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Development and Evaluation of Weak-Post W-Beam Guardrail in Mow Strips

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DEVELOPMENT AND EVALUATION OF WEAK-POST W-BEAM GUARDRAIL IN MOW STRIPS

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16. Abstract

The objective of this study was to adapt and evaluate a weak-post, W-beam guardrail system for use within mow strips and other pavements. The weak-post guardrail system was originally designed as the MGS bridge rail and has also been adapted for use on culverts. It was envisioned that the weak-post design would absorb the impact forces and prevent damage to the mow strips, thereby minimizing maintenance and repair costs.

Evaluation of the weak posts in mow strips began with three rounds of dynamic bogie testing. Round 1 of bogie testing showed that 4-in. (102-mm) thick concrete would sustain only minor spalling from impacts to the posts. However, the posts would push through 4-in. and 6-in. (102-mm and 152-mm) thick asphalt mow strips. During Round 2, 24-in. (610-mm) long, 4-in. x 4-in. (102-mm x 102-mm) sockets with 10-in. x 9-in (254-mm x 229-mm) shear plates were utilized to better distribute the impact load to the asphalt pavement and prevent damage. However, Round 3 of bogie testing consisted of dual-post impacts, and the asphalt suffered from shear block fracture between the two 24-in. (610-mm) sockets and the back edge of the mow strip. A dual-post test within a 4-in. (102-mm) thick concrete pad showed only minor spalling.

A full-scale MASH 3-11 test was conducted on the weak-post guardrail system installed within an asphalt mow strip. Due to the Round 3 testing results, the asphalt thickness was increased to 6 in. (152 mm), and the socket depth was increased to 30 in. (762 mm). The 2270P pickup was contained and safely redirected, and all MASH safety criteria were satisfied. Unfortunately, the asphalt fractured, and a 2½-in. (64-mm) wide crack ran from socket to socket throughout the impact region of the system. Therefore, the weak-post guardrail system was crashworthy, but would require repairs in its current configuration. The system could also be installed in a concrete mow strip to prevent pavement damage.

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UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Dr. Cody Stolle, Research Assistant Professor.

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1 INTRODUCTION

1.1 Background

Over the years, it has become desirable to place a longitudinal concrete slab or continuous asphalt pavement under W-beam guardrail systems in order to reduce the time and costs for mowing operations around guardrail posts. Unfortunately, prior research has demonstrated that standard strong-post W-beam guardrails may not perform in an acceptable manner when the guardrail posts are placed directly in an asphalt or concrete pavement that restricts post rotation. Rail ruptures have been attributed to a loss of energy dissipation in the barrier system when posts were restricted from rotating through the soil [1-2].

Currently, guardrail posts installed within mow strips have required a blocked-out area or “leave-out” that surrounds each post. Leave-outs allow posts to rotate through the soil, which results in acceptable safety performances for standard W-beam guardrails [3-6]. Many leave-out designs incorporate weak cement, grout mixes, or rubber/foam pads that restrict plant growth but crumble away under impact loads. After an impact event, the debris is removed, soil is retamped, a new post is driven into place, and a new batch of the weak cement/grout is poured into the leave-out. Therefore, significant effort is required to reset a post after an impact. Examples of typical grout-filled leave-outs before and after impact are shown in Figure 1.

In 2010, the Midwest Guardrail System (MGS) Bridge Rail was developed utilizing S3x5.7 (S76x8.5) steel posts at half-post spacing, or 37½ in. (953 mm) on center, to support standard W-beam guardrail segments [7-8]. The posts were installed in tubular steel sockets that were side-mounted to a concrete bridge deck, as shown in Figure 2. Energy was dissipated during impact events through bending of the weak posts instead of post rotation through soil. The MGS bridge rail was successfully crash tested to the Teat Level 3 (TL-3) safety performance standards of the *Manual for Assessing Safety Hardware* (MASH) [9].

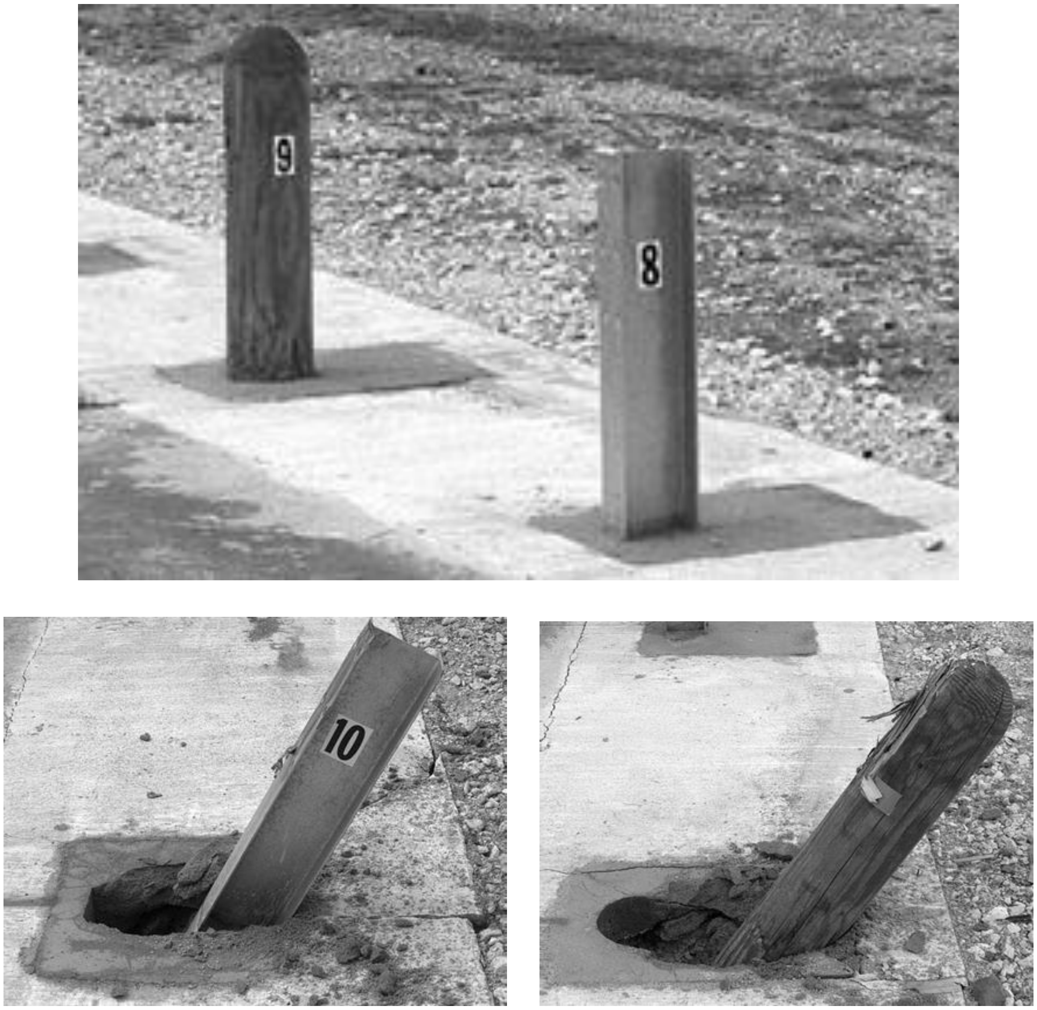


Figure 1. Pre- and Post-Test Photos of Posts in Grout-Filled Leave-Outs [3]

Figure 2. MGS Bridge Rail Installation

Since the MGS bridge rail posts were installed in rigid sleeves, it was believed that the MGS Bridge Rail could be adapted for use in guardrail applications where mow strips similarly restrict the movement of the posts below the groundline. Ideally, this application would eliminate the need for leave-outs around guardrail posts installed in unyielding pavements. Additionally, the use of sockets would minimize costs and labor time during installation and repairs to damaged posts.

1.2 Objective

The objective of this research effort was to adapt the weak-post, MGS bridge rail for use in mow strips and other pavements. Ideally, the steel guardrail system components would withstand the impact loads and dissipate enough energy to leave the mow strip undamaged. Thus, system repairs would require only the removal and replacement of damaged barrier components (posts and rail segments). The new guardrail system was to be evaluated according to MASH TL-3 safety performance criteria.

1.3 Research Approach

The project was completed via a series of tasks. First, a review of multiple Departments of Transportation (DOTs) standards was conducted to determine typical mow strip widths, thicknesses, and materials (concrete or asphalt), and to select a critical mow strip configuration for testing. Next, dynamic component testing was conducted to evaluate pavement damage resulting from impacts into posts with various socket configurations. Based on the component testing results, a design configuration was selected and full-scale crash tested according to MASH TL-3 conditions. Finally, conclusions and recommendations were formed concerning the final system design and installation practices.

2 REVIEW OF MOW STRIP STANDARDS AND PRACTICES

Before the MGS bridge rail could be adapted for use in mow strips, it was vital to identify the mow strip configurations currently being installed. Of specific importance to this project were the thicknesses, widths, and pavement materials of typical mow strip installations, as these characteristics determine the strength of a mow strip. Therefore, a review was conducted on the mow strip standards from the various members of the Midwest States Pooled Fund Program. The results of this review are summarized in Table 1.

Table 1. Typical Mow Strip Configurations of Pooled Fund Members

State DOT	Typical Mow Strip Configuration		
	Material	Thickness	Width
Wisconsin	Asphalt	4 in.	4 ft
South Dakota	Asphalt	>4 in.	4 ft
Iowa	Asphalt	4 in.	4 ft
Wyoming	Asphalt	4 in.	3 ft
New Jersey	Asphalt	4–6 in.	>2 ft
Missouri	Asphalt	3–4 in.	4 ft
Nebraska	Asphalt	4 in.	4 ft
Illinois	Concrete Asphalt	4 in. 4 in.	4 ft 4 ft
Ohio	Concrete Asphalt	4 in. 3–4 in.	4 ft 4 ft
Kansas	Concrete	4 in.	4 ft

From the ten State Departments of Transportation (DOTs) that participated in the review, nine installed asphalt mow strips, while three installed concrete mow strips (two states used both). Thicknesses were reported between 3 to 6 in. (76 to 152 mm), although 4 in. (102 mm) was the most commonly utilized thickness. Typical mow strip widths were consistently reported as 4 ft (1.2 m), with only two states allowing narrower mow strips.

The results of this review indicated that a 4-in. (102-mm) thick, 4-ft (1.2-m) wide asphalt mow strip was the most commonly utilized configuration. Therefore, it was desired for the weak-post guardrail system to be compatible with 4-in. (102-mm) thick, 4-ft (1.2-m) wide asphalt mow strips. However, through discussions with the project sponsors, other mow strip configurations would be acceptable if stronger mow strips were necessary to prevent damage. As such, the use of asphalt thicknesses up to 6 in. (152 mm) and/or the use of concrete as the pavement material were also options for the mow strip design. Dynamic component testing would be conducted to evaluate the mow strip configurations and determine the required strength to prevent pavement damage.

3 COMPONENT TESTING CONDITIONS

3.1 Purpose

One of the objectives for the new guardrail system was to prevent damage to the mow strip, thereby minimizing repair time and costs. As such, it was important to quantify the expected level of damage that various mow strip configurations would incur while supporting S3x5.7 (S76x8.5) guardrail posts. Dynamic component testing was conducted to evaluate various mow strips and aid in the selection of the final system design configuration.

3.2 Scope

Dynamic component testing was conducted with a bogie vehicle impacting an S3x5.7 (S76x8.5) post installed within concrete and asphalt mow strips of various widths. Additionally, some of the tests utilized steel sockets of varying depths to support the posts. Altogether, 11 component tests were conducted over three rounds of component testing. The tests were conducted on an iterative basis in order to determine the minimum size and strength of a mow strip to prevent damage during vehicle impacts to the weak-post guardrail system.

3.3 Equipment and Instrumentation

Equipment and instrumentation utilized to collect and record data during the dynamic bogie tests included a bogie vehicle, accelerometers, a retroreflective speed trap, high-speed and standard-speed digital video, and still cameras.

3.3.1 Bogie Vehicle

A rigid-frame bogie was used to impact the posts. A variable-height, detachable impact head was used in the testing. The bogie head was constructed of 2½-in. x 2½-in. (64-mm x 64-mm), $^{5}/_{16}$-in. (8-mm) thick square steel tubing, with ¾-in. (19-mm) neoprene belting attached to the front of the head to prevent local damage to the post from the impact. The impact head was bolted to the bogie vehicle, creating a rigid frame with an impact height of 12 in. (305 mm), which was selected to simulate the bumper height of a small car. The bogie with the impact head is shown in Figure 3. The weight of the bogie with the addition of the mountable impact head and accelerometers was approximately 1,800 lb (820 kg).

Figure 3. Rigid-Frame Bogie on Guidance Track

The tests were conducted using a steel corrugated beam guardrail to guide the tire of the bogie vehicle. A pickup truck was used to push the bogie vehicle to the required impact velocity. After reaching the target velocity, the push vehicle braked, allowing the bogie to be free-rolling as it came off the track. A remote braking system was installed on the bogie, allowing it to be brought safely to rest after the test.

3.3.2 Accelerometers

During each component test, an accelerometer system was mounted on the bogie vehicle near its center of gravity to measure accelerations in the longitudinal, lateral, and vertical directions. However, only the longitudinal acceleration was processed and reported. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filters conforming to SAE J211/1 specifications [10]. Four different accelerometer systems were utilized throughout the component testing program. Table 2 contains a breakdown of the accelerometers utilized during each component test.

Table 2. Accelerometers Utilized during Each Component Test

Round of Testing	Test No.	Accelerometers			
		SLICE-1	SLICE-2	DTS	EDR-3
1	MS-1	X			X
	MS-2	X			X
	MS-3	X			X
	MS-4	X			X
2	MS-5			X	X
	MSSP-1		X		
	MSSP-2		X		
	MSSP-3		X		
	MSSP-4		X		
3	MSSP-5		X		
	MSSP-6		X		

The first two systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The acceleration sensors were mounted inside the bodies of custom-built SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The third accelerometer system was a two-arm piezoresistive accelerometer system manufactured by Endevco of San Juan Capistrano, California. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. The accelerometers were configured and controlled using a system developed and manufactured by DTS. More specifically, data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M. The SIM was configured with 16 MB SRAM and eight sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were crashworthy. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The fourth system, Model EDR-3, was a triaxial piezoresistive accelerometer system manufactured by Instrumented System Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM, a range of ±200 g's, a sample rate of 3,200 Hz, and a 1,120 Hz low-pass filter. The "DynaMax 1 (DM-1)" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

At the time of testing, the EDR-3 transducer was not calibrated to ISO 17025 standards, due to the lack of an ISO 17025 calibration laboratory with the capabilities of calibrating the unit. However, the EDR-3 was calibrated by IST, which provided traceable documentation for the calibration. MwRSF also recognizes that the EDR-3 does not satisfy the 10,000 Hz sample frequency recommended by MASH. Following numerous test comparisons, the EDR-3 has been shown to provide equivalent results to the DTS unit, which does satisfy MASH criteria and has ISO 17025 calibration traceability. Therefore, MwRSF has continued to use the EDR-3 as a backup device during physical impact testing.

3.3.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the bogie vehicle before impact. Three retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the vehicle. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box activating the LED flashes. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

3.3.4 Digital Photography

At a minimum, one AOS high-speed digital video camera, one GoPro digital video camera, and one JVC digital camera were used to document each test. The AOS high-speed camera had a frame rate of 500 frames per second, the GoPro video camera had a frame rate of 120 frames per second, and the JVC digital video camera had a frame rate of 29.97 frames per second. The cameras were typically placed laterally from the post, with a view perpendicular to the bogie’s direction of travel. A Nikon D50 digital still camera was used to document pre- and post-test conditions for all tests.

3.4 End of Test Determination

When the impact head initially contacted the test article, the force exerted by the surrogate test vehicle was directly perpendicular. However, as the post rotated, the surrogate test vehicle’s orientation and path moved farther from perpendicular. This introduced two sources of error: (1) the contact force between the impact head and the post had a vertical component and (2) the impact head slid upward along the test article. Therefore, only the initial portion of the accelerometer trace is typically used, since variations in the data become significant as the system rotates and the surrogate test vehicle overrides the system. Additionally, guidelines were established to define the end-of-test time using the high-speed video of the impact. The first occurrence of either of the following events was used to determine the end of the test: (1) the test article fractures or (2) the surrogate vehicle overrides/loses contact with the test article.

3.5 Data Processing

The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications [10]. The pertinent acceleration signal was extracted from the bulk of the data signals. The processed acceleration data was then multiplied by the mass of the bogie to get the impact force using Newton's Second Law. Next, the acceleration trace was integrated to find the change in velocity versus time. Initial velocity of the bogie, calculated from the speed trap data, was then used to determine the bogie velocity, and the calculated velocity trace was integrated to find the bogie's displacement. This displacement was also the displacement of the post. Combining the previous results, a force vs. deflection curve was plotted for each test. Finally, integration of the force vs. deflection curve provided the energy vs. deflection curve for each test.

4 COMPONENT TESTING – ROUND 1

4.1 Purpose

The original MGS bridge rail system utilized 4-in. x 4-in. (102-mm x 102-mm) steel tube sockets to support the S3x5.7 (S76x8.5) posts to the bridge deck. The sockets were designed to be rigid and prevent movement of the posts below the groundline during impacts. However, it was unclear if sockets would be necessary for these posts installed in mow strips, as the concrete/asphalt may have enough strength to prevent movement of the posts at the groundline. To explore this possibility, Round 1 of component testing was conducted to evaluate the damage associated with both asphalt and concrete mow strips without sockets.

4.2 Scope

Round 1 of component testing consisted of four tests on S3x5.7 (S76x8.5) posts installed within various mow strips without sockets, as shown in Figures 4 through 6. Test nos. MS-1 and MS-3 were conducted with the posts installed with a 4-in. (102-mm) thick concrete mow strip, test no. MS-2 was conducted with a 4-in. (102-mm) thick asphalt mow strip, and test no. MS-4 was conducted with a 6-in. (152-mm) thick asphalt mow strip. For Test MS-1, the post was installed through a 4-in. x 4-in. (102-mm x 102-mm) leave-out formed in the concrete during casting of the mow strip, while the post for MS-3 was installed through a 4-in. (102-mm) diameter hole cored in the concrete. The posts for MS-2 and MS-4 were driven through the asphalt and into the ground without any holes or leave-outs in the pavement. All mow strips were 4 ft (1.2 m) wide, and the posts were installed at the center of the mow strip width.

The unreinforced concrete mow strip was constructed from a concrete mix with a compressive strength of 4,000 psi (28 MPa). The asphalt mow strip was constructed from a 52-34 grade binder typically utilized in highway shoulder construction in Nebraska. The S3x5.7 (S76x8.5) posts were designated as A36 steel. However, the posts were fabricated from a 50 ksi

(345 MPa) steel that also satisfied A992 requirements. This increased strength resulted in a more critical evaluation of the mow strips. Material specifications, mill certifications, and certificates of conformity for the installation materials are shown in Appendix A.

The bogie vehicle impacted the posts at a height of 12 in. (305 mm), a targeted impact speed of 20 mph (32 km/h), and an angle of 90 degrees, thus causing strong-axis bending. This impact condition was selected to provide a critically high load to the post and the supporting mow strip. The same impact conditions were used previously when evaluating the adaptation of the MGS bridge rail for use on culvert headwalls [11]. The complete test matrix for Round 1 of component testing is shown in Table 3.

Table 3. Component Testing Matrix, Round 1

Test No.	Mow Strip			Installation Hole	Impact Height in. (mm)	Impact Speed mph (km/h)	Impact Angle Deg.
	Material	Thickness in. (mm)	Width ft (m)				
MS-1	Concrete	4 (102)	4 (1.2)	4” dia. hole	12 (305)	20 (32)	90°
MS-2	Asphalt	4 (102)	4 (1.2)	NA	12 (305)	20 (32)	90°
MS-3	Concrete	4 (102)	4 (1.2)	4”x4” leave-out	12 (305)	20 (32)	90°
MS-4	Asphalt	6 (152)	4 (1.2)	NA	12 (305)	20 (32)	90°

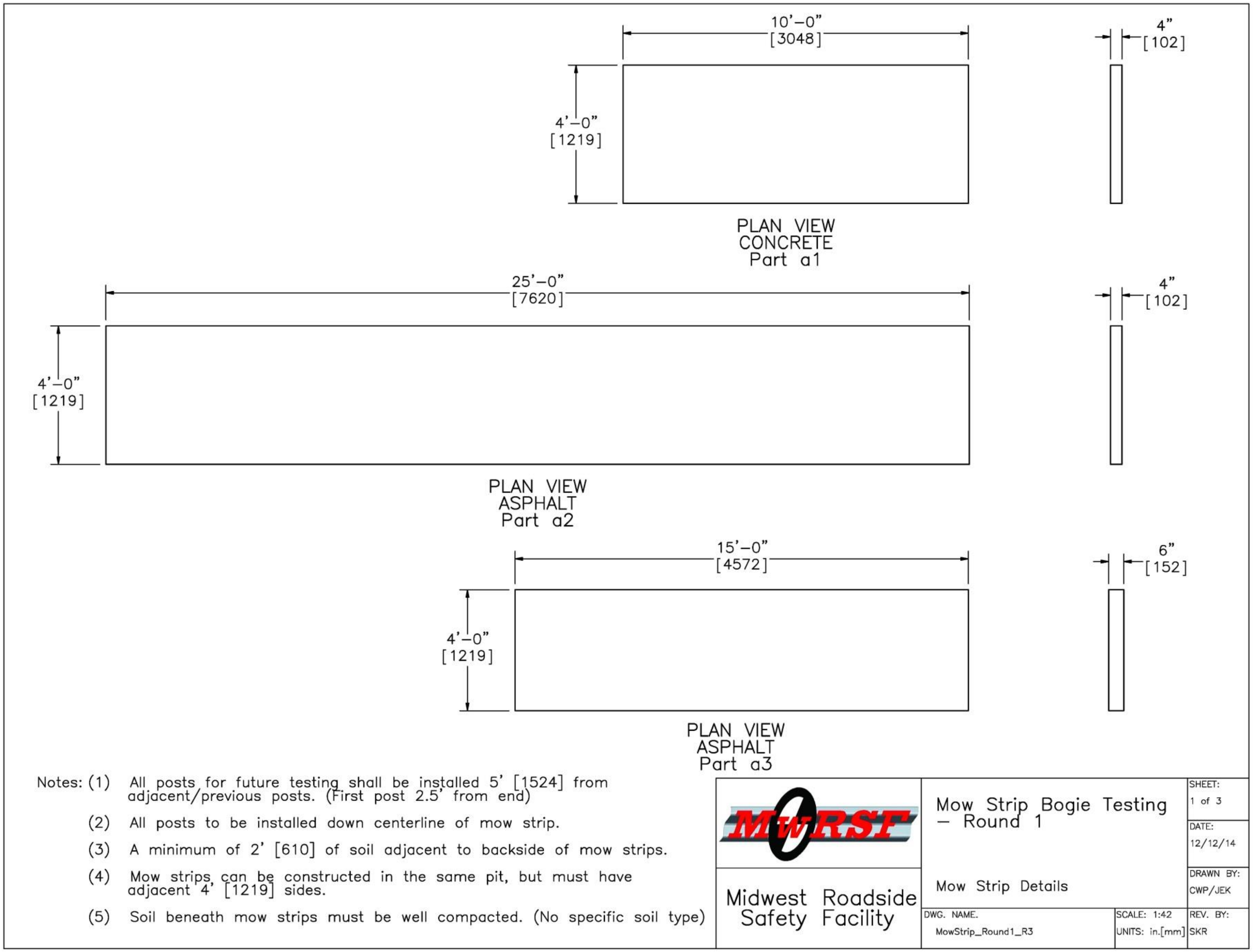
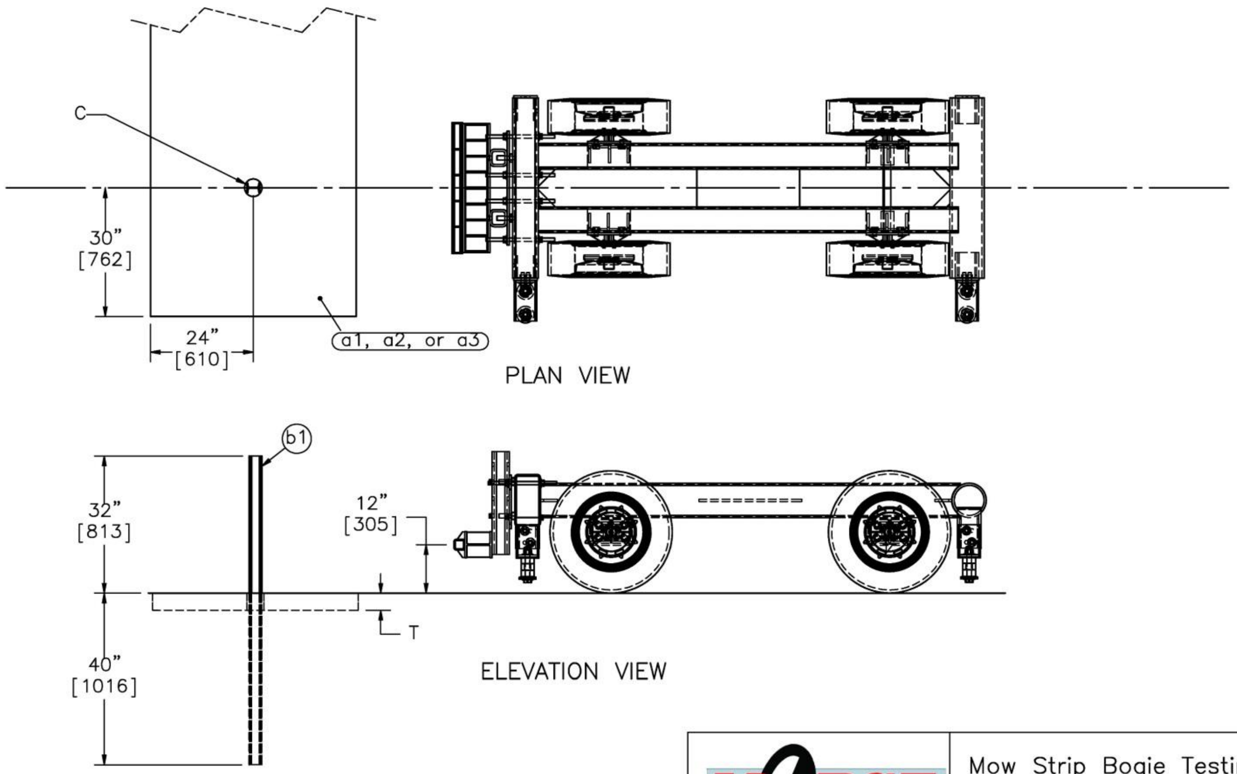


Figure 4. Testing Mow Strip Configurations, Component Testing Round 1

Test No.	Test Qty.	Pavement Material	Pavement Designator	Pavement Thickness "T"	Bogie No.	Cutout "C"	Embedment Depth in. [mm]	Load Height in. [mm]	Impact Speed mph [km/h]	Impact Axis
MS–1	1	Concrete	a1	4" [102]	3	4"x4" [102x102]	40 [1016]	12 [305]	20 [32.2]	Strong
MS–2	1	Asphalt	a2	4" [102]	3	NA	40 [1016]	12 [305]	20 [32.2]	Strong
MS–3	1	Concrete	a1	4" [102]	3	ø4" [102] Circle	40 [1016]	12 [305]	20 [32.2]	Strong
MS–4	1	Asphalt	a3	6" [152]	3	NA	40 [1016]	12 [305]	20 [32.2]	Strong



Notes: (1) A minimum of 2' [610] of soil adjacent to backside of mow strip.

(2) Posts driven directly through asphalt in Test Nos. MS–2 and MS–4.

(3) Posts shall be installed greater than 3" [76] from the edge of pavement or adjacent post.

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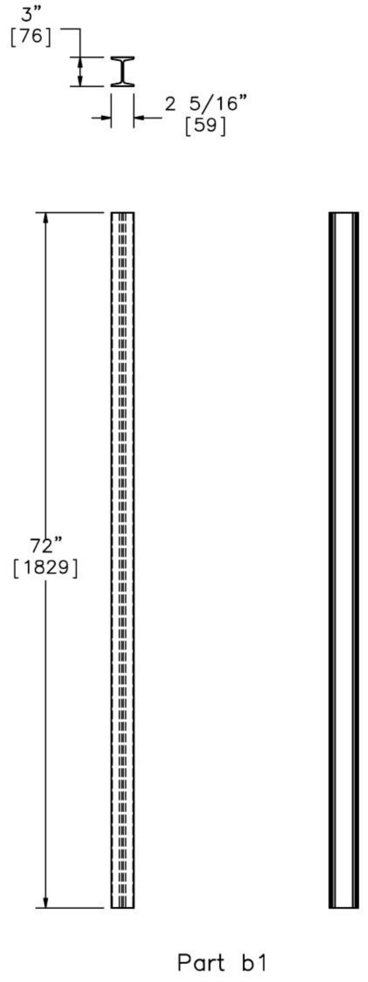
Mow Strip Bogie Testing – Round 1

Testing Setup

SHEET: 2 of 3
DATE: 12/12/14
DRAWN BY: CWP/JEK
DWG. NAME. MowStrip_Round1_R3
SCALE: 1:36
UNITS: in.[mm]
REV. BY: SKR

Figure 5. Bogie Testing Matrix and Setup, Component Testing Round 1

Item No.	QTY.	Description	Material Specification
a1	1	10'x4'x4" [3048x1219x102] Concrete Mow Strip	Min. 4000 psi [27.6 MPa] Comp. Strength
a2	1	25'x4'x4" [7620x1219x102] Asphalt Mow Strip	52–34 Grade Binder
a3	1	15'x4'x6" [4572x1219x152] Asphalt Mow Strip	52–34 Grade Binder
b1	4	S3x5.7 [S76x8.5] 72" [1829] Long Line Post	ASTM A36



MwRSF

Midwest Roadside Safety Facility

Mow Strip Bogie Testing – Round 1

Post Detail

SHEET: 3 of 3
DATE: 12/12/14
DRAWN BY: CWP/JEK
DWG. NAME. MowStrip_Round1_R3
SCALE: 1:16
UNITS: in.[mm]
REV. BY: SKR

Figure 6. Post Details and Bill of Materials, Component Testing Round 1

4.3 Results

Through component testing, the performance of each mow strip configuration was evaluated in terms of both structural integrity and resistance force. Mow strips would be deemed adequate if no damage was sustained during the impact event, allowing quick and easy repair of the system. Additionally, accelerometer data for each test was processed to obtain acceleration, velocity, and deflection data, as well as force vs. deflection and energy vs. deflection curves. Although the individual transducers produced similar results, the values described herein were calculated from the SLICE data curves in order to provide a common basis for comparing results from multiple tests. Test results for all transducers are provided in Appendix B.

4.3.1 Test No. MS-1

Test no. MS-1 was conducted on July 17, 2013 at approximately 11:00 a.m. The weather conditions, per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 4.

Table 4. Weather Conditions, Test No. MS-1

Temperature	88° F
Humidity	47%
Wind Speed	9 mph
Wind Direction	210° From True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.0 in.
Previous 7-Day Precipitation	0.0 in.

During test no. MS-1, the bogie impacted the S3x5.7 (S76x8.5) steel post at a speed of 19.7 mph (31.7 km/h) and an angle of 90 degrees, causing strong-axis bending in the post. By 0.008 sec after impact, a plastic hinge had formed in the post at groundline. The post continued to bend backward until the bogie head overrode the top of the post 0.121 sec after impact.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 7. Upon impact, the resistance force increased rapidly to a peak force of 14.5 kips (64.5 kN) at a displacement of 1.1 in. (28 mm). The force remained above 10 kips (4.5 kN) for the next 5 in. (127 mm) of displacement. By 0.030 sec and a displacement of 10 in. (254 mm), the bogie head was sliding up the post as it bent over, resulting in a reduction of force. Subsequently, the resistance force oscillated below 8.5 kips (37.8 kN) until the bogie head overrode the post at a displacement of 34.0 in. (864 mm). At this deflection, 122.5 k-in. (13.8 kJ) of energy was dissipated.

Damage to the test article consisted of plastic bending of the post at the groundline and minimal surface spalling at the back edge of the concrete hole. The spalling was less than ¼ in. (6 mm) deep, and cracking was not evident. The post was removed without causing further damage. Thus, a new post could be installed without repairs to the concrete. Time-sequential photographs and pre- and post-impact photographs are shown in Figures 8 and 9, respectively.

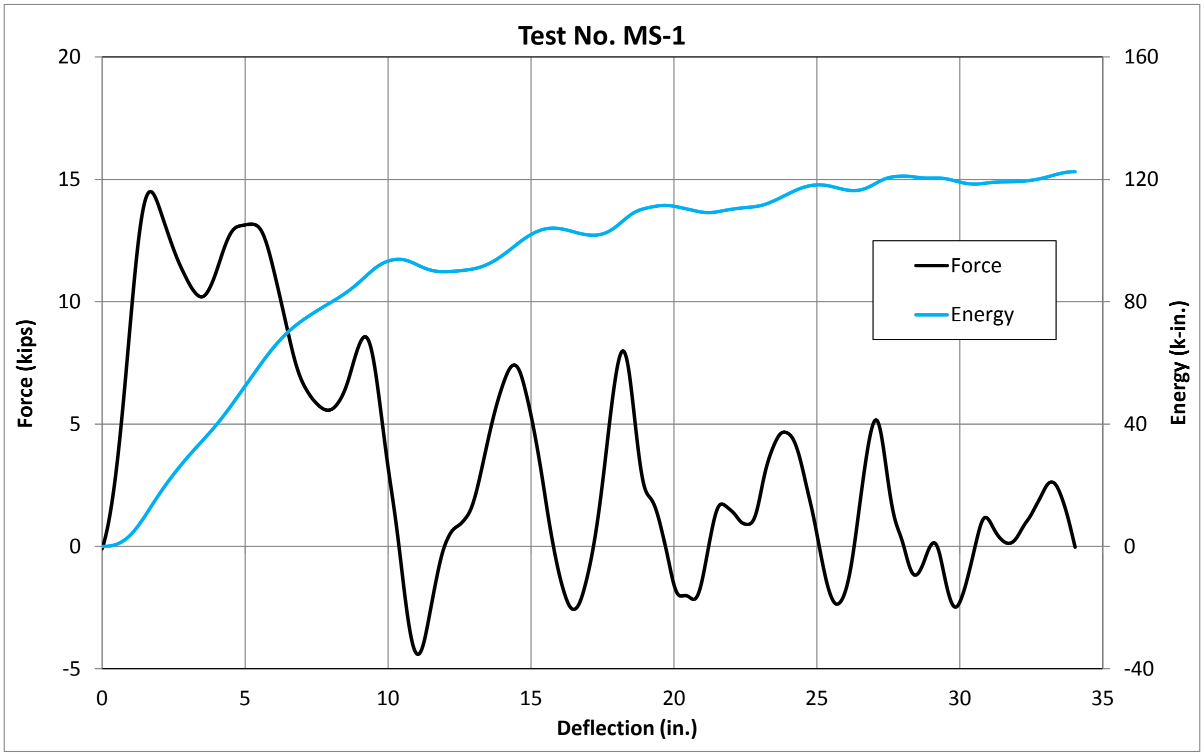


Figure 7. Force vs. Deflection and Energy vs. Deflection, Test No. MS-1

0.000 sec

0.020 sec

0.040 sec

0.060 sec

0.080 sec

0.100 sec

0.120 sec

0.140 sec

Figure 8. Time-Sequential Photographs, Test No. MS-1

Figure 9. Pre- and Post-Impact Photographs, Test No. MS-1

4.3.2 Test No. MS-2

Test no. MS-2 was conducted on July 17, 2013 at approximately 12:00 p.m. The weather conditions, per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 5.

Table 5. Weather Conditions, Test No. MS-2

Temperature	90° F
Humidity	42%
Wind Speed	9 mph
Wind Direction	210° From True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.0 in.
Previous 7-Day Precipitation	0.0 in.

During test no. MS-2, the bogie impacted the S3x5.7 (S76x8.5) steel post at a speed of 19.4 mph (31.2 km/h) and an angle of 90 degrees, causing strong-axis bending in the post. By 0.006 sec after impact, a plastic hinge had formed in the post at the groundline. The post continued to bend backward until the bogie head overrode the top of the post 0.128 sec after impact.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 10. Upon impact, the resistance force increased rapidly to a peak force of 12.1 kips (53.8 kN) at a displacement of 1.8 in. (46 mm). The force remained above 10 kips (4.5 kN) through a displacement of 9.8 in. (249 mm). At 0.032 sec and a displacement of 10 in. (254 mm), the bogie head was sliding up the post as it bent over, resulting in a reduction of force. Subsequently, the resistance force oscillated below 5 kips (22.2 kN) until the bogie head overrode the post at a displacement of 34.0 in. (864 mm). At this deflection, 134.2 k-in. (15.2 kJ) of energy was dissipated.

Damage to the test article consisted of plastic bending of the post at the groundline and displacement and spalling of the asphalt. The post displaced backward approximately 2.5 in. (64 mm) into the asphalt mow strip, which caused displacement and spalling of the asphalt. Removal of the post caused further spalling and cracking to the asphalt. Time-sequential photographs and pre- and post-impact photographs are shown in Figures 11 and 12, respectively.

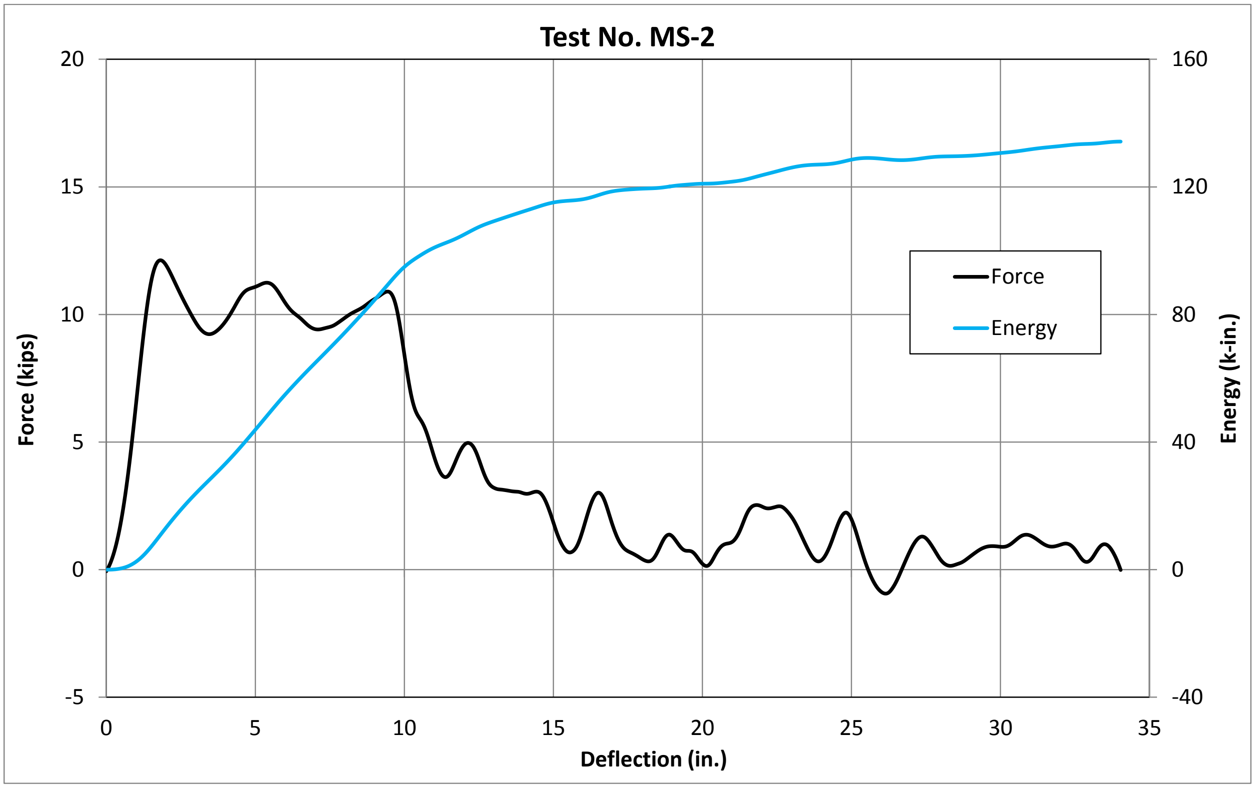
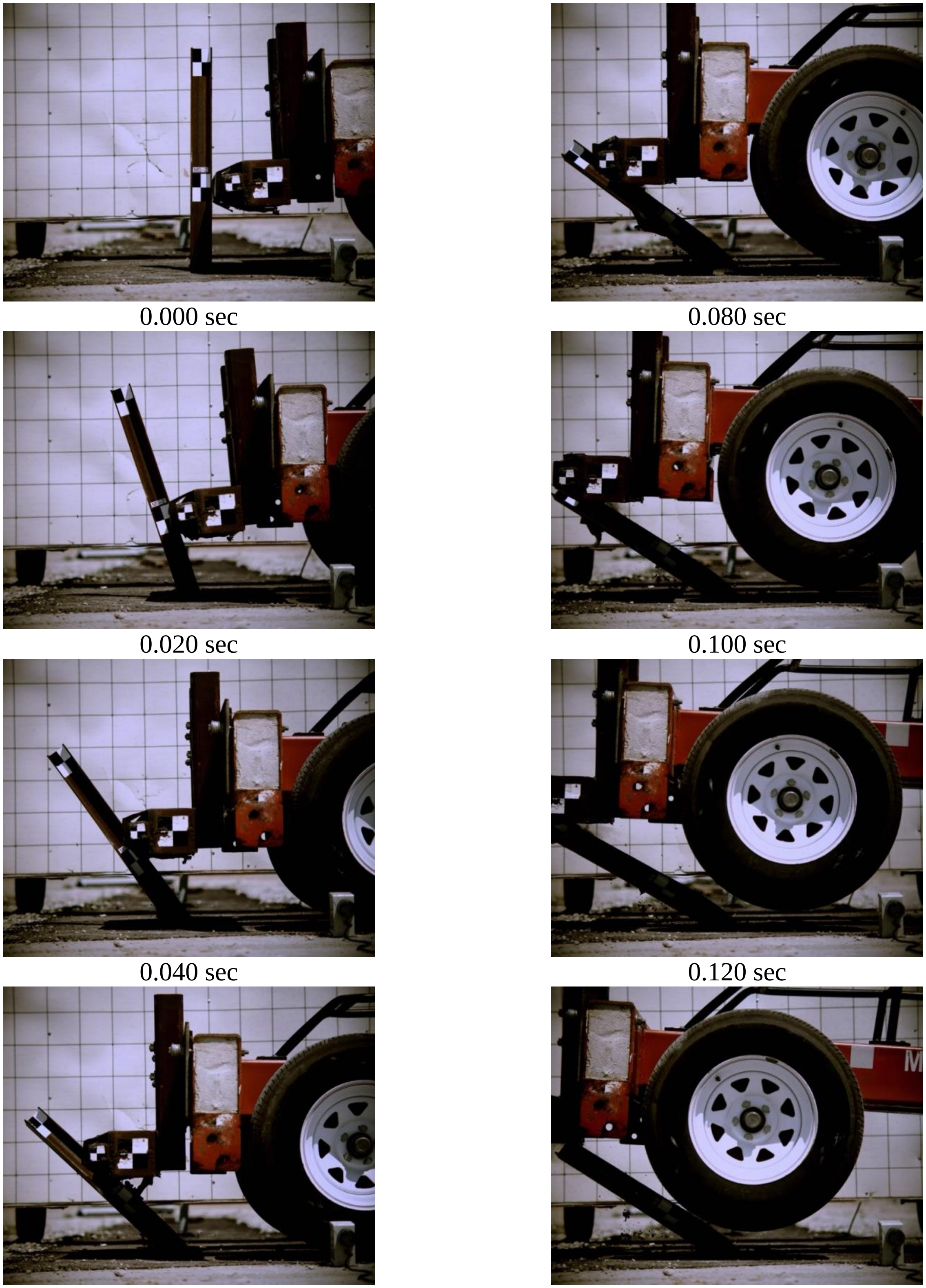


Figure 10. Force vs. Deflection and Energy vs. Deflection, Test No. MS-2



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0.040 sec

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0.080 sec

0.100 sec

0.120 sec

0.140 sec

Figure 11. Time-Sequential Photographs, Test No. MS-2

Figure 12. Pre- and Post-Impact Photographs, Test No. MS-2

4.3.3 Test No. MS-3

Test no. MS-3 was conducted on July 31, 2013 at approximately 1:00 p.m. The weather conditions, per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 6.

Table 6. Weather Conditions, Test No. MS-3

Temperature	85° F
Humidity	51%
Wind Speed	7 mph
Wind Direction	030° From True North
Sky Conditions	Cloudy
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.72 in.
Previous 7-Day Precipitation	0.72 in.

During test no. MS-3, the bogie impacted the S3x5.7 (S76x8.5) steel post at a speed of 20.8 mph (33.5 km/h) and an angle of 90 degrees, causing strong-axis bending in the post. By 0.006 sec after impact, a plastic hinge had formed in the post at the groundline. The post continued to bend backward until the bogie head overrode the top of the post 0.109 sec after impact.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 13. Upon impact, the resistance force increased rapidly to peaks of 13.9 kips (61.8 kN) and 14.7 kips (65.4 kN) at displacements of 1.2 in. (30 mm) and 6.9 in. (175 mm), respectively. At 0.030 sec and a displacement of 10 in. (254 mm), the bogie head was sliding up the post as it bent over, resulting in a reduction of force. Subsequently, the resistance force oscillated below 6 kips (26.7 kN) until the bogie head overrode the post at a displacement of 32.3 in. (820 mm). At this deflection, 132.8 k-in. (15.0 kJ) of energy was dissipated.

Damage to the test article consisted of plastic bending of the post at the groundline and some surface spalling at the back edge of the concrete hole. However, the spalling was less than ¼ in. (6 mm) deep, and cracking was not evident. The post was removed without causing further damage, so a new post could be installed without repairs to the concrete. Time-sequential photographs and pre- and post-impact photographs are shown in Figures 14 and 15, respectively.

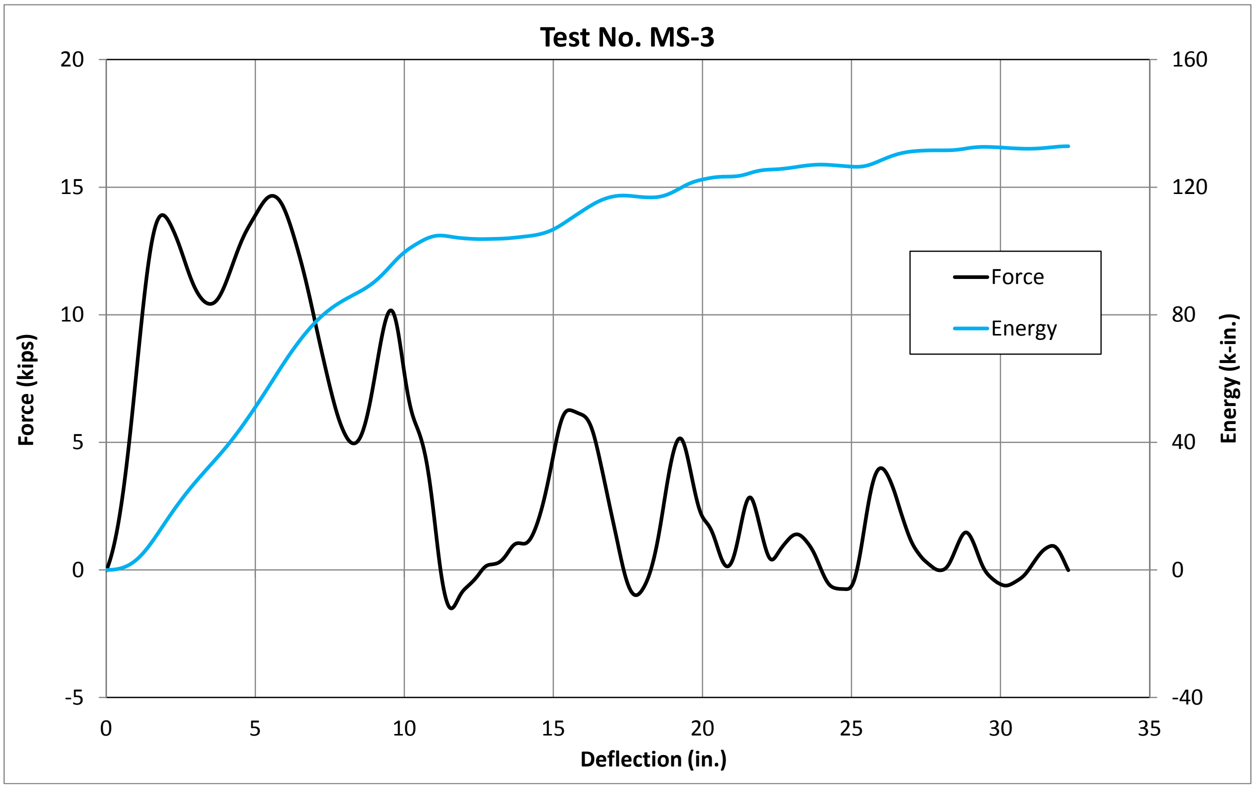
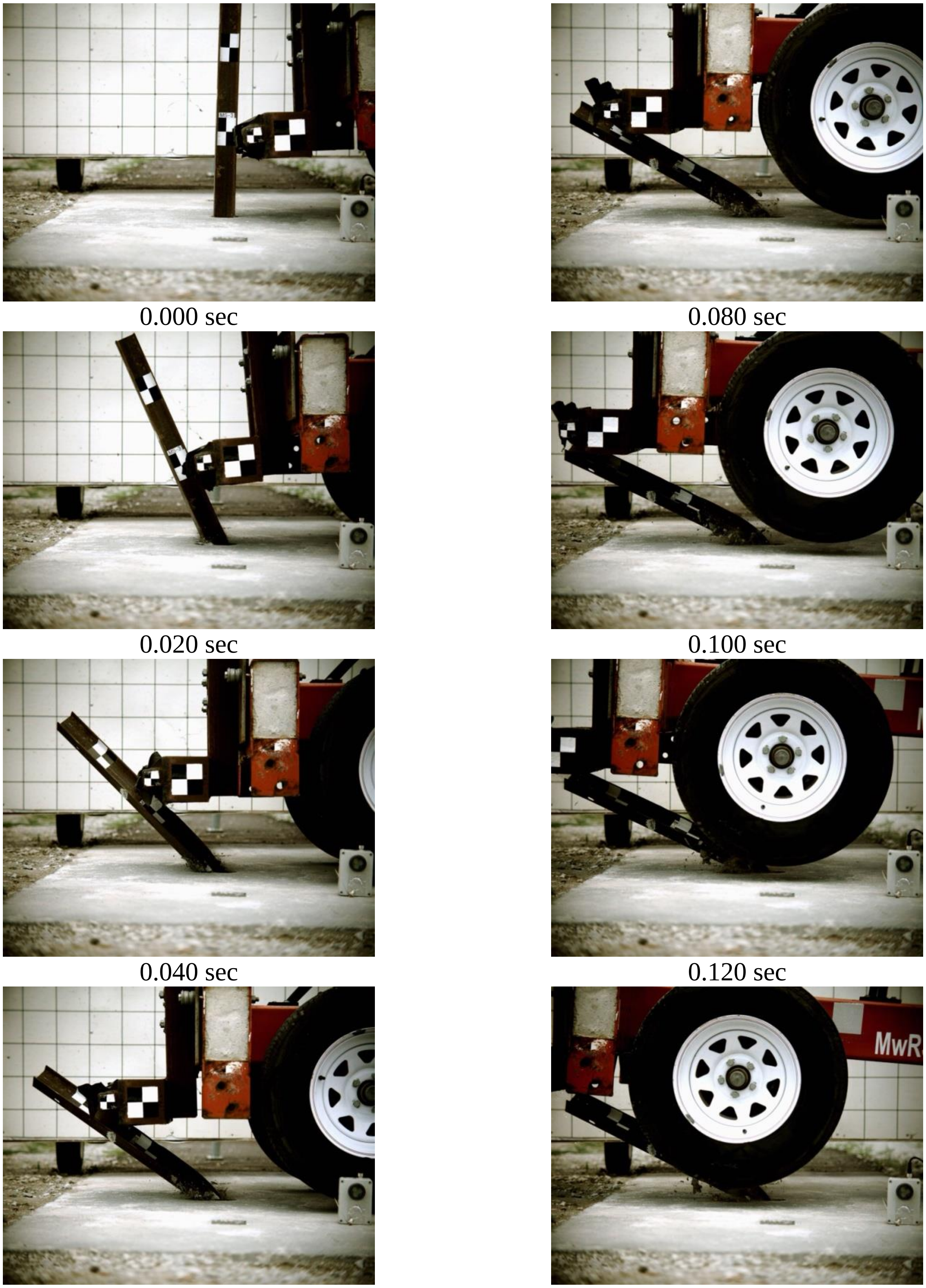


Figure 13. Force vs. Deflection and Energy vs. Deflection, Test No. MS-3



0.000 sec

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0.040 sec

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0.080 sec

0.100 sec

0.120 sec

0.140 sec

Figure 14. Time-Sequential Photographs, Test No. MS-3

Figure 15. Pre- and Post-Impact Photographs, Test No. MS-3

4.3.4 Test No. MS-4

Test no. MS-4 was conducted on July 31, 2013 at approximately 2:00 p.m. The weather conditions, per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 7.

Table 7. Weather Conditions, Test No. MS-4

Temperature	85° F
Humidity	49%
Wind Speed	5 mph
Wind Direction	280° From True North
Sky Conditions	Cloudy
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.72 in.
Previous 7-Day Precipitation	0.72 in.

During test no. MS-4, the bogie impacted the S3x5.7 (S76x8.5) steel post at a speed of 23.8 mph (38.3 km/h) and an angle of 90 degrees, causing strong-axis bending in the post. By 0.008 sec after impact, a plastic hinge had formed in the post at the groundline. The post continued to bend backward until the bogie head overrode the top of the post 0.088 sec after impact.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 16. Upon impact, the resistance force increased rapidly to 13.9 kips (61.8 kN) at a displacement of 1.8 in. (46 mm). The force remained above 8 kips (35kN) until reaching a peak force of 14.2 kips (63.2 kN) at a displacement of 11.5 in. (292 mm). At 0.028 sec and a displacement of 12 in. (305 mm), the bogie head was sliding up the post as it bent over, resulting in a reduction of force. Subsequently, the resistance force oscillated below 5 kips (22.2

kN) until the bogie head overrode the post at a displacement of 31.4 in. (798 mm). At this deflection, 155.2 k-in. (17.5 kJ) of energy was dissipated.

Damage to the test article consisted of plastic bending of the post at the groundline and displacement and spalling of the asphalt. The post translated backward approximately 2 in. (51 mm) into the asphalt mow strip, which caused displacement and spalling of the asphalt. Removal of the post caused further spalling and cracking in the asphalt. Time-sequential photographs and pre- and post-impact photographs are shown in Figures 17 and 18, respectively.

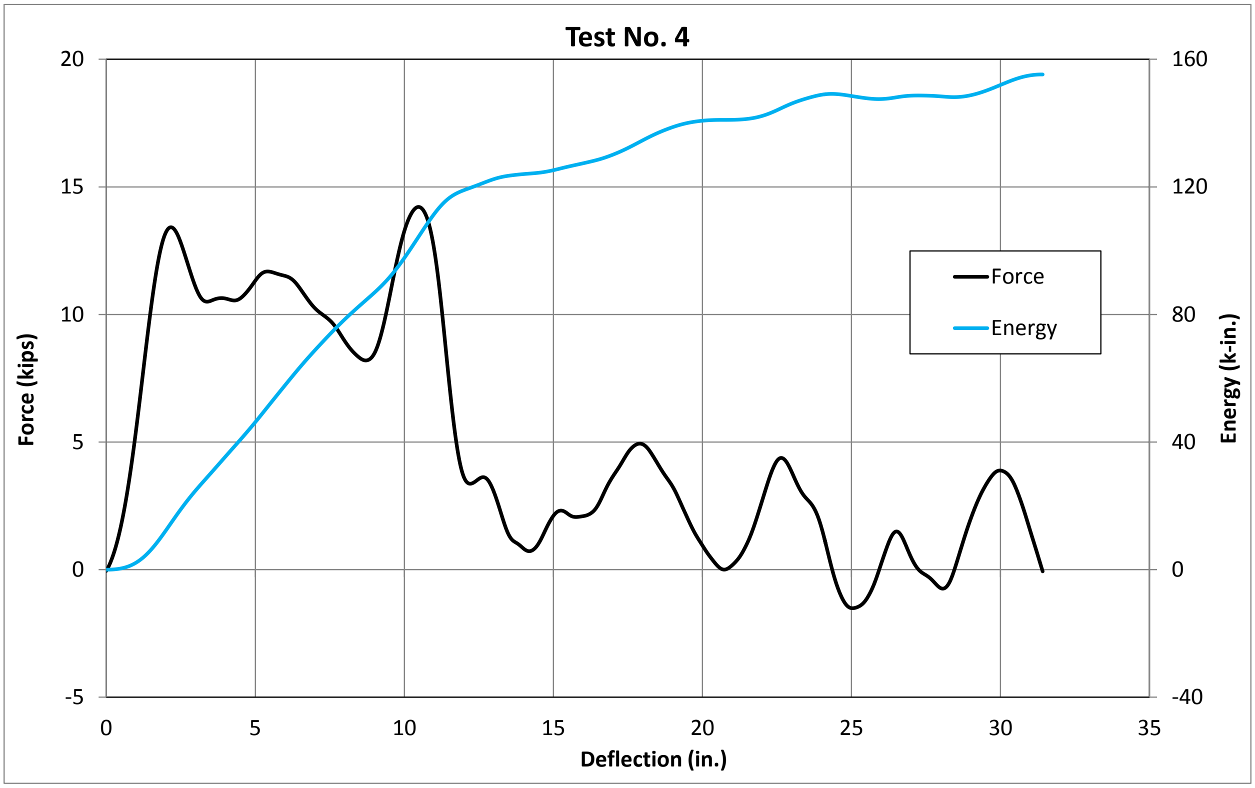
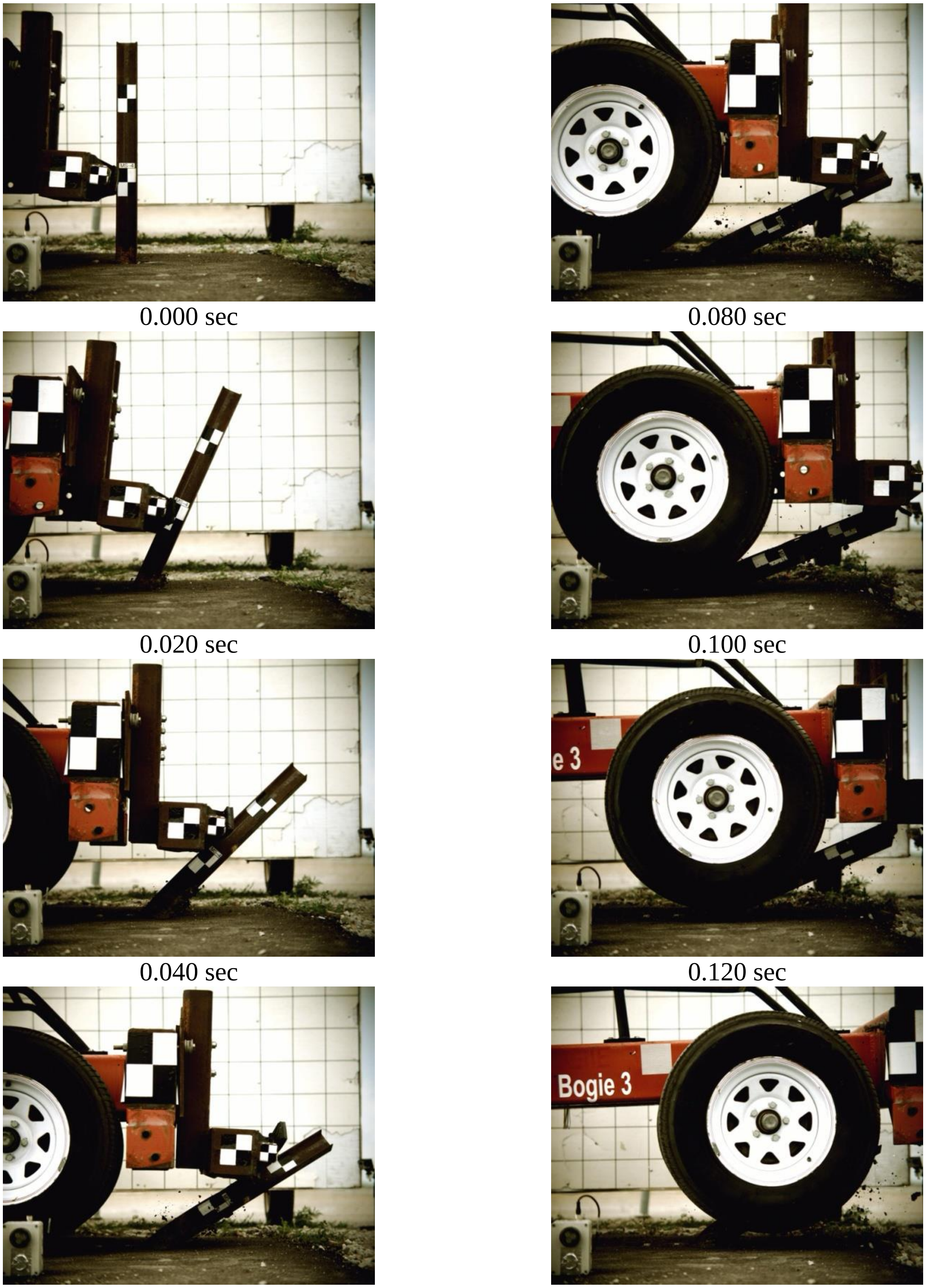


Figure 16. Force vs. Deflection and Energy vs. Deflection, Test No. MS-4



0.000 sec

0.080 sec

0.020 sec

0.100 sec

0.040 sec

0.120 sec

0.060 sec

0.140 sec

Figure 17. Time-Sequential Photographs, Test No. MS-4

Figure 18. Pre- and Post-Impact Photographs, Test No. MS-4

4.4 Discussion

The results from Round 1 of dynamic component testing are summarized in Table 8, and force vs. displacement and energy vs. displacement comparisons for all four tests are shown in Figures 19 and 20, respectively. The results from these four tests were similar in terms of resistance forces, absorbed energy, and post behavior, as a plastic hinge formed in the post at the groundline during each test. However, the damage sustained by the mow strips was dependent upon the mow strip material. The concrete mow strips remained intact and sustained only minor spalling along the back edges of the post holes. Both post hole types, the 4-in. x 4-in. (102-mm x 102-mm) leave-out and the 4-in. (102-mm) diameter cored hole, performed similarly, and repairs to the concrete mow strip would not be necessary during replacement of damaged system posts.

Damage to the asphalt mow strips was more prominent than the concrete mow strips, as the posts translated backward at least 2 in. (51 mm) through both the 4-in. and 6-in. (102-mm and 152-mm) thick asphalt mow strips. This displacement caused spalling and cracking that would likely require repairs after impact events. Further asphalt damage occurred when the damaged posts were removed. Therefore, asphalt mow strips were susceptible to permanent damage when guardrail posts were driven directly into the pavement.

The resistance forces recorded during all four of these tests were very similar, with peak forces between 12 and 15 kips (53 and 67 kN). Additionally, significant drops in force between 9 and 12 in. (229 and 305 mm) of displacement correlated to the times when the bogie head began to slide up the posts as they bent over. As a result, the energy absorbed during the tests was very similar, especially over the first 10 to 15 in. (254 to 381 mm) of deflection. Only small differences in forces could be seen between the concrete and asphalt mow strips. The concrete mow strips tended to be slightly stiffer, as they created higher initial peaks through the first 7 in. (178 mm) of displacement. This behavior may be a result of the posts translating through the asphalt mow strips during the first parts of test nos. MS-2 and MS-4, while the concrete prevented post translation at the groundline in test nos. MS-1 and MS-3.

From these results, a 4-in. (102-mm) thick unreinforced concrete mow strip was shown to be strong enough to support the guardrail posts without sustaining significant damage during impacts. Unfortunately, asphalt mow strips up to 6 in. (152 mm) thick proved too weak to prevent damage and would require repairs. The addition of some type of load-distribution mechanism may be necessary to prevent damage from occurring to asphalt mow strips. This idea was explored in Round 2 of bogie testing.

Table 8. Results Summary, Component Testing – Round 1

Test No.	Mow Strip		Impact Angle deg.	Impact Velocity mph (km/h)	Peak Force kips (kN)	Average Force kips (kN)		Total Energy Absorbed k-in. (kJ)	Mow Strip Damage
	Material	Thickness in. (mm)				@ 10”	@15”		
MS-1	Concrete 4” Dia. Hole	4 (102)	90	19.8 (31.9)	14.5 (64.5)	9.3 (41.4)	6.8 (30.2)	122.5 (13.8)	Minor spalling
MS-2	Asphalt	4 (102)	90	19.4 (31.2)	12.1 (53.8)	9.5 (42.3)	7.7 (34.3)	134.2 (15.2)	Displacement, spalling, and cracking
MS-3	Concrete 4”x4” hole	4 (102)	90	20.8 (33.5)	14.7 (65.4)	10.0 (44.5)	7.2 (32.0)	132.8 (15.0)	Minor spalling
MS-4	Asphalt	6 (152)	90	23.8 (38.3)	14.2 (63.2)	9.7 (43.1)	8.4 (37.4)	155.2 (17.5)	Displacement, spalling, and cracking

*All tests conducted by impacting S3x5.7 (S76x8.5) posts at a height of 12 in. (305 mm).

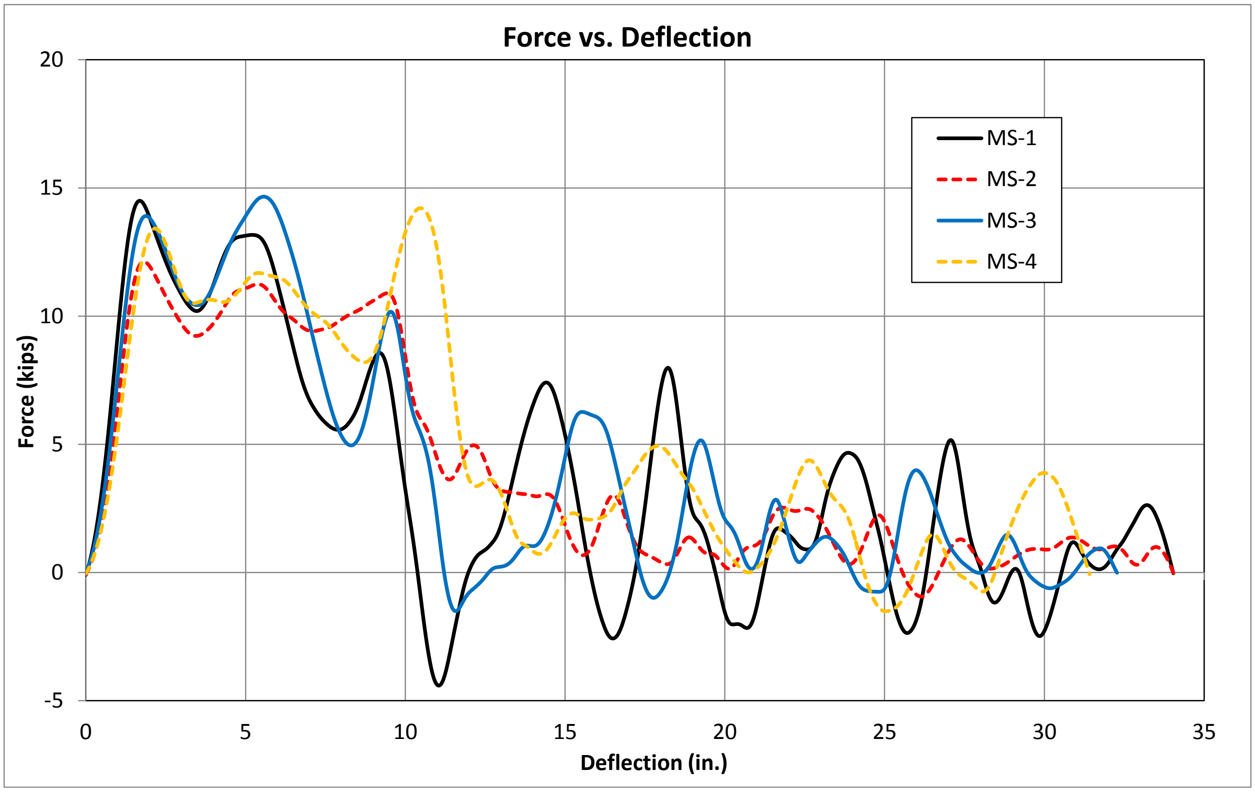


Figure 19. Force vs. Deflection Comparison, Component Testing - Round 1

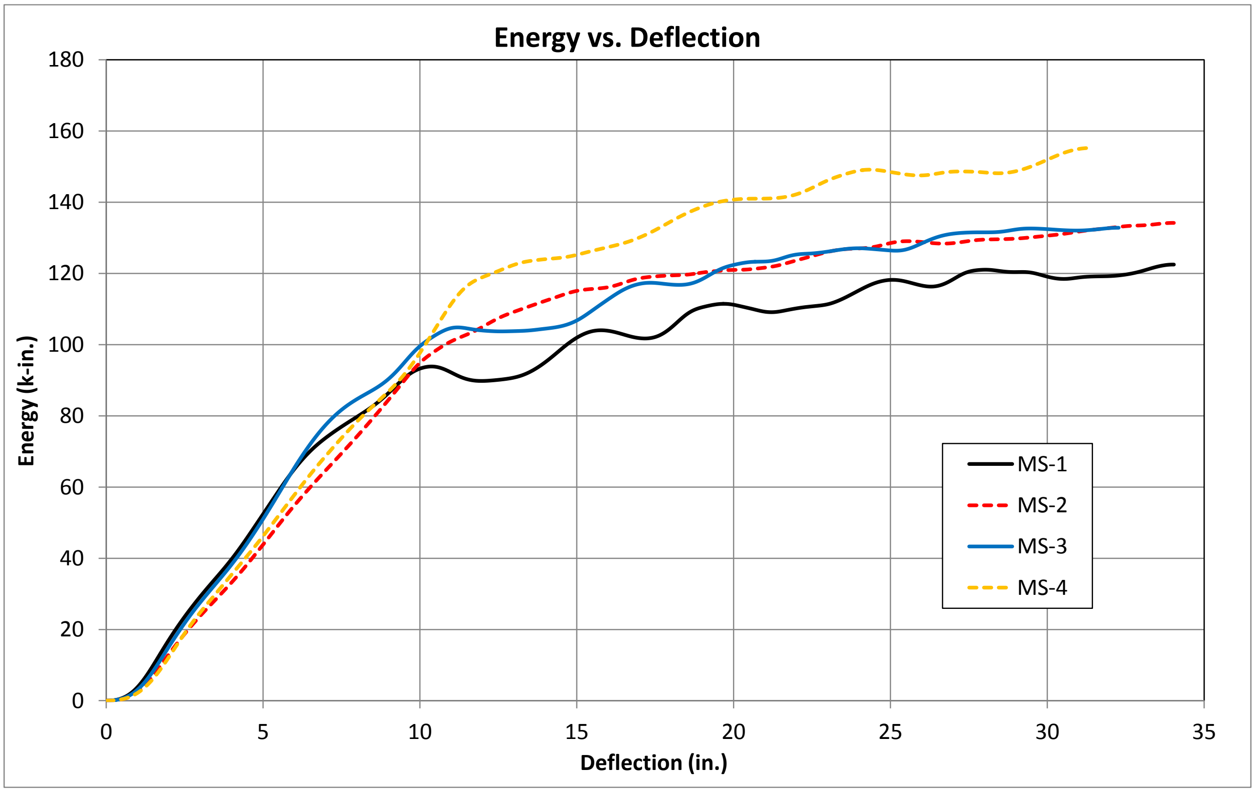


Figure 20. Energy vs. Deflection Comparison, Component Testing - Round 1

5 COMPONENT TESTING – ROUND 2, SOCKETED POSTS

5.1 Purpose

From the first round of dynamic component testing, it was determined that asphalt pavements were not strong enough to support driven S3x5.7 (S76x8.5) guardrail posts without sustaining damage during impact events. The impact load needed to be distributed over a larger area of the asphalt to prevent the post from translating and rotating through the asphalt. Therefore, Round 2 of dynamic component testing was conducted to evaluate the use of steel sockets or sleeves with and without shear plates within asphalt mow strips to prevent pavement damage.

5.2 Scope

Round 2 of component testing consisted of five tests conducted on S3x5.7 (S76x85) posts installed within 4-in. (102-mm) thick asphalt mow strips, as shown in Figures 21 through 24. In all five tests, steel sockets measuring 4 in. x 4 in. x ¼ in. (102 mm x 102 mm x 6 mm) were utilized to house the guardrail posts and distribute the load. In test nos. MSSP-1 through MSSP-4, a steel shear plate was welded to the backside of the socket to further distribute the impact load. The test article in test no. MS-5 did not utilize a shear plate on the socket. The length, or embedment depth, of the socket varied throughout the testing matrix to evaluate the minimum depth required to prevent damage. All tests were conducted with an impact height of 12 in. (305 mm) and a targeted impact speed of 20 mph (32 km/h). Four of the tests were conducted with impact angles of 90 degrees causing strong-axis bending, while test no. MSSP-2 was conducted at a 0 degree impact angle to evaluate longitudinal impacts (weak-axis bending) to the post and socket assembly. The complete test matrix for Round 2 component testing is shown in Table 9.

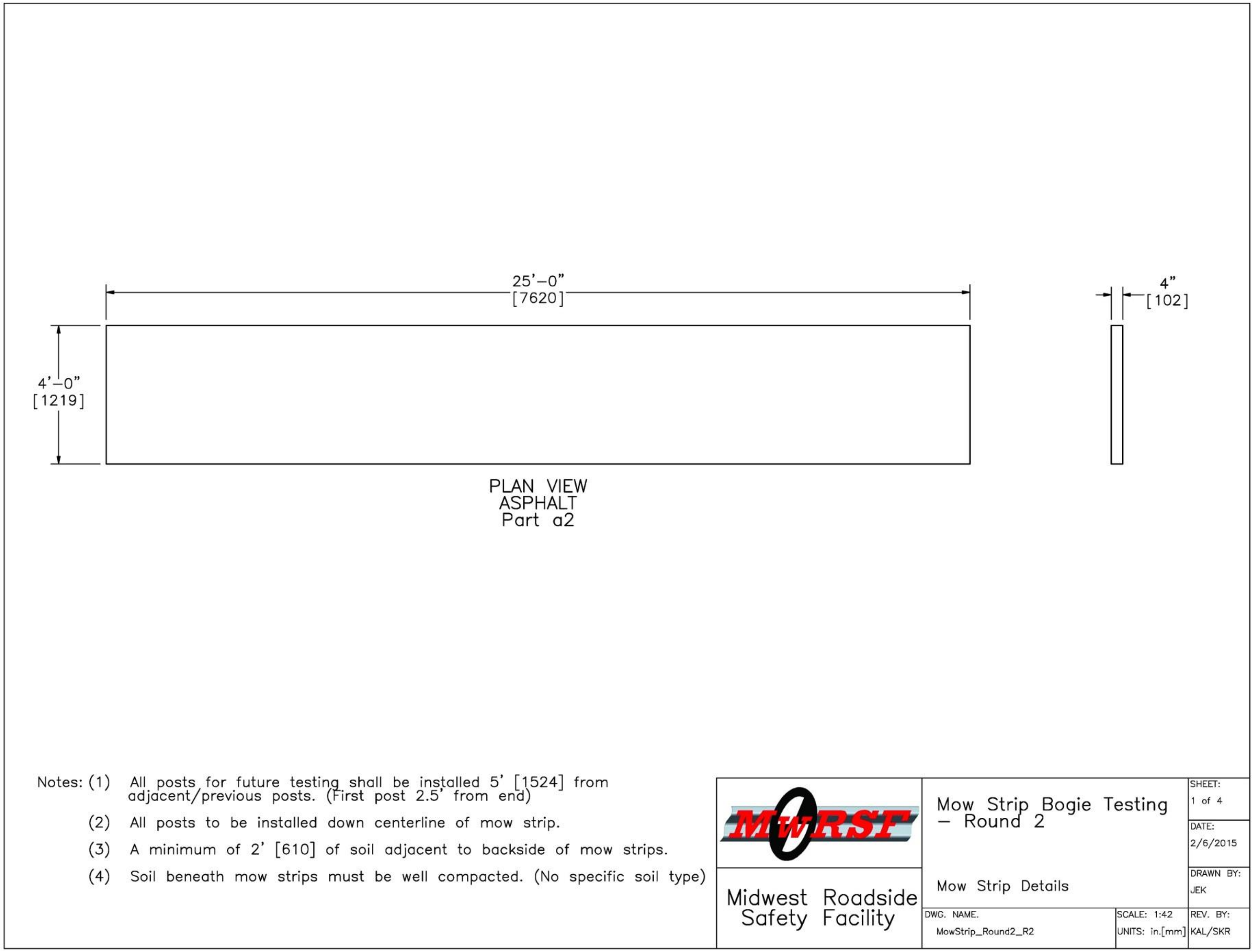
The same 4-in. (102-mm) asphalt pad from the first round of component testing was utilized during Round 2 of component testing. The S3x5.7 (S76x8.5) posts were designated as

A36 steel. However, the posts were fabricated from 50-ksi (345-MPa) steel that also satisfied A992 requirements. This increased strength resulted in a more critical evaluation of the mow strips. The sockets were fabricated from A500 Grade B steel, and the plates were cut from A572 Grade 50 steel. Material specifications, mill certifications, and certificates of conformity for the installation materials are shown in Appendix A.

All of the sockets were installed by driving them into the asphalt mow strip. Initially, the sockets were just capped with a flat plate at the bottom. However, when this configuration was driven into the mow strip, it punched a hole larger than the socket into the asphalt. Subsequently, two steel plates were welded to the base of the socket to form a triangular wedge. Through an experimentation process, the wedge plates shown in Figure 23 were developed to prevent damage to the asphalt and provide a tight fit around the socket. This design allowed the socket to be driven into place with minimal damage to the asphalt and provided a tight fit between the asphalt and the socket. The asphalt damage corresponding to both a wedge-shaped base and a flat base are illustrated in Figure 25.

Table 9. Component Testing Matrix, Round 2

Test No.	Mow Strip			Socket Depth in. (mm)	Post Length in. (mm)	Shear Plate	Impact Speed mph (km/h)	Impact Angle deg.
	Material	Thickness in. (mm)	Width ft (m)					
MS-5	Asphalt	4 (102)	4 (1.2)	30 (762)	62 (1,575)	No	20 (32)	90°
MSSP-1	Asphalt	4 (102)	4 (1.2)	30 (762)	62 (1,575)	Yes	20 (32)	90°
MSSP-2	Asphalt	4 (102)	4 (1.2)	30 (762)	62 (1,575)	Yes	20 (32)	0°
MSSP-3	Asphalt	4 (102)	4 (1.2)	20 (508)	52 (1,321)	Yes	20 (32)	90°
MSSP-4	Asphalt	4 (102)	4 (1.2)	24 (610)	56 (1,422)	Yes	20 (32)	90°



Notes: (1) All posts for future testing shall be installed 5' [1524] from adjacent/previous posts. (First post 2.5' from end)

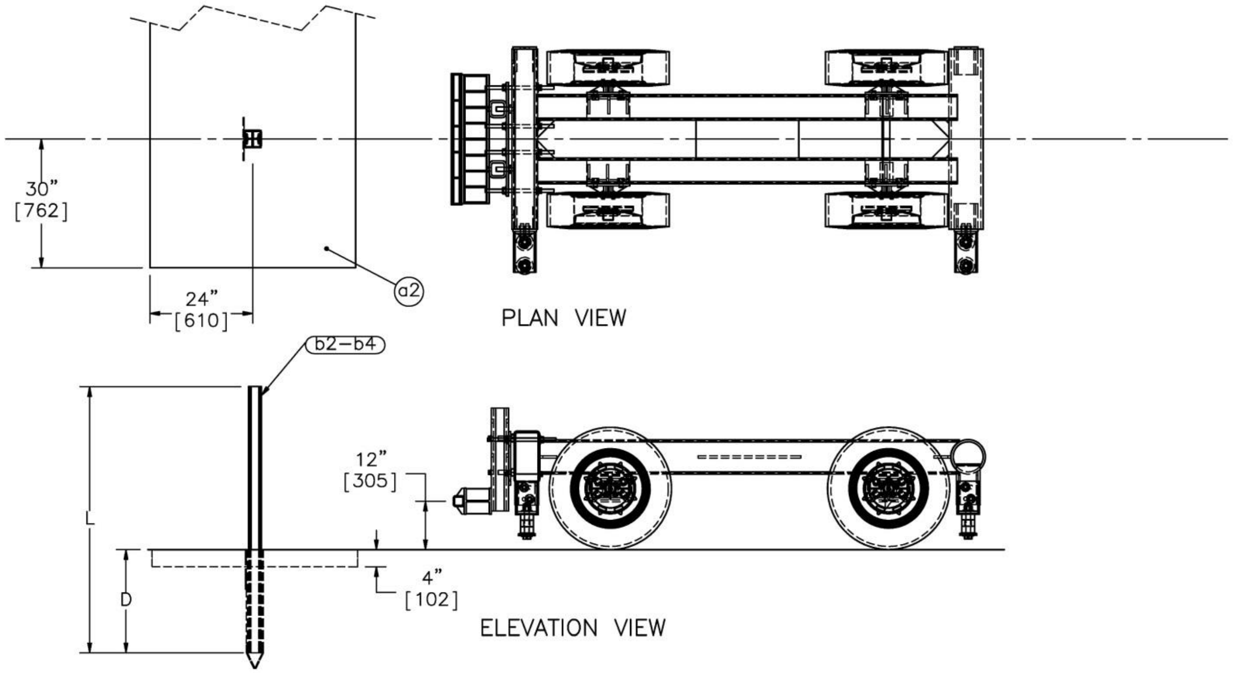
(2) All posts to be installed down centerline of mow strip.

(3) A minimum of 2' [610] of soil adjacent to backside of mow strips.

(4) Soil beneath mow strips must be well compacted. (No specific soil type)

Figure 21. Mow Strip Configuration, Component Testing Round 2

Test No.	Test Qty.	Bogie No.	Socket	Socket Depth "D" in. [mm]	Post Length "L" in. [mm]	Shear Plate	Load Height in. [mm]	Impact Speed mph [km/h]	Impact Angle
MS–5	1	3	4"x4"x1/4" [102x102x6]	30" [762]	62" [1575]	NA	12 [305]	20 [32.2]	90°
MSSP–1	1	3	4"x4"x1/4" [102x102x6]	30" [762]	62" [1575]	10"x9"x1/4" [254x229x6]	12 [305]	20 [32.2]	90°
MSSP–2	1	3	4"x4"x1/4" [102x102x6]	30" [762]	62" [1575]	10"x9"x1/4" [254x229x6]	12 [305]	20 [32.2]	0°
MSSP–3	1	3	4"x4"x1/4" [102x102x6]	20" [508]	52" [1321]	10"x9"x1/4" [254x229x6]	12 [305]	20 [32.2]	90°
MSSP–4	1	3	4"x4"x1/4" [102x102x6]	24" [610]	56" [1422]	10"x9"x1/4" [254x229x6]	12 [305]	20 [32.2]	90°



Notes: (1) A minimum of 2' [610] of soil adjacent to backside of mow strip.
(2) Sockets driven directly through asphalt. Posts inserted into sockets.

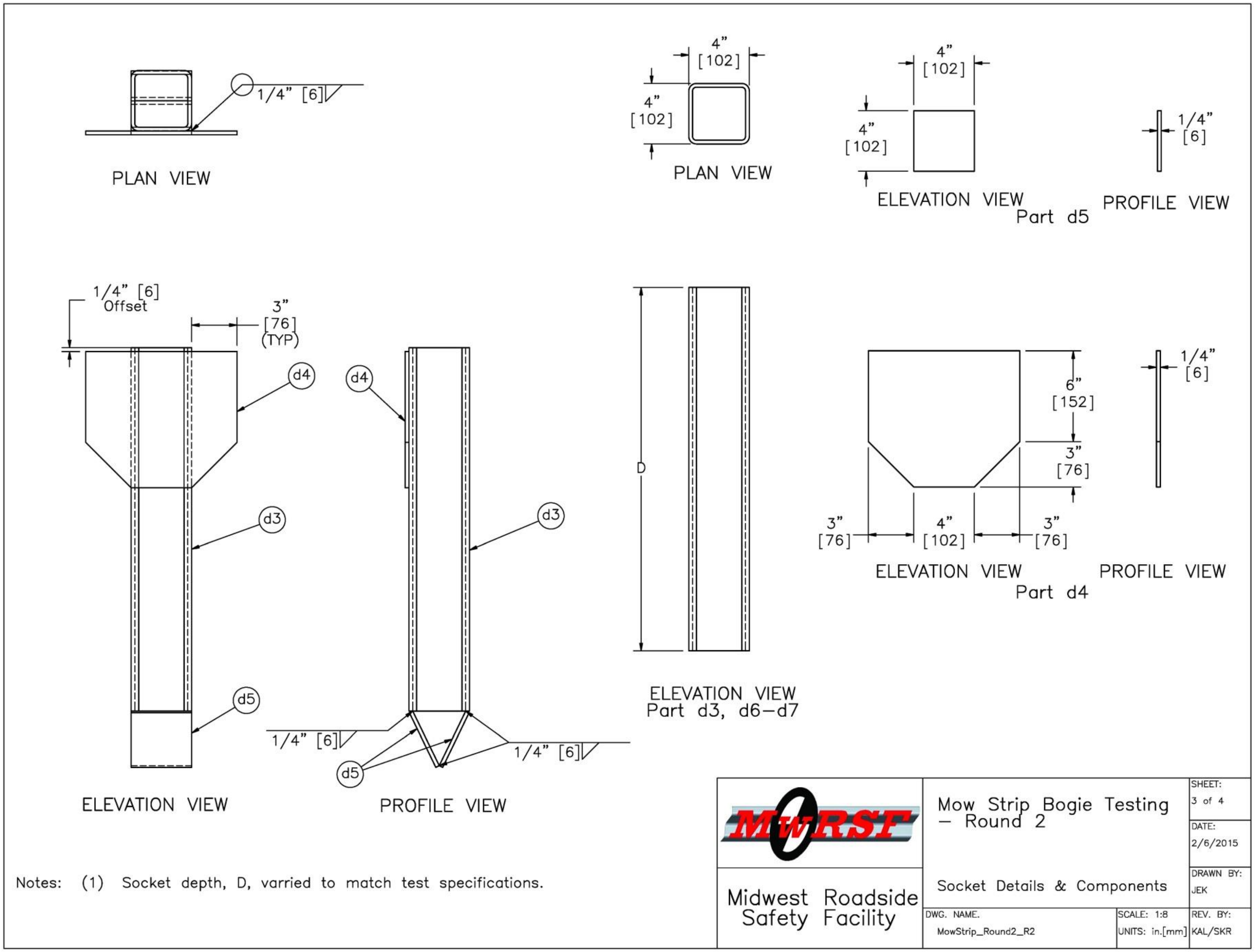
Midwest Roadside Safety Facility

Mow Strip Bogie Testing – Round 2

Testing Setup

SHEET: 2 of 4
DATE: 2/6/2015
DRAWN BY: JEK
DWG. NAME. MowStrip_Round2_R2
SCALE: 1:36
UNITS: in.[mm]
REV. BY: KAL/SKR

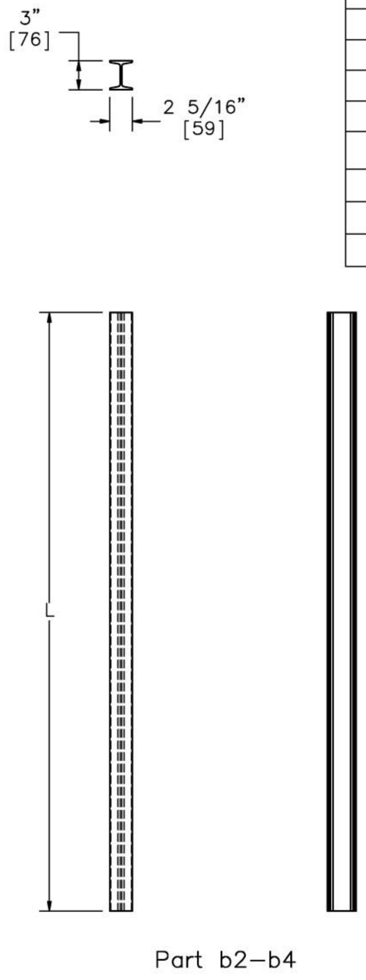
Figure 22. Bogie Testing Matrix and Setup, Component Testing Round 2



Notes: (1) Socket depth, D, varried to match test specifications.

Figure 23. Post Socket Details, Component Testing Round 2

Item No.	QTY.	Description	Material Spec
a2	1	25'x4'x4" [7620x1219x102] Asphalt Mow Strip	52–34 Grade Binder
b2	3	S3x5.7 [S76x8.5] 62" [1575] Long Line Post	ASTM A36
b3	1	S3x5.7 [S76x8.5] 56" [1422] Long Line Post	ASTM A36
b4	1	S3x5.7 [S76x8.5] 52" [1321] Long Line Post	ASTM A36
d3	3	4"x4"x3/8" [102x102x10] Square Socket, 24" [610] Long	ASTM A500 Grade B Steel Galvanized
d4	5	10"x9"x1/4" [254x229x6] Steel Soil Plate	ASTM A572 Grade 50 Steel Galvanized
d5	10	4"x4"x1/4" [102x102x6] Steel Plate	ASTM A572 Grade 50 Steel Galvanized
d6	1	4"x4"x3/8" [102x102x10] Square Socket, 24" [610] Long	ASTM A500 Grade B Steel Galvanized
d7	1	4"x4"x3/8" [102x102x10] Square Socket, 20" [508] Long	ASTM A500 Grade B Steel Galvanized



Notes: (1) Post length, L, varried to match test specifications.

Midwest Roadside Safety Facility

Mow Strip Bogie Testing – Round 2

Post Detail

SHEET: 4 of 4
DATE: 2/6/2015
DRAWN BY: JEK
DWG. NAME. MowStrip_Round2_R2
SCALE: 1:16
UNITS: in.[mm]
REV. BY: KAL/SKR

Figure 24. Post Details and Bill of Materials, Component Testing Round 2

Flat Bottom Socket

Wedged Bottom of Socket

Figure 25. Installation Results by Bottom Socket Shape

5.3 Results

5.3.1 Test No. MS-5

Test no. MS-5 was conducted on August 23, 2013 at approximately 11:30 a.m. The weather conditions, per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 10.

Table 10. Weather Conditions, Test No. MS-5

Temperature	86° F
Humidity	57%
Wind Speed	13 mph
Wind Direction	170° From True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.01 in.
Previous 7-Day Precipitation	0.01 in.

During test no. MS-5, the bogie impacted the S3x5.7 (S76x8.5) steel post at a speed of 21.7 mph (34.9 km/h) and an angle of 90 degrees, thus causing strong-axis bending in the post. At 0.004 sec after impact, the socket began displacing through the asphalt, and by 0.010 sec, a plastic hinge had formed in the post at the groundline. The post continued to bend backward until the bogie head overrode the top of the post 0.116 sec after impact.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 26. Upon impact, the resistance force increased rapidly to 13.6 kips (60.5 kN) at a displacement of 2.0 in. (51 mm). The force then peaked at 14.7 kips (65.4 kN) at a displacement of 5.7 in. (145 mm). At 0.030 sec and a displacement of 10 in. (254 mm), the bogie head was sliding up the post as it bent over, resulting in a force reduction. Subsequently, the resistance force oscillated until the bogie head overrode the post at a displacement of 35.5 in. (902 mm). At this deflection, 140 k-in. (15.8 kJ) of energy was dissipated.

Damage to the test article consisted of plastic bending of the post at the groundline, rotation of the steel socket, and displacement and spalling of the asphalt. The socket had rotated backward leaving a 1-in. (25-mm) gap between the asphalt and the front edge of the socket. Additionally, the asphalt on the back side of the socket displaced, which caused cracking and spalling. The post was easily removed from the socket without further damage to the asphalt. However, the asphalt displacement would require repairs, and the socket would need to be reset prior to replacing the damaged post. The backside of the socket sustained minor deformations from the post bearing against it, but the damage was minimal and the socket remained reusable. Time-sequential photographs and pre- and post-impact photographs are shown in Figures 27 and 28, respectively.

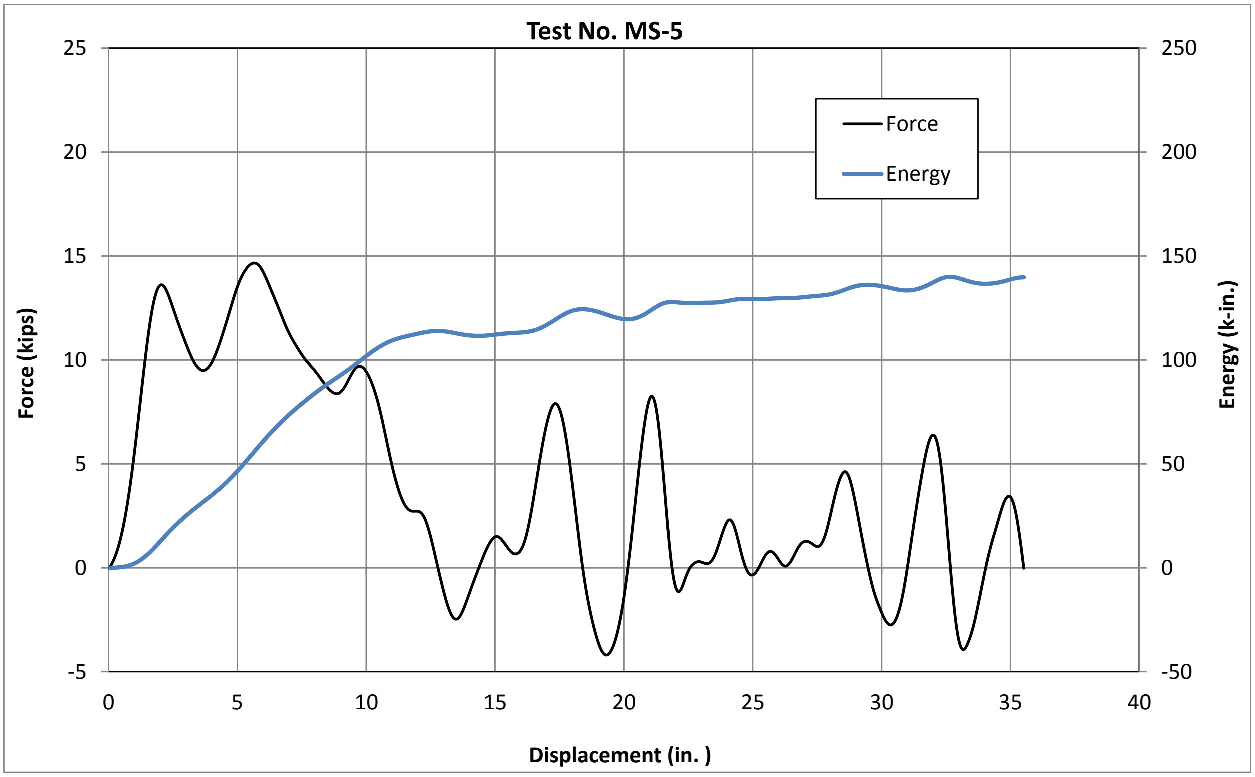


Figure 26. Force vs. Deflection and Energy vs. Deflection, Test No. MS-5

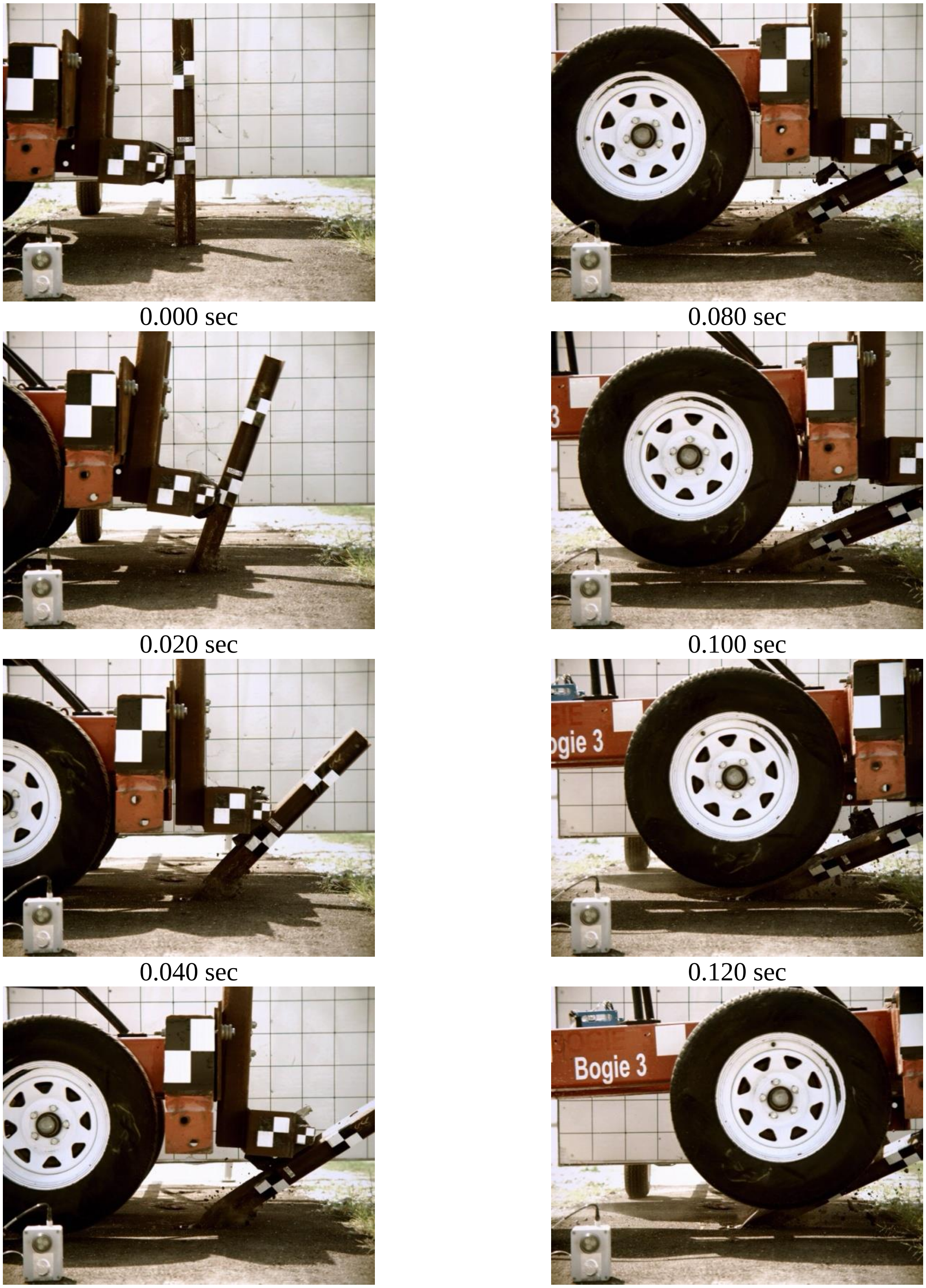


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Figure 27. Time-Sequential Photographs, Test No. MS-5

Figure 28. Pre- and Post-Impact Photographs, Test No. MS-5

5.3.2 Test No. MSSP-1

Test no. MSSP-1 was conducted on May 30, 2014 at approximately 3:00 p.m. The weather conditions, per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 11.

Table 11. Weather Conditions, Test No. MSSP-1

Temperature	85° F
Humidity	48%
Wind Speed	13 mph
Wind Direction	140° From True North
Sky Conditions	Cloudy
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	1.34 in.

During test no. MSSP-1, the bogie impacted the S3x5.7 (S76x8.5) steel post at a speed of 21.4 mph (34.4 km/h) and an angle of 90 degrees, thus causing strong-axis bending in the post. By 0.010 sec, a plastic hinge had formed in the post at the groundline. The post continued to bend backward until the bogie head overrode the top of the post 0.098 sec after impact.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 29. Upon impact, the resistance force increased rapidly and peaked at 16.5 kips (73.4 kN) at a displacement of 3.6 in. (91 mm). At 0.020 sec and a displacement of 7 in. (178 mm), the bogie head was sliding up the post as it bent over, resulting in the force dropping below 10 kips (4.5 kN). The resistance force oscillated below 5 kips (22.2 kN) until the bogie head overrode the post at a displacement of 31.4 in. (798 mm). At this deflection, 122.1 k-in. (13.8 kJ) of energy was dissipated.

Damage to the test article consisted of plastic bending of the post at the groundline, displacement of the steel socket through the asphalt, and minor bending of the steel shear plate. The socket rotated backward, leaving a ¼-in. (6-mm) gap between the asphalt and the front edge of the socket. The free edges of the shear plate were bent forward slightly due to the socket displacement. The post was easily removed from the socket, and a new one could be installed plumb. Thus, no repairs were necessary on the asphalt or socket to replace the damaged post. Time-sequential photographs and pre- and post-impact photographs are shown in Figures 30 and 31, respectively.

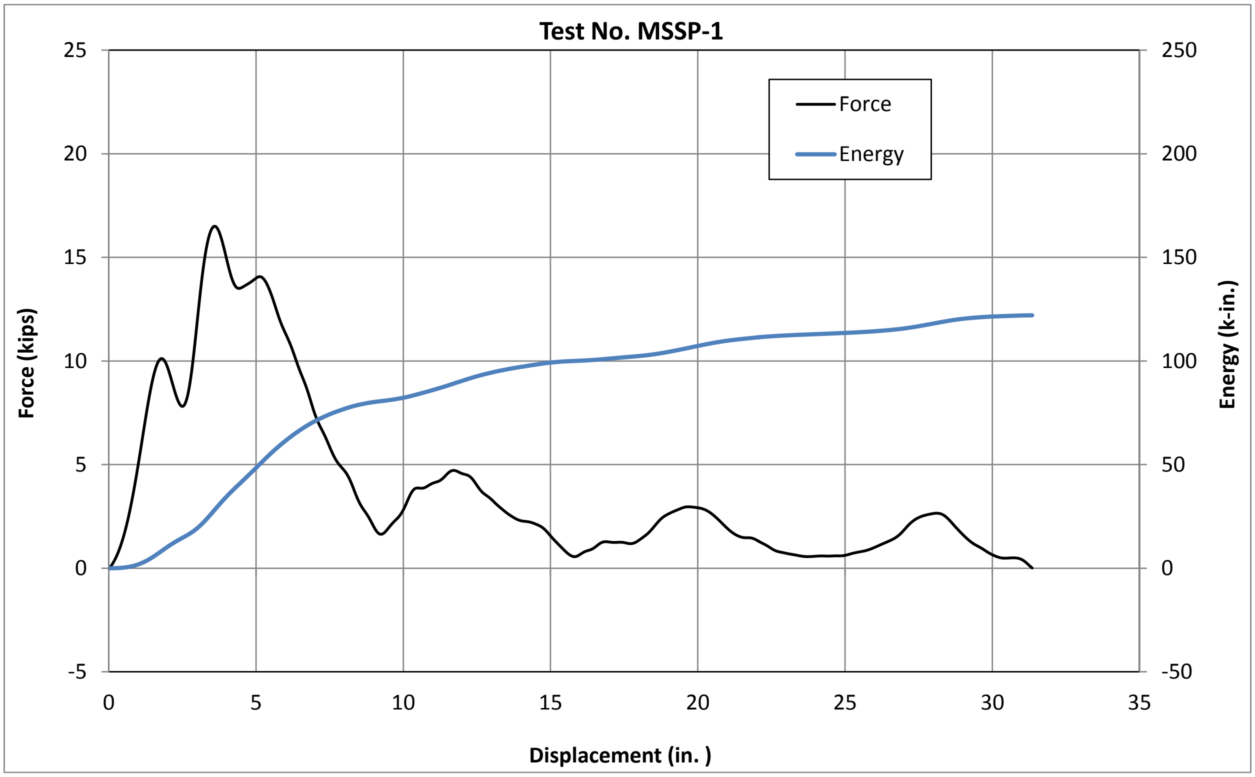

Figure 29. Force vs. Deflection and Energy vs. Deflection, Test No. MSSP-1

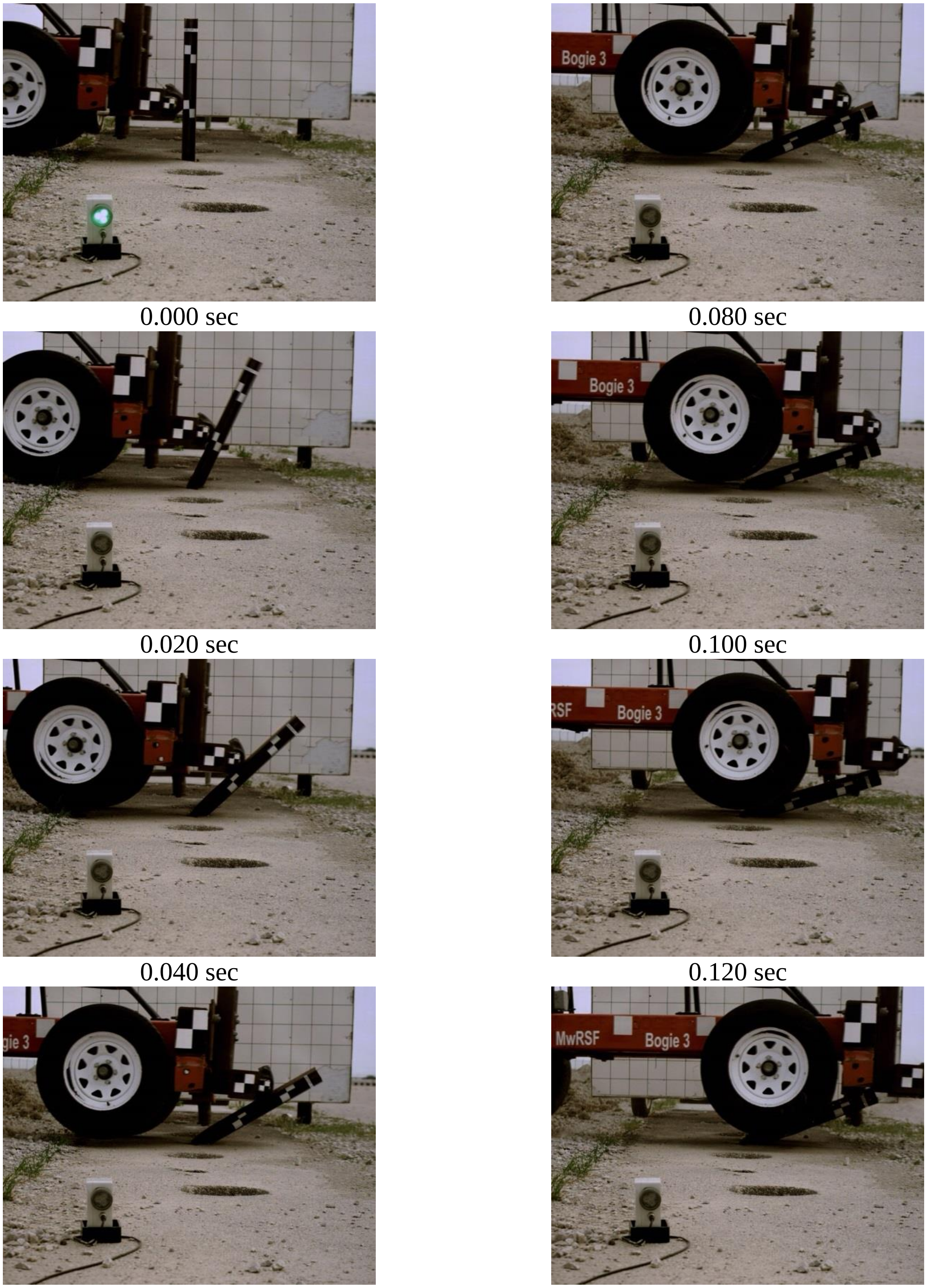

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Figure 30. Time-Sequential Photographs, Test No. MSSP-1

Figure 31. Pre- and Post-Impact Photographs, Test No. MSSP-1

5.3.3 Test No. MSSP-2

Test no. MSSP-2 was conducted on June 4, 2014 at approximately 4:00 p.m. The weather conditions, per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 12.

Table 12. Weather Conditions, Test No. MSSP-2

Temperature	79° F
Humidity	56%
Wind Speed	13 mph
Wind Direction	020° From True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	1.54 in.
Previous 7-Day Precipitation	2.27 in.

Since damage was minimal during test no. MSSP-1, the same socket was utilized for test no. MSSP-2 without removing or resetting the socket. During test no. MSSP-2, the bogie impacted the S3x5.7 (S76x8.5) steel post at a speed of 20.1 mph (32.3 km/h) and an angle of 0 degrees, thus causing weak-axis bending in the post. By 0.008 sec after impact, a plastic hinge had formed in the post at the groundline. The post continued to bend backward until the bogie head overrode the top of the post 0.104 sec after impact.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 32. Upon impact, the resistance force increased rapidly to a peak of 5.4 kips (24.0 kN) at a displacement of 1.8 in. (46 mm). Another force peak of 4.9 kips (21.8 kN) occurred at 10.1 in. (257 mm) before the bogie head began to slide up the post as it bent over. Subsequently, the resistance force oscillated below 3.5 kips (15.6 kN) until the bogie head overrode the post at a displacement of 33.4 in. (848 mm). At this deflection, 80.6 k-in. (9.1 kJ) of energy was dissipated.

Damage to the test article consisted of plastic bending of the post at the groundline and minor displacement of the socket. The socket had rotated slightly, leaving a ⅛-in. (3-mm) gap between the asphalt and the upstream edge of the socket. The post was easily removed from the socket, and a new one could be installed plumb. Thus, no repairs were necessary on the asphalt or socket to replace the damaged post. Time-sequential photographs and pre- and post-impact photographs are shown in Figures 33 and 34, respectively.

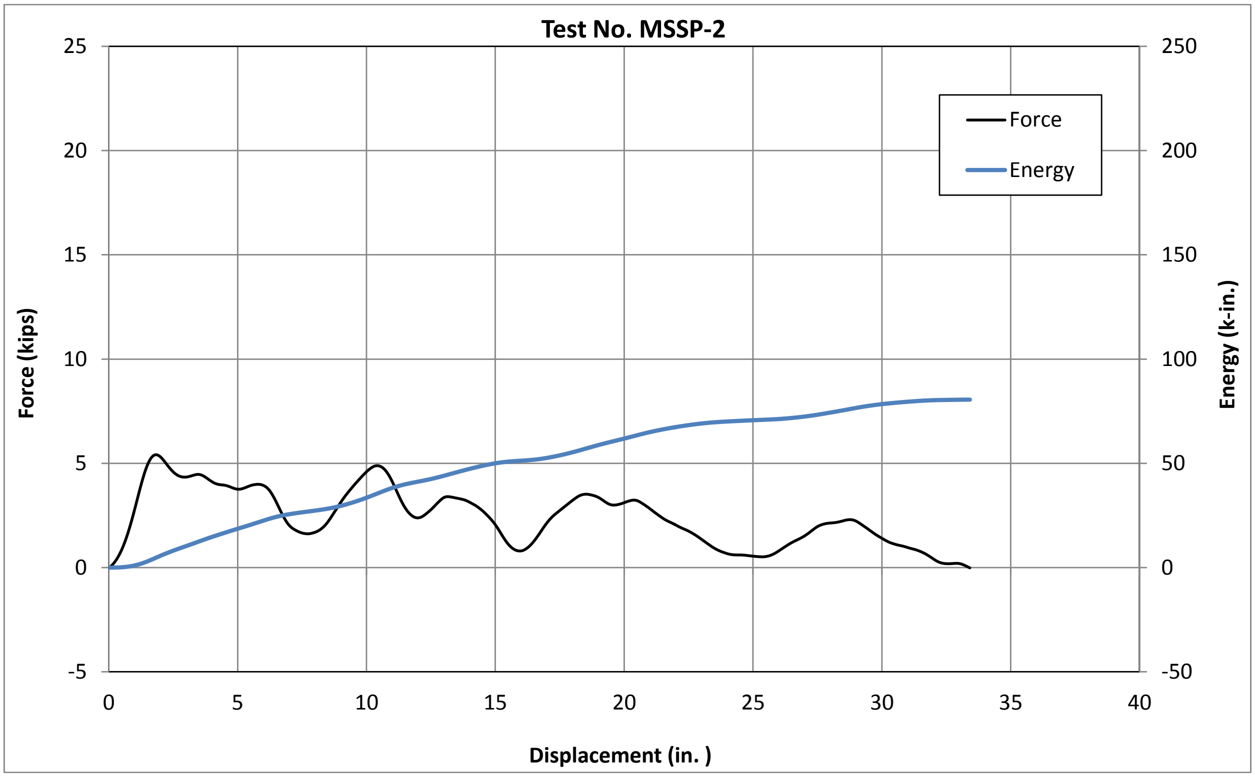

Figure 32. Force vs. Deflection and Energy vs. Deflection, Test No. MSSP-2

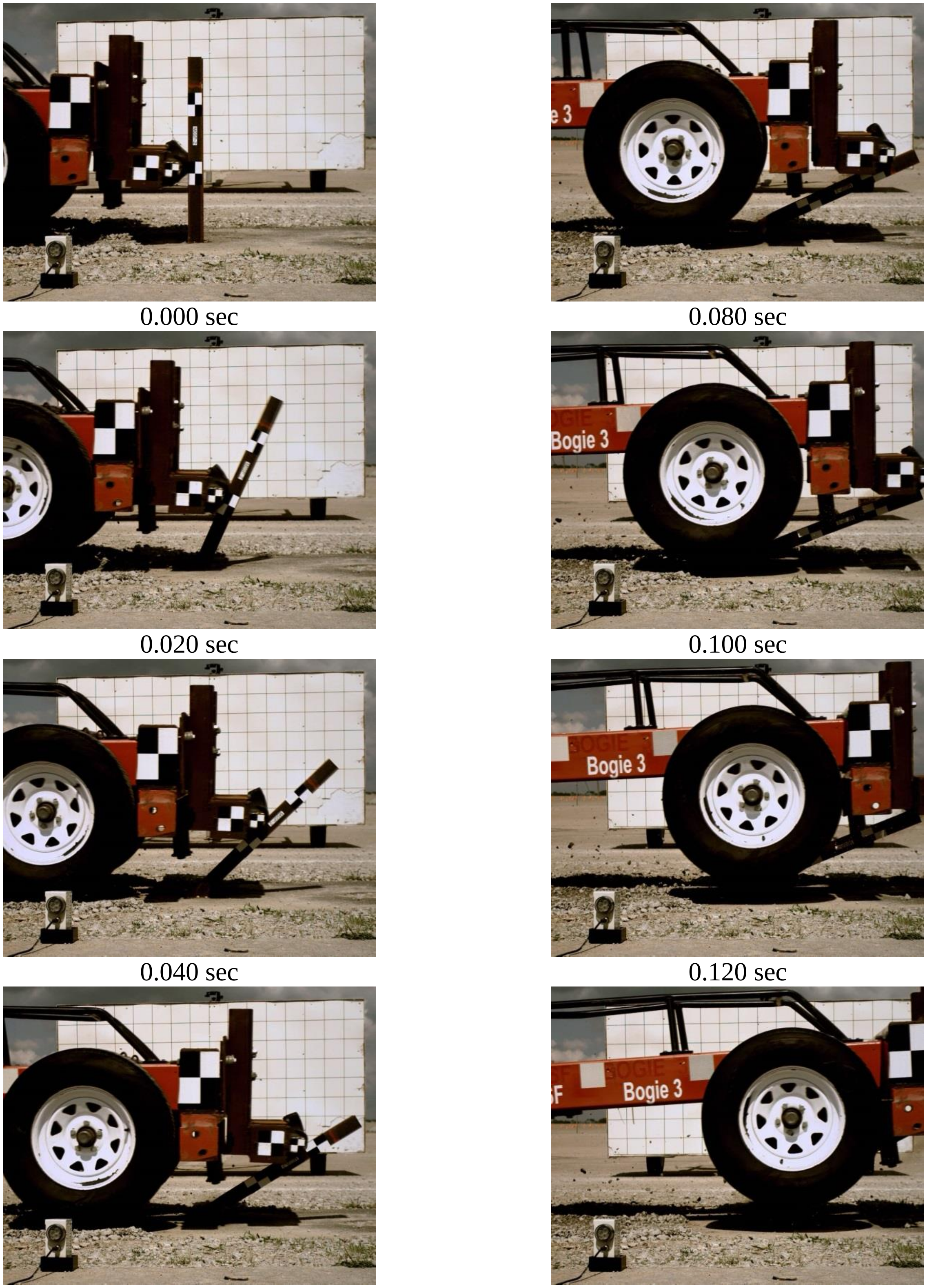

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Figure 33. Time-Sequential Photographs, Test No. MSSP-2

Figure 34. Pre- and Post-Impact Photographs, Test No. MSSP-2

5.3.1 Test No. MSSP-3

Test no. MSSP-3 was conducted on July 24, 2014 at approximately 2:20 p.m. The weather conditions, per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 13.

Table 13. Weather Conditions, Test No. MSSP-3

Temperature	87° F
Humidity	43%
Wind Speed	24 mph
Wind Direction	160° From True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

During test no. MSSP-3, the bogie impacted the S3x5.7 (S76x8.5) steel post at a speed of 20.5 mph (33.0 km/h) and an angle of 90 degrees, thus causing strong-axis bending in the post. At 0.006 seconds after impact, the socket began displacing through the asphalt, and by 0.018 seconds, shear cracks had formed between the socket and the backside of the asphalt. By 0.040 sec, the asphalt behind the socket had completely broken free from the mow strip and was displacing backward. The socket and post continued to rotate backward until the bogie head overrode the top of the post 0.156 sec after impact.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 35. Upon impact, the resistance force increased rapidly to 12.6 kips (56.0 kN) at a displacement of 1.8 in. (46 mm). The force then peaked at 20.0 kips (89.0 kN) at a displacement of 4.1 in. (104 mm). At a displacement of 12 in. (305 mm), the asphalt behind the socket had broken away. Subsequently, the resistance force dropped and oscillated below 5 kips

(22.2 kN) until the bogie head overrode the post at a displacement of 41.0 in. (1,041 mm). At this deflection, the 190.5 k-in. (21.5 kJ) of energy was dissipated.

Damage to the test article consisted largely of asphalt cracking, fracture, and displacement. The asphalt behind the socket and post assembly fractured from the mow strip due to three large shear cracks formed between the socket and the back edge of the asphalt strip. Additional asphalt cracks were found directly in front of the socket's original position. These cracks and fractures allowed the socket and post assembly to rotate backward during impact. Time-sequential photographs and pre- and post-impact photographs are shown in Figures 36 and 37, respectively.

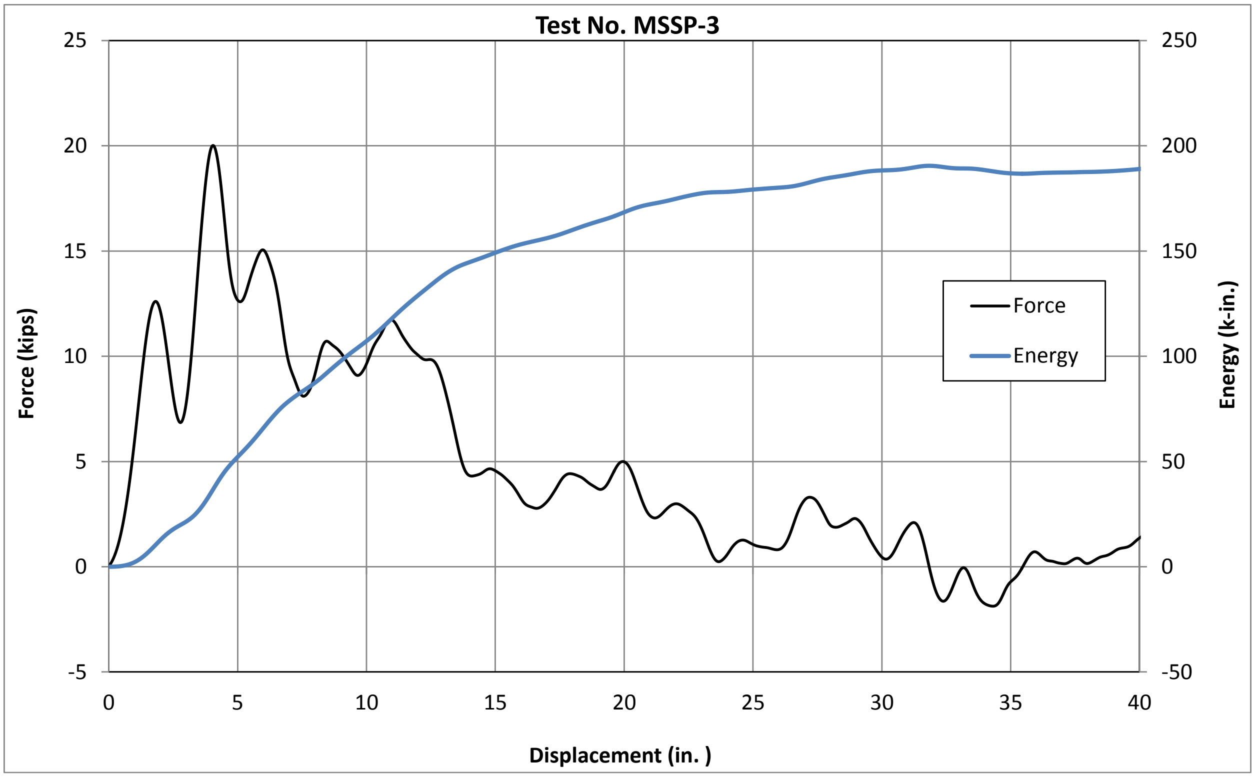

Figure 35. Force vs. Deflection and Energy vs. Deflection, Test No. MSSP-3

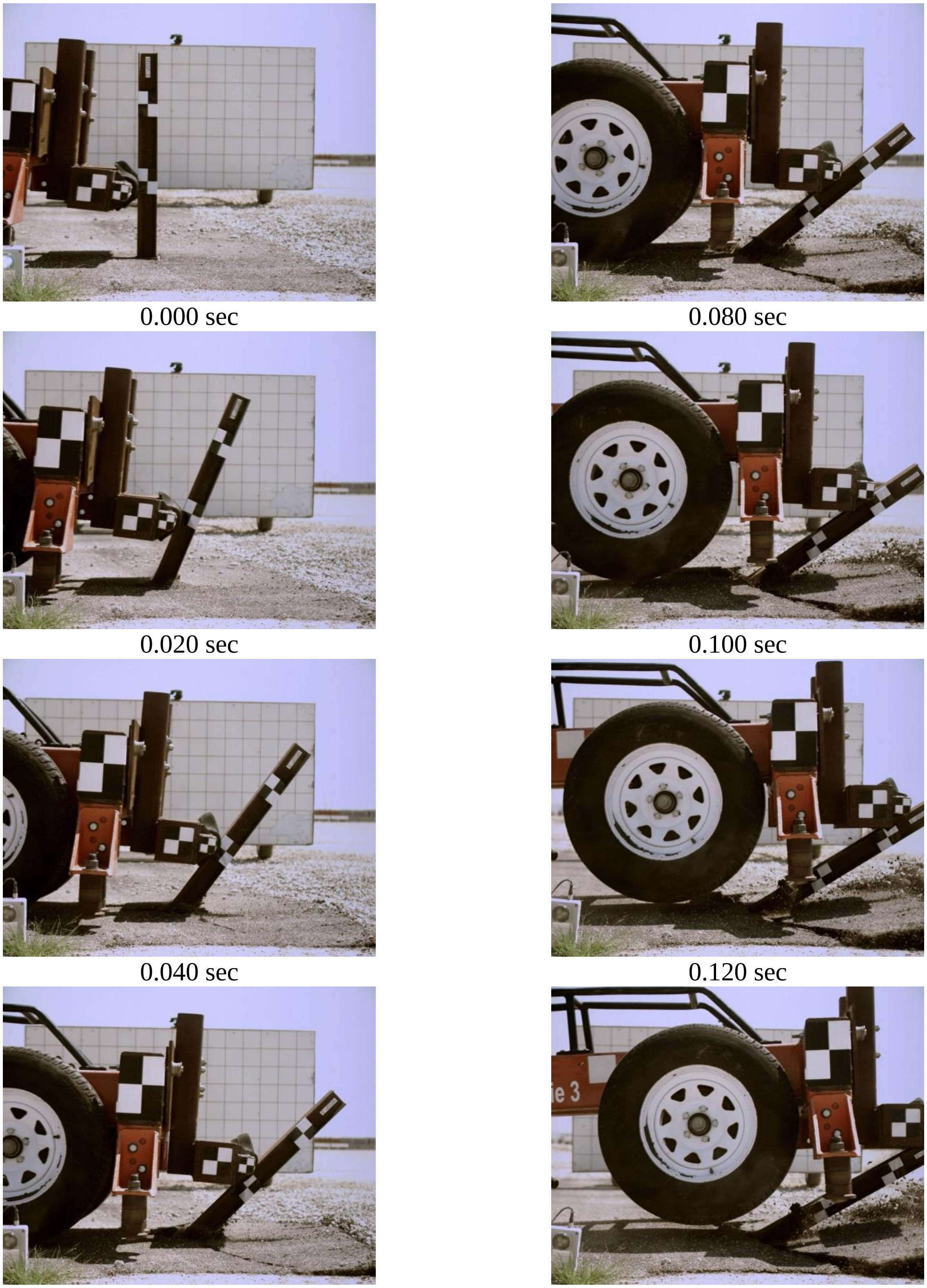

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Figure 36. Time-Sequential Photographs, Test No. MSSP-3

Figure 37. Pre- and Post-Impact Photographs, Test No. MSSP-3

5.3.1 Test No. MSSP-4

Test no. MSSP-4 was conducted on August 8, 2014 at approximately 2:15 p.m. The weather conditions, per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 14.

Table 14. Weather Conditions, Test No. MSSP-4

Temperature	80° F
Humidity	60%
Wind Speed	6 mph
Wind Direction	130° From True North
Sky Conditions	Cloudy
Visibility	9 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.21 in.
Previous 7-Day Precipitation	0.27 in.

During test no. MSSP-4, the bogie impacted the S3x5.7 (S76x8.5) steel post at a speed of 20.8 mph (33.5 km/h) and an angle of 90 degrees, thus causing strong-axis bending in the post. At 0.008 sec after impact, the socket began displacing through the asphalt, and by 0.010 sec, a plastic hinge had formed in the post at the groundline. The post continued to bend backward until the bogie head overrode the top of the post 0.104 sec after impact.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 38. Upon impact, the resistance force increased rapidly to a peak force of 16.3 kips (72.5 kN) at a displacement of 3.5 in. (89 mm). By 0.030 sec and a displacement of 10 in. (254 mm), the bogie head was sliding up the post as it bent over, resulting in a force reduction. Subsequently, the resistance force oscillated below 3 kips (13.3 kN) until the bogie head overrode the post at a displacement of 31.2 in. (792 mm). At this deflection, 142.1 k-in. (16.1 kJ) of energy was dissipated.

Damage to the test article consisted of plastic bending of the post at the groundline, displacement of the steel socket, and slight bending of the shear plate. The socket had rotated backward, leaving a ½-in. (13-mm) gap between the asphalt and the front edge of the socket. Due to this movement, the free edges of the shear plate were bent slightly forward. The post was easily removed from the socket, and a new one could be installed plumb. Thus, no repairs were necessary for the asphalt or socket to replace the damaged post. Time-sequential photographs and pre- and post-impact photographs are shown in Figures 39 and 40, respectively.

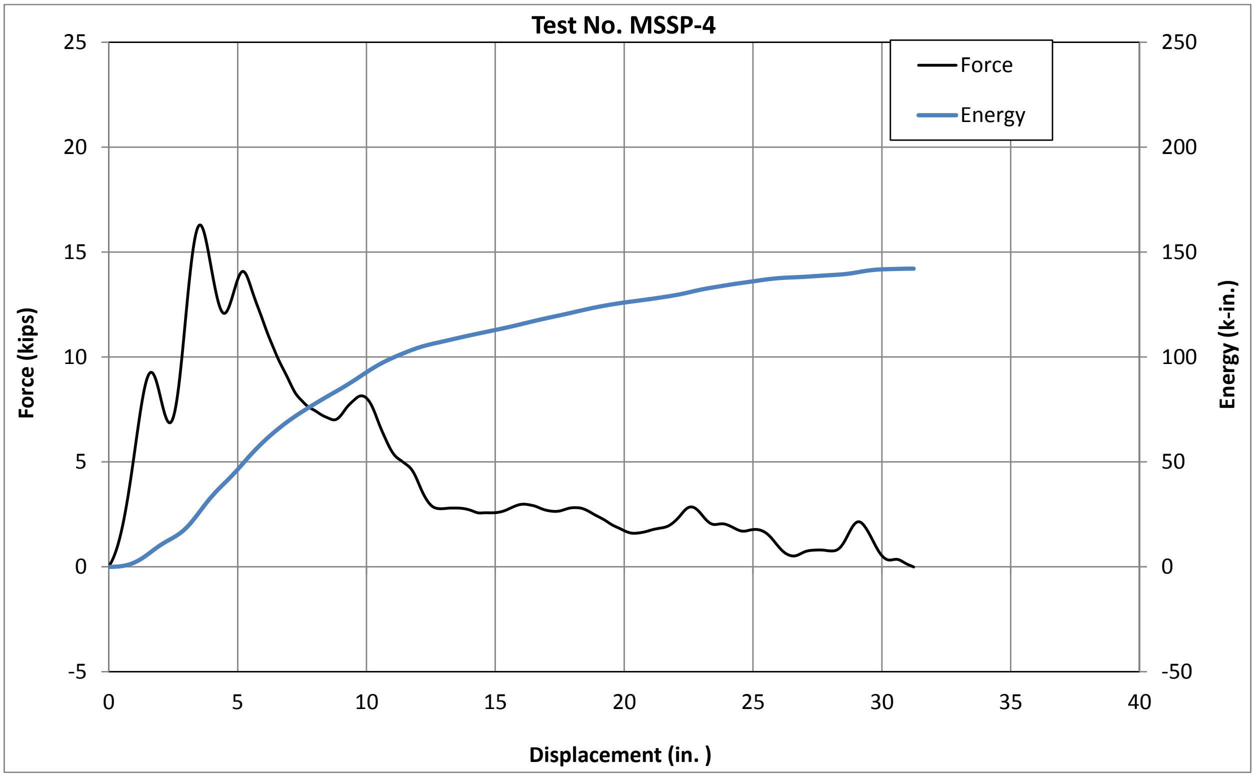

Figure 38. Force vs. Deflection and Energy vs. Deflection, Test No. MSSP-4

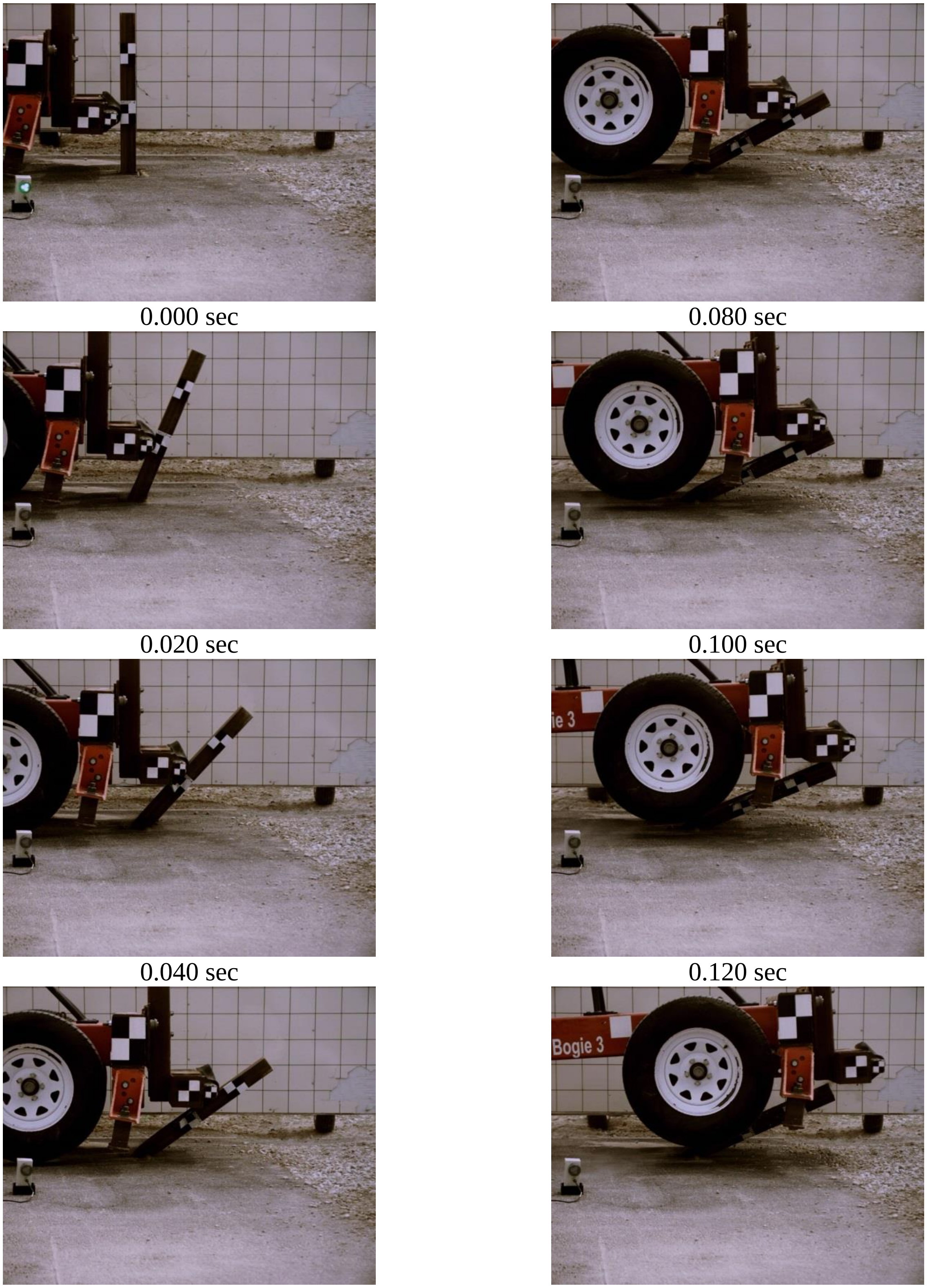

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Figure 39. Time-Sequential Photographs, Test No. MSSP-4

Figure 40. Pre- and Post-Impact Photographs, Test No. MSSP-4

5.4 Discussion

The results from Round 2 of dynamic component testing are summarized in Table 15. The addition of the 4-in. (102-mm) square socket used in test no. MS-5 reduced the amount of asphalt displacement and damage sustained during the test. However, the 1 in. (25 mm) of socket displacement at the groundline was greater than desired and would prevent a replacement post from being installed plumb. The addition of the 10-in. x 9-in. x ¼-in. (254-mm x 229-mm x 6-mm) shear plate further reduced asphalt damage and limited the socket to displacements that would allow for post replacement without resetting the socket. Thus, the steel shear plate would be necessary for installations to prevent damage to asphalt mow strips during vehicle impacts into the barrier system.

Even with the addition of the shear plate, the depth of the socket proved to be a critical factor, as shown in test nos. MSSP-1, MSSP-3, and MSSP-4. In test no. MSSP-3, the socket with a 20-in. (508-mm) embedment depth was too weak, as it overloaded the asphalt and caused major cracking and fracture of the mow strip. Subsequently, the 20-in. (508-mm) long socket rotated through the soil and the S3x5.7 (S76x8.5) post did not yield. Alternatively, in test nos. MSSP-1 and MSSP-4, socket embedment depths of 30 in. (762 mm) and 24 in. (610 mm) resulted in socket displacements of ¼ in. (6 mm) and ½ in. (13 mm) respectively. Both of these socket displacements/rotations allowed for a replacement post to be installed plumb without repairs to the asphalt or resetting the socket. Note, displacements greater than ½ in. (13 mm) would likely require repair work prior to installing a new post.

One test was also conducted along the longitudinal axis, thus causing weak-axis bending of the post. Test no. MSSP-2 was conducted on a 30-in. (762-mm) long socket with the shear plate oriented parallel to the impact trajectory. Thus, the shear plate had minimal effect on the socket's resistance to displacement. The test resulted in a minimal socket displacement of ⅛ in.

(3 mm). Due to the reduction in the bending strength of the S3x5.7 (S76x8.5) post in the weak axis as compared to the strong axis, longitudinal impacts did not appear to cause significant damage to the socket or asphalt mow strip, and similar results would be expected if a longitudinal test were conducted on a 24-in. (610-mm) long socket.

Force vs. displacement and energy vs. displacement comparisons for all five tests are shown in Figures 41 and 42, respectively. The resistance forces and absorbed energies for each test corresponded to the failure mechanism of that test. The three tests that resulted in strong-axis bending of the post, test nos. MS-1, MSSP-1, and MSSP-4, had similar peak loads, force curve shapes, and absorbed energies. Test no. MSSP-3 showed a much different load curve, as the asphalt around the socket fractured and allowed the socket to rotate during the impact event. This behavior prolonged the impact duration and resulted in increased energy absorption. As would be expected, test no. MSSP-2, which resulted in weak-axis bending of the post, showed a much lower resistive force.

Table 15. Results Summary, Component Testing – Round 2

Test No.	Mow Strip		Socket Emb. Depth in. (mm)	Shear Plate	Impact Angle deg.	Impact Velocity mph (km/h)	Peak Force kips (kN)	Average Force kips (kN)		Total Energy Absorbed k-in. (kJ)	Mow Strip Damage
	Material	Thickness in. (mm)						@10”	@15”		
MS-5	Asphalt	4 (102)	30 (762)	No	90	21.7 (34.9)	14.7 (65.4)	10.2 (45.4)	7.5 (33.4)	140.0 (15.8)	1” Socket Movement
MSSP-1	Asphalt	4 (102)	30 (762)	Yes	90	21.4 (34.4)	16.5 (73.4)	8.2 (36.5)	6.2 (27.6)	122.1 (13.8)	¼” Socket Movement
MSSP-2	Asphalt	4 (102)	30 (762)	Yes	0	20.1 (32.3)	5.4 (24.0)	3.3 (14.7)	3.3 (14.7)	80.6 (9.1)	⅛” Socket Movement
MSSP-3	Asphalt	4 (102)	20 (508)	Yes	90	20.5 (33.0)	20.0 (89.0)	10.7 (47.6)	10.0 (445)	190.5 (21.5)	Asphalt Cracking and Fracture
MSSP-4	Asphalt	4 (102)	24 (610)	Yes	90	20.8 (33.5)	16.3 (72.5)	9.3 (41.4)	7.5 (33.4)	142.1 (16.1)	½” Socket Movement

*All tests conducted by impacting S3x5.7 (S76x8.5) posts at a height of 12 in. (305 mm).

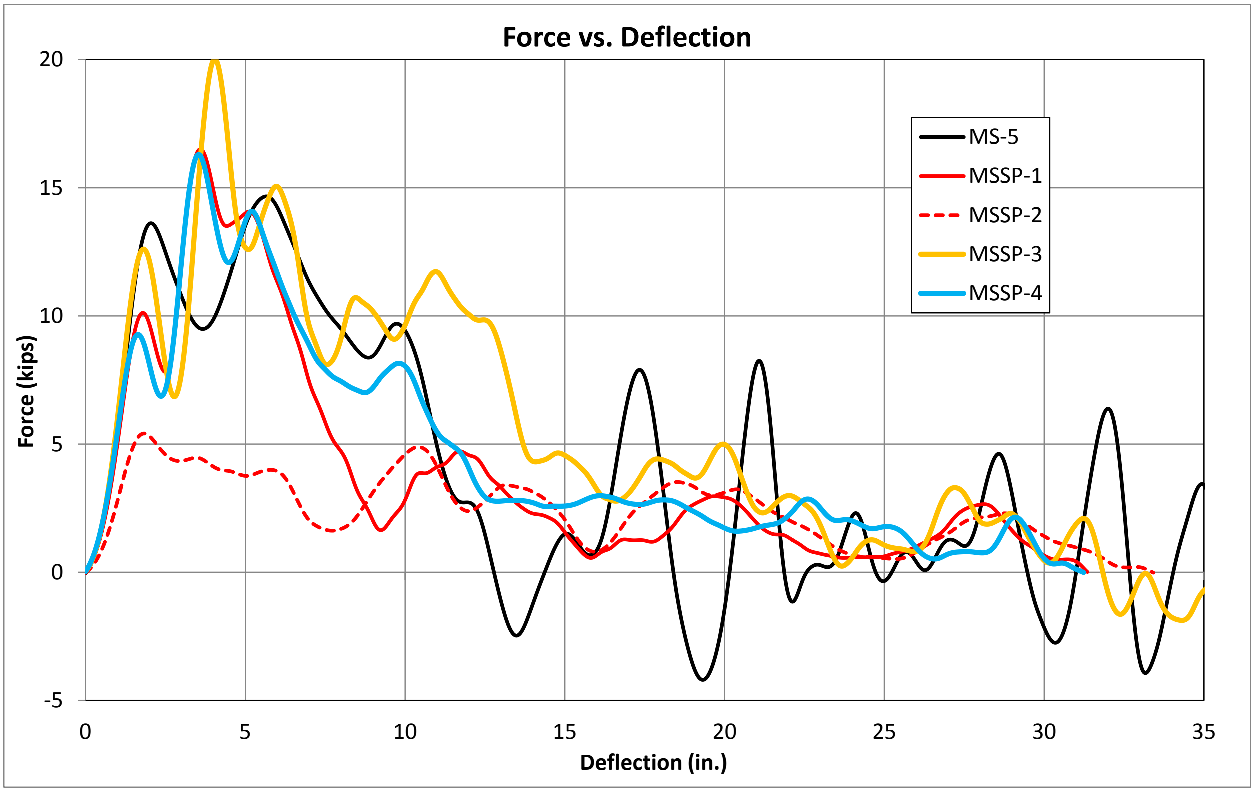


Figure 41. Force vs. Deflection Comparison, Component Testing - Round 2

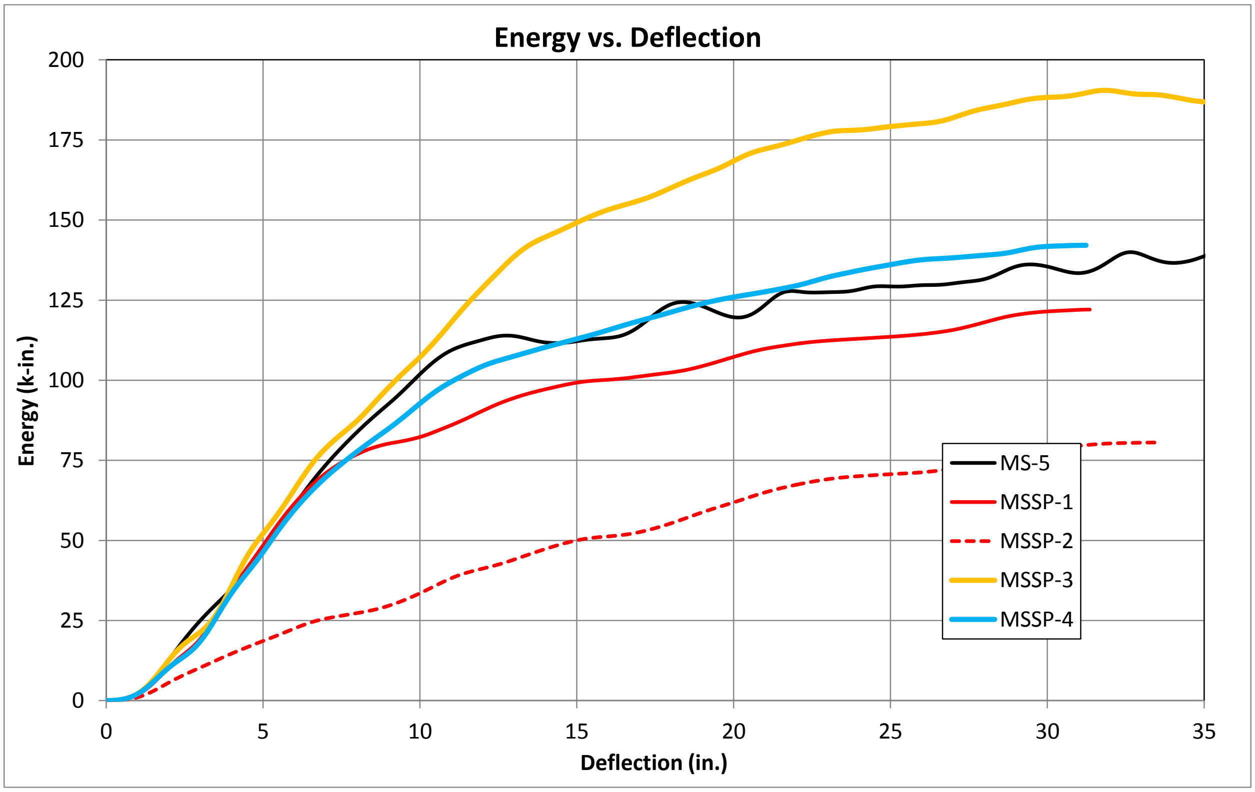


Figure 42. Energy vs. Deflection Comparison, Component Testing - Round 2

6 COMPONENT TESTING – ROUND 3, DUAL-POST TESTING

6.1 Purpose

The first two rounds of component testing were conducted on weak guardrail posts installed within mow strips to evaluate the damage associated with various pavement types and socket sizes. These tests revealed that a 4-in. (102-mm) thick concrete mow strip was strong enough to support an S3x5.7 (S76x8.5) post and prevent damage mow strip during impact events. The 4-in. (102-mm) thick asphalt mow strip required a steel tube socket with a minimum embedment depth of 24 in. (610 mm) and a backside shear plate to distribute impact loads and prevent damage to the pavement. All of these tests were conducted on single posts within the mow strip and actual barrier system installations will have multiple posts spaced at 37.5-in. (953-mm) intervals. Previous full-scale crash testing has shown that up to 11 posts may be loaded during a single vehicle impact event [7]. Therefore, it was deemed necessary to investigate damage to both mow strip pavements that would result from loading multiple posts simultaneously.

6.2 Scope

Round 3 of component testing consisted of two tests conducted on dual S3x5.7 (S76x85) posts installed 37.5 in. (953 mm) apart within mow strips, as shown in Figures 43 through 46. Test no. MSSP-5 was conducted within a 4-in. (102-mm) thick asphalt mow strip and utilized 24-in. (610-mm) long, 4-in. x 4-in. x ¼-in. (102-mm x 102-mm x 6-mm) steel tube sockets to support the posts. Additionally, 9-in. x 10-in. x ¼-in. (229-mm x 254-mm x 6-mm) shear plates were welded to the backside of the sockets to distribute the impact loads. Two plates were welded to the base of each socket to form a wedge, which allowed the socket to be driven into place without damaging the surrounding asphalt. Test no. MSSP-6 was conducted within a 4-in.

(102-mm) thick, unreinforced concrete mow strip. The dual posts were installed through 4-in. (102-mm) square leave-outs in the concrete and had an embedment depth of 40 in. (1,016 mm).

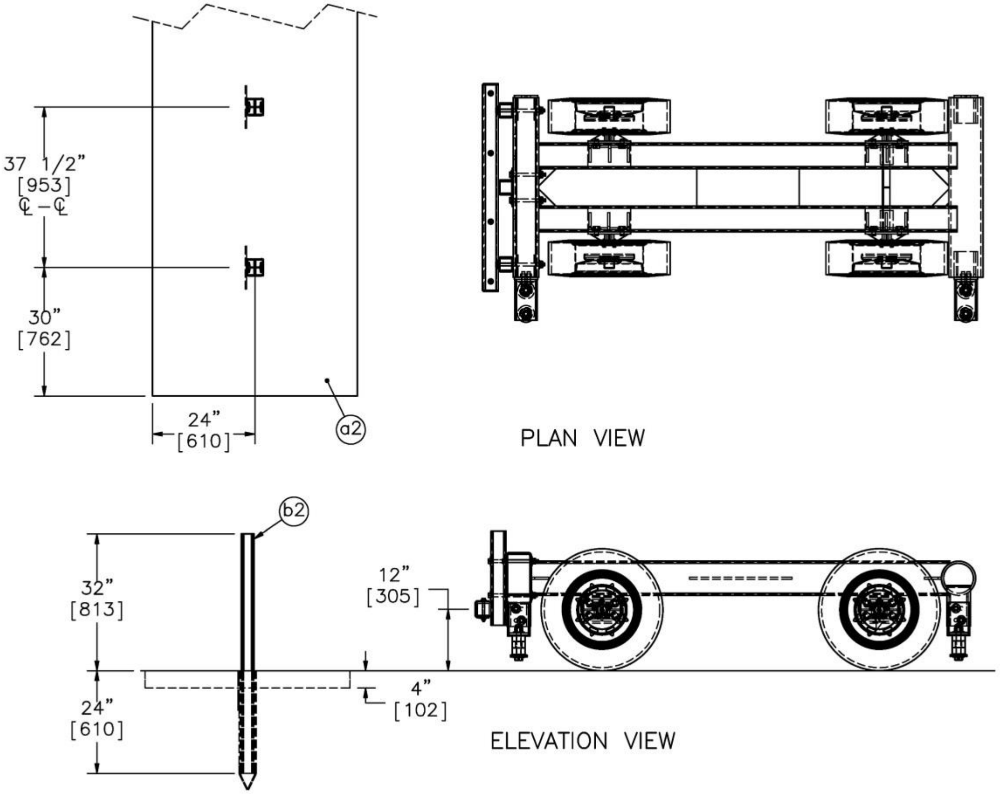
The dual-post tests under Round 3 of component testing were conducted with the same impact conditions utilized during the previous rounds of component testing. The bogie vehicle impacted the posts at a height of 12 in. (305 mm) and a target impact speed of 20 mph (32 km/h) and at an angle of 90 degrees, thus causing strong-axis bending. The complete test matrix for Round 3 of component testing is shown in Table 16.

The unreinforced concrete mow strip was constructed from a concrete mix with a compressive strength of 4,000 psi (28 MPa). The asphalt mow strip was constructed from a 52-34 grade binder typically utilized in highway shoulder construction in Nebraska. The S3x5.7 (S76x8.5) posts were designated as A36 steel. However, the posts were fabricated from 50-ksi (345-MPa) steel that also satisfied A992 requirements. This increased strength resulted in a more critical evaluation of the mow strips. The sockets were fabricated from A500 Grade B steel, and the plates were cut from A572 Grade 50 steel. Material specifications, mill certifications, and certificates of conformity for the installation materials are shown in Appendix A.

Table 16. Component Testing Matrix, Round 3

Test No.	Mow Strip		Posts	Post Spacing in. (mm)	Post Installation	Impact Speed mph (km/h)	Impact Angle deg.
	Material	Thickness in. (mm)					
MSSP-5	Asphalt	4 (102)	Dual S3x5.7	37.5 (953)	24” Long Socket with Shear Plate	20 (32)	90°
MSSP-6	Concrete	4 (102)	Dual S3x5.7	37.5 (953)	4”x4” Hole in Concrete	20 (32)	90°

Test No.	Test Qty.	Mow Strip	Bogie No.	Socket	Shear Plate	Embedment Depth in. [mm]	Load Height in. [mm]	Impact Speed mph [km/h]	Impact Angle
MSSP-5	1	4" Asphalt	3	4"x4"x1/4" [102x102x6]	10"x9"x1/4" [254x229x6]	24 [610]	12 [305]	20 [32.2]	90°



Notes: (1) Socket driven directly through asphalt. Post inserted into socket.
(2) A minimum of 2' (610) of soil adjacent to backside of mow strip.

MwRSF
Midwest Roadside Safety Facility

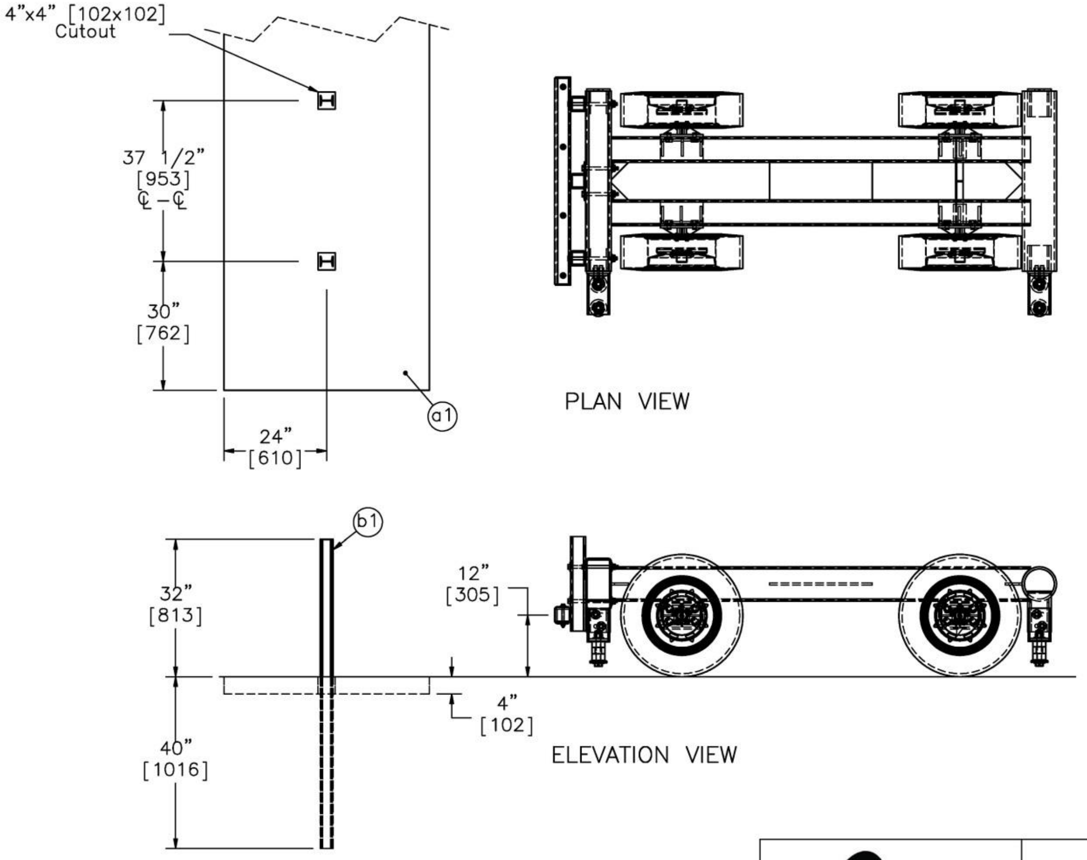
Mow Strip Bogie Testing – Round 3

Asphalt Test Setup

SHEET: 1 of 4
DATE: 2/6/2015
DRAWN BY: JEK
DWG. NAME. MowStrip_Round3_R3
SCALE: 1:36
UNITS: in.[mm]
REV. BY: KAL/SKR

Figure 43. Test Setup and Asphalt Mow Strip Configuration, Component Testing Round 3

Test No.	Test Qty.	Mow Strip	Bogie No.	Embedment Depth in. [mm]	Load Height in. [mm]	Impact Speed mph [km/h]	Impact Angle
MSSP-6	1	4" Concrete	3	40 [1016]	12 [305]	20 [32.2]	90°



Notes: (1) Posts driven through 4"x4" [102x102] leavouts in the concrete mow strip.

(2) A minimum of 2' [610] of soil adjacent to backside of mow strip.

Midwest Roadside Safety Facility

Mow Strip Bogie Testing – Round 3

Concrete Test Setup

SHEET: 2 of 4
DATE: 2/6/2015
DRAWN BY: JEK
DWG. NAME. MowStrip_Round3_R3
SCALE: 1:36
UNITS: in.[mm]
REV. BY: KAL/SKR

Figure 44. Test Setup and Concrete Mow Strip Configuration, Component Testing Round 3

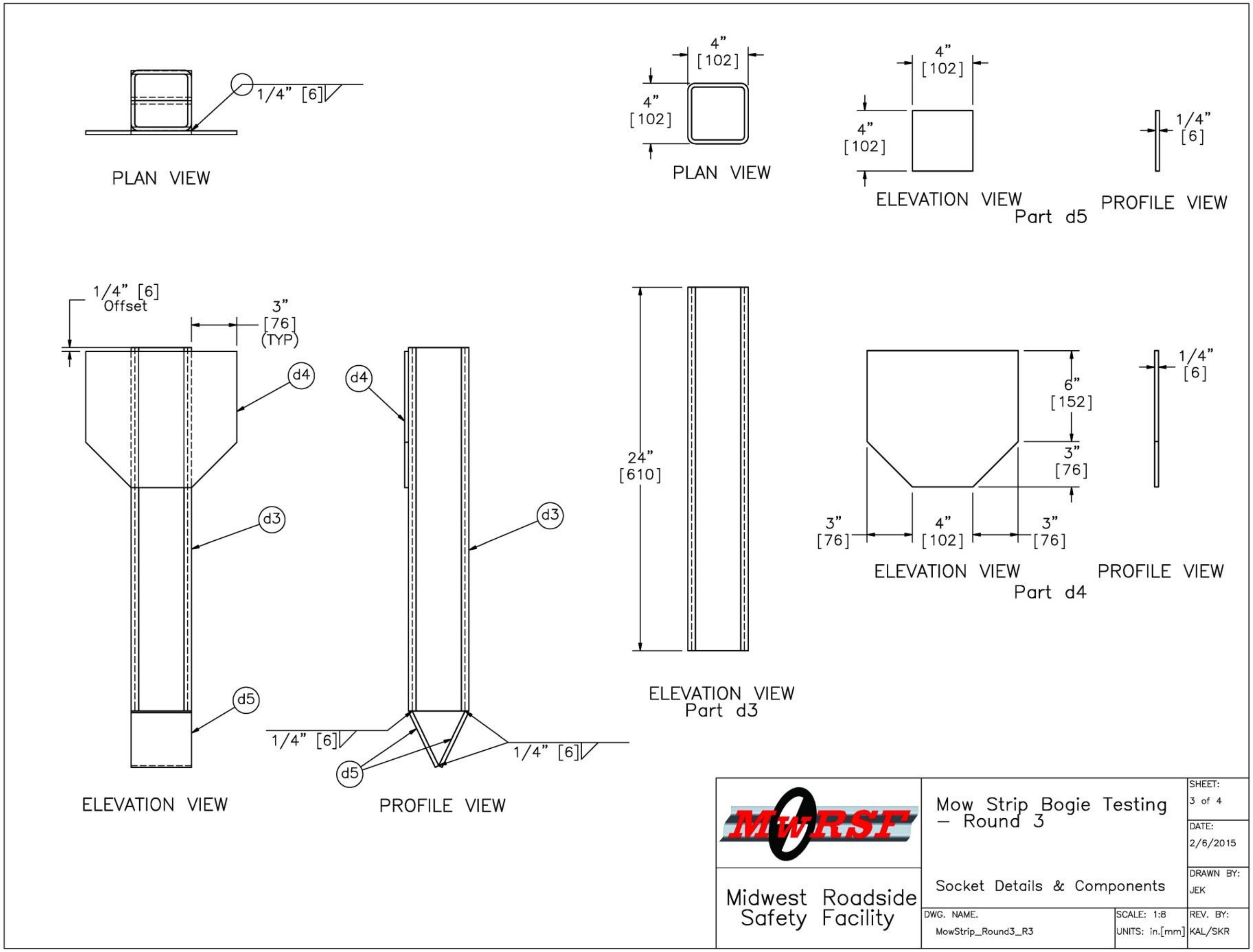
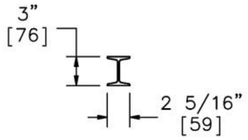
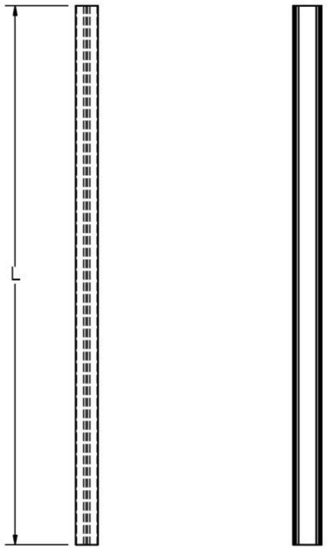


Figure 45. Post Socket Details, Component Testing Round 3

Item No.	QTY.	Description	Material Spec
a1	1	10'x4'x4" [3048x1219x102] Concrete Mow Strip	Min. 4000 psi [27.6 MPa] Comp. Strength
a2	1	25'x4'x4" [7620x1219x102] Asphalt Mow Strip	52–34 Grade Binder
b1	2	S3x5.7 [S76x8.5] 72" [1829] Long Line Post	ASTM A36
b2	2	S3x5.7 [S76x8.5] 56" [1422] Long Line Post	ASTM A36
d3	2	4"x4"x3/8" [102x102x10] Square Socket, 24" [610] Long	ASTM A500 Grade B Steel Galvanized
d4	2	10"x9"x1/4" [254x229x6] Steel Soil Plate	ASTM A572 Grade 50 Steel Galvanized
d5	4	4"x4"x1/4" [102x102x6] Steel Plate	ASTM A572 Grade 50 Steel Galvanized





Part b1–b2

Notes: (1) Post length, L, varied to match test specifications

Midwest Roadside Safety Facility

Mow Strip Bogie Testing – Round 3

Post Detail

SHEET: 4 of 4
DATE: 2/6/2015
DRAWN BY: JEK
DWG. NAME. MowStrip_Round3_R3
SCALE: 1:16
UNITS: in.[mm]
REV. BY: KAL/SKR

Figure 46. Post Details and Bill of Materials, Component Testing Round 3

6.3 Results

6.3.1 Test No. MSSP-5

Test no. MSSP-5 was conducted on August 25, 2014 at approximately 2:40 p.m. The weather conditions, per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 17.

Table 17. Weather Conditions, Test No. MSSP-5

Temperature	79° F
Humidity	49%
Wind Speed	17 mph
Wind Direction	330° From True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.21in.
Previous 7-Day Precipitation	0.62in.

During test no. MSSP-5, the bogie impacted the dual S3x5.7 (S76x8.5) steel posts at a speed of 18.6 mph (29.9 km/h) and an angle of 90 degrees, thus causing strong-axis bending in the posts. At 0.010 sec after impact, the sockets began displacing through the asphalt, and the posts begun to bend and yield at the groundline. At 0.020 seconds, shear cracks began to form in the asphalt behind the sockets. By 0.042 sec, the asphalt behind the sockets had completely broken free from the rest of mow strip and was displacing backward. The sockets and posts continued to rotate backward until the bogie head overrode the posts 0.150 sec after impact.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 47. Upon impact, the resistance force increased rapidly to 17.3 kips (77.0 kN) at a displacement of 1.4 in. (36 mm). The force then peaked at 27.3 kips (121.4 kN) at a displacement of 3.8 in. (97 mm). By 0.042 sec and a displacement of 10 in. (254 mm), the asphalt behind the sockets had broken away, which allowed the sockets and posts to rotate backward. Subsequently, the resistive force dropped steadily until the bogie head overrode the posts at a displacement of 19.5 in. (495 mm). At this deflection, 227.9 k-in. (25.7 kJ) of energy was dissipated.

Damage to the test article consisted of post bending, socket displacement, and asphalt cracking, fracture, and displacement. The asphalt behind the socket and post assemblies fractured away from the mow strip due to large shear cracks, which formed between the two sockets and also extended from the outside edges of the sockets to the back of the asphalt mow strip. These cracks were measured to be between 1.5 in. and 3 in. (38 mm and 76 mm) wide directly behind the sockets. An additional asphalt crack was found directly behind the left socket extending parallel to the direction of impact. These cracks and fractures allowed the socket and post assemblies to rotate backward during impact. The posts were bent at the groundline, though not to the degree shown in test no. MSSP-4 due to the rotation of the sockets. Time-sequential photographs and pre- and post-impact photographs are shown in Figures 48 and 49, respectively.

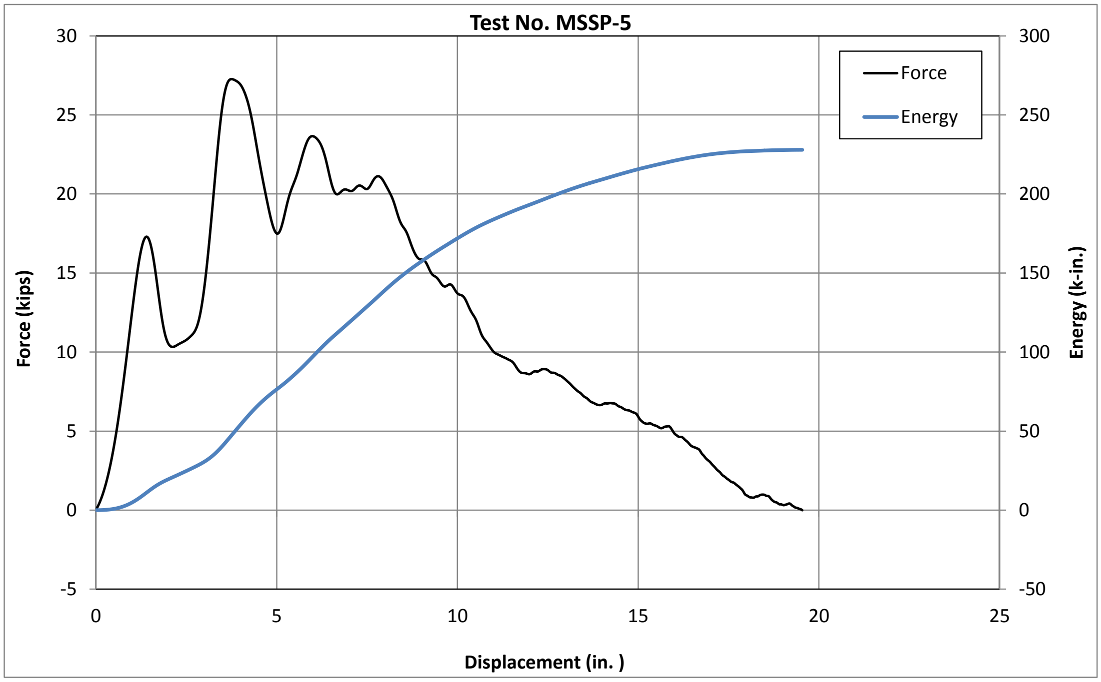
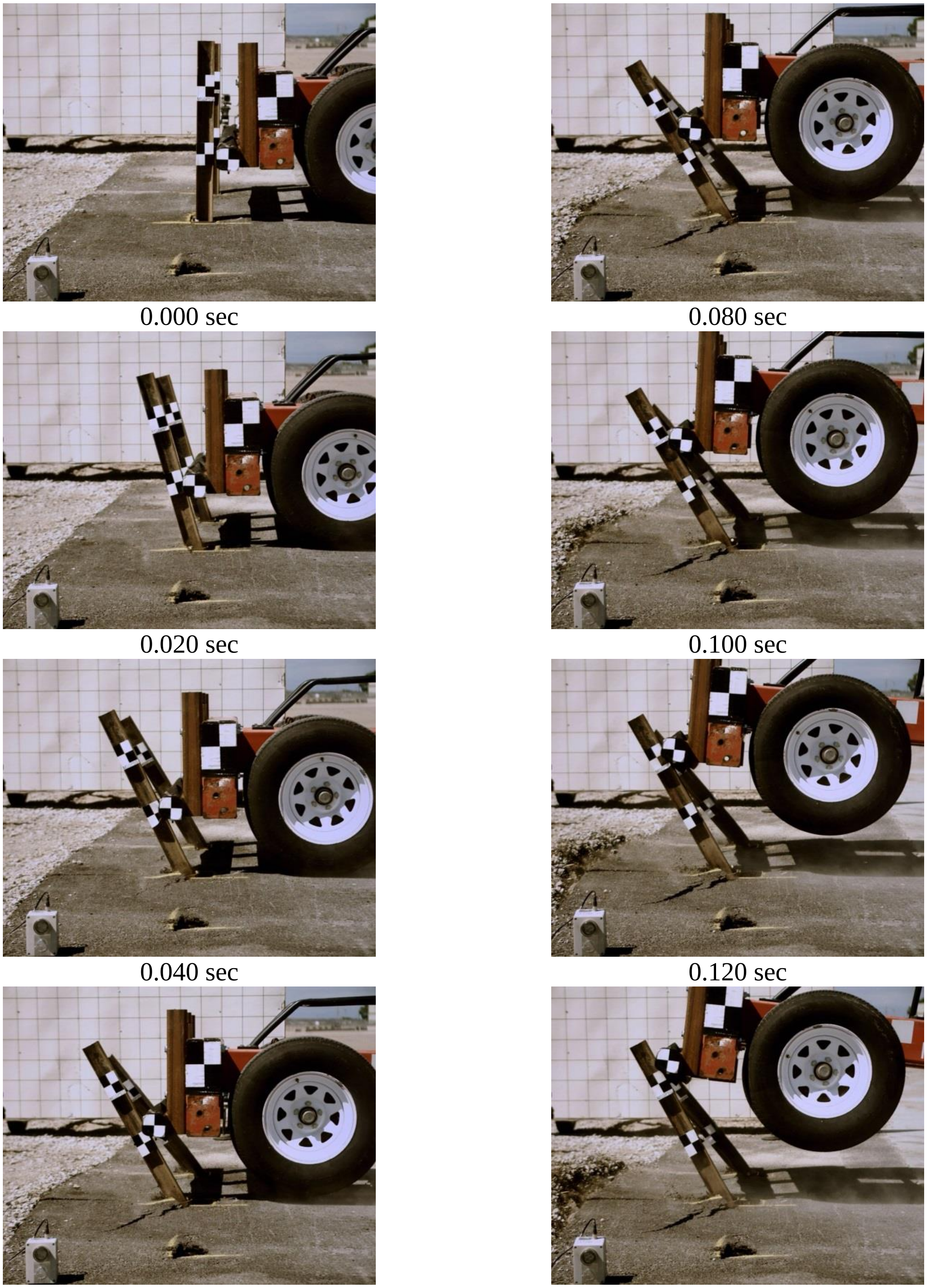


Figure 47. Force vs. Deflection and Energy vs. Deflection, Test No. MSSP-5



0.000 sec

0.020 sec

0.040 sec

0.060 sec

0.080 sec

0.100 sec

0.120 sec

0.140 sec

Figure 48. Time-Sequential Photographs, Test No. MSSP-5

Figure 49. Pre- and Post-Impact Photographs, Test No. MSSP-5

6.3.1 Test No. MSSP-6

Test no. MSSP-6 was conducted on January 23, 2015 at approximately 11:30 a.m. The weather conditions, per the National Oceanic and Atmosphere Administration (station 14939/LNK), were reported and are shown in Table 18.

Table 18. Weather Conditions, Test No. MSSP-6

Temperature	40° F
Humidity	55%
Wind Speed	14 mph
Wind Direction	200° From True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.0 in.
Previous 7-Day Precipitation	0.0 in.

During test no. MSSP-6, the bogie impacted the dual S3x5.7 (S76x8.5) steel posts at a speed of 20.1 mph (32.3 km/h) and an angle of 90 degrees, thus causing strong-axis bending in the posts. By 0.010 sec after impact, the posts had begun to bend at the groundline, and at 0.016 sec, concrete spalling began directly behind the posts. The posts continued to bend backward until the bogie head overrode the top of the posts.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 50. Upon impact, the resistance force increased rapidly and peaked at 28.3 kips (125.9 kN) at a displacement of 3.6 in. (91 mm). By 0.030 sec and a displacement of 8 in. (203 mm), the bogie head was sliding up the posts as they continued to bend. Subsequently, the resistance force steadily decreased until the bogie head overrode the posts at a displacement of 22.4 in. (569 mm). At this deflection, 249.3 k-in. (28.2 kJ) of energy was dissipated.

Damage to the test article consisted of plastic bending of the posts at the groundline and some surface spalling at the back edges of the concrete holes. However, the spalling was less than ¼ in. (6 mm) deep, and cracking was not evident. The posts were removed without causing further damage. Thus, new posts could be installed without repairs to the concrete. Time-sequential photographs and pre- and post-impact photographs are shown in Figures 51 and 52, respectively.

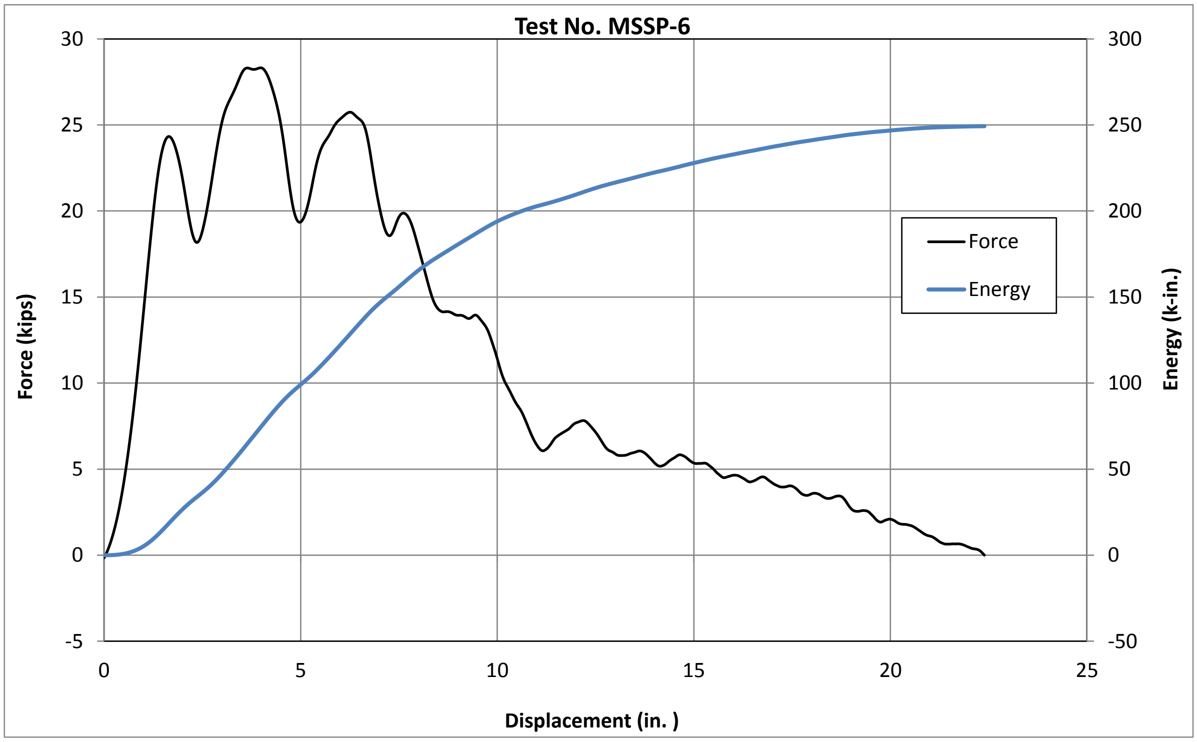
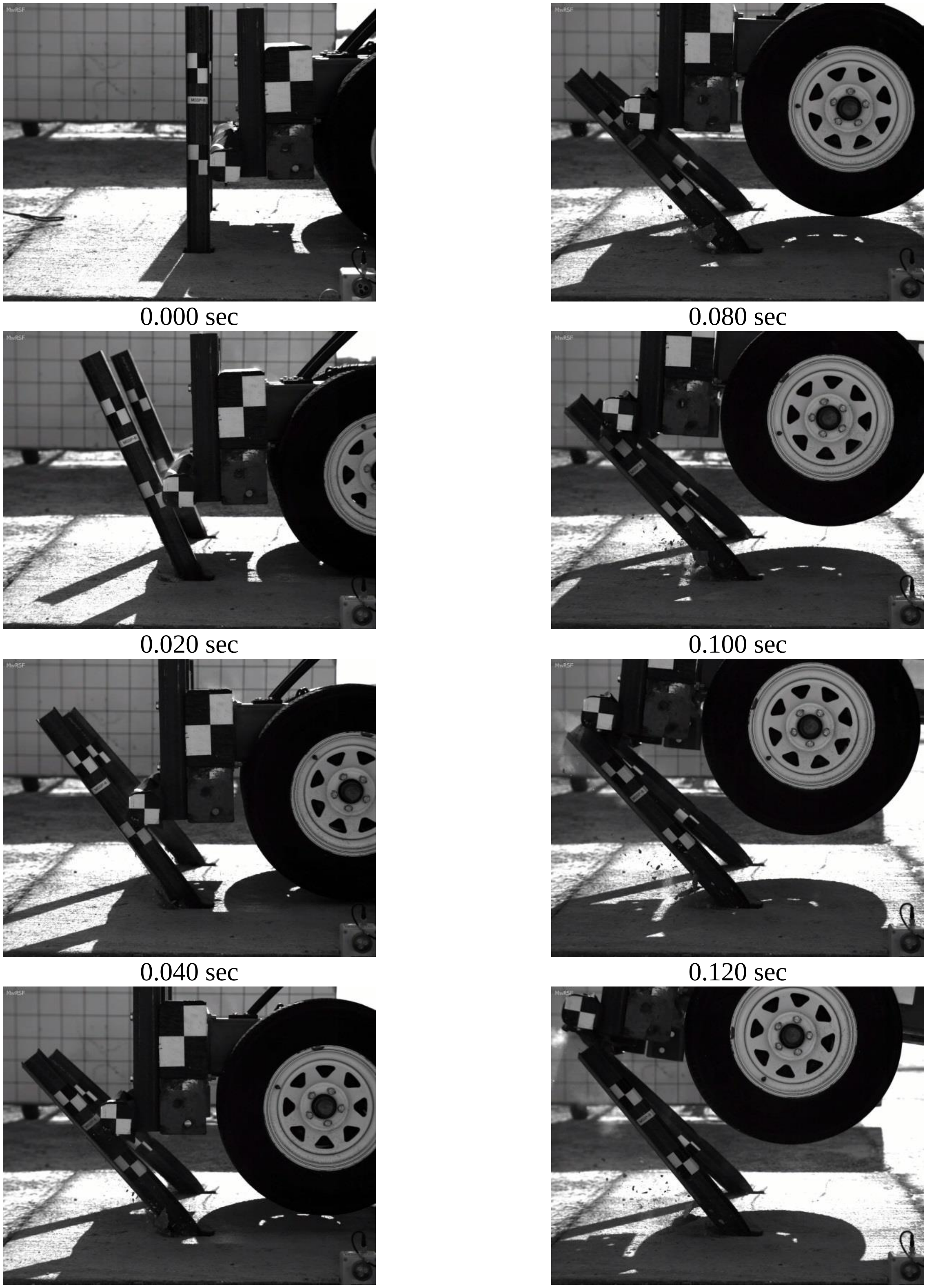


Figure 50. Force vs. Deflection and Energy vs. Deflection, Test No. MSSP-6



0.000 sec

0.080 sec

0.020 sec

0.100 sec

0.040 sec

0.120 sec

0.060 sec

0.140 sec

Figure 51. Time-Sequential Photographs, Test No. MSSP-6

Figure 52. Pre- and Post-Impact Photographs, Test No. MSSP-6

6.4 Discussion

The results from Round 3 of dynamic component testing are summarized in Table 19. In test no. MSSP-5, the asphalt mow strip cracked and fractured due to the combined loading of the dual S3x5.7 (S76x8.5) posts installed in 24-in. (610-mm) deep sockets. Recall, the 24-in. (610-mm) socket was successfully tested in a single post configuration in test no. MSSP-4 of Round 2 component testing. However, the addition of a second post produced excessive shear loads and mow strip failure. The fracture shape of the asphalt behind the socket and post assemblies was consistent with a shear block failure pattern. Essentially, loading two posts close together doubled the shear loads as compared to a single post, while the shear area behind the posts was only minimally increased. Similar block shear failure of the asphalt would be expected for this configuration if utilized in an actual barrier system installation. Thus, a stronger mow strip would be required to prevent damage observed in actual barrier installations.

In test no. MSSP-6, the concrete mow strip withstood the impact loads imparted by the dual S3x5.7 (S76x8.5) posts without sustaining any significant damage. The spalling that occurred on the backside of the leave-out holes was only cosmetic damage and did not affect the strength of the concrete mow strip.

Force vs. displacement and energy vs. displacement comparisons for both tests are shown in Figures 53 and 54, respectively. The resistance force curves between the two tests were similar in shape. However, the magnitude of the force curve from test no. MSSP-6 was higher due to the asphalt pavement fracture in test no. MSSP-5, which allowed the socket to rotate backward. As a result, the absorbed energy for the concrete mow strip configuration was higher than that of the asphalt mow strip configuration.

Table 19. Results Summary, Component Testing – Round 3

Test No.	Mow Strip		Posts	Socket Emb. Depth in. (mm)	Shear Plate	Impact Velocity mph (km/h)	Peak Force kips (kN)	Average Force kips (kN)		Total Energy Absorbed k-in. (kJ)	Mow Strip Damage
	Material	Thickness in. (mm)						@10”	@15”		
MSSP-5	Asphalt	4 (102)	Dual S3x5.7	24 (610)	Yes	18.6 (29.9)	27.3 (121.4)	17.2 (76.5)	14.4 (64.1)	227.9 (25.7)	Asphalt Cracking and Fracture
MSSP-6	Concrete	4 (102)	Dual S3x5.7	NA	No	20.1 (32.3)	28.3 (125.9)	19.4 (86.3)	15.2 (67.6)	249.3 (28.2)	Minor Concrete Spalling

*All tests conducted by impacting S3x5.7 (S76x8.5) posts at a height of 12 in. (305 mm).

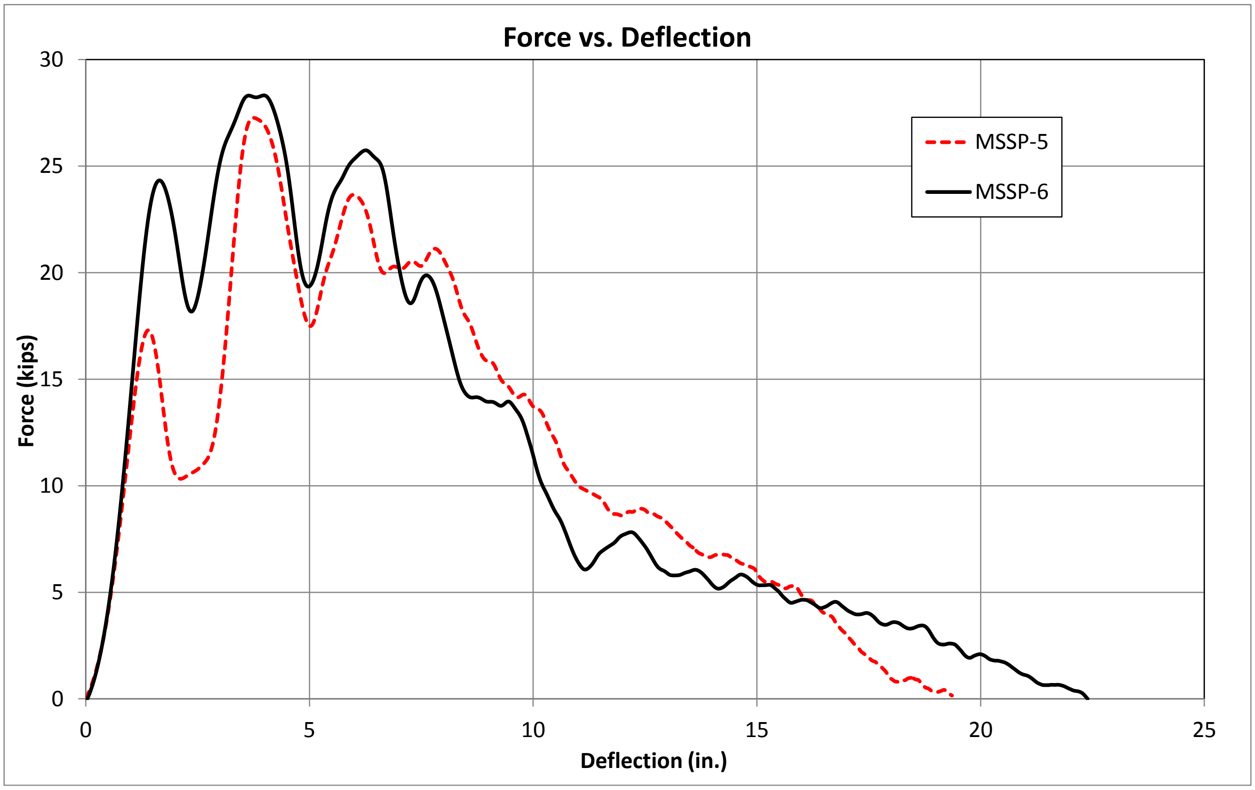


Figure 53. Force vs. Deflection Comparison, Component Testing - Round 3

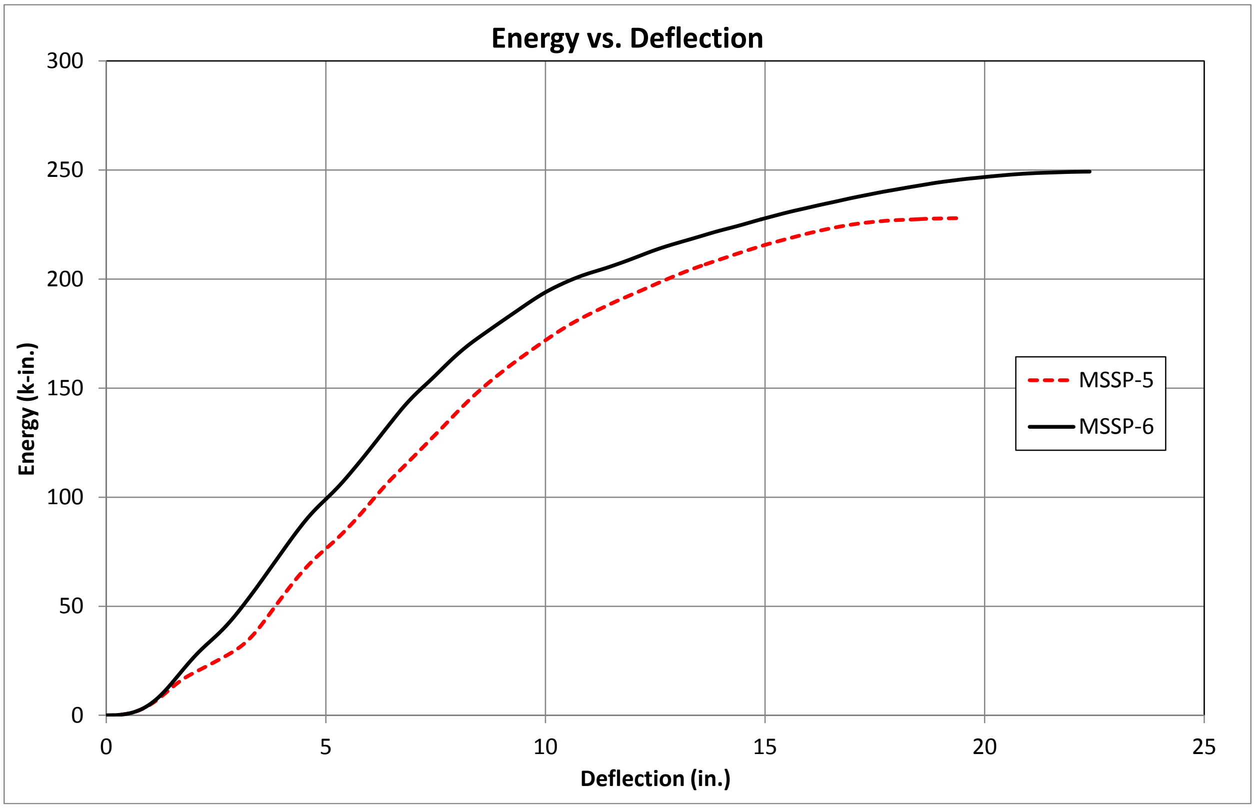


Figure 54. Energy vs. Deflection Comparison, Component Testing – Round 3

7 BARRIER DESIGN DETAILS

Component testing results illustrated that asphalt mow strips were susceptible to damage and shear fracture even when utilizing a 24-in. (610-mm) long steel socket with a backside shear plate to support the S3x5.7 (S76x8.5) guardrail posts. However, the project sponsors desired to continue testing with an asphalt mow strip due to the frequent use of asphalt mow strips. Three options were identified to strengthen the mow strip and reduce the impact loads to the mow strip: (1) increase the thickness of the mow strip; (2) increase the width of the mow strip; and (3) increase the embedment depth of the socket. After reviewing these options, the project sponsors elected to utilize both options 1 and 3. Thus, the thickness of the mow strip was increased to 6 in. (152 mm), and the embedment depth of the sockets was increased to 30 in. (762 mm).

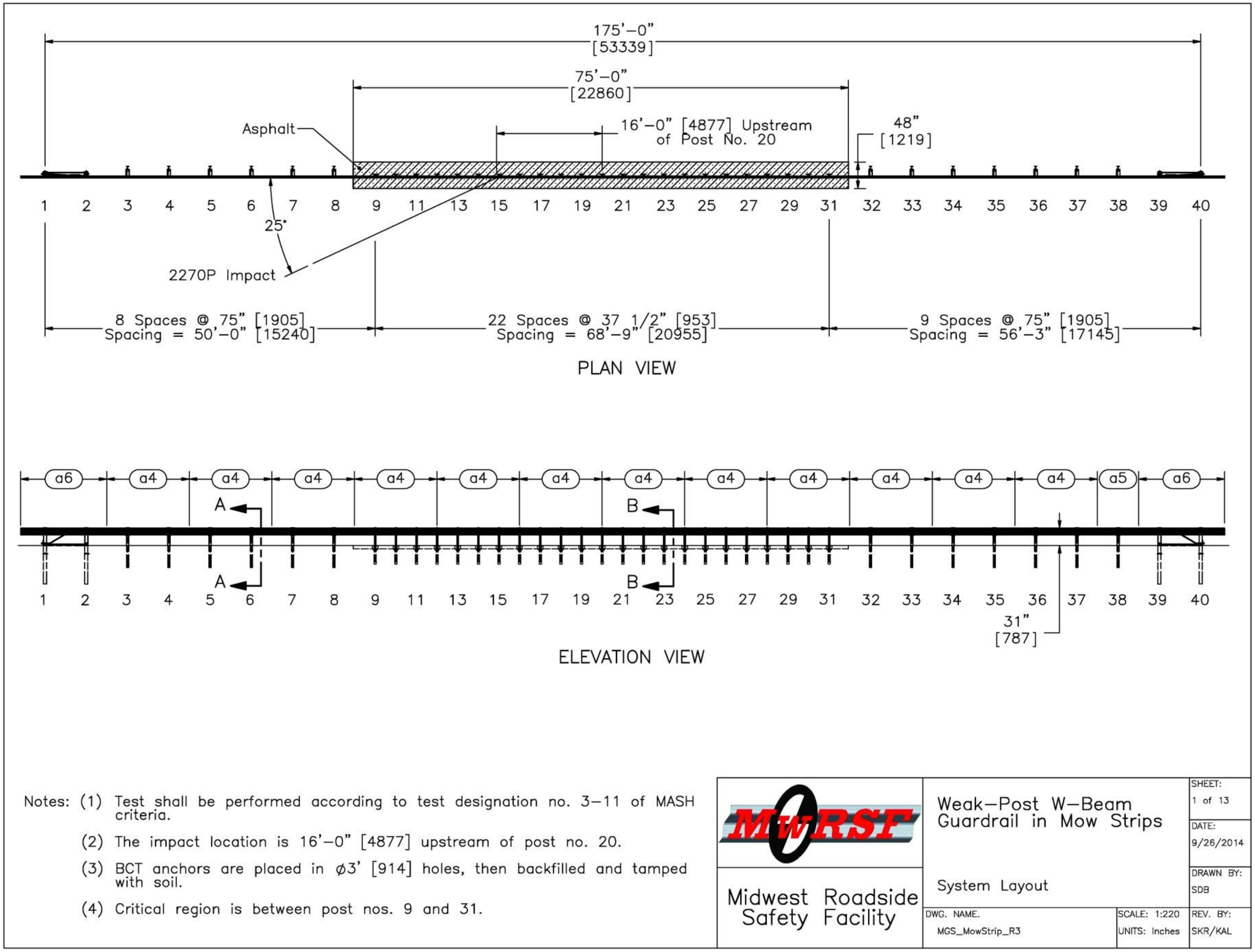
The weak-post guardrail test installation was 175 ft (53.3 m) long and consisted of W-beam guardrail, a combination of strong and weak guardrail posts, an asphalt mow strip, and guardrail end anchorage systems, as shown in Figures 55 through 67. Photographs of the test installation are shown in Figures 68 and 69. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix C.

The W-beam guardrail was mounted with a top-rail height of 31 in. (787 mm) throughout the entire system. The middle of the guardrail installation was constructed along the centerline of a 75-ft (22.9-m) long by 4-ft (1.2-m) wide by 6-in. (152-mm) thick asphalt mow strip. Within this region, the 12-ga (2.66-mm thick) W-beam guardrail was supported by 23 S3x5.7 (S76x8.5) weak posts spaced at 37.5 in. (953 mm) on center. The W-beam was connected to the weak posts utilizing $^{5}/_{16}$-in. (8-mm) diameter bolts and 1¾-in. x 1¾-in. (44-mm x 44-mm) square washers.

As utilized in the original weak-post MGS bridge rail system, 6-in. (152-mm) long backup plates were intended to be utilized between each weak post and the W-beam rail. However, an error in the design drawings resulted in specifying the 12-in. (305-mm) long backup plates previously used in the non-blocked MGS system [12]. Thus, the test installation was assembled utilizing the 12-in. (305-mm) long backup plates at weak post locations. Unfortunately, the 12-in. (305-mm) long backup plates do not fit within the 8-in. (203-mm) space between the bolts at W-beam rail splices. Therefore, weak posts that coincided with W-beam rail splice locations did not have backup plates.

Each weak post was inserted into a 4-in. x 4-in. x ¼-in. (102-mm x 102-mm x 6-mm) steel tube socket, which measured 30 in. (762 mm) long and had a 10-in. x 9-in. x ¼-in. (254-mm x 229-mm x 6-mm) shear plate welded to its backside. Steel plates were welded to the bottom of each socket to form a wedge, so that the socket could be installed by driving it through the asphalt pavement, similar to the previous component test installations. However, the additional pavement thickness, in combination with cooler temperatures, caused the asphalt pad to crack during the installation of the first two posts. Therefore, 3-in. (76-mm) diameter holes were cored in the asphalt prior to driving the remaining sockets to prevent any further damage during the installation of the system.

Standard MGS guardrail was placed directly upstream and downstream of the simulated asphalt mow strip. The MGS utilized W6x8.5 (W152x12.6) strong posts spaced at 75 in. (1,905 mm) on center. Standard 12-in. (305-mm) deep timber blockouts were utilized in the connection between the guardrail and the strong posts in these regions of the system. The ends of the installation consisted of guardrail trailing-end anchorage systems, as shown in Figures 57 through 62. This guardrail anchor was developed to simulate the strength of other crashworthy end terminals and was successfully crash tested to MASH TL-3 standards as a trailing-end anchor [13].



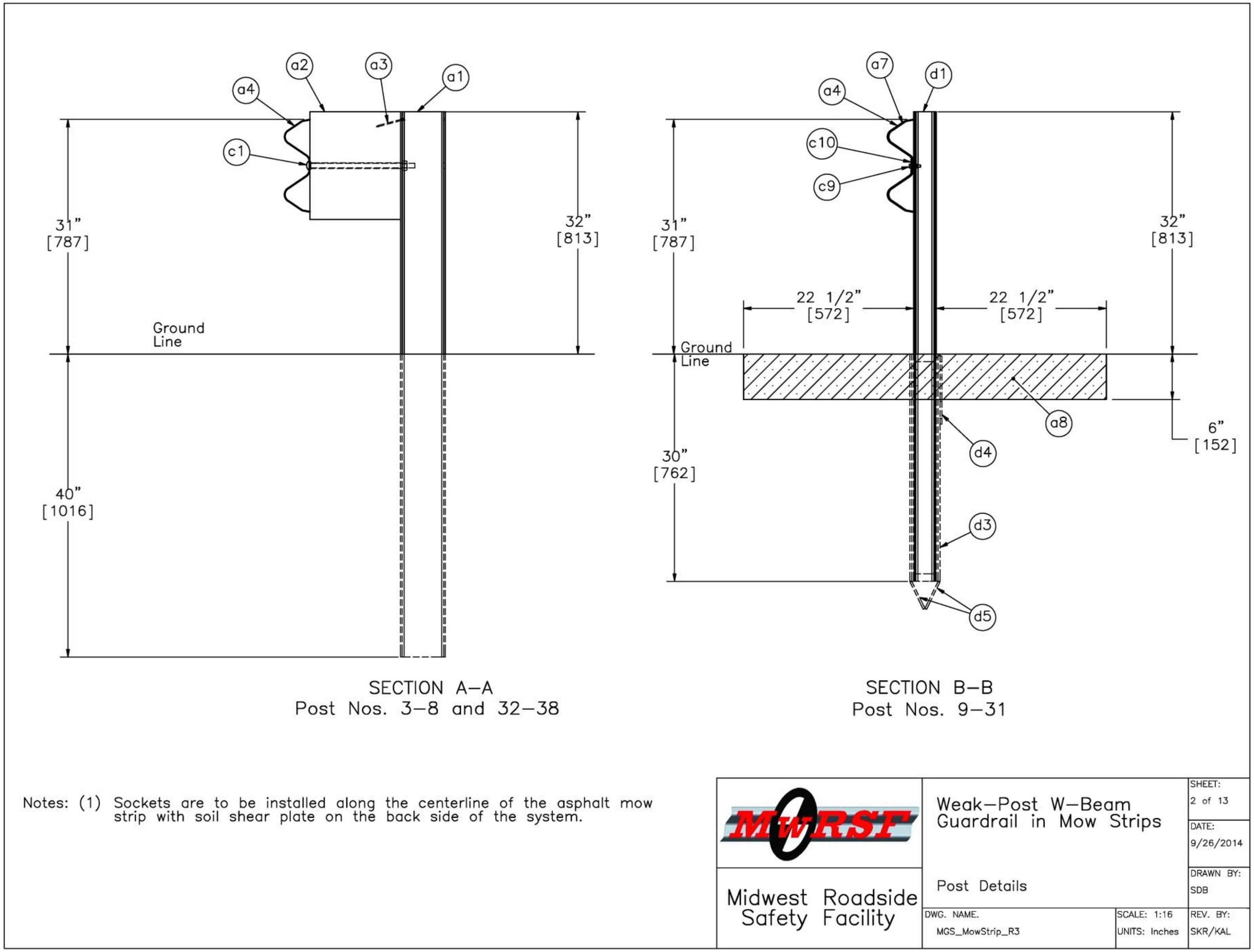
Notes: (1) Test shall be performed according to test designation no. 3–11 of MASH criteria.

(2) The impact location is 16'–0" [4877] upstream of post no. 20.

(3) BCT anchors are placed in ø3' [914] holes, then backfilled and tamped with soil.

(4) Critical region is between post nos. 9 and 31.

Figure 55. Test Installation Layout, Test No. MGSMS-1



Notes: (1) Sockets are to be installed along the centerline of the asphalt mow strip with soil shear plate on the back side of the system.

Figure 56. Guardrail Post Details, Test No. MGSMS-1

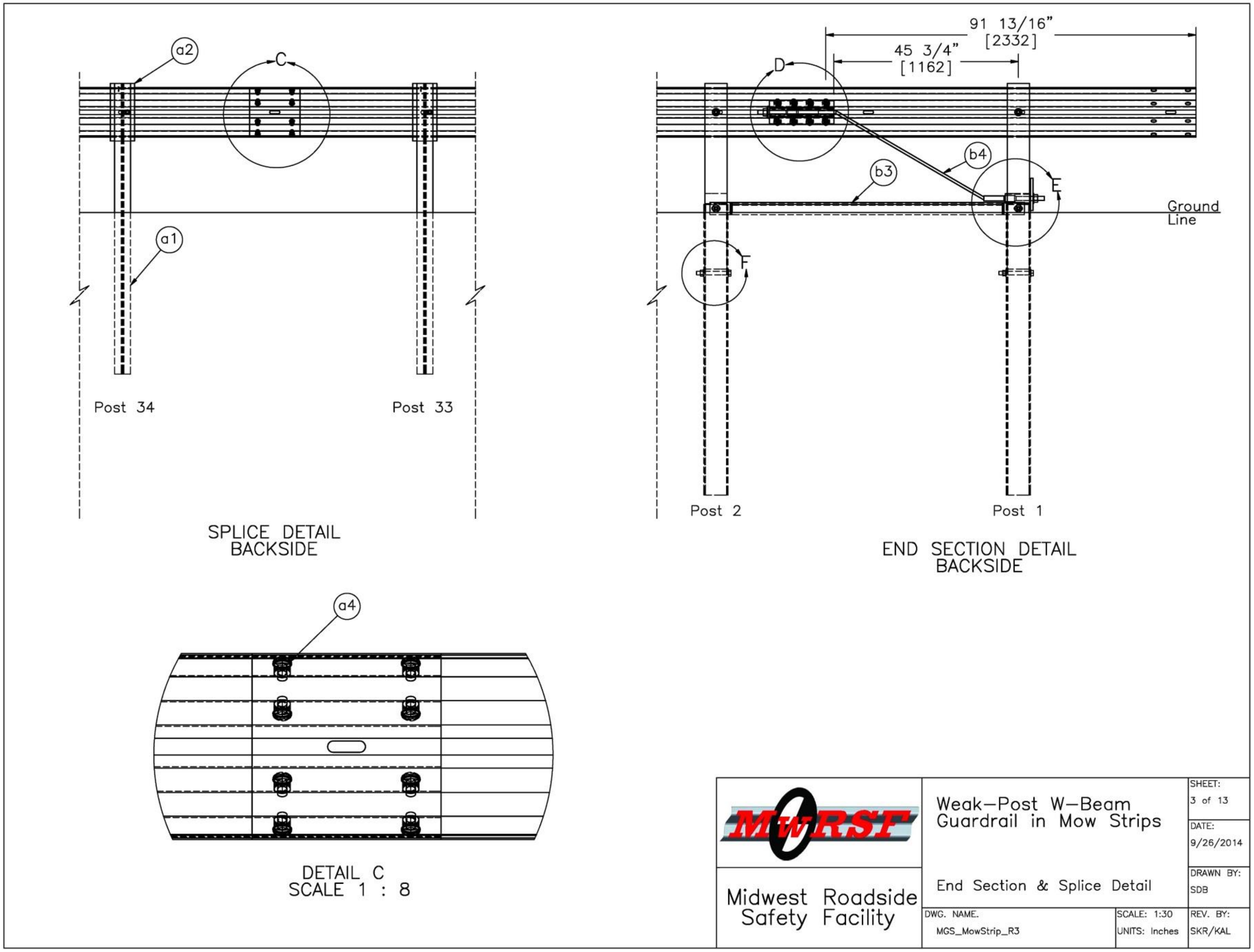


Figure 57. Anchorage and Splice Details, Test No. MGSMS-1

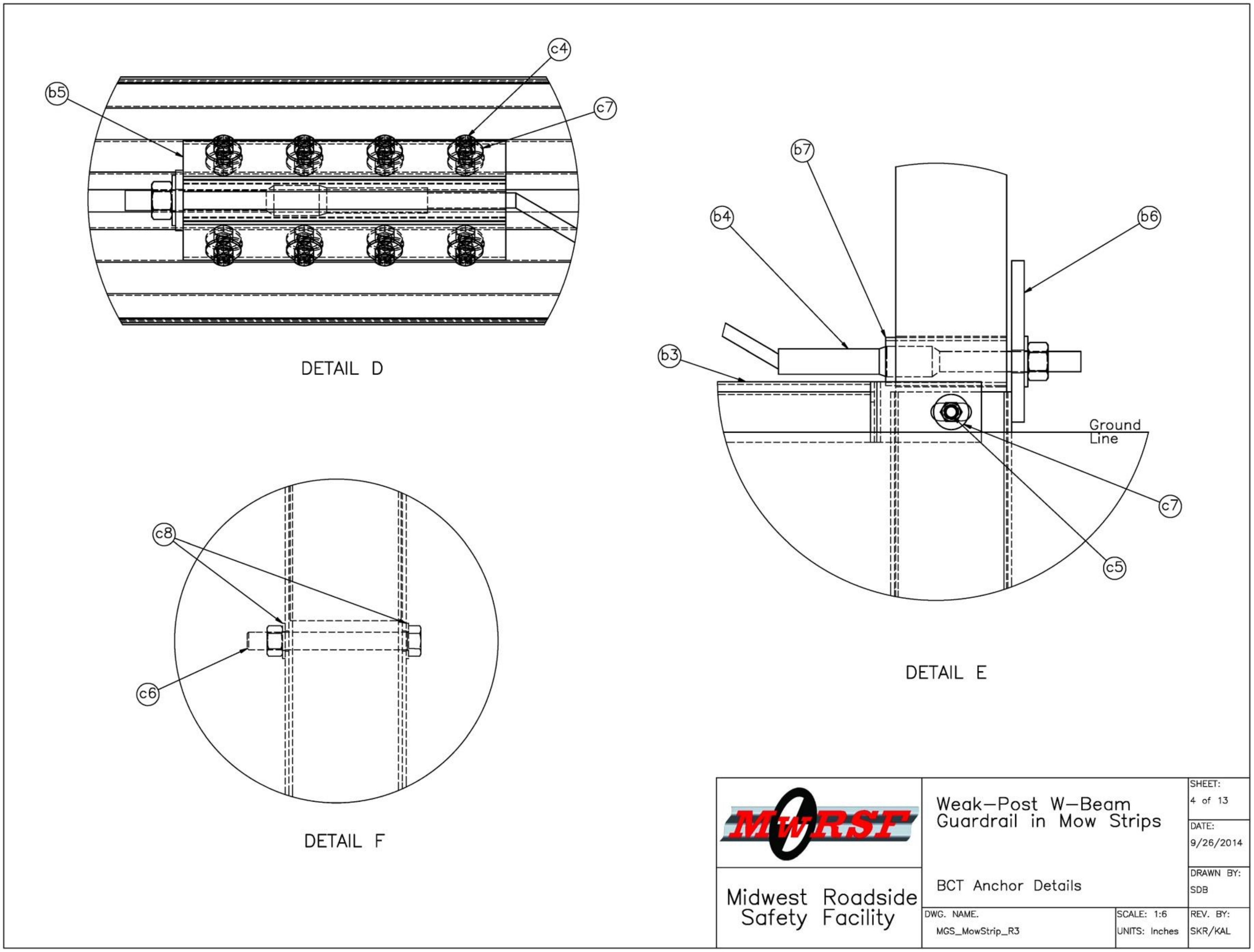


Figure 58. Anchorage Component Details, Test No. MGSMS-1

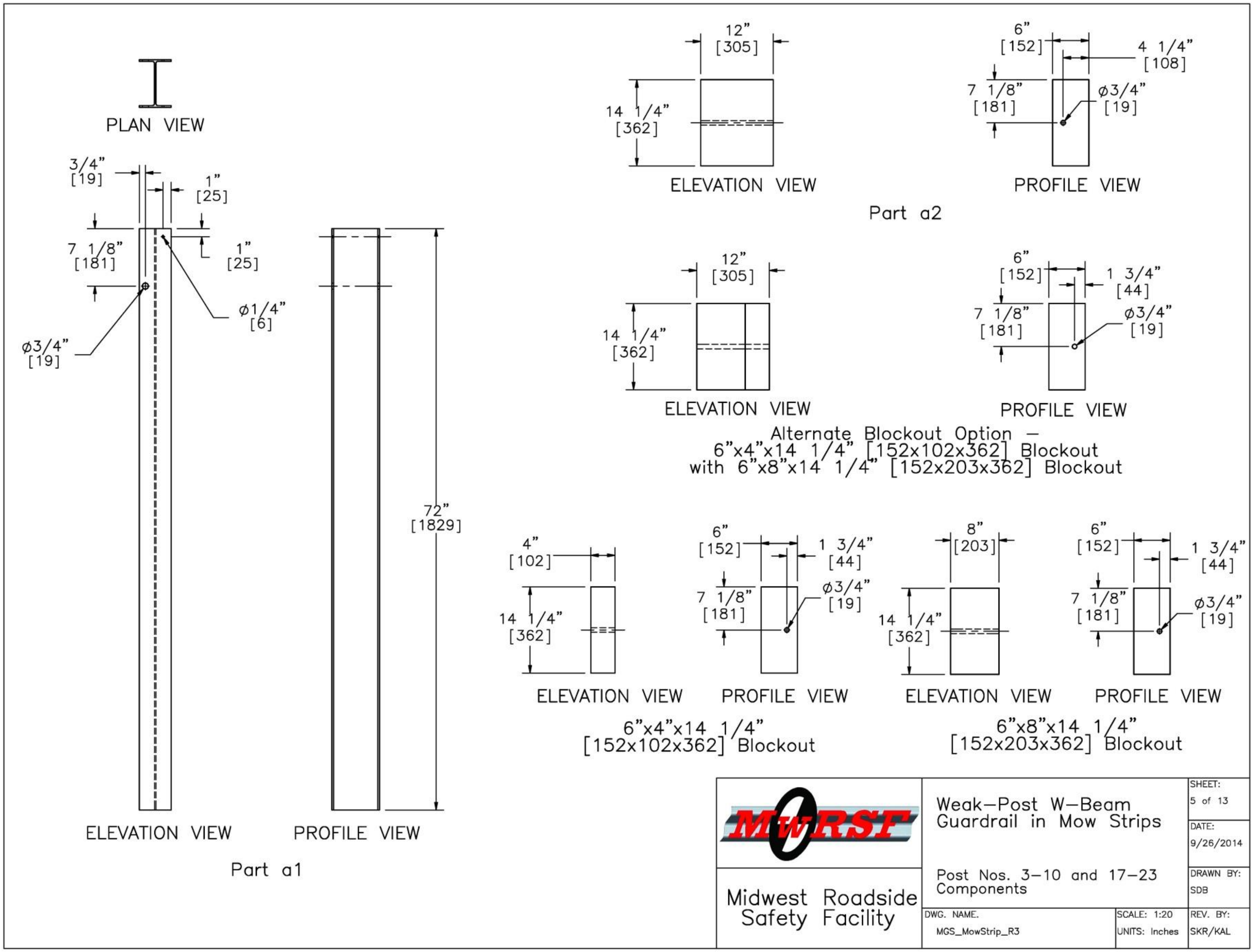


Figure 59. Post and Blockout Details, Test No. MGSMS-1

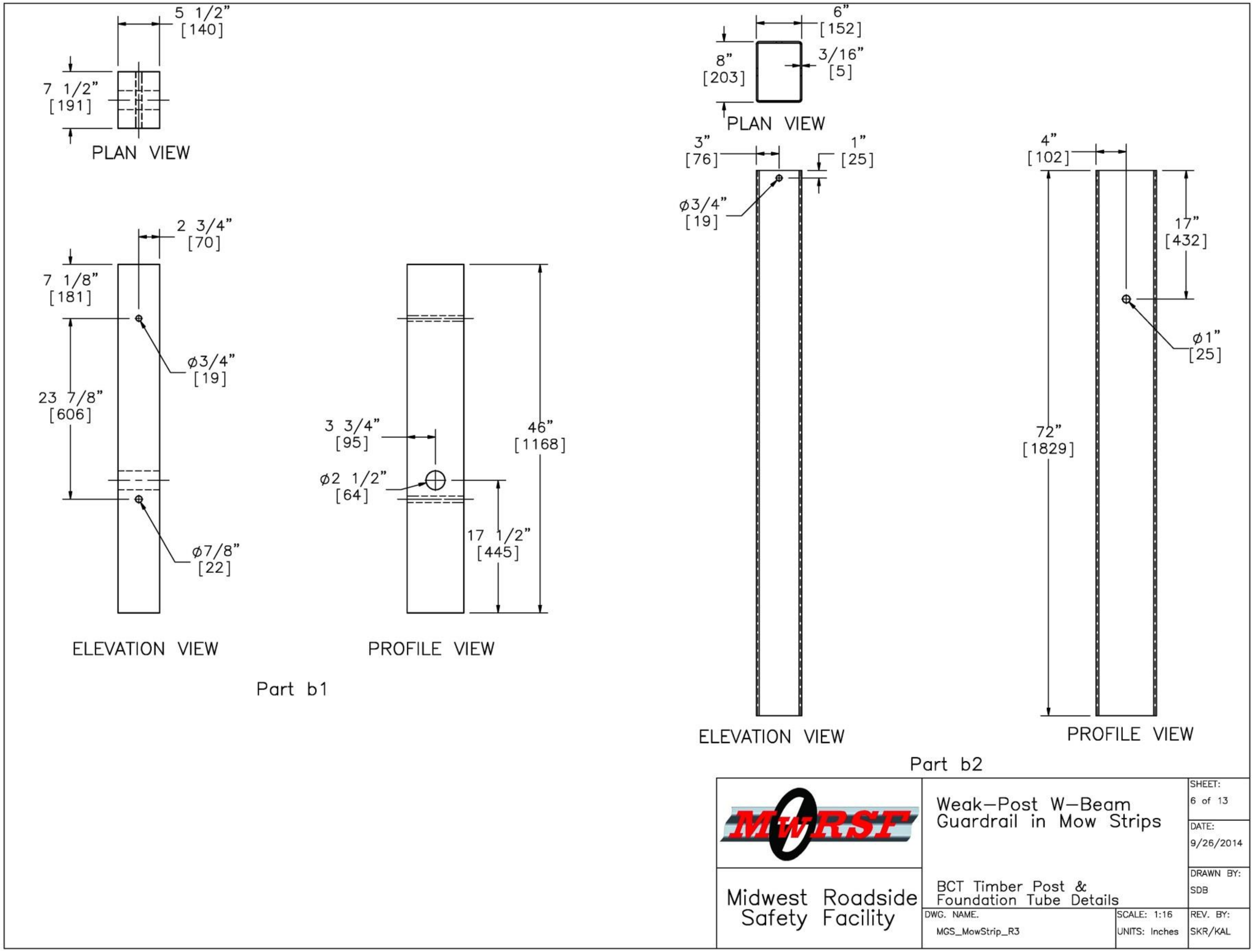


Figure 60. BCT Post and Foundation Tube Details, Test No. MGSMS-1

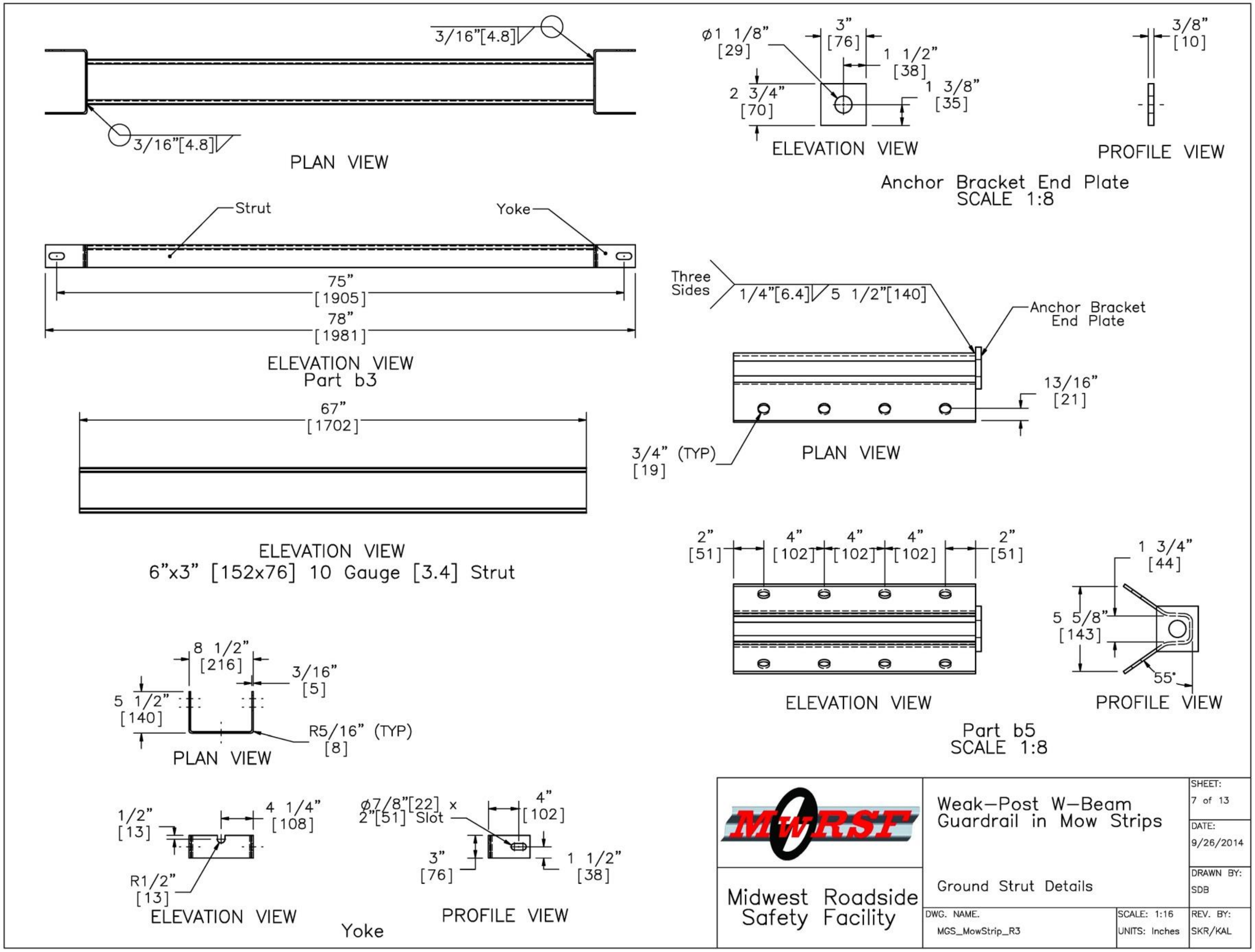


Figure 61. Anchorage Components Details, Test No. MGSMS-1

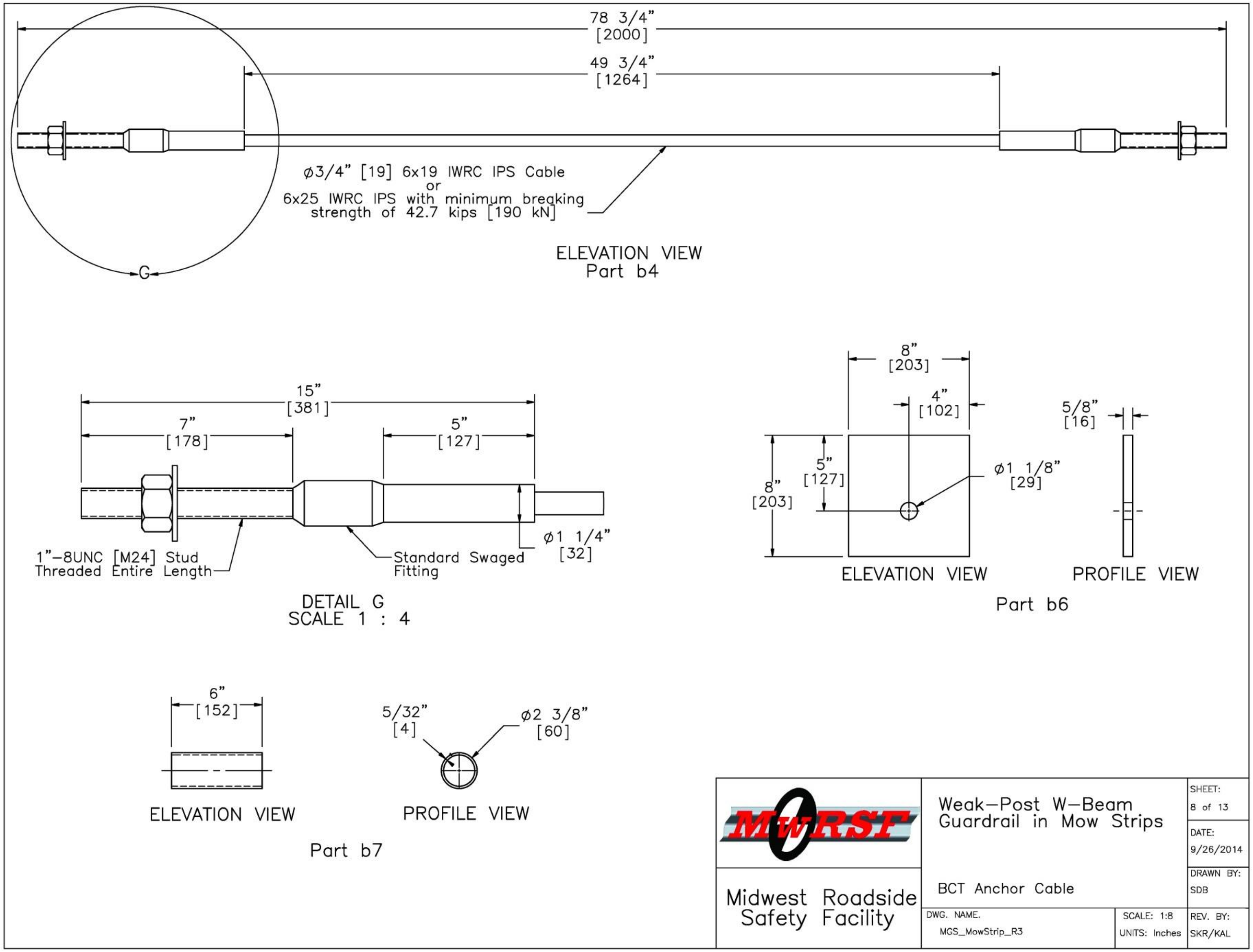


Figure 62. Cable Anchor Details, Test No. MGSMS-1

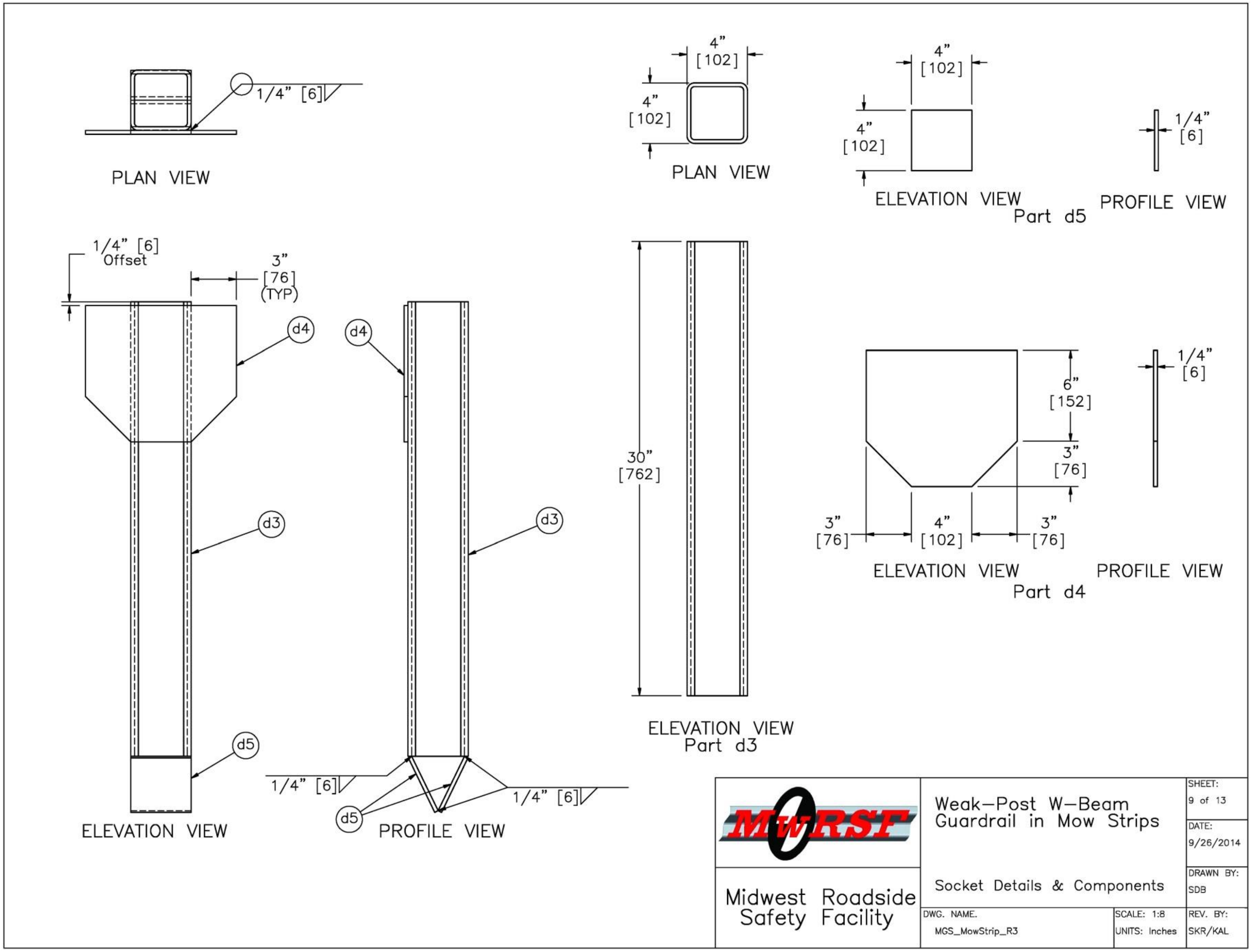


Figure 63. Post Socket Details, Test No. MGSMS-1

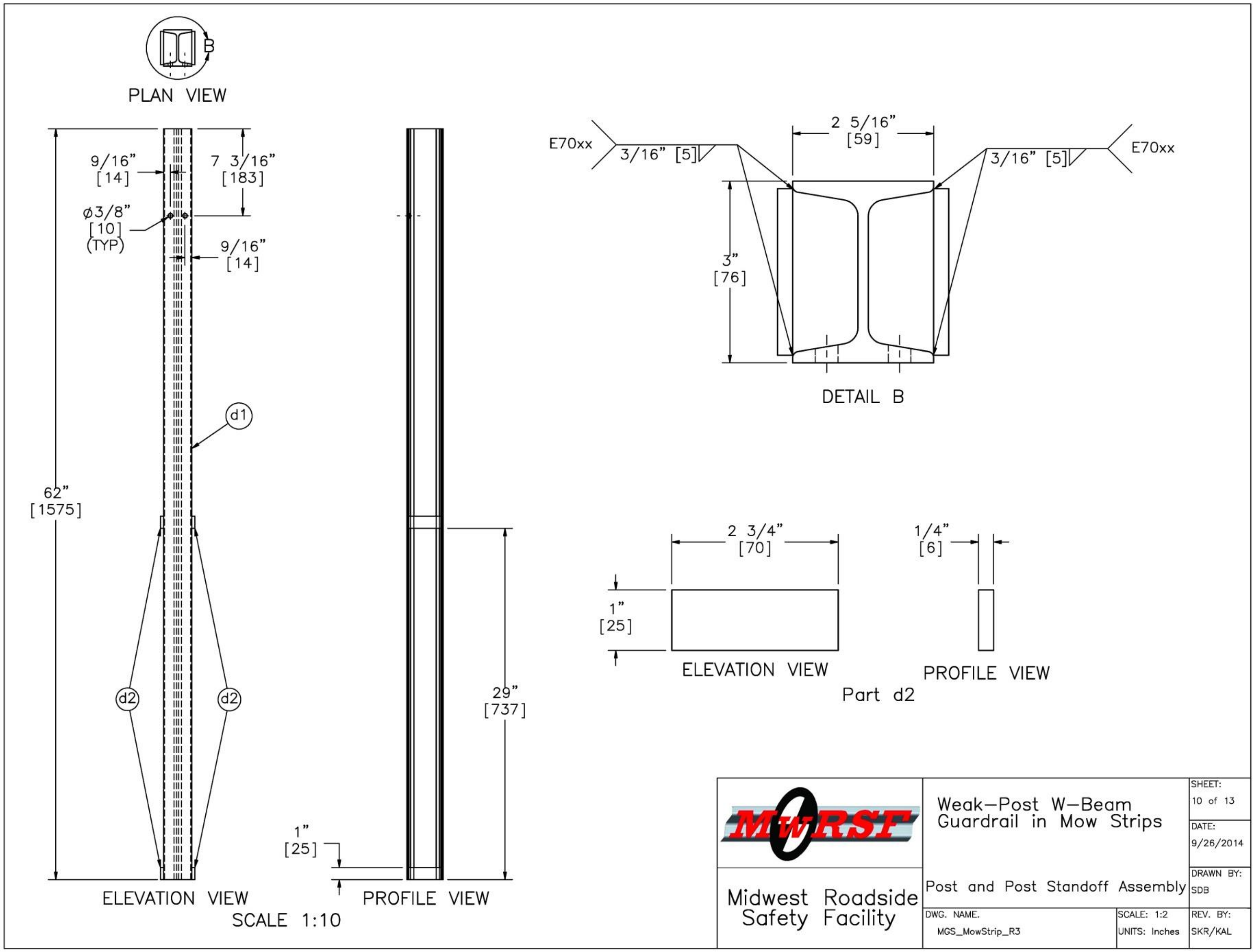


Figure 64. Weak-Post Details, Test No. MGSMS-1

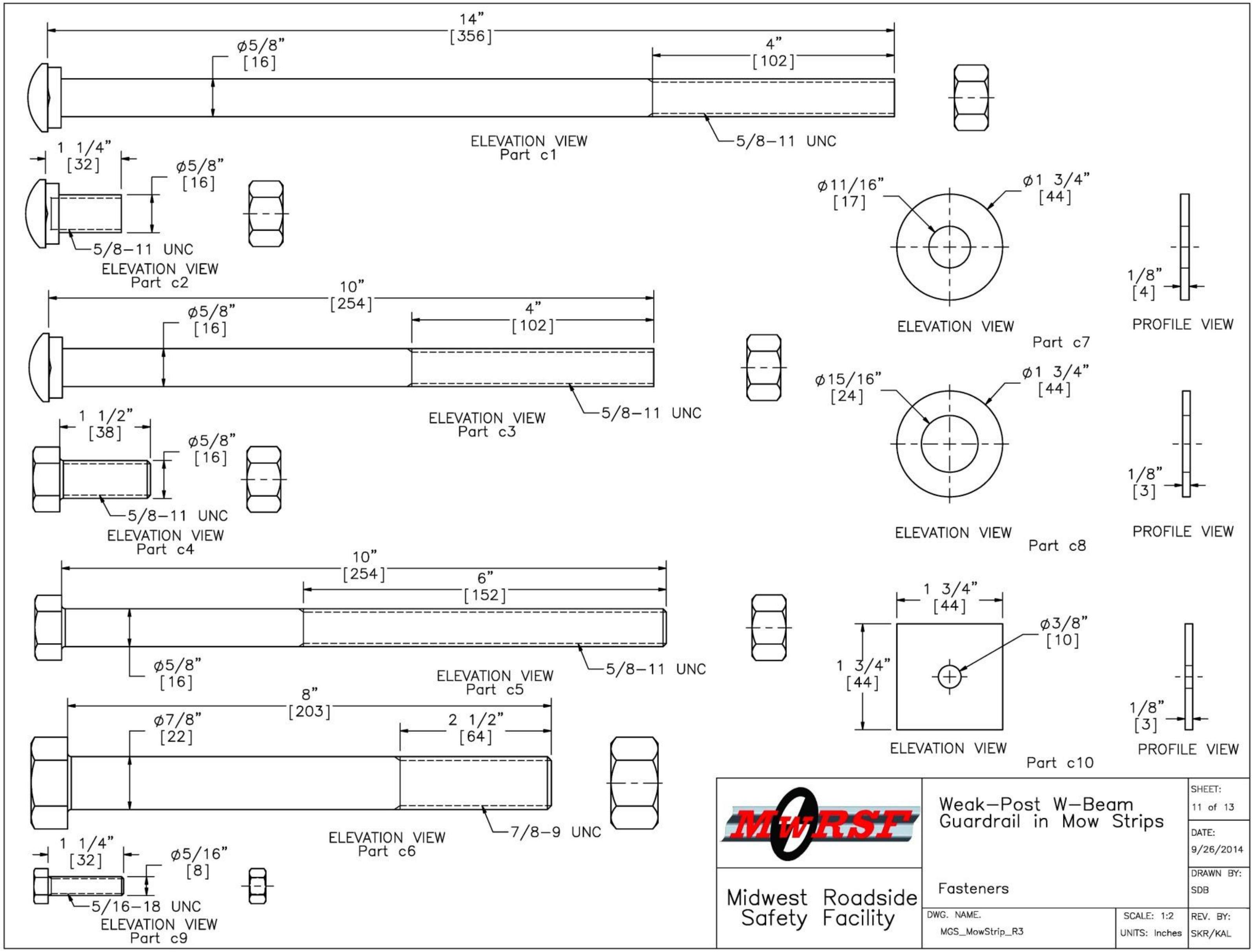


Figure 65. Attachment Hardware Details, Test No. MGSMS-1

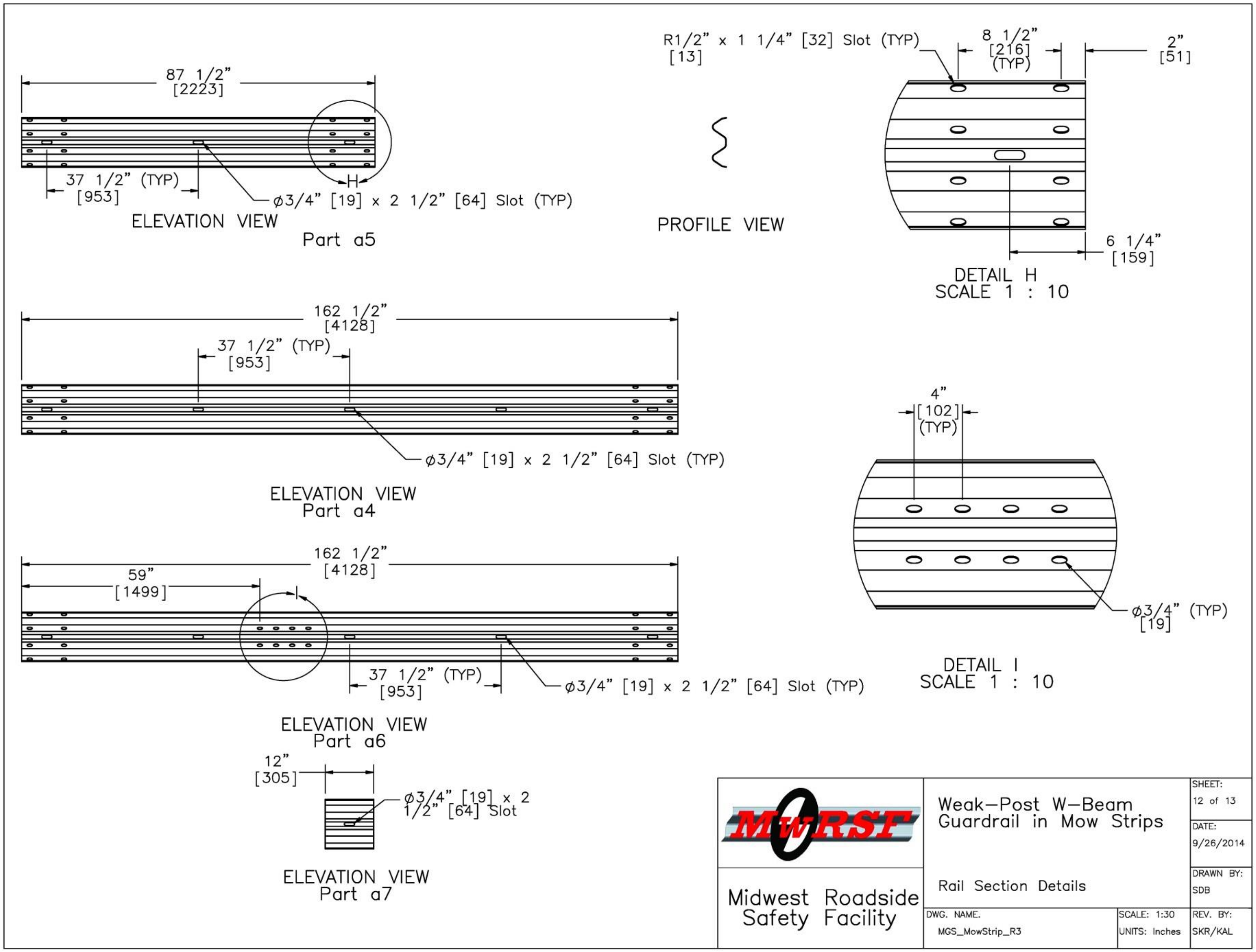


Figure 66. W-Beam Guardrail and Backup Plate Details, Test No. MGSMS-1

Item No.	QTY.	Description	Material Spec	Hardware Guide
a1	13	W6x8.5 [W152x12.6], 72" Long [1829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa] Steel Galv. or W6x9 [W152x13.4] ASTM A36 Min. 36 ksi [248 MPa] Steel Galv.	PWE06
a2	13	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No. 1 or better	PDB10a-b
a3	13	16D Double Head Nail	–	–
a4	12	12'-6" [3810] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv.	RWM08a
a5	1	6'-3" [1905] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv.	RWM01a
a6	2	12'-6" [3810] W-Beam MGS End Section	12 gauge [2.7] AASHTO M180 Galv.	RWM14a
a7	23	12" [305] W-Beam Backup Plate	12 gauge [2.7] AASHTO M180	RWB01a
a8	1	75'x4'x6" [22860x1219x152] Asphalt Mow Strip	52-34 Grade Binder	–
b1	4	BCT Timber Post - MGS Height	SYP Grade No. 1 or better (No knots, 18" [457] above or below ground tension face)	–
b2	4	72" [1829] Long Foundation Tube	ASTM A500 Grade B Galv.	PTE06
b3	2	Strut and Yoke Assembly	ASTM A36 Steel Galv.	–
b4	4	BCT Cable Anchor Assembly	ϕ3/4" [19] 6x19 IWRC IPS Galvanized Wire Rope or Equivalent	FCA01
b5	2	Anchor Bracket Assembly	ASTM A36 Steel Galv.	FPA01
b6	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel Galv.	FPB01
b7	2	2 3/8" [60] O.D. x 6" Long [152] BCT Post Sleeve	ASTM A53 Grade B Schedule 40 Galv.	FMM02
c1	13	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	FBB06
c10	23	1 3/4"x1 3/4"x1/8" [44x44x3] Square A36 Steel Washer	ASTM A36 Galvanized	RWR01
c2	112	5/8" [16] Dia. UNC, 1 1/4" [32] Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	FBB01
c3	4	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	FBB03
c4	16	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	FBX16a
c5	4	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 A Galv.	FBX16a
c6	4	7/8" [22] Dia. UNC, 8" [203] Long Hex Head Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBX20a
c7	44	5/8" [16] Dia. Plain Round Washer	ASTM F844 Galv.	FWC14a
c8	8	7/8" [22] Dia. Plain Round Washer	ASTM F844 Galv.	–
c9	23	5/16" [8] Dia. UNC, 1 1/4" [32] Long Hex Bolt and Nut	ASTM A307 Galvanized	FBX08a
d1	23	S3x5.7 [S76x8.5] by 62" [1575] Long Steel Post	ASTM A992 Grade 50 Steel Galvanized	–
d2	92	2 3/4"x1"x1/4" [70x25x6] Post Standoff	ASTM A36 Steel Galvanized	–
d3	23	4"x4"x3/8" [102x102x10] Square Socket, 30" [762] Long	ASTM A500 Grade B Steel Galvanized	–
d4	23	10"x9"x1/4" [254x229x6] Steel Soil Plate	ASTM A572 Grade 50 Steel Galvanized	–
d5	46	4"x4"x1/4" [102x102x6] Steel Plate	ASTM A572 Grade 50 Steel Galvanized	–

MwRSF
Midwest Roadside Safety Facility

Weak-Post W-Beam Guardrail in Mow Strips

Bill of Materials

SHEET: 13 of 13
DATE: 9/26/2014
DRAWN BY: SDB
DWG. NAME. MGS_MowStrip_R3
SCALE: None
UNITS: Inches
REV. BY: SKR/KAL

Figure 67. Bill of Materials, Test No. MGSMS-1

Figure 68. Test Installation Photographs, Test No. MGSMS-1

Figure 69. Test Installation Photographs, Test No. MGSMS-1

8 TEST REQUIREMENTS AND EVALUATION CRITERIA

8.1 Test Requirements

Longitudinal barriers, such as W-beam guardrails, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH [9]. According to TL-3 of MASH, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 20.

Table 20. MASH TL-3 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed, mph (km/h)	Angle, deg.	
Longitudinal Barrier	3-10	1100C	2,425 (1,100)	62 (100)	25	A,D,F,H,I
	3-11	2270P	5,000 (2,270)	62 (100)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 21.

Prior research has shown successful safety performance for small cars impacting the original weak-post MGS bridge rail system from which this guardrail system was adapted [7-8]. The MASH 3-10 small car test conducted on the MGS bridge rail system did not show potential for any occupant risk problems arising from vehicle pocketing, wheel snagging on the guardrail posts, occupant compartment penetration, potential for rail rupture, or vehicular instabilities due to vaulting or climbing the rail. Additionally, the MASH 3-11 pickup truck test imparted significantly greater impact loads and higher displacements to the system compared to the 1100C test. Since the current project sought to develop proper attachment of the weak-post system to prevent damage to mow strips, the 2270P test was identified as the critical test in the system evaluation. Therefore, the 1100C small car test, MASH test designation no. 3-10, was deemed unnecessary for evaluation of the weak-post guardrail system in mow strips.

8.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy, (2) occupant risk, and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the guardrail system to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 21 and are defined in greater detail in MASH. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in MASH.

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), and the Acceleration Severity Index (ASI) were determined and reported on the test summary sheet. Additional discussion on PHD, THIV, and ASI is provided in MASH.

8.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil-dependent system, additional W6x16 (W152x23.8) posts are to be installed near the impact region utilizing the same installation procedures as the system itself. Prior to full-scale crash testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of

7.5 kips (33.4 kN) at post deflections between 5 and 20 in. (127 and 508 mm) measured at a height of 25 in. (635 mm). If dynamic testing near the system is not desired, MASH permits a static test to be conducted instead and compared against the results of a previously-established baseline test. In this situation, the soil must provide a resistance of at least 90 percent of the static baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Further details can be found in Appendix B of MASH.

Table 21. MASH Evaluation Criteria for Longitudinal Barriers

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">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></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></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>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

9 TEST CONDITIONS

9.1 Test Facility

The testing facility was located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles (8.0 km) northwest of the University of Nebraska-Lincoln city campus.

9.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half those of the test vehicle. The test vehicle was released from the tow cable before impact with the barrier system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch [14] was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

9.3 Test Vehicles

For test no. MGSMS-1, a 2007 Dodge Ram 1500 was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,225 lb (2,371 kg), 5,016 lb (2,275 kg), and 5,182 lb (2,351 kg), respectively. The test vehicle is shown in Figure 70, and vehicle dimensions are shown in Figure 71.

Figure 70. Test Vehicle, Test No. MGSMS-1

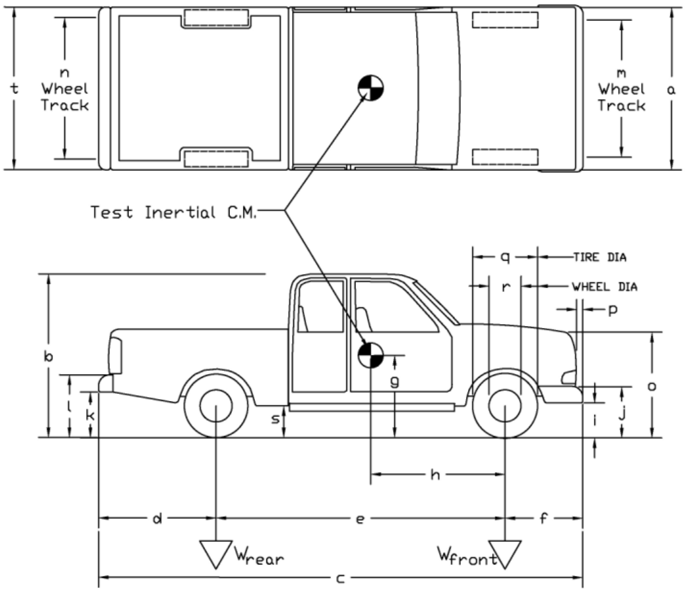
Date: 12/16/2014 **Test Number:** MGSMS-1 **Model:** Ram 1500

Make: Dodge **Vehicle I.D.#:** 1D7HA18267S249208

Tire Size: 275/60/20 **Year:** 2007 **Odometer:** 161253

Tire Inflation Pressure: 35 psi

***(All Measurements Refer to Impacting Side)**



Vehicle Geometry -- in. (mm)

a	78	(1981)	b	75 1/2	(1918)
c	227 1/4	(5772)	d	46 3/4	(1187)
e	140 1/2	(3569)	f	40	(1016)
g	29 3/8	(746)	h	61 4/5	(1569)
i	16 1/4	(413)	j	30	(762)
k	21 1/2	(546)	l	29 1/2	(749)
m	68 1/2	(1740)	n	68 1/4	(1734)
o	46	(1168)	p	3	(76)
q	32 1/2	(826)	r	21 1/2	(546)
s	16	(406)	t	75 1/4	(1911)

Wheel Center Height Front	15 3/8	(391)
Wheel Center Height Rear	15 1/8	(384)
Wheel Well Clearance (F)	36 1/4	(921)
Wheel Well Clearance (R)	38 3/4	(984)
Frame Height (F)	19 1/8	(486)
Frame Height (R)	25 3/4	(654)

Engine Type Gasoline

Engine Size 5.7L

Transmition Type:

[✓ Automatic] Manual

FWD [✓ RWD] 4WD

Mass Distribution lb (kg)

Gross Static	LF	1453 (659)	RF	1459 (662)
	LR	1111 (504)	RR	1159 (526)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2904 (1317)	2810 (1275)	2912 (1321)
W-rear	2324 (1054)	2206 (1001)	2270 (1030)
W-total	5228 (2371)	5016 (2275)	5182 (2351)

GVWR Ratings

Front 3700 lb
Rear 3900lb
Total 6700 lb

Dummy Data

Type: Hybrid II
Mass: 166 lbs
Seat Position: Passenger side

Note any damage prior to test: lower passenger side rear door and box side dent and scrape

Figure 71. Vehicle Dimensions, Test No. MGSMS-1

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [15] was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The location of the final c.g. is shown in Figures 71 and 72. Data used to calculate the location of the c.g. and ballast information are shown in Appendix D.

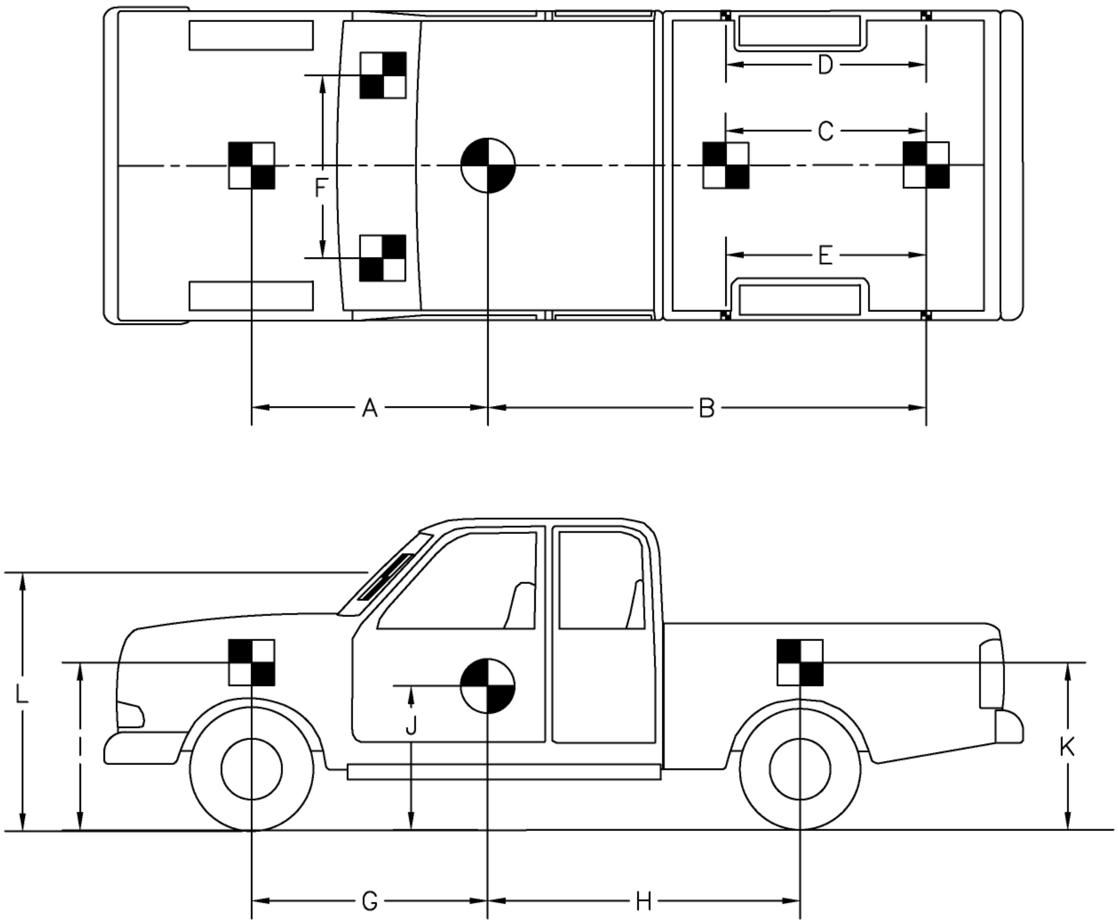
Square, black- and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figure 72. Round, checkered targets were placed on the center of gravity on the left-side door, the right-side door, and the roof of the vehicle.

The front wheels of the test vehicle were aligned to vehicle standards, except the toe-in value was adjusted to zero so that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted on the left side of the vehicle’s dash and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed videos. A remote-controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

9.4 Simulated Occupant

For test no MGSMS-1, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the right-front seat of the test vehicle with the seat belt fastened. The dummy, which had a final weight of 166 lb (75 kg), was represented by model no.

572, serial no. 451, and was manufactured by Android Systems of Carson, California. As recommended by MASH, the dummy was not included in calculating the c.g location.



TEST #: MGSMS-1

TARGET GEOMETRY-- in. (mm)

A	**73**	**(1854)**	**E**	**64**	**(1626)**	**I**	**40 1/2**	**(1029)**
B	**96 3/4**	**(2457)**	**F**	**43**	**(1092)**	**J**	**29 3/8**	**(746)**
C	**31 3/8**	**(797)**	**G**	**61 7/8**	**(1572)**	**K**	**43**	**(1092)**
D	**64**	**(1626)**	**H**	**78 5/8**	**(1997)**	**L**	**63 7/8**	**(1622)**

Figure 72. Target Geometry, Test No. MGSMS-1

9.5 Data Acquisition Systems

9.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. All of the accelerometers were mounted near the center of gravity of the test vehicle. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filters conforming to SAE J211/1 specifications [10].

The primary accelerometer system, the DTS unit, was a two-arm piezoresistive accelerometer system manufactured by Endevco. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. The accelerometers were configured and controlled using a system developed and manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. More specifically, data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M. The SIM was configured with 16 MB SRAM and eight sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were crashworthy. The “DTS TDAS Control” computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The secondary accelerometer system, the SLICE-2 unit, was a modular data acquisition system manufactured by DTS. The acceleration sensors were mounted inside the body of a custom-built SLICE 6DX event data recorder and recorded data at 10,000 Hz to the onboard microprocessor. The SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g’s, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter.

The “SLICEWare” computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

9.5.2 Rate Transducers

The primary angle rate sensor, the ARS-1500, with a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) was used to measure the rates of rotation of the test vehicles. The angular-rate sensor was mounted on an aluminum block inside the test vehicle near the center of gravity and recorded data at 10,000 Hz to the DTS SIM. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The “DTS TDAS Control” computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

A secondary angle rate sensor system used to measure the rates of rotation of the test vehicle was mounted inside the body of the SLICE-2. Each SLICE MICRO Triax ARS had a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the onboard microprocessor. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The “SLICEWare” computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

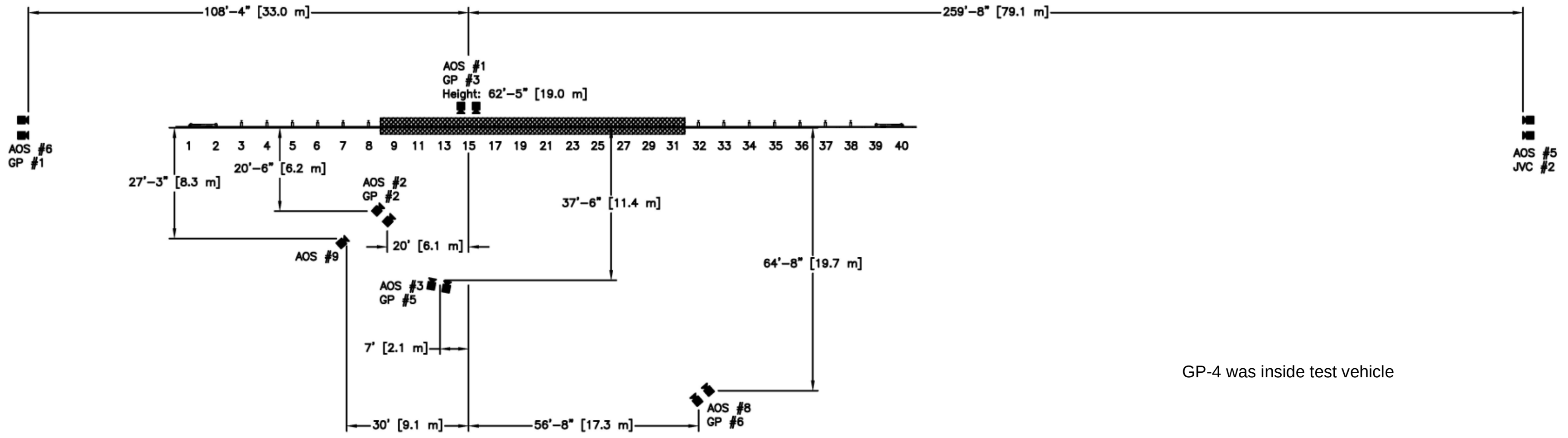
9.5.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the test vehicle before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the vehicle. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box activating the LED flashes. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

9.5.4 Digital Photography

Seven AOS high-speed digital video cameras, six GoPro digital video cameras, and one JVC digital video camera were utilized to film test no. MGSMS-1. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 73.

The high-speed videos were analyzed using ImageExpress MotionPlus and RedLake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A Nikon D50 digital still camera was used to document pre- and post-test conditions.



GP-4 was inside test vehicle

No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS Vitcam CTM	500	Cosmicar 12.5 mm Fixed	12.5
AOS-2	AOS Vitcam CTM	500	Sigma 28-70 mm	35
AOS-3	AOS Vitcam CTM	500	Sigma 50 mm Fixed	50
AOS-5	AOS X-PRI Gigabit	500	Cannon TV Zoom 17-102 mm	102
AOS-6	AOS X-PRI Gigabit	500	Fujinon 50 mm Fixed	50
AOS-8	AOS S-VIT 1531	500	Sigma 28-70 mm	50
AOS-9	AOS TRI-VIT	500	Sigma 24-135 mm	135
GP-1	GoPro Hero 3	120		
GP-2	GoPro Hero 3	120		
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		

Figure 73. Camera Locations, Speeds, and Lens Settings, Test No. MGSMS-1

10 FULL-SCALE CRASH TEST NO. MGSMS-1

10.1 Static Soil Test

Before full-scale crash test no. MGSMS-1 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix E, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

10.2 Test No. MGSMS-1

The 5,182-lb (2,351-kg) pickup truck impacted the weak-post guardrail system at a speed of 63.0 mph (101.4 km/h) and an angle of 25.2 degrees. A summary of the test results and sequential photographs are shown in Figure 74. Additional sequential photographs are shown in Figures 75 through 78. Documentary photographs of the crash test are shown in Figure 79.

10.3 Weather Conditions

Test no. MGSMS-1 was conducted on December 5, 2014 at approximately 2:00 p.m. The weather conditions, as per the National Oceanic and Atmospheric Administration (station 14939/LNK), were reported and are shown in Table 22.

Table 22. Weather Conditions, Test No. MGSMS-1

Temperature	52° F
Humidity	61%
Wind Speed	3 mph
Wind Direction	30° from True North
Sky Conditions	Sunny
Visibility	5.0 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.0 in.
Previous 7-Day Precipitation	0.0 in.

10.4 Test Description

Initial vehicle impact was to occur 16 ft (4.9 m) upstream from the rail splice at post no. 20, as shown in Figure 80, which was selected using the CIP plots found in Section 2.3 of MASH to maximize loading at a splice and the probability of wheel snag. The actual point of impact was 1 in. (25 mm) downstream from the targeted impact point. A sequential description of the impact events is contained in Table 23. The vehicle came to rest 119.8 ft (36.5 m) downstream from the point of impact and 3.8 ft (1.2 m) in front of the system. The vehicle trajectory and final position are shown in Figures 74 and 81.

Table 23. Sequential Description of Impact Events, Test No. MGSMS-1

TIME (sec)	EVENT
0.000	The vehicle impacted the barrier 3½ in. upstream from post no. 15.
0.004	Post no. 15 began to deflect backward, and the right side of the bumper began to deform.
0.008	Post nos. 14 and 16 began to deflect backward, and the right-front fender contacted the rail.
0.012	Post nos. 13 and 17 began to deflect backward, and the right headlight deformed.
0.016	Post nos. 18 – 21 deflected backward.
0.018	The rail began to flatten between post nos. 15 and 16.
0.024	Post no. 22 began to deflect backward.
0.030	Post no. 23 began to deflect backward.
0.038	Vehicle hood began to deform.
0.042	Right-front tire contacted post no. 16, causing the rail to release from post no. 16.
0.050	Asphalt cracks formed around post no. 16, and the asphalt began to shift backward.
0.056	The rail released from post nos. 15 and 17.
0.058	The vehicle began to yaw away from the system.
0.064	The rail released from post no. 18.
0.070	Right-front tire overrode post no. 16, and the vehicle began to roll toward the system.
0.074	Right-front tire contacted post no. 17, and asphalt cracks were visible between post nos. 15 and 19.
0.084	The right headlight became detached.

0.100	Right-front tire contacted post no. 18, and the rail released from post no. 19.
0.122	Right-front tire contacted post no. 19.
0.128	The rail released from post no. 20, and the right-front tire deflated.
0.136	Soil heaves were visible behind the system as the asphalt shifted backward.
0.142	Asphalt cracking was visible between post nos. 14 and 22.
0.164	Front bumper contacted post no. 20.
0.172	The rail released from post no. 21.
0.180	Right-rear tire contacted post no. 16.
0.192	The right-rear quarter panel contacted the rail between post nos. 15 and 16.
0.196	The rail released form post no. 22.
0.244	Right-rear tire contacted post no. 17.
0.252	Right-front tire contacted post no. 21.
0.278	The vehicle was parallel to the system.
0.286	Right-front tire contacted post no. 22.
0.290	Right-front tire became airborne.
0.298	The rail released from post no. 23.
0.328	The right-front tire contacted post no. 23, and the right-rear tire contacted post no. 19.
0.340	The vehicle reached its maximum lateral deflection into the barrier.
0.368	Vehicle began to roll away from the system.
0.376	Right-front tire contacted post no. 24, causing the rail to release.
0.390	The vehicle began to yaw back toward the system.
0.422	Left-front tire regained contact with the ground.
0.668	The vehicle exited the system at a speed of 34 mph and at angle of 9.7 degrees.
0.786	The vehicle was again parallel with the system.
1.070	Left-front tire deflated.
1.742	A secondary impact occurred as the right-front fender contacted the rail upstream from post no. 39.

10.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 82 through 88. Barrier damage consisted of guardrail bending and tearing, post bending, asphalt cracking and displacement, socket displacement, and contact marks on the guardrail and posts. The length of vehicle contact along the barrier was approximately 37 ft (11.3 m), which spanned from 4 in. (102 mm) upstream from post no. 15 to 10 in. (254 mm) upstream from post no. 27. A secondary impact resulted in only minor deformations to the rail and posts and had a contact length of 8 ft (2.4 m), spanning from 16 in. (406 mm) downstream from post no. 37 to the splice between post nos. 38 and 39.

The W-beam guardrail displaced backward and had various bends, kinks, and scrapes between post nos. 13 and 29. The bottom of the guardrail was flattened between post nos. 15 and 22 and had a 10-in. (254-mm) long vertical tear in the downstream guardrail segment at the splice at post no. 20. The tear began at the bottom of the rail, extended vertically through the slot for the bottom downstream splice bolt, and continued upward and downstream until it terminated in the middle of the rail, as shown in Figure 88. All splice locations were measured before and after the test. The maximum splice movement of ⅝ in. (16 mm) was recorded at two adjacent splices in the contact region, which were located at post nos. 16 and 20. The rail and backup plates disengaged from post nos. 11 and 15 through 27. The detached backup plates were scattered behind the guardrail system. Only two of the plates traveled further than 15 ft (4.6 m) from the system, with the furthest found 25 ft (7.6 m) behind the guardrail system.

Nearly all of the posts outside of the contacted area were twisted and/or bent toward impact region. The upstream anchor post had a ¼-in. (6-mm) soil gap on the upstream side of the post. Post nos. 13 through 15 and 27 were bent backward slightly, due to the lateral force on the rail. Post nos. 16 through 26 were all severely bent and twisted from direct vehicle contact during the impact event. Tears were found in various flanges of post nos. 16 through 21 due to bending and contact with the top of the sockets.

The asphalt mow strip was cracked and fractured down its centerline between post nos. 11 and 30, over a total length of 60 ft (18.3 m). The cracking was indicative of a shear block failure in the asphalt as it ran along the backside shear plates of each socket. The crack had a maximum opening width of 2½ in. (64 mm) between post nos. 22 and 23 and steadily decreased to hairline cracks at its ends. The asphalt behind the fracture shifted laterally and caused the soil to heave behind the asphalt between post nos. 16 through 26. Additionally, the asphalt cracking allowed the sockets to translate and rotate backward. The maximum lateral displacement of the sockets was measured to be 1½ in. (38 mm) at multiple post locations in the impact region.

The maximum permanent set of the rail and posts for the barrier system was 16½ in. (419 mm) located at the midspan between post nos. 17 and 18 and 29 in. (737 mm) at post no. 19, as measured in the field. The maximum lateral dynamic deflections of the rail and posts were 42.3 in. (1,074 mm) at post no. 18 and 34.2 in. (869 mm) at post no. 19, as determined from high-speed digital video analysis. The working width of the system was found to be 47.3 in. (1,201 mm), also determined from high-speed digital video analysis. Post no. 1, part of the upstream anchor, had displaced ¼ in. (6 mm) downstream. The downstream BCT anchor posts did not displace.

10.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 89 and 90. The maximum occupant compartment deformations are listed in Table 24 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH-established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix F.

The majority of the damage was concentrated on the right-front corner of the vehicle where the impact occurred. The right-front bumper and fender were crushed inward, and the right headlight was disengaged. The plastic around the bumper was cracked and partially disengaged, and there was a kink in the bumper 13 in. (330 mm) from center. A 10-in. (254-mm) long tear in the fender was found behind the right headlight, and the front portion of the right fender was disengaged. A large dent was found above the wheel well spanning the length of the fender. The right side of the vehicle had various scrapes and gouges along its length. An 8-in. (203-mm) dent was located under the right taillight, while the taillight itself was partially disengaged. A kink was found in the rear bumper 21 in. (533 mm) from center.

The right-front tire was disengaged and deflated. A 3½-in. (89-mm) long tear was found on the tire sidewall, and the rim was cracked and gouged. The right-front brake caliper was disengaged and brake fluid was leaking. The steering knuckle was broken, and the wheel hub was fractured. The left-front tire was also deflated and the tire's rim was scraped. The roof and window glass remained undamaged.

Table 24. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	¼ (6)	≤ 9 (229)
Floor Pan & Transmission Tunnel	⅛ (4)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	¼ (6)	≤ 12 (305)
Side Door (Above Seat)	0 (0)	≤ 9 (229)
Side Door (Below Seat)	¼ (6)	≤ 12 (305)
Roof	0 (0)	≤ 4 (102)
Windshield	0 (0)	≤ 3 (76)

10.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 25. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 25. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 74. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix G.

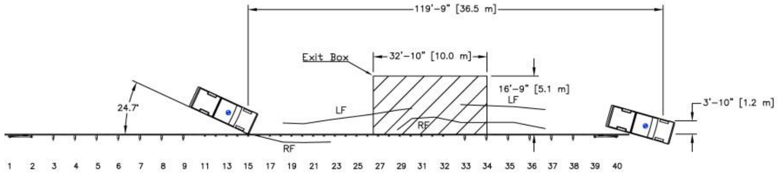
Table 25. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSMS-1

Evaluation Criteria		**Transducer**		**MASH Limits**
		DTS (primary)	**SLICE-2**	
OIV ft/s (m/s)	Longitudinal	-15.76 (-4.80)	-15.85 (-4.83)	≤ 40 (12.2)
	Lateral	-15.01 (-4.58)	-16.18 (-4.93)	≤40 (12.2)
ORA g’s	Longitudinal	-10.91	-10.97	≤ 20.49
	Lateral	-8.02	-7.59	≤ 20.49
MAX. ANGULAR DISPL. deg.	Roll	-9.7	-9.3	≤75
	Pitch	-5.1	-5.2	≤75
	Yaw	-34.0	-33.4	not required
THIV ft/s (m/s)		21.00 (6.40)	21.69 (6.61)	not required
PHD g’s		11.55	11.46	not required
ASI		0.63	0.65	not required

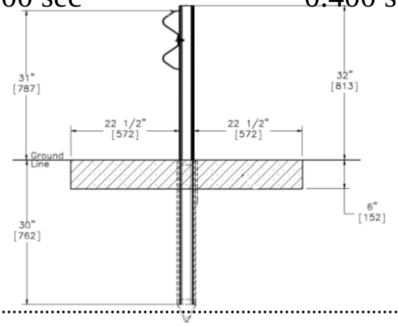
10.8 Discussion

The analysis of the test results for test no. MGSMS-1 showed that the weak-post guardrail system in an asphalt mow strip adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. There were no detached elements or fragments which showed potential for penetrating the occupant compartment or presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate or ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix G, were deemed acceptable because they did not adversely influence occupant risk safety criteria or cause rollover. After impact, the vehicle exited the barrier at an angle of 9.7 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. MGSMS-1, conducted on the weak-post guardrail system in an asphalt mow strip, was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-11.

0.000 sec 0.100 sec 0.200 sec 0.300 sec 0.400 sec



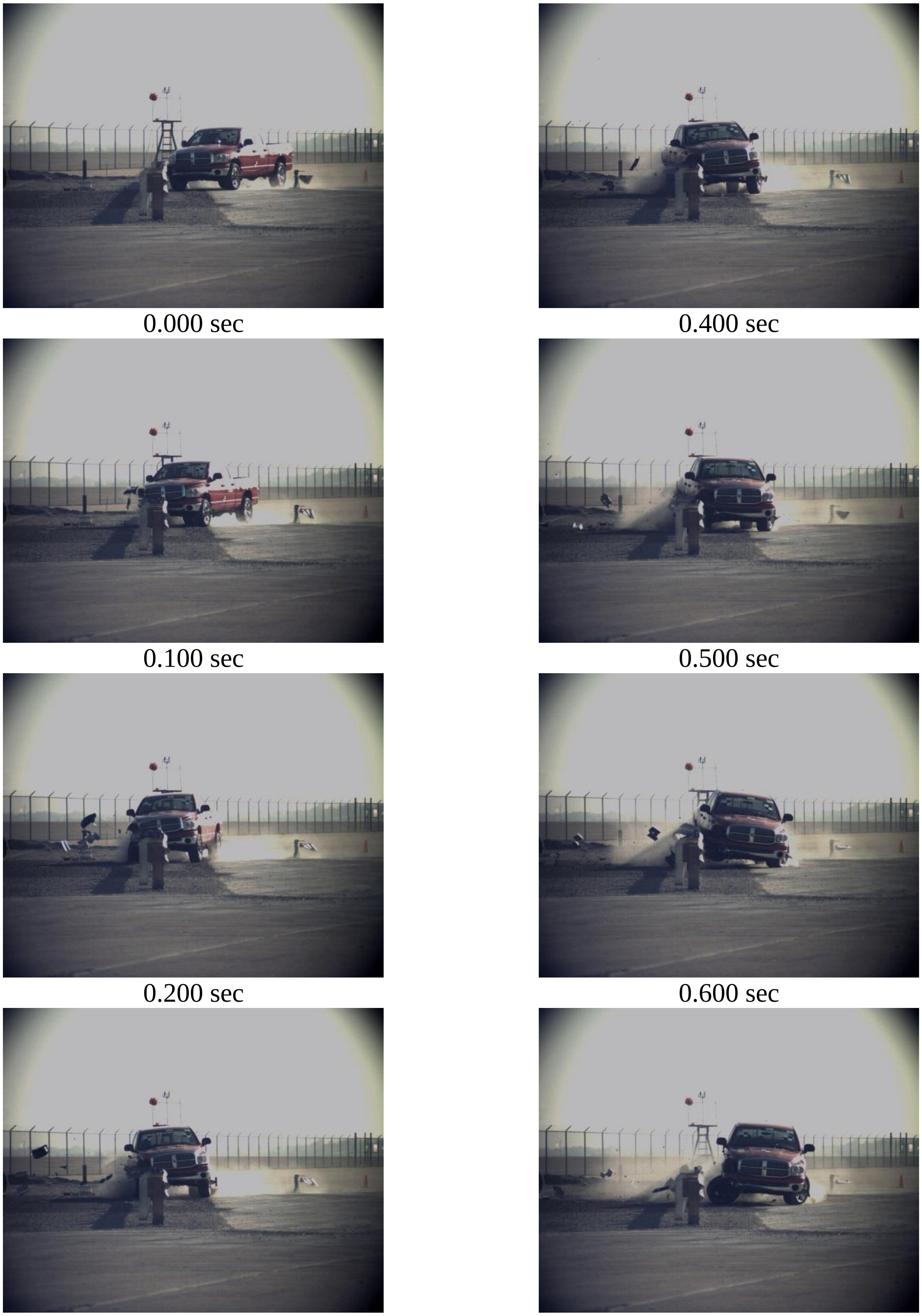
- Test Agency ...... MwRSF
- Test Number MGSMS-1
- Date 12/5/2015
- MASH Test Designation 3-11
- Test Article ...... Weak-Post Guardrail Installed in Mow Strip
- Total Length ...... 175 ft (53.3 m)
- Key Component – W-beam Guardrail
    - Thickness ...... 12-ga. (2.67 mm)
    - Connection to Post ...... 5/16-in. (8-mm) dia. bolt & 1.75-in. (44-mm) sq. washer
- Key Component – S3x5.7 Posts
    - Spacing ...... 37.5 in. (953 mm)
- Key Component - Socket
    - Tube ...... 4 in. x 4 in. x ¼ in. (102 mm x 102 x 6 mm)
    - Embedment Depth ...... 30 in. (762 mm)
    - Backside Shear Plate ...... 10 in. x 9 in. x ¼ in. (254 mm x 229 mm x 6 mm)
- Key Component – Asphalt Mow Strip
    - Thickness ...... 6 in. (152 mm)
    - Width ...... 4 ft (1.2 m)
- Vehicle Make /Model ...... 2007 Dodge Ram 1500
    - Curb ...... 5,228 lb (2,371 kg)
    - Test Inertial ...... 5,016 lb (2,275 kg)
    - Gross Static ...... 5,182 lb (2,351 kg)
- Impact Conditions
    - Speed ...... 63.0 mph (101.4 km/h)
    - Angle ...... 25.2 deg.
    - Impact Location ...... 16-ft (4.9 m) US of Splice at Post No. 20
- Impact Severity (IS) ...... 121 kip-ft (164 kJ) > 106 kip-ft (144 kJ) limit from MASH
- Exit Conditions
    - Speed ...... 34.7 mph (55.9 km/h)
    - Angle ...... -9.7 deg.
- Exit Box Criterion ...... Pass
- Vehicle Stability ...... Satisfactory
- Vehicle Stopping Distance ...... 119.8 ft (36.5 m)



- Test Vehicle Damage ...... Moderate
    - VDS [16] 01-RFQ-3
    - CDC [17] 01-RFEN-3
    - Maximum Interior Deformation ...... ¼ in. (6 mm) at toe plan
- Article Damage ...... Moderate
- Maximum Test Article Deflections
    - Permanent Set ...... 29 in. (737 mm)
    - Dynamic ...... 42.3 in. (1,074 mm)
    - Working Width ...... 47.3 in. (1,201 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		DTS (primary)	SLICE-2	
OIV ft/s (m/s)	Longitudinal	-15.76 (-4.80)	-15.85 (-4.83)	≤ 40 (12.2)
	Lateral	-15.01 (-4.58)	-16.18 (-4.93)	≤ 40 (12.2)
ORA g's	Longitudinal	-10.91	-10.97	≤ 20.49
	Lateral	-8.02	-7.59	≤ 20.49
MAX ANGULAR DISP. deg.	Roll	-9.7	-9.3	≤75
	Pitch	-5.1	-5.2	≤75
	Yaw	-34.0	-33.4	NA
THIV – ft/s (m/s)		21.00 (6.40)	21.69 (6.61)	NA
PHD – g's		11.55	11.46	NA
ASI		0.63	0.65	NA

Figure 74. Summary of Test Results and Sequential Photographs, Test No. MGSMS-1



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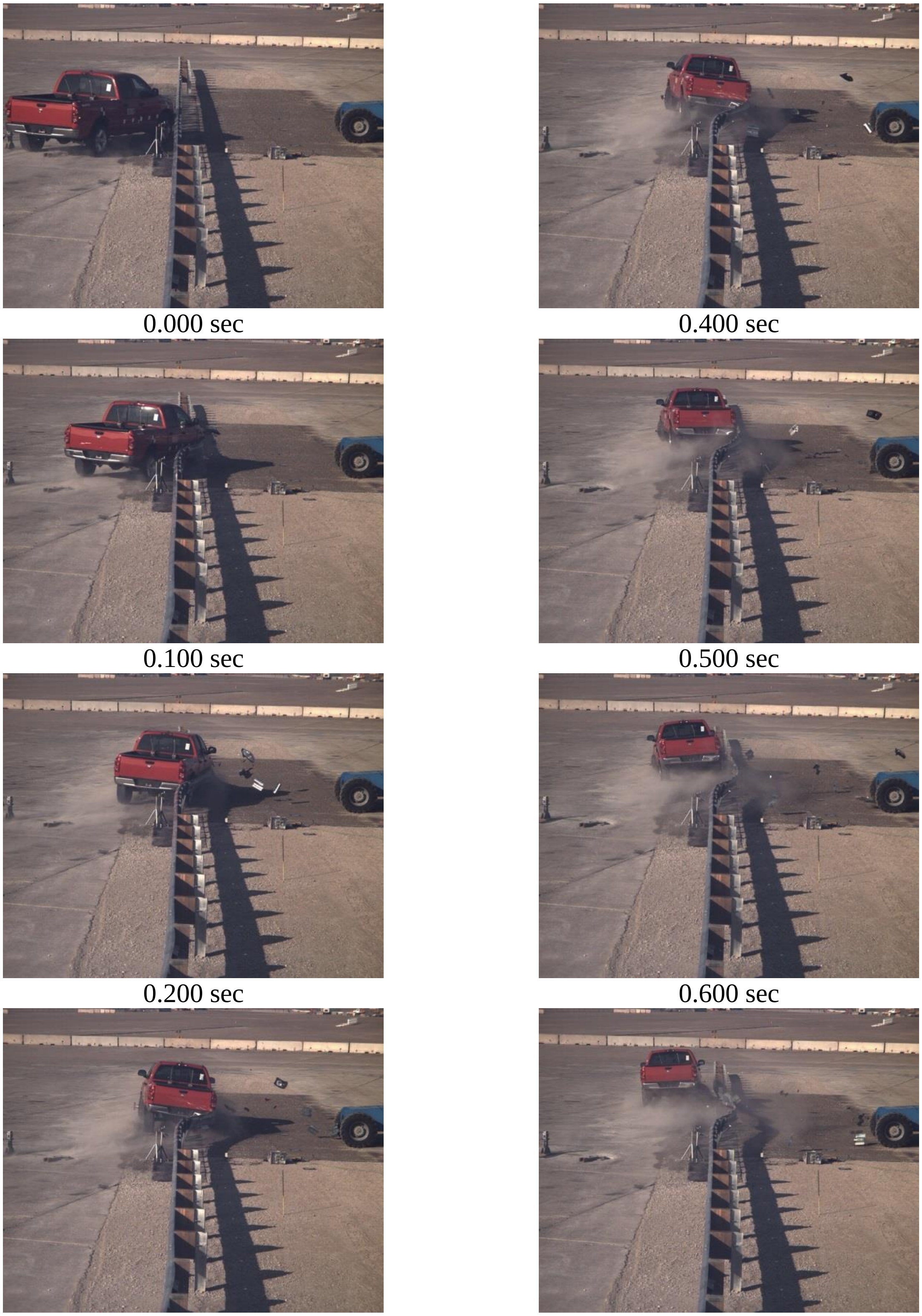
0.800 sec

Figure 75. Additional Sequential Photographs, Test No. MGSMS-1



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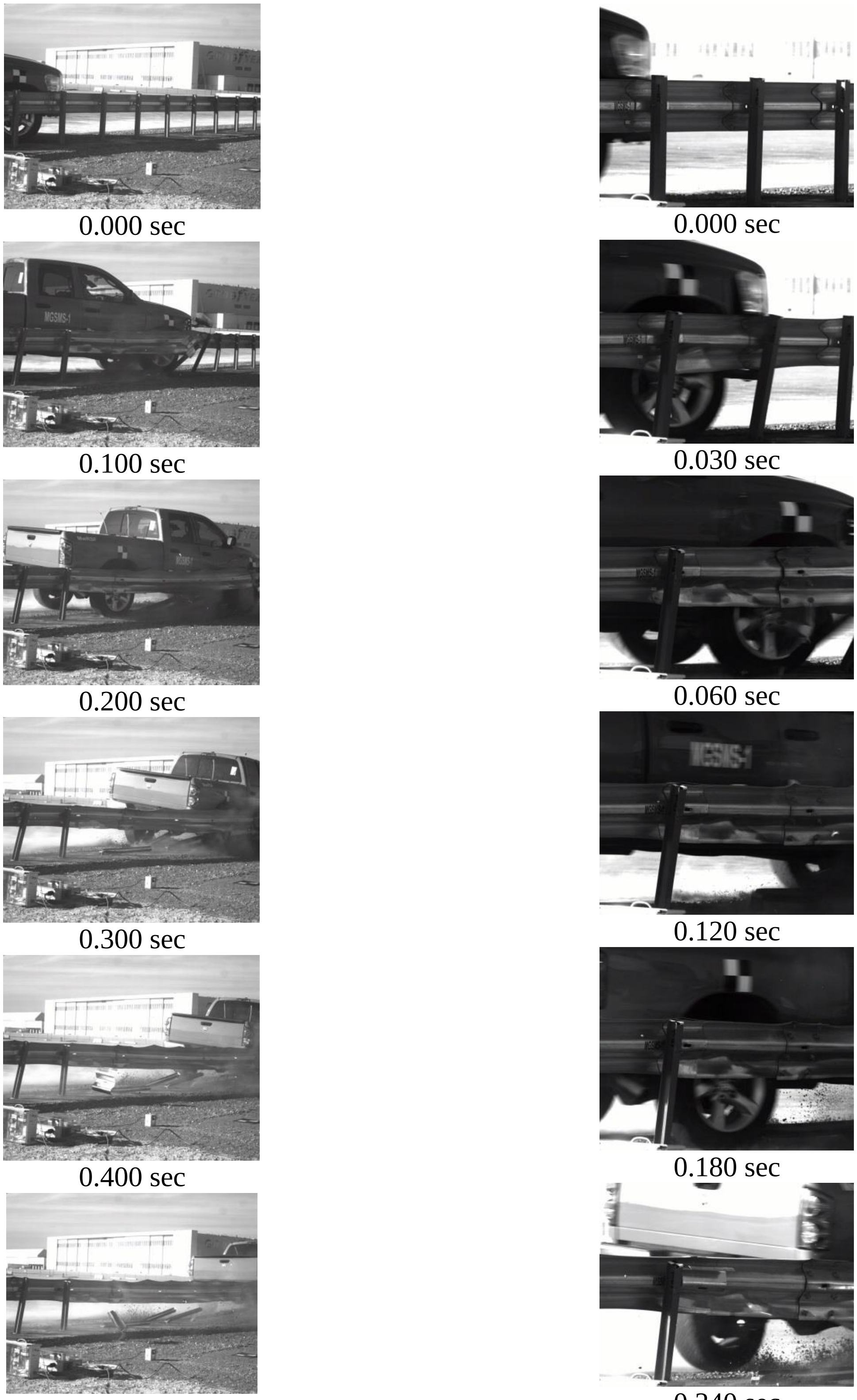
0.600 sec

0.800 sec

Figure 76. Additional Sequential Photographs, Test No. MGSMS-1



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0.400 sec

0.500 sec

0.000 sec

0.030 sec

0.060 sec

0.120 sec

0.180 sec

0.240 sec

Figure 77. Additional Sequential Photographs, Test No. MGSMS-1

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0.100 sec

0.200 sec

0.300 sec

0.400 sec

0.500 sec

0.000 sec

0.100 sec

0.200 sec

0.300 sec

0.400 sec

0.500 sec

Figure 78. Additional Sequential Photographs, Test No. MGSMS-1

Figure 79. Documentary Photographs, Test No. MGSMS-1

Figure 80. Impact Location, Test No. MGSMS-1

Figure 81. Vehicle Final Position and Trajectory Marks, Test No. MGSMS-1

Figure 82. System Damage, Test No. MGSMS-1

Figure 83. System Damage – Post Nos. 12 Through 17, Test No. MGSMS-1

Figure 84. System Damage – Post Nos. 18 Through 20, Test No. MGSMS-1

Figure 85. System Damage – Post Nos. 21 Through 23, Test No. MGSMS-1

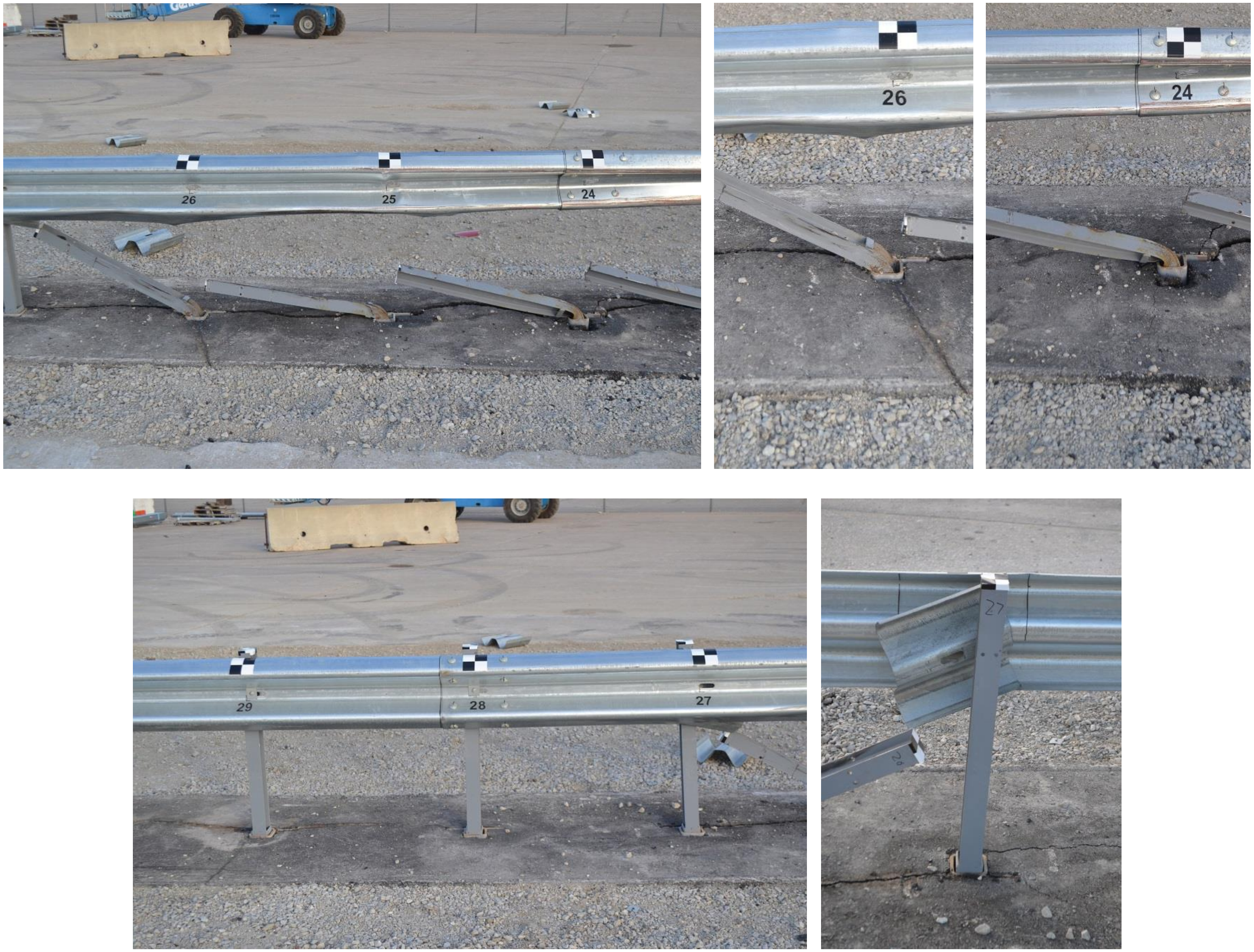


Figure 86. System Damage – Post Nos. 24 Through 29, Test No. MGSMS-1

Figure 87. System Damage – Asphalt Fracture and Anchor Movement, Test No. MGSMS-1

Figure 88. System Damage – Rail Tearing, Test No. MGSMS-1

Figure 89. Vehicle Damage, Test No. MGSMS-1

Figure 90. Vehicle Damage, Test No. MGSMS-1

11 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this project was to adapt the weak-post, MGS bridge rail system for use within asphalt mow strips. The new W-beam guardrail system was to withstand the impact force and dissipate energy through post bending, thereby limiting damage to the mow strip. It was desired that damaged barrier components could be replaced without requiring repairs to the mow strip in order to minimize maintenance costs.

The project began with a review of mow strip standards and practices from the Midwest States Pooled Fund Program members. Both asphalt and concrete mow strips were commonly used, and thicknesses varied between 3 in. (76 mm) and 6 in. (152 mm). However, a 4 ft (1.2 m) width was nearly unanimous for a standard mow strip. As such, the weak-post guardrail system was evaluated for use within 4-ft (1.2-mm) wide paved mow strips using either asphalt or concrete materials.

Dynamic bogie testing was conducted on weak posts installed in pavements to quantify the amount of damage expected within various mow strip configurations. Round 1 component testing consisted of four bogie impact tests on single S3x5.7 (S76x8.5) guardrail posts installed directly within the pavement. The posts were driven through the asphalt mow strips, while 4-in. (102-mm) square leave-outs and 4-in. (102-mm) diameter cored holes in the concrete allowed the posts to be driven through the concrete and into the underlying soil. Results from the Round 1 testing showed that the weak posts bent over and formed plastic hinges near the groundline. The 4-in. (102-mm) thick concrete mow strips suffered only minor spalling on the backside of the hole and leave-out. However, both the 4-in. (102-mm) and 6-in. (152-mm) thick asphalt mow strips spalled, cracked, and displaced, allowing the post to shift over 2 in. (51 mm) backward, as measured at the groundline. Removal of the damaged posts caused additional cracking in the asphalt pavements. Thus, distribution of the impact loads was required to prevent damage and repair concerns within asphalt mow strips.

Round 2 component testing consisted of five bogie impact tests on S3x5.7 (S76x8.5) posts installed within 4-in. x 4-in. x ¼-in. (102-mm x 102-mm x 6-mm) steel tube sockets, which were driven into the center of a 4-in. (102-mm) thick asphalt mow strip. The sockets had varied embedment depths ranging between 20 in. (508 mm) and 30 in. (762 mm). The first test on a 30-in. (762-mm) long socket resulted in the socket displacing 1 in. (25 mm) through the asphalt. Subsequently, 10-in. x 9-in. x ¼-in. (254-mm x 229-mm x 6-mm) shear plates were added to the backside of the sockets for the remainder of the component tests. With the addition of the shear plate, sockets measuring 30 in. (762 mm) and 24 in. (610 mm) resulted in displacements of ¼ in. (6 mm) and ½ in. (13 mm), respectively. Both of these displacements allowed a replacement post to be installed plumb without repair work to the asphalt or the socket. Testing on a 20-in. (508-mm) long socket resulted in asphalt shear fracture behind the socket and large displacements for the asphalt and the socket. Additionally, a single longitudinal impact test was conducted along the weak axis of the post installed in a 30-in. (762-mm) deep socket. The reduced strength of the post in the weak axis produced only ⅛ in. (3 mm) of socket displacement.

Round 3 of dynamic component testing consisted of two tests on dual S3x5.7 (S76x8.5) weak posts spaced 37.5 in. (953 mm) apart to evaluate the ability of the mow strip pavement to withstand impact loading from multiple adjacent posts. Test no. MSSP-5 was conducted with dual posts installed in 24-in. (610-mm) deep sockets with backside shear plates driven into a 4-in. (102-mm) thick asphalt mow strip. During the test, the asphalt behind the sockets fractured and displaced backward. The crack pattern resembled a shear block failure, as the fracture extended between the two socket shear plates and then to the back edge of the mow strip at approximately 45 degree angles. Test no. MSSP-6 was conducted with dual posts installed within 4-in. (102-mm) square leave-outs placed in a 4-in. (102-mm) thick unreinforced concrete mow strip. Similar to the previous single-post testing, the concrete sustained only minor spalling on the back edges of the leave-outs and would not require repair during replacement of the damaged posts.

Due to the widespread use of asphalt pavements as mow strips, the project sponsors desired to continue utilizing an asphalt mow strip during full-scale crash testing of the system. In an attempt to minimize the damage to the mow strip, the embedment depth of the socket was increased to 30 in. (762 mm), and the thickness of the mow strip was increased to 6 in. (152 mm). The full-scale test installation was 175 ft (53.3 m) long, though only the middle 75 ft (22.9 m) of the guardrail was installed over a simulated asphalt mow strip. The sockets and S3x5.7 (S76x8.5) weak posts were installed down the center of the mow strip at 37½-in. (953-mm) spacing. Soil fill was utilized in front of and behind the mow strip to create an even groundline around the barrier system. Standard MGS was installed upstream and downstream from the mow strip.

Test no. MGSMS-1 was conducted on the 31-in. (787-mm) tall weak-post guardrail installation in accordance with MASH test designation no. 3-11. During the test, the 2270P was contained and smoothly redirected. The barrier system had a maximum dynamic deflection of 42.3 in. (1,074 mm) and a working width of 47.3 in. (1,201 mm). Test no. MGSMS-1 satisfied all of the safety performance evaluation criteria for MASH TL-3 longitudinal barriers, as summarized in Table 26.

Unfortunately, the full-scale test also resulted in a large, 60-ft (18.3-m) long crack forming down the center of the asphalt mow strip throughout the impact region. The crack extended along the back side of the sockets, had a maximum opening width of 2½ in. (64 mm), and allowed the sockets to rotate and displace backward up to 1½ in. (38 mm). Consequently, repairs to the asphalt and resetting of the sockets would be necessary when replacing damaged posts and rail segments. As such, the system did not to meet the design goal of limiting damage to the mow strip and preventing costly repairs. However, since the full-scale test satisfied the MASH TL-3 criteria, a couple options are recommended for installing this weak-post guardrail system within mow strips.

First, if asphalt damage during impact events was allowable, the system could be installed as tested. Of course, repairs to the mow strip would be expected when repairing impacted sections of the weak-post guardrail system, but the system would perform in a crashworthy manner. Mow strip repairs may include resetting of displaced sockets, filling of cracks and gaps around the socket, and/or the removal and replacement of damaged asphalt sections. During initial installation, the asphalt should be placed and compacted with standard rolling techniques for highway pavements, and the socket assemblies should be driven through the paved asphalt. Although the full-scale test utilized a 6-in. (152-mm) thick asphalt mow strip, a 4-in. (102-mm) thick asphalt mow strip should result in the same safety performance for the system. The thicker pavement was only selected in an attempt to prevent asphalt damage, an objective that was not achieved. Once the asphalt cracked along its center, the mow strip provided minimal resistance to prevent the socket from rotating backward. As such, the as-tested, weak-post guardrail system should perform adequately when installed down the center of an asphalt mow strip with a minimum width of 4 ft (1.2 m) and a minimum thickness of 4 in. (102 mm).

Second, if mow strip damage from impact events was not desirable, the weak-post guardrail system should be utilized within a concrete mow strip. Dynamic bogie testing on dual posts illustrated that 4-in. (102-mm) thick concrete mow strips do not carry the risk of block shear fracture associated with asphalt pavements. Thus, damage in the form of concrete cracking and/or fracture would not be expected for concrete pavements. Additionally, dynamic bogie testing has shown that there is no need for a post socket within a concrete mow strip. The concrete mow strip was strong enough to contain the post and cause plastic bending at groundline. The concrete mow strip should have a minimum thickness of 4 in. (102 mm), a minimum width of 4 ft (1.2 m), and a minimum strength of 4,000 psi (28 MPa). Although not initially required for strength, reinforcement of the mow strip is recommended to prevent cracking and deterioration resulting from temperature shrinkage, freeze-thaw cycles, and/or settlement of the soil. Either 4-in. (102-mm) square leave-outs or 4-in. (102-mm) diameter cored holes should be placed along the center of the mow strip to allow for driving of the S3x5.7 (S76x8.5) posts. The posts should have a length of 6 ft (1.8 m) and an embedment depth of 40 in. (1,016 mm) to match the dimensions of the posts evaluated during bogie testing.

Even though the steel sockets are not needed for installation of the system in concrete, the 2¾-in. x 1-in. x ¼-in. steel standoffs welded to the sides of the S3x5.7 (S76x8.5) posts are still recommended for future installations. These post standoffs were originally developed as shims to prevent excess movement of the posts within the socket tube. However, full-scale testing of these posts within both the mow strip system and the original MGS bridge rail system illustrated that the welded standoff plates created stress concentrations in the post during weak-axis bending and led to tearing of the upstream flanges. Thus, the post bent over as though it was hinged at groundline once the tearing had occurred. This phenomenon is important as recent full-scale testing of small cars into weak-post systems has shown a propensity to result in floor pan tearing as the vehicle traverses over the top of weak posts during redirection [18-19]. Welding these standoff plates to weak posts will encourage the posts to tear and lie flat on the ground instead of rebounding upward and penetrating into the occupant compartment. Accordingly, the plates should be welded so that the top of the plate is even with the groundline, or 40 in. (1,016 mm) from the bottom of the post, as shown in Figure 91.

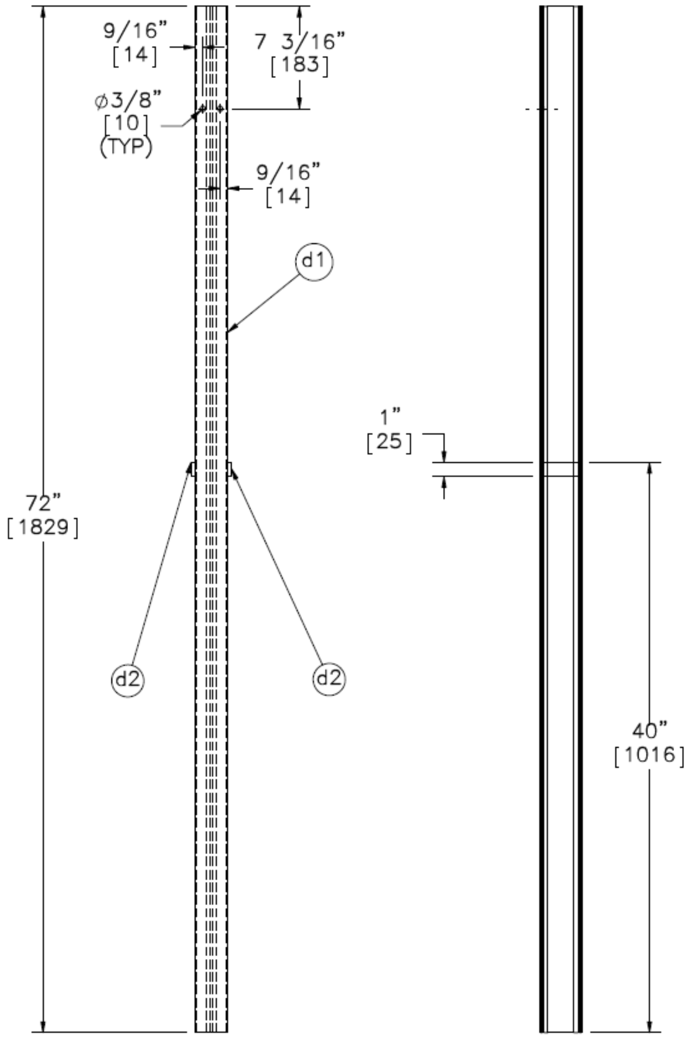


Figure 91. Recommended Post for Installations in Concrete Mow Strips

There is potential for the weak-post guardrail system to be implemented within an asphalt mow strip without the use of sockets, assuming that damage to the pavement was allowable. The sockets and shear plates were implemented only to distribute load throughout the asphalt and prevent pavement damage. Since this proved unsuccessful, the socket assemblies may provide minimal benefits to the system. Driving the posts directly through the asphalt may result in similar safety performance to that observed in the full-scale crash test. However, it may also slightly modify the stiffness of the system if the plastic hinge in the post forms at a different location (e.g., at the soil surface after the asphalt mow strip has fractured). Further testing and evaluation would be necessary to demonstrate that the system remains crashworthy in asphalt mow strips without the use of steel sockets.

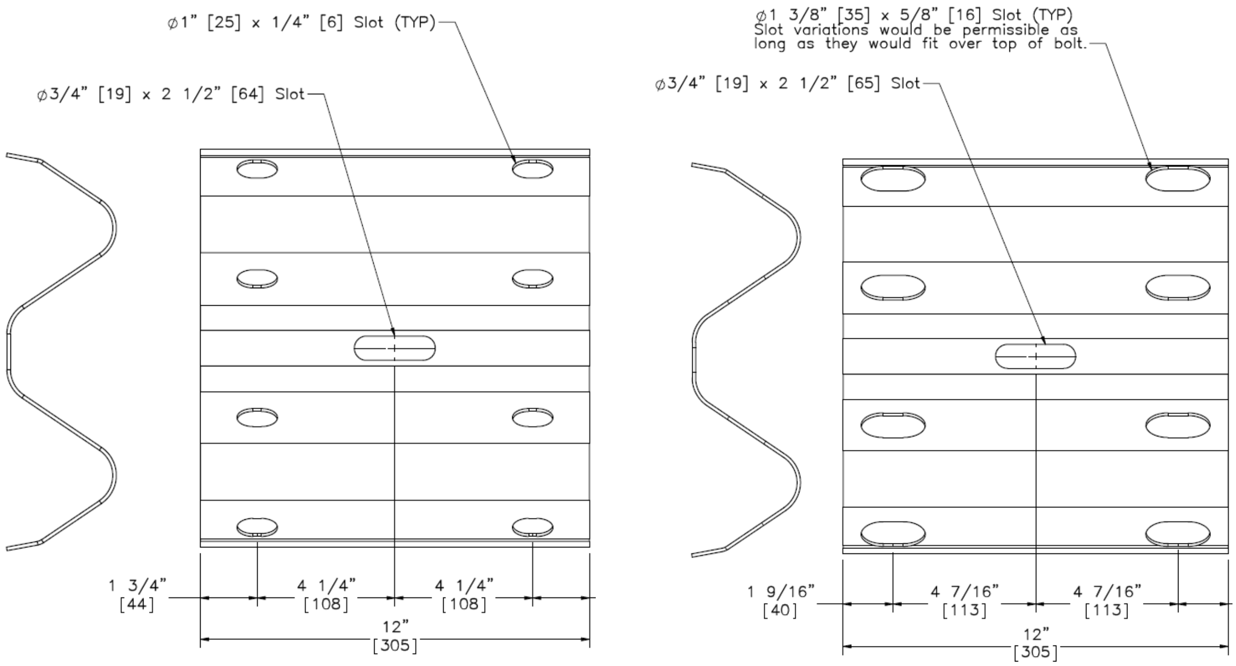
Some users may still desire a guardrail system compatible with asphalt mow strips that does not damage the pavement. It is believed that this objective is obtainable, either through a variation of the weak-post guardrail system evaluated herein or a different configuration not yet evaluated. However, further design, testing, and analysis is required to develop such a system.

Regardless of the anchorage conditions for the S3x5.7 (S76x8.5) posts for this weak-post guardrail system, the use of 12-in. (305-mm) long backup plates behind the rail is recommended. The partial rail tearing observed during test no. MGSMS-1 was caused when the test vehicle impacted a post and caused it to deflect downstream and twist such that its flange contacted the bottom of the rail directly below the downstream splice bolts. Then, as the vehicle’s right-front bumper and fender loaded the splice, the tear propagated to span half of the rail height. If a long backup plate had been installed at this location, the tear may have never occurred.

The original MGS bridge rail utilized 6-in. (152-mm) long backup plates at every post, including splice locations since the splice bolts are 8 in. (203 mm) apart. Unfortunately, the design drawings for the full-scale test specified 12-in. (305-mm) backup plates (taken from the non-blocked MGS drawings) instead of the 6-in. (152 mm) backup plates, and these larger backup plates could not be installed over the splice bolts, which are 8½ in. (216 mm) apart, without additional holes in the plate. As such, backup plates were not installed at locations where posts coincided with rail splices. The lack of backup plate material may have contributed to the partial rail tearing in test no. MGSMS-1. However, the tearing would have likely still occurred had 6-in. (152-mm) backup plates been utilized, because the 6-in. (152-mm) backup plates do not extend below the splice bolts where the tear initiated. Similar rail tearing has been observed in other 2270P testing on S3x5.7 (S76x8.5) weak-post guardrail systems that utilized 5⅝-in (143-mm) backup plates at all post locations [20].

To prevent rail tearing due to post contact near rail splices, a longer backup should be utilized to protect the rail around all posts, especially at splice locations. Therefore, the utilization of a 12-in. (305-mm) long backup plate is recommended for the weak-post guardrail system in mow strips, regardless of the type of mow strip. Further, the benefit of reducing the propensity for rail tearing could be achieved for other similar S3x5.7 (S76x8.5) weak-post guardrail systems, including the original MGS bridge rail and the weak-post guardrail attached to culverts, if 12-in. (305-mm) backup plates were utilized instead of 6-in. (152-mm) backup plates.

Since 12-in. (305-mm) long backup plates are unable to be installed at guardrail splices, holes or slots need to be cut into the backup plate to allow the guardrail bolts to pass through the plate. The backup plates could utilize the same splice bolt slot pattern that is currently punched into the ends of every guardrail segment. Utilizing this design, the backup plate could be attached to the guardrail and assembled as a part of the splice. Alternatively, a backup plate could be configured to fit over the back of assembled guardrail splices at the time of mounting the rail to a post. Under these conditions, the slots would need to be enlarged to fit around the splice bolts and nuts. Both of these design options are shown in Figure 92 and should be equally effective in reducing the risk of rail tearing.



(A) (B)

Figure 92. 12-in. (152-mm) Backup Plates with (A) Standard Splice Slots and (B) Enlarged Slots

The weak-post guardrail system was designed as part of a family of non-proprietary, 31-in. (787-mm) high, W-beam guardrail systems commonly referred to as the MGS. The weak-post guardrail within mow strip systems was designed with a similar lateral stiffness and overall system performance as the original MGS and MGS bridge rail. Therefore, a stiffness transition between the weak-post guardrail in mow strips system and adjacent standard MGS installations is unnecessary. A 75-in. (1.9-m) spacing is recommended between the last S3x5.7 (S76x8.5) weak post and the first standard guardrail post of the adjacent MGS installation. The adjacent MGS may be either blocked or non-blocked.

Finally, installations should be constructed with the guardrail terminals (or end anchorages) located a sufficient distance away from the weak-post guardrail system to prevent the two systems from interfering with the proper performance of one another. As such, the following implementation guidelines should be considered in addition to guardrail length of need requirements:

1. A recommended minimum length of 12 ft – 6 in. (3.8 m) of standard MGS between the first S3x5.7 (S76x8.5) weak post and the interior end of an acceptable TL-3 guardrail end terminal.
2. A recommended minimum barrier length of 50 ft (15.2 m) before the first S3x5.7 (S76x8.5) weak post, which includes standard MGS and a crashworthy guardrail end terminal. This guidance applies to the downstream end as well.
3. For flared guardrail applications, a recommended minimum length of 25 ft (7.6 m) between the first S3x5.7 (S76x8.5) weak post and the start of the flared section (i.e. bend between flared and tangent sections).

Table 26. Summary of Safety Performance Evaluation Results

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. MGSMS-1</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">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>S</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td><td>S</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></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>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

12 REFERENCES

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13. Mongiardini, M., Faller, R.K., Reid, J.D., Sicking, D.L., Stolle, C.S., and Lechtenberg, K.A., Downstream Anchoring Requirements for the Midwest Guardrail System, Research Report No. TRP-03-279-13, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 28, 2013.

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17. *Collision Deformation Classification – Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

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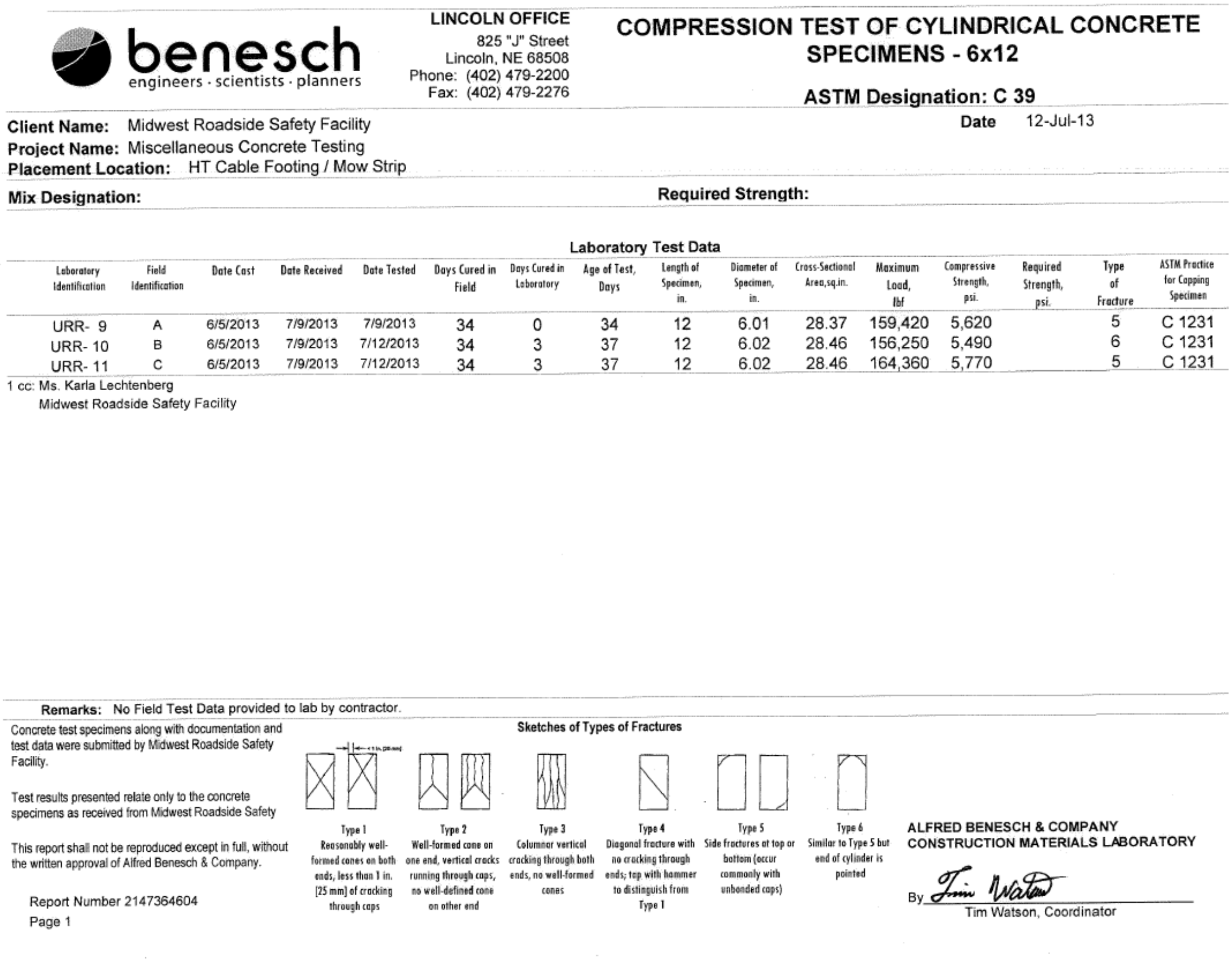
13 APPENDICES

Appendix A. Material Specifications – Component Testing

Table A-1. Material Certification Listing for Dynamic Component Tests

Test Nos.											**Description**	**Material Specification**	**Reference**
MS-1	**MS-2**	**MS-3**	**MS-4**	**MS-5**	**MSSP-1**	**MSSP-2**	**MSSP-3**	**MSSP-4**	**MSSP-5**	**MSSP-6**			
X		X								X	10'x4'x4" [3048x1219x102] Concrete Mow Strip	4000 psi [27.6 MPa] Comp. Strength	MixCode: 24013000 and benesch 7/12/13
	X			X	X	X					25'x4'x4" [7620x1219x102] Asphalt Mow Strip	52-34 Grade Binder	email from 7/25/13
			X								15'x4'x6" [4572x1219x152] Asphalt Mow Strip	52-34 Grade Binder	email from 7/25/13
							X	X	X		25'x4'x4" [7620x1219x102] Asphalt Mow Strip	52-34 Grade Binder	Cather & Sons 6/25/14
X	X	X	X							X	S3x5.7 [S76x8.5] 72" [1829] Long Post	ASTM A36	H# G106836
				X	X	X					S3x5.7 [S76x8.5] 62" [1575] Long Post	ASTM A36	H# 59058160
								X	X		S3x5.7 [S76x8.5] 56" [1422] Long Post	ASTM A36	H# G106836
							X				S3x5.7 [S76x8.5] 52" [1321] Long Post	ASTM A36	H# G106836
				X	X	X	X	X	X		4"x4"x3/8" [102x102x10] Steel Socket (various lengths)	ASTM A500 Grade B Steel Galvanized	H# 1401127
				X	X	X	X	X	X		4"x4"x1/4" [102x102x6] Steel Plate (wedge)	ASTM A572 Grade 50 Steel Galvanized	H# B408684
					X	X	X	X	X		10"x9"x1/4" [254x229x6] Steel Soil Plate	ASTM A572 Grade 50 Steel Galvanized	H# B408684



benesch
engineers · scientists · planners

LINCOLN OFFICE
825 "J" Street
Lincoln, NE 68508
Phone: (402) 479-2200
Fax: (402) 479-2276

COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 6x12

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility
Date 12-Jul-13
Project Name: Miscellaneous Concrete Testing
Placement Location: HT Cable Footing / Mow Strip

Mix Designation:
Required Strength:

Laboratory Test Data

Laboratory Identification	Field Identification	Date Cast	Date Received	Date Tested	Days Cured in Field	Days Cured in Laboratory	Age of Test, Days	Length of Specimen, in.	Diameter of Specimen, in.	Cross-Sectional Area,sq.in.	Maximum Load, lbf	Compressive Strength, psi.	Required Strength, psi.	Type of Fracture	ASTM Practice for Capping Specimen
URR- 9	A	6/5/2013	7/9/2013	7/9/2013	34	0	34	12	6.01	28.37	159,420	5,620		5	C 1231
URR- 10	B	6/5/2013	7/9/2013	7/12/2013	34	3	37	12	6.02	28.46	156,250	5,490		6	C 1231
URR- 11	C	6/5/2013	7/9/2013	7/12/2013	34	3	37	12	6.02	28.46	164,360	5,770		5	C 1231

1 cc: Ms. Karla Lechtenberg
Midwest Roadside Safety Facility

Remarks: No Field Test Data provided to lab by contractor.

Concrete test specimens along with documentation and test data were submitted by Midwest Roadside Safety Facility.

Test results presented relate only to the concrete specimens as received from Midwest Roadside Safety

This report shall not be reproduced except in full, without the written approval of Alfred Benesch & Company.

Report Number 2147364604
Page 1

Sketches of Types of Fractures

Type 1
Reasonably well-formed cones on both ends, less than 1 in. [25 mm] of cracking through caps

Type 2
Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end

Type 3
Columnar vertical cracking through both ends, no well-formed cones

Type 4
Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type 1

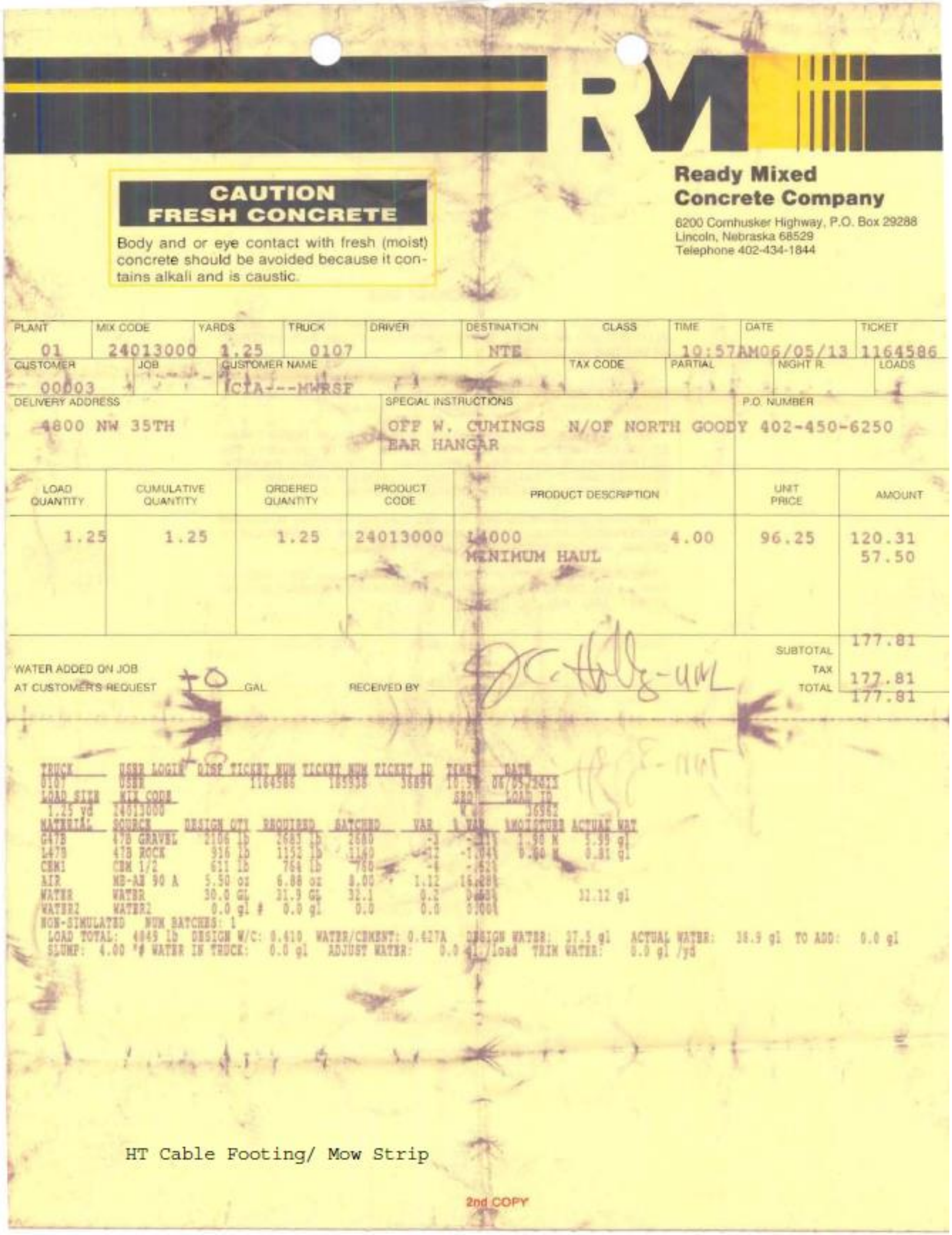
Type 5
Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6
Similar to Type 5 but end of cylinder is pointed

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By Tim Watson
Tim Watson, Coordinator

Figure A-1. Concrete Mow Strip Material Specification, MS-1, MS-3, and MSSP-6



Ready Mixed Concrete Company
6200 Cornhusker Highway, P.O. Box 29288
Lincoln, Nebraska 68529
Telephone 402-434-1844

CAUTION FRESH CONCRETE
Body and or eye contact with fresh (moist) concrete should be avoided because it contains alkali and is caustic.

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
01	24013000	1.25	0107		NTE		10:57AM	06/05/13	1164586

CUSTOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R.	LOADS
00003		CIA---MWRSF				

DELIVERY ADDRESS: 4800 NW 35TH

SPECIAL INSTRUCTIONS: OFF W. CUMINGS N/OF NORTH GOODY 402-450-6250
EAR HANGAR

P.O. NUMBER:

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION		UNIT PRICE	AMOUNT
1.25	1.25	1.25	24013000	14000	4.00	96.25	120.31
				MINIMUM HAUL			57.50

SUBTOTAL 177.81
TAX
TOTAL 177.81
177.81

WATER ADDED ON JOB AT CUSTOMER'S REQUEST +0 GAL

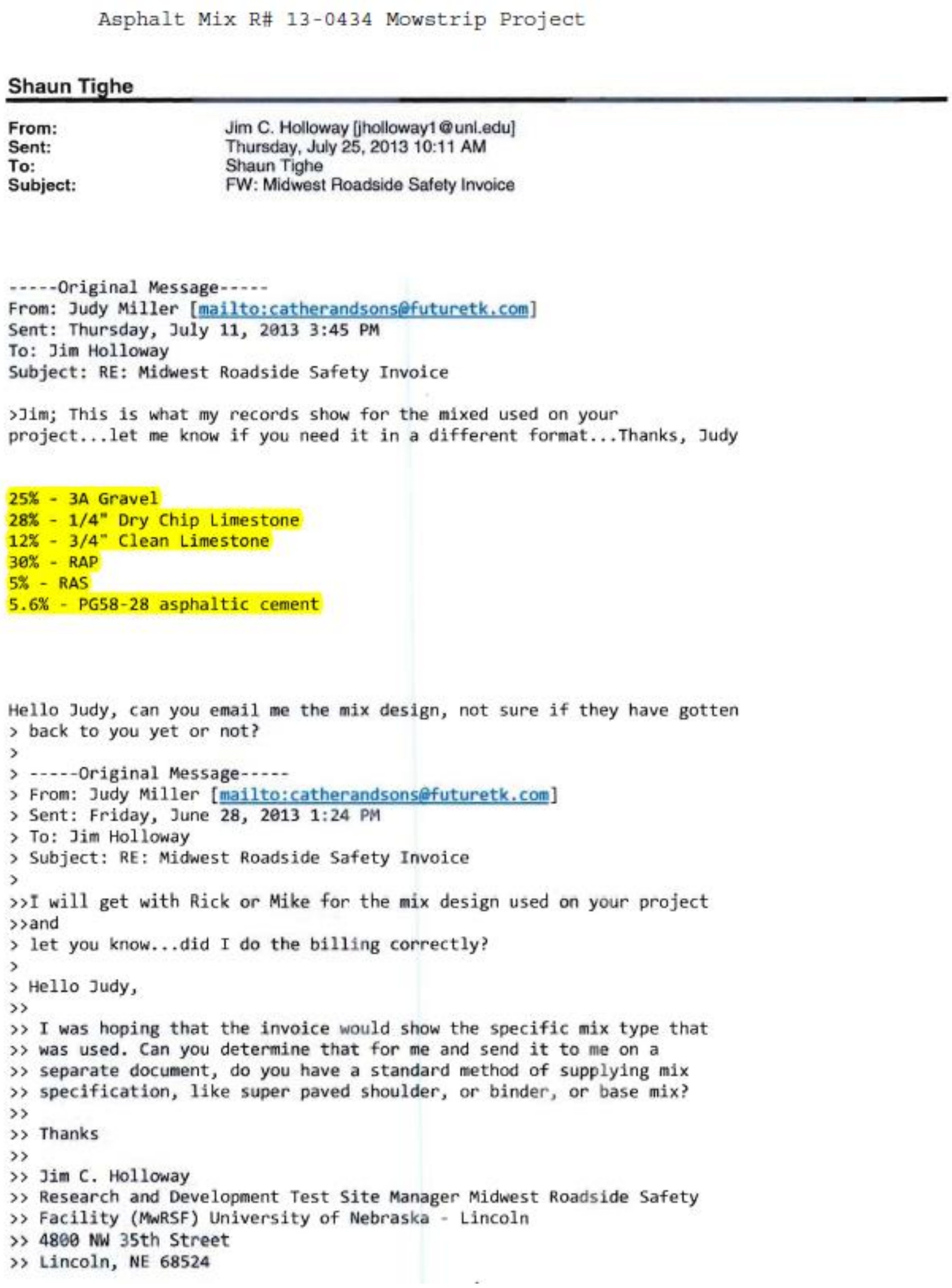
RECEIVED BY JC Holtz-UNL

```
TRUCK      USER LOGIN  DISP TICKET NUM TICKET NUM TICKET ID  TIME   DATE
0107       USER                1164586     185938     36894  10:5   06/05/2013
LOAD SIZE  MIX CODE                                          SEQ    LOAD ID
 1.25 yd   24013000                                          W 0       36962
MATERIAL   SOURCE      DESIGN QTY  REQUIRED   BATCHED    VAR   % VAR  %MOISTURE ACTUAL WAT
G47B       47B GRAVEL    2106 lb    2683 lb    2680       -3   -.11%    1.90 M    5.99 gl
L47B       47B ROCK       916 lb    1152 lb    1140      -12  -1.04%    0.60 M    0.81 gl
CEM1       CEM 1/2        611 lb     764 lb     760       -4   -.52%
AIR        MB-AE 90 A    5.50 oz    6.88 oz    8.00     1.12  16.28%
WATER      WATER         30.0 GL    31.9 GL    32.1      0.2   0.63%             32.12 gl
WATER2     WATER2         0.0 gl #   0.0 gl     0.0      0.0   0.00%
NON-SIMULATED   NUM BATCHES: 1
 LOAD TOTAL:  4845 lb  DESIGN W/C: 0.410  WATER/CEMENT: 0.427A   DESIGN WATER:  37.5 gl   ACTUAL WATER:   38.9 gl  TO ADD:   0.0 gl
 SLUMP:  4.00 "# WATER IN TRUCK:   0.0 gl   ADJUST WATER:    0.0 gl /load  TRIM WATER:    0.0 gl /yd
```

HT Cable Footing/ Mow Strip

2nd COPY

Figure A-2. Concrete Mow Strip Material Specification, MS-1, MS-3, and MSSP-6



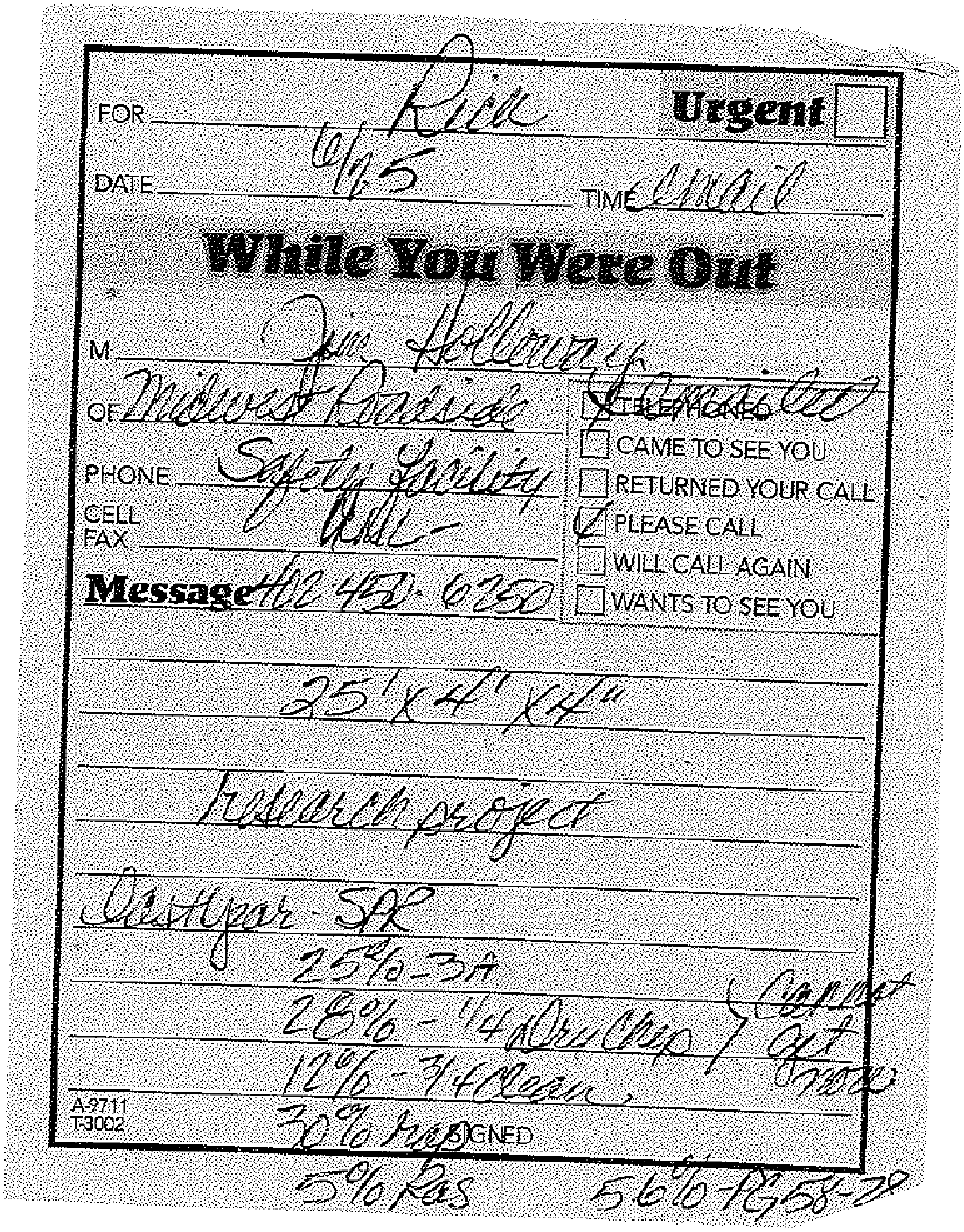
Asphalt Mix R# 13-0434 Mowstrip Project

Shaun Tighe

From: Jim C. Holloway [jholloway1@unl.edu]
Sent: Thursday, July 25, 2013 10:11 AM
To: Shaun Tighe
Subject: FW: Midwest Roadside Safety Invoice

```
-----Original Message-----
From: Judy Miller [mailto:catherandsons@futuretk.com]
Sent: Thursday, July 11, 2013 3:45 PM
To: Jim Holloway
Subject: RE: Midwest Roadside Safety Invoice

>Jim; This is what my records show for the mixed used on your
project...let me know if you need it in a different format...Thanks, Judy


25% - 3A Gravel
28% - 1/4" Dry Chip Limestone
12% - 3/4" Clean Limestone
30% - RAP
5% - RAS
5.6% - PG58-28 asphaltic cement



Hello Judy, can you email me the mix design, not sure if they have gotten
> back to you yet or not?
>
> -----Original Message-----
> From: Judy Miller [mailto:catherandsons@futuretk.com]
> Sent: Friday, June 28, 2013 1:24 PM
> To: Jim Holloway
> Subject: RE: Midwest Roadside Safety Invoice
>
>>I will get with Rick or Mike for the mix design used on your project
>>and
> let you know...did I do the billing correctly?
>
> Hello Judy,
>>
>> I was hoping that the invoice would show the specific mix type that
>> was used. Can you determine that for me and send it to me on a
>> separate document, do you have a standard method of supplying mix
>> specification, like super paved shoulder, or binder, or base mix?
>>
>> Thanks
>>
>> Jim C. Holloway
>> Research and Development Test Site Manager Midwest Roadside Safety
>> Facility (MwRSF) University of Nebraska - Lincoln
>> 4800 NW 35th Street
>> Lincoln, NE 68524
```

Figure A-3. Asphalt Mow Strips Material Specification, MS-2, MS-4 – 5, and MSSP-1 – 2



FOR Rick **Urgent** ☐

DATE 6/15 TIME email

While You Were Out

M Jim Holloway of Commission

OF Midwest Roadside

PHONE Safety Facility

CELL
FAX [illegible] -

Message 402 472-6250

☒ TELEPHONED
☐ CAME TO SEE YOU
☐ RETURNED YOUR CALL
☑ PLEASE CALL
☐ WILL CALL AGAIN
☐ WANTS TO SEE YOU

25' x 4' x 4"

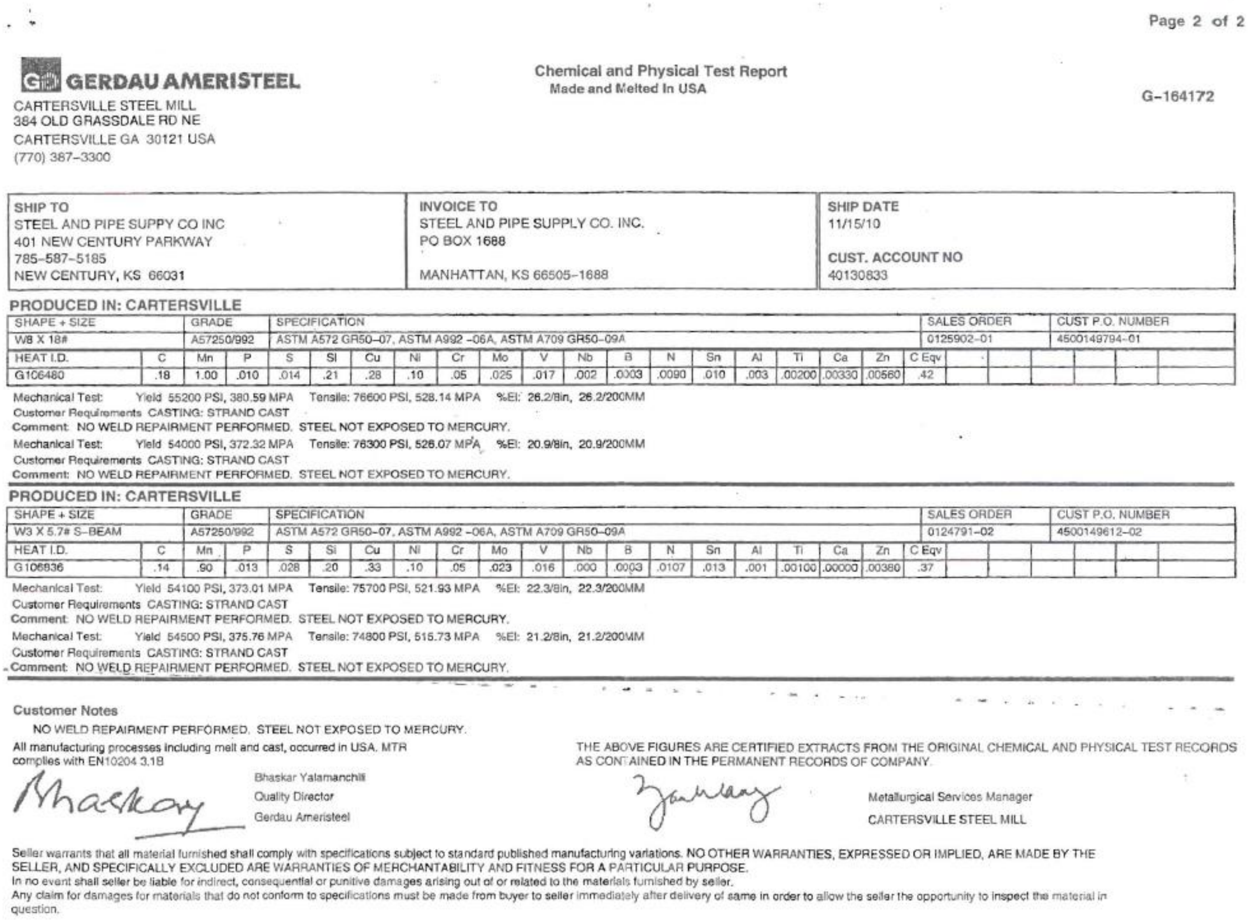
research project

Overlay - SPR
25% - 3A
28% - 1/4 Dri Chip / Cannot get now
12% - 3/4 Clean
30% rap
5% Ras 56% PG 58-28

A-9711
T-3002

SIGNED

Figure A-4. Asphalt Mow Strip Material Specification, MSSP-3 – MSSP-5



Page 2 of 2

GERDAU AMERISTEEL
CARTERSVILLE STEEL MILL
384 OLD GRASSDALE RD NE
CARTERSVILLE GA 30121 USA
(770) 387–3300

Chemical and Physical Test Report
Made and Melted In USA

G–164172

SHIP TO	INVOICE TO	SHIP DATE
STEEL AND PIPE SUPPY CO INC 401 NEW CENTURY PARKWAY 785–587–5185 NEW CENTURY, KS 66031	STEEL AND PIPE SUPPLY CO. INC. PO BOX 1688 MANHATTAN, KS 66505–1688	11/15/10 CUST. ACCOUNT NO 40130833

PRODUCED IN: CARTERSVILLE

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
W8 X 18#	A57250/992	ASTM A572 GR50–07, ASTM A992 –06A, ASTM A709 GR50–09A	0125902–01	4500149794–01

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	Zn	C Eqv
G106480	.18	1.00	.010	.014	.21	.28	.10	.05	.025	.017	.002	.0003	.0090	.010	.003	.00200	.00330	.00560	.42

Mechanical Test: Yield 55200 PSI, 380.59 MPA Tensile: 76600 PSI, 528.14 MPA %El: 26.2/8in, 26.2/200MM
Customer Requirements CASTING: STRAND CAST
Comment: NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.
Mechanical Test: Yield 54000 PSI, 372.32 MPA Tensile: 76300 PSI, 526.07 MPA %El: 20.9/8in, 20.9/200MM
Customer Requirements CASTING: STRAND CAST
Comment: NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.

PRODUCED IN: CARTERSVILLE

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
W3 X 5.7# S–BEAM	A57250/992	ASTM A572 GR50–07, ASTM A992 –06A, ASTM A709 GR50–09A	0124791–02	4500149612–02

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	Zn	C Eqv
G106836	.14	.90	.013	.028	.20	.33	.10	.05	.023	.016	.000	.0003	.0107	.013	.001	.00100	.00000	.00380	.37

Mechanical Test: Yield 54100 PSI, 373.01 MPA Tensile: 75700 PSI, 521.93 MPA %El: 22.3/8in, 22.3/200MM
Customer Requirements CASTING: STRAND CAST
Comment: NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.
Mechanical Test: Yield 54500 PSI, 375.76 MPA Tensile: 74800 PSI, 515.73 MPA %El: 21.2/8in, 21.2/200MM
Customer Requirements CASTING: STRAND CAST
Comment: NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.

Customer Notes

NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.

All manufacturing processes including melt and cast, occurred in USA. MTR complies with EN10204 3.1B

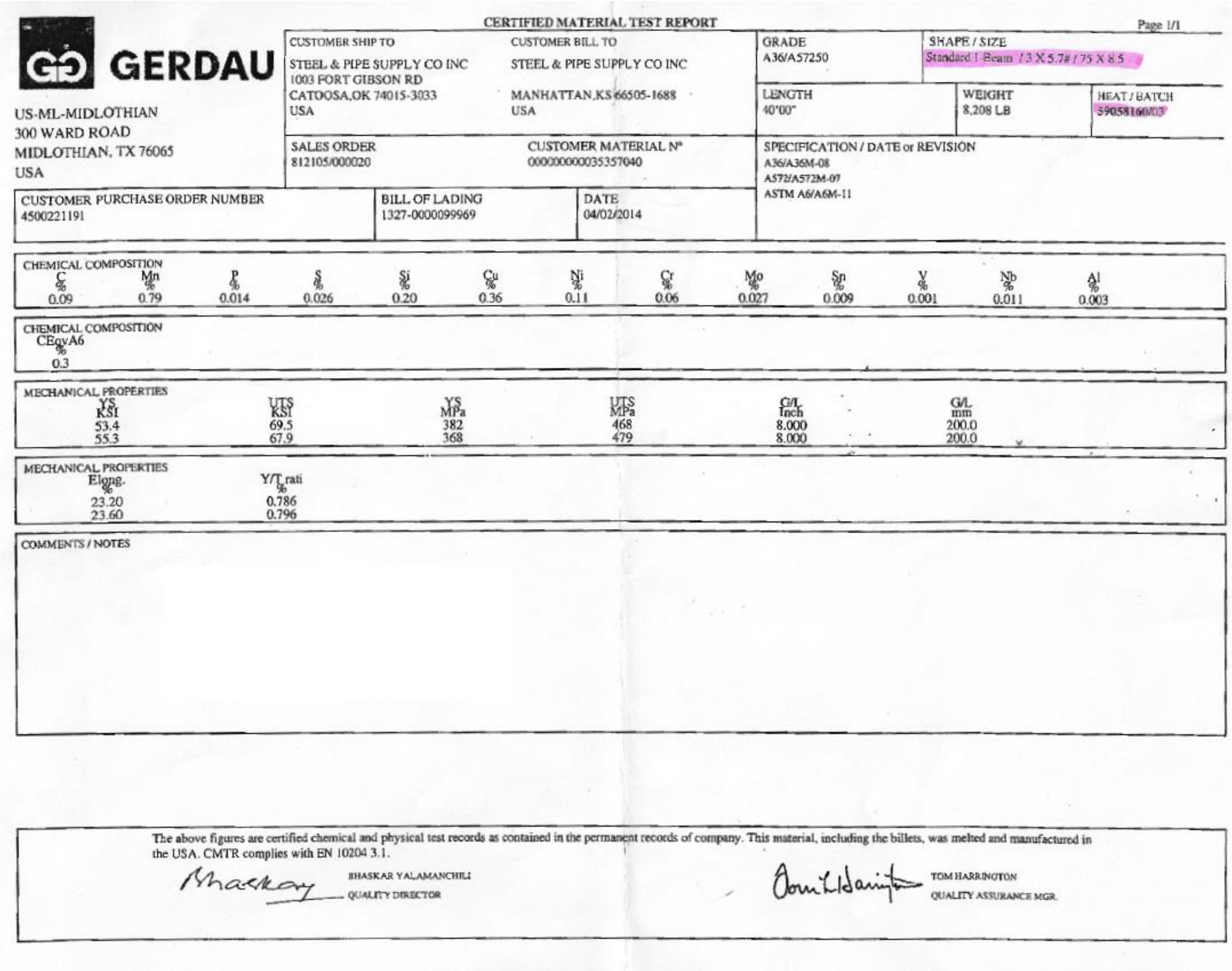
THE ABOVE FIGURES ARE CERTIFIED EXTRACTS FROM THE ORIGINAL CHEMICAL AND PHYSICAL TEST RECORDS AS CONTAINED IN THE PERMANENT RECORDS OF COMPANY.

Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

Metallurgical Services Manager
CARTERSVILLE STEEL MILL

Seller warrants that all material furnished shall comply with specifications subject to standard published manufacturing variations. NO OTHER WARRANTIES, EXPRESSED OR IMPLIED, ARE MADE BY THE SELLER, AND SPECIFICALLY EXCLUDED ARE WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.
In no event shall seller be liable for indirect, consequential or punitive damages arising out of or related to the materials furnished by seller.
Any claim for damages for materials that do not conform to specifications must be made from buyer to seller immediately after delivery of same in order to allow the seller the opportunity to inspect the material in question.

Figure A-5. S3x5.7 Posts Material Specification, MS-1 – 4, and MSSP-3 – 6



GERDAU

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO
STEEL & PIPE SUPPLY CO INC
1003 FORT GIBSON RD
CATOOSA,OK 74015-3033
USA

CUSTOMER BILL TO
STEEL & PIPE SUPPLY CO INC
MANHATTAN,KS 66505-1688
USA

GRADE: A36/A57250

SHAPE / SIZE: Standard I-Beam / 3 X 5.7# / 75 X 8.5

LENGTH: 40'00"

WEIGHT: 8,208 LB

HEAT / BATCH: 59058160/03

SALES ORDER: 812105/000020

CUSTOMER MATERIAL Nº: 000000000035357040

SPECIFICATION / DATE or REVISION
A36/A36M-08
A572/A572M-07
ASTM A6/A6M-11

CUSTOMER PURCHASE ORDER NUMBER: 4500221191

BILL OF LADING: 1327-0000099969

DATE: 04/02/2014

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.09	0.79	0.014	0.026	0.20	0.36	0.11	0.06	0.027	0.009	0.001	0.011	0.003

CHEMICAL COMPOSITION

CEqvA6 %
0.3

MECHANICAL PROPERTIES

YS KSI	UTS KSI	YS MPa	UTS MPa	G/L Inch	G/L mm
53.4	69.5	382	468	8.000	200.0
55.3	67.9	368	479	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	Y/T rati %
23.20	0.786
23.60	0.796

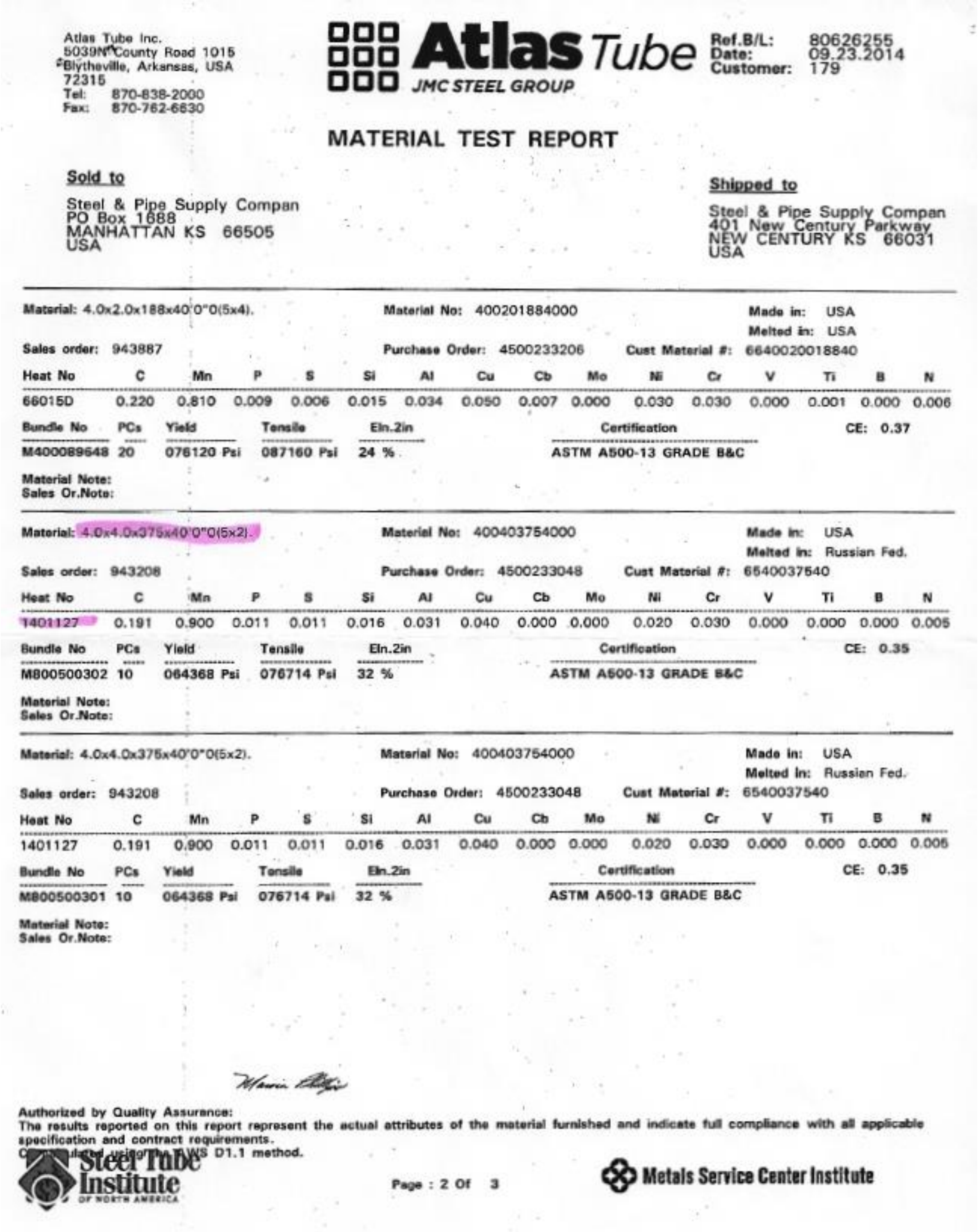
COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

TOM HARRINGTON
QUALITY ASSURANCE MGR.

Figure A-6. 62-in. S3x5.7 Post Material Specification, MS-5 and MSSP-1 – 2



Atlas Tube Inc.
5039N County Road 1015
Blytheville, Arkansas, USA
72315
Tel: 870-838-2000
Fax: 870-762-6630

Atlas *Tube*
JMC STEEL GROUP

Ref.B/L: 80626255
Date: 09.23.2014
Customer: 179

MATERIAL TEST REPORT

Sold to

Steel & Pipe Supply Compan
PO Box 1688
MANHATTAN KS 66505
USA

Shipped to

Steel & Pipe Supply Compan
401 New Century Parkway
NEW CENTURY KS 66031
USA

Material: 4.0x2.0x188x40'0"0(5x4). **Material No:** 400201884000 **Made in:** USA
Melted in: USA
Sales order: 943887 **Purchase Order:** 4500233206 **Cust Material #:** 6640020018840

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
66015D	0.220	0.810	0.009	0.006	0.015	0.034	0.050	0.007	0.000	0.030	0.030	0.000	0.001	0.000	0.006

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.37
M400089648	20	076120 Psi	087160 Psi	24 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 4.0x4.0x375x40'0"0(5x2). **Material No:** 400403754000 **Made in:** USA
Melted in: Russian Fed.
Sales order: 943208 **Purchase Order:** 4500233048 **Cust Material #:** 6540037540

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
1401127	0.191	0.900	0.011	0.011	0.016	0.031	0.040	0.000	0.000	0.020	0.030	0.000	0.000	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.35
M800500302	10	064368 Psi	076714 Psi	32 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 4.0x4.0x375x40'0"0(5x2). **Material No:** 400403754000 **Made in:** USA
Melted in: Russian Fed.
Sales order: 943208 **Purchase Order:** 4500233048 **Cust Material #:** 6540037540

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
1401127	0.191	0.900	0.011	0.011	0.016	0.031	0.040	0.000	0.000	0.020	0.030	0.000	0.000	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.35
M800500301	10	064368 Psi	076714 Psi	32 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

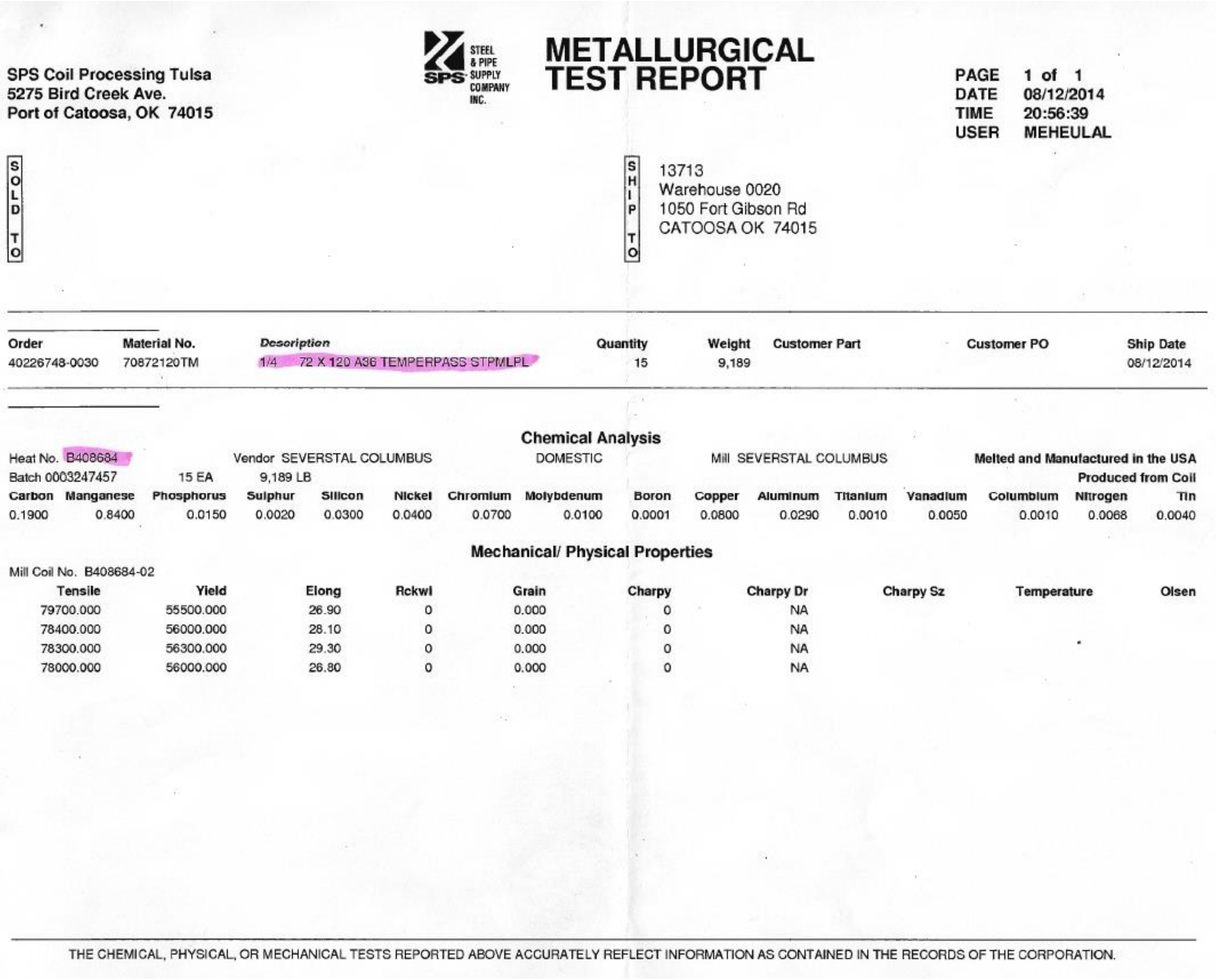
Authorized by Quality Assurance:
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
C[illegible]lated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 2 Of 3

Metals Service Center Institute

Figure A-7. Steel Sockets Material Specification, MS-5 and MSSP-1 – 5



SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

STEEL & PIPE SUPPLY COMPANY INC.

METALLURGICAL TEST REPORT

PAGE	**1 of 1**
DATE	**08/12/2014**
TIME	**20:56:39**
USER	**MEHEULAL**

SOLD TO

SHIP TO
13713
Warehouse 0020
1050 Fort Gibson Rd
CATOOSA OK 74015

Order	Material No.	*Description*	Quantity	Weight	Customer Part	Customer PO	Ship Date
40226748-0030	70872120TM	1/4 72 X 120 A36 TEMPERPASS STPMLPL	15	9,189			08/12/2014

Chemical Analysis

Heat No. B408684 Vendor SEVERSTAL COLUMBUS DOMESTIC Mill SEVERSTAL COLUMBUS **Melted and Manufactured in the USA**
Batch 0003247457 15 EA 9,189 LB **Produced from Coil**

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.1900	0.8400	0.0150	0.0020	0.0300	0.0400	0.0700	0.0100	0.0001	0.0800	0.0290	0.0010	0.0050	0.0010	0.0068	0.0040

Mechanical/ Physical Properties

Mill Coil No. B408684-02

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
79700.000	55500.000	26.90	0	0.000	0	NA			
78400.000	56000.000	28.10	0	0.000	0	NA			
78300.000	56300.000	29.30	0	0.000	0	NA			
78000.000	56000.000	26.80	0	0.000	0	NA			

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.

Figure A-8. ¼-in. Thick Steel Plate Material Specification, MS-5 and MSSP-1 – 5

Appendix B. Bogie Test Results

The results of the recorded data from each accelerometer for every dynamic component test are provided in the summary sheets found in this appendix. Summary sheets include acceleration, velocity, and deflection vs. time plots, as well as force vs. deflection and energy vs. deflection plots.

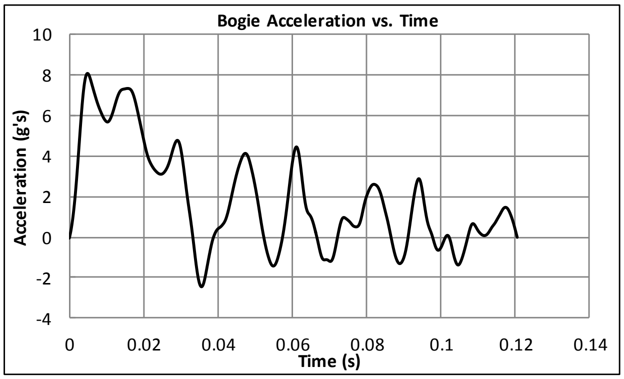
MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Post Installed in Mow Strip	
Test Number:	MS-1	
Test Date:	17-Jul-2013	
Failure Type:	Post Bending	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Mow Strip		
Pavement:	4" Concrete	
Mow Strip Prep:	4"x4" hole - blocked out during installation	
Socket		
Socket:	NA - Post placed in hole and driven into soil	
Bottom:	NA	
Fins:	NA	
Bogie Properties		
Impact Velocity:	19.75 mph (29 fps)	8.83 m/s
Impact Height:	12 in.	30.5 cm
Bogie Mass:	1799 lbs	816 kg

Test Results Summary		
Max. Deflection:	34.0	in.
Peak Force:	14.5	k
Initial Linear Stiffness:	8.6	k/in.
Total Energy:	122.5	k-in.

Data Acquired	
Acceleration Data:	DTS-SLICE



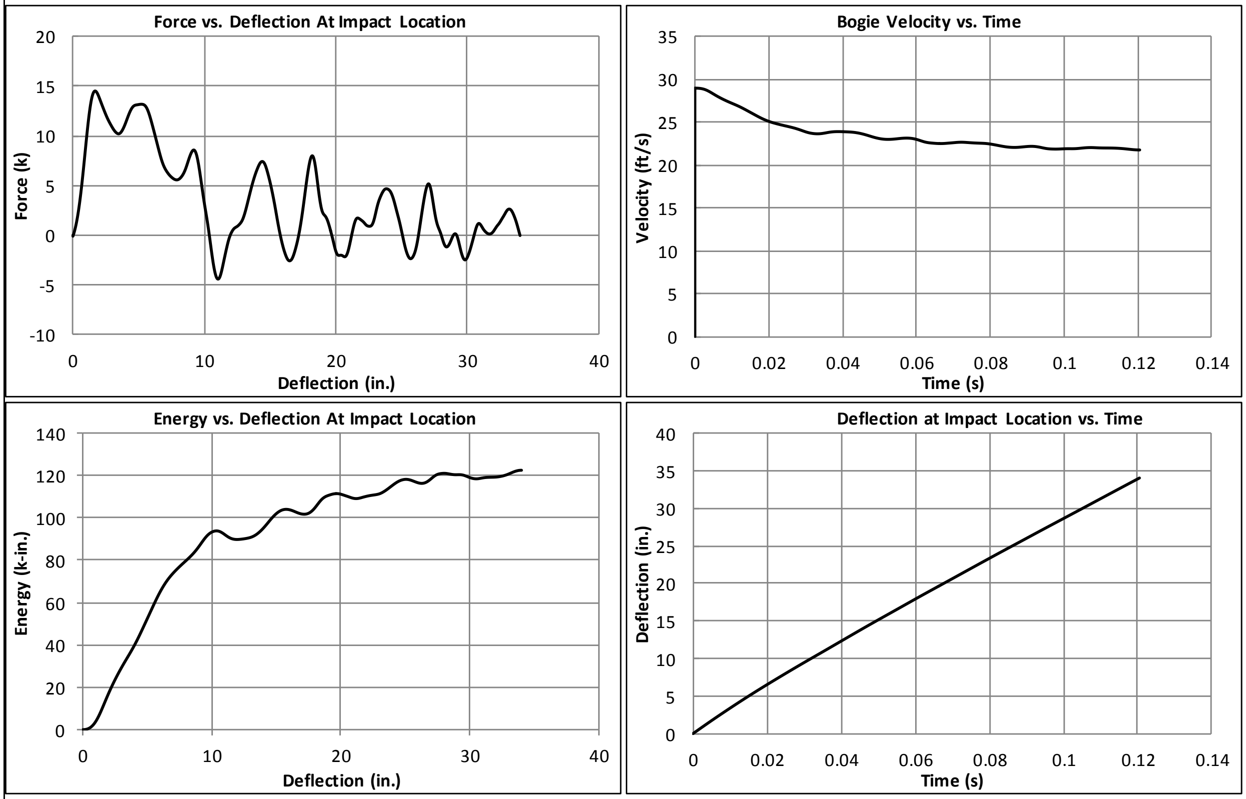


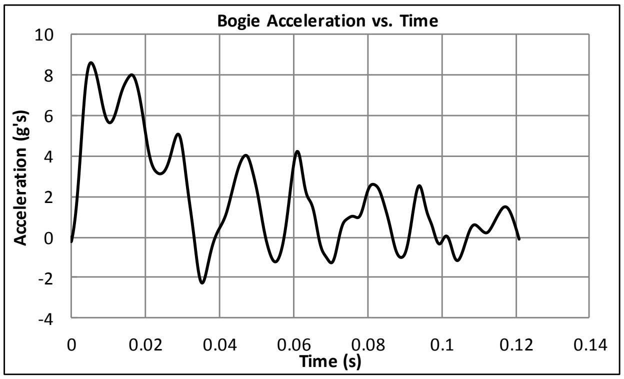
Figure B-1. Test No. MS-1 Results (SLICE-1)

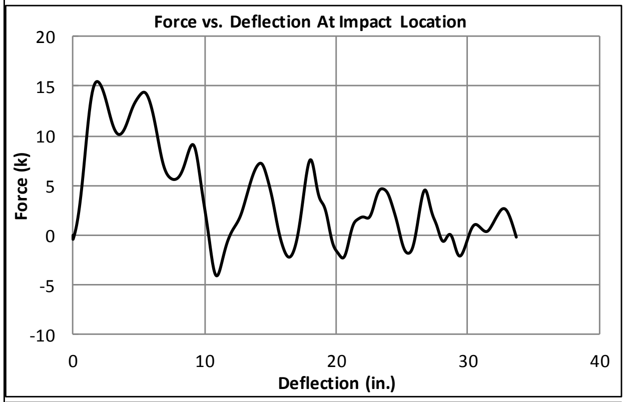
MIDWEST ROADSIDE SAFETY FACILITY

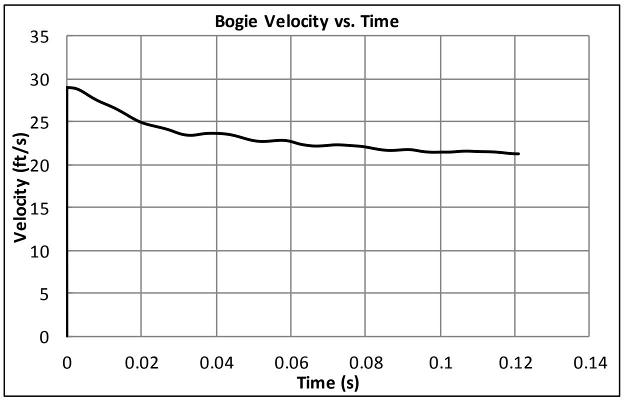
Bogie Test Summary

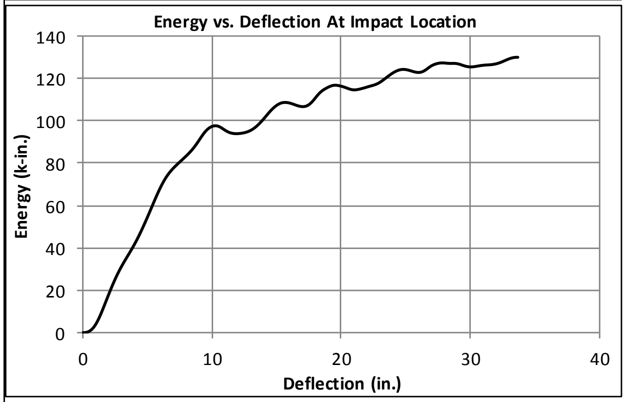
Test Information	Post Installed in Mow Strip	
Test Number:	MS-1	
Test Date:	17-Jul-2013	
Failure Type:	Post Bending	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Mow Strip		
Pavement:	4" Concrete	
Mow Strip Prep:	4"x4" hole - blocked out during installation	
Socket		
Socket:	NA - Post placed in hole and driven into soil	
Bottom:	NA	
Fins:	NA	
Bogie Properties		
Impact Velocity:	19.75 mph (29 fps)	8.83 m/s
Impact Height:	12 in.	30.5 cm
Bogie Mass:	1799 lbs	816 kg

Test Results Summary		
Max. Deflection:	33.7	in.
Peak Force:	15.5	k
Initial Linear Stiffness:	8.4	k/in.
Total Energy:	130.0	k-in.
Data Acquired		
Acceleration Data:	EDR-3	


Bogie Acceleration vs. Time


Force vs. Deflection At Impact Location


Bogie Velocity vs. Time


Energy vs. Deflection At Impact Location

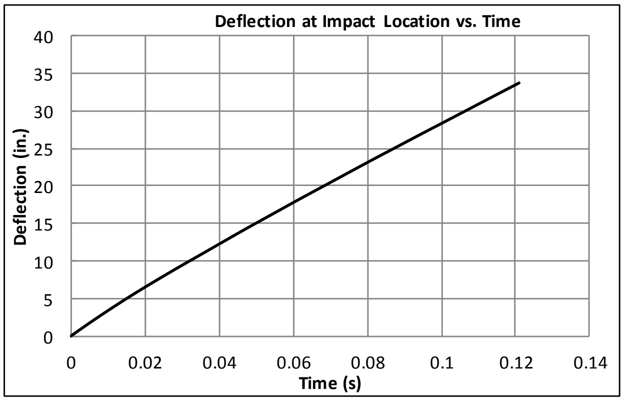

Deflection at Impact Location vs. Time

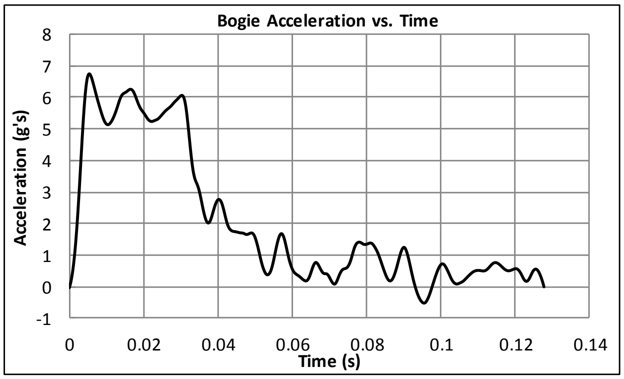
Figure B-2. Test No. MS-1 Results (EDR-3)

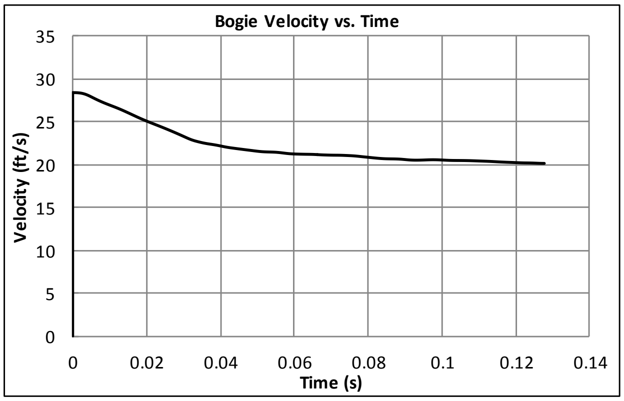
MIDWEST ROADSIDE SAFETY FACILITY

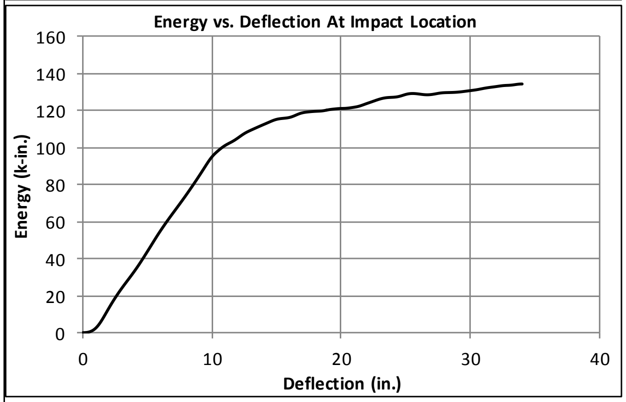
Bogie Test Summary

Test Information	Post Installed in Mow Strip	
Test Number:	MS-2	
Test Date:	17-Jan-2013	
Failure Type:	Post Bending - Asphalt Displacement	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Mow Strip		
Pavement:	4" Asphalt	
Mow Strip Prep:	None	
Socket		
Socket:	NA - Post driven through asphalt	
Bottom:	NA	
Fins:	NA	
Bogie Properties		
Impact Velocity:	19.35 mph (28.4 fps)	8.65 m/s
Impact Height:	12 in.	30.5 cm
Bogie Mass:	1799 lbs	816 kg

Test Results Summary		
Max. Deflection:	34.0	in.
Peak Force:	12.1	k
Initial Linear Stiffness:	6.6	k/in.
Total Energy:	134.2	k-in.
Data Acquired		
Acceleration Data:	DTS-SLICE	







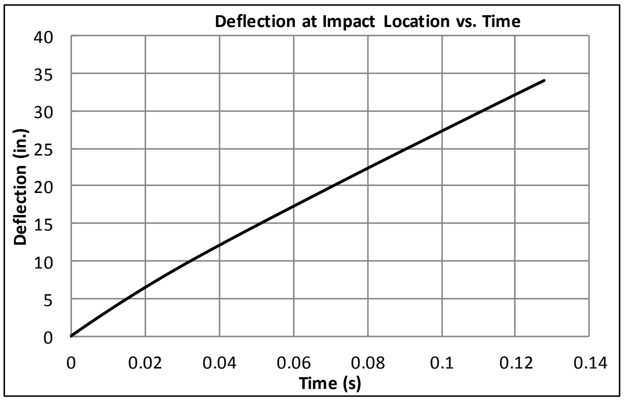


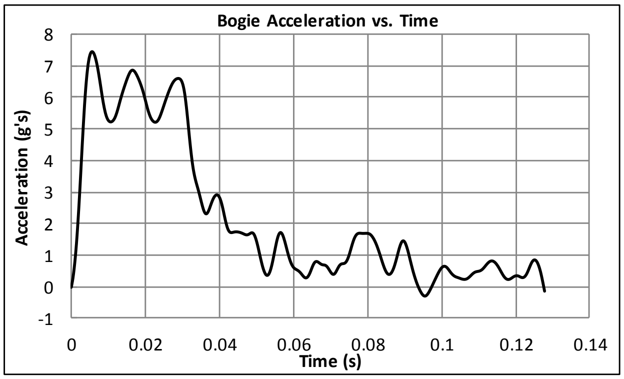
Figure B-3. Test No. MS-2 Results (SLICE-1)

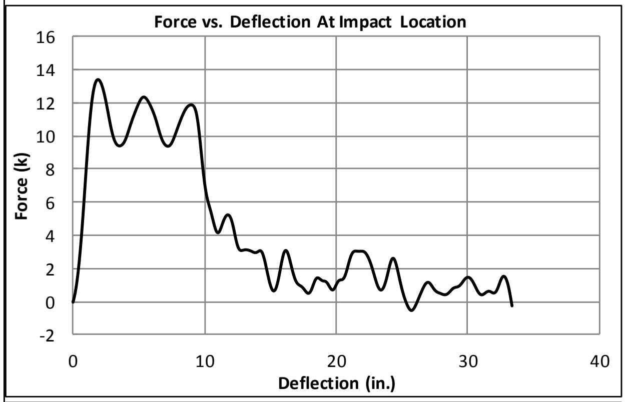
MIDWEST ROADSIDE SAFETY FACILITY

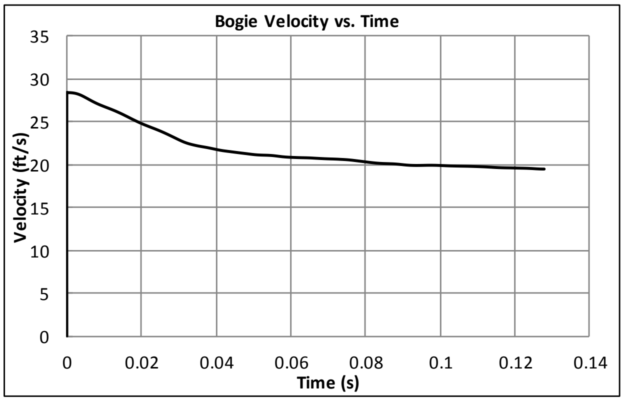
Bogie Test Summary

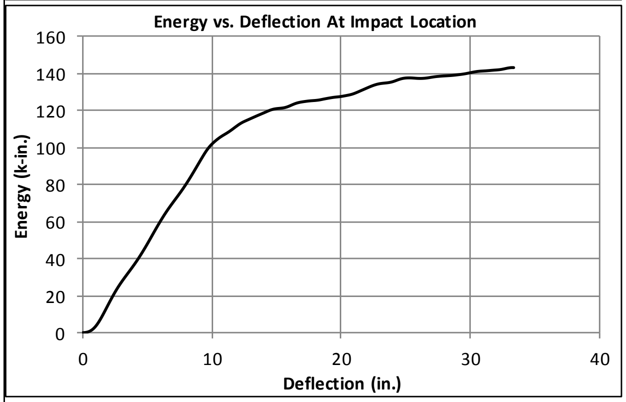
Test Information	Post Installed in Mow Strip	
Test Number:	MS-2	
Test Date:	17-Jan-2013	
Failure Type:	Post Bending - Asphalt Displacement	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Mow Strip		
Pavement:	4" Asphalt	
Mow Strip Prep:	None	
Socket		
Socket:	NA - Post driven through asphalt	
Bottom:	NA	
Fins:	NA	
Bogie Properties		
Impact Velocity:	19.35 mph (28.4 fps)	8.65 m/s
Impact Height:	12 in.	30.5 cm
Bogie Mass:	1799 lbs	816 kg

Test Results Summary		
Max. Deflection:	33.4	in.
Peak Force:	13.4	k
Initial Linear Stiffness:	7.0	k/in.
Total Energy:	143.1	k-in.
Data Acquired		
Acceleration Data:	EDR-3	









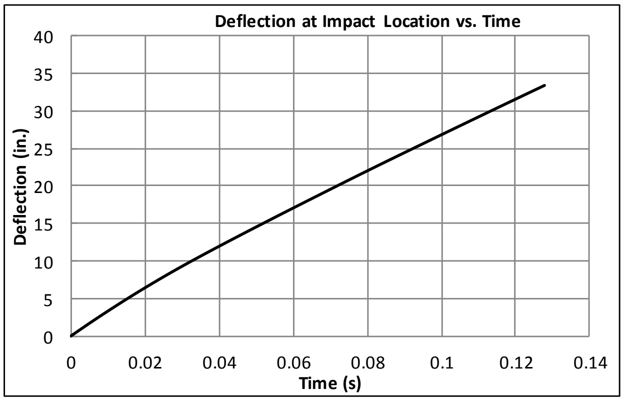
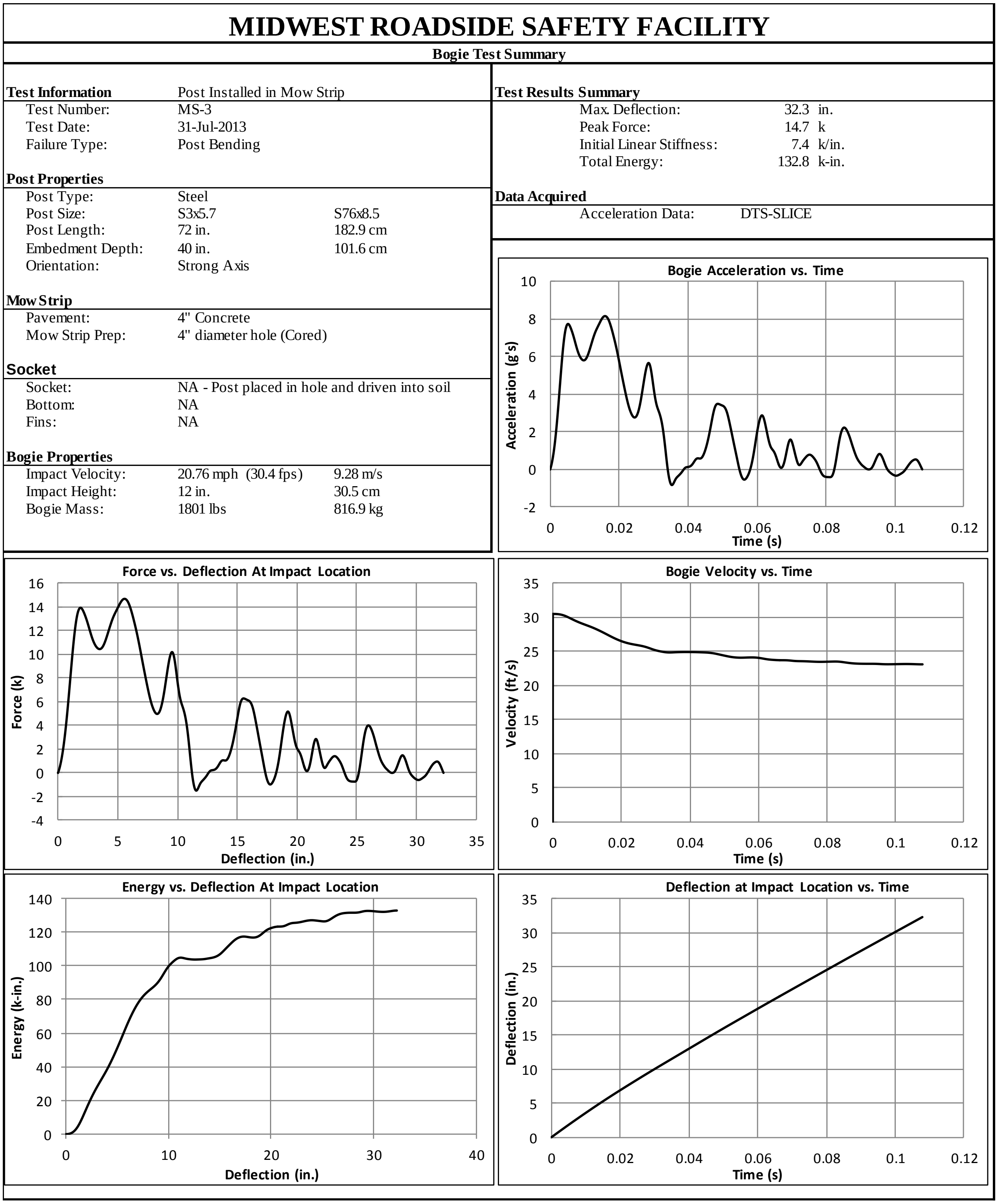


Figure B-4. Test No. MS-2 Results (EDR-3)



MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Post Installed in Mow Strip	
Test Number:	MS-3	
Test Date:	31-Jul-2013	
Failure Type:	Post Bending	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Mow Strip		
Pavement:	4" Concrete	
Mow Strip Prep:	4" diameter hole (Cored)	
Socket		
Socket:	NA - Post placed in hole and driven into soil	
Bottom:	NA	
Fins:	NA	
Bogie Properties		
Impact Velocity:	20.76 mph (30.4 fps)	9.28 m/s
Impact Height:	12 in.	30.5 cm
Bogie Mass:	1801 lbs	816.9 kg

Test Results Summary		
Max. Deflection:	32.3	in.
Peak Force:	14.7	k
Initial Linear Stiffness:	7.4	k/in.
Total Energy:	132.8	k-in.

Data Acquired

Acceleration Data: DTS-SLICE

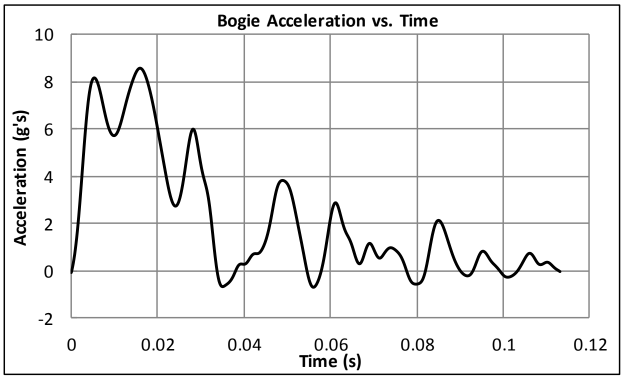
Figure B-5. Test No. MS-3 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Post Installed in Mow Strip	
Test Number:	MS-3	
Test Date:	31-Jul-2013	
Failure Type:	Post Bending	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Mow Strip		
Pavement:	4" Concrete	
Mow Strip Prep:	4" diameter hole (Cored)	
Socket		
Socket:	NA - Post placed in hole and driven into soil	
Bottom:	NA	
Fins:	NA	
Bogie Properties		
Impact Velocity:	20.76 mph (30.4 fps)	9.28 m/s
Impact Height:	12 in.	30.5 cm
Bogie Mass:	1799 lbs	816 kg

Test Results Summary		
Max. Deflection:	33.4	in.
Peak Force:	15.4	k
Initial Linear Stiffness:	2.8	k/in.
Total Energy:	138.8	k-in.
Data Acquired		
Acceleration Data:	EDR-3	



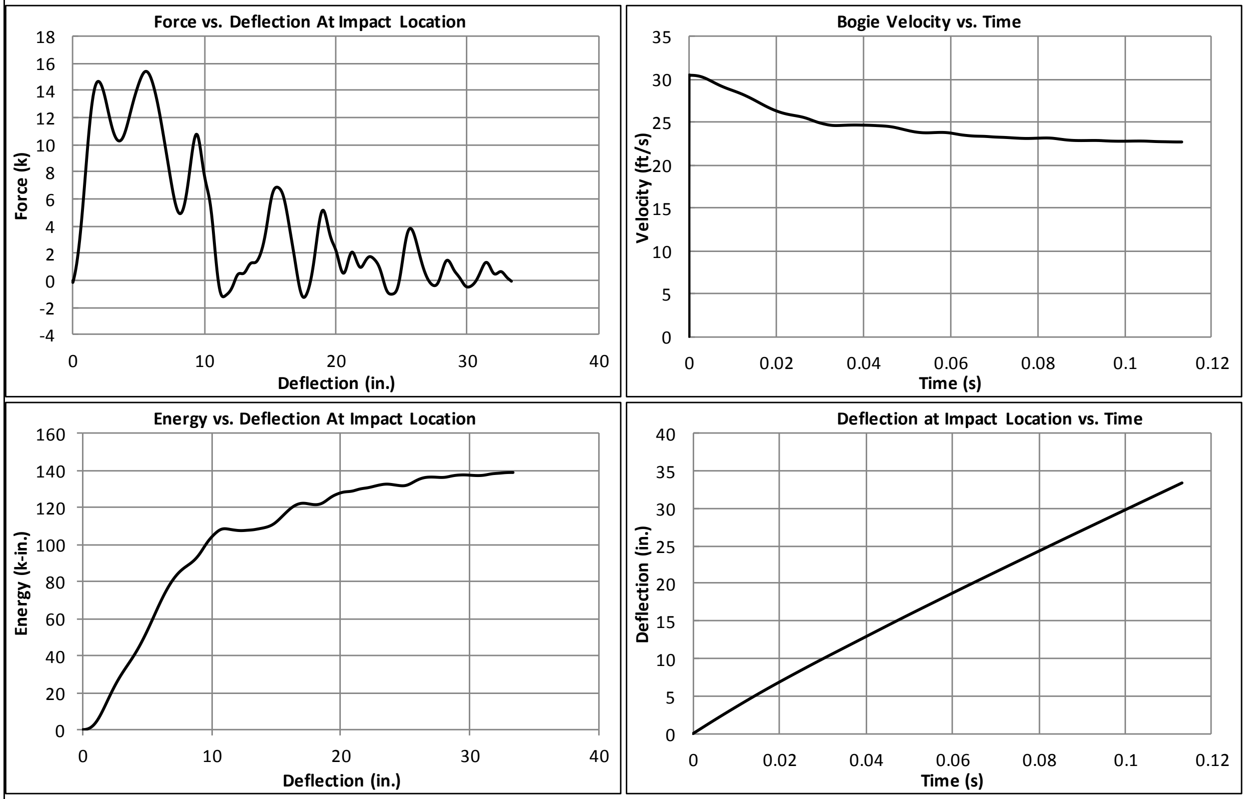


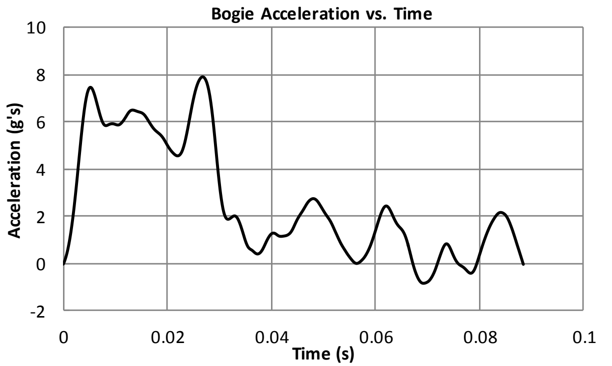
Figure B-6. Test No. MS-3 Results (EDR-3)

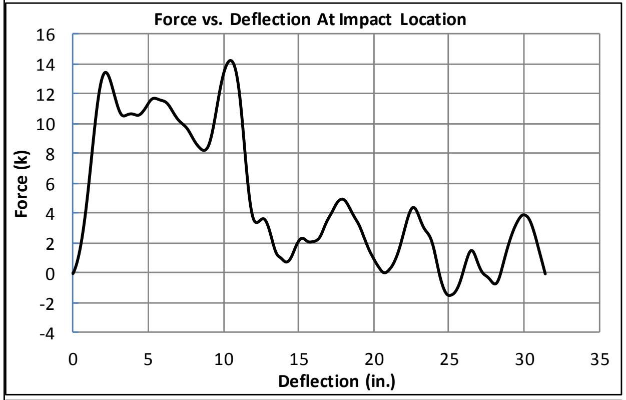
MIDWEST ROADSIDE SAFETY FACILITY

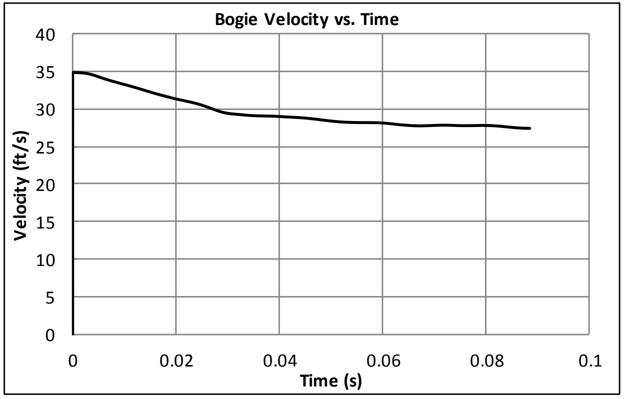
Bogie Test Summary

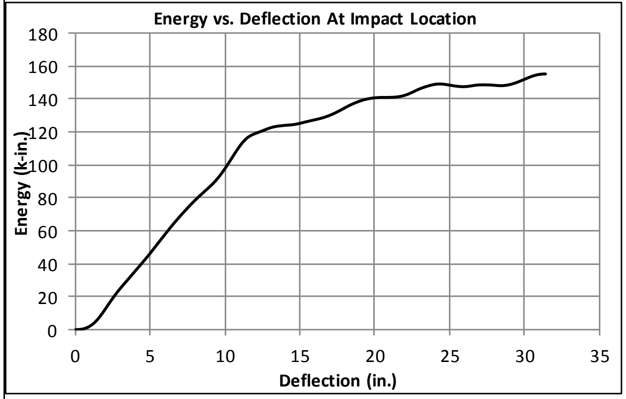
Test Information	Post Installed in Mow Strip	
Test Number:	MS-4	
Test Date:	31-Jul-2013	
Failure Type:	Post Bending - Asphalt Movement	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Mow Strip		
Pavement:	6" Asphalt	
Mow Strip Prep:	None	
Socket		
Socket:	NA - Post driven through asphalt	
Bottom:	NA	
Fins:	NA	
Bogie Properties		
Impact Velocity:	23.76 mph (34.8 fps)	10.62 m/s
Impact Height:	12 in.	30.5 cm
Bogie Mass:	1801 lbs	816.9 kg

Test Results Summary		
Max. Deflection:	31.4	in.
Peak Force:	14.2	k
Initial Linear Stiffness:	6.2	k/in.
Total Energy:	155.2	k-in.
Data Acquired		
Acceleration Data:	DTS-SLICE	









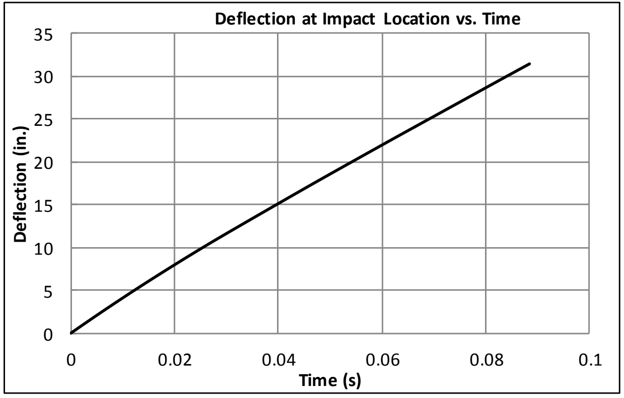


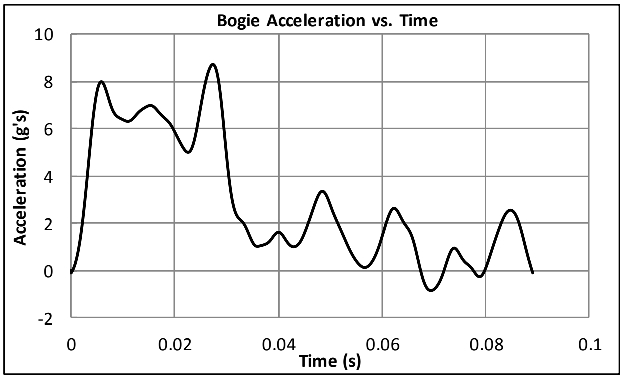
Figure B-7. Test No. MS-4 Results (SLICE-1)

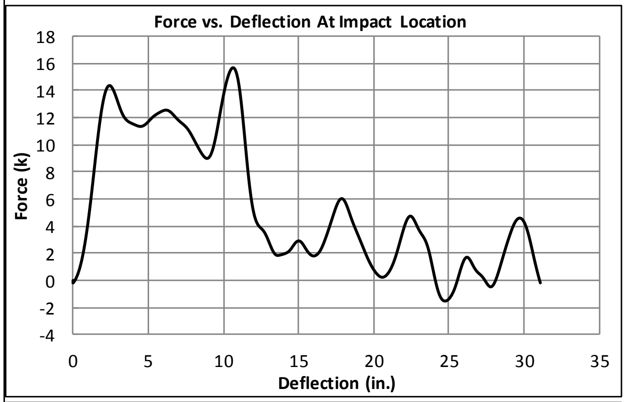
MIDWEST ROADSIDE SAFETY FACILITY

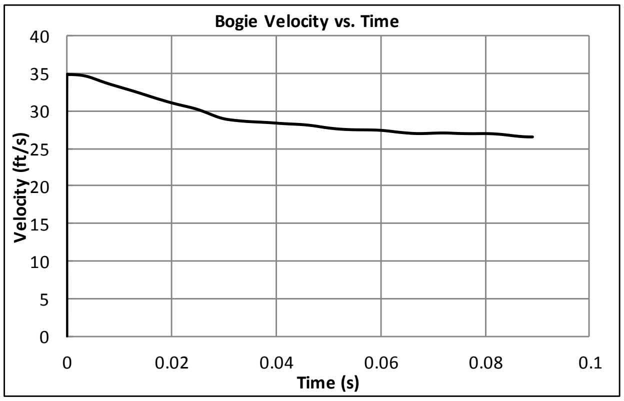
Bogie Test Summary

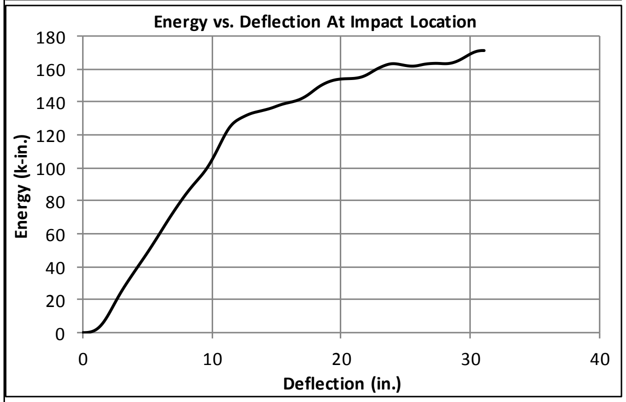
Test Information	Post Installed in Mow Strip	
Test Number:	MS-4	
Test Date:	31-Jul-2013	
Failure Type:	Post Bending - Asphalt Movement	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Mow Strip		
Pavement:	6" Asphalt	
Mow Strip Prep:	None	
Socket		
Socket:	NA - Post driven through asphalt	
Bottom:	NA	
Fins:	NA	
Bogie Properties		
Impact Velocity:	23.76 mph (34.8 fps)	10.62 m/s
Impact Height:	12 in.	30.5 cm
Bogie Mass:	1799 lbs	816 kg

Test Results Summary		
Max. Deflection:	31.1	in.
Peak Force:	15.7	k
Initial Linear Stiffness:	1.5	k/in.
Total Energy:	171.3	k-in.
Data Acquired		
Acceleration Data:	EDR-3	









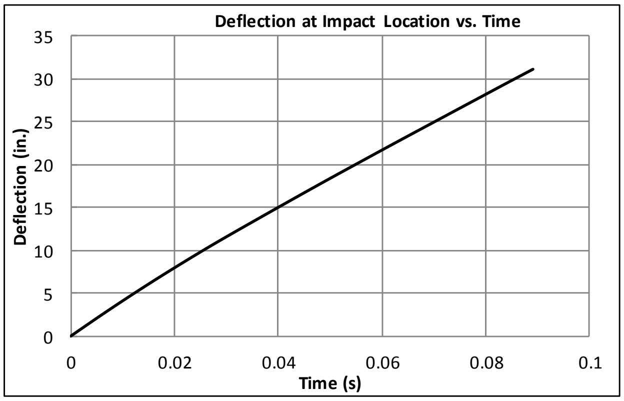


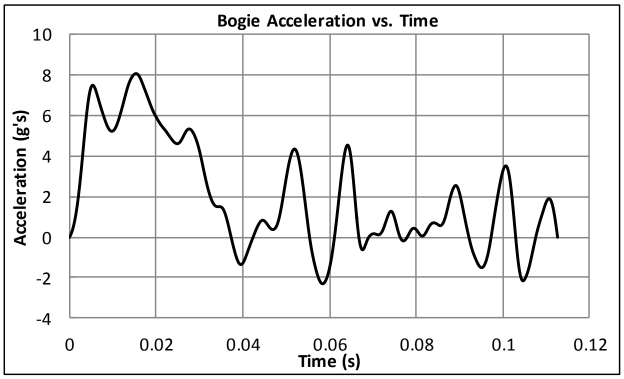
Figure B-8. Test No. MS-4 Results (EDR-3)

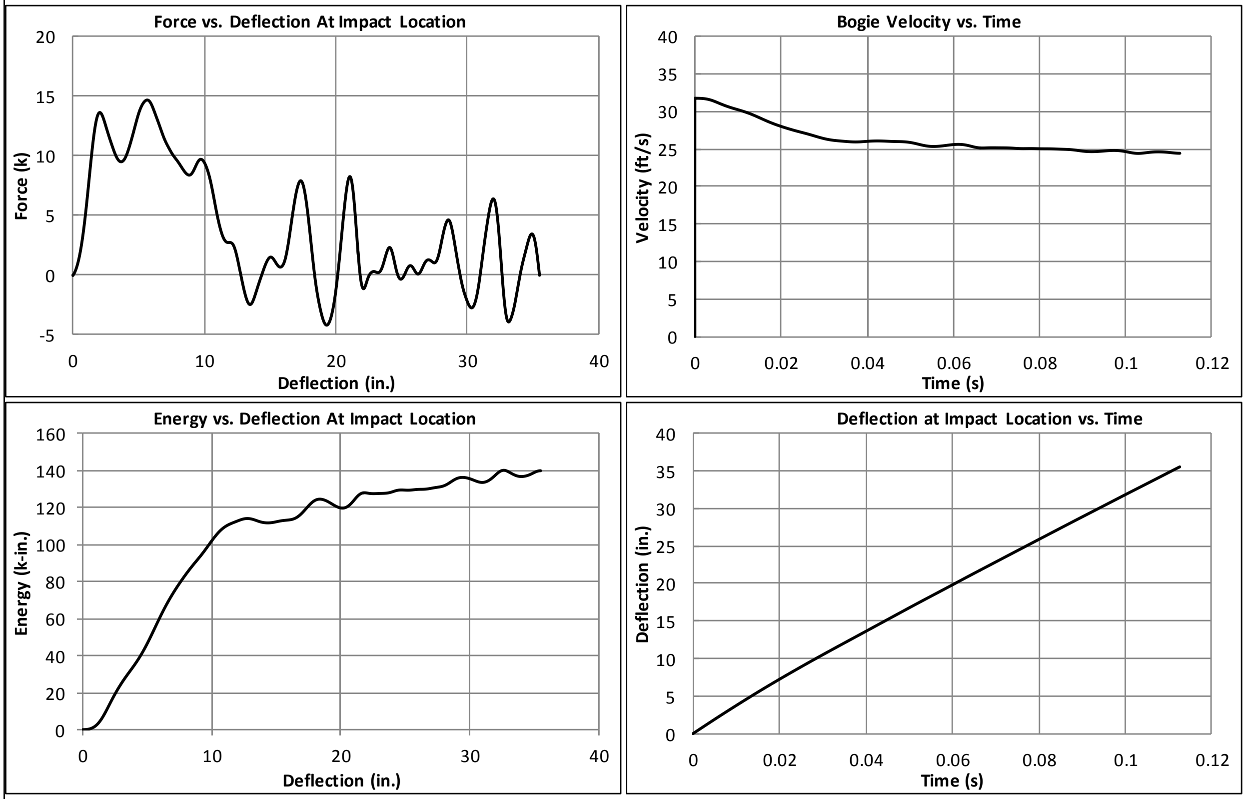
MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Post Installed in Mow Strip	
Test Number:	MS-5	
Test Date:	23-Aug-2013	
Failure Type:	Post Bending - Asphalt Movement	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	62 in.	157.5 cm
Embedment Depth:	30 in.	76.2 cm
Orientation:	0° - Strong Axis	
Mow Strip		
Pavement:	4" Asphalt	
Mow Strip Prep:	NA	
Socket		
Socket:	4"x4"x1/4" Tube	
Bottom:	Triangular Wedge	
Fins:	NA	
Bogie Properties		
Impact Velocity:	21.65 mph (31.8 fps)	9.68 m/s
Impact Height:	12 in.	30.5 cm
Bogie Mass:	1821 lbs	826 kg

Test Results Summary		
Max. Deflection:	35.5	in.
Peak Force:	14.7	k
Initial Linear Stiffness:	6.7	k/in.
Total Energy:	140.0	k-in.
Data Acquired		
Acceleration Data:	DTS	


Bogie Acceleration vs. Time

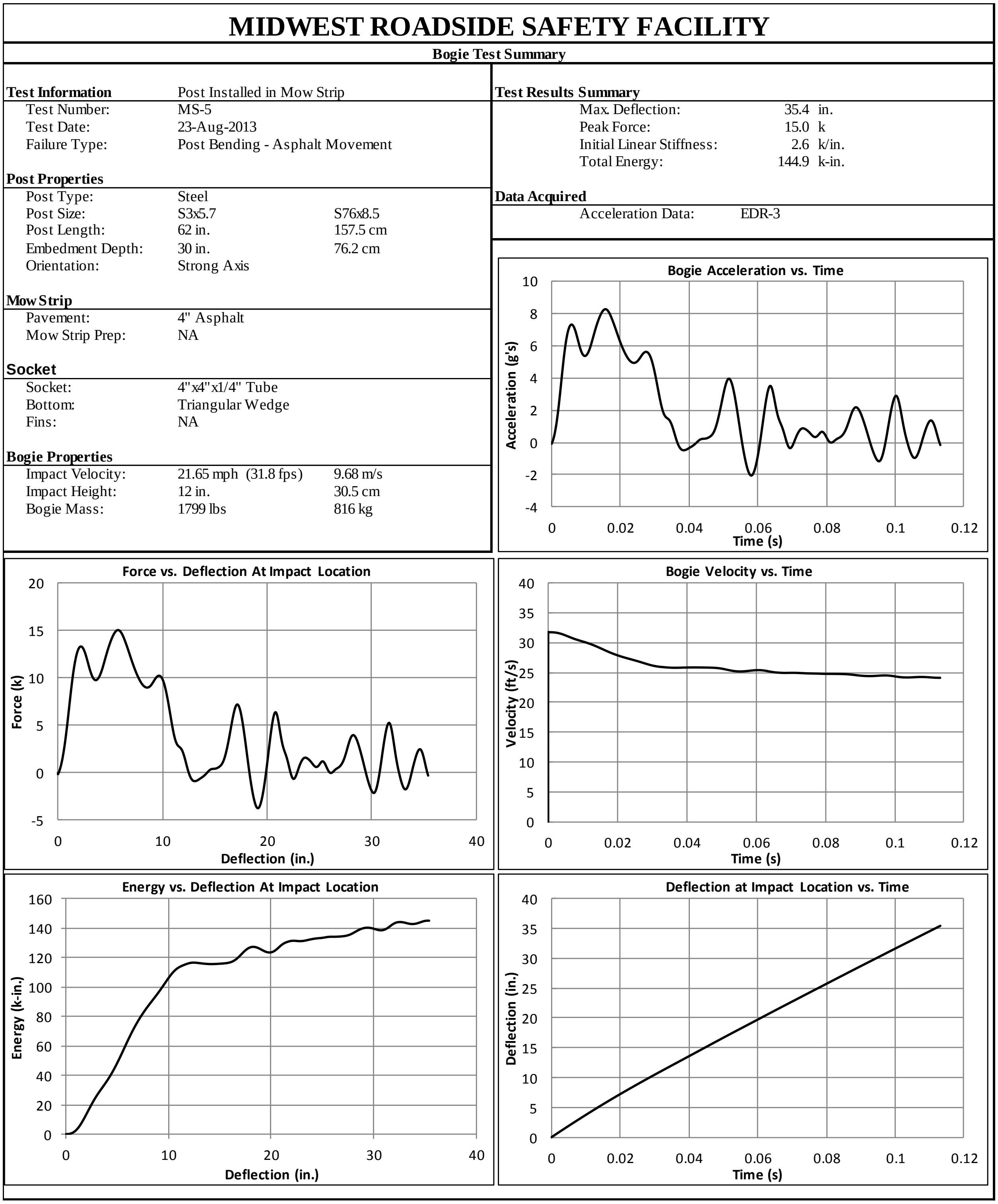

Force vs. Deflection At Impact Location

Bogie Velocity vs. Time

Energy vs. Deflection At Impact Location

Deflection at Impact Location vs. Time

Figure B-9. Test No. MS-5 Results (DTS)



MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Post Installed in Mow Strip	
Test Number:	MS-5	
Test Date:	23-Aug-2013	
Failure Type:	Post Bending - Asphalt Movement	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	S76x8.5
Post Length:	62 in.	157.5 cm
Embedment Depth:	30 in.	76.2 cm
Orientation:	Strong Axis	
Mow Strip		
Pavement:	4" Asphalt	
Mow Strip Prep:	NA	
Socket		
Socket:	4"x4"x1/4" Tube	
Bottom:	Triangular Wedge	
Fins:	NA	
Bogie Properties		
Impact Velocity:	21.65 mph (31.8 fps)	9.68 m/s
Impact Height:	12 in.	30.5 cm
Bogie Mass:	1799 lbs	816 kg

Test Results Summary		
Max. Deflection:	35.4	in.
Peak Force:	15.0	k
Initial Linear Stiffness:	2.6	k/in.
Total Energy:	144.9	k-in.

Data Acquired

Acceleration Data: EDR-3

Figure B-10. Test No. MS-5 Results (EDR-3)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Bogie vs. Post/Socket in 4" asphalt
Test Number:	MSSP-1
Test Date:	5/30/2014
Failure Type:	Post Bending

Post Properties

Post Size:	S3x5.7
Post Length:	62"
Embedment Depth:	30"
Orientation:	90° - Strong Axis

Socket

Socket:	4" x 4" x 1/4" Tube, 30" long
Bottom:	Triangluar Wedge
Shear Plate:	10" x 9" x 1/4" Plate on back side of socket

Mow Strip

Pavement:	4" Thick Asphalt

Bogie Properties

Impact Velocity:	21.4 mph	(31.38 ft/s)
Impact Height:	12"	
Bogie Mass:	1928 lb	

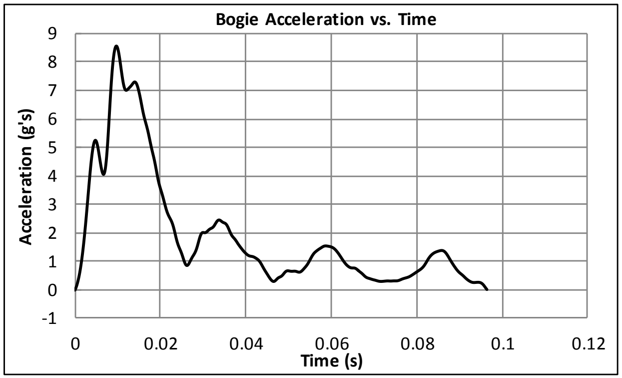
Data Acquired

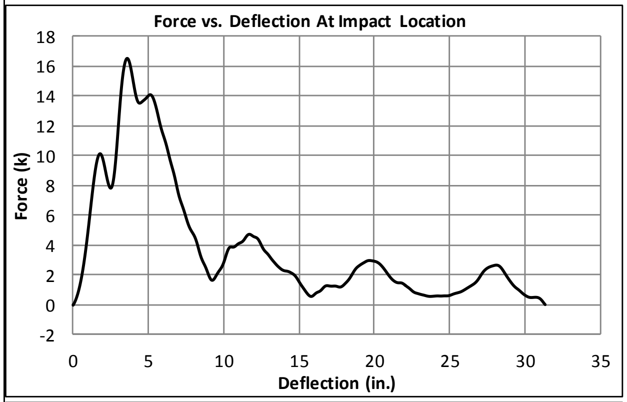
Accelerometer:	SLICE-2

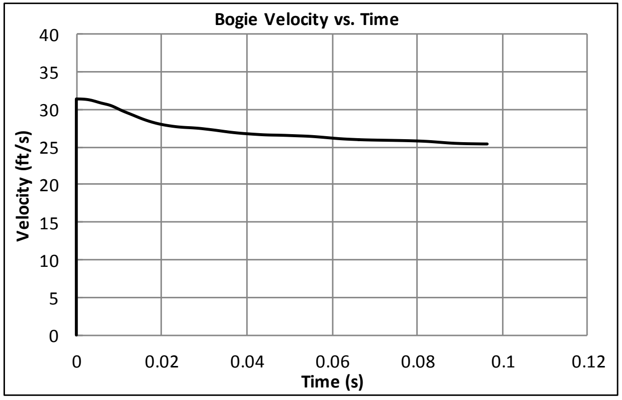
Test Results Summary

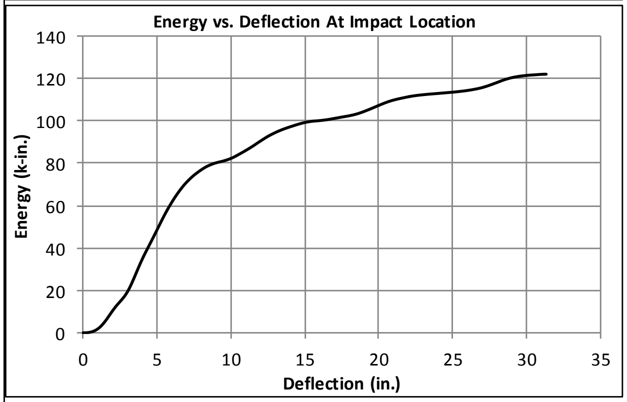
Event Duration:	0.0964	sec
Max. Deflection:	31.4	in.
Peak Force:	16.5	k
Initial Linear Stiffness:	4.6	k/in.
Total Energy:	122.1	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	9.66	8.22	6.62	5.36
Energy (k-in.)	48.3	82.2	99.2	107.2


Bogie Acceleration vs. Time


Force vs. Deflection At Impact Location


Bogie Velocity vs. Time


Energy vs. Deflection At Impact Location

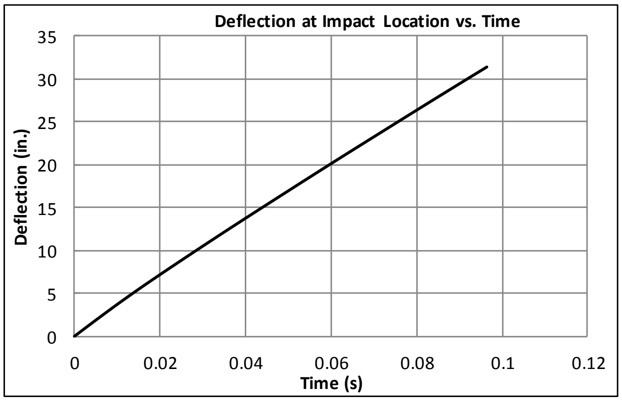
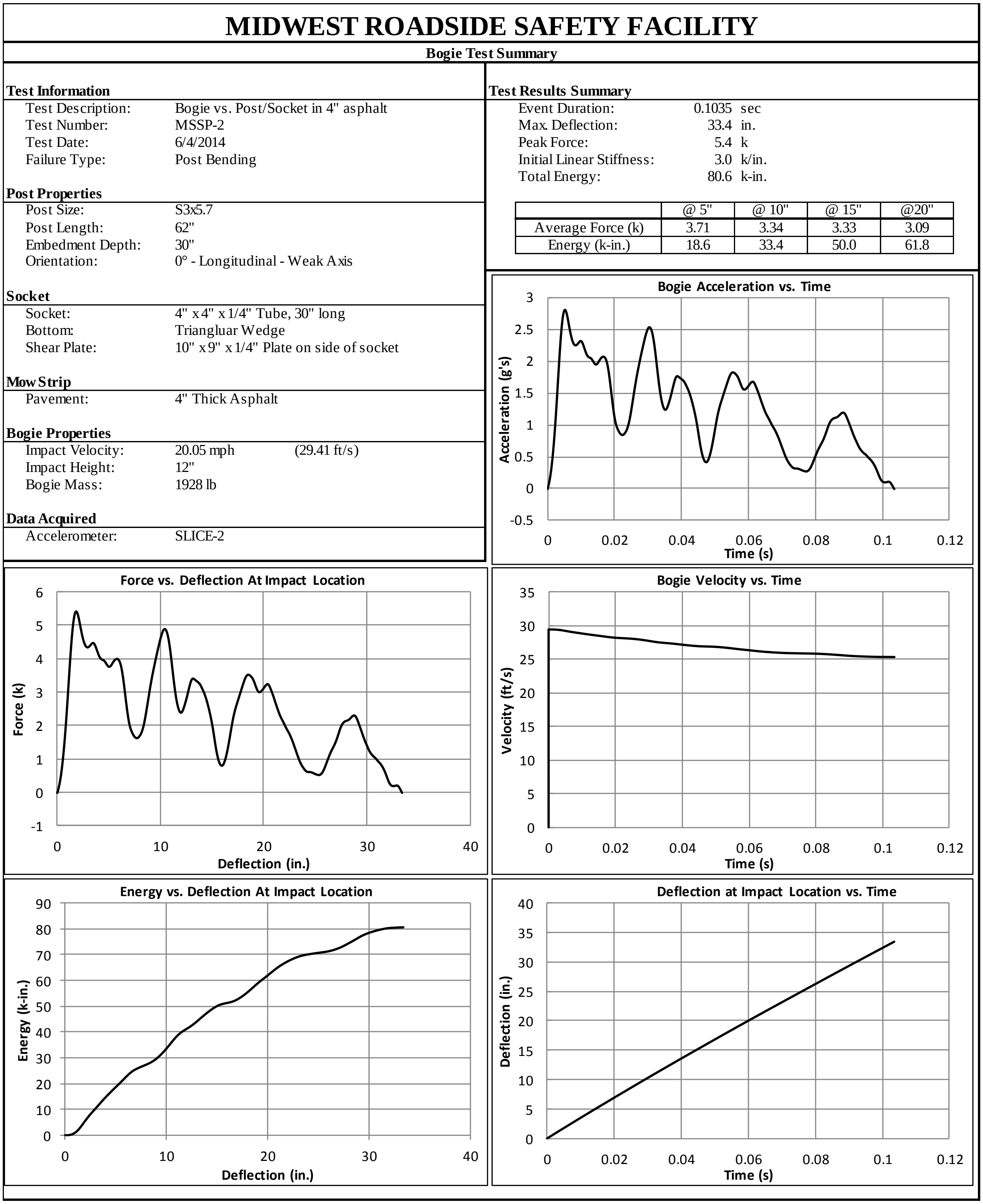

Deflection at Impact Location vs. Time

Figure B-11. Test No. MSSP-1 Results (SLICE-2)



MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description: Bogie vs. Post/Socket in 4" asphalt
Test Number: MSSP-2
Test Date: 6/4/2014
Failure Type: Post Bending

Post Properties

Post Size: S3x5.7
Post Length: 62"
Embedment Depth: 30"
Orientation: 0° - Longitudinal - Weak Axis

Socket

Socket: 4" x 4" x 1/4" Tube, 30" long
Bottom: Triangluar Wedge
Shear Plate: 10" x 9" x 1/4" Plate on side of socket

Mow Strip

Pavement: 4" Thick Asphalt

Bogie Properties

Impact Velocity: 20.05 mph (29.41 ft/s)
Impact Height: 12"
Bogie Mass: 1928 lb

Data Acquired

Accelerometer: SLICE-2

Test Results Summary

Event Duration: 0.1035 sec
Max. Deflection: 33.4 in.
Peak Force: 5.4 k
Initial Linear Stiffness: 3.0 k/in.
Total Energy: 80.6 k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	3.71	3.34	3.33	3.09
Energy (k-in.)	18.6	33.4	50.0	61.8

Bogie Acceleration vs. Time

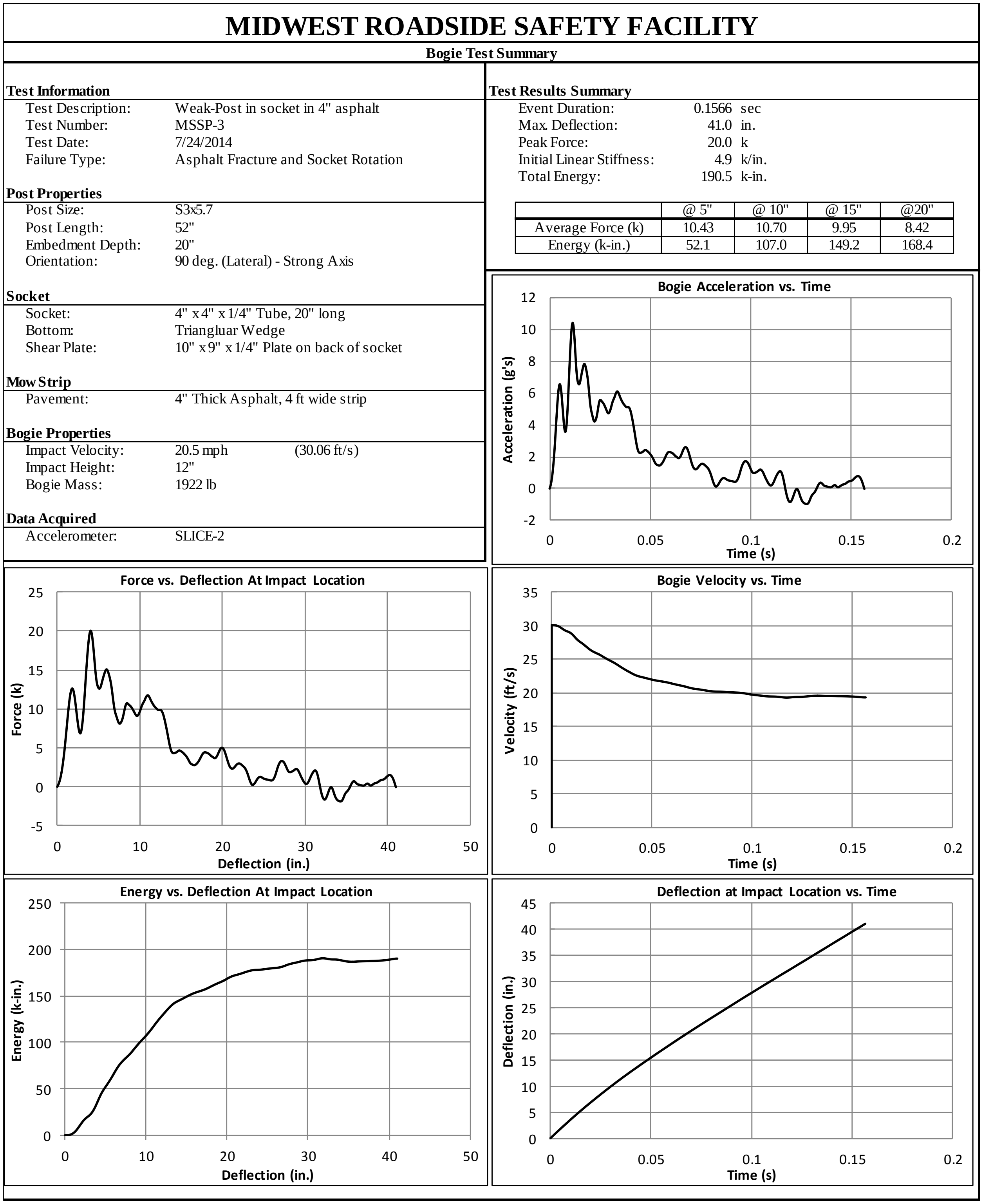
Force vs. Deflection At Impact Location

Bogie Velocity vs. Time

Energy vs. Deflection At Impact Location

Deflection at Impact Location vs. Time

Figure B-12. Test No. MSSP-2 Results (SLICE-2)



MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Weak-Post in socket in 4" asphalt
Test Number:	MSSP-3
Test Date:	7/24/2014
Failure Type:	Asphalt Fracture and Socket Rotation

Post Properties

Post Size:	S3x5.7
Post Length:	52"
Embedment Depth:	20"
Orientation:	90 deg. (Lateral) - Strong Axis

Socket

Socket:	4" x 4" x 1/4" Tube, 20" long
Bottom:	Triangluar Wedge
Shear Plate:	10" x 9" x 1/4" Plate on back of socket

Mow Strip

Pavement:	4" Thick Asphalt, 4 ft wide strip

Bogie Properties

Impact Velocity:	20.5 mph	(30.06 ft/s)
Impact Height:	12"	
Bogie Mass:	1922 lb	

Data Acquired

Accelerometer:	SLICE-2

Test Results Summary

Event Duration:	0.1566	sec
Max. Deflection:	41.0	in.
Peak Force:	20.0	k
Initial Linear Stiffness:	4.9	k/in.
Total Energy:	190.5	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	10.43	10.70	9.95	8.42
Energy (k-in.)	52.1	107.0	149.2	168.4

Figure B-13. Test No. MSSP-3 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Weak-Post in socket in 4" asphalt
Test Number:	MSSP-4
Test Date:	8/8/2014
Failure Type:	Post Bending

Post Properties

Post Size:	S3x5.7
Post Length:	56"
Embedment Depth:	24"
Orientation:	90 deg. (Lateral) - Strong Axis

Socket

Socket:	4" x 4" x 1/4" Tube, 24" long
Bottom:	Triangluar Wedge
Shear Plate:	10" x 6" x 1/4" Plate on back of socket

Mow Strip

Pavement:	4" Thick Asphalt, 4 ft wide strip

Bogie Properties

Impact Velocity:	20.83 mph	(30.55 ft/s)
Impact Height:	12"	
Bogie Mass:	1922 lb	

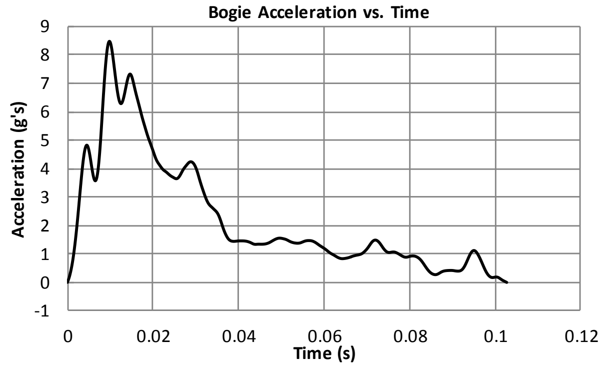
Data Acquired

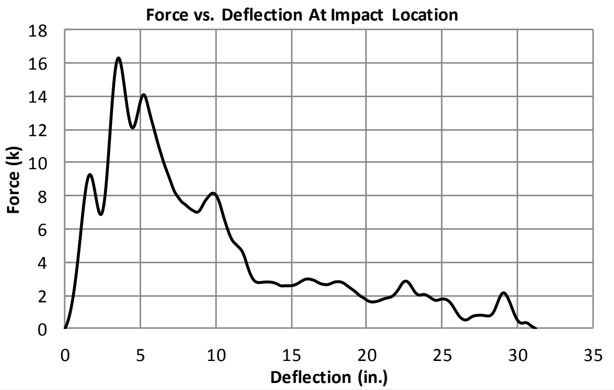
Accelerometer:	SLICE-2

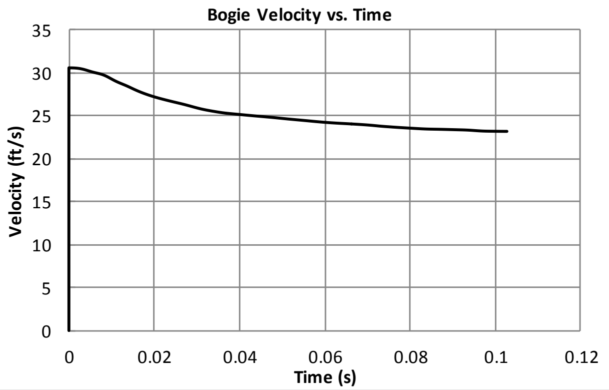
Test Results Summary

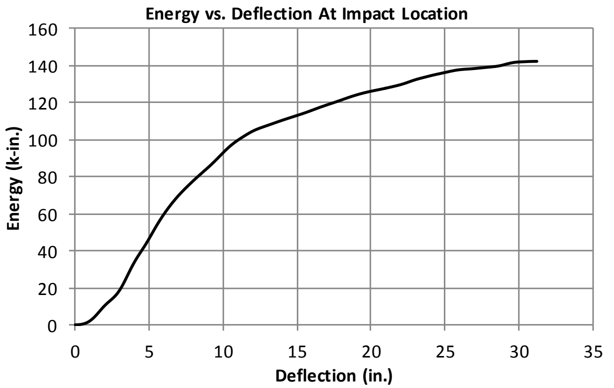
Event Duration:	0.1027	sec
Max. Deflection:	31.2	in.
Peak Force:	16.3	k
Initial Linear Stiffness:	4.6	k/in.
Total Energy:	142.1	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	9.26	9.26	7.53	6.30
Energy (k-in.)	46.3	92.6	112.9	125.9


Bogie Acceleration vs. Time


Force vs. Deflection At Impact Location


Bogie Velocity vs. Time


Energy vs. Deflection At Impact Location

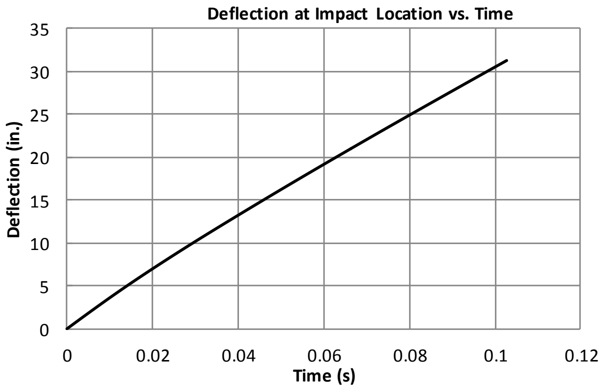
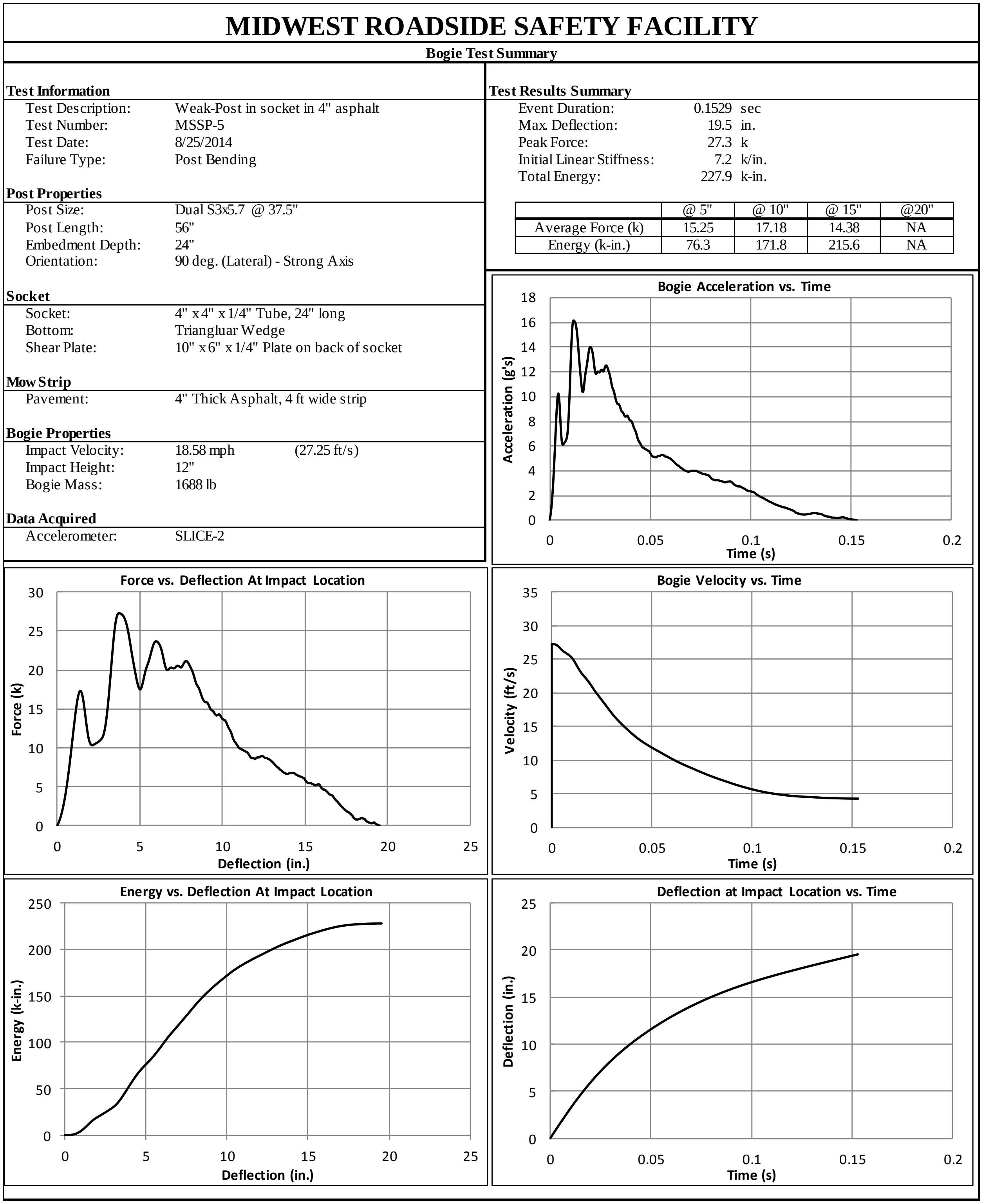

Deflection at Impact Location vs. Time

Figure B-14. Test No. MSSP-4 Results (SLICE-2)



MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Weak-Post in socket in 4" asphalt
Test Number:	MSSP-5
Test Date:	8/25/2014
Failure Type:	Post Bending

Post Properties

Post Size:	Dual S3x5.7 @ 37.5"
Post Length:	56"
Embedment Depth:	24"
Orientation:	90 deg. (Lateral) - Strong Axis

Socket

Socket:	4" x 4" x 1/4" Tube, 24" long
Bottom:	Triangluar Wedge
Shear Plate:	10" x 6" x 1/4" Plate on back of socket

Mow Strip

Pavement:	4" Thick Asphalt, 4 ft wide strip

Bogie Properties

Impact Velocity:	18.58 mph	(27.25 ft/s)
Impact Height:	12"	
Bogie Mass:	1688 lb	

Data Acquired

Accelerometer:	SLICE-2

Test Results Summary

Event Duration:	0.1529	sec
Max. Deflection:	19.5	in.
Peak Force:	27.3	k
Initial Linear Stiffness:	7.2	k/in.
Total Energy:	227.9	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	15.25	17.18	14.38	NA
Energy (k-in.)	76.3	171.8	215.6	NA

Figure B-15. Test No. MSSP-5 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description: Dual Post Impact
Test Number: MSSP-6
Test Date: 1/23/2015
Failure Type: Post Bending

Post Properties

Post Type: Steel
Post Size: (Dual) S3x5.7 @ 37.5" Spacing
Post Length: (2) 72"
Embedment Depth: 40"
Orientation: 90 deg. (Strong axis)

Mow Strip

Pavement: Concrete
Depth: 4"
Width: 4 ft

Bogie Properties

Impact Velocity: 20.13 mph (29.53 ft/s)
Impact Height: 12"
Bogie Mass: 1684 lb

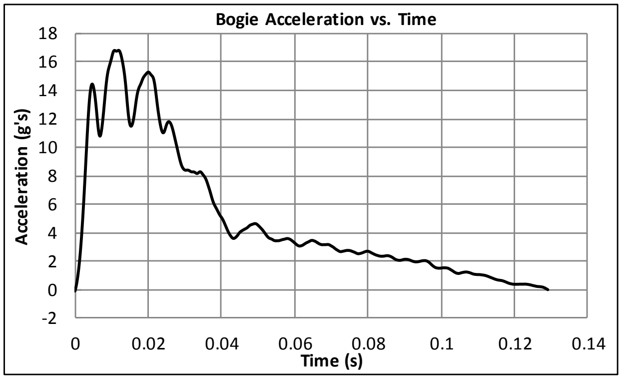
Data Acquired

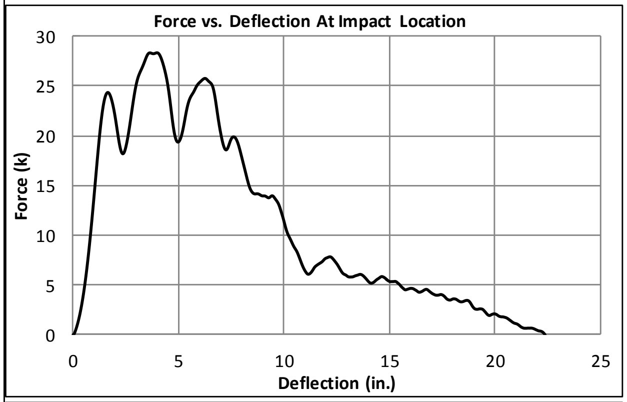
Accelerometer: SLICE-2
Camera Data: AOS-9, @ 165" Laterally from post

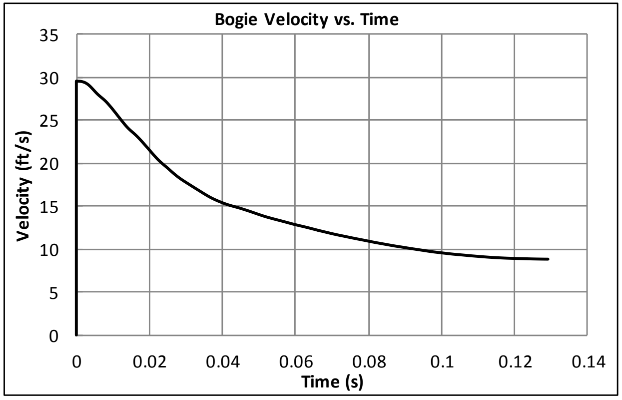
Test Results Summary

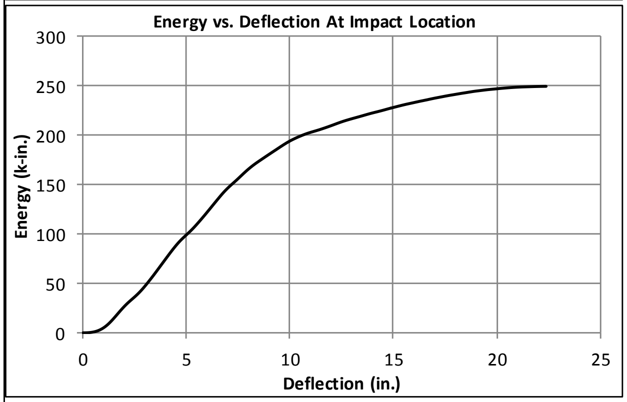
Event Duration: 0.1291 sec
Max. Deflection: 22.4 in.
Peak Force: 28.3 k
Initial Linear Stiffness: 14.8 k/in.
Total Energy: 249.3 k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	19.72	19.39	15.19	12.34
Energy (k-in.)	98.6	193.9	227.9	246.8


Bogie Acceleration vs. Time


Force vs. Deflection At Impact Location


Bogie Velocity vs. Time


Energy vs. Deflection At Impact Location

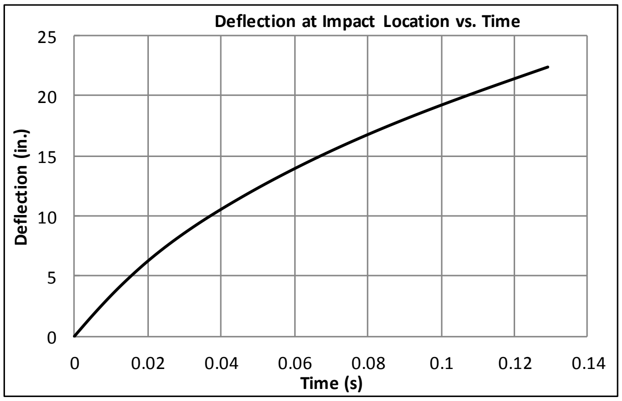
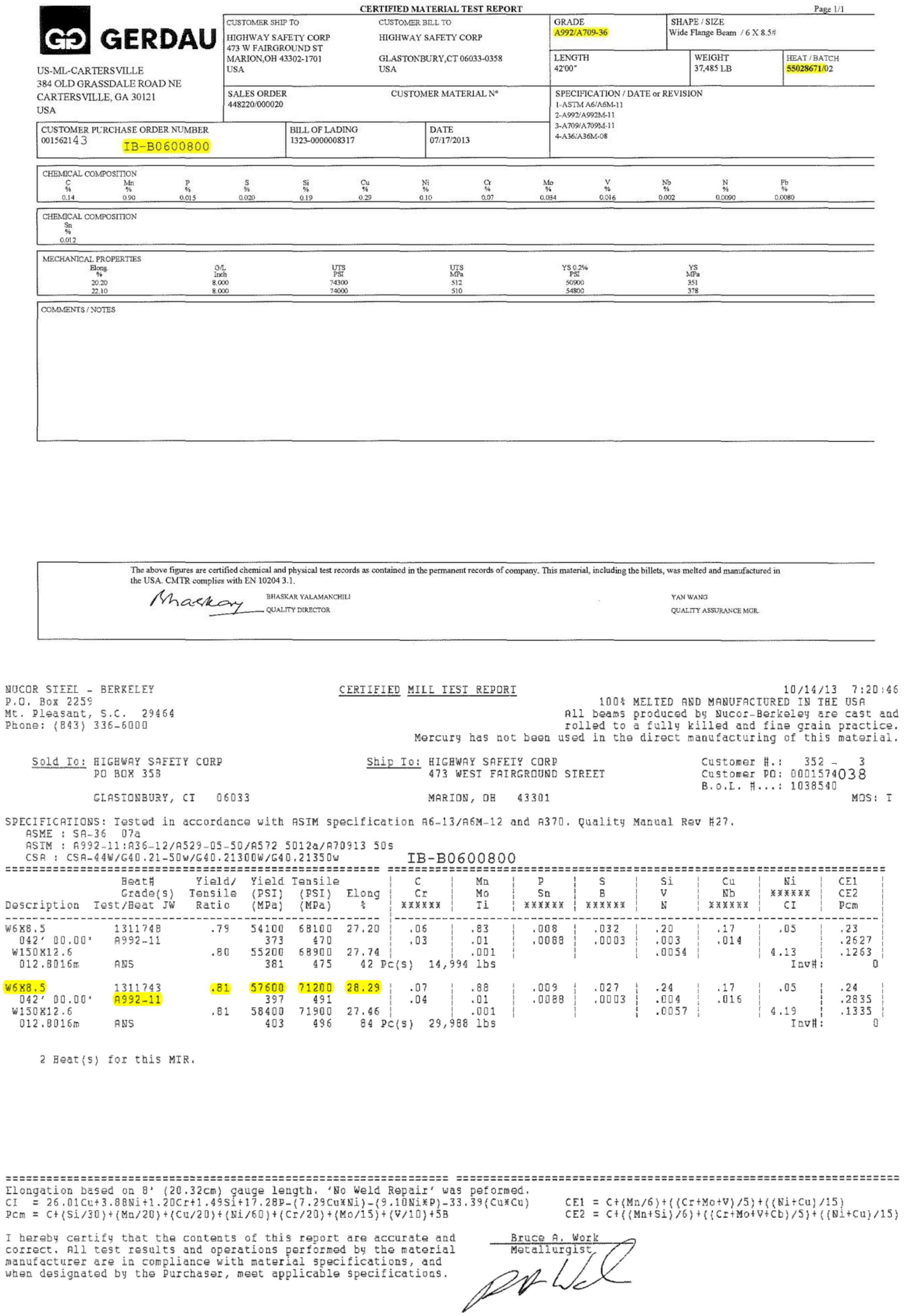

Deflection at Impact Location vs. Time

Figure B-16. Test No. MSSP-6 Results (SLICE-2)

Appendix C. Material Specifications – Full-Scale Test Installation

Table C-1. Material Certification Listing for Test No. MGSMS-1

Item No.	Description	Material Specification	Reference
a1	W6x8.5 [W152x12.6], 72" [1829] Long Steel Post	ASTM A992 Min. 50 ksi [345 MPa] Steel Galv. or W6x9 [W152x13.4] ASTM A36 Min. 36 ksi [248 MPa] Steel Galv.	H#55028671 and H#1311743
a2	6x12x14 1/4" [152x305x362] Timber Blockout for Steel Posts	SYP Grade No.1 or better	COI: CNWP 4/23/14
a3	16D	Double Head Nail	TYC 16DUP
a4	12'-6" [3810] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv.	H#4614
a5	6'-3" [1905] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv.	H#515681
a6	12'-6" [3810] W-Beam MGS End Section	12 gauge [2.7] AASHTO M180 Galv.	H#4614
a7	75'x4'x6" [22860x1219x152] Asphalt Mow Strip	52-34 Grade Binder	Rick 9/17
a8	12" [305] W-Beam Backup Plate	12 gauge [2.7] AASHTO M180	H#174700
b1	BCT Timber Post - MGS Height	SYP Grade No. 1 or better (No knots, 18" [457] above or below ground tension face)	COI: CNWP 4/19/12 and COI: CNWP 5/10/13
b2	72" [1829] Long Foundation Tube	ASTM A500 Grade B Galv.	H#Y85912 and H#0173175
b3	Strut and Yoke Assembly	ASTM A36 Steel Galv.	H# 163375
b4	BCT Cable Anchor Assembly	3/4" [19] 6x19 IWRC IPS Galvanized Wire Rope	H#97852
b5	Anchor Bracket Assembly	ASTM A36 Steel Galv.	H#V911470 and H#4153095
b6	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel Galv.	H#18486 and H#6106195
b7	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40 Galv.	H#280638
c1	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	ASTM A307 Galv., Nut ASTM A563 A Galv.	LOT#25512 and H#NF13102751
c2	5/8" [16] Dia. UNC, 1 1/4" [32] Guardrail Bolt and Nut	ASTM A307 Galv., Nut ASTM A563 A Galv.	H#20289510 and H#10296970
c3	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	ASTM A307 Galv., Nut ASTM A563 A Galv.	LOT#130809L H#10240100 and H# 1231650
c4	5/8" [16] Dia. UNC, 1 1/4" [32] Long Hex Head Bolt and Nut	ASTM A307 Galv., Nut ASTM A563 A Galv.	H# C10070002
c5	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	ASTM A307 Galv., Nut ASTM A563 A Galv.	H#JK1110419701
c6	7/8" [22] Dia. UNC, 8" [203] Long Hex Head Bolt and Nut	ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	BOLT: PFC LOT#17071802 NUT: PFC LOT#10011913
c7	5/8" [16] Dia. Plain Round Washer	ASTM F844 Galv.	LOT#HO1779897 and H#8280068
c8	7/8" [22] Dia. Plain Round Washer	ASTM F844 Galv.	LOT#HO1788740 and H#82800072
c9	5/16" [8] Dia. UNC, 1 1/4" [32] Long Hex Bolt and Nut	ASTM A307 Galvanized	product# 91309A585 and product# 90473A030
c10	1 3/4"x1 3/4"x1/8" [44x44x3] Square A36 Steel Washer	ASTM A36 Galvanized	H# A312890
d1	S3x5.7 [S76x8.5] by 62" [1575] Long Steel Post	ASTM A992 Grade 50 Steel Galvanized	H# 59058160
d2	2 3/4"x1"x1/4" [70x25x6] Post Standoff	ASTM A36 Steel Galvanized	H# B408684
d3	4"x4"x3/8" [102x102x10] Square Socket, 30" [762] Long	ASTM A500 Grade B Steel Galvanized	H# 1401127
d4	10"x9"x1/4" [254x229x6] Steel Soil Plate	ASTM A572 Grade 50 Steel Galvanized	H# B408684
d5	4"x4"x1/4" [102x102x6] Steel Plate	ASTM A572 Grade 50 Steel Galvanized	H# B408684



GERDAU

US-ML-CARTERSVILLE
384 OLD GRASSDALE ROAD NE
CARTERSVILLE, GA 30121
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
HIGHWAY SAFETY CORP 473 W FAIRGROUND ST MARION,OH 43302-1701 USA	HIGHWAY SAFETY CORP GLASTONBURY,CT 06033-0358 USA	A992/A709-36	Wide Flange Beam / 6 X 8.5#

LENGTH	WEIGHT	HEAT / BATCH
42'00"	37,485 LB	55028671/02

SALES ORDER	CUSTOMER MATERIAL N°
448220/000020	

SPECIFICATION / DATE or REVISION
1-ASTM A6/A6M-11
2-A992/A992M-11
3-A709/A709M-11
4-A36/A36M-08

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
001562143 IB-B0600800	1323-0000008317	07/17/2013

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	N %	Pb %
0.14	0.90	0.015	0.020	0.19	0.29	0.10	0.07	0.034	0.016	0.002	0.0090	0.0080

CHEMICAL COMPOSITION

Sn %
0.012

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS 0.2% PSI	YS MPa
20.20	8.000	74300	512	50900	351
22.10	8.000	74000	510	54800	378

COMMENTS / NOTES

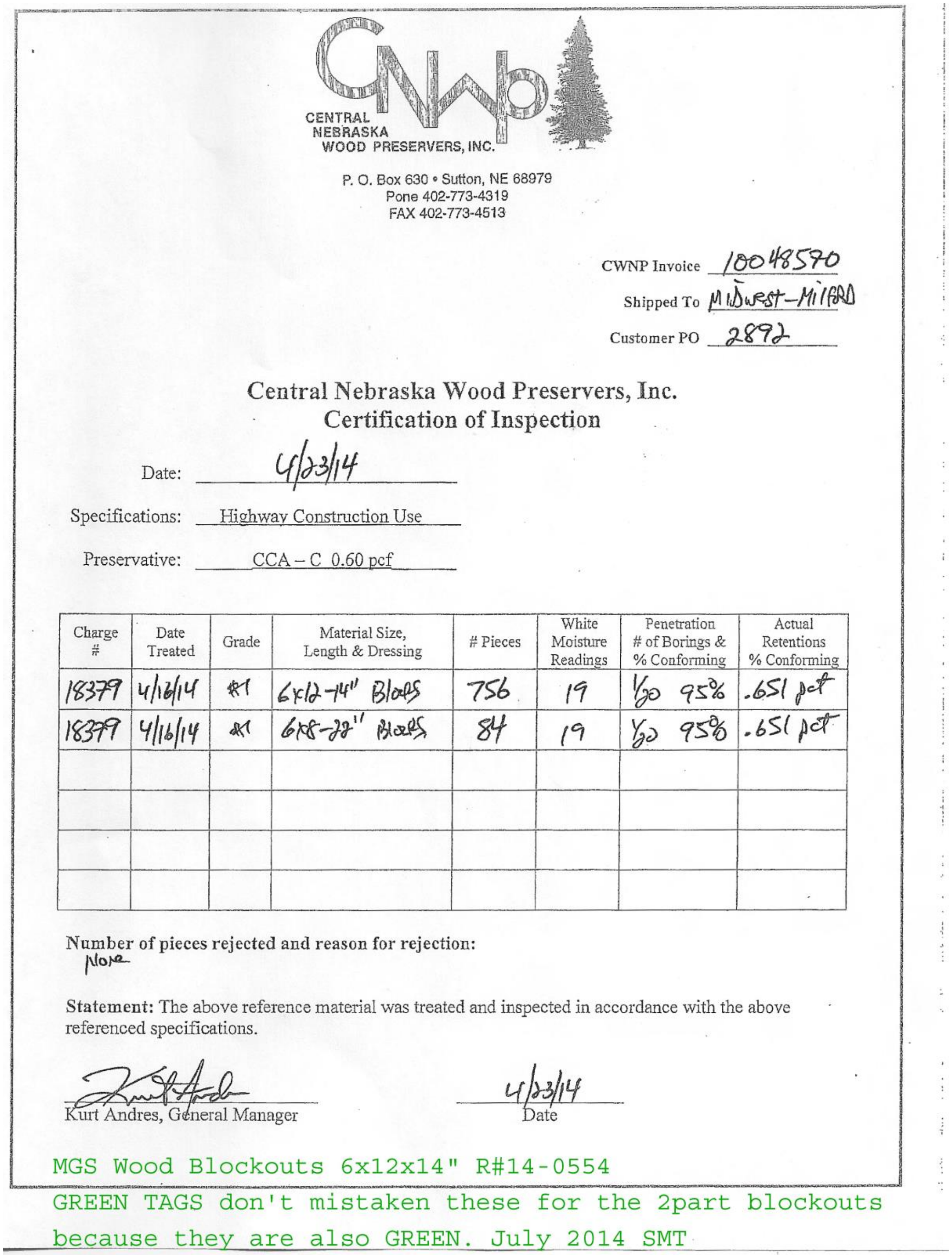
The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

Bhaskar
BHASKAR YALAMANCHILI
QUALITY DIRECTOR

YAN WANG
QUALITY ASSURANCE MGR.

```
NUCOR STEEL - BERKELEY                    CERTIFIED MILL TEST REPORT                              10/14/13  7:20:46
P.O. Box 2259                                                               100% MELTED AND MANUFACTURED IN THE USA
Mt. Pleasant, S.C.  29464                                                 All beams produced by Nucor-Berkeley are cast and
Phone: (843) 336-6000                                                     rolled to a fully killed and fine grain practice.
                                                               Mercury has not been used in the direct manufacturing of this material.

    Sold To: HIGHWAY SAFETY CORP                     Ship To: HIGHWAY SAFETY CORP                  Customer #.:   352 -   3
             PO BOX 358                                       473 WEST FAIRGROUND STREET           Customer PO: 0001574038
                                                                                                   B.o.L. #...: 1038540
             GLASTONBURY, CT   06033                          MARION, OH   43301                                       MOS: T

SPECIFICATIONS: Tested in accordance with ASTM specification A6-13/A6M-12 and A370. Quality Manual Rev #27.
   ASME : SA-36  07a
   ASTM : A992-11:A36-12/A529-05-50/A572 5012a/A70913 50s
   CSA : CSA-44W/G40.21-50w/G40.21300W/G40.21350w          IB-B0600800
=============================================================== ====================================================================
               Beat#     Yield/  Yield Tensile        |   C    |   Mn   |   P    |   S    |   Si   |   Cu   |   Ni   |  CE1   |
               Grade(s)  Tensile (PSI)  (PSI)  Elong  |   Cr   |   Mo   |   Sn   |   B    |   V    |   Nb   | ****** |  CE2   |
Description  Test/Heat JW  Ratio (MPa)  (MPa)    %    | ****** |   Ti   | ****** | ****** |   N    | ****** |   CI   |  Pcm   |
----------------------------------------------------- |----------------------------------------------------------------------|
W6X8.5         1311748      .79  54100  68100  27.20  |  .06   |  .83   |  .008  |  .032  |  .20   |  .17   |  .05   |  .23   |
 042' 00.00"   A992-11             373    470         |  .03   |  .01   |  .0088 |  .0003 |  .003  |  .014  |        |  .2627 |
 W150X12.6                  .80  55200  68900  27.74  |        |  .001  |        |        |  .0054 |        |  4.13  |  .1263 |
  012.8016m    ANS                 381    475    42 Pc(s)  14,994 lbs                                          Inv#:        0

W6X8.5         1311743      .81  57600  71200  28.29  |  .07   |  .88   |  .009  |  .027  |  .24   |  .17   |  .05   |  .24   |
 042' 00.00"   A992-11             397    491         |  .04   |  .01   |  .0088 |  .0003 |  .004  |  .016  |        |  .2835 |
 W150X12.6                  .81  58400  71900  27.46  |        |  .001  |        |        |  .0057 |        |  4.19  |  .1335 |
  012.8016m    ANS                 403    496    84 Pc(s)  29,988 lbs                                          Inv#:        0

    2 Heat(s) for this MTR.




=============================================================== ====================================================================
Elongation based on 8' (20.32cm) gauge length. 'No Weld Repair' was peformed.
CI  = 26.01Cu+3.88Ni+1.20Cr+1.49Si+17.28P-(7.29Cu*Ni)-(9.10Ni*P)-33.39(Cu*Cu)      CE1 = C+(Mn/6)+((Cr+Mo+V)/5)+((Ni+Cu)/15)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B                 CE2 = C+((Mn+Si)/6)+((Cr+Mo+V+Cb)/5)+((Ni+Cu)/15)

I hereby certify that the contents of this report are accurate and      Bruce A. Work
correct. All test results and operations performed by the material      Metallurgist
manufacturer are in compliance with material specifications, and
when designated by the Purchaser, meet applicable specifications.
```

Figure C-1. W6x8.5 (W152x12.6) Steel Guardrail Posts, Test No. MGSMS-1



CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

CWNP Invoice 10048570

Shipped To MiDwest-Milford

Customer PO 2892

Central Nebraska Wood Preservers, Inc.
Certification of Inspection

Date: 4/23/14

Specifications: Highway Construction Use

Preservative: CCA – C 0.60 pcf

Charge #	Date Treated	Grade	Material Size, Length & Dressing	# Pieces	White Moisture Readings	Penetration # of Borings & % Conforming	Actual Retentions % Conforming
18379	4/16/14	#1	6x12-14" Blocks	756	19	1/20 95%	.651 pcf
18379	4/16/14	#1	6x8-22" Blocks	84	19	1/20 95%	.651 pcf

Number of pieces rejected and reason for rejection:
None

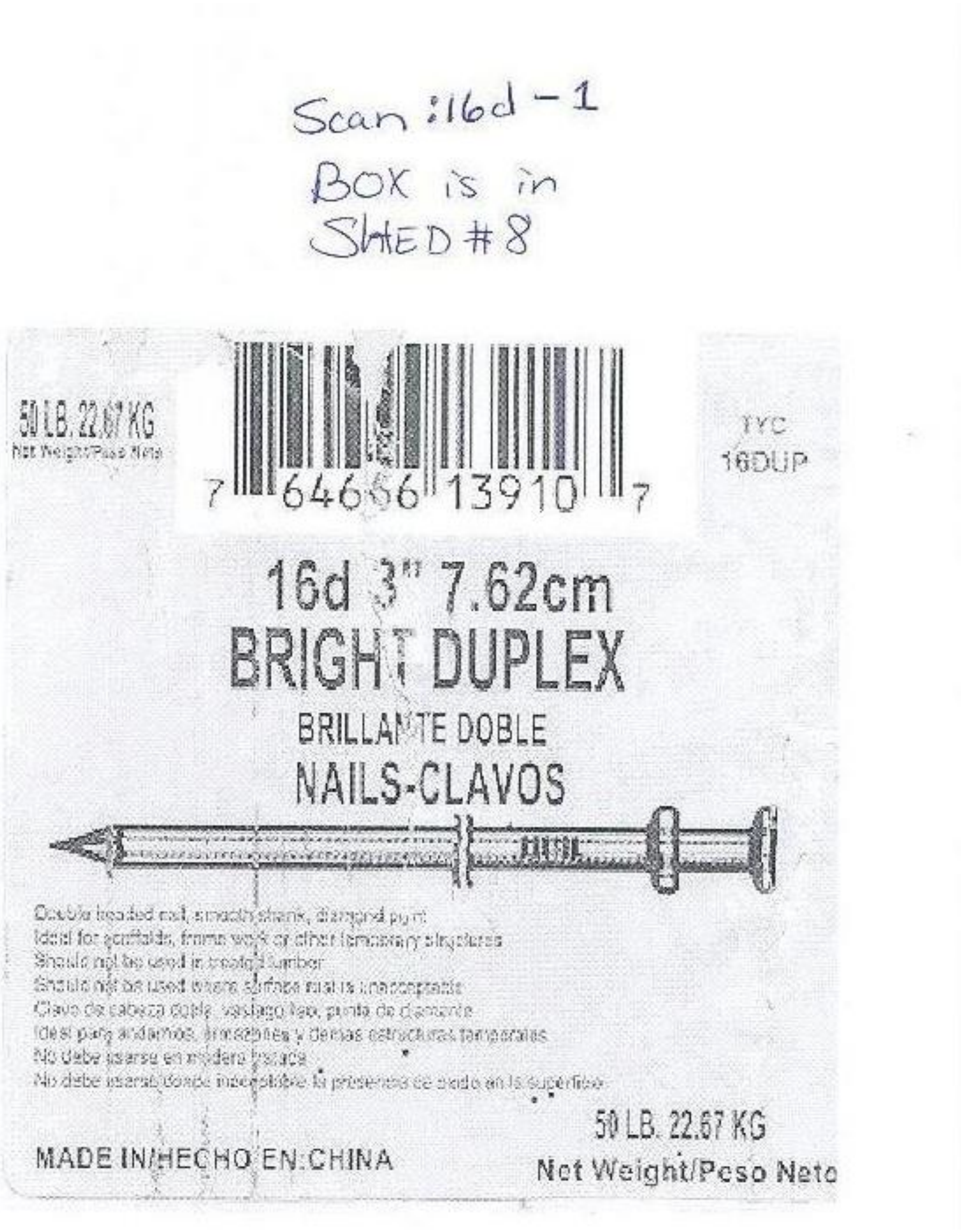
Statement: The above reference material was treated and inspected in accordance with the above referenced specifications.

Kurt Andres, General Manager

4/23/14
Date

MGS Wood Blockouts 6x12x14" R#14-0554
GREEN TAGS don't mistaken these for the 2part blockouts
because they are also GREEN. July 2014 SMT

Figure C-2. Timber Blockout Material Specification, Test No. MGSMS-1



Scan :16d - 1
BOX is in
SHED # 8

50 LB. 22.67 KG
Net Weight/Peso Neto

7 64666 13910 7

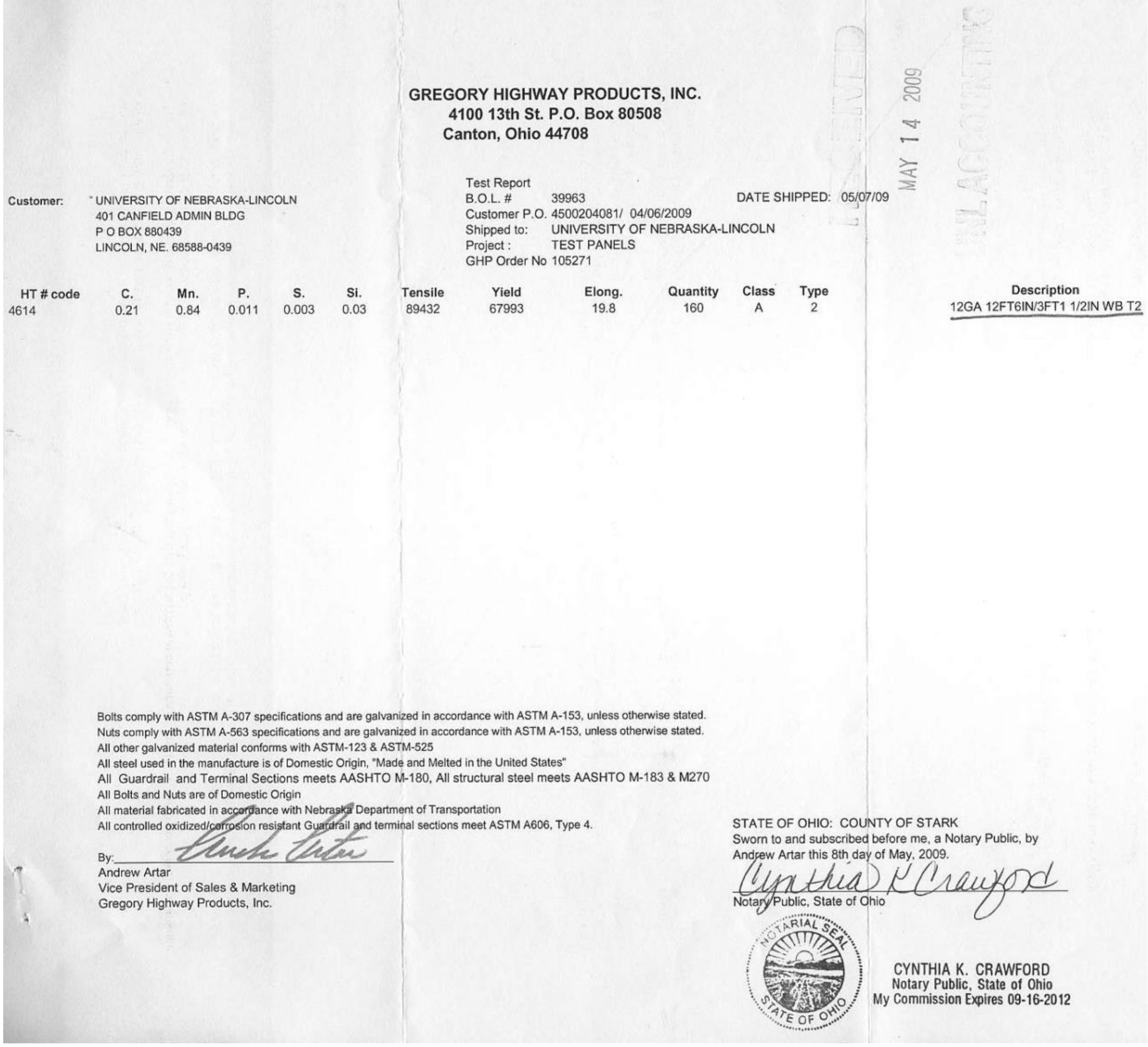
TYC
16DUP

16d 3" 7.62cm
BRIGHT DUPLEX
BRILLANTE DOBLE
NAILS-CLAVOS

Double headed nail, smooth shank, diamond point
Ideal for scaffolds, frame work or other temporary structures
Should not be used in treated lumber
Should not be used where surface rust is unacceptable
Clavo de cabeza doble, vastago liso, punta de diamante
Ideal para andamios, armazones y demas estructuras temporales
No debe usarse en madera tratada
No debe usarse donde inaceptable la presencia de oxido en la superficie

50 LB. 22.67 KG
MADE IN/HECHO EN:CHINA
Net Weight/Peso Neto

Figure C-3. 16D Blockout Nail Material Specification, Test No. MGSMS-1



GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. P.O. Box 80508
Canton, Ohio 44708

Customer:
UNIVERSITY OF NEBRASKA-LINCOLN
401 CANFIELD ADMIN BLDG
P O BOX 880439
LINCOLN, NE. 68588-0439

Test Report
B.O.L. # 39963
DATE SHIPPED: 05/07/09
Customer P.O. 4500204081/ 04/06/2009
Shipped to: UNIVERSITY OF NEBRASKA-LINCOLN
Project : TEST PANELS
GHP Order No 105271

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
4614	0.21	0.84	0.011	0.003	0.03	89432	67993	19.8	160	A	2	12GA 12FT6IN/3FT1 1/2IN WB T2

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-525
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

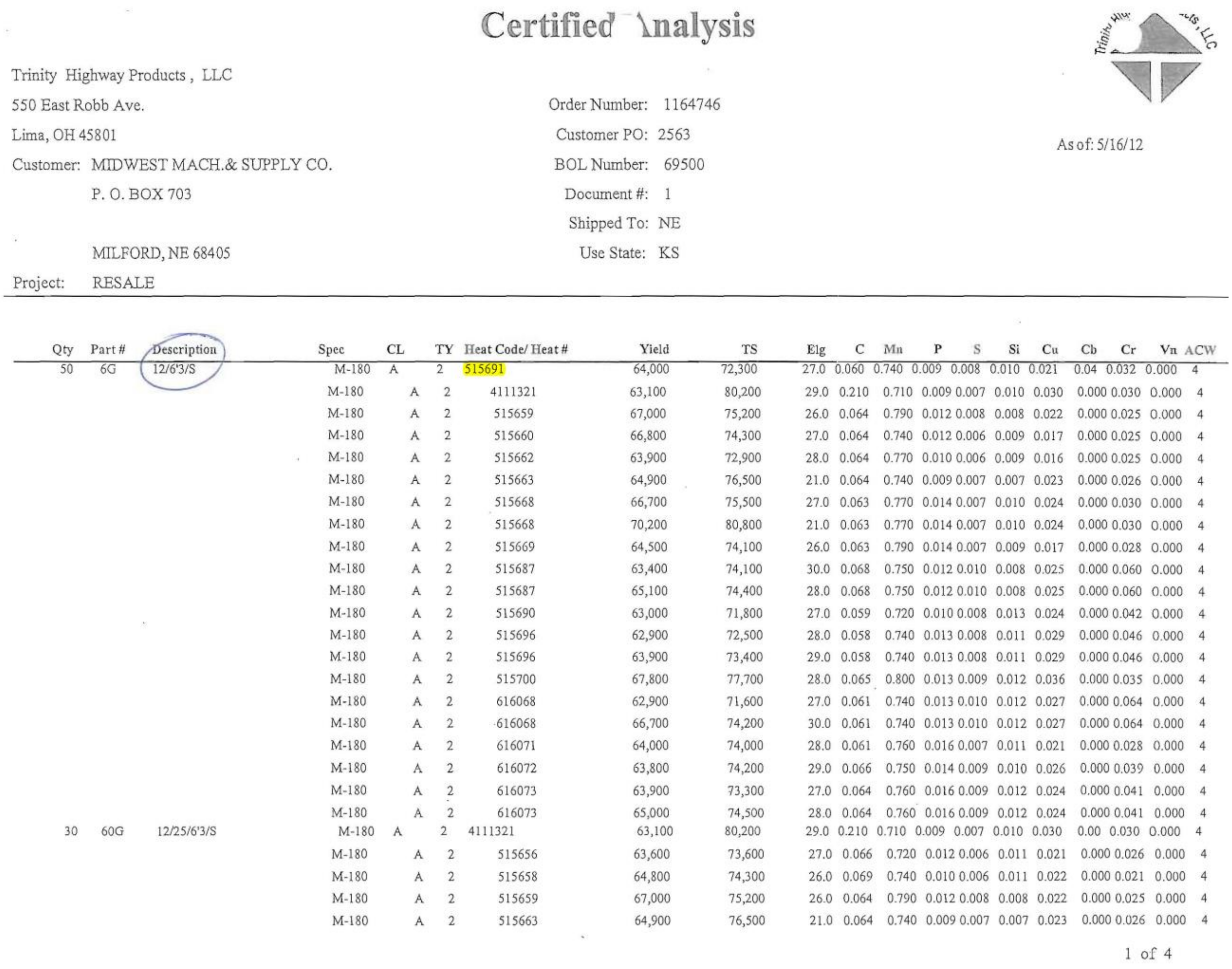
By:
Andrew Artar
Vice President of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 8th day of May, 2009.

Cynthia K Crawford
Notary Public, State of Ohio

CYNTHIA K. CRAWFORD
Notary Public, State of Ohio
My Commission Expires 09-16-2012

Figure C-4. 12.5-ft (3.8-m) W-Beam Guardrail Material Specification, Test No. MGSMS-1



Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

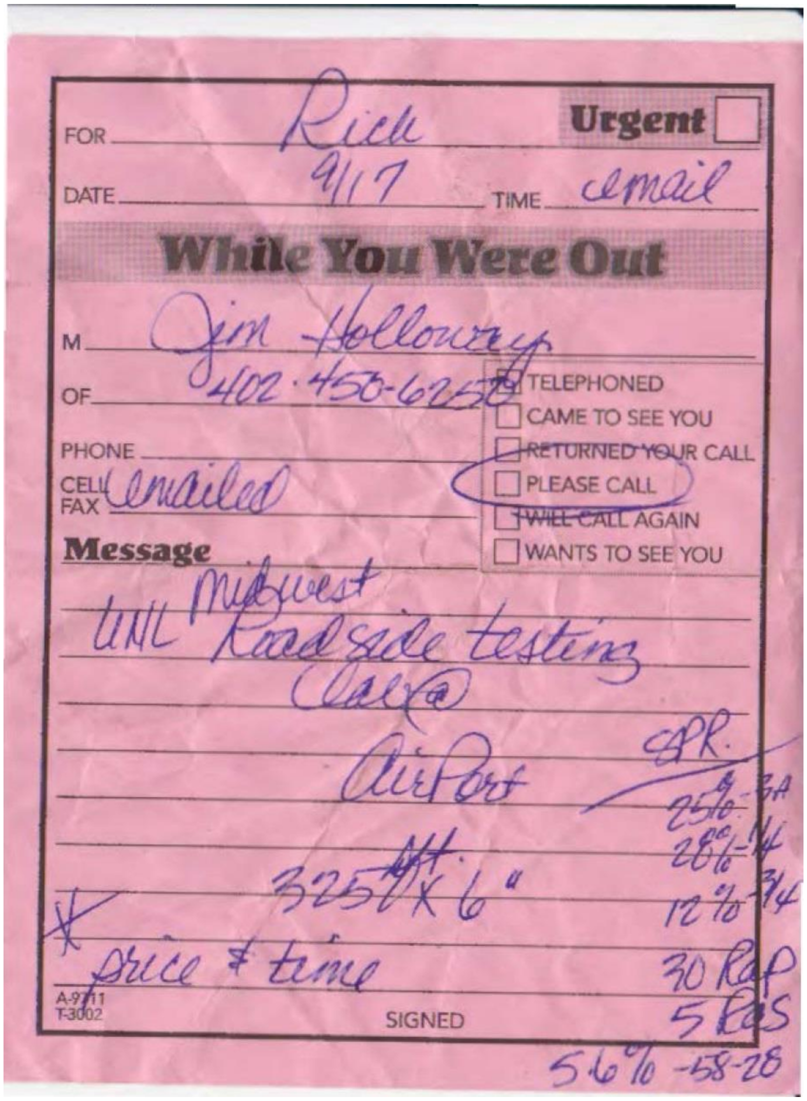
Order Number: 1164746
Customer PO: 2563
BOL Number: 69500
Document #: 1
Shipped To: NE
Use State: KS

As of: 5/16/12

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
50	6G	12/6'3/S	M-180	A	2	515691	64,000	72,300	27.0	0.060	0.740	0.009	0.008	0.010	0.021	0.04	0.032	0.000	4
			M-180	A	2	4111321	63,100	80,200	29.0	0.210	0.710	0.009	0.007	0.010	0.030	0.000	0.030	0.000	4
			M-180	A	2	515659	67,000	75,200	26.0	0.064	0.790	0.012	0.008	0.008	0.022	0.000	0.025	0.000	4
			M-180	A	2	515660	66,800	74,300	27.0	0.064	0.740	0.012	0.006	0.009	0.017	0.000	0.025	0.000	4
			M-180	A	2	515662	63,900	72,900	28.0	0.064	0.770	0.010	0.006	0.009	0.016	0.000	0.025	0.000	4
			M-180	A	2	515663	64,900	76,500	21.0	0.064	0.740	0.009	0.007	0.007	0.023	0.000	0.026	0.000	4
			M-180	A	2	515668	66,700	75,500	27.0	0.063	0.770	0.014	0.007	0.010	0.024	0.000	0.030	0.000	4
			M-180	A	2	515668	70,200	80,800	21.0	0.063	0.770	0.014	0.007	0.010	0.024	0.000	0.030	0.000	4
			M-180	A	2	515669	64,500	74,100	26.0	0.063	0.790	0.014	0.007	0.009	0.017	0.000	0.028	0.000	4
			M-180	A	2	515687	63,400	74,100	30.0	0.068	0.750	0.012	0.010	0.008	0.025	0.000	0.060	0.000	4
			M-180	A	2	515687	65,100	74,400	28.0	0.068	0.750	0.012	0.010	0.008	0.025	0.000	0.060	0.000	4
			M-180	A	2	515690	63,000	71,800	27.0	0.059	0.720	0.010	0.008	0.013	0.024	0.000	0.042	0.000	4
			M-180	A	2	515696	62,900	72,500	28.0	0.058	0.740	0.013	0.008	0.011	0.029	0.000	0.046	0.000	4
			M-180	A	2	515696	63,900	73,400	29.0	0.058	0.740	0.013	0.008	0.011	0.029	0.000	0.046	0.000	4
			M-180	A	2	515700	67,800	77,700	28.0	0.065	0.800	0.013	0.009	0.012	0.036	0.000	0.035	0.000	4
			M-180	A	2	616068	62,900	71,600	27.0	0.061	0.740	0.013	0.010	0.012	0.027	0.000	0.064	0.000	4
			M-180	A	2	616068	66,700	74,200	30.0	0.061	0.740	0.013	0.010	0.012	0.027	0.000	0.064	0.000	4
			M-180	A	2	616071	64,000	74,000	28.0	0.061	0.760	0.016	0.007	0.011	0.021	0.000	0.028	0.000	4
			M-180	A	2	616072	63,800	74,200	29.0	0.066	0.750	0.014	0.009	0.010	0.026	0.000	0.039	0.000	4
			M-180	A	2	616073	63,900	73,300	27.0	0.064	0.760	0.016	0.009	0.012	0.024	0.000	0.041	0.000	4
			M-180	A	2	616073	65,000	74,500	28.0	0.064	0.760	0.016	0.009	0.012	0.024	0.000	0.041	0.000	4
30	60G	12/25/6'3/S	M-180	A	2	4111321	63,100	80,200	29.0	0.210	0.710	0.009	0.007	0.010	0.030	0.00	0.030	0.000	4
			M-180	A	2	515656	63,600	73,600	27.0	0.066	0.720	0.012	0.006	0.011	0.021	0.000	0.026	0.000	4
			M-180	A	2	515658	64,800	74,300	26.0	0.069	0.740	0.010	0.006	0.011	0.022	0.000	0.021	0.000	4
			M-180	A	2	515659	67,000	75,200	26.0	0.064	0.790	0.012	0.008	0.008	0.022	0.000	0.025	0.000	4
			M-180	A	2	515663	64,900	76,500	21.0	0.064	0.740	0.009	0.007	0.007	0.023	0.000	0.026	0.000	4

1 of 4

Figure C-5. 6.25-ft (1.9-m) W-Beam Guardrail Material Specification, Test No. MGSMS-1



FOR Rick **Urgent** ☐

DATE 9/17 TIME email

While You Were Out

M Jim Holloway

OF 402·450-6250

PHONE

CELL/FAX emailed

☒ TELEPHONED
☐ CAME TO SEE YOU
☐ RETURNED YOUR CALL
[✓ ☐ PLEASE CALL]
☐ WILL CALL AGAIN
☐ WANTS TO SEE YOU

Message

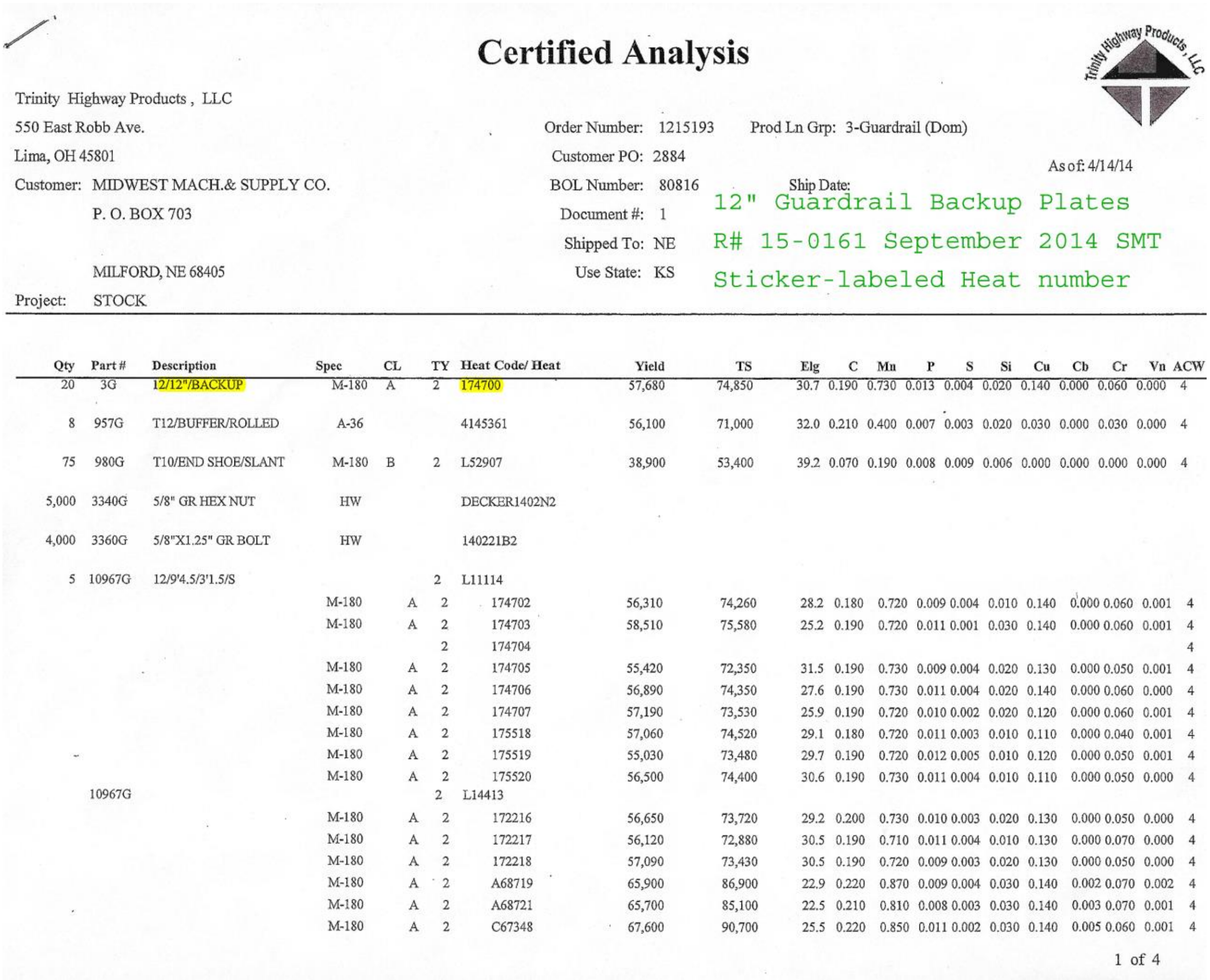
UNL Midwest Roadside testing
Call @
AirPort
325 ft. x 6"
price & time

SPR.
25% - 3A
28% - 1/4
12% - 3/4
30 Rap
5 Ras
56% -58-28

A-9711
T-3002

SIGNED

Figure C-6. Asphalt Mow Strip Material Specification, Test No. MGSMS-1



Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: STOCK

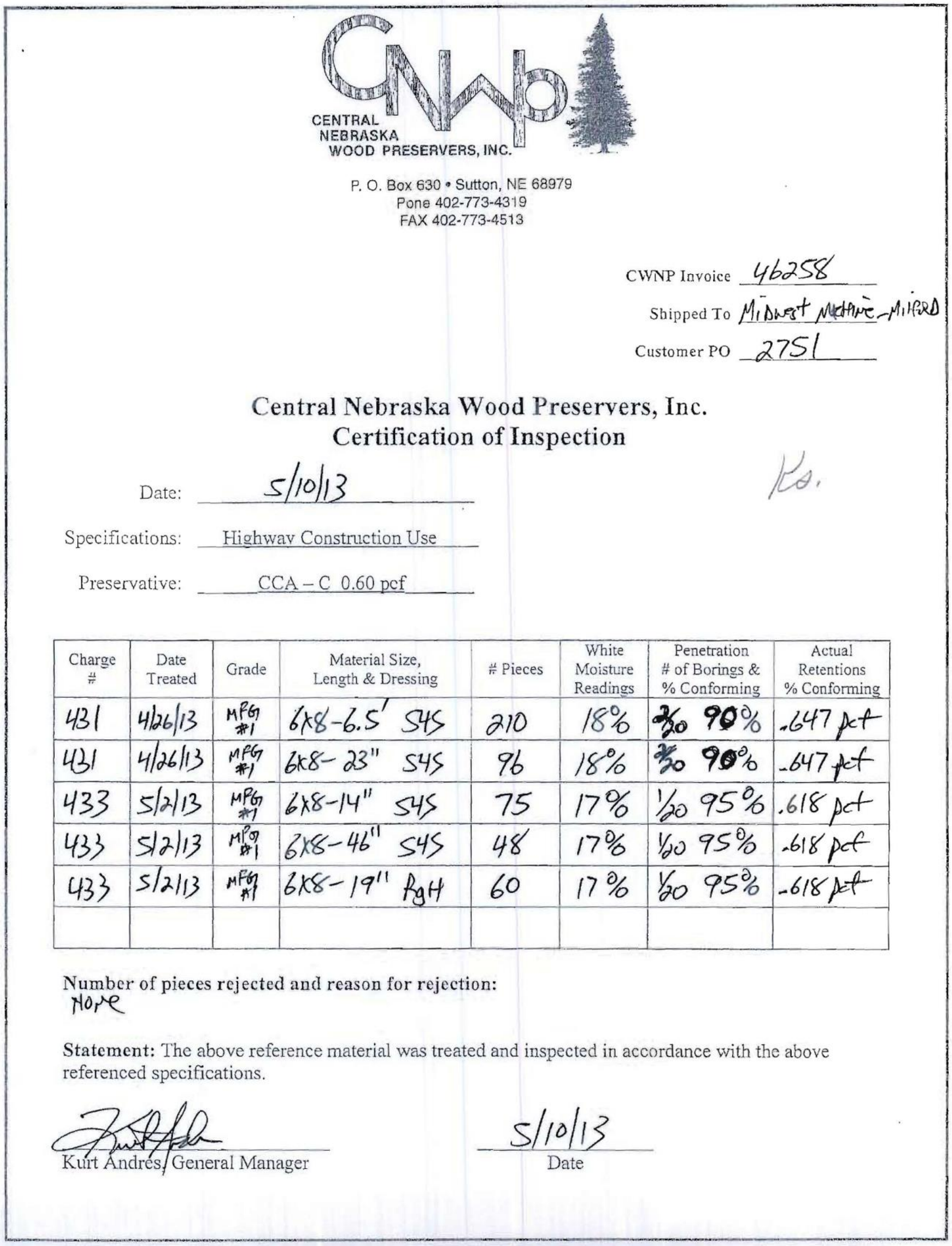
Order Number: 1215193
Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 2884
As of: 4/14/14
BOL Number: 80816
Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

12" Guardrail Backup Plates
R# 15-0161 September 2014 SMT
Sticker-labeled Heat number

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
20	3G	12/12"/BACKUP	M-180	A	2	174700	57,680	74,850	30.7	0.190	0.730	0.013	0.004	0.020	0.140	0.000	0.060	0.000	4
8	957G	T12/BUFFER/ROLLED	A-36			4145361	56,100	71,000	32.0	0.210	0.400	0.007	0.003	0.020	0.030	0.000	0.030	0.000	4
75	980G	T10/END SHOE/SLANT	M-180	B	2	L52907	38,900	53,400	39.2	0.070	0.190	0.008	0.009	0.006	0.000	0.000	0.000	0.000	4
5,000	3340G	5/8" GR HEX NUT	HW			DECKER1402N2													
4,000	3360G	5/8"X1.25" GR BOLT	HW			140221B2													
5	10967G	12/9'4.5/3'1.5/S			2	L11114													
			M-180	A	2	174702	56,310	74,260	28.2	0.180	0.720	0.009	0.004	0.010	0.140	0.000	0.060	0.001	4
			M-180	A	2	174703	58,510	75,580	25.2	0.190	0.720	0.011	0.001	0.030	0.140	0.000	0.060	0.001	4
					2	174704													4
			M-180	A	2	174705	55,420	72,350	31.5	0.190	0.730	0.009	0.004	0.020	0.130	0.000	0.050	0.001	4
			M-180	A	2	174706	56,890	74,350	27.6	0.190	0.730	0.011	0.004	0.020	0.140	0.000	0.060	0.000	4
			M-180	A	2	174707	57,190	73,530	25.9	0.190	0.720	0.010	0.002	0.020	0.120	0.000	0.060	0.001	4
			M-180	A	2	175518	57,060	74,520	29.1	0.180	0.720	0.011	0.003	0.010	0.110	0.000	0.040	0.001	4
			M-180	A	2	175519	55,030	73,480	29.7	0.190	0.720	0.012	0.005	0.010	0.120	0.000	0.050	0.001	4
			M-180	A	2	175520	56,500	74,400	30.6	0.190	0.730	0.011	0.004	0.010	0.110	0.000	0.050	0.000	4
	10967G				2	L14413													
			M-180	A	2	172216	56,650	73,720	29.2	0.200	0.730	0.010	0.003	0.020	0.130	0.000	0.050	0.000	4
			M-180	A	2	172217	56,120	72,880	30.5	0.190	0.710	0.011	0.004	0.010	0.130	0.000	0.070	0.000	4
			M-180	A	2	172218	57,090	73,430	30.5	0.190	0.720	0.009	0.003	0.020	0.130	0.000	0.050	0.000	4
			M-180	A	2	A68719	65,900	86,900	22.9	0.220	0.870	0.009	0.004	0.030	0.140	0.002	0.070	0.002	4
			M-180	A	2	A68721	65,700	85,100	22.5	0.210	0.810	0.008	0.003	0.030	0.140	0.003	0.070	0.001	4
			M-180	A	2	C67348	67,600	90,700	25.5	0.220	0.850	0.011	0.002	0.030	0.140	0.005	0.060	0.001	4

1 of 4

Figure C-7. W-Beam Backup Plate Material Specification, Test No. MGSMS-1



CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

CWNP Invoice 46258
Shipped To MiDwest Machine-Milford
Customer PO 2751

Central Nebraska Wood Preservers, Inc.
Certification of Inspection

Kd.

Date: 5/10/13

Specifications: Highway Construction Use

Preservative: CCA – C 0.60 pcf

Charge #	Date Treated	Grade	Material Size, Length & Dressing	# Pieces	White Moisture Readings	Penetration # of Borings & % Conforming	Actual Retentions % Conforming
431	4/26/13	MPG #1	6x8-6.5' S4S	210	18%	2/20 90%	.647 pcf
431	4/26/13	MPG #1	6x8- 23" S4S	96	18%	2/20 90%	.647 pcf
433	5/2/13	MPG #1	6x8-14" S4S	75	17%	1/20 95%	.618 pcf
433	5/2/13	MPG #1	6x8-46" S4S	48	17%	1/20 95%	.618 pcf
433	5/2/13	MPG #1	6x8-19" RgH	60	17%	1/20 95%	.618 pcf

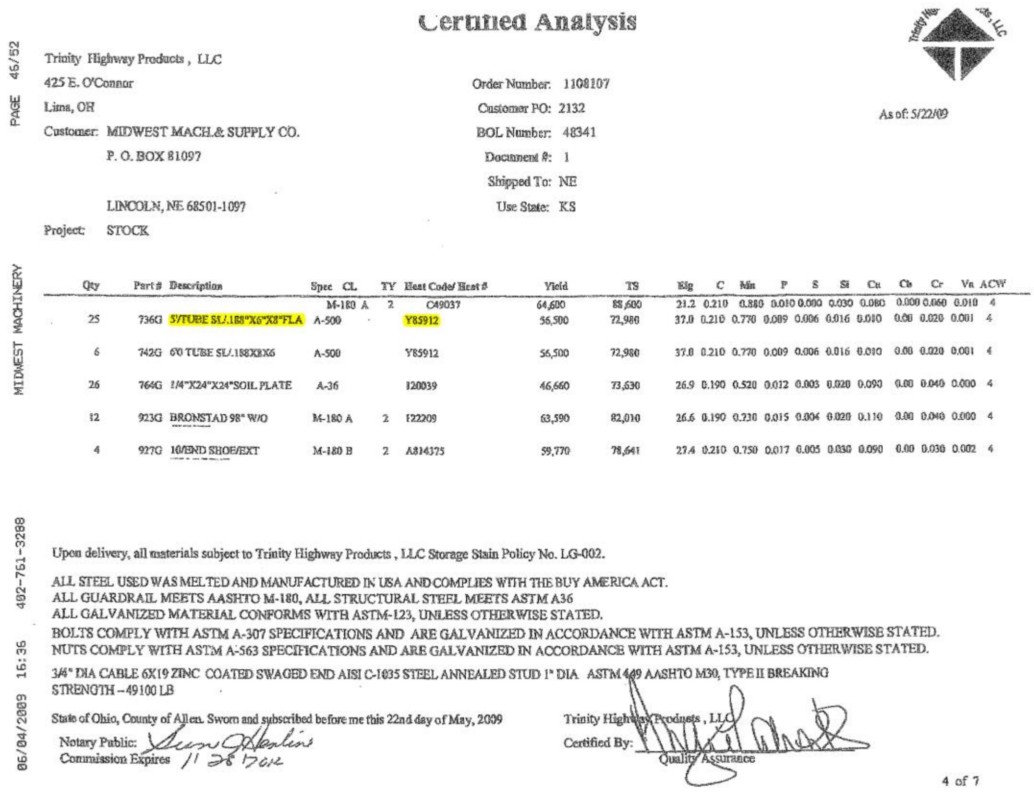
Number of pieces rejected and reason for rejection:
None

Statement: The above reference material was treated and inspected in accordance with the above referenced specifications.

Kurt Andres, General Manager

5/10/13
Date

Figure C-8. Timber BCT Posts Material Specification, Test No. MGSMS-1



PAGE 46/52

Certified Analysis

Trinity Highway Products , LLC
425 E. O'Connor
Lima, OH
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097
Project: STOCK

Order Number: 1108107
Customer PO: 2132
BOL Number: 48341
Document #: 1
Shipped To: NE
Use State: KS

As of: 5/22/09

MIDWEST MACHINERY

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
			M-180	A	2	C49037	64,600	88,600	21.2	0.210	0.880	0.010	0.000	0.030	0.080	0.000	0.060	0.010	4
25	736G	5'/TUBE SL/.188"X6"X8"FLA	A-500			Y85912	56,500	72,980	37.0	0.210	0.770	0.009	0.006	0.016	0.010	0.00	0.020	0.001	4
6	742G	6'0 TUBE SL/.188X8X6	A-500			Y85912	56,500	72,980	37.0	0.210	0.770	0.009	0.006	0.016	0.010	0.00	0.020	0.001	4
26	764G	1/4"X24"X24"SOIL PLATE	A-36			120039	46,660	73,630	26.9	0.190	0.520	0.012	0.003	0.020	0.090	0.00	0.040	0.000	4
12	923G	BRONSTAD 98" W/O	M-180	A	2	122209	63,590	82,010	26.6	0.190	0.730	0.015	0.004	0.020	0.110	0.00	0.040	0.000	4
4	927G	10/END SHOE/EXT	M-180	B	2	A814375	59,770	78,641	27.4	0.210	0.750	0.017	0.005	0.030	0.090	0.00	0.030	0.002	4

06/04/2009 16:35 402-751-3288

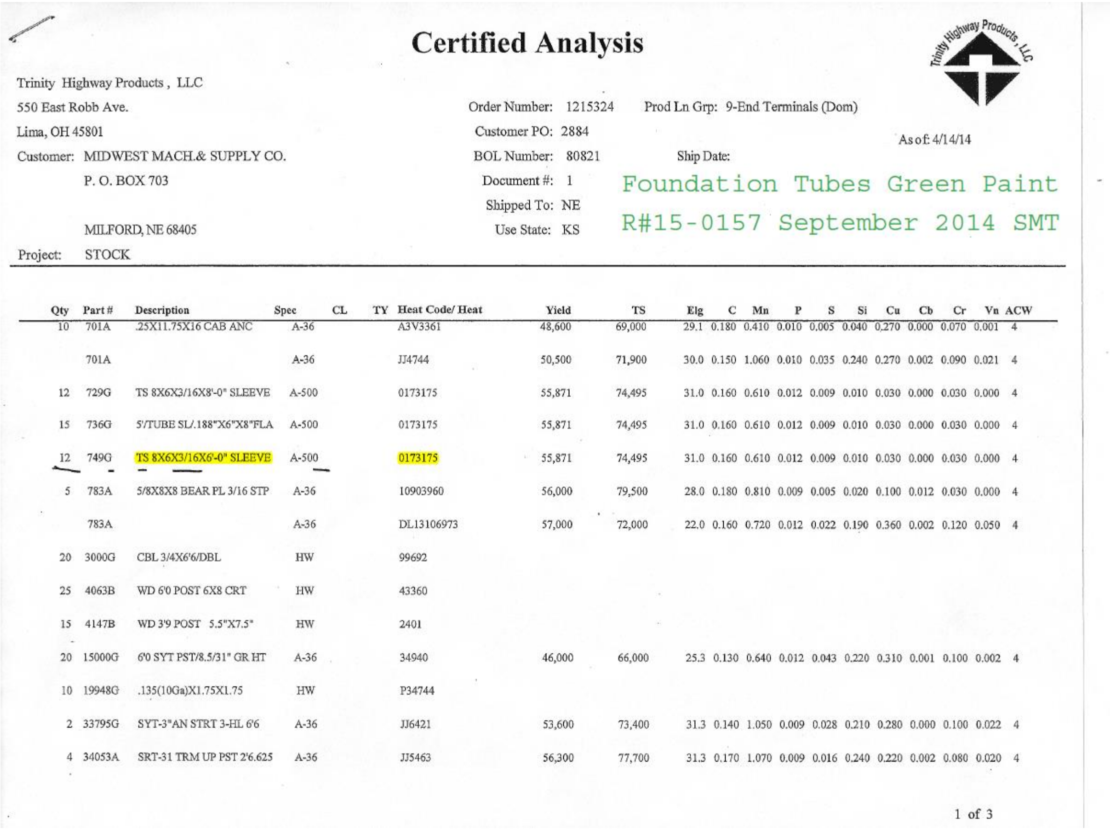
Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH -- 49100 LB

State of Ohio, County of Allen. Sworn and subscribed before me this 22nd day of May, 2009
Notary Public:
Commission Expires 11 28 2012

Trinity Highway Products , LLC
Certified By:
Quality Assurance

4 of 7



Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: STOCK

Order Number: 1215324 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2884
BOL Number: 80821 Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

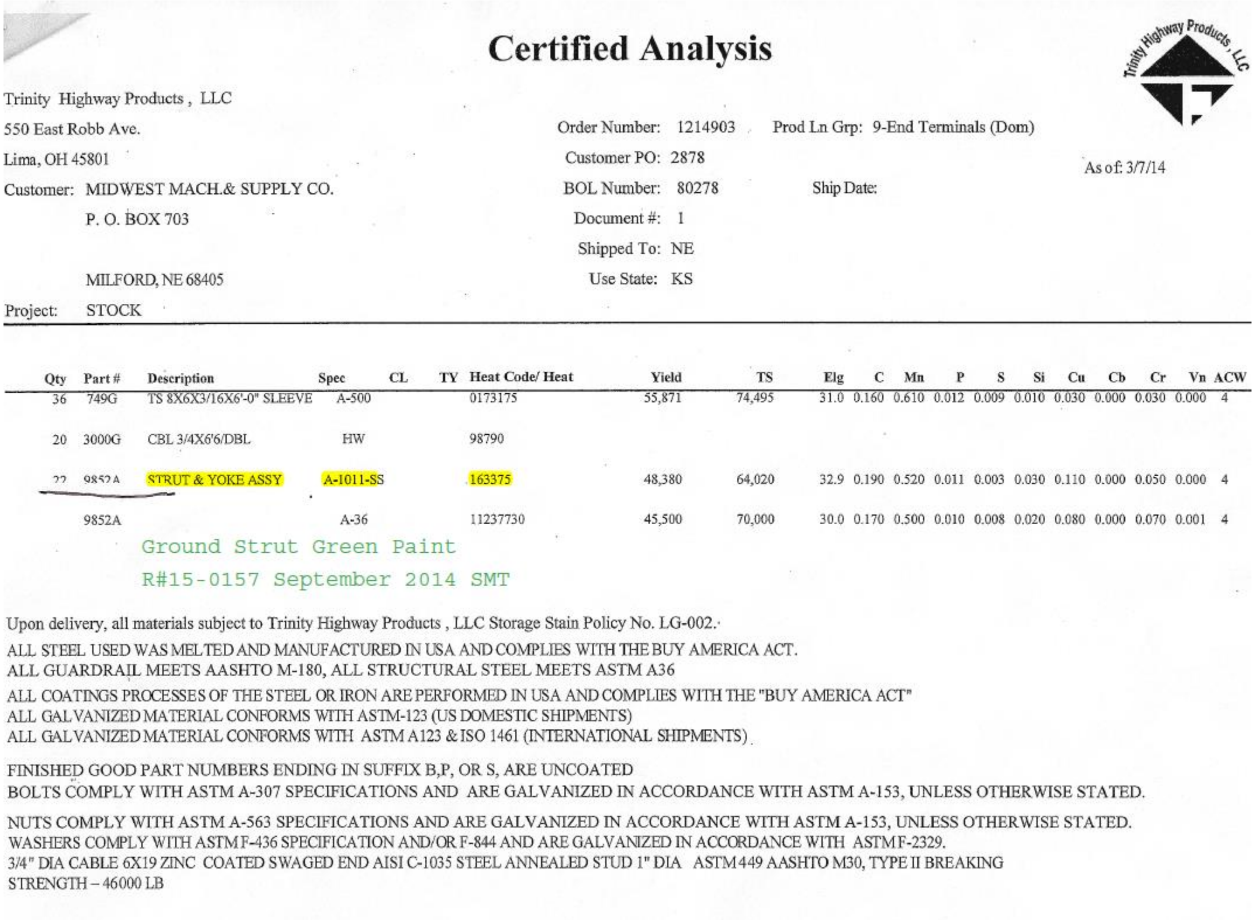
As of: 4/14/14

Foundation Tubes Green Paint
R#15-0157 September 2014 SMT

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	701A	.25X11.75X16 CAB ANC	A-36			A3V3361	48,600	69,000	29.1	0.180	0.410	0.010	0.005	0.040	0.270	0.000	0.070	0.001	4
	701A		A-36			JJ4744	50,500	71,900	30.0	0.150	1.060	0.010	0.035	0.240	0.270	0.002	0.090	0.021	4
12	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
15	736G	5'/TUBE SL/.188"X6"X8"FLA	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
12	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
5	783A	5/8X8X8 BEAR PL 3/16 STP	A-36			10903960	56,000	79,500	28.0	0.180	0.810	0.009	0.005	0.020	0.100	0.012	0.030	0.000	4
	783A		A-36			DL13106973	57,000	72,000	22.0	0.160	0.720	0.012	0.022	0.190	0.360	0.002	0.120	0.050	4
20	3000G	CBL 3/4X6'6/DBL	HW			99692													
25	4063B	WD 6'0 POST 6X8 CRT	HW			43360													
15	4147B	WD 3'9 POST 5.5"X7.5"	HW			2401													
20	15000G	6'0 SYT PST/8.5/31" GR HT	A-36			34940	46,000	66,000	25.3	0.130	0.640	0.012	0.043	0.220	0.310	0.001	0.100	0.002	4
10	19948G	.135(10Ga)X1.75X1.75	HW			P34744													
2	33795G	SYT-3"AN STRT 3-HL 6'6	A-36			JJ6421	53,600	73,400	31.3	0.140	1.050	0.009	0.028	0.210	0.280	0.000	0.100	0.022	4
4	34053A	SRT-31 TRM UP PST 2'6.625	A-36			JJ5463	56,300	77,700	31.3	0.170	1.070	0.009	0.016	0.240	0.220	0.002	0.080	0.020	4

1 of 3

Figure C-9. Steel Foundation Tubes Material Specifications, Test No. MGSMS-1



Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405

Project: STOCK

Order Number: 1214903
Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2878
BOL Number: 80278
Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 3/7/14

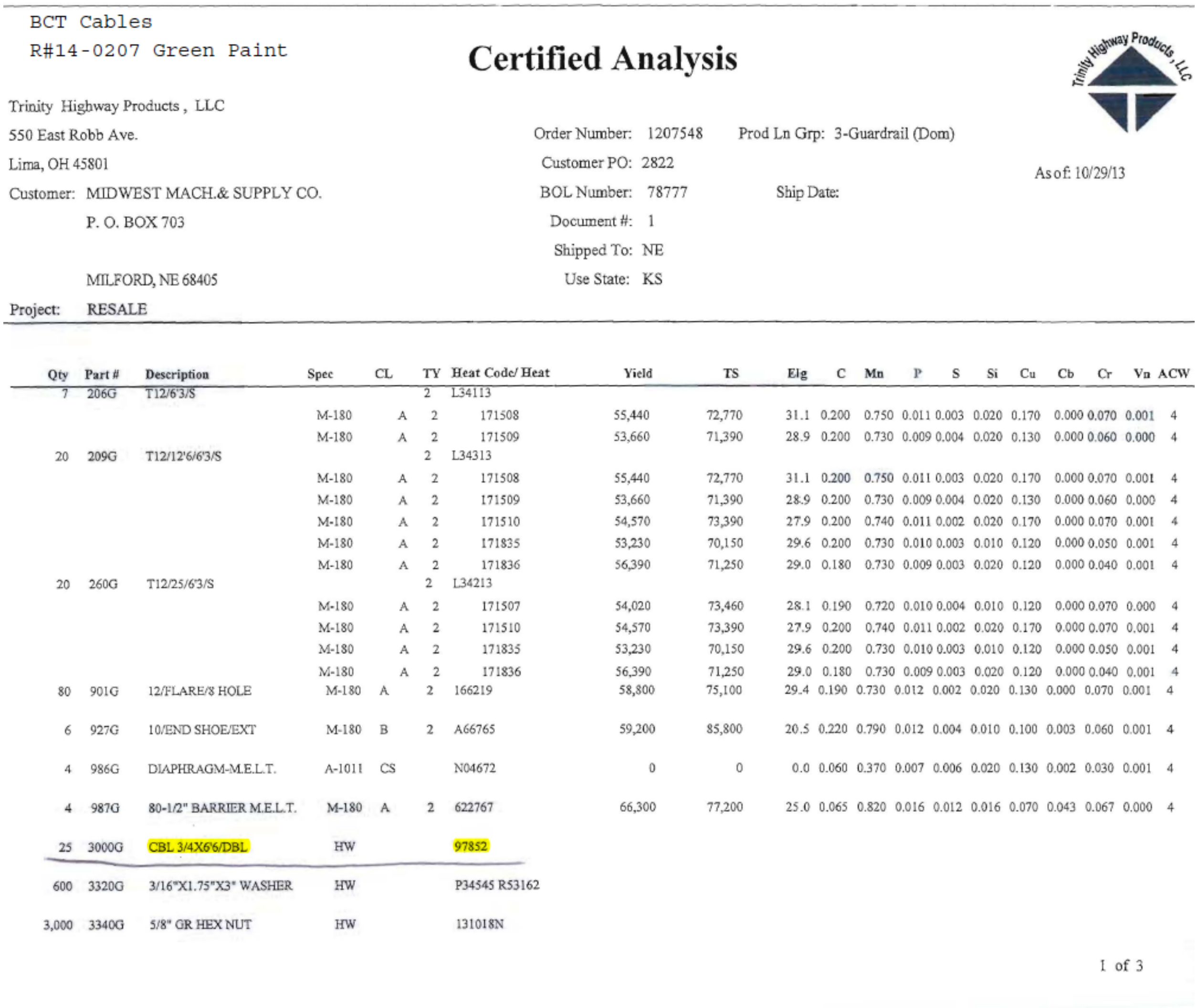
Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
36	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
20	3000G	CBL 3/4X6'6/DBL	HW			98790													
22	9852A	STRUT & YOKE ASSY	A-1011-SS			163375	48,380	64,020	32.9	0.190	0.520	0.011	0.003	0.030	0.110	0.000	0.050	0.000	4
	9852A		A-36			11237730	45,500	70,000	30.0	0.170	0.500	0.010	0.008	0.020	0.080	0.000	0.070	0.001	4

Ground Strut Green Paint
R#15-0157 September 2014 SMT

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)
FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

Figure C-10. Ground Strut Material Specification, Test No. MGSMS-1



BCT Cables
R#14-0207 Green Paint

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

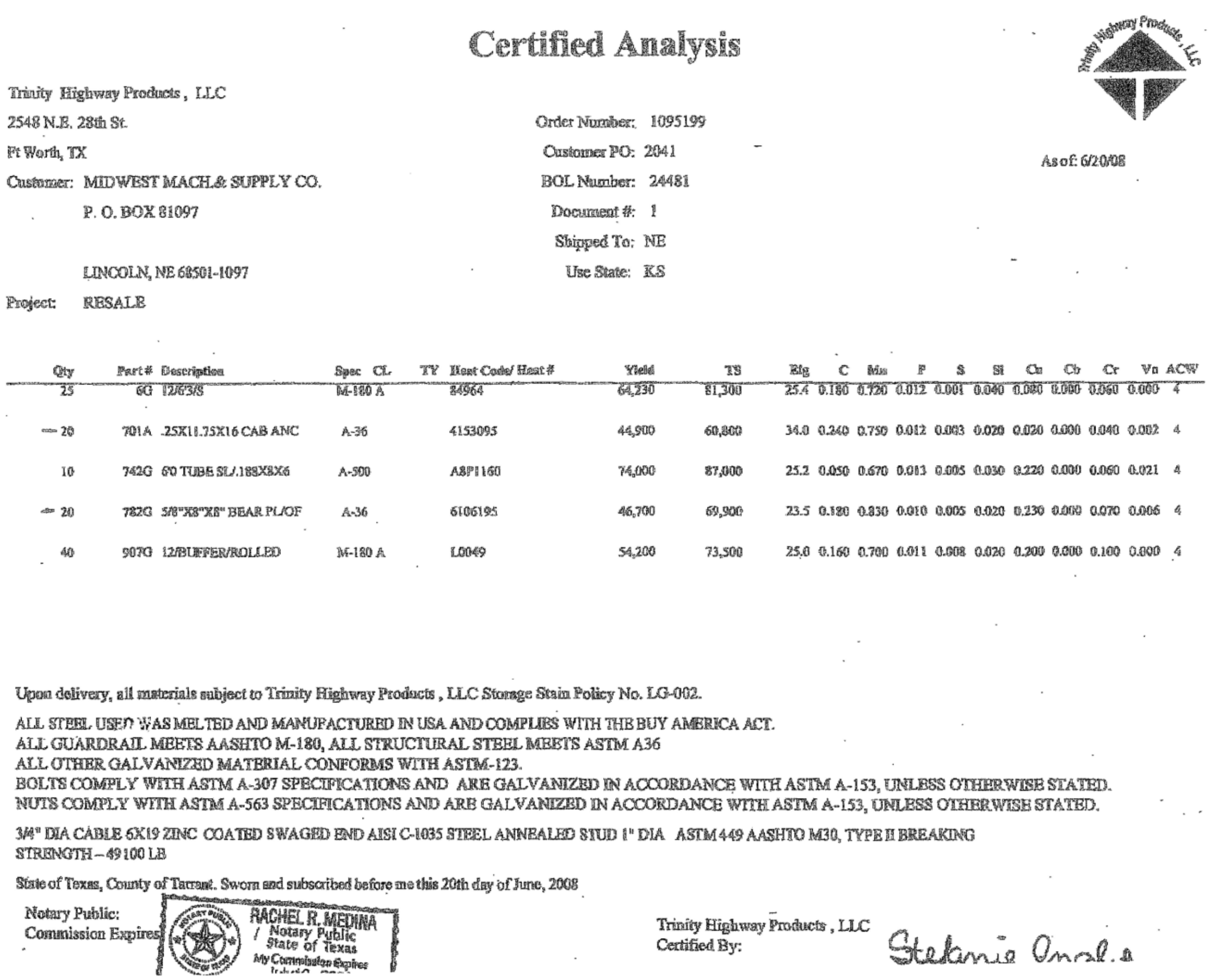
Order Number: 1207548
Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 2822
BOL Number: 78777
Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 10/29/13

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
7	206G	T12/6'3/S			2	L34113													
			M-180	A	2	171508	55,440	72,770	31.1	0.200	0.750	0.011	0.003	0.020	0.170	0.000	0.070	0.001	4
			M-180	A	2	171509	53,660	71,390	28.9	0.200	0.730	0.009	0.004	0.020	0.130	0.000	0.060	0.000	4
20	209G	T12/12'6/6'3/S			2	L34313													
			M-180	A	2	171508	55,440	72,770	31.1	0.200	0.750	0.011	0.003	0.020	0.170	0.000	0.070	0.001	4
			M-180	A	2	171509	53,660	71,390	28.9	0.200	0.730	0.009	0.004	0.020	0.130	0.000	0.060	0.000	4
			M-180	A	2	171510	54,570	73,390	27.9	0.200	0.740	0.011	0.002	0.020	0.170	0.000	0.070	0.001	4
			M-180	A	2	171835	53,230	70,150	29.6	0.200	0.730	0.010	0.003	0.010	0.120	0.000	0.050	0.001	4
			M-180	A	2	171836	56,390	71,250	29.0	0.180	0.730	0.009	0.003	0.020	0.120	0.000	0.040	0.001	4
20	260G	T12/25/6'3/S			2	L34213													
			M-180	A	2	171507	54,020	73,460	28.1	0.190	0.720	0.010	0.004	0.010	0.120	0.000	0.070	0.000	4
			M-180	A	2	171510	54,570	73,390	27.9	0.200	0.740	0.011	0.002	0.020	0.170	0.000	0.070	0.001	4
			M-180	A	2	171835	53,230	70,150	29.6	0.200	0.730	0.010	0.003	0.010	0.120	0.000	0.050	0.001	4
			M-180	A	2	171836	56,390	71,250	29.0	0.180	0.730	0.009	0.003	0.020	0.120	0.000	0.040	0.001	4
80	901G	12/FLARE/8 HOLE	M-180	A	2	166219	58,800	75,100	29.4	0.190	0.730	0.012	0.002	0.020	0.130	0.000	0.070	0.001	4
6	927G	10/END SHOE/EXT	M-180	B	2	A66765	59,200	85,800	20.5	0.220	0.790	0.012	0.004	0.010	0.100	0.003	0.060	0.001	4
4	986G	DIAPHRAGM-M.E.L.T.	A-1011	CS		N04672	0	0	0.0	0.060	0.370	0.007	0.006	0.020	0.130	0.002	0.030	0.001	4
4	987G	80-1/2" BARRIER M.E.L.T.	M-180	A	2	622767	66,300	77,200	25.0	0.065	0.820	0.016	0.012	0.016	0.070	0.043	0.067	0.000	4
25	3000G	CBL 3/4X6'6/DBL	HW			97852													
600	3320G	3/16"X1.75"X3" WASHER	HW			P34545 R53162													
3,000	3340G	5/8" GR HEX NUT	HW			131018N													

1 of 3

Figure C-11. BCT Cable Anchor Material Specification, Test No. MGSMS-1



Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Project: RESALE

Order Number: 1095199
Customer PO: 2041
BOL Number: 24481
Document #: 1
Shipped To: NE
Use State: KS

As of: 6/20/08

Qty	Part#	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	6G	12/63/S	M-180	A		84964	64,230	81,300	25.4	0.180	0.720	0.012	0.001	0.040	0.080	0.000	0.060	0.000	4
20	701A	.25X11.75X16 CAB ANC	A-36			4153095	44,900	60,800	34.0	0.240	0.750	0.012	0.003	0.020	0.020	0.000	0.040	0.002	4
10	742G	60 TUBE SL/.188X8X6	A-500			A8P1160	74,000	87,000	25.2	0.050	0.670	0.013	0.005	0.030	0.220	0.000	0.060	0.021	4
20	782G	5/8"X8"X8" BEAR PL/OF	A-36			6106195	46,700	69,900	23.5	0.180	0.830	0.010	0.005	0.020	0.230	0.000	0.070	0.006	4
40	907G	12/BUFFER/ROLLED	M-180	A		L0049	54,200	73,500	25.0	0.160	0.700	0.011	0.008	0.020	0.200	0.000	0.100	0.000	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

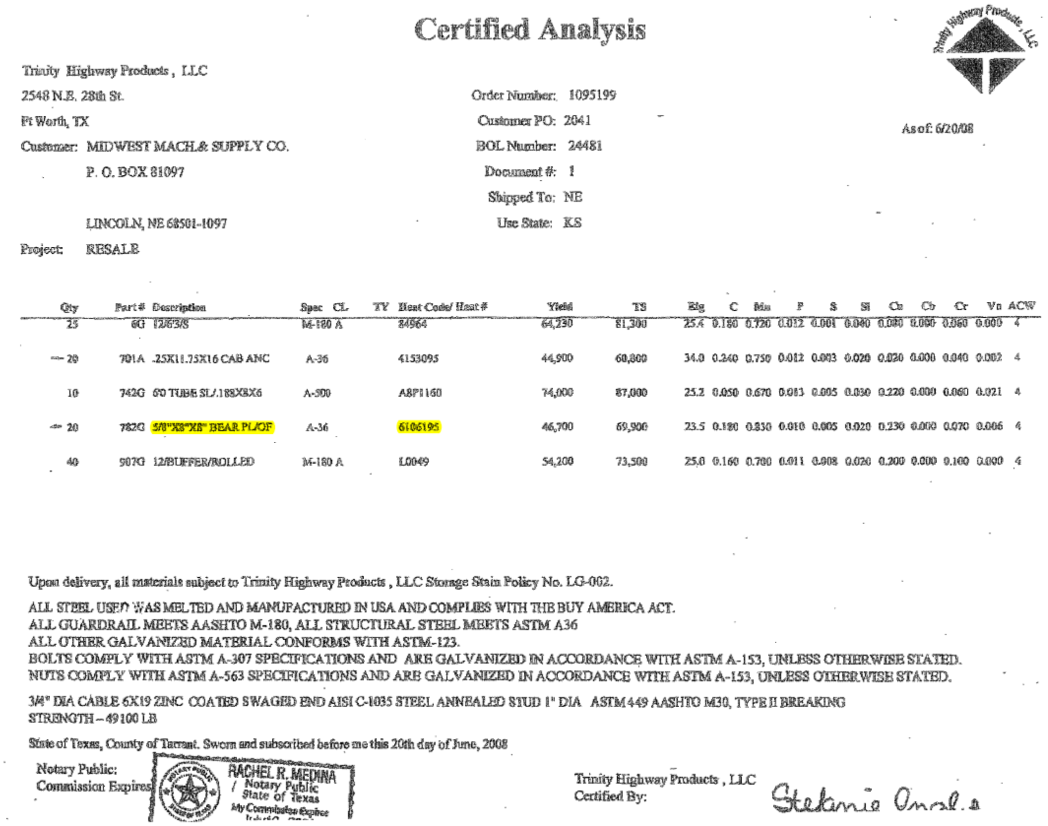
State of Texas, County of Tarrant. Sworn and subscribed before me this 20th day of June, 2008

Notary Public:
Commission Expires

RACHEL R. MEDINA
Notary Public
State of Texas
My Commission Expires

Trinity Highway Products , LLC
Certified By: Stefanie Onal.a

Figure C-12. Cable Anchor Bracket Assembly Material Specification, Test No. MGSMS-1



Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097
Project: RESALE

Order Number: 1095199
Customer PO: 2041
BOL Number: 24481
Document #: 1
Shipped To: NE
Use State: KS

As of: 6/20/08

Qty	Part#	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	6G	12/6'3/S	M-180	A		84964	64,230	81,300	25.4	0.180	0.720	0.012	0.001	0.040	0.080	0.000	0.060	0.000	4
20	701A	.25X11.75X16 CAB ANC	A-36			4153095	44,900	60,800	34.0	0.240	0.750	0.012	0.003	0.020	0.020	0.000	0.040	0.002	4
10	742G	6'0 TUBE SL/.188X8X6	A-500			A8P1160	74,000	87,000	25.2	0.050	0.670	0.013	0.005	0.030	0.220	0.000	0.060	0.021	4
20	782G	5/8"X8"X8" BEAR PL/OF	A-36			6106195	46,700	69,900	23.5	0.180	0.830	0.010	0.005	0.020	0.230	0.000	0.070	0.006	4
40	907G	12/BUFFER/ROLLED	M-180	A		L0049	54,200	73,500	25.0	0.160	0.700	0.011	0.008	0.020	0.200	0.000	0.100	0.000	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

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ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

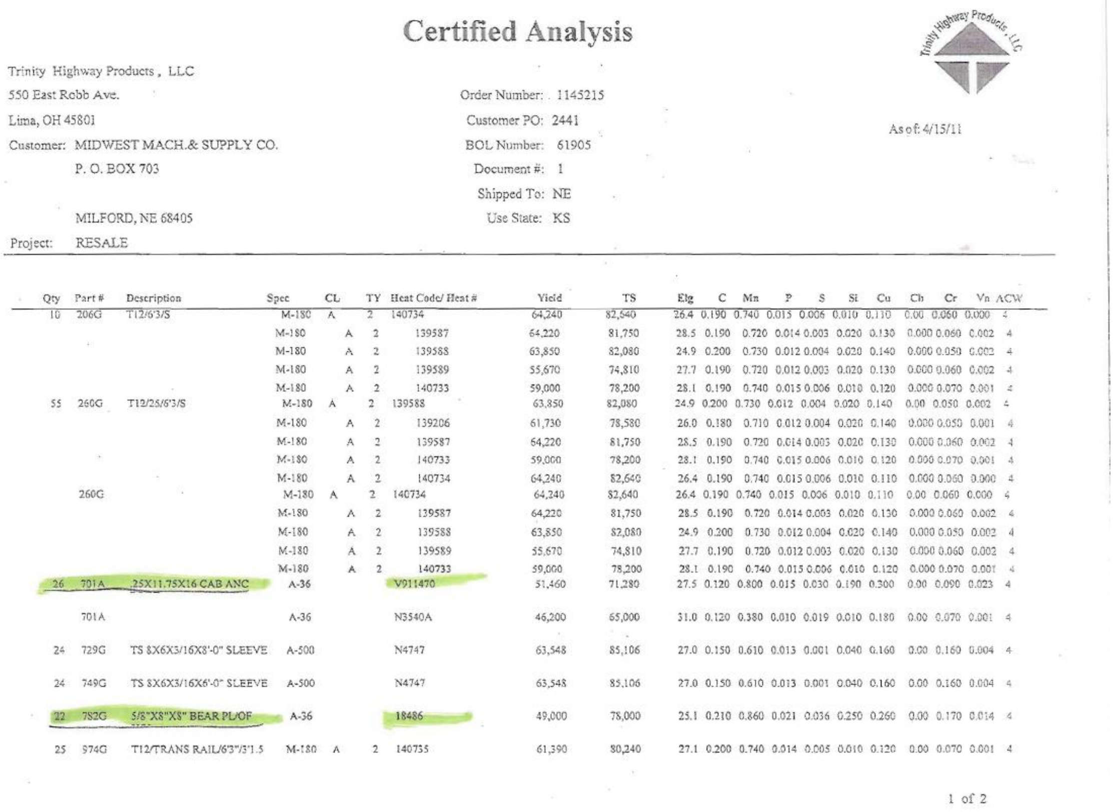
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 20th day of June, 2008

Notary Public:
Commission Expires

RACHEL R. MEDINA
Notary Public
State of Texas
My Commission Expires

Trinity Highway Products , LLC
Certified By: Stefanie Onal



Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1145215
Customer PO: 2441
BOL Number: 61905
Document #: 1
Shipped To: NE
Use State: KS

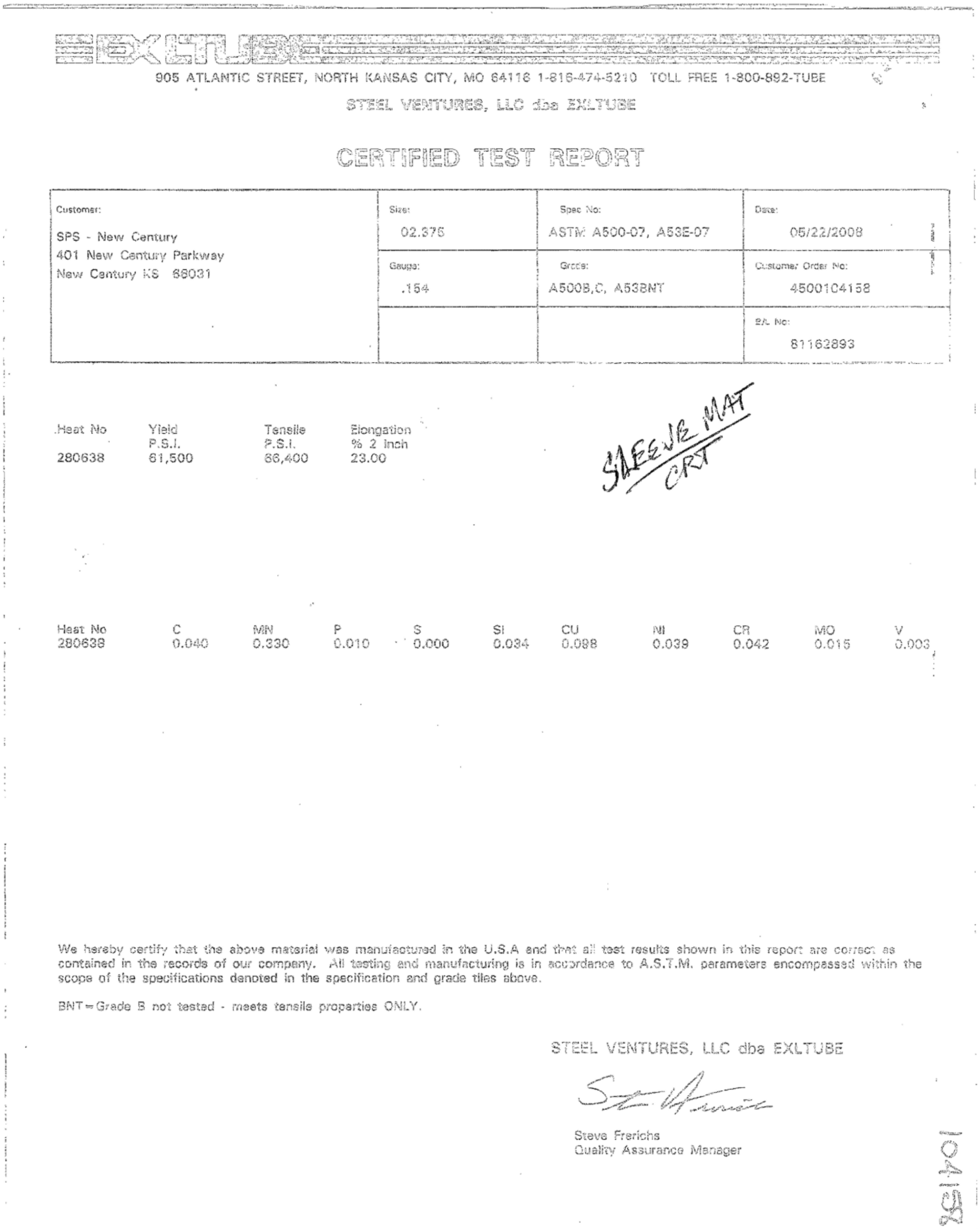
As of: 4/15/11

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	206G	T12/6'3/S	M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.00	0.060	0.000	4
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.000	0.050	0.002	4
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	4
55	260G	T12/25/6'3/S	M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.00	0.050	0.002	4
			M-180	A	2	139206	61,730	78,580	26.0	0.180	0.710	0.012	0.004	0.020	0.140	0.000	0.050	0.001	4
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	4
			M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.000	0.060	0.000	4
	260G		M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.00	0.060	0.000	4
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.000	0.050	0.002	4
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	4
26	701A	.25X11.75X16 CAB ANC	A-36			V911470	51,460	71,280	27.5	0.120	0.800	0.015	0.030	0.190	0.300	0.00	0.090	0.023	4
	701A		A-36			N3540A	46,200	65,000	31.0	0.120	0.380	0.010	0.019	0.010	0.180	0.00	0.070	0.001	4
24	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.160	0.00	0.160	0.004	4
24	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.160	0.00	0.160	0.004	4
22	782G	5/8"X8"X8" BEAR PL/OF	A-36			18486	49,000	78,000	25.1	0.210	0.860	0.021	0.036	0.250	0.260	0.00	0.170	0.014	4
25	974G	T12/TRANS RAIL/6'3"/3'1.5	M-180	A	2	140735	61,390	80,240	27.1	0.200	0.740	0.014	0.005	0.010	0.120	0.00	0.070	0.001	4

1 of 2

Figure C-13. Anchor Bearing Plates Material Specifications, Test No. MGSMS-1

H# 280638



EXLTUBE

905 ATLANTIC 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: SPS - New Century 401 New Century Parkway New Century KS 66031	Size: 02.375	Spec No: ASTM A500-07, A53E-07	Date: 05/22/2008
	Gauge: .154	Grade: A500B,C, A53BNT	Customer Order No: 4500104158
			B/L No: 81162893

Heat No	Yield P.S.I.	Tensile P.S.I.	Elongation % 2 inch
280638	61,500	86,400	23.00

SLEEVE MAT
CRT

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
280638	0.040	0.330	0.010	0.000	0.034	0.098	0.039	0.042	0.015	0.003

We hereby certify that the above material was manufactured in the U.S.A and 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.

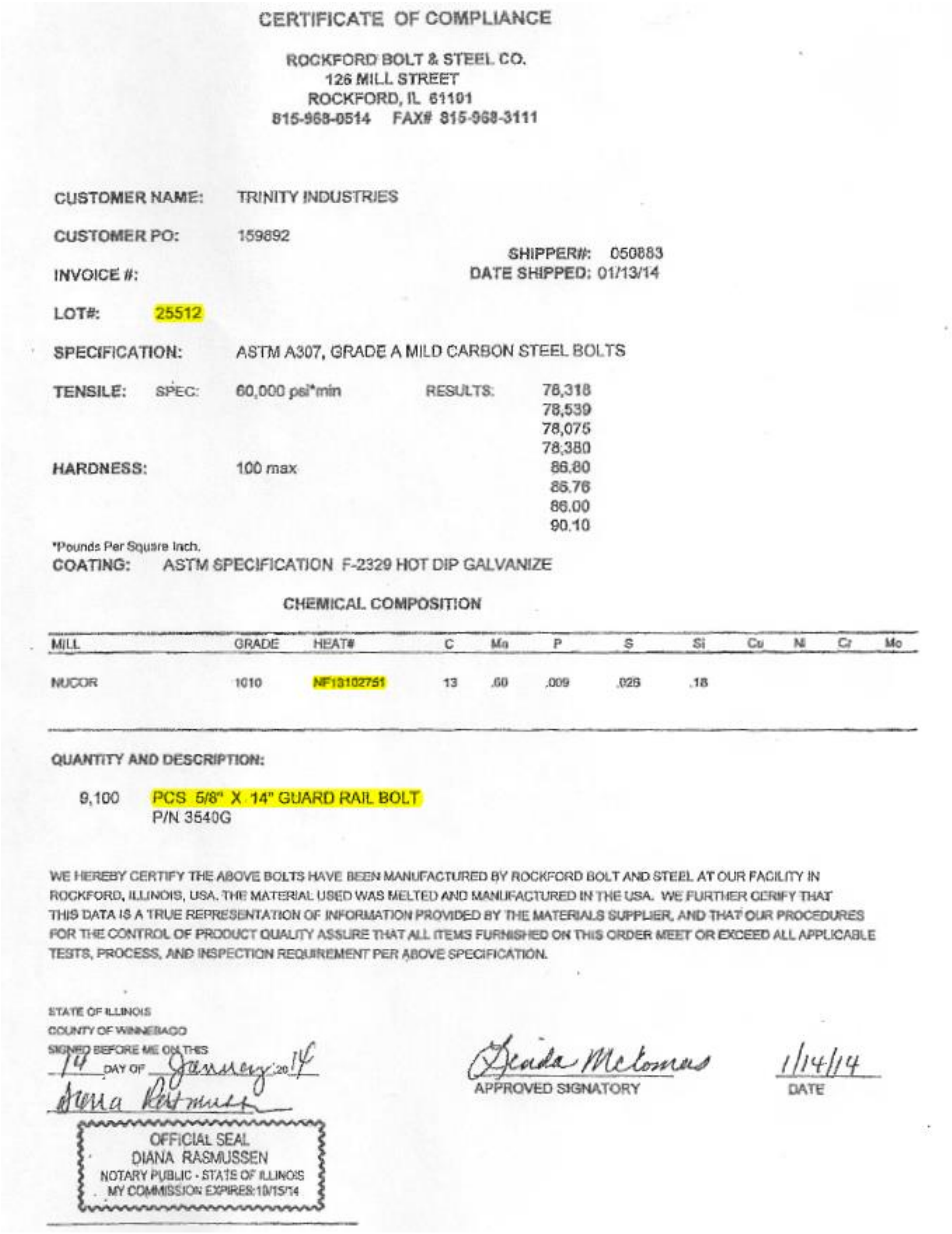
BNT=Grade B not tested - meets tensile properties ONLY.

STEEL VENTURES, LLC dba EXLTUBE

Steve Frerichs
Quality Assurance Manager

104158

Figure C-14. BCT Post Sleeve Material Specification, Test No. MGSMS-1



CERTIFICATE OF COMPLIANCE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER PO: 159692

SHIPPER#: 050883

INVOICE #:

DATE SHIPPED: 01/13/14

LOT#: 25512

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

TENSILE: SPEC: 60,000 psi*min RESULTS: 78,318
78,539
78,075
78,380

HARDNESS: 100 max 86.80
86.76
86.00
90.10

*Pounds Per Square Inch.

COATING: ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	Si	Cu	Ni	Cr	Mo
NUCOR	1010	NF13102751	13	.60	.009	.026	.18				

QUANTITY AND DESCRIPTION:

9,100 PCS 5/8" X 14" GUARD RAIL BOLT
P/N 3540G

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL AT OUR FACILITY IN ROCKFORD, ILLINOIS, USA. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE USA. WE FURTHER CERIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENT PER ABOVE SPECIFICATION.

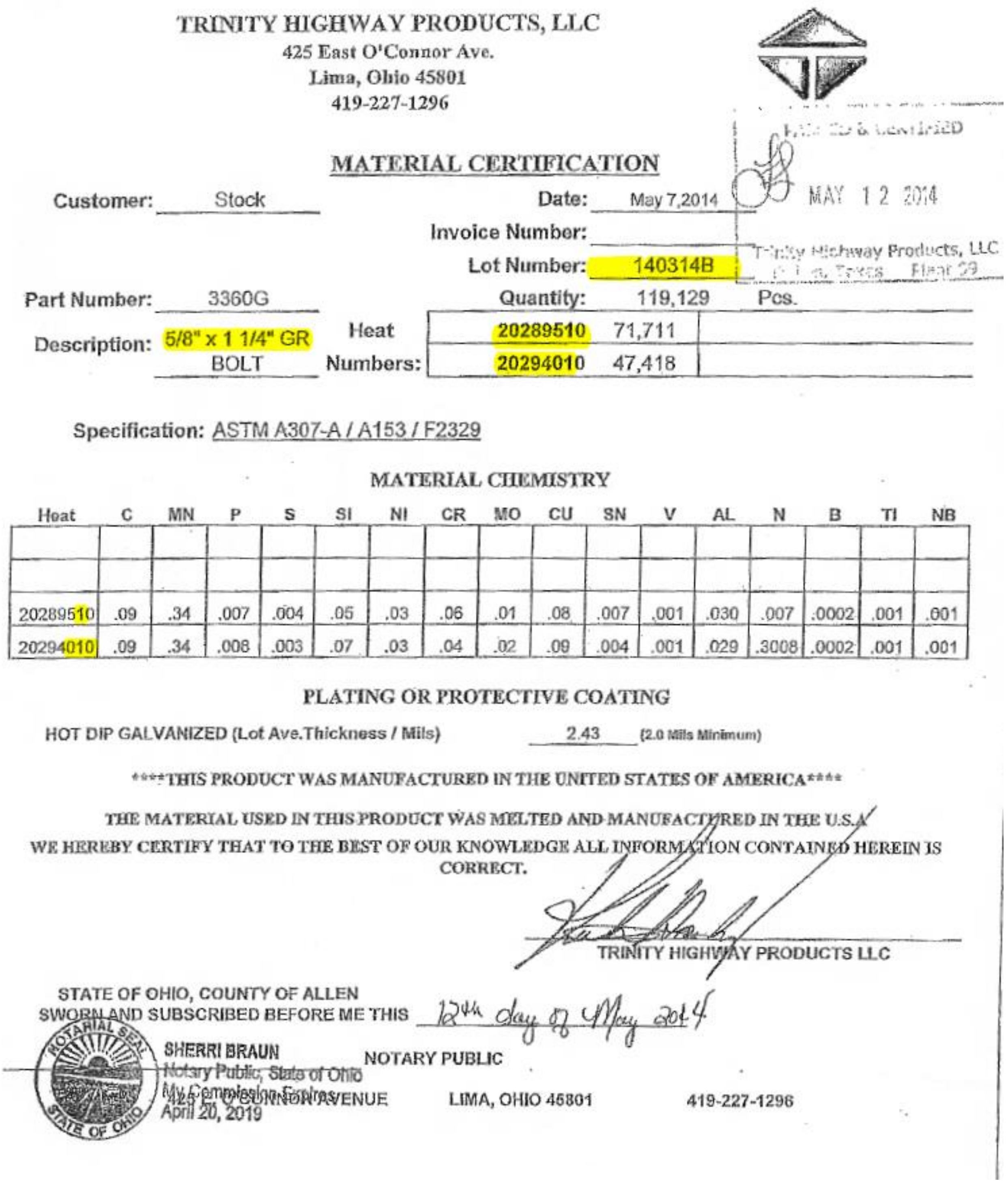
STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS
14 DAY OF January 20 14

APPROVED SIGNATORY

1/14/14
DATE

OFFICIAL SEAL
DIANA RASMUSSEN
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES: 10/15/14

Figure C-15. ⅝-in. Dia. x 14-in. Guardrail Bolt Material Specs, Test No. MGSMS-1



TRINITY HIGHWAY PRODUCTS, LLC
425 East O'Connor Ave.
Lima, Ohio 45801
419-227-1296

[illegible] & CERTIFIED
MAY 12 2014
Trinity Highway Products, LLC
[illegible], Texas Plant 29

MATERIAL CERTIFICATION

Customer: Stock

Date: May 7,2014

Invoice Number:

Lot Number: 140314B

Part Number: 3360G

Quantity: 119,129 Pcs.

Description: 5/8" x 1 1/4" GR BOLT

Heat Numbers:	
20289510	71,711
20294010	47,418

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
20289510	.09	.34	.007	.004	.05	.03	.06	.01	.08	.007	.001	.030	.007	.0002	.001	.001
20294010	.09	.34	.008	.003	.07	.03	.04	.02	.09	.004	.001	.029	.3008	.0002	.001	.001

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.43 (2.0 Mils Minimum)

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A

WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

TRINITY HIGHWAY PRODUCTS LLC

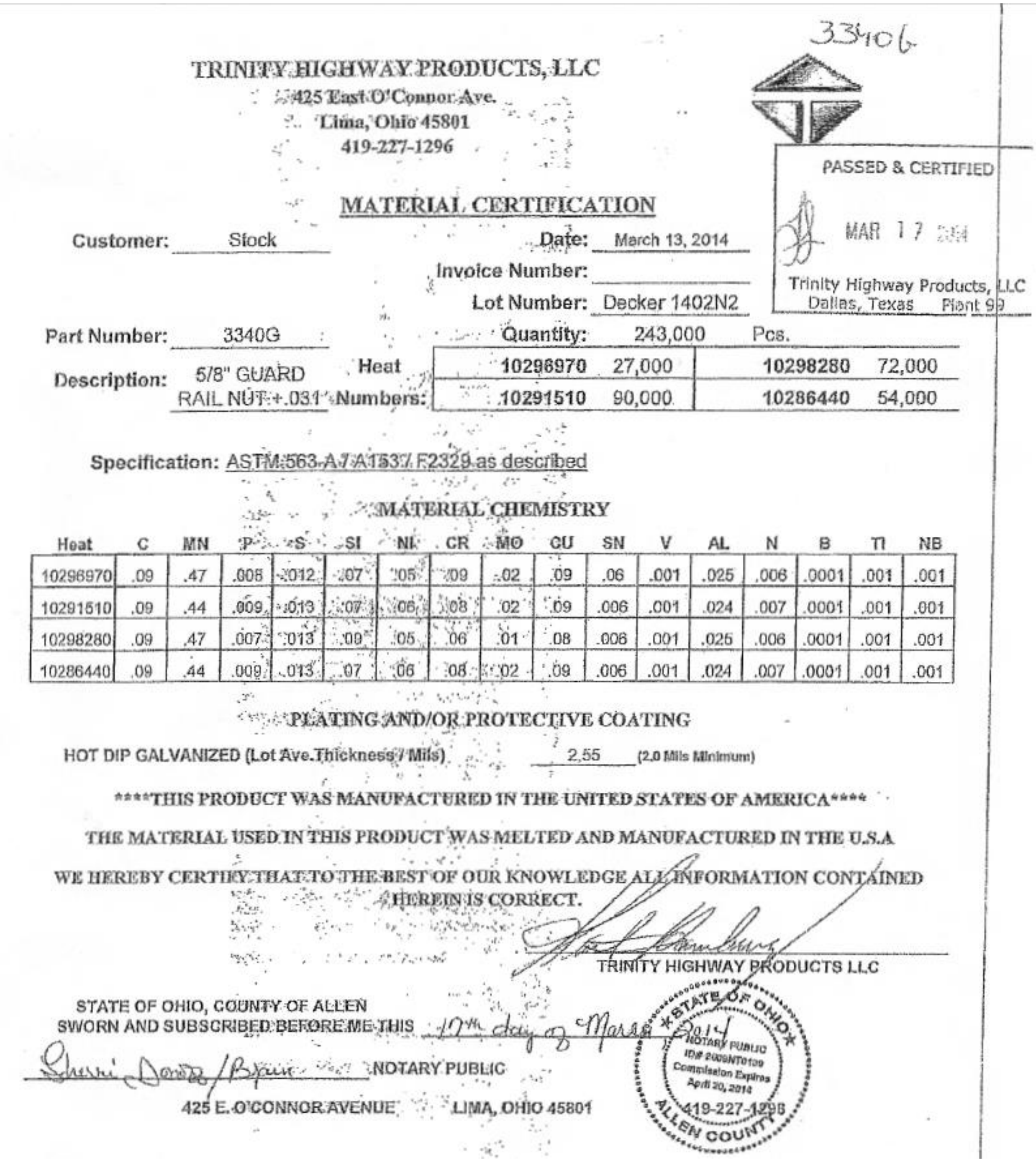
STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 12th day of May 2014

SHERRI BRAUN
Notary Public, State of Ohio
My Commission Expires
April 20, 2019

NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 45801 419-227-1296

Figure C-16. ⅝-in. Dia. x 1¼-in. Guardrail Bolt Material Specs, Test No. MGSMS-1



3340G

TRINITY HIGHWAY PRODUCTS, LLC
425 East O'Connor Ave.
Lima, Ohio 45801
419-227-1296

PASSED & CERTIFIED
MAR 17 2014
Trinity Highway Products, LLC
Dallas, Texas Plant 99

MATERIAL CERTIFICATION

Customer: Stock

Date: March 13, 2014

Invoice Number:

Lot Number: Decker 1402N2

Part Number: 3340G

Quantity: 243,000 Pcs.

Description: 5/8" GUARD RAIL NUT +.031

Heat Numbers:			
10296970	27,000	10298280	72,000
10291510	90,000	10286440	54,000

Specification: ASTM 563 A / A153 / F2329 as described

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
10296970	.09	.47	.008	.012	.07	.05	.09	.02	.09	.06	.001	.025	.006	.0001	.001	.001
10291510	.09	.44	.009	.013	.07	.06	.08	.02	.09	.006	.001	.024	.007	.0001	.001	.001
10298280	.09	.47	.007	.013	.09	.05	.06	.01	.08	.006	.001	.025	.006	.0001	.001	.001
10286440	.09	.44	.009	.013	.07	.06	.08	.02	.09	.006	.001	.024	.007	.0001	.001	.001

PLATING AND/OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.55 (2.0 Mils Minimum)

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A

WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

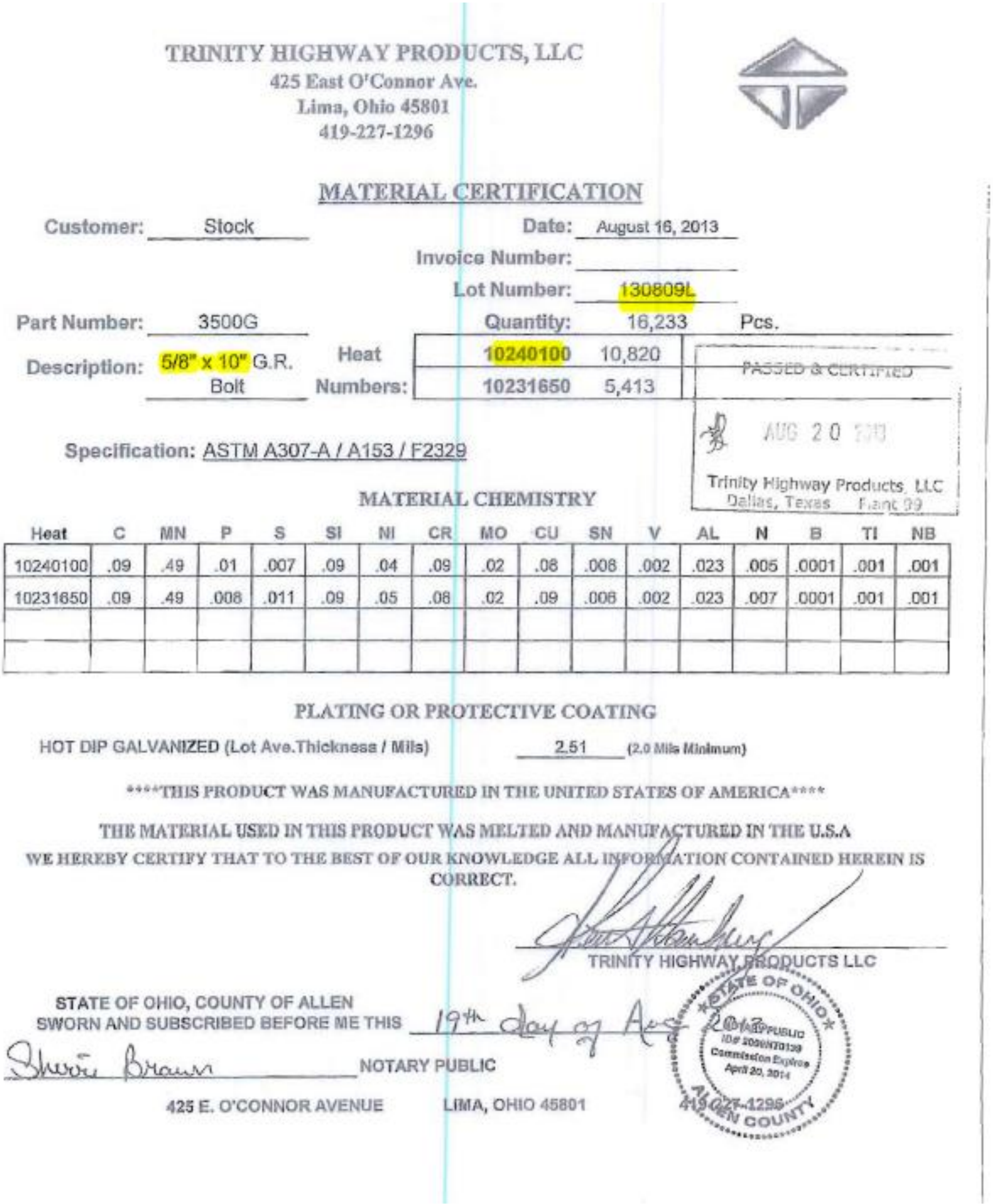
TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 17th day of March 2014

NOTARY PUBLIC
425 E. O'CONNOR AVENUE LIMA, OHIO 45801

ID# 2009NT0139
Commission Expires April 20, 2014

Figure C-17. ⅝-in. Dia. Guardrail Nut Material Specification, Test No. MGSMS-1



TRINITY HIGHWAY PRODUCTS, LLC
425 East O'Connor Ave.
Lima, Ohio 45801
419-227-1296

MATERIAL CERTIFICATION

Customer: Stock

Date: August 16, 2013

Invoice Number:

Lot Number: 130809L

Part Number: 3500G

Quantity: 16,233 Pcs.

Description: 5/8" x 10" G.R. Bolt

Heat Numbers:	
10240100	10,820
10231650	5,413

PASSED & CERTIFIED
AUG 20 2013
Trinity Highway Products, LLC
Dallas, Texas Plant 99

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
10240100	.09	.49	.01	.007	.09	.04	.09	.02	.08	.008	.002	.023	.005	.0001	.001	.001
10231650	.09	.49	.008	.011	.09	.05	.08	.02	.09	.006	.002	.023	.007	.0001	.001	.001

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.51 (2.0 Mils Minimum)

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A

WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

TRINITY HIGHWAY PRODUCTS LLC

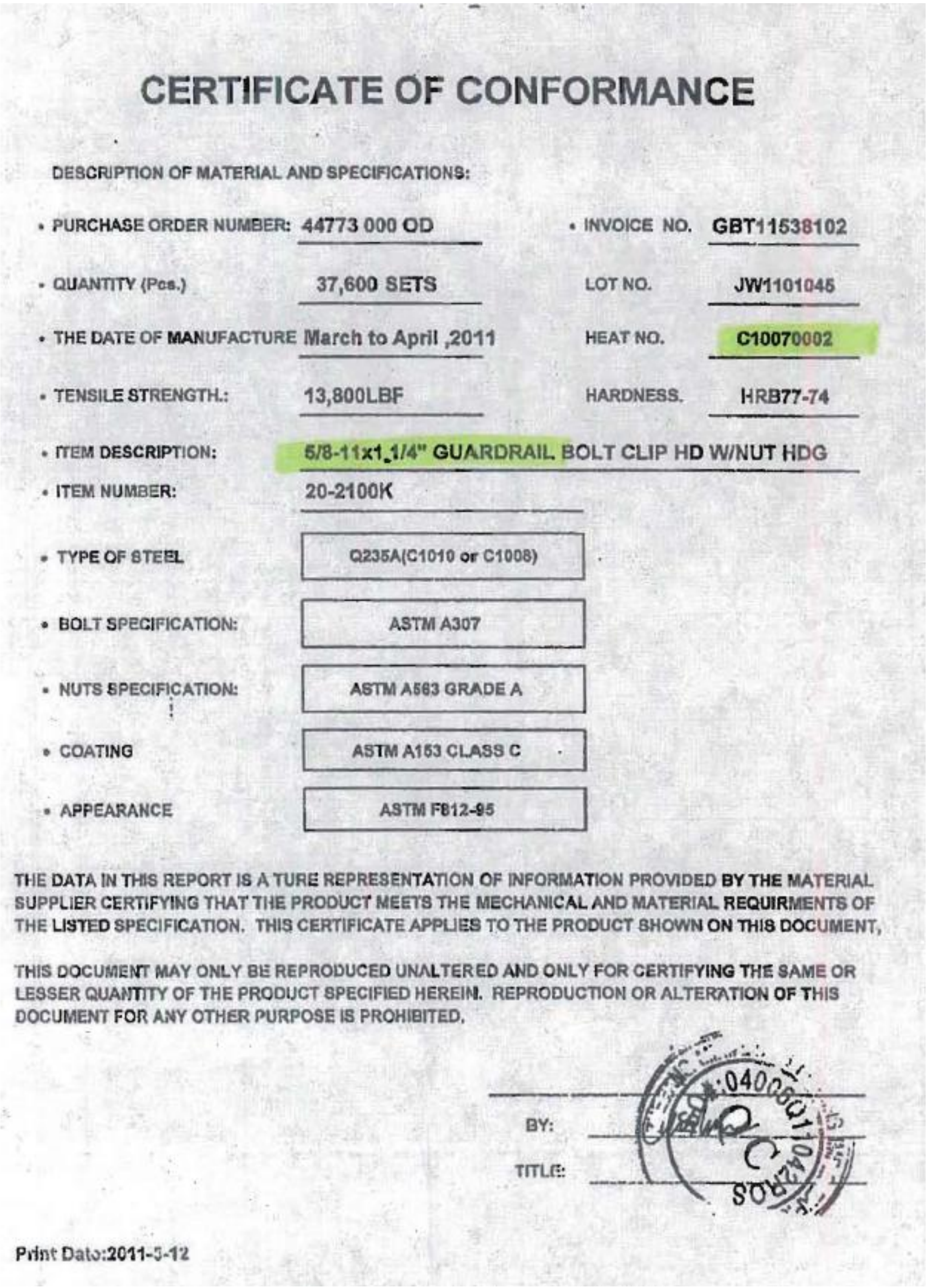
STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 19th day of Aug 2013

Sheri Brown NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 45801 419-227-1296

Commission Expires April 20, 2014

Figure C-18. ⅝-in. Dia. x 10-in. Guardrail Bolt Material Specification, Test No. MGSMS-1



CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS:

- PURCHASE ORDER NUMBER: 44773 000 OD
- INVOICE NO. GBT11538102
- QUANTITY (Pcs.) 37,600 SETS
- LOT NO. JW1101045
- THE DATE OF MANUFACTURE March to April ,2011
- HEAT NO. C10070002
- TENSILE STRENGTH.: 13,800LBF
- HARDNESS. HRB77-74
- ITEM DESCRIPTION: 5/8-11x1.1/4" GUARDRAIL BOLT CLIP HD W/NUT HDG
- ITEM NUMBER: 20-2100K
- TYPE OF STEEL Q235A(C1010 or C1008)
- BOLT SPECIFICATION: ASTM A307
- NUTS SPECIFICATION: ASTM A563 GRADE A
- COATING ASTM A153 CLASS C
- APPEARANCE ASTM F812-95

THE DATA IN THIS REPORT IS A TURE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER CERTIFYING THAT THE PRODUCT MEETS THE MECHANICAL AND MATERIAL REQUIRMENTS OF THE LISTED SPECIFICATION. THIS CERTIFICATE APPLIES TO THE PRODUCT SHOWN ON THIS DOCUMENT,

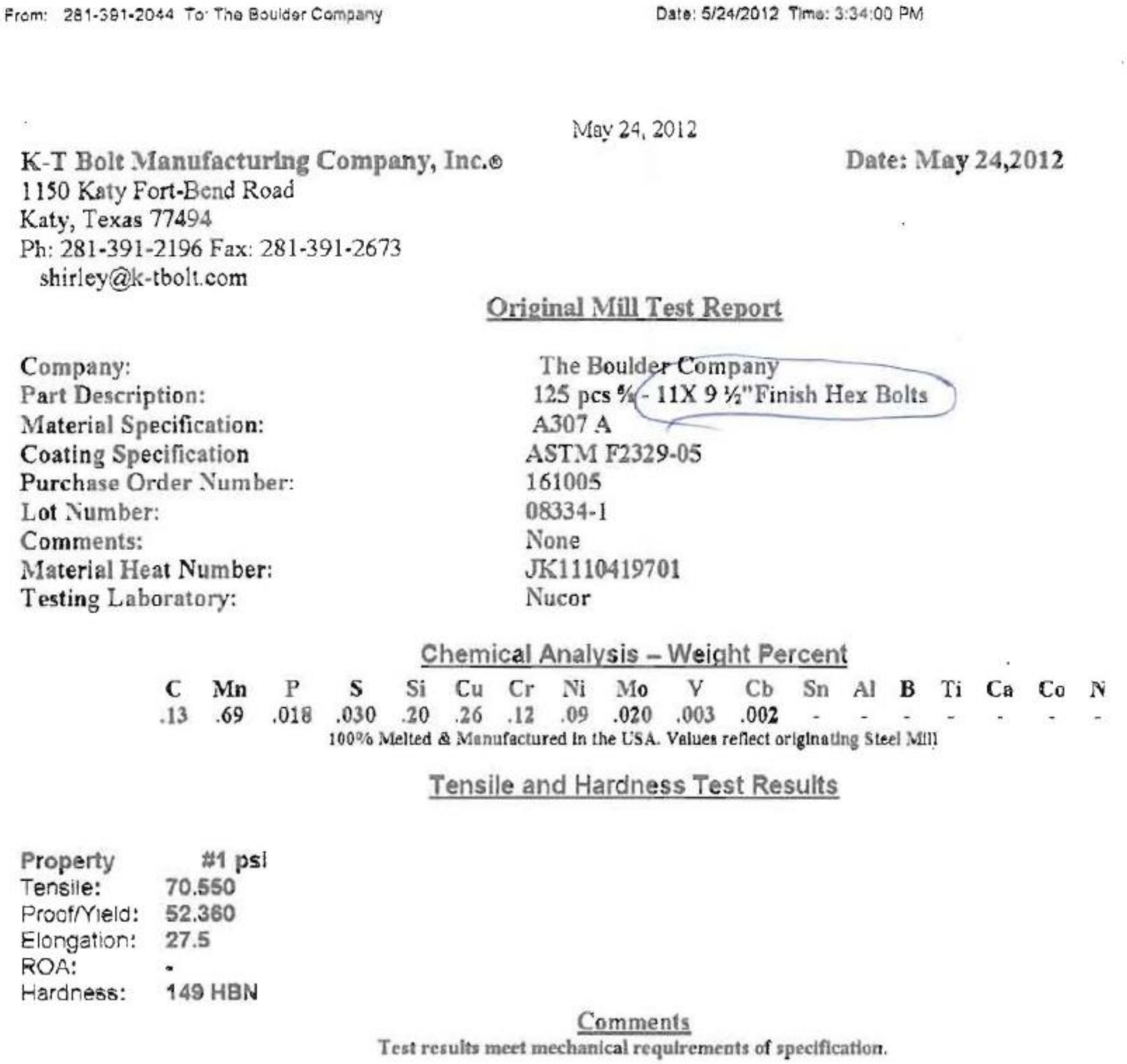
THIS DOCUMENT MAY ONLY BE REPRODUCED UNALTERED AND ONLY FOR CERTIFYING THE SAME OR LESSER QUANTITY OF THE PRODUCT SPECIFIED HEREIN. REPRODUCTION OR ALTERATION OF THIS DOCUMENT FOR ANY OTHER PURPOSE IS PROHIBITED.

BY:
TITLE:

QC

Print Dato:2011-3-12

Figure C-19. ⅝-in. Dia. x 1½-in. Hex Bolt Material Specification, Test No. MGSMS-1



From: 281-391-2044 To: The Boulder Company Date: 5/24/2012 Time: 3:34:00 PM

May 24, 2012

K-T Bolt Manufacturing Company, Inc.®
1150 Katy Fort-Bend Road
Katy, Texas 77494
Ph: 281-391-2196 Fax: 281-391-2673
shirley@k-tbolt.com

Date: May 24,2012

Original Mill Test Report

Company:	The Boulder Company
Part Description:	125 pcs ⅝ - 11X 9 ½"Finish Hex Bolts
Material Specification:	A307 A
Coating Specification	ASTM F2329-05
Purchase Order Number:	161005
Lot Number:	08334-1
Comments:	None
Material Heat Number:	JK1110419701
Testing Laboratory:	Nucor

Chemical Analysis – Weight Percent

C	Mn	P	S	Si	Cu	Cr	Ni	Mo	V	Cb	Sn	Al	B	Ti	Ca	Co	N
.13	.69	.018	.030	.20	.26	.12	.09	.020	.003	.002	-	-	-	-	-	-	-

100% Melted & Manufactured in the USA. Values reflect originating Steel Mill

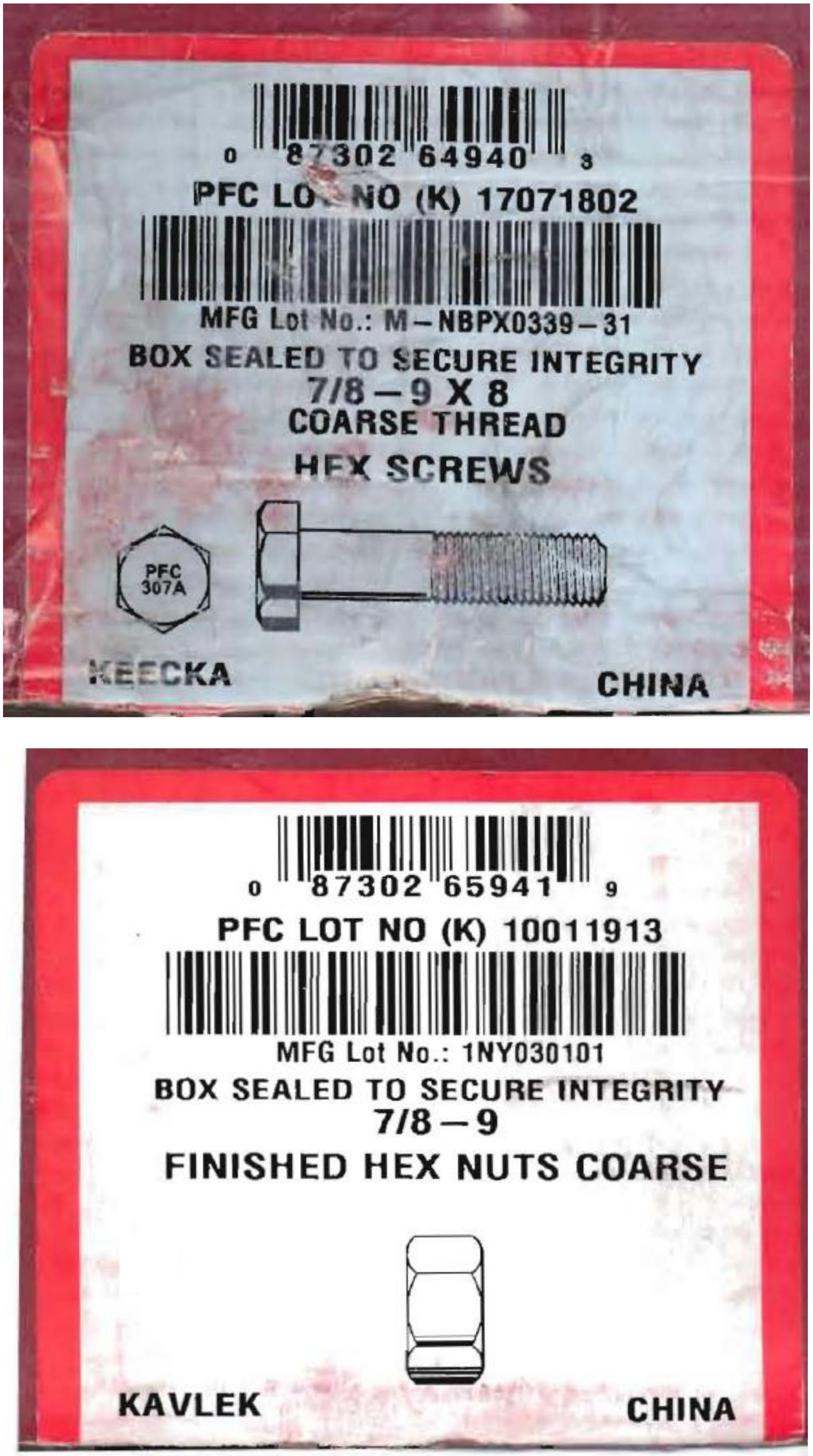
Tensile and Hardness Test Results

Property	#1 psi
Tensile:	70.550
Proof/Yield:	52.360
Elongation:	27.5
ROA:	-
Hardness:	149 HBN

Comments

Test results meet mechanical requirements of specification.

Figure C-20. ⅝-in. Dia. x 10-in. Hex Bolt Material Specification, Test No. MGSMS-1



0 87302 64940 3

PFC LOT NO (K) 17071802

MFG Lot No.: M – NBPX0339 – 31

BOX SEALED TO SECURE INTEGRITY

7/8 – 9 X 8

COARSE THREAD

HEX SCREWS

PFC 307A

KEECKA CHINA

0 87302 65941 9

PFC LOT NO (K) 10011913

MFG Lot No.: 1NY030101

BOX SEALED TO SECURE INTEGRITY

7/8 – 9

FINISHED HEX NUTS COARSE

KAVLEK CHINA

Figure C-21. ⅞-in. Dia. x 8-in Hex Bolt and Nut Material Specs, Test No. MGSMS-1

(1) 1JY82

Pk-25

H#8280068 PCS./PZS.25
Made in/Hecho en China
LOT#HO1779897

0 08236 83130 6

Flat Washers SAE
Arandelas Planas SAE
5/8
M15.9

Figure C-22. ⅝-in. Dia. Round Washer Material Specification, Test No. MGSMS-1

(1) 1JY86

Pk-10

H#8280072 PCS./PZS.10
Made in/Hecho en China
LOT#HO1788740

0 08236 83134 4

Flat Washers SAE
Arandelas Planas SAE
7/8
M22.2

Figure C-23. ⅞-in. Dia. Round Washer Material Specification, Test No. MGSMS-1

McMASTER-CARR

Packing List

600 N County Line Rd
Elmhurst IL 60126-2081
630-600-3600
chi.sales@mcmaster.com

University of Nebraska
Midwest Roadside Safety Facility
M W R S F
4630 Nw 36TH St
Lincoln NE 68524-1802
Attention: Shaun M Tighe

Purchase Order
E000177486

Order Placed By
Shaun M Tighe

McMaster-Carr Number
1796341-01

Page 1 of 1

10/01/2014

Line		Product	Ordered	Shipped
1	**91309A585**	Low-Strength Zinc-Plated Steel Cap Screw, 5/16"-18 Fully Threaded, 1-1/4" Long, Packs of 100	**1 Pack**	**1**
2	**90473A030**	Zinc-Plated Grade 2 Steel Hex Nut, 5/16"-18 Thread Size, 1/2" Width, 17/64" Height, Packs of 100	**1 Pack**	**1**

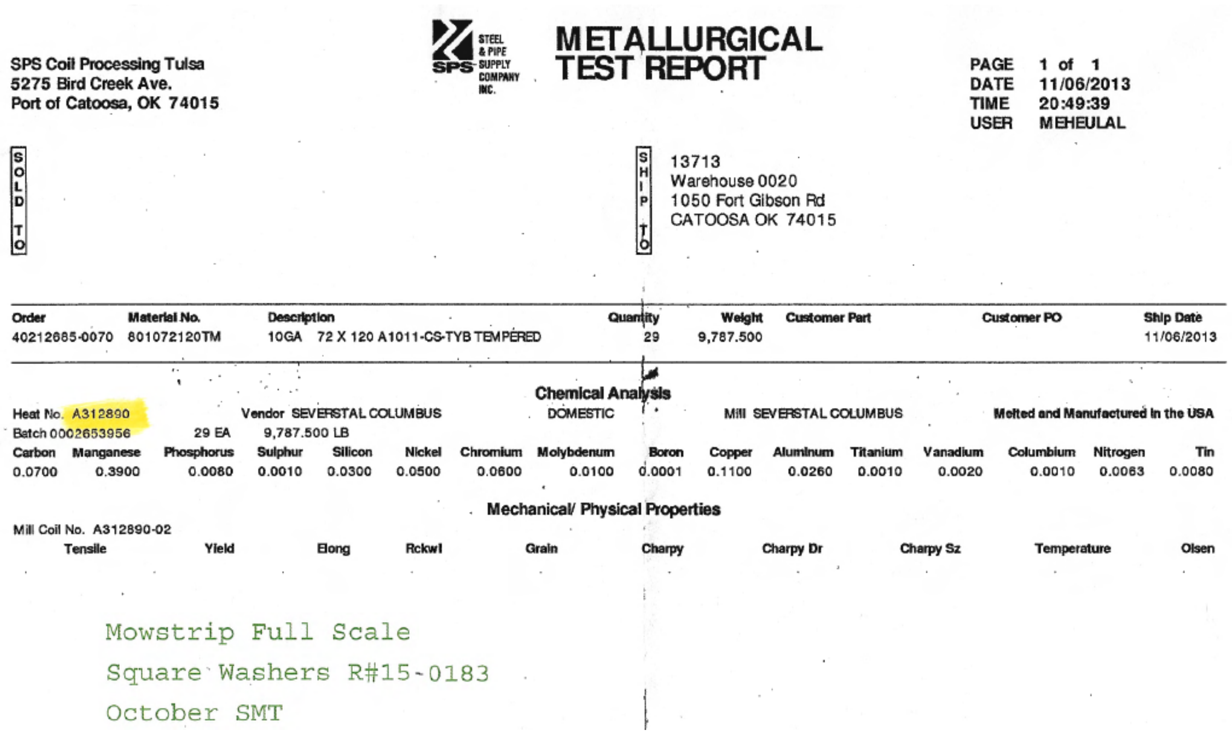
Certificate of compliance

This is to certify that the above items were supplied in accordance with the description and as illustrated in the catalog. In all other respects this transaction remains subject to our standard terms and conditions of sale, which can be found at www.mcmaster.com/terms.

Ray Connelly
Sales Manager

Mowstrip 5/16" hardware

Figure C-24. $^{5}/_{16}$-in x 1¼-in Hex Bolt and Nut Material Specification, Test No. MGSMS-1



SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

STEEL & PIPE SUPPLY COMPANY INC.

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 11/06/2013
TIME 20:49:39
USER MEHEULAL

SOLD TO

SHIP TO
13713
Warehouse 0020
1050 Fort Gibson Rd
CATOOSA OK 74015

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40212685-0070	801072120TM	10GA 72 X 120 A1011-CS-TYB TEMPERED	29	9,787.500			11/06/2013

Chemical Analysis

Heat No. A312890 Vendor SEVERSTAL COLUMBUS DOMESTIC Mill SEVERSTAL COLUMBUS Melted and Manufactured in the USA
Batch 0002653956 29 EA 9,787.500 LB

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.0700	0.3900	0.0080	0.0010	0.0300	0.0500	0.0600	0.0100	0.0001	0.1100	0.0260	0.0010	0.0020	0.0010	0.0063	0.0080

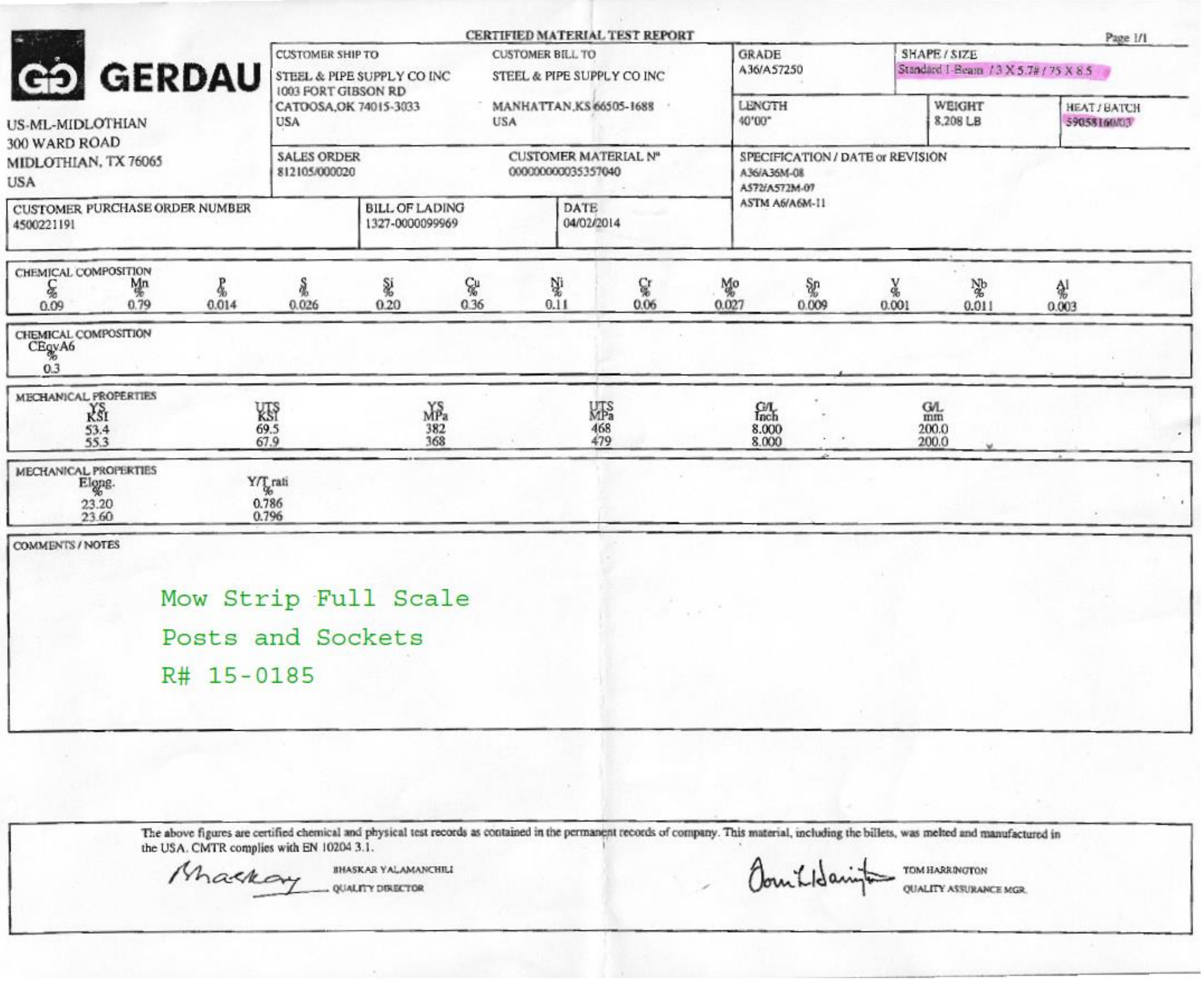
Mechanical/ Physical Properties

Mill Coil No. A312890-02

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen

Mowstrip Full Scale
Square Washers R#15-0183
October SMT

Figure C-25. 1¾-in. Square Washer Material Specification, Test No. MGSMS-1



GERDAU

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO
STEEL & PIPE SUPPLY CO INC
1003 FORT GIBSON RD
CATOOSA,OK 74015-3033
USA

CUSTOMER BILL TO
STEEL & PIPE SUPPLY CO INC
MANHATTAN,KS 66505-1688
USA

GRADE
A36/A57250

SHAPE / SIZE
Standard I-Beam / 3 X 5.7# / 75 X 8.5

LENGTH
40'00"

WEIGHT
8,208 LB

HEAT / BATCH
59058160/03

SALES ORDER
812105/000020

CUSTOMER MATERIAL Nº
000000000035357040

SPECIFICATION / DATE or REVISION
A36/A36M-08
A572/A572M-07
ASTM A6/A6M-11

CUSTOMER PURCHASE ORDER NUMBER
4500221191

BILL OF LADING
1327-0000099969

DATE
04/02/2014

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.09	0.79	0.014	0.026	0.20	0.36	0.11	0.06	0.027	0.009	0.001	0.011	0.003

CHEMICAL COMPOSITION

CEqvA6 %
0.3

MECHANICAL PROPERTIES

YS KSI	UTS KSI	YS MPa	UTS MPa	G/L Inch	G/L mm
53.4	69.5	382	468	8.000	200.0
55.3	67.9	368	479	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	Y/T rati %
23.20	0.786
23.60	0.796

COMMENTS / NOTES

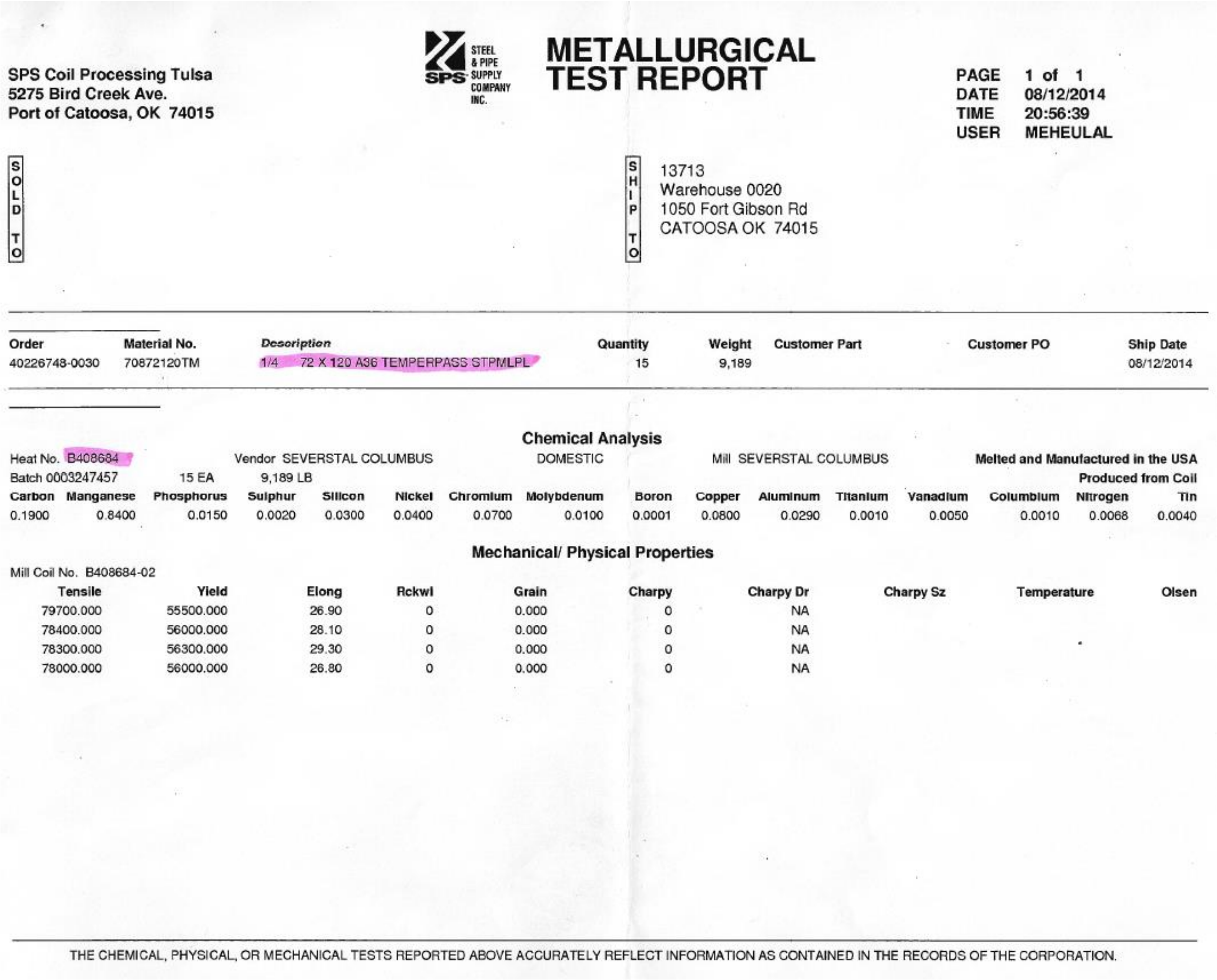
Mow Strip Full Scale
Posts and Sockets
R# 15-0185

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

TOM HARRINGTON
QUALITY ASSURANCE MGR.

Figure C-26. S3x5.7 Weak Post Material Specification, Test No. MGSMS-1



SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

STEEL & PIPE SUPPLY COMPANY INC.

METALLURGICAL TEST REPORT

PAGE	**1 of 1**
DATE	**08/12/2014**
TIME	**20:56:39**
USER	**MEHEULAL**

SOLD TO

SHIP TO
13713
Warehouse 0020
1050 Fort Gibson Rd
CATOOSA OK 74015

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40226748-0030	70872120TM	1/4 72 X 120 A36 TEMPERPASS STPMLPL	15	9,189			08/12/2014

Chemical Analysis

Heat No. B408684 Vendor SEVERSTAL COLUMBUS DOMESTIC Mill SEVERSTAL COLUMBUS **Melted and Manufactured in the USA**
Batch 0003247457 15 EA 9,189 LB **Produced from Coil**

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.1900	0.8400	0.0150	0.0020	0.0300	0.0400	0.0700	0.0100	0.0001	0.0800	0.0290	0.0010	0.0050	0.0010	0.0068	0.0040

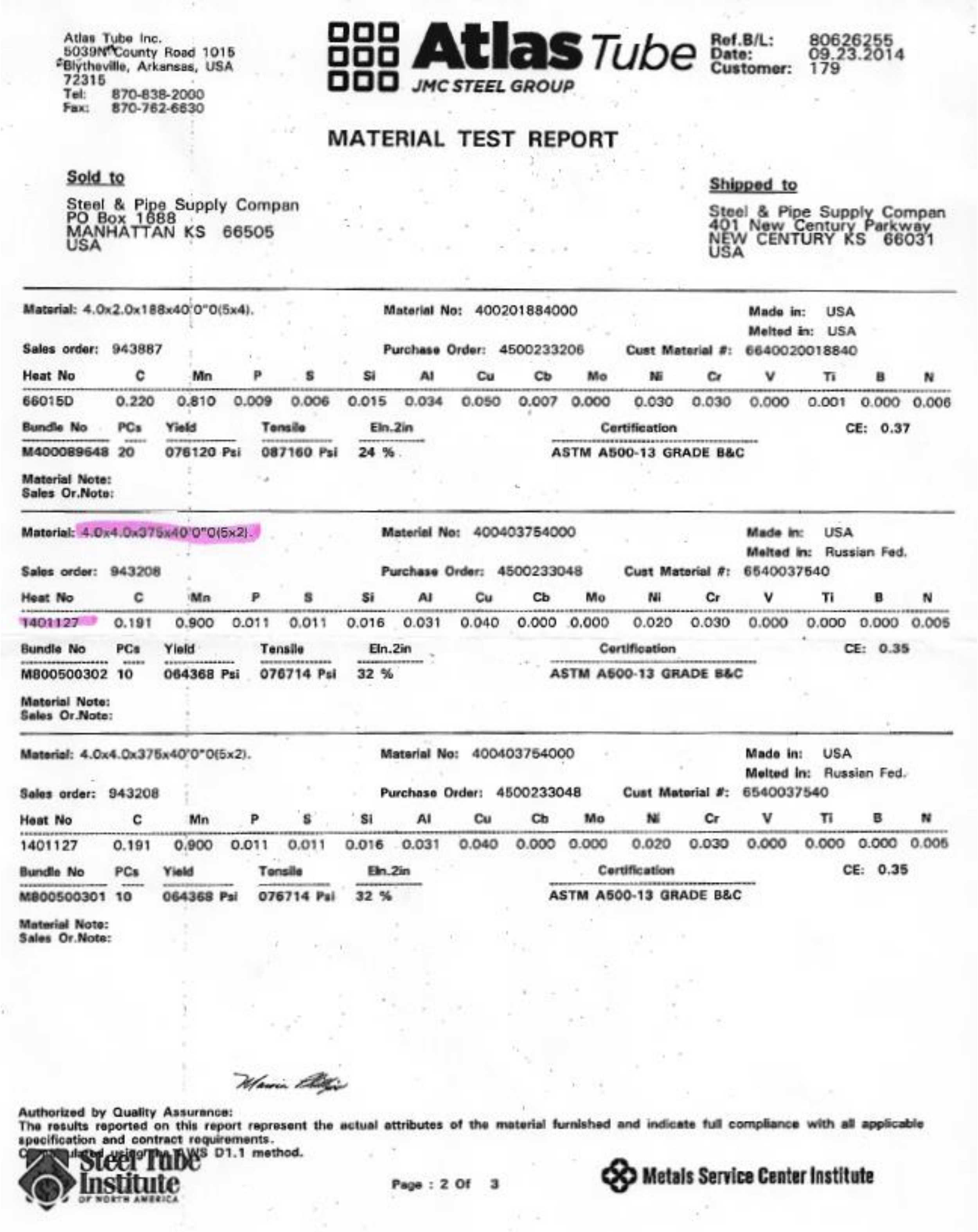
Mechanical/ Physical Properties

Mill Coil No. B408684-02

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
79700.000	55500.000	26.90	0	0.000	0	NA			
78400.000	56000.000	28.10	0	0.000	0	NA			
78300.000	56300.000	29.30	0	0.000	0	NA			
78000.000	56000.000	26.80	0	0.000	0	NA			

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.

Figure C-27. ¼-in Thick Steel Plate Material Specification, Test No. MGSMS-1



Atlas Tube Inc.
5039N County Road 1015
Blytheville, Arkansas, USA
72315
Tel: 870-838-2000
Fax: 870-762-6630

Atlas Tube
JMC STEEL GROUP

Ref.B/L: 80626255
Date: 09.23.2014
Customer: 179

MATERIAL TEST REPORT

Sold to

Steel & Pipe Supply Compan
PO Box 1688
MANHATTAN KS 66505
USA

Shipped to

Steel & Pipe Supply Compan
401 New Century Parkway
NEW CENTURY KS 66031
USA

Material: 4.0x2.0x188x40'0"0(5x4). **Material No:** 400201884000 **Made in:** USA
Melted in: USA
Sales order: 943887 **Purchase Order:** 4500233206 **Cust Material #:** 6640020018840

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
66015D	0.220	0.810	0.009	0.006	0.015	0.034	0.050	0.007	0.000	0.030	0.030	0.000	0.001	0.000	0.006

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification
M400089648	20	076120 Psi	087160 Psi	24 %	ASTM A500-13 GRADE B&C

CE: 0.37

Material Note:
Sales Or.Note:

Material: 4.0x4.0x375x40'0"0(5x2). **Material No:** 400403754000 **Made in:** USA
Melted in: Russian Fed.
Sales order: 943208 **Purchase Order:** 4500233048 **Cust Material #:** 6540037540

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
1401127	0.191	0.900	0.011	0.011	0.016	0.031	0.040	0.000	0.000	0.020	0.030	0.000	0.000	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification
M800500302	10	064368 Psi	076714 Psi	32 %	ASTM A500-13 GRADE B&C

CE: 0.35

Material Note:
Sales Or.Note:

Material: 4.0x4.0x375x40'0"0(5x2). **Material No:** 400403754000 **Made in:** USA
Melted in: Russian Fed.
Sales order: 943208 **Purchase Order:** 4500233048 **Cust Material #:** 6540037540

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
1401127	0.191	0.900	0.011	0.011	0.016	0.031	0.040	0.000	0.000	0.020	0.030	0.000	0.000	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification
M800500301	10	064368 Psi	076714 Psi	32 %	ASTM A500-13 GRADE B&C

CE: 0.35

Material Note:
Sales Or.Note:

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.
C[illegible]ulated using the [illegible]WS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 2 Of 3

Metals Service Center Institute

Figure C-28. Steel Post Socket Material Specification, Test No. MGSMS-1

Appendix D. Vehicle Center of Gravity Determination

Test: MGSMS-1 Vehicle: Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vert CG (in.)	Vert M (lb-in.)
+	Unbalasted Truck (Curb)	5228	29.15376	152415.9
+	Brake receivers/wires	6	50	300
+	Brake Frame	7	27	189
+	Brake Cylinder (Nitrogen)	28	27	756
+	Strobe/Brake Battery	5	33	165
+	Hub	27	15.375	415.125
+	CG Plate (EDRs)	4	34	136
-	Battery	-42	40.5	-1701
-	Oil	-6	20	-120
-	Interior	-88	24	-2112
-	Fuel	-161	20	-3220
-	Coolant	-14	37	-518
-	Washer fluid	-1	42	-42
BALLAST	Water			0
	DTS Rack	17	32	544
	Misc.			0
				147208

Estimated Total Weight (lb)	5010
Vertical CG Location (in.)	29.38283

wheel base (in.) 140.5

MASH Targets	Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	5016	16.0
Long CG (in.)	63 ± 4	61.79	-1.20913
Lat CG (in.)	NA	-0.27263	NA
Vert CG (in.)	≥ 28	29.38	1.38283

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb)

	Left	Right
Front	1497	1407
Rear	1158	1166

FRONT	2904 lb
REAR	2324 lb
TOTAL	5228 lb

TEST INERTIAL WEIGHT (lb)

(from scales)

	Left	Right
Front	1438	1372
Rear	1090	1116

FRONT	2810 lb
REAR	2206 lb
TOTAL	5016 lb

Figure D-1. Vehicle Mass Distribution, Test No. MGSMS-1

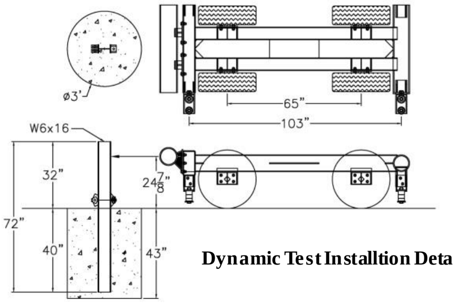
Appendix E. Static Soil Tests

Dynamic Set up

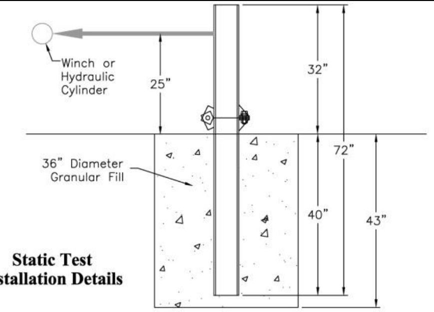
Post-Test Photo of Post

Static Load Test

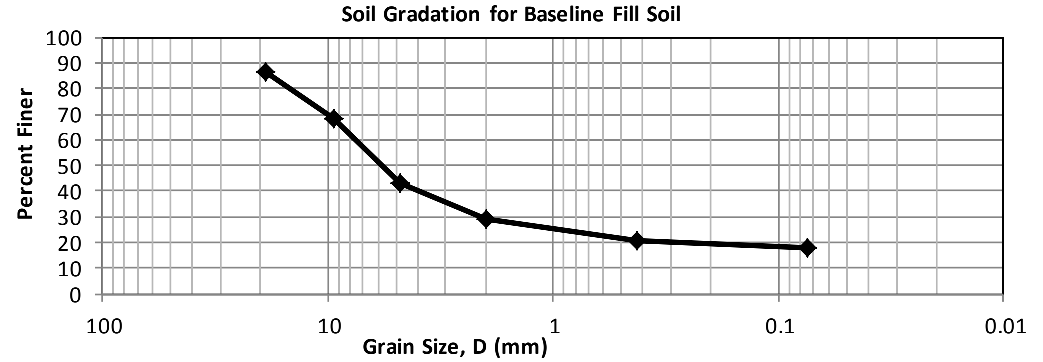
Post-Test Photo of Post

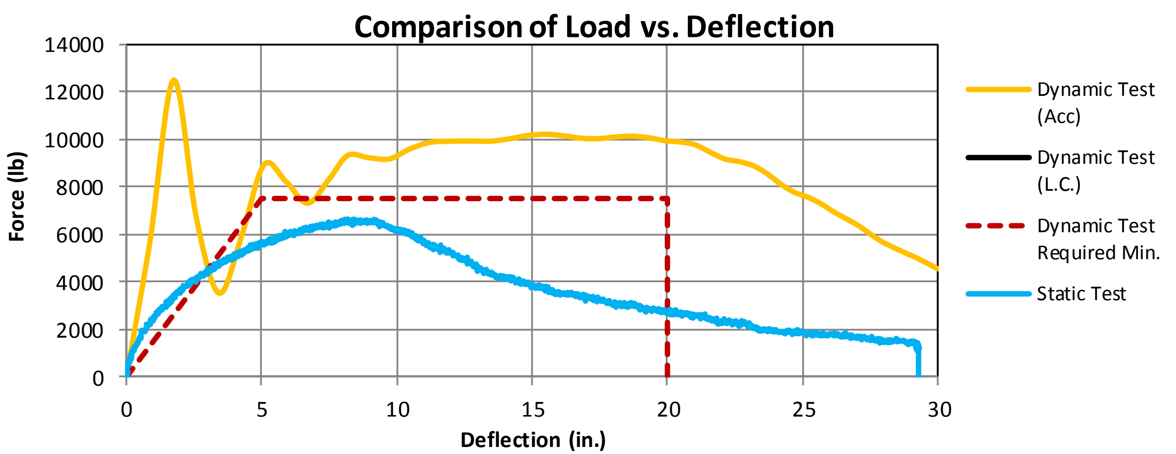


Dynamic Test Installtion Details



Static Test Installation Details



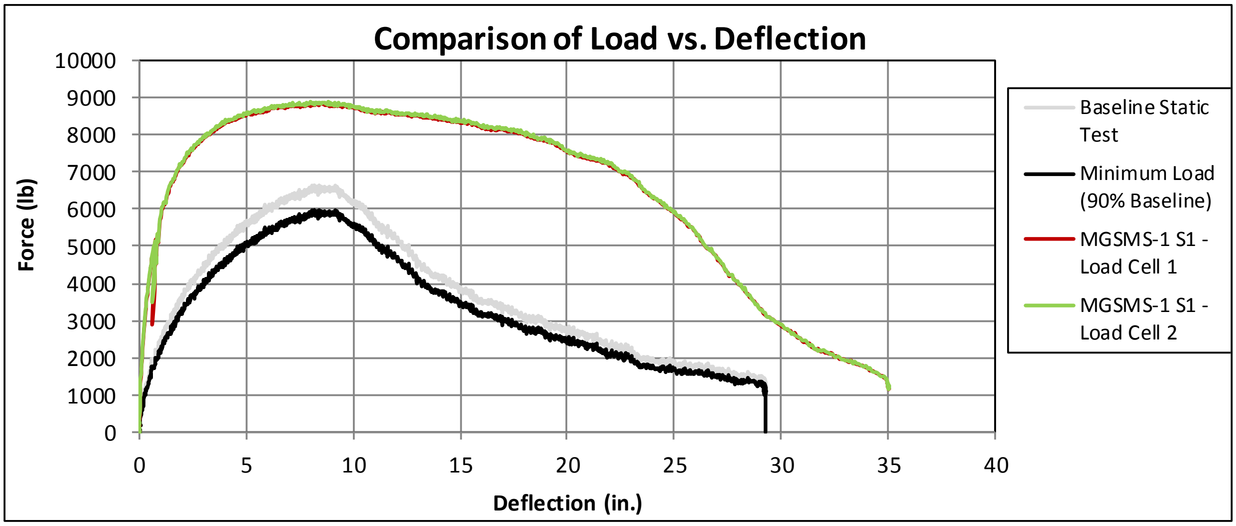


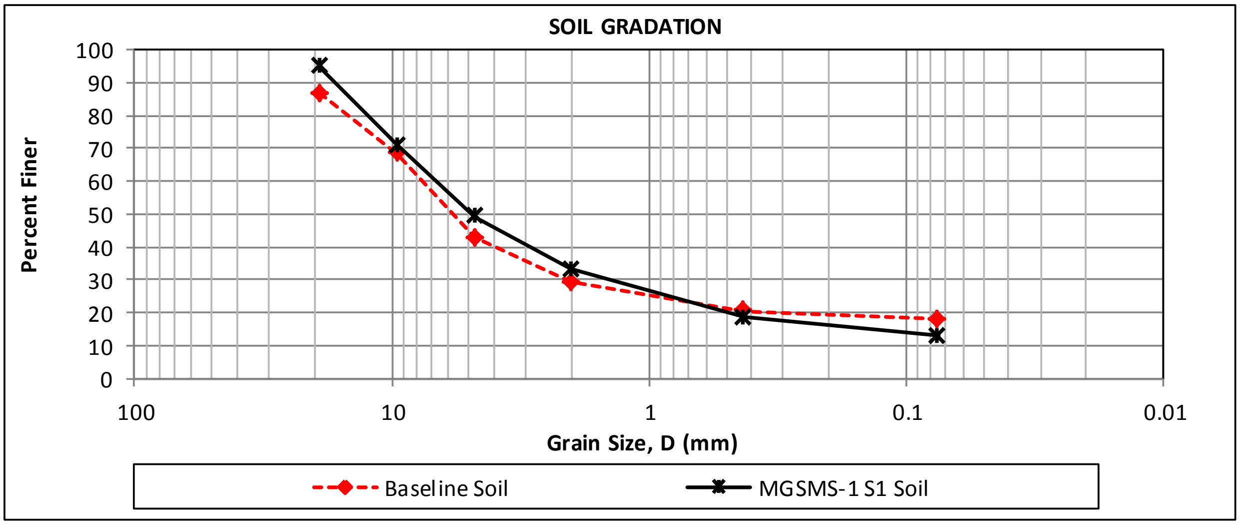
Date..	4/4/2012
Test Facility & Site Location.....................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487).........	Well Graded Gravel (GW)
Fill material description (ASTM D2487)......	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure.....	3 Pass, 8" Lift
Bogie Weight..	1,844 lb
Impact Velocity.....................................	20.07 mph

Figure E-1. Soil Strength, Initial Calibration Tests

Static Load Test Setup

Post-Test Photo of Post


Comparison of Load vs. Deflection


SOIL GRADATION

Date	12/4/2014
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well Graded Gravel (GW)
Fill material description (ASTM D2487)	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	8-inch lifts tamped with a pneumatic compactor

Figure E-2. Static Soil Test, Test No. MGSMS-1

Appendix F. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MGSMS-1
VEHICLE: Ram 1500

Note: If impact is on driver side need to enter negative number for Y

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	26 2/3	15	4 1/2	26 3/7	15	4 4/7	- 2/9	0	0
2	29 3/5	19 3/7	1 1/3	29 3/7	19 1/2	1 1/2	- 1/6	0	1/7
3	30	24 1/2	1 7/9	29 4/5	24 1/2	1 6/7	- 1/4	0	0
4	28	28 2/7	2 1/4	27 3/4	28 1/3	2 2/5	- 2/9	0	1/6
5	22	14 1/3	1 3/8	21 3/4	14 1/3	1 1/2	- 1/5	0	1/8
6	24	19 1/7	-2 5/8	23 3/4	19 1/5	-2 1/2	- 1/5	0	1/9
7	24	22 1/2	-2 2/3	23 5/7	22 1/2	-2 4/7	- 1/5	0	1/9
8	23 5/6	28 1/6	-2 5/7	23 2/3	28 1/5	-2 3/5	- 1/7	0	1/8
9	18 1/8	11 1/3	- 1/9	17 8/9	11 1/3	0	- 1/4	0	1/8
10	19 1/6	14 5/9	-2 1/9	19	14 5/9	-2	- 1/4	0	0
11	21	18 4/5	-4 8/9	20 5/6	18 5/6	-4 3/4	- 1/7	0	1/8
12	21	22 1/3	-4 4/5	20 3/4	22 3/8	-4 2/3	- 1/5	0	1/9
13	21	28	-4 5/6	20 6/7	28	-4 5/7	- 1/5	-0	1/9
14	13 4/9	6	3/5	13 1/4	6	5/7	- 1/5	-0	1/9
15	17	13 3/8	-4 2/3	16 3/4	13 3/8	-4 4/7	- 1/5	-0	1/8
16	17 1/3	19 3/5	-5 1/2	17 1/6	19 5/9	-5 3/8	- 1/5	-0	1/9
17	17 3/8	25 2/5	-5 1/2	17 1/5	25 3/7	-5 3/8	- 1/5	0	0
18	17 1/3	29	-5 1/2	17 1/8	29	-5 1/2	- 1/5	0	0
19	7 2/3	5 1/7	-1	7 3/7	5 1/6	- 5/6	- 1/5	0	1/9
20	11 1/2	12 1/2	-6 1/3	11 2/9	12 1/2	-6 1/5	- 1/4	0	0
21	11 3/5	16 3/8	-6 1/5	11 3/7	16 2/5	-6 1/8	- 1/6	0	0
22	11 1/2	22 1/2	-6 1/5	11 1/4	22 1/2	-6 1/8	- 2/7	-0	0
23	11 1/2	29	-6 2/7	11 1/4	29	-6 2/9	- 1/5	0	0
24	1 5/6	3 7/9	-1 2/9	1 3/5	3 4/5	-1 1/9	- 2/9	0	1/9
25	1 1/3	12	-3 5/6	1 1/5	12	-3 3/4	- 1/8	-0	0
26	1 1/3	15 1/4	-3 5/6	1 1/6	15 1/3	-3 3/4	- 1/5	0	0
27	1 1/3	19 1/6	-3 8/9	1	19 1/6	-3 5/6	- 2/9	-0	0
28	1 1/3	27	-3 4/5	1 1/9	27	-3 3/4	- 1/4	0	0
29							0	0	0
30							0	0	0
31							0	0	0

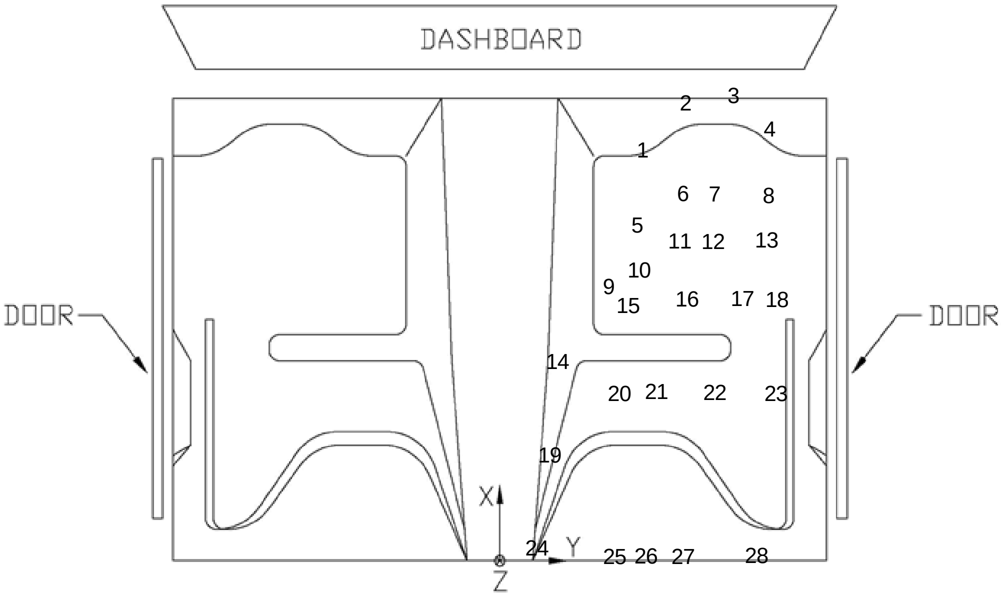


Figure F-1. Floor Pan Deformation Data, Test No. MGSMS-1

TEST: MGSMS-1
VEHICLE: Ram 1500

Note: If impact is on driver side need to enter negative number for Y

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	9 1/3	-1	27 4/9	9 2/5	-1	27 1/2	0	- 1/5	0
	A2	11	9 5/6	26 2/7	11	9 5/8	26 1/3	0	- 2/9	0
	A3	11 1/8	26 8/9	25	11 1/6	26 3/4	25 1/8	0	- 1/6	0
	A4	8 2/5	-1 1/7	19 1/7	8 1/2	-1 1/3	19 1/4	0	- 1/5	1/9
	A5	9	10	19 1/4	9	9 4/5	19 1/4	0	- 1/5	0
	A6	10	30 4/5	14 4/7	10	30 3/5	14 3/5	-0	- 1/5	0
SIDE PANEL	B1	20 4/7	32 5/7	3 2/3	20 3/5	32 1/2	3 2/3	0	- 1/4	0
	B2	21 1/4	32 2/3	-1 4/7	21 1/5	32 1/2	-1 5/9	-0	- 2/9	0
	B3	24 5/6	32 3/4	3 2/3	24 4/5	32 1/2	3 2/3	-0	- 1/5	-0
IMPACT SIDE DOOR	C1	3 4/5	35	18 1/2	3 1/2	35	18 1/2	- 1/4	-0	-0
	C2	-3 5/7	35	17 2/3	-4	35	17 3/5	- 2/7	-0	-0
	C3	-13 1/3	34 4/5	16 2/3	-13 1/2	34 7/8	16 2/3	- 2/9	0	-0
	C4	5 7/8	34 2/5	4 1/5	5 5/8	34 1/5	4 2/9	- 1/4	- 1/5	0
	C5	1 3/8	34 1/3	2 1/7	1 1/8	34 1/7	2	- 1/4	- 1/6	-0
	C6	-10 3/5	34 3/7	2 1/2	-10 5/6	34 3/8	2 1/2	- 2/9	-0	-0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

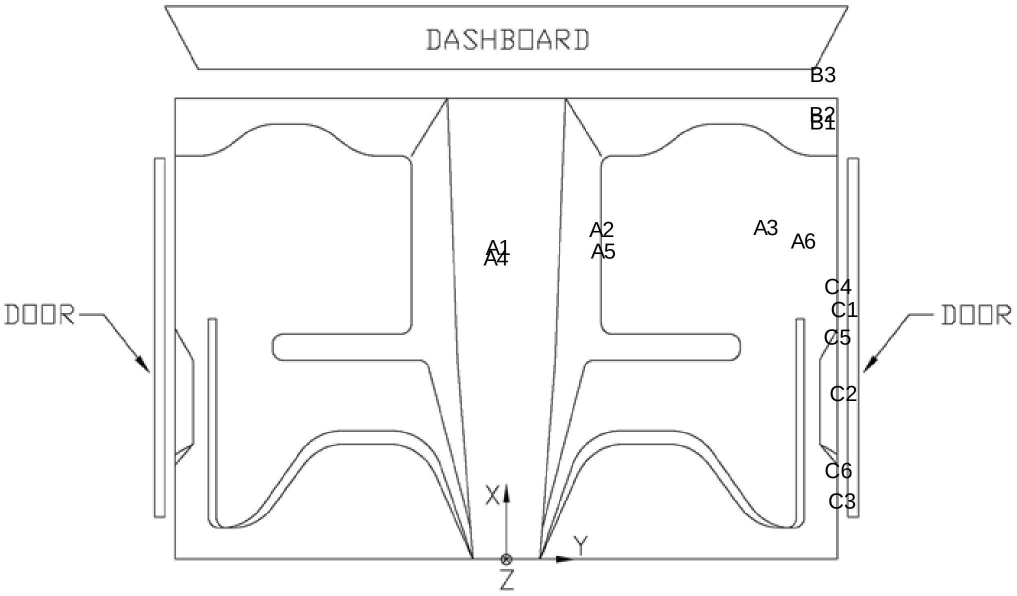


Figure F-2. Occupant Compartment Deformation Data – Set 1, Test No. MGSMS-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MGSMS-1
VEHICLE: Ram 1500

Note: If impact is on driver side need to enter negative number for Y

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	28 5/6	3 3/4	27	28 8/9	3 4/7	26 5/8	0	- 1/6	- 1/3
	A2	30 1/4	14 1/2	26 1/5	30 2/5	14 1/3	26	1/8	- 1/6	- 1/4
	A3	30 1/3	31 2/3	26	30 3/8	31 2/5	25 5/7	0	- 1/4	- 1/3
	A4	26 5/7	4	18 5/6	26 7/9	3 4/5	18 4/7	0	- 1/4	- 1/4
	A5	27 2/5	15 1/9	19 1/2	27 4/9	14 5/6	19 1/5	0	- 2/7	- 1/4
	A6	27 5/8	36 1/6	16 1/9	27 2/3	35 5/6	15 3/4	0	- 1/3	- 1/3
SIDE PANEL	B1	36 5/7	38 7/9	3 8/9	36 2/3	38 1/2	3 1/2	-0	- 1/4	- 1/3
	B2	36 5/9	39	-1 3/8	36 1/2	38 5/6	-1 2/3	-0	- 1/4	- 1/3
	B3	40 8/9	38 5/6	3 1/3	40 7/8	38 3/5	3	-0	- 2/9	- 1/3
IMPACT SIDE DOOR	C1	22 1/9	40 1/7	21	22	40	20 5/6	- 1/5	- 1/8	- 1/7
	C2	14 5/9	40	21 1/6	14 3/8	40	21	- 1/5	-0	- 1/7
	C3	5	39 7/8	21 3/5	4 3/4	40	21 2/5	- 1/5	0	- 1/6
	C4	22 1/6	40 1/3	6 2/3	22	40 1/9	6 2/5	- 1/5	- 1/5	- 1/4
	C5	17 2/5	40 1/3	5 1/7	17 1/5	40 1/6	4 5/6	- 1/5	- 1/6	- 1/3
	C6	5 5/8	40 1/3	7 1/6	5 4/9	40 1/3	7	- 1/5	-0	- 1/5
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

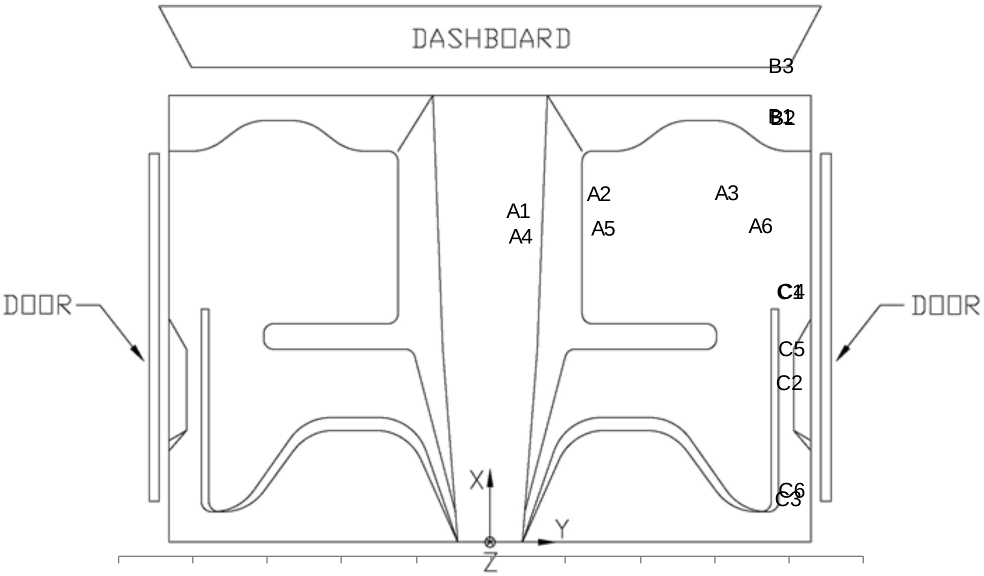
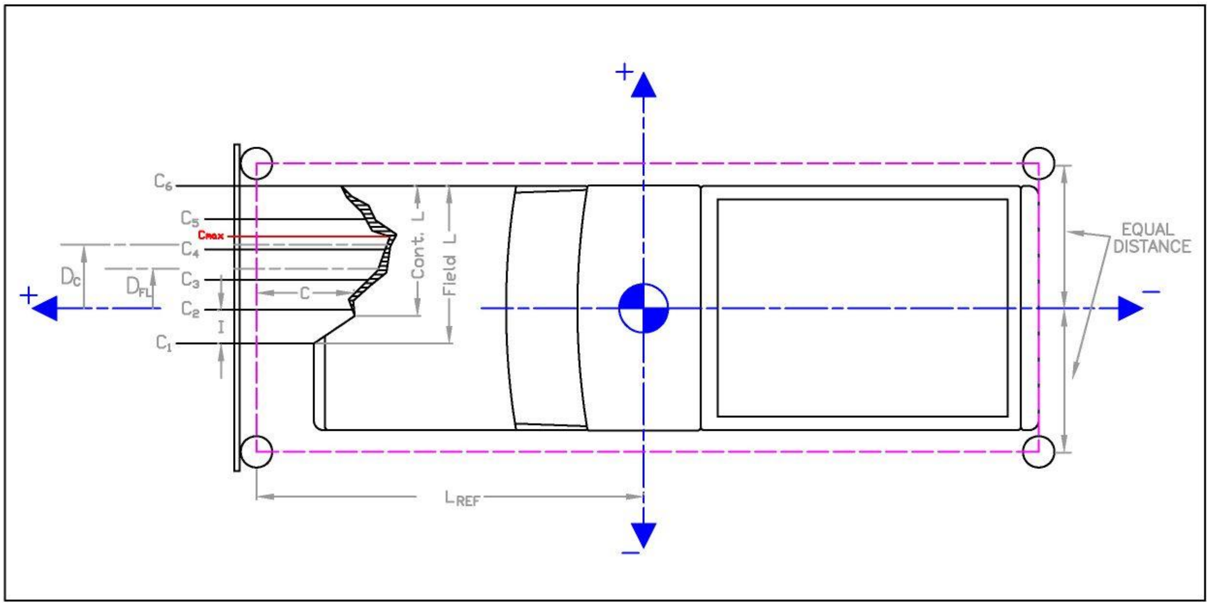


Figure F-3. Occupant Compartment Deformation Data – Set 2, Test No. MGSMS-1

Date: 12/15/2014 **Test Number:** MGSMS-1

Make: Dodge **Model:** Ram 1500 **Year:** 2007



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	107	(2718)
Width of contact and induced crush - Field L:	29	(737)
Crush measurement spacing interval (L/5) - I:	5.8	(147)
Distance from center of vehicle to center of Field L - D_{FL}:	24.5	(622)
Width of Contact Damage:	29	(737)
Distance from center of vehicle to center of contect damage - D_C:	24 1/2	(622)

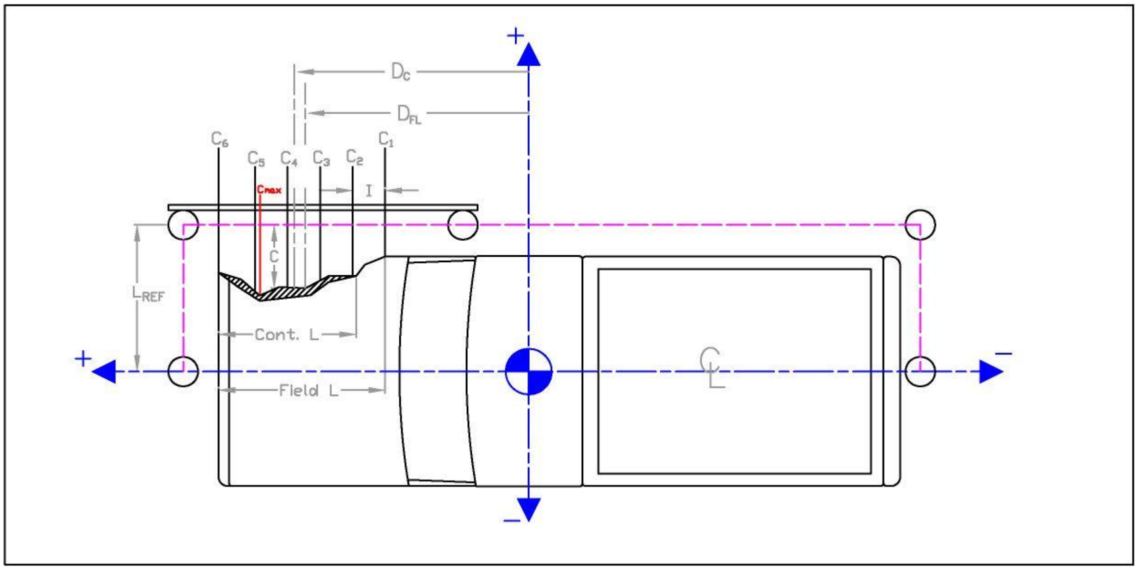
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	Crush Measurement		**Lateral Location**		**Original Profile Measurement**		**Dist. Between Ref. Lines**		**Actual Crush**	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	6	(152)	10	(254)	10 3/4	(273)	-4 2/7	-(109)	- 1/2	-(12)
C_2	7 1/4	(184)	15 4/5	(401)	11 5/7	(297)			- 1/6	-(4)
C_3	9 1/2	(241)	21 3/5	(549)	12 7/8	(327)			1	(23)
C_4	14 1/4	(362)	27 2/5	(696)	15	(380)			3 4/7	(91)
C_5	na	NA	33 1/5	(843)	18 3/8	(467)			NA	NA
C_6	na	NA	39	(991)	29	(737)			NA	NA
C_{MAX}	14 1/4	(362)	27 1/4	(692)	15	(380)			3 4/7	(91)

Figure F-4. Exterior Vehicle Crush (NASS) - Front, Test No. MGSMS-1

Date: 12/15/2014 **Test Number:** MGSMS-1

Make: Dodge **Model:** Ram 1500 **Year:** 2007



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	41	(1041)
Width of contact and induced crush - Field L:	227 1/4	(5772)
Crush measurement spacing interval (L/5) - I:	45.45	(1154)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-11.75	-(298)
Width of Contact Damage:	227 1/4	(5772)
Distance from vehicle c.g. to center of contect damage - D_C:	11 3/4	(298)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been remeoved)

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-125 3/8	-(3185)	15 3/8	(391)	-9	-(229)	NA	NA
C_2	2	(51)	-80	-(2030)	10 1/2	(267)			1/2	(13)
C_3	3	(76)	-34 1/2	-(876)	11 4/7	(294)			4/9	(11)
C_4	2 1/2	(64)	11	(279)	11 1/4	(286)			1/4	(6)
C_5	na	NA	56 3/7	(1433)	10 1/2	(267)			NA	NA
C_6	na	NA	101 7/8	(2588)	37	(940)			NA	NA
C_{MAX}	11	(279)	80	(2032)	11 1/4	(286)			8 3/4	(222)

Figure F-5. Exterior Vehicle Crush (NASS) - Side, Test No. MGSMS-1

Appendix G. Accelerometer and Rate Transducer Data Plots, Test No. MGSMS-1

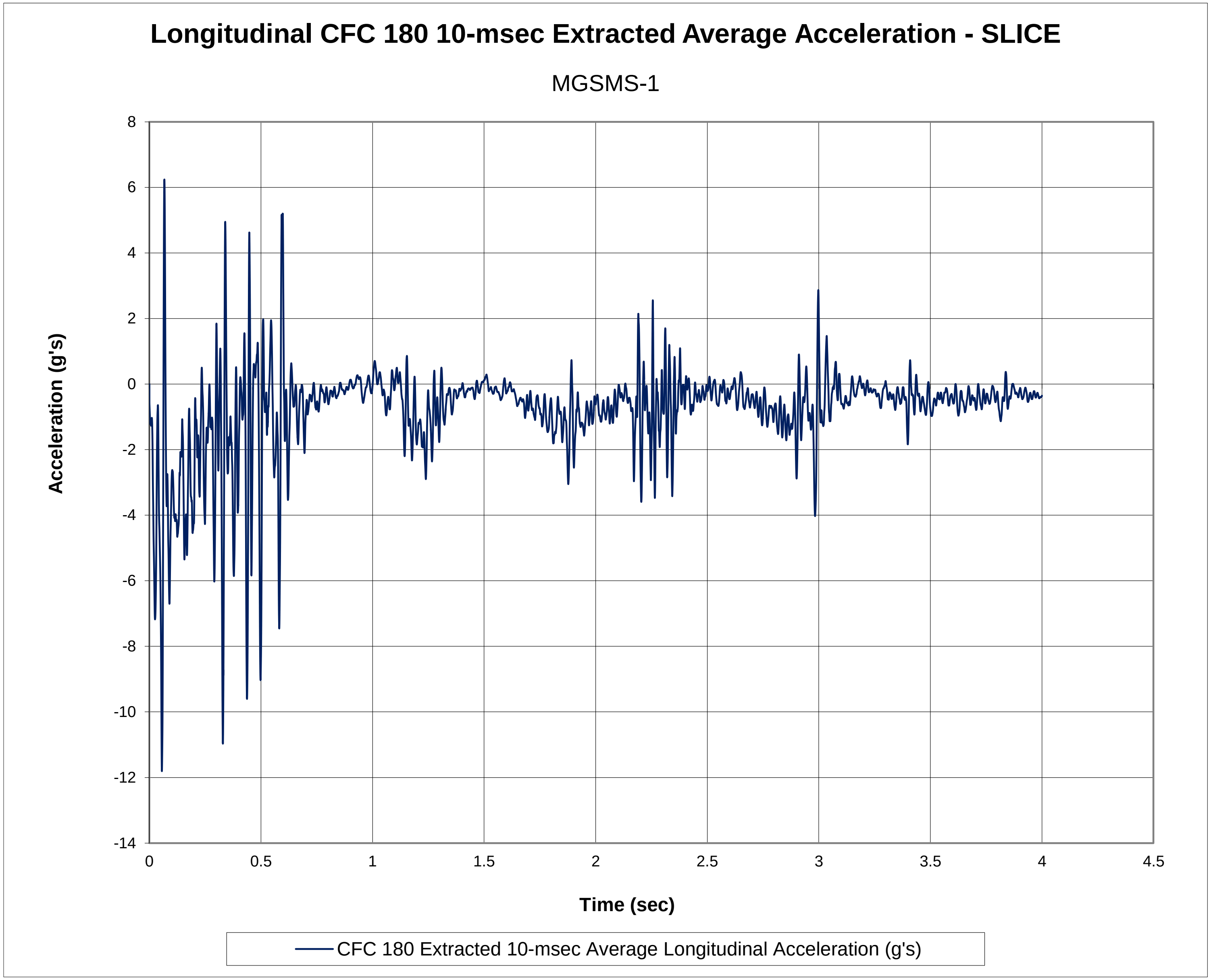


Figure G-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSMS-1

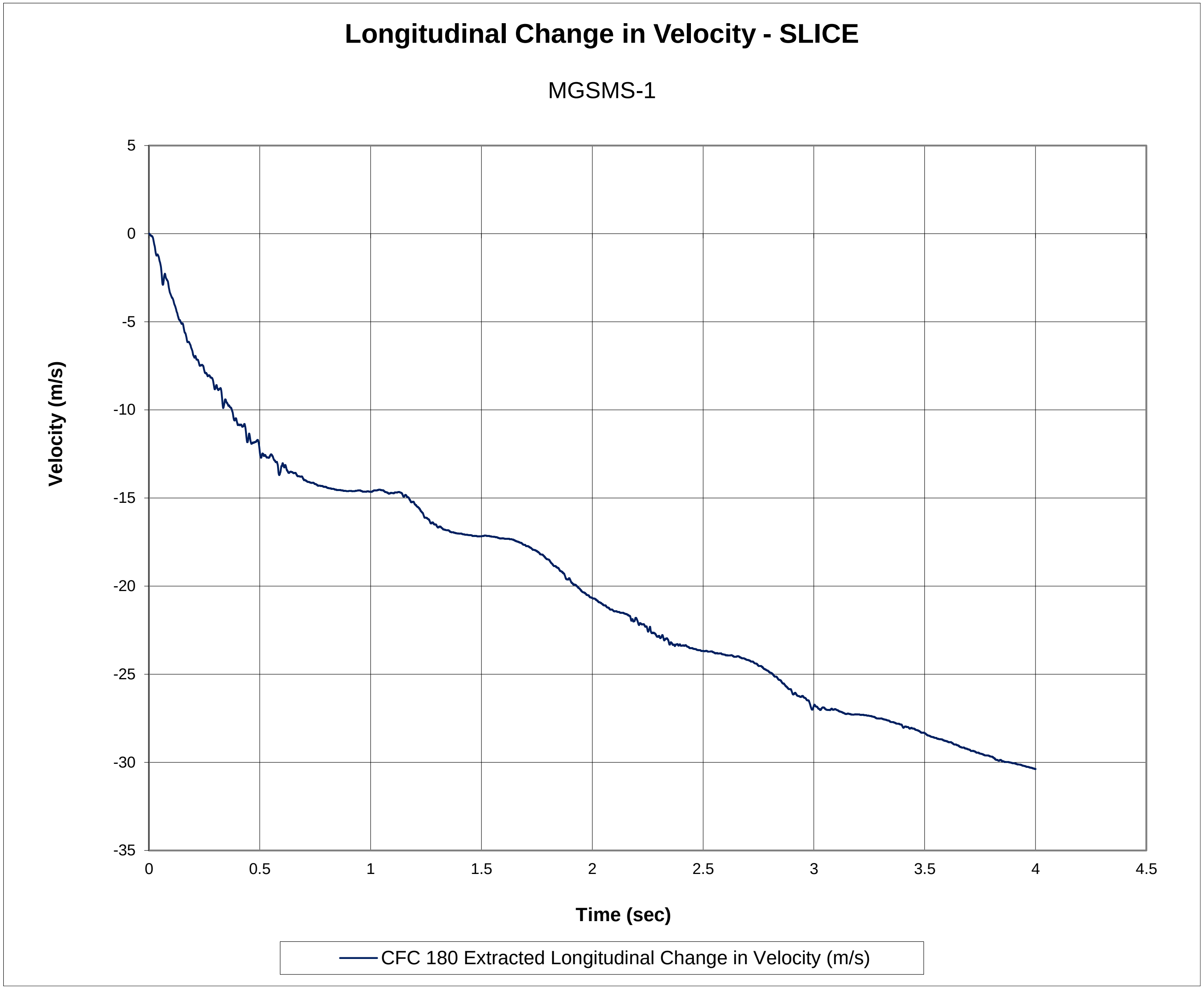


Figure G-2. Longitudinal Change in Velocity (SLICE-2), Test No. MGSMS-1

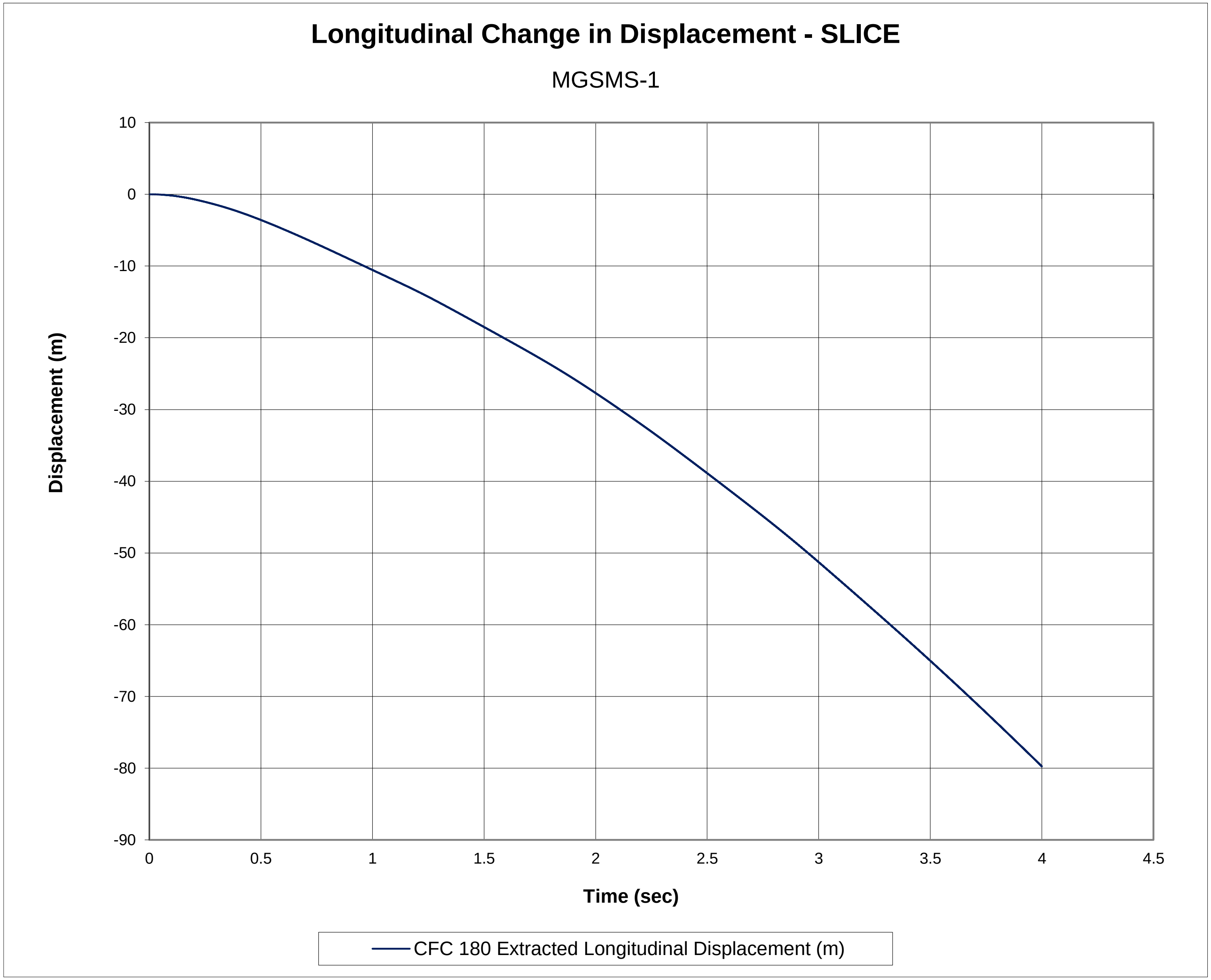


Figure G-3. Longitudinal Change in Displacement (SLICE-2), Test No. MGSMS-1

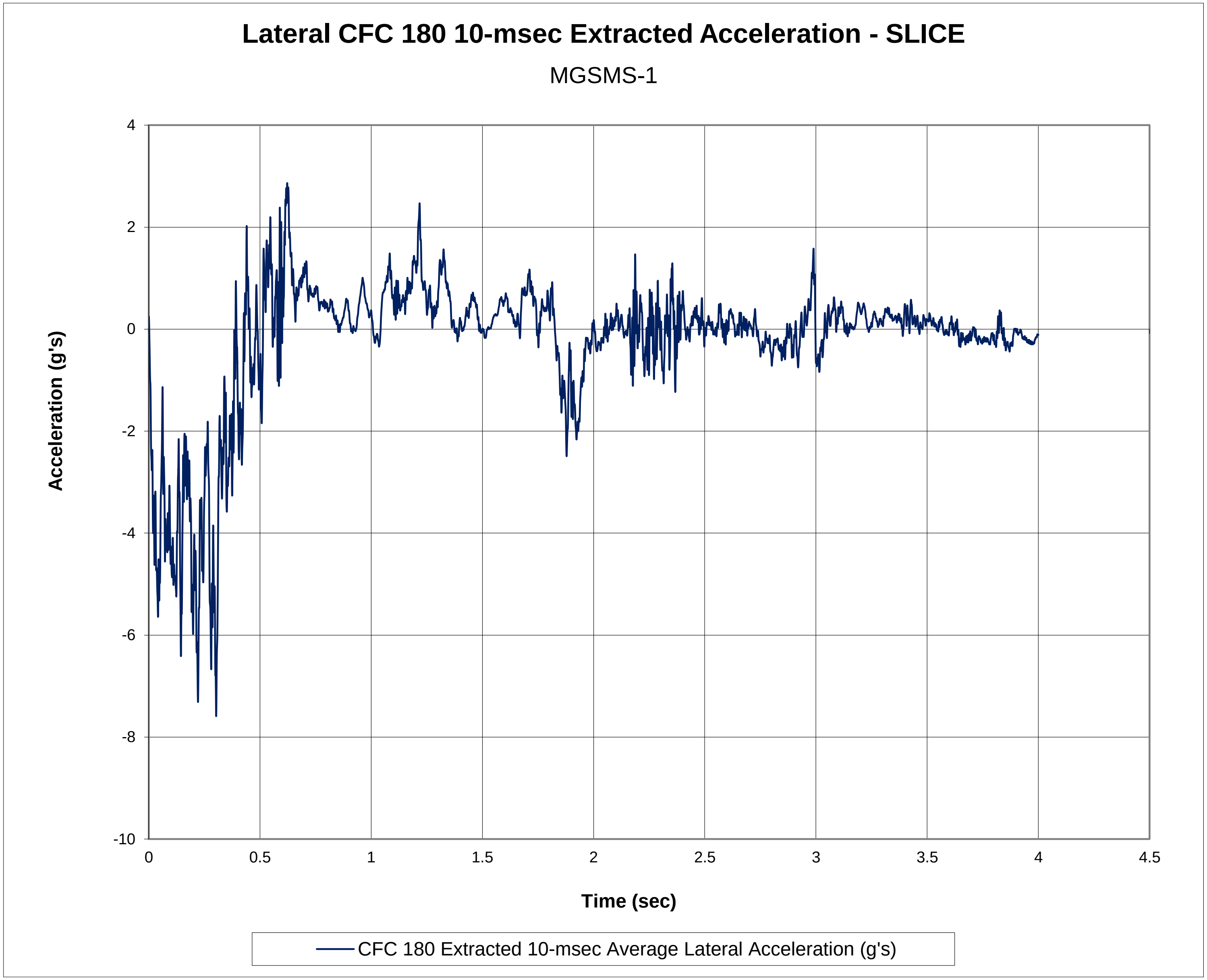


Figure G-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSMS-1

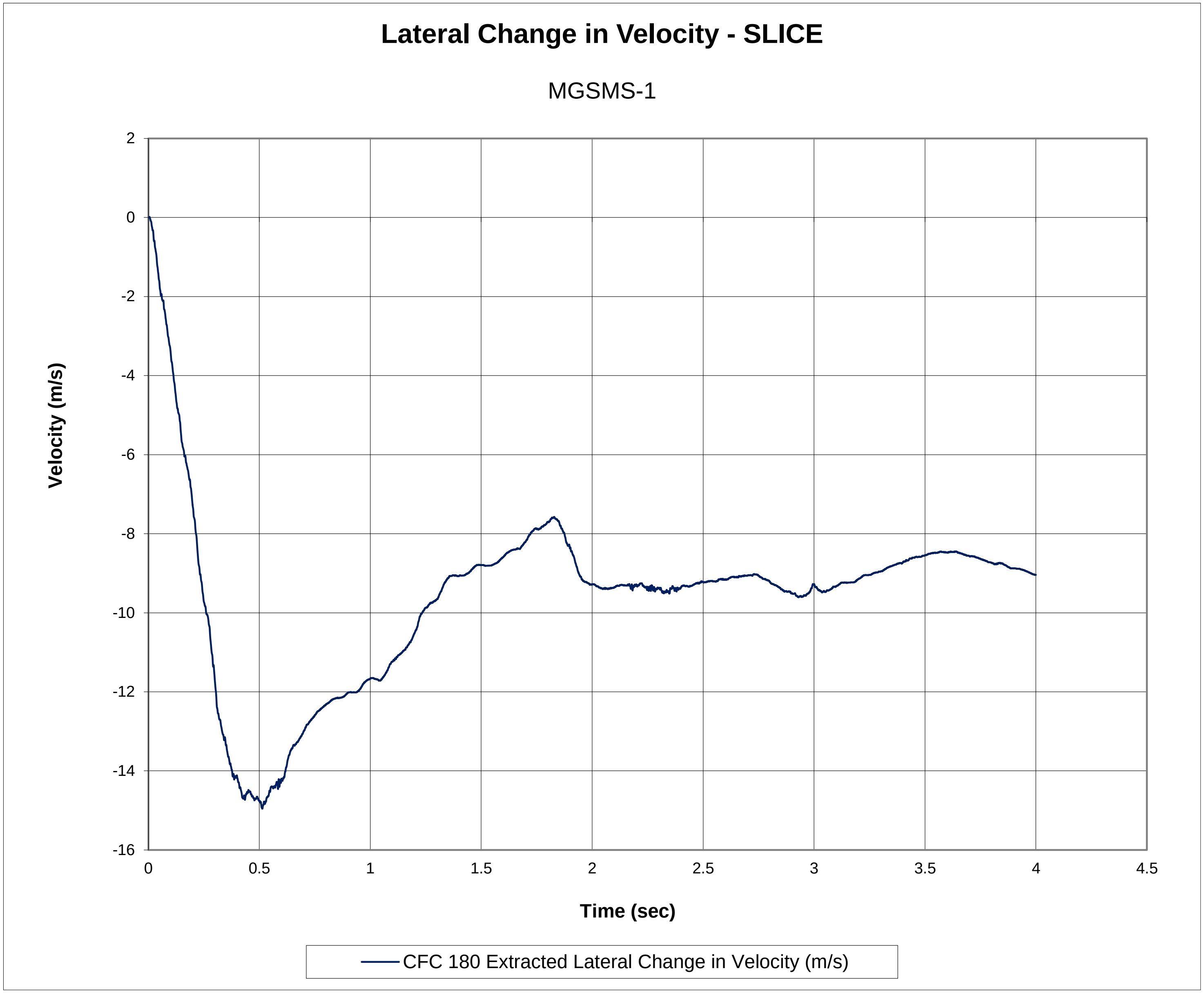


Figure G-5. Lateral Change in Velocity (SLICE-2), Test No. MGSMS-1

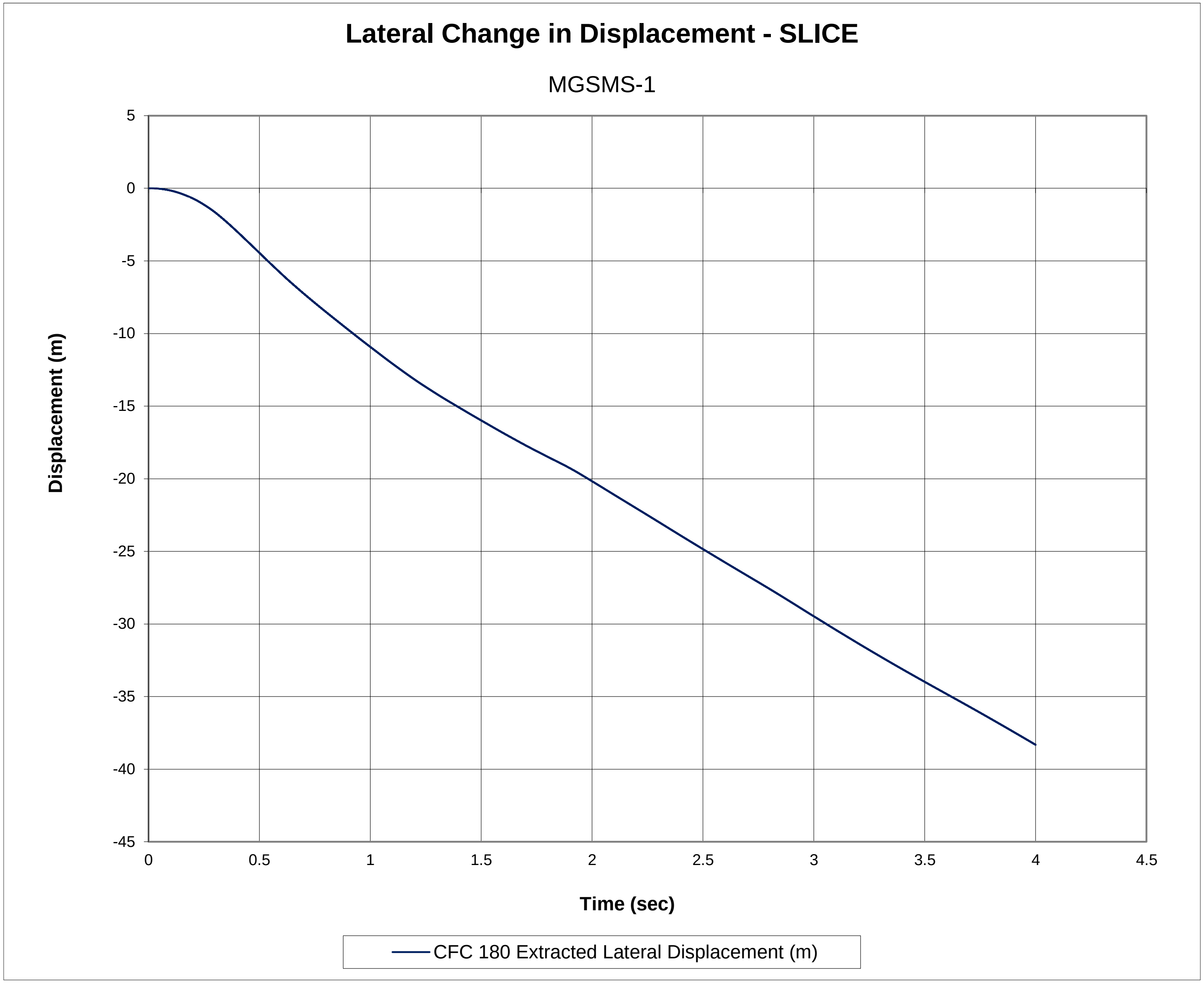


Figure G-6. Lateral Change in Displacement (SLICE-2), Test No. MGSMS-1

Figure G-7. Vehicle Angular Displacements (SLICE-2), Test No. MGSMS-1

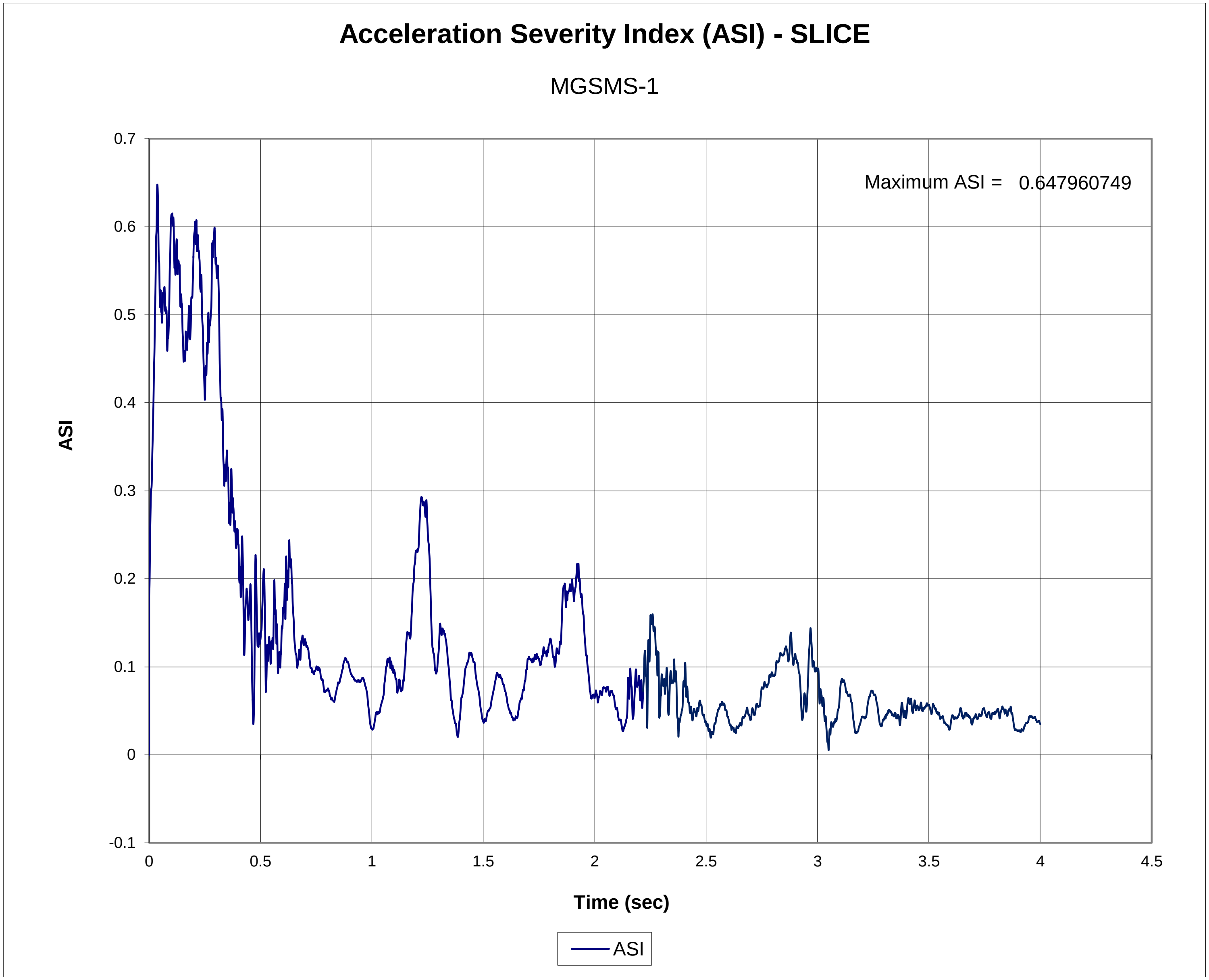


Figure G-8. Acceleration Severity Index (SLICE-2), Test No. MGSMS-1

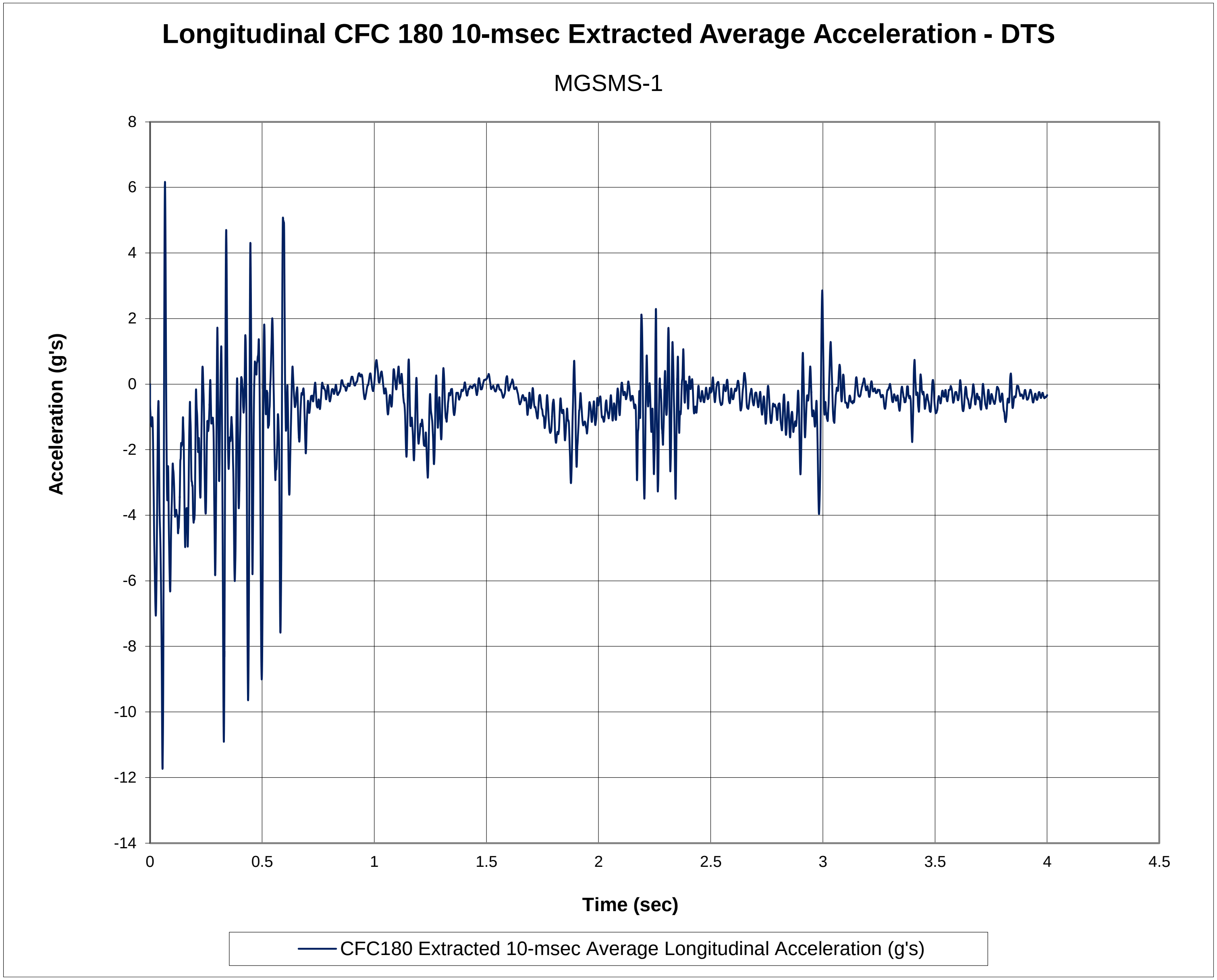


Figure G-9. 10-ms Average Longitudinal Deceleration (DTS), Test No. MGSMS-1

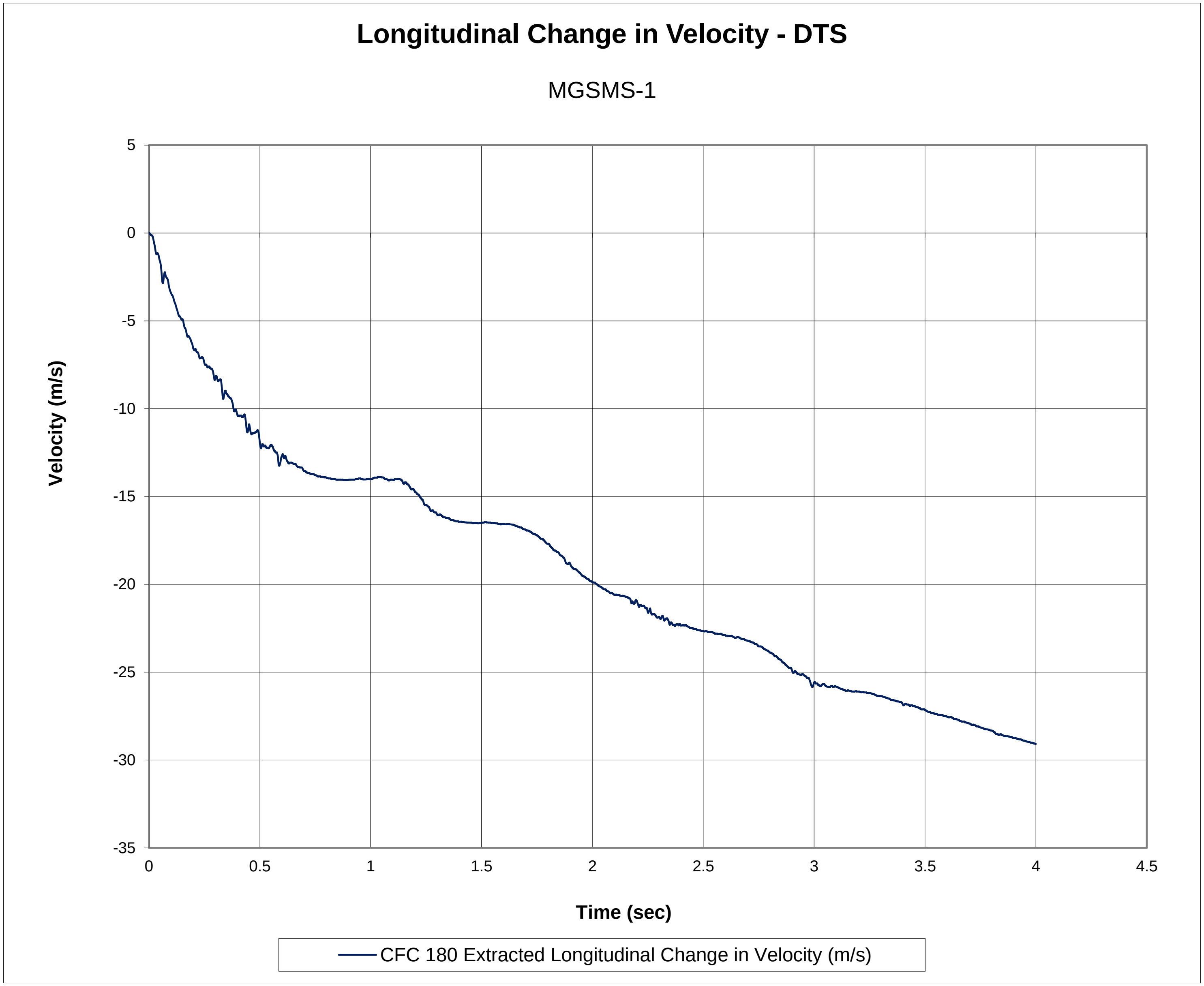


Figure G-10. Longitudinal Change in Velocity (DTS), Test No. MGSMS-1

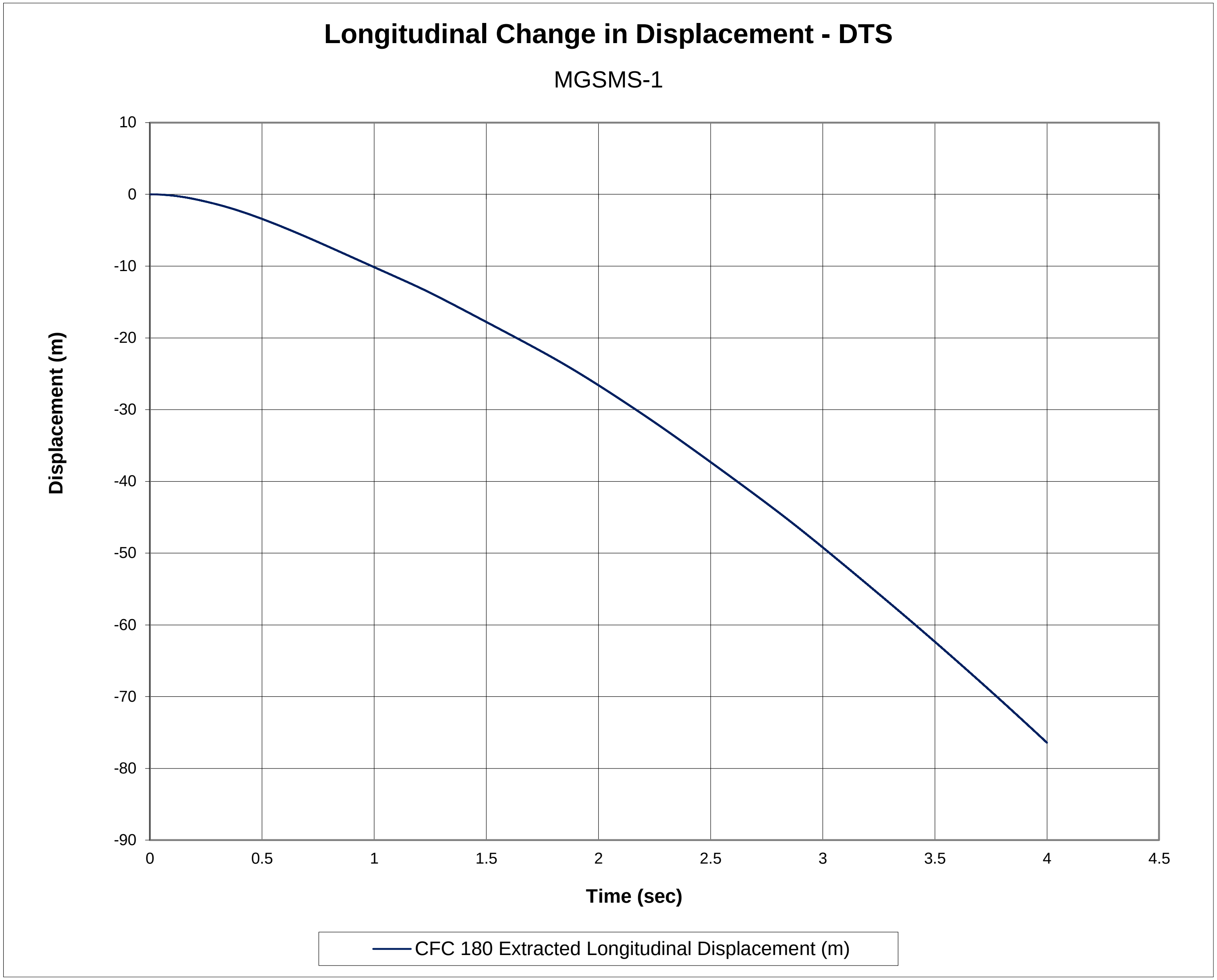


Figure G-11. Longitudinal Change in Displacement (DTS), Test No. MGSMS-1

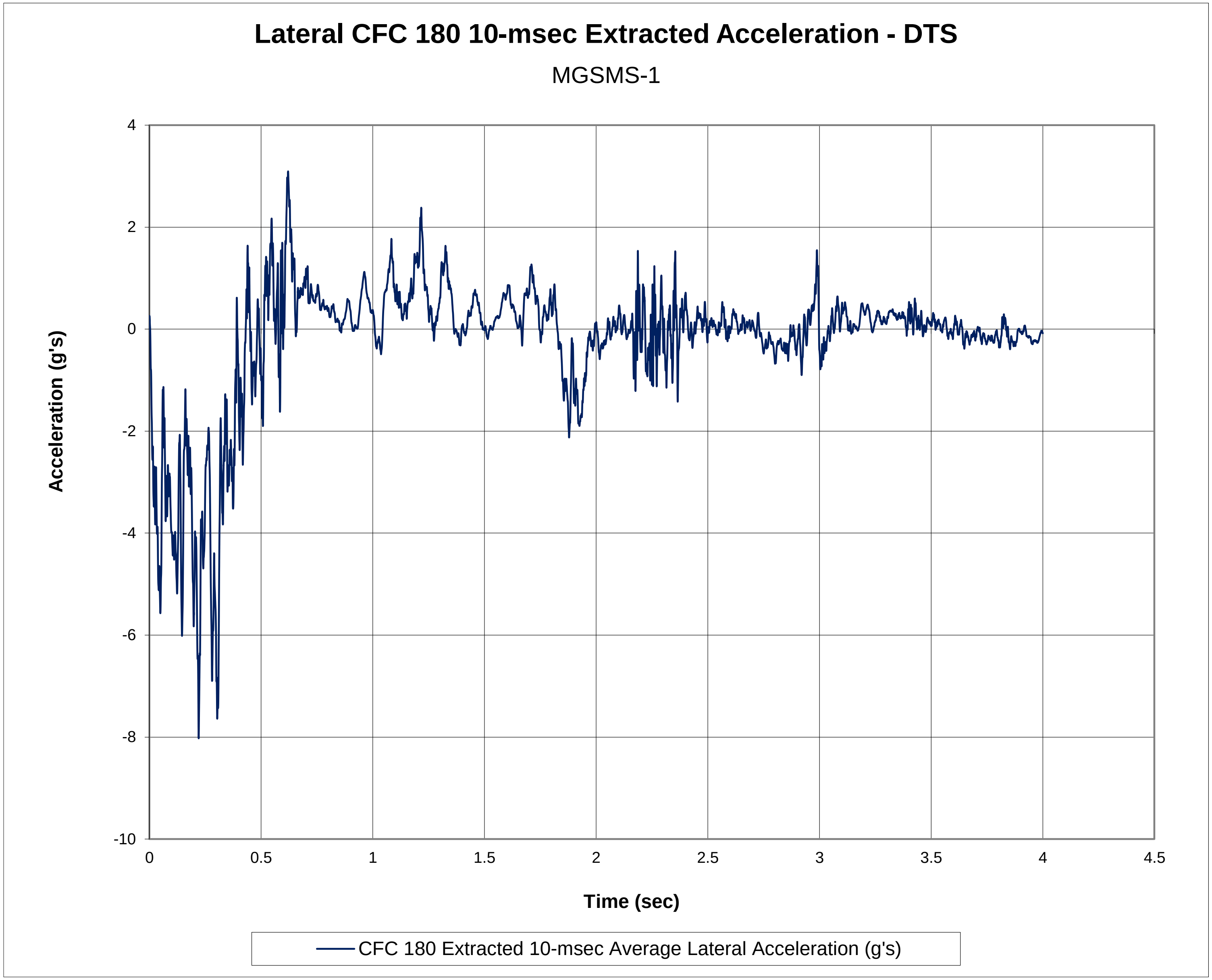


Figure G-12. 10-ms Average Lateral Deceleration (DTS), Test No. MGSMS-1

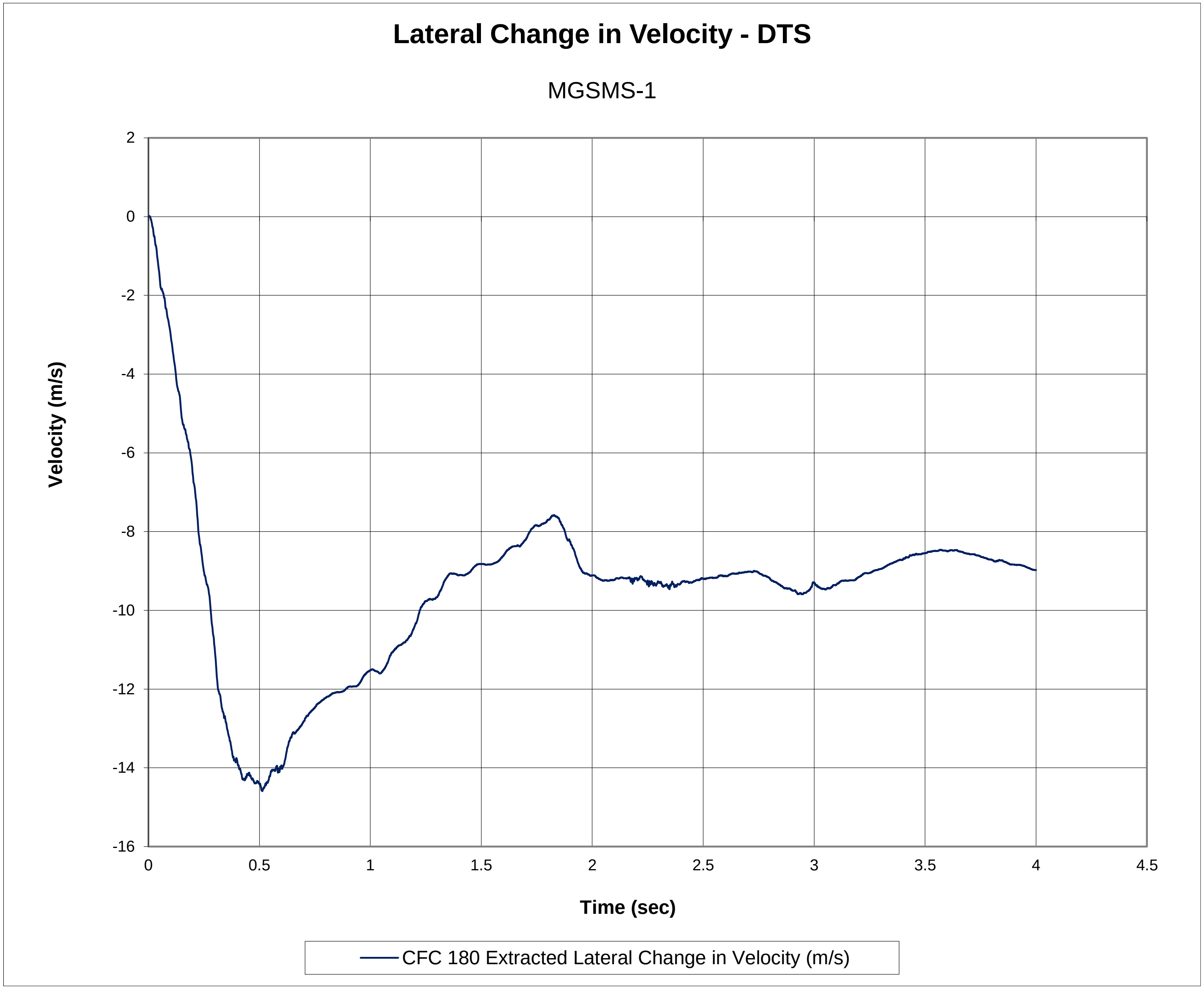


Figure G-13. Lateral Change in Velocity (DTS), Test No. MGSMS-1

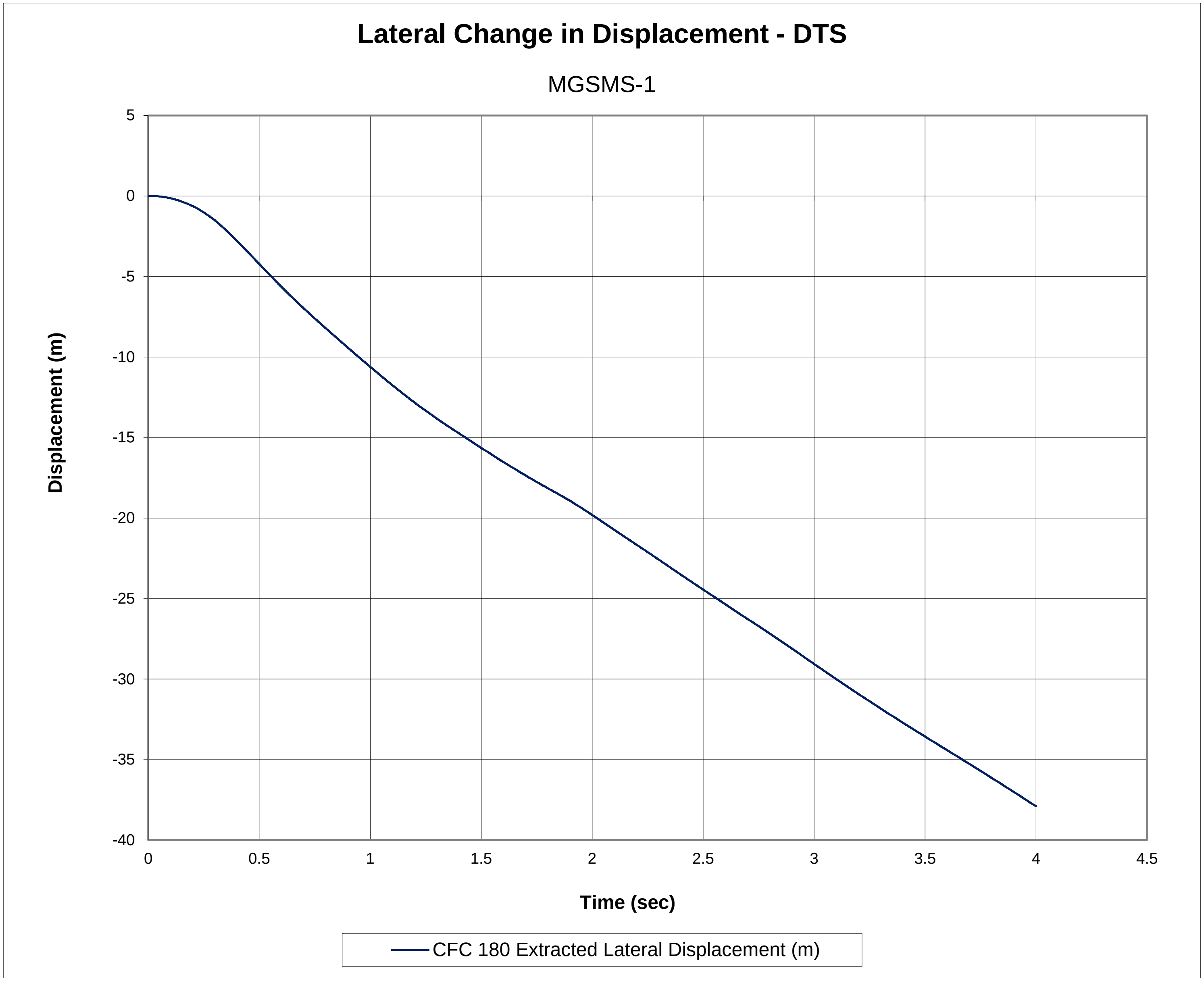


Figure G-14. Lateral Change in Displacement (DTS), Test No. MGSMS-1

Figure G-15. Vehicle Angular Displacements (DTS), Test No. MGSMS-1

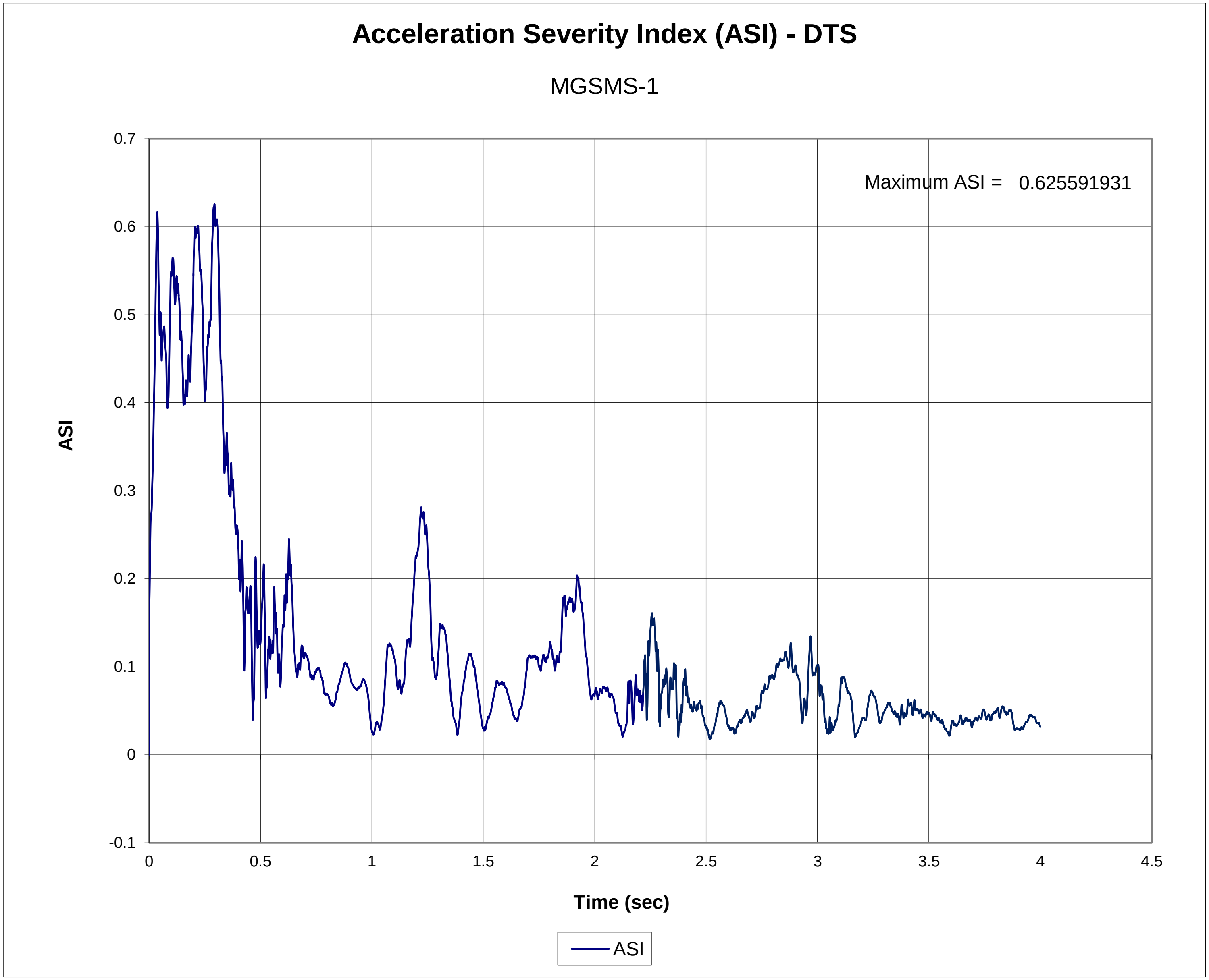


Figure G-16. Acceleration Severity Index (DTS), Test No. MGSMS-1

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