All Tests Reproducibility		Mean	5.84	34.15	24.53	41.40	47.98	35.57
		Std Dev	0.181	0.952	1.016	1.570	1.015	1.044
		CV (%)	3.1%	2.8%	4.1%	3.8%	2.1%	2.9%

5.4.2 Qualification Corridors

The NHTSA response requirements for thorax with arm impact qualification were determined by applying the methodology described in Section 4.1 and summarized in Table 5.4.2.

Table 5.4.2. Thorax With Half-Arm Qualification Corridors

parameter		units	NHTSA R&R Range		ISO 15830-2		NHTSA Response Requirements	
			Min	Max	Min	Max	Min	Max
Peak Probe Force		kN	5.5	6.2	4.9	5.8	5.3	6.2
Peak T4 Y-acceleration		g	32.3	36.1	28	37	28	37
Peak T12 Y-acceleration		g	22.5	26.6	22	28	22	28
Peak Deflection	Thorax Rib 1	mm	38.3	44.5	35	47	35	47
	Thorax Rib 2	mm	46.0	50.0	46	56	46	56
	Thorax Rib 3	mm	33.5	37.7	39	46	33.5	40.5

5.4.3 Discussion

The thorax with half-arm test has been eliminated from ISO 15830-5 and will be replaced with an "arm-only" test. While NHTSA is contributing to the development of the proposed arm-only test, the new test still needs refinement and lab-to-lab evaluation before it can be considered for inclusion in the qualification requirements. In the interim, NHTSA has chosen to maintain the thorax with half-arm qualification test because it is believed that an assessment of the arm's contribution to the thoracic response is warranted. For comparison purposes, the previous ISO corridors (ISO 15830-2) have been used in Table 5.4.2.

All the CV values in the NHTSA R&R study for the thorax with half-arm impact tests were below 5 percent with the lone exception of Lab B's repeatability CV for peak T12 acceleration, which was only marginally above 5 percent. An inspection of the data reveals that the peak T12 acceleration for Lab B's first test was substantially lower than that recorded in each of the four subsequent tests in the series, however that test would still meet the response requirements.

The NHTSA R&R ranges were within the ISO response corridors for peak T4 and T12 y-acceleration, as well as for peak deflections of thoracic ribs 1 and 2. For the peak probe force parameter, the NHTSA R&R maximum values, 6.2 kN, was greater than the ISO value, 5.8 kN. Therefore, the NHTSA response requirement was adjusted to 5.3-6.2 kN. Likewise, for peak deflection of thorax rib 3, the NHTSA R&R minimum value, 33.5 mm, was less than the ISO value, 39 mm, so the NHTSA response requirement was adjusted to 33.5-40.5 mm.

5.5 Thorax Without Arm Impact

5.5.1 R&R Results

R&R results for the thorax without arm impact tests are summarized in Table 5.5.1.

Table 5.5.1. Thorax Without Arm Impact R&R Results

	Lab/ Dummy No.	Test No.	Peak Pendulum Force (kN)	Peak T4 Y-Axis Accel (g)	Peak T12 Y-Axis Accel (g)	Peak Deflection Middle LED (mm)		
						Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
Repeatability	Lab A EA-7820	Mean	3.57	17.07	18.40	37.68	38.32	33.15
		Std Dev	0.03	0.32	1.95	1.60	1.37	1.60
		CV (%)	1.0%	1.9%	10.6%	4.2%	3.6%	4.8%
	Lab B EA-7820	Mean	3.65	17.38	16.93	38.53	38.58	34.24
		Std Dev	0.02	0.05	0.65	1.05	0.64	0.54
		CV (%)	0.4%	0.3%	3.9%	2.7%	1.7%	1.6%
	Lab C EA-7820	Mean	3.45	16.64	16.44	37.59	40.79	35.19
		Std Dev	0.02	0.49	0.73	1.76	0.67	0.91
		CV (%)	0.4%	3.0%	4.5%	4.7%	1.7%	2.6%
	VRTC EA-7820	Mean	3.64	16.53	16.24	39.15	39.23	34.18
		Std Dev	0.03	0.18	0.22	1.12	0.34	1.10
		CV (%)	0.8%	1.1%	1.4%	2.8%	0.9%	3.2%
	VRTC EB-8888	Mean	3.50	15.62	15.82	41.05	40.75	34.82
		Std Dev	0.01	0.52	0.31	0.95	0.39	1.03
		CV (%)	0.4%	3.3%	1.9%	2.3%	1.0%	3.0%
	VRTC EE-8800	Mean	3.60	14.96	15.10	39.86	41.05	33.84
		Std Dev	0.03	0.17	0.15	1.04	0.47	0.44
		CV (%)	0.8%	1.1%	1.0%	2.6%	1.2%	1.3%
All Tests Reproducibility		Mean	3.57	16.36	16.49	38.98	39.78	34.24
		Std Dev	0.077	0.901	1.326	1.707	1.316	1.137
		CV (%)	2.2%	5.5%	8.0%	4.4%	3.3%	3.3%

5.5.2 Qualification Corridors

The NHTSA response requirements for thorax with arm impact qualification were determined by applying the methodology described in Section 4.1 and summarized in Table 5.5.2.

Table 5.5.2. Thorax Without Arm Qualification Corridors

			NHTSA R&R Range		ISO 15830-5		NHTSA Response Requirements	
parameter		units	Min	Max	Min	Max	Min	Max
Peak Probe Force		kN	3.4	3.7	3.2	3.8	3.2	3.8
Peak T4 Y-acceleration		g	14.7	18.0	14	20	14	20
Peak T12 Y-acceleration		g	14.8	18.1	14	22	14	22
Peak Deflection	Thorax Rib 1	mm	35.6	42.4	33	43	33	43
	Thorax Rib 2	mm	37.2	42.4	35	43	35	43
	Thorax Rib 3	mm	32.0	36.5	32	40	32	40

5.5.3 Discussion

The CV values for repeatability and reproducibility were below 5 percent for peak pendulum force and for peak deflection of all three thoracic ribs. For peak T4 accelerations, the repeatability CV values for each individual dummy was also below 5 percent, however the reproducibility CV for the combined dummies was marginally greater than 5 percent. This result is primarily attributed to the responses exhibited by dummy EE-8800 which, although they were on the low end of the corridor, still were within the requirements. The CV for repeatability of peak T12 accelerations at Lab A was greater than 10 percent. Despite the large CV value, all of the responses were within the response requirements.

The NHTSA R&R ranges are all within the ISO ranges and thus the NHTSA response requirements are consistent with the ISO values.

5.6 Abdomen Impact Test

5.6.1 R&R Results

R&R results for the abdomen impact tests are summarized in Table 5.6.1.

Table 5.6.1. Abdomen Impact R&R Results

	Lab/ Dummy No.	Test No.	Peak Pendulum Force (kN)	Peak T12 Y-Axis Accel (g)	Peak Deflection - Middle LED (mm)	
					Abdomen Rib 1	Abdomen Rib 2
Repeatability	Lab A EA-7820	Mean	2.89	16.59	36.34	36.22
		Std Dev	0.09	0.44	0.76	1.08
		CV (%)	3.00%	2.63%	2.10%	2.97%
	Lab B EA-7820	Mean	2.99	15.94	36.53	35.69
		Std Dev	0.01	0.40	0.67	0.46
		CV (%)	0.4%	2.5%	1.8%	1.3%
	Lab C EA-7820	Mean	2.89	15.65	36.19	36.15
		Std Dev	0.02	0.52	0.89	0.72
		CV (%)	0.5%	3.3%	2.5%	2.0%
	VRTC EA-7820	Mean	3.01	15.63	35.25	36.15
		Std Dev	0.01	0.20	0.45	0.78
		CV (%)	0.4%	1.3%	1.3%	2.2%
	VRTC EB-8888	Mean	3.01	17.06	32.86	33.67
		Std Dev	0.03	0.39	0.36	0.55
		CV (%)	1.1%	2.3%	1.1%	1.6%
	VRTC EE-8800	Mean	2.87	15.31	35.91	36.04
		Std Dev	0.02	0.16	0.32	0.27
		CV (%)	0.8%	1.1%	0.9%	0.7%
All Tests Reproducibility		Mean	2.94	16.03	35.51	35.65
		Std Dev	0.07	0.70	1.39	1.11
		CV (%)	2.5%	4.4%	3.9%	3.1%

5.6.2 Qualification Corridors

The NHTSA response requirements for abdomen impact qualification were determined by applying the methodology described in Section 4.1 and summarized in Table 5.6.2.

Table 5.6.2. Abdomen Impact Qualification Corridors

parameter		units	NHTSA R&R Range		ISO 15830-5		NHTSA Response Requirements	
			Min	Max	Min	Max	Min	Max
Peak Probe Force		kN	2.8	3.1	2.7	3.1	2.7	3.1
Peak T12 Y-acceleration		g	14.6	17.4	15	20	14.5	19.5
Peak Deflection	Abdomen Rib 1	mm	32.7	38.3	33	40	32.5	39.5
	Abdomen Rib 2	mm	33.4	37.9	30	36	32	38

5.6.3 Discussion

All the CV values in the NHTSA R&R study were below 5 percent.

The NHTSA R&R range for peak pendulum force is within the ISO range and therefore the NHTSA response requirement is consistent with the ISO corridor. For peak T12 y-acceleration, the minimum value of the NHTSA R&R range, 14.6 g, is less than the minimum ISO value, 15 g. Therefore, the NHTSA response requirement was adjusted to 14.5-19.5 g. Similarly, the NHTSA R&R minimum value for peak deflection of abdomen rib 1, 32.7 mm, was less than the corresponding ISO value, 33 mm. Conversely, the NHTSA R&R maximum value for peak deflection of abdomen rib 2, 37.9 mm, exceeded the corresponding ISO value, 36 mm. Thus, the NHTSA response requirements were adjusted as follows: abdomen rib 1 peak deflection: 32.5-39.5 mm; abdomen rib 2 peak deflection: 32-38 mm.

5.7 Pelvis Impact Test

5.7.1 R&R Results

R&R results for the pelvis impact tests are summarized in Table 5.7.1.

Table 5.7.1. Pelvis Impact R&R Results

Lab/ Dummy No.		Test No.	Peak Pendulum Force (kN)	Peak T12 Y-Axis Accel (g)	Peak Pelvis Y-Axis Accel (g)	Peak Pubic Y-Axis Force (kN)	Peak Sacro Y-Axis Force (kN)
Repeatability	Lab A EA-7820	Mean	7.75	13.36	47.05	1.58	2.12
		Std Dev	0.19	0.48	1.65	0.05	0.05
		CV (%)	2.4%	3.6%	3.5%	3.0%	2.2%
	Lab B EA-7820	Mean	7.64	12.96	45.25	1.47	2.11
		Std Dev	0.09	0.39	0.87	0.02	0.07
		CV (%)	1.2%	3.0%	1.9%	1.0%	3.1%
	Lab C EA-7820	Mean	7.58	13.15	45.51	1.40	2.07
		Std Dev	0.13	0.63	1.62	0.06	0.07
		CV (%)	1.7%	4.8%	3.6%	3.9%	3.4%
	Lab D EA-7820	Mean	7.40	13.14	44.17	1.52	2.00
		Std Dev	0.09	0.39	1.46	0.01	0.02
		CV (%)	1.3%	2.9%	3.3%	0.8%	1.0%
	VRTC 016	Mean	7.30	12.58	41.83	1.36	1.97
		Std Dev	0.11	0.43	1.82	0.02	0.01
		CV (%)	1.6%	3.4%	4.4%	1.3%	0.7%
	VRTC 014	Mean	7.67	12.22	40.67	1.36	2.08
		Std Dev	0.02	0.29	0.89	0.02	0.02
		CV (%)	0.3%	2.4%	2.2%	1.7%	0.7%
	VRTC 011	Mean	7.45	12.92	43.42	1.43	2.13
		Std Dev	0.05	0.20	1.84	0.02	0.05
		CV (%)	0.7%	1.6%	4.2%	1.7%	2.2%
All Tests Reproducibility		Mean	7.54	12.89	44.03	1.45	2.07
		Std Dev	0.18	0.52	2.46	0.08	0.07
		CV (%)	2.4%	4.1%	5.6%	5.6%	3.4%

5.7.2 Qualification Corridors

The NHTSA response requirements for pelvis impact qualification were determined by applying the methodology described in Section 4.1 and summarized in Table 5.7.2.

Table 5.7.2. Pelvis Impact Qualification Corridors

		NHTSA R&R Range		ISO 15830-5		NHTSA Response Requirements	
parameter	units	Min	Max	Min	Max	Min	Max
Peak Probe Force	kN	7.18	7.90	6.8	8.2	6.8	8.2
Peak T12 Y-acceleration	g	11.8	14.0	10	14	10	14
Peak Pelvis Y-acceleration	g	39.6	48.5	37	47	38.5	48.5
Peak Pubic Y-axis Force	kN	1.30	1.59	monitor		1.30	1.59
Peak Sacroiliac Y-axis Force	kN	1.86	2.28	n/a	n/a	1.86	2.28

5.7.3 Discussion

All of the CV results for the pelvis impact tests were below 5 percent with the exception of the reproducibility of the peak pelvis y-acceleration and peak pubic y-force, which were both just above 5 percent. While each individual dummy exhibited low CV values for repeatability, the results for dummy EA-7820 at Lab A were elevated as compared to the other test results in the series and these results contributed to the reproducibility CVs above 5 percent.

The ISO corridors encompass the NHTSA R&R ranges for probe force and T12 y-acceleration and were therefore adopted for the NHTSA response requirements. Meanwhile, the maximum value of the NHTSA R&R range for pelvis y-acceleration exceeded that of the ISO corridors and therefore the NHTSA response requirements are set at 38.5 to 48.5g. Finally, NHTSA has added requirements for pubic y-axis force and sacroiliac y-axis force as these parameters are believed to be meaningful for side impact injury prediction. Since the ISO corridors do not contain these parameters, the NHTSA R&R ranges have been used for the NHTSA response requirements.

5.8 Sled Tests

5.8.1 R&R Results

The results for the sled R&R tests are shown in Table 5.8.1 through

Table 5.8.4.

Table 5.8.1. NHTSA 6.7 m/s Rigid Flat Wall Sled Test Peak Results Summary

NHTSA (Maltese) 6.7 m/s Rigid Flat Wall Sled Test											
Channel	Units	CFC	OSRP 1			OSRP 2			Combined		
			Avg	Std Dev	% CV	Avg	Std Dev	% CV	Avg	Std Dev	% CV
Thorax Load Wall Sum	N	1000	8313.3	272.7	3.3	7920.0	298.0	3.8	8116.6	334.2	4.1
Abdomen Load Wall Sum	N	1000	2473.5	75.5	3.1	2655.7	121.0	4.6	2564.6	134.5	5.2
Pelvis Load Wall Sum	N	1000	11708.2	126.6	1.1	10956.7	524.8	4.8	11332.4	534.8	4.7
Upper Neck Y-axis Force	N	1000	552.6	5.0	0.9	508.8	3.2	0.6	530.7	24.3	4.6
Upper Neck X-axis Moment	N·m	600	40.2	0.4	0.9	39.4	0.5	1.3	39.8	0.6	1.5
Lower Neck Y-axis Force	N	1000	919.4	23.2	2.5	934.0	4.1	0.4	926.7	16.9	1.8
Lower Neck X-axis Moment	N·m	600	143.8	0.7	0.5	141.4	1.0	0.7	142.6	1.5	1.1
Shoulder Y-axis Force	N	600	-1735.4	40.5	2.3	-1822.8	21.0	1.2	-1779.1	55.9	3.1
T1 Y-axis Accel.	g	180	38.1	0.6	1.5	37.4	0.1	0.4	37.8	0.5	1.4
T4 Y-axis Accel.	g	180	33.6	0.9	2.7	34.7	0.8	2.4	34.2	1.0	2.9
T12 Y-axis Accel.	g	180	43.9	1.8	4.1	38.7	0.4	1.0	41.3	3.0	7.4
Thorax Rib 1 Deflection	mm	600	66.0	0.6	0.9	61.3	2.0	3.2	63.6	2.9	4.5
Thorax Rib 2 Deflection	mm	600	68.4	0.7	1.0	65.4	1.0	1.5	66.9	1.8	2.7
Thorax Rib 3 Deflection	mm	600	61.1	0.5	0.8	55.7	0.5	0.9	58.4	3.0	5.1
Abdominal Rib 1Deflection	mm	600	37.2	0.6	1.5	34.2	0.4	1.2	35.7	1.7	4.7
Abdominal Rib 2 Deflection	mm	600	23.6	0.8	3.5	22.5	0.8	3.5	23.0	0.9	4.1
Pelvis Y-axis Accel.	g	1000	65.4	0.6	0.9	67.7	1.4	2.1	66.5	1.6	2.4
Pubic Y-Axis Force	N	600	-1636.2	32.0	2.0	-1633.8	8.6	0.5	-1635.0	21.0	1.3

Table 5.8.2. NHTSA 6.7 m/s Padded Flat Wall Sled Test Peak Results Summary

NHTSA (Maltese) 6.7 m/s Padded Flat Wall Sled Test											
Channel	Units	CFC	OSRP 1			OSRP 2			Combined		
			Avg	Std Dev	% CV	Avg	Std Dev	% CV	Avg	Std Dev	% CV
Thorax Load Wall Sum	N	1000	5441.7	82.3	1.5	5313.3	83.2	1.6	5377.5	102.1	1.9
Abdomen Load Wall Sum	N	1000	2403.3	75.1	3.1	2329.2	138.9	6.0	2366.2	107.8	4.6
Pelvis Load Wall Sum	N	1000	6172.9	134.7	2.2	6001.3	325.3	5.4	6087.1	241.7	4.0
Upper Neck Y-axis Force	N	1000	475.5	11.1	2.3	447.8	11.5	2.6	461.6	18.2	3.9
Upper Neck X-axis Moment	N·m	600	33.4	0.8	2.4	34.5	0.3	0.9	34.0	0.8	2.4
Lower Neck Y-axis Force	N	1000	885.0	19.5	2.2	876.0	18.6	2.1	880.5	17.7	2.0
Lower Neck X-axis Moment	N·m	600	131.1	3.0	2.3	128.1	0.5	0.4	129.6	2.6	2.0
Shoulder Y-axis Force	kN	600	-1171.7	110.4	9.4	-1264.4	62.1	4.9	-1218.1	94.8	7.8
T1 Y-axis Accel.	g	180	22.5	0.7	3.3	22.7	1.2	5.1	22.6	0.9	3.9
T4 Y-axis Accel.	g	180	23.6	1.2	5.2	24.6	2.1	8.6	24.1	1.6	6.8
T12 Y-axis Accel.	g	180	32.8	1.2	3.8	35.9	1.2	3.2	34.4	2.0	5.9
Thorax Rib 1 Deflection	mm	600	38.8	2.2	5.6	38.2	1.7	4.4	38.5	1.8	4.6
Thorax Rib 2 Deflection	mm	600	50.2	0.6	1.2	45.8	1.0	2.2	48.0	2.5	5.3
Thorax Rib 3 Deflection	mm	600	45.1	0.3	0.7	40.3	1.2	3.0	42.7	2.8	6.5
Abdominal Rib 1Deflection	mm	600	28.1	0.5	1.7	26.0	1.3	4.9	27.0	1.4	5.3
Abdominal Rib 2 Deflection	mm	600	18.3	0.9	4.9	18.6	1.5	8.0	18.5	1.1	6.0
Pelvis Y-axis Accel.	g	1000	40.2	0.7	1.8	39.7	1.2	3.0	39.9	0.9	2.4
Pubic Y-Axis Force	N	600	-1174.0	26.0	2.2	-1138.7	103.0	9.0	-1156.4	69.9	6.0

Table 5.8.3. Heidelberg 6.8 m/s Rigid Wall Sled Test Peak Results Summary

Heidelberg 6.8 m/s Rigid Wall Sled Test											
Channel	**Units**	**CFC**	**OSRP 1**			**OSRP 2**			**Combined**		
			Avg	**Std Dev**	**% CV**	**Avg**	**Std Dev**	**% CV**	**Avg**	**Std Dev**	**% CV**
Thorax Load Wall Sum	N	1000	9476.4	362.3	3.8	8490.3	296.1	3.5	8983.4	606.2	6.7
Pelvis Load Wall Sum	N	1000	12671.2	504.6	4.0	12119.0	320.7	2.6	12395.1	493.5	4.0
Upper Neck Y-axis Force	N·m	600	556.5	12.7	2.3	507.0	6.6	1.3	531.8	27.8	5.2
Upper Neck X-axis Moment	N·m	600	50.9	2.4	4.8	41.8	1.8	4.4	46.3	5.2	11.2
Lower Neck Y-axis Force	kN	1000	1129.3	40.0	3.5	1034.4	15.8	1.5	1081.8	57.6	5.3
Lower Neck X-axis Moment	N·m	600	143.8	2.8	1.9	140.0	1.5	1.1	141.9	2.9	2.0
Shoulder Y-axis Force	kN	600	-2749.6	77.6	2.8	-2477.0	19.9	0.8	-2613.3	153.3	5.9
T1 Y-axis Accel.	g	180	39.6	0.7	1.7	46.3	2.1	4.5	42.9	3.8	8.8
T4 Y-axis Accel.	g	180	35.9	1.6	4.4	37.6	3.7	9.9	36.7	2.8	7.7
T12 Y-axis Accel.	g	180	55.3	2.8	5.0	52.9	1.9	3.7	54.1	2.6	4.8
Thorax Rib 1 Deflection	mm	600	See Note 1								
Thorax Rib 2 Deflection	mm	600	50.3	1.2	2.3	49.1	1.2	2.4	49.7	1.3	2.6
Thorax Rib 3 Deflection	mm	600	33.4	0.6	1.8	27.6	0.4	1.6	30.5	3.1	10.1
Abdominal Rib 1Deflection	mm	600	6.6	0.6	8.8	6.4	0.5	8.1	6.5	0.5	8.2
Abdominal Rib 2 Deflection	mm	600	31.2	0.7	2.3	27.8	0.8	3.0	29.5	1.9	6.5
Pelvis Y-axis Accel.	g	1000	69.4	3.5	5.1	69.8	2.3	3.3	69.6	2.8	4.0
Pubic Y-Axis Force	kN	600	-1705.0	38.3	2.2	-1752.1	61.2	3.5	-1728.6	54.2	3.1
Note 1: Thorax Rib 1 Deflection responses are suspect; plots contain flat tops; refer to Appendix D.											

Table 5.8.4. Wayne State 6.8 m/s Rigid Wall Sled Test Peak Summary

Wayne State 6.8 m/s Rigid Wall Sled Test											
Channel	Units	CFC	OSRP 1			OSRP 2			Combined		
			Avg	Std Dev	% CV	Avg	Std Dev	% CV	Avg	Std Dev	% CV
Shoulder load wall sum	N	1000	5326.8	151.4	2.8	4794.5	110.0	2.3	5060.7	314.7	6.2
Thorax Load Wall Sum	N	1000	4416.1	188.6	4.3	4476.2	436.7	9.8	4446.1	302.6	6.8
Abdomen Load Wall Sum	N	1000	3530.3	355.6	10.1	3258.8	180.8	5.5	3394.6	292.9	8.6
Pelvis Plate Force	N	1000	10130.2	173.6	1.7	10012.8	55.1	0.5	10071.5	131.9	1.3
Upper Neck Y-axis Force	N	1000	619.9	20.7	3.3	572.3	86.7	15.2	596.1	62.1	10.5
Upper Neck X-axis Moment	N·m	600	42.03	2.89	6.9	37.03	0.72	2.0	39.53	3.32	8.4
Lower Neck Y-axis Force	N	1000	1049.6	22.7	2.1	973.3	43.3	4.5	1011.5	52.0	5.1
Lower Neck X-axis Moment	N·m	600	131.43	2.29	1.7	136.83	3.80	2.8	134.13	4.08	3.0
Shoulder Y-axis Force	N	600	-2707.4	56.4	2.1	-2487.6	20.3	0.8	-2597.5	126.2	4.9
T1 Y-axis Accel.	g	180	41.47	1.35	3.3	43.47	1.53	3.5	42.47	1.69	4.0
T4 Y-axis Accel.	g	180	36.37	1.19	3.3	37.43	1.50	4.0	36.90	1.35	3.7
T12 Y-axis Accel.	g	180	63.37	1.92	3.0	57.83	2.35	4.1	60.60	3.59	5.9
Thorax Rib 1 Deflection	mm	600	65.87	0.49	0.7	65.33	0.06	0.1	65.60	0.43	0.7
Thorax Rib 2 Deflection	mm	600	43.53	1.33	3.1	49.23	2.67	5.4	46.38	3.65	7.9
Thorax Rib 3 Deflection	mm	600	32.63	1.34	4.1	28.30	1.04	3.7	30.47	2.61	8.6
Abdominal Rib 1Deflection	mm	600	30.47	1.89	6.2	24.37	0.67	2.7	27.42	3.57	13.0
Abdominal Rib 2 Deflection	mm	600	31.07	2.40	7.7	25.60	1.25	4.9	28.33	3.49	12.2
Pelvis Y-axis Accel.	g	1000	68.03	0.45	0.7	73.07	3.23	4.4	70.55	3.44	4.9
Pubic Y-Axis Force	N	600	-1.69	0.01	0.6	-1.64	0.02	1.3	-1.66	0.03	1.8

5.8.2 Discussion

As noted above in 4.3, sled testing conducted for this analysis was completed prior to NHTSA's initial research on the RibEye system and therefore this testing was completed using IR-TRACCs to measure rib deflections. In addition, the shoulder rib IR-TRACCs were removed from the dummies to eliminate the potential for damage to the instruments.

5.8.2.1 NHTSA 6.7 m/s Rigid Flat Wall Tests

In the NHTSA 6.7 m/s Rigid Flat Wall Tests, all repeatability CV values were below 5 percent for both dummies. The reproducibility CVs were also below 5 percent with the exception of three responses: abdomen load wall forces, T12 y-acceleration, and Thorax Rib 3 deflection. Of these responses, the abdomen load wall forces and Thorax Rib 3 deflection were only slightly greater than 5 at 5.2 and 5.1, respectively. T12 accelerations were repeatable for each individual dummy, however, OSRP-1 responses were consistently higher than that of OSRP-2.

5.8.2.2 NHTSA 6.7 m/s Padded Flat Wall Tests

As compared to the rigid wall tests, the NHTSA 6.7 m/s Padded Flat Wall Tests exhibited slightly higher CV values for repeatability and reproducibility. This observation, to some degree, may be attributed to possible variations in the stiffness of the ETHAFOAM padding and the method by which it is adhered to the impact wall. Despite this additional source of variation, the majority of the repeatability CV values were below 5 percent in the padded wall tests. Dummy OSRP-1 had three repeatability values greater than 5 percent: shoulder Y-force (9.4), T4 lateral acceleration (5.2), and thorax rib 1 displacement (5.6). The shoulder Y-force repeatability value is the result of one test in which the force was significantly higher than in the other two tests in the series. The sled wall does not extend vertically to the level of the shoulder (see Figure 4-3), thus the shoulder is not directly loaded by the wall, but rather via loads transmitted through the arm. Additionally, the dummy's head is not restrained and thus the NHTSA padded load wall condition might not accurately replicate the loading that would occur in a full-vehicle test. There were no observed differences in the dummy positioning or movement prior to impacting the wall.

Repeatability CV results for OSRP-2 were also mostly less than 5 percent in the NHTSA padded flat wall tests. CV results greater than 5 percent included: abdomen load wall forces (6.0), pelvis load wall forces (5.4), T1 and T4 lateral accelerations (5.1 and 8.6, respectively), abdomen rib 2 displacement (8.0) and pubic Y-force (9.0). The abdomen rib 2 CV value (8.0) can be attributed to the relatively small magnitude of the mean response value (avg. = 18.6mm); the standard deviation of the response is a reasonably low value of 1.5mm. The pubic Y-force CV result (9.0) is questionable due to the irregular responses recorded by the load cell. As demonstrated in Figure C-19 of Appendix C, there were multiple sporadic spikes in the response curves. As a result, the peak values were selected by visual review of the response curve. The pubic Y-force response curve for Test 2 of the series exhibited an unexplained spike which occurred at nearly the same instant in time as the peak responses selected for the other two tests. As a result, the peak value selected for Test 2 had to be chosen at a different time (when no unexplained spikes occurred) and was noticeably lower than that of the other two tests.

Several of the reproducibility CV results were greater than 5 percent: shoulder Y-force, T4 and T12 lateral accelerations, thorax rib 2 and 3 displacements, abdomen rib 1 and 2 displacements, and pubic Y-force. Thorax rib 2 displacement CV (5.3) was only slightly greater than 5 percent. While the CV for thorax rib 3 displacement was higher (6.5), its response magnitude was less than that of thorax rib 2, meaning that the overall peak thoracic rib displacement value would come from thorax rib 2's response. Additionally, it should be noted again that thoracic displacements in these sled tests were measured using IR-TRACCs; the dummy configuration planned for future Agency use will utilize the RibEye measurement system. Abdomen rib 1 and 2 exhibited CVs of 5.3 and 6.0, respectively, however, the magnitudes of the displacements were low and their standard deviations (1.4 mm and 1.1 mm, respectively) were both within reason. The pubic Y-force reproducibility was also affected by the unexplained spikes observed in the response of dummy OSRP-2 (refer to Fig. C-19).

5.8.2.3 Heidelberg Rigid Wall Sled Tests

The majority of repeatability responses for each dummy were less than 5 percent in the Heidelberg Rigid Wall test configuration. For OSRP-1 two CV values were greater than 5 percent: abdomen rib 1 displacement and pelvis lateral acceleration. The CV for abdomen rib 1 was 8.8, however this is a direct result of the low magnitude of the mean response, only 6.6 mm. The standard deviation of the response was a mere 0.6 mm, which is very low. Pelvis lateral acceleration was only slightly higher than 5 percent at 5.1.

Similarly, OSRP-2 only had two measures with CVs above 5 percent: T4 lateral acceleration and abdomen rib 1 displacement. And similar to the observation for OSRP-1, the mean abdomen rib 1 displacement was only 6.4 mm and the standard deviation was a reasonable 0.5 mm.

Several reproducibility responses in the Heidelberg Rigid Wall tests were above 5 percent. There are a number of factors which likely contribute to this result, including the reproducibility of each dummy's initial position relative to their respective impact walls; the frictional forces between each dummy and the bench seat that is present as the dummy slides toward the impact wall; and the time of impact and duration of interaction of each dummy with their respective load walls and individual load plates. Additionally, it's worth noting that the dummy's arm is positioned differently in the Heidelberg test as compared to the NHTSA test protocol. Whereas the NHTSA test positions the arm aligned with the dummy's torso, the Heidelberg test positioned the arm at approximately 20 degrees forward relative to the spine. This resulted in the arm bending around the torso for the Heidelberg test whereas the arm compressed laterally against the torso in the NHTSA tests.

Reproducibility responses that exceeded 5 percent included: thorax plate loading, upper neck Y-force, upper neck X-moment, lower neck Y-force, shoulder Y-force, T1 and T4 lateral accelerations, and the displacements for thorax rib 3, abdomen ribs 1 and 2. With regard to the neck forces and moments, this may have been the result of having no method of head restraint which led to unrealistic head excursions. The arm positioning and subsequent bending under load likely had a negative impact on the shoulder response reproducibility. Thorax rib 3's point of impact was near the lower edge of the thorax plate and any variation in the amount of plate coverage on the rib would have resulted in variable rib displacements. Abdomen rib 1's mean response was low and although the CV score was above 5 percent, the actual variation in response was low.

5.8.2.4 Wayne State Rigid Wall Tests

Before discussing the CV values from the tests, it's worth noting that the Wayne State Rigid Wall test was a severe test condition. This observation is supported by the thorax rib 1 displacement responses. As seen in Appendix D, the thorax rib 1 deflection measurements exhibited a flat-top response near the maximum range of the transducer. This severity potentially makes this test condition a poor choice for evaluating repeatability and reproducibility. This observation should be taken into account as the CV analysis is presented.

The majority of repeatability responses for each dummy were less than 5 percent in the Wayne State Rigid Wall test configuration. For OSRP-1, four CV values were greater than 5 percent: abdomen load wall force, upper neck X-moment, and displacements of abdomen ribs 1 and 2. It appears that the variation in abdomen rib displacement and abdomen load wall force may be related. In one of the three repeat tests, the abdomen load wall force was approximately 20 percent lower than that observed in the remaining two tests. In that same test, the abdomen rib displacements were approximately 15 percent less. Although review of the high-speed video doesn't reveal any obvious differences in dummy kinematics, it's possible that the abdomen ribs interacted differently with the abdomen load plate in the one outlier test. Similar to observations in other test conditions, the variation observed in the neck response may be attributed to the unrealistic lack of head restraint.

OSRP-2 also had four CV values that exceeded 5 percent: thorax and abdomen load wall forces, upper neck Y-force, and thorax rib 2 displacement. The thorax load wall force was approximately 4050 N in the first test and increased with each successive test by roughly 400 N. Review of the high-speed video doesn't reveal any obvious differences in dummy kinematics and thus it's unclear what may have caused this trend, although it may be related to the earlier discussion of test severity and exercising the thoracic ribs near their maximum displacement levels.

Reproducibility responses that exceeded 5 percent included: all of the load plate forces (shoulder, thorax, abdomen and pelvis), upper neck Y-force, upper neck X-moment, lower neck Y-force, T12 lateral accelerations, and the displacements for thorax ribs 2 and 3, and abdomen ribs 1and 2. In assessing reproducibility of the responses, the test severity should again be considered.

6 References

International Organization for Standardization. (2018). *Design and performance specifications for the WorldSID 50th percentile male side impact dummy* (ISO TS 15830-5).

Rhule, H., Millis, W., Mallory, A., & Stricklin, J. (2019, July). *Determination of optimal RibEye LED locations in the WorldSID 50th percentile male dummy* (Report No. DOT HS 812 758). National Highway Traffic Safety Administration.

Rhule, H., Moorhouse, K., Donnelly, B., & Stricklin, J. (2009). *Comparison of WorldSID and ES-2RE Biofidelity Using an Updated Biofidelity Ranking System.* Proceedings of the 21st International Conference on the Enhanced Safety of Vehicles (Report No. 09-0563).

In addition to these references, two additional reports are currently in preparation by NHTSA's VRTC and are expected to be published in 2022. They are:

WorldSID-50th Percentile Male Qualification Procedures Manual.

Evaluation of RibEye Installed in the WorldSID 50th Percentile Dummy.

Appendix A: Qualification Test Data

Table A.1. Frontal Head Drop Results

Lab/ Dummy	Test Number	Peak Resultant Acceleration (g)	Peak Lateral (Ay) Acceleration (g)	Lab/ Dummy	Test Number	Peak Resultant Acceleration (g)	Peak Lateral (Ay) Acceleration (g)
Lab A EA-7820	1	253.4	10.6	VRTC OSRP-1	1	240.9	10.9
	2	251.0	7.5		2	229.2	5.3
	3	248.5	7.0		3	233.8	13.0
	4	250.4	9.6		4	231.6	10.8
	5	248.3	14.9		5	233.1	10.8
Lab B EA-7820	1	235.5	9.1	VRTC OSRP-2	1	238.6	6.8
	2	247.9	3.6		2	236.1	12.3
	3	239.0	10.9		3	236.1	3.0
	4	228.2	9.1		4	230.7	11.5
	5	244.0	8.8		5	234.0	2.6
Lab C ES-7820	1	255.4	10.5	VRTC 014	1	241.9	7.9
	2	256.0	5.2		2	241.1	23.4[1]
	3	255.6	2.2		3	238.9	4.0
	4	255.2	5.6		4	238.3	15.7[1]
	5	254.5	13.8		5	239.8	3.6
Lab D EA-7820	1	254.3	2.0	VRTC 016	1	235.3	11.6
	2	253.9	5.8		2	233.1	9.6
	3	249.4	4.0		3	234.0	2.2
	4	248.2	5.6		4	234.1	13.6
	5	250.9	5.7		5	231.6	4.6

[1] Peak lateral (Y-axis) acceleration exceeded recommended limit of 15g; however, X- and Z-axis accelerations were consistent with tests not exceeding 15g peak lateral acceleration.

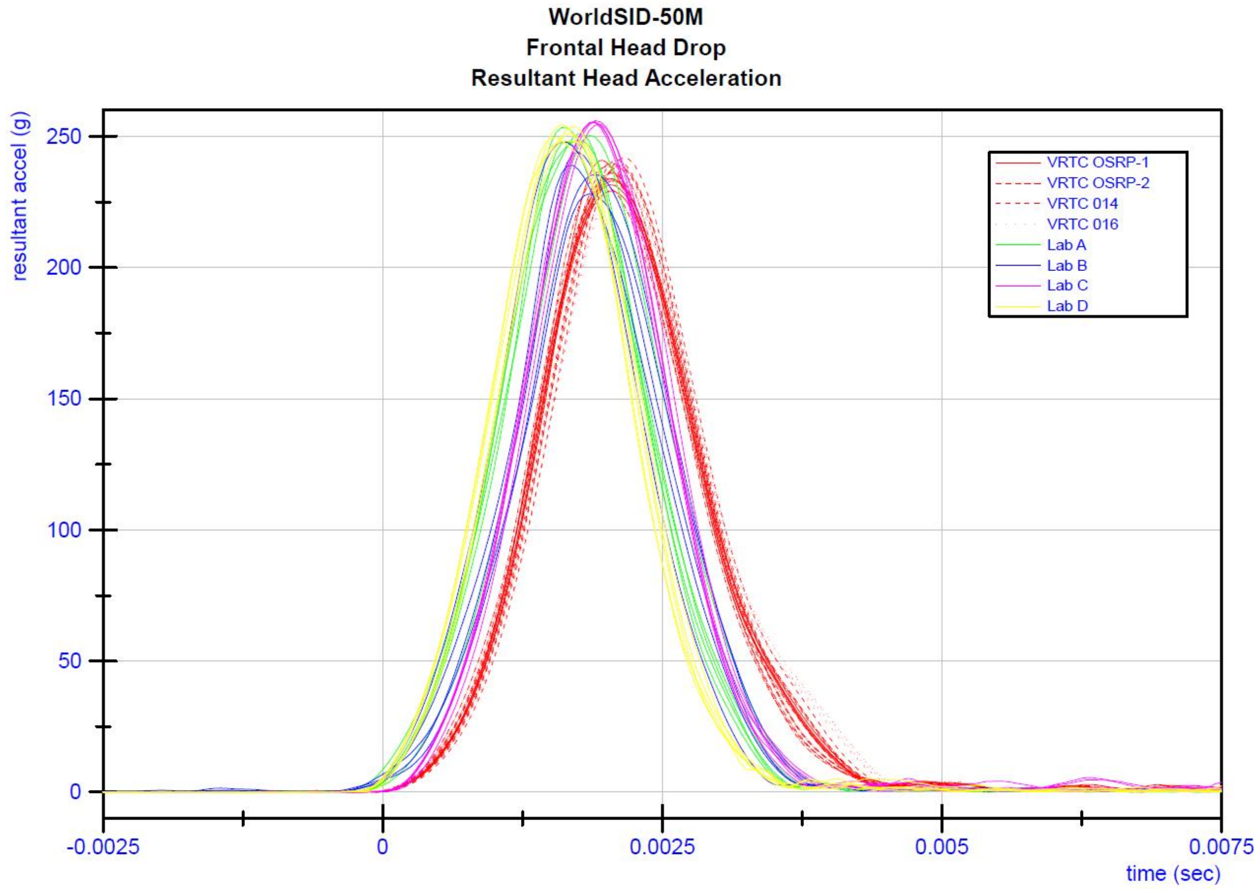

Figure A-1. Frontal Head Drop Resultant Acceleration

Table A.2. Lateral Head Drop Test Results

Lab/ Dummy	Left/ Right	Test Number	Peak Resultant Accel (g)	Peak Fore/Aft (Ax) Accel (g)
Lab A EA-7820	Left	1	122.3	5.1
		2	122.9	3.5
		3	128.2	4.1
		4	122.9	5.7
		5	112.8	2.5
Lab B EA-7820	Left	1	120.0	5.4
		2	121.0	4.4
		3	122.0	4.9
		4	121.6	3.0
		5	122.1	2.5
Lab C ES-7820	Left	1	120.4	1.8
		2	121.7	3.2
		3	119.9	1.6
		4	118.9	3.3
		5	115.7	1.2
	Right	1	123.1	2.5
		2	122.4	1.8
		3	122.8	1.2
		4	118.7	1.7
		5	119.9	3.9
Lab D EA-7820	Left	1	113.0	2.6
		2	116.9	2.6
		3	115.9	2.1
		4	117.0	1.8
		5	122.1	4.0
	Right	1	119.9	2.1
		2	111.1	1.6
		3	121.0	2.9
		4	n/a	n/a
		5	122.6	3.3
VRTC OSRP-1	Left	1	118.0	4.8
		2	116.7	4.5
		3	117.1	5.2
		4	117.0	10.4
		5	115.8	8.7
VRTC OSRP-1	Right	1	118.6	1.8
		2	114.8	6.9
		3	119.2	7.9
		4	116.7	1.8
		5	117.8	7.0
VRTC OSRP-2	Left	1	117.4	3.4
		2	118.2	11.0
		3	117.7	6.1
		4	116.0	2.4
		5	116.2	4.8
	Right	1	119.3	10.8
		2	114.8	2.9
		3	118.5	1.6
		4	119.7	10.2
		5	118.5	4.4
VRTC 014	Left	1	118.0	7.4
		2	117.8	3.4
		3	117.6	5.6
		4	117.6	8.4
		5	116.3	4.8
	Right	1	116.8	4.7
		2	118.3	6.0
		3	118.7	3.6
		4	118.0	7.5
		5	119.4	5.6
VRTC 016	Left	1	112.7	13.6
		2	110.5	3.0
		3	110.9	4.1
		4	111.5	8.4
		5	112.4	8.9
	Right	1	112.7	3.4
		2	112.3	3.4
		3	111.3	3.9
		4	111.9	4.3
		5	112.5	3.2

Note: Lab D, right side, test 4 exhibited an unusual resultant head acceleration response curve and has therefore been omitted from the analysis.

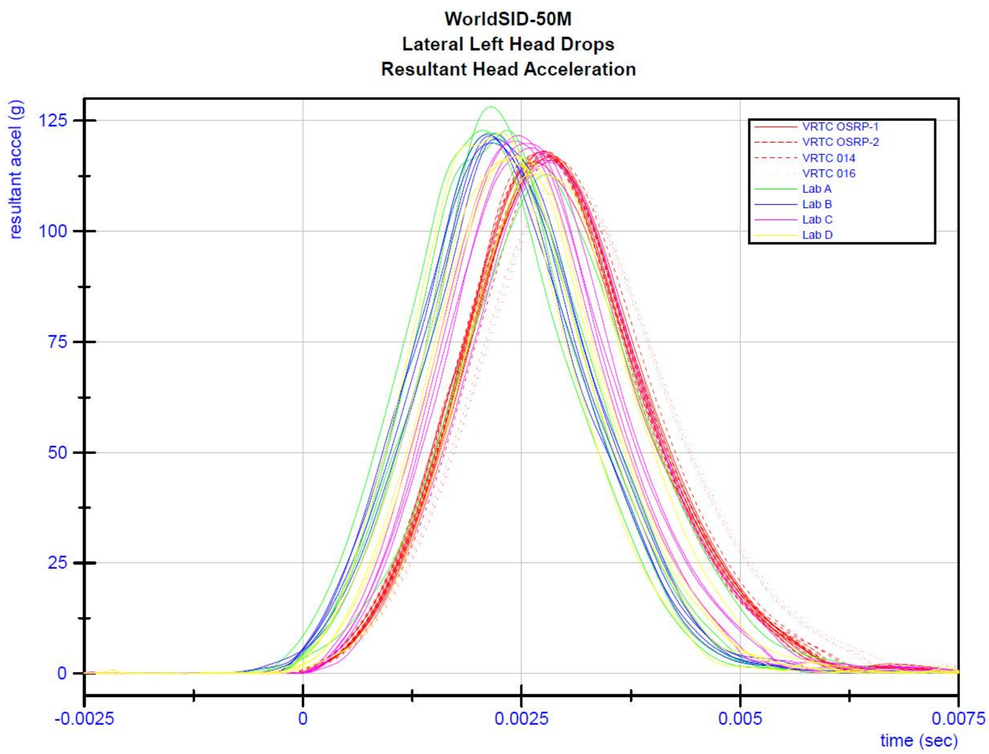

Figure A-2. Lateral Left Head Drop Resultant Acceleration

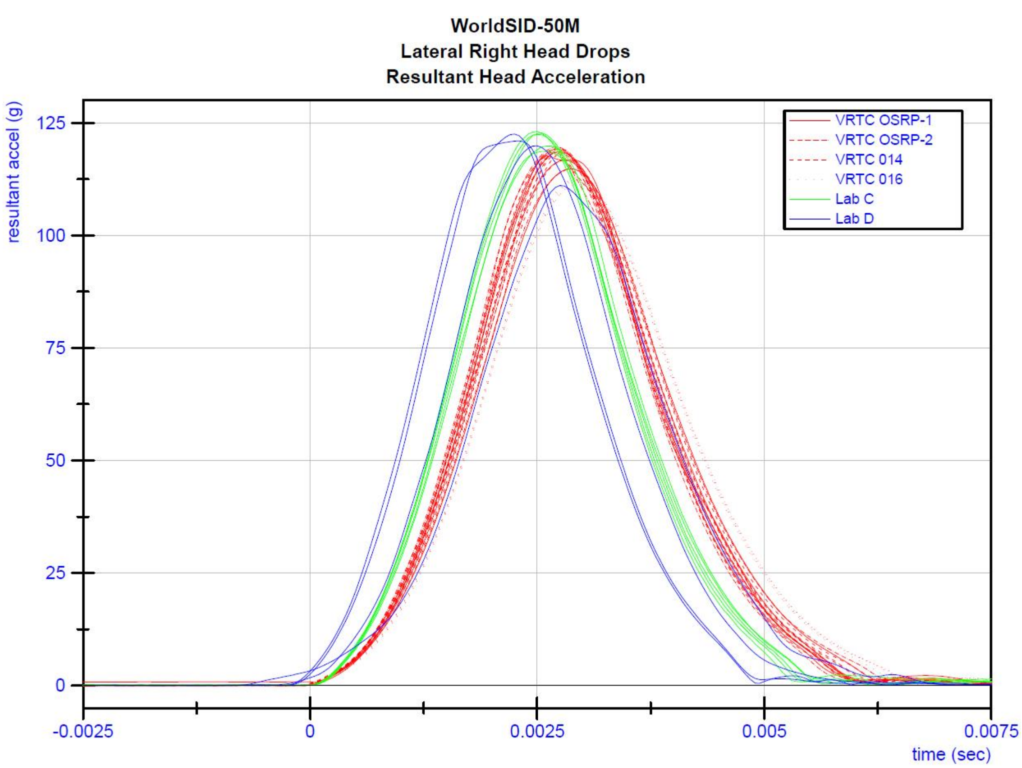

Figure A-3. Lateral Right Head Drop Resultant Acceleration

Table A.3. Lateral Neck Pendulum Test Results – Outside Labs

Lab/ Dummy S/N	Test #	Side	Velocity	Pendulum Pulse			D-Plane		Occipital Condyle		Peak Headform Angular Velocity (deg/s)
				4 ms	8 ms	12 ms	Peak Rotation (deg)	time - Peak to 0 deg (msec)	Peak Moment (Nm)	time - Peak to 0 Nm (msec)	
Lab A EA7820	1	Left	3.45	0.87	1.77	2.76	54.5	62.8	61.9	78.5	2319.5
	2		3.45	0.89	1.83	2.85	55.1	64.4	62.5	78.1	2343.5
	3		3.45	0.96	1.96	2.92	54.9	63.5	63.0	77.7	2337.5
	4		3.44	0.93	1.89	2.83	55.1	64.6	62.5	77.5	2322.7
	5		3.45	0.93	1.90	2.87	55.6	64.7	62.8	77.8	2334.8
Lab B EA7820	1	Left	3.38	0.96	1.85	2.83	55.2	63.2	61.7	76.9	2280.5
	2		3.41	0.93	1.82	2.86	55.1	65.8	61.7	77.0	2291.2
	3		3.42	0.93	1.80	2.79	55.4	65.5	61.6	76.6	2279.1
	4		3.41	0.96	1.88	2.94	56.4	62.3	61.9	77.0	2308.0
	5		3.41	0.94	1.87	2.94	56.0	62.2	62.2	76.7	2315.6
Lab C EA7820	1	Left	3.32	0.90	1.74	2.64	52.9	62.3	59.7	77.3	2220.8
	2		3.39	0.99	1.89	2.87	53.7	61.1	61.1	77.4	2280.9
	3		3.39	0.92	1.75	2.65	53.4	61.2	60.9	77.2	2264.4
	4		3.35	0.96	1.86	2.74	52.9	61.3	60.0	77.7	2238.9
	5		3.39	0.93	1.78	2.66	53.4	60.6	60.8	77.2	2253.3
	1	Right	3.40	0.96	1.84	2.76	52.8	61.8	62.9	76.6	2301.0
	2		3.39	0.95	1.83	2.75	53.0	62.4	62.5	76.7	2299.8
	3		3.38	0.97	1.82	2.74	52.5	61.7	62.4	76.7	2277.7
	4		3.37	0.86	1.67	2.54	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]
	5		3.38	0.95	1.83	2.77	52.9	66.0	62.2	76.9	2288.1
Lab D EA7820	1	Left	3.36	0.91	1.84	2.87	54.3	64.0	62.1	75.7	2280.5
	2		3.36	0.92	1.85	2.94	53.4	62.9	61.7	77.3	2291.8
	3		3.36	0.95	1.86	2.94	53.1	57.9	61.9	77.0	2285.6
	4		3.36	0.92	1.85	2.82	53.0	64.1	61.9	77.3	2282.7
	5		3.36	0.93	1.83	2.87	52.9	64.1	61.8	77.1	2280.9

[1] Test did not meet pendulum pulse requirements

Table A.4. Lateral Neck Pendulum Test Results - VRTC

Lab/ Dummy S/N	Test #	Side	Velocity (m/s)	Pendulum Pulse 4 ms	8 ms	12 ms	D-Plane Peak Rotation (deg)	time - Peak to 0 deg (msec)	Occipital Condyle Peak Moment (Nm)	time - Peak to 0 Nm (msec)	Peak Headform Angular Velocity (deg/s)
VRTC EB9641	1	Left	3.40	1.03	1.98	2.99	55.71	67.85	52.63	75.45	2180.8
	2		3.40	1.08	2.07	3.03	56.05	66.9	52.84	74.6	2179.5
	3		3.40	1.09	2.06	3.06	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]
	4		3.40	0.94	1.86	2.80	55.74	67.45	51.63	75.45	2147.4
	5		3.40	1.04	1.95	2.91	56.02	67.1	52.13	74.65	2173.0
	1	Right	3.34	0.95	1.89	2.87	54.75	66.7	59.26	75.95	2211.3
	2		3.34	0.97	1.86	2.90	55.28	66.65	58.47	75.7	2200.3
	3		3.34	1.05	2.04	3.12	55.13	66.9	59.66	75.6	2219.0
	4		3.37	1.01	1.98	3.02	55.75	66.2	59.89	75.95	2229.9
	5		3.38	1.00	1.94	2.90	55.73	66.7	59.57	75.9	2219.0
VRTC DW6607	1	Left	3.40	1.04	2.02	3.07	55.78	64.3	55.66	75.05	2235.8
	2		3.40	1.02	1.95	2.93	56.05	64.75	55.11	74.7	2229.9
	3		3.40	0.99	1.94	2.87	56.05	64.65	54.74	74.6	2214.4
	4		3.40	1.01	1.97	2.93	56.03	64.8	55.03	74.8	2225.3
	5		3.40	1.00	1.96	2.89	56.11	64.7	54.93	75.05	2218.7
	1	Right	3.40	1.05	2.00	3.07	55.25	64.55	56.07	74.45	2249.2
	2		3.40	1.08	2.12	3.23	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]
	3		3.40	1.09	2.06	3.03	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]
	4		3.40	1.06	2.03	3.09	55.78	64.8	55.52	74.45	2248.8
	5		3.40	1.07	2.08	3.10	55.79	65.45	55.70	74.45	2249.8
VRTC EE9391	1	Left	3.39	1.03	2.03	3.09	58.32	67.65	65.95	78.5	2412.3
	2		3.39	0.99	1.92	2.95	58.32	66.65	66.03	78.65	2395.5
	3		3.39	0.95	1.92	2.91	58.39	67.15	66.28	78.4	2398.6
	4		3.39	0.97	1.88	2.83	58.63	66.85	65.16	78.8	2392.6
	5		3.39	0.98	1.87	2.81	56.93	65.7	61.84	76.3	2307.1
	1	Right	3.38	0.98	1.93	2.92	56.81	65.2	63.85	75.5	2330.5
	2		3.39	0.98	1.95	3.00	56.67	64.25	64.08	75.05	2346.4
	3		3.39	0.97	1.90	2.87	56.59	64.45	63.64	75.2	2323.6
	4		3.39	1.02	1.99	3.06	56.92	64.3	64.11	75.25	2346.6
	5		3.41	0.98	1.99	3.08	56.96	64.65	64.22	75.4	2347.4

[1] Test did not meet pendulum pulse requirements

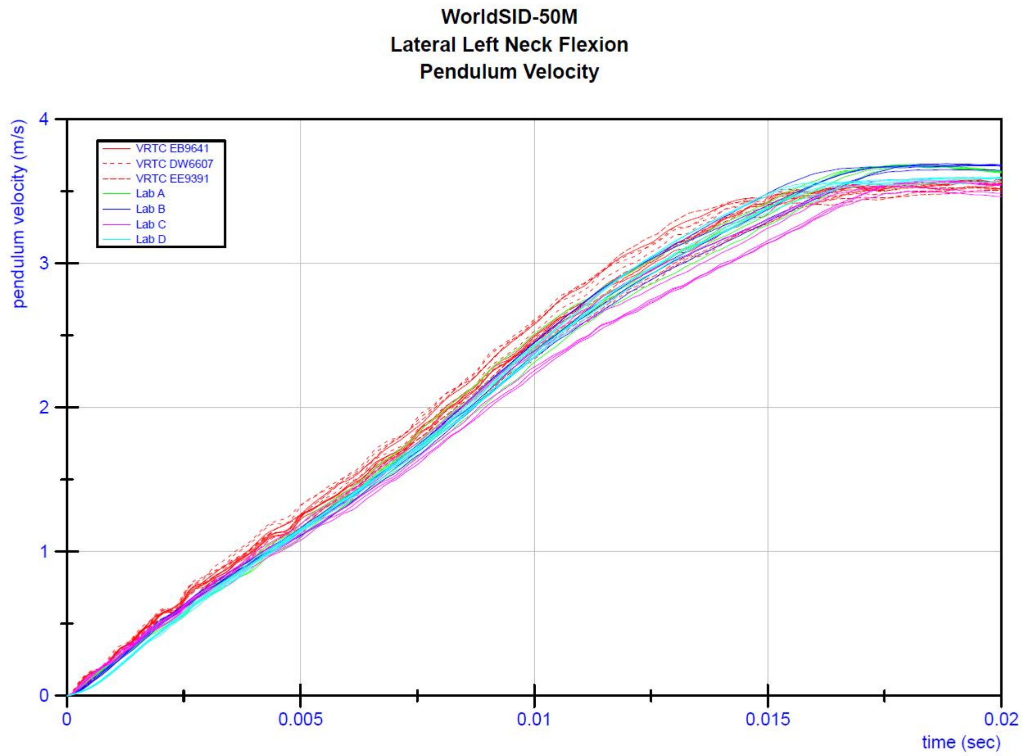

Figure A-4. Lateral Left Neck Pendulum Velocity

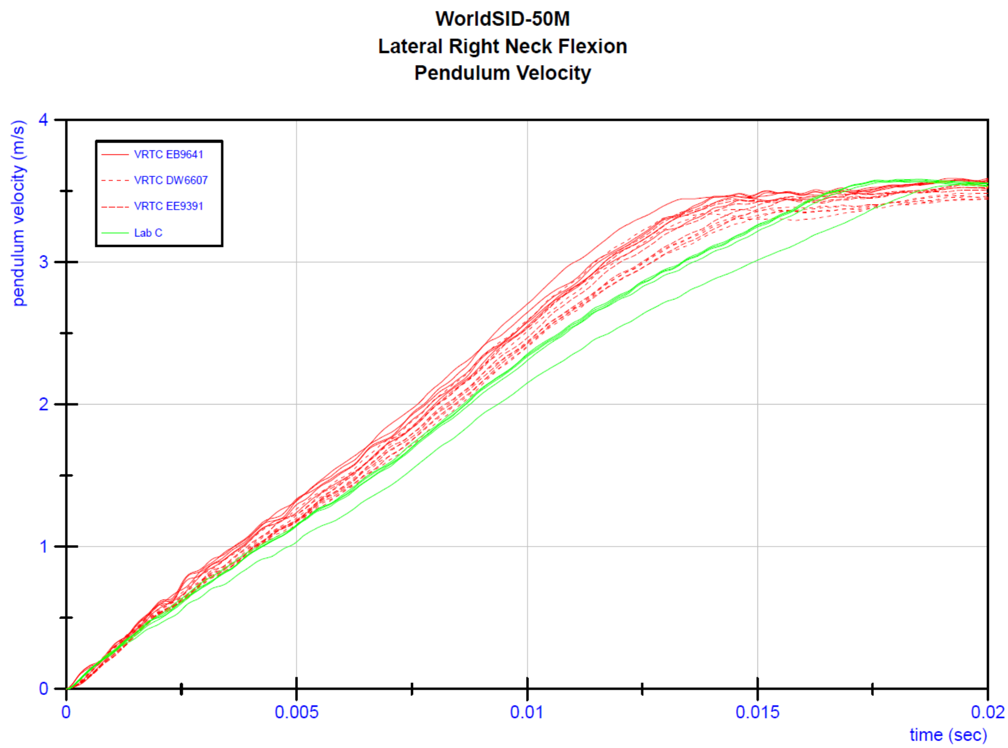

Figure A-5. Lateral Right Neck Pendulum Velocity

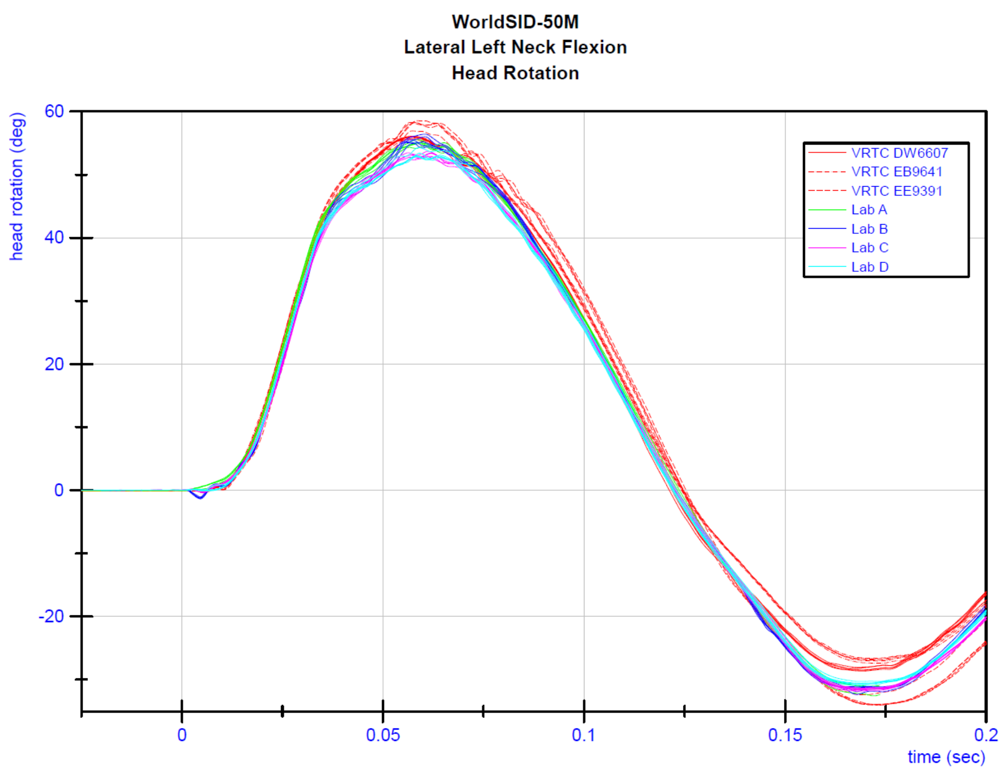

Figure A-6. Lateral Left Neck Pendulum – Head Rotation

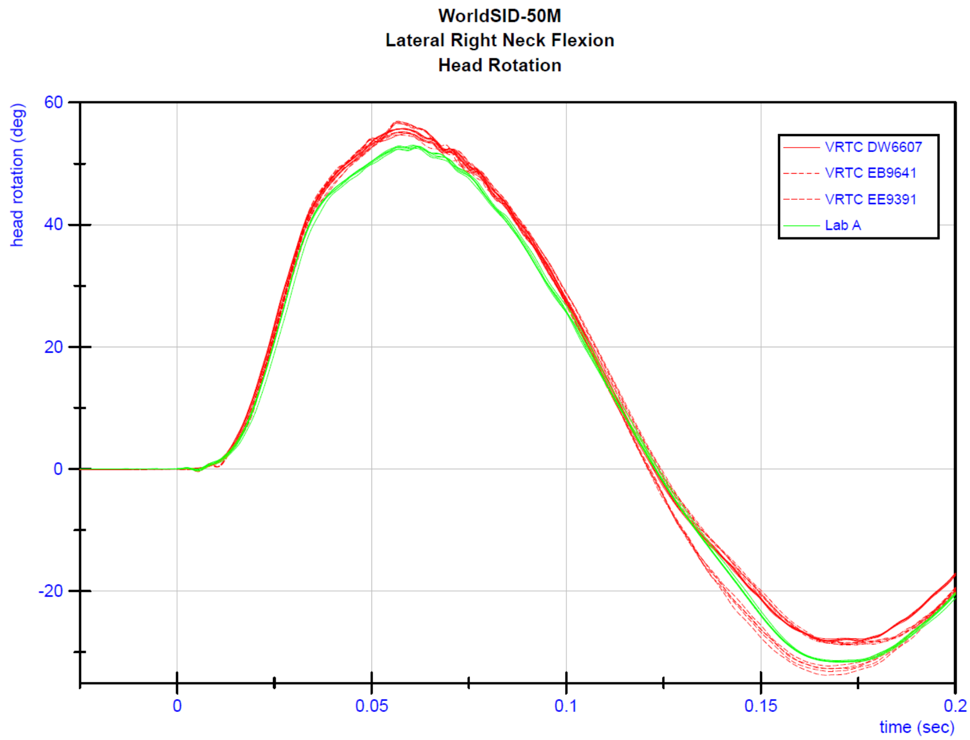

Figure A-7. Lateral Right Neck Pendulum – Head Rotation

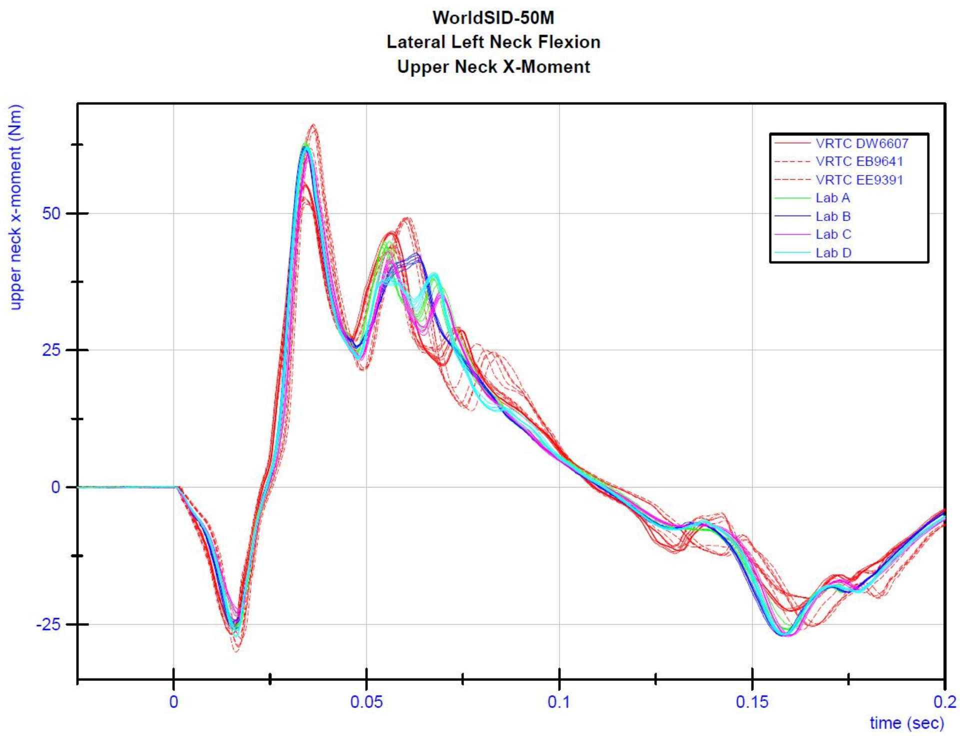

Figure A-8. Lateral Left Neck Pendulum – Neck X-Moment

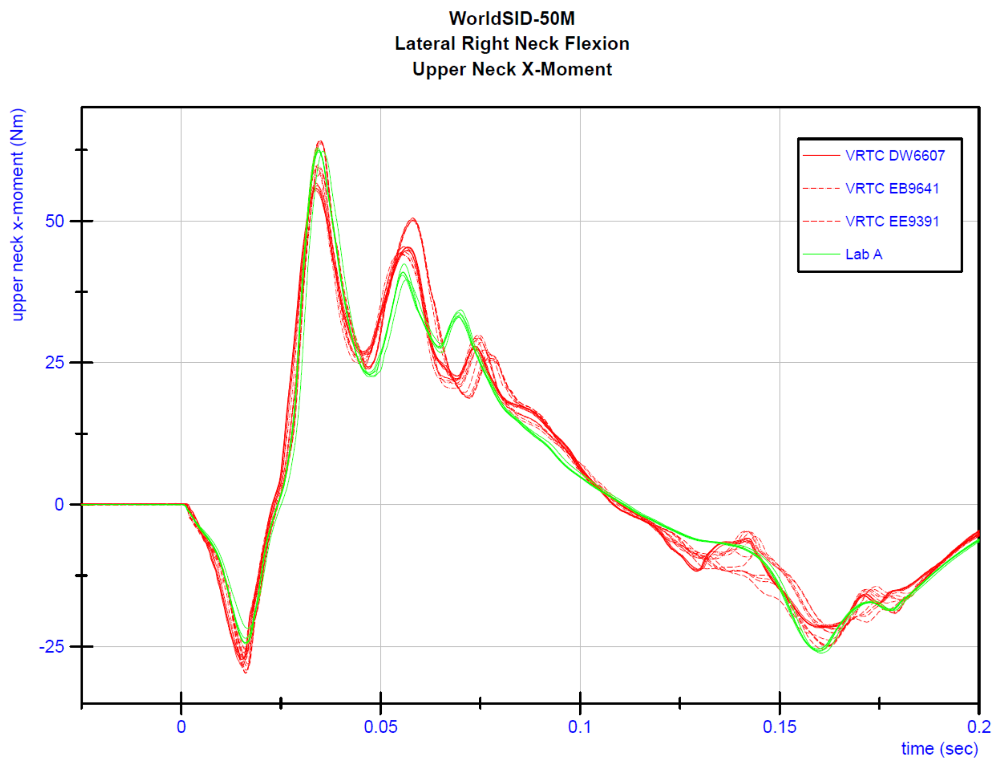

Figure A-9. Lateral Right Neck Pendulum – Neck X-Moment

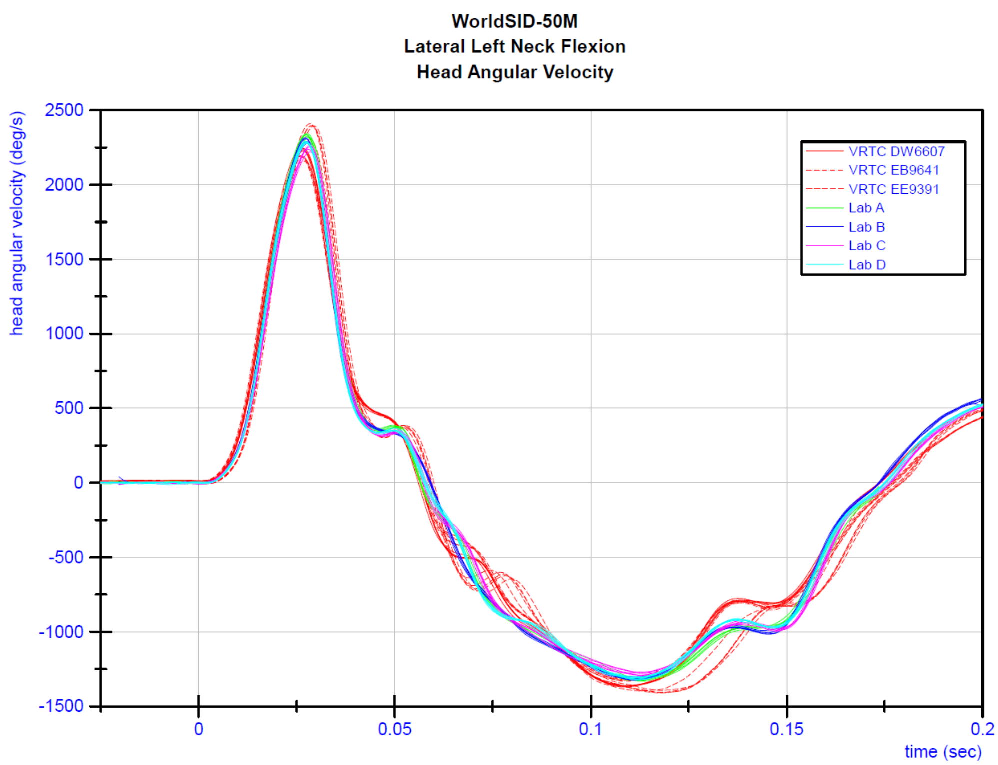

Figure A-10. Lateral Left Neck Pendulum – Head Angular Velocity

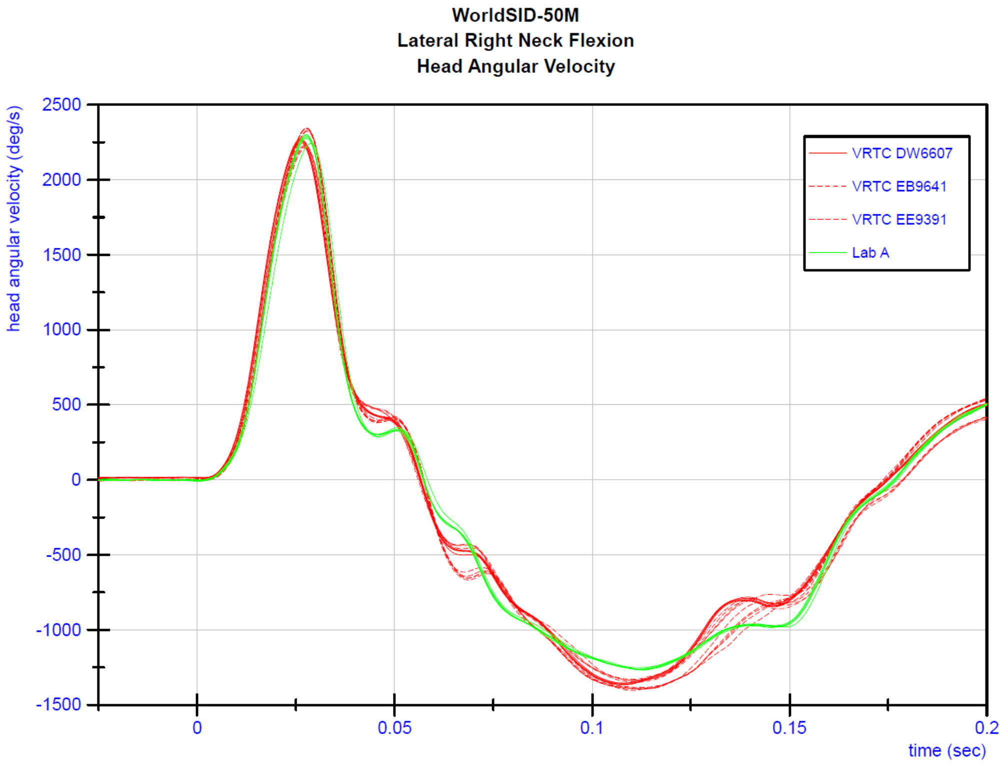

Figure A-11. Lateral Right Neck Pendulum – Head Angular Velocity

Table A.5. Neck Torsion Test Results – Outside Labs

Lab/ Neck S/N	Side	Test No.	Impact Velocity (m/s)	Pendulum Pulse 10 ms (m/s)	Pendulum Pulse 15 ms (m/s)	Pendulum Pulse 20 ms (m/s)	Peak Lower Neck Z Moment (N-m)	Peak Neck Fixture Rotation (deg)	Decay Time to 0 deg from peak angle (ms)	Peak Head Angular Rate Ꮚz (deg/sec)
Lab A	Left	3	5.20	2.14	3.32	4.43	37.0	45.9	39.3	1478.3
		4	5.20	2.11	3.23	4.31	36.9	46.5	39.6	1478.4
		5	5.21	2.18	3.31	4.37	37.4	46.6	39.5	1492.3
		6	5.21	2.09	3.15	4.17	n/a[1]	n/a[1]	n/a[1]	n/a[1]
		7	5.21	2.12	3.19	4.24	n/a[1]	n/a[1]	n/a[1]	n/a[1]
Lab B	Left	2	5.21	2.23	3.26	4.41	39.0	44.5	39.7	1438.1
		3	5.26	2.23	3.31	4.53	39.4	45.4	39.8	1470.3
		4	5.21	2.30	3.39	4.61	38.9	45.1	39.7	1459.5
		5	5.22	2.26	3.36	4.66	39.1	45.4	39.6	1485.9
		6	5.28	2.33	3.39	4.61	39.9	46.3	39.0	1515.7
Lab C	Left	4	5.21	2.21	3.33	4.46	37.9	46.1	40.1	1499.5
		5	5.19	2.22	3.37	4.51	38.1	46.3	39.8	1505.8
		7	5.20	2.17	3.29	4.43	37.9	45.9	39.9	1495.3
		8	5.20	2.21	3.39	4.52	38.0	46.1	39.8	1502.7
		9	5.20	2.16	3.25	4.35	37.8	45.9	39.8	1490.7
Lab D	Left	11	5.20	2.19	3.37	4.52	38.6	45.6	40.2	1483.0
		12	5.20	2.21	3.35	4.51	38.4	45.8	40.3	1487.5
		14	5.20	2.16	3.31	4.48	38.3	46.0	40.2	1490.7
		15	5.20	2.17	3.34	4.50	38.4	46.0	40.0	1489.4
		16	5.20	2.16	3.33	4.48	38.3	46.1	40.1	1496.2
	Right	1	5.20	2.14	3.28	4.40	38.6	46.0	40.1	1515.5
		3	5.20	2.21	3.40	4.53	38.6	46.4	40.1	1524.4
		4	5.17	2.13	3.26	4.35	38.4	46.1	40.0	1502.3
		5	5.20	2.16	3.31	4.43	38.5	46.1	40.1	1508.8
		7	5.20	2.25	3.43	4.57	38.6	46.5	40.4	1540.3

[1] Test did not meet pendulum pulse requirements

Table A.6. Neck Torsion Test Results - VRTC

Lab/ Neck S/N	Side	Test No.	Impact Velocity (m/s)	Pendulum Pulse 10 ms (m/s)	Pendulum Pulse 15 ms (m/s)	Pendulum Pulse 20 ms (m/s)	Peak Lower Neck Z Moment (N-m)	Peak Neck Fixture Rotation (deg)	Decay Time to 0 deg from peak angle (ms)	Peak Head Angular Rate Ɯz (deg/sec)
VRTC EB9641	Left	1	5.20	2.15	3.36	4.52	36.8	46.5	39.4	1500.0
		2	5.21	2.18	3.34	4.48	36.6	46.0	39.1	1481.9
		3	5.20	2.32	3.55	4.69	37.0	46.3	39.1	1504.2
		4	5.20	2.33	3.60	4.77	36.9	46.5	39.4	1511.0
		5	5.20	2.29	3.51	4.63	36.9	49.3	39.3	1498.5
		6	5.21	2.21	3.40	4.56	36.0	46.9	39.8	1484.7
	Right	1	5.20	2.19	3.39	4.49	36.8	46.7	39.6	1497.0
		2	5.20	2.15	3.31	4.43	36.7	46.5	39.7	1480.0
		3	5.21	2.24	3.45	4.61	37.0	46.7	39.7	1517.0
		4	5.21	2.23	3.45	4.62	37.0	46.8	39.8	1513.8
		5	5.21	2.23	3.42	4.56	37.0	46.7	39.6	1501.0
VRTC DW6607	Left	1	5.20	2.32	3.56	4.75	38.2	46.4	38.5	1500.2
		2	5.20	2.31	3.57	4.80	38.3	46.5	38.6	1522.0
		3	5.20	2.23	3.46	4.66	38.2	46.3	38.6	1500.9
		4	5.20	2.29	3.53	4.75	38.2	46.3	38.6	1503.1
		5	5.20	2.25	3.52	4.72	38.3	46.3	38.5	1507.7
	Right	1	5.20	2.21	3.45	4.58	38.4	45.5	38.6	1478.7
		2	5.21	2.23	3.46	4.67	38.5	45.8	38.5	1496.8
		3	5.20	2.22	3.44	4.63	38.0	45.8	38.8	1500.1
		4	5.20	2.22	3.46	4.67	38.2	46.5	39.0	1516.8
		5	5.20	2.40	3.72	4.98	n/a[1]	n/a[1]	n/a[1]	n/a[1]
VRTC EE9391	Left	1	5.23	2.32	3.52	4.74	38.1	46.5	37.8	1551.1
		2	5.23	2.24	3.40	4.58	38.0	46.5	37.9	1524.7
		3	5.22	2.28	3.47	4.63	38.1	46.4	37.8	1528.2
		4	5.23	2.37	3.57	4.78	38.2	46.6	37.8	1553.1
		5	5.22	2.32	3.54	4.70	38.2	46.5	37.8	1546.0
	Right	1	5.23	2.26	3.45	4.69	38.3	45.8	37.5	1559.8
		2	5.23	2.32	3.50	4.71	38.6	46.2	37.5	1558.6
		3	5.22	2.31	3.46	4.64	38.5	45.8	37.2	1523.8
		4	5.22	2.29	3.46	4.65	38.5	45.7	37.3	1537.6
		5	5.22	2.31	3.51	4.67	38.5	46.0	37.5	1549.9

[1] Test did not meet pendulum pulse requirements

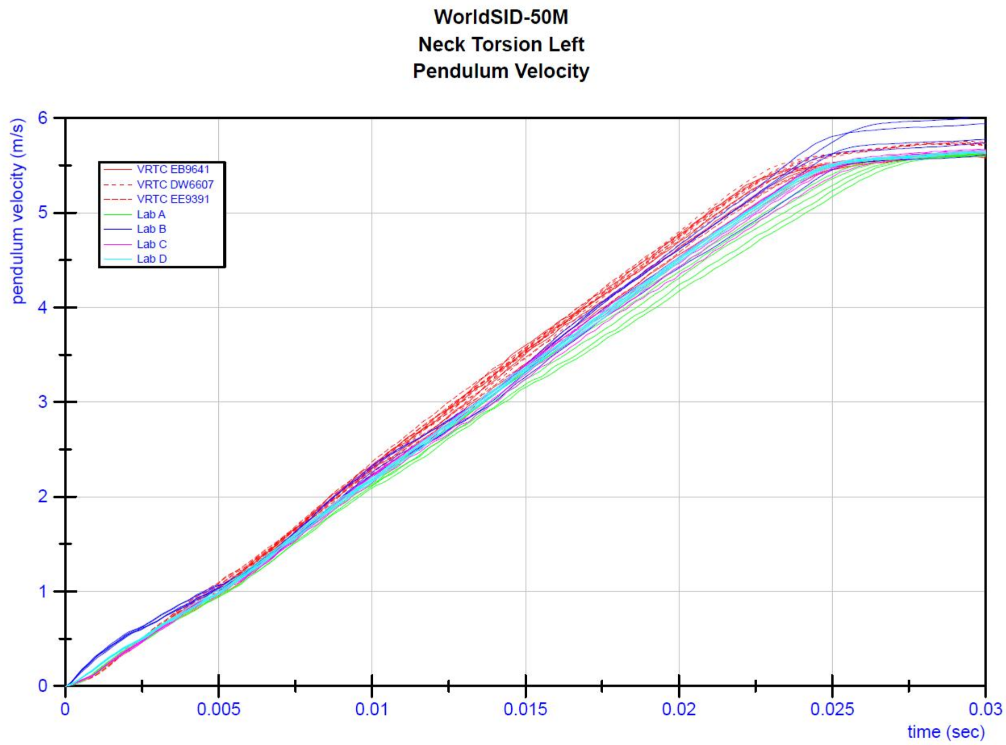

Figure A-12. Neck Torsion Left – Pendulum Velocity

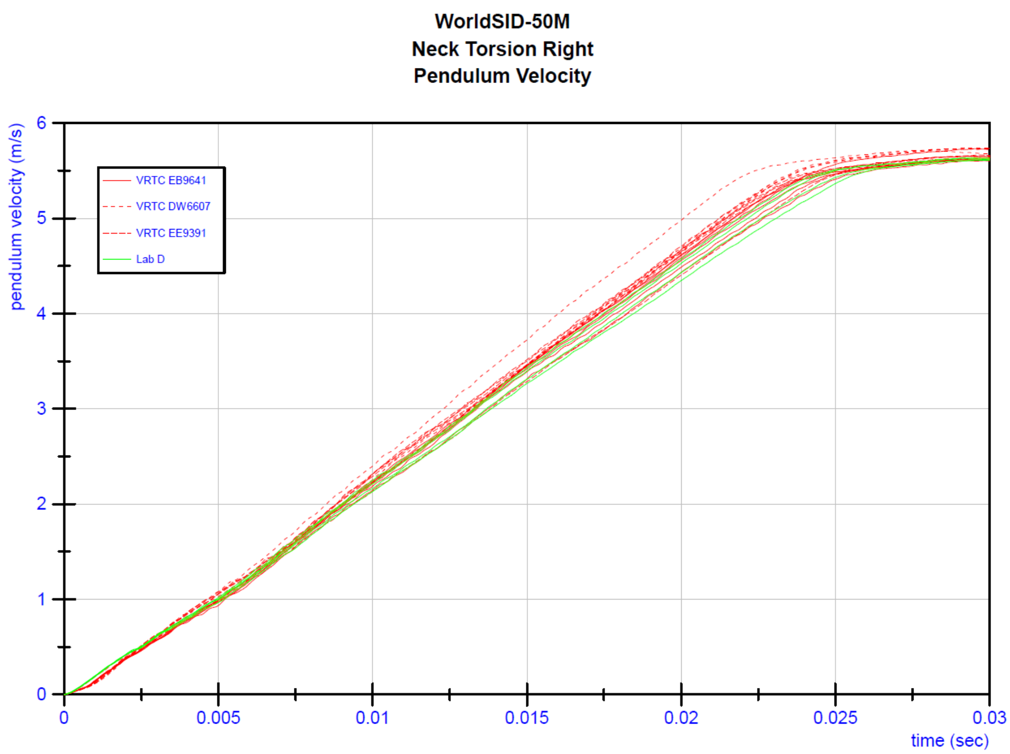

Figure A-13. Neck Torsion Right – Pendulum Velocity

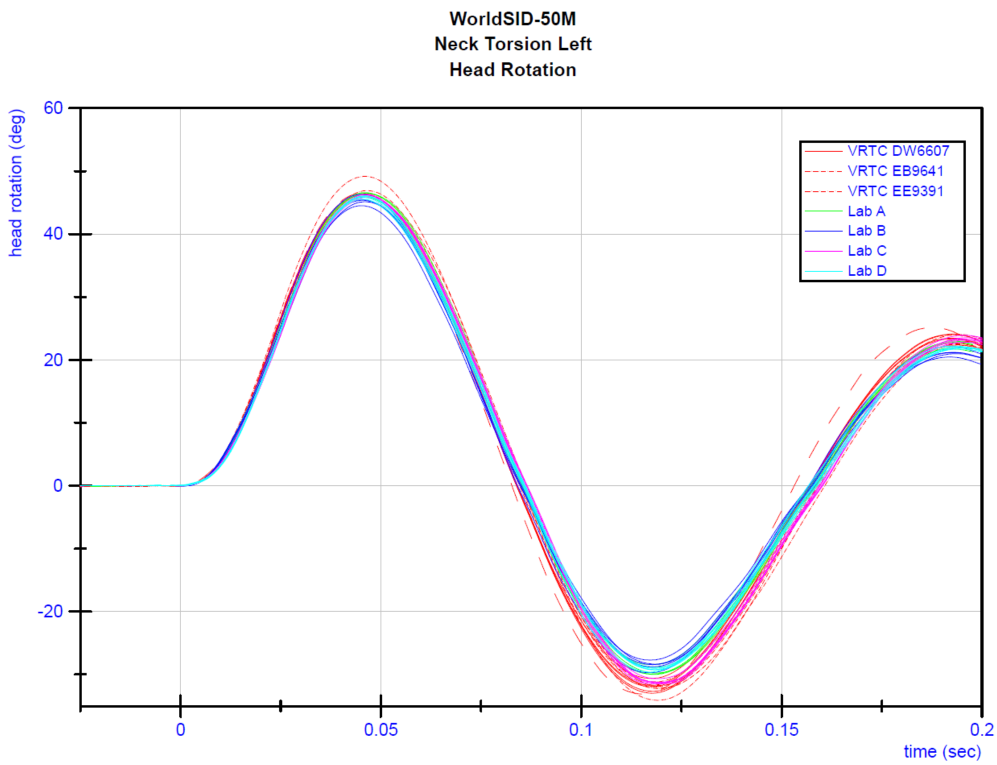

Figure A-14. Neck Torsion Left – Head Rotation

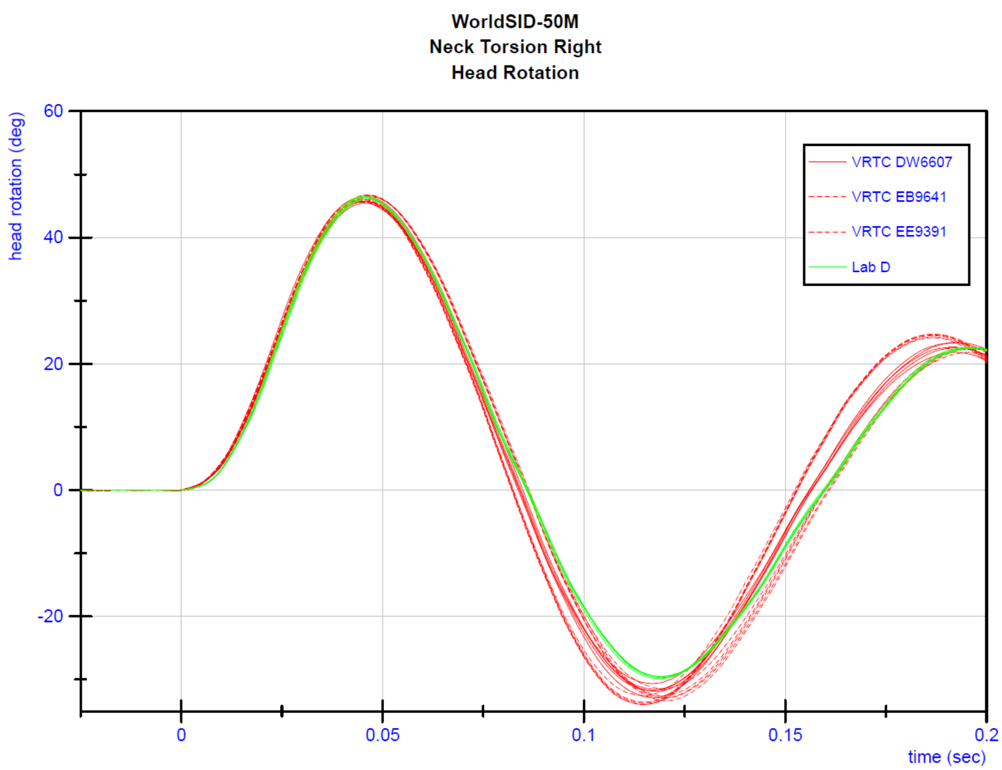

Figure A-15. Neck Torsion Right – Head Rotation

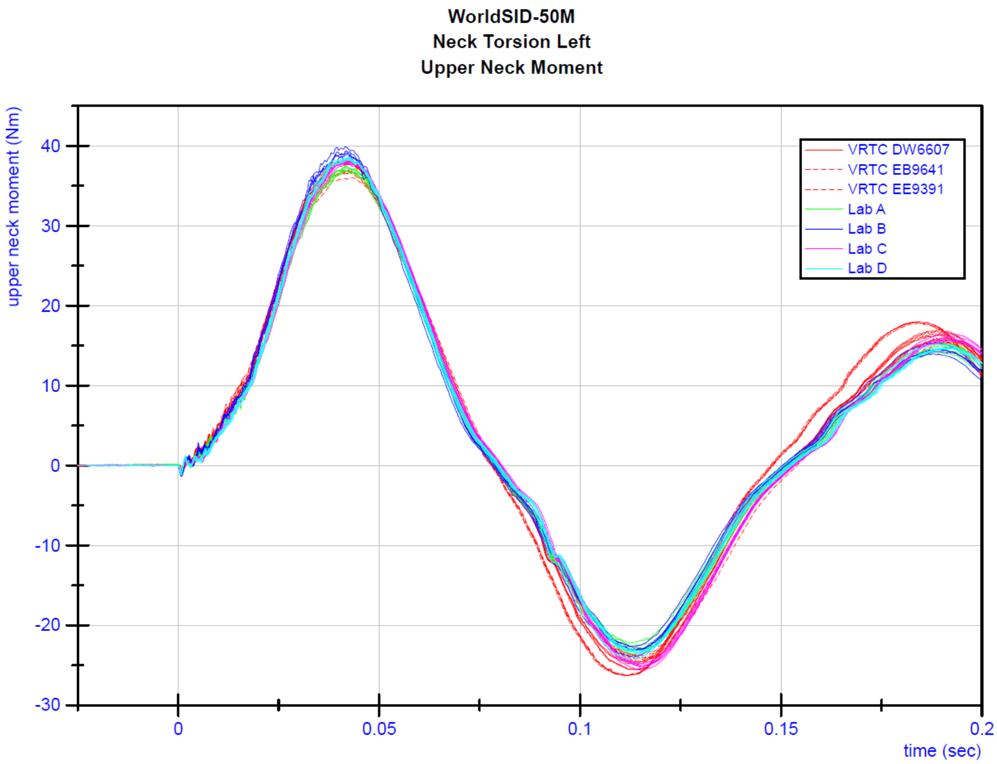

Figure A-16. Neck Torsion Left – Neck Z-Moment

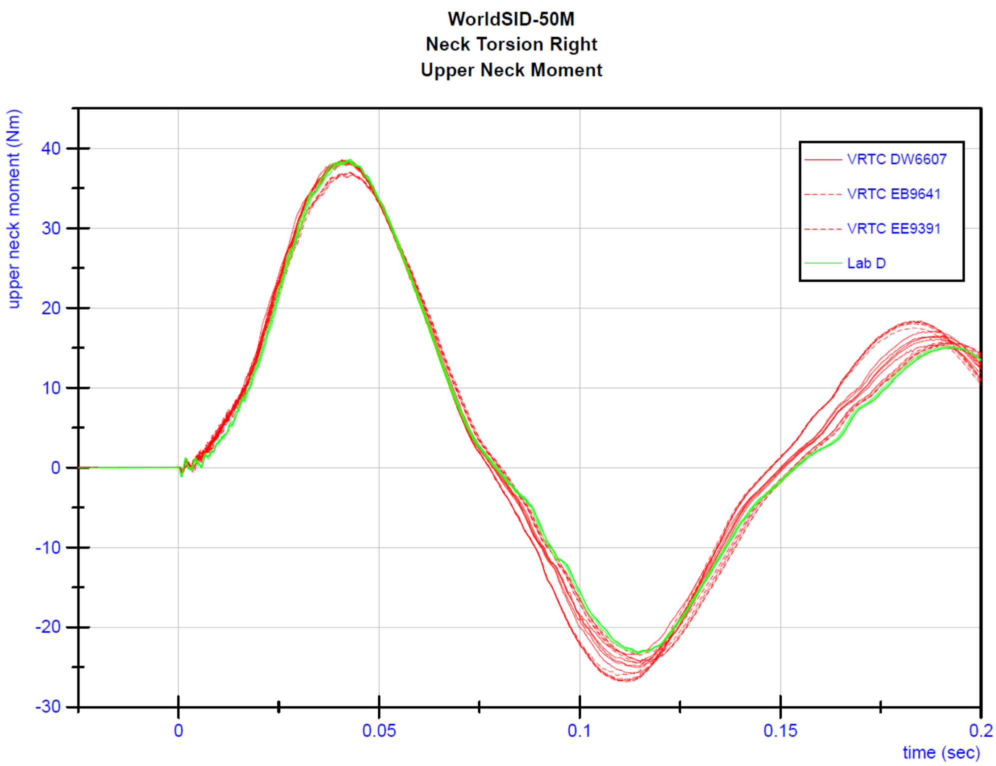

Figure A-17. Neck Torsion Right – Neck Z-Moment

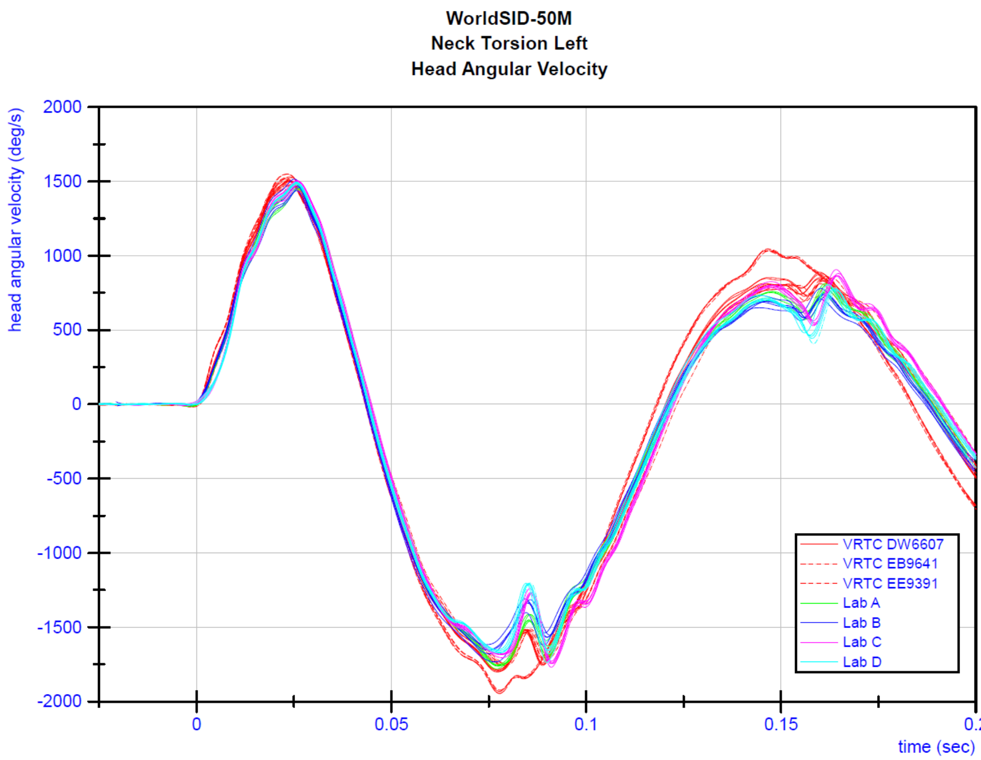

Figure A-18. Neck Torsion Left – Head Angular Velocity

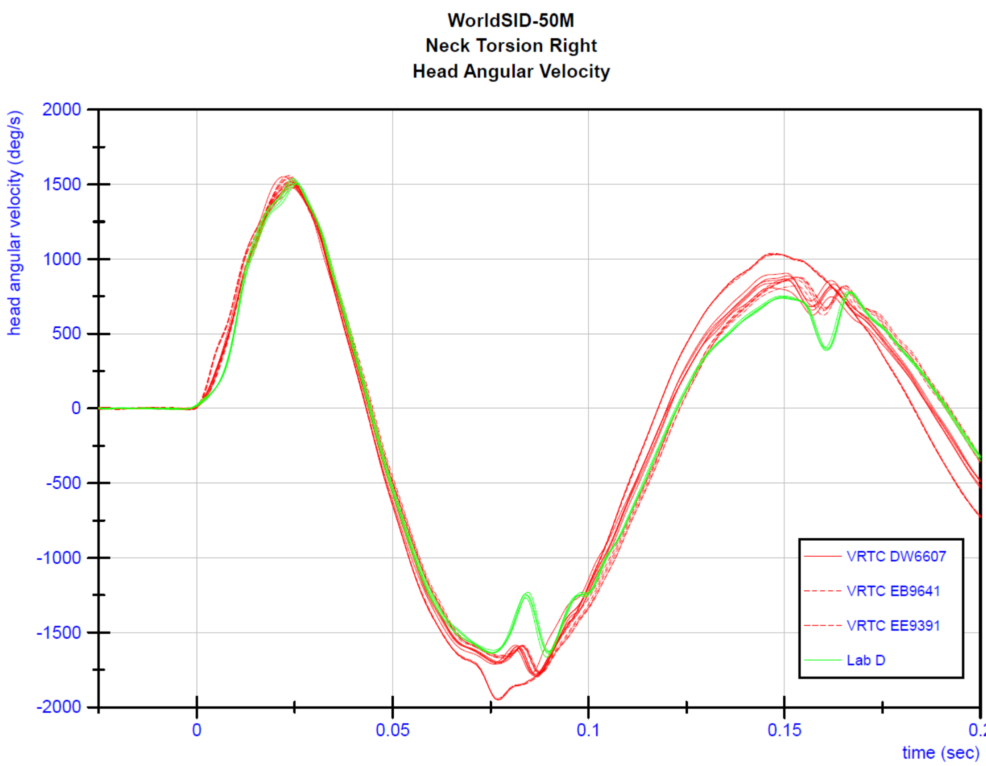

Figure A-19. Neck Torsion Left – Head Angular Velocity

Table A.7. Shoulder Impact Test Results

Lab/ Dummy No.	Test No.	Pendulum Impact Velocity (m/s)	Peak Pendulum Force (kN)	Peak Shoulder Deflection Mid LED (mm)	Peak Shoulder Force (kN)
Lab A EA-7820	1	4.36	2.88	42.6	1.61
	2	4.36	3.05	41.7	1.65
	3	4.36	3.20	42.1	1.64
	4	4.35	3.20	42.1	1.65
	5	4.35	3.19	42.7	1.63
Lab B EA-7820	1	4.32	3.19	41.2	1.65
	2	4.30	2.84	41.4	1.64
	3	4.30	2.90	42.2	1.62
	4	4.32	2.89	41.0	1.63
	5	4.31	2.97	41.2	1.65
Lab C EA-7820	3	4.32	2.89	42.1	1.61
	4	4.34	3.08	41.7	1.59
	5	4.34	2.99	42.4	1.59
	6	4.35	3.01	42.4	1.61
	7	4.35	2.83	41.0	1.57
VRTC EA-7820	1	4.29	2.98	41.1	1.69
	2	4.29	2.99	41.0	1.67
	3	4.29	2.97	40.7	1.66
	4	4.29	3.01	39.8	1.66
	5	4.30	2.99	40.3	1.68
VRTC EB-8888	1	4.31	2.95	45.0	1.63
	2	4.30	2.94	45.6	1.61
	3	4.30	2.92	46.1	1.59
	4	4.28	2.91	45.9	1.60
	5	4.30	2.92	45.9	1.59
VRTC EE-8800	1	4.29	2.80	39.6	1.67
	2	4.28	2.79	38.5	1.69
	3	4.29	2.74	38.5	1.67
	4	4.29	2.74	39.2	1.65
	5	4.29	2.76	39.4	1.65

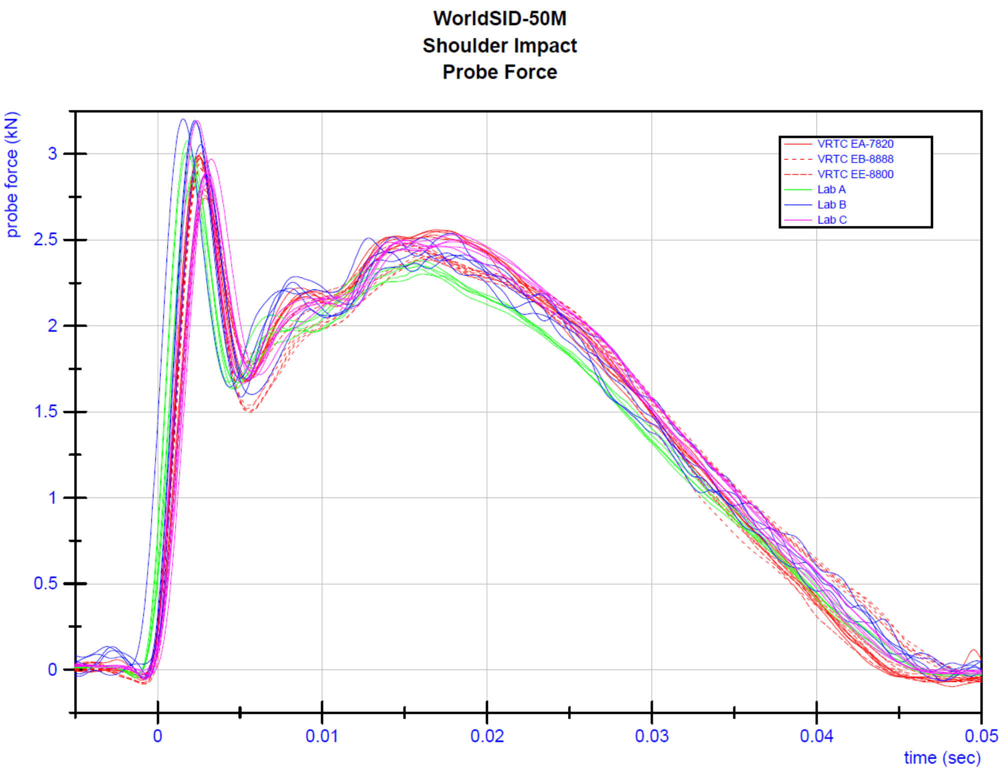

Figure A-20. Shoulder Impact – Probe Force

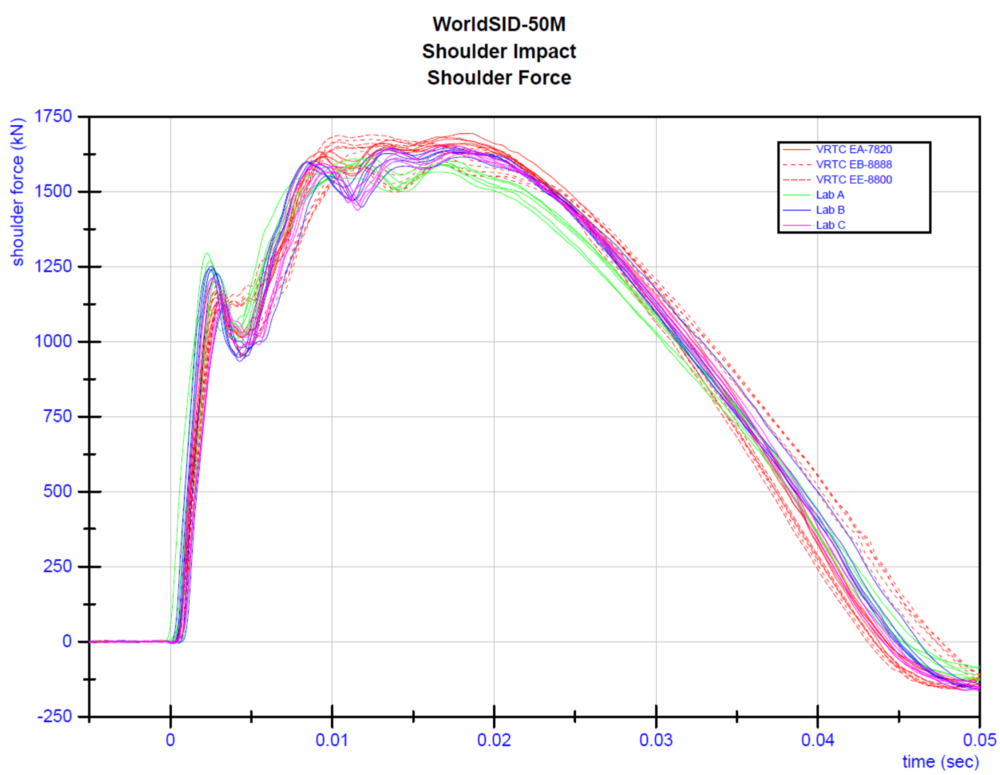

Figure A-21. Shoulder Impact – Shoulder Force

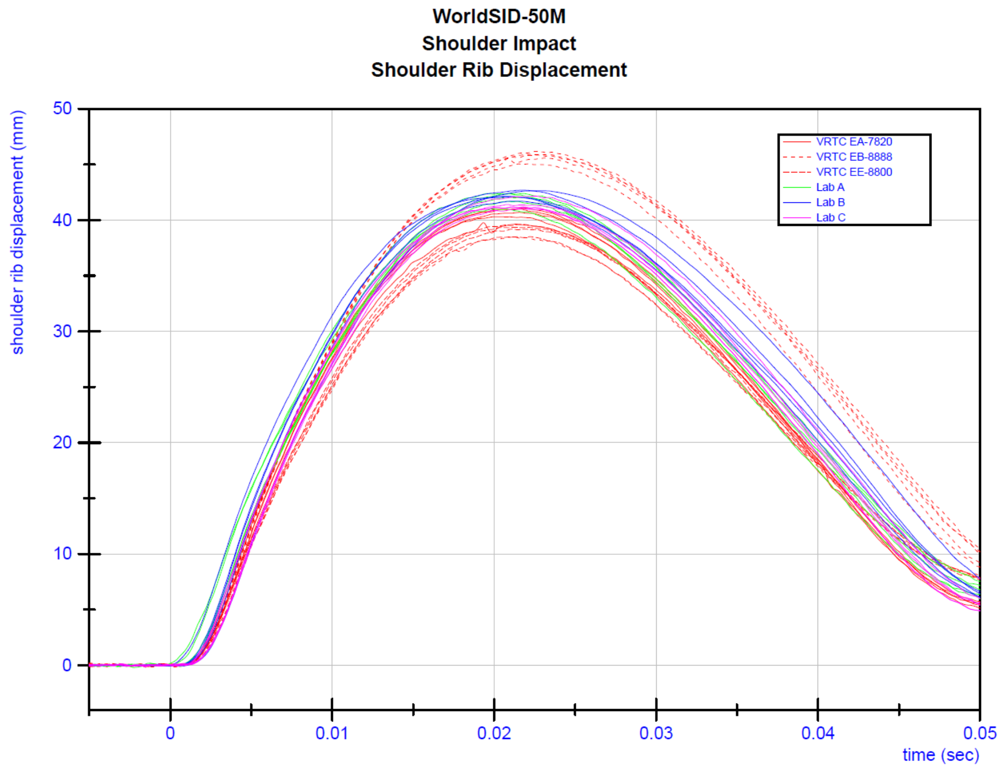

Figure A-22. Shoulder Impact – Shoulder Rib Displacement

Table A.8. Thorax With Arm Impact Test Results

Lab/ Dummy No.	Test No.	Pendulum Impact Velocity (m/s)	Peak Pendulum Force (kN)	Peak T4 Y-Axis Accel (g)	Peak T12 Y-Axis Accel (g)	Peak Deflection Middle LED (mm)		
						Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
Lab A EA-7820	1	6.75	6.10	36.3	25.8	41.6	47.5	34.5
	2	6.75	5.90	33.3	25.9	42.6	47.6	35.4
	3	6.76	6.00	33.1	26.2	41.4	49.1	36.3
	4	6.74	5.89	34.7	25.7	40.8	49.9	37.2
	5	6.73	6.04	34.7	26.2	39.2	48.7	36.8
Lab B EA-7820	1	6.68	5.71	31.7	22.1	42.1	50.4	39.1
	2	6.68	6.02	34.6	25.3	40.6	47.2	35.0
	3	6.68	6.11	34.2	25.2	39.6	47.9	35.6
	4	6.68	6.07	34.5	25.2	38.3	49.9	36.4
	5	6.68	5.95	34.8	25.5	41.6	47.7	35.5
Lab C EA-7820	3	6.68	5.75	33.0	23.1	38.2	46.5	34.9
	4	6.70	5.69	33.3	22.5	40.2	47.7	34.4
	7	6.70	5.73	34.8	24.5	40.3	49.2	35.9
	8	6.68	5.74	34.6	24.1	41.1	47.9	34.1
	9	6.70	5.63	34.1	23.7	41.6	47.5	34.3
VRTC EA-7820	1	6.71	6.08	33.5	24.3	42.4	47.7	35.0
	2	6.71	6.05	32.9	24.1	39.6	47.2	34.8
	3	6.70	6.11	33.9	24.3	39.2	47.4	35.2
	4	6.70	5.95	33.5	24.2	40.6	46.2	34.5
	5	6.70	5.92	33.2	24.5	41.3	47.0	34.9
VRTC EB-8888	1	6.70	5.71	33.6	24.7	43.0	48.8	36.6
	2	6.69	5.53	35.6	24.1	44.3	47.3	35.5
	3	6.69	5.58	33.9	24.0	43.4	47.8	36.1
	4	6.68	5.57	35.4	23.6	43.4	46.4	35.2
	5	6.70	5.65	34.1	24.2	42.9	47.5	35.7
VRTC EE-8800	1	6.69	5.79	35.3	25.8	42.6	47.7	35.4
	2	6.70	5.70	34.3	24.7	42.9	48.5	36.7
	3	6.68	5.73	33.8	23.7	42.3	48.6	35.9
	4	6.69	5.75	35.0	24.6	41.9	48.1	35.2
	5	6.69	5.71	34.8	24.2	42.8	48.5	35.0

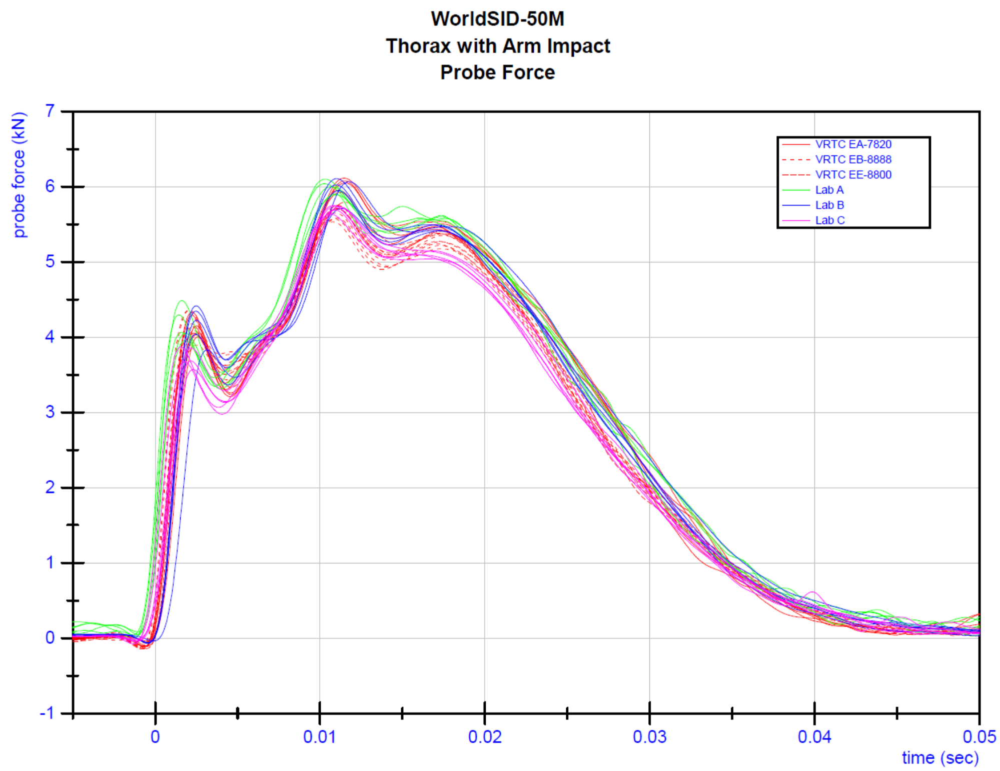

Figure A-23. Thorax With Arm Impacts – Probe Force

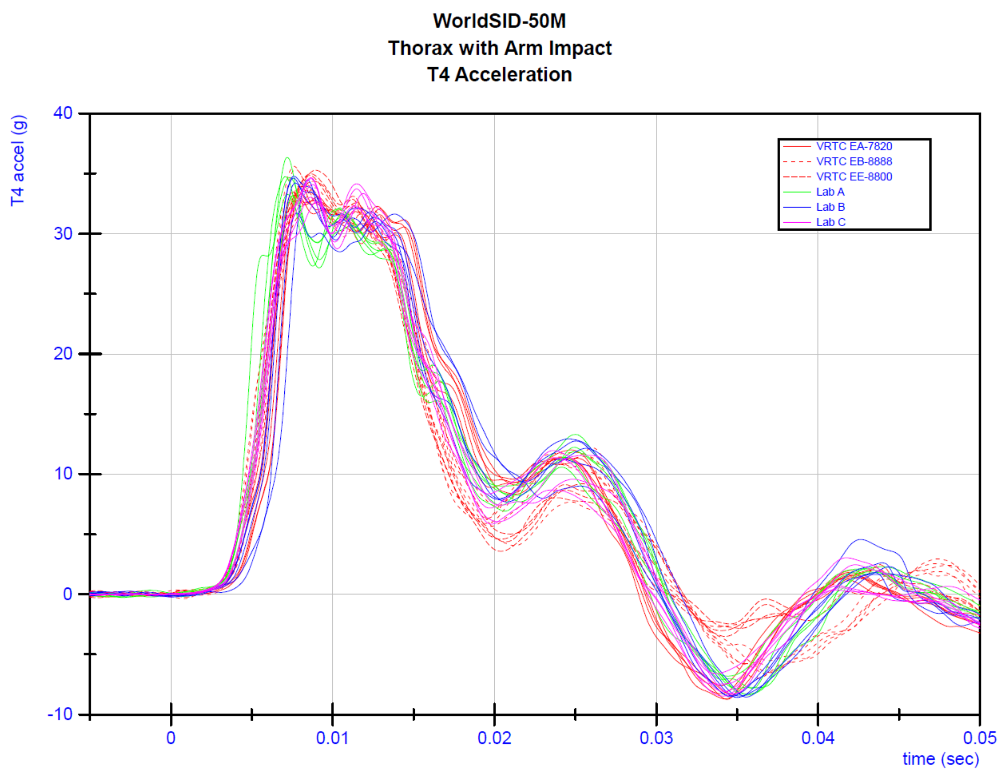

Figure A-24. Thorax With Arm Impacts – T4 Acceleration

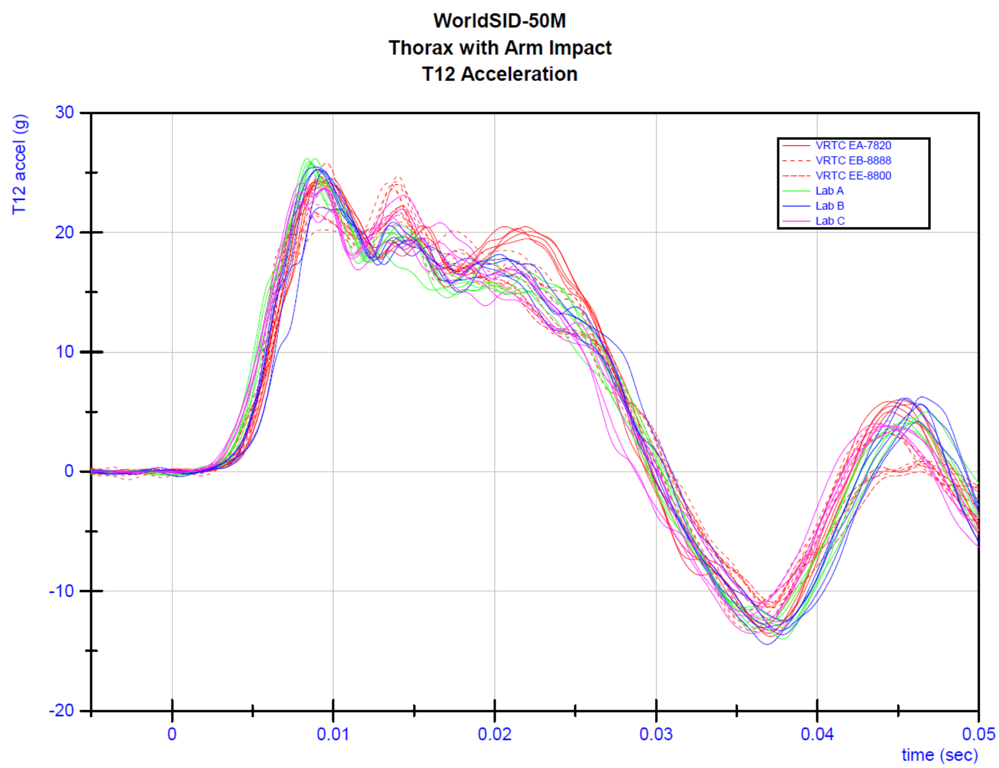

Figure A-25. Thorax With Arm Impacts – T12 Acceleration

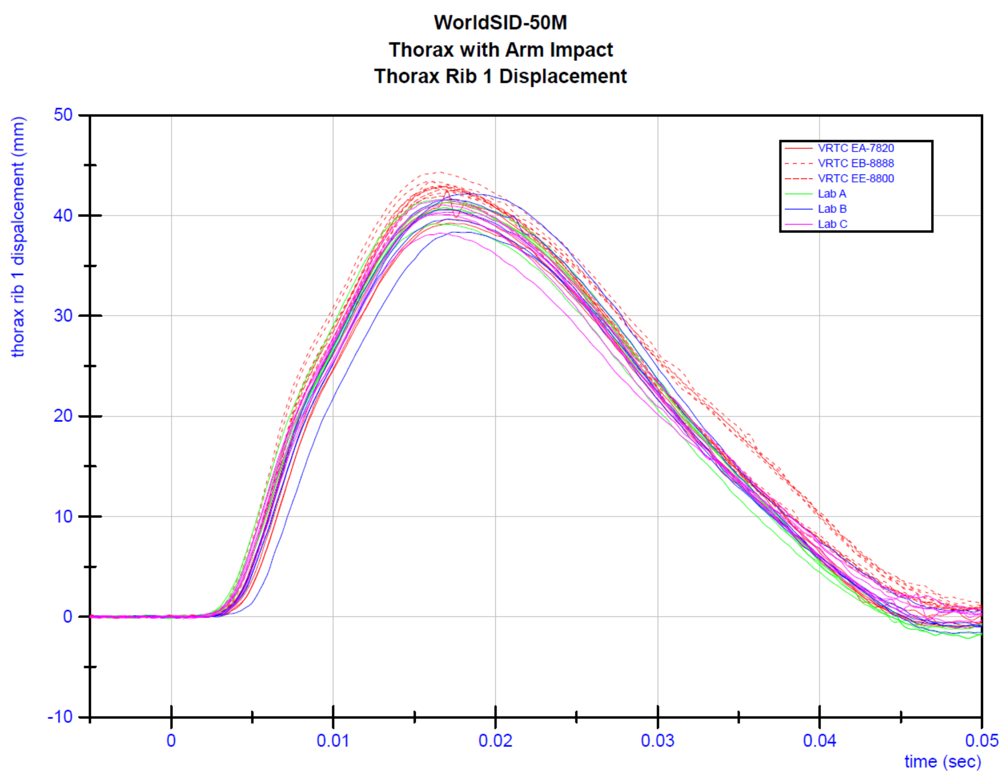

Figure A-26. Thorax With Arm Impacts – Thorax Rib 1 Displacement

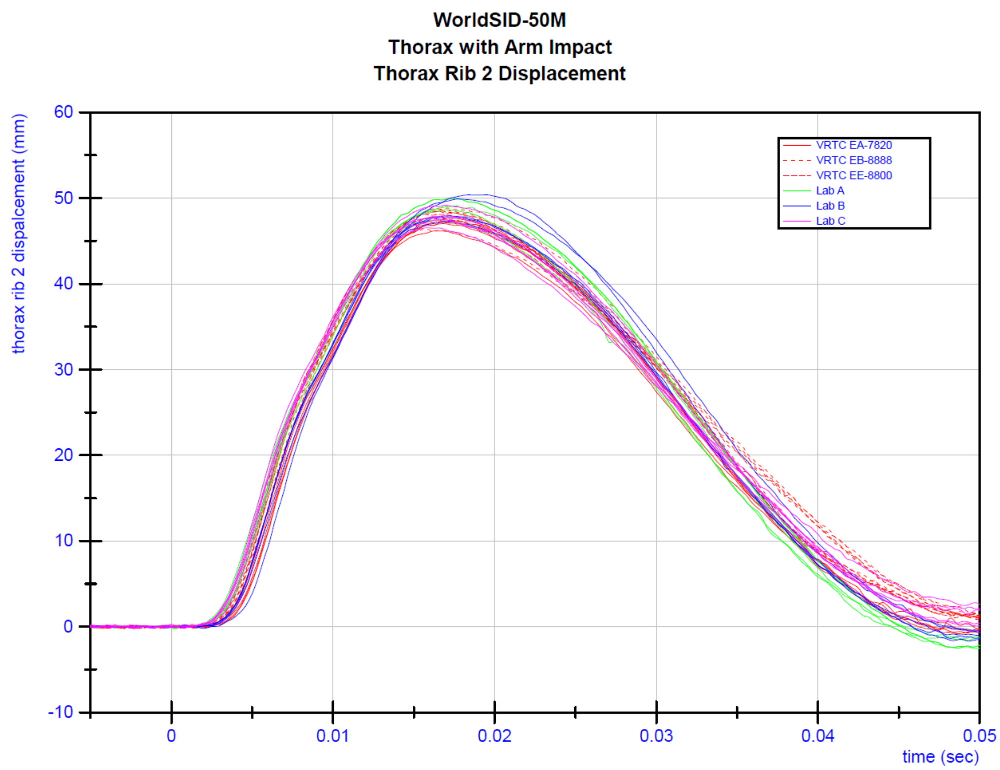

Figure A-27. Thorax With Arm Impacts – Thorax Rib 2 Displacement

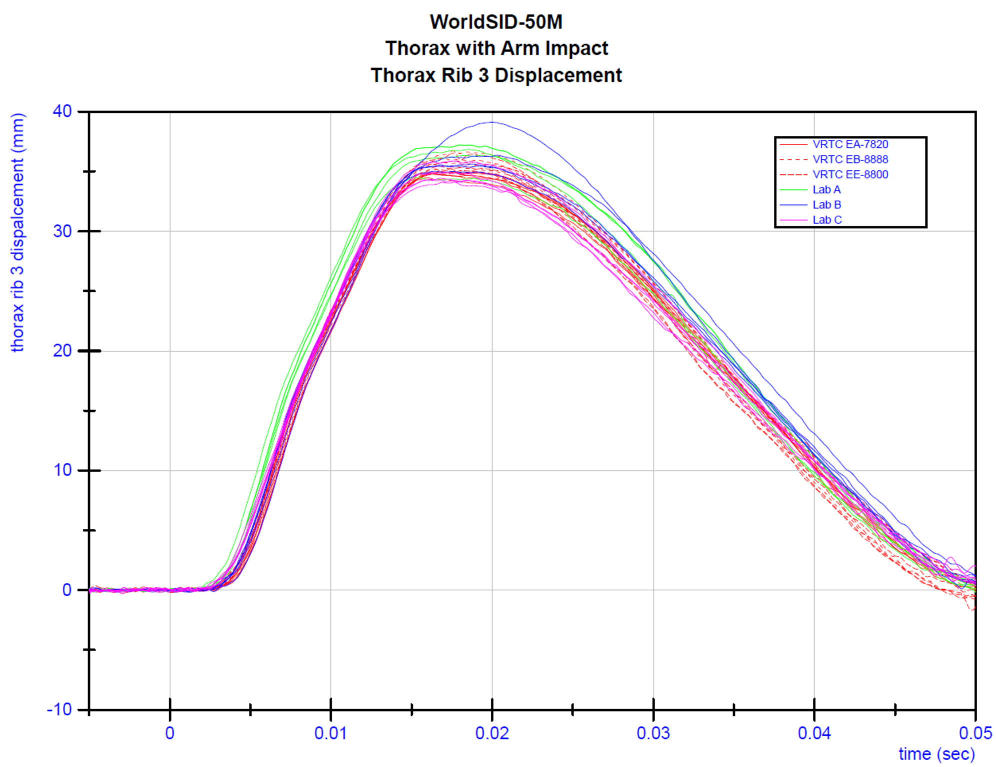

Figure A-28. Thorax With Arm Impacts – Thorax Rib 3 Displacement

Table A.9. Thorax Without Arm Impact Test Results

Lab/ Dummy No.	Test No.	Pendulum Impact Velocity (m/s)	Peak Pendulum Force (kN)	Peak T4 Y-Axis Accel (g)	Peak T12 Y-Axis Accel (g)	Peak Deflection Middle LED (mm)		
						Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
Lab A EA-7820	1	4.36	3.55	16.7	16.2	39.5	39.1	33.5
	2	4.35	3.54	17.2	17.1	38.3	39.0	33.7
	3	4.36	3.54	16.8	18.2	37.6	38.6	33.7
	4	4.36	3.59	17.0	21.2	35.1	35.9	30.4
	5	4.36	3.62	17.5	19.3	37.8	39.0	34.5
Lab B EA-7820	1	4.31	3.62	17.4	18.0	36.8	37.9	33.5
	2	4.31	3.66	17.3	17.0	39.2	37.9	34.6
	3	4.31	3.65	17.4	16.2	39.3	38.7	34.0
	4	4.31	3.66	17.4	16.8	39.1	39.0	34.2
	5	4.31	3.65	17.4	16.7	38.2	39.3	34.9
Lab C EA-7820	1	4.35	3.45	15.9	15.2	36.0	40.5	35.7
	2	4.37	3.44	16.5	16.5	35.4	39.7	33.9
	5	4.35	3.44	16.8	16.9	39.0	41.3	34.6
	6	4.35	3.46	17.0	16.5	39.3	41.1	36.0
	7	4.35	3.47	17.0	17.1	38.2	41.3	35.8
VRTC EA-7820	1	4.30	3.63	16.2	16.2	40.2	39.3	33.9
	2	4.30	3.66	16.6	16.0	40.3	39.1	33.4
	3	4.29	3.59	16.6	16.6	39.2	38.7	33.0
	4	4.28	3.65	16.6	16.3	38.1	39.4	35.5
	5	4.31	3.67	16.6	16.1	37.9	39.6	35.2
VRTC EB-8888	1	4.29	3.52	16.3	16.2	41.0	41.3	35.7
	2	4.30	3.49	15.6	15.8	39.6	40.6	35.8
	3	4.30	3.50	15.8	15.5	41.3	40.8	34.9
	4	4.30	3.49	14.9	15.5	42.2	40.3	33.3
	5	4.30	3.51	15.5	16.0	41.2	40.6	34.3
VRTC EE-8800	1	4.29	3.59	15.1	15.0	41.5	41.8	33.9
	2	4.29	3.63	15.1	15.3	39.8	40.7	33.4
	3	4.30	3.63	14.8	15.0	38.6	40.7	33.7
	4	4.29	3.59	15.1	15.2	39.8	41.3	34.6
	5	4.28	3.57	14.7	15.0	39.6	40.8	33.7

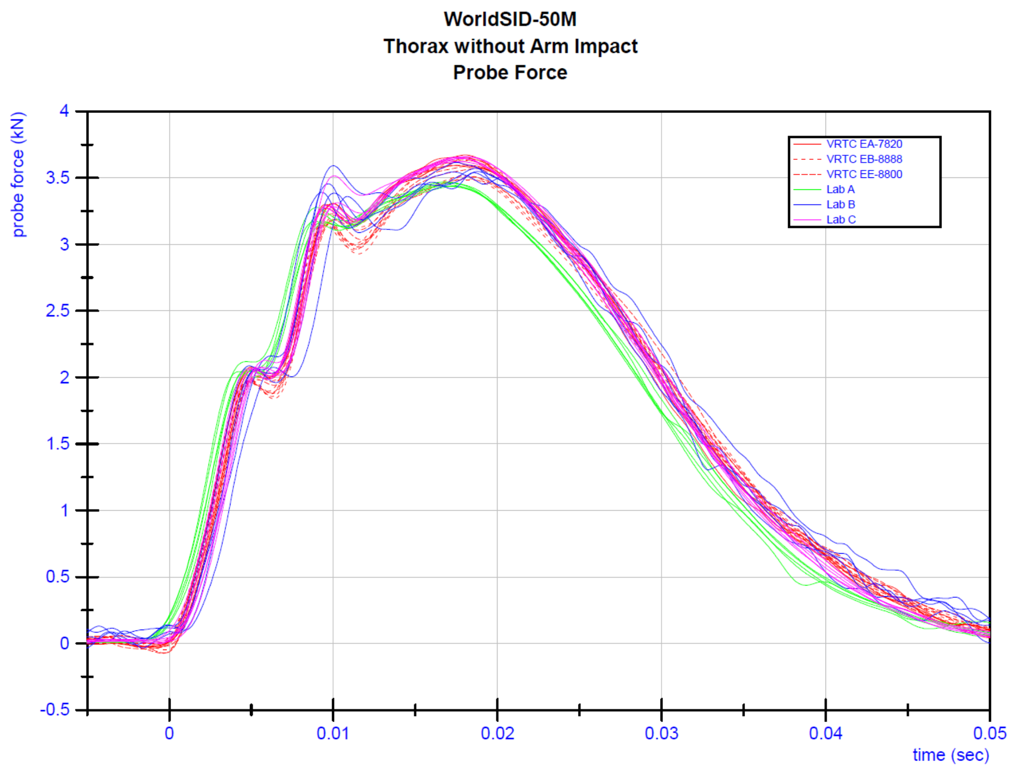

Figure A-29. Thorax Without Arm Impacts – Probe Force

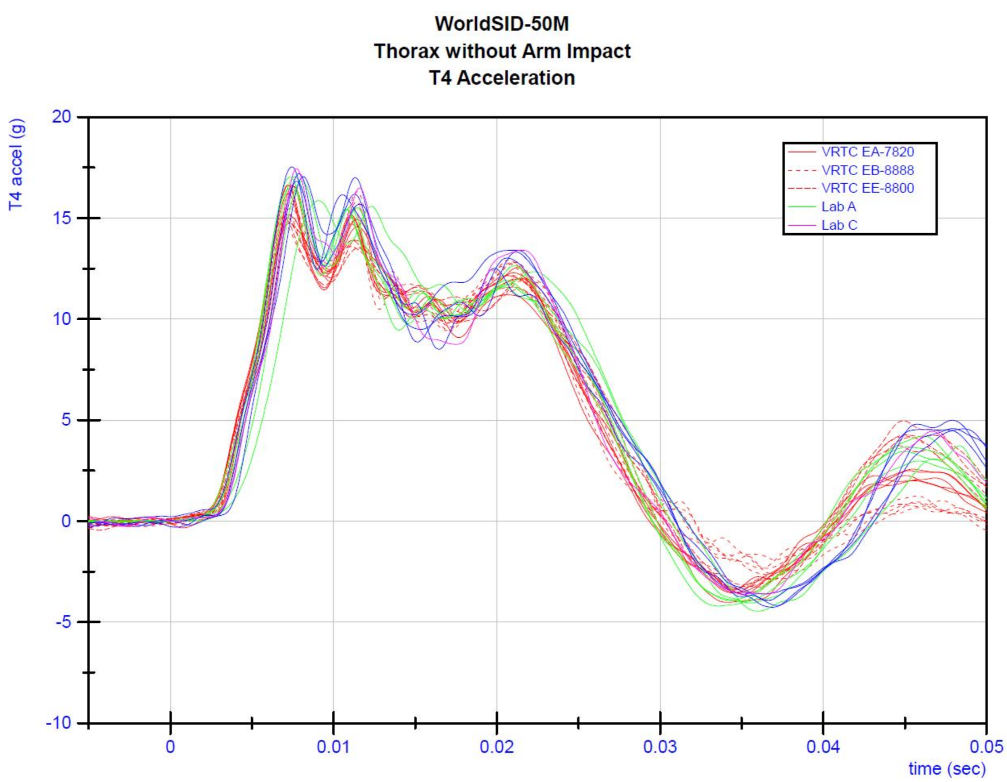

Figure A-30. Thorax With Arm Impacts – T4 Acceleration

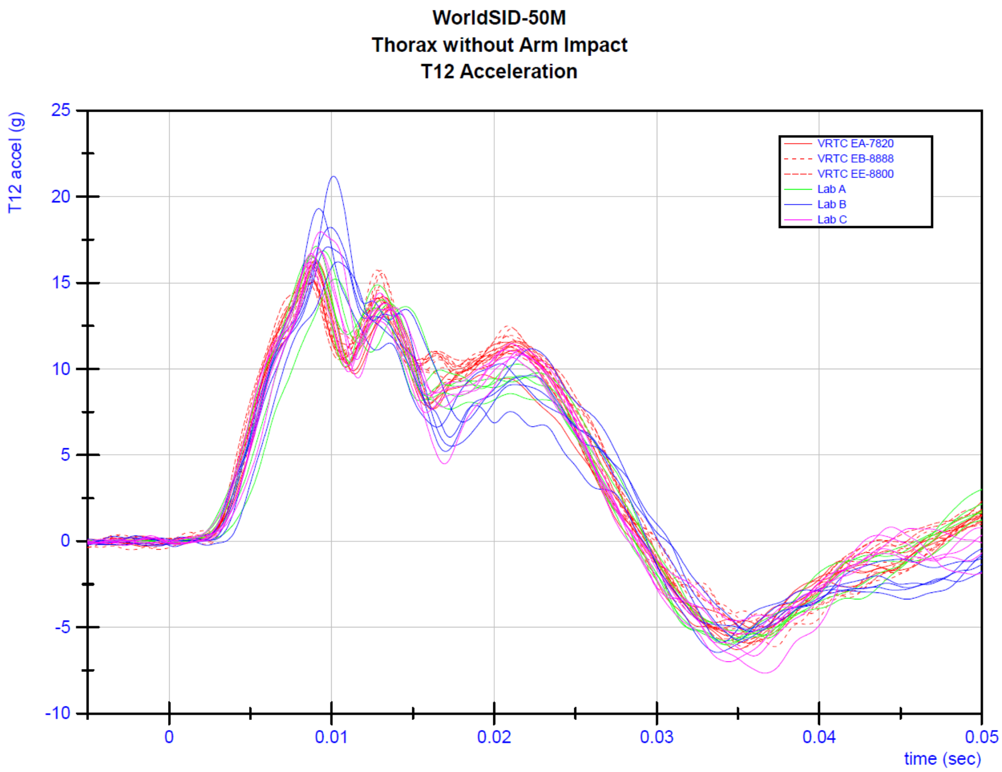

Figure A-31. Thorax With Arm Impacts – T12 Acceleration

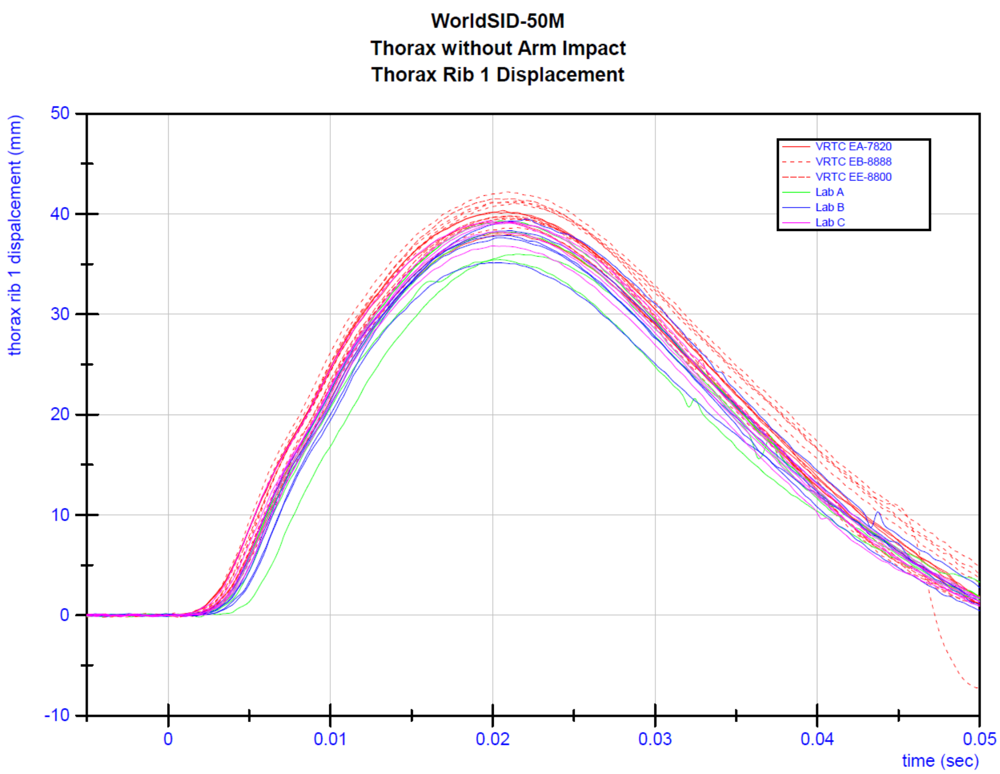

Figure A-32. Thorax With Arm Impacts – Thorax Rib 1 Displacements

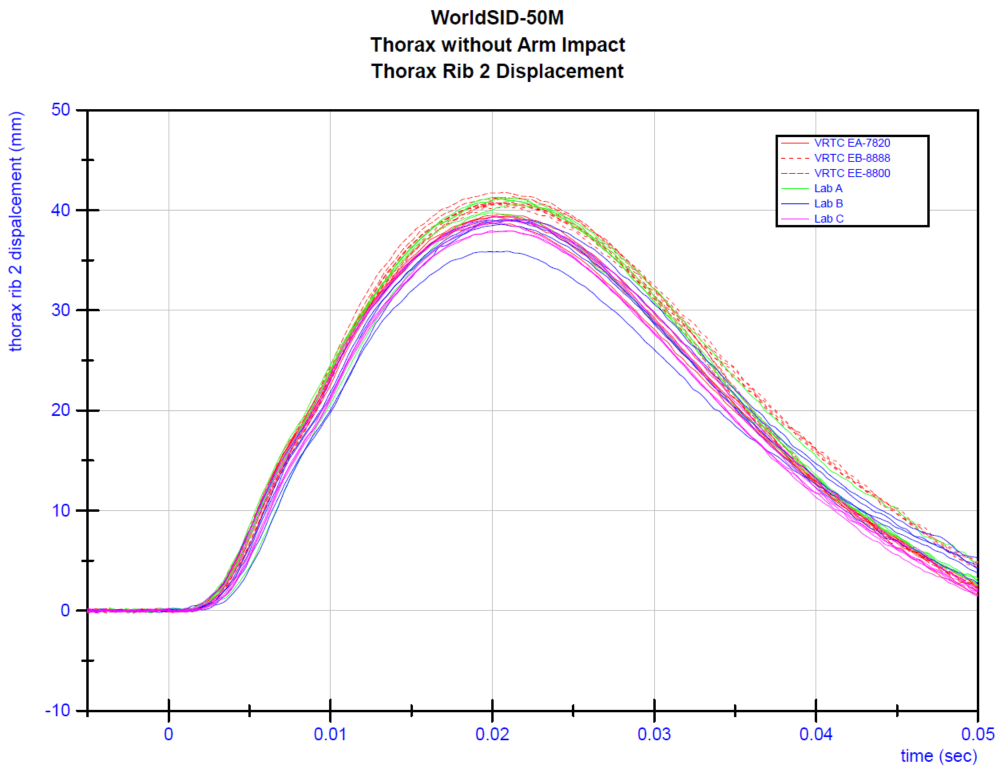

Figure A-33. Thorax With Arm Impacts – Thorax Rib 2 Displacements

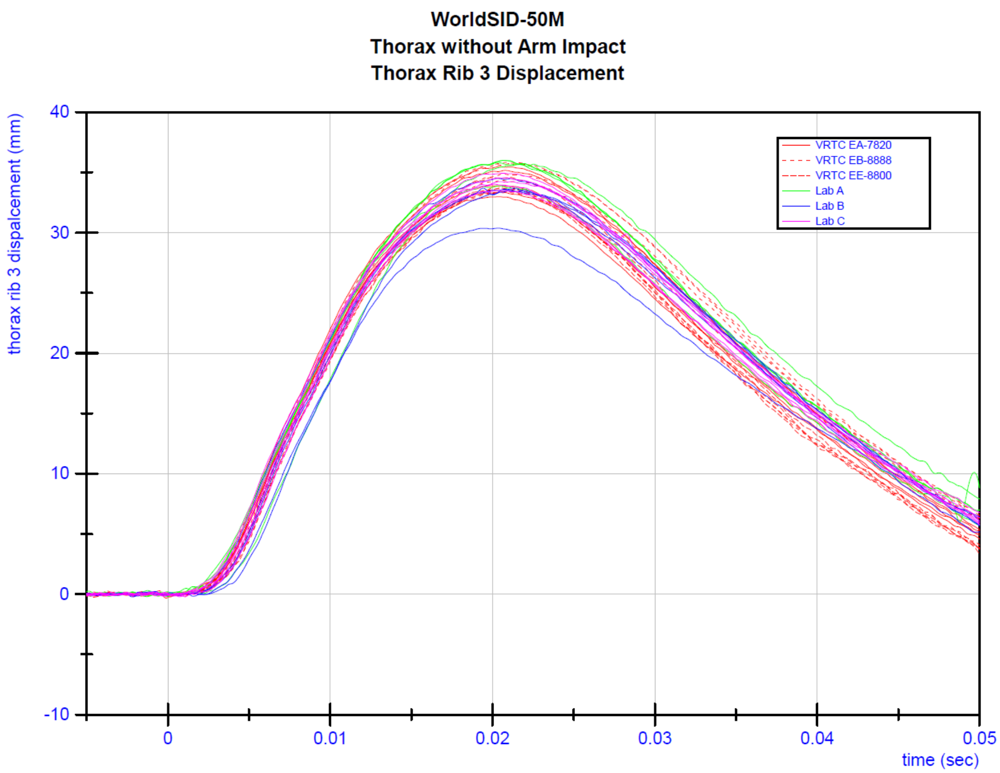

Figure A-34. Thorax With Arm Impacts – Thorax Rib 3 Displacements

Table A.10. Abdomen Impact Test Results

Lab/ Dummy No.	Test No.	Pendulum Impact Velocity (m/s)	Peak Pendulum Force (kN)	Peak T12 Y-Axis Accel (g)	Peak Deflection - Middle LED (mm)	
					Abdomen Rib 1	Abdomen Rib 2
Lab A EA-7820	1	4.36	2.82	15.9	36.5	36.9
	2	4.35	2.93	16.6	35.2	34.5
	3	4.34	3.02	17.0	36.3	37.2
	4	4.34	2.86	16.5	37.3	36.5
	5	4.34	2.82	16.9	36.4	36.1
Lab B EA-7820	1	4.31	2.99	15.6	35.5	35.1
	2	4.31	2.98	15.6	36.3	36.3
	3	4.31	2.99	16.5	37.3	35.5
	4	4.31	3.01	15.7	36.6	35.7
	5	4.31	2.99	16.2	37.0	35.9
Lab C EA-7820	1	4.34	2.91	14.8	35.0	36.6
	2	4.35	2.87	15.9	35.7	36.0
	3	4.36	2.89	15.8	36.1	36.9
	4	4.35	2.87	15.7	37.1	36.2
	5	4.35	2.88	16.1	37.1	35.0
VRTC EA-7820	1	4.31	3.00	15.4	35.2	37.2
	2	4.30	3.01	15.6	35.6	36.6
	3	4.30	2.99	15.6	35.8	36.0
	4	4.29	3.02	15.8	34.6	35.7
	5	4.30	3.01	15.9	35.1	35.2
VRTC EB-8888	1	4.31	3.07	17.6	32.3	33.8
	2	4.31	3.01	17.1	32.7	32.8
	3	4.31	2.99	16.9	33.0	33.8
	4	4.30	3.00	16.5	33.1	34.2
	5	4.29	3.00	17.1	33.1	33.7
VRTC EE-8800	1	4.31	2.89	15.3	35.5	35.8
	2	4.28	2.86	15.1	35.8	36.0
	3	4.29	2.84	15.5	36.1	36.0
	4	4.30	2.85	15.2	35.8	35.9
	5	4.29	2.89	15.5	36.4	36.5

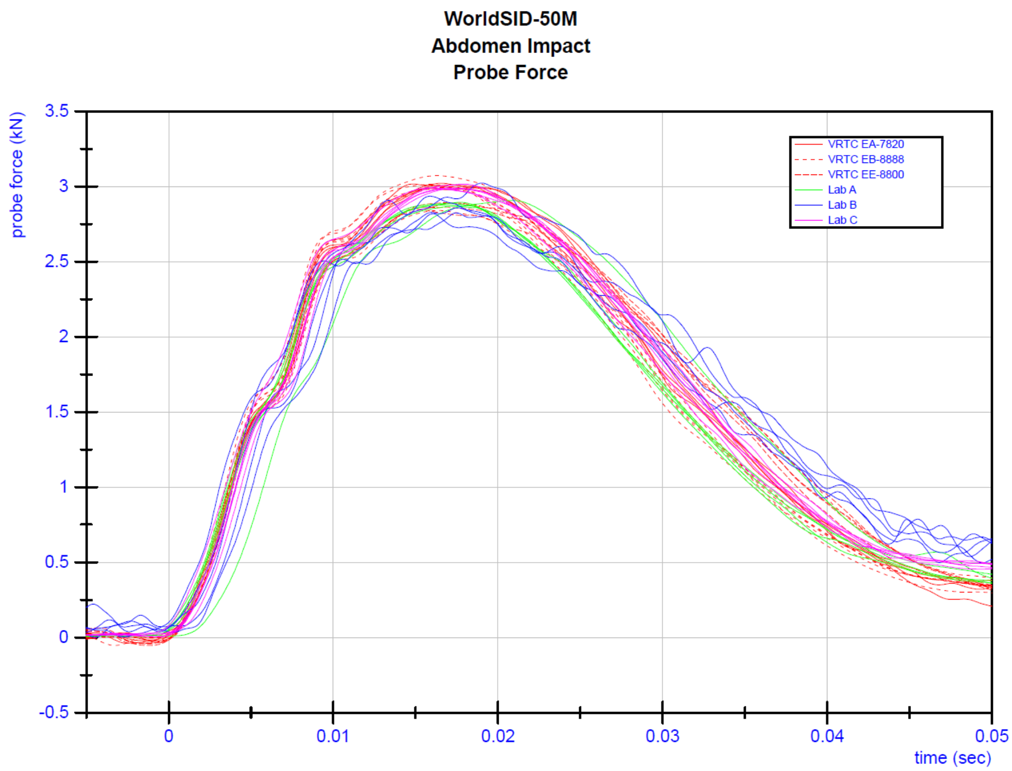

Figure A-35. Abdomen Impacts – Probe Force

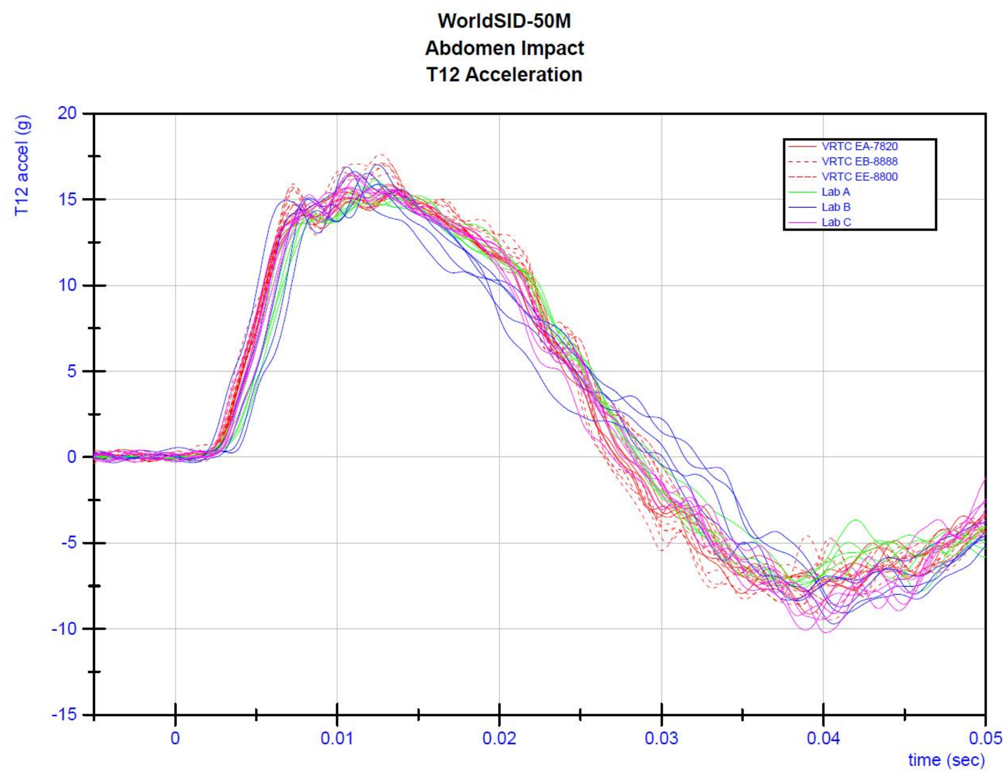

Figure A-36. Abdomen Impacts – T12 Acceleration

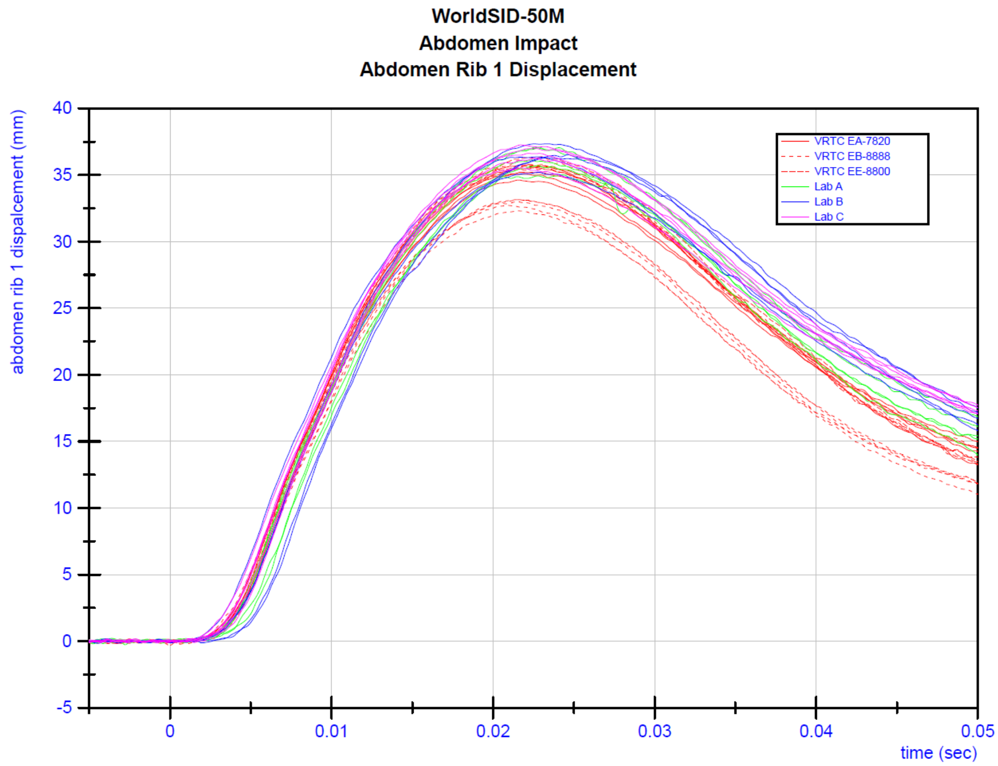

Figure A-37. Abdomen Impacts – Abdomen Rib 1 Displacement

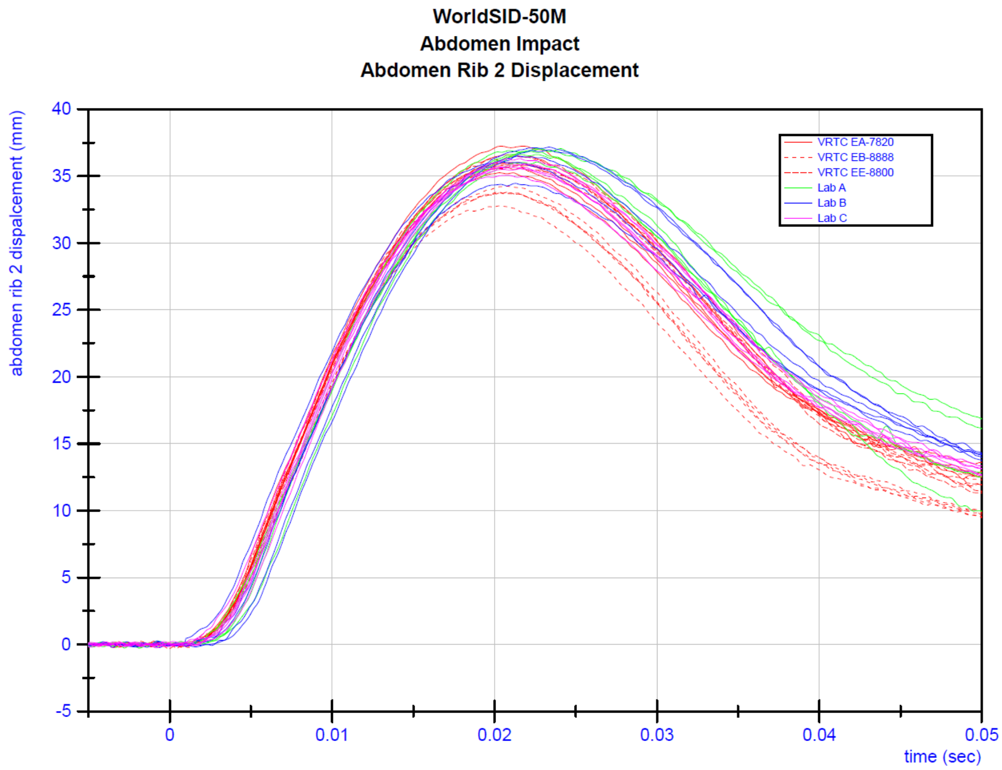

Figure A-38. Abdomen Impacts – Abdomen Rib 2 Displacement

Table A.11. Pelvis Impact Test Results

Lab/ Dummy No.	Test No.	Pendulum Impact Velocity (m/s)	Peak Pendulum Force (kN)	Peak T12 Y-Axis Accel (g)	Peak Pelvis Y-Axis Accel (g)	Peak Pubic Y-Axis Force (kN)	Peak Sacro Y-Axis Force (kN)
Lab A EA-7820	1	6.73	7.46	13.7	47.8	1.53	2.18
	2	6.73	7.67	13.2	44.1	1.52	2.15
	3	6.73	7.88	13.9	48.0	1.60	2.11
	4	6.72	7.92	12.6	48.0	1.63	2.06
	5	6.71	7.83	13.4	47.4	1.60	2.13
Lab B EA-7820	1	6.72	7.66	12.5	45.5	1.47	2.04
	2	6.72	7.74	13.4	44.6	1.46	2.01
	3	6.72	7.72	13.3	46.0	1.48	2.13
	4	6.74	7.53	12.6	45.9	1.49	2.17
	5	6.74	7.60	12.8	44.0	1.46	2.07
	6	6.72	7.63	12.6	45.8	1.48	2.15
Lab C EA-7820	1	6.70	7.80	12.7	46.6	1.47	2.04
	2	6.73	7.55	12.4	42.9	1.43	1.98
	3	6.73	7.52	13.6	46.3	1.40	2.09
	4	6.73	7.53	13.2	44.9	1.36	2.08
	5	6.73	7.48	13.9	46.7	1.34	2.17
Lab D EA-7820	1	6.66	7.48	12.7	41.7	1.50	1.99
	2	6.70	7.44	12.9	44.5	1.52	2.02
	3	6.66	7.29	13.3	45.0	1.51	2.02
	4	6.68	7.30	13.2	44.3	1.53	1.97
	5	6.67	7.47	13.7	45.4	1.52	2.01
VRTC 016	1	6.70	7.12	12.9	38.8	1.33	1.96
	2	6.72	7.26	12.9	43.3	1.36	1.99
	3	6.70	7.41	12.9	42.5	1.36	1.96
	4	6.72	7.35	12.3	41.6	1.36	1.97
	5	6.70	7.35	12.0	42.9	1.38	1.96
VRTC 014	1	6.70	7.70	12.4	39.5	1.40	2.07
	2	6.70	7.65	12.5	40.6	1.34	2.08
	3	6.70	7.66	12.0	40.2	1.37	2.06
	4	6.68	7.69	12.3	41.8	1.37	2.08
	5	6.70	7.64	11.8	41.3	1.35	2.10
VRTC 011	1	6.70	7.44	13.0	40.9	1.47	2.08
	2	6.70	7.46	13.2	42.6	1.44	2.10
	3	6.70	7.37	12.8	43.2	1.41	2.19
	4	6.70	7.52	12.9	45.5	1.43	2.10
	5	6.70	7.47	12.6	44.9	1.40	2.16

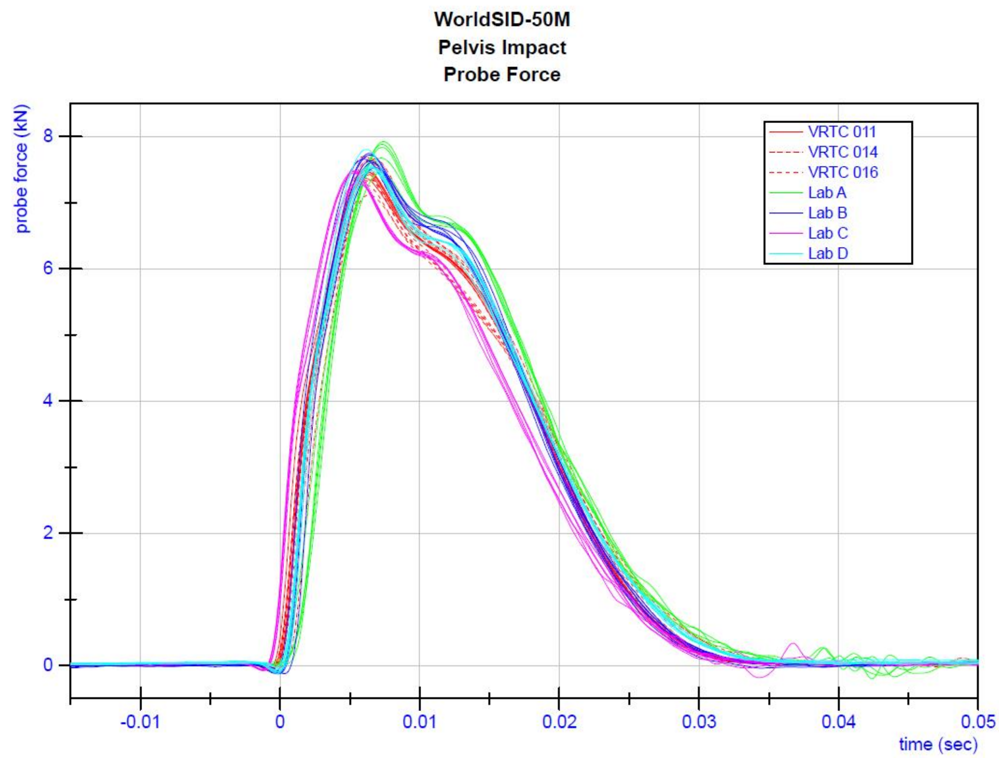

Figure A-39. Pelvis Impacts – Probe Force

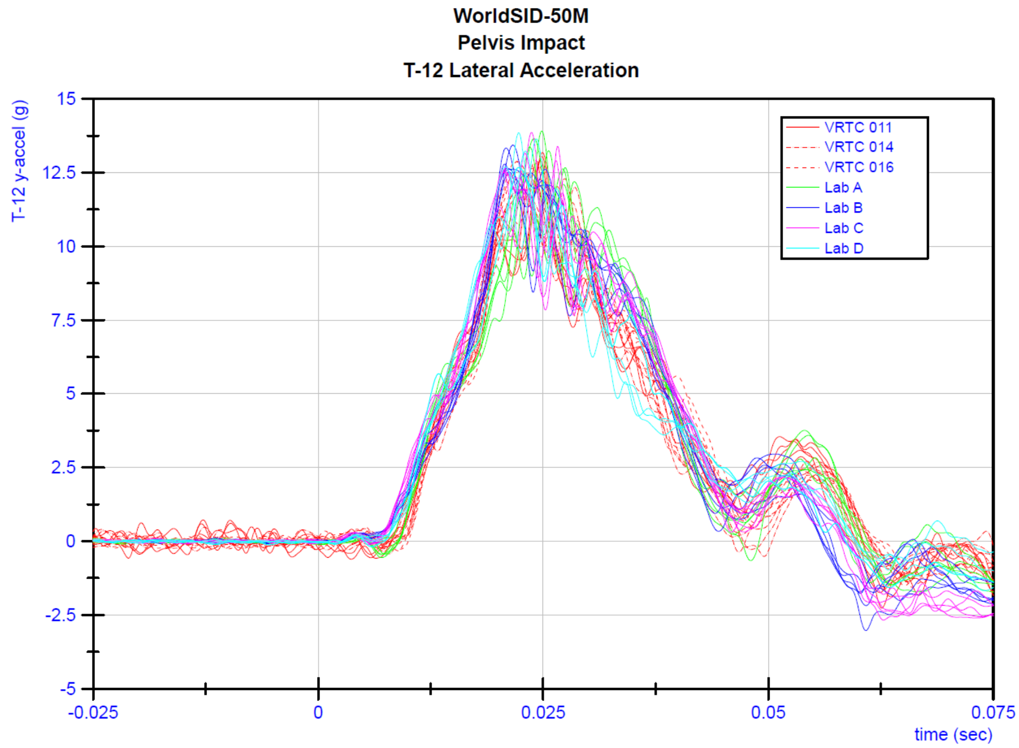

Figure A-40. Pelvis Impacts – T12 Acceleration

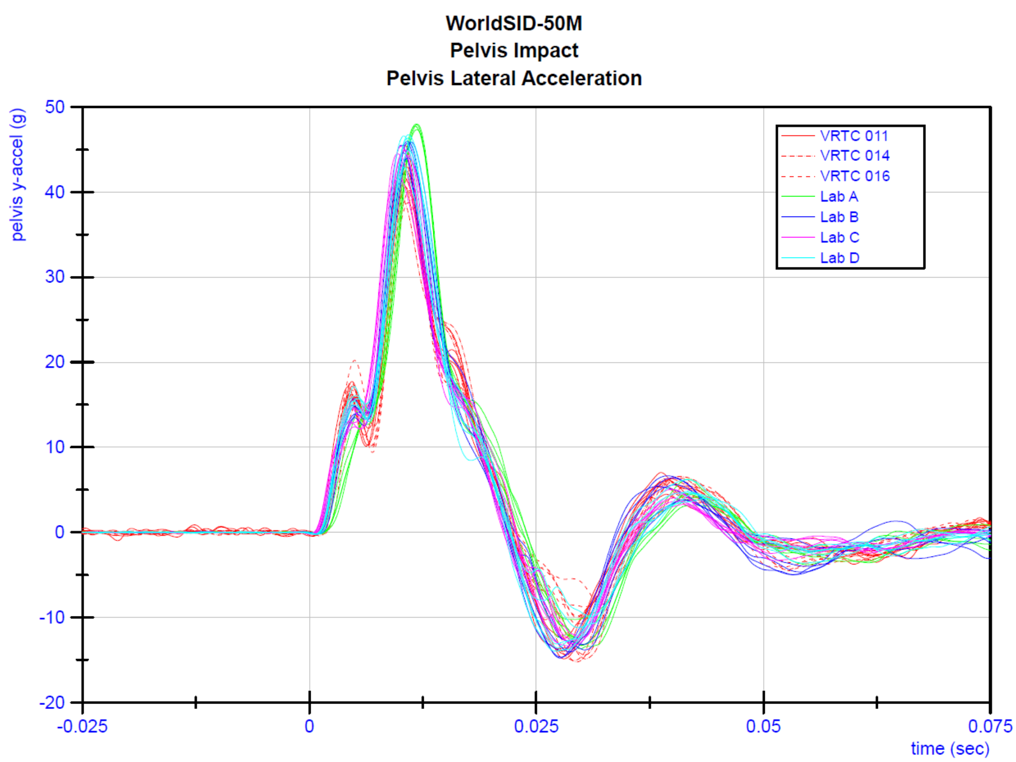

Figure A-41. Pelvis Impacts – Pelvis Y-Acceleration

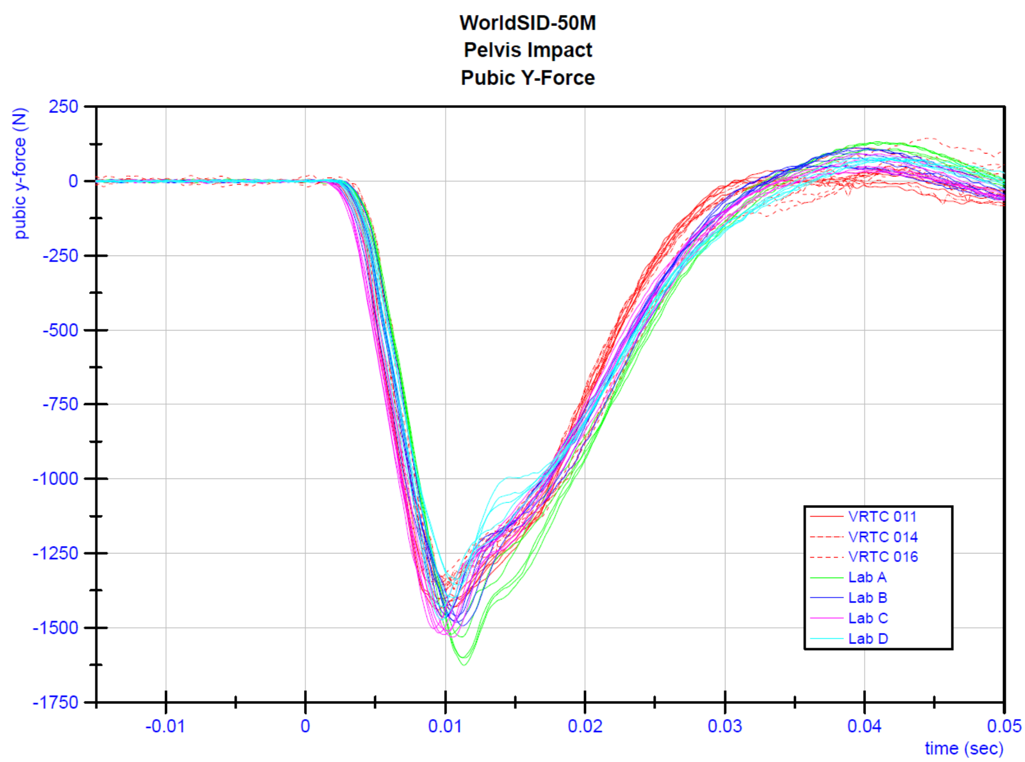

Figure A-42. Pelvis Impacts – Pubic Y-Force

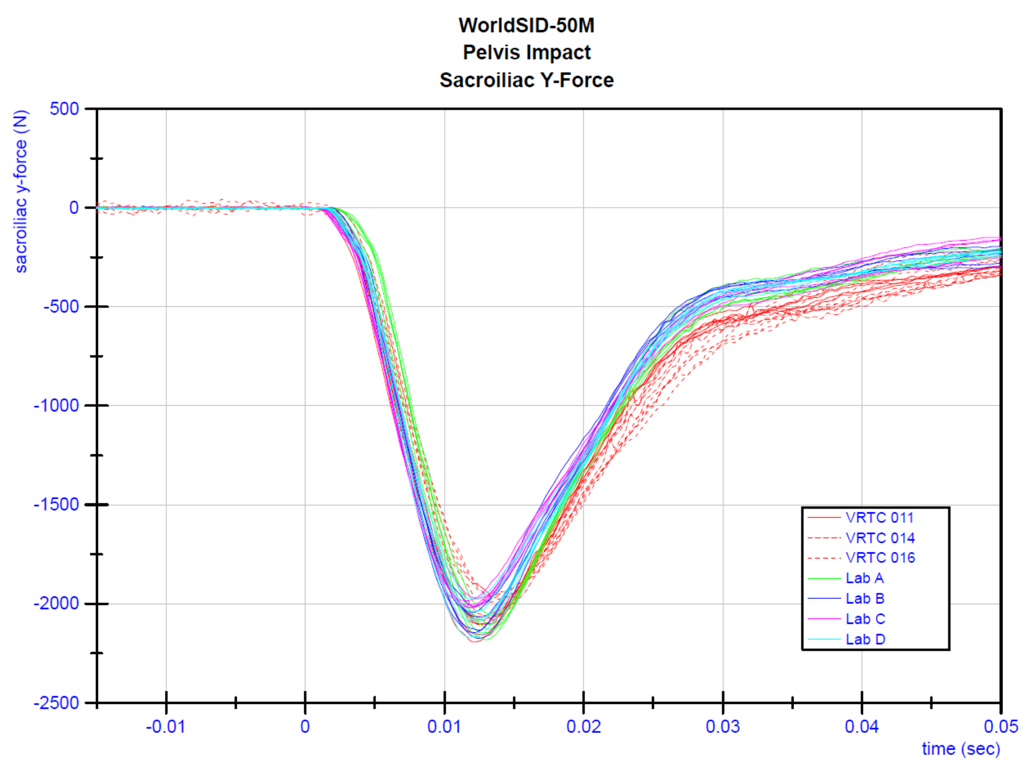

Figure A-43. Pelvis Impacts – Sacroiliac Y-Force

Appendix B: NHTSA 6.7 m/s Rigid Flat Wall Sled Tests

Table B.1. NHTSA (Maltese) 6.7 m/s Rigid Flat Wall Sled Test

Channel	Units	CFC	1		2		3		OSRP 1			OSRP 2			Combined		
			OSRP 1	OSRP 2	OSRP 1	OSRP 2	OSRP 1	OSRP 2	Avg	Std Dev	% CV	Avg	Std Dev	% CV	Avg	Std Dev	% CV
Thorax Plate Force	N	1000	8594.9	8226.1	8294.5	7630.9	8050.4	7902.9	8313.3	272.7	3.3	7920.0	298.0	3.76	8116.6	334.2	4.1
Abdomen Plate Force	N	1000	2560.5	2677.2	2432.7	2525.3	2427.2	2764.5	2473.5	75.5	3.1	2655.7	121.0	4.56	2564.6	134.5	5.2
Pelvis Plate Force	N	1000	11814.5	11432.0	11568.1	11044.5	11742.0	10393.5	11708.2	126.6	1.1	10956.7	524.8	4.79	11332.4	534.8	4.7
Upper Neck Y-axis Force	N	1000	558.4	512.5	550.1	507.1	549.3	506.8	552.6	5.0	0.9	508.8	3.2	0.63	530.7	24.3	4.6
Upper Neck X-axis Moment	N·m	600	40.6	39.7	40.1	39.6	39.9	38.8	40.2	0.4	0.9	39.4	0.5	1.33	39.8	0.6	1.5
Lower Neck Y-axis Force	N	1000	941.5	937.2	895.3	929.5	921.4	935.4	919.4	23.2	2.5	934.0	4.1	0.44	926.7	16.9	1.8
Lower Neck X-axis Moment	N·m	600	144.6	142.4	143.3	141.3	143.4	140.4	143.8	0.7	0.5	141.4	1.0	0.70	142.6	1.5	1.1
Shoulder Y-axis Force	N	600	-1781.8	-1847.0	-1717.5	-1809.5	-1706.8	-1811.9	-1735.4	40.5	2.3	-1822.8	21.0	1.15	-1779.1	55.9	3.1
Shoulder Rib Deflection	mm	600	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1
T1 Y-axis Accel.	g	180	37.4	37.5	38.3	37.6	38.5	37.3	38.1	0.6	1.5	37.4	0.1	0.37	37.8	0.5	1.4
T4 Y-axis Accel.	g	180	34.6	34.9	33.3	35.4	32.9	33.8	33.6	0.9	2.7	34.7	0.8	2.36	34.2	1.0	2.9
T12 Y-axis Accel.	g	180	42.5	39.0	45.9	39.0	43.2	38.3	43.9	1.8	4.1	38.7	0.4	1.00	41.3	3.0	7.4
Thorax Rib 1 Deflection	mm	600	65.6	61.2	66.7	59.4	65.7	63.3	66.0	0.6	0.9	61.3	2.0	3.20	63.6	2.9	4.5
Thorax Rib 2 Deflection	mm	600	69.1	66.1	67.8	64.3	68.3	65.9	68.4	0.7	1.0	65.4	1.0	1.48	66.9	1.8	2.7
Thorax Rib 3 Deflection	mm	600	60.6	55.8	61.6	55.2	61.2	56.2	61.1	0.5	0.8	55.7	0.5	0.88	58.4	3.0	5.1
Abdominal Rib 1Deflection	mm	600	36.8	33.9	36.9	34.7	37.8	34.1	37.2	0.6	1.5	34.2	0.4	1.22	35.7	1.7	4.7
Abdominal Rib 2 Deflection	mm	600	22.7	21.8	23.6	23.4	24.4	22.3	23.6	0.8	3.5	22.5	0.8	3.55	23.0	0.9	4.1
Pelvis Y-axis Accel.	g	1000	66.0	69.2	65.0	67.5	65.0	66.4	65.4	0.6	0.9	67.7	1.4	2.14	66.5	1.6	2.4
Pubic Y-Axis Force	N	600	-1648.5	-1634.2	-1660.3	-1642.2	-1599.9	-1625.1	-1636.2	32.0	2.0	-1633.8	8.6	0.53	-1635.0	21.0	1.3

Note 1: Shoulder IR-TRACC was removed due to potential of exceeding maximum stroke length

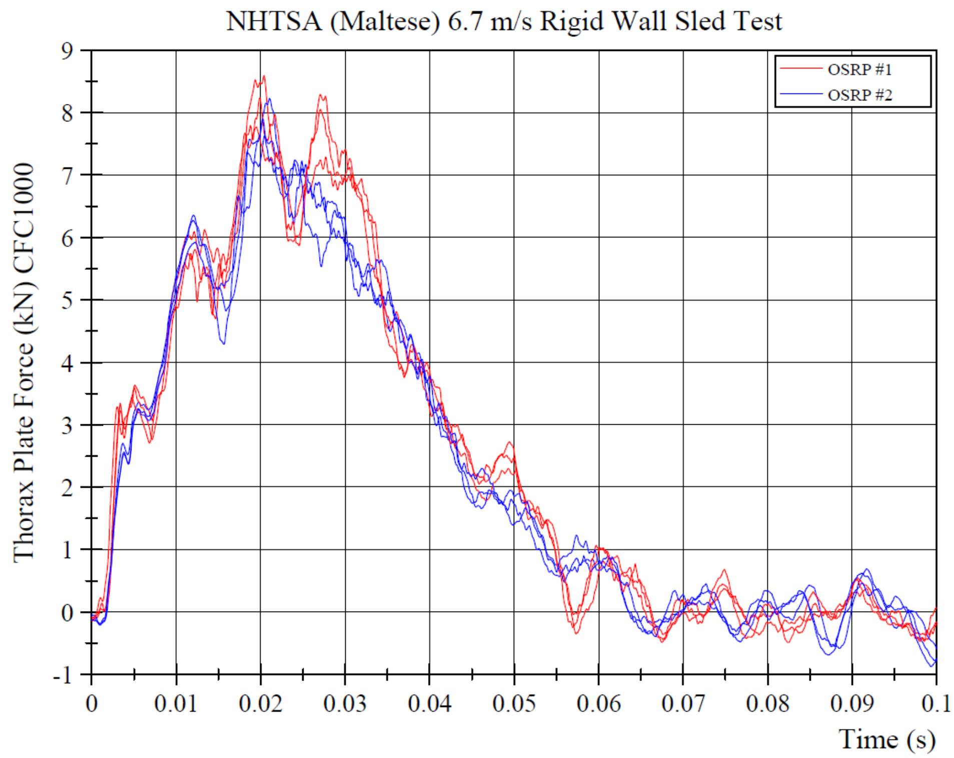

Figure B-1. NHTSA Rigid Wall – Thorax Plate Force

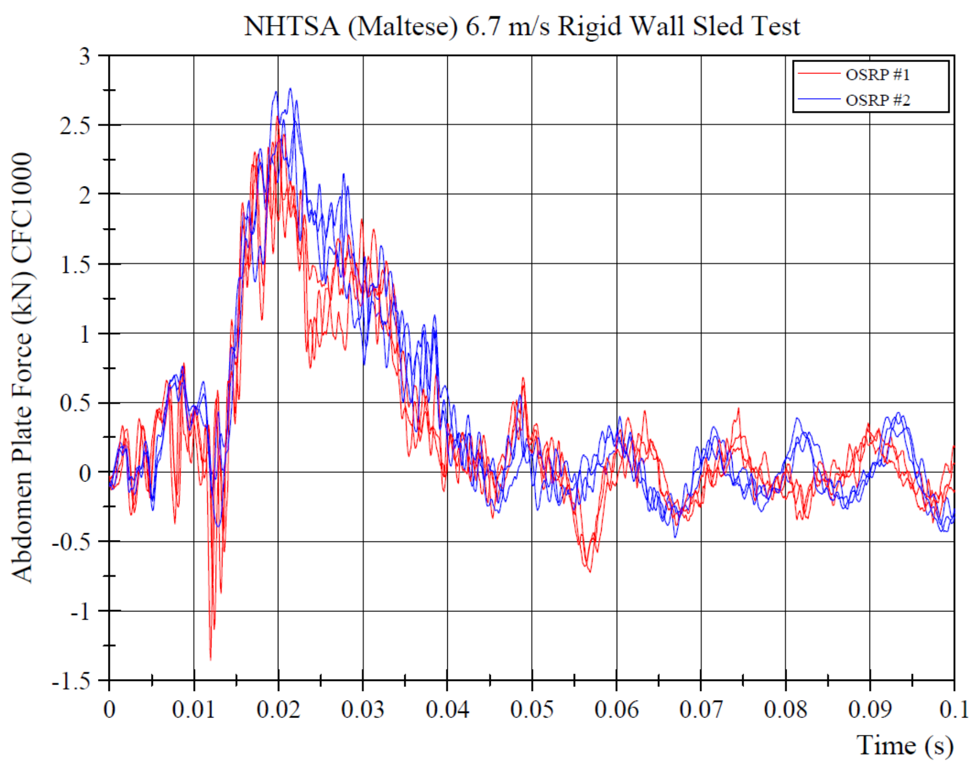

Figure B-2. NHTSA Rigid Wall – Abdomen Plate Force

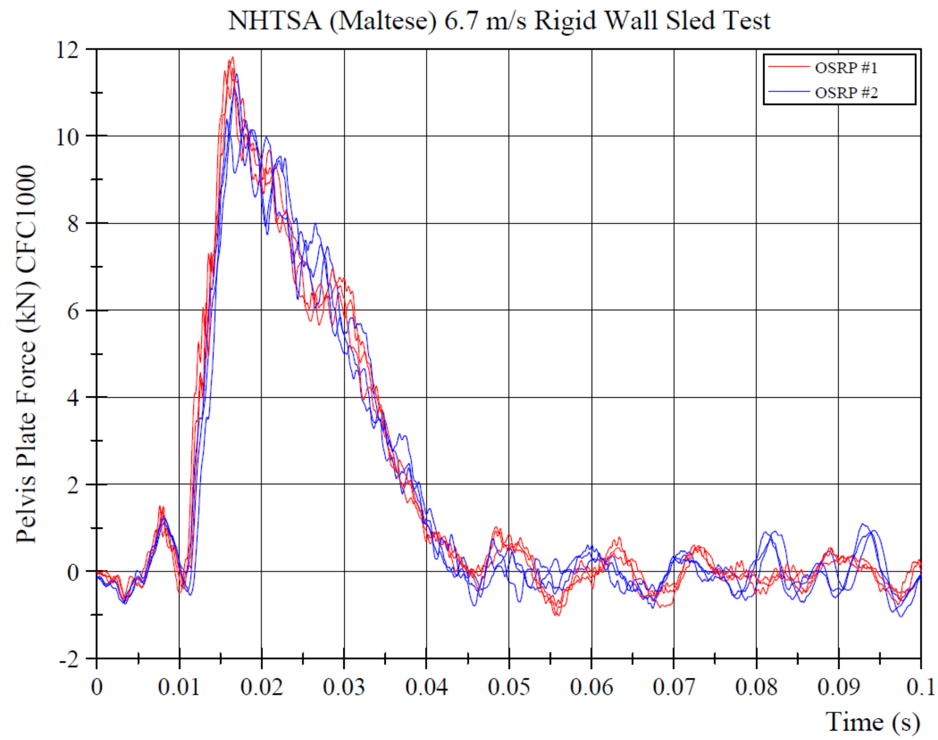

Figure B-3. NHTSA Rigid Wall – Pelvis Plate Force

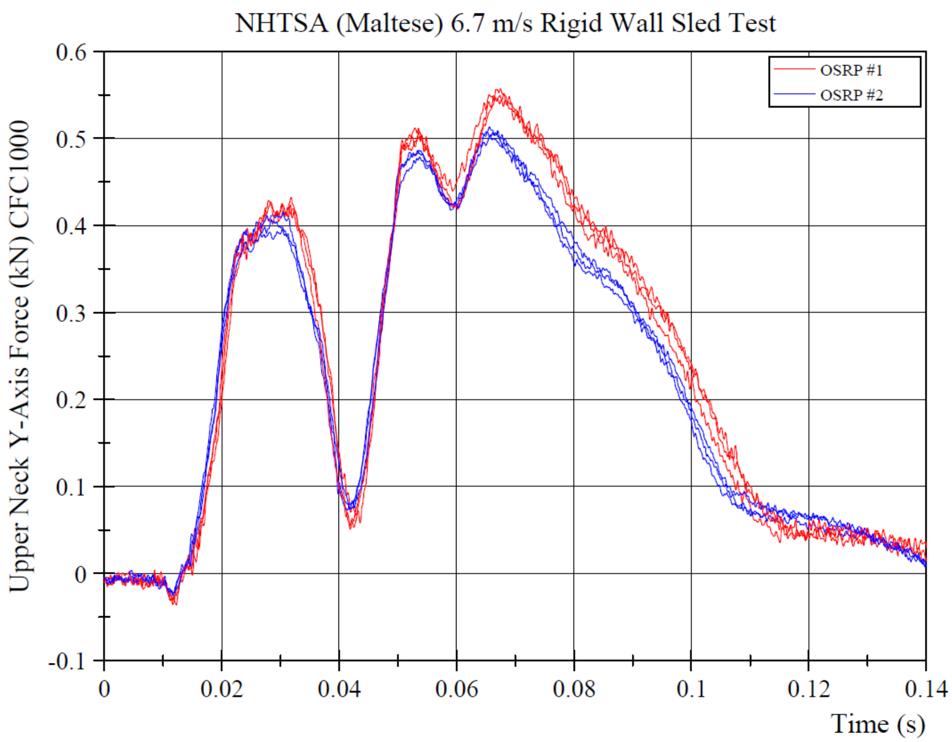

Figure B-4. NHTSA Rigid Wall – Upper Neck Y-Force

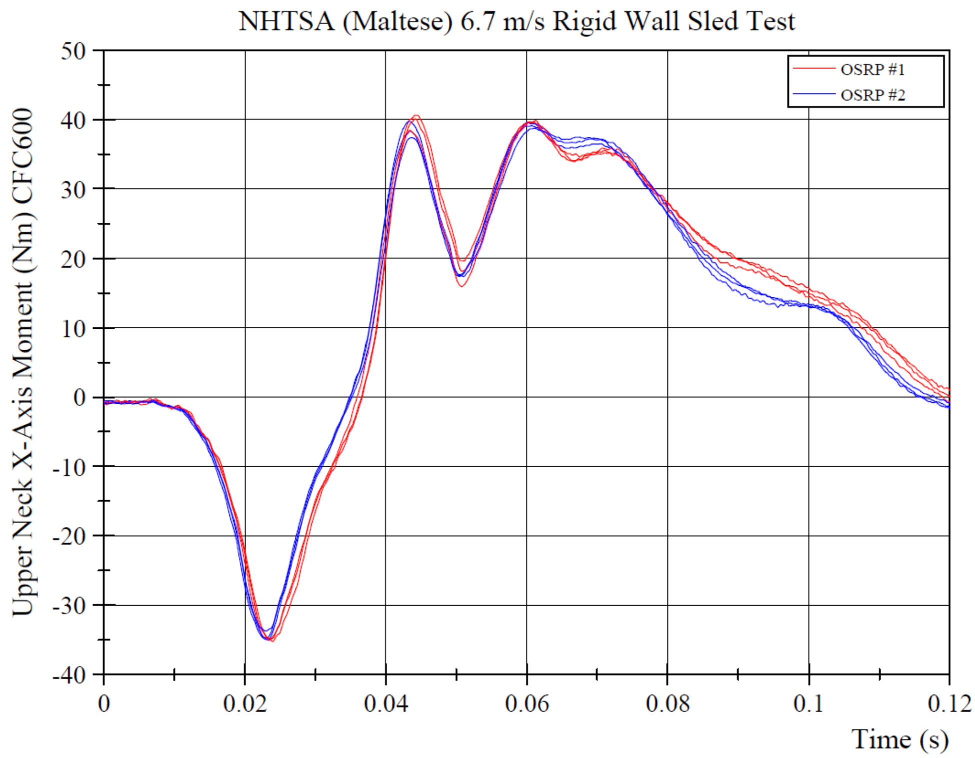

Figure B-5. NHTSA Rigid Wall – Upper Neck X-Moment

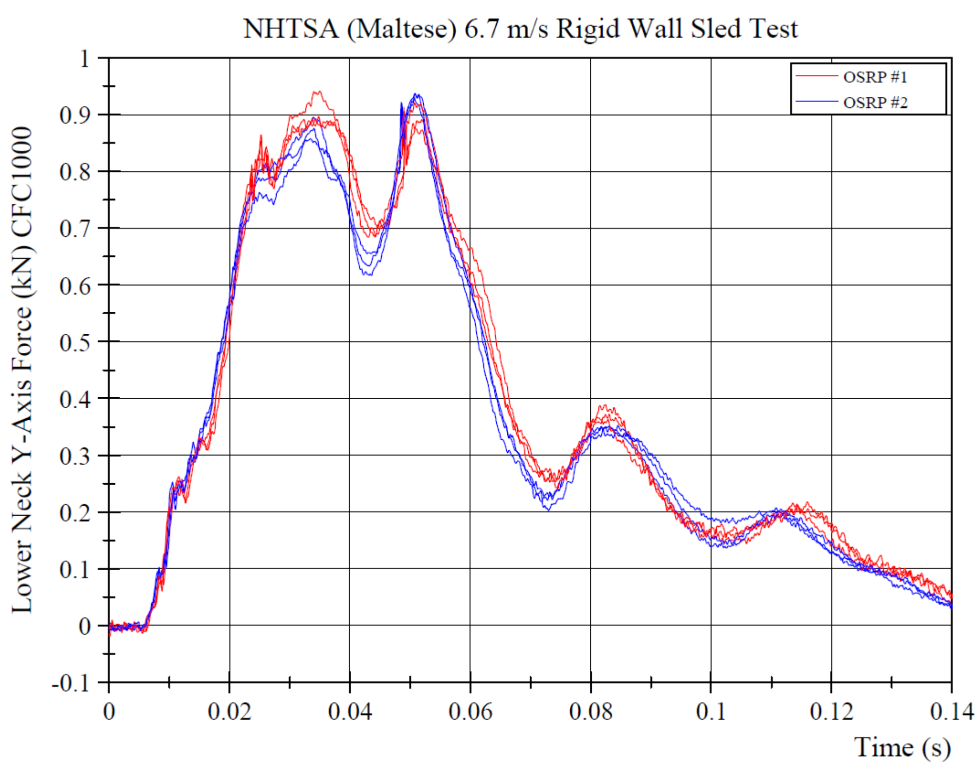

Figure B-6. Lower Neck Y-Force

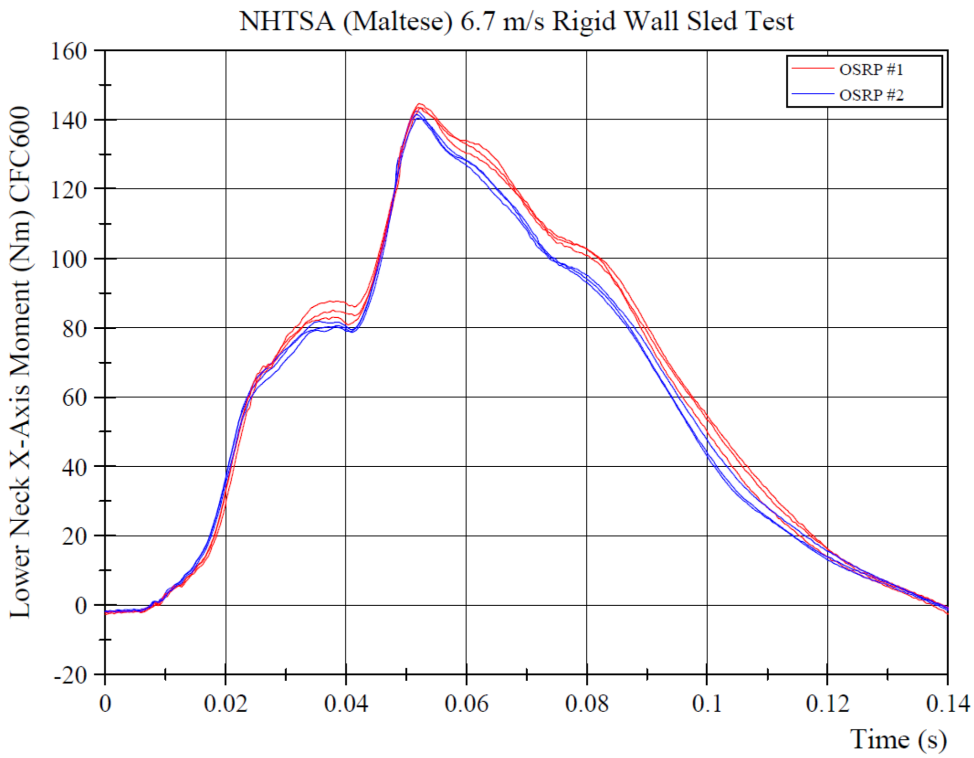

Figure B-7. NHTSA Rigid Wall – Lower Neck X-Moment

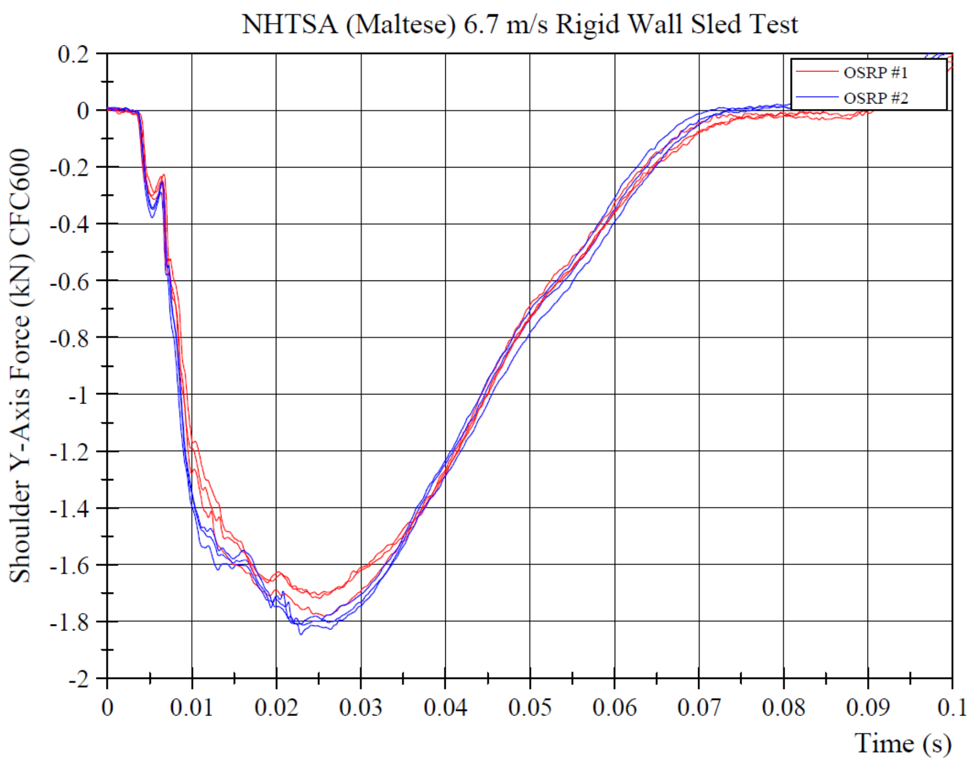

Figure B-8. NHTSA Rigid Wall – Shoulder Y-Force

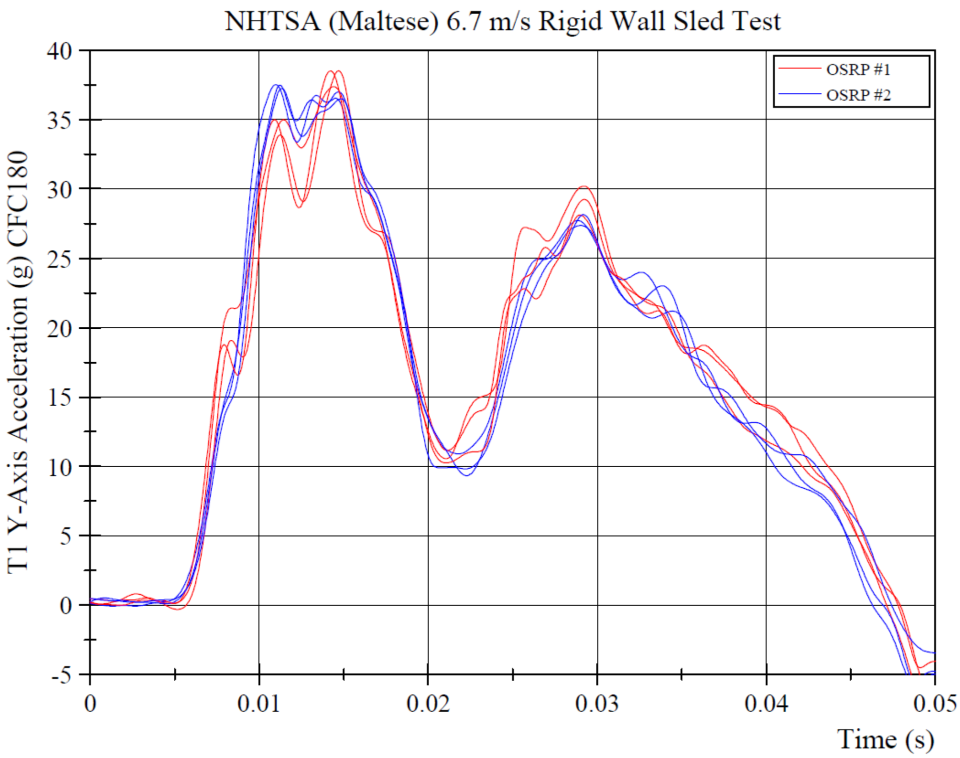

Figure B-9. NHTSA Rigid Wall – T1 Y-Acceleration

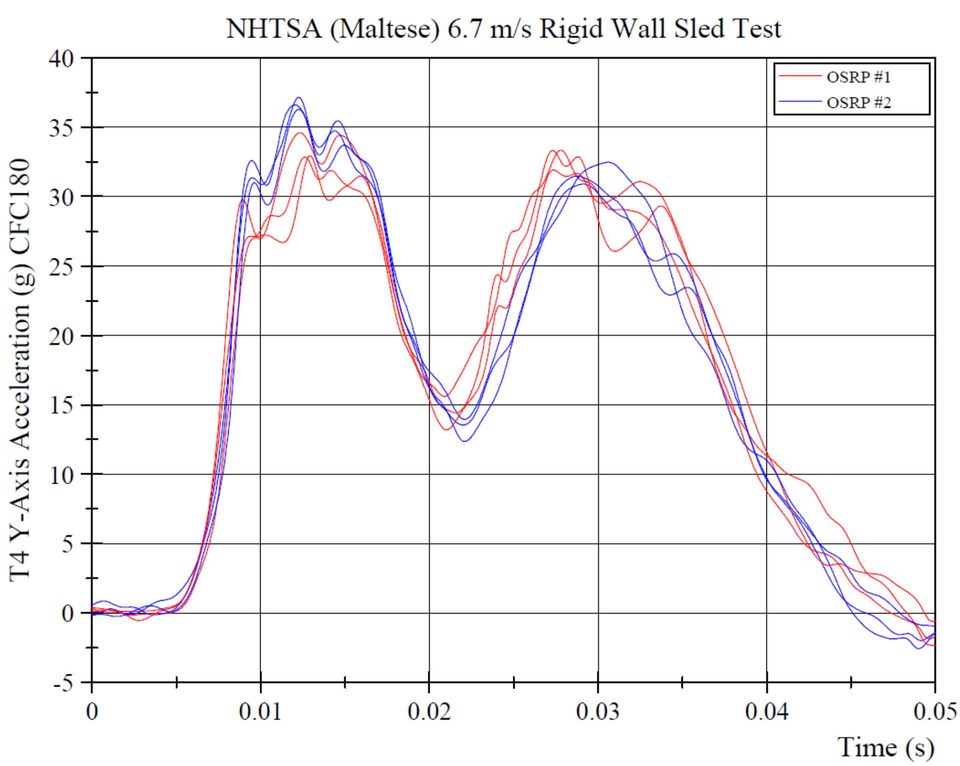

Figure B-10. NHTSA Rigid Wall – T4 Y-Acceleration

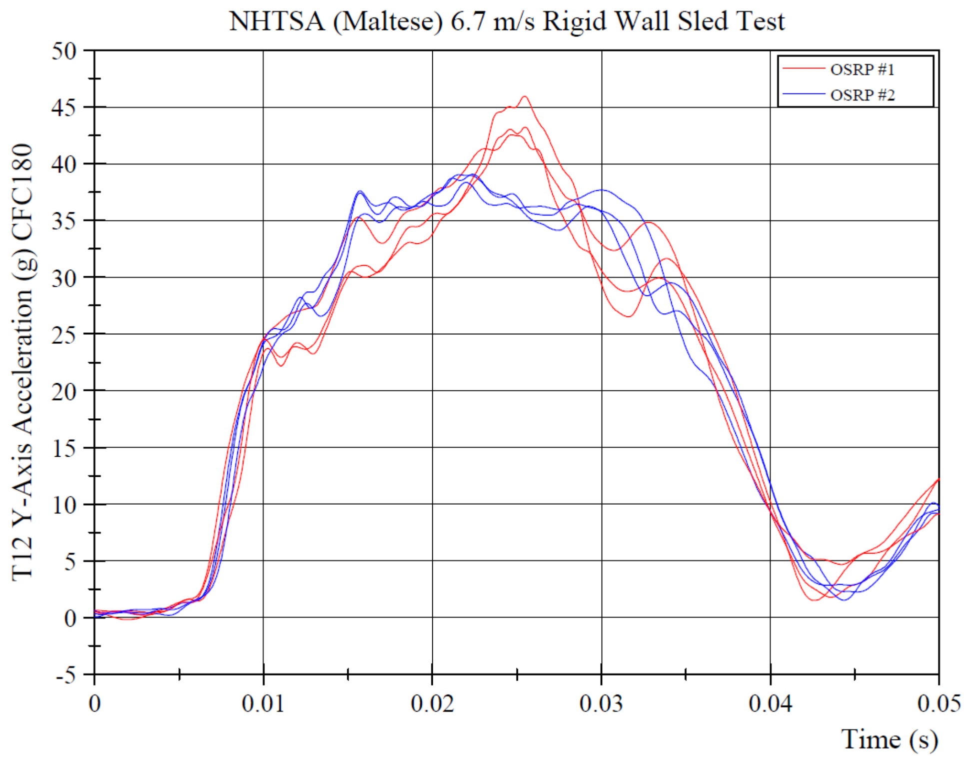

Figure B-11. NHTSA Rigid Wall – T12 Y-Acceleration

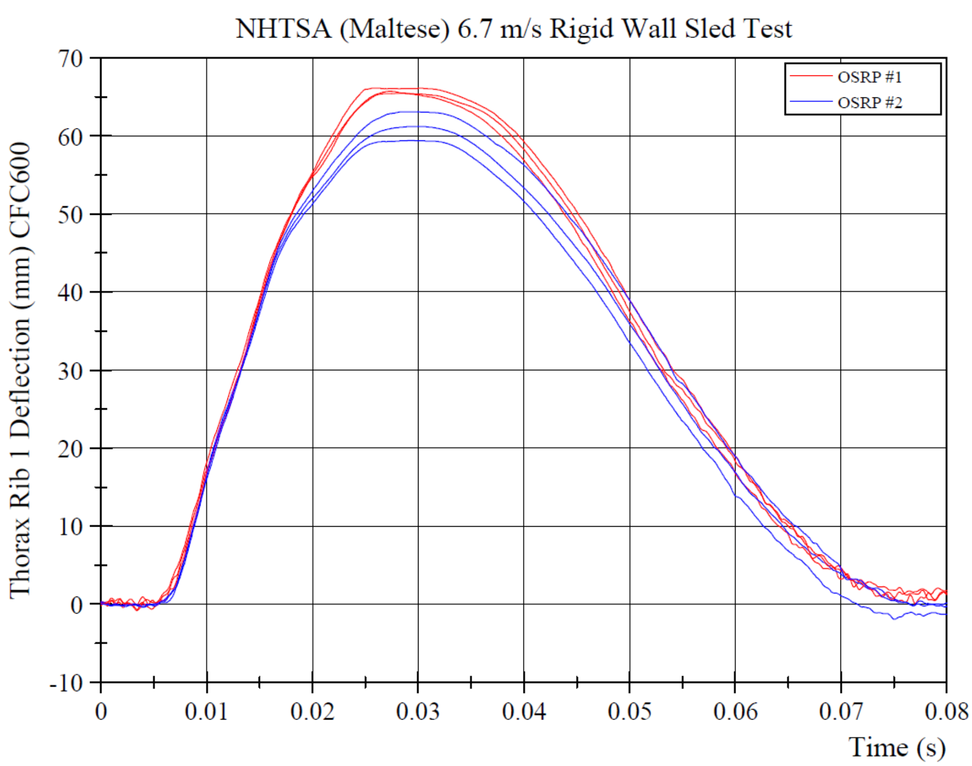

Figure B-12. NHTSA Rigid Wall – Thorax Rib 1 Displacement

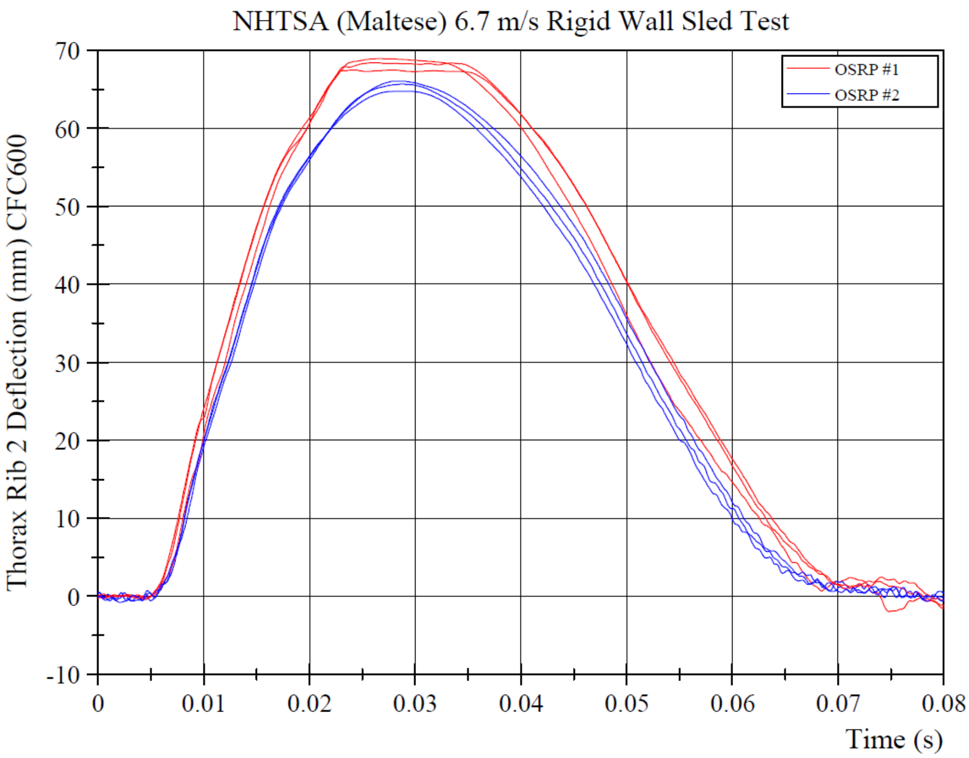

Figure B-13. NHTSA Rigid Wall – Thorax Rib 2 Displacement

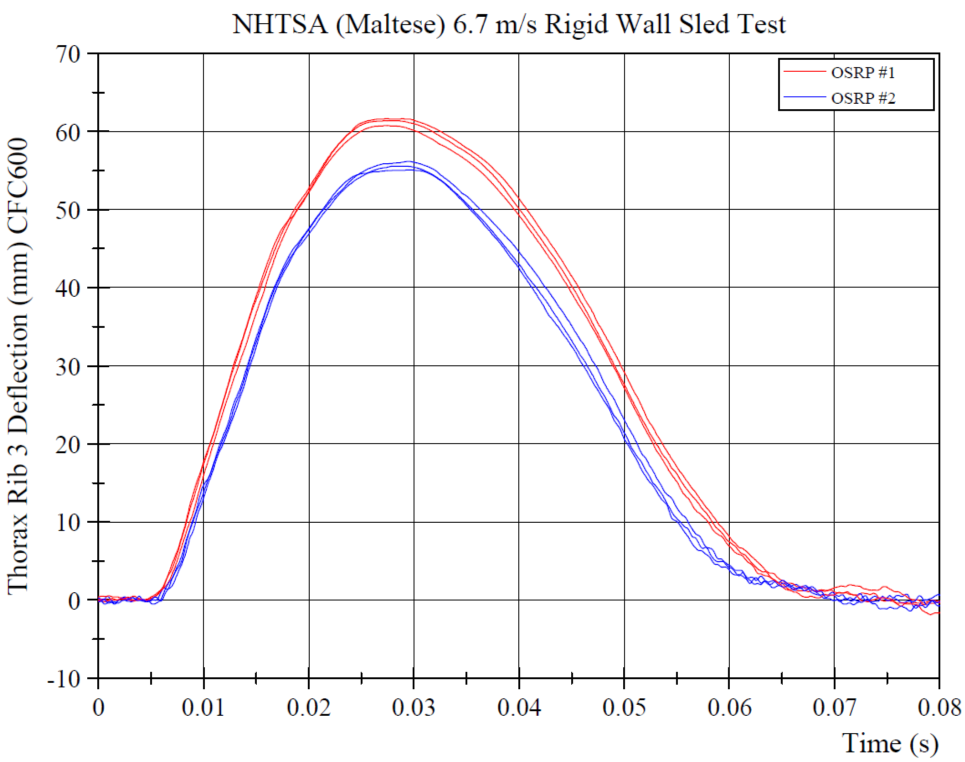

Figure B-14. NHTSA Rigid Wall – Thorax Rib 3 Displacement

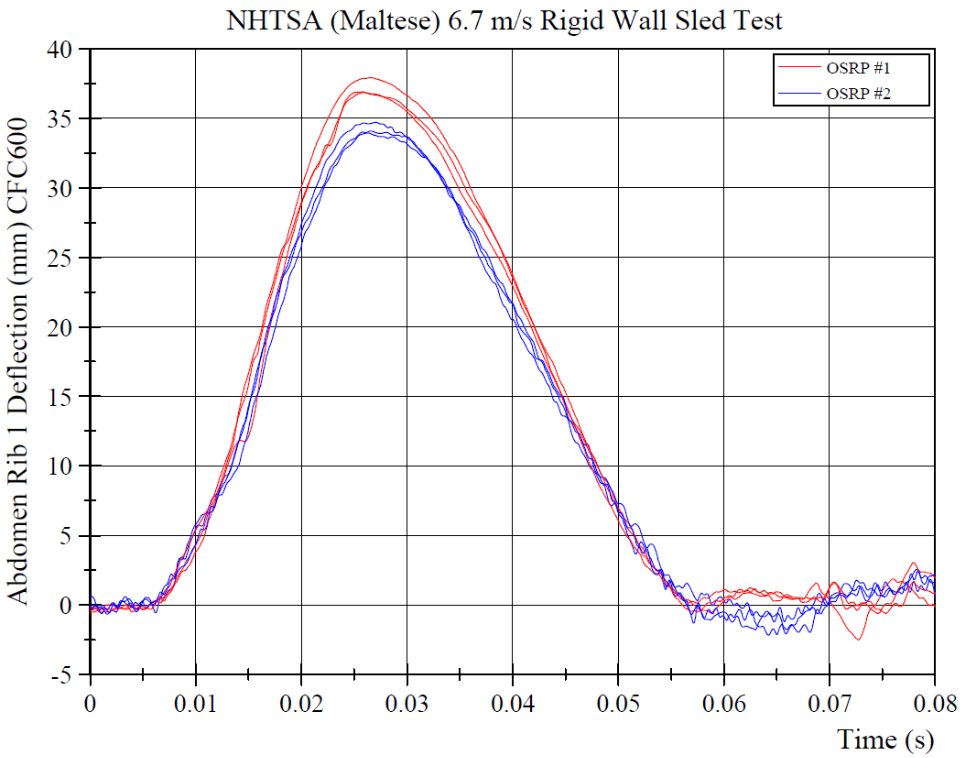

Figure B-15. NHTSA Rigid Wall – Abdomen Rib 1 Displacement

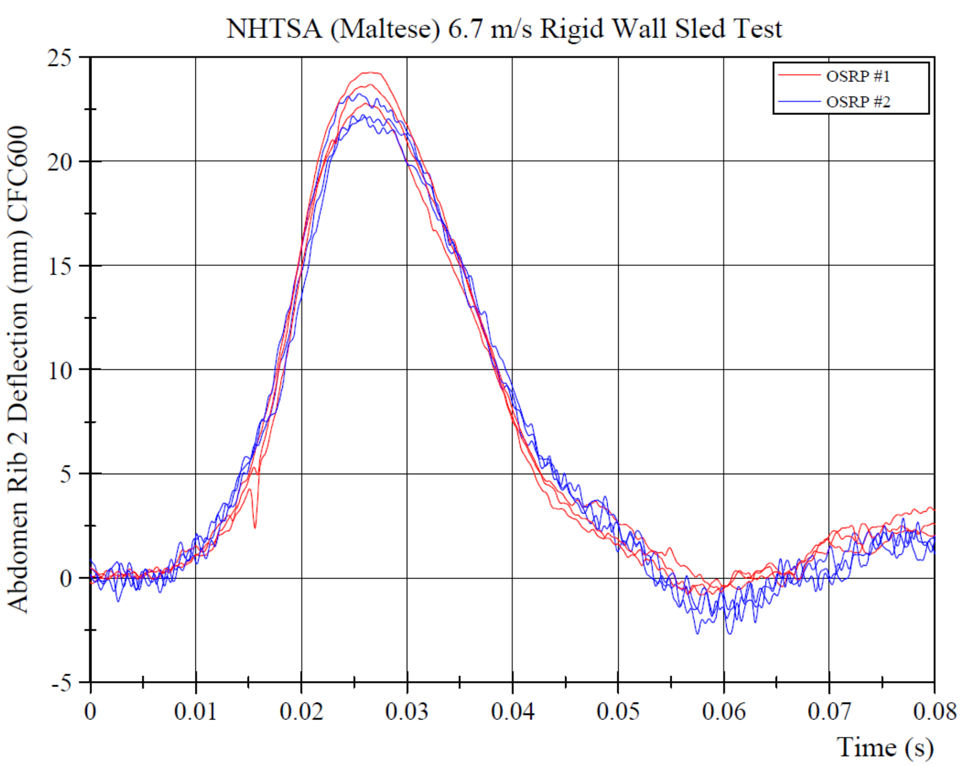

Figure B-16. NHTSA Rigid Wall – Abdomen Rib 2 Displacement

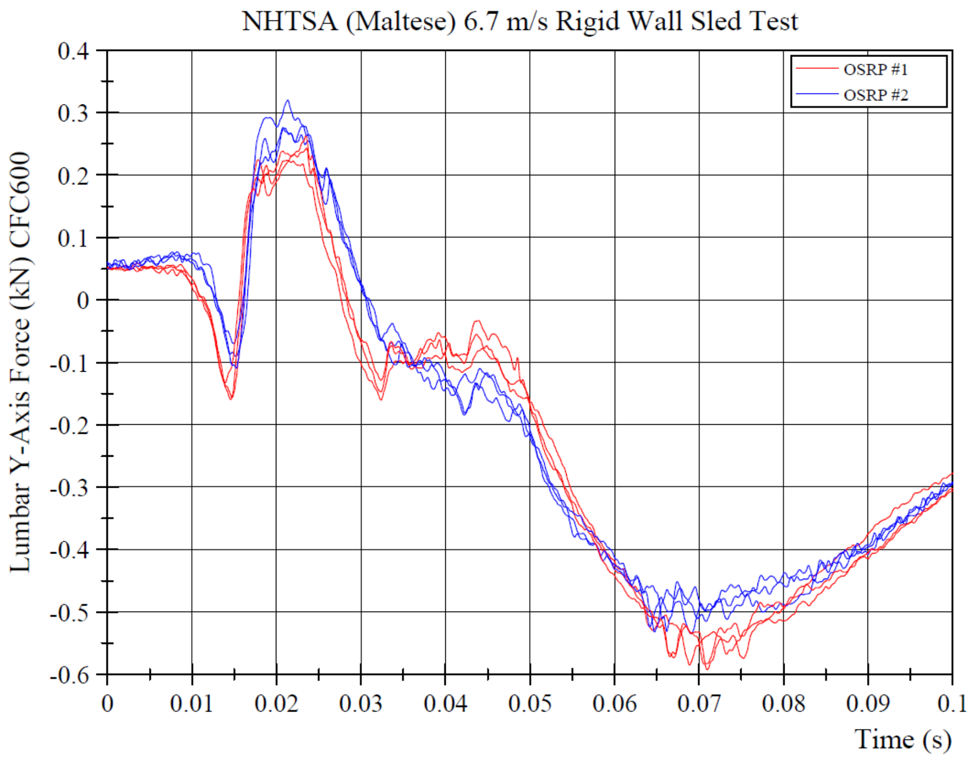

Figure B-16. NHTSA Rigid Wall – Lumbar Y-Force

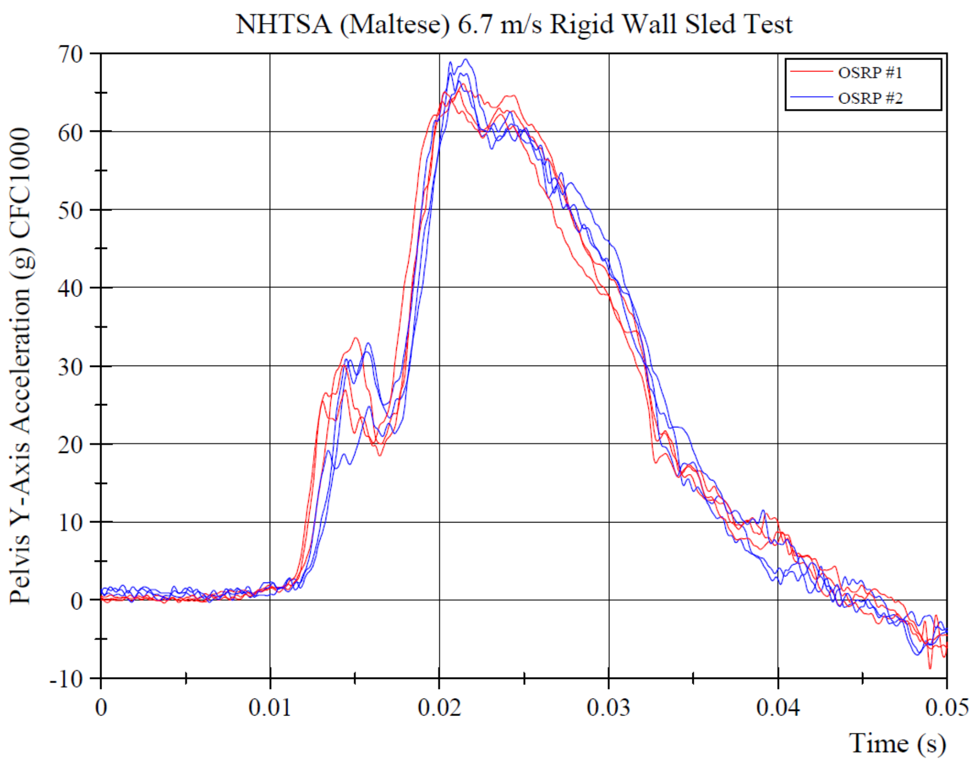

Figure B-17. NHTSA Rigid Wall – Pelvis Y-Acceleration

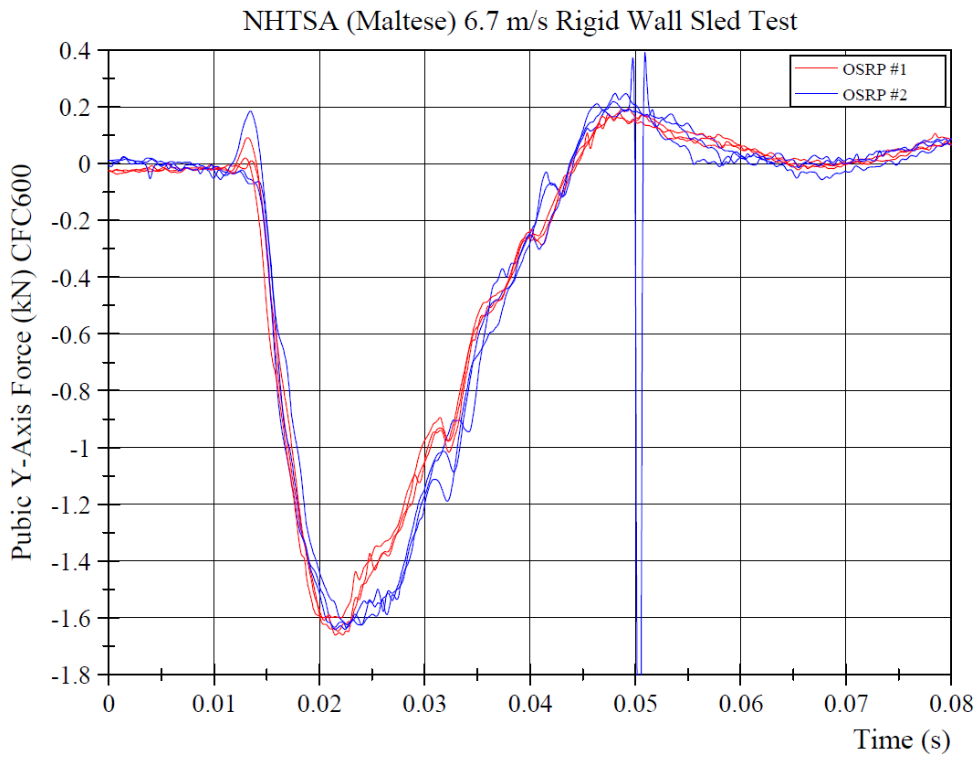

Figure B-18. NHTSA Rigid Wall – Pubic Y-Force

Appendix C: NHTSA 6.7 m/s Padded Flat Wall Sled Tests

Table C.1. NHTSA (Maltese) 6.7 m/s Padded Flat Wall Sled Test Results

Channel	Units	CFC	1		2		3		OSRP 1			OSRP 2			Combined		
			OSRP 1	OSRP 2	OSRP 1	OSRP 2	OSRP 1	OSRP 2	Avg	Std Dev	% CV	Avg	Std Dev	% CV	Avg	Std Dev	% CV
Thorax Plate Force	N	1000	5531.1	5353.3	5425.0	5217.7	5369.1	5369.0	5441.7	82.3	1.5	5313.3	83.2	1.6	5377.5	102.1	1.9
Abdomen Plate Force	N	1000	2489.6	2265.9	2367.8	2233.1	2352.6	2488.4	2403.3	75.1	3.1	2329.2	138.9	6.0	2366.2	107.8	4.6
Pelvis Plate Force	N	1000	6303.2	5675.0	6034.2	6003.2	6181.2	6325.6	6172.9	134.7	2.2	6001.3	325.3	5.4	6087.1	241.7	4.0
Upper Neck Y-axis Force	N	1000	469.3	452.8	468.8	434.7	488.3	455.9	475.5	11.1	2.3	447.8	11.5	2.6	461.6	18.2	3.9
Upper Neck X-axis Moment	N·m	600	33.2	34.2	32.7	34.6	34.3	34.8	33.4	0.8	2.4	34.5	0.3	0.9	34.0	0.8	2.4
Lower Neck Y-axis Force	N	1000	867.7	866.3	881.0	897.5	906.1	864.3	885.0	19.5	2.2	876.0	18.6	2.1	880.5	17.7	2.0
Lower Neck X-axis Moment	N·m	600	129.7	127.5	129.0	128.5	134.6	128.2	131.1	3.0	2.3	128.1	0.5	0.4	129.6	2.6	2.0
Shoulder Y-axis Force	N	600	-1109.6	-1242.7	-1106.4	-1216.1	-1299.2	-1334.5	-1171.7	110.4	9.4	-1264.4	62.1	4.9	-1218.1	94.8	7.8
Shoulder Rib Deflection	mm	600	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1	Note 1
T1 Y-axis Accel.	g	180	22.6	22.8	21.7	21.4	23.2	23.7	22.5	0.7	3.3	22.7	1.2	5.1	22.6	0.9	3.9
T4 Y-axis Accel.	g	180	22.7	26.4	23.1	22.3	25.0	25.1	23.6	1.2	5.2	24.6	2.1	8.6	24.1	1.6	6.8
T12 Y-axis Accel.	g	180	31.7	37.2	32.5	35.1	34.2	35.4	32.8	1.2	3.8	35.9	1.2	3.2	34.4	2.0	5.9
Thorax Rib 1 Deflection	mm	600	37.5	37.3	37.6	37.0	41.4	40.1	38.8	2.2	5.6	38.2	1.7	4.4	38.5	1.8	4.6
Thorax Rib 2 Deflection	mm	600	50.0	44.7	49.8	46.4	50.9	46.5	50.2	0.6	1.2	45.8	1.0	2.2	48.0	2.5	5.3
Thorax Rib 3 Deflection	mm	600	45.0	40.2	45.5	39.1	44.9	41.5	45.1	0.3	0.7	40.3	1.2	3.0	42.7	2.8	6.5
Abdominal Rib 1Deflection	mm	600	27.6	26.8	28.5	24.5	28.1	26.7	28.1	0.5	1.7	26.0	1.3	4.9	27.0	1.4	5.3
Abdominal Rib 2 Deflection	mm	600	18.8	18.9	18.8	17.0	17.3	19.9	18.3	0.9	4.9	18.6	1.5	8.0	18.5	1.1	6.0
Pelvis Y-axis Accel.	g	1000	41.0	40.3	40.1	40.4	39.6	38.3	40.2	0.7	1.8	39.7	1.2	3.0	39.9	0.9	2.4
Pubic Y-Axis Force	N	600	-1156.9	-1179.0	-1203.9	-1021.6	-1161.2	-1215.5	-1174.0	26.0	2.2	-1138.7	103.0	9.0	-1156.4	69.9	6.0

Note 1: Shoulder IR-TRACC was removed due to potential of exceeding maximum stroke length

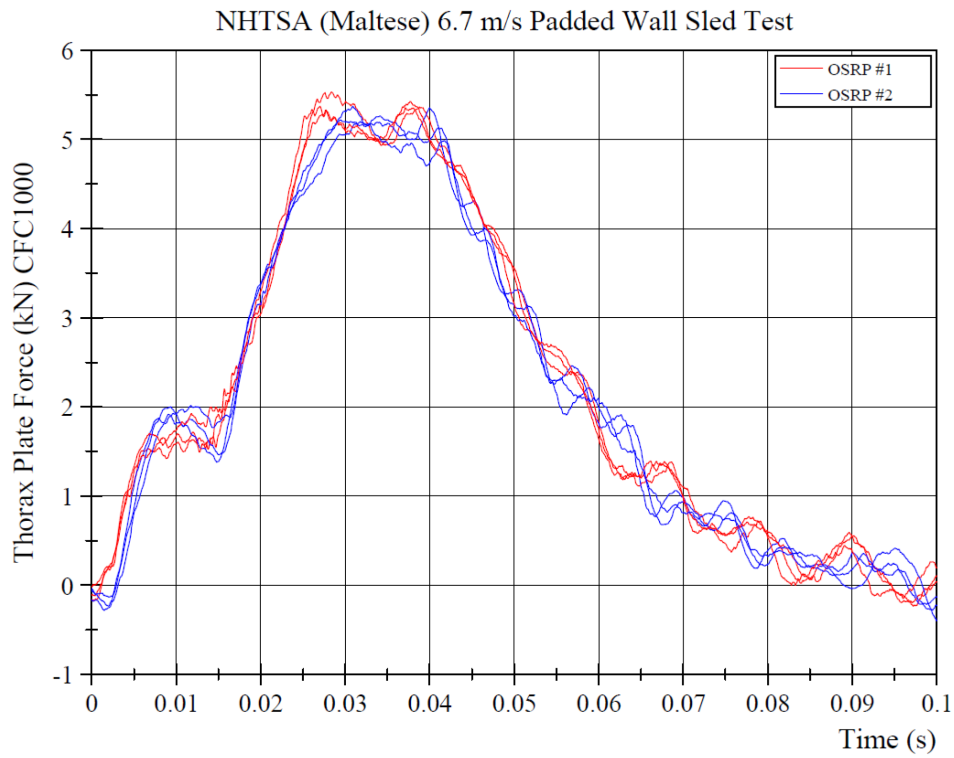

Figure C-1. NHTSA Padded Wall Tests – Thorax Plate Force

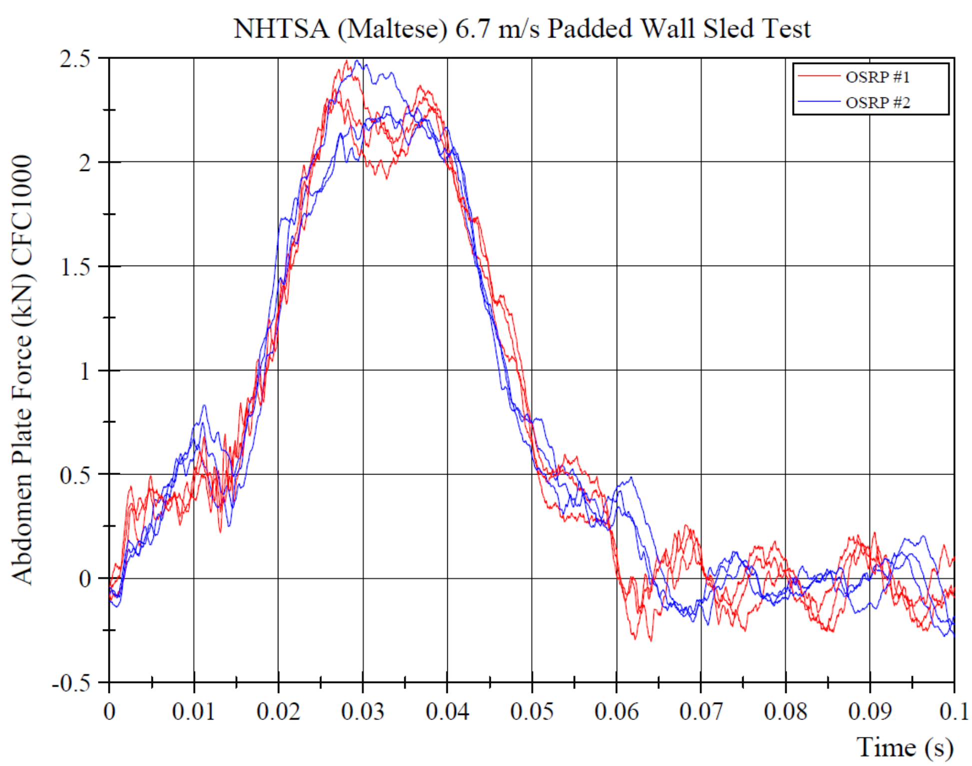

Figure C-2. NHTSA Padded Wall Tests – Abdomen Plate Force

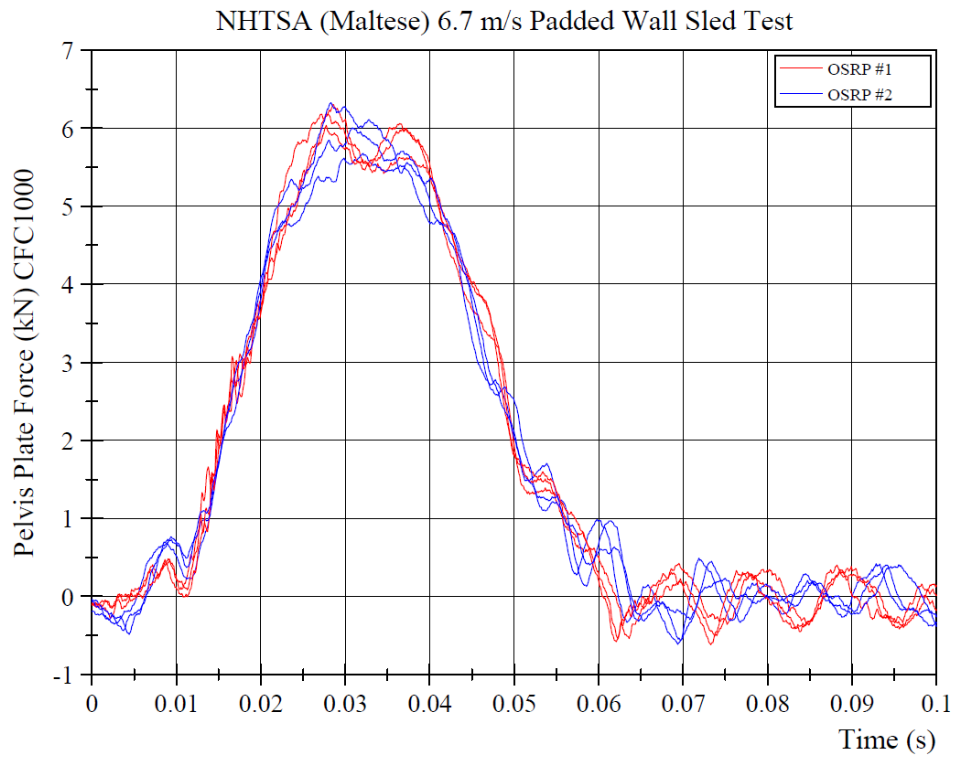

Figure C-3. NHTSA Padded Wall Tests – Pelvis Plate Force

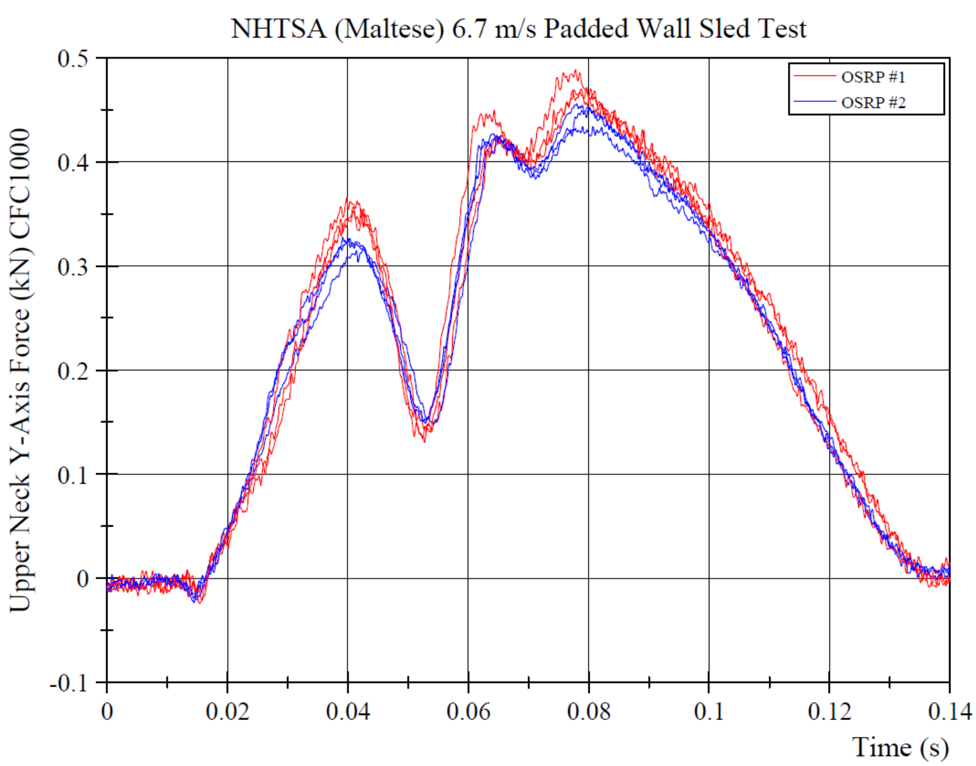

Figure C-4. NHTSA Padded Wall Tests – Upper Neck Y-Force

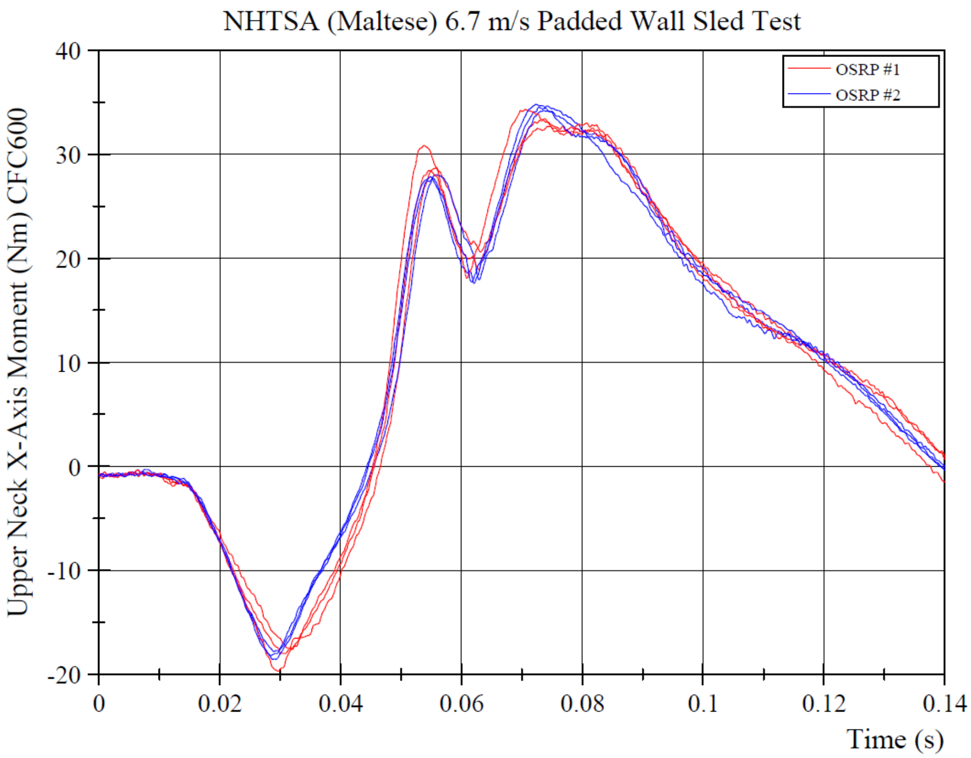

Figure C-5. NHTSA Padded Wall Tests – Upper Neck X-Moment

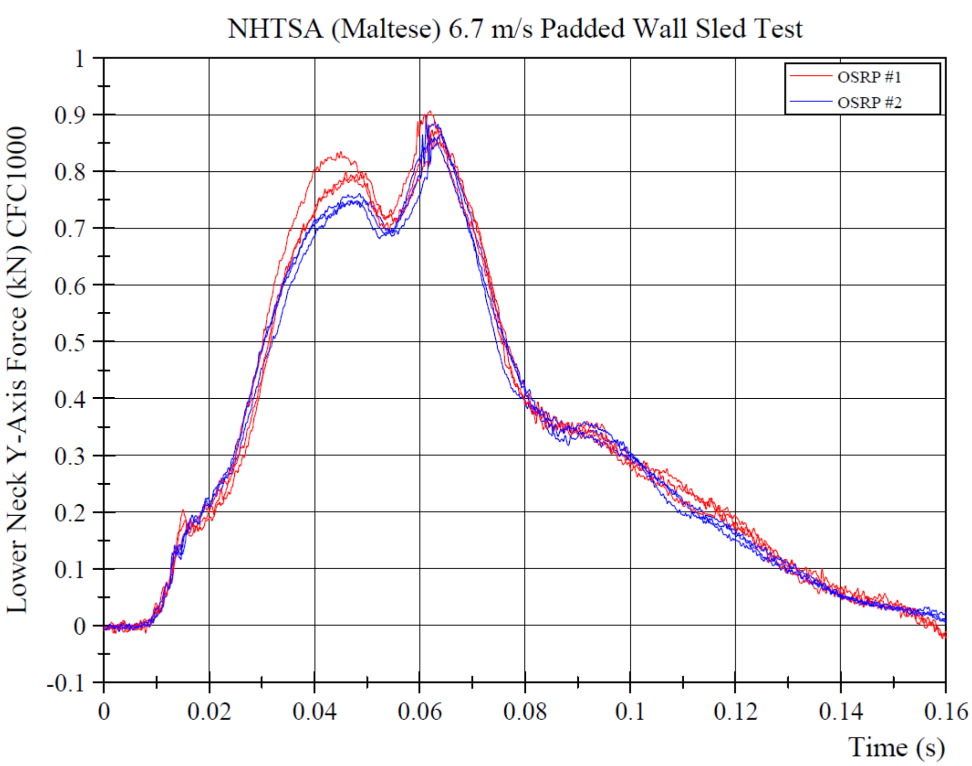

Figure C-6. NHTSA Padded Wall Tests – Lower Neck Y-Force

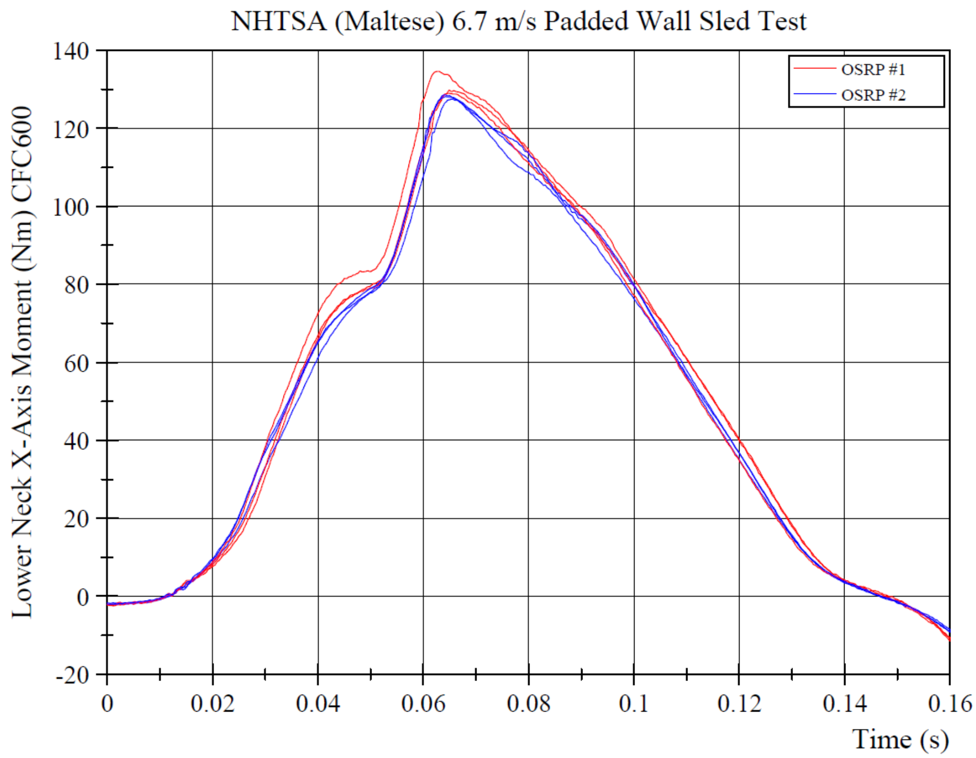

Figure C-7. NHTSA Padded Wall Tests – Lower Neck X-Moment

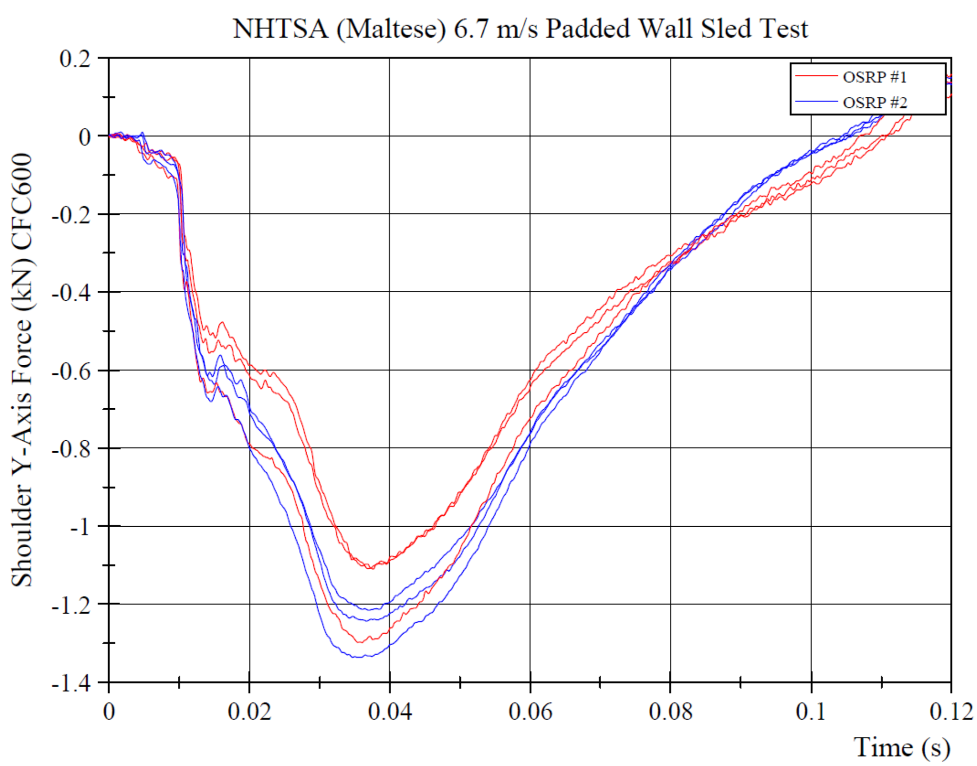

Figure C-8. NHTSA Padded Wall Tests – Shoulder Y-Force

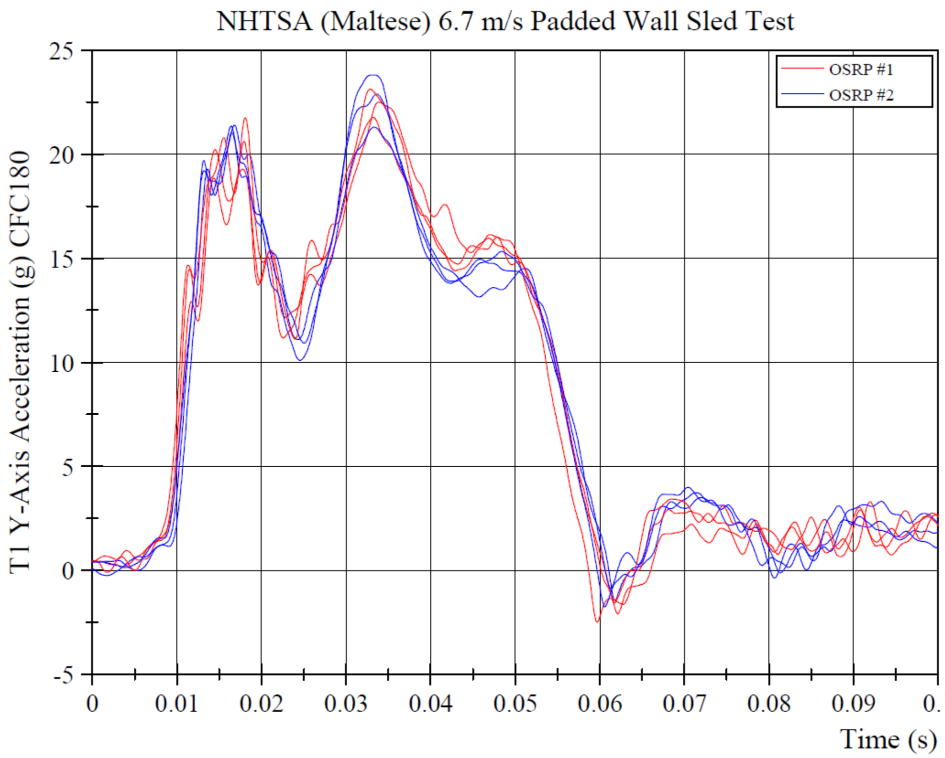

Figure C-9. NHTSA Padded Wall Tests – T1 Lateral Acceleration

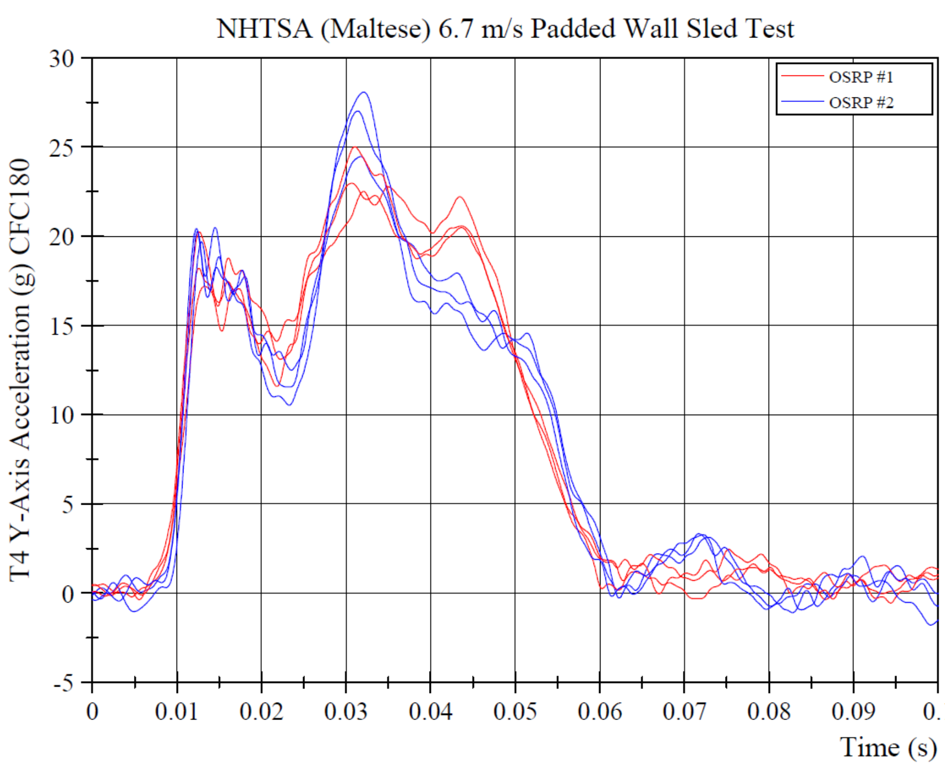

Figure C-10. NHTSA Padded Wall Tests – T4 Lateral Acceleration

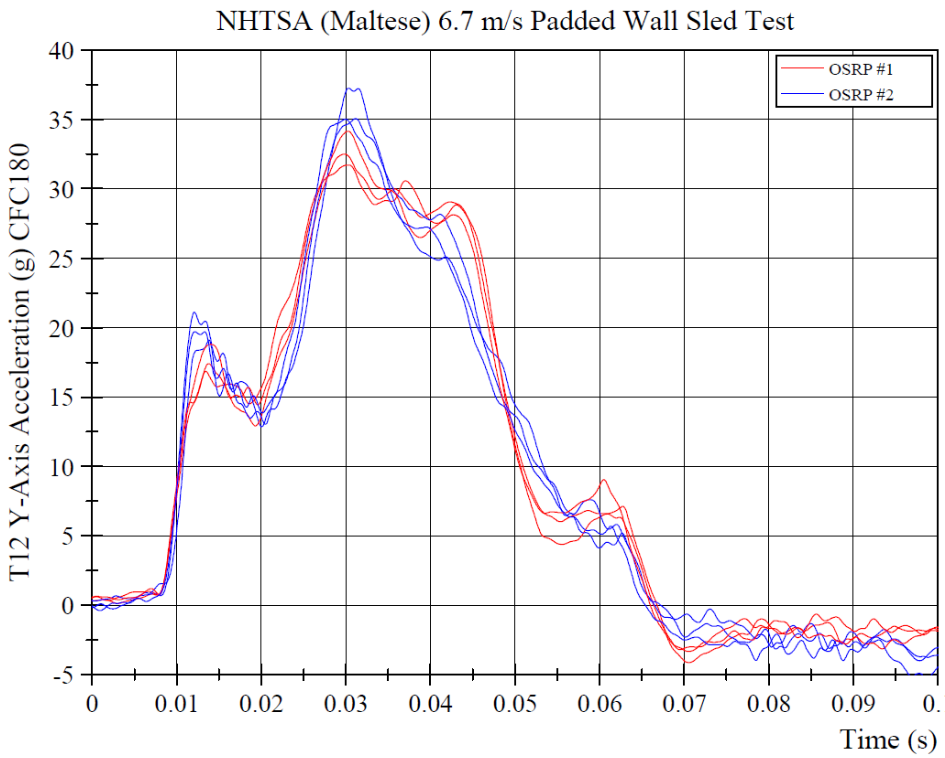

Figure C-11. NHTSA Padded Wall Tests – T12 Lateral Acceleration

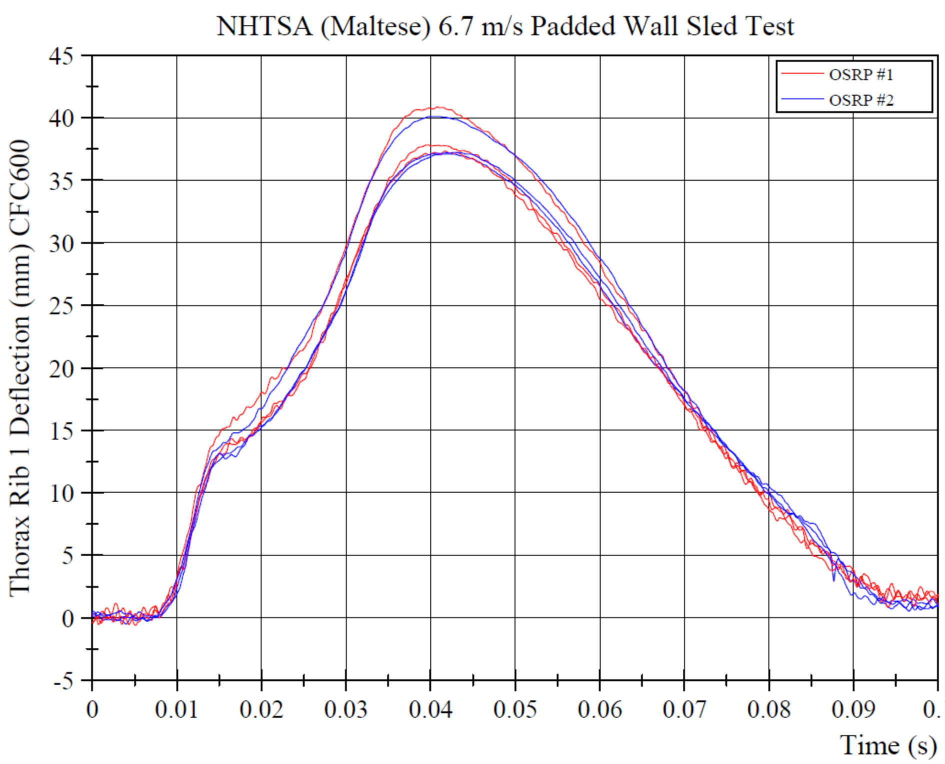

Figure C-12. NHTSA Padded Wall Tests – Thorax Rib 1 Displacement

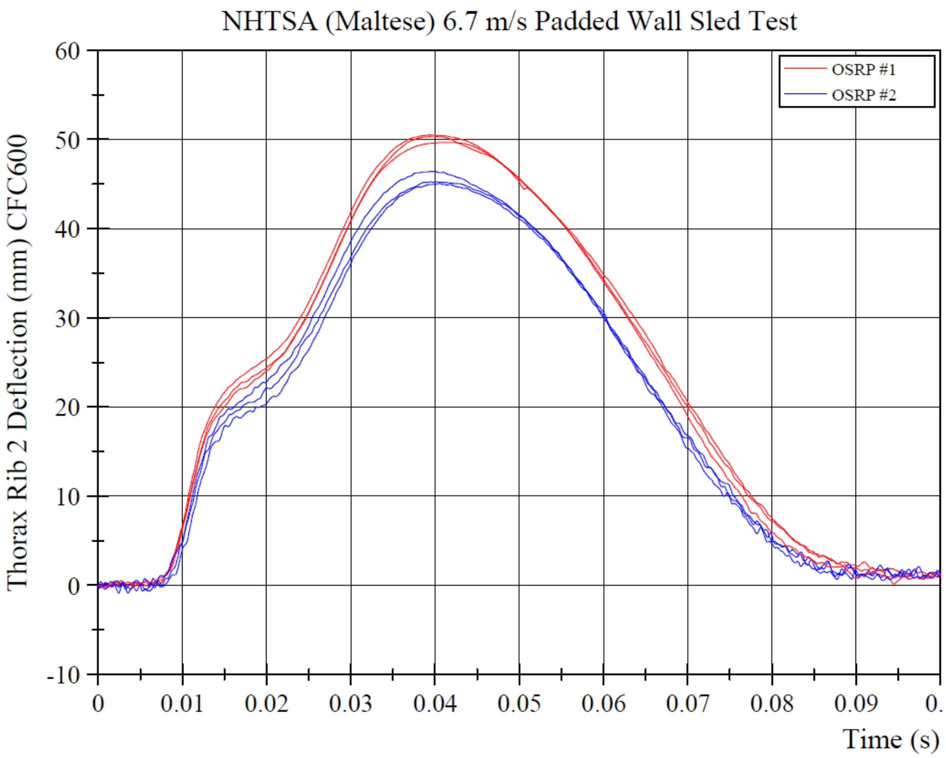

Figure C-13. NHTSA Padded Wall Tests – Thorax Rib 2 Displacement

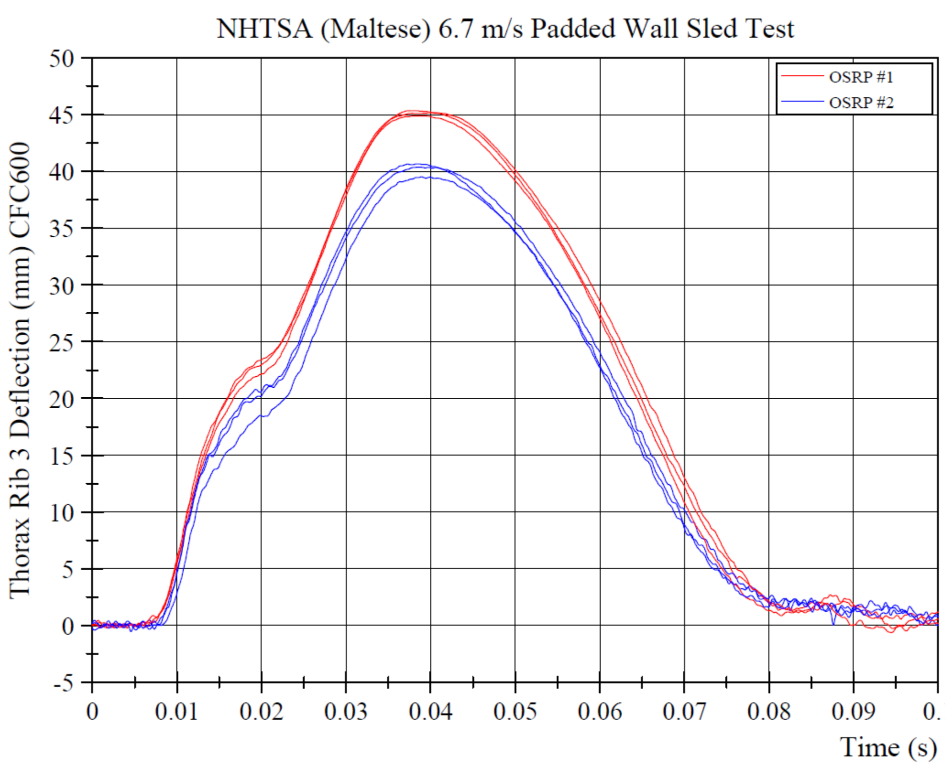

Figure C-14. NHTSA Padded Wall Tests – Thorax Rib 3 Displacement

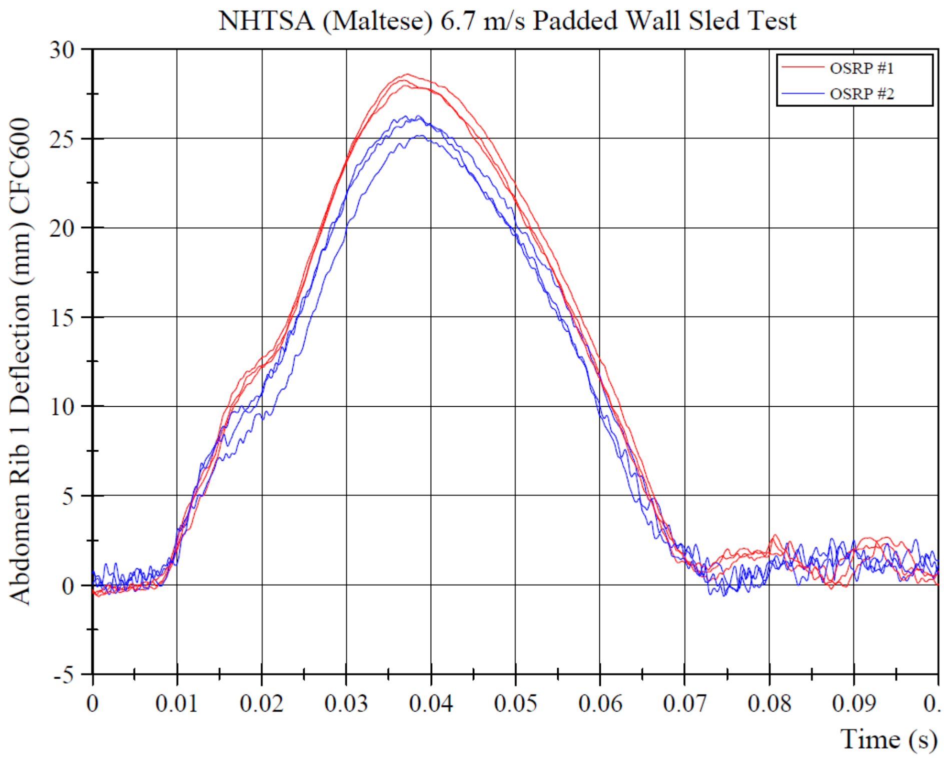

Figure C-15. NHTSA Padded Wall Tests – Abdomen Rib 1 Displacement

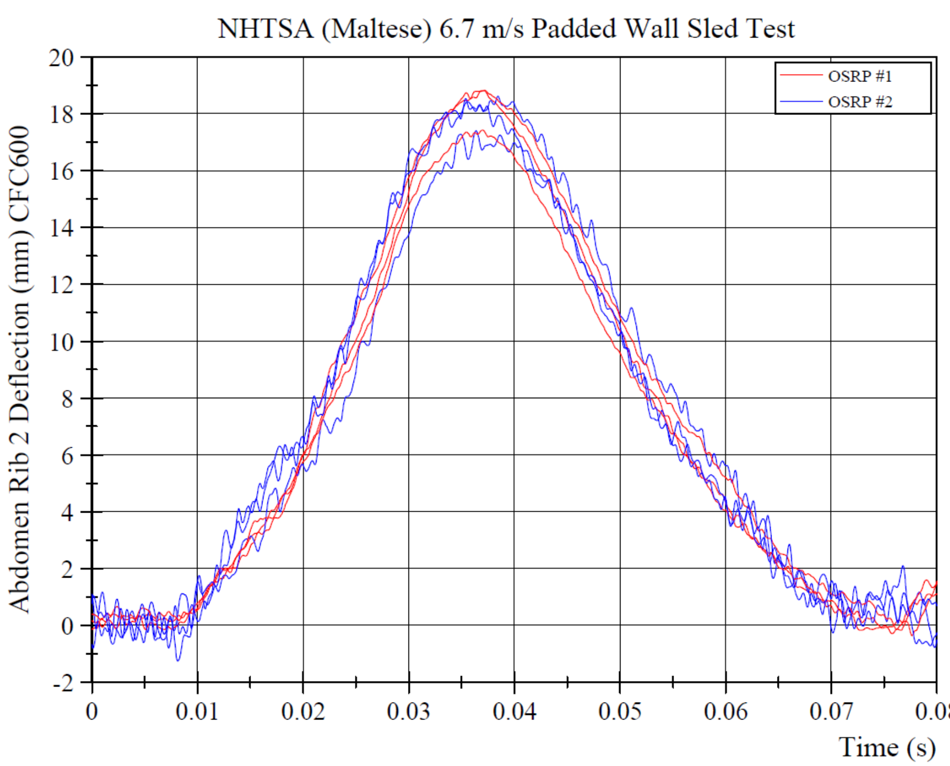

Figure C-16. NHTSA Padded Wall Tests – Abdomen Rib 2 Displacement

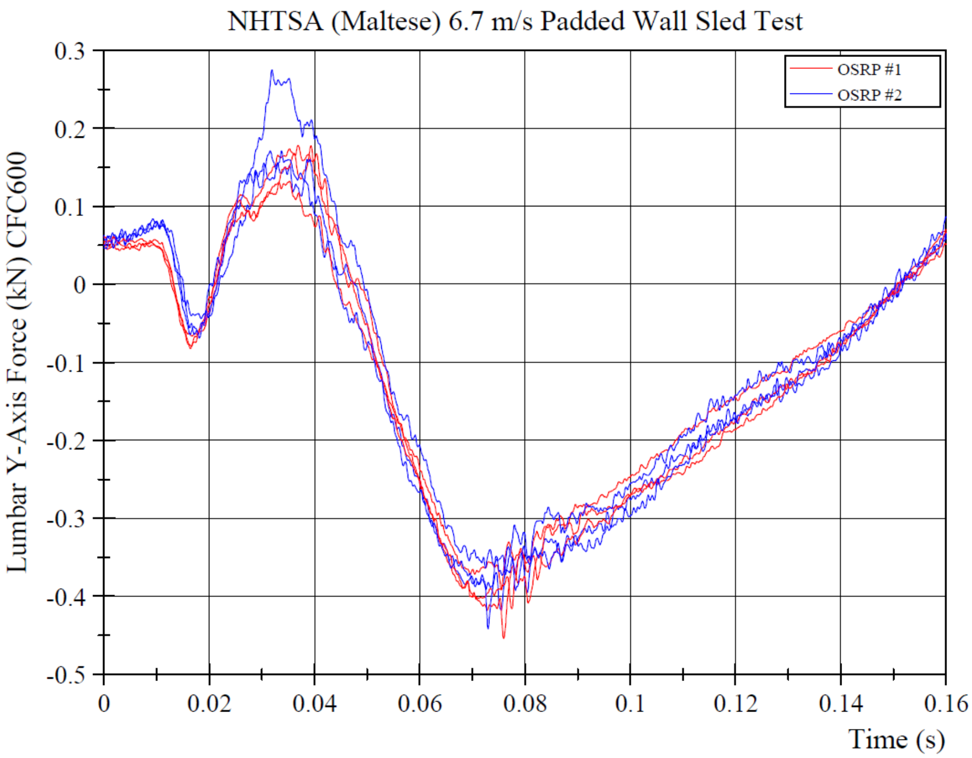

Figure C-17. NHTSA Padded Wall Tests – Lumbar Y-Force

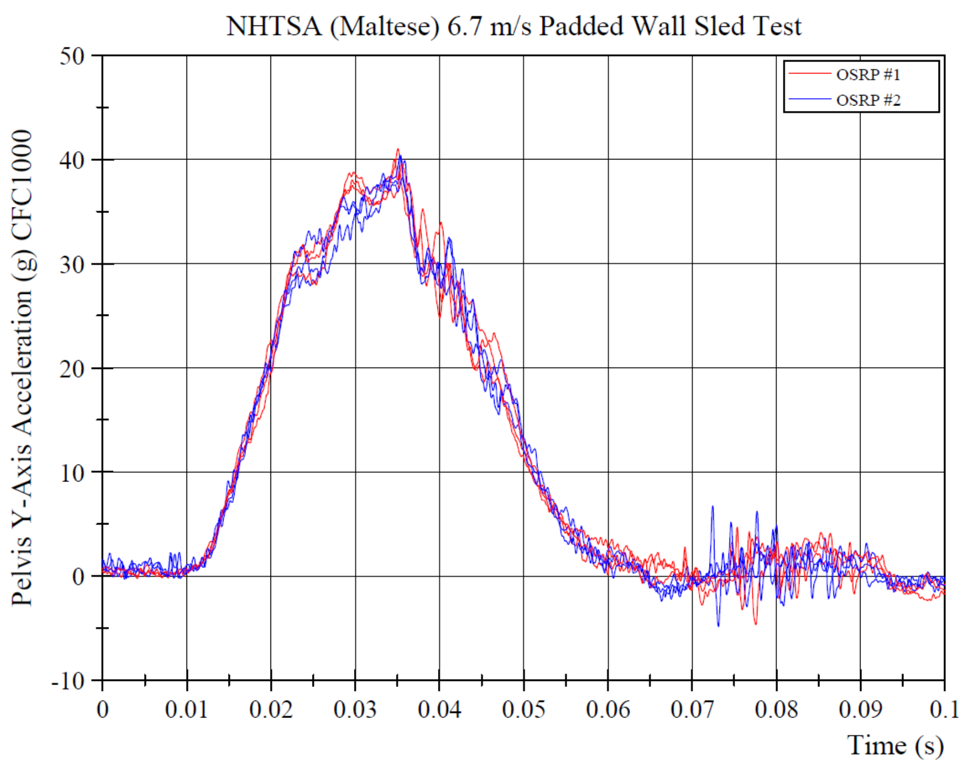

Figure C-18. NHTSA Padded Wall Tests – Pelvis Y-Acceleration

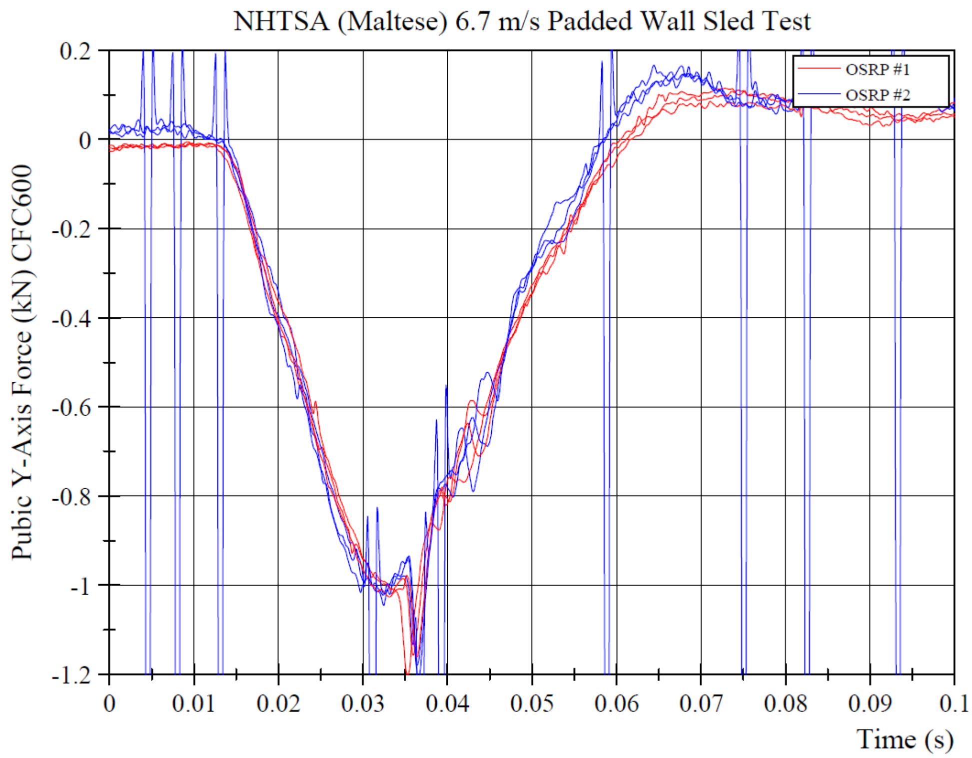

Figure C-19. NHTSA Padded Wall Tests – Pubic Y-Force

Appendix D: Heidelberg 6.8 m/s Rigid Wall Sled Test Data

Table D.1. Heidelberg 6.8 m/s Rigid Wall Sled Test

Channel	Units	CFC	1		2		3		4		5		OSRP 1			OSRP 2			Combined		
			OSRP 1	**OSRP 2**	**OSRP 1**	**OSRP 2**	**OSRP 1**	**OSRP 2**	**OSRP 1**	**OSRP 2**	**OSRP 1**	**OSRP 2**	**Avg**	**Std Dev**	**% CV**	**Avg**	**Std Dev**	**% CV**	**Avg**	**Std Dev**	**% CV**
Thorax Plate Force	N	1000	9538.1	8421.1	9111.7	8234.6	10058.8	8234.3	9265.5	8628.6	9408.1	8932.8	9476.4	362.3	3.8	8490.3	296.1	3.5	8983.4	606.2	6.7
Pelvis Plate Force	N	1000	13023.5	12395.3	12111.4	11826.4	13248.4	11754.0	12786.2	12162.3	12186.7	12457.2	12671.2	504.6	4.0	12119.0	320.7	2.6	12395.1	493.5	4.0
Upper Neck Y-axis Force	N	1000	557.0	507.0	537.4	501.2	572.2	517.9	553.8	507.0	562.1	502.1	556.5	12.7	2.3	507.0	6.6	1.3	531.8	27.8	5.2
Upper Neck X-axis Moment	N·m	600	52.4	41.9	46.9	39.1	53.1	41.1	51.4	43.7	50.7	43.1	50.9	2.4	4.8	41.8	1.8	4.4	46.3	5.2	11.2
Lower Neck Y-axis Force	N	1000	1180.0	1048.9	1077.2	1010.4	1150.9	1027.1	1134.2	1045.9	1104.0	1039.7	1129.3	40.0	3.5	1034.4	15.8	1.5	1081.8	57.6	5.3
Lower Neck X-axis Moment	N·m	600	143.2	142.3	141.1	138.6	148.3	140.6	144.0	139.5	142.2	138.8	143.8	2.8	1.9	140.0	1.5	1.1	141.9	2.9	2.0
Shoulder Y-axis Force	N	600	-2859.5	-2500.6	-2683.1	-2445.4	-2785.2	-2480.4	-2750.1	-2481.8	-2670.0	-2476.6	-2749.6	77.6	2.8	-2477.0	19.9	0.8	-2613.3	153.3	5.9
Shoulder Rib Deflection	mm	600	See Note 1																		
T1 Y-axis Accel.	g	180	40.4	48.8	38.9	48.0	39.5	45.0	40.2	45.6	39.0	43.9	39.6	0.7	1.7	46.3	2.1	4.5	42.9	3.8	8.8
T4 Y-axis Accel.	g	180	35.7	38.4	34.0	37.7	38.4	34.7	35.6	43.3	35.6	34.0	35.9	1.6	4.4	37.6	3.7	9.9	36.7	2.8	7.7
T12 Y-axis Accel.	g	180	59.9	55.0	54.2	54.9	52.6	51.7	54.5	50.6	55.2	52.5	55.3	2.8	5.0	52.9	1.9	3.7	54.1	2.6	4.8
Thorax Rib 1 Deflection	mm	600	See Note 2																		
Thorax Rib 2 Deflection	mm	600	50.0	50.7	48.7	49.2	51.9	49.6	50.3	48.1	50.5	47.8	50.3	1.2	2.3	49.1	1.2	2.4	49.7	1.3	2.6
Thorax Rib 3 Deflection	mm	600	34.3	27.4	33.4	27.1	33.7	28.3	32.7	27.6	33.1	27.8	33.4	0.6	1.8	27.6	0.4	1.6	30.5	3.1	10.1
Abdominal Rib 1Deflection	mm	600	7.1	7.1	6.3	6.2	7.3	6.2	5.8	6.6	6.5	5.7	6.6	0.6	8.8	6.4	0.5	8.1	6.5	0.5	8.2
Abdominal Rib 2 Deflection	mm	600	32.1	27.8	30.9	27.2	31.8	28.0	30.5	27.1	30.7	29.1	31.2	0.7	2.3	27.8	0.8	3.0	29.5	1.9	6.5
Pelvis Y-axis Accel.	g	1000	74.8	72.1	70.0	69.3	66.6	68.2	65.8	72.2	69.6	67.3	69.4	3.5	5.1	69.8	2.3	3.3	69.6	2.8	4.0
Pubic Y-Axis Force	N	600	-1761.5	-1834.9	-1678.7	-1688.6	-1707.9	-1796.4	-1715.4	-1727.8	-1661.7	-1712.8	-1705.0	38.3	2.2	-1752.1	61.2	3.5	-1728.6	54.2	3.1

Note 1: Shoulder IR-TRACC was removed due to potential of exceeding maximum stroke length

Note 2: Thorax Rib 1 IR-TRACCs appeared to reach maximum stroke capacity, or "flat top" (refer to Figure D.10.)

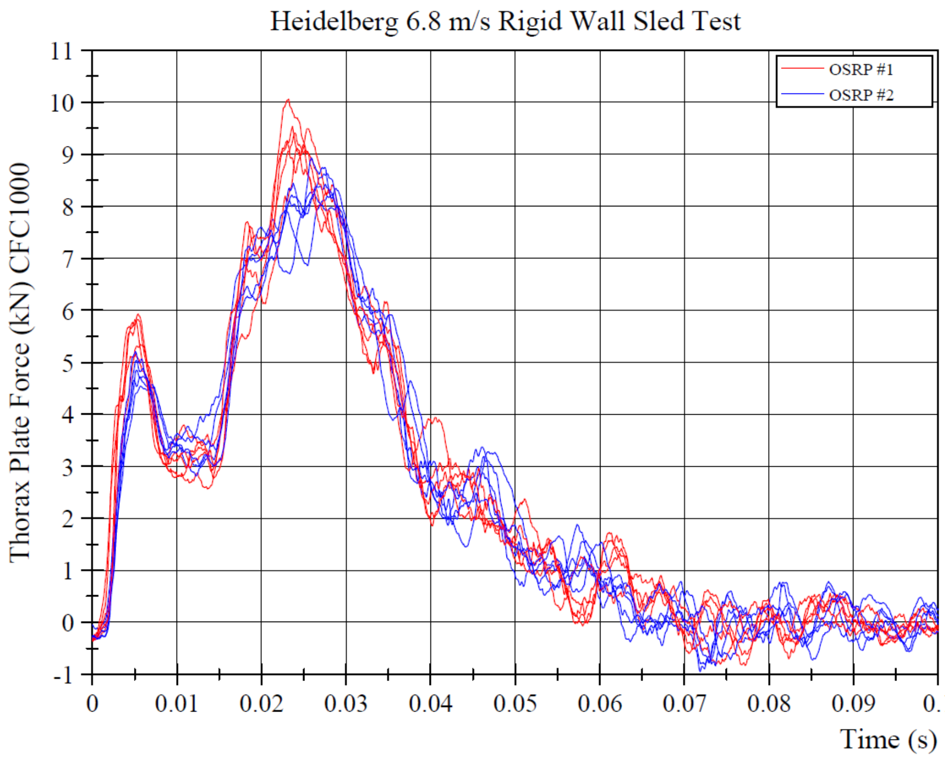

Figure D-1. Heidelberg Rigid Wall – Thorax Plate Force

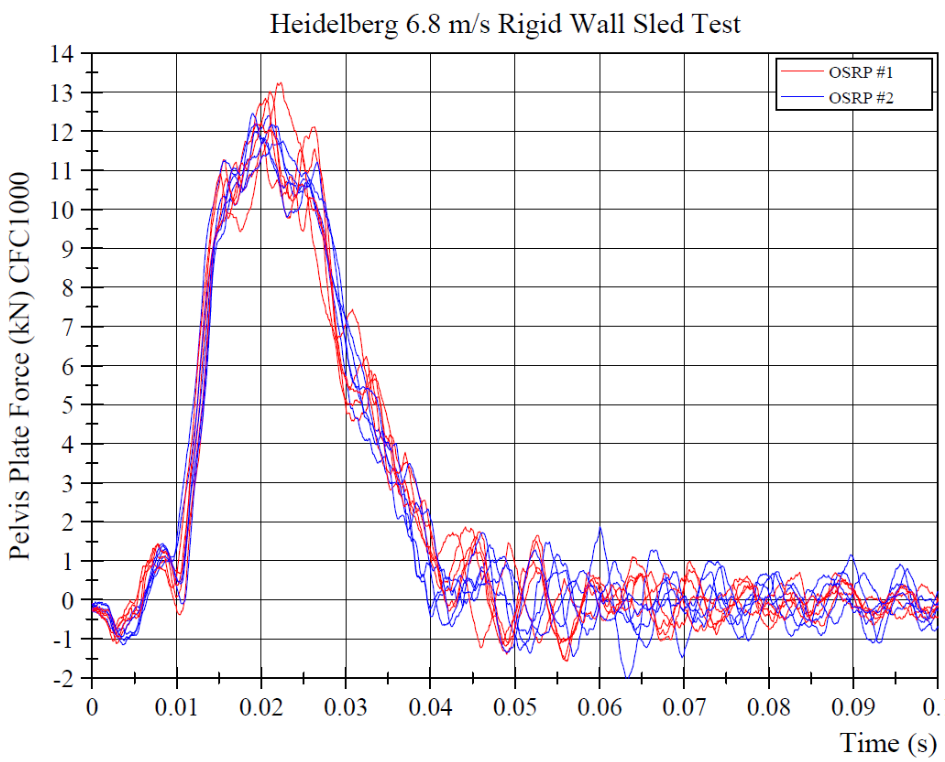

Figure D-2. Heidelberg Rigid Wall – Pelvis Plate Force

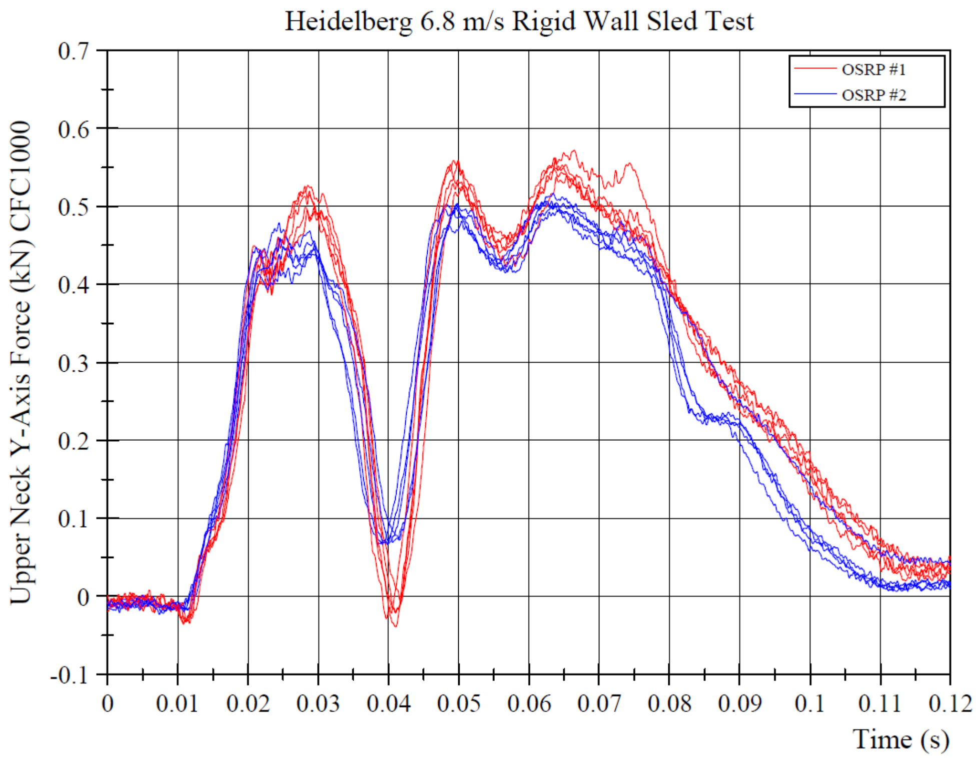

Figure D-3. Heidelberg Rigid Wall – Upper Neck Y-Force

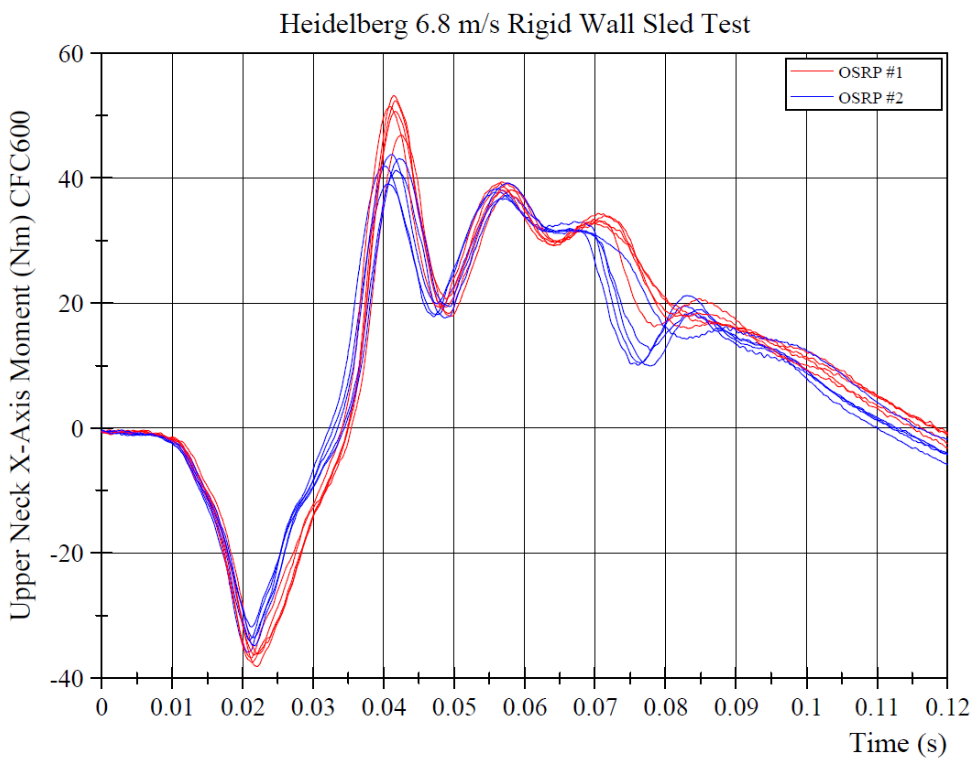

Figure D-4. Heidelberg Rigid Wall – Upper Neck X-Moment

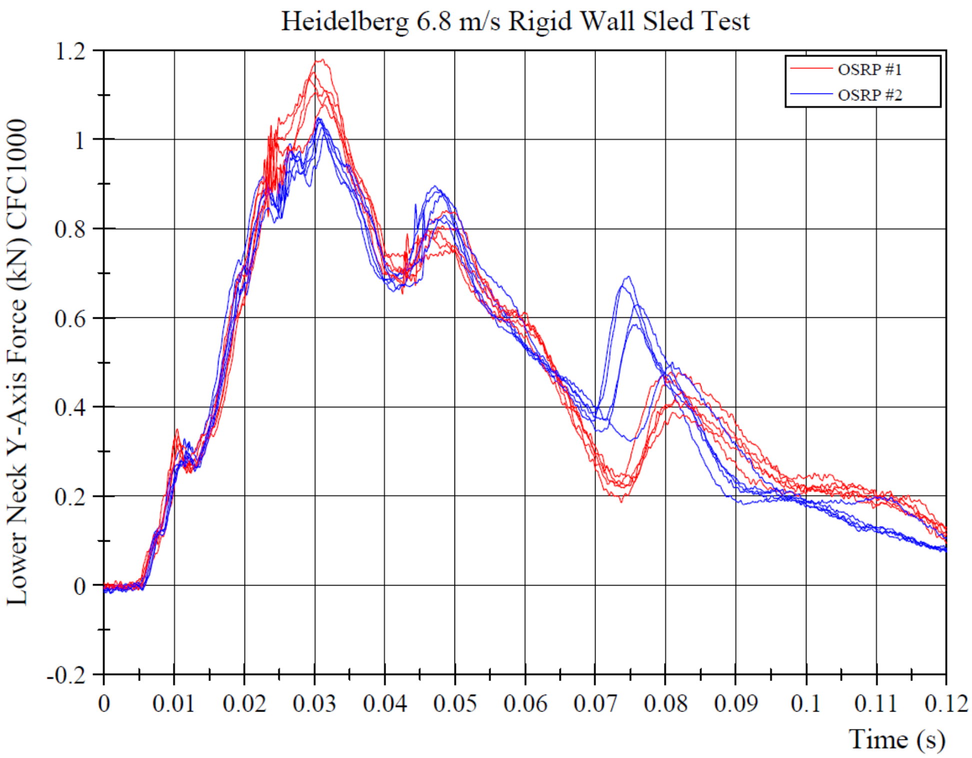

Figure D-5. Heidelberg Rigid Wall – Lower Neck Y-Force

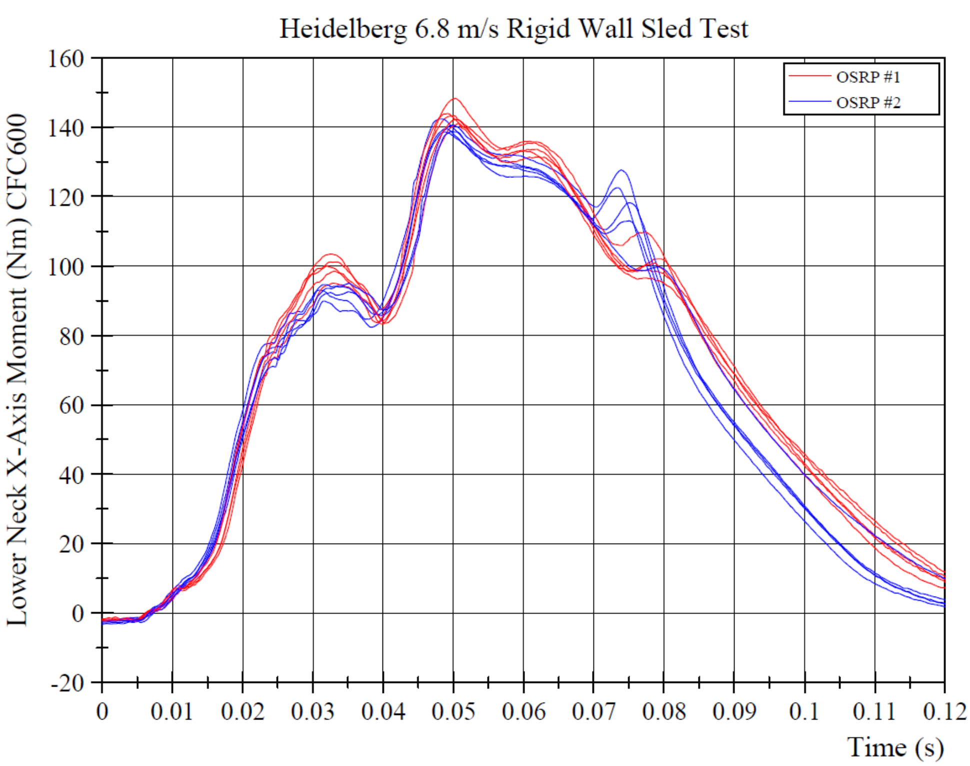

Figure D-6. Heidelberg Rigid Wall – Lower Neck X-Moment

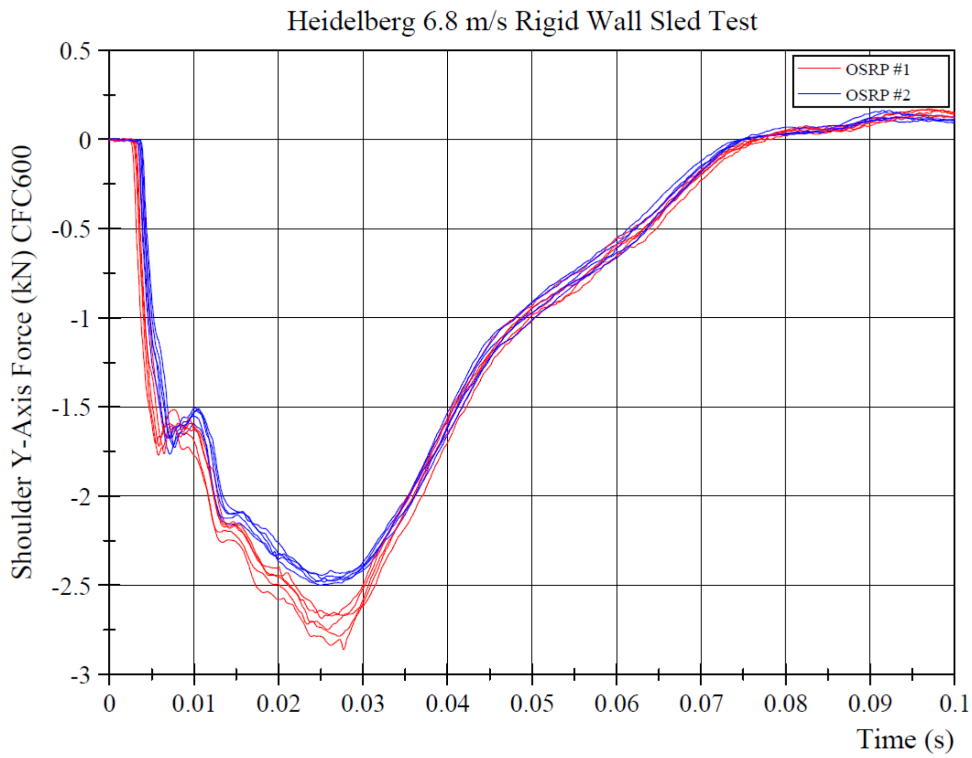

Figure D-7. Heidelberg Rigid Wall – Shoulder Y-Force

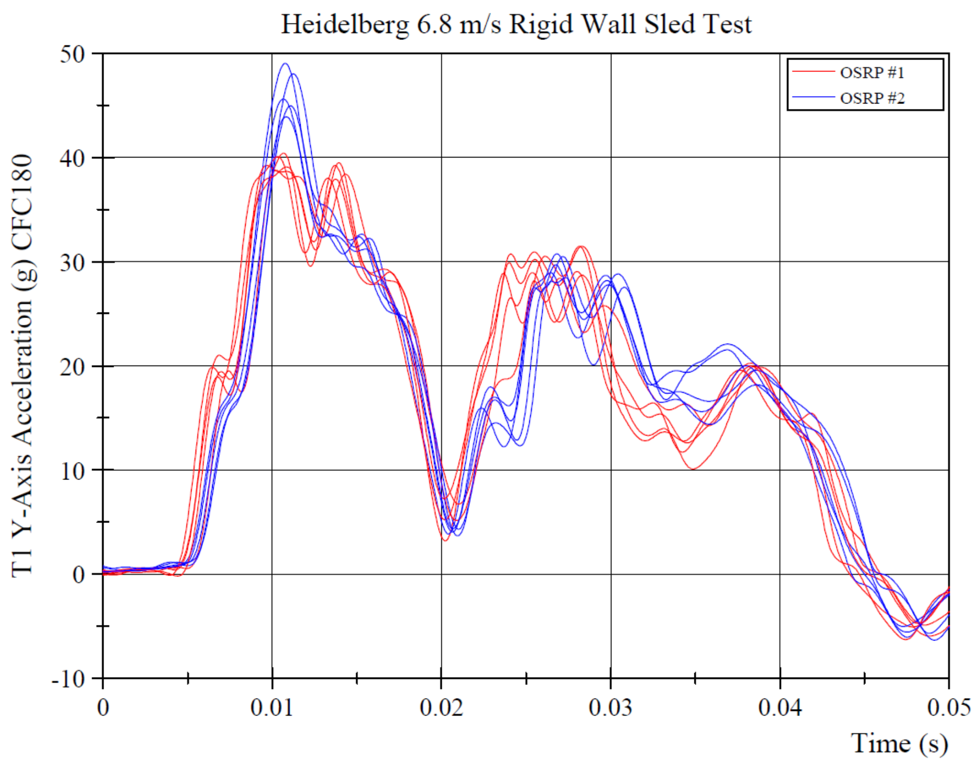

Figure D-8. Heidelberg Rigid Wall – T1 Y-Acceleration

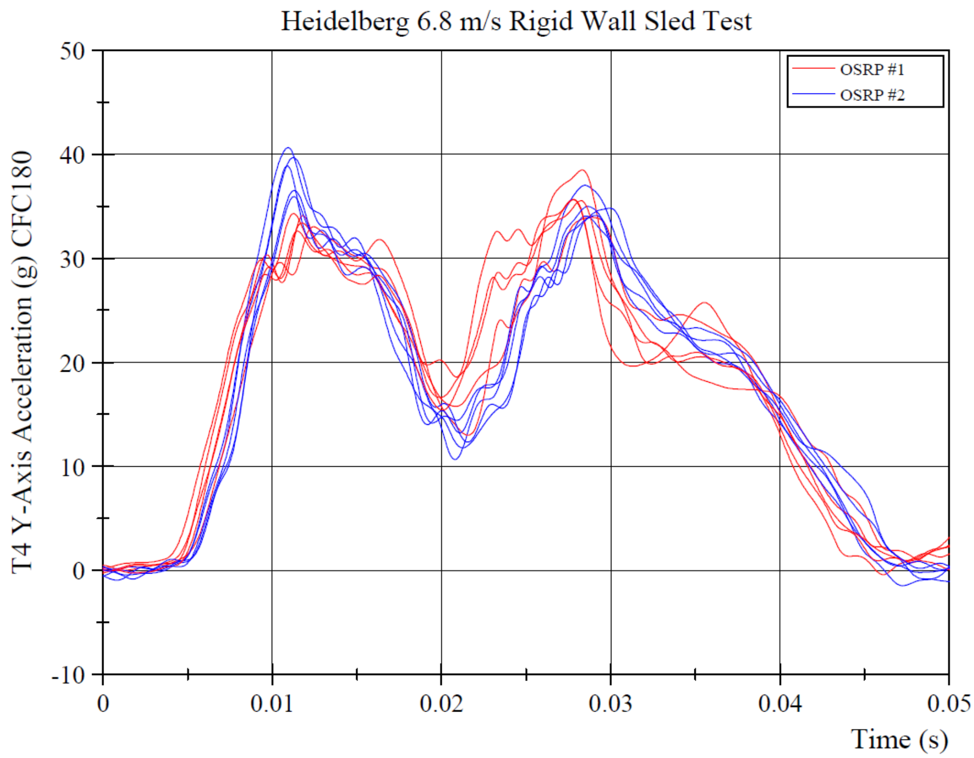

Figure D-9. Heidelberg Rigid Wall – T4 Y-Acceleration

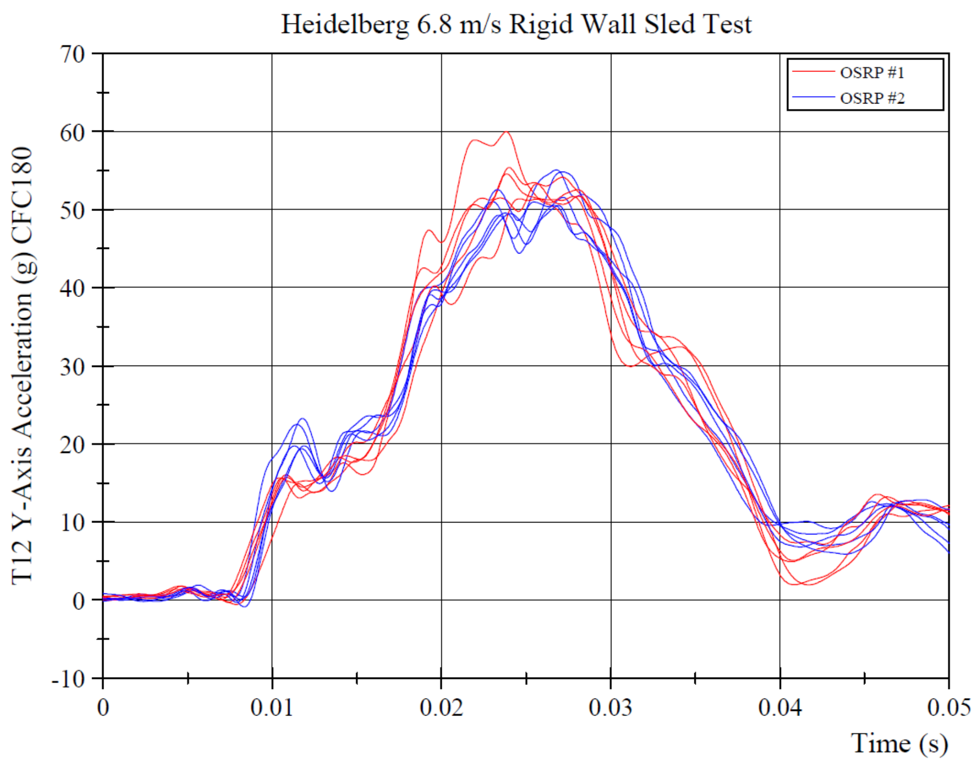

Figure D-10. Heidelberg Rigid Wall – T12 Y-Acceleration

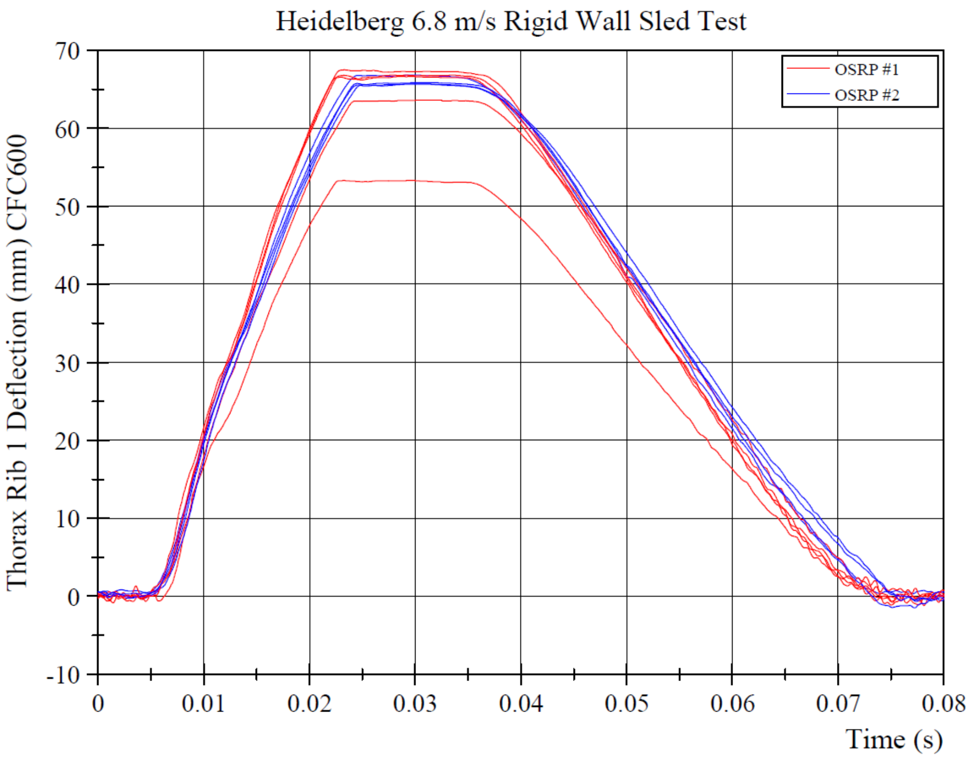

Figure D-11. Heidelberg Rigid Wall – Thorax Rib 1 Displacement

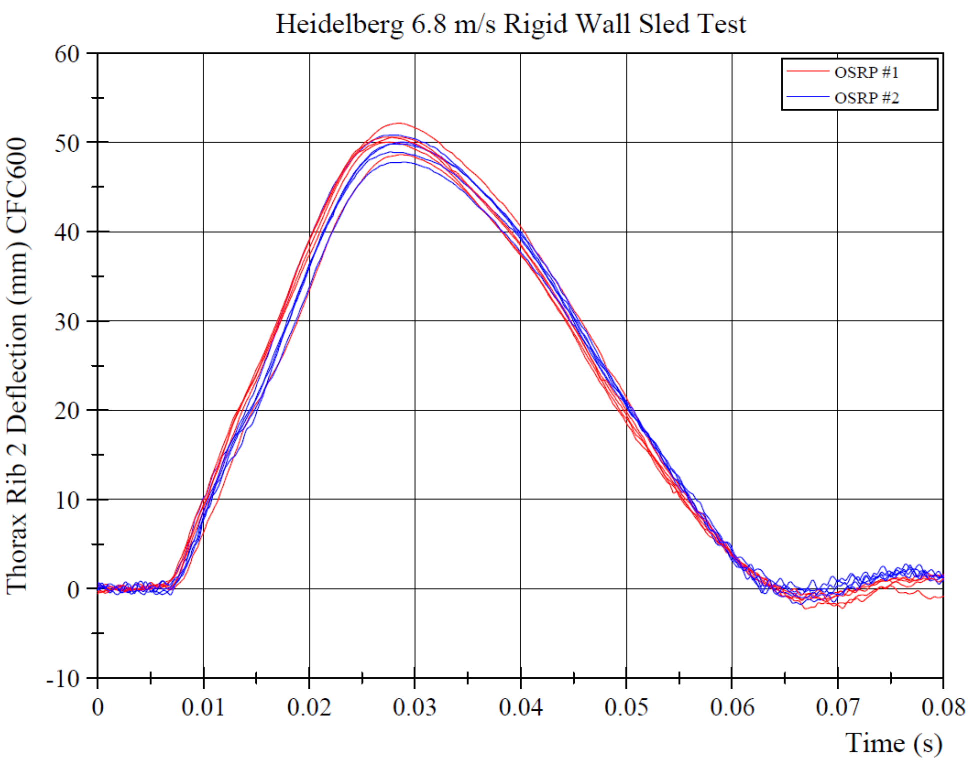

Figure D-12. Heidelberg Rigid Wall – Thorax Rib 2 Displacement

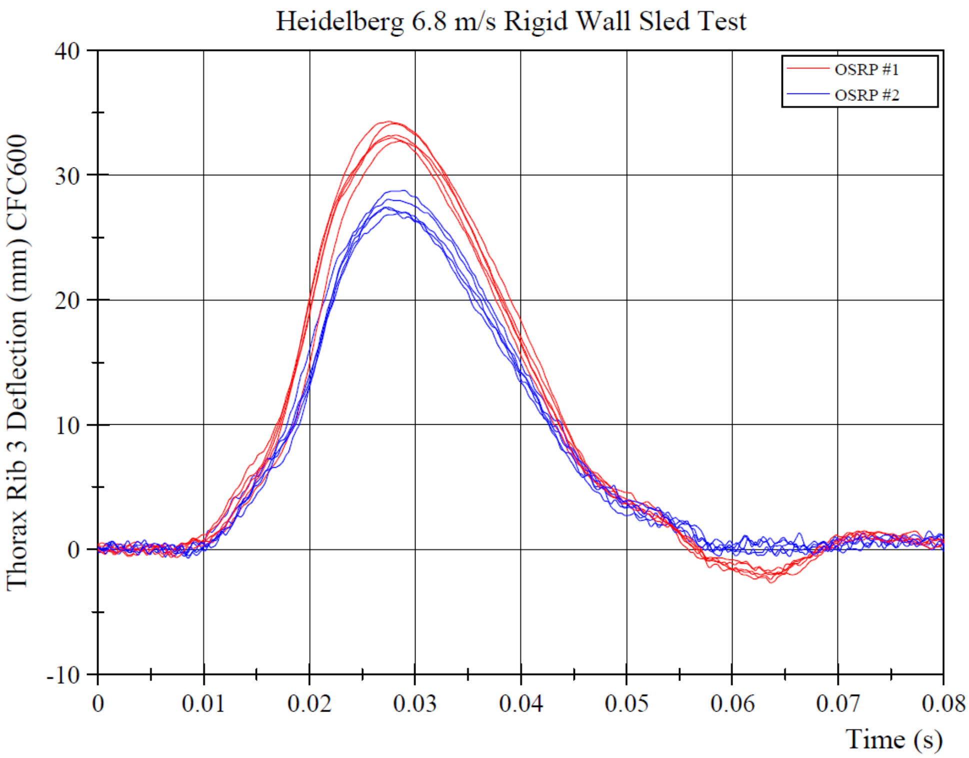

Figure D-13. Heidelberg Rigid Wall – Thorax Rib 3 Displacement

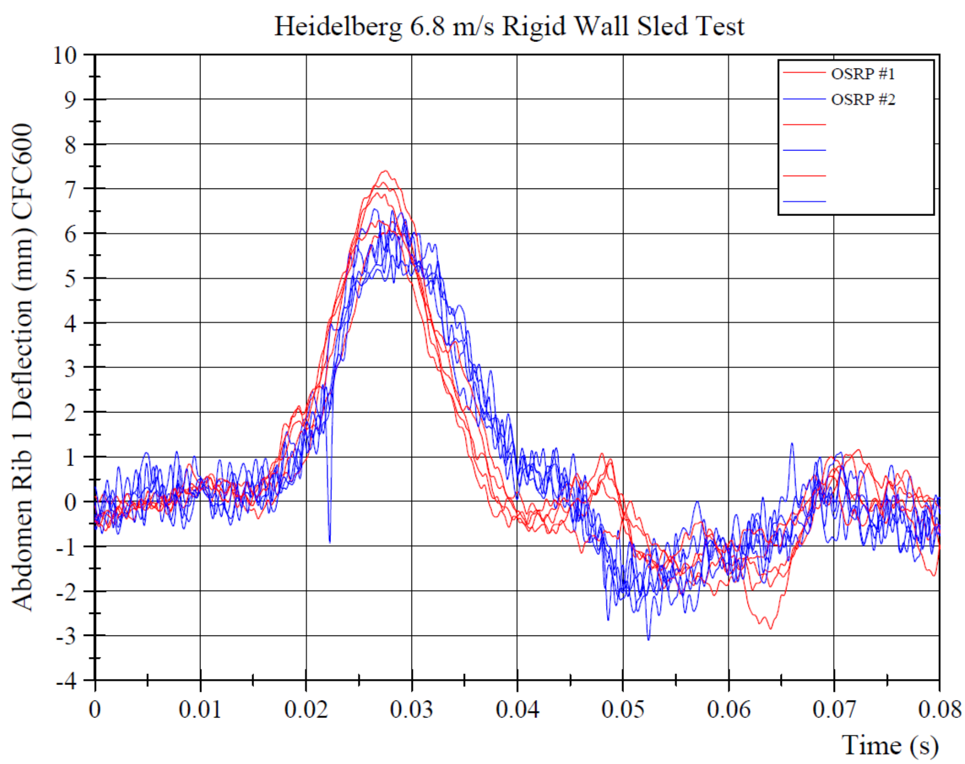

Figure D-14. Heidelberg Rigid Wall – Abdomen Rib 1 Displacement

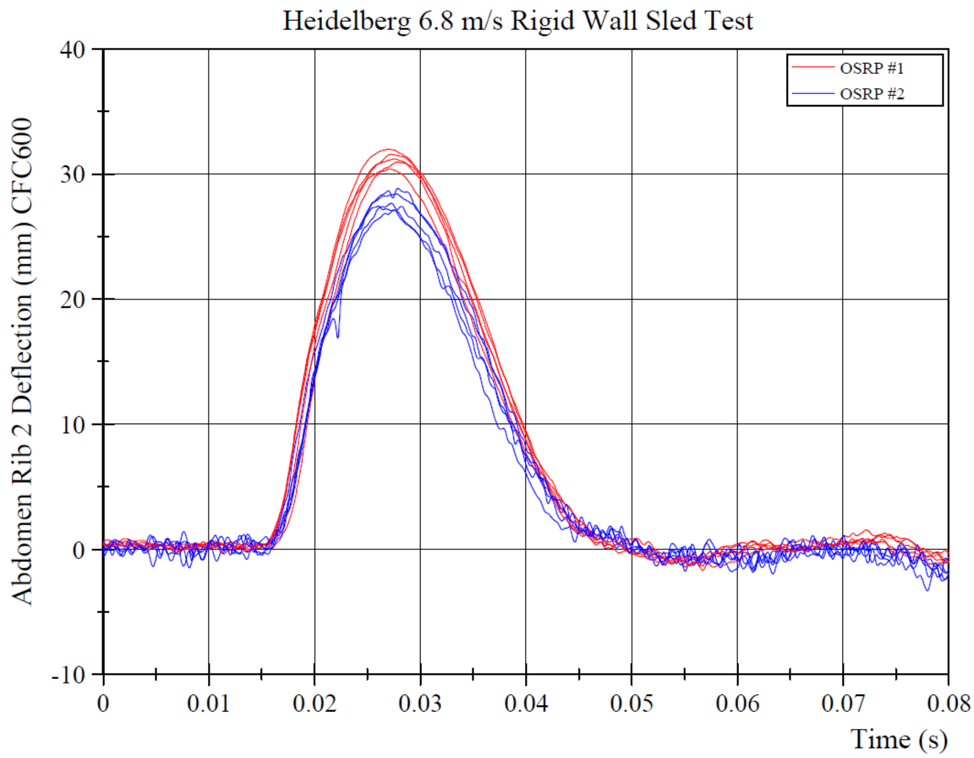

Figure D-15. Heidelberg Rigid Wall – Abdomen Rib 2 Displacement

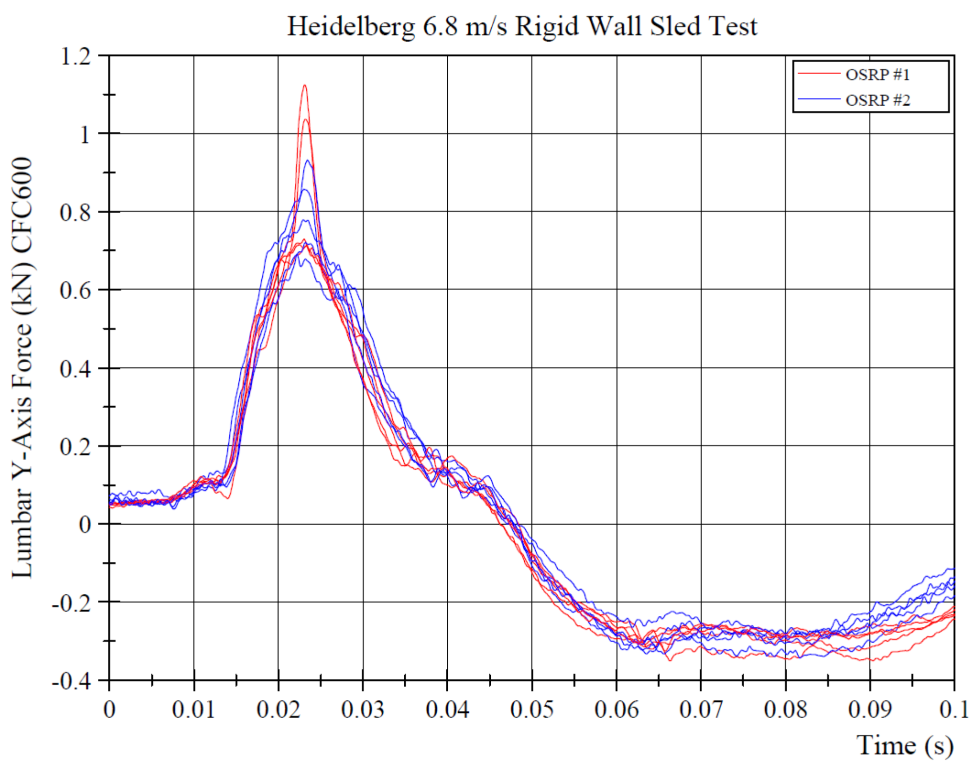

Figure D-16. Heidelberg Rigid Wall – Lumbar Y-Force

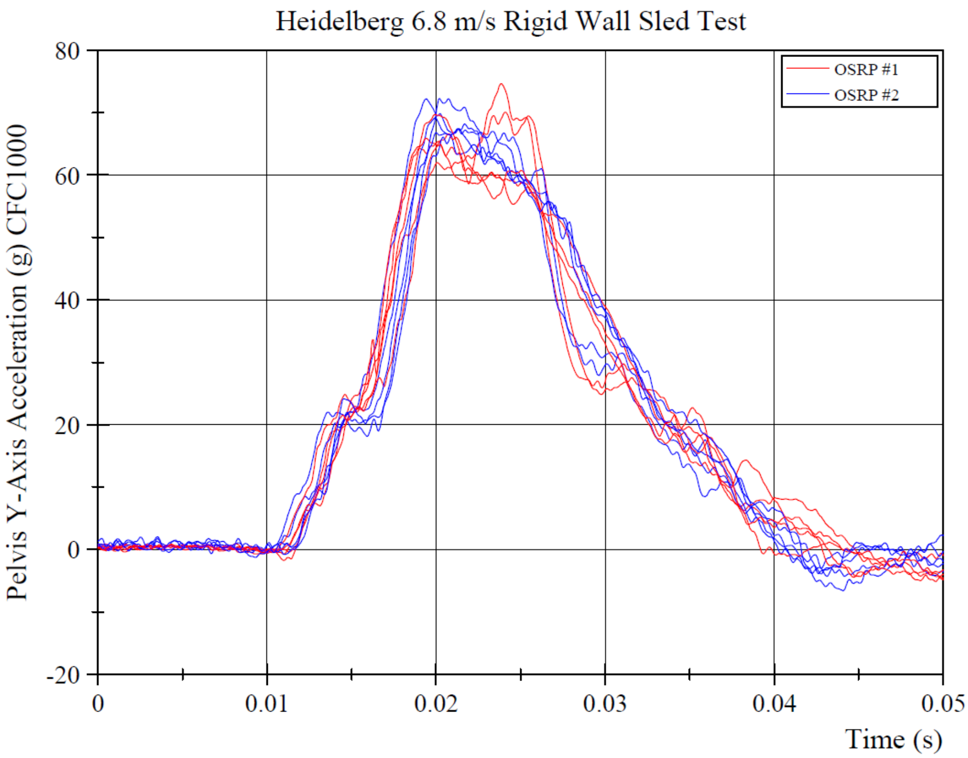

Figure D-17. Heidelberg Rigid Wall – Pelvis Y-Acceleration

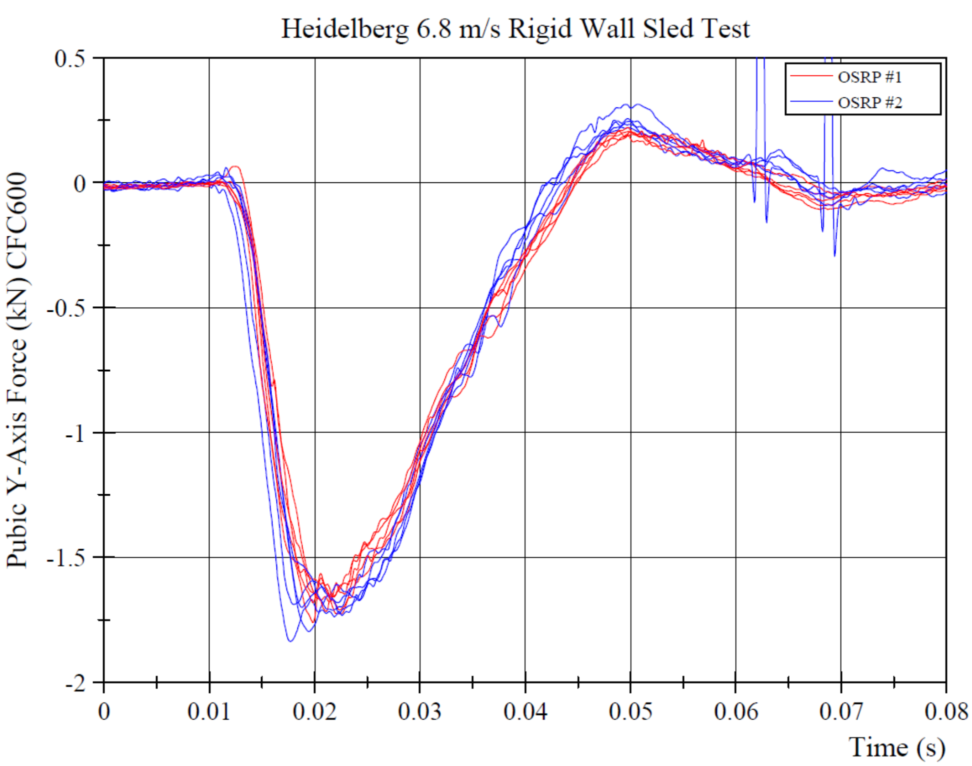

Figure D-18. Heidelberg Rigid Wall – Pubic Y-Force

Appendix E: Wayne State 6.8 m/s Rigid Wall Sled Test Data

Table E.1. Wayne State 6.8 m/s Rigid Wall Sled Test

Channel	Units	CFC	Test 1		Test 2		Test 3		OSRP 1			OSRP 2			Combined		
			OSRP 1	OSRP 2	OSRP 1	OSRP 2	OSRP 1	OSRP 2	Avg	Std Dev	% CV	Avg	Std Dev	% CV	Avg	Std Dev	% CV
Shoulder Plate Force	kN	1000	5202.9	4688.9	5281.9	4908.5	5495.6	4786.3	5326.8	151.4	2.8	4794.5	110.0	2.3	5060.7	314.7	6.2
Thorax Plate Force	kN	1000	4203.0	4052.9	4561.6	4450.4	4483.6	4925.2	4416.1	188.6	4.3	4476.2	436.7	9.8	4446.1	302.6	6.8
Abdomen Plate Force	kN	1000	3120.2	3194.9	3717.5	3118.7	3753.2	3462.9	3530.3	355.6	10.1	3258.8	180.8	5.5	3394.6	292.9	8.6
Pelvis Plate Force	kN	1000	10278.3	9996.6	9939.1	10074.2	10173.1	9967.5	10130.2	173.6	1.7	10012.8	55.1	0.6	10071.5	131.9	1.3
Upper Neck Y-axis Force	kN	1000	642.9	477.5	602.8	591.9	613.9	647.5	619.9	20.7	3.3	572.3	86.7	15.1	596.1	62.1	10.4
Upper Neck X-axis Moment	N·m	600	38.6	36.2	43.8	37.4	43.6	37.5	42.0	2.9	7.0	37.0	0.7	1.9	39.5	3.3	8.4
Lower Neck Y-axis Force	kN	1000	1023.6	926.3	1060.3	982.4	1065.0	1011.4	1049.6	22.7	2.2	973.3	43.3	4.4	1011.5	52.0	5.1
Lower Neck X-axis Moment	N·m	600	130.8	133.1	129.6	140.6	134.0	136.9	131.4	2.3	1.7	136.9	3.8	2.8	134.2	4.1	3.0
Shoulder Y-axis Force	kN	600	-2770.8	-2503.4	-2688.8	-2494.7	-2662.6	-2464.7	-2707.4	56.4	2.1	-2487.6	20.3	0.8	-2597.5	126.2	4.9
Shoulder Rib Deflection	mm	600	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
T1 Y-axis Accel.	g	180	42.7	45.1	40.2	42.9	42.2	45.1	41.7	1.3	3.1	44.3	1.2	2.8	43.0	1.8	4.3
T4 Y-axis Accel.	g	180	37.2	35.9	36.7	33.6	34.9	36.5	36.3	1.2	3.3	35.3	1.5	4.3	35.8	1.3	3.7
T12 Y-axis Accel.	g	180	63.6	60.5	65.1	57.4	61.4	55.7	63.4	1.9	3.0	57.9	2.4	4.2	60.6	3.6	5.9
Thorax Rib 1 Deflection	mm	600	65.9	65.4	65.8	65.3	66.1	65.6	65.9	0.2	0.2	65.4	0.1	0.2	65.7	0.3	0.5
Thorax Rib 2 Deflection	mm	600	45.0	46.1	42.4	50.2	43.5	50.9	43.6	1.3	3.1	49.1	2.6	5.3	46.4	3.5	7.6
Thorax Rib 3 Deflection	mm	600	30.9	27.1	33.5	29.4	33.3	29.2	32.6	1.4	4.3	28.6	1.3	4.5	30.6	2.5	8.2
Abdominal Rib 1Deflection	mm	600	28.5	24.1	31.7	24.6	31.4	24.0	30.6	1.8	5.9	24.3	0.3	1.3	27.4	3.6	13.3
Abdominal Rib 2 Deflection	mm	600	28.4	25.9	32.8	26.6	32.0	25.1	31.1	2.4	7.6	25.9	0.7	2.7	28.5	3.2	11.4
Pelvis Y-axis Accel.	g	1000	68.0	71.1	67.4	76.8	68.5	71.3	68.0	0.6	0.8	73.1	3.2	4.4	70.5	3.5	4.9
Pubic Y-Axis Force	kN	600	-1697.6	-1649.5	-1680.1	-1615.0	-1679.0	-1650.9	-1685.6	10.4	0.6	-1638.5	20.3	1.2	-1662.0	29.6	1.8

Note 1: Shoulder IRRTRACC was removed due to potential of exceeding maximum stroke length

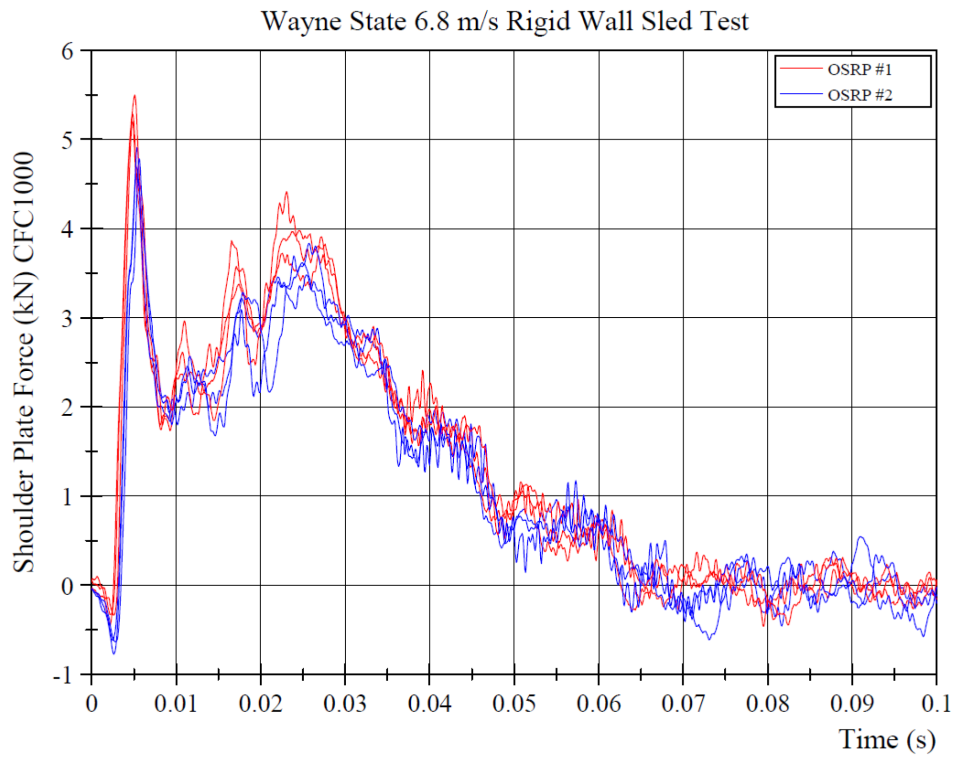

Figure E-1. Wayne State Rigid Wall – Shoulder Plate Force

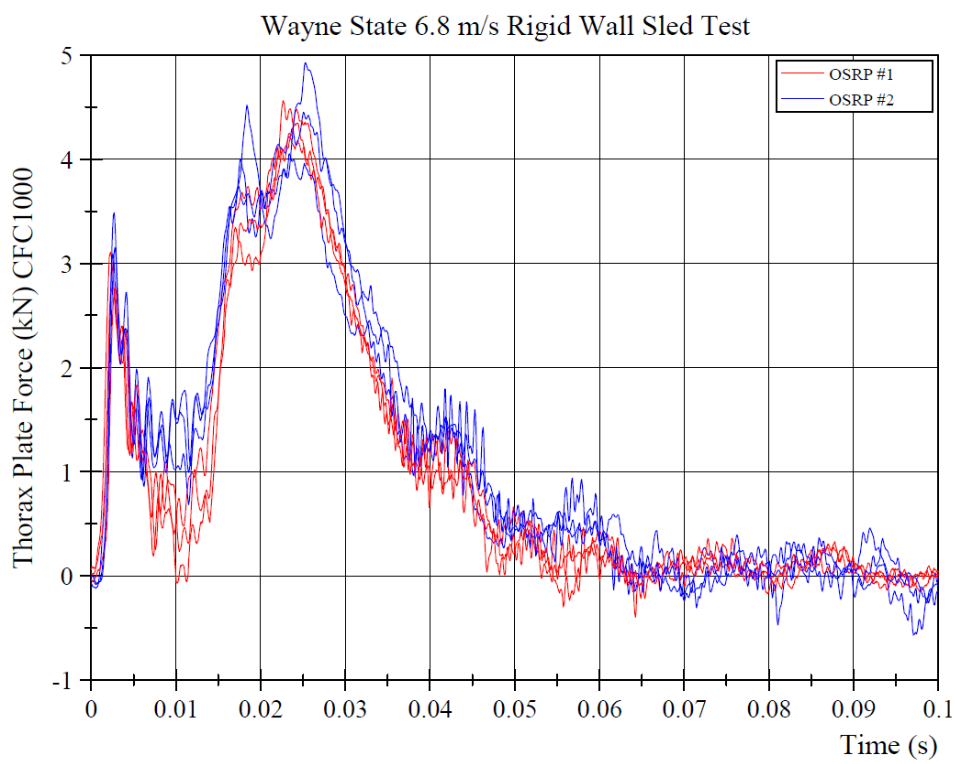

Figure E-2. Wayne State Rigid Wall – Thorax Plate Force

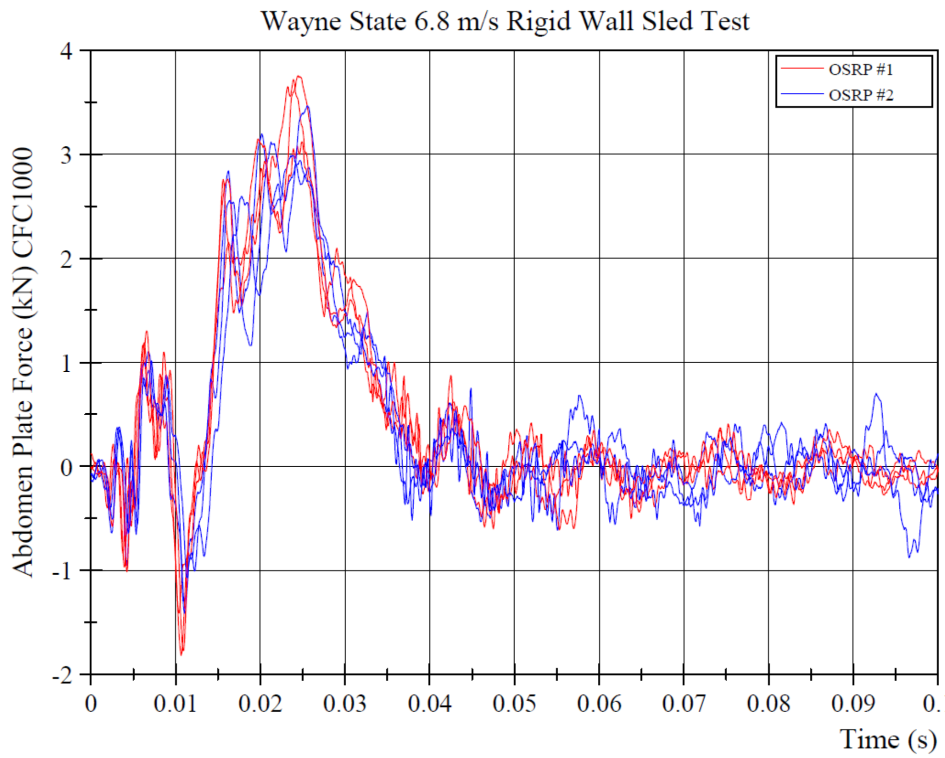

Figure E-3. Wayne State Rigid Wall – Abdomen Plate Force

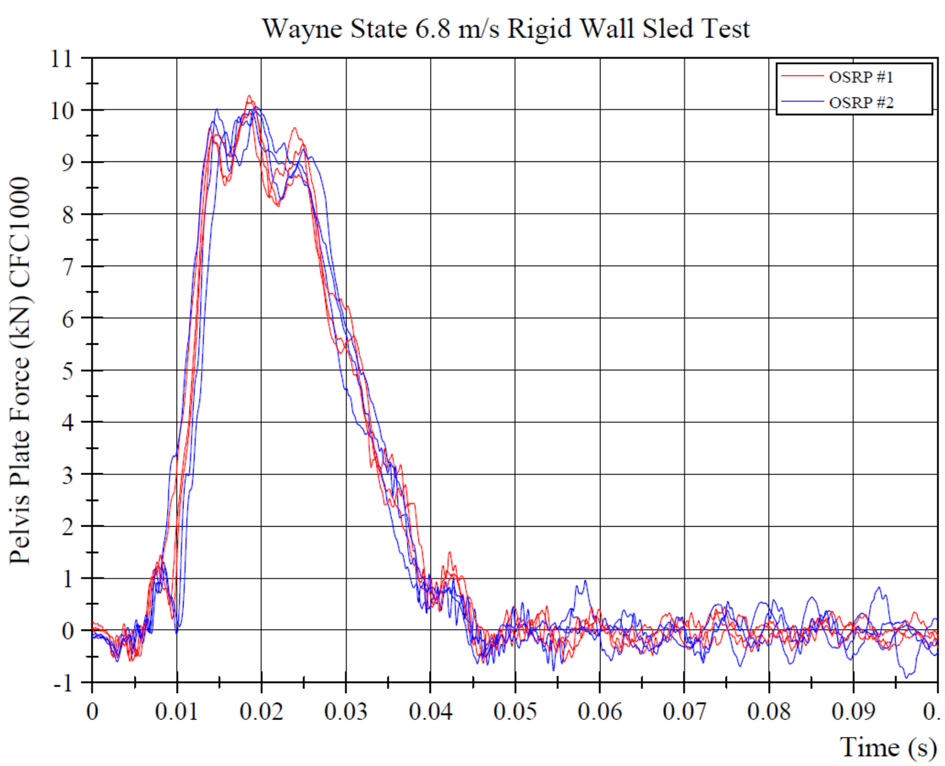

Figure E-4. Wayne State Rigid Wall – Pelvis Plate Force

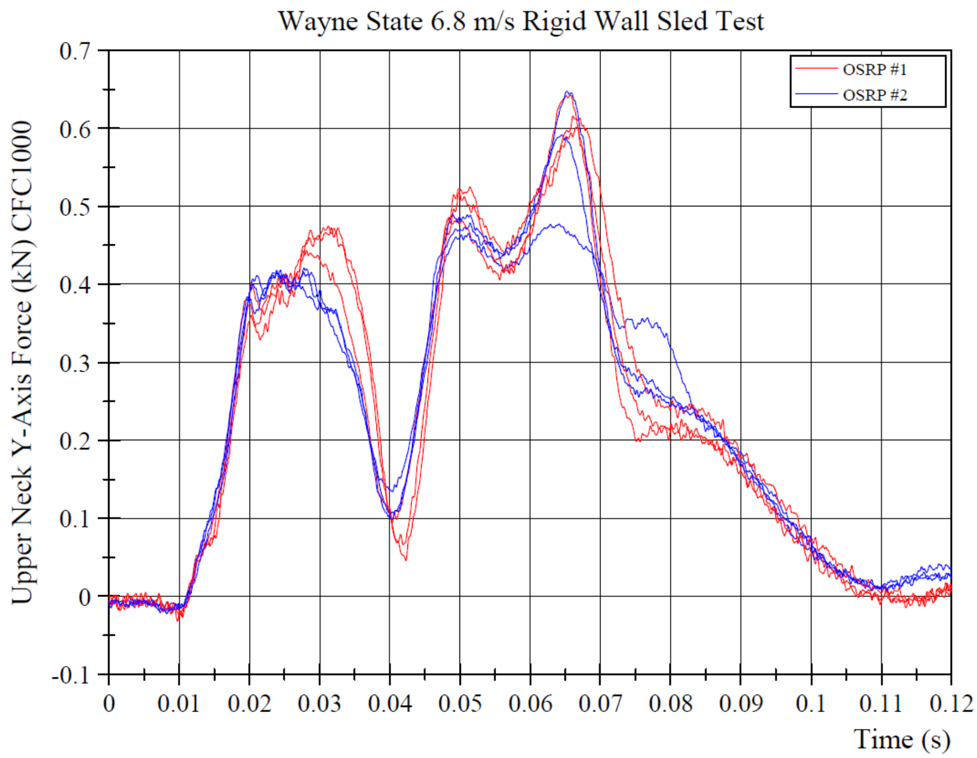

Figure E-5. Wayne State Rigid Wall – Upper Neck Y-Force

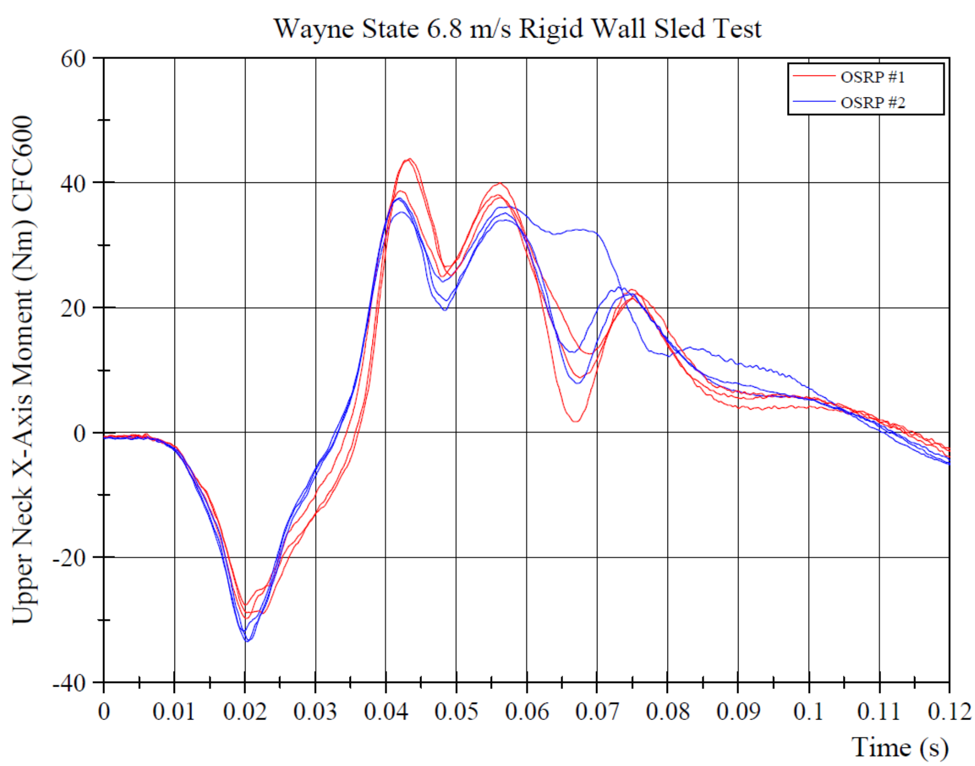

Figure E-6. Wayne State Rigid Wall – Upper Neck X-Moment

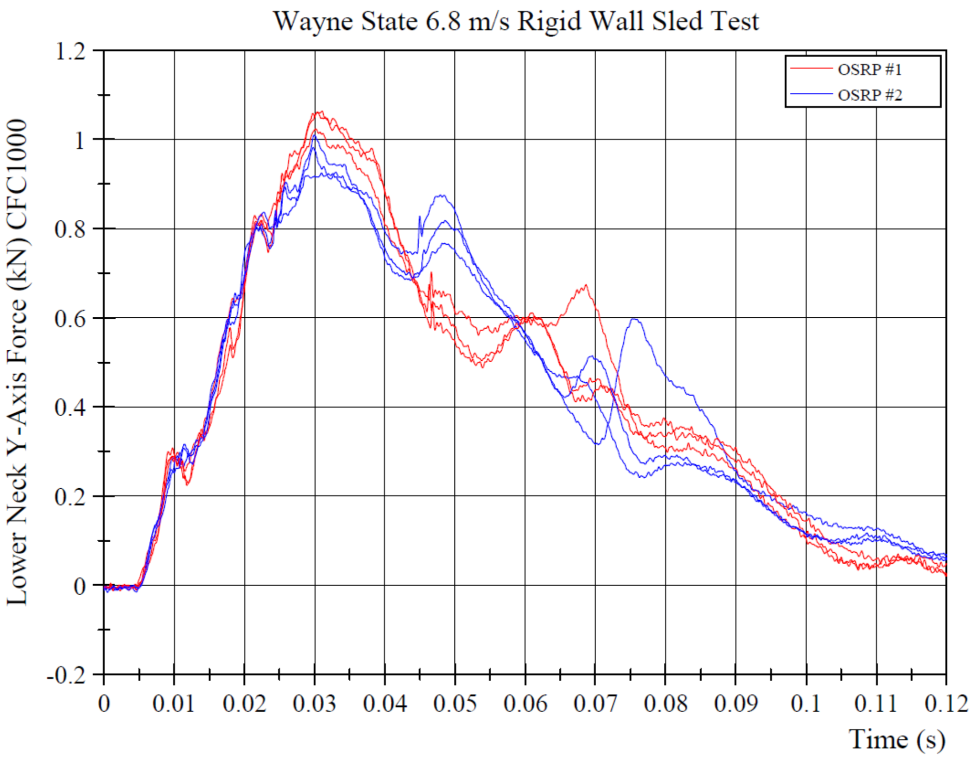

Figure E-7. Wayne State Rigid Wall – Lower Neck Y-Force

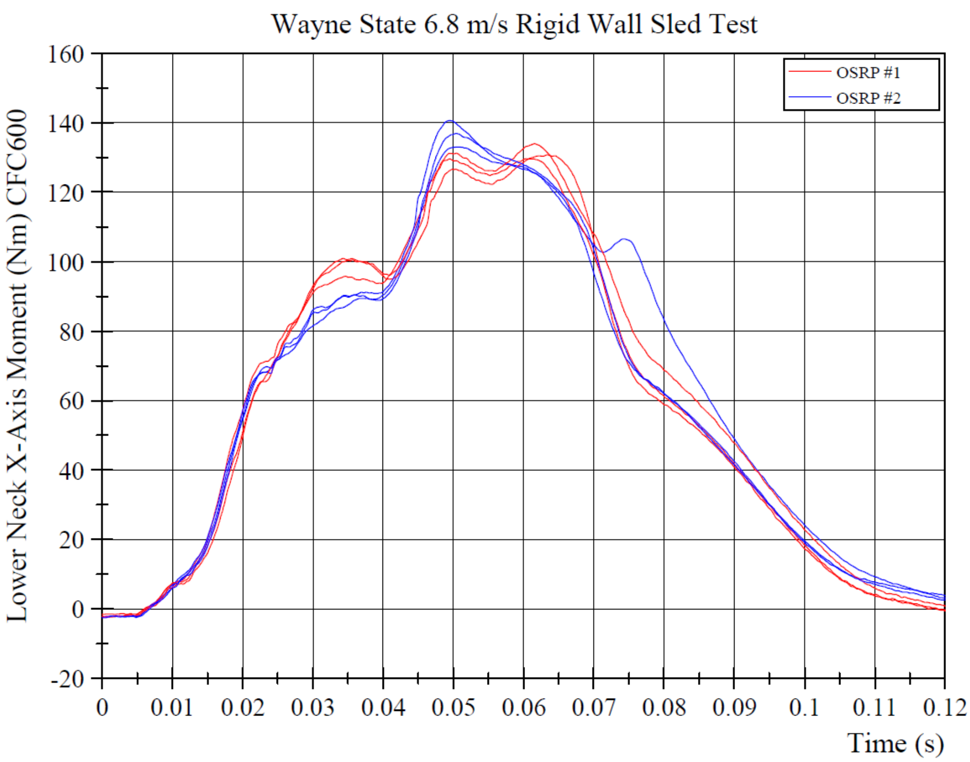

Figure E-8. Wayne State Rigid Wall – Lower Neck X-Moment

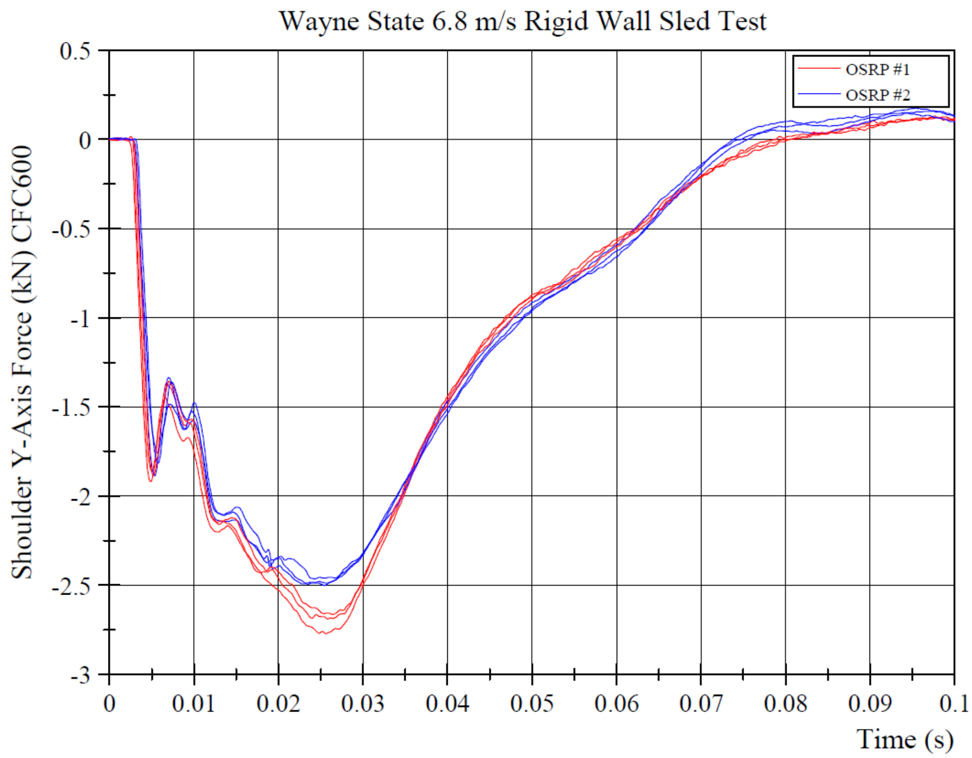

Figure E-9. Wayne State Rigid Wall – Shoulder Y-Force

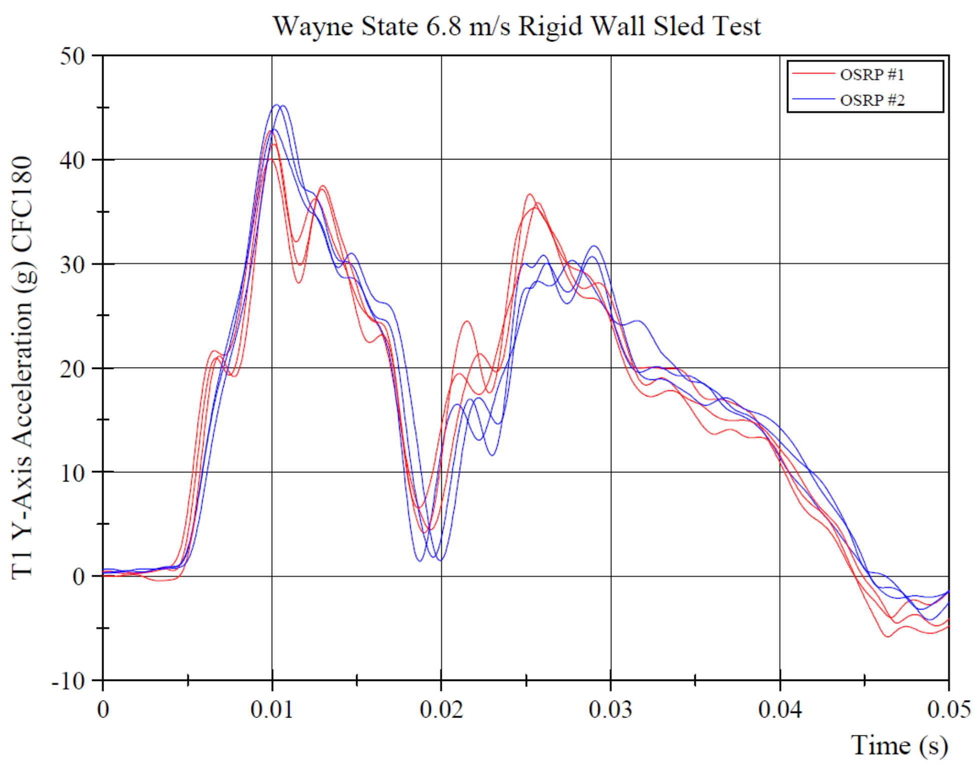

Figure E-10. Wayne State Rigid Wall – T1 Y-Acceleration

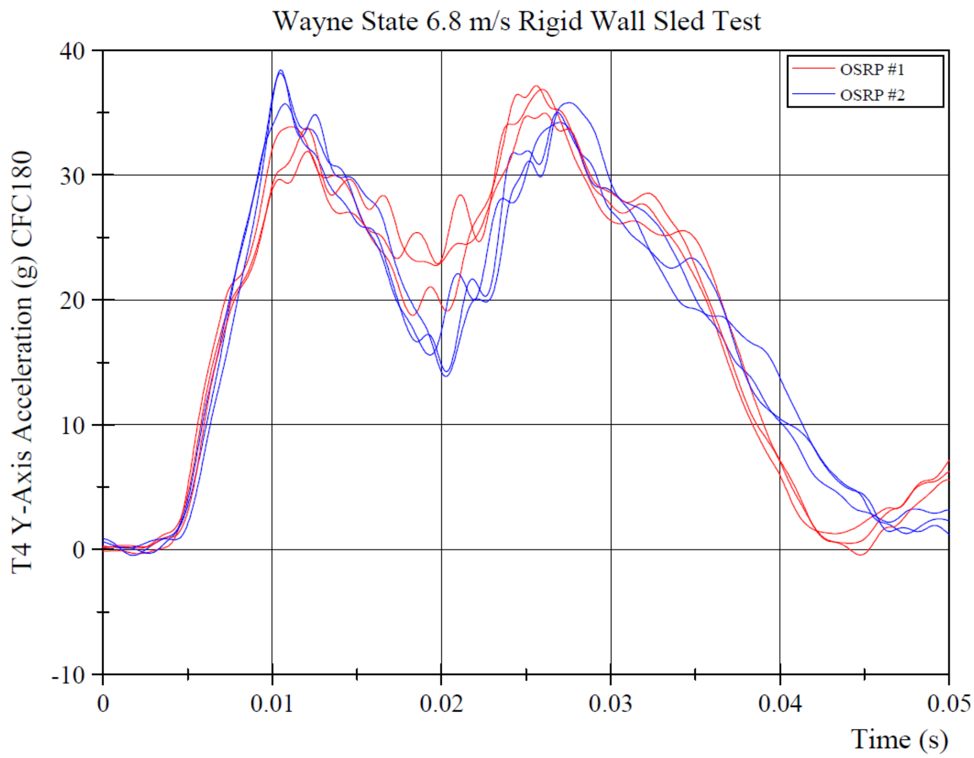

Figure E-11. Wayne State Rigid Wall – T4 Y-Acceleration

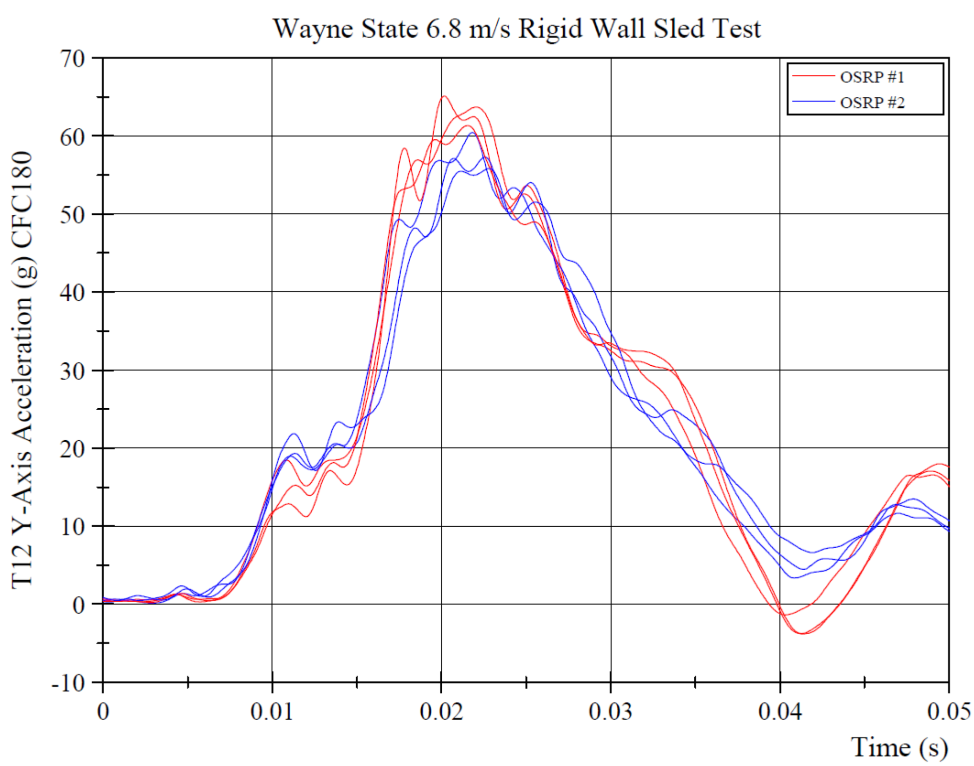

Figure E-12. Wayne State Rigid Wall – T12 Y-Acceleration

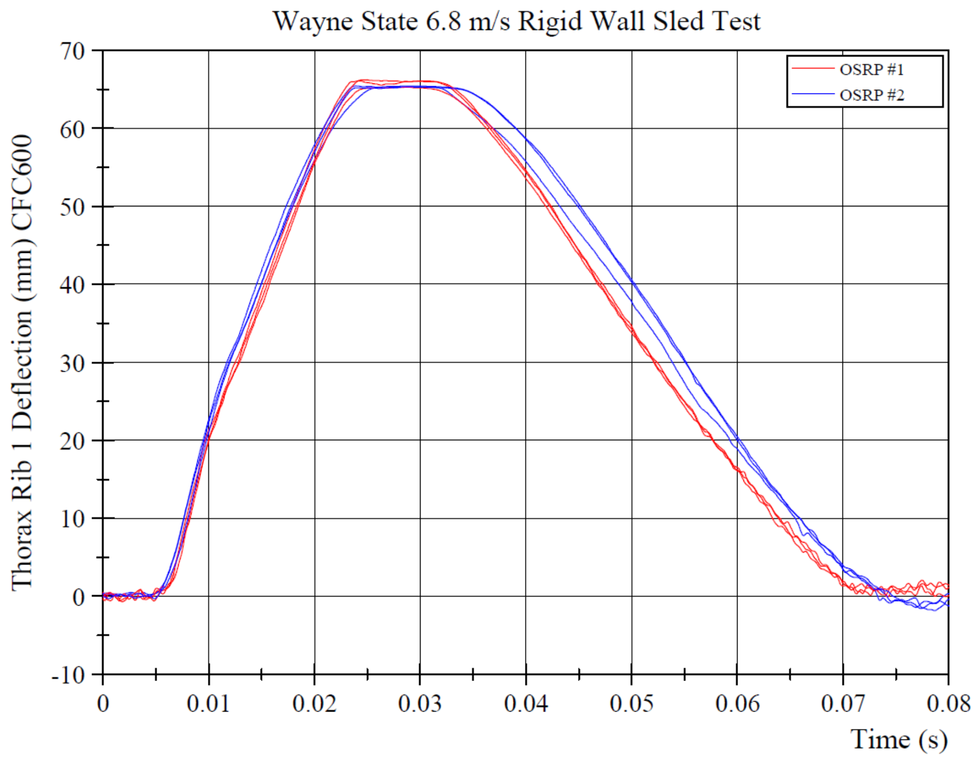

Figure E-13. Wayne State Rigid Wall – Thorax Rib 1 Displacement

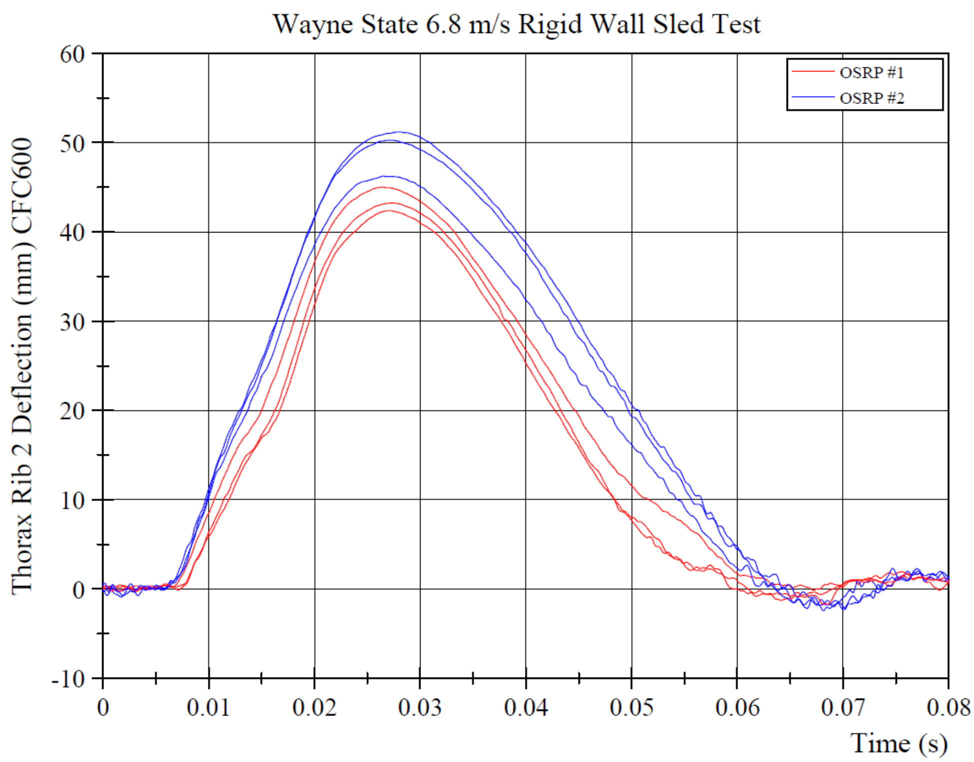

Figure E-14. Wayne State Rigid Wall – Thorax Rib 2 Displacement

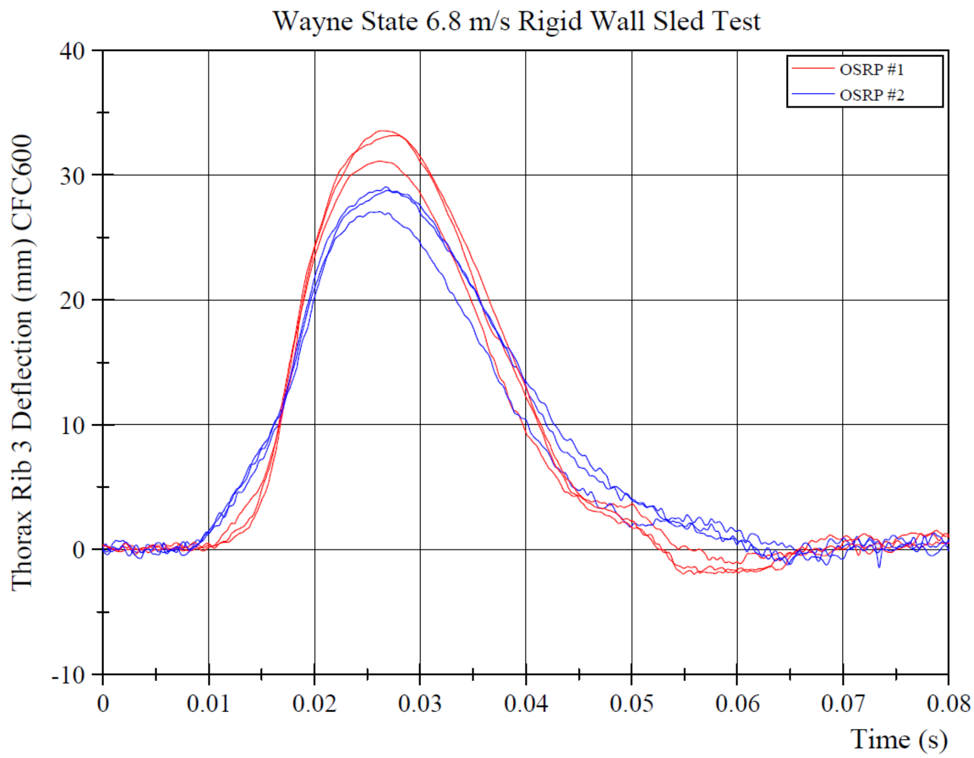

Figure E-15. Wayne State Rigid Wall – Thorax Rib 3 Displacement

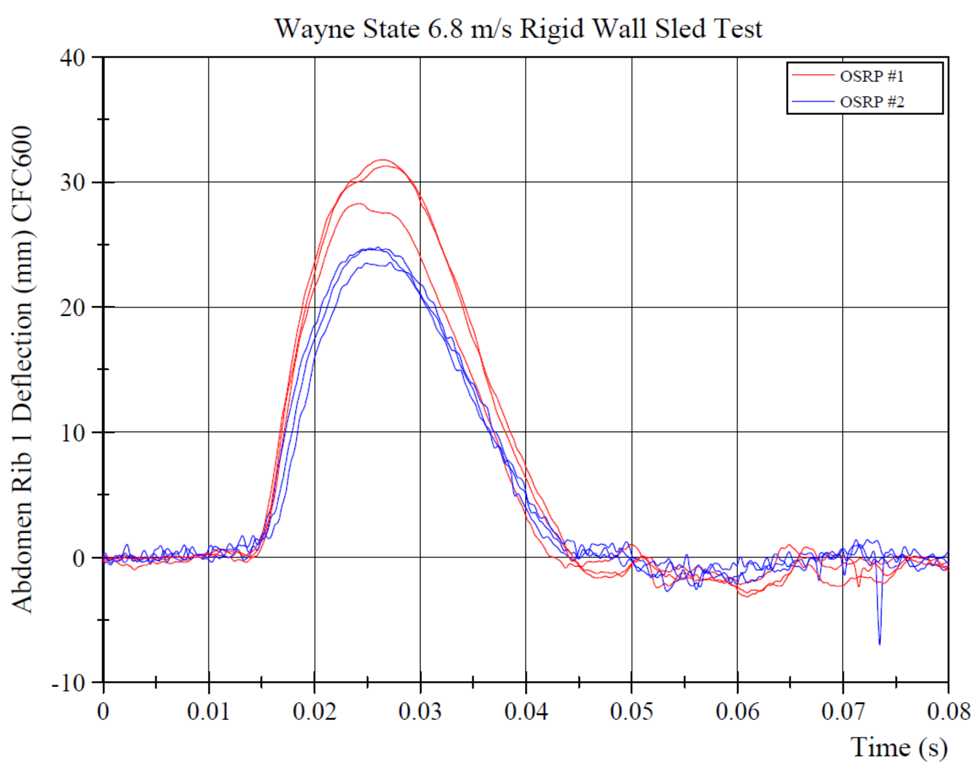

Figure E-16. Wayne State Rigid Wall – Abdomen Rib 1 Displacement

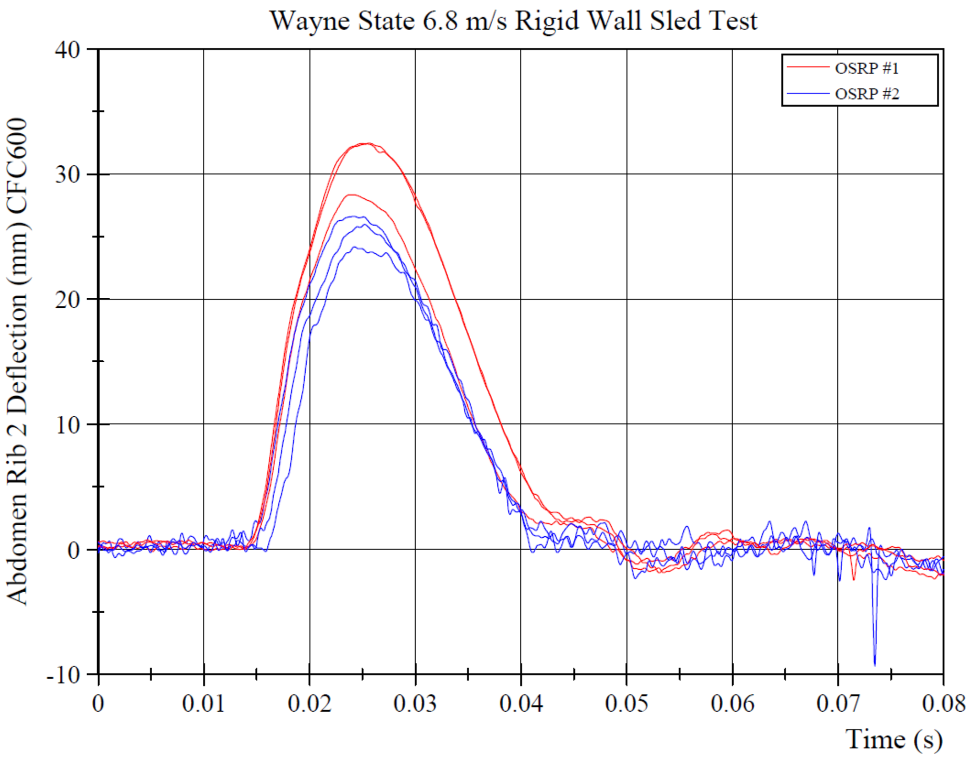

Figure E-17. Wayne State Rigid Wall – Abdomen Rib 2 Displacement

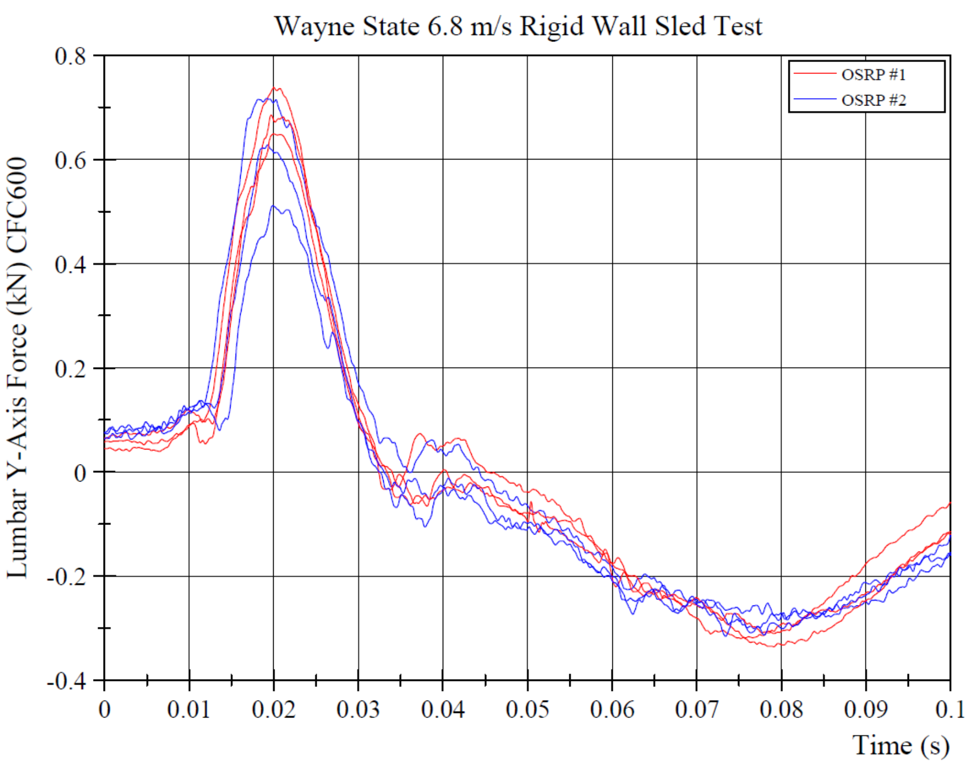

Figure E-18. Wayne State Rigid Wall – Lumbar Y-Force

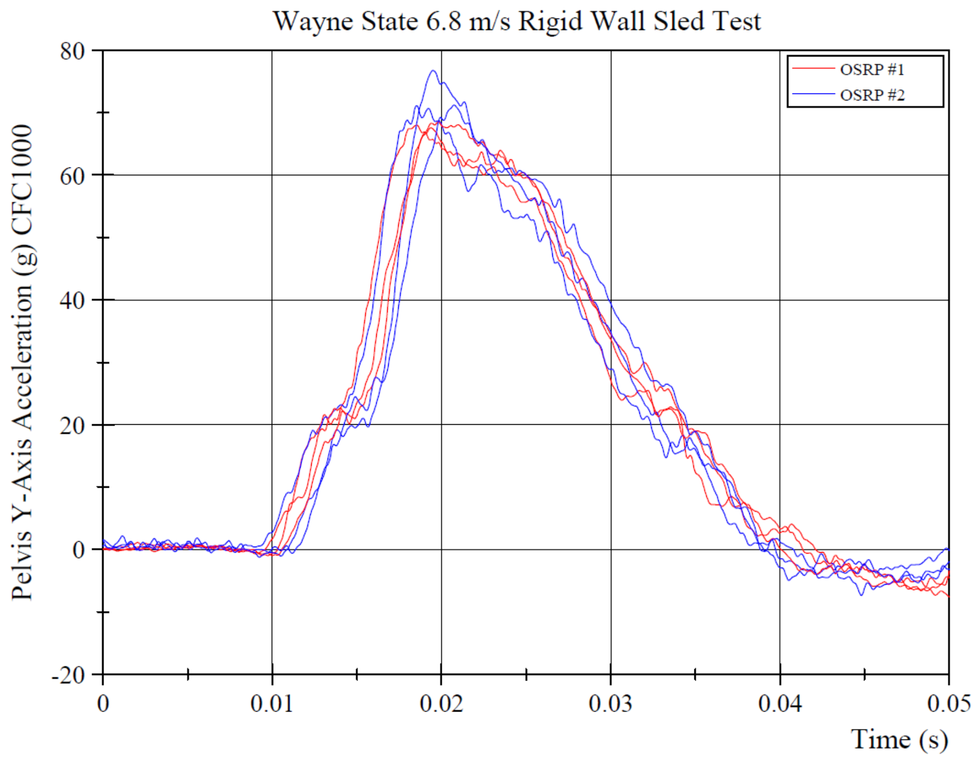

Figure E-19. Wayne State Rigid Wall – Pelvis Y-Acceleration

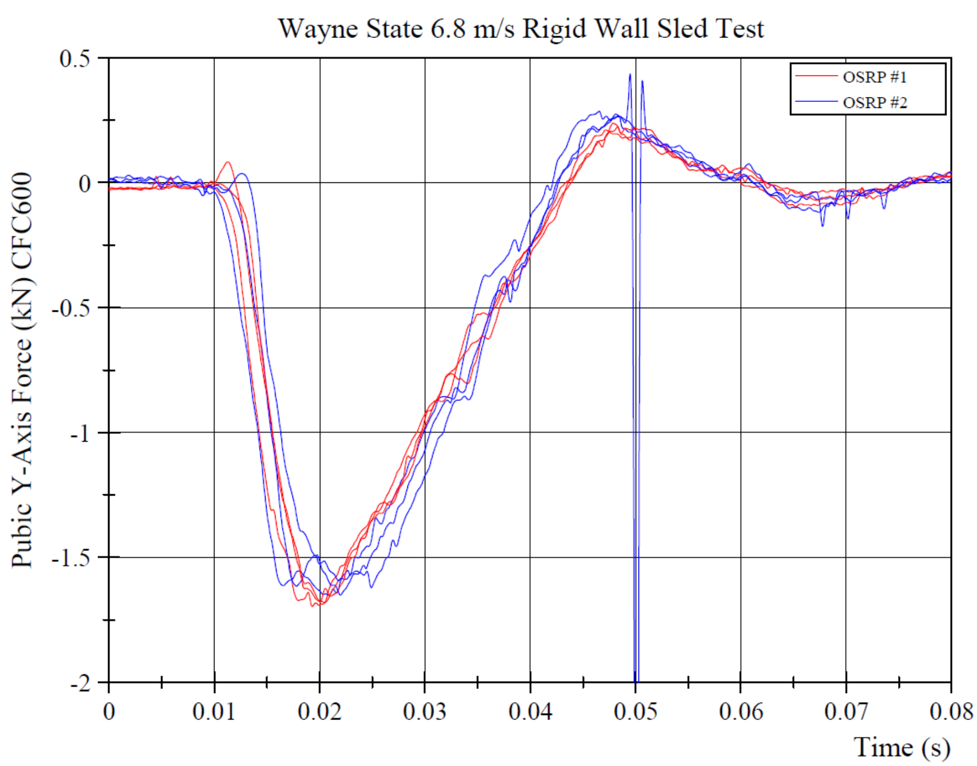

Figure E-20. Wayne State Rigid Wall – Pubic Y-Force

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