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Evaluation of Motorcycle Helmet Test Procedures

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16. Abstract

FMVSS No. 218, *Motorcycle helmets*, specifies minimum performance requirements for helmets designed for use by motorcyclists and other motor vehicle users. FMVSS No. 218 includes three performance test types that have remained largely unchanged since it was first published in 1973: an impact attenuation test, a penetration test, and a retention system test. In 2013 NHTSA initiated a helmet testing research program with compliance test labs. Based upon this testing, adjustments were made to the test procedures and were evaluated in this study. In continuation of NHTSA's motorcycle helmet research, the testing described in this report aimed to achieve the following: (1) assess the feasibility of conducting modified FMVSS No. 218 tests and other performance tests, and refining test procedures as necessary; and (2) evaluate the repeatability of each of the modified test procedures assessed.

Six helmet models were tested in six test types. Two test types were based on tests included in FMVSS No. 218, while four test types were based on tests included in international standards. Four models were used for the impact attenuation, retention system, and chin bar tests. Five helmets of each helmet model were used for these test types. The other two helmet models were used for the positional stability, face shield, and rigid projection tests. Fifteen helmets of each helmet model were used for these test types.

Overall, the results from the six helmet models tested showed that conducting these tests was feasible and the results for all test procedures were generally repeatable. Although the results for a small number of individual helmet models showed elevated variation, that variation was not substantial enough to prevent the tests from differentiating the performance of the tested helmets.

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Executive Summary

Federal Motor Vehicle Safety Standard (FMVSS) No. 218, *Motorcycle helmets*, specifies minimum performance requirements for helmets designed for use by motorcyclists and other motor vehicle users. FMVSS No. 218 has three performance test types that have remained largely unchanged since it was first published in 1973: an impact attenuation test, a penetration test, and a retention system test. The impact attenuation test consists of placing the helmet on a headform and dropping it on both a flat anvil and a hemispherical anvil under any of four environmental conditions. The performance criteria of this test type include a peak acceleration of the headform as well as accelerations that cannot exceed cumulative duration limits. The penetration test consists of dropping a striker on the outer surface of the helmet from a specified height. To meet the specifications of this test type, the striker cannot make direct contact with the surface of the headform. The retention system test consists of applying a preliminary load on the retention assembly of the helmet, then adding an additional quasi-static load to the assembly. To meet the performance criteria of this test type, the retention system and its components must withstand the load without separation, and the adjustable portion of the retention system cannot move more than a specified distance as measured between the preliminary and final loading positions.

In 2013 the National Highway Traffic Safety Administration initiated a helmet testing research program with compliance test labs. The results were presented at the 2019 Society of Automotive Engineers (SAE) Government Industry Meeting (Nguyen & Kuppa, 2019). Based upon this testing, adjustments were made to the test procedures and were evaluated in this study.

In continuation of NHTSA's motorcycle helmet research, the testing described in this report aimed to achieve the following:

1) Evaluate and assess the feasibility of conducting modified FMVSS No. 218 tests and other performance tests, and refine test procedures as necessary. The tests conducted include these.
    - Impact attenuation and retention system tests from FMVSS No. 218 using the ASTM F2220 headforms instead of the DOT headforms
    - Chin bar impact attenuation tests using a test procedure based on British Standard Institution (BSI) 6658 (British Standard Institution, 1985)
    - Positional stability tests using a test procedure based on ASTM F1446-11a (ASTM International, 2011)
    - Face shield penetration tests using a test procedure based on the Economic Commission for Europe (ECE) R.22 (United Nations Economic Commission for Europe, 2021)
    - External rigid projection tests using a test procedure based on ECE R.22
2) Evaluate the repeatability of each of the modified test procedures assessed.

Six helmet models were tested during this series: HJC F70,[1] Bilt Vertex,[2] Scorpion EXO Covert X,[3] Shoei Neotec II,[4] Schuberth M1 Pro,[5] and Shark Street Drak.[6] The first four models were used for the impact attenuation, retention system, and chin bar tests. Five helmets of each helmet model were used for these test types. The other two helmet models were used for the positional stability, face shield and rigid projection tests. Fifteen helmets of each helmet model were used for these test types.

Repeatability for the impact attenuation, retention system, and chin bar tests was evaluated using the percentage coefficient of variation (%CV) and a one-way analysis of variance (ANOVA). Repeatability for the positional stability, face shield, and rigid projection tests was evaluated by comparing the number of tests that met the performance requirements specified in the reference standard among each helmet model.

Repeatability results for each test type:

- Repeatability for the impact attenuation tests was reasonable, with %CV less than 8.5% for every helmet.
- Retention system test repeatability was also reasonable for most helmets. Retention systems remained intact during all retention system tests with the HJC F70, Bilt Vertex, and Shoei Neotec II helmets, while the straps separated during four out of the five tests with the Scorpion EXO Covert X helmets. For the retention system movement performance criterion, the %CV in retention system tests was elevated for the Shoei Neotec II, but ANOVA analysis suggested that the variability in that helmet's performance was not substantial enough to obscure the performance differences between the helmet models.
- In chin bar tests, the %CV for the Scorpion EXO Covert X helmets was elevated; however, ANOVA analysis suggested that the variability in that helmet's performance was not substantial enough to obscure the performance differences between the helmet models.
- In positional stability tests, all tests except one Shark Street Drak helmet remained on the headform, indicating reasonable repeatability.
- For the face shield tests, none of the helmets produced small fragments, indicating reasonable repeatability.
- In rigid projection tests, results for all helmets were repeatable by allowing the shear bar to pass under the helmet uninterrupted.

Overall, this test series showed that all test types could be successfully conducted with the stated modifications, and the test procedures produced results with reasonable repeatability. For tests where individual helmet models showed elevated variation, this variation was not substantial enough to prevent the tests from differentiating the performance of the tested helmets.

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[1] HJC America, Inc., La Habra, CA.
[2] Comoto Holdings, Inc., Philadelphia, PA.
[3] Kido Sports Co., Ltd., Seoul, South Korea.
[4] Shoei Co., Ltd, Tokyo, Japan.
[5] Schuberth GmbH, Magdeburg, Germany.
[6] Shark, Marseille, France.

Introduction

Background on FMVSS No. 218

FMVSS No. 218, *Motorcycle helmets*, specifies minimum performance requirements for helmets designed for use by motorcyclists and other motor vehicle users. When FMVSS No. 218 was first published in 1973 (38 Fed. Reg., 22391, 1973), it was largely based on American National Standards Institute (ANSI) Z90.1-1971 test types and specifications (ANSI, 1971). It was primarily focused on establishing protection related to impact attenuation, penetration resistance, and retention system strength. These test types and specifications have remained essentially unchanged.

FMVSS No. 218 includes three performance evaluation test types: an impact attenuation test, a penetration test, and a retention system test. The impact attenuation test consists of placing the helmet on the appropriately sized headform and dropping it twice at the same impact location at either 6 m/s on a flat anvil or at 5.6 m/s on a hemispherical anvil under any of the four environmental conditions: ambient, high temperature, low temperature, or water immersion. This is repeated at four impact locations. To meet the specifications of this test type, the peak acceleration of the headform cannot exceed 400 g, accelerations over 200 g cannot exceed a cumulative duration of 2 ms, and accelerations over 150 g cannot exceed a cumulative duration of 4 ms. The cumulative duration requirements are also called dwell time requirements.

The penetration test consists of dropping a 3 kg striker on the outer surface of the helmet (fitted onto the appropriately sized headform) from a height of 3 m. To meet the specifications of this test type, the striker cannot make direct contact with the surface of the headform.

The retention system test consists of applying a 22.7 kgf[7] preliminary load on the retention assembly of the helmet, then increasing to a load of 136 kgf on the assembly. To meet the performance criteria of this test type, the retention system and its components must withstand the load without separation, and the adjustable portion of the retention system cannot move more than 25 mm as measured between the pre-load and final loading positions.

Motorcycle helmets that are currently available on the market can be categorized into four types shown in Figure 1. Half helmets only cover the top of the head. Full helmets cover the back and sides of the head as well as the top but maintain no coverage of the chin. Some full helmets are equipped with face shields. Complete helmets cover the entirety of the head and chin with a solid surface and include a face shield. Modular helmets are similar to complete helmets, with the exception that the chin bar and face shield are adjustable/removable.

[7] Kilogram-force (kgf) is a non-standard unit. 1 kgf = 9.80665 N.

Figure 1. Types of Motorcycle Helmets

In 2013 NHTSA initiated a helmet testing research program with compliance test labs. The results were presented at the 2019 SAE Government Industry Meeting (Nguyen & Kuppa, 2019; NHTSA, n.d.).[8] [9] Based upon this testing, adjustments were made to the test procedures and were evaluated in this study.

Modifications to Reference Test Methods

One of the goals of this test series was to evaluate replacing the specified DOT headforms with the ASTM F2220 headforms in FMVSS No. 218 impact attenuation and retention system tests. The ASTM headforms are also known as International Organization for Standardization (ISO, 1983) headforms due to their original specifications outlined in ISO 6220.[10] The ASTM headforms come in six different sizes and the shape is representative of the human head. The increase in available sizes allows for improved helmet fit during testing. The ASTM headforms are available in urethane and magnesium construction, along with full and half headform designs. These variations of ASTM headforms, as well as the standard DOT headforms, can be seen in Figure 2.

[9] Test data is located on the NHTSA Research Component Database, test numbers 3001 to 3050. www.nhtsa.gov/research-data/research-testing-databases#/component

[10] A footnote in 16 C.F.R. Chapter II Subchapter B Part 1203 Subpart A (www.ecfr.gov/current/title-16/chapter-II/subchapter-B/part-1203/subpart-A) reads,
"Although the draft ISO/DIS 6220-1983 standard was never adopted as an international standard, it has become a consensus national standard because all recent major voluntary standards used in the United States for testing bicycle helmets establish their headform dimensions by referring to the draft ISO standard."

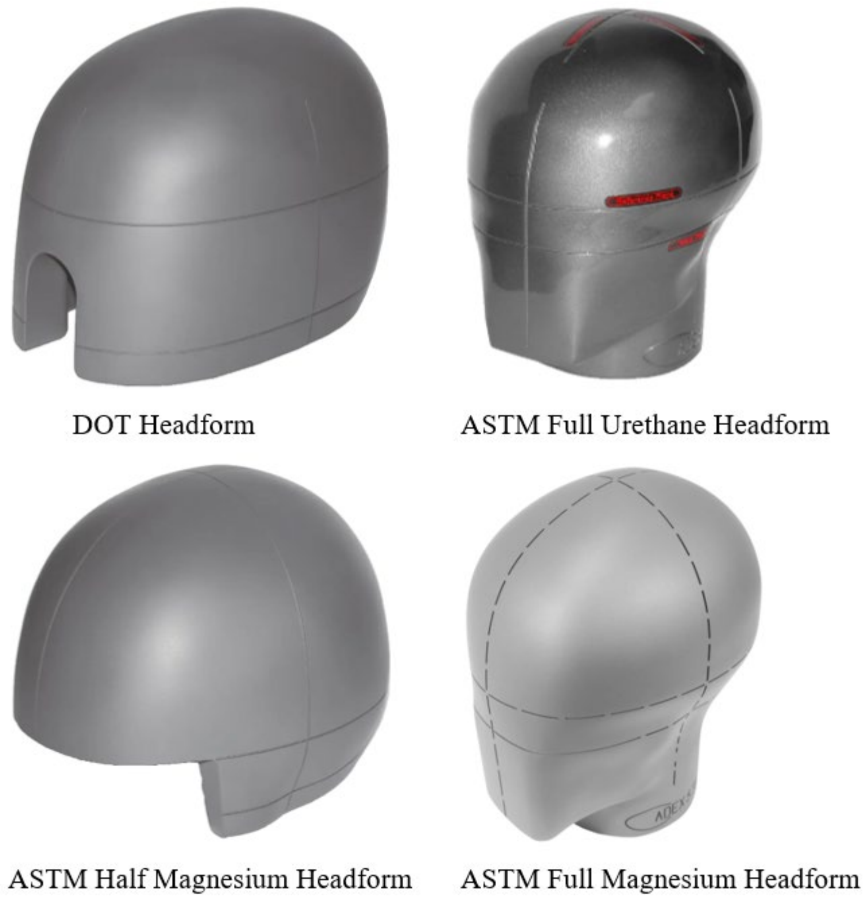

Figure 2. DOT Versus ASTM Headforms

This test series also aimed to evaluate performance test types adopted in various international helmet standards. Modifications to these additional test types were based on findings from NHTSA's previous motorcycle helmet research. The first additional performance test type is a chin bar impact attenuation test based on BSI 6658 British Standard Institution (1986). Complete and modular helmets have chin bars that could protect the chin from impact, but currently FMVSS No. 218 does not have a test type to ensure a minimum level of energy absorption capability to reduce injury.

The next additional test type is a positional stability test based on ASTM F1446-11a. Unlike the current quasi-static retention system test type included in FMVSS No. 218, this test type evaluates the ability of the helmet to be retained on the headform during a dynamic event. International standards include similar positional stability test types. The next additional test type is a face shield penetration test that is based on ECE R.22. This test type evaluates the resistance of the face shield to penetration by small objects. Currently, FMVSS No. 218 does not contain any test type to evaluate the ability of face shields to withstand penetration. The final additional test type is an external rigid projection test based on ECE R.22. This test type evaluates the effect of the rotational force induced when a rigid projection on the outer surface of the helmet slides across a surface. Currently, FMVSS No. 218 requires that rigid external projections be limited to those required for operation of essential accessories and to be no greater than 5 mm; however, there is no test procedure to evaluate this requirement. This additional test type could replace the current requirements with a more enforceable approach of addressing this safety need.

A summary of the modifications to the reference test methods can be found in Table 1.

Table 1. Test Procedure Modifications

	Reference Standard	Modified Test Procedure

Impact Attenuation based on FMVSS No. 218	• DOT headforms
	  ○ Drop weights:
	    Small = 3.5 ± 0.1 kg
	    Medium = 5.0 ± 0.1 kg
	    Large = 6.1 ± 0.1 kg
		• ASTM headforms (half magnesium)
		  ○ Drop weights:
		    A = 3.1 ± 0.10 kg
		    C = 3.6 ± 0.10 kg
		    E = 4.1 ± 0.12 kg
		    J = 4.7 ± 0.14 kg
		    M = 5.6 ± 0.16 kg
		    O = 6.1 ± 0.18 kg

Retention System based on FMVSS No. 218	• DOT headforms	• ASTM headforms (half magnesium)
Chin Bar based on BSI 6658	• Striker mass: 5 + 0.2/- 0 kg • Drop striker from a height of 2.5 m ± 5 mm	• Striker mass: 5 ± 0.05 kg • Drop striker from a height necessary to achieve an impact speed of 7 ± 0.2 m/s
Positional Stability based on ASTM F1446-11a	• Helmet tested in both the face-up and face-down positions • Does not specify drop mass or height	• Helmet only tested in the face-down position • Drop mass: 10 ± 0.05 kg • Drop height: 600 ± 15 mm
Face Shield based on ECE R.22	• Drop mass: 3 ± 0.025 kg • Drop striker from a height of 1 + 0.005/- 0 m	• Drop mass: 3 ± 0.05 kg • Drop striker from a height necessary to achieve an impact speed of 4.4 ± 0.2 m/s
Rigid Projection based on ECE R.22	• Total mass of carriage: 5 + 0/- 0.2 kg • Drop mass: 15 + 0.5/- 0 kg • Drop height: 500 + 5/- 0 mm • Initial load on carriage: 400 + 10/- 0 N	• Total mass of carriage: 5 ± 0.05 kg • Drop mass: 15 ± 0.05 kg • Drop height: 500 ± 15 mm • Initial load on carriage: 400 ± 10 N

Objectives

The test series described in this report aimed to achieve the following.

1) Assess the feasibility of conducting modified FMVSS No. 218 tests and other performance tests, and refining test procedures as necessary
2) Evaluate the repeatability of each of the modified test procedures assessed

Methods

Test Matrix

Three types of helmets were tested for this series: complete, modular, and full helmets. Impact attenuation, retention system, and chin bar tests were conducted on complete and modular helmets. Full helmets underwent the positional stability, face shield, and rigid projection tests. Two helmet models for each helmet type were selected based on brand prevalence, passing results in FMVSS No. 218 compliance testing (NHTSA, n.d.),[11] and availability for purchase. The test matrix was a small sample size; as such, the models tested were not selected to reflect a large range of results nor the entire motorcycle helmet market. Five helmets of each complete and modular helmet model were tested, with each helmet being subjected to all three test types in the order listed in Table 2. Fifteen helmets of each full helmet model were tested, with each helmet being subjected to all three test types in the order listed in Table 2. The order of test types was critical to ensure that any damage sustained from one test type would not affect the results of the remaining test types. The difference in the number of helmets tested was because the impact attenuation, retention system, and chin bar tests collect numerical data while the positional stability, face shield, and rigid projection tests rely on observations of test outcomes. For the observation-based tests, since numerical statistics could not be used, additional tests were required to sufficiently determine repeatability by simply comparing how the helmets performed. Helmets ranged in size from medium to extra-large. The full test matrix is in Table 2.

Table 2. Test Matrix

Brand	Model	Type	Size	# of Helmets Tested	Impact Attenuation	Retention System	Chin Bar	Positional Stability	Face Shield	Rigid Projection
HJC	F70	Complete	M	5	x	x	x			
Bilt	Vertex	Complete	L	5	x	x	x			
Scorpion	EXO Covert X	Modular	M	5	x	x	x			
Shoei	Neotec II	Modular	XL	5	x	x	x			
Schuberth	M1 Pro	Full	XL	15				x	x	x
Shark	Street Drak	Full	XL	15				x	x	x

Prior to testing, all tags and cosmetic accessories were removed, and each helmet was weighed, as shown in Table 3. Discrete size (the measurement used to select the appropriately sized headform for testing) was then determined, and test lines were drawn for all helmets. Testing was then conducted so that all tests of each test type were performed consecutively. For example, impact attenuation tests were performed on all helmet models undergoing that test type, followed by retention system tests on all helmets undergoing that test type, and so on. All testing was conducted under ambient conditions with no additional pre-conditioning.

[11] After this research was completed, the Scorpion EXO Covert X was recalled in June 2024 for non-compliant retention systems. www.nhtsa.gov/equipment-detail/SCORPION%252520EXO/COVERT%252520X%252520HELMET/a__5649081#recalls. The Bilt Vertex was recalled in January 2023 for non-compliant retention system integrity and adequate penetration protection. www.nhtsa.gov/equipment-detail/BILT%252520HELMET/BILT%252520VERTEX/a__5553976#recalls

Table 3. Helmet Weights

	Helmet Weight (kg)
HJC F70	1.6
Bilt Vertex	1.4
Scorpion EXO Covert X	1.4
Shoei Neotec II	1.6
Schuberth M1 Pro	1.4
Shark Street Drak	1.2

Discrete Size Measurements and Test Setups

NHTSA's Vehicle Research and Test Center (VRTC) had previously developed a repeatable method for measuring the discrete size and helmet positioning index (HPI) for motorcycle helmets (Wietholter & Rains, 2023). The discrete size is a measurement of the internal circumference of a helmet and is used to select the appropriately sized headform for testing. Accurately selecting the headform size is critical since test results could be affected if the helmet fits too tightly or too loosely on the headform. The HPI is defined as the distance from the basic plane to the brow opening along the midsagittal plane. It is used to position the helmet on the headform for measurements and testing. The procedure that was developed previously was followed for this series and consisted of first selecting the correct ASTM reference headform using Table 4 based on the manufacturer reference label on the helmet (Snell Foundation, 2014). If the number on the label corresponded to two headform sizes, the procedure was repeated for both reference headforms. Any removable padding inside the helmet, such as ear pads, were removed prior to measuring the discrete size. These were placed back into the helmet during weighing and testing of the helmet.

Table 4. ASTM Headform Sizing

		Largest Size Specified (cm) and Largest US Hat Size					
		< 51 *< 6 3/8*	52 - 53 *6 4/8 – 6 5/8*	54 - 56 *6 6/8 - 7*	57 - 59 *7 1/8 – 7 3/8*	60 - 61 *7 4/8 – 7 6/8*	> 61 *> 7 6/8*
Smallest Size Specified (cm)	< 51	A	A - C	A - E	A - J	A – M	A - O
	52-53		C	C - E	C - J	C – M	C - O
	54-56			E	E - J	E – M	E - O
	57-59				J	J – M	J - O
	60-61					M	M - O
	> 61						O

The helmet was then placed on the reference headform, and a 4.5 kg (10 lb) static load was placed on the apex of the helmet. The helmet was adjusted so that it was centered laterally and seated firmly on the reference headform. The helmet was then adjusted so that the brow opening was horizontal to within one degree using an inclinometer. The distance between the basic plane and the brow opening was then measured and recorded as the "HPI (as measured)" for that helmet model. The location of the basic plane on the headform can be seen in Figure 7. The peripheral vison requirement from FMVSS No. 218 was then checked with a go/no-go gauge and brow block to physically confirm the requirements were met as seen in Figure 3, and the angle at the brow opening of the helmet was recorded.

Figure 3. Peripheral Vision Measurement

Then, the test reference line was drawn on the outside of the helmet using a line drawing jig as shown in Figure 4.

Figure 4. Test Reference Line Drawn on Helmet

To draw the internal test reference line, the helmet was positioned in a helmet holder such that the outer test reference line was horizontal and lined up with lasers. The helmet holder was removed from under the fixture and a marking jig was moved into place. The marking jig was lined up with the lasers and the depth stopper was set. The marking jig was then raised, and the helmet holder was moved back underneath the fixture. The marking jig was then lowered until the depth stopper was reached and the inside of the helmet was marked. The helmet was then removed from under the fixture. This setup is shown in Figure 5.

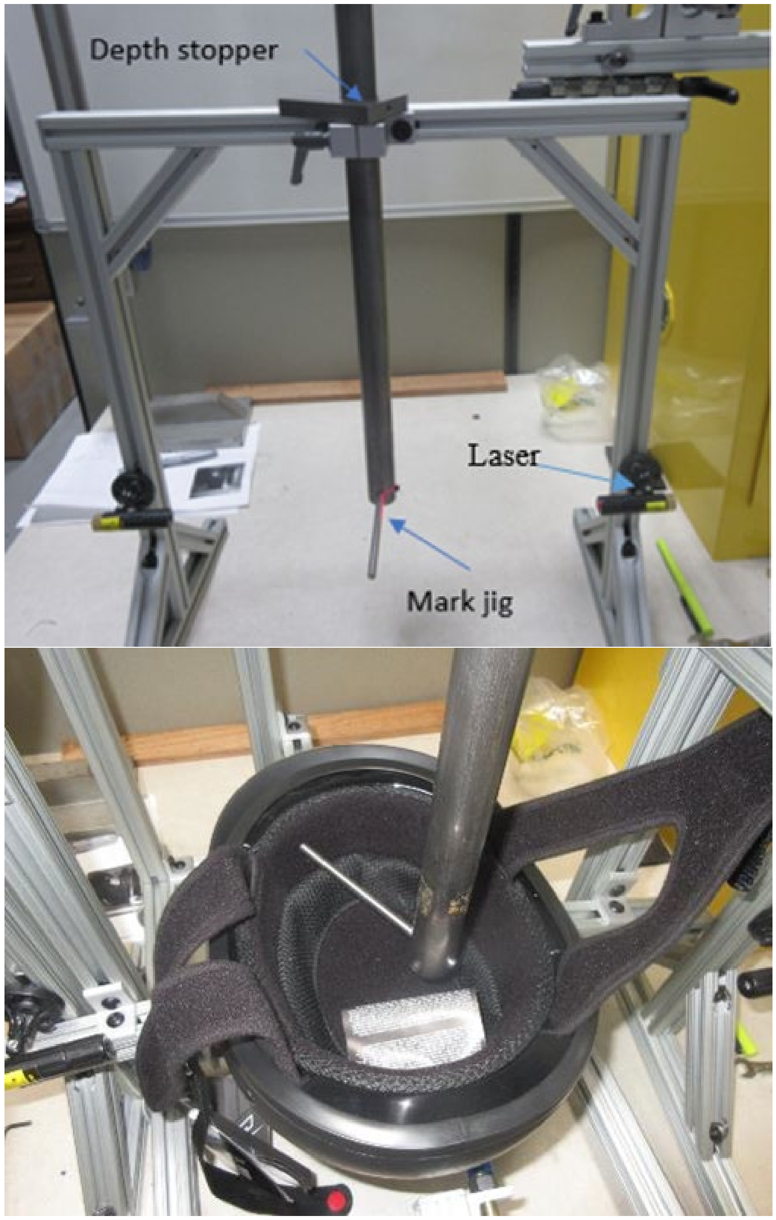

Figure 5. Marking Jig Setup

To measure the discrete size of the helmet, the center of the band on a handheld scissor tool was aligned with the internal test reference line. The handheld scissor tool was then squeezed to compress the comfort liner to maximum compression and the internal circumference of the helmet at the level of the reference line was recorded to the nearest centimeter (cm). This can be seen in Figure 6. This measurement was taken three times with a three-minute wait time between repeats. The maximum measured discrete size was determined to be the final discrete size for that helmet model. This discrete size was then used to determine the appropriately sized ASTM headform according to Table 4.

Figure 6. Measuring Discrete Size With Handheld Scissor Tool

If the headform determined from this procedure differed from the headform indicated on the helmet manufacturer label, the procedure was repeated with the different size headform. A new test reference line was drawn corresponding to the new headform to ensure the procedure resulted in a similar discrete size measurement. If the procedure was performed twice due to the helmet manufacturer label corresponding to two headform sizes, and this resulted in two headform options, the larger of the two headforms was used for testing.

The discrete size and HPI (as measured) were determined using one helmet of each model and were applicable to all other helmets of the same model. The test lines were drawn on all helmets after all discrete size measurements were completed. The reference plane was based on the DOT headform measurements but was translated and drawn onto the equivalent location on the ASTM headforms. The location of the test line and reference plane is shown in Figure 7 by the solid black line and dashed line (NHTSA, 2024).

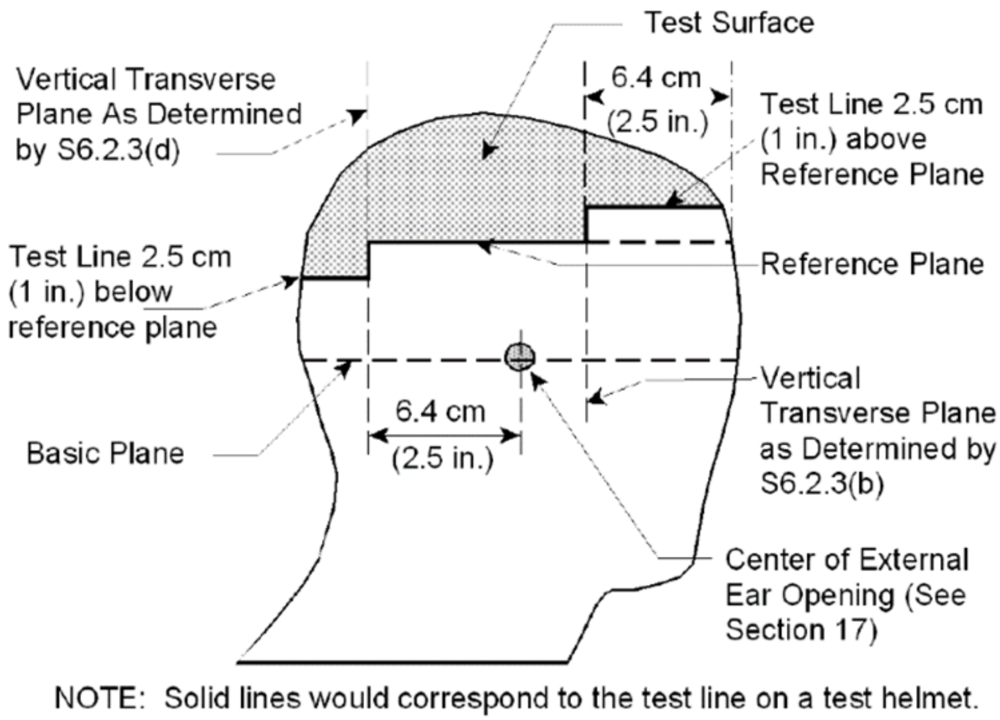

Figure 7. Location of Test Line

Discrete Size Measurements

The discrete size measurement method was able to determine the appropriately sized headform for each helmet model. Table 5 shows the discrete size and HPI (as measured) for each helmet. Although the discrete size measurement for the Shoei Neotec II indicated that the J or M headform could be used, the larger headform (M) was selected. This was done because a looser fitting helmet might shift more on the headform than a tighter fitting helmet and reduce the repeatability of the test. The discrete size (as measured) was consistently at the low end of the manufacturer discrete size range. This is consistent with the findings from previous discrete size evaluations (Wietholter & Rains, 2023).

Table 5. Discrete Size Measurement Results

	Manufacturer Discrete Size (cm)	Discrete Size (as measured) (cm)	ASTM Headform	HPI (as measured) (mm)
HJC F70	57-58	57	J	46
Bilt Vertex	59-60	59	J	28
Scorpion EXO Covert X	57-58	57	J	31
Shoei Neotec II	61-62	59-60	M	31
Schuberth M1 Pro	61	60	M	39
Shark Street Drak	61	61	M	43

Impact Attenuation

The impact attenuation tests were performed on a Cadex Monorail Impact Machine.[12] The tests were performed according to the procedures found in Appendix A. The procedure for this test was based on the protocol established in FMVSS No. 218 Section 7 (NHTSA, 2024), except that the ASTM half magnesium headforms were used rather than the DOT headforms.

Each helmet was tested eight times: with the flat and hemispherical anvil, two locations per anvil, and two impacts per location. FMVSS No. 218 specifies that any location on the helmet can be tested as long as the test is conducted in accordance with S7.1.2. For this series, the test locations were determined to be the right front, right rear, left front, and left rear of each helmet. All locations were at the midpoint between the midsagittal plane and coronal plane of the headform and located 65 mm above the test line. The right front and left rear locations were tested with the flat anvil and the right rear and left front locations were tested with the hemispherical anvil. The four test modes are shown in Figure 8.

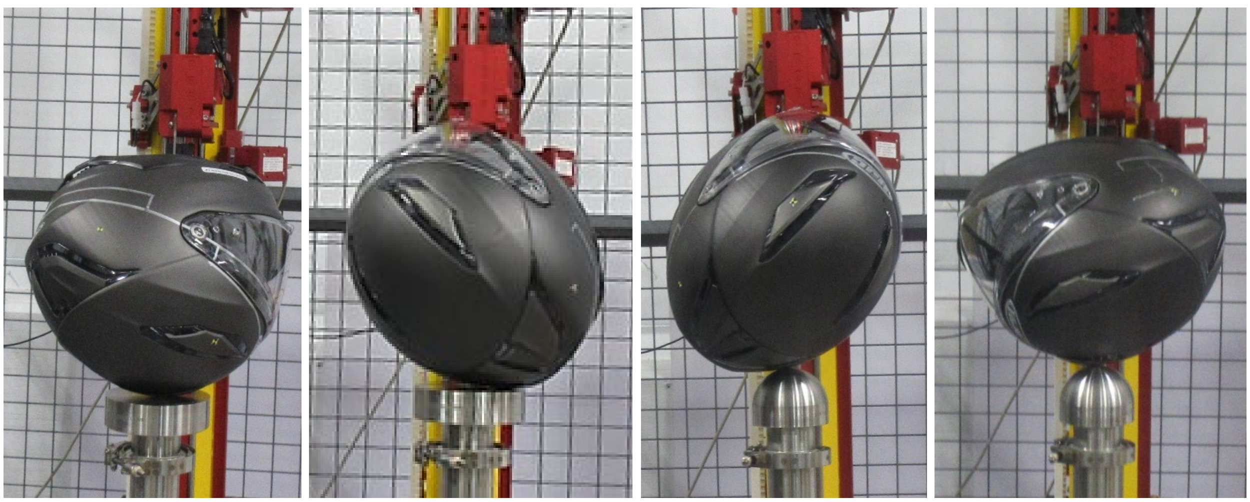

Figure 8. Impact Attenuation Test Modes

Prior to each test, the helmet was centered on the midsagittal plane of the headform and positioned according to the HPI (as measured). Since the ASTM half headforms do not contain a face region, the basic plane is not shown on the front of the headform. Due to this, in order to position the helmet according to the HPI (as measured), the distance between the basic plane and the front edge of the headform above the face region (brow edge) was first measured for each headform size. The helmet was then positioned based on the distance between the brow opening of the helmet and the brow edge of the headform. The headform markings are shown in Figure 9.

[12] Cadex Inc., Quebec, Canada. www.cadexinc.com/equipment/machines/impact-machines/uniaxial-monorail

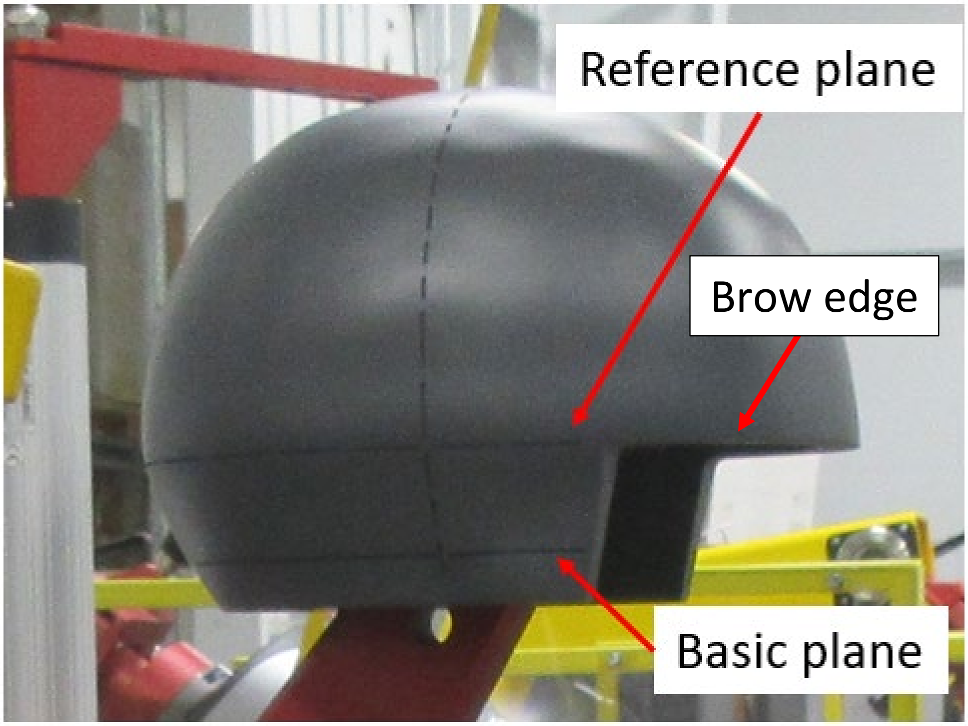

Figure 9. ASTM Half Headform Markings

While positioning, it was discovered that the lack of a chin structure on the ASTM half headforms meant that the chin strap of the helmets could not be secured enough to keep the helmet in place. This issue was mitigated by placing a piece of foam[13] under the chin strap to act as a chin surface during testing, as shown in Figure 10. Per the FMVSS No. 218 test procedure (NHTSA, 2024), the chin strap is tightened just enough to prevent the helmet from moving prior to impact. The foam was able to provide a surface for the chin strap that prevented the helmet from moving prior to impact for all four helmet models. The foam was stiff enough for the chin strap to be tightened and was reused for all impact attenuation tests that were conducted. However, it was soft enough to mold to the shape of all four helmet models without causing unrepresentative stress to the chin strap or the padding inside the helmet.

[13] Polyethylene closed cell foam 2.2 PCF – SHT. 180 mm x 55 mm x 55 mm or equivalent.

Figure 10. Foam Under Chin Strap

The headform and helmet were dropped from a height necessary to achieve the required impact speed of 5.8 m/s to 6.2 m/s for the flat anvil and 5 m/s to 5.4 m/s for the hemispherical anvil. The total drop assembly weights (entire assembly including the headform but not the helmet) required are shown in Table 6.

Table 6. Impact Attenuation Drop Weight

ASTM Headform	Drop Assembly Weight (Includes Weight of Half Headform) (kg)
A	3.1 ± 0.1
C	3.6 ± 0.1
E	4.1 ± 0.12
J	4.7 ± 0.14
M	5.6 ± 0.16
O	6.1 ± 0.18

High-speed video was recorded for the duration of the test (Phantom Miro R3215) at 1000 frames per second. An accelerometer (PCB 353B18)[14] was placed at the center of gravity (CG) of the headform and recorded the acceleration of the headform using the Cadex data acquisition system. An example of the overall test setup is shown in Figure 11.

[14] PCB Piezotronics, Inc., Depew, NY [division of PCB Piezotronics Europe GmbH, Hückelhoven, Germany].

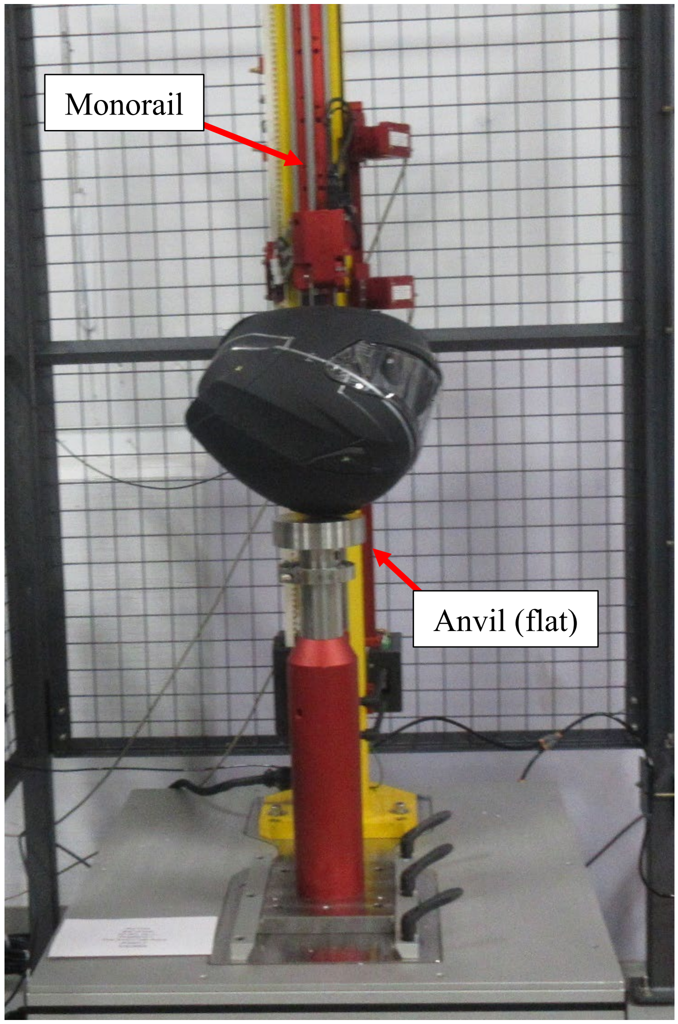

Figure 11. Impact Attenuation (Right front, flat anvil condition) – Overall Setup

During testing, it was discovered that the face shield or vent covers would frequently break off during a test. Often, resecuring the fractured piece would have required forcing it back into place or securing it with tape or glue. Since it was unclear what effect these actions could have on future tests, for this series, any piece of the helmet that detached during a test was left off the helmet for the remaining tests. An example of a detached face shield and vent cover are shown in Figure 12.

Figure 12. Detached Face Shield and Vent Cover

Retention System

The retention system tests were performed on a Cadex Static Tensile Load for Retention Machine test device[15] The tests were performed according to the procedures found in Appendix A. The procedure for this test was based on the protocol established in FMVSS No. 218 Section 7, except that the ASTM half magnesium headforms were used instead of the DOT headforms.

[15] Cadex Inc., Quebec, Canada. www.cadexinc.com/equipment/machines/retention-machines/stl-for-retention-machinen

Each helmet was secured on the headform and positioned according to the HPI (as measured), similarly to the impact attenuation tests. The retention system was fastened around the two rollers and the upper linear variable displacement transducer (LVDT) was placed on the apex of the helmet. The test fixture then applied a pre-load of 22.7 kgf to the retention system, as measured by a load cell located in the lower piston of the fixture and held for 30 seconds. The distance between the upper and lower LVDTs was recorded. The load was then increased to 136 kgf and held for 120 seconds. After the 120 seconds, the distance between the upper and lower LVDTs were recorded and the load was released. Real-time video was recorded for the duration of the test. Each helmet was only tested once, and an example of the overall test setup is shown in Figure 13.

Figure 13. Retention System – Overall Setup

Chin Bar

The chin bar tests were performed on the same Cadex Monorail Impact Machine as used in the impact attenuation tests with a BSI Chin Bar Kit[16] installed at the base of the monorail. The tests were performed according to the procedures found in Appendix A. The procedure for this test was based on the protocol established in BSI 6658 British Standard Institution (1986), except for the minor modifications specified in Table 1.

Each helmet was secured to the appropriately sized ASTM full magnesium headform and positioned according to the HPI (as measured). The flat impactor was lined up with the center of the chin bar (right to left, and top to bottom) as much as possible. BSI 6658 does not specify an impact location, so this location was chosen for repeatability purposes. The impactor was raised to the height necessary to achieve an impact speed of 7 ± 0.2 m/s and released. Each helmet was only tested once, and an example of the overall test setup is shown in Figure 14.

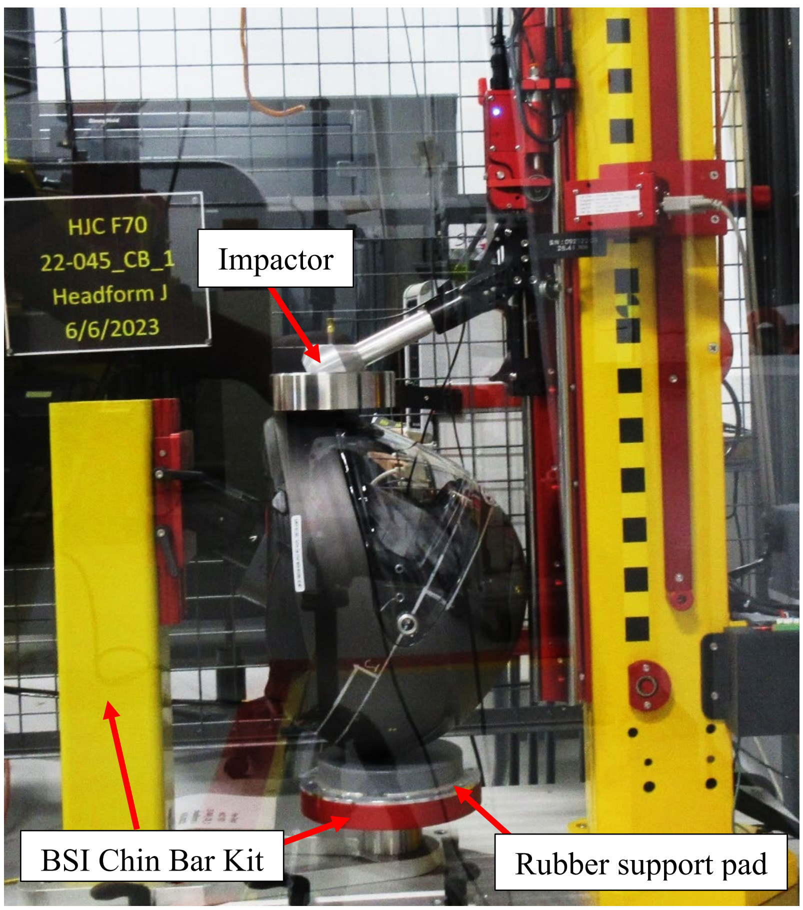

Figure 14. Chin Bar – Overall Setup

High-speed video (Phantom Miro R3215)[17] was recorded for the duration of the test at 1000 frames per second. An accelerometer (PCB 353B18) was placed at the CG of the impactor and recorded the acceleration of the impactor using the Cadex data acquisition system.

[16] Cadex Inc., Quebec, Canada. www.cadexinc.com/equipment/accessories/chin-bar-bsi
[17] Vision Research Inc., Wayne, NJ.

Since these tests were performed after the retention system tests on the same helmets, if the retention system was undamaged or partially damaged during the retention system test, the system was fastened as normal for the chin bar test. If the retention system was completely broken during the retention system test, the chin bar test was conducted without fastening the retention system. The helmet was sufficiently secured by a rubber support pad that prevented movement of the helmet during the test.

It was observed that the impactor and arm were not adjustable and were not always able to be aligned with the center (top to bottom) of the chin bar of the helmet, depending on the size of the helmet. As depicted in Figure 14, the apex of the helmet was aligned as close to the monorail system as possible without contact, however the impact location was higher (closer to the apex of the helmet) than the center of the chin bar. Future work could consider refining the chin bar kit to mitigate this equipment limitation.

Positional Stability

The positional stability tests were performed on a Cadex American Roll Off fixture.[18] The tests were performed according to the procedures found in Appendix A. The procedure for this test was based on the protocol established in ASTM F1446-11a, except for the minor modifications specified in Table 1.

The appropriately sized ASTM full urethane headform was selected for each helmet and was secured to the fixture in the face down configuration. Each helmet was then secured to the headform and positioned according to the HPI (as measured). The hook was then attached to the rear center edge of the helmet and the cable was directed over the helmet along the midsagittal plane. The guide rod and drop weight were attached to the opposite end of the cable. To run the test, the top of the guide rod was held steady while the drop weight was raised to the top of the guide rod. Both the drop weight and guide rod were then released. High-speed video (Phantom Miro R3215) was recorded for the duration of the test at 1000 frames per second. Each helmet was only tested once. An example of the overall test setup is shown in Figure 15.

[18] Cadex Inc., Quebec, Canada. www.cadexinc.com/equipment/machines/roll-off-machines/american-roll-off

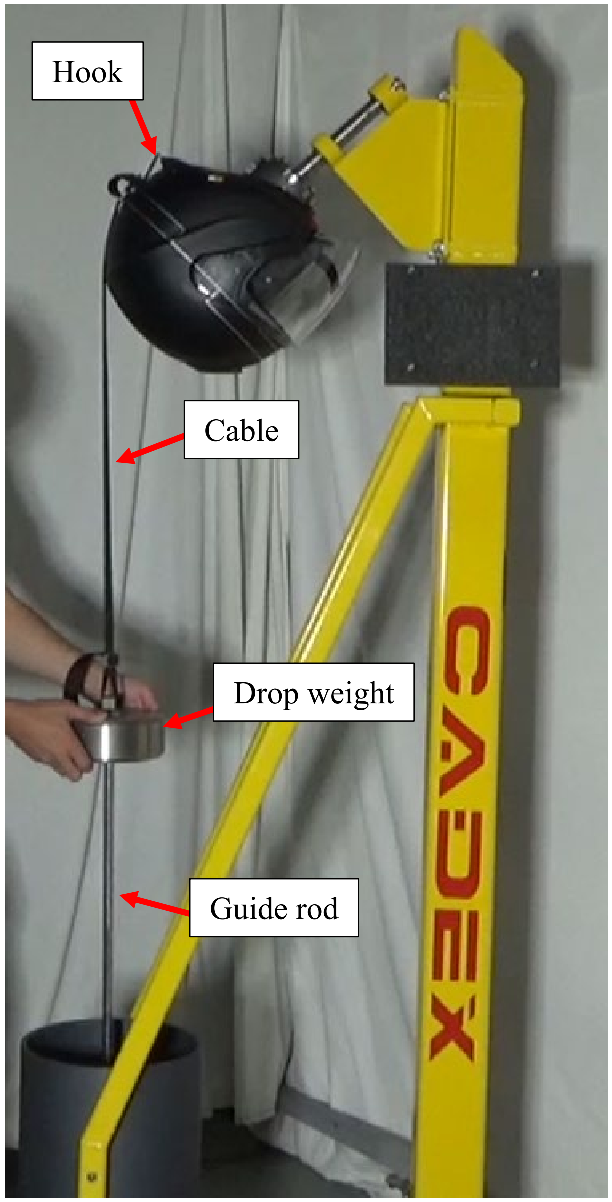

Figure 15. Positional Stability – Overall Setup

Face Shield Penetration

The face shield tests were performed on a Cadex Monorail Impact Machine[19] with a Mechanical Resistance of Visors jig.[20] The tests were performed according to the procedures found in Appendix A. The procedure for this test was based on the protocol established in ECE R.22, except for the minor modifications specified in Table 1.

Prior to the first test of each helmet model, the height of the punch was adjusted so that its point would be located 1 mm below the surface of the headform once it was attached. This differs from

[19] This is the same machine used for the impact attenuation test and the chin bar test.
[20] Cadex Inc., Quebec, Canada. www.cadexinc.com/equipment/machines/optical-machines/mechanical-resistance-of-visors-jig

ECE R.22, which states that the point of the punch should be located not less than 5 mm above the headform. This change was consistent with previous research testing (Nguyen & Kuppa, 2019). The appropriately sized ASTM full urethane headform was then attached to the fixture so that the basic plane was vertical, and a contact switch was placed on the headform at the location of the punch. The other lead of the contact switch was attached to the monorail, so if the punch made contact with the tape, the switch would close. The helmet was then secured to the headform and positioned according to the HPI (as measured). If the helmet had both a face shield and a sun visor, both features were lowered and tested together. The punch was positioned to rest on the face shield. The impactor was then raised to a height necessary to achieve a velocity of 4.4 m/s +/- 0.2 m/s and released. High-speed video (Phantom Miro R3215) was recorded for the duration of the test at 1000 frames per second. The signal from the contact switch was also recorded for each test. Each helmet was tested once. An example of the overall test setup is shown in Figure 16.

Figure 16. Face Shield Penetration – Overall Setup

Rigid Projection

The rigid projection tests were performed on a Cadex Projection and Surface Friction (Method B) machine.[21] The tests were performed according to the procedures found in Appendix A. The procedure for this test was based on the protocol established in ECE R.22, except for the minor modifications specified in Table 1.

Rigid projections were defined as any structure more than 2 mm above the outer surface of the helmet shell. The height of the projections was measured with a steel scale. The Schuberth M1 Pro had two projections (top vent and rear rib), while the Shark Street Drak had one projection (top vent). These projections can be seen in Figure 17.

Figure 17. Rigid Projections

Initially, the ear covers on the Shark Street Drak were identified as rigid projections, however they only protruded from the surface of the helmet shell on the upper portion of the cover. They were flush with the shell on the sides and bottom edges. The design of the test fixture was such that the headform could not be positioned so that the shear bar could impact the top of the ear covers, so only the bottom of the covers could be tested. Therefore, these projections were not pursued. Future work could include modifying the equipment in order to test all projections on the helmet.

The appropriately sized ASTM full urethane headform was attached to the fixture and the helmet was positioned so that its front edge was tilted backwards 25 mm from the HPI (as measured). An example of the overall test setup is shown in Figure 18. The headform and helmet were then positioned so that the projection was centered on the carriage, positioned 50 mm from the shear edge attached to the carriage, and aligned with the load cell on the front edge of the carriage. The helmet was then lowered until a load of 400 Newtons (N) was applied from the projection onto the load cell. The drop weight was then released, sliding the shear bar across the projection. High-speed video (Phantom Miro R3215) was recorded for the duration of the test at 1000 frames per second. Each projection on each helmet was tested once.

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[21] Cadex Inc., Quebec, Canada. www.cadexinc.com/equipment/machines/projection-surface-friction/projection-surface-friction-b

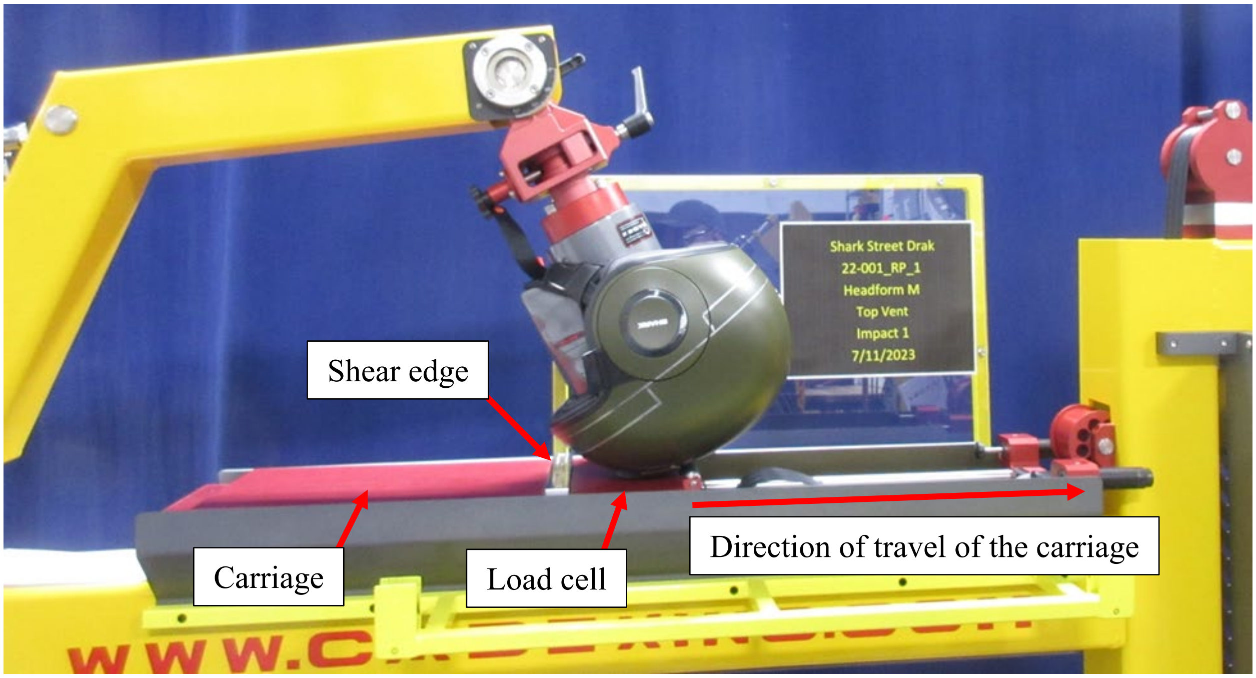

Figure 18. Rigid Projection – Overall Setup

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Results

All data traces for the impact attenuation tests, retention system tests, and chin bar tests are shown in Appendix B. Information for all tests is located in the NHTSA test database. While performance criteria were not a focus of this research, the data presented below is evaluated based on the performance criteria stated in the reference regulation for each test.

Impact Attenuation

The results of the impact attenuation tests with the complete and modular helmets can be seen in Tables 7, 8, and 9. For comparative purposes, the results of these tests were evaluated using the performance criteria specified in FMVSS No. 218: the peak acceleration must not exceed 400 g, accelerations in excess of 200 g must not exceed a cumulative duration of 2.0 ms, and accelerations in excess of 150 g must not exceed a cumulative duration of 4.0 ms.

For the HJC F70, the highest peak acceleration was 195 g, the cumulative duration above 200 g was zero milliseconds for all tests, and the highest cumulative duration above 150 g was 2.9 ms. For the Bilt Vertex, the highest peak acceleration was 206 g, the highest cumulative duration above 200 g was 0.6 ms, and the highest cumulative duration above 150 g was 3.2 ms. For the Scorpion EXO Covert X, the highest peak acceleration was 219 g, the highest cumulative duration above 200 g was 0.4 ms, and the highest cumulative duration above 150 g was 3.0 ms. For the Shoei Neotec II, the highest peak acceleration was 204 g, the highest cumulative duration above 200 g was 0.9 ms, and the highest cumulative duration above 150 g was 2.8 ms.

When comparing this data to the performance criteria in FMVSS No. 218, all tests had peak accelerations below 400 g, with the highest peak acceleration being 219 g. With respect to the 2 ms dwell time requirement, only seven tests reached 200 g for any duration, and none exceeded 2 ms over that acceleration limit. With respect to the 4 ms dwell time requirement, none of the 80 tests with the hemispherical anvil exceeded 150 g for any duration. Although 68 of the flat anvil tests resulted in accelerations exceeding 150 g, the dwell time at that acceleration level did not exceed 4 ms in any of the tests. In summary, all helmets met the FMVSS No. 218 limits.

Table 7. Impact Attenuation Results – Peak Acceleration (in g's)

Helmet Model	Type	Helmet Number	Flat Anvil				Hemispherical Anvil			
			Right Front		Left Rear		Right Rear		Left Front	
			Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2
HJC F70	Complete	22-044	157	195	152	168	83	92	91	103
		22-045	164	194	149	175	87	98	86	101
		22-046	155	185	145	168	85	96	83	98
		22-047	158	185	143	168	77	88	83	99
		22-048	143	186	141	169	85	104	81	99
Bilt Vertex	Complete	22-051	170	191	139	163	89	115	100	110
		22-052	158	206	138	174	84	126	97	101
		22-053	169	201	139	176	84	103	99	114
		22-054	158	205	131	163	83	107	91	116
		22-055	160	193	130	163	81	104	93	111
Scorpion EXO Covert X	Modular	22-030	154	178	166	182	94	97	82	80
		22-031	132	165	185	198	97	96	89	90
		22-032	167	196	195	219	89	102	81	84
		22-033	154	177	186	187	93	91	82	84
		22-034	156	182	182	201	84	86	79	84
Shoei Neotec II	Modular	22-037	148	175	181	203	101	105	99	111
		22-038	160	191	187	204	112	116	113	107
		22-039	152	172	171	187	113	117	98	107
		22-040	155	183	164	194	113	118	99	110
		22-041	156	173	166	193	110	116	103	107

Table 8. Impact Attenuation Results – 2ms Dwell Time (in msec)

Helmet Model	Type	Helmet Number	Flat Anvil				Hemispherical Anvil			
			Right Front		Left Rear		Right Rear		Left Front	
			Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2
HJC F70	Complete	22-044	-	-	-	-	-	-	-	-
		22-045	-	-	-	-	-	-	-	-
		22-046	-	-	-	-	-	-	-	-
		22-047	-	-	-	-	-	-	-	-
		22-048	-	-	-	-	-	-	-	-
Bilt Vertex	Complete	22-051	-	-	-	-	-	-	-	-
		22-052	-	**0.6**	-	-	-	-	-	-
		22-053	-	**0.3**	-	-	-	-	-	-
		22-054	-	**0.6**	-	-	-	-	-	-
		22-055	-	-	-	-	-	-	-	-
Scorpion EXO Covert X	Modular	22-030	-	-	-	-	-	-	-	-
		22-031	-	-	-	-	-	-	-	-
		22-032	-	-	-	**1.4**	-	-	-	-
		22-033	-	-	-	-	-	-	-	-
		22-034	-	-	-	**0.4**	-	-	-	-
Shoei Neotec II	Modular	22-037	-	-	-	**0.9**	-	-	-	-
		22-038	-	-	-	**0.8**	-	-	-	-
		22-039	-	-	-	-	-	-	-	-
		22-040	-	-	-	-	-	-	-	-
		22-041	-	-	-	-	-	-	-	-

Table 9. Impact Attenuation Results – 4ms Dwell Time (in msec)

Helmet Model	Type	Helmet Number	Flat Anvil				Hemispherical Anvil			
			Right Front		Left Rear		Right Rear		Left Front	
			Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2
HJC F70	Complete	22-044	**1.2**	**2.9**	**0.7**	**1.5**	-	-	-	-
		22-045	**1.9**	**2.8**	-	**1.9**	-	-	-	-
		22-046	**1.1**	**2.6**	-	**1.3**	-	-	-	-
		22-047	**1.6**	**2.8**	-	**1.4**	-	-	-	-
		22-048	-	**2.8**	-	**1.5**	-	-	-	-
Bilt Vertex	Complete	22-051	**2.4**	**2.9**	-	**2.0**	-	-	-	-
		22-052	**2.3**	**3.0**	-	**2.8**	-	-	-	-
		22-053	**2.4**	**3.0**	-	**3.2**	-	-	-	-
		22-054	**2.4**	**3.0**	-	**2.8**	-	-	-	-
		22-055	**2.4**	**3.0**	-	**2.7**	-	-	-	-
Scorpion EXO Covert X	Modular	22-030	**1.1**	**2.4**	**2.0**	**2.6**	-	-	-	-
		22-031	-	**1.4**	**2.7**	**2.9**	-	-	-	-
		22-032	**2.3**	**2.9**	**2.8**	**3.0**	-	-	-	-
		22-033	**1.5**	**2.4**	**2.6**	**2.8**	-	-	-	-
		22-034	**1.8**	**2.7**	**2.5**	**2.9**	-	-	-	-
Shoei Neotec II	Modular	22-037	-	**2.4**	**2.5**	**2.8**	-	-	-	-
		22-038	**1.7**	**2.8**	**2.6**	**2.8**	-	-	-	-
		22-039	**0.8**	**2.4**	**2.3**	**2.7**	-	-	-	-
		22-040	**1.3**	**2.7**	**1.9**	**2.8**	-	-	-	-
		22-041	**1.3**	**2.3**	**2.1**	**2.8**	-	-	-	-

Tables 10, 11, and 12 show the comparison between the results of this test series and the results of FMVSS No. 218 compliance testing with these helmet models conducted between 2019 and 2022. The data shown for this test series is the average of the five tests conducted with each helmet model, whereas the data shown for the compliance test is a single test with each helmet model. While the impact locations were not consistent between this test series and the compliance tests, in general, the compliance tests recorded higher peak accelerations. The ASTM headforms used in this test series are available in more sizes and are more representative of a human head as compared to the DOT headforms used in the compliance tests. The improved geometry and size options means that the headform that more appropriately fits the helmet can be used for testing. This improved fit with the ASTM headforms could reduce stresses within the helmet that are unrepresentative of how the helmet would be worn in the field. The reduction of these unrepresentative stresses could be an explanation for the reduced peak acceleration recorded during this test series.

Table 10. Impact Attenuation Results Comparison – Peak Acceleration (in g's)

Helmet Model	Type		Flat Anvil				Hemispherical Anvil			
			Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2
HJC F70	Complete	Average of VRTC Tests	Right Front		Left Rear		Right Rear		Left Front	
			155	189	146	170	83	96	85	100
		Compliance Test	Right		Rear		Left		Front	
			187	198	158	189	127	132	93	117
Bilt Vertex	Complete	Average of VRTC Tests	Right Front		Left Rear		Right Rear		Left Front	
			163	199	135	168	84	111	96	110
		Compliance Test	Right Front		Left Rear		Right Rear		Left Front	
			141	150	160	192	100	187	70	86
Scorpion EXO Covert X	Modular	Average of VRTC Tests	Right Front		Left Rear		Right Rear		Left Front	
			153	179	183	198	91	94	83	84
		Compliance Test	Right		Front		Rear		Left	
			174	205	166	193	88	117	97	117
Shoei Neotec II	Modular	Average of VRTC Tests	Right Front		Left Rear		Right Rear		Left Front	
			154	179	174	196	110	114	102	108
		Compliance Test	Right		Rear		Left		Front	
			186	198	177	183	115	112	114	108

Table 11. Impact Attenuation Results Comparison – 2ms Dwell Time (in msec)

Helmet Model	Type		Flat Anvil				Hemispherical Anvil			
			Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2
HJC F70	Complete	Average of VRTC Tests	Right Front		Left Rear		Right Rear		Left Front	
			-	-	-	-	-	-	-	-
		Compliance Test	Right		Rear		Left		Front	
			-	-	-	-	-	-	-	-
Bilt Vertex	Complete	Average of VRTC Tests	Right Front		Left Rear		Right Rear		Left Front	
			-	**0.3**	-	-	-	-	-	-
		Compliance Test	Right Front		Left Rear		Right Rear		Left Front	
			-	-	-	-	-	-	-	-
Scorpion EXO Covert X	Modular	Average of VRTC Tests	Right Front		Left Rear		Right Rear		Left Front	
			-	-	-	**0.4**	-	-	-	-
		Compliance Test	Right		Front		Rear		Left	
			-	**0.6**	-	-	-	-	-	-
Shoei Neotec II	Modular	Average of VRTC Tests	Right Front		Left Rear		Right Rear		Left Front	
			-	-	-	**0.3**	-	-	-	-
		Compliance Test	Right		Rear		Left		Front	
			-	-	-	-	-	-	-	-

Table 12. Impact Attenuation Results Comparison – 4ms Dwell Time (in msec)

Helmet Model	Type		Flat Anvil				Hemispherical Anvil			
			Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2
HJC F70	Complete	Average of VRTC Tests	Right Front		Left Rear		Right Rear		Left Front	
			1.2	2.8	0.1	1.5	-	-	-	-
		Compliance Test	Right		Rear		Left		Front	
			2.1	3.0	1.0	1.8	-	-	-	-
Bilt Vertex	Complete	Average of VRTC Tests	Right Front		Left Rear		Right Rear		Left Front	
			2.4	3.0	-	2.7	-	-	-	-
		Compliance Test	Right Front		Left Rear		Right Rear		Left Front	
			-	-	0.7	2.5	-	1.3	-	-
Scorpion EXO Covert X	Modular	Average of VRTC Tests	Right Front		Left Rear		Right Rear		Left Front	
			1.3	2.4	2.5	2.8	-	-	-	-
		Compliance Test	Right		Front		Rear		Left	
			2.8	3.0	2.4	3.0	-	-	-	-
Shoei Neotec II	Modular	Average of VRTC Tests	Right Front		Left Rear		Right Rear		Left Front	
			1.0	2.5	2.3	2.8	-	-	-	-
		Compliance Test	Right		Rear		Left		Front	
			2.4	2.7	1.5	2.6	-	-	-	-

While testing the Bilt Vertex helmets, the visor or one of the vent covers would frequently break off during a test. After eight impacts were completed, all five of the Bilt Vertex helmets had fractured the face shield bracket and at least two of the vent covers. The face shield bracket also fractured during one test with one of the Scorpion EXO Covert X helmets. Often, resecuring the fractured piece would have required forcing it back into place or securing it with tape or glue. Since it was unclear what effect these actions could have on future tests, for this series, any piece of the helmet that detached during a test was left off the helmet for the remaining tests.

Retention System

The results of the retention system tests with the complete and modular helmets can be seen in Table 13. For comparative purposes, the results of these tests were evaluated using the performance criteria specified in FMVSS No. 218: the retention system or its components must attain the 136 kgf load without separation and the adjustable portion of the retention system test device must not move more than 25 mm, measured between the preliminary and test load positions. This requirement to not move more than 25 mm will be hereby referred to as the retention system movement criterion. The straps remained intact during all tests with the HJC F70, Bilt Vertex, and Shoei Neotec II, and the highest retention system movement was 12.0 mm, 13.4 mm, and 17.5 mm for these three helmet models, respectively. These measurements are below the performance limit specified in FMVSS No. 218.

Table 13. Retention System Results

Helmet Model	Type	Helmet Number	Did the straps separate?	Retention System Movement (mm)
HJC F70	Complete	22-044	No	11.0
		22-045	No	10.4
		22-046	No	12.0
		22-047	No	10.8
		22-048	No	11.1
Bilt Vertex	Complete	22-051	No	12.8
		22-052	No	13.2
		22-053	No	12.6
		22-054	No	13.4
		22-055	No	13.2
Scorpion EXO Covert X	Modular	22-030	Yes	NA
		22-031	Yes	NA
		22-032	No	14.1
		22-033	Yes	NA
		22-034	Yes	NA
Shoei Neotec II	Modular	22-037	No	17.5
		22-038	No	11.9
		22-039	No	14.5
		22-040	No	15.5
		22-041	No	15.2

The straps fully separated on one out of the five Scorpion EXO Covert X helmets, and partially separated on three others. The retention system movement measurement was not applicable to the tests where the straps separated. However, the one test with the Scorpion EXO Covert X that did not result in strap separation had a retention system movement measurement of 14.1 mm. This was also below the performance limit specified in FMVSS No. 218. Figure 19 shows the fully and partially separated straps.

Figure 19. Scorpion EXO Covert X Separated Straps

Figure 20 shows the force versus time plots of the five tests with the Scorpion EXO Covert X helmets. The gray line is the test that did not result in strap separation. It was able to hold the 136 kgf load for the full 120 seconds without any sharp declines in load. The orange, yellow, and green lines are the tests where the strap partially separated. As the fixture increased the load to 136 kgf, the stitching of the retention system started to rip from the fabric, causing a sharp decrease in the measured load. Once this was detected, the test fixture aborted the test and released the load before the strap completely separated. The blue line is the test where the strap fully separated, and the load sharply dropped to zero. Since all other retention system tests held the load for the full 120 seconds, the force versus time plots for those tests are similar to the gray line, as seen in Appendix B.

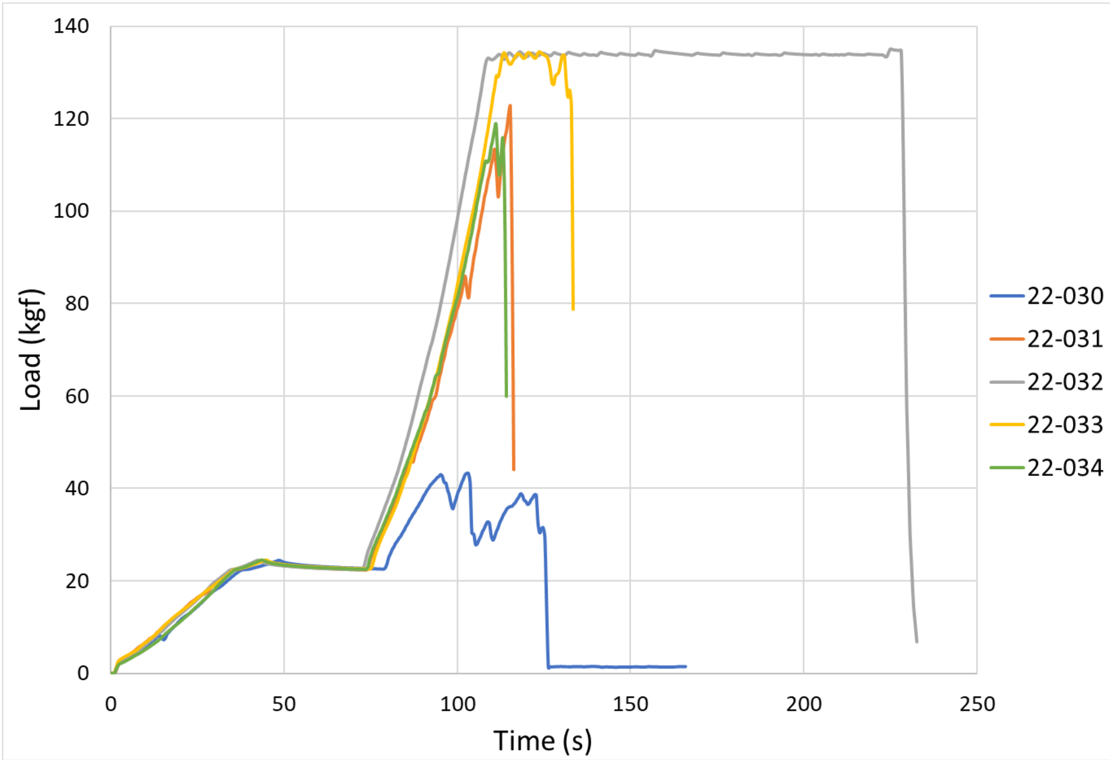

Figure 20. Force Versus Time – Scorpion EXO Covert X Retention System Tests

Table 14 shows the comparison between the results of this test series and the results of FMVSS No. 218 compliance testing with these helmet models conducted between 2019 and 2022. The data shown for this test series is the average of the five tests conducted with each helmet model, whereas the data shown for the compliance test is a single test with each helmet model. The compliance tests produced similar results to the tests conducted in this series, except for the Scorpion EXO Covert X. This helmet met the performance criteria in the compliance test conducted in 2021. However, it is noted that in February 2023, NHTSA OVSC tested a random sample of helmets, and two out of the four Scorpion EXO Covert X helmets did not meet the performance criteria (Huber, 2023). In June 2024, the manufacturer of these helmets issued a voluntary recall (NHTSA, 2024). When comparing the results for the other three helmets tested in this study with the 2019-2022 compliance testing that used DOT headforms, the use of the ASTM headforms does not appear to affect the results of the test.

Table 14. Retention System Results Comparison

Helmet Model	Type		Did the straps separate?	Retention System Movement (mm)
HJC F70	Complete	Average of VRTC Tests	5/5 No	11.1
		Compliance Test	No	11.2
Bilt Vertex	Complete	Average of VRTC Tests	5/5 No	13.0
		Compliance Test	No	11.4
Scorpion EXO Covert X	Modular	Average of VRTC Tests	1/5 No	14.1
		Compliance Test	No	18.4
Shoei Neotec II	Modular	Average of VRTC Tests	5/5 No	14.9
		Compliance Test	No	13.2

Chin Bar

The results of the chin bar tests with the complete and modular helmets can be seen in Table 15. For comparative purposes, the results of these tests were evaluated using the performance criterion specified in BSI 6658: the acceleration of the impactor could not exceed 300 g. The highest peak acceleration for the HJC F70, Bilt Vertex, and Shoei Neotec II were 115 g, 122 g, and 151 g, respectively. These measurements are below the performance limit specified in BSI 6658. The data for the HJC F70 helmet number 22-044 was not collected due to equipment error, so helmet number 22-049 was also tested to complete the five repeat tests. The highest peak acceleration for the Scorpion EXO Covert X was 304 g. All other tests were below 300 g.

Table 15. Chin Bar Results

Helmet Model	Type	Helmet Number	Peak Accel (g)
HJC F70	Complete	22-045	115
		22-046	107
		22-047	109
		22-048	102
		22-049	111
Bilt Vertex	Complete	22-051	121
		22-052	111
		22-053	122
		22-054	116
		22-055	105
Scorpion EXO Covert X	Modular	22-030	296
		22-031	225
		22-032	244
		22-033	271
		22-034	304
Shoei Neotec II	Modular	22-037	124
		22-038	119
		22-039	143
		22-040	151
		22-041	138

Positional Stability

The results for the positional stability tests with the full helmets can be seen in Table 16. For comparative purposes, the results of these tests were evaluated using the performance criterion specified in ASTM F1446-11a: the retention system must remain intact and the helmet must remain on the headform. All Schuberth M1 Pro helmets stayed on the headform and the helmet moved about the same amount during all 15 tests. One out of the 15 Shark Street Drak helmets did not stay on the headform. While the other 14 tests resulted in the helmet staying on the headform, there was variation in the amount of movement the helmet experienced during the test.

Table 16. Positional Stability Results

Helmet Model	Type	Helmet Number	Did the helmet stay on the headform?
Schuberth M1 Pro	Full	22-010	Yes
		22-011	Yes
		22-012	Yes
		22-013	Yes
		22-014	Yes
		22-015	Yes
		22-016	Yes
		22-017	Yes
		22-018	Yes
		22-019	Yes
		22-020	Yes
		22-021	Yes
		22-022	Yes
		22-023	Yes
		22-024	Yes
Shark Street Drak	Full	22-001	Yes
		22-002	Yes
		22-003	No
		22-004	Yes
		22-005	Yes
		22-006	Yes
		22-007	Yes
		22-008	Yes
		22-009	Yes
		22-058	Yes
		22-059	Yes
		22-060	Yes
		22-061	Yes
		22-062	Yes
		22-063	Yes

During this series, it was observed that the only test when the helmet moved enough to expose the coronal plane of the headform was the test where the helmet came fully off the headform. None of the tests where the helmet stayed on the headform moved enough to expose the coronal plane of the headform above the reference plane. The coronal plane and reference plane are shown in Figure 21 for reference.

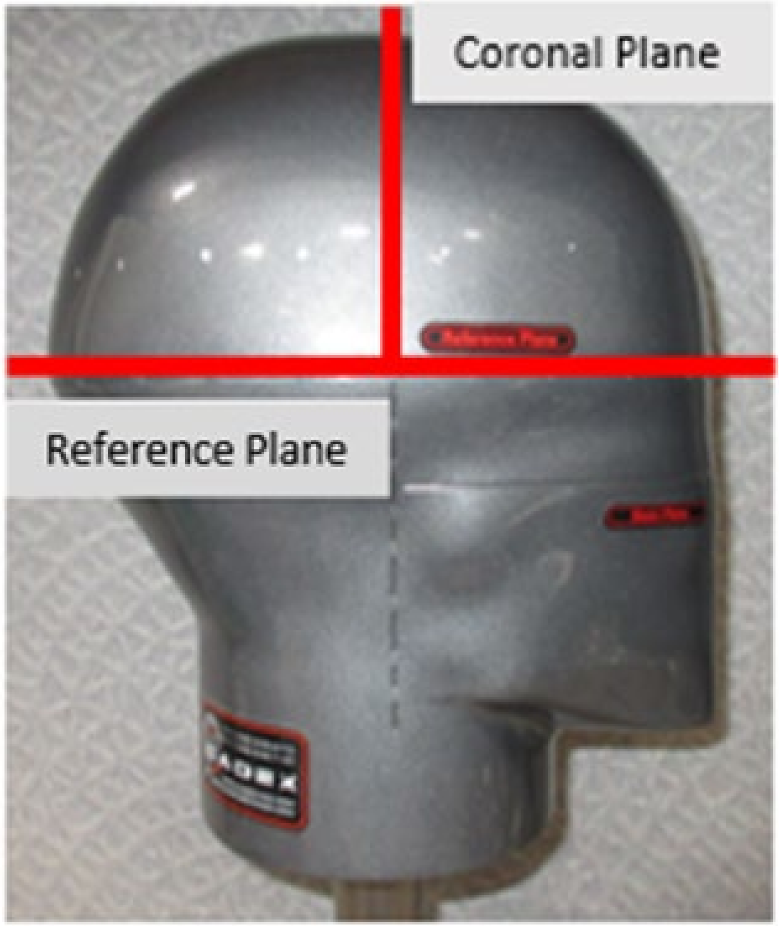

Figure 21. Coronal Plane and Reference Plane on ASTM Polyurethane Headform

Face Shield Penetration

The results of the face shield tests with the full helmets can be seen in Table 17. The face shield tests conducted with Schuberth M1 Pro helmets 22-010 to 22-012 were inadvertently performed without deploying the inner sun visor, so these results were excluded from the analysis. These tests were re-run with helmets 22-025 to 22-027. For comparative purposes, the results of these tests were evaluated using the performance criterion specified in ECE R.22: the face shield cannot break into sharp splinters, as defined as any segment having an angle less than 60°. This angle was measured on post-test images using a digital protractor. None of the helmets produced small fragments, however, all the tests with the Shark Street Drak helmets penetrated through the face shield and recorded contact between the headform and the punch.

Table 17. Face Shield Penetration Results

Helmet Model	Type	Helmet Number	Number of Small Fragments
Schuberth M1 Pro	Full	22-013	0
		22-014	0
		22-015	0
		22-016	0
		22-017	0
		22-018	0
		22-019	0
		22-020	0
		22-021	0
		22-022	0
		22-023	0
		22-024	0
		22-025	0
		22-026	0
		22-027	0
Shark Street Drak	Full	22-001	0
		22-002	0
		22-003	0
		22-004	0
		22-005	0
		22-006	0
		22-007	0
		22-008	0
		22-009	0
		22-058	0
		22-059	0
		22-060	0
		22-061	0
		22-062	0
		22-063	0

The Shark Street Drak helmets had goggles instead of a full coverage face shield, and the impact location was positioned just above the nose bridge of the goggles. Figure 22 shows the punch penetrated into the goggles and the headform that was seen after each test with the Shark Street Drak.

Figure 22. Shark Street Drak Face Shield Penetration Damage

Rigid Projection

The results of the rigid projection tests with the full helmets can be seen in Table 18. For comparative purposes, the results of these tests were evaluated using the performance criterion specified in ECE R.22: the projection must shear away, detach, or otherwise not prevent the bar from sliding past the projection. The shear bar was able to slide past the projection during all tests with both helmet models. During all tests of the top vent, the vent partially or fully detached, which allowed the shear bar to continue moving down the track. During all tests of the rear rib with the Schuberth M1 Pro, the helmet rotated on the headform, which moved the rib out of the way of the shear bar. This caused the shear bar to move past the helmet without interruption.

Table 18. Rigid Projection Results

Helmet Model	Type	Helmet Number	Did the shear bar slide past the top vent?	Did the shear bar slide past the rear rib?
Schuberth M1 Pro	Full	22-010	Yes	Yes
		22-011	Yes	Yes
		22-012	Yes	Yes
		22-013	Yes	Yes
		22-014	Yes	Yes
		22-015	Yes	Yes
		22-016	Yes	Yes
		22-017	Yes	Yes
		22-018	Yes	Yes
		22-019	Yes	Yes
		22-020	Yes	Yes
		22-021	Yes	Yes
		22-022	Yes	Yes
		22-023	Yes	Yes
		22-024	Yes	Yes
Shark Street Drak	Full	22-001	Yes	
		22-002	Yes	
		22-003	Yes	
		22-004	Yes	
		22-005	Yes	
		22-006	Yes	
		22-007	Yes	
		22-008	Yes	
		22-009	Yes	
		22-058	Yes	
		22-059	Yes	
		22-060	Yes	
		22-061	Yes	
		22-062	Yes	
		22-063	Yes	

Repeatability Analysis

The repeatability of test types that output numerical data, such as the impact attenuation test, retention system test, and chin bar test was evaluated using statistical analyses including %CV and one-way ANOVA. The %CV was calculated by dividing the sample standard deviation by the average and multiplying by 100. This quantified the variability of the data normalized to the average response. If the %CV was elevated, suggesting possible issues with repeatability, the data was also analyzed using the one-way ANOVA. To perform the ANOVA analysis, the five tests performed on each helmet model were compared to each other. ANOVA p-values below .05 indicate statistically significant differences in performance between the helmets. Although ANOVA results are not direct assessments of repeatability, p-values below .05 do suggest that the variation in the assessed helmets was not so large that it obscured the differences between the helmets.

The repeatability of test types that do not output numerical data, such as the positional stability test, face shield test, and rigid projection test was evaluated by comparing the number of tests that met or did not meet the performance criteria specified in the reference standard.

Impact Attenuation

For the impact attenuation tests, each impact was evaluated separately since it could not be assumed that any of the four impact locations or the first and second impact at each location would give the same responses. Table 19 shows the sample standard deviation, average, and %CV for all peak acceleration data collected during the impact attenuation tests. Percent CV was not calculated for 2 ms dwell time or 4 ms dwell time since the average values for those metrics are so small, any variation in the results leads to exaggerated %CVs.

Table 19. Impact Attenuation Peak Acceleration Percent CV Results

		Flat Anvil				**Hemispherical Anvil**			
		Right Front		**Left Rear**		**Right Rear**		**Left Front**	
		Impact 1	**Impact 2**	**Impact 1**	**Impact 2**	**Impact 1**	**Impact 2**	**Impact 1**	**Impact 2**
HJC F70	St. Dev.	7.5	5.2	4.5	2.9	4.1	6.0	3.7	1.9
	Average	155.4	189.0	145.9	169.5	83.4	95.7	84.6	99.8
	%CV	4.8	2.7	3.1	1.7	4.9	6.2	4.4	1.9
Bilt Vertex	St. Dev.	6.0	6.7	4.5	6.7	2.9	9.4	3.8	5.9
	Average	162.9	199.3	135.5	168.1	84.3	111.2	96.0	110.3
	%CV	3.7	3.3	3.3	4.0	3.4	8.4	3.9	5.3
Scorpion EXO Covert X	St. Dev.	12.5	11.2	10.6	14.4	4.9	6.0	3.6	3.5
	Average	152.6	179.4	182.7	197.6	91.2	94.3	82.8	84.3
	%CV	8.2	6.2	5.8	7.3	5.4	6.4	4.3	4.2
Shoei Neotec II	St. Dev.	4.7	8.1	9.7	7.2	5.3	5.3	6.1	1.8
	Average	154.1	178.8	173.8	196.2	109.7	114.2	102.2	108.3
	%CV	3.0	4.5	5.6	3.7	4.8	4.7	6.0	1.7

All calculated %CVs were below 8.5%. In general, the highest %CVs occurred on the second impact at the right rear location, and with the Scorpion EXO Covert X.

Retention System

For the retention system tests, strap separation was evaluated as a non-numerical output, while retention system movement was evaluated as a numerical output. Three helmet models had consistent results with respect to the strap separation criterion, meeting this requirement in every test. Results for the fourth helmet model, the Scorpion EXO Covert X, were also generally consistent, with strap separation in 4 out of 5 tests. Table 20 shows the %CV results for retention system movement. Red cells indicate an elevated %CV of over 10 percent.

Table 20. Retention System Percent CV Results

HJC F70	St. Dev.	0.6
	Average	11.1
	CV	5.3
Bilt Vertex	St. Dev.	0.3
	Average	13.0
	%CV	2.5
Scorpion EXO Covert X	St. Dev.	NA
	Average	NA
	%CV	NA
Shoei Neotec II	St. Dev.	2.0
	Average	14.9
	%CV	13.6

Since retention system movement could only be measured for one test with the Scorpion EXO Covert X, a %CV could not be calculated for that helmet model. Two of the other three helmet models had a %CV of less than 6%, while the Shoei Neotec II had a %CV of 13.6% with a range of movement from 11.9 mm to 17.5 mm. The one-way ANOVA analysis for the retention system tests resulted in a *p*-value of .001, indicating that the variability within the repeated tests was not so large that it obscured the statistically significant differences between the helmet models. Figure 23 shows this relationship between the results from the four helmet models. Although the results for the Shoei Neotec II have more variability, the average response for that helmet model is still significantly higher than the other two helmet models.

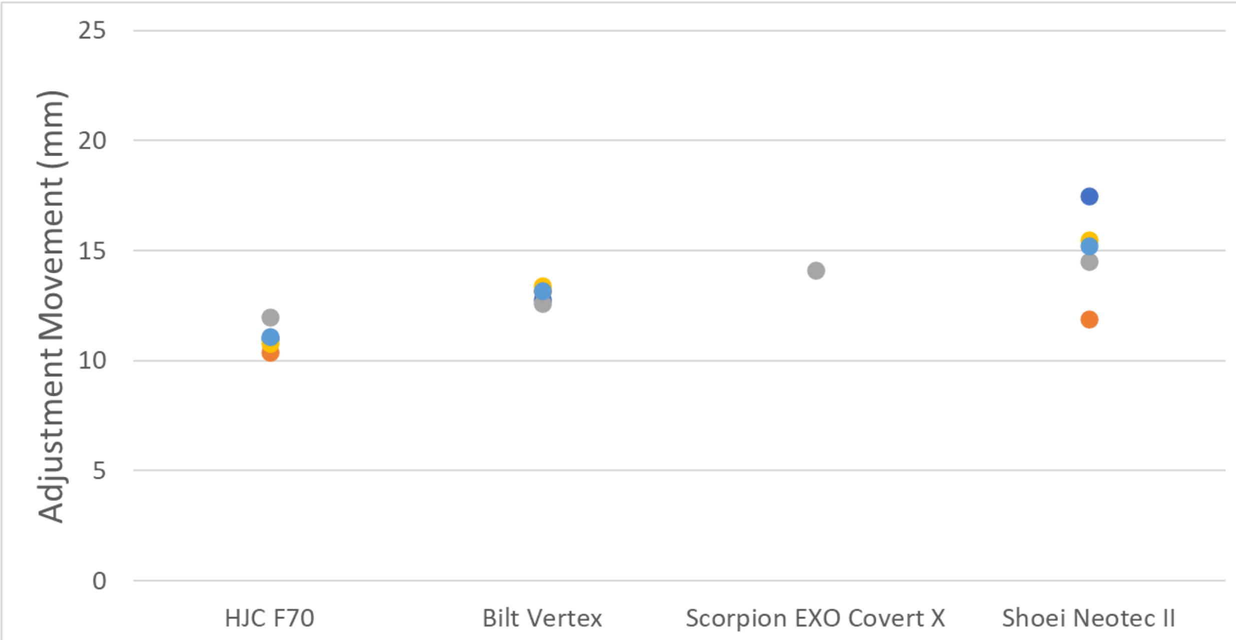

Figure 23. Retention System Movement Results

Chin Bar

Table 21 shows the standard deviation, average, and %CV for all peak acceleration data collected during the chin bar tests. Red cells indicate an elevated %CV greater than 10%.

Table 21. Chin Bar Peak Acceleration Percentage CV Results

HJC F70	St. Dev.	4.7
	Average	108.8
	%CV	4.3
Bilt Vertex	St. Dev.	6.9
	Average	114.9
	%CV	6.0
Scorpion EXO Covert X	St. Dev.	33.4
	Average	268.1
	%CV	12.5
Shoei Neotec II	St. Dev.	13.4
	Average	134.9
	%CV	9.9

Of the four calculated %CVs, only the Scorpion EXO Covert X was elevated. Four out of the five tests with the Scorpion EXO Covert X had responses below the 300 g limit specified in BSI 6658, ranging from 225 g to 296 g. However, the fifth test had a response over the BSI 6658 performance limit, at 304 g. The cause of this variability and the proximity to the performance limit could be the design of the chin bar on this helmet model. There was a sticker on the side of the removable chin bar that read “Does not protect chin from impacts.” There was also a warning in the owner’s manual shown in Figure 24. This warning was not discovered until the helmets had been received and testing had begun. NHTSA tested these helmets regardless of the warning for research purposes.

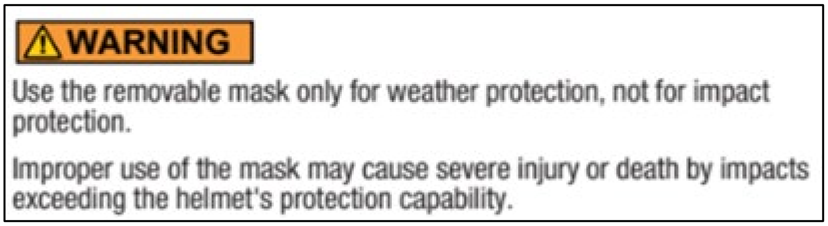

Figure 24. Scorpion EXO Covert X Warning Label

The one-way ANOVA analysis for the chin bar tests resulted in a *p*-value of less than .001, indicating that the variability within the repeated tests was not large enough to obscure the statistically significant differences between the helmet models. Figure 25 shows this relationship between the results from the four helmet models. Although the results for the Scorpion EXO Covert X have more variability, the average response for that helmet model is significantly higher than the other three helmet models, likely due to the fact that the chin bar was not meant for impact protection.

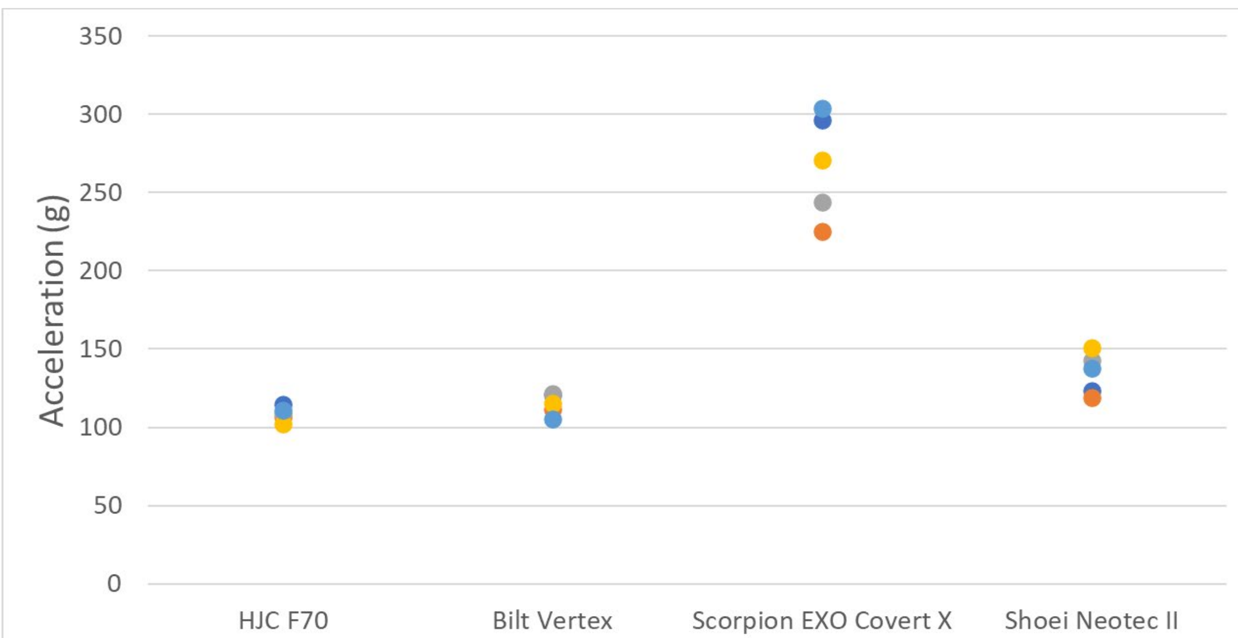

Figure 25. Chin Bar Peak Acceleration Results

Positional Stability

All Schuberth M1 Pro helmets met the performance criterion for the positional stability tests as stated in ASTM F1446-11a (the retention system must remain intact and the helmet must remain on the headform). One out of the 15 Shark Street Drak helmets did not meet the performance criterion. This could be due to slight differences during test set up. The Shark Street Drak fit more loosely around the back of the headform compared to the Schuberth M1 Pro, so positioning it consistently was more difficult. The chin strap on the Shark Street Drak also had more padding than the Schuberth M1 Pro. This made it more difficult to position and tighten consistently on the headform. Despite the one test that did not meet the performance criterion, overall, the repeatability was reasonable.

Face Shield Penetration

All the helmets that were tested met the performance criterion as specified in ECE R.22 (the face shield must not break into sharp splinters, defined as any segment having an angle less than 60°). It was also observed that all the tests with the Schuberth M1 Pro helmets did not have contact between the punch and the headform, while contact was recorded during all tests with the Shark Street Drak helmets. These results indicated excellent repeatability of this procedure on these helmets.

Rigid Projection

During all tests of the top vent with both helmet models tested, the vent partially or fully detached, which allowed the shear bar to continue moving down the track. During all tests of the rear rib with the Schuberth M1 Pro, the helmet rotated slightly on the headform, as intended, to allow the shear bar to move past the helmet without interruption. The consistency of helmet performance showed that this test procedure had excellent repeatability.

Summary

The objectives of this motorcycle helmet test series were to assess the feasibility of conducting modified FMVSS No. 218 tests and other performance tests, refine test procedures as necessary, and evaluate the repeatability of each of the modified test procedures. Research test procedures were based on existing procedures in FMVSS No. 218 and in other helmet test procedures used internationally with minor modifications based on NHTSA's previous motorcycle helmet research.

A summary specific to each test procedure evaluated in this test series is provided below.

Impact Attenuation

The impact attenuation tests were successfully conducted using the ASTM F2220 half magnesium headforms. All impact attenuation tests had peak accelerations below 400 g, all cumulative durations above 200 g were less than 2 ms, and all cumulative durations above 150 g were less than 4 ms. This means that all tests met the performance criteria specified in FMVSS No. 218.

It was noted that, while positioning, the lack of a chin structure on the ASTM half headforms meant that the chin strap of the helmets could not be secured enough to keep the helmet in place. This issue was mitigated by placing a piece of foam under the chin strap to act as a chin surface during testing. Additionally, during testing it was discovered that the visor or one of the vent covers would frequently break off during a test. Often, resecuring the fractured piece would have required forcing it back into place or securing it with tape or glue. Since it was unclear what effect these actions could have on future tests, for this series, any piece of the helmet that detached during a test was left off the helmet for the remaining tests.

All impact attenuation tests showed acceptable repeatability with all CVs being below 8.5%.

Retention System

The retention system tests were successfully conducted using the ASTM F2220 half magnesium headforms. No additional test procedure refinements were required. Results showed that the straps did not separate during 16 out of 20 tests and all tests had retention system movement of less than 25 mm. Meaning that 16 out of 20 tests met the performance criteria specified in FMVSS No. 218.

Three helmet models tested had consistent results with respect to the strap separation criterion, meeting this requirement in every test. Results for the fourth helmet model were also generally consistent, with strap separation in 4 out of 5 tests. With respect to the retention system movement criterion, two helmet models had a CV of less than 6%, while one helmet model had a CV of 13.6%. The %CV for the retention system movement criterion for the fourth helmet model could not be calculated since the straps separated during 4 out of the 5 tests conducted. The one-way ANOVA analysis for the retention system tests resulted in a p-value of .001, indicating that the variability within the repeated tests was not large enough to obscure the differences between the helmet models. This shows that, despite an elevated %CV for one helmet model, the test procedure is still robust enough to differentiate the performance of the helmet models.

Chin Bar

The chin bar impact attenuation tests were all conducted successfully with the modified test procedures based on BSI 6658. During testing, it was observed that the impactor and arm were not adjustable and were not always able to be aligned with the center of the chin bar of the helmet depending on the size of the helmet. Future work could consider refining the chin bar kit to mitigate this equipment limitation.

Results showed that all chin bar tests with 3 out of the 4 helmet models had peak accelerations below 300 g, meaning they met the performance criteria specified in BSI 6658. The CVs for these three helmet models were also below 10%, showing reasonable repeatability. For one helmet model, four out of the five repeats had a peak acceleration above 300 g, and the %CV was elevated, at 12.5%. It was noted that the chin bar on this helmet was not intended for impact protection based on its label. Similar to the retention system test assessment, the one-way ANOVA analysis resulted in a *p*-value of less than .001, indicating that variability within the repeated tests was not large enough to obscure the statistically significant differences between the helmet models. This shows that, despite an elevated %CV for one helmet model, the test procedure is still robust enough to differentiate the performance of the helmet models.

Positional Stability

The positional stability tests based on ASTM F1446-11a were successfully completed in the face down configuration. No additional test procedure refinements were required. For one helmet model, all helmets stayed on the headform, while for the other helmet model, one of the 15 tests did not stay on the headform. Thus, 29 out of the 30 tests met the performance criterion specified in ASTM F1446-11a. Despite the one test that did not meet the performance criterion, overall, the repeatability was reasonable.

Face Shield Penetration

The face shield penetration tests based on ECE R.22 were successfully performed. During this series, the punch was allowed to make contact with the headform and presence of headform contact was recorded for each test. None of the helmets that were tested produced small fragments, meaning all tests met the performance criteria specified in ECE R.22. For one helmet model, headform contact was not recorded during any test; however, contact was recorded during all tests with the other helmet model. The results were consistent for every test of both helmet models, indicating excellent repeatability of this procedure.

Rigid Projection

The rigid projection tests were successfully completed based on ECE R.22. Rigid projections were defined as any structure more than 2 mm above the outer surface of the helmet shell. The height of the projections was measured with a steel scale. One helmet model had two projections (top vent and rear rib), while the other model had one projection (top vent). During test setup, it was observed that the design of the test fixture was such that the headform could not be positioned so that the shear bar could impact another identified projection (the top of the ear covers). Therefore, testing of these projections was not pursued. Future work could include modifying the equipment in order to test all identified projections on the helmet.

During all tests of the top vent with both helmet models tested, the vent partially or fully detached, which allowed the shear bar to continue moving down the track. During all tests of the rear rib, the helmet rotated slightly on the headform, as intended, to allow the shear bar to move past the helmet without interruption. This means that all tests met the performance criteria specified in ECE R.22. Since results were consistent in every test, these helmets showed excellent repeatability of this test procedure.

Overall, these six helmet models tested showed that conducting these tests was feasible and the test procedures were repeatable.

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Appendix A: Research Test Procedures

1. Testing Sequence

Complete Helmets

1. Remove tags and accessories that will not be in place during testing from all helmets. This includes all cosmetic items. Note what was removed.
2. Weigh all helmets.
3. Determine discrete size and HPI (as measured) on model A, helmet 1.
4. Draw the test line on all helmets of model A using the measurement determined in step 3.
5. Repeat steps 3 and 4 for model B.
6. Perform impact attenuation test on all helmets of model A.
7. Perform impact attenuation test on all helmets of model B.
8. Perform retention system test on all helmets of model A.
9. Perform retention system test on all helmets of model B.
10. Perform chin bar test on all helmets of model A.
11. Perform chin bar test on all helmets of model B.

Modular Helmets

1. Remove tags and accessories that will not be in place during testing from all helmets. This includes all cosmetic items. Note what was removed.
2. Weigh all helmets.
3. Determine discrete size and HPI (as measured) on model A, helmet 1.
4. Draw the test line on all helmets of model A using the measurement determined in step 3.
5. Repeat steps 3 and 4 for model B.
6. Perform impact attenuation test on all helmets of model A.
7. Perform impact attenuation test on all helmets of model B.
8. Perform retention system test on all helmets of model A.
9. Perform retention system test on all helmets of model B.
10. Perform chin bar test on all helmets of model A.
11. Perform chin bar test on all helmets of model B.

Full Helmets

1. Remove tags and accessories that will not be in place during testing from all helmets. This includes all cosmetic items. Note what was removed.
2. Weigh all helmets.
3. Determine discrete size and HPI (as measured) on model A, helmet 1.
4. Draw the test line on all helmets of model A using the measurement determined in step 3.
5. Repeat steps 3 and 4 for model B.
6. Perform positional stability test on all helmets of model A.
7. Perform positional stability test on all helmets of model B.
8. Perform face shield penetration test on all helmets of model A.
9. Perform face shield penetration test on all helmets of model B.
10. Perform rigid projection test on all helmets of model A.
11. Perform rigid projection test on all helmets of model B.

2. Discrete Size Measurement

Drawing Test Reference Line (Outside Surface of Helmet)

1. Condition helmets in ambient conditions.
2. Remove any non-permanent, non-essential accessories from helmet (e.g., remove visors from half helmet). Also remove extra padding (such as ear pads) from the interior of the helmet. Make notes of what was removed.
3. Using the reference label on helmet (supplied by manufacturer) select the correct ASTM reference headform using the table below. If the label numerical value falls into more than one headform size, the procedure will be followed using both headform sizes.

Table A-1. Headform Size Chart

		Largest Size Specified (cm) and Largest US Hat Size					
		< 51 *< 6 3/8*	52 - 53 *6 4/8 – 6 5/8*	54 - 56 *6 6/8 - 7*	57 - 59 *7 1/8 – 7 3/8*	60 - 61 *7 4/8 – 7 5/8*	> 61 *> 7 5/8*
Smallest Size Specified (cm)	< 51	A	A - C	A - E	A - J	A – M	A - O
	52-53		C	C - E	C - J	C – M	C - O
	54-56			E	E - J	E – M	E - O
	57-59				J	J – M	J - O
	60-61					M	M - O
	> 61						O

4. After selecting the reference headform, place headform with basic, reference, and test reference planes horizontal on a rotating stand and align marker from drawing jig with the test reference line.

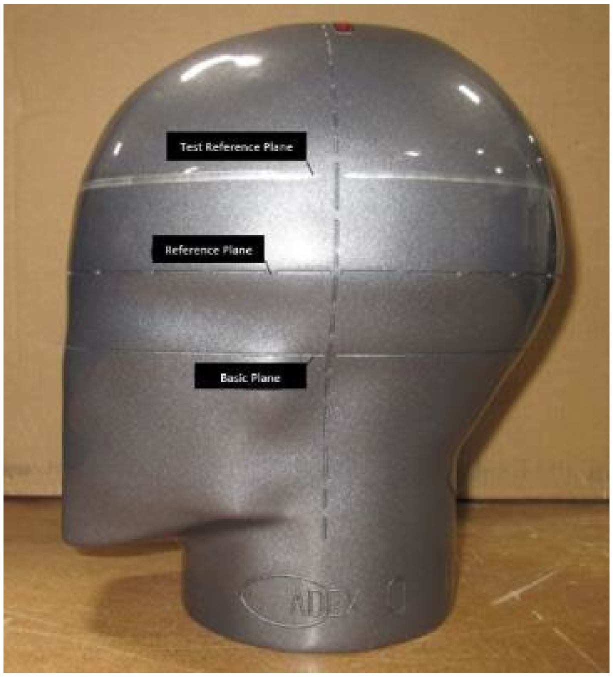

Figure A-1. ReferenceHeadform

5. Place helmet on the headform and apply a 4.5 kg (10 lb) static vertical load through the helmet's apex. Center the helmet laterally and seat firmly on the reference headform.
6. Position the helmet onto the reference headform so that the brow opening is parallel to the basic plane and centered on the midsagittal plane and allows for the test reference line to remain on the outer shell when drawn.
7. Use an inclinometer, placed against the brow opening, to set the brow opening parallel to the basic plane, horizontal (0) +/- 1°.
8. Check the peripheral vision using the go/no-go gauge and brow block (25.4 mm (1 inch) block) measured at the intersection of the midsagittal and basic planes.
9. Record the angle measurement and note any observations about the angle measurement.
10. Record the distance from the lowest point of the brow opening to the basic plane at the front of the reference headform along the midsagittal plane of the headform (HPI (as measured)).
    a. The HPI is the distance from the lowest point of the brow opening at the lateral midpoint of the helmet to the basic plane of the reference headform. The HPI is used to ensure consistent and proper placement of the helmet on the headform.
11. Maintain load in Step 5 and draw the "test reference line" on the outer surface of the helmet, as shown by the red line below. Use the line drawing jig to do this.
12. Take a photo of the test reference line drawn on the helmet.

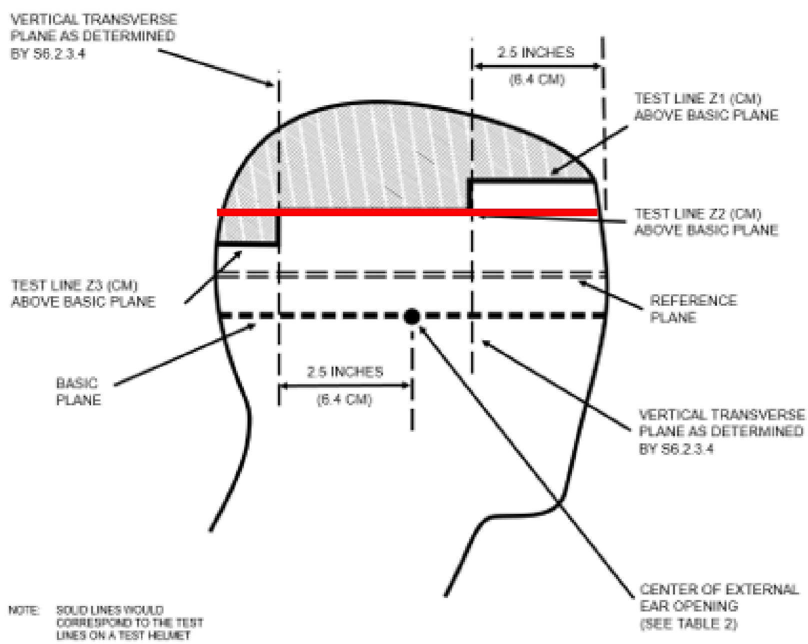

Figure A-2. Location of Test Reference Line

Drawing Internal Reference Line and Handheld Scissor Tool Measurement

1. Place the helmet into the helmet holder. Align the test reference line on the outer shell of the helmet with the lasers so that the test reference line is horizontal. Once aligned, tighten the holder clamps so that the helmet is held firmly in place.
    a. Laser height may need adjusted depending on helmet.
2. Keeping the lasers in the same position, remove the helmet holder from below the fixture.
3. Slide over the marking jig. Lower the marking jig until aligned with the lasers. Set depth stopper.
4. Slide the marking jig up and slide the helmet back into place. Lower the jig until the depth stopper is reached and mark the inside of the helmet.
5. Take a photo of the internal test reference line.
6. Remove the marking jig and place the handheld scissor tool in the helmet and align the center of the band with the internal reference line.
7. Squeeze the scissor tool to compress the comfort liner to maximum compression.
8. Record the measurement to the nearest centimeter.
9. Repeat Step 8 to take at least 3 independent measurements, with a three-minute wait time between repeats.
10. The maximum of all measured discrete sizes must be designated the overall discrete size measurement for the helmet model.
11. Use the headform size selection chart to determine the appropriate ASTM headform for testing.

Post-Measurement/Drawing Test Line

1. If the procedure results in two headforms of different size due to the reference label corresponding to two different reference headforms, proceed with the larger of the two headforms.
2. If the selected headform is a different size than the reference headform, repeat the procedure with the new headform. If the headform size changes again, notify the team.
3. Position the helmet on the selected headform as in Step 11 of the discrete size measurement procedure and draw the test line on the outer surface of the helmet along the portions of the planes that intersect with the helmet surface as shown by the solid black line in the figure above and described below:
    a. A plane 2.5 cm above and parallel to the test reference line in the anterior portion of the headform.
    b. A vertical transverse plane 6.4 cm behind the point on the anterior surface of the headform at the intersection of the midsagittal plane and test reference line.
    c. The test reference line of the headform.
    d. A vertical transverse plane 6.4 cm behind the center of the external ear opening in a side view.
    e. A plane 2.5 cm below and parallel to the test reference line in the posterior portion of the headform.
4. Take a photo of the test line drawn on the helmet.
5. Replace any padding that was removed for measurement but will be used during testing.

3. Impact Attenuation (based on FMVSS No. 218)

Drop tower with complete and modular helmets (5 repeats)

1. Select the appropriately sized, instrumented, ASTM half magnesium headform for the helmet to be tested, based on the helmet discrete size measurement.
    a. Ensure the combined weight of the headform and supporting assembly is within the required limits.

Table A-2. Drop Assembly Weight

ASTM Headform	Drop Assembly Weight (Includes Weight of Half Headform) (kg)
A	3.1 ± 0.1
C	3.6 ± 0.1
E	4.1 ± 0.12
J	4.7 ± 0.14
M	5.6 ± 0.16
O	6.1 ± 0.18

2. Create test placards for each test that include test number, helmet manufacturer/model, helmet inventory number, headform size, anvil shape, impact location, impact number, and test date.
3. Secure the selected headform and instrumentation to the drop tower.

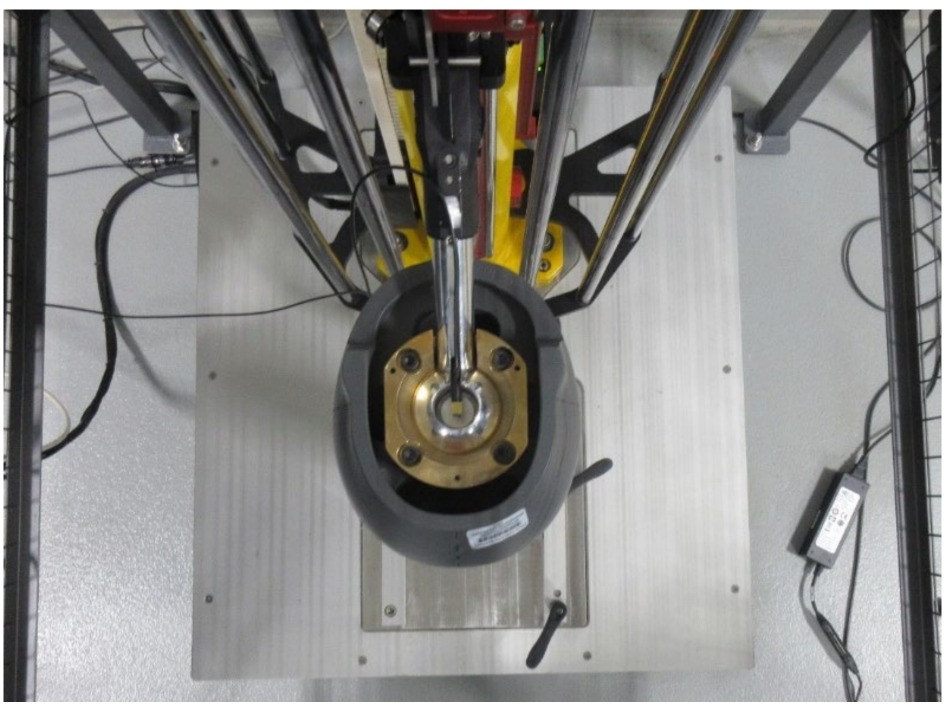

Figure A-3. Headform Attached to Drop Tower

4. Prior to conducting the first test for each set of repeats, perform a series of check drops onto a 2.54 cm open blue modular elastomer programmer (MEP) calibration pad.

a. Align the point of contact of the headform and the accelerometer axis vertically.

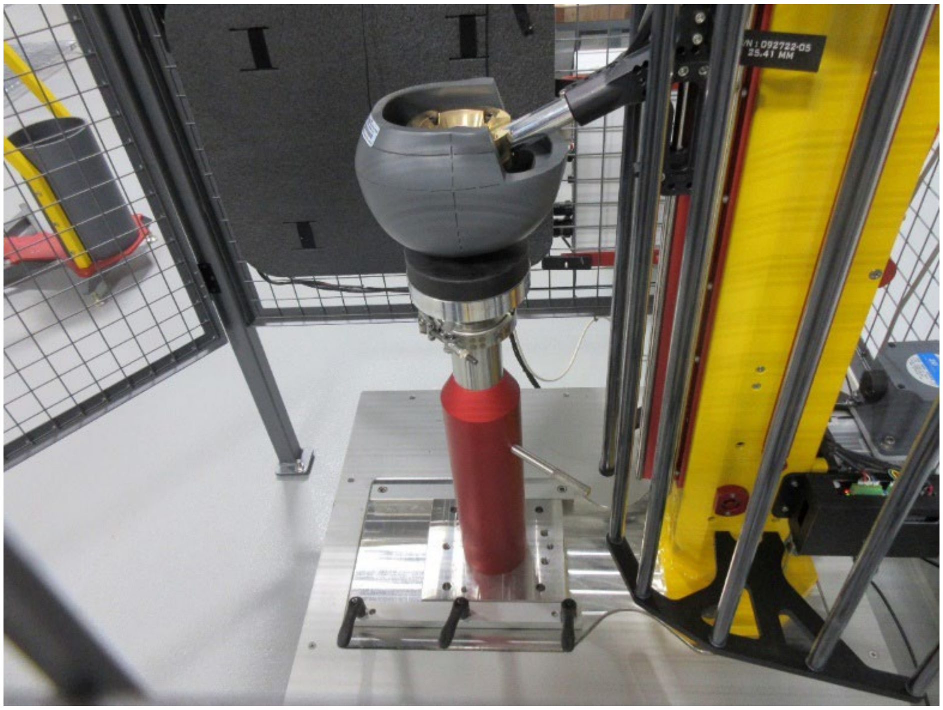

Figure A-4. Headform Aligned With MEP Pad

b. Perform three drops without recording data.
c. Perform three additional drops while recording data.

5. Ensure that at least one of the three drops recorded an acceleration greater than 375 g.
6. Determine the desired impact locations on the test helmet. These can be anywhere above the test line and separated by at least one-sixth of the maximum circumference of the helmet in the test area.
    a. In general, the helmet is split up into front right, front left, rear right, and rear left. Each section contains one impact location.
    b. All locations were midway between the midsagittal plane and transversal plane of the headform and located 65 mm above the test line. The right front and left rear locations were tested with the flat anvil and the right rear and left front locations were tested with the hemispherical anvil.

Figure A-5. Impact Locations on Helmet

7. Attach the flat anvil to the test fixture.

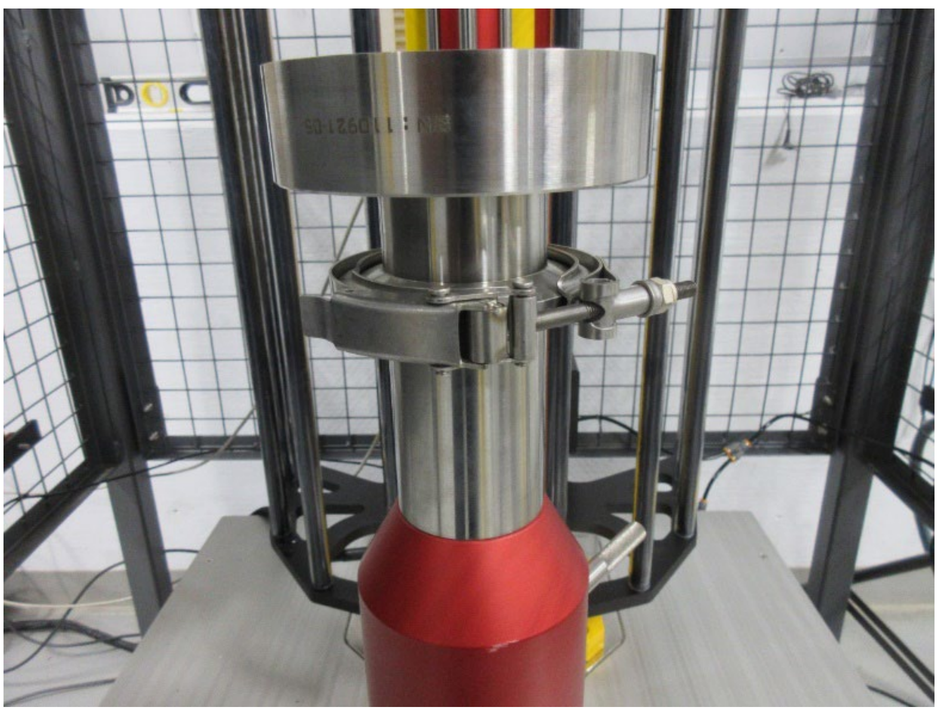

Figure A-6. Flat Anvil Attached to Fixture

8. Place the test helmet onto the headform and position according to the HPI (as measured). Tighten the chinstrap only enough to prevent slippage during freefall, do not overtighten.
    a. If needed, place a piece of foam under the chin strap to act as a chin surface during testing.

Figure A-7. Measuring the HPI

9. Mark the impact location on the anvil in a water-based marker or wax pencil.
10. Line up the impact site on the anvil with the impact site on the test helmet.
11. Take at least the following pre-test photos:
    a. Location of the test line on the test helmet.
    b. Helmet/headform lined up with the anvil from the side.
    c. Helmet/headform lined up with the anvil from the front.
    d. Test placard.
12. Close and lock the gate.
13. Turn on the lights for the high-speed camera.
14. Turn on the camera but do not arm.
15. Input the test.id., test position, and type of anvil into the software.
16. Record the temperature and humidity.
17. Raise the drop assembly to the height necessary to achieve the required impact speed (hemispherical anvil: 5.0 m/s – 5.4 m/s, flat anvil: 5.8 m/s – 6.2 m/s).
    a. Once the trolley has cleared the velocimeter, arm the high-speed camera.
18. Record the drop height.
19. Release the drop assembly and trigger the data acquisition system simultaneously to record the acceleration-time trace.
20. Export the data from the test equipment. Record the following results of the test:
    a. Peak accelerations (reported in g) must be rounded to the nearest integer.[22]
    b. Dwell times (reported in ms) must be rounded to the tenths place.
21. Turn off the lights and download the high-speed video.

[22] 0.5 rounds up

22. Take at least the following post-test photos:
    a. Helmet/headform from the side.
    b. Helmet/headform from the front.
    c. Any damage to the helmet.
    d. Helmet label and inventory number.
23. Repeat steps 8-22 for the same helmet, anvil, and impact location. The distance between the two impact locations should not be more than 1.9 cm.
    a. If any piece of the helmet breaks off during a test, remove it for the remaining tests and note the damage and removal.
24. Repeat steps 8-23 for the same helmet and anvil at the second impact location.
    a. Reposition the helmet as necessary after each impact to realign the helmet with the HPI.
25. Replace the flat anvil with the hemispherical anvil and repeat steps 8-24. This will give a total of 8 tests per test helmet.
26. After all 8 tests are performed, take additional pictures of any damage to the test helmet.
27. After conducting the final test in a set of repeats, perform another series of check drops (step 4) with the same headform.
    a. Ensure that at least one of the three drops recorded an acceleration greater than 375 g, and that the average of the pre-test checks and the average of the post-test checks do not differ by more than 15 g.

4. **<u>Retention System (based on FMVSS No. 218)</u>**

Retention system test machine with complete and modular helmets (5 repeats)

1. Select the appropriately sized, ASTM half magnesium headform for the helmet to be tested, based on the helmet discrete size measurement.
2. Create test placards for each test that include test name, test number, helmet manufacturer/model, helmet inventory number, headform size.
3. Secure the headform to the retention system test machine.

Figure A-8. Headform Attached to Retention System Fixture

4. Place the test helmet onto the headform and position according to the HPI (as measured).

Figure A-9. Measuring HPI

5. Fasten the retention system around the two freely moving rollers (diameter of 1.3 cm and a 7.6 cm center-to-center separation). Ensure the helmet's buckle avoids contact with the rollers.

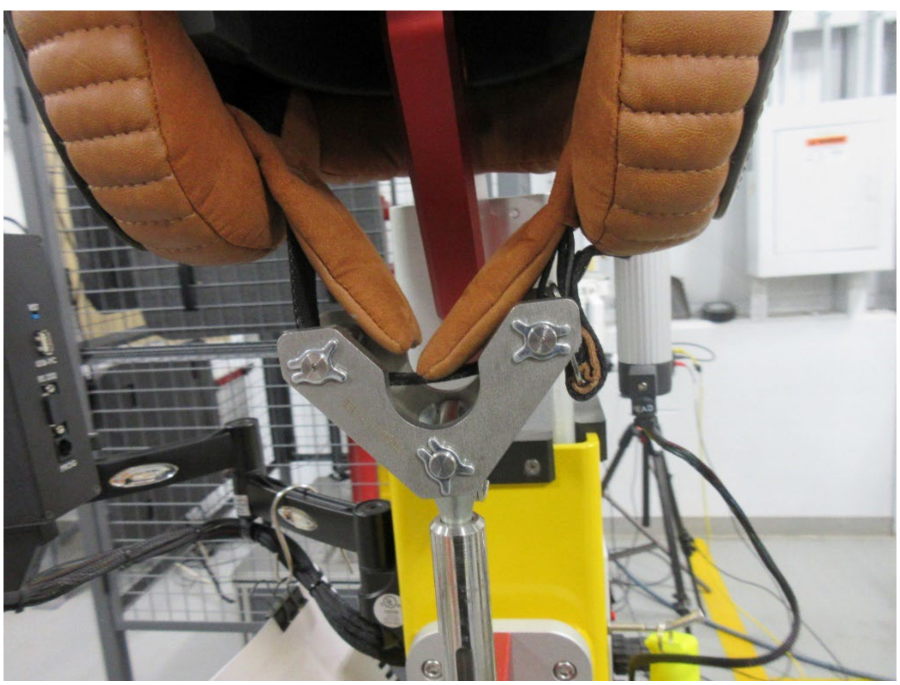

Figure A-10. Retention System Attached to Rollers

6. Place the upper LVDT on the apex of the helmet.
7. Take at least the following pre-test photos:
    a. Helmet/headform from the front.
    b. Helmet/headform from the side.
    c. Close up of chin strap on the rollers.
8. Start recording real-time video.
9. Press start on the retention system machine. The machine will:
    a. Apply a pre-load of 22.7 kgf (+4.5 kgf, - 0 kgf) in the direction normal to the basic plane and hold for 30 seconds.
    b. Record the vertical distance between the apex of the helmet (upper LVDT) and the extremity of the adjustable portion of the retention system test device (lower LVDT).
    c. Increase the load to 136 kgf (+0 kgf, - 4.5 kgf) at a rate of 2 cm/min (must be 1 – 3 cm/min) measured between the roller assembly and the headform. Maintain the load for 120 seconds (+0 s, - 10 s).
    d. After 120 seconds (+0 s, - 10 s) at the full test load, measure and record the vertical distance between the apex of the helmet (upper LVDT) and the extremity of the adjustable portion of the retention system test device (lower LVDT).
    e. Release the load.
10. Stop recording video.
11. Export the data from the machine using the software.
12. Take at least the following post-test photos:
    a. Helmet/headform from the front.
    b. Helmet/headform from the side.
    c. Close up of chin strap on the rollers.
    d. Any damage to the retention system.
    e. Helmet label and inventory number.

5. Chin Bar (based on BSI 6658, Appendix R)

Drop tower with complete and modular helmets (5 repeats)

1. Select the appropriately sized, ASTM full magnesium headform for the helmet to be tested, based on the helmet discrete size measurement.
2. Create test placards for each test that include test name, test number, helmet manufacturer/model, helmet inventory number, headform size.
3. Attach the headform to the test fixture so that the headform is angled backwards 28° below the horizontal.

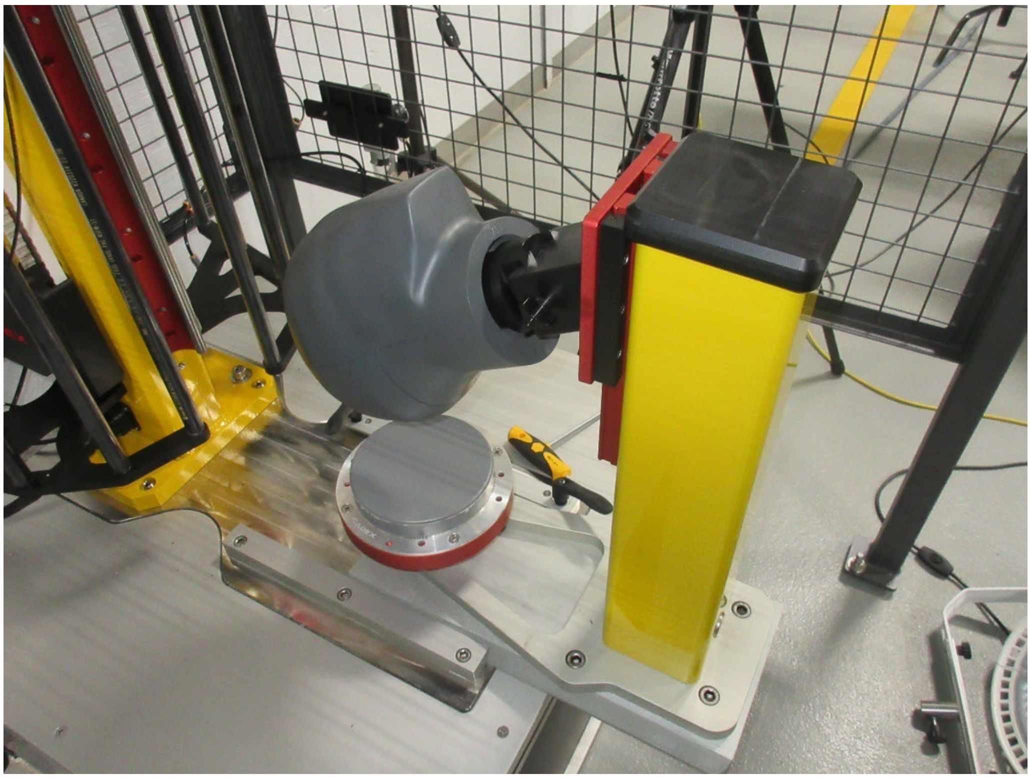

Figure A-11. Headform Attached to Chin Bar Fixture

4. Place the helmet onto the headform and adjust according to the HPI (as measured). Secure the helmet onto the headform as tight as possible using the retention system straps.

Figure A-12. Measuring HPI

5. Raise the adjustable support to lightly contact the rear of the helmet shell. This adjustable support is topped by a layer 23 +/- 1 mm thick of natural vulcanized rubber complying with BS 1154.

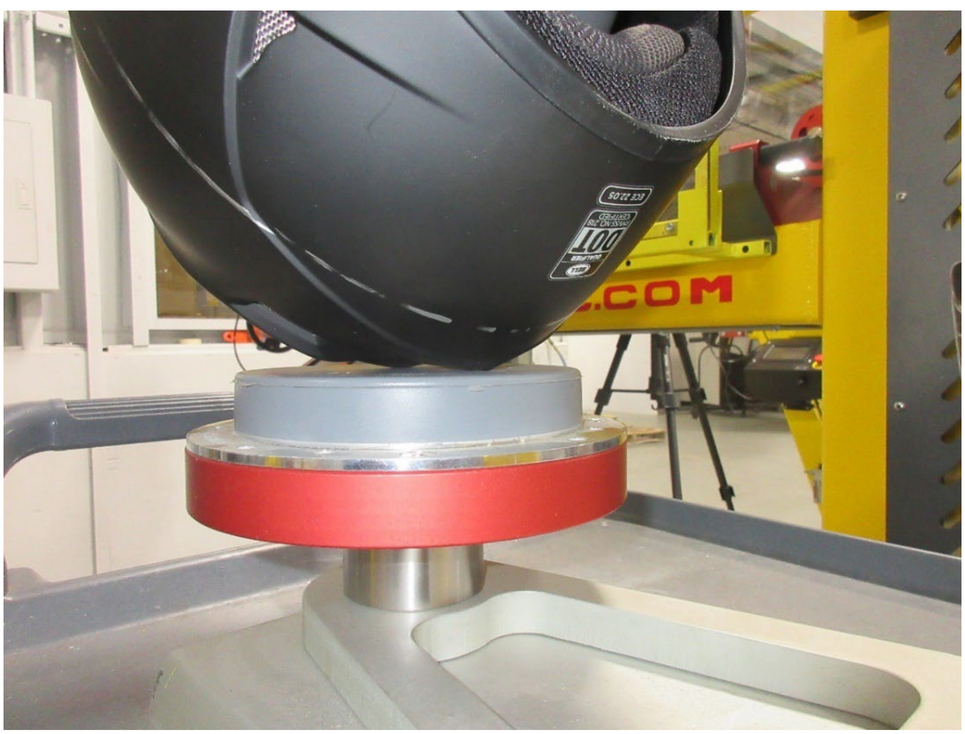

Figure A-13. Helmet Supported by Rubber Pad

6. Lower the striker (mass of 5 kg (+/- 0.05 kg)[23] and having a flat impact face of diameter 130 +/- 3 mm with an accelerometer measuring within 5° from vertical) to line up the desired impact location of the helmet. Unless otherwise noted, this desired location will be the center of the chin bar.
    a. If the center of the chin bar cannot be reached, align as close to the center of the chin bar without contacting equipment

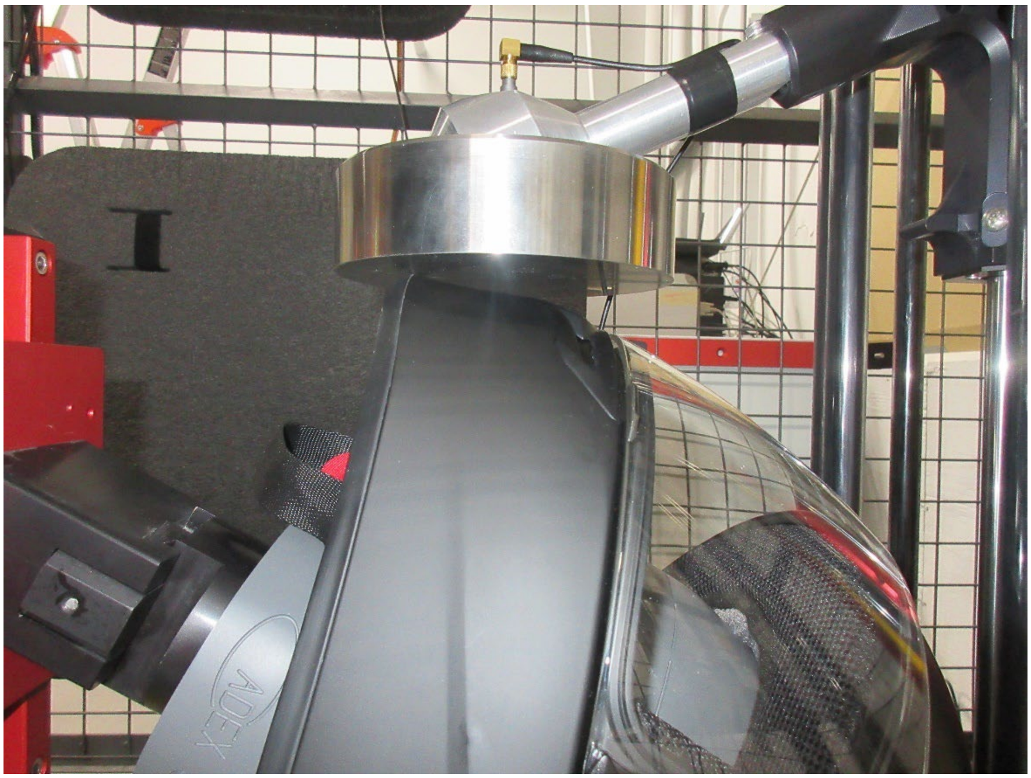

Figure A-14. Striker Aligned with Chin Bar

7. Take at least the following pre-test photos:
    a. Close up of helmet/headform/striker from the side.
    b. Close up of helmet/headform/striker from the apex of the helmet.
8. Close and lock the gate.
9. Turn on the lights for the high-speed camera.
10. Turn on the camera but do not arm.
11. Input the test.id., test position, and type of anvil into the software.
12. Record the temperature and humidity.
13. Raise the striker to a height necessary to achieve an impact speed of 7 m/s +/- 0.2 m/s.
    a. Once the trolley has cleared the velocimeter, arm the high-speed camera.
14. Drop the striker.
15. Export the data from the test fixture.

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[23] The drop mass purchased and used for this series was designed to meet the BSI standard, which has a tolerance of +0.2/-0 kg for the drop mass. The drop mass used in this series weighed 5.152 kg.

    a. Record the peak deceleration of the striker.

16. Turn off the lights and download the high-speed video.
17. Take at least the following post-test photos:
    a. Close up of helmet/headform/striker from the side.
    b. Close up of helmet/headform/striker from the apex of the helmet.
    c. Any damage to the chin bar after removing the helmet from the fixture.
    d. Helmet label and inventory number.
18. Examine the chin bar and its lining/padding for any damage. It must not develop or generate any additional hazard for the wearer and any internal padding must remain in place.

6. **Positional Stability (based on ASTM F1446-11a, Section 12.7.2)**

Positional stability (aka roll off) machine with full helmets (15 repeats)

1. Select the appropriately sized, ASTM full urethane headform for the helmet to be tested, based on the helmet discrete size measurement.
2. Create test placards for each test that include test name, test number, helmet manufacturer/model, helmet inventory number, and headform size.
3. Attach the headform to the plate on the roll off fixture in the 45° face down configuration.

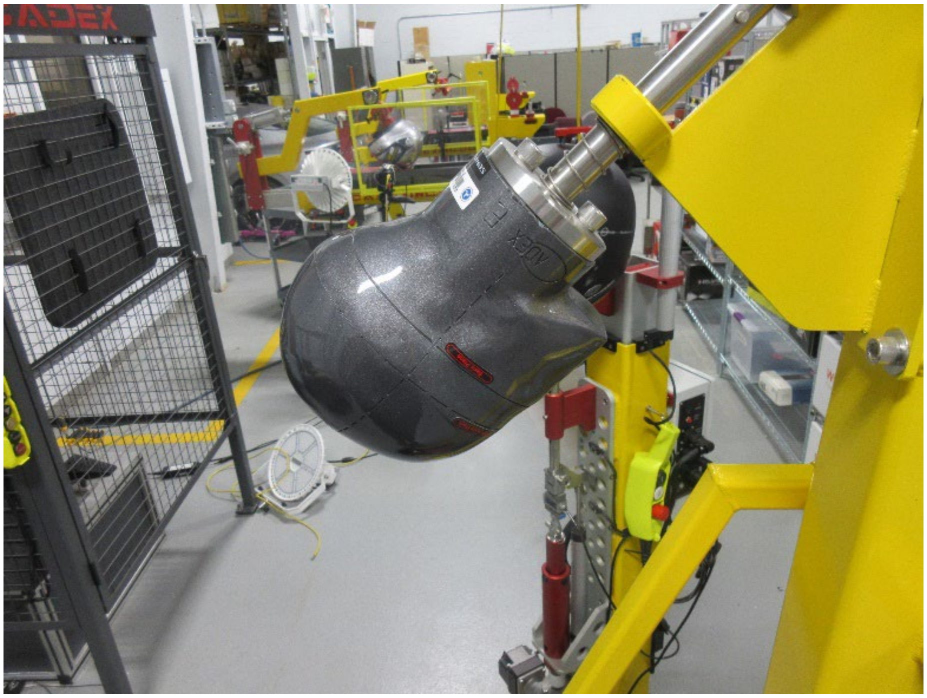

Figure A-15. Headform Attached to Positional Stability Fixture

4. Place the helmet onto the headform and adjust according to the HPI (as measured). Secure the helmet onto the headform using the retention system straps and tighten as much as possible.
5. Using the roll off cable (less than 0.2 kg with an elongation of no more than 18 mm/m when a 1,000 N force is applied) and hook attached to the guide rod (0.9 to 1.4 kg, and 600 mm +/- 15 mm between the two end plates), place the hook on the far center edge of the helmet. The cable should be directed over the helmet and along the midsagittal plane and attached to the guide rod. Let the guide rod and drop weight (10 kg +/- 0.05 kg) hang.

Figure A-16. Hook Attached to Test Helmet

6. Take at least the following pre-test photos:
    a. Helmet/headform from the side.
    b. Helmet/headform from the front.
    c. Close up of the location of the hook on the helmet.
7. Turn on cameras and lights. Start recording high-speed video.
8. Holding the top end of the guide rod steady, raise the weight to the top end of the guide rod. Drop both the weight and the guide rod to run the test.
9. Turn off the lights and download the high-speed video.
10. Take at least the following post-test photos:
    a. Helmet/headform from the side.
    b. Helmet/headform from the front.
    c. Any damage to the retention system.
    d. Helmet label and inventory number.

7. **Face Shield Penetration (based on ECE R22, Section 7.8.2)**

Drop tower with full helmets (15 repeats)

1. Select the appropriately sized, ASTM full urethane headform for the helmet to be tested, based on the helmet discrete size measurement.
2. Create test placards for each test that include the test name, test number, helmet manufacturer/model, helmet inventory number, and headform size.
3. Adjust the height of the punch so that it's point will be located 1 mm below the surface of the headform once attached.
4. Attach the headform to the test fixture under the punch (0.3 kg +/- 0.01 kg), face up so that the basic plane is vertical.
    a. The angle of the cone that forms the punch head must be 60° +/- 1 degree.
    b. The radius of the rounded top of the punch head must be 0.5 mm +/- 0.1 mm.
5. Place a contact switch on the headform at the location of the punch to measure contact during the test.

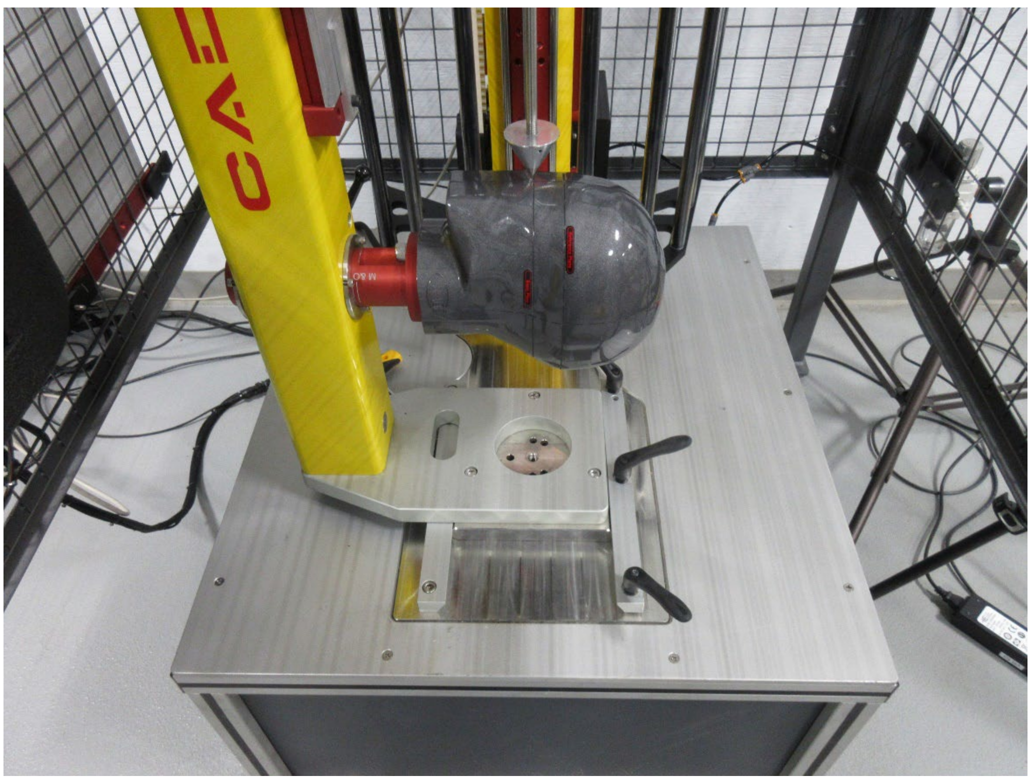

Figure A-17. Headform Attached to Face Shield Fixture

6. Place the helmet on the headform and adjust to match the HPI (as measured). Tighten the chin strap as much as possible.
    a. If the helmet has both a face shield and a sun visor, lower both layers and test them together.

Figure A-18. Face Shield Penetration Test Setup

7. Take at least the following pre-test photos:
    a. Full set-up.
    b. Close up of helmet/headform/punch from the side.
    c. Close up of helmet/headform/punch from the apex of the helmet.
    d. Close up of helmet/headform/punch from above the punch.
8. Close and lock the gate.
9. Turn on the lights for the high-speed camera.
10. Turn on the camera but do not arm.
11. Input the test.id., test position, and type of anvil into the software.
12. Record the temperature and humidity.
13. Raise the drop mass (3 kg +/- 0.05 kg) to a height necessary to achieve a velocity of 4.4 +/- 0.2 m/s.
    a. Once the trolley has cleared the velocimeter, arm the high-speed camera.
14. Drop the mass.
    a. Note if the face shield breaks or the punch contacts the headform.
15. Turn off the lights and download the high-speed video.
16. Take at least the following post-test photos:
    a. Helmet/headform/punch from the side.
    b. Helmet/headform/punch from the apex of the helmet.
    c. Helmet/headform/punch from above the punch.
    d. Any damage to the face shield after removing the helmet from the fixture, including any broken pieces and their measured angles.
    e. Helmet label and inventory number.

8. Rigid Projection (based on ECE R22, Method B, Section 7.4.2)

Projection and surface friction test machine with full helmets (15 repeats)

1. Select the appropriately sized, full urethane headform for the helmet to be tested, based on the helmet discrete size measurement.
2. Identify all projections to be tested. External projections are greater than 2 mm above the outer surface of the shell. For this test, the rim of the shell and the upper and lower edges of the visor situated within an area bounded by a sector of 120° divided symmetrically by the vertical longitudinal plane of symmetry of the helmet do not constitute a projection.
    a. If a projection is identified that cannot be tested with the equipment, make notes about the occurrence.

Figure A-19. Example of a Rigid Projection

3. Create test placards for each test that include the test name, test number, helmet manufacturer/model, helmet inventory number, headform size, and projection location.
4. Attach the headform to the helmet support system.
5. Open the safety cage and raise the weight until it clicks into place. Ensure that the strap is not twisted and can move freely.
6. Remove the shear bar (6 mm height, 25 mm width, with the uppermost edges machined to 1 mm radius, case-hardened to a depth of approximately 0.5 mm) from the carriage.
    a. The carriage and shear bar must have a total mass of 5 kg +/- 0.05 kg.
    b. The rollers across the strap must have a diameter of at least 60 mm.
7. Slide the carriage as far backward as possible. Gently pull the strap to get the slack away from the roller and fold it underneath the carriage track.

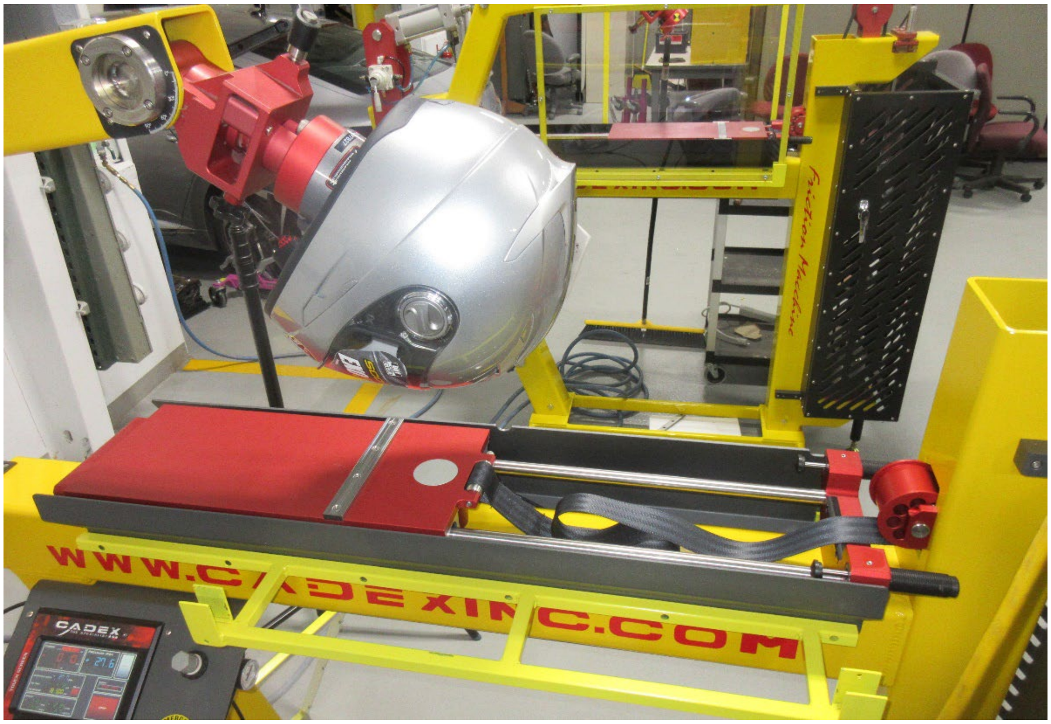

Figure A-20. Helmet Attached to Rigid Projection Fixture

8. Drop the weight (15 kg +/- 0.05 kg) from a height of up to 450 mm and verify that the speed of the unloaded carriage after 250 mm of travel is 4 +/- 0.1 m/s.
    a. This requirement must be verified after every 500 helmet tests or once every three months, whichever is sooner.
9. Re-setup the carriage following steps 5 and 7. Install the shear bar to the carriage.
10. Place the test helmet onto the headform and tip the helmet back so that the front edge of the helmet is displaced by 25 mm from the HPI (as measured). Secure the retention system strap as much as possible and put the visor in the closed position.
11. Adjust the headform support system using the wheel on the machine so that the chosen projection is centered on the carriage and positioned 50 mm from the shear edge. Align the projection with the circular load cell on the front edge of the carriage.
12. Lower the headform onto the load cell until a load of 400 N (+/- 10 N) is reached.

Figure A-21. Rigid Projection Test Setup

13. Take at least the following pre-test photos:
    a. Helmet/headform perpendicular to the direction of travel of the carriage.
    b. Helmet/headform in line with the direction of travel of the carriage.
    c. Close up of the projection.
14. Turn on lights and high-speed camera.
15. Start recording high-speed video.
16. Run the test. The free drop height must be 500 +/- 15 mm.
17. Download the data from the test fixture.
18. Turn off the lights and download the high-speed video.
19. Take at least the following post-test photos:
    a. Helmet/headform perpendicular to the direction of travel of the carriage.
    b. Helmet/headform in line with the direction of travel of the carriage.
    c. After removing the helmet from the headform, any damage to the helmet.
    d. Any piece that sheared off the helmet.
    e. Helmet label and inventory number.
20. Repeat steps 3-20 for each projection identified in step 2.

Appendix B: Time History Data

Impact Attenuation

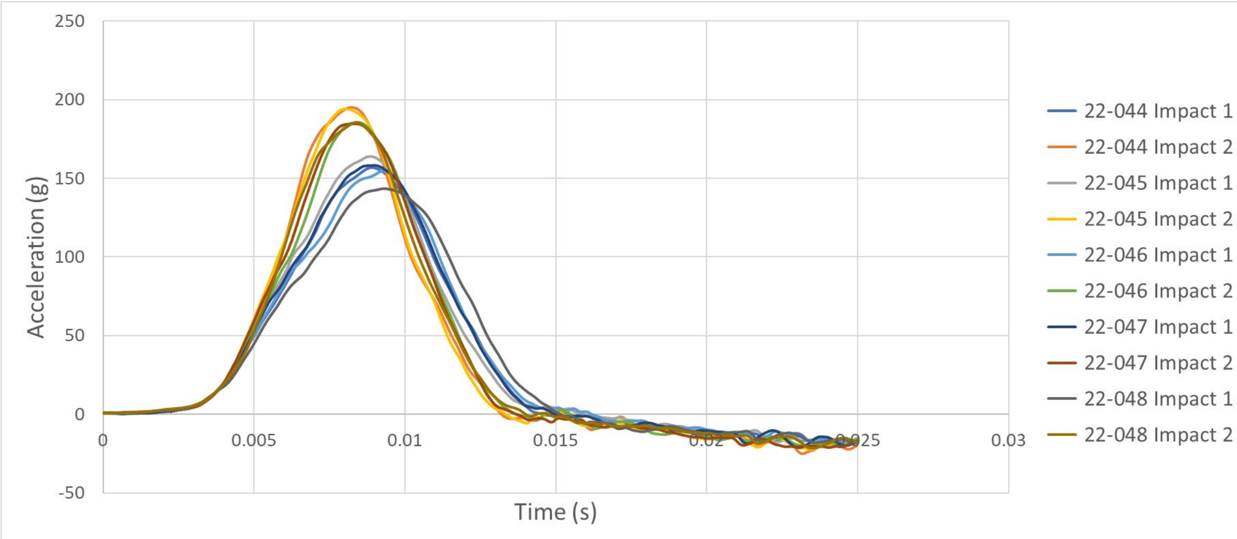

Figure B-1. HJC F70 Right Front Flat Anvil

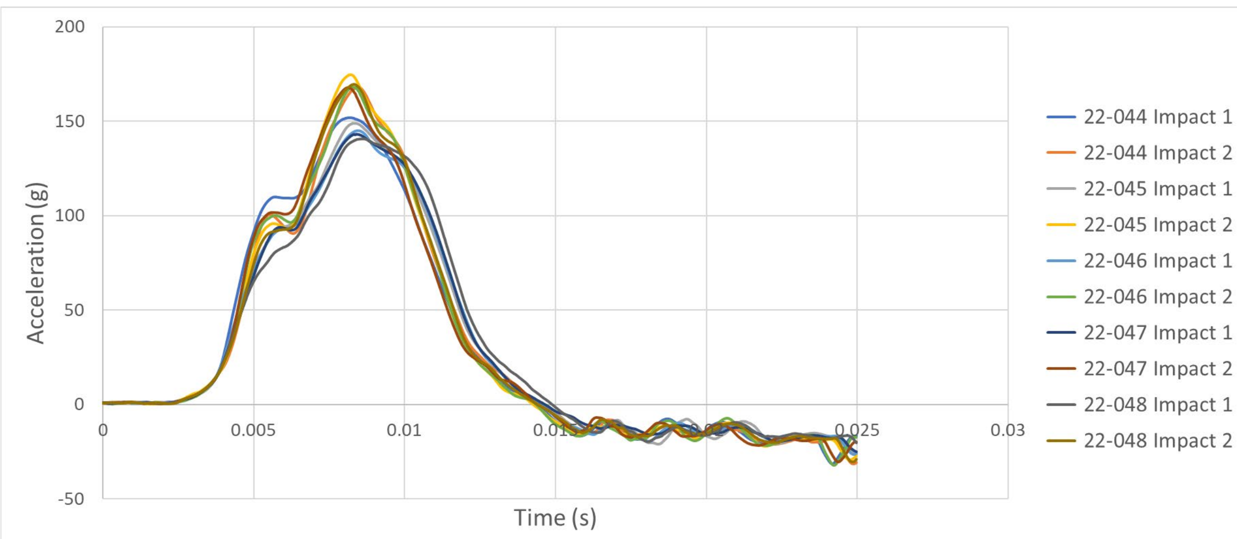

Figure B-2. HJC F70 Left Rear Flat Anvil

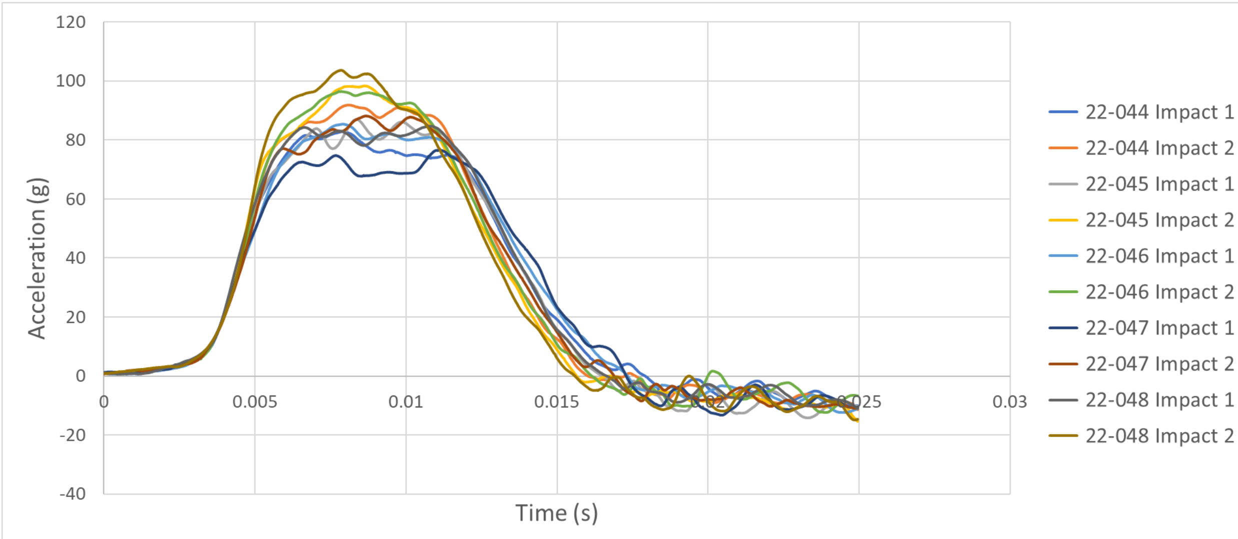

Figure B-3. HJC F70 Right Rear Hemispherical Anvil

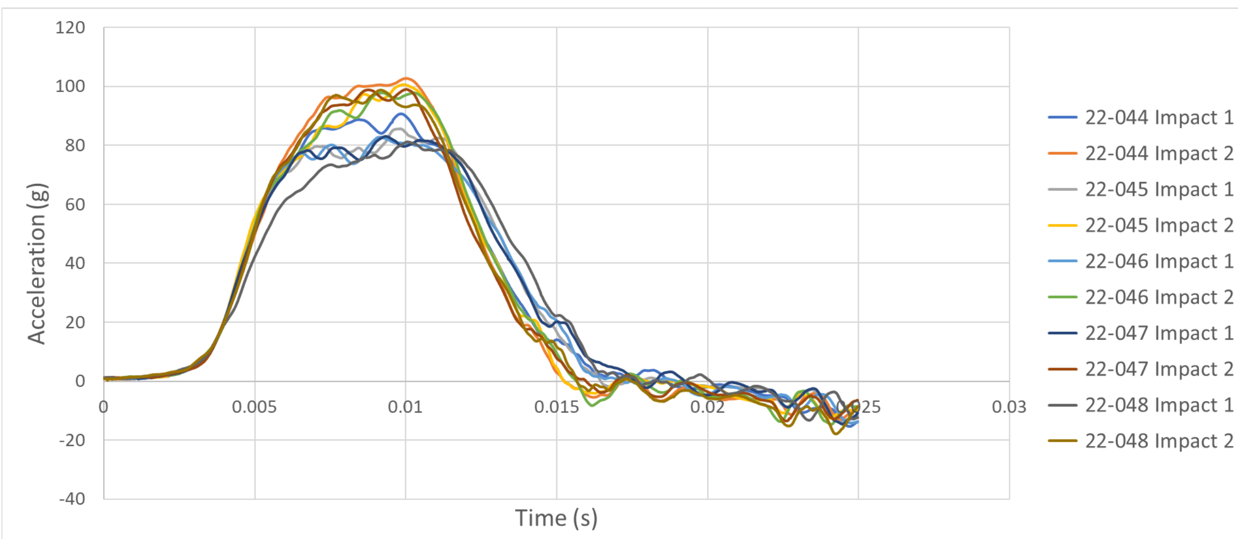

Figure B-4. HJC F70 Left Front Hemispherical Anvil

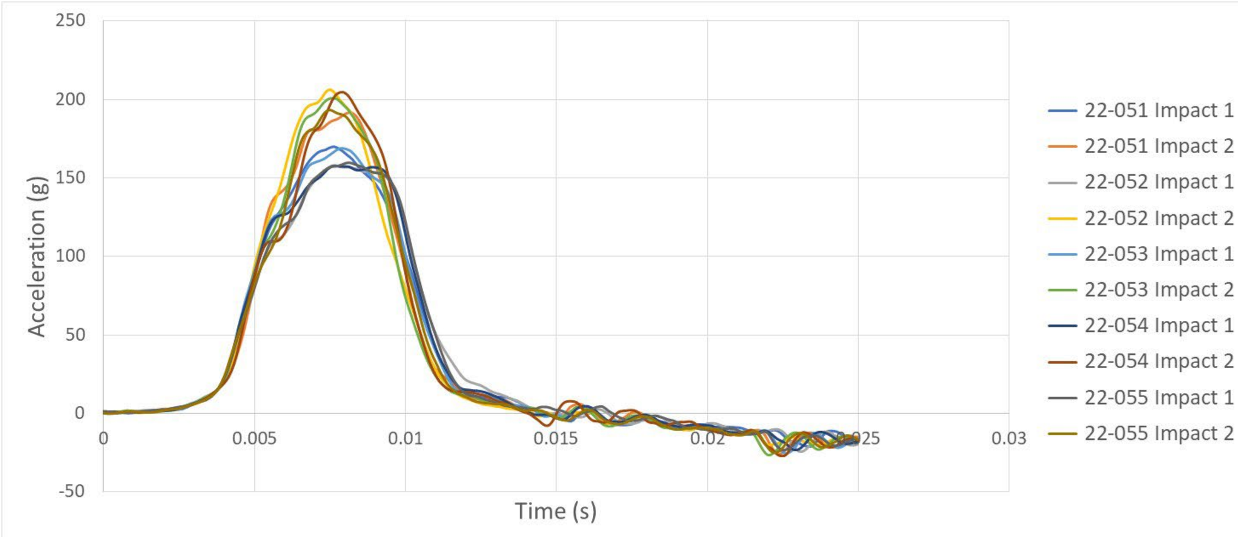

Figure B-5. Bilt Vertex Right Front Flat Anvil

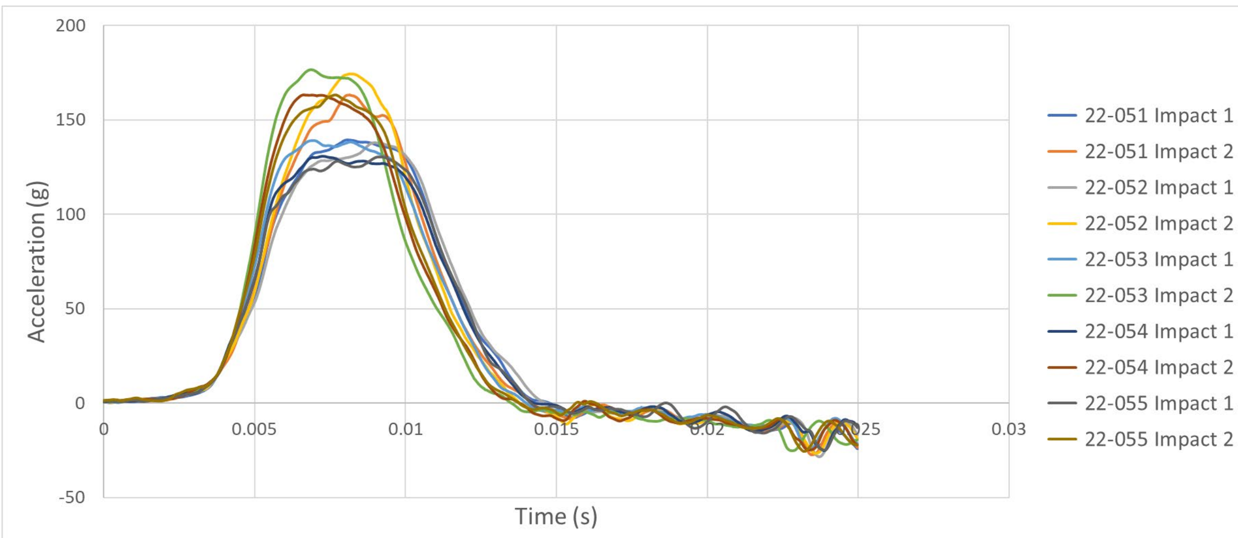

Figure B-6. Bilt Vertex Left Rear Flat Anvil

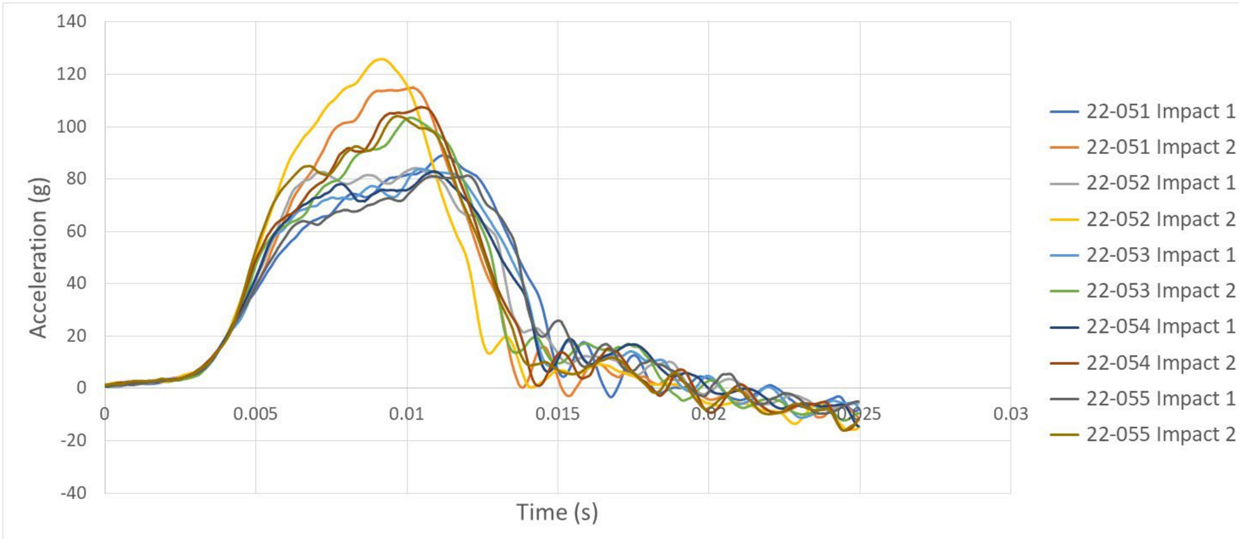

Figure B-7. Bilt Vertex Right Rear Hemispherical Anvil

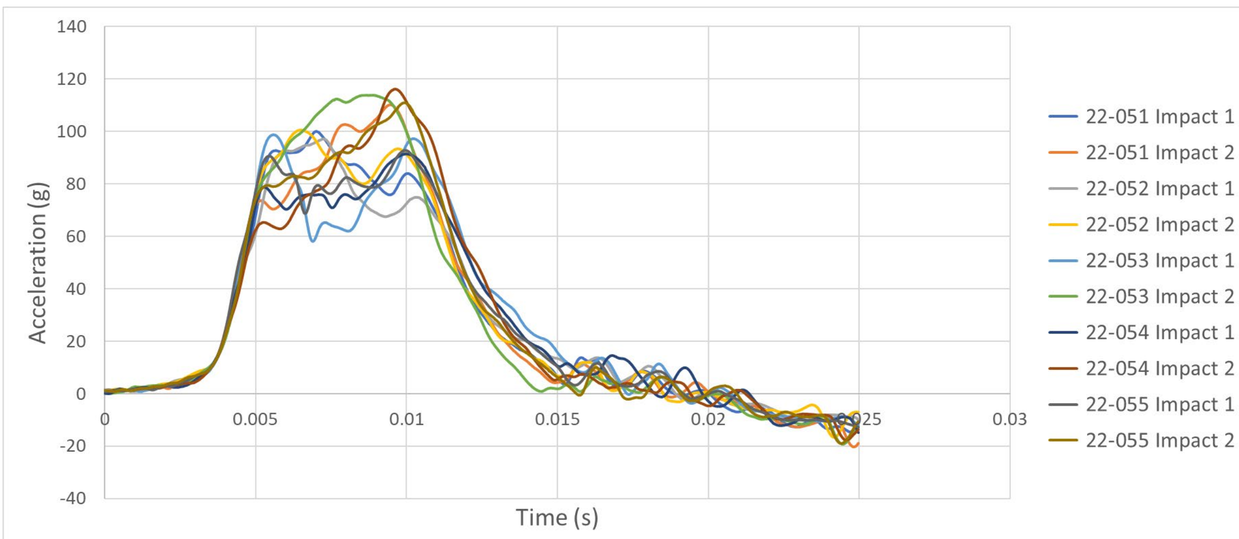

Figure B-8. Bilt Vertex Left Front Hemispherical Anvil

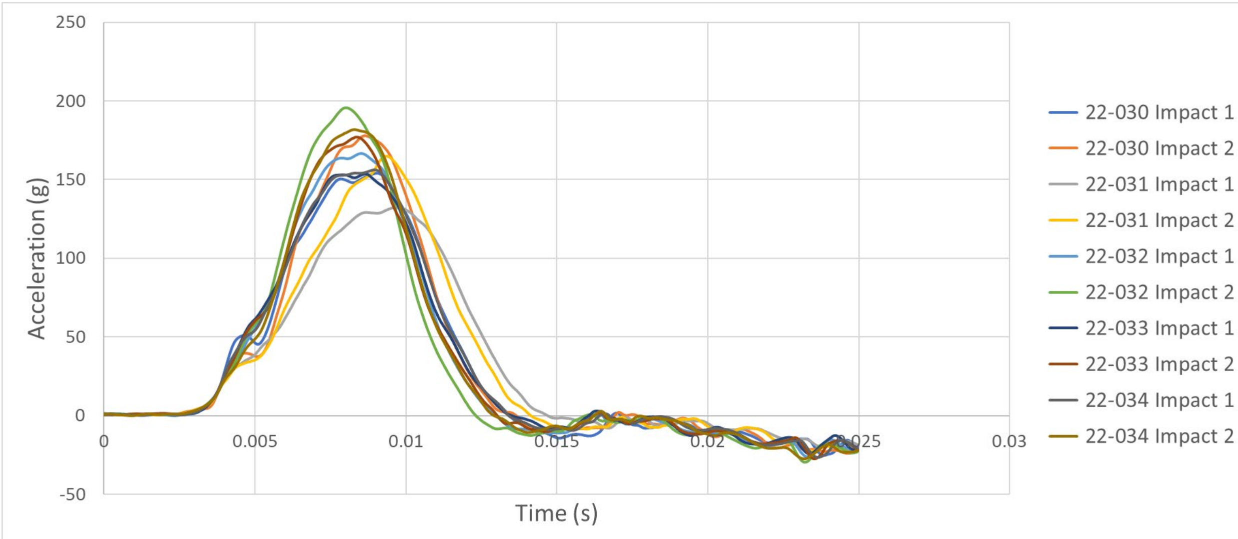

Figure B-9. Scorpion EXO Covert X Right Front Flat Anvil

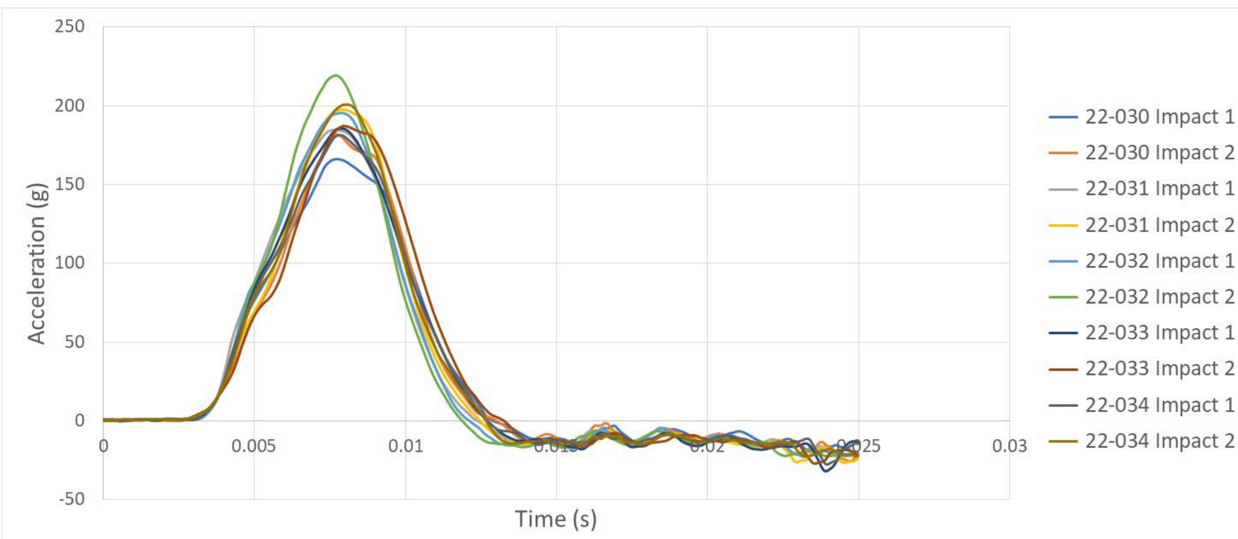

Figure B-10. Scorpion EXO Covert X Left Rear Flat Anvil

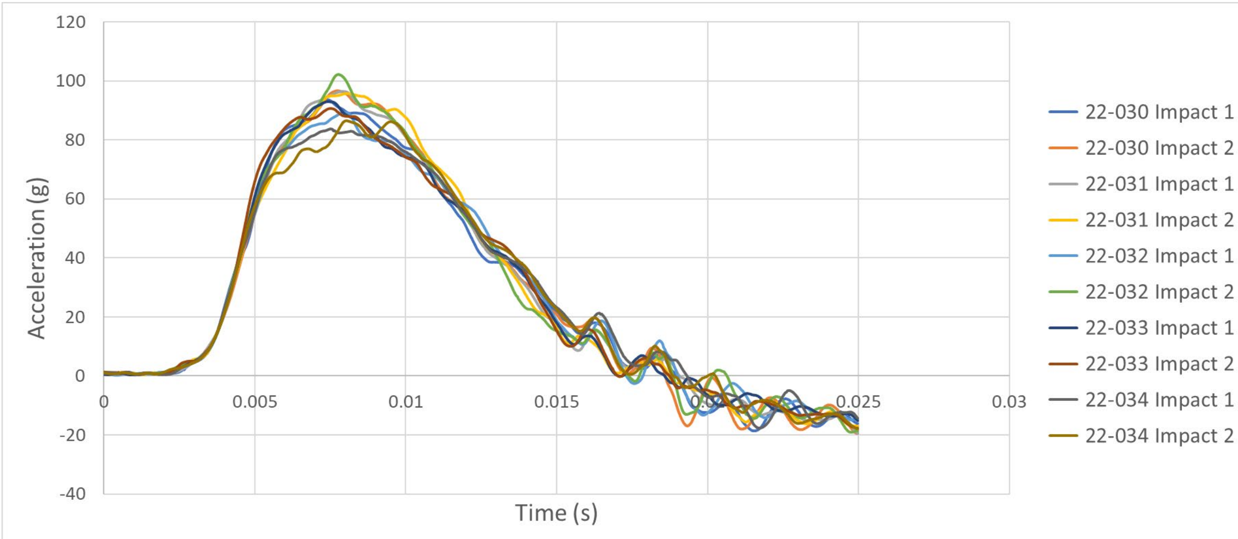

Figure B-11. Scorpion EXO Covert X Right Rear Hemispherical Anvil

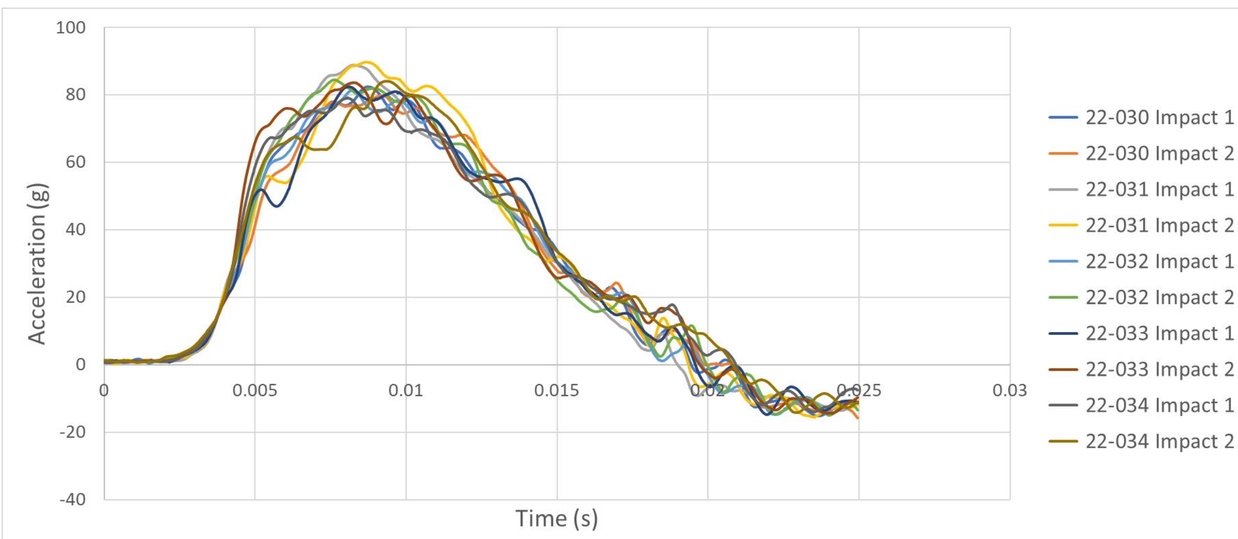

Figure B-12. Scorpion EXO Covert X Left Front Hemispherical Anvil

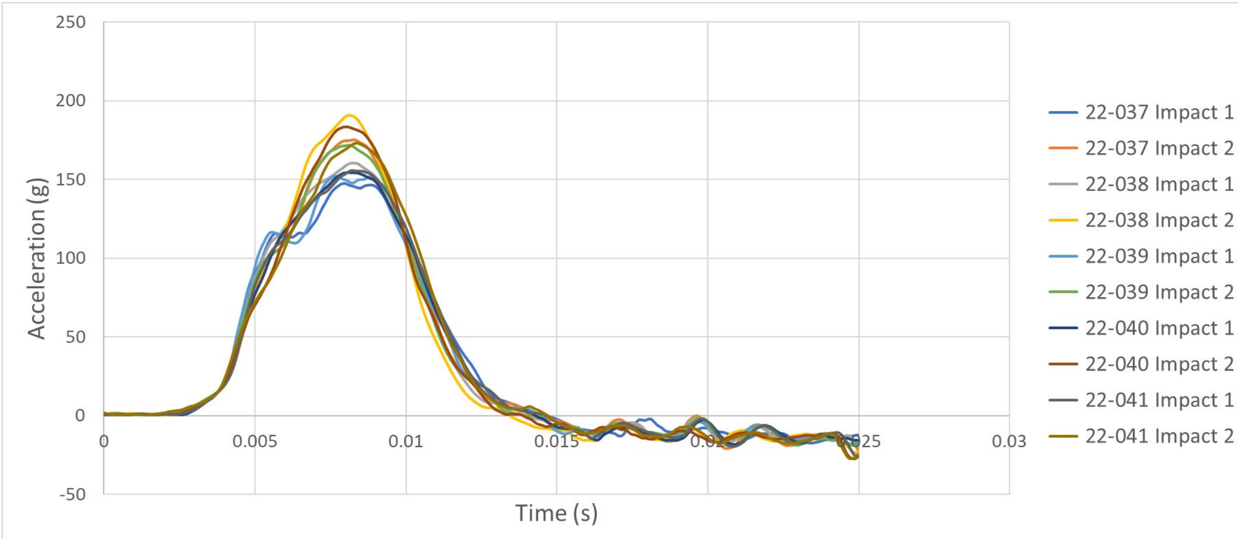

Figure B-13. Shoei Neotec II Right Front Flat Anvil

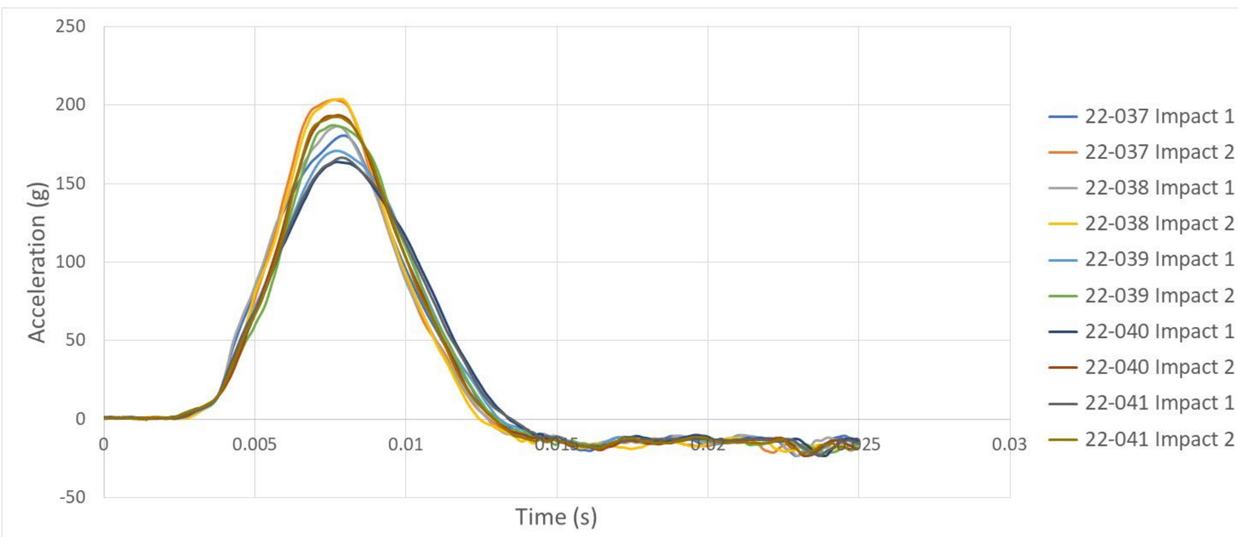

Figure B-14. Shoei Neotec II Left Rear Flat Anvil

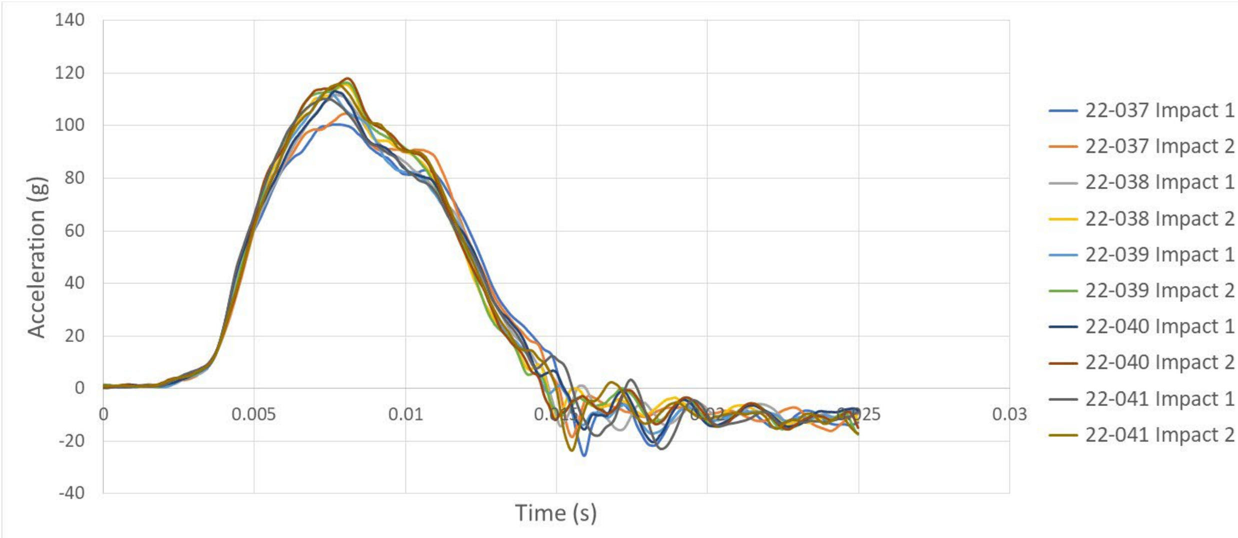

Figure B-15. Shoei Neotec II Right Rear Hemispherical Anvil

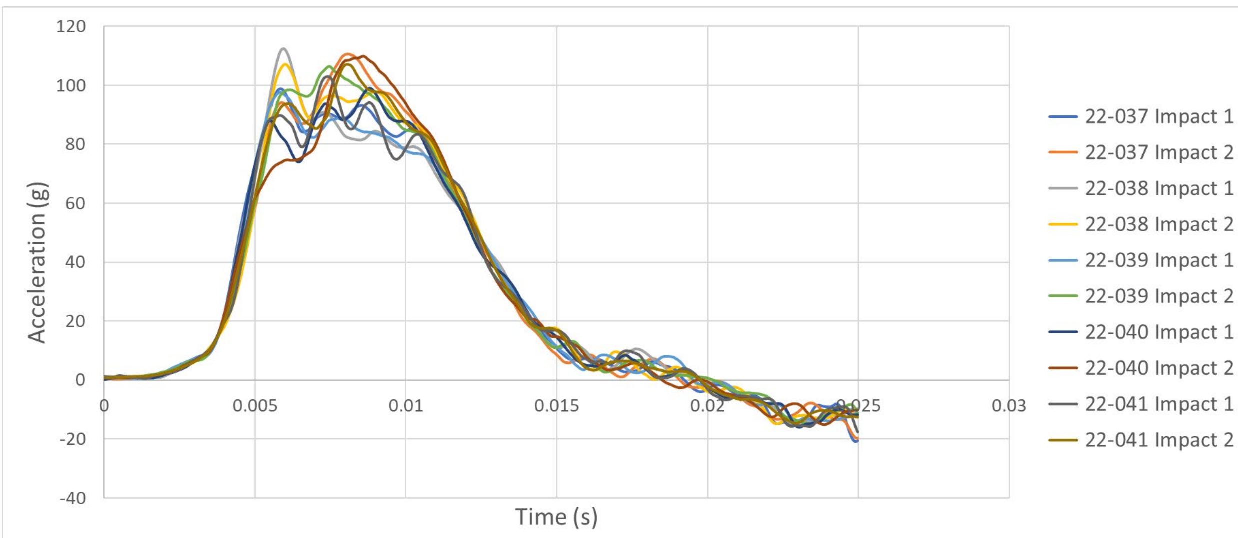

Figure B-16. Shoei Neotec II Left Front Hemispherical Anvil

Retention System

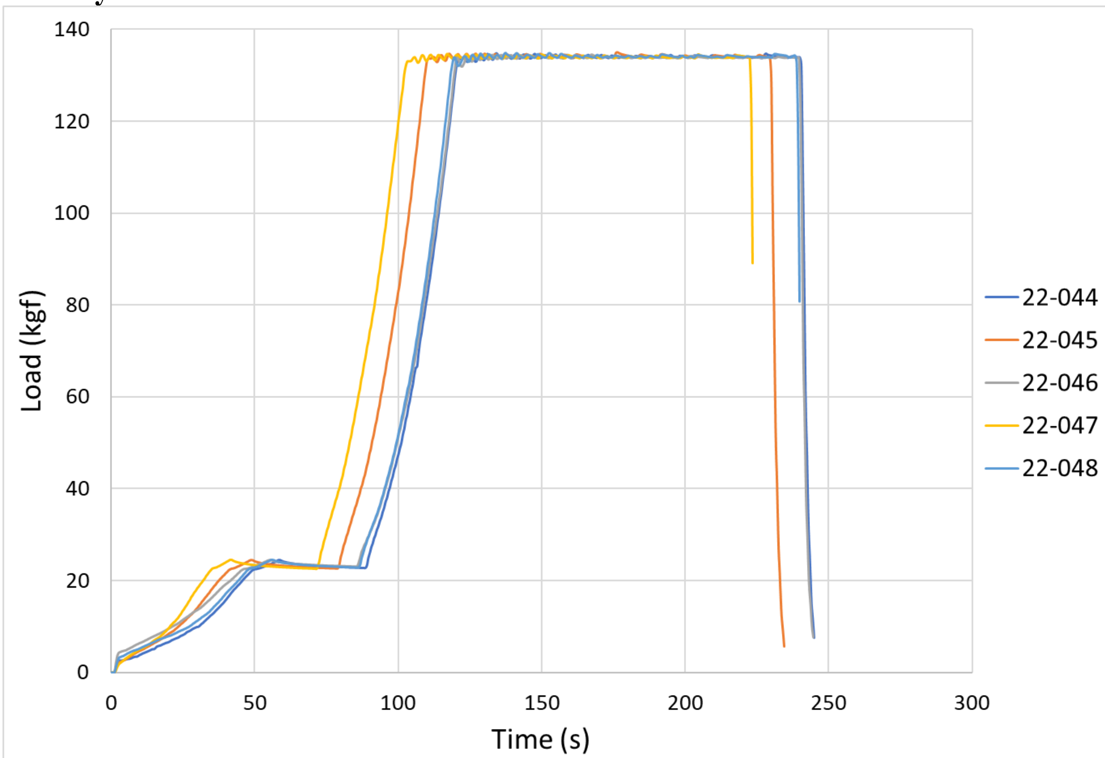

Figure B-17. HJC F70

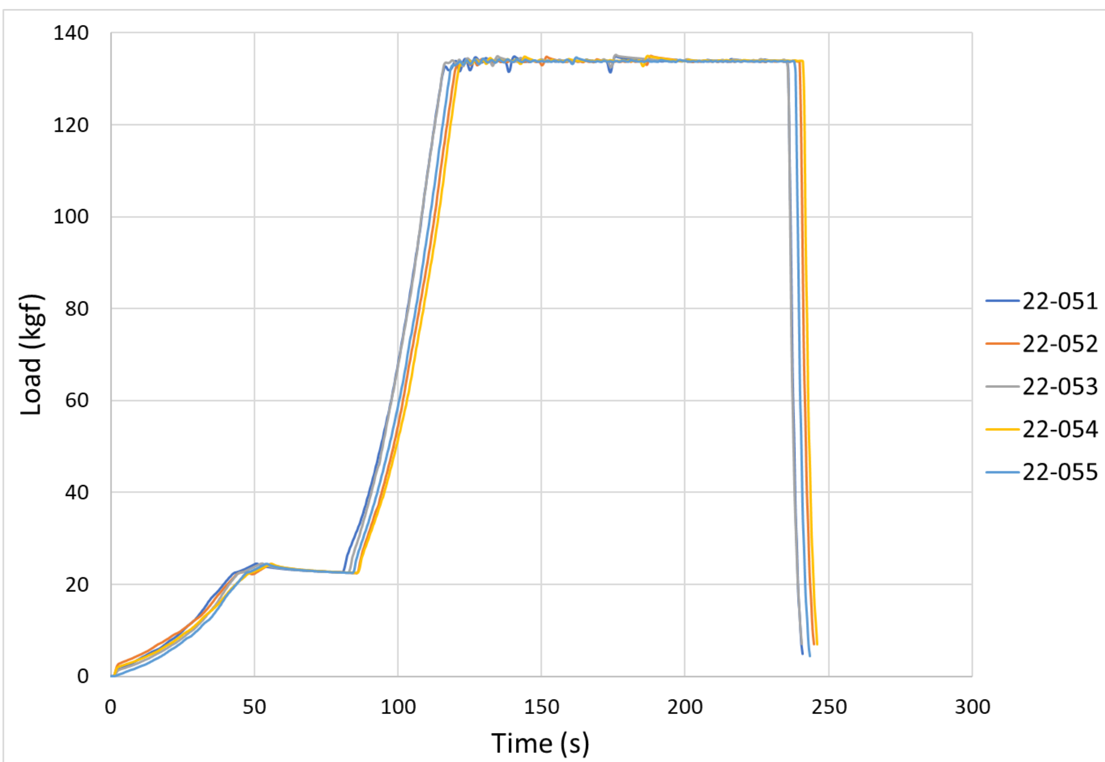

Figure B-18. Bilt Vertex

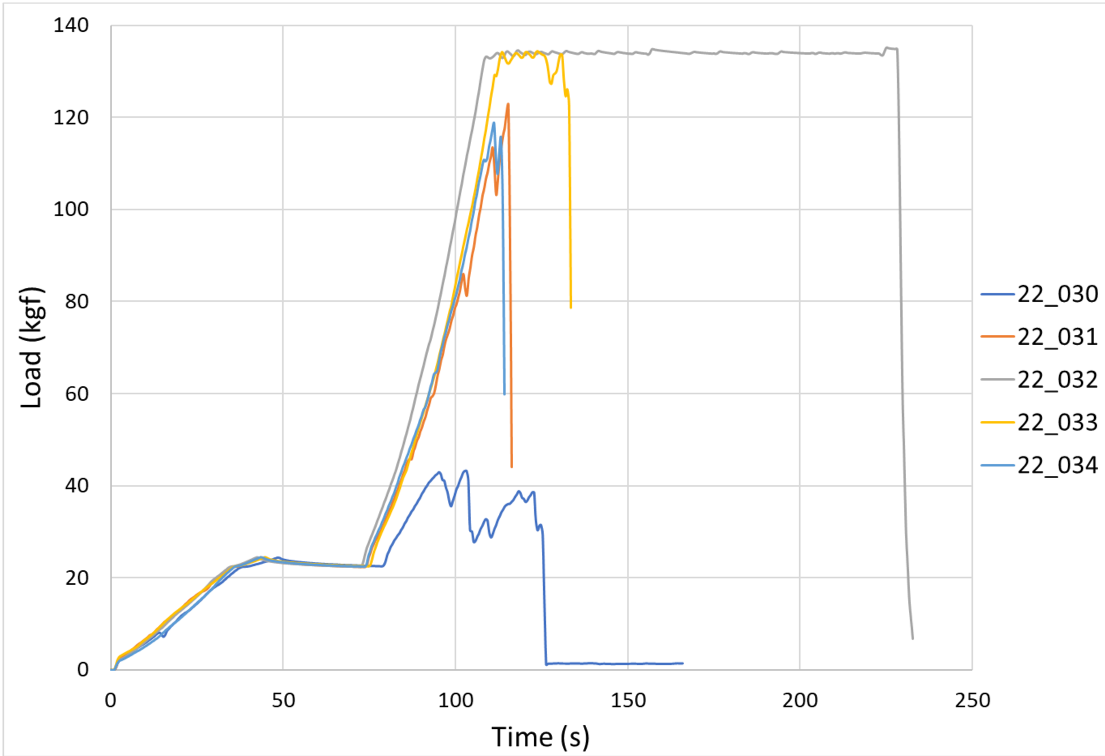

Figure B-19. Scorpion EXO Covert X

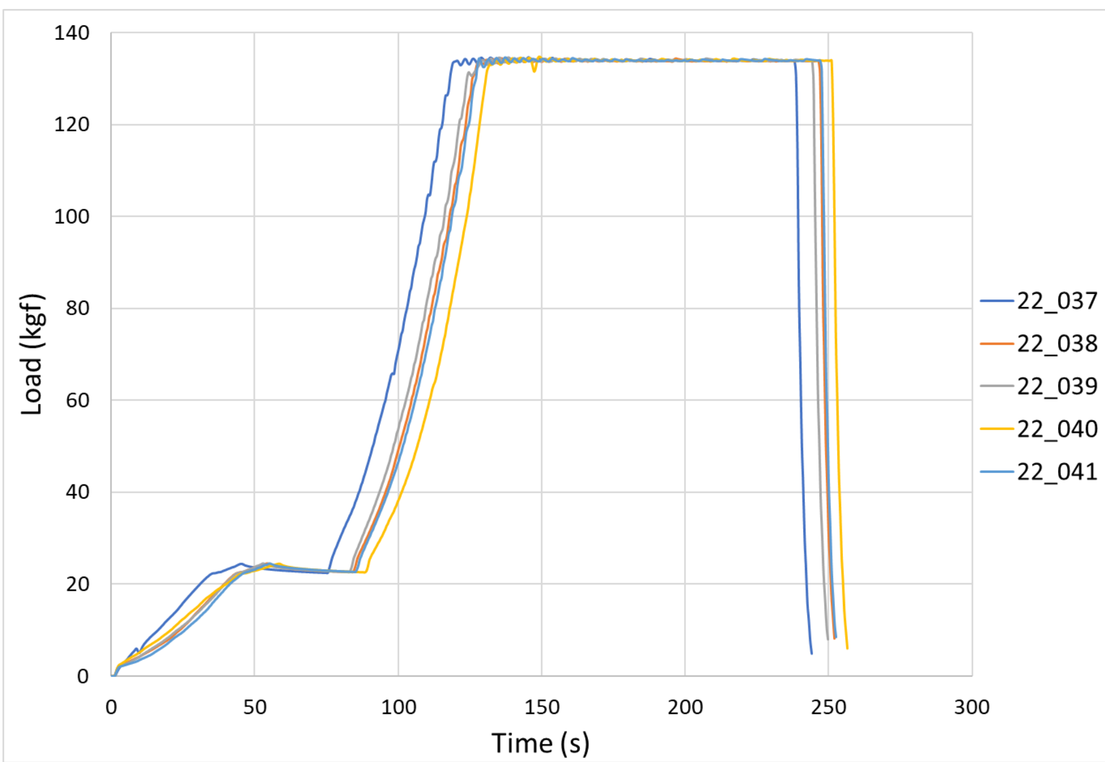

Figure B-20. Shoei Neotec II

Chin Bar

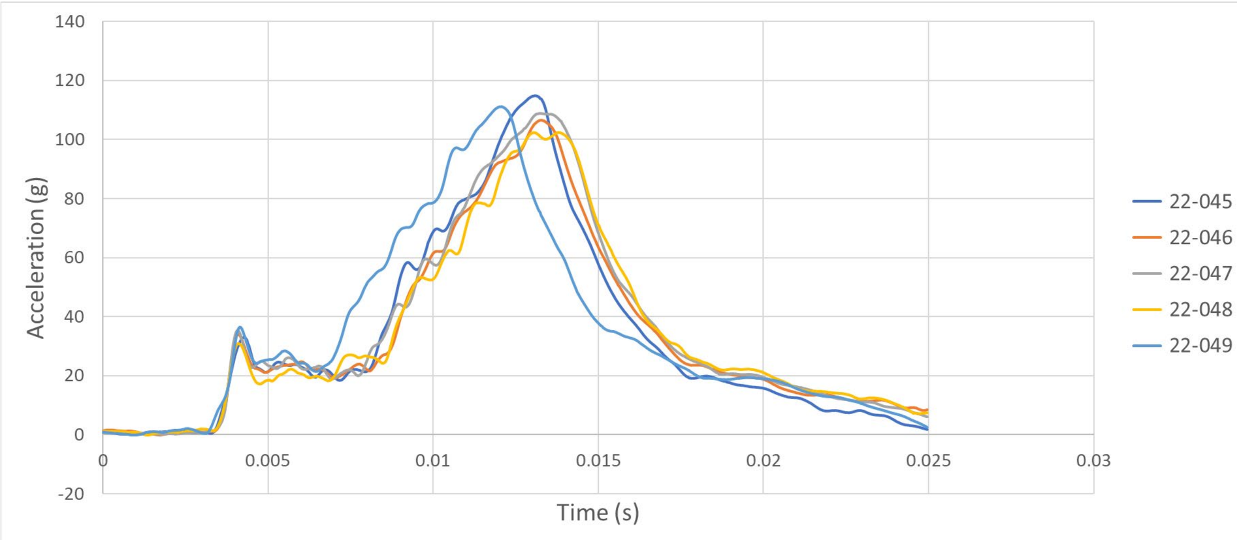

Figure B-21. HJC F70

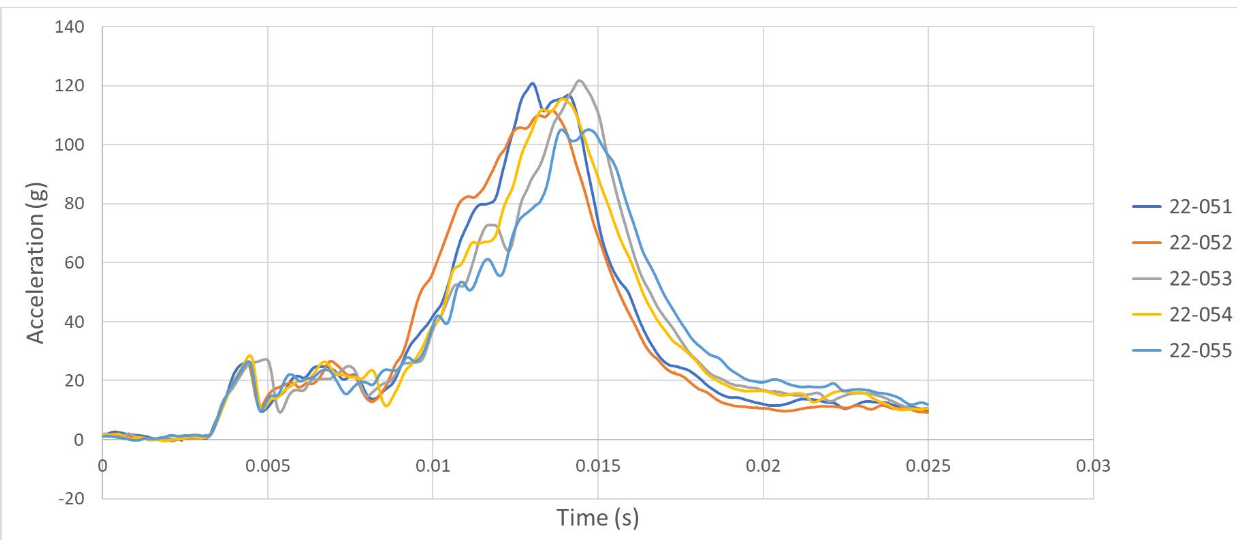

Figure B-22. Bilt Vertex

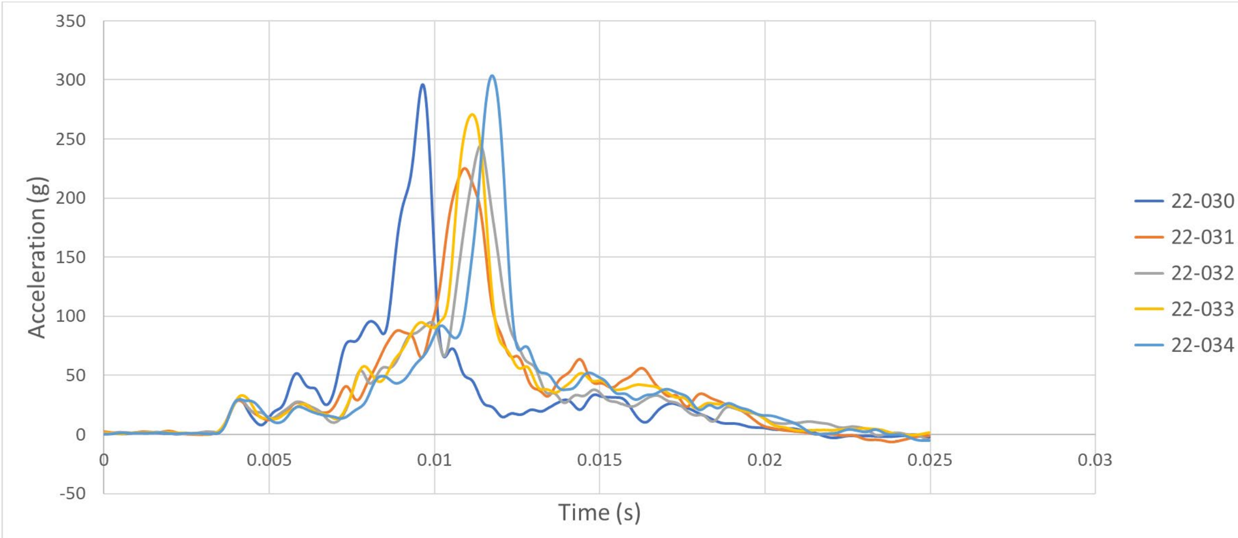

Figure B-23. Scorpion EXO Covert X

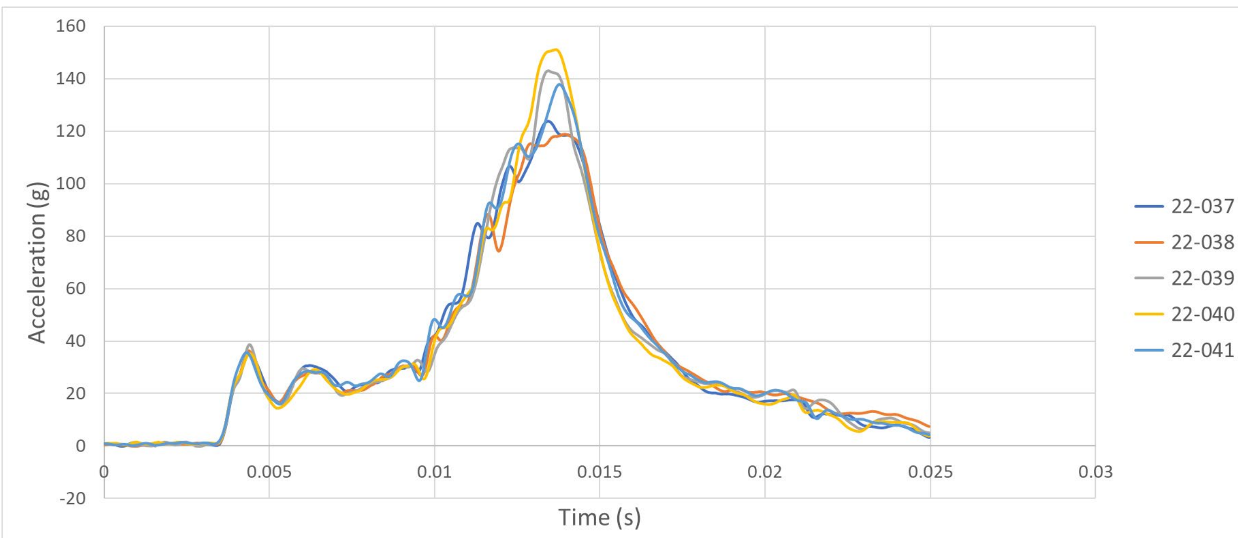

Figure B-24. Shoei Neotec II

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