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This project was performed in cooperation with the US Department of Transportation, Federal Highway Administration, under the research project titled "DEVLEOPMENT AND CRASH TESTING OF A STEEL POST-AND-BEAM BRIDGE RAILING IN COMPLIANCE WITH MASH 2016, TEST LEVEL 4, FOR USE IN CALIFORNIA". This work was performed at the request of Caltrans Division of Engineering Services, Structures and Engineering Services.

16. ABSTRACT

Three full-scale crash tests of the California ST-75 Bridge Rail (ST-75) were completed to meet the Implementation Agreement for Manual for Assessing Safety Hardware (MASH) 2016. California Department of Transportation (Caltrans) needed a MASH 2016 compliant steel post and beam bridge rail to replace existing NCHRP Report 350 (Report 350) rails. The July 2019 Caltrans "MASH Implementation for California Bridge Railings" identified the ST-75 as a design intended to replace existing Caltrans bridge rails: the ST-10, ST-20S, ST-30 and the ST-70.

The ST-75 is a 914 mm (36 in) vehicular and a 1067 mm (42 in) high combination (vehicular and bicycle) bridge rail. The rail elements are ASTM A500/A500M, Grade B, hollow structural 203 mm x 102 mm x 8 mm (8 in x 4 in x 5/16 in) sections bolted to A709 Grade 36 steel posts. The post spacing is 3m (10 feet) and are anchored using ASTM F1554, Grade 105, bolts to a 6-inch-high concrete curb. The tested ST-75 rail was 28.7 m (94 feet) long and constructed and tested at the Caltrans Dynamic Test Facility in West Sacramento, CA. The first 21.3 m (70 feet) of the rail was mounted to a simulated bridge deck overhang which connected to a concrete anchor block with last 7.3 m (24 feet) of the downstream rail mounted to a reaction slab.

The full suite of MASH 2016 Test Level 4 (TL-4) crash tests were conducted; Test 4-10 (1100C), 4-11 (2270P) and 4-12 (10000S) (test designations 110MASH4C19-01, 110MASH4P18-02, 110MASH4S19-02 respectively). All three tests met MASH 2016 evaluation criteria for TL-4 longitudinal barriers. The results of all three tests were within the limits of MASH 2016 guidelines.

17. KEY WORDS

Barriers, Crash Test, Bridge rail, Vehicle Impact Test, Steel, Post-and-beam

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DEVELOPMENT AND CRASH TESTING OF A STEEL POST-AND-BEAM BRIDGE RAILING, CALIFORNIA ST-75

STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
DIVISION OF RESEARCH, INNOVATION AND SYSTEM INFORMATION
OFFICE OF SAFETY INNOVATION AND COOPERATIVE RESEARCH
ROADSIDE SAFETY RESEARCH GROUP

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Report Prepared by .... David Whitesel, P.E.

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DEPARTMENT OF TRANSPORTATION
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DISCLAIMER STATEMENT

UNCERTAINTY OF MEASUREMENT STATEMENT

The Caltrans Roadside Safety Research Group (RSRG) has determined the uncertainty of measurements in the testing of roadside safety hardware as well as in standard full-scale crash testing of roadside safety features. The results contained in this report are only for the tested article(s) and not any other articles based on the same design. Information regarding the uncertainty of measurements for critical parameters is available upon request by the California Department of Transportation Roadside Safety Research Group.

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1. **Introduction**

1.1. Problem

In 2016, the California Department of Transportation (Caltrans) established a timeline for the implementation of the Manual for Assessing Safety Hardware (MASH) (AASHTO, 2016). MASH is a testing standard for evaluating the safety of roadside hardware. The Caltrans timeline was consistent with the 2015 American Association of State Highway Transportation Officials (AASHTO) and Federal Highway Administration (FHWA) Joint Implementation Agreement. The agreement specifies that new installations of roadside safety hardware comply with MASH 2016 for Federal Aid Eligibility. Caltrans adopted that all bridge rail projects that include permanent and full bridge rail replacements advertised on or after October 31, 2019 meet MASH criteria. Caltrans currently has no MASH-compliant top mounted bridge rails.

1.2. Objective

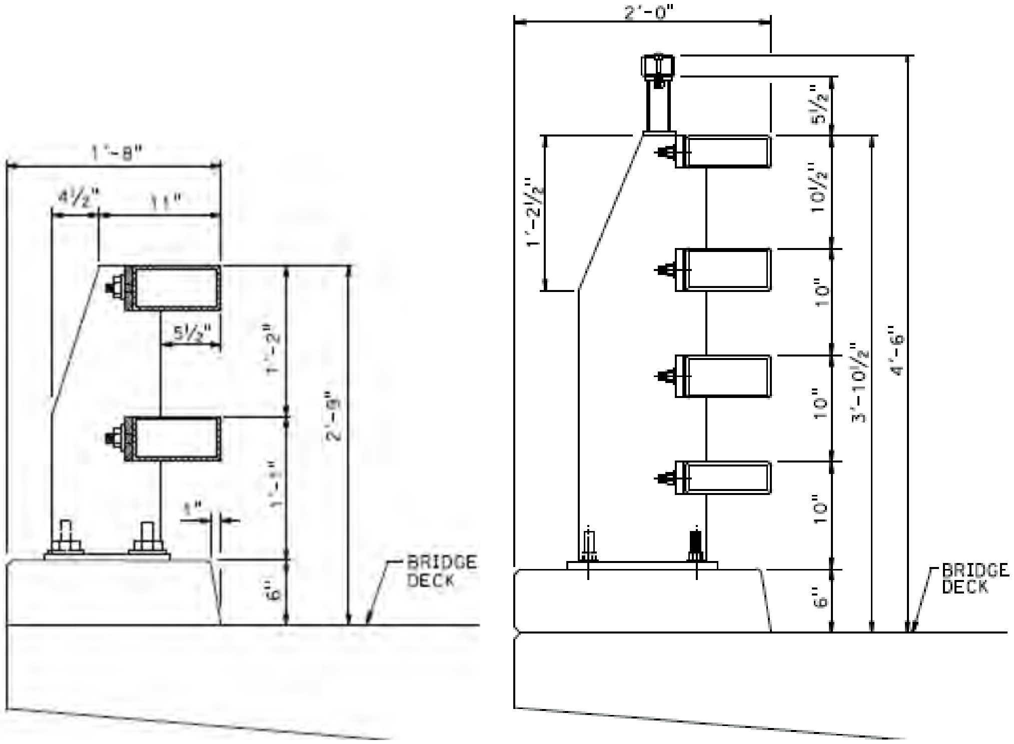
The objective of this research project is to construct a test section of the CA ST-75 and then conduct the required crash tests for MASH 2016 Test Level 4 (TL-4) for longitudinal barriers.

1.3. Background

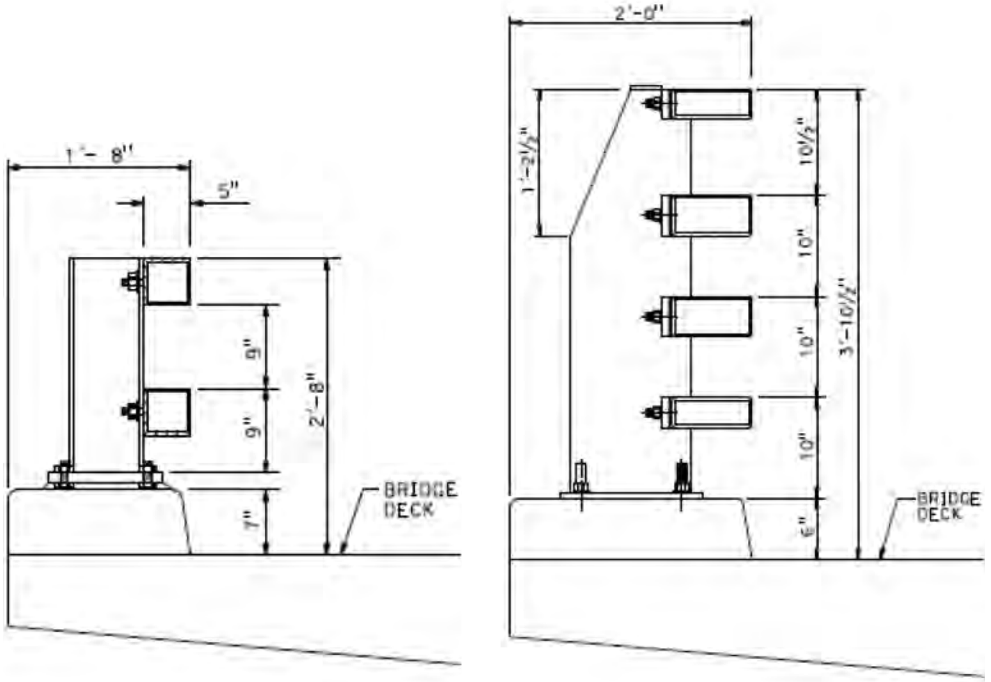
Due to the recent adoption of MASH, few steel post and beam bridge rails have been tested for MASH compliance. Caltrans has used the ST-20S and ST-70 since the mid-2000s as steel post-and-beam bridge railings. The ST-70 Bridge Rail has the same details as California ST-20S, except the CA ST-70 does not have the bicycle railing mounted on the top. The ST-20 was tested in 2003 by Caltrans and meets TL-4 crash test requirements of National Cooperative Highway Research Committee Report 350 guidelines (Report 350) (NCHRP, 1993). Crash testing for the CA ST-20 showed that there was no vehicular contact with the railing or post for the top bicycle railing. To improve performance, the tested version of the ST-20 was modified to lessen the level of snagging demonstrated in Test 651 (4-11) by extending the rail element further away from the post by increasing the rail width an additional 50 mm (2 in) and increasing the curb width by the same amount. The tested version of the ST-20 was modified to improve performance and renamed the ST-20S. This modified version was renamed the ST-20S. The July 2019 Caltrans “MASH Implementation for California Bridge Railings” identified the ST-75 bridge rail as design meant to replace both the ST-20S and the ST-70.

Two additional steel post and beam bridge rails, the California ST-10 and ST-30, were also identified to be replaced by the ST-75. In 2013 Caltrans tested the 838 mm (33 in) high ST-10 for MASH compliance. Test 3-11, the 2270P pickup test, resulted in the test vehicle rolling onto its side, exceeding the maximum roll angle of 75 degrees and failing the test. This rolling behavior and resulting failure was possibly an anomaly or outlier based on other 3-11 tests on similar height and configuration bridge rails (Roger Bligh, 2017).

During the ST-75 project, a taller steel post and beam bridge rail was developed, the ST-76. The ST-76 is identical to the ST-75 except the curb is 12 in tall instead of 6 in, resulting in a vehicular rail height of 42 in and overall height of 48 rather than 36 in and 42 in, respectively. Due to similarities of the two rails and crash test performance of the ST-75, no crash testing is currently planned for the ST-76. Although not covered in this project report, the ST-76 is being evaluated for MASH compliance by using the results of the ST-75 testing.



California ST-10 Bridge Rail California ST-20S Bridge Rail



California ST-30 Bridge Rail California ST-70 Bridge Rail

Figure 1-1 Existing Caltrans Steel Post and Beam Bridge Rails
(Caltrans, 2019)

1.4. Literature Search

A literature and product search were conducted prior to project initiation related to MASH TL-4 steel post and beam bridge rails. The results of the search concluded that MASH testing had not been conducted by the roadside safety community on a bridge rail similar enough to the ST-75 that would eliminate the need for all crash testing.

1.5. Scope

The full MASH 2016 TL-4 test matrix for longitudinal barriers requires three full-scale crash tests: a small car impacting at 100 kph (62 mph) and 25°, a pickup impacting also at 100 kph (62 mph) and 25°, and a single-unit truck impacting at 90 kph (56 mph) and 15°. All three tests were planned to be performed and evaluated in accordance with MASH 2016 TL- 4 evaluation criteria for longitudinal barriers. For this testing, the ST-75 Bridge Rail was constructed at the Caltrans crash testing facility following Caltrans construction standards.

2. Test Article Details

2.1. Barrier Design

The ST-75 bridge rail was designed to be a MASH compliant replacement for two similar Caltrans steel post and beam bridge rails: the ST-20S and ST-70. The design and load evaluation were completed by Caltrans Division of Engineering Services, Structures and Engineering Services. The design of the ST-75 focused on the structural integrity of the barriers subject to MASH TL-4 loading in compliance with 2012, Sixth Edition, AASHTO LRFD Bridge Design Specification with California Amendments. The three barrier components (Rail, Post, & Curb) and the deck overhang were separately evaluated against flexural, shear, and torsional demands under different limit states in accordance with AASHTO LRFD with California Amendments. In addition to the hand calculations, a finite element analysis study was conducted using the software CSiBridge in order to determine the demands on each component. Strengths and demands of the rail, post, and curb were then assessed under Extreme II Limit State, and the overhang under Extreme II and Strength I Limit State. For comparison and informational reasons, LS-Dyna simulations for the MASH TL-4 tests for longitudinal barriers are compared to the real-world crash tests. The results are shown in a separate report included in Appendix E: Finite Element Modeling Report of this report.

The design consists of a steel railing and posts mounted on a concrete curb that is 914 mm (36 in) high to the top of the traffic railing and 1067 mm (42 in) high to the top of the bicycle rail. The ST-75 posts are spaced 3 m (10 ft) apart. Each post is anchored to the bridge deck using anchor bolts and anchor bars (see cross-section below). The detail sheets, which were used to construct the test article, are shown in the Appendix (Figure 10-1 through Figure 10-5). The material design strengths are as follows (C = Compressive Strength, T = Tensile Strength): Concrete, 24.8 Mpa (3.6 ksi) (C), reinforcing bars 413.7 Mpa (60 ksi) (T), structural steel posts 248.2 Mpa (36 ksi) (T), and structural steel rails 317.2 Mpa (46 ksi) (T).

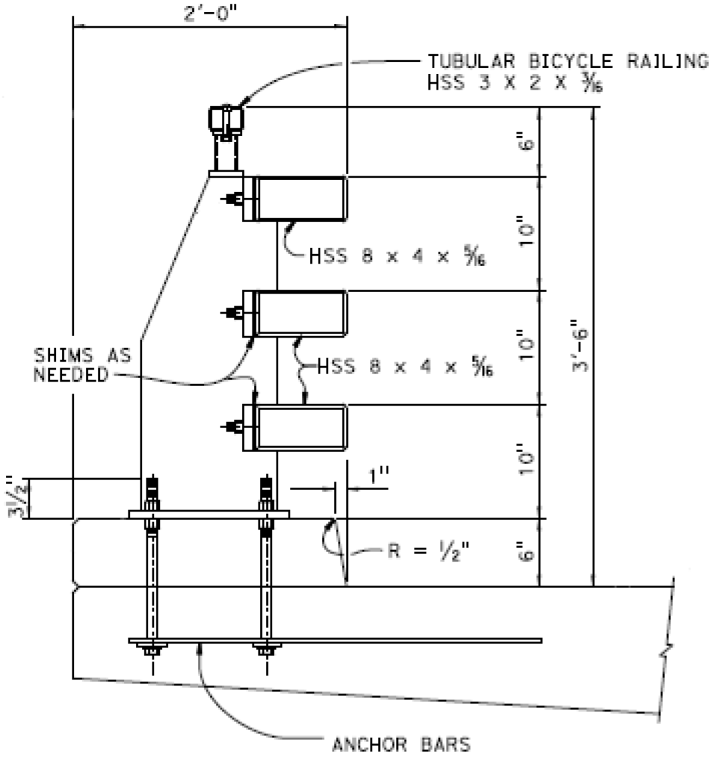


Figure 2-1 ST-75 Cross-Section

2.2. Construction

A section of the ST-75 bridge rail, 29 m (94 ft) in length, was constructed in 2018 at the Caltrans Dynamic Test Facility. The upstream 21 m (70 ft) was installed on a simulated bridge deck. To reduce cost, the remaining 7 m (24 ft) was installed on a newly constructed slab foundation on the downstream side where vehicle impact loading would not occur or would be minimal. The new simulated bridge deck consisted of an overhang rigidly attached to a Portland Cement Concrete anchor block that was constructed for a previous project. To ensure the new overhang (bridge deck) was adequately secured to the anchor block, the top 305 mm (12 in) of anchor block were removed to allow for the addition of new deck reinforcing steel (rebar). During construction, strain gauges were installed at strategic locations in the deck, curb and post anchor bolts so that loading during impact could be determined.

Construction was completed in different stages. First, the existing simulated bridge deck and top 305 mm (12 in) of concrete of the existing anchor block were removed. The concrete slab foundation for the downstream end was then constructed, leaving rebar and anchor bolts exposed for future construction of the concrete curb and installation of the ST-75 steel bridge rail. Then, after addition of new rebar for the ST-75 bridge rail, the next concrete pour was to repair the top 305 mm (12 in) of the anchor block and construct the new bridge deck, again leaving rebar and anchor bolts exposed for future construction of the concrete curb and installation of the ST-75 steel bridge rail. Each concrete pour was sampled and cast into standard 152 mm x 305 mm (6 in x 12 in) cylinders for testing. The minimum 28-day concrete for any of the three concrete pours was 38 MPa (5,500 psi). A615 Grade 60 rebar with a tested yield strength of approximately 63 ksi (434 MPa) minimum was used for reinforcement. The ST-75 posts were A709 Grade

36 steel and the rails were A500 Grade B steel. Construction details can be found in the Appendix, Figure 10-1 through Figure 10-5. Concrete strength test results and material certifications can be found in the Appendix, Section 11.

Once adequate concrete strength was obtained, the ST-75 steel posts were mounted to the exposed anchor bolts. The tubular rail elements and bicycle rail were then added and connection adjustments were made to level and straighten barrier alignment. Construction photos are shown below.

Figure 2-2 Top 12 Inches of Concrete Being Removed from Anchor Block

Figure 2-3 Rebar and Strain Gauges in Place for Anchor Block Concrete Replacement and Deck Overhang

Figure 2-4 Uniaxial Strain Gauges and Cable Prior to Deck Pour

Figure 2-5 Rebar in Slab Footing for Downstream Section

Figure 2-6 Downstream Section on Slab Complete

Figure 2-7 Reaction Block and Deck Rebar in Place for Concrete Pour

Figure 2-8 Formwork and Rebar in Place for Simulated Deck Concrete Pour

Figure 2-9 Simulated Deck Concrete Pour Complete

Figure 2-10 Bridge Rail Curb Concrete Pour

Figure 2-11 Completed Bridge Rail

3. Test Requirements and Evaluation Criteria

3.1. Crash Test Matrix

MASH Test Level 4 for longitudinal barriers consists of three crash tests as follows:

1. A 1,100 kg (2,420 lbs.) small car at 100 kph (62 mph) and a 25° impact angle (MASH 2016 Test No. 4-10).
2. A 2,270 kg (5,000 lbs.) pickup truck at 100 kph (62 mph) and a 25° impact angle (MASH 2016 Test No. 4-11).
3. A 10,000 kg (22,000 lbs) single-unit truck at 90 kph (56 mph) and a 15° impact angle (MASH 2016 Test No. 4-12).

The objective of this project is to verify that the ST-75 Bridge Rail meets the evaluation criteria of MASH Test 4-10, 4-11, and 4-12.

3.2. Evaluation Criteria

The evaluation criteria for longitudinal barriers are those set forth in MASH 2016 Table 2-2. For Test 4-10 and 4-11 they are A, D, F, H, and I. For Test 4-12 they are: A, D, and G. Evaluation Criteria are explained later in Table 5-3.

4. Test Conditions

4.1. Test Facilities

Crash testing was conducted at the Caltrans Dynamic Test Facility in West Sacramento, California. The test area is a large, flat, asphalt concrete surface. At the time of testing, there were no obstructions nearby.

4.2. Test Vehicles

4.2.1. Test 4-10

The vehicle for Test 4-10 was a 2017 Nissan Versa S in good condition. The MASH 2016 1100C test vehicle for the ST-75 Bridge Rail was assigned test identification number 110MASH4C19-01. The vehicle was free of major body damage and not missing any structural parts. It was not modified in any way and had no standard equipment missing. The test inertial mass of 1084 kg (2389 lb) was within the recommended mass limits of MASH 2016. Test vehicle measurement sheets are shown in the appendix, Table 9-7 through Table 9-10. To achieve the desired impact speed, the vehicle was towed with a 2:1 mechanical advantage. A speed control device was installed in the tow vehicle, which limited the acceleration of the vehicle once the target impact speed was reached. The steering was accomplished by means of a guidance rail anchored to the ground and a guide arm attached to the vehicle wheel hub. Remote braking was possible at any time during the test via radio control. The vehicle was released from the guidance rail a short distance before impact. Photos of the test vehicle are shown in Figure 4-1 through Figure 4-6. See Appendix Figure 9-1 and Figure 9-2 for more information on vehicle equipment and instrumentation.

Figure 4-1 MASH 4-10 Test Vehicle Front Right

Figure 4-2 MASH 4-10 Test Vehicle Passenger Side

Figure 4-3 MASH 4-10 Test Vehicle Front

Figure 4-4 MASH 4-10 Test Vehicle Driver Side

Figure 4-5 MASH 4-10 Test Vehicle Rear

Figure 4-6 MASH 4-10 Test Vehicle at Impact Point

4.2.2. Test 4-11

The test vehicle for Test 4-11 was a 2018 Dodge RAM 1500 Quad Cab pickup. The MASH 2016 2270P test for the ST-75 Bridge Rail was assigned test identification number 110MASH4P18-02. The vehicle was free of major body damage and not missing any structural parts. It was not modified in any way and had no standard equipment missing. The test inertial mass of 2252 kg (4965 lb) was within the recommended mass limits of MASH 2016. The height of the vehicle center of gravity was 748 mm (29.4 inches) and was above the minimum recommended in MASH of 710 mm (28 inches). Test vehicle measurement sheets are shown in the appendix, Table 9-15 through Table 9-21. To achieve the desired impact speed, the vehicle was self-powered. A speed control device was installed in the vehicle to limit the acceleration of the vehicle once the target impact speed was reached. The steering was accomplished by means of a guidance rail anchored to the ground and a guide arm attached to the vehicle wheel hub. The electric power steering system was de-energized prior to testing to reduce steering harmonics and improve lateral impact point accuracy. Remote braking was possible at any time during the test via radio control. The vehicle was released from the guidance rail and power to the engine was killed a short distance before impact. Photos of the test vehicle are shown in Figure 4-7 through Figure 4-13. See Appendix Figure 9-3 through Figure 9-5 for more information on vehicle equipment and instrumentation.

Figure 4-7 MASH 4-11 Test Vehicle Front Right

Figure 4-8 MASH 4-11 Test Vehicle Passenger Side

Figure 4-9 MASH 4-11 Test Vehicle Front

Figure 4-10 MASH 4-11 Test Vehicle Driver Side

Figure 4-11 MASH 4-11 Test Vehicle Rear

Figure 4-12 MASH 4-11 Test Vehicle Ballast

Figure 4-13 MASH 4-11 Test Vehicle at Impact Point

4.2.3. Test 4-12

The test vehicle for Test 4-12 was a 2013 International 4300 SBA. The test vehicle complied with all MASH 2016 requirements for 10000S vehicles. The MASH 2016 10000S test for the ST-75 bridge rail was assigned test identification number 110MASH4S19-02. The vehicle was in good condition and not missing any standard equipment. The cargo box was strengthened according to Ford's *2005 Body Builder Layout Book* to reduce the chance of it separating from the frame and reducing loading on the barrier during the test, Figure 4-22 and Figure 4-24. The curb weight of the vehicle was 6683 kg (14733 lb). With instrumentation, other equipment, and ballast installed, the test inertial mass was 10014 kg (22077 lb), which was within the recommended mass limits of MASH 2016. See Figure 4-20 for ballast in the cargo box. The ballast consisted of three 1.5 m by 1.5 m by 51 mm (5 ft by 5 ft by 2 in) steel plates placed on top of wood posts laying on the cargo bed. Each plate weighed approximately 907 kg (2000 lbs). They were mounted uniformly across the length and width of the cargo bed using 8 threaded rods through the bed to c-channel brackets under the bed. The wood posts were spliced to each other with steel plates and wood screws, and secured to the cargo bed with wood screws and angle brackets. The center of mass of the ballast was 1588 mm (62.5 in) from the ground, which was within MASH recommended limits of 1600 mm +/- 50 mm (63 in +/- 2 in). Test vehicle measurement sheets are shown in the appendix, Table 9-25 through Table 9-28. To achieve the desired impact speed, it was necessary to push the test vehicle with a Ford F-350 Dually in addition to its own self-power to get up to the target impact speed. The Ford F-350 Dually backed off the test vehicle about 213.4 m (700 ft) prior to impact. A speed control device was installed in the push vehicle, which limited the acceleration of the push vehicle once the target impact speed was reached. The speed governor of the test vehicle was reprogrammed to limit speed the maximum speed to 90.1 kph (56 mph). The steering was accomplished by means of a guidance rail anchored to the ground and a guide arm attached to the vehicle wheel hub. Remote braking was possible at any time during the test via radio control. The vehicle was released from the guidance rail and power to the engine was killed a short distance before impact. Photos of the test vehicle are shown in Figure 4-14 through Figure 4-24. See Appendix Figure 9-6 and Figure 9-7 for more information on vehicle equipment and instrumentation.

Figure 4-14 MASH 4-12 Test Vehicle Front Right

Figure 4-15 MASH 4-12 Test Vehicle Passenger Side

Figure 4-16 MASH 4-12 Test Vehicle Front

Figure 4-17 MASH 4-12 Test Vehicle Driver Side

Figure 4-18 MASH 4-12 Test Vehicle Rear

Figure 4-19 MASH 4-12 Test Vehicle at Impact Point

Figure 4-20 MASH 4-12 Test Vehicle Ballast in Cargo Box

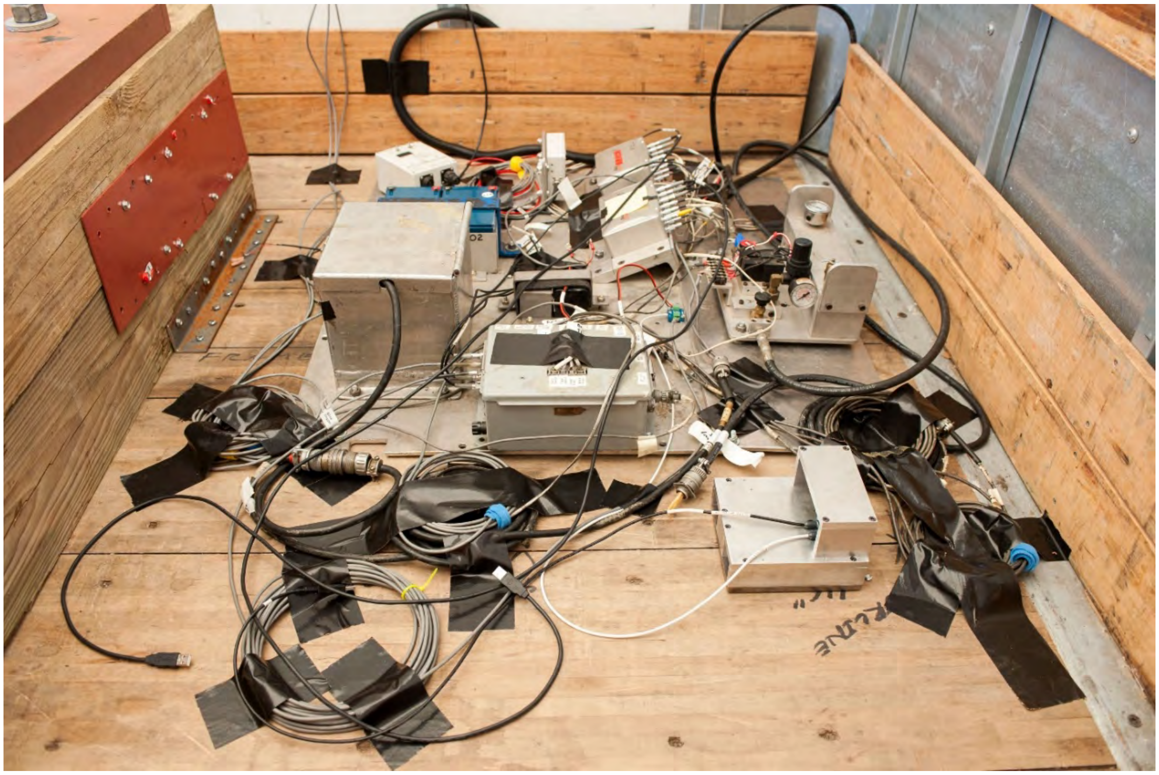


Figure 4-21 MASH 4-12 Test Vehicle Instrumentation Equipment in Cargo Box

Figure 4-22 MASH 4-12 Test Vehicle Front Shear Plate

Figure 4-23 MASH 4-12 Test Vehicle Ballast Mounting Plate

Figure 4-24 MASH 4-12 Test Vehicle Rear Shear Plate

4.3. Test Documentation

The tests were documented through the use of still cameras, video cameras, high-definition high-speed digital video cameras, and both GMH Engineering Data Brick III and DTS SLICE data acquisition systems to record accelerations and angular rate changes. The impact phase of each crash test was recorded with five high-definition high-speed digital video cameras, a normal-speed DVC format video camera, digital SLR cameras and action cameras mounted inside and outside the test vehicle set to record video. The test vehicle and barrier were photographed before and after impact with the DVC format camera and a digital SLR camera.

For Tests 4-10 and 4-11, four sets of orthogonal accelerometers and angular rate sensors were mounted at the center of gravity of the test vehicles (as per MASH 2016 specifications) to measure lateral, longitudinal, and vertical accelerations, and roll, pitch, and yaw rates, respectively. The data was analyzed in Test Risk Assessment Program version 2.3.11 (TRAP) to determine the occupant impact velocities, ridedown accelerations, and maximum vehicle rotation. For test 4-12, two sets of accelerometers and angular rate sensors were mounted in the vehicle cab and two sets were mounted in the vehicle cargo box. TRAP was also used to determine 50 ms average accelerations and maximum vehicle rotation at the locations where the instruments were mounted (inside the cab and inside the cargo box). See Appendix Figure 9-1 through Figure 9-7 for more information on vehicle instrumentation and test documentation.

5. Test 110MASH4C19-01 (4-10)

5.1. Impact Description and Results

The Critical Impact Point selected was 3.6 ft (1.1 meters) upstream from the centerline of post 4, as recommended in Table 2-7 of MASH 2016 (AASHTO, 2016). The impact angle of 25° was set with a Total Station. The intended impact speed was 100 kph (62 mph).

Figure 5-1 Test Article Impact Area Pre-Test 4-10

Figure 5-2 Test Article Downstream of Impact Area Pre-Test 4-10

5.2. Test Description

The crash was performed in the late morning of April 11, 2019. According to the Sacramento Executive Station, weather conditions were as follows: cloudy, temperature approximately 63 deg F, and wind of approximately 13 mph from the west-northwest (WNW). The vehicle was traveling approximately north-northeast (NNE).

The 1100C vehicle impacted the barrier at 102.1 kph (63.4 mph) and 25.0°. The vehicle impact point on the ST-75 bridge rail was approximately 1.3 m (4.2 ft) upstream of the centerline of post 4, which was about 180 mm (7 in) upstream of the Critical Impact Point. The vehicle was contained and smoothly redirected at an exit speed and angle of 79.8 kph (49.6 mph) and 7.7°, respectively. There was evidence that the passenger-side of the front bumper had snagged slightly on the edge of post 4 but it was not severe enough to cause excessively high ridedown accelerations, occupant impact velocities, or occupant compartment deformations. After exiting the bridge rail, the remote brakes were applied. The car came to a stop about 65 m (213 feet) downstream of and 17 m (56 feet) on the traffic side of the impact point. Still photos of the vehicle during the test are shown in Figure 5-3 through Figure 5-5. A detailed description of the sequential events is shown in the table below.

Table 5-1 Test 110MASH4C19-01 Test Sequence of Events

Time (s)	EVENT
0.000	Vehicle front-right bumper impacted the lower rail
0.002	Vehicle bumper begins to deform
0.012	Vehicle hood begins to deform
0.016	Vehicle grill begins to contact upper rail
~0.034	Vehicle passenger door contacts rails
~0.050	Vehicle begins to noticeably yaw and redirect, windshield begins to spider-crack
0.086	Surrogate Occupant head contacts passenger window
0.098	Passenger window shatters from door distortion
0.152	Vehicle is approximately parallel to rail face
0.160	Rear passenger taillight contacts top rail
0.168	Rear passenger taillight begins to shatter
~0.294	Vehicle exits test article with exit angle and speed of 7.7° and 79.8 kph (49.6 mph)

Figure 5-3 Test 4-10 Downstream Camera Impact View

Figure 5-4 Test 4-10 Upstream Camera Impact View

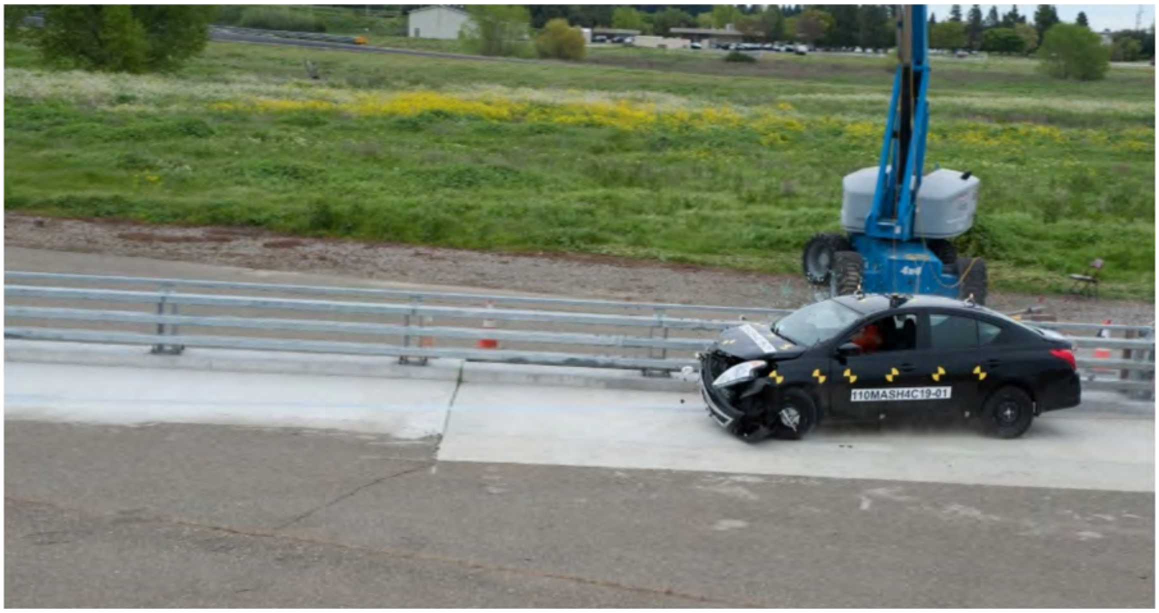


Figure 5-5 Test 4-10 Pan Camera Impact View

5.3. Barrier Damage

There was no significant damage to the barrier. The only damage was extremely minor surface scrapes and gouges of the steel rail. Barrier damage is shown in Figure 5-6 through Figure 5-9. The orange contact marks are from the front right tire. The green contact marks are from the rear right tire. Dynamic deflection of the bridge rail measured from overhead video was 15 mm (0.6 in). There was no permanent deflection. String potentiometer and strain gage data were collected during the test. They do not fall under the Scope of Accreditation but are available upon request.

Figure 5-6 Test 4-10 Overview of Barrier Post-Test

Figure 5-7 Test 4-10 Vehicle Marks on ST-75 Impact Point Post-Test

Figure 5-8 Test 4-10 Post 4 Post-Test

Figure 5-9 Test 4-10 Downstream of Post 4 Post-Test

5.4. Vehicle Damage

The 1100C front right corner, passenger's side, and front end of the test vehicle sustained damage during the impact. The entire length of the passenger side of the vehicle made contact with the barrier. The front passenger wheel was pushed back and partially torn off. The entire front bumper cover separated from the vehicle along with both headlights. The windshield spider-cracked and was pushed sideways about two inches, creating a separation at the driver's side "A" pillar. The passenger side front window was shattered and broken out due to door deformation. The remaining window glass was undamaged. The interior metal bumper, it's support bracket and connecting frame member were deformed, possibly from snagging slightly on the upstream vertical member of post 4. The hood and front right door and front fender were severely damaged. The airbags did not deploy because the vehicle was towed and there was no power to the airbag system. The maximum amount of passenger compartment deformation measured by known points was 125 mm (4.9 in), which occurred at the toe pan/wheel well area of the floorboard. All interior deformation measurements are shown in Table 9-11 through Table 9-14.

Figure 5-10 Test 4-10 Test Vehicle Damage (Right Side)

Figure 5-11 Test 4-10 Test Vehicle Damage (Rear Right)

Figure 5-12 Test 4-10 Test Vehicle Damage (Front Left)

Figure 5-13 Test 4-10 Test Vehicle Damage (Front Right)

Figure 5-14 Test 4-10 Test Vehicle Occupant Compartment Floorboard Deformation

Figure 5-15 Test 4-10 Test Vehicle Occupant Compartment Deformation (Front Seat Area)

Figure 5-16 Test 4-10 Test Vehicle Windshield Separation

Figure 5-17 Test 4-10 Test Vehicle Front Right Bumper and Bumper Support Member Deformation

Table 5-2 Test 110MASH4C19-01 Test Data Summary Sheet


0.000 sec. [Frame 274]


0.042 sec. [Frame 295]


0.084 sec. [Frame 316]

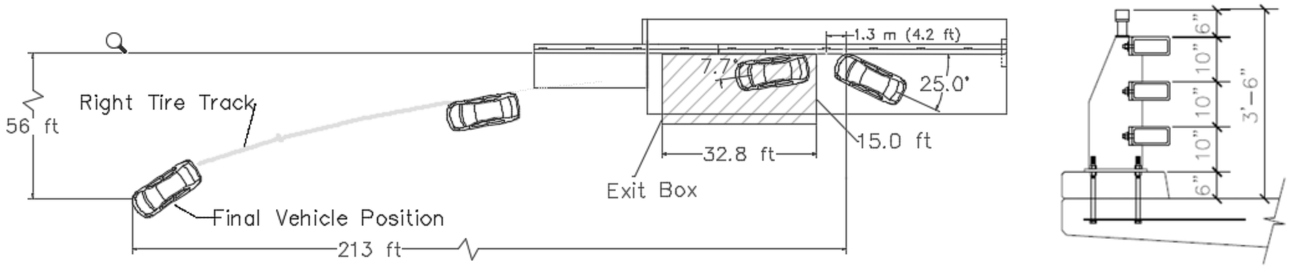

0.126 sec. [Frame 337]


0.168 sec. [Frame 358]


0.210 sec. [Frame 379]


0.252 sec. [Frame 400]


0.294 sec. [Frame 421]



Test Agency	California, Department of Transportation
Test Number	110MASH4C19-01
Test Designation	MASH16 Test 4-10
Date	4/11/2019
Test Article	CA ST-75 Bridge Rail
Total Length	100 ft (30.5 m)
Key Elements – Barrier	
• Description	CA ST-75 Bridge Rail
• Base Width	24 in (610 mm)
• Height	36 in (910 mm)
Test Vehicle	
• Designation/Make/Model	1100C / 2017 Nissan Versa
• Curb	2344 lb (1063 kg)
• Test Inertial	2389 lb (1084 kg)
• Gross Static	2568 lb (1165 kg)
Impact Conditions	
• Speed	63.4 mph (102.1 kph)
• Angle	25.0°
• Location/Orientation	4.2 ft (1.3 m) upstream of middle of post 4
• Impact Severity	58 kip-ft (78 kJ)
Exit Conditions	
• Speed	49.6 mph (79.8 kph)
• Angle	7.7 °
Exit Box Criterion	Pass

Post-impact Trajectory

- Vehicle Stability: Satisfactory
- Stopping Distance (from point of impact) Approx. 213 ft (64.9 m) downstream and 56 ft (17.0 m) laterally in front

Test Article Damage	Minor scrapes
Test Article Deflections	
• Permanent Set	0.0 in (0 mm)
• Dynamic	0.6 in (15 mm)
• Working Width	24.0 in (610 mm) at barrier base
Vehicle Damage	Moderate to Heavy
• VDS[3]	01-RFQ-7, 01-RD-4, 03-RP-4, 04-RBQ-3
• CDC[4]	01RRAK5, 03RDAS2
• Maximum Deformation	Approx. 4.9 in (125 mm) at Floorboard/wheel well
• Vehicle Snagging	Minor snagging of right side of front bumper on post 4
• Vehicle Pocketing	None

Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		DataBrick 327	SLICE-656	SLICE-659	
OIV Ft/s (m/s)	Long.	21.3 (6.5)	23.3 (7.1)	23.6 (7.2)	±40 (12.2)
	Lat.	33.1 (10.1)	33.8 (10.3)	34.4 (10.5)	±40 (12.2)
ORA g's	Long.	-3.4	-3.9	-3.8	±20.49
	Lat.	-9.9	-10.4	-10.4	±20.49
Max Angle Deg.	Roll	5.7	5.5	6.3	±75
	Pitch	-4.4	-4.5	-4.6	±75
	Yaw	-38.3	-39.7	-39.7	N/A
THIV – ft/s (m/s)		39.7 (12.1)	41.0 (12.5)	41.3 (12.6)	N/A
PHD – g's		10.0	10.5	10.5	N/A
ASI		2.83	2.92	2.98	N/A

5.5. Discussion of Test Results

5.5.1. General Evaluation Methods

MASH 2016 recommends that crash test performance be assessed according to three evaluation factors: (1) structural adequacy, (2) occupant risk, and (3) post-impact vehicular response.

The structural adequacy and occupant risk associated with the ST-75 Bridge Rail were evaluated using evaluation criteria found in Tables 2.2A (Recommended Test Matrices for Longitudinal Barriers), 5.1A (Safety Evaluation Guidelines for Structural Adequacy), and 5.1B (Safety Evaluation Guidelines for Occupant Risk) of MASH 2016. The post-impact vehicular response was evaluated using Section 5.2.3 of MASH 2016.

5.5.2. Structural Adequacy

The structural adequacy of the ST-75 Bridge Rail was acceptable during Test 4-10.

Refer to Table 5-3 for the assessment summary of the safety evaluation criteria for the ST-75 Bridge Rail.

5.5.3. Occupant Risk

The occupant risk was acceptable. As mentioned previously, all interior deformation measurements were below the maximum MASH 2016 limits. All interior deformation measurements are shown in Table 9-11 through Table 9-14.

There was no occupant compartment penetration or potential for it. The occupant compartment was not compromised. The dummy head protruded slightly beyond the plane of the passenger side window when it was broken but did not show potential for striking any portion of the barrier. Occupant impact velocities and ridedown accelerations were below MASH 2016 limits. The yaw, pitch, and roll of the vehicle were within acceptable limits.

Refer to Table 5-3 for the assessment summary of the safety evaluation criteria for the ST-75 Bridge Rail.

5.5.4. Vehicle Trajectory

The vehicle trajectory was acceptable. The exit trajectory was within the exit box.

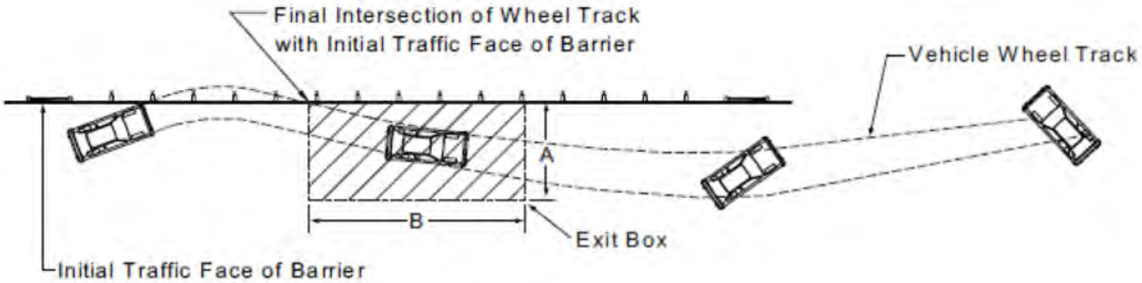


Figure 5-18 Exit Box for Longitudinal Barriers (AASHTO, 2016)

Refer to Table 5-3 for the assessment summary of the safety evaluation criteria for the ST-75 Bridge Rail.

Table 5-3 110MASH4C19-01 Assessment Summary

<table>
<tr><th>Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td>Structural Adequacy
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation, although controlled lateral deflection of the test article is acceptable.</td><td>The vehicle was contained and redirected smoothly.</td><td>PASS</td></tr>
<tr><td>Occupant Risk
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or personnel in a work zone.
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E.</td><td>The barrier did not detach any elements, fragments, and/or other debris.
Deformations of, or intrusions into, the occupant compartment were within MASH 2016 limits.</td><td>PASS</td></tr>
<tr><td>Occupant Risk
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>The vehicle remained upright during and after the collision.</td><td>PASS</td></tr>
<tr><td>Occupant Risk
H. Occupant Impact Velocities (OIV) (see Appendix A, Section A5.2.2 for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits, ft/s (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
</table></td><td><u>DAS Long. ft/sec (m/s)</u>
DB 327: 21.3 (6.5)
SLICE 656: 23.3 (7.1)
SLICE 659: 23.6 (7.2)
<u>DAS Lat. ft/sec (m/s)</u>
DB 327: 33.1 (10.1)
SLICE 656: 33.8 (10.3)
SLICE 659: 34.4 (10.5)</td><td>PASS</td></tr>
<tr><td>Occupant Risk
I. The occupant ridedown acceleration (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (G)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 G</td><td>20.49 G</td></tr>
</table></td><td><u>DAS Long. G Lat. G</u>
DB 327: -3.4 -9.9
SLICE 656: -3.9 -10.4
SLICE 659: -3.8 -10.4</td><td>PASS</td></tr>
<tr><td>Vehicle Trajectory
It is preferable that the vehicle be smoothly redirected, and this is typically indicated when the vehicle leaves the barrier within the "exit box". The concept of the exit box is defined by the initial traffic face of the barrier and a line parallel to the initial traffic face of the barrier, at a distance A plus the width of the vehicle plus 16 percent of the length of the vehicle, starting at the final intersection (break) of the wheel track with the initial traffic face of the barrier for a distance of B. All wheel tracks of the vehicle should not cross the parallel line within the distance B.</td><td>A = 15.0 ft (4.57 m)
B = 32.8 ft (10 m)</td><td>PASS</td></tr>
</table>

6. Test 110MASH4P18-02 (4-11)

6.1. Impact Description and Results

The Critical Impact Point selected was 1.3 meters (4.3 ft) from the centerline of post 5, as recommended in Table 2-7 of MASH 2016 (AASHTO, 2016). The impact angle of 25° was set with a Total Station. The intended impact speed was 100 kph (62 mph).

Figure 6-1 Test 4-11 Critical Impact Point Pre-Test

Figure 6-2 Bridge Railing Downstream of Critical Impact Point Pre-Test

6.2. Test Description

The crash was performed the afternoon of September 12, 2018. According to the Sacramento Executive Station, weather conditions were as follows: cloudy, temperature approximately 74 deg F, and wind of approximately 5 mph from the southwest (SW). The vehicle was traveling approximately north-northeast (NNE).

The 2270P vehicle impacted the barrier at 102.0 kph (63.4 mph) and angle of 26.3°. The vehicle impact point on the ST-75 Bridge Rail was approximately 1.6 meters (5.3 ft) upstream from the centerline of post 5, which was 0.3 m (12 inches) upstream of the Critical Impact Point. The vehicle was contained and smoothly redirected with an exit speed and angle of 86 kph (54 mph) and 6°, respectively. After exiting the bridge rail, the remote brakes were applied. The vehicle came to a stop about 66.8 m (219 ft) downstream and 12.5 m (41 ft) on the traffic side of the impact point. Still photos of the vehicle during the test are shown in Figure 6-3 through Figure 6-5. A detailed description of the sequential events is shown in the table below.

Table 6-1 Test 110MASH4P18-02 Test Sequence of Events

Time (s)	EVENT
0.000	Vehicle front-right bumper impacted the middle rail
0.002	Vehicle bumper begins to deform
0.004	Vehicle hood begins to override top rail
0.030	Vehicle hood contacts handrail
~0.036	Vehicle hood begins to deform
0.038	Front passenger door impacts rail
0.046	Vehicle begins to redirect
0.048	Top of front passenger door begins to deform and bend outward
0.058	Passenger side airbag begins to deploy
0.060	Front grill begins to detach from vehicle
0.068	Vehicle hood is at maximum override
0.158	Vehicle is approximately parallel to rail face
0.168	Rear passenger taillight contacts top rail and begins to shatter
0.300	Vehicle exits test article with exit angle and speed of 6° and 86 kph (54 mph)

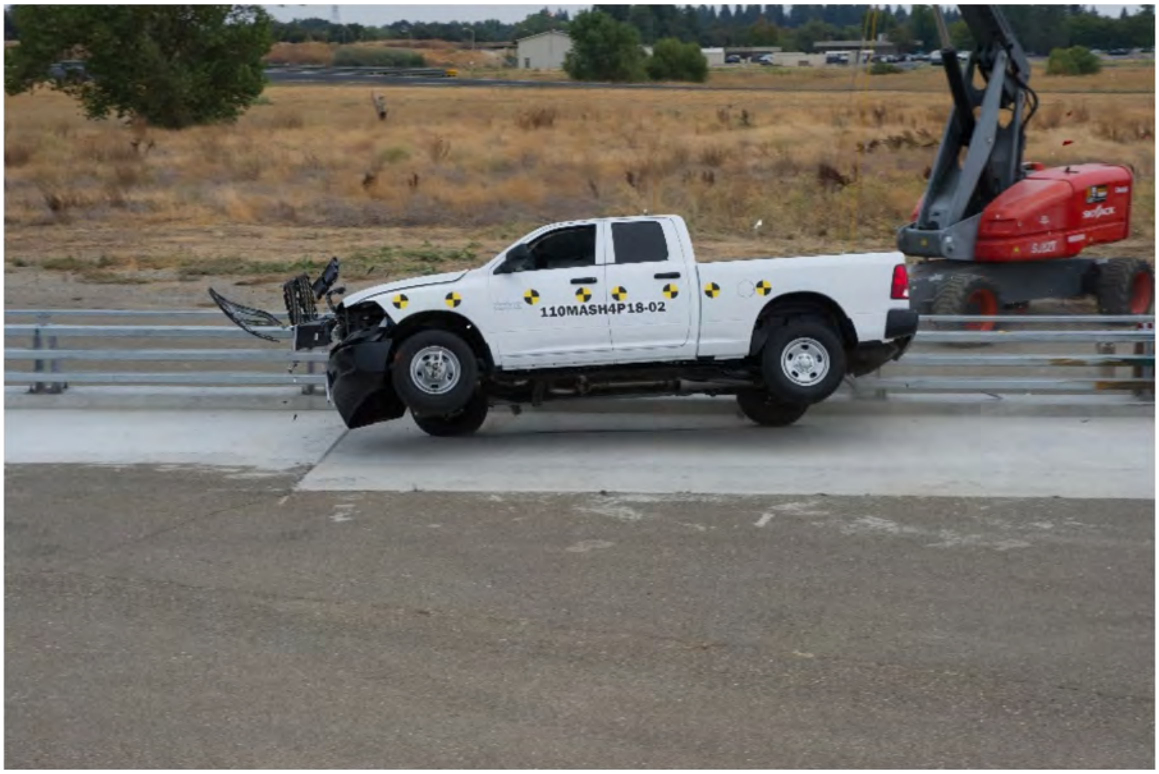


Figure 6-3 Test 4-11 Pan Camera Impact View

Figure 6-4 Test 4-11 Downstream Camera Impact View

Figure 6-5 Test 4-11 Upstream Impact View

6.3. Barrier Damage

There was no significant damage to the barrier. The only damage was extremely minor surface scrapes and gouges of the steel rail, and minor spalling of the concrete curb. Barrier damage is shown in Figure 6-6 through Figure 6-8. The orange contact marks are from the front right tire. The green contact marks are from the rear right tire. Dynamic deflection of the bridge rail measured from overhead video was 30 mm (1.2 in). There was no permanent deflection. String potentiometer and strain gage data were collected during the test. They do not fall under the Scope of Accreditation but are available upon request.

Figure 6-6 Test 4-11 Vehicle Marks on ST-75 at Impact Point Post-Test

Figure 6-7 Test 4-11 Minor Concrete Spalling of Concrete Curb Post-Test

Figure 6-8 Test 4-11 ST-75 Bridge Rail Post-Test Downstream of Impact Post-Test

6.4. Vehicle Damage

The 2270P front right corner and right side of the test vehicle sustained most of the damage from the impact. The front bumper was damaged, mainly the front right portion during initial impact with the barrier. The right headlight was shattered and detached from the vehicle. The front passenger wheel was pushed back significantly but the suspension system remained attached except for the aluminum lower control arm front connection to the frame. The entire length of the passenger side of the vehicle made contact with the barrier including the right front fender, right doors, and the right side of the bed. All of the test vehicle doors remained closed and latched during impact except the window frame of the front passenger door deformed outward, creating an opening. The windshield had minor cracking and the remaining window glass was undamaged. The front grill and left headlight were also detached during the impact. The maximum amount of passenger compartment deformation measured by known points was 100 mm (4.0 in), which occurred at the footwell. All interior deformations were below the maximum MASH 2016 limits and are shown in Figure 9-22 through Figure 9-24.

Figure 6-9 Test 4-11 Test Vehicle Damage (Rear Right)

Figure 6-10 Test 4-11 Test Vehicle Damage (Front Right)

Figure 6-11 Test 4-11 Test Vehicle Damage (Left Side)

Figure 6-12 Test 4-11 Test Vehicle Damage (Front)

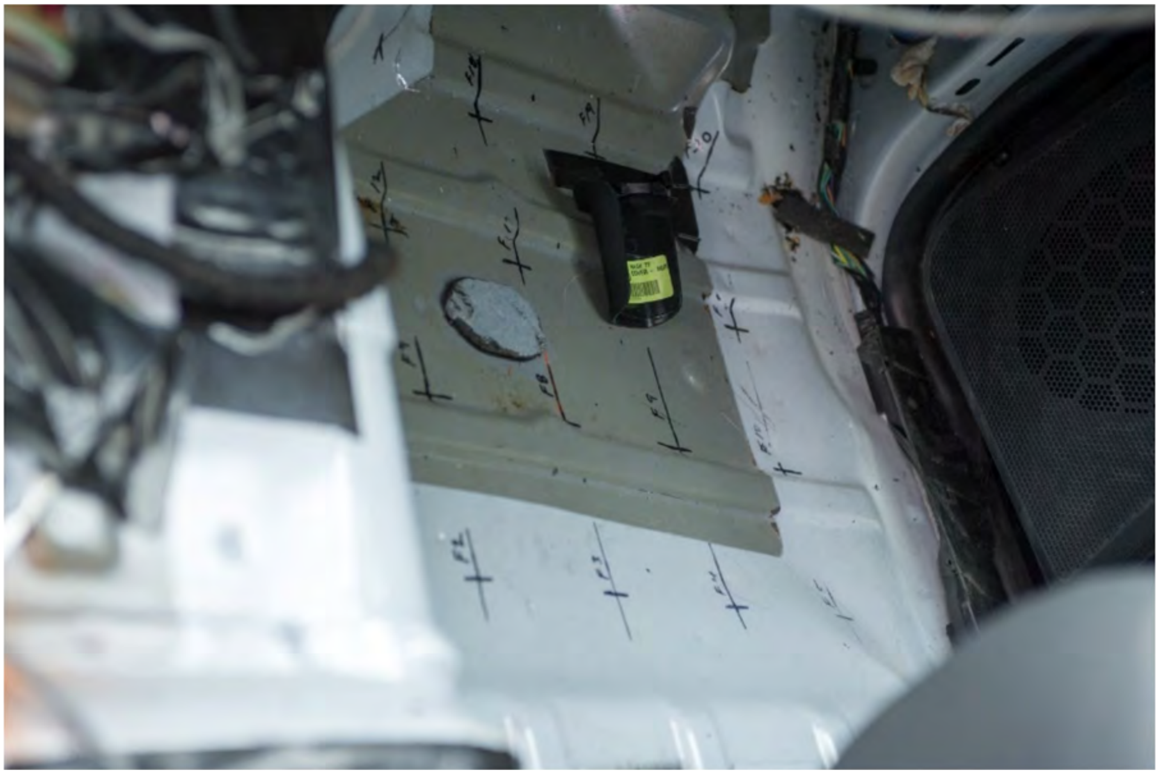


Figure 6-13 Test 4-11 Test Vehicle Damage Front Passenger Floorpan (Occupant Compartment Deformation)

Figure 6-14 Test 4-11 Test Vehicle Front Right Wheel Deformation

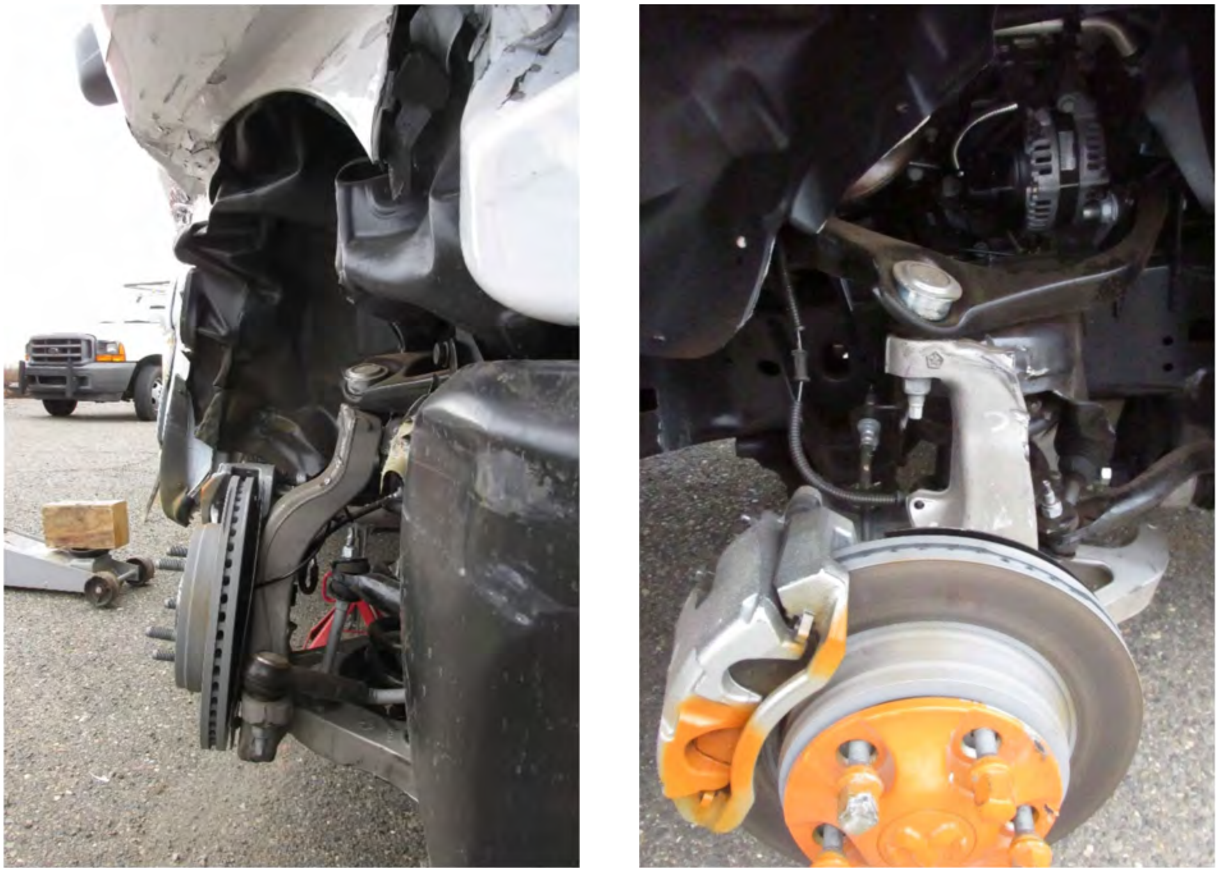


Figure 6-15 Test 4-11 Test Vehicle Front Right Suspension (with wheel removed)

Figure 6-16 Test 4-11 Test Vehicle Front Right Suspension Lower Control Arm Connector Fracture

Table 6-2 Test 110MASH4P18-02 Test Data Summary Sheet


0.000 sec. [Frame 166]


0.060 sec. [Frame 196]


0.120 sec. [Frame 226]

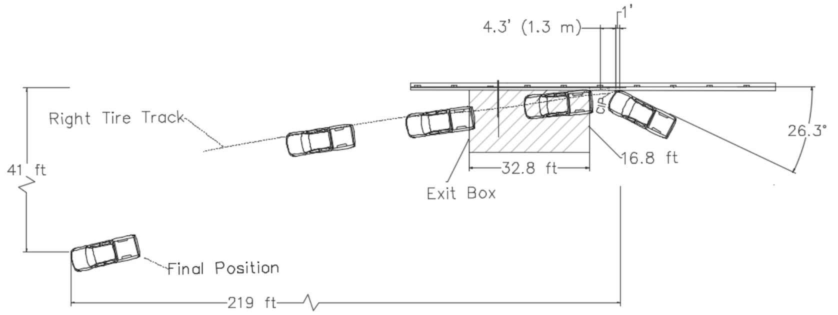

0.180 sec. [Frame 256]

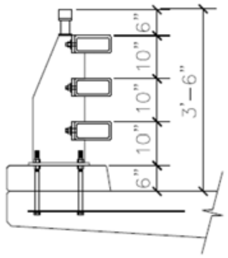

0.240 sec. [Frame 286]


0.300 sec. [Frame 316]


0.360 sec. [Frame 346]


0.420 sec. [Frame 376]





Test Agency: California, Department of Transportation
Test Number: 110MASH4P18-02
Test Designation: MASH16 Test 4-11
Date: 9/12/2018
Test Article: CA ST-75 Bridge Rail
Total Length: 100 ft (30.5 m)
Key Elements – Barrier
- Description: CA ST-75 Bridge Rail
- Base Width: 24 in (610 mm)
- Height: 36 in (910 mm)

Test Vehicle
- Designation/Make/Model: 2270P/ 2018 Dodge RAM 1500 Quad Cab
- Curb: 4768 lb (2163 kg)
- Test Inertial: 4965 lb (2252 kg)
- Gross Static: 4965 lb (2252 kg)

Impact Conditions
- Speed: 63.4 mph (102.0 kph)
- Angle: 26.3°
- Location/Orientation: 5.3 ft (1.6 m) upstream of middle of post
- Impact Severity: 130.7 kip-ft (177.2 kJ)

Exit Conditions
- Speed: 54 mph (86 kph)
- Angle: 6 °

Exit Box Criterion: Pass
Post-impact Trajectory
- Vehicle Stability: Satisfactory
- Stopping Distance (from point of impact) Approx., 219 ft downstream and 41 ft laterally in front

Test Article Damage: Minor scrapes
Test Article Deflections
- Permanent Set: 0.0 in (0 mm)
- Dynamic: 1.2 in (30 mm)
- Working Width: 24.0 in (610 mm)

Vehicle Damage: Moderate
- VDS[3]: 01-RFQ-5, 01-RD-3, 03-RP-3, 04-RBQ-3
- CDC[4]: 01RRMK2, 03RDMS2
- Maximum Deformation: Approx. 4 in (100 mm) at Floorboard/wheel well
- Vehicle Snagging: None
- Vehicle Pocketing: None

Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		DataBrick 328	SLICE-656	
OIV Ft/s (m/s)	Long.	14.4 (4.4)	16.4 (5.0)	±40 (12.2)
	Lat.	30.8 (9.4)	30.5 (9.3)	±40 (12.2)
ORA g's	Long.	-4.1	-5.6	±20.49
	Lat.	-11.0	-11.5	±20.49
Max Angle Deg.	Roll	21.6	19.4	±75
	Pitch	2.1	-4.0	±75
	Yaw	-40.3	-40.0	N/A
THIV – ft/s (m/s)		34.8 (10.6)	34.8 (10.6)	N/A
PHD – g's		11.7	12.6	N/A
ASI		2.29	2.31	N/A

6.5. Discussion of Test Results

6.5.1. General Evaluation Methods

MASH 2016 recommends that crash test performance be assessed according to three evaluation factors: (1) structural adequacy, (2) occupant risk, and (3) post-impact vehicular response.

The structural adequacy and occupant risk associated with the ST-75 Bridge Rail were evaluated using evaluation criteria found in Tables 2.2A (Recommended Test Matrices for longitudinal barriers), 5.1A (Safety Evaluation Guidelines for Structural Adequacy), and 5.1B (Safety Evaluation Guidelines for Occupant Risk) of MASH 2016. The post-impact vehicular response was evaluated using section 5.2.3 of MASH 2016.

6.5.2. Structural Adequacy

The structural adequacy of the ST-75 Bridge Rail was acceptable during Test 4-11.

Refer to Table 6-3 for the assessment summary of the safety evaluation criteria for the ST-75 Bridge Rail for Test 4-11.

6.5.3. Occupant Risk

The occupant risk was acceptable. As mentioned previously, the interior deformations were below MASH 2016 limits. All interior deformation measurements are shown in Table 9-22 through Table 9-24. There was no occupant compartment penetration or potential for it. The occupant compartment was not compromised. Occupant impact velocities and ridedown accelerations were below MASH 2016 limits. The yaw, pitch, and roll of the vehicle were within acceptable limits.

Refer to Table 6-3 for the assessment summary of the safety evaluation criteria for the ST-75 Bridge Rail for Test 4-11.

6.5.4. Vehicle Trajectory

The vehicle trajectory was acceptable. The exit trajectory was within the exit box. The yaw, pitch, and roll of the vehicle were below the maximum limits.

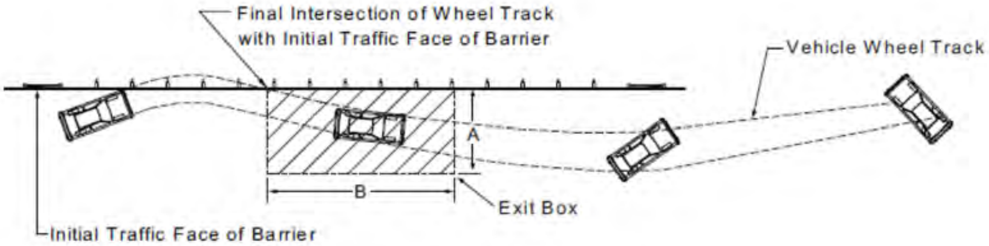


Figure 6-17 Exit Box for Longitudinal Barriers (AASHTO, 2016)

Refer to Table 6-3 for the assessment summary of the safety evaluation criteria for the ST-75 Bridge Rail for Test 4-11.

Table 6-3 110MASH4P18-02 Assessment Summary

<table>
<tr><th>Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td>Structural Adequacy
A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>The vehicle was contained and redirected smoothly.</td><td>PASS</td></tr>
<tr><td>Occupant Risk
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or personnel in a work zone.
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E.</td><td>The barrier did not detach any elements, fragments, and/or other debris</td><td>PASS</td></tr>
<tr><td>Occupant Risk
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>The vehicle remained upright during and after the collision.</td><td>PASS</td></tr>
<tr><td>Occupant Risk
H. Occupant Impact Velocities (OIV) (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits, ft/s (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
</table></td><td><u>DB3</u>
Long.= 14.4 ft/s (4.4 m/s)
Lat.= 30.8 ft/s (9.4 m/s)
<u>SLICE</u>
Long.= 16.4 ft/s (5.0 m/s)
Lat.= 30.5 ft/s (9.3 m/s)</td><td>PASS</td></tr>
<tr><td>Occupant Risk
I. The occupant ridedown acceleration (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (G)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 G</td><td>20.49 G</td></tr>
</table></td><td><u>DB3</u>
Long. -4.1 G
Lateral -11.0 G
<u>SLICE</u>
Long. -5.6 G
Lateral -11.5 G</td><td>PASS</td></tr>
<tr><td>Vehicle Trajectory
It is preferable that the vehicle be smoothly redirected, and this is typically indicated when the vehicle leaves the barrier within the "exit box". The concept of the exit box is defined by the initial traffic face of the barrier and a line parallel to the initial traffic face of the barrier, at a distance A plus the width of the vehicle plus 16 percent of the length of the vehicle, starting at the final intersection (break) of the wheel track with the initial traffic face of the barrier for a distance of B. All wheel tracks of the vehicle should not cross the parallel line within the distance B.</td><td>A = 16.8ft (5.11 m)
B = 32.8 ft (10 m)</td><td>PASS</td></tr>
</table>

7. Test 110MASH4S19-02 (4-12)

7.1. Impact Description and Results

The Critical Impact Point selected was 1.5 meters (5.0 ft) from the centerline of post 5, as recommended in Table 2-7 of MASH 2016 (AASHTO, 2016). The impact angle of 15° was set with a Total Station. The intended impact speed was 90 kph (56 mph).

Figure 7-1 Test 4-12 ST-75 Impact Area with Checkered Tape at Impact Point Pre-Test

Figure 7-2 Test 4-12 ST-75 Post 5 Downstream of Impact Point Pre-Test

Figure 7-3 Test 4-12 ST-75 Post 5 Downstream of Impact Point Pre-Test

Figure 7-4 Test 4-12 ST-75 Post 6 Downstream of Impact Point Pre-Test

7.2. Test Description

The crash was performed just before noon on June 19, 2019. According to the Sacramento Executive Station, weather conditions were as follows: fair, temperature approximately 82 deg F, and wind of approximately 3 mph from the south. The vehicle was traveling approximately north-northeast (NNE).

The 10000S vehicle impacted the barrier at a speed of 87.6 kph (54.4 mph) and angle of 15.3°. The vehicle impacted the ST-75 Bridge Rail at approximately 1.4 meters (4.9 ft) upstream from the centerline of post 4, which was approximately 75 mm (3 in) downstream of the Critical Impact Point. The vehicle was contained and smoothly redirected at an exit speed and angle of 79.8 kph (49.6 mph) and 8°, respectively. During the impact, the cargo box leaned over the bridge rail approximately 21 inches (not within the Lab's Scope of Accreditation) for a Working Width of about 45 inches at a height of approximately 11.5-12 ft. After exiting the bridge rail, the remote brakes were applied. The vehicle came to a stop, after rolling onto the driver side of the vehicle, about 73.5 ft (241 feet) downstream of and 15.5 m (51 feet) on the non-traffic side of the impact point. Still photos of the vehicle during the test are shown in Figure 7-5 through Figure 7-7. A detailed description of the sequential events is shown in the table below.

Table 7-1 Test 110MASH4S19-02 Test Sequence of Events

Time (s)	EVENT
0.000	Vehicle front-right bumper impacted the top rail
0.006	Vehicle bumper begins to deform
0.010	Vehicle hood begins to override top rail
0.040	Vehicle passenger side front wheel well contacts handrail and begins to deform
~0.078	Vehicle begins to redirect
~0.088	Front passenger door impacts rail
~0.164	Vehicle passenger side front wheel well is at maximum override
0.280	Rear right corner of vehicle contacts steel rails, vehicle is approximately parallel to bridge rail
~0.760	Vehicle exits test article with exit angle and speed of 8° and 79.8 kph (49.6 mph)

Figure 7-5 Test 4-12 Across Camera Impact View

Figure 7-6 Test 4-12 Downstream Camera Impact View

Figure 7-7 Test 4-12 Upstream Camera Impact View

7.3. Barrier Damage

There was minor to moderate damage to the barrier. The traffic side of the base plates at Posts 3, 4, and 5 were permanently deformed from the moment created during impact, see Figure 7-11 through Figure 7-13. The deformation left a gap between the middle portion of the plate and concrete curb. Base plate deformation at Posts 3, 4, and 5 were approximately 8 mm (5/16 in), 6 mm (1/4 in), less than 2 mm (1/16 in), respectively. As a result of the base plate deformation, the anchor bolts bent outward. The anchor bolt bending and after impact straightening, as part of barrier repairs, was thought to be a concern due to the high levels of plastic deformation. To better understand the condition of the bolts, bolt material properties were investigated. A barrier quasi-static (push) test and bolt tensile tests were performed to determine remaining bolt strength and roughly how far the bolts had elongated or otherwise progressed into yield. These tests are not within the Lab's Scope of Accreditation. The results showed that the bolts at Posts 3 and 4 (which were impacted during the crash test) were slightly in the plastic range and the Post 6 bolt (which was deformed during the push test) had high residual strength but was far into the plastic range. The tensile tests for Posts 3 and 4 concluded that after the TL-4 impact, the bolts were still above design tensile strength requirements and still had some ductility. However, the bending caused by the base plate deformed the threads enough to potentially complicate repairs if a post needed to be removed. A brief summary of the quasi-static push test and tensile load tests are shown in 11 Appendix C: Quasi-static Push Test and Anchor Bolt Tensile Testing. Photos of the anchor bolts at posts 3 and 4 with the posts removed are also included in Appendix C.

Other damage to the barrier included minor surface scrapes and gouges. See Figure 7-8 through Figure 7-13 for photos of barrier damage. The orange contact marks are from the front right tire. The green contact marks are from the rear right tire. String potentiometer and strain gage data were collected during the test. They do not fall under the Scope of Accreditation but are available upon request. The dynamic and permanent deflections could not be determined from overhead video. They were, however, able to be measured from string potentiometers using a data acquisition system collecting measurements at 10,000 sample/sec. The dynamic and permanent deflections from string potentiometers (not within the Scope of Accreditation) were 83 mm (3.25 in) and 38 mm (1.5 in), respectively.

Figure 7-8 Test 4-12 Vehicle Marks on ST-75 Impact Point Between Posts 3 and 4 Post-Test

Figure 7-9 Test 4-12 Vehicle Marks on ST-75 at Post 4 Downstream of Impact Point Post-Test

Figure 7-10 Test 4-12 ST-75 Post 5 Downstream of Impact Point Post-Test

Figure 7-11 Test 4-12 ST-75 Post 3 Post-Test

Figure 7-12 Test 4-12 Post 3 Bent Bottom Plate Close Up Post-Test

Figure 7-13 Test 4-12 Post 4 Bent Bottom Plate Close Up Post-Test

7.4. Vehicle Damage

The 10000S front right corner and passenger's side of the test vehicle sustained most of the damage from the initial impact with the steel rail and post system. The entire length of the passenger side of the vehicle made contact with the bridge rail. The driver's side of the front bumper was deformed, the headlight was torn loose, and part of the right front fender was broken off. The right front wheel and suspension remained intact with the exception that the ends of the leaf springs fractured near their mounts at both forward and rear connection points. The left front and rear suspension remained attached as well as all the vehicle wheels and tires. All tires remained inflated. The steps on the passenger side were deformed from making contact with the steel rail. The driver's side door, A-pillar, fender, and cab roof were deformed when the vehicle rolled onto its side, including cracking the windshield. All the window glass was undamaged during interaction with the test article. Nearly all the damage to the cargo box also occurred when the vehicle rolled onto its side. The shear plates on the frame were slightly bent but otherwise remained intact. The bed shifted a minor amount. The threaded rods to secure the ballast were undamaged and helped to keep motion of the ballast to a minimum. Photos of the vehicle post-impact can be found in Figure 7-14 through Figure 7-24. The maximum amount of passenger compartment deformation measured by known points was 81 mm (3.2 in), which occurred at the floorboard. All interior deformations were below the maximum MASH 2016 limits. All interior deformation measurements are shown in Table 9-29 through Table 9-32.

Figure 7-14 Test 4-12 Test Vehicle Top Post-Test

Figure 7-15 MASH 4-12 Test Vehicle Undercarriage After Impact

Figure 7-16 MASH 4-12 Test Vehicle Ballast After Impact

Figure 7-17 MASH 4-12 Test Vehicle Front Undercarriage and Suspension After Impact

Figure 7-18 MASH 4-12 Test Vehicle Undercarriage and Suspension After Impact

Figure 7-19 Test 4-12 Test Vehicle (Impact, Right Side) Post-Test (righted)

Figure 7-20 Test 4-12 Test Vehicle (Front Right) Post-Test (righted)

Figure 7-21 Test 4-12 Test Vehicle (Front) Post-Test (righted)

Figure 7-22 Test 4-12 Test Vehicle (Left Side) Post-Test (righted)

Figure 7-23 Test 4-12 Test Vehicle (Front Left Side) Post-Test (righted)

Figure 7-24 Test 4-12 Test Vehicle (Rear Left) Post-Test (righted)

Figure 7-25 Test 4-12 Test Vehicle (Rear) Post-Test (righted)

Figure 7-26 Test 4-12 Test Vehicle (Front Right) Post-Test (righted)

Figure 7-27 Test 4-12 Test Vehicle Occupant Compartment Deformation Post-Test

Table 7-2 Test 110MASH4S19-02 Test Data Summary Sheet


0.000 sec. [Frame 288]


0.160 sec. [Frame 368]


0.320 sec. [Frame 448]

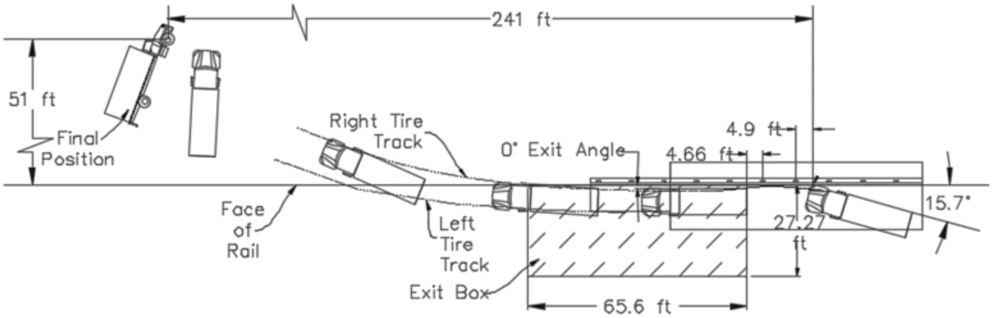

0.480 sec. [Frame 528]

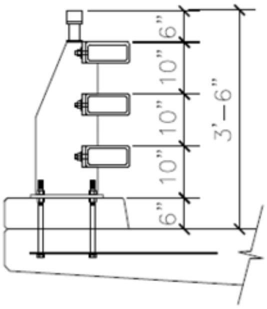

0.640 sec. [Frame 608]


0.800 sec. [Frame 688]


0.960 sec. [Frame 768]


1.120 sec. [Frame 848]





Test Agency	California, Department of Transportation
Test Number	110MASH4S19-02
Test Designation	MASH16 Test 4-12
Date	6/19/2019
Test Article	CA ST-75 Bridge Rail
Total Length	100 ft (30.5 m)
Key Elements – Barrier	
• Description	CA ST-75 Bridge Rail
• Base Width	24 in (610 mm)
• Height	36 in (910 mm)
Test Vehicle	
• Designation/Make/Model	10000S/ 2013 International 4300 SBA
• Curb	14733 lb (6683 kg)
• Test Inertial	22077 lb (10014 kg)
• Gross Static	22077 lb (10014 kg)
Impact Conditions	
• Speed	54.4 mph (87.5 kph)
• Angle	15.3°
• Location/Orientation	4.7 ft (1.4 m) upstream of middle of post
• Impact Severity	151 kip-ft (205 kJ)
Exit Conditions	
• Speed	49.6 mph (79.8 kph)
• Angle	8 °
• Exit Box Criterion	Pass
Post-impact Trajectory	
• Vehicle Stability	Not applicable
• Stopping Distance (from point of impact) Approx. 241 ft	
• (73.5 m) downstream and 51 ft (15.5 m)	
Test Article Damage	Deformed post plates, permanent deflection in rail

Test Article Deflections	
• Permanent Set*	1.5 in (38 mm)
• Dynamic*	3.25 in (83 mm)
• Working Width**	~45 in (1140 mm), at a height of approximately 11.5-12 ft above ground
Vehicle Damage	Moderate
• VDS[3]	01-RFQ-2, 01-RD-2, 03-RBQ-2, 03-RP-2, 09-L&T-2
• CDC[4]	01RREK2, 03RDES2, 09LDGW3
• Maximum Deformation	Approx. 3.2 in (81 mm) at Floorboard/wheel well
• Vehicle Snagging	None
• Vehicle Pocketing	None

Transducer Data

Measured Value		Transducer		
		DataBrick 328 (cab)	SLICE-656 (cargo box)	SLICE-659 (cargo box)
50 ms Average (g)	Long.	-3.7	-1.4	-2.0
	Lat.	-7.6	-17.2	-7.2
Max Angle Deg.	Roll	-110.8	-113.6	-112.4
	Pitch	11.9	7.1	6.1
	Yaw	82.3	96.0	90.5
Max Angle During Impact Deg.	Roll	18.5	17.9	18.6

* Measured with string potentiometers, not within Scope of Accreditation

** Estimated from upstream high-speed video, not within Scope of Accreditation

7.5. Discussion of Test Results

7.5.1. General Evaluation Methods

MASH 2016 recommends that crash test performance be assessed according to three evaluation factors: (1) structural adequacy, (2) occupant risk, and (3) post-impact vehicular response.

The structural adequacy and occupant risk associated with the ST-75 Bridge Rail were evaluated using evaluation criteria found in Tables 2.2A (Recommended Test Matrices for longitudinal barriers), 5.1A (Safety Evaluation Guidelines for Structural Adequacy), and 5.1B (Safety Evaluation Guidelines for Occupant Risk) of MASH 2016. The post-impact vehicular response was evaluated using Section 5.2.3 of MASH 2016.

7.5.2. Structural Adequacy

The structural adequacy of the ST-75 Bridge Rail was acceptable in MASH Test 4-12.

Refer to Table 7-3 for the assessment summary of the safety evaluation criteria for Test 4-12 of the ST-75 Bridge Rail.

7.5.3. Occupant Risk

The occupant risk was acceptable. The maximum amount of passenger compartment deformation measured by known points was 81 mm (3.2 in), which occurred at the floorboard. All interior deformations were below the maximum MASH 2016 limits. All interior deformation measurements are shown in Table 9-29 through Table 9-32. There was no occupant compartment penetration or potential for it. The occupant compartment was not compromised. The vehicle rolled onto its side after it lost contact with the bridge rail. However, it is preferable but not a requirement of MASH Test 4-12 that the vehicle remain upright during and after impact.

Refer to Table 7-3 for the assessment summary of the safety evaluation criteria for Test 4-12 of the ST-75 Bridge Rail.

7.5.4. Vehicle Trajectory

The vehicle trajectory was acceptable. The exit trajectory was within the exit box.

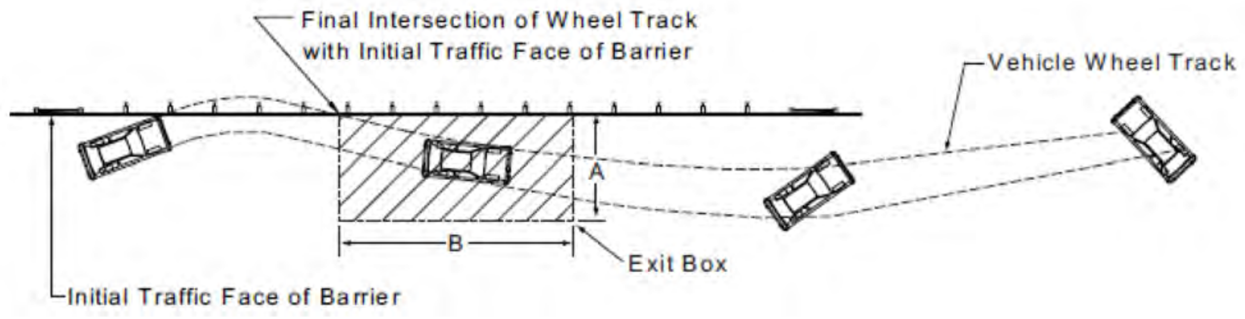


Figure 7-28 Exit Box for Longitudinal Barriers (AASHTO, 2016)

Refer to Table 7-3 for the assessment summary of the safety evaluation criteria for Test 4-12 of the ST-75 Bridge Rail.

Table 7-3 110MASH4S19-02 Assessment Summary

Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation, although controlled lateral deflection of the test article is acceptable.	The vehicle was contained and redirected smoothly.	PASS
Occupant Risk D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E.	The barrier did not detach any elements, fragments, and/or other debris	PASS
Occupant Risk E. It is preferable, although not essential, that the vehicle remain upright during and after the collision.	The vehicle rolled onto the driver's side and skidded until it came to rest.	PASS
Vehicle Trajectory It is preferable that the vehicle be smoothly redirected, and this is typically indicated when the vehicle leaves the barrier within the "exit box". The concept of the exit box is defined by the initial traffic face of the barrier and a line parallel to the initial traffic face of the barrier, at a distance A plus the width of the vehicle plus 16 percent of the length of the vehicle, starting at the final intersection (break) of the wheel track with the initial traffic face of the barrier for a distance of B. All wheel tracks of the vehicle should not cross the parallel line within the distance B.	A = 27.27 ft (8.31 m) B = 65.6 ft (20 m)	PASS

8. Conclusions and Recommendations

Based on the physical crash testing involved in this project, the following conclusions can be drawn:

1. The ST-75 Bridge Rail can successfully redirect an 1100-kg (2420 lbs) small car impacting at 100 kph (62 mph) and 25°.
2. The ST-75 Bridge Rail can successfully redirect a 2270-kg (5000 lbs) pickup car impacting at 100 kph (62 mph) and 25°.
3. The ST-75 Bridge Rail can successfully redirect a 10000-kg (22000 lbs) single-unit truck impacting at 90 kph (56 mph) and 15°.

As tested, The ST-75 Bridge Rail meets the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware 2016* (MASH 2016) criteria for Test 4-10, Test 4-11, and Test 4-12 for longitudinal barriers. Based on the successful completion of these tests the ST-75 Bridge Rail meets the MASH 2016 safety criteria for a Test Level 4 (TL-4) longitudinal barrier.

For reduced maintenance after more severe hits such as Test 4-12 in this report, it is recommended to stiffen the post base plates in order to reduce or eliminate the type of deformation observed in Test 4-12. The ST-75 demonstrated it has significant remaining capacity to contain and redirect the 10000S test vehicle and stiffening the base plate would likely not compromise this capacity. Also, this base plate change should have no adverse effect on the results of Tests 4-10 and 4-11 since the post base plates were already rigid enough to withstand those impacts without permanent deformation. The statements in this paragraph are outside the Lab's Scope of Accreditation.

Implementation will be carried out by Caltrans Division of Engineering Services, Structures and Engineering Services. They will be responsible for the preparation of Standard Plans (if required) and specifications for the California ST-75 Bridge Rail, with technical support from the Division of Research, Innovation and System Information.

9. **Appendix A: Vehicle Equipment and Test Data**

9.1. Test Vehicle Equipment

9.1.1. Test 110MASH4C19-01

The vehicle used for this test was a 2017 Nissan Versa Sedan. Since the vehicle was towed and not self-powered, the fuel in the gas tank was pumped out and gaseous CO_2 added to purge the gas vapors and eliminate oxygen. One pair of 12-volt wet cell batteries was mounted in the vehicle. The batteries powered two GMH DataBrick 3 transient data recorders. Each DataBrick 3 was connected to a set of orthogonal accelerometers and angular rate sensors, and one with an optical switch to measure impact speed. Two DTS SLICE MICRO systems were also installed each with a set of triaxial accelerometers and angular rate sensors. A 12-volt deep-cycle gel cell battery powered the Electronic Control Box. The Databrick 3 with the optical switch had a power-related data loss so the impact speed had to be determined using an overhead camera rather than the optical switch.

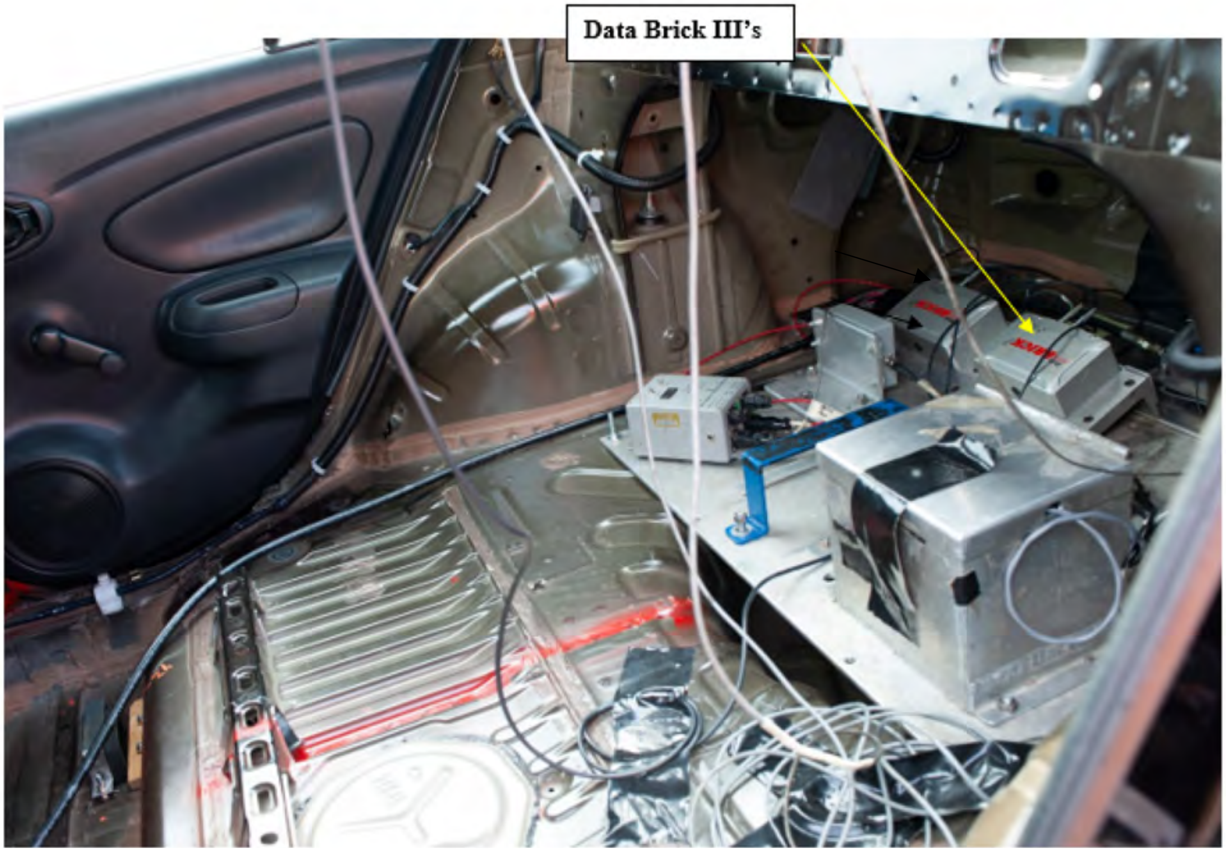


Figure 9-1 Data Brick III's installed for Test 4-10

Figure 9-2 Test 4-10 Vehicle Dummy and Instrumentation

A 4800 kPA (700 psi) CO_2 system, actuated by a solenoid valve, controlled remote braking after the impact and emergency braking if necessary. Part of this system was a pneumatic ram which was attached to the brake pedal. The operating pressure for the ram was adjusted through a pressure regulator during a series of trial runs prior to the actual test. Adjustments were made to ensure the shortest stopping distance without locking up the wheels. When activated, the brakes could be applied in less than 100 milliseconds.

A speed control device was connected in-line with the engine ignition coil power circuits on the tow vehicle. It was used to regulate the speed based on the signal from the tow vehicle transmission speed sensor. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap comprised of two tape switches (set at a specific distance apart) and a digital timer.

9.1.2. Test 110MASH4P18-02

The vehicle used for this test was a 2018 Dodge RAM 1500 Quad Cab. One pair of 12-volt wet cell batteries was mounted in the vehicle. The batteries powered two GMH DataBrick 3 transient data recorders. Each DataBrick 3 was connected to a set of orthogonal accelerometers and angular rate sensors, and one with an optical switch to measure impact speed. Two DTS SLICE MICRO systems were also installed each with a set of triaxial accelerometers and angular rate sensors. A 12-volt deep-cycle gel cell battery powered the Electronic Control Box. The Databrick 3 with the optical switch had a power-related data loss so the impact speed had to be determined using an overhead camera rather than the optical switch.

Figure 9-3 Test 4-11 Vehicle Instrumentation

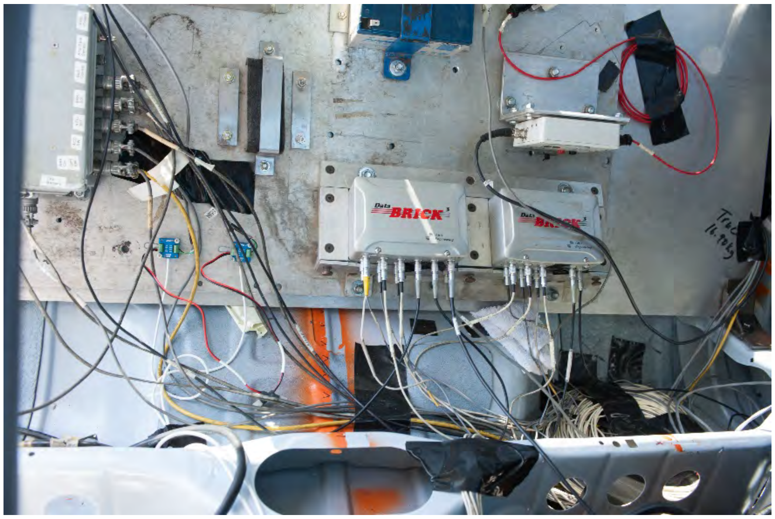


Figure 9-4 Test 4-11 Vehicle Instrumentation

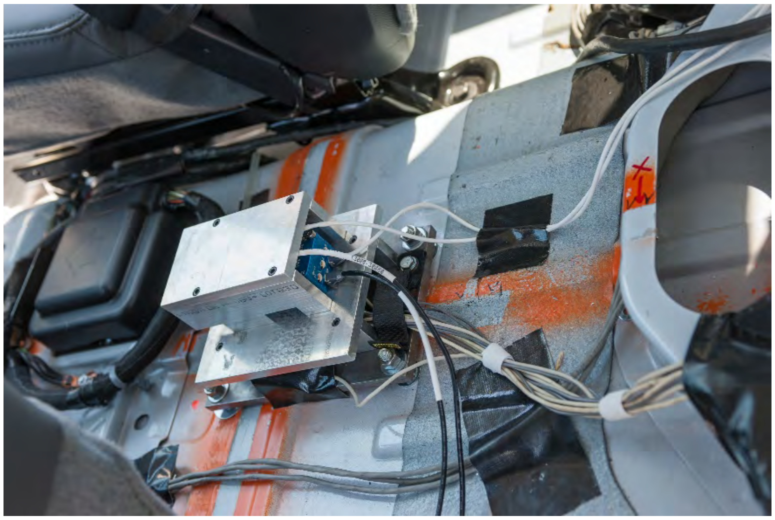


Figure 9-5 Test 4-11 Accelerometers and Angular Rate Sensors

A 4800 kPA (700 psi) CO_2 system, actuated by a solenoid valve, controlled remote braking after the impact and emergency braking if necessary. Part of this system was a pneumatic ram which was attached to the brake pedal. The operating pressure for the ram was adjusted through a pressure regulator during a series of trial runs prior to the actual test. Adjustments were made to ensure the shortest stopping distance without locking up the wheels. When activated, the brakes could be applied in less than 100 milliseconds.

A speed control device was connected in-line with the with the engine ignition coil power circuits on the test vehicle. It was used to regulate the speed based on drive shaft rotation detected by an optical sensor. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap comprised of two tape switches (set at a specific distance apart) and a digital timer.

9.1.3. Test 110MASH4S19-02

The vehicle used for this test was a 2013 International 4300 SBA. One pair of 12-volt wet cell batteries was mounted in the vehicle. The batteries powered two GMH DataBrick 3 transient data recorders that were mounted in the cab of the vehicle. Each DataBrick 3 was connected to a set of orthogonal accelerometers and angular rate sensors, and one with an optical switch to measure impact speed. Two DTS SLICE MICRO systems were also installed in the cargo box area. Each had a set of triaxial accelerometers and angular rate sensors. A 12-volt deep-cycle gel cell battery powered the Electronic Control Box. The Databrick 3 with the optical switch had a power-related data loss so the impact speed had to be determined using an overhead camera rather than the optical switch.

Figure 9-6 Test 4-12 Accelerometers and Angular Rate Sensors in Cab

Figure 9-7 Test 4-12 Accelerometers, Angular Rate Sensors, and other Instrumentation in Cargo Box

A 4800 kPA (700 psi) CO_2 system, actuated by a solenoid valve, controlled remote braking after the impact and emergency braking if necessary. Part of this system was a pneumatic ram which was attached to the brake pedal. The operating pressure for the ram was adjusted through a pressure regulator during a series of trial runs prior to the actual test. Adjustments were made to ensure the shortest stopping distance without locking up the wheels. When activated, the brakes could be applied in less than 100 milliseconds.

The test vehicle speed was controlled by an onboard speed limiter that is standard for this type vehicle. Before the test the vehicle's limiter was programed by a local service provider. To ensure that the limiter was set properly, a series of test runs were conducted using a GHM Engineering HFW80 Fifth Wheel Sensor.

The test vehicle was pushed by another vehicle so that the impact speed could be reached in the limited distance of roughly 640 m (2100 ft) available at the testing facility. A set push distance was established. Once the push vehicle had traveled this distance, it slowed down and allowed the test vehicle to continue accelerating until it reached the target speed. Onboard the push vehicle a speed control device was connected in-line with the engine ignition coil power circuits. It was used to regulate the speed based on the signal from the vehicle transmission speed sensor. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap comprised of two tape switches (set at a specific distance apart) and a digital timer.

9.2. Test Vehicle Guidance System

A rail guidance system directed the vehicle into the barrier. The guidance rail, anchored at approximately 3.8 m (12.5 ft) intervals along its length was used to guide a mechanical arm, which was attached to the hub of the front left wheel of the vehicle. A plate and lever were used to trigger the release pin on the guidance arm, thereby releasing the vehicle from the guidance system before impact.

Figure 9-8 Typical Guidance System Layout

Figure 9-9 Guide Arm Releasing from Test Vehicle

Figure 9-10 Guide Arm Released from Vehicle

9.3. Photo - Instrumentation

Several high-speed video cameras recorded the impact during the test. The high-speed video frame rates were set to 500 frames per second. The types of cameras and their locations are shown in Figure 9-11 and Table 9-1 thru Table 9-3. The origin of the coordinates is at the intended point of impact.

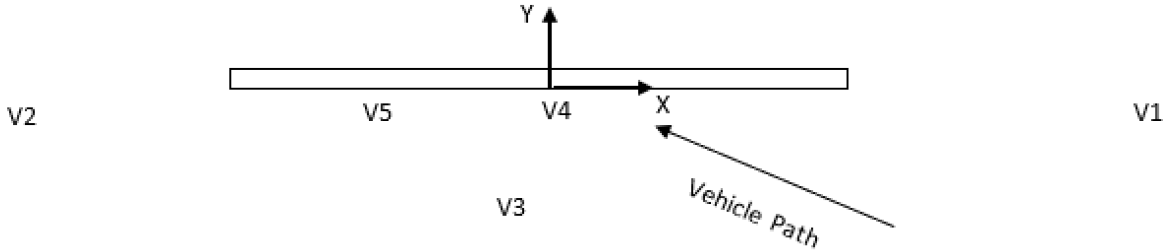


Figure 9-11 High-Speed Video Camera Locations (Not to Scale)

Table 9-1 110MASH4C19-01 Camera Types and Location Coordinates

Camera Location	Camera Make/Model	Camera Serial No.	Lens	Lens Serial No.	Coordinates, ft. (m)		
					x	y	z*
V1 Upstream	Vision Research Miro 111	22361	35 mm	173792	88.6 (27.0)	0.2 0.06)	4 (1.2)
V2 Downstream	Olympus iSpeed3	1400014	28-200 mm	402495	-278.2 (-84.8)	1.8 (0.55)	7 (2.1)
V3 Across	Olympus iSpeed3	1400022	20 mm	182398	-0.6 (-.18)	-54.1 (-16.5)	5.5 (1.7)
V4 Upstream Tower	Vision Research Miro 110	13235	20 mm	447169	2.4 (0.73)	-4.4 (-1.3)	25 (7.6)
V5 Downstream Tower	Vision Research Miro 110	13234	14 mm	217706	-27.3 (-8.3)	-8.9 (-2.7)	35 (10.7)

Table 9-2 110MASH4P18-02 Camera Types and Location Coordinates

Camera Location	Camera Make/Model	Camera Serial No.	Lens	Lens Serial No.	Coordinates, ft. (m)		
					x	y	z*
V1 Upstream	Olympus iSpeed3	1400012	35 mm	173792	88.4 (26.9)	-0.3 (-0.1)	5 (1.5)
V2 Downstream	Olympus iSpeed3	1400014	28-200 mm	402495	-277.7 (-84.6)	3.3 (1.0)	7 (2.1)
V3 Across	Olympus iSpeed3	1400022	20 mm	182398	-0.9 (-0.3)	-54.0 (-16.5)	5.0 (1.5)
V4 Upstream Tower	Vision Research Miro 110	13235	20 mm	447169	2.4 (0.73)	-4.4 (-1.3)	25 (7.6)
V5 Downstream Tower	Vision Research Miro 110	13234	14 mm	217706	-27.3 (-8.3)	-8.7 (-2.7)	35 (10.7)

Table 9-3 110MASH4S19-02 Camera Types and Location Coordinates

Camera Location	Camera Make/Model	Camera Serial No.	Lens	Lens Serial No.	Coordinates, ft. (m)		
					x	y	z*
V1 Upstream	Vision Research Miro 111	22361	35 mm	173792	86.1 (26.2)	2.0 (0.6)	5 (1.5)
V2 Downstream	Olympus iSpeed3	1400014	28-200 mm	402495	-323.4 (-98.6)	1.1 (0.3)	10 (3)
V3 Across	Olympus iSpeed3	1400022	20 mm	182398	0.9 (0.3)	-53.9 (-16.4)	5.0 (1.5)
V4 Upstream Tower	Vision Research Miro 110	13234	14 mm	217706	0.9 (0.3)	-5.2 (-1.6)	25 (7.6)
V5 Downstream Tower	Vision Research Miro 110	13235	20 mm	447169	-36.5 (-11.1)	-7.6 (-2.3)	25 (7.6)

*Camera elevations were estimated.

The following are the pretest procedures that were required to enable video data reduction to be performed using the Research's video analysis software (Phantom Camera Control):

1. Butterfly targets were attached to the top and sides of the test vehicle. The targets were located on the vehicle at intervals of 500 mm (19.7 in) and 1000 mm (39.4 in). The targets established scale factors.
2. Flashbulbs, mounted on the test vehicle, were electronically triggered to establish initial vehicle-to-barrier contact and the time of the application of the vehicle brakes.
3. High-speed digital video cameras were all time-coded using a portable computer and were triggered as the test vehicle passed over a tape switch located on the vehicle path upstream of impact.

9.4. Electronic Instrumentation and Data

Transducer data were recorded at 10,000 samples/second on two separate GMH Engineering, Data Brick, Model III, digital transient data recorders (TDRs) and two separate Diversified Technical Systems, Inc. (DTS) SLICE Micro data acquisition systems that were mounted in the test vehicle. The DataBricks were each connected to a set of accelerometers and a set of angular rate sensors that were located at the center of gravity. The DTS SLICE units each contain a set of accelerometers and angular rate sensors and were mounted at the center of gravity. The TDR data were reduced using a desktop personal computer. DADiSP 6.7 version B02 was used for pre-processing. TRAP was used for the post-processing. Accelerometer and angular rate sensor specifications are shown in Table 9-4 thru Table 9-6.

Table 9-4 Test 110MASH4C19-01 Accelerometer and Angular Rate Sensor Specifications

Type	Manufacturer	Model	Serial #	Location	Range	Orientation
Accelerometer	Endevco	7264M14-200-2	J16416	CG	±200 g	Longitudinal
Accelerometer	Measurement Specialties	64CM32	MS13328	CG	±200 g	Lateral
Accelerometer	Measurement Specialties	64CM32	MS13366	CG	±200 g	Vertical
Angular Rate Sensors	Data Acquisition Systems	ARS-1500 (1000HZ)	AR4018	CG	±1500 deg/s	Roll
Angular Rate Sensors	Data Acquisition Systems	ARS-1500 (1000HZ)	AR4217	CG	±1500 deg/s	Pitch
Angular Rate Sensors	Data Acquisition Systems	ARS-1500 (1000HZ)	ARS3348	CG	±1500 deg/s	Yaw
Triaxial Accelerometer	Diversified Technical Systems	SLICE MICRO 500 g	AC00200	CG	±500 g	
Triaxial Angular Rate Sensors	Diversified Technical Systems	SLICE MICRO 1500 degree/sec	AR00165	CG	±1500 deg/s	
Triaxial Accelerometer	Diversified Technical Systems	SLICE MICRO 500 g	AC00223	CG	±500 g	
Triaxial Angular Rate Sensors	Diversified Technical Systems	SLICE MICRO 1500 degree/sec	AR00166	CG	±1500 deg/s	

Table 9-5 Test 110MASH4P18-02 Accelerometer and Angular Rate Sensor Specifications

Type	Manufacturer	Model	Serial #	Location	Range	Orientation
Accelerometer	Measurement Specialties	64CM32	MS13361	CG	±200 g	Longitudinal
Accelerometer	Measurement Specialties	64CM32	MS13329	CG	±200 g	Lateral
Accelerometer	Measurement Specialties	64CM32	MS13364	CG	±200 g	Vertical
Angular Rate Sensors	Data Acquisition Systems	ARS-1500 (1000HZ)	ARS3355	CG	±1500 deg/s	Roll
Angular Rate Sensors	Data Acquisition Systems	ARS-1500 (1000HZ)	ARS3336	CG	±1500 deg/s	Pitch
Angular Rate Sensors	Data Acquisition Systems	ARS-1500 (1000HZ)	ARS4019	CG	±1500 deg/s	Yaw
Triaxial Accelerometer	Diversified Technical Systems	SLICE MICRO 500 g	AC00200	CG	±500 g	
Triaxial Angular Rate Sensors	Diversified Technical Systems	SLICE MICRO 1500 degree/sec	AR00165	CG	±1500 deg/s	
Triaxial Accelerometer	Diversified Technical Systems	SLICE MICRO 500 g	AC00223	CG	±500 g	

Table 9-6 Test 110MASH4S19-02 Accelerometer and Angular Rate Sensor Specifications

Type	Manufacturer	Model	Serial #	Location	Range	Orientation
Accelerometer	Measurement Specialties	64CM32	MS13361	CG	±200 g	Longitudinal
Accelerometer	Measurement Specialties	64CM32	MS13329	CG	±200 g	Lateral
Accelerometer	Measurement Specialties	64CM32	MS13364	CG	±200 g	Vertical
Angular Rate Sensors	Data Acquisition Systems	ARS-1500 (1000HZ)	ARS3355	CG	±1500 deg/s	Roll
Angular Rate Sensors	Data Acquisition Systems	ARS-1500 (1000HZ)	ARS3336	CG	±1500 deg/s	Pitch
Angular Rate Sensors	Data Acquisition Systems	ARS-1500 (1000HZ)	ARS4019	CG	±1500 deg/s	Yaw
Triaxial Accelerometer	Diversified Technical Systems	SLICE MICRO 500 g	AC00200	CG	±500 g	
Triaxial Angular Rate Sensors	Diversified Technical Systems	SLICE MICRO 1500 degree/sec	AR00165	CG	±1500 deg/s	
Triaxial Accelerometer	Diversified Technical Systems	SLICE MICRO 500 g	AC00223	CG	±500 g	
Triaxial Angular Rate Sensors	Diversified Technical Systems	SLICE MICRO 1500 degree/sec	AR00166	CG	±1500 deg/s	

A rigid stand with three retro-reflective 90° polarizing tape strips spaced 1000 mm (39.4 in) apart was placed on the ground near the test article and alongside the path of the test vehicle. The strips were measured immediately before the test to account for any thermal expansion. The test vehicle had an onboard optical sensor that produced sequential impulses or "event blips" as the vehicle passed the reflective tape strips. The event blips were recorded concurrently with the accelerometer signals on the TDR, serving as "event markers". The impact velocity of the vehicle could be determined from these sensor impulses, the data record time, and the known distance between the tape strips. A pressure sensitive tape switch on the front bumper of the vehicle closed at the instant of impact and triggered two events: 1) "event marker" was added to the recorded data, and 2) a flashbulb mounted on the top of the vehicle was activated. One set of pressure activated tape switches, connected to a speed trap, was placed 4 m apart just upstream of the test article to check the impact speed of the test vehicle (not a reported measurement). The layout for all the pressure sensitive tape switches and reflective tape is shown in Figure 9-12.

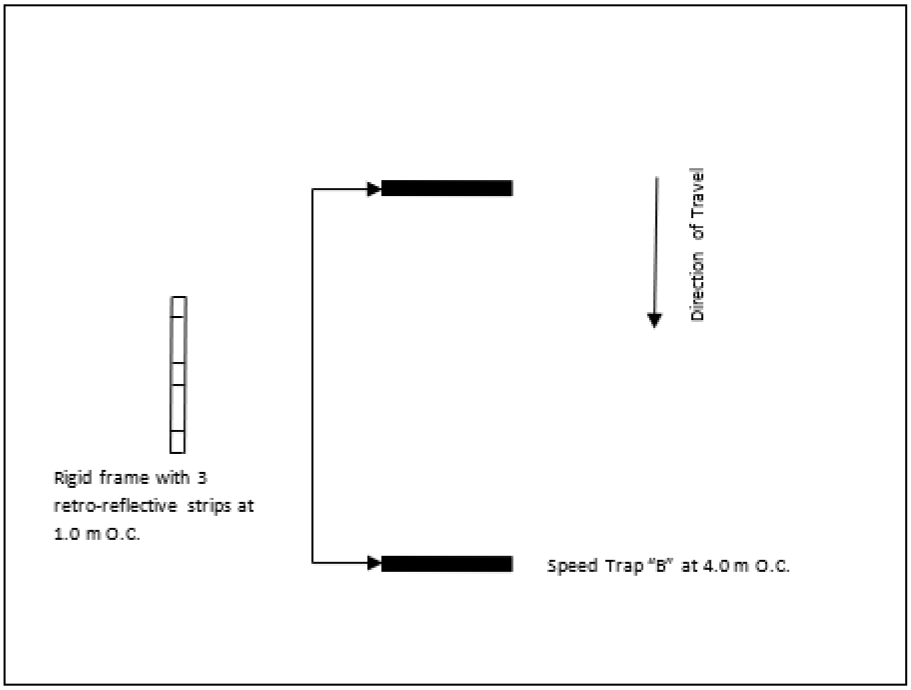


Figure 9-12 Speed Trap Tape Layout

9.5. Vehicle Measurements

9.5.1. Test 110MASH4C19-01

Table 9-7 Test 4-10 Exterior Vehicle Measurements

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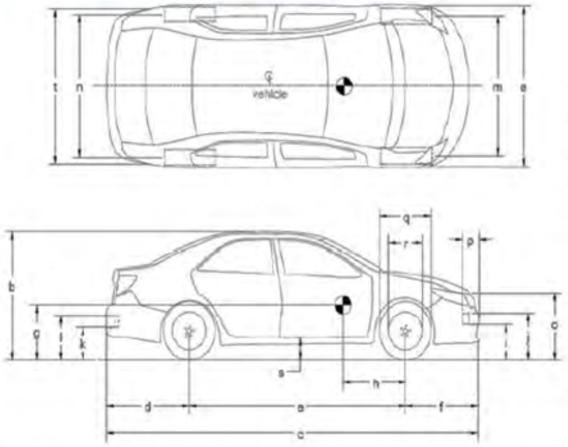
Attachment 5.4.5 --- 1100C and 1500A Small Car Parameters

Date: 2/14/2019 Test Number: 110MASH4C19-01 Model: Nissan
Make: Versa VIN: 3N1CN7APXHL832031
Tire Size: P185/65R15 Year: 2017 Odometer: 61526
Tire Inflation Pressure: 33psi Tape Measure Used: 5M-CP01 CLE:*** DRISI 1901
Measure by: Dave Sawko Staff: CC, VH, SW Scale Set Used: 2500 lbs

(All Measurements Refer to Impacting Side)



Vehicle Geometry - mm (inches)

a	1691	(66.57)	b	1498	(58.98)
c	4488	(176.69)	d	1024	(40.31)
e	2599	(102.32)	f	866	(34.09)
g	N/A	N/A	h	1086	(42.76)
i*	420	(16.54)	j*	567	(22.32)
k	408	(16.06)	l	548	(21.57)
m	1485	(58.46)	n	1485	(58.46)
o**	791	(31.14)	p	188	(7.4)
q	620	(24.41)	r	415	(16.34)
s	310	(12.2)	t	1672	(65.83)

Wheel Center Height Front:	292	(11.5)
Wheel Center Height Rear:	303	(11.93)
Wheel Well Clearance (F)	120	(4.72)
Wheel Well Clearance (R)	140	(5.51)
Frame Height (F):	175	(6.89)
Frame Height (R):	225	(8.86)
Engine Type:	gas	
Engine Size:	1.6 L	

Transmission Type:
Automatic or Manual: Manual
FWD or RWD or 4WD: FWD

* i & j taken from the functional bumper (may be inside bumper cover)
** o taken from top of radiator support bracket, centerline of vehicle
*** CLE is the inventory number and should be located on the door jamb of the vehicle.

Mass Distribution

Left Front:	333.3	(734.79)	Scale: red		Right Front:	297.45	(655.75)	Scale: green
Left Rear:	222.6	(490.74)	Scale: yellow		Right Rear:	230.3	(507.72)	Scale: blue

Weights

kg (lbs)	Curb		Test Inertial		Gross Static	
W_{front}	628.4	(1385.36)	630.75	(1390.54)	672.85	(1483.36)
W_{rear}	434.95	(958.88)	452.9	(998.46)	492.15	(1084.99)
W_{total}	1063.35	(2344.25)	1083.65	(2389)	1165	(2568.34)

GAWR & GVWR I

Front:	1750	(3858.02)
Back:	1708	(3765.43)
Total:	3389	(7471.34)

Dummy Data
Type: Hybrid III Dummy
Mass: 81.3 kg (179.2 lbs)
Seat Position: Passenger Side Front

Note any damage prior to test: Small scrape on back passenger panel.

Data Transferred to Electronic Copy By: Christopher Caldwell Date: 3/22/2019

Transfer Checked by: David Whitesel Date: 5/15/2019

Christopher Caldwell reviewed calculations on 8/20/2014

Table 9-8 Test 4-10 CG Calculation: Curb Weight

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Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #1: Curb Weight

Make:	Versa	Test Number:	110MASH4C19-01
Model:	Nissan	Date:	2/14/2019
Year:	2017	Temperature:	70 °F
VIN:	3N1CN7APXHL832031	Scale Set Used:	2500 lbs
Fuel in Tank:	1/4 tank		
Fuel Removed:	none		
Measured By:	Dave S. Steve W.		
Support Staff	Vue H.		

W1 = Left Front (LF) = 329.95 kg
Scale Used: red

W2 = Right Front (RF) = 298.45 kg
Scale Used: green

W3 = Left Rear (LR) = 211.75 kg
Scale Used: yellow

W4 = Right Rear (RR) = 223.2 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 1062.2 kg
Wtotal (calculated) = 1063.35 kg

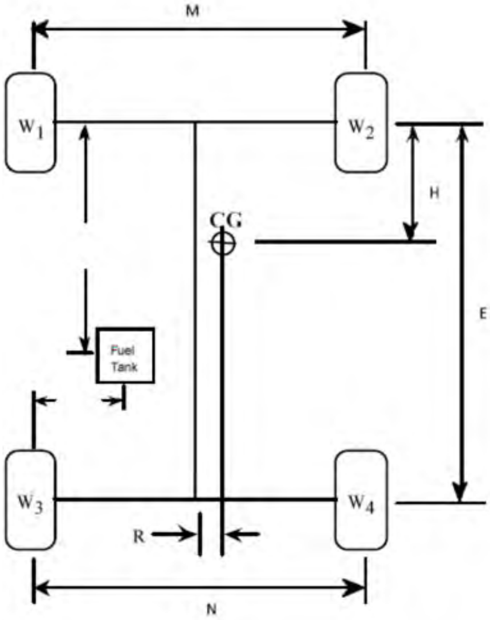
Distance between front wheels:
M = 1485 mm

Distance between rear wheels:
N = 1485 mm

Distance from front to rear wheels:
E = 2599 mm

Distance from front wheels back to CG:
H = 1063 mm

Distance from vehicle centerline to CG:
R = -14 mm



$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

Data Transferred to Electronic Copy By: Christopher Caldwell Date: 2/26/2019
Transfer Checked by: David Whitesel Date: 5/15/2019

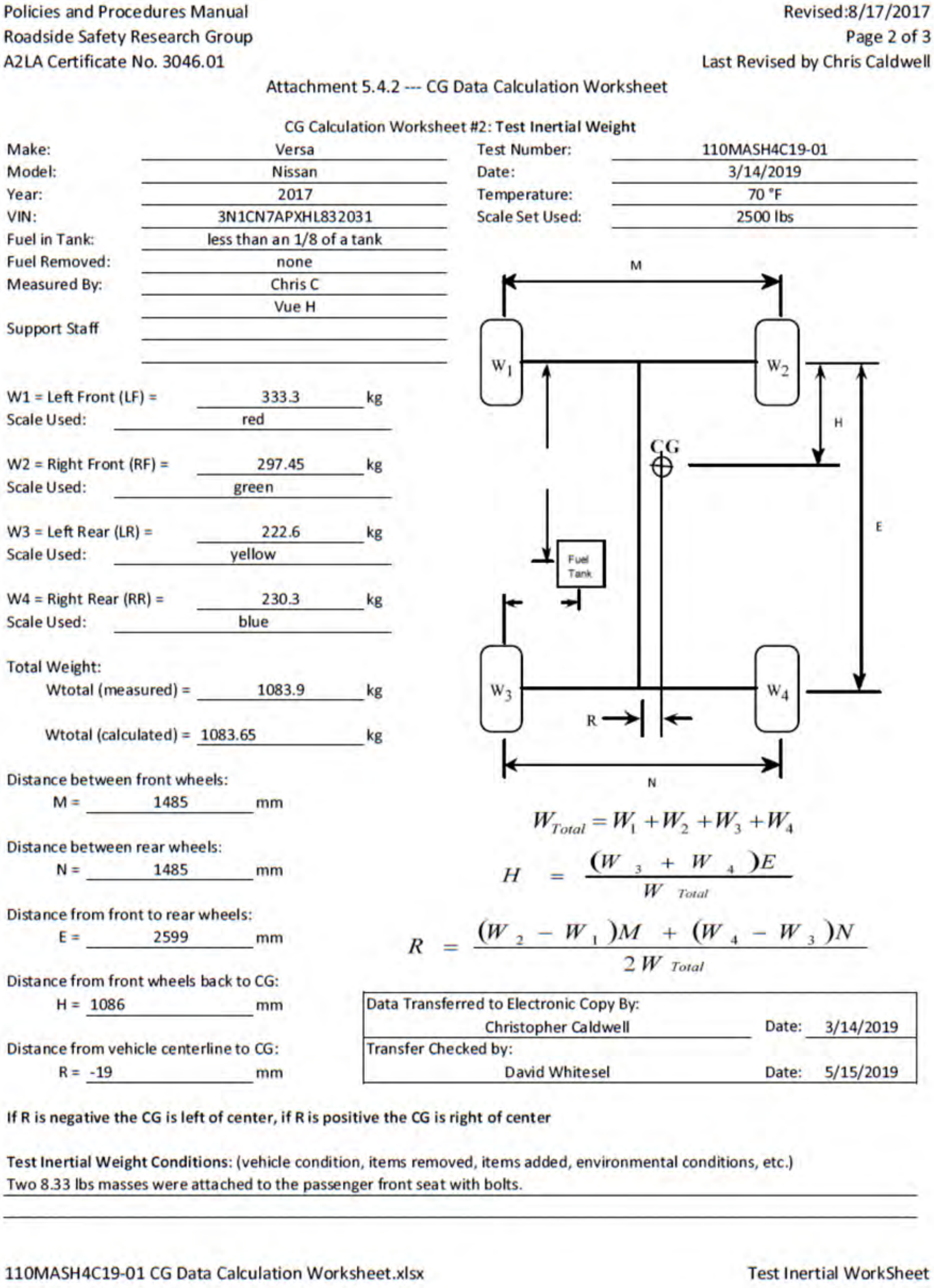
If R is negative the CG is left of center, if R is positive the CG is right of center

Curb Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)

110MASH4C19-01 CG Data Calculation Worksheet.xlsx

Curb WorkSheet

Table 9-9 Test 4-10 CG Calculation: Test Inertial Weight



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Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #2: **Test Inertial Weight**

Make: Versa
Model: Nissan
Year: 2017
VIN: 3N1CN7APXHL832031
Fuel in Tank: less than an 1/8 of a tank
Fuel Removed: none
Measured By: Chris C
Vue H
Support Staff

Test Number: 110MASH4C19-01
Date: 3/14/2019
Temperature: 70 °F
Scale Set Used: 2500 lbs

W1 = Left Front (LF) = 333.3 kg
Scale Used: red

W2 = Right Front (RF) = 297.45 kg
Scale Used: green

W3 = Left Rear (LR) = 222.6 kg
Scale Used: yellow

W4 = Right Rear (RR) = 230.3 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 1083.9 kg

Wtotal (calculated) = 1083.65 kg

Distance between front wheels:
M = 1485 mm

Distance between rear wheels:
N = 1485 mm

Distance from front to rear wheels:
E = 2599 mm

Distance from front wheels back to CG:
H = 1086 mm

Distance from vehicle centerline to CG:
R = -19 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

Data Transferred to Electronic Copy By:
Christopher Caldwell Date: 3/14/2019
Transfer Checked by:
David Whitesel Date: 5/15/2019

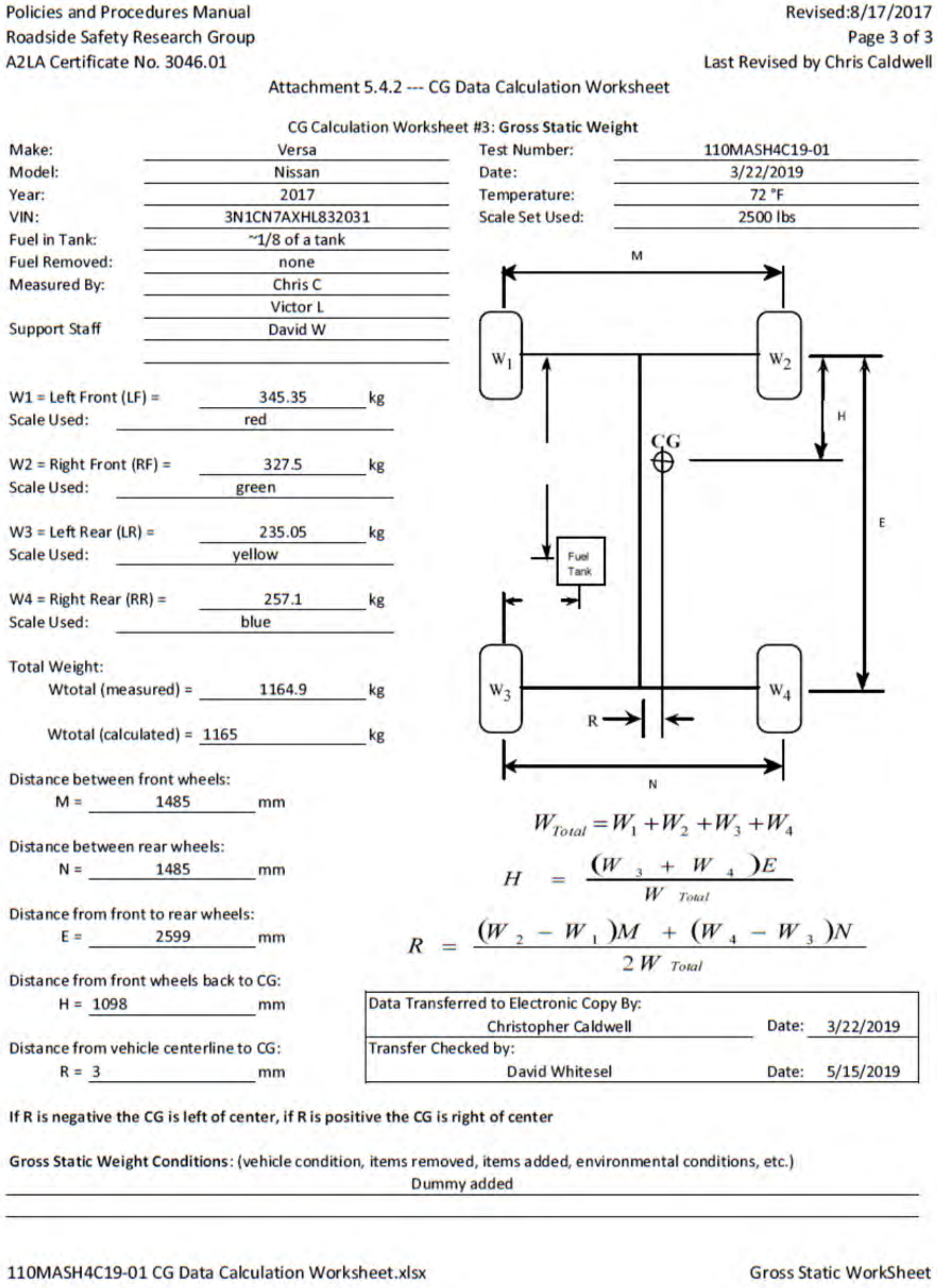
If R is negative the CG is left of center, if R is positive the CG is right of center

Test Inertial Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Two 8.33 lbs masses were attached to the passenger front seat with bolts.

110MASH4C19-01 CG Data Calculation Worksheet.xlsx

Test Inertial WorkSheet

Table 9-10 Test 4-10 CG Calculation: Gross Static Weight



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Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #3: **Gross Static Weight**

Make: Versa
Model: Nissan
Year: 2017
VIN: 3N1CN7AXHL832031
Fuel in Tank: ~1/8 of a tank
Fuel Removed: none
Measured By: Chris C
Victor L
Support Staff David W

Test Number: 110MASH4C19-01
Date: 3/22/2019
Temperature: 72 °F
Scale Set Used: 2500 lbs

W1 = Left Front (LF) = 345.35 kg
Scale Used: red

W2 = Right Front (RF) = 327.5 kg
Scale Used: green

W3 = Left Rear (LR) = 235.05 kg
Scale Used: yellow

W4 = Right Rear (RR) = 257.1 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 1164.9 kg

Wtotal (calculated) = 1165 kg

Distance between front wheels:
M = 1485 mm

Distance between rear wheels:
N = 1485 mm

Distance from front to rear wheels:
E = 2599 mm

Distance from front wheels back to CG:
H = 1098 mm

Distance from vehicle centerline to CG:
R = 3 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

Data Transferred to Electronic Copy By: Christopher Caldwell Date: 3/22/2019
Transfer Checked by: David Whitesel Date: 5/15/2019

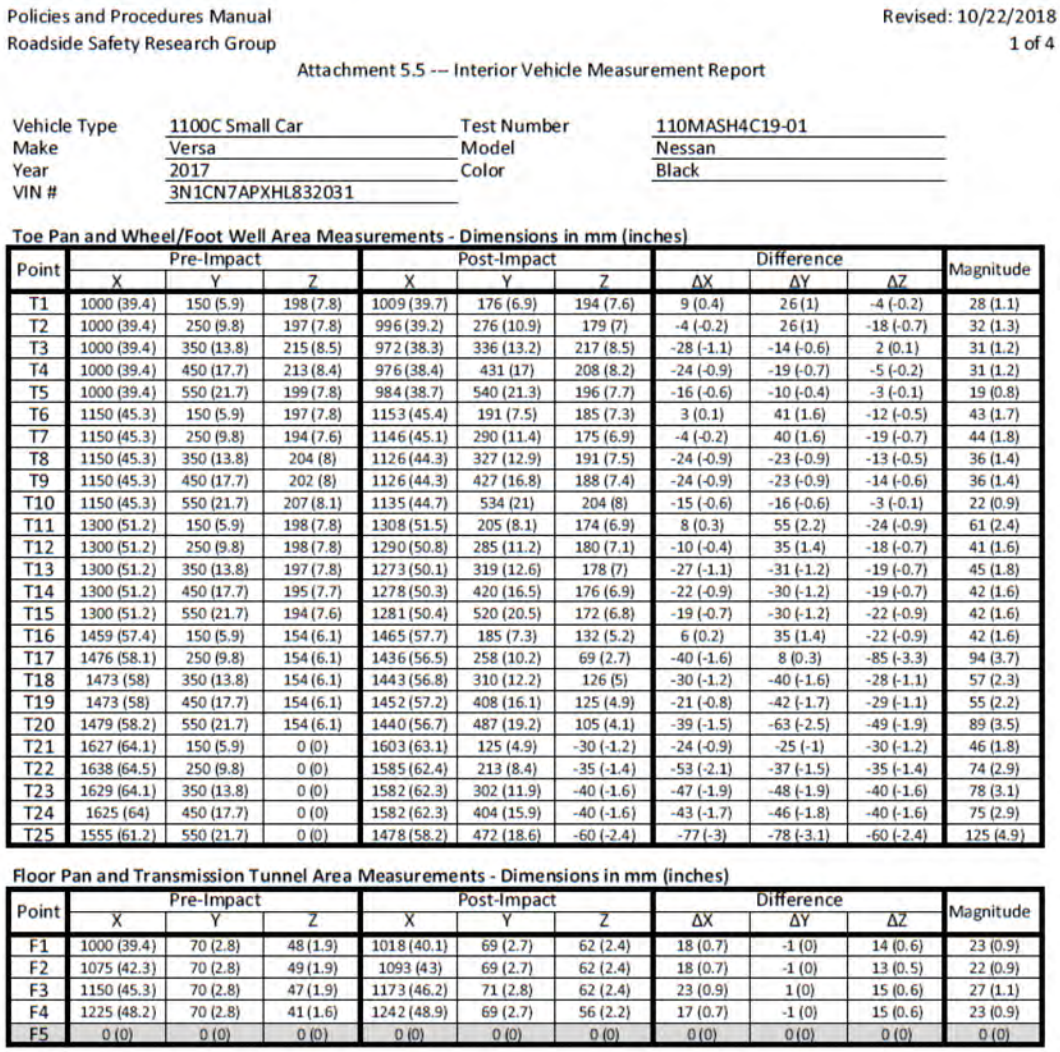
If R is negative the CG is left of center, if R is positive the CG is right of center

Gross Static Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Dummy added

110MASH4C19-01 CG Data Calculation Worksheet.xlsx

Gross Static WorkSheet

Table 9-11 Test 4-10 Interior Floor and Transmission Tunnel Pre, Post, and Deformation Measurements



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Attachment 5.5 -– Interior Vehicle Measurement Report

Vehicle Type	1100C Small Car	Test Number	110MASH4C19-01
Make	Versa	Model	Nessan
Year	2017	Color	Black
VIN #	3N1CN7APXHL832031		

Toe Pan and Wheel/Foot Well Area Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
T1	1000 (39.4)	150 (5.9)	198 (7.8)	1009 (39.7)	176 (6.9)	194 (7.6)	9 (0.4)	26 (1)	-4 (-0.2)	28 (1.1)
T2	1000 (39.4)	250 (9.8)	197 (7.8)	996 (39.2)	276 (10.9)	179 (7)	-4 (-0.2)	26 (1)	-18 (-0.7)	32 (1.3)
T3	1000 (39.4)	350 (13.8)	215 (8.5)	972 (38.3)	336 (13.2)	217 (8.5)	-28 (-1.1)	-14 (-0.6)	2 (0.1)	31 (1.2)
T4	1000 (39.4)	450 (17.7)	213 (8.4)	976 (38.4)	431 (17)	208 (8.2)	-24 (-0.9)	-19 (-0.7)	-5 (-0.2)	31 (1.2)
T5	1000 (39.4)	550 (21.7)	199 (7.8)	984 (38.7)	540 (21.3)	196 (7.7)	-16 (-0.6)	-10 (-0.4)	-3 (-0.1)	19 (0.8)
T6	1150 (45.3)	150 (5.9)	197 (7.8)	1153 (45.4)	191 (7.5)	185 (7.3)	3 (0.1)	41 (1.6)	-12 (-0.5)	43 (1.7)
T7	1150 (45.3)	250 (9.8)	194 (7.6)	1146 (45.1)	290 (11.4)	175 (6.9)	-4 (-0.2)	40 (1.6)	-19 (-0.7)	44 (1.8)
T8	1150 (45.3)	350 (13.8)	204 (8)	1126 (44.3)	327 (12.9)	191 (7.5)	-24 (-0.9)	-23 (-0.9)	-13 (-0.5)	36 (1.4)
T9	1150 (45.3)	450 (17.7)	202 (8)	1126 (44.3)	427 (16.8)	188 (7.4)	-24 (-0.9)	-23 (-0.9)	-14 (-0.6)	36 (1.4)
T10	1150 (45.3)	550 (21.7)	207 (8.1)	1135 (44.7)	534 (21)	204 (8)	-15 (-0.6)	-16 (-0.6)	-3 (-0.1)	22 (0.9)
T11	1300 (51.2)	150 (5.9)	198 (7.8)	1308 (51.5)	205 (8.1)	174 (6.9)	8 (0.3)	55 (2.2)	-24 (-0.9)	61 (2.4)
T12	1300 (51.2)	250 (9.8)	198 (7.8)	1290 (50.8)	285 (11.2)	180 (7.1)	-10 (-0.4)	35 (1.4)	-18 (-0.7)	41 (1.6)
T13	1300 (51.2)	350 (13.8)	197 (7.8)	1273 (50.1)	319 (12.6)	178 (7)	-27 (-1.1)	-31 (-1.2)	-19 (-0.7)	45 (1.8)
T14	1300 (51.2)	450 (17.7)	195 (7.7)	1278 (50.3)	420 (16.5)	176 (6.9)	-22 (-0.9)	-30 (-1.2)	-19 (-0.7)	42 (1.6)
T15	1300 (51.2)	550 (21.7)	194 (7.6)	1281 (50.4)	520 (20.5)	172 (6.8)	-19 (-0.7)	-30 (-1.2)	-22 (-0.9)	42 (1.6)
T16	1459 (57.4)	150 (5.9)	154 (6.1)	1465 (57.7)	185 (7.3)	132 (5.2)	6 (0.2)	35 (1.4)	-22 (-0.9)	42 (1.6)
T17	1476 (58.1)	250 (9.8)	154 (6.1)	1436 (56.5)	258 (10.2)	69 (2.7)	-40 (-1.6)	8 (0.3)	-85 (-3.3)	94 (3.7)
T18	1473 (58)	350 (13.8)	154 (6.1)	1443 (56.8)	310 (12.2)	126 (5)	-30 (-1.2)	-40 (-1.6)	-28 (-1.1)	57 (2.3)
T19	1473 (58)	450 (17.7)	154 (6.1)	1452 (57.2)	408 (16.1)	125 (4.9)	-21 (-0.8)	-42 (-1.7)	-29 (-1.1)	55 (2.2)
T20	1479 (58.2)	550 (21.7)	154 (6.1)	1440 (56.7)	487 (19.2)	105 (4.1)	-39 (-1.5)	-63 (-2.5)	-49 (-1.9)	89 (3.5)
T21	1627 (64.1)	150 (5.9)	0 (0)	1603 (63.1)	125 (4.9)	-30 (-1.2)	-24 (-0.9)	-25 (-1)	-30 (-1.2)	46 (1.8)
T22	1638 (64.5)	250 (9.8)	0 (0)	1585 (62.4)	213 (8.4)	-35 (-1.4)	-53 (-2.1)	-37 (-1.5)	-35 (-1.4)	74 (2.9)
T23	1629 (64.1)	350 (13.8)	0 (0)	1582 (62.3)	302 (11.9)	-40 (-1.6)	-47 (-1.9)	-48 (-1.9)	-40 (-1.6)	78 (3.1)
T24	1625 (64)	450 (17.7)	0 (0)	1582 (62.3)	404 (15.9)	-40 (-1.6)	-43 (-1.7)	-46 (-1.8)	-40 (-1.6)	75 (2.9)
T25	1555 (61.2)	550 (21.7)	0 (0)	1478 (58.2)	472 (18.6)	-60 (-2.4)	-77 (-3)	-78 (-3.1)	-60 (-2.4)	125 (4.9)

Floor Pan and Transmission Tunnel Area Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
F1	1000 (39.4)	70 (2.8)	48 (1.9)	1018 (40.1)	69 (2.7)	62 (2.4)	18 (0.7)	-1 (0)	14 (0.6)	23 (0.9)
F2	1075 (42.3)	70 (2.8)	49 (1.9)	1093 (43)	69 (2.7)	62 (2.4)	18 (0.7)	-1 (0)	13 (0.5)	22 (0.9)
F3	1150 (45.3)	70 (2.8)	47 (1.9)	1173 (46.2)	71 (2.8)	62 (2.4)	23 (0.9)	1 (0)	15 (0.6)	27 (1.1)
F4	1225 (48.2)	70 (2.8)	41 (1.6)	1242 (48.9)	69 (2.7)	56 (2.2)	17 (0.7)	-1 (0)	15 (0.6)	23 (0.9)
F5	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

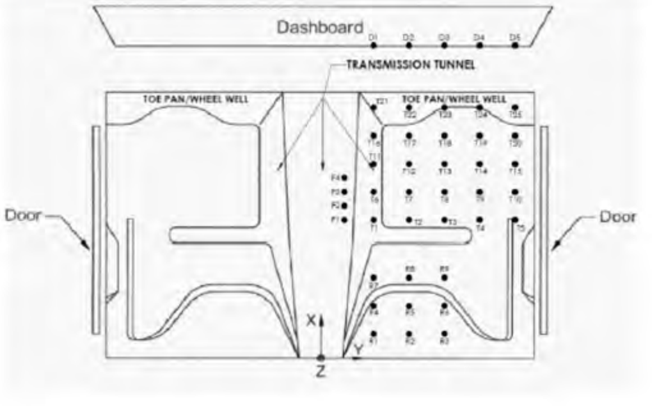

Table 9-12 Test 4-10 Interior Side Front Panel and Roof Pre, Post, and Deformation Measurements

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Roadside Safety Research Group

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Attachment 5.5 --- Interior Vehicle Measurement Report

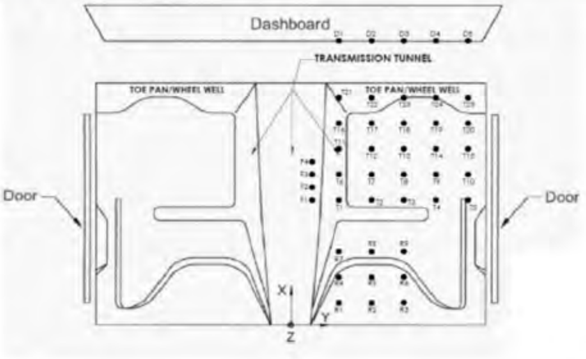
Vehicle Type	1100C Small Car	Test Number	110MASH4C19-01
Make	Versa	Model	Nessan
Year	2017	Color	Black
VIN #	3N1CN7APXHL832031		

Side Front Panal Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
S1	1428 (56.2)	643 (25.3)	111 (4.4)	1395 (54.9)	579 (22.8)	52 (2)	-33 (-1.3)	-64 (-2.5)	-59 (-2.3)	93 (3.7)
S2	1426 (56.1)	644 (25.4)	0 (0)	1372 (54)	571 (22.5)	-58 (-2.3)	-54 (-2.1)	-73 (-2.9)	-58 (-2.3)	108 (4.2)
S3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
S4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
S5	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
S6	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
S7	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
S8	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
S9	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
S10	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Roof Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
R1	600 (23.6)	150 (5.9)	-1066 (-42)	599 (23.6)	148 (5.8)	-1077 (-42.4)	-1 (0)	-2 (-0.1)	-11 (-0.4)	11 (0.4)
R2	600 (23.6)	250 (9.8)	-1068 (-42)	599 (23.6)	249 (9.8)	-1079 (-42.5)	-1 (0)	-1 (0)	-11 (-0.4)	11 (0.4)
R3	600 (23.6)	350 (13.8)	-1062 (-41.8)	598 (23.5)	348 (13.7)	-1076 (-42.4)	-2 (-0.1)	-2 (-0.1)	-14 (-0.6)	14 (0.6)
R4	700 (27.6)	150 (5.9)	-1058 (-41.7)	699 (27.5)	148 (5.8)	-1066 (-42)	-1 (0)	-2 (-0.1)	-8 (-0.3)	8 (0.3)
R5	700 (27.6)	250 (9.8)	-1055 (-41.5)	699 (27.5)	249 (9.8)	-1070 (-42.1)	-1 (0)	-1 (0)	-15 (-0.6)	15 (0.6)
R6	700 (27.6)	350 (13.8)	-1052 (-41.4)	696 (27.4)	347 (13.7)	-1068 (-42)	-4 (-0.2)	-3 (-0.1)	-16 (-0.6)	17 (0.7)
R7	800 (31.5)	150 (5.9)	-1040 (-40.9)	800 (31.5)	149 (5.9)	-1056 (-41.6)	0 (0)	-1 (0)	-16 (-0.6)	16 (0.6)
R8	800 (31.5)	250 (9.8)	-1036 (-40.8)	799 (31.5)	250 (9.8)	-1056 (-41.6)	-1 (0)	0 (0)	-20 (-0.8)	20 (0.8)
R9	800 (31.5)	350 (13.8)	-1030 (-40.6)	800 (31.5)	351 (13.8)	-1054 (-41.5)	0 (0)	1 (0)	-24 (-0.9)	24 (0.9)
R10	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)



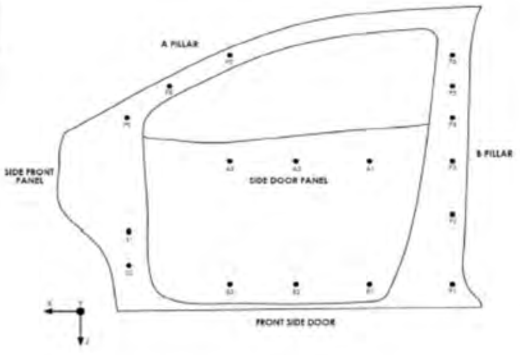
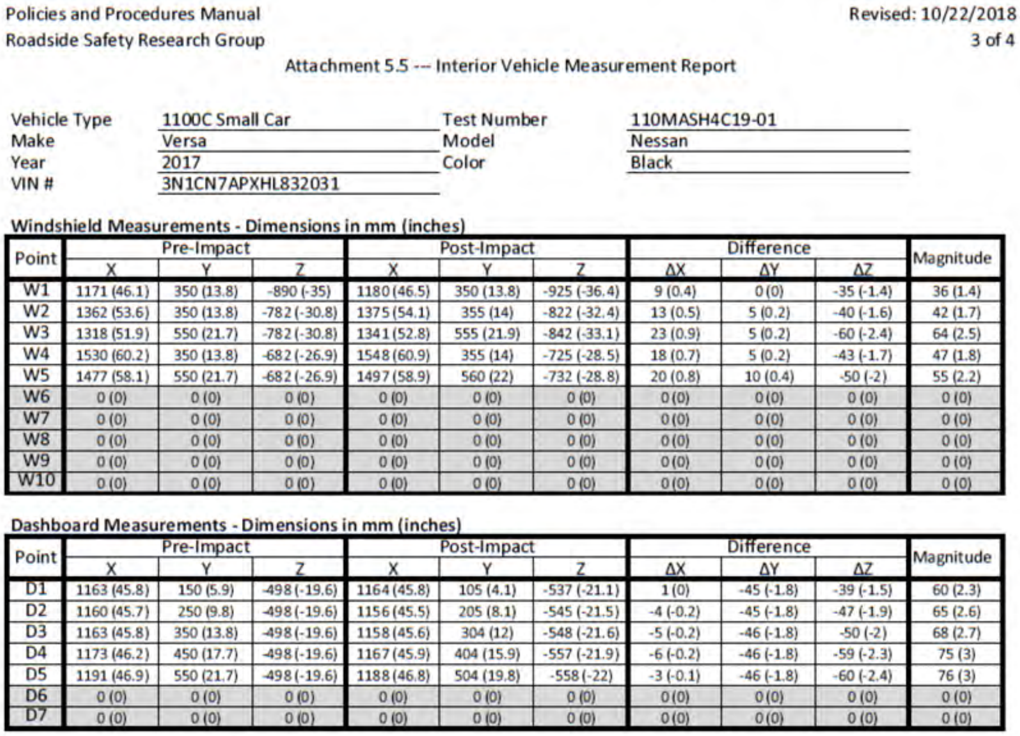


Table 9-13 Test 4-10 Interior Windshield and Dashboard Pre, Post, and Deformation Measurements



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Revised: 10/22/2018
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Attachment 5.5 --- Interior Vehicle Measurement Report

Vehicle Type	1100C Small Car	Test Number	110MASH4C19-01
Make	Versa	Model	Nessan
Year	2017	Color	Black
VIN #	3N1CN7APXHL832031		

Windshield Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
W1	1171 (46.1)	350 (13.8)	-890 (-35)	1180 (46.5)	350 (13.8)	-925 (-36.4)	9 (0.4)	0 (0)	-35 (-1.4)	36 (1.4)
W2	1362 (53.6)	350 (13.8)	-782 (-30.8)	1375 (54.1)	355 (14)	-822 (-32.4)	13 (0.5)	5 (0.2)	-40 (-1.6)	42 (1.7)
W3	1318 (51.9)	550 (21.7)	-782 (-30.8)	1341 (52.8)	555 (21.9)	-842 (-33.1)	23 (0.9)	5 (0.2)	-60 (-2.4)	64 (2.5)
W4	1530 (60.2)	350 (13.8)	-682 (-26.9)	1548 (60.9)	355 (14)	-725 (-28.5)	18 (0.7)	5 (0.2)	-43 (-1.7)	47 (1.8)
W5	1477 (58.1)	550 (21.7)	-682 (-26.9)	1497 (58.9)	560 (22)	-732 (-28.8)	20 (0.8)	10 (0.4)	-50 (-2)	55 (2.2)
W6	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
W7	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
W8	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
W9	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
W10	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Dashboard Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
D1	1163 (45.8)	150 (5.9)	-498 (-19.6)	1164 (45.8)	105 (4.1)	-537 (-21.1)	1 (0)	-45 (-1.8)	-39 (-1.5)	60 (2.3)
D2	1160 (45.7)	250 (9.8)	-498 (-19.6)	1156 (45.5)	205 (8.1)	-545 (-21.5)	-4 (-0.2)	-45 (-1.8)	-47 (-1.9)	65 (2.6)
D3	1163 (45.8)	350 (13.8)	-498 (-19.6)	1158 (45.6)	304 (12)	-548 (-21.6)	-5 (-0.2)	-46 (-1.8)	-50 (-2)	68 (2.7)
D4	1173 (46.2)	450 (17.7)	-498 (-19.6)	1167 (45.9)	404 (15.9)	-557 (-21.9)	-6 (-0.2)	-46 (-1.8)	-59 (-2.3)	75 (3)
D5	1191 (46.9)	550 (21.7)	-498 (-19.6)	1188 (46.8)	504 (19.8)	-558 (-22)	-3 (-0.1)	-46 (-1.8)	-60 (-2.4)	76 (3)
D6	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
D7	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

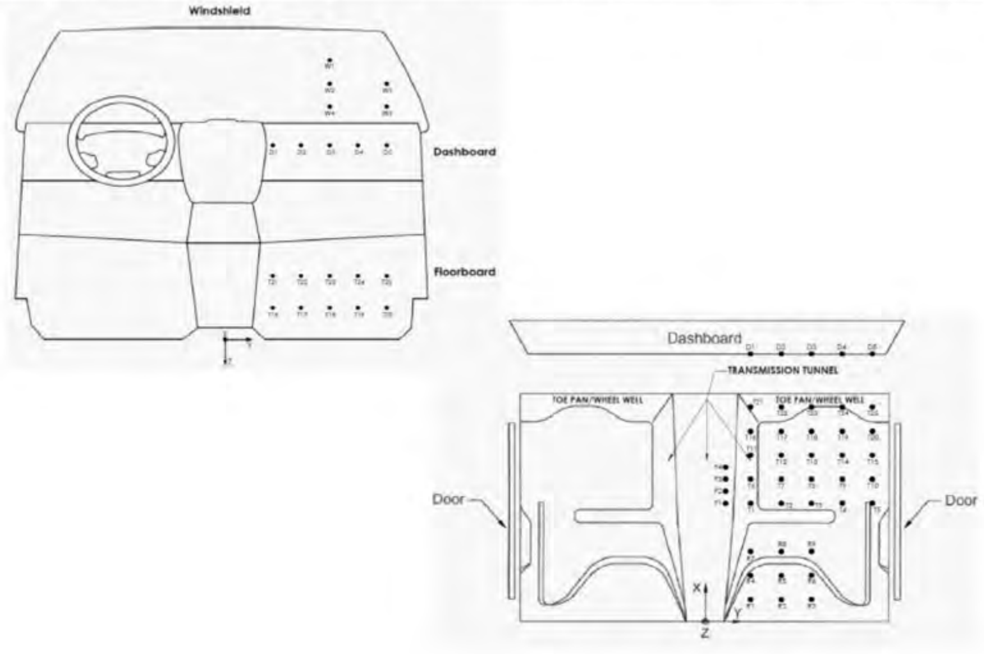
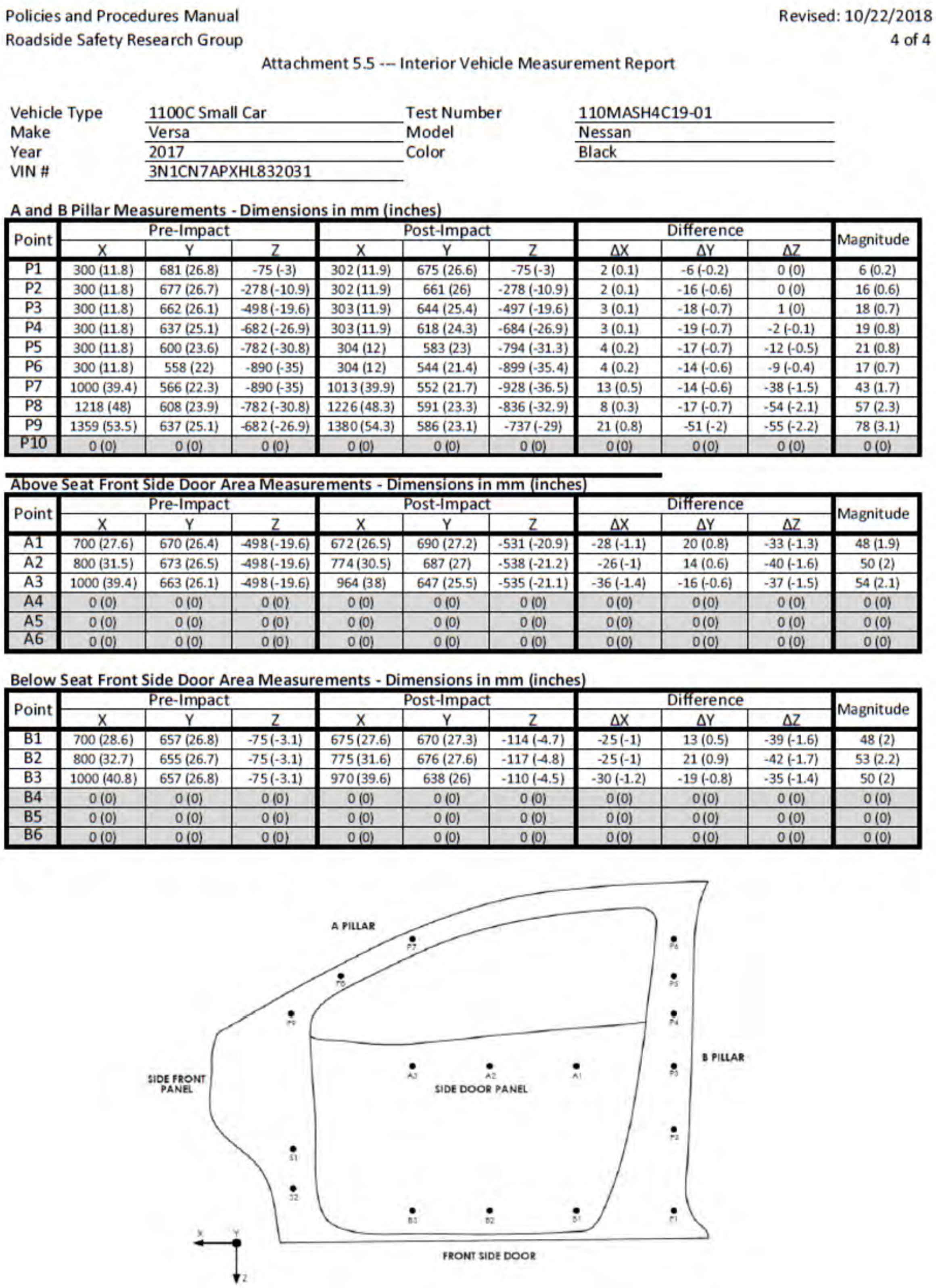


Table 9-14 Test 4-10 Interior Side Pre, Post, and Deformation Measurements



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Attachment 5.5 -- Interior Vehicle Measurement Report

Vehicle Type	1100C Small Car	Test Number	110MASH4C19-01
Make	Versa	Model	Nessan
Year	2017	Color	Black
VIN #	3N1CN7APXHL832031		

A and B Pillar Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
P1	300 (11.8)	681 (26.8)	-75 (-3)	302 (11.9)	675 (26.6)	-75 (-3)	2 (0.1)	-6 (-0.2)	0 (0)	6 (0.2)
P2	300 (11.8)	677 (26.7)	-278 (-10.9)	302 (11.9)	661 (26)	-278 (-10.9)	2 (0.1)	-16 (-0.6)	0 (0)	16 (0.6)
P3	300 (11.8)	662 (26.1)	-498 (-19.6)	303 (11.9)	644 (25.4)	-497 (-19.6)	3 (0.1)	-18 (-0.7)	1 (0)	18 (0.7)
P4	300 (11.8)	637 (25.1)	-682 (-26.9)	303 (11.9)	618 (24.3)	-684 (-26.9)	3 (0.1)	-19 (-0.7)	-2 (-0.1)	19 (0.8)
P5	300 (11.8)	600 (23.6)	-782 (-30.8)	304 (12)	583 (23)	-794 (-31.3)	4 (0.2)	-17 (-0.7)	-12 (-0.5)	21 (0.8)
P6	300 (11.8)	558 (22)	-890 (-35)	304 (12)	544 (21.4)	-899 (-35.4)	4 (0.2)	-14 (-0.6)	-9 (-0.4)	17 (0.7)
P7	1000 (39.4)	566 (22.3)	-890 (-35)	1013 (39.9)	552 (21.7)	-928 (-36.5)	13 (0.5)	-14 (-0.6)	-38 (-1.5)	43 (1.7)
P8	1218 (48)	608 (23.9)	-782 (-30.8)	1226 (48.3)	591 (23.3)	-836 (-32.9)	8 (0.3)	-17 (-0.7)	-54 (-2.1)	57 (2.3)
P9	1359 (53.5)	637 (25.1)	-682 (-26.9)	1380 (54.3)	586 (23.1)	-737 (-29)	21 (0.8)	-51 (-2)	-55 (-2.2)	78 (3.1)
P10	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Above Seat Front Side Door Area Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
A1	700 (27.6)	670 (26.4)	-498 (-19.6)	672 (26.5)	690 (27.2)	-531 (-20.9)	-28 (-1.1)	20 (0.8)	-33 (-1.3)	48 (1.9)
A2	800 (31.5)	673 (26.5)	-498 (-19.6)	774 (30.5)	687 (27)	-538 (-21.2)	-26 (-1)	14 (0.6)	-40 (-1.6)	50 (2)
A3	1000 (39.4)	663 (26.1)	-498 (-19.6)	964 (38)	647 (25.5)	-535 (-21.1)	-36 (-1.4)	-16 (-0.6)	-37 (-1.5)	54 (2.1)
A4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
A5	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
A6	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Below Seat Front Side Door Area Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
B1	700 (28.6)	657 (26.8)	-75 (-3.1)	675 (27.6)	670 (27.3)	-114 (-4.7)	-25 (-1)	13 (0.5)	-39 (-1.6)	48 (2)
B2	800 (32.7)	655 (26.7)	-75 (-3.1)	775 (31.6)	676 (27.6)	-117 (-4.8)	-25 (-1)	21 (0.9)	-42 (-1.7)	53 (2.2)
B3	1000 (40.8)	657 (26.8)	-75 (-3.1)	970 (39.6)	638 (26)	-110 (-4.5)	-30 (-1.2)	-19 (-0.8)	-35 (-1.4)	50 (2)
B4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
B5	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
B6	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

9.5.2.Test 110MASH4P18-02

Table 9-15 Test 4-11 Exterior Vehicle Measurements

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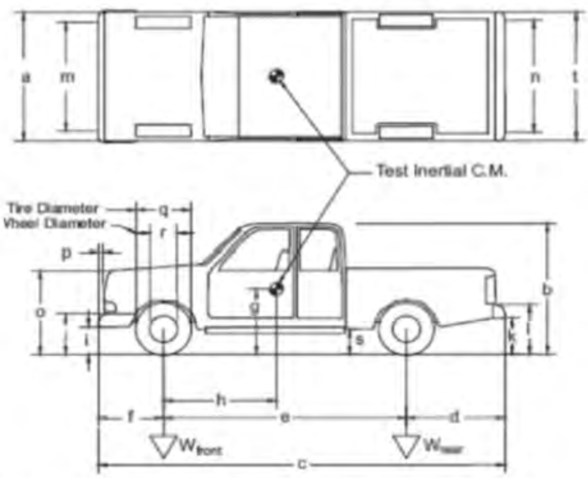
Attachment 5.4.6 --- 2270P Truck Parameters

Date: 7/10/2018 Test Number: 110MASH4P18-02 Model: Dodge
Make: Ram 1500 VIN: 1C6RR6FG7JS293929
Tire Size: P265/70R17 Year: 2018 Odometer: 46
Tire Inflation Pressure: 40 psi Tape Measure Used: 5m-CP02 CLE:** DRISI 1801
Measured by: Chris C Staff: Steve W, Dave S Scale Set Used: 2500 lbs

*(All Measurements Refer to Impacting Side)



Vehicle Geometry - mm (inches)

a	1977	(77.8)	b	1917	(75.5)
c *	5823	(229.3)	d	1233	(48.5)
e	3569	(140.5)	f	1020	(40.2)
g	748	(29.4)	h	1554	(61.2)
i	340	(13.4)	j	655	(25.8)
k	532	(20.9)	l	771	(30.4)
m	1736	(68.3)	n	1718	(67.6)
o	1160	(45.7)	p	120	(4.7)
q	790	(31.1)	r	470	(18.5)
s	380	(15)	t	1908	(75.1)

Wheel Center Height Front:	385	(15.2)
Wheel Center Height Rear:	385	(15.2)
Wheel Well Clearance (F)	160	(6.3)
Wheel Well Clearance (R)	215	(8.5)
Frame Height (F):	330	(13)
Frame Height (R):	360	(14.2)

Engine Type: V6
Engine Size: 3.6L
Transmission Type:
Automatic or Manual: Automatic
FWD or RWD or 4WD: RWD

Mass Distribution - kg (lbs)

** CLE is the inventory number and should be located on the door jamb of the vehicle.

Left Front:	619	(1365.5)	Scale: red		Right Front:	607.5	(1339.2)	Scale: green
Left Rear:	527	(1162.6)	Scale: yellow		Right Rear:	497.7	(1097.2)	Scale: blue

Weights

kg (lbs)	Curb		Test Inertial		Gross Static	
W_{front}	1221.3	(2692.4)	1226.9	(2704.7)	1226.9	(2704.7)
W_{rear}	941.7	(2075.9)	1025.1	(2259.8)	1025.1	(2259.8)
W_{total}	2162.9	(4768.3)	2251.9	(4964.5)	2251.9	(4964.5)

*Used calibrated 100ft steel tape to take this measurement. Tape's SO# 1-B6E6F-20-1. Measure as 19ft-1.25 inches and converted to mm. Chris C 7-10-18.

GVWA Ratings - kg (lbs)

Front:	1679	(3701.5)
Back:	1770	(3902.1)
Total:	3449	(7603.6)

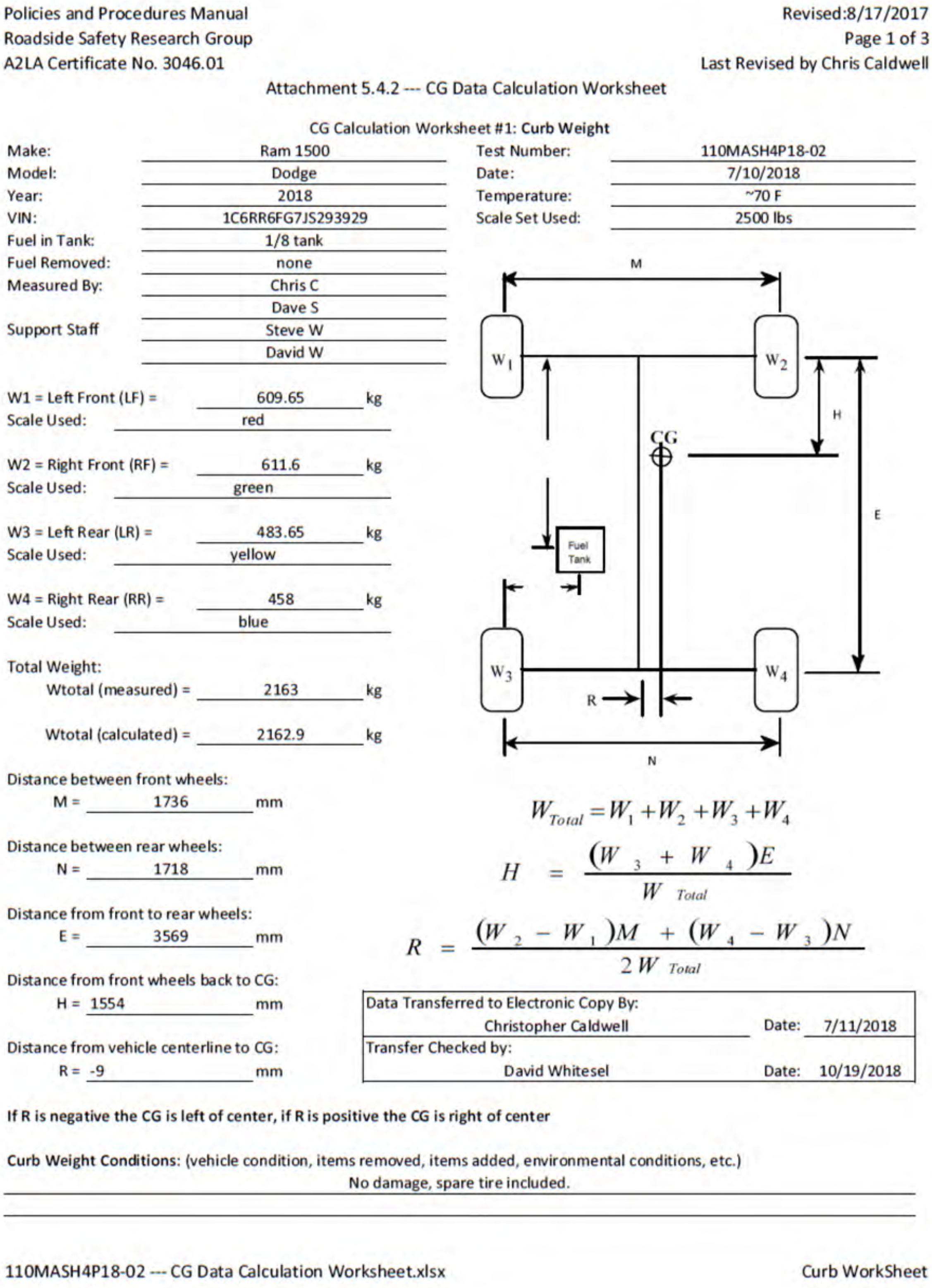
Dummy Data
Type: N/A
Mass: N/A
Seat Position: N/A

GVWR Ratings: 3085 kg (6800 lbs)
Note any damage prior to test: No damage to vehicle

Data Transferred to Electronic Copy By: Christopher Caldwell Date: 8/29/2018
Transfer Checked by: David Whitesel Date: 10/19/2018

Christopher Caldwell reviewed calculations 8/20/2014

Table 9-16 Test 4-11 CG Calculation: Curb Weight



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Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #1: **Curb Weight**

Make:	Ram 1500	Test Number:	110MASH4P18-02
Model:	Dodge	Date:	7/10/2018
Year:	2018	Temperature:	~70 F
VIN:	1C6RR6FG7JS293929	Scale Set Used:	2500 lbs
Fuel in Tank:	1/8 tank		
Fuel Removed:	none		
Measured By:	Chris C		
	Dave S		
Support Staff	Steve W		
	David W		

W1 = Left Front (LF) = 609.65 kg
Scale Used: red

W2 = Right Front (RF) = 611.6 kg
Scale Used: green

W3 = Left Rear (LR) = 483.65 kg
Scale Used: yellow

W4 = Right Rear (RR) = 458 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 2163 kg

Wtotal (calculated) = 2162.9 kg

Distance between front wheels:
M = 1736 mm

Distance between rear wheels:
N = 1718 mm

Distance from front to rear wheels:
E = 3569 mm

Distance from front wheels back to CG:
H = 1554 mm

Distance from vehicle centerline to CG:
R = -9 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

Data Transferred to Electronic Copy By:
Christopher Caldwell Date: 7/11/2018
Transfer Checked by:
David Whitesel Date: 10/19/2018

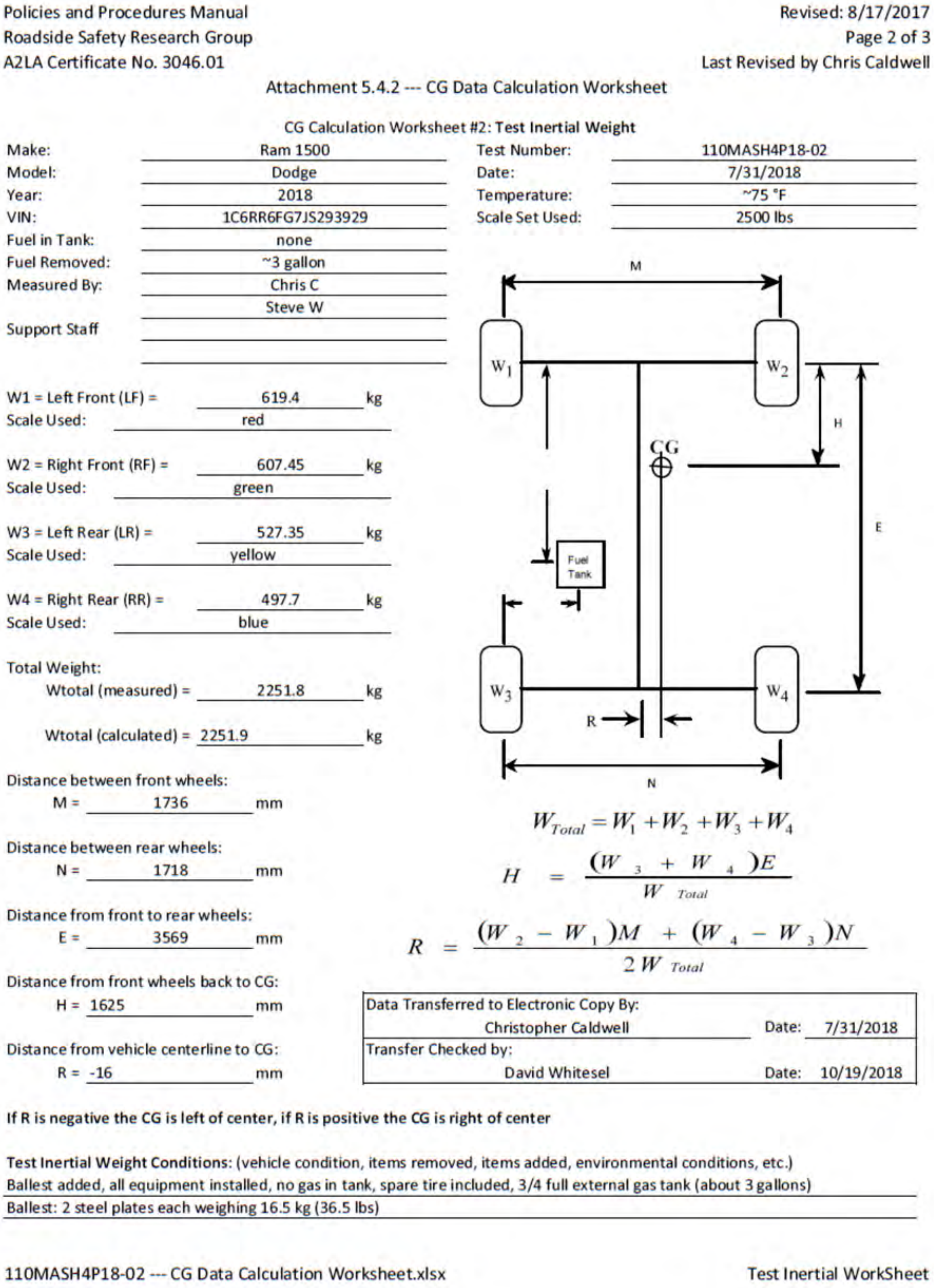
If R is negative the CG is left of center, if R is positive the CG is right of center

Curb Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
No damage, spare tire included.

110MASH4P18-02 --- CG Data Calculation Worksheet.xlsx

Curb WorkSheet

Table 9-17 Test 4-11 CG Calculation: Test Inertial Weight



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Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #2: Test Inertial Weight

Make: Ram 1500
Model: Dodge
Year: 2018
VIN: 1C6RR6FG7JS293929
Fuel in Tank: none
Fuel Removed: ~3 gallon
Measured By: Chris C
Steve W
Support Staff

Test Number: 110MASH4P18-02
Date: 7/31/2018
Temperature: ~75 °F
Scale Set Used: 2500 lbs

W1 = Left Front (LF) = 619.4 kg
Scale Used: red

W2 = Right Front (RF) = 607.45 kg
Scale Used: green

W3 = Left Rear (LR) = 527.35 kg
Scale Used: yellow

W4 = Right Rear (RR) = 497.7 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 2251.8 kg

Wtotal (calculated) = 2251.9 kg

Distance between front wheels:
M = 1736 mm

Distance between rear wheels:
N = 1718 mm

Distance from front to rear wheels:
E = 3569 mm

Distance from front wheels back to CG:
H = 1625 mm

Distance from vehicle centerline to CG:
R = -16 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

Data Transferred to Electronic Copy By:
Christopher Caldwell Date: 7/31/2018
Transfer Checked by:
David Whitesel Date: 10/19/2018

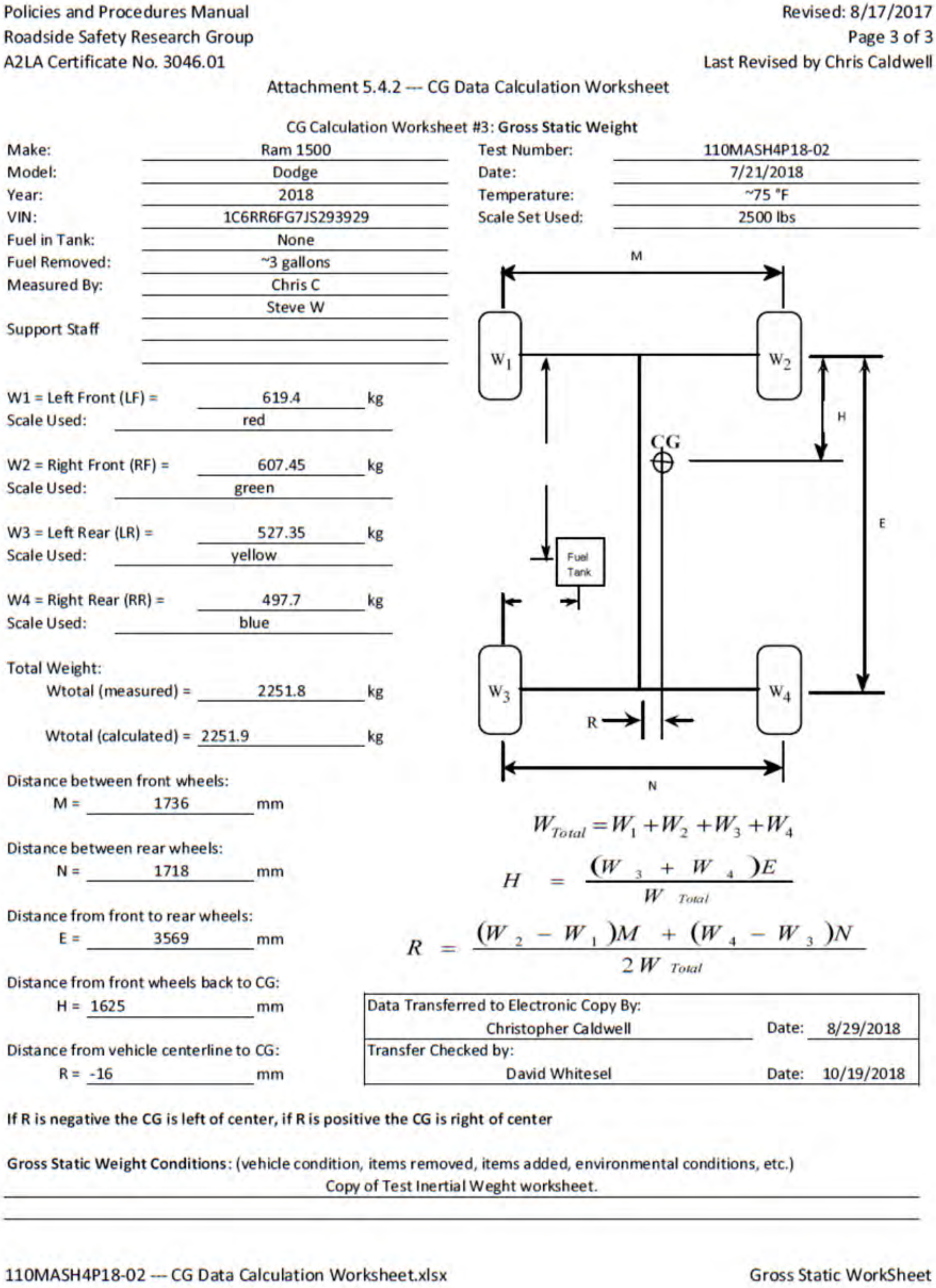
If R is negative the CG is left of center, if R is positive the CG is right of center

Test Inertial Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Ballest added, all equipment installed, no gas in tank, spare tire included, 3/4 full external gas tank (about 3 gallons)
Ballest: 2 steel plates each weighing 16.5 kg (36.5 lbs)

110MASH4P18-02 --- CG Data Calculation Worksheet.xlsx

Test Inertial WorkSheet

Table 9-18 Test 4-11 CG Calculation: Gross Static Weight



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Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #3: **Gross Static Weight**

Make: Ram 1500
Model: Dodge
Year: 2018
VIN: 1C6RR6FG7JS293929
Fuel in Tank: None
Fuel Removed: ~3 gallons
Measured By: Chris C
Steve W
Support Staff

Test Number: 110MASH4P18-02
Date: 7/21/2018
Temperature: ~75 °F
Scale Set Used: 2500 lbs

W1 = Left Front (LF) = 619.4 kg
Scale Used: red

W2 = Right Front (RF) = 607.45 kg
Scale Used: green

W3 = Left Rear (LR) = 527.35 kg
Scale Used: yellow

W4 = Right Rear (RR) = 497.7 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 2251.8 kg

Wtotal (calculated) = 2251.9 kg

Distance between front wheels:
M = 1736 mm

Distance between rear wheels:
N = 1718 mm

Distance from front to rear wheels:
E = 3569 mm

Distance from front wheels back to CG:
H = 1625 mm

Distance from vehicle centerline to CG:
R = -16 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

Data Transferred to Electronic Copy By: Christopher Caldwell Date: 8/29/2018
Transfer Checked by: David Whitesel Date: 10/19/2018

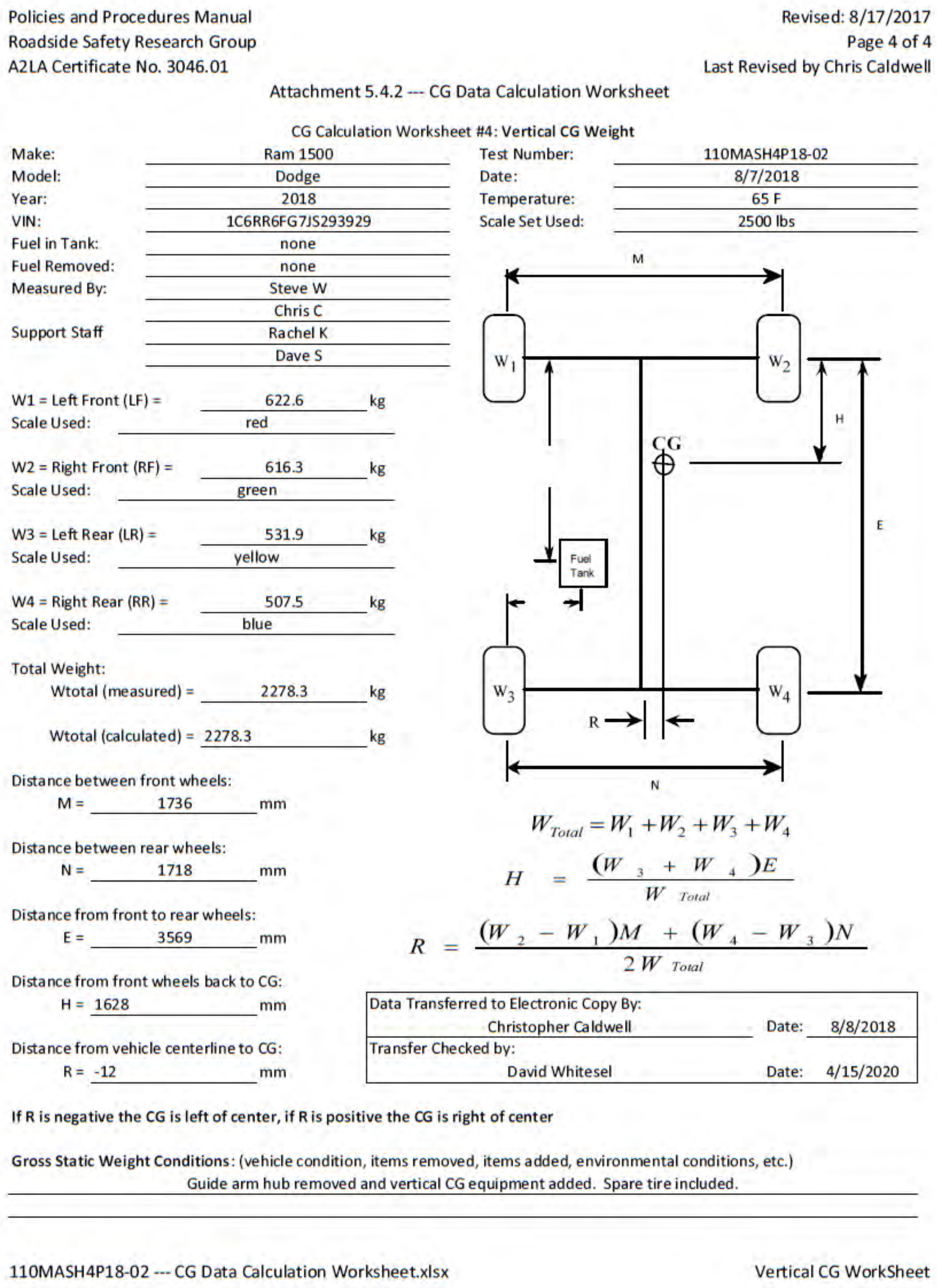
If R is negative the CG is left of center, if R is positive the CG is right of center

Gross Static Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Copy of Test Inertial Weght worksheet.

110MASH4P18-02 --- CG Data Calculation Worksheet.xlsx

Gross Static WorkSheet

Table 9-19 Test 4-11 CG Calculation: Vertical CG Weight



Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #4: **Vertical CG Weight**

Make:	Ram 1500	Test Number:	110MASH4P18-02
Model:	Dodge	Date:	8/7/2018
Year:	2018	Temperature:	65 F
VIN:	1C6RR6FG7JS293929	Scale Set Used:	2500 lbs
Fuel in Tank:	none		
Fuel Removed:	none		
Measured By:	Steve W		
	Chris C		
Support Staff	Rachel K		
	Dave S		

W1 = Left Front (LF) = 622.6 kg
Scale Used: red

W2 = Right Front (RF) = 616.3 kg
Scale Used: green

W3 = Left Rear (LR) = 531.9 kg
Scale Used: yellow

W4 = Right Rear (RR) = 507.5 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 2278.3 kg

Wtotal (calculated) = 2278.3 kg

Distance between front wheels:
M = 1736 mm

Distance between rear wheels:
N = 1718 mm

Distance from front to rear wheels:
E = 3569 mm

Distance from front wheels back to CG:
H = 1628 mm

Distance from vehicle centerline to CG:
R = -12 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

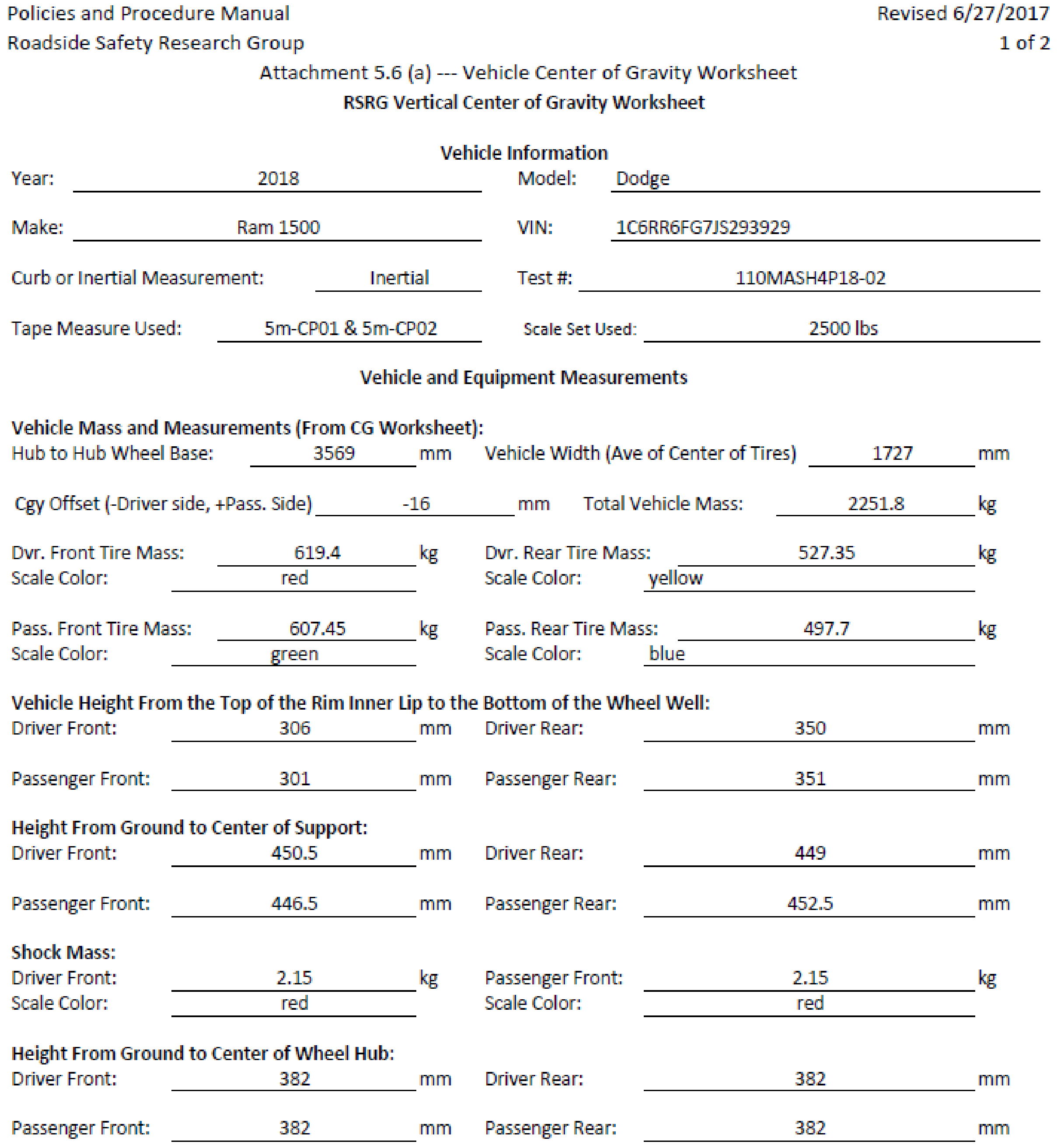
$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

Data Transferred to Electronic Copy By:	Christopher Caldwell	Date:	8/8/2018
Transfer Checked by:	David Whitesel	Date:	4/15/2020

If R is negative the CG is left of center, if R is positive the CG is right of center

Gross Static Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Guide arm hub removed and vertical CG equipment added. Spare tire included.

Table 9-20 Test 4-11 Vertical CG Calculation: Worksheet



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Attachment 5.6 (a) --- Vehicle Center of Gravity Worksheet

RSRG Vertical Center of Gravity Worksheet

Vehicle Information

Year: 2018
Model: Dodge
Make: Ram 1500
VIN: 1C6RR6FG7JS293929
Curb or Inertial Measurement: Inertial
Test #: 110MASH4P18-02
Tape Measure Used: 5m-CP01 & 5m-CP02
Scale Set Used: 2500 lbs

Vehicle and Equipment Measurements

Vehicle Mass and Measurements (From CG Worksheet):

Hub to Hub Wheel Base: 3569 mm
Vehicle Width (Ave of Center of Tires) 1727 mm
Cgy Offset (-Driver side, +Pass. Side) -16 mm
Total Vehicle Mass: 2251.8 kg
Dvr. Front Tire Mass: 619.4 kg
Scale Color: red
Dvr. Rear Tire Mass: 527.35 kg
Scale Color: yellow
Pass. Front Tire Mass: 607.45 kg
Scale Color: green
Pass. Rear Tire Mass: 497.7 kg
Scale Color: blue

Vehicle Height From the Top of the Rim Inner Lip to the Bottom of the Wheel Well:

Driver Front: 306 mm
Driver Rear: 350 mm
Passenger Front: 301 mm
Passenger Rear: 351 mm

Height From Ground to Center of Support:

Driver Front: 450.5 mm
Driver Rear: 449 mm
Passenger Front: 446.5 mm
Passenger Rear: 452.5 mm

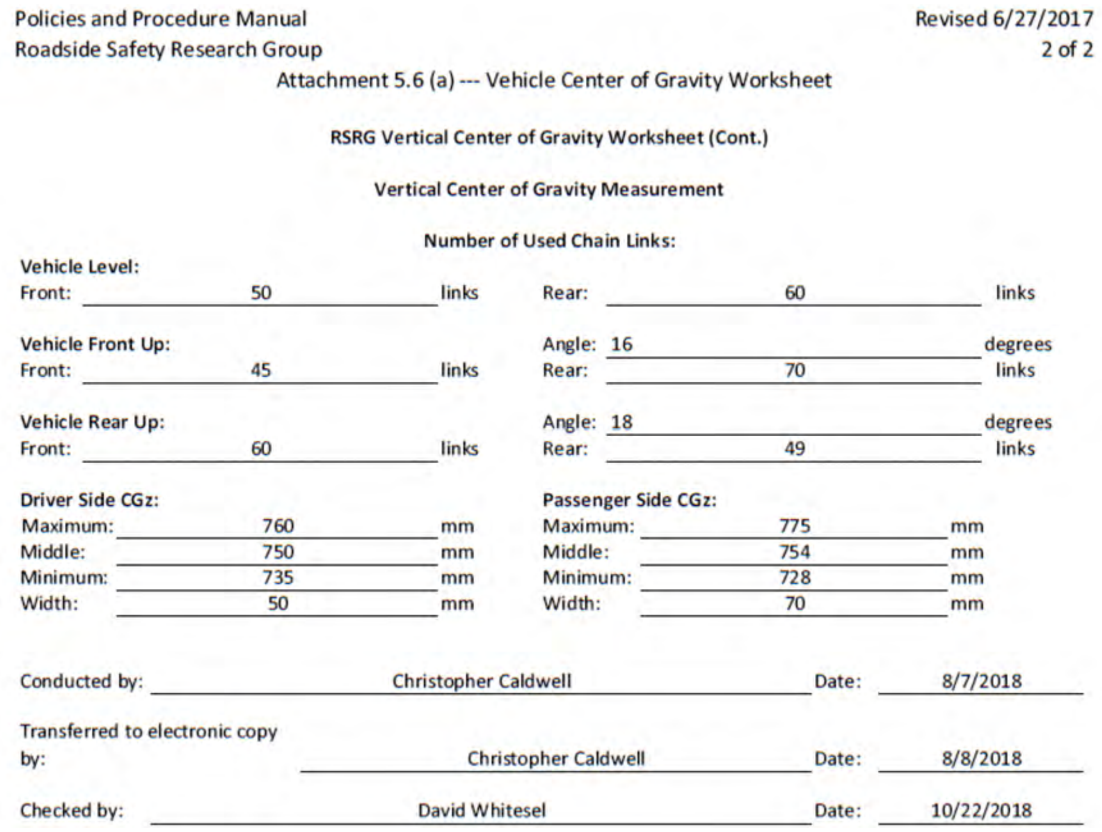
Shock Mass:

Driver Front: 2.15 kg
Scale Color: red
Passenger Front: 2.15 kg
Scale Color: red

Height From Ground to Center of Wheel Hub:

Driver Front: 382 mm
Driver Rear: 382 mm
Passenger Front: 382 mm
Passenger Rear: 382 mm

Table 9-20 Test 4-11 Vertical CG Calculation: Worksheet (continued)



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Attachment 5.6 (a) --- Vehicle Center of Gravity Worksheet

RSRG Vertical Center of Gravity Worksheet (Cont.)

Vertical Center of Gravity Measurement

Number of Used Chain Links:

Vehicle Level:
Front: 50 links — Rear: 60 links

Vehicle Front Up: — Angle: 16 degrees
Front: 45 links — Rear: 70 links

Vehicle Rear Up: — Angle: 18 degrees
Front: 60 links — Rear: 49 links

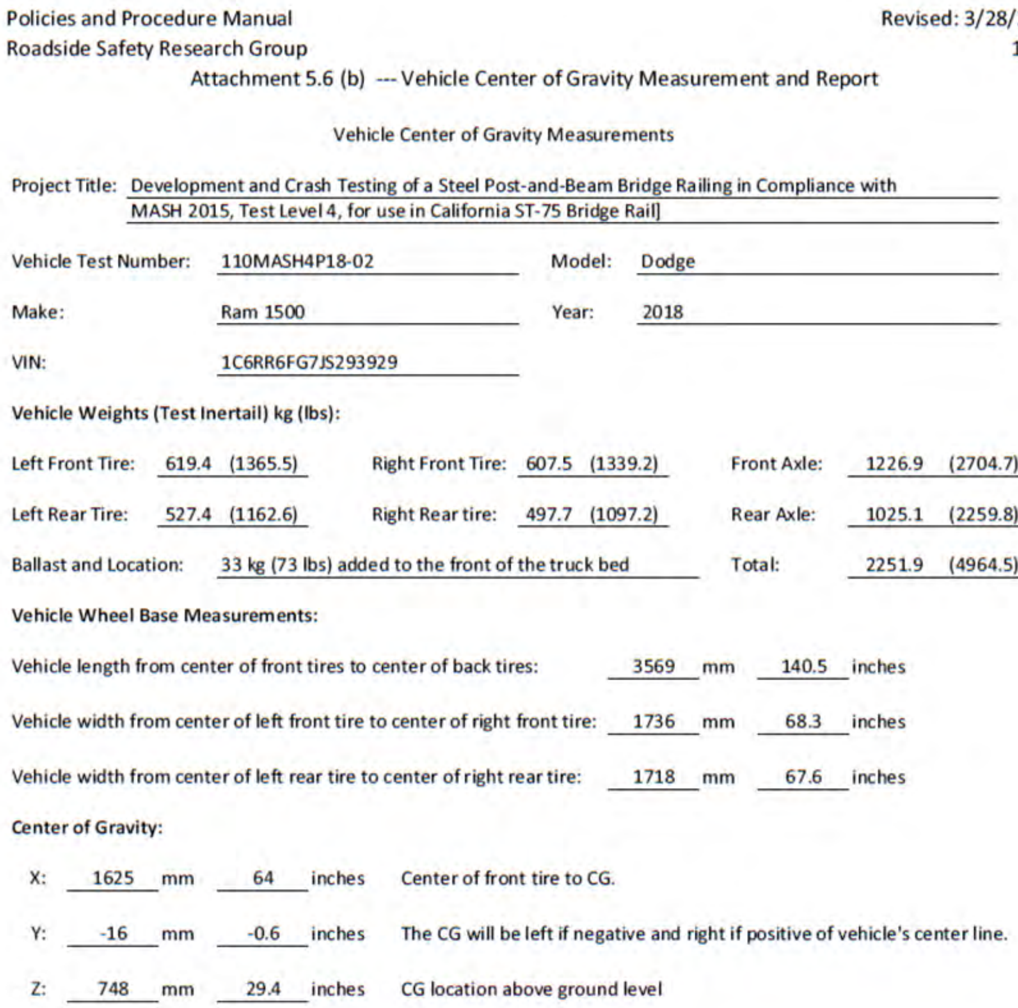
Driver Side CGz:			**Passenger Side CGz:**		
Maximum:	760	mm	Maximum:	775	mm
Middle:	750	mm	Middle:	754	mm
Minimum:	735	mm	Minimum:	728	mm
Width:	50	mm	Width:	70	mm

Conducted by: Christopher Caldwell Date: 8/7/2018

Transferred to electronic copy by: Christopher Caldwell Date: 8/8/2018

Checked by: David Whitesel Date: 10/22/2018

Table 9-21 Test 4-11 Vertical CG Calculation: Measurement and Report



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Attachment 5.6 (b) --- Vehicle Center of Gravity Measurement and Report

Vehicle Center of Gravity Measurements

Project Title: Development and Crash Testing of a Steel Post-and-Beam Bridge Railing in Compliance with MASH 2015, Test Level 4, for use in California ST-75 Bridge Rail]

Vehicle Test Number: 110MASH4P18-02

Model: Dodge

Make: Ram 1500

Year: 2018

VIN: 1C6RR6FG7JS293929

Vehicle Weights (Test Inertail) kg (lbs):

Left Front Tire:	619.4 (1365.5)	Right Front Tire:	607.5 (1339.2)	Front Axle:	1226.9 (2704.7)
Left Rear Tire:	527.4 (1162.6)	Right Rear tire:	497.7 (1097.2)	Rear Axle:	1025.1 (2259.8)

Ballast and Location: 33 kg (73 lbs) added to the front of the truck bed

Total: 2251.9 (4964.5)

Vehicle Wheel Base Measurements:

Vehicle length from center of front tires to center of back tires: 3569 mm 140.5 inches

Vehicle width from center of left front tire to center of right front tire: 1736 mm 68.3 inches

Vehicle width from center of left rear tire to center of right rear tire: 1718 mm 67.6 inches

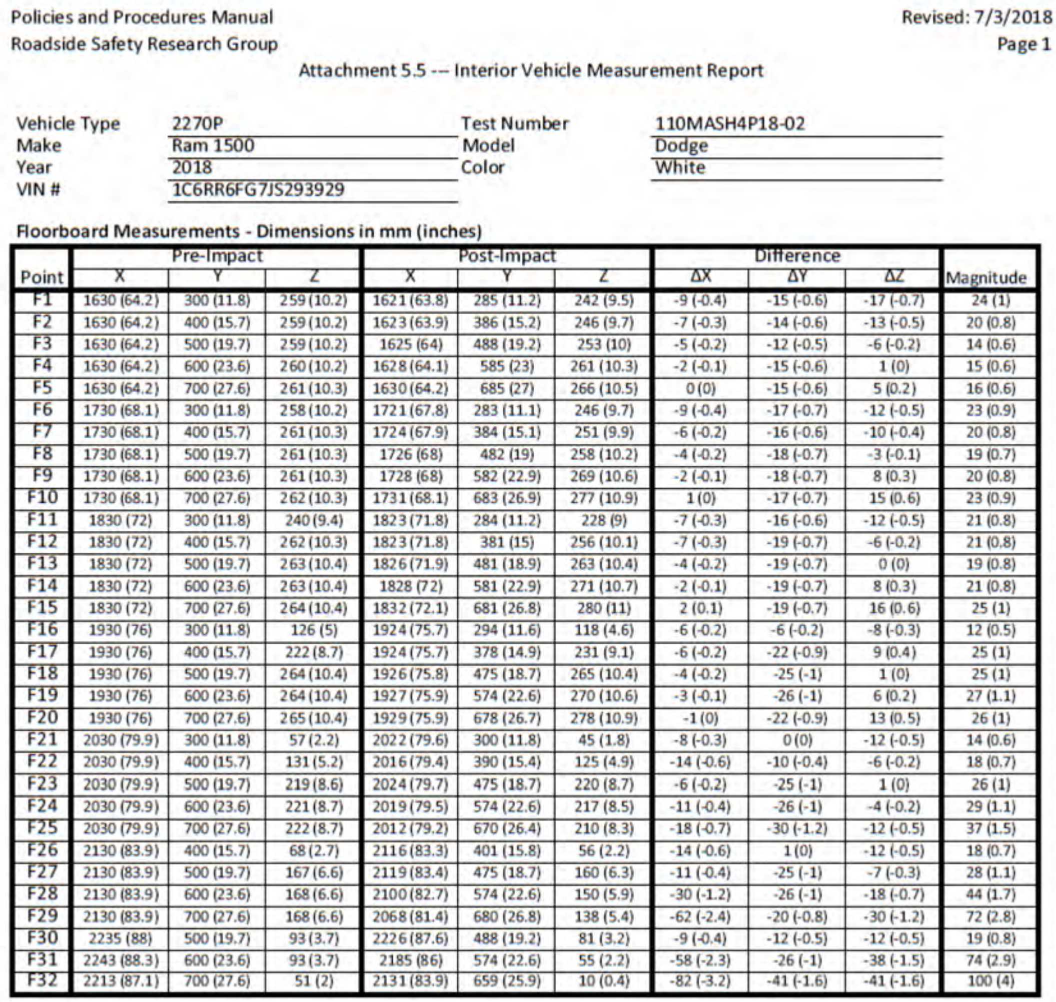
Center of Gravity:

X: 1625 mm 64 inches Center of front tire to CG.

Y: -16 mm -0.6 inches The CG will be left if negative and right if positive of vehicle's center line.

Z: 748 mm 29.4 inches CG location above ground level

Table 9-22 Test 4-11 Interior Floor Pre, Post, and Deformation Measurements



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Attachment 5.5 --- Interior Vehicle Measurement Report

Vehicle Type 2270P
Make Ram 1500
Year 2018
VIN # 1C6RR6FG7JS293929
Test Number 110MASH4P18-02
Model Dodge
Color White

Floorboard Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
F1	1630 (64.2)	300 (11.8)	259 (10.2)	1621 (63.8)	285 (11.2)	242 (9.5)	-9 (-0.4)	-15 (-0.6)	-17 (-0.7)	24 (1)
F2	1630 (64.2)	400 (15.7)	259 (10.2)	1623 (63.9)	386 (15.2)	246 (9.7)	-7 (-0.3)	-14 (-0.6)	-13 (-0.5)	20 (0.8)
F3	1630 (64.2)	500 (19.7)	259 (10.2)	1625 (64)	488 (19.2)	253 (10)	-5 (-0.2)	-12 (-0.5)	-6 (-0.2)	14 (0.6)
F4	1630 (64.2)	600 (23.6)	260 (10.2)	1628 (64.1)	585 (23)	261 (10.3)	-2 (-0.1)	-15 (-0.6)	1 (0)	15 (0.6)
F5	1630 (64.2)	700 (27.6)	261 (10.3)	1630 (64.2)	685 (27)	266 (10.5)	0 (0)	-15 (-0.6)	5 (0.2)	16 (0.6)
F6	1730 (68.1)	300 (11.8)	258 (10.2)	1721 (67.8)	283 (11.1)	246 (9.7)	-9 (-0.4)	-17 (-0.7)	-12 (-0.5)	23 (0.9)
F7	1730 (68.1)	400 (15.7)	261 (10.3)	1724 (67.9)	384 (15.1)	251 (9.9)	-6 (-0.2)	-16 (-0.6)	-10 (-0.4)	20 (0.8)
F8	1730 (68.1)	500 (19.7)	261 (10.3)	1726 (68)	482 (19)	258 (10.2)	-4 (-0.2)	-18 (-0.7)	-3 (-0.1)	19 (0.7)
F9	1730 (68.1)	600 (23.6)	261 (10.3)	1728 (68)	582 (22.9)	269 (10.6)	-2 (-0.1)	-18 (-0.7)	8 (0.3)	20 (0.8)
F10	1730 (68.1)	700 (27.6)	262 (10.3)	1731 (68.1)	683 (26.9)	277 (10.9)	1 (0)	-17 (-0.7)	15 (0.6)	23 (0.9)
F11	1830 (72)	300 (11.8)	240 (9.4)	1823 (71.8)	284 (11.2)	228 (9)	-7 (-0.3)	-16 (-0.6)	-12 (-0.5)	21 (0.8)
F12	1830 (72)	400 (15.7)	262 (10.3)	1823 (71.8)	381 (15)	256 (10.1)	-7 (-0.3)	-19 (-0.7)	-6 (-0.2)	21 (0.8)
F13	1830 (72)	500 (19.7)	263 (10.4)	1826 (71.9)	481 (18.9)	263 (10.4)	-4 (-0.2)	-19 (-0.7)	0 (0)	19 (0.8)
F14	1830 (72)	600 (23.6)	263 (10.4)	1828 (72)	581 (22.9)	271 (10.7)	-2 (-0.1)	-19 (-0.7)	8 (0.3)	21 (0.8)
F15	1830 (72)	700 (27.6)	264 (10.4)	1832 (72.1)	681 (26.8)	280 (11)	2 (0.1)	-19 (-0.7)	16 (0.6)	25 (1)
F16	1930 (76)	300 (11.8)	126 (5)	1924 (75.7)	294 (11.6)	118 (4.6)	-6 (-0.2)	-6 (-0.2)	-8 (-0.3)	12 (0.5)
F17	1930 (76)	400 (15.7)	222 (8.7)	1924 (75.7)	378 (14.9)	231 (9.1)	-6 (-0.2)	-22 (-0.9)	9 (0.4)	25 (1)
F18	1930 (76)	500 (19.7)	264 (10.4)	1926 (75.8)	475 (18.7)	265 (10.4)	-4 (-0.2)	-25 (-1)	1 (0)	25 (1)
F19	1930 (76)	600 (23.6)	264 (10.4)	1927 (75.9)	574 (22.6)	270 (10.6)	-3 (-0.1)	-26 (-1)	6 (0.2)	27 (1.1)
F20	1930 (76)	700 (27.6)	265 (10.4)	1929 (75.9)	678 (26.7)	278 (10.9)	-1 (0)	-22 (-0.9)	13 (0.5)	26 (1)
F21	2030 (79.9)	300 (11.8)	57 (2.2)	2022 (79.6)	300 (11.8)	45 (1.8)	-8 (-0.3)	0 (0)	-12 (-0.5)	14 (0.6)
F22	2030 (79.9)	400 (15.7)	131 (5.2)	2016 (79.4)	390 (15.4)	125 (4.9)	-14 (-0.6)	-10 (-0.4)	-6 (-0.2)	18 (0.7)
F23	2030 (79.9)	500 (19.7)	219 (8.6)	2024 (79.7)	475 (18.7)	220 (8.7)	-6 (-0.2)	-25 (-1)	1 (0)	26 (1)
F24	2030 (79.9)	600 (23.6)	221 (8.7)	2019 (79.5)	574 (22.6)	217 (8.5)	-11 (-0.4)	-26 (-1)	-4 (-0.2)	29 (1.1)
F25	2030 (79.9)	700 (27.6)	222 (8.7)	2012 (79.2)	670 (26.4)	210 (8.3)	-18 (-0.7)	-30 (-1.2)	-12 (-0.5)	37 (1.5)
F26	2130 (83.9)	400 (15.7)	68 (2.7)	2116 (83.3)	401 (15.8)	56 (2.2)	-14 (-0.6)	1 (0)	-12 (-0.5)	18 (0.7)
F27	2130 (83.9)	500 (19.7)	167 (6.6)	2119 (83.4)	475 (18.7)	160 (6.3)	-11 (-0.4)	-25 (-1)	-7 (-0.3)	28 (1.1)
F28	2130 (83.9)	600 (23.6)	168 (6.6)	2100 (82.7)	574 (22.6)	150 (5.9)	-30 (-1.2)	-26 (-1)	-18 (-0.7)	44 (1.7)
F29	2130 (83.9)	700 (27.6)	168 (6.6)	2068 (81.4)	680 (26.8)	138 (5.4)	-62 (-2.4)	-20 (-0.8)	-30 (-1.2)	72 (2.8)
F30	2235 (88)	500 (19.7)	93 (3.7)	2226 (87.6)	488 (19.2)	81 (3.2)	-9 (-0.4)	-12 (-0.5)	-12 (-0.5)	19 (0.8)
F31	2243 (88.3)	600 (23.6)	93 (3.7)	2185 (86)	574 (22.6)	55 (2.2)	-58 (-2.3)	-26 (-1)	-38 (-1.5)	74 (2.9)
F32	2213 (87.1)	700 (27.6)	51 (2)	2131 (83.9)	659 (25.9)	10 (0.4)	-82 (-3.2)	-41 (-1.6)	-41 (-1.6)	100 (4)

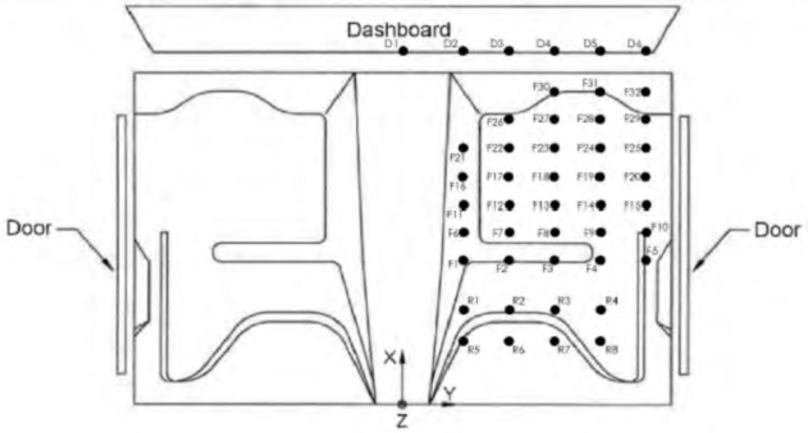

Table 9-23 Test 4-11 Interior Dash and Roof Pre, Post, and Deformation Measurements

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Attachment 5.5 --- Interior Vehicle Measurement Report

Vehicle Type	2270P	Test Number	110MASH4P18-02
Make	Ram 1500	Model	Dodge
Year	2018	Color	White
VIN #	1C6RR6FG7JS293929		

Dashboard Measurements - Dimensions in mm (inches)

	Pre-Impact			Post-Impact			Difference			
Point	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	Magnitude
D1	1731 (68.1)	0 (0)	-515 (-20.3)	1734 (68.3)	0 (0)	-526 (-20.7)	3 (0.1)	0 (0)	-11 (-0.4)	11 (0.4)
D2	1818 (71.6)	300 (11.8)	-515 (-20.3)	1816 (71.5)	301 (11.9)	-526 (-20.7)	-2 (-0.1)	1 (0)	-11 (-0.4)	11 (0.4)
D3	1818 (71.6)	400 (15.7)	-515 (-20.3)	1818 (71.6)	400 (15.7)	-526 (-20.7)	0 (0)	0 (0)	-11 (-0.4)	11 (0.4)
D4	1825 (71.9)	500 (19.7)	-515 (-20.3)	1824 (71.8)	500 (19.7)	-526 (-20.7)	-1 (0)	0 (0)	-11 (-0.4)	11 (0.4)
D5	1836 (72.3)	600 (23.6)	-515 (-20.3)	1835 (72.2)	600 (23.6)	-526 (-20.7)	-1 (0)	0 (0)	-11 (-0.4)	11 (0.4)
D6	1848 (72.8)	700 (27.6)	-515 (-20.3)	1847 (72.7)	703 (27.7)	-526 (-20.7)	-1 (0)	3 (0.1)	-11 (-0.4)	11 (0.5)

Roof Measurements - Dimensions in mm (inches)

	Pre-Impact			Post-Impact			Difference			
Point	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	Magnitude
R1	1330 (52.4)	300 (11.8)	-1060 (-41.7)	1324 (52.1)	304 (12)	-1068 (-42)	-6 (-0.2)	4 (0.2)	-8 (-0.3)	11 (0.4)
R2	1330 (52.4)	400 (15.7)	-1055 (-41.5)	1325 (52.2)	401 (15.8)	-1063 (-41.9)	-5 (-0.2)	1 (0)	-8 (-0.3)	9 (0.4)
R3	1330 (52.4)	500 (19.7)	-1048 (-41.3)	1325 (52.2)	502 (19.8)	-1057 (-41.6)	-5 (-0.2)	2 (0.1)	-9 (-0.4)	10 (0.4)
R4	1330 (52.4)	600 (23.6)	-1037 (-40.8)	1326 (52.2)	603 (23.7)	-1045 (-41.1)	-4 (-0.2)	3 (0.1)	-8 (-0.3)	9 (0.4)
R5	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
R6	1230 (48.4)	300 (11.8)	-1070 (-42.1)	1224 (48.2)	303 (11.9)	-1075 (-42.3)	-6 (-0.2)	3 (0.1)	-5 (-0.2)	8 (0.3)
R7	1230 (48.4)	400 (15.7)	-1065 (-41.9)	1224 (48.2)	404 (15.9)	-1072 (-42.2)	-6 (-0.2)	4 (0.2)	-7 (-0.3)	10 (0.4)
R8	1230 (48.4)	500 (19.7)	-1059 (-41.7)	1225 (48.2)	503 (19.8)	-1068 (-42)	-5 (-0.2)	3 (0.1)	-9 (-0.4)	11 (0.4)
R9	1230 (48.4)	600 (23.6)	-1048 (-41.3)	1229 (48.4)	604 (23.8)	-1056 (-41.6)	-1 (0)	4 (0.2)	-8 (-0.3)	9 (0.4)
R10	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

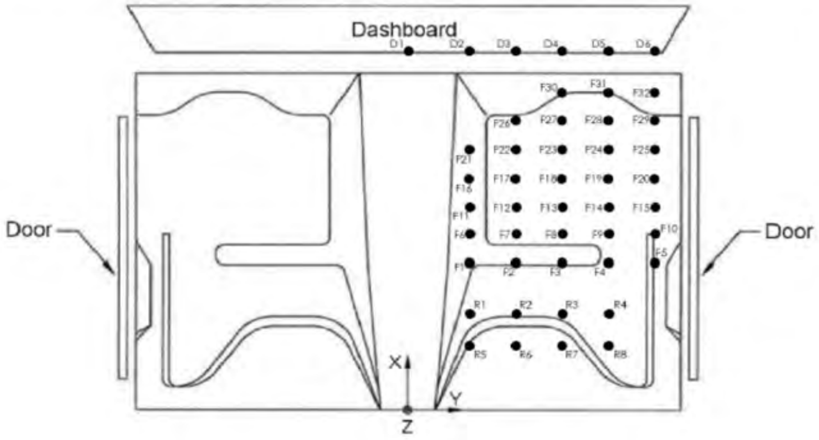
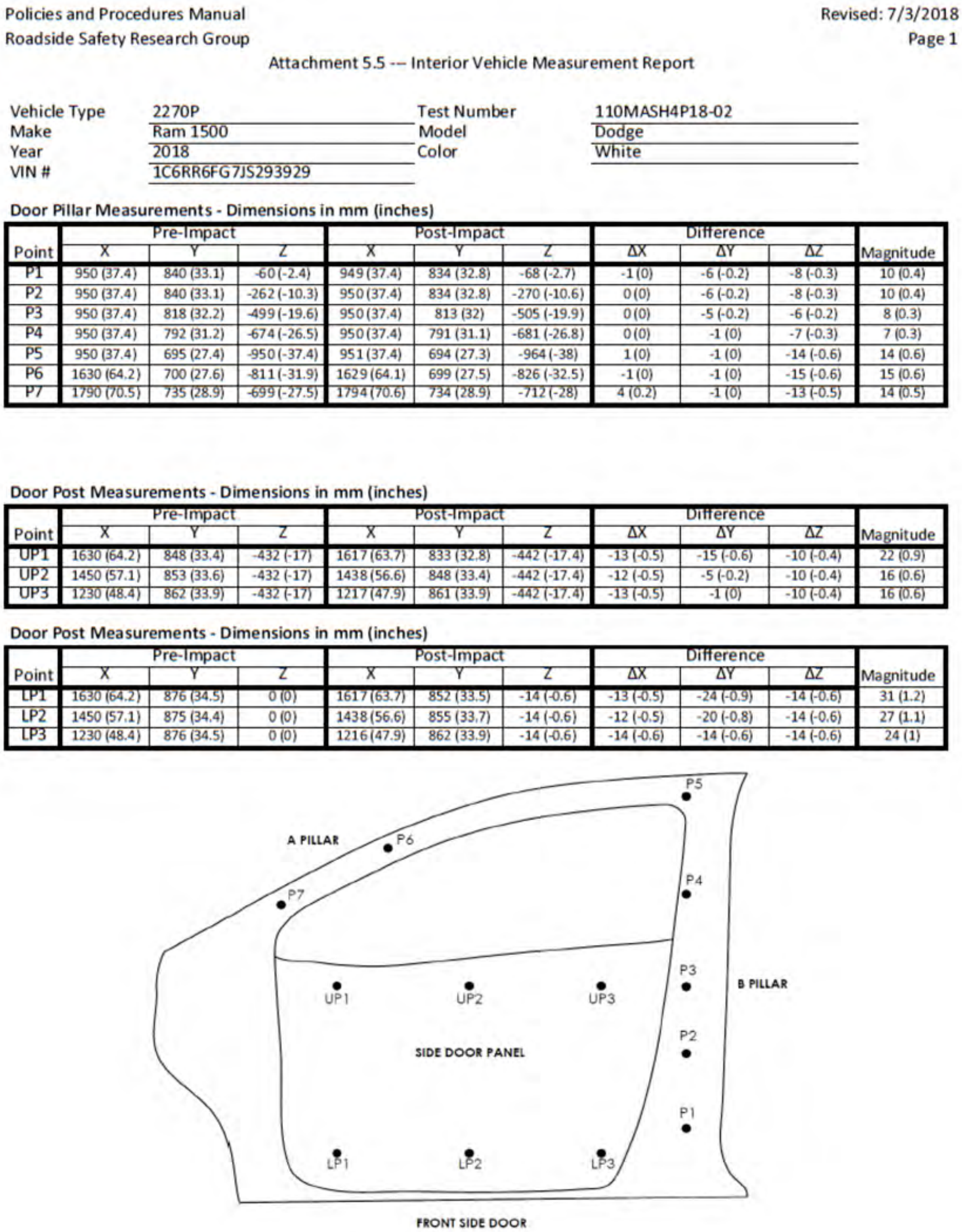


Table 9-24 Test 4-11 Interior Door Pre, Post, and Deformation Measurements



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Attachment 5.5 -- Interior Vehicle Measurement Report

Vehicle Type	2270P	Test Number	110MASH4P18-02
Make	Ram 1500	Model	Dodge
Year	2018	Color	White
VIN #	1C6RR6FG7JS293929		

Door Pillar Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
P1	950 (37.4)	840 (33.1)	-60 (-2.4)	949 (37.4)	834 (32.8)	-68 (-2.7)	-1 (0)	-6 (-0.2)	-8 (-0.3)	10 (0.4)
P2	950 (37.4)	840 (33.1)	-262 (-10.3)	950 (37.4)	834 (32.8)	-270 (-10.6)	0 (0)	-6 (-0.2)	-8 (-0.3)	10 (0.4)
P3	950 (37.4)	818 (32.2)	-499 (-19.6)	950 (37.4)	813 (32)	-505 (-19.9)	0 (0)	-5 (-0.2)	-6 (-0.2)	8 (0.3)
P4	950 (37.4)	792 (31.2)	-674 (-26.5)	950 (37.4)	791 (31.1)	-681 (-26.8)	0 (0)	-1 (0)	-7 (-0.3)	7 (0.3)
P5	950 (37.4)	695 (27.4)	-950 (-37.4)	951 (37.4)	694 (27.3)	-964 (-38)	1 (0)	-1 (0)	-14 (-0.6)	14 (0.6)
P6	1630 (64.2)	700 (27.6)	-811 (-31.9)	1629 (64.1)	699 (27.5)	-826 (-32.5)	-1 (0)	-1 (0)	-15 (-0.6)	15 (0.6)
P7	1790 (70.5)	735 (28.9)	-699 (-27.5)	1794 (70.6)	734 (28.9)	-712 (-28)	4 (0.2)	-1 (0)	-13 (-0.5)	14 (0.5)

Door Post Measurements - Dimensions in mm (inches)

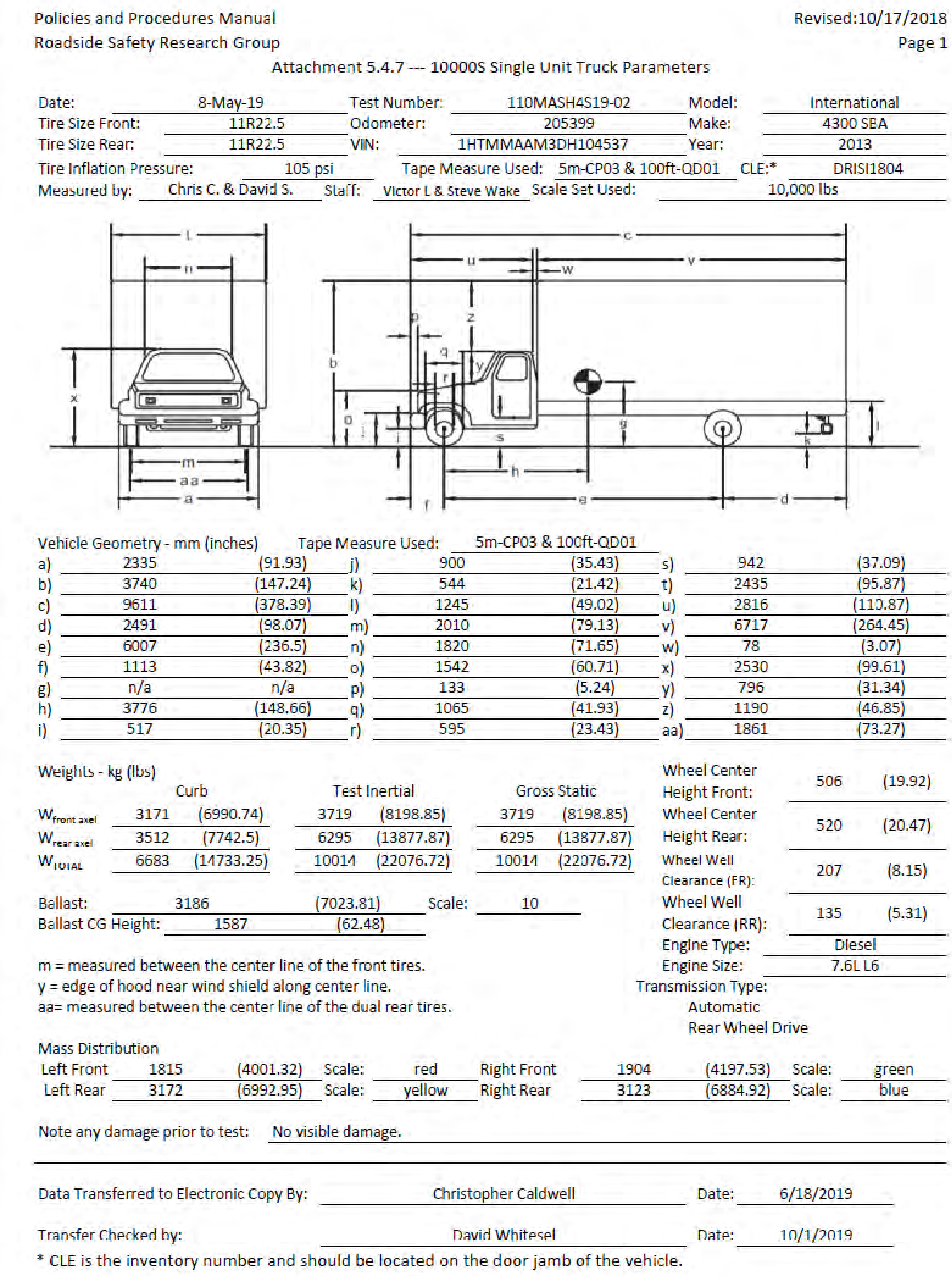
Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
UP1	1630 (64.2)	848 (33.4)	-432 (-17)	1617 (63.7)	833 (32.8)	-442 (-17.4)	-13 (-0.5)	-15 (-0.6)	-10 (-0.4)	22 (0.9)
UP2	1450 (57.1)	853 (33.6)	-432 (-17)	1438 (56.6)	848 (33.4)	-442 (-17.4)	-12 (-0.5)	-5 (-0.2)	-10 (-0.4)	16 (0.6)
UP3	1230 (48.4)	862 (33.9)	-432 (-17)	1217 (47.9)	861 (33.9)	-442 (-17.4)	-13 (-0.5)	-1 (0)	-10 (-0.4)	16 (0.6)

Door Post Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
LP1	1630 (64.2)	876 (34.5)	0 (0)	1617 (63.7)	852 (33.5)	-14 (-0.6)	-13 (-0.5)	-24 (-0.9)	-14 (-0.6)	31 (1.2)
LP2	1450 (57.1)	875 (34.4)	0 (0)	1438 (56.6)	855 (33.7)	-14 (-0.6)	-12 (-0.5)	-20 (-0.8)	-14 (-0.6)	27 (1.1)
LP3	1230 (48.4)	876 (34.5)	0 (0)	1216 (47.9)	862 (33.9)	-14 (-0.6)	-14 (-0.6)	-14 (-0.6)	-14 (-0.6)	24 (1)

9.5.3.Test 110MASH4S19-02

Table 9-25 Test 4-12 Exterior Vehicle Measurements



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Attachment 5.4.7 --- 10000S Single Unit Truck Parameters

Date:	8-May-19	Test Number:	110MASH4S19-02	Model:	International
Tire Size Front:	11R22.5	Odometer:	205399	Make:	4300 SBA
Tire Size Rear:	11R22.5	VIN:	1HTMMAAM3DH104537	Year:	2013
Tire Inflation Pressure:	105 psi	Tape Measure Used:	5m-CP03 & 100ft-QD01	CLE:*	DRISI1804
Measured by:	Chris C. & David S.	Staff:	Victor L & Steve Wake	Scale Set Used:	10,000 lbs

Vehicle Geometry - mm (inches) Tape Measure Used: 5m-CP03 & 100ft-QD01

a)	2335	(91.93)	j)	900	(35.43)	s)	942	(37.09)
b)	3740	(147.24)	k)	544	(21.42)	t)	2435	(95.87)
c)	9611	(378.39)	l)	1245	(49.02)	u)	2816	(110.87)
d)	2491	(98.07)	m)	2010	(79.13)	v)	6717	(264.45)
e)	6007	(236.5)	n)	1820	(71.65)	w)	78	(3.07)
f)	1113	(43.82)	o)	1542	(60.71)	x)	2530	(99.61)
g)	n/a	n/a	p)	133	(5.24)	y)	796	(31.34)
h)	3776	(148.66)	q)	1065	(41.93)	z)	1190	(46.85)
i)	517	(20.35)	r)	595	(23.43)	aa)	1861	(73.27)

Weights - kg (lbs)

	Curb		Test Inertial		Gross Static	
$W_{front\ axel}$	3171	(6990.74)	3719	(8198.85)	3719	(8198.85)
$W_{rear\ axel}$	3512	(7742.5)	6295	(13877.87)	6295	(13877.87)
W_{TOTAL}	6683	(14733.25)	10014	(22076.72)	10014	(22076.72)

Wheel Center Height Front:	506	(19.92)
Wheel Center Height Rear:	520	(20.47)
Wheel Well Clearance (FR):	207	(8.15)
Wheel Well Clearance (RR):	135	(5.31)

Ballast: 3186 (7023.81) Scale: 10
Ballast CG Height: 1587 (62.48)

Engine Type: Diesel
Engine Size: 7.6L L6
Transmission Type:
Automatic
Rear Wheel Drive

m = measured between the center line of the front tires.
y = edge of hood near wind shield along center line.
aa= measured between the center line of the dual rear tires.

Mass Distribution

Left Front	1815	(4001.32)	Scale:	red	Right Front	1904	(4197.53)	Scale:	green
Left Rear	3172	(6992.95)	Scale:	yellow	Right Rear	3123	(6884.92)	Scale:	blue

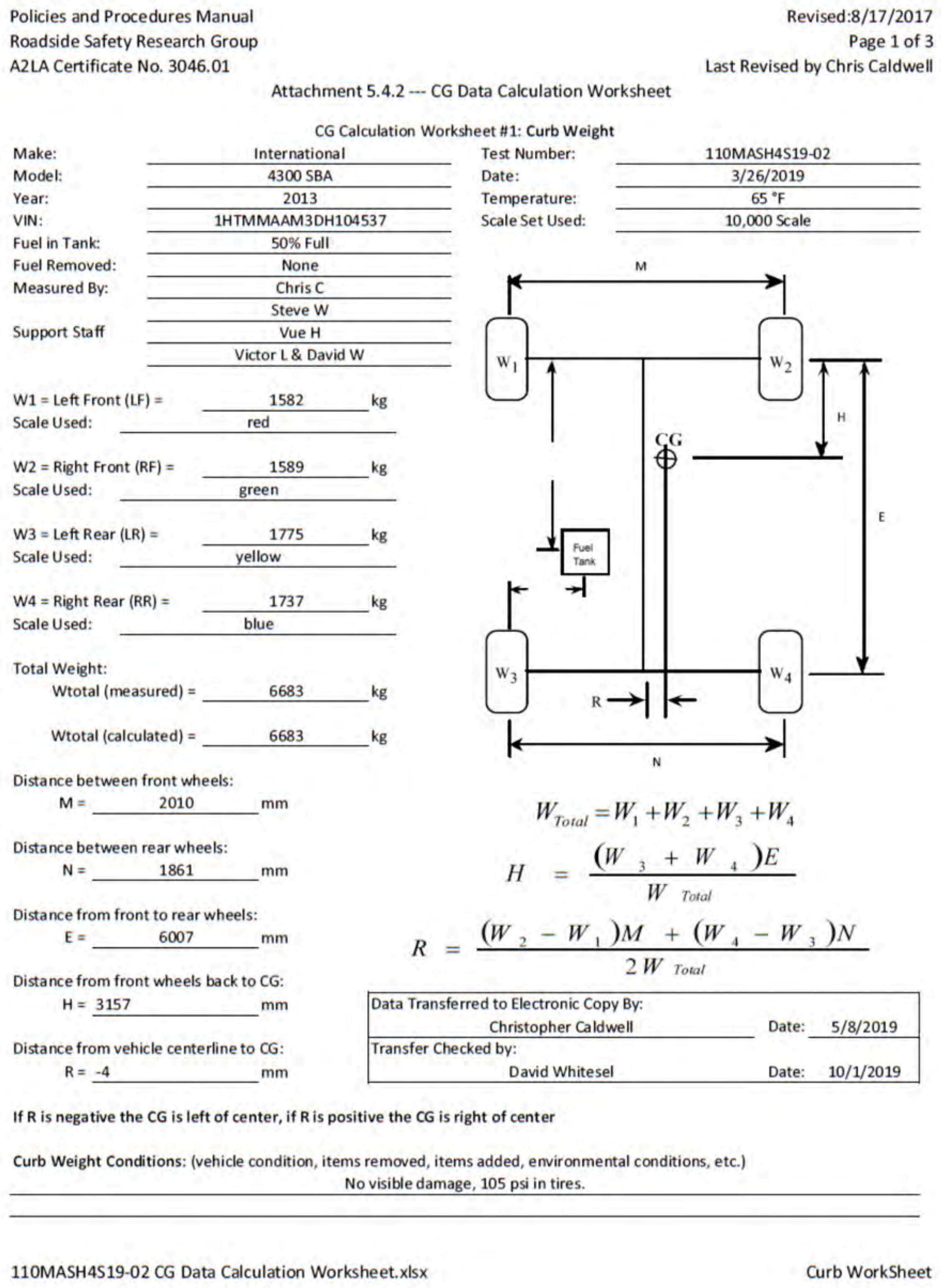
Note any damage prior to test: No visible damage.

Data Transferred to Electronic Copy By: Christopher Caldwell Date: 6/18/2019

Transfer Checked by: David Whitesel Date: 10/1/2019

* CLE is the inventory number and should be located on the door jamb of the vehicle.

Table 9-26 Test 4-12 CG Calculation: Curb Weight



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Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #1: **Curb Weight**

Make: International
Model: 4300 SBA
Year: 2013
VIN: 1HTMMAAM3DH104537
Fuel in Tank: 50% Full
Fuel Removed: None
Measured By: Chris C
Steve W
Support Staff Vue H
Victor L & David W

Test Number: 110MASH4S19-02
Date: 3/26/2019
Temperature: 65 °F
Scale Set Used: 10,000 Scale

W1 = Left Front (LF) = 1582 kg
Scale Used: red

W2 = Right Front (RF) = 1589 kg
Scale Used: green

W3 = Left Rear (LR) = 1775 kg
Scale Used: yellow

W4 = Right Rear (RR) = 1737 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 6683 kg

Wtotal (calculated) = 6683 kg

Distance between front wheels:
M = 2010 mm

Distance between rear wheels:
N = 1861 mm

Distance from front to rear wheels:
E = 6007 mm

Distance from front wheels back to CG:
H = 3157 mm

Distance from vehicle centerline to CG:
R = -4 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

Data Transferred to Electronic Copy By:
Christopher Caldwell Date: 5/8/2019
Transfer Checked by:
David Whitesel Date: 10/1/2019

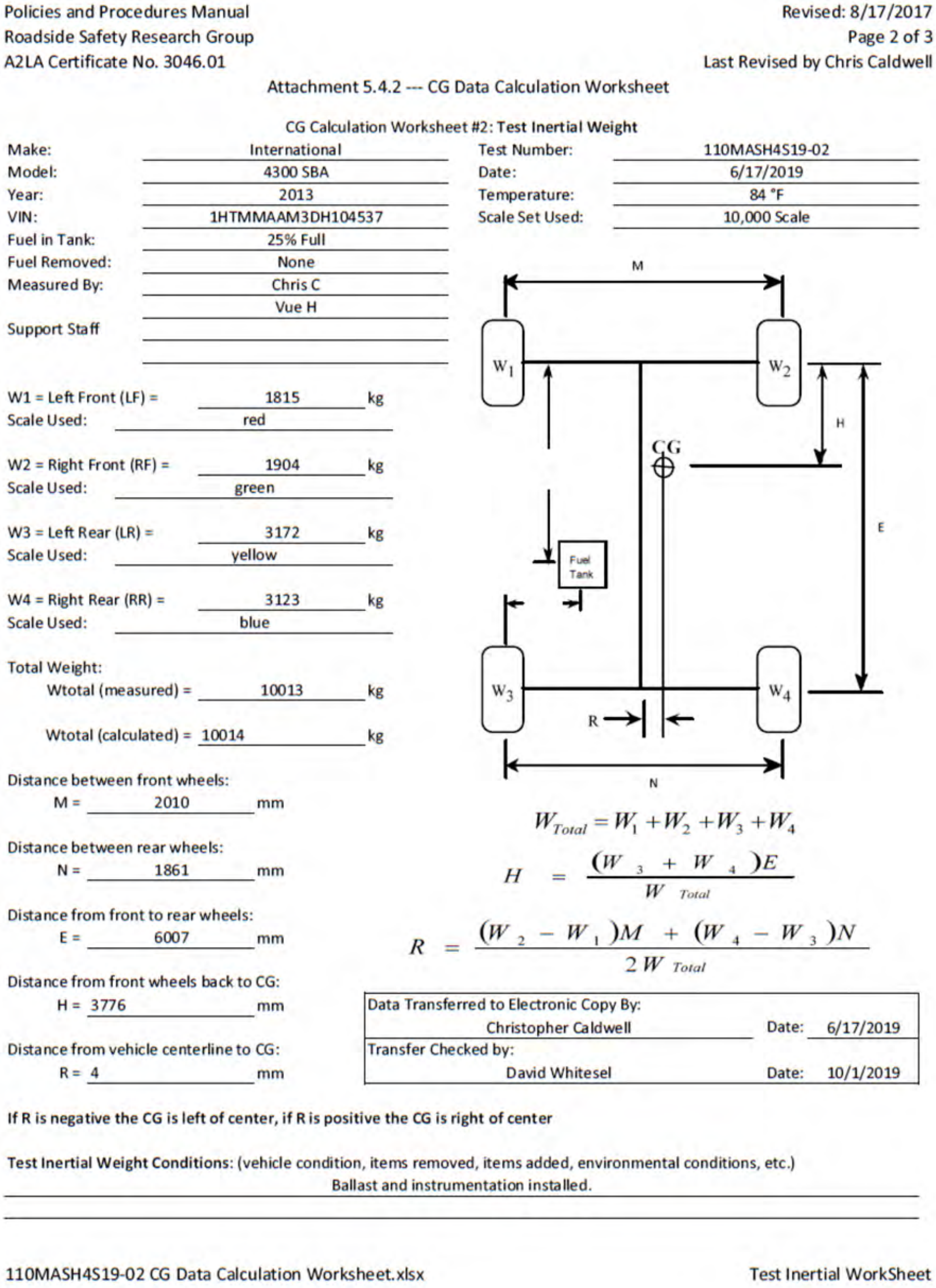
If R is negative the CG is left of center, if R is positive the CG is right of center

Curb Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
No visible damage, 105 psi in tires.

110MASH4S19-02 CG Data Calculation Worksheet.xlsx

Curb WorkSheet

Table 9-27 Test 4-12 CG Calculation: Test Inertial Weight



Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #2: Test Inertial Weight

Make: International
Model: 4300 SBA
Year: 2013
VIN: 1HTMMAAM3DH104537
Fuel in Tank: 25% Full
Fuel Removed: None
Measured By: Chris C
Vue H
Support Staff

Test Number: 110MASH4S19-02
Date: 6/17/2019
Temperature: 84 °F
Scale Set Used: 10,000 Scale

W1 = Left Front (LF) = 1815 kg
Scale Used: red

W2 = Right Front (RF) = 1904 kg
Scale Used: green

W3 = Left Rear (LR) = 3172 kg
Scale Used: yellow

W4 = Right Rear (RR) = 3123 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 10013 kg

Wtotal (calculated) = 10014 kg

Distance between front wheels:
M = 2010 mm

Distance between rear wheels:
N = 1861 mm

Distance from front to rear wheels:
E = 6007 mm

Distance from front wheels back to CG:
H = 3776 mm

Distance from vehicle centerline to CG:
R = 4 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

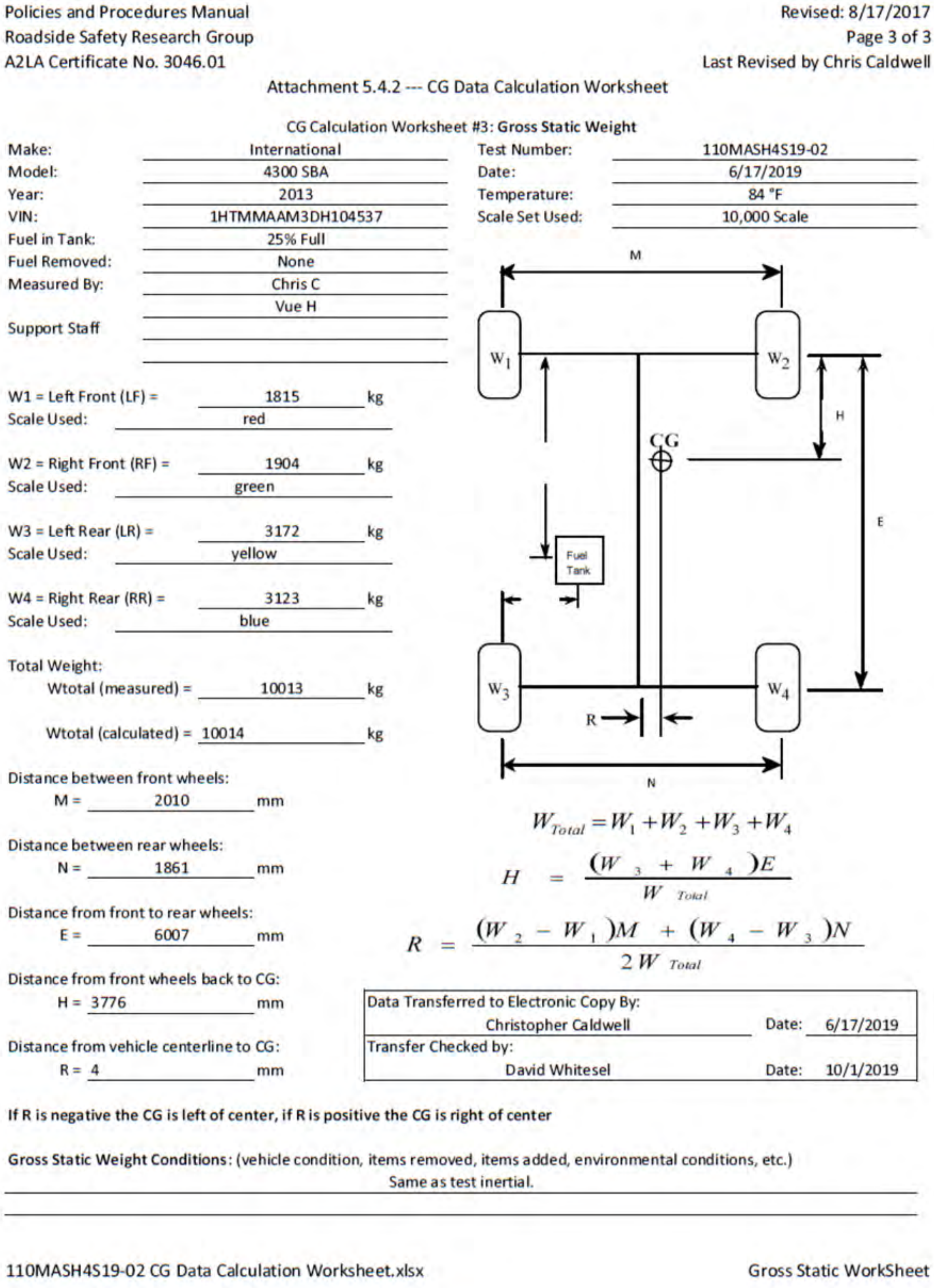
$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

Data Transferred to Electronic Copy By:
Christopher Caldwell Date: 6/17/2019
Transfer Checked by:
David Whitesel Date: 10/1/2019

If R is negative the CG is left of center, if R is positive the CG is right of center

Test Inertial Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Ballast and instrumentation installed.

Table 9-28 Test 4-12 CG Calculation: Gross Static Weight



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Revised: 8/17/2017
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Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #3: Gross Static Weight

Make: International
Model: 4300 SBA
Year: 2013
VIN: 1HTMMAAM3DH104537
Fuel in Tank: 25% Full
Fuel Removed: None
Measured By: Chris C
Vue H
Support Staff

Test Number: 110MASH4S19-02
Date: 6/17/2019
Temperature: 84 °F
Scale Set Used: 10,000 Scale

W1 = Left Front (LF) = 1815 kg
Scale Used: red

W2 = Right Front (RF) = 1904 kg
Scale Used: green

W3 = Left Rear (LR) = 3172 kg
Scale Used: yellow

W4 = Right Rear (RR) = 3123 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 10013 kg

Wtotal (calculated) = 10014 kg

Distance between front wheels:
M = 2010 mm

Distance between rear wheels:
N = 1861 mm

Distance from front to rear wheels:
E = 6007 mm

Distance from front wheels back to CG:
H = 3776 mm

Distance from vehicle centerline to CG:
R = 4 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

Data Transferred to Electronic Copy By:
Christopher Caldwell Date: 6/17/2019
Transfer Checked by:
David Whitesel Date: 10/1/2019

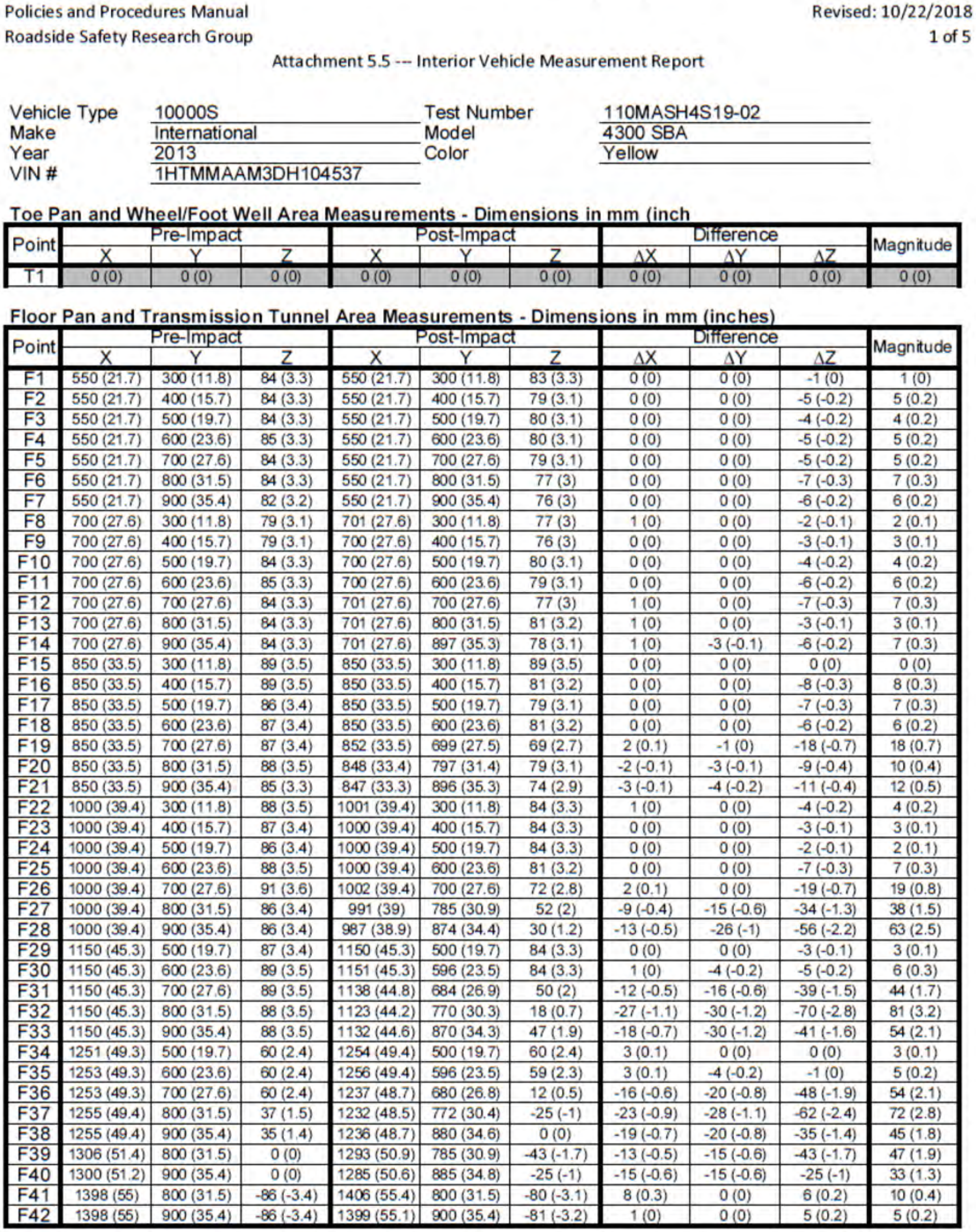
If R is negative the CG is left of center, if R is positive the CG is right of center

Gross Static Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Same as test inertial.

110MASH4S19-02 CG Data Calculation Worksheet.xlsx

Gross Static WorkSheet

Table 9-29 Test 4-10 Interior Floor and Transmission Tunnel Pre, Post, and Deformation Measurements



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Attachment 5.5 --- Interior Vehicle Measurement Report

Vehicle Type	10000S	Test Number	110MASH4S19-02
Make	International	Model	4300 SBA
Year	2013	Color	Yellow
VIN #	1HTMMAAM3DH104537		

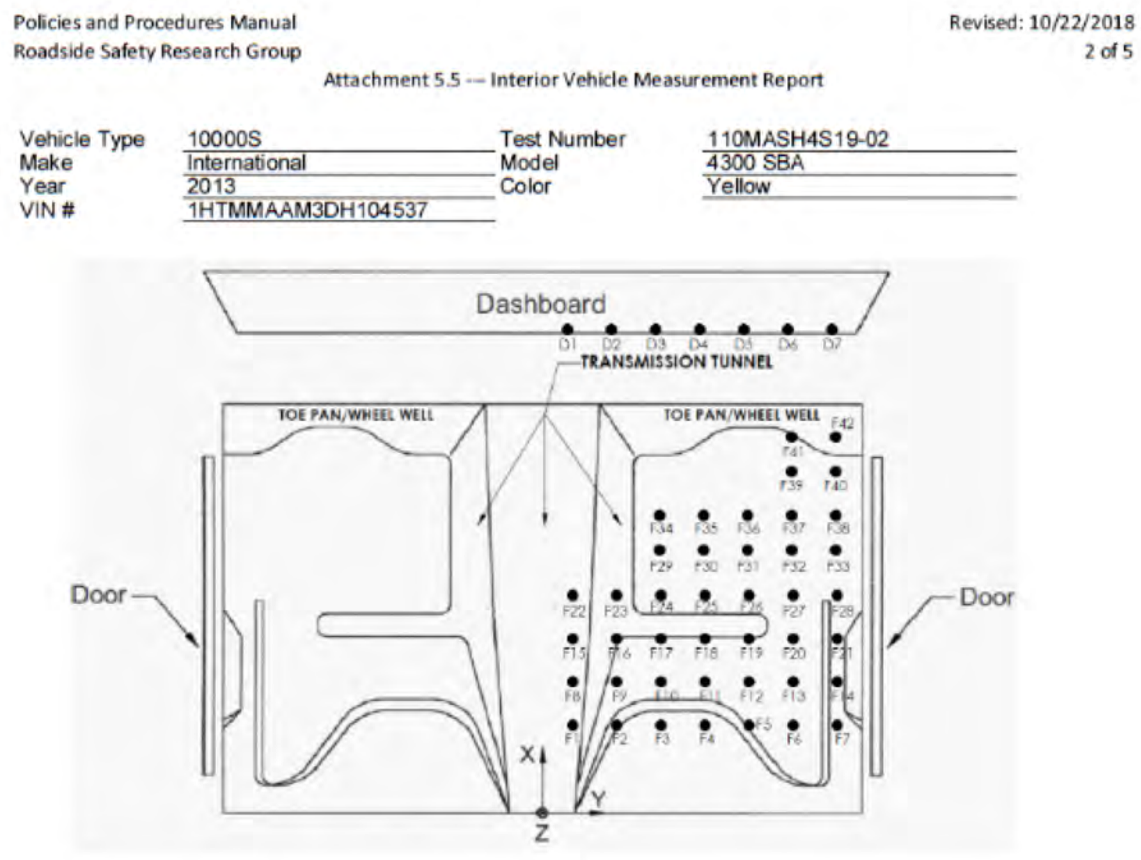
Toe Pan and Wheel/Foot Well Area Measurements - Dimensions in mm (inch

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
T1	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Floor Pan and Transmission Tunnel Area Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
F1	550 (21.7)	300 (11.8)	84 (3.3)	550 (21.7)	300 (11.8)	83 (3.3)	0 (0)	0 (0)	-1 (0)	1 (0)
F2	550 (21.7)	400 (15.7)	84 (3.3)	550 (21.7)	400 (15.7)	79 (3.1)	0 (0)	0 (0)	-5 (-0.2)	5 (0.2)
F3	550 (21.7)	500 (19.7)	84 (3.3)	550 (21.7)	500 (19.7)	80 (3.1)	0 (0)	0 (0)	-4 (-0.2)	4 (0.2)
F4	550 (21.7)	600 (23.6)	85 (3.3)	550 (21.7)	600 (23.6)	80 (3.1)	0 (0)	0 (0)	-5 (-0.2)	5 (0.2)
F5	550 (21.7)	700 (27.6)	84 (3.3)	550 (21.7)	700 (27.6)	79 (3.1)	0 (0)	0 (0)	-5 (-0.2)	5 (0.2)
F6	550 (21.7)	800 (31.5)	84 (3.3)	550 (21.7)	800 (31.5)	77 (3)	0 (0)	0 (0)	-7 (-0.3)	7 (0.3)
F7	550 (21.7)	900 (35.4)	82 (3.2)	550 (21.7)	900 (35.4)	76 (3)	0 (0)	0 (0)	-6 (-0.2)	6 (0.2)
F8	700 (27.6)	300 (11.8)	79 (3.1)	701 (27.6)	300 (11.8)	77 (3)	1 (0)	0 (0)	-2 (-0.1)	2 (0.1)
F9	700 (27.6)	400 (15.7)	79 (3.1)	700 (27.6)	400 (15.7)	76 (3)	0 (0)	0 (0)	-3 (-0.1)	3 (0.1)
F10	700 (27.6)	500 (19.7)	84 (3.3)	700 (27.6)	500 (19.7)	80 (3.1)	0 (0)	0 (0)	-4 (-0.2)	4 (0.2)
F11	700 (27.6)	600 (23.6)	85 (3.3)	700 (27.6)	600 (23.6)	79 (3.1)	0 (0)	0 (0)	-6 (-0.2)	6 (0.2)
F12	700 (27.6)	700 (27.6)	84 (3.3)	701 (27.6)	700 (27.6)	77 (3)	1 (0)	0 (0)	-7 (-0.3)	7 (0.3)
F13	700 (27.6)	800 (31.5)	84 (3.3)	701 (27.6)	800 (31.5)	81 (3.2)	1 (0)	0 (0)	-3 (-0.1)	3 (0.1)
F14	700 (27.6)	900 (35.4)	84 (3.3)	701 (27.6)	897 (35.3)	78 (3.1)	1 (0)	-3 (-0.1)	-6 (-0.2)	7 (0.3)
F15	850 (33.5)	300 (11.8)	89 (3.5)	850 (33.5)	300 (11.8)	89 (3.5)	0 (0)	0 (0)	0 (0)	0 (0)
F16	850 (33.5)	400 (15.7)	89 (3.5)	850 (33.5)	400 (15.7)	81 (3.2)	0 (0)	0 (0)	-8 (-0.3)	8 (0.3)
F17	850 (33.5)	500 (19.7)	86 (3.4)	850 (33.5)	500 (19.7)	79 (3.1)	0 (0)	0 (0)	-7 (-0.3)	7 (0.3)
F18	850 (33.5)	600 (23.6)	87 (3.4)	850 (33.5)	600 (23.6)	81 (3.2)	0 (0)	0 (0)	-6 (-0.2)	6 (0.2)
F19	850 (33.5)	700 (27.6)	87 (3.4)	852 (33.5)	699 (27.5)	69 (2.7)	2 (0.1)	-1 (0)	-18 (-0.7)	18 (0.7)
F20	850 (33.5)	800 (31.5)	88 (3.5)	848 (33.4)	797 (31.4)	79 (3.1)	-2 (-0.1)	-3 (-0.1)	-9 (-0.4)	10 (0.4)
F21	850 (33.5)	900 (35.4)	85 (3.3)	847 (33.3)	896 (35.3)	74 (2.9)	-3 (-0.1)	-4 (-0.2)	-11 (-0.4)	12 (0.5)
F22	1000 (39.4)	300 (11.8)	88 (3.5)	1001 (39.4)	300 (11.8)	84 (3.3)	1 (0)	0 (0)	-4 (-0.2)	4 (0.2)
F23	1000 (39.4)	400 (15.7)	87 (3.4)	1000 (39.4)	400 (15.7)	84 (3.3)	0 (0)	0 (0)	-3 (-0.1)	3 (0.1)
F24	1000 (39.4)	500 (19.7)	86 (3.4)	1000 (39.4)	500 (19.7)	84 (3.3)	0 (0)	0 (0)	-2 (-0.1)	2 (0.1)
F25	1000 (39.4)	600 (23.6)	88 (3.5)	1000 (39.4)	600 (23.6)	81 (3.2)	0 (0)	0 (0)	-7 (-0.3)	7 (0.3)
F26	1000 (39.4)	700 (27.6)	91 (3.6)	1002 (39.4)	700 (27.6)	72 (2.8)	2 (0.1)	0 (0)	-19 (-0.7)	19 (0.8)
F27	1000 (39.4)	800 (31.5)	86 (3.4)	991 (39)	785 (30.9)	52 (2)	-9 (-0.4)	-15 (-0.6)	-34 (-1.3)	38 (1.5)
F28	1000 (39.4)	900 (35.4)	86 (3.4)	987 (38.9)	874 (34.4)	30 (1.2)	-13 (-0.5)	-26 (-1)	-56 (-2.2)	63 (2.5)
F29	1150 (45.3)	500 (19.7)	87 (3.4)	1150 (45.3)	500 (19.7)	84 (3.3)	0 (0)	0 (0)	-3 (-0.1)	3 (0.1)
F30	1150 (45.3)	600 (23.6)	89 (3.5)	1151 (45.3)	596 (23.5)	84 (3.3)	1 (0)	-4 (-0.2)	-5 (-0.2)	6 (0.3)
F31	1150 (45.3)	700 (27.6)	89 (3.5)	1138 (44.8)	684 (26.9)	50 (2)	-12 (-0.5)	-16 (-0.6)	-39 (-1.5)	44 (1.7)
F32	1150 (45.3)	800 (31.5)	88 (3.5)	1123 (44.2)	770 (30.3)	18 (0.7)	-27 (-1.1)	-30 (-1.2)	-70 (-2.8)	81 (3.2)
F33	1150 (45.3)	900 (35.4)	88 (3.5)	1132 (44.6)	870 (34.3)	47 (1.9)	-18 (-0.7)	-30 (-1.2)	-41 (-1.6)	54 (2.1)
F34	1251 (49.3)	500 (19.7)	60 (2.4)	1254 (49.4)	500 (19.7)	60 (2.4)	3 (0.1)	0 (0)	0 (0)	3 (0.1)
F35	1253 (49.3)	600 (23.6)	60 (2.4)	1256 (49.4)	596 (23.5)	59 (2.3)	3 (0.1)	-4 (-0.2)	-1 (0)	5 (0.2)
F36	1253 (49.3)	700 (27.6)	60 (2.4)	1237 (48.7)	680 (26.8)	12 (0.5)	-16 (-0.6)	-20 (-0.8)	-48 (-1.9)	54 (2.1)
F37	1255 (49.4)	800 (31.5)	37 (1.5)	1232 (48.5)	772 (30.4)	-25 (-1)	-23 (-0.9)	-28 (-1.1)	-62 (-2.4)	72 (2.8)
F38	1255 (49.4)	900 (35.4)	35 (1.4)	1236 (48.7)	880 (34.6)	0 (0)	-19 (-0.7)	-20 (-0.8)	-35 (-1.4)	45 (1.8)
F39	1306 (51.4)	800 (31.5)	0 (0)	1293 (50.9)	785 (30.9)	-43 (-1.7)	-13 (-0.5)	-15 (-0.6)	-43 (-1.7)	47 (1.9)
F40	1300 (51.2)	900 (35.4)	0 (0)	1285 (50.6)	885 (34.8)	-25 (-1)	-15 (-0.6)	-15 (-0.6)	-25 (-1)	33 (1.3)
F41	1398 (55)	800 (31.5)	-86 (-3.4)	1406 (55.4)	800 (31.5)	-80 (-3.1)	8 (0.3)	0 (0)	6 (0.2)	10 (0.4)
F42	1398 (55)	900 (35.4)	-86 (-3.4)	1399 (55.1)	900 (35.4)	-81 (-3.2)	1 (0)	0 (0)	5 (0.2)	5 (0.2)

Table 9-29 (continued)



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Attachment 5.5 — Interior Vehicle Measurement Report

Vehicle Type	10000S	Test Number	110MASH4S19-02
Make	International	Model	4300 SBA
Year	2013	Color	Yellow
VIN #	1HTMMAAM3DH104537		

Table 9-30 Test 4-10 Interior Roof Pre, Post, and Deformation Measurements

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Attachment 5.5 — Interior Vehicle Measurement Report

Vehicle Type 10000S
Make International
Year 2013
VIN # 1HTMMAAM3DH104537

Test Number 110MASH4S19-02
Model 4300 SBA
Color Yellow

Roof Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
R1	550 (21.7)	300 (11.8)	-1378 (-54.3	554 (21.8)	301 (11.9)	-1385 (-54.5)	4 (0.2)	1 (0)	-7 (-0.3)	8 (0.3)
R2	550 (21.7)	400 (15.7)	-1375 (-54.1	554 (21.8)	400 (15.7)	-1380 (-54.3)	4 (0.2)	0 (0)	-5 (-0.2)	6 (0.3)
R3	550 (21.7)	500 (19.7)	-1369 (-53.9	554 (21.8)	501 (19.7)	-1373 (-54.1)	4 (0.2)	1 (0)	-4 (-0.2)	6 (0.2)
R4	550 (21.7)	600 (23.6)	-1361 (-53.6	556 (21.9)	600 (23.6)	-1366 (-53.8)	6 (0.2)	0 (0)	-5 (-0.2)	8 (0.3)
R5	550 (21.7)	700 (27.6)	-1358 (-53.5	557 (21.9)	701 (27.6)	-1364 (-53.7)	7 (0.3)	1 (0)	-6 (-0.2)	9 (0.4)
R6	550 (21.7)	800 (31.5)	-1375 (-54.1	557 (21.9)	798 (31.4)	-1375 (-54.1)	7 (0.3)	-2 (-0.1)	0 (0)	7 (0.3)
R7	700 (27.6)	300 (11.8)	-1406 (-55.4	704 (27.7)	300 (11.8)	-1414 (-55.7)	4 (0.2)	0 (0)	-8 (-0.3)	9 (0.4)
R8	700 (27.6)	400 (15.7)	-1402 (-55.2	704 (27.7)	400 (15.7)	-1409 (-55.5)	4 (0.2)	0 (0)	-7 (-0.3)	8 (0.3)
R9	700 (27.6)	500 (19.7)	-1399 (-55.1	705 (27.8)	500 (19.7)	-1404 (-55.3)	5 (0.2)	0 (0)	-5 (-0.2)	7 (0.3)
R10	700 (27.6)	600 (23.6)	-1362 (-53.6	705 (27.8)	598 (23.5)	-1366 (-53.8)	5 (0.2)	-2 (-0.1)	-4 (-0.2)	7 (0.3)
R11	700 (27.6)	700 (27.6)	-1375 (-54.1	706 (27.8)	700 (27.6)	-1376 (-54.2)	6 (0.2)	0 (0)	-1 (0)	6 (0.2)
R12	700 (27.6)	800 (31.5)	-1369 (-53.9	707 (27.8)	797 (31.4)	-1370 (-53.9)	7 (0.3)	-3 (-0.1)	-1 (0)	8 (0.3)
R13	850 (33.5)	300 (11.8)	-1400 (-55.1	854 (33.6)	300 (11.8)	-1409 (-55.5)	4 (0.2)	0 (0)	-9 (-0.4)	10 (0.4)
R14	850 (33.5)	400 (15.7)	-1399 (-55.1	854 (33.6)	400 (15.7)	-1404 (-55.3)	4 (0.2)	0 (0)	-5 (-0.2)	6 (0.3)
R15	850 (33.5)	500 (19.7)	-1390 (-54.7	855 (33.7)	500 (19.7)	-1399 (-55.1)	5 (0.2)	0 (0)	-9 (-0.4)	10 (0.4)
R16	850 (33.5)	600 (23.6)	-1362 (-53.6	855 (33.7)	600 (23.6)	-1366 (-53.8)	5 (0.2)	0 (0)	-4 (-0.2)	6 (0.3)
R17	850 (33.5)	700 (27.6)	-1364 (-53.7	857 (33.7)	700 (27.6)	-1366 (-53.8)	7 (0.3)	0 (0)	-2 (-0.1)	7 (0.3)
R18	850 (33.5)	800 (31.5)	-1352 (-53.2	862 (33.9)	796 (31.3)	-1355 (-53.3)	12 (0.5)	-4 (-0.2)	-3 (-0.1)	13 (0.5)
R19	1000 (39.4)	300 (11.8)	-1340 (-52.8	982 (38.7)	304 (12)	-1348 (-53.1)	-18 (-0.7)	4 (0.2)	-8 (-0.3)	20 (0.8)
R20	1000 (39.4)	400 (15.7)	-1329 (-52.3	976 (38.4)	403 (15.9)	-1338 (-52.7)	-24 (-0.9)	3 (0.1)	-9 (-0.4)	26 (1)
R21	1000 (39.4)	500 (19.7)	-1309 (-51.5	976 (38.4)	508 (20)	-1320 (-52)	-24 (-0.9)	8 (0.3)	-11 (-0.4)	28 (1.1)
R22	1000 (39.4)	600 (23.6)	-1291 (-50.8	964 (38)	606 (23.9)	-1301 (-51.2)	-36 (-1.4)	6 (0.2)	-10 (-0.4)	38 (1.5)
R23	1000 (39.4)	700 (27.6)	-1290 (-50.8	961 (37.8)	707 (27.8)	-1293 (-50.9)	-39 (-1.5)	7 (0.3)	-3 (-0.1)	40 (1.6)
R24	1000 (39.4)	800 (31.5)	-1258 (-49.5	955 (37.6)	806 (31.7)	-1260 (-49.6)	-45 (-1.8)	6 (0.2)	-2 (-0.1)	45 (1.8)

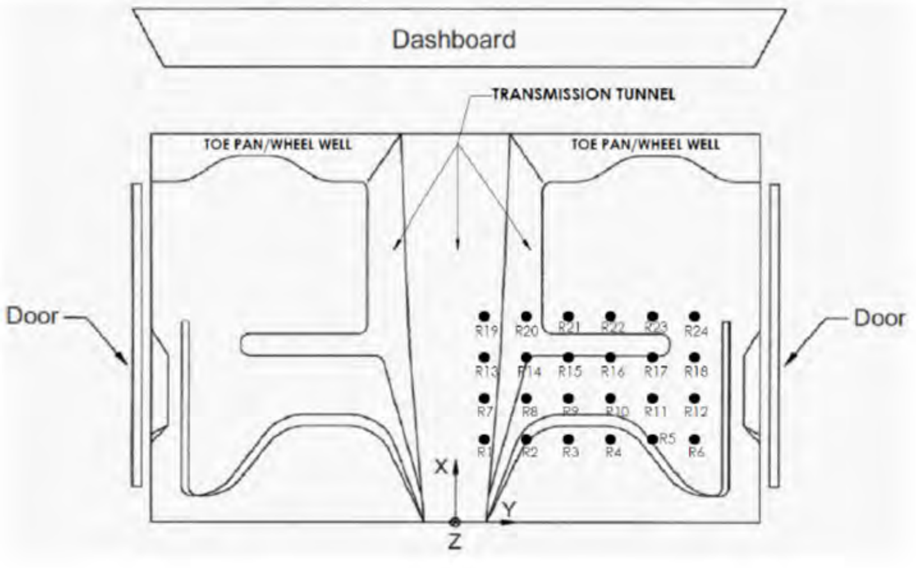
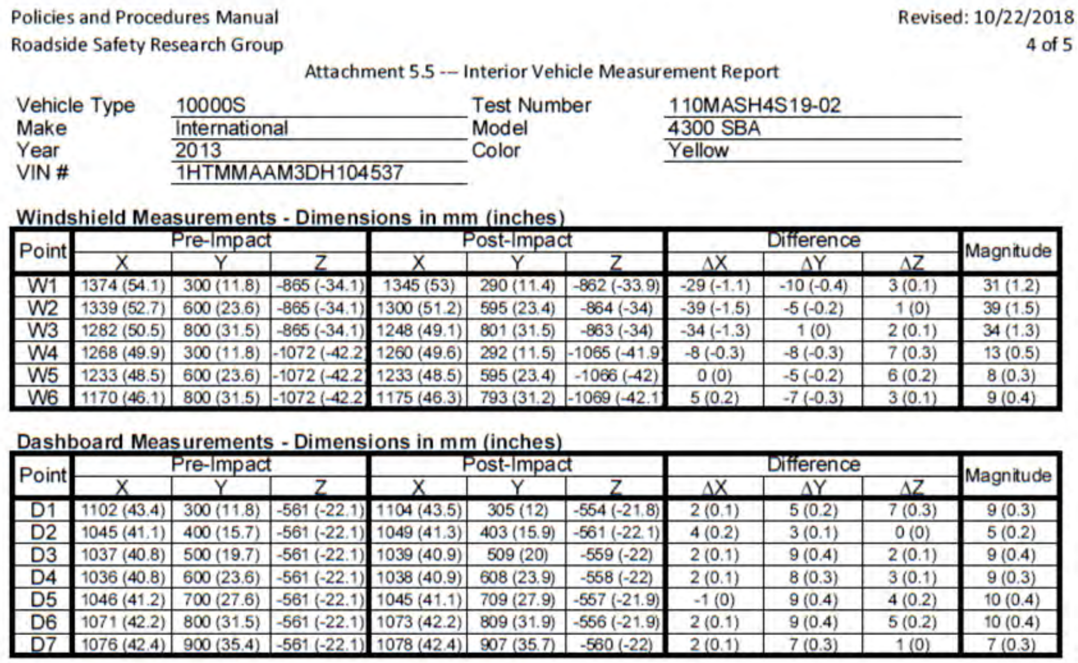


Table 9-31 Test 4-10 Interior Windshield and Dashboard Pre, Post, and Deformation Measurements



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Attachment 5.5 -– Interior Vehicle Measurement Report

Vehicle Type	10000S	Test Number	110MASH4S19-02
Make	International	Model	4300 SBA
Year	2013	Color	Yellow
VIN #	1HTMMAAM3DH104537		

Windshield Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
W1	1374 (54.1)	300 (11.8)	-865 (-34.1)	1345 (53)	290 (11.4)	-862 (-33.9)	-29 (-1.1)	-10 (-0.4)	3 (0.1)	31 (1.2)
W2	1339 (52.7)	600 (23.6)	-865 (-34.1)	1300 (51.2)	595 (23.4)	-864 (-34)	-39 (-1.5)	-5 (-0.2)	1 (0)	39 (1.5)
W3	1282 (50.5)	800 (31.5)	-865 (-34.1)	1248 (49.1)	801 (31.5)	-863 (-34)	-34 (-1.3)	1 (0)	2 (0.1)	34 (1.3)
W4	1268 (49.9)	300 (11.8)	-1072 (-42.2	1260 (49.6)	292 (11.5)	-1065 (-41.9	-8 (-0.3)	-8 (-0.3)	7 (0.3)	13 (0.5)
W5	1233 (48.5)	600 (23.6)	-1072 (-42.2	1233 (48.5)	595 (23.4)	-1066 (-42)	0 (0)	-5 (-0.2)	6 (0.2)	8 (0.3)
W6	1170 (46.1)	800 (31.5)	-1072 (-42.2	1175 (46.3)	793 (31.2)	-1069 (-42.1	5 (0.2)	-7 (-0.3)	3 (0.1)	9 (0.4)

Dashboard Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
D1	1102 (43.4)	300 (11.8)	-561 (-22.1)	1104 (43.5)	305 (12)	-554 (-21.8)	2 (0.1)	5 (0.2)	7 (0.3)	9 (0.3)
D2	1045 (41.1)	400 (15.7)	-561 (-22.1)	1049 (41.3)	403 (15.9)	-561 (-22.1)	4 (0.2)	3 (0.1)	0 (0)	5 (0.2)
D3	1037 (40.8)	500 (19.7)	-561 (-22.1)	1039 (40.9)	509 (20)	-559 (-22)	2 (0.1)	9 (0.4)	2 (0.1)	9 (0.4)
D4	1036 (40.8)	600 (23.6)	-561 (-22.1)	1038 (40.9)	608 (23.9)	-558 (-22)	2 (0.1)	8 (0.3)	3 (0.1)	9 (0.3)
D5	1046 (41.2)	700 (27.6)	-561 (-22.1)	1045 (41.1)	709 (27.9)	-557 (-21.9)	-1 (0)	9 (0.4)	4 (0.2)	10 (0.4)
D6	1071 (42.2)	800 (31.5)	-561 (-22.1)	1073 (42.2)	809 (31.9)	-556 (-21.9)	2 (0.1)	9 (0.4)	5 (0.2)	10 (0.4)
D7	1076 (42.4)	900 (35.4)	-561 (-22.1)	1078 (42.4)	907 (35.7)	-560 (-22)	2 (0.1)	7 (0.3)	1 (0)	7 (0.3)

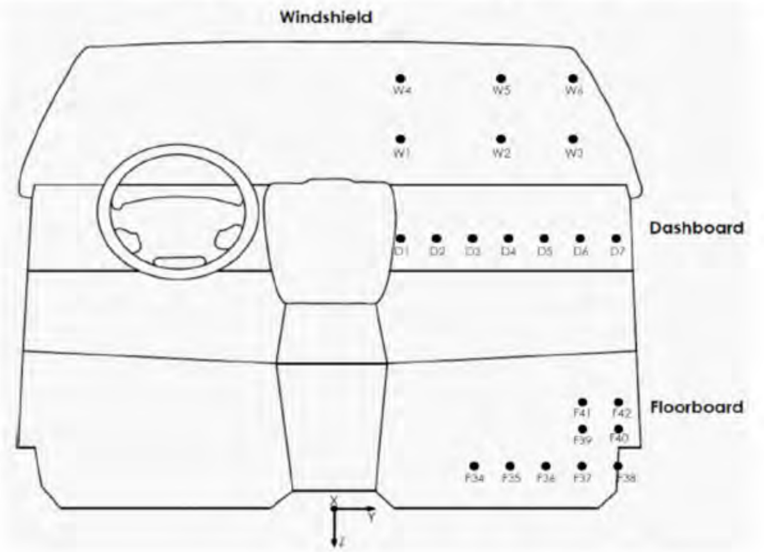
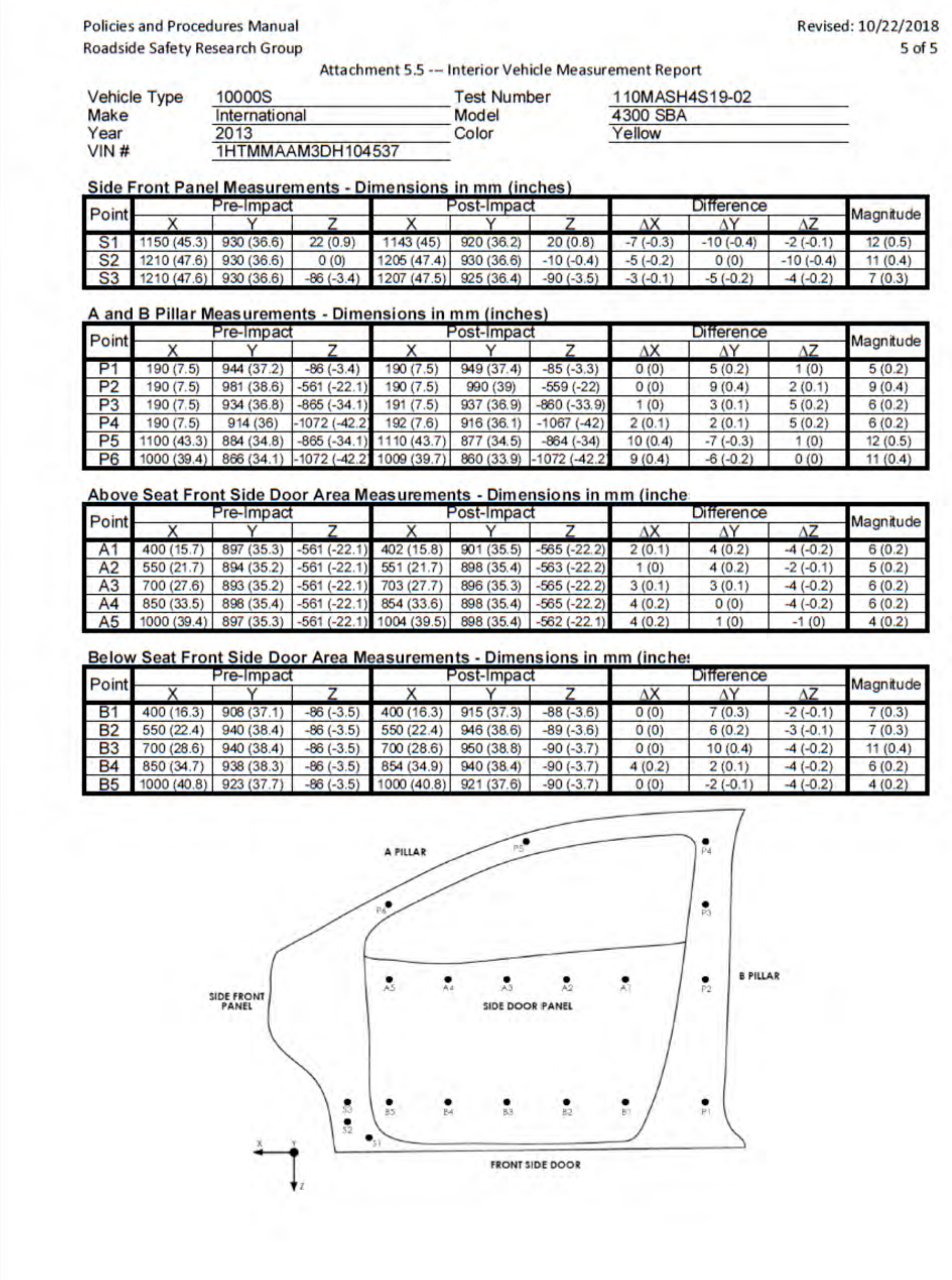


Table 9-32 Test 4-10 Side Pre, Post, and Deformation Measurements



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Roadside Safety Research Group

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Attachment 5.5 -- Interior Vehicle Measurement Report

Vehicle Type 10000S
Make International
Year 2013
VIN # 1HTMMAAM3DH104537
Test Number 110MASH4S19-02
Model 4300 SBA
Color Yellow

Side Front Panel Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
S1	1150 (45.3)	930 (36.6)	22 (0.9)	1143 (45)	920 (36.2)	20 (0.8)	-7 (-0.3)	-10 (-0.4)	-2 (-0.1)	12 (0.5)
S2	1210 (47.6)	930 (36.6)	0 (0)	1205 (47.4)	930 (36.6)	-10 (-0.4)	-5 (-0.2)	0 (0)	-10 (-0.4)	11 (0.4)
S3	1210 (47.6)	930 (36.6)	-86 (-3.4)	1207 (47.5)	925 (36.4)	-90 (-3.5)	-3 (-0.1)	-5 (-0.2)	-4 (-0.2)	7 (0.3)

A and B Pillar Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
P1	190 (7.5)	944 (37.2)	-86 (-3.4)	190 (7.5)	949 (37.4)	-85 (-3.3)	0 (0)	5 (0.2)	1 (0)	5 (0.2)
P2	190 (7.5)	981 (38.6)	-561 (-22.1)	190 (7.5)	990 (39)	-559 (-22)	0 (0)	9 (0.4)	2 (0.1)	9 (0.4)
P3	190 (7.5)	934 (36.8)	-865 (-34.1)	191 (7.5)	937 (36.9)	-860 (-33.9)	1 (0)	3 (0.1)	5 (0.2)	6 (0.2)
P4	190 (7.5)	914 (36)	-1072 (-42.2	192 (7.6)	916 (36.1)	-1067 (-42)	2 (0.1)	2 (0.1)	5 (0.2)	6 (0.2)
P5	1100 (43.3)	884 (34.8)	-865 (-34.1)	1110 (43.7)	877 (34.5)	-864 (-34)	10 (0.4)	-7 (-0.3)	1 (0)	12 (0.5)
P6	1000 (39.4)	866 (34.1)	-1072 (-42.2	1009 (39.7)	860 (33.9)	-1072 (-42.2	9 (0.4)	-6 (-0.2)	0 (0)	11 (0.4)

Above Seat Front Side Door Area Measurements - Dimensions in mm (inche

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
A1	400 (15.7)	897 (35.3)	-561 (-22.1)	402 (15.8)	901 (35.5)	-565 (-22.2)	2 (0.1)	4 (0.2)	-4 (-0.2)	6 (0.2)
A2	550 (21.7)	894 (35.2)	-561 (-22.1)	551 (21.7)	898 (35.4)	-563 (-22.2)	1 (0)	4 (0.2)	-2 (-0.1)	5 (0.2)
A3	700 (27.6)	893 (35.2)	-561 (-22.1)	703 (27.7)	896 (35.3)	-565 (-22.2)	3 (0.1)	3 (0.1)	-4 (-0.2)	6 (0.2)
A4	850 (33.5)	898 (35.4)	-561 (-22.1)	854 (33.6)	898 (35.4)	-565 (-22.2)	4 (0.2)	0 (0)	-4 (-0.2)	6 (0.2)
A5	1000 (39.4)	897 (35.3)	-561 (-22.1)	1004 (39.5)	898 (35.4)	-562 (-22.1)	4 (0.2)	1 (0)	-1 (0)	4 (0.2)

Below Seat Front Side Door Area Measurements - Dimensions in mm (inche:

Point	Pre-Impact			Post-Impact			Difference			Magnitude
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ	
B1	400 (16.3)	908 (37.1)	-86 (-3.5)	400 (16.3)	915 (37.3)	-88 (-3.6)	0 (0)	7 (0.3)	-2 (-0.1)	7 (0.3)
B2	550 (22.4)	940 (38.4)	-86 (-3.5)	550 (22.4)	946 (38.6)	-89 (-3.6)	0 (0)	6 (0.2)	-3 (-0.1)	7 (0.3)
B3	700 (28.6)	940 (38.4)	-86 (-3.5)	700 (28.6)	950 (38.8)	-90 (-3.7)	0 (0)	10 (0.4)	-4 (-0.2)	11 (0.4)
B4	850 (34.7)	938 (38.3)	-86 (-3.5)	854 (34.9)	940 (38.4)	-90 (-3.7)	4 (0.2)	2 (0.1)	-4 (-0.2)	6 (0.2)
B5	1000 (40.8)	923 (37.7)	-86 (-3.5)	1000 (40.8)	921 (37.6)	-90 (-3.7)	0 (0)	-2 (-0.1)	-4 (-0.2)	4 (0.2)

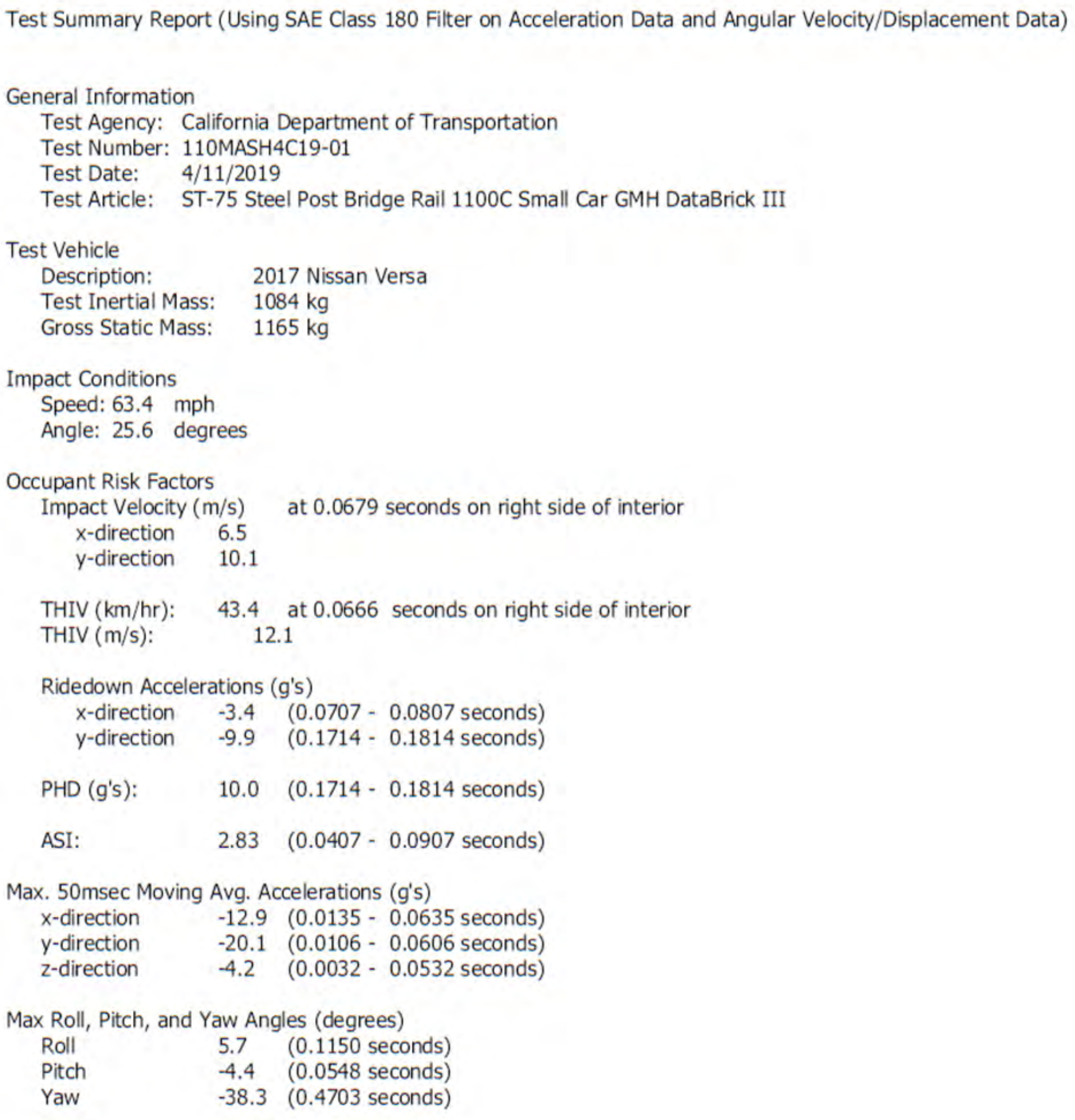
9.6. Data Plots

The TRAP data plots and summary sheets are shown in Figure 9-13 through Figure 9-62 The plots included are the accelerations, angular rate sensor rates, angular rate sensor degrees, Acceleration Severity Index (ASI), and TRAP test summary sheets. All data were analyzed using TRAP.

9.6.1. Data Plots - Test 110MASH4C19-01 (Test 4-10)

As mentioned previously, data was lost from one of the GMH Engineering DataBrick 3's. The data from the remaining DataBrick 3 and both SLICE systems were analyzed using TRAP. The TRAP results sheets and data plots are shown below.

Databrick 3 Plots (DB327)



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Test Summary Report (Using SAE Class 180 Filter on Acceleration Data and Angular Velocity/Displacement Data)


General Information
    Test Agency:   California Department of Transportation
    Test Number:   110MASH4C19-01
    Test Date:     4/11/2019
    Test Article:  ST-75 Steel Post Bridge Rail 1100C Small Car GMH DataBrick III

Test Vehicle
    Description:           2017 Nissan Versa
    Test Inertial Mass:    1084 kg
    Gross Static Mass:     1165 kg

Impact Conditions
    Speed: 63.4   mph
    Angle:  25.6   degrees

Occupant Risk Factors
    Impact Velocity (m/s)      at 0.0679 seconds on right side of interior
        x-direction      6.5
        y-direction      10.1

    THIV (km/hr):        43.4    at 0.0666  seconds on right side of interior
    THIV (m/s):              12.1

    Ridedown Accelerations (g's)
        x-direction      -3.4    (0.0707 -  0.0807 seconds)
        y-direction      -9.9    (0.1714 -  0.1814 seconds)

    PHD (g's):           10.0    (0.1714 -  0.1814 seconds)

    ASI:                 2.83    (0.0407 -  0.0907 seconds)

Max. 50msec Moving Avg. Accelerations (g's)
    x-direction          -12.9   (0.0135 -  0.0635 seconds)
    y-direction          -20.1   (0.0106 -  0.0606 seconds)
    z-direction          -4.2    (0.0032 -  0.0532 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)
    Roll                 5.7     (0.1150 seconds)
    Pitch                -4.4    (0.0548 seconds)
    Yaw                  -38.3   (0.4703 seconds)
```

Figure 9-13 Test 4-10 TRAP Summary Sheet (DataBrick 3)

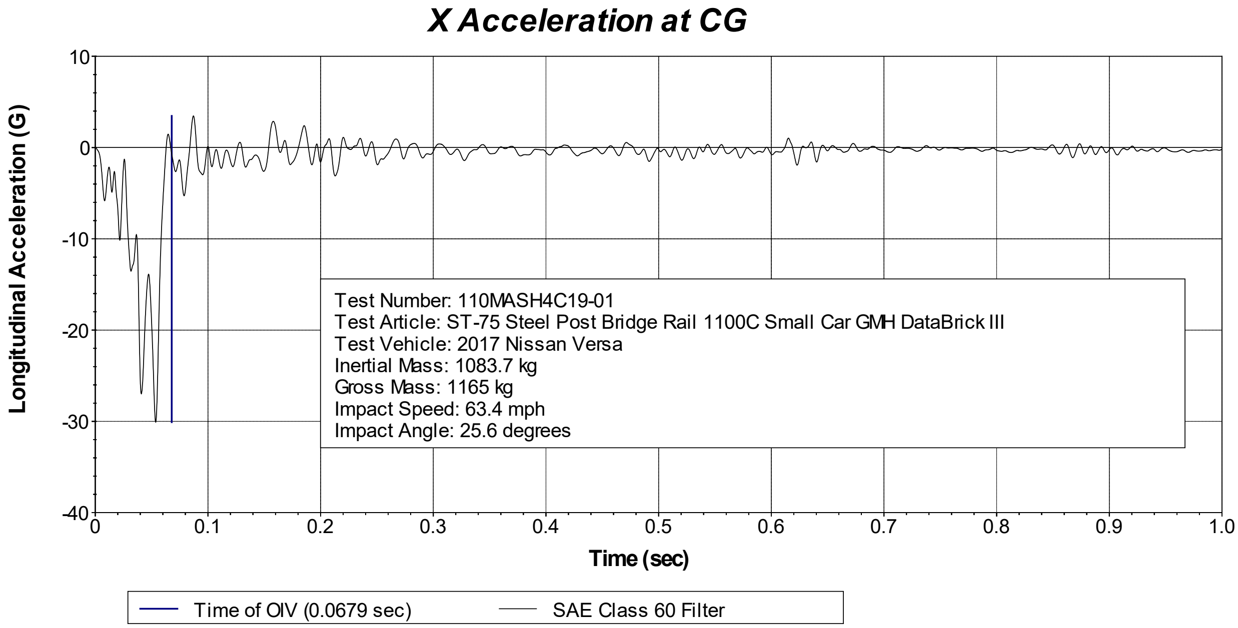


Figure 9-14 Test 4-10 Longitudinal Acceleration (Databrick 3)

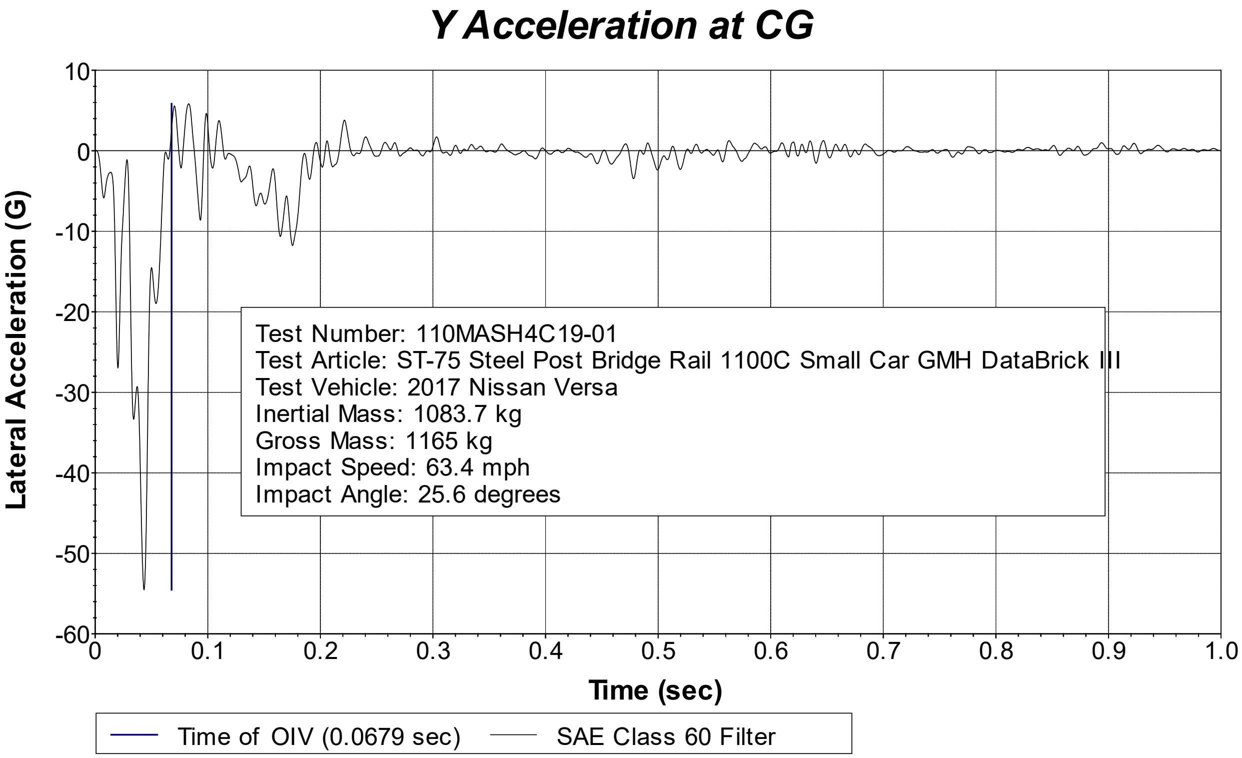


Figure 9-15 Test 4-10 Lateral Acceleration (Databrick 3)

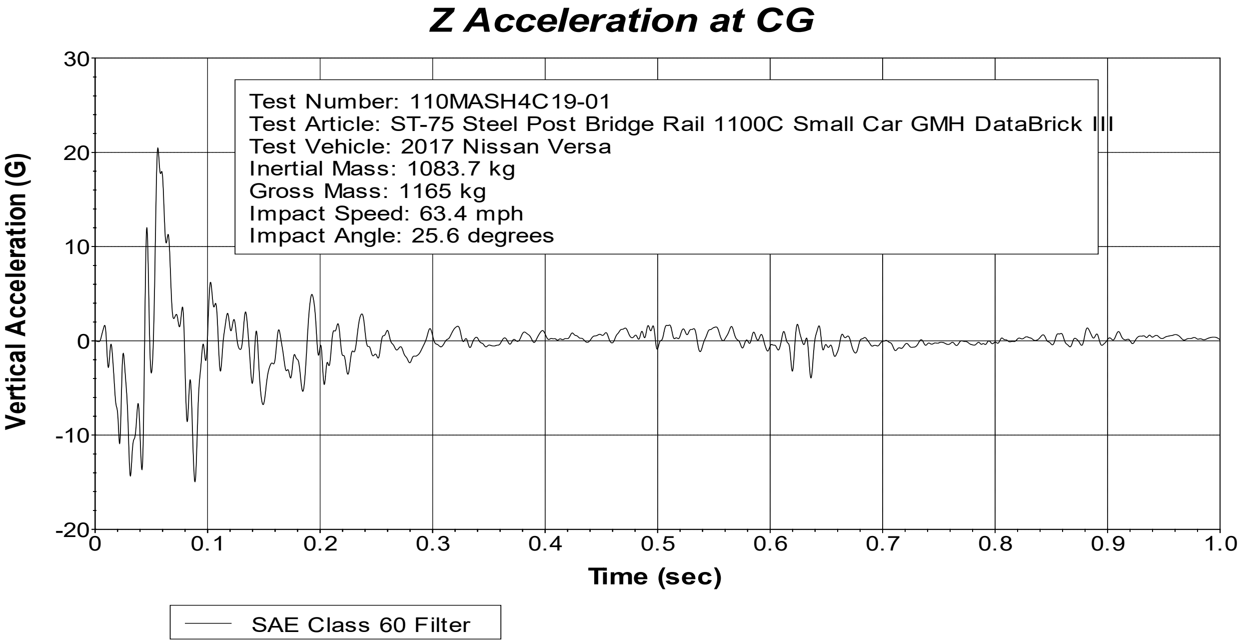


Figure 9-16 Test 4-10 Vertical Acceleration (Databrick 3)

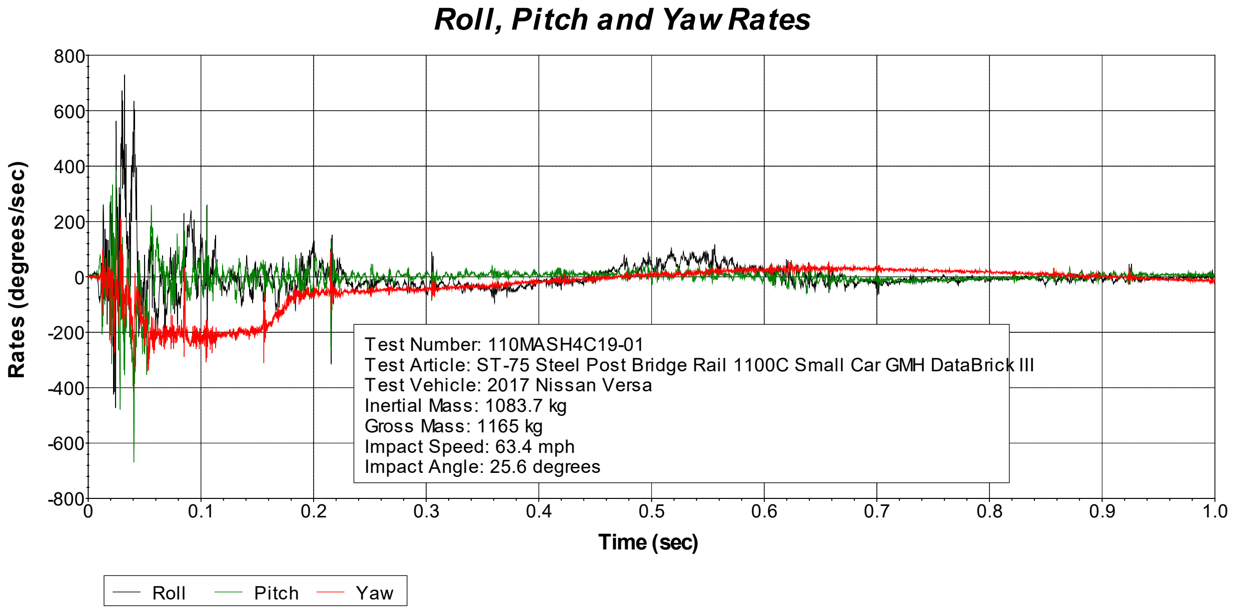


Figure 9-17 Test 4-10 Roll, Pitch, and Yaw Rates (DataBrick 3)

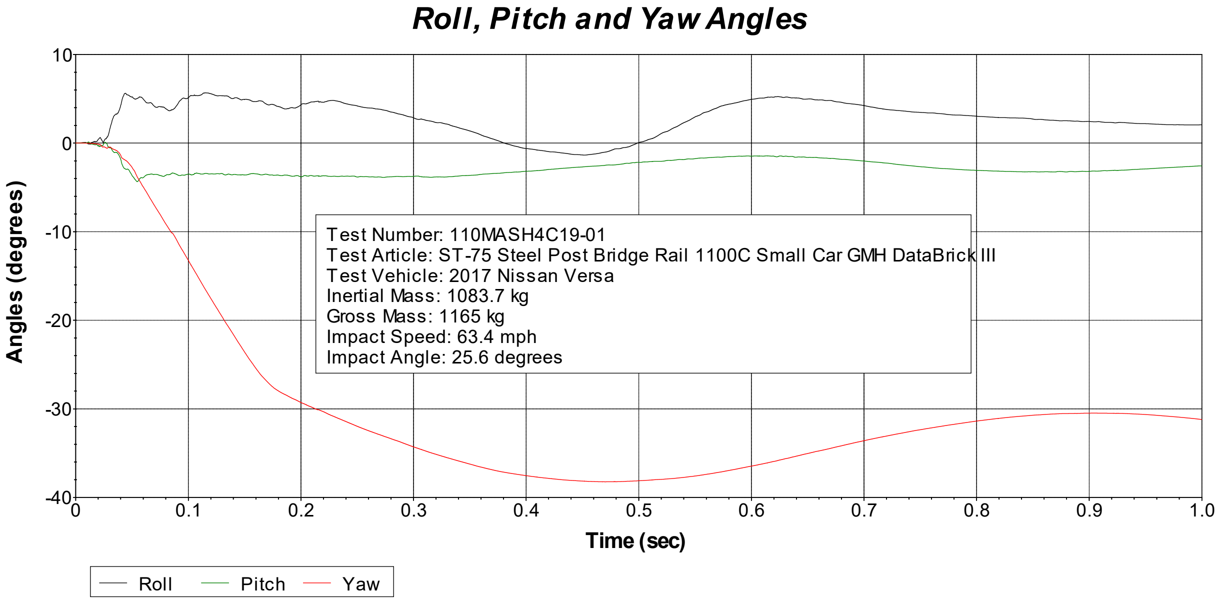


Figure 9-18 Test 4-10 Roll, Pitch, and Yaw Angles (DataBrick 3)

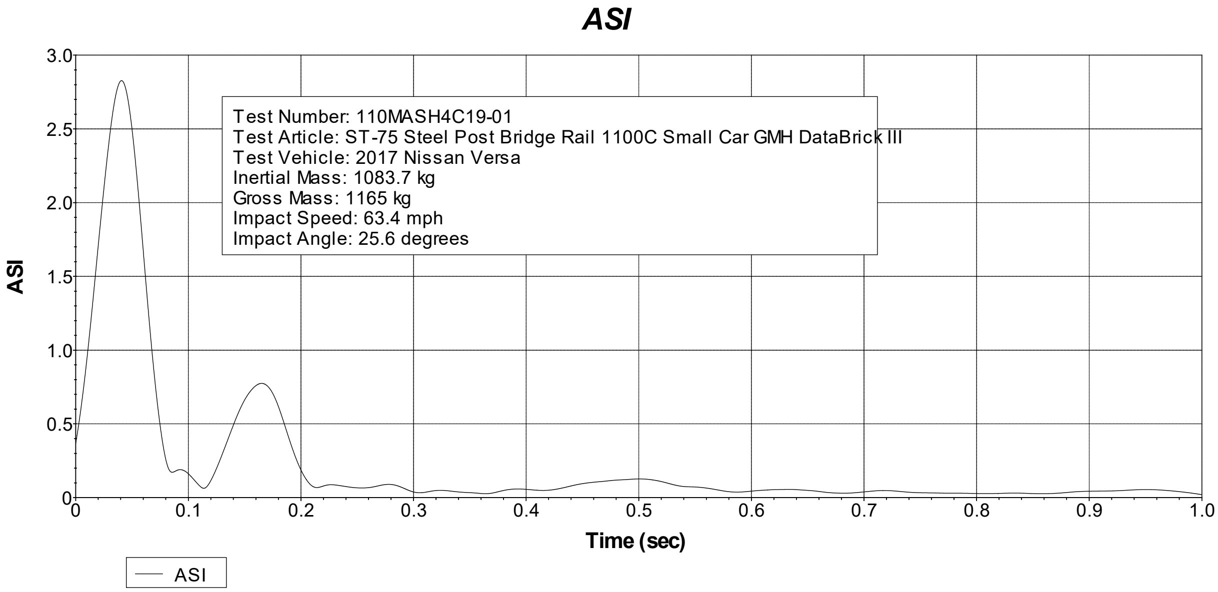
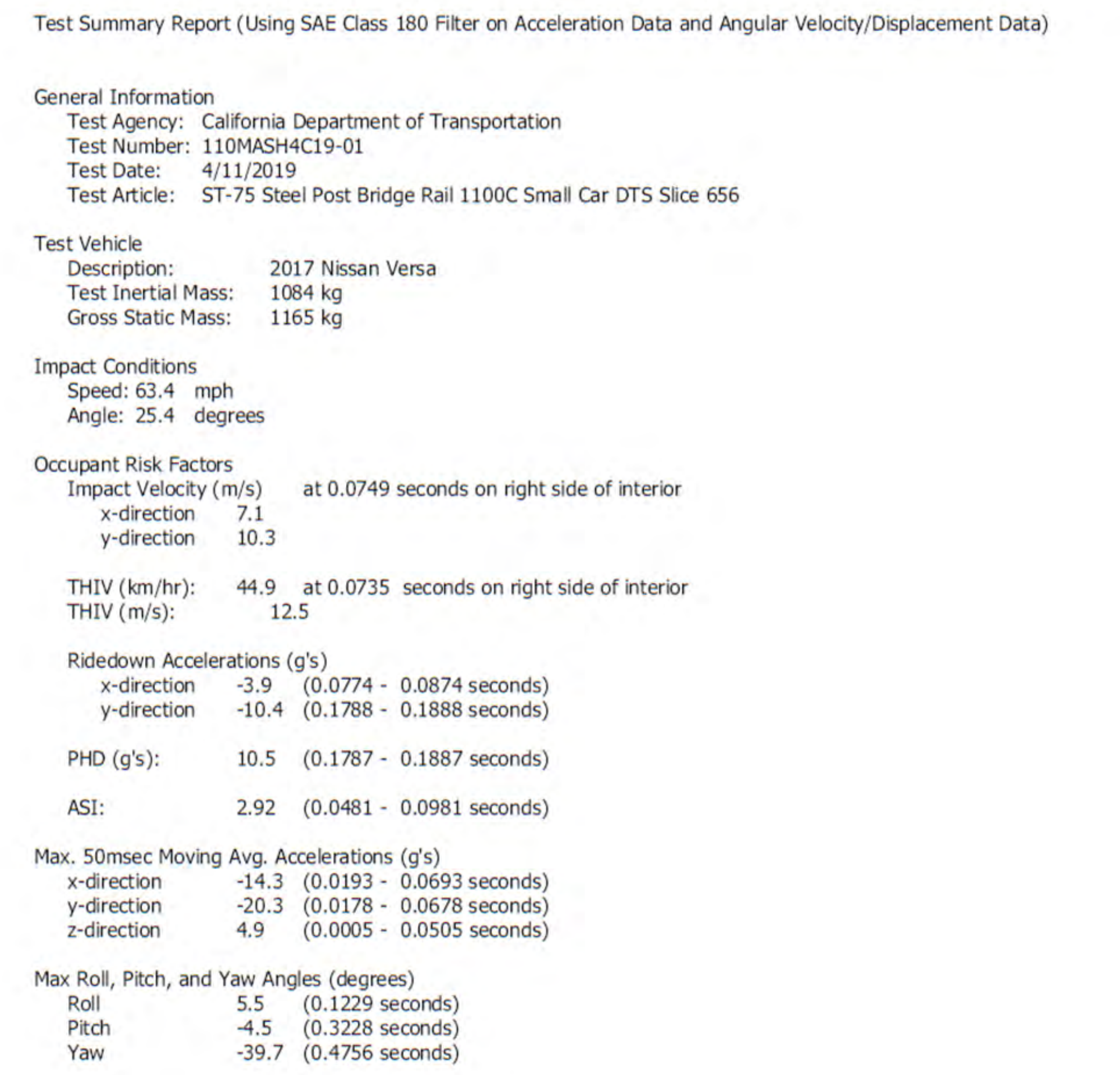


Figure 9-19 Test 4-10 Acceleration Severity Index (DataBrick 3)

SLICE BASE 656 Plots



```
Test Summary Report (Using SAE Class 180 Filter on Acceleration Data and Angular Velocity/Displacement Data)


General Information
    Test Agency:   California Department of Transportation
    Test Number:   110MASH4C19-01
    Test Date:     4/11/2019
    Test Article:  ST-75 Steel Post Bridge Rail 1100C Small Car DTS Slice 656

Test Vehicle
    Description:          2017 Nissan Versa
    Test Inertial Mass:   1084 kg
    Gross Static Mass:    1165 kg

Impact Conditions
    Speed: 63.4   mph
    Angle: 25.4   degrees

Occupant Risk Factors
    Impact Velocity (m/s)      at 0.0749 seconds on right side of interior
        x-direction      7.1
        y-direction      10.3

    THIV (km/hr):        44.9    at 0.0735  seconds on right side of interior
    THIV (m/s):              12.5

    Ridedown Accelerations (g's)
        x-direction      -3.9    (0.0774 -  0.0874 seconds)
        y-direction      -10.4   (0.1788 -  0.1888 seconds)

    PHD (g's):           10.5    (0.1787 -  0.1887 seconds)

    ASI:                 2.92    (0.0481 -  0.0981 seconds)

Max. 50msec Moving Avg. Accelerations (g's)
    x-direction          -14.3   (0.0193 -  0.0693 seconds)
    y-direction          -20.3   (0.0178 -  0.0678 seconds)
    z-direction          4.9     (0.0005 -  0.0505 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)
    Roll                 5.5     (0.1229 seconds)
    Pitch                -4.5    (0.3228 seconds)
    Yaw                  -39.7   (0.4756 seconds)
```

Figure 9-20 Test 4-10 TRAP Summary Sheet (SLICE 656)

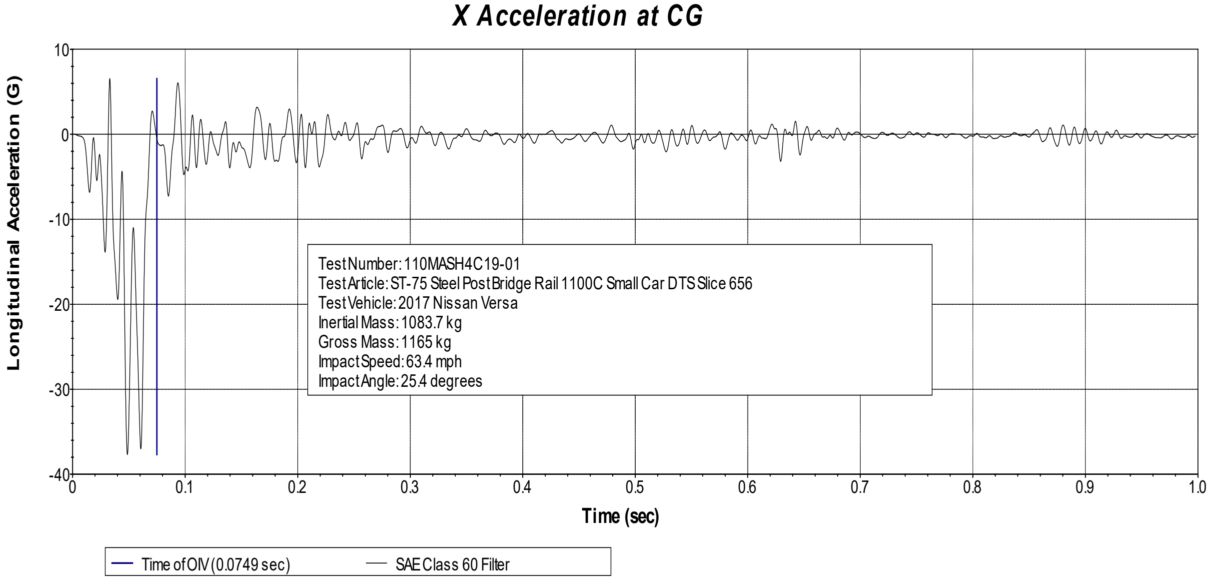


Figure 9-21 Test 4-10 Longitudinal Acceleration (SLICE 656)

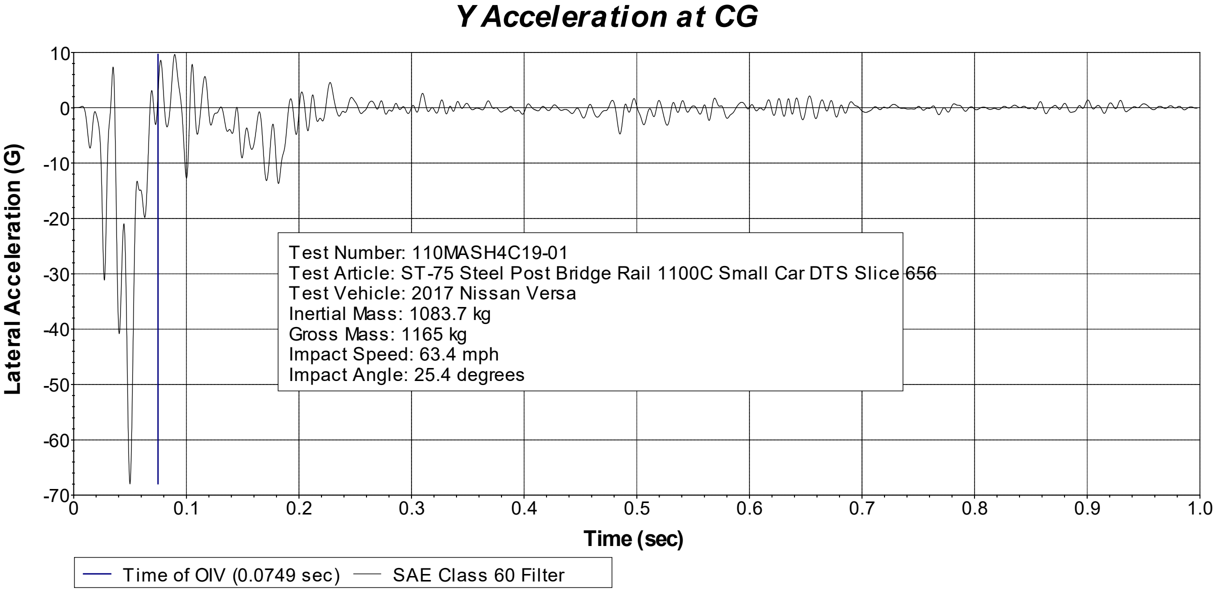


Figure 9-22 Test 4-10 Lateral Acceleration (SLICE 656)

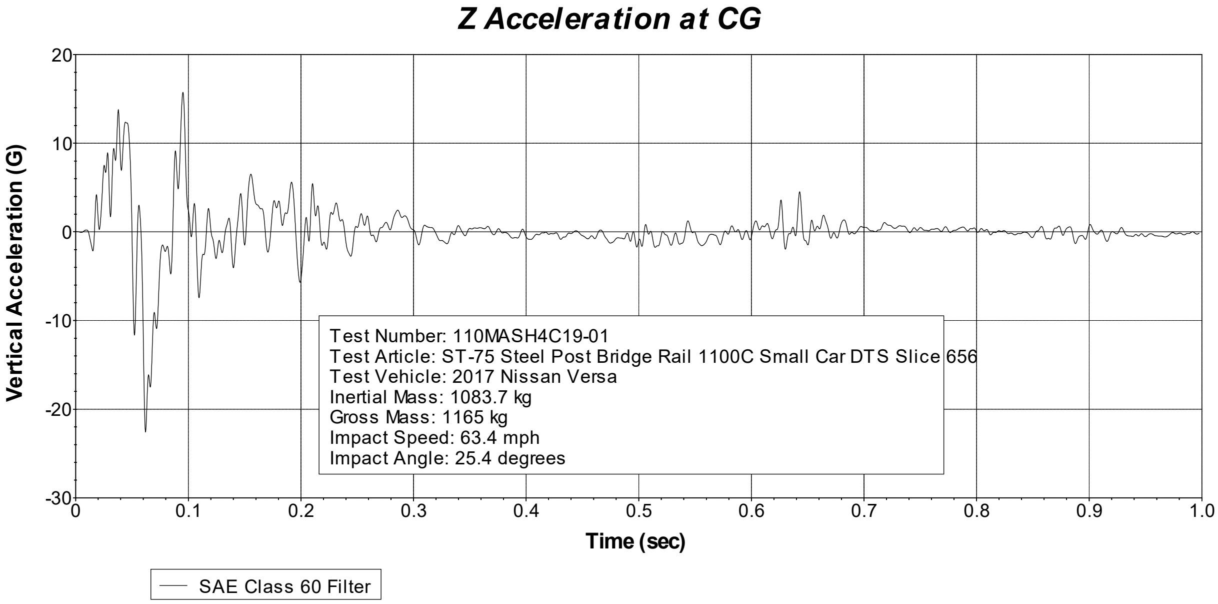


Figure 9-23 Test 4-10 Vertical Acceleration (SLICE 656)

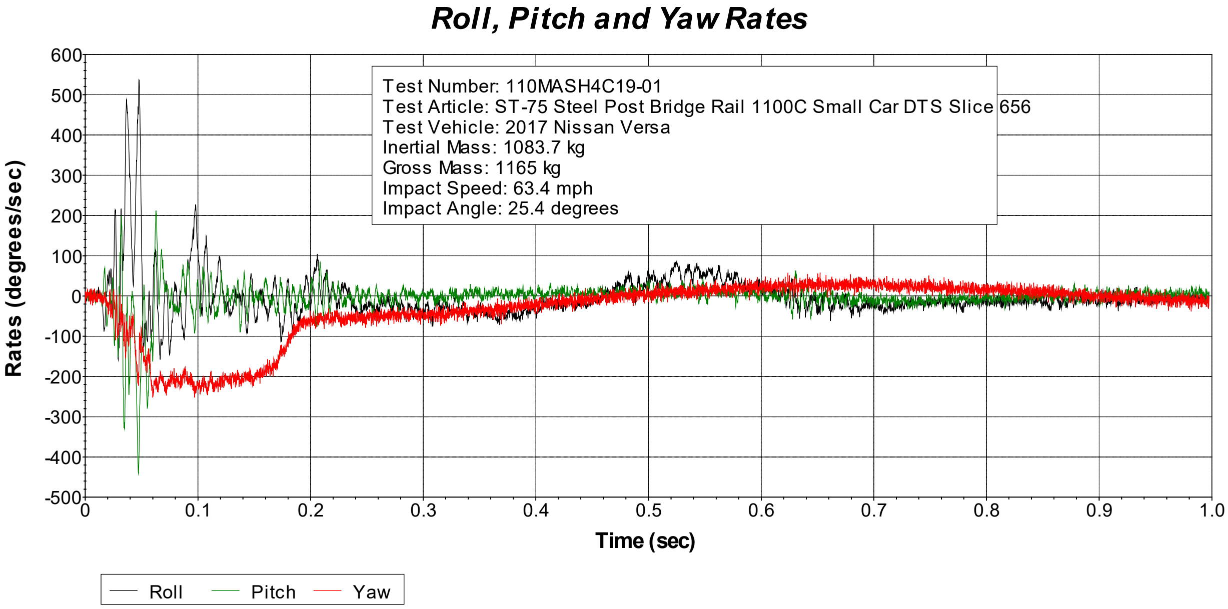


Figure 9-24 Test 4-10 Roll, Pitch, and Yaw Rates (SLICE 656)

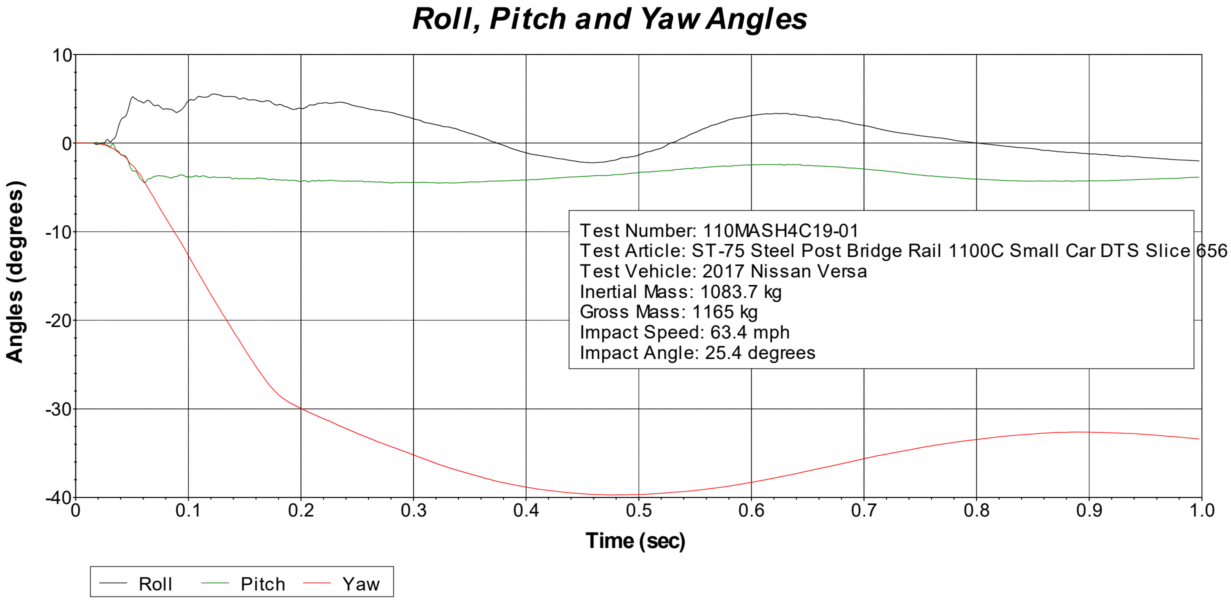


Figure 9-25 Test 4-10 Roll, Pitch, and Yaw Angles (SLICE 656)

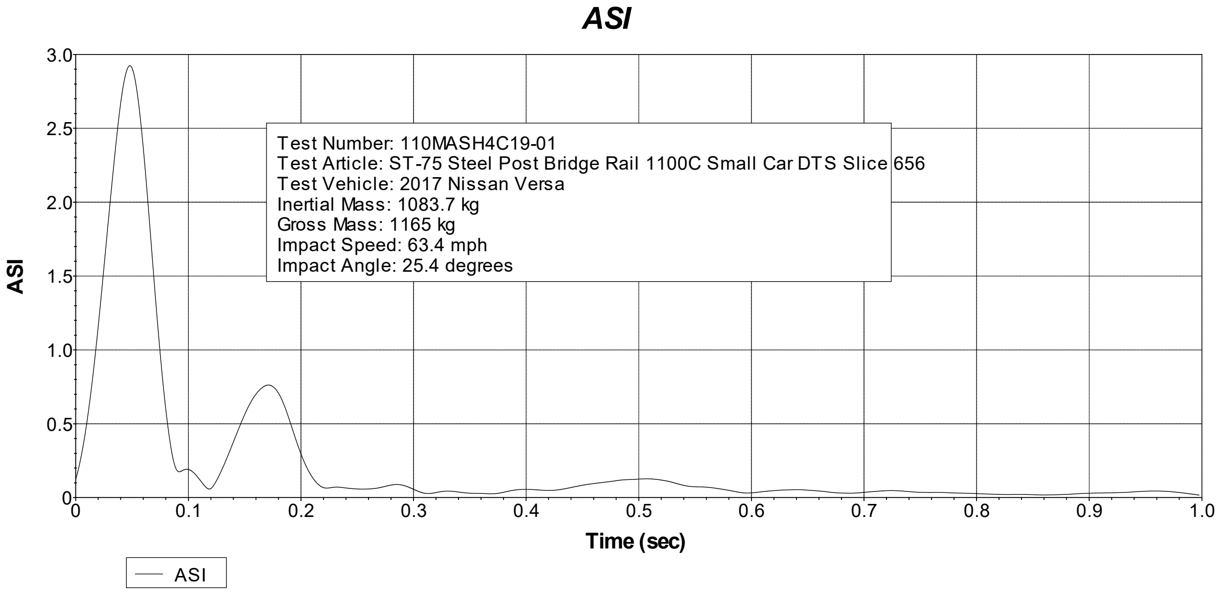
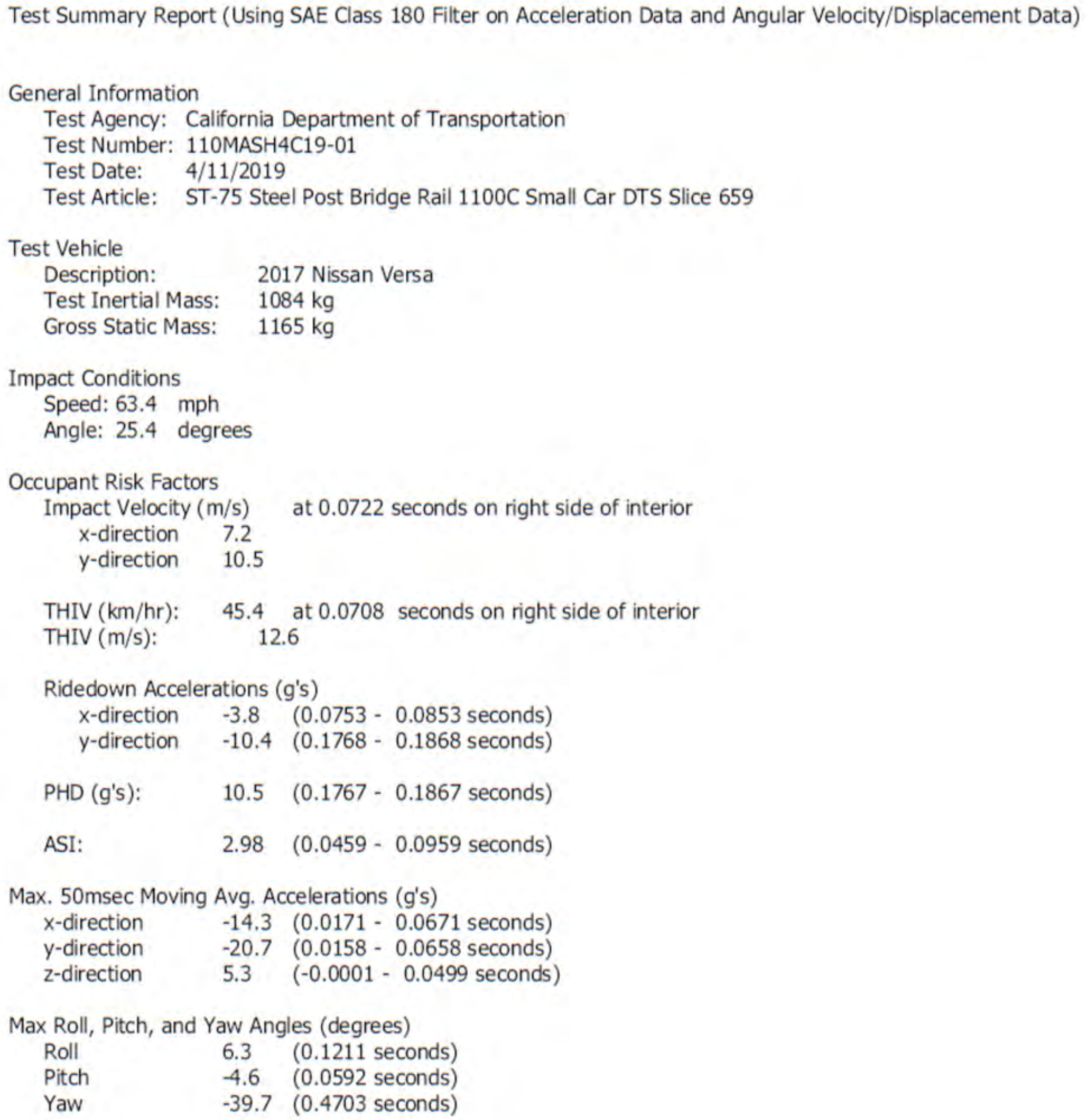


Figure 9-26 Test 4-10 Acceleration Severity Index (SLICE 656)

SLICE BASE 659 Plots



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Test Summary Report (Using SAE Class 180 Filter on Acceleration Data and Angular Velocity/Displacement Data)


General Information
    Test Agency:   California Department of Transportation
    Test Number:  110MASH4C19-01
    Test Date:      4/11/2019
    Test Article:   ST-75 Steel Post Bridge Rail 1100C Small Car DTS Slice 659

Test Vehicle
    Description:            2017 Nissan Versa
    Test Inertial Mass:    1084 kg
    Gross Static Mass:     1165 kg

Impact Conditions
    Speed: 63.4   mph
    Angle:  25.4   degrees

Occupant Risk Factors
    Impact Velocity (m/s)      at 0.0722 seconds on right side of interior
        x-direction      7.2
        y-direction      10.5

    THIV (km/hr):      45.4    at 0.0708  seconds on right side of interior
    THIV (m/s):            12.6

    Ridedown Accelerations (g's)
        x-direction      -3.8     (0.0753 -  0.0853 seconds)
        y-direction      -10.4   (0.1768 -  0.1868 seconds)

    PHD (g's):           10.5    (0.1767 -  0.1867 seconds)

    ASI:                    2.98    (0.0459 -  0.0959 seconds)

Max. 50msec Moving Avg. Accelerations (g's)
    x-direction          -14.3   (0.0171 -  0.0671 seconds)
    y-direction          -20.7   (0.0158 -  0.0658 seconds)
    z-direction          5.3      (-0.0001 -  0.0499 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)
    Roll                   6.3      (0.1211 seconds)
    Pitch                  -4.6     (0.0592 seconds)
    Yaw                    -39.7   (0.4703 seconds)
```

Figure 9-27 Test 4-10 TRAP Summary Sheet (SLICE 659)

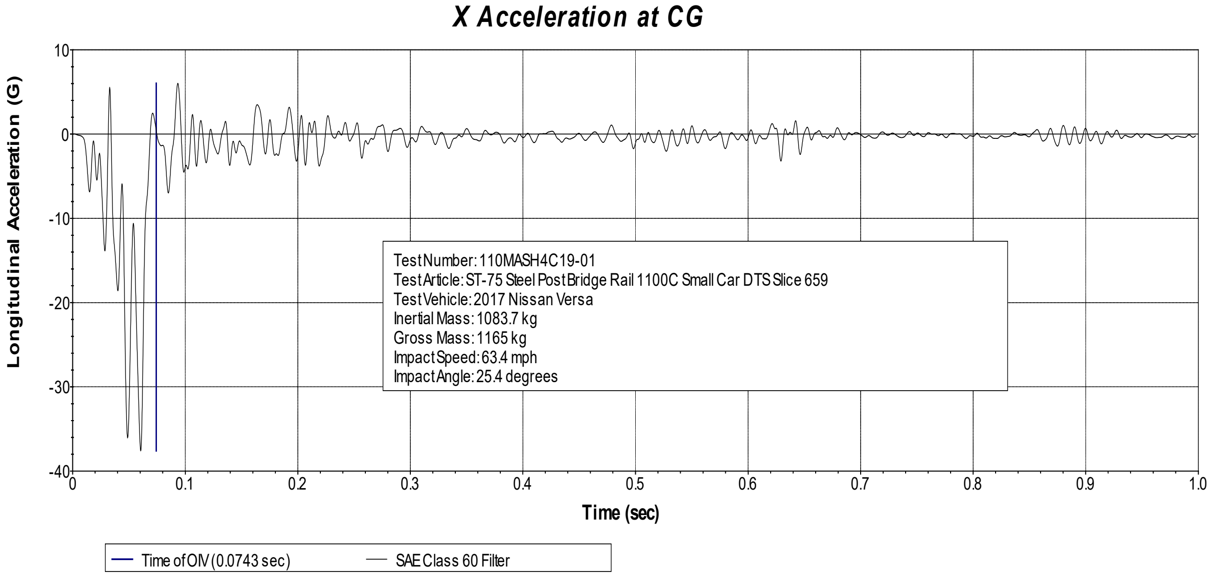


Figure 9-28 Test 4-10 Longitudinal Acceleration (SLICE 659)

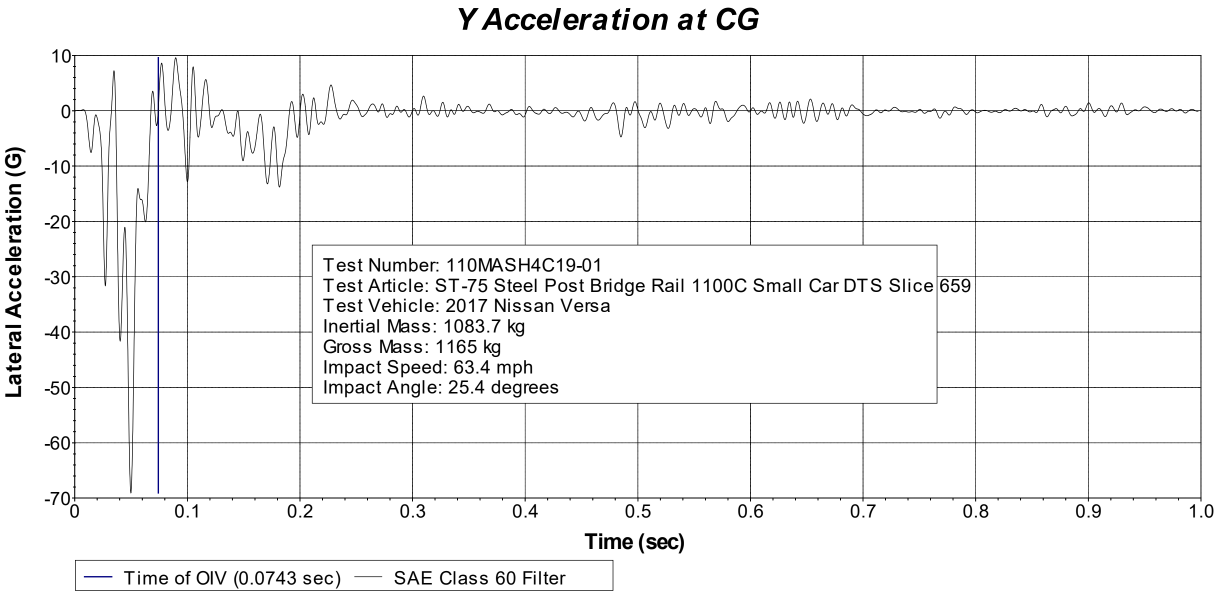


Figure 9-29 Test 4-10 Lateral Acceleration (SLICE 659)

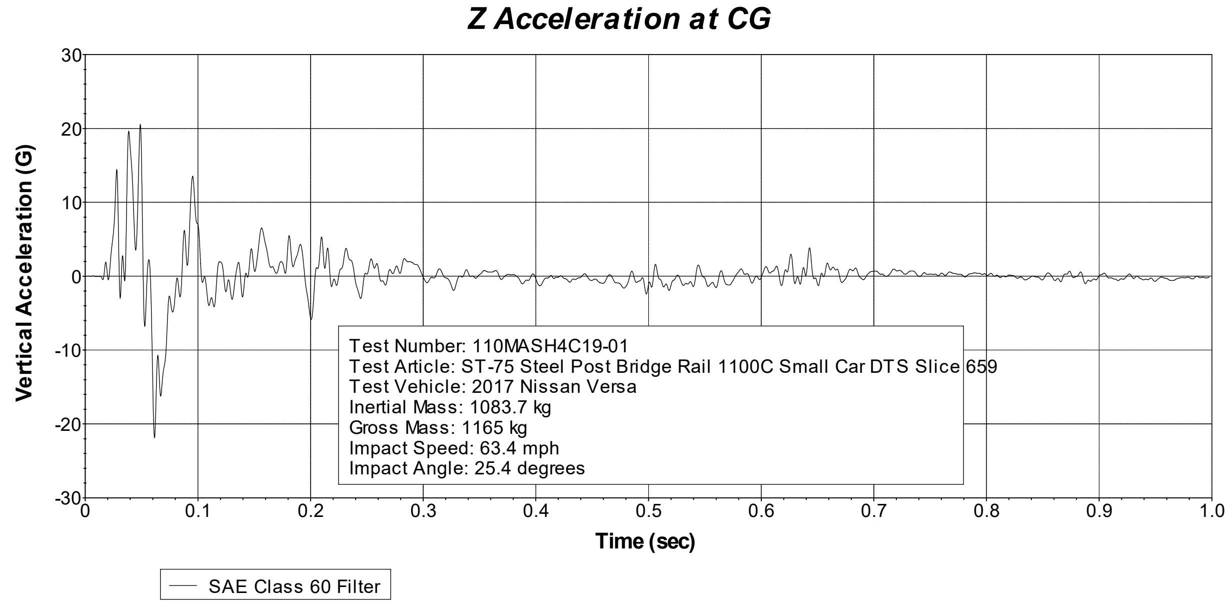


Figure 9-30 Test 4-10 Vertical Acceleration (SLICE 659)

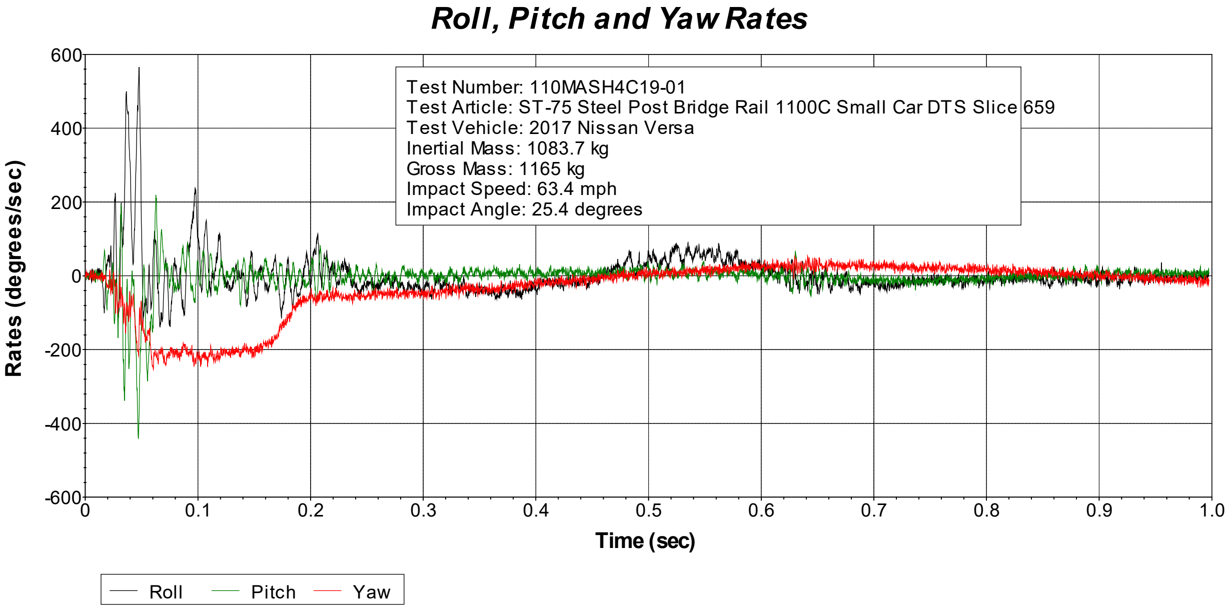


Figure 9-31 Test 4-10 Roll, Pitch, and Yaw Rates (SLICE 659)

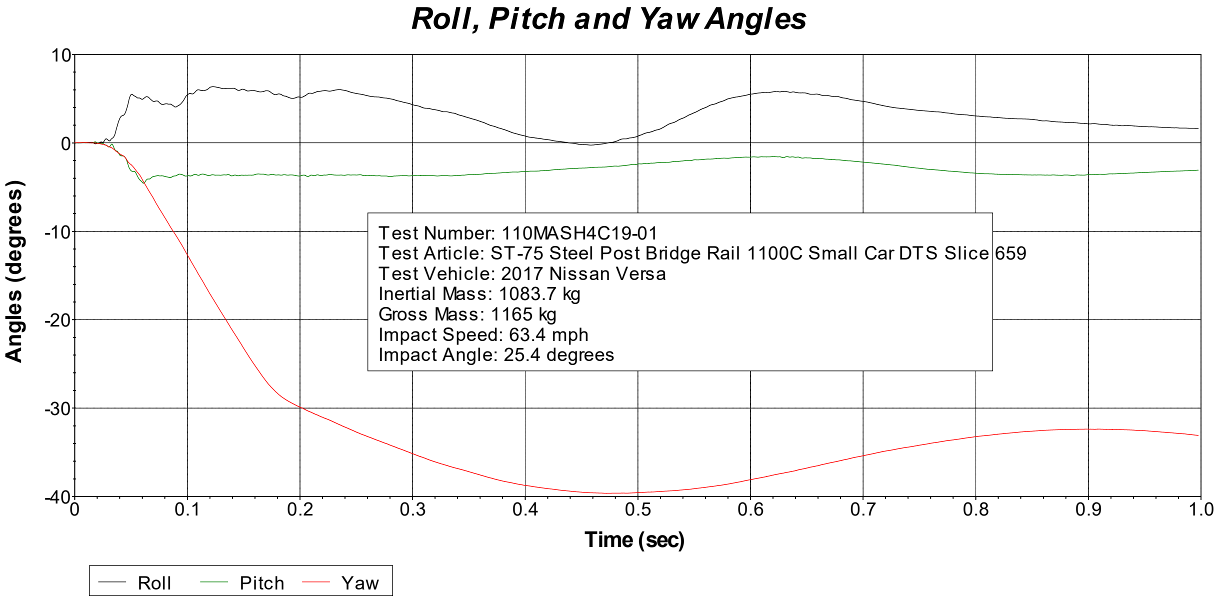


Figure 9-32 Test 4-10 Roll, Pitch, and Yaw Angles (SLICE 659)

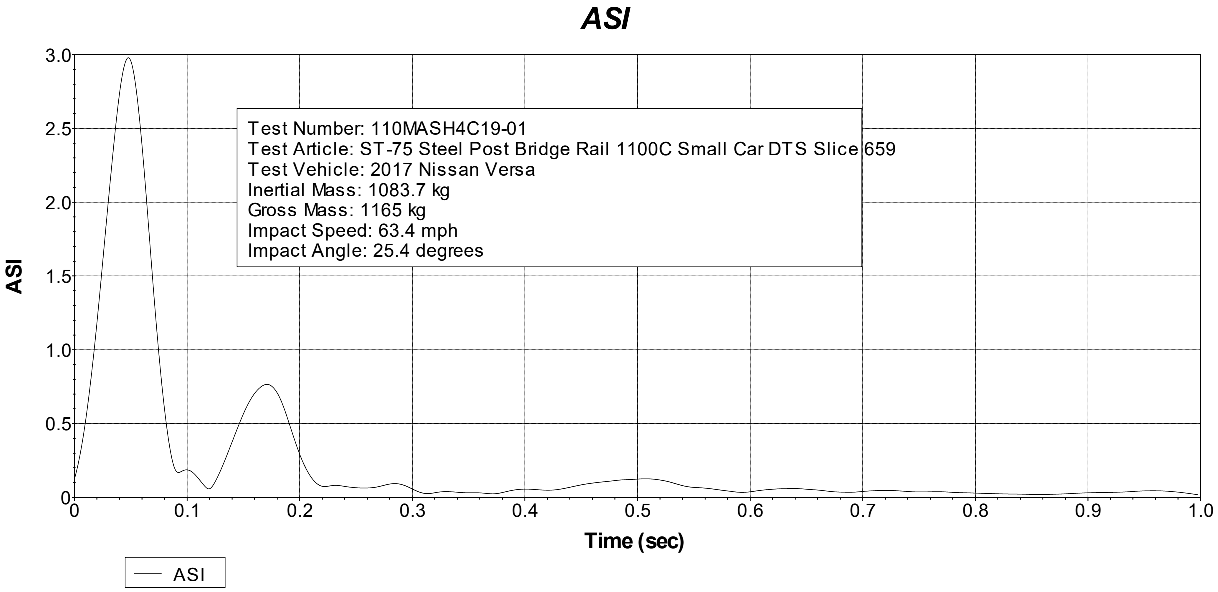
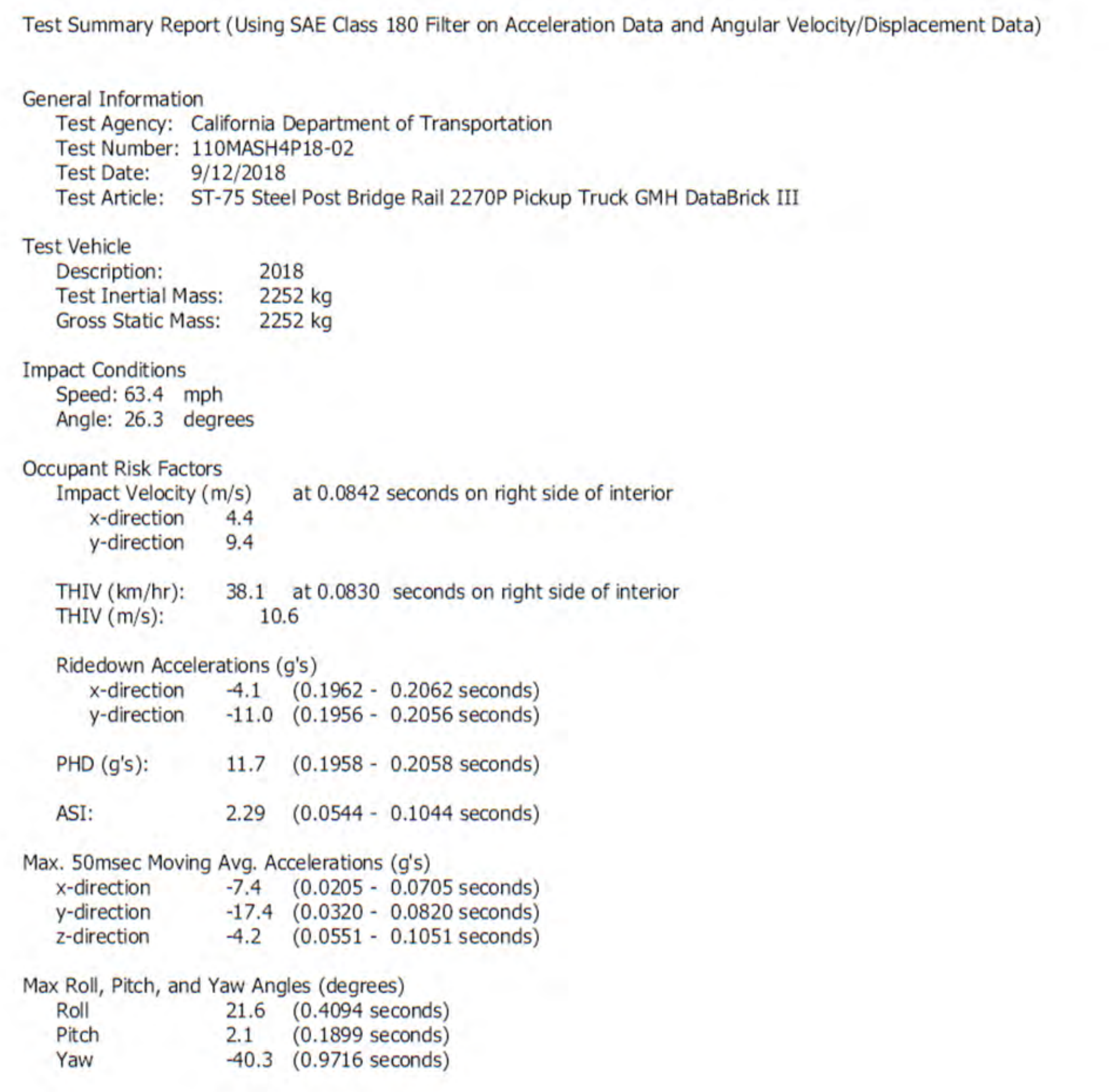


Figure 9-33 Test 4-10 Acceleration Severity Index (SLICE 659)

9.6.2. Data Plots - Test 110MASH4P18-02 (Test 4-11)

Data from one GMH Engineering DataBrick 3 and one SLICE system were analyzed with TRAP. The test summary sheets and data plots are shown below.

Databrick 3 (DB328)



```
Test Summary Report (Using SAE Class 180 Filter on Acceleration Data and Angular Velocity/Displacement Data)

General Information
    Test Agency:   California Department of Transportation
    Test Number:   110MASH4P18-02
    Test Date:     9/12/2018
    Test Article:  ST-75 Steel Post Bridge Rail 2270P Pickup Truck GMH DataBrick III

Test Vehicle
    Description:          2018
    Test Inertial Mass:   2252 kg
    Gross Static Mass:    2252 kg

Impact Conditions
    Speed: 63.4   mph
    Angle:  26.3   degrees

Occupant Risk Factors
    Impact Velocity (m/s)       at 0.0842 seconds on right side of interior
        x-direction     4.4
        y-direction     9.4

    THIV (km/hr):       38.1    at 0.0830  seconds on right side of interior
    THIV (m/s):              10.6

    Ridedown Accelerations (g's)
        x-direction     -4.1    (0.1962 -  0.2062 seconds)
        y-direction     -11.0   (0.1956 -  0.2056 seconds)

    PHD (g's):          11.7    (0.1958 -  0.2058 seconds)

    ASI:                2.29    (0.0544 -  0.1044 seconds)

Max. 50msec Moving Avg. Accelerations (g's)
    x-direction         -7.4    (0.0205 -  0.0705 seconds)
    y-direction         -17.4   (0.0320 -  0.0820 seconds)
    z-direction         -4.2    (0.0551 -  0.1051 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)
    Roll                21.6    (0.4094 seconds)
    Pitch               2.1     (0.1899 seconds)
    Yaw                 -40.3   (0.9716 seconds)
```

Figure 9-34 Test 4-11 TRAP Summary Sheet (DataBrick 3)

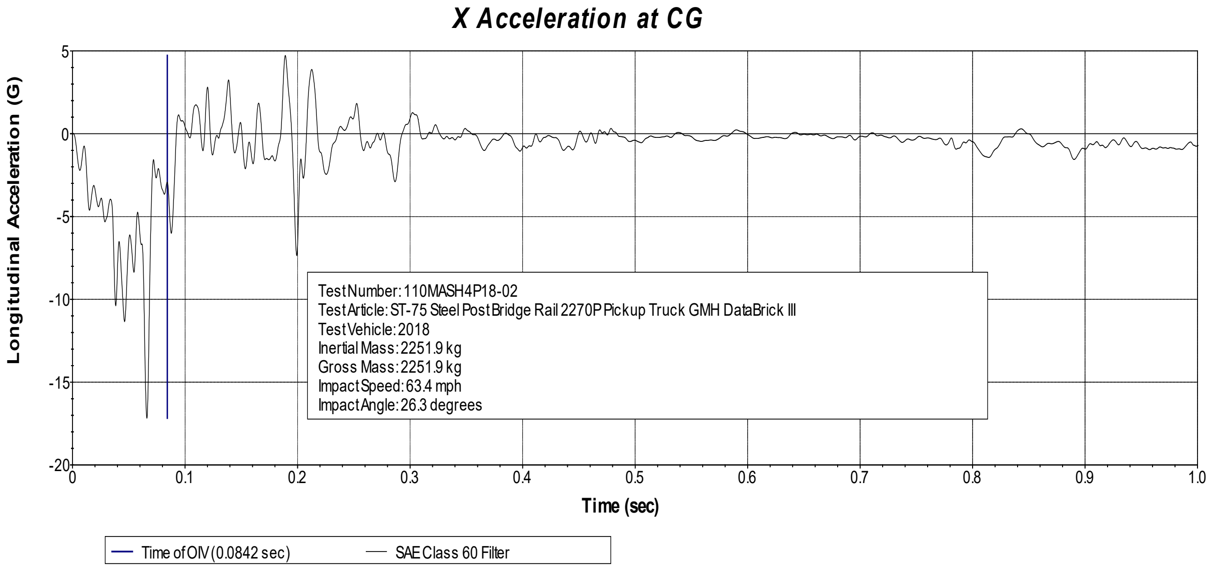


Figure 9-35 Test 4-11 Longitudinal Acceleration (DataBrick 3)

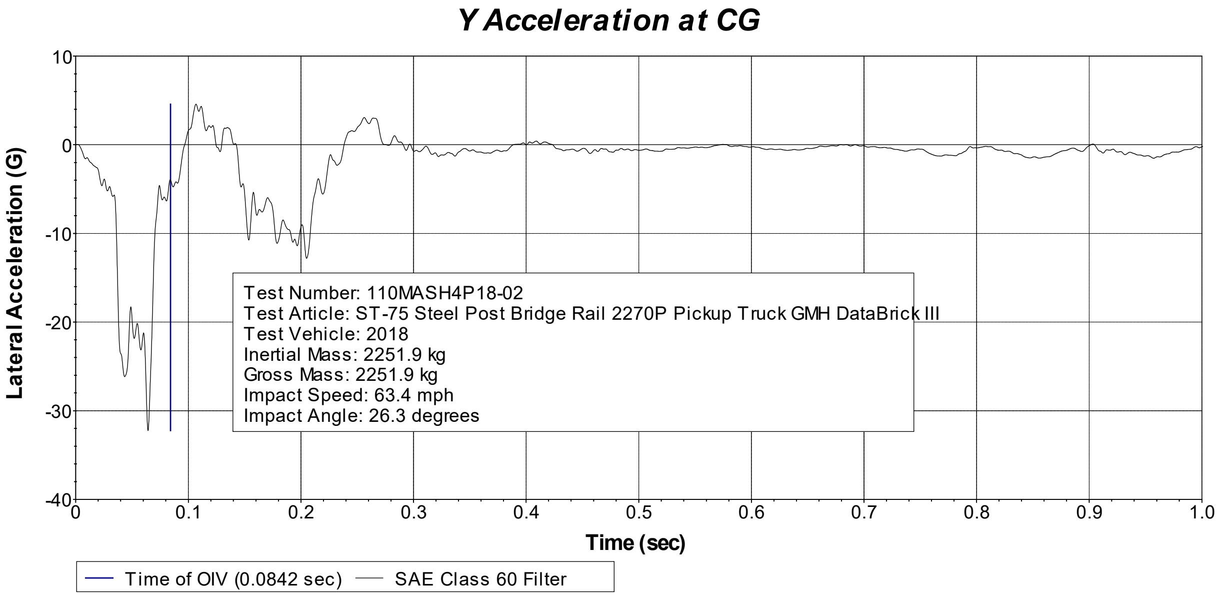


Figure 9-36 Test 4-11 Lateral Acceleration (DataBrick 3)

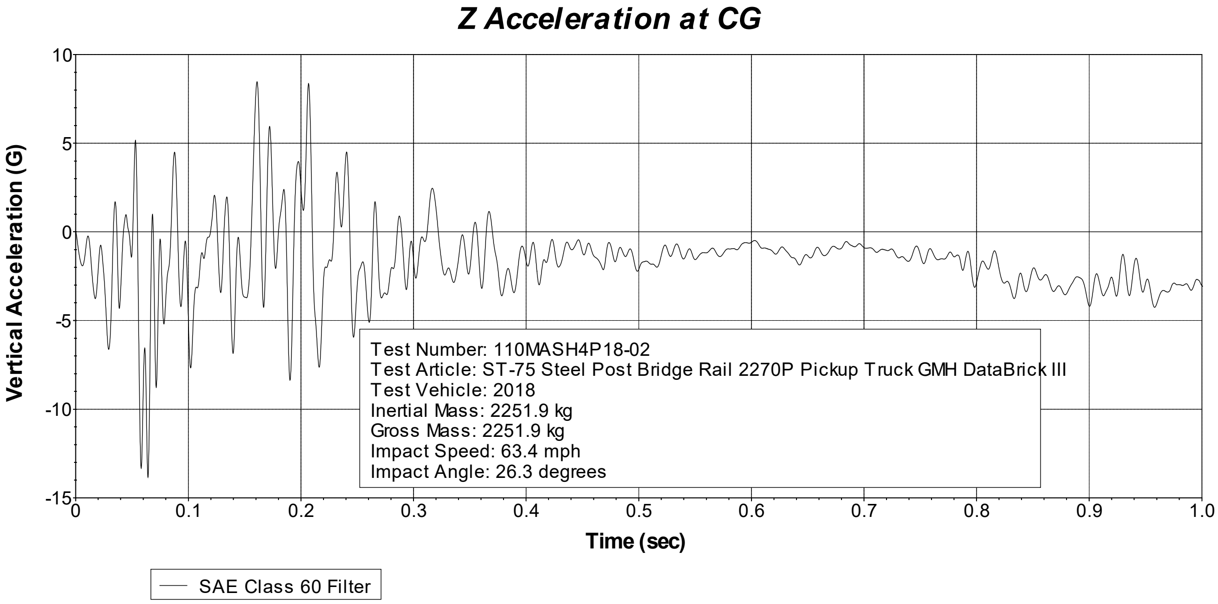


Figure 9-37 Test 4-11 Vertical Acceleration (DataBrick 3)

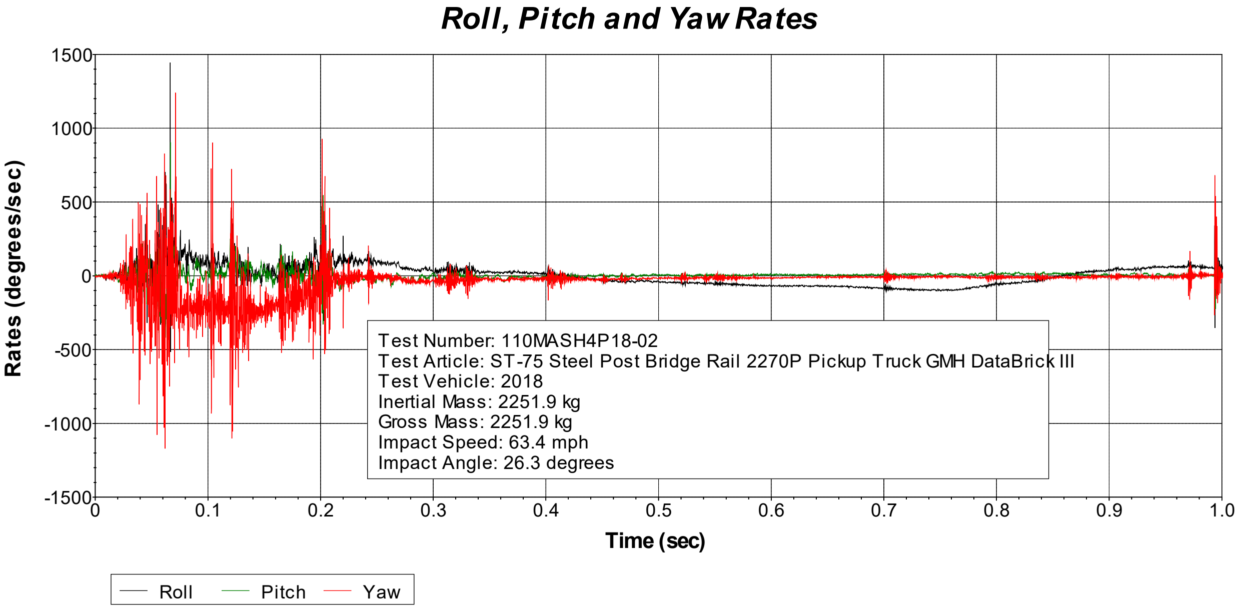


Figure 9-38 Test 4-11 Roll, Pitch, and Yaw Rates (DataBrick 3)

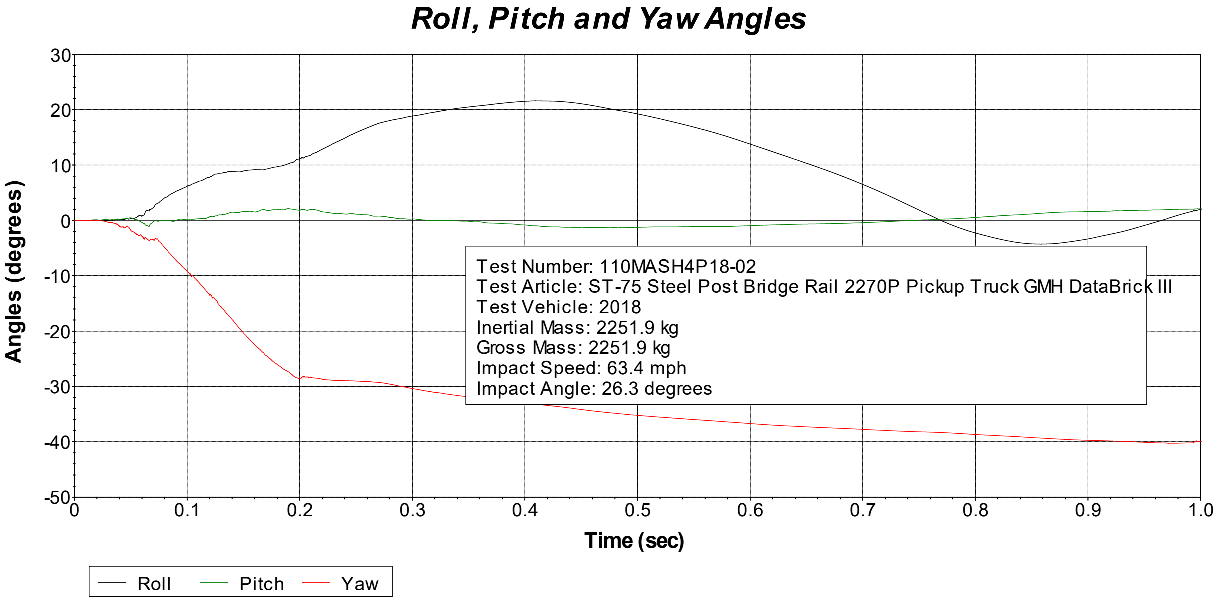


Figure 9-39 Test 4-11 Roll, Pitch, and Yaw Angles (DataBrick 3)

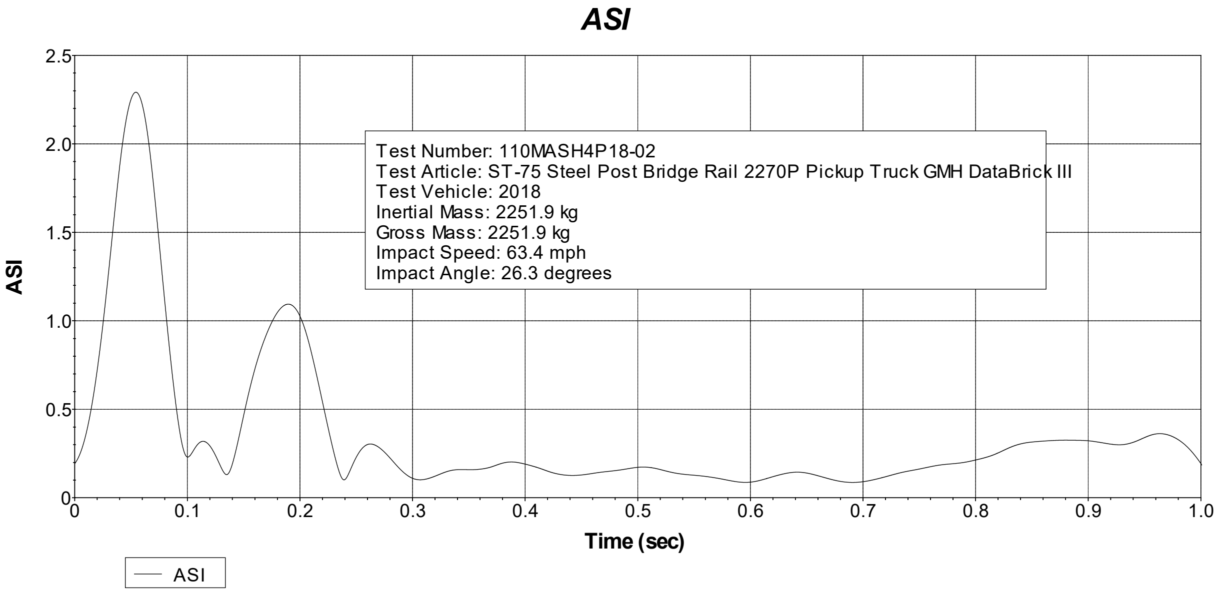
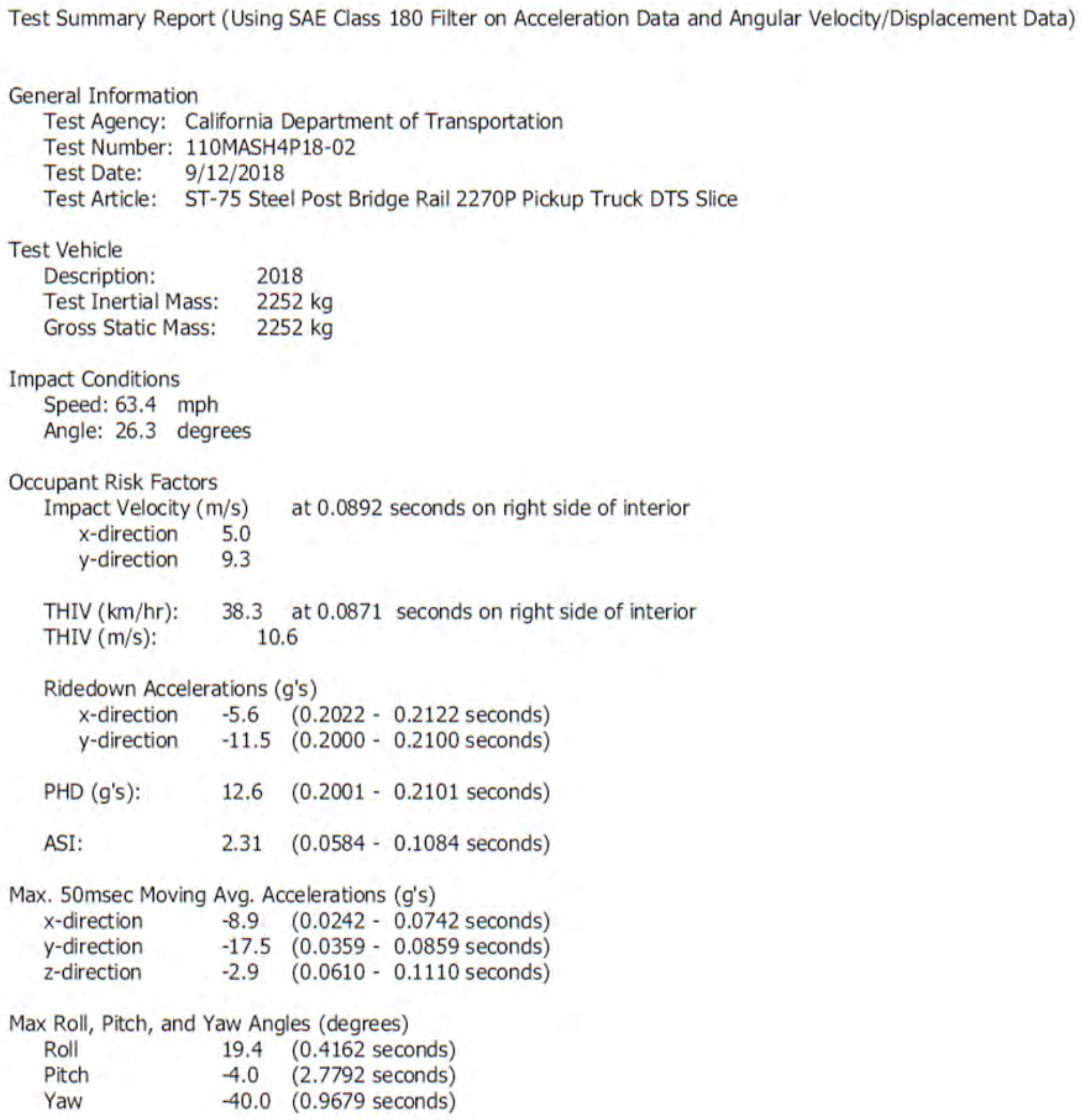


Figure 9-40 Test 4-11 Acceleration Severity Index (DataBrick 3)

SLICE 656 Data Plots



```
Test Summary Report (Using SAE Class 180 Filter on Acceleration Data and Angular Velocity/Displacement Data)

General Information
    Test Agency:   California Department of Transportation
    Test Number:   110MASH4P18-02
    Test Date:     9/12/2018
    Test Article:  ST-75 Steel Post Bridge Rail 2270P Pickup Truck DTS Slice

Test Vehicle
    Description:          2018
    Test Inertial Mass:   2252 kg
    Gross Static Mass:    2252 kg

Impact Conditions
    Speed: 63.4   mph
    Angle:  26.3   degrees

Occupant Risk Factors
    Impact Velocity (m/s)      at 0.0892 seconds on right side of interior
        x-direction       5.0
        y-direction       9.3

    THIV (km/hr):         38.3    at 0.0871  seconds on right side of interior
    THIV (m/s):               10.6

    Ridedown Accelerations (g's)
        x-direction       -5.6    (0.2022 -  0.2122 seconds)
        y-direction       -11.5   (0.2000 -  0.2100 seconds)

    PHD (g's):            12.6    (0.2001 -  0.2101 seconds)

    ASI:                  2.31    (0.0584 -  0.1084 seconds)

Max. 50msec Moving Avg. Accelerations (g's)
    x-direction           -8.9    (0.0242 -  0.0742 seconds)
    y-direction           -17.5   (0.0359 -  0.0859 seconds)
    z-direction           -2.9    (0.0610 -  0.1110 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)
    Roll                  19.4    (0.4162 seconds)
    Pitch                 -4.0    (2.7792 seconds)
    Yaw                   -40.0   (0.9679 seconds)
```

Figure 9-41 Test 4-11 TRAP Summary Sheet (SLICE 656)

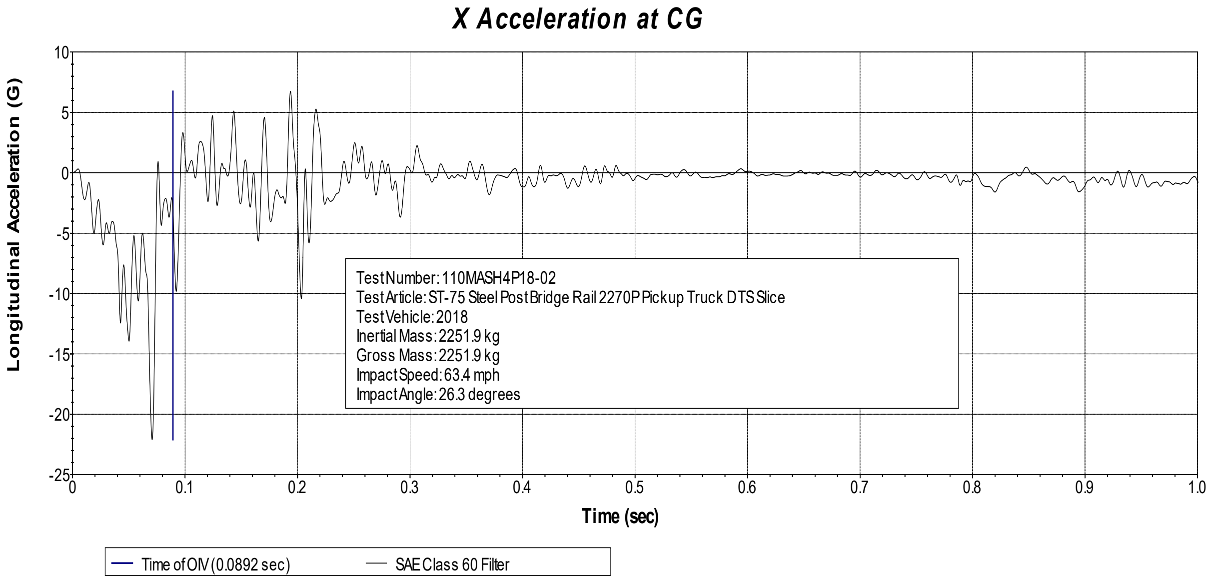


Figure 9-42 Test 4-11 Longitudinal Acceleration (SLICE 656)

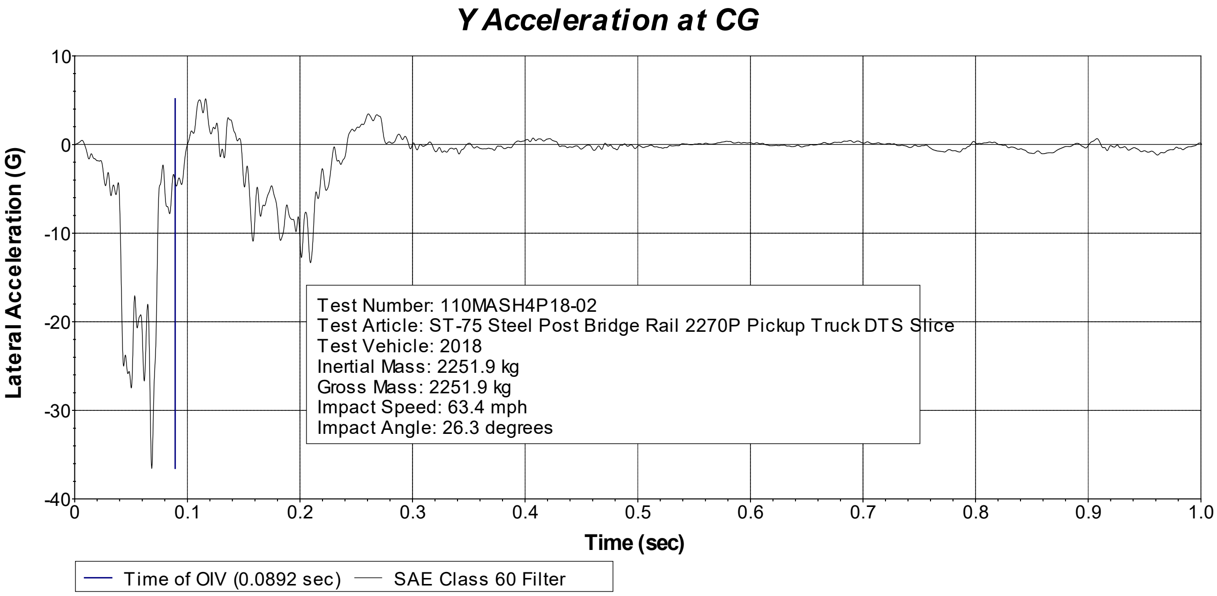


Figure 9-43 Test 4-11 Lateral Acceleration (SLICE 656)

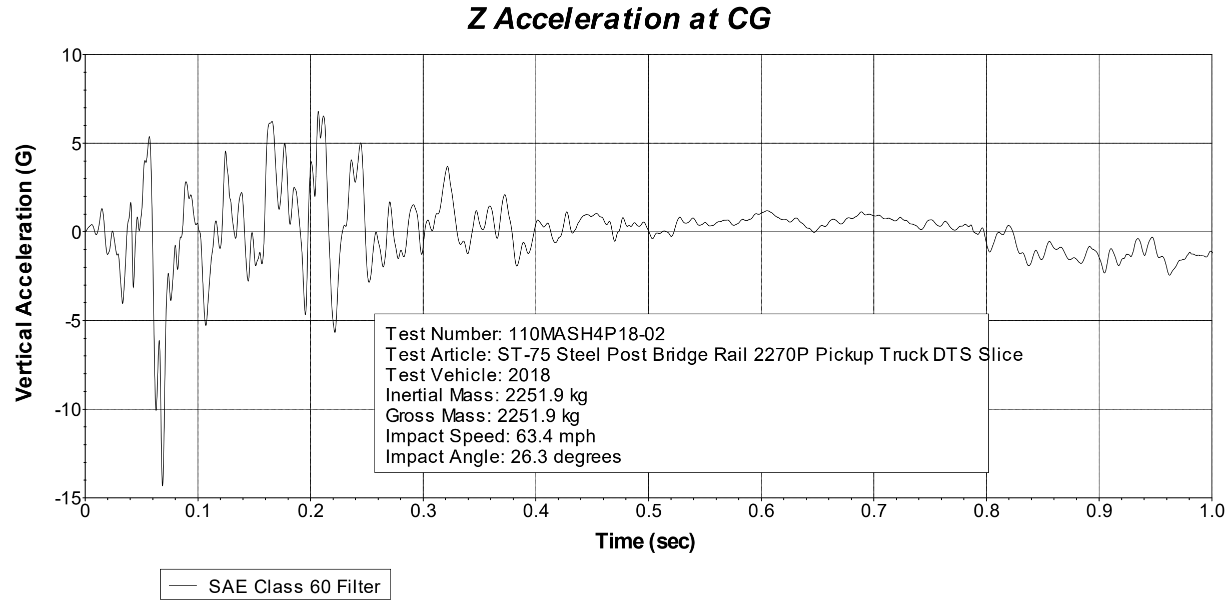


Figure 9-44 Test 4-11 Vertical Acceleration (SLICE 656)

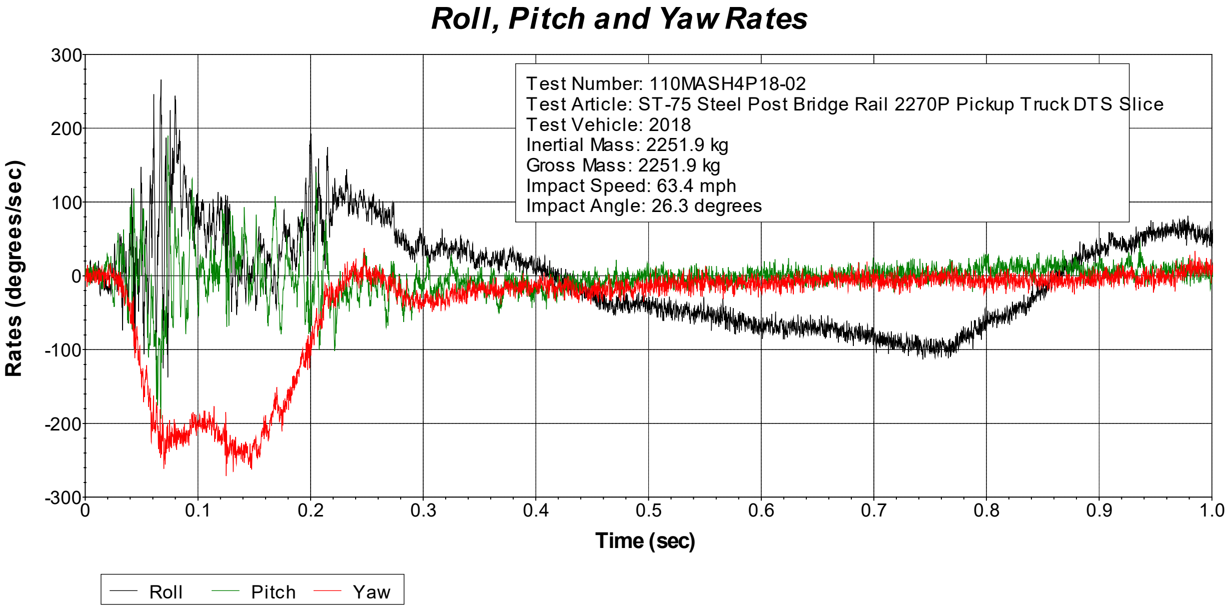


Figure 9-45 Test 4-11 Roll, Pitch, and Yaw Rates (SLICE 656)

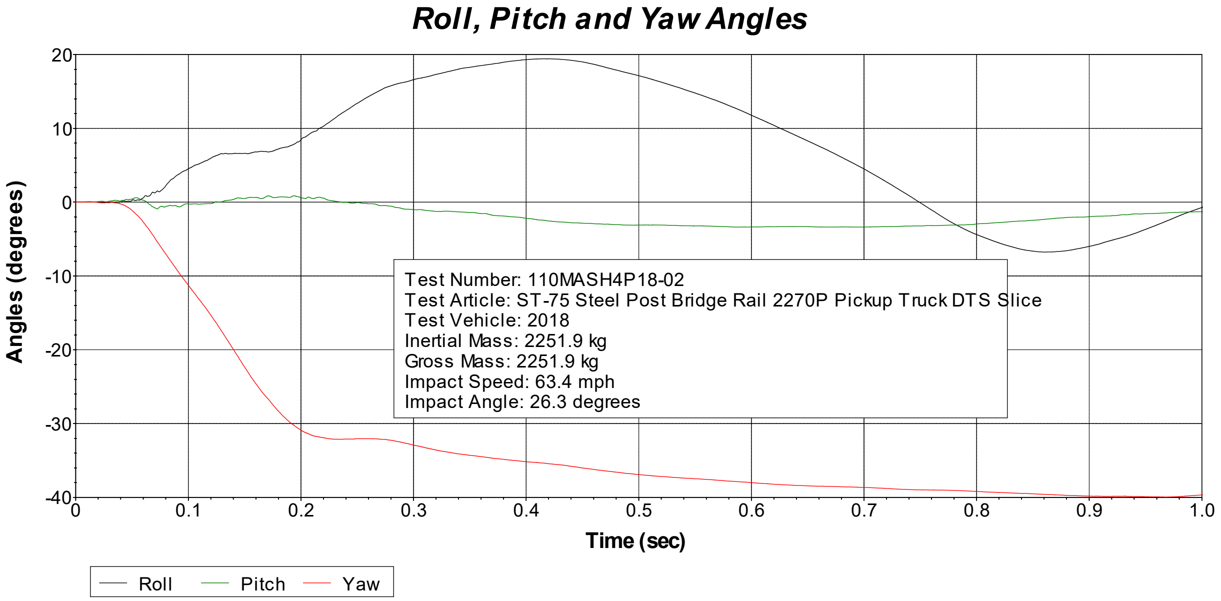


Figure 9-46 Test 4-11 Roll, Pitch, and Yaw Angles (SLICE 656)

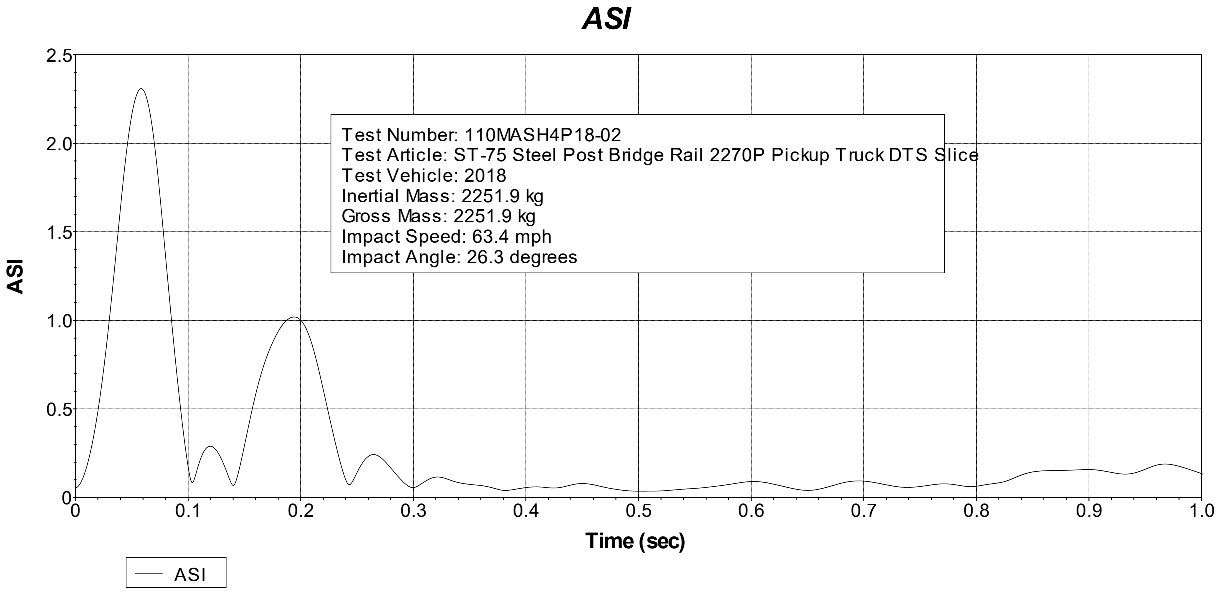


Figure 9-47 Test 4-11 Acceleration Severity Index (SLICE 656)

9.6.3.Data Plots - Test 110MASH4S19-02 (Test 4-12)

Two sets of accelerometers and angular rate sensors were installed in both the cab and cargo box area. One set of instrumentation in the cab was lost before it could be downloaded. The data plots for the three functional sets of instrumentation are shown below.

Databrick 328 Data Plots (Inside Cab)

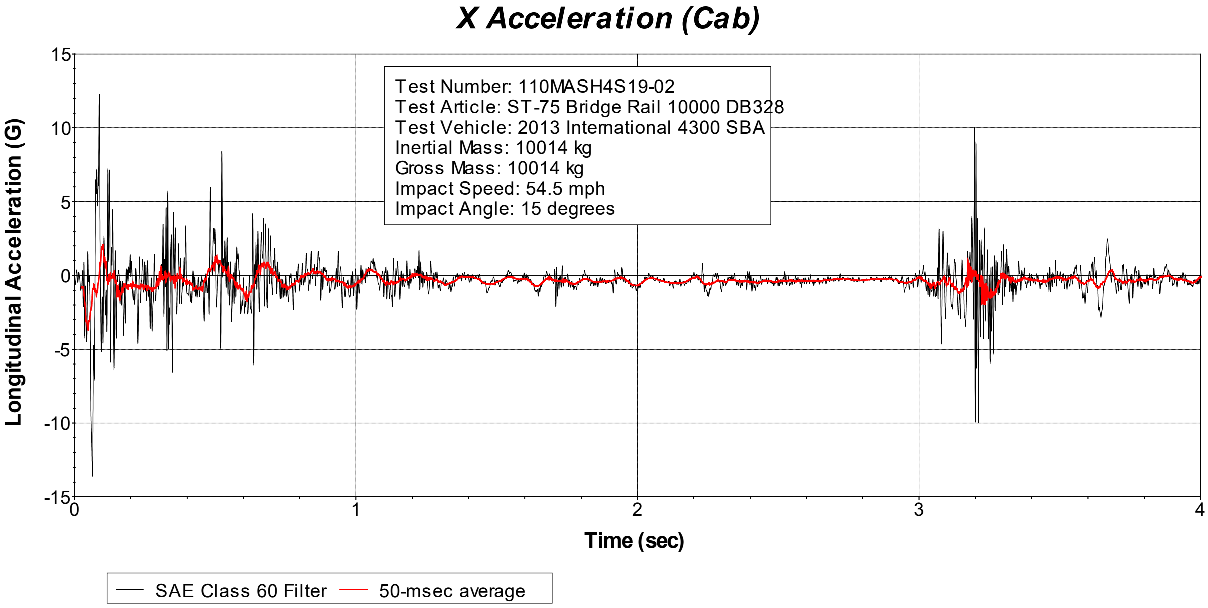


Figure 9-48 Test 4-12 Longitudinal Acceleration Inside Cab (Databrick 3)

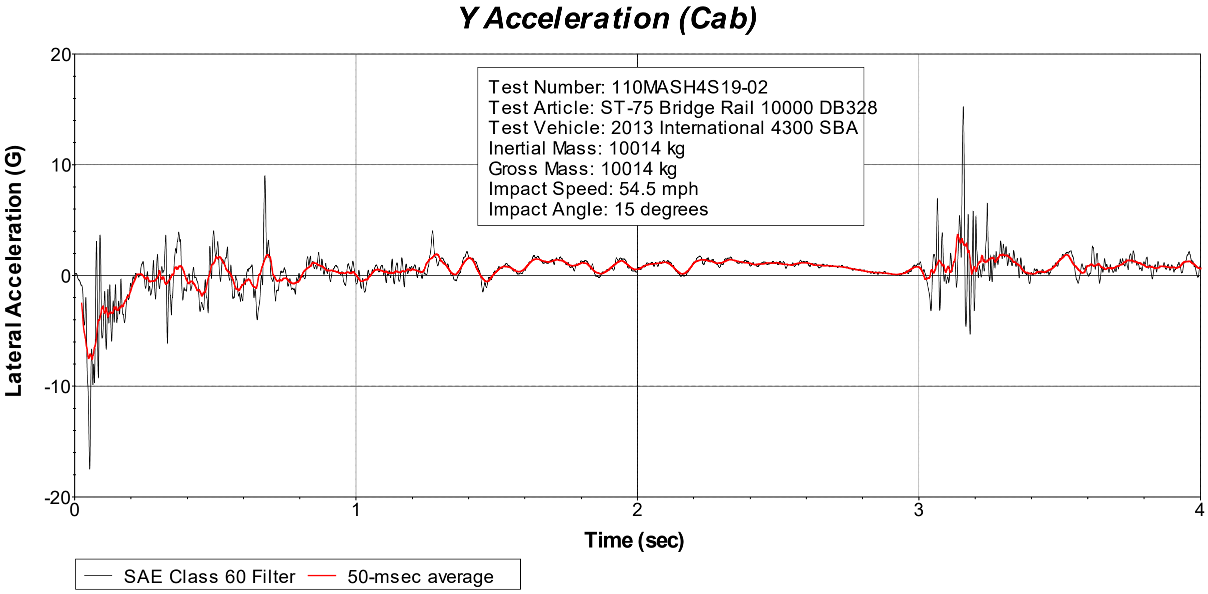


Figure 9-49 Test 4-12 Lateral Acceleration Inside Cab (Databrick 3)

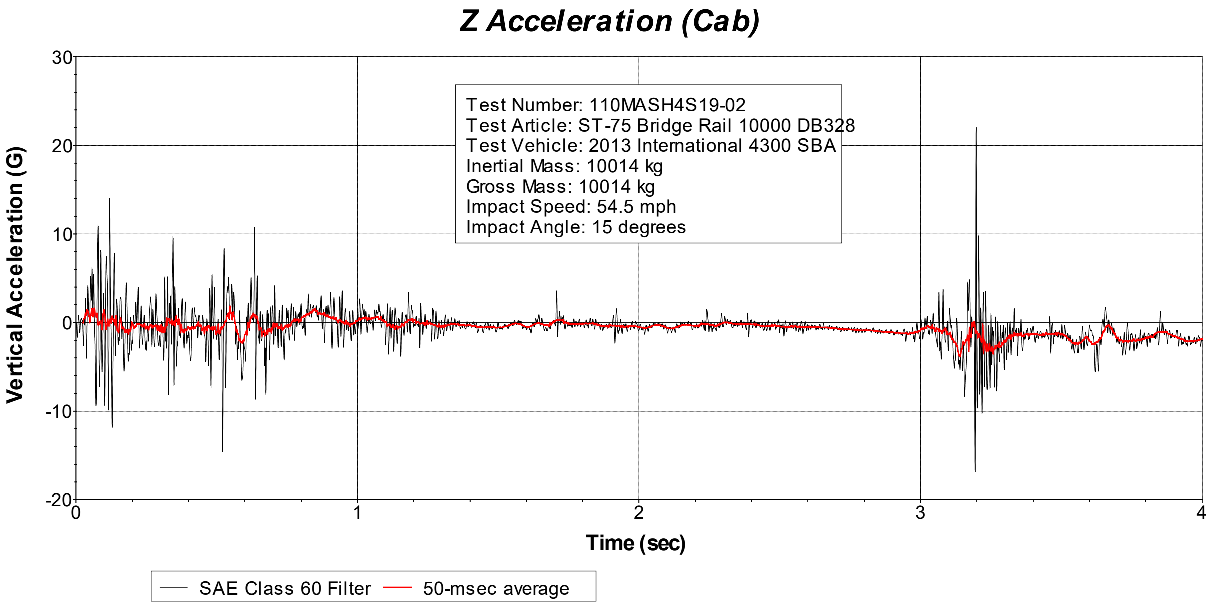


Figure 9-50 Test 4-12 Vertical Acceleration Inside Cab (Databrick 3)

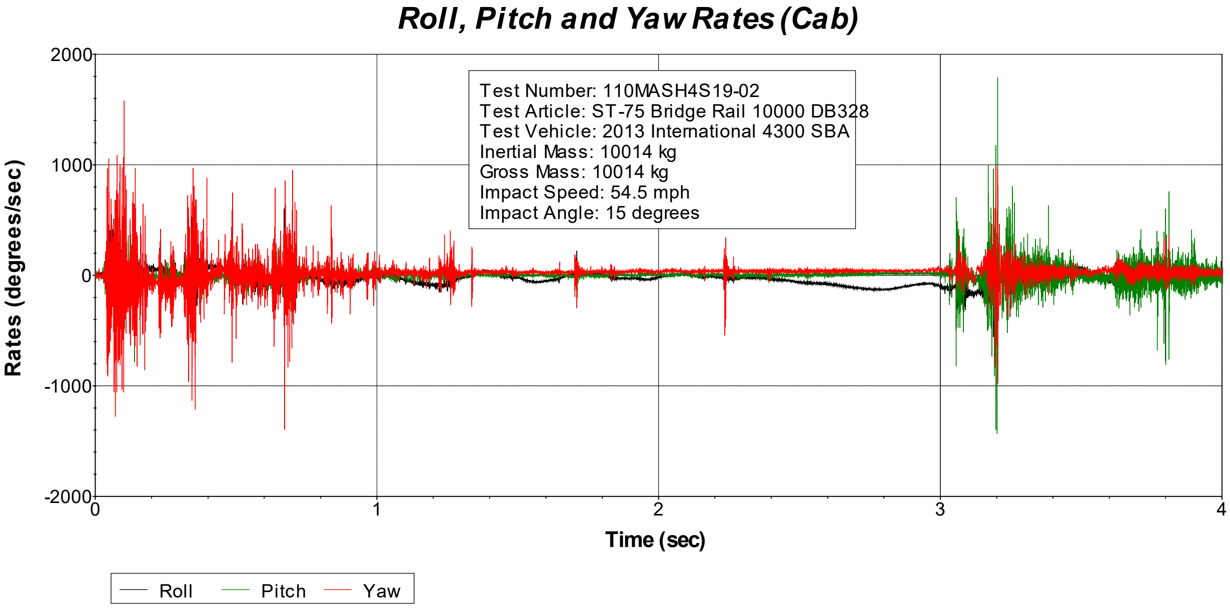


Figure 9-51 Test 4-12 Roll, Pitch, and Yaw Rates Inside Cab (Databrick 3)

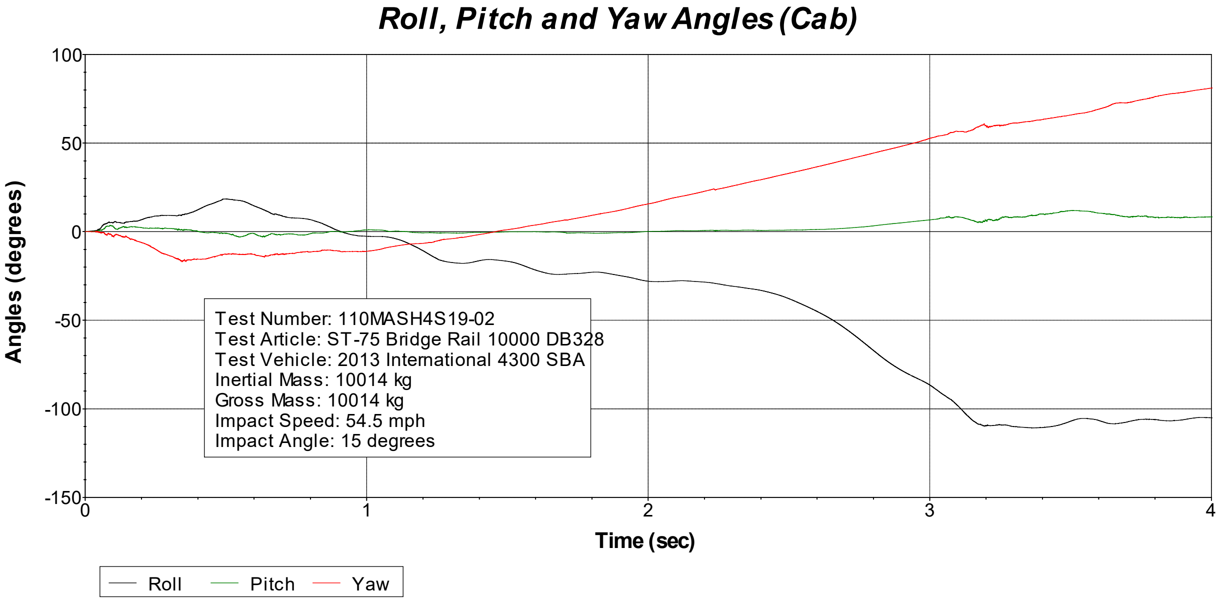


Figure 9-52 Test 4-12 Roll, Pitch, and Yaw Angles Inside Cab (Databrick 3)

SLICE BASE 656 Data Plots (Inside Cargo Box)

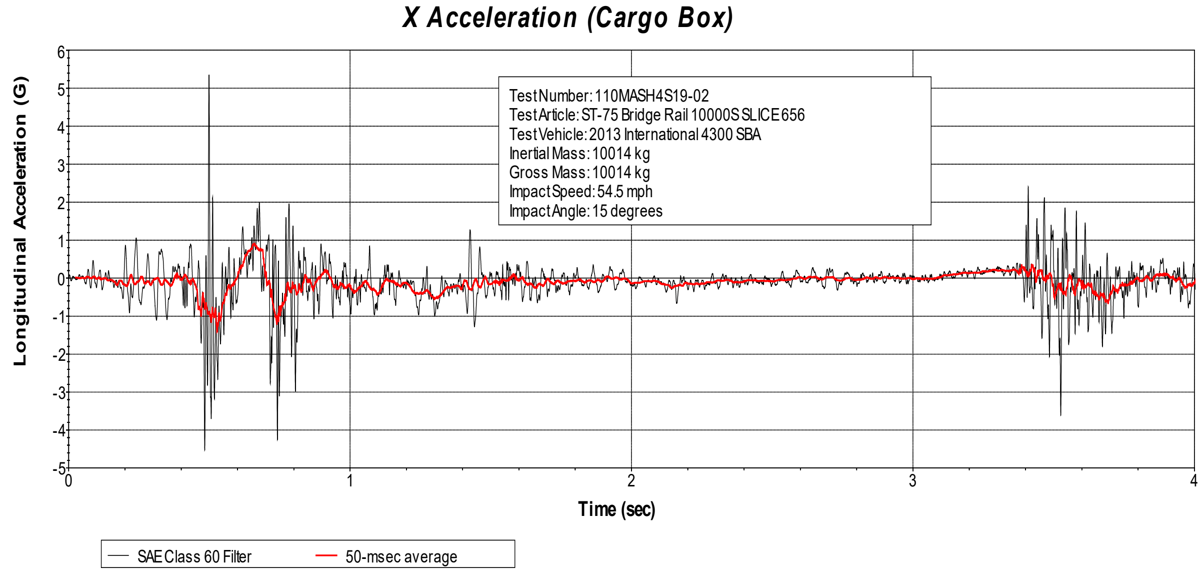


Figure 9-53 Test 4-12 Longitudinal Acceleration Inside Cargo Box (SLICE 656)

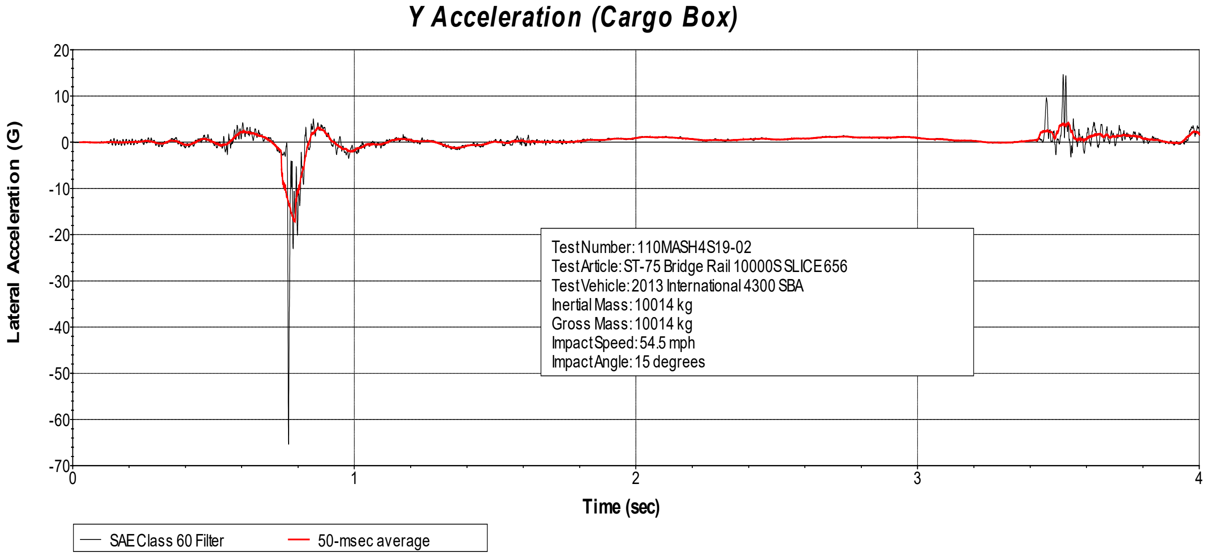


Figure 9-54 Test 4-12 Longitudinal Acceleration Inside Cargo Box (SLICE 656)

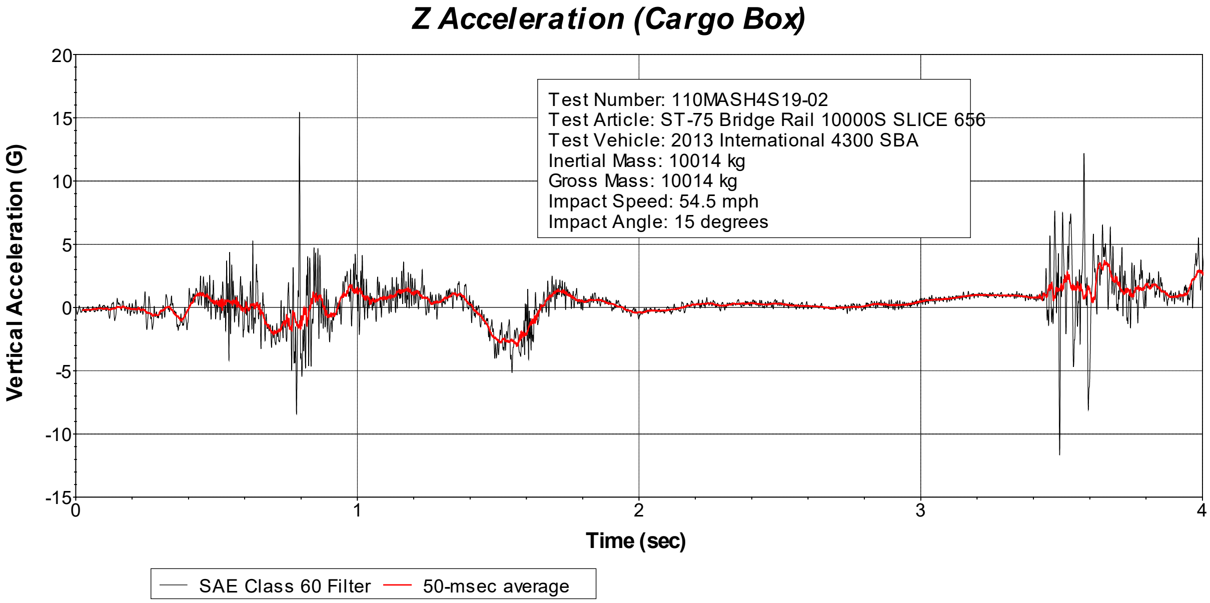


Figure 9-55 Test 4-12 Vertical Acceleration Inside Cargo Box (SLICE 656)

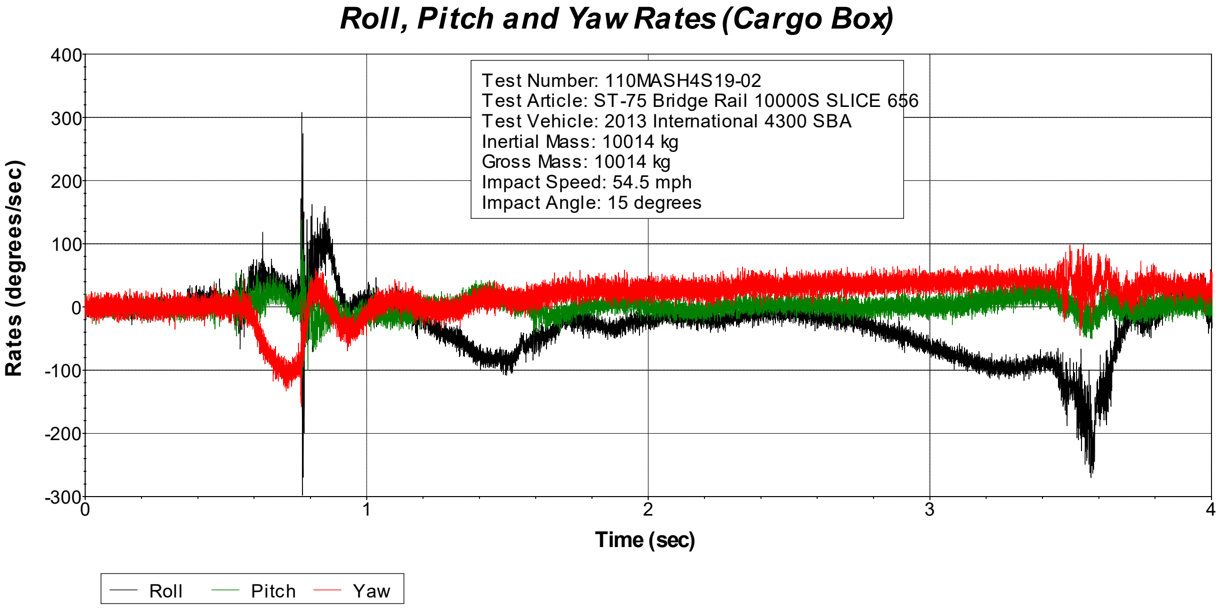
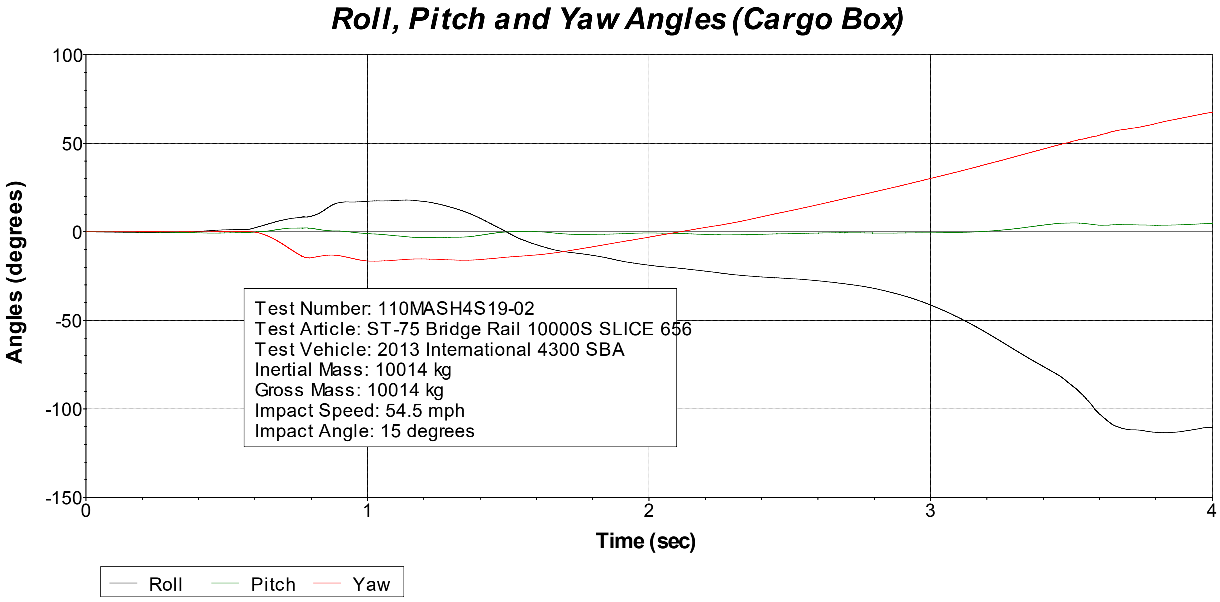


Figure 9-56 Test 4-12 Roll, Pitch, and Yaw Rates Inside Cargo Box (SLICE 656)



Test Number: 110MASH4S19-02
Test Article: ST-75 Bridge Rail 10000S SLICE 656
Test Vehicle: 2013 International 4300 SBA
Inertial Mass: 10014 kg
Gross Mass: 10014 kg
Impact Speed: 54.5 mph
Impact Angle: 15 degrees

Figure 9-57 Test 4-12 Roll, Pitch, and Yaw Angles Inside Cargo Box (SLICE 656)

SLICE BASE 659 Data Plots (Inside Cargo Box)

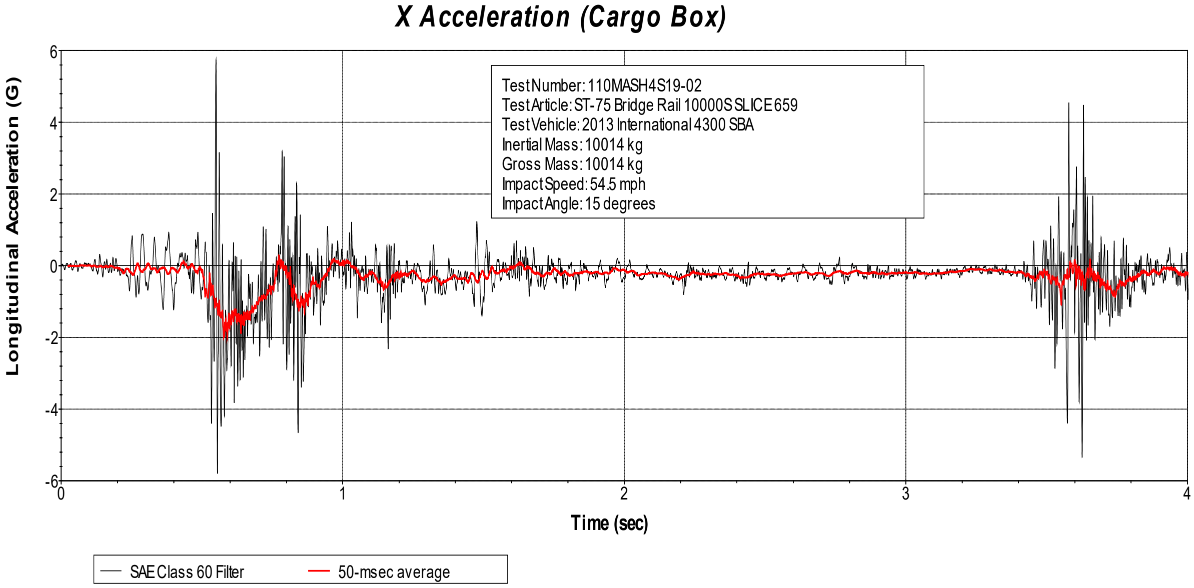


Figure 9-58 Test 4-12 Longitudinal Acceleration Inside Cargo Box (SLICE 659)

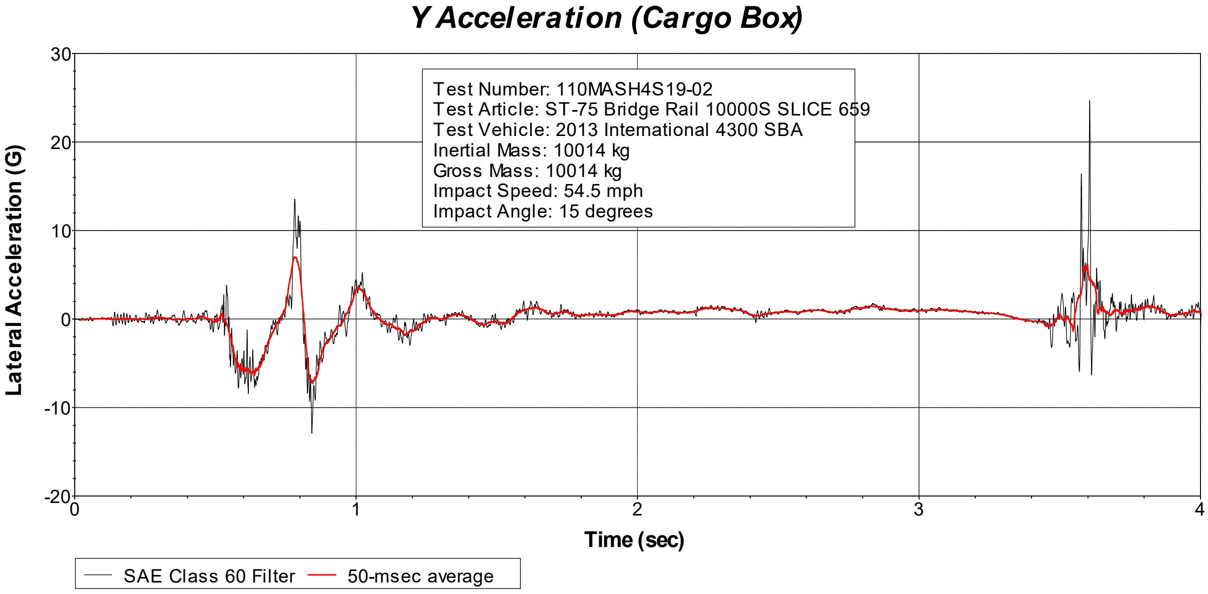


Figure 9-59 Test 4-12 Longitudinal Acceleration Inside Cargo Box (SLICE 659)

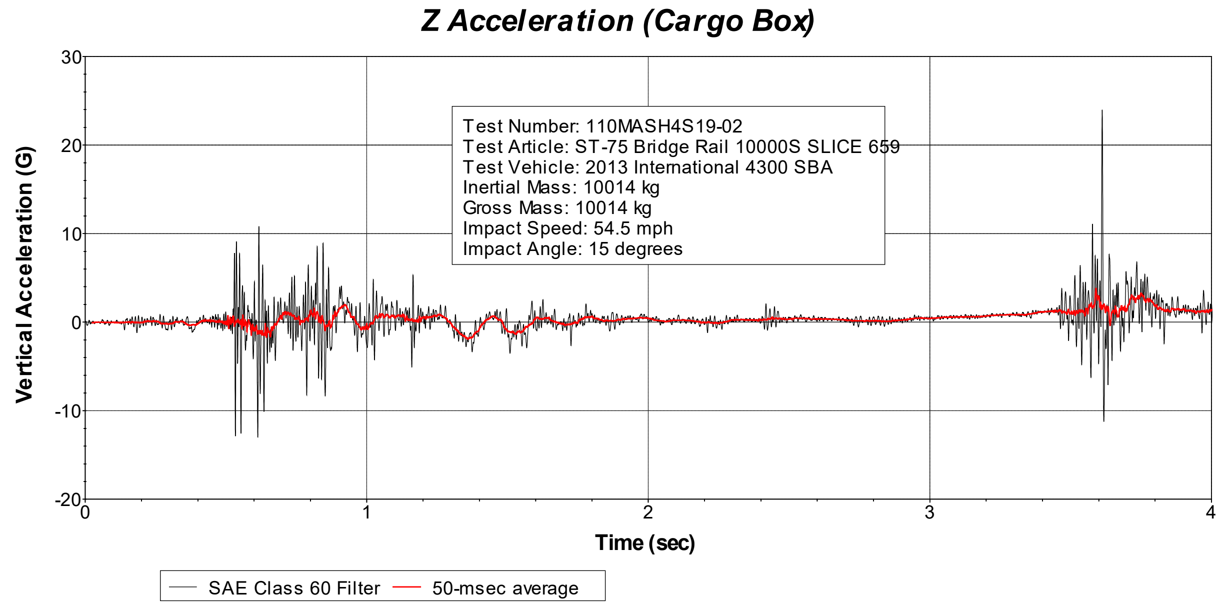


Figure 9-60 Test 4-12 Vertical Acceleration Inside Cargo Box (SLICE 659)

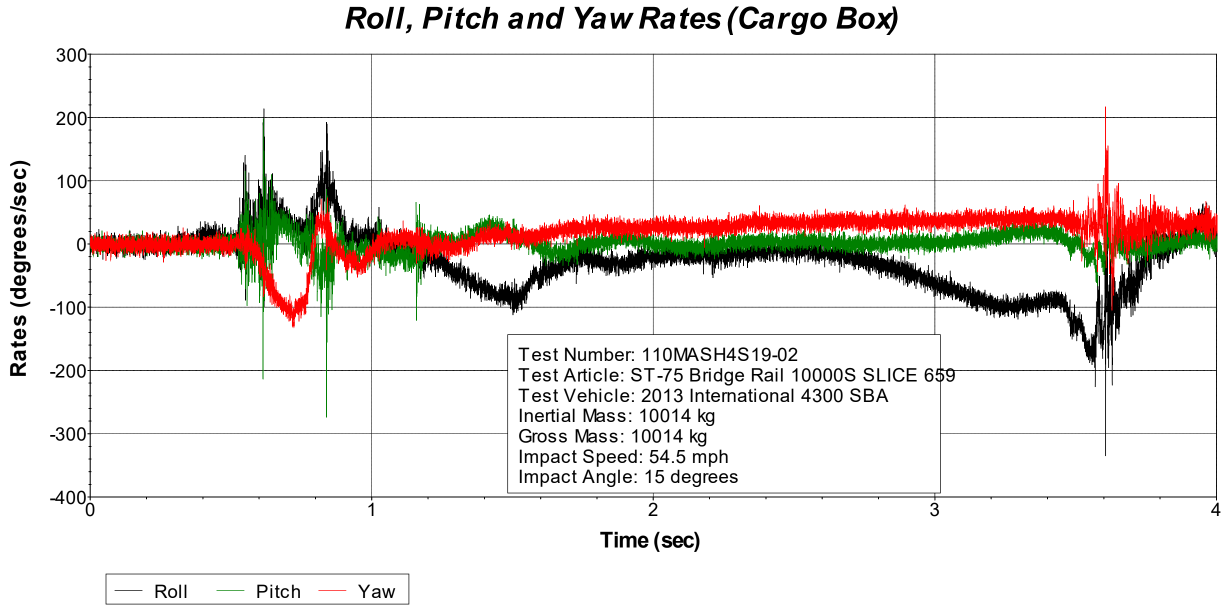


Figure 9-61 Test 4-12 Roll, Pitch, and Yaw Rates Inside Cargo Box (SLICE 659)

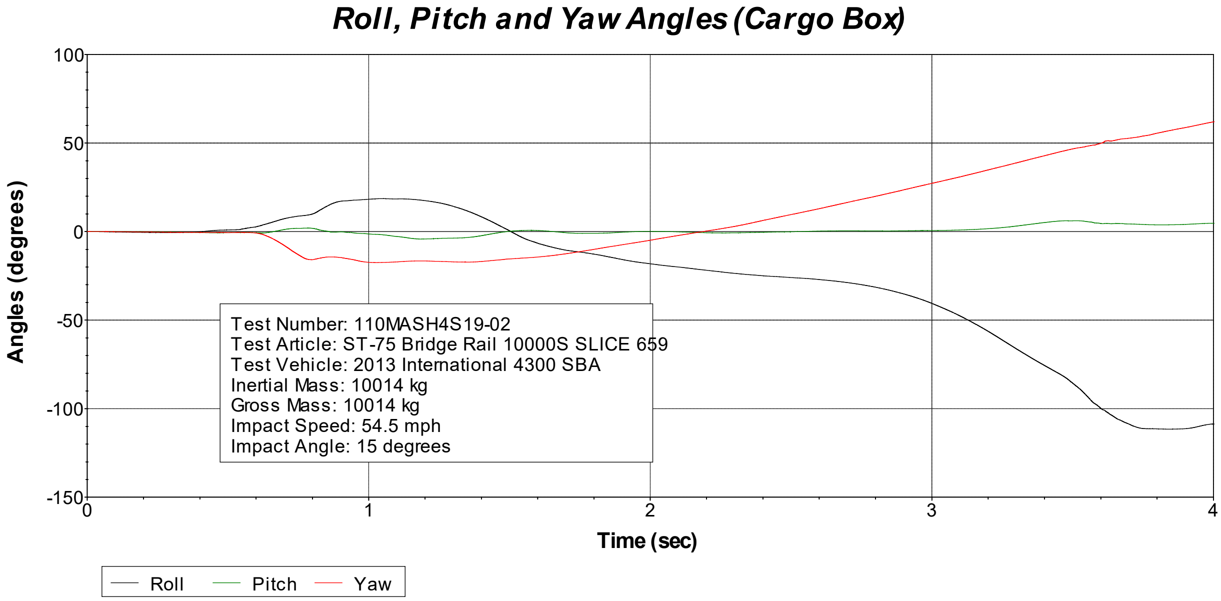


Figure 9-62 Test 4-12 Roll, Pitch, and Yaw Angles Inside Cargo Box (SLICE 659)

10. Appendix B: Detail Drawings

The following details in Figure 10-1 through Figure 10-5 were used for the construction of the ST-75 Bridge Rail test article.

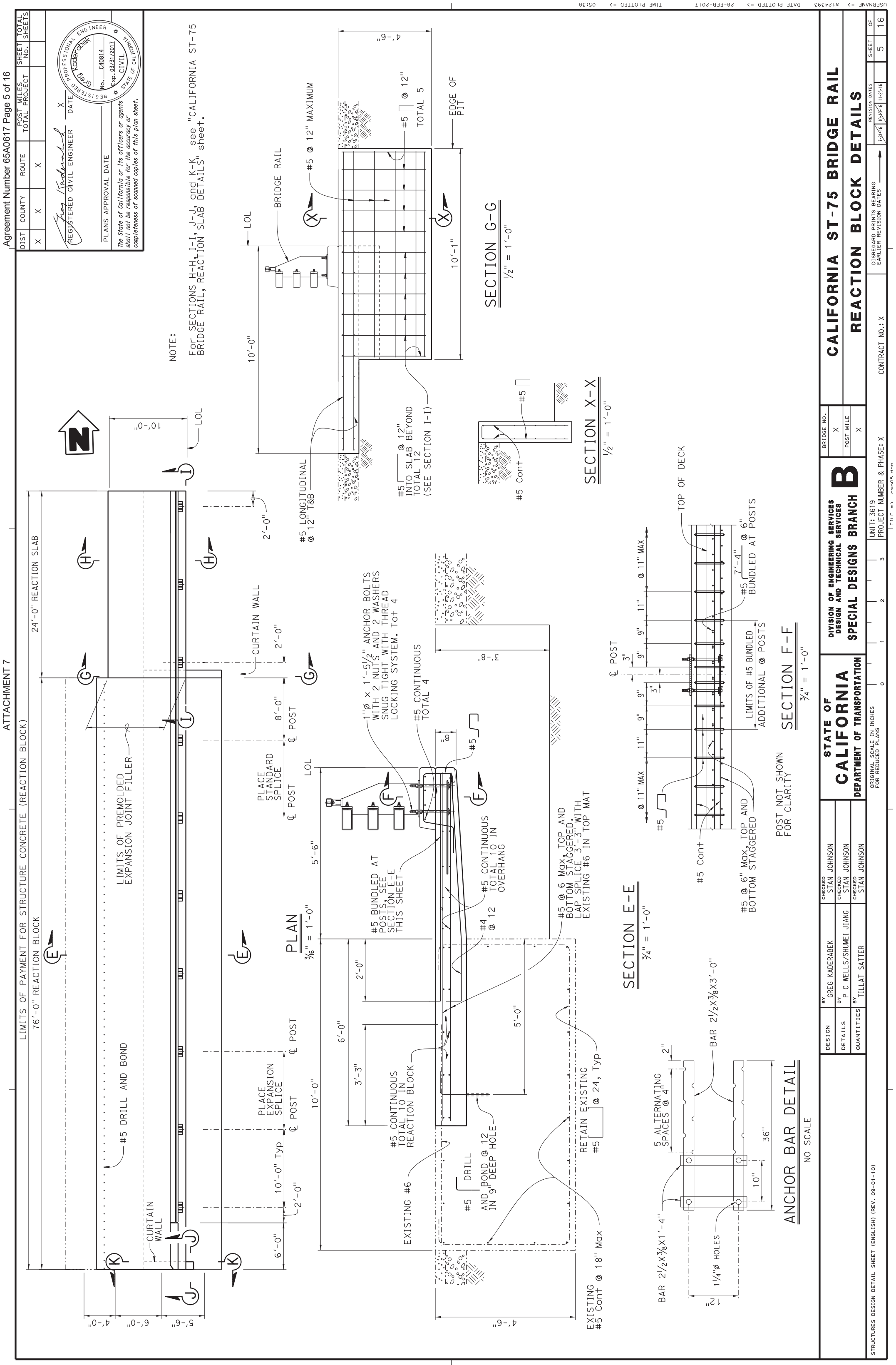


Figure 10-1 ST-75 Test Article Reaction Block Details

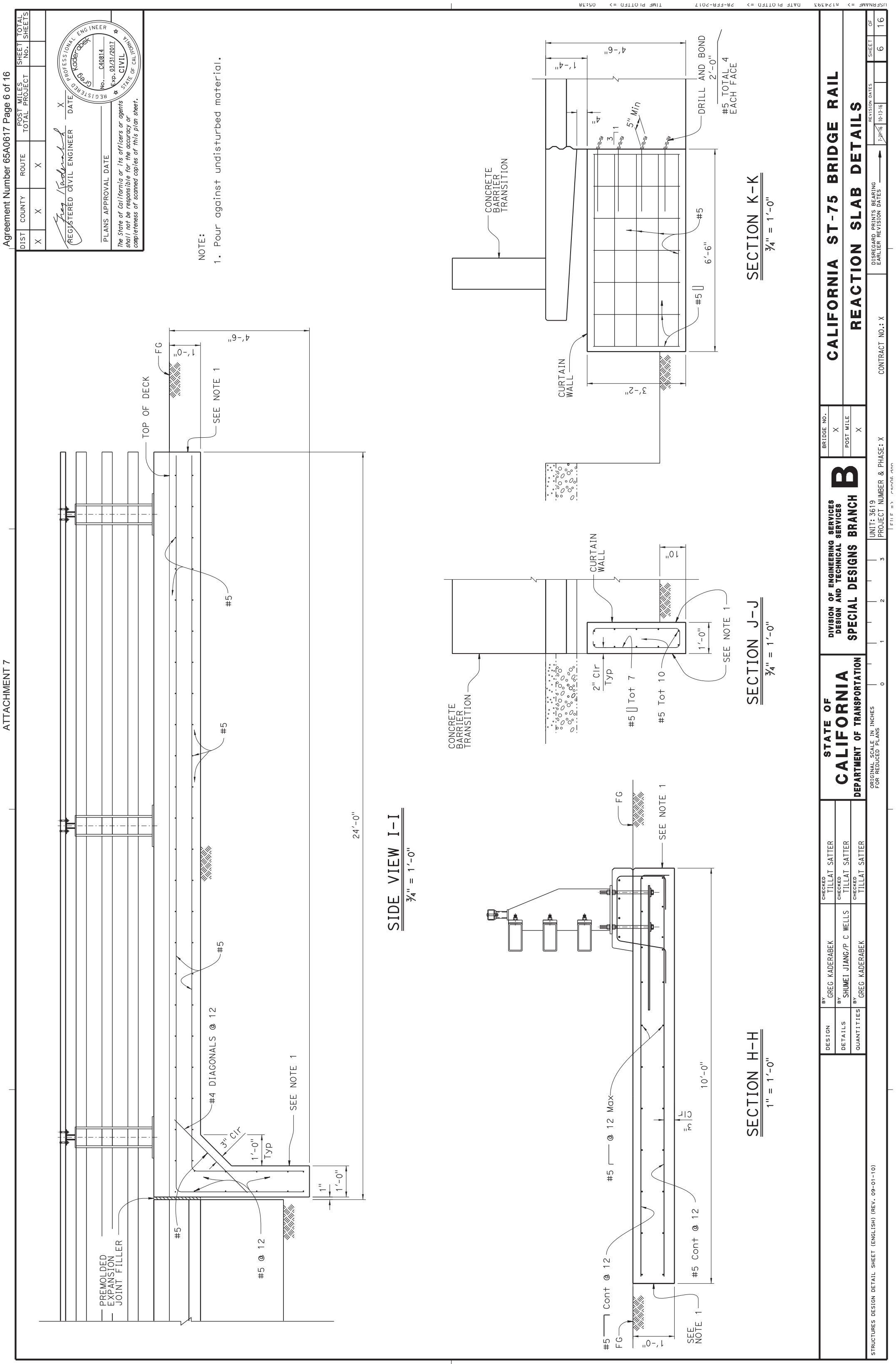


Figure 10-2 ST-75 Test Article Reaction Slab Details

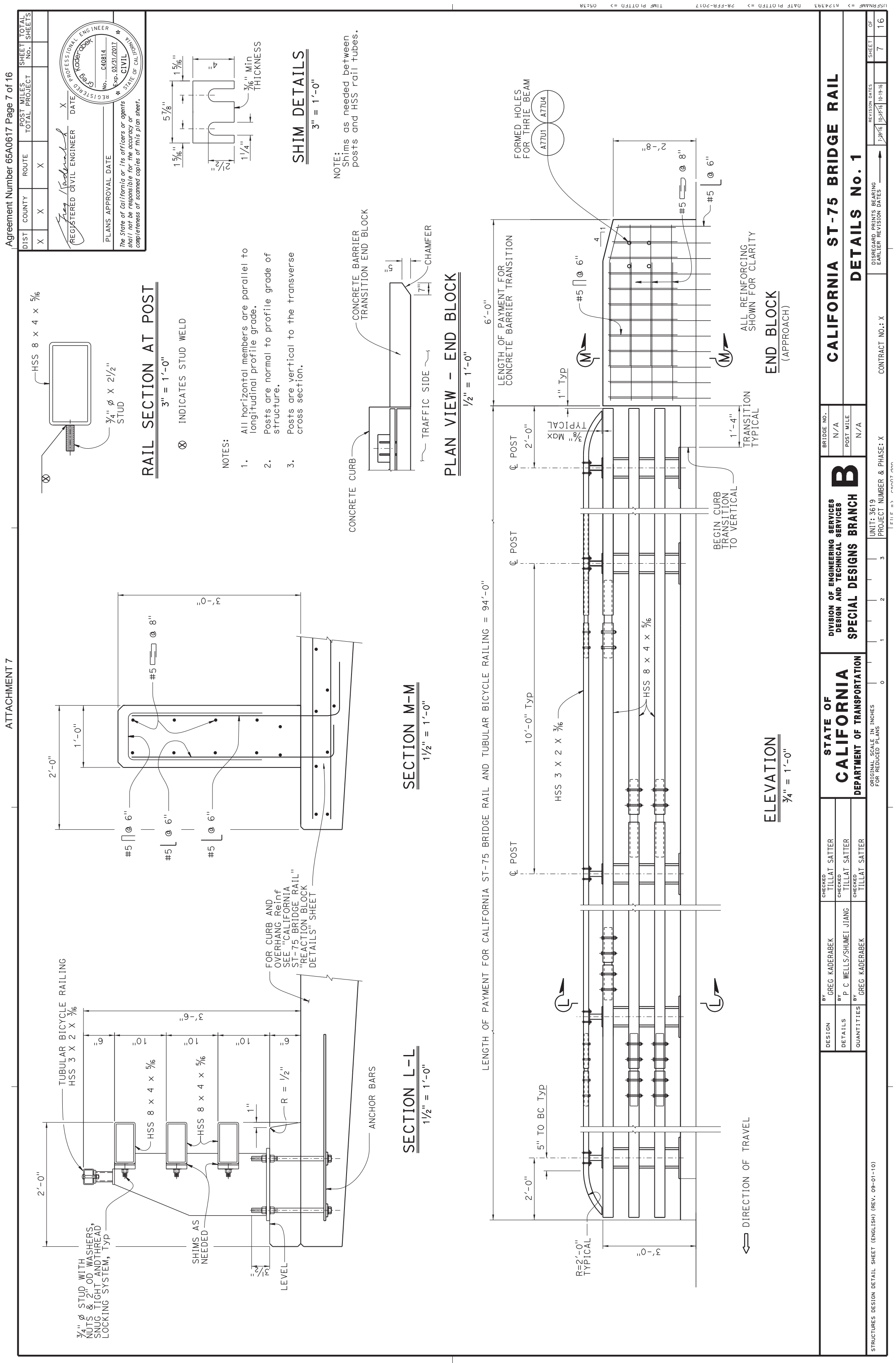


Figure 10-3 ST-75 Test Article Details 1

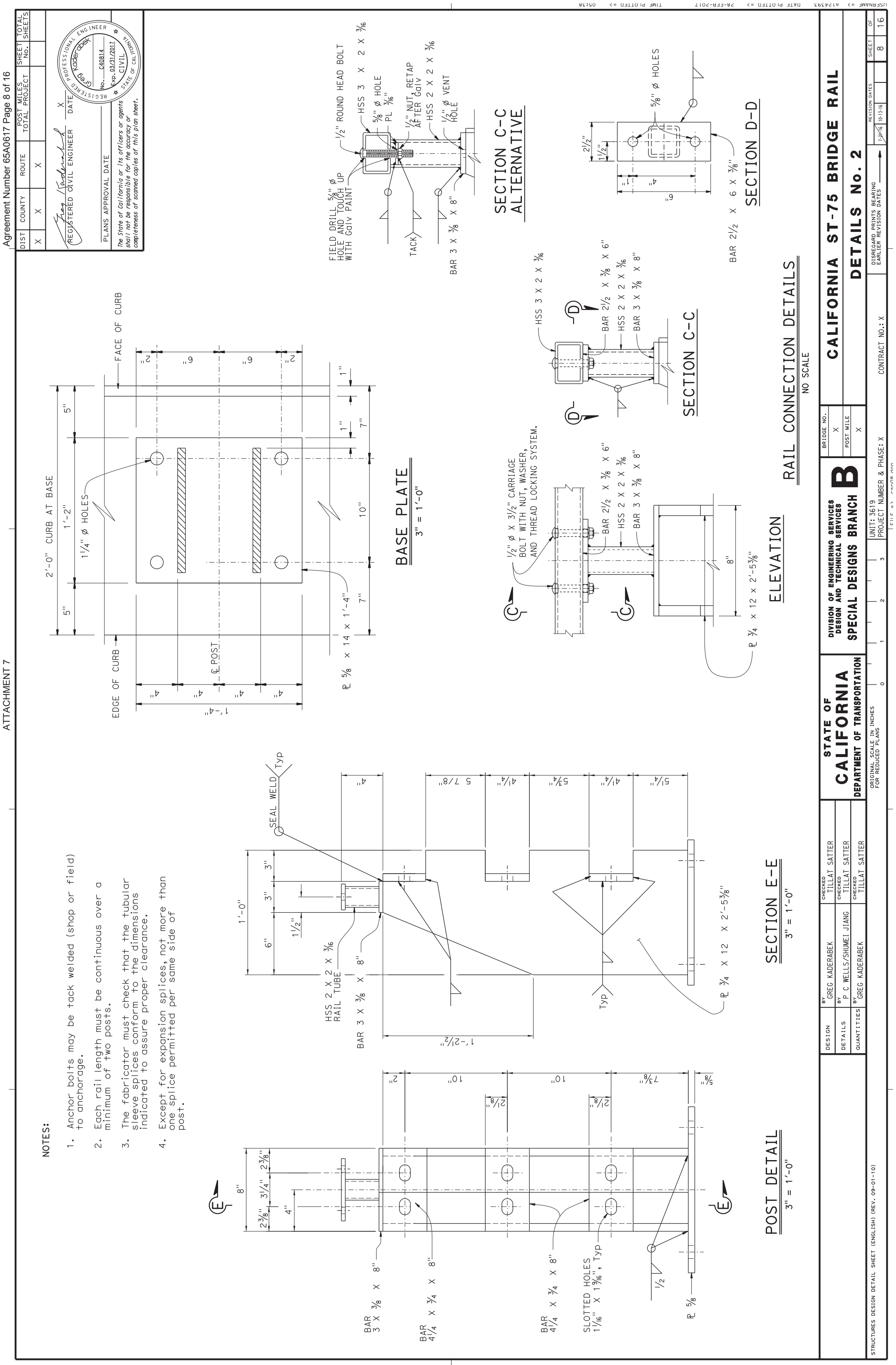


Figure 10-4 ST-75 Test Article Details 2

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ATTACHMENT 7

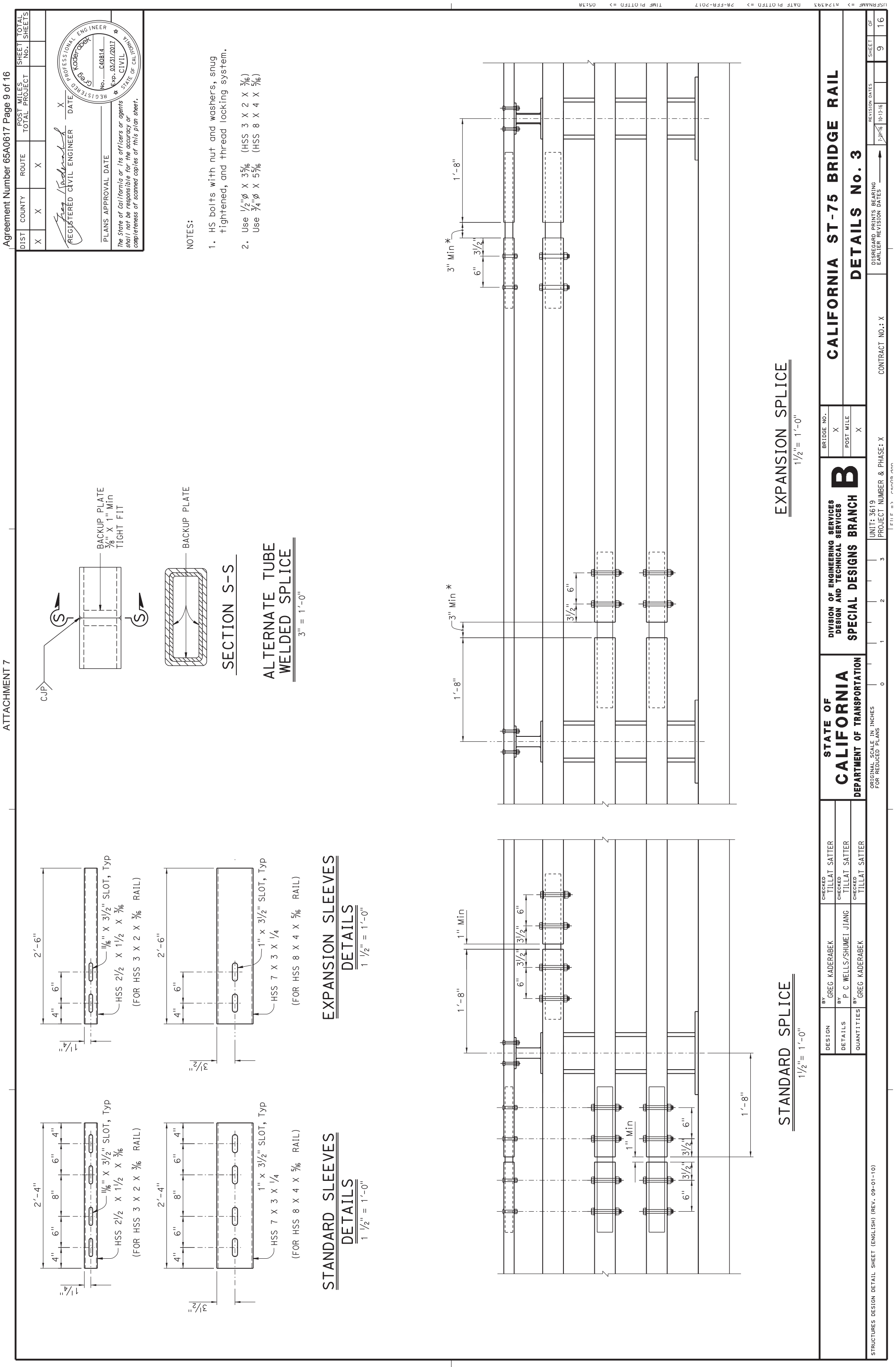


Figure 10-5 ST-75 Test Article Details 3

11. Appendix C: Quasi-static Push Test and Anchor Bolt Tensile Testing

The results of the push test and tensile testing are outside the scope of the Lab's accreditation.

11.1. Quasi-static Push Test

To better understand barrier lateral strength and to measure the force-deflection curve a quasi-static push test was performed on a section of the barrier that was undamaged from the three full-scale crash tests. A load frame was modified to provide the desired load height and attached to the simulated bridge deck using threaded anchor rods. The anchor rods were installed in holes cored through the simulated bridge deck and restrained with nuts and washers above the load frame and also under the deck. A hydraulic ram was attached to the load frame and a horizontal load was applied 813 mm (32 in) above the deck surface at the centerline of Post 6. The barrier was loaded at a fairly constant displacement rate of about 60 mm/min (2.4 in/min). The load gradually increased until the upstream traffic-side anchor bolt failed at a post deflection of 97 mm (3.8 in) and load of 390 kN (110,000 lbf). Deflections were measured with string potentiometers. See Figure 11-1 for the test results and test setup.

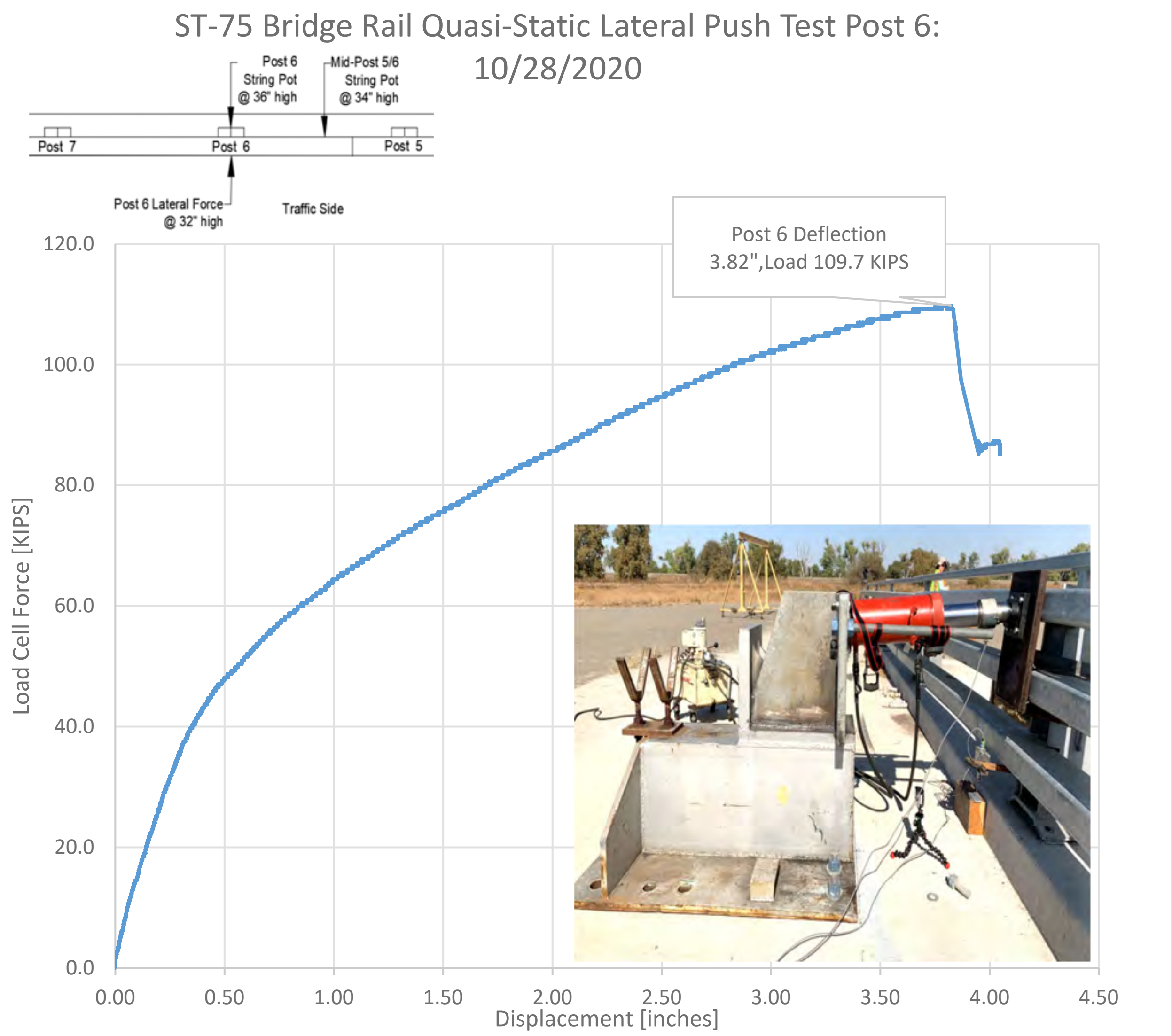


Figure 11-1 Load vs Displacement Test Setup and Curve for Quasi-static Push Test at Post 6

11.2. Anchor Bolt Tensile Testing

During barrier demolition, the traffic-side anchor bolts at posts 3 and 4 as well as the deformed but still intact downstream traffic-face anchor bolt at post 6 were saved for tensile testing according to ASTM A449. The anchor bolts were straightened to during removal of the bridge rail posts and to prepare them for tensile testing. Photos of the anchor bolts at posts 3 and 4 during barrier demolition are shown in Figure 11-2 and Figure 11-3. The anchor bolts at Post 6 after the pushover test and after straightening are shown in Figure 11-4 Post 6 Anchor Bolts with Post Removed. The purpose of the tensile testing was to determine how much residual capacity (strength) was in each anchor bolt and evaluate the level of strain in each bolt. It was thought that straightening the bolts as part of a repair after an impact would cause additional plastic deformation in the bolts so this additional testing would potentially provide some very useful information about repairs after an impact. As seen in Figure 7-12 and Figure 7-13, the bolts at Post 4 had undergone more deformation than those at Post 3 so it would be expected that they would have less residual strain capacity. Because the post was tested until failure, it would be expected that the anchor bolt would have even less residual strain capacity than those at Post 4. Looking at the results shown in Figure 11-6, the approximate yield stress (Stress at Offset) was less than the Tensile Strength for both Posts 3 and 4, but the difference was greater at Post 3. The Post 6 anchor bolt Stress at Offset and Tensile Strength were essentially the same. This shows that the bolts at Posts 3 and 4 were slightly in the plastic range (Post 3 less than Post 4) and the Post 6 bolt had residual strength despite being far in the plastic range. As a side note about Figure 11-5, the results were printed in Metric Units but the technician also recorded all results in English units and handwrote them on the printed results.

Figure 11-2 Post 3 Anchor Bolts with Post Removed

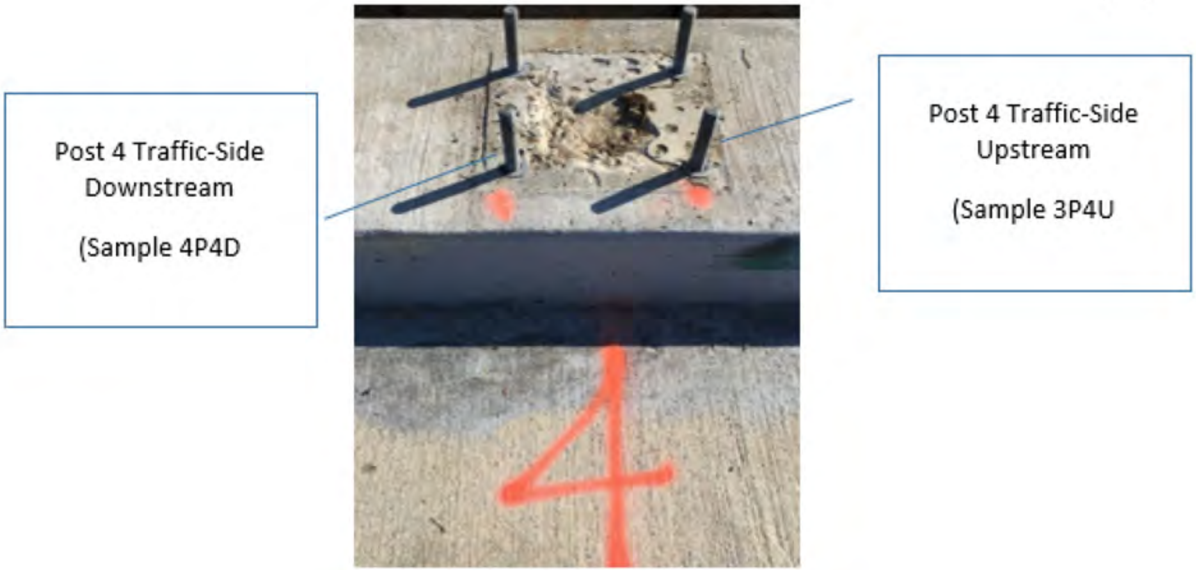
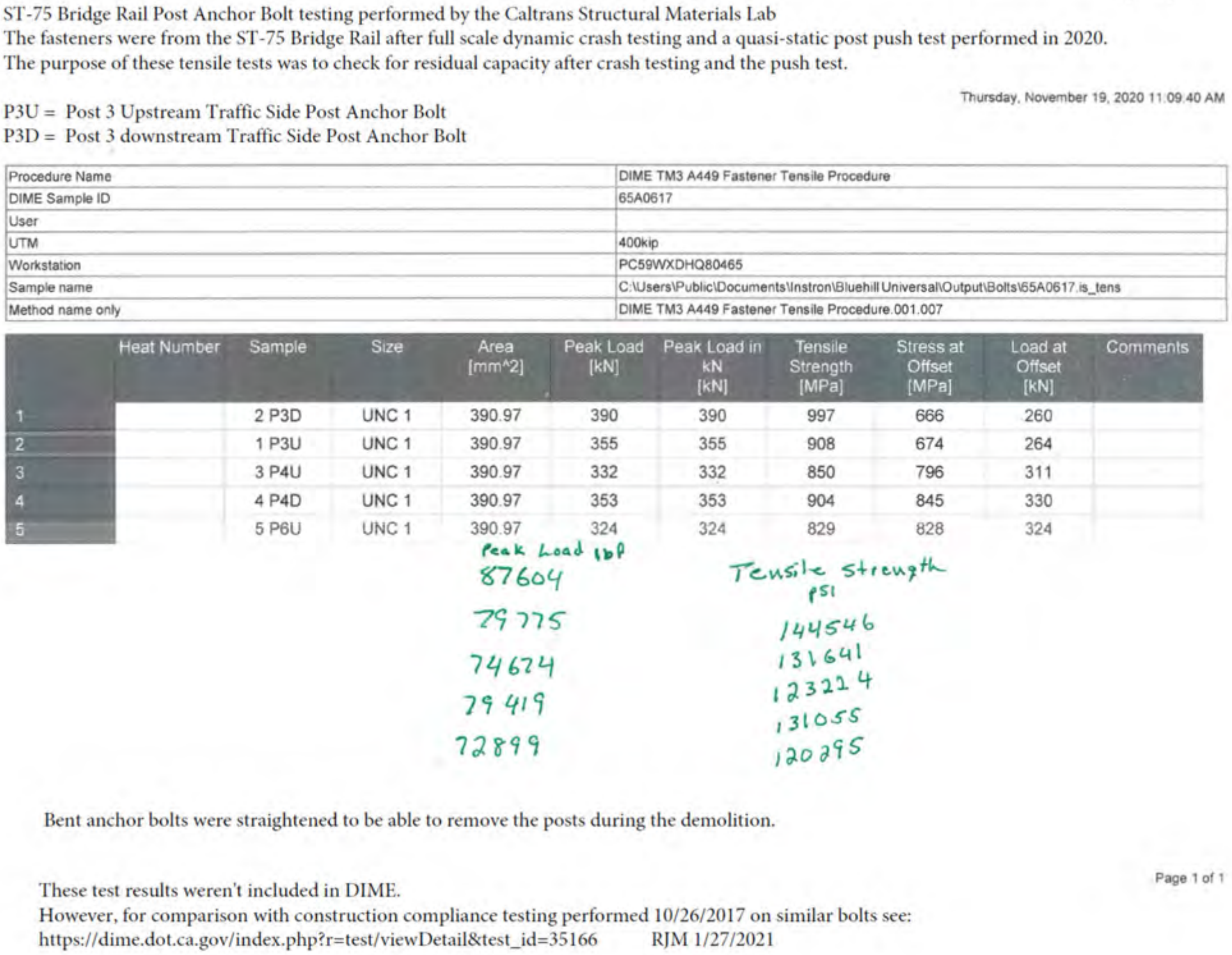


Figure 11-3 Post 4 Anchor Bolts with Post Removed

Figure 11-4 Post 6 Anchor Bolts with Post Removed



ST-75 Bridge Rail Post Anchor Bolt testing performed by the Caltrans Structural Materials Lab
The fasteners were from the ST-75 Bridge Rail after full scale dynamic crash testing and a quasi-static post push test performed in 2020.
The purpose of these tensile tests was to check for residual capacity after crash testing and the push test.

Thursday, November 19, 2020 11:09:40 AM

P3U = Post 3 Upstream Traffic Side Post Anchor Bolt
P3D = Post 3 downstream Traffic Side Post Anchor Bolt

Procedure Name	DIME TM3 A449 Fastener Tensile Procedure
DIME Sample ID	65A0617
User	
UTM	400kip
Workstation	PC59WXDHQ80465
Sample name	C:\Users\Public\Documents\Instron\Bluehill Universal\Output\Bolts\65A0617.is_tens
Method name only	DIME TM3 A449 Fastener Tensile Procedure.001.007

	Heat Number	Sample	Size	Area [mm^2]	Peak Load [kN]	Peak Load in kN [kN]	Tensile Strength [MPa]	Stress at Offset [MPa]	Load at Offset [kN]	Comments
1		2 P3D	UNC 1	390.97	390	390	997	666	260	
2		1 P3U	UNC 1	390.97	355	355	908	674	264	
3		3 P4U	UNC 1	390.97	332	332	850	796	311	
4		4 P4D	UNC 1	390.97	353	353	904	845	330	
5		5 P6U	UNC 1	390.97	324	324	829	828	324	

Peak Load lbf	Tensile strength psi
87604	144546
79775	131641
74624	123224
79419	131055
72899	120295

Bent anchor bolts were straightened to be able to remove the posts during the demolition.

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These test results weren't included in DIME.
However, for comparison with construction compliance testing performed 10/26/2017 on similar bolts see:
https://dime.dot.ca.gov/index.php?r=test/viewDetail&test_id=35166 RJM 1/27/2021

Figure 11-5 Tensile Test (ASTM A449) Results for Anchor Bolts at Posts 3 and 4 (Post Crash Test), and Post 6 (Post Quasistatic Push Test)

Sample	Peak Load (lbf)	Tensile Strength (psi)	Stress at Offset (psi)
1 P3U (Post 3 Upstream)	79,775	131,641	97,800
2 P3D (Post 3 downstream)	87,604	144,546	96,600
3 P4U (Post 4 Upstream)	74,624	123,224	115,000
4 P4D (Post 4 Downstream)	79,419	131,055	123,000
5 P6U (Post 6 Downstream, mislabeled)	72,899	120,295	120,000

Figure 11-6 Summary of Tensile Test Results in English Units

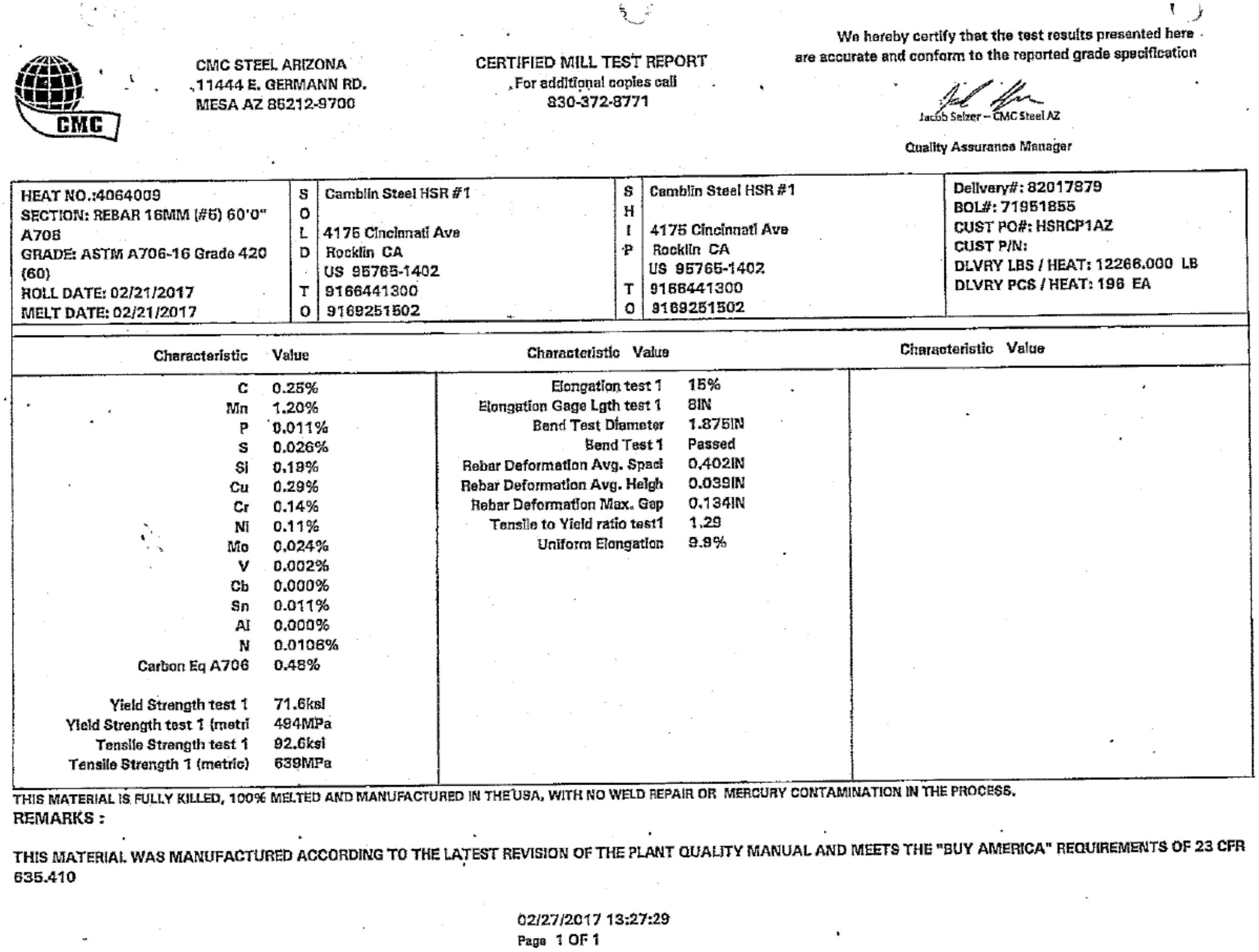
12. Appendix D: Material Properties and Certifications

The concrete cylinder breaks and material certifications in Appendix C are not within the Lab's Scope of Accreditation.

ST-75 Bridge Rail Concrete Cylinder Break Results (Average of Two Cylinders)

	Mix Z5685210 (Deck Pour)	**Mix Z5605210 (Curb Pour)**
Age (Days)	Compressive Strength (psi)	Compressive Strength (psi)
7	4210	4000
14	5360 (15-day break)	4820
21	5480	5300
28	5700	5500

Grade 60 #5 Rebar (1 of 1)



CMC

CMC STEEL ARIZONA
11444 E. GERMANN RD.
MESA AZ 85212-9700

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

Jacob Selzer – CMC Steel AZ
Quality Assurance Manager

HEAT NO.:4064009 SECTION: REBAR 16MM (#5) 60'0" A706 GRADE: ASTM A706-16 Grade 420 (60) ROLL DATE: 02/21/2017 MELT DATE: 02/21/2017	SOLD TO	Camblin Steel HSR #1 4175 Cincinnati Ave Rocklin CA US 95765-1402 9166441300 9169251502	SHIP TO	Camblin Steel HSR #1 4175 Cincinnati Ave Rocklin CA US 95765-1402 9166441300 9169251502	Delivery#: 82017879 BOL#: 71951855 CUST PO#: HSRCP1AZ CUST P/N: DLVRY LBS / HEAT: 12266.000 LB DLVRY PCS / HEAT: 196 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.25%	Elongation test 1	15%		
Mn	1.20%	Elongation Gage Lgth test 1	8IN		
P	0.011%	Bend Test Diameter	1.875IN		
S	0.026%	Bend Test 1	Passed		
Si	0.19%	Rebar Deformation Avg. Spaci	0.402IN		
Cu	0.29%	Rebar Deformation Avg. Heigh	0.039IN		
Cr	0.14%	Rebar Deformation Max. Gap	0.134IN		
Ni	0.11%	Tensile to Yield ratio test1	1.29		
Mo	0.024%	Uniform Elongation	9.9%		
V	0.002%				
Cb	0.000%				
Sn	0.011%				
Al	0.000%				
N	0.0106%				
Carbon Eq A706	0.48%				
Yield Strength test 1	71.6ksi				
Yield Strength test 1 (metri	494MPa				
Tensile Strength test 1	92.6ksi				
Tensile Strength 1 (metric)	639MPa				

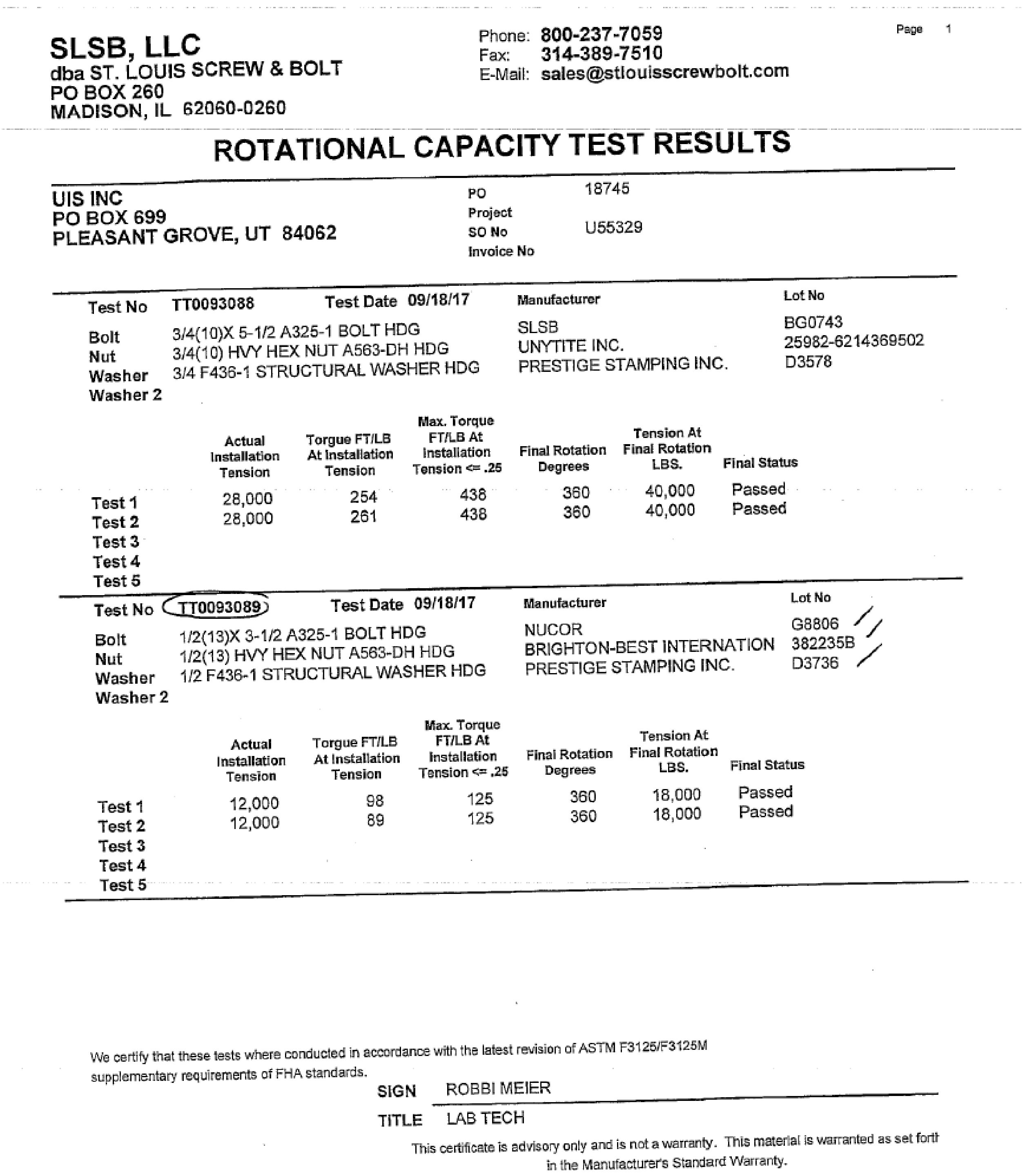
THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

THIS MATERIAL WAS MANUFACTURED ACCORDING TO THE LATEST REVISION OF THE PLANT QUALITY MANUAL AND MEETS THE "BUY AMERICA" REQUIREMENTS OF 23 CFR 635.410

02/27/2017 13:27:29
Page 1 OF 1

½" Diam. x 3.5" Bolt Assembly (1 of 5)



SLSB, LLC
dba ST. LOUIS SCREW & BOLT
PO BOX 260
MADISON, IL 62060-0260

Phone: 800-237-7059
Fax: 314-389-7510
E-Mail: sales@stlouisscrewbolt.com

Page 1

ROTATIONAL CAPACITY TEST RESULTS

UIS INC
PO BOX 699
PLEASANT GROVE, UT 84062

PO 18745
Project
SO No U55329
Invoice No

Test No TT0093088 **Test Date** 09/18/17

		Manufacturer	Lot No
Bolt	3/4(10)X 5-1/2 A325-1 BOLT HDG	SLSB	BG0743
Nut	3/4(10) HVY HEX NUT A563-DH HDG	UNYTITE INC.	25982-6214369502
Washer	3/4 F436-1 STRUCTURAL WASHER HDG	PRESTIGE STAMPING INC.	D3578
Washer 2			

	Actual Installation Tension	Torgue FT/LB At Installation Tension	Max. Torque FT/LB At Installation Tension <= .25	Final Rotation Degrees	Tension At Final Rotation LBS.	Final Status
Test 1	28,000	254	438	360	40,000	Passed
Test 2	28,000	261	438	360	40,000	Passed
Test 3						
Test 4						
Test 5						

Test No TT0093089 **Test Date** 09/18/17

		Manufacturer	Lot No
Bolt	1/2(13)X 3-1/2 A325-1 BOLT HDG	NUCOR	G8806
Nut	1/2(13) HVY HEX NUT A563-DH HDG	BRIGHTON-BEST INTERNATION	382235B
Washer	1/2 F436-1 STRUCTURAL WASHER HDG	PRESTIGE STAMPING INC.	D3736
Washer 2			

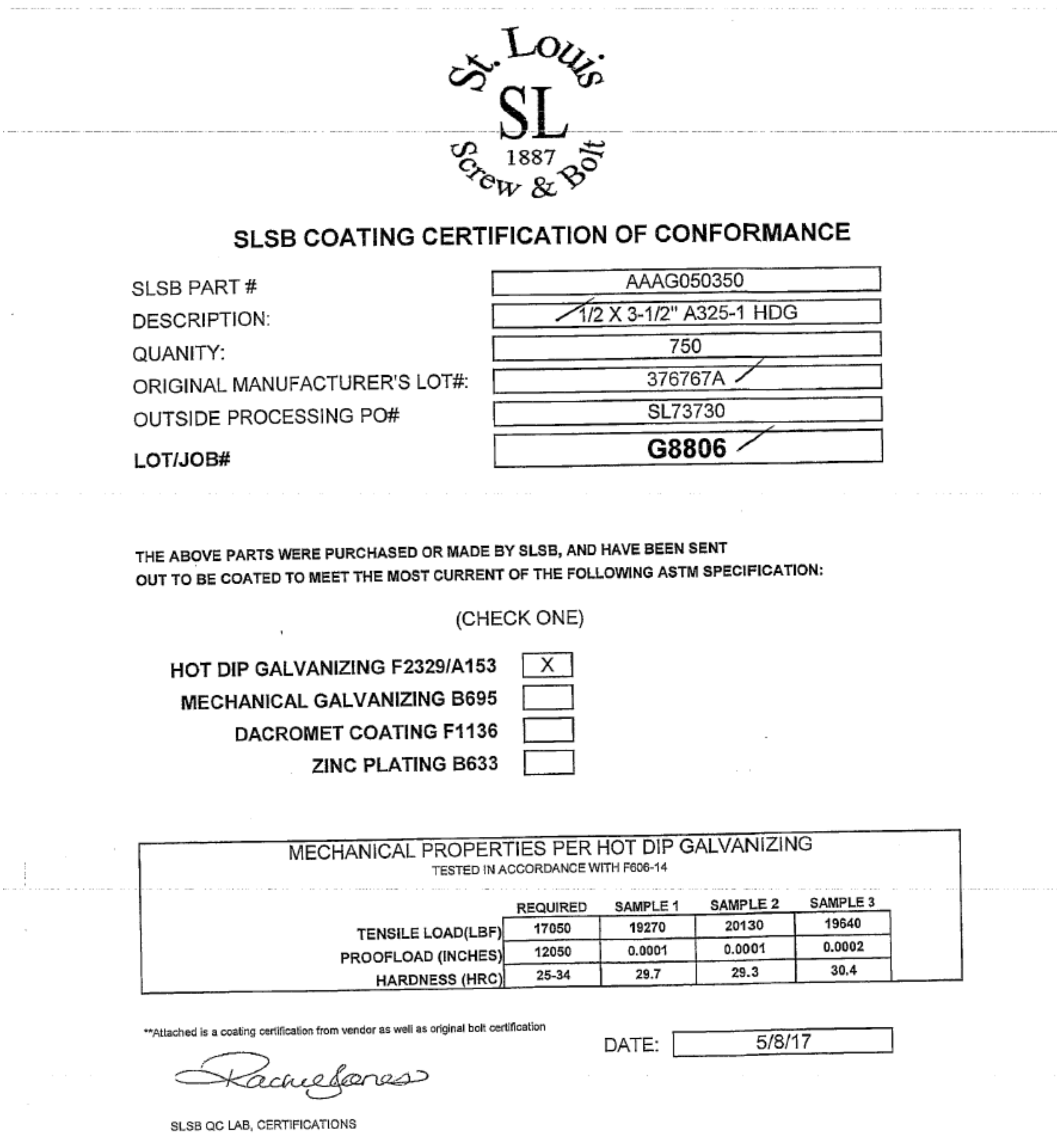
	Actual Installation Tension	Torgue FT/LB At Installation Tension	Max. Torque FT/LB At Installation Tension <= .25	Final Rotation Degrees	Tension At Final Rotation LBS.	Final Status
Test 1	12,000	98	125	360	18,000	Passed
Test 2	12,000	89	125	360	18,000	Passed
Test 3						
Test 4						
Test 5						

We certify that these tests where conducted in accordance with the latest revision of ASTM F3125/F3125M supplementary requirements of FHA standards.

SIGN ROBBI MEIER
TITLE LAB TECH

This certificate is advisory only and is not a warranty. This material is warranted as set forth in the Manufacturer's Standard Warranty.

½" Diam. x 3.5" Bolt Assembly (2 of 5)



St. Louis
SL
1887
Screw & Bolt

SLSB COATING CERTIFICATION OF CONFORMANCE

SLSB PART #	AAAG050350
DESCRIPTION:	1/2 X 3-1/2" A325-1 HDG
QUANITY:	750
ORIGINAL MANUFACTURER'S LOT#:	376767A
OUTSIDE PROCESSING PO#	SL73730
LOT/JOB#	**G8806**

THE ABOVE PARTS WERE PURCHASED OR MADE BY SLSB, AND HAVE BEEN SENT OUT TO BE COATED TO MEET THE MOST CURRENT OF THE FOLLOWING ASTM SPECIFICATION:

(CHECK ONE)

- **HOT DIP GALVANIZING F2329/A153** ☒
- **MECHANICAL GALVANIZING B695** ☐
- **DACROMET COATING F1136** ☐
- **ZINC PLATING B633** ☐

MECHANICAL PROPERTIES PER HOT DIP GALVANIZING
TESTED IN ACCORDANCE WITH F606-14

	REQUIRED	SAMPLE 1	SAMPLE 2	SAMPLE 3
TENSILE LOAD(LBF)	17050	19270	20130	19640
PROOFLOAD (INCHES)	12050	0.0001	0.0001	0.0002
HARDNESS (HRC)	25-34	29.7	29.3	30.4

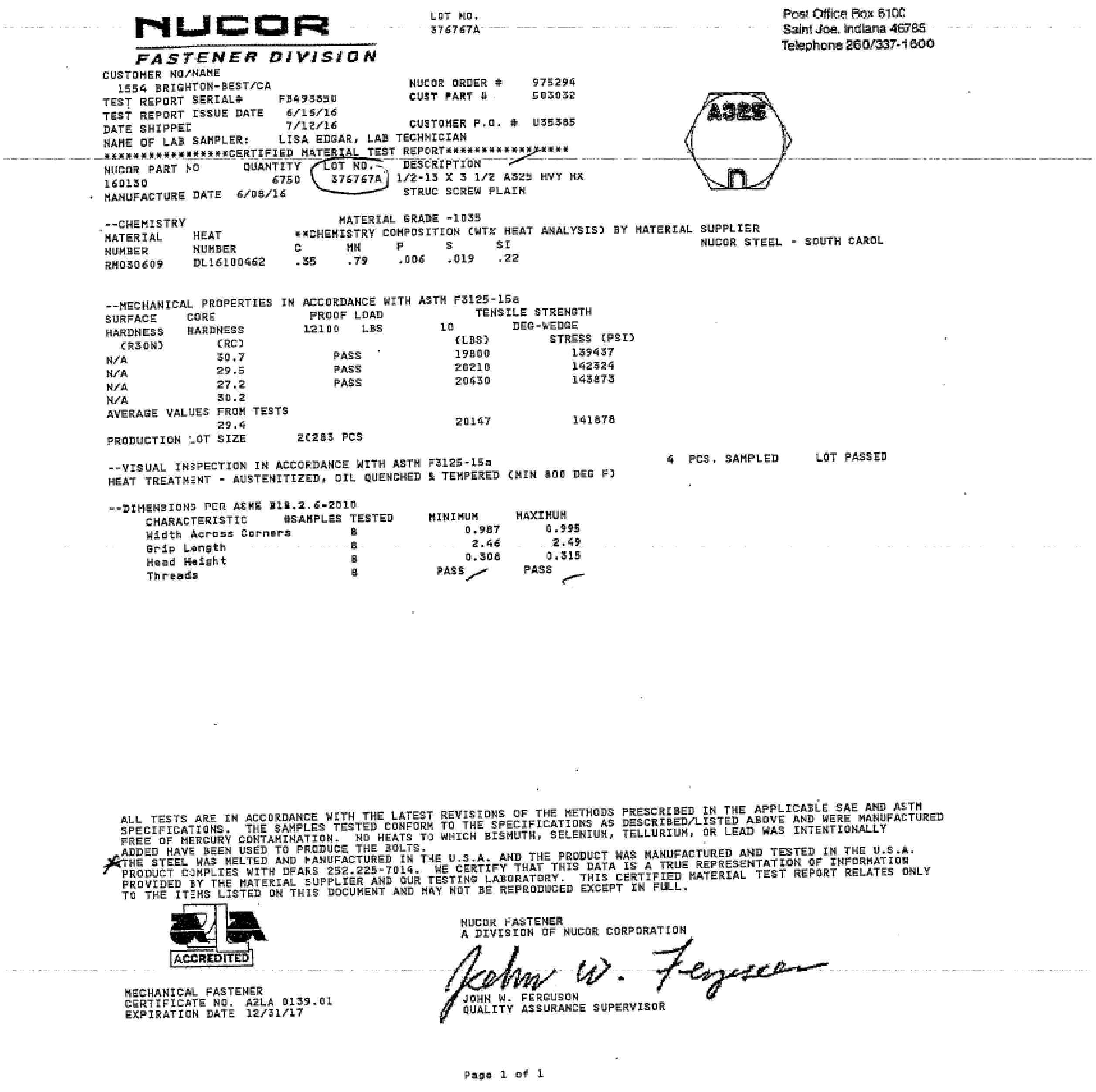
**Attached is a coating certification from vendor as well as original bolt certification

DATE: 5/8/17

Rachel Jones

SLSB QC LAB, CERTIFICATIONS

½" Diam. x 3.5" Bolt Assembly (3 of 5)



NUCOR
FASTENER DIVISION

LOT NO.
376767A

Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
1554 BRIGHTON-BEST/CA
TEST REPORT SERIAL# F3498350
TEST REPORT ISSUE DATE 6/16/16
DATE SHIPPED 7/12/16
NAME OF LAB SAMPLER: LISA EDGAR, LAB TECHNICIAN

NUCOR ORDER # 975294
CUST PART # 503032
CUSTOMER P.O. # U35385

A325

*****************CERTIFIED MATERIAL TEST REPORT********************

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
160130	6750	376767A	1/2-13 X 3 1/2 A325 HVY HX STRUC SCREW PLAIN

MANUFACTURE DATE 6/08/16

--CHEMISTRY MATERIAL GRADE -1035
**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER
NUCOR STEEL - SOUTH CAROL

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI
RM030609	DL16100462	.35	.79	.006	.019	.22

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM F3125-15a

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 12100 LBS	TENSILE STRENGTH 10 DEG-WEDGE (LBS)	STRESS (PSI)
N/A	30.7	PASS	19800	139437
N/A	29.5	PASS	20210	142324
N/A	27.2	PASS	20430	143873
N/A	30.2			
AVERAGE VALUES FROM TESTS	29.4		20147	141878

PRODUCTION LOT SIZE 20283 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM F3125-15a 4 PCS. SAMPLED LOT PASSED
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2010

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	0.987	0.995
Grip Length	8	2.46	2.49
Head Height	8	0.308	0.315
Threads	8	PASS	PASS

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO HEATS TO WHICH BISMUTH, SELENIUM, TELLURIUM, OR LEAD WAS INTENTIONALLY ADDED HAVE BEEN USED TO PRODUCE THE BOLTS.

THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A. PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

A2LA
ACCREDITED

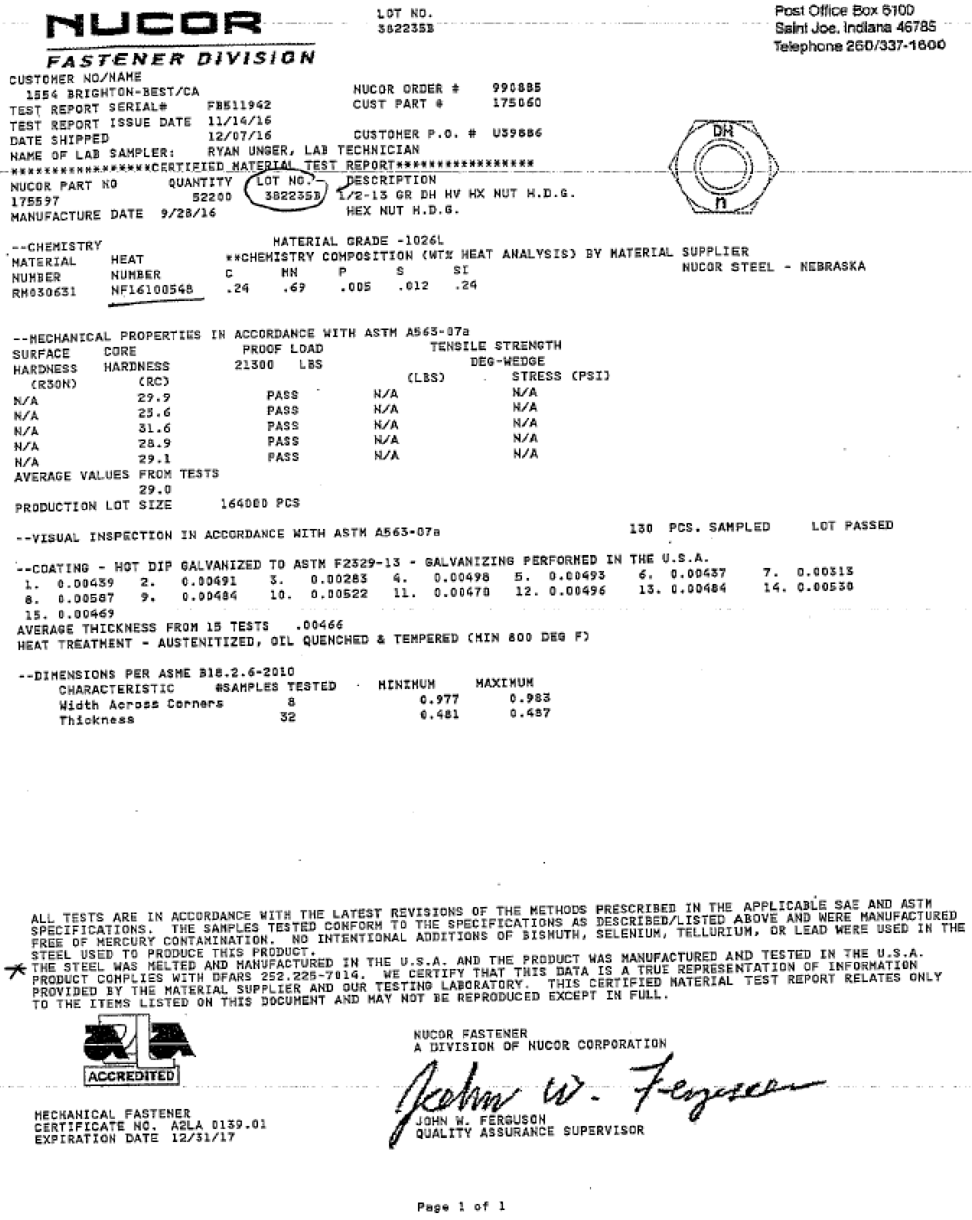
MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/17

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

½" Diam. x 3.5" Bolt Assembly (4 of 5)



NUCOR
FASTENER DIVISION

LOT NO.
3822358

Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
1554 BRIGHTON-BEST/CA

TEST REPORT SERIAL#	FB511942	NUCOR ORDER #	990885
TEST REPORT ISSUE DATE	11/14/16	CUST PART #	175060
DATE SHIPPED	12/07/16	CUSTOMER P.O. #	U39886
NAME OF LAB SAMPLER:	RYAN UNGER, LAB TECHNICIAN		

****************CERTIFIED MATERIAL TEST REPORT*****************

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175597	52200	3822358	1/2-13 GR DH HV HX NUT H.D.G.
MANUFACTURE DATE 9/28/16			HEX NUT H.D.G.

MATERIAL GRADE -1026L

--CHEMISTRY

**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER
NUCOR STEEL - NEBRASKA

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI
RM030631	NF16100548	.24	.69	.005	.012	.24

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-07a

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 21300 LBS	TENSILE STRENGTH DEG-WEDGE (LBS)	STRESS (PSI)
N/A	29.9	PASS	N/A	N/A
N/A	25.6	PASS	N/A	N/A
N/A	31.6	PASS	N/A	N/A
N/A	28.9	PASS	N/A	N/A
N/A	29.1	PASS	N/A	N/A
AVERAGE VALUES FROM TESTS				
	29.0			

PRODUCTION LOT SIZE 164080 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-07a 130 PCS. SAMPLED LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-13 - GALVANIZING PERFORMED IN THE U.S.A.

1. 0.00439	2. 0.00491	3. 0.00283	4. 0.00498	5. 0.00493	6. 0.00437	7. 0.00318
8. 0.00587	9. 0.00484	10. 0.00522	11. 0.00470	12. 0.00496	13. 0.00484	14. 0.00530
15. 0.00469						

AVERAGE THICKNESS FROM 15 TESTS .00466
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2010

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	0.977	0.983
Thickness	32	0.481	0.487

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO INTENTIONAL ADDITIONS OF BISMUTH, SELENIUM, TELLURIUM, OR LEAD WERE USED IN THE STEEL USED TO PRODUCE THIS PRODUCT.
* THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A. PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

A2LA
ACCREDITED

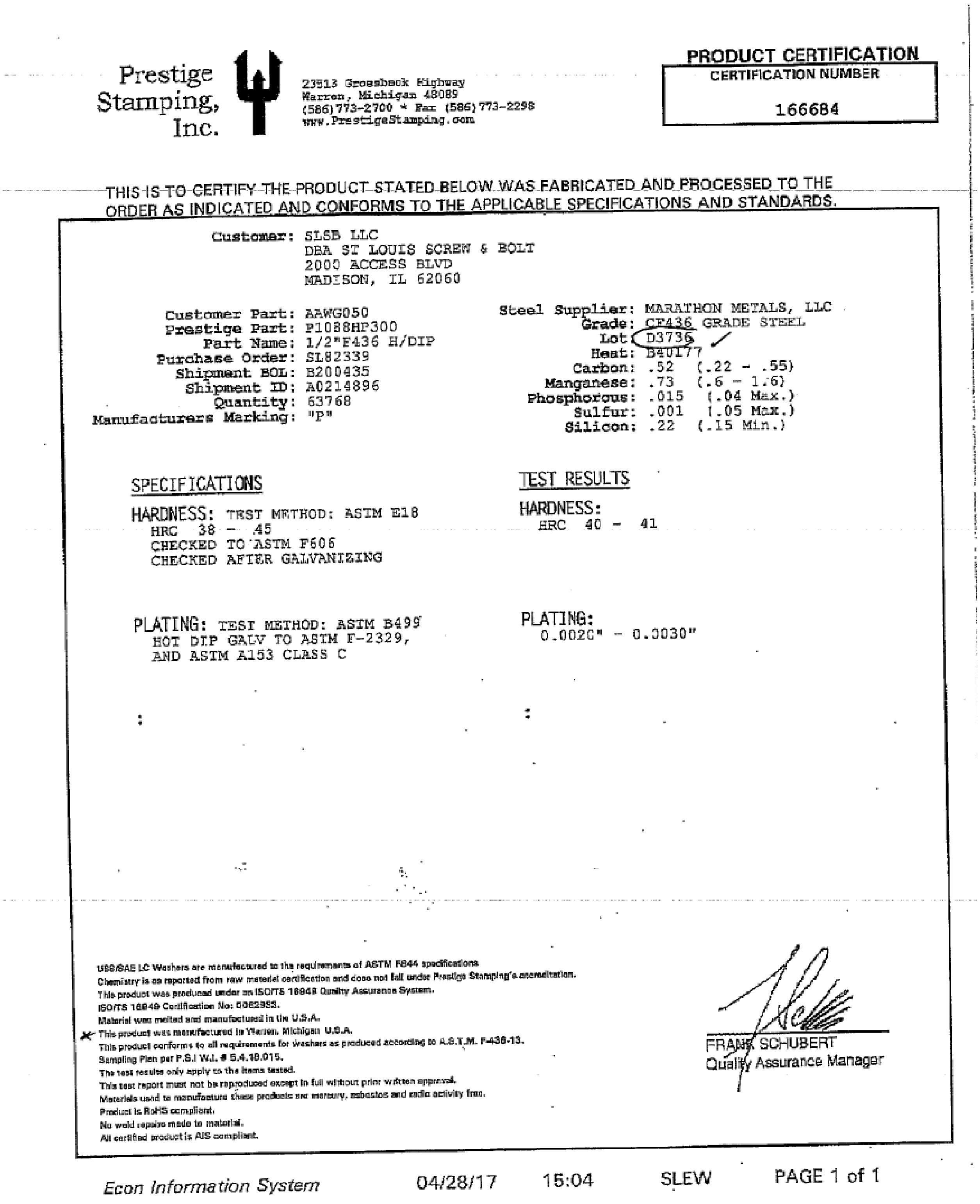
MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/17

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

½” Diam. x 3.5” Bolt Assembly (5 of 5)



Prestige Stamping, Inc.

23513 Groesbeck Highway
Warren, Michigan 48089
(586) 773-2700 * Fax (586) 773-2298
www.PrestigeStamping.com

PRODUCT CERTIFICATION

CERTIFICATION NUMBER
166684

THIS IS TO CERTIFY THE PRODUCT STATED BELOW WAS FABRICATED AND PROCESSED TO THE ORDER AS INDICATED AND CONFORMS TO THE APPLICABLE SPECIFICATIONS AND STANDARDS.

Customer: SLSB LLC
DBA ST LOUIS SCREW & BOLT
2000 ACCESS BLVD
MADISON, IL 62060

Customer Part: AAWG050
Prestige Part: P1088HP300
Part Name: 1/2"F436 H/DIP
Purchase Order: SL82339
Shipment BOL: B200435
Shipment ID: A0214896
Quantity: 63768
Manufacturers Marking: "P"

Steel Supplier: MARATHON METALS, LLC
Grade: CF436 GRADE STEEL
Lot: D3736 ✓
Heat: B40177
Carbon: .52 (.22 - .55)
Manganese: .73 (.6 - 1.6)
Phosphorous: .015 (.04 Max.)
Sulfur: .001 (.05 Max.)
Silicon: .22 (.15 Min.)

SPECIFICATIONS

HARDNESS: TEST METHOD: ASTM E18
HRC 38 - 45
CHECKED TO ASTM F606
CHECKED AFTER GALVANIZING

PLATING: TEST METHOD: ASTM B499
HOT DIP GALV TO ASTM F-2329,
AND ASTM A153 CLASS C

TEST RESULTS

HARDNESS:
HRC 40 - 41

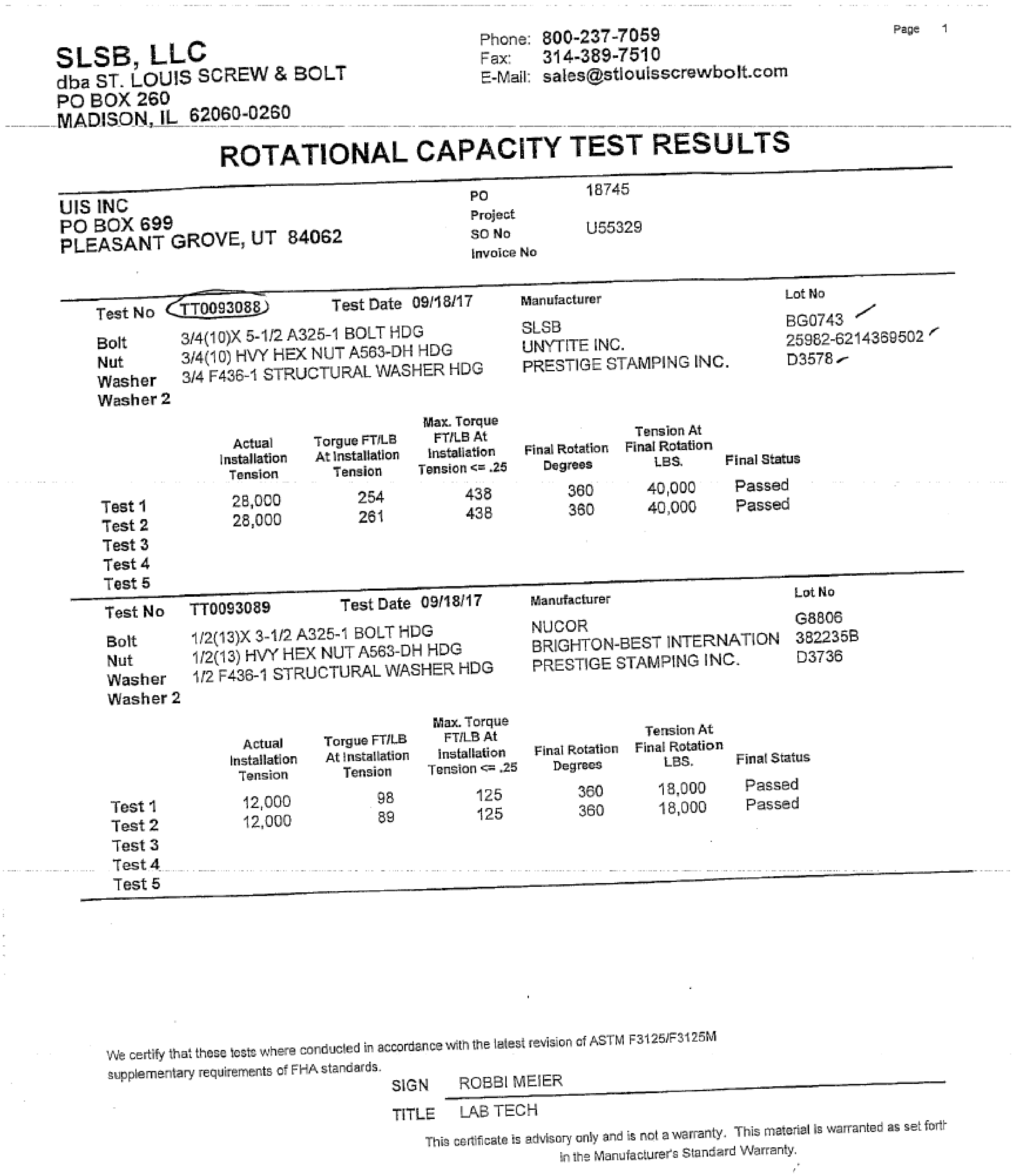
PLATING:
0.0020" - 0.0030"

USS/SAE LC Washers are manufactured to the requirements of ASTM F844 specifications
Chemistry is as reported from raw material certification and does not fall under Prestige Stamping's accreditation.
This product was produced under an ISO/TS 16949 Quality Assurance System.
ISO/TS 16949 Certification No: 0062353.
Material was melted and manufactured in the U.S.A.
This product was manufactured in Warren, Michigan U.S.A.
This product conforms to all requirements for washers as produced according to A.S.T.M. F-436-13.
Sampling Plan per P.S.I W.I. # 5.4.18.015.
The test results only apply to the items tested.
This test report must not be reproduced except in full without prior written approval.
Materials used to manufacture these products are mercury, asbestos and radio activity free.
Product is RoHS compliant.
No weld repairs made to material.
All certified product is AIS compliant.

FRANK SCHUBERT
Quality Assurance Manager

Econ Information System 04/28/17 15:04 SLEW PAGE 1 of 1

<u>¾" Diam. x 5.5" Bolt Assembly (1 of 6)</u>



Page 1

SLSB, LLC
dba ST. LOUIS SCREW & BOLT
PO BOX 260
MADISON, IL 62060-0260

Phone: 800-237-7059
Fax: 314-389-7510
E-Mail: sales@stlouisscrewbolt.com

ROTATIONAL CAPACITY TEST RESULTS

UIS INC
PO BOX 699
PLEASANT GROVE, UT 84062

PO 18745
Project
SO No U55329
Invoice No

Test No TT0093088 **Test Date** 09/18/17

		Manufacturer	Lot No
Bolt	3/4(10)X 5-1/2 A325-1 BOLT HDG	SLSB	BG0743
Nut	3/4(10) HVY HEX NUT A563-DH HDG	UNYTITE INC.	25982-6214369502
Washer	3/4 F436-1 STRUCTURAL WASHER HDG	PRESTIGE STAMPING INC.	D3578
Washer 2			

	Actual Installation Tension	Torgue FT/LB At Installation Tension	Max. Torque FT/LB At Installation Tension <= .25	Final Rotation Degrees	Tension At Final Rotation LBS.	Final Status
Test 1	28,000	254	438	360	40,000	Passed
Test 2	28,000	261	438	360	40,000	Passed
Test 3						
Test 4						
Test 5						

Test No TT0093089 **Test Date** 09/18/17

		Manufacturer	Lot No
Bolt	1/2(13)X 3-1/2 A325-1 BOLT HDG	NUCOR	G8806
Nut	1/2(13) HVY HEX NUT A563-DH HDG	BRIGHTON-BEST INTERNATION	382235B
Washer	1/2 F436-1 STRUCTURAL WASHER HDG	PRESTIGE STAMPING INC.	D3736
Washer 2			

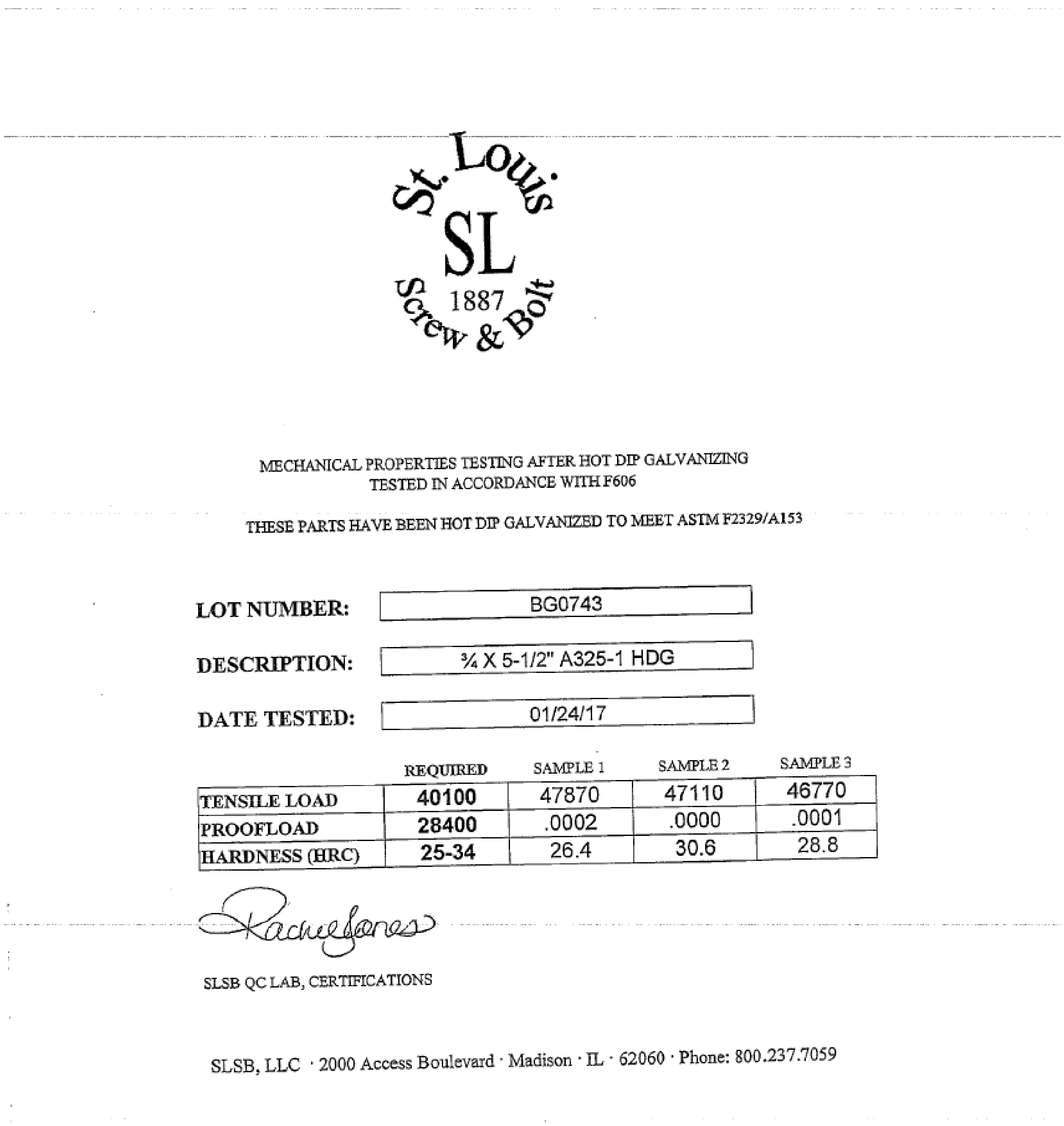
	Actual Installation Tension	Torgue FT/LB At Installation Tension	Max. Torque FT/LB At Installation Tension <= .25	Final Rotation Degrees	Tension At Final Rotation LBS.	Final Status
Test 1	12,000	98	125	360	18,000	Passed
Test 2	12,000	89	125	360	18,000	Passed
Test 3						
Test 4						
Test 5						

We certify that these tests where conducted in accordance with the latest revision of ASTM F3125/F3125M supplementary requirements of FHA standards.

SIGN ROBBI MEIER
TITLE LAB TECH

This certificate is advisory only and is not a warranty. This material is warranted as set forth in the Manufacturer's Standard Warranty.

¾” Diam. x 5.5” Bolt Assembly (2 of 6)



St. Louis
SL
1887
Screw & Bolt

MECHANICAL PROPERTIES TESTING AFTER HOT DIP GALVANIZING
TESTED IN ACCORDANCE WITH F606

THESE PARTS HAVE BEEN HOT DIP GALVANIZED TO MEET ASTM F2329/A153

LOT NUMBER: BG0743

DESCRIPTION: ¾ X 5-1/2" A325-1 HDG

DATE TESTED: 01/24/17

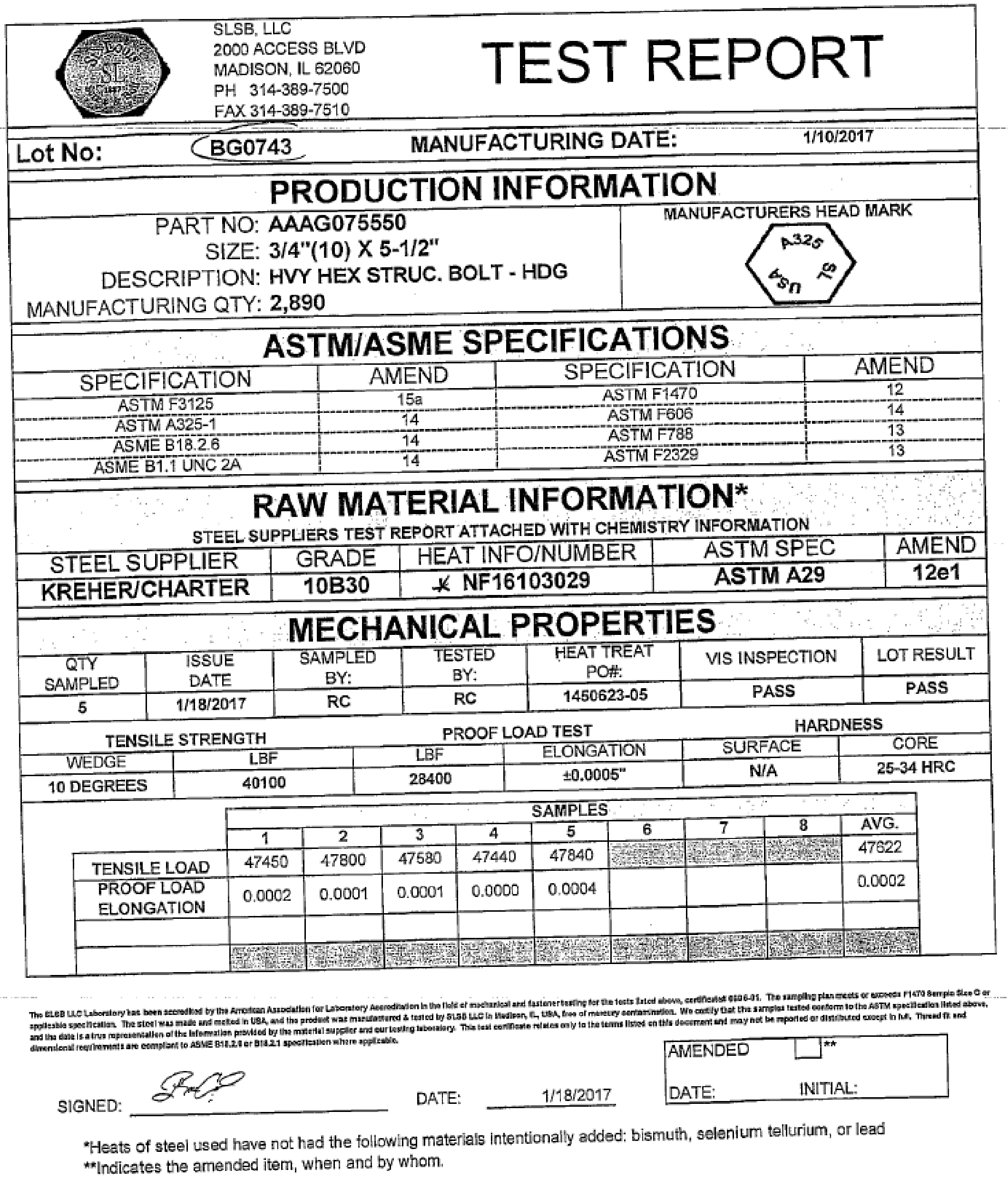
	REQUIRED	SAMPLE 1	SAMPLE 2	SAMPLE 3
TENSILE LOAD	**40100**	47870	47110	46770
PROOFLOAD	**28400**	.0002	.0000	.0001
HARDNESS (HRC)	**25-34**	26.4	30.6	28.8

Rachel Jones

SLSB QC LAB, CERTIFICATIONS

SLSB, LLC · 2000 Access Boulevard · Madison · IL · 62060 · Phone: 800.237.7059

¾" Diam. x 5.5" Bolt Assembly (3 of 6)



SLSB, LLC
2000 ACCESS BLVD
MADISON, IL 62060
PH 314-389-7500
FAX 314-389-7510

TEST REPORT

Lot No: BG0743 **MANUFACTURING DATE:** 1/10/2017

PRODUCTION INFORMATION

PART NO: **AAAG075550**
SIZE: **3/4"(10) X 5-1/2"**
DESCRIPTION: **HVY HEX STRUC. BOLT - HDG**
MANUFACTURING QTY: **2,890**

MANUFACTURERS HEAD MARK

ASTM/ASME SPECIFICATIONS

SPECIFICATION	AMEND	SPECIFICATION	AMEND
ASTM F3125	15a	ASTM F1470	12
ASTM A325-1	14	ASTM F606	14
ASME B18.2.6	14	ASTM F788	13
ASME B1.1 UNC 2A	14	ASTM F2329	13

RAW MATERIAL INFORMATION*

STEEL SUPPLIERS TEST REPORT ATTACHED WITH CHEMISTRY INFORMATION

STEEL SUPPLIER	GRADE	HEAT INFO/NUMBER	ASTM SPEC	AMEND
KREHER/CHARTER	10B30	✗ NF16103029	ASTM A29	12e1

MECHANICAL PROPERTIES

QTY SAMPLED	ISSUE DATE	SAMPLED BY:	TESTED BY:	HEAT TREAT PO#:	VIS INSPECTION	LOT RESULT
5	1/18/2017	RC	RC	1450623-05	PASS	PASS

TENSILE STRENGTH		PROOF LOAD TEST		HARDNESS	
WEDGE	LBF	LBF	ELONGATION	SURFACE	CORE
10 DEGREES	40100	28400	±0.0005"	N/A	25-34 HRC

	SAMPLES								
	1	2	3	4	5	6	7	8	AVG.
TENSILE LOAD	47450	47800	47580	47440	47840	▨	▨	▨	47622
PROOF LOAD ELONGATION	0.0002	0.0001	0.0001	0.0000	0.0004				0.0002
	▨	▨	▨	▨	▨	▨	▨	▨	▨

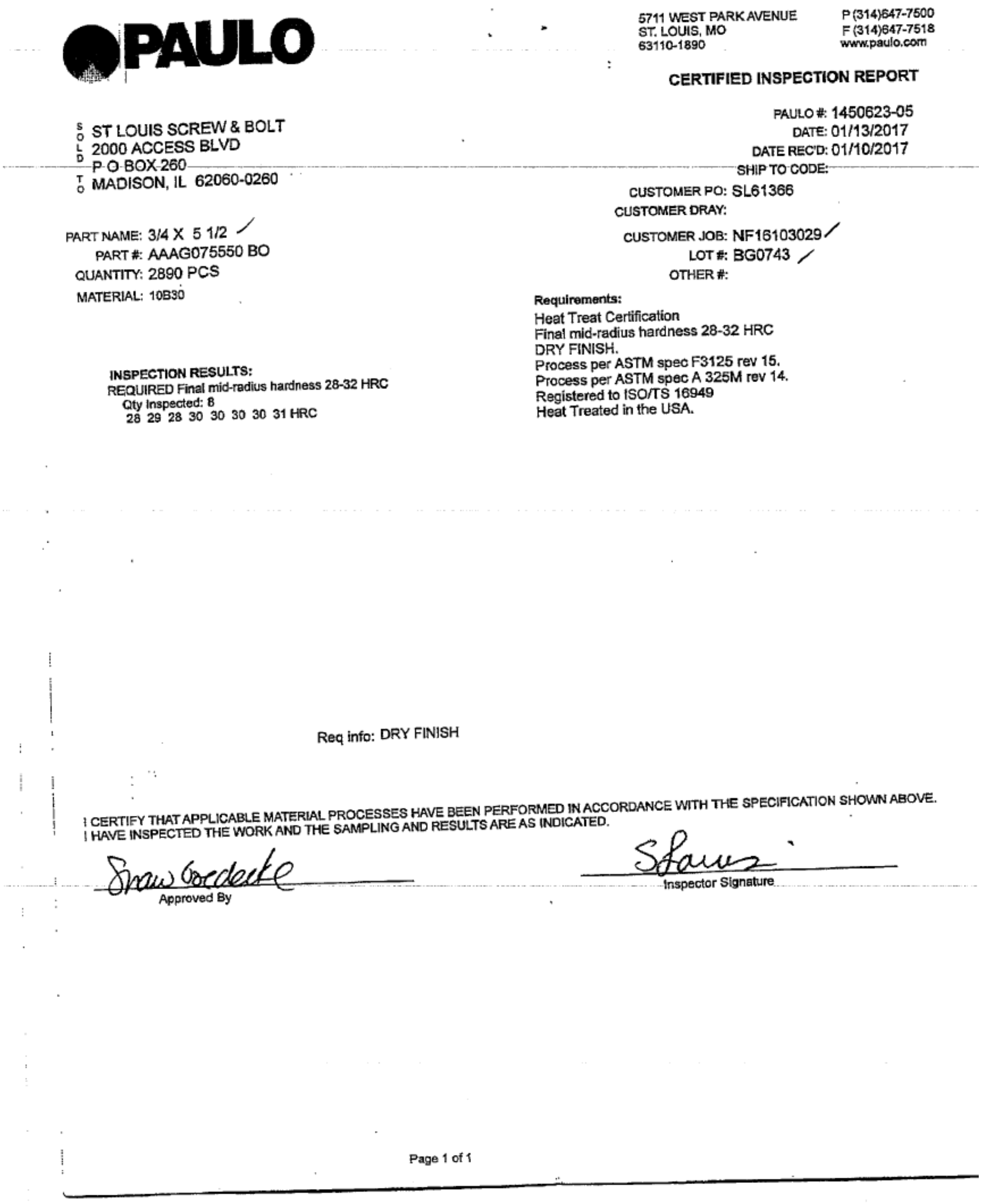
The SLSB LLC Laboratory has been accredited by the American Association for Laboratory Accreditation in the field of mechanical and fastener testing for the tests listed above, certificate# 6506-01. The sampling plan meets or exceeds F1470 Sample Size C or applicable specification. The steel was made and melted in USA, and the product was manufactured & tested by SLSB LLC in Madison, IL, USA, free of mercury contamination. We certify that the samples tested conform to the ASTM specification listed above, and the data is a true representation of the information provided by the material supplier and our testing laboratory. This test certificate relates only to the items listed on this document and may not be reported or distributed except in full. Thread fit and dimensional requirements are compliant to ASME B18.2.6 or B18.2.1 specification where applicable.

AMENDED ☐**
DATE: INITIAL:

SIGNED:
DATE: 1/18/2017

*Heats of steel used have not had the following materials intentionally added: bismuth, selenium tellurium, or lead
**Indicates the amended item, when and by whom.

¾" Diam. x 5.5" Bolt Assembly (4 of 6)



PAULO

5711 WEST PARK AVENUE
ST. LOUIS, MO
63110-1890

P (314)647-7500
F (314)647-7518
www.paulo.com

CERTIFIED INSPECTION REPORT

PAULO #: 1450623-05
DATE: 01/13/2017
DATE REC'D: 01/10/2017
SHIP TO CODE:

SOLD TO
ST LOUIS SCREW & BOLT
2000 ACCESS BLVD
P O BOX 260
MADISON, IL 62060-0260

CUSTOMER PO: SL61366
CUSTOMER DRAY:
CUSTOMER JOB: NF16103029
LOT #: BG0743
OTHER #:

PART NAME: 3/4 X 5 1/2
PART #: AAAG075550 BO
QUANTITY: 2890 PCS
MATERIAL: 10B30

Requirements:
Heat Treat Certification
Final mid-radius hardness 28-32 HRC
DRY FINISH.
Process per ASTM spec F3125 rev 15.
Process per ASTM spec A 325M rev 14.
Registered to ISO/TS 16949
Heat Treated in the USA.

INSPECTION RESULTS:
REQUIRED Final mid-radius hardness 28-32 HRC
Qty Inspected: 8
28 29 28 30 30 30 30 31 HRC

Req info: DRY FINISH

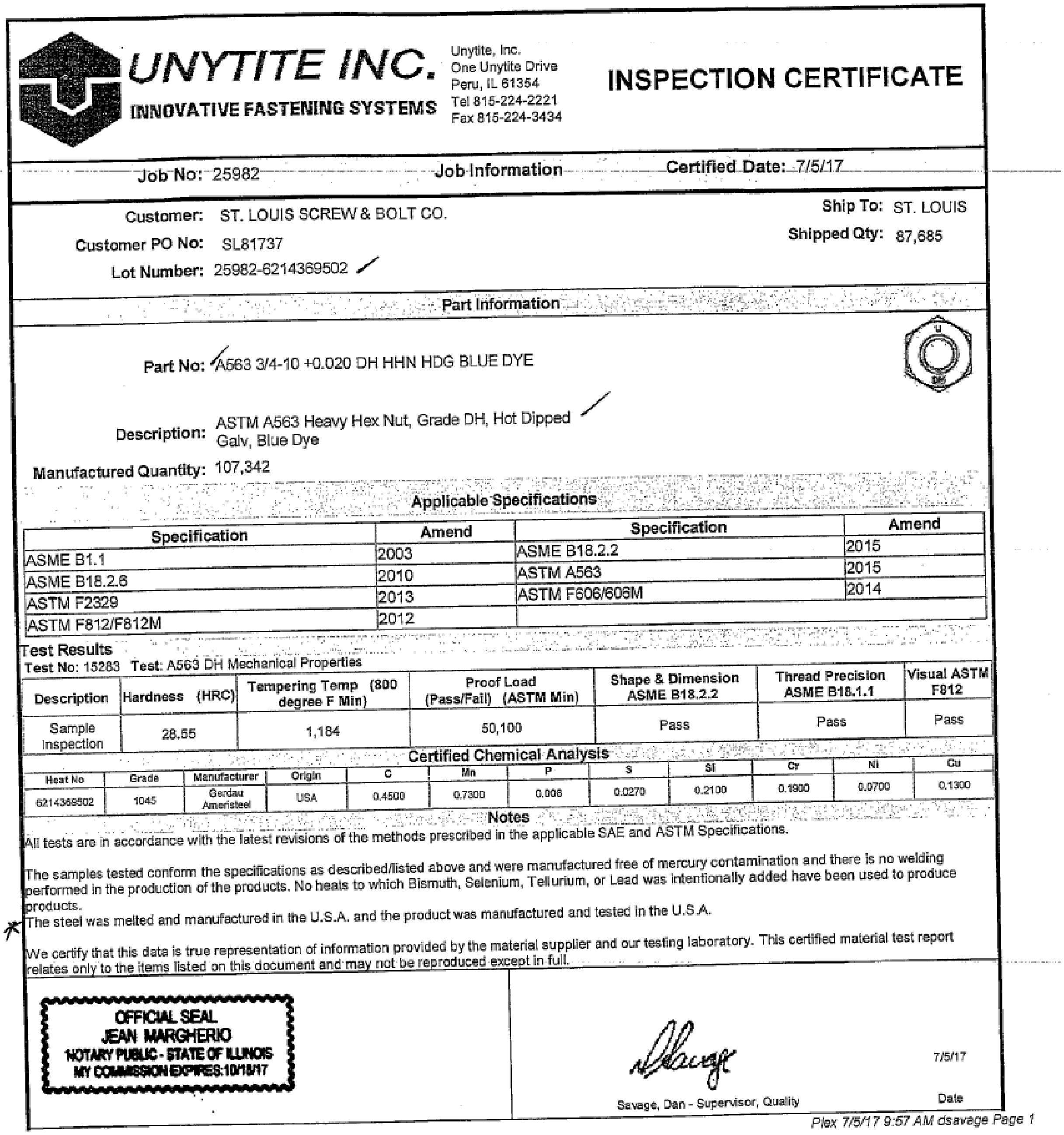
I CERTIFY THAT APPLICABLE MATERIAL PROCESSES HAVE BEEN PERFORMED IN ACCORDANCE WITH THE SPECIFICATION SHOWN ABOVE.
I HAVE INSPECTED THE WORK AND THE SAMPLING AND RESULTS ARE AS INDICATED.

Approved By

Inspector Signature

Page 1 of 1

¾" Diam. x 5.5" Bolt Assembly (5 of 6)



UNYTITE INC.
INNOVATIVE FASTENING SYSTEMS

Unytite, Inc.
One Unytite Drive
Peru, IL 61354
Tel 815-224-2221
Fax 815-224-3434

INSPECTION CERTIFICATE

Job No: 25982 **Job Information** **Certified Date:** 7/5/17

Customer: ST. LOUIS SCREW & BOLT CO.
Customer PO No: SL81737
Lot Number: 25982-6214369502 ✓
Ship To: ST. LOUIS
Shipped Qty: 87,685

Part Information

Part No: ✓A563 3/4-10 +0.020 DH HHN HDG BLUE DYE

Description: ASTM A563 Heavy Hex Nut, Grade DH, Hot Dipped Galv, Blue Dye ✓

Manufactured Quantity: 107,342

Applicable Specifications

Specification	Amend	Specification	Amend
ASME B1.1	2003	ASME B18.2.2	2015
ASME B18.2.6	2010	ASTM A563	2015
ASTM F2329	2013	ASTM F606/606M	2014
ASTM F812/F812M	2012		

Test Results
Test No: 15283 **Test:** A563 DH Mechanical Properties

Description	Hardness (HRC)	Tempering Temp (800 degree F Min)	Proof Load (Pass/Fail) (ASTM Min)	Shape & Dimension ASME B18.2.2	Thread Precision ASME B18.1.1	Visual ASTM F812
Sample Inspection	28.55	1,184	50,100	Pass	Pass	Pass

Certified Chemical Analysis

Heat No	Grade	Manufacturer	Origin	C	Mn	P	S	Si	Cr	Ni	Cu
6214369502	1045	Gerdau Ameristeel	USA	0.4500	0.7300	0.008	0.0270	0.2100	0.1900	0.0700	0.1300

Notes

All tests are in accordance with the latest revisions of the methods prescribed in the applicable SAE and ASTM Specifications.

The samples tested conform the specifications as described/listed above and were manufactured free of mercury contamination and there is no welding performed in the production of the products. No heats to which Bismuth, Selenium, Tellurium, or Lead was intentionally added have been used to produce products.

* The steel was melted and manufactured in the U.S.A. and the product was manufactured and tested in the U.S.A.

We certify that this data is true representation of information provided by the material supplier and our testing laboratory. This certified material test report relates only to the items listed on this document and may not be reproduced except in full.

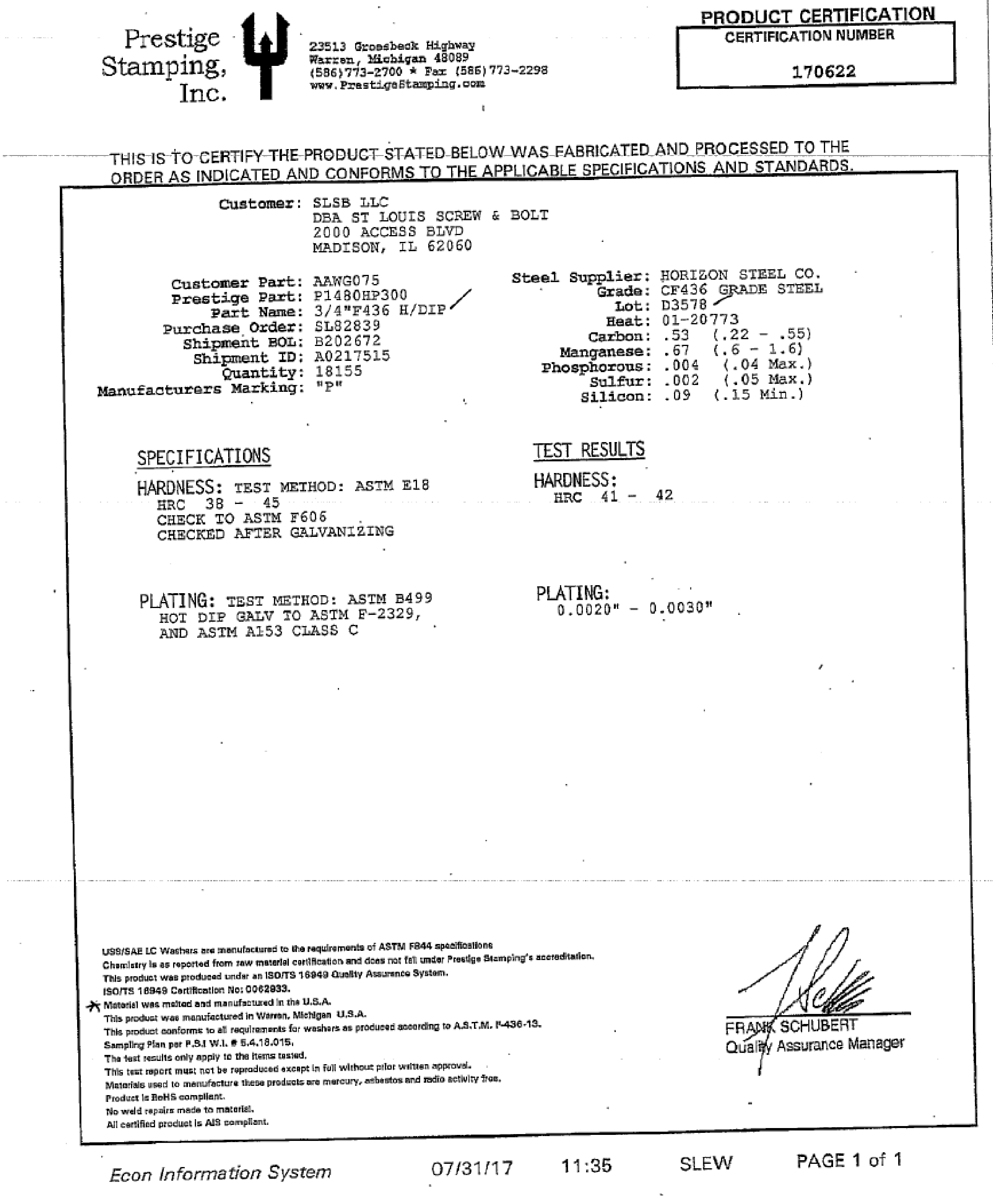
JEAN MARGHERIO
MY COMMISSION EXPIRES:10/18/17

Savage, Dan - Supervisor, Quality

7/5/17
Date

Plex 7/5/17 9:57 AM dsavage Page 1

¾" Diam. x 5.5" Bolt Assembly (6 of 6)



Prestige Stamping, Inc.

23513 Groesbeck Highway
Warren, Michigan 48089
(586)773-2700 * Fax (586)773-2298
www.PrestigeStamping.com

PRODUCT CERTIFICATION
CERTIFICATION NUMBER
170622

THIS IS TO CERTIFY THE PRODUCT STATED BELOW WAS FABRICATED AND PROCESSED TO THE ORDER AS INDICATED AND CONFORMS TO THE APPLICABLE SPECIFICATIONS AND STANDARDS.

Customer: SLSB LLC
DBA ST LOUIS SCREW & BOLT
2000 ACCESS BLVD
MADISON, IL 62060

Customer Part: AAWG075
Prestige Part: P1480HP300
Part Name: 3/4"F436 H/DIP
Purchase Order: SL82839
Shipment BOL: B202672
Shipment ID: A0217515
Quantity: 18155
Manufacturers Marking: "P"

Steel Supplier: HORIZON STEEL CO.
Grade: CF436 GRADE STEEL
Lot: D3578
Heat: 01-20773
Carbon: .53 (.22 - .55)
Manganese: .67 (.6 - 1.6)
Phosphorous: .004 (.04 Max.)
Sulfur: .002 (.05 Max.)
Silicon: .09 (.15 Min.)

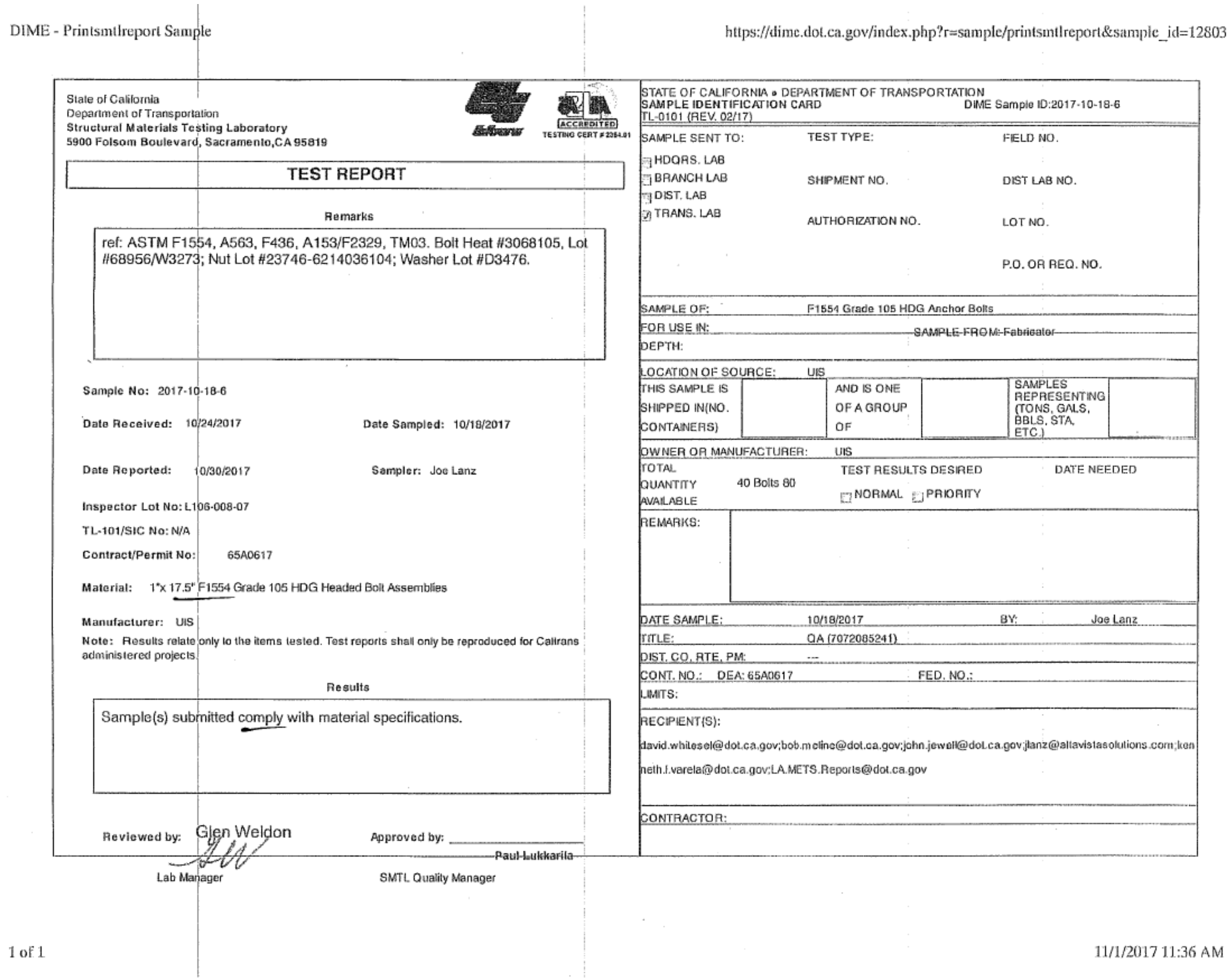
SPECIFICATIONS	TEST RESULTS
HARDNESS: TEST METHOD: ASTM E18 HRC 38 - 45 CHECK TO ASTM F606 CHECKED AFTER GALVANIZING	HARDNESS: HRC 41 - 42
PLATING: TEST METHOD: ASTM B499 HOT DIP GALV TO ASTM F-2329, AND ASTM A153 CLASS C	PLATING: 0.0020" - 0.0030"

USS/SAE LC Washers are manufactured to the requirements of ASTM F844 specifications
Chemistry is as reported from raw material certification and does not fall under Prestige Stamping's accreditation.
This product was produced under an ISO/TS 16949 Quality Assurance System.
ISO/TS 16949 Certification No: 0062833.
* Material was melted and manufactured in the U.S.A.
This product was manufactured in Warren, Michigan U.S.A.
This product conforms to all requirements for washers as produced according to A.S.T.M. F-436-13.
Sampling Plan per P.S.I W.I. # 5.4.18.015.
The test results only apply to the items tested.
This test report must not be reproduced except in full without prior written approval.
Materials used to manufacture these products are mercury, asbestos and radio activity free.
Product is RoHS compliant.
No weld repairs made to material.
All certified product is AIS compliant.

FRANK SCHUBERT
Quality Assurance Manager

Econ Information System 07/31/17 11:35 SLEW PAGE 1 of 1

1” Diam. x 17.5” Concrete Anchor Bolt Assembly (1 of 5)



DIME - Printsmtlreport Sample https://dime.dot.ca.gov/index.php?r=sample/printsmtlreport&sample_id=12803

State of California
Department of Transportation
Structural Materials Testing Laboratory
5900 Folsom Boulevard, Sacramento,CA 95819

ACCREDITED
TESTING CERT # 2254.01

TEST REPORT

Remarks

ref: ASTM F1554, A563, F436, A153/F2329, TM03. Bolt Heat #3068105, Lot #68956/W3273; Nut Lot #23746-6214036104; Washer Lot #D3476.

Sample No: 2017-10-18-6

Date Received: 10/24/2017 **Date Sampled:** 10/18/2017

Date Reported: 10/30/2017 **Sampler:** Joe Lanz

Inspector Lot No: L106-008-07

TL-101/SIC No: N/A

Contract/Permit No: 65A0617

Material: 1"x 17.5" F1554 Grade 105 HDG Headed Bolt Assemblies

Manufacturer: UIS

Note: Results relate only to the items tested. Test reports shall only be reproduced for Caltrans administered projects.

Results

Sample(s) submitted comply with material specifications.

Reviewed by: Glen Weldon
Lab Manager

Approved by: ~~Paul Lukkarila~~
SMTL Quality Manager

STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION
SAMPLE IDENTIFICATION CARD DIME Sample ID:2017-10-18-6
TL-0101 (REV. 02/17)

SAMPLE SENT TO:
☐ HDQRS. LAB
☐ BRANCH LAB
☐ DIST. LAB
☑ TRANS. LAB

TEST TYPE:
SHIPMENT NO.
AUTHORIZATION NO.

FIELD NO.
DIST LAB NO.
LOT NO.
P.O. OR REQ. NO.

SAMPLE OF: F1554 Grade 105 HDG Anchor Bolts
FOR USE IN: ~~SAMPLE FROM: Fabricator~~
DEPTH:

LOCATION OF SOURCE: UIS

THIS SAMPLE IS SHIPPED IN(NO. CONTAINERS)		AND IS ONE OF A GROUP OF		SAMPLES REPRESENTING (TONS, GALS, BBLS, STA, ETC.)	

OWNER OR MANUFACTURER: UIS
TOTAL QUANTITY AVAILABLE 40 Bolts 80
TEST RESULTS DESIRED ☐ NORMAL ☐ PRIORITY
DATE NEEDED

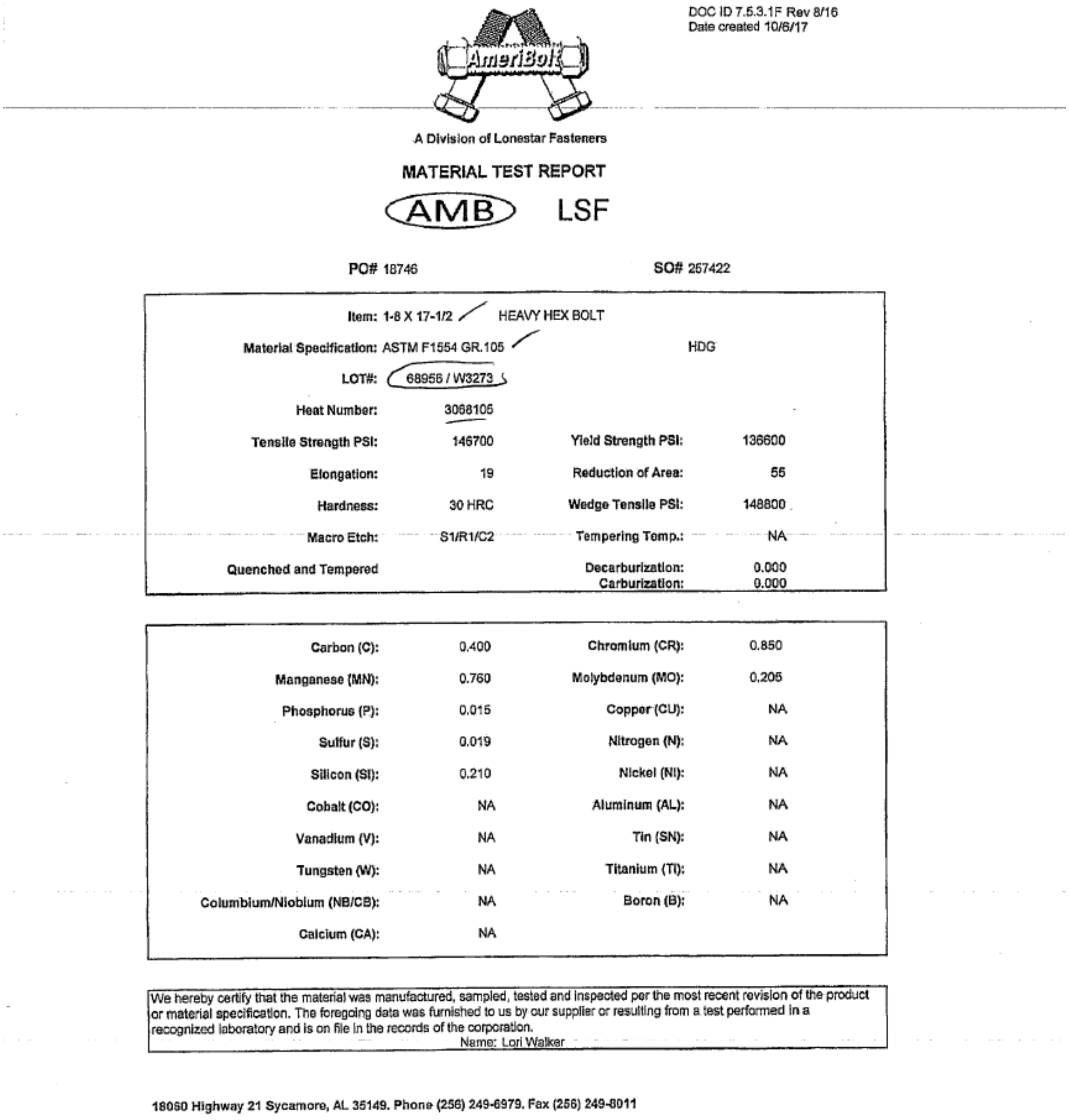
REMARKS:

DATE SAMPLE: 10/18/2017 BY: Joe Lanz
TITLE: QA (7072085241)
DIST. CO. RTE. PM: ---
CONT. NO.: DEA: 65A0617 FED. NO.:
LIMITS:
RECIPIENT(S):
david.whitesel@dot.ca.gov;bob.meline@dot.ca.gov;john.jewell@dot.ca.gov;jlanz@altavistasolutions.com;kenneth.l.varela@dot.ca.gov;LA.METS.Reports@dot.ca.gov

CONTRACTOR:

1 of 1 11/1/2017 11:36 AM

1” Diam. x 17.5” Concrete Anchor Bolt Assembly (2 of 5)



DOC ID 7.5.3.1F Rev 8/16
Date created 10/6/17

A Division of Lonestar Fasteners

MATERIAL TEST REPORT

AMB LSF

PO# 18746 **SO#** 257422

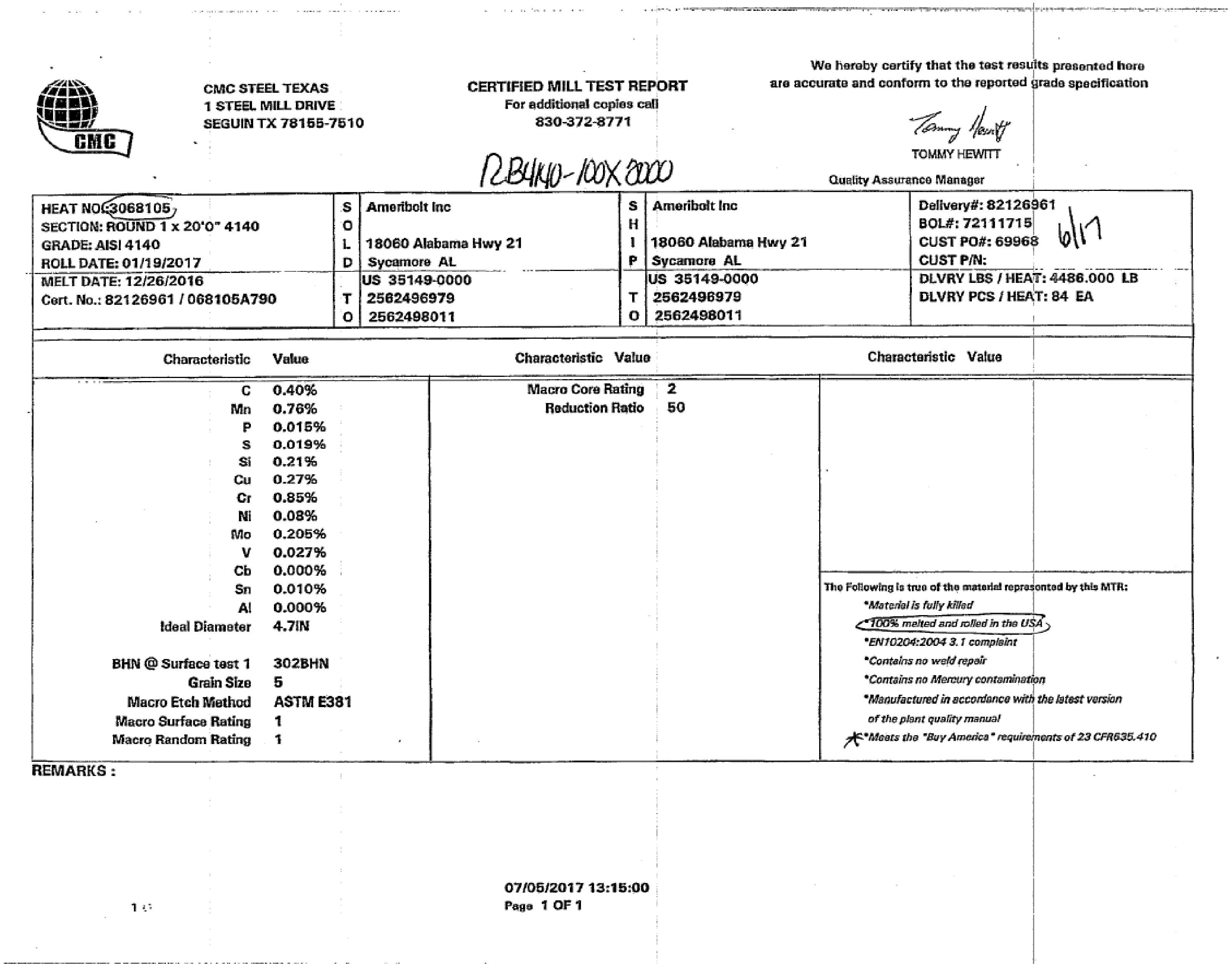
Item:	1-8 X 17-1/2 HEAVY HEX BOLT		
Material Specification:	ASTM F1554 GR.105		HDG
LOT#:	68956 / W3273		
Heat Number:	3068105		
Tensile Strength PSI:	146700	**Yield Strength PSI:**	136600
Elongation:	19	**Reduction of Area:**	55
Hardness:	30 HRC	**Wedge Tensile PSI:**	148800
Macro Etch:	S1/R1/C2	**Tempering Temp.:**	NA
Quenched and Tempered		**Decarburization:**	0.000
		Carburization:	0.000

Carbon (C):	0.400	**Chromium (CR):**	0.850
Manganese (MN):	0.760	**Molybdenum (MO):**	0.205
Phosphorus (P):	0.015	**Copper (CU):**	NA
Sulfur (S):	0.019	**Nitrogen (N):**	NA
Silicon (SI):	0.210	**Nickel (NI):**	NA
Cobalt (CO):	NA	**Aluminum (AL):**	NA
Vanadium (V):	NA	**Tin (SN):**	NA
Tungsten (W):	NA	**Titanium (TI):**	NA
Columbium/Niobium (NB/CB):	NA	**Boron (B):**	NA
Calcium (CA):	NA		

We hereby certify that the material was manufactured, sampled, tested and inspected per the most recent revision of the product or material specification. The foregoing data was furnished to us by our supplier or resulting from a test performed in a recognized laboratory and is on file in the records of the corporation.
Name: Lori Walker

18060 Highway 21 Sycamore, AL 35149. Phone (256) 249-6979. Fax (256) 249-8011

1” Diam. x 17.5” Concrete Anchor Bolt Assembly (3 of 5)



CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

RB4140-100X2000

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

Tommy Hewitt
TOMMY HEWITT
Quality Assurance Manager

HEAT NO: 3068105 SECTION: ROUND 1 x 20'0" 4140 GRADE: AISI 4140 ROLL DATE: 01/19/2017	S O L D	Ameribolt Inc 18060 Alabama Hwy 21 Sycamore AL	S H I P	Ameribolt Inc 18060 Alabama Hwy 21 Sycamore AL	Delivery#: 82126961 BOL#: 72111715 CUST PO#: 69968 6/17 CUST P/N:
MELT DATE: 12/26/2016 Cert. No.: 82126961 / 068105A790	 T O	US 35149-0000 2562496979 2562498011	 T O	US 35149-0000 2562496979 2562498011	DLVRY LBS / HEAT: 4486.000 LB DLVRY PCS / HEAT: 84 EA

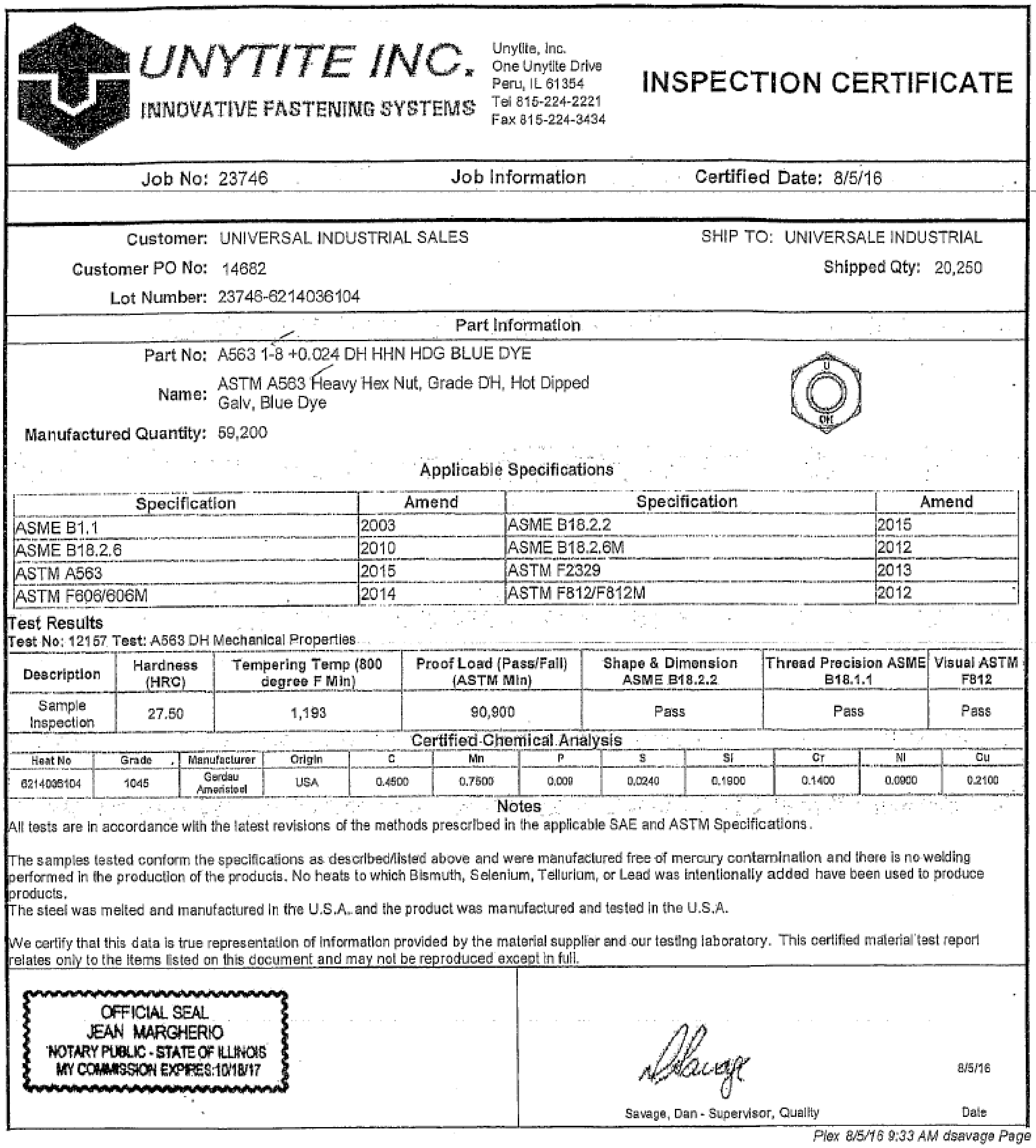
Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.40%	Macro Core Rating	2		
Mn	0.76%	Reduction Ratio	50		
P	0.015%				
S	0.019%				
Si	0.21%				
Cu	0.27%				
Cr	0.85%				
Ni	0.08%				
Mo	0.205%				
V	0.027%				
Cb	0.000%				
Sn	0.010%				
Al	0.000%				
Ideal Diameter	4.7IN				
BHN @ Surface test 1	302BHN				
Grain Size	5				
Macro Etch Method	ASTM E381				
Macro Surface Rating	1				
Macro Random Rating	1				

The Following is true of the material represented by this MTR:
- *Material is fully killed*
- *100% melted and rolled in the USA*
- *EN10204:2004 3.1 complaint*
- *Contains no weld repair*
- *Contains no Mercury contamination*
- *Manufactured in accordance with the latest version of the plant quality manual*
- *Meets the "Buy America" requirements of 23 CFR635.410*

REMARKS :

07/05/2017 13:15:00
Page 1 OF 1

1" Diam. x 17.5" Concrete Anchor Bolt Assembly (4 of 5)



UNYTITE INC.
INNOVATIVE FASTENING SYSTEMS

Unytite, Inc.
One Unytite Drive
Peru, IL 61354
Tel 815-224-2221
Fax 815-224-3434

INSPECTION CERTIFICATE

Job No: 23746 — Job Information — Certified Date: 8/5/16

Customer: UNIVERSAL INDUSTRIAL SALES
SHIP TO: UNIVERSALE INDUSTRIAL
Customer PO No: 14682
Shipped Qty: 20,250
Lot Number: 23746-6214036104

Part Information

Part No: A563 1-8 +0.024 DH HHN HDG BLUE DYE
Name: ASTM A563 Heavy Hex Nut, Grade DH, Hot Dipped Galv, Blue Dye
Manufactured Quantity: 59,200

Applicable Specifications

Specification	Amend	Specification	Amend
ASME B1.1	2003	ASME B18.2.2	2015
ASME B18.2.6	2010	ASME B18.2.6M	2012
ASTM A563	2015	ASTM F2329	2013
ASTM F606/606M	2014	ASTM F812/F812M	2012

Test Results
Test No: 12157 Test: A563 DH Mechanical Properties

Description	Hardness (HRC)	Tempering Temp (800 degree F Min)	Proof Load (Pass/Fail) (ASTM Min)	Shape & Dimension ASME B18.2.2	Thread Precision ASME B18.1.1	Visual ASTM F812
Sample Inspection	27.50	1,193	90,900	Pass	Pass	Pass

Certified Chemical Analysis

Heat No	Grade	Manufacturer	Origin	C	Mn	P	S	Si	Cr	Ni	Cu
6214036104	1045	Gerdau Ameristeel	USA	0.4500	0.7500	0.009	0.0240	0.1900	0.1400	0.0900	0.2100

Notes

All tests are in accordance with the latest revisions of the methods prescribed in the applicable SAE and ASTM Specifications.

The samples tested conform the specifications as described/listed above and were manufactured free of mercury contamination and there is no welding performed in the production of the products. No heats to which Bismuth, Selenium, Tellurium, or Lead was intentionally added have been used to produce products.
The steel was melted and manufactured in the U.S.A. and the product was manufactured and tested in the U.S.A.

We certify that this data is true representation of information provided by the material supplier and our testing laboratory. This certified material test report relates only to the items listed on this document and may not be reproduced except in full.

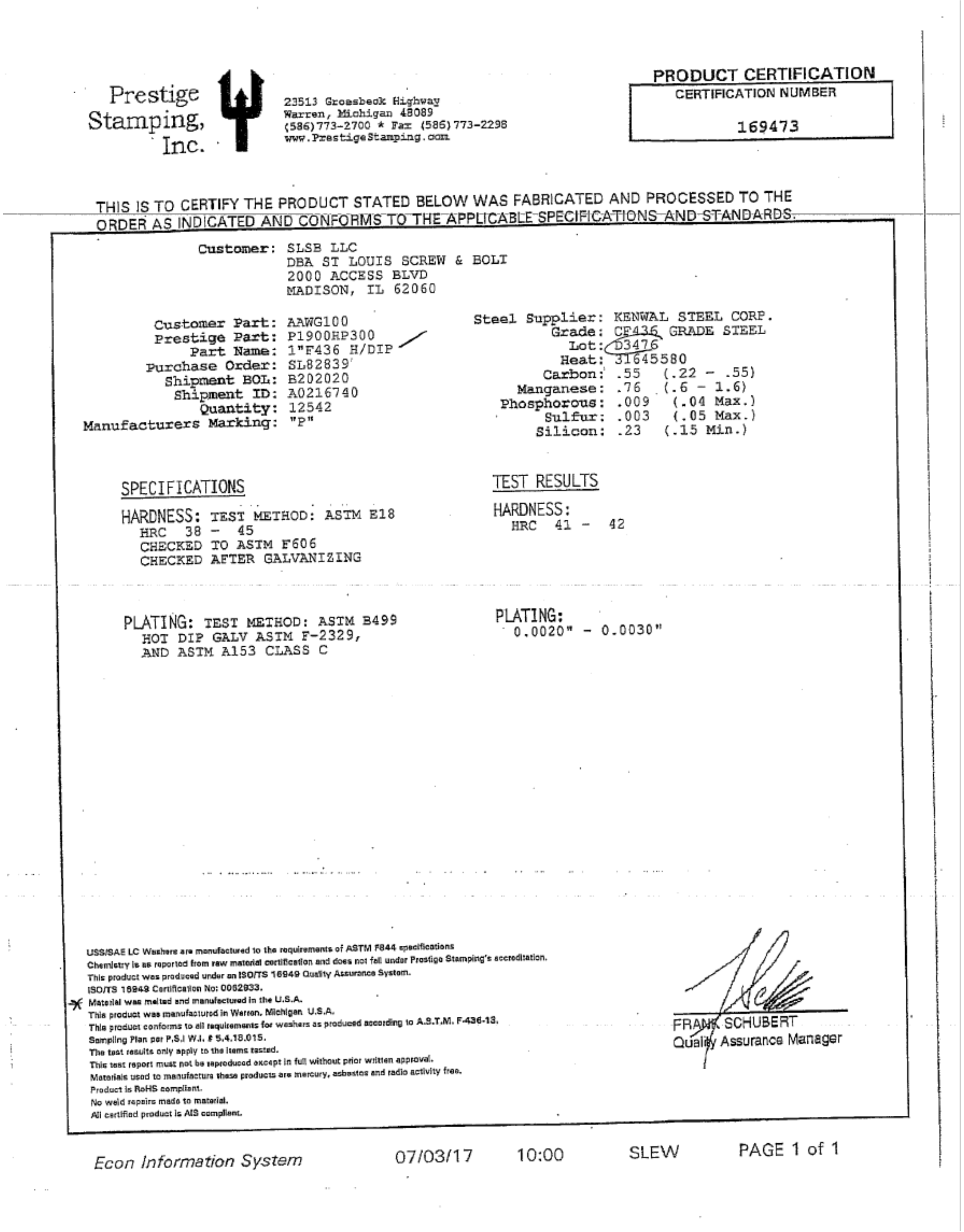
OFFICIAL SEAL
JEAN MARGHERIO
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/18/17

8/5/16

Savage, Dan - Supervisor, Quality — Date

Plex 8/5/16 9:33 AM dsavage Page 1

1” Diam. x 17.5” Concrete Anchor Bolt Assembly (5 of 5)



Prestige Stamping, Inc.

23513 Groesbeck Highway
Warren, Michigan 48089
(586)773-2700 * Fax (586)773-2298
www.PrestigeStamping.com

PRODUCT CERTIFICATION

CERTIFICATION NUMBER
169473

THIS IS TO CERTIFY THE PRODUCT STATED BELOW WAS FABRICATED AND PROCESSED TO THE ORDER AS INDICATED AND CONFORMS TO THE APPLICABLE SPECIFICATIONS AND STANDARDS.

Customer: SLSB LLC
DBA ST LOUIS SCREW & BOLT
2000 ACCESS BLVD
MADISON, IL 62060

Customer Part: AAWG100
Prestige Part: P1900HP300
Part Name: 1"F436 H/DIP
Purchase Order: SL82839
Shipment BOL: B202020
Shipment ID: A0216740
Quantity: 12542
Manufacturers Marking: "P"

Steel Supplier: KENWAL STEEL CORP.
Grade: CF436 GRADE STEEL
Lot: D3476
Heat: 31645580
Carbon: .55 (.22 - .55)
Manganese: .76 (.6 - 1.6)
Phosphorous: .009 (.04 Max.)
Sulfur: .003 (.05 Max.)
Silicon: .23 (.15 Min.)

SPECIFICATIONS

HARDNESS: TEST METHOD: ASTM E18
HRC 38 - 45
CHECKED TO ASTM F606
CHECKED AFTER GALVANIZING

PLATING: TEST METHOD: ASTM B499
HOT DIP GALV ASTM F-2329,
AND ASTM A153 CLASS C

TEST RESULTS

HARDNESS:
HRC 41 - 42

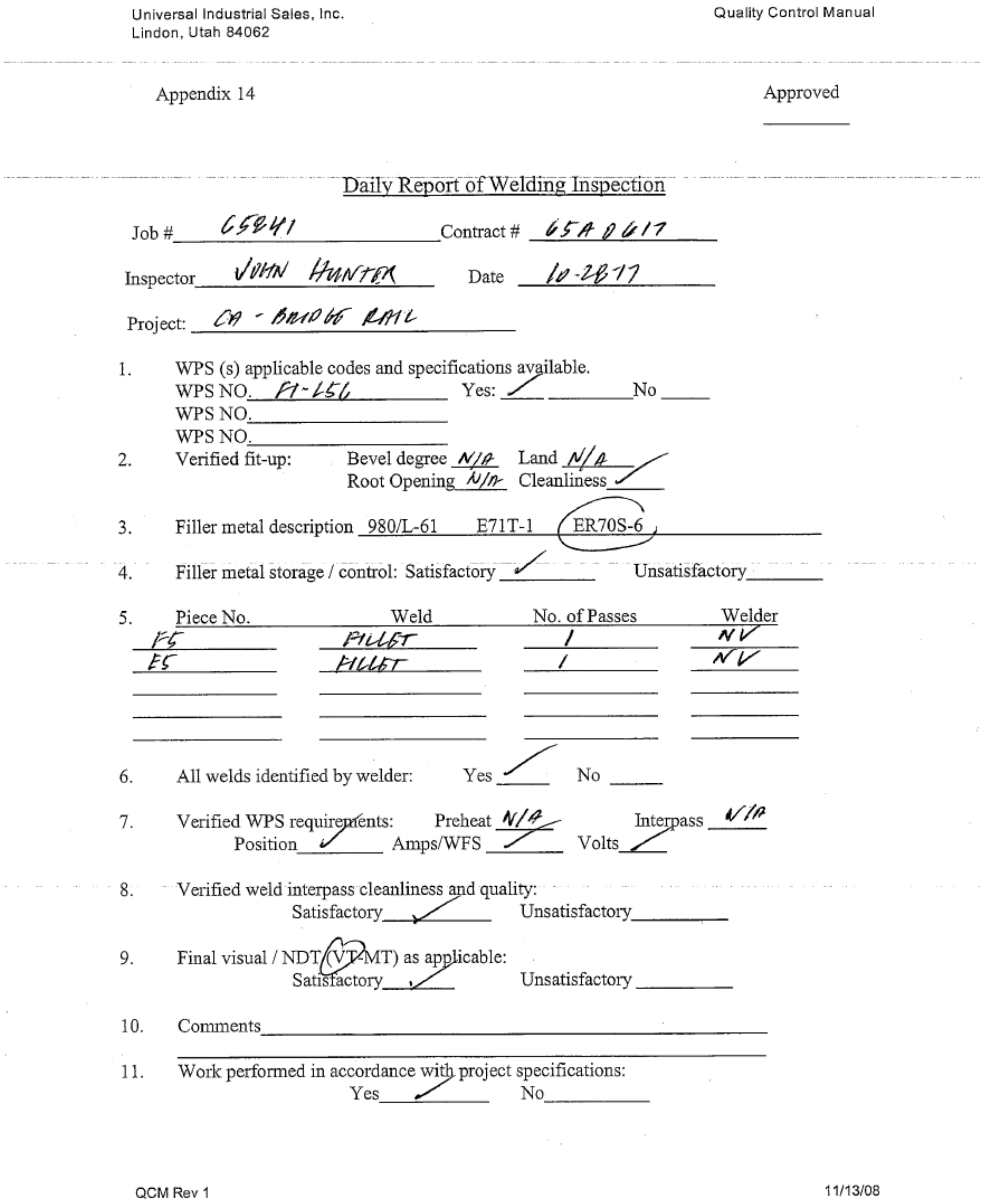
PLATING:
0.0020" - 0.0030"

USS/SAE LC Washers are manufactured to the requirements of ASTM F844 specifications
Chemistry is as reported from raw material certification and does not fall under Prestige Stamping's accreditation.
This product was produced under an ISO/TS 16949 Quality Assurance System.
ISO/TS 16949 Certification No: 0062933.
✱ Material was melted and manufactured in the U.S.A.
This product was manufactured in Warren, Michigan U.S.A.
This product conforms to all requirements for washers as produced according to A.S.T.M. F-436-13.
Sampling Plan per P.S.I W.I. # 5.4.18.015.
The test results only apply to the items tested.
This test report must not be reproduced except in full without prior written approval.
Materials used to manufacture these products are mercury, asbestos and radio activity free.
Product is RoHS compliant.
No weld repairs made to material.
All certified product is AIS compliant.

FRANK SCHUBERT
Quality Assurance Manager

Econ Information System 07/03/17 10:00 SLEW PAGE 1 of 1

Tubular Rail (1 of 16)



Universal Industrial Sales, Inc.
Lindon, Utah 84062

Quality Control Manual

Appendix 14

Approved ________

Daily Report of Welding Inspection

Job # 65241 Contract # 65A0617

Inspector JOHN HUNTER Date 10-28-17

Project: CA - BRIDGE RAIL

1. WPS (s) applicable codes and specifications available.
   WPS NO. F1-L56 Yes: ✓ ________ No _____
   WPS NO.________
   WPS NO.________
2. Verified fit-up: Bevel degree N/A Land N/A ✓
   Root Opening N/A Cleanliness ✓
3. Filler metal description 980/L-61 E71T-1 [✓ ER70S-6]
4. Filler metal storage / control: Satisfactory ✓ Unsatisfactory________
5.

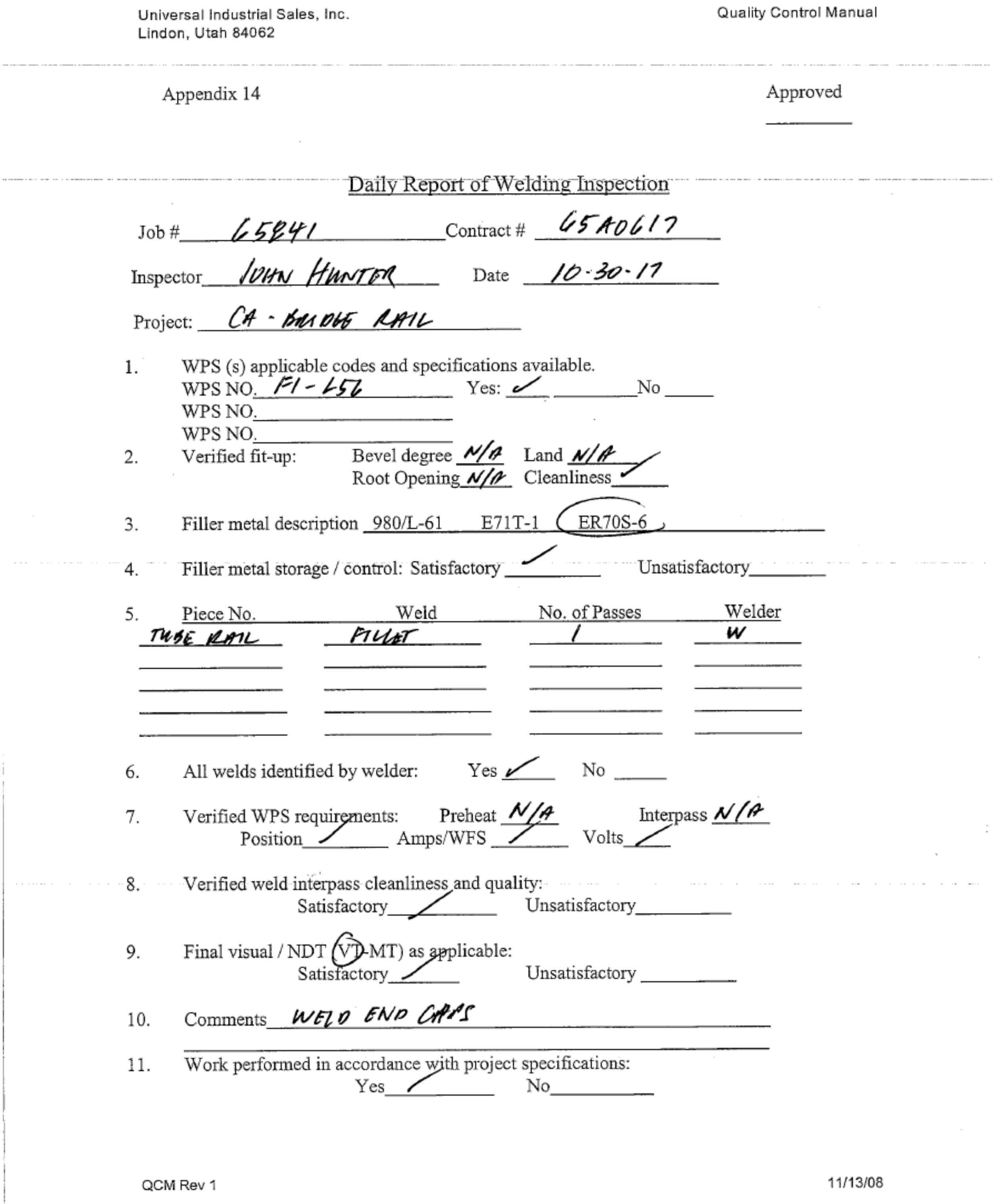
Piece No.	Weld	No. of Passes	Welder
F5	FILLET	1	NV
E5	FILLET	1	NV

6. All welds identified by welder: Yes ✓ No _____
7. Verified WPS requirements: Preheat N/A Interpass N/A
   Position ✓ Amps/WFS ✓ Volts ✓
8. Verified weld interpass cleanliness and quality:
   Satisfactory ✓ Unsatisfactory________
9. Final visual / NDT ([✓ VT]-MT) as applicable:
   Satisfactory ✓ Unsatisfactory ________
10. Comments________
11. Work performed in accordance with project specifications:
    Yes ✓ No________

QCM Rev 1

11/13/08

Tubular Rail (2 of 16)



Universal Industrial Sales, Inc.
Lindon, Utah 84062

Quality Control Manual

Appendix 14

Approved ________

Daily Report of Welding Inspection

Job # 65841 Contract # 65A0617

Inspector JOHN HUNTER Date 10-30-17

Project: CA - BRIDGE RAIL

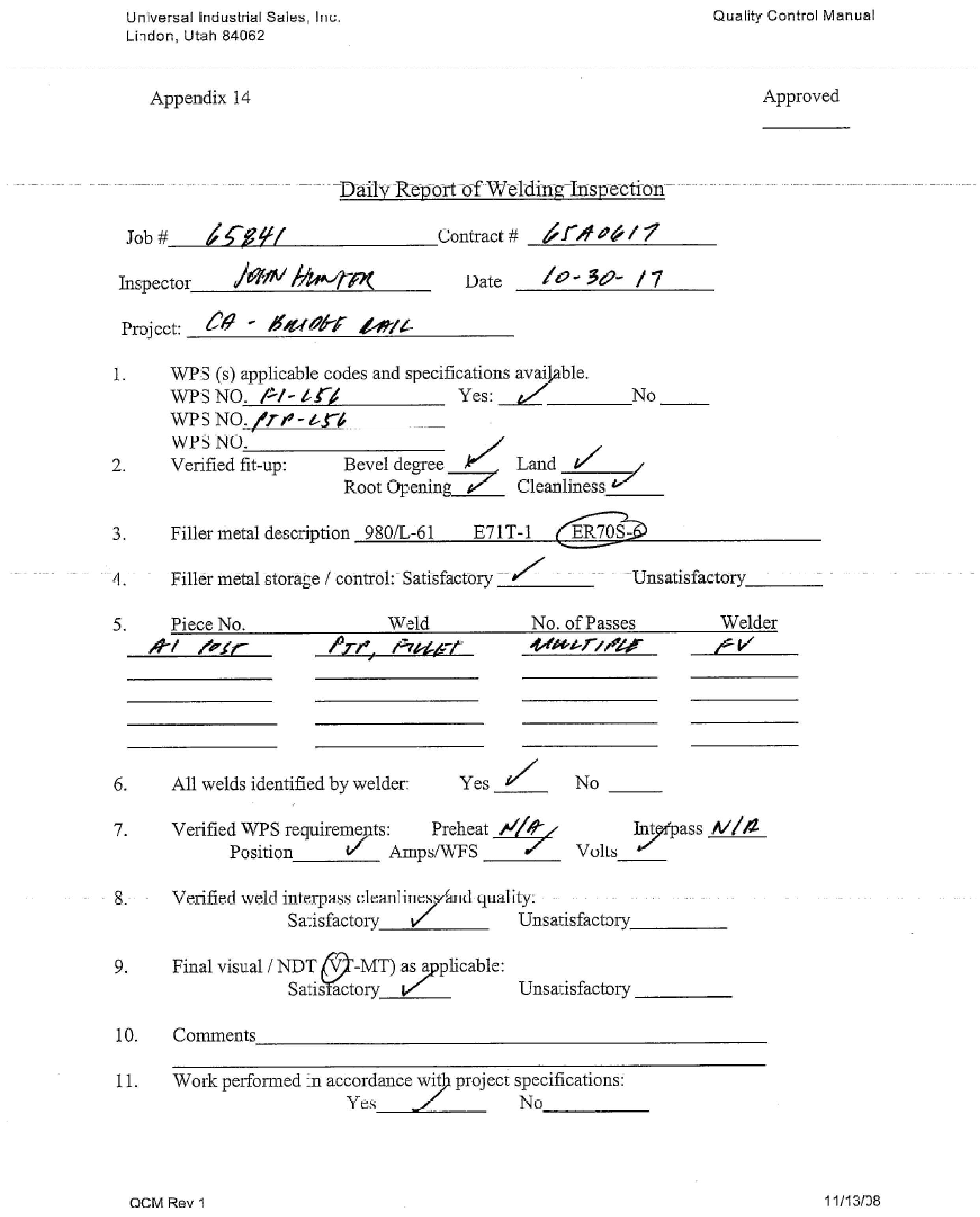
1. WPS (s) applicable codes and specifications available.
   WPS NO. F1-L56 Yes: ✓ ________ No _____
   WPS NO.____________
   WPS NO.____________
2. Verified fit-up: Bevel degree N/A Land N/A ✓
   Root Opening N/A Cleanliness ✓
3. Filler metal description 980/L-61 E71T-1 [✓ ER70S-6]
4. Filler metal storage / control: Satisfactory ✓ Unsatisfactory________
5.

Piece No.	Weld	No. of Passes	Welder
TUBE RAIL	FILLET	1	W

6. All welds identified by welder: Yes ✓ No _____
7. Verified WPS requirements: Preheat N/A Interpass N/A
   Position ✓ Amps/WFS ✓ Volts ✓
8. Verified weld interpass cleanliness and quality:
   Satisfactory ✓ Unsatisfactory__________
9. Final visual / NDT ([✓ VT]-MT) as applicable:
   Satisfactory ✓ Unsatisfactory __________
10. Comments WELD END CAPS
11. Work performed in accordance with project specifications:
    Yes ✓ No__________

QCM Rev 1 11/13/08

Tubular Rail (3 of 16)



Universal Industrial Sales, Inc.
Lindon, Utah 84062

Quality Control Manual

Appendix 14

Approved

Daily Report of Welding Inspection

Job # 65841 Contract # 65A0617

Inspector JOHN HUNTER Date 10-30-17

Project: CA - BRIDGE RAIL

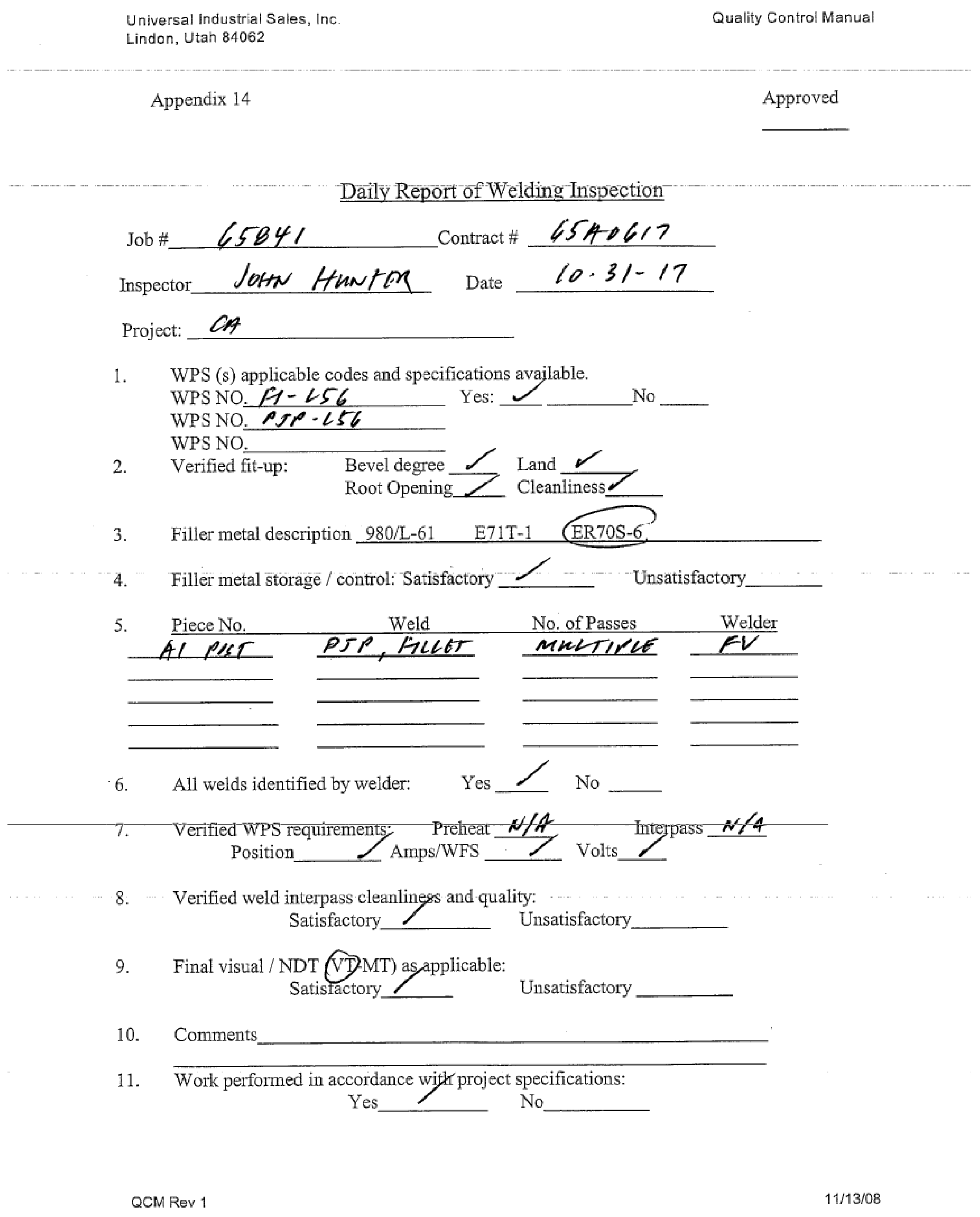
1. WPS (s) applicable codes and specifications available.
   WPS NO. F1-L56 Yes: ✓ No
   WPS NO. PJP-L56
   WPS NO.
2. Verified fit-up: Bevel degree ✓ Land ✓
   Root Opening ✓ Cleanliness ✓
3. Filler metal description 980/L-61 E71T-1 [✓ ER70S-6]
4. Filler metal storage / control: Satisfactory ✓ Unsatisfactory
5.

Piece No.	Weld	No. of Passes	Welder
A1 POST	PJP, FILLET	MULTIPLE	FV

6. All welds identified by welder: Yes ✓ No
7. Verified WPS requirements: Preheat N/A Interpass N/A
   Position ✓ Amps/WFS ✓ Volts ✓
8. Verified weld interpass cleanliness and quality:
   Satisfactory ✓ Unsatisfactory
9. Final visual / NDT ([✓ VT]-MT) as applicable:
   Satisfactory ✓ Unsatisfactory
10. Comments
11. Work performed in accordance with project specifications:
    Yes ✓ No

QCM Rev 1 11/13/08

Tubular Rail (4 of 16)



Universal Industrial Sales, Inc.
Lindon, Utah 84062

Quality Control Manual

Appendix 14

Approved ________

Daily Report of Welding Inspection

Job # 65841 Contract # 65A0617

Inspector JOHN HUNTER Date 10-31-17

Project: CA

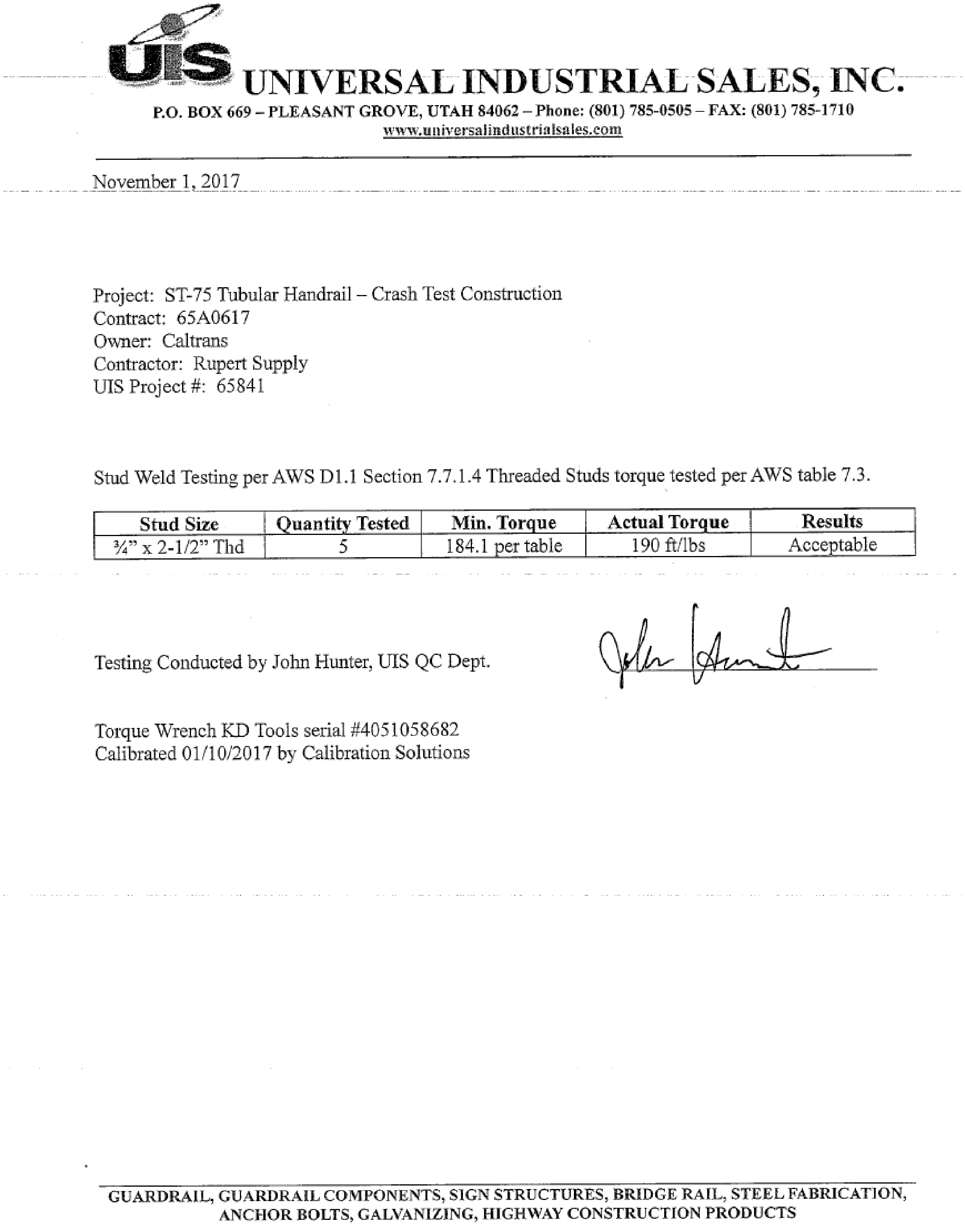
1. WPS (s) applicable codes and specifications available.
   WPS NO. F1-L56 Yes: ✓ No ____
   WPS NO. PJP-L56
   WPS NO. ____
2. Verified fit-up: Bevel degree ✓ Land ✓
   Root Opening ✓ Cleanliness ✓
3. Filler metal description 980/L-61 E71T-1 [✓ ER70S-6]
4. Filler metal storage / control: Satisfactory ✓ Unsatisfactory ____
5.

Piece No.	Weld	No. of Passes	Welder
A1 PLST	PJP, FILLET	MULTIPLE	FV

6. All welds identified by welder: Yes ✓ No ____
7. Verified WPS requirements: Preheat N/A Interpass N/A
   Position ✓ Amps/WFS ✓ Volts ✓
8. Verified weld interpass cleanliness and quality:
   Satisfactory ✓ Unsatisfactory ____
9. Final visual / NDT ([✓ VT] MT) as applicable:
   Satisfactory ✓ Unsatisfactory ____
10. Comments ____
11. Work performed in accordance with project specifications:
    Yes ✓ No ____

QCM Rev 1 11/13/08

Tubular Rail (5 of 16)



UNIVERSAL INDUSTRIAL SALES, INC.
P.O. BOX 669 – PLEASANT GROVE, UTAH 84062 – Phone: (801) 785-0505 – FAX: (801) 785-1710
www.universalindustrialsales.com

November 1, 2017

Project: ST-75 Tubular Handrail – Crash Test Construction
Contract: 65A0617
Owner: Caltrans
Contractor: Rupert Supply
UIS Project #: 65841

Stud Weld Testing per AWS D1.1 Section 7.7.1.4 Threaded Studs torque tested per AWS table 7.3.

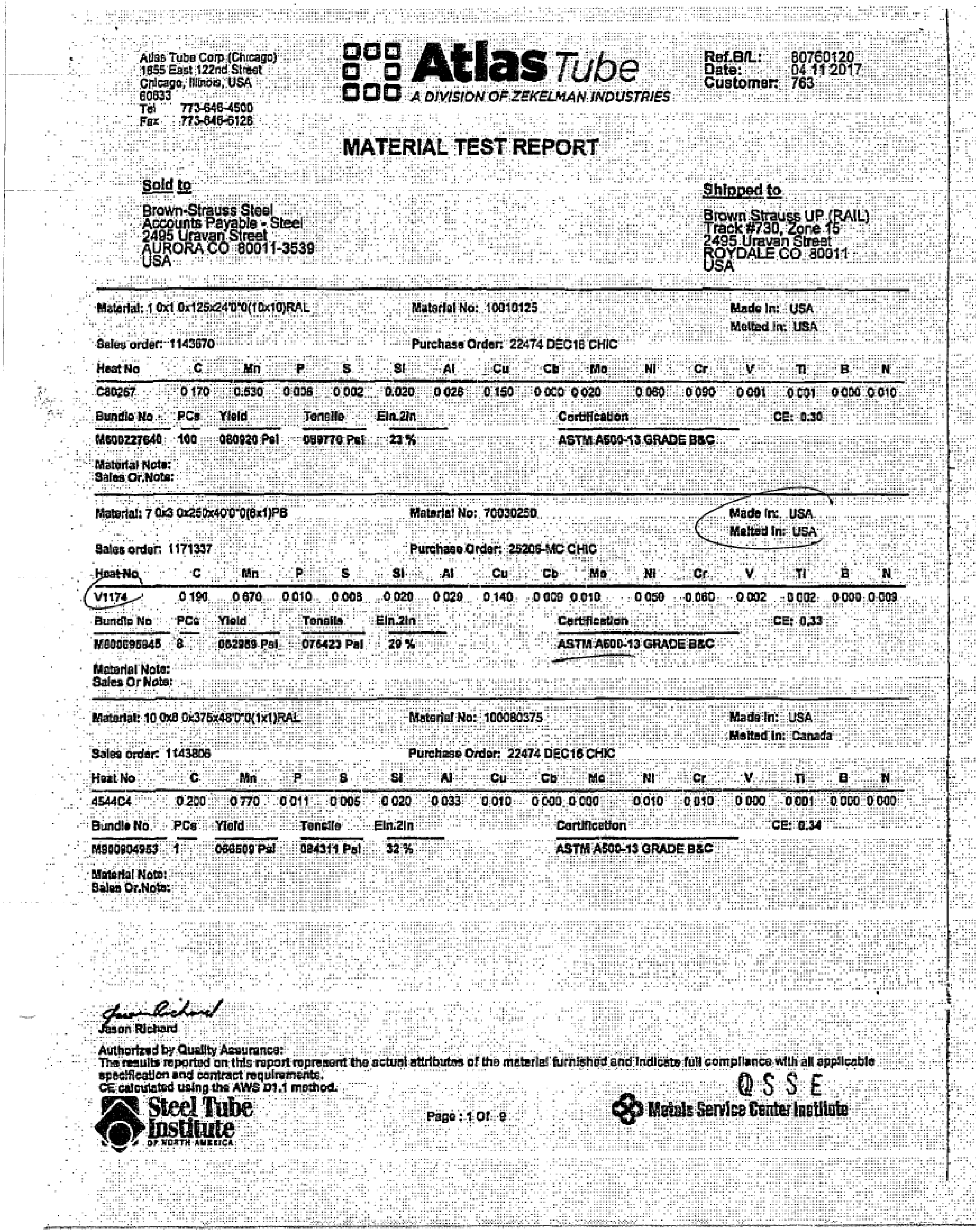
Stud Size	Quantity Tested	Min. Torque	Actual Torque	Results
¾" x 2-1/2" Thd	5	184.1 per table	190 ft/lbs	Acceptable

Testing Conducted by John Hunter, UIS QC Dept.

Torque Wrench KD Tools serial #4051058682
Calibrated 01/10/2017 by Calibration Solutions

GUARDRAIL, GUARDRAIL COMPONENTS, SIGN STRUCTURES, BRIDGE RAIL, STEEL FABRICATION, ANCHOR BOLTS, GALVANIZING, HIGHWAY CONSTRUCTION PRODUCTS

Tubular Rail (6 of 16)



Atlas Tube Corp (Chicago)
1855 East 122nd Street
Chicago, Illinois, USA
60633
Tel 773-646-4500
Fax 773-646-6128

Atlas *Tube*
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80760120
Date: 04 11 2017
Customer: 763

MATERIAL TEST REPORT

Sold to

Brown-Strauss Steel
Accounts Payable - Steel
2495 Uravan Street
AURORA CO 80011-3539
USA

Shipped to

Brown Strauss UP (RAIL)
Track #730, Zone 15
2495 Uravan Street
ROYDALE CO 80011
USA

Material: 1 0x1 0x125x24'0"0(10x10)RAL **Material No:** 10010125 **Made In:** USA
Melted In: USA
Sales order: 1143670 **Purchase Order:** 22474 DEC16 CHIC

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
C80267	0 170	0.530	0 006	0 002	0.020	0 026	0.150	0 000	0 020	0 060	0 090	0 001	0 001	0 000	0 010

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.30
M600227640	100	080920 Psi	099770 Psi	23 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 7 0x3 0x250x40'0"0(8x1)PB **Material No:** 70030250 **Made In:** USA
Melted In: USA
Sales order: 1171337 **Purchase Order:** 25206-MC CHIC

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
V1174	0 190	0 670	0.010	0.008	0 020	0 029	0 140	0 009	0.010	0 050	0.060	0.002	0 002	0 000	0 009

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0,33
M600695845	8	062959 Psi	076423 Psi	29 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or Note:

Material: 10 0x8 0x375x48'0"0(1x1)RAL **Material No:** 100080375 **Made In:** USA
Melted In: Canada
Sales order: 1143806 **Purchase Order:** 22474 DEC16 CHIC

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
4544C4	0 200	0 770	0 011	0 005	0 020	0 033	0 010	0 000	0 000	0 010	0 010	0 000	0 001	0 000	0 000

Bundle No.	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.34
M900904953	1	068509 Psi	084311 Psi	32 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Jason Richard
Jason Richard

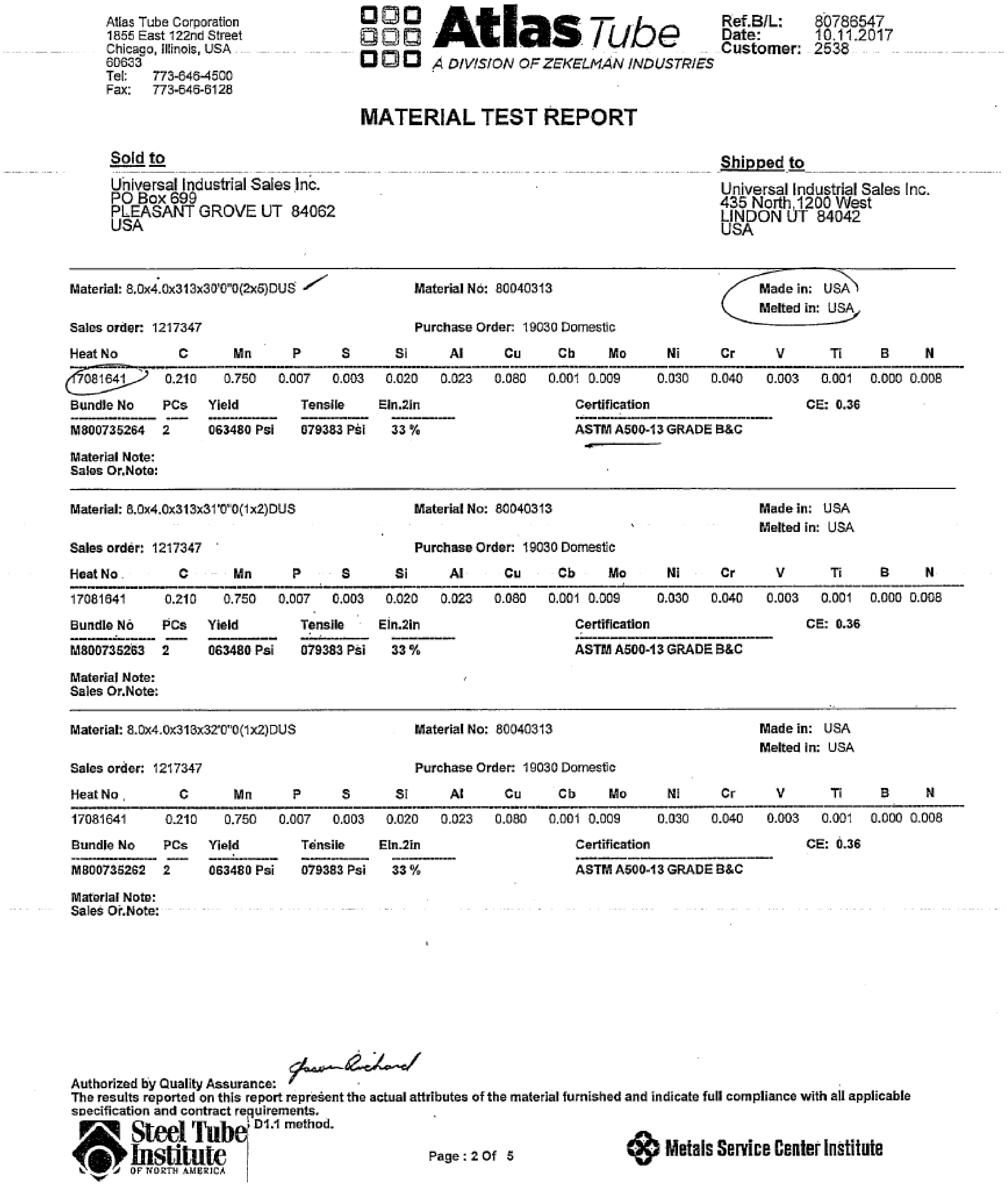
Authorized by Quality Assurance:
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
CE calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 1 Of 9

Q S S E
Metals Service Center Institute

Tubular Rail (7 of 16)



Atlas Tube Corporation
1855 East 122nd Street
Chicago, Illinois, USA
60633
Tel: 773-646-4500
Fax: 773-646-6128

Atlas *Tube*
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80786547
Date: 10.11.2017
Customer: 2538

MATERIAL TEST REPORT

Sold to
Universal Industrial Sales Inc.
PO Box 699
PLEASANT GROVE UT 84062
USA

Shipped to
Universal Industrial Sales Inc.
435 North 1200 West
LINDON UT 84042
USA

Material: 8.0x4.0x313x30'0"0(2x5)DUS **Material No:** 80040313 **Made in:** USA **Melted in:** USA

Sales order: 1217347 **Purchase Order:** 19030 Domestic

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
17081641	0.210	0.750	0.007	0.003	0.020	0.023	0.080	0.001	0.009	0.030	0.040	0.003	0.001	0.000	0.008

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800735264	2	063480 Psi	079383 Psi	33 %	ASTM A500-13 GRADE B&C	0.36

Material Note:
Sales Or.Note:

Material: 8.0x4.0x313x31'0"0(1x2)DUS **Material No:** 80040313 **Made in:** USA **Melted in:** USA

Sales order: 1217347 **Purchase Order:** 19030 Domestic

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
17081641	0.210	0.750	0.007	0.003	0.020	0.023	0.080	0.001	0.009	0.030	0.040	0.003	0.001	0.000	0.008

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800735263	2	063480 Psi	079383 Psi	33 %	ASTM A500-13 GRADE B&C	0.36

Material Note:
Sales Or.Note:

Material: 8.0x4.0x313x32'0"0(1x2)DUS **Material No:** 80040313 **Made in:** USA **Melted in:** USA

Sales order: 1217347 **Purchase Order:** 19030 Domestic

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
17081641	0.210	0.750	0.007	0.003	0.020	0.023	0.080	0.001	0.009	0.030	0.040	0.003	0.001	0.000	0.008

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800735262	2	063480 Psi	079383 Psi	33 %	ASTM A500-13 GRADE B&C	0.36

Material Note:
Sales Or.Note:

Authorized by Quality Assurance: Jason Richard
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.

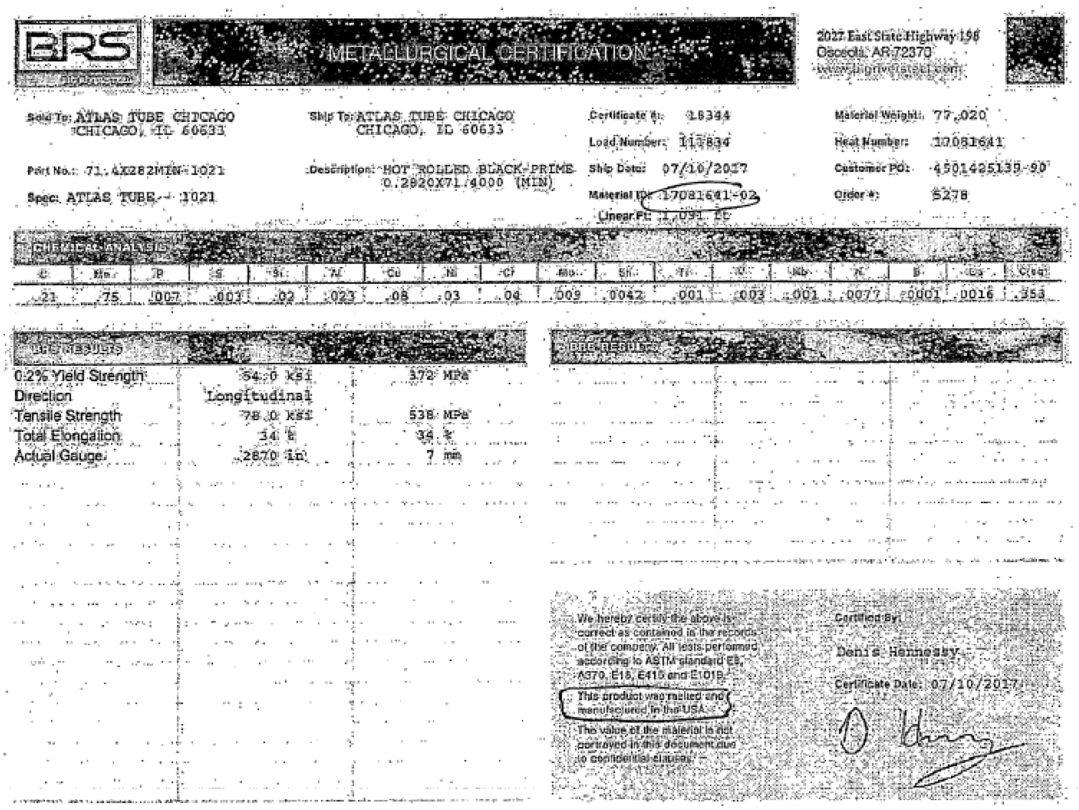
Steel Tube Institute OF NORTH AMERICA

D1.1 method.

Page : 2 Of 5

Metals Service Center Institute

Tubular Rail (8 of 16)



BRS

METALLURGICAL CERTIFICATION

2027 East State Highway 198
Osceola, AR 72370
www.bigriversteel.com

Sold To: ATLAS TUBE CHICAGO CHICAGO, IL 60633	Ship To: ATLAS TUBE CHICAGO CHICAGO, IL 60633	Certificate #: 18344	Material Weight: 77,020
		Load Number: 111834	Heat Number: 17081641
Part No.: 71.4X282MIN-1021	Description: HOT ROLLED BLACK PRIME 0.2820X71.4000 (MIN)	Ship Date: 07/10/2017	Customer PO: 4501425139-90
Spec: ATLAS TUBE - 1021		Material ID: 17081641-02	Order #: 5278
		Linear Ft: 1,091 Ft	

CHEMICAL ANALYSIS

C	Mn	P	S	Si	Al	Cu	Ni	Cr	Mo	Sn	Ti	V	Nb	N	B	Ca	C(eq)
.21	.75	.007	.003	.02	.023	.08	.03	.04	.009	.0042	.001	.003	.001	.0077	.0001	.0016	.353

0.2% Yield Strength	54.0 ksi	372 MPa
Direction	Longitudinal	
Tensile Strength	78.0 ksi	538 MPa
Total Elongation	34 %	34 %
Actual Gauge	.2870 in	7 mm

We hereby certify the above is correct as contained in the records of the company. All tests performed according to ASTM standard E8, A370, E18, E415 and E1019.

This product was melted and manufactured in the USA.

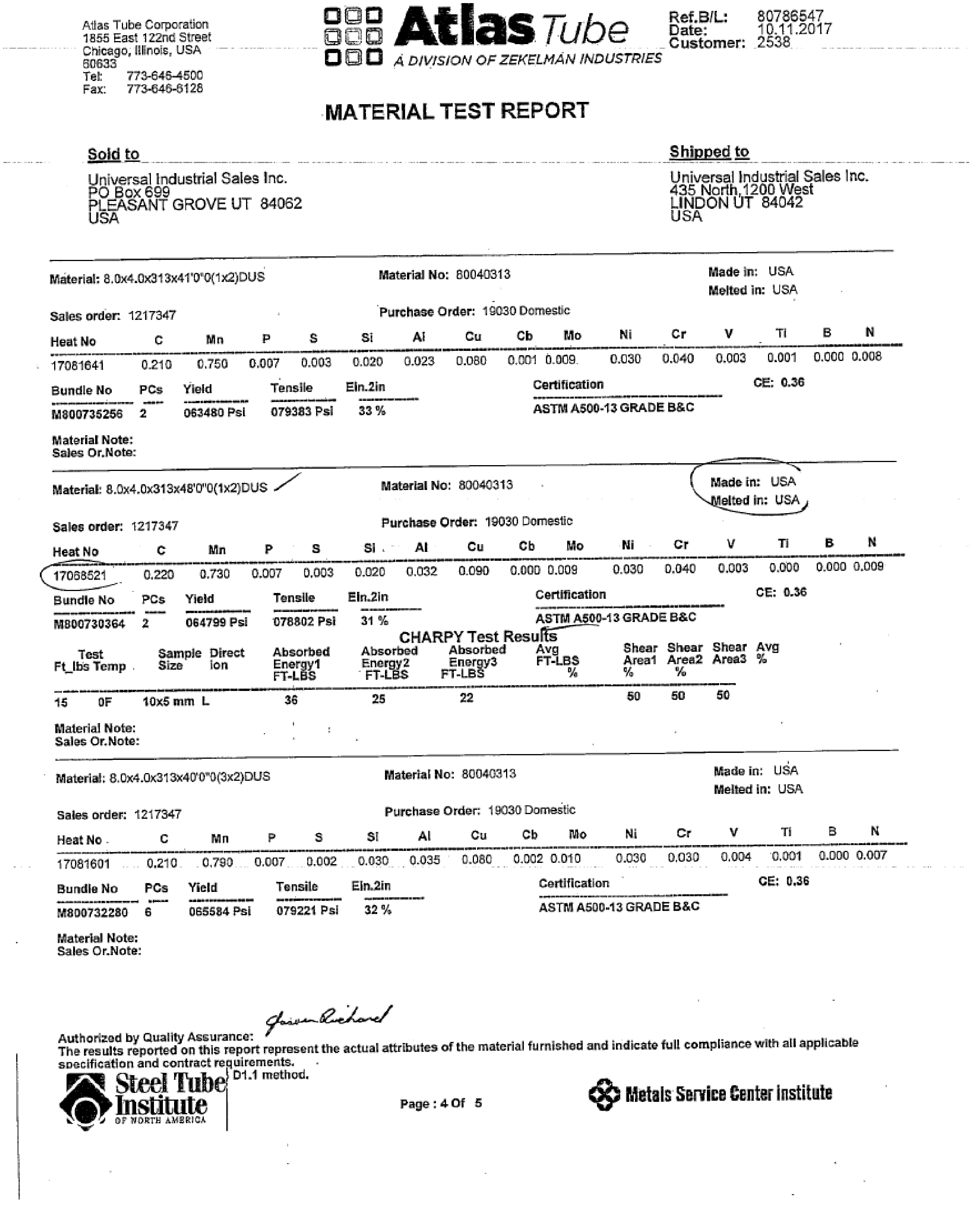
The value of the material is not portrayed in this document due to confidential clauses.

Certified By:

Denis Hennessy

Certificate Date: 07/10/2017

Tubular Rail (9 of 16)



Atlas Tube Corporation
1855 East 122nd Street
Chicago, Illinois, USA
60633
Tel: 773-646-4500
Fax: 773-646-6126

Atlas *Tube*
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80786547
Date: 10.11.2017
Customer: 2538

MATERIAL TEST REPORT

Sold to

Universal Industrial Sales Inc.
PO Box 699
PLEASANT GROVE UT 84062
USA

Shipped to

Universal Industrial Sales Inc.
435 North,1200 West
LINDON UT 84042
USA

Material: 8.0x4.0x313x41'0"0(1x2)DUS
Material No: 80040313
Made in: USA
Melted in: USA
Sales order: 1217347
Purchase Order: 19030 Domestic

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
17081641	0.210	0.750	0.007	0.003	0.020	0.023	0.080	0.001	0.009	0.030	0.040	0.003	0.001	0.000	0.008

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.36
M800735256	2	063480 Psi	079383 Psi	33 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 8.0x4.0x313x48'0"0(1x2)DUS
Material No: 80040313
Made in: USA
Melted in: USA
Sales order: 1217347
Purchase Order: 19030 Domestic

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
17068521	0.220	0.730	0.007	0.003	0.020	0.032	0.090	0.000	0.009	0.030	0.040	0.003	0.000	0.000	0.009

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.36
M800730364	2	064799 Psi	078802 Psi	31 %	ASTM A500-13 GRADE B&C	

CHARPY Test Results

Test Ft_lbs	Temp	Sample Size	Direct ion	Absorbed Energy1 FT-LBS	Absorbed Energy2 FT-LBS	Absorbed Energy3 FT-LBS	Avg FT-LBS %	Shear Area1 %	Shear Area2 %	Shear Area3	Avg %
15	0F	10x5 mm	L	36	25	22		50	50	50	

Material Note:
Sales Or.Note:

Material: 8.0x4.0x313x40'0"0(3x2)DUS
Material No: 80040313
Made in: USA
Melted in: USA
Sales order: 1217347
Purchase Order: 19030 Domestic

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
17081601	0.210	0.790	0.007	0.002	0.030	0.035	0.080	0.002	0.010	0.030	0.030	0.004	0.001	0.000	0.007

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.36
M800732280	6	065584 Psi	079221 Psi	32 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Authorized by Quality Assurance: Jason Richard
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
D1.1 method.

Steel Tube Institute OF NORTH AMERICA

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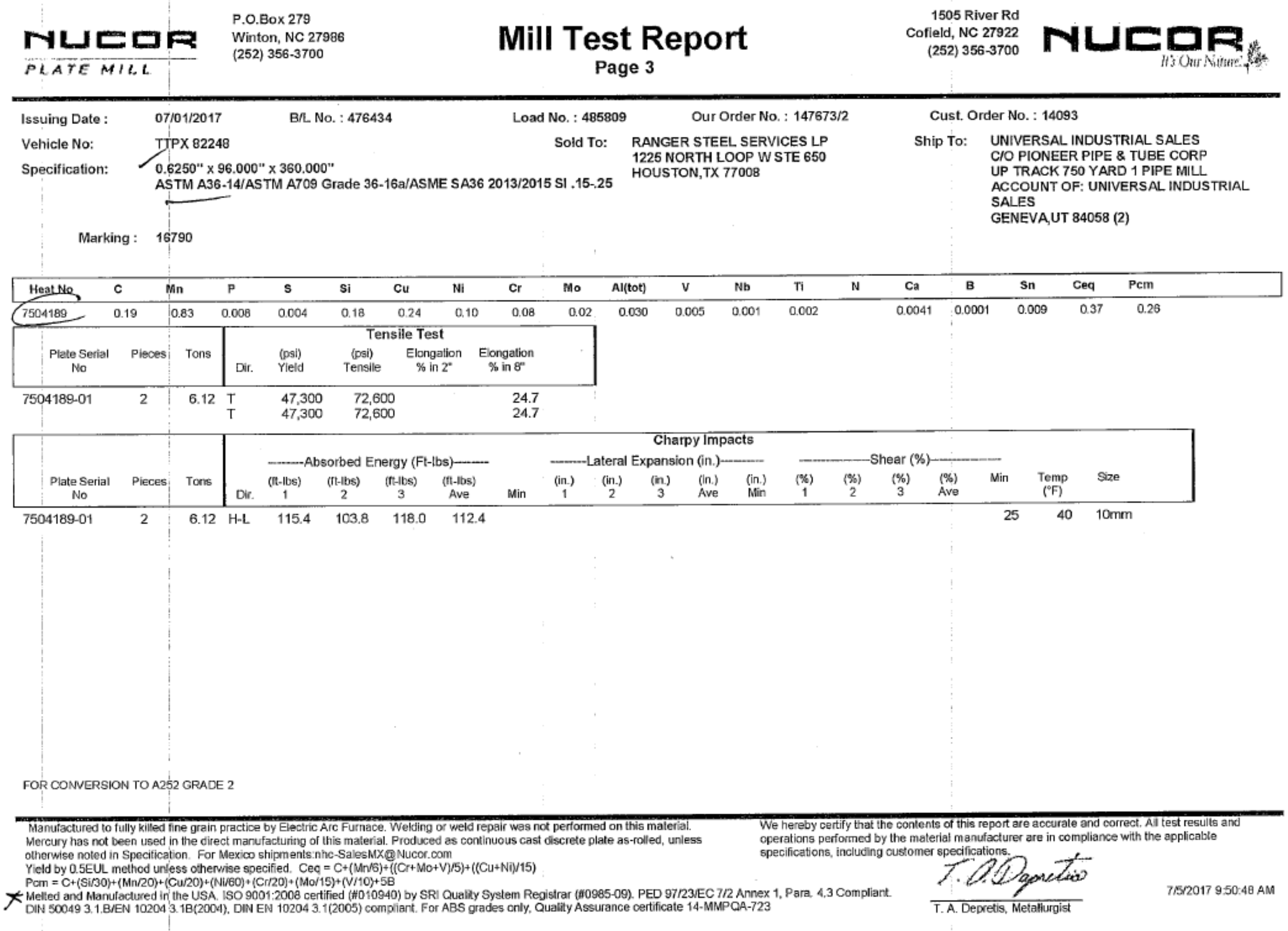
Metals Service Center Institute

Tubular Rail (10 of 16)



NUCOR
PLATE MILL

P.O.Box 279
Winton, NC 27986
(252) 356-3700

Mill Test Report
Page 3

1505 River Rd
Cofield, NC 27922
(252) 356-3700

NUCOR
It's Our Nature.

Issuing Date : 07/01/2017 B/L No. : 476434 Load No. : 485809 Our Order No. : 147673/2 Cust. Order No. : 14093

Vehicle No: TTPX 82248

Specification: 0.6250" x 96.000" x 360.000"
ASTM A36-14/ASTM A709 Grade 36-16a/ASME SA36 2013/2015 SI .15-.25

Sold To:
RANGER STEEL SERVICES LP
1225 NORTH LOOP W STE 650
HOUSTON,TX 77008

Ship To:
UNIVERSAL INDUSTRIAL SALES
C/O PIONEER PIPE & TUBE CORP
UP TRACK 750 YARD 1 PIPE MILL
ACCOUNT OF: UNIVERSAL INDUSTRIAL SALES
GENEVA,UT 84058 (2)

Marking : 16790

Heat No	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al(tot)	V	Nb	Ti	N	Ca	B	Sn	Ceq	Pcm
7504189	0.19	0.83	0.008	0.004	0.18	0.24	0.10	0.08	0.02	0.030	0.005	0.001	0.002		0.0041	0.0001	0.009	0.37	0.26

			Tensile Test				
Plate Serial No	Pieces	Tons	Dir.	(psi) Yield	(psi) Tensile	Elongation % in 2"	Elongation % in 8"
7504189-01	2	6.12	T	47,300	72,600		24.7
			T	47,300	72,600		24.7

			Charpy Impacts																	
				Absorbed Energy (Ft-lbs)					Lateral Expansion (in.)					Shear (%)						
Plate Serial No	Pieces	Tons	Dir.	(ft-lbs) 1	(ft-lbs) 2	(ft-lbs) 3	(ft-lbs) Ave	Min	(in.) 1	(in.) 2	(in.) 3	(in.) Ave	(in.) Min	(%) 1	(%) 2	(%) 3	(%) Ave	Min	Temp (°F)	Size
7504189-01	2	6.12	H-L	115.4	103.8	118.0	112.4											25	40	10mm

FOR CONVERSION TO A252 GRADE 2

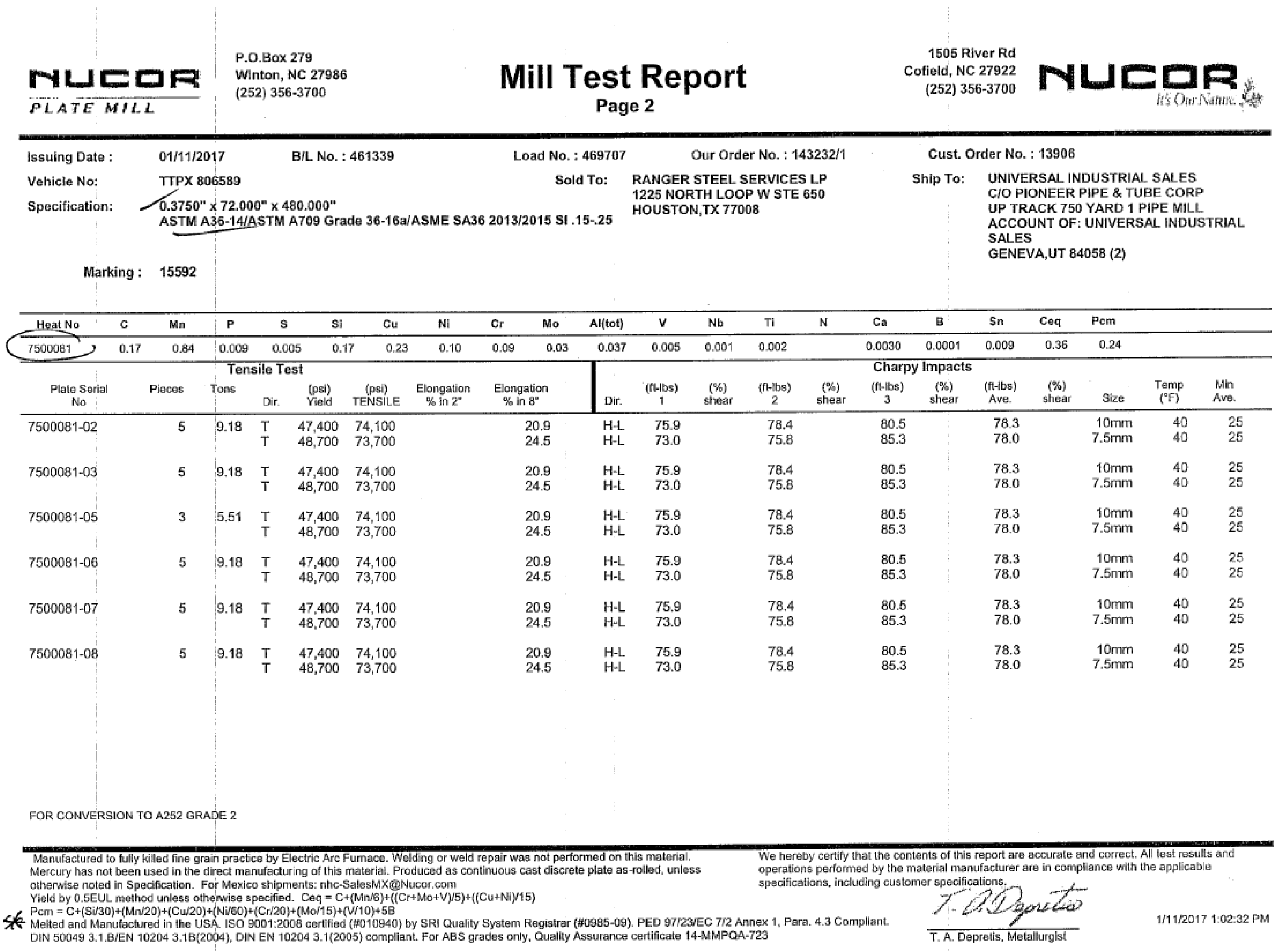
Manufactured to fully killed fine grain practice by Electric Arc Furnace. Welding or weld repair was not performed on this material. Mercury has not been used in the direct manufacturing of this material. Produced as continuous cast discrete plate as-rolled, unless otherwise noted in Specification. For Mexico shipments:nhc-SalesMX@Nucor.com
Yield by 0.5EUL method unless otherwise specified. Ceq = C+(Mn/6)+((Cr+Mo+V)/5)+((Cu+Ni)/15)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B
Melted and Manufactured in the USA. ISO 9001:2008 certified (#010940) by SRI Quality System Registrar (#0985-09). PED 97/23/EC 7/2 Annex 1, Para. 4.3 Compliant.
DIN 50049 3.1.B/EN 10204 3.1B(2004), DIN EN 10204 3.1(2005) compliant. For ABS grades only, Quality Assurance certificate 14-MMPQA-723

We hereby certify that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with the applicable specifications, including customer specifications.

T. A. Depretis
T. A. Depretis, Metallurgist

7/5/2017 9:50:48 AM

Tubular Rail (11 of 16)



NUCOR
PLATE MILL

P.O.Box 279
Winton, NC 27986
(252) 356-3700

Mill Test Report

Page 2

1505 River Rd
Cofield, NC 27922
(252) 356-3700

NUCOR
It's Our Nature.

Issuing Date : 01/11/2017 B/L No. : 461339 Load No. : 469707 Our Order No. : 143232/1 Cust. Order No. : 13906

Vehicle No: TTPX 806589

Specification: 0.3750" x 72.000" x 480.000"
ASTM A36-14/ASTM A709 Grade 36-16a/ASME SA36 2013/2015 SI .15-.25

Marking : 15592

Sold To:
RANGER STEEL SERVICES LP
1225 NORTH LOOP W STE 650
HOUSTON,TX 77008

Ship To:
UNIVERSAL INDUSTRIAL SALES
C/O PIONEER PIPE & TUBE CORP
UP TRACK 750 YARD 1 PIPE MILL
ACCOUNT OF: UNIVERSAL INDUSTRIAL
SALES
GENEVA,UT 84058 (2)

Heat No	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al(tot)	V	Nb	Ti	N	Ca	B	Sn	Ceq	Pcm
7500081	0.17	0.84	0.009	0.005	0.17	0.23	0.10	0.09	0.03	0.037	0.005	0.001	0.002		0.0030	0.0001	0.009	0.36	0.24

		Tensile Test						Charpy Impacts											
Plate Serial No	Pieces	Tons	Dir.	(psi) Yield	(psi) TENSILE	Elongation % in 2"	Elongation % in 8"	Dir.	(ft-lbs) 1	(%) shear	(ft-lbs) 2	(%) shear	(ft-lbs) 3	(%) shear	(ft-lbs) Ave.	(%) shear	Size	Temp (°F)	Min Ave.
7500081-02	5	9.18	T	47,400	74,100		20.9	H-L	75.9		78.4		80.5		78.3		10mm	40	25
			T	48,700	73,700		24.5	H-L	73.0		75.8		85.3		78.0		7.5mm	40	25
7500081-03	5	9.18	T	47,400	74,100		20.9	H-L	75.9		78.4		80.5		78.3		10mm	40	25
			T	48,700	73,700		24.5	H-L	73.0		75.8		85.3		78.0		7.5mm	40	25
7500081-05	3	5.51	T	47,400	74,100		20.9	H-L	75.9		78.4		80.5		78.3		10mm	40	25
			T	48,700	73,700		24.5	H-L	73.0		75.8		85.3		78.0		7.5mm	40	25
7500081-06	5	9.18	T	47,400	74,100		20.9	H-L	75.9		78.4		80.5		78.3		10mm	40	25
			T	48,700	73,700		24.5	H-L	73.0		75.8		85.3		78.0		7.5mm	40	25
7500081-07	5	9.18	T	47,400	74,100		20.9	H-L	75.9		78.4		80.5		78.3		10mm	40	25
			T	48,700	73,700		24.5	H-L	73.0		75.8		85.3		78.0		7.5mm	40	25
7500081-08	5	9.18	T	47,400	74,100		20.9	H-L	75.9		78.4		80.5		78.3		10mm	40	25
			T	48,700	73,700		24.5	H-L	73.0		75.8		85.3		78.0		7.5mm	40	25

FOR CONVERSION TO A252 GRADE 2

Manufactured to fully killed fine grain practice by Electric Arc Furnace. Welding or weld repair was not performed on this material. Mercury has not been used in the direct manufacturing of this material. Produced as continuous cast discrete plate as-rolled, unless otherwise noted in Specification. For Mexico shipments: nhc-SalesMX@Nucor.com
Yield by 0.5EUL method unless otherwise specified. Ceq = C+(Mn/6)+((Cr+Mo+V)/5)+((Cu+Ni)/15)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B
Melted and Manufactured in the USA. ISO 9001:2008 certified (#010940) by SRI Quality System Registrar (#0985-09). PED 97/23/EC 7/2 Annex 1, Para. 4.3 Compliant. DIN 50049 3.1.B/EN 10204 3.1B(2004), DIN EN 10204 3.1(2005) compliant. For ABS grades only, Quality Assurance certificate 14-MMPQA-723

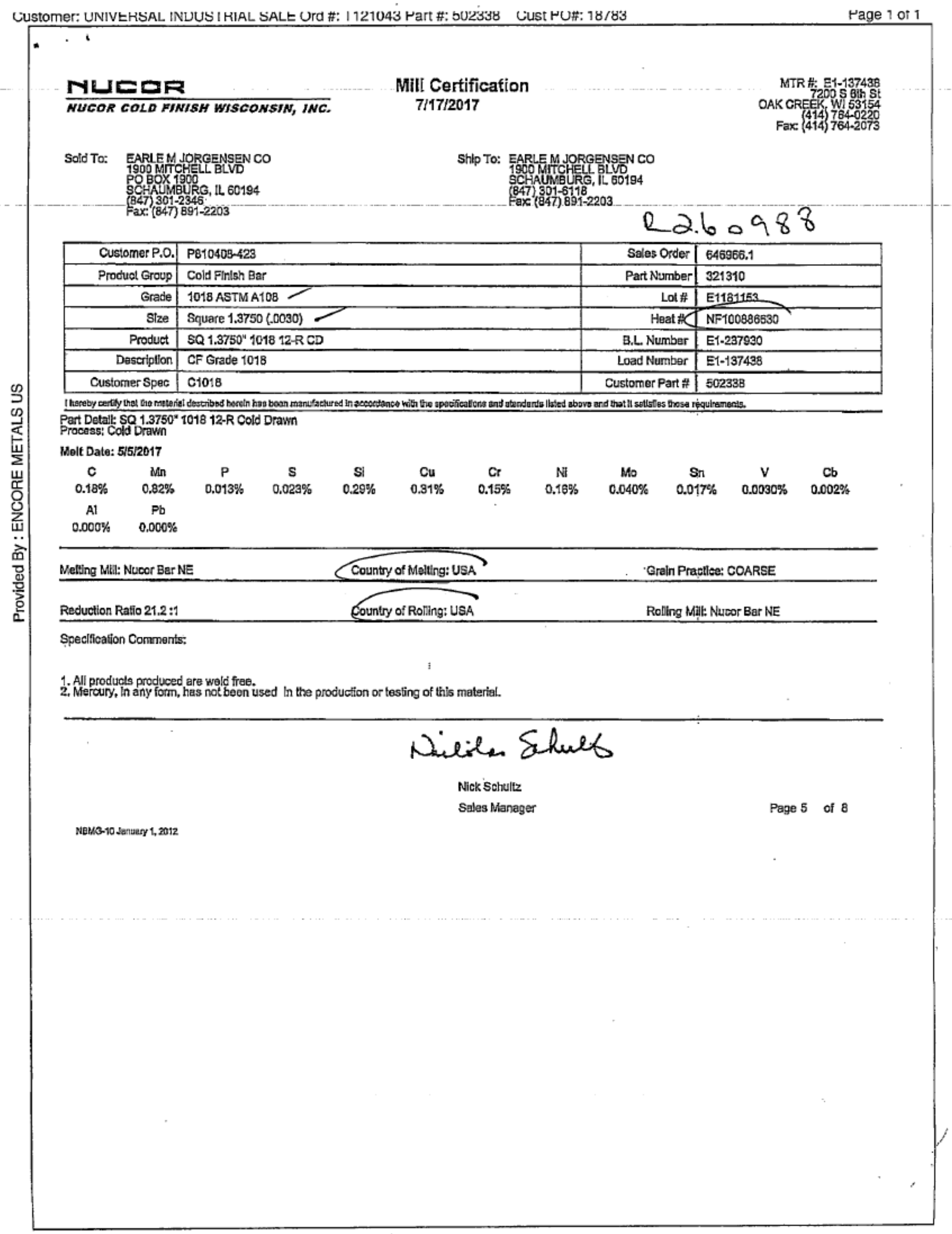
We hereby certify that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with the applicable specifications, including customer specifications.

T. A. Depretis

T. A. Depretis, Metallurgist

1/11/2017 1:02:32 PM

Tubular Rail (12 of 16)



Customer: UNIVERSAL INDUSTRIAL SALE Ord #: 1121043 Part #: 502338 Cust PO#: 18783 Page 1 of 1

NUCOR
NUCOR COLD FINISH WISCONSIN, INC.

Mill Certification
7/17/2017

MTR #: E1-137438
7200 S 6th St
OAK CREEK, WI 53154
(414) 764-0220
Fax: (414) 764-2073

Sold To:
EARLE M JORGENSEN CO
1900 MITCHELL BLVD
PO BOX 1900
SCHAUMBURG, IL 60194
(847) 301-2346
Fax: (847) 891-2203

Ship To:
EARLE M JORGENSEN CO
1900 MITCHELL BLVD
SCHAUMBURG, IL 60194
(847) 301-6118
Fax: (847) 891-2203

R260988

Customer P.O.	P610408-423	Sales Order	646966.1
Product Group	Cold Finish Bar	Part Number	321310
Grade	1018 ASTM A108	Lot #	E1161153
Size	Square 1.3750 (.0030)	Heat #	NF100886630
Product	SQ 1.3750" 1018 12-R CD	B.L. Number	E1-237930
Description	CF Grade 1018	Load Number	E1-137438
Customer Spec	C1018	Customer Part #	502338

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Part Detail: SQ 1.3750" 1018 12-R Cold Drawn
Process: Cold Drawn

Melt Date: 5/5/2017

C	Mn	P	S	Si	Cu	Cr	Ni	Mo	Sn	V	Cb
0.18%	0.82%	0.013%	0.023%	0.29%	0.31%	0.15%	0.16%	0.040%	0.017%	0.0030%	0.002%
Al	Pb										
0.000%	0.000%										

Melting Mill: Nucor Bar NE
Country of Melting: USA
Grain Practice: COARSE

Reduction Ratio 21.2 :1
Country of Rolling: USA
Rolling Mill: Nucor Bar NE

Specification Comments:

1. All products produced are weld free.
2. Mercury, in any form, has not been used in the production or testing of this material.

Nicholas Schultz

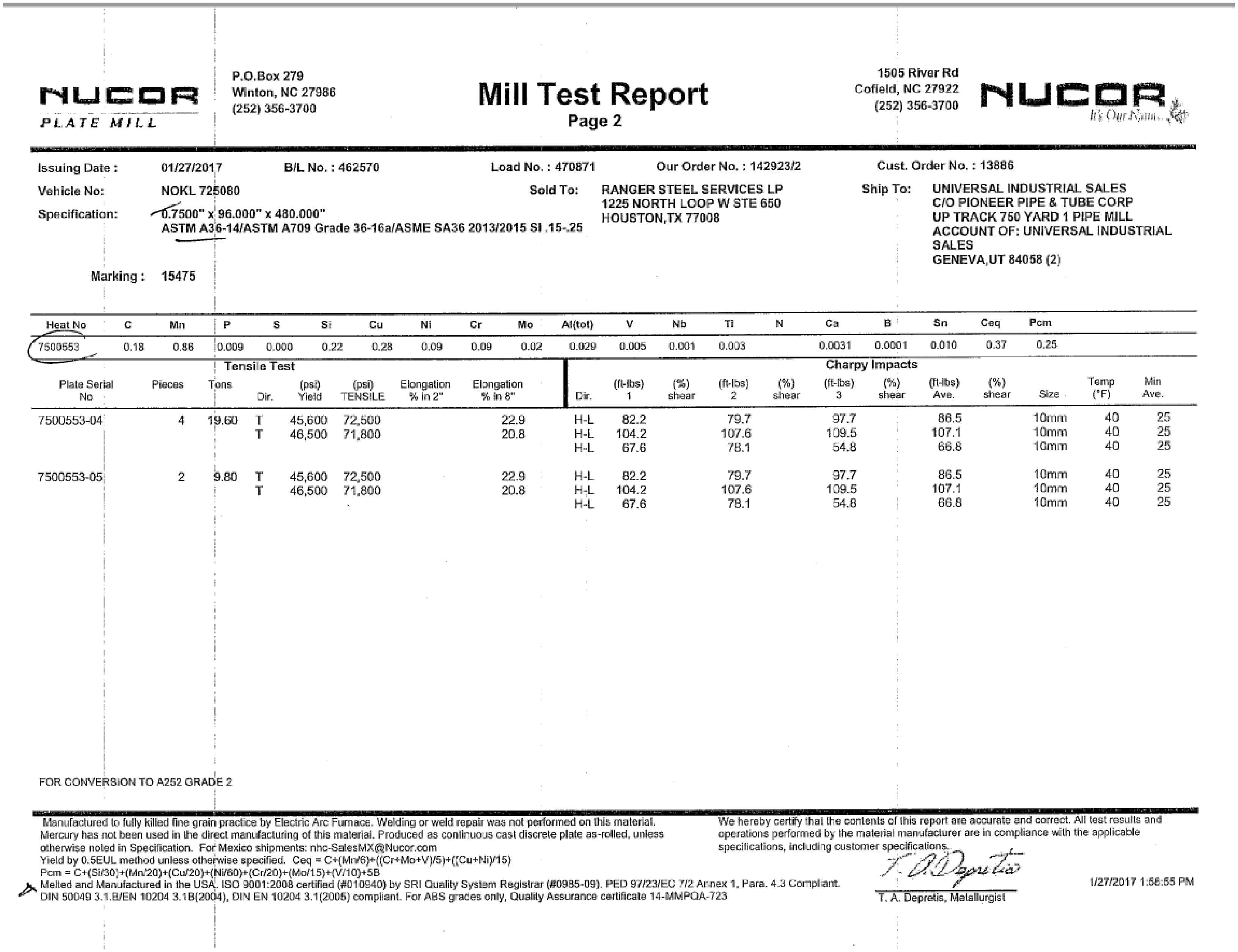
Nick Schultz
Sales Manager

Page 5 of 8

NBMG-10 January 1, 2012

Provided By : ENCORE METALS US

Tubular Rail (13 of 16)



NUCOR
PLATE MILL

P.O.Box 279
Winton, NC 27986
(252) 356-3700

Mill Test Report
Page 2

1505 River Rd
Cofield, NC 27922
(252) 356-3700

NUCOR
It's Our Nature

Issuing Date : 01/27/2017 B/L No. : 462570 Load No. : 470871 Our Order No. : 142923/2 Cust. Order No. : 13886

Vehicle No: NOKL 725080

Specification: 0.7500" x 96.000" x 480.000"
ASTM A36-14/ASTM A709 Grade 36-16a/ASME SA36 2013/2015 SI .15-.25

Marking : 15475

Sold To:
RANGER STEEL SERVICES LP
1225 NORTH LOOP W STE 650
HOUSTON,TX 77008

Ship To:
UNIVERSAL INDUSTRIAL SALES
C/O PIONEER PIPE & TUBE CORP
UP TRACK 750 YARD 1 PIPE MILL
ACCOUNT OF: UNIVERSAL INDUSTRIAL SALES
GENEVA,UT 84058 (2)

Heat No	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al(tot)	V	Nb	Ti	N	Ca	B	Sn	Ceq	Pcm
7500553	0.18	0.86	0.009	0.000	0.22	0.28	0.09	0.09	0.02	0.029	0.005	0.001	0.003		0.0031	0.0001	0.010	0.37	0.25

			Tensile Test					Charpy Impacts											
Plate Serial No	Pieces	Tons	Dir.	(psi) Yield	(psi) TENSILE	Elongation % in 2"	Elongation % in 8"	Dir.	(ft-lbs) 1	(%) shear	(ft-lbs) 2	(%) shear	(ft-lbs) 3	(%) shear	(ft-lbs) Ave.	(%) shear	Size	Temp (°F)	Min Ave.
7500553-04	4	19.60	T	45,600	72,500		22.9	H-L	82.2		79.7		97.7		86.5		10mm	40	25
			T	46,500	71,800		20.8	H-L	104.2		107.6		109.5		107.1		10mm	40	25
								H-L	67.6		78.1		54.8		66.8		10mm	40	25
7500553-05	2	9.80	T	45,600	72,500		22.9	H-L	82.2		79.7		97.7		86.5		10mm	40	25
			T	46,500	71,800		20.8	H-L	104.2		107.6		109.5		107.1		10mm	40	25
								H-L	67.6		78.1		54.8		66.8		10mm	40	25

FOR CONVERSION TO A252 GRADE 2

Manufactured to fully killed fine grain practice by Electric Arc Furnace. Welding or weld repair was not performed on this material. Mercury has not been used in the direct manufacturing of this material. Produced as continuous cast discrete plate as-rolled, unless otherwise noted in Specification. For Mexico shipments: nhc-SalesMX@Nucor.com
Yield by 0.5EUL method unless otherwise specified. Ceq = C+(Mn/6)+((Cr+Mo+V)/5)+((Cu+Ni)/15)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B
Melted and Manufactured in the USA. ISO 9001:2008 certified (#010940) by SRI Quality System Registrar (#0985-09). PED 97/23/EC 7/2 Annex 1, Para. 4.3 Compliant. DIN 50049 3.1.B/EN 10204 3.1B(2004), DIN EN 10204 3.1(2005) compliant. For ABS grades only, Quality Assurance certificate 14-MMPQA-723

We hereby certify that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with the applicable specifications, including customer specifications.

T. A. Depretis, Metallurgist

1/27/2017 1:58:55 PM

Tubular Rail (14 of 16)

Certified Test Report

NORTH STAR BLUESCOPE STEEL LLC
6767 County Road 9
Delta, Ohio 43515
Telephone: (888) 822-2112

Customer: Universal Roll Forming, Inc.
Pleasant Grove, UT 84062
Customer P.O.: 16884
Cust. Ref/Part # n/a

Order # 381263
Line Item # 1
Heat # 216188
Coil # 1727102

Ord Width (mm/in) 1524.000 / 60.000
Ord Gauge (mm/in) 4.775 / 0.188
Material Description ASTM A1018-50-15, For Conv. to ASTM A572-50-15, ASTM A709-15,SAE J1442,ASTM A656-50--13
Production Date/Time Jun 18 2017 4:23PM

Weight (kg/lb) 19436 / 42849

Heat Chemical Analysis (wt%)

Type	C	Mn	P	S	Si	Al	Cu	Cr	Ni	Mo	Sn	N	B	V	Nb	Ti	Ca	Pb
Heat	0.05	0.57	0.013	0.002	0.02	0.02	0.11	0.06	0.08	0.01	0.00	0.008	0.0000	0.001	0.018	0.001	0.002	0.000

Mechanical Test Report

	Yield Strength	Tensile Strength	% Elongation in 2 inches
Tail	60,080 psi	70,080 psi	33.2%

This hot rolled steel has been produced to conform to DIN/EN 10204:2005 3.1 and has been manufactured to a fully killed fine grain practice. This hot rolled steel has been produced and tested in accordance with each of the following applicable standards: ASTM E1806-09, ASTM E415-14, ASTM A751-14, ASTM 1370-14, JIS Z2201:1998, JIS Z 2241:2011. Pressure Equipment Directive (PED) 97/23/EC 7/2, Annex I, Paragraph 4.3 Compliant. This report certifies that the above test results are representative of those contained in the records of North Star BlueScope Steel LLC for the material identified in this test report and is intended to comply with the requirements of the material description. North Star BlueScope Steel LLC is not responsible for the inability of this material to meet specific applications. Any modifications to this certification as provided negates the validity of this test report. All reproductions must have the written approval of North Star BlueScope Steel. This product was manufactured, melted, cast, and hot-rolled (min. 3:1 reduction ratio), entirely within the U.S.A at North Star BlueScope Steel LLC, Delta, Ohio. This material was not exposed to Mercury or any alloy which is liquid at ambient temperature during processing or while in North Star BlueScope Steel LLC possession. Test equipment calibration certificates are available upon request. NIST traceability is established through test equipment calibration certificates which are available upon request. Uncertainty calculations are calculated in accordance with NIST standards and are maintained at a 4:1 ratio in accordance with NIST standards. Uncertainty data is available upon request.

Tim Mitchell

Manager Quality Assurance and Technology

Date Issued: Jun 20, 2017 16:32:01
Revision#: 01

Tubular Rail (15 of 16)

Certified Test Report

NORTH STAR BLUESCOPE STEEL LLC
6767 County Road 9
Delta, Ohio 43515
Telephone: (888) 822-2112

Customer: Universal Roll Forming, Inc.
Pleasant Grove, UT 84062

Customer P.O.: 16884

Cust. Ref/Part # n/a

Order # 381263

Line Item # 1

Heat # 215579

Coil # 1721952

Ord Width (mm/in) 1524.000 / 60.000

Ord Gauge (mm/in) 4.775 / 0.188

Material Description ASTM A1018-50-15, For Conv. to ASTM A572-50-15, ASTM A709-15,SAE J1442,ASTM A656-50--13

Production Date/Time May 31 2017 5:55PM

Weight (kg/lb) 19236 / 42408

Heat Chemical Analysis (wt%)

Type	C	Mn	P	S	Si	Al	Cu	Cr	Ni	Mo	Sn	N	B	V	Nb	Ti	Ca	Pb
Heat	0.05	0.58	0.016	0.004	0.02	0.02	0.11	0.07	0.08	0.02	0.00	0.008	0.0001	0.001	0.019	0.001	0.002	0.001

Mechanical Test Report

	Yield Strength	Tensile Strength	% Elongation in 2 inches
Tail	59,080 psi	69,930 psi	33.6%

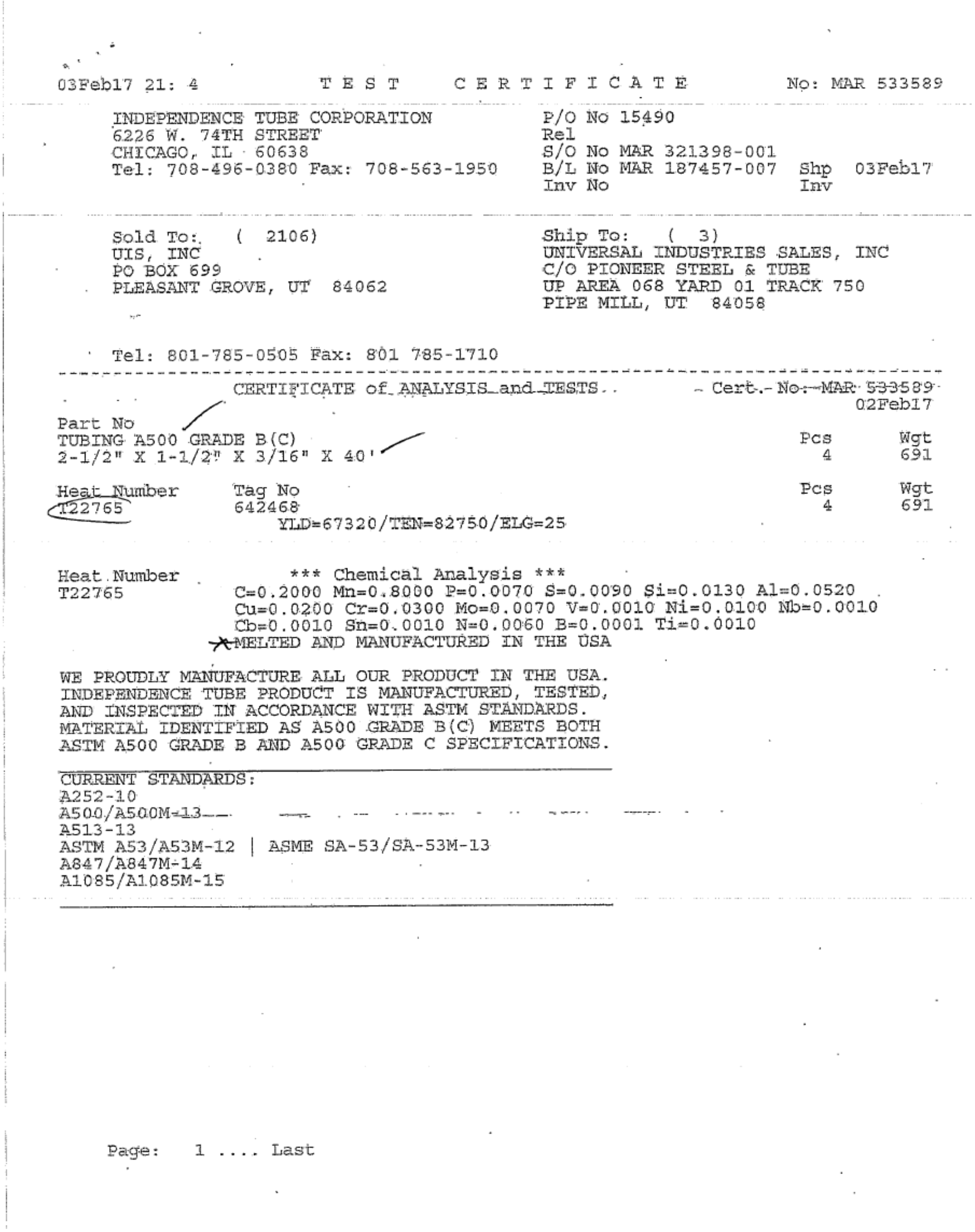
This hot rolled steel has been produced to conform to DIN/EN 10204:2005 3.1 and has been manufactured to a fully killed fine grain practice. This hot rolled steel has been produced and tested in accordance with each of the following applicable standards: ASTM E1806-09, ASTM E415-14, ASTM A751-14, ASTM 1370-14, JIS Z2201:1998, JIS Z 2241:2011. Pressure Equipment Directive (PED) 97/23/EC 7/2, Annex I, Paragraph 4.3 Compliant. This report certifies that the above test results are representative of those contained in the records of North Star BlueScope Steel LLC for the material identified in this test report and is intended to comply with the requirements of the material description. North Star BlueScope Steel LLC is not responsible for the inability of this material to meet specific applications. Any modifications to this certification as provided negates the validity of this test report. All reproductions must have the written approval of North Star BlueScope Steel. → This product was manufactured, melted, cast, and hot-rolled (min. 3:1 reduction ratio), entirely within the U.S.A at North Star BlueScope Steel LLC, Delta, Ohio. This material was not exposed to Mercury or any alloy which is liquid at ambient temperature during processing or while in North Star BlueScope Steel LLC possession. Test equipment calibration certificates are available upon request. NIST traceability is established through test equipment calibration certificates which are available upon request. Uncertainty calculations are calculated in accordance with NIST standards and are maintained at a 4:1 ratio in accordance with NIST standards. Uncertainty data is available upon request.

Tim Mitchell

Manager Quality Assurance and Technology

Date Issued: Jun 20, 2017 16:31:48
Revision#: 01

Tubular Rail (16 of 16)



03Feb17 21: 4 TEST CERTIFICATE No: MAR 533589

INDEPENDENCE TUBE CORPORATION
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 15490
Rel
S/O No MAR 321398-001
B/L No MAR 187457-007 Shp 03Feb17
Inv No Inv

Sold To: (2106)
UIS, INC
PO BOX 699
PLEASANT GROVE, UT 84062

Ship To: (3)
UNIVERSAL INDUSTRIES SALES, INC
C/O PIONEER STEEL & TUBE
UP AREA 068 YARD 01 TRACK 750
PIPE MILL, UT 84058

Tel: 801-785-0505 Fax: 801 785-1710

CERTIFICATE of ANALYSIS and TESTS ~~Cert. No: MAR 533589~~
02Feb17

Part No
TUBING A500 GRADE B(C)
2-1/2" X 1-1/2" X 3/16" X 40'

		Pcs	Wgt
Part No TUBING A500 GRADE B(C) 2-1/2" X 1-1/2" X 3/16" X 40'		4	691
Heat Number T22765	Tag No 642468 YLD=67320/TEN=82750/ELG=25	4	691

Heat Number
T22765

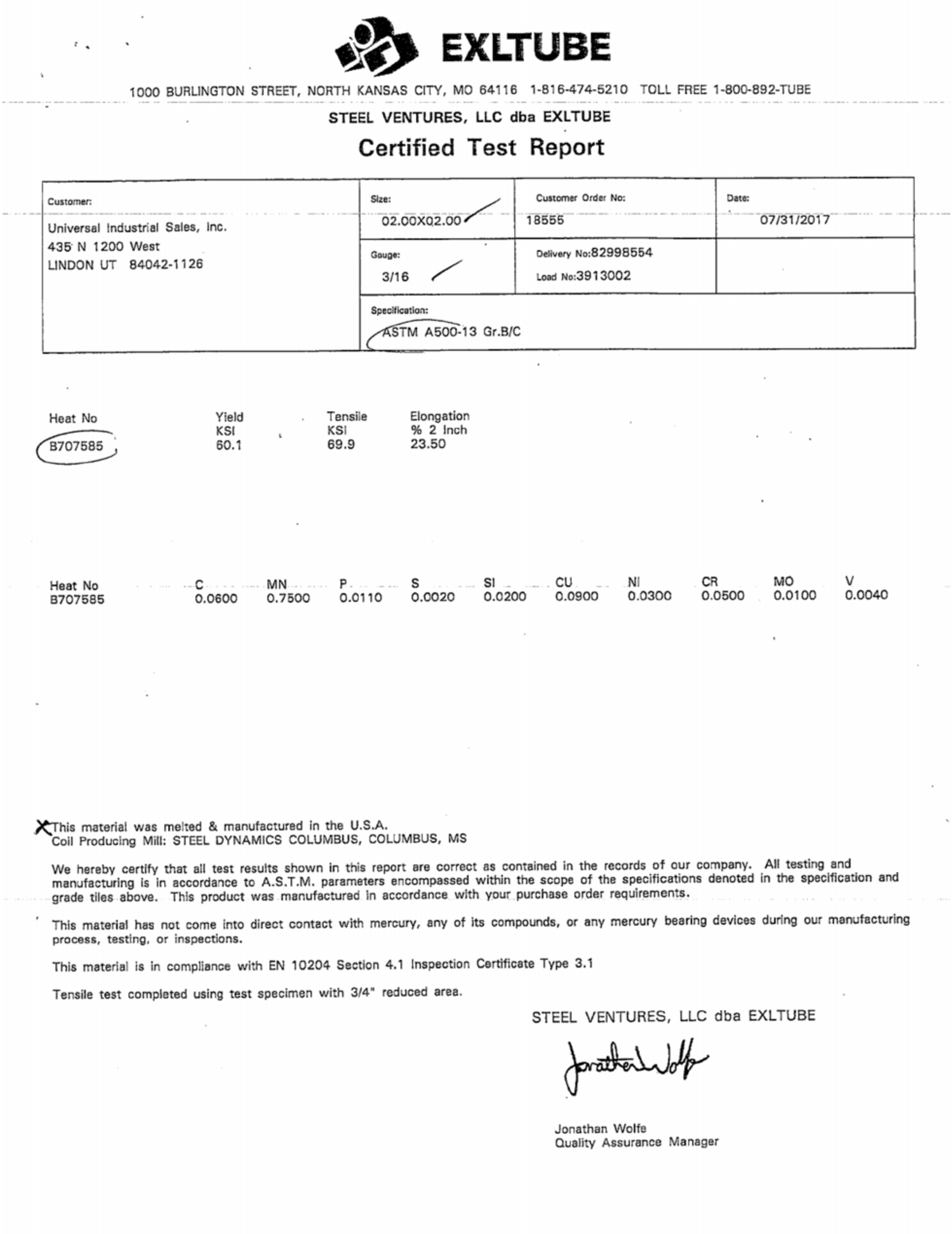
*** Chemical Analysis ***
C=0.2000 Mn=0.8000 P=0.0070 S=0.0090 Si=0.0130 Al=0.0520
Cu=0.0200 Cr=0.0300 Mo=0.0070 V=0.0010 Ni=0.0100 Nb=0.0010
Cb=0.0010 Sn=0.0010 N=0.0060 B=0.0001 Ti=0.0010
*MELTED AND MANUFACTURED IN THE USA

WE PROUDLY MANUFACTURE ALL OUR PRODUCT IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH
ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

CURRENT STANDARDS:
A252-10
A500/A500M-13
A513-13
ASTM A53/A53M-12 | ASME SA-53/SA-53M-13
A847/A847M-14
A1085/A1085M-15

Page: 1 .... Last

Hand Rail (1 of 3)



EXLTUBE

1000 BURLINGTON STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

Certified Test Report

Customer:
Universal Industrial Sales, Inc.
435 N 1200 West
LINDON UT 84042-1126

Size: 02.00X02.00

Customer Order No: 18555

Date: 07/31/2017

Gauge: 3/16

Delivery No: 82998554
Load No: 3913002

Specification: ASTM A500-13 Gr.B/C

Heat No	Yield KSI	Tensile KSI	Elongation % 2 Inch
B707585	60.1	69.9	23.50

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
B707585	0.0600	0.7500	0.0110	0.0020	0.0200	0.0900	0.0300	0.0500	0.0100	0.0040

This material was melted & manufactured in the U.S.A.
Coil Producing Mill: STEEL DYNAMICS COLUMBUS, COLUMBUS, MS

We hereby certify that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade tiles above. This product was manufactured in accordance with your purchase order requirements.

This material has not come into direct contact with mercury, any of its compounds, or any mercury bearing devices during our manufacturing process, testing, or inspections.

This material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

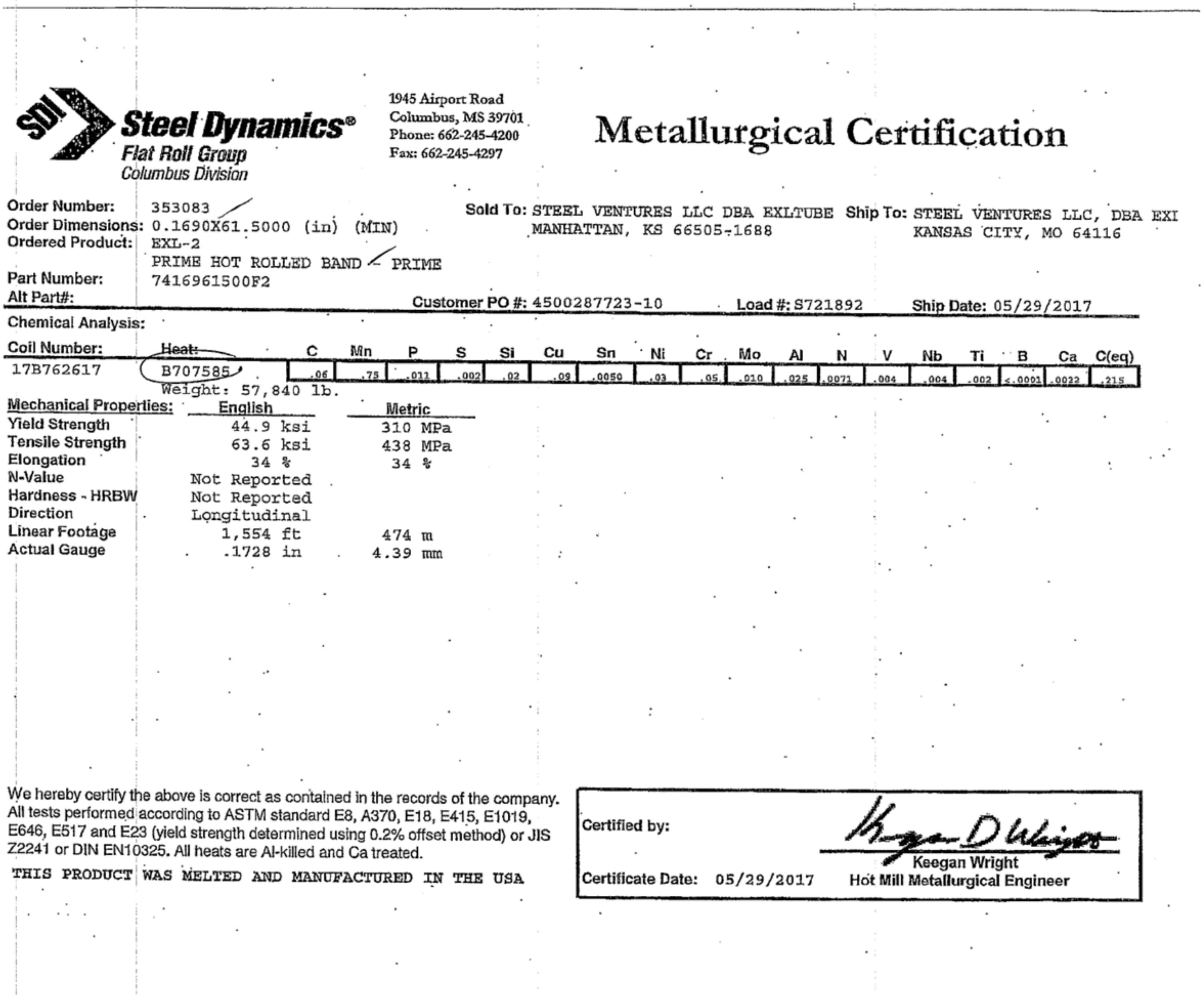
Tensile test completed using test specimen with 3/4" reduced area.

STEEL VENTURES, LLC dba EXLTUBE

Jonathan Wolfe

Jonathan Wolfe
Quality Assurance Manager

Handrail (2 of 3)



Steel Dynamics®
Flat Roll Group
Columbus Division

1945 Airport Road
Columbus, MS 39701
Phone: 662-245-4200
Fax: 662-245-4297

Metallurgical Certification

Order Number: 353083
Order Dimensions: 0.1690X61.5000 (in) (MIN)
Ordered Product: EXL-2
PRIME HOT ROLLED BAND - PRIME
Part Number: 7416961500F2
Alt Part#:

Sold To: STEEL VENTURES LLC DBA EXLTUBE
MANHATTAN, KS 66505-1688

Ship To: STEEL VENTURES LLC, DBA EXI
KANSAS CITY, MO 64116

Customer PO #: 4500287723-10 **Load #:** S721892 **Ship Date:** 05/29/2017

Chemical Analysis:

Coil Number:	~~Heat:~~	C	Mn	P	S	Si	Cu	Sn	Ni	Cr	Mo	Al	N	V	Nb	Ti	B	Ca	C(eq)
17B762617	B707585	.06	.75	.011	.002	.02	.09	.0050	.03	.05	.010	.025	.0071	.004	.004	.002	<.0001	.0022	.215

Weight: 57,840 lb.

Mechanical Properties:	English	Metric
Yield Strength	44.9 ksi	310 MPa
Tensile Strength	63.6 ksi	438 MPa
Elongation	34 %	34 %
N-Value	Not Reported	
Hardness - HRBW	Not Reported	
Direction	Longitudinal	
Linear Footage	1,554 ft	474 m
Actual Gauge	.1728 in	4.39 mm

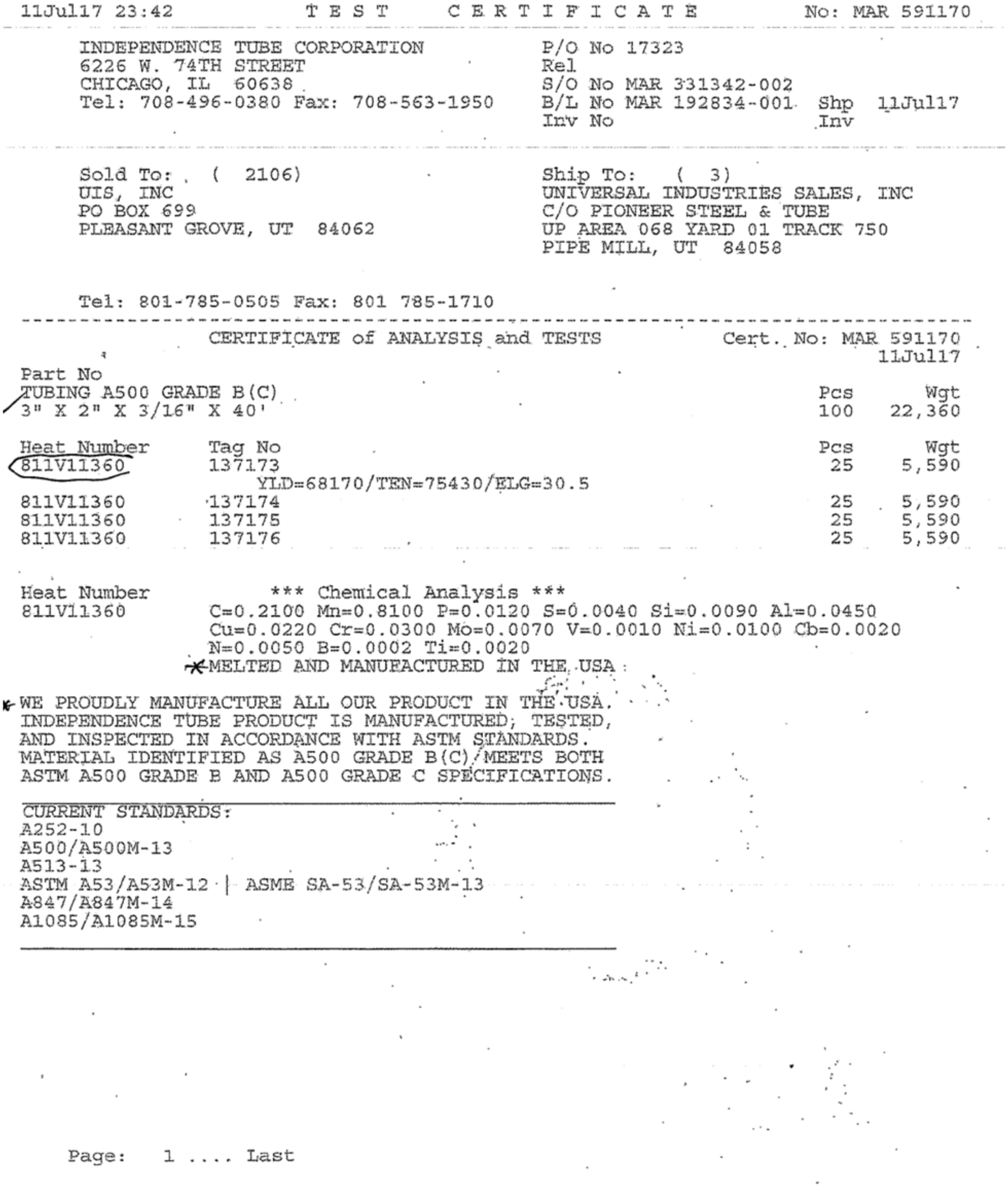
We hereby certify the above is correct as contained in the records of the company. All tests performed according to ASTM standard E8, A370, E18, E415, E1019, E646, E517 and E23 (yield strength determined using 0.2% offset method) or JIS Z2241 or DIN EN10325. All heats are Al-killed and Ca treated.

THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE USA

Certified by: Keegan D Wright
Keegan Wright
Hot Mill Metallurgical Engineer

Certificate Date: 05/29/2017

Handrail (3 of 3)



11Jul17 23:42 TEST CERTIFICATE No: MAR 591170

INDEPENDENCE TUBE CORPORATION
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 17323
Rel
S/O No MAR 331342-002
B/L No MAR 192834-001 Shp 11Jul17
Inv No Inv

Sold To: (2106)
UIS, INC
PO BOX 699
PLEASANT GROVE, UT 84062

Ship To: (3)
UNIVERSAL INDUSTRIES SALES, INC
C/O PIONEER STEEL & TUBE
UP AREA 068 YARD 01 TRACK 750
PIPE MILL, UT 84058

Tel: 801-785-0505 Fax: 801 785-1710

CERTIFICATE of ANALYSIS and TESTS Cert. No: MAR 591170
11Jul17

Part No		Pcs	Wgt
TUBING A500 GRADE B(C) 3" X 2" X 3/16" X 40'		100	22,360
Heat Number	Tag No	Pcs	Wgt
811V11360	137173 YLD=68170/TEN=75430/ELG=30.5	25	5,590
811V11360	137174	25	5,590
811V11360	137175	25	5,590
811V11360	137176	25	5,590

Heat Number *** Chemical Analysis ***
811V11360 C=0.2100 Mn=0.8100 P=0.0120 S=0.0040 Si=0.0090 Al=0.0450
Cu=0.0220 Cr=0.0300 Mo=0.0070 V=0.0010 Ni=0.0100 Cb=0.0020
N=0.0050 B=0.0002 Ti=0.0020
*MELTED AND MANUFACTURED IN THE USA

WE PROUDLY MANUFACTURE ALL OUR PRODUCT IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH
ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

CURRENT STANDARDS:
A252-10
A500/A500M-13
A513-13
ASTM A53/A53M-12 | ASME SA-53/SA-53M-13
A847/A847M-14
A1085/A1085M-15

Page: 1 .... Last

13. References

1. *Manual for Assessing Safety Hardware, Second Edition 2016 (MASH 2016).* American Association of State Highway and Transportation Officials. Washington, DC. 2016.
2. John Jewell. VEHICULAR CRASH TESTS OF THE CALIFORNIA ST-20 BRIDGE RAIL. California Department of Transportation. Sacramento. 2004.
3. *Vehicle Damage Scale for Traffic Crash Investigators.* Texas Department of Public Safety. Austin. 2006.
4. *Collision Deformation Classification SAE Recommended Practice J224 MAR80.* Society of Automotive Engineers. New York, NY. 1980
5. *Test Risk Assessment Program.* Texas Transportation Institute. Austin. 2014.
6. *Recommended Procedures for the Safety Performance Evaluation of Highway Features,* Transportation Research Board, National Cooperative Highway Research Program Report 350, 1993.

14. Appendix E: Finite Element Modeling Report

14.1. Objective

Finite element (FE) analyses were performed using Livermore Software Technology Corporation's (LSTC) LS-Dyna, which is a commercial finite element program commonly used for crash testing simulations which can provide an idea of how a real-world test article may perform during crash testing. The purpose of the modeling was to build a finite element model of the ST-75 bridge rail, run the crash test simulations, and compare the results of the simulations with that of their real-world crash tests.

14.2. ST-75 Bridge Rail Model

The ST-75 Bridge Rail is a MASH Test Level 4 Bridge Rail. The height of the barrier is 1067 mm (42 in) which includes a 152 mm (6 in) pedestrian hand/bicycle rail at the top. The profile of the barrier consists of three 203 mm x 102 mm (8 in x 4 in) steel rail tubes and a 152 mm (6 in) reinforced concrete curb. The steel tubes are spaced evenly over 762 mm (30 in) and steel posts are spaced 3 m (10 ft) apart. The test article and finite element model are both 30.5 m (100 ft) long. A finite element model was developed that consisted of a fully constrained shell model of the three 203 mm x 102 mm (8 in x 4 in) steel rail tubes and the 152 mm (6 in) curb. Fully constrained means that all the nodes that make up the mesh in the model are constrained so that they cannot translate or rotate in any direction or axis. The model used didn't include the pedestrian hand/bicycle rail as it wasn't considered a structural component of the design at the time. However, including it in future simulations may provide information on 2270P hood snag potential and interaction of the 10000S front fender and cargo box.

Figure 14-1 ST-75 Bridge Rail CAD Model Front

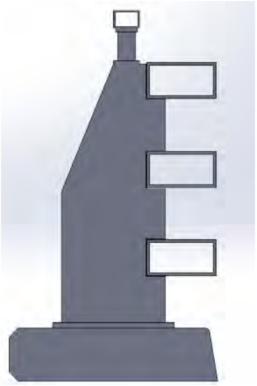


Figure 14-2 – ST-75 Bridge Rail CAD Model Profile

Figure 14-3 – ST-75 Bridge Rail FE Shell Model Profile

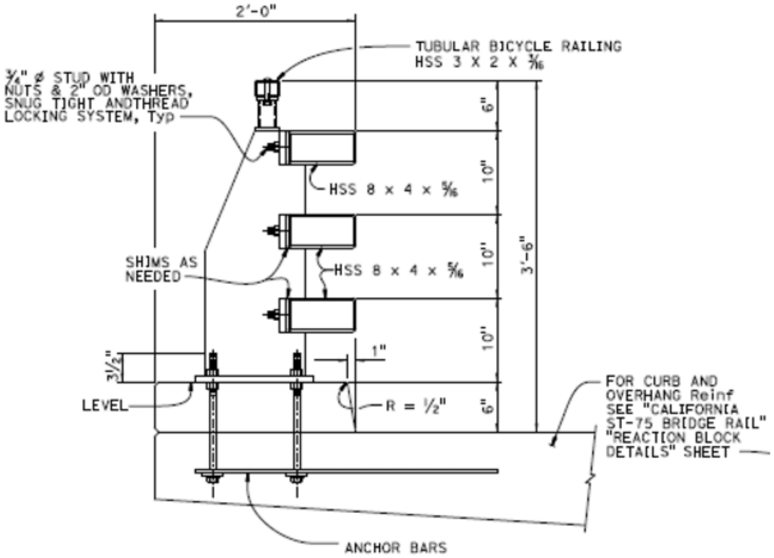


Figure 14-4 – Typical Section and Dimension for the ST-75 Bridge Rail

14.3. Vehicle Models

The pickup truck and the small car models were provided by the Center for Collision Safety and Analysis (CCSA) Finite Element Models webpage, https://www.ccsa.gmu.edu/models/. This section describes which models were used and how they were modified.

14.3.1. 2270P Truck

The truck model used for MASH 2270P truck test simulations was the 2270-kg 2007 Chevy Silverado coarse version 3a that was posted December 2016. The only change to the vehicle model was to increase the velocity of the vehicle model to match the required speed for MASH Test Level 4 Longitudinal Barriers. For the simulation, the 2270P truck impacted the test article at a speed of 100.0 kph (62.2 mph) and an angle of 25 degrees whereas in the real-world test the impact speed and angle were 102.0 kph (63.4 mph) and 26.3 degrees, respectively.

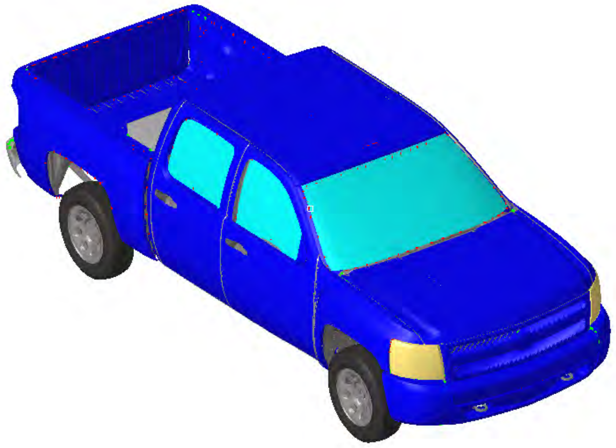


Figure 14-5 2270P Truck

14.3.2. 1100C Car

The car model used for MASH 1100C car test simulations was the 1100-kg 2010 Toyota Yaris coarse version 1l that was posted December 2016. The only change to the vehicle model was to increase the velocity of the vehicle model to match the required speed for MASH Test Level 4 Longitudinal Barriers. For the simulation, the 1100C truck impacted the test article at a speed of 100.0 kph (62.2 mph) and an angle of 25 degrees whereas in the real-world test the impact speed and angle were 102.1 kph (63.4 mph) and 25.0 degrees, respectively.

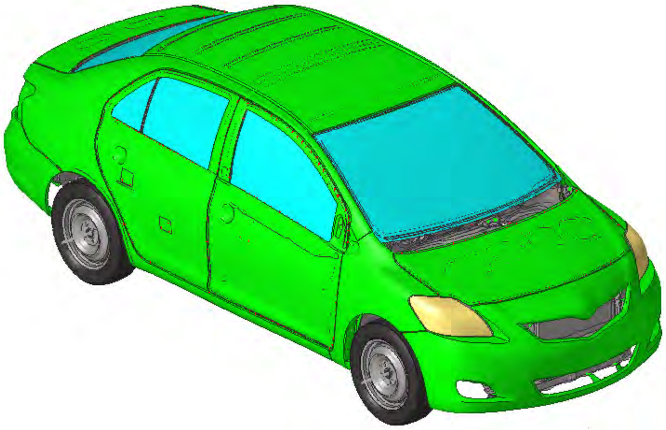


Figure 14-6 1100C Car

14.3.3. 10000S Single-Unit Van Truck

The single-unit van truck model used for MASH 10000S single-unit van truck test simulations was the Ford Single Unit Truck that was posted November 3, 2008 on the National Crash Analysis Center (NCAC) website. Unfortunately, the link to this model no longer exists on the NCAC website but the same model can be found on the National Highway Traffic Safety Administration (NHTSA) website at https://www.nhtsa.gov/crash-simulation-vehicle-models#crash-simulation-vehicle-models-models. The model is of a 1996 Ford 8,150 kg (18,000 lbs) van body truck which was designed to meet the properties of the NCHRP Report 350 8000S single-unit van truck. A MASH 10000S model is unavailable at the time this report was written. Therefore, the Ford Single Unit Truck was modified in the following ways. The shape of the ballast in the bed of the truck was changed so that the ballast's center of gravity was 1,600 mm (63 in) above the ground. The density of the ballast was increased so that the total mass of the truck was 10,000 kg (22,050 lbs). The wheelbase and overall length of the truck were not changed. Therefore, the wheelbase is short 750 mm (29.5 in) and the overall length is short 1,300 mm (51.2 in) of the properties given in MASH for a 10000S truck. The velocity of the vehicle model was increased to match the required speed for MASH Test level 4 test Longitudinal Barriers. For the simulation, the 10000S truck impacted the test article at a speed of 90.0 kph (55.9 mph) and an angle of 15 degrees whereas in the real-world test the impact speed and angle were 87.6 kph (54.4 mph) and of 15.3 degrees, respectively.

Figure 14-7 10000S Single-Unit Van Truck

14.4. Comparing Modeling Data to Real World Data

14.4.1. 2270P Truck

This section compares the results of test 110MASH4P18-02 and the results of the 2270P finite element model. Table 14-1 compares the center of gravity, mass, and wheel base between the 2018 Dodge Ram 1500 used in the crash test and the 2007 Chevrolet Silverado used in the finite element modeling. Section 14.4.2 compares the TRAP results and section 14.4.3 compares the impact sequence of test 110MASH4P18-02 to the FE simulation.

Table 14-1 Center of Gravity for 2270P Truck Test Vehicle and LS-Dyna Finite Element Model

	Vehicle Type	X*	Y**	Z	Mass	Wheel Base
Test 110MASH4P18-02	2018 Dodge Ram 1500	64.0” (1625 mm)	-0.6” (-16 mm)	29.4” (748 mm)	4964.5 lb (2251.9 kg)	140.5” (3569 mm)
2270P Vehicle Model	2007 Chevrolet Silverado	65.7” (1670 mm)	0.0” (0.0 mm)	28.8” (731.5 mm)	5005.6 lb (2270.5 kg)	144.0” (3660 mm)

* Behind centerline of front tire

** Negative means CG is on the driver side of the vehicle’s centerline

14.4.2. TRAP Data Comparison

Both the 2270P simulation and test 110MASH4P18-02 met the criteria provided in MASH for testing longitudinal barriers at Test Level 4. Most of the results were at or below the preferred range. When the data are compared to each other, the occupant impact velocities in the test were almost twice those in the simulation while the ridedown accelerations for the simulation were lower than those in the test. The maximum roll, pitch, and yaw angles in the test and the simulation were similar in maximum magnitude but the crash test values occur slightly later than in the simulations. Perhaps this is due to the barrier being modeled as fully restrained and unable to move (causing redirection to occur sooner) or the model vehicle being more rigid than the actual vehicle, or a combination thereof. Table 14-2 shows the results of the TRAP analysis and Figure 14-8 through Figure 14-18 are graphs of the TRAP analysis for test 110MASH4P18-02 and the finite element model.

Table 14-2 TRAP Results Data Comparison for Full Scale and FE Models for 2270P Truck (Absolute Values)

Data Results	**MASH Criteria**	**Test 110MASH4P18-02** **2018 Dodge Ram 1500**	**LS-Dyna Truck Simulation** **2007 Chevrolet Silverado**
Longitudinal Occupant Impact Velocity	Preferred = 30 ft/s (9.1 m/s) Max = 40 ft/s (12.2 m/s)	14.4 ft/s (4.4 m/s)	5.9 ft/s (1.8 m/s)
Longitudinal Ridedown Acceleration **10 msec Average**	Preferred = 15.0 G Max = 20.49 G	4.1 G	13.4 G
Lateral Occupant Impact Velocity	Preferred = 30 ft/s (9.1 m/s) Max = 40 ft/s (12.2 m/s)	30.8 ft/s (9.4 m/s)	15.7 ft/s (4.8 m/s)
Lateral Ridedown Acceleration **10 msec Average**	Preferred = 15.0 G Max = 20.49 G	11 G	18.2 G
PHD	n/a	11.7 G	18.2
ASI	n/a	2.29	1.98
Max Roll	<75 Degrees	21.6 degrees	27.8 degrees
Max Pitch	<75 Degrees	2.1 degrees	7.6 degrees
Max Yaw	n/a	40.3 degrees	30.0 degrees

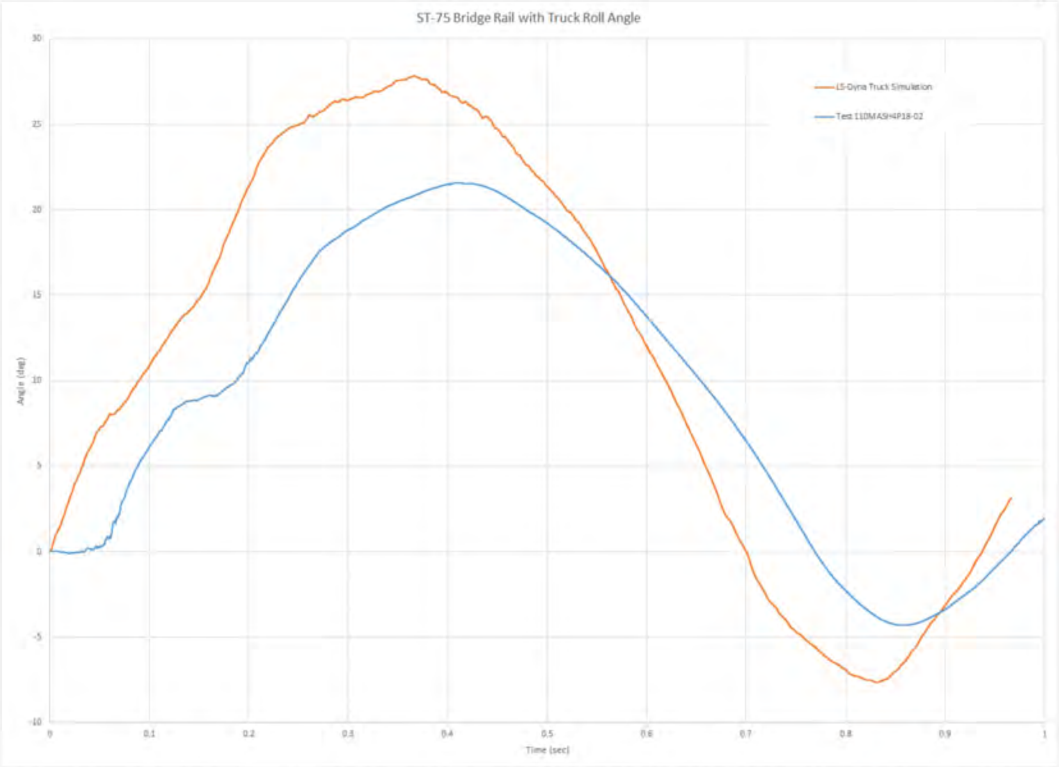


Figure 14-8 Graph of Roll Angles for Full Scale and FE Model TRAP Results for 2270P Truck

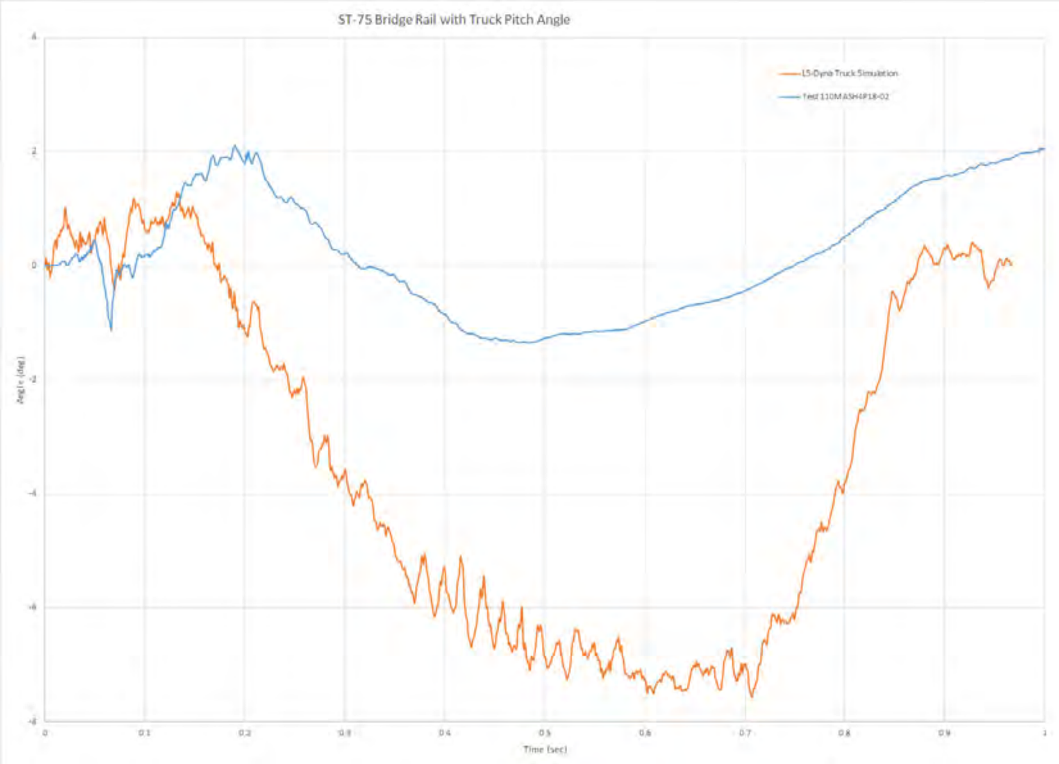


Figure 14-9 Graph of Pitch Angles for Full Scale and FE Model TRAP Results for 2270P Truck

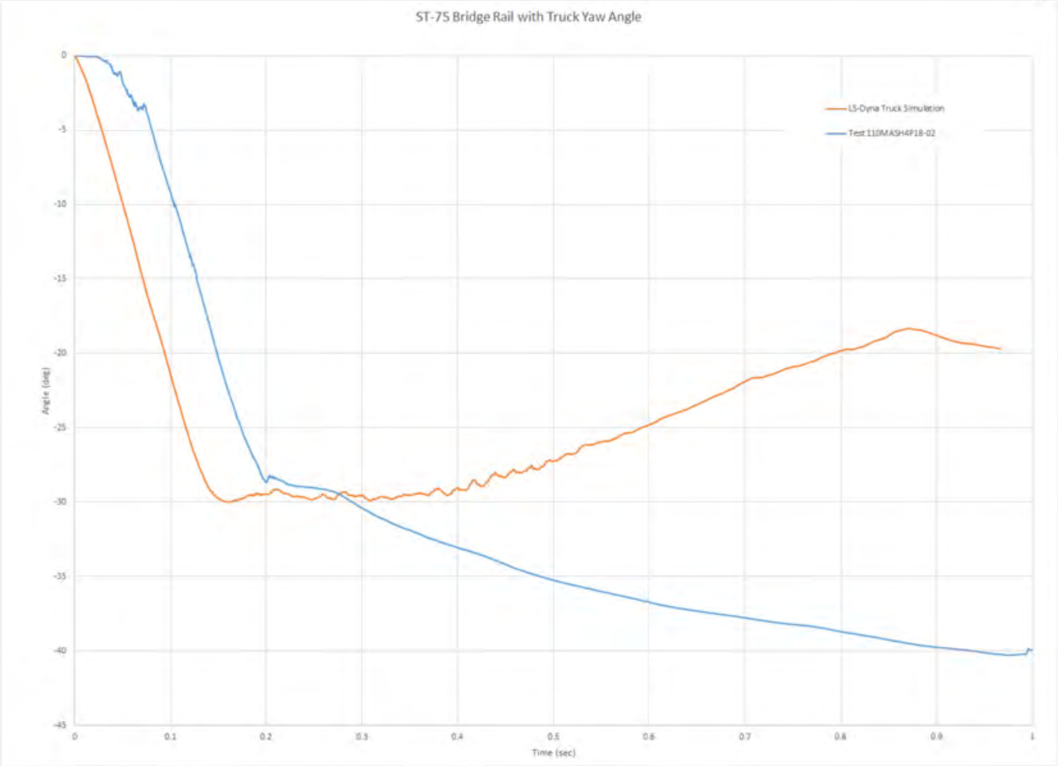


Figure 14-10 Graph of Yaw Angles for Full Scale and FE Model TRAP Results for 2270P Truck

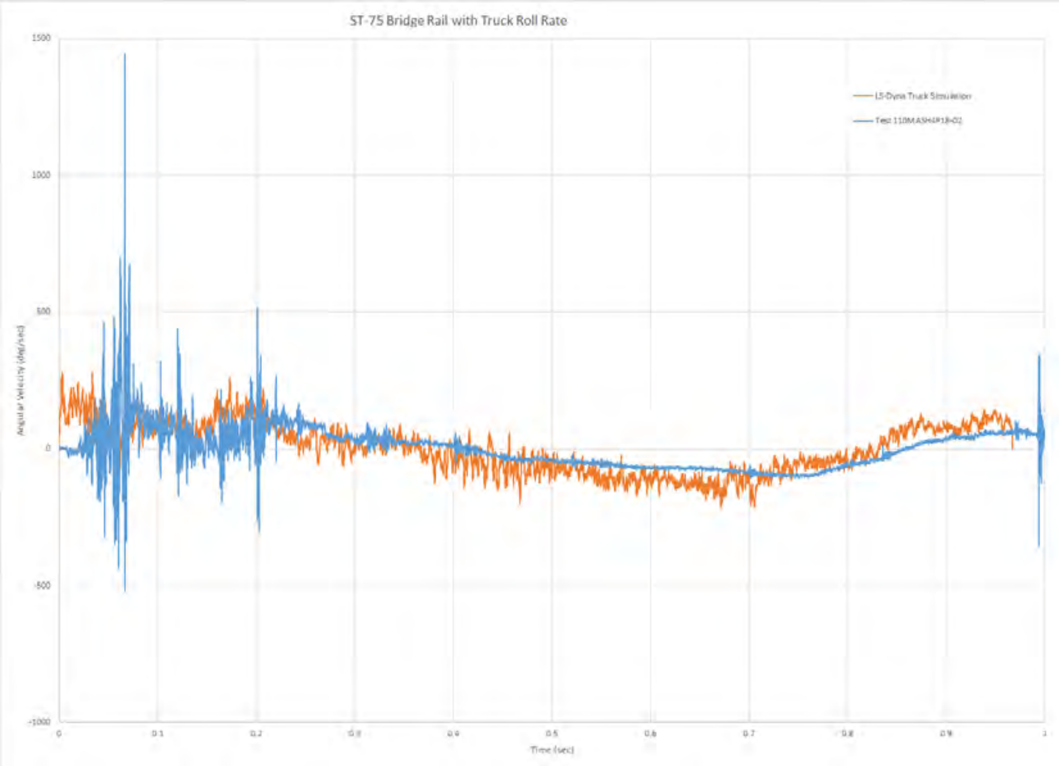


Figure 14-11 Graph of Roll Rates for Full Scale and FE Model TRAP Results for 2270P Truck

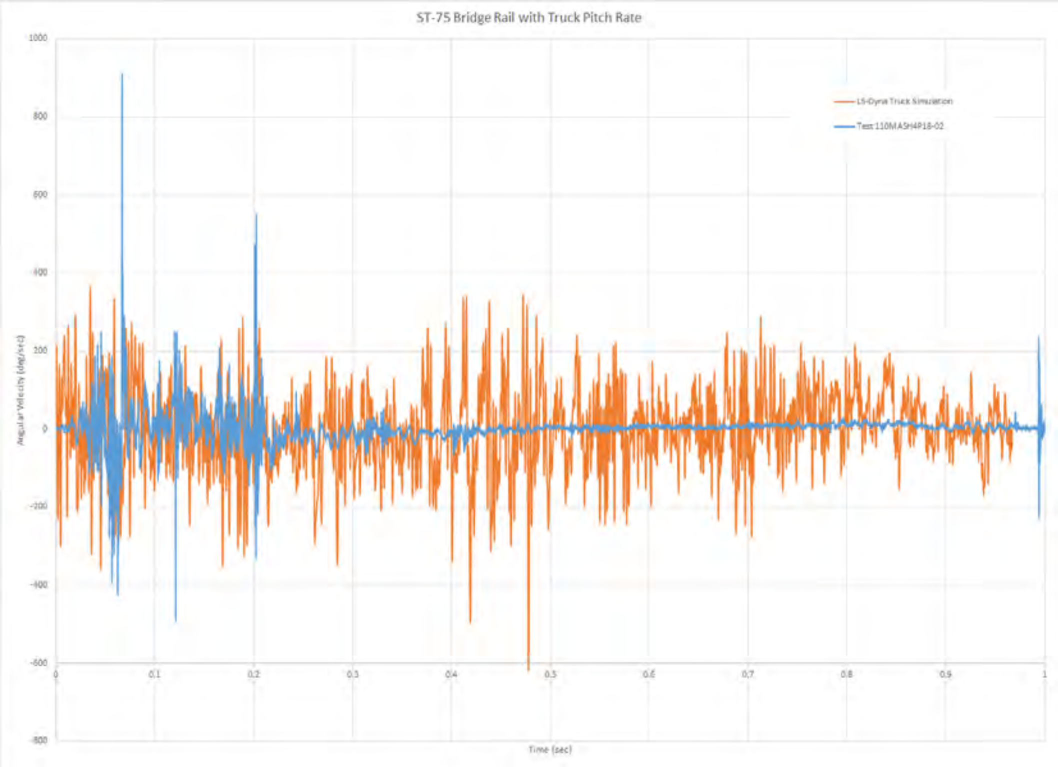


Figure 14-12 Graph of Pitch Rates for Full Scale and FE Model TRAP Results for 2270P Truck

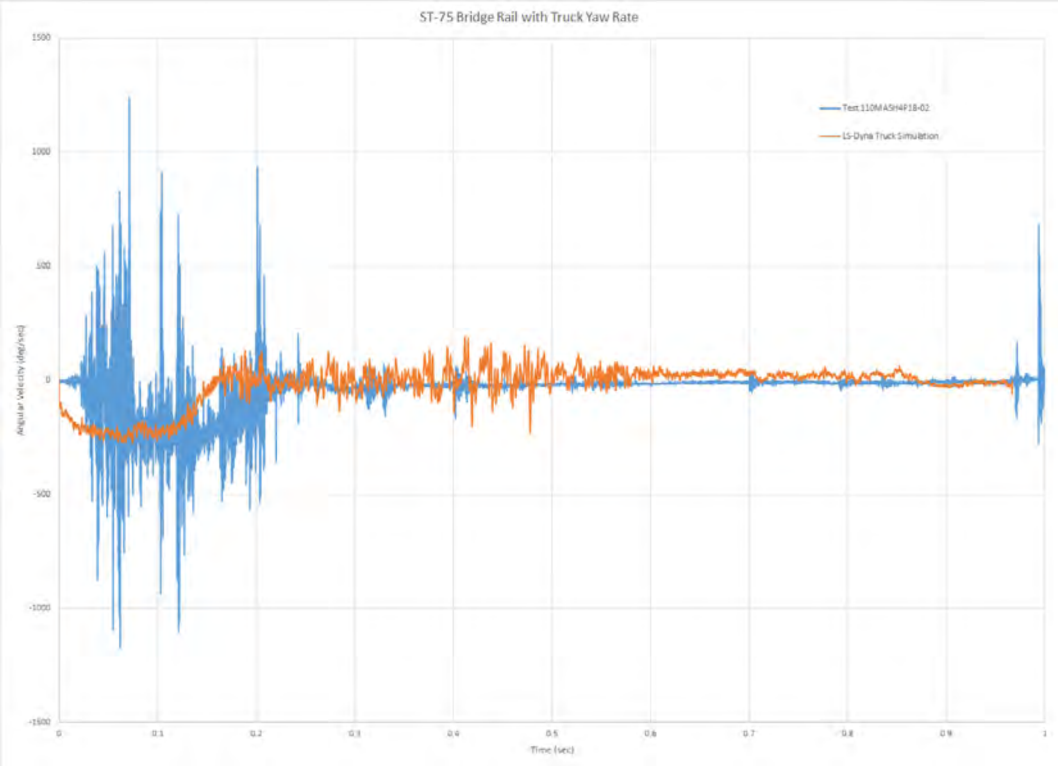


Figure 14-13 Graph of Yaw Rates for Full Scale and FE Model TRAP Results for 2270P Truck

Figure 14-14 Graph of Longitudinal Accelerations for Full Scale and FE Model TRAP Results for 2270P Truck

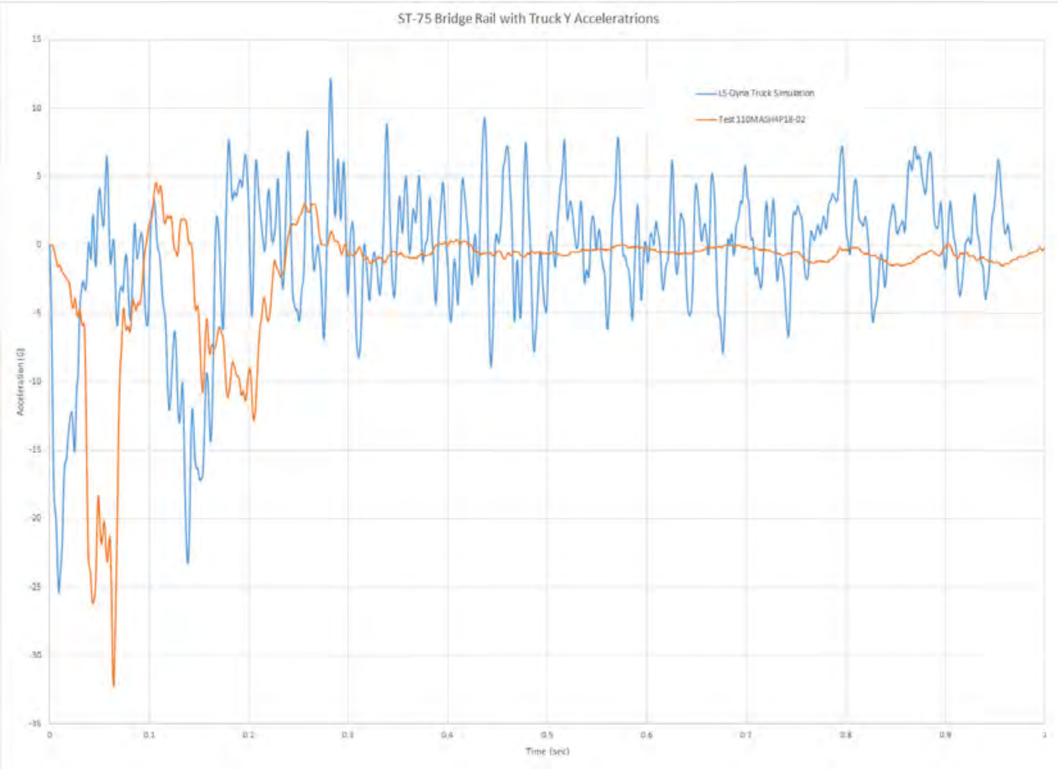


Figure 14-15 Graph of Lateral Accelerations for Full Scale and FE Model TRAP Results for 2270P Truck

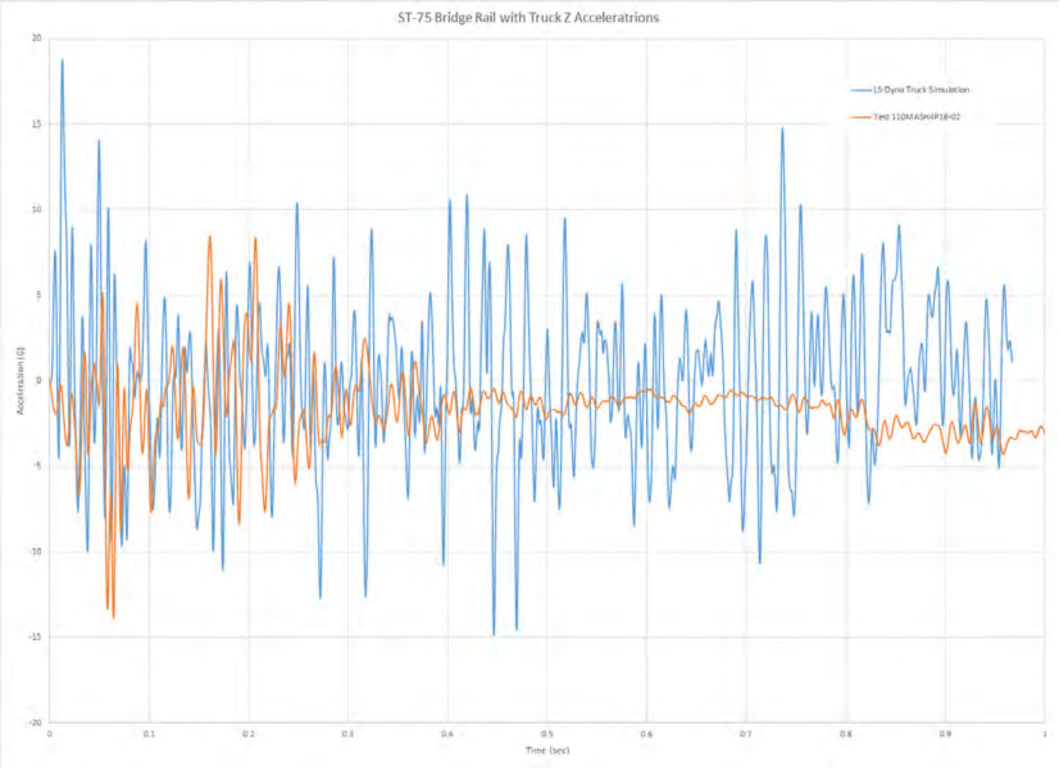


Figure 14-16 Graph of Vertical Accelerations for Full Scale and FE Model TRAP Results for 2270P Truck

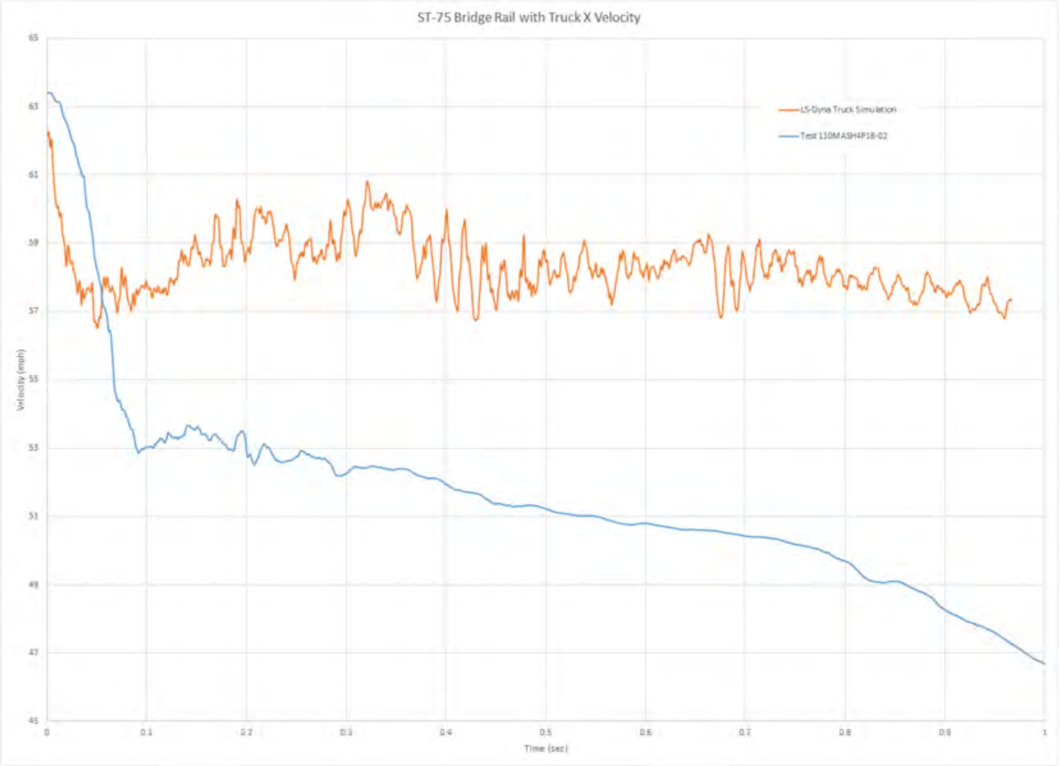


Figure 14-17 Graph of Longitudinal Velocities for Full Scale and FE Model TRAP Results for 2270P Truck

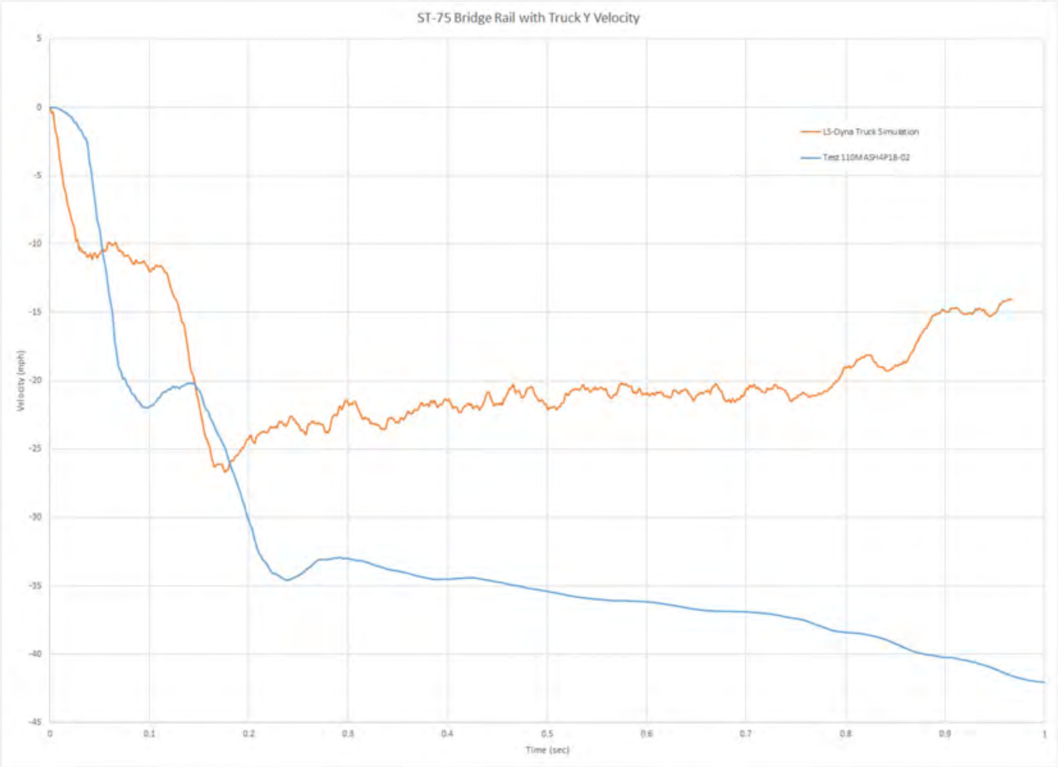


Figure 14-18 Graph of Lateral Velocities for Full Scale and FE Model TRAP Results for 2270P Truck

14.4.3. Visual Comparison

A visual comparison of test 110MASH4P18-02 and the 2270P simulation shows that the vehicles' interaction with the barrier to be similar. They appear to diverge from each other once the vehicle loses contact with the barrier. Figure 14-19 is a sequence of pictures showing the vehicles' interaction with the test article for both the full-scale test and the finite element model.

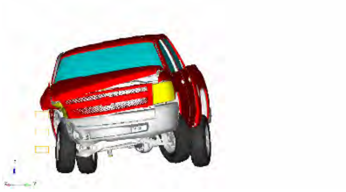
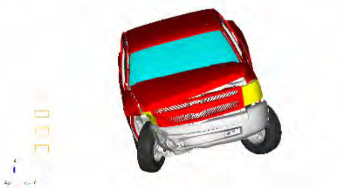
Test 110MASH4P18-02: 2018 Dodge Ram 1500	**Time**	**LS-Dyna Truck Simulation: 2007 Chevrolet Silverado**
	0.00 sec	
	0.06 sec	
	0.12 sec	
	0.18 sec	
	0.24 sec	
	0.36 sec	
	0.60 sec	

Figure 14-19 Visual Comparison of Actual Crash Test and Simulations for 2270P Truck

14.5. 1100C Small Car

This section compares the results of test 110MASH4C19-01 and the results of the 1100C finite element model. Table 14-3 compares the center of gravity, mass, and wheel base between the 2017 Nissan Versa used in the crash test and the 2010 Toyota Yaris used in the finite element modeling. Section 14.5.1 compares the TRAP results and section 14.5.2 compares the impact sequence of test 110MASH4C19-01 to the FE simulation.

Table 14-3 Center of Gravity for 1100C Car Test Vehicle and LS-Dyna Finite Element Model

	Vehicle Type	X*	Y**	Z	Mass	Wheel Base
Test 110MASH4C19-01	2017 Nissan Versa	42.8” (1086 mm)	-1.9” (-19 mm)	N/A	2389 lb (1083.7 kg)	102.3” (2599 mm)
1100C Vehicle Model	2010 Toyota Yaris	40.4” (1025 mm)	-0.1” (-3.0 mm)	21.9” (557 mm)	2427.3 lb (1101 kg)	99.9” (2538 mm)

* Behind centerline of front tire

** Negative means CG is on the driver side of the centerline

14.5.1. TRAP Data Comparison

The TRAP data for test 110MASH4C19-01 met the criteria in MASH for a Test Level 4 longitudinal barrier but the 1100C finite element model’s longitudinal and lateral ridedown accelerations did not meet the criteria. The higher accelerations might be caused by the simulation barrier being fully constrained. The posts and beams in the full-scale test article move and deform. The post can slide within the limit of the holes for the anchor bolts and the posts and beam will bend and flex during the impact. This will absorb some of the energy of the impact. In the simulation this movement is not allowed and more of the energy of the impact is felt by the vehicle. Additionally, the FE model does not deform as much as the test vehicle meaning that the model does not lose as much energy as the test vehicle during the impact. The maximum roll, pitch, and yaw angles in the 1100C simulation and test 110MASH4C19-01 were similar. Table 14-4 shows the results of the TRAP analysis and Figure 14-20 through Figure 14-30 are graphs of the TRAP analysis for test 110MASH4C19-01 and the finite element model.

Table 14-4 TRAP Data Comparison for Full Scale and FE Model TRAP Results for 1100C Car (Absolute Values)

Data Results	**MASH Criteria**	**Test 110MASH4C19-01** **2017 Nissan Versa**	**LS-Dyna Car Simulation** **2010 Toyota Yaris**
Longitudinal Occupant Impact Velocity	Preferred = 30 ft/s (9.1 m/s) Max = 40 ft/s (12.2 m/s)	21.3 ft/s (6.5 m/s)	13.5 ft/s (4.1 m/s)
Longitudinal Ridedown Acceleration 10 msec Average	Preferred = 15.0 G Max = 20.49 G	3.4 G	22.2 G
Lateral Occupant Impact Velocity	Preferred = 30 ft/s (9.1 m/s) Max = 40 ft/s (12.2 m/s)	33.1 ft/s (10.1 m/s)	21.3 ft/s (6.5 m/s)

Lateral Ridedown Acceleration **10 msec Average**	Preferred = 15.0 G Max = 20.49 G	9.9 G	22.0 G
PHD	n/a	10.0 G	30.9 G
ASI	n/a	2.83	2.63
Max Roll	<75 Degrees	5.7 degrees	8.3 degrees
Max Pitch	<75 Degrees	4.4 degrees	4.4 degrees
Max Yaw	n/a	38.3 degrees	56.8 degrees

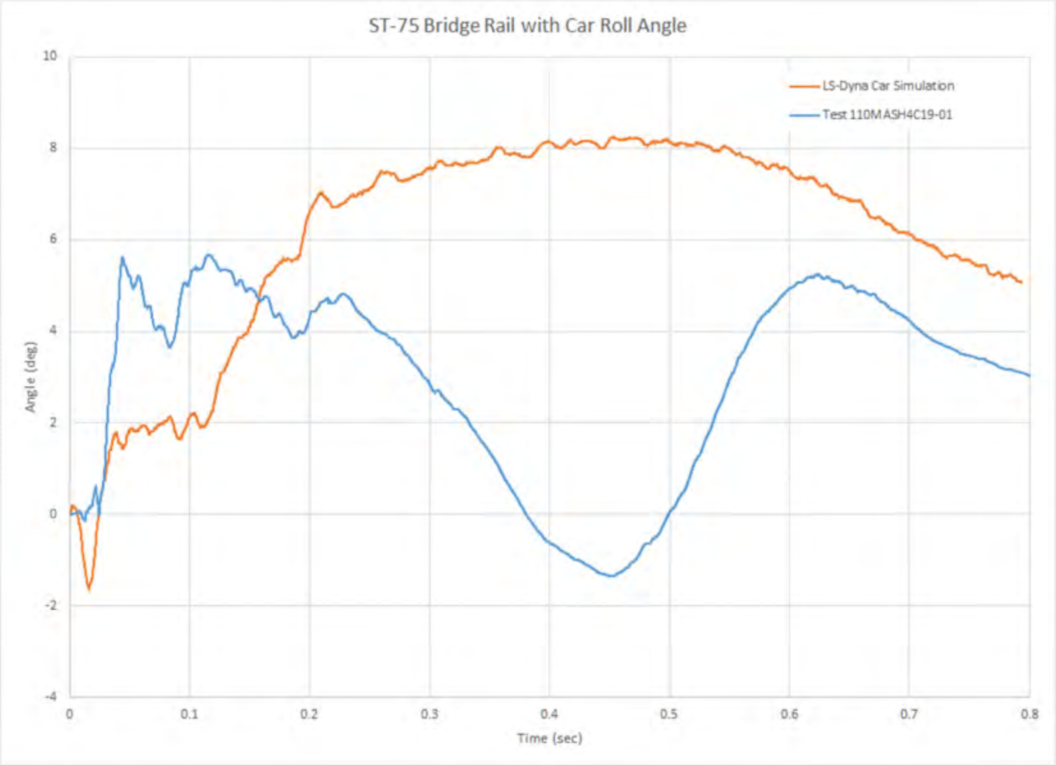


Figure 14-20 Graph of Roll Angles for Full Scale and FE Model TRAP Results for 1100C Car

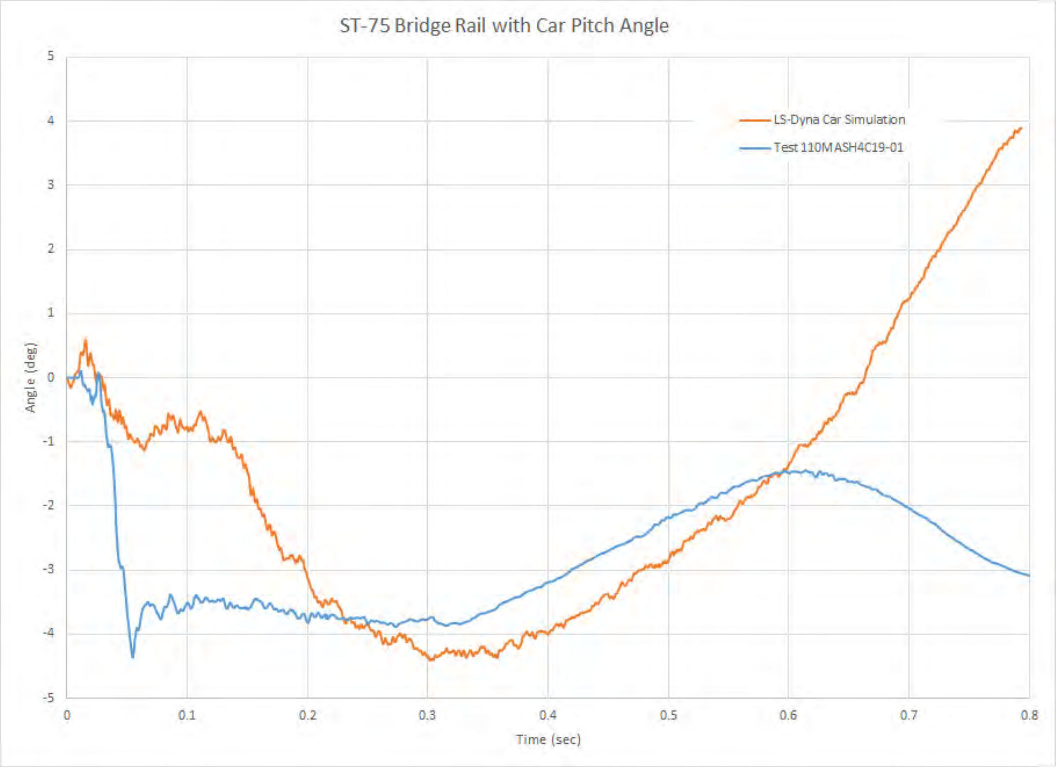


Figure 14-21 Graph of Pitch Angles for Full Scale and FE Model TRAP Results for 1100C Car

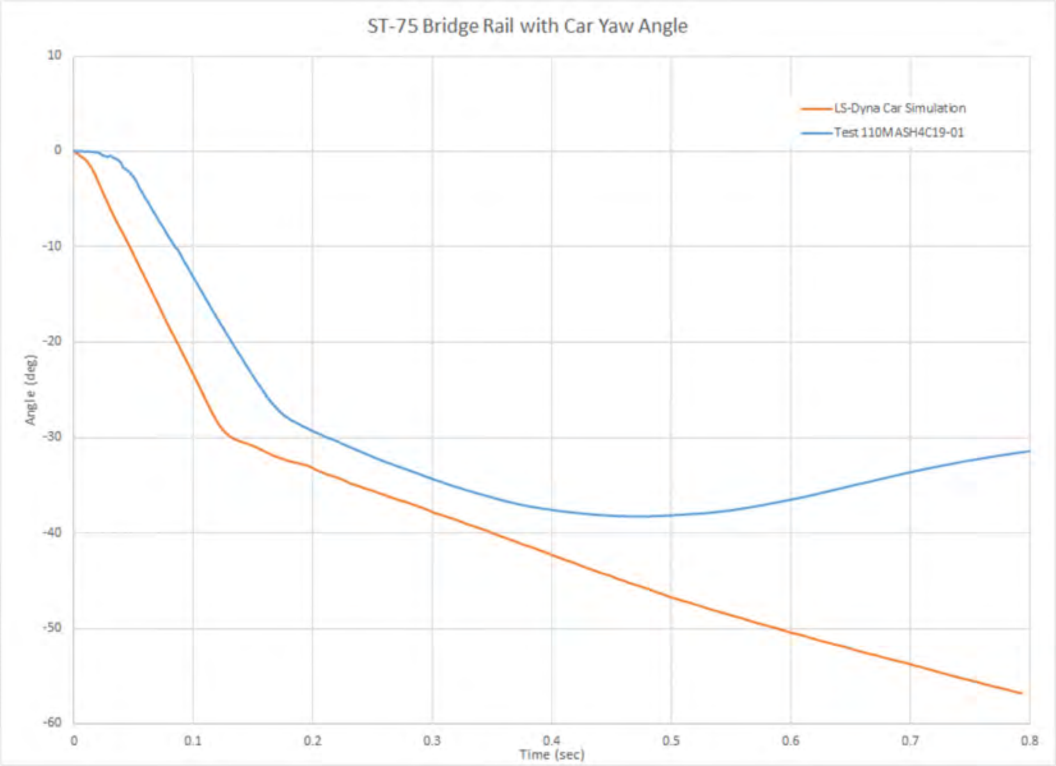


Figure 14-22 Graph of Yaw Angles for Full Scale and FE Model TRAP Results for 1100C Car

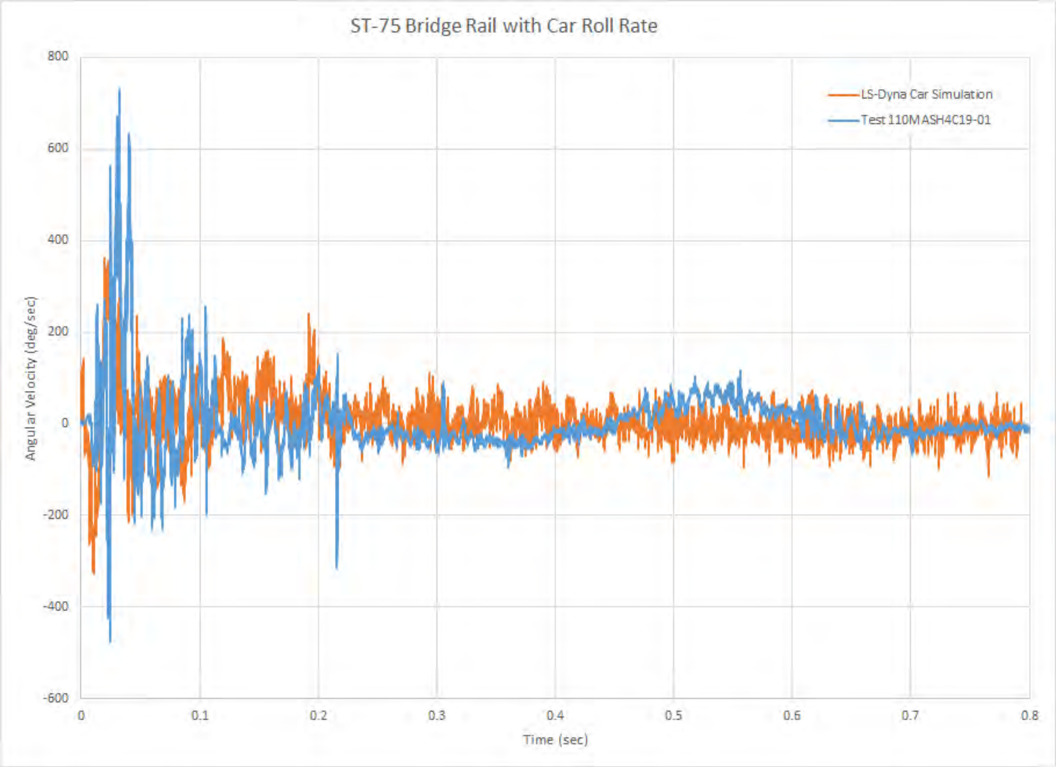


Figure 14-23 Graph of Roll Rates for Full Scale and FE Model TRAP Results for 1100C Car

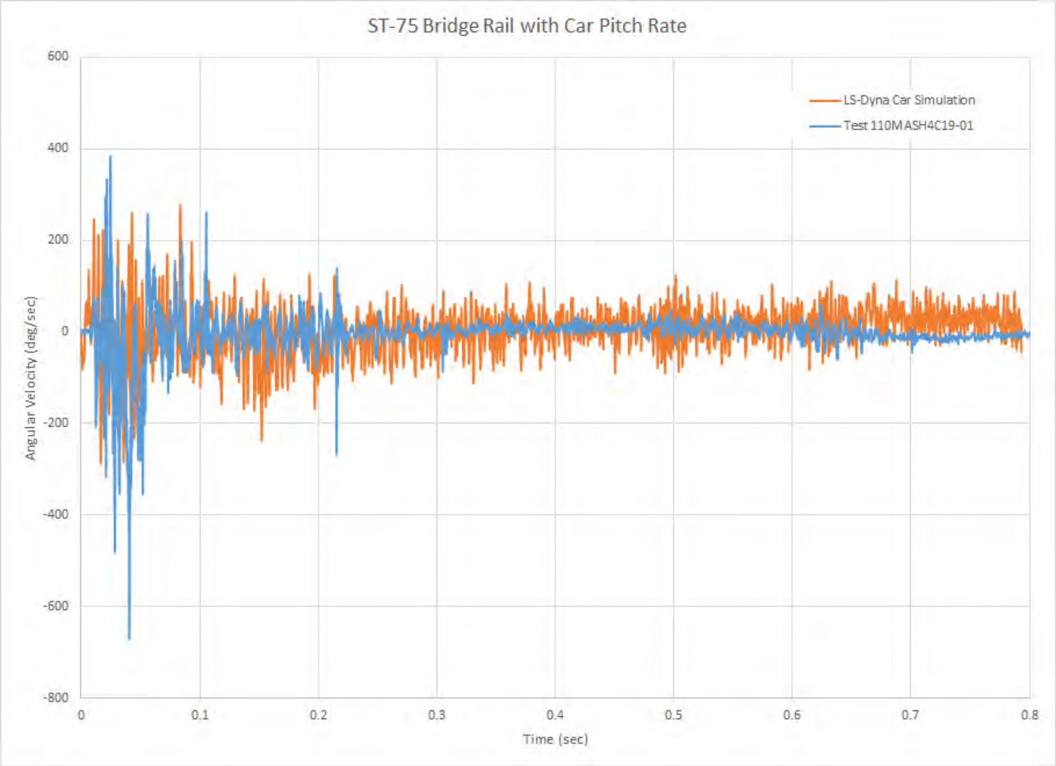


Figure 14-24 Graph of Pitch Rates for Full Scale and FE Model TRAP Results for 1100C Car

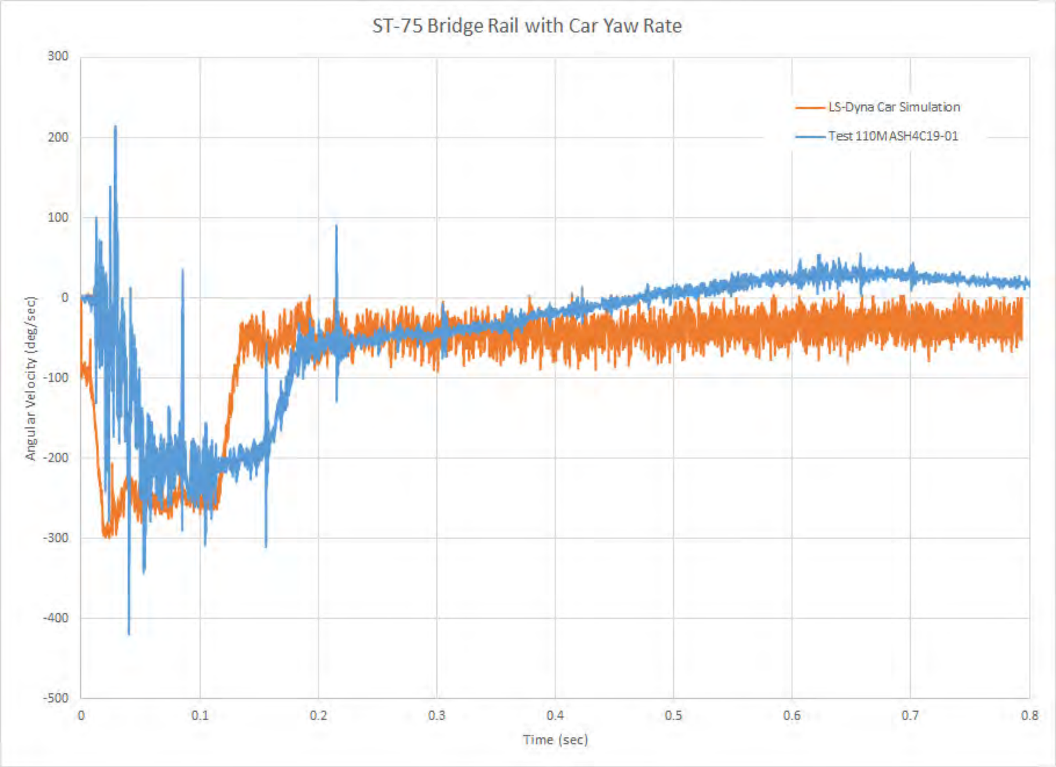


Figure 14-25 Graph of Yaw Rates for Full Scale and FE Model TRAP Results for 1100C Car

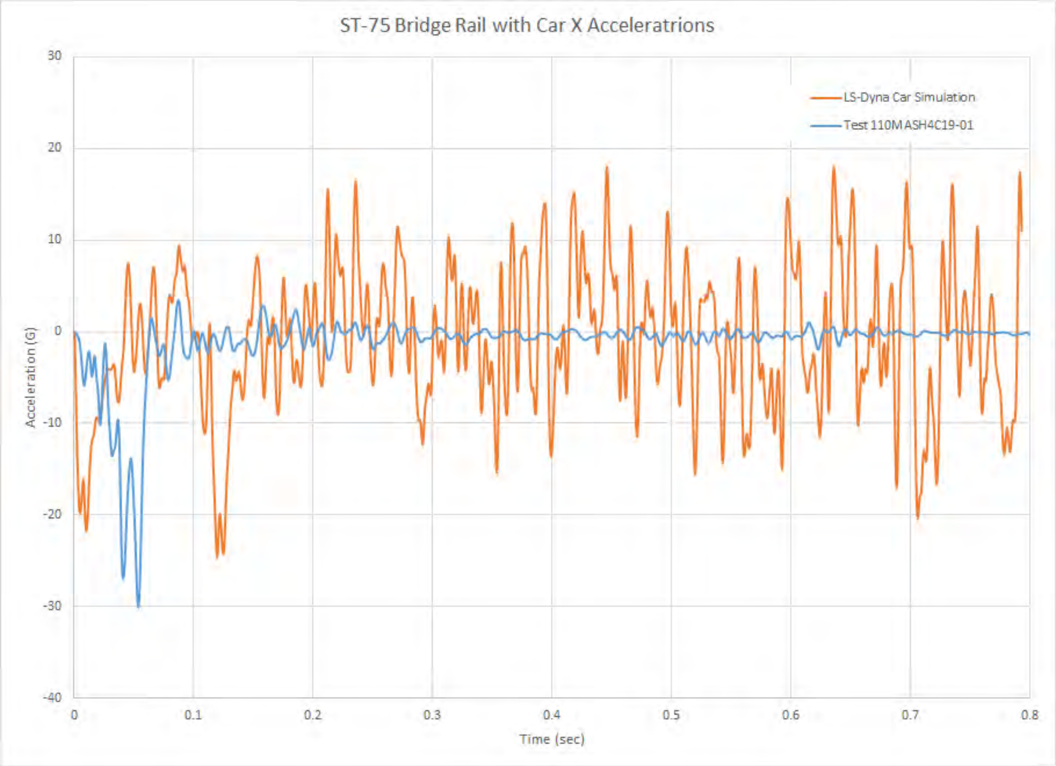


Figure 14-26 Graph of Longitudinal Accelerations for Full Scale and FE Model TRAP Results for 1100C Car

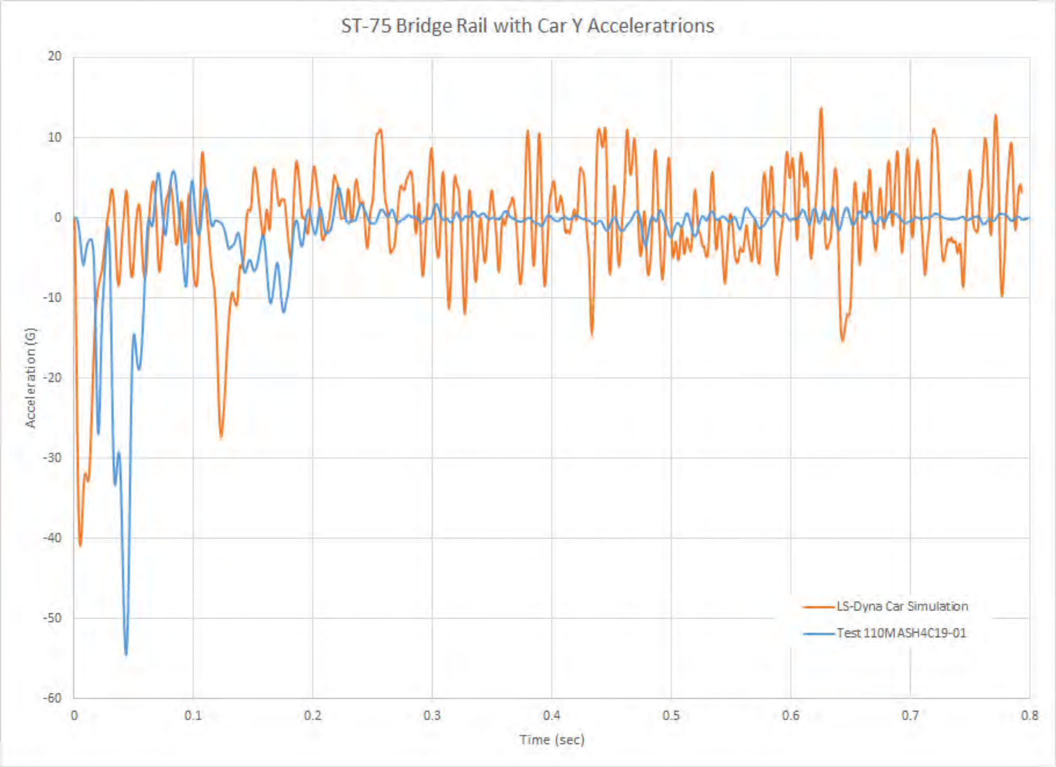


Figure 14-27 Graph of Lateral Accelerations for Full Scale and FE Model TRAP Results for 1100C Car

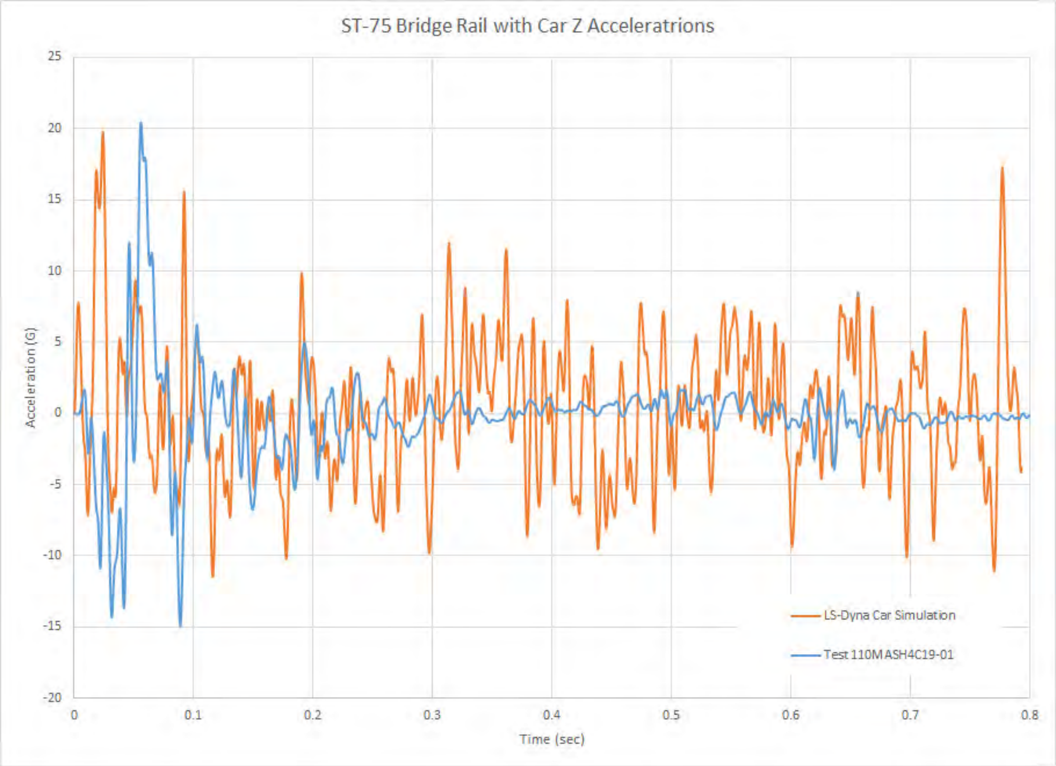


Figure 14-28 Graph of Vertical Accelerations for Full Scale and FE Model TRAP Results for 1100C Car

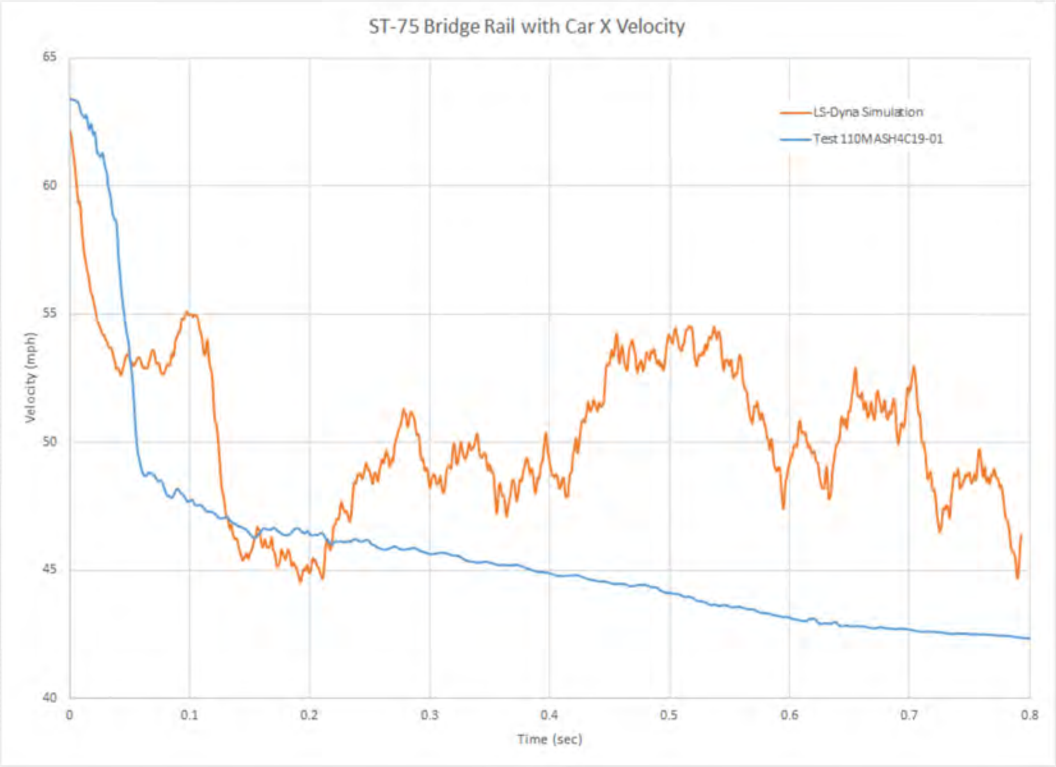


Figure 14-29 Graph of Longitudinal Velocity for Full Scale and FE Model TRAP Results for 1100C Car

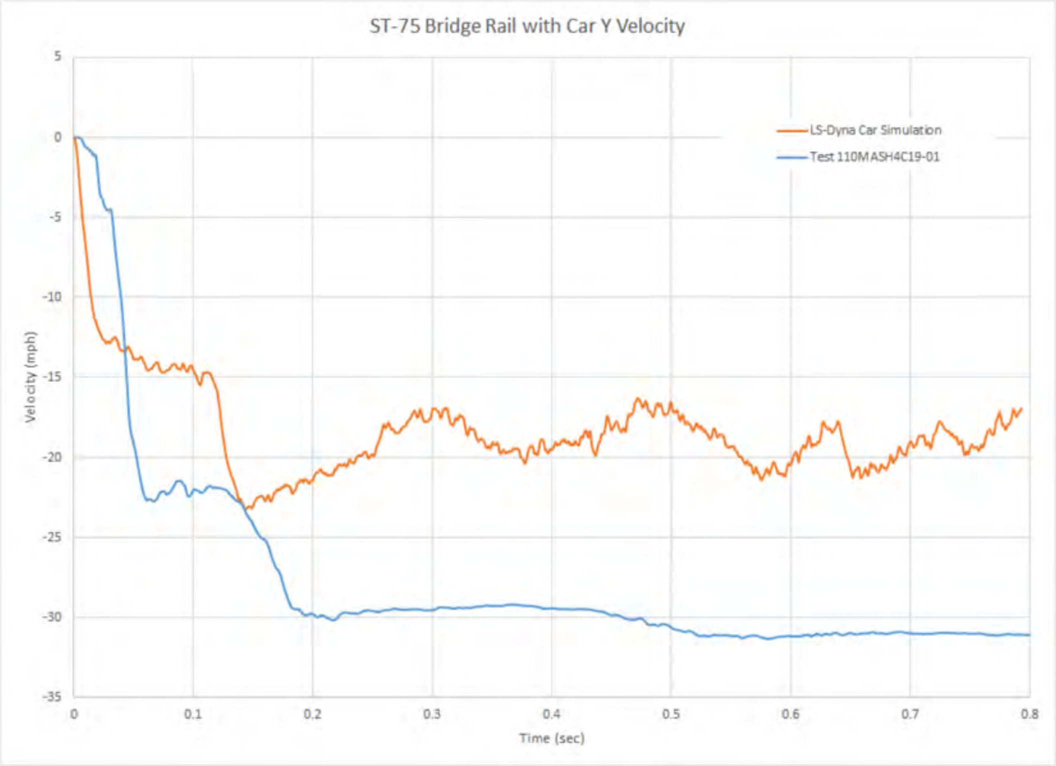


Figure 14-30 Graph of Lateral Velocity for Full Scale and FE Model TRAP Results for 1100C Car

14.5.2. Visual Comparison

A visual comparison of test 110MASH4C19-01 and the 1100C simulation shows that the vehicles' interaction with the barrier were similar. Figure 14-31 is a sequence of pictures showing the vehicles' interaction with the test article for both the full-scale test and the finite element model.

Test 110MASH4C19-01: 2017 Nissan Versa	**Time**	**LS-Dyna Car Simulation: 2010 Toyota Yaris**
	0.00 sec	
	0.06 sec	
	0.12 sec	
	0.18 sec	
	0.24 sec	
	0.30 sec	
	0.36 sec	

Figure 14-31 Visual Comparison of Actual Crash Test and Simulations for 1100C Small Car

14.6. 10000S Single Unit Truck

This section compares the results of test 110MASH4S19-02 and the results of the 10000S finite element model. Table 14-5 compares the center of gravity, mass, and wheel base between the 2013 4300 SBA International used in the crash test and the 1996 Ford F800 used in the finite element modeling. Section 14.6.1 compares the TRAP results and section 14.6.2 compares the impact sequence of test 110MASH4S19-02 to the FE simulation.

Table 14-5 Center of Gravity for 10000S Single Unit Truck and LS-Dyna Finite Element Model

	Vehicle Type	X*	Y**	Z	Mass	Wheel Base
Test 110MASH4S19-02	2013 4300 SBA International	148.7” (3776 mm)	0.2” (4 mm)	N/A	22077 lb (10014 kg)	236.5” (6007 mm)
10000S Vehicle Model	1996 Ford F800	126.2” (3206 mm)	-0.4” (-9 mm)	N/A	22046 lb (10000 kg)	208.7” (5300 mm)

* Behind centerline of front tire

** Negative means CG is on the driver side of the centerline

14.6.1. TRAP Data Comparison

MASH does not provide criteria for TRAP data. The TRAP results for test 110MASH4S19-02 and the 10000S simulation were similar to each other with two exceptions. The lateral occupant impact velocity for the test was over twice that in the simulation. The maximum roll angle for the simulation was about twice the roll in the test. As in the pickup test, it seems the real-world test roll, pitch, and yaw angles lag behind those in the simulation. Again, perhaps this is due to the barrier being fully constrained as well as the simulation vehicle’s wheelbase being 750 mm (29.5 in) shorter than the test vehicle. Damage to the post plates was observed in the real-world test, which shows the barrier does not perform as fully constrained when impacted with the 10000S vehicle. Table 14-6 shows the results of the TRAP analysis and Figure 14-32 through Figure 14-42 are graphs of the TRAP analysis for test 110MASH4S19-02 and the finite element model.

Table 14-6 TRAP Data Comparison for Full Scale and FE Model TRAP Results for 10000S Single Unit Truck (Absolute Values)

Data Results	MASH Criteria	Test 110MASH4S19-02 2013 4300 SBA International	Finite Element Model 1996 Ford F800
Longitudinal Occupant Impact Velocity	n/a	3.6 ft/s (1.1 m/s)	3.3 ft/s (1.0 m/s)
Longitudinal Ridedown Acceleration 10 msec Average	n/a	2.2 G	1.5 G
Lateral Occupant Impact Velocity	n/a	25.3 ft/s (7.7 m/s)	10.5 ft/s (3.2 m/s)
Lateral Ridedown Acceleration 10 msec Average	n/a	3.7 G	5.2 G
PHD	n/a	4.1	5.2
ASI	n/a	1.89	0.44
Max Roll	n/a	19.6	36.8 degrees
Max Pitch	n/a	3.2	4.0 degrees
Max Yaw	n/a	16.6	14.8 degrees

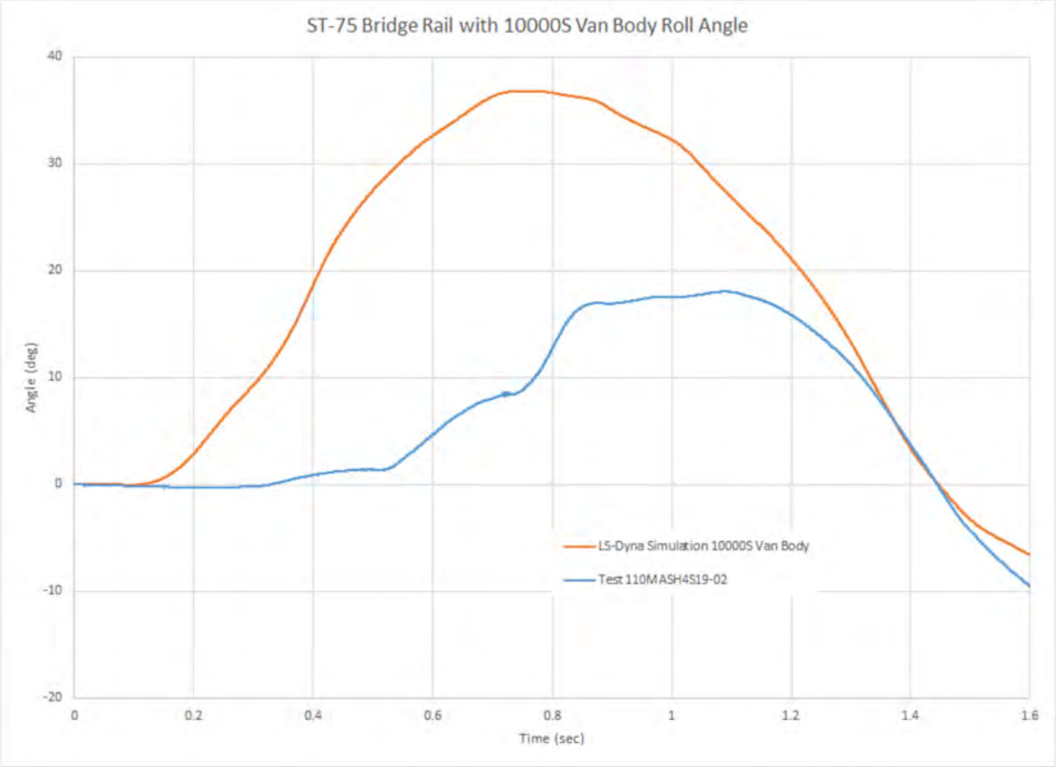


Figure 14-32 Graph of Roll Angles for Full Scale and FE Model TRAP Results for 10000S Single Unit Truck

Figure 14-33 Graph of Pitch Angles for Full Scale and FE Model TRAP Results for 10000S Single Unit Truck

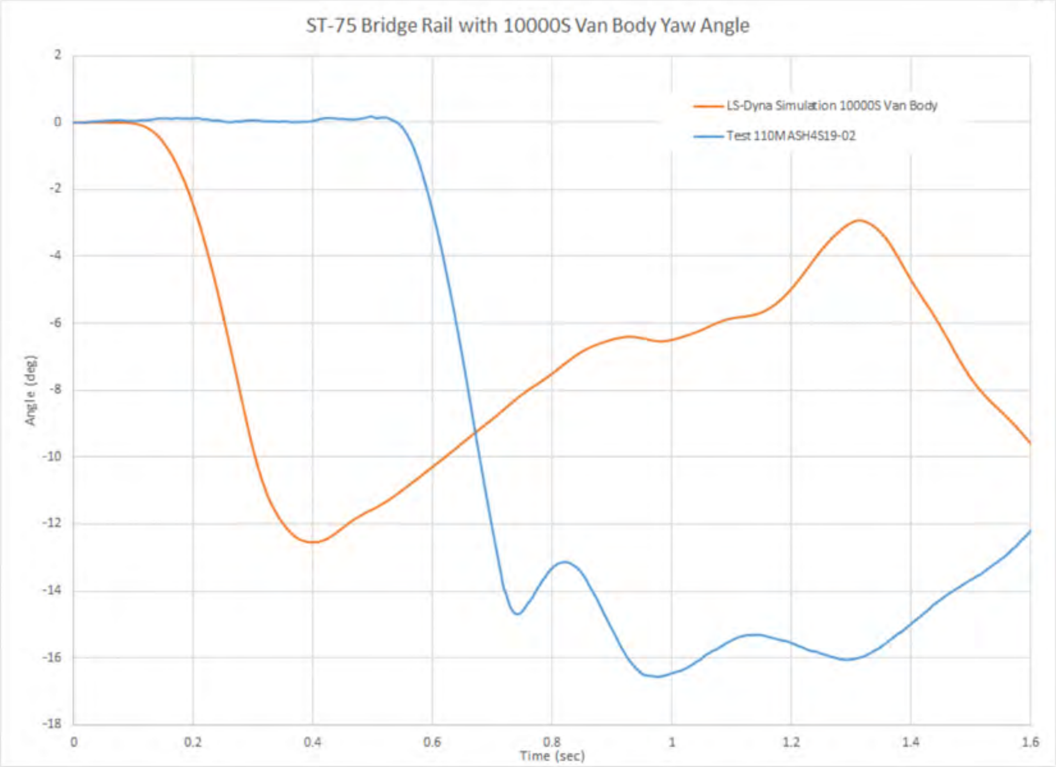


Figure 14-34 Graph of Yaw Angles for Full Scale and FE Model TRAP Results for 10000S Single Unit Truck

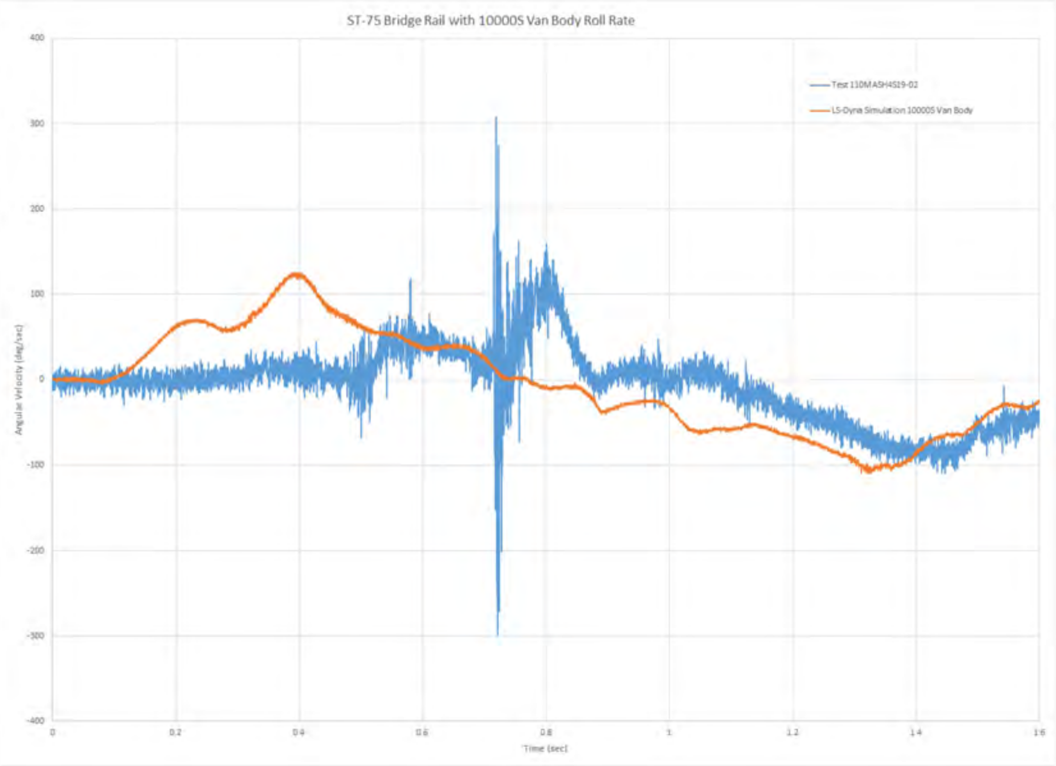


Figure 14-35 Graph of Roll Rates for Full Scale and FE Model TRAP Results for 10000S Single Unit Truck

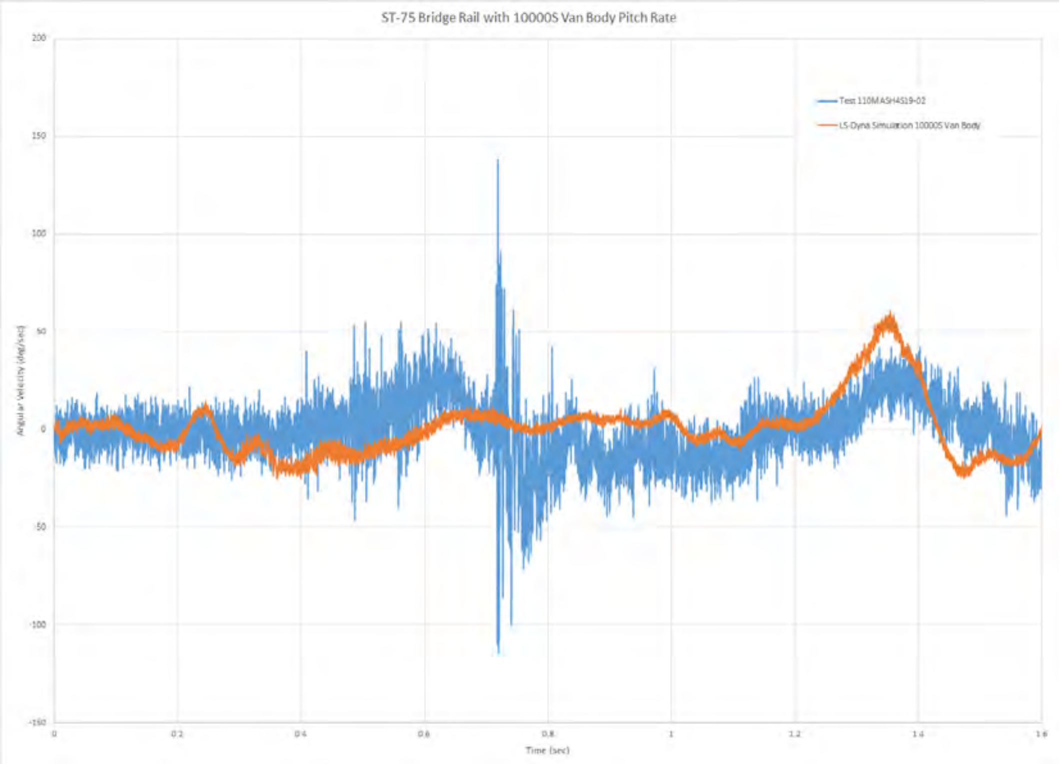


Figure 14-36 Graph of Pitch Rates for Full Scale and FE Model TRAP Results for 10000S Single Unit Truck

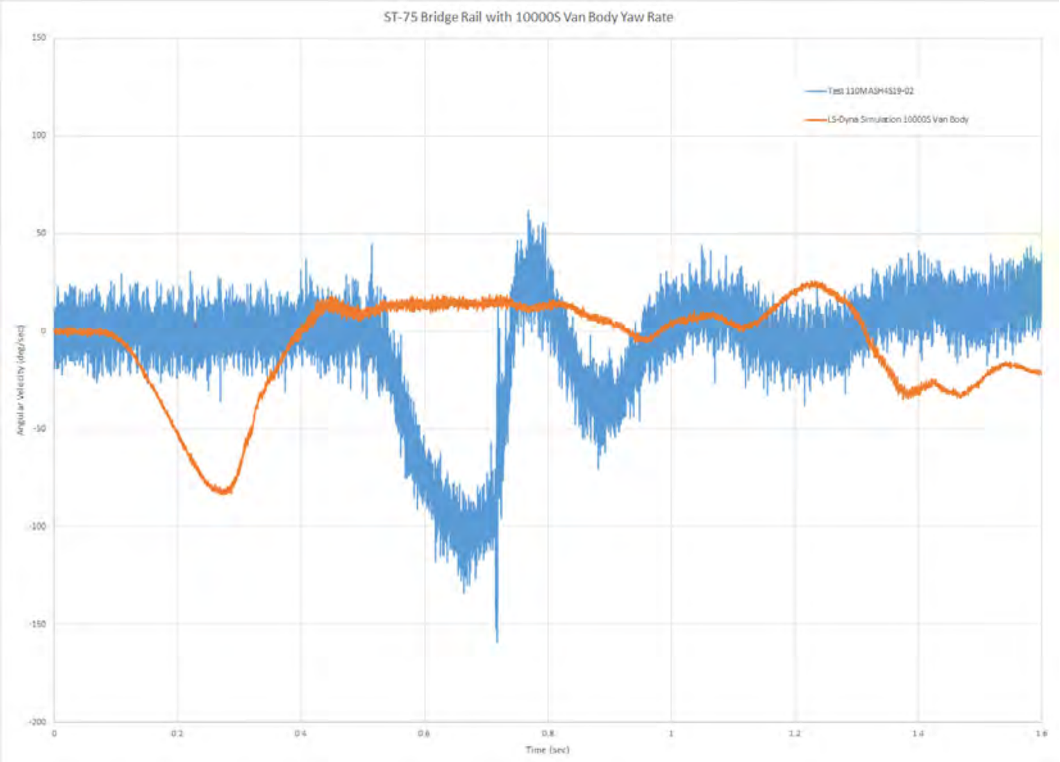


Figure 14-37 Graph of Yaw Rates for Full Scale and FE Model TRAP Results for 10000S Single Unit Truck

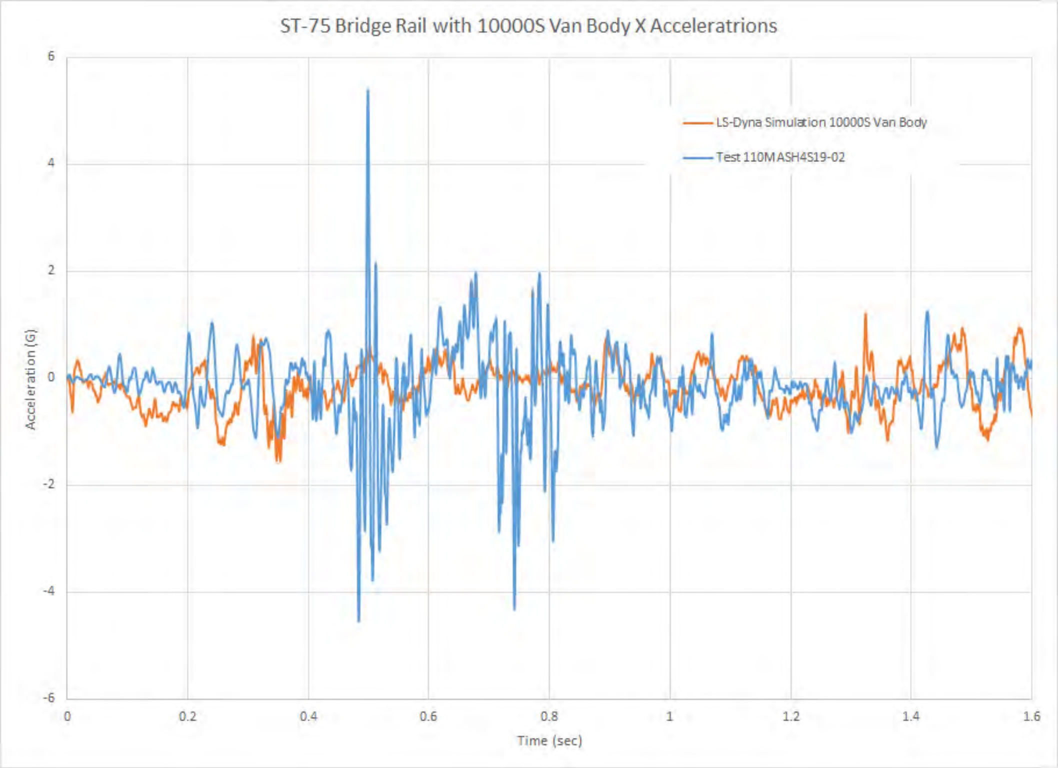


Figure 14-38 Graph of Longitudinal Accelerations for Full Scale and FE Model TRAP Results for 10000S Single Unit Truck

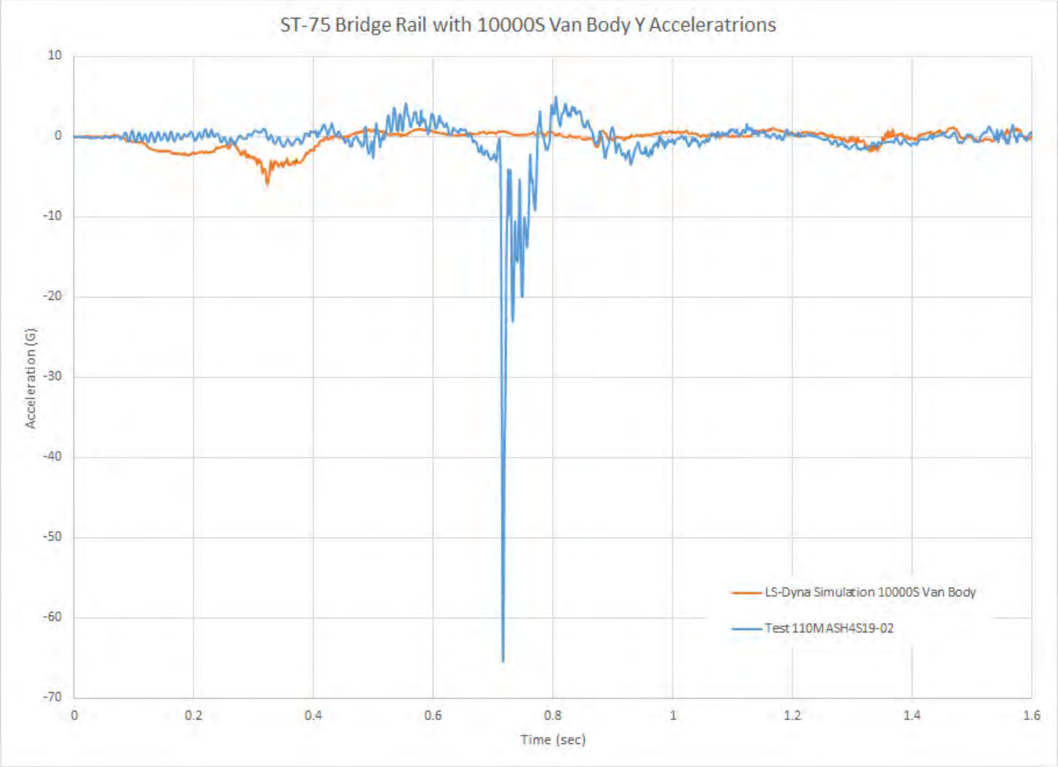


Figure 14-39 Graph of Lateral Accelerations for Full Scale and FE Model TRAP Results for 10000S Single Unit Truck

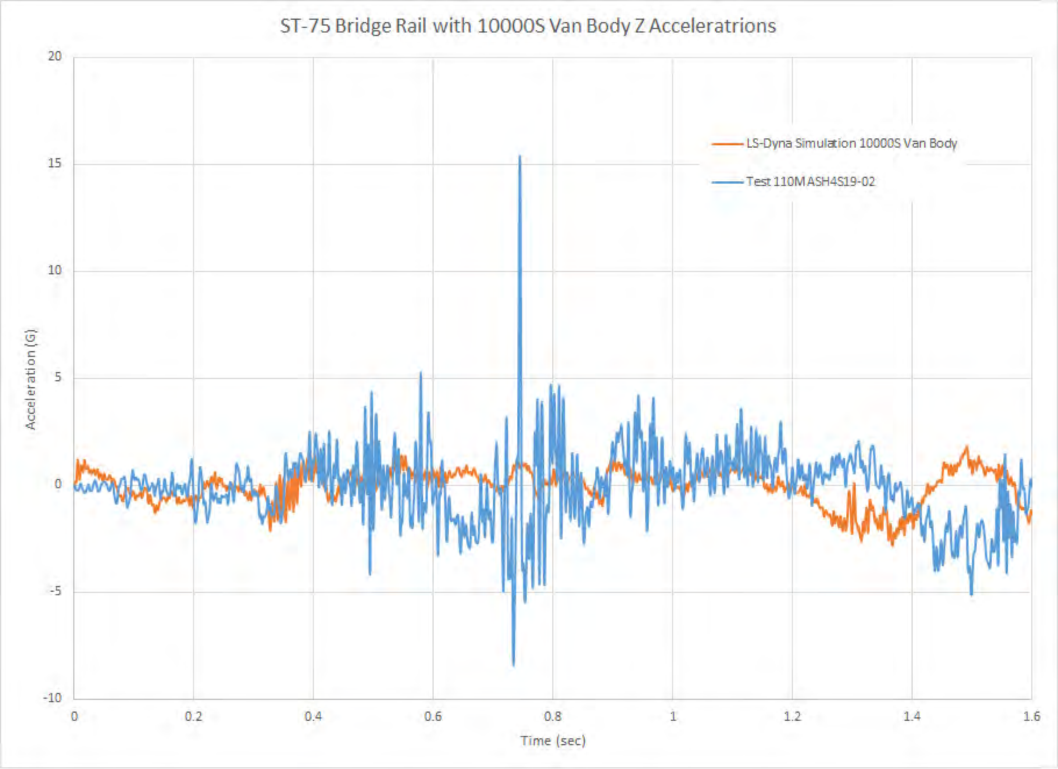


Figure 14-40 Graph of Vertical Accelerations for Full Scale and FE Model TRAP Results for 10000S Single Unit Truck

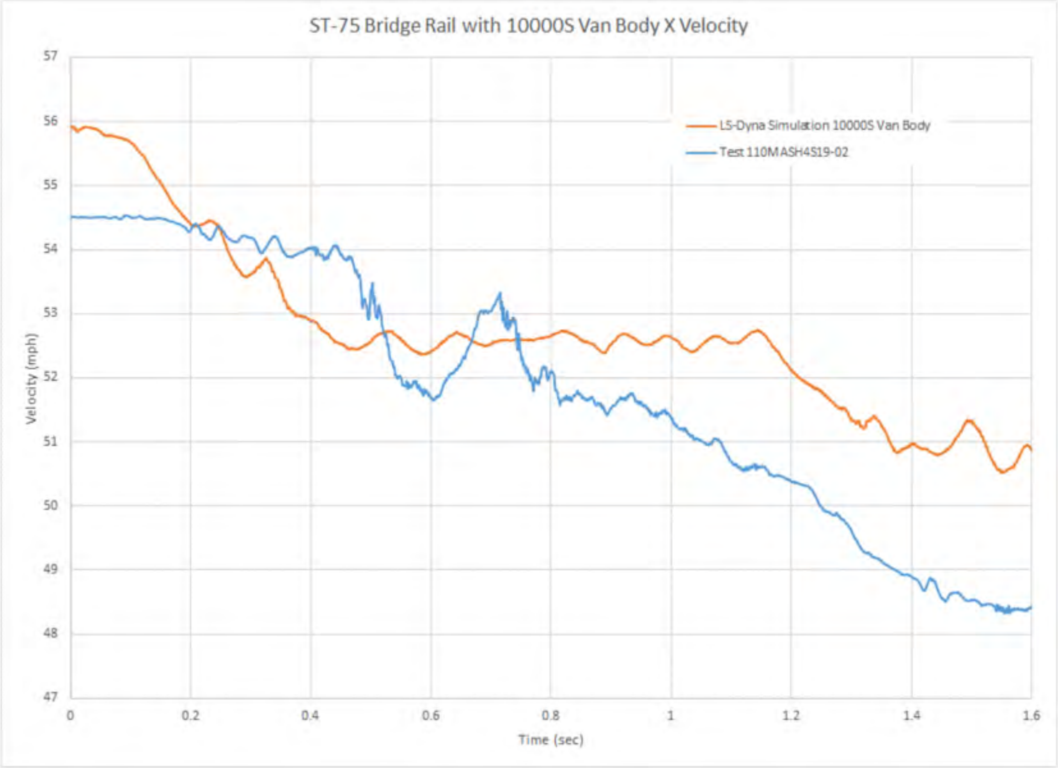


Figure 14-41 Graph of Longitudinal Velocity for Full Scale and FE Model TRAP Results for 10000S Single Unit Truck

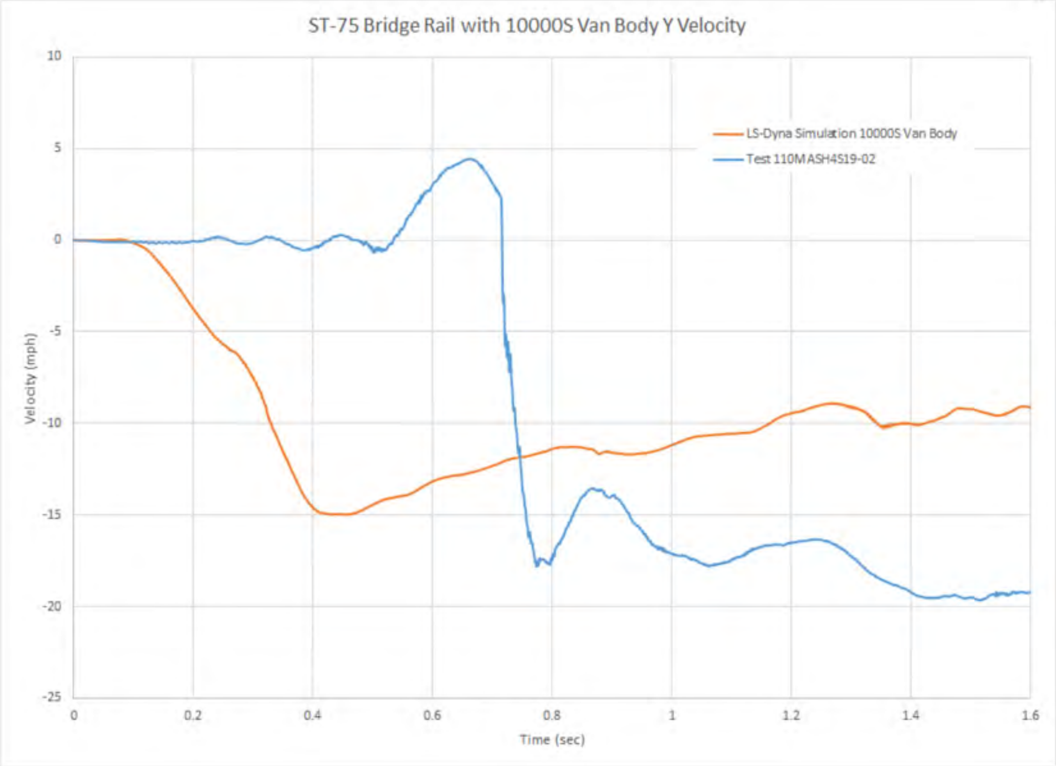


Figure 14-42 Graph of Lateral Velocity for Full Scale and FE Model TRAP Results for 10000S Single Unit Truck

14.6.2. Visual Comparison

Visually comparing test 110MASH4S19-02 to the FE simulation shows that the vehicles' interaction with the test article were similar for about 0.5 seconds. From the initial impact, the vehicle's cargo box in the simulation overrode the top of the barrier. From about 0.5 seconds and on the simulation continued to rotate over and override the barrier while the full-scale test vehicle began to recover and rotate back onto its wheels. The photos are not shown in the figure below, but the simulation vehicle will eventually rotate away from the barrier and back onto its wheels. Figure 14-43 is a sequence of pictures showing the vehicles' interaction with the test article for both the full-scale test and the finite element model.

Test 110MASH4S19-02: 2013 4300 SBA International	**Time**	**Finite Element Model: 1996 Ford F800**
	0.00 sec	
	0.09 sec	
	0.18 sec	
	0.27 sec	
	0.36 sec	
	0.54 sec	
	0.72 sec	

Figure 14-43 Visual Comparison of Actual Crash Test and Simulations for 10000S Single Unit Truck

14.7. Conclusions

A fully constrained finite element shell model of the ST-75 steel bridge was developed, ran, and compared to full-scale crash test results. Comparing the TRAP results showed that the simulations tended to predict lower velocities and higher accelerations. While the 2270P truck model predicted the full-scale test would pass MASH Test Level 4 criteria, the 1100C car model predicted a failure due to high accelerations. The higher acceleration may be due to the barrier model being full constrained and the vehicle models deforming less than their real-world counter parts. Comparing the simulations to the full-scale crash tests showed that the interaction of the vehicles with the barrier were similar except for the 10000S single-unit van truck. The cargo box in the simulation overrode the top of the barrier which allowed the vehicle to roll further over the barrier compared to its real-world counterpart. Even with the additional roll the simulation vehicle eventually rolled back onto its wheels and was redirected as designed by the barrier.

Improvements to future finite element models will include the pedestrian hand/bicycle rail if the real-world test article includes the rail to see its effect on hood snag with the 2270P test and effect on the 10000S test. In the case of the ST-75, the physical crash testing of the test article built with a handrail did not show any potential for hood snag in the 2270P test but the handrail may have reduced cargo box override in the 10000S test. Other test articles may be different. Instead of fully constraining the rails in the barrier model the rails can be fully constrained every 3 m (10 ft) to represent posts and better match the full-scale test article. This might lower the accelerations in the 1100C car simulation since the rails will be allowed to translate and rotate. This would also likely improve the 10000S simulation as the barrier did not perform as fully constrained in the real-world test, as evidenced by damage to the post plates.

15. Document Revision History

Date	**Description**