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POST WELD AND EPOXY ANCHORAGE VARIATIONS FOR W-BEAM GUARDRAIL ATTACHED TO LOW-FILL CULVERTS

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16. Abstract (Limit: 200 words)

The research effort consisted of two objectives for dealing with alterations to the W-beam guardrail system developed for attachment to the top of low-fill culverts. This effort included: (1) investigation of an alternative weld detail to simplify the three-pass fillet weld on the front flange of the post and (2) development of an epoxy anchorage option as opposed to through-bolting. These system modifications were evaluated through four dynamic, bogie tests conducted under the same impact conditions as the original system component testing.

Based on a survey of the Pooled Fund member states, two different single-pass weld details were evaluated as a replacement for the 3-pass fillet weld used on the front flange of the post in the original system. However, both single-pass welds resulted in large tears in the base plate adjacent to the front flange. The 3-pass weld detail was successful with a post assembly fabricated from 50 ksi (345 MPa) steel materials. Thus, the 3-pass weld will continue to be recommended for use, while the post and base plate may be composed of ASTM A36 or Grade 50 steel parts.

Anchor pullout was encountered for an embedment depth of 6 in. (152 mm), while an 8-in. (203-mm) embedment showed no signs of anchor failure. Thus, an 8 in. (203 mm) minimum embedment depth was recommended for the epoxied anchorage design.

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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 Ms. Karla Lechtenberg, Research Associate Engineer.

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1 INTRODUCTION

1.1 Introduction

W-beam guardrail systems often span across reinforced concrete box culverts in order to prevent motorists from encountering hazardous conditions near the openings. For low-fill culverts of widths exceeding the maximum unsupported length of long-span systems, a few W-beam guardrail designs are available for direct attachment to the top culvert slab. One such guardrail system was developed in 2002 by the Midwest Roadside Safety Facility (MwRSF) [1]. This system utilized a ½-in. (13-mm) thick steel plate welded to the bottom of each guardrail post with a $^{5}/_{16}$-in. (8-mm) three-pass fillet weld on the front (tension) flange and a ¼-in. (6-mm) fillet weld on the web and back (compression) flange. The post assembly was anchored to the culvert slab using four 1-in. (25-mm) diameter through bolts. Finally, the back-side of the post was offset 18 in. (457 mm) from the inside of the culvert headwall to prevent interaction between the posts and the rigid headwall as the system deflects during an impact event. This system was successfully developed and full-scale crash tested according to the Test Level 3 (TL-3) safety performance guidelines found in National Cooperative Highway Research Program (NCHRP) Report No. 350 [2]. Drawings for this system are shown in Figures 1 and 2.

During the implementation of the W-beam guardrail system for attachment to concrete box culverts, various State Departments of Transportation (DOTs) have raised questions concerning the use of the three-pass fillet weld on the front flange of the attachment post. Multiple States have expressed a desire to simplify the weld to a single-pass detail. Therefore, a need exists to re-examine the use of the three-pass fillet weld and determine whether a simplified alternative weld detail could be utilized in combination with the other details of the post-to-plate attachment.

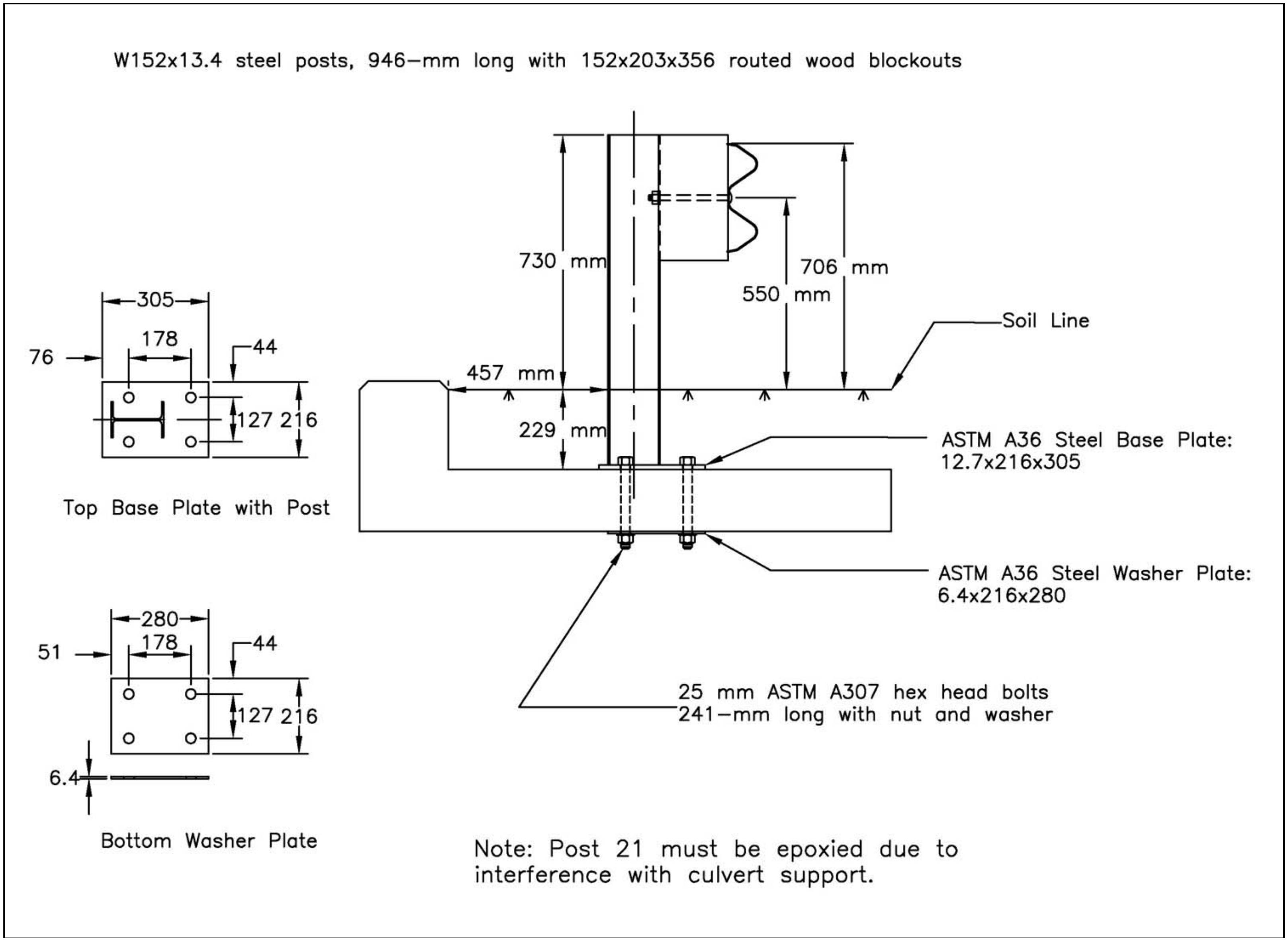


Figure 1. Original System Details for Guardrail Attachment to Culverts [1]

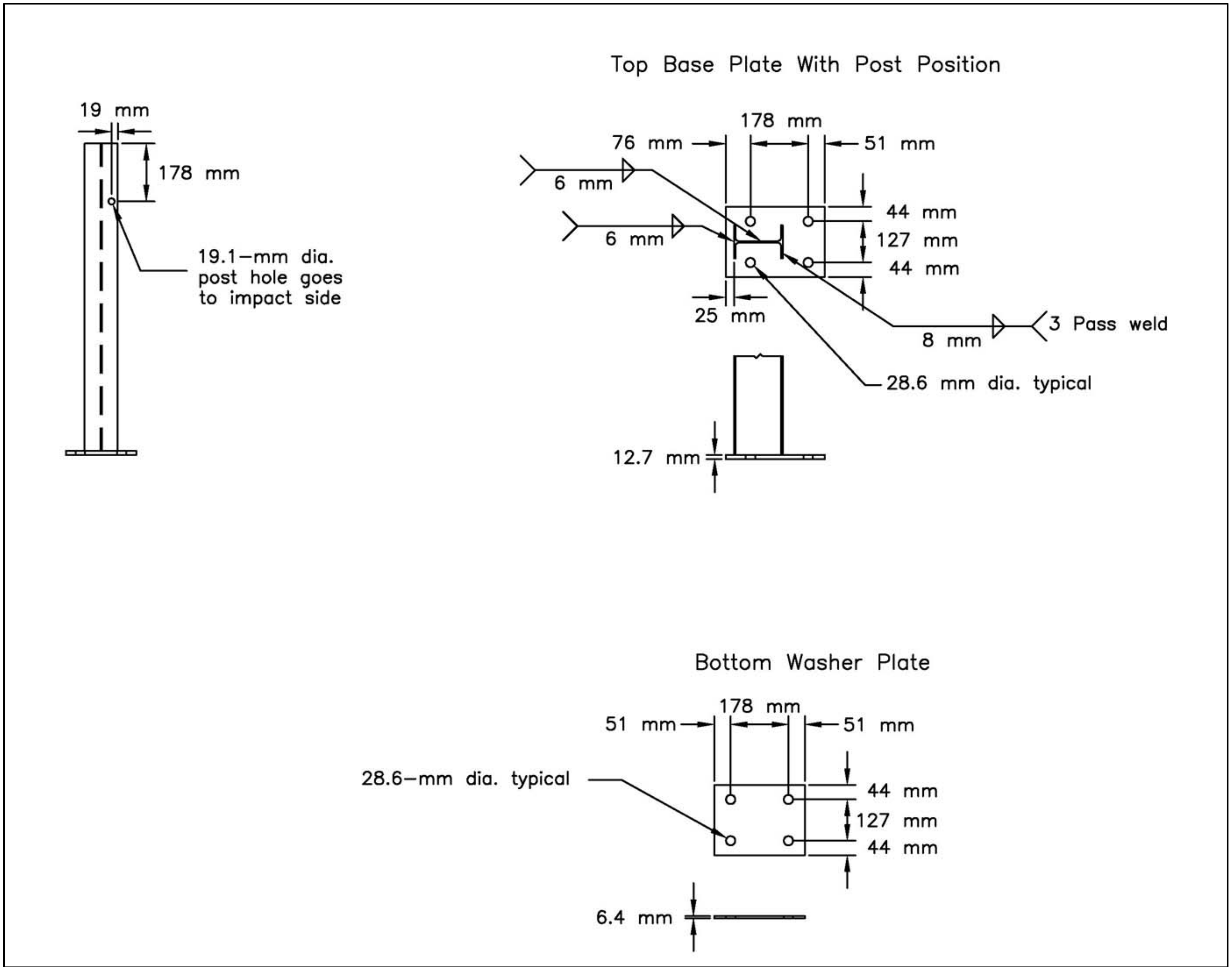


Figure 2. Original System Post and Weld Details [1]

Installation problems have resulted when the guardrail post location coincides with a vertical support wall found inside the culvert. For this scenario, vertical through-bolts cannot be utilized to anchor the guardrail posts to the culvert slab since space is not available to place the lower bearing plate or access the lower end of the through-bolt and attach a nut. Unfortunately, alternative anchorage options, such as epoxy anchorage of threaded rods, have not been previously developed. Therefore, a need exists to evaluate the required embedment depth and epoxy strength to anchor posts to the culvert top slab.

1.2 Objective

This research effort consisted of two objectives investigating modifications to the W-beam guardrail system developed for attachment to the top of low-fill culverts. The first objective was to re-examine the use of the three-pass fillet weld on the front flange of the post and determine if an alternative weld detail can be utilized to simplify the post fabrication. The second objective was to develop an epoxy anchor option as an alternative to the through-bolt anchorage of the guardrail attached to culvert system. In developing these potential alterations, it was essential that the post-to-culvert attachment remained intact under dynamic loading where large deformations are observed.

1.3 Scope

Over the last several years, multiple State DOTs have discussed the use of alternative weld details for the post attachment to culvert slabs. As such, MwRSF reviewed the current weld details for the culvert-mounted steel post from the members of the Midwest States Pooled Fund program as well surveyed the member states to obtain recommendations for a standardized weld detail. Subsequently, MwRSF selected the preferred alternative weld details for the culvert post and evaluated their performance through dynamic component testing. Additionally, the minimum embedment depth required to anchor the 1-in. (25-mm) diameter bolts or rods utilizing an epoxy adhesive was evaluated through the same dynamic component testing. A total of four dynamic bogie tests were be performed on culvert posts anchored to MwRSF's concrete tarmac. Finally, conclusions and recommendations were made for revising the weld detail and utilizing epoxied anchor rods instead of through-bolts.

2 COMPONENT TESTING PARAMETERS

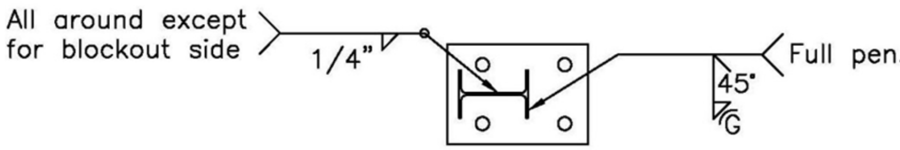
2.1 Purpose

During the initial development of the W-beam guardrail system mounted on top of a culvert, multiple component tests were conducted to evaluate the post-to-culvert attachment [1]. Design variations on both base plate thickness and weld details were explored to find a combination that resulted in the anchorage system remaining intact through large deformations. All post rotations were expected to include plastic deformations in the post and plate. Configurations resulting in tearing of the plate and/or weld failure were not considered for the final design. This bogie testing study resulted in the selection of a ½-in. (13-mm) thick base plate, a $^{5}/_{16}$-in. (8-mm) three-pass fillet weld on the front (tension) flange, and a ¼-in. (6-mm) fillet weld on the web and back-side (compression) flange. This attachment configuration (in combination with through bolts) was then successfully full-scale crash tested according to the TL-3 impact safety standards of NCHRP Report No. 350 [2]. Therefore, the design alternatives to the post-to-culvert attachment proposed in this study were subjected to the same dynamic bogie testing. Only the alternatives that provided enough strength to resist material tearing, fracture, and anchor pullout would be recommended for use.

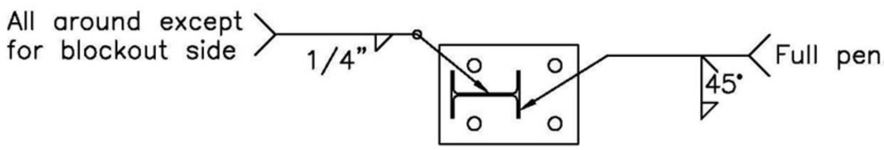
2.2 Selection of Alternative Weld Details

Through a review of State DOT drawings and recommendations for the simplification of the post-to-plate attachment, five different weld options were identified as possible replacements to the 3-pass, $^{5}/_{16}$-in (8-mm) fillet weld. These five weld options are shown in Figure 3. Weld Option A included a ¼-in. (6-mm) fillet weld on the web and back flange and a full penetration weld on the front flange with minor grinding to reduce residual stresses. Weld Option B was the same as Weld Option A, but without the grinding. Weld Option C utilized a single-pass $^{5}/_{16}$-in.

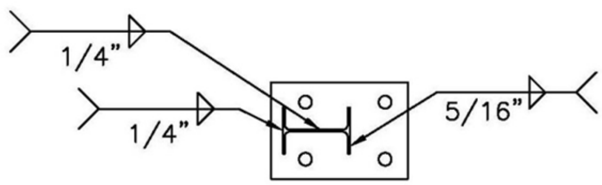
(8-mm) weld on the front flange while maintaining the ¼-in. (6-mm) fillet welds on the web and back flange. Finally, Weld Options D and E utilized only single fillet welds around the entire base of the post measuring $^{5}/_{16}$ in. (8 mm) and ¼ in. (6 mm), respectively.



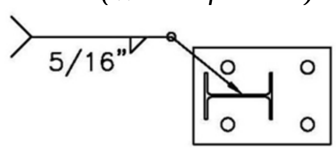
(Weld Option A)



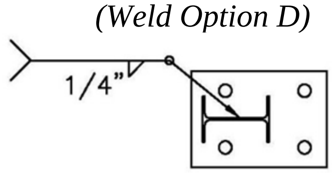
(Weld Option B)



(Weld Option C)



(Weld Option D)



(Weld Option E)

Figure 3. Proposed Standardized Weld Options

These five weld options were presented to the members of the Midwest States Pooled Fund program, and each member state was asked to indicate which two weld options were considered most desirable. Overwhelmingly, Weld Options D and E were the most desired. Therefore, Weld Options D and E were selected to be evaluated through dynamic bogie testing.

2.3 Component Testing Setup

Four bogie tests were conducted on the proposed alterations to the original guardrail post attachment to culverts. Similar to the component tests conducted during the development of the original system, each test involved the bogie vehicle impacting the post assembly at a height of 30⅝ in. (778 mm). Note, this impact height corresponds to the 21.65 in. (550 mm) height to the center of the guardrail above ground line plus the 9 in. (229 mm) depth of soil fill on the culvert. Additionally, the dimensions of the post and the base plate remained unchanged. Thus, the W6x9 (W152x13.4) steel posts were 37 in. (940 mm) in length, and the base plates measured 8½ in. x 12 in. x ½ in. (216 mm x 305 mm x 13 mm). Finally, the targeted impact speed and angle remained the same at 10 mph (16 km/h) and 0 degrees (strong-axis bending), respectively.

The post and base plate assembly developed and tested for the original system utilized all ASTM A36 steel components. However, in the years since that project was completed, the use of higher Grade 50 ksi (345 MPa) steel has become more prominent for standard rolled shapes, and obtaining A36 wide-flange sections has become increasingly more difficult. Therefore, researchers identified the need to utilize the higher grade steel posts to evaluate the future use of this guardrail system. Subsequently, ASTM A992 W6x9 (W152x13.4) steel posts were used in all four of the bogie tests presented herein. It was also recognized that Grade 50 steel plate was also becoming more prominent. Thus, after tearing was observed in the base plates during the first two bogie tests, the plate material was also upgraded to 50 ksi (345 MPa) steel for test nos. CGSA-3 and CGSA-4.

For test nos. CGSA-1 through CGSA-3, several attempts were made to simplify the post-to-plate attachment weld by using only single-pass fillet welds. The size of the fillet welds varied between ¼ in. and $^{5}/_{16}$ in. (6 mm and 8 mm), as shown in Table 1. Only test no. CGSA-4 utilized a different weld on the front flange than the rest of the post (i.e., web and back flange). Test no. CGSA-4 utilized the same weld detail as the original post design with a 3-pass, $^{5}/_{16}$-in. (8-mm) fillet weld on the front flange (weld “Y”) and a ¼-in. (6-mm) fillet weld throughout the rest of the joint (weld “X”).

Similar to the original system, the posts were anchored to the concrete tarmac by four 1-in. (25-mm) diameter, ASTM A307 threaded rods epoxied into the concrete. However, the embedment depth of the anchor rods was varied between tests in an attempt to evaluate the minimum required embedment depth. In test nos. CGSA-1 and CGSA-2, the rods were embedded at 12 in. (305 mm) below the ground line. Test nos. CGSA-3 and CGSA-4 used embedment depths of 6 in. (152 mm) and 8 in. (203 mm), respectively. Powers Fasteners epoxy AC100+ Gold with a minimum bond strength of 1,305 psi (9.0 MPa) was used during this study.

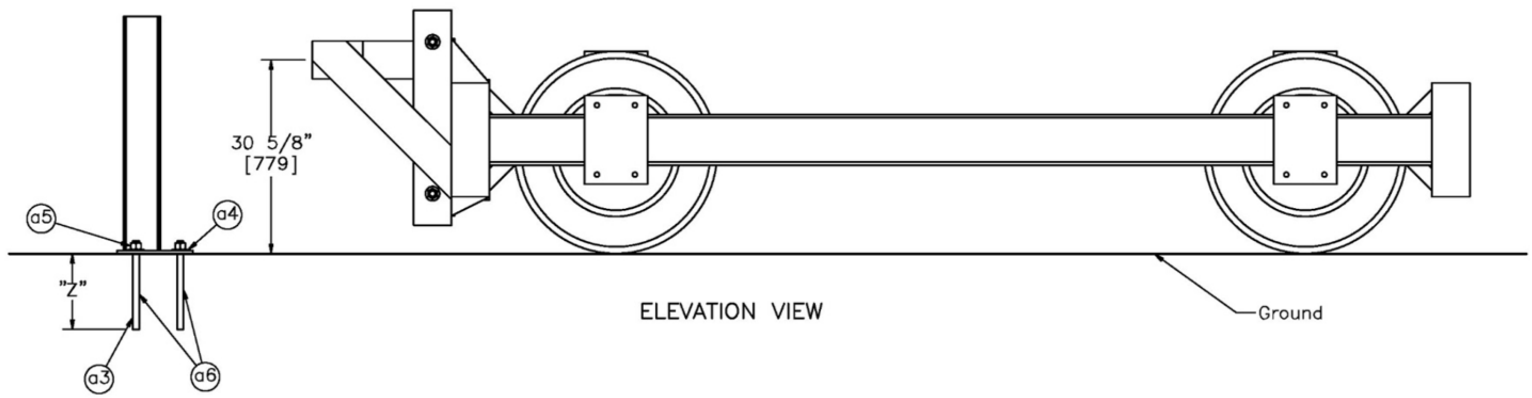
Variations in system components are outlined in the dynamic component test matrix shown in Table 1. System design drawings and test setups are shown in Figures 4 through 9, and a pretest photographs are shown in Figure 10. Material specifications, mill certifications, and certificates of conformance for all materials are shown in Appendix A.

Table 1. Dynamic Component Testing Matrix

Test No.	Post Material	Base Plate Material	Fillet Weld “X”	Fillet Weld “Y” (Front Flange)	Anchor Embedment Depth
CGSA-1	A992	A36	Single Pass $^{5}/_{16}$ in. (8 mm)	Single Pass $^{5}/_{16}$ in. (8 mm)	12 in. (305 mm)
CGSA-2	A992	A36	Single Pass $^{1}/_{4}$ in. (6 mm)	Single Pass $^{1}/_{4}$ in. (6 mm)	12 in. (305 mm)
CGSA-3	A992	A529 / A572 (Gr. 50)	Single Pass $^{5}/_{16}$ in. (8 mm)	Single Pass $^{5}/_{16}$ in. (8 mm)	6 in. (152 mm)
CGSA-4	A992	A529 / A572 (Gr. 50)	Single Pass $^{1}/_{4}$ in. (6 mm)	Triple Pass $^{5}/_{16}$ in. (8 mm)	8 in. (203 mm)

Test No.	Impact Speed mph [km/h]	Bogie No.	Fillet Weld "X" in. [mm] (See Sheet 2)	Fillet Weld "Y" in. [mm] (See Sheet 2)	Embedment Depth "Z" in. [mm]
CGSA-1	10 [16.1]	2	5/16 [8]	5/16 [8]	12 [305]
CGSA-2	10 [16.1]	2	1/4 [6]	1/4 [6]	12 [305]
CGSA-3	10 [16.1]	2	5/16 [8]	5/16 [8]	6 [152]
CGSA-4	10 [16.1]	2	1/4 [6]	5/16 [8]*	8 [203]

* Triple Pass



Notes: (1) Threaded rods are to be epoxied in the tarmac with Powers Fasteners AC100+ Gold epoxy or an equivalent epoxy with a minimum bond strength of 1,305 psi [9.0 MPa].

(2) 1" [25] dia. threaded rods were cut to a length equal to 2 in. [51] plus the embedment depth.

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Culvert Guardrail System Attachment

Bogie Setup

SHEET: 1 of 6
DATE: 2/25/2013
DRAWN BY: DMH/MDM/JGP
DWG. NAME. CulvertGuardrailSystem_R11
SCALE: 1:24
UNITS: in.[mm]
REV. BY: SKR/KAL/RKF

Figure 4. Bogie Testing Setup, Test Nos. CGSA-1 through CGSA-4

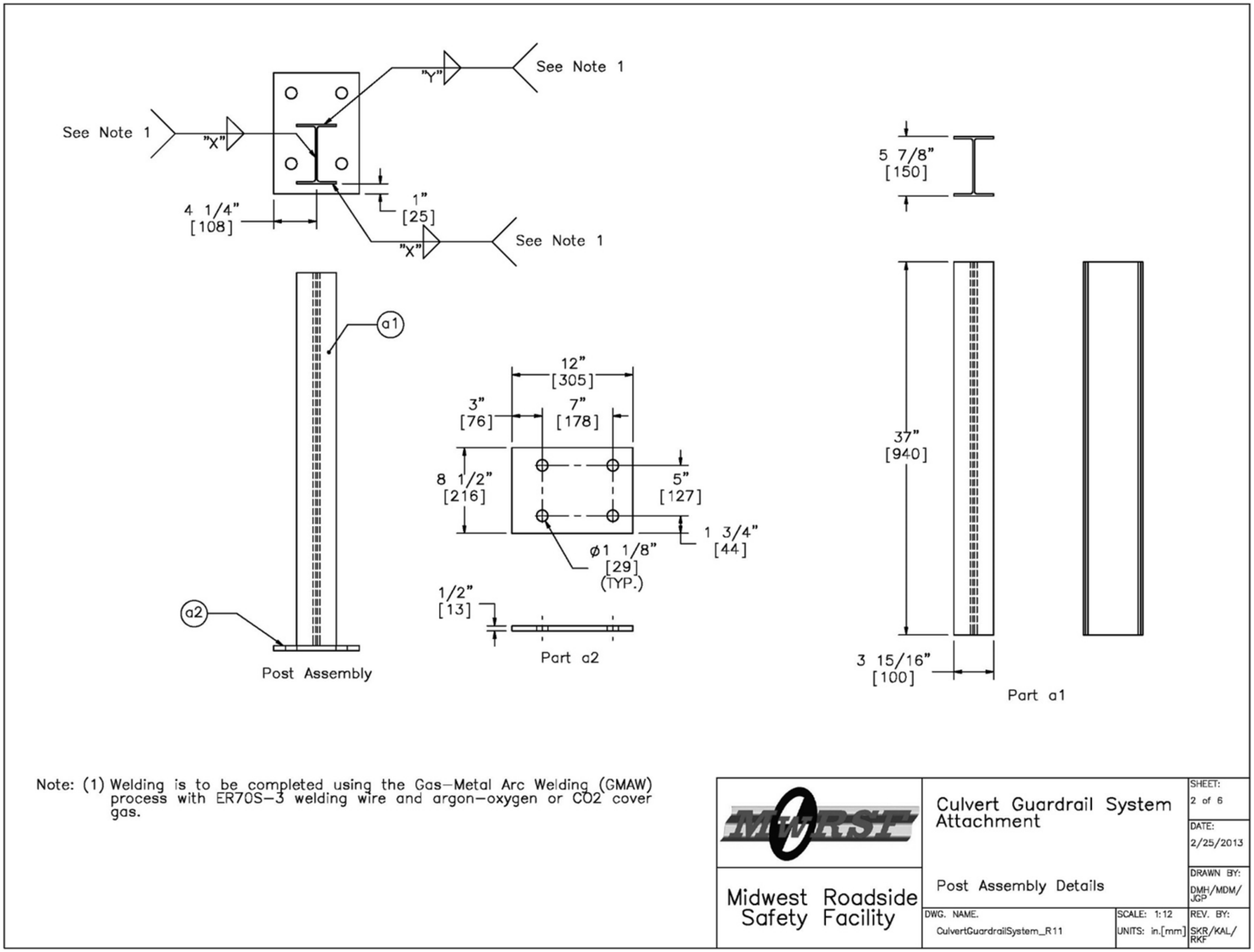


Figure 5. Post Assembly and Weld Details, Test Nos. CGSA-1 through CGSA-4

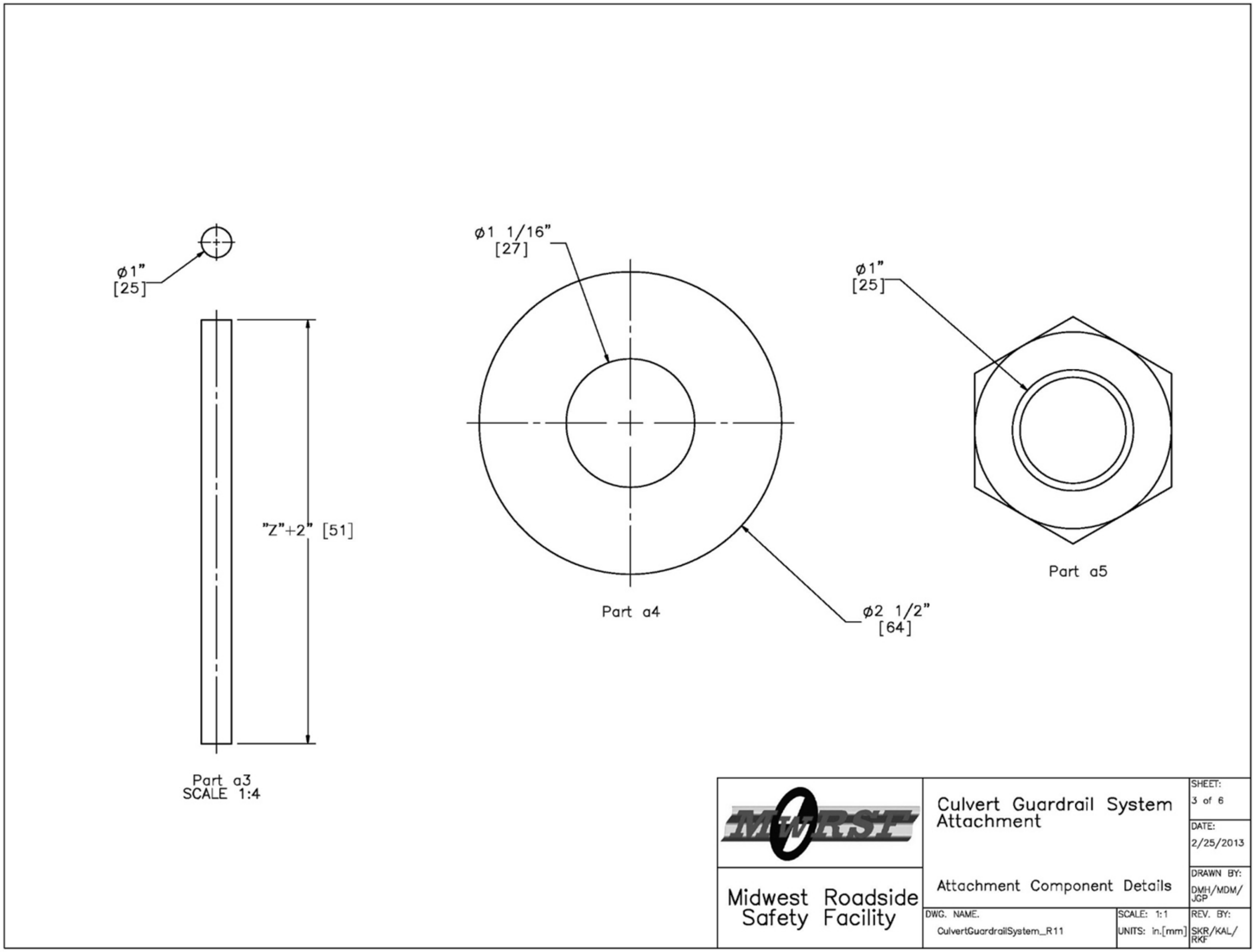


Figure 6. Attachment Component Details, Test Nos. CGSA-1 through CGSA-4

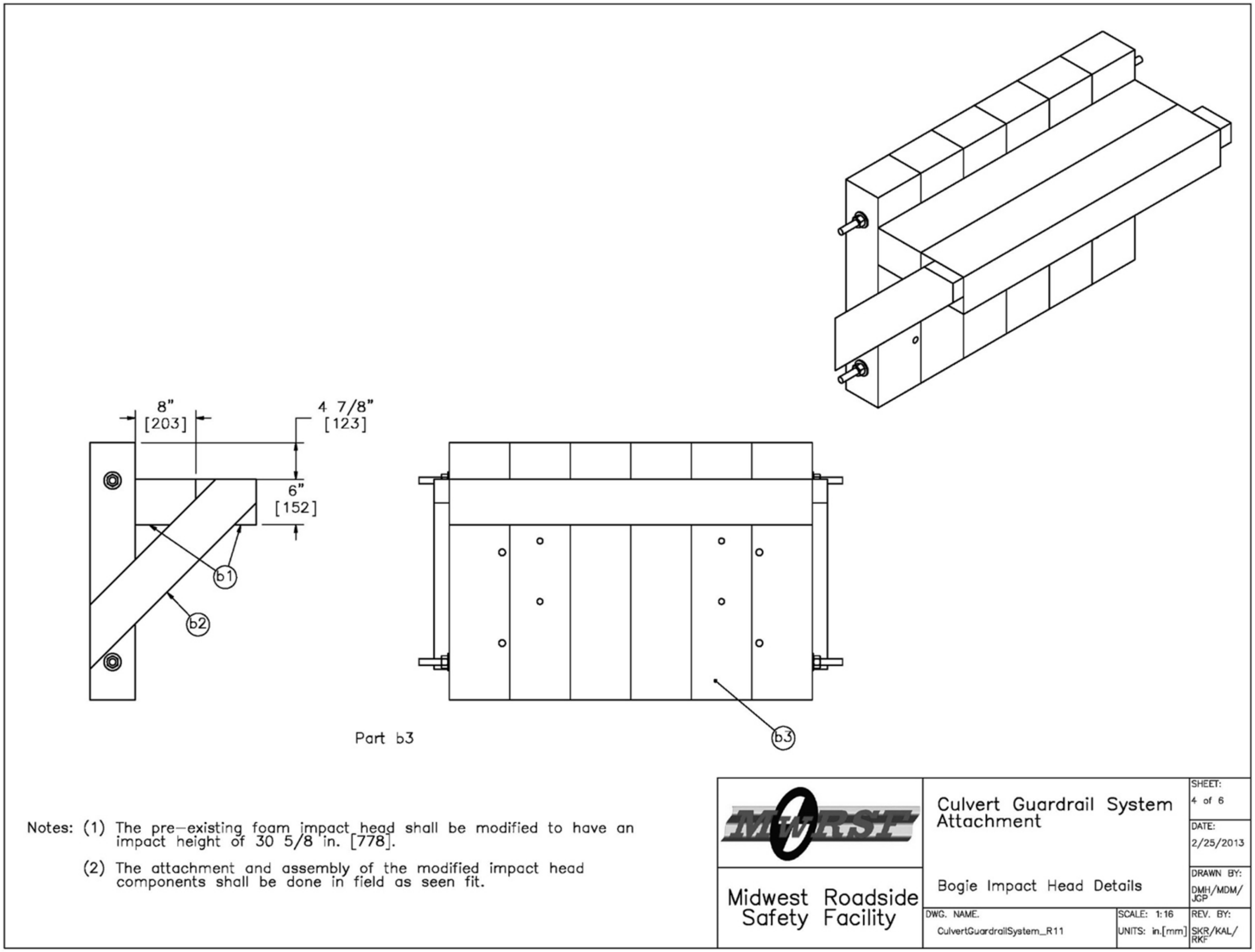


Figure 7. Bogie Impact Head Details, Test Nos. CGSA-1 through CGSA-4

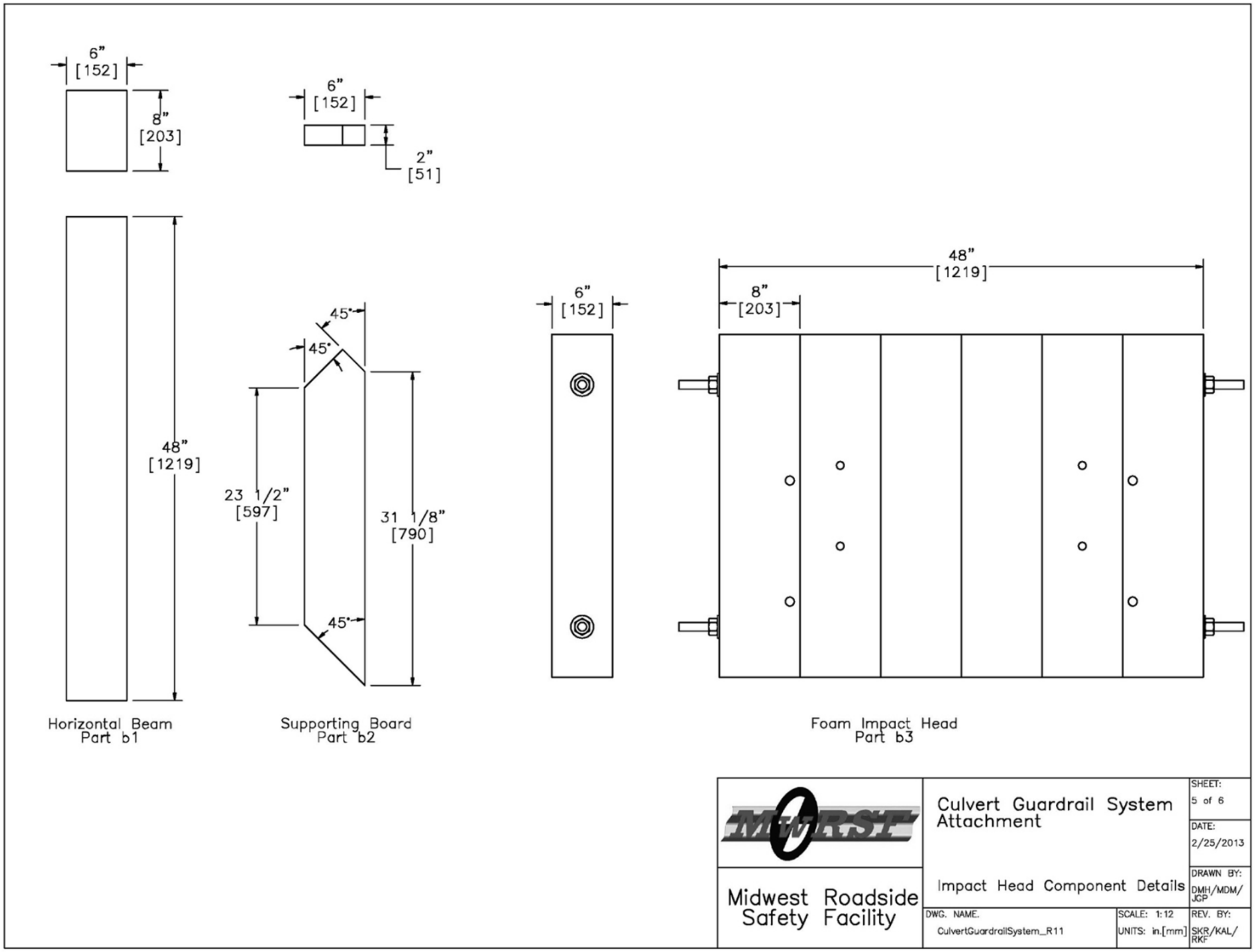


Figure 8. Impact Head Component Details, Test Nos. CGSA-1 through CGSA-4

Culvert Guardrail System Attachment Test Nos. CGSA-1 & 2				
Item No.	QTY.	Description	Material Specification	Hardware Guide
a1	1	37" [940] Long, W6x8.5 [W152x12.6] or W6x9 [W152x13.4] Post	ASTM A992 Min. 50 ksi [345 MPa]	–
a2	1	1/2"x8 1/2"x12" [13x216x305] Top Base Plate	ASTM A36	–
a3	4	1" [25] Dia. UNC, Variable Length Threaded Rod	SAE J429 Grade 2/ASTM A307 Grade C/ ASTM F1554 Grade 36	–
a4	4	1" [25] Dia. Flat Washer	ASTM F844	–
a5	4	1" [25] Dia. UNC Hex Nut	ASTM A563A	–
a6	–	Powers Fasteners AC100+ Gold Epoxy	Minimum Bond Strenght = 1,305 psi [9.0 MPa]	
b1	2	6"x8"x48" [152x203x1219] Horizontal Beam	Wood	–
b2	2	2"x6"x34" [51x152x864] Supporting Board	Wood	–
b3	1	Impact Head	Wood	–

Culvert Guardrail System Attachment Test Nos. CGSA-3 & 4				
Item No.	QTY.	Description	Material Specification	Hardware Guide
a1	1	37" [940] Long, W6x8.5 [W152x12.6] or W6x9 [W152x13.4] Post	ASTM A992 Min. 50 ksi [345 MPa]	–
a2	1	1/2"x8 1/2"x12" [13x216x305] Top Base Plate	ASTM A529 Gr. 50 or ASTM A572 Gr. 50 Depending on Availability	–
a3	4	1" [25] Dia. UNC, Variable Length Threaded Rod	SAE J429 Grade 2/ASTM A307 Grade C/ ASTM F1554 Grade 36	–
a4	4	1" [25] Dia. Flat Washer	ASTM F844	–
a5	4	1" [25] Dia. UNC Hex Nut	ASTM A563A	–
a6	–	Powers Fasteners AC100+ Gold Epoxy	Minimum Bond Strenth = 1,305 psi [9.0 MPa]	–
b1	2	6"x8"x48" [152x203x1219] Horizontal Beam	Wood	–
b2	2	2"x6"x34" [51x152x864] Supporting Board	Wood	–
b3	1	Impact Head	Wood	–

Midwest Roadside Safety Facility

Culvert Guardrail System Attachment

Bill of Materials

SHEET: 6 of 6
DATE: 2/25/2013
DRAWN BY: DMH/MDM/JGP
DWG. NAME. CulvertGuardrailSystem_R11
SCALE: NONE
UNITS: in.[mm]
REV. BY: SKR/KAL/RKF

Figure 9. Bill of Materials, Test Nos. CGSA-1 through CGSA-4

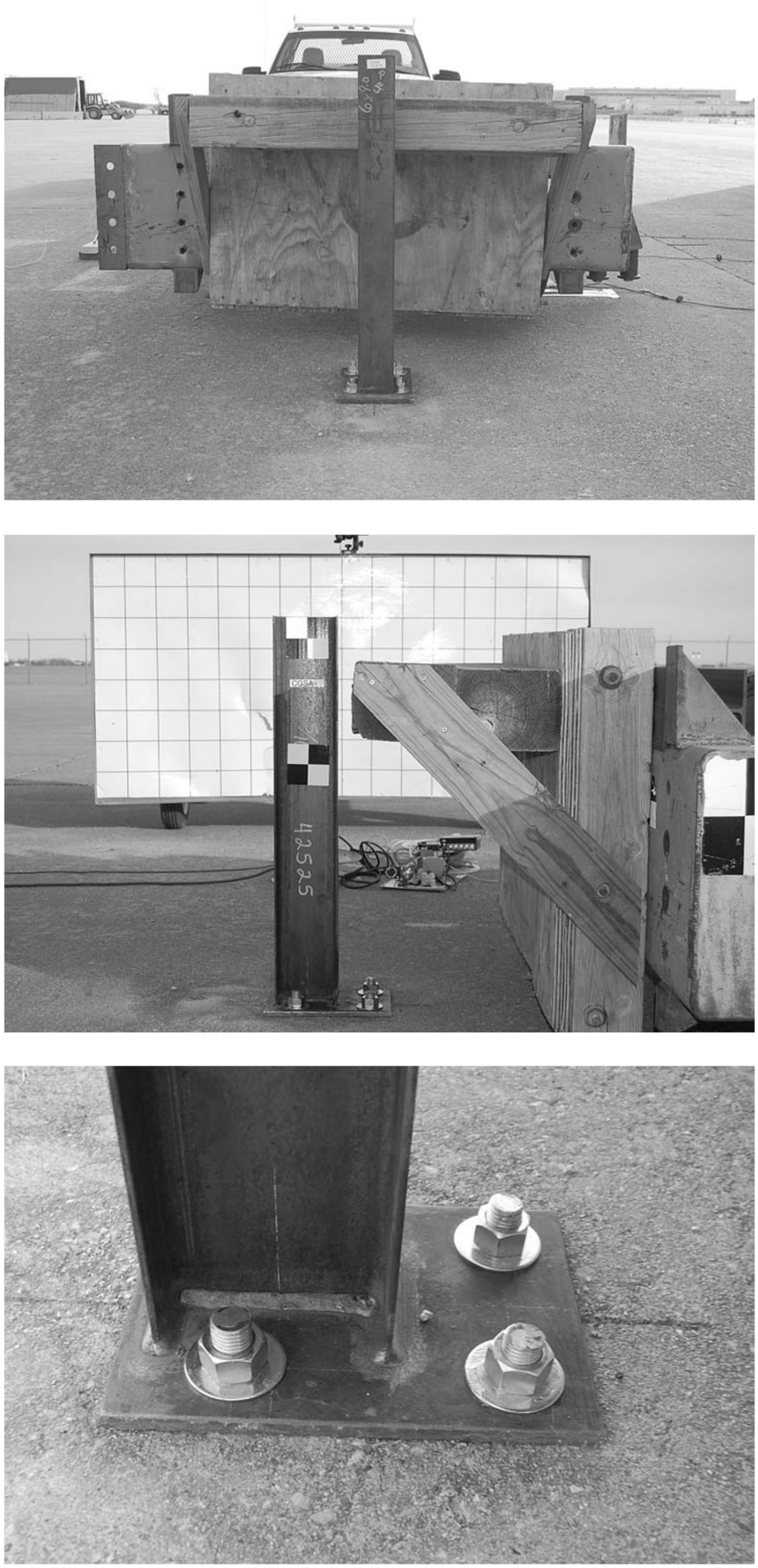


Figure 10. Pre-test Installation Photographs

2.4 Test Facility

Physical testing of the steel post-to-culvert attachments was conducted at the MwRSF outdoor testing facility, which is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport. The facility is approximately 5 miles (8 km) northwest from the University of Nebraska-Lincoln's city campus.

2.5 Equipment and Instrumentation

Equipment and instrumentation utilized to collect and record data during the dynamic bogie tests included a bogie, onboard accelerometers, pressure tape switches, high-speed and standard-speed digital video cameras, and a digital still camera.

2.5.1 Bogie

A rigid-frame bogie was used to impact the posts. A customized, detachable wooden impact head, shown previously in Figures 7 and 8, was used in the testing. The bogie head consisted of six vertical and two horizontal 6 in. x 8 in. (152 mm x 203 mm) wood posts. This impact head matched the one used previously during the original component testing of the post-to-culvert attachment. The impact head was bolted to the bogie vehicle, thus creating a rigid frame with an impact height of 30⅝ in. (778 mm), as shown in Figure 11. The weight of the bogie with the addition of the mountable impact head was 4,996 lb (2,266 kg), 4,999 lb (2,268 kg), 5,010 lb (2,273 kg), and 4,995 lb (2,266 kg) for test nos. CGSA-1, CGSA-2, CGSA-3, and CGSA-4, respectively.

The tests were conducted using a steel pipe guidance track to steer the bogie vehicle into a centered, head-on impact with the test article. A pickup truck was used to propel the bogie vehicle to the targeted impact velocity of 10 mph (16 km/h), at which point the pickup truck braked, allowing the bogie to become a free projectile as it came off the track.

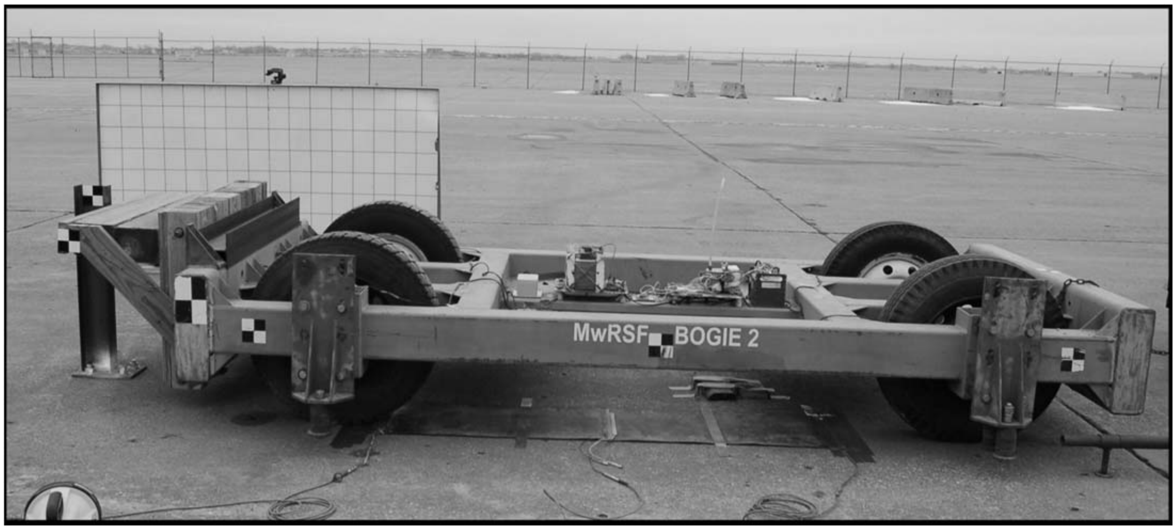


Figure 11. Rigid-Frame Bogie

2.5.2 Accelerometers

A total of three different environmental shock and vibration sensor/recorder systems were used during the component tests to measure the accelerations in the bogie's longitudinal direction. However, only two accelerometers were utilized on any individual test. The accelerometer systems utilized during each of the four bogie tests are shown in Table 2. All of the accelerometers were mounted near the center of gravity of the bogie. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications [3].

Table 2. Accelerometer System Used During Each Bogie Test

Test No.	DTS	DTS-SLICE	EDR-3
CGSA-1	X		X
CGSA-2	X	X	
CGSA-3	X		X
CGSA-4		X	X

One accelerometer system used three piezoresistive accelerometers manufactured by Endevco of San Juan Capistrano, California. The 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 with a range of ±500 g's and controlled using a Diversified Technical Systems, Inc. (DTS) Sensor Input Module (SIM), Model TDAS3-SIM-16M manufactured by DTS of Seal Beach, California. The SIM was configured with 16 MB SRAM and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack which was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

A second system, SLICE 6DX, was a modular data acquisition system manufactured by DTS of Seal Beach, California. The acceleration sensors were mounted inside the body of the 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 programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

An additional system, Model EDR-3, was a triaxial piezoresistive accelerometer system manufactured by 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.

2.5.3 Pressure Tape Switches

Three pressure tape switches were spaced at approximately 3.3 ft (1 m) intervals for test nos. CGSA-1 and CGSA-2. The three tape switches were spaced at 18 in. (457 mm) intervals for test nos. CGSA-3 and CGSA-4. The pressure tape switches were placed near the end of the bogie track and used to determine the speed of the bogie just before the impact. As the left-front tire of the bogie passed over each tape switch, a strobe light was fired sending an electronic timing signal to the data acquisition system. The system recorded the signals and the time each occurred. The speed was then calculated using the spacing between the sensors and the time between the signals. Strobe lights and high-speed video analysis are used only as a backup in the event that vehicle speeds cannot be determined from the electronic data.

2.5.4 Photography Cameras

Two high-speed AOS VITcam digital video cameras were used to document each test. The high-speed AOS cameras each had a frame rate of 500 frames per second. One camera was placed laterally from the post, with a view perpendicular to the bogie's direction of travel. The other camera was focused on the base of the post, and was placed at various angles for the four tests. Additionally, a Nikon D50 digital camera was used to document pre-test and post-test conditions for each post.

2.6 End of Test Determination

During an impact, the data acquisition system records the accelerations that the bogie observes from all sources, not just the post. Thus, vibrations in the bogie vehicle, impact head, and accelerometer mounting assembly are also recorded and result in a high frequency acceleration trace. Since the bogie vehicle may still be vibrating after the impact event, the data may extend beyond the failure of the post. For this reason, the end of the test needed to be defined.

In general, the end of test time was identified as the time that the acceleration trace subsided back toward zero and it was clear that the continuation of vibrations were not caused by the interaction with the post. Additionally, the test duration was limited by the bogie-post contact time so that there were no unreasonably long test durations. For each test, the high-speed video was used to establish the length of time that the bogie head was actually in contact with the post, and this time was then used to define the end of the test.

2.7 Data Processing

Initially the electronic accelerometer data was filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications. 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 verses time. Initial velocity of the bogie, calculated from the pressure switch data, was then used to determine the bogie velocity. The calculated velocity trace was integrated to find the bogie's displacement. This displacement is also the displacement of the post at impact height. 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 COMPONENT TESTING RESULTS AND DISCUSSION

3.1 Results

Analysis of the bogie test results was focused on two main areas, material damage and force vs. deflection characteristics. Care was taken to document all system damage in the form of plastic deformation, tearing, fracture, and anchor pullout. Additionally, the accelerometer data was analyzed to obtain the force applied by the bogie vehicle impact and the deflection of the post at impact height. This data was then used to find total energy (the area under the force versus deflection curve) dissipated during each test. The forces, displacements, and energies described herein were calculated from the data recorded by the DTS unit for test nos. CGSA-1, CGSA-2, and CGSA-3. For test no. CGSA-4, the DTS system was not used, so the values were calculated from the DTS-SLICE data. Individual test results are provided in Appendix B for all accelerometers.

3.1.1 Test No. CGSA-1

For test no. CGSA-1, the post was connected to the base plate using a $^{5}/_{16}$-in. (8-mm) fillet weld all around the base of the post. To anchor the post assembly, four 1-in. (25-mm) diameter threaded rods were epoxied into the tarmac with an embedment depth of 12 in. (305 mm). During test no. CGSA-1, the bogie impacted the post at a speed of 9.8 mph (15.8 km/h). As a result, the post rotated backward, and the bogie was eventually brought to a stop at a displacement of 21.7 in. (546 mm) as determined from the DTS data. Post-test inspection revealed that both the back flange and the web of the post had buckled and the base place was bent upward. Although the weld held, the plate was torn adjacent to the weld on the front flange, and the tearing extended around the flange and 1 in. (25 mm) toward the back of the plate on both sides.

Force vs. deflection and energy vs. deflection curves were created from the DTS accelerometer data, as shown in Figure 12. Early in the impact event, a maximum resistance of 18.1 kips (80.5 kN) was recorded at 4.7 in. (119 mm) of deflection. Video analysis confirmed this peak force corresponded to the time just prior to the plate beginning to tear, or 0.034 seconds after impact. After the onset of tearing, the resistance force decreased and remained relatively constant. At the maximum deflection of 21.7 in. (551 mm), the post assembly had absorbed 191.7 k-in. (21.7 kJ) of energy. Time-sequential and post-impact photographs are shown in Figures 13 through 15.

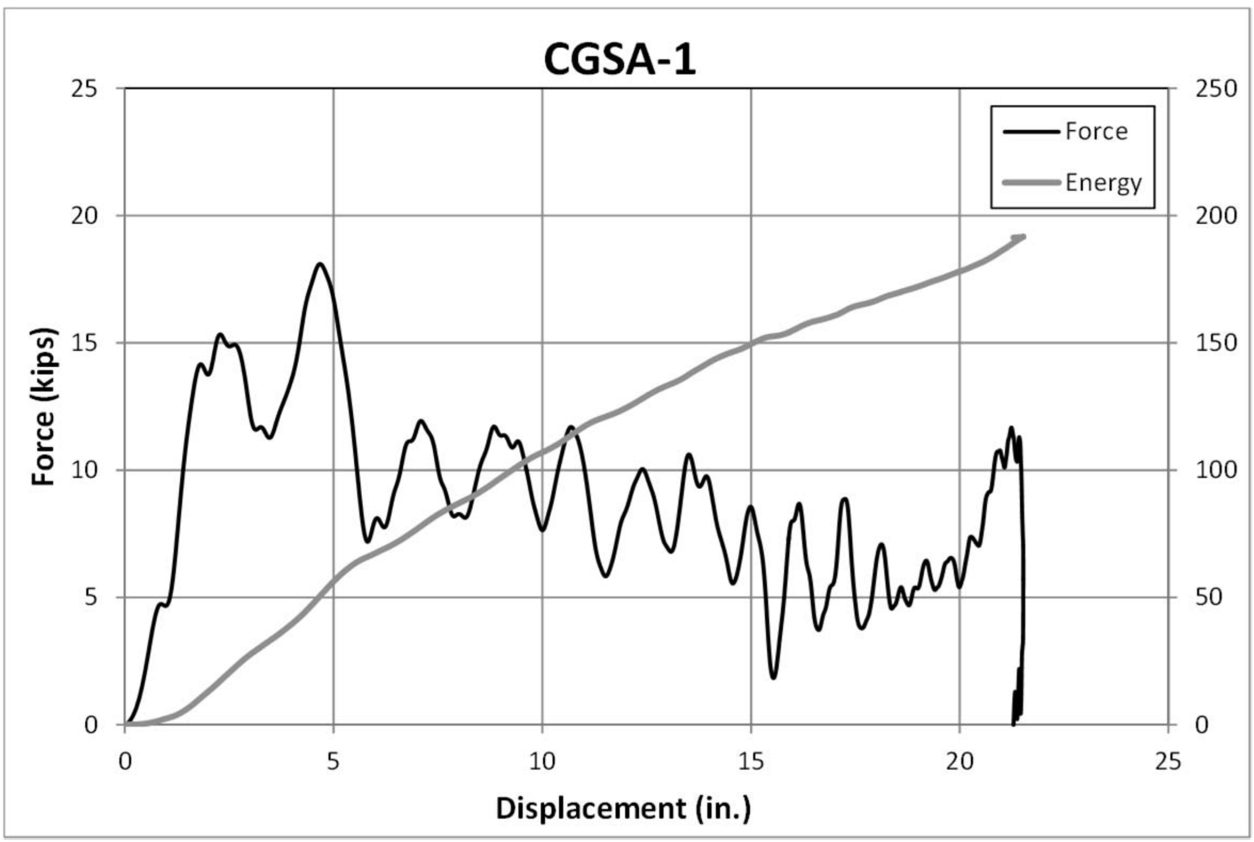
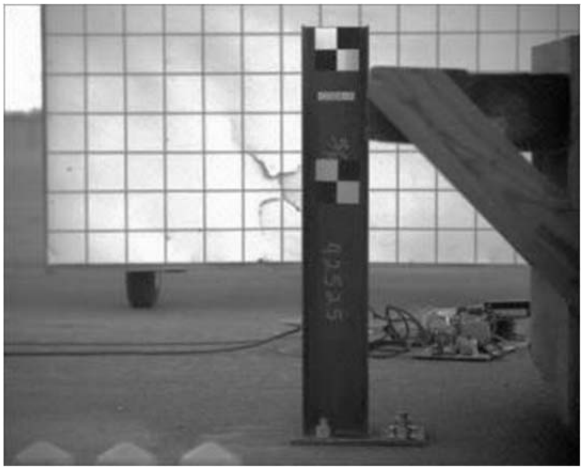


Figure 12. Force vs. Deflection and Energy vs. Deflection, Test No. CGSA-1



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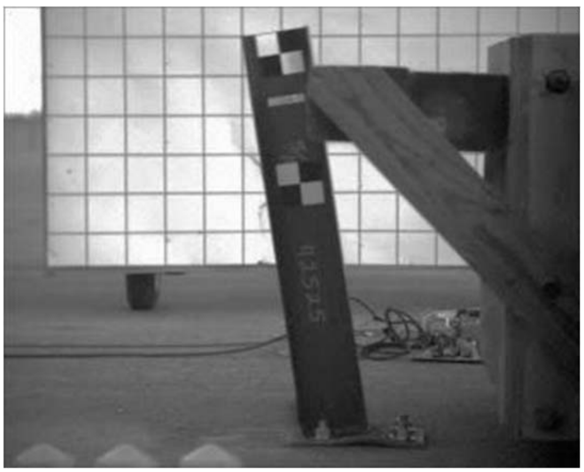

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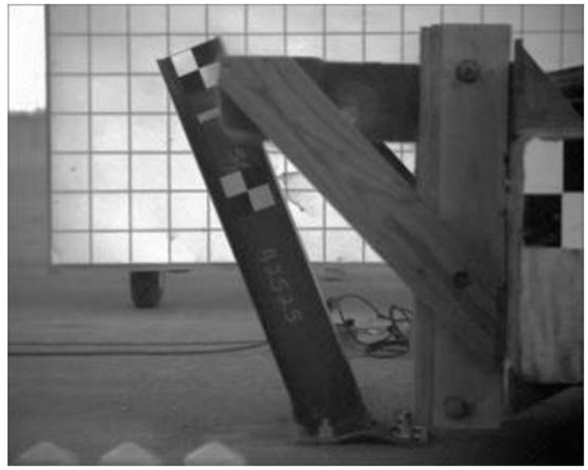

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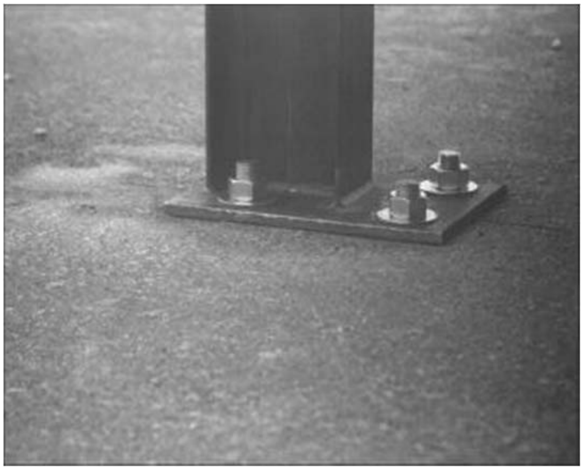
Figure 13. Time-Sequential Photographs, Test No. CGSA-1



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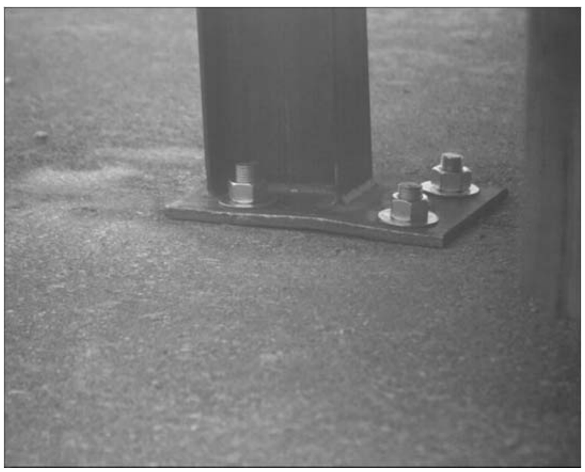

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Figure 14. Time-Sequential Photographs, Test No. CGSA-1

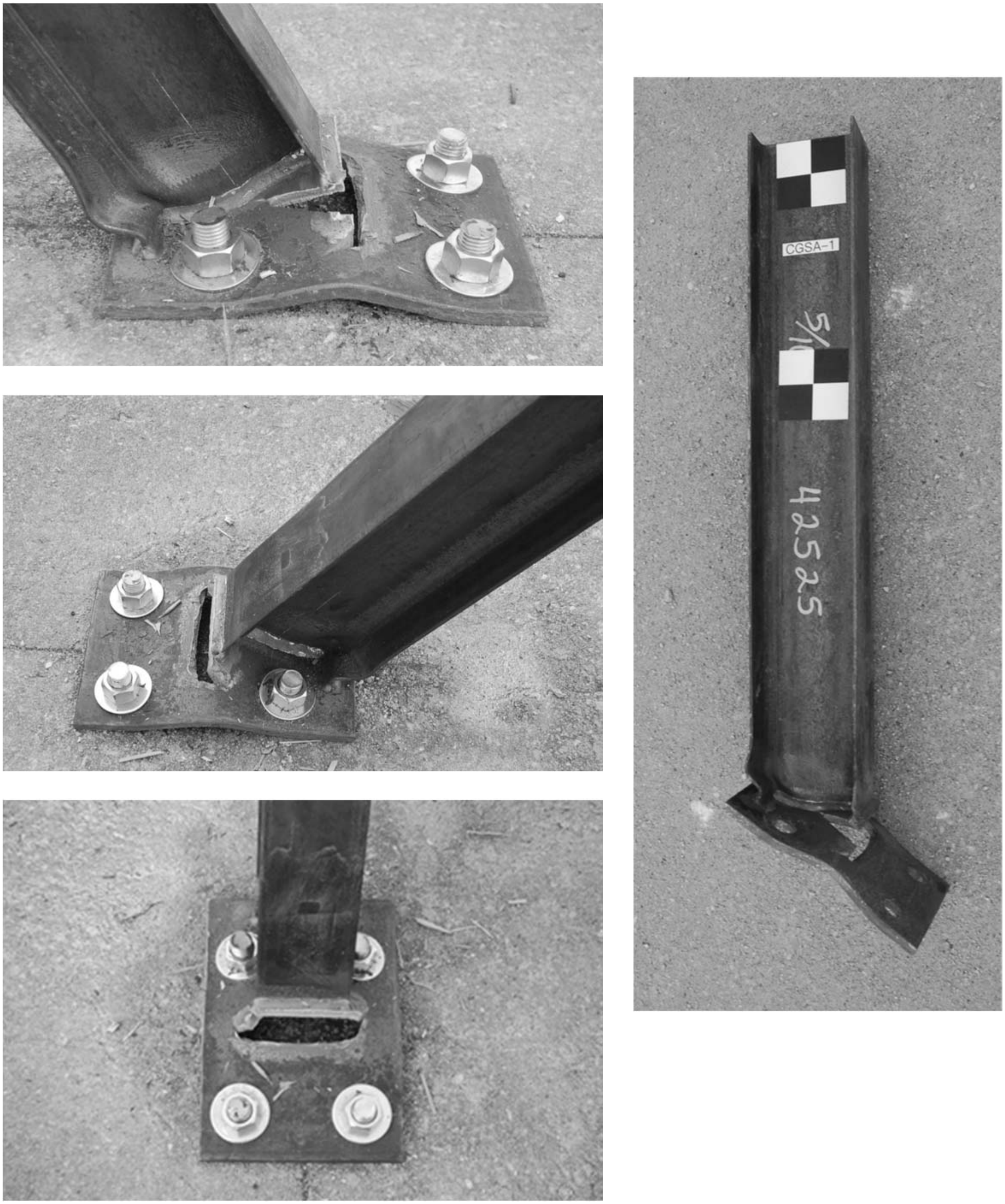

Figure 15. Post-Impact Photographs, Test No. CGSA-1

3.1.2 Test No. CGSA-2

For test no. CGSA-2, the post was connected to the base plate using a ¼-in. (6-mm) fillet weld all around the base of the post. To anchor the post assembly, four 1-in. (25-mm) diameter threaded rods were epoxied into the tarmac with an embedment depth of 12 in. (305 mm). During test no. CGSA-2, the bogie impacted the post at a speed of 9.6 mph (15.4 km/h). As a result, the post rotated backward, and the bogie eventually overrode the top of the post at a displacement of 23.2 in. (589 mm) as determined from the DTS data. Post-test examination revealed failure modes similar to test no. CGSA-1. The back flange of the post had buckled, and the plate was torn adjacent to the front flange weld and continued approximately ¾ in. (19 mm) backward on each side.

Force vs. deflection and energy vs. deflection curves were created from the DTS accelerometer data, as shown in Figure 16. Early in the impact event, a maximum force of 13.8 kips (61.4 kN) was recorded at a deflection of 5.0 in. (127 mm). Video analysis confirmed this peak force occurred just prior to the onset of plate tearing, or 0.030 seconds after impact. Once tearing began, the resistance force decreased and remained relatively constant. At a maximum deflection of 23.2 in. (589 mm), the post assembly had absorbed 183.2 k-in. (20.7 kJ) of energy. Time-sequential and post-impact photographs are shown in Figures 17 through 19.

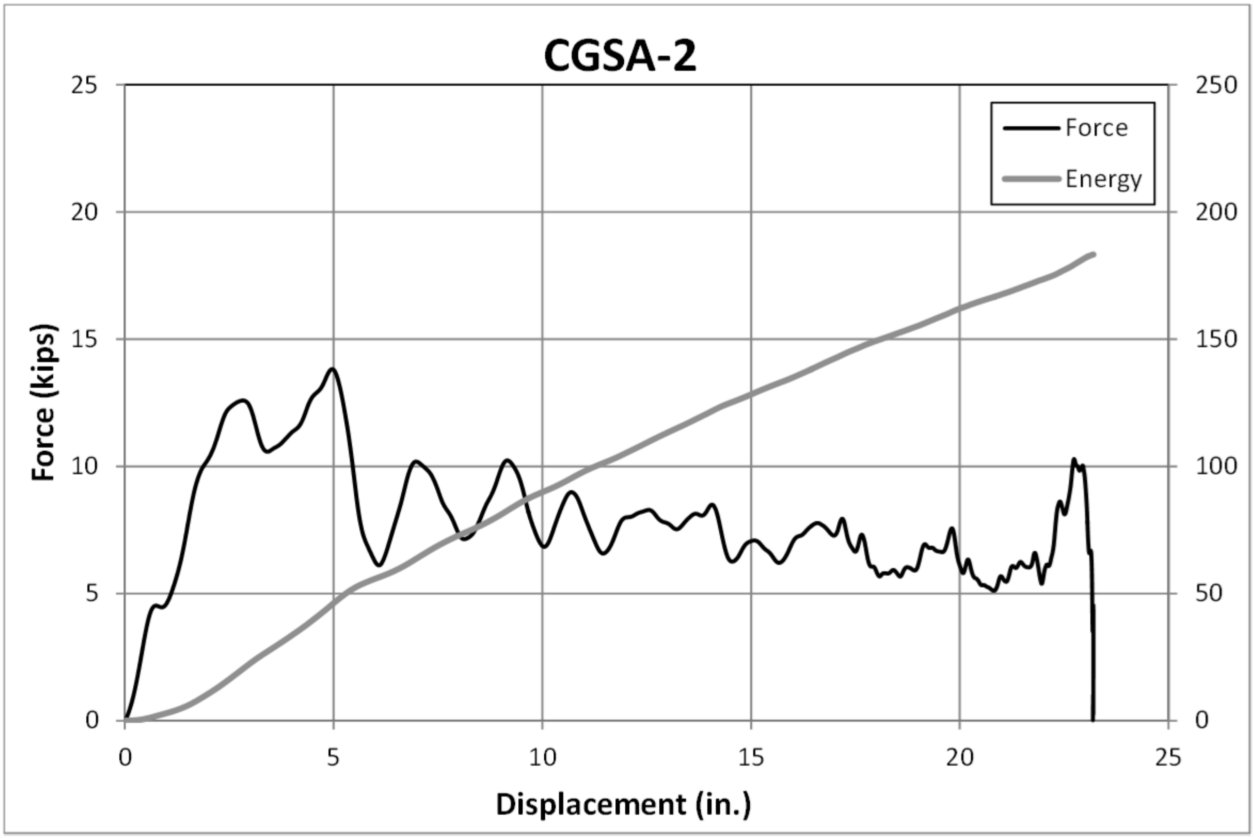

Figure 16. Force vs. Deflection and Energy vs. Deflection, Test No. CGSA-2

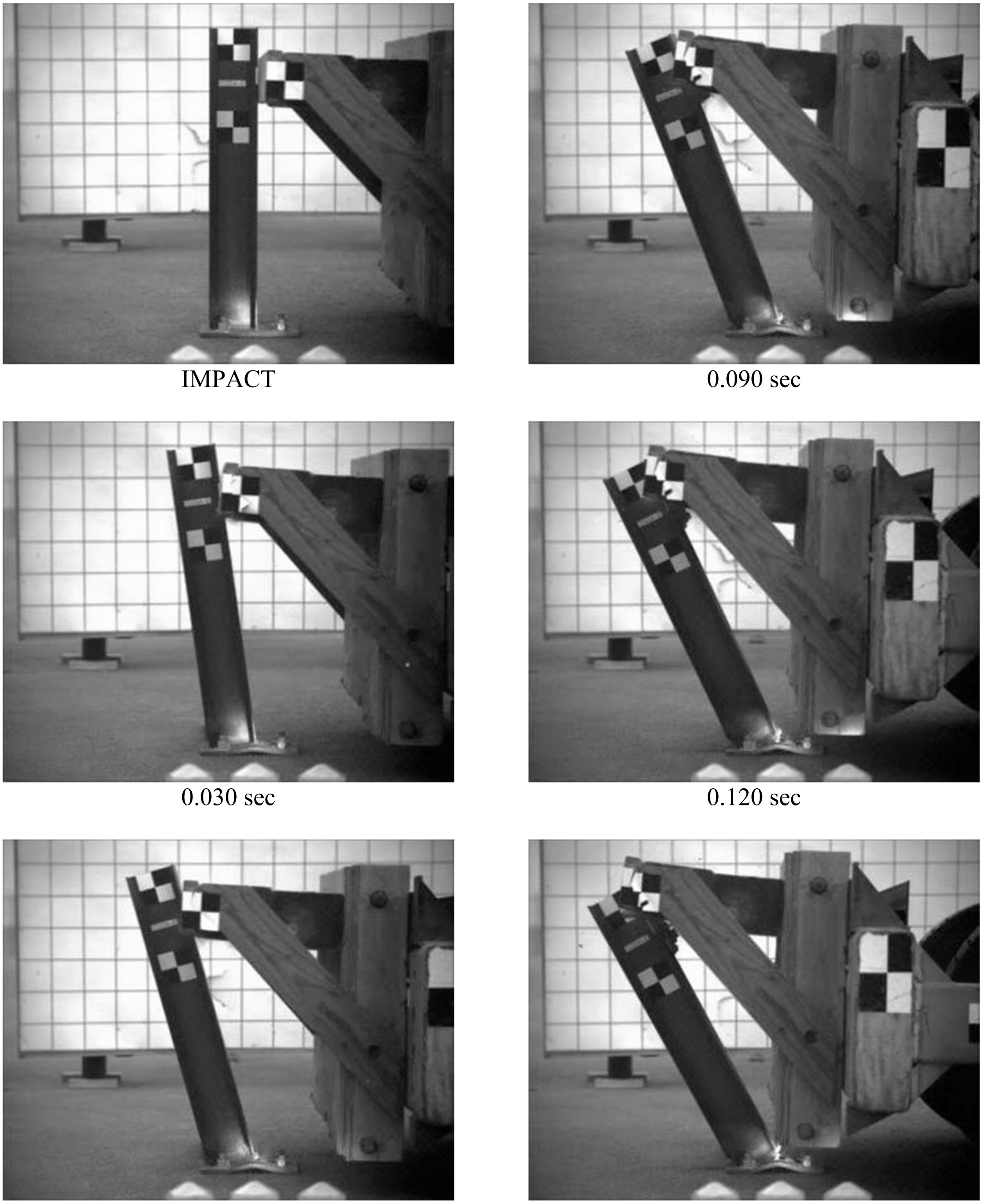

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Figure 17. Time-Sequential Photographs, Test No. CGSA-2

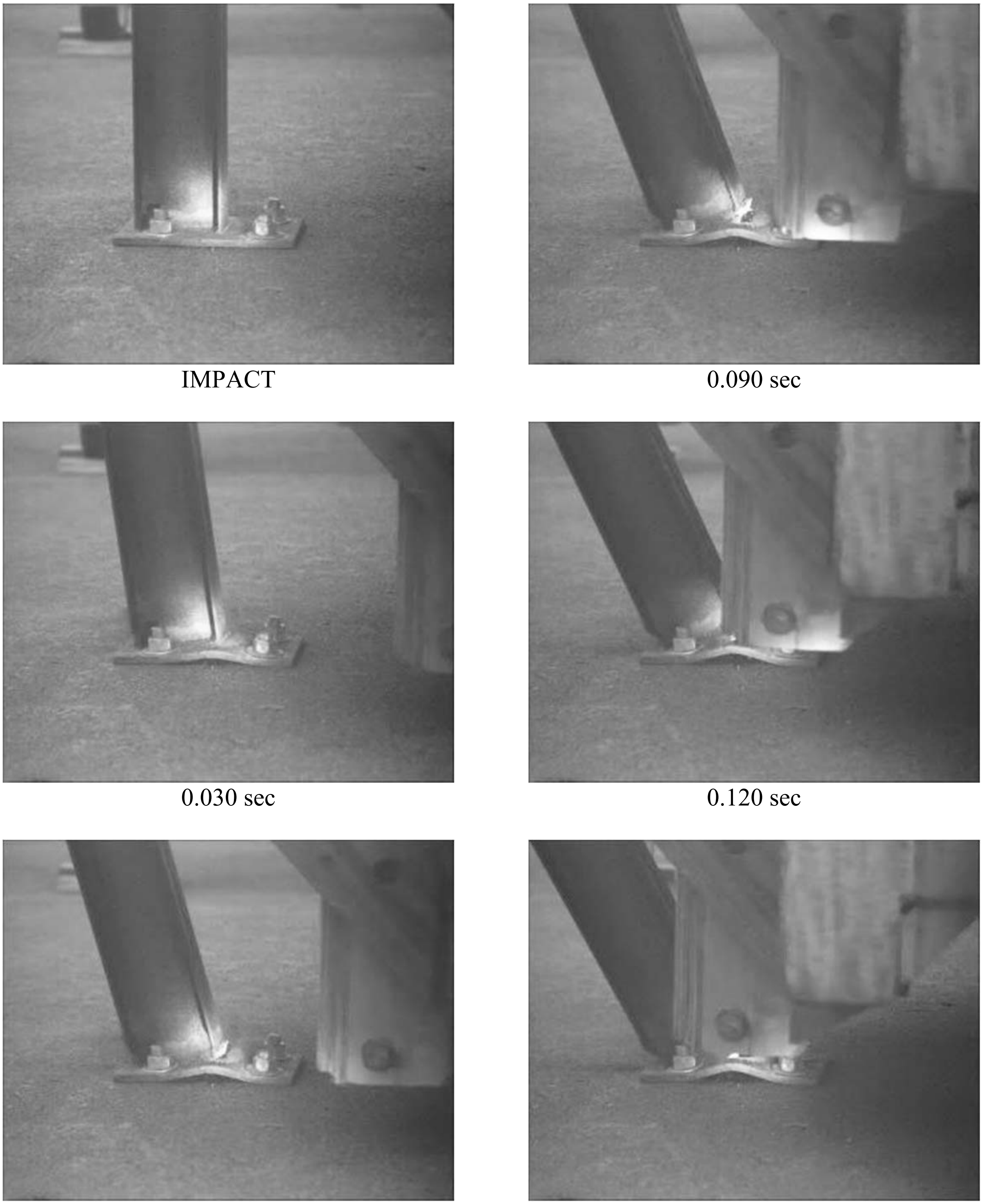

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Figure 18. Time-Sequential Photographs, Test No. CGSA-2

Figure 19. Post-Impact Photographs, Test No. CGSA-2

3.1.3 Test No. CGSA-3

For test no. CGSA-3, the post was connected to the base plate using a $^{5}/_{16}$-in. (8-mm) fillet weld all around the base of the post. To anchor the post assembly, four 1-in. (25-mm) diameter threaded rods were epoxied into the tarmac with an embedment depth of 6 in. (152 mm). During test no. CGSA-3, the bogie impacted the post at a speed of 9.7 mph (15.6 km/h). As a result, the post rotated backward, and the bogie eventually overrode the top of the post. At 0.020 sec after impact, concrete cracks began to form around the front anchor rods, and by 0.026 seconds, the anchor rods were pulled out of the concrete. The post assembly then rotated about the back of the plate causing the back anchors to bend. At approximately 0.150 seconds, the base of the bogie head impacted the post and caused the back anchor rods to pull out.

Force vs. deflection and energy vs. deflection curves were created from the DTS accelerometer data, as shown in Figure 20. Note, the curves only show the interaction forces and energies related to the primary impact. The plotted data was extracted prior to the secondary impact between the bottom of the bogie head and the base of the post. Early in the test, peak forces of 16.0 kips and 13.0 kips (71.2 kN and 57.8 kN) were recorded. Once the anchorage failed at approximately 5 in. (127 mm) of deflection, the resistance force decreased quickly and was nearly zero when the base of bogie impacted the post at 15.1 in. (384 mm) of deflection. Prior to this secondary impact, the assembly had absorbed 80.4 k-in. (9.1 kJ) of energy. Time-sequential and post-impact photographs are shown in Figures 21 through 23.

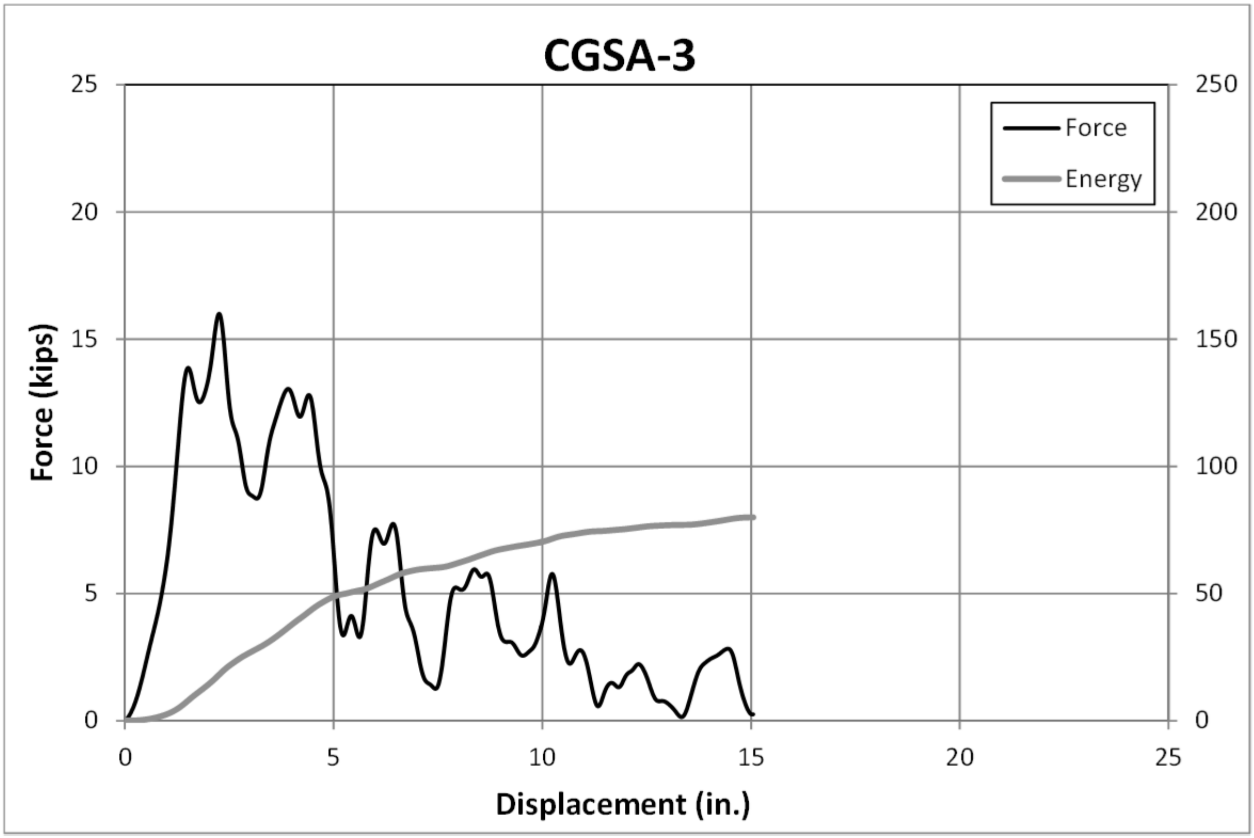
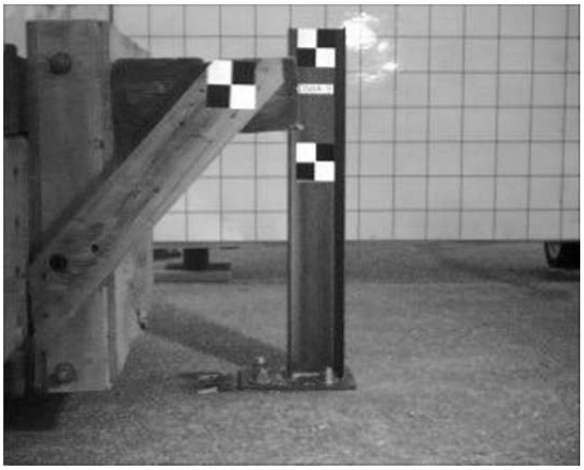


Figure 20. Force vs. Deflection and Energy vs. Deflection, Test No. CGSA-3



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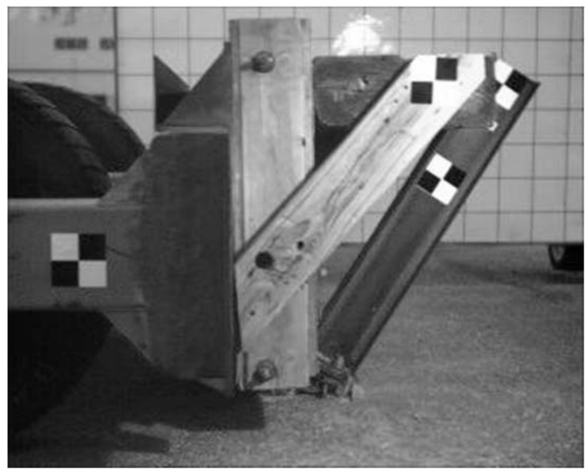

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Figure 21. Time-Sequential Photographs, Test No. CGSA-3


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Figure 22. Time-Sequential Photographs, Test No. CGSA-3

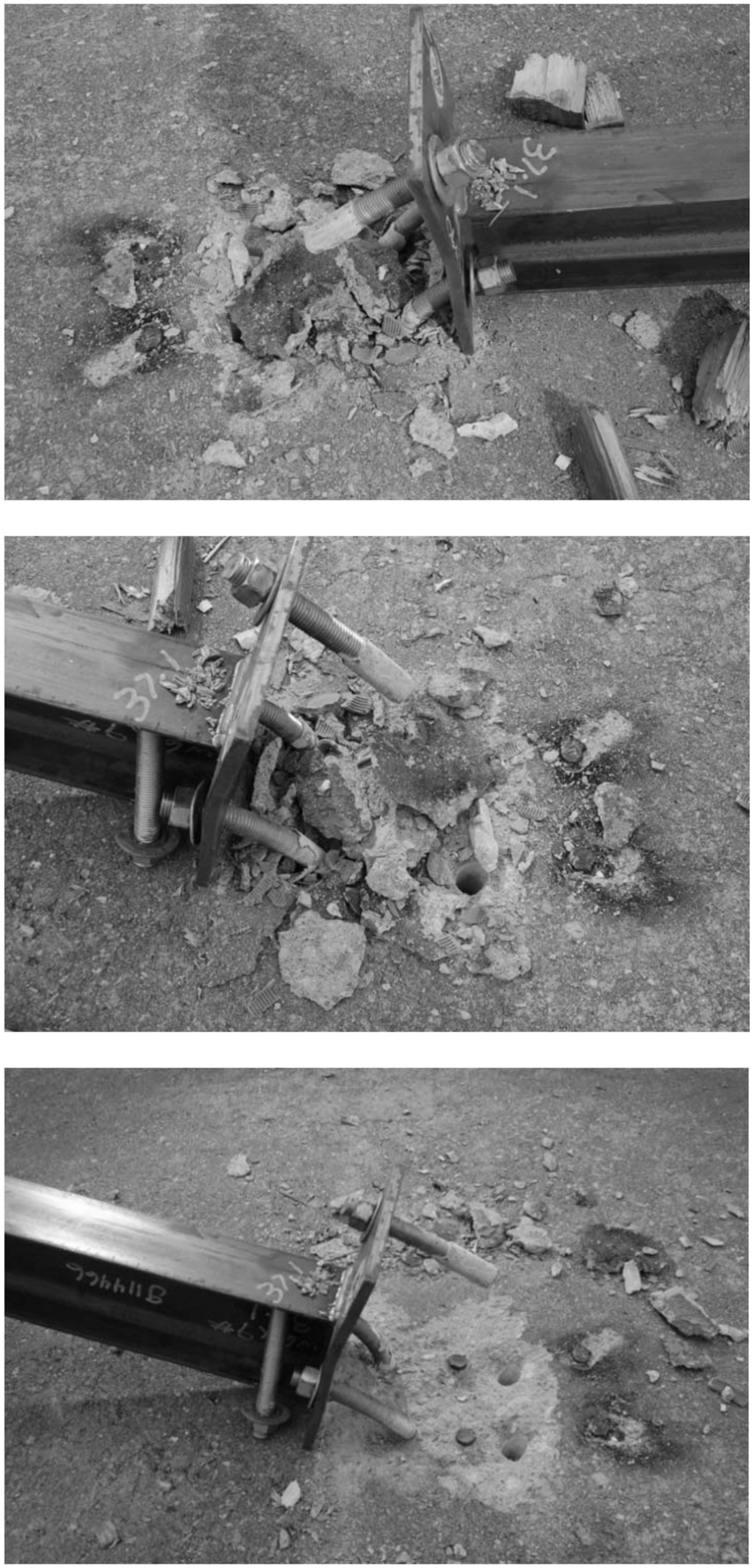

Figure 23. Post-Impact Photographs, Test No. CGSA-3

3.1.4 Test No. CGSA-4

For test no. CGSA-4, the post was connected to the base plate using a 3-pass, $^{5}/_{16}$-in. (8-mm) fillet weld on the front flange and a single-pass ¼-in. (6-mm) fillet weld on the web and back flange. To anchor the post assembly, four 1-in. (25-mm) diameter threaded rods were epoxied into the tarmac with an embedment depth of 8 in. (203 mm). During test no. CGSA-4, the bogie impacted the post at a speed of 11.6 mph (18.7 km/h). As a result, the post bent backward, and the bogie eventually overrode the top of the post at a displacement of 20.3 in. (516 mm) as determined from the DTS-SLICE data. Post-test examination revealed buckling of the back flange and web of the post along with bending of the base plate. No evidence of plate tearing or weld failure was present.

Force vs. deflection and energy vs. deflection curves were created from the DTS-SLICE accelerometer data, as shown in Figure 24. Early in the test, multiple force spikes of around 20 kips (89 kN) were recorded within the first 6 in. (152 mm) of deflection. The resistance force then steadily declined until the bogie overrode the post at a deflection of 20.3 in. (516 mm). The post assembly absorbed a total of 189.7 k-in. (21.4 kJ) of energy. Time-sequential and post-impact photographs are shown in Figures 25 through 27.

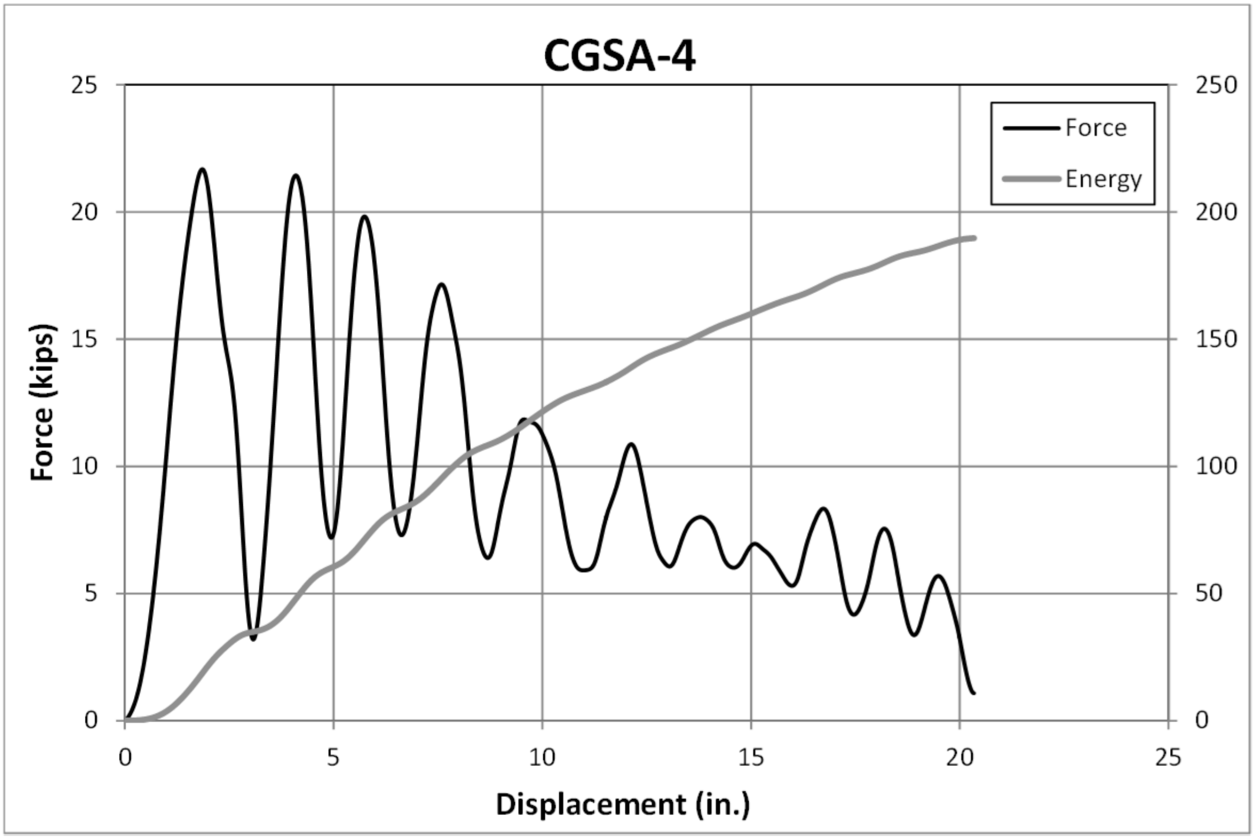

Figure 24. Force vs. Deflection and Energy vs. Deflection, Test No. CGSA-4

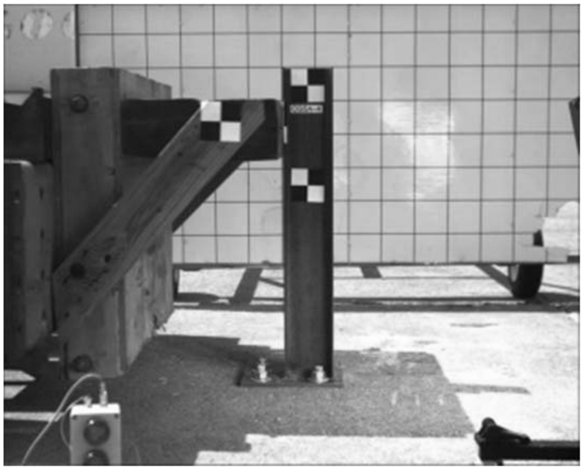

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Figure 25. Time-Sequential Photographs, Test No. CGSA-4

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Figure 26. Time-Sequential Photographs, Test No. CGSA-4

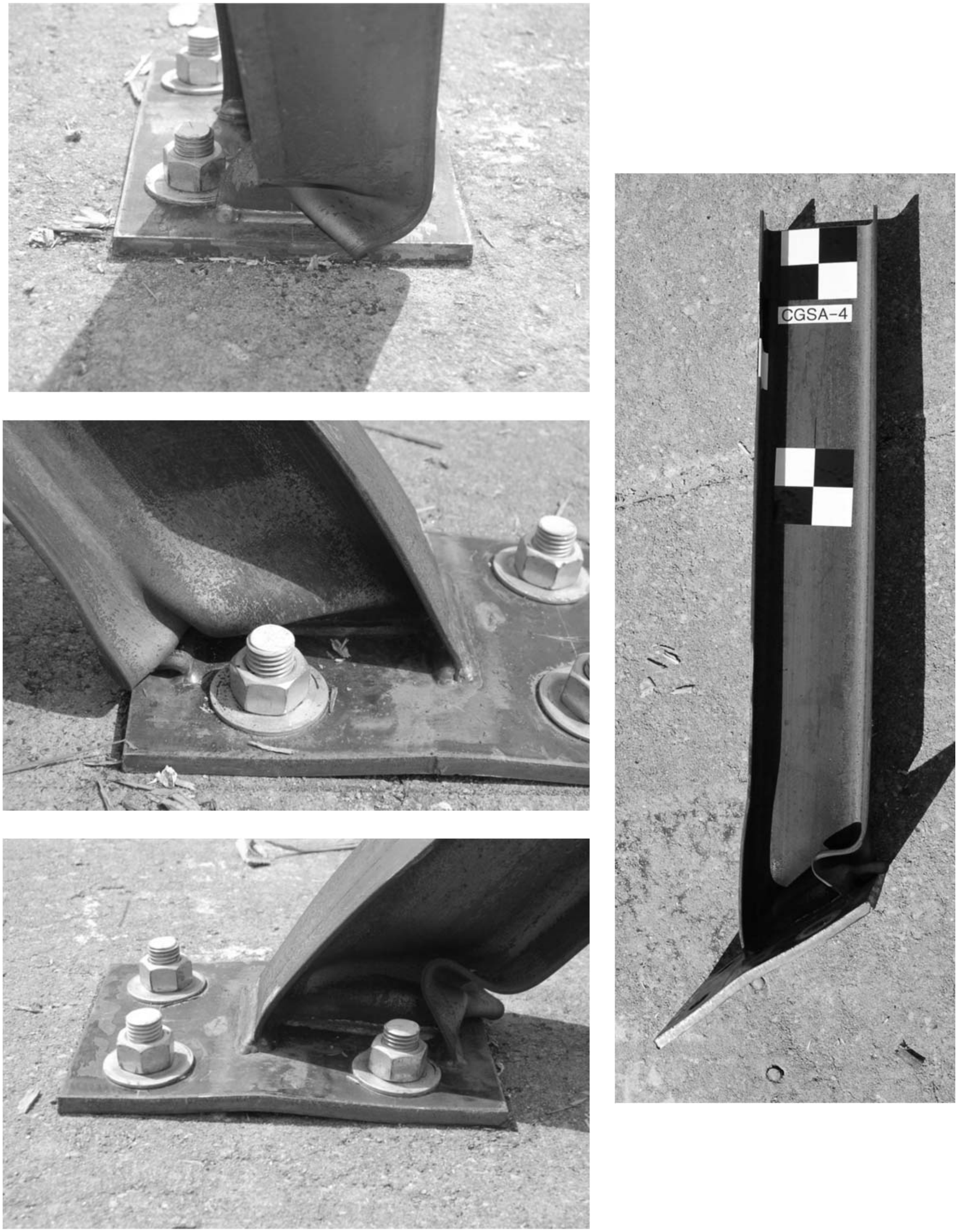


Figure 27. Post-Impact Photographs, Test No. CGSA-4

3.2 Discussion

Results from the bogie testing program are summarized in Table 3. Both the weld detail and the embedment depth of the anchors were shown to be critical for the attachment of guardrail posts to the culvert slab. Test nos. CGSA-1 and CGSA-2 attempted to simplify the weld on the front flange of the post by using single-pass $^5/_{16}$-in. (8-mm) and $^1/_4$-in. (6-mm) fillet welds, respectively. However, both tests resulted in large tears in the base plate adjacent to the weld on the front flange. In an effort to prevent plate tearing, the base plate material was changed from A36 to A572 Grade 50 for test nos. CGSA-3 and CGSA-4. Although plate tearing did not occur in the A572 plates, the anchor pullout failure of test no. CGSA-3 prevented a full analysis of the single-pass, $^5/_{16}$-in. (8-mm) weld. As a result, only the 3-pass, $^5/_{16}$-in. (8-mm) weld used in test no. CGSA-4 (same as the original system) has been proven effective in anchoring the guardrail post and preventing material fracture.

Table 3. Test Results from Bogie Testing Matrix

Test No.	Fillet Weld in. (mm)	Anchor Embedment in. (mm)	Impact Velocity mph (km/h)	Average Force kips (kN)			Primary Failure Mechanism
				@ 10 in.	@ 15 in.	@ 20 in.	
CGSA-1	$^5/_{16}$ (8)	12 (305)	9.8 (15.8)	10.7 (47.6)	10.0 (44.5)	8.9 (39.6)	Plate Tearing
CGSA-2	$^1/_4$ (6)	12 (305)	9.6 (15.4)	9.0 (40.0)	8.6 (38.3)	8.1 (36.0)	Plate Tearing
CGSA-3	$^5/_{16}$ (8)	6 (152)	9.7 (15.6)	7.0 (31.1)	5.3 (23.6)	NA	Anchor Pullout
CGSA-4	3-Pass $^5/_{16}$ (3-Pass 8)	8 (203)	11.6 (18.7)	12.1 (53.8)	10.7 (47.6)	9.5 (42.3)	Post Buckling

As mentioned in the previous paragraph, test no. CGSA-3 resulted in the epoxied anchor rods pulling out of the concrete. Thus, the 6-in. (152-mm) embedment depth was deemed too shallow to develop the full anchor load of the guardrail post attachment. Alternatively, the 8-in.

(203-mm) embedment depth utilized in test no. CGSA-4 provided the necessary anchorage strength throughout the duration of the test and showed no signs of premature failure. Therefore, the recommended minimum embedment depth for epoxied anchor rods was set as 8 in. (203 mm).

3.3 Comparison to Original Testing Results

Test no. CGSA-4 provided the desired anchorage results by preventing weld fracture, plate tearing, and anchor pullout. However, both the post and base plate utilized in test no. CGSA-4 were fabricated from steel materials with a minimum yield stress of 50 ksi (345 MPa), while the original system was fabricated and tested utilizing A36 steel components. Therefore, it was important to quantify any differences in resistance that results from the change in material grade.

The force vs. displacement and energy vs. displacement curves from the four bogie tests conducted for this study and the curves from the bogie test conducted in the original study, test no. KCB-7 [1], are shown in Figures 28 and 29, respectively. The 50-ksi (345-MPa) steel of test no. CGSA-4 resulted in higher peak forces of the first 8 in. (203 mm) of deflection. However, after 20 in. (508 mm) of deflection, there was only a 6 percent difference in the total energy absorbed between test nos. CGSA-4 and KCB-7. Thus, both post assemblies would be expected to perform similarly when used in a full-system installation. The use of either steel grade should be acceptable for use in the W-beam guardrail system attached to low-fill culverts.

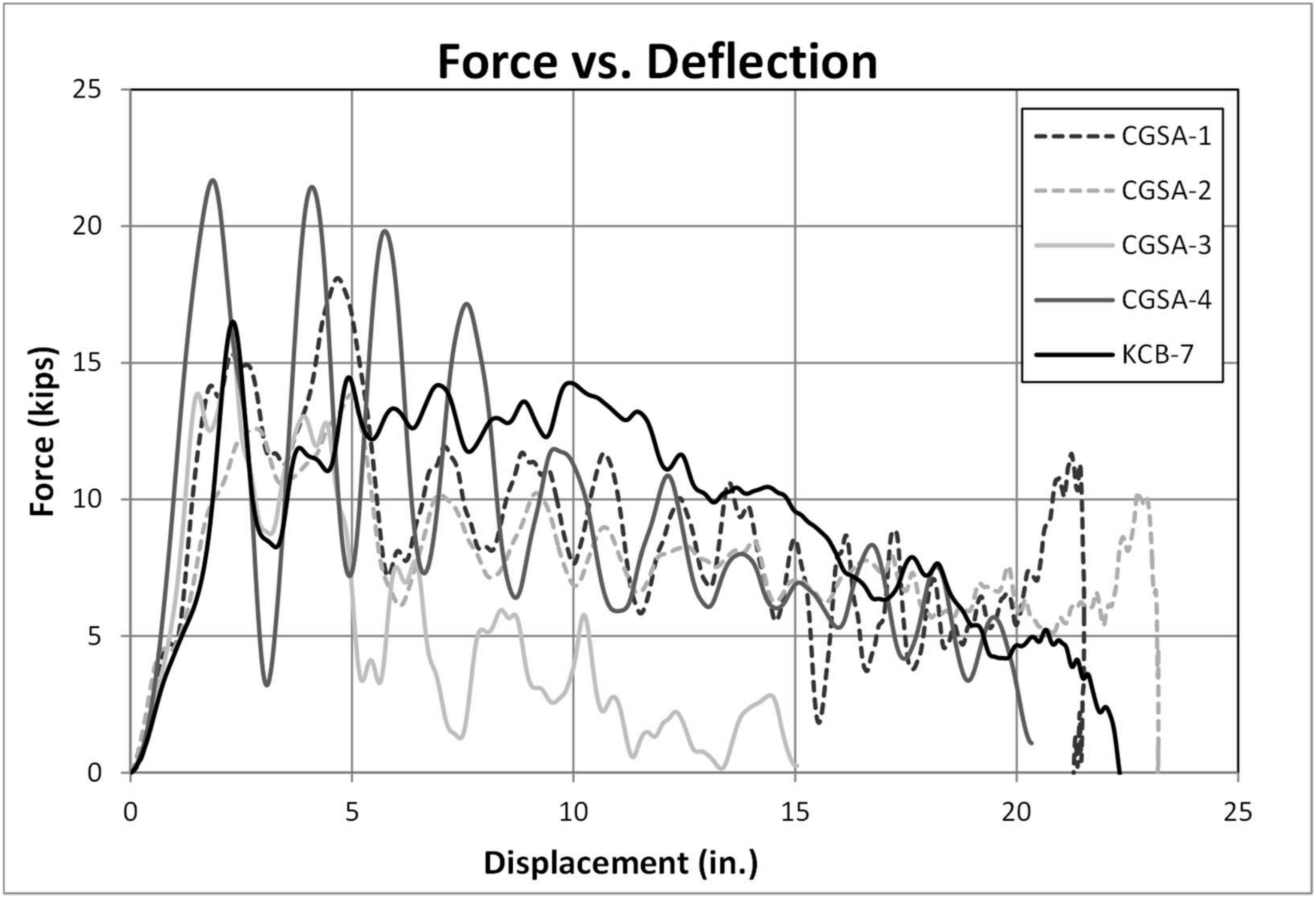


Figure 28. Comparison of Force vs. Deflection Curves

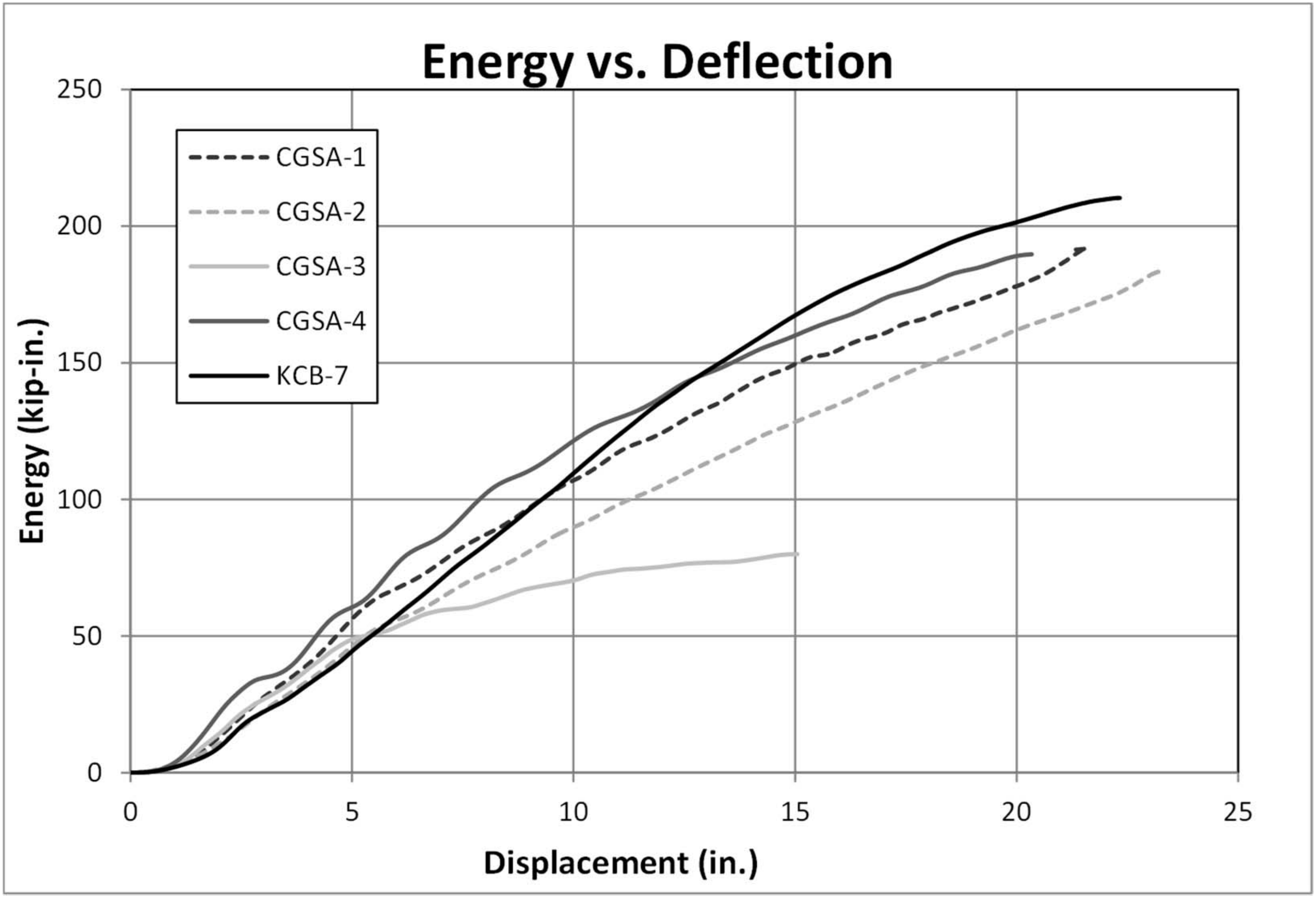


Figure 29. Comparison of Energy vs. Deflection Curves

4 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Two objectives were contained within this research effort to determine alternatives to the W-beam guardrail system for attachment to the top of low-fill culverts. The first objective was to determine if an alternative weld detail could be utilized to simplify the three-pass fillet weld on the front flange of the post. The second objective was to develop an epoxy anchor alternative to bolting through the top slab of the culvert. These system modifications were evaluated through a series of four dynamic, bogie tests conducted under the same impact conditions utilized in the original development study.

Both $^{1}/_{4}$-in. and $^{5}/_{16}$-in. (6-mm and 8-mm) fillet weld options were explored. However, both of these weld details resulted in large tears in the base plate adjacent to front flange of the post in test nos. CGSA-1 and CGSA-2. An attempt was made to utilize a 50-ksi (345-MPa) steel base plate with the $^{5}/_{16}$-in. (8-mm) weld to prevent tearing, but the epoxy anchors failed during test no. CGSA-3 prior to the development of the full lateral resistance of the post assembly. Only test no. CGSA-4, which utilized the original weld details from the as-tested system, resisted the full impact load without component failure. Therefore, the recommended weld details for the post-to-base plate remain the same with a 3-pass, $^{5}/_{16}$–in. (8-mm) fillet weld on the front flange and a $^{1}/_{4}$-in. (6-mm) fillet weld on the web and back flange.

Although the simplified fillet weld details explored during this study resulted in component fractures, it is recognized that other weld options (e.g., full penetration welds) may provide adequate strength and durability. However, until these options are evaluated through similar dynamic tests, the use of alternative weld details remains unverified. Thus, MwRSF will continue to recommend the use of the original weld details for the post-to-plate assemblies.

The post assembly used in test no. CGSA-4 was fabricated from 50-ksi (345-MPa) steel with a minimum yield stress of 50 ksi (345 MPa) as opposed to the A36 components utilized in the original system. However, this variation in steel grades resulted in only minor changes to the resistance characteristics of the post. In fact, when comparing the test results between test nos. CGSA-4 and KCB-7 (conducted with A36 steel components during the original system development study), the total energy absorbed through 20 in. (508 mm) of deflection was found to differ by only 6 percent. Thus, a complete guardrail installation would be expected to perform similarly when using either steel grade for the post assembly. Subsequently, both ASTM A36 and Grade 50 steel post and base plate components are recommended for use in the W-beam guardrail attached to culvert slabs. This conclusion is significant because A36 components may be more difficult to find, and recent trends have shown that manufactures are supplying higher grade materials more frequently.

In evaluating the potential for an epoxied anchor option as opposed to the original through-bolt anchorage, tests were conducted utilizing Powers Fasteners AC100+ Gold epoxy and various embedment depths. Identical to the original system design, four 1-in. (25-mm) diameter, ASTM A307 threaded rods where used to anchor the base plate to the concrete tarmac. A 6-in. (152-mm) embedment depth was utilized in test no. CGSA-3, but the anchor rods were pulled out of the concrete during the impact event. Subsequently, the embedment depth was increased to 8 in. (203 mm) for test no. CGSA-4, and the anchors successfully held the impact load without any signs of failure. Therefore, it is recommended to utilize a minimum embedment depth of 8 in. (203 mm) when using the epoxy anchorage option instead of through-bolts.

The epoxy resin should have a minimum bond strength equal to or greater than that provided by the Powers Fasteners AC100+ Gold epoxy, 1,305 psi (9.0 MPa), and the epoxy anchors should be installed according to manufacturer specifications. When the system is installed with the recommended minimum 10-in. (254-mm) offset between the post and the inside face of the headwall, anchor strength reductions due to edge effects are eliminated. However, for installations to a culvert without a headwall, a 12-in. (305-mm) offset is recommended between the epoxy anchors and the edge of the culvert. During installation, the culvert and drilled holes should be dry and free of dirt and debris to provide optimum conditions to develop the bond. Finally, the concrete should be in good condition (i.e., minimal cracking) and have a minimum compressive strength of 4,000 psi.

5 REFERENCES

1. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Reid, J.D., and Holloway, J.C., *NCHRP 350 Development and Testing of a Guardrail Connection to Low-Fill Culverts*, Report No. TRP-03-114-02, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, November 1, 2002.

2. Ross, H.E., Sicking, D.L., Zimmer, R.A., and Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program (NCHRP) Report No. 350, Transportation Research Board, Washington, D.C., 1993.

3. 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. Material Specifications

Table A-1. Material Certification List, Test Nos. CGSA-1 and CGSA-2

Description	Material Specifications and/or Grade	Material Reference
W6x9 [W152x13.4] Post, 37" [940] long	ASTM A992 Min. 50 ksi [345 MPa]	Heat No. 22603040
Base Plate, 1/2" x 8 1/2" x 12" [13x216x305]	ASTM A36	Heat No. JW1110217202
1" [25] dia.-UNC Threaded Rod, 14" [356] long	SAE J429 Grade 2 ASTM A307 Grade C ASTM F1554 Grade 36	CoC - 6/1/2009
1" [25] dia. Flat Washer	ASTM F844	CoC - 2/7/2011
1" [25] dia. - 8 UNC Nut	ASTM A563A	CoC - 6/1/2009
Powers Fasteners Epoxy - AC100+ Gold	Min. Bond Strength 1,305 psi	Lot# C117 Exp.: December 2012

Table A-2. Material Certification List, Test Nos. CGSA-3 and CGSA-4

Description	**Material Specifications and/or Grade**	**Material Reference**
W6x9 [W152x13.4] Post, 37" [940] long	ASTM A992 Min. 50 ksi [345 MPa]	Heat No. 22603040
Base Plate, 1/2" x 8 1/2" x 12" [13x216x305]	ASTM A36	Heat No. JW1110217202
1" [25] dia.-UNC Threaded Rod, 14" [356] long	SAE J429 Grade 2 ASTM A307 Grade C ASTM F1554 Grade 36	CoC - 6/1/2009
1" [25] dia. Flat Washer	ASTM F844	CoC - 2/7/2011
1" [25] dia. - 8 UNC Nut	ASTM A563A	CoC - 6/1/2009
Powers Fasteners Epoxy - AC100+ Gold	Min. Bond Strength 1,305 psi	C222/ APR13

Bill To:
STEEL AND PIPE SUPPLY
P.O. BOX 1688
MANHATTAN KS
66502 US

Ship To: 9
STEEL AND PIPE SUPPLY
401 NEW CENTURY PARKWAY
GARDNER KS
66031 US

Order Date:07/21/2011
PO No:45/163465
Mill Order No:3912767
Load No:1392569
Manifest No:2088305

CERTIFIED MATERIAL TEST REPORT
GERDAU AMERISTEEL
GERDAU AMERISTEEL
Midlothian Mill
300 Ward Road
Midlothian, TX 76065

SPECIFICATIONS	SIZE	GRADE	LENGTH	PRODUCT
ASTM A6-09. A992-06a. A572-07	W 6 X 9# / W150 X 13.5	992/572-50	20 FT / 6.096 M	WF BEAMS

HEAT NO: 22603040

CHEMICAL ANALYSIS

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	Nb	CE
.06	.90	.026	.012	.23	.39	.08	.15	.028	.009	.002	.003	.018	.28

PHYSICAL PROPERTIES

Yield Strength		Tensile Strength		Specimen Area		Elongation	Gage Length		Bend Test	ROA
KSI	MPa	KSI	MPa	Sq In	Sq cm	%			Dia. Result	%
63.4	437.1	77.1	531.6	0.269	1.74	24.6	8 In	200 mm		
62.6	431.6	77.6	535.0	0.268	1.73	23.3	8 In	200 mm		

TENSILE TEST RATIOS

YLD/TENS	TENS/YLD	YLD/TENS	TENS/YLD
.82	1.22	.81	1.24

Remarks

MATERIAL COMPLIES WITH ASTM A709-50 & 50S FOR NON-TENSION COMPONENTS.

All manufacturing processes of this product, including electric arc MELTING and continuous CASTING, occurred in the U.S.A.
CMTR complies with EN 10204 3.1

"I hereby certify that the contents of this report are correct and accurate. All tests and operations performed by this material manufacturer or its sub-contractors, when applicable, are in compliance with the requirements of the material spe

Signed: [signature] Date: Aug. 17, 2011 Signed: ____________ Date: ____________
Tom L. Harrington: Quality Assurance Manager Notary Public (if applicable)

Page: 1 of 2

Figure A-1. W6x9 (W152x13.4) Steel Posts, Test Nos. CGSA-1 and CGSA-2

STOCK

PO# 43945

G-176137

GERDAU AMERISTEEL

Chemical and Physical Test Report
Made and Melted In USA

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

SHIP TO	INVOICE TO	SHIP DATE
STEEL AND PIPE SUPPLY CO. INC. 1003 FORT GIBSON ROAD 918-266-6325 PORT CATOOSA, OK 74015	STEEL AND PIPE SUPPLY CO. INC. PO BOX 1688 MANHATTAN, KS 66505-1688	05/20/11 **CUST. ACCOUNT NO** 40130833

PRODUCED IN: CARTERSVILLE

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
W8 X 28#	A57250/992	ASTM A572 GR50-07, ASTM A992 -06A, ASTM A709 GR50-10	1036171-01	4500159641-01

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	B	N	Sn	Al	Ti	Ca	Zn	C Eqv
G112783	.08	1.16	.009	.019	.28	.25	.08	.04	.023	.033	.0006	.0097	.009	.001	.00100	.00000	.00120	.37

Mechanical Test: Yield 54700 PSI, 377.14 MPA Tensile: 70300 PSI, 484.7 MPA %El: 24.5/8in, 24.5/200MM
Customer Requirements CASTING: STRAND CAST
Comment: NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.
Mechanical Test: Yield 54200 PSI, 373.7 MPA Tensile: 70000 PSI, 482.63 MPA %El: 27.5/8in, 27.5/200MM
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
W6 X 9#	A57250/992	ASTM A572 GR50-07, ASTM A992 -06A, ASTM A709 GR50-10	1025598-20	4500157482-20

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	Zn	C Eqv
G113099	.17	.93	.015	.027	.22	.30	.09	.09	.025	.016	.001	.0004	.0078	.011	.001	.00100	.00060	.00160	.41

Mechanical Test: Yield 54600 PSI, 376.45 MPA Tensile: 75700 PSI, 521.93 MPA %El: 20.4/8in, 20.4/200MM
Customer Requirements CASTING: STRAND CAST
Comment: NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.
Mechanical Test: Yield 55000 PSI, 379.21 MPA Tensile: 77300 PSI, 532.96 MPA %El: 22.3/8in, 22.3/200MM
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

Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

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

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-2. W6x9 (W152x13.4) Steel Posts, Test Nos. CGSA-3 and CGSA-4

SOLD TO:	STEEL & PIPE SUPPLY CO INC PO BOX 1688 MANHATTAN, KS 66502-1688	NUCOR *NUCOR CORPORATION* *NUCOR STEEL TEXAS*	Page: 1

CERTIFIED MILL TEST REPORT

Ship from:

Nucor Steel - Texas
8812 Hwy 79 W
JEWETT, TX 75846
800-527-6445

SHIP TO: STEEL & PIPE
1003 FORT GIBSON
CATOOSA, OK 00000-

Date: 12-Apr-2011
B.L. Number: 568696
Load Number: 181752

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative. NBMG-08 March 9, 2011

HEAT NUM. *	DESCRIPTION	PHYSICAL TESTS: YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	CHEMICAL TESTS: C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	4500157212												
JW0910611902	Nucor Steel - Texas	49,400	70,800	25.0%			.12	.79	.019	.040	.21	.45	.33
	3-1/2x2-1/2x1/4" Angle	341MPa	488MPa				.15	.17	.038	.004	.002		
	20' A36	50,200	71,500	25.0%									
	ASTM A36/A36M-08, A709/709M-09a	346MPa	493MPa										
	GR36, ASME SA36-07 Ed 09 Ad												
PO# =>	4500157651												
JW1110216701	Nucor Steel - Texas	44,200	65,600	23.0%			.10	.82	.008	.030	.18	.34	.30
	3/4x10" Flat	305MPa	452MPa				.17	.10	.041	.002	.001		
	20' A36	43,700	64,000	22.0%									
	ASTM A36/A36M-08, A709/A709M-09a	301MPa	441MPa										
	GR36, ASME SA36-07 Ed 09 Ad												
	ASTM A709/A709M-08 GR 36												
	ASME SA36-2007 EDITION-2009 ADDE												
	NDA												
PO# =>	4500157651												
JW1110217202	Nucor Steel - Texas	46,900	69,000	26.0%			.12	.81	.013	.040	.20	.31	.33
	1/2x12" Flat	323MPa	476MPa				.15	.16	.049	.003	.001		
	20' A36	46,800	68,400	24.0%									
	ASTM A36/A36M-08, A709/A709M-09a	323MPa	472MPa										
	GR36, ASME SA36-07 Ed 09 Ad												
	ASTM A709/A709M-08 GR 36												
	ASME SA36-2007 EDITION-2009 ADDE												
	NDA												

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form have not been used in the production of this material.

QUALITY ASSURANCE: Nathan Stewart

Figure A-3. ½-in. (13-mm) Thick Base Plate, Test Nos. CGSA-1 and CGSA-2

NUCOR
NUCOR STEEL TUSCALOOSA, INC.

MILL TEST CERTIFICATE

1700 HOLT RD N.E.
Tuscaloosa, AL 35404-1000
800-827-8872

Page #:1 of 1

Load Number	Tally	Mill Order Number	P.O. Number	Part Number	Certificate Number	Date
386513	00000000410154	N-105963-007	4500156614		L325787-1	05/19/2011 08:58

Grade	Customer:
Order Description: A572/A709, 0.5000 IN x 96.000 IN x 240.000 IN Quality Plan Description: A57250/A70950: ASTM A572-07 GR 50/A709-08 GR 50	Sold TO: STEEL & PIPE SUPPLY CO., INC. MANHATTAN KS Ship TO: Kansas City Warehouse New Century KS

Shipped Item	Heat/Slab Number	Certified By	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Cb	V	Al	Ti	N2	B	Ca	Sn	CEV
1E0881C	B1R6601-01 ***	B1R6601	0.06	1.18	0.007	0.005	0.06	0.27	0.08	0.06	0.019	0.000	0.047	0.033	0.001	0.009	0.0001	0.0029	0.009	0.31

Shipped Item	Certified By	Heat Number	Yield ksi	Tensile ksi	Y/T %	ELONGATION %		Bend OK?	Hard HB	Charpy Impacts (ft-lbf)					Shear %				Test Temp
						2"	8"			Size mm	1	2	3	Avg	1	2	3	Avg	
1E0881C	S1E0881FTT	B1R6601 ***	54.8	68.6	79.9	38.8													
1E0881C	S1E0881MTT	B1R6601 ***	65.6	74.8	87.7	31.5													

Items: 1 PCS: 8 Weight: 26137 LBS

Mercury has not come in contact with this product during the manufacturing process not has any mercury been used by the manufacturing process. Certified in accordance with EN 10204 3.1. No weld repair has been performed on this material. Manufactured to a fully killed fine grain practice. ** Produced from Coil **
ISO 9001:2008 Registered, PED Certified

**** indicates Heats melted and Manufactured in the U.S.A.

We hereby certify that the product described above passed all of the tests required by the specifications.

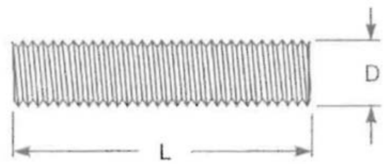
April Pitts
April Pitts - QA Engineer

Figure A-4. ½-in. (13-mm) Thick Base Plate, Test Nos. CGSA-3 and CGSA-4

Page 1 of 2	Fastenal Product Standard	REV-03
Date: December 1, 2010	FASTENAL	TROD.LC.Z

Threaded Rod, Low Carbon, Zinc Plated

The information below lists the required dimensional, chemical and physical characteristics of the products in this purchase order. If the order received does not meet these requirements, it may result in a supplier corrective action request, which could jeopardize your status as an approved vendor. Unless otherwise specified, all referenced consensus standards must be adhered to in their entirety.



Diameter	Nominal Size	D (Major Diameter)	
		Max.	Min.
4-40 *	.1120	.1112	.1061
6-32 *	.1380	.1372	.1312
8-32 *	.1640	.1631	.1571
10-24 *	.1900	.1890	.1818
10-32 *	.1900	.1891	.1831
12-24 *	.2160	.2150	.2078
1/4-20	.2500	.2489	.2367
1/4-28	.2500	.2490	.2392
5/16-18	.3125	.3113	.2982
5/16-24	.3125	.3114	.3006
3/8-16	.3750	.3737	.3595
3/8-24	.3750	.3739	.3631
7/16-14	.4375	.4361	.4206
7/16-20	.4375	.4362	.4240
1/2-13	.5000	.4985	.4822
1/2-20	.5000	.4987	.4865
9/16-12	.5625	.5609	.5437
9/16-18	.5625	.5611	.5480
5/8-11	.6250	.6233	.6051
5/8-18	.6250	.6236	.6105
3/4-10	.7500	.7482	.7288
3/4-16	.7500	.7485	.7343
7/8-9	.8750	.8731	.8523
7/8-14	.8750	.8734	.8579
1-8	1.000	.9980	.9755
1-14 *	1.000	.9984	.9881
1 1/8-7	1.125	1.1228	1.0982
1 1/8-12	1.125	1.1232	1.1060
1 1/4-7	1.250	1.2478	1.2232
1 1/4-12	1.250	1.2482	1.2310
1 3/8-6	1.375	1.3726	1.3453
1 1/2-6	1.500	1.4976	1.4703
1 1/2-12	1.500	1.4981	1.4809
1 3/4-5	1.750	1.7473	1.7165
2-4.5	2.000	1.9971	1.9641

* Class 2A threads shall be used for sizes where 1A is not applicable

Length	Tolerance
3'	+/- 1/4"
6' - 12'	+/- 1/2"

Length shall be measured form end to end

Page 2 of 2	Fastenal Product Standard	REV-03
Date: December 1, 2010	FASTENAL	TROD.LC.Z

Specification Requirements:

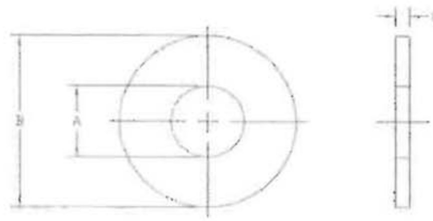
- Standard: ASME B18.31.3
- Material &
- Mechanical Properties: ASTM A307, Grade A
- Thread requirements: Roll threaded to ASME, B1.1 UNC & UNF, and UNS Class 1A.
- Coating: Fe/Zn 3AT Per ASTM F1941

Figure A-5. 1-in. (25-mm) Diameter Threaded Rods, Test Nos. CGSA-1 through 4

Page 1 of 1	Fastenal Product Standard	REV-01
Date: February 7, 2011	FASTENAL	FW.LC.USS.Z

Flat Washers, Low Carbon, USS, Zinc Plated

The information below lists the required dimensional, chemical and physical characteristics of the products in this purchase order. If the order received does not meet these requirements, it may result in a supplier corrective action request, which could jeopardize your status as an approved vendor. Unless otherwise specified, all referenced consensus standards must be adhered to in their entirety.



USS Flat Washers									
Nominal Washer Size	A			B			C		
	Inside Diameter			Outside Diamter			Thickness		
	Basic	Tolerance Plus	Tolerance Minus	Basic	Tolerance Plus	Tolerance Minus	Basic	Max	Min
3/16	.250	.015	.005	.562	.015	.005	.049	.065	.036
1/4	.312	.015	.005	.734	.015	.007	.065	.080	.051
5/16	.375	.015	.005	.875	.030	.007	.083	.104	.064
3/8	.438	.015	.005	1.000	.030	.007	.083	.104	.064
7/16	.500	.015	.005	1.250	.030	.007	.083	.104	.064
1/2	.562	.015	.005	1.375	.030	.007	.109	.132	.086
9/16	.625	.015	.005	1.469	.030	.007	.109	.132	.086
5/8	.688	.030	.007	1.750	.030	.007	.134	.160	.108
3/4	.812	.030	.007	2.000	.030	.007	.148	.177	.122
7/8	.938	.030	.007	2.250	.030	.007	.165	.192	.136
1	1.062	.030	.007	2.500	.030	.007	.165	.192	.136
1-1/8	1.250	.030	.007	2.750	.030	.007	.165	.192	.136
1-1/4	1.375	.030	.007	3.000	.030	.007	.165	.192	.136
1-3/8	1.500	.045	.010	3.250	.045	.010	.180	.213	.153
1-1/2	1.625	.045	.010	3.500	.045	.010	.180	.213	.153
1-5/8	1.750	.045	.010	3.750	.045	.010	.180	.213	.153
1-3/4	1.875	.045	.010	4.000	.045	.010	.180	.213	.153
1-7/8	2.000	.045	.010	4.250	.045	.010	.180	.213	.153
2	2.125	.045	.010	4.500	.045	.010	.180	.213	.153
2-1/4	2.375	.045	.010	4.750	.045	.010	.220	.248	.193
2-1/2	2.625	.045	.010	5.000	.045	.010	.238	.280	.210
2-3/4	2.875	.065	.010	5.250	.065	.010	.259	.310	.228
3	3.125	.065	.010	5.500	.065	.010	.284	.327	.249

Specification Requirements:

- Dimensions: ASME B18.21.1, Type A Plain Washers.
- Material: Carbon steel.
- Coating: ASTM B633, SC1, Type III.

Figure A-6. 1-in. (25-mm) Flat Washers, Test Nos. CGSA-1 through 4

Fastenal Product Standard: FNL.FHN.GRA.Z

Finished Hex Nuts, Grade A, Zinc Plated

The information below lists the required dimensional, chemical and physical characteristics of the products in this purchase order. If the order received does not meet these requirements, it may result in a supplier corrective action request, which could jeopardize your status as an approved vendor. Unless otherwise specified, all referenced consensus standards must be adhered to in their entirety.

Nominal Size	F		G		H	
	Width Across Flats		Width Across Corners		Thickness	
	Max.	Min.	Max.	Min.	Max.	Min.
1/4	.438	.428	.505	.488	.226	.212
5/16	.500	.489	.577	.557	.273	.258
3/8	.563	.551	.650	.628	.337	.320
7/16	.688	.675	.794	.768	.385	.365
1/2	.750	.736	.866	.840	.448	.427
9/16	.875	.861	1.010	.982	.496	.473
5/8	.938	.922	1.083	1.051	.559	.535
3/4	1.125	1.088	1.299	1.240	.665	.617
7/8	1.312	1.269	1.516	1.447	.776	.724
1	1.500	1.450	1.732	1.653	.887	.831
1 1/8	1.688	1.631	1.949	1.859	.999	.939
1 1/4	1.875	1.812	2.165	2.066	1.094	1.030
1 3/8	2.062	1.994	2.382	2.273	1.206	1.138
1 1/2	2.250	2.175	2.598	2.480	1.317	1.245
1 5/8	2.43	2.35	2.805	2.679	1.416	1.364
1 3/4	2.625	2.538	3.031	2.893	1.540	1.460
1 7/8	2.813	2.722	3.247	3.103	1.651	1.567
2	3.000	2.900	3.464	3.306	1.763	1.675
2 1/4	3.375	3.263	3.897	3.719	1.986	1.890
2 1/2	3.750	3.625	4.330	4.133	2.209	2.105
2 3/4	4.125	3.988	4.763	4.546	2.431	2.319
3	4.5	4.350	5.196	4.959	2.654	2.534

Specification Requirements:

- Dimensions: ASME B18.2.2 for ¼" thru 1 ½"
  Over 1 ½" see dimensions above and FIM limits to the ASME B18.2.2 Heavy Hex Nut Standard
- Material &
- Mechanical Properties: Grade A per ASTM A563 for ¼" to 1 ½".
  For sizes over 1 ½, hardness test only to HRB-68 to HRC-32
- Thread requirements: ANSI B1.1 UNC & UNF Class 2B
- Finish: Fe/Zn 3AT Per ASTM F1941

Page 1 of 1 June 1, 2009

This document was printed on 6/1/2009 and was current at that time. Please check current revision date to avoid using obsolete copies.

Figure A-7. 1-in. (25-mm) Hex Nuts, Test Nos. CGSA-1 through 4

Appendix B. Bogie Test Results

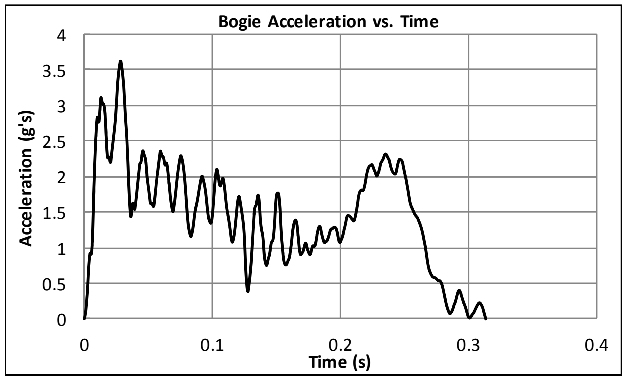
The results of the recorded data from each accelerometer used during each dynamic bogie test are provided in the summary sheets found in this appendix. Summary sheets include acceleration, velocity, and displacement versus time plots as well as force and energy versus displacement plots.

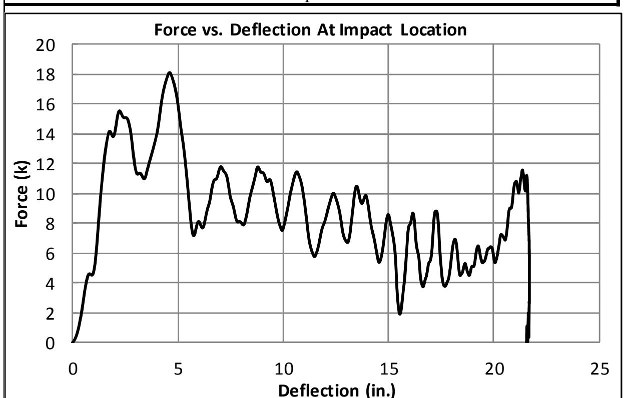
MIDWEST ROADSIDE SAFETY FACILITY

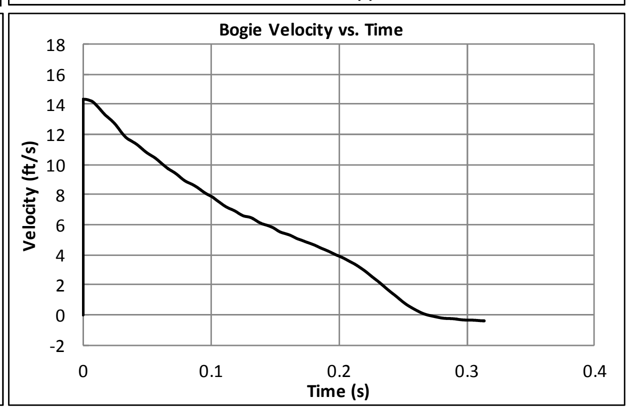
Bogie Test Summary

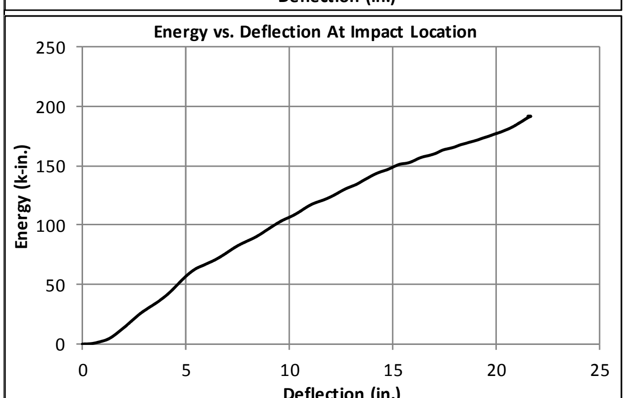
Test Information	Bogie - Culvert Guardrail Post	
Test Number:	cgsa-1	
Test Date:	13-Jan-2012	
Failure Type:	Flange Buckling - Plate Tearing	
Post Assembly Properties		
Post Material	Steel - A992	
Post Size:	W6x9	W150x13.4
Post Length:	37 in.	94 cm
Orientation:	Strong Axis - Centered On Post	
Plate Material:	A36 Steel	
Plate Thickness:	1/2"	
Weld Design:	5/16" single pass fillet	
Anchorage		
Threaded rods:	1" diameter A307	
Embedment Depth:	12"	30.5 cm
Epoxy:	Powers Fasteners AC100+ Gold	
Bogie Properties		
Impact Velocity:	9.78 mph (14.3 fps)	4.37 m/s
Impact Height:	30.625 in.	77.8 cm
Bogie Mass:	4996 lbs	2266.1 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS-5 Perpendicular - 25'	

Test Results Summary		
Max. Deflection:	21.7	in.
Peak Force:	18.1	k
Initial Linear Stiffness:	8.0	k/in.
Total Energy:	191.7	k-in.









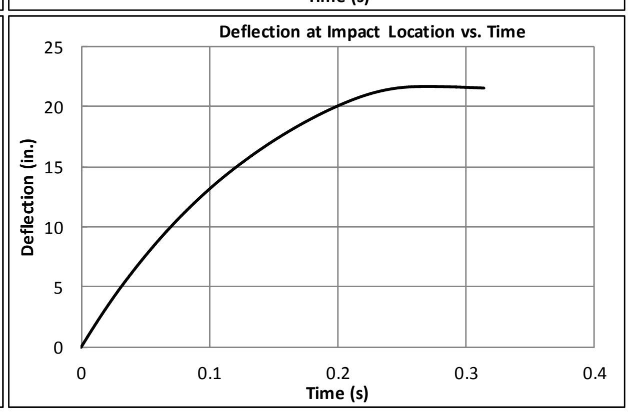


Figure B-1. Results of Test No. CGSA-1 (DTS)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information — Bogie - Culvert Guardrail Post

Test Number:	cgsa-1	
Test Date:	13-Jan-2012	
Failure Type:	Flange Buckling - Plate Tearing	

Post Assembly Properties

Post Material	Steel - A992	
Post Size:	W6x9	W150x13.4
Post Length:	37 in.	94 cm
Orientation:	Strong Axis - Centered On Post	
Plate Material:	A36 Steel	
Plate Thickness:	1/2"	
Weld Design:	5/16" single pass fillet	

Anchorage

Threaded rods:	1" diameter A307	
Embedment Depth:	12"	30.5 cm
Epoxy:	Powers Fasteners AC100+ Gold	

Bogie Properties

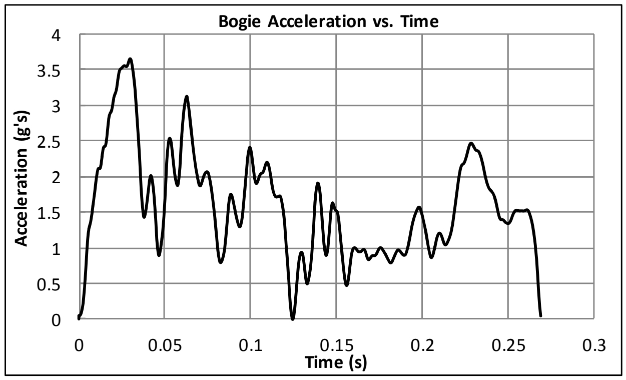
Impact Velocity:	9.78 mph (14.3 fps)	4.37 m/s
Impact Height:	30.625 in.	77.8 cm
Bogie Mass:	4996 lbs	2266.1 kg

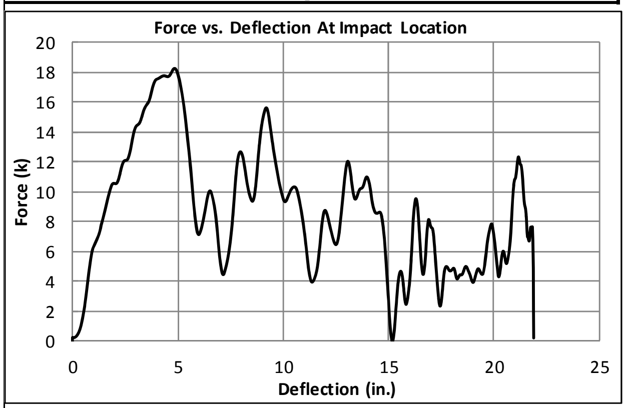
Data Acquired

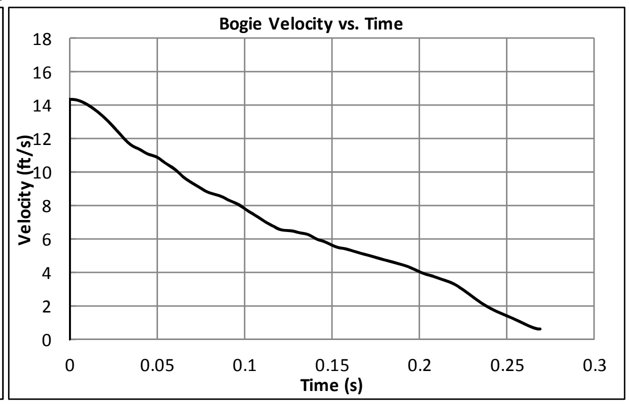
Acceleration Data:	EDR-3
Camera Data:	AOS-5 Perpendicular - 25'

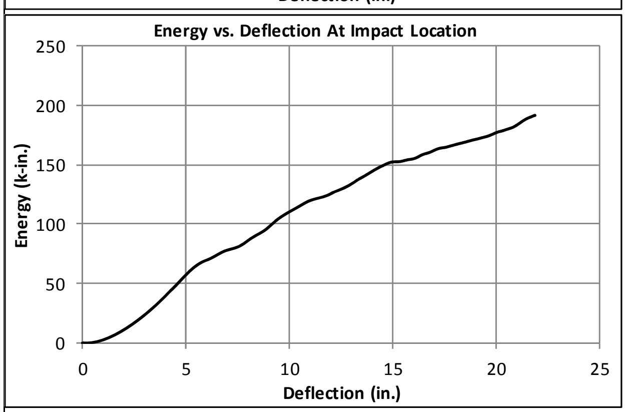
Test Results Summary

Max. Deflection:	21.9	in.
Peak Force:	18.2	k
Initial Linear Stiffness:	3.8	k/in.
Total Energy:	191.5	k-in.









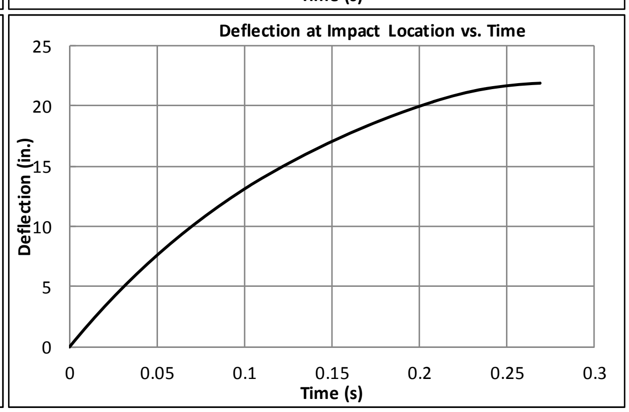


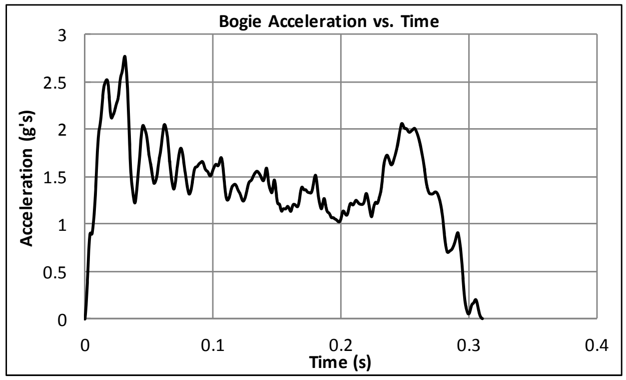
Figure B-2. Results of Test No. CGSA-1 (EDR-3)

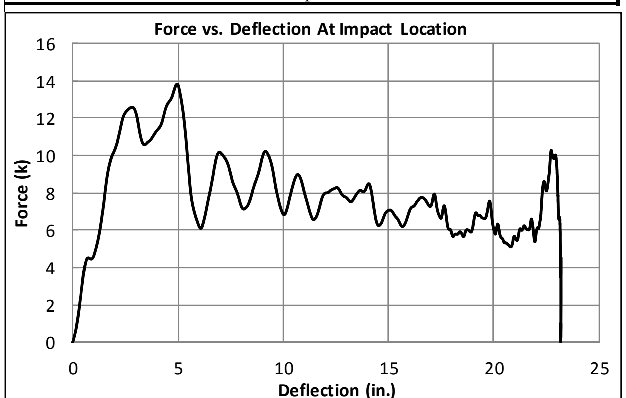
MIDWEST ROADSIDE SAFETY FACILITY

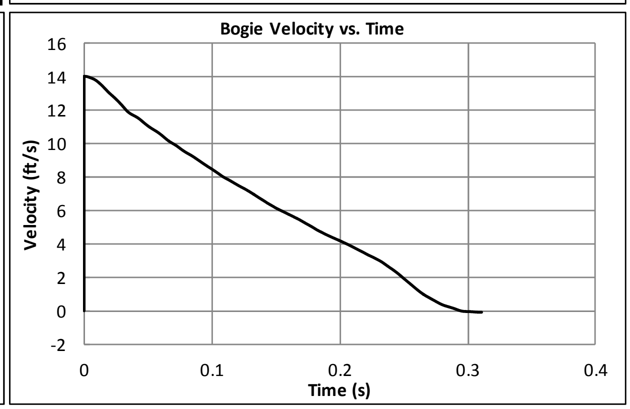
Bogie Test Summary

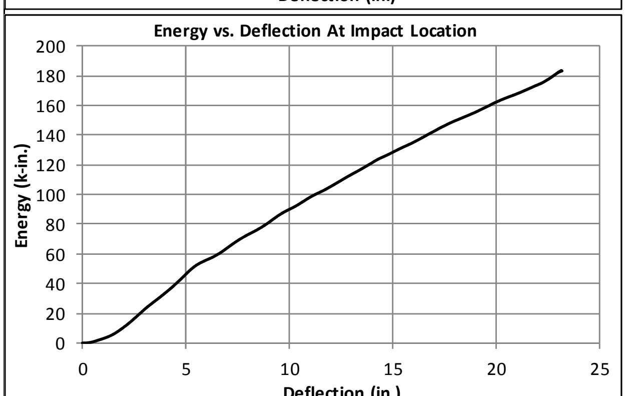
Test Information	Bogie - Culvert Guardrail Post	
Test Number:	cgsa-2	
Test Date:	24-Jan-2012	
Failure Type:	Flange Buckling - Plate Tearing	
Post Assembly Properties		
Post Material	Steel A992	
Post Size:	W6x9	W150x13.4
Post Length:	37 in.	94 cm
Orientation:	Strong Axis - Centered On Post	
Plate Material:	A36 Steel	
Plate Thickness:	1/2"	
Weld Design:	1/4" single pass fillet	
Anchorage		
Threaded rods:	1" diameter A307	
Embedment Depth:	12"	30.5 cm
Epoxy:	Powers Fasteners AC100+ Gold	
Bogie Properties		
Impact Velocity:	9.55 mph (14 fps)	4.27 m/s
Impact Height:	30.625 in.	77.8 cm
Bogie Mass:	4999 lbs	2267.5 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS-5 Perpendicular - 25'	

Test Results Summary		
Max. Deflection:	23.2	in.
Peak Force:	13.8	k
Initial Linear Stiffness:	2.8	k/in.
Total Energy:	183.2	k-in.









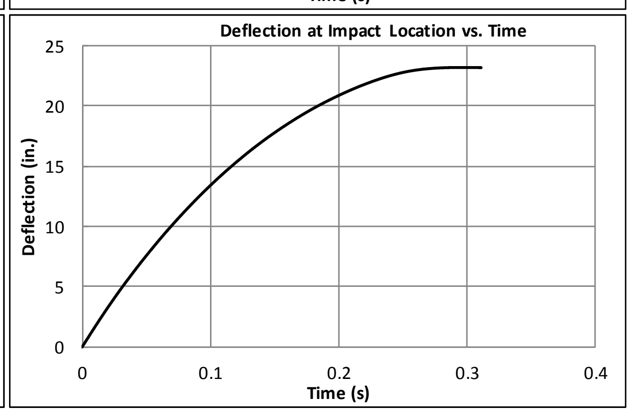


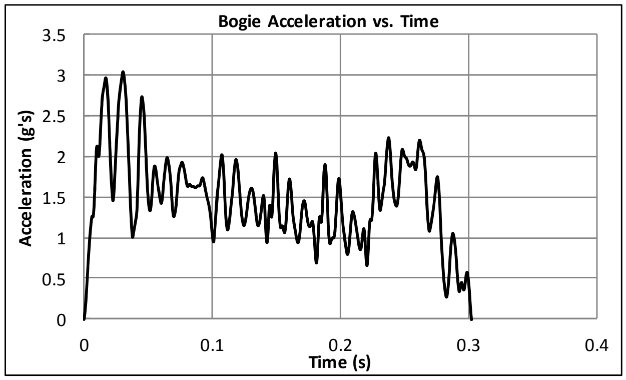
Figure B-3. Results of Test No. CGSA-2 (DTS)

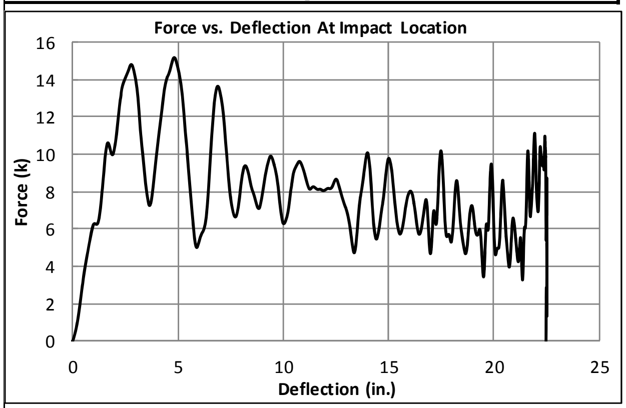
MIDWEST ROADSIDE SAFETY FACILITY

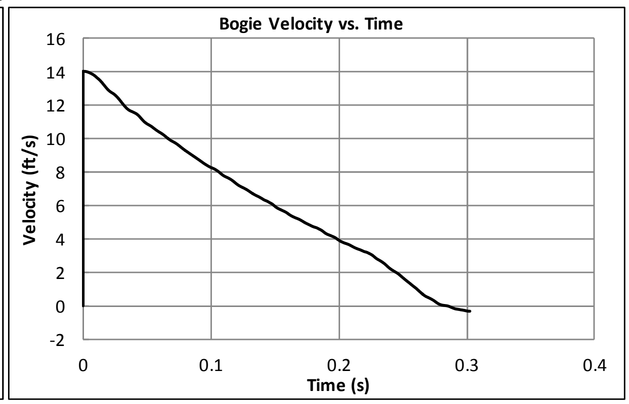
Bogie Test Summary

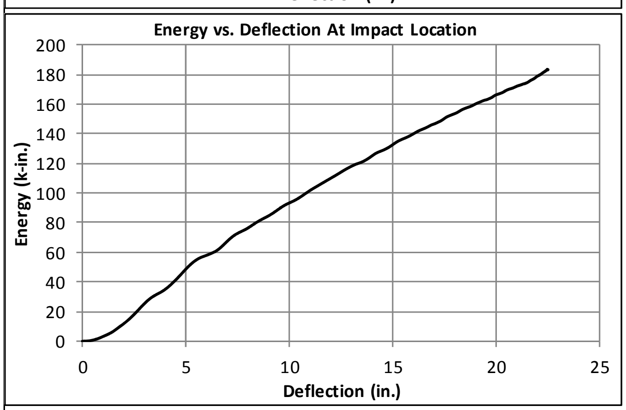
Test Information	Bogie - Culvert Guardrail Post	
Test Number:	cgsa-2	
Test Date:	24-Jan-2012	
Failure Type:	Flange Buckling - Plate Tearing	
Post Assembly Properties		
Post Material	Steel - A992	
Post Size:	W6x9	W150x13.4
Post Length:	37 in.	94 cm
Orientation:	Strong Axis - Centered On Post	
Plate Material:	A36 Steel	
Plate Thickness:	1/2"	
Weld Design:	1/4" single pass fillet	
Anchorage		
Threaded rods:	1" diameter A307	
Embedment Depth:	12"	30.5 cm
Epoxy:	Powers Fasteners AC100+ Gold	
Bogie Properties		
Impact Velocity:	9.55 mph (14 fps)	4.27 m/s
Impact Height:	30.625 in.	77.8 cm
Bogie Mass:	4999 lbs	2267.5 kg
Data Acquired		
Acceleration Data:	DTS - SLICE	
Camera Data:	AOS-5 Perpendicular - 25'	

Test Results Summary		
Max. Deflection:	22.5	in.
Peak Force:	15.2	k
Initial Linear Stiffness:	5.3	k/in.
Total Energy:	183.3	k-in.









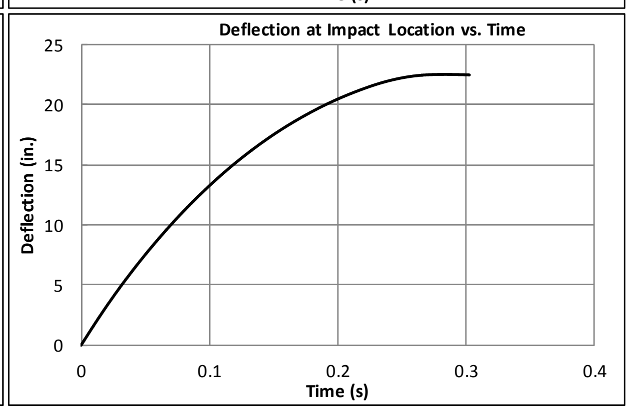


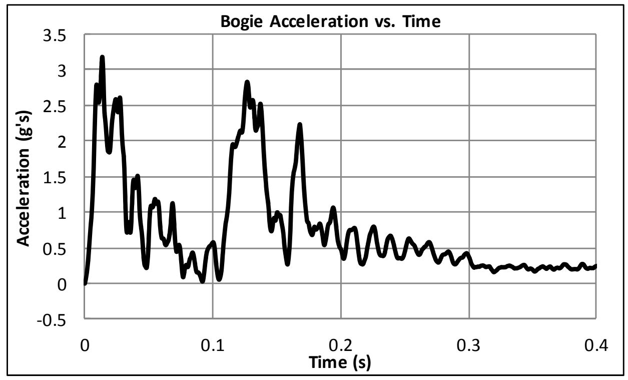
Figure B-4. Results of Test No. CGSA-2 (DTS-SLICE)

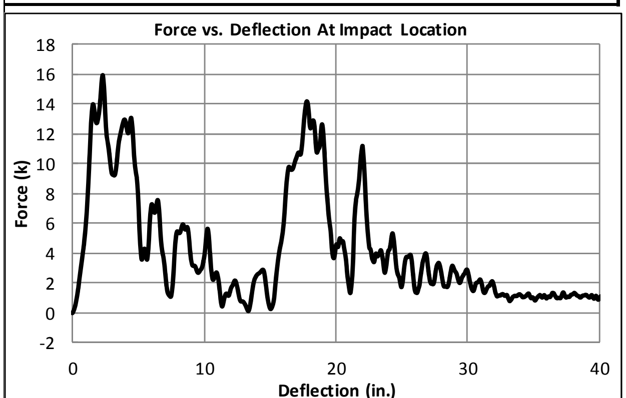
MIDWEST ROADSIDE SAFETY FACILITY

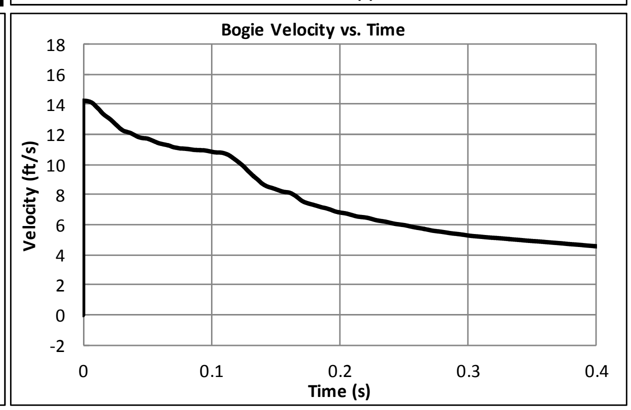
Bogie Test Summary

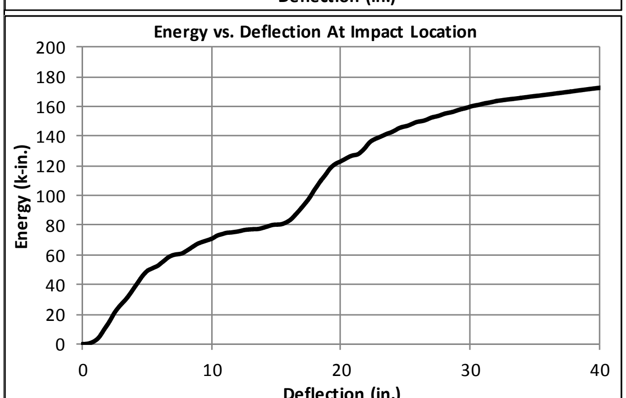
Test Information	Bogie vs. Anchored Post	
Test Number:	CGSA-3	
Test Date:	7-Mar-2012	
Failure Type:	Anchorage Failure	
Post Assembly Properties		
Post Material	Steel - A992	
Post Size:	W6x9	W152x13.4
Post Length:	37 in.	94 cm
Orientation:	Strong Axis	
Plate Material:	A572 Grade-50	
Plate Thickness:	1/2"	
Weld Design:	5/16" Single-Pass Fillet	
Anchorage		
Threaded rods:	1" Diameter A307	
Embedment Depth:	6 in.	15.2 cm
Epoxy:	Powers Fasteners AC100+ Gold	
Bogie Properties		
Impact Velocity:	9.71 mph (14.2 fps)	4.34 m/s
Impact Height:	30.625 in.	77.8 cm
Bogie Mass:	5010 lbs	2272.5 kg
Data Acquired		
Acceleration Data:	DTS - BJ69H	
Camera Data:	AOS-5 & 6	

Test Results Summary		
Max. Deflection:	15.1	in.
Peak Force:	15.9	k
Initial Linear Stiffness:	6.9	k/in.
Total Energy:	80.4	k-in.









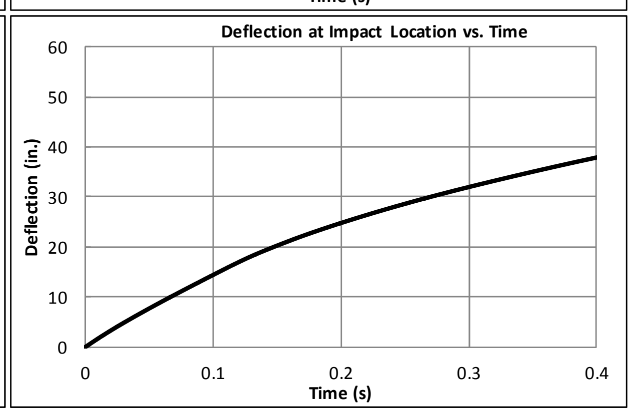


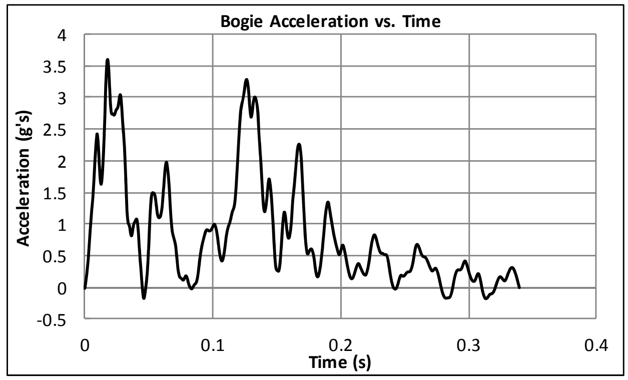
Figure B-5. Results of Test No. CGSA-3 (DTS)

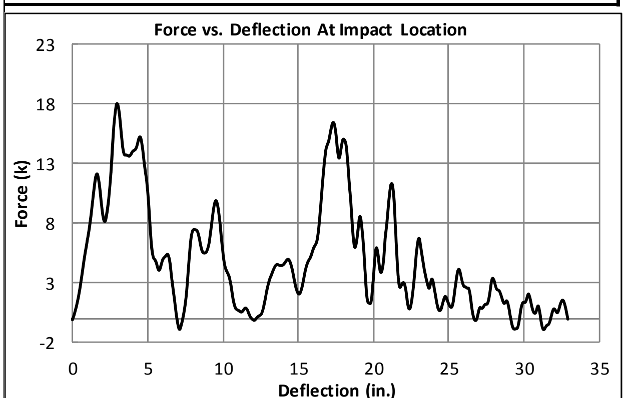
MIDWEST ROADSIDE SAFETY FACILITY

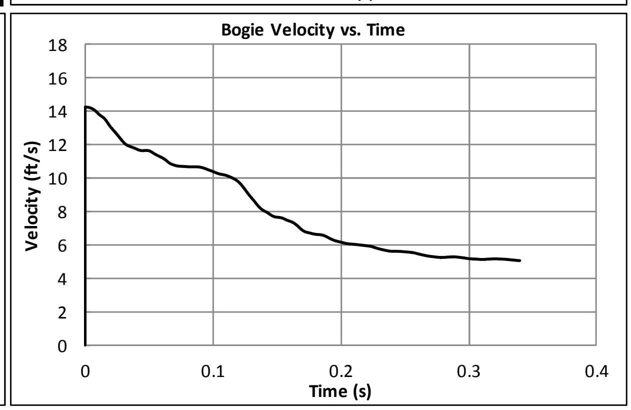
Bogie Test Summary

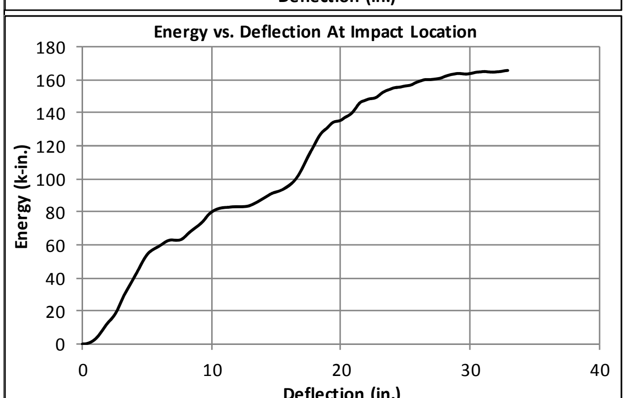
Test Information	Bogie vs. Anchored Post	
Test Number:	CGSA-3	
Test Date:	7-Mar-2012	
Failure Type:	Anchorage Failure	
Post Assembly Properties		
Post Material	Steel - A992	
Post Size:	W6x9	W152x13.4
Post Length:	37 in.	94 cm
Orientation:	Strong Axis	
Plate Material:	A572 Grade-50	
Plate Thickness:	1/2"	
Weld Design:	5/16" Single-Pass Fillet	
Anchorage		
Threaded rods:	1" Diameter A307	
Embedment Depth:	6 in.	15.2 cm
Epoxy:	Powers Fasteners AC100+ Gold	
Bogie Properties		
Impact Velocity:	9.71 mph (14.2 fps)	4.34 m/s
Impact Height:	30.625 in.	77.8 cm
Bogie Mass:	5010 lbs	2272.5 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 & 6	

Test Results Summary		
Max. Deflection:	15.1	in.
Peak Force:	18.0	k
Initial Linear Stiffness:	6.1	k/in.
Total Energy:	92.2	k-in.









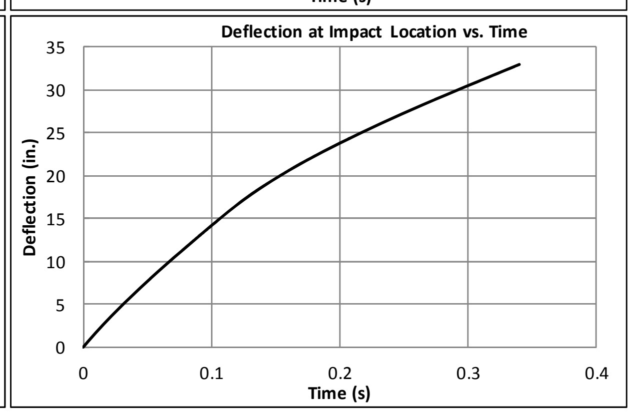


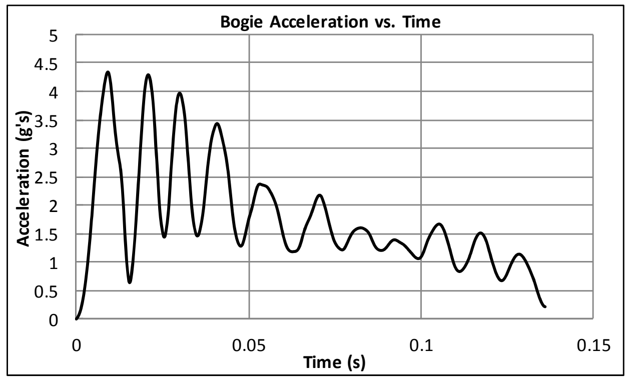
Figure B-6. Results of Test No. CGSA-3 (EDR-3)

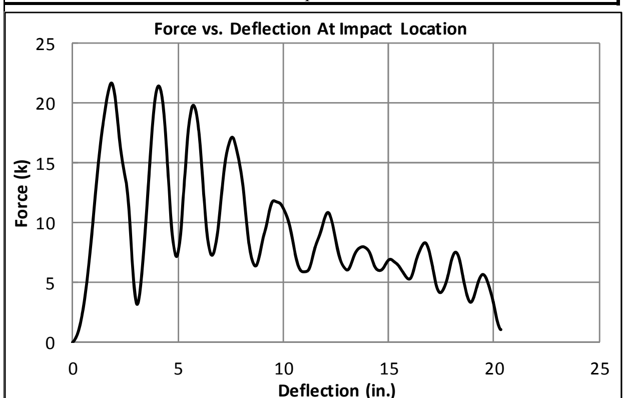
MIDWEST ROADSIDE SAFETY FACILITY

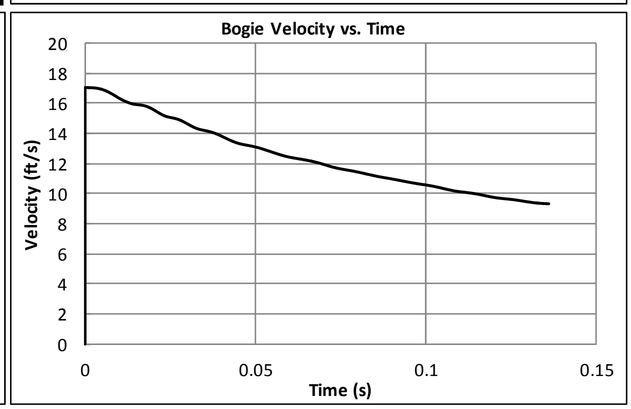
Bogie Test Summary

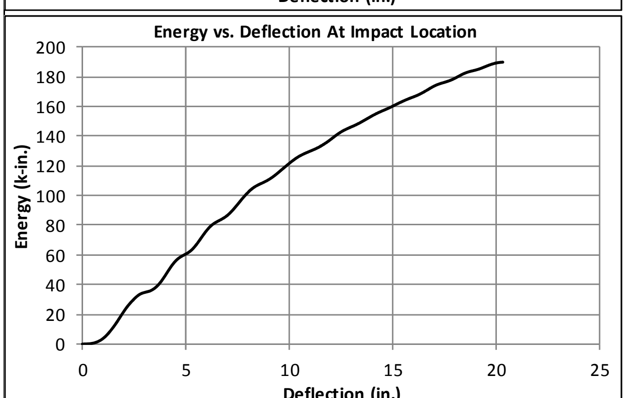
Test Information	Bogie vs. Post	
Test Number:	CGSA-4	
Test Date:	13-Apr-2012	
Failure Type:	Post and Plate Yielding	
Post Assembly Properties		
Post Material	Steel - A992	
Post Size:	W6x9	W152x13.4
Post Length:	37 in.	94 cm
Orientation:	strong axis	
Plate Material:	A572 Grade-50	
Plate Thickness:	1/2"	
Weld Design:	5/16" 3-pass fillet on front flange 1/4" fillet on web and back flange	
Anchorage		
Threaded rods:	1" Diameter A307	
Embedment Depth:	8 in.	20.3 cm
Epoxy:	Powers Fasteners AC100+ Gold	
Bogie Properties		
Impact Velocity:	11.63 mph (17.1 fps)	5.2 m/s
Impact Height:	30.625 in.	77.8 cm
Bogie Mass:	4995 lbs	2265.7 kg
Data Acquired		
Acceleration Data:	DTS - SLICE	
Camera Data:	AOS-5 Perpendicular - 140"	

Test Results Summary		
Max. Deflection:	20.3	in.
Peak Force:	21.7	k
Initial Linear Stiffness:	12.3	k/in.
Total Energy:	189.7	k-in.









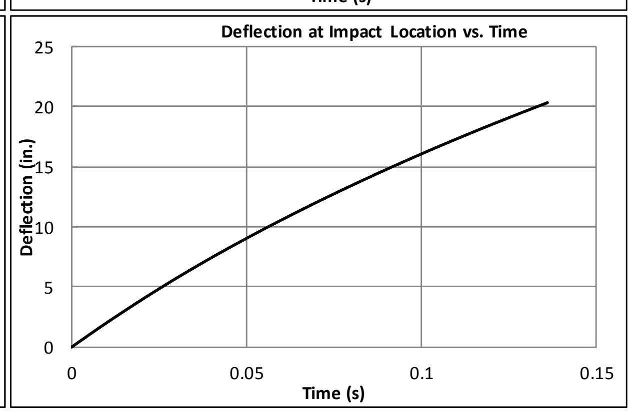


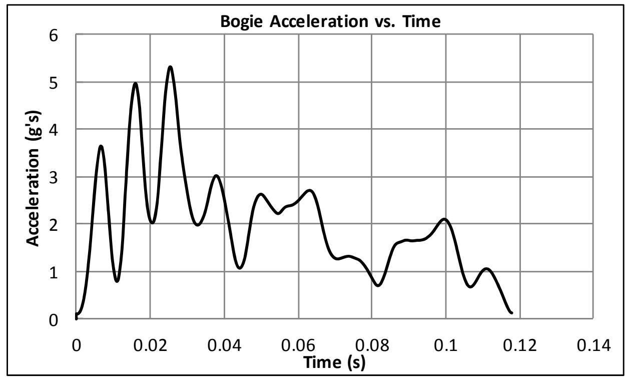
Figure B-7. Results of Test No. CGSA-4 (DTS-SLICE)

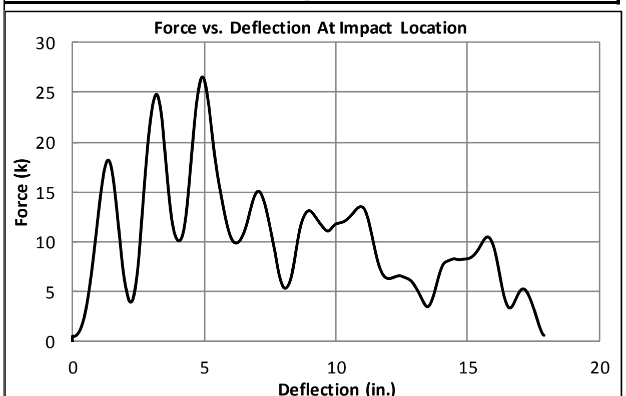
MIDWEST ROADSIDE SAFETY FACILITY

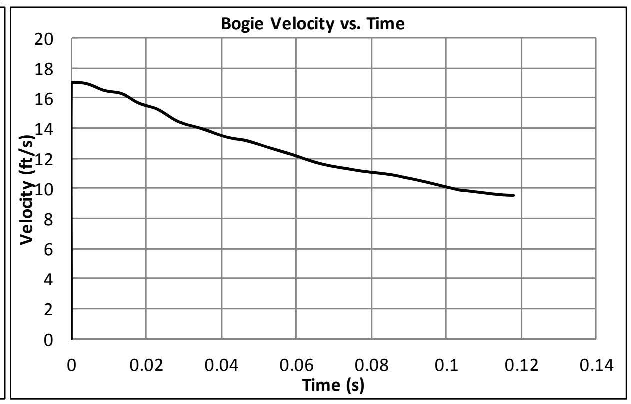
Bogie Test Summary

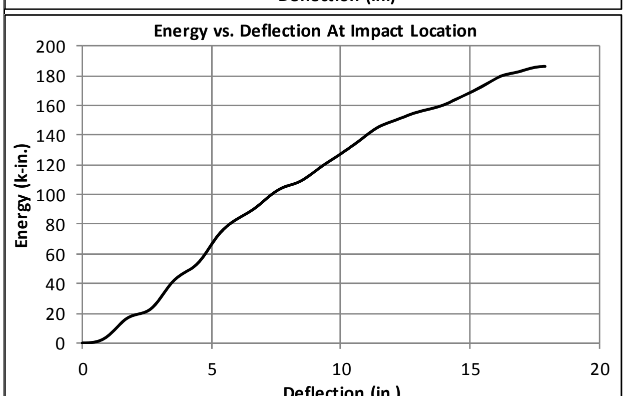
Test Information	Bogie vs. Post	
Test Number:	CGSA-4	
Test Date:	13-Apr-2012	
Failure Type:	Post and Plate Yielding	
Post Assembly Properties		
Post Material	Steel -A992	
Post Size:	W6x9	W152x13.4
Post Length:	37 in.	94 cm
Orientation:	strong axis	
Plate Material:	A572 Grade-50	
Plate Thickness:	1/2"	
Weld Design:	5/16" 3-pass fillet on front flange 1/4" fillet on web and back flange	
Anchorage		
Threaded rods:	1" Diameter A307	
Embedment Depth:	8 in.	20.3 cm
Epoxy:	Powers Fasteners AC100+ Gold	
Bogie Properties		
Impact Velocity:	11.63 mph (17.1 fps)	5.2 m/s
Impact Height:	30.625 in.	77.8 cm
Bogie Mass:	4995 lbs	2265.7 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 140	

Test Results Summary		
Max. Deflection:	17.9	in.
Peak Force:	26.5	k
Initial Linear Stiffness:	5.4	k/in.
Total Energy:	186.1	k-in.









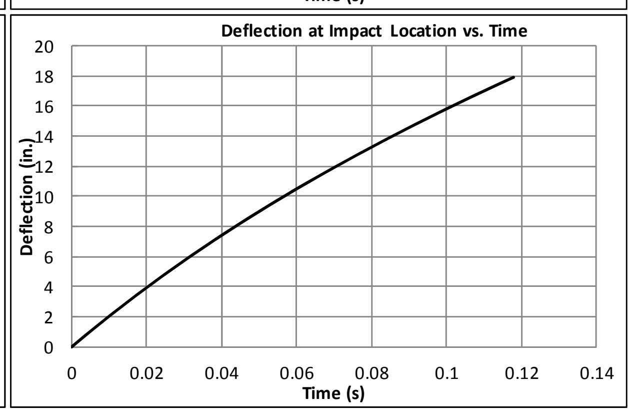


Figure B-8. Results of Test No. CGSA-4 (EDR-3)

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