U.S. Department of Transportation
National Highway Traffic Safety Administration

NHTSA

DOT HS 813 211 November 2021

Repeatability and Reproducibility Of the FMVSS No. 213 Side Impact Test

DISCLAIMER

Suggested APA Format Reference:

Wietholter, K., & Louden, A. (2021, November). *Repeatability and reproducibility of the FMVSS No. 213 side impact test.* National Highway Traffic Safety Administration.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 813 211		
4. Title and Subtitle Repeatability and Reproducibility of the FMVSS No. 213 Side Impact Test		5. Report Date November 2021 6. Performing Organization Code NHTSA/NSR-130
7. Authors Kedryn Wietholter, Allison E. Louden; National Highway Traffic Safety Administration		8. Performing Organization Report No.
9. Performing Organization Name and Address National Highway Traffic Safety Administration Vehicle Research and Test Center P.O. Box 37 East Liberty, OH 43319		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Ave., SE Washington, DC 20590		13.Type of Report and Period Covered Final Report 14. Sponsoring Agency Code NHTSA/NSR-130
15. Supplementary Notes		

16. Abstract

In January 2014, NHTSA released a Notice of Proposed Rulemaking (NPRM) to amend Federal Motor Vehicle Safety Standard (FMVSS) No. 213 to include a side impact test and additional performance requirements for child restraint systems. Since the NPRM was released, NHTSA has modified the sled-on-sled test buck to minimize variability in installation, be more durable, and better match the proposed frontal FMVSS No. 213 seat assembly. The modified FMVSS No. 213 side impact test was evaluated for repeatability and reproducibility at two different laboratories with both an acceleration and deceleration sled system. Test results were analyzed, per laboratory, and proved repeatable on the acceleration sled and mostly repeatable on the deceleration sled tests having percent coefficient of variation (CV) results below 10 percent for most configurations. Comparing the sled tests on the acceleration and deceleration sleds, the reproducibility results were well below 10 percent CV for the forward-facing CRS configurations. The rear-facing convertible CRS configuration had elevated percent CVs for both HIC15 and chest deflection of 16.0 and 10.5. NHTSA attributes these differences between the acceleration and deceleration sleds to test set-ups and limited testing. Results observed with forward-facing tests on the acceleration and deceleration sled systems show that the modified FMVSS No. 213 sled test fixtures, procedures, and specification can be repeatable and reproducible on different sled systems.

17. Key Words		18. Distribution Statement This document is available to the public from the DOT, BTS, National Transportation Library, Repository & Open Science Access Portal, rosap.ntl.bts.gov.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 32	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Table of Contents

List of Tables

List of Figures

Executive Summary

In January 2014 the National Highway Traffic Safety Administration released a Notice of Proposed Rulemaking (NPRM) to amend Federal Motor Vehicle Safety Standard (FMVSS) No. 213 to include a side impact test and additional performance requirements for child restraint systems (CRSs). The test procedure simulates a near-side crash environment experienced by a child restrained in a CRS with an internal harness in the rear seat of a passenger car. The "sled-on-sled" was based upon a test buck created by TK Holding, Inc. (Takata), and then further developed by NHTSA to have a representative sled pulse, impact direction, door and armrest response. NHTSA's Vehicle Research and Test Center (VRTC) completed the test development on a HYGE acceleration sled at Transportation Research Center Inc. (TRC). Initially, to determine if the side impact test was feasible on other sled types, NHTSA contracted with the Kettering University Crash Safety Center (KCS) to complete testing on a deceleration sled. The initial testing showed that the side impact test was feasible and repeatable on the deceleration sled.

Since the NPRM was released NHTSA has modified the sled-on-sled test buck to minimize variability in installation, be more durable, and better match the proposed frontal FMVSS No. 213 seat assembly. The modifications included an updated D-ring location, increased seat back height, simplified door and armrest shapes, modified lower anchor bracket, and incorporation of a seat cushion assembly representative of current vehicles.

To quantify the repeatability and reproducibility (R&R) of the modified side impact test buck in acceleration and deceleration test environments, additional testing was completed on the TRC acceleration sled and KCS deceleration sled. Sled tests were conducted with the following specifications: the sliding seat acceleration within the proposed acceleration corridor and an impact test speed (relative velocity) 31.4 km/h ± 0.8 km/h (19.5 mph ± 5 mph) for the sliding seat.

To assess CRS performance, testing included the use of CRABI 12-month-old (CRABI 12 MO) and Q series side impact 3-year-old (Q3s) anthropomorphic test devices (ATDs). The CRABI 12 MO was used in the rear-facing (RF) configuration with infant and convertible as well as forward-facing (FF) convertible CRSs. The Q3s ATD was tested in both RF and FF configurations with convertible CRSs. Analysis was performed for injury criteria proposed in the FMVSS No. 213 NPRM: HIC15 and chest displacement for the Q3s ATD. Additionally, head contact with the armrest/door structure was analyzed for the proposed containment criteria for the CRABI 12 MO ATD.

For all sled tests on the acceleration sled, the sliding seat was within the acceleration corridor specified for all the accelerometers used. The relative velocities of the sliding seat for all sled tests were also within the specification. The acceleration sled system produced repeatable results for the overall sled velocity and the sliding seat accelerometers. The average calculated test velocities using the three sliding seat accelerometers were 31.7 km/h (19.7 mph), 31.5 km/h (19.6 mph), and 31.6 km/h (19.6 mph).

On the deceleration sled, the sliding seat was mostly within the acceleration corridor specified for all accelerometers used, although the lower position accelerometer was not always in the corridor. Additionally, the KCS deceleration sled system showed more variability with the overall sled velocity. The average calculated test velocities using the three sliding seat accelerometers were 31.1 km/h (19.3 mph), 31.4 km/h (19.5 mph), and 31.7 km/h (19.7 mph).

The coefficient of variation (CV) was used to evaluate the repeatability and reproducibility of the FMVSS No. 213 side test fixtures and procedures. The acceleration sled tests results showed that the tests were repeatable amongst themselves with the highest percent CV being 4.3 percent for HIC15 and 3.9 percent for chest displacement for the Q3s. The deceleration sled test results showed that the tests were repeatable amongst themselves except for the rear-facing test configuration using the Q3s. The highest percent CV for HIC15 was 5.7 percent with the CRABI 12 MO and 4.4 percent with the Q3s. The highest percent CV for chest displacement for the forward-facing CRS was 1.9 percent, but was 16.1 percent for the rear-facing CRS with the Q3s. However, note that this is based on testing of only one CRS test configuration.

For most of the deceleration sled tests, the percent CV results were less than 10 percent; and therefore, considered repeatable. The exception was the rear-facing Q3s chest deflection results; it is unknown why results were elevated for this configuration. Possibilities include limited testing, variation in test set-up, variation in the overall sled velocity, and/or other factors. However, the elevated percent CV results were not seen with the CRABI 12 MO in the rear-facing configuration.

To quantitatively evaluate the reproducibility of the side impact test, percent CV calculations including both acceleration and deceleration sled tests were completed. To evenly compare the types of sleds, three tests from acceleration and three tests from deceleration were used. Forward-facing Q3s tests had excellent percent CV results well below 10 percent for both HIC15 and chest deflection. For the rear-facing Q3s tests, the proposed injury criteria had elevated percent CVs for both HIC15 and chest deflection of 16.0 and 10.5 percent, respectively. As stated before, it is unclear if the tests on the deceleration sled had other factors affecting the overall results. There was no visual difference in occupant kinematics through comparison of videos and still photos. However, the elevated percent CV results were based on one child restraint in the rear-facing configuration. The same CRS was shown repeatable at each laboratory for the HIC15 measure.

The CRABI 12 MO also saw elevated percent CVs for HIC15 of 11.1 and 12.8 percent for reproducibility; however, this was analyzed for comparison purposes only as head containment is the only proposed requirement. At both labs, there was no head contact with the door/armrest structure for any test.

Comparing the sled tests on the acceleration and deceleration sleds, the reproducibility results were well below 10 percent CV for the forward-facing CRS configurations. The rear-facing convertible CRS configuration had elevated percent CVs for both HIC15 and chest deflection of 16.0 and 10.5, respectively. NHTSA attributes these differences between the acceleration and deceleration sleds to test set-ups and limited testing. Results observed with forward-facing tests on the acceleration and deceleration sled systems show that the modified FMVSS No. 213 sled test fixtures, procedures, and specification can be repeatable and reproducible on different sled systems.

1. Introduction

In January 2014 NHTSA released a Notice of Proposed Rulemaking to amend Federal Motor Vehicle Safety Standard (FMVSS) No. 213[1] to include a side impact test and additional performance requirements for child restraint systems. The test procedure simulates a near-side crash environment experienced by a child restrained in a CRS with an internal harness in the rear seat of a passenger car. The "sled-on-sled" was based upon a test buck created by TK Holding, Inc. (Takata) and then further developed by NHTSA to have a representative sled pulse, impact direction, door and armrest response.[2]

NHTSA's Vehicle Research and Test Center completed the test development on a HYGE acceleration sled at Transportation Research Center Inc.[3] The HYGE principal simulates the deceleration conditions of an impact, but in reverse. TRC's system uses different sized pins and pressures to simulate the actual sled pulse. The acceleration side impact sled set-up is shown in Figure 1.

Figure 1. TRC Acceleration Sled Set-up

[1] 79 FR 4570; Available at www.regulations.gov/document?D=NHTSA-2014-0012-0001

[2] Sullivan, L., Louden, A., & Echemendia, C. (2013, December). *Child restraint side impact test procedure development.* National Highway Traffic Safety Administration. www.regulations.gov/document?D=NHTSA-2014-0012-0002

[3] Transportation Research Center Inc. (n.d.). *HYGE sled*. [Web page] www.trcpg.com/what-we-do/active-passive-safety/hyge-sled/

Initially, to determine if the side impact test was feasible on other sled types, NHTSA contracted with Kettering University Crash Safety Center to complete testing on a deceleration sled.[4] The deceleration sled, built by Global Test and Engineering Services, propels the sled up to the speed desired using pneumatic power and by tuning the hydraulic fluid to the sled pulse desired. The deceleration sled used is shown in Figure 2. Initial testing showed that the side impact test methods were feasible and repeatable on the deceleration sled.[5, 6]

Figure 2. KCS Deceleration Sled Set-up

Since the NPRM was released, NHTSA has modified the sled-on-sled test buck to minimize variability in installation, be more durable, and better match the proposed frontal FMVSS No. 213 seat assembly. The modifications, illustrated in Figure 3, included an updated D-ring location, increased seat back height, simplified door and armrest shapes, modified lower anchor bracket, and incorporation of seat cushion assembly representative of current vehicles. The sliding seat weight was 1290 Newtons (290 pounds) after rebuilding with all modifications.[7]

[4] https://www.kettering.edu/research/labs

[5] Brelin-Fornari, J., & Janca, S. (2014, April). *Development of NHTSA's side impact test procedure for child restraint systems using a deceleration sled: final report, part 1* (Report No. DOT HS 811 994). National Highway Traffic Safety Administration. www.nhtsa.gov/sites/nhtsa.dot.gov/files/811994-sideimpcttest-chrestraintdecelsled_pt1.pdf

[6] Brelin-Fornari, J., & Janca, S. (2014, May). *Development of NHTSA's side impact test procedure for child restraint systems using a deceleration sled: final report, part 2* (Report No. DOT HS 811 995). National Highway Traffic Safety Administration. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/811995-sideimpcttest-chrestraintdecelsled_pt2.pdf

[7] The sliding seat weight was 1,223 Newtons (275 pounds) based on the NPRM drawings.

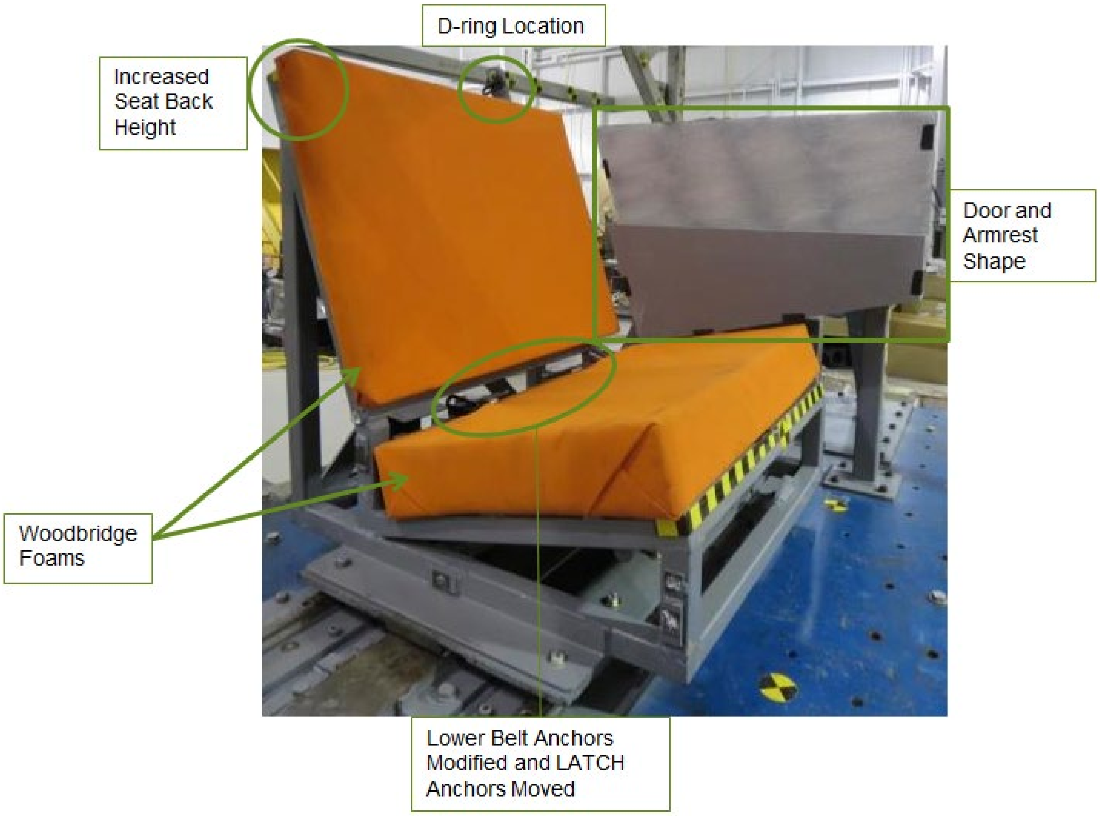

Figure 3. Sliding Seat Buck Modifications

To quantify the R&R of the modified FMVSS No. 2013 side impact test buck in acceleration and deceleration test environments, additional testing was completed on both the TRC acceleration sled and KCS deceleration sled.[8] This report details the sled test methodology and results comparing the acceleration and deceleration sled tests for repeatability and reproducibility.

[8] Brelin-Fornari, J. (in press). *Final report on CRS side impact study of repeatability and reproducibility using a deceleration sled.* National Highway Traffic Safety Administration.

2. Sled Test Methods

Sled testing was completed to evaluate the repeatability and reproducibility of the FMVSS No. 213 side test fixtures and procedures. Using the acceleration sled at TRC and the deceleration sled at KCS, sled tests were conducted with the following specifications: the sliding seat acceleration corridor with the coordinates, shown in Table 1, and an impact test speed of 31.4 km/h ± 0.8 km/h (19.5 mph ± 0.5 mph) for the sliding seat. The impact test speed is calculated from the relative velocity of the sliding seat fixture.

Table 1. Acceleration Corridor Coordinates

Upper		Lower	
Time (ms)	Acceleration (g)	Time (ms)	Acceleration (g)
0	0.5	2	0
6	25.5	13	18.5
44	25.5	40	18.5
58	0	48	0

Throughout both series, a 620 kPa (90 PSI) ± 5 percent honeycomb was used to control the deceleration of the sliding seat to achieve the appropriate acceleration within the corridor. The honeycomb that was used on the TRC acceleration sled had dimensions of 343 millimeters (13.5 inches) by 114 millimeters (4.5 inches) with a 305-millimeter (12-inch) thickness. The KCS deceleration sled used honeycomb with the dimension of 343 millimeters (13.5 inches) by 108 millimeters (4.25 inches) with a 305-millimeter (12-inch) thickness.

Accelerometers were used on the rear leg of the sliding seat assembly to measure acceleration, which was integrated to calculate velocity. The relative velocity was calculated by subtracting the overall sled velocity from the sliding seat velocity. The test speed was defined as the relative velocity at the time the sliding seat contacted the honeycomb.

For the majority of the testing, an Endevco 7290E damped accelerometer was used on a mount at the upper section on the tube, while two Endevco 7231C non-damped accelerometers were used in the middle and lower sections. Figure 4 shows the locations of the accelerometers on the rear leg of the sliding seat structure.

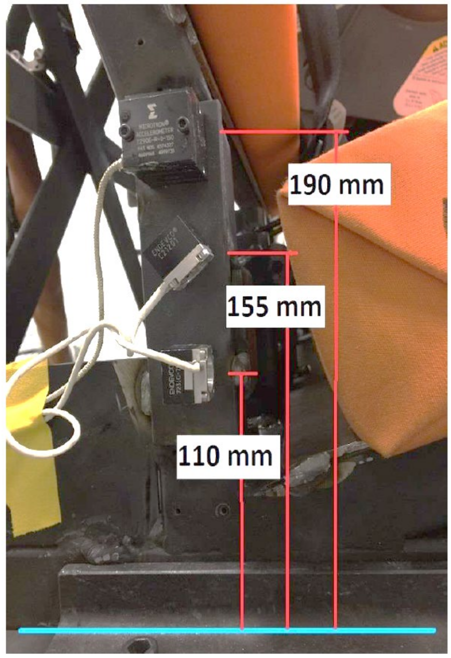

Figure 4. Accelerometer Placement on Rear Leg of Sliding Seat

2.1. Instrumentation

To assess CRS performance, testing included the CRABI 12 MO and Q series side impact 3-year-old (Q3s) anthropomorphic test devices. The CRABI 12 MO was used in the RF configuration with infant and convertible as well as FF convertible CRSs. A list of instrumentation used for the CRABI 12 MO ATD can be found in Table 2.

Table 2. Instrumentation in CRABI 12 MO

Location	Measurement	Instrument	Channels
Head	Head C.G. Acceleration	Tri-Axial Accelerometer	3
Neck	Upper Neck Forces & Moments	Six-Channel Load Cell	6
Thorax	Chest Acceleration	Tri-Axial Accelerometer	3
Pelvis	Pelvis Acceleration	Tri-Axial Accelerometer	3
Total			15

The Q3s ATD was tested in both RF and FF configurations with convertible and combination CRSs. Table 3 contains the list of instrumentation used in the Q3s ATD.

Table 3. Instrumentation in Q3s

Location	Measurement	Instrument	Channels
Head	Head C.G. Acceleration	Tri-Axial Accelerometer	3
Neck	Upper Neck Forces & Moments	Six-Channel Load Cell	6
Shoulder	Shoulder Displacement	String Potentiometer	1
Upper Spine	Upper Spine Acceleration	Tri-Axial Accelerometer	3
Thorax	Chest Displacement	IR-TRACC	1
Lumbar Spine	Lumbar Spine Forces & Moments	Six-Channel Load Cell	6
Pelvis	Pelvis Acceleration	Tri-Axial Accelerometer	3
Pubic	Pubic Force	One-Channel Load Cell	1
Total			24

All the above data was collected. However, analysis was only performed for injury criteria proposed in the FMVSS No. 213 NPRM: HIC15 and chest displacement for the Q3s ATD. Additionally, head contact with the armrest/door structure was analyzed for proposed containment criteria for the CRABI 12 MO ATD as well as HIC15 for comparison purposes.

2.2. Test Matrix

A series of sled tests used the CRABI 12MO and Q3s ATD in child restraints with configurations of lower anchorages only (LA Only) and lower anchorages and tether (LATCH) were completed. The series included three repeats of each configuration to analyze repeatability. Table 4 details the test matrix completed with additional information on each CRS in Appendix A.

Table 4. Test Matrix

ATD	CRS	Orientation
CRABI 12 MO	Chicco KeyFit 30	RF Infant
CRABI 12 MO	Britax Boulevard	RF Convertible
CRABI 12 MO	Cosco Apt 40RF	FF Convertible
Q3s	Graco Comfort Sport	RF Convertible
Q3s	Graco Comfort Sport	FF Convertible
Q3s	Evenflo Maestro	FF Combination

For all the configurations tested, the belts were tensioned, as given in Table 5, using a three-prong belt tensioning gauge (Borroughs BT3329S). Occasionally, the lower anchorages were unable to be accessed or accurately measured using the device, so CRS movement of less than 25.4 millimeters (1 inch) was targeted instead. The CRSs were measured with a digital measuring device (FARO arm) to align the ATD and CRS laterally on the seat assembly and to set them similarly on the sliding seat for all repeats.

Table 5. Belt Tensioning Targets

Belt Type	Tension
Harness	8.9-13.3 N (2-3 lb)
Lower Anchorages	53.4-66.7 N (12-15 lb)
Tether Anchorage	44.5-53.4 N (10-12 lb)
Belts for CRSs	53.4-66.7 N (12-15 lb)
Belts for BPBs	8.9-13.3 N (2-3 lb)

3. Sled Test Results

3.1. Acceleration Sled Results

For all sled tests on the acceleration sled, the sliding seat was within the sliding seat acceleration corridor specified for all the accelerometers used. Figure 5 shows the sliding seat acceleration for the entire series with each CRS test from the test matrix represented by three curves of repeat tests.

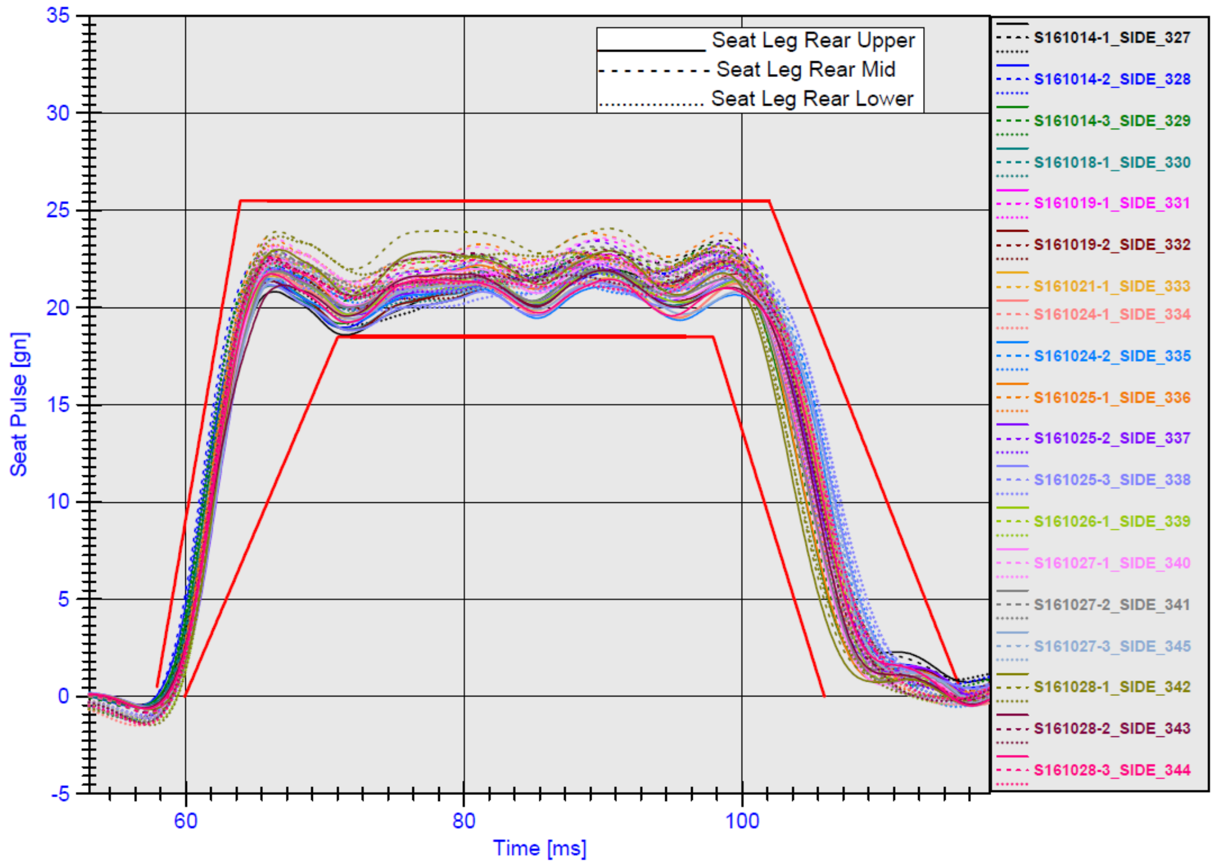

Figure 5. Sliding Seat Acceleration Results

The calculated test speeds for all sled tests were also within the target test speed specification of 31.4 km/h ± 0.8 km/h (19.5 mph ± 5 mph). Table 6 details the overall sled velocity and the relative velocity results for all accelerometers at impact.

Table 6. Acceleration Sled Relative Velocity Results

VDB No.	VRTC Test No.	Overall Sled Velocity (km/h)	Relative Velocity from Damped Rear Leg SEATRE00 (UPPER) (7290E) (km/h)	Relative Velocity from Non-Damped Rear Leg SEATRERD (MIDDLE) (7231C) (km/h)	Relative Velocity from Rear Leg SEATRER1 (LOW) (7231C)R (km/h)
V10008	SIDE_327	32.7	31.7	31.7	31.6
V10009	SIDE_328	32.7	31.8	31.7	31.5
V10010	SIDE_329	32.5	31.6	31.6	31.5
V10011	SIDE_330	32.7	31.8	31.8	31.6
V10012	SIDE_331	32.8	31.9	31.9	31.6
V10013	SIDE_332	32.7	31.8	31.8	31.5
V10014	SIDE_333	32.7	31.7	31.4	N/A
V10015	SIDE_334	32.7	31.8	31.5	31.8
V10016	SIDE_335	32.7	31.7	31.4	31.5
V10017	SIDE_336	32.7	31.7	31.4	31.6
V10018	SIDE_337	32.7	31.7	31.5	31.5
V10019	SIDE_338	32.5	31.6	31.4	31.3
V10020	SIDE_339	32.7	31.7	31.4	31.6
V10021	SIDE_340	32.7	31.8	31.4	31.5
V10022	SIDE_341	32.5	31.7	31.4	31.6
V10023	SIDE_345	32.7	31.7	31.4	31.5
V10024	SIDE_342	32.7	31.8	31.5	31.8
V10025	SIDE_343	32.5	31.6	31.3	31.4
V10026	SIDE_344	32.7	31.8	31.4	31.7
	Average	32.7	31.7	31.5	31.6

As shown in the table, the acceleration sled system produced repeatable results for the overall sled velocity and the sliding seat accelerometers. The average calculated test velocities using the three sliding seat accelerometers were 31.7 km/h (19.7 mph), 31.5 km/h (19.6 mph), and 31.6 km/h (19.6 mph).

The FMVSS No. 213 proposed injury criteria results are reported below in Table 7. Data above the proposed criteria for the Q3s, HIC15 limit of 570 and chest deflection limit of 23 millimeters, were highlighted in red. The data point marked with an asterisk had questionable IR-TRACC results.

Table 7. ATD Results

VDB No.	VRTC Test No.	ATD	Orientation	HIC 15	Chest Deflection (mm)	Door Contact
V10008	SIDE_327	CRABI 12 MO	RF Infant	442	N/A	No
V10009	SIDE_328	CRABI 12 MO	RF Infant	464	N/A	No
V10010	SIDE_329	CRABI 12 MO	RF Infant	475	N/A	No
V10011	SIDE_330	CRABI 12 MO	RF Convertible	799	N/A	No
V10012	SIDE_331	CRABI 12 MO	RF Convertible	770	N/A	No
V10013	SIDE_332	CRABI 12 MO	RF Convertible	811	N/A	No
V10014	SIDE_333	CRABI 12 MO	FF Convertible	695	N/A	No
V10015	SIDE_334	CRABI 12 MO	FF Convertible	786	N/A	No
V10016	SIDE_335	CRABI 12 MO	FF Convertible	804	N/A	No
V10017	SIDE_336	Q3s	RF Convertible	616	28.4	N/A
V10018	SIDE_337	Q3s	RF Convertible	621	27.0	N/A
V10019	SIDE_338	Q3s	RF Convertible	658	27.9	N/A
V10020	SIDE_339	Q3s	FF Convertible	672	21.6	N/A
V10021	SIDE_340	Q3s	FF Convertible	716	20.6	N/A
V10022	SIDE_341	Q3s	FF Convertible	691	20.1*	N/A
V10023	SIDE_345	Q3s	FF Convertible	724	21.8	N/A
V10024	SIDE_342	Q3s	FF Combination	914	23.1	N/A
V10025	SIDE_343	Q3s	FF Combination	937	23.8	N/A
V10026	SIDE_344	Q3s	FF Combination	993	23.5	N/A

*The data point had questionable IR-TRACC results.
CRABI 12 MO HIC15 results are shown for comparison purposes only.

Analysis of each type of CRS model and its configuration showed similar responses of the ATDs in each of tested configuration.

3.2. Deceleration Sled Results

For all sled tests, the sliding seat was mostly within the acceleration corridor specified for all accelerometers used, although the lower position accelerometer was not always in the corridor. Figure 6 shows the sliding seat acceleration for the entire series with each CRS test represented by three curves.

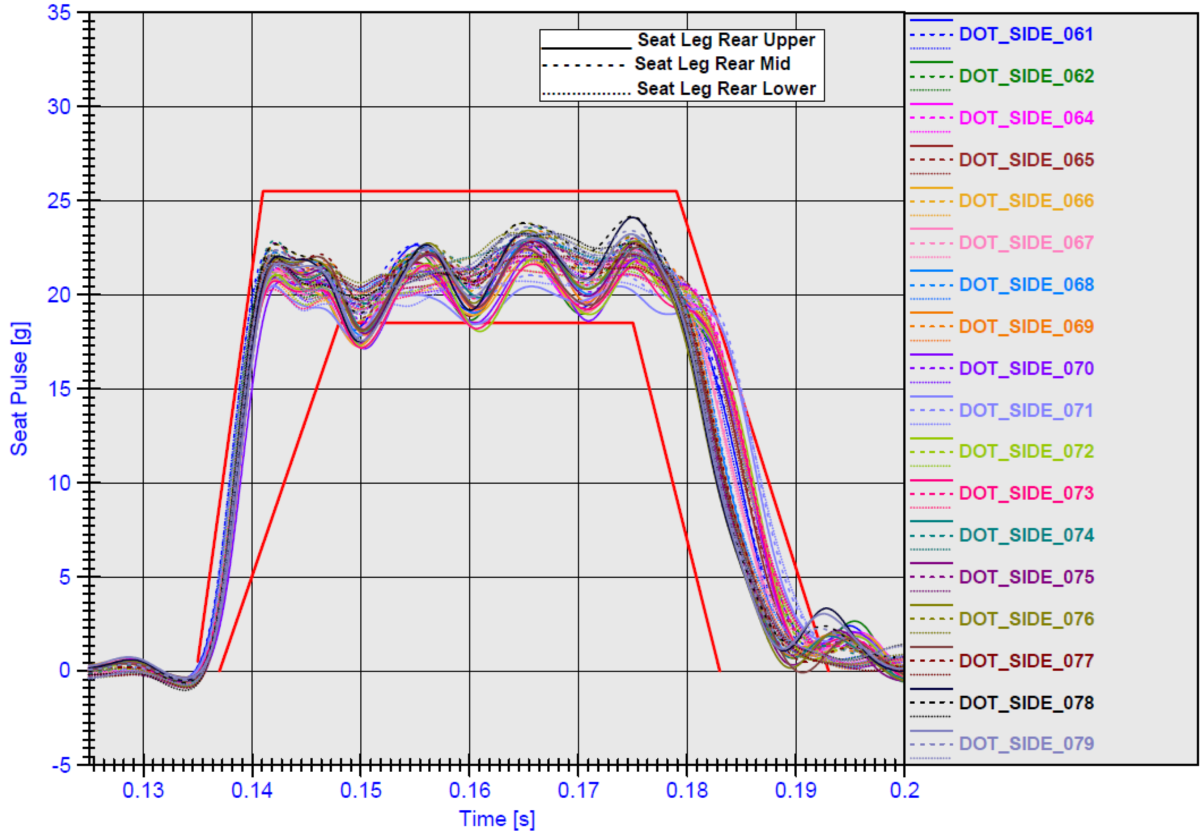

Figure 6. Deceleration Sled Sliding Seat Acceleration Results

Only 2 of the 48 calculated relative velocities of the sliding seat at impact were not within the specification. Table 8 details the overall sled velocity and the relative velocity results for all accelerometers at impact for the series.

Table 8. Deceleration Sled Relative Velocity Results

VDB No.	Test Number	Overall Sled Velocity (km/h)	Relative Velocity from Damped Rear Leg SEATRE00 (UPPER) (7290E) (km/h)	Relative Velocity from Non-Damped Rear Leg SEATRERD (MIDDLE) (7231C) (km/h)	Relative Velocity from Rear Leg SEATRER1 (LOW) (7231C)R (km/h)
V11800	061	33.5	31.4	31.7	31.9
V11801	062	33.3	31.5	31.7	32.0
V11805	067	32.7	31.2	31.5	31.7
V11802	064	33.3	31.7	31.9	32.0
V11803	065	33.0	31.5	31.7	32.0
V11804	066	32.8	31.4	31.9	32.3
V11806	068	32.7	31.2	31.9	31.9
V11807	069	32.3	30.7	31.1	31.4
V11808	070	32.2	30.7	31.2	31.5
V11809	071	32.7	31.2	31.7	32.0
V11810	072	32.5	31.1	31.4	31.7
V11811	073	32.3	30.7	31.1	31.5
V11812	074	32.3	30.7	31.1	31.5
V11813	075	32.3	30.7	31.1	31.7
V11814	076	32.3	30.6	30.7	31.2
V11815	077	32.3	30.4	30.7	31.4
	Average	32.7	31.1	31.4	31.7

The KCS deceleration sled system had some variability with the overall sled velocity. There were also differences between the three accelerometers used to calculate relative velocity. The average calculated test velocities using the three sliding seat accelerometers were 31.1 km/h (19.3 mph), 31.4 km/h (19.5 mph), and 31.7 km/h (19.7 mph).

The FMVSS No. 213 proposed injury criteria results are reported in Table 9. Data above the proposed criteria for the Q3s, HIC15 limit of 570 and chest deflection limit of 23 millimeters, were highlighted in red.

Table 9. Deceleration Sled ATD Results

VDB No.	VRTC Test No.	ATD	Orientation	HIC 15	Chest Deflection [mm]	Door Contact
V11809	SIDE_071	CRABI 12 MO	RF Infant	573	N/A	No
V11810	SIDE_072	CRABI 12 MO	RF Infant	526	N/A	No
V11811	SIDE_073	CRABI 12 MO	RF Infant	572	N/A	No
V11812	SIDE_074	CRABI 12 MO	RF Convertible	670	N/A	No
V11813	SIDE_075	CRABI 12 MO	RF Convertible	598	N/A	No
V11814	SIDE_076	CRABI 12 MO	RF Convertible	635	N/A	No
V11815	SIDE_077	CRABI 12 MO	FF Convertible	962	N/A	No
V11806	SIDE_068	Q3s	RF Convertible	457	33.5	N/A
V11807	SIDE_069	Q3s	RF Convertible	481	26.7	N/A
V11808	SIDE_070	Q3s	RF Convertible	483	24.9	N/A
V11802	SIDE_064	Q3s	FF Convertible	693	22.7	N/A
V11803	SIDE_065	Q3s	FF Convertible	665	22.0	N/A
V11804	SIDE_066	Q3s	FF Convertible	683	22.7	N/A
V11800	SIDE_061	Q3s	FF Combination	917	23.3	N/A
V11801	SIDE_062	Q3s	FF Combination	963	23.3	N/A
V11805	SIDE_067	Q3s	FF Combination	882	23.9	N/A

CRABI 12 MO HIC15 results are shown for comparison purposes only.

The analysis of each type of CRS model and its configuration showed overall similar ATD responses. The Q3s in the rear-facing configuration had some differences with the chest deflection. Additional video comparisons of these three tests showed the ATD kinematic responses were similar during each test.

4. Repeatability Analysis

The coefficient of variation was used to objectively evaluate the repeatability and reproducibility of the FMVSS No. 213 side test fixtures and procedures. The CV is calculated by dividing the standard deviation by the average; multiplying the CV by 100 computes the percent CV. Since variation in test results is likely contributable to more than just the test fixtures and procedure, a percent CV at or below 10 percent indicates results are similar.

The percent CV values for the acceleration and deceleration sled tests are listed in Table 10 and are considered the repeatability of the tests at each laboratory. The acceleration sled tests results showed that the tests were repeatable amongst themselves with the highest percent CV being 4.3 percent for HIC15 and 3.9 percent for chest displacement for the Q3s. The deceleration sled test results showed that the tests were repeatable amongst themselves with the exception of the rear-facing test configuration using the Q3s. The highest percent CV for HIC15 was 5.7 percent with the CRABI 12 MO and 4.4 percent with the Q3s. The highest percent CV for chest displacement for the forward-facing CRS was 1.9 percent, but was 16.1 percent for the rear-facing CRS with the Q3s. However, note that this is based on testing of just one CRS configuration.

Acceleration Sled System				Deceleration Sled System			
CRS Model		%CV		CRS Model		%CV	
	Quantity of Tests	HIC15	Chest Displacement		Quantity of Tests	HIC15	Chest Displacement
Graco Comfort Sport FF Q3s	n=4	3.4%	3.9%	Graco Comfort Sport FF Q3s	n=3	2.1%	1.9%
Evenflo Maestro FF Q3s	n=3	4.3%	1.3%	Evenflo Maestro FF Q3s	n=3	4.4%	1.4%
Graco Comfort Sport RF Q3s	n=3	3.6%	2.5%	Graco Comfort Sport RF Q3s	n=3	3.0%	16.1%
Chicco KeyFit 30 RF CRABI	n=3	3.7%	N/A	Chicco KeyFit 30 RF CRABI	n=3	4.7%	N/A
Britax Boulevard RF CRABI	n=3	2.7%	N/A	Britax Boulevard RF CRABI	n=3	5.7%	N/A

Table 10. Acceleration and Deceleration Repeatability Results

For most of the deceleration sled testing, the percent CV results for sled tests were less than 10 percent and therefore considered repeatable; the exception was the rear-facing Q3s chest deflection results. It is unknown why results were elevated for this configuration. Possibilities include limited testing, variation in test set-up, variation in the overall sled velocity, and/or other factors. However, the elevated percent CV results were not seen with the CRABI 12 MO in the rear-facing configuration.

5. Reproducibility Analysis

5.1. Corridor and Velocity

Sliding seat acceleration and relative velocity data on the acceleration and deceleration sleds were compared. The average sliding seat accelerations in the proposed corridor are shown in Figure 7. The results were similar although the sliding seat on the deceleration sled had more oscillations, especially in the accelerometer in the lower position on the rear leg. The accelerometers were filtered at CFC 60 for the analysis.

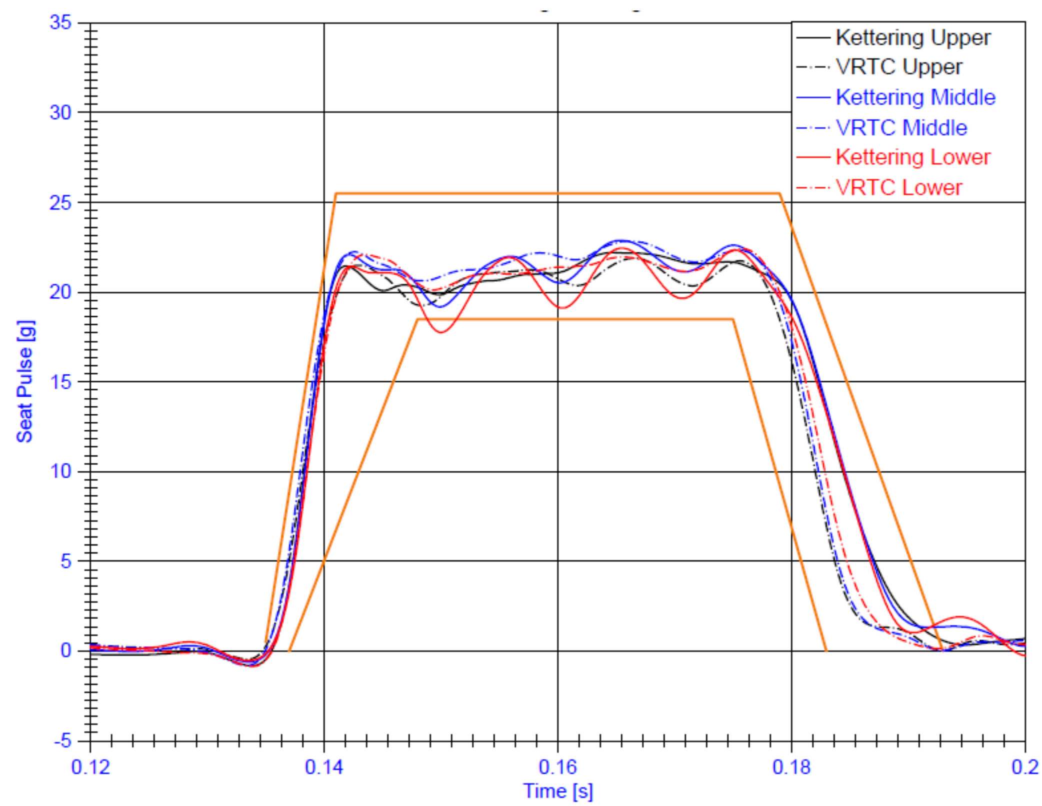

Figure 7. Sliding Seat Acceleration Results Comparison

The comparisons of the average relative velocities at impact between the acceleration and deceleration tests are shown in Table 11 as well as the average overall sled accelerations and velocities. The calculated test speeds were all within 31.4 km/h ± 0.8 km/h, with the deceleration sled tests trending lower than the acceleration sled tests.

Table 11. Relative Velocity Results Comparisons

Sled Type	Average Sled Overall Acceleration [g]	Average Sled Overall Velocity (km/h)	Relative Velocity from Damped Rear Leg (UPPER) (7290E) (km/h)	Relative Velocity from Non-Damped Rear Leg (MIDDLE) (7231C) (km/h)	Relative Velocity from Rear Leg (LOW) (7231C)R (km/h)
Acceleration (TRC)	23.5	32.7	31.7	31.5	31.6
Deceleration (KCS)	20.7	32.7	31.1	31.4	31.7

To quantitatively evaluate the reproducibility of the side impact test, percent CV calculations including both acceleration and deceleration sled tests were completed. To evenly compare the types of sleds, three tests from the acceleration and three tests from deceleration were used. Acceleration sled test number SIDE_341 was removed from analysis because the test had questionable chest deflection results. Table 12 shows the quantity of tests used to compare and the percent CV results for the different CRS configurations and its corresponding proposed injury responses. However, it is important to note the data set is limited.

Table 12. Acceleration and Deceleration Reproducibility Results

Reproducibility - Acceleration and Deceleration Sled Systems			
CRS Model	%CV		
	Quantity of Tests	HIC15	Chest Displacement
Graco Comfort Sport FF Q3s	n=6	3.4%	3.6%
Evenflo Maestro FF Q3s	n=6	4.2%	1.2%
Graco Comfort Sport RF Q3s	n=6	16.0%	10.5%
Chicco KeyFit 30 RF CRABI	n=6	11.1%	N/A
Britax Boulevard RF CRABI	n=6	12.8%	N/A

The forward-facing Q3s tests had excellent percent CV results well below 10 percent for both HIC15 and chest deflection. For the rear-facing Q3s tests, the proposed injury criteria had elevated percent CVs for both HIC15 and chest deflection of 16.0 and 10.5 percent, respectively. As stated before, it is unclear if the tests on the deceleration sled had other factors affecting the overall results. There was no visual difference in occupant kinematics through comparison of videos and still photos. However, the elevated percent CV results were based on one child restraint in the rear-facing configuration. That particular CRS was shown repeatable at each laboratory for the HIC15 measure.

The CRABI 12 MO also saw elevated percent CVs for HIC15 of 11.1 and 12.8 percent; however, this was analyzed for comparison purposes only as head containment is the only proposed requirement. At both labs, there was no head contact with the door/armrest structure for any test.

Further analysis, although limited, conducted with an additional rear facing CRS (Diono Olympia) provided more data on the overall repeatability and reproducibility as shown in Table 13. The results showed that between the two labs, similar HIC15 values can be obtained. Unfortunately, the test on the acceleration sled had questionable data for the chest deflection so results could not be compared. However, the variability with the chest deflection on the deceleration sled was still shown. Again, this could be related to set-up with the ATD or overall set-up of the sled system.

Table 13. Additional Injury Results Comparisons

Test No.	ATD	CRS	Orientation	HIC 15	Chest Deflection [mm]
TRC_SIDE_324	Q3s	Diono Olympia	RF Convertible	1001	N/A
KCS_SIDE_078	Q3s	Diono Olympia	RF Convertible	979	34.3
KCS_SIDE_079	Q3s	Diono Olympia	RF Convertible	955	27.4

6. Discussion

6.1. Test Set-up Differences

The FMVSS No. 213 side impact test procedures were developed on the TRC HYGE acceleration sled system. The test parameters specified in the NPRM were based on the results of tests conducted by the agency. Testing on the deceleration sled at KCS resulted in some differences in the overall set-up. One of the key differences was the initial spacing between the sliding seat and honeycomb. For tests conducted at TRC on the acceleration sled, this spacing was 265 millimeters (Figure 8), while it was 800 millimeters for the tests at KCS (Figure 9).[9] The objectives of the test procedure were met because the specifications were that the sliding seat acceleration must be in the corridor and the test speed at impact must be 31.4 km/h ± 0.8 km/h (19.5 mph ± 5 mph.).

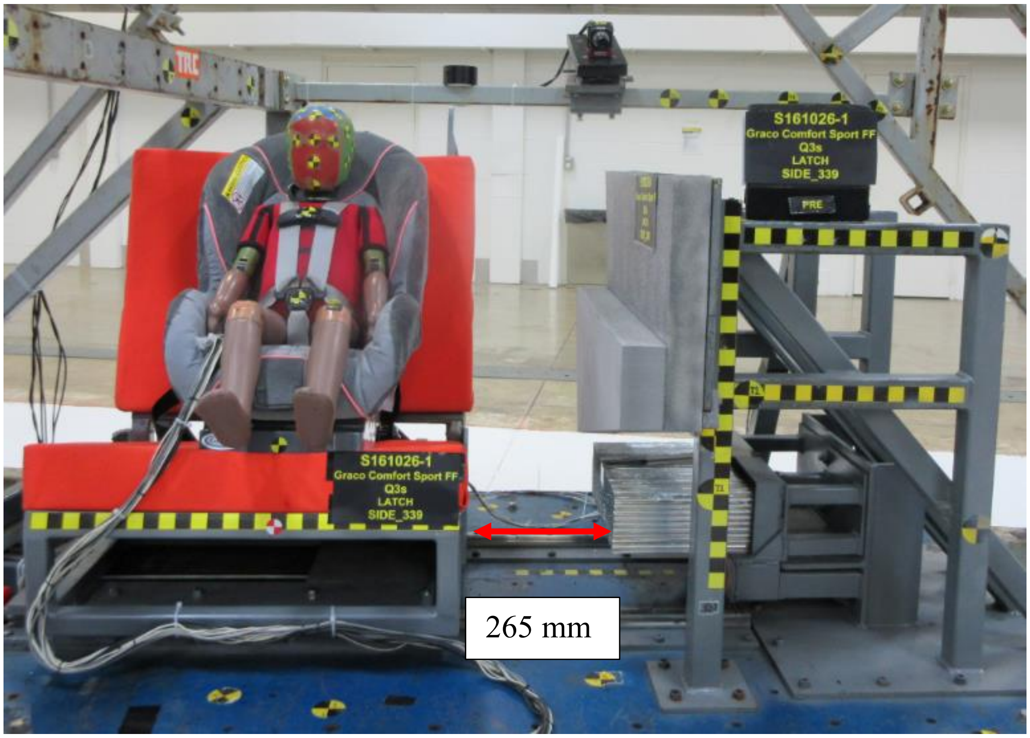

Figure 8. Acceleration Set-up

---

[9] The KCS deceleration set-up parameters were approved by NHTSA. It is unknown at this time if other sled types and systems (acceleration or deceleration sleds) would have or need different spacing.

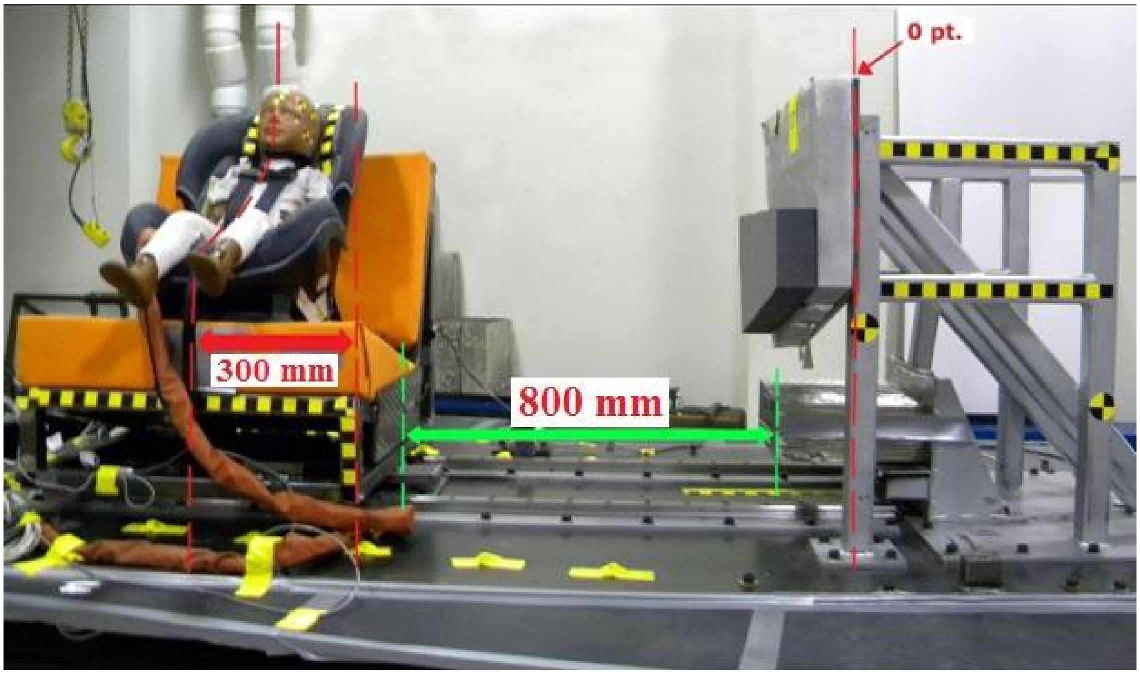

Figure 9. Deceleration Set-up

The test set-up could affect the sliding seat velocity and honeycomb size used for deceleration. The NPRM drawing package proposed a honeycomb specification of 552 kPa (80 PSI) ± 10 percent. Due to the increased weight of the sliding seat since the NPRM (see page 2), it was necessary to use 621 kPa (90 PSI) honeycomb to meet the specified acceleration corridor for the sliding seat. Also, the honeycomb supplier conducted analysis on the proposed tolerance for the honeycomb; it was determined that a tighter tolerance was needed to maintain uniformity and consistent deceleration. This resulted in the following revised honeycomb specifications, which were used for the tests on the acceleration sled described in this report: 621 kPa (90 PSI) ± 5 percent with dimensions of 343 millimeters (13.5 inches) by 114 millimeters (4.5 inches) with a 305-millimeter (12-inch) thickness. The revised honeycomb specification was verified on the TRC acceleration sled system and had good repeatability, as shown in previous sections.

The KCS deceleration sled used honeycomb with the same crush strength of 621 kPa (90 PSI) ± 5 percent but with dimensions of 343 millimeters (13.5 inches) by 108 millimeters (4.25 inches) with a 305-millimeter (12-inch) thickness. The deceleration honeycomb size was based on the KCS sled system and the area needed to decelerate its sliding seat to meet the corridor. Different sled systems may require slightly different height and width dimensions to meet the corridor, but it is recommended to keep the same thickness of 305 millimeters (12 inches), to maintain crush performance and consistent spacing with the door and armrest.

6.2. Accelerometer Placement

Accelerometers were mounted at the same location on the sliding seat in both the acceleration and deceleration sled tests as shown in Figure 4. However, it was noted that there were differences in the calculated relative velocity results for a given test depending on the accelerometer type and location. Table 11 showed the average relative velocity results for a given accelerometer and location on the acceleration and deceleration sleds. There was a difference between the three accelerometers of 0.2 km/h (0.1 mph) for the acceleration sled and 0.6 km/h (0.4 mph) for the deceleration sled. Therefore, it may be important to specify the accelerometer type and location to be used for determining the relative velocity of the sliding seat.

6.3. Occupant Kinematics

Occupant kinematics were analyzed between the acceleration and deceleration sled tests to determine the effect of the different set-ups. Specifically, head motion out of the seat (perpendicular to the seat back) was quantified using 2D image analysis software.

Head motion was different between the two sled types. Figure 10 shows a comparison of head movement for the forward-facing CRS Q3s tests. For the VRTC tests on the TRC acceleration sled, sliding seat to honeycomb impact occurred around 63 milliseconds. For the KCS deceleration sled tests, impact occurred around 138 milliseconds. Due to the difference in timing, caused by the difference in set-up, there is a difference in the location of the head relative to the CRS and simulated door at impact. For the acceleration sled tests, the sliding seat impacted the honeycomb at a head position about 50 millimeters from its starting location. For deceleration sled tests, the head had reached its maximum excursion of 100 millimeters and had moved back to approximately 95 millimeters from its starting position at impact with the honeycomb. A similar difference in head motion was observed for the rear-facing CRS Q3s tests, which could be a factor in their elevated HIC15 percent CV, although it did not appear to affect the results of the forward-facing CRS Q3s tests. Even with the different impact times and head location, the overall occupant kinematics were similar throughout the event.

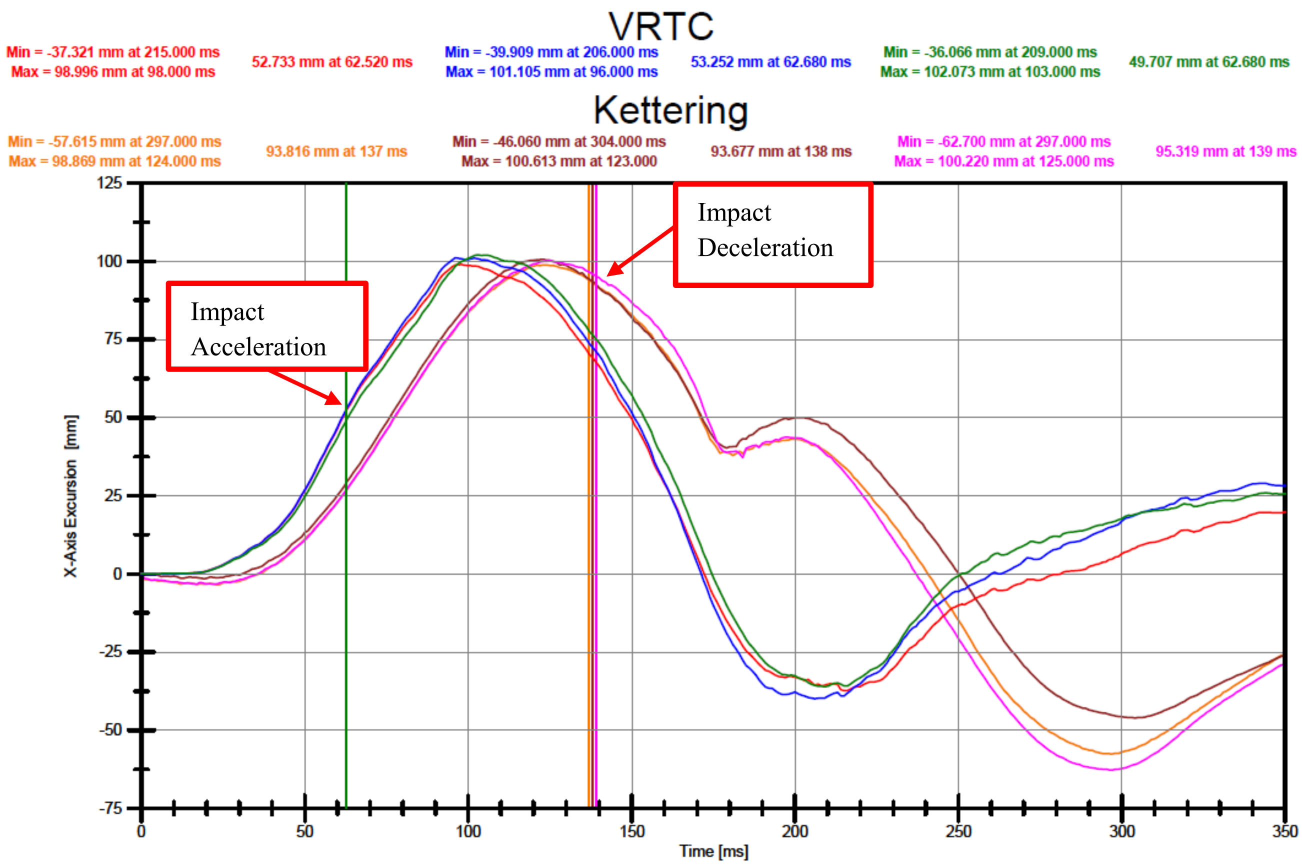

Figure 10. Head Motion Comparison

6.4. Dummy Durability

Throughout both test series, minimal ATD damage was noted. The Q3s ATD right femur was bent during testing and was replaced. Additionally, it was noted that the Q3s shoulder joint was loosening, although the "Nose Spring Ball Plunger" was not replaced during VRTC testing because the shoulder detent could still be used.

7. Summary

Since the NPRM was released, NHTSA has modified the sled-on-sled test buck to minimize variability in installation, be more durable, and better match the proposed frontal FMVSS No. 213 seat assembly. The modifications included an updated D-ring location, increased seat back height, simplified door and armrest shapes, modified lower anchor bracket, and incorporation of seat cushion assembly representative of current vehicles.

The modified FMVSS No. 213 side impact test was evaluated for repeatability by conducting repeat sled tests on acceleration and deceleration sled systems at two different laboratories. Test results were analyzed, per laboratory, and proved repeatable on acceleration sled and mostly repeatable on the deceleration sled (with the exception of the rear-facing chest deflection test sequence) having percent CV results below 10 percent.

Comparing the sled tests on the acceleration and deceleration sleds, the reproducibility results were well below 10 percent CV for the forward-facing CRS configurations. The rear-facing convertible CRS configuration had elevated percent CVs for both HIC15 and chest deflection of 16.0 and 10.5, respectively. NHTSA attributes these differences between the acceleration and deceleration sleds to test set-ups and limited testing. Results observed with forward-facing tests on the acceleration and deceleration sled systems show that the modified FMVSS No. 213 sled test fixtures, procedures, and specification can be repeatable and reproducible on different sled systems.

Appendix A. CRS Selection

1

2

3

4

5

6

1. Chicco KeyFit30 (Manufactured August 2014)
2. Britax Boulevard (Manufactured January 2015)
3. Cosco Apt 40RF (Manufactured February 2015)
4. Graco Comfort Sport (Manufactured March 2014, April 2014, May 2014, April 2015)
5. Evenflo Maestro (Manufactured October 2014)
6. Diono Olympia (Manufactured January 2015)

DOT HS 813 211
November 2021

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

15435-110221-v2