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16. Abstract
This small-scale study used sled testing to explore the effects of two commercially available CRS (child restraint system) LATCH (Lower Anchors and Tethers for Children) energy management features on the loads delivered to the vehicle LATCH hardware and the resulting anthropomorphic test device (ATD) accelerations and excursions. Paired sled tests were conducted with/without the Diono SuperLATCH connectors and with/without Britax RipStitch tethers. The sled tests used the weighted Hybrid III 6-year-old ATD and a modified version of the FMVSS 213 bench. In high-severity frontal crash tests, the SuperLATCH reduced the ATD head injury criterion (HIC) but had no effect on lower anchor loads, chest accelerations, and ATD head/knee excursions. The Britax RipStitch tether reduced tether webbing loads but increased lower anchor loads and did not reduce any ATD acceleration or excursion measures. This data suggests these features do not offer the expected safety benefits under the conditions tested.

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Table of Contents

Background **1**

Objectives **1**

Methods **1**

Results **5**

Performance of SuperLATCH 6

Performance of RipStitch Tether 9

Discussion and Conclusions **11**

References **12**

Table of Figures

Figure 1. CRS used for testing: (a) R100, (b) Boulevard, and (c) Sure Ride 2

Figure 2. The frontal bench used for the test series 2

Figure 3. Examples that provide comparison of the two test pulses 3

Figure 4. Minor damage observed on R100 CRS 6

Figure 5. Comparison of peak lower anchor loads produced by the R100 with and without SuperLATCH 6

Figure 6. Load time histories for the SuperLATCH and regular LATCH lower anchors 7

Figure 7. Comparison of HIC and ATD excursions 8

Figure 8. ATD chest acceleration clip (3ms) 8

Figure 9. Failure of CRS back shell panel with RipStitch tether (top) and with RipStitch feature removed (bottom) 9

Figure 10. Illustration of post-test torn stitching of RipStitch tether in test NT1409 10

Figure 11. Tether and LA loads for Boulevard 10

Figure 12. ATD responses and excursions for Boulevard 11

Table of Tables

Table 1. Summary of energy management test conditions 4

Table 2. Summary of energy management test results 5

Background

Several child restraint manufacturers have load-limiting features designed into the LATCH (Lower Anchors and Tethers for Children) lower connectors or tethers of child restraint systems (CRS). These features are intended to reduce the peak forces and accelerations experienced by the CRS and the occupant by absorbing energy and extending the time available to stop during an impact event (an effect sometimes called "ride-down"). The force levels necessary to activate/deform these elements are relatively high because there is a safety tradeoff made between lowered peak forces/accelerations and higher occupant excursions; the latter can increase the likelihood of occupant contact with the interior of the vehicle. Therefore, this hardware deformation is desirable primarily in more severe crash events.

In addition to reducing occupant injury risk, these energy-absorbing features would also be expected to lower the peak loads delivered to the LATCH hardware (lower anchor bars and tether anchor brackets) in the vehicle, reducing the likelihood of vehicle hardware failure. Although these features can use a variety of mechanisms, some CRS models currently equipped with energy management features have deformable metal elements in the lower connector system or loops of webbing stitched into the tether that are intended to tear if a certain webbing load is exceeded. This project used dynamic sled testing of two commercial CRS products with load limiting features, along with one baseline product with no advertised load limiting features to explore performance.

Objectives

A small pilot test series was conducted to determine the effects of load limiting features on ATD excursions, ATD accelerations and loads delivered to LATCH vehicle hardware.

Methods

The CRSs selected for the test series include the Diono R100 Radian with SuperLATCH, the Britax Boulevard with RipStitch tether, and the Evenflo SureRide, all shown in Figure 1. The Diono R100 Radian SuperLATCH is a type of lower attachment hardware designed to reduce the loads delivered to the vehicle lower connectors. The Britax Boulevard includes a tether with a portion of webbing with pull-out stitching that can tear at high loads, absorbing energy while increasing the length of the tether strap. It also has energy-absorbing features in the CRS base. The Evenflo Sure Ride has no advertised energy absorption features and was used as a baseline comparison for the other two models. All the CRSs were rated for use forward facing with children who weigh 22 to 65 lb.

a b c

Figure 1. CRS used for testing: (a) R100, (b) Boulevard, and (c) Sure Ride

The dynamic tests were performed using a preliminary test bench design shown in Figure 2 that is a potential replacement for the FMVSS No. 213 frontal impact bench. It consists of the vehicle seat portion of the buck assembly published in the Federal Docket (Federal Docket No. NHTSA-2013-0055-0002, [March 17, 2015]), except that the seat back has been extended upwards by 50 mm to create a longer/taller seat back support surface. This bench was mounted facing forward on the impact sled at the University of Michigan Transportation Research Institute.

Figure 2. The frontal bench used for the test series

The CRS were secured using all or a portion of the LATCH system. For the tests of the SuperLATCH, it was desired to maximize the loads delivered to the lower connectors, so these runs and the baseline comparison test were conducted without the use of the tether. For the tests focusing on the RipStitch tether, the tests and the baseline comparisons were conducted using the full LATCH system.

The weighted Hybrid III 6-year-old ATD (49 CFR Subpart S - Hybrid III Six-Year-Old Weighted Child Test Dummy, July 16, 2004) was used for all tests to represent a large child occupant. The ATD was instrumented with head and chest accelerometers. The lower LATCH anchors were instrumented to measure three axis loads exerted on the anchor bars. In addition, belt load cells were used on the webbing securing the CRS when possible. Although the weighted 6-year-old is not used in FMVSS 213 to measure occupant excursions or acceleration-based data, both were collected during these tests. While HIC and chest clip cannot be compared to the IARV levels and risk of occupant injury, these measures can still be used between tests in a comparative way to show trends in the ATD data that are related to the LATCH energy management feature performance.

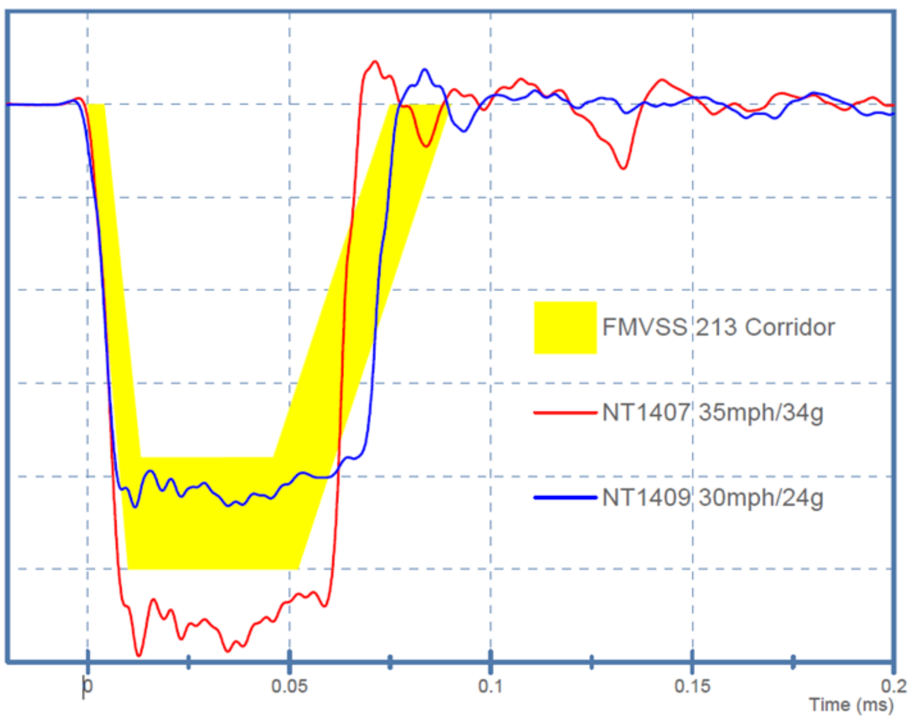

Figure 3. Examples that provide comparison of the two test pulses

The current FMVSS 213 test protocol was used to install the CRS on the bench and the ATD in the seat. The LATCH belts were tightened per the FMVSS 213 tensioning protocol. The original intent was to use a more severe vehicle pulse (i.e., similar to the 2001 Toyota Echo NCAP pulse) than that used for normal FMVSS 213 testing. This more severe crash was expected to be closer to the crash scenario where the benefits of the energy management systems would be most pronounced. However, in the initial series, the Britax Boulevard exhibited structural failure in two trials under the higher load, so the remaining two tests were run with pulses nearer to the FMVSS 213 corridor. Figure 3 shows examples of the two crash pulses used.

Table 1 summarizes the matrix of test conditions. To evaluate the effects of the SuperLATCH feature, four tests were conducted with the R100: two using the R100 product as purchased and two where the SuperLATCH was replaced by a webbing -based LATCH belt. The same approach was used with the RipStitch tether, with two tests run on Boulevard products as purchased and two run with the RipStitch feature unstitched and removed. This comparison was not carried out as planned due to structural issues seen with the high crash pulse, so the usable data consist of two runs, one with RipStitch and one without at a pulse close to the FMVSS 213 pulse. The SureRide was tested twice at the higher pulse, to provide comparison data from another product that did not include RipStitch or SuperLATCH. The SureRide was run secured by only lower anchors once and again with full LATCH.

Table 1. Summary of energy management test conditions

TestID	Test Pulse (Velocity [mph] /Peak g)	CRS Type	Install Type	Energy Management Feature
NT1401	34.7 / 33.8	Diono Radian R100	LA	SuperLATCH belt used
NT1402	34.4 / 33.7	Diono Radian R100	LA	None – Standard LATCH belt used
NT1403	34.7 / 34.0	Diono Radian R100	LA	SuperLATCH belt used
NT1404	34.9 / 33.9	Diono Radian R100	LA	None – Standard LATCH belt used
NT1405	34.7 / 33.7	Evenflo SureRide	LATCH	None
NT1406	34.7 / 31.4	Evenflo SureRide	LA	None
NT1407	35.0 / 33.6	Britax Boulevard	LATCH	Versa-tether
NT1408	35.2 / 33.4	Britax Boulevard	LATCH	None – Versa-tether stitching removed
NT1409	30.3 / 24.8	Britax Boulevard	LATCH	Versa-tether
NT1410	30.4 / 24.8	Britax Boulevard	LATCH	None – Versa-tether stitching removed

Results

Table 2 summarizes the primary response variables collected during the test.

Table 2. Summary of energy management test results

TestID	HIC (36 ms)	Chest 3ms Clip (g)	Head Excur (mm)	Knee Excur (mm)	Left Lower LATCH Belt Force (N)	Right Lower LATCH Belt Force (N)	Top Tether Belt Force (N)	Structural Issues
NT1401	1178	61	839	837	9649	9748	n/a	CRS cracked near belt path on right side.
NT1402	1428	61	858	849	10129	10071	n/a	CRS cracked near belt path on both sides.
NT1403	1278	59	863	855	10077	10021	n/a	CRS cracked near belt path on both sides.
NT1404	1515	61	837	844	9747	9803	n/a	CRS cracked near belt path on both sides.
NT1405	678	53	719	889	6045	6001	5506	
NT1406	773	55	884	917	8320	8509	n/a	Recline foot pushed into CRS shell on right.
NT1407	294*	59*	865*	870*	7541*	7605*	1844**	Back support of CRS fractured and the portion anchoring the shoulder harness moved forward during the test.
NT1408	464*	50*	750*	806*	4795*	5124*	3440**	Back support of CRS fractured and the portion anchoring the shoulder harness moved forward during the test.
NT1409	579	46	654	807	4802	4869	2040**	
NT1410	551	40	628	783	3461	3724	3050**	

** Catastrophic structural CRS failure makes reported values not applicable.*

*** Load reported is on one strap of a V-tether configuration and represent roughly half of the load on both sides of the tether webbing.*

Performance of SuperLATCH

Sled runs NT1401-04 compare the peak LATCH loads recorded, two tests with SuperLATCH and two tests with conventional LATCH. After the test, the R100 had minor cracks in the plastic covering the connector hardware. These cracks did not show any evidence of compromising the structure or function of the CRS. An example of the damage is shown in Figure 4.

Figure 4. Minor damage observed on R100 CRS

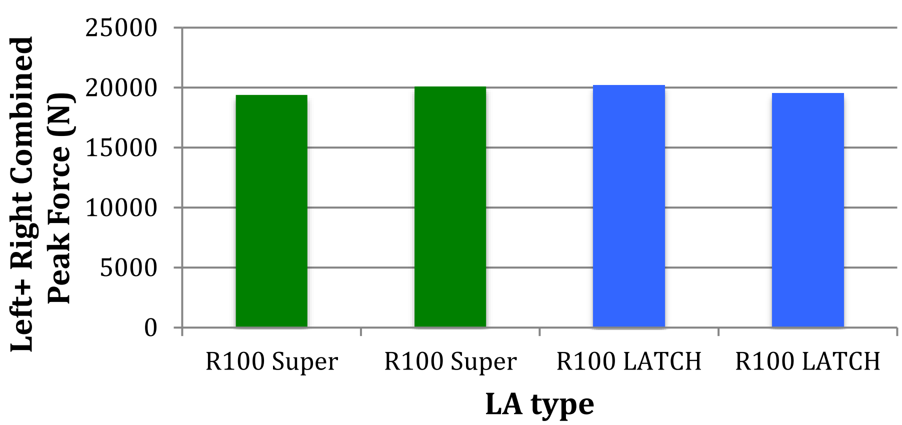

Figure 5. Comparison of peak lower anchor loads produced by the R100 with and without SuperLATCH

Figure 5 compares the peak combined left and right-side LATCH loads for the four runs, with and without SuperLATCH. The data shows no consistent reduction in force for the runs with SuperLATCH in this loading scenario. Figure 6 shows the load time histories for the same four runs. All four runs have a similar shape load curve, suggesting there was no plastic deformation of the lower anchors. The Evenflo baseline runs are not included in this comparison because the combined mass of occupant and CRS is quite different between the two conditions due to the high mass of the R100 (~13 kg), and this mass is directly proportional to the peak loads, so no meaningful comparison can be made.

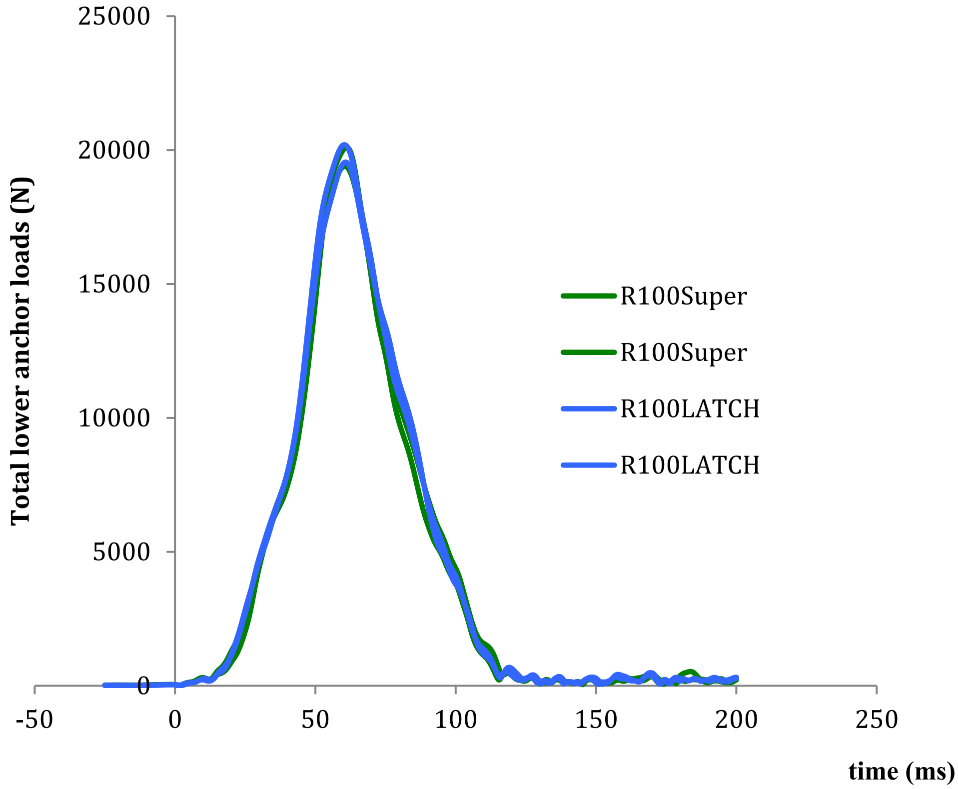

Figure 6. Load time histories for the SuperLATCH and regular LATCH lower anchors

Figure 7 compares the HIC and ATD forward excursions for the high severity pulse runs of the R100 w/ SuperLATCH, the R100 w/Conventional LATCH, and the Evenflo SureRide. The plot shows that HIC was higher for the ATDs in the runs without SuperLATCH. The ATD head and knee excursion measures were very similar across the R100 runs. The Evenflo run produced much lower HIC values and slightly higher excursions. Figure 8 compares chest 3ms clip values and shows all R100 tests produce similar responses while the SureRide produces a lower level of sustained chest acceleration. Due to the severity of the sled pulse and the weighted ATD, comparisons with the FMVSS 213 IARVs are not meaningful.

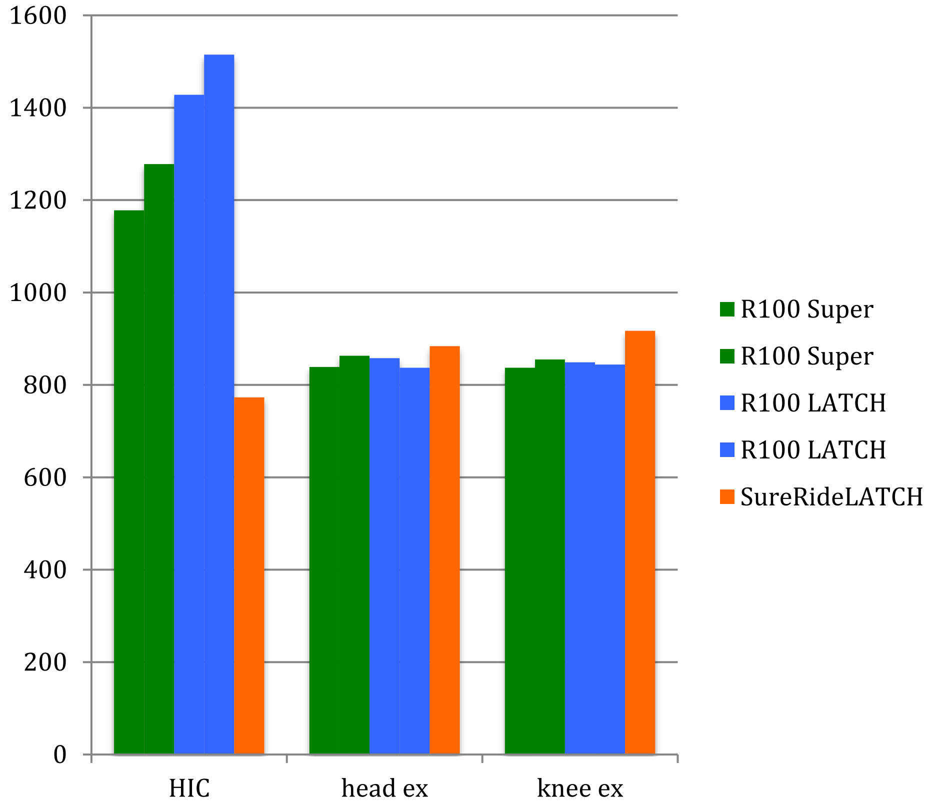

Figure 7. Comparison of HIC and ATD excursions

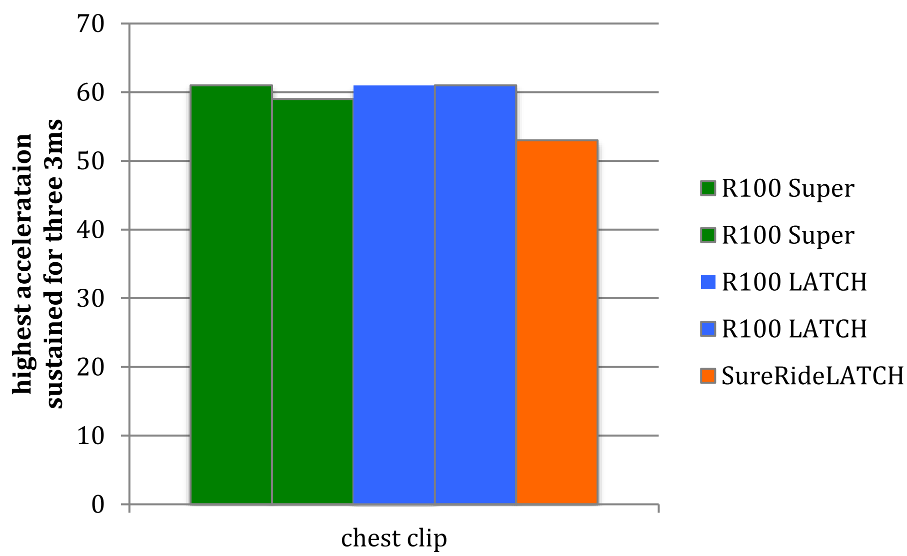

Figure 8. ATD chest acceleration clip (3ms)

Performance of RipStitch Tether

Figure 9. Failure of CRS back shell panel with RipStitch tether (top) and with RipStitch feature removed (bottom)

The Britax Boulevard experienced a failure of the CRS shell structure in the two initial tests conducted with the more severe crash pulse. In both tests, the center back portion of the CRS broke free of the CRS shell, as shown in Figure 9, regardless of the presence or absence of the RipStitch tether feature.

Because the Boulevard shell failures changed the tether loading, the two high severity tests were not valid sources of data to compare the performance and effects of the tether features. These two tests were rerun with new CRS using a test pulse closer to the FMVSS 213 pulse. Figure 10 shows a post-test photo of the stitching in the RipStitch tether, showing that it was damaged during testing as it absorbed energy.

Figure 10. Illustration of post-test torn stitching of RipStitch tether in test NT1409

Figure 11 shows the force measured on the tether and at the lower connectors for the two successful Boulevard tests. The data show that the RipStitch tether delivers higher loads to the lower anchors and lower loads to the tether. Figure 12 shows the ATD acceleration-based and excursion responses. The test with the RipStitch tether shows slightly higher HIC, higher chest clip, higher head excursions and higher knee excursions than the test with the energy absorbing stitching removed. All response values measured were below the FMVSS 213 limits.

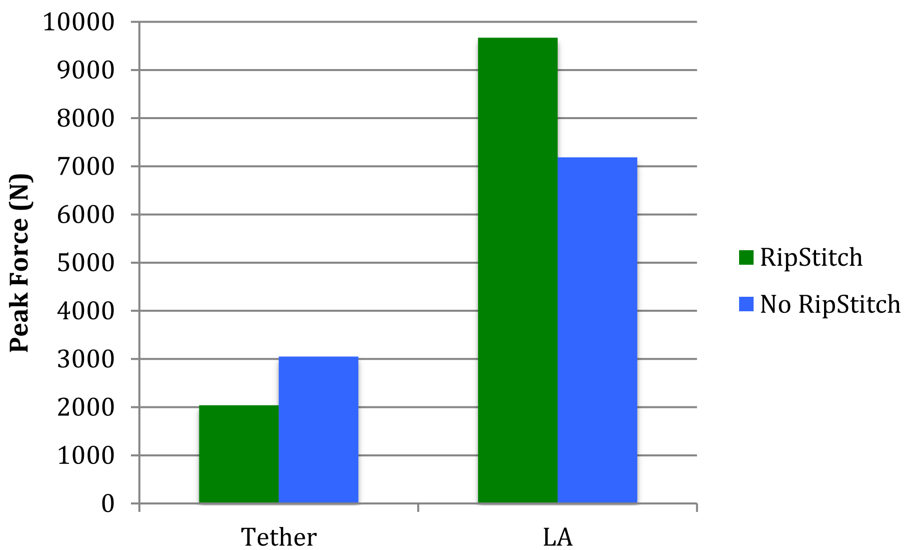

Figure 11. Tether and LA loads for Boulevard

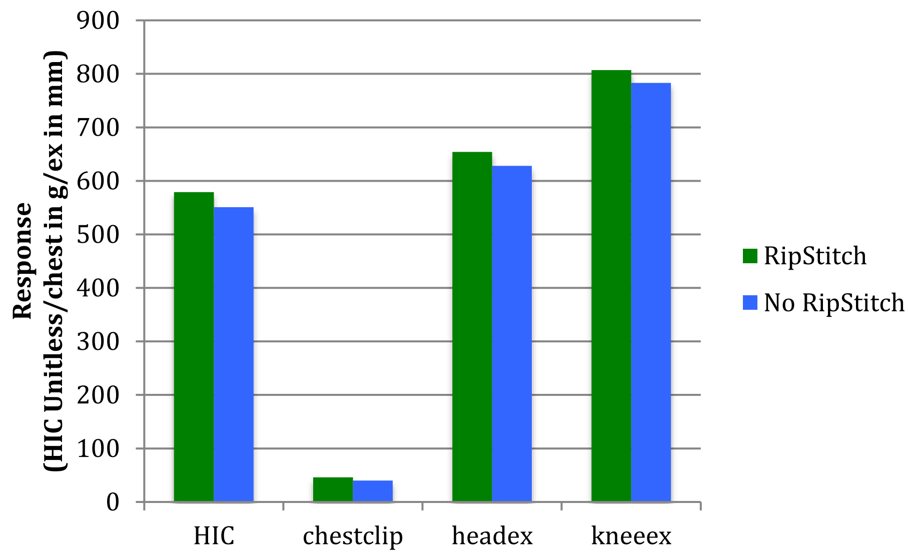

Figure 12. ATD responses and excursions for Boulevard

Discussion and Conclusions

The study described is a small-scale investigation of the performance of energy absorbing LATCH features offered on commercial CRS products. Paired tests of CRS with and without the energy management features were used to determine the effects. Because these features are traditionally thought to be most appropriate to severe crash protection, the project employed sled tests with a more severe crash pulse than normally used in FMVSS 213, along with some tests conducted near the FMVSS 213 pulse.

The data show that in this test series, SuperLATCH did not reduce the loads delivered to the lower anchors in the vehicle during impact and the lower anchor loads were very similar and repeatable for the four runs with and without SuperLATCH. SuperLATCH was associated with a more than 200-point reduction in HIC value, but no difference was seen for chest accelerations, or head/knee excursion levels.

It was hypothesized that the SuperLATCH connectors would reduce the peak load delivered to the lower connectors in the vehicle. The CRS manufacturer had previously stated that use of SuperLATCH would allow caregivers to secure CRS with LATCH beyond the vehicle manufacturer has stated mass limits for lower anchors. No evidence was found to support the claim.

The Britax Boulevards tested did not remain intact when tested with the more severe crash pulse. When tested at a severity near the FMVSS 213 specified crash, the RipStitch tether altered the distribution of load between the tether and lower anchors. The tether saw lower loads and the lower anchor forces increased. The ATD head accelerations, chest accelerations, as well as head and knee excursions all increased slightly for the test that included the RipStitch tether. FMVSS 213 does not establish relevant IARVs for this test configuration with the weighted 6YO. Given the small magnitude of the differences in the ATD responses, more comparative tests would be needed to determine if these trends constitute a true difference in performance.

This preliminary study of the effect of currently available LATCH energy management features would suggest that their benefits are limited and that there is more room for improvement to reduce injury risk for children riding in CRS through improved CRS designs. The results also show that current FMVSS 213 test procedures would be sufficient for evaluating dynamic performance of energy management features.

References

CFR 49, Transportation, Section 571.213 Child restraint systems., 2011.

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