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PHASE II EVALUATION OF FLOOR PAN TEARING FOR CABLE BARRIER SYSTEMS

Submitted by

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The objective of this research effort was to mitigate the potential for floor pan tearing and penetration into the occupant compartment by modifying the posts utilized in a prototype cable barrier system. A series of dynamic component tests were conducted on the modified Midwest Weak Post (MWP). A bogie vehicle was equipped with a simulated floor pan designed to replicate the height, thickness, and strength of the floor pan of a Kia Rio. Two methods of post modification were investigated, including edge protection on the top of the MWP as well as weakening of the MWP at the ground line.
Two methods of edge protection were tested, including a 3½-in. x 2½-in. x $^{3}/_{16}$-in. (89-mm x 64-mm x 5-mm) thick steel tube cap and 2⅛-in. x 1⅜-in. x 7-gauge (54-mm x 35-mm x 5-mm) bent steel plates. Weakening of the MWPs was accomplished through two ¾-in. (19-mm) diameter holes drilled through the weak-axis of the posts at the ground line. Both methods of edge protection showed potential for mitigating the propensity for floor pan tearing. In all but one test, the posts caused creasing on the simulated floor pan. In one test, test no. MWPFP-23, the edge protector connection bolt sheared and allowed the posts' free edges to contact and tear the simulated floor pan, which would not be expected in full-scale crash testing with the 1100C vehicle. The bogie testing of MWPs with ¾-in. (19-mm) diameter weakening holes with steel plate edge protectors mounted at the top of the posts resulted in only minor creasing on the simulated floor pan. Thus, a combination of weakening holes and edge protectors using steel bent plates at top of the MWP was recommended for further evaluation through full-scale vehicle crash testing.</td></tr>
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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. Test nos. MWPFP-22 through MWPFP-26 were non-certified component tests conducted for research and development purposes only and are outside the scope of the MwRSF's A2LA Accreditation.

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1 INTRODUCTION

1.1 Background

In recent years, the Midwest Pooled Fund Program has been developing a non-proprietary, high-tension, cable median barrier in conjunction with the Midwest Roadside Safety Facility (MwRSF). The barrier was to be developed for placement anywhere within a 6H:1V V-ditch, as well as to satisfy the Test Level 3 (TL-3) evaluation criteria of the *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) [1]. The most recent design prototype was a four cable system supported by Midwest Weak Posts (MWPs) [2], as shown in Figure 1.

Figure 1. Current Cable Median Barrier Prototype

Development of the cable median barrier has progressed through multiple crash tests in accordance with MASH 2009 and 2016 TL-3 [1, 3]. Note that there is no difference between MASH 2009 and MASH 2016 test designation nos. 3-10 and 3-11 for longitudinal barriers, including the cable barriers studied in this research, except that additional occupant compartment deformation measurements are required by MASH 2016.

Full-scale testing and evaluation with a 1500A mid-size sedan and 2270P pickup trucks resulted in satisfactory system performance [4]. However, full-scale crash testing with the 1100C small car has resulted in the top of the post tearing the vehicle's floor pan and penetrating into the occupant compartment as the vehicle overrode various system posts [5].

Review of the test vehicles and high-speed videos revealed that the tears were caused by a combination of the post's weak-axis bending strength and cross-sectional geometry. The strength of the post, specifically the elastic restoration force of the MWP, caused the top of each overridden post to press up against the undercarriage of the vehicle. The cross-sectional geometry of the MWP contained free, or exposed, edges that transmitted the post contact forces into the floor pan and ultimately resulted in scraping, gouging, and tearing. These tears were deemed penetrations into the vehicle's occupant compartment and prevented the full-scale crash tests from satisfying the MASH 2009 safety criteria. Therefore, modifications to the MWP were needed to prevent penetration into the occupant compartment.

In a previous research study, modifications, including edge rounding, steel plate edge protectors, and post weakening techniques, were investigated [6]. Three different weakening patterns were evaluated: (1) ¾-in. (19-mm) diameter holes; (2) three ⅜-in. (10-mm) diameter holes; and (3) ⅜-in. x 1⅛-in. (10-mm x 29-mm) slots. All three weakening patterns demonstrated the ability to reduce the propensity for floor pan tearing. However, additional bogie testing of the posts resulted in significant reductions in strong-axis strength for the latter two weakening patterns. The ¾-in. (19-mm) diameter hole resulted in a 10 percent reduction in strong-axis bending strength, and thus, was recommended for further evaluation through full-scale vehicle crash testing. Moreover, the edge protectors showed promise to prevent tearing. The steel plate edge protectors welded at the top of the MWP successfully mitigated floor pan tearing as the free-edge side of the posts only created creases in the simulated floor pan. The tears that occurred in the floor pan during the test were the result of contact with the sharp corner in the continuous edge of the MWP, which was a result of a fabrication error. Therefore, these tears were not considered a result of the edge protectors, and the use of edge protectors was deemed an effective tearing mitigation method.

The MWP with ¾-in. (19-mm) diameter weakening holes and rounded top edges was evaluated in accordance with MASH 2016 test designation no. 3-10 [7]. The modified cable barrier system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. However, floor pan tearing occurred, and the test was deemed unacceptable according to the MASH 2016 TL-3 safety criteria. Further investigation of post edge protectors and post weakening mechanisms may mitigate the risk of floor pan tearing.

1.2 Objectives

The objective of the research described herein was to mitigate the propensity for vehicle floor pan tearing observed in full-scale vehicle crash tests of a prototype cable median barrier. This objective was accomplished by evaluating modifications made to the MWP utilized in the current cable median barrier prototype.

1.3 Scope

The research objective was achieved through completion of several tasks. Modifications, including post weakening mechanisms and edge protectors, were investigated and evaluated through dynamic component testing with a surrogate vehicle equipped with a simulated small car floor pan. Next, conclusions and recommendations were made pertaining to potential post modifications to mitigate floor pan tearing.

2 COMPONENT TESTING CONDITIONS

2.1 Purpose

Dynamic component testing has demonstrated that post weakening and edge protectors can mitigate the propensity for guardrail posts to tear or penetrate a vehicle's floor pan [6]. The weakening holes were placed on the upstream and downstream flanges of the MWPs to maximize weakening along the longitudinal barrier axis, or about the post's weak-axis, while minimizing their effect on the strong-axis bending strength of the post. Moreover, the edge protectors at the top of the post were deemed an effective tearing mitigation method. Therefore, the effects of the combination of edge protectors and post weakening needed to be quantified through dynamic component testing.

2.2 Scope

A total of five bogie tests were conducted in order to evaluate the propensity for floor pan tearing associated with post modifications. Each test involved two posts being impacted and overrun by a bogie vehicle equipped with a simulated car floor pan. The posts within each individual test were identical in both configuration and orientation. The posts were spaced 8 feet (2.4 m) apart and were offset 4¼ in. (108 mm) laterally so that the posts contacted the simulated floor pan independently. The posts were installed in either an 8-in. (203-mm) diameter hole cored into the tarmac or an 18-in. (457-mm) hole augured into a soil test pit, and the post was then driven in the center of the hole. Both hole types were backfilled with soil compacted to MASH 2016 specifications. The posts were oriented at a 0-degree angle, thus creating an impact about the post's weak axis of bending, except in the last test, where the post was oriented at a -25-degree angle, thus representing the MASH 2016 impact angle of the cable barrier installed on the roadside instead of a median. The bogie vehicle impacted the posts at a height of 12 in. (305 mm) above the groundline at a targeted impact speed of 25 mph (40 km/h).

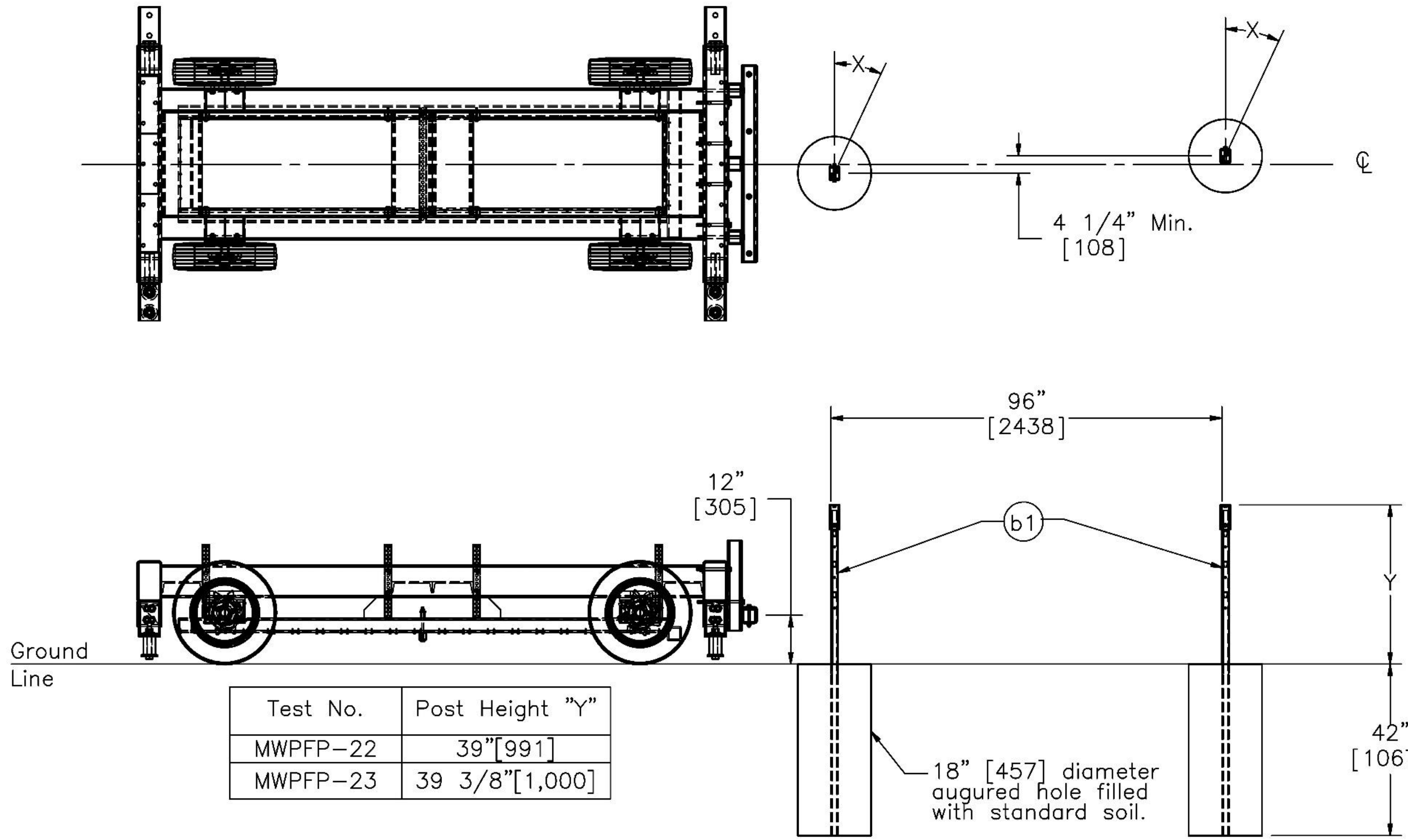
Four different post configurations were evaluated. The first test was conducted on the MWP with ¾-in. (19-mm) diameter weakening holes and a 6-in. (152-mm) long, 3½-in. x 2½-in. x $^{3}/_{16}$-in. (89-mm x 64-mm x 5-mm) thick steel tube cap mounted at the top of the posts. The other four tests were conducted on the MWP with 2⅛-in. x 1⅜-in. x 7-gauge (54-mm x 35-mm x 5-mm) bent steel plates as edge protectors mounted to the top of the posts. In the latter two tests, the MWP was also modified with ¾-in. (19-mm) diameter weakening holes.

The dynamic test matrix is summarized in Table 1, and the test setups are shown in Figures 2 through 23. Material specifications, mill certifications, and certificates of conformity for the posts and bogie floor pan material are shown in Appendix B.

Table 1. Dynamic Testing Matrix

Test	Midwest Weak Post				Soil or Rigid Sleeve	Targeted Impact Conditions		
	Above Ground Height in. (mm)	MWP Modifications				Speed mph (km/h)	Height in. (mm)	Angle (Deg.)
		Cap Edge Radius in. (mm)	Cap	Groundline Holes in. (mm)				
MWPFP-22	39 (991)	⅝ (16)	Steel tube cap Bolt 5 in. (127 mm) from top of cap Ø½ in. (13 mm) connection bolt	Ø¾ (19)	Soil	25 (40)	12 (305)	0
MWPFP-23	39⅜ (1000)	⅝ (16)	U-plates ⅛ in. (3 mm) off post, bolt 3 in. (76 mm) from top of cap, Ø⅜ in. (10 mm) connection bolt	NA	Soil	25 (40)	12 (305)	0
MWPFP-24	39⅜ (1000)	⅝ (16)	U-plates ⅛ in. (3 mm) off post, bolt 4 in. (102 mm) from top of cap, Ø⅜ in. (10 mm) connection bolt	NA	Rigid Sleeve	25 (40)	12 (305)	0
MWPFP-25	39⅜ (1000)	⅝ (16)	U-plates ⅛ in. (3 mm) off post, bolt 4 in. (102 mm) from top of cap, Ø⅜ in. (10 mm) connection bolt	Ø¾ (19)	Rigid Sleeve	25 (40)	12 (305)	0
MWPFP-26	39⅜ (1000)	⅝ (16)	U-plates ⅛ in. (3 mm) off post, bolt 4 in. (102 mm) from top of cap, Ø½ in. (13 mm) connection bolt	Ø¾ (19)	Rigid Sleeve	25 (40)	12 (305)	-25

NA – Not Applicable



Test No.	Post Height "Y"
MWPFP-22	39"[991]
MWPFP-23	39 3/8"[1,000]

Figure 2. Double Post Dynamic Component Test Setup, Test Nos. MWPFP-22 and MWPFP-23

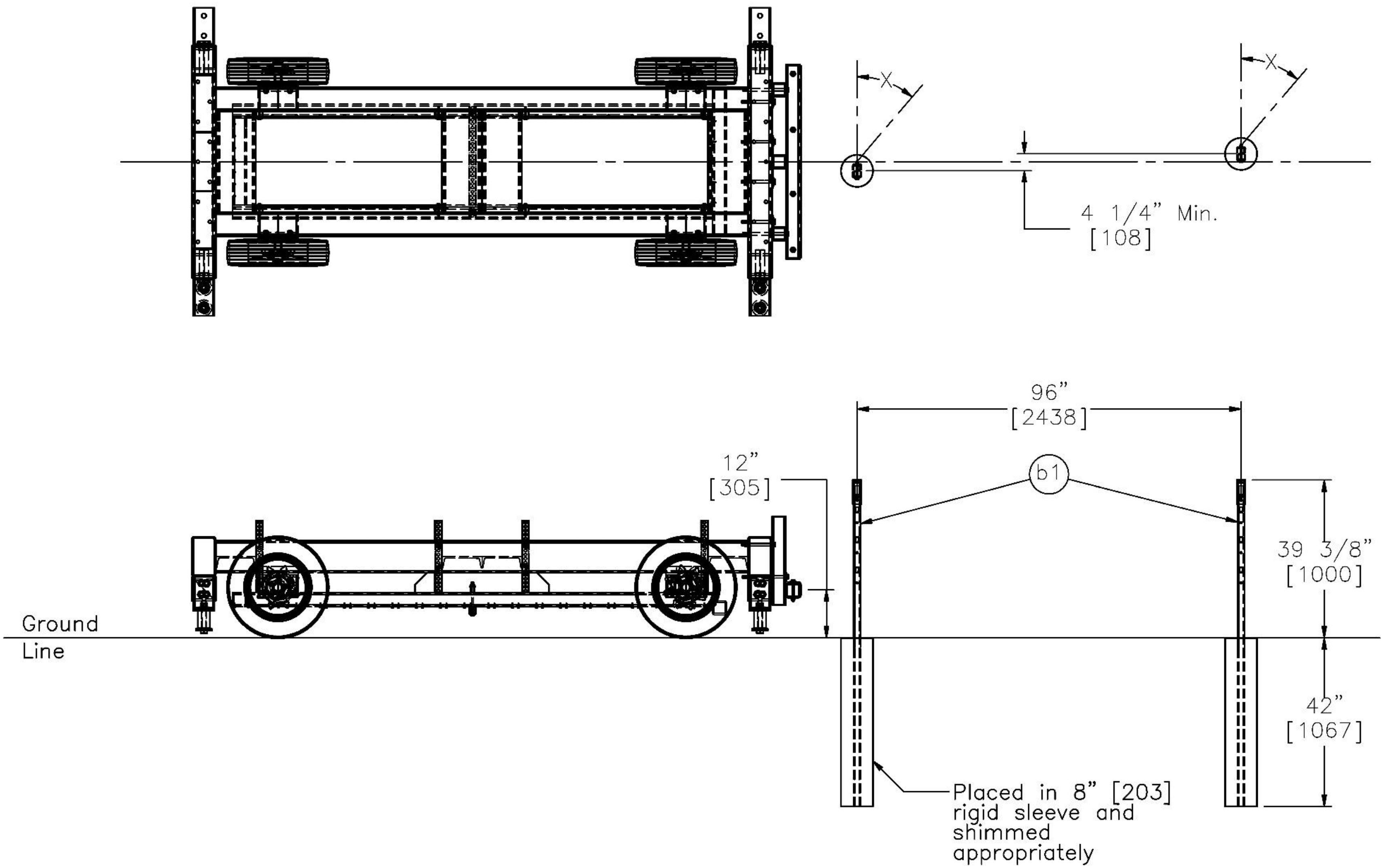


Figure 3. Double Post Dynamic Component Test Setup, Test Nos. MWPFP-24 through MWPFP-26

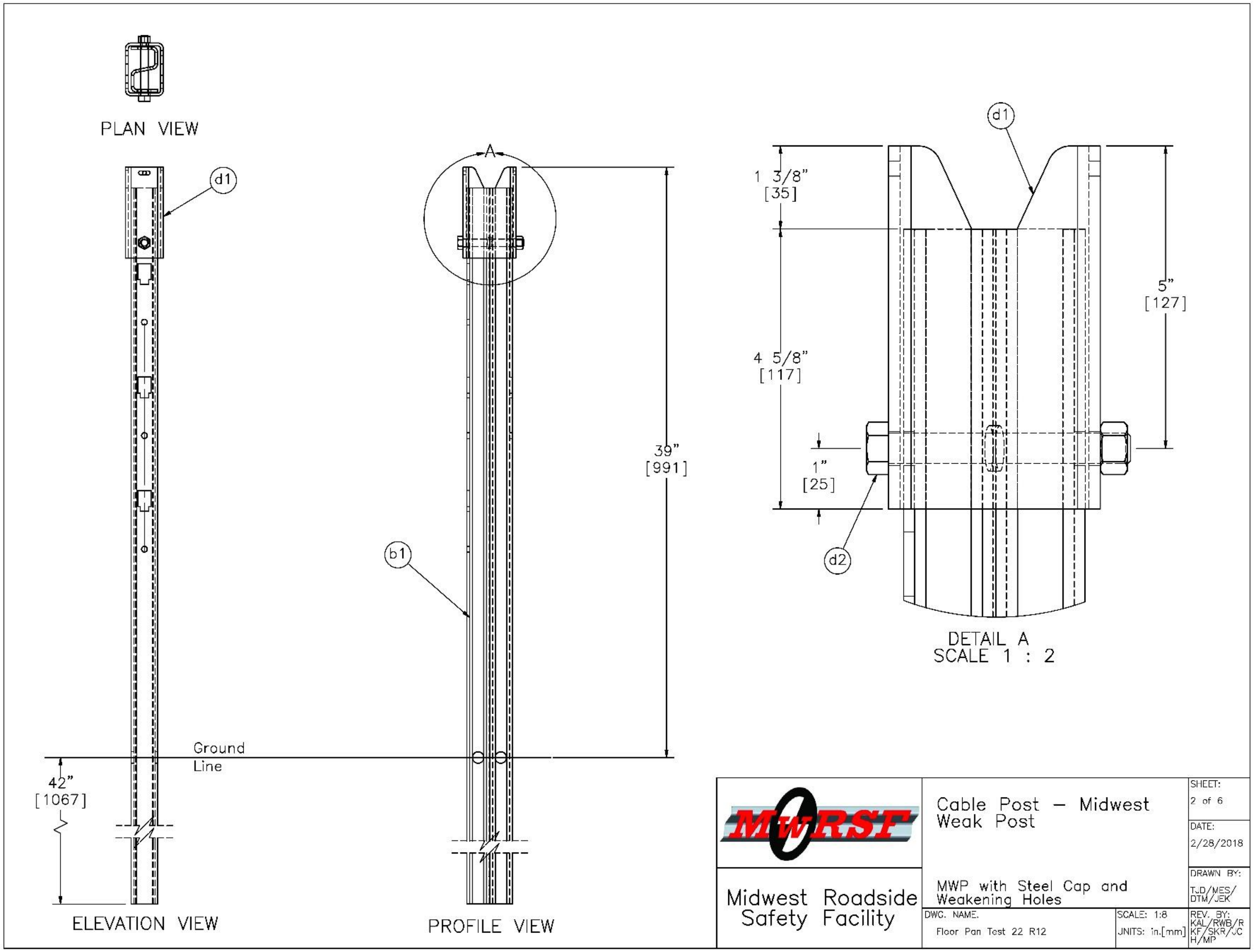


Figure 4. Modified MWP with Steel Cap and Weakening Holes, Test No. MWPFP-22

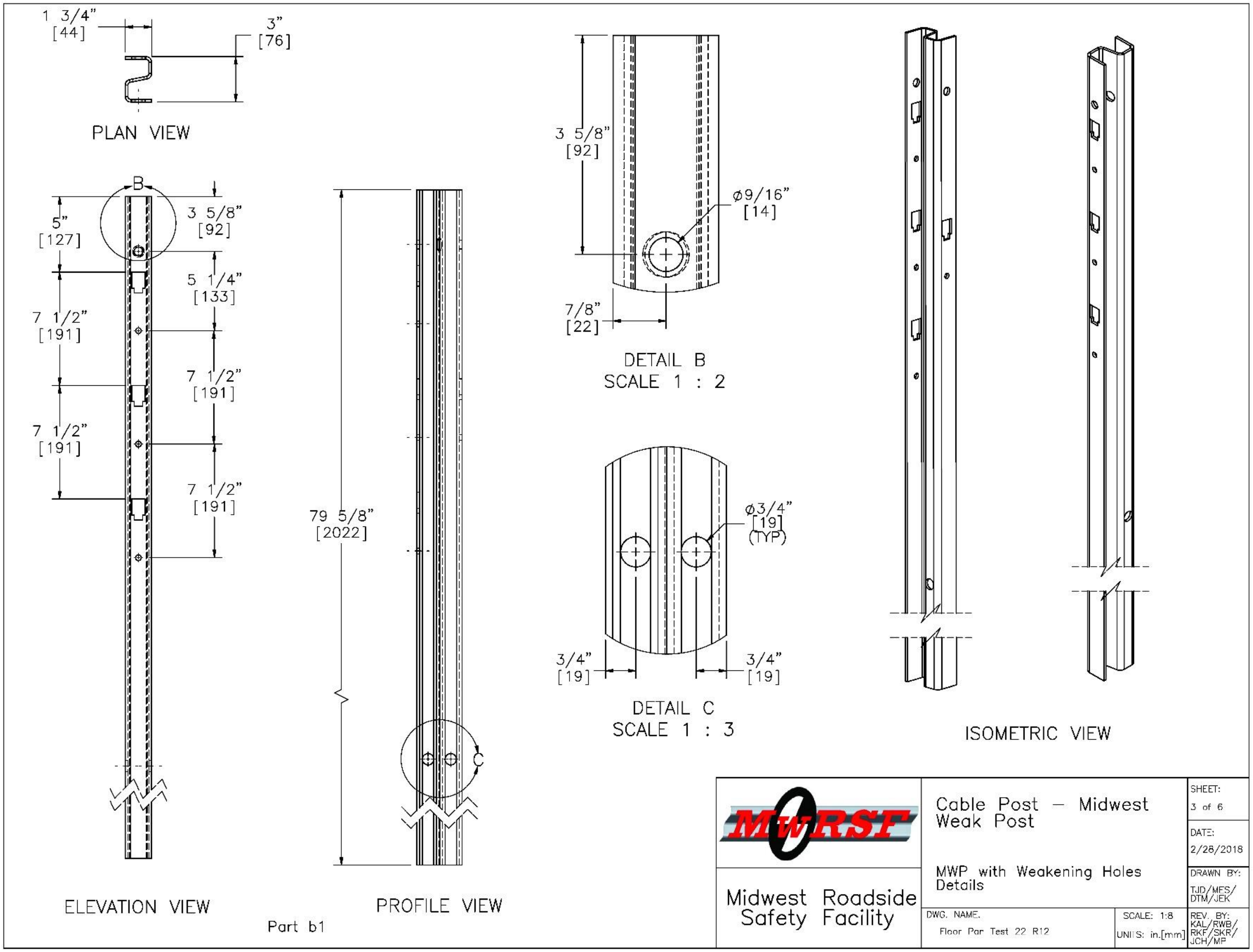


Figure 5. MWP with Weakening Holes Details, Test No. MWPFP-22

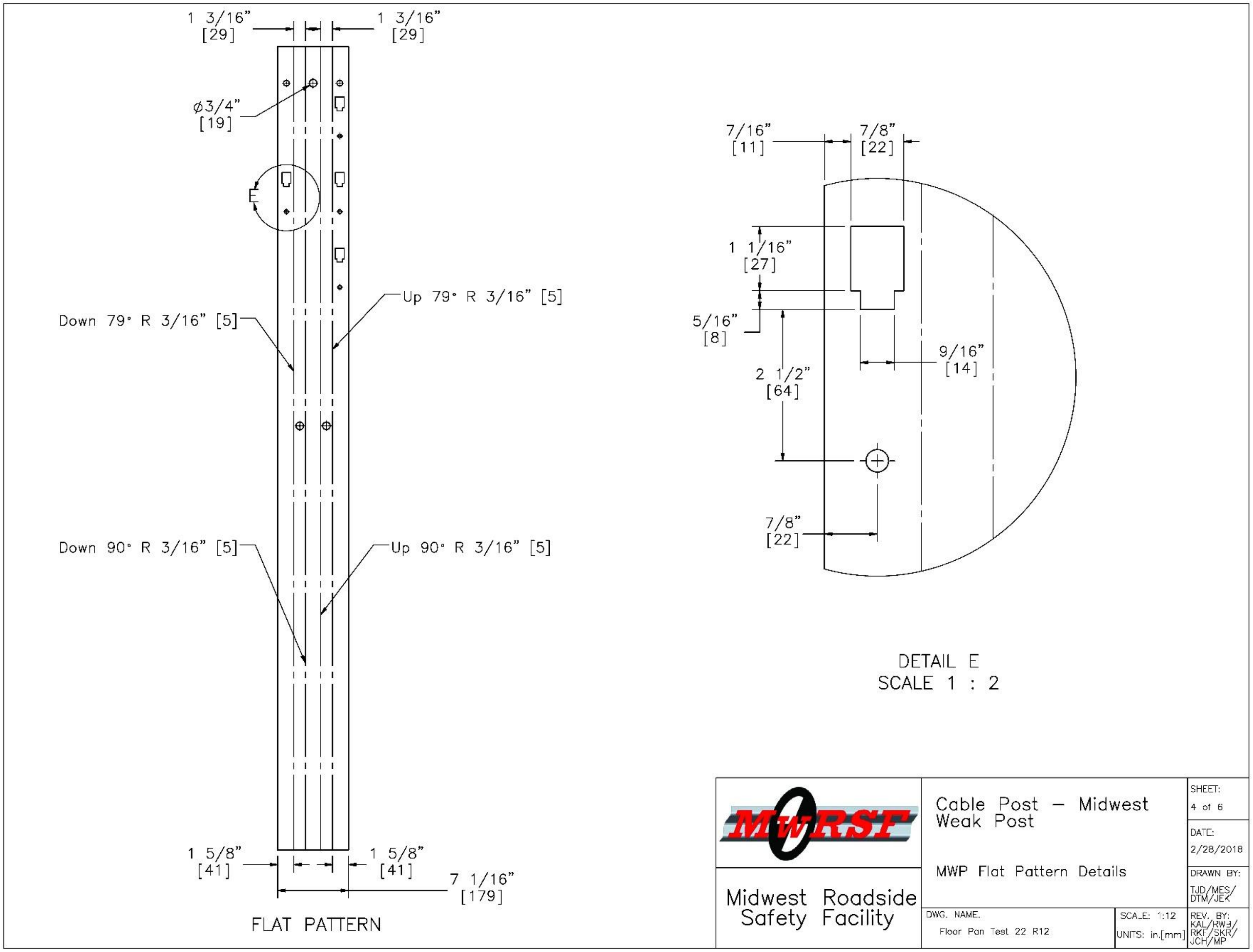


Figure 6. MWP Flat Pattern Details, Test No. MWPFP-22

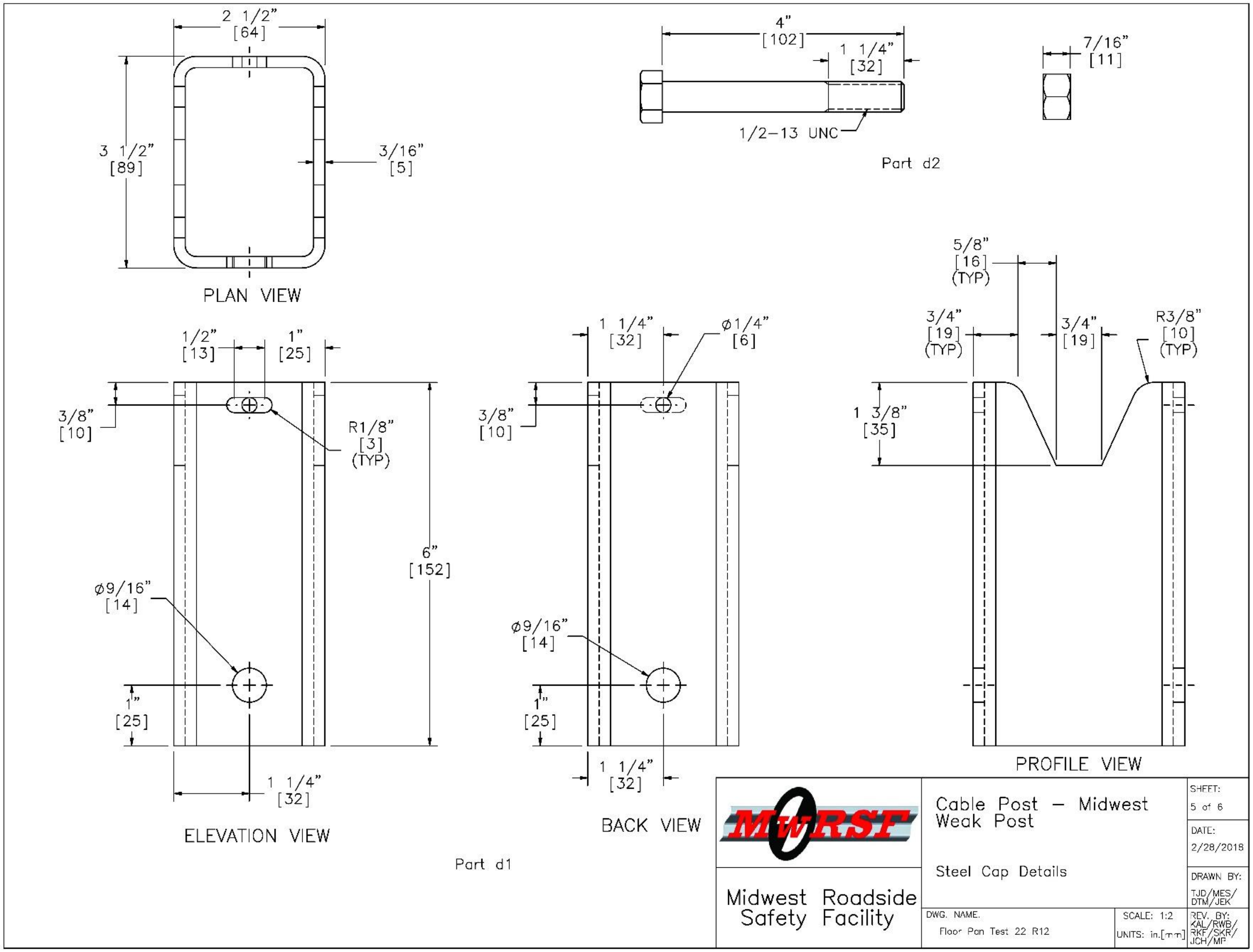


Figure 7. Steel Cap Details, Test No. MWPFP-22

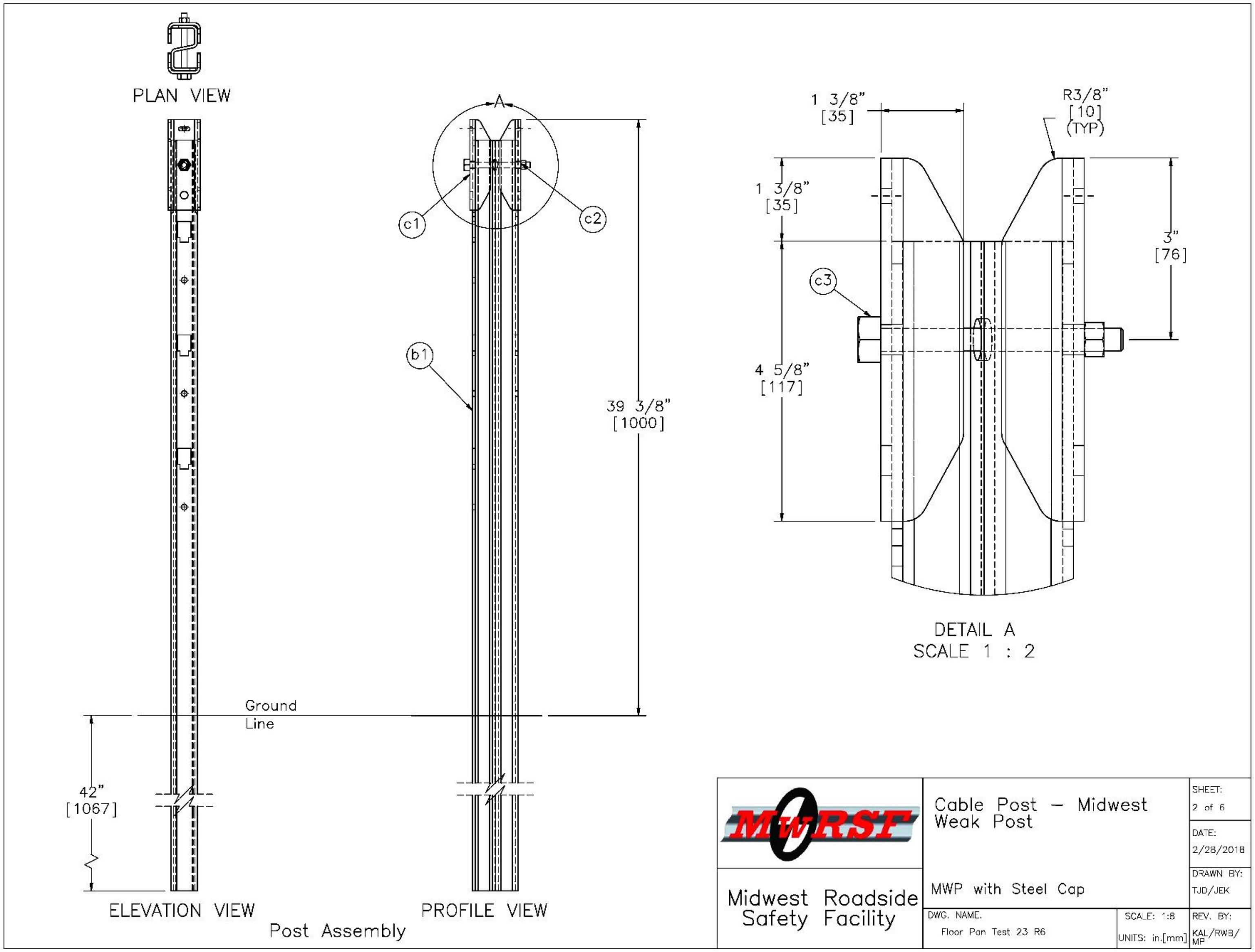


Figure 8. MWP with Steel Cap, Test No. MWPFP-23

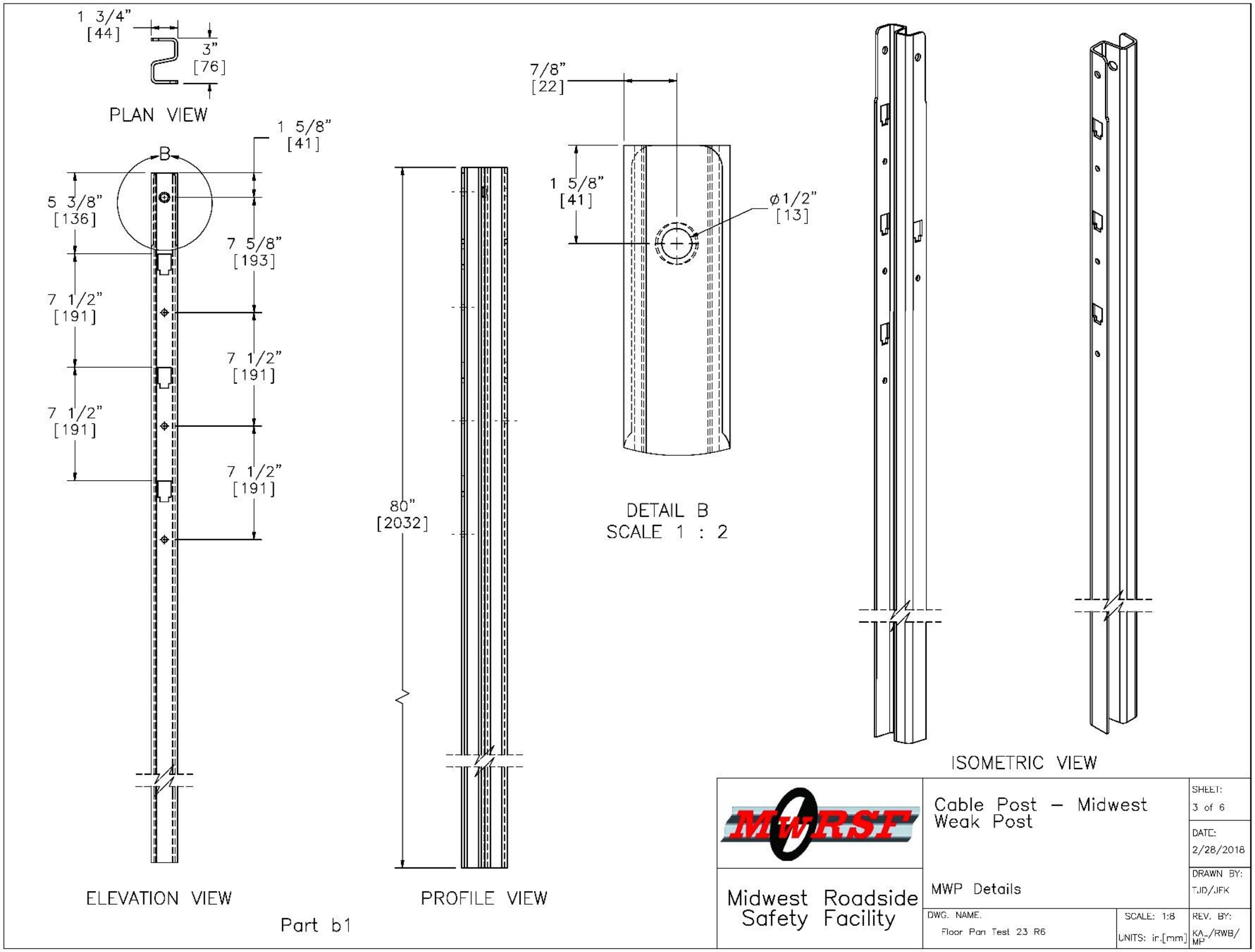


Figure 9. MWP Details, Test No. MWPFP-23

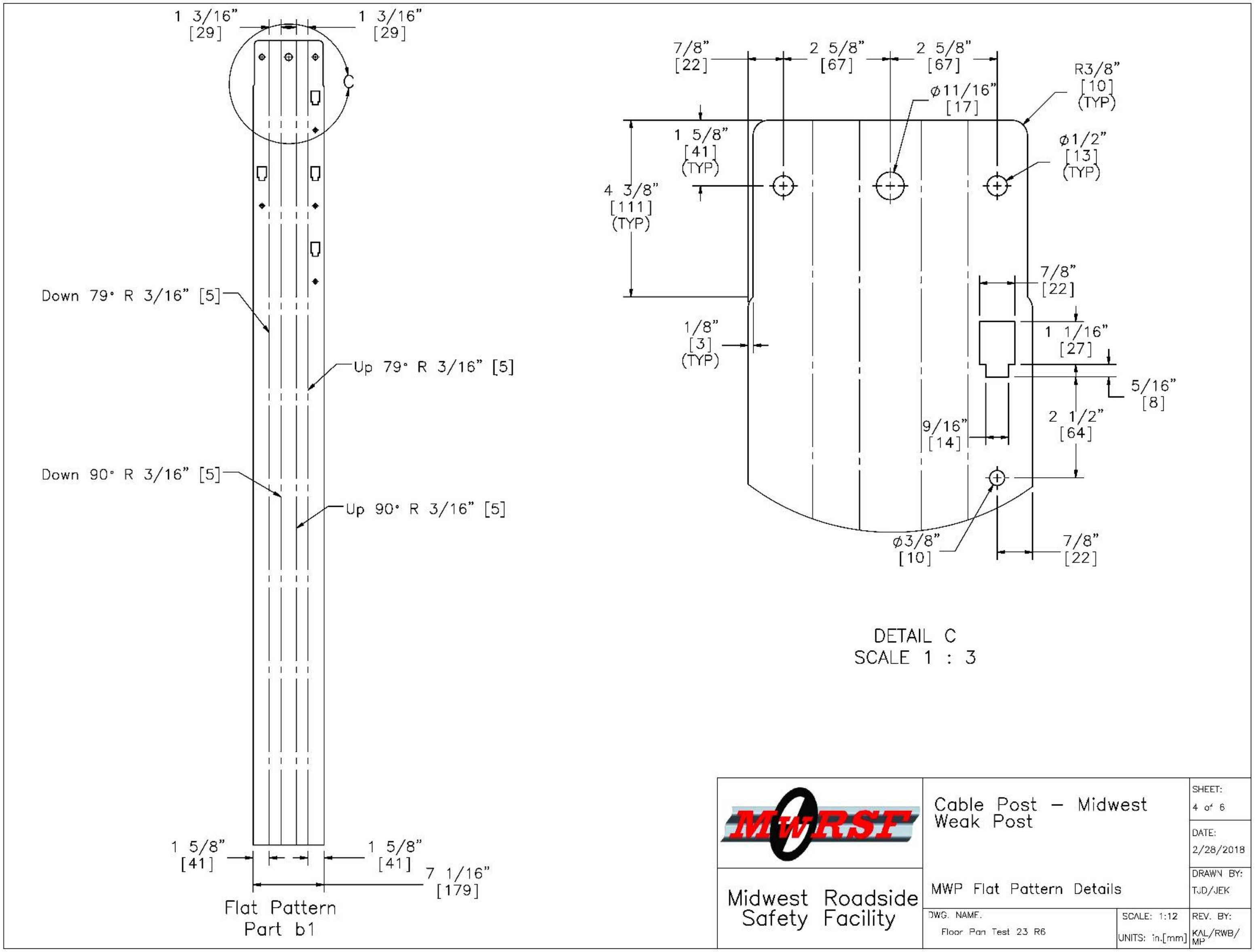
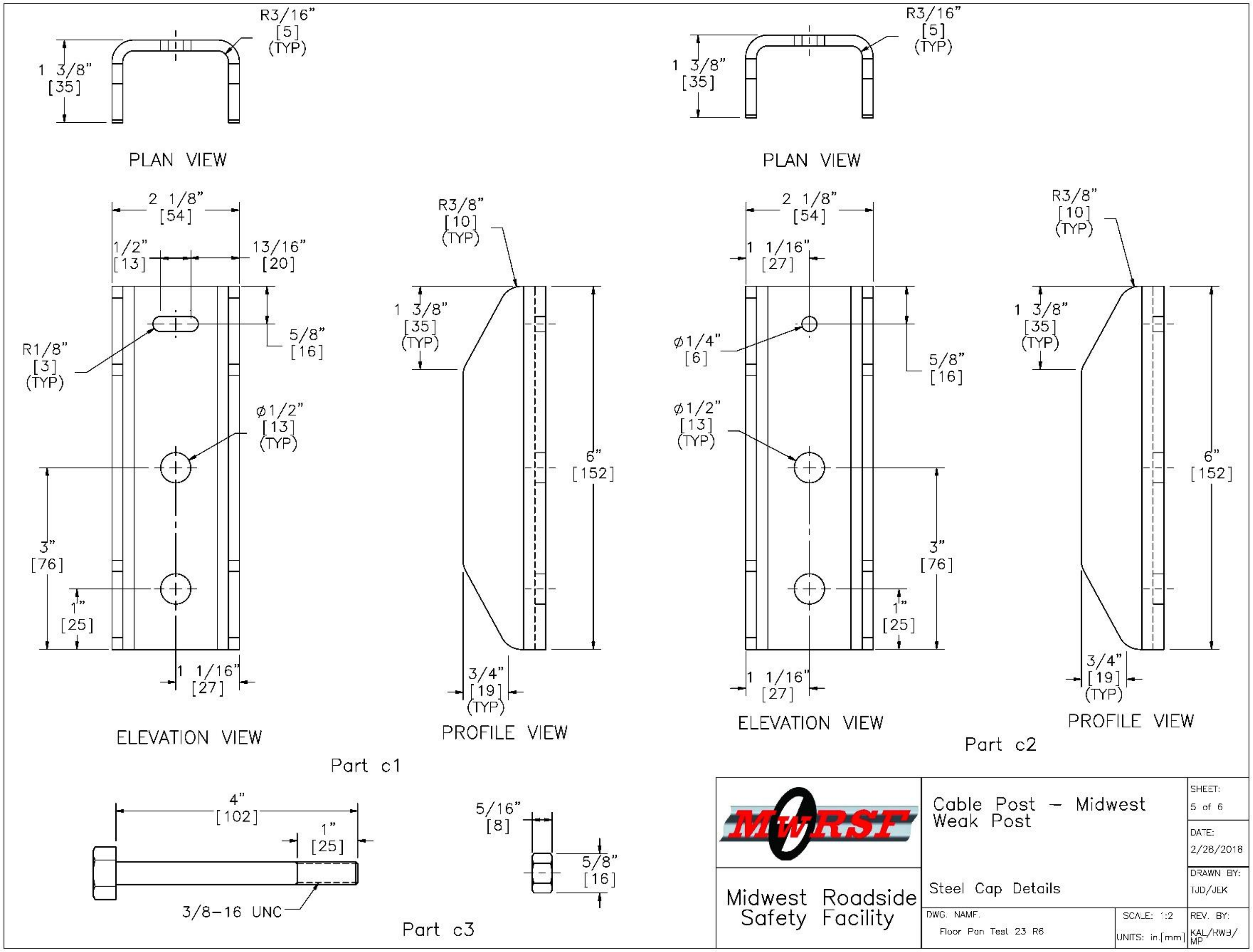


Figure 10. MWP Flat Pattern Details, Test No. MWPFP-23



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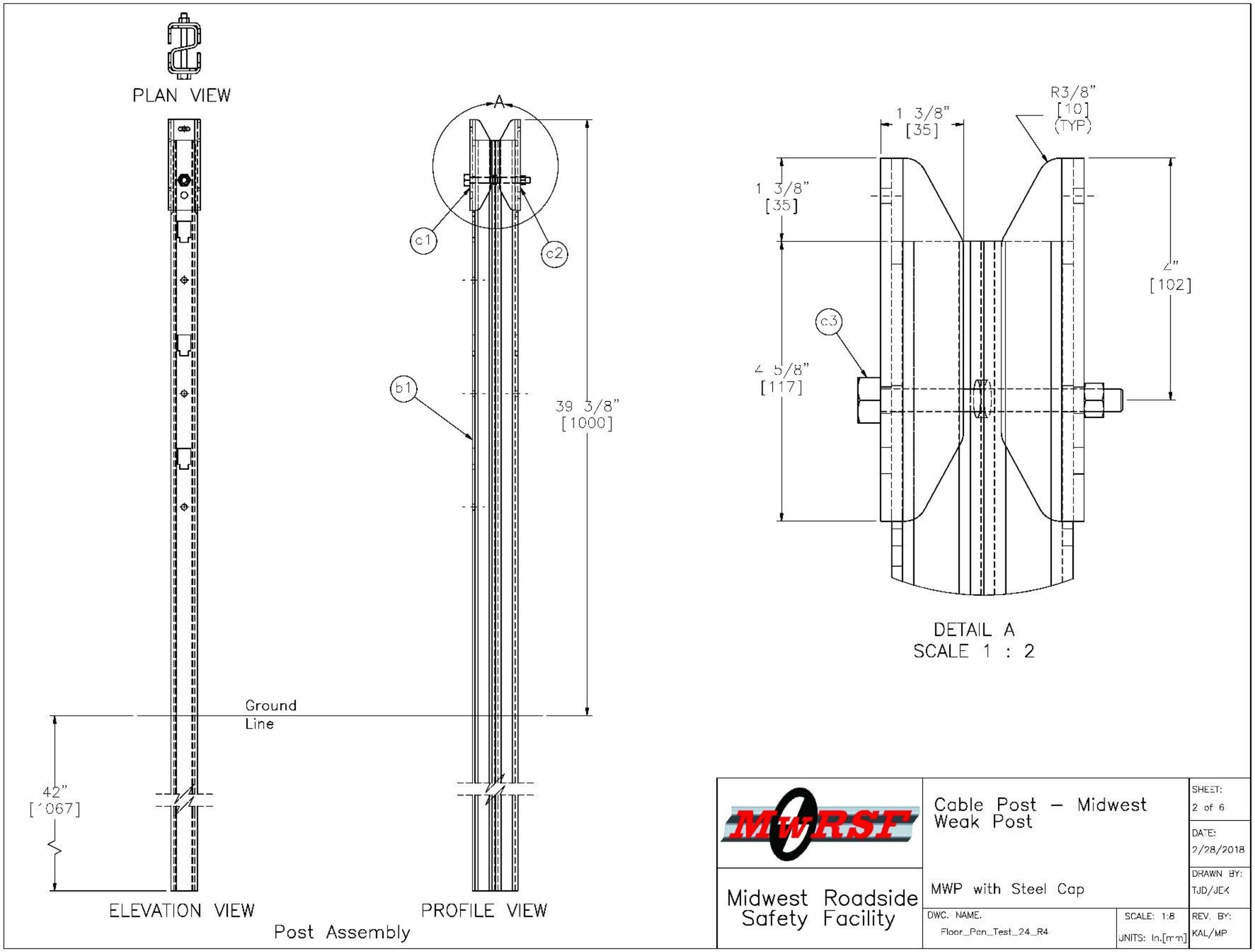


Figure 12. MWP with Steel Cap, Test No. MWPFP-24

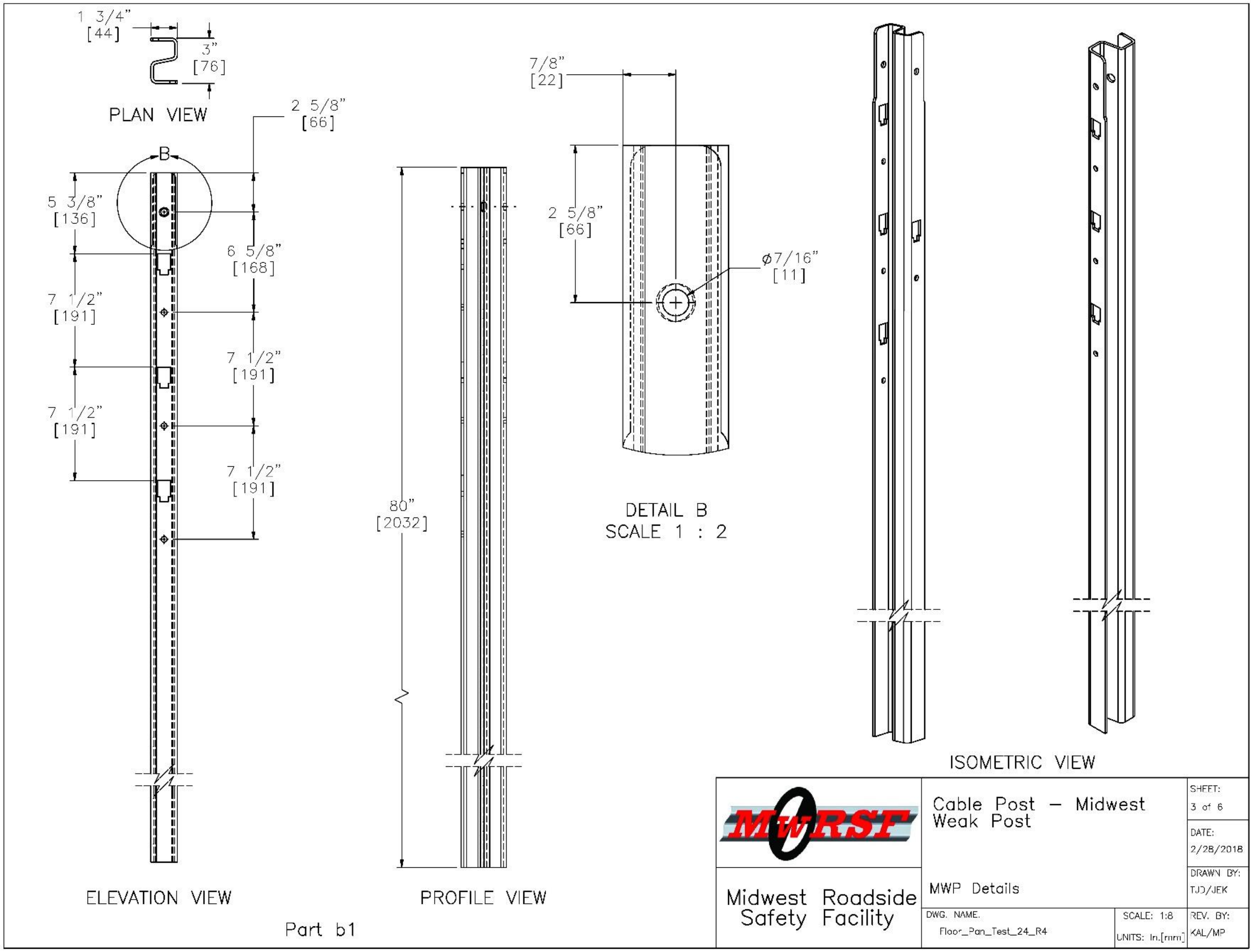
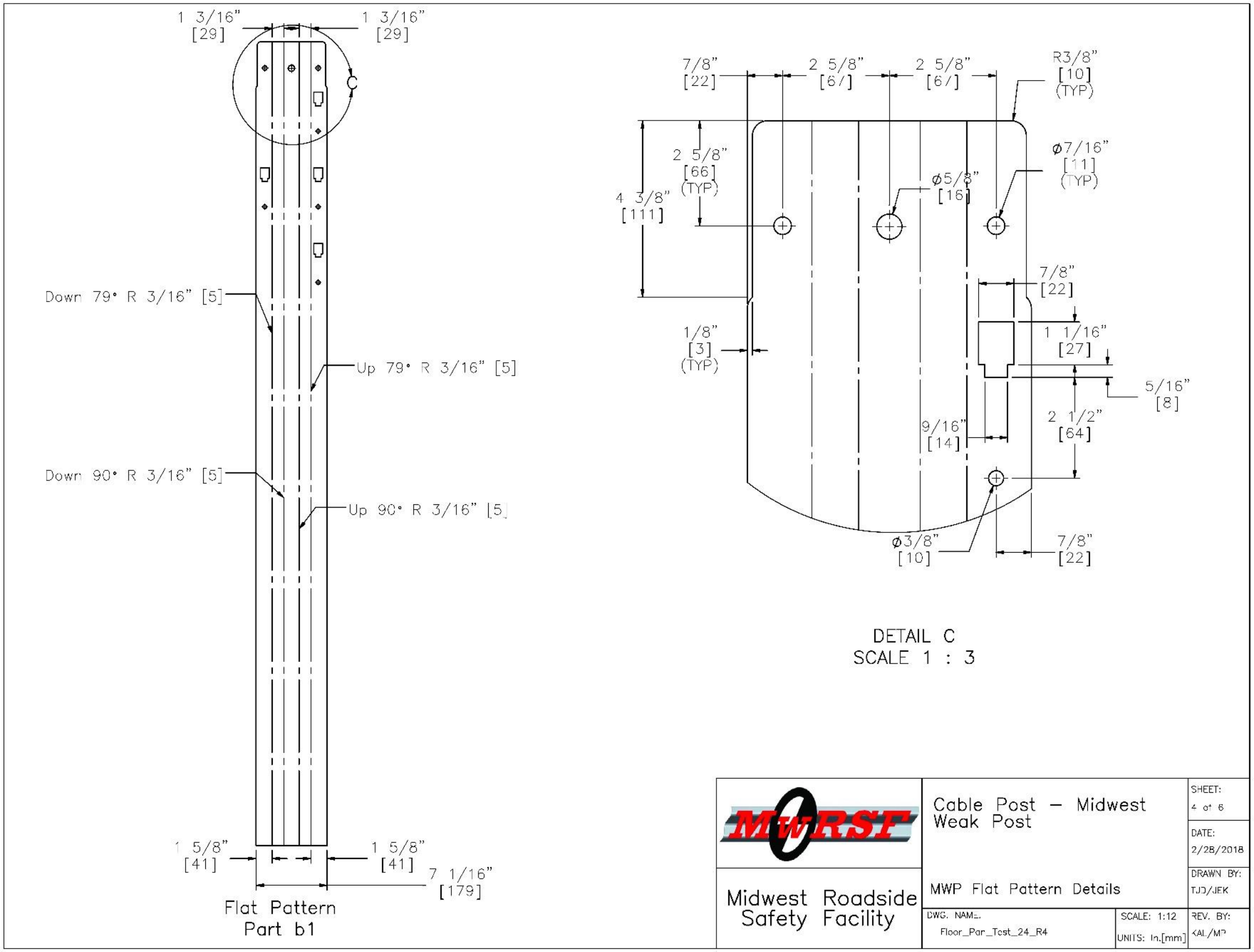


Figure 13. MWP Details, Test No. MWPFP-24



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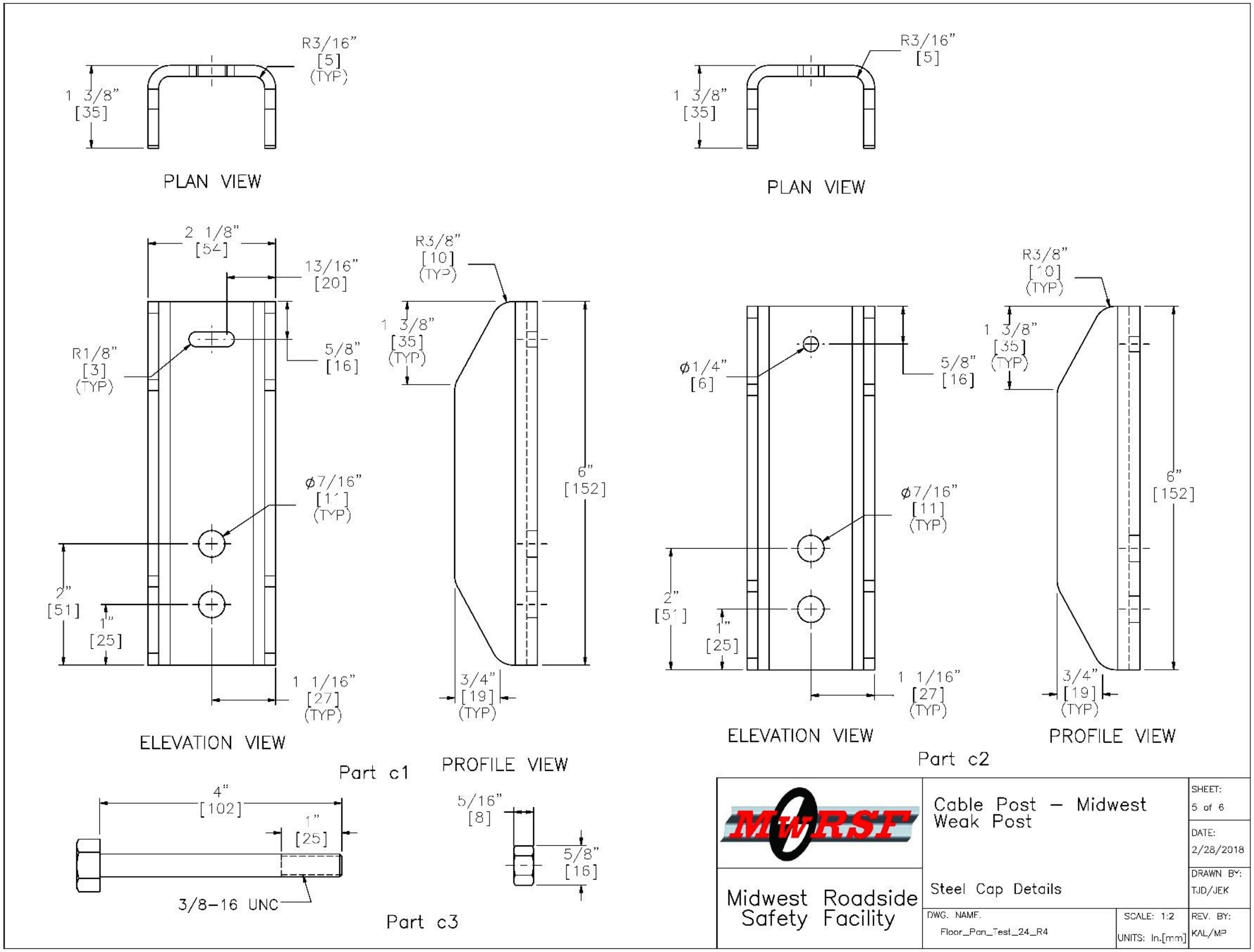

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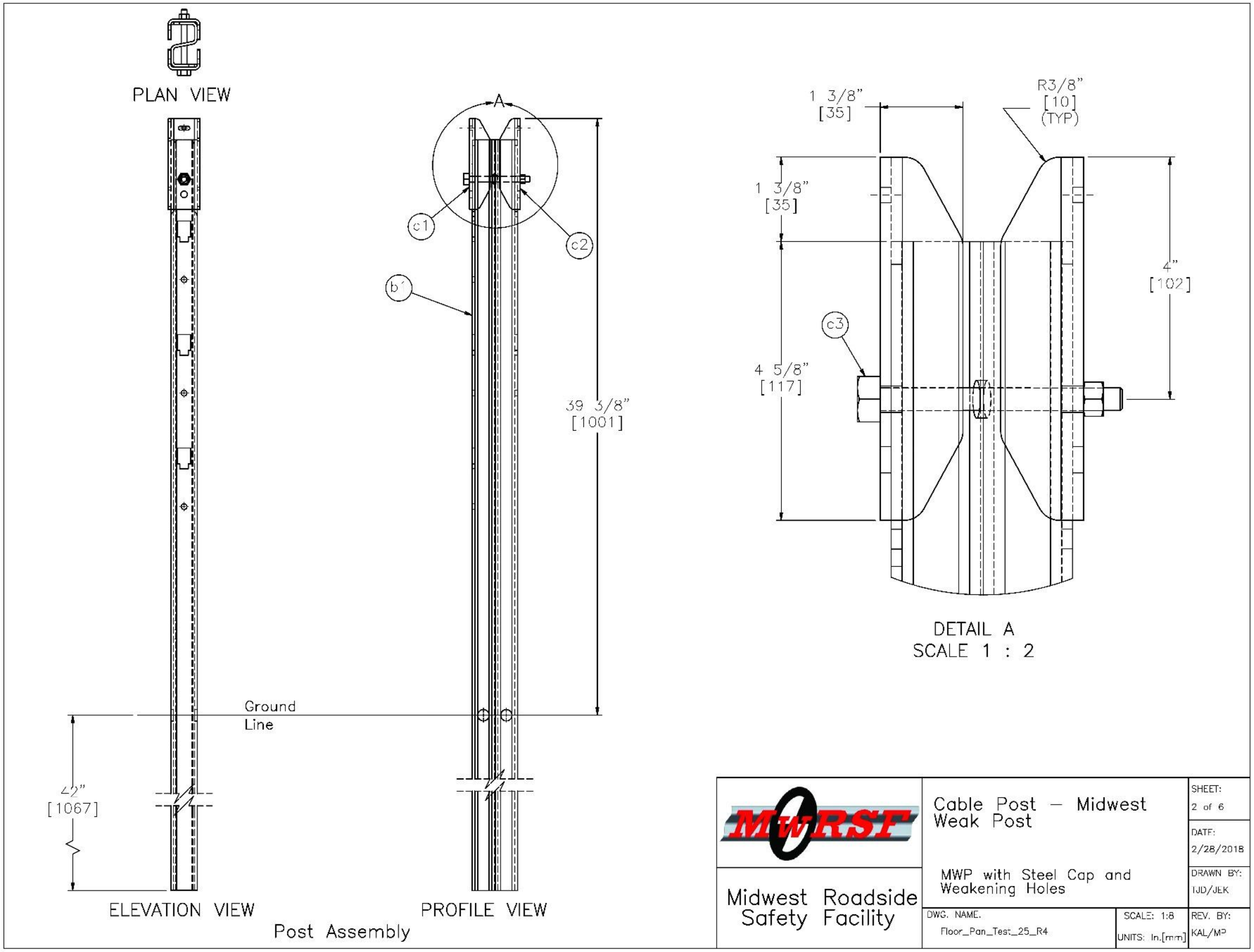


Figure 16. MWP with Steel Cap and Weakening Holes, Test No. MWPFP-25

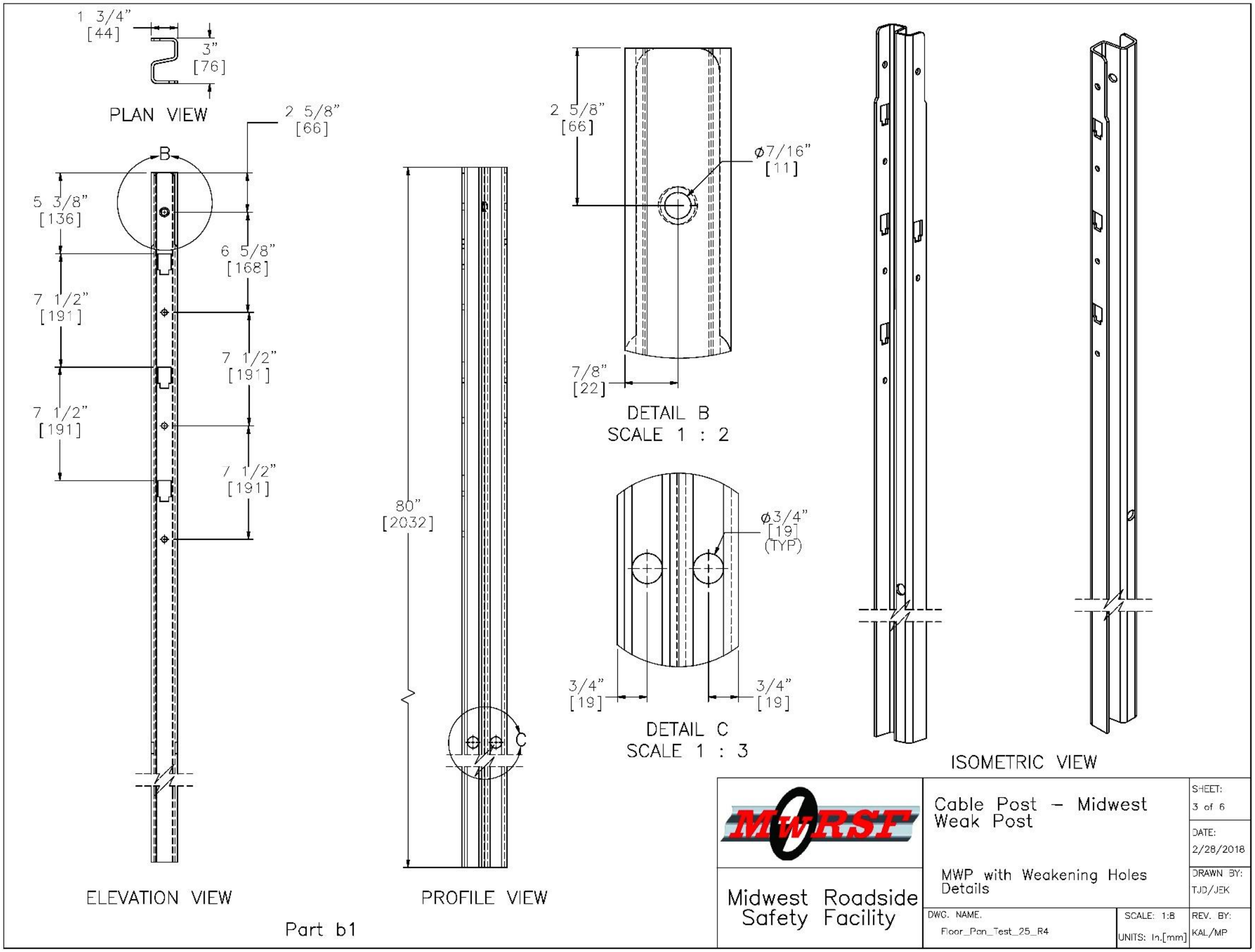


Figure 17. MWP with Weakening Holes Details, Test No. MWPFP-25

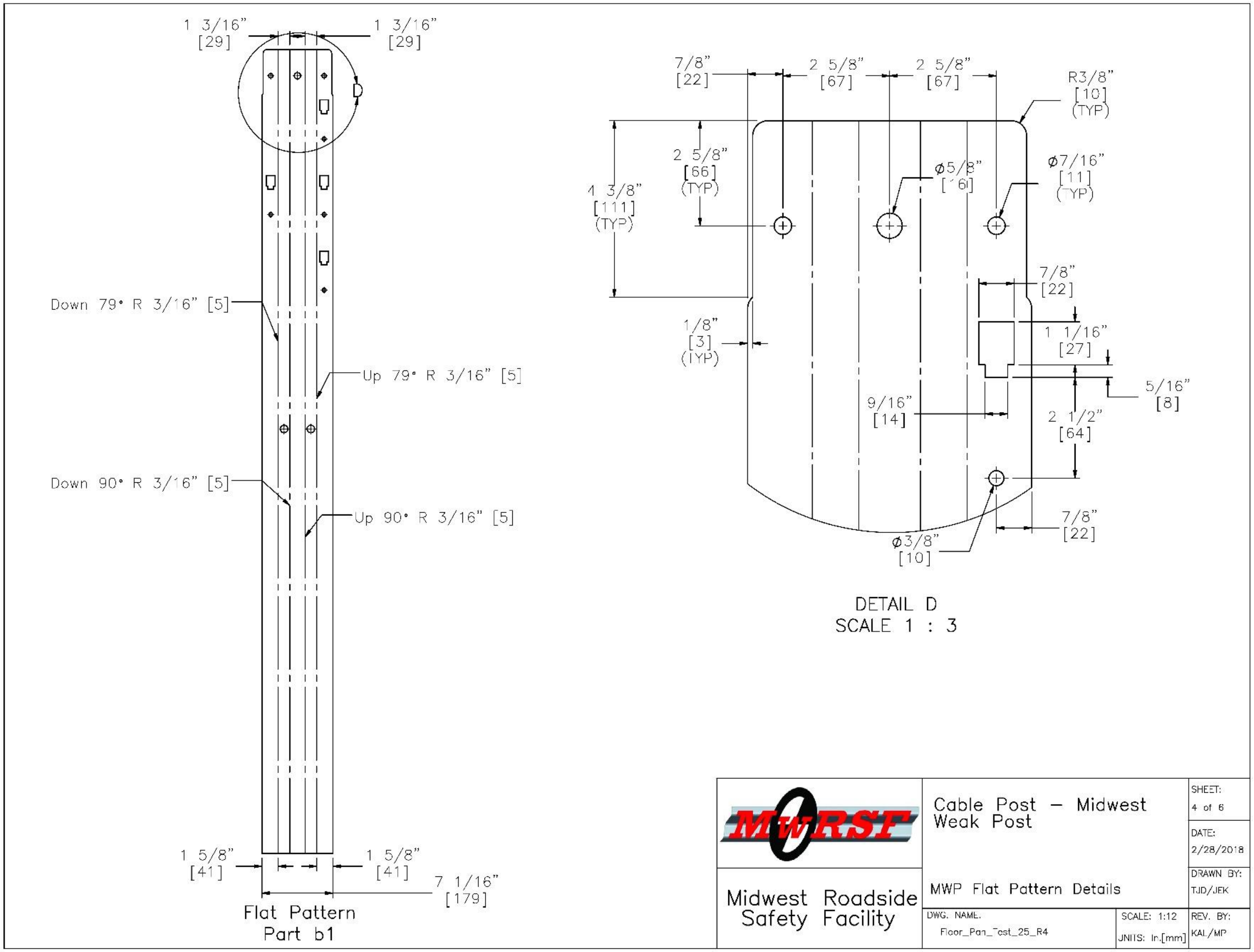
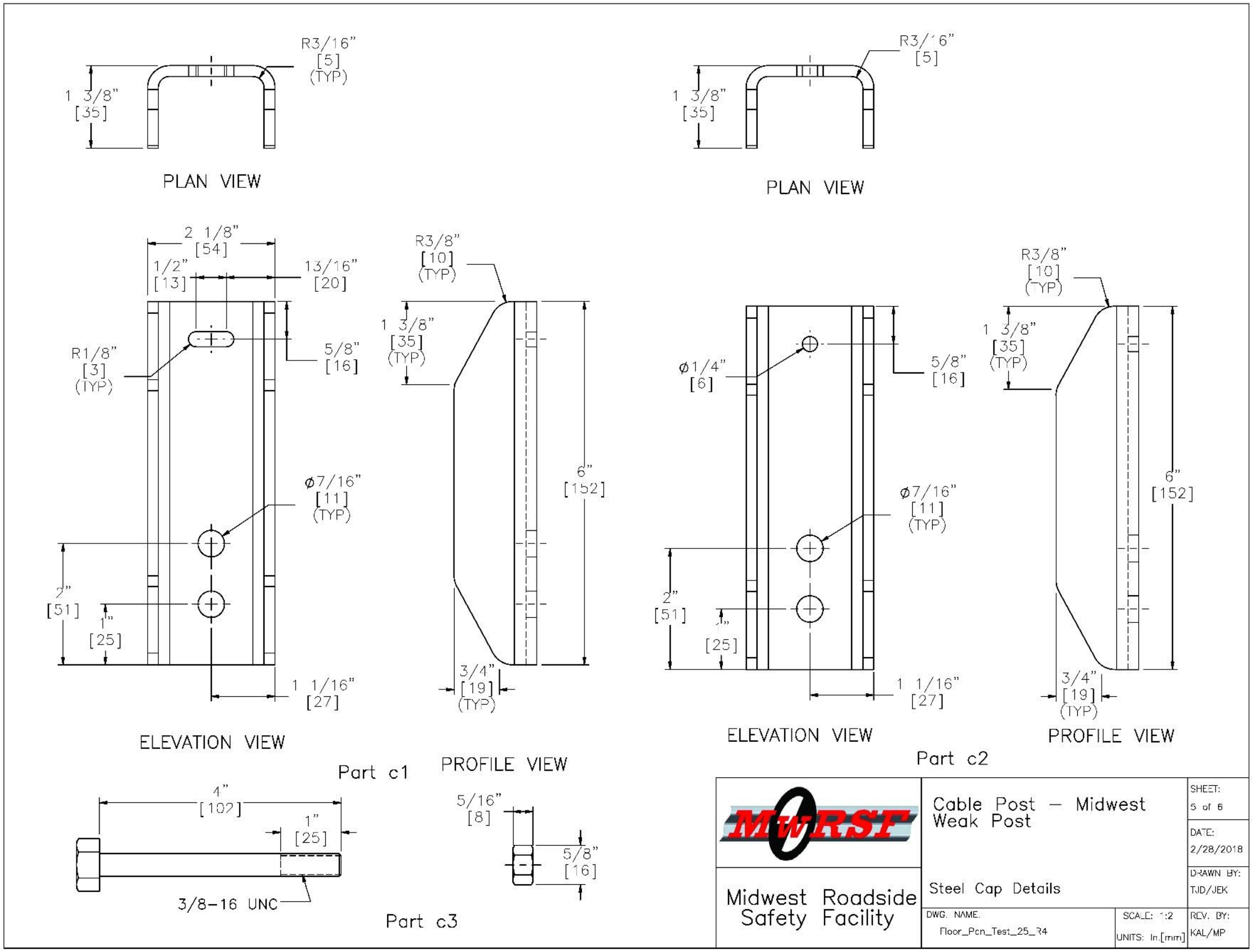


Figure 18. MWP Flat Pattern Details, Test No. MWPFP-25



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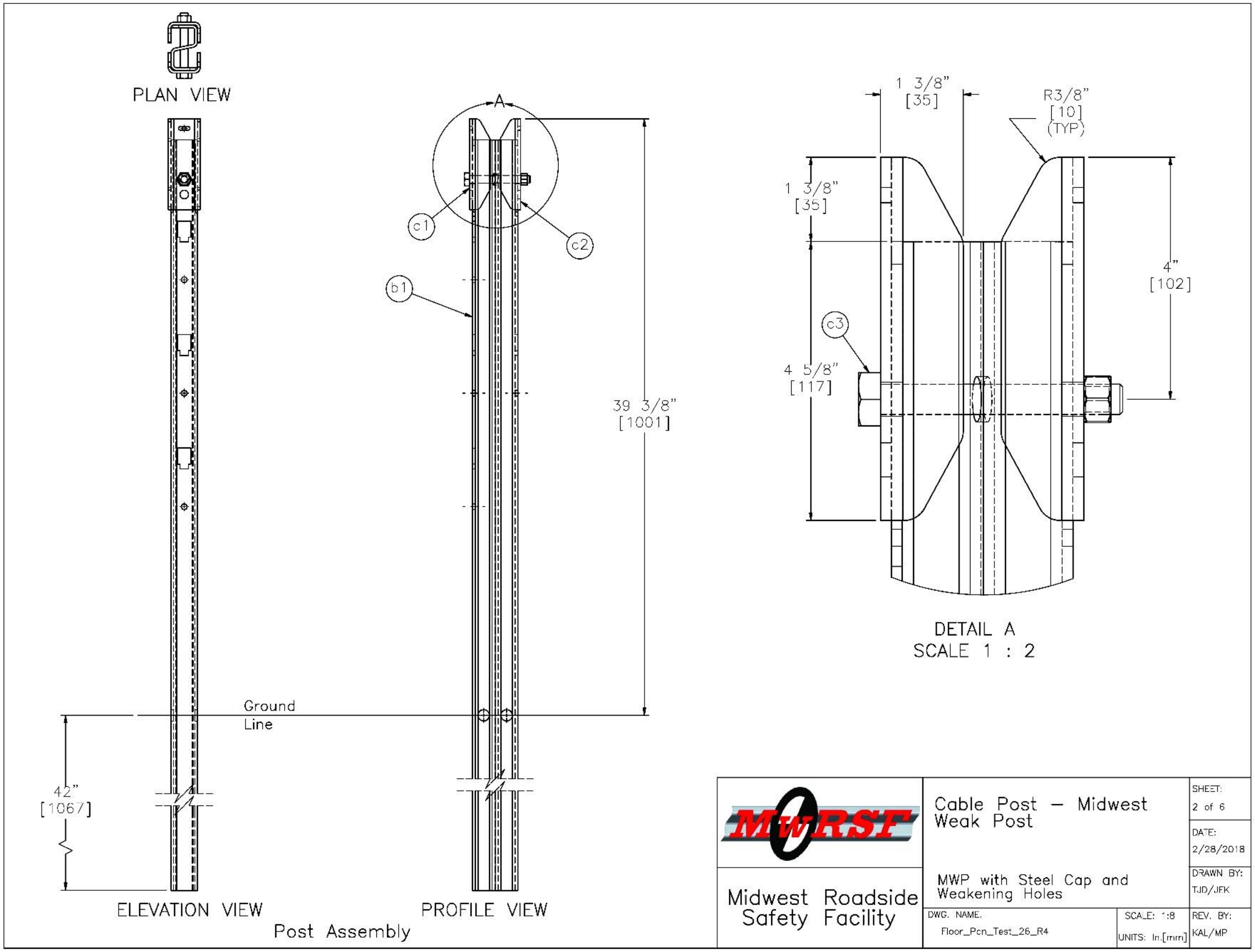
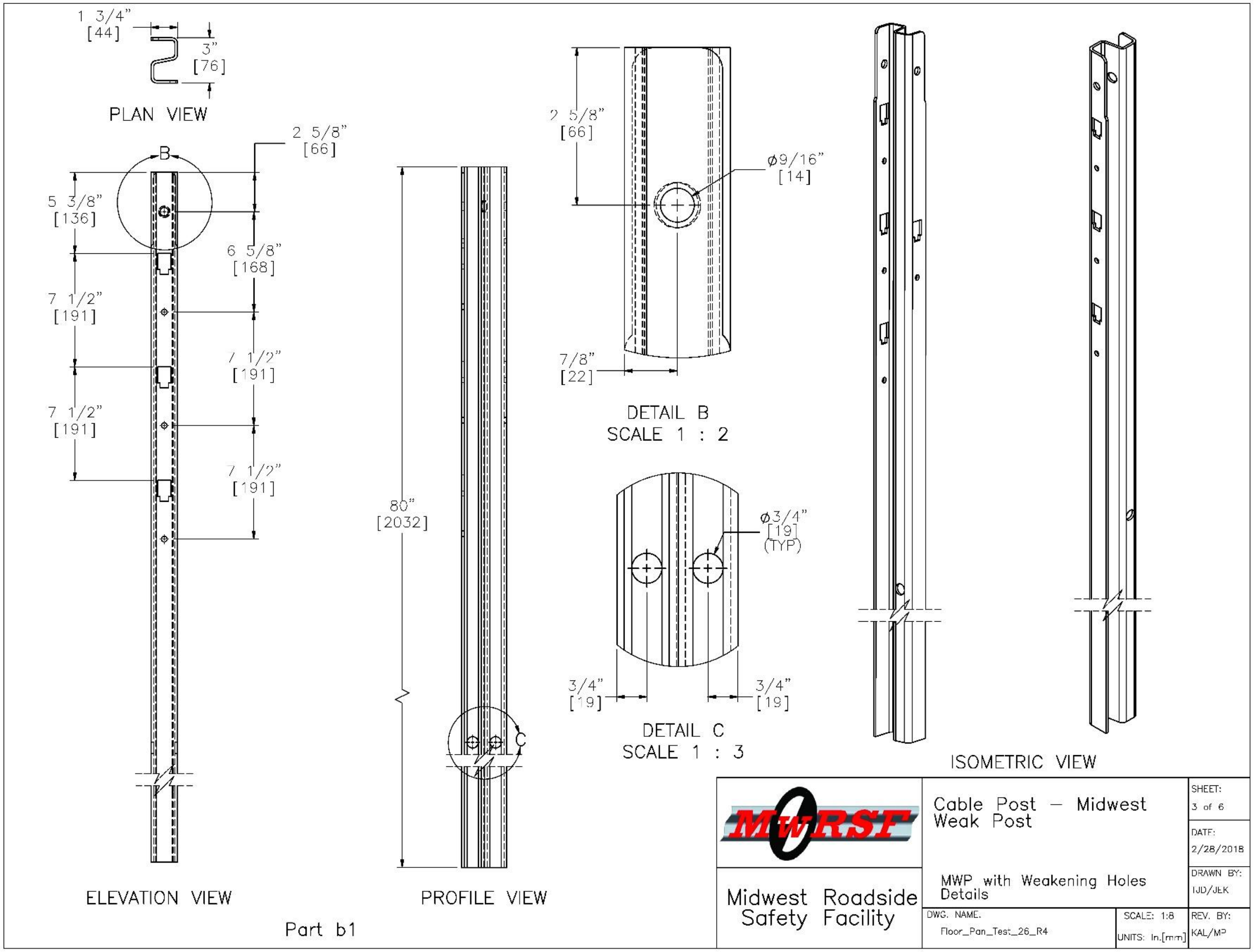


Figure 20. MWP with Steel Cap and Weakening Holes, Test No. MWPFP-26



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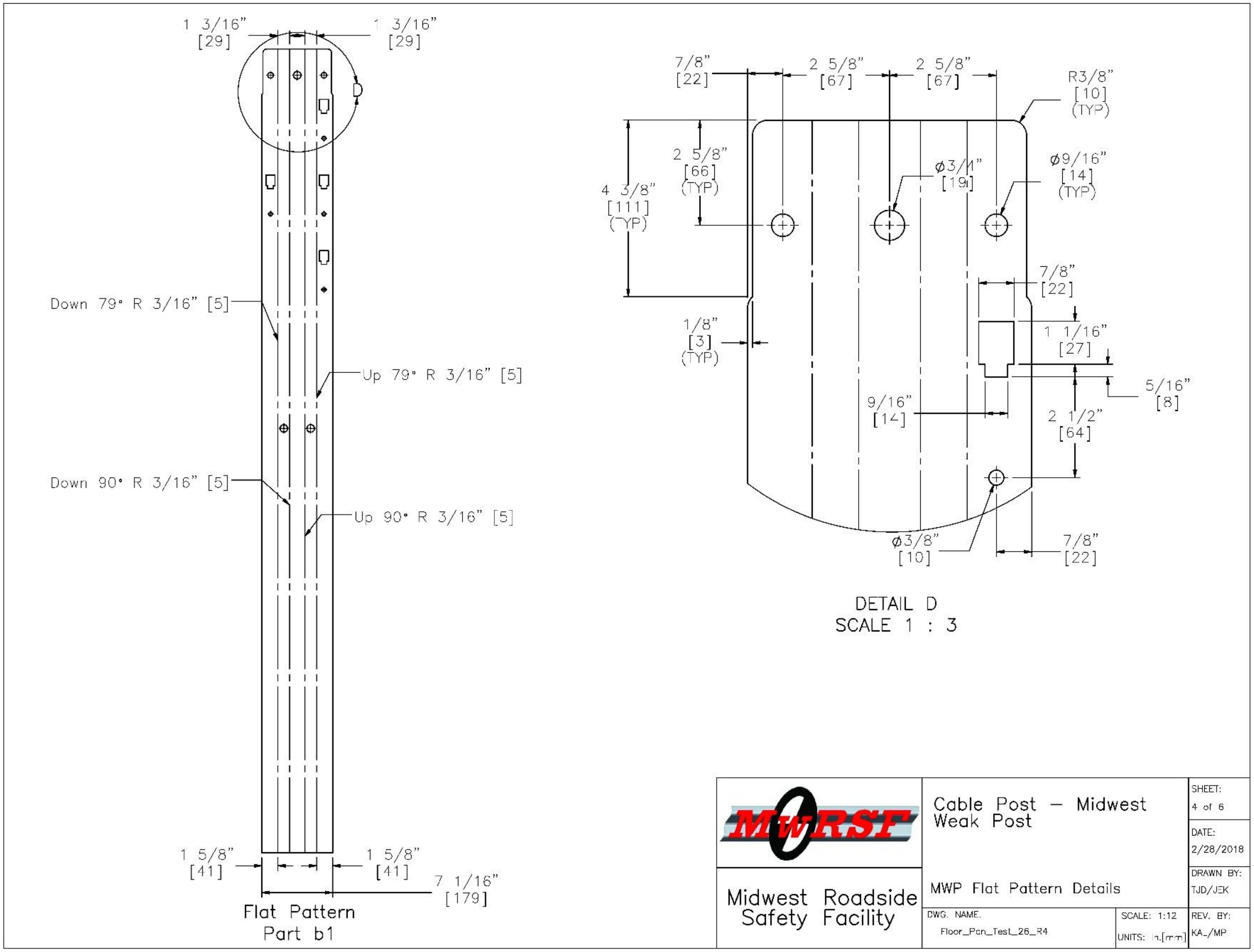

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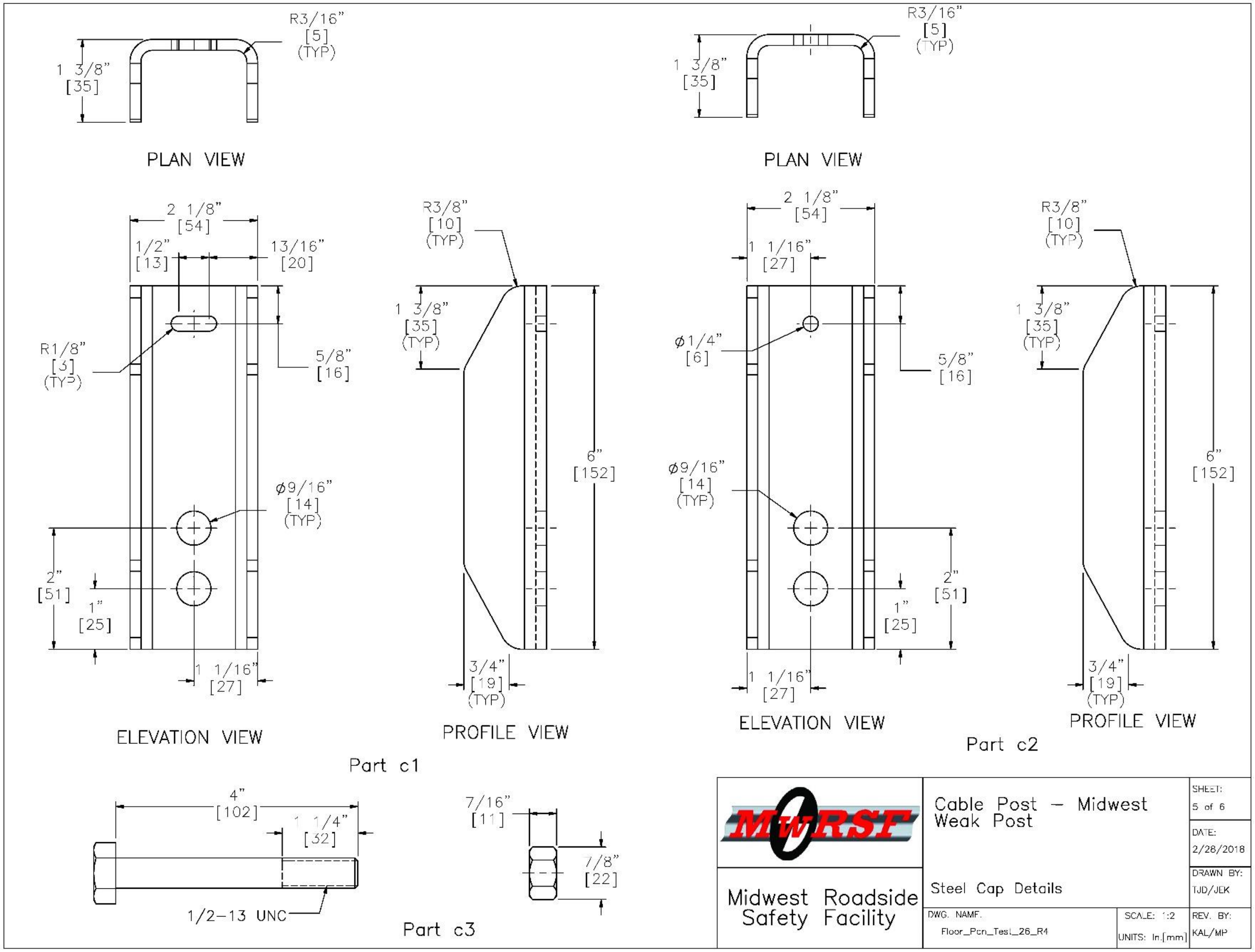


Figure 23. Steel Cap Details, Test No. MWPFP-26

2.3 Equipment and Instrumentation

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

2.3.1 Bogie Vehicle

A rigid-frame bogie equipped with a simulated small car floor pan was used to impact the posts. The simulated floor pan consisted of a 120-in. x 23¾-in. (3,048-mm x 603-mm) sheet of 24-gauge (0.61-mm) ASTM A653 steel. The sheet steel was mounted to the bottom of an undercarriage frame at a height of 8 in. (203 mm), which matched the height of the Kia Rio floor pans from the previous full-scale crash tests. The undercarriage frame was constructed from 3½-in. x 3½-in. x ⅜-in. (89-mm x 89-mm x 10-mm) steel tubes and was bolted to the inside of the bogie vehicle's frame. The front beam of the undercarriage frame was positioned in front of the simulated floor pan and shifted downward 1¾ in. (44 mm). This vertical offset prevented the top of the post from snagging on the front edge of the sheet steel, and acted as a stiff cross member of the vehicle's undercarriage (e.g., frame element, axle, etc.) that caused the post to bend down and spring back upward toward the floor pan as the bogie overrode the top of the post. A 1¾-in. (44-mm) square tube was bolted underneath and across the middle of the simulated floor pan to create a second location where the post would be pushed down and allowed to spring back upward. Photographs of the bogie vehicle are shown in Figure 24, while details of the simulated vehicle undercarriage are shown in Appendix A.

The bogie impact head consisted of a 2½-in. x 2½-in. x ¼-in. (64-mm x 64-mm x 6-mm) steel tube mounted to the front of the bogie at a height of 12 in. (305 mm), measured to the center of the tube. A ¾-in. (19-mm) thick neoprene pad was wrapped around the tube to prevent local damage to the posts during the impacts. The weight of the bogie with the addition of the simulated floor pan, the mountable impact head, and accelerometers was approximately 2,400 lb (1,089 kg).

A pickup truck with a reverse-cable tow system was used to propel the bogie to a target impact speed of 25 mph (40 km/h). When the bogie approached the end of the guidance system, it was released from the tow cable, allowing it to be free rolling when it impacted the post. A remote-controlled braking system was installed on the bogie, allowing it to be brought safely to rest after the test.

Figure 24. Rigid-Frame Bogie with Simulated Floor Pan

2.3.2 Accelerometers

One environmental shock and vibration sensor/recorder system was mounted near the center of gravity of the bogie vehicle to measure the accelerations in the longitudinal, lateral, and vertical directions. However, only the longitudinal acceleration was processed and reported.

The SLICE-2 accelerometer unit was a modular data acquisition system manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. 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.

2.3.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the bogie vehicle before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the bogie 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.

2.3.4 Digital Photography

A combination of one AOS high-speed digital video camera and multiple GoPro digital video cameras were used to document each test. In test no. MWPFP-22, six GoPro digital video cameras were used, while five were used in test no. MWPFP-23. In test nos. MWPFP-24 through MWFPF-26, four GoPro video cameras were used. The AOS high-speed camera had a frame rate of 500 frames per second, and the GoPro video cameras had a frame rate of 120 or 240 frames per second. Two cameras - one AOS and one GoPro - were placed laterally away from the post, with a view perpendicular to the bogie's direction of travel. The remaining cameras were placed at various locations on and around the bogie - two cameras with view of the bogie's floor pan and the remainder placed with a view of the posts. A Nikon digital still camera was also used to document pre- and post-test conditions for all tests.

2.4 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 [8]. 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 retroreflective optic 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 is 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.

3 DYNAMIC COMPONENT TESTING RESULTS AND DISCUSSION

3.1 Results

A total of five dynamic component tests were conducted on modified versions of the MWP with the simulated vehicle floor pan bogie to evaluate floor pan tearing mitigation. These tests were conducted with two posts in series. The two posts were spaced such that the bogie vehicle would only be in contact with one post at a time. A summary of each bogie test, including sequential and post-test photographs, is provided in the following sections. The accelerometer data for each test was processed in order to obtain force vs. deflection and energy vs. deflection curves. Detailed accelerometer results for each test are provided in Appendix C.

3.1.1 Test No. MWPFP-22

Test no. MWPFP-22 was conducted on MWPs with ¾-in. (19-mm) diameter weakening holes in the weak-axis flanges at the groundline and a 6-in. (152-mm) long steel tube cap mounted at the top of the posts. The cap was fabricated from a 3½-in. x 2½-in. x $^{3}/_{16}$-in. (89-mm x 64-mm x 5-mm) ASTM A500 Grade B steel tube. A ½-in. (13-mm) diameter by 4-in. (102-mm) long SAE J429 Grade 5 bolt and an SAE J995 Grade 5 nut were used to connect the cap to the post. The bolt was located 5 in. (127 mm) down from the top of the cap and 3-5/8 in. (92 mm) down from the top of the post. The posts were installed in 18-in. (457-mm) diameter holes filled with MASH 2016 strong soil with a 0-degree orientation angle, thus creating an impact about the post's weak axis of bending. During test no. MWPFP-22, the bogie impacted the first post at a speed of 26.0 mph (41.8 km/h). The bogie impacted the second post at 0.222 seconds and caused similar deformation as observed in the first post. The bogie overrode both posts.

The posts were bent plastically near the ground line, and tearing was found in both posts, as shown in Figure 25. The tears initiated from the weakening holes on the impact side of the posts and extended into the webs and adjacent flanges. Contact marks were found on the top half of the posts and on the steel tube cap. The top corners of both posts left creasing on the bottom side of the simulated floor pan. Creasing was found in both the front and rear bays of the simulated floor pan, as shown in Figure 26. The cap used in test no. MWPFP-22 was not as tight of a fit as desired due to the use of a standard HSS tube size that was available. Consequently, extensive snagging of the cap on the underside of the bogie vehicle occurred during test no. MWPFP-22.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data. Additionally, the high-speed video was analyzed to determine the times when the bogie overrode each post, the posts contacted the simulated floor pan, and the posts lost contact with the bogie vehicle. Results from the data and video analysis are shown in Figure 27. The peak impact loads and absorbed energies were relatively constant between the two posts.

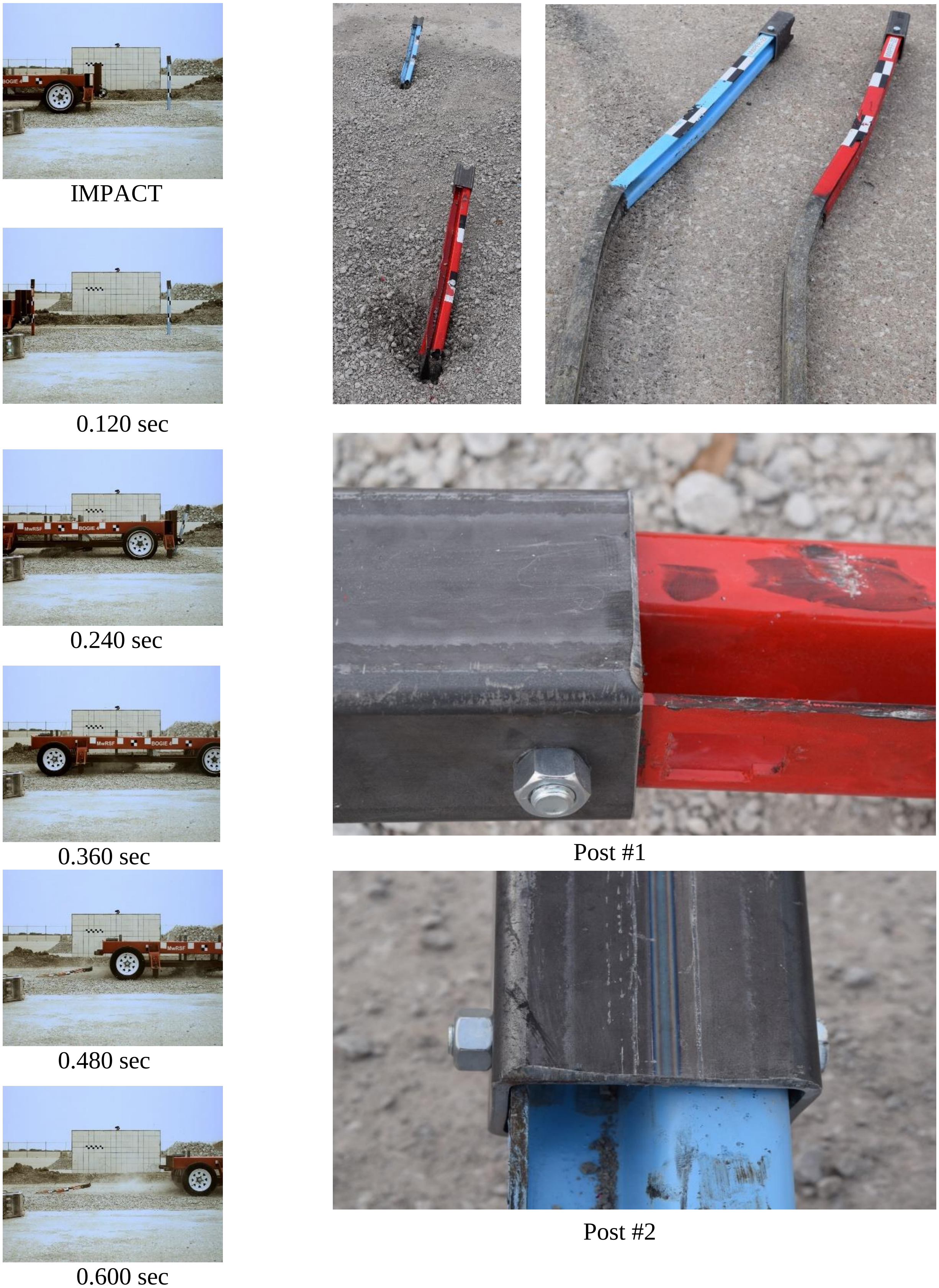
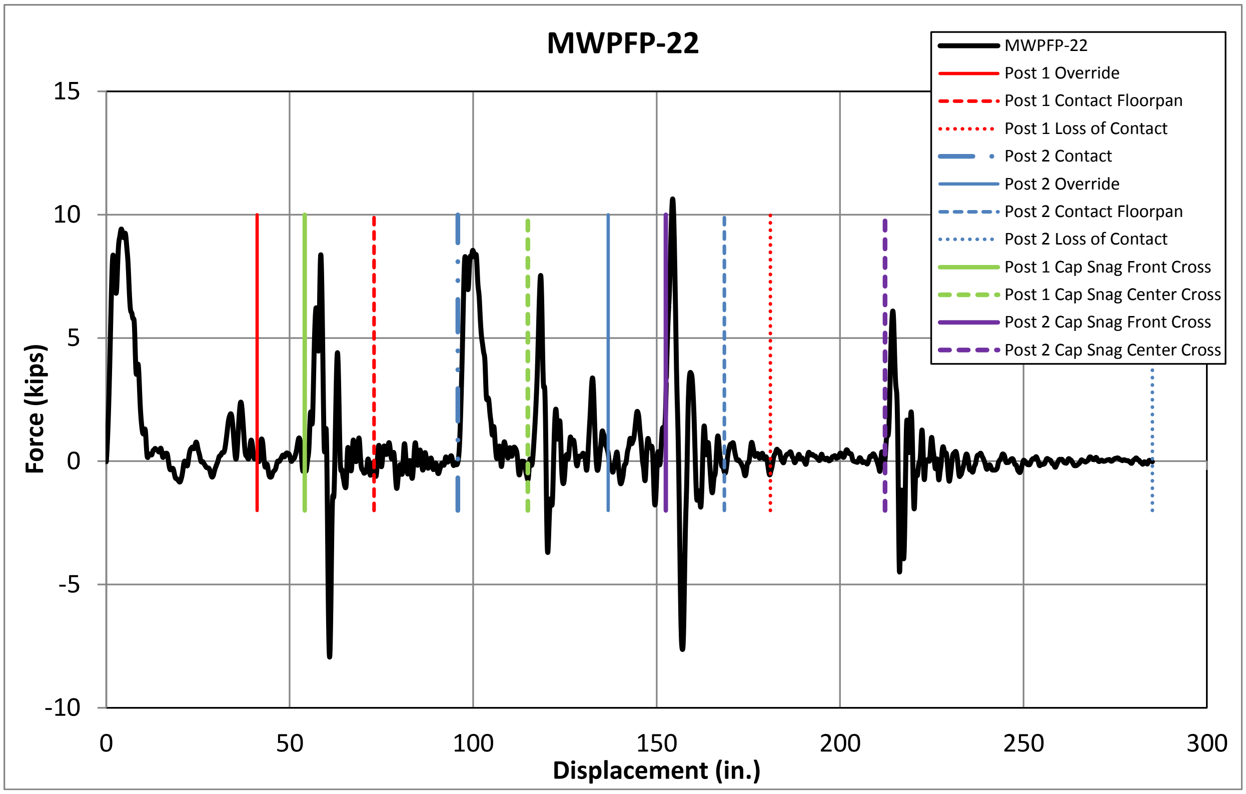
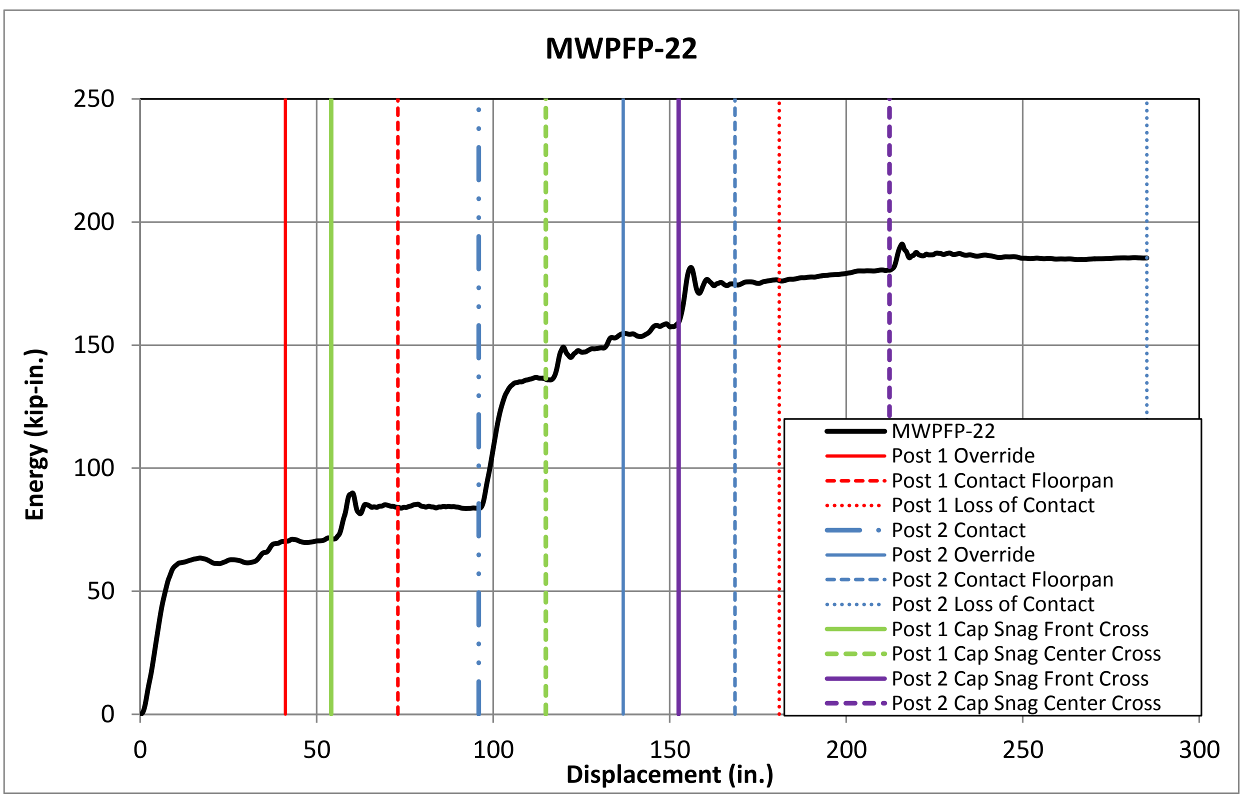


Figure 25. Time-Sequential and Post-Impact Photographs, Test No. MWPFP-22

Figure 26. Simulated Floor Pan Damage, Test No. MWPFP-22



(a)



(b)

Figure 27. (a) Force vs. Deflection and (b) Energy vs. Deflection, Test No. MWPFP-22

3.1.2 Test No. MWPFP-23

Test no. MWPFP-23 was conducted on MWPs with steel plate edge protectors mounted to the top of the posts to protect the floor pan from the free edges of the posts. Each plate was 2⅛-in. x 1⅜-in. x 7-gauge (54-mm x 35-mm x 5-mm) and fabricated by bending a hot-rolled ASTM A1011 HSLA Grade 50 steel plate. A ⅜-in. (10-mm) diameter by 4-in. (102-mm) long SAE J429 Grade 5 bolt and an SAE J995 Grade 5 nut were used to connect the caps to the post. The bolt was located 3 in. (76 mm) down from the top of the cap and 1⅝ in. (41 mm) down from the top of the post. The posts were installed in an 18-in. (457-mm) diameter hole filled with MASH 2016 strong soil with a 0-degree orientation angle, thus creating an impact about the post's weak axis of bending. During test no. MWPFP-23, the bogie impacted the first post at a speed of 25.9 mph (41.7 km/h). The bogie impacted the second post at 0.232 seconds and overrode both posts.

Sequential and post damage photographs are shown in Figure 28. The posts were bent plastically near the ground line, and the top corners of both posts left moderate creasing on the bottom of the simulated floor pan as well as tearing at the rear of the simulated floor pan. During test no. MWPFP-23, one side of the cap snagged on the underside of the bogie and the connection bolt sheared. After the cap disengaged and exposed the post edges, a tear formed in the simulated floorboard. The simulated floor pan damage is shown in Figure 29.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data. Additionally, the high-speed video was analyzed to determine the times when the bogie overrode each post, the posts contacted the simulated floor pan, and the posts lost contact with the bogie vehicle. Results from the data and video analysis are shown in Figure 30. The peak impact loads and absorbed energies were relatively constant between the two posts.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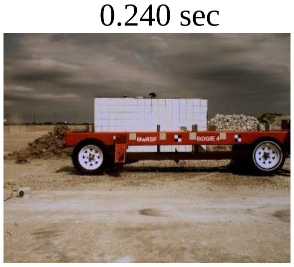
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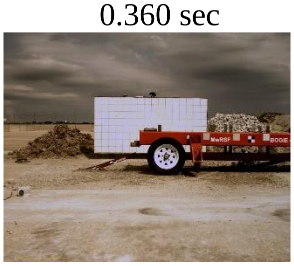
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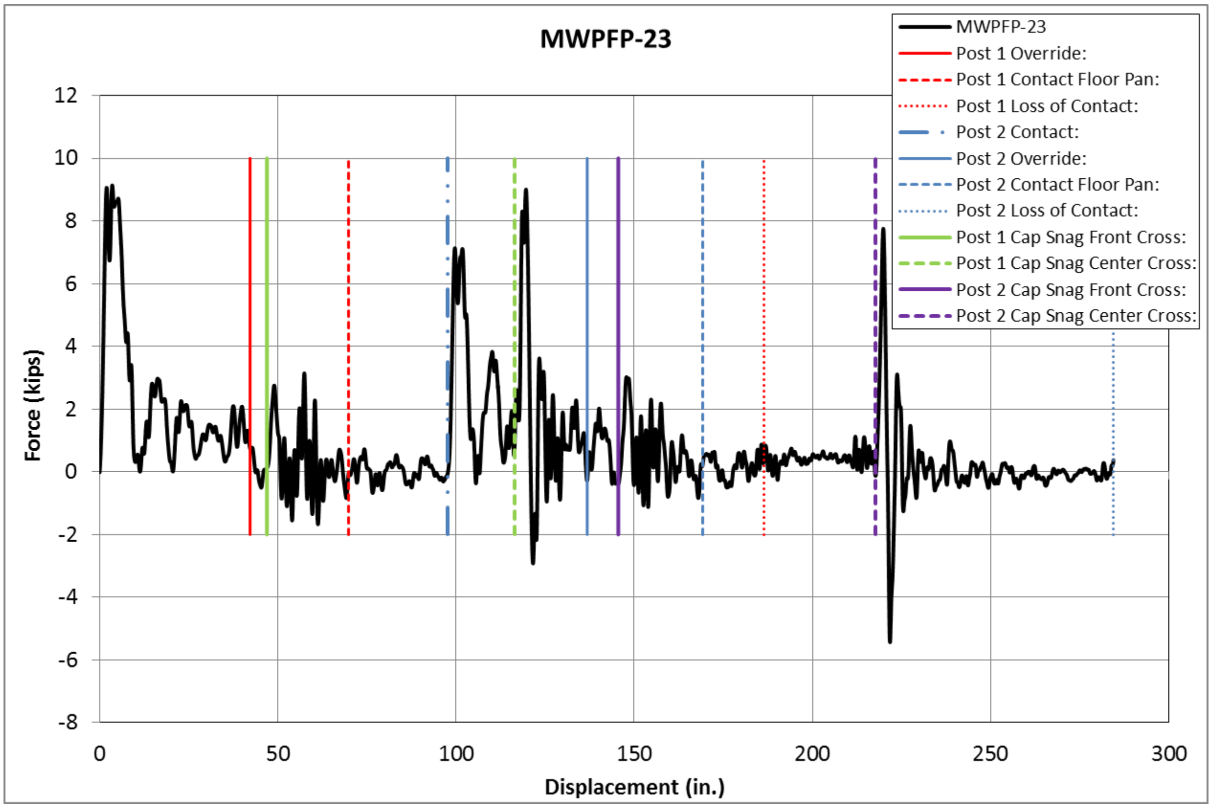
Post #1

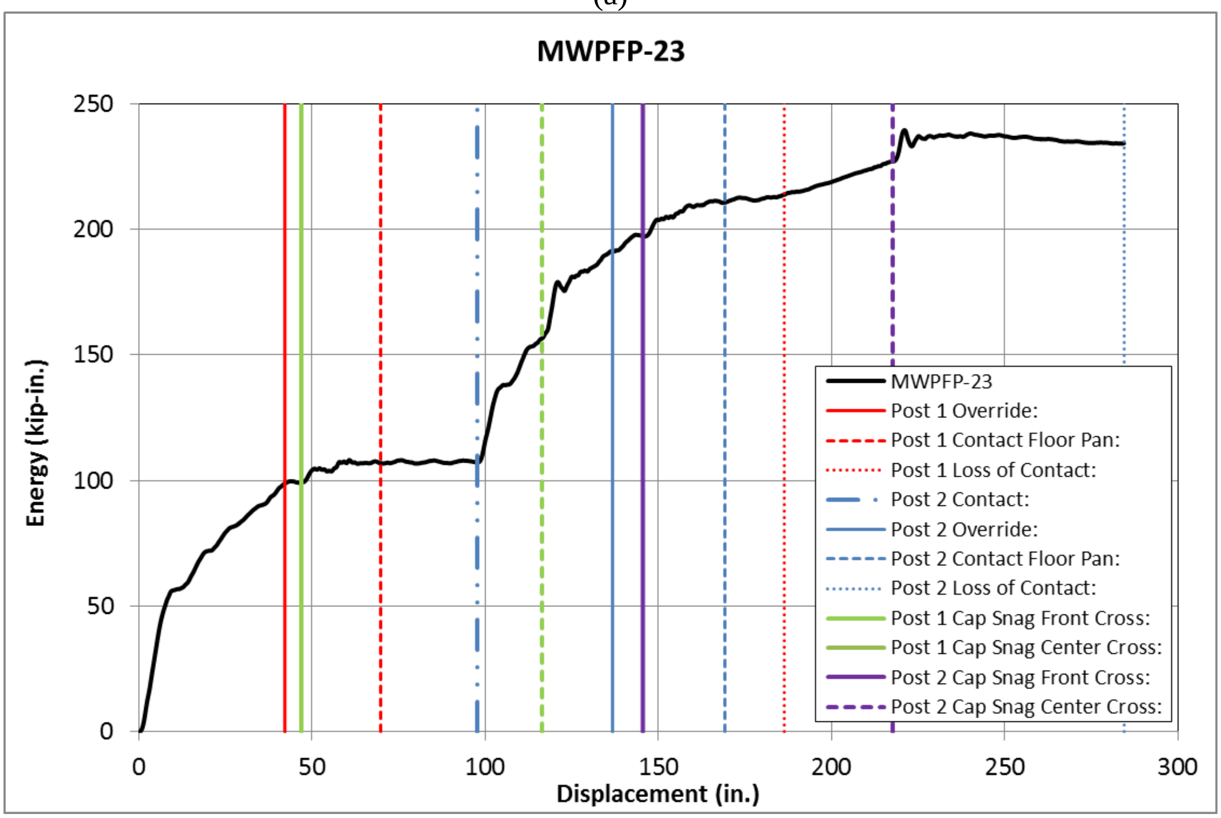

Post #2

Figure 28. Time-Sequential and Post-Impact Photographs, Test No. MWPFP-23

Figure 29. Simulated Floor Pan Damage, Test No. MWPFP-23



(a)



(b)

Figure 30. (a) Force vs. Deflection and (b) Energy vs. Deflection, Test No. MWPFP-23

3.1.3 Test No. MWPFP-24

Test no. MWPFP-24 was conducted on MWPs with steel plate edge protectors mounted to the top of the posts. Upon review of the test results, it was believed that placing the hole in the center of the cap allowed it to rotate slightly, causing a gap to form at the bottom of the cap which allowed the snagging. Therefore, shifting the hole for the connection bolt down would help eliminate the rotation of the cap. Each plate was 2⅛-in. x 1⅜-in. x 7-gauge (54-mm x 35-mm x 5-mm) and fabricated by bending a hot-rolled ASTM A1011 HSLA Grade 50 steel plate. A ⅜-in. (10-mm) diameter by 4-in. (102-mm) long SAE J429 Grade 5 bolt and an SAE J995 Grade 5 nut were used to connect the caps to the post. The bolt was located 4 in. (102 mm) down from the top of the cap and 2⅝ in. (67 mm) down from the top of the post.

The posts were installed in 8-in. (203-mm) diameter holes cored into the tarmac. The holes were then backfilled with the MASH strong soil. The posts were embedded with a 0-degree orientation angle, thus creating an impact about the post’s weak axis of bending. During test no. MWPFP-24, the bogie impacted the first MWP at a speed of 27.2 mph (43.8 km/h). The bogie then impacted the second post at 0.214 seconds. The bogie overrode both posts.

Sequential and post damage photographs are shown in Figure 31. The posts were bent plastically near the ground line, and the top corners of both posts left minor creasing on the bottom of the simulated floor pan, as shown in Figure 32. During the test, the edge protector retainer bolt for post no. 2 sheared upon impact with the second floor pan’s horizontal member, which allowed both edge protectors to disengage. This disengagement allowed the posts’ free edges to impact the bogie floor pan, but did not cause tearing.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data. Additionally, the high-speed video was analyzed to determine the times when the bogie overrode each post, the posts contacted the simulated floor pan, and the posts lost contact with the bogie vehicle. Results from the data and video analysis are shown in Figure 33. The recorded loads were lower for the bogie impact with the second post. This finding was likely due to a combination of a reduced impact velocity and a higher impact point on the second post. The reduced impact velocity resulted from the energy absorbed by the impact with the first post, while the higher impact point was caused by the bogie pitching upward as it overrode the first post.

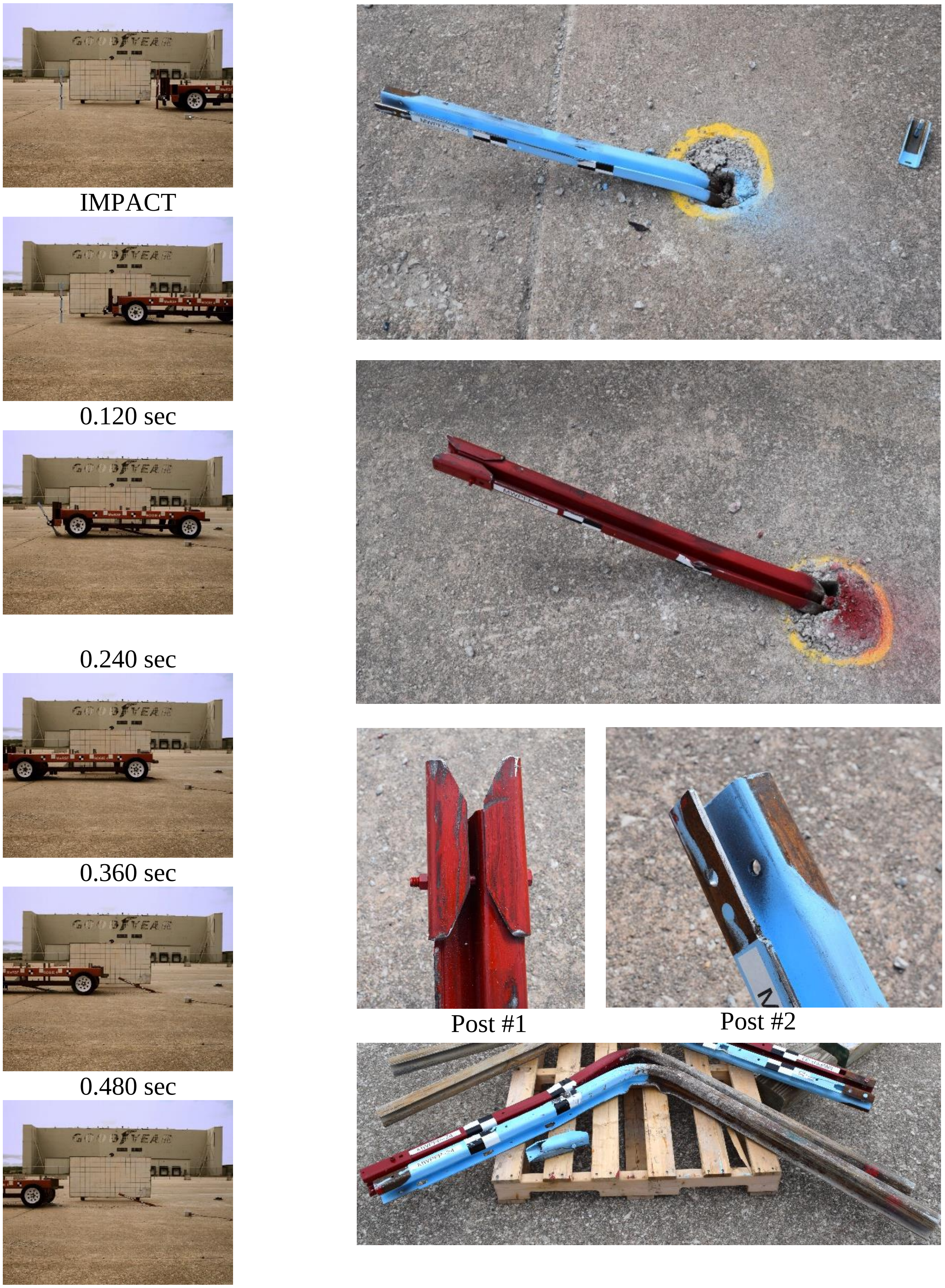
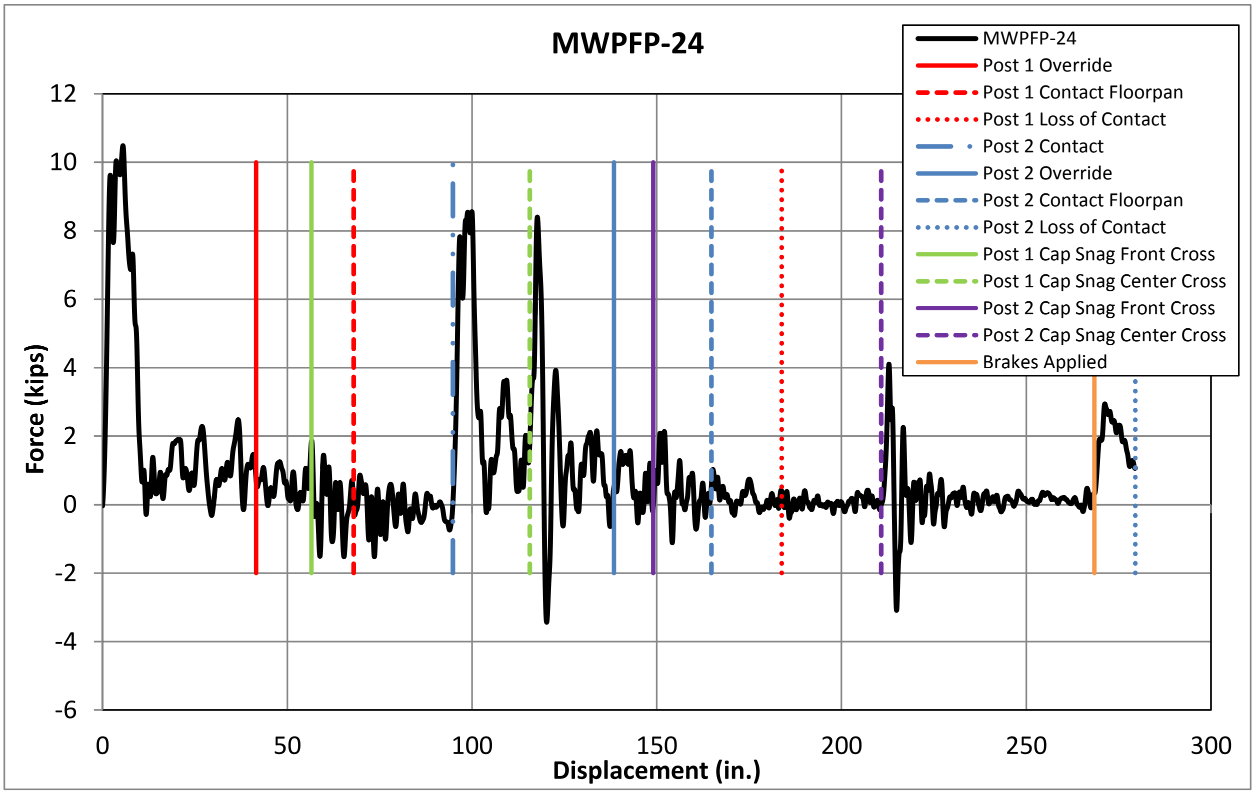
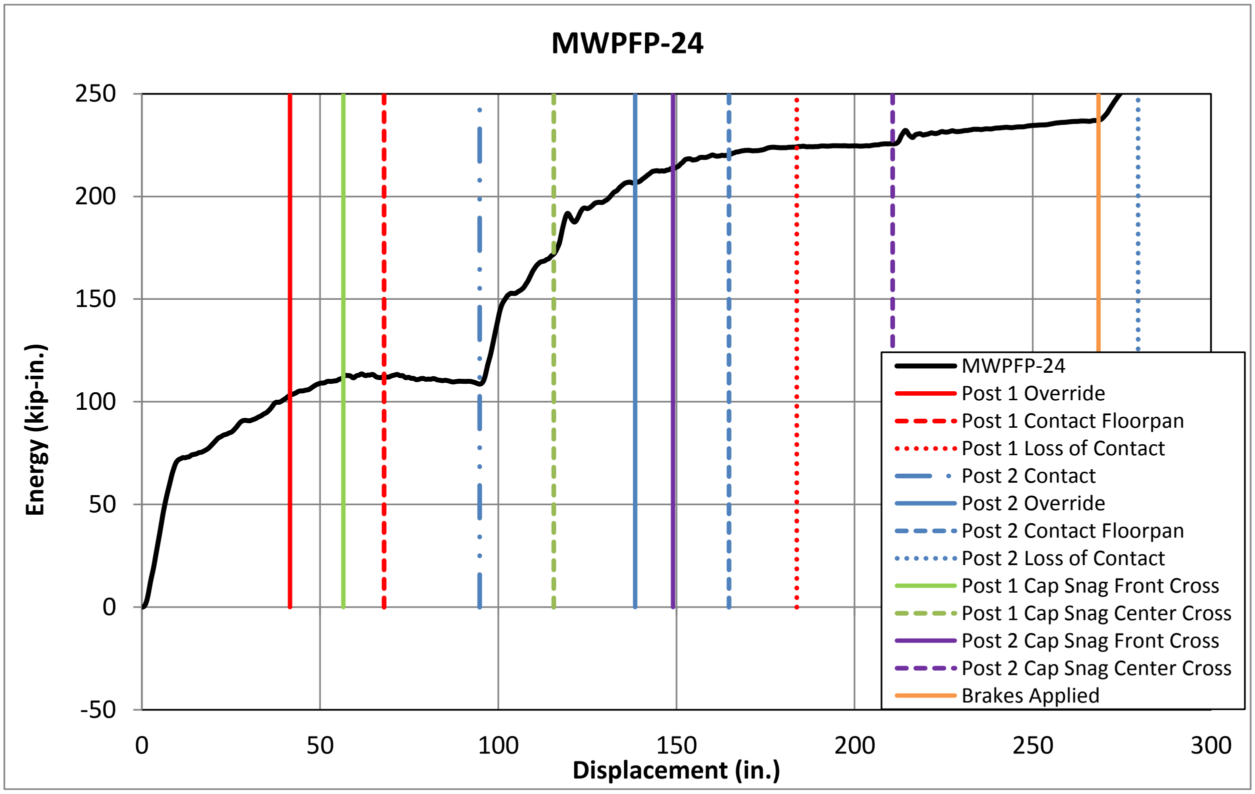


Figure 31. Time-Sequential and Post-Impact Photographs, Test No. MWPFP-24

Figure 32. Simulated Floor Pan Damage, Test No. MWPFP-24



(a)



(b)

Figure 33. (a) Force vs. Deflection and (b) Energy vs. Deflection, Test No. MWPFP-24

3.1.4 Test No. MWPFP-25

Test no. MWPFP-25 was conducted on MWPs with ¾-in. (19-mm) diameter weakening holes in the weak-axis flanges at the groundline and steel plate edge protectors mounted at the top of the posts. Similar to test no. MWPFP-24, the edge protector connection bolt was located 4 in. (102 mm) down from the top of the cap and 2⅝ in. (67 mm) down from the top of the post. The posts were installed in 8-in. (203-mm) diameter rigid sleeves that were backfilled with MASH 2016 strong soil. The posts were embedded with a 0-degree orientation angle, thus creating an impact about the post's weak axis of bending. During test no. MWPFP-25, the bogie impacted the first MWP at a speed of 27.4 mph (44.1 km/h). The bogie then impacted the second post at 0.210 seconds. The bogie overrode both posts.

Sequential and post damage photographs are shown in Figure 34. The posts were bent plastically near the groundline, and tearing was found in both posts. The tears initiated from the weakening holes on the impact side of the posts and extended into the webs and adjacent flanges. The tears initiated from the weakening holes on the impact side of the posts and extended into the webs and adjacent flanges. Contact marks were found on the top half of the posts and on the edge protectors. Minor creasing was found in both the front and rear bays of the simulated floor pan, as shown in Figure 35. In test no. MWPFP-25, minor snagging of the cap occurred on the underside of the bogie vehicle. Moreover, in reviewing the hardware after the test, the connection bolt had bent slightly.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data. Additionally, the high-speed video was analyzed to determine the times when the bogie overrode each post, the posts contacted the simulated floor pan, and the posts lost contact with the bogie vehicle. Results from the data and video analysis are shown in Figure 36. The peak impact loads and absorbed energies were relatively constant between the two posts.

IMPACT

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Post #1

Post #2

Figure 34. Time-Sequential and Post-Impact Photographs, Test No. MWPFP-25

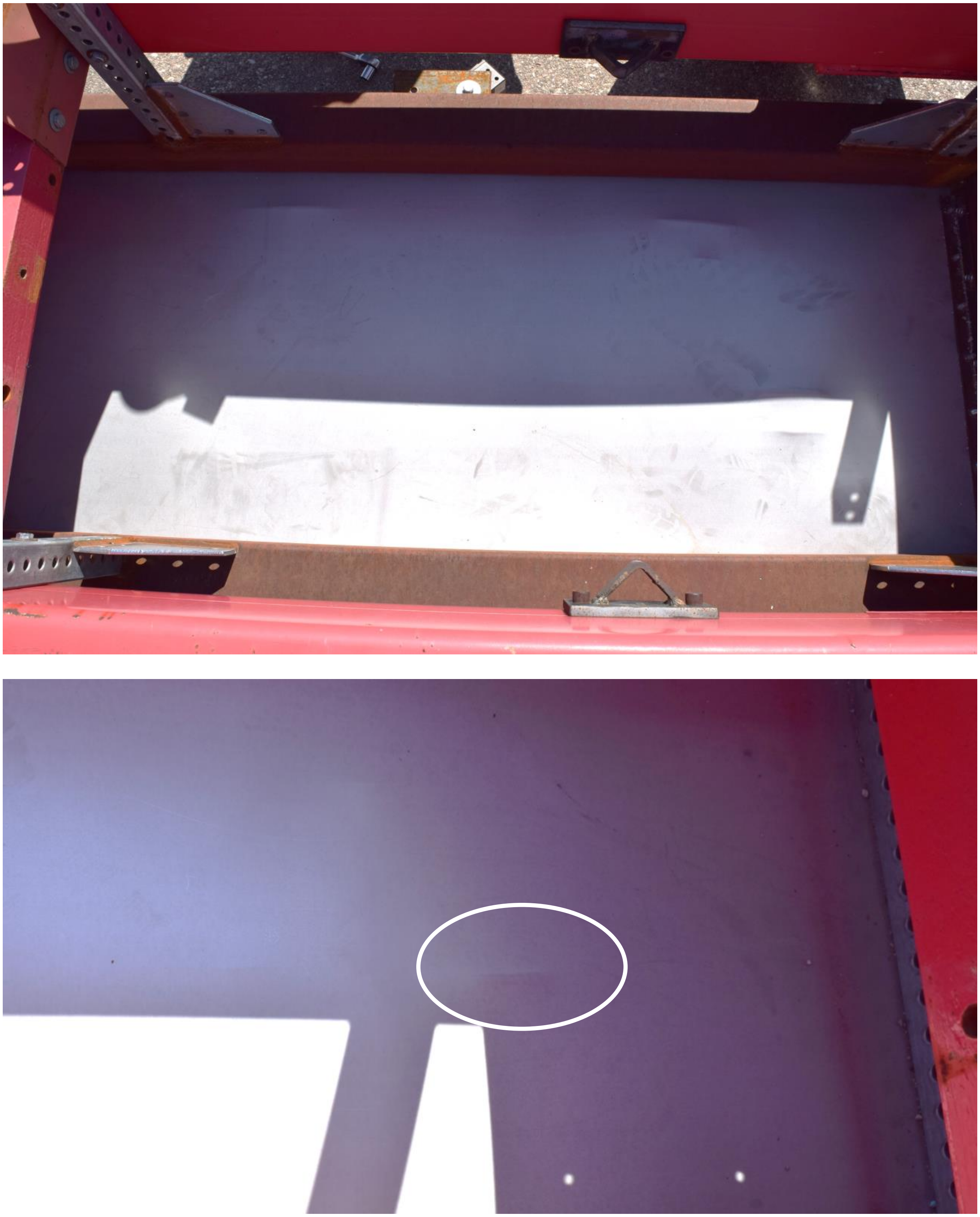
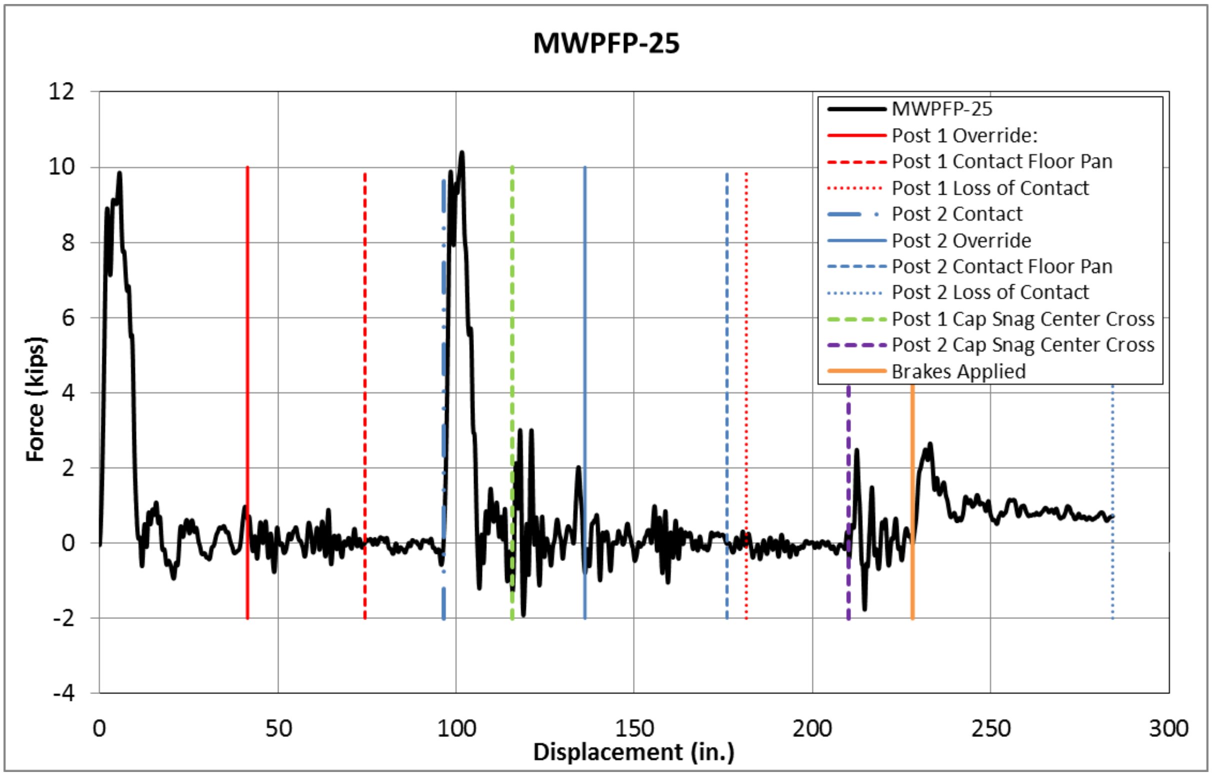
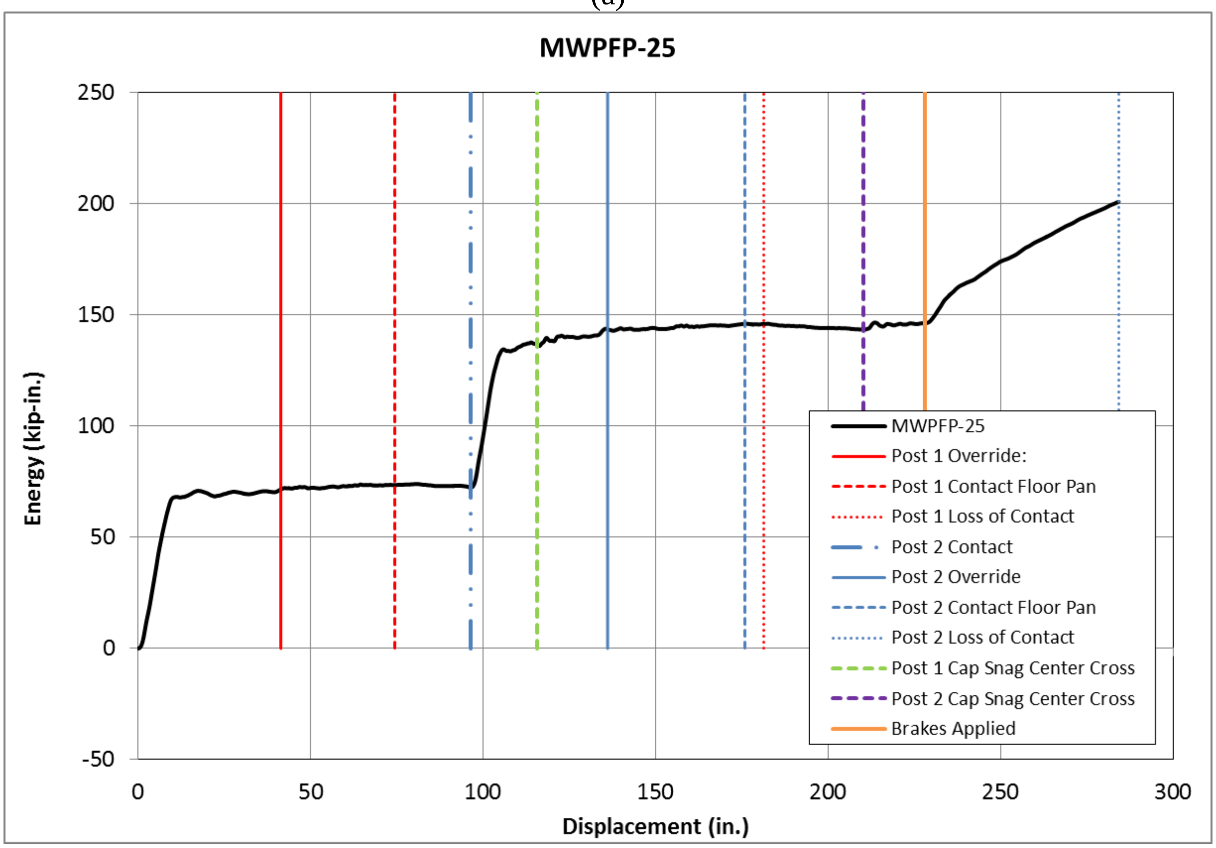


Figure 35. Simulated Floor Pan Damage, Test No. MWPFP-25



(a)



(b)

Figure 36. Force vs. Deflection and Energy vs. Deflection, Test No. MWPFP-25

3.1.5 Test No. MWPFP-26

The test setup for test no. MWPFP-26 was identical to test no. MWPFP-25 apart from the impact orientation, which was targeted at -25 degrees for test no. MWPFP-26. Since bolt bending was seen in test no. MWPFP-25, the size of the edge protector connection bolt was increased in test no. MWPFP-26. Consequently, the bolt size was increased to a ½-in. (13-mm) diameter by 4-in. (102-mm) long SAE J429 Grade 5 bolt and a SAE J995 Grade 5 nut.

The posts were installed in 8-in. (203-mm) diameter rigid sleeves, which were backfilled with MASH 2016 strong soil. The posts were embedded with a -25-degree orientation angle matching the impact angle in MASH 2016 if the cable barrier system were installed on the roadside as opposed to the median. During the test, the bogie impacted the first post at a speed of 26.7 mph (43.0 km/h). The bogie then impacted the second post at 0.212 seconds. The bogie overrode both posts.

Sequential and post damage photographs are shown in Figure 37. The posts were bent plastically near the groundline, and tearing was found in both posts. The tears initiated from the weakening holes on the impact side of the posts and extended into the webs and adjacent flanges. Contact marks were found on the top half of the posts and on the edge protectors. Minor creasing was found in both the front and rear bays of the simulated floor pan, as shown in Figure 38. In addition, snagging of the cap on the underside of the bogie vehicle was reduced and connection bolt bending was eliminated.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data. Additionally, the high-speed video was analyzed to determine the times when the bogie overrode each post, the posts contacted the simulated floor pan, and the posts lost contact with the bogie vehicle. Results from the data and video analysis are shown in Figure 39. The peak impact loads and absorbed energies were relatively constant between the two posts.

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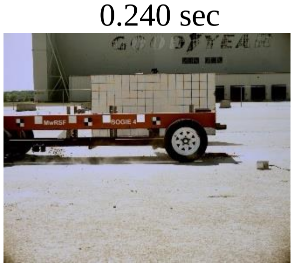

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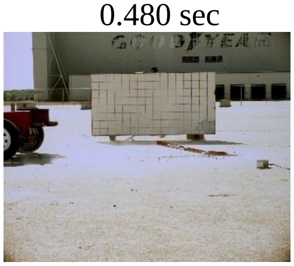

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Post #1

Post #2

Figure 37. Time-Sequential and Post-Impact Photographs, Test No. MWPFP-26

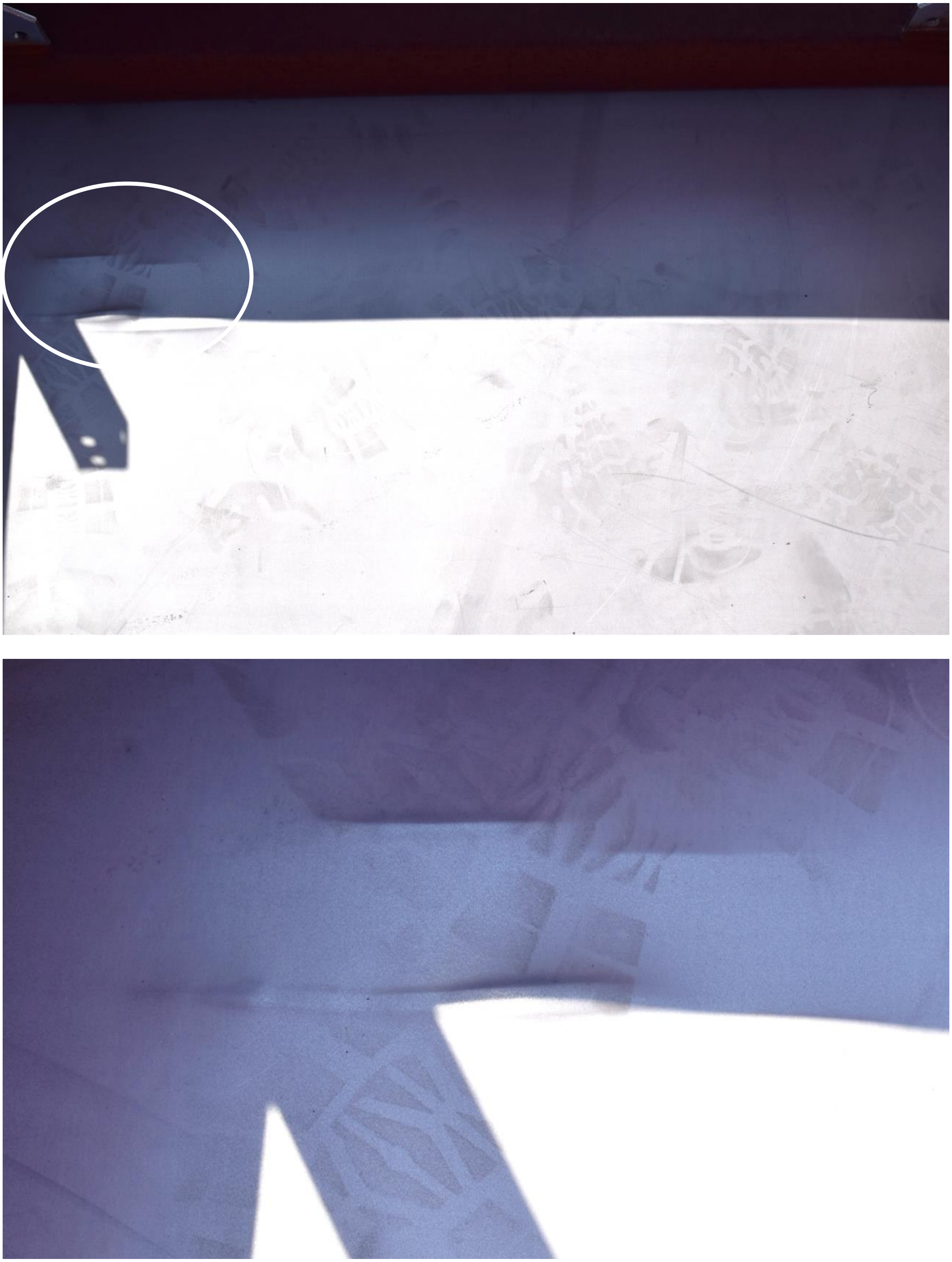
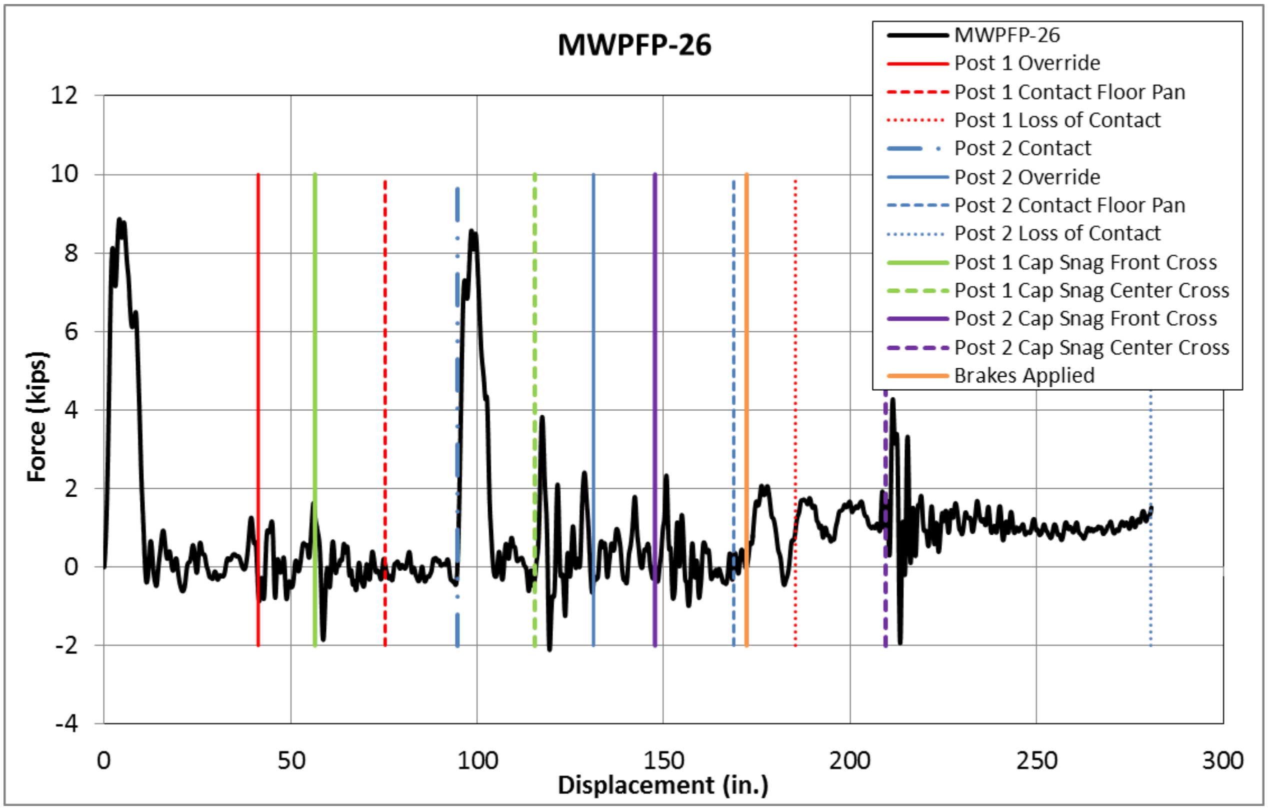
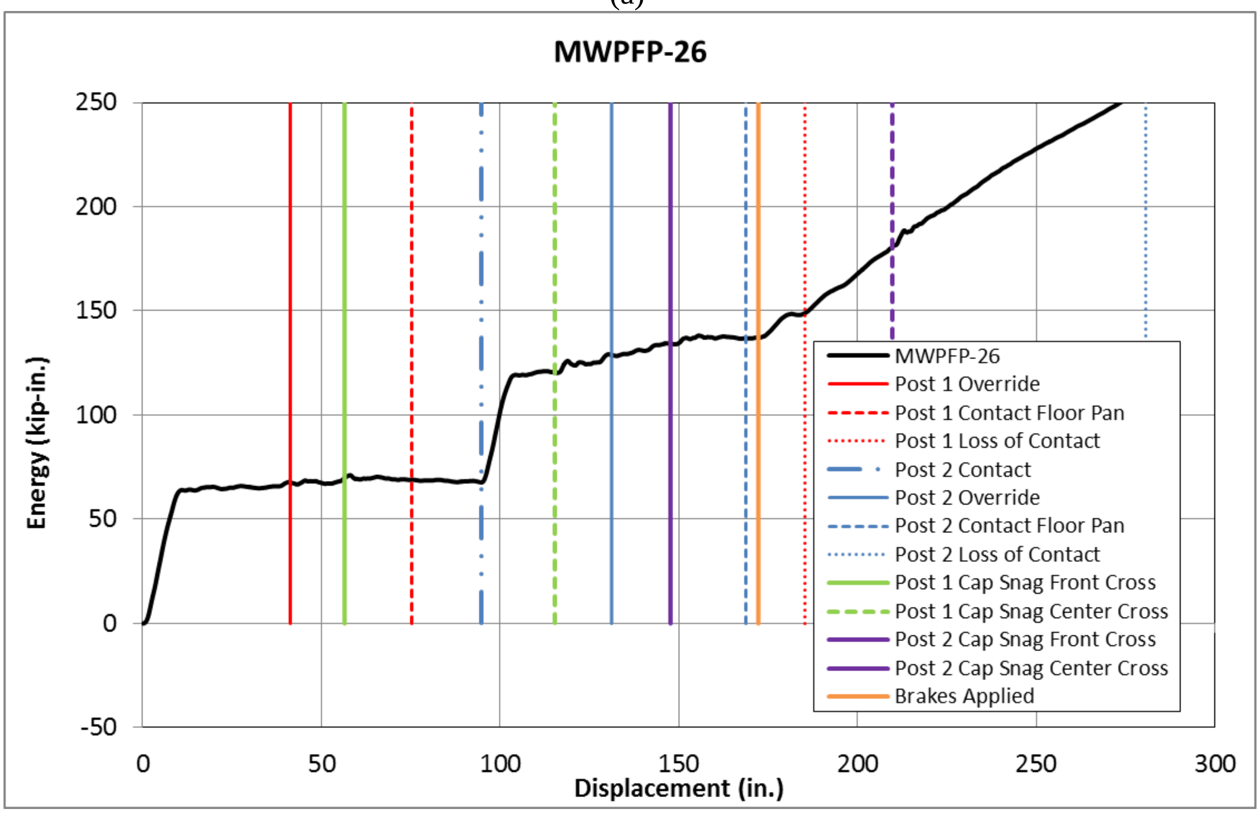


Figure 38. Simulated Floor Pan Damage, Test No. MWPFP-26



(a)



(b)

Figure 39. (a) Force vs. Deflection and (b) Energy vs. Deflection, Test No. MWPFP-26

3.2 Discussion

A total of five dynamic component tests utilizing a bogie vehicle with a simulated floor pan were conducted on modified configurations of the MWP. The tests were conducted to investigate methods to mitigate floor pan tearing observed during full-scale vehicle crash tests of a prototype, non-proprietary, high-tension cable median barrier. The results from the bogie testing matrix are summarized in Table 2. The bogie impact speed was relatively consistent throughout the testing matrix as the impact velocity varied between 25.9 and 27.4 mph (41.7 and 44.1 km/h).

The first test, test no. MWPFP-22, was conducted on MWPs weakened with ¾-in. (19-mm) diameter holes. The posts were oriented at 0 degrees with a 6-in. (152-mm) long, 3½-in. x 2½-in. x $^{3}/_{16}$-in. (89-mm x 64-mm x 5-mm) thick steel tube cap affixed to the top of the posts to prevent tearing of vehicle undercarriage. During test no. MWPFP-22, the floor pan damage consisted of creasing, and post damage consisted of bending and tearing.

Test nos. MWPFP-23 and MWPFP-24 were conducted on MWPs with steel plate edge protectors mounted to the top of the posts. In test no. MWPFP-23, the posts were installed in an 18-in. (457-mm) diameter hole filled with MASH 2016 strong soil with a 0-degree orientation angle. In test no. MWPFP-24, the posts were installed in an 8-in. (203-mm) diameter rigid sleeve with a 0-degree orientation angle. In both tests, the edge protector connection bolt sheared and allowed the posts' free edges to contact the simulated floor pan. However, the edge protector disengagement caused floor pan tearing in only one test, test no. MWPFP-23.

Test nos. MWPFP-25 and MWPFP-26 were conducted on MWPs with ¾-in. (19-mm) diameter weakening holes at the groundline and edge protectors affixed to the top of the posts. In test no. MWPFP-25, the posts were oriented at 0 degrees, whereas in test no. MWPFP-26, the posts were oriented at -25 degrees. In both tests, the posts bent and tore at the groundline, and contact marks were found on the edge protectors. During both tests, the simulated floor pan was creased from the contact with the edge protectors.

Dynamic component testing results illustrated that both edge protectors and groundline weakening holes in the MWP significantly decreased the propensity for floor pan tearing in the bogie vehicle. However, the cap used in test no. MWPFP-22 was not as tight of a fit as desired due to the use of a standard HSS tube size that was available. Consequently, extensive snagging of the cap on the underside of the bogie vehicle occurred during test no. MWPFP-22. In test nos. MWPFP-23 and MWPFP-24, the edge protector connection bolts sheared due to the bolt impacting the cross member of the bogie vehicle, which would not be expected in full-scale crash testing with the 1100C vehicle.

It is believed that the edge protectors consisting of two U-shaped bent plates bolted to the weakened MWP with a ½-in. (13-mm) diameter through bolt placed at 4 in. (102 mm) down from the top of the cap and 2⅝ in. (67 mm) down from the top of the weakened MWP could eliminate the floor pan tearing. It should be noted that a tube of similar shape could also reduce the propensity for floor pan tearing. Therefore, a combination of weakening holes and edge protectors using steel bent plates at top of the MWP was recommended for further evaluation through full-scale vehicle crash testing.

Table 2. Component Testing Summary, Floor Pan Tearing Evaluation, Test Nos. MWPFP-22 through MWPFP-26

Test	Modified Midwest Weak Post			Impact Conditions			Cap Damage	Post Damage	Floorboard Damage	
	Modifications to Post									
	Top Radius in. (mm)	Cap	Groundline Holes in. (mm)	Speed mph (km/h)	Height in. (mm)	Angle (deg.)			Front Bay	Rear Bay
MWPFP-22	⅝ (16)	Steel tube cap bolt 5 in. (127 mm) from top of cap Ø½ in. (13 mm) connection bolt	Ø¾ (19)	26.0 (41.9)	12 (305)	0	Snagging	Bending, tearing	4 short creases	2 short creases
MWPFP-23	⅝ (16)	U-plates ⅛ in. (3 mm) off post, bolt 3 in. (76 mm) from top of cap, Ø⅜ in. (10 mm) connection bolt	NA	25.9 (41.7)	12 (305)	0	U-plate removed by bolt shear, Contact marks	Bending	4 short creases 2 long creases	4 short creases 1 short tear 2 long creases
MWPFP-24	⅝ (16)	U-plates ⅛ in. (3 mm) off post, bolt 4 in. (102 mm) from top of cap, Ø⅜ in. (10 mm) connection bolt	NA	27.2 (43.7)	12 (305)	0	U-plate removed by bolt shear, Contact marks	Bending	3 short creases 3 long creases	4 short creases 3 long creases
MWPFP-25	⅝ (16)	U-plates ⅛ in. (3 mm) off post, bolt 4 in. (102 mm) from top of cap, Ø⅜ in. (10 mm) connection bolt	Ø¾ (19)	27.4 (44.1)	12 (305)	0	Contact marks	Bending, tearing	4 short creases	None
MWPFP-26	⅝ (16)	U-plates ⅛ in. (3 mm) off post, bolt 4 in. (102 mm) from top of cap, Ø½ in. (10 mm) connection bolt	Ø¾ (19)	26.7 (42.9)	12 (305)	-25	Contact marks	Bending, tearing	2 short creases	None

NA – Not Applicable

4 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this research study was to investigate design modifications, including post weakening mechanisms and edge protectors, as potential techniques to mitigate floor pan tearing and occupant compartment penetration for the prototype cable barrier system. The design modifications were evaluated through dynamic component testing using a bogie vehicle equipped with a simulated small car floor pan.

A total of five dynamic component tests were conducted on a series of two MWPs spaced 8 ft (2.4 m) apart and offset 4¼ in. (108 mm) from each other with a targeted impact speed of 25 mph (40 km/h). Testing of the MWPs weakened with ¾-in. (19-mm) diameter holes and a steel tube cap mounted at the top of the post resulted in minor creasing of the floor pan. The cap was not as tight of a fit as desired due to the use of a standard HSS tube size that was available. Consequently, extensive snagging of the cap on the underside of the bogie vehicle occurred.

Dynamic component testing was continued with two simulated floor pan tests on the MWP with steel plate edge protectors mounted to the top of the posts. In both tests, the edge protector connection bolts sheared due to the bolt impacting the cross member of the bogie vehicle. The disengagement of the edge protectors allowed the posts' free edges to contact the simulated floor pan in both tests. However, tearing of the floor pan and penetration into occupant compartment occurred in only one test, test no. MWPFP-23.

Another two dynamic component tests were conducted on the MWP with ¾-in. (19-mm) diameter weakening holes and steel plate edge protectors mounted to the top of the posts. Minor creasing was found in both the front and rear bays of the simulated floor pan for impact angles of both 0 and -25 degrees.

Dynamic component testing results illustrated that both edge protectors and groundline weakening holes in the MWP significantly decreased the propensity for floor pan tearing and occupant compartment penetration of the bogie vehicle. In two tests, the edge protectors disengaged due to the retainer bolts shearing after impacting the cross member of the bogie vehicle with simulated floor pan. This phenomenon would not be expected in full-scale crash testing with the 1100C vehicle. Therefore, it was recommended that the MWP be modified with a combination of groundline weakening holes and top of post edge protectors to prevent floor pan tearing during future testing and development of the prototype cable median barrier system.

5 REFERENCES

1. *Manual for Assessing Safety Hardware, Second Edition*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2016.

2. Bielenberg, R.W., Schmidt, T.L., Faller, R.K., Rosenbaugh, S.K., Lechtenberg, K.A., Reid, J.D., and Sicking, D.L., *Design of an Improved Post for use in a Non-Proprietary, High-Tension, Cable Median Barrier,* Research Report No. TRP-03-286-15, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, May 7, 2015.

3. *Manual for Assessing Safety Hardware*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2009.

4. Bielenberg, R.W., Rosenbaugh, S.K., Faller, R.K., Humphrey, B.M., Schmidt, T.L., Lechtenberg, K.A., and Reid, J.D., *MASH Test Nos. 3-17 and 3-11 on a Non-Proprietary Cable Median Barrier*, Research Report No. TRP-03-303-15, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, November 3, 2015.

5. Kohtz, J.E., Bielenberg, R.W., Rosenbaugh, S.K., Faller, R.K., Lechtenberg, K.A., and Reid, J.D., *MASH Test Nos. 3-11 and 3-10 on a Non-Proprietary Cable Median Barrier,* Research Report No. TRP-03-327-16, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, May 17, 2016.

6. Rosenbaugh, S.K., Hartwell, J.A., Bielenberg R.W., Faller, R.K., Holloway J.C., and Lechtenberg, K.A., *Evaluation of Floor pan Tearing and Cable Splices for Cable Barrier Systems*, Research Report No. TRP-03-324-15, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, May 16, 2017.

7. Hartwell, J.A., Lechtenberg, K.A., Rosenbaugh, S.K., Bielenberg, R.W., Faller, R.K., and Reid, J.D., *MASH Test No. 3-10 of a Non-Proprietary, High-Tension Cable Median Barrier for Use in 6H:1V V-Ditch*, Research Report No. TRP-03-331-16, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, May 10, 2017.

8. Society of Automotive Engineers (SAE), *Instrumentation for Impact Test – Part 1 – Electronic Instrumentation*, SAE J211/1 MAR95, New York City, NY, July, 2007.

6 APPENDICES

Appendix A. Bogie Floor Pan Drawings

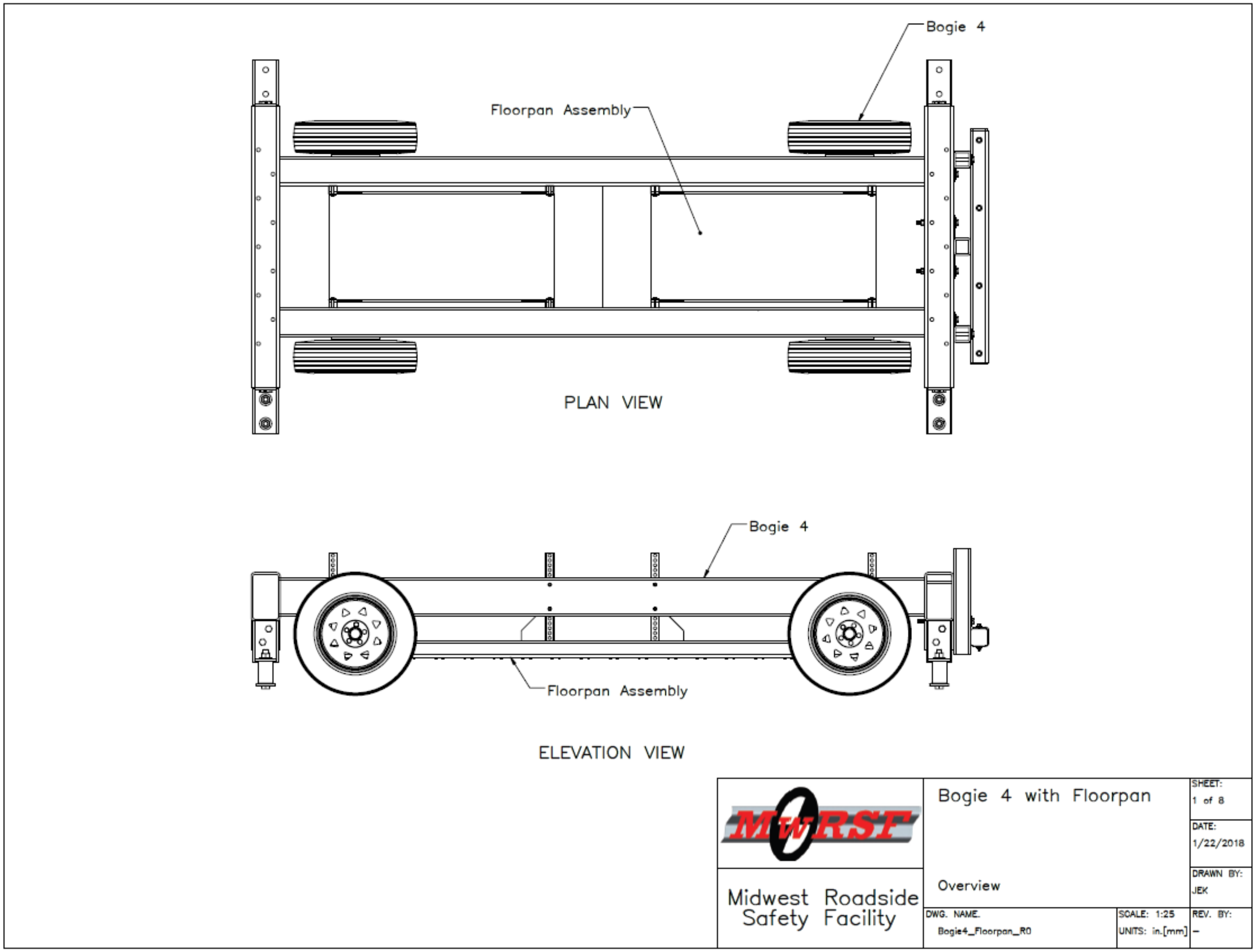


Figure A-1. Bogie with Floor Pan, Test Nos. MWPFP-22 through MWPFP-26

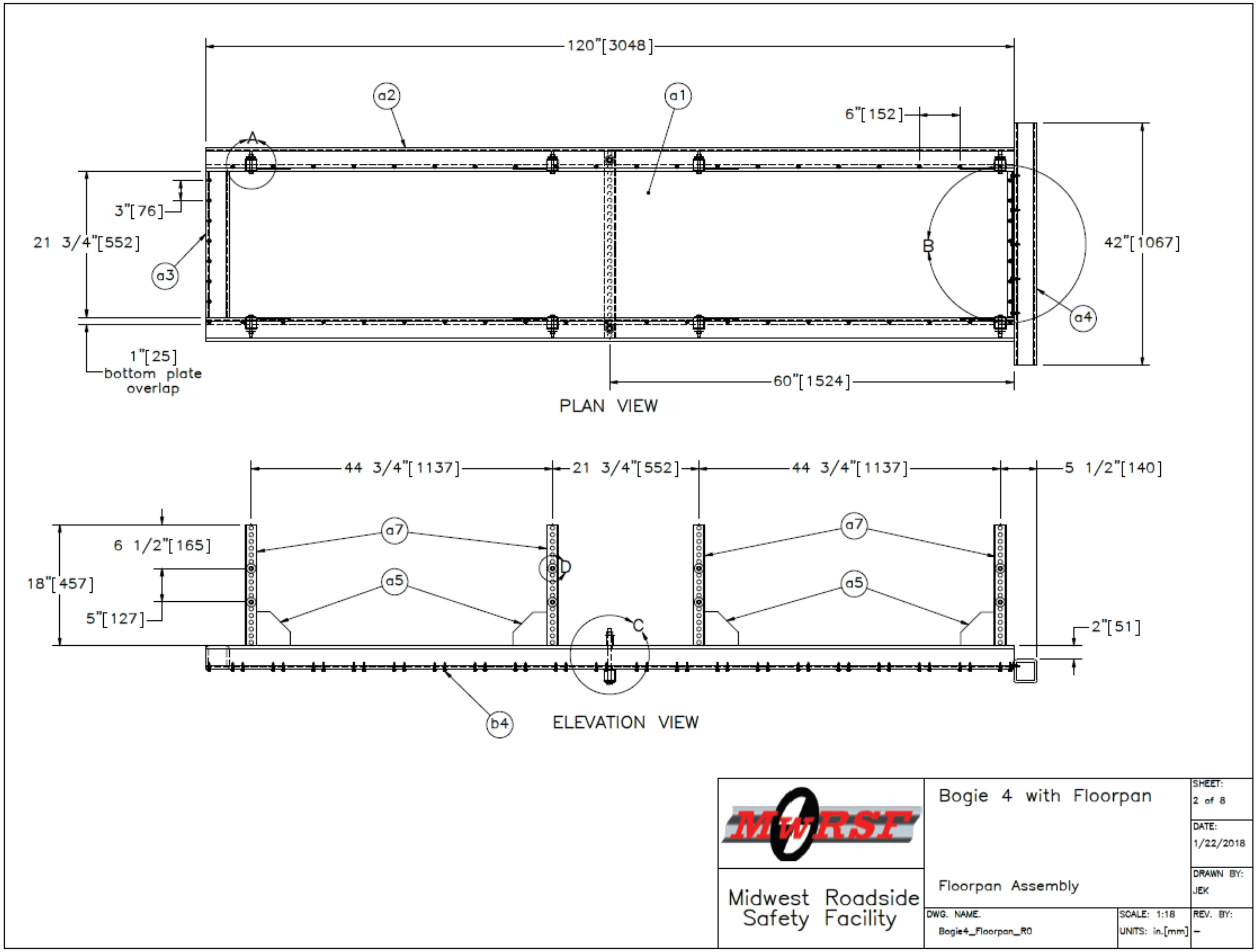


Figure A-2. Floor Pan Assembly, Test Nos. MWPFP-22 through MWPFP-26

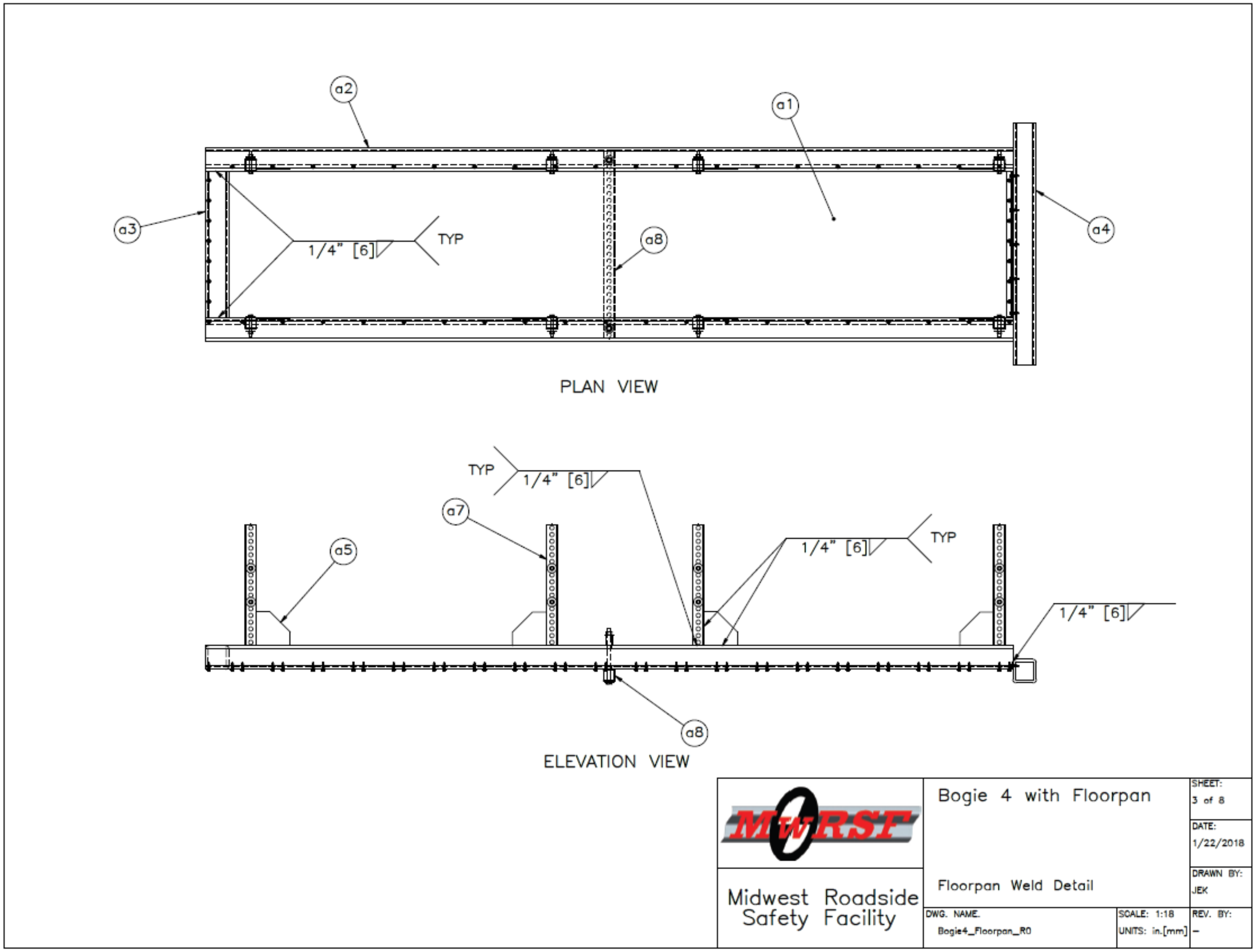


Figure A-3. Floor Pan Weld Detail, Test Nos. MWPFP-22 through MWPFP-26

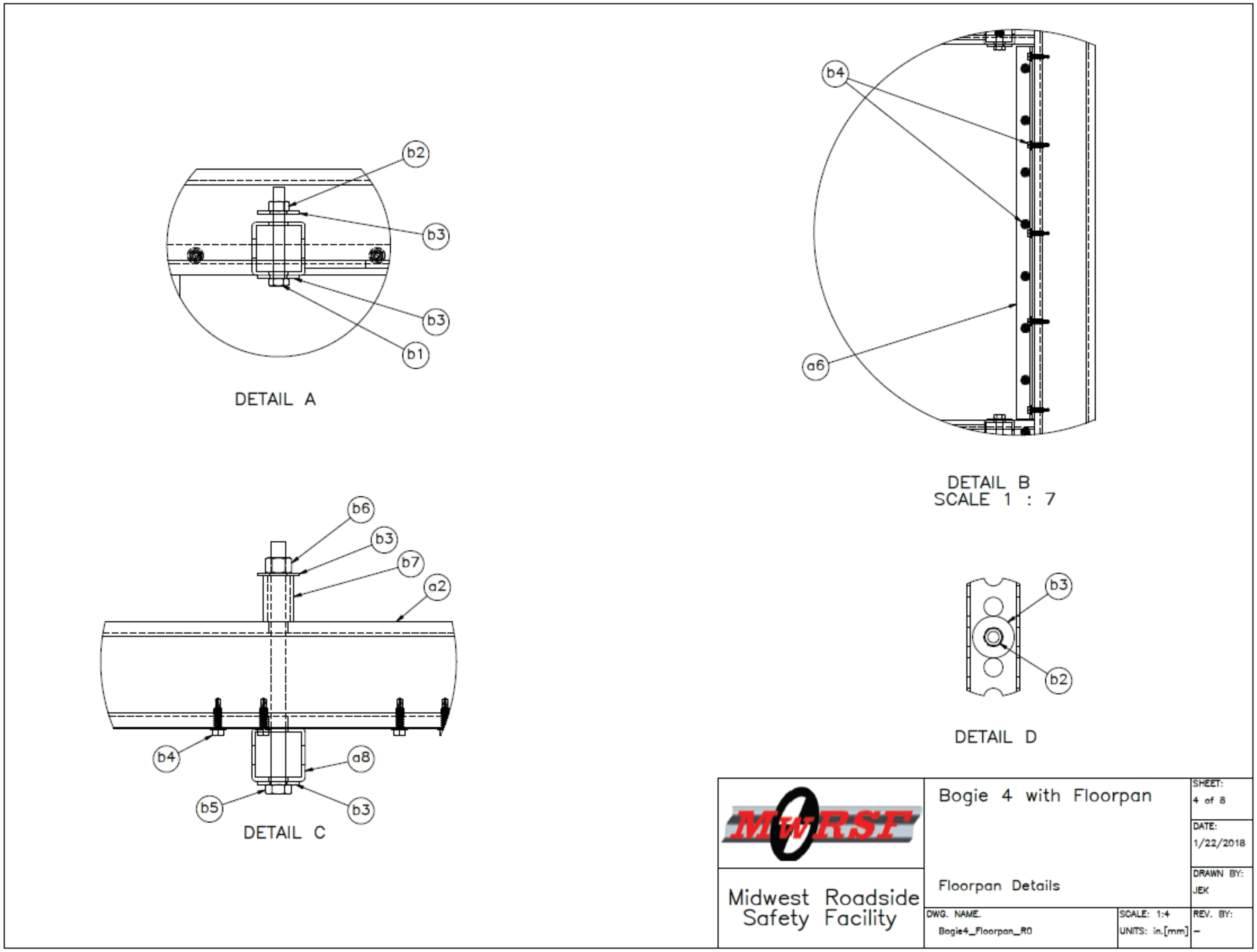


Figure A-4. Floor Pan Details, Test Nos. MWPFP-22 through MWPFP-26

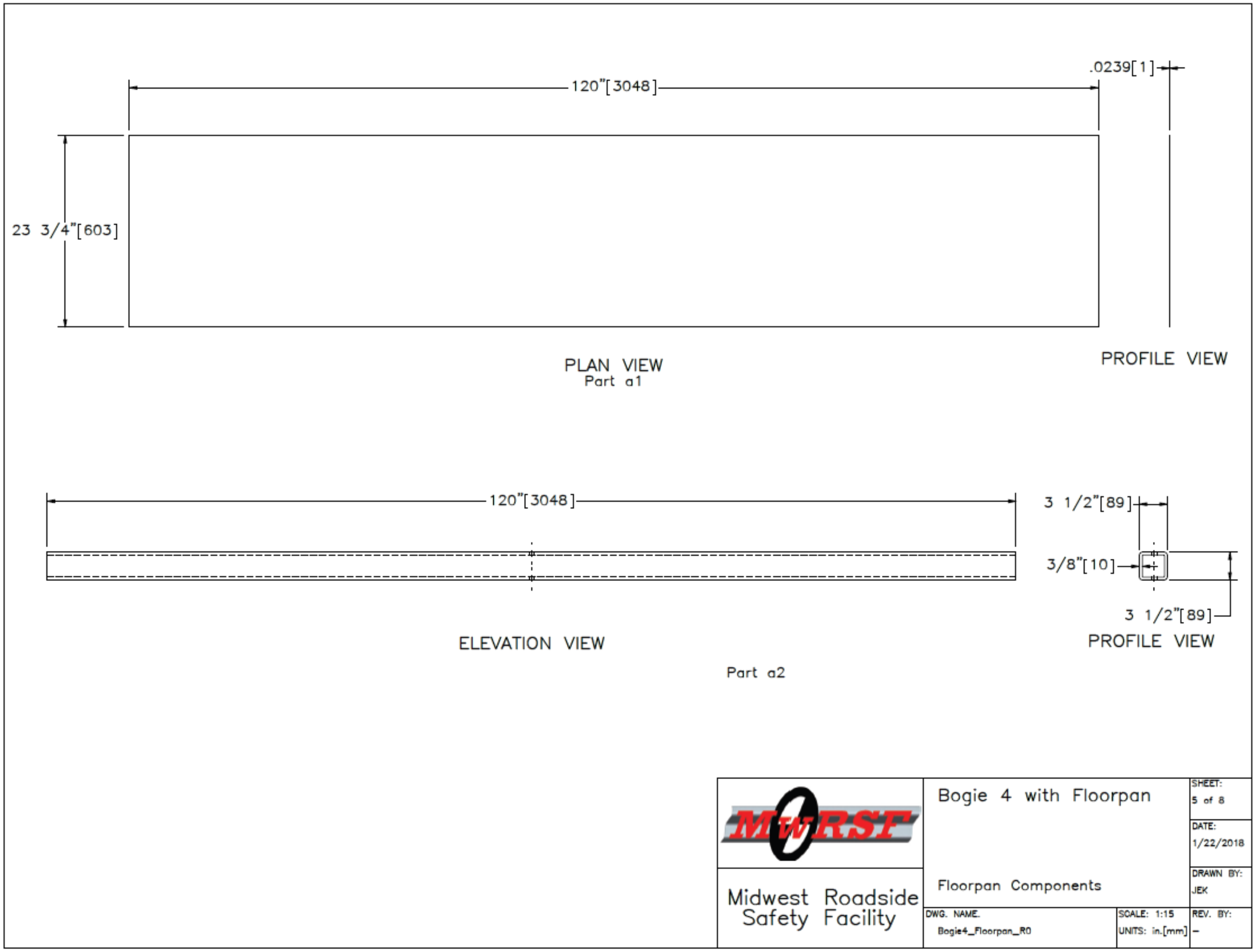


Figure A-5. Floor Pan Components, Test Nos. MWPFP-22 through MWPFP-26

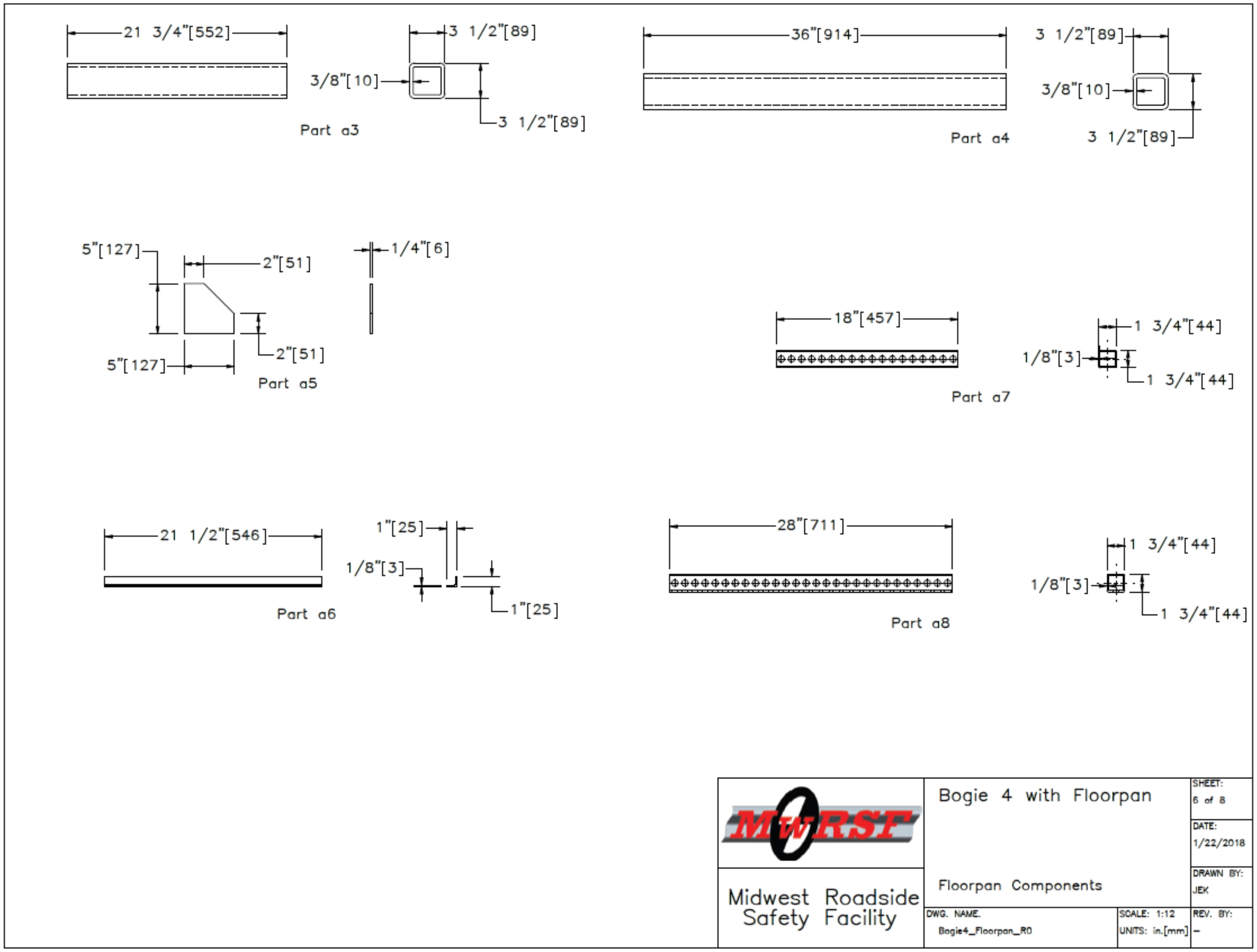


Figure A-6. Floor Pan Components, Test Nos. MWPFP-22 through MWPFP-26

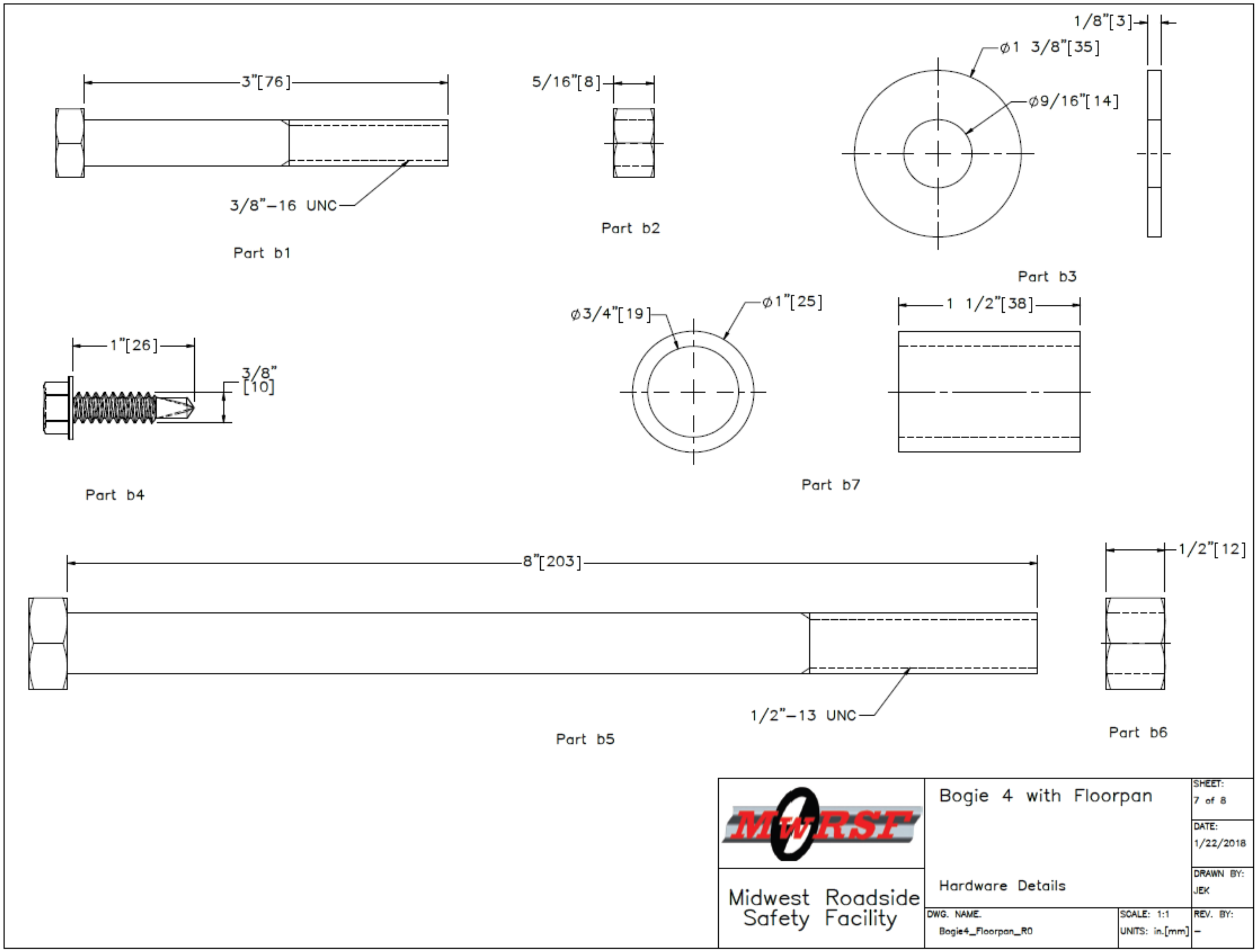


Figure A-7. Hardware Details, Test Nos. MWPFP-22 through MWPFP-26

Appendix B. Material Specifications

Table A-1. Bill of Materials, Test Nos. MWPFP-22 through MWPFP-26

Item No.	Description	Material Specification	References
a1	3"x1-3/4"x7 Gauge [76x44x4.6] x 80" [2032] Long Bent Z-Section Post	Hot-Rolled ASTM A1011 HSLA Gr. 50	H#438314
a2	3 1/2" [89] x 2 1/2" [64] x 3/16" [5] x 6" [152] Long Steel Tube	ASTM A500 Grade B	H#542296
a3	24-Gauge [0.6-mm] Sheet Steel	ASTM A653	H#2410835
a4	½-in. [13-mm] Hex Nuts	ASTM A563 DH	H#331508621
a5	½-in. [13-mm] Hex Bolts	ASTM A449 or ASTM A325	H#321505784

*** TEST REPORT ***

SHIPPER NO/MILL ORDER F122521 3628996

REPORT DATE: 10/20,2014 PAGE: 1 OF 1
INVOICE DATE: 10/20,2014 INV NO: F306083
CUST P.O. NO: 01015461
CUSTOMER CD: 62380-1040

COIL/LIFT IDS
OSP: 06025311
ARCELORMITTAL:

VEH. ID. UP /249146

ArcelorMittal

ArcelorMittal USA Inc.
Quality Department 2-104
3210 Watling Street
East Chicago, Indiana 46312

I certify that the test results shown are correct as contained in the records of ArcelorMittal Indiana Harbor and in compliance with the requirements of the order.

P. J. Hollingsworth

Peter J. Hollingsworth
Division Manager, Quality Assurance

SOLD TO: NORFOLK IRON & METAL CO
PO BOX 1129
NORFOLK NE 68702-1129

SHIP TO: NORFOLK IRON & METAL CO
THEIR SIDING
3003 N VICTORY RD - WEST PIT
NORFOLK NE 68702

SPECIFICATION:

ARCELORMITTAL / HOT ROLL BLACK STEEL / COILS / HSLAS-F 50 / INCLUSION SHAPE CONTROL / ASTM A1011-14 GR 50 / NON TEMPER ROLLED / MILL EDGE

ORDER DESCRIPTION: QTY (LBS) HEAT NO.
.1750 IN X 60.0000 IN COIL 1 65660 438314
COMMODITY: AGNCY:
PART # 27509 DESC: LASER CUT / PAINTED

TEST PARAMETER	AGENCY	BY	POS	DIR		UOM
YIELD STRENGTH	ASTM E8,A370	HT		L	60,400	psi
TENSILE STRENGTH	ASTM E8,A370	HT		L	71,100	psi
TOTAL ELONGATION	ASTM E8,A370	HT		L	29	%@2in
YIELD STRENGTH	ASTM E8,A370	HT		L	57,700	psi
TENSILE STRENGTH	ASTM E8,A370	HT		L	69,100	psi
TOTAL ELONGATION	ASTM E8,A370	HT		L	30	%@2in

R#16-0104 MWP Posts

Orange Paint

September 2015

HEAT (wt.%)	C	MN	P	S	SI	CU	NI	MO	CR	CB	V	AL	SN
438314	.06	.93	.013	.003	.01	.02	.01	.01	.04	.025	.002	.03	.01
	TI	N	B										
	.014	.0050	.0001										

MELTED AND MANUFACTURED IN USA

ilac-MRA A2LA ACCREDITED
Testing Certs 0111.01, 0111.02 and 2333.01

ArcelorMittal Indiana Harbor has an A2LA accredited testing laboratory in the fields of chemical testing (certificate 0111-01) and mechanical testing (certificate 0111-02). Charpy impact testing may be performed by ArcelorMittal Burns Harbor's A2LA accredited testing laboratory (certificate 2333.01) per ASTM E23. All tests were performed by ArcelorMittal Indiana Harbor laboratories, unless otherwise specified in accordance with the following: chemical analysis per ASTM E415 and E1019. All tests performed to the current version of the standard, unless otherwise noted. These results relate only to the items from the heat or coil tested. Test certificates are prepared in accordance with procedures outlined in DIN EN 10204;2005 Type 3.1. Test results marked with: - an asterisk (*) were reported by an external accredited laboratory - an (@) were reported by a non-accredited laboratory. Uncertainties of measurements were estimated and are available when requested. The management systems for manufacture of this product were certified to ISO 9001 (Certificate 40715), ISO/TS 16949 (Certificates 38325 and 41440) and ISO 14001 (Certificates 36274 and 42270).

This report shall not be reproduced except in full.

FORM THP1 REC. 10/2011

Figure B-1. Midwest Weak Posts, Test Nos. MWPFP-22 through MWPFP-26

NORFOLK IRON & METAL CO.

02/25/2016
M.T.R. Cover Sheet

NORFOLK IRON NORFOLK
3001 N VICTORY RD
NORFOLK, NE 68702

RIVERS METAL PRODUCTS
3100 N 38TH ST
LINCOLN, NE 68504

Sales Order 01107115
Customer PO: 42962

Certifications For The Material You Ordered Are Listed Below
Thank You For Your Business

Heat	Item	Item Description	Width	Length
542296	05495	TUBE 3-1/2x 2-1/2x 3/16 A500B	.0000	240.0000

R#16-409 3-1/2x2-1/2x3/16" ASTM A500
H#542296 4Cable Floor Pan Tube Cap Bogie Testing
March 2016 SMT

23Nov15 12:17 T E S T C E R T I F I C A T E No: CHI 365414

INDEPENDENCE TUBE CORPORATION
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 01018894
Rel
S/O No CHI 251816-003
B/L No CHI 149366-005 Shp 24Nov15
Inv No Inv

Sold To: (1403)
NORFOLK IRON & METAL
P.O. BOX 1129
NORFOLK, NE 68701

Ship To: (1)
NORFOLK IRON & METAL
3001 NORTH VICTORY RD
NORFOLK, NE 68702

Tel: 402-371-1810 Fax: 402 379-5409

CERTIFICATE of ANALYSIS and TESTS Cert. No: CHI 365414
20Nov15

Part No 05495
TUBING A500 GRADE B(C)
3-1/2" X 2-1/2" X 3/16" X 20'

Pcs 25 Wgt 3,435

Heat Number 542296
Tag No 808759
YLD=65073/TEN=78006/ELG=33.85
Pcs 25 Wgt 3,435

Heat Number 542296
*** Chemical Analysis ***
C=0.2032 Mn=0.7920 P=0.0110 S=0.0051 Si=0.0160 Al=0.0360
Cu=0.0150 Cr=0.0340 Mo=0.0020 V=0.0010 Ni=0.0120 Nb=0.0010
N=0.0038 B=0.0001 Ti=0.0010
MELTED AND MANUFACTURED IN THE USA

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.

CURRENT STANDARDS:
................................A500/A500M-13
................................A513-12
................................A252-10
................................A847/A847M-12

MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH
ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

Figure B-2. 3½-in. x 2½-in. x $^{3}/_{16}$-in. (89-mm x 64-mm x 5-mm) Tube, Test Nos. MWPFP-22 through MWPFP-26

NUCOR

Berkeley Division of NUCOR Corporation
ISO/TS 16949 Registered

DELIVER TO: certs

phoenix metals

METALLURGICAL TEST REPORT
Nucor Steel - Berkeley
a division of NUCOR corporation

P.O. Box 2259
Mt. Pleasant, SC 29465

Phone: 843-336-6000
Sales Fax: 843-336-6150

Issuance Date 10/02/14 MTR# 1243953 MTR BER INQUIRIES@NUCOR.COM

Sold To: PHOENIX METALS COMPANY
PO BOX 805

NORCROSS, GA 30091

Ship To: PHOENIX METALS
12420 MEANS COURT
PO BOX 7849
CHARLOTTE, NC 28278

Ship date 10/02/14
Bill of Lading # 1096908
Vehicle # 51237

P/O # 0309281
Mill Order # 356338-1
Part # 5444 A60 023

Gauge x Width .0230 MIN X 48.0000 MIN A60
GALVANNEAL
ASTM A653 / CS TYPE B (LFQ) / 2013
Chemistry certification only

Total Wgt 44650.00 LB

Heat	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	V	Nb	N	Ti	B	Ca
2410835	.02	.16	.011	.003	.02	.08	.03	.03	.00	.005	.030	.003	.001	.005	.001	.003	.002

Coil(tag)/Heat-Bar : 149412.100 2410835-4 (22400.00 LB) 149412.200 2410835-4 (22250.00 LB)

Mill Test Reports according to EN10204 3.1

All material is sold subject to the description, specifications and terms and conditions set forth on the face and reverse side of Nucor Steel - Berkeley's sales order acknowledgment.

Tensile Testing, when applicable, is performed in accordance with ASTM A-370 specifications. Specimen is machined to standard rectangular test configuration (Figure 3 of ASTM A-370) with a 2" gage length. Yield Strength is determined at 0.2% offset.

This material has been produced in compliance with the chemistry and established rolling practices of the ordered specification. If material is ordered to a chemical composition only and if physical testing is not a requirement of the customer's order, testing is not performed by the producer.

We hereby certify the above information is correct as contained in the records of the corporation.

Ann Gillespie
Cold Mill Metallurgist

Robert Moses
Chief Metallurgist

** 100% MELTED AND MANUFACTURED IN THE USA *

R#16-410 Sheet Steel 24Gauge
Floor Pan for Bogie Tests 4Cable R&D
H#2410835 March 2016 SMT

Figure B-3. 24-Gauge (0.6-mm) Sheet Steel for Simulated Floor pan, Test Nos. MWPFP-22 through MWPFP-26

ISO/TS 16949 BUREAU VERITAS Certification

GEM-YEAR TESTING LABORATORY
CERTIFICATE OF INSPECTION

MANUFACTURER : GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2015/10/27

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 210097114
COMMODITY : FINISHED HEX NUT GR-5
SIZE : 1/2-13 NC
LOT NO : 1N1580436
SHIP QUANTITY : 75,000 PCS
HEADMARKS : GENIUS SYMBOL & 2 ARC LINES(120 DEGREE)
COUNTRY OF ORIGIN : CHINA

PACKING NO : GEM151009010
INVOICE NO : GEM/FNL-151027ED
PART NO : 1136310
SAMPLING PLAN : ASME B18.18/ASTM F1470
HEAT NO : 331508621
MATERIAL : 1015A
FINISH : TRIVALENT ZINC PER ASTM F1941

PERCENTAGE COMPOSITION OF CHEMISTRY :

Chemistry	Al%	C%	Mn%	P%	S%	Si%
Spec. : MIN.	0.0200	0.1300	0.3000			
MAX.		0.1800	0.6000	0.0300	0.0350	0.1000
Test Value	0.0490	0.1500	0.4100	0.0160	0.0060	0.0400

R#16-411 H#331508621
4CableRD FloorPan
Tube Cap Hardware
March 2016 SMT

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME/ANSI B18.2.2-2010

SAMPLED BY : DWTING

INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
WIDTH ACROSS CORNERS	6 PCS	JIS B1071		21.340-21.990 MM	21.420-21.620 MM	6	0
THICKNESS	6 PCS	JIS B1071		10.850-11.370 MM	10.940-11.340 MM	6	0
WIDTH ACROSS FLATS	6 PCS	JIS B1071		18.700-19.050 MM	18.740-18.990 MM	6	0
SURFACE DISCONTINUITIES	29 PCS	ASTM F812			PASSED	29	0
THREAD	15 PCS	JIS B1071		2B	PASSED	15	0

MECHANICAL PROPERTIES : ACCORDING TO SAE J 995-2012

SAMPLED BY : LI JUN

INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	15 PCS	ASTM F606/F606M		Max. 32 HRC	10-13 HRC	15	0
PROOF LOAD	6 PCS	ASTM F606/F606M		Min. 17,000 LBF	OK	6	0

ALL TESTS ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM/SAE/ASME/MIL-STD-120 SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

WE CERTIFY THE PARTS ARE ROHS COMPLIANT.

SIGNATURE : Jerry

Figure B-4. ½-in. (13-mm) Nuts, Test Nos. MWPFP-22 through MWPFP-26

QUALITY CERTIFICATE

NINGBO JINDING FASTENING PIECE CO., LTD

XIJINGTANG JIULONGHU NINGBO CHINA TEL:+86-574-86530122 FAX: +86-574-86530858

Customer:	FASTENAL COMPANY PURCHASING--IMPORT	Date :	2015-12-18
Product:	HEX CAP SCREWS	Contract No:	15JDF702T
Class:	5	Invoice No:	15-01115573
Size:	1/2-13X4	Lot No:	3385860026
Marking:	JDF three radius	Order No.	210099619
Quantity:	6.200 mpcs	Part No.	110120390
		Production Date	2015-11-28
Dimensions Of SPEC:		Certificate No.:	201512020064

Inspection Items		Standard	Result	Sample	Pass
Visual Appearance		------------	OK	22	22
Body Diameter		0.493-0.500	0.494-0.496	4	4
Thread	Go	3A	OK	15	15
	No Go	2A	OK	15	15
Width Across Flats		0.750-0.736	0.737-0.741	4	4
Width Across Corners		0.866-0.840	0.846-0.850	4	4
Major Diameter		0.488-0.498	0.495-0.496	15	15
Head Height		0.323-0.302	0.311-0.313	4	4
Total Length		3.920-4.000	3.946-3.947	15	15
Thread Length		min 1.250	1.252-1.256	15	15
Mechanical Properties					
CharacTeristics		Standard	Result		
Surface Hardness	[30N]	MAX 54	44-46	15	15
Core Hardness	[HRC]	25-34	27.5-28	15	15
Wedge Strength	[psi]	min 119880	134973-136134	4	4
Yield Strength	[psi]	min 91869	109430-111752	4	4
Elongation	[%]	min 14	17.5-18.0	4	4
Reduction Of area	[%]	min 35	49.4-51.9	4	4
Proof Load	[lb]	12100	12100	4	4
Decarburization		N≥1/2H1 HV0.3	295.35 295.34 312.65	4	4
HV2>=HV1-30, HV3<=HV1+30		G 0.0006max			
CHEMICAL COMPOSITION(%)					

Heat No		C	Si	Mn	P	S	Cr	Ni	Cu	Mo	B
XG35ACR	321505784	0.36	0.04	0.73	0.013	0.005	0.28	0.01	0.02		
Thickness	[UM]		min 5			12.1-13.3		22		22	

Surface Coating: ZPCr3+(coating test method: X ray according to ASTM B568M 2007 standard test method for measurement of coating thickness by X-Ray spectrometry)

Thread Specification: ASME B1.1 2008, UNIFIED INCH SCREW THREADS(UN AND UNR THREAD FORM)

Sampling Dimension Specification: ASME B18.18-2011 inspection and quality assurance for high-volume machine assembly fasteners

Dimension Specification: ASME B18.2.1 2012, HEX CAP SCREWS

Sampling mechanical properties specification: ASTM F1470 2012 Standard Guide for Fastener Sampling for Specified Mechanical Properties and Performance Inspection

Mechanical Properties: SAE J429 2014, MECHANICAL AND MATERIAL REQUIREMENTS FOR EXTERNALLY THREADED FASTENERS

Surface Defect:ASTM F788/F788M-2013, SURFACE DISCONTINUITIES OF BOLTS, SCREWS, AND STUDS

Plating Specification: ASTM 1941 2015, Electrodeposited Coatings On Threaded Fasteners

Quality Control Supervisor | Quality Control Manager

NINGBO JINDING FASTENING PIECE CO., LTD INSPECTION DEP 宁波金鼎紧固件有限公司质检科

R#16-411 H#321505784
4CableRD Floor Pan
Tube Cap Hardware BOLTS

尹巍

Figure B-5. ½-in. (13-mm) Bolts, Test Nos. MWPFP-22 through MWPFP-26

Appendix C. Bogie Test Results

The results of the recorded data from each accelerometer for every dynamic bogie 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

Test Description:	Evaluation of Floorboard Tearing
Test Number:	MWPFP-22
Test Date:	3/22/2016
Failure Type:	bottom of tube cap face snag lateral supports

Post Properties

Post Type:	MWP-8 TYPE POSTS
Post Size:	MWP with (2) 3/4 in. holes at groundline
Post Length:	81.25"
Embedment Depth:	42"
Orientation:	0°

Soil Properties

Gradation:	MASH Strong Soil
Moisture Content:	NA
Compaction Method:	HEAVY HE-8

Bogie Properties

Impact Velocity:	26.02 mph	(38.17 ft/s)
Impact Height:	12"	
Bogie Mass:	2410 lb	

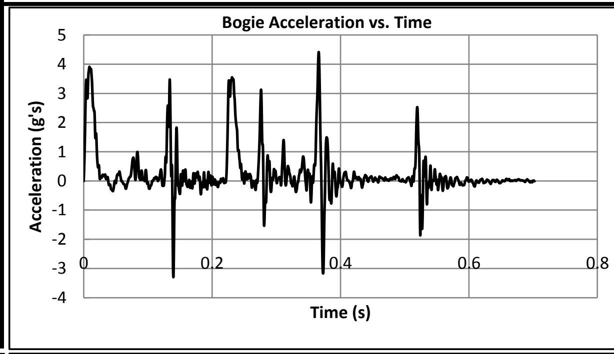
Data Acquired

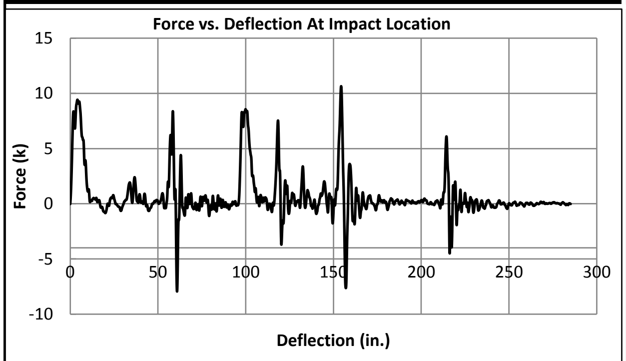
Accelerometer:	SLICE-2
Camera Data:	GoPros, AOS-8 perpendicular

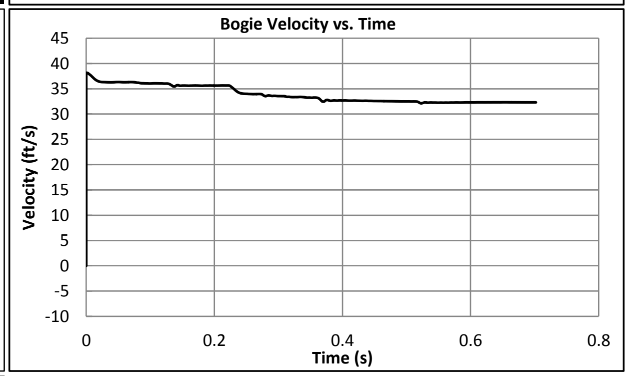
Test Results Summary

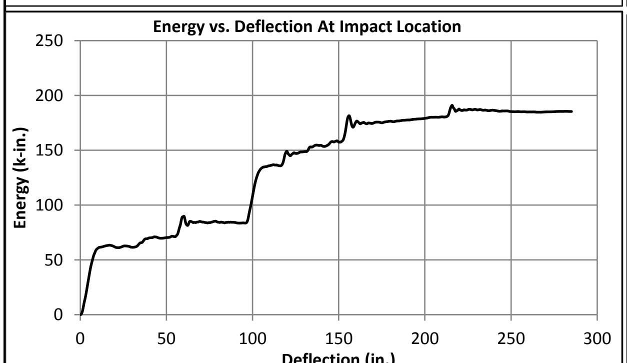
Event Duration:	0.7020	sec
Max. Deflection:	285.1	in.
Peak Force:	10.6	k
Initial Linear Stiffness:	2.3	k/in.
Total Energy:	191.0	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	6.78	6.03	4.20	3.10
Energy (k-in.)	33.9	60.3	62.9	61.9









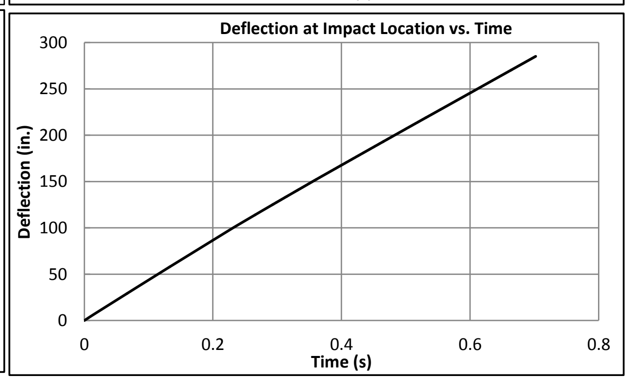


Figure C-1. Test No. MWPFP-22 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	U-Shaped Plates (cap)
Test Number:	MWPFP-24
Test Date:	4/27/2016
Failure Type:	cap bolt sheared on heavy cross member

Post Properties

Post Type:	MWP Post Material
Post Size:	Standard MWP
Post Length:	76.625"
Embedment Depth:	42"
Orientation:	0°

Soil Properties

Gradation:	MASH Strong Soil
Moisture Content:	NA
Compaction Method:	SMALL HAND TAMPER

Bogie Properties

Impact Velocity:	27.16 mph	(39.84 ft/s)
Impact Height:	12"	
Bogie Mass:	2410 lb	

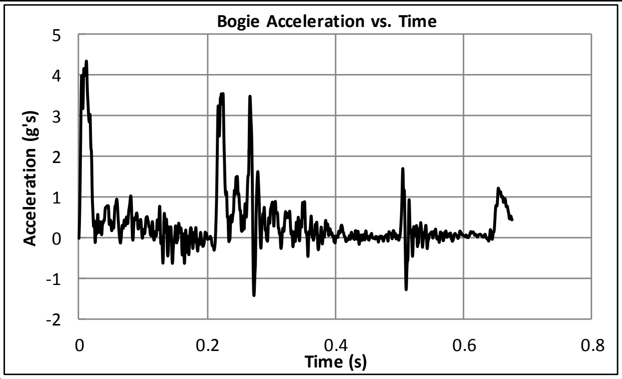
Data Acquired

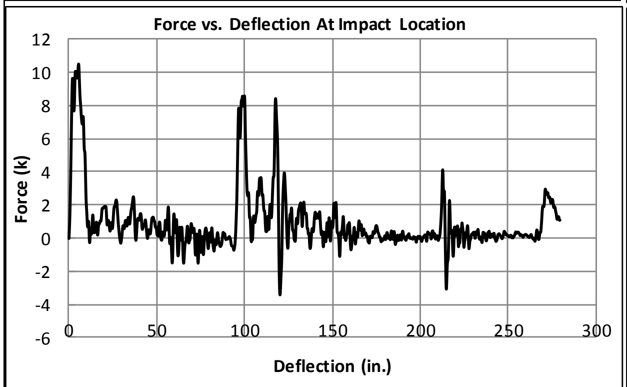
Accelerometer:	SLICE-2
Camera Data:	GoPros, AOS-8 perpendicular

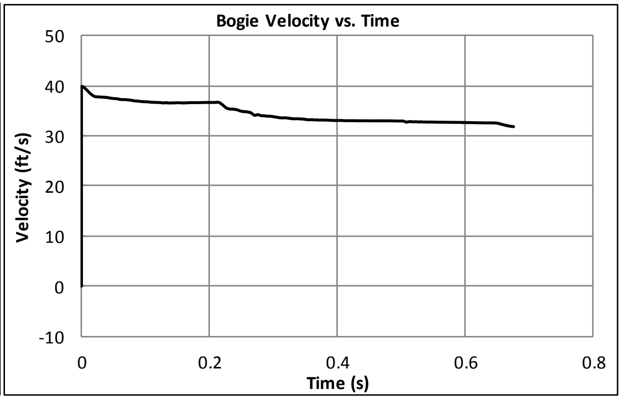
Test Results Summary

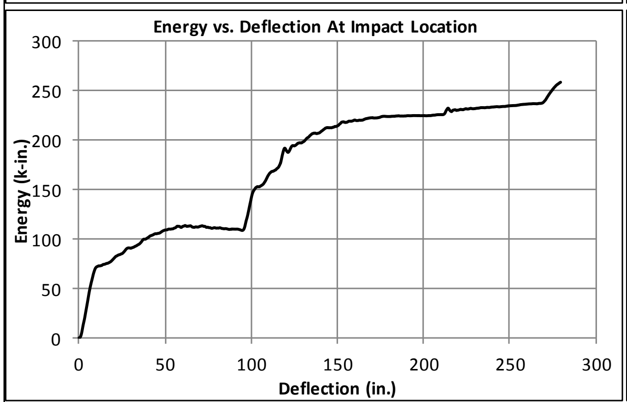
Event Duration:	0.6760	sec
Max. Deflection:	279.6	in.
Peak Force:	10.5	k
Initial Linear Stiffness:	1.9	k/in.
Total Energy:	258.4	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	7.12	7.13	4.97	3.98
Energy (k-in.)	35.6	71.3	74.5	79.6









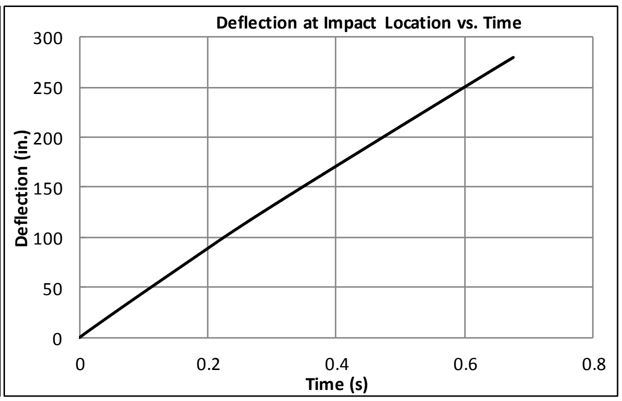


Figure C-2. Test No. MWPFP-23 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	U-Shaped Plates (cap)
Test Number:	MWPFP-24
Test Date:	4/27/2016
Failure Type:	cap bolt sheared on heavy cross member

Post Properties

Post Type:	MWP Post Material
Post Size:	Standard MWP
Post Length:	76.625"
Embedment Depth:	42"
Orientation:	0°

Soil Properties

Gradation:	MASH Strong Soil
Moisture Content:	NA
Compaction Method:	SMALL HAND TAMPER

Bogie Properties

Impact Velocity:	27.16 mph	(39.84 ft/s)
Impact Height:	12"	
Bogie Mass:	2410 lb	

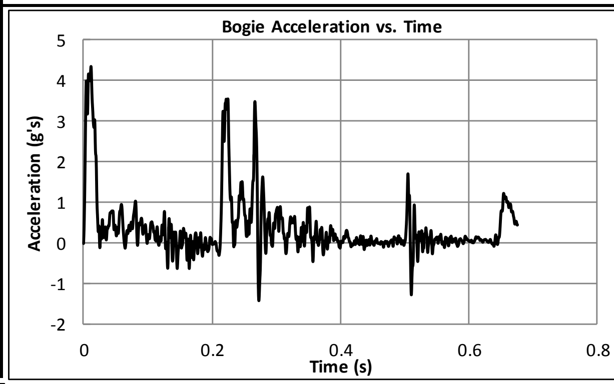
Data Acquired

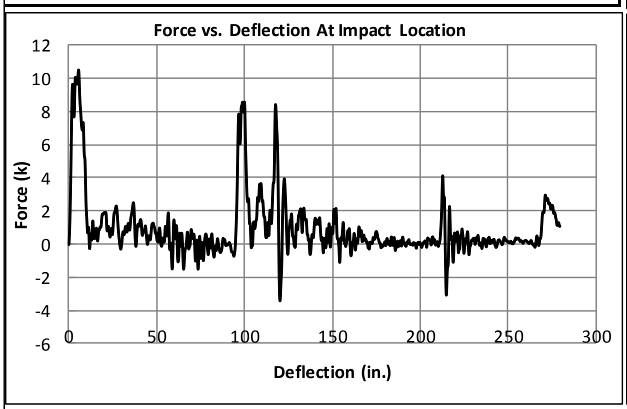
Accelerometer:	SLICE-2
Camera Data:	GoPros, AOS-8 perpendicular

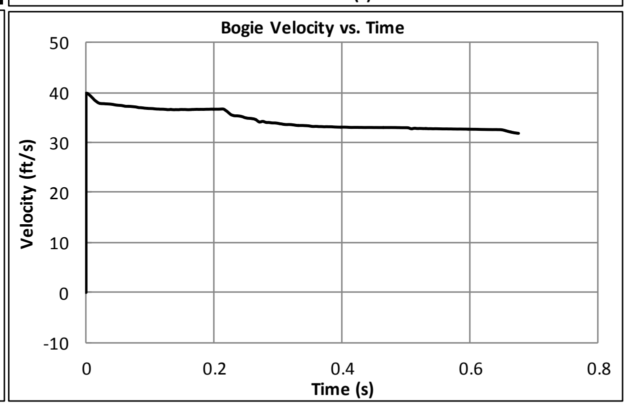
Test Results Summary

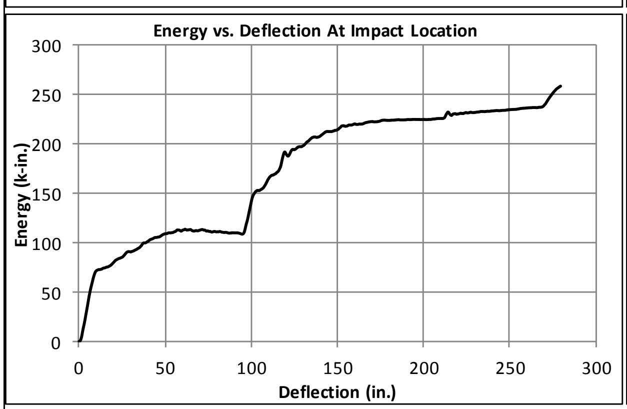
Event Duration:	0.6760	sec
Max. Deflection:	279.6	in.
Peak Force:	10.5	k
Initial Linear Stiffness:	1.9	k/in.
Total Energy:	258.4	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	7.12	7.13	4.97	3.98
Energy (k-in.)	35.6	71.3	74.5	79.6









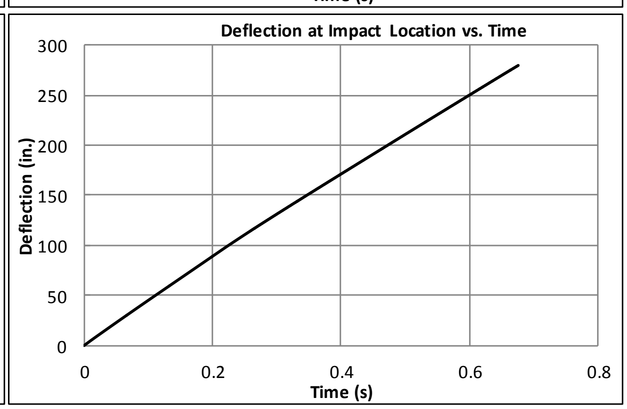


Figure C-3. Test No. MWPFP-24 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description: U-Shape Plates (cap)
Test Number: MWPFP-25
Test Date: 5/3/2016
Failure Type: breakaway at groundline holes

Post Properties

Post Type: MWP-8 TYPE POSTS
Post Size: Standard MWP
Post Length: 79.625"
Embedment Depth: 42"
Orientation: 0°

Soil Properties

Gradation: MASH Strong Soil
Moisture Content: NA
Compaction Method: SMALL HAND TAMPER

Bogie Properties

Impact Velocity: 27.38 mph (40.16 ft/s)
Impact Height: 12"
Bogie Mass: 2410 lb

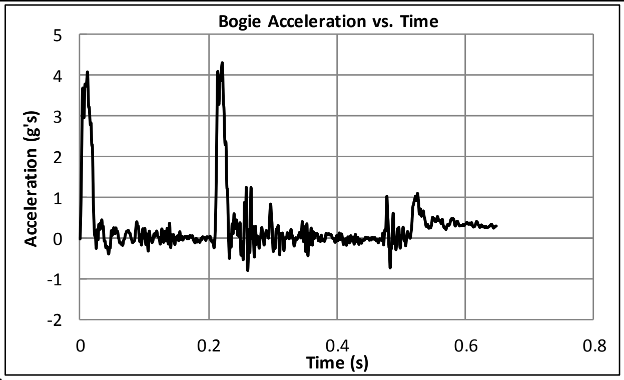
Data Acquired

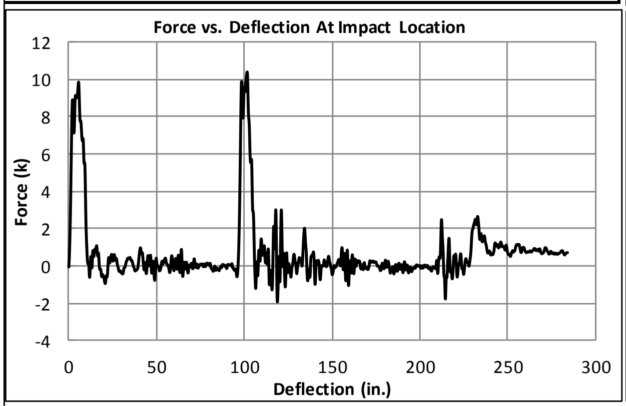
Accelerometer: SLICE-2
Camera Data: GoPros, AOS-8 perpendicular

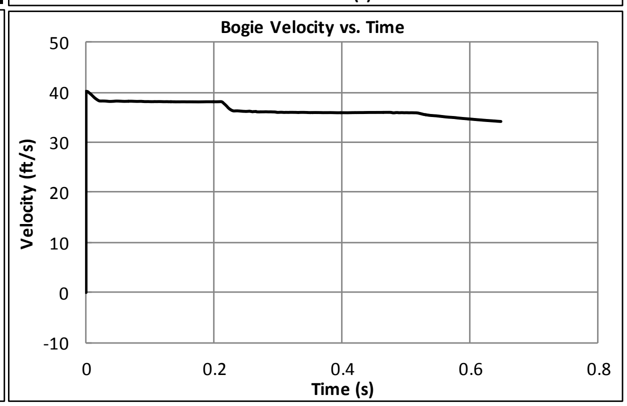
Test Results Summary

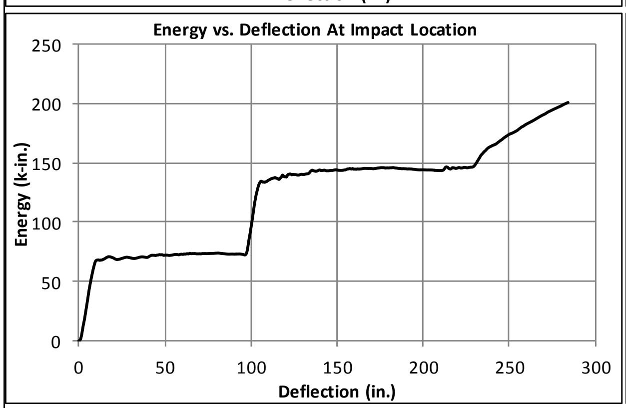
Event Duration: 0.6485 sec
Max. Deflection: 284.2 in.
Peak Force: 10.4 k
Initial Linear Stiffness: 0.1 k/in.
Total Energy: 200.9 k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	6.60	6.75	4.61	3.49
Energy (k-in.)	33.0	67.5	69.2	69.9









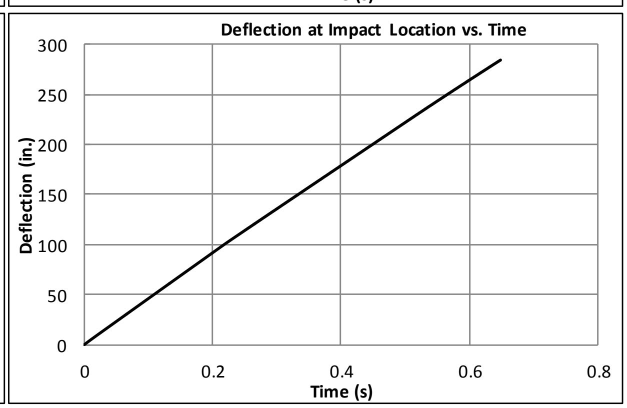


Figure C-4. Test No. MWPFP-25 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	U-Shaped plates (caps)
Test Number:	MWPFP-26
Test Date:	5/5/2016
Failure Type:	Breakaway at groundline holes

Post Properties

Post Type:	MWP-8 Post
Post Size:	Standrad MWP
Post Length:	79.625"
Embedment Depth:	42"
Orientation:	-25

Soil Properties

Gradation:	MASH Strong Soil
Moisture Content:	NA
Compaction Method:	SMALL HAND TAMPER

Bogie Properties

Impact Velocity:	26.67 mph	(39.11 ft/s)
Impact Height:	12"	
Bogie Mass:	2410 lb	

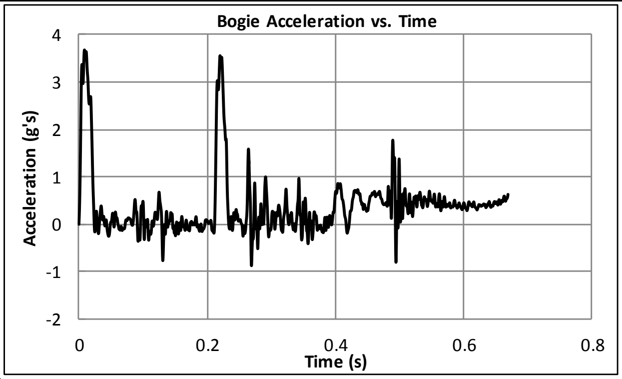
Data Acquired

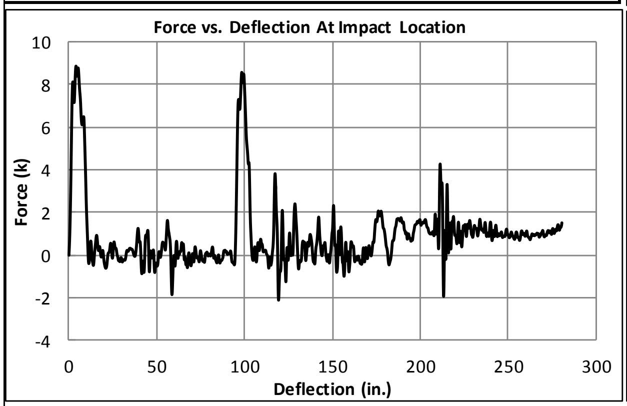
Accelerometer:	SLICE-2
Camera Data:	GoPros, AOS-8 perpendicular

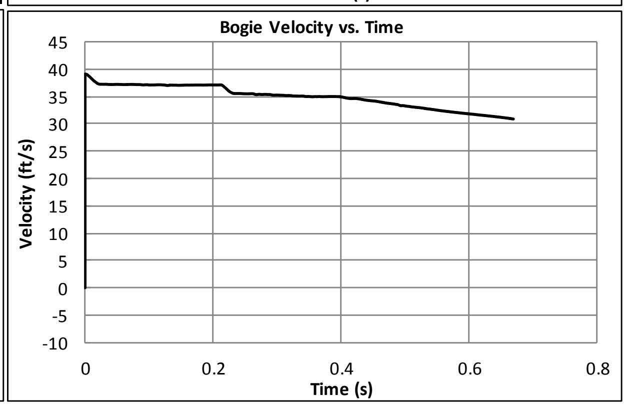
Test Results Summary

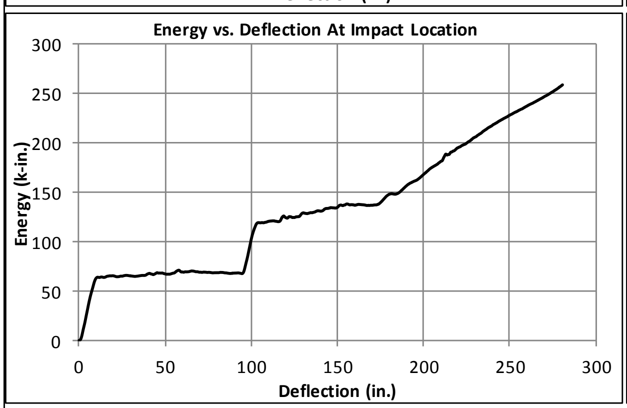
Event Duration:	0.6695	sec
Max. Deflection:	280.7	in.
Peak Force:	8.9	k
Initial Linear Stiffness:	2.2	k/in.
Total Energy:	258.7	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	6.18	6.30	4.26	3.28
Energy (k-in.)	30.9	63.0	63.9	65.5









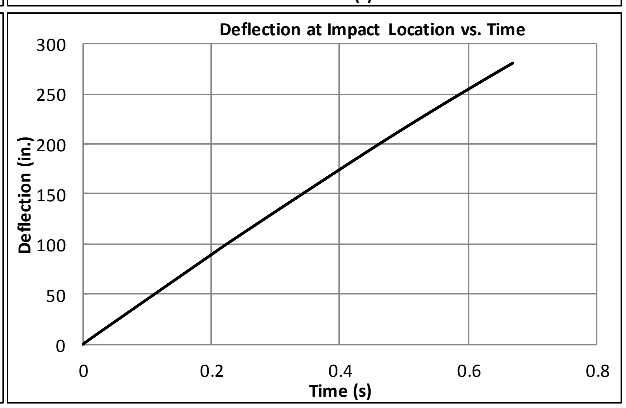


Figure C-5. Test No. MWPFP-26 Results, (SLICE-2)

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