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DOWNSTREAM ANCHORING REQUIREMENTS FOR THE MIDWEST GUARDRAIL SYSTEM

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16. Abstract (Limit: 200 words)
Most state Departments of Transportation use simple adaptations of crashworthy guardrail end terminals as downstream anchorage systems, which typically include breakaway posts and an anchor cable. The safety performance of these downstream anchorage systems, when struck in reverse-direction impacts, is not well-known. A research study was proposed to analyze and crash test one trailing-end anchorage system involving a modified Breakaway Cable Terminal (BCT) terminal to the MGS guardrail. Bogie component tests were used to validate computer simulation models of the downstream end anchorage. Crash simulations with vehicles similar to the 2270P pickup truck and 1100C small car identified in the Manual for Assessing Safety Hardware (MASH) were used to determine (1) an effective critical impact point of the downstream system at the end of the length of need (LON) and (2) the location which maximizes the instability, snag, and wedging potential of a small car beneath the anchor cable. The end of the LON was defined as a downstream critical impact point (CIP) at which the terminal would no longer redirect an errant vehicle but instead gate and permit the vehicle to encroach behind the system. Two crash tests were conducted. A 5,172 lb (2,346 kg), 2270P pickup impacted the 6th post from the downstream trailing anchorage at 63.0 mph (101.4 km/h) and 26.4 deg, which caused the terminal to gate, and the vehicle proceeded behind the system. A second test, consisting of a 2,619 lb (1,188 kg) 1100C small car impacting the system 4 in. (102 mm) upstream of the 3rd post from the downstream trailing anchor at 62.0 mph (99.8 km/h) and 25.5 deg, resulted in acceptable redirection. Based on these crash tests and the simulations, recommended guidelines were provided for shielding obstacles behind the downstream anchorage of an MGS guardrail.

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This report was completed with funding from the Wisconsin Department of Transportation. The contents of this report reflect the views and opinions of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Wisconsin Department of Transportation nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

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. BCTRS-1, BCTRS-2, MGSEA-1, DSAP-1, and DSAP-2 were non-compliant component tests conducted for research and development purposes only.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Mr. Scott Rosenbaugh, Research Associate Engineer.

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1 INTRODUCTION

1.1 Background

In 2004, the Federal Highway Administration (FHWA) published a memorandum which provided guidelines for the selection of W-beam barrier terminals [1]. Within this document, the primary purpose of a guardrail end treatment system was defined as "providing anchorage for the barrier to allow the development of the full tensile strength of the W-beam rail element for all impacts occurring within the barrier length of need (LON) while minimizing injury to vehicle occupants in the event of a crash near or at the end of the terminal." This definition of end terminals explicitly indicates a need to minimize the potential for injuries resulting from impacts occurring in close proximity to a guardrail end terminal. Although downstream end terminals are commonly placed outside the clear zone of vehicles in opposing travel lanes, or on the trailing end of systems with one-directional traffic flow, the potential risks of impacts near these anchorage systems are still largely unknown.

Downstream anchorage systems for guardrail used by most state departments of transportation (DOTs) are generally simple adaptations of crashworthy end terminals, which typically include breakaway posts and an anchor cable. Based on the successful performance of crashworthy end terminals under reverse-direction impacts with pickup trucks, it is generally believed that these simplified, non-crashworthy downstream anchors will perform adequately when struck by pickup trucks. As stated in the FHWA memorandum, most W-beam guardrail terminals are considered to be gating devices. This characteristic means that when struck at or near the nose, the end treatment will yield, thus allowing the vehicle to continue into the area immediately laterally behind and beyond the terminal. The gating definition does not apply to end-on impacts. However, the location along the downstream segment of a guardrail where pickup trucks are no longer contained and redirected has yet to be adequately determined.

Further, these downstream end anchor designs may not perform in an acceptable manner when impacted by small cars. Severe vehicle snag could occur, thus resulting in unacceptable occupant ridedown accelerations and occupant impact velocities as well as vehicle instabilities.

1.2 Objectives

The objective of this research project was to assess the safety performance of a non-proprietary, trailing-end terminal attached to the Midwest Guardrail System (MGS) according to the Test Level 3 (TL-3) requirements of the American Association of State Highway Officials (AASTHO) *Manual for Assessing Safety Hardware* (MASH) [2]. In particular, the research focused on: (1) determining the downstream end of the guardrail system's LON for impacts with pickup trucks and (2) investigating the potential risks for small passenger cars to become unstable when impacting a non-proprietary, trailing-end terminal.

1.3 Scope

The scope of this research study was to identify the downstream end of the length of need, identify the critical impact location to maximize instability of an errant small car, evaluate the impact performance of the downstream end anchorage of the MGS according to modified 3-37 test conditions described in MASH, and determine the shielded window for hazards placed behind a downstream guardrail terminal.

1.4 Methods Used

The research approach consisted of three distinct phases: bogie testing; computer simulation modeling; and crash testing. First, bogie tests were conducted to evaluate the reaction of the MGS end anchorage in various loading conditions, including splitting of the wood post and a pull test of the cable anchor. Next, computer simulation models of the bogie tests were simulated using LS-DYNA [3] and validated against test results. These validated models were then inserted into a model of the MGS guardrail, and impacts were simulated using a 2270P pickup model and an 1100C small car model. The end of the LON was estimated based on the simulations, and a crash test consisting of a 2270P vehicle impacting the downstream anchor at nominally 62.1 mph (100.0 km/h) and 25 degrees was conducted. In addition, the location identified in the simulations with the maximum small car instability and entrapment beneath the anchor cable was selected for crash testing an 1100C small car at nominally 62.1 mph (100.0 km/h) and 25 degrees. Results of the simulations and crash tests were used to identify recommended envelopes for allowing hazards to be located behind the guardrail system.

2 LITERATURE REVIEW

2.1 Development of the MGS Downstream Anchorage System

Breakaway cable terminal (BCT) anchorage systems, and their derivatives, have often been used as an economical means of providing tensile anchorage to a corrugated-beam guardrail system. Variations of the BCT are frequently used by many state DOTs, having been adopted for use in many crashworthy terminal ends. The original BCT terminal was first developed in the early 1970's by researchers at Southwest Research Institute (SwRI) [4] as part of multiple National Cooperative Highway Research Program (NCHRP) projects. Over time, this general end terminal had evolved in order to meet various crash testing requirements. In general, most end anchorage systems derived from BCT terminals have used the following main components: (1) steel foundation tubes with or without soil plates; (2) a steel compression strut between the tube foundations; (3) two breakaway wood posts; and (4) a steel cable anchor system.

Steel foundation tubes were first introduced in NCHRP Research Digest 124 as an alternative foundation for the BCT [5]. The steel foundation tubes enhance the post-soil resistance by distributing the load in a more homogenous manner, while also allowing for easier post replacement if fractured. The soil resistance can be further increased by attaching bearing plates to the foundation tubes, which increases the area of the tube exposed to the soil. The use of a compression strut between the tube foundations was first introduced during the development of the Eccentric Loader Terminal (ELT) to maximize the soil resistance by coupling two foundation tubes [6].

The end wood posts were designed to fail (i.e., break) in a controlled manner in order to allow an impacting vehicle to pass through without imposing a sudden deceleration or rapidly changing its trajectory. This release behavior minimizes the risk of vehicle rollover or snag on a cable anchorage system or on strong posts. Wood has historically been selected for use as a breakaway post due to it being readily available, relatively low cost, brittle fracture behavior, and the ability to control load duration and fracture energy with holes drilled through the post at the ground level.

Steel anchor cables have been used to develop the tensile strength of the rail for impacts occurring beyond the LON of the barrier. The concept of these cable anchor systems is simple; one end of the steel cable is anchored to the end post and the corresponding steel foundation tube near the ground line, while the other end of the cable is connected to the back of the rail through a mounting bracket. For many crashworthy guardrail end terminals, the bracket-to-rail connection has been designed so that it can be quickly released during end-on impacts where energy-absorbing heads are pushed down the rail.

2.2 Prior Reverse-Direction Testing of Guardrail End Terminals

Historically, the reverse-direction impact performance of a typical guardrail terminal has been assessed before it could be deemed crashworthy and approved for use along U.S. highways and roadways. In both MASH [2] and NCHRP Report No. 350 [7], the required trailing-end terminal crash test corresponds to designation no. 37. This specific impact scenario considers the case in which the terminal may be placed in the clear zone of opposing traffic and serves to evaluate the safety performance of the terminal when it is hit by an errant vehicle departing the opposite lane. This testing condition may provide useful information about the behavior of an anchor system located on the downstream end of the barrier.

Neglecting the different impact side of the vehicle, a reverse-direction terminal impact is fundamentally similar to the impact of the downstream end anchorage in the direction of normal travel flow. Recently Texas Transportation Institute (TTI) designed and tested a non-proprietary downstream anchorage for W-beam guardrail systems [8]. A full-scale crash test was run to assess the safety performance of the downstream end anchor design when impacted by the small passenger car under modified MASH test designation 3-37 conditions.

A broader evaluation of reverse-direction impact conditions on proprietary end terminals is available in Reference 9. Impact conditions and test results for reverse-direction crashes into both downstream trailing-end terminals and common upstream guardrail end terminals are summarized in Tables 1 and 2.

The end terminal systems summarized in Table 1 make use of a cable anchorage to ensure an appropriate longitudinal resistance of the rail during vehicular LON impacts. The cable anchorage allows the use of steel posts or breakaway wood posts. As such, the problems that were reported during the reverse-direction testing of these systems can be used to draw a synthesis of potential hazards and related solutions that could be helpful in the design of a trailing-end terminal.

Although cable anchors are advantageous to efficiently anchor the end of a guardrail system, these anchors may adversely affect system performance when struck with reverse-direction or trailing-end impact conditions. From an analysis of the reverse-direction full-scale crash tests summarized in Table 2, two major potential hazards related to cable anchors emerged: (1) snag on the anchor cable and (2) engagement of the bearing plate with the vehicle undercarriage after the cable end post release.

A cable anchor may snag on components of an impacting vehicle, including the bumper, a wheel, or the undercarriage. The median configuration of the FLEAT end terminal adopted a T-shaped post breaker assembly, which was attached to the back of the end post to facilitate the release and rotation of the post and the subsequent release of the cable anchor during a reverse-direction impact [10]. This post breaker mechanism assures a controlled release of the anchor, reducing the propensity for cable anchor plate entrapment and an associated potential instability

Table 1. Selected End Terminals with Reverse-Direction Impact Testing

System Properties	Terminal Type				
	FLEAT Median [10]	**ET-2000 [11]**	**SRT [12]**	**BEST [13, 14]**	**TxDOT Terminal [8]**
Post Type [steel/wood]	Steel	Wood (x8) 6"x10" (152x254	Wood (x2) 5½"x7½" (140 mm x 191 mm) + Wood (x8) 6"x8" (152 mm x 203 mm)	Wood (x2) 5½"x7½" (140 mm x 191 mm) + Wood (x5) 6"x8" (152 mm x 203 mm)	Wood (x2) 5½"x7½" (140 mm x 190 mm)
Foundation Tube Locations	Post nos. 1,2,4	Post nos. 1-4	Post nos. 1-2	Post nos. 1-2	Post nos. 1-2
Ground Strut Type	Tube	Angle	Channel	Tube	Angle
Unbolted Post Locations	Post no. 1	Post nos. 1,3	Post nos. 2-4, 6-10	None	Post no. 1
Flared/Straight	Flared	Straight	Flared (parabolic w/ max offset of 4 ft at post 1)	Straight	Straight

Table 2. Test Designation No. 3-37 Crash Test Results for End Terminals (NCHRP Report No. 350 and MASH)

Test Parameters	Terminal Type				
	FLEAT Median [10]	**ET-2000 [11]**	**SRT [12]**	**BEST [13-14]**	**TxDOT Terminal [8]**
Impact Point	3 ft–3¼ in. (1 m) upstream Post no. 4	Post no. 5	Post no. 5	Midspan post nos. 3&4	3 ft (0.9 m) upstream Post no. 3
End of the LOL	N/A	Post 3	N/A	N/A	N/A
Vehicle	2000P	2000P	2000P	2000P	1100C
Impact Speed mph (km/h)	60.8 (97.8)	63.1 (101.5)	62.7 (100.9)	63.1 (101.5)	61.9 (99.6)
Impact Angle (deg)	20.8	20.9	21	20.5	25.3
Snagging w/ cable anchor?	Yes (solved w/ deflector bracket)	No	No	No	No

or unacceptable ridedown decelerations. Although this device was originally designed for impacts occurring on the back side of the rail, the same concept may be effectively implemented to accommodate vehicular impacts occurring on the front side of the rail. Even though the FLEAT post breaker releases the end cable away from the anchor post during an impact event, the loose end of the cable may still pose a hazard to the errant vehicle. For example, the bearing plate used to transfer the load from the cable to the anchor post and foundation tube may become trapped in the vehicle's suspension.

A reverse-direction impact with an SRT terminal caused a pickup truck to yaw and eventually roll over due to cable anchor entrapment and snag with the vehicle suspension [12]. In addition to increased instability, any snag associated with the cable anchor could lead to unacceptable ridedown decelerations. In order to reduce the propensity for bearing plate snag on a vehicle's suspension, designers of the SRT installed a slotted anchor plate secured to the end post with two screws to cleanly release away from the post after post fracture. This slotted bearing plate is shown in Figure 1. The slotted anchor plate cleanly released away from the anchor cable during a reverse-direction impact, thus leading to acceptable performance of the end terminal system.

Recently, TTI conducted a full-scale reverse-direction crash test with an 1100C vehicle into a non-proprietary, end anchor design [8]. The 1100C vehicle was believed to be more critical than the 2270P vehicle for the reverse-direction test, because the small car had a greater propensity to wedge under the rail and potentially snag on the end anchor. The crash-tested end anchor design, developed for the Texas Department of Transportation (TxDOT), was similar to the MGS end anchorage system [15], which was adopted from the modified BCT system and installed tangent to the roadway. The end anchor uses two BCT posts embedded into foundation tubes with a cable anchor. The two minor differences between the TxDOT anchor and MGS end

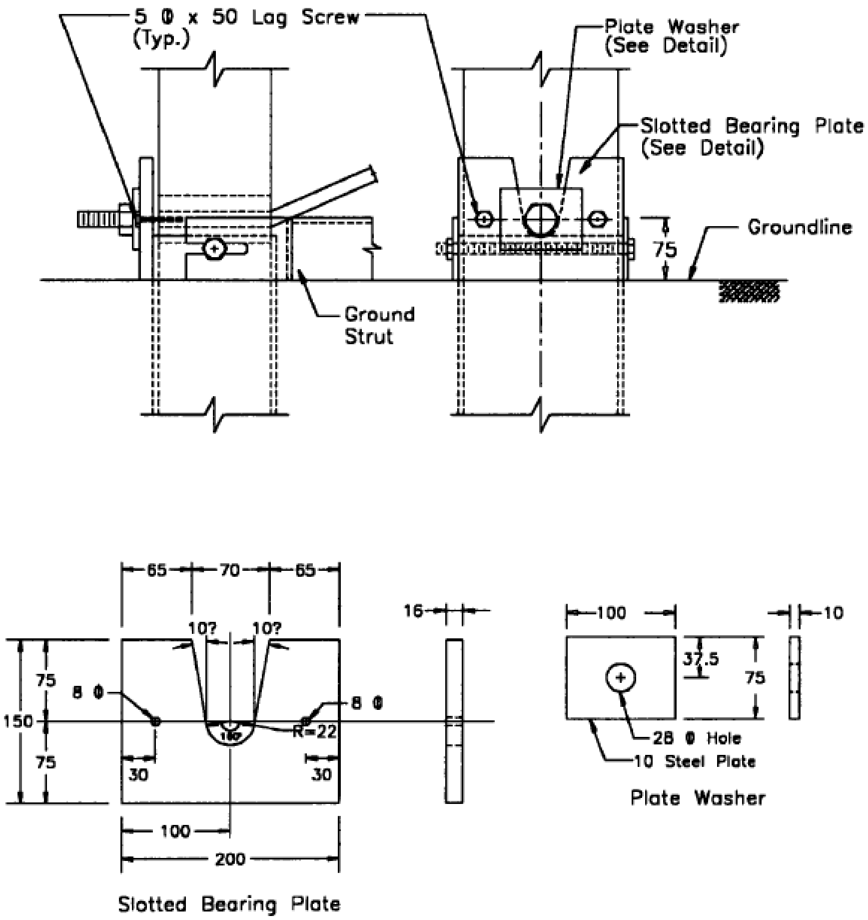


Figure 1. SRT End Terminal Slotted Bearing Plate [12]

anchorage were: (1) two C3x5 (C76x7.4) channel sections connected the foundation tubes instead of one C6x8.2 (C152x12.2) ground strut with two yokes; and (2) the W-beam rail was simply supported at the end post with a shelf angle bracket. The TTI end anchor design was successfully tested in combination with a 31-in. tall, 8-in. blocked MGS system.

The 1100C vehicle impacted the system 15 ft - 7½ in. (4.8 m) upstream from the downstream end post. Although test results were successful, no specific investigation was noted to identify the critical impact location. The simple support condition at the end post may facilitate guardrail lift when the passenger car impacts the system in close proximity to the anchorage. This situation, which could increase the exposure of the vehicle's front end to the cable anchor, may lead to instability due to snag of the impacting wheel on the cable. Further, the objectives of that research project did not include the determination of the end of the guardrail LON for the 2270P vehicle.

At present, limited research has been carried out to assess the safety of a guardrail barrier for vehicular impacts occurring in close proximity to non-crashworthy downstream anchorage systems. In fact, NCHRP Report No. 350 [7] nor MASH [2] do not specifically require a safety evaluation of a guardrail system under vehicular impacts occurring in close proximity to a downstream or trailing-end anchorage system.

2.3 Literature Review Summary

Previous pickup truck testing of end terminals using anchor cables under reverse-direction impact conditions indicated that vehicle interaction with the cable anchor occurred. In the case of small passenger cars, this vehicle interaction with the anchor cable may cause instabilities or excessive occupant risk values. Only one full-scale crash test was conducted on a non-proprietary, trailing-end terminal using a MASH small passenger car under reverse-direction impact conditions, which did not indicate any particular problems. However, there remains concern that increased vehicle snag may occur when considering a different impact point.

3 REVIEW STATE DOT TRAILING-END ANCHORAGES

A standards review was conducted for the member states of the Midwest States Pooled Fund Program as well as for the states of California, Texas, and New York. This review indicated that different types of guardrail anchors were used for trailing-end terminals. Although the anchor requirements prescribed in the plans for each specific state vary, treatments generally pertained to one of two classes: (1) treatments inside or (2) treatments outside of the clear zone of traffic in opposite travel lanes. From the standard plans that were reviewed for the noted state DOTs, the end anchorage systems, or trailing-end terminals, are rarely considered to be part of the downstream LON.

When the downstream anchorage terminal is located within the clear zone of opposing traffic, most state DOTs use proprietary end terminals that have been successfully crash tested and evaluated under NCHRP Report No. 350 criteria [7] or the more recent MASH standards [2]. In those cases in which a crashworthy guardrail end terminal is not used, a crash cushion would be required for many scenarios.

When the downstream anchorage terminal is located outside the clear zone of the traffic coming from the opposing direction, various generic guardrail end terminals have been used, including adaptations of the Breakaway Cable Terminal (BCT) system. In general, these terminals consist of a straight segment of guardrail with one or two breakaway wood posts embedded into steel foundation tubes with a cable anchorage system. The use of steel foundation tubes increases the post soil resistance as compared to traditional soil-installed posts, allowing for a more controlled wood post fracture as well as easier post replacement. In most cases, these end anchorage systems use a ground strut to connect the first two posts together to improve the load distribution between end posts and increase the anchorage capacity.

A summary of the generic trailing-end terminals in use by selected state DOTs is provided in Tables 3 and 4. From this review, it appeared that when non-proprietary, trailing-end terminals were utilized, the following two types were most often considered: (1) systems based on BCT posts and (2) systems buried in the backslope. In some cases, concrete anchorage system may be used as well. The drawings and the specifications for each system listed in Tables 3 and 4 can be found in Appendix A. The Wisconsin trailing-end anchorage system in use with many guardrail systems is shown in Figure 2.

The main advantage of non-proprietary anchor systems based on BCT posts is economics and ease of maintenance. Moreover, the use of BCT wood posts with a hole drilled at ground level allows for a controlled failure during vehicular impacts. On the other hand, the cable anchorage hardware at the end of the guardrail system may create a hazard for small cars. During a reverse-direction impact, a small car could be trapped or snagged on the sloped cable anchor, thus potentially increasing the ridedown acceleration to unacceptable values or causing vehicle rollover.

In addition to steel tube post foundations, concrete post foundations were historically used and are still in use by some state DOTs. Missouri DOT requires that posts are embedded into a concrete foundation. A concrete soil foundation was also previously used by Ohio DOT, but the concrete foundation was recently transitioned to a steel post foundation because it was believed to provide a stronger anchorage. A particular system proposed by the California Department of Transportation (Caltrans) [16] and the Minnesota DOT [17] consists of embedding the cable anchorage directly into a buried concrete foundation as an alternative to attaching the end of the cable to the end post through a classic bearing plate. Although constraining the cable anchor to a buried concrete block can increase the tensile resistance provided to the rail during an impact in close proximity to the anchorage, the cable would not be

Table 3. Summary of Non-Proprietary, Trailing-End Terminals for Reviewed State DOTs

State DOT	Terminal Designation	Rail Height (in.)	BCT Posts?	Cable Anchor?	Note	Trailing End Only?
IL [18]	Type 1B	31	Y	Y	Only to be installed where transition to dirt mound is possible. Flared system.	N
	Type 2	31	Y	Y	Only to be installed where end-on impacts are not a consideration.	Y
IA [19]	BA-203	31	Y	Y	Must be out of clear zone of opposing traffic.	Y
	BA-204	31	Y	Y	Must be out of clear zone of opposing traffic.	Y
KS [20]	MGS Type II	31	Y	Y	Thrie beam w/ asymmetrical transition to barrier rail.	Y
MN [17]	Standard plate 8307R (Specification reference 2554)					
	i) Strut Anchorage	27⅛	Y	Y	Must be out of clear zone of opposing traffic.	Y
	ii) Buried Anchorage Assembly	27⅛	Y	Y	Anchorage buried in soil.	Y
	Standard plate 8338C (Specification reference 2554)					
	i) Strut Anchorage	27⅛	N (Steel posts)	Y	Must be out of clear zone of opposing traffic.	Y
	ii) Buried Anchorage Assembly	27⅛	N (Steel posts)	Y	Anchorage buried in soil.	Y
MO [21]	Drawing 606.00AT					
	i) Steel foundation tubes	27	Y	Y	Must be out of clear zone of opposing traffic.	Y
	ii) Concrete foundation	27	Y	Y	Must be out of clear zone of opposing traffic.	Y
	iii) Anchored in backslope rail	27	N	N	For use with available back slopes. Anchorage provided by concrete block or steel post.	N
NE [22]	Special Plan C	27	Y	Y	Must be out of clear zone of opposing traffic.	Y
OH [23]	Type T Drawing GR-4.2	27¾	Y	Y	Must be out of clear zone of opposing traffic. The previous version w/ concrete foundation was replaced w/ steel foundation tubes.	Y

Table 4. Summary of Non-Proprietary, Trailing-End Terminals for Reviewed State DOTs (continued)

State DOT	Terminal Designation	Rail Height (in.)	BCT Posts?	Cable Anchor?	Note	Trailing End Only?
SD [24]	Drawing 630.80	28 (32)	Y	Y	Either W-beam or thrie beam configuration. Must be out of clear zone of opposing traffic.	Y
	Drawing 630.32	28	N	N	Must be out of clear zone of opposing traffic.	Y
	Drawing 630.02	32	N	N	Thrie beam. Must be out of clear zone of opposing traffic.	Y
WI [25]	Type 2 Drawing S.D.D. 14 B 16-40	31¾	Y	Y	For one-way roadway only	Y
WY [26]	Type C Drawing 606-1 (sheet 10)	27	Y	Y	Must be out of clear zone of opposing traffic.	Y
	Type D (low-speed terminal) Drawing 606-1 (sheet 11)	27	Y	Y	Must be out of clear zone of opposing traffic.	N (only for short radius)
TX [27]	Metal Beam Guard Fence Anchor Terminal GF (31) DAT-11	31	Y	Y	Must be out of clear zone of opposing traffic.	Y
CA [16]	Type SFT Drawing A77H1	27¾	Y	Y	Must be out of clear zone of opposing traffic. Thrie beam w/ asymmetrical transition to barrier rail.	Y
	Single thrie beam barrier end anchor Drawing A78E1	32	Y	Y	Must be out of clear zone of opposing traffic. Thrie beam w/ asymmetrical transition to barrier rail.	Y
	Anchored in backslope rail	NA	N	N	Must be out of clear zone of opposing traffic. Thrie beam w/ asymmetrical transition to barrier rail.	N
NY [28]	Anchored in backslope rail	NA	N	N	Anchorage provided by concrete foundation.	Y

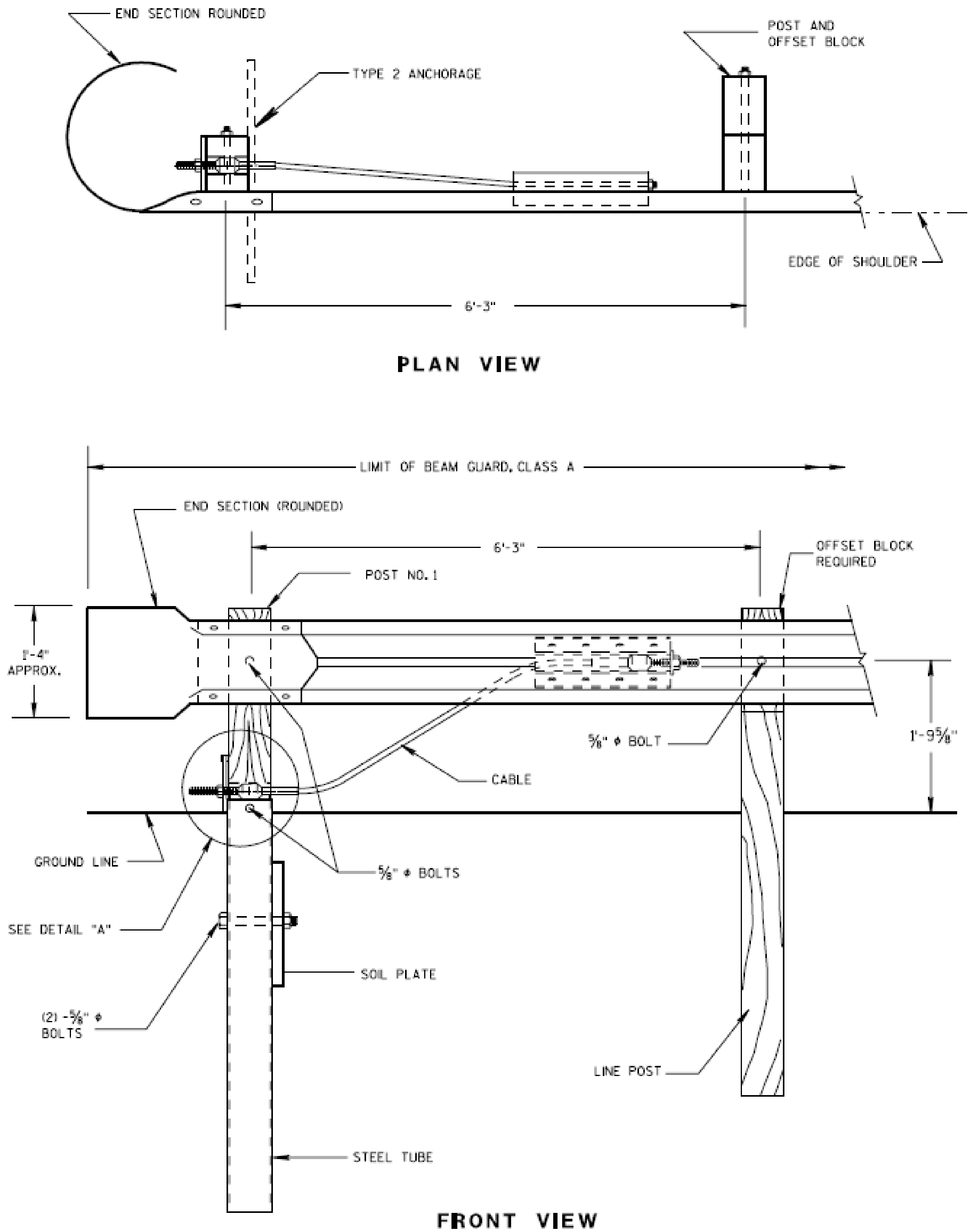


Figure 2. BCT Post Trailing-End Terminal Adopted by Wisconsin DOT [25]

able to release in a controlled manner if a vehicle wedged under and/or snagged on it. As such, there are concerns for excessive vehicle snagging on the cable anchor for this specific type of configuration.

For guardrail systems with rail splices located at the midspan between posts, such as the MGS, the reviewed state DOT standards, except for the Iowa DOT [19], considered adding an extra line post at the farthest downstream splice. By altering the post spacing near the trailing-end terminal, the W-beam system terminates at a BCT post instead of extending one half span beyond the last BCT post.

A particular solution adopted by the Iowa DOT for trailing-end terminals was based on the use of BCT posts and a cable anchor in combination with a thrie beam rail element at the end of the barrier, as shown in Figure 3. Although this particular design requires the use of a transition between the thrie beam and the W-beam guardrail, the increased shielding area provided by the thrie-beam rail in lieu of W-beam rail may reduce the potential for vehicle snag on the cable anchor at the trailing end.

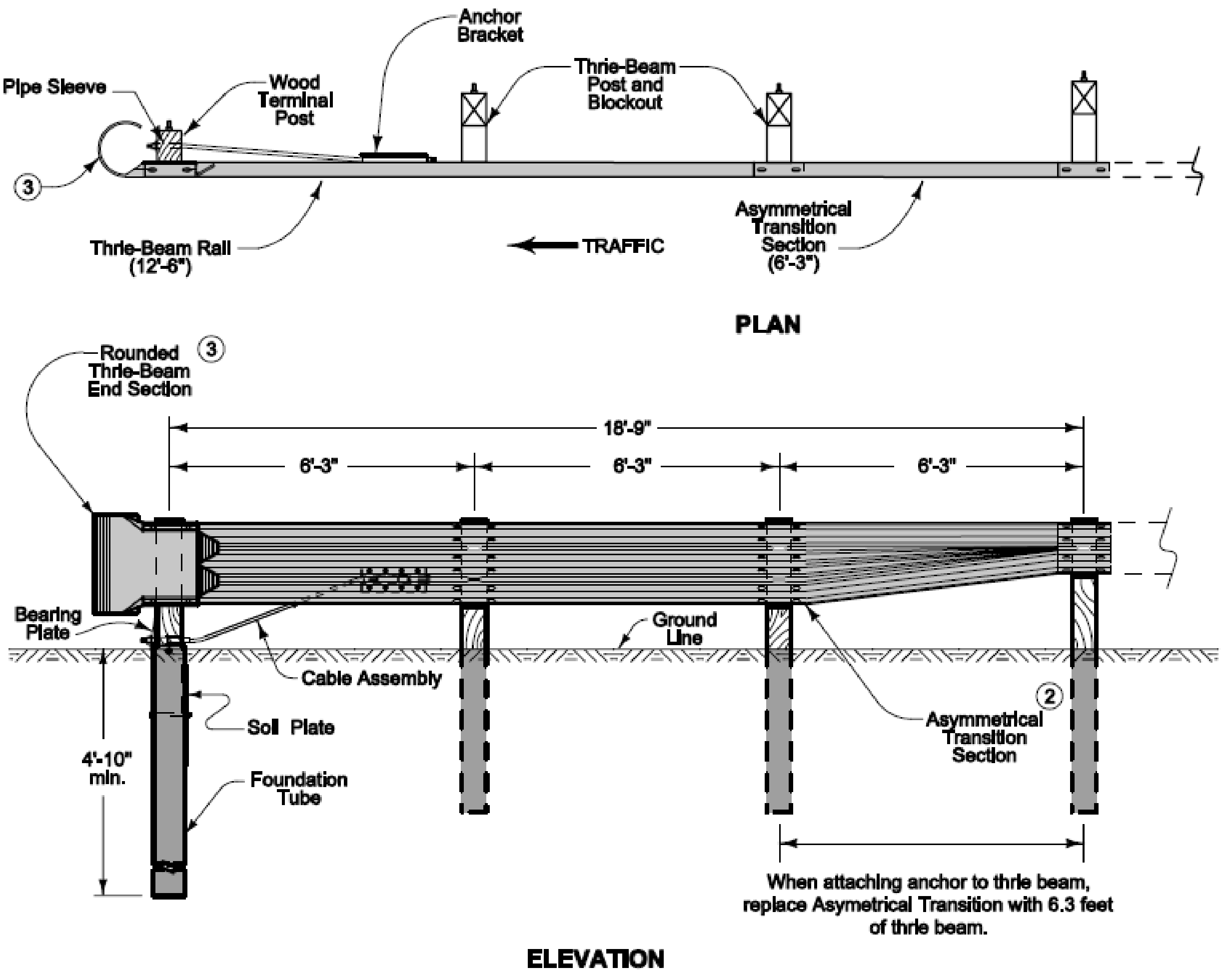


Figure 3. Trailing-End Terminal Adopted by Iowa DOT with BCT Posts and Thrie Beam [19].

4 DYNAMIC COMPONENT TEST CONDITIONS AND INSTRUMENTATION

4.1 Purpose and Scope

Most non-proprietary, trailing-end terminal designs use 5½-in. x 7½-in. (140-mm x 191-mm) BCT wood posts embedded into steel foundation tubes connected with a ground strut. Unfortunately, limited information is available regarding the splitting resistance of the BCT wood posts, the soil foundation tube resistance, or the overall dynamic capacity of a trailing-end terminal system that uses these standard components. Therefore, a series of dynamic component tests were performed to investigate and measure the noted behaviors and/or capacities.

Three test series were conducted on BCT end anchorages. The first test series, test nos. BCTRS-1 and BCTRS-2, consisted of eccentric shear loading on a BCT post to evaluate post splitting. Second, component test no. MGSEA-1 consisted of a pull test of the soil foundation tube. The third test series, test nos. DSAP-1 and DSAP-2, consisted of pull tests of a cable attached to a BCT foundation tube and subsequently connected to a W-beam guardrail.

The information desired from the bogie tests was to determine force versus deflection response. These results were then used to find total energy dissipated during each test by calculating the area under the force versus deflection curve.

4.2 Test Facility

All dynamic tests were conducted at the MwRSF outdoor testing facility located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport. The facility is approximately 5 miles (8 km) northwest of the University of Nebraska's city campus in Lincoln, Nebraska.

4.3 Test Equipment and Instrumentation

Equipment and instrumentation utilized to collect and record data during the dynamic bogie testing program included a bogie, accelerometers, load cells, string potentiometers, pressure tape switches, high-speed and standard-speed digital video cameras, and still cameras. For test nos. MGSEA-1, DSAP-1 and DSAP-2, one or two tensile load cells and a string potentiometer were also used.

4.3.1 Bogie Vehicle

For test nos. BCTRS-1 and BCTRS-2, a rigid-frame bogie was used to impact the BCT wood posts. A fixed-height, eccentric, detachable impact head was used during the testing program. The impact head was constructed from a 12-in. x 12-in. x 1-in. (305-mm x 305-mm x 25-mm) steel plate that was welded to a 12-in. x 12-in. x 1-in. (305-mm x 305-mm x 25-mm) base mounting plate and reinforced with two triangular gussets, as shown in Figure 4, and was mounted with a center-of-head height of 24⅞ in. (632 mm). The centerline of the bogie was aligned with the center of the post. The eccentric head was designed to transfer weak-axis bending and twisting loads to the post by impacting a shear transfer device attached with a bolt through the guardrail post bolt hole in the post. The weight of the bogie with the addition of the mountable impact head and accelerometers was 1,590 lb (721 kg).

Figure 4. Rigid-Frame Bogie used for Test Nos. BCTRS-1 and BCTRS-2

Test nos. BCTRS-1 and BCTRS-2 were conducted using a steel corrugated beam guardrail to guide the tire of the bogie vehicle. A pickup truck was used to push the bogie vehicle to the required impact velocity. After reaching the target velocity, the push vehicle braked, thus allowing the bogie to be free rolling as it came off the track. A remote-control braking system was installed on the bogie, thus allowing it to be brought safely to rest after the test.

For test nos. MGSEA-1, DSAP-1, and DSAP-2, a rigid-frame bogie was used to pull the end anchor system. The total mass of the bogie vehicle was 4,753, 5,086, and 4,780 lb (2,156, 2,307, and 2,168 kg) for test nos. MGSEA-1, DSAP-1, and DSAP-2, respectively. Four 3x7 wire rope cables were connected in a parallel configuration and used to pull on various components. The wire ropes were terminated with thimble (or cable saver) terminations and attached to the back of the bogie vehicle using a high-strength nylon strap and a pin-and-shackle connection. The bogie vehicle and the pull cable used for test nos. MGSEA-1, DSAP-1, and DSAP-2 are shown in Figure 5.

Figure 5. Rigid-Frame Bogie used for Test Nos. MGSEA-1, DSAP-1, and DSAP-2

A pickup truck with a reverse cable tow system was used to propel the bogie to a target impact speed of 15 mph (24 km/h) for test no. MGSEA-1 and 25 mph (40 km/h) for test nos. DSAP-1 and DSAP-2. A steel corrugated beam guardrail guided the tire of the bogie vehicle. When the bogie approached the end of the guidance system, it was released from the tow cable, thus allowing it to be free rolling when it started to tension the pull cable. A remote-control braking system was installed on the bogie, thus allowing it to be brought safely to rest after the test.

4.3.2 Accelerometers

Two environmental shock and vibration sensor/recorder systems were mounted on the bogie vehicle near its center-of-gravity (c.g.) to measure the acceleration in the longitudinal, lateral, and vertical directions for each test, except only one system was used for test no. DSAP-2. However, only the longitudinal acceleration was processed and reported. The type of accelerometer systems used for each specific component test is shown in Table 5.

Table 5. Accelerometer Systems Used for Dynamic Component Tests

Test No.	Accelerometer
BCTRS-1	EDR-3, DTS
BCTRS-2	EDR-3, DTS
MGSEA-1	EDR-3, DTS-SLICE
DSAP-1	EDR-3, DTS
DSAP-2	EDR-3

The first accelerometer system was a two-arm piezoresistive accelerometer system manufactured by Endevco of San Juan Capistrano, California. One accelerometer was used to measure longitudinal acceleration at a sample rate of 10,000 Hz. The accelerometer was configured and controlled using a system developed and manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. More specifically, data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M. The SIM was configured with 16 MB SRAM and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were crashworthy systems. 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, 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.

A third accelerometer system was a modular data acquisition system manufactured by DTS of Seal Beach, California. The acceleration sensor was 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.

4.3.3 Tensile Load Cells

A load cell was installed in line with the pull cable for test nos. MGSEA-1, DSAP-1, and DSAP-2. One additional load cell was installed in line with the cable anchor for test nos. DSAP-1 and DSAP-2. The positioning and setup of the load cells are shown in Figures 6 and Figure 7.

The load cells were manufactured by Transducer Techniques and conformed to model no. TLL-50K with a load range up to 50 kip (222 kN). During testing, output voltage signals were sent from the load cells to a National Instruments data acquisition board, acquired with LabView software, and stored permanently on a personal computer. The data collection rate for the load cells was 10,000 samples per second (10,000 Hz).

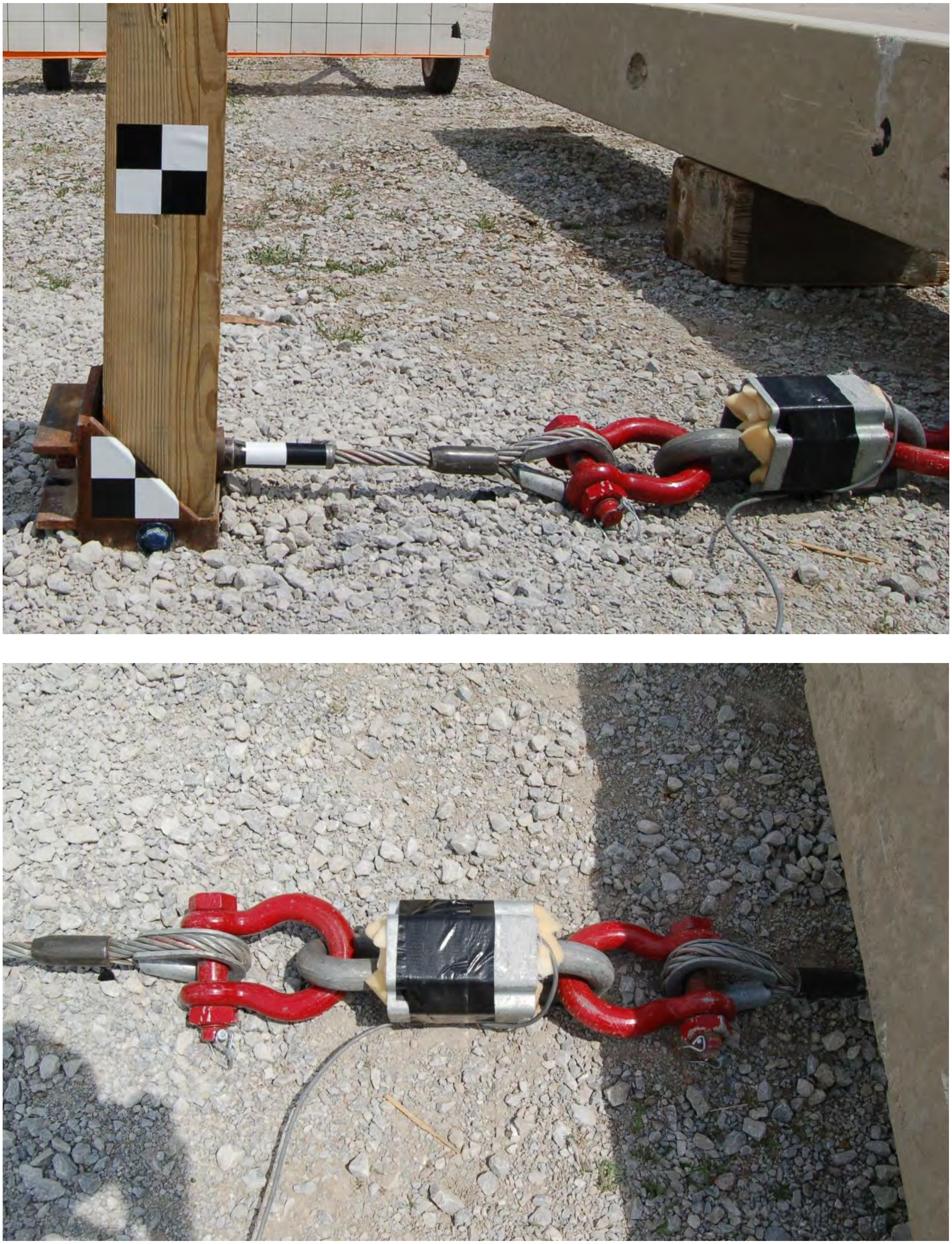


Figure 6. Tensile Load Cell Location, Test No. MGSEA-1

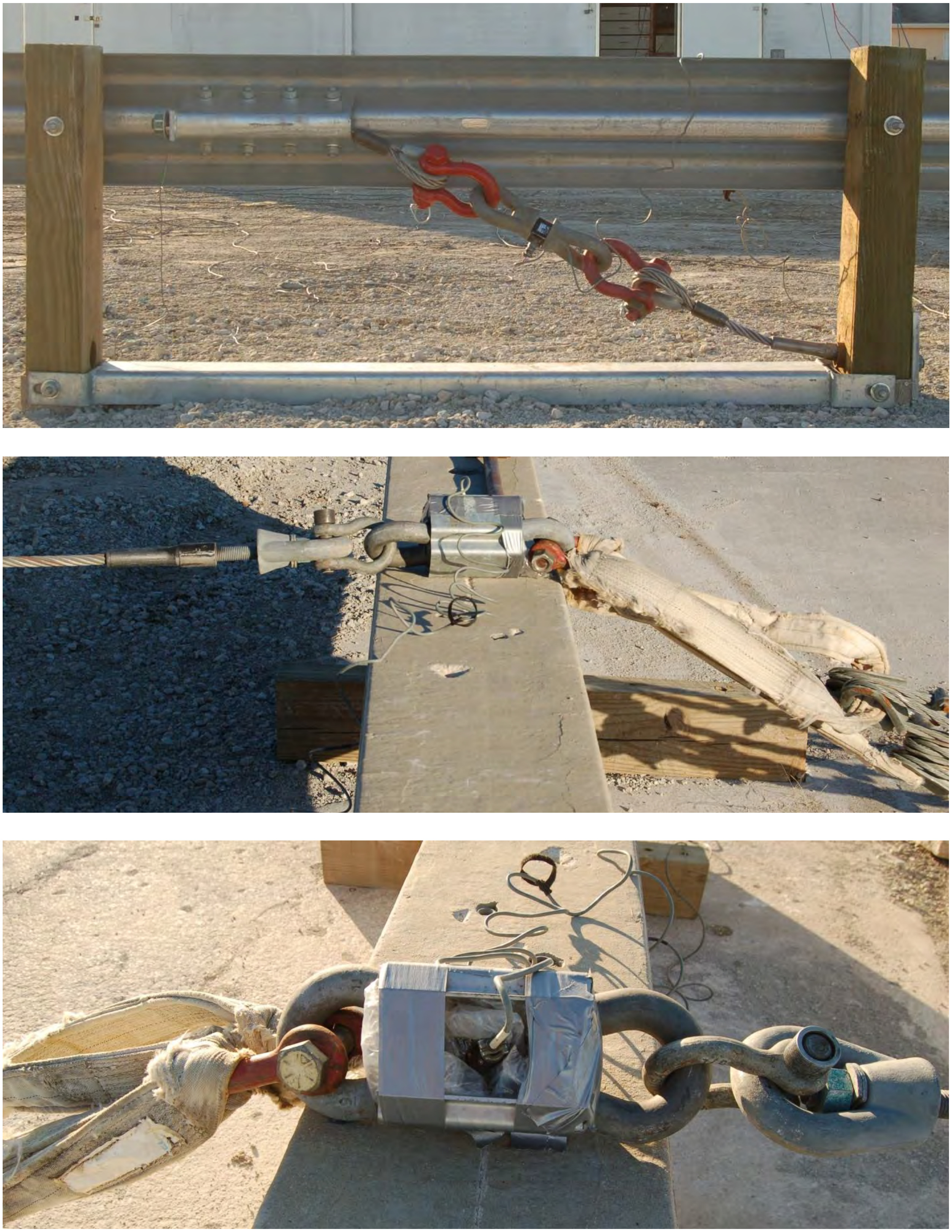


Figure 7. Tensile Load Cell Setup, Test Nos. DSAP-1 and DSAP-2

4.3.4 Compressive Load Cells

Two compressive load cells were also used in test no. DSAP-1. The compressive load cells are shown in Figure 8. One compressive load cells was placed between the nut and the modified cable anchor bracket at the end of the system, and one was attached between the nut and anchor bracket on the pull cable side of the system.

The washer-type compressive load cells were manufactured by Transducer Techniques and conformed to model no. LWO-80 with a load range up to 80 kip (356 kN). During testing, output voltage signals were sent from the load cells to a National Instruments data acquisition board, acquired with LabView software, and stored permanently on a personal computer. The data collection rate for the load cells was 10,000 samples per second (10,000 Hz).

4.3.5 String Potentiometers

A linear displacement transducer, or string potentiometer, was installed at the ground line of the post in test no. MGSEA-1 to determine the displacement of the post. For test nos. DSAP-1 and DSAP-2, the string potentiometer was attached at the ground line of the very end BCT post to measure the anchor systems displacement. The positioning and setup of the string potentiometer are shown in Figure 9. The string potentiometer used was a UniMeasure PA-50 with a range of 50 in. (1,270 mm). A Measurements Group Vishay Model 2310 signal conditioning amplifier was used to condition and amplify the low-level signals to high-level outputs for multichannel, simultaneous dynamic recording in the “LabView” software. The sample rate of the string potentiometer was 1,000 Hz.

4.3.6 Pressure Tape Switches

For test nos. BCTRS-1 and BCTRS-2, three pressure tape switches, spaced at approximately 18-in. (457-mm) intervals and placed near the end of the bogie track, were used to determine the speed of the bogie before impact. As the right-front tire of the bogie passed over

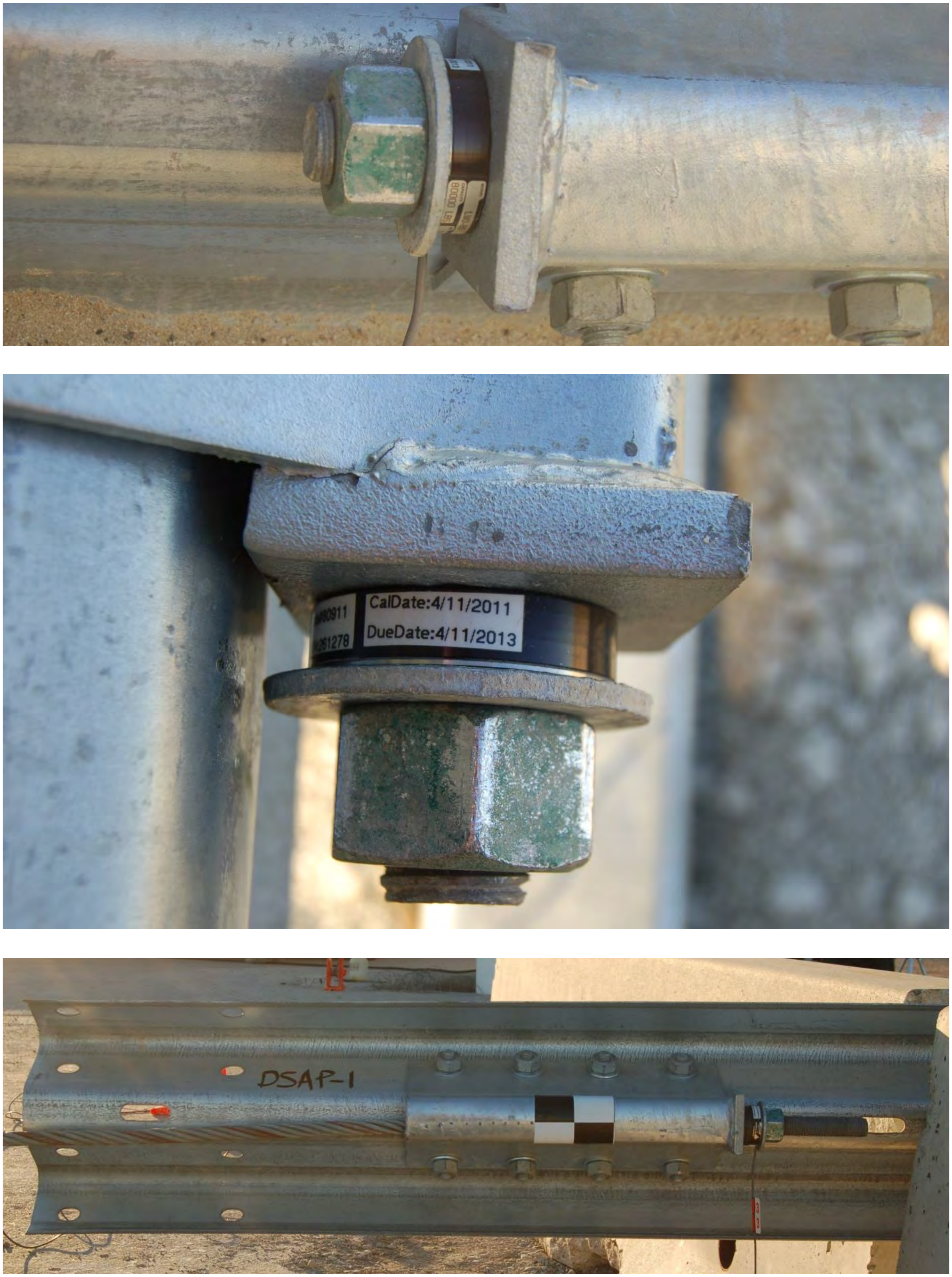


Figure 8. Compressive Load Cell Placement, Test No. DSAP-1

Figure 9. String Pot Backup Structure and Attachment Location, Test Nos. MGSEA-1, DSAP-1 and DSAP-2

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.

4.3.7 Digital Photography

AOS X-PRI high-speed digital video cameras and JVC digital video cameras were used to document each test. The AOS high-speed camera had a frame rate of 500 frames per second and the JVC digital video camera had a frame rate of 29.97 frames per second. The number of AOS VITcam cameras and JVC digital video cameras, and their location for each specific test are listed in Tables 6 and 7, respectively. A Nikon D50 digital still camera was also used to document pre- and post-test conditions for all tests.

Table 6. Number and Location of High-Speed Cameras Used for Dynamic Component Tests

<table>
<tr><th>Test No.</th><th># of AOS X-PRI</th><th>Location</th></tr>
<tr><td>BCTRS-1</td><td>2</td><td rowspan="2">Laterally from post, with view perpendicular to bogie’s direction of travel:
Camera 1 pointing at back side of post.
Camera 2 pointing at front side of post.</td></tr>
<tr><td>BCTRS-2</td><td>2</td></tr>
<tr><td>MGSEA-1</td><td>1</td><td>Laterally from post, with view perpendicular to bogie’s direction of travel.</td></tr>
<tr><td>DSAP-1</td><td>2</td><td rowspan="2">Perpendicular to the system, pointing toward the back side of the rail:
Camera 1 focused on end anchor.
Camera 2 focused on connection between end of W-beam rail and pull cable.</td></tr>
<tr><td>DSAP-2</td><td>2</td></tr>
</table>

Table 7. Number and Location of JVC Digital Cameras Used for Dynamic Component Tests

Test No.	# of JVC Cameras	Location
BCTRS-1	2	Laterally from post, with view perpendicular to bogie's direction of travel: Camera 1 pointing at back side of post. Camera 2 pointing at front side of post.
BCTRS-2	2	
MGSEA-1	3	Two cameras perpendicular, and one camera parallel to bogie's direction of travel: Camera 1 (perpendicular) pointing at front side of post. Camera 2 (perpendicular) pointing at rear side of post. Camera 3 (parallel) pointing at post from side opposite to bogies' direction of travel.
DSAP-1	3	Two cameras perpendicular, and one camera parallel to the system: Camera 1 (perpendicular) pointing at front side of W-beam rail. Camera 2 (perpendicular) pointing at rear side of W-beam rail. Camera 3 (parallel) pointing at anchor end post.
DSAP-2	3	

4.4 End of Test and Loading Event Determination

When the impact head initially contacts the test article, the force exerted by the surrogate test vehicle is directly perpendicular. However, as the post rotates, the surrogate test vehicle's orientation and path moves further from perpendicular. This introduces two sources of error: (1) the contact force between the impact head and the post has a vertical component and (2) the impact head slides upward along the test article. Therefore, only the initial portion of the accelerometer trace may be used since variations in the data become significant as the system rotates, and the surrogate test vehicle overrides the system. For this reason, the end of the test needed to be defined.

Guidelines were established to define the end of test time using the high-speed video of the crash test. The first occurrence of any one of the following three events was used to determine the end of the test: (1) the test article fractures; (2) the surrogate vehicle overrides/loses contact with the test article; or (3) a maximum post rotation of 45 degrees is achieved.

The BCT posts fractured after impact with the bogie in test nos. BCTRS-1 and BCTRS-2. The test was determined to be completed after both halves of the BCT post fractured at the ground line and disengaged from the impact head.

For test no. MGSEA-1, the test was determined to be completed when the post and foundation tube had come to rest. During the test event, after the foundation tube had displaced more than 6 in. (152 mm), the wire rope connected to the load cell assembly and the bogie ruptured, resulting in a premature end-of-test event. Data collection and analysis ceased after the string pot data indicated very small perturbations from the permanent set at static equilibrium.

For test nos. DSAP-1 and DSAP-2, the W-beam was pulled downstream by the modified BCT cable anchor and the BCT posts fractured. The steel post with blockout was twisted downstream and released from the rail. After the rail had either disengaged from or fractured all three of the posts, data collection and analysis was terminated, and the test was determined to be completed.

4.5 Data Processing

4.5.1 Accelerometers

The electronic accelerometer data obtained in the dynamic testing was filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications [29]. The pertinent acceleration 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 pressure tape switch data, was then used to determine the bogie velocity. The calculated velocity trace was then integrated to find the bogie's displacement, which is also the deflection of the post. Combining the previous results, a force versus deflection curve was plotted for each test. Finally, integration of the force versus deflection curve provided the energy versus deflection curve for each test.

4.5.2 Load Cells

For test nos. MGSEA-1, BCTRS-1, and BCTRS-2, force data was measured with the load cell transducers and filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications [29]. The pertinent voltage signal was extracted from the bulk of the data signal similar to the acceleration data. The filtered voltage data was converted to load using the following equation:

$$\text{Load} = \left[\frac{1}{\text{Gain}}\right]\left[\frac{\text{Filtered Load Cell Data}}{\left(\frac{(\text{Calibration Factor})(\text{Excitation Voltage})}{\text{Full} - \text{Scale Load}}\right)\left(\frac{1\text{ V}}{1000\text{ mV}}\right)}\right]$$

Details behind the theory and equations used for processing and filtering the load cell data are located in SAE J211/1. The gain and excitation voltage were recorded for each test. The full-scale load for the TLL 50K load cells was 50 kip (222 kN). The calibration factor varied depending on the specific load cell being used. The load cell data was recorded in a data file and processed in a specifically-designed Excel spreadsheet. Force versus time plots were created to describe the load imparted to the system.

4.5.3 String Potentiometers

For test nos. MGSEA-1, BCTRS-1, and BCTRS-2, the pertinent data from the string potentiometers was extracted from the bulk signal similar to the accelerometer and load cell data. The extracted data signal was converted to a displacement using the transducer's calibration factor. Displacement versus time plots were created to describe the motion of the system at groundline. The exact moment of impact could not be determined from the string potentiometer data as impact may have occurred a few milliseconds prior to post movement. Thus, the extracted time shown in the displacement versus time plots should not be taken as a precise time after impact, but rather a general time in relation to the impact event.

5 COMPONENT TEST – ECCENTRICALLY LOADED BCT POST

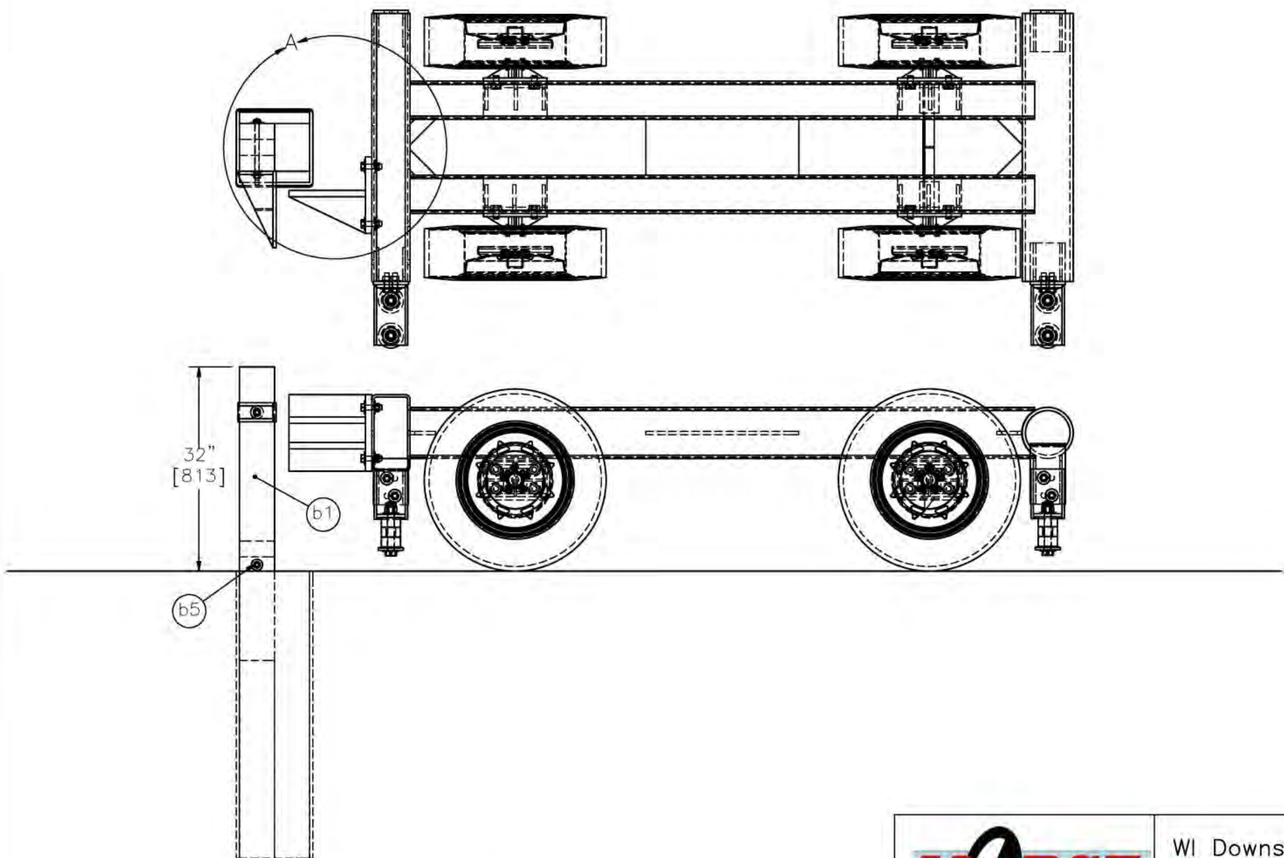
5.1 Test Setup and Instrumentation

Bogie test nos. BCTRS-1 and BCTRS-2 were conducted on BCT wood posts to determine their dynamic properties under an eccentric loading condition. This phenomenon may occur when the rail pulls on the post through the bolted connection in an end anchorage system. Details of the test setup are shown in Figures 10 through 16. Photographs of the test setup are shown in Figure 17. Material specifications, mill certifications, and certificates of conformity for the BCT post materials used in test nos. BCTRS-1 and BCTRS-2 are shown in Appendix B.

Each test was conducted on a 5½-in. x 7½-in. (140-mm x 191-mm) BCT wood post embedded 14 in. (356 mm) into a rigid sleeve. A rigid, steel shear-and-torsion extension (STE) was attached to the BCT post through the post-to-rail attachment hole drilled through the post parallel with the strong axis. The resulting top mounting height of the STE was 26⅜ in. (670 mm). An eccentric impact head, as described in Section 4.3.1, was mounted on the front of a 1,590-lb (721-kg) bogie vehicle and on the same side as the STE attached to the BCT post, such that the bogie head would impact the STE. This setup applied an eccentric impulse load to the BCT post, which approximates the tensile forces transferred between the rail and a BCT post without a cable anchor connection.

The target impact speed and angle were 15 mph (24 km/h) and 0 degrees (i.e., a weak axis bending), respectively. The protrusion attached to the post was impacted by the eccentric bogie head at a nominal offset of 3 in. (76 mm) from the post's side face, as shown in Figure 17. The centerline of the protrusion was located at 24⅞ in. (632 mm) above the ground line.

TEST QUANTITY	ESTIMATED BOGIE WEIGHT (lb)	BOGIE NO.	BOGIE SPEED (mph)
2	1,700	3	15



Notes: (1) Place spacer at the bottom of the rigid sleeve to raise the post to the correct height.

(2) Shim post tight in the rigid sleeve with shim material.

(3) Place high-speed camera on the impact side.

Midwest Roadside Safety Facility

WI Downstream Anchorage

BCT Post in Rigid Sleeve

SHEET: 1 of 7

DATE: 9/23/2011

DRAWN BY: DMH/JGP

DWG. NAME. WI_DS_anchor_BCT_R5

SCALE: 1:24

UNITS: Inches

REV. BY: MM/KAL/JDR

Figure 10. Bogie Testing Matrix and Setup, Test Nos. BCTRS-1 and BCTRS-2

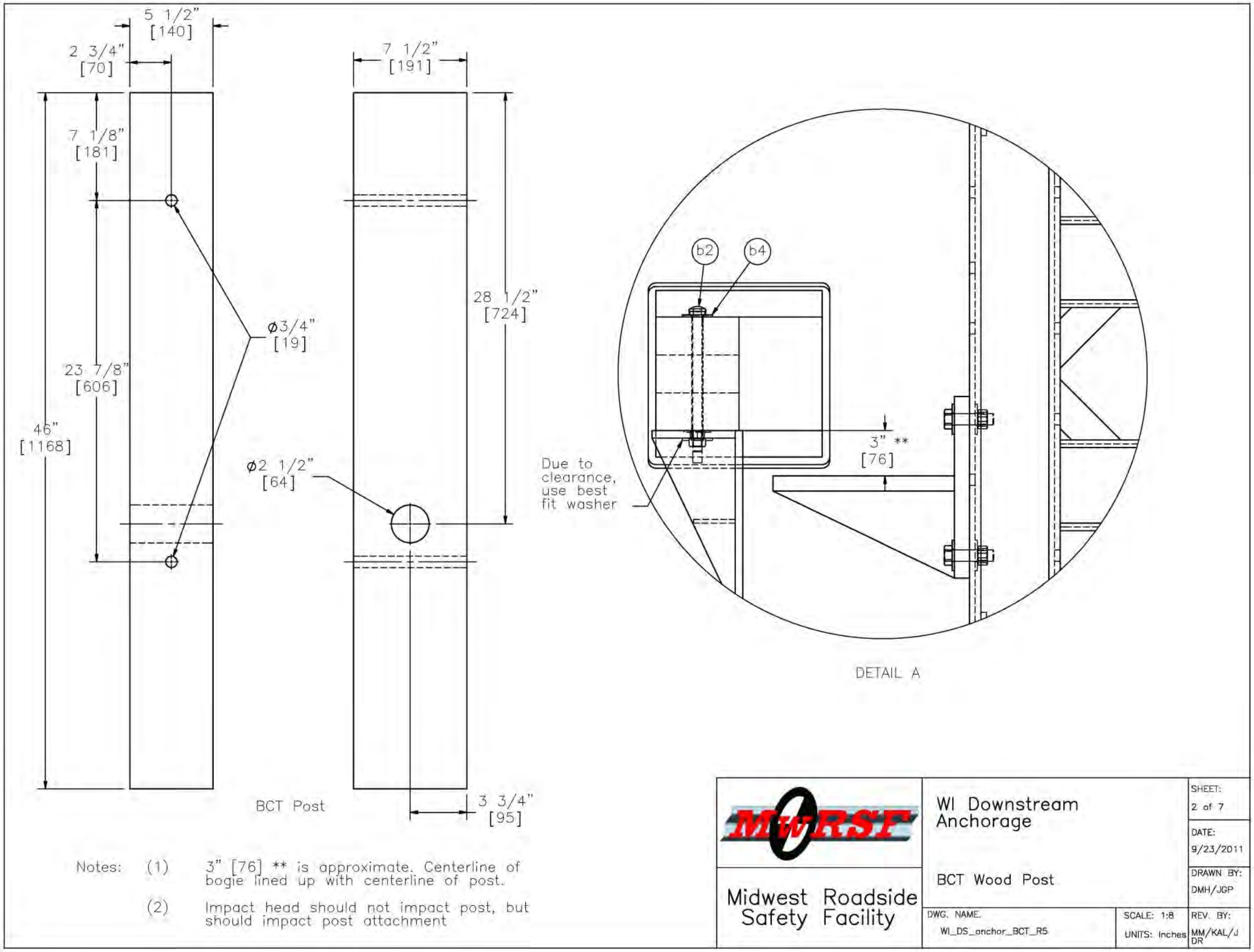


Figure 11. BCT Wood Post, Test Nos. BCTRS-1 and BCTRS-2

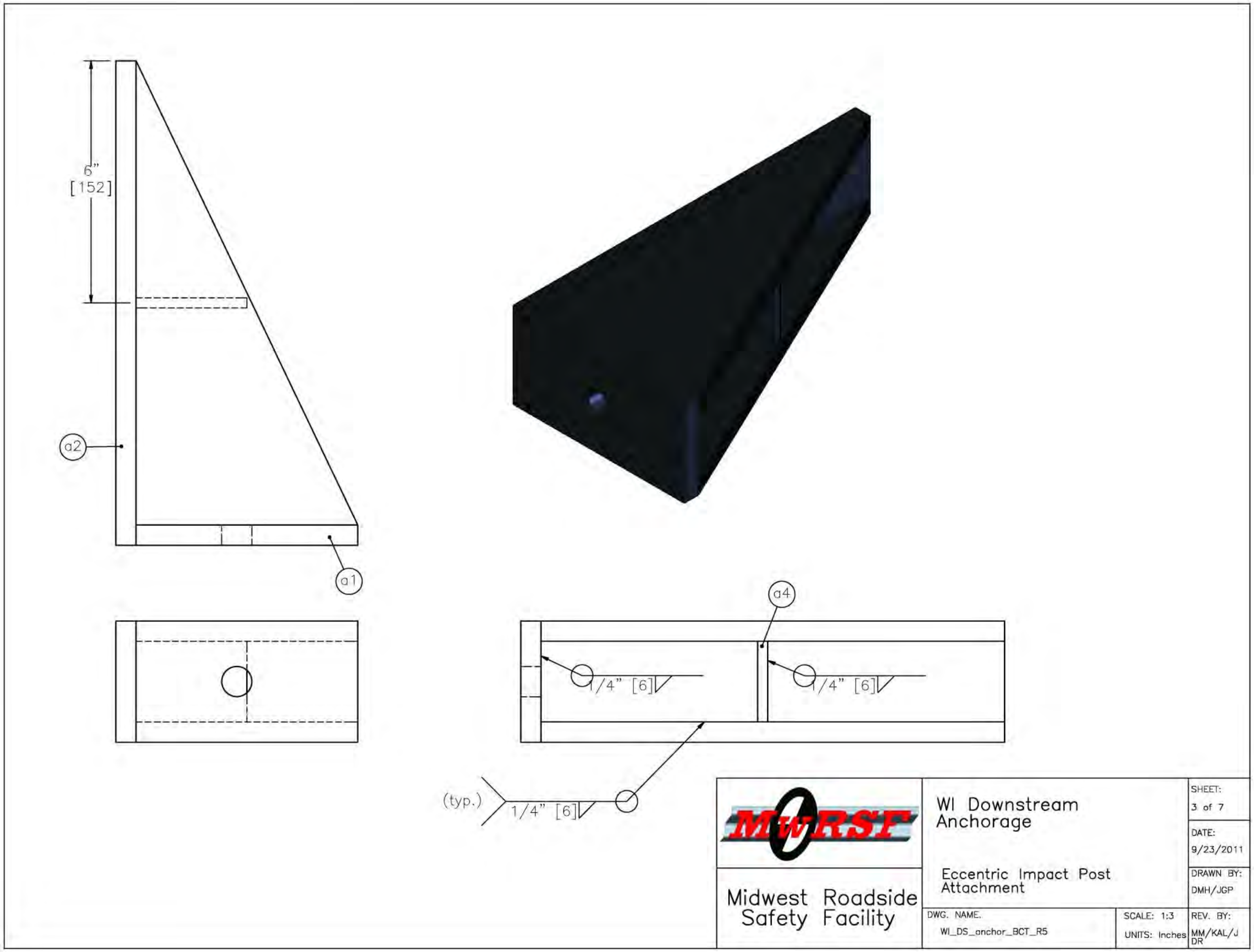


Figure 12. Eccentric Impact Post Attachment, Test Nos. BCTRS-1 and BCTRS-2

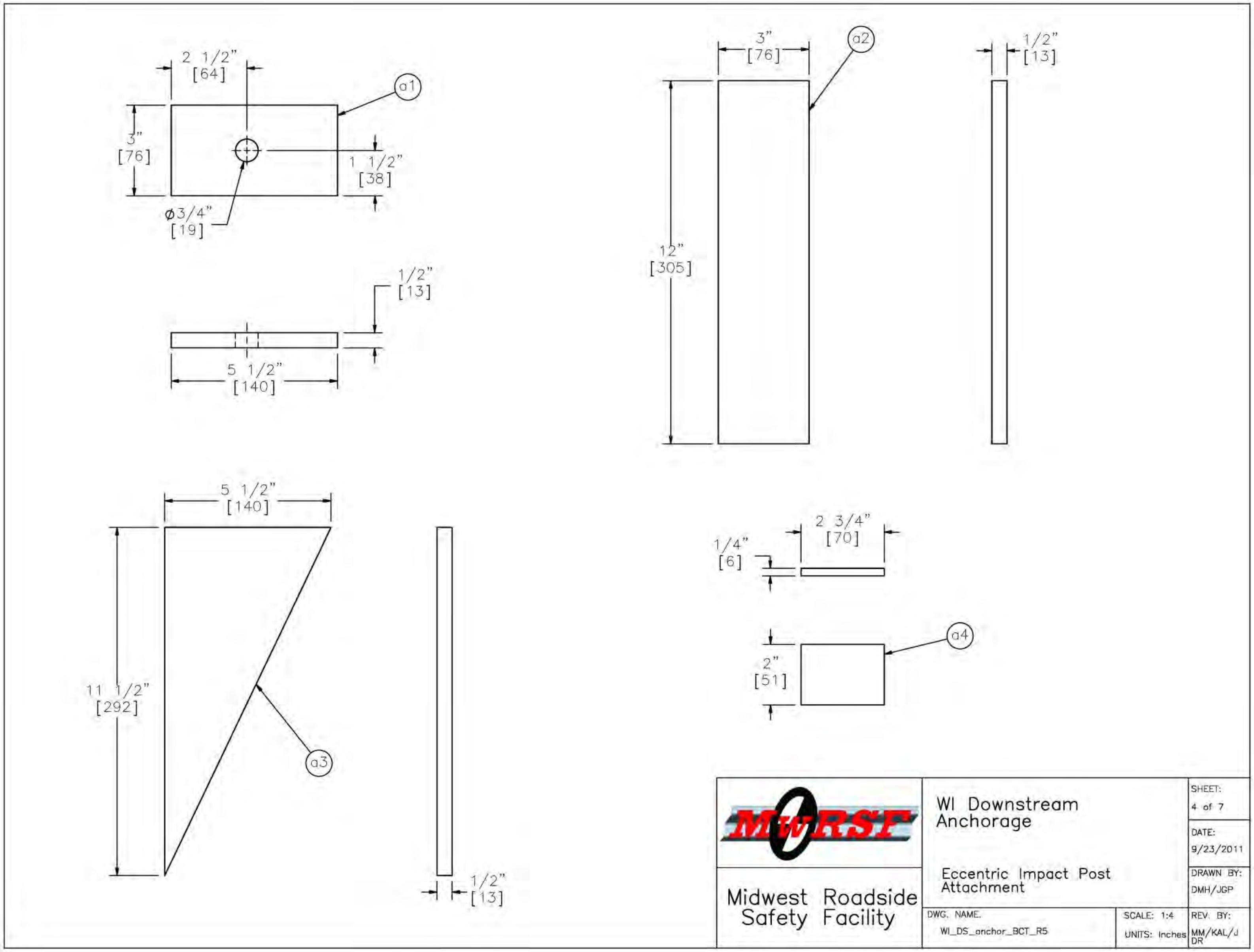


Figure 13. Eccentric Impact Post Attachment Components, Test Nos. BCTRS-1 and BCTRS-2

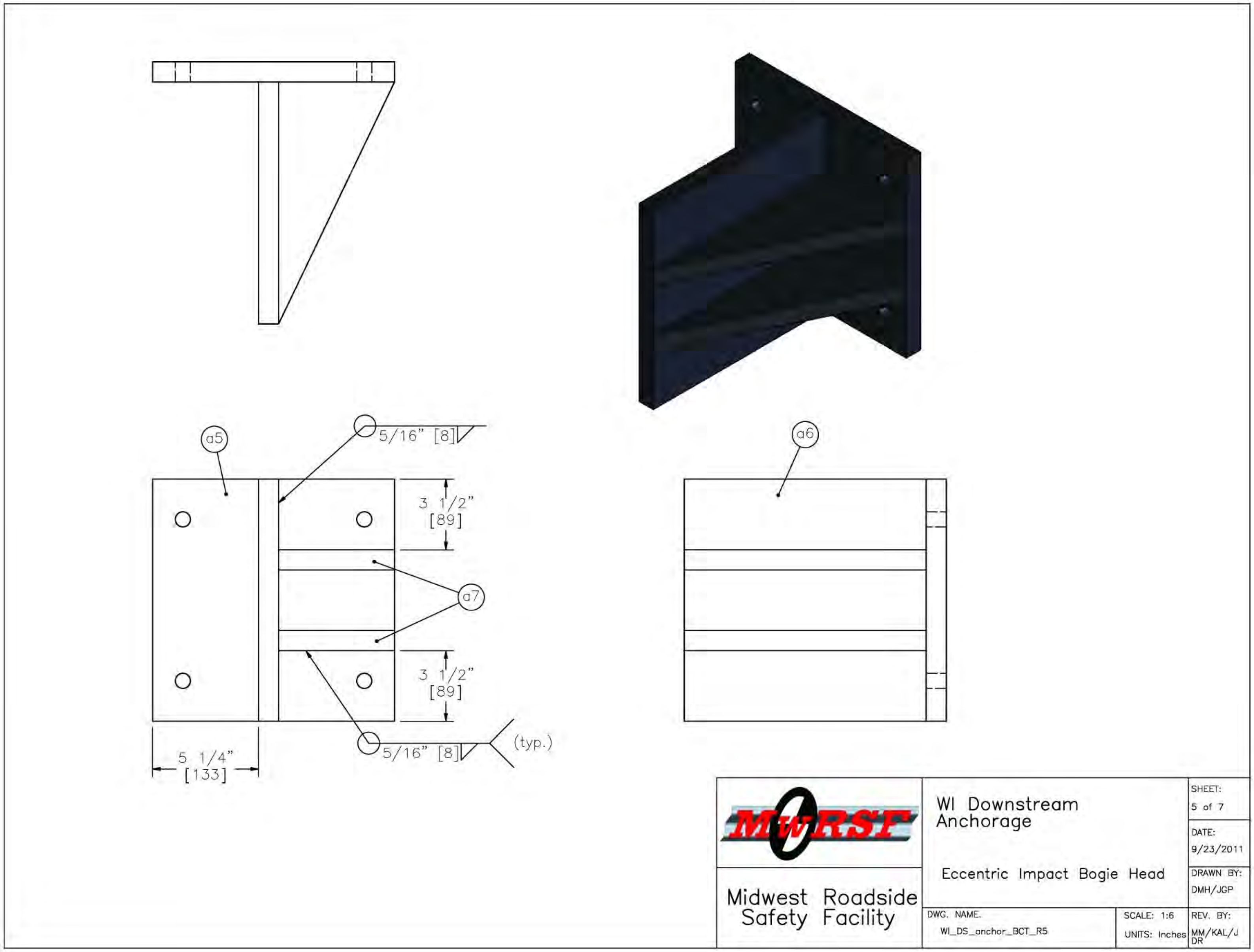


Figure 14. Eccentric Impact Bogie Head, Test Nos. BCTRS-1 and BCTRS-2

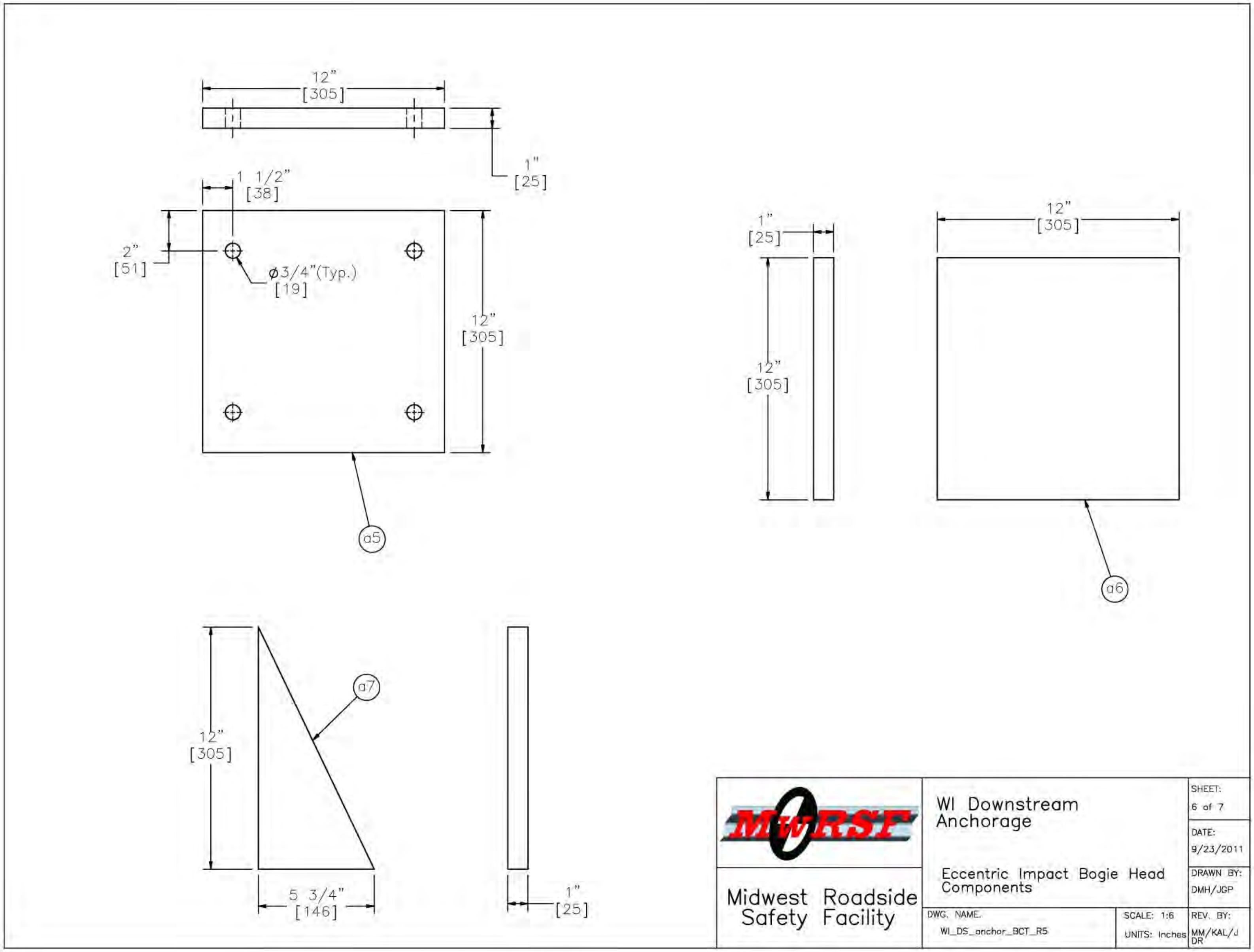


Figure 15. Eccentric Impact Bogie Head Components, Test Nos. BCTRS-1 and BCTRS-2

Item No.	QTY.	Description	Material Specification	Hardware Guide
a1	1	5 1/2x3x1/2" [140x76x13] Eccentric Impact Post Attachment Backplate	ASTM A36 Steel	–
a2	1	12x3x1/2" [305x76x13] Eccentric Impact Post Attachment Impactplate	ASTM A36 Steel	–
a3	2	1/2" [13] Eccentric Impact Post Attachment Gusset	ASTM A36 Steel	–
a4	1	1/4" [6] Eccentric Impact Post Attachment Supportplate	ASTM A36 Steel	–
a5	1	12x12x1" [305x305x25] Eccentric Impact Head Backplate	ASTM A36 Steel	–
a6	1	12x12x1" [305x305x25] Eccentric Impact Head Impactplate	ASTM A36 Steel	–
a7	2	1" [25] Eccentric Impact Head Gusset	ASTM A36 Steel	–
b1	1	BCT Timber Post –MGS Height	SYP Grade No. 1 or better	PDF01
b2	1	5/8" [16] Dia. x 10" [356] long Guardrail Bolt and Nut	Bolt ASTM A307 or Grade 2 Steel/ Nut ASTM A563 DH	FBB06
b3	2	5/8" [16] Dia. Plain Round Washer	ASTM A307 or Grade 2 Steel	FWC16a
b4	2	3/4" [19] Dia. Plain Round Washer	ASTM A307 or Grade 2 Steel	FWC20a
b5	1	5/8" [16] Dia. Hex Bolt and Nut	Bolt ASTM A307 or Grade 2 Steel/ Nut ASTM A563 DH	FBX16a

Midwest Roadside Safety Facility

WI Downstream Anchorage

Bill of Materials

SHEET: 7 of 7

DATE: 9/23/2011

DRAWN BY: DMH/JGP

DWG. NAME. WI_DS_anchor_BCT_R5

SCALE: N/A
UNITS: Inches

REV. BY: MM/KAL/JDR

Figure 16. Bill of Materials, Test Nos. BCTRS-1 and BCTRS-2

Figure 17. Test Setup, Test Nos. BCTRS-1 and BCTRS-2

The accelerometer data were processed in order to obtain acceleration, velocity, and deflection curves, as well as force versus deflection and energy versus deflection curves. The values described herein were calculated from the DTS data curves. Although the acceleration data was applied to the impact location, the data came from the c.g. of the bogie. Error was added to the data; since, the bogie was not perfectly rigid and sustained vibrations. The bogie may have also rotated during impact, causing differences in accelerations between the bogie center of mass and the bogie impact head. However, these sources of error were believed to be minor in comparison with the magnitudes of the data obtained. Filtering procedures were applied to the data to smooth out vibrations, and the rotations of the bogie during testing were deemed minor. One useful aspect of using accelerometer data was that it included influences of the post inertia on the reaction force. This was important as the mass of the post would affect barrier performance as well as test results.

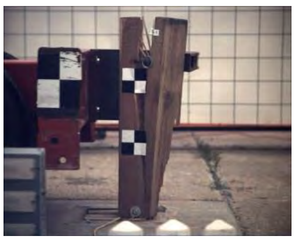
5.2 Results

5.2.1 Test No. BCTRS-1

During test no. BCTRS-1, the eccentric bogie head impacted the protrusion mounted on the left side of the 5½-in. x 7½-in. (140-mm x 191-mm) BCT wood post at a speed of 15.6 mph (25.1 km/h), which caused multiaxial loading, consisting of longitudinal shear, weak-axis bending, and torsion. Time-sequential and post-impact photographs are shown in Figure 18. After initially bending, the post split into two pieces along a fracture plane which was nearly perpendicular to the bogie vehicle's direction of motion. The fracture started at the top of the post and moved downward, but the split terminated above the through-hole at the ground line. At 0.046 sec, the bogie impacted the second portion of the post, which subsequently fractured at the ground line at 0.066 sec.

IMPACT

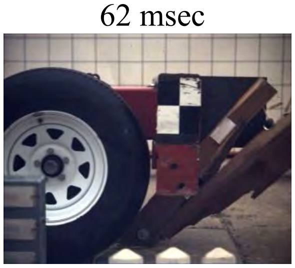
22 msec



32 msec

42 msec

62 msec



102 msec

Figure 18. Time-Sequential and Post-Impact Photographs, Test No. BCTRS-1

Force versus deflection and energy versus deflection curves created from the DTS accelerometer data are shown in Figure 19. The results from all transducers used during the test are provided in Appendix C. A large force spike occurred over the first 1.0 in. (25 mm) of deflection, and was caused by the inertial resistance of the post. After this initial spike, the force dropped to a relatively constant average value of 3.1 kip (14 kN) through a deflection of 4.8 in. (122 mm). At 0.018 sec after impact, and a bogie displacement of 5.0 in. (127 mm), the eccentrically-loaded BCT post split through a vertical plane, and the back half of the post fractured above the BCT hole. The final force spike occurred between a bogie displacement of 15 and 20 in. (381 and 508 mm) when the remaining portion of the post was impacted by the bogie vehicle. The second portion of the post fractured at 0.066 sec. The energy dissipated corresponding to the complete fracture of the first portion of the post at 5.9 in. (150 mm) was 19.0 kip-in. (2.1 kJ). The total energy dissipated due to fracture of both post sections was 59.9 kip-in. (6.8 kJ).

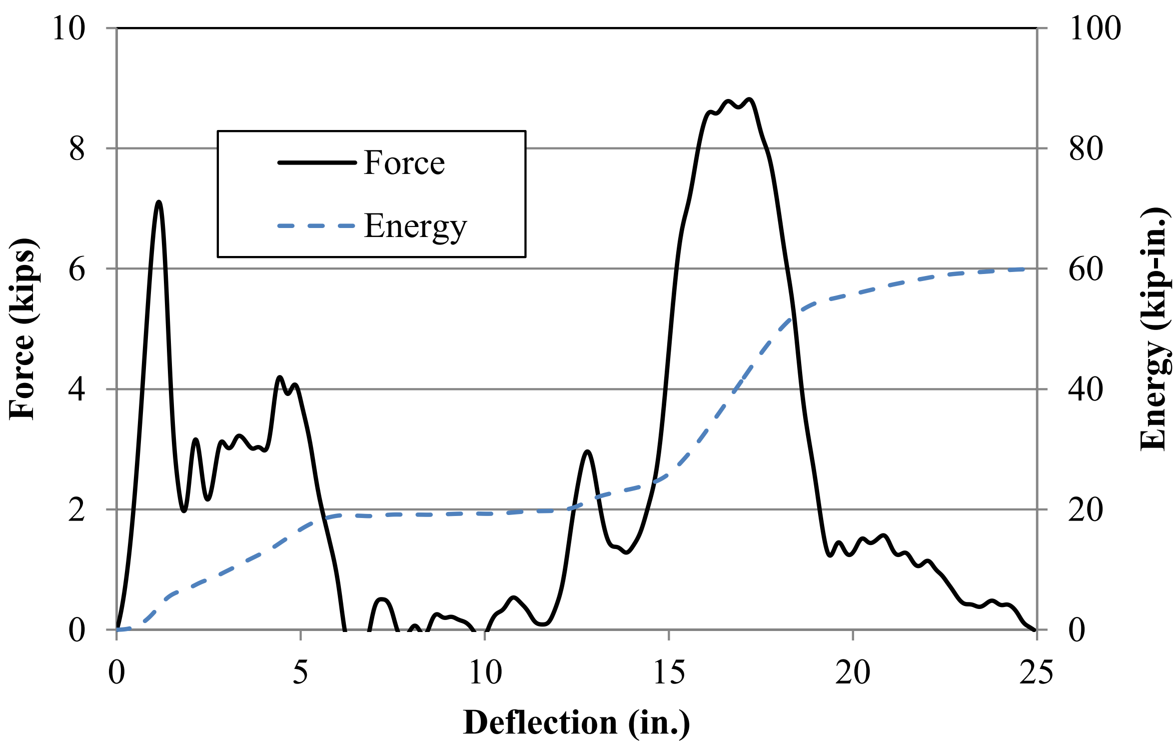


Figure 19. Force vs. Deflection and Energy vs. Deflection, Test No. BCTRS-1

5.2.2 Test No. BCTRS-2

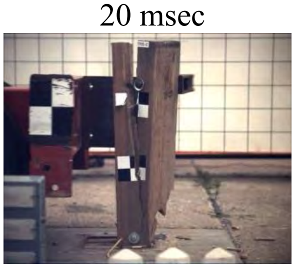
During test no. BCTRS-2, the eccentric bogie head impacted the STE mounted on the face of the 5½-in. and 7½-in. (140-mm x 191-mm) BCT wood post at a speed of 15.3 mph (24.6 km/h), which caused multi-axial loading, consisting of lateral shear, weak-axis bending, and torsion. Time-sequential and post-impact photographs are shown in Figure 20. After initially bending and twisting, the post split in two pieces along a vertical fracture plane perpendicular to the bogie vehicle's direction of motion at 0.016 sec. The fracture started at the top of the post and moved downward, where the post portion connected to the STE fractured at the ground line. The bogie vehicle impacted the second portion of the post at 0.0513 sec. At 0.0645 sec, the second portion of the post fractured at the ground line. The results from all transducers used during the test are provided in Appendix C.

Force versus deflection and energy versus deflection curves created from the DTS accelerometer data are shown in Figure 21. An inertial force spike occurred over the first inch (25 mm) of deflection. After this initial force spike, the force dropped to a relatively constant average value of 5.0 kips (22 kN) through a deflection of approximately 3 in. (76 mm). This deflection was due to a combination of post bending and twisting. The resistance force increased to 7.4 kip (32.9 kN) at 0.016 sec and a bogie displacement of 3.7 in. (94 mm). The post then split through a plane that was nearly perpendicular to the bogie vehicle's direction of motion. The energy dissipated due to the splitting fracture of the first portion of the post was 26.0 kip-in. (2.9 kJ). The bogie vehicle subsequently impacted the remaining portion of the post at 0.0513 sec with a bogie displacement of 12.8 in. (325 mm), which fractured at a bogie vehicle displacement of 15.9 in. (404 mm) and a load of 10.7 kip (47.6 kN). The energy corresponding to the complete fracture of the BCT post with STE attachment was 62.6 kip-in. (7.1 kJ).

IMPACT

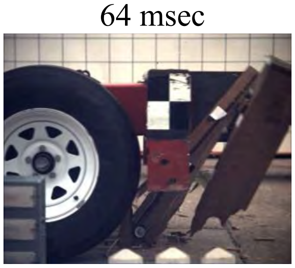
14 msec

20 msec



28 msec

64 msec



98 msec

Figure 20. Time-Sequential and Post-Impact Photographs, Test No. BCTRS-2

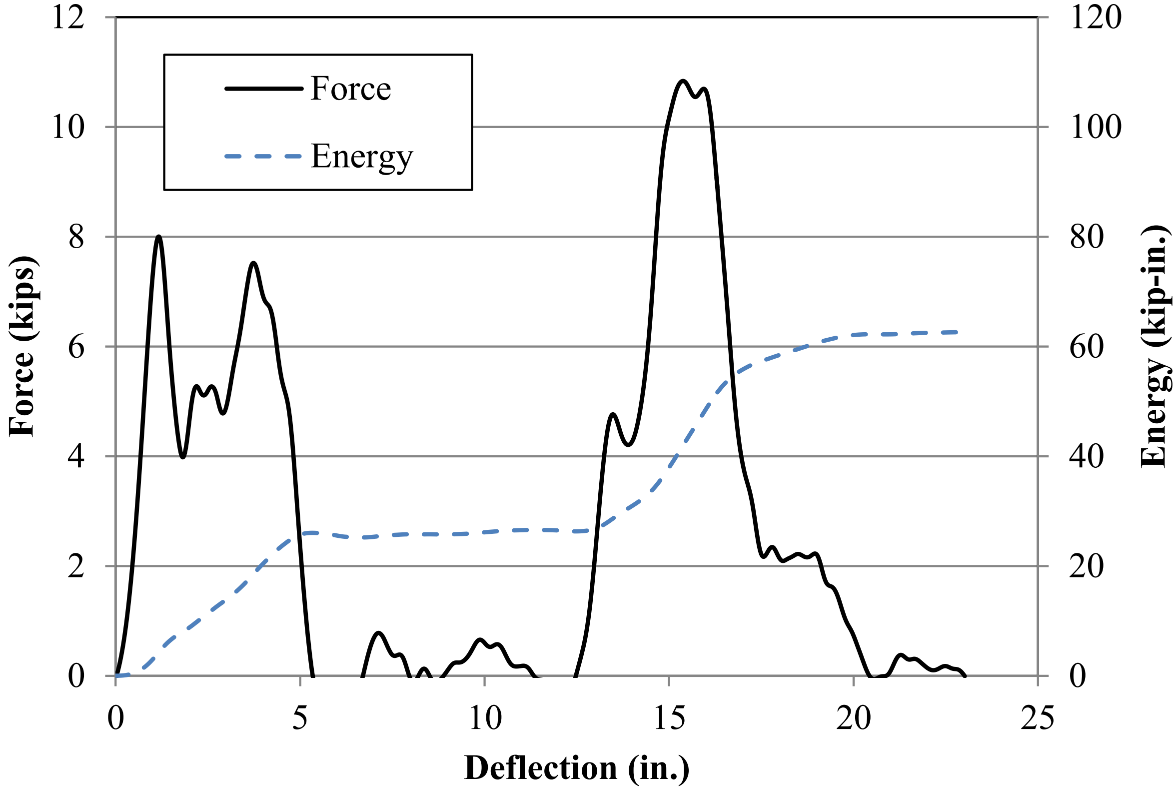


Figure 21. Force vs. Deflection and Energy vs. Deflection, Test No. BCTRS-2

5.3 Discussion

In both test nos. BCTRS-1 and BCTRS-2, the BCT post split into two pieces as a consequence of the impact force transferred by the rigid steel STE to the wood post. The impact speeds utilized in test nos. BCTRS-1 and BCTRS-2 were 15.6 mph and 15.3 mph (25.1 and 24.6 km/h), respectively. The energies associated with the fracture of the first post portion varied from 19.0 kip-in. (2.1 kJ) to 26.0 kip-in. (2.9 kJ) for test nos. BCTRS-1 and BCTRS-2, respectively. Although the splitting energies varied by 7.0 kip-in. (0.8 kJ), the posts dissipated approximately the same total amount of energy when the complete fracture of the BCT posts occurred.

Wood is a heterogeneous, laminated composite material with variable material properties. These variations likely contributed to the differences between the splitting energies in the BCT posts in test nos. BCTRS-1 and BCTRS-2. The plane of splitting in test no. BCTRS-1 was angled such that the fracture plane terminated above the BCT hole in the post, which was located at the ground line. The split in test no. BCTRS-2 was also angled, but the splitting plane intersected the BCT hole on the back side of the post. Thus, the second post portion had a larger cross-sectional area at the BCT hole in test no. BCTRS-1 compared to the post in test no. BCTRS-2. Therefore, even though the fracture force was higher for the second portion of the post in test no. BCTRS-2 than in test no. BCTRS-1, the overall fracture energies of the posts were very similar at 59.9 kip-in. (6.8 kJ) for test no. BCTRS-1 and 62.6 kip-in. (7.1 kJ) for test no. BCTRS-2, respectively. Force versus deflection and energy versus deflection comparison plots are shown in Figures 22 and 23, respectively.

Posts which are subjected to splitting in full-scale crash tests or real-world crashes may not be subjected to complete fracture. As a result, the splitting energies may be more representative of splitting capacities of the posts than the energy dissipation due to weak-axis post fracture. Although the energy required to initiate and propagate vertical splitting in wood is lower than the energy required to fracture the wood in the weak axis, the combined effect of splitting and subsequent fracture of both split pieces of wood dissipated more energy than only weak-axis fracture.

Splitting and weak-axis fracture energies of the two BCT posts in test nos. BCTRS-1 and BCTRS-2 were compared to weak-axis fracture energies of controlled-release terminal (CRT) posts embedded in rigid sleeves. CRT posts are 6 in. x 8 in. x 72 in. (152 mm x 203 mm x 1,829 mm) timber posts embedded directly in soil, and are often used in lieu of steel breakaway posts for strong-post systems. Rigid sleeve tests of CRTs dissipated energy in a range spanning between 11.6 and 35.4 kip-in. (1.3 and 4.0 kJ) [31]. BCT splitting energies in test nos. BCTRS-1 and BCTRS-2 were similar to weak-axis CRT fracture energies, and the combined splitting and post fracture dissipated almost double the upper range of CRT fracture energy.

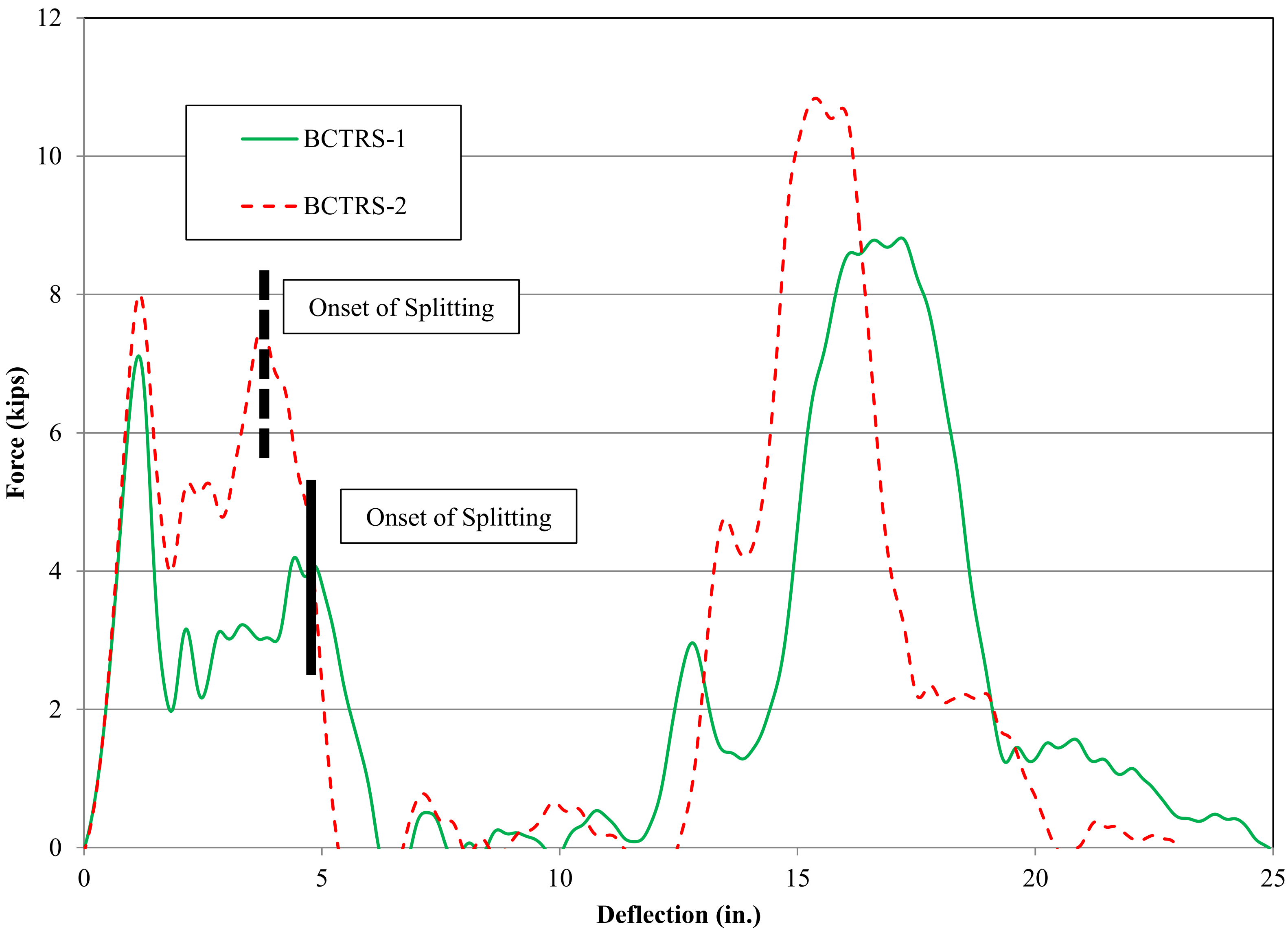


Figure 22. Force vs. Deflection Comparison, Test Nos. BCTRS-1 and BCTRS-2

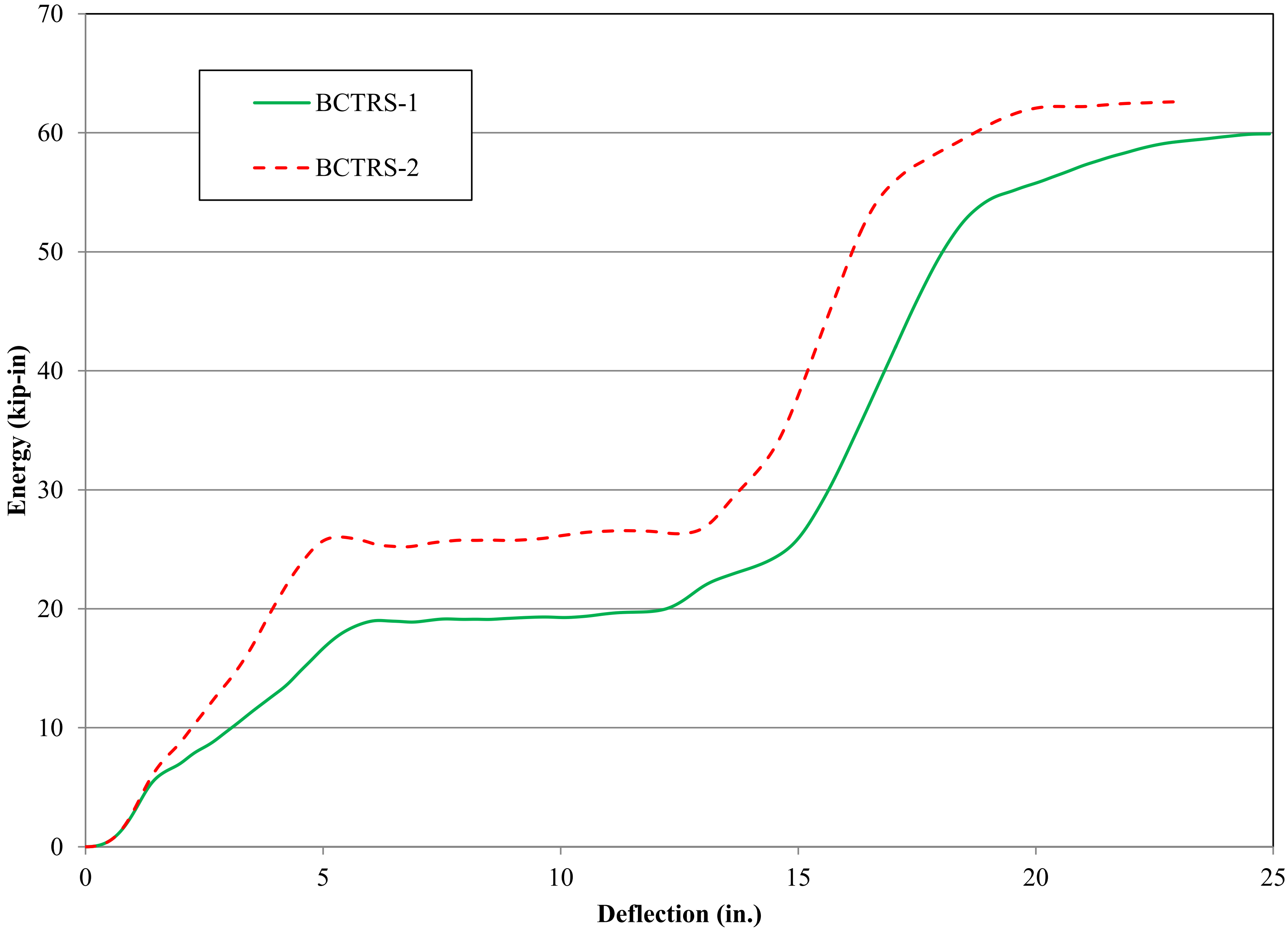


Figure 23. Energy vs. Deflection Comparison, Test Nos. BCTRS-1 and BCTRS-2

6 DYNAMIC COMPONENT TEST – FOUNDATION TUBE

6.1 Test Setup and Instrumentation

Bogie test no. MGSEA-1 was conducted by pulling on a single 6-in. x 8-in. x 72 in. (152-mm x 203-mm x 1,829-mm) foundation tube embedded into a compacted, coarse, crushed limestone material, as recommended by MASH. Details of the test setup are shown in Figures 24 through 34. Photographs of the setup are shown in Figures 35 and 36. Materials specifications, mill certifications, and certificates of conformity for the system materials used in test no. MGSEA-1 are shown in Appendix B.

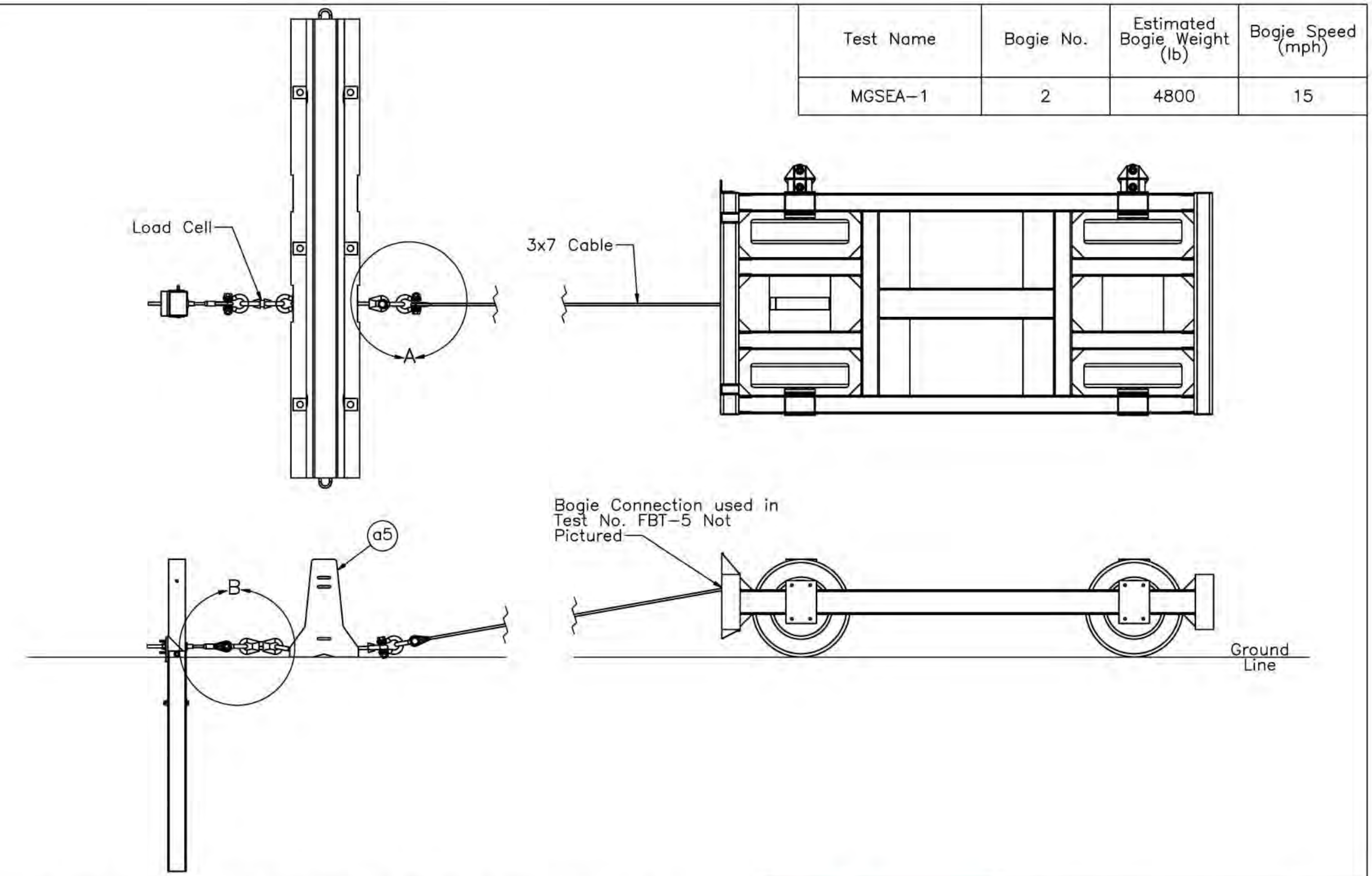
To account for potential inertial effects, a BCT post was placed into a foundation tube. A plate welded on the back side of the foundation tube was attached to a modified BCT anchor cable that contained a tension load cell. The instrumented anchor cable was then connected to a pull cable using an eye nut. The other end of the pull cable was attached to a 4,780-lb (2,168-kg) bogie vehicle. The target traveling speed was 15 mph (24 km/h).

The displacement of the foundation tube and the load at the ground line were measured using a string potentiometer and a load cell located in line with the anchor cable, respectively. During the test, the load cell cable connector became disconnected. Unfortunately, load cell data was lost when the wire disconnected early in the event. As a result, the force data was derived from the acceleration measured at the c.g. of the bogie vehicle.

6.2 Results

Time-sequential and post-test photographs of test no. MGSEA-1 are shown in Figure 37. During test no. MGSEA-1, the anchor foundation tube was pulled by the cable attached to the bogie vehicle, which was traveling at an initial speed of 16.1 mph (26.0 km/h) when the cable started to be tensioned. As a consequence of the pull force, the foundation tube rotated through the ground over a maximum dynamic displacement of 6.5 in. (165 mm). The final permanent

Test Name	Bogie No.	Estimated Bogie Weight (lb)	Bogie Speed (mph)
MGSEA-1	2	4800	15



Note:
(1) Use a parallel combination of three 3x7 cables as towing cables.
(2) High-speed camera perpendicular to the BCT post.
(3) Accelerometers on bogie: EDR-3 and DTS.
(4) Use a 50-kip tension load cell and string potentiometer.
(5) Details of standard temporary F-shape Concrete Barrier (a5) not included in this drawing set.

Midwest Roadside Safety Facility

WI Downstream Anchorage Anchor Post

Test Setup

SHEET: 1 of 11
DATE: 10/11/2012
DRAWN BY: MDM/CWP
REV. BY: MM/RWB/KAL
DWG. NAME. WI-DS-Anchor-Post-R7
SCALE: 1:50
UNITS: Inches

Figure 24. Bogie Testing Matrix and Setup, Test No. MGSEA-1

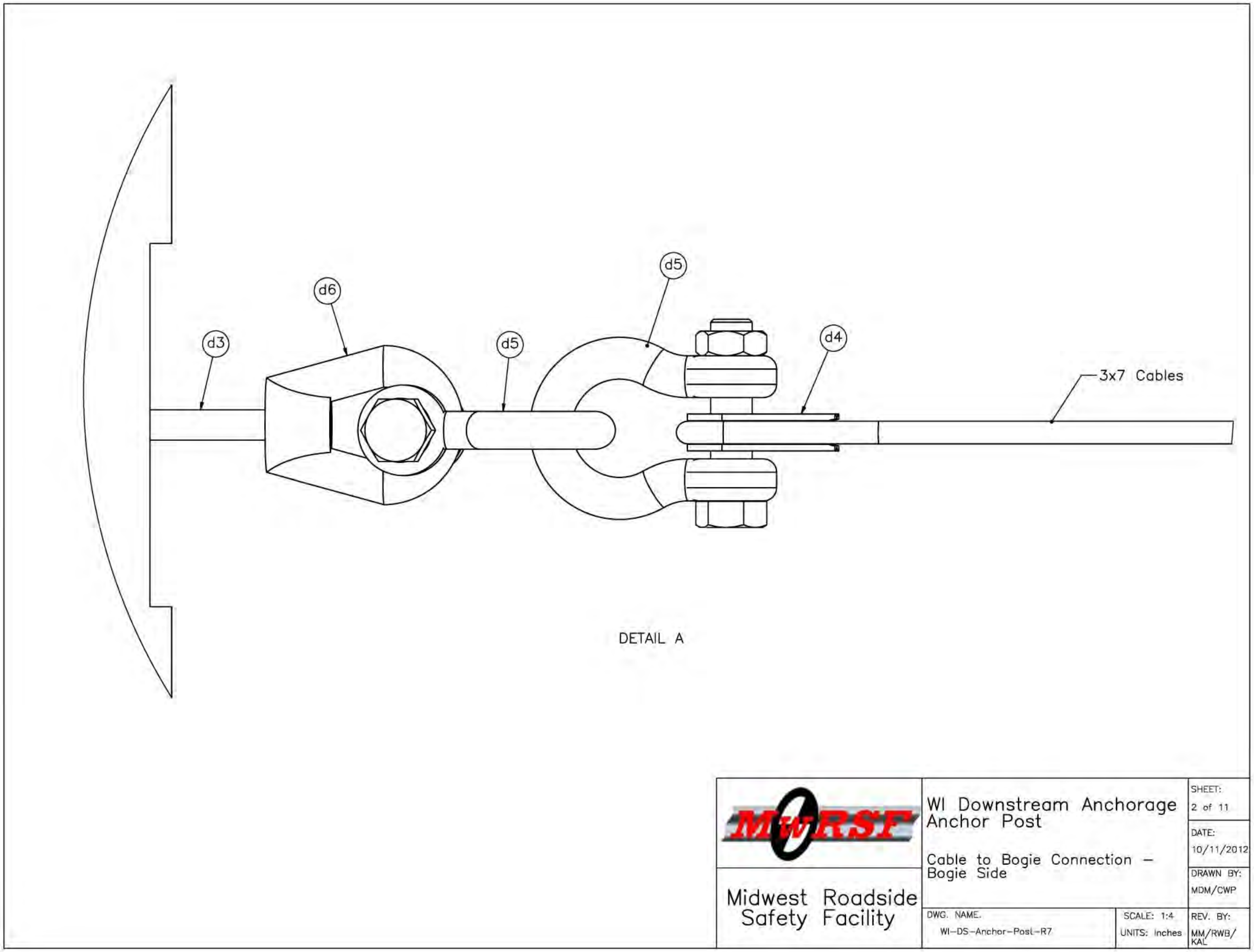


Figure 25. Bogie Testing Matrix and Setup, Test No. MGSEA-1

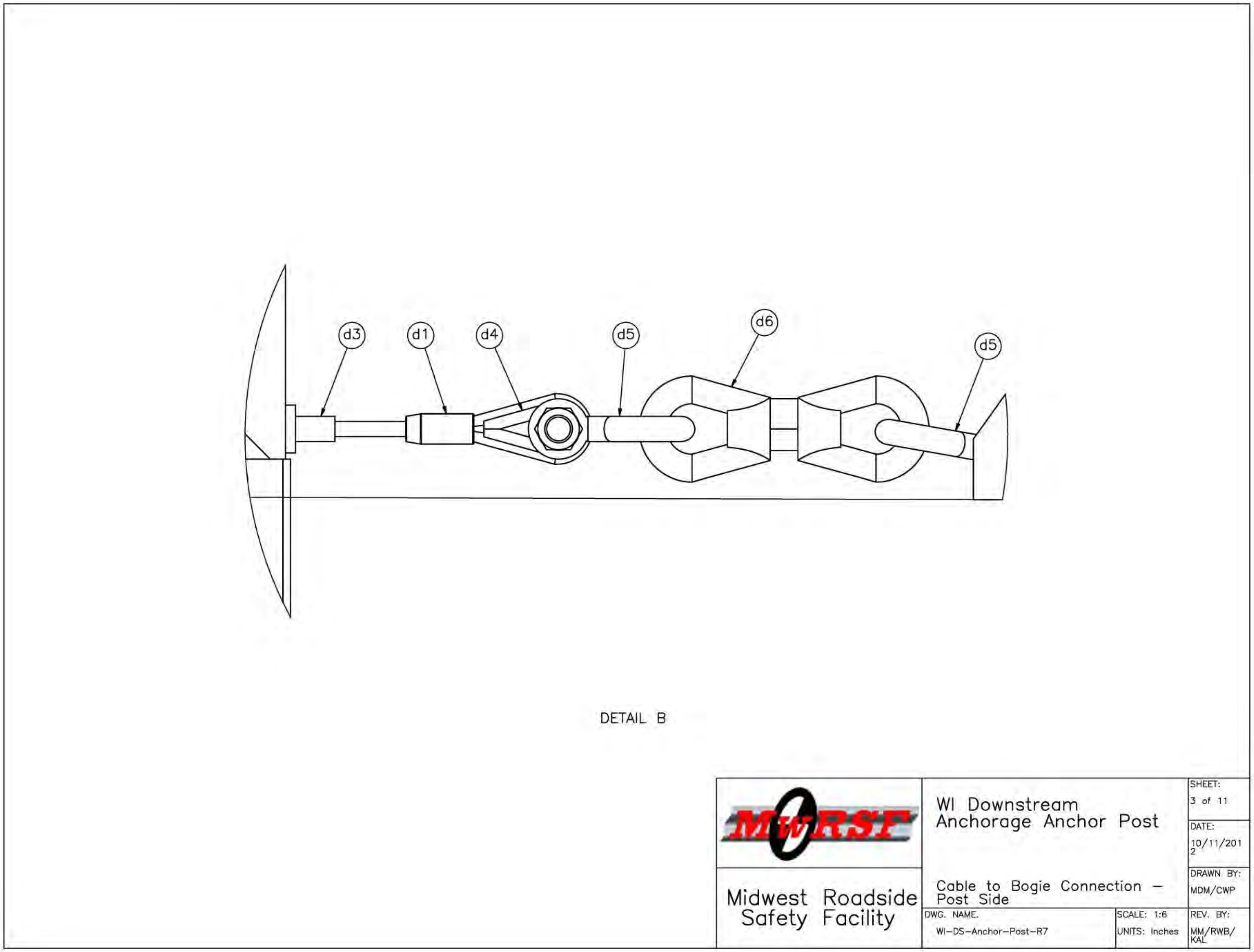


Figure 26. Bogie Testing Matrix and Setup, Test No. MGSEA-1

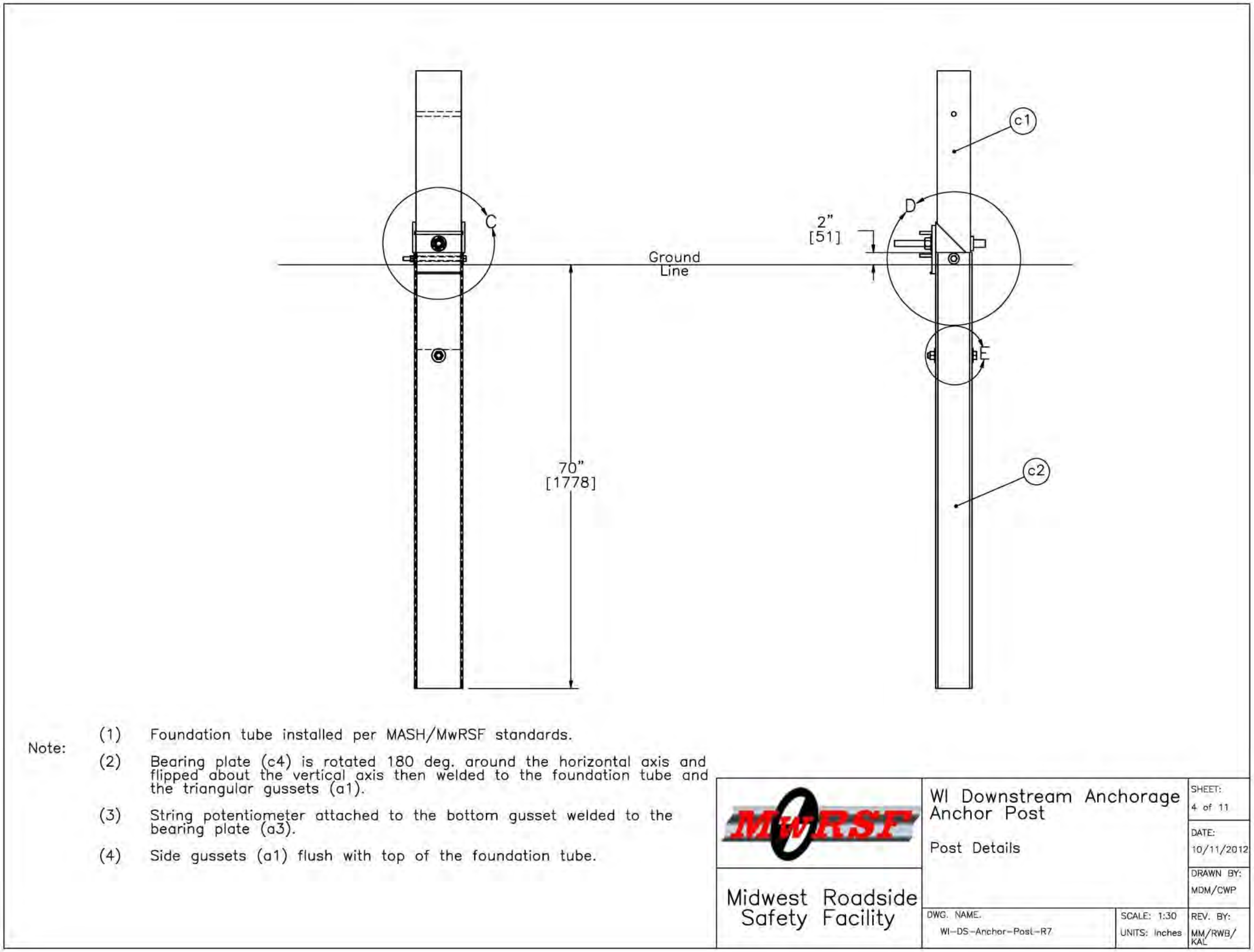


Figure 27. Post Details, Test No. MGSEA-1

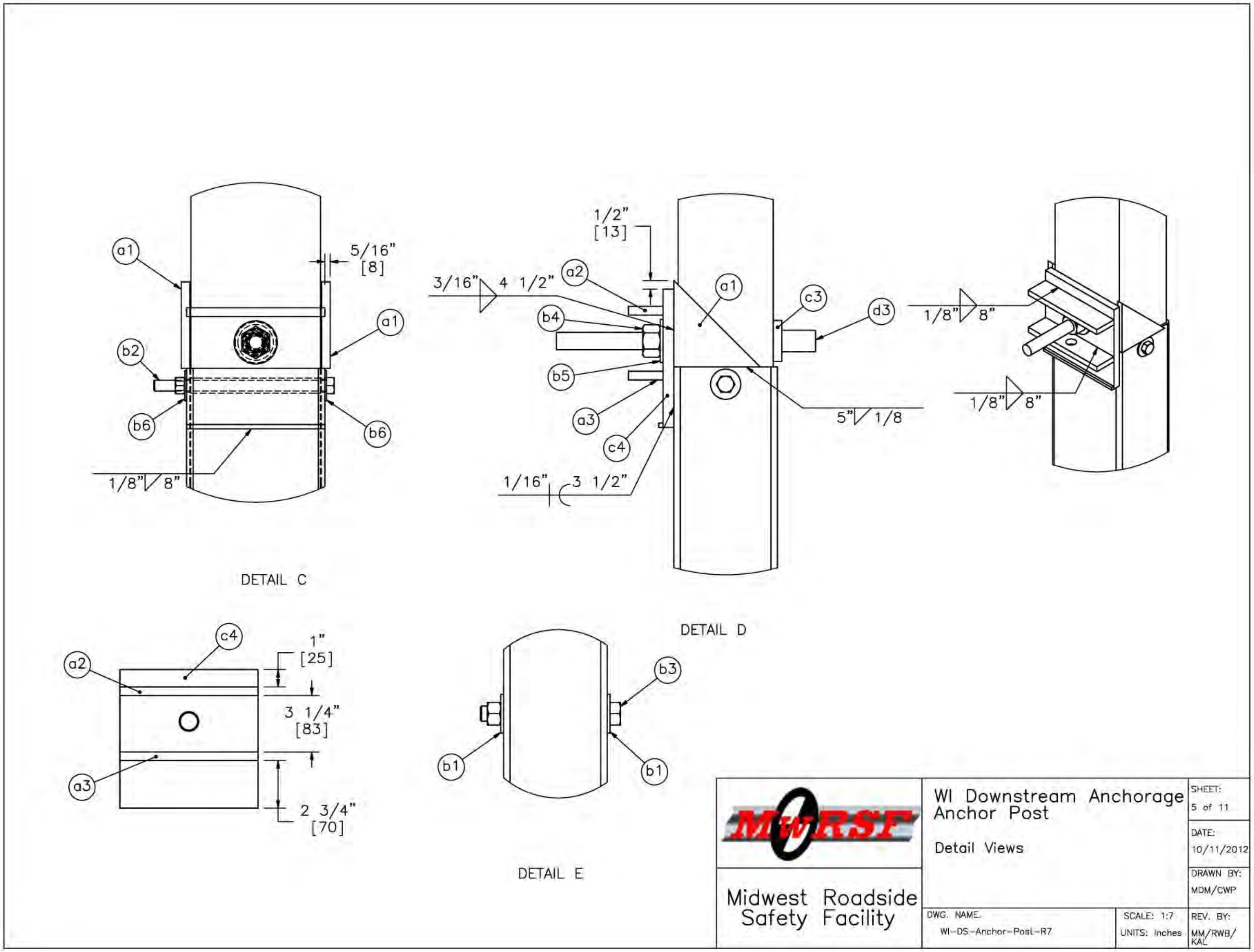
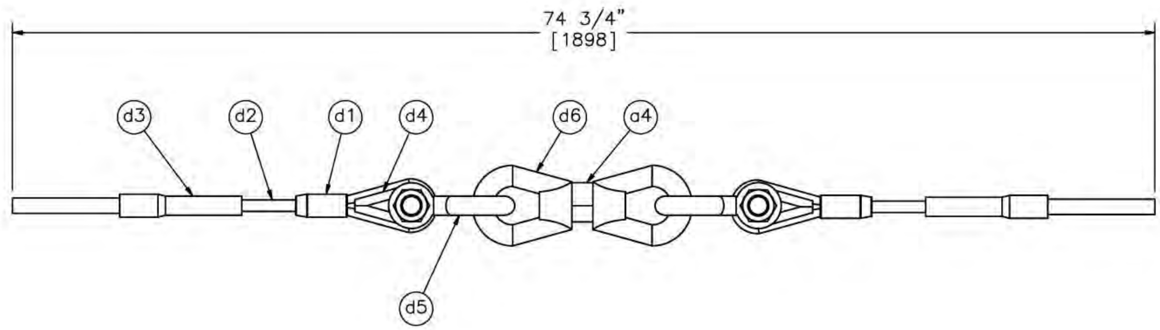


Figure 28. Bogie Testing Matrix and Setup, Test No. MGSEA-1



Note: (1) 6x25 IWRC IPS cables meet the minimum breaking strength of 42.7 kips [190 kN] and may be substituted for the 6x19 IWRC IPS cables.

MwRSF Midwest Roadside Safety Facility	WI Downstream Anchorage Anchor Post	SHEET: 6 of 11
		DATE: 10/11/2012
	Modified BCT Cable with Load Cell Assembly	DRAWN BY: MDM/CWP
	DWG. NAME. WI-DS-Anchor-Post-R7	SCALE: 1:10 UNITS: Inches
		REV. BY: MM/RWB/KAL

Figure 29. Bogie Testing Matrix and Setup, Test No. MGSEA-1

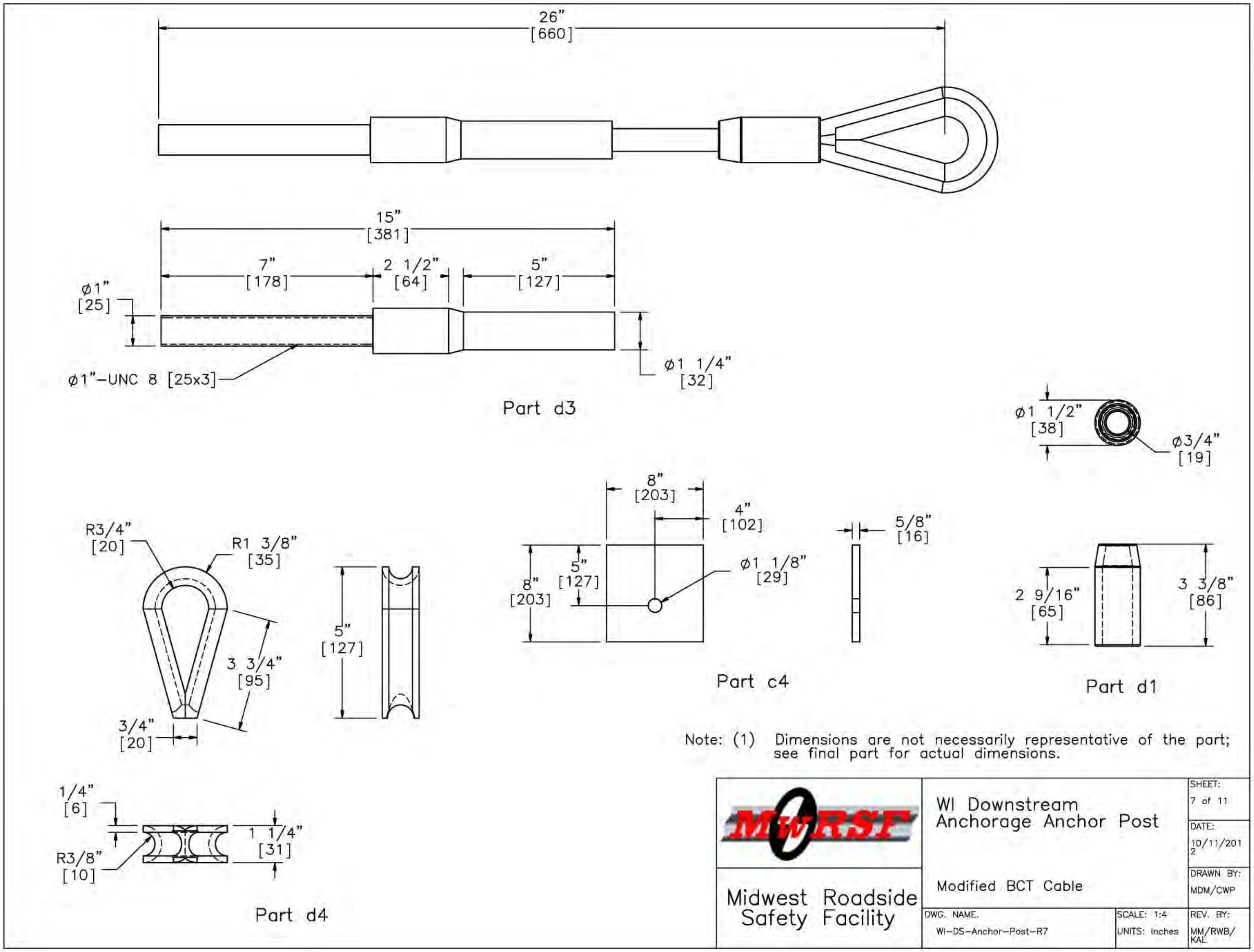


Figure 30. Bogie Testing Matrix and Setup, Test No. MGSEA-1

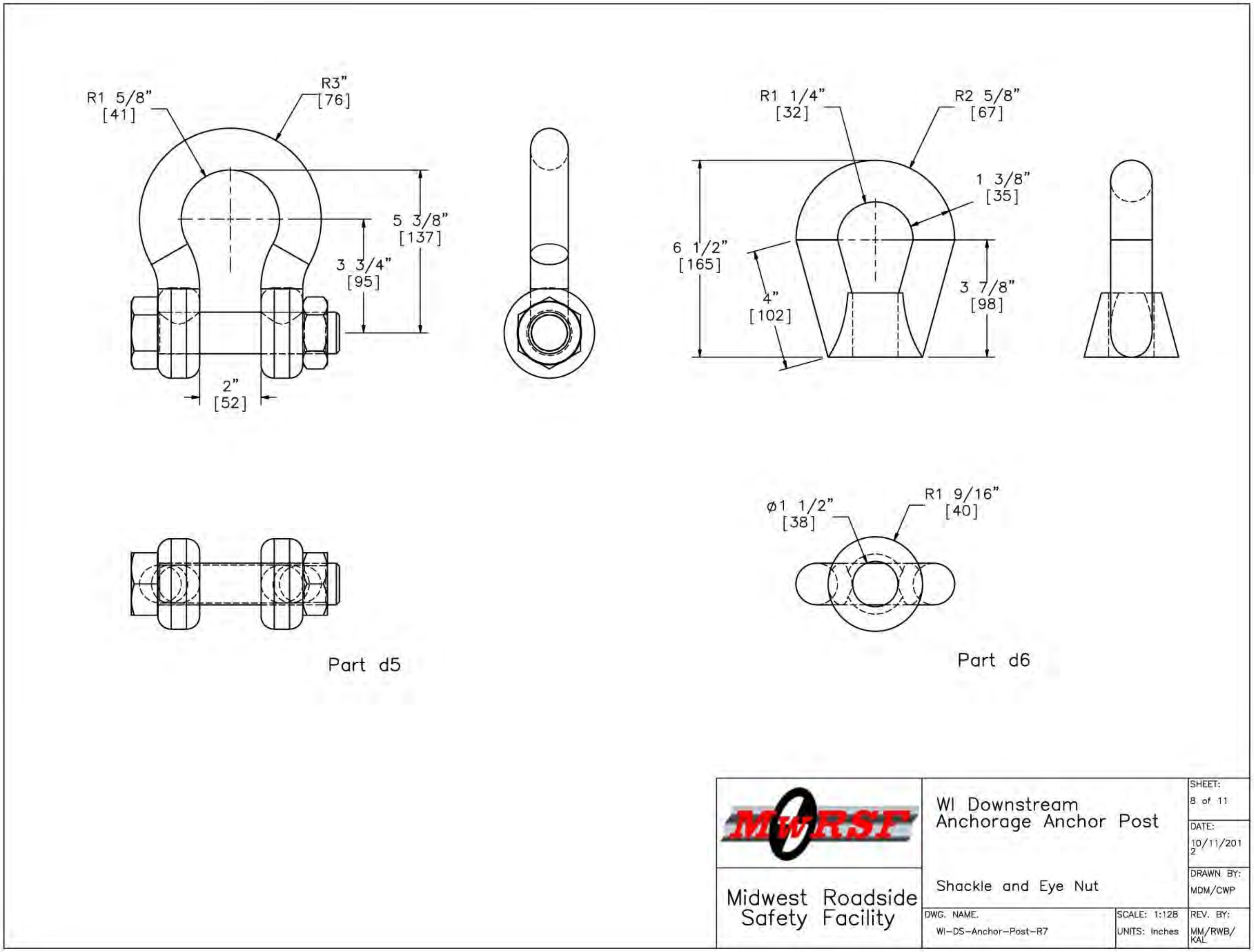


Figure 31. Bogie Testing Matrix and Setup, Test No. MGSEA-1

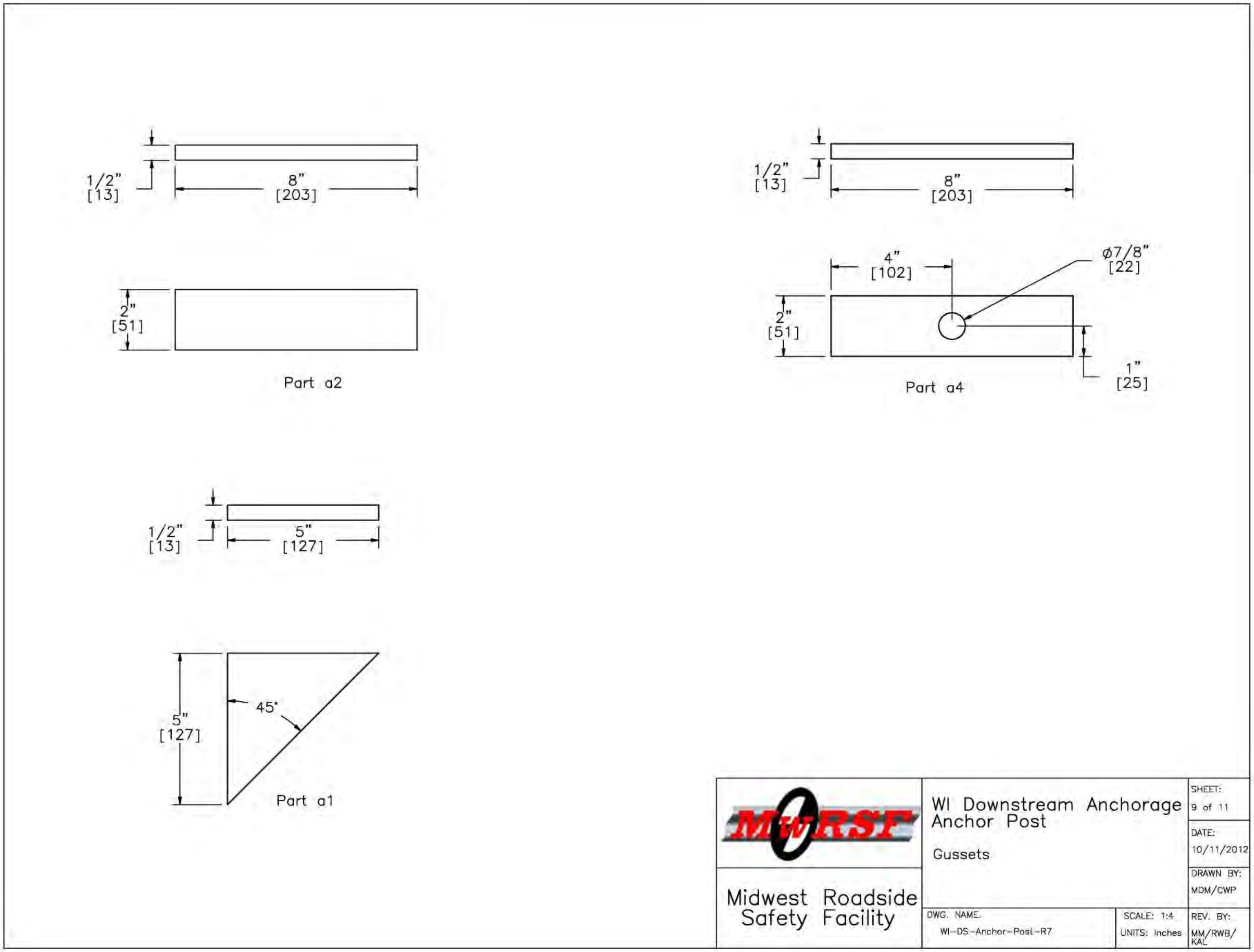


Figure 32. Bogie Testing Matrix and Setup, Test No. MGSEA-1

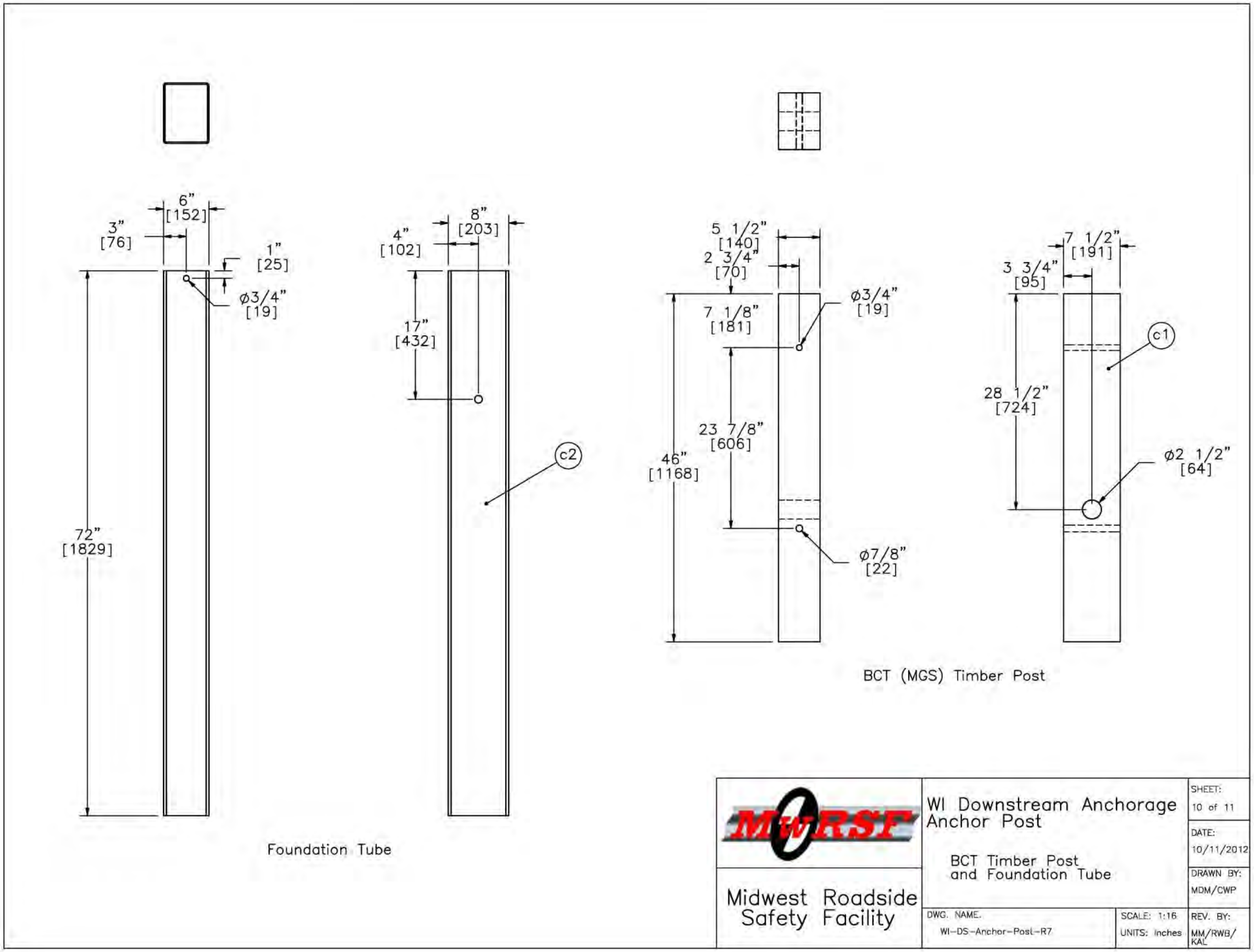


Figure 33. Bogie Testing Matrix and Setup, Test No. MGSEA-1

Item No.	Quantity	Description	Material Specification	Hardware Guide
a1	2	Side Gusset–5"x5"x1/2" [127x127x12.7]	ASTM A36	–
a2	1	Top Gusset–8"x2"x1/2" [203x51x12.7]	ASTM A36	–
a3	1	Bottom Plate–8"x2"x1/2" [203x51x12.7]	ASTM A36	–
a4	1	50 kip Tension Load Cell	TLL–50K–PTB	–
a5	1	Temporary F–Shape Concrete Barrier Element	–	SWG09
b1	2	7/8" [22.2] Dia. Flat Washer	ASTM A153	FWC22a
b2	1	5/8" [15.9] Dia. x 10" [254] Long Hex Head Bolt and Nut	ASTM A307 and A563 DH	FBX16a
b3	1	7/8" [22.2] Dia. x 7 1/2" [191] Long Hex Head Bolt and Nut	ASTM A307 and A563 DH	FBX22a
b4	1	1" [25] Dia. Hex Nut	ASTM A563 DH Galvanized	FBX24a
b5	1	1" [25] Dia. Flat Washer	SAE Grade 5	FWC24a
b6	2	5/8" [15.9] Dia. Flat Washer	ASTM A153	FWC16a
c1	1	BCT Timber Post – MGS Height	SYP Grade No. 1 or better	PDF01
c2	1	72" [1829] Foundation Tube	ASTM A53 Grade B	PTE06
c3	1	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40	FMM02
c4	1	5x8x5/8" [127x203x15.9] Anchor Bearing Plate	ASTM A36 Steel	FPB01
d1	2	115–HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–
d2	2	3/4" [19] 6x19 IWRC IPS Wire Rope	IPS Galvanized	–
d3	2	BCT Anchor Cable End Swage Fitting	Grade 5 – Galvanized	–
d4	3	Crosby Heavy Duty HT–3/4" [19] Dia. Cable Thimble	As Manufactured	–
d5	4	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 – As Supplied	–
d6	3	Chicago Hardware Drop–Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNF 12 [M36]	As Supplied, Stock No. 107	–

Midwest Roadside Safety Facility

WI Downstream Anchorage Anchor Post

Bill of Materials

SHEET: 11 of 11

DATE: 10/11/2012

DRAWN BY: MDM/CWP

DWG. NAME. WI–DS–Anchor–Post–R7

SCALE: None
UNITS: Inches

REV. BY: MM/RWB/KAL

Figure 34. Bogie Testing Matrix and Setup, Test No. MGSEA-1

Figure 35. Test Setup, Test No. MGSEA-1

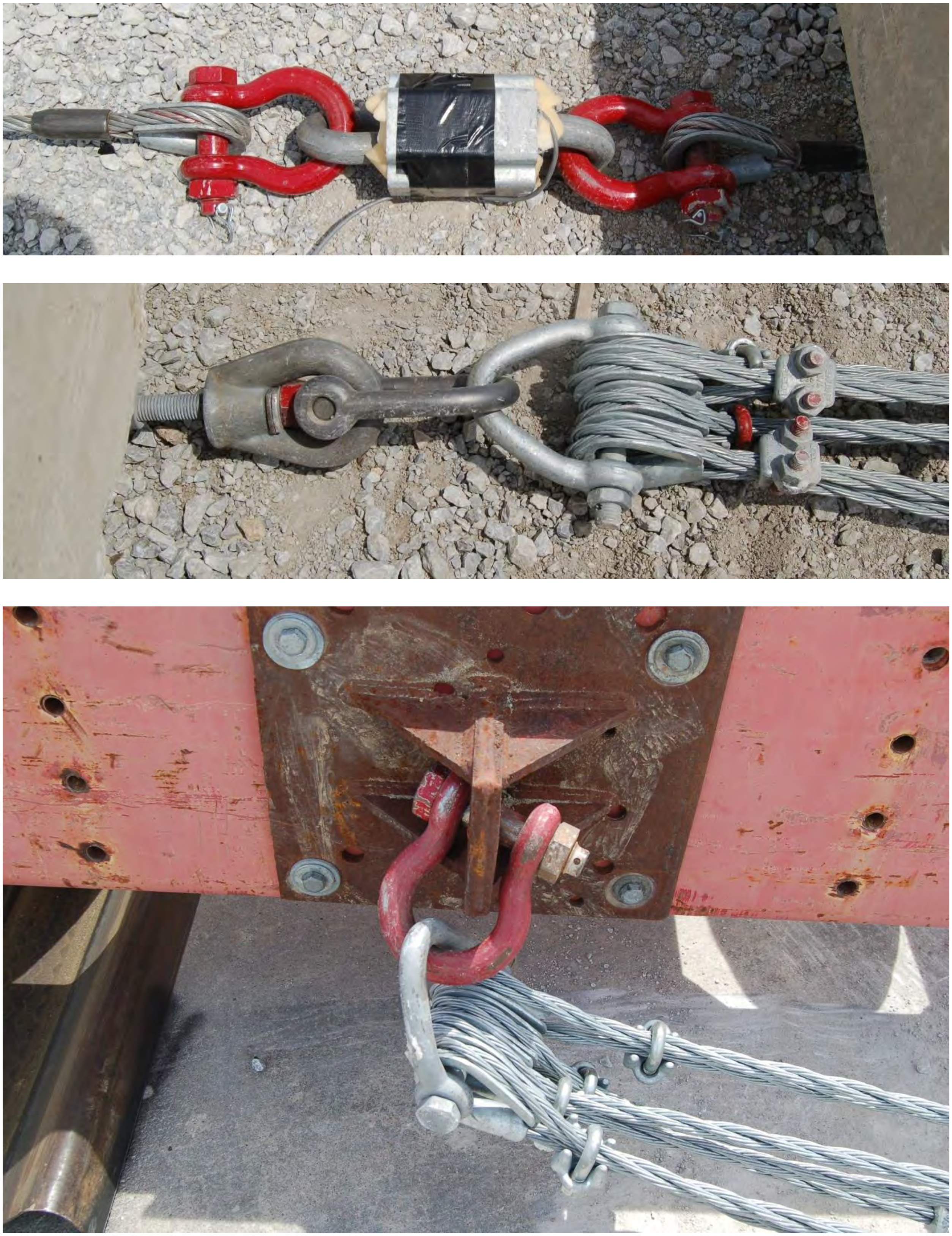
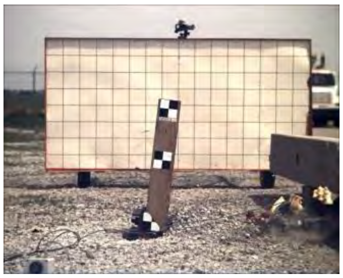


Figure 36. Test Setup, Test No. MGSEA-1

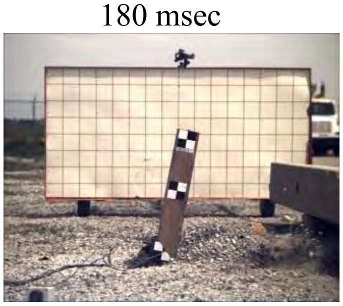
IMPACT

60 msec

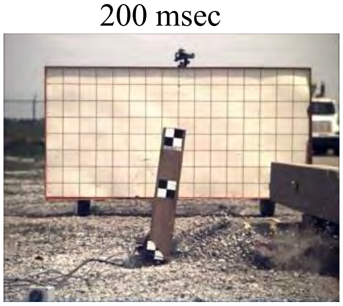


140 msec

180 msec



200 msec



240 msec

Figure 37. Time-Sequential and Post-Impact Photographs, Test No. MGSEA-1

set deflection was 4.2 in. (107 mm), as measured using the string potentiometer attached to the back of the tube at ground line. The steel foundation tube bent slightly, thus initiating a plastic hinge at about 8½ in. (216 mm) from its top edge.

The load cell cable connector became disconnected almost immediately after the pull cable was tensioned. Thus, the force was obtained using acceleration data from the bogie vehicle. Although the acceleration measured at the bogie center of mass may include damping effects due to the extension of the pull cable and a time shift, it still provides useful information related to load resistance of the foundation tube embedded into the soil. The maximum peak load was 43.4 kips (193 kN), as obtained from DTS-SLICE accelerometer data.

Force versus time and deflection versus time curves were plotted and are shown in Figure 38. The results from all transducers used in the test are provided in Appendix C. An intensive investigation into event timing was conducted to determine the approximate start times for string pot, accelerometer, and load cell curves. Although visual clues to indicate times of low and high tension were available, the most convenient reference was derived from the instrumentation cable which disconnected from the tension load cell at approximately 0.131 sec after the pull cable began to stretch. It was clearly identifiable in the high-speed video when the data cable disconnected. As a result, high-speed video of the post deflection was used to relate the time of maximum foundation tube deflection to the load cell data. Accelerometer data was also matched to similar load events in the load cell data. Therefore, researchers believe that the load and soil tube displacement curves plotted against time in Figure 38 are representative of the events that occurred in the test.

6.3 Discussion

The force measured by the accelerometer mounted on the bogie, DTS-SLICE, indicated that the maximum force encountered by the BCT anchor cable was approximately 43.4 kip (193

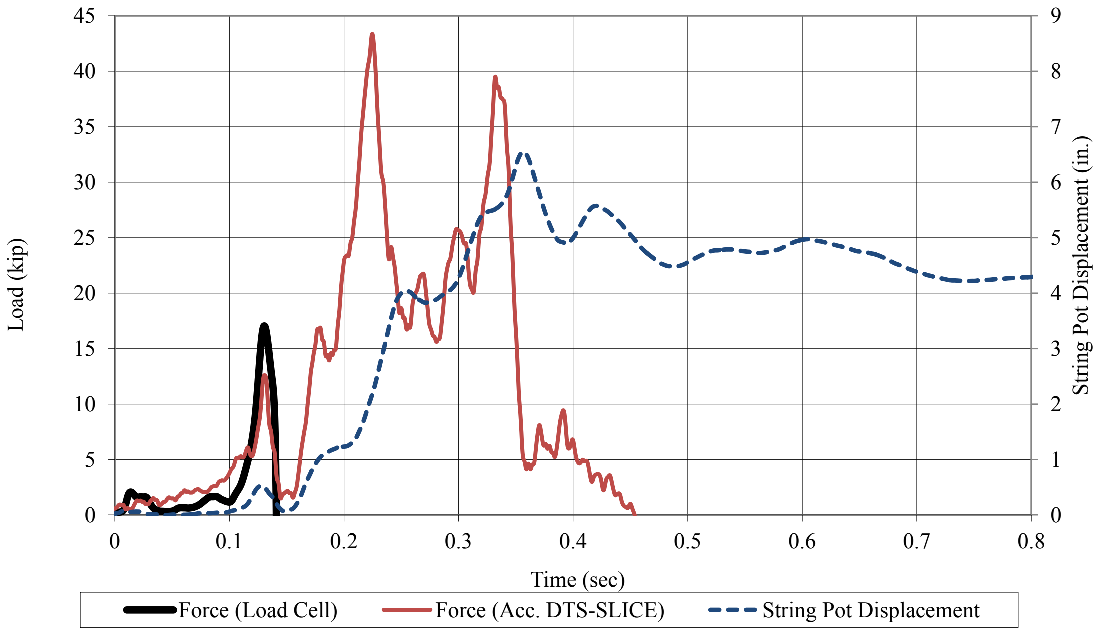


Figure 38. Forces vs. Time and Displacement vs. Time, Test No. MGSEA-1

kN), leading to a maximum displacement of the soil tube of approximately 6.5 in. (165 mm) as measured by the string pot. However, real-world soil strengths may be lower than provided by the coarse, compacted crushed limestone recommended by MASH and used for this bogie testing effort. Larger deflections of soil tubes may occur when anchor loads approach the failure limits of a guardrail system's end anchorage.

The force versus deflection curve of the soil foundation tube in test nos. MGSEA-1 is shown in Figure 39. An initial tension pulse caused the force on the foundation tube to ramp up to 13 kip (58 kN), and the deflection increased approximately proportional to the load to a maximum of 0.5 in. (13 mm), after which point the force and deflection dropped to nearly zero. This indicated the foundation tube and soil interaction was initially linearly elastic. The largest force impulse, experienced at approximately 2 in. (51 mm) of deflection, was required to overcome inertia and move the soil and foundation tube. A relatively steady force was recorded between 3 and 5 in. (76 and 127 mm) of displacement before the final force spike and maximum deflection were reached.

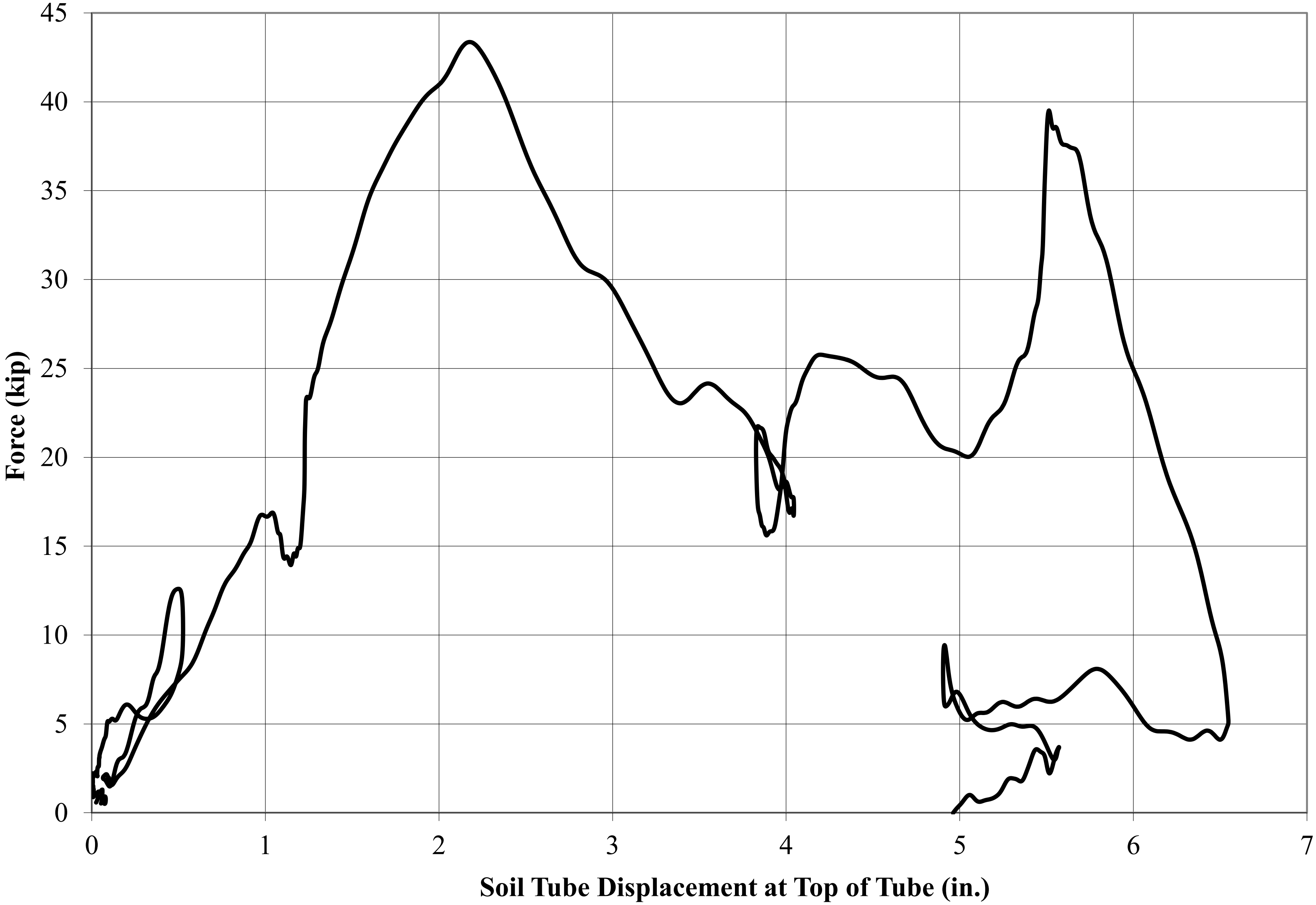


Figure 39. Bogie Force vs. Soil Tube Displacement Measured by String Pot, Test No. MGSEA-1

7 DYNAMIC COMPONENT TESTS – END ANCHOR SYSTEM

7.1 Test Setup and Instrumentation

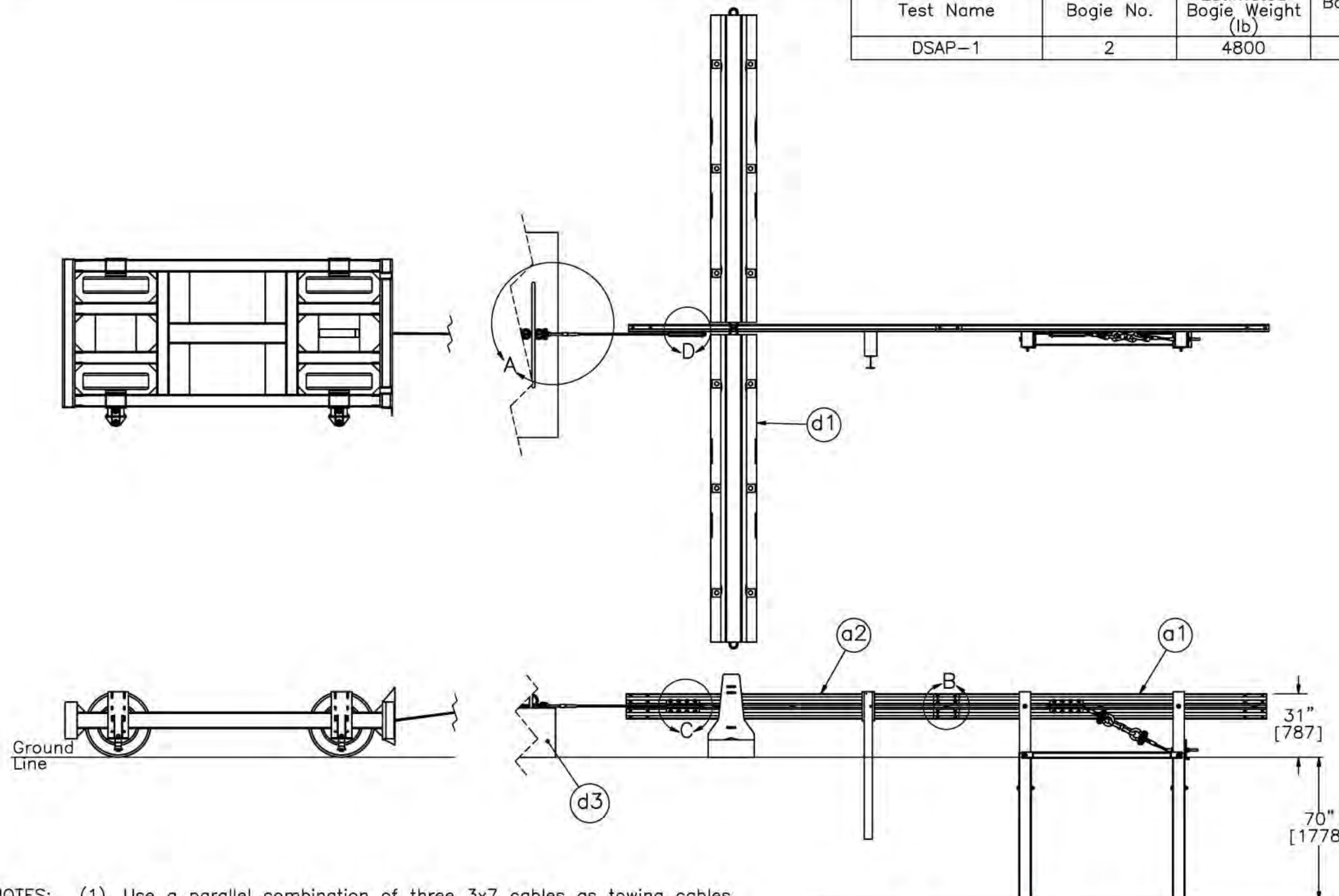
Bogie test nos. DSAP-1 and DSAP-2 were conducted on a modified MGS end anchorage system consisting of two BCT posts and a steel W6x8.5 (W152x12.6) post, two 12 ft-6 in. (3,810 mm) long W-beam segments, and an instrumented cable anchor connecting the W-beam rail to the end BCT post. The test matrix and test setup are shown in Figures 40 through 50. Photographs of the test setup are shown in Figures 51 and 52. Material specifications, mill certifications, and certificates of conformity for the system materials used in test nos. DSAP-1 and DSAP-2 are shown in Appendix B.

The same modified cable anchor that was instrumented with a load cell, as used in test no. MGSEA-1, was used for test nos. DSAP-1 and DSAP-2 and is shown in Figures 42 through 45. A second load cell was placed between the cable anchor attached to the free end of the W-beam rail and the pull cable. The other end of the pull cable was connected to a 4,780-lb (2,168-kg) bogie vehicle. The target bogie speed was 25 mph (40 km/h).

For test nos. DSAP-1 and DSAP-2, the force was measured using the two load cells. For test no. DSAP-1, two probationary 80-kip (356-kN) washer-type, compressive load cells were placed on the threaded swage ends of the pull cable and the modified anchor cable at the anchor bracket connection. For test nos. DSAP-1 and DSAP-2, the acceleration of the bogie vehicle's c.g. was also measured as a backup and for comparison purposes.

For test nos. DSAP-1 and DSAP-2, a string pot was anchored to a flanged U-channel post embedded in the soil approximately 4 ft (1.2 m) from the upstream anchorage post. The string pot was secured to the foundation tube of the upstream post to track the displacement of the anchor tube in both tests.

Test Name	Bogie No.	Estimated Bogie Weight (lb)	Bogie Speed (mph)
DSAP–1	2	4800	25



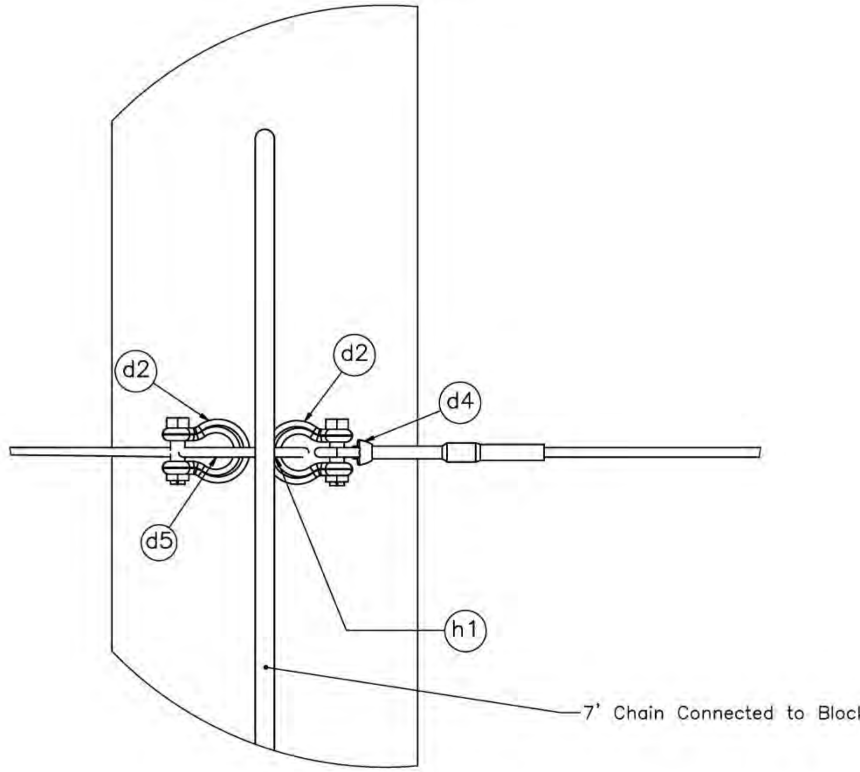
NOTES:
(1) Use a parallel combination of three 3x7 cables as towing cables.
(2) Similar setup to FBT–4.
(3) Temporary barriers are set on blocks to raise them up such that the W–beam rail fit between the top and bottom loop bars.
(4) High–speed camera perpendicular to the BCT posts.
(5) Accelerometers on bogie: EDR–3 and DTS.
(6) Use two 50–kip tension load cells and one string potentiometer.

MwRSF
Midwest Roadside Safety Facility

WI DS Anchorage Anchor Pull Test
Bogie Setup

SHEET: 1 of 11
DATE: 3/13/12
DRAWN BY: MDM/DMH/RJT
DWG. NAME. WI–DS–anchor–pull–R6
SCALE: 1:70
UNITS: in.[mm]
REV. BY: MM/RWB/KAL

Figure 40. Bogie Testing Matrix and Setup, Test Nos. DSAP-1 and DSAP-2



DETAIL A

NOTE:

(1) Constrain both ends of a 7' long chain to the top of the concrete block and pass the towing cables between the concrete block and the chain.

(2) Use an eye-nut (d4) to connect the cable anchor (c5) to the clevis (d2).

(3) Connect ends of the tow cables to a nylon strap (minimum rating 50 kips).

(4) Connect each eye of the nylon strap to the clevis on the downstream side of Detail A.

Midwest Roadside Safety Facility

WI DS Anchorage Anchor Pull Test

Connection Details

SHEET: 2 of 11	DATE: 3/13/12	DRAWN BY: MDM/DMH/RJT
DWG. NAME. WI-DS-anchor-pull-R6	SCALE: 1:16 UNITS: in.[mm]	REV. BY: MM/RWB/KAL

Figure 41. Connection Details, Test Nos. DSAP-1 and DSAP-2

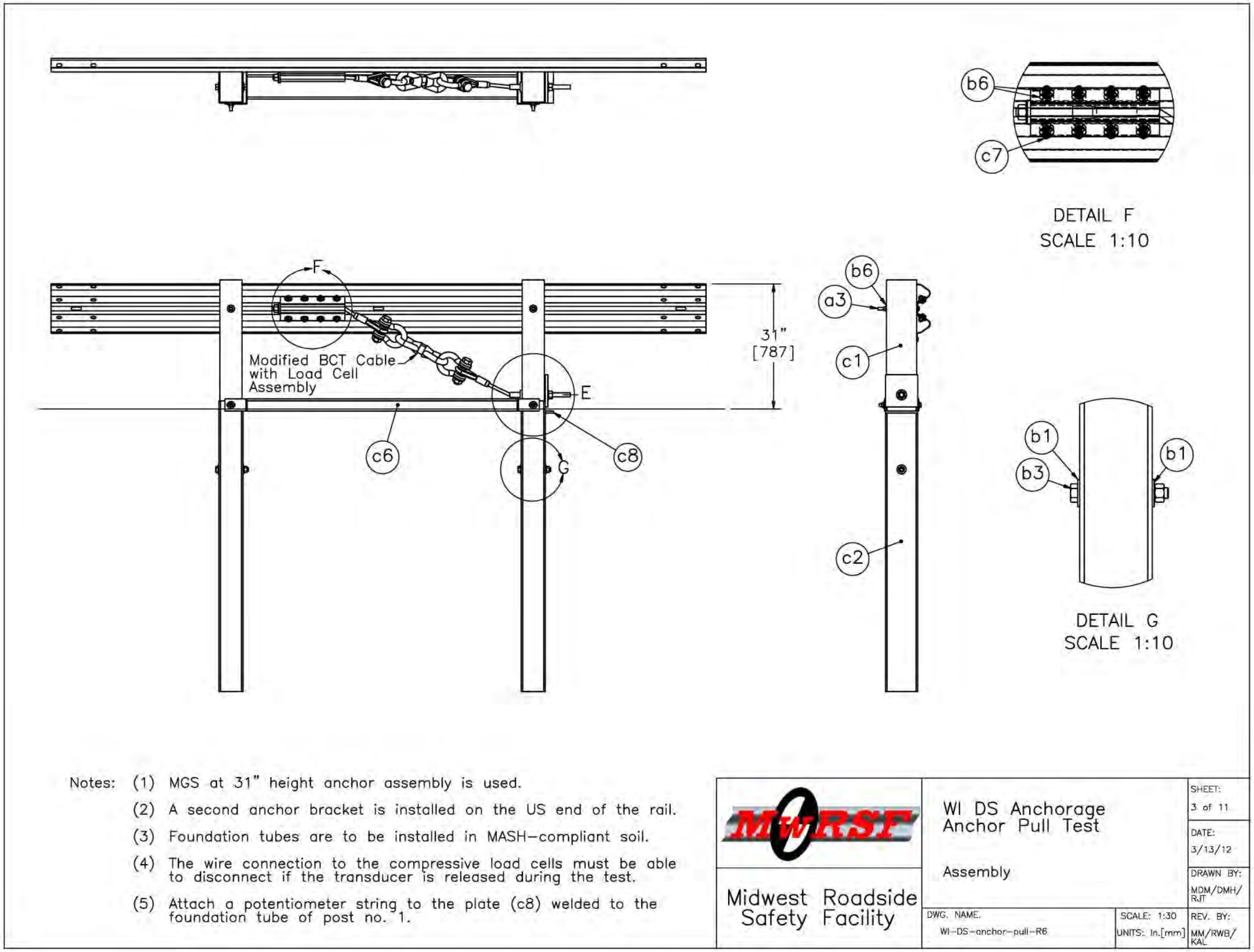


Figure 42. Modified BCT Cable Assembly, Test Nos. DSAP-1 and DSAP-2

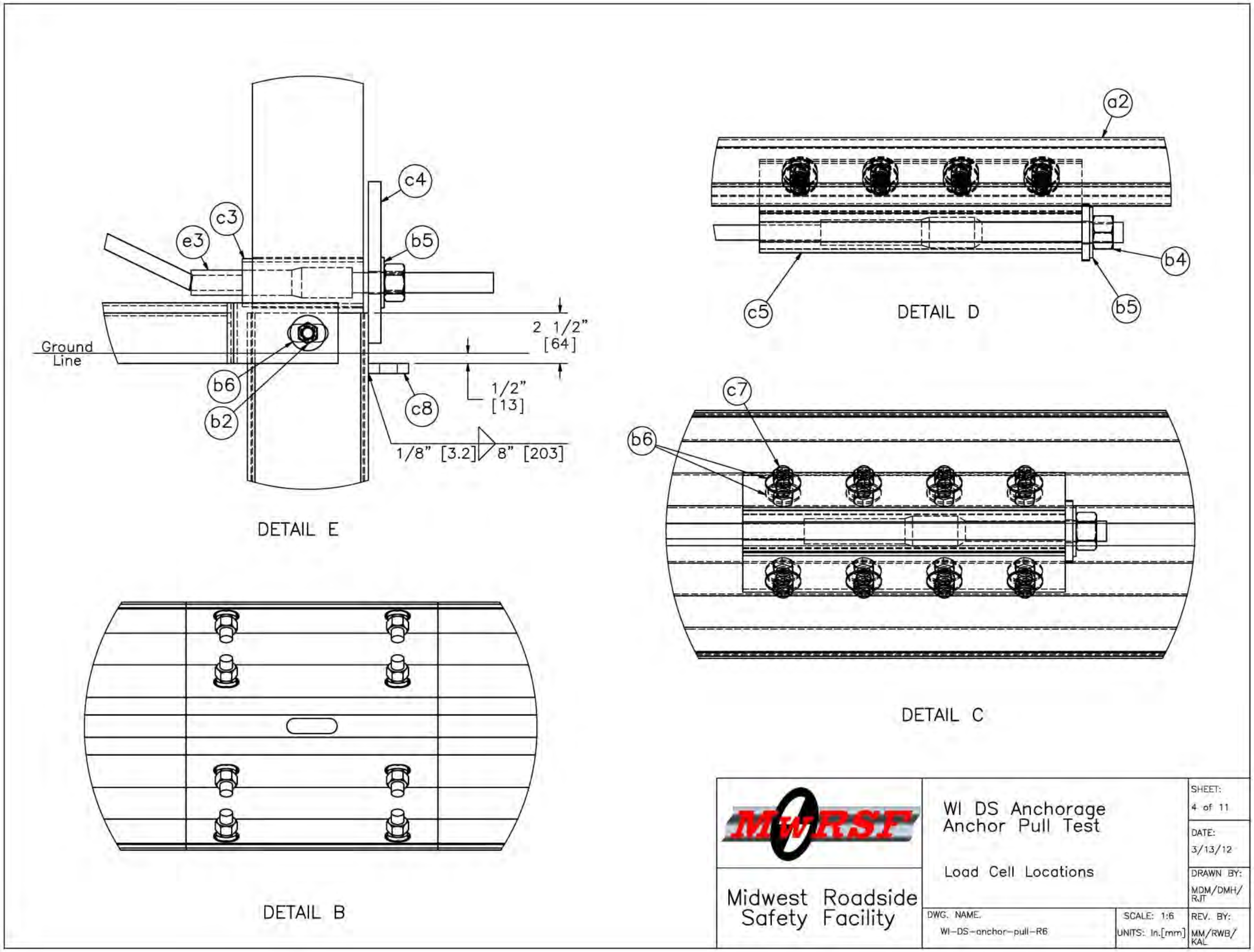


Figure 43. Load Cell Locations, Test Nos. DSAP-1

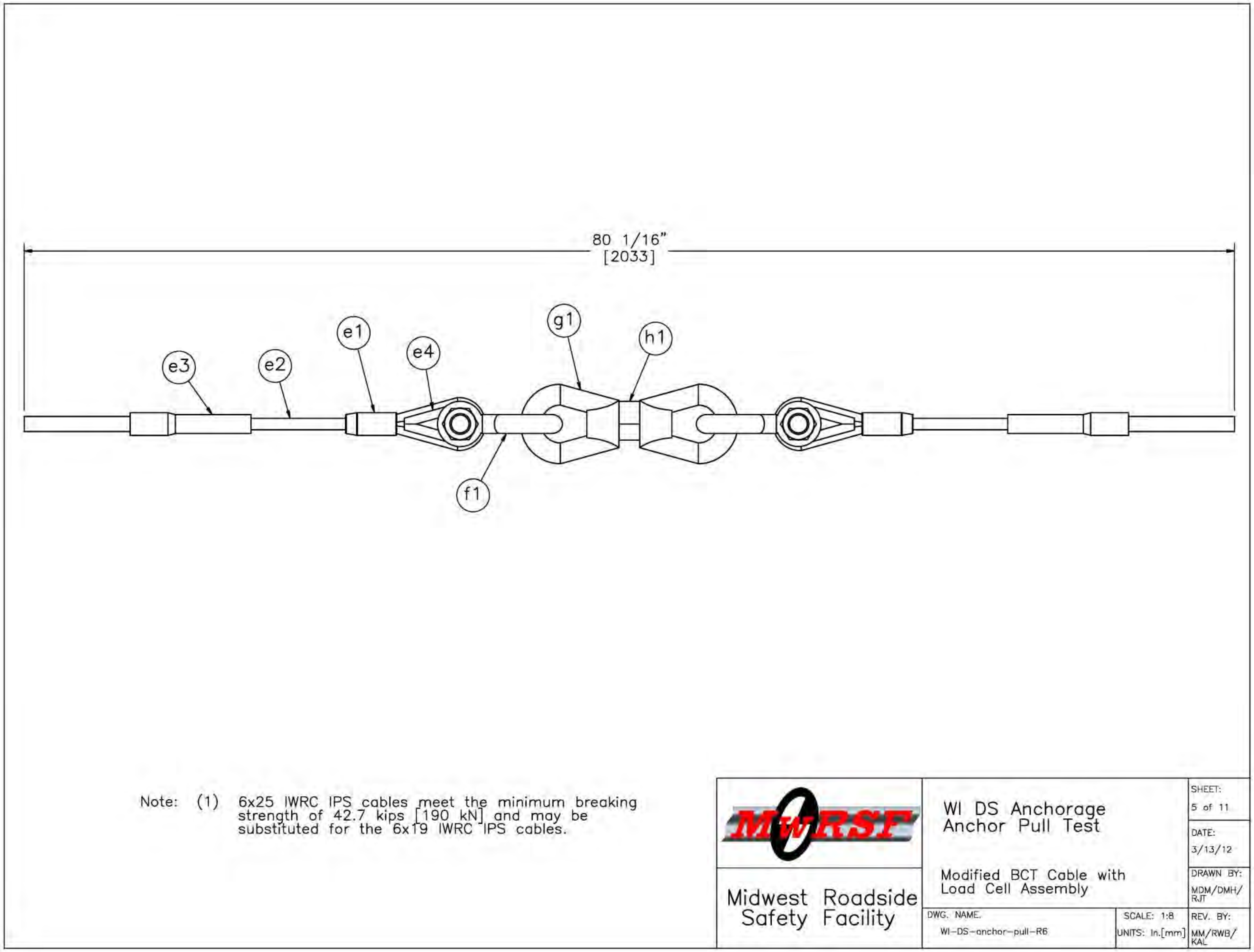


Figure 44. Modified BCT Cable with Load Cell Assembly, Test Nos. DSAP-1 and DSAP-2

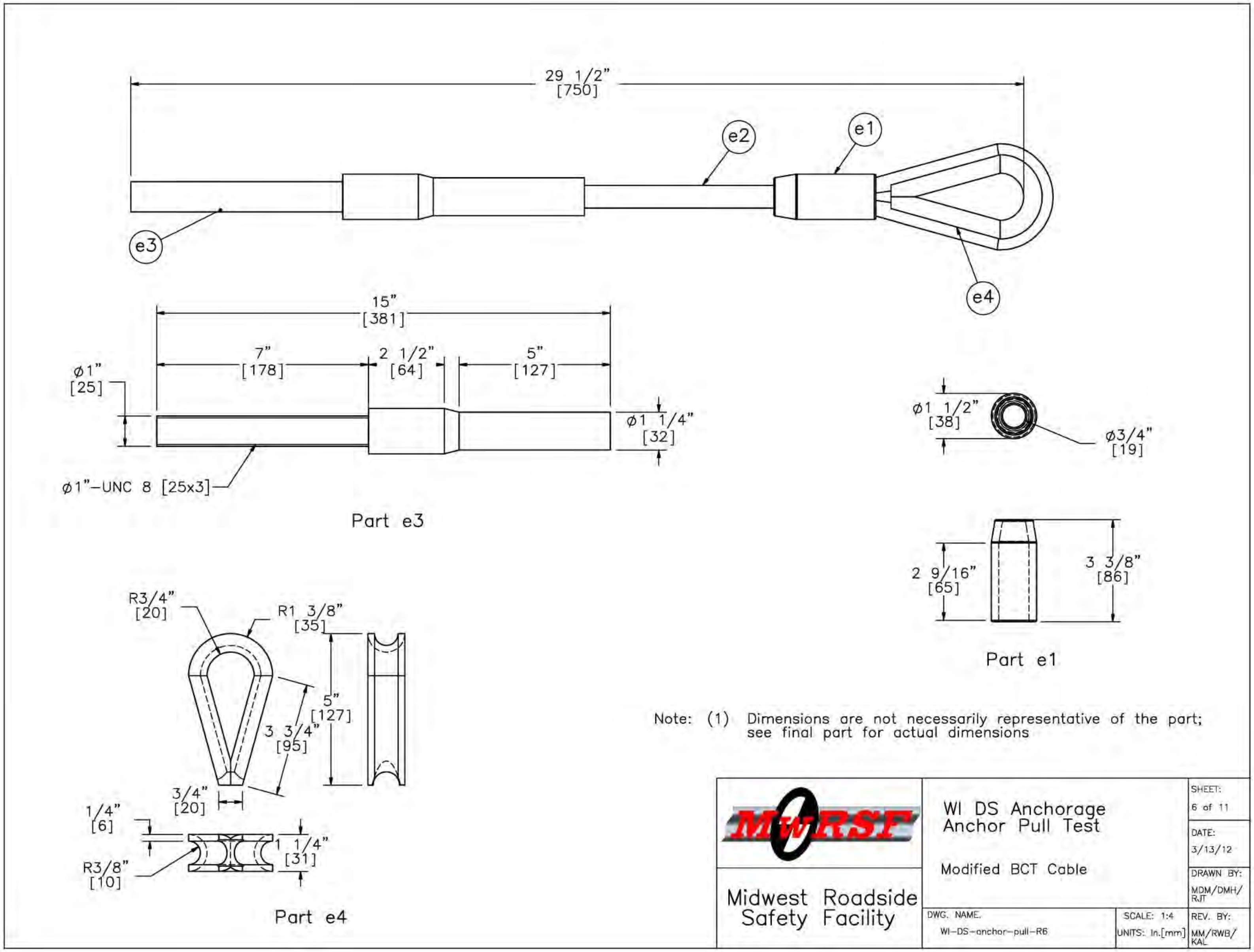


Figure 45. Modified BCT Cable, Test Nos. DSAP-1 and DSAP-2

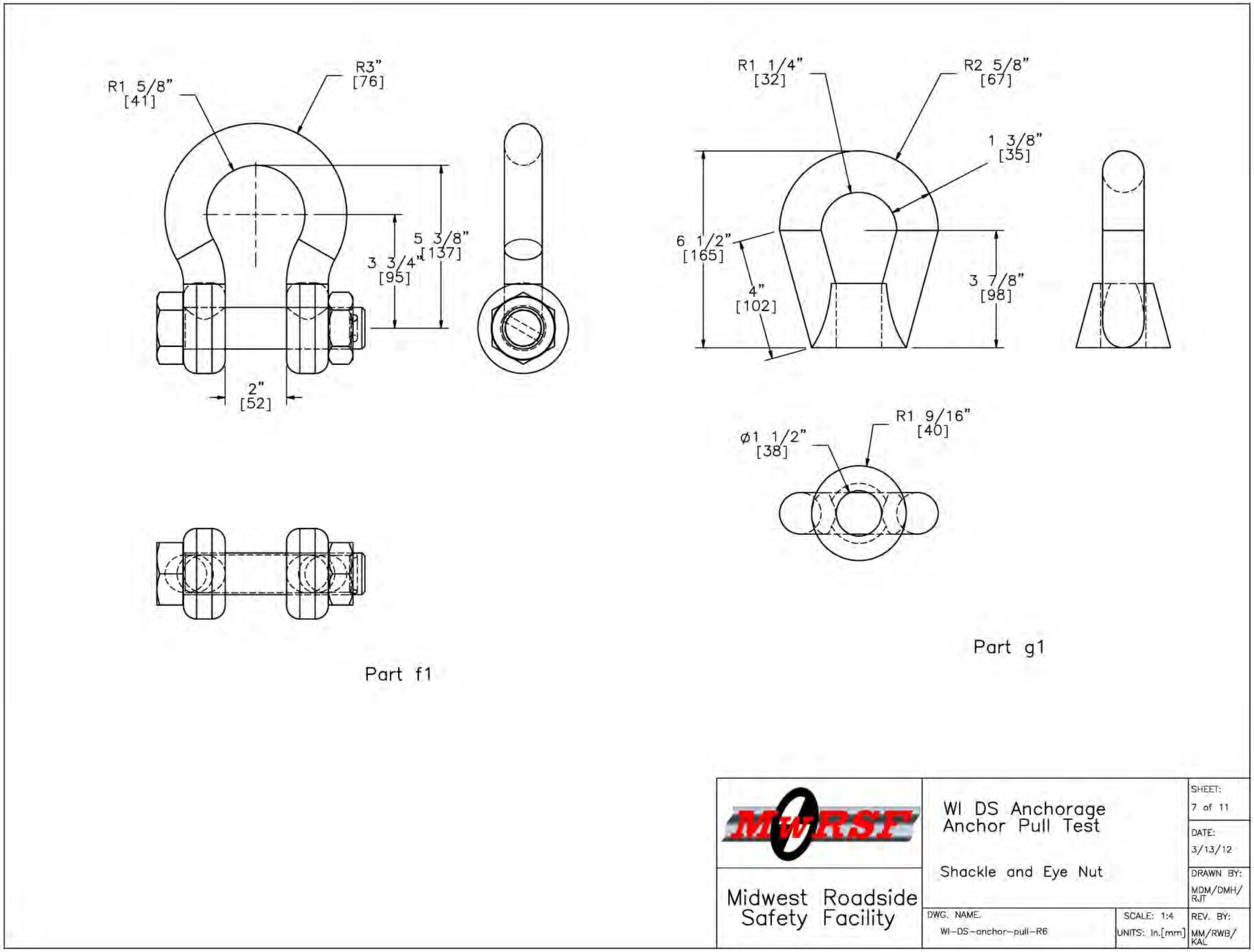


Figure 46. Shackle and Eye Nut, Test Nos. DSAP-1 and DSAP-2

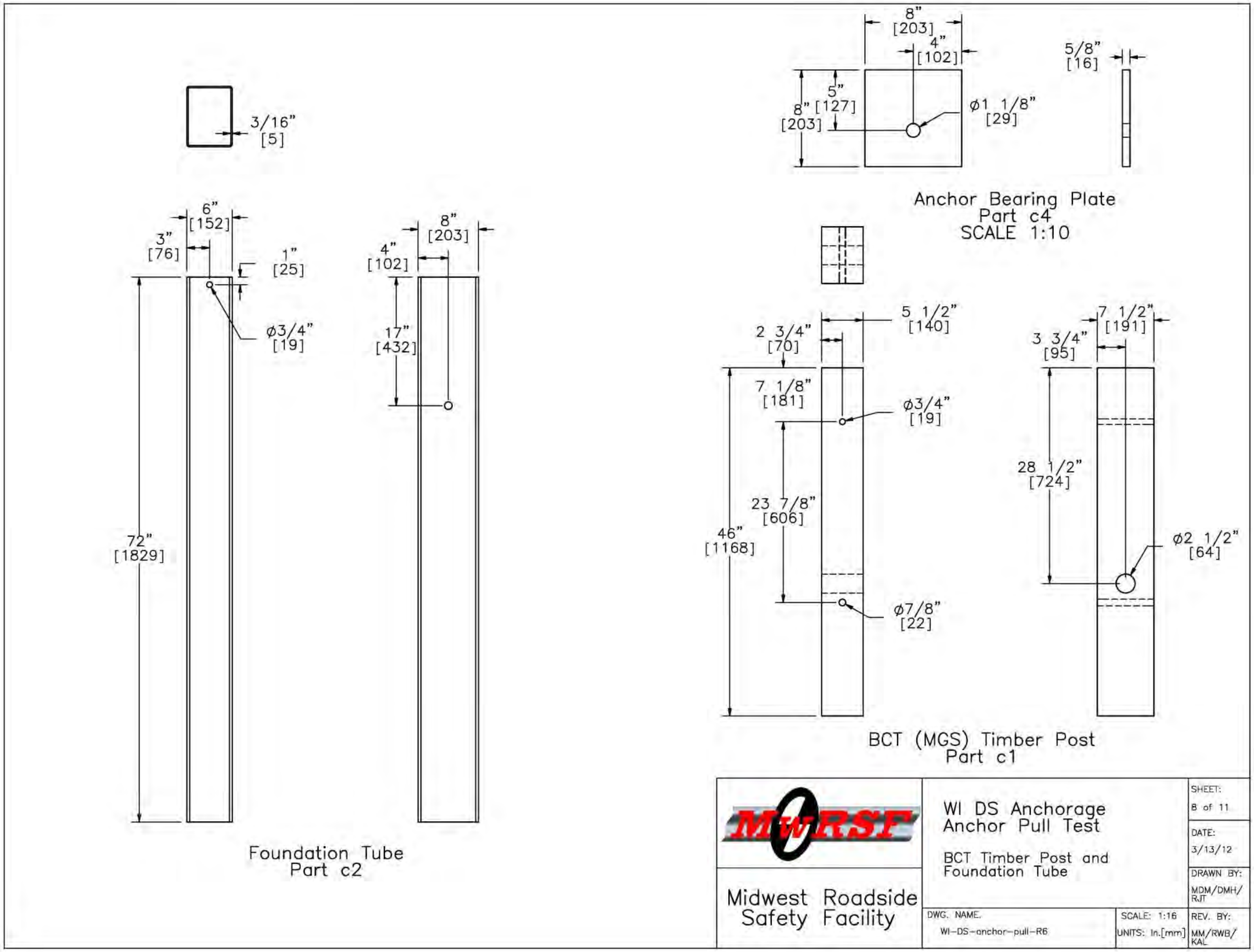


Figure 47. BCT Timber Post and Foundation Tube, Test Nos. DSAP-1 and DSAP-2

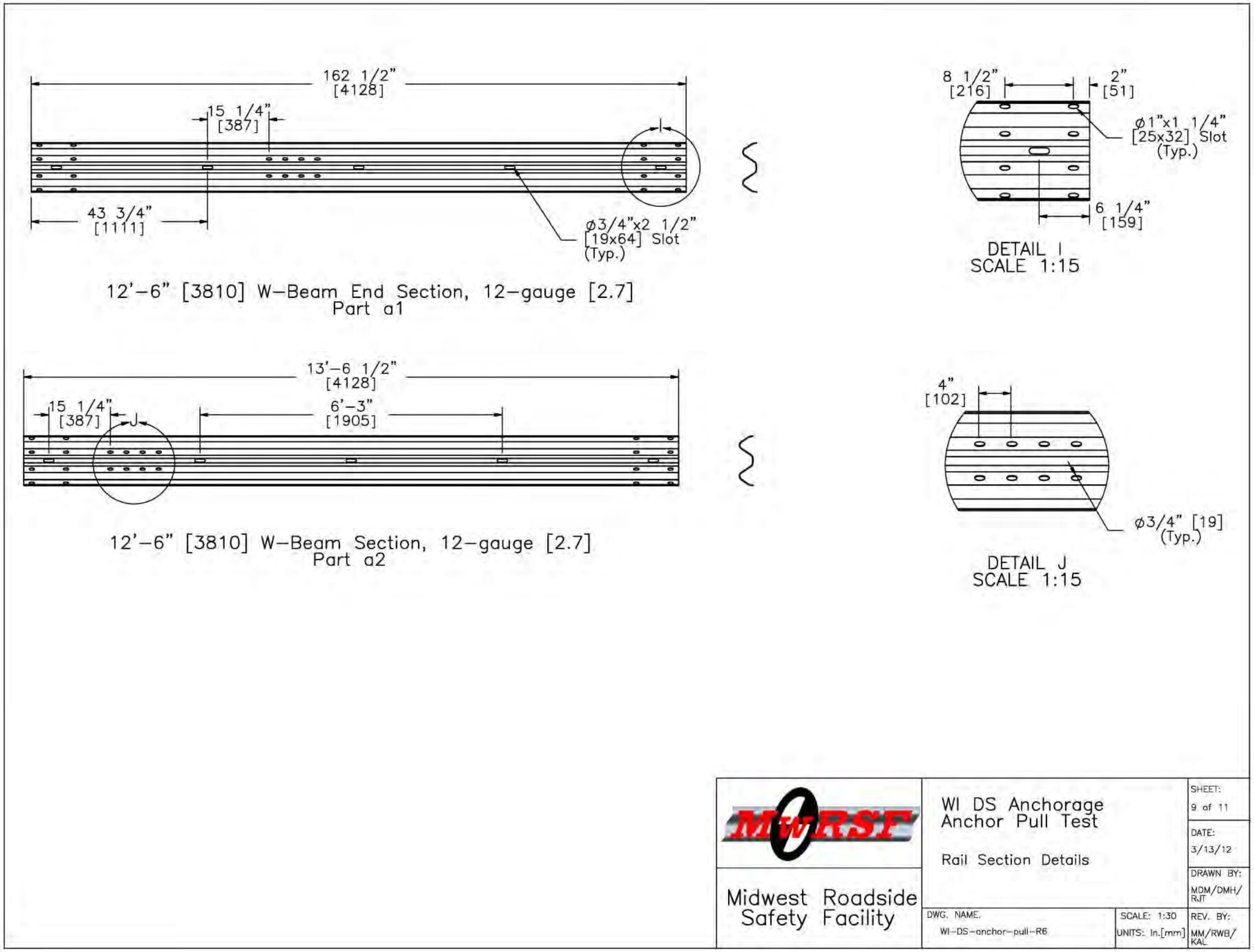


Figure 48. Rail Section Details, Test Nos. DSAP-1 and DSAP-2

Item No.	QTY.	Description	Material Specification	Hardware Guide
a1	1	12'–6" [3810] W–Beam MGS End Section	12 gauge [2.7] AASHTO M180	RWM14a
a2	1	12'–6" [3810] W–Beam MGS Section	12 gauge [2.7] AASHTO M180	RWM04a
a3	2	5/8" [16] Dia. x 10" [254] Long Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 DH	FBB03
a4	8	5/8" [16] Dia. x 1 1/2" [38] Long Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 DH	FBB01
a5	1	W6x8.5 [W152x12.6] 72" [1830] long	ASTM A992 Min. 50 ksi [345 MPa] (W6x9 ASTM A36 Min. 36 ksi [248 MPa])	PWE06
a6	1	6x12x14 1/4" [152x305x362] Blockout	SYP Grade No.1 or better	–
b1	4	7/8" [22] Dia. Flat Washer	Grade 2	FWC22a
b2	2	5/8" [16] Dia. x 10" [254] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 DH	FBX16a
b3	2	7/8" [22] Dia. x 7 1/2" [191] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 DH	FBX22a
b4	3	1" [25] Dia. Hex Nut	ASTM A563 DH Galvanized	FBX24a
b5	3	1" [25] Dia. Flat Washer	Grade 2	FWC24a
b6	38	5/8" [16] Dia. Flat Washer	Grade 2	FWC16a
c1	2	BCT Timber Post – MGS Height	SYP Grade No. 1 or better	PDF01
c2	2	72" [1829] Foundation Tube	ASTM A53 Grade B	PTE06
c3	1	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40	FMM02
c4	1	8x8x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel	FPB01
c5	2	Anchor Bracket Assembly	ASTM A36 Steel	FPA01
c6	1	Strut and Yoke Assembly	ASTM A36 Steel Galvanized	–
c7	16	5/8" [16] Dia. x 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 DH	FBX16a
c8	1	8"x2"x1/2" [203x51x13]–Plate for String Potentiometer	ASTM A36 Steel	–
d1	2	Temporary F–Shape Barrier	–	ROM02
d2	2	Connecting Clevis (from FBT–4)	–	–
d3	1	Concrete Block–MN Noise Wall	–	–
d4	1	ϕ1 Eye Nut (from FBT–4)	–	–
d5	1	D–Ring (from FBT–4)	–	–

MwRSF

Midwest Roadside Safety Facility

WI DS Anchorage Anchor Pull Test

Bill of Materials

SHEET: 10 of 11

DATE: 3/13/12

DRAWN BY: MDM/DMH/RJT

DWG. NAME. WI–DS–anchor–pull–R6

SCALE: None

UNITS: In.[mm]

REV. BY: MM/RWB/KAL

Figure 49. Bill of Materials, Test Nos. DSAP-1 and DSAP-2

Item No.	QTY.	Description	Material Specification
e1	2	115-HT Mechanical Splice – 3/4" [19] Dia.	As Supplied
e2	3	3/4" [19] Dia. 6x19 IWRC IPS Wire Rope	IPS Galvanized
e3	4	BCT Anchor Cable End Swage Fitting	Grade 5 – Galvanized
e4	2	Crosby Heavy Duty HT-3/4" [19] Dia. Cable Thimble	Stock No. 1037773 – Galvanized
f1	2	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 – As Supplied
g1	2	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNF 12 [M36]	As Supplied, Stock No. 107
h1	2	TLL-50K-PTB Load Cell	NA

Midwest Roadside Safety Facility

WI DS Anchorage
Anchor Pull Test

Bill of Materials

SHEET:	DATE:	DRAWN BY:	DWG. NAME.	SCALE:	UNITS:	REV. BY:
11 of 11	3/13/12	MDM/DMH/RJT	WI-DS-anchor-pull-R6	None	In.[mm]	MM/RWB/KAL

Figure 50. Bill of Materials, Test Nos. DSAP-1 and DSAP-2 (cont'd)

Figure 51. Bogie Test Setup, Test Nos. DSAP-1 and DSAP-2

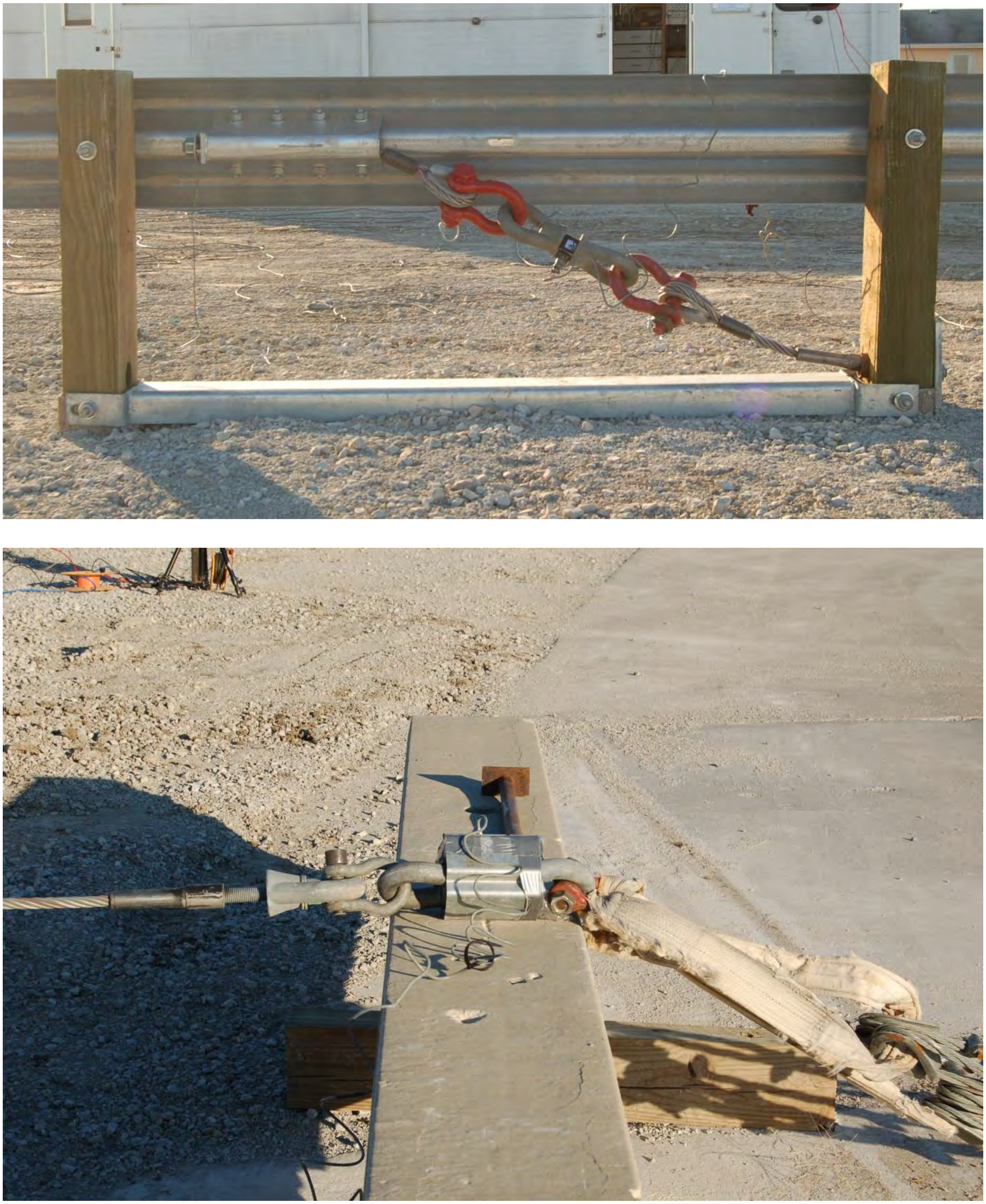


Figure 52. Load Cell Setup, Test Nos. DSAP-1 and DSAP-2

7.2 Test Results

7.2.1 Test No. DSAP-1

During test no. DSAP-1, the nylon strap used in the connection joint between the pull cable and upstream end of the guardrail ruptured. As a consequence, the anchorage was only partially loaded, and no damage occurred to the wood posts or the post-to-rail connection.

The force versus time curve and deflection versus time curve for test no. DSAP-1 are shown in Figure 53. The load measured by the two compressive load cells in test no. DSAP-1 were discarded, because it was determined that the washer-type load cell is extremely sensitive to small misalignments. The results from all tranducers used during the test are provided in Appendix C. The maximum force measured by the tension load cell attached to the anchor cable was approximately 18 kip (80 kN) at approximately 0.13 sec after the start of the pull event. The maximum displacement, as measured by the string potentiometer connected to the top of the foundation tube of the end post, was approximately 0.31 in. (8 mm) and occurred in concomitance to the peak force in the anchor cable. Time-sequential and post-impact photographs are shown in Figures 54 and 55, respectively. Due to the uncertainty associated with the start time in the string pot and load cells, the start time used for the load cell, anchor cable, and string pot data should be considered approximate. Therefore, force versus displacement and energy versus displacement curves were not plotted.

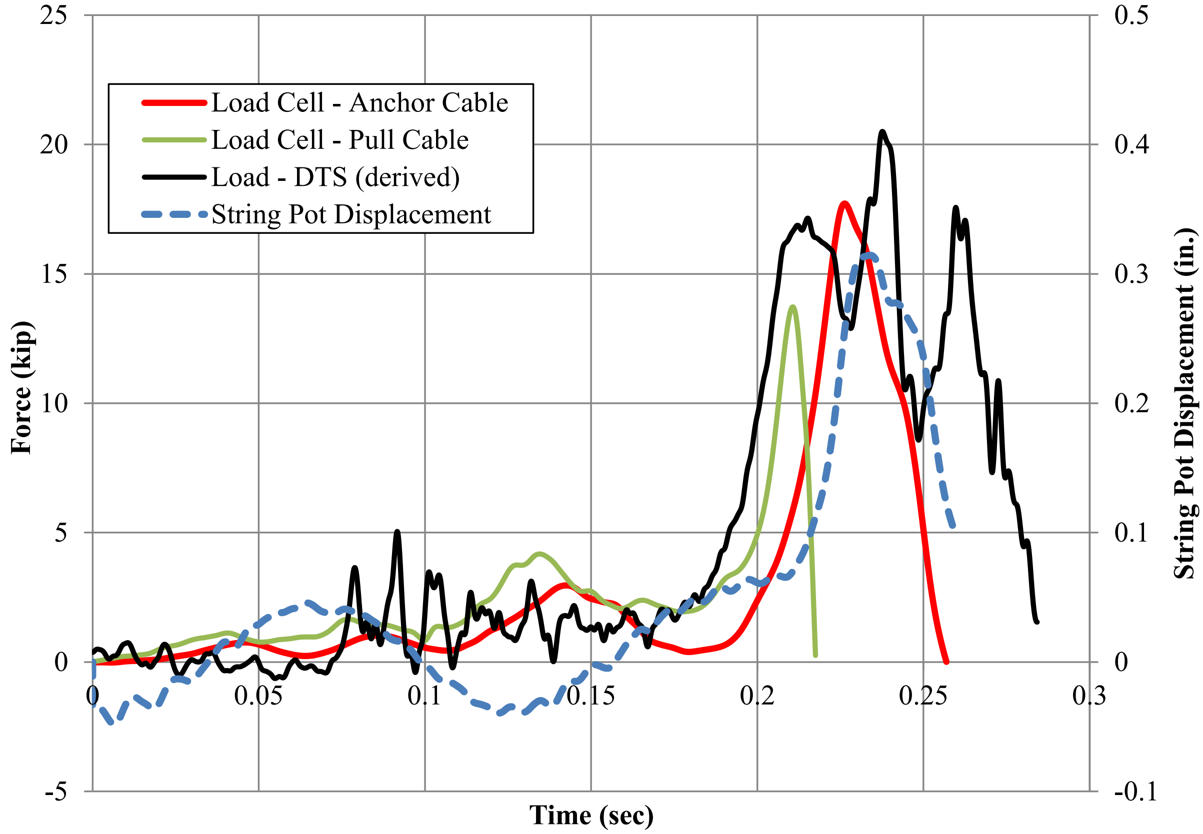


Figure 53. Forces vs. Time and Displacement vs. Time, Test No. DSAP-1

7.2.2 Test No. DSAP-2

Test no. DSAP-2 was conducted as a repeat of test no. DSAP-1; since, the nylon strap that was used to connect the pull cable to the anchor cable ruptured during the first test. As the pull cable started to be tensioned in test no. DSAP-2, the rail was pulled upstream, causing the two wood BCT posts to deflect upstream. The pull force was almost immediately transferred to the two foundation tubes, which rotated through the soil. When the cable anchor was tensioned, a downward vertical force component was applied to the rail. This force deformed the upper side of the rail slot at the connection with each of the two BCT posts due to the contact with the post bolt. The end BCT post fractured at the ground line first, followed immediately after by the other BCT post. After the fracture of the two BCT wood posts, the W6x8.5 (W152x12.6) steel


0.000 sec


0.020 sec


0.036 sec


0.048 sec


0.060 sec


0.140 sec

Figure 54. Time-Sequential Photographs, Test No. DSAP-1

Figure 55. Post-Impact Photographs, Test No. DSAP-1

post and the wood blockout twisted upstream. When the rail finally released away from the bolted connection, the steel post came back to its original untwisted configuration. The rail was eventually pulled downstream until it was brought to a stop by a steel chain connected to its upstream end and anchored to a concrete barrier.

The force versus time and the deflection versus time curves for test no. DSAP-2 were processed from transducer data. Event start times for the load cells, accelerometer, and string pot data were approximated, and the processed data are shown in Figure 56. Technical difficulties with the pull cable load cell rendered pull cable tension data unusable. The results from all transducers used during the test are provided in Appendix C. As illustrated in the force versus time curve, two peak forces of about 21 kip (93 kN) and 35 kip (156 kN) occurred at around 0.06 sec and 0.10 sec, respectively. Two local maximum displacements of about 0.5 in. (13 mm) and 0.9 in. (23 mm) were measured by the string potentiometer connected to the base of the end post. These two local peak displacements occurred at nearly the same time as two local force peaks. Time-sequential photographs are shown in Figures 56 and 57. Post-impact photographs are shown in Figure 58.

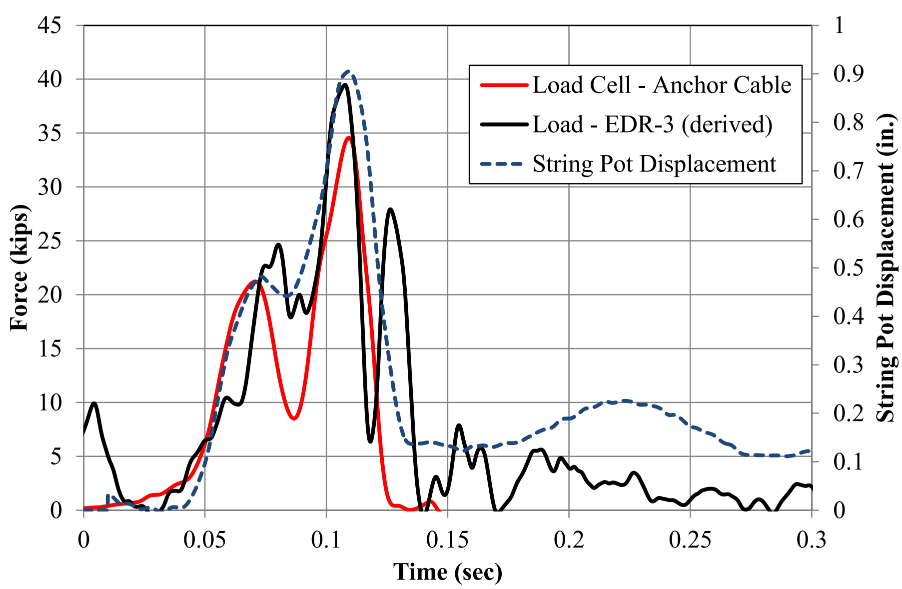


Figure 56. Force vs. Time and Displacement vs. Time, Test No. DSAP-2

0.000 sec

0.120 sec

0.080 sec

0.140 sec

0.100 sec

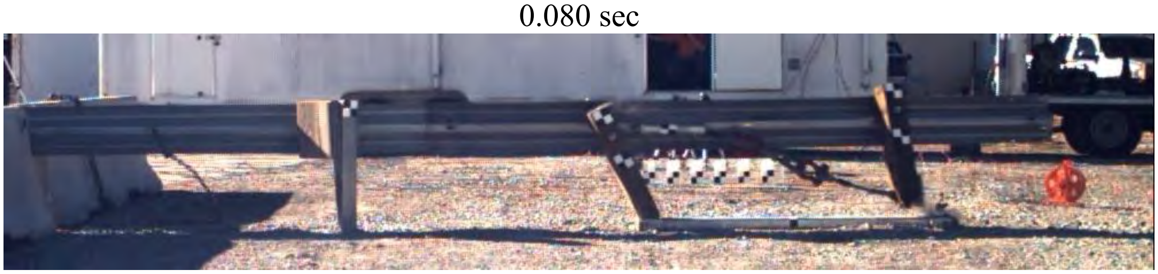
0.200 sec

Figure 57. Time-Sequential Photographs – Front View, Test No. DSAP-2

0.000 sec

0.070 sec

0.080 sec



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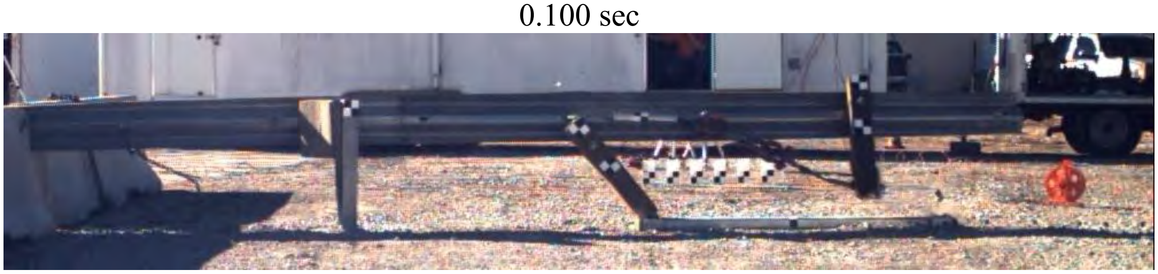

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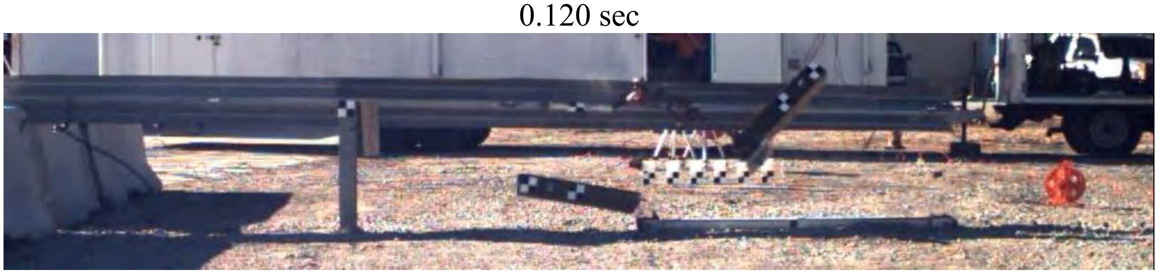

0.180 sec

Figure 58. Time-Sequential Photographs – Rear View, Test No. DSAP-2

Figure 59. Post-Impact Photographs, Test No. DSAP-2

7.3 Discussion

For test no. DSAP-2, several important observations were made. The increased tension in the anchor cable caused the farthest downstream anchor post to fracture first. The post was pulled upward and upstream by the releasing anchor cable, but it remained attached to the rail following fracture until it had rotated nearly 90 degrees. The second post from the downstream end also fractured at nearly the same time, but the post largely rotated around the BCT hole toward the ground level, and the post released away from the rail during fracture. Neither post was split due to the BCT loading through the post bolts.

The upward motion of the downstream BCT post after fracture was likely the result of the angle of the anchor cable between its attachment point on the W-beam and the BCT post. As the anchor cable tension increased, the angle of the cable resulted in a vertical force and a shear load applied longitudinally to the post. The lifting load from the cable pulling on the post was clearly visible at 0.120 sec into test no. DSAP-2, as shown in Figures 57 and 58.

The maximum load sustained by the end anchorage was between 35 and 40 kip (156 and 178 kN). A reasonable limit for estimating the capacity of an end anchorage would thus be 35 kip (156 kN). The anchor cable load versus downstream foundation tube displacement is shown in Figure 60. The loading curve of the anchor was linear through 0.40 in. (10 mm). The maximum load of 35 kip (156 kN) occurred at nearly the same time as the maximum deflection of 0.90 in. (23 mm). The anchor rebounded 0.75 in. (19 mm) in the soil, with a maximum permanent set deflection of 0.15 in. (4 mm). It should be noted that the rebound force curve was not relevant, because the anchor cable load cell disengaged from the soil foundation tube after the BCT post fractured and the bearing plate was released.

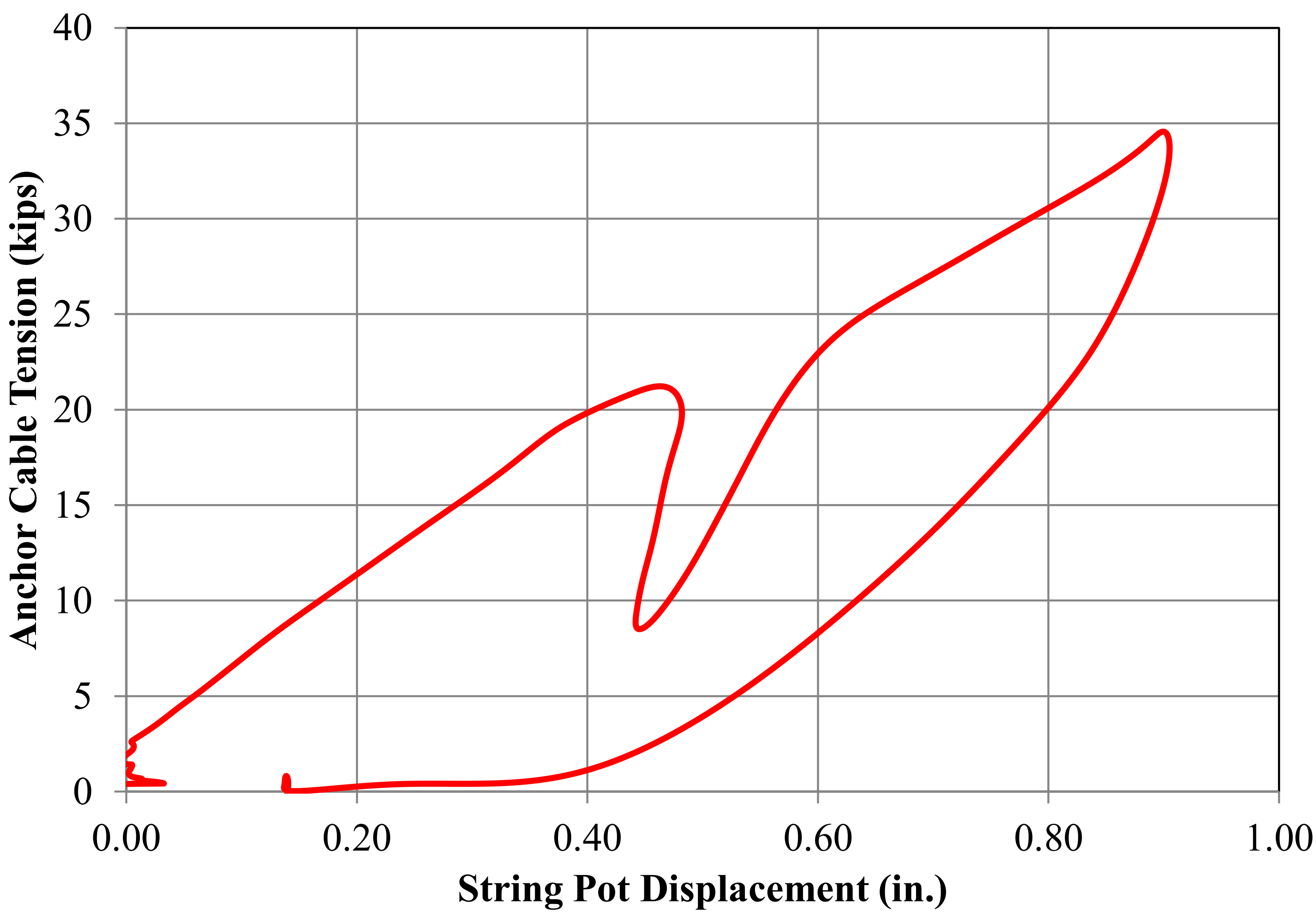

Figure 60. Anchor Cable Load vs. Downstream Foundation Tube Displacement, Test No. DSAP-2

8 NUMERICAL SIMULATIONS – COMPONENT MODELING

Results from the bogie testing program were used to generate models of the MGS end anchorage components. Simulations were then used to validate the models in predicting and replicating component behaviors observed in the physical tests. The non-linear finite element code LS-DYNA was used to perform this simulation effort [30]. First, models of wood CRT posts were created to compare simulated behavior against physical testing. Then, models of each of the three bogie testing efforts – eccentric post splitting tests, soil foundation tube tests, and downstream end anchorage system tests – were created and simulated, and results were evaluated.

8.1 Wood Post Models

The two BCT wood posts within the downstream end anchorage were modeled using an isotropic elasto-plastic material model. A bilinear material curve was used to characterize stress-strain behavior using elastic and plastic moduli equal to1,595 ksi (11 GPa) and 36 ksi (250 MPa), respectively. The yield stress of the wood material was set equal to 0.87 ksi (6 MPa). A failure criterion was defined based on a maximum plastic strain of 8 percent.

The calibration of the material parameters was based on a series of dynamic component tests performed at MwRSF. During a previous research effort, 6-in. x 8-in. (152-mm x 203-mm) CRT wood posts embedded in a rigid foundation were impacted at angles of 0, 45, and 90 degrees relative to the strong-axis impact direction [31]. One sample simulation used to validate the wood material model is shown in Figure 61. The material parameters were calibrated in order to match as close as possible the wood resistance that was measured in the various impact configurations. A comparison was made between the experimental and simulated force versus displacement and energy versus displacement curves for the three impact angles considered with the CRT wood posts (i.e., 0, 45, and 90 deg with respect to the post's strong axis of bending), as shown in Figures 62 through 67. The results indicated that the modeled wood behavior, using an isotropic material model and the mentioned mechanical properties, was capable of reproducing dynamic wood post strength in a stable and efficient manner. Beside the particular geometry of the CRT wood posts that were used for the calibration process, this material model was deemed suitable for modeling other similar wood post geometries with a weakening hole, such as BCT wood posts used in downstream end anchor systems.

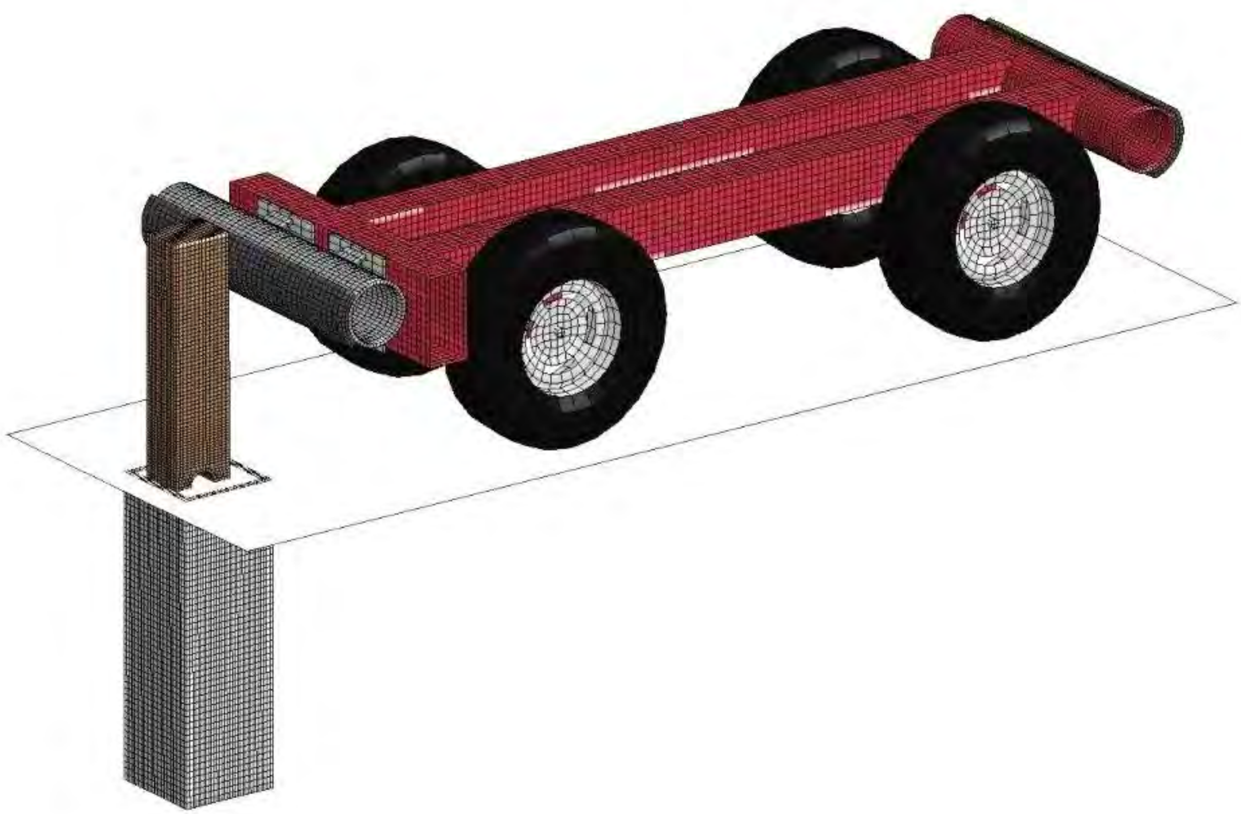

Figure 61. Sample Wood Post Impact Simulation to Validate Wood Material Model

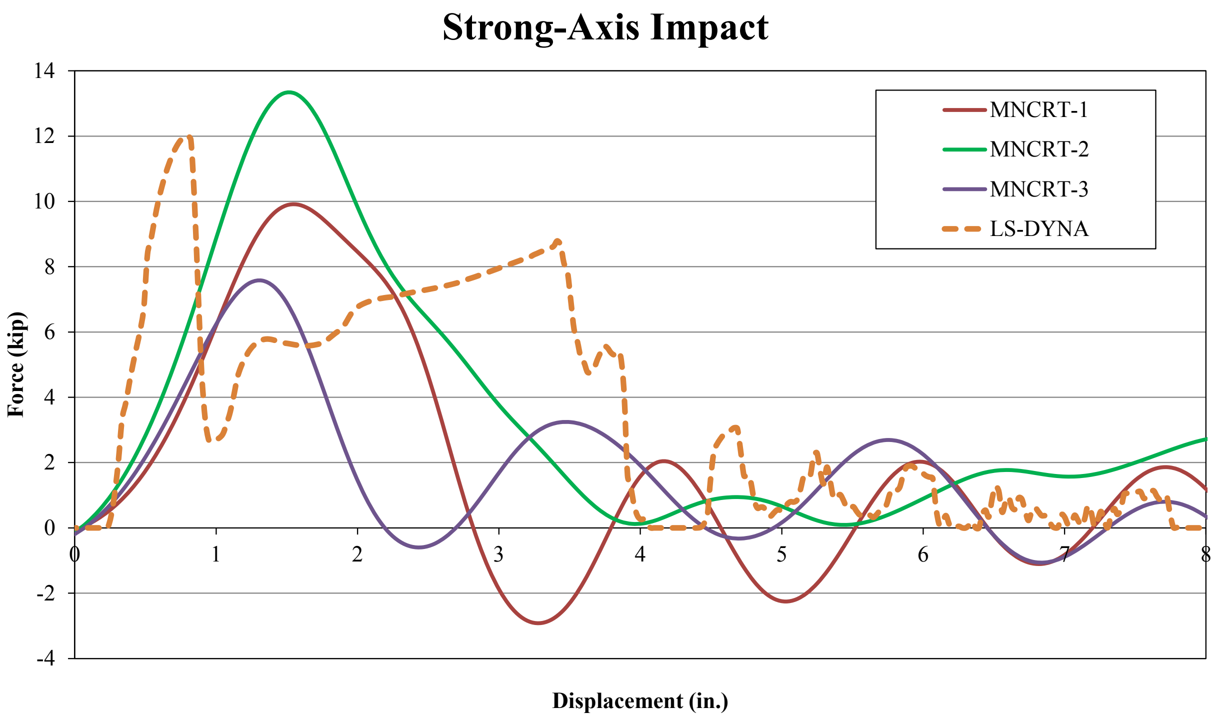

Figure 62. Force vs. Deflection, Simulation and Tests on CRT Posts at 0-deg Impact

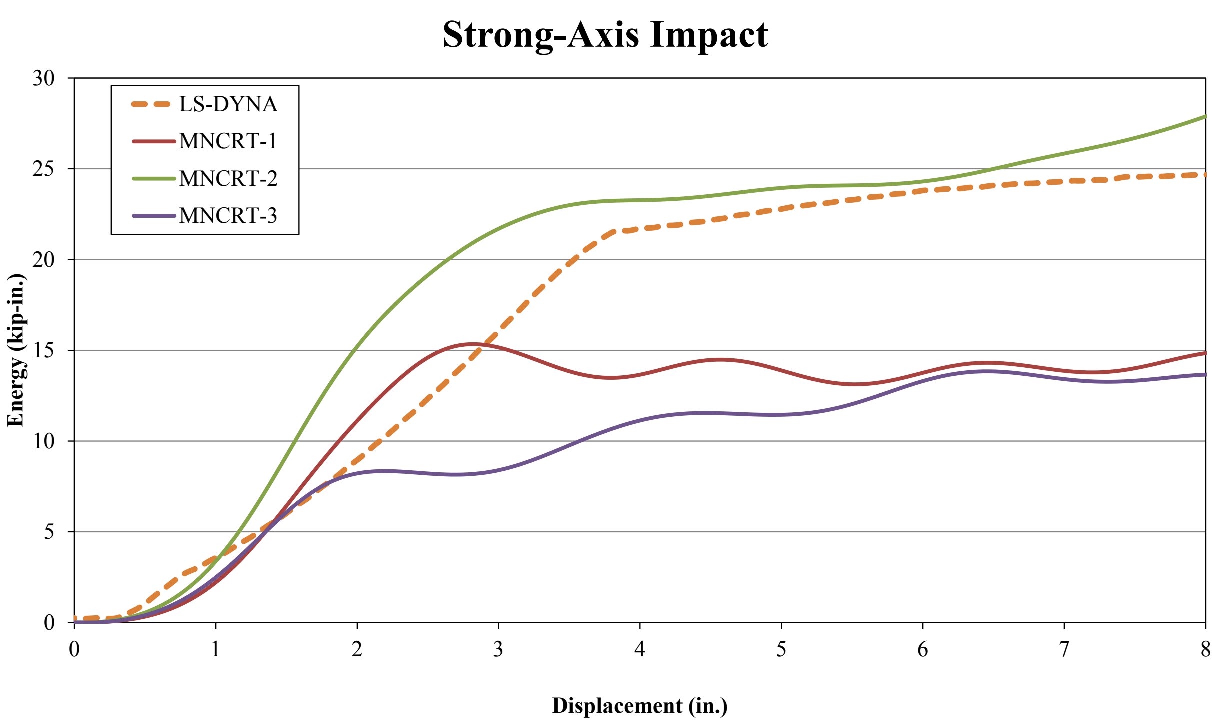

Figure 63. Energy vs. Deflection, Simulation and Tests on CRT Posts at 0-deg Impact

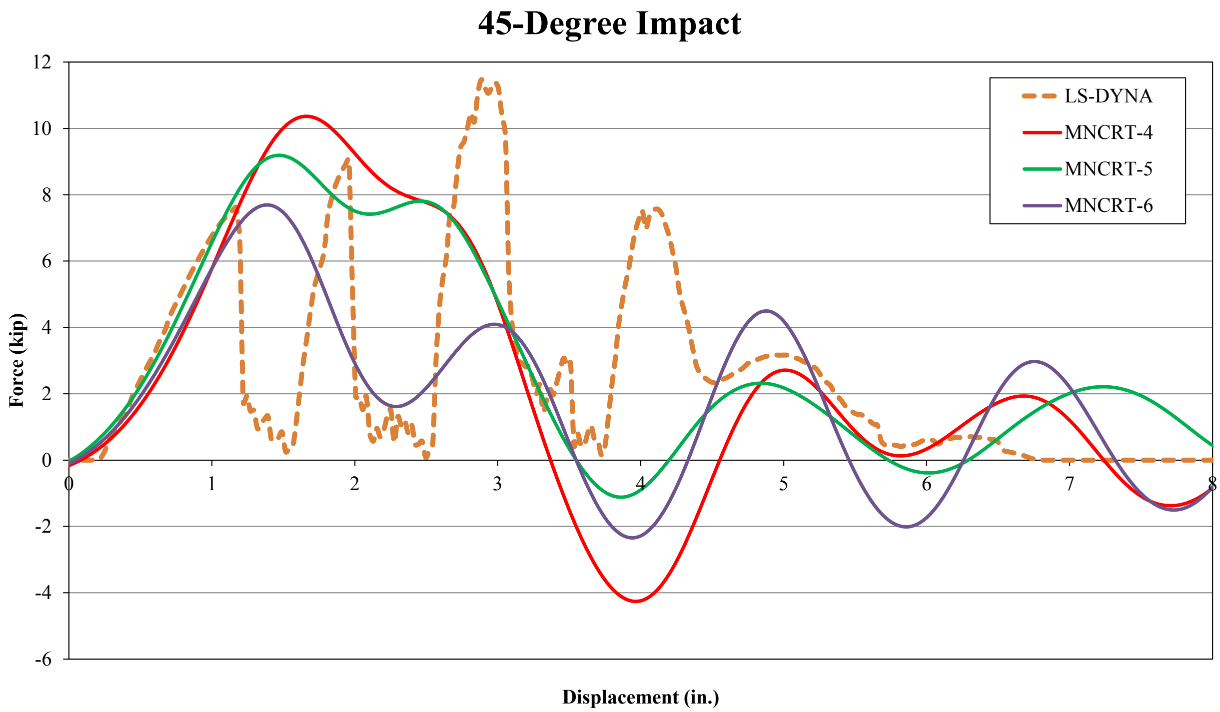

Figure 64. Force vs. Deflection, Simulation and Tests on CRT Posts at 45-deg Impact

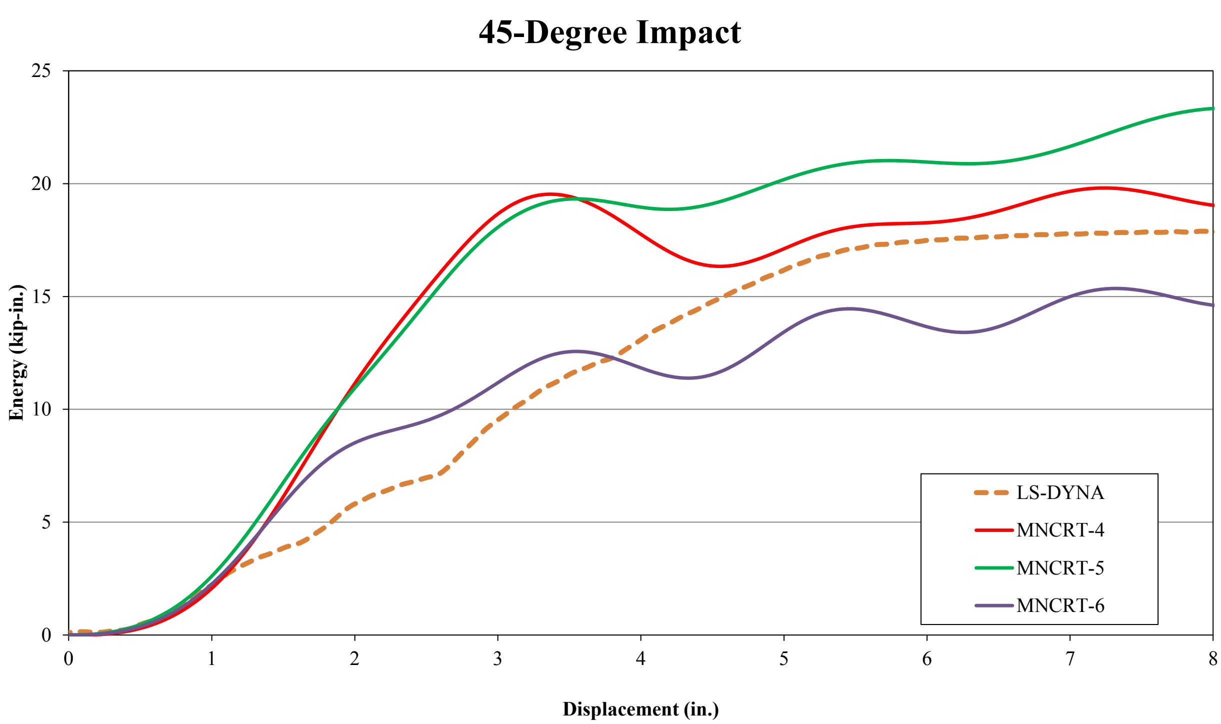

Figure 65. Energy vs. Deflection, Simulation and Tests on CRT Posts at 45-deg Impact

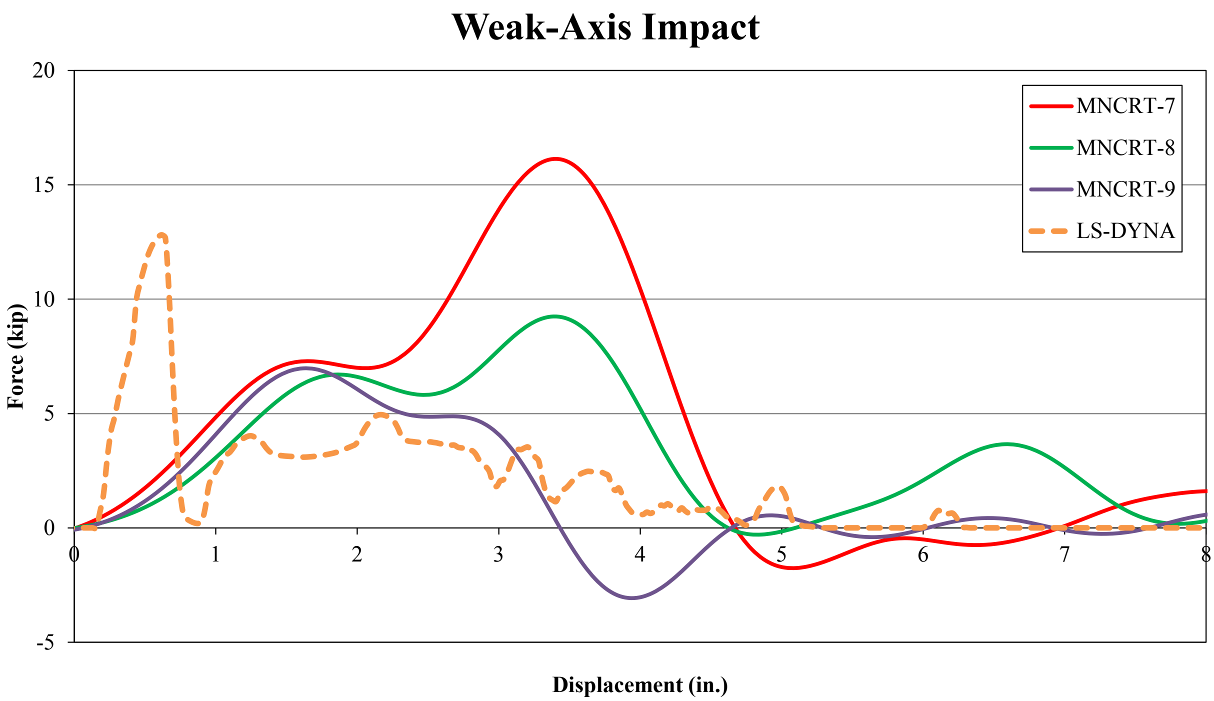

Figure 66. Force vs. Deflection Curves, Simulation and Tests on CRT Posts at 90-deg Impact

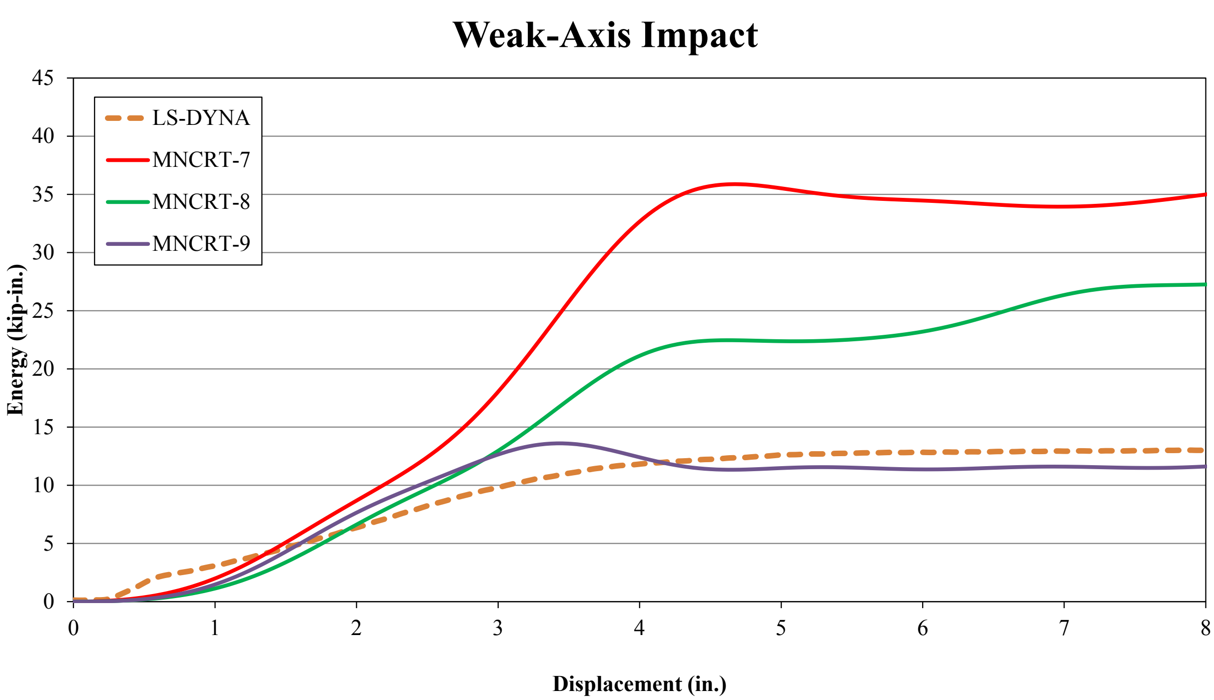

Figure 67. Energy vs. Deflection, Simulation and Tests on CRT Posts at 90-deg Impact

8.2 Wood Splitting Simulation – Eccentrically-Loaded BCT Post

A variation of the BCT wood post model was successfully developed to investigate splitting of the post in two pieces with a vertical fracture plane passing through the upper bolted connection between the rail and post. An example of a BCT post splitting simulation model is shown in Figure 68. The post model was comprised of two parts, which were connected using tied nodes along a vertical plane through the center of the post. Time-sequential photographs of test no. BCTRS-1 and the wood post splitting simulation are shown in Figure 69.

Experimental results from test nos. BCTRS-1 and BCTRS-2 were used to calibrate the wood post model. The comparison of the force versus deflection and energy versus deflection behaviors from numerical simulations and experimental results are shown in Figures 70 and 71, respectively.

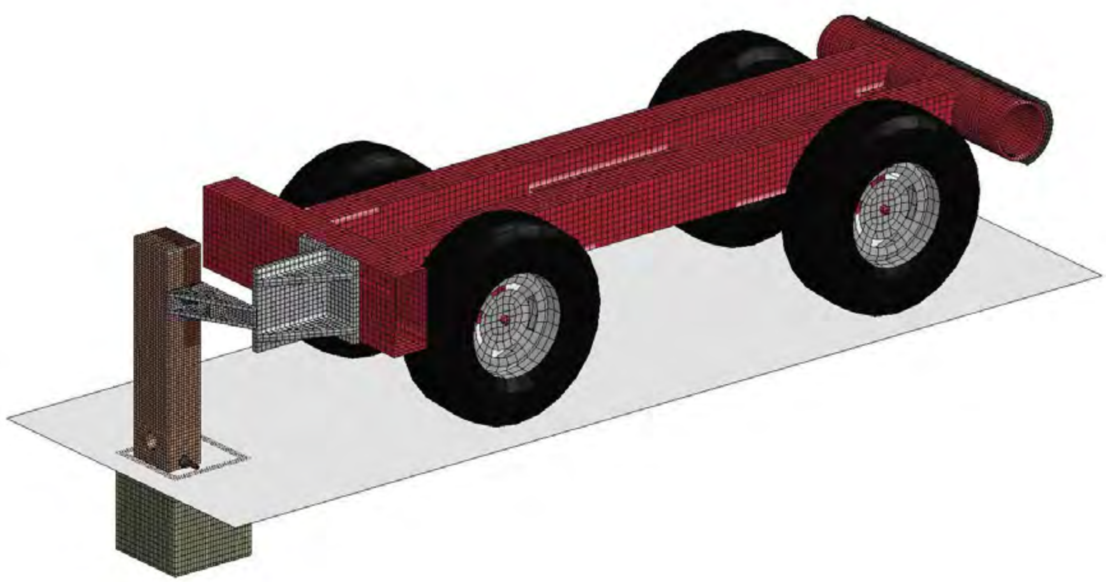

Figure 68. Example Simulation of Test Nos. BCTRS-1 and BCTRS-2 to Validate Wood Model

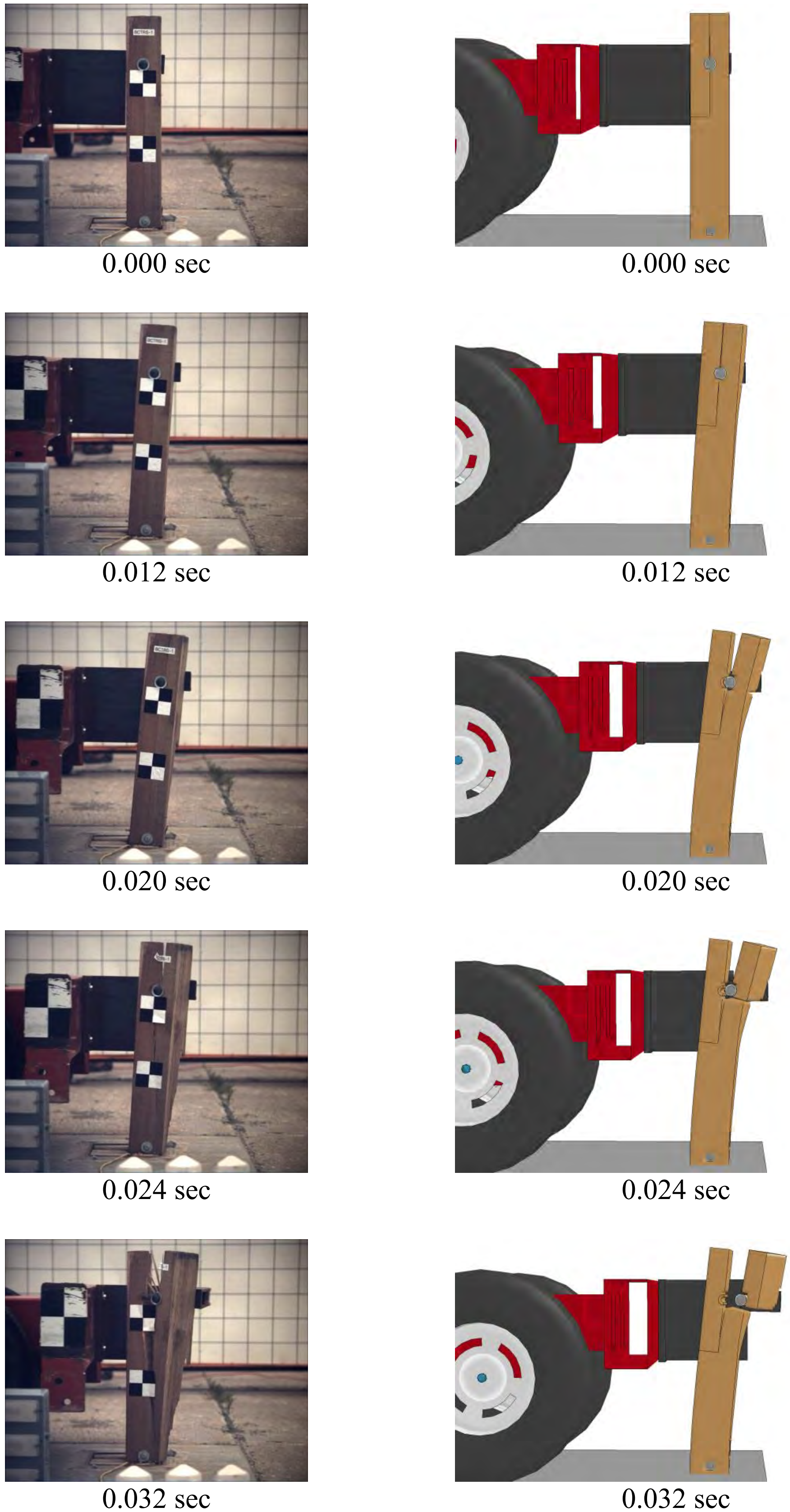

Figure 69. Time-Sequential Images, Test BCTRS-1 and Simulation

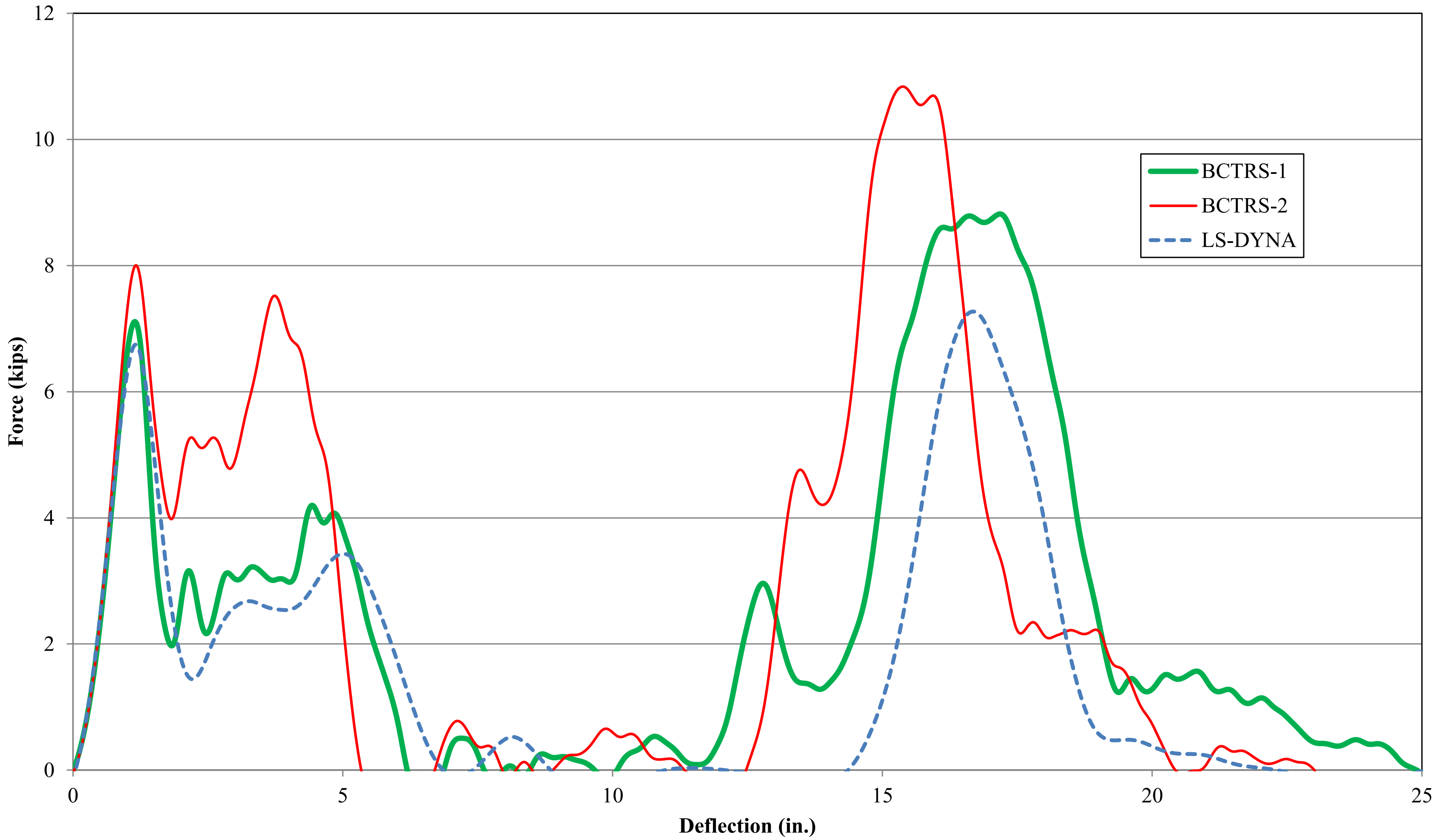

Figure 70. Force vs. Deflection, Simulation and Eccentric Tests on BCT Posts

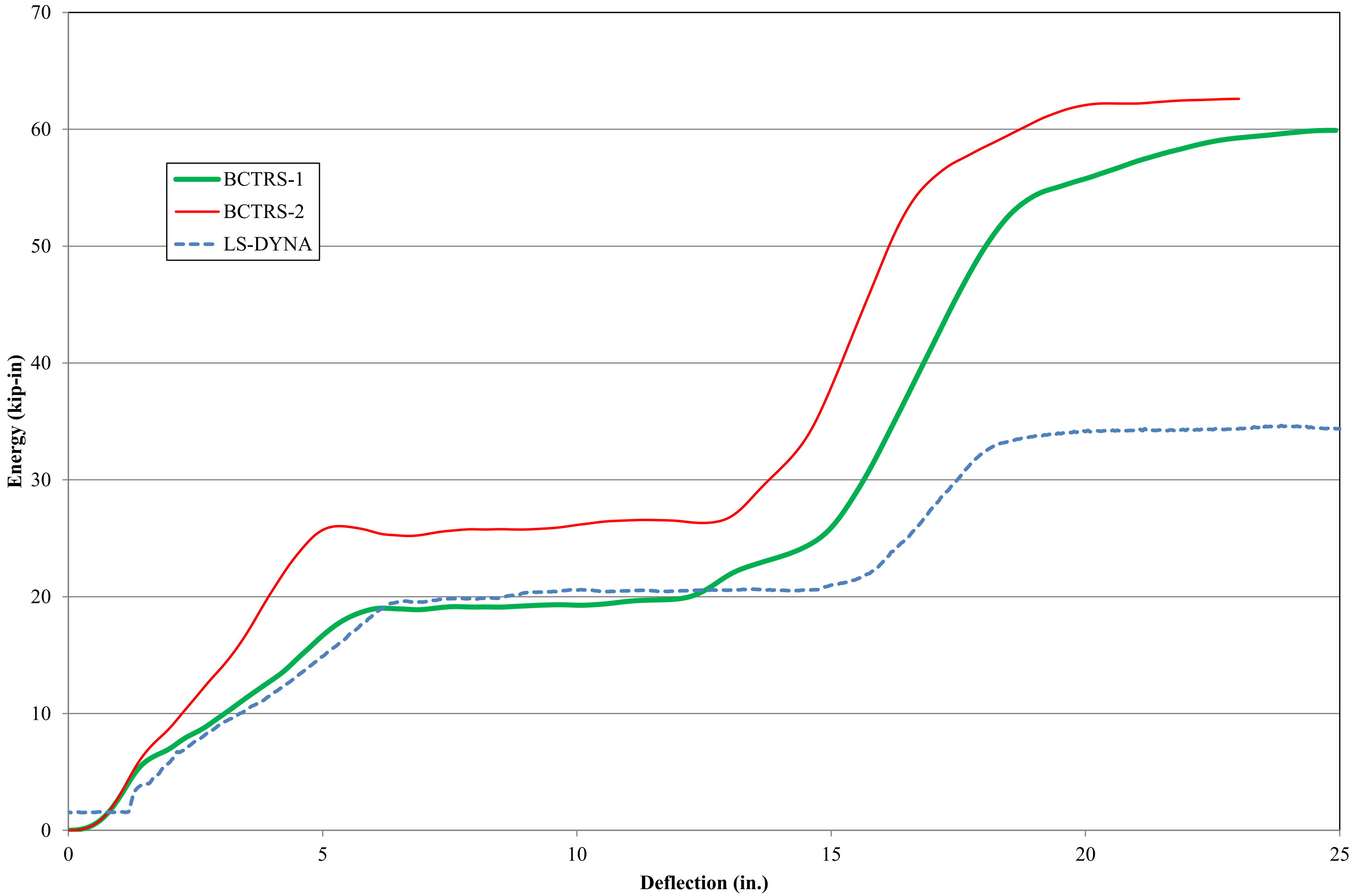

Figure 71. Energy vs. Deflection, Simulation and Eccentric Tests on BCT Posts

Based on the simulation results, the force versus deflection characteristics of the wood post model with splitting capability were representative of the lower bound of the force versus deflection behavior during the initial phase of the post splitting. Complete post fracture dissipated approximately 38 kip-in. (4.3 kJ), or approximately 63 percent of the energy dissipated in test nos. BCTRS-1 and BCTRS-2. Splitting occurred along the vertical plane, thus separating two parts of the post model. The split terminated at the junction between the separate post parts, after which time the smaller post piece separated from the post and was projected in front of the bogie vehicle. The simulation was terminated after the bogie contacted and fractured the remaining piece of the modeled BCT post.

Similar to the CRT simulation effort, the weak-axis, secondary impact of the post dissipated much less energy in the model than observed in the test. Whereas the results of the initial phase of post splitting were very similar to test no. BCTRS-1, secondary fracture occurred at a significantly lower energy level. This result indicated that BCT post splitting behavior may be reproduced with the use of improved wood models capable of accurately simulating weak-axis fracture.

8.3 Soil Foundation Tube and Soil Resistance Model

One important aspect of downstream anchorage modeling is the dynamic behavior of soil foundation tubes. Due to the difficulty associated with modeling soil with a compacted, coarse crushed limestone material that is often used in full-scale crash testing, a simplified soil tube model was developed and evaluated with non-linear soil springs. A 50-in. (1,270-mm) long pull cable, consistent with wire rope properties derived from ¾-in. (19-mm) diameter 3x7 guardrail wire rope [32], was attached to the modified BCT soil foundation tube with a modified, reinforced bearing plate, as shown in Figure 72. A 2,452-lb (1,112-kg) discrete mass was attached to the end of the wire rope and was prescribed an initial velocity of 15 mph (6.7 m/s).

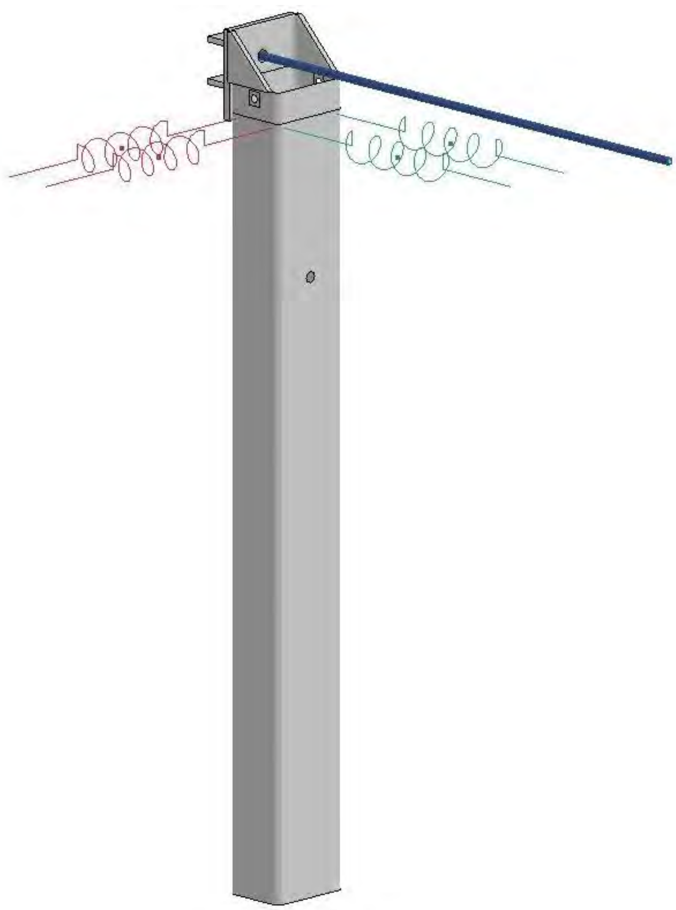

Figure 72. Soil FoundationTube and Soil Resistance Model

Results from the simulation of test no. MGSEA-1 were compared with physical test results and are shown in Figure 73. The force versus deflection behavior of the soil foundation tube model is shown in Figure 74. The soil tube was modeled with shell elements with a thickness of 0.1875 in. (4.76 mm), and prescribed with rigid material constrained against translational motion in any direction as well as constrained against twisting about the vertical axis. As a result, the modeled soil tube could not exactly replicate the behavior of the actual soil tube in the test, which accelerated and displaced soil. Soil displacement in the test culminated in both inertial and compressive loads transferred to the soil tube, and the top opening of the soil tube remained above ground throughout the deflection.

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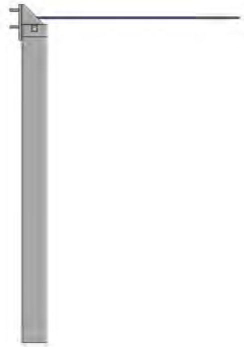

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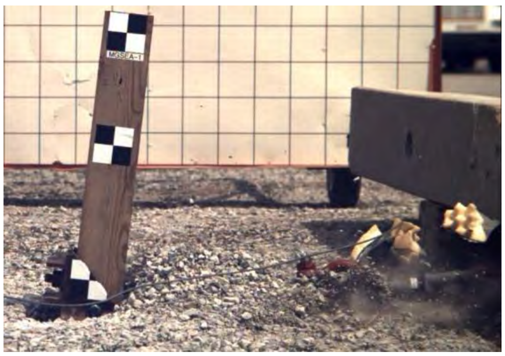

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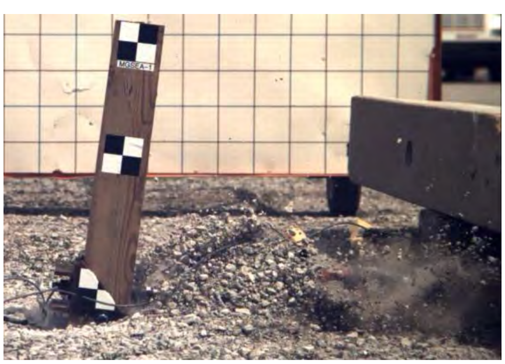

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Figure 73. Time-Sequential Images, Test and Simulation, MGSEA-1

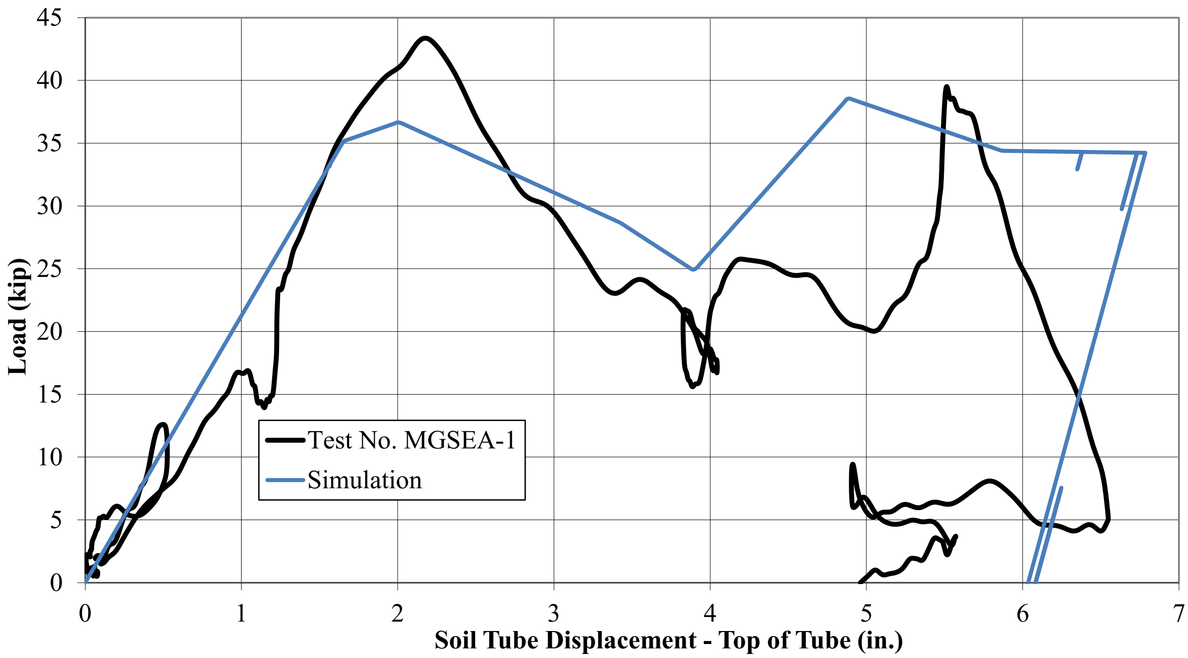


Figure 74. Force vs. Deflection, Test and Simulation, Test No. MGSEA-1

Historically, soil stiffness has had a significant effect on end anchorage motion. A test of an MGS long-span system spanning a box culvert resulted in a permanent set of the downstream anchor post soil tube of 9 in. (229 mm), and the downstream anchor post was lifted up and extended partially out of the ground after the test [33]. During a test and evaluation of a maximum flare rate used in combination with the MGS system, the MGS end anchorage deflected 1.5 in. (38 mm) and lifted partially out of the ground [34]. The dynamic loads applied to the anchors in these two tests were likely much higher than observed in many other full-scale crash tests. Nonetheless, the very large dynamic deflections of the soil foundation tubes may not be solely explained by the large anchor loads. Static soil tests conducted before and after revision of soil compaction practices at MwRSF indicated an increase in approximate static soil strength from 6 kip (27 kN) to 12 kip (53 kN). Lower soil strength may have contributed to the increased anchor deflections. In addition, soil inertia affected overall deflection in test no. DSAP-2.

Despite these difficulties, the force versus deflection behaviors for the soil foundation tubes in MGSEA-1 and the simulation with non-linear soil springs were very similar over the first 4 in. (102 mm) of deflection, as measured at the string potentiometer attachment location. A similar downstream soil foundation tube in test no. DSAP-2 only experienced a deflection of 0.9 in. (23 mm) before the BCT posts were fractured, with a string pot attached at the same location. Thus, it is not anticipated that deflections greater than 4 in. (102 mm) will occur in any future crash testing efforts utilizing a strong, heavily-compacted soil, to the model was considered accurate.

8.4 Validation of the Downstream Anchorage

The downstream end anchorage model was validated against the data obtained from the dynamic component test no. DSAP-2, in which an end anchor system was pulled by a dynamic impulsive load applied at the upstream end of the rail segment through a bogie vehicle and a tow cable. A more complete description of the test setup for test no. DSAP-2 was provided in Section 7.2.2.

Test no. DSAP-2 was simulated using modeled components of an MGS end anchorage system, as shown in Figure 75. The model consisted of two BCT posts inserted into steel foundation tubes connected by a ground strut. A cable anchor was also attached to a W-beam rail and with a bearing plate in contact with the end BCT post.

The MGS anchorage model was simulated and compared to the results from the bogie test. A comparison of the cable anchor force versus deflection of the top of the soil tube was made between test no. DSAP-2 and the numerical simulation, as shown in Figure 76. Time-sequential photographs of the test and simulation were compared and are shown in Figure 77. Both the test and simulation were assumed to start after the W-beam rail began to deflect downstream. The displacement corresponding to maximum load and the maximum displacement were 0.9 in. (23 mm) in test no. DSAP-2, whereas the displacement corresponding to the maximum load and the maximum displacement were 0.99 in. and 1.03 in. (25.1 mm and 26.2 mm) in the simulation, respectively.

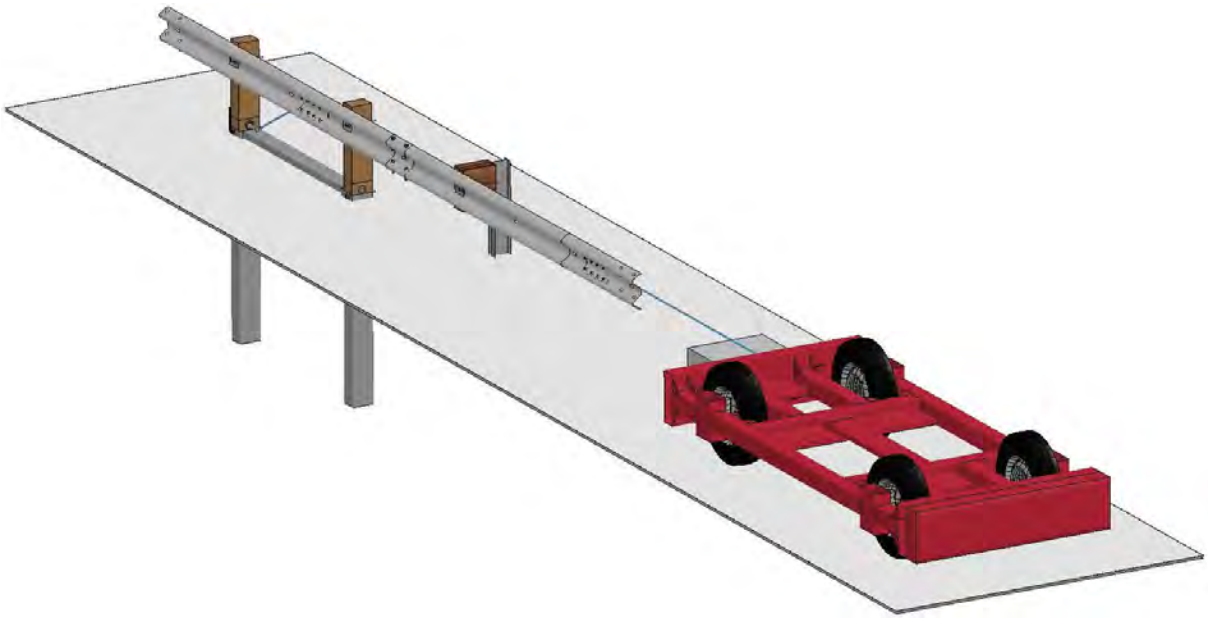


Figure 75. Model of Test No. DSAP-2 Used to Validate End Anchor

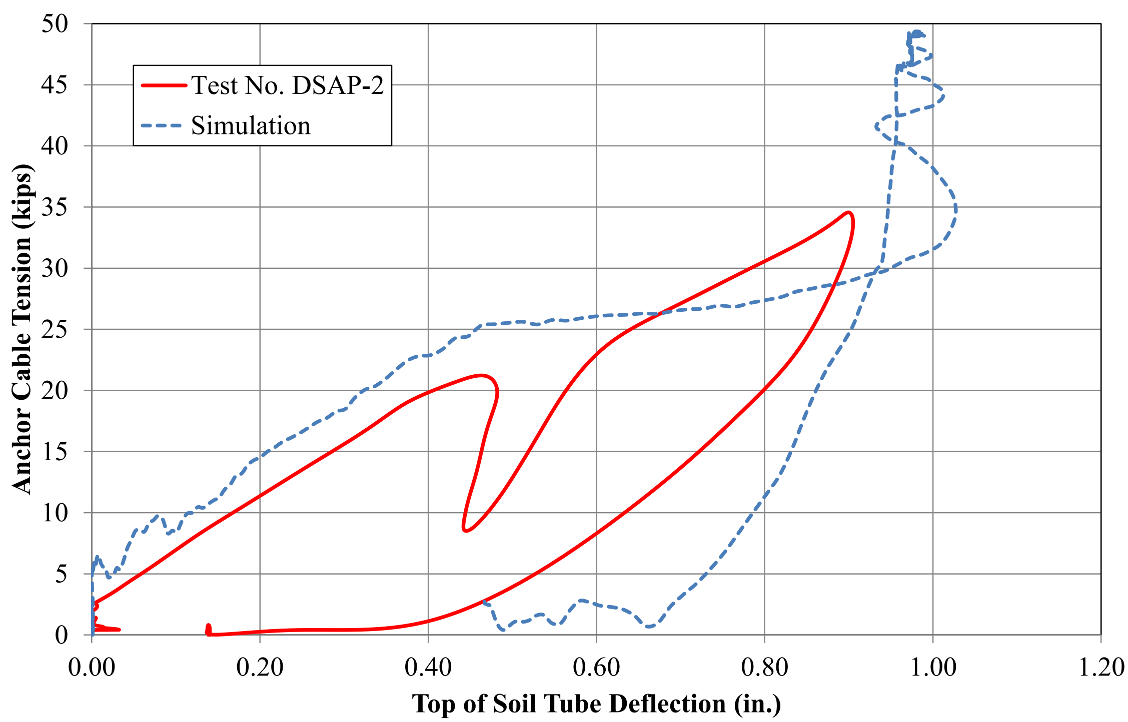
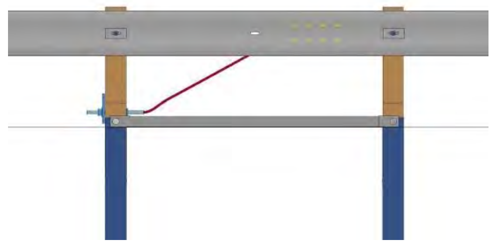


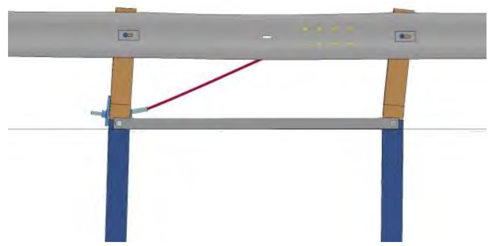
Figure 76. BCT Cable Force vs. Top of Soil Tube Deflection, Test and Simulation

0.000 sec



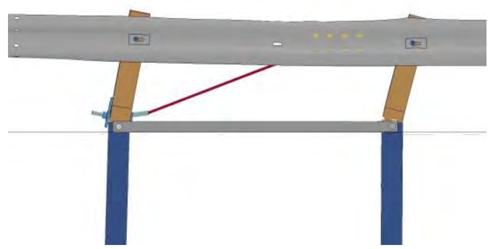
0.000 sec

0.040 sec



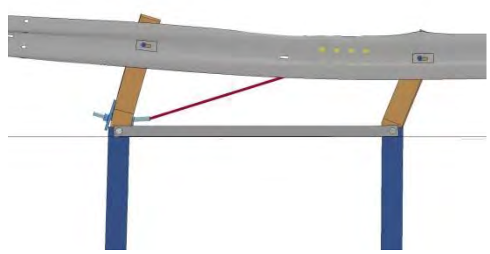
0.020 sec

0.070 sec



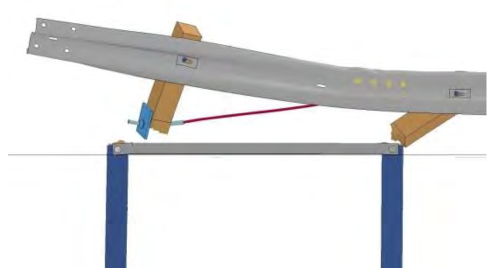
0.030 sec

0.086 sec



0.040 sec

0.100 sec



0.60 sec

Figure 77. Time-Sequential Images, Test and Simulation, Test No. DSAP-2

Immediately after simulation began, the W-beam rail was pulled downstream, as shown in Figure 77. The upstream anchor post fractured through the cross-section between 0.030 to 0.040 sec, and the downstream anchor post fractured between 0.040 sec and 0.048 sec. By contrast, the downstream anchor post fractured abruptly at 0.040 sec during test no. DSAP-2, and the upstream post fractured between at 0.076 and 0.122 sec. The downstream anchor post rotated around the ground line, whereas the upstream anchor post was pulled downstream by the cable anchor and post bolt in both the test and simulation.

Several differences were noted between the simulation and bogie test of the downstream anchorage. First, a short length of wire rope was simulated to model the pull cable between the bogie and the rail. Thus, there was a large impulse force applied to the simulated system, causing immediate system deflection. In test no. DSAP-2, the bogie vehicle was attached to a long pull cable which initially rested on the ground. As a result, the system was loaded more gradually. The more gradual increase in loading also resulted in delayed post fracture in the test compared to the simulation.

Second, there was no modeled slack in the BCT anchor cable. As a result, the cable was almost immediately loaded in tension after the W-beam displaced downstream. Furthermore, the "geometrical stretch" noted in previous literature of slack wire rope during tensioning [32] was not taken into account in the wire rope model, which led to higher forces culminating from small deflections in the anchor cable. Thus, the anchor cable model over-predicted the cable anchor forces through much of the simulation.

Third, wood post modeling in LS-DYNA is subject to significant variation when wood posts fracture in weak-axis bending. Test and simulation results for the wood post tests shown in Figures 66 and 67 indicated that weak-axis impacts dissipated more energy and resulted in higher resistive forces on average through a deflection of 4 in. (102 mm) during the physical tests than observed in simulations. Posts were optimized using strong-, weak-, and oblique-axis impacts, resulting in post models which tended to: overpredict loads and energy dissipated in strong-axis impacts; approximately matched the energy and force levels in angled-axis impacts; and underestimated loads and energy in weak-axis impacts. Thus, the BCT posts, which were subjected to weak-axis loading, fractured at lower loads and energy levels in the simulation than observed in the bogie test no. DSAP-2.

Despite these differences, the simulated load versus deflection behavior of the anchor and soil foundation tube reasonably reflected the behavior observed in the bogie test. Furthermore, an approximately 40-ms delay seemed to be present between the test and simulation, as events occurring in the simulation analogously occurred in the physical test 40 ms later. When additional uncertainties in the analysis, variability on repeated tests, and modeling constraints were taken into account, the simulated model of the MGS end anchorage was determined to be a good candidate for modeling the downstream end anchor for simulations of vehicular impact events.

9 NUMERICAL MODEL OF THE MGS BARRIER

Information gleaned from the actual and simulated bogie component testing program was used to generate models of an MGS barrier with the associated downstream anchorage system. Numerical simulations of full-scale crash tests were performed to determine potential critical impact points (CIPs) which may occur during an impact in close proximity to the downstream anchorage with both the 1100C and 2270P vehicles. The CIP of the pickup truck is frequently defined as the point at which it is unclear whether the system will contain and redirect the vehicle or the end of the system will gate and permit the vehicle to pass through. The small car CIP corresponds to the point/location which maximizes propensity for the small car to underride the barrier and become ensnared by the anchor cable.

An LS-DYNA model of a 175-ft (53.3 m) long MGS system was created. The W-beam rails, rail slots, splice bolts and posts were modeled in detail for the first ten spans from the downstream end, including the end anchorage. The LS-DYNA model is shown in Figure 78.

Detailed bolted connections were modeled between the cable-anchor bracket and the back of the most downstream rail segment and for the splice joints between the first six rail segments from the downstream end of the system. Also, the rail slots used for the connection to the first ten posts from the downstream end were characterized by a finer mesh in order to better simulate the plastic deformation in this area.

9.1 Simulated Scenarios and Results

9.1.1 Identification of Critical Impact Scenario for 1100C

The numerical model of a Dodge Neon passenger car was used to simulate full-scale crash tests at different impact locations in close proximity to the downstream end anchorage of the MGS barrier model previously described. Simulated impact scenarios considered a top rail mounting height of both 31 in. (787 mm) and 32 in. (813 mm).

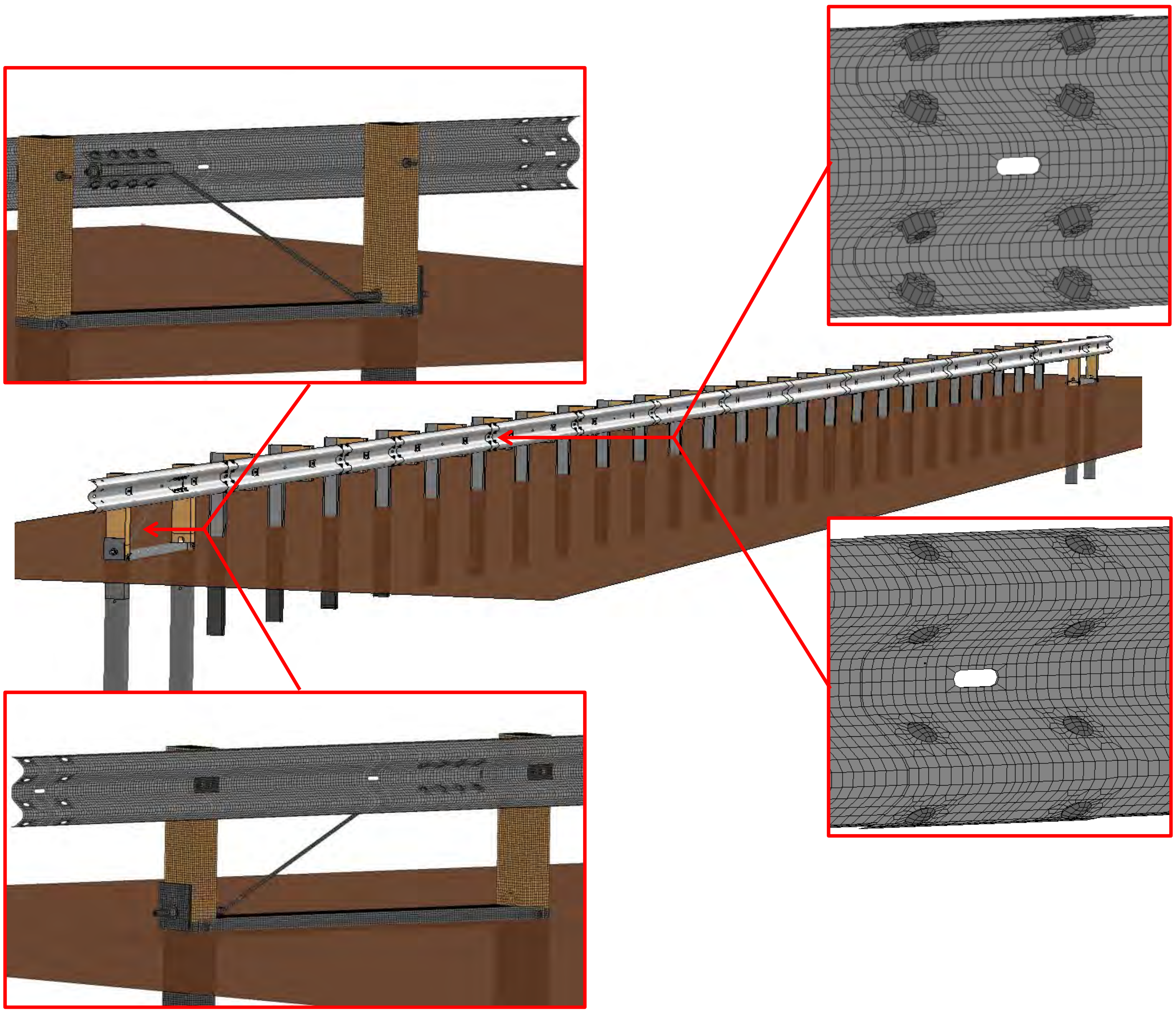


Figure 78. LS_DYNA Model Used to Simulate Impact in Close proximity to the Downstream End Anchor

To identify the critical impact location, full-scale crash tests were simulated with initial impact points at each quarter of guardrail span in the range starting from a quarter span upstream from the end post through midspan between the first two line posts. For all of these simulated scenarios, the initial impact speed and angle were 62 mph (100 km/h) and 25 degrees, respectively.

In the analysis of the simulation results, specific focus was given to the interaction between the vehicle's front end and the cable anchor. This interaction, at the instant when the end post fracture was initiated, is shown in Figures 79 through 81. Impact points between the second and third posts resulted in maximum vehicle snag on the BCT cable. In addition, impacts which occurred within the span of the anchor resulted in vehicle contact with the BCT bearing plate following the end post fracture, as shown in Figure 82. This interference between the bearing plate and the impacting tire did not lead to any vehicle instability in the simulations. However, in an actual full-scale crash test, this situation could lead to the potential for the vehicle to be trapped if the sharp edge of the bearing plate cut through the tire and hooked the vehicle's wheel.

Further simulations were also performed using BCT wood posts that exceeded the minimum required strength, with focus on impacts occurring between post nos. 2 and 3 to maximize vehicle snag on the anchor cable. A comparison between the results obtained with a standard wood strength and with strength of the BCT wood posts in the expected upper boundary is shown in Figure 83. The simulations with stronger BCT wood posts showed an increase in vehicle snag on the cable anchor. In particular, for an initial impact occurring at the midspan between the second and third posts from the downstream end of the rail, the cable anchor slid onto the inner side of the impacting tire. In the simulations, the vehicle eventually disengaged

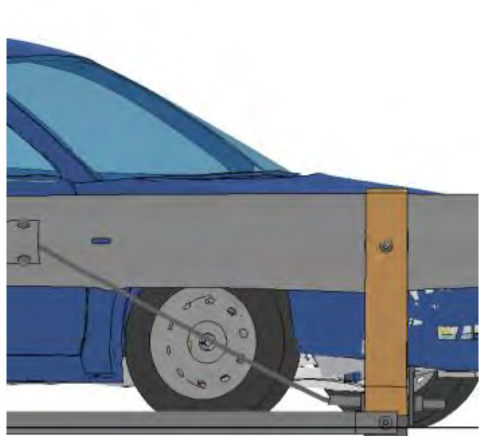
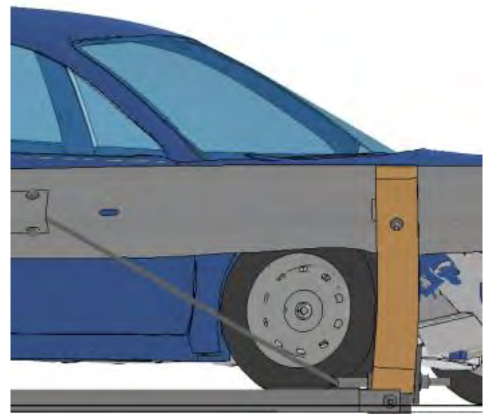
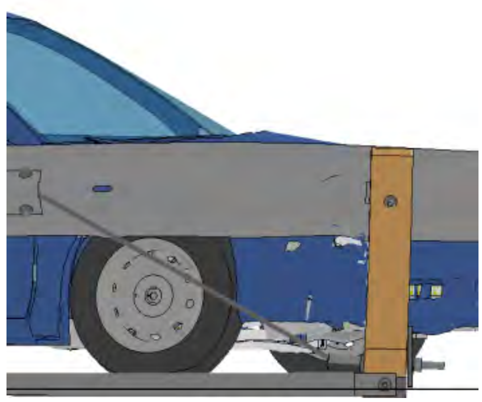
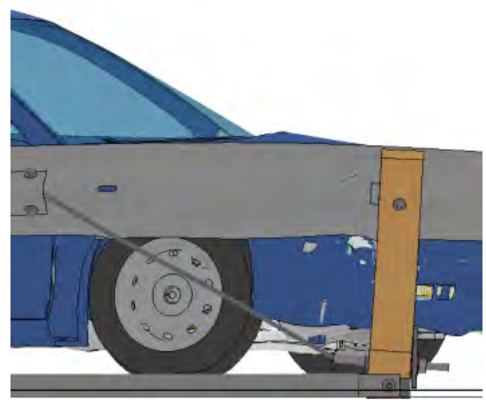
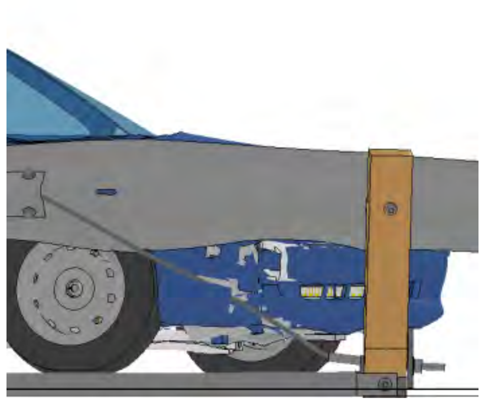
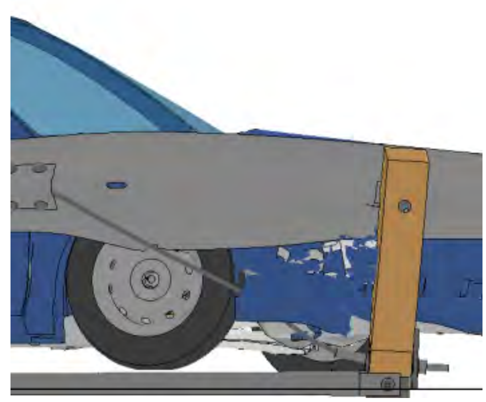
Impact Location	Rail Height (in.)	
	31	32
1st + ¼ span upstream from last post		
1st + ½ span upstream from last post		
1st + ¾ span upstream from last post		

Figure 79. Vehicle-Cable Interaction at Onset of End Post Fracturing

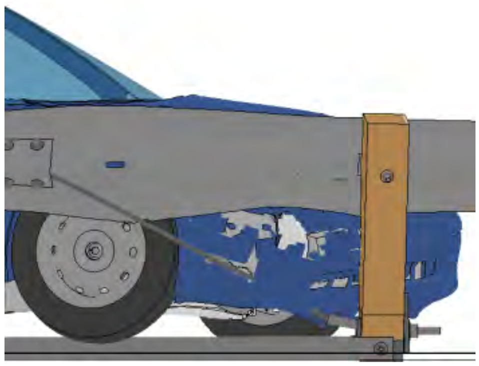
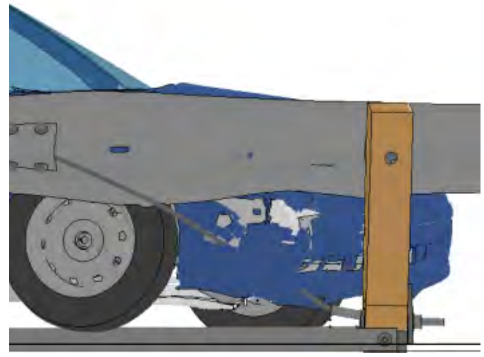
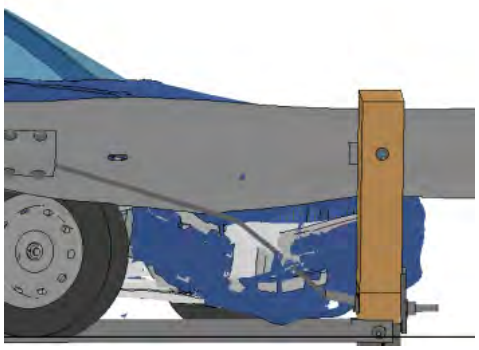
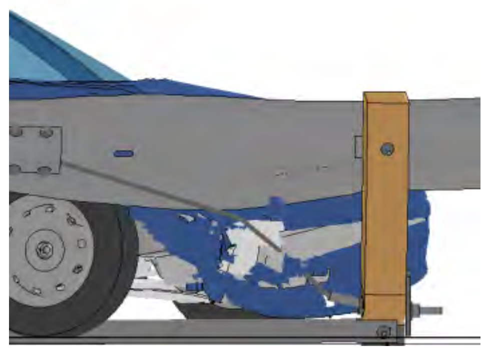
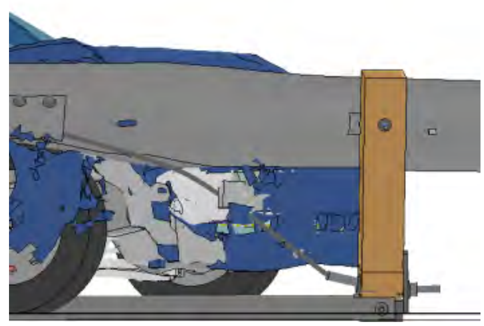
Impact Location	Rail Height (in.)	
	31	32
2nd Post		
2nd Post + ¼ span		
2nd Post + ½ span (CIP Impact)	Simulation Instabilities	

Figure 80. Vehicle-Cable Interaction at Onset of End Post Fracturing (continued)

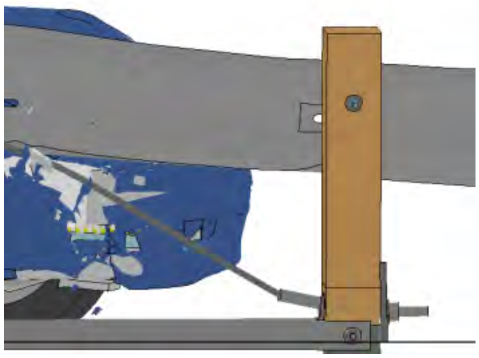
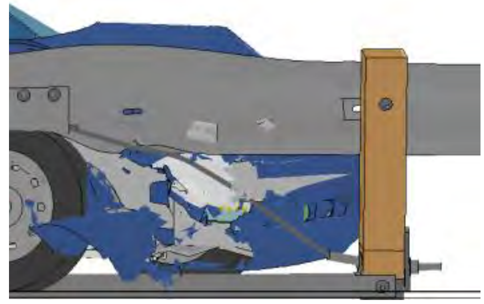
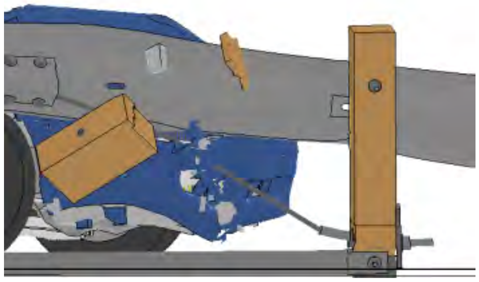
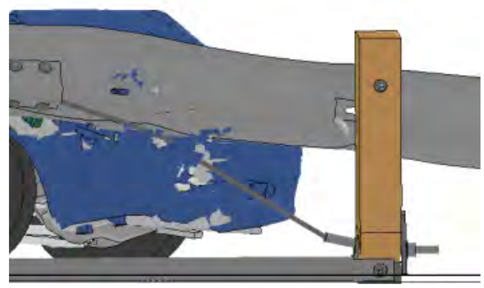
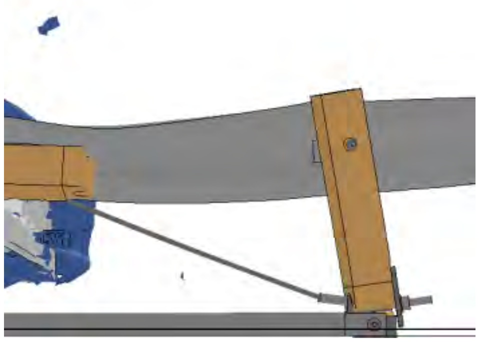
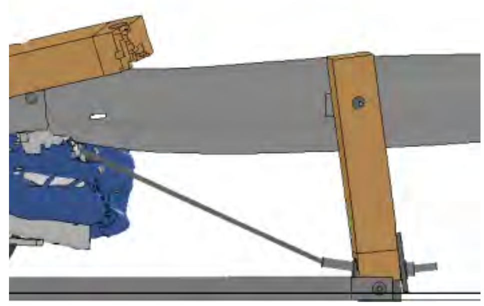
Impact Location	Rail Height (in.)	
	31	32
2nd Post + ¾ span		
3rd Post		
3rd Post + ½ span	End Post Broken Before Contact w/ Cable 	

Figure 81. Vehicle-Cable Interaction at Onset of End Post Fracturing (continued)

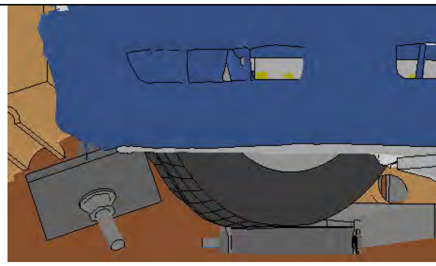
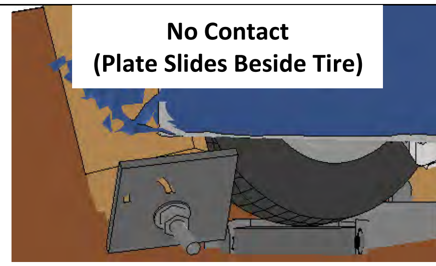
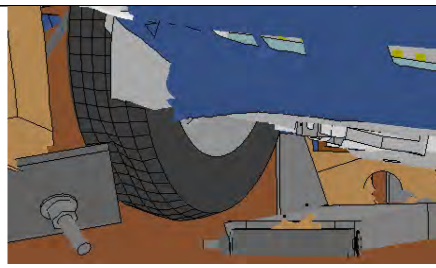
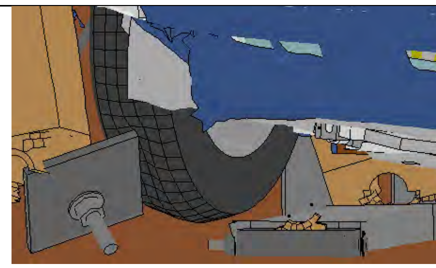
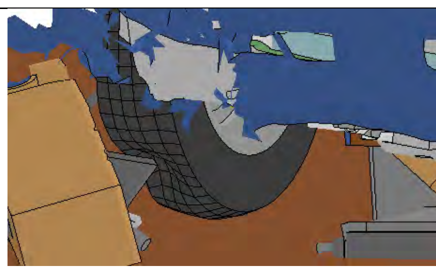
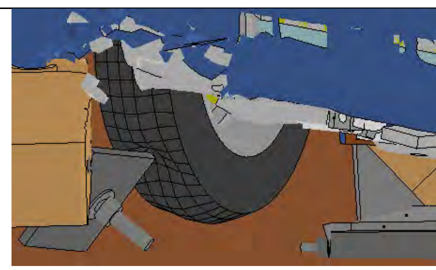
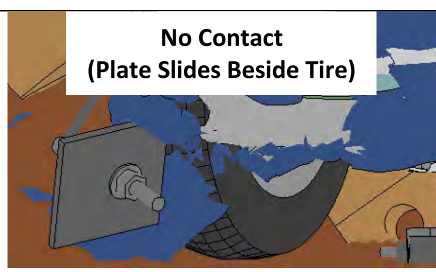
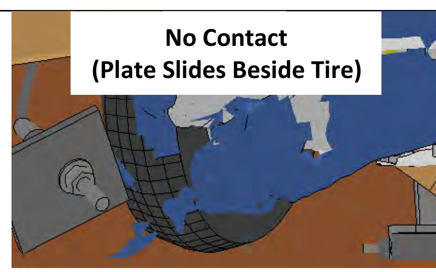
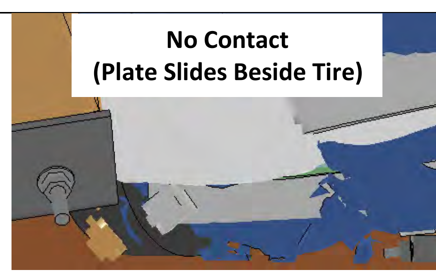
Impact Location	Rail Height (in.)	
	31	32
1st Post + ¼ span		
1st Post + ½ span		
1st Post + ¾ span		
2nd Post		
2nd Post + ¼ span		

Figure 82. Tire-Bearing Plate Contact Occuring for Various Initial Impact Points – 1100C

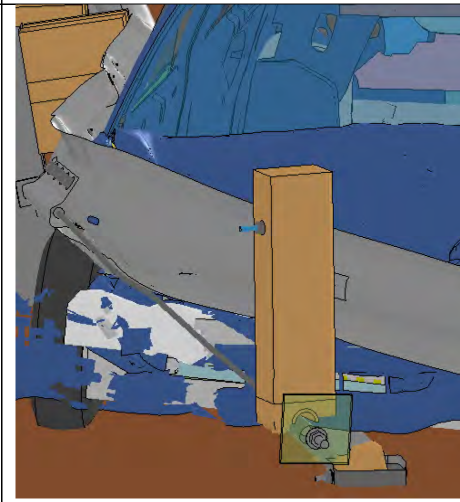
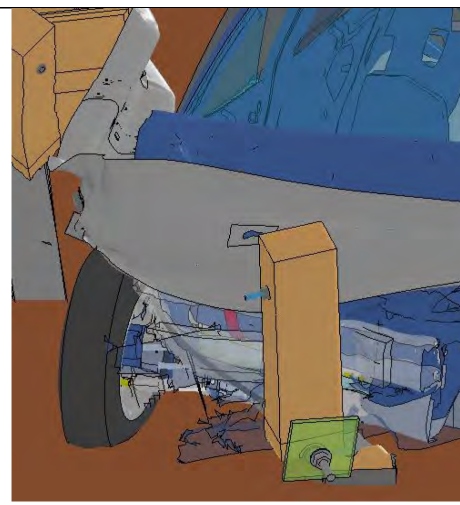
Wood Strength	Impact Location		
	2nd Post + ¼ span	2nd Post + ½ span (CIP Impact)	3rd Post
Standard			
Increased			

Figure 83. Vehicle-Cable Interaction for Critical Impact Points with 32-in. (813-mm) Tall MGS

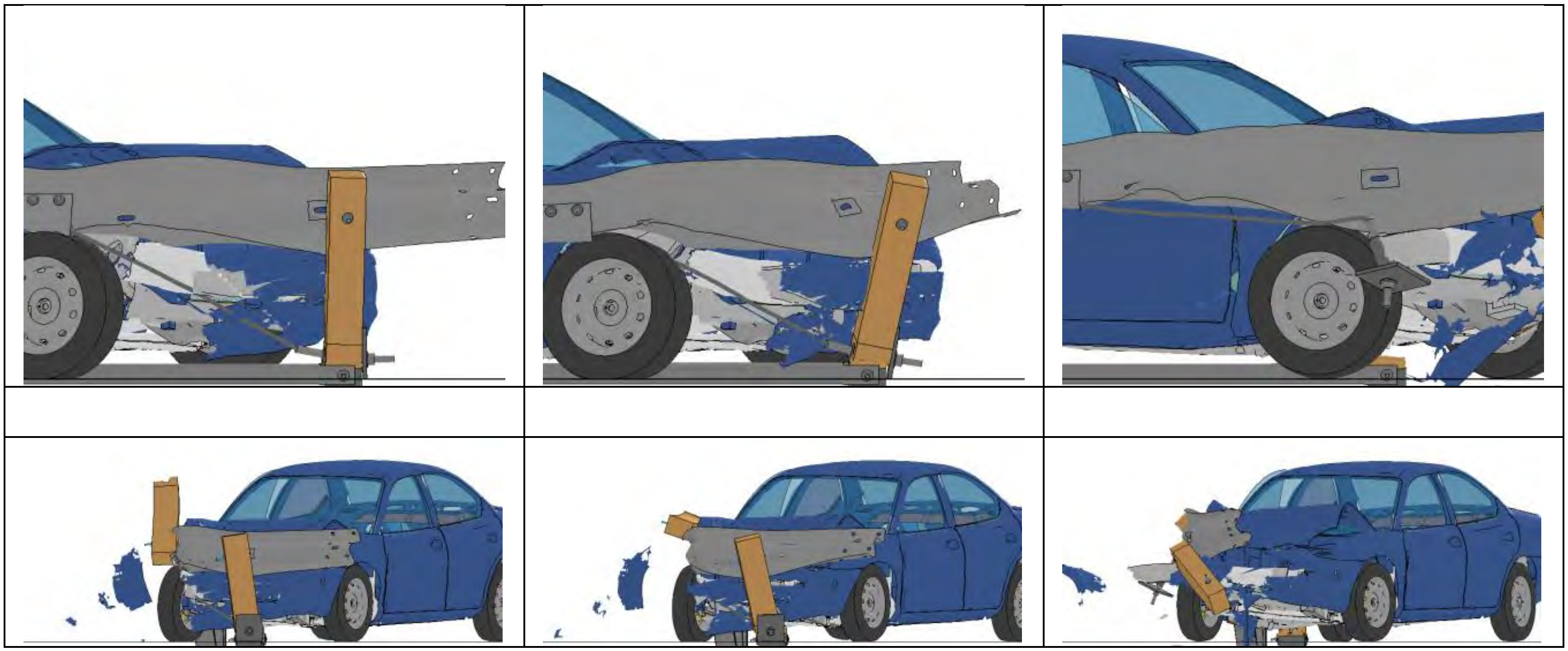


Figure 84. Impact at Midspan of 2nd and 3rd Post from Downstream End with 32-in. (813-mm) Tall MGS (Strong Wood)

from the cable without instability, as shown in Figure 84. However, this situation may potentially be dangerous and cause increased occupant risk values during a full-scale crash test.

The simulated full-scale crash tests of the 1100C passenger car in close proximity to the downstream end anchorage of the MGS system identified two potential critical situations: (a) interference between the bearing plate and the impacting right-front tire and (b) snagging of the vehicle's front end on the anchor cable. Impacts in which the anchor cable interacts with the inner side of the front wheel were deemed more critical for vehicle instability and occupant risk.

The simulated impact utilized a BCT wood material model which was approximately representative of the upper boundary of wood strength, a 32-in. (813-mm)-high top rail mounting height, and an impact location between the second and third posts upstream from the downstream end post. During this simulation, the vehicle engaged the BCT cable, but the cable did not become snagged on the vehicle suspension. However, a different geometry of the vehicle's front-end, such as front bumper, engine hood, front fender, and wheel well, may allow the anchor cable to penetrate more deeply behind the impacting wheel, increasing snag potential and consequently causing excessive occupant decelerations and vehicle instability. This simulation scenario was determined to be the most critical impact to evaluate end anchorage crashworthiness.

Further investigation was carried out to assess potential advantages and disadvantages of a simple support between the rail and the downstream end post during an impact occurring at the identified critical impact point. An example of the simply-supported end post is shown in Figure 85. A simply-supported end may be realized as a BCT post which retains the rail at the desired height through use of an angle bracket or shelf to support the rail. Although a simple support may decrease the load applied to the BCT wood post, it may also allow for increased wedging of the vehicle's front end; since, there would be no vertical constraint applied to the end of the rail.

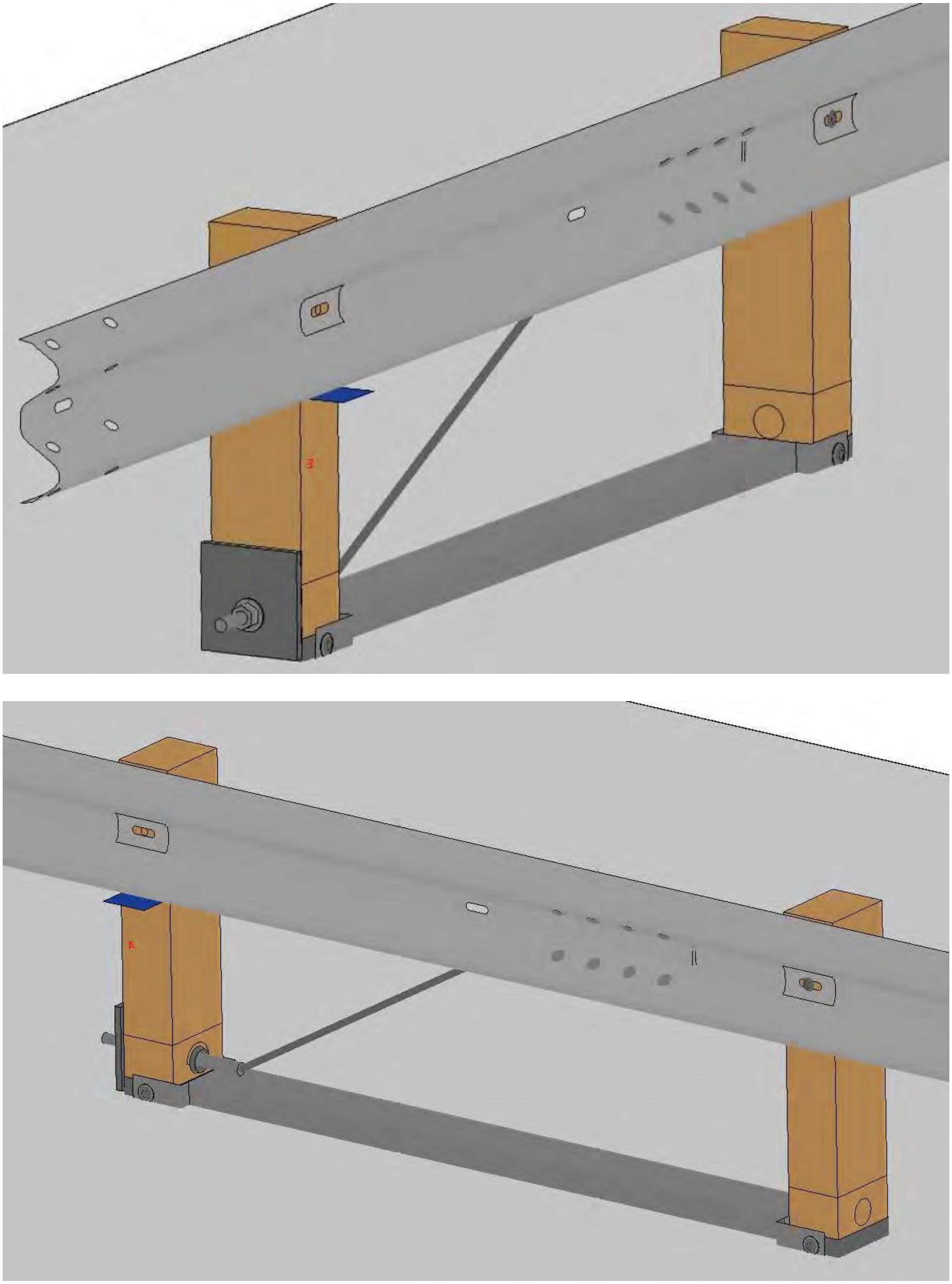


Figure 85. Simple Support (Shown in Blue) at Downstream End Post

The increased wedging or prying action of the rail by the front end of the vehicle could adversely affect vehicular stability and occupant risk by increasing the likelihood of vehicle snagging on the anchor cable.

The comparison of simulated impact scenarios with a bolted connection and a simple support between the rail and the downstream end post confirmed the initial concern about increased vehicle snag on the cable. In the case with a simple support, the cable penetrated more deeply into the wheel well and did not come out while the vehicle continued to proceed downstream. Simulation sequentials are shown in Figure 86. In both simulated scenarios, the initial impact occurred at the midspan between the second and third posts from the downstream end of the rail with the top of the rail at 32 in. (813 mm) from ground level and with BCT wood posts modeled with strengths at the expected upper boundary.

9.1.2 Determination of Downstream End of LON

9.1.2.1 BCT End Posts with Nominal Strength

For the determination of the end of the LON, the numerical model of a Chevrolet Silverado pickup developed by the National Crash Analysis Center (NCAC) [35] was used to simulate full-scale crash tests against the 31-in. (787-mm) tall MGS barrier model in close proximity to the downstream guardrail end anchorage. The simulated full-scale crash tests considered initial impact locations varying from the fourth to the ninth posts upstream from the end of the of the downstream anchorage rail section. For clarification, the MGS end anchorage BCT posts would be positioned at post nos. 1 and 2. Simulations were analyzed with and without failure of the connection between the right-front wheel and suspension, as shown in Figures 87 and 88. Suspension failure was modeled by terminating the simulation, deleting the rigid joint, and re-starting the simulation. Suspension failure time was estimated by examining wheel snag on posts and comparing simulated snag to known suspension failures in crash tests.

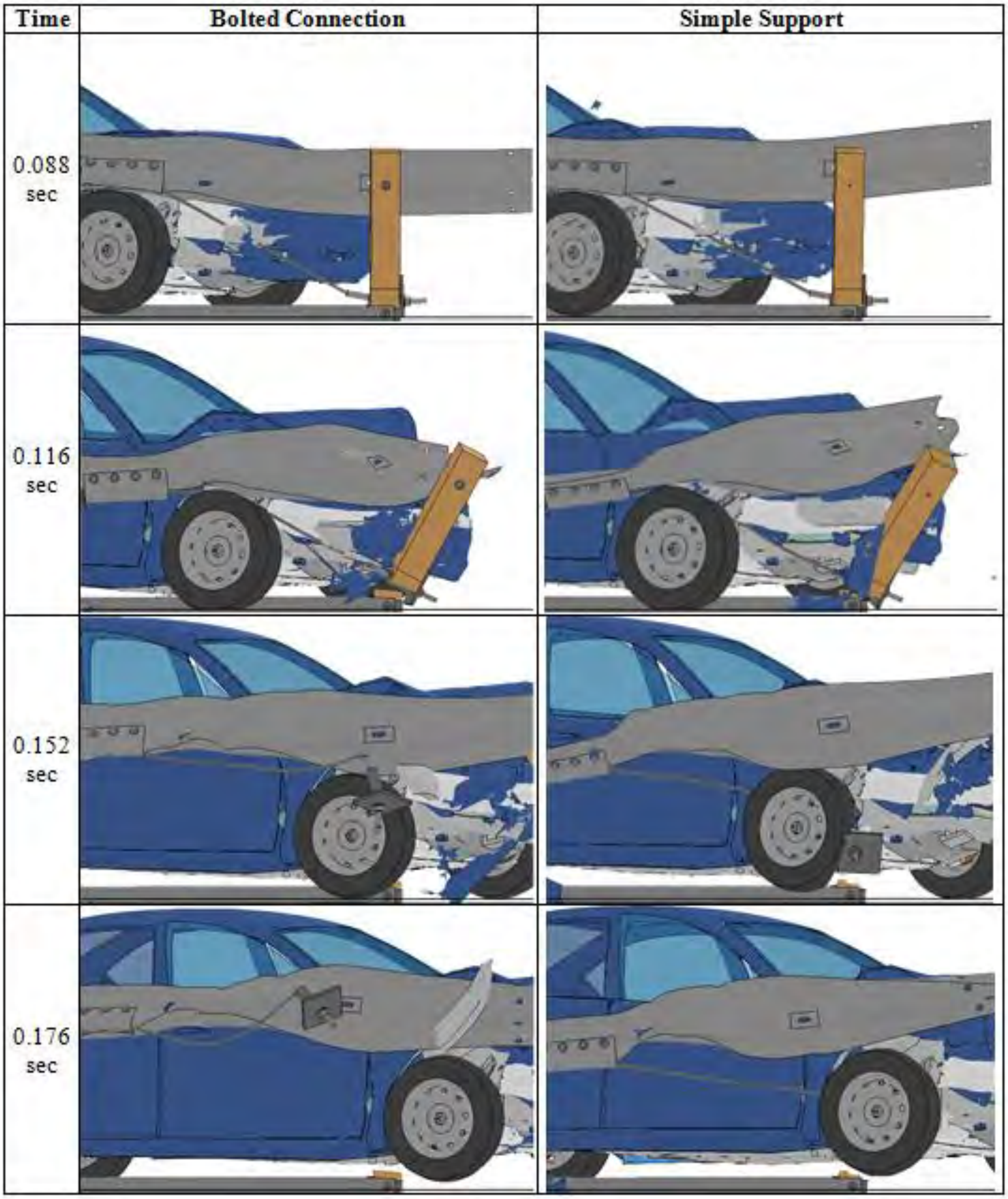


Figure 86. Simulated Impact at the 1100C CIP (Bolted Connection and Simple Support)

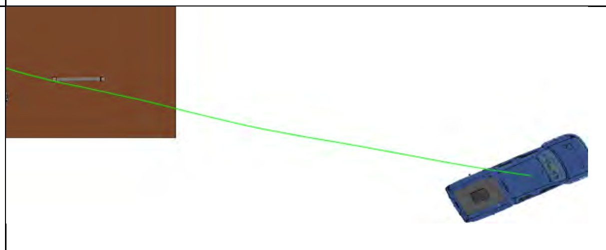
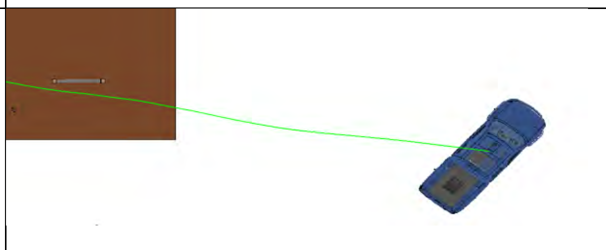
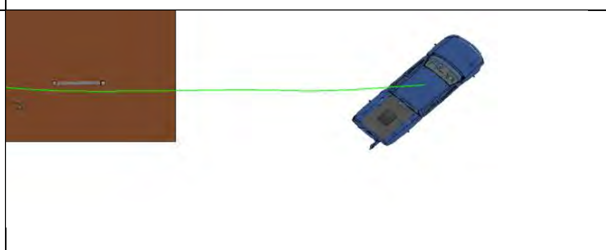
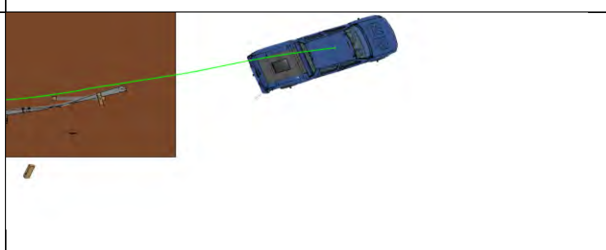
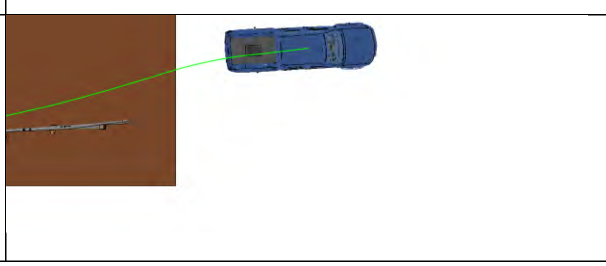
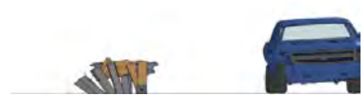
Impact Location	Overhead	Downstream
4th Post		
5th Post		
6th Post		
7th Post		
8th Post		

Figure 87. Trajectories and Lateral Positions of 2270P Vehicle for Various Impact Points – Without Suspension Failure

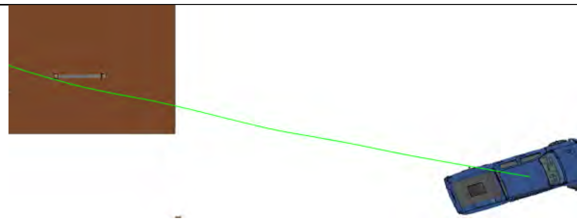
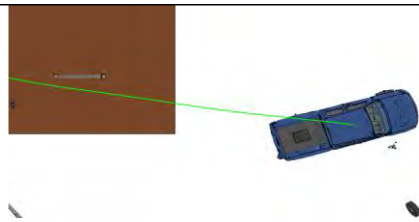
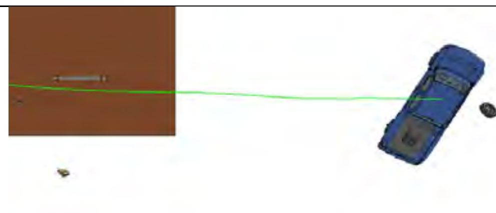
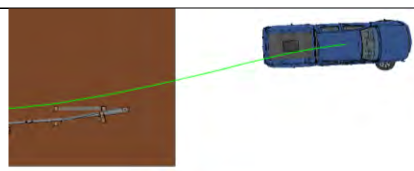
Impact Location	Overhead	Downstream
4th Post		
5th Post		
6th Post		
7th Post		
8th Post		

Figure 88. Trajectories and Lateral Positions of 2270P Vehicle for Various Impact Points – With Suspension Failure

For a 175-ft (53-m) MGS guardrail system with upstream and downstream end anchors, a 2270P truck was predicted to cause system gating at the downstream end of the barrier for all impacts occurring downstream from the sixth post from the downstream end. When impacts occurred downstream of the sixth post from the downstream end, the pickup began to yaw and redirect, but the path of the c.g. continued to encroach behind the system after passing the downstream anchorage. Impacts occurring upstream of the sixth post from the guardrail end resulted in vehicle redirection and successful capture, as shown in Figures 87 and 88. Impacts occurring at the sixth post upstream from the downstream end represented a transition between capturing and redirecting the vehicle, and system gating permitting the vehicle to travel through the system. This transition in impact behavior was defined as the end of the LON. The trajectory of the pickup truck with and without suspension failure as well as system damage sustained during impacts at the end of the LON are shown in Figures 89 through 91.

A direct comparison of the c.g. trajectory of pickup trucks with and without suspension failure during impacts at the end of the LON is shown in Figure 92. Results are applicable for a 175-ft (53-m) long MGS system with a 31-in (787-mm) top guardrail mounting height. Similar results were obtained using the model of the wood BCT anchor posts characterized by the possibility to split along a vertical fracture plane passing through the upper bolted connection between the rail and the post. With this more refined model of the BCT wood posts, the anchor posts fractured at their base when the pickup truck approached the downstream end.

9.1.2.2 BCT End Posts with Lowest Expected Strength

Wood may present some considerable scatter in its mechanical strength properties. Although higher-strength wood posts were determined to be more critical with respect to small car redirections, a reduced resistance of the BCT posts at the downstream end anchorage could affect the safe redirection of the pickup truck. As such, the effect of low wood strength on the

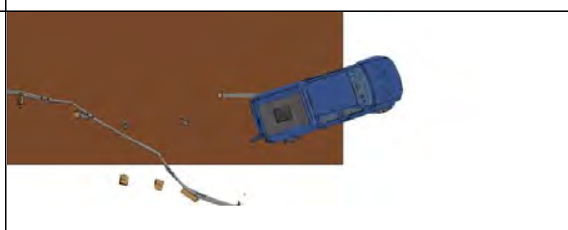
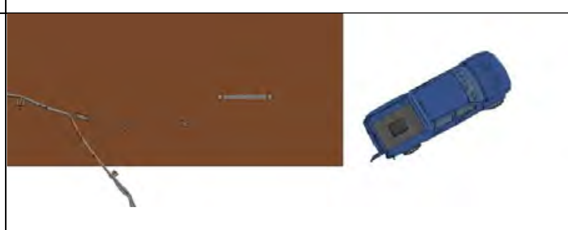
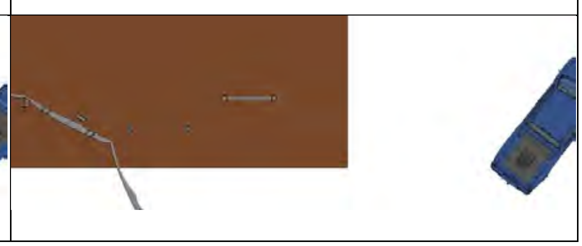
Time	No Suspension Failure	Suspension Failure
0.080 sec		
0.290 sec		
0.450 sec		
0.608 sec		
0.810 sec		
1.090 sec		

Figure 89. Simulated Kinematics of 2270P for Impact at Identified End of LON (Overhead)

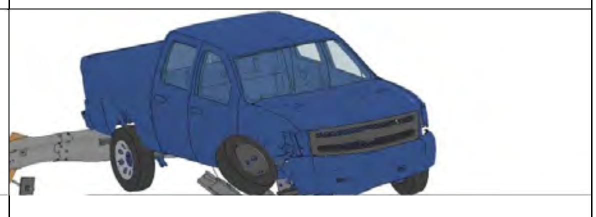
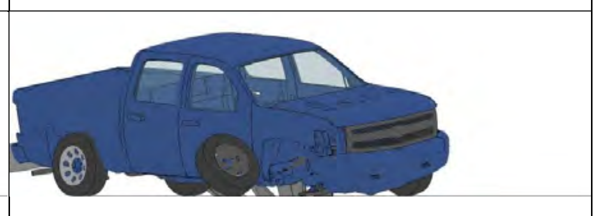
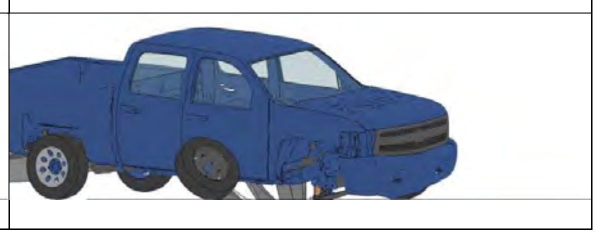
Time	No Suspension Failure	Suspension Failure
0.080 sec		
0.290 sec		
0.450 sec		
0.608 sec		
0.810 sec		
1.090 sec		

Figure 90. Simulated Kinematics of 2270P for Impact at Identified End of LON

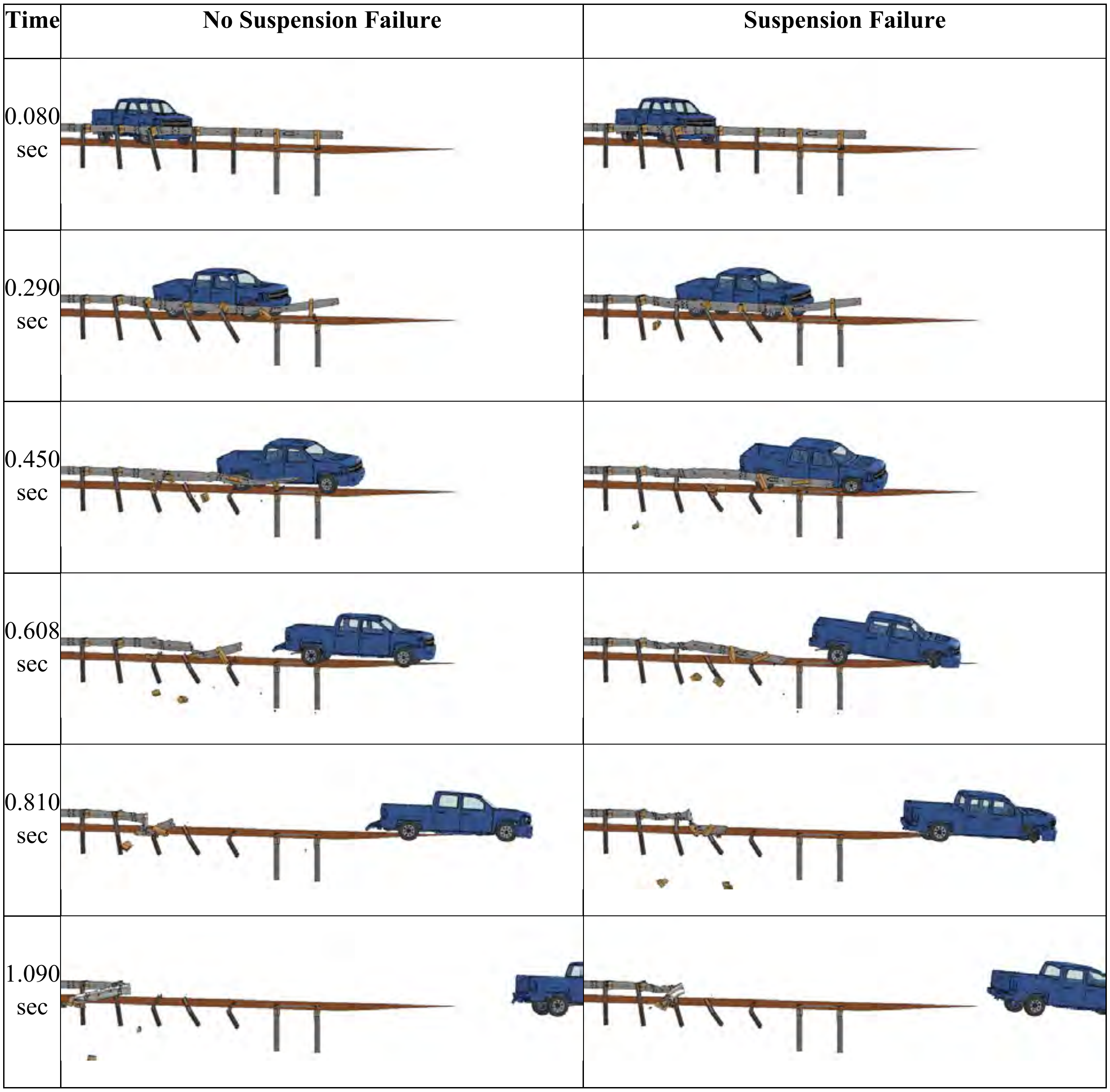


Figure 91. Simulated Kinematics of 2270P for Impact at Identified End of LON

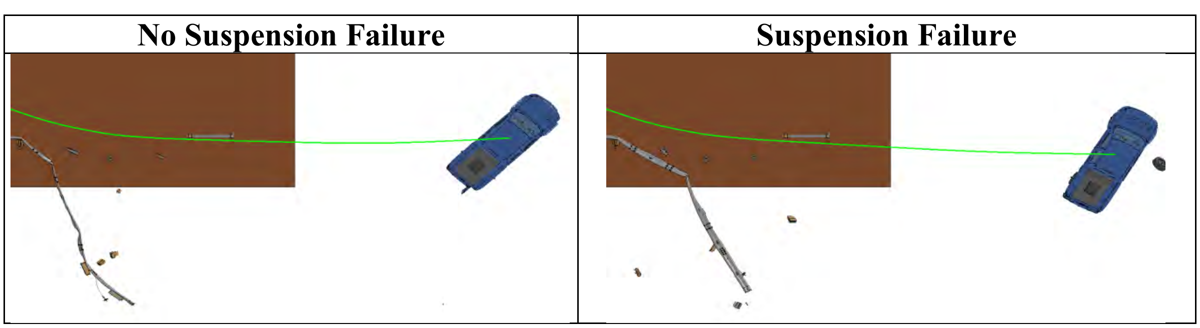


Figure 92. Simulated Trajectory of the 2270P c.g. for Impact at Identified End of LON

location of the downstream LON and vehicle redirection was investigated. Further investigation was performed by simulating vehicular impacts occurring at this nominally identified end of the LON (i.e., sixth post from the downstream end, or fourth steel post from the downstream end) with the end anchor wood BCT posts characterized by a reduced strength. A 50-percent reduction in the maximum strain at failure for the wood material model of the BCT posts was considered to represent the worst reasonable condition to evaluate the redirection capacity of the barrier system.

Crashes were simulated using the 2270P model with and without suspension failure. The maximum vehicle lateral penetration at each post location downstream from the considered initial impact point is shown in Table 8 along with a comparison of the corresponding values obtained considering BCT posts with a standard wood resistance. In general, larger barrier deflections occurred when the impacting wheel disconnected from the pickup truck. Pickup truck redirection under the various conditions for an impact occurring at the sixth post from the downstream end of the of the 31-in (787-mm) tall MGS system is shown in Figure 93. Although the 2270P pickup truck showed an increased pitch angle with a reduced strength of the anchor BCT wood posts, the vehicle was still safely redirected by the barrier.

Table 8. Maximum Simulated Deflection for 2270P Impact at 6th Post (End of LON)

Wood Strength	**Maximum Vehicle Penetration (in.) Corresponding to Impact at Post No. 6**				
	5th	**4th**	**3rd**	**2nd**	**1st**
Nominal	38 (40)	55 (62)	73 (76)	82 (87)	87 (96)
Reduced	43 (45)	63 (69)	74 (83)	85 (99)	93 (113)

* Values in parentheses indicate case w/ suspension failure

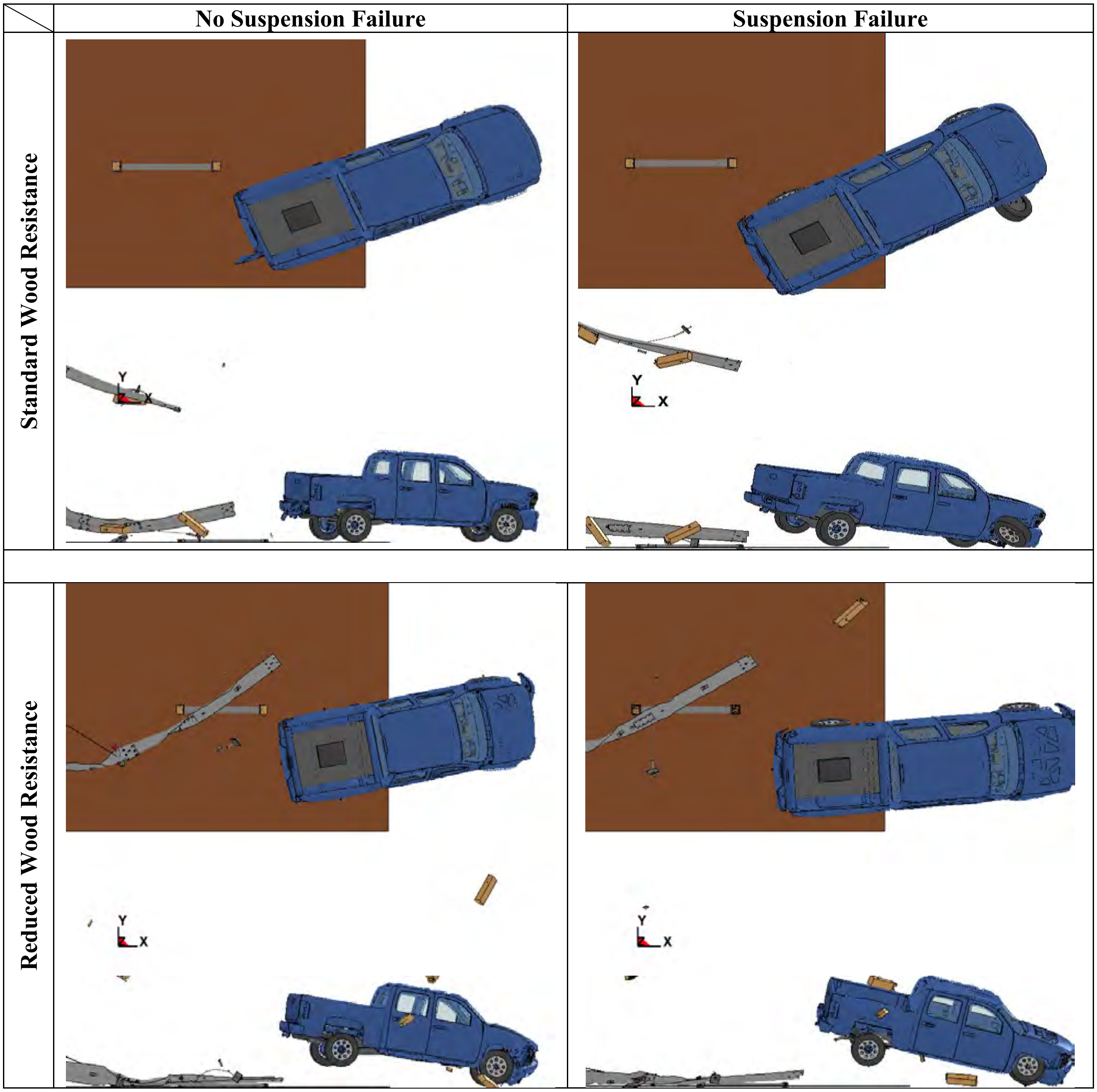


Figure 93. Vehicle Redirection for Impact Occurring at 6th Post from Downstream End

The simulated full-scale crash tests in close proximity to the downstream end anchorage of a 31-in (787-mm tall) MGS barrier indicated that the 2270P pickup is redirected for vehicular impacts occurring at or upstream of the sixth post from the downstream end. Further investigation that simulated scenarios involving a potential failure of the pickup's front suspension and/or a reduced resistance of the anchor BCT posts due to the expected natural scatter in the strength properties of wood confirmed a LON at the sixth post from the downstream end as the best candidate for full-scale crash testing.

It should be noted that for an initial impact at the second post from the downstream end, the bearing plate disengaged away from the fractured BCT end post and engaged the vehicle's tire, as shown in Figure 94. Although this interference between the front tire and the bearing plate did not result in any vehicle instability in the simulation, there is still a potential that the vehicle could snag and become unstable if the edge of the bearing plate cuts through the tire.

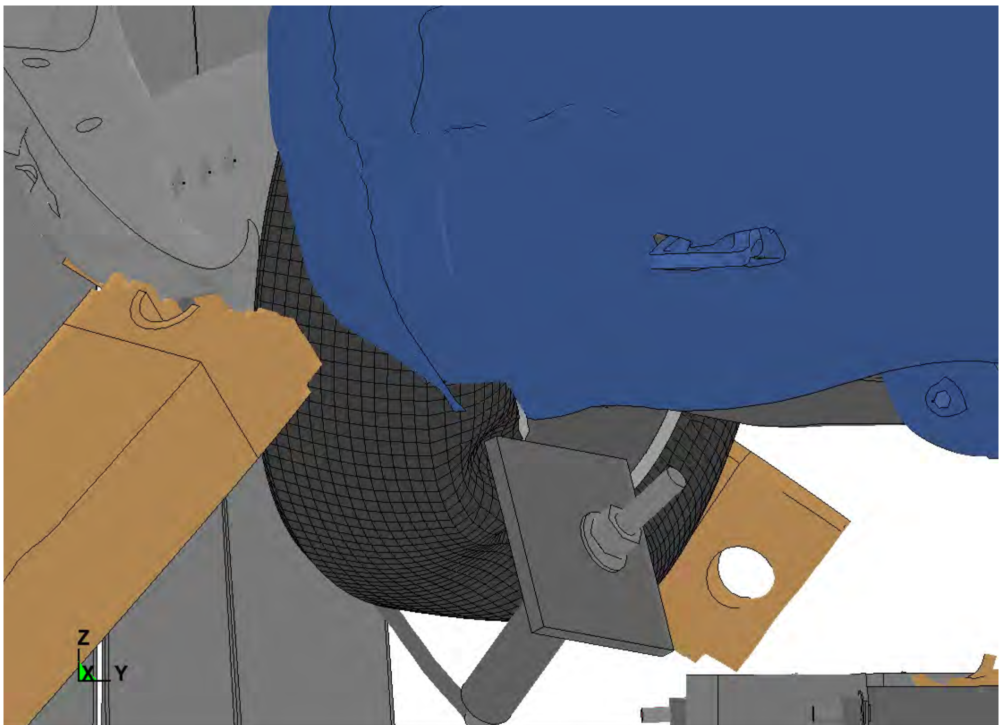


Figure 94. Tire-Bearing Plate Contact for Impact at 2nd Post from Downstream End - 2270P

10 TEST REQUIREMENTS AND EVALUATION CRITERIA

10.1 Test Requirements

Crashworthy W-beam guardrail terminals must satisfy impact safety standards in order to be accepted by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH [2]. According to TL-3 of MASH, W-beam guardrail terminals must be subjected to up to nine full-scale vehicle crash tests, as summarized in Table 9.

Table 9. MASH TL-3 Crash Test Conditions for Guardrail Terminals

Test Article	Test Designation No.	Test Vehicle		Impact Conditions		Evaluation Criteria [1,2]
		Type	Weight lb [kg]	Speed (mph [km/h])	Angle deg	
Guardrail Trailing-End Terminal	3-30	1100C	2,425 [1,100]	62 [100]	0	C,D,F,H,I,N
	3-31	2270P	5,000 [2,268]		0	
	3-32	1100C	2,425 [1,100]		5-15	
	3-33	2270P	5,000 [2,268]		5-15	
	3-34	1100C	2,425 [1,100]		25	
	3-35	2270P	5,000 [2,268]		25	A,D,F,H,I
	3-36	2270P	5,000 [2,268]		25	
	3-37	2270P	5,000 [2,268]		25	C,D,F,H,I,N
	3-38	1500A	3,300 [1,500]		0	

[1] Evaluation criteria explained in Table 10.
[2] For gating terminals.

For this specific effort, the full-scale vehicle crash testing program was focused on the investigation and evaluation of the safety performance of MwRSF's trailing end guardrail terminal. Thus, only MASH test designation no. 3-37 was considered and involved a reverse-direction impact. In particular, two modified versions of test designation no. 3-37 were considered: a modified test no. 3-37 with the intent of assessing the end of the length of need rather than maximizing vehicle snag and instability, and a modified test no. 3-37 with a 1100C passenger car instead of a 2270P pickup truck. These two variations of MASH test designation no. 3-37 were identified as modified 3-37-a (2270P) and 3-37-b (1100C).

10.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the guardrail system to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 10 and defined in greater detail in MASH. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in MASH.

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

10.3 Soil Strength Requirements

In order to limit the variation of soil strength among testing agencies, foundation soil must satisfy the recommended performance characteristics set forth in Chapter 3 and Appendix B of MASH. Testing facilities must first subject the designated soil to a dynamic post test to demonstrate a minimum dynamic load of 7.5 kips (33.4 kN) at deflections between 5 and 20 in. (127 and 508 mm). If satisfactory results are observed, a static test is conducted using an identical test installation. The results from this static test become the baseline requirement for soil strength in future full-scale crash testing programs in which the designated soil is used. An additional post installed near the impact point is statically tested on the day of full-scale crash test in the same manner as used in the baseline static test. The full-scale crash test can be conducted only if the static test results show a soil resistance equal to or greater than 90 percent of the baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Alternatively, a dynamic post test could also be performed on the test day to demonstrate that the soil strength meets the minimum 7.5-kip (33.4 kN) lateral capacity. Otherwise, the crash test must be postponed until the soil demonstrates adequate post-soil strength.

Table 10. MASH Evaluation Criteria for Gating End Terminals Under Test No. 3-37

<table>
<tr><td rowspan="2">Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td>C.</td><td>Acceptable test article performance may be redirection, controlled penetration, or controlled stopping of the vehicle.</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D.</td><td>Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:
<table>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
</table></td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:
<table>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g's</td><td>20.49 g's</td></tr>
</table></td></tr>
<tr><td>Vehicle Trajectory</td><td>N.</td><td>Vehicle trajectory behind the test article is acceptable.</td></tr>
</table>

11 TEST CONDITIONS

11.1 Test Facility

The testing facility is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles (8 km) northwest of the University of Nebraska-Lincoln.

11.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch [36] was used to steer the test vehicles. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

11.3 Test Vehicles

For test no. WIDA-1, a 2007 Dodge Ram QuadCab 1500 was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,016 lb (2,275 kg), 5,002 lb (2,269 kg), and 5,172 lb (2,346 kg), respectively. The test vehicle is shown in Figure 95, and vehicle dimensions are shown in Figure 96.

For test no. WIDA-2, a 2006 Kia Rio was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,491 lb (1,130 kg), 2,449 lb (1,111 kg), and 2,619 lb

(1,188 kg), respectively. The test vehicle is shown in Figure 97, and vehicle dimensions are shown in Figure 98.

The longitudinal component of the c.g. was determined using the measured axle weights. The Suspension Method [37] was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The vertical component of the c.g. for the 1100C vehicle was estimated based on historical c.g. height measurements. The location of the final c.g. for the pickup truck and the passenger car is shown in Figures 96 and 98, respectively. Data used to calculate the location of the c.g. and ballast information are shown in Appendix D.

Square, black- and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 99 and 100. Round, checkered targets were placed on the c.g. on the left-side door, the right-side door, and the roof of the vehicle.

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

Figure 95. Test Vehicle, Test No. WIDA-1

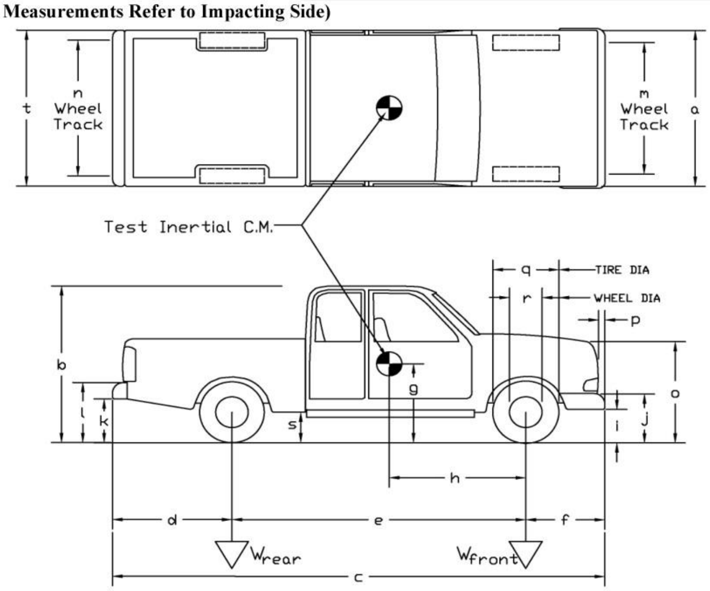
Date: 5/18/2012 **Test Number:** WIDA-1 **Model:** 2270P

Make: Dodge Ram 1500 **Vehicle I.D.#:** 1D7HA18K17J601990

Tire Size: 265/70 R17 **Year:** 2007 **Odometer:** 207534

Tire Inflation Pressure: 35psi

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



Vehicle Geometry -- in. (mm)

a	78 (1981)	b	75 (1905)
c	228 (5791)	d	47 1/2 (1207)
e	140 1/2 (3569)	f	40 (1016)
g	28 1/8 (715)	h	64 5/8 (1640)
i	16 (406)	j	29 (737)
k	20 1/2 (521)	l	28 1/2 (724)
m	67 3/8 (1711)	n	67 5/8 (1718)
o	45 (1143)	p	3 1/4 (83)
q	31 (787)	r	18 1/2 (470)
s	15 1/8 (384)	t	75 1/4 (1911)

Wheel Center Height Front	15 1/8 (384)
Wheel Center Height Rear	14 7/8 (378)
Wheel Well Clearance (F)	36 (914)
Wheel Well Clearance (R)	38 (965)
Frame Height (F)	18 5/8 (473)
Frame Height (R)	24 1/2 (622)
Engine Type	V-6 gas
Engine Size	3.7L

Transmission Type: (Automatic) Manual

FWD (RWD) 4WD

Mass Distribution lb (kg)

Gross Static	LF	1417 (643)	RF	1389 (630)
	LR	1167 (529)	RR	1199 (544)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2753 (1249)	2703 (1226)	2806 (1273)
W-rear	2263 (1026)	2299 (1043)	2366 (1073)
W-total	5016 (2275)	5002 (2269)	5172 (2346)

GVWR Ratings

Front	3700
Rear	3900
Total	6700

Dummy Data

Type: Hybrid II
Mass: 170 lb
Seat Position: Passenger

Note any damage prior to test: Small scrapes and small dents in passenger side door and box side

Figure 96. Vehicle Dimensions, Test No. WIDA-1

Figure 97. Test Vehicle, Test No. WIDA-2

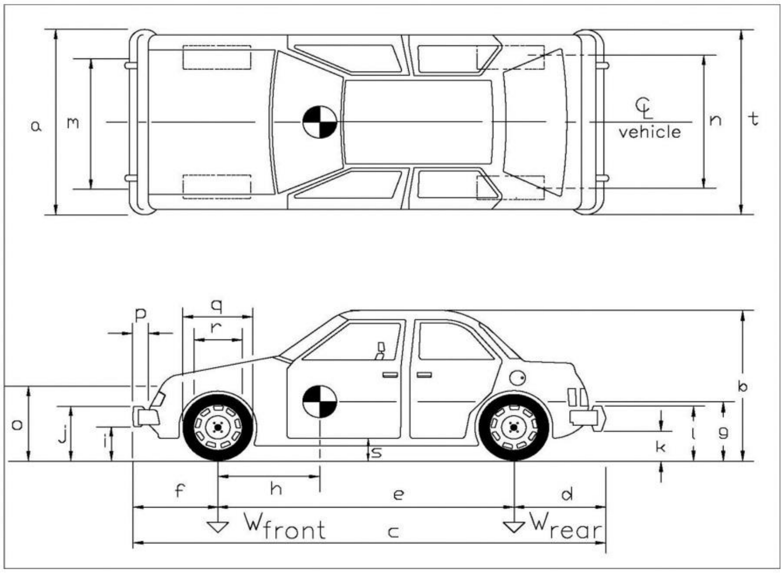
Date: 6/5/2012 **Test Number:** WIDA-2 **Model:** 1100C

Make: Kia Rio **Vehicle I.D.#:** KNADE123X66033140

Tire Size: 185/65 R14 **Year:** 2006 **Odometer:** 159638

Tire Inflation Pressure: 32 psi

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



Vehicle Geometry -- in. (mm)

a	61 3/4	(1568)	b	57 3/4	(1467)
c	167	(4242)	d	36	(914)
e	98 5/8	(2505)	f	32 3/8	(822)
g	20	(508)	h	35 7/8	(911)
i	9 1/2	(241)	j	23	(584)
k	13	(330)	l	25	(635)
m	57 1/4	(1454)	n	57 1/4	(1454)
o	28 1/4	(718)	p	4	(102)
q	23 1/4	(591)	r	15 3/8	(391)
s	12 1/4	(311)	t	61 1/2	(1562)

Wheel Center Height Front	10 7/8	(276)
Wheel Center Height Rear	11 1/8	(283)
Wheel Well Clearance (F)	25 3/4	(654)
Wheel Well Clearance (R)	25 1/2	(648)
Frame Height (F)	6 1/2	(165)
Frame Height (R)	16	(406)
Engine Type	4cyl gas	
Engine Size	1.6L	

Mass Distribution lb (kg)

Gross Static	LF	805 (365)	RF	845 (383)
	LR	476 (216)	RR	493 (224)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	1610 (730)	1558 (707)	1650 (748)
W-rear	881 (400)	891 (404)	969 (440)
W-total	2491 (1130)	2449 (1111)	2619 (1188)

Transmition Type: (Automatic) Manual

(FWD) RWD 4WD

GVWR Ratings

Front	1918
Rear	1874
Total	3638

Dummy Data

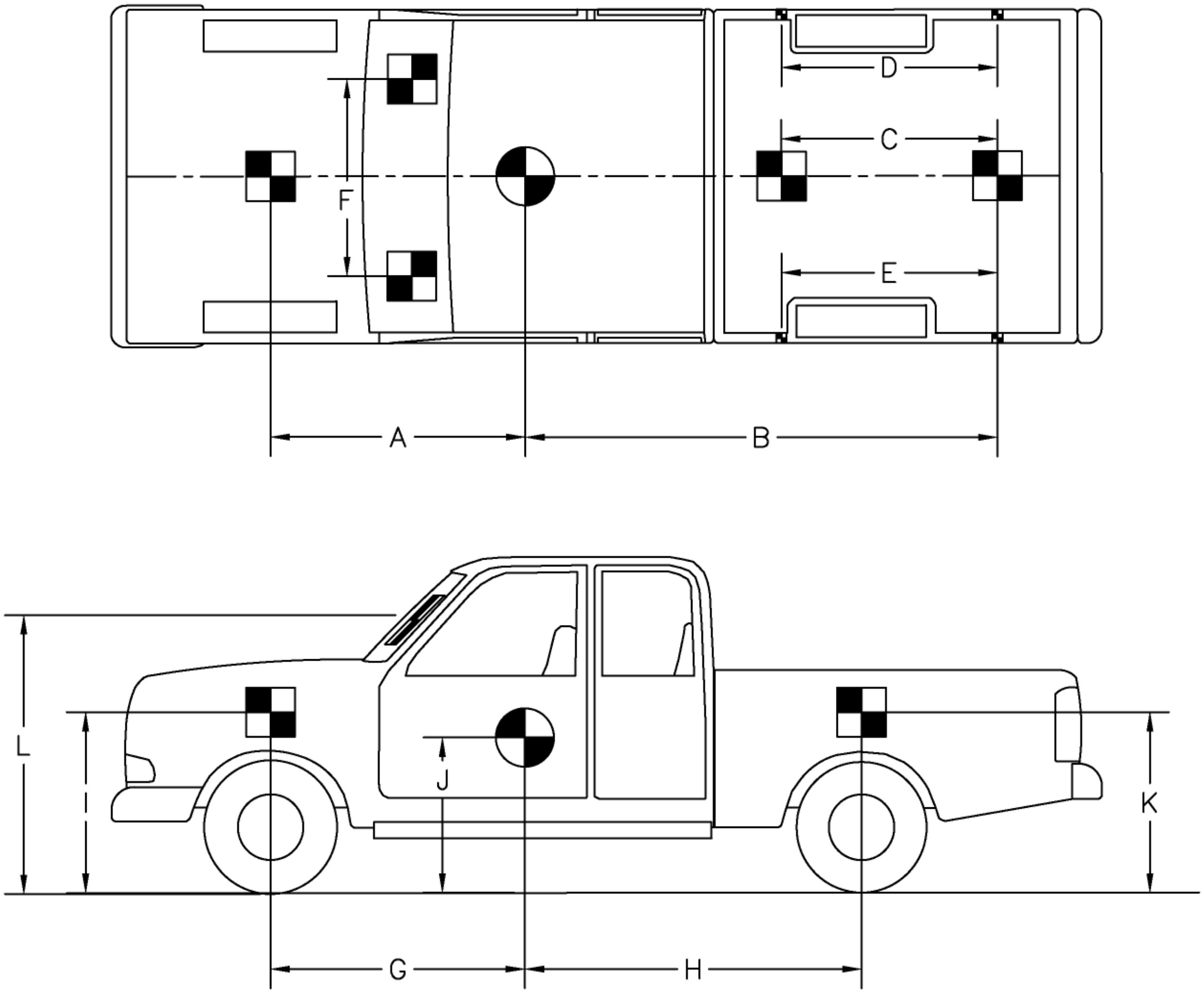
Type: Hybrid 1

Mass: 170 lb

Seat Position: passenger

Note any damage prior to test: None

Figure 98. Vehicle Dimensions, Test No. WIDA-2

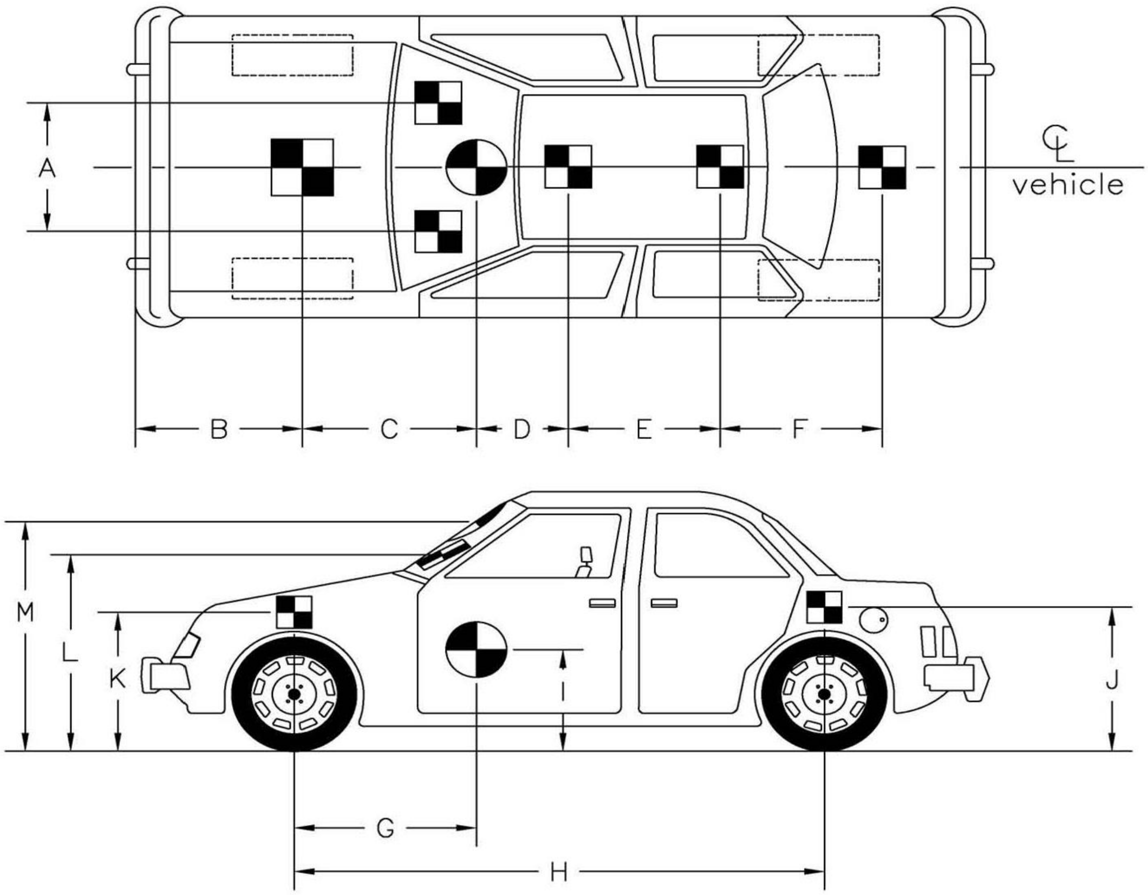


TEST #: WIDA-1

TARGET GEOMETRY-- in. (mm)

A	**81**	**(2057)**	**E**	**64**	**(1626)**	**I**	**40**	**(1016)**
B	**99**	**(2515)**	**F**	**1 1/2**	**(38)**	**J**	**28 1/8**	**(715)**
C	**48**	**(1219)**	**G**	**64 5/8**	**(1640)**	**K**	**42**	**(1067)**
D	**64**	**(1626)**	**H**	**76**	**(1930)**	**L**	**63**	**(1600)**

Figure 99. Target Geometry, Test No. WIDA-1



TEST #: WIDA-2

TARGET GEOMETRY-- in. (mm)

A	31 1/4	(794)	E	42 3/4	(1086)	I	20	(508)
B	21 3/4	(552)	F	35 3/4	(908)	J	30	(762)
C	45	(1143)	G	35 7/8	(911)	K	29 3/4	(756)
D	9 3/4	(248)	H	98 5/8	(2505)	L	45 1/4	(1149)
						M	52 3/4	(1340)

Figure 100. Target Geometry, Test No. WIDA-2

11.4 Simulated Occupant

For test nos. WIDA-1 and WIDA-2, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footware, was placed in the right-front seat of the test vehicle with the seat belt fastened. The dummy, which had a final weight of 170 lb (77 kg), was represented by model no. 572, serial no. 451, and was manufactured by Android Systems of Carson, California. As recommended by MASH, the dummy was not included in calculating the c.g location.

11.5 Data Acquisition Systems

11.5.1 Accelerometers

Three environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. All of the accelerometers were mounted near the c.g. of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [29].

The first accelerometer system was a two-arm piezoresistive accelerometer system manufactured by Endevco of San Juan Capistrano, California. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. The accelerometers were configured and controlled using a system developed and manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. More specifically, data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M. The SIM was configured with 16 MB SRAM and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were crashworthy. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The second accelerometer system 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.

The third 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.

11.5.2 Rate Transducers

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

A second angle rate sensor system, the SLICE MICRO Triax ARS, with a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) was used to measure the rates of rotation of the test vehicles. The angular rate 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 raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

11.5.3 Tensile Load Cell

A tensile load cell was installed in line with the cable anchor at the upstream end of the barrier system for test no. WIDA-1. The positioning and setup of the load cells are shown in Figure 101.

The load cell was manufactured by Transducer Techniques and conformed to model no. TLL-50K with a load range up to 50,000 lb (222.4 kN). During testing, output voltage signals were sent from the load cells to a National Instruments data acquisition board, acquired with the "LabView" software, and stored permanently on a personal computer. The data collection rate for the load cells was 10,000 samples per second (10,000 Hz).

11.5.4 String Potentiometer

A linear displacement transducer, or string potentiometer, was installed on the upstream side of the most upstream BCT post (post no. 1) to determine the displacement of the post for test no. WIDA-1. The positioning and setup of the string potentiometer are shown in Figure 102. The string potentiometer used was a UniMeasure PA-50 with a range of 50 in. (1,270 mm). A Measurements Group Vishay Model 2310 signal conditioning amplifier was used to condition and amplify the low-level signals to high-level outpus for multichannel simultaneous dynamic recording in the "LabVIEW" software. The sample rate of the string potentiometers was 1,000 Hz.

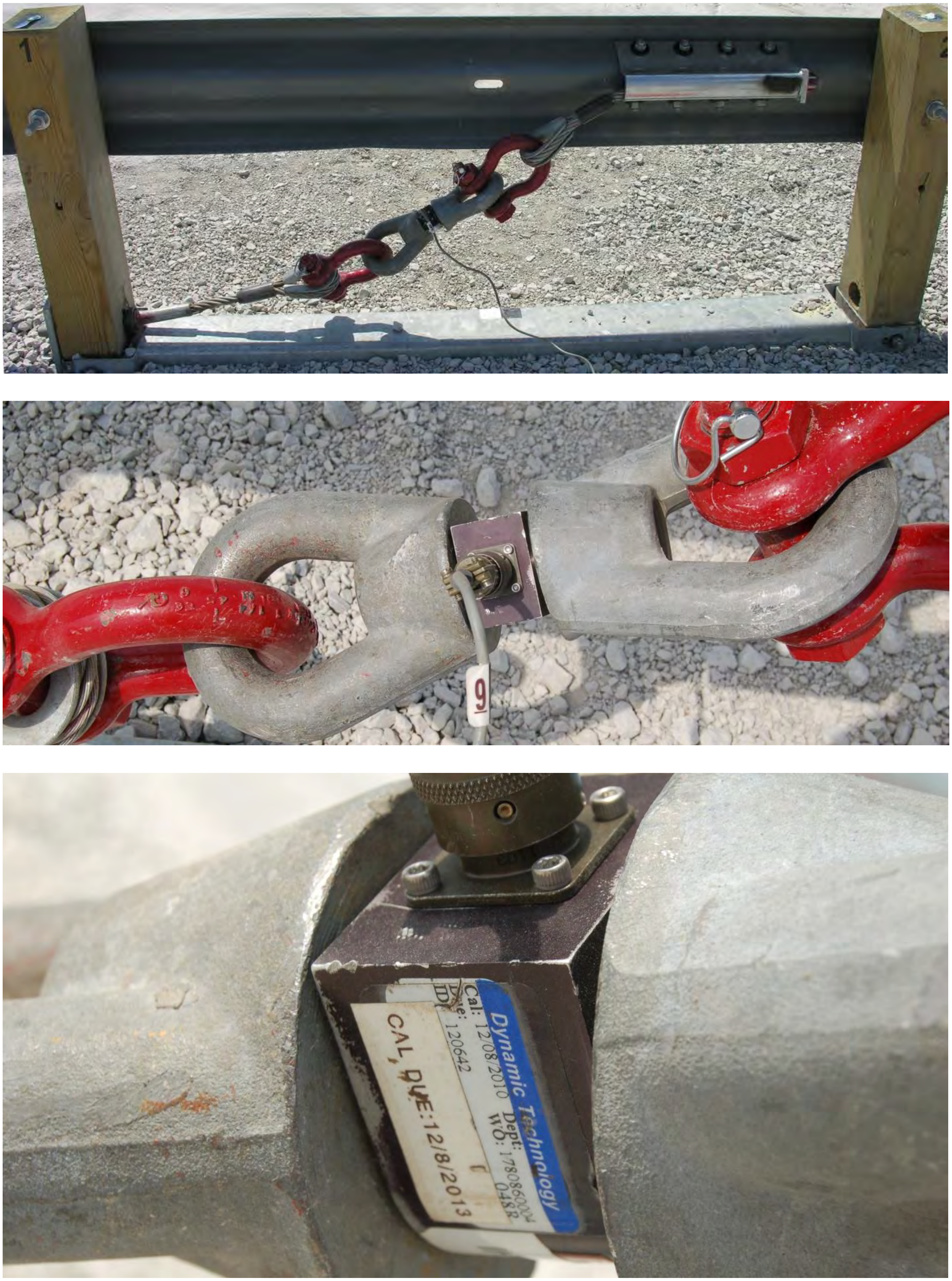


Figure 101. Load Cell Setup, Test No. WIDA-1

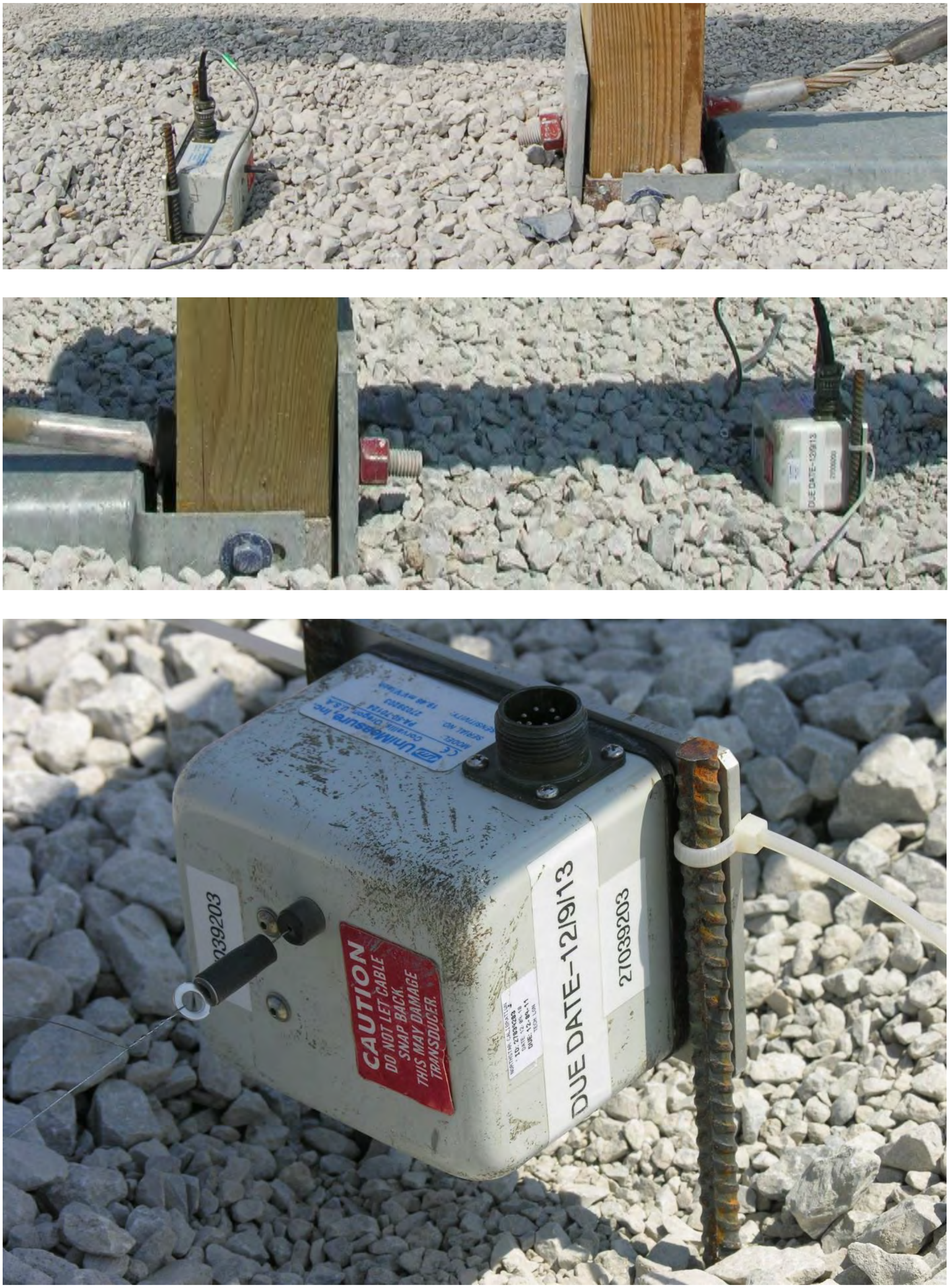


Figure 102. String Pot Setup, Test No. WIDA-1

11.5.5 Pressure Tape Switches

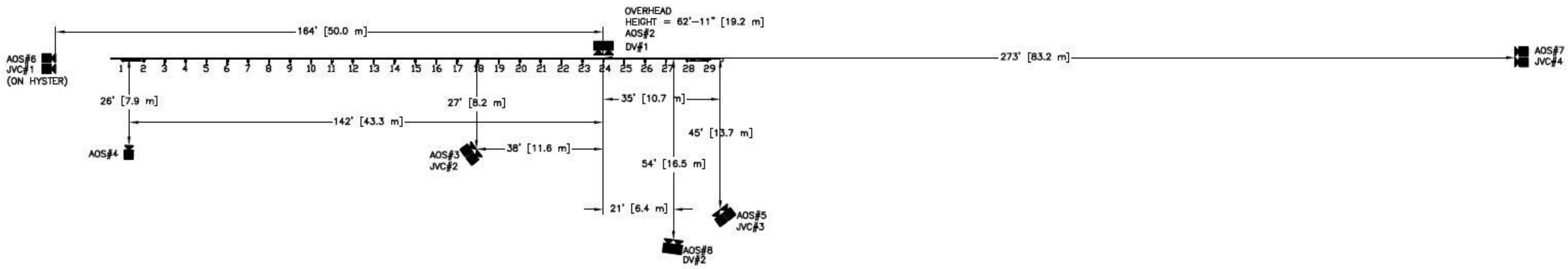
For both test nos. WIDA-1 and WIDA-2, three pressure-activated tape switches, spaced at approximately 6.56-ft (2-m) intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the right-front tire of the test vehicle passed over it. Test vehicle speeds were determined from electronic timing mark data recorded using TestPoint and LabVIEW computer software programs. Strobe lights and high-speed video analysis are used only as a backup in the event that vehicle speed cannot be determined from the electronic data.

11.5.6 Digital Photography

Three AOS VITcam high-speed digital video cameras, three AOS X-PRI high-speed digital video cameras, one AOS S-VIT 1531 high-speed digital video cameras, four JVC digital video cameras, and two Canon digital video cameras were utilized to film test no. WIDA-1. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 103.

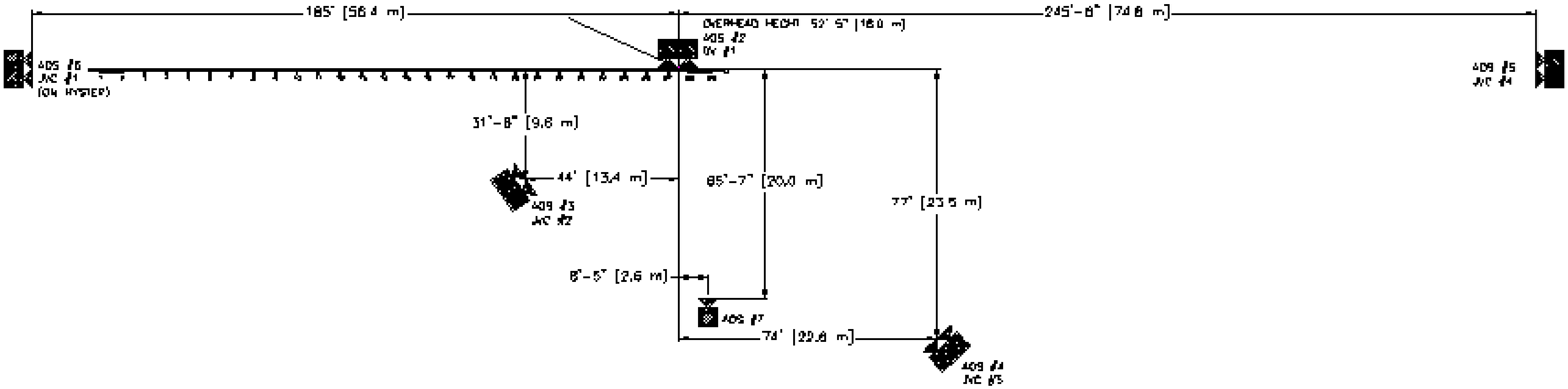
Three AOS VITcam high-speed digital video cameras, three AOS X-PRI high-speed digital video cameras, four JVC digital video cameras, and one Canon digital video camera were utilized to film test no. WIDA-2. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 104.

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



	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	2	AOS Vitcam CTM	500	Cosmicar 12.5 mm fixed	-
	3	AOS Vitcam CTM	500	Sigma 24-135 mm	24
	4	AOS Vitcam CTM	500	Fujinon 50 mm fixed	-
	5	AOS X-PRI Gigabit	500	Sigma 24-70 mm	24
	6	AOS X-PRI Gigabit	500	Sigma 50 mm fixed	-
	7	AOS X-PRI Gigabit	500	Canon 17-102 mm	102
	8	AOS S-VIT 1531	500	Osowa 28-80 mm	45
Digital Video	1	JVC – GZ-MC500 (Everio)	29.97		
	2	JVC – GZ-MG27u (Everio)	29.97		
	3	JVC – GZ-MG27u (Everio)	29.97		
	4	JVC – GZ-MG27u (Everio)	29.97		
	1	Canon ZR90	29.97		
	2	Canon ZR10	29.97		

Figure 103. Camera Locations, Speeds, and Lens Settings, Test No. WIDA-1



	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	2	AOS Vitcam CTM	500	Cosmicar 12.5 mm fixed	-
	3	AOS Vitcam CTM	500	Fujinon 50 mm fixed	-
	4	AOS Vitcam CTM	500	Sigma 24-70 mm	35
	5	AOS X-PRI Gigabit	500	Sigma 24-135 mm	100
	6	AOS X-PRI Gigabit	500	Sigma 50 mm fixed	-
	7	AOS X-PRI Gigabit	500	Canon 17-102 mm	75
Digital Video	1	JVC – GZ-MC500 (Everio)	29.97		
	2	JVC – GZ-MG27u (Everio)	29.97		
	3	JVC – GZ-MG27u (Everio)	29.97		
	4	JVC – GZ-MG27u (Everio)	29.97		
	1	Canon ZR90	29.97		

Figure 104. Camera Locations, Speeds, and Lens Settings, Test No. WIDA-2

12 MGS BARRIER WITH STANDARD MGS END ANCHORAGE

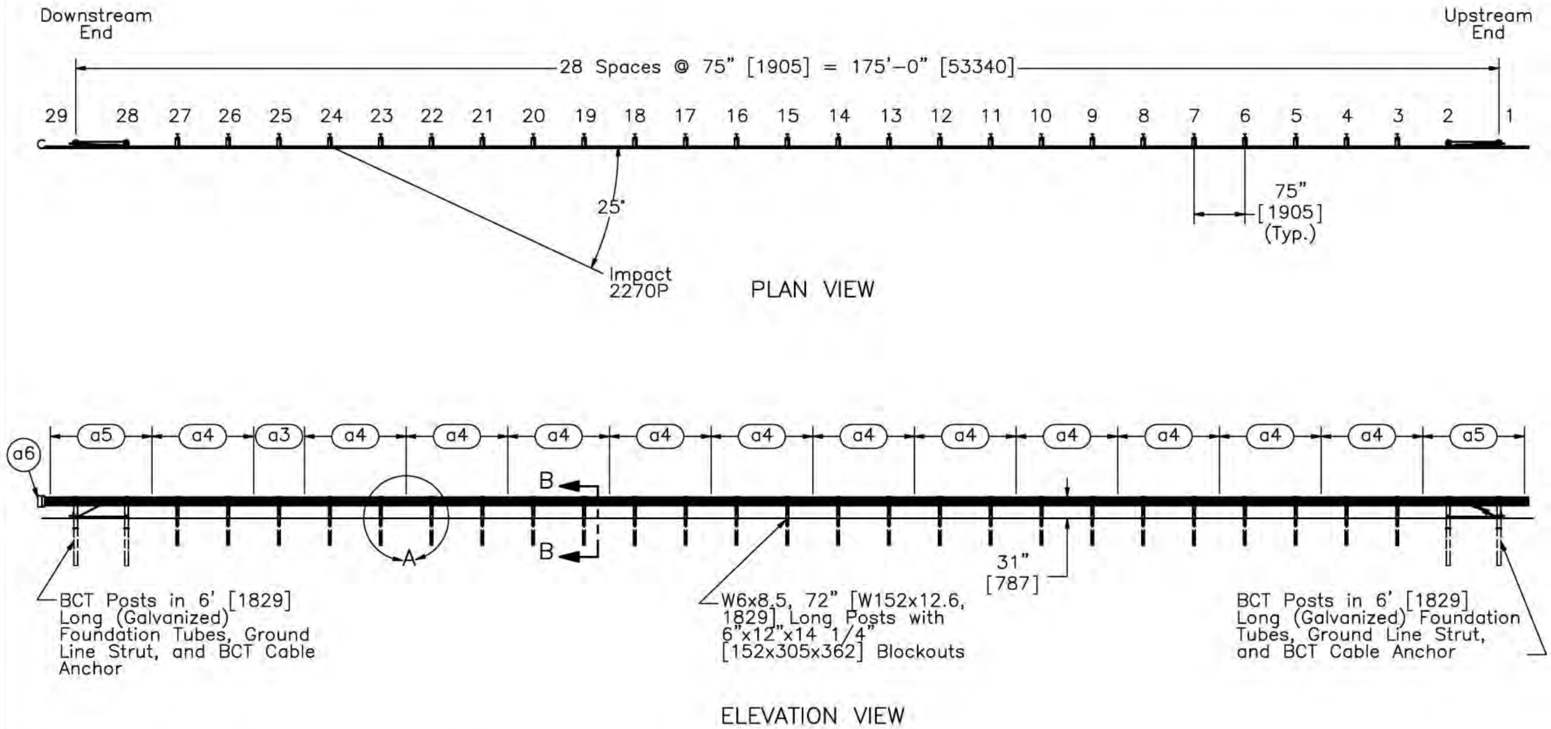
The test installation consisted of 181 ft – 3 in. (55.2 m) of MGS along with a standard MGS tension end anchorage system on each end, as shown in Figures 105 through 119. Photographs of the test installation are shown in Figures 120 through 122. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix B.

The system was constructed with twenty-nine posts. Post nos. 3 through 27 were galvanized, ASTM A36, W6x8.5 (W152x12.6) sections measuring 72 in. (1,829 mm) long. The post material was acceptable with either ASTM A36 or A992 steel. Post nos. 1, 2, 28, and 29 were 5½-in. wide x 7½-in. deep x 46-in. long (140-mm x 191-mm x 1,168-mm) breakaway cable terminal (BCT) timber posts. All posts were spaced 75 in. (1,905 mm) on center and placed in a compacted, coarse, crushed limestone material, as recommended by MASH [2]. Posts nos. 3 through 27 had a soil embedment depth of 40 in. (1,016 mm).

Both the upstream and downstream MGS end anchorage systems were adaptations of the original modified BCT end terminal system but installed tangent. Each anchorage consisted of two BCT timber posts set into a 6-in. wide x 8-in. deep x 72-in. long (152-mm x 203-mm x 1,829-mm), ASTM A500 Grade B, steel foundation tube. The two 6-ft (1,829-mm) steel foundation tubes were connected at the ground line with a strut and yoke assembly. The BCT end anchorage posts were placed in the foundation tube such that their top was 32 in. (813 mm) from the groundline. One end of a ¾-in (19-mm) diameter 6x19 wire rope was attached on the back side of the W-beam, and the other end passed through the hole at the bottom of the end post and was secured through a 8-in. x 8-in. x ⅝-in (203-mm x 203-mm x 16-mm) steel bearing plate. A modified BCT anchor cable was used at the upstream anchor in lieu of a standard cable anchor in test no. WIDA-1 in order to allow for load cell placement, as shown in Figures 110 and 111.

Wood blocks measuring 6 in. x 8 in. x 14 ¼ in. (152 mm x 203 mm x 362 mm) were nailed to 6 in. x 4 in. x 14 ¼ in. (152 mm x 102 mm x 362 mm) blocks to form larger 6 in. x 12 in. x 14 ¼ in. (152 mm x 305 mm x 362 mm) offset blocks to space the rail away from the front face of each steel post. Standard 12-gauge (2.66-mm thick) W-beam rails with additional post bolt slots at half-post spacing intervals were mounted between post nos. 1 through 29. The W-beam top rail height was 31 in. (787 mm) above the ground with a 24⅞-in. (632-mm) center mounting height, such that the center of the rail was mounted 7⅛ in. (181 mm) from the top of the BCT timber posts. Rail splices were located at the midspan locations between posts. The lap splice connections between the rail sections were configured to reduce vehicle snag potential at the splice during the crash test.

The installation for test no. WIDA-2 was identical to the system used for test no. WIDA-1, except that the rail was raised 1 in. (25 mm) to provide a top guardrail height of 32 in. (813 mm), as shown in Figures 123 and 124. Photographs of the test installation are shown in Figures 125 through 127. Material specifications, mill certifications, and certificates of conformity are shown in Appendix B. A complete set of drawings for the MGS system with a 32 in. (813 mm) mounting height is provided in Appendix E



Notes: (1) Impact location for the 2270P is at the centerline of post no. 24.

(2) The BCT anchor posts are placed in ⌀3' [914] holes.

(3) Critical region located between post nos. 21 and 29.

(4) A string potentiometer and tension load cell shall be placed within the upstream anchorage system.

(5) A high-speed digital video camera is to be placed perpendicular to downstream anchor.

(6) Avoid activating vehicle brakes in the first 100' [30480] downstream of post no. 29.

(7) Allow for a minimum lateral clearance of 30' [9144] behind the system in the first 75' [22860] downstream of post no. 29.

(8) Paint the downstream bearing plate and BCT cable two different colors.

MwRSF Midwest Roadside Safety Facility	Wisconsin DOT Project MGS with Standard Downstream Anchorage System	SHEET: 1 of 15
		DATE: 5/25/2012
	System Layout	DRAWN BY: JGP
	DWG. NAME. DS-Anchorage-31in_R5 / SCALE: 1:225 UNITS: in.[mm]	REV. BY: KAL/RKF

Figure 105. Test Installation Layout, Test No. WIDA-1

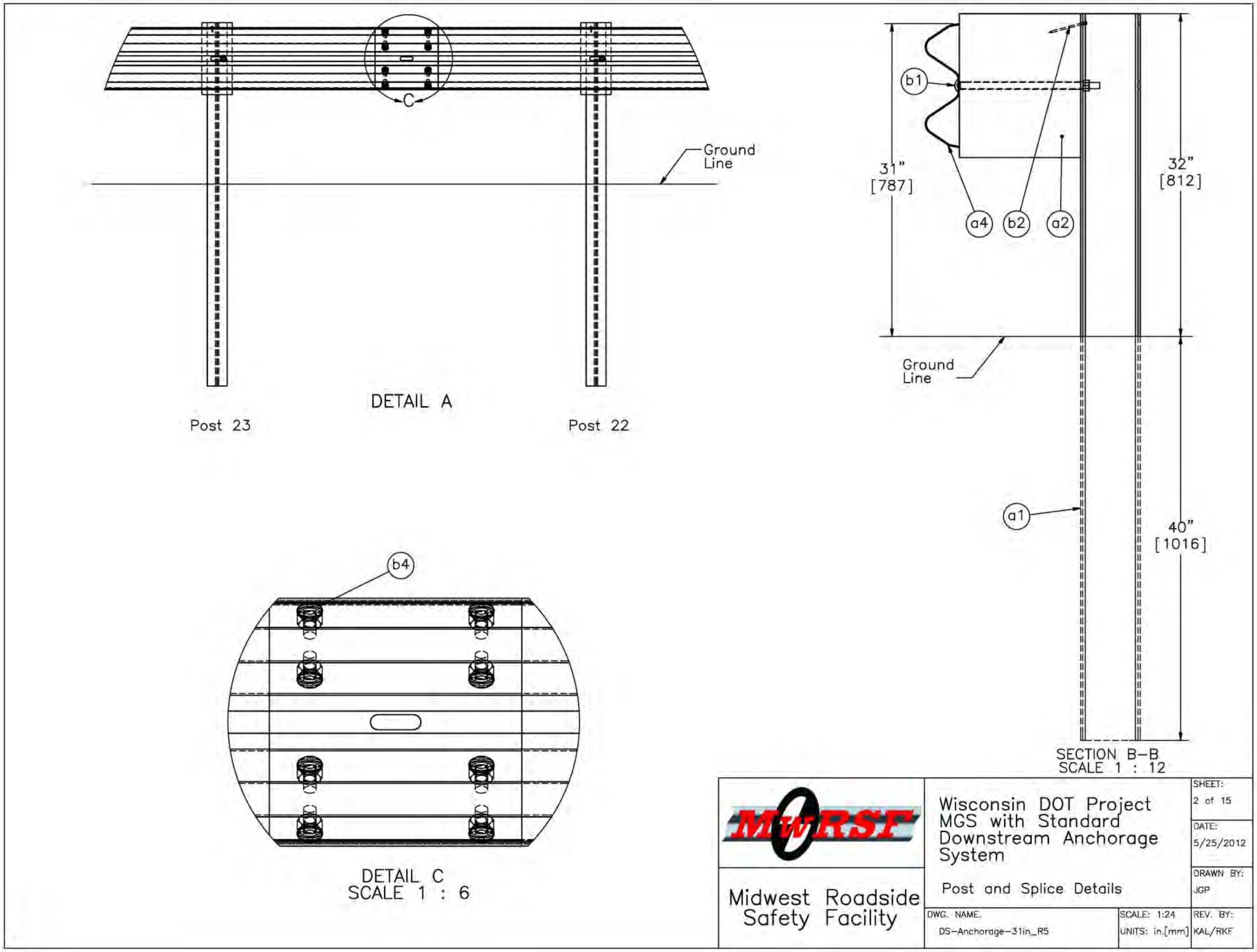


Figure 106. 31-in. (787-mm) Tall Blocked MGS Details, Test No. WIDA-1

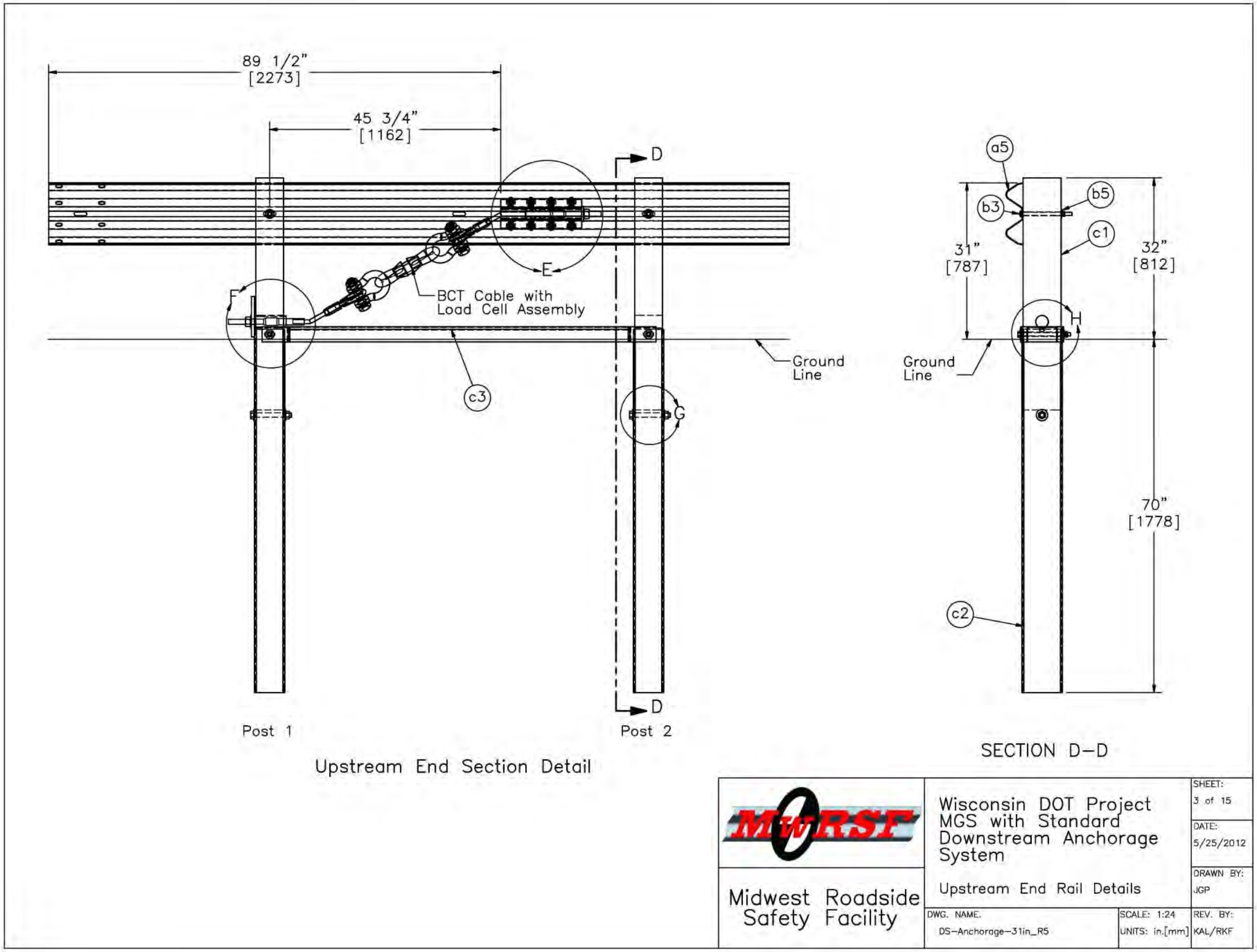


Figure 107. Upstream End Anchor Details, Test No. WIDA-1

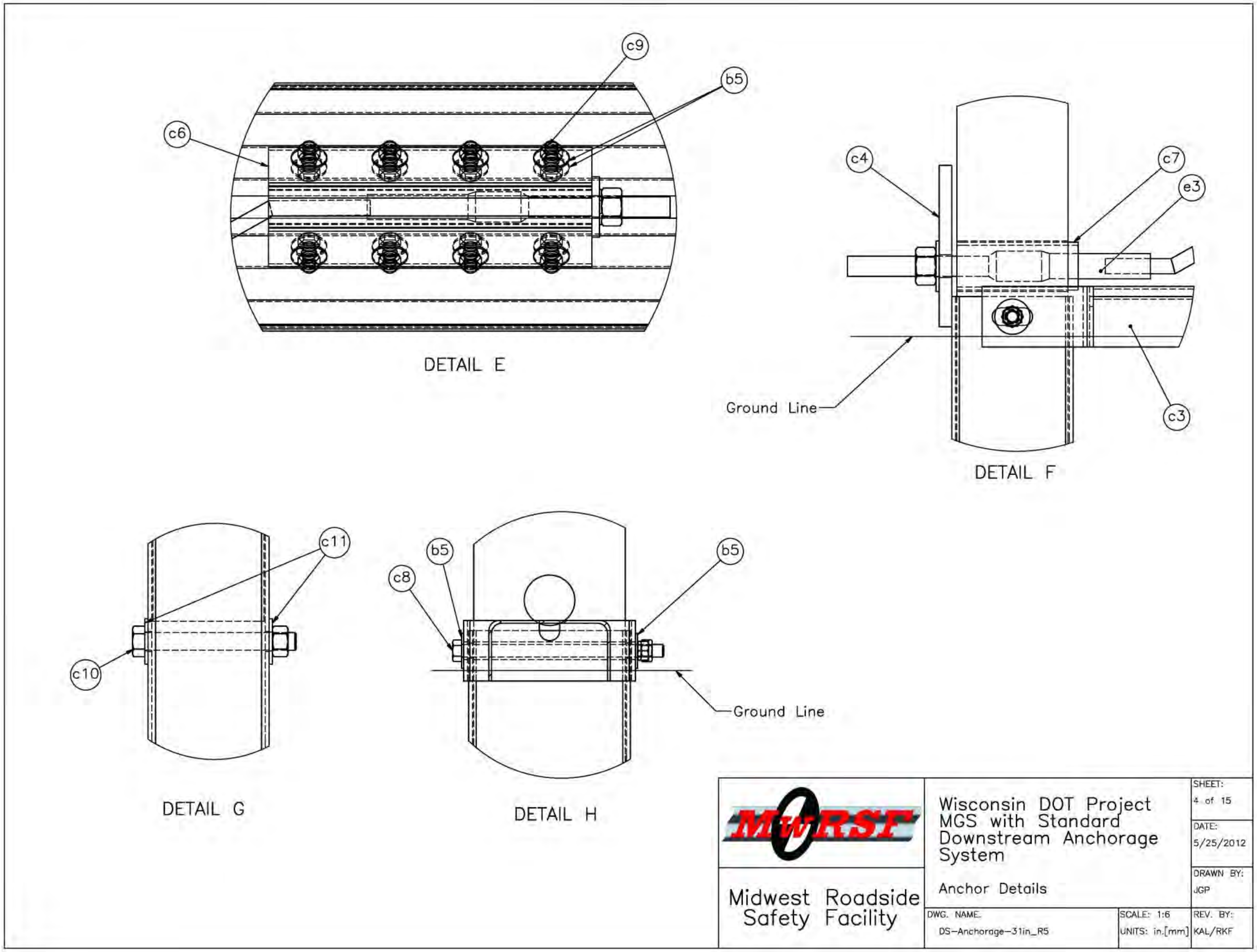


Figure 108. Anchor Details, Test No. WIDA-1

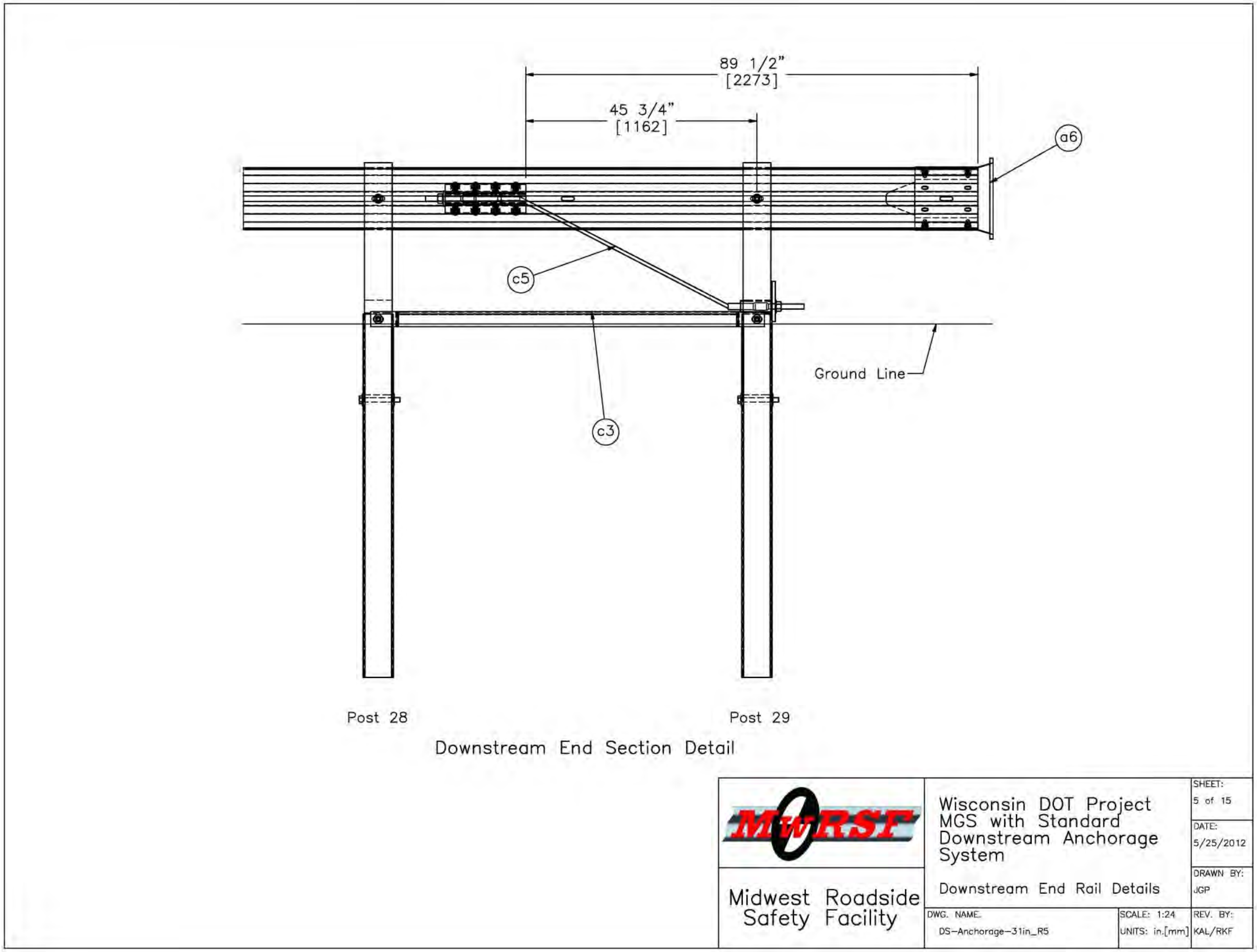


Figure 109. Downstream End Anchor Details, Test No. WIDA-1

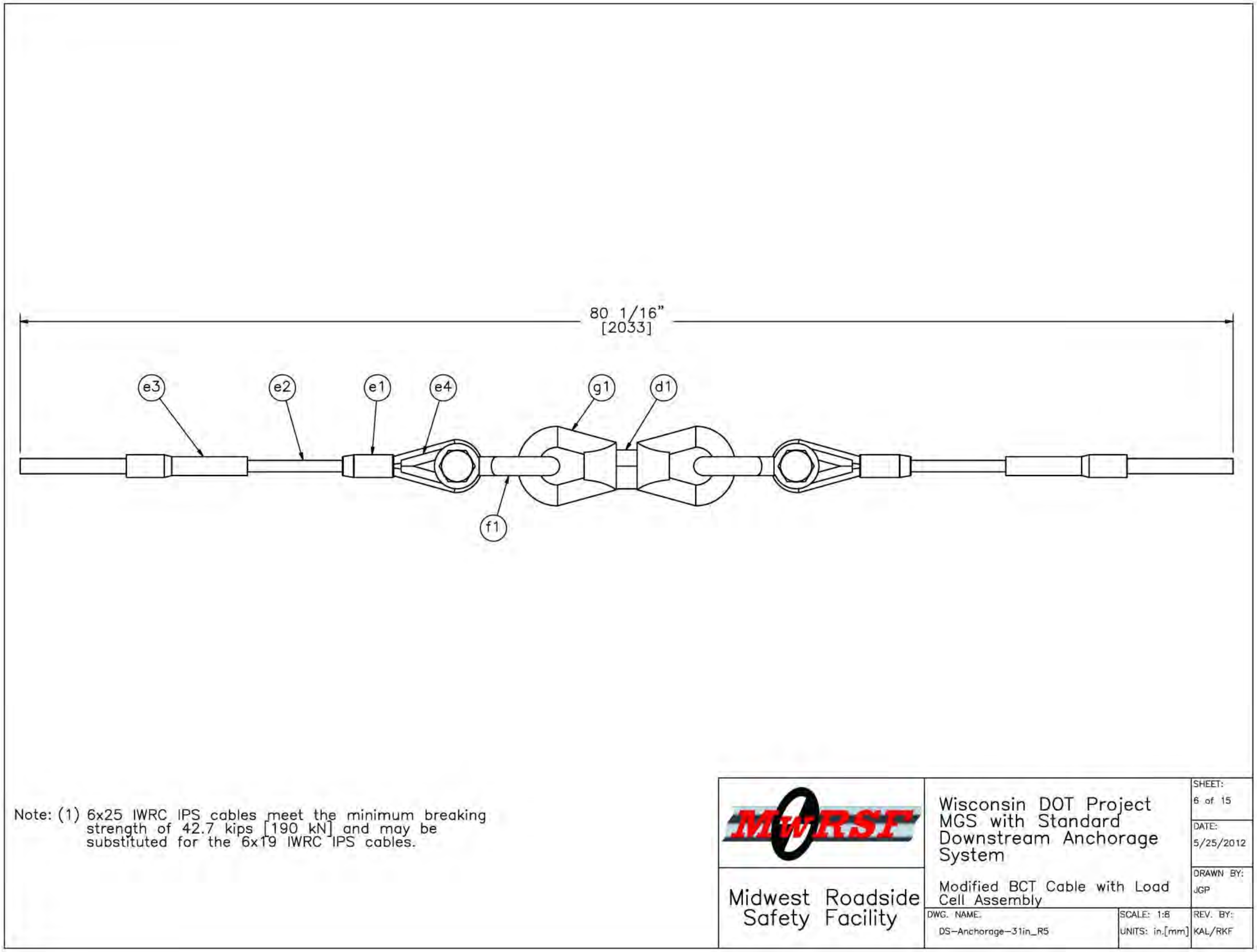


Figure 110. Modified BCT Cable with Load Cell Assembly, Test No. WIDA-1

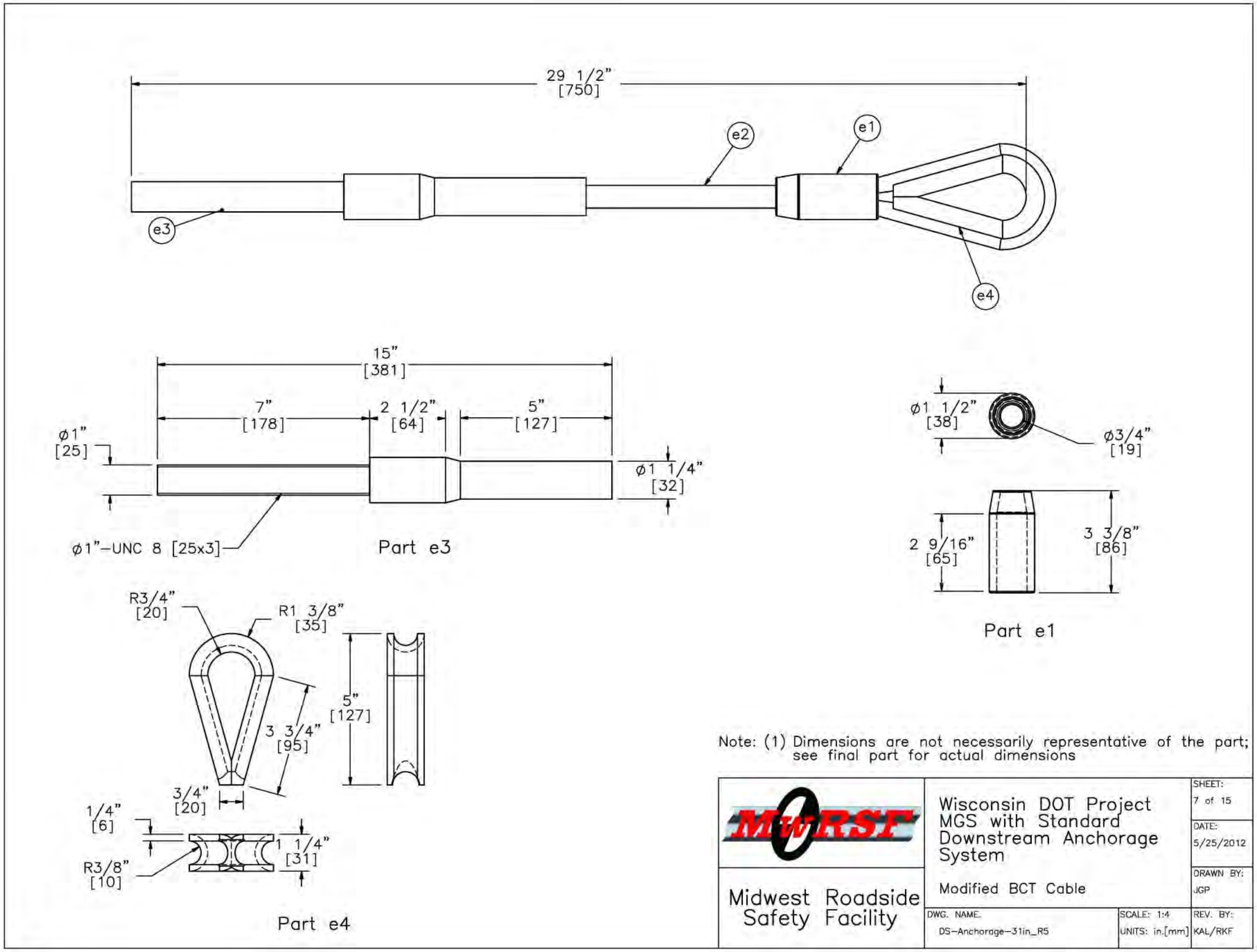


Figure 111. Modified BCT Cable, Test No. WIDA-1

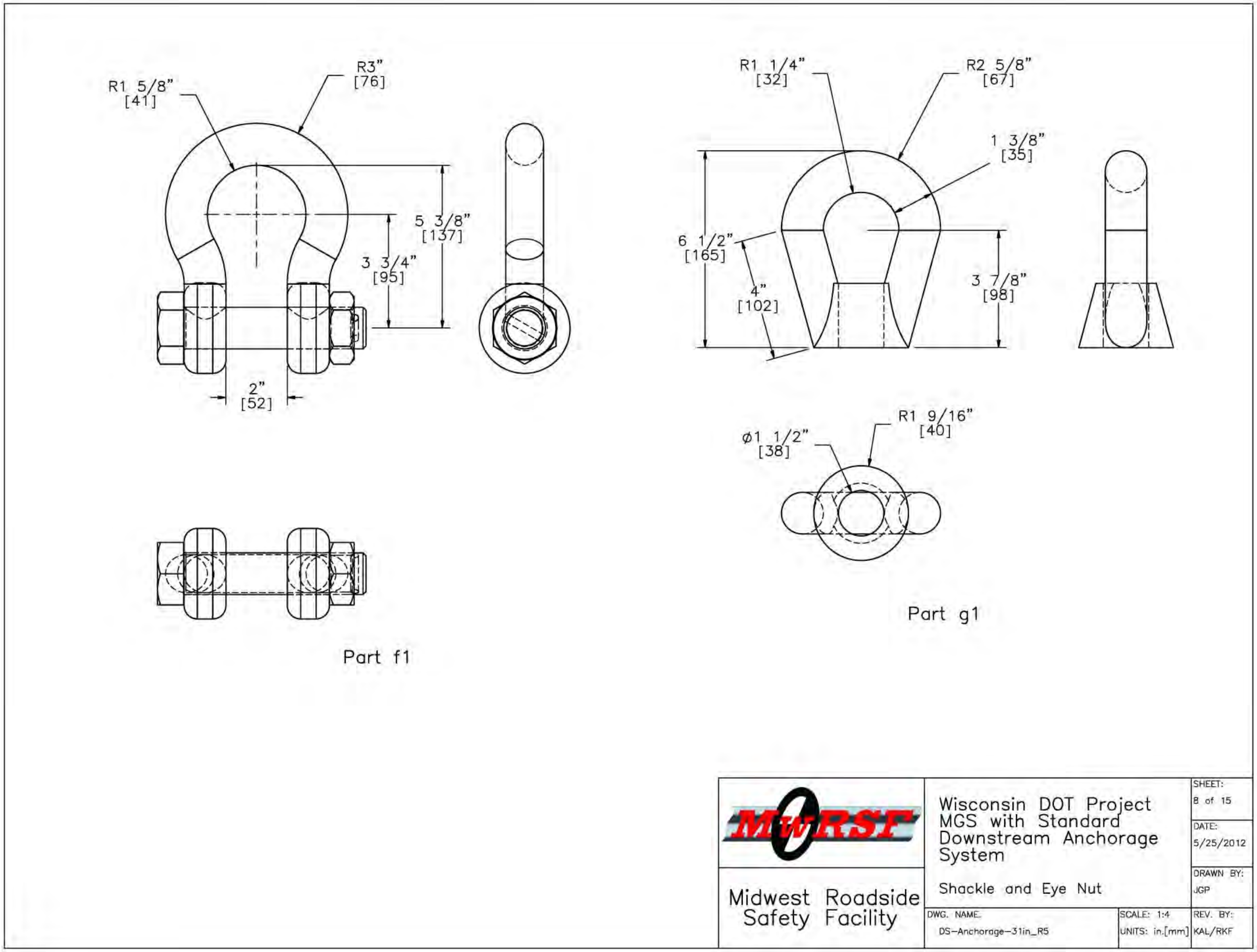


Figure 112. Shackle and Eye Nut for Modified BCT Cable, Test No. WIDA-1

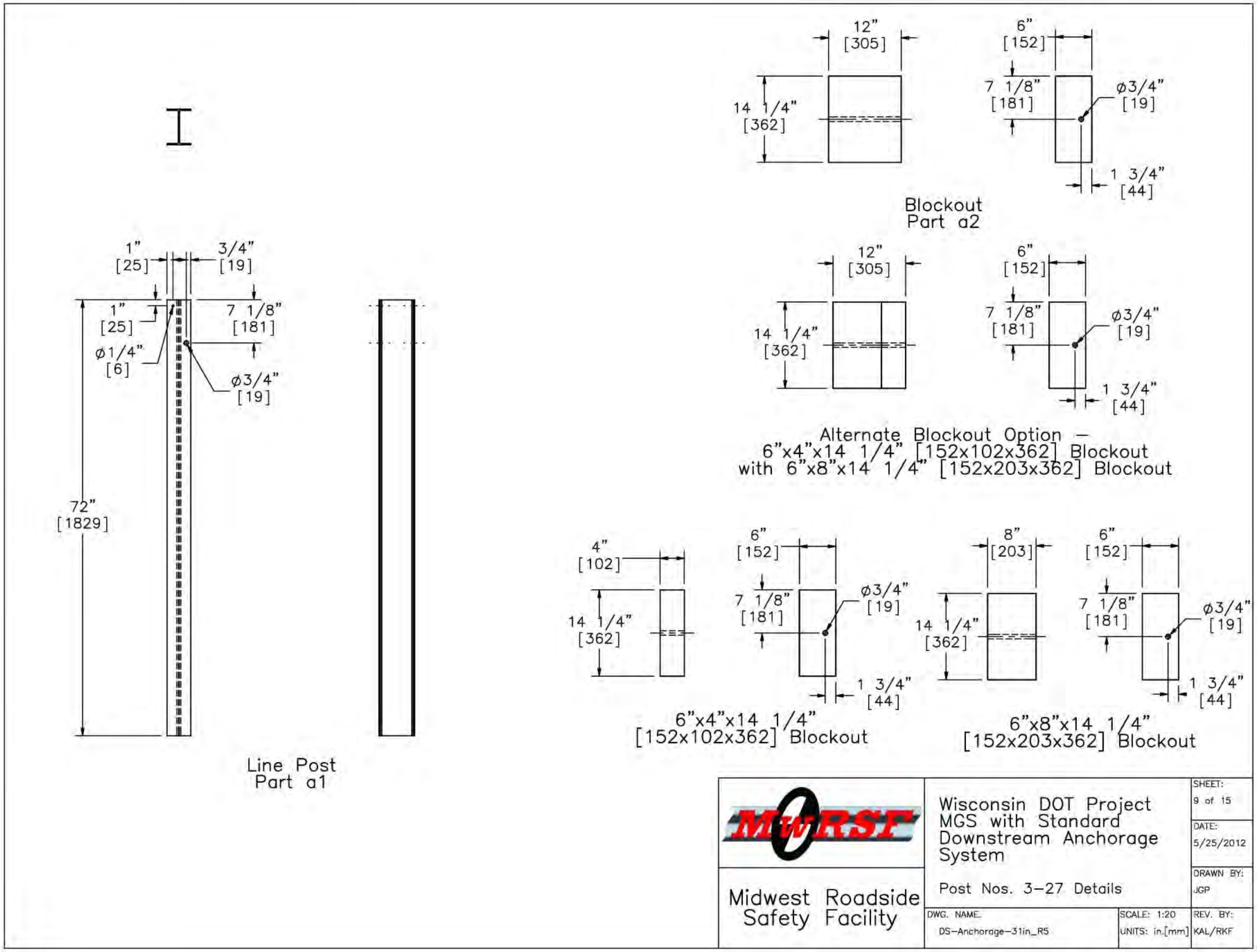


Figure 113. Line Post Details, Test No. WIDA-1

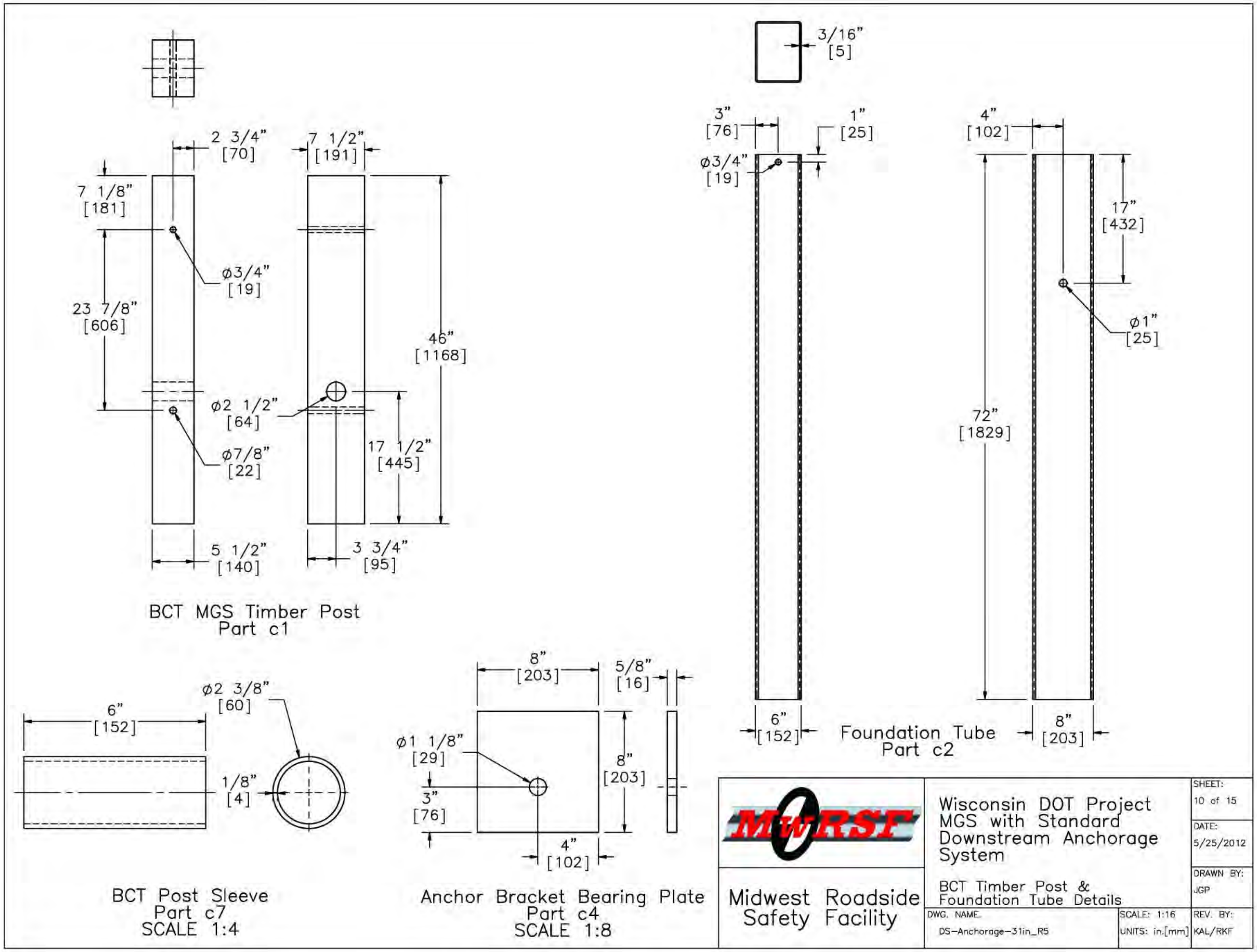


Figure 114. Anchor Post Details, Test No. WIDA-1

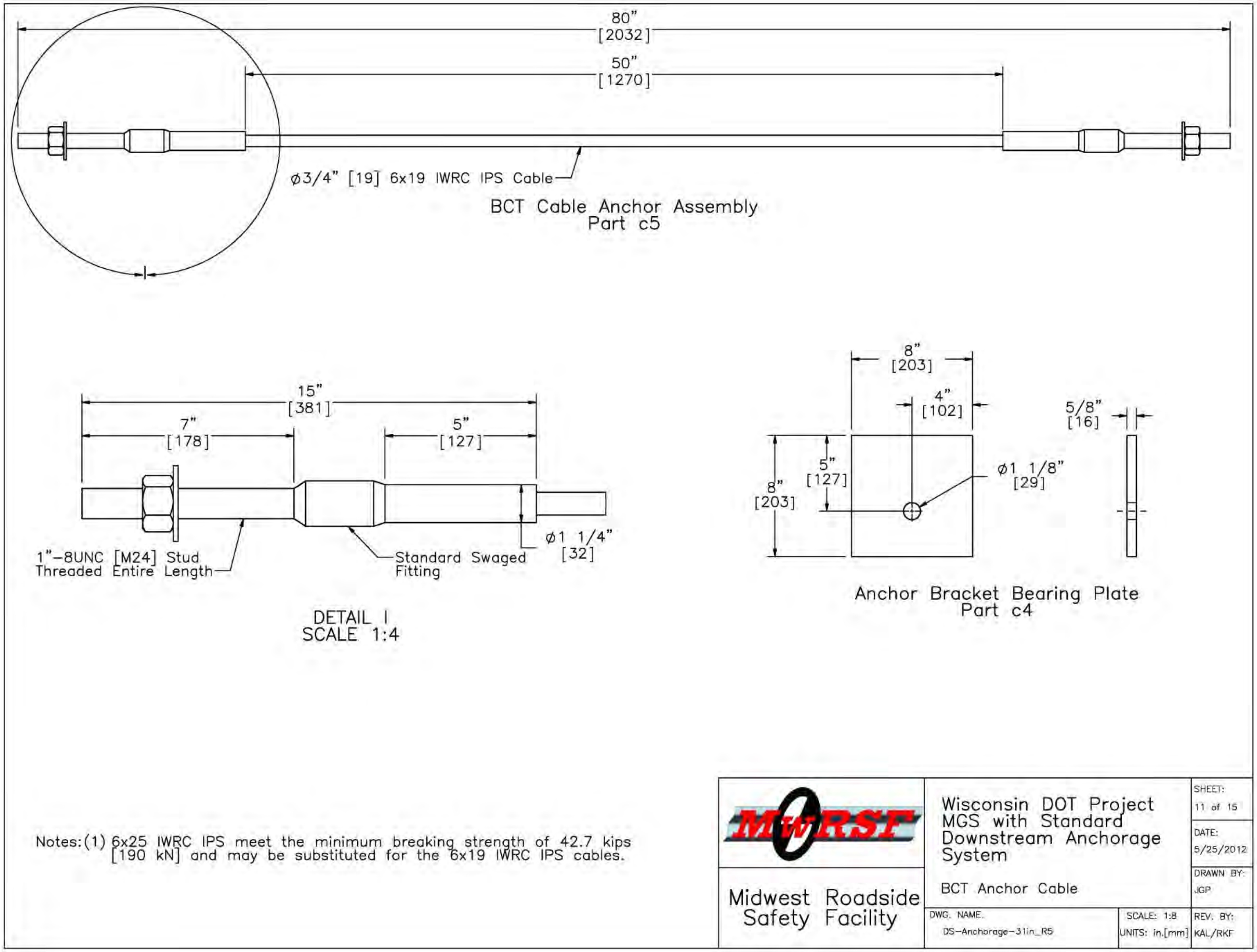


Figure 115. BCT Anchor Cable Details, Test No. WIDA-1

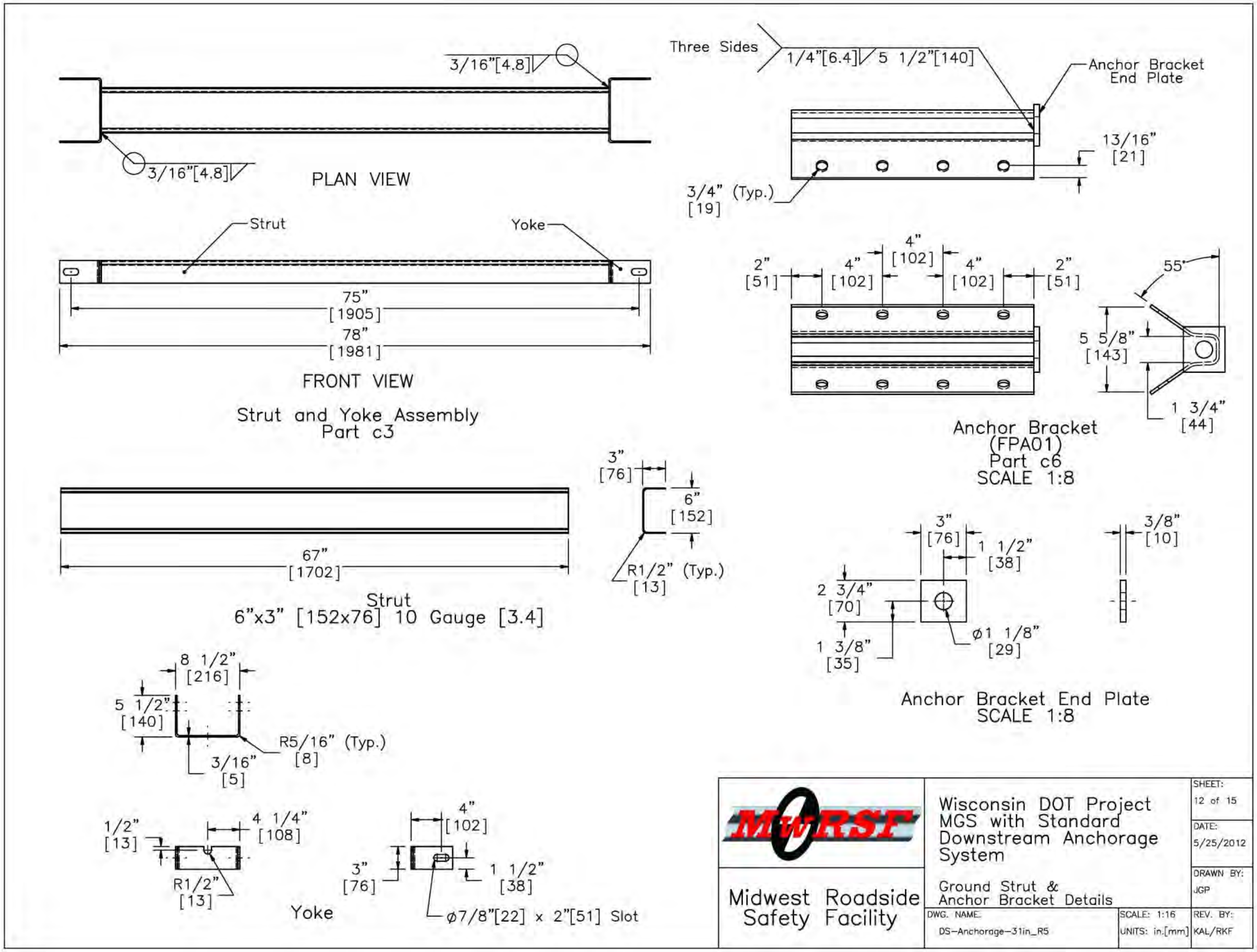


Figure 116. Ground Strut and Anchor Bracket Details, Test No. WIDA-1

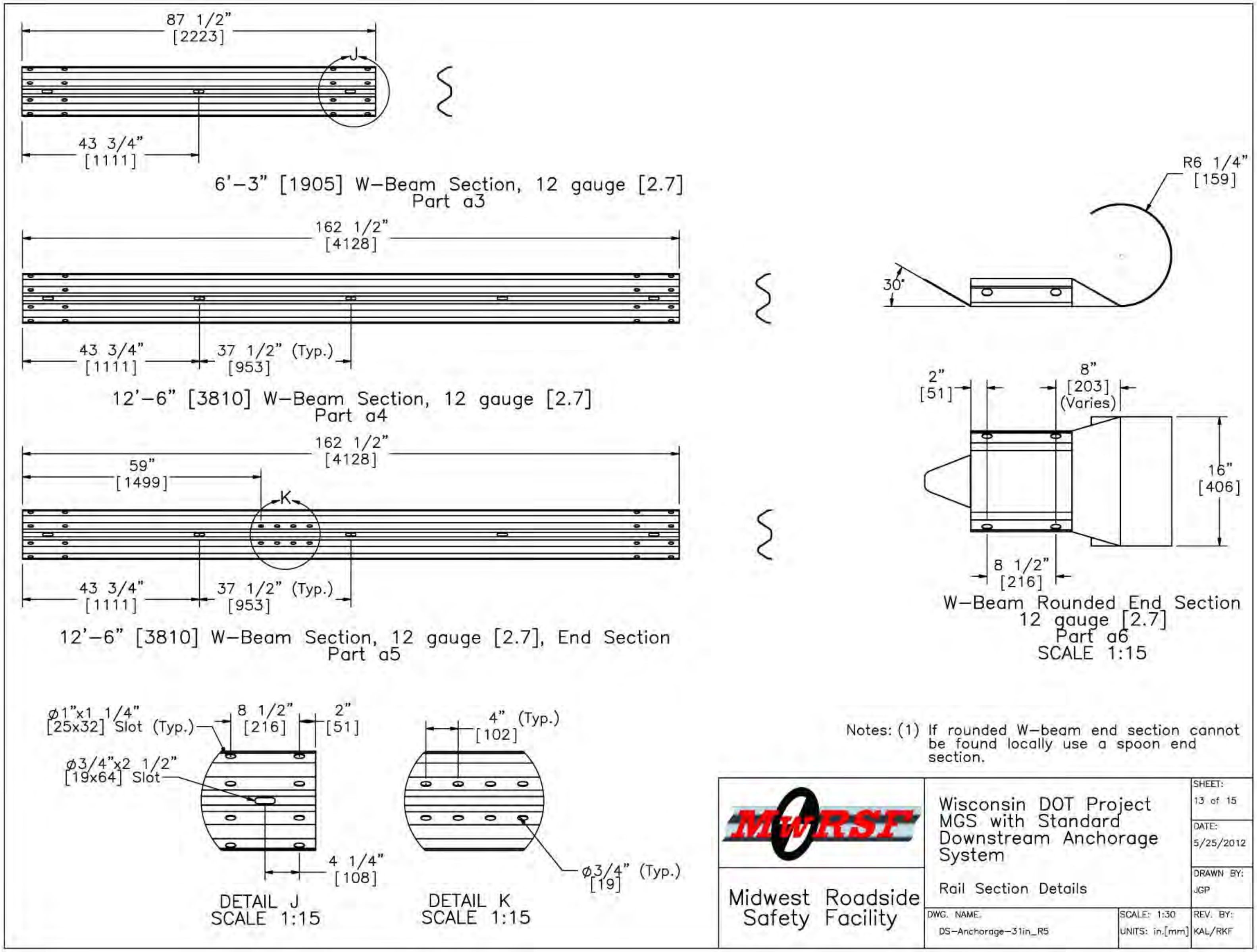


Figure 117. W-Beam Guardrail Details, Test No. WIDA-1

ItemNo.	QTY.	Description	Material Specification	Hardware Guide
a1	25	W6x8.5 6' Long [W152x12.6 1829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa] (W6x9 ASTM A36 Min. 36 ksi [248 MPa])	PWE06
a2	25	6x12x14 1/4" [152x305x362] Blockout	SYP Grade No. 1 or better	PDB10a-b
a3	1	6'-3" [1905] W-Beam MGS Section	12 gauge [2.7] AASHTO M180	RWM01a
a4	12	12'-6" [3810] W-Beam MGS Section	12 gauge [2.7] AASHTO M180	RWM04a
a5	2	12'-6" [3810] W-Beam MGS End Section	12 gauge [2.7] AASHTO M180	RWM14a
a6	1	W-Beam Rounded End Section	12 gauge [2.7] AASHTO M180	RWE03a
b1	25	5/8" Dia. x 14" Long [M16x356] Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 A	FBB06
b2	25	16D Double Head Nail	–	–
b3	4	5/8" Dia. x 10" [M16x254] Long Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 A	FBB03
b4	116	5/8" Dia. x 1 1/2" Long [M16x38] Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 A	FBB01
b5	46	5/8" [16] Dia. Flat Washer	ASTM F844 or SAE Grade 2 Steel	FWC16a
c1	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better	PDF01
c2	4	72" [1829] Long Foundation Tube	ASTM A53 Grade B	PTE06
c3	2	Strut and Yoke Assembly	ASTM A36 Steel Galvanized	–
c4	2	8x8x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel	FPB01
c5	1	BCT Anchor Cable Assembly	ø3/4" [19] 6x19 IWRC IPS Galvanized Wire Rope	FCA01
c6	2	Anchor Bracket Assembly	ASTM A36 Steel	FPA01
c7	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40	FMM02
c8	4	5/8" Dia. x 10" [M16x254] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 A	FBX16a
c9	16	5/8" Dia. x 1 1/2" Long [M16x38] Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 A	FBX16a
c10	4	7/8" Dia. x 7 1/2" [M22x191] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM A563 A	FBX22a
c11	8	7/8" [22] Dia. Flat Washer	ASTM F844 or SAE Grade 2 Steel	FWC22a

MwRSF
Midwest Roadside Safety Facility

Wisconsin DOT Project
MGS with Standard Downstream Anchorage System

Bill of Materials

SHEET: 14 of 15
DATE: 5/25/2012
DRAWN BY: JGP
DWG. NAME. DS-Anchorage-31in_R5
SCALE: NONE
UNITS: in.[mm]
REV. BY: KAL/RKF

Figure 118. Bill of Materials, Test No. WIDA-1

Item No.	QTY.	Description	Material Specification
d1	1	TLL-50K-PTB Load Cell	NA
e1	2	115-HT Mechanical Splice - 3/4" [19] Dia.	As Supplied
e2	2	3/4" [190] 6x19 IWRC IPS Wire Rope	IPS Galvanized
e3	4	BCT Anchor Cable End Swage Fitting	SAE Grade 5 - Galvanized
e4	2	Crosby Heavy Duty HT-3/4" [19] Dia. Cable Thimble	As Manufactured
f1	2	Crosby G2130 or S2130 Bolt Type Shackle - 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 - As Supplied
g1	2	Chicago Hardware Drop-Forged Heavy Duty Eye Nut - Drilled and Tapped 1 1/2" [38] Dia. - UNF 12 [M36]	As Supplied, Stock No. 107

Midwest Roadside Safety Facility	Wisconsin DOT Project MGS with Standard Downstream Anchorage System Bill of Materials Continued		SHEET: 15 of 15 DATE: 5/25/2012 DRAWN BY: JGP
	DWG. NAME. DS-Anchorage-31in_R5	SCALE: NONE UNITS: in.[mm]	REV. BY: KAL/RKF

Figure 119. Bill of Materials, Test No. WIDA-1 (continued)

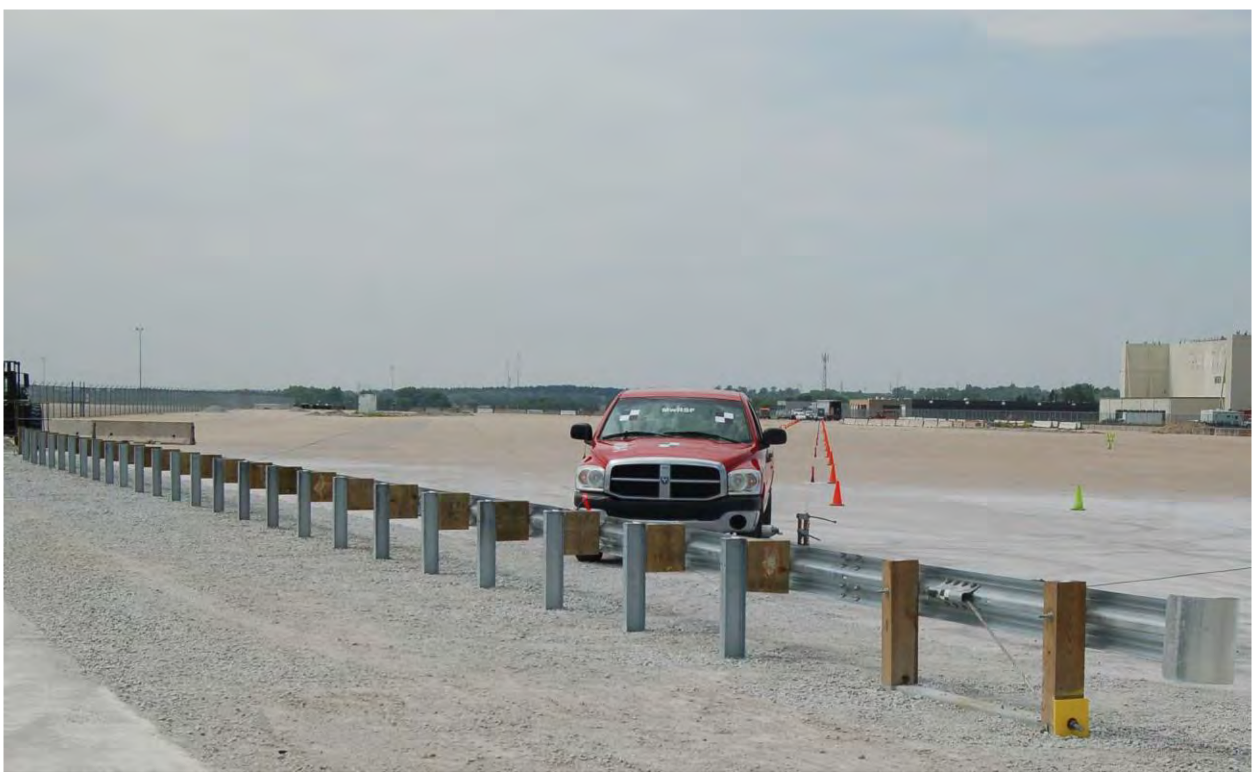
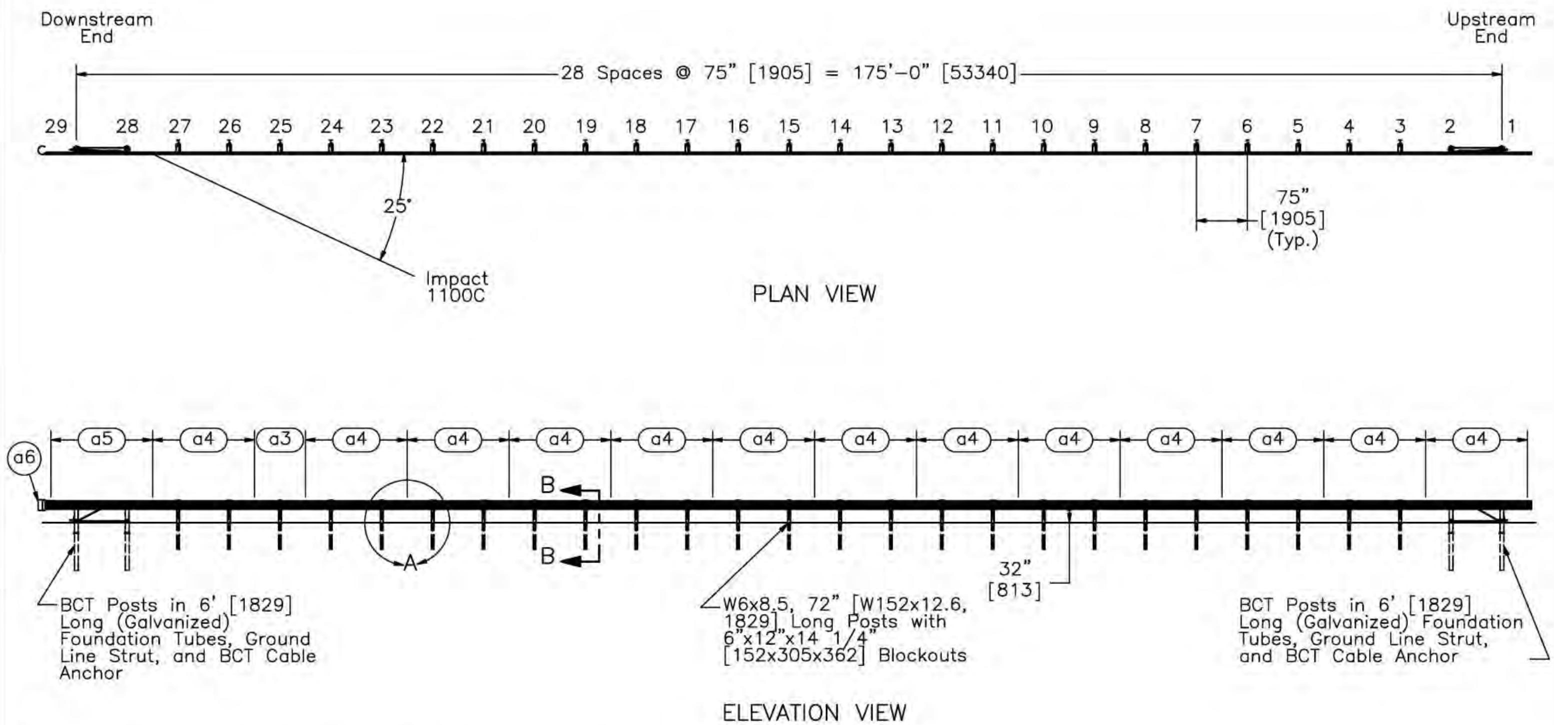


Figure 120. Test Installation Photographs, Test No. WIDA-1

Figure 121. Test Installation Photographs, Test No. WIDA-1

Figure 122. Test Installation Photographs, Test No. WIDA-1



Notes: (1) Impact location for the 1100C is the midspan of post nos. 27 and 28.

(2) The BCT anchor posts are placed in ϕ3' [914] holes.

(3) Critical region located between post nos. 21 and 29.

(4) A high-speed digital video camera shall be placed perpendicular to downstream anchor.

(5) Vehicle is expected to gate through.

(6) Avoid activating vehicle brakes in the first 100' [30480] downstream of post no. 29.

(7) Allow for a minimum lateral clearance of 30' [9144] behind the system in the first 75' [22860] downstream of post no. 29.

(8) Paint the downstream bearing plate and BCT cable two different colors.

(9) Put marks on foundation tube bolts.

MwRSF Midwest Roadside Safety Facility	Wisconsin DOT Project MGS with Standard Downstream Anchorage System System Layout	SHEET: 1 of 11 DATE: 5/25/2012 DRAWN BY: CWP
	DWG. NAME. DS-Anchorage-32in_R3 / SCALE: 1:225 UNITS: in.[mm]	REV. BY: KAL/RKF

Figure 123. Test Installation Layout, Test No. WIDA-2

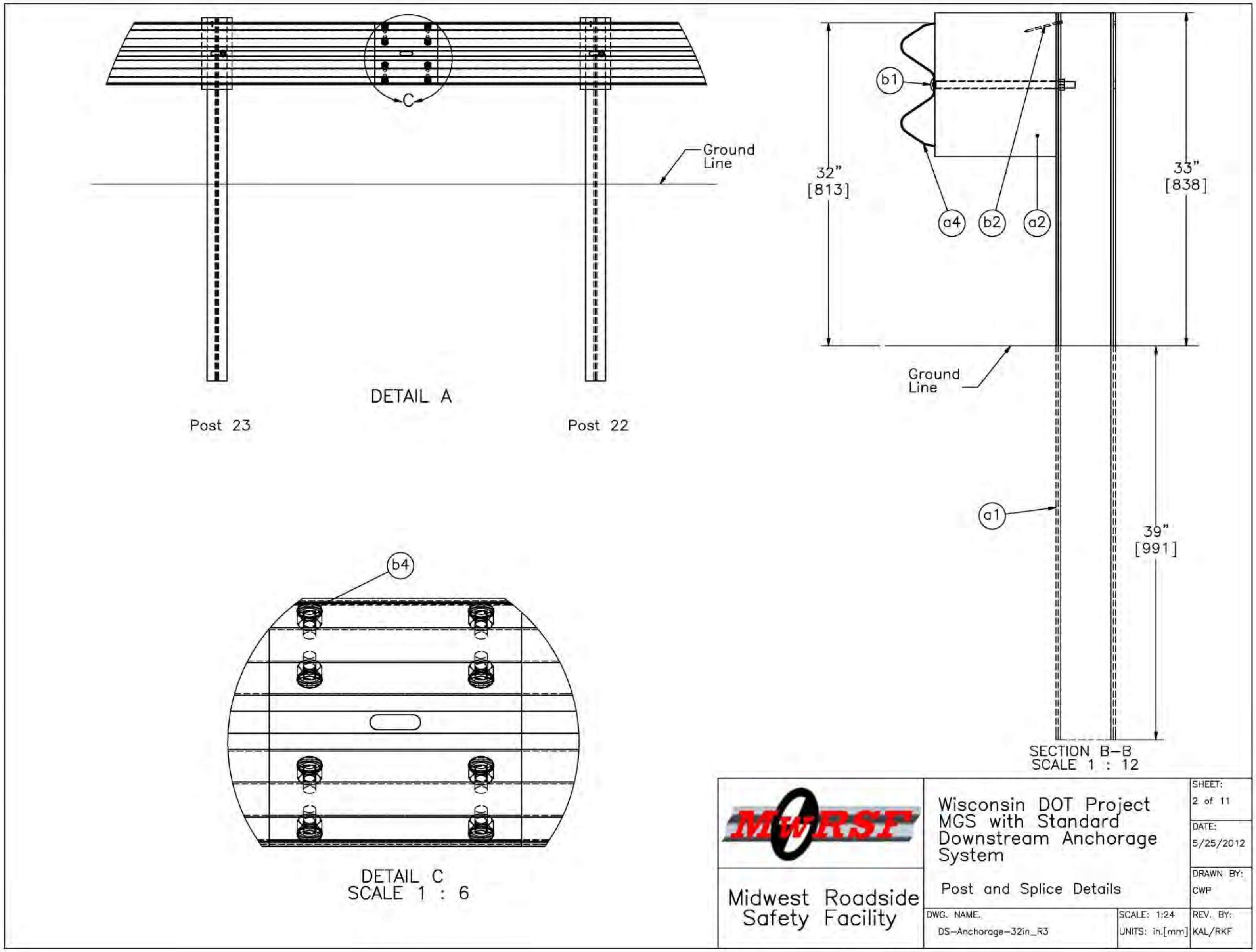


Figure 124. 32-in. (813-mm) Tall Blocked MGS Details, Test No. WIDA-2

Figure 125. Test Installation Photographs, Test No. WIDA-2

Figure 126. Test Installation Photographs, Test No. WIDA-2

Figure 127. Test Installation Photographs, Test No. WIDA-2

13 FULL-SCALE CRASH TEST NO. WIDA-1

13.1 Dynamic Soil Test

Before full-scale test no. WIDA-1 was conducted, the strength of the foundation soil was evaluated with a dynamic test, as described in MASH. The dynamic test results are shown in Appendix F. For the first 10 in. (254 mm) of deflection, the soil force exceeded the minimum force required by more than double. The force averaged 17 kip (76 kN) whereas the minimum is 7.5 kip (33 kN). Between 10 and 18 in. (254 and 457 mm), the soil strength was more than 10 kip (44 kN), which is 25 percent greater than the minimum required strength. After 18 in. (457 mm), the deflection of the post had dissipated most of the energy due to the high soil strength. Therefore, the force dropped off rapidly before even reaching 20 in. (508 mm) of deflection. However, the soil was more than capable of providing adequate post-soil strength, and full-scale crash testing was then conducted on the barrier system.

It should be noted that the measured forces were determined from accelerometers attached to the c.g. of the bogie vehicle. The accelerations are believed to provide an accurate assessment of the post-soil capacity.

13.2 Test No. WIDA-1

The 5,172-lb (2,346-kg) pickup truck impacted the downstream segment of the MGS trailing-end terminal at a speed of 63.0 mph (101.4 km/h) and at an angle of 26.4 degrees. A summary of the test results and sequential photographs are shown in Figure 129. Additional sequential photographs are shown in Figures 130 through 132. Documentary photographs of the crash test are shown in Figure 133.

13.3 Weather Conditions

Test no. WIDA-1 was conducted on May 18, 2012 at approximately 2:30 pm. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were documented and are shown in Table 11 [38].

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

Temperature	90° F
Humidity	16 %
Wind Speed	33 mph
Wind Direction	160° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.0 in.
Previous 7-Day Precipitation	0.0 in.

13.4 Test Description

Initial vehicle impact was to occur at the centerline of post no. 24, as shown in Figure 134, which was selected using LS-DYNA analysis to identify the end of the LON, as described in section 9.1.2. The actual point of impact was 1 in. (25 mm) upstream from post no. 24, or the sixth post upstream from the downstream end of the barrier. A sequential description of the impact events is contained in Table 12. The vehicle came to rest facing downstream, located 232 ft – 1 in. (70.7 m) downstream from initial impact point and 5 ft – 3 in. (1.6 m) laterally behind the traffic-side face of the guardrail. The vehicle trajectory and final position are shown in Figures 129 and 135.

Table 12. Sequential Description of Impact Events, Test No. WIDA-1

TIME (sec)	EVENT
0.000	Front bumper impacted rail 1 in. upstream from intended impact location.
0.022	Post no. 29 deflected upstream.
0.058	Post no. 25 disengaged from rail.
0.080	Right-front tire overrode post no. 25.
0.082	Vehicle yawed away from barrier.
0.118	Post no. 26 disengaged from rail.
0.150	Post no. 27 disengaged from rail.
0.166	Post no. 28 fractured at its base.
0.188	Post no. 29 developed a vertical fracture.
0.208	Post no. 29 disengaged from rail.
0.250	Post no. 24 disengaged from rail.
0.280	Vehicle impacted post no. 29.
0.292	Bearing plate on downstream cable anchor pulled through post no. 29.
0.296	Vehicle pitched down.
0.330	Vehicle became parallel to system with a velocity of 45.3 mph (72.9 km/h).
0.350	Post no. 29 fractured at the ground line.
0.354	Rail span downstream from post no. 25 rotated backward around post no. 25.
0.378	Buffer end rotated forward and impacted the vehicle's front end.
0.396	Vehicle's grill disengaged from vehicle.
0.406	Vehicle exited system with speed of 43.5 mph (70.0 km/h) and angle of 4.2 degrees away from the barrier.
0.412	Vehicle rolled away from barrier.
0.464	A bend formed in rail at post no. 27.
0.590	Vehicle rolled toward barrier.
1.452	Vehicle yawed toward barrier.
1.476	Vehicle pitched down.

13.5 Barrier Damage

Damage to the barrier was extensive, as shown in Figures 136 through 141. Barrier damage consisted of deformed W-beam rail and guardrail posts, disengaged rail and wood blockouts, contact marks on posts and guardrail, and fractured end anchorage BCT posts. The length of vehicle contact along the barrier was approximately 34 ft – 4½ in. (10.5 m), which spanned from the actual impact point at 1 in. (25 mm) upstream of post no. 24 to the downstream end of the guardrail.

The wood blockouts detached from post nos. 25 through 27. The bolt pulled through the W-beam rail slots at the post connections between post nos. 24 and 29. A ¼-in. (6-mm) and a ½-in. (13 mm) tear occurred in the rail slot for post nos. 24 and 28, respectively, as shown in Figure 137. Small cracks formed at the downstream edge of the rail slot for post no. 29. Post nos. 21 and 22 rotated downstream. Post nos. 23 and 24 both rotated backward, and their front flange twisted downstream. Post nos. 25 through 27 bent about 30 degrees from the ground and twisted downstream. Both post nos. 26 and 27 encountered contact marks and gouges. A 7-in. (178-mm) long contact mark started at 7½ in. (191 mm) from the top of post no. 26. Two contact marks, 6-in. (152-mm) and 3-in. (76-mm) long, started at the top of the front flange of post no. 27 and at ¼ in. (6 mm) from the top of the back flange, respectively. Post nos. 28 and 29 fractured at their foundation tubes.

The rail buckled at post no. 25, post no. 27, and 27¼ in. (692 mm) downstream of post no. 28, as shown in Figure 138. Kinks in the top and/or bottom corrugations of the rail were found between post nos. 22 and 29, as shown in Figure 136. Flattening and folding of the bottom corrugation of the W-beam rail occurred between post nos. 24 and 29. The bottom corrugation was folded upward at two main locations downstream of the initial impact point. The first location where the rail folded started at 6 in. (152 mm) from post no. 24, and extended downstream for 40¼ in. (1,022 mm), while the second location started 23 in. (584 mm) downstream of post no. 27 and ended 7 in. (178 mm) downstream of post no. 29. The bottom corrugation of the rail was also flattened at two locations. The first flattened segment started 6 in.

(152 mm) downstream from the rail splice connection between post nos. 25 and 26 and ended 23 in. (584 mm) downstream of post no. 27. The second flattened location extended from 28½ in. (724 mm) upstream to 29 in. (737 mm) downstream of post no. 29. In addition, the swage connector between the downstream anchor cable and the corresponding bearing plate was slightly bent and the metal sleeve through which the cable passed was deformed, as shown in Figure 141.

The maximum separation between the W-beam sections was ⅜ in. (10 mm) long and occurred at the splice connections between post nos. 2 and 3, 4 and 5, 22 and 23, and 26 and 27. No separation occurred at the splice connections between post nos. 6 and 7 as well as 27 and 28. The splice between post nos. 25 and 26 was separated ¼ in. (6 mm) longitudinally. A separation of ⅛ in. (3 mm) was measured for all the remaining splice connections. A summary of the splice separation together with details of the slippage for each of the splice bolts is provided in Appendix G.

The permanent set of the rail and post was 26 ft – 6⅜ in. (8.1 m) at post no. 29 and 21¼ in. (540 mm) at post no. 25, respectively, as measured in the field. The maximum rail and post dynamic deflection was 32 ft – 6.6 in. (9.9 m) at the downstream end of the W-beam rail and 34¾ in. (883 mm) at post no. 28, respectively, as determined from high-speed digital video analysis. The working width of the system coincided with the lateral dynamic barrier deflection which was 32 ft – 6.6 in. (9.9 m).

The main objective for impacts occurring in close proximity to the end of the LON is to safely redirect the vehicle rather than to prevent the barrier or debris from contacting the shieled hazard. As such, the working width based on the maximum vehicle penetration behind the original traffic-side face of the barrier system versus the working width based on maximum deflection should be considered to determine the allowable hazard envelope near MGS trailing end guardrail terminals. For test no. WIDA-1, the maximum lateral vehicle extension behind the traffic-side face of the barrier was 124 in. (3,150 mm). However, careful attention should be paid to hazards located behind the barrier which may either be damaged or fall when struck by the gating W-beam rail and anchorage system.

13.6 Upstream End Anchor Loads

The tensile force was measured in the upstream cable anchor and plotted against the ground line displacement of the upstream BCT end post, as shown in Figure 128. A peak load of 18.5 kip (82.3 kN) was measured at a displacement of about 0.9 in. (22.9 mm).

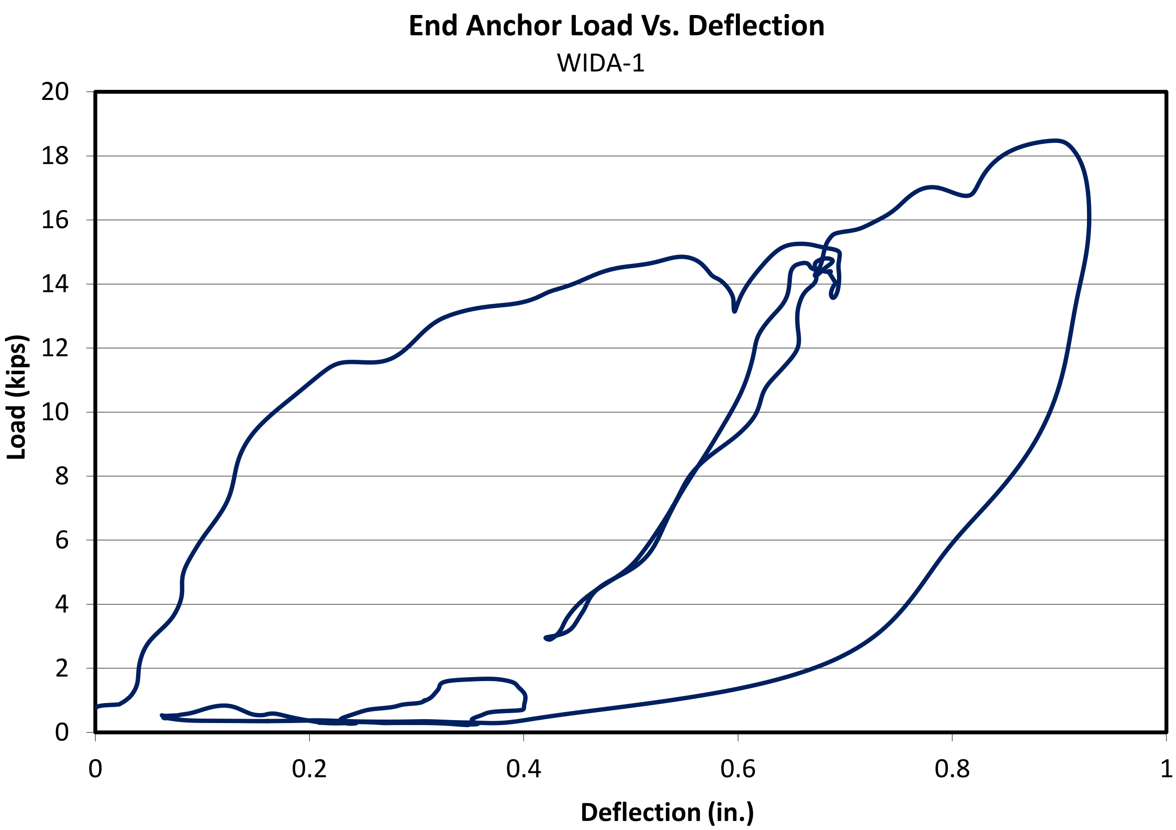


Figure 128. Force vs. Deflection at Upstream End Anchorage, Test No. WIDA-1

13.7 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 142 through 144. The maximum occupant compartment deformations are listed in Table 13 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix H.

Table 13. Maximum Occupant Compartment Deformations by Location, Test No. WIDA-1

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	⅜ (10)	≤ 9 (229)
Floor Pan & Transmission Tunnel	¼ (6)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	0	≤ 12 (305)
Side Door (Above Seat)	½ (13)	≤ 9 (229)
Side Door (Below Seat)	¼ (6)	≤ 12 (305)
Roof	0	≤ 4 (102)
Windshield	½ (13)	≤ 3 (76)

The majority of the damage was concentrated on the right-front corner of the vehicle where the impact occurred. The right side of the front bumper was dented about 2 in. (51 mm). The right-front fender crushed inward about 6 in. (152 mm) and crushed inward above the wheel well. The back of the right-front quarter panel was dented 2¼ in. (57 mm). The right-front tire encountered contact marks and scuffing, and the inner side of the metal rim had contact marks and minor scrapes. Minor denting and scraping were observed on the vehicle right side. The front of the right-front door was slightly dented and encountered contact marks. The right-rear tire encountered light scuffing and the right taillight was partially disengaged.

The right-side headlight and the radiator grill disengaged from the vehicle. The center of the front bumper was dented. The front of the hood had a minor gap on the left side. The windshield and all the other glass were undamaged.

13.8 Occupant Risk

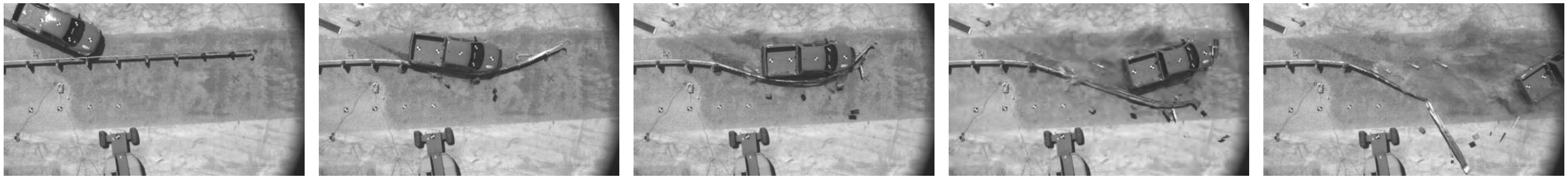
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 14. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 14. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 129. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix I.

Table 14. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. WIDA-1

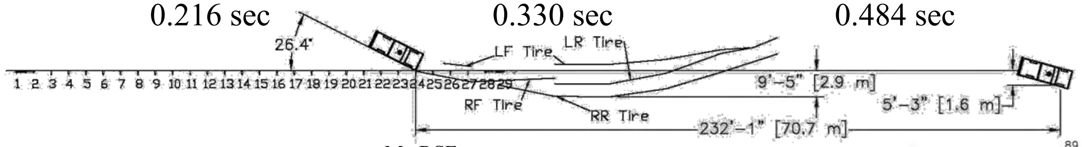
Evaluation Criteria		**Transducer**			**MASH Limits**
		EDR-3	**DTS**	**DTS-SLICE**	
OIV ft/s (m/s)	Longitudinal	-15.27 (-4.65)	-14.64 (-4.46)	-14.56 (-4.44)	≤ 40 (12.2)
	Lateral	-14.85 (-4.53)	-14.83 (-4.52)	-15.13 (-4.61)	≤ 40 (12.2)
ORA g's	Longitudinal	-8.13	-7.48	-8.01	≤ 20.49
	Lateral	-6.25	-6.91	-6.31	≤ 20.49
THIV ft/s (m/s)		NA	20.07 (6.12)	19.74 (6.02)	not required
PHD g's		NA	9.36	9.5	not required
ASI (according to MASH)		0.53	0.53	0.54	not required

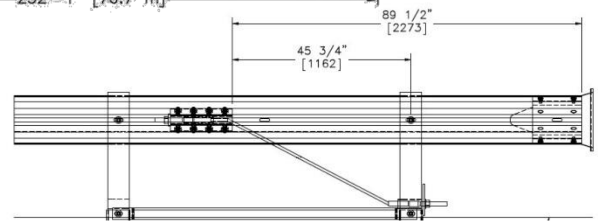
13.9 Discussion

The analysis of the test results for test no. WIDA-1 showed that the MGS barrier with a non-proprietary, downstream end anchor system (i.e., trailing-end terminal) adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix I, were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. Therefore, test no. WIDA-1 was determined to be acceptable according to the MASH safety performance criteria for modified test designation no. 3-37.



0.000 sec 0.216 sec 0.330 sec 0.484 sec 0.748 sec





- Test Agency .... MwRSF
- Test Number WIDA-1
- Date 05/18/2012
- MASH Test Designation No. .... Modified 3-37
- Test Article .... MGS with MGS End Anchorage
- Total Length .... 181 ft – 3 in. (55.3 m)
- Key Component – W-Beam Rail
  - Thickness .... 12 gauge (2.66 mm)
  - Top Mounting Height .... 31 in. (787 mm)
- Key Component – Line Posts (Nos. 3-27)
  - Type W6x8.5 (152x12.6)
  - Length .... 72 in. (1,829 mm)
  - Spacing .... 75 in. (1,905 mm)
  - Material .... ASTM A992 or A36
- Key Component – Wood Spacer Blocks
  - Dimensions .... 6 x 12 x 72 in. (152 x 305 x 1,829 mm)
- Key Component – MGS End Anchorage
  - BCT Post Dimensions .... 5 ½ x 7 ½ x 46 in. (140 x 191 x 1,168 mm)
  - BCT Post Material .... SYP Grade 1
  - Foundation Tube Dimensions .... 6 x 8 x $^3/_{16}$ x 72 in. (152 x 203 x 5 x 1,829 mm)
  - Foundation Tube Material .... ASTM A53 Grade B
  - Strut and Yoke Assembly .... ASTM A36 Galvanized
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make /Model .... 2007 Dodge Ram 1500 Quad Cab
  - Curb .... 5,016 lb (2,275 kg)
  - Test Inertial .... 5,002 lb (2,269 kg)
  - Gross Static .... 5,172 lb (2,346 kg)
- Impact Conditions
  - Speed .... 63.0 mph (101.4 km/h)
  - Angle (vehicle c.g.) .... 26.4 deg
  - Angle (vehicle orientation) .... 25.8 deg
  - Impact Location .... 1 in. (25 mm) upstream from post no. 24
- Exit Conditions
  - Speed .... 43.5 mph (70.0 km/h)
  - Angle (vehicle c.g.) .... 4.2 deg
  - Angle (vehicle orientation) .... -6.5 deg
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 232 ft – 1 in. (70.7 m) downstream
  5 ft – 3 in. (1.6 m) laterally behind
- Vehicle Damage .... Moderate
  - VDS[39] 01-RFQ-3
  - CDC[40] 01-RFEN-4
  - Maximum Interior Deformation .... ½ in. (13 mm)
- Test Article Damage .... Extensive
- Maximum Test Article Deflections
  - Permanent Set .... 26 ft – 6⅜ in. (8.1 m)
  - Dynamic .... 32 ft – – 6.6 in. (9.9 m) (*)
  - Working Width .... 32 ft – 6.6 in. (9.9 m) (*) (barrier)
    (10 ft – 4 in. (3.2 m) (+)) (vehicle)
- Impact Severity (IS) .... 131.3 kip-ft (178.0 kJ) > 106 kip-ft (144 kJ) MASH limit
- Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		EDR-3	DTS	DTS-SLICE	
OIV ft/s (m/s)	Longitudinal	-15.27 (-4.65)	-14.64 (-4.46)	-14.56 (-4.44)	≤ 40 (12.2)
	Lateral	-14.85 (-4.53)	-14.83 (-4.52)	-15.13 (-4.61)	≤ 40 (12.2)
ORA g's	Longitudinal	-8.13	-7.48	-8.01	≤ 20.49
	Lateral	-6.25	-6.91	-6.31	≤ 20.49
THIV – ft/s (m/s)		N/A	20.07 (6.12)	19.74 (6.02)	Not required
PHD – g's		N/A	9.36	9.50	Not required
ASI (MASH)		0.53	0.53	0.54	Not required
Roll Angle – degree		N/A	5.8	10.2	75
Pitch Angle – degree		N/A	3.0	4.5	75
Yaw Angle - degree		N/A	-62.7	-62.5	Not required

(*) Downstream W-beam rotated backward almost 90 degrees.
(+) Maximum vehicle penetration behind traffic-side face of rail at end post.

Figure 129. Summary of Test Results and Sequential Photographs, Test No. WIDA-1

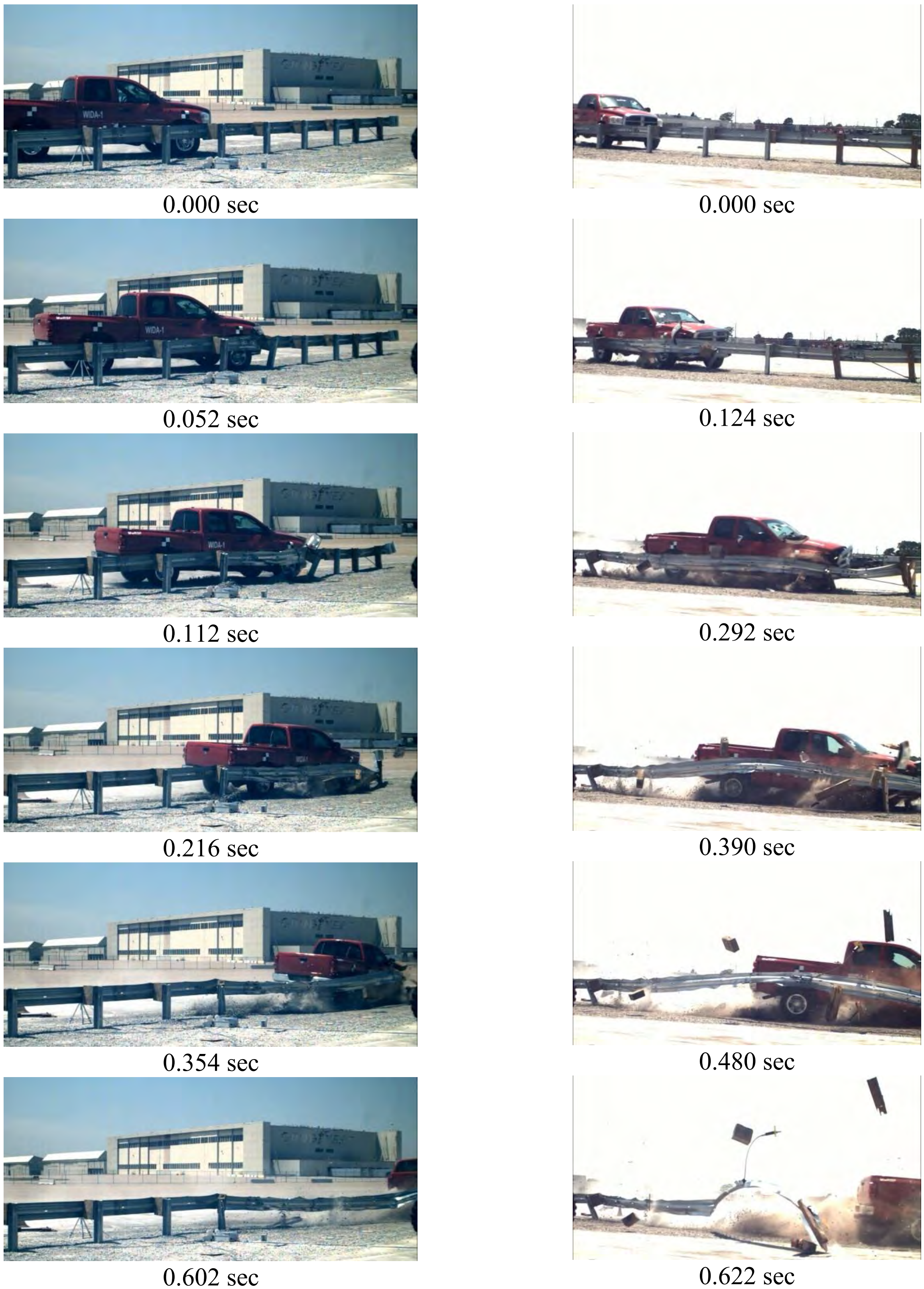


Figure 130. Additional Sequential Photographs, Test No. WIDA-1

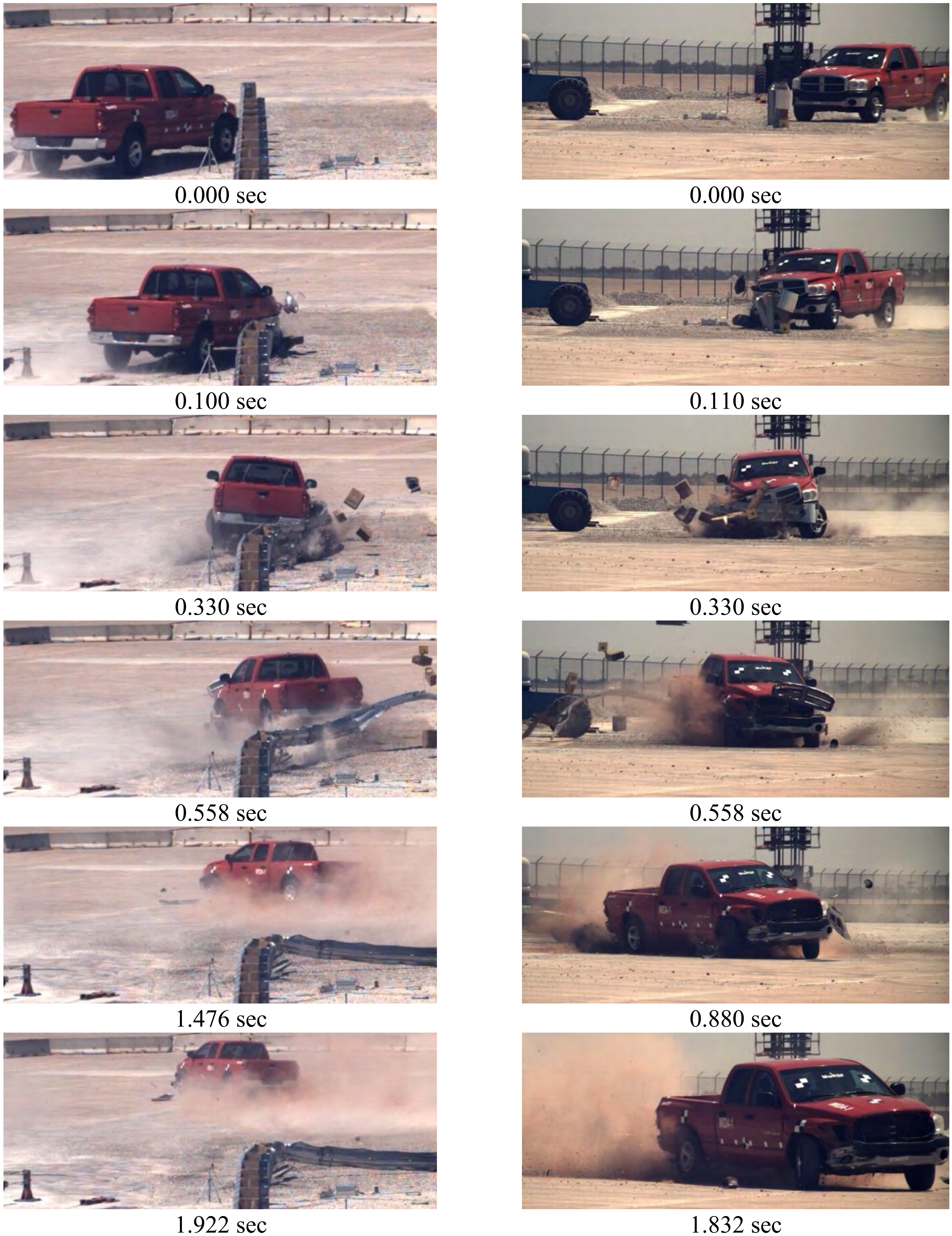


Figure 131. Additional Sequential Photographs, Test No. WIDA-1

0.000 sec

0.134 sec

0.268 sec

0.354 sec

0.472 sec

0.718 sec

Figure 132. Additional Sequential Photographs, Test No. WIDA-1

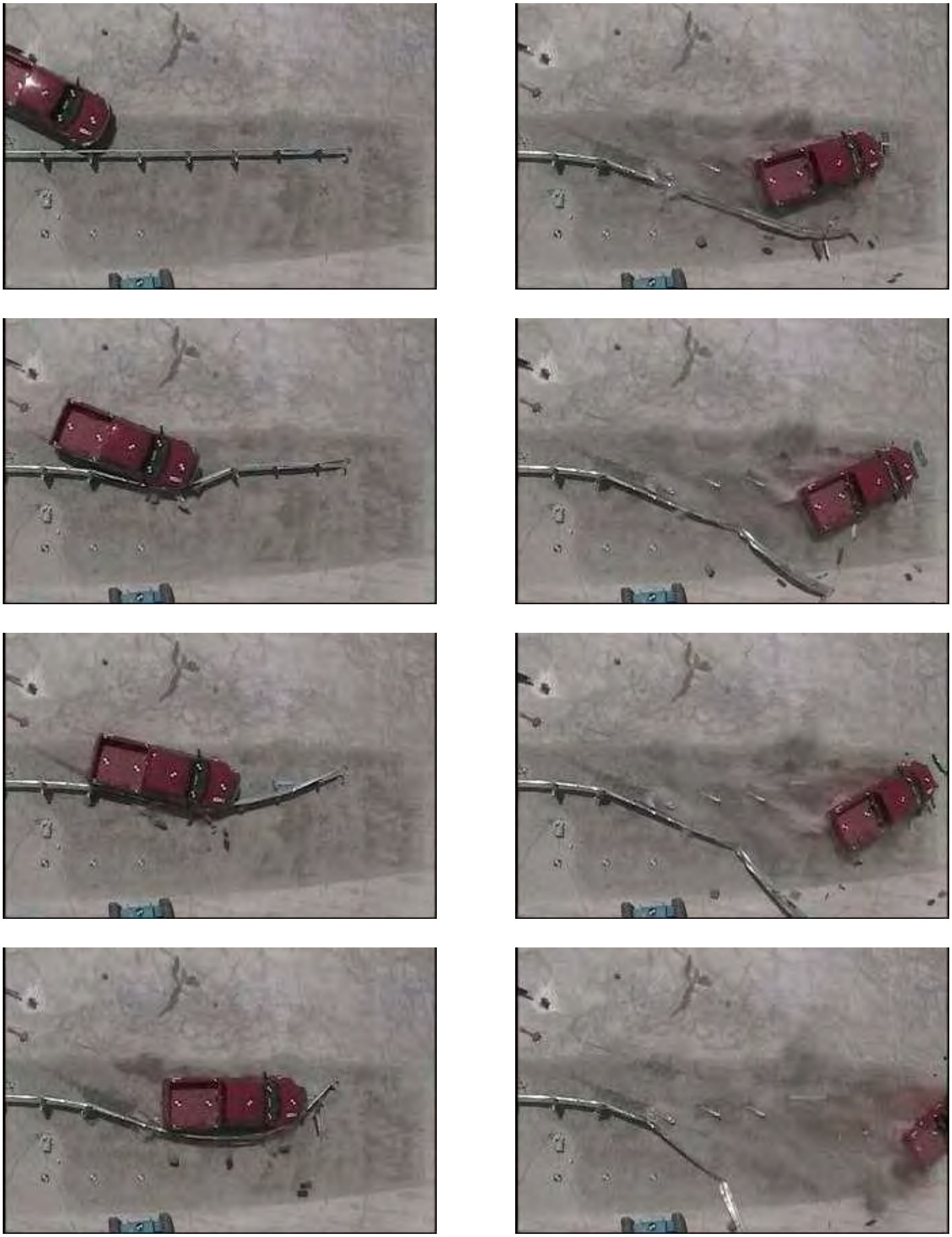


Figure 133. Documentary Photographs, Test No. WIDA-1

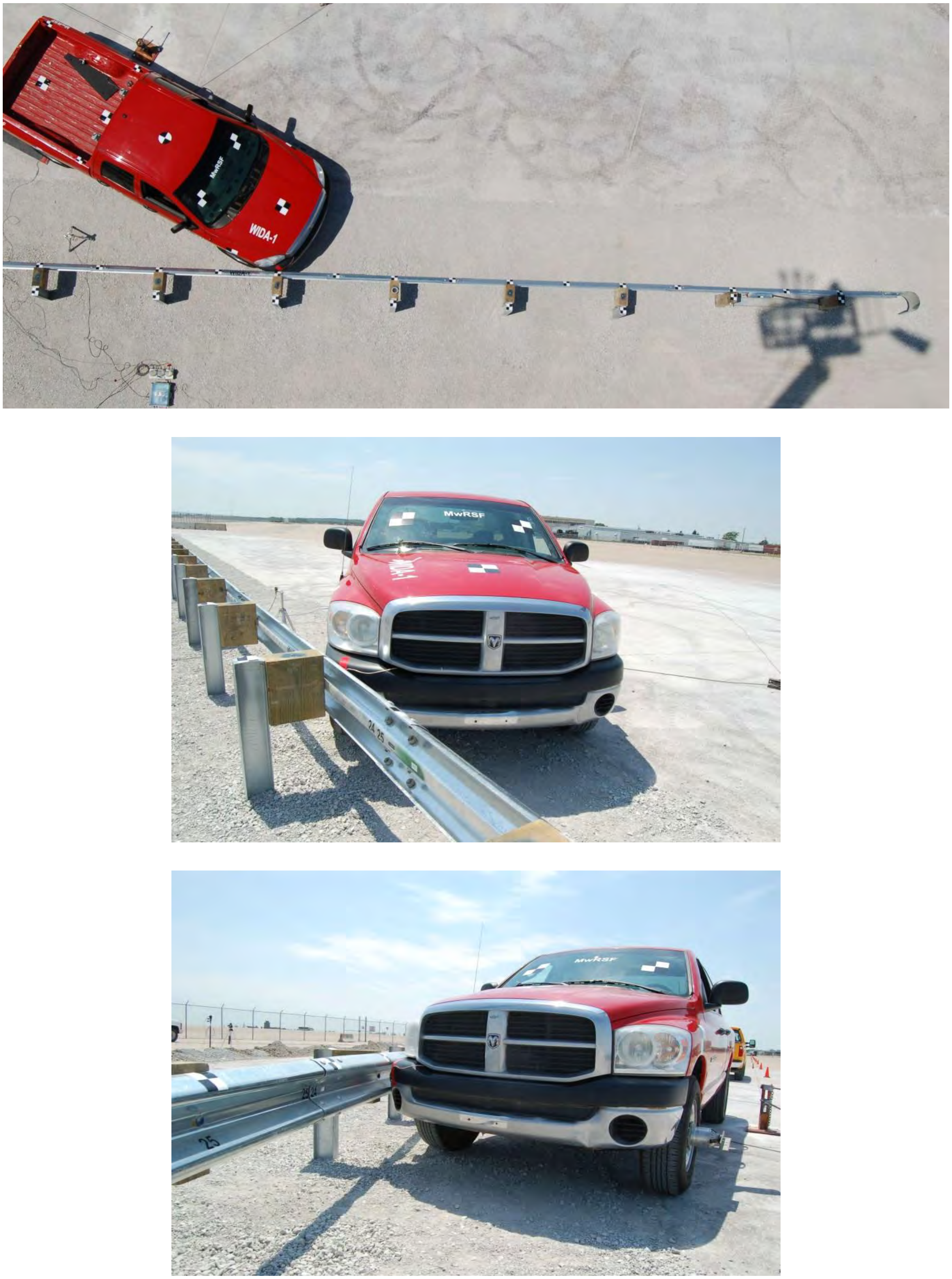


Figure 134. Impact Location, Test No. WIDA-1

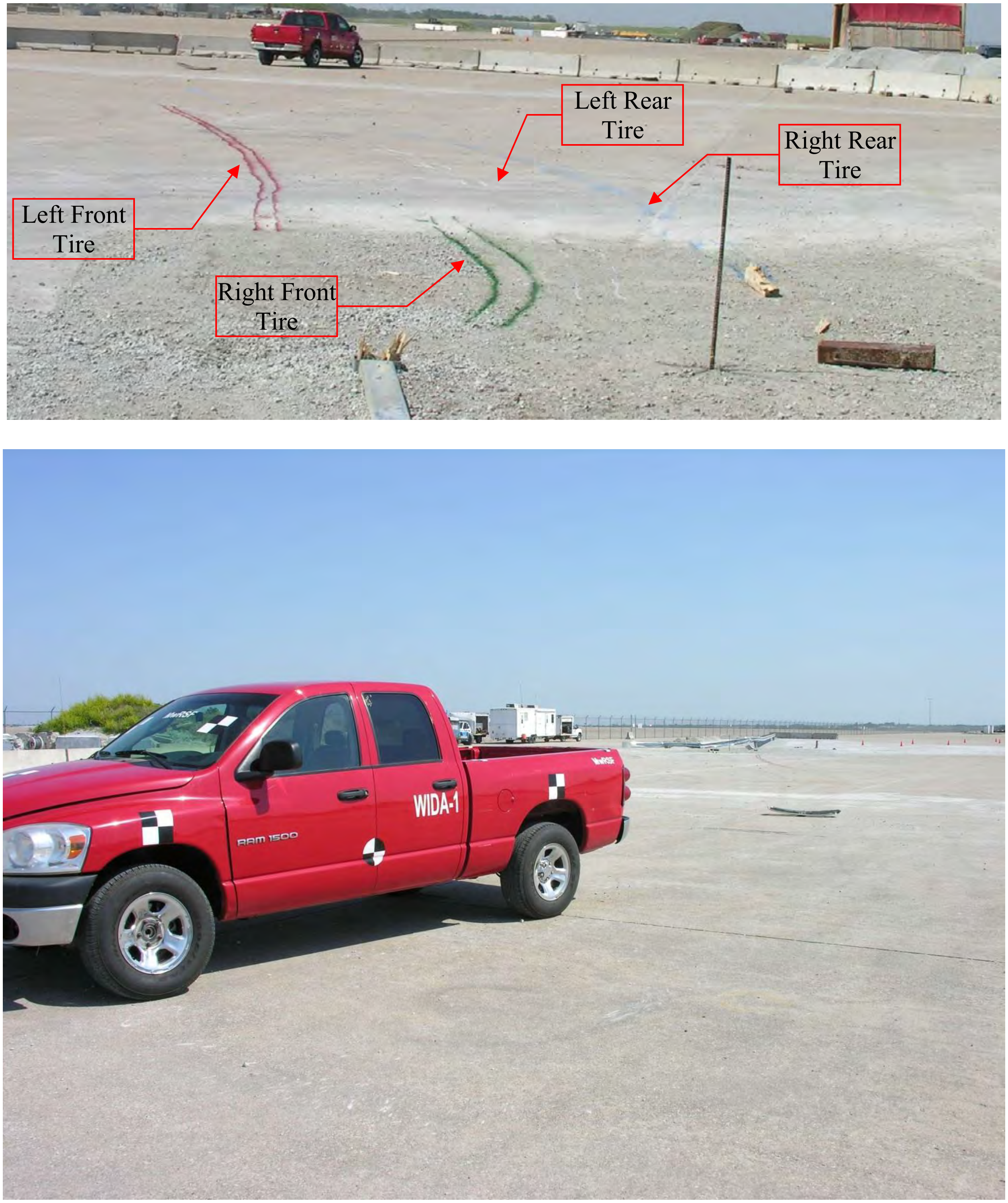


Figure 135. Vehicle Final Position and Trajectory Marks, Test No. WIDA-1

Figure 136. System Damage, Test No. WIDA-1

Figure 137. Rail Slot Tearing at Post Nos. 24 and 28, Test No. WIDA-1

Figure 138. Details of Rail Damage, Test No. WIDA-1

Figure 139. System Damage at Post Nos. 21 through 24, Test No. WIDA-1

Figure 140. System Damage at Post Nos. 25 through 29, Test No. WIDA-1

Figure 141. Anchor Cable Damage, Test No. WIDA-1

Figure 142. Vehicle Damage, Test No. WIDA-1

Figure 143. Vehicle Damage, Test No. WIDA-1

Figure 144. Undercarriage and Suspension Damage, Test No. WIDA-1

14 FULL-SCALE CRASH TEST NO. WIDA-2

14.1 Static Soil Test

Before full-scale crash test no. WIDA-2 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static soil test results, as shown in Appendix F, demonstrated that a soil resistance above the baseline test limits was available. Thus, the soil provided adequate strength, and full-scale crash testing was conducted on the barrier system.

14.2 Test No. WIDA-2

The 2,619-lb (1,188-kg) small passenger car impacted the downstream MGS end anchorage of a 32-in (813-mm) high MGS barrier at a speed of 62.0 mph (99.8 km/h) and at an angle of 25.5 degrees. A summary of the test results and sequential photographs are shown in Figure 145. Additional sequential photographs are shown in Figures 146 through 148. Documentary photographs of the crash test are shown in Figure 149.

14.3 Weather Conditions

Test no. WIDA-2 was conducted on June 5, 2012 at approximately 2:00 pm. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were documented and are shown in Table 15 [41].

Table 15. Weather Conditions, Test No. WIDA-2

Temperature	85° F
Humidity	36 %
Wind Speed	0 mph
Wind Direction	0° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.0 in.
Previous 7-Day Precipitation	0.07 in.

14.4 Test Description

Initial vehicle impact was to occur at the midspan between post nos. 27 and 28, as shown in Figure 150, which was selected using LS-DYNA analysis to maximize the probability of wheel snag on the cable anchor, as described in section 9.1.1. The actual point of impact was 4 in. (102 mm) upstream from the midspan between post nos. 27 and 28, or near the midspan between the second and third posts upstream from the downstream end of the barrier. A sequential description of the impact events is contained in Table 16. The vehicle came to rest with its front end facing the downstream anchor at 77 ft (23.5 m) downstream from initial impact point and 27 ft – 11 in. (8.5 m) laterally behind the traffic-side face of the guardrail. The vehicle trajectory and final position are shown in Figures 145 and 151.

Table 16. Sequential Description of Impact Events, Test No. WIDA-2

TIME (sec)	EVENT
0	Initial impact occurred 4 in. (102 mm) upstream from midspan between post nos. 27 and 28.
0.004	Post no. 28 deflected backward.
0.012	Vehicle hood crushed and bent at impacting corner.
0.018	Post no. 29 deflected upstream.
0.042	Right-front fender underrode rail between post nos. 28 and 29.
0.05	Right-front tire contacted post no. 28, which fractured.
0.074	Front bumper contacted post no. 29.
0.084	Guardrail between post nos. 26 and 27 bent backward.
0.098	Guardrail between post nos. 28 and 29 flattened.
0.110	Vehicle pitched downward.
0.112	Vehicle windshield detached from vehicle frame.
0.114	Vehicle rolled toward barrier.
0.126	Vehicle hood overrode guardrail end terminal, and post nos. 22 through 27 deflected upstream.
0.14	Post nos. 28 and 29 rose into air.
0.146	Bearing plate contacted vehicle’s front end.

0.154	Left-rear tire was airborne.
0.160	Bearing plate lost contact with vehicle at right-front quarter panel.
0.162	Guardrail rotated backward.
0.164	Guardrail twisted 180 degrees.
0.216	Right-rear wheel rose into air.
0.248	Vehicle exited system at speed of 32.2 mph (51.8 km/h) and angle of 15.9 degrees.
0.356	Left-front wheel rose into air.
0.358	Guardrail at post no. 27 buckled.
0.436	Vehicle yawed toward system.
0.512	Right-rear tire contacted ground level.
0.594	Left-rear tire re-contacted ground.

14.5 Barrier Damage

Damage to the barrier was extensive, as shown in Figures 152 through 156. Barrier damage consisted of deformed W-beam rail and guardrail posts, disengaged rail and wood blockouts, contact marks on posts and guardrail, and fractured end anchorage BCT posts. The length of vehicle contact along the barrier, which spanned from the actual impact point, was approximately 12 ft – 5 in. (3.8 m), at 4 in. (102 mm) upstream from the midspan between post nos. 27 and 28, to 5 in. (127 mm) upstream from the end of the guardrail.

Kinks in the top corrugation of the rail were found between post nos. 28 and 29, as shown in Figures 152 through 156. Flattening of the bottom corrugation of rail started at 4 in. (102 mm) upstream from post no. 28 and extended through 6 in. (152 mm) upstream from post no. 29. The bolt pulled through the W-beam rail slots at the post connections between post nos. 27 and 29, as shown in Figure 153. The W-beam rail buckled at post no. 27, and plastic deformation occurred on the top side of the W-beam rail slot at post nos. 27 through 29, as shown in Figure 154. The upper-front corner of the wood blockout at post no. 27 was fractured off and a ⅜-in (10-mm) gap formed between the blockout and the front flange of the post. A ½-in. (13-mm) soil gap formed in front of post no. 27, as shown in Figure 155. Post no. 28 fractured into three pieces beginning at the bolt connection to the rail through the ground line. Post no. 29 fractured at the ground line.

The swage connector between the downstream anchor cable and the corresponding bearing plate was bent, and the metal sleeve through which the cable passed was deformed, as shown in Figure 156. The ground strut connecting the foundation tubes of post nos. 28 and 29 had contact marks, and the foundation tube of post no. 28 was bent backward.

The separation between the W-beam sections and the slippage of the connection bolts were measured for the five most downstream splice joints. The maximum separation between the W-beam sections was ½ in. (13 mm) long and occurred at the splice connections between post nos. 20 and 21. A ⅜-in. (10-mm) long separation occurred at the splice connection between post nos. 22 and 23, while the two splices between post nos. 25 and 28 were separated ¼ in. (6 mm) longitudinally. A minimum separation of ⅛ in. (3 mm) was measured for the splice connection between post nos. 24 and 25. A summary of the splice separation together with details of the slippage for each of the splice bolts is provided in Appendix G.

The permanent set of the rail and post was 9 ft – 6¼ in. (2.9 m) at post no. 29 and 2 in. (51 mm) at post no. 27, respectively, as measured in the field. The maximum rail and post dynamic deflection was 12 ft – 3.3 in. (3.7 m) at the downstream end of the W-beam rail and 14 in. (356 mm) at post no. 28, respectively, as determined from high-speed digital video analysis. The working width of the system coincided with the lateral dynamic barrier deflection, which was 12 ft – 3.3 in. (3.7 m). It should be noted that the values for the permanent set and dynamic deflection of the barrier were calculated based on the farthest position of the buffer end after the W-beam rail, which disengaged from post nos. 28 and 29, rotated backward almost 90 degrees around post no. 27 where the initial impact point occurred. No vehicle working width data was collected from the vehicle, because the terminal gated and the vehicle was not redirected.

14.6 Vehicle Damage

The damage to the vehicle was extensive, as shown in Figures 157 through 161. The maximum occupant compartment deformations are listed in Table 17 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix H.

Table 17. Maximum Occupant Compartment Deformations by Location, Test No. WIDA-2

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	1 (25)	≤ 9 (229)
Floor Pan & Transmission Tunnel	½ (13)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	¼ (6)	≤ 12 (305)
Side Door (Above Seat)	½ (13)	≤ 9 (229)
Side Door (Below Seat)	½ (13)	≤ 12 (305)
Roof	0	≤ 4 (102)
Windshield	½ (13)	≤ 3 (76)

The majority of the damage was concentrated on the vehicle's front end, including both the left-front and right-front quarter panels due to contact with the barrier posts, rail, and the bearing plate attached to end of the cable anchor. The front end crushed inward, with a consequent deformation of the left-front and right-front fenders. The front bumper was completely detached, and the supporting bracket plate behind the bumper was dented. The left-side headlight assembly was partially disengaged. The radiator grill and right-side headlight assembly were disengaged from the vehicle. The radiator crushed back to the engine compartment and was partially twisted. The engine deformed backwards. The hood disconnected and was located against the vehicle's left-front fender with its front crushed in and the right corner deformed beneath below.

The left-front fender crushed inward, and a 1-in. (25-mm) separation was found between the left-front door and the back of the fender. The right-front fender crushed inward and back with a tear above the wheel well. Contact marks, denting, and scraping were observed on the right side of the vehicle. The right-front tire was partially de-beaded, and the internal-side rim was bent. The lower control arm of the right-front suspension disengaged.

The windshield, which separated from the vehicle in the early stage of the crash test, was located downstream from the vehicle and encountered spider-web cracks. The windshield sealing tape running around the vehicle frame had several irregularities, which indicated that a post-factory windshield installation was made with poor quality. In particular, the presence of dirt surrounding the sealing tape connection with the upper part of the windshield indicated that the glue did not adhere properly. The roof and remaining window glass remained undamaged. A dent was located at the center of the right A-pillar. Traces of yellow paint used to identify the bearing plate in the high-speed videos were found on the front bumper supporting rail, the engine alternator, the lower-right corner of the right-front suspension, and the right-front quarter panel, as shown in Figures 161 and 162.

14.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 18. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 18. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 129. The recorded data from the accelerometers and the rate transducers are shown graphically in

Appendix I. Due to technical difficulties, the DTS unit did not collect angular data from the rate transducer, but the DTS did collect acceleration data.

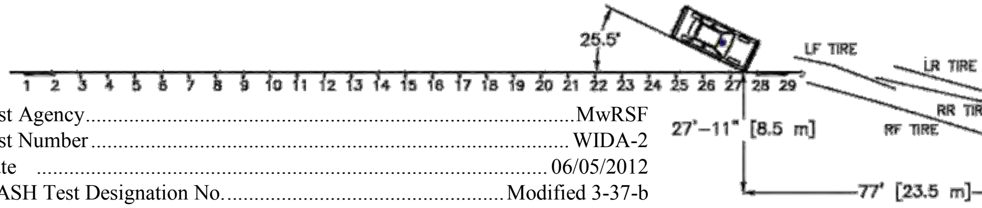
Table 18. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. WIDA-2

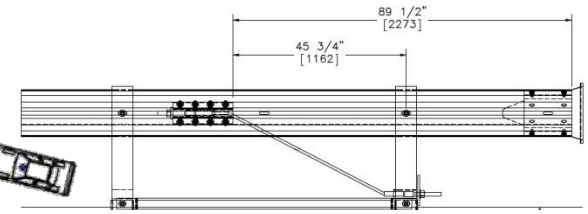
Evaluation Criteria		**Transducer**			**MASH Limits**
		EDR-3	**DTS**	**DTS-SLICE**	
OIV ft/s (m/s)	Longitudinal	-37.06 (-11.30)	-34.89 (-10.63)	-36.56 (-11.14)	≤ 40 (12.2)
	Lateral	-15.22 (-4.64)	-15.64 (-4.77)	-14.46 (-4.41)	≤ 40 (12.2)
ORA g's	Longitudinal	-14.87	-14.89	-14.77	≤ 20.49
	Lateral	4.13	-4.53	5.32	≤ 20.49
THIV ft/s (m/s)		NA	NA	42.24 (12.87)	not required
PHD g's		NA	NA	11.48	not required
ASI		1.34	1.29	1.31	not required

14.8 Discussion

The analysis of the test results for test no. WIDA-2 showed that the non-proprietary, downstream end anchor system (i.e., trailing-end terminal) did not adversely affect the stability of the 1100C vehicle. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix I, were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. Therefore, test no. WIDA-2 was determined to be acceptable according to the MASH safety performance criteria for modified test designation no. 3-37.

0.000 sec | 0.146 sec | 0.260 sec | 0.414 sec | 0.678 sec





- Test Agency .... MwRSF
- Test Number WIDA-2
- Date 06/05/2012
- MASH Test Designation No. .... Modified 3-37-b
- Test Article .... MGS with MGS End Anchorage
- Total Length .... 181 ft – 3 in. (55.3 m)
- Key Component – W-Beam Rail
  - Thickness .... 12 gauge (2.66 mm)
  - Top Mounting Height .... 32 in. (813 mm)
- Key Component – Line Posts (Nos. 3-27)
  - Type W6x8.5 (152x12.6)
  - Length .... 72 in. (1,829 mm)
  - Spacing .... 75 in. (1,905 mm)
  - Material .... ASTM A992 or A36
- Key Component – Wood Spacer Blocks
  - Dimensions .... 6 x 12 x 72 in. (152 x 305 x 1,829 mm)
- Key Component – MGS End Anchorage
  - BCT Post Dimensions .... 5 ½ x 7 ½ x 46 in. (140 x 191 x 1,168 mm)
  - BCT Post Material .... SYP Grade 1
  - Foundation Tube Dimensions .... 6 x 8 x $^3/_{16}$ x 72 in. (152 x 203 x 5 x 1,829 mm)
  - Foundation Tube Material .... ASTM A53 Grade B
  - Strut and Yoke Assembly .... ASTM A36 Galvanized
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make /Model .... 2006 Kia Rio
  - Curb .... 2,491 lb (1,130 kg)
  - Test Inertial .... 2,449 lb (1,111 kg)
  - Gross Static .... 2,619 lb (1,188 kg)
- Impact Conditions
  - Speed .... 62.0 mph (99.8 km/h)
  - Angle (vehicle c.g.) .... 25.5 deg
  - Angle (vehicle orientation) .... 21.2 deg
  - Impact Location 4 in. (102 mm) US of midspan btwn post nos. 27 & 28
- Exit Conditions
  - Speed .... 32.2 mph (51.8 km/h)
  - Angle (vehicle c.g.) .... 15.9 deg
  - Angle (vehicle orientation) .... 28.0 deg

- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 77 ft (23.5 m) downstream
  27 ft – 11 in. (8.5 m) laterally behind
- Vehicle Damage .... Extensive
  - VDS[39] 1-RFQ-6
  - CDC[40] 01-FDAW-5
  - Maximum Interior Deformation .... 1 in. (25 mm)
- Test Article Damage .... Extensive
- Maximum Test Article Deflections
  - Permanent Set .... 9 ft – 6¼ in. (2.9 m)
  - Dynamic .... 12 ft – 3.3 in. (3.7 m) (*)
  - Working Width .... 12 ft – 3.3 in. (3.7 m) (*)
- Impact Severity (IS) .... 58.3 kip-ft (79.0 kJ) > 51 kip-ft (69.7 kJ) MASH limit
- Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		EDR-3	DTS	DTS-SLICE	
OIV ft/s (m/s)	Longitudinal	-37.06 (-11.30)	-34.89 (-10.63)	-36.56 (-11.14)	≤ 40 (12.2)
	Lateral	-15.22 (-4.64)	-15.64 (-4.77)	-14.46 (-4.41)	≤ 40 (12.2)
ORA g's	Longitudinal	-14.87	-14.89	-14.77	≤ 20.49
	Lateral	4.13	-4.53	5.32	≤ 20.49
THIV – ft/s (m/s)		N/A	N/A	42.24 (12.87)	Not required
PHD – g's		N/A	N/A	11.48	Not required
ASI		1.34	1.29	1.31	Not required
Roll Angle – degree		N/A	N/A	10.5	75
Pitch Angle – degree		N/A	N/A	-7.4	75
Yaw Angle - degree		N/A	N/A	33.1	N/A

(*)W-beam rotated backward almost 90 degrees. Vehicle was not redirected.

Figure 145. Summary of Test Results and Sequential Photographs, Test No. WIDA-2

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0.050 sec

0.098 sec

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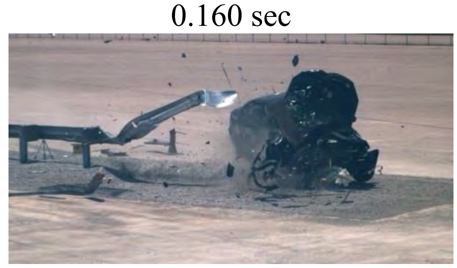
0.142 sec

0.160 sec

0.190 sec



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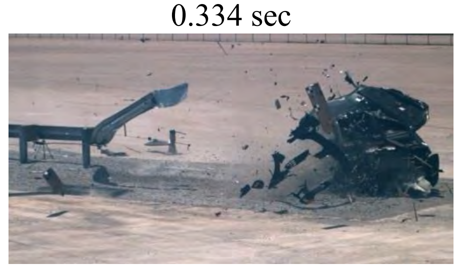
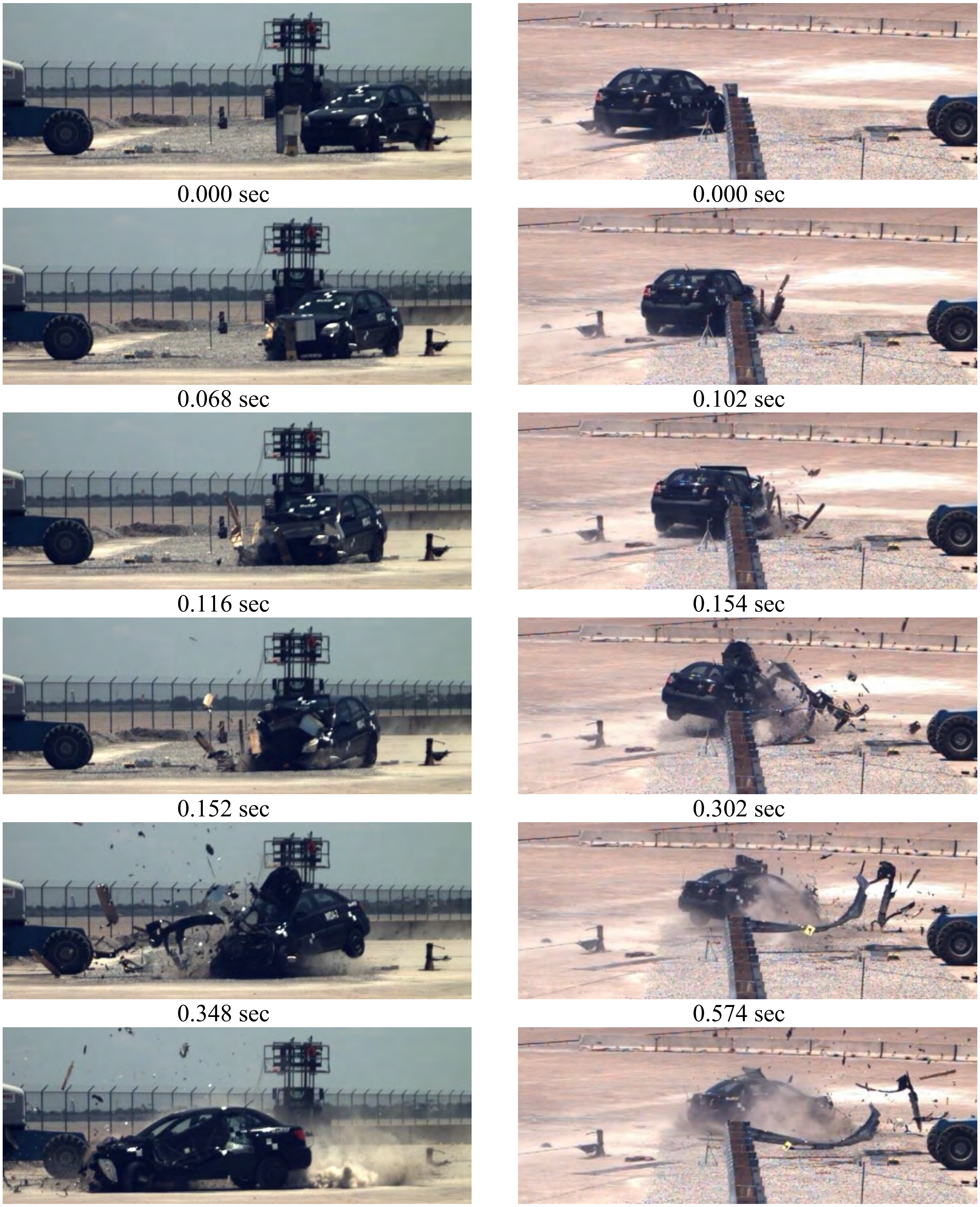


0.458 sec

Figure 146. Additional Sequential Photographs, Test No. WIDA-2



0.000 sec | 0.000 sec
0.068 sec | 0.102 sec
0.116 sec | 0.154 sec
0.152 sec | 0.302 sec
0.348 sec | 0.574 sec
0.912 sec | 0.690 sec

Figure 147. Additional Sequential Photographs, Test No. WIDA-2

Figure 148. Additional Sequential Photographs, Test No. WIDA-2

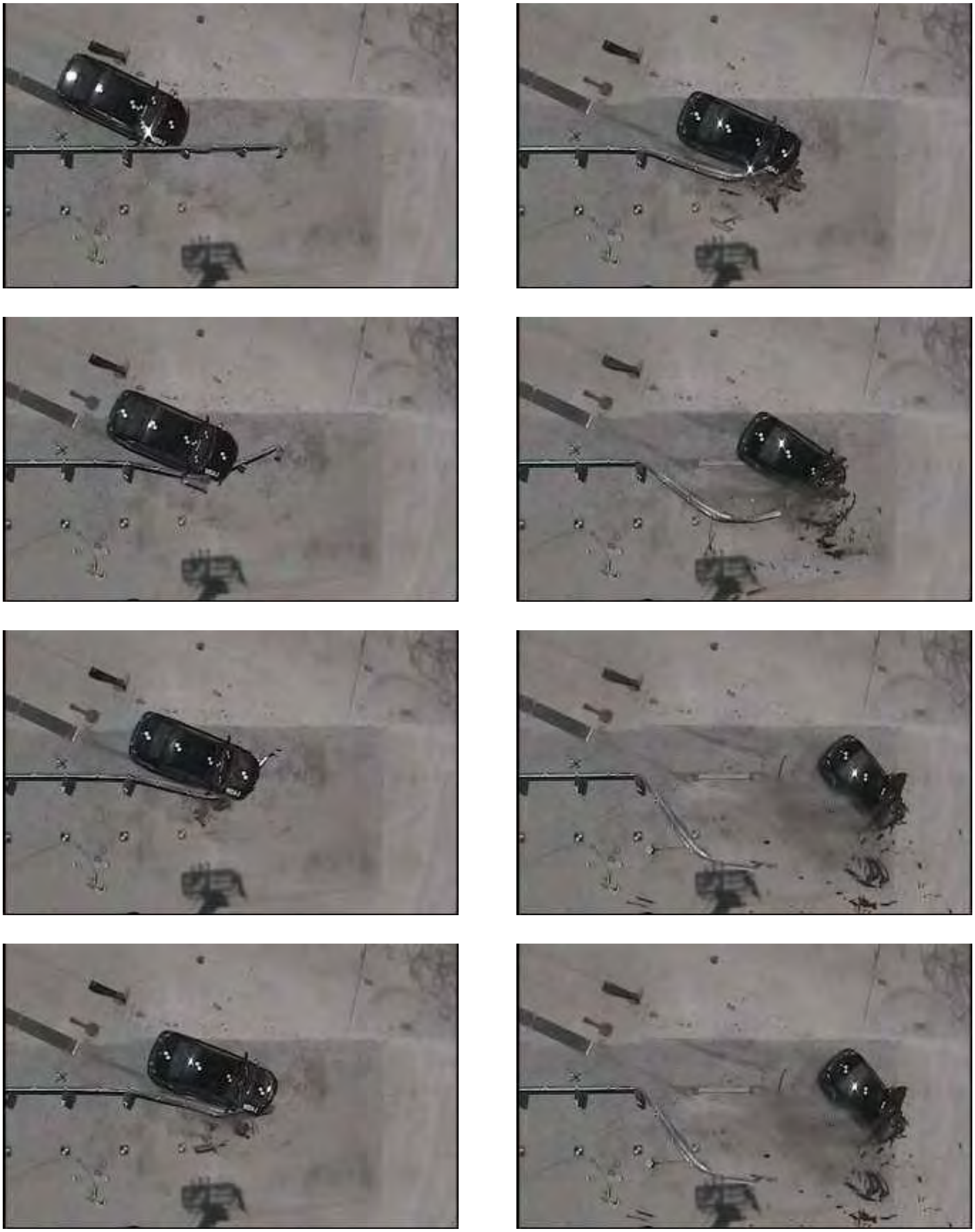


Figure 149. Documentary Photographs, Test No. WIDA-2

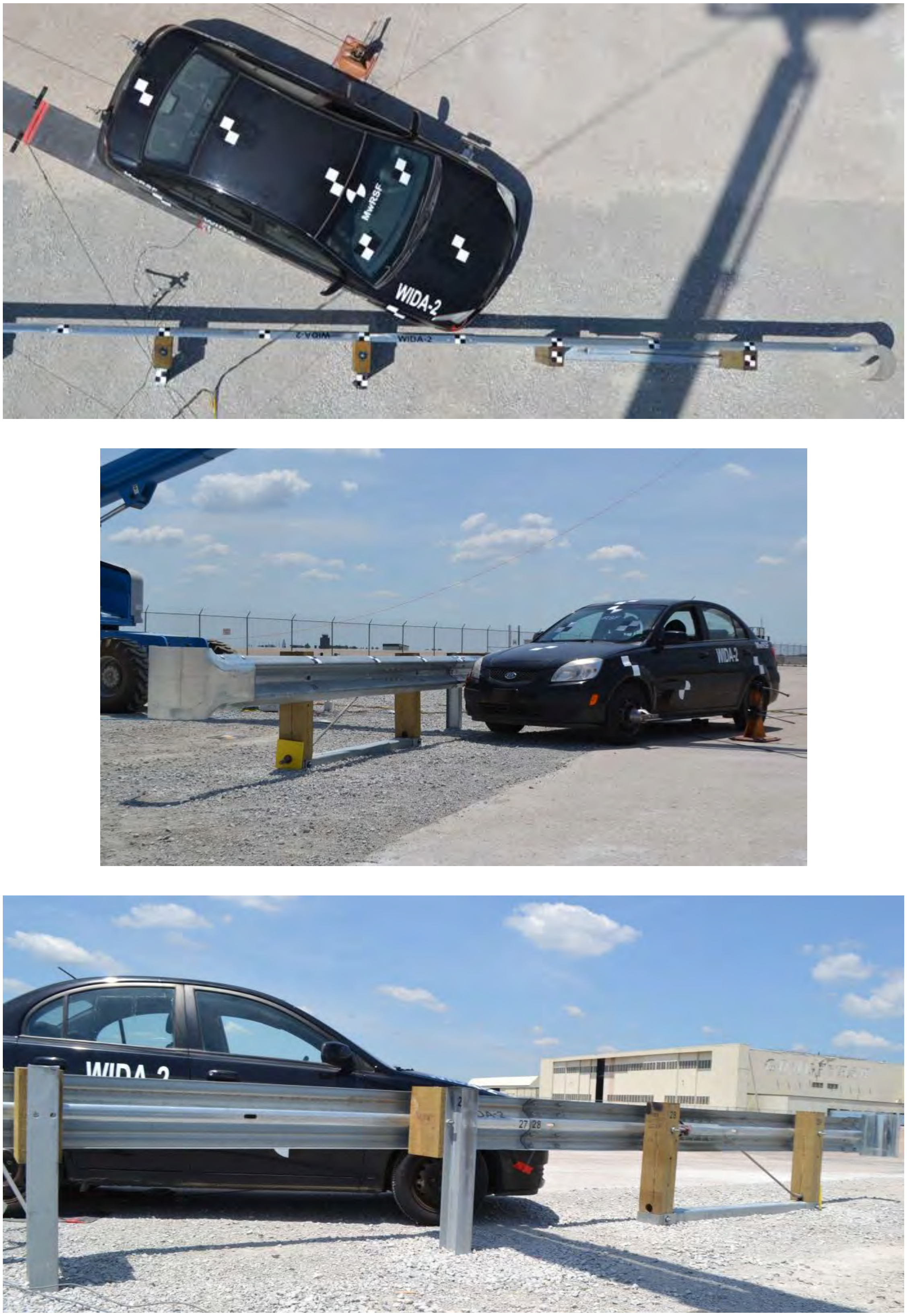


Figure 150. Impact Location, Test No. WIDA-2

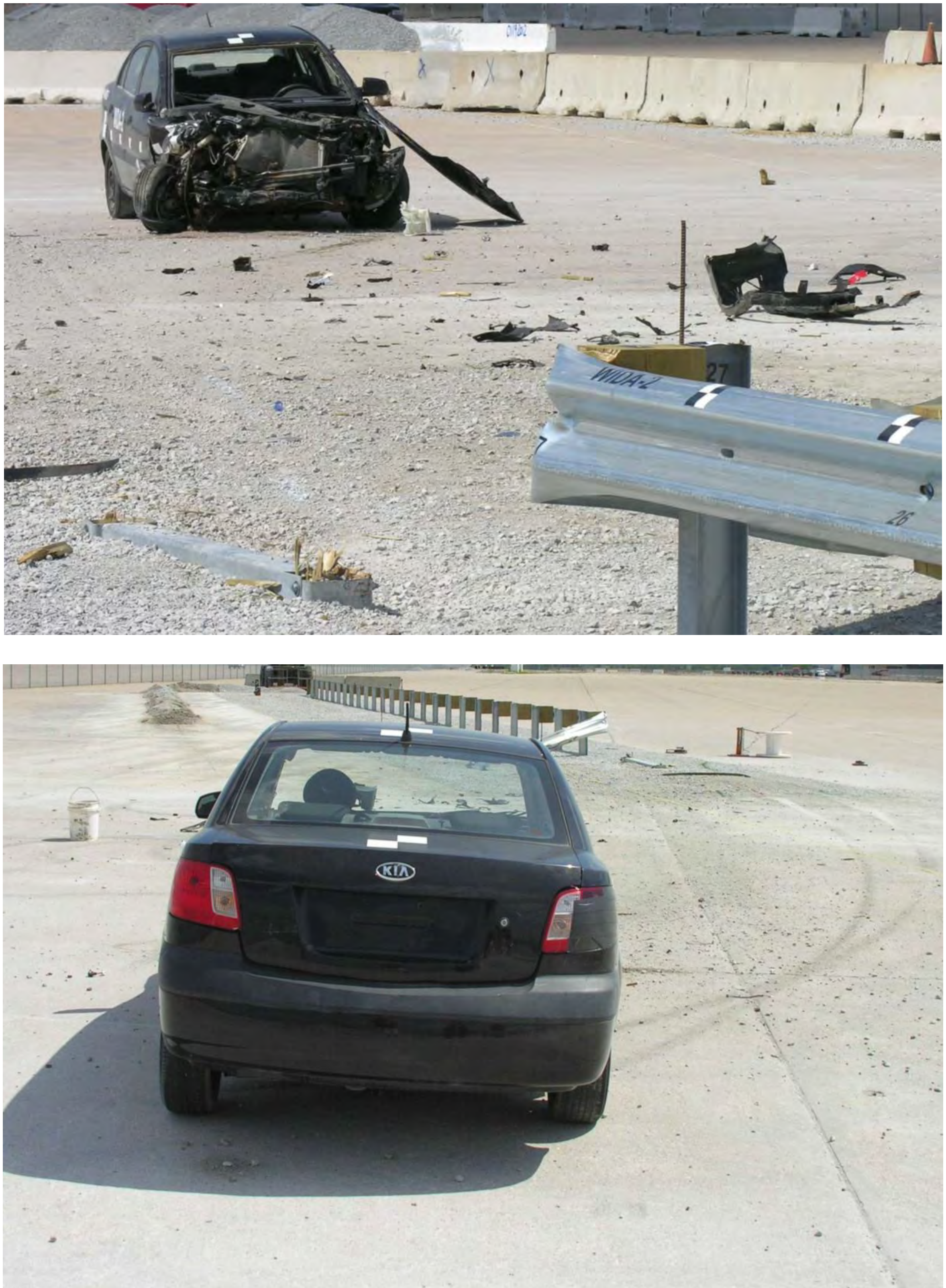


Figure 151. Vehicle Final Position and Trajectory Marks, Test No. WIDA-2

Figure 152. System Damage, Test No. WIDA-2

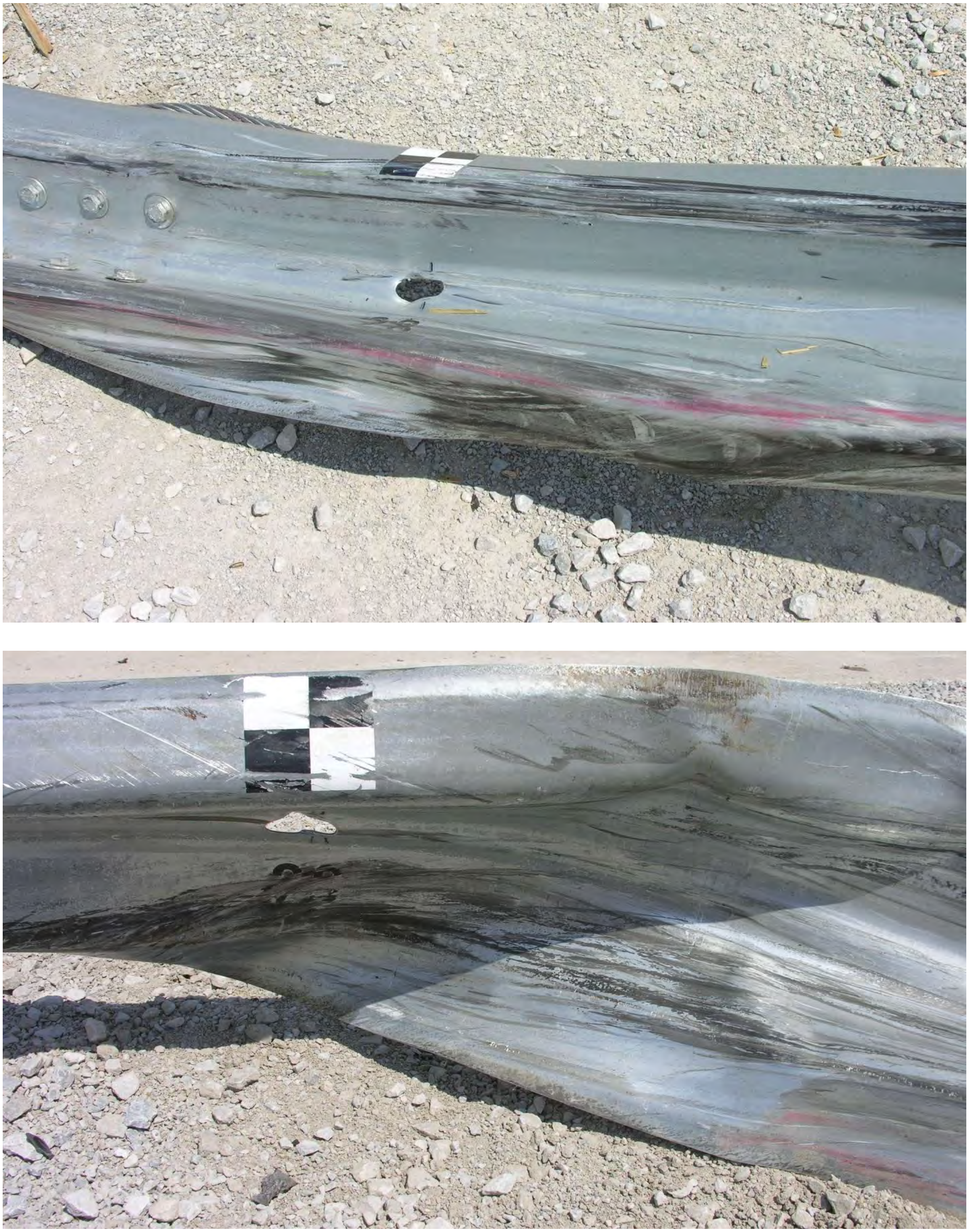


Figure 153. Rail Slot Tearing at Post Nos. 27 and 29, Test No. WIDA-2

Figure 154. Rail Damage, Test No. WIDA-2

221

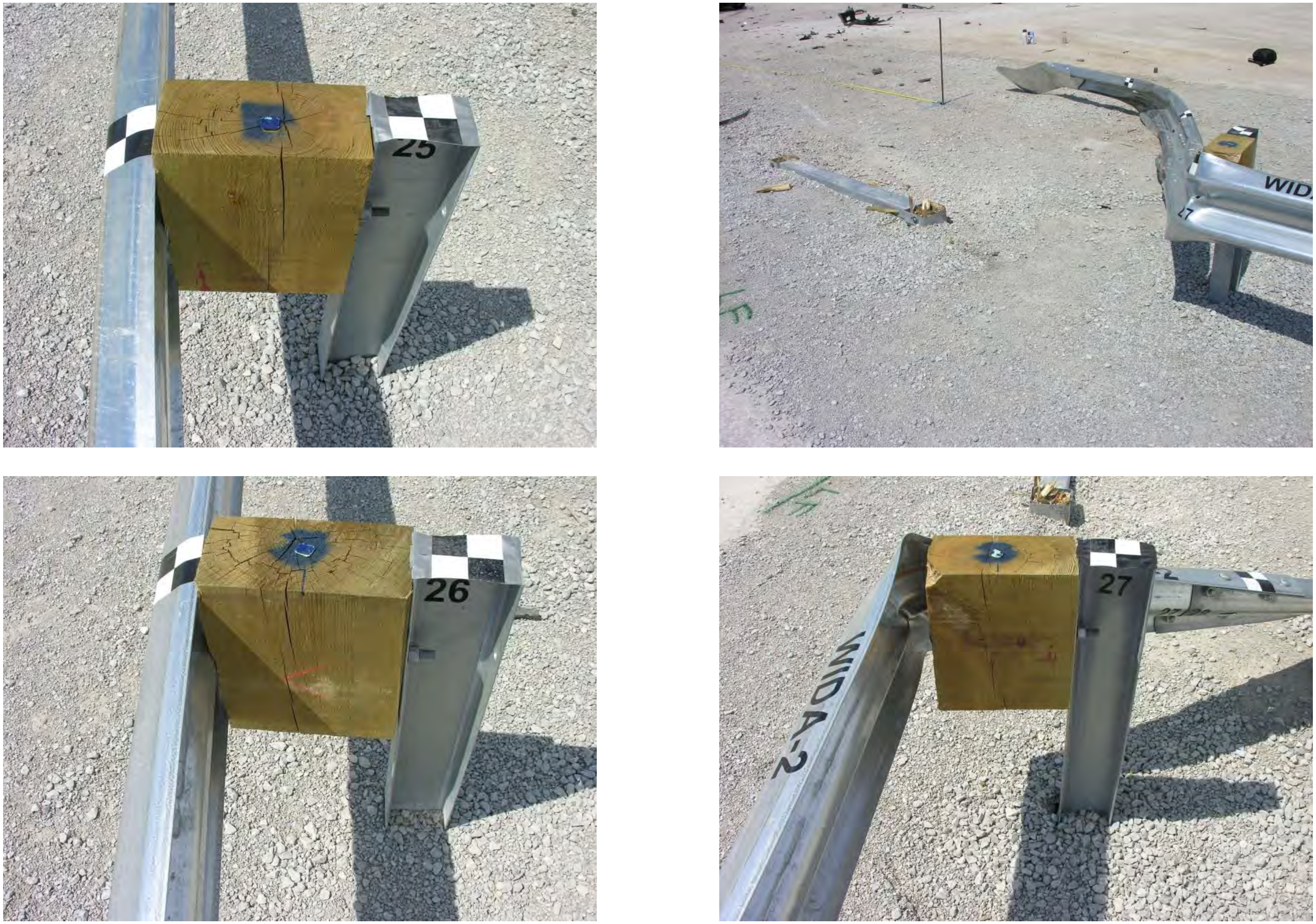


Figure 155. System Damage at Post Nos. 25 through 29, Test No. WIDA-2

Figure 156. Anchor Cable Damage, Test No. WIDA-2

Figure 157. Vehicle Damage, Test No. WIDA-2

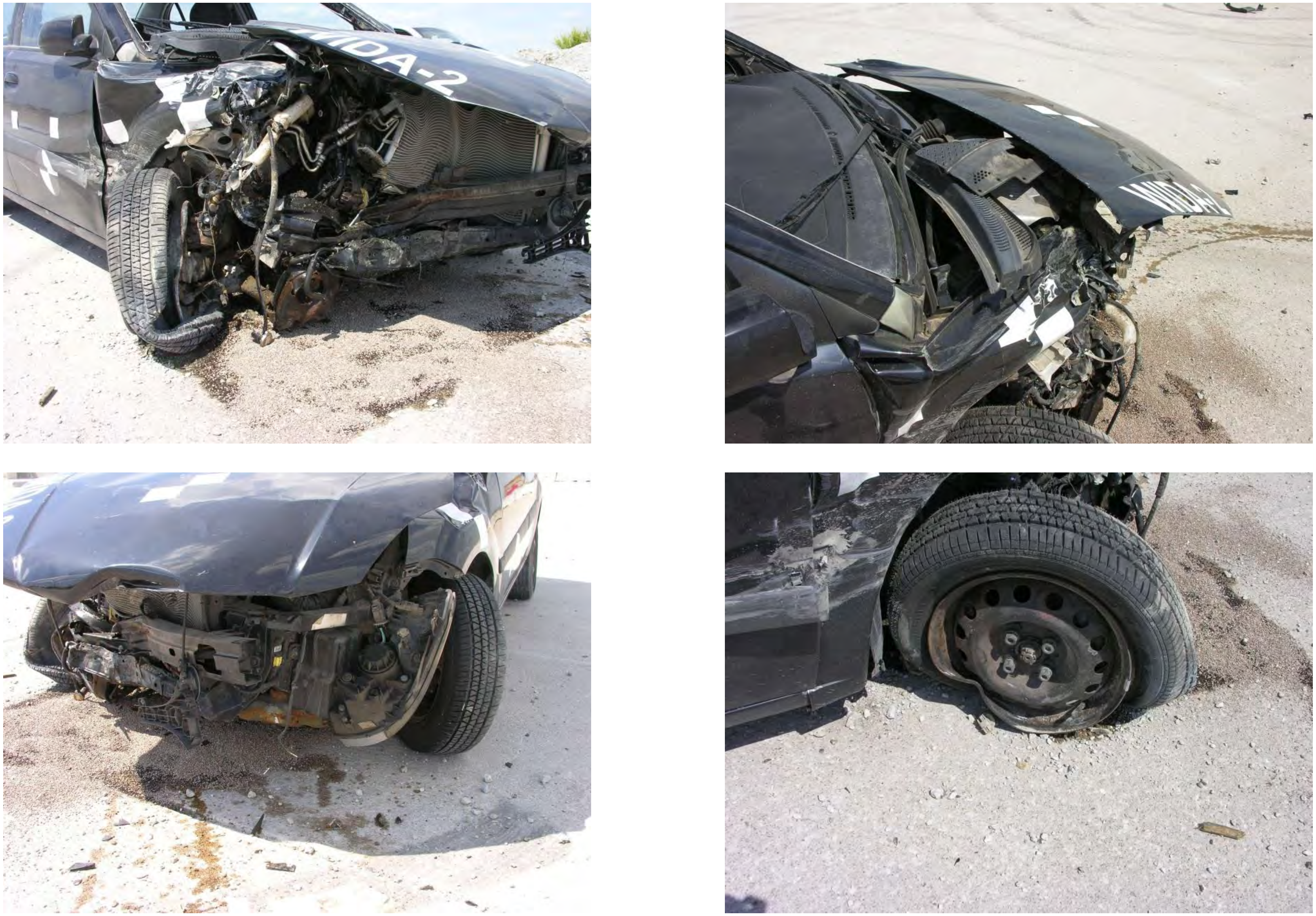


Figure 158. Vehicle Damage, Test No. WIDA-2

Figure 159. Vehicle Damage - Windshield Glue Strip, Test No. WIDA-2

Figure 160. Vehicle Damage - Windshield, Test No. WIDA-2

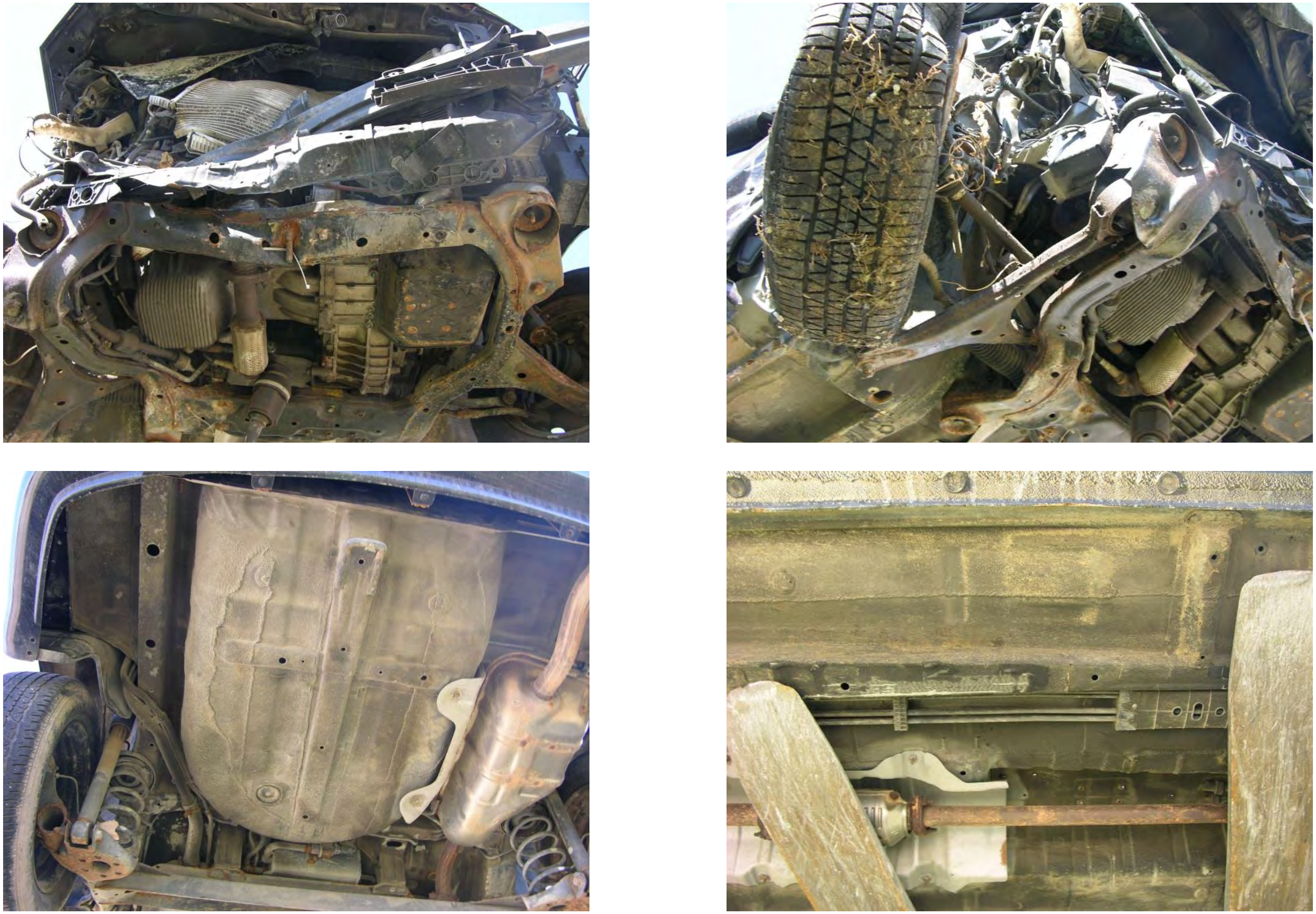


Figure 161. Vehicle Undercarriage Damage, Test No. WIDA-2

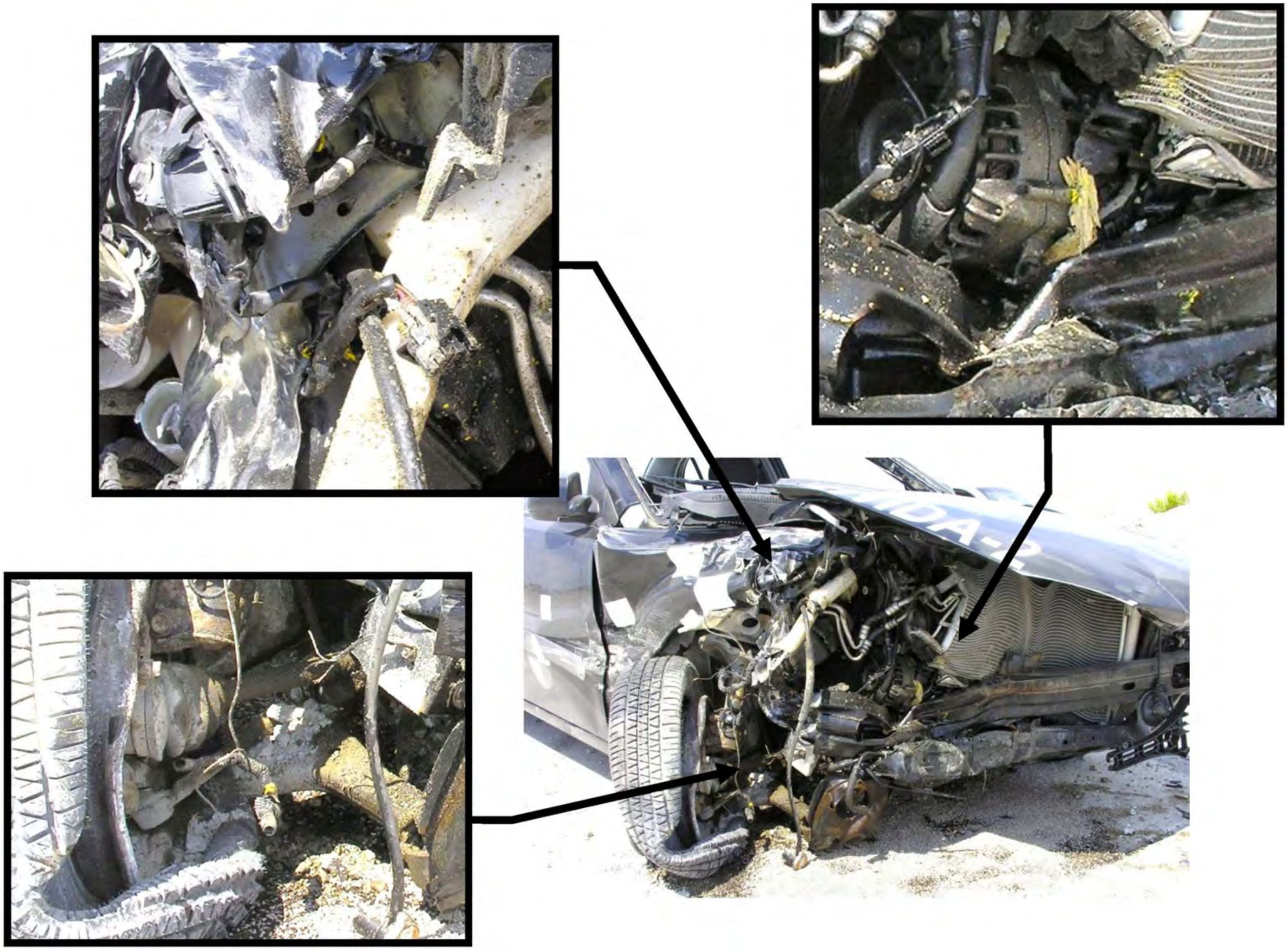


Figure 162. Traces of Bearing Plate Motion Path along Vehicle’s Front End, Test No. WIDA-2

15 ANALYSIS AND DISCUSSION

During test no. WIDA-2, the 1100C vehicle experienced substantial snag on the downstream end anchorage, which lead to a longitudinal OIV value close to the maximum MASH acceptable limit. The peak longitudinal deceleration measured at the vehicle's c.g. occurred when the vehicle's front end contacted the bearing plate. This chapter provides an analysis of the potential causes for this vehicle snag.

As indicated by an analysis of the high-speed videos, the bearing plate slid along the right-front end of the vehicle and then onto the side of the right-front quarter panel. Eventually, the bearing plate lost contact with the vehicle after tearing the sheet metal of the right-front quarter panel above the right-front wheel well. Further, traces of the yellow-colored paint used to identify the bearing plate were found along the motion path of the plate while contacting vehicle components, such as the front bumper supporting rail, the radiator, the engine alternator, and the sheet metal of the right-front quarter panel, as shown in Figure 162. Due to the debris and dust that were covering the view of the high-speed video cameras, it was not always possible to clearly identify the location of the anchor cable when the right-front wheel was passing in close proximity to the cable during the impact event. In particular, it was not possible to directly determine whether the cable anchor slid onto the inner side of the impacting tire. Nevertheless, indirect evidence that the cable moved to the inner side of the tire is provided by the analysis of some events occurring immediately before or after the time during which the cable anchor was not visible in the high-speed videos. A description of this indirect evidence is provided in the following paragraphs.

Inspection of video, barrier damage, and vehicle damage indicated that the impacting tire slid under the anchor cable. This evidence was provided by the sudden rotation of the end wood post after it fractured at its base as a consequence of a direct impact with the vehicle's front bumper. Although the end post was already tilted more than 45 degrees with respect to its initial vertical configuration, it abruptly began to rotate as a consequence of a pull force applied by the bearing plate, which was still in contact with the fractured post base. The sequence of this rotation event is shown in Figure 163. The sudden tensioning of the anchor cable indicated that the right-front tire wedged under the cable. Further, the wedging under the cable anchor may have been facilitated by a preexisting outward tilt angle of the wheel after it snagged on the previous BCT wood post. In fact, a post-impact investigation showed a large deformation of the external side of the right-front rim, thus indicating considerable snag occurred on the wood post immediately upstream from the end post. This first snag event may have been the cause for the disengagement of the lower suspension arm from the vehicle frame. As a consequence of the damage to the corresponding suspension, the right-front wheel may have been deformed toward the barrier prior to impact with the second BCT post and anchor cable.

Figure 163. Spinning of Downstream Anchor End Post, Test No. WIDA-2

Further, evidence suggests that after initially sliding on the top of the wheel, the cable likely slid on the inner side of the tire. In fact, had the cable been in contact with the outer side of the wheel, it would have been immediately pushed backward, and the bearing plate would have been unable to contact the vehicle's front end and right-front side.

16 DESIGN GUIDELINES FOR MGS DOWNSTREAM END ANCHORAGE

LS-DYNA computer simulations were conducted for impacts occurring downstream from the identified end of the LON (i.e., the sixth post from the downstream end of the rail) using the 2270P pickup truck. These runs indicated that the post impact trajectory would be largely parallel with the barrier, and larger lateral vehicle penetrations would be expected for impacts occurring into the remaining downstream segment of the barrier and trailing-end terminal. For those cases where the vehicle would be allowed to safely travel behind the barrier within the clear zone located downstream from the end post, it would still be possible to shield hazards located farther behind the guardrail if larger system deflections and vehicle penetrations were allowed. As such, guidelines were proposed for shielding hazards located in close proximity to the crashworthy MGS downstream end anchorage system.

The comparison between simulated and actual vehicle kinematics during full-scale vehicle crash test no. WIDA-1 indicated that the numerical model can reasonably replicate an impact in close proximity to the tested, non-proprietary, MGS downstream anchorage system with the 2270P pickup truck. A comparison of the simulated and actual kinematics during test no. WIDA 1 is shown in Figures 164 and 165. A comparison of simulated and actual maximum penetration of the pickup truck at each post location is shown in Figure 166.

Actual and simulated dynamic deflections of the 2270P pickup impacting the 181 ft – 3 in. (55.3 m) long MGS at approximately 62.1 mph (100 km/h) and 25 degrees were used to develop placement guidelines for shielding hazards located in close proximity to the downstream end of a 31-in. (787-mm) tall barrier. These guidelines were based on the predicted maximum penetration of the 2270P vehicle at each post location utilizing various initial impact points along the MGS and the downstream anchorage system obtained from the simulation and full-scale crash test.

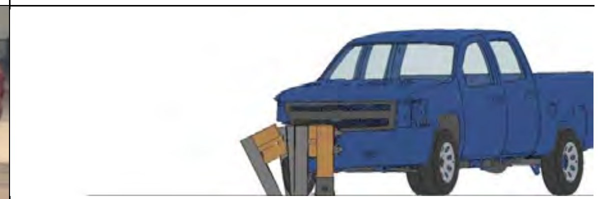
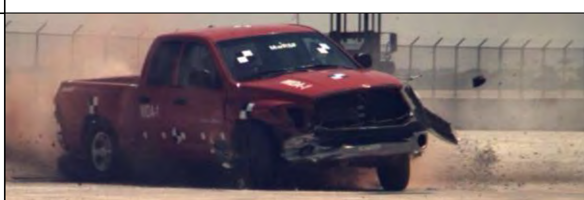
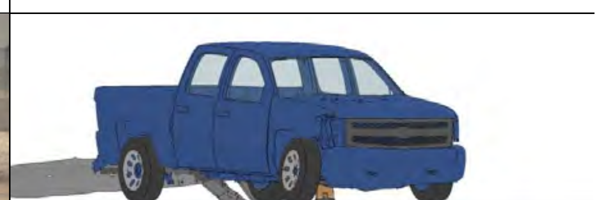
Time	Full-Scale Crash Test	Predicted Kinematics
0.080 sec		
0.290 sec		
0.450 sec		
0.608 sec		
0.810 sec		
1.090 sec		

Figure 164. Redirection of 2270P at Identified End of LON

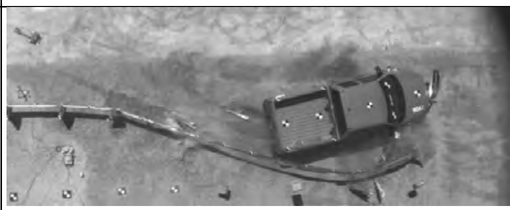
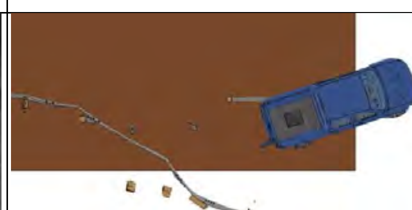
Time	Full-Scale Crash Test	Predicted Kinematics
0.080 sec		
0.290 sec		
0.450 sec		
0.608 sec		
0.810 sec		

Figure 165. Redirection of 2270P at Identified End of LON

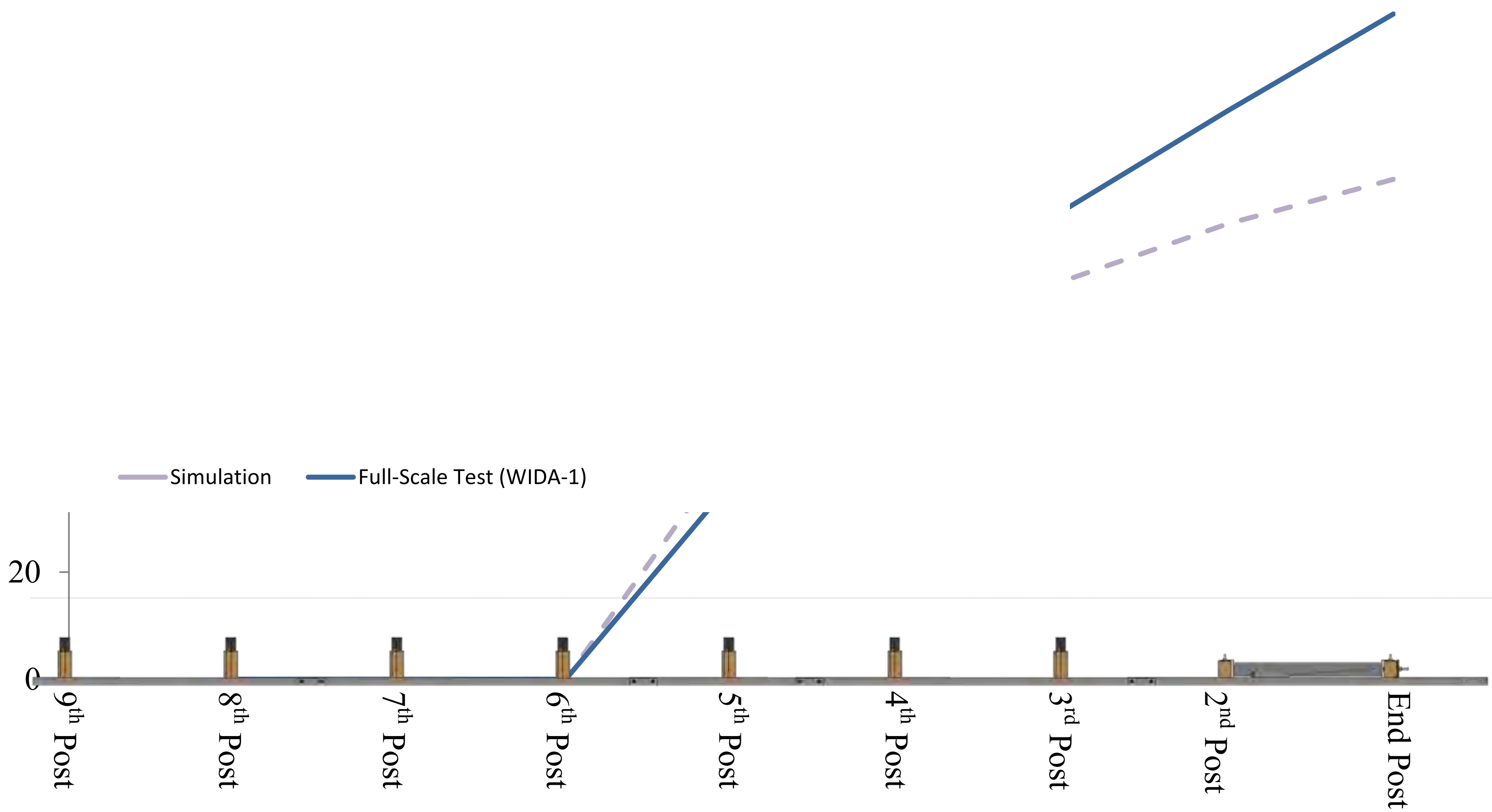


Figure 166. Predicted and Actual Maximum Penetration of 2270P in Test No. WIDA-1

The maximum lateral pickup truck penetration predicted at each post location downstream of simulated initial impact points varying between the second and the ninth posts from the downstream end anchor post are tabulated in Table 19. The vehicle penetration values measured from the high-speed videos of test no. WIDA-1 are also shown in Table 19.

Table 19. Maximum Lateral Vehicle Displacement of 2270P for Simulated Impact Scenarios and Test no. WIDA-1

Impact point – Post Number Increasing from Downstream End of Rail	Maximum Lateral Vehicle Displacement (in.) Post Number Increasing from Downstream End of Rail (1)							
	1st	2nd	3rd	4th	5th	6th	7th	8th
2nd	34	0						
2nd + ½ span	52	20						
2nd + ¾ span	58	27						
3rd	71	38	0					
4th	98 (98)	73 (71)	41 (44)					
5th	124 (103)	95 (81)	71 (60)	45 (43)				
6th (2) End of LON	93 (113)	85 (99)	74 (83)	63 (69)	43 (45)			
6th (2) Test WIDA-1	124	106	87	65	37			
7th	22 (0)	37 (29)	43 (47)	56 (61)	61 (62)	43 (44)		
8th	0 (NA(3))	0 (NA(3))	21 (24)	40 (41)	53 (53)	57 (57)	45 (46)	
9th	0 (0)	0 (0)	0 (0)	19 (18)	39 (35)	52 (49)	56 (55)	45 (45)

(1) Values in parentheses indicate case with suspension failure (for impacts between the 9th and 4th post from downstream)
(2) End of LON
(3) Simulation terminated due to numerical instabilities

Simulations predicted vehicular redirection for all impacts occurring upstream from the sixth post from the downstream end of the rail. For impacts occurring at the ninth, eighth, and seventh posts upstream from the downstream end of the rail, the maximum vehicle dynamic deflections occurred two spans downstream from the corresponding initial impact point and were

56 in., 57 in., and 61 in. (1,422 mm, 1,448 mm, and 1,549 mm), respectively. These values are consistent with a maximum MGS working width of about 60 in. (1,524 mm), as evaluated from previous full-scale crash tests. As such, a conservative safe distance of 60 in. (1,524 mm) was proposed for locations upstream from the fifth post away from the downstream end of the rail. However, it should be noted that some decreased adjustment in the proposed minimum required working width of 60 in. (1,524 mm) could be made for locations upstream from the seventh post from the downstream end of the rail. Of course, the reduced working width should be determined by the results observed in a crash testing program for specific variations of the 31-in. (787-mm) tall MGS.

For an impact at the sixth post from the downstream end of the rail, the simulated maximum vehicle penetration was similar to the full-scale crash test for the first two spans after the initial contact (i.e., until the fourth post from the end of the simulated rail). Beyond that point, the simulation underestimated the actual measured vehicle penetration. The penetration curve derived from the full-scale crash test was considered for post locations at or downstream from the fourth post from the downstream end of the rail, with a maximum penetration of 65 in., 87 in., 106 in., and 125 in. (1,651 mm, 2,210 mm, 2,692 mm, and 3175 mm), at the fourth, third, second, and end posts, respectively.

The proposed guidelines for shielding hazards located in close proximity to the downstream end of a 31-in. (787-mm) tall barrier when using the crashworthy MGS downstream anchorage system are shown in Figure 167. Assuming a full-gating condition as a worst-case scenario for an impact at or downstream from the fifth post from the downstream end of the rail, the corresponding penetration curve would be a straight line at an angle of 25 degrees with respect to the horizontal axis. Although a full-gating scenario is very improbable for an initial impact at the fifth post from the downstream end of the rail, this new penetration curve would intersect the boundary previously considered for safe hazard placement at the second post from the downstream end of the rail. Thus, this curve of a hypothetical full-gate penetration could be considered downstream of the second post from the downstream end of the rail in case of a highly dangerous hazard, such as a tree or a pillar.

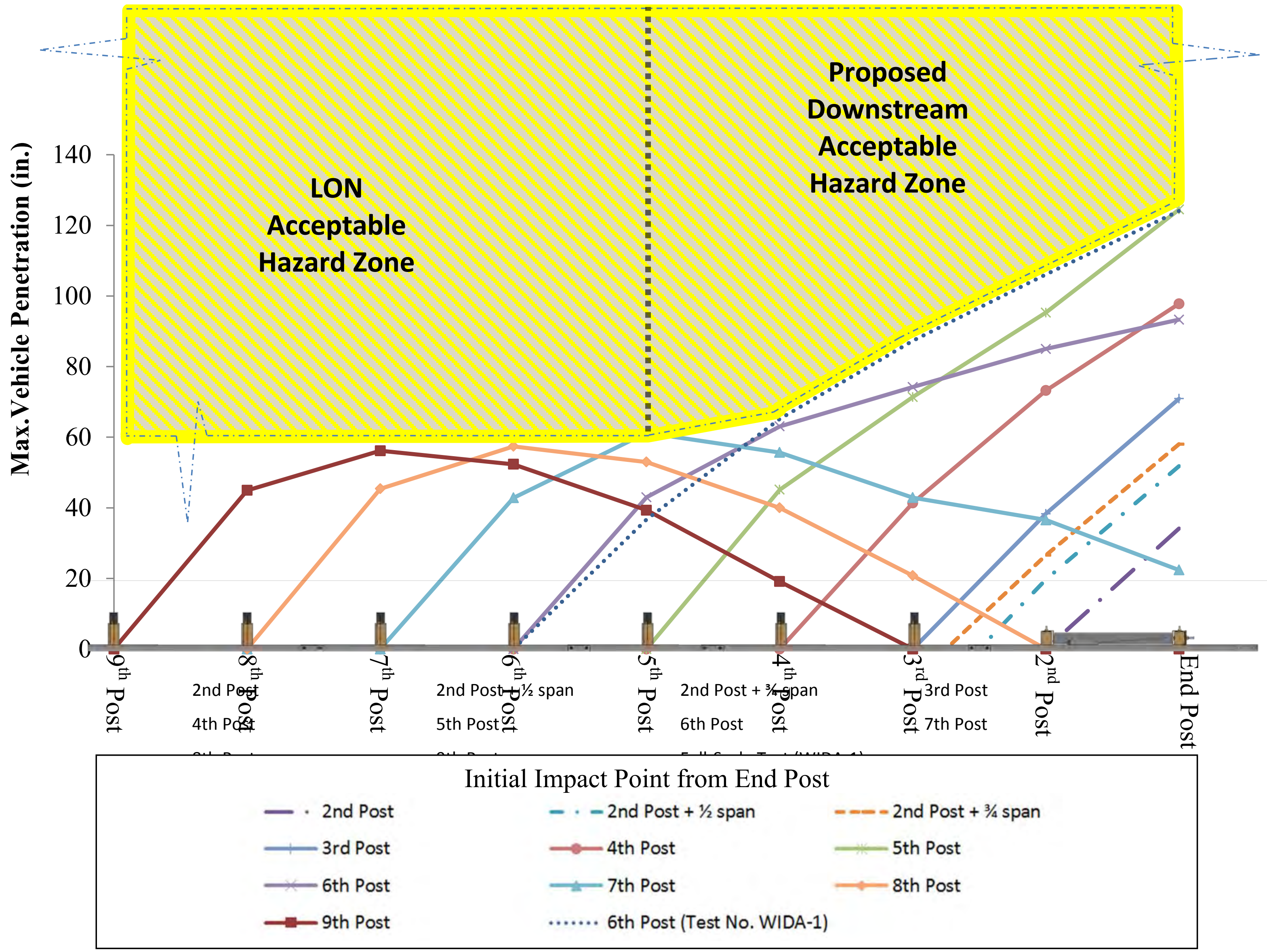


Figure 167. Proposed MGS Placement Guidelines for Shielding Hazards Near MGS Downstream End Anchorage or Trailing-End Terminal

17 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Component tests were conducted on critical components of the non-proprietary trailing-end anchorage system (MGS end anchorage). Test nos. BCTRS-1 and BCTRS-2 consisted of an eccentric bogie impact with a BCT post installed in a rigid sleeve to measure BCT post splitting energies and loads. Loads and energies for the tests were 7.4 kip (32.9 kN) and 19.0 kip-in. (2.1 kJ) for test no. BCTRS-1, versus 3.1 kip (14 kN) and 26.0 kip-in. (2.9 kJ) for test no. BCTRS-2. Test no. MGSEA-1 utilized a bogie weighing 4,753 lb (2,156 kg) and traveling at approximately 16 mph (26 km/h) to pull a soil foundation tube downstream. The peak displacement recorded in the test was 6.5 in. (165 mm), and the maximum load recorded was 43.4 kips (193 kN). These two tests were used to calibrate computer simulation models of end anchorage components. Lastly, a component test of the entire end anchorage assembly was conducted by attaching a pull cable to a section of W-beam guardrail attached to a steel post with blockout and the MGS end anchorage system. The 4,780-lb (2,168-kg) bogie vehicle was accelerated to 25 mph (40 km/h) and used to pull the end anchorage to fracture. The dynamic capacity of the end anchorage system was 35 kip (156 kN), measured by a tension load cell in the BCT anchor cable.

A non-proprietary, downstream end anchorage system for 31-in. (787-mm) tall guardrail was crash tested and evaluated according to the MASH impact safety standards. The anchorage was an adaptation of the original modified BCT anchor system but installed tangent. It consisted of two BCT timber posts set into 6-in. wide x 8-in. deep x 72-in. long (152-mm x 203-mm x 1,829-mm), steel foundation tubes. The two steel foundation tubes were connected at the ground line through a strut and yoke assembly. A ¾-in. (19-mm) diameter 6x19 wire rope connected the back of the W-beam to the bottom of the end post. Two full-scale crash tests were performed on the system under MASH modified designation no. 3-37. Test no. WIDA-1 was conducted with a 5,172-lb (2,346-kg) pickup truck to identify the end of the LON, while test no. WIDA-2 was conducted with a 2,619-lb (1,188-kg) small passenger car to assess any potential vehicle instability. Both tests were performed at a targeted initial impact speed and angle of 62 mph (100 km/h) and 25 degrees, respectively. The top-rail mounting height was 31 in. (787 mm) and 32 in. (813 mm) for test nos. WIDA-1 and WIDA-2, respectively.

Both test nos. WIDA-1 and WIDA-2 satisfied the crash test criteria set for by MASH for a modified test designation no. 3-37, as summarized in Table 20. Test no. WIDA-1 indicated that the 2270P pickup truck was completely redirected for an initial impact occurring at the sixth post from the non-proprietary, downstream MGS end anchorage system. Test no. WIDA-2 with the 1100C small passenger car indicated that, although considerable snag occurred, occupant risk values and vehicle stability were within the MASH acceptable limits.

Researchers believe that there may be some combination of vehicle front-end geometries, slack anchor cables, and rail heights which could culminate in a higher risk of snagging than what was observed in test no. WIDA-2 as well as in the simulations. In the event that a vehicle becomes snagged on the anchor cable, occupant risk criteria may be exceeded, or the vehicle may become unstable. However, the likelihood of a vehicle interacting with a downstream MGS end anchorage system with the necessary combination of high speed, high angle, susceptible front-end profile, and cable geometry necessary to cause snag, which was not observed in the crash test, is relatively low. In addition, there is currently no supporting research to assert that excessively slack anchor cables increase the risk for vehicle snag. However, it is recommended that excessive anchor cable slack be removed to facilitate the development of optimal tension in the rail and to reduce an opportunity for anchor cable snag behind an impacting vehicle's wheel.

Numerical simulations indicated that a simple-support connection between the W-beam rail and the end post would increase the penetration of the cable anchor into the wheel well. Thus, this type of connection is not recommended. Future design improvements should consider either shielding the anchor cable from the tire of the impacting vehicle or allowing the bearing plate to promptly release after the end post fractures. The latter option would eliminate the potential for the vehicle's front end to become being entangled with the cable once it is free to move upon fracture of the end post.

In addition, guardrail placement guidelines were proposed for safely shielding hazards located behind the downstream segment of a 31-in. (787-mm) tall MGS attached to the crashworthy MGS downstream end anchorage or trailing-end terminal.

Table 20. Results Summary of Safety Performance Evaluations

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. WIDA-1</th><th>Test No. WIDA-2</th></tr>
<tr><td>Structural Adequacy</td><td>C.</td><td colspan="3">Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="9">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td><td>S</td><td>S</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g's</td><td>20.49 g's</td></tr>
<tr><td>Vehicle Trajectory</td><td>N.</td><td colspan="3">Vehicle trajectory behind the test article is acceptable.</td><td>S</td><td>S</td></tr>
<tr><td colspan="5">MASH Test Designation</td><td>Modified 3-37</td><td>Modified 3-37</td></tr>
<tr><td colspan="5">Pass/Fail</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

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19 APPENDICES

Appendix A. State DOT's Plans and/or Design Details for Downstream End Anchorages

Drawings of trailing-end terminals that have been adopted by the members of the Midwest States Pooled Fund Program as well as the states of California, New York, and Texas are included herein.

Illinois

1) Type 1B
2) Type 2

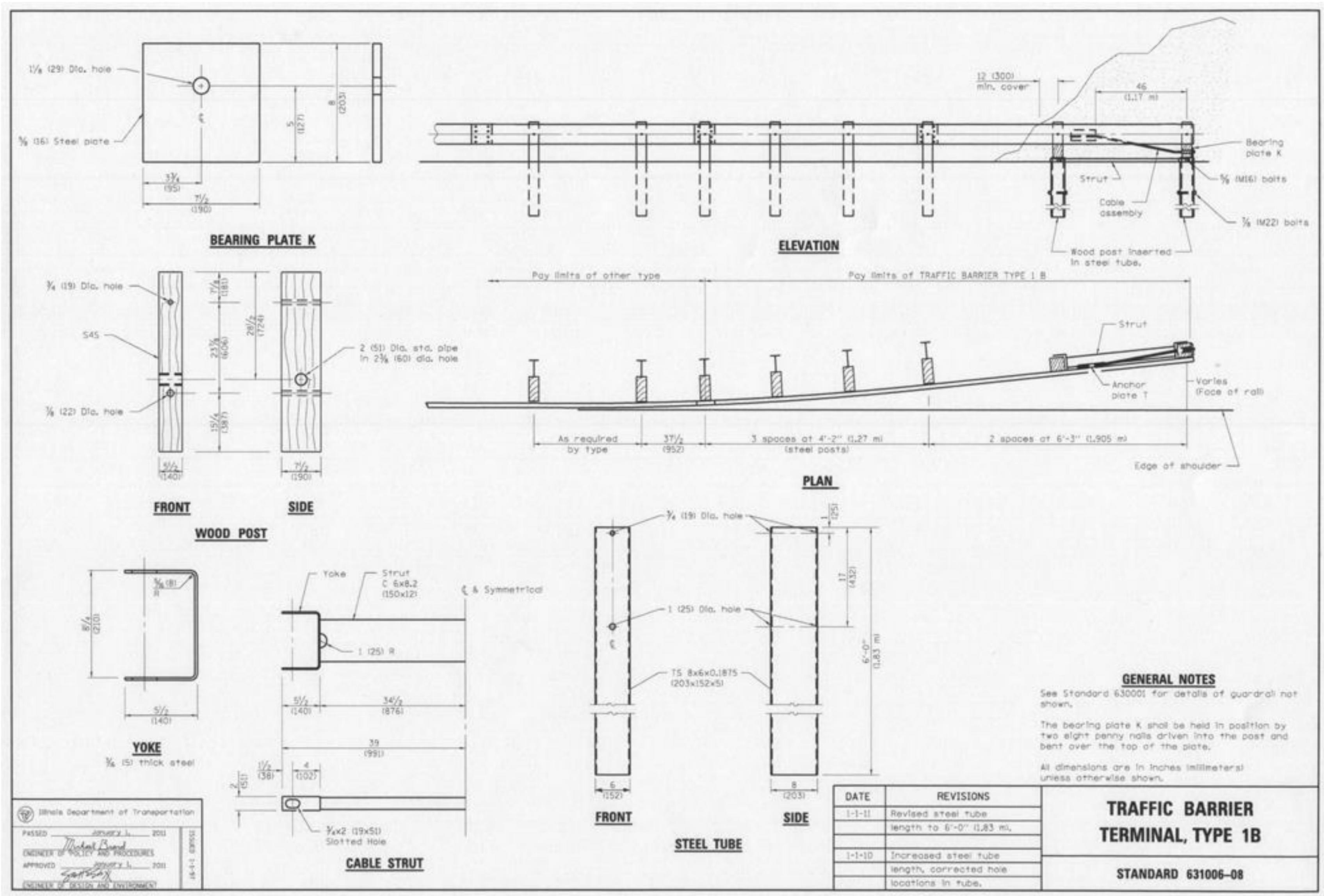


Figure A-1. Illinois DOT Terminal Type 1B

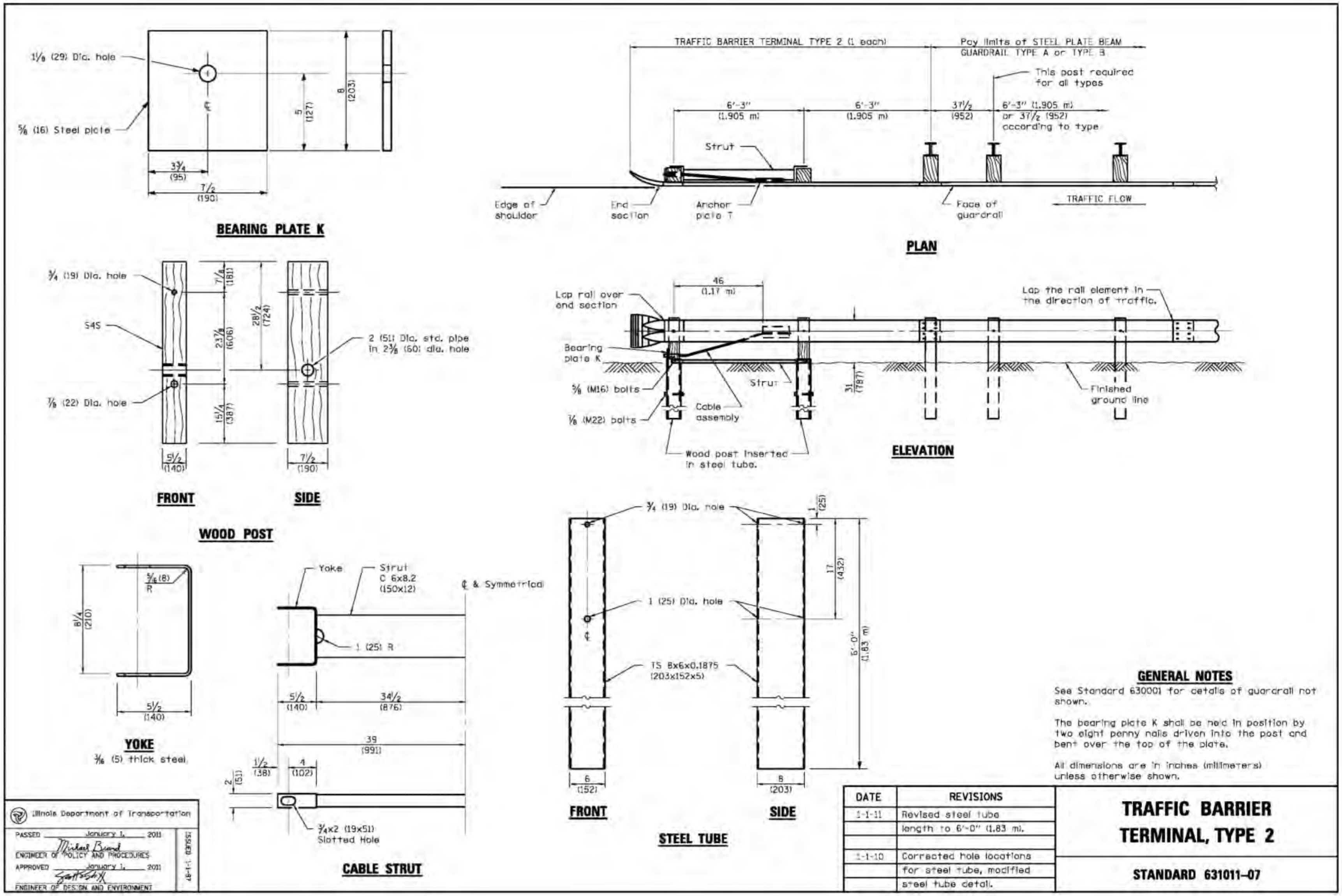


Figure A-2. Illinois DOT Terminal Type 2

Iowa

1) BA-203
2) BA-204

DESIGNER INFO

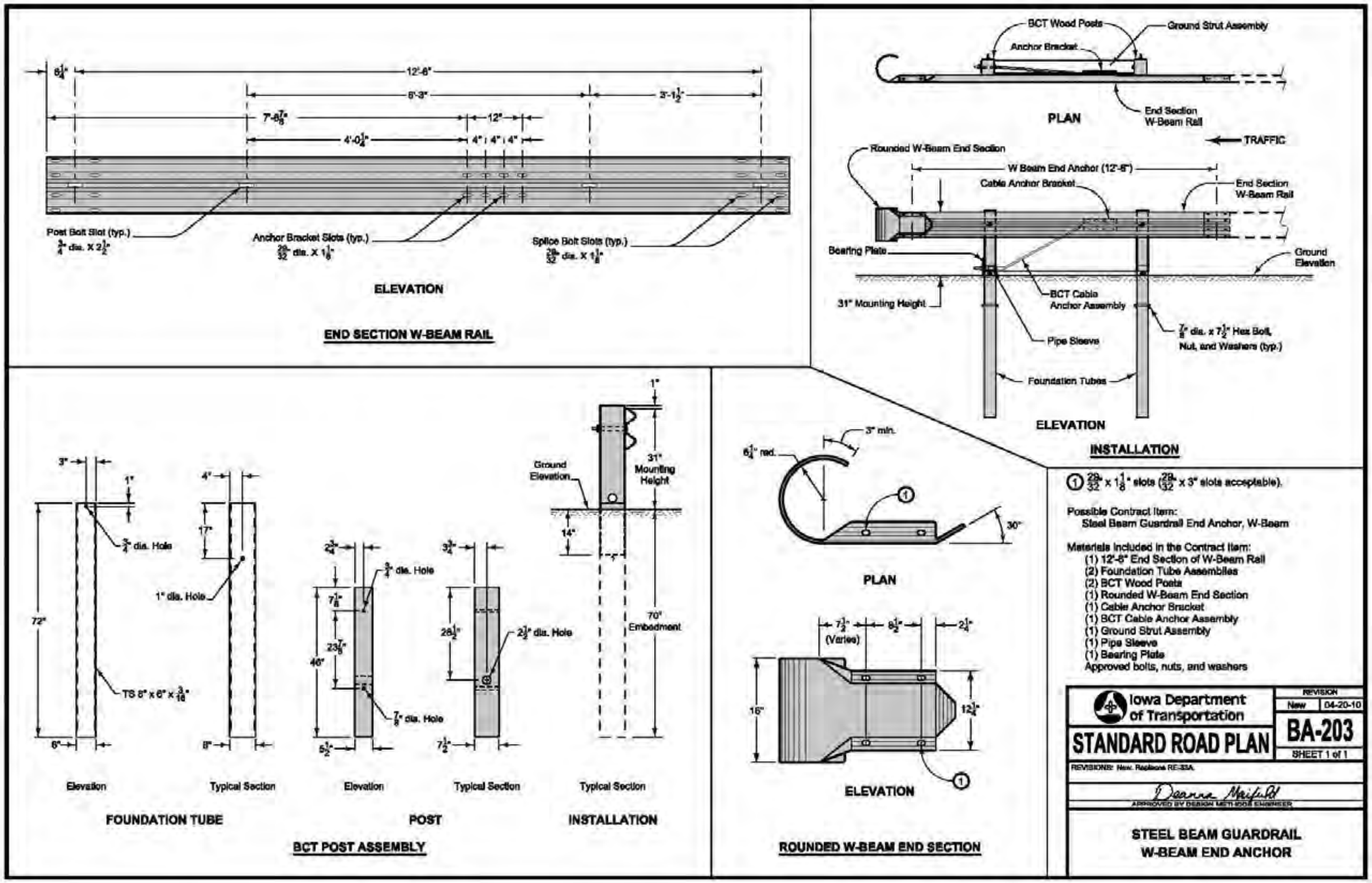


Figure A-3. Iowa DOT Terminal BA-203

DESIGNER INFO

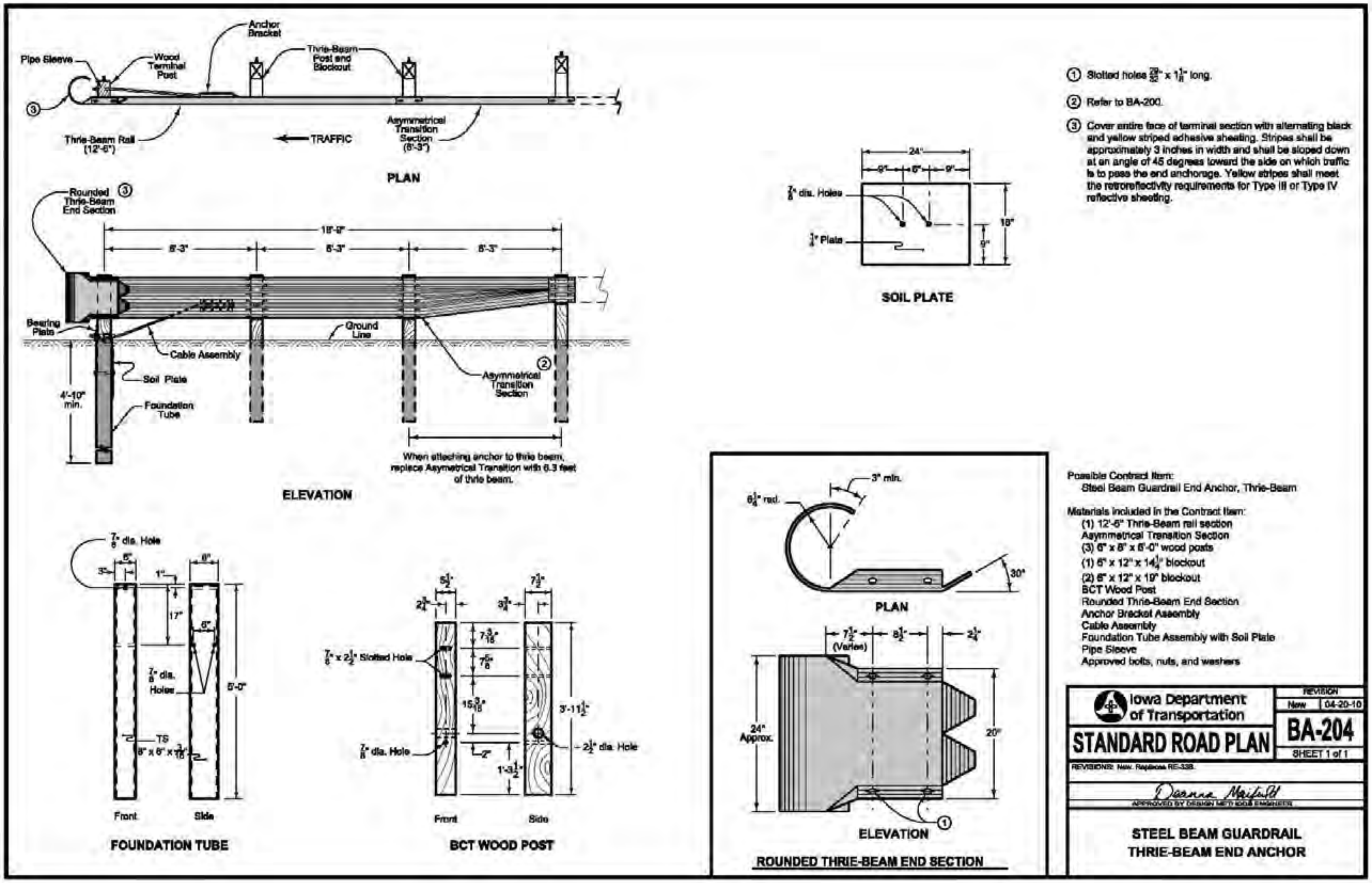


Figure A-4. Iowa DOT Terminal BA-204

Kansas

1) MGS Type II

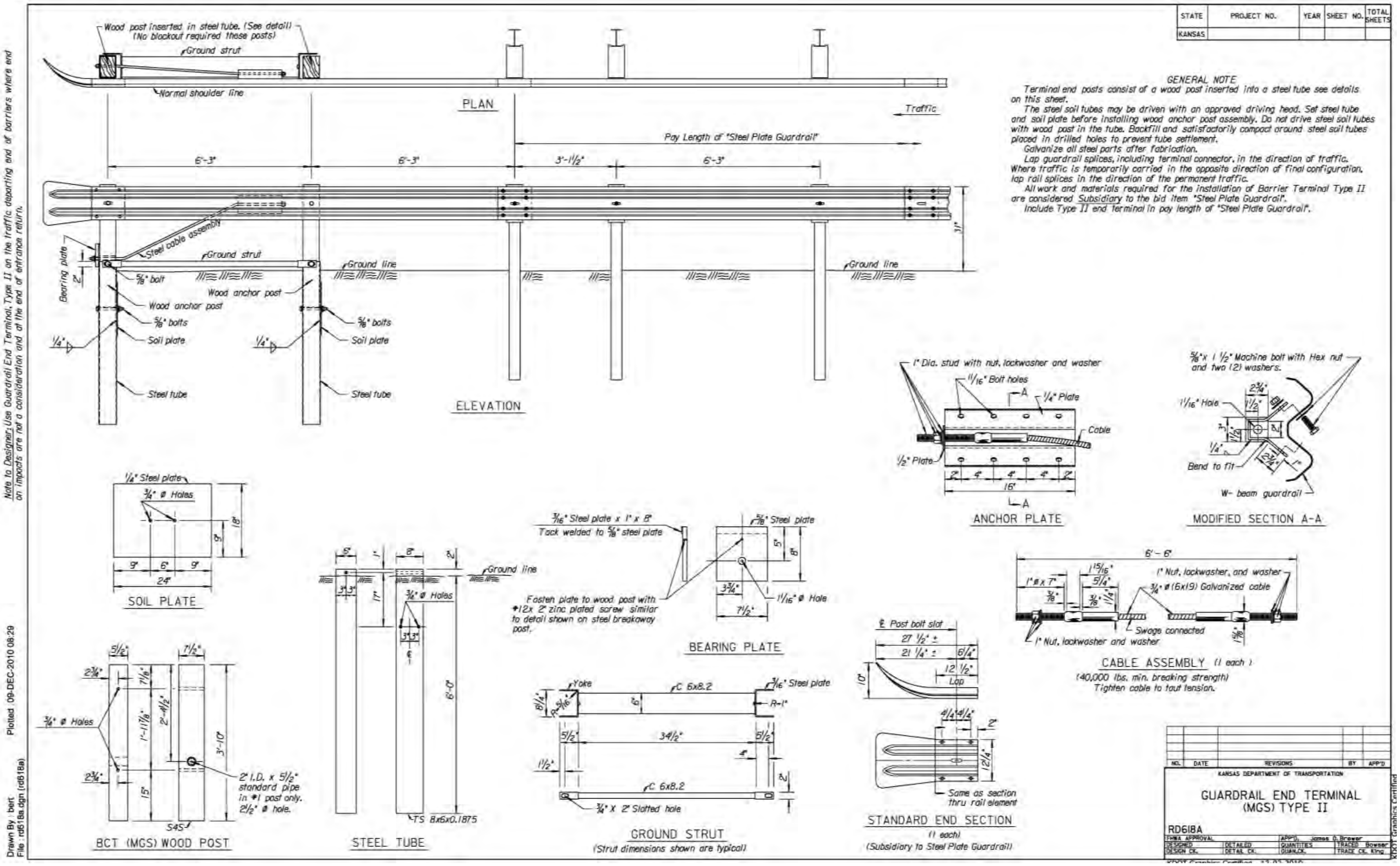


Figure A-5. Kansas DOT Terminal MGS Type II

Minnesota

1) Standard plate 8307R (Specification reference 2554)
    a. Strut Anchorage
    b. Buried Anchorage Assembly
2) Standard plate 8308R (Specification reference 2554)
    a. Strut Anchorage
    b. Buried Anchorage Assembly

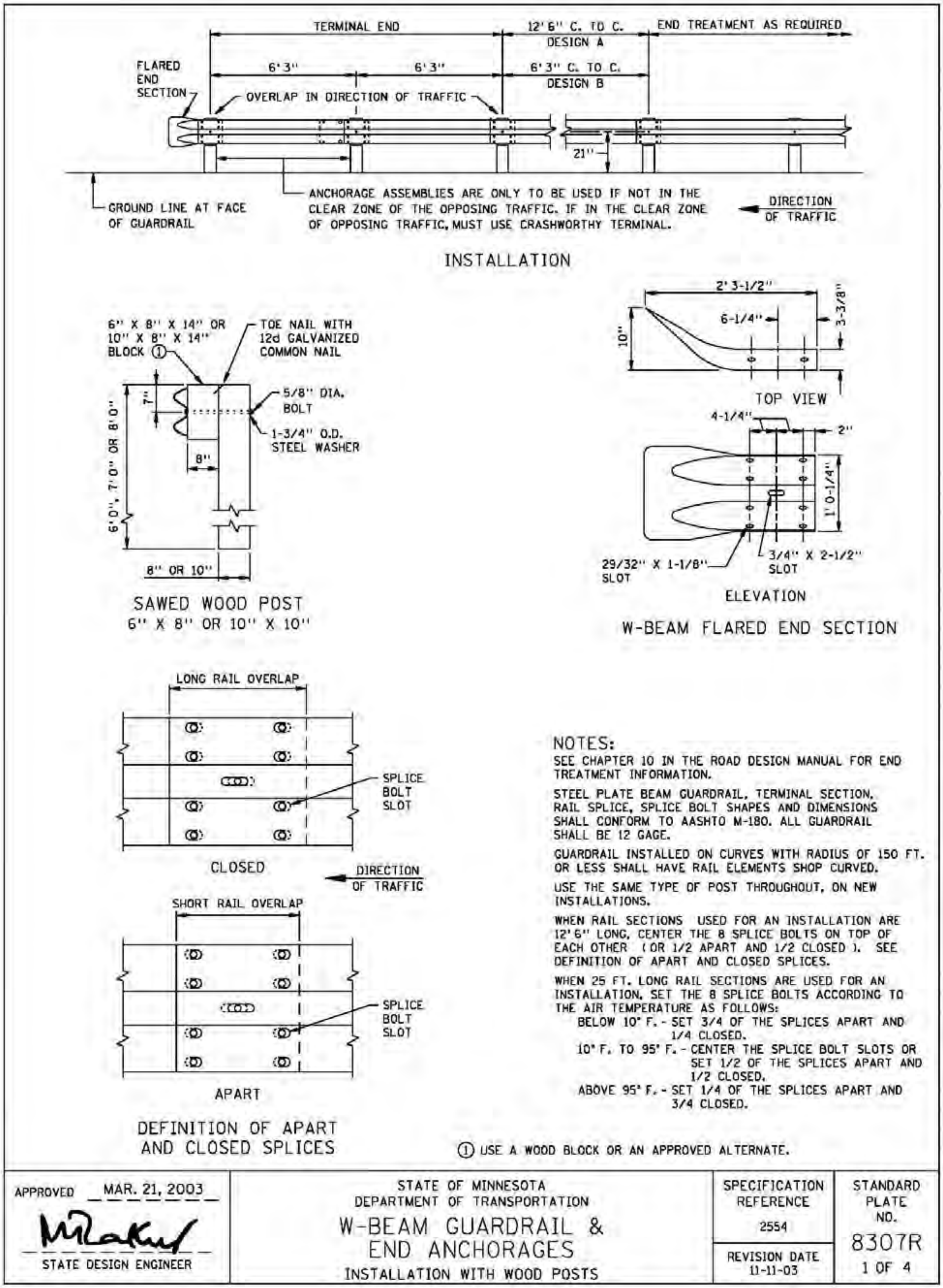


Figure A-6. Minnesota DOT Standard plate 8307R

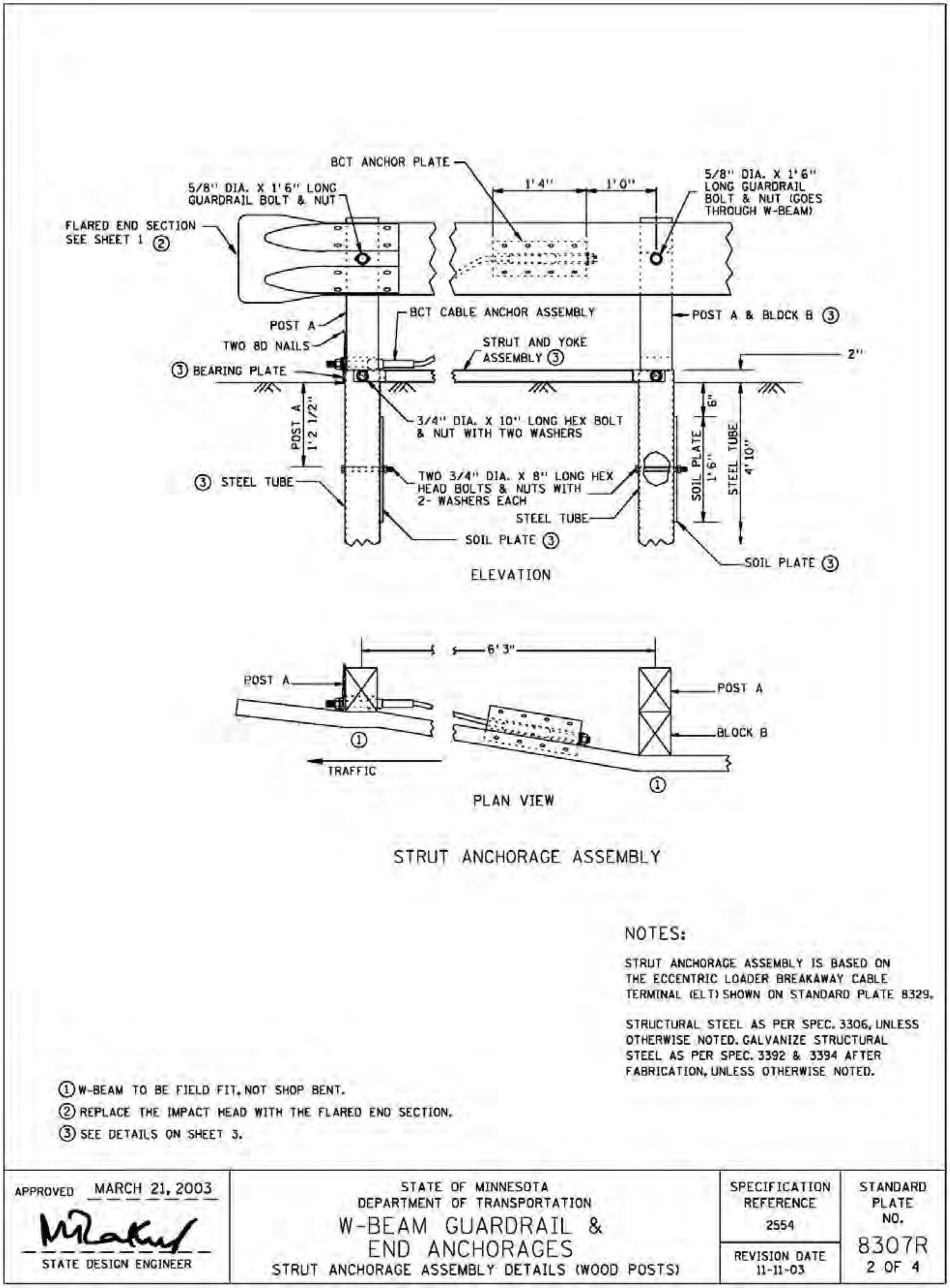


Figure A-7. Minnesota DOT Standard plate 8307R

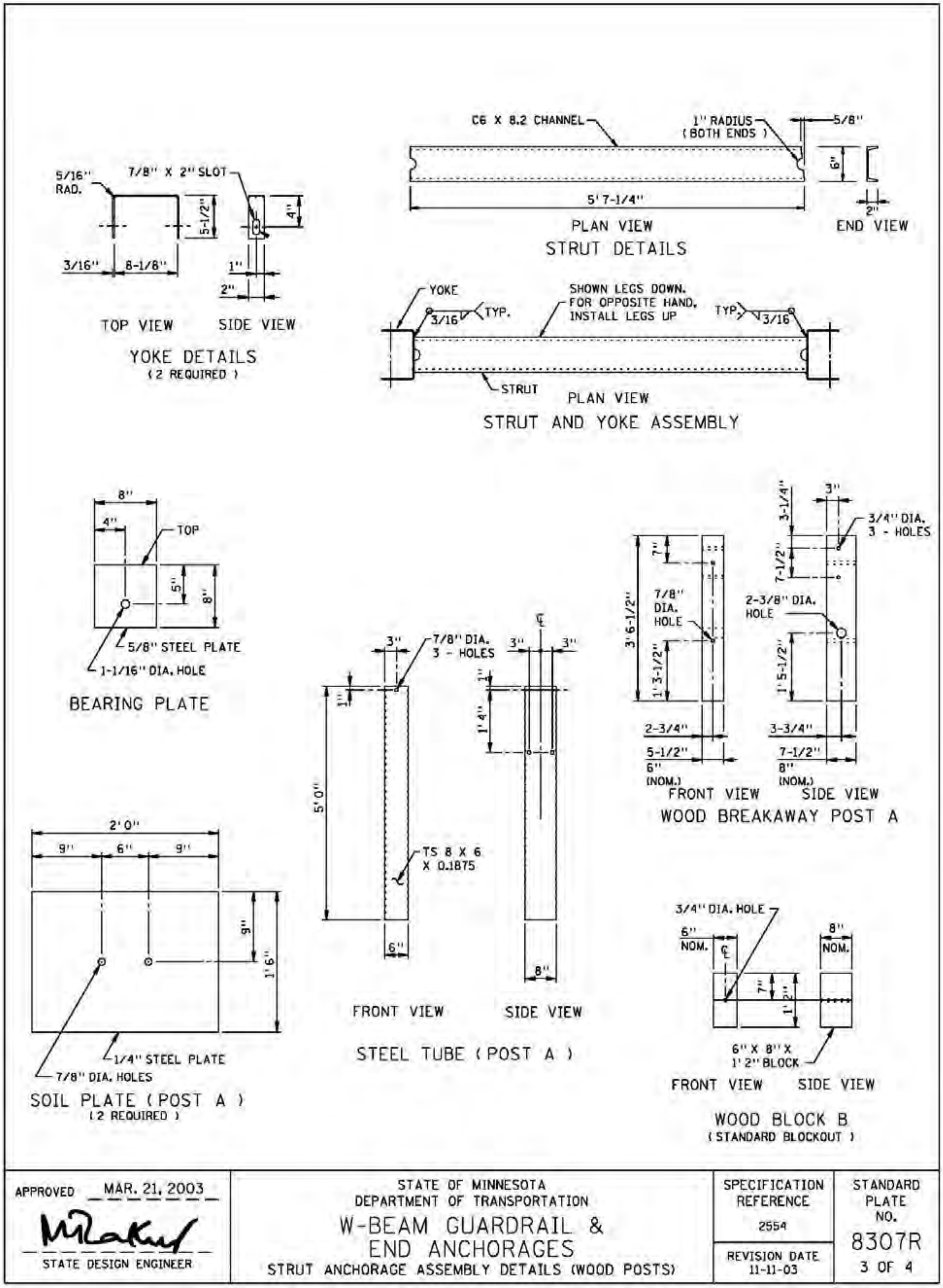


Figure A-8. Minnesota DOT Standard plate 8307R

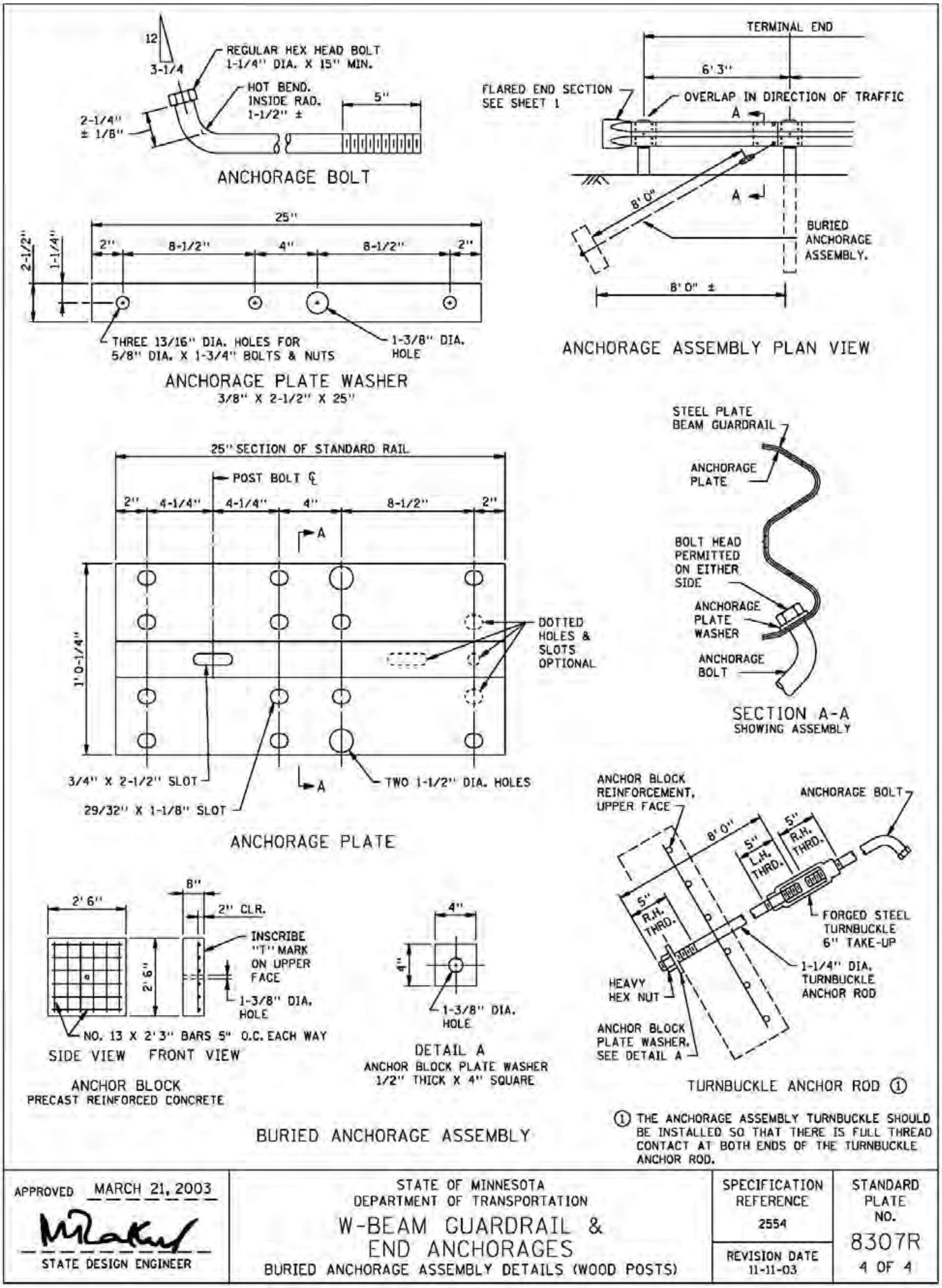


Figure A-9. Minnesota DOT Standard plate 8307R

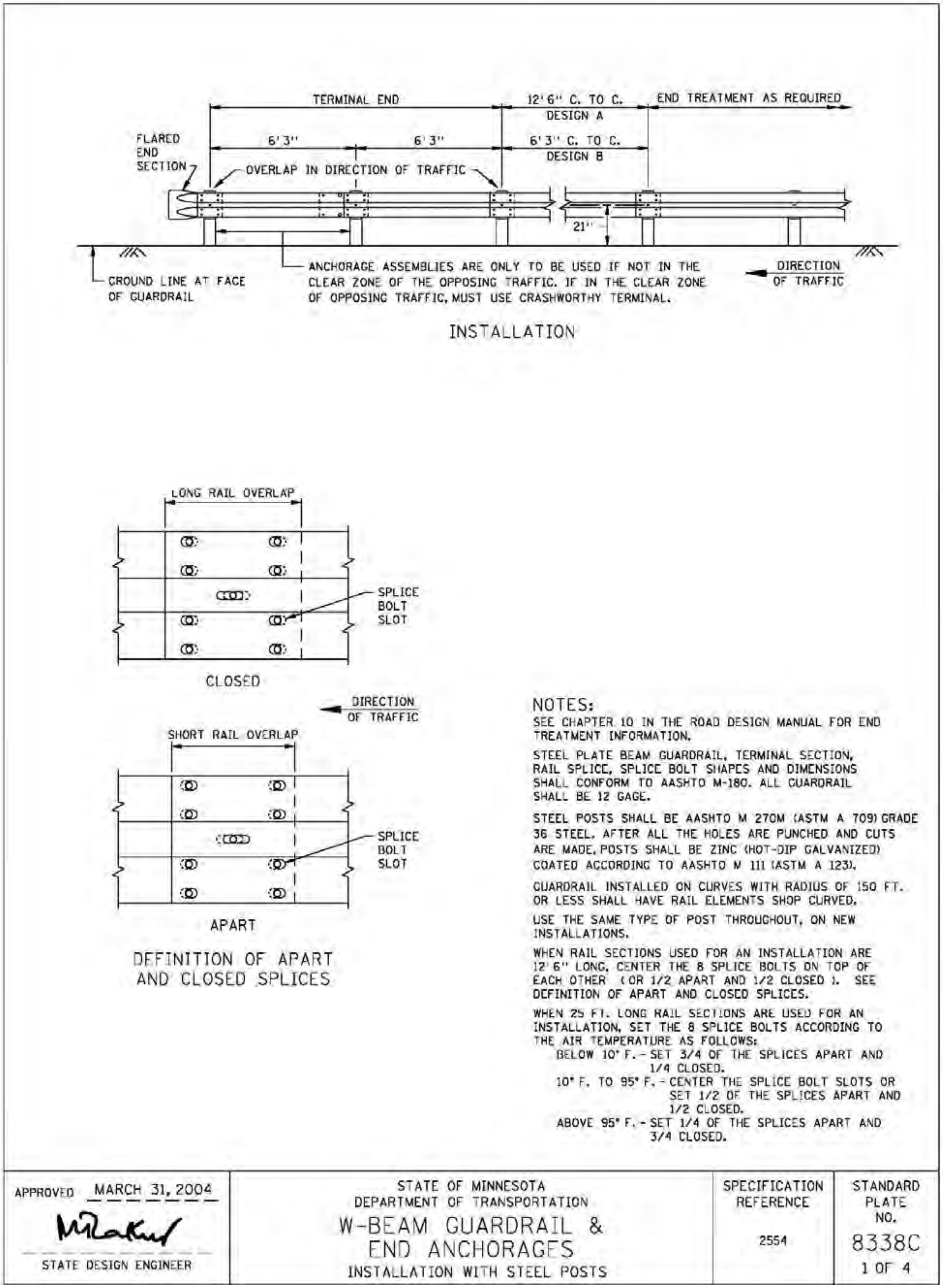


Figure A-10. Minnesota DOT Standard plate 8308R

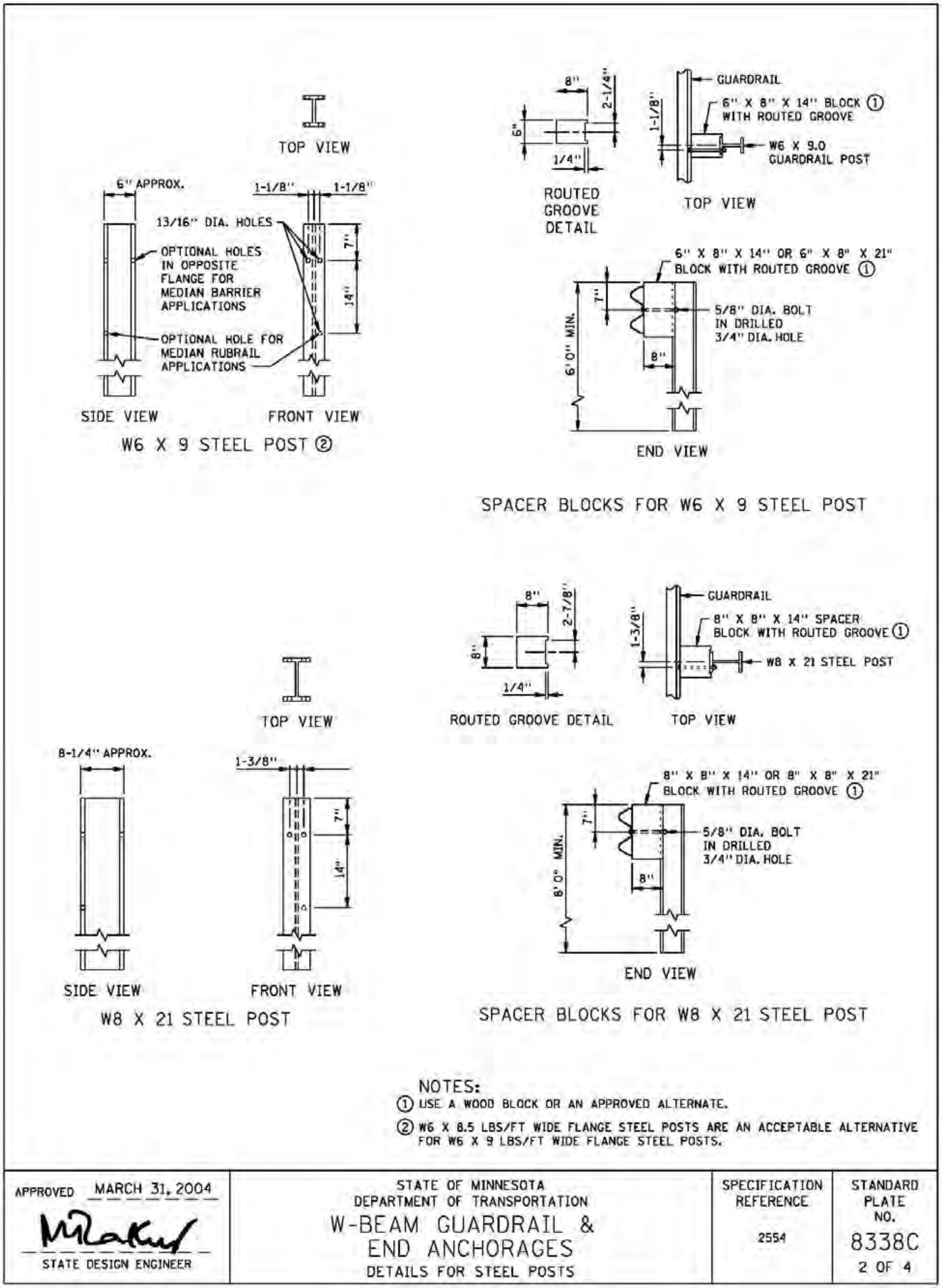


Figure A-11. Minnesota DOT Standard plate 8308R

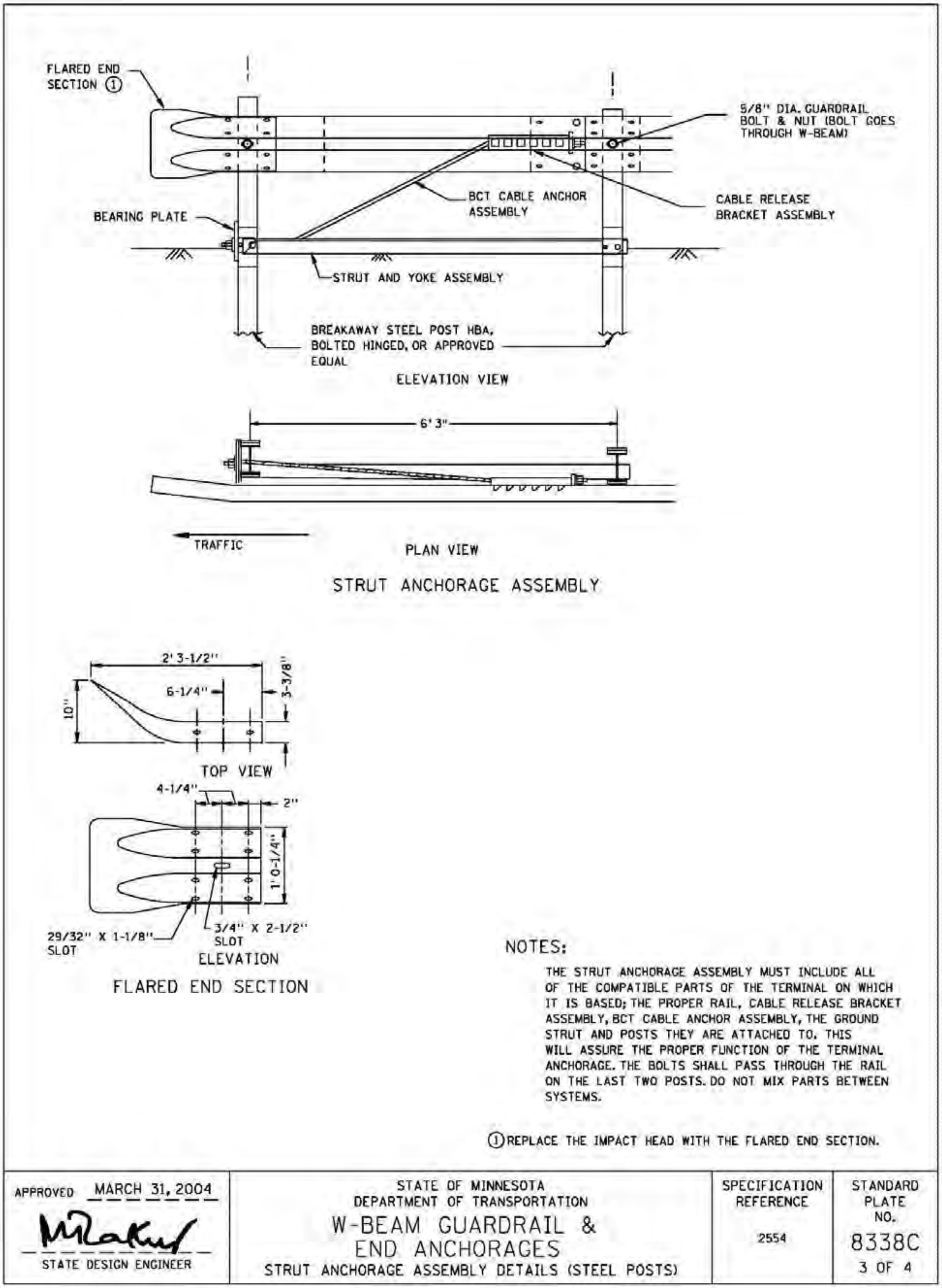


Figure A-12. Minnesota DOT Standard plate 8308R

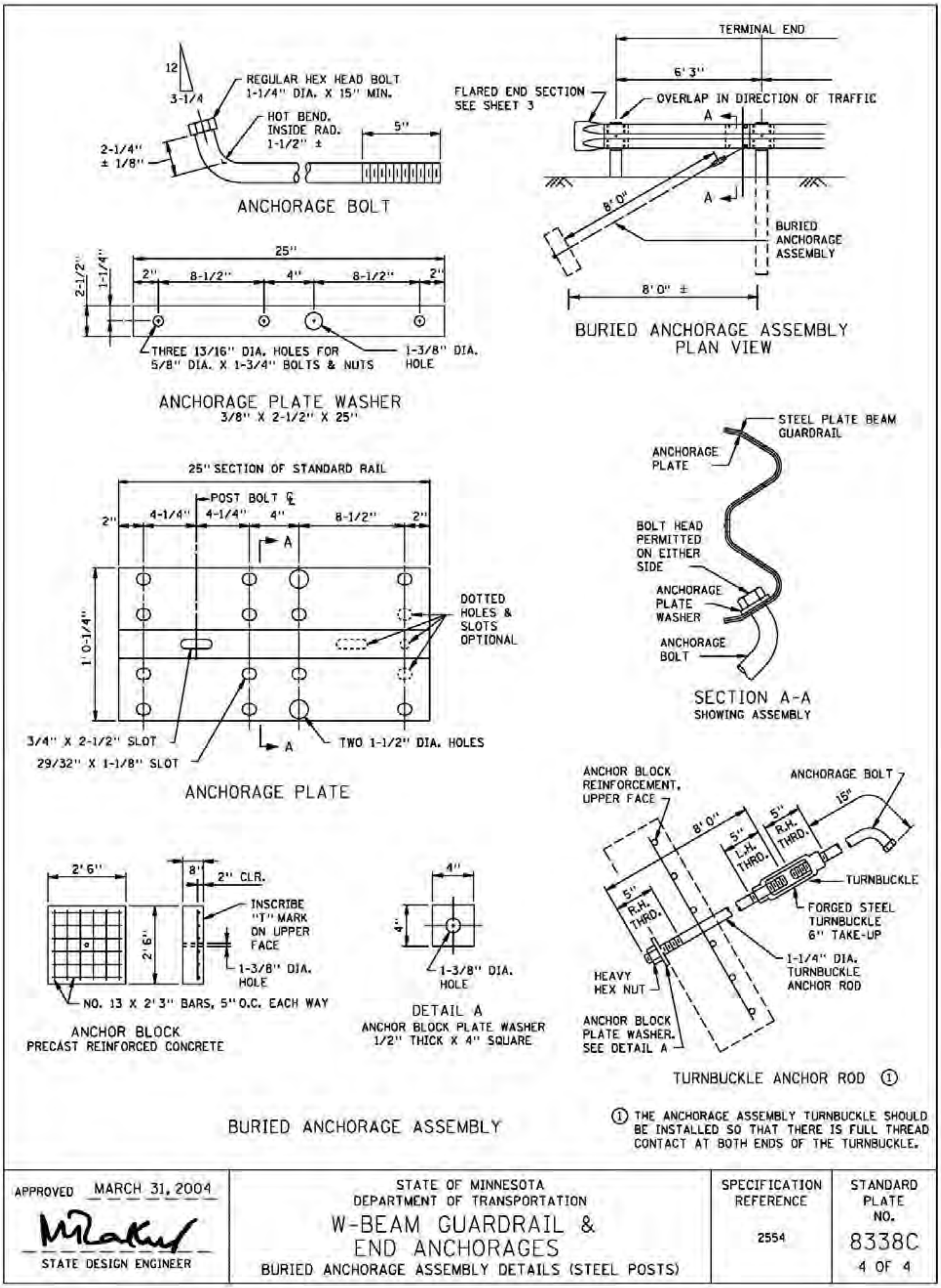


Figure A-13. Minnesota DOT Standard plate 8308R

Missouri

1) Drawing 606.00AT
    a. Steel foundation tubes
    b. Concrete foundation
    c. Anchored in backslope rail

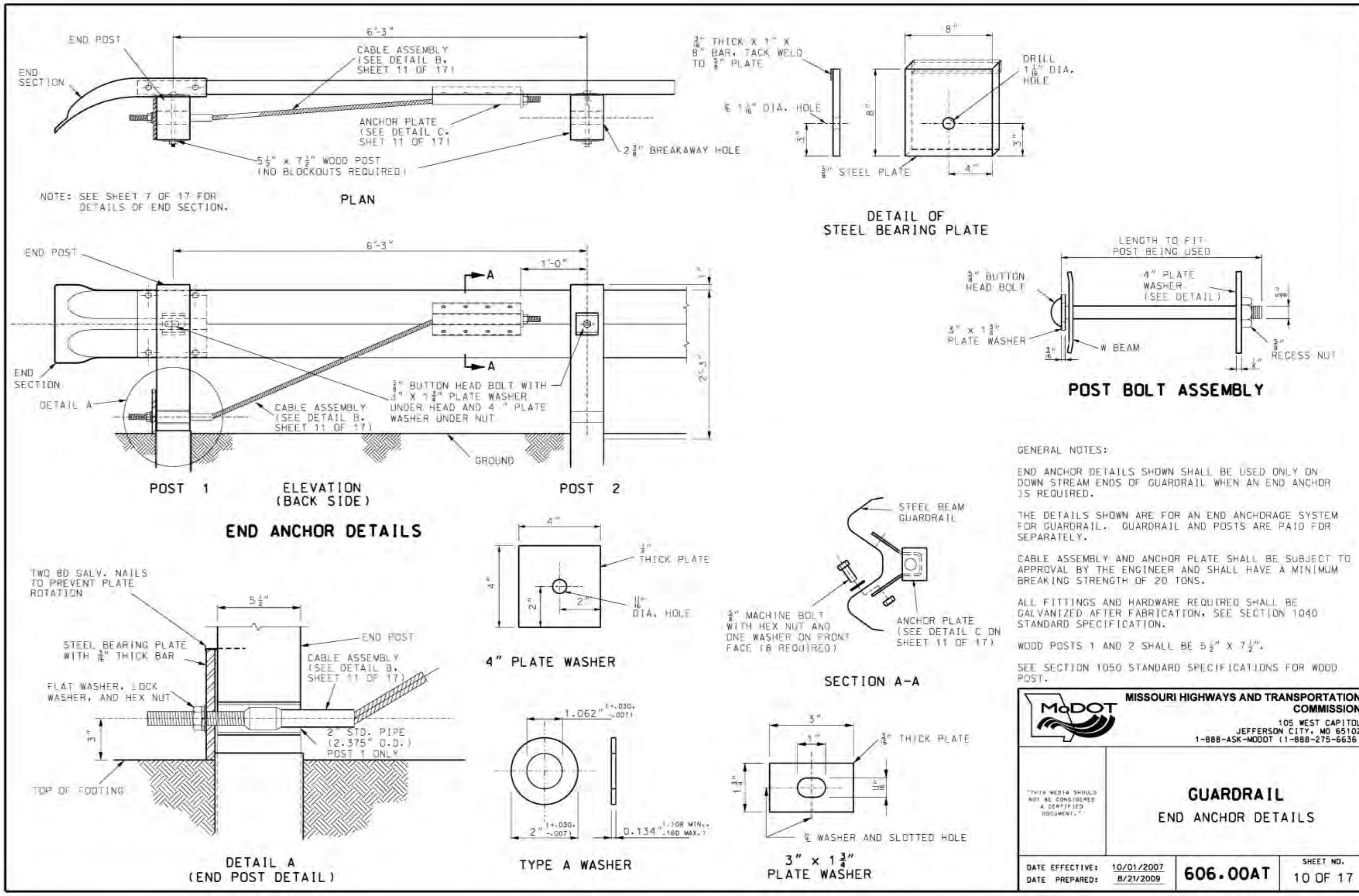


Figure A-14. Missouri DOT Drawing 606.00AT

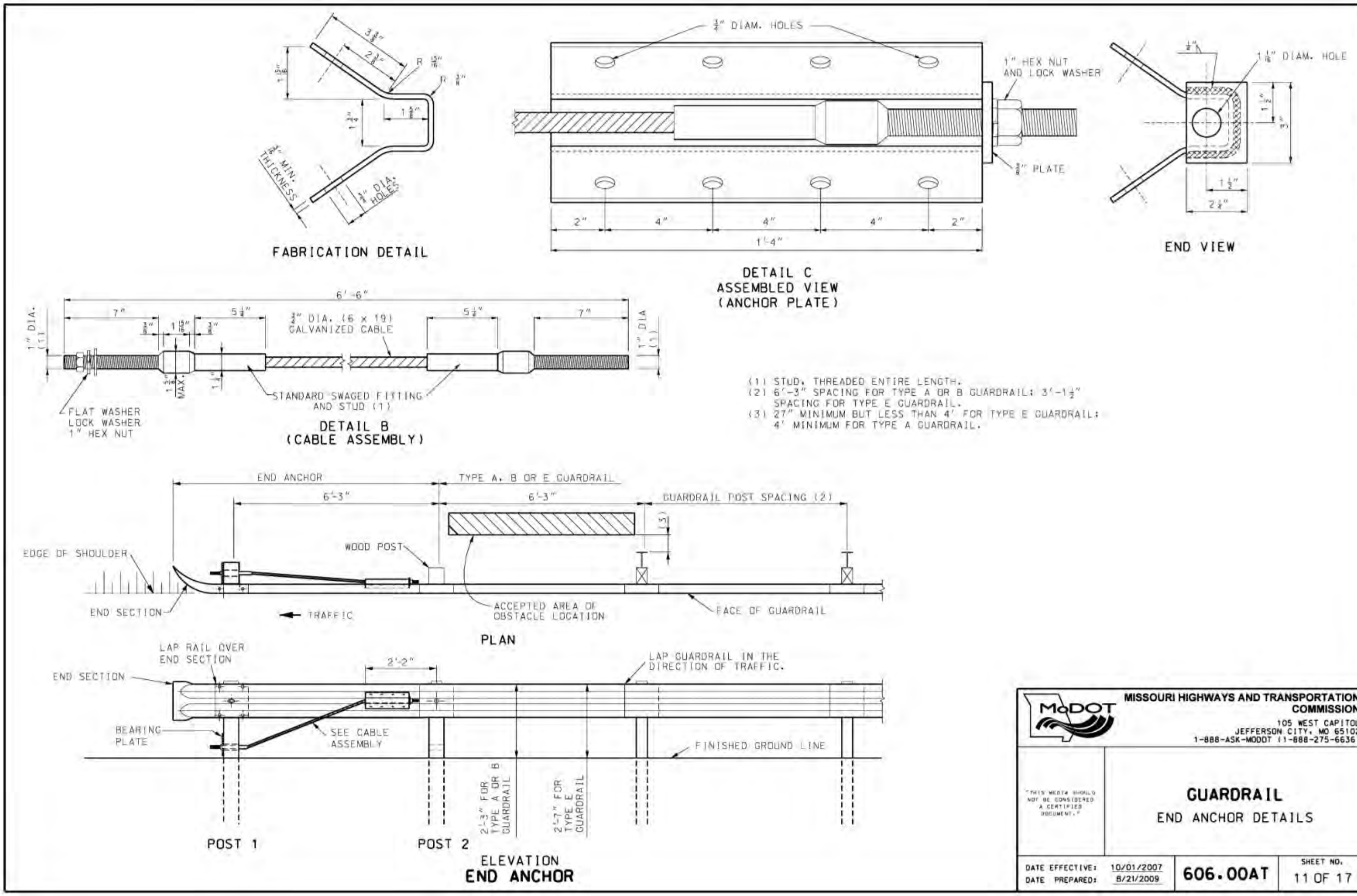


Figure A-15. Missouri DOT Drawing 606.00AT

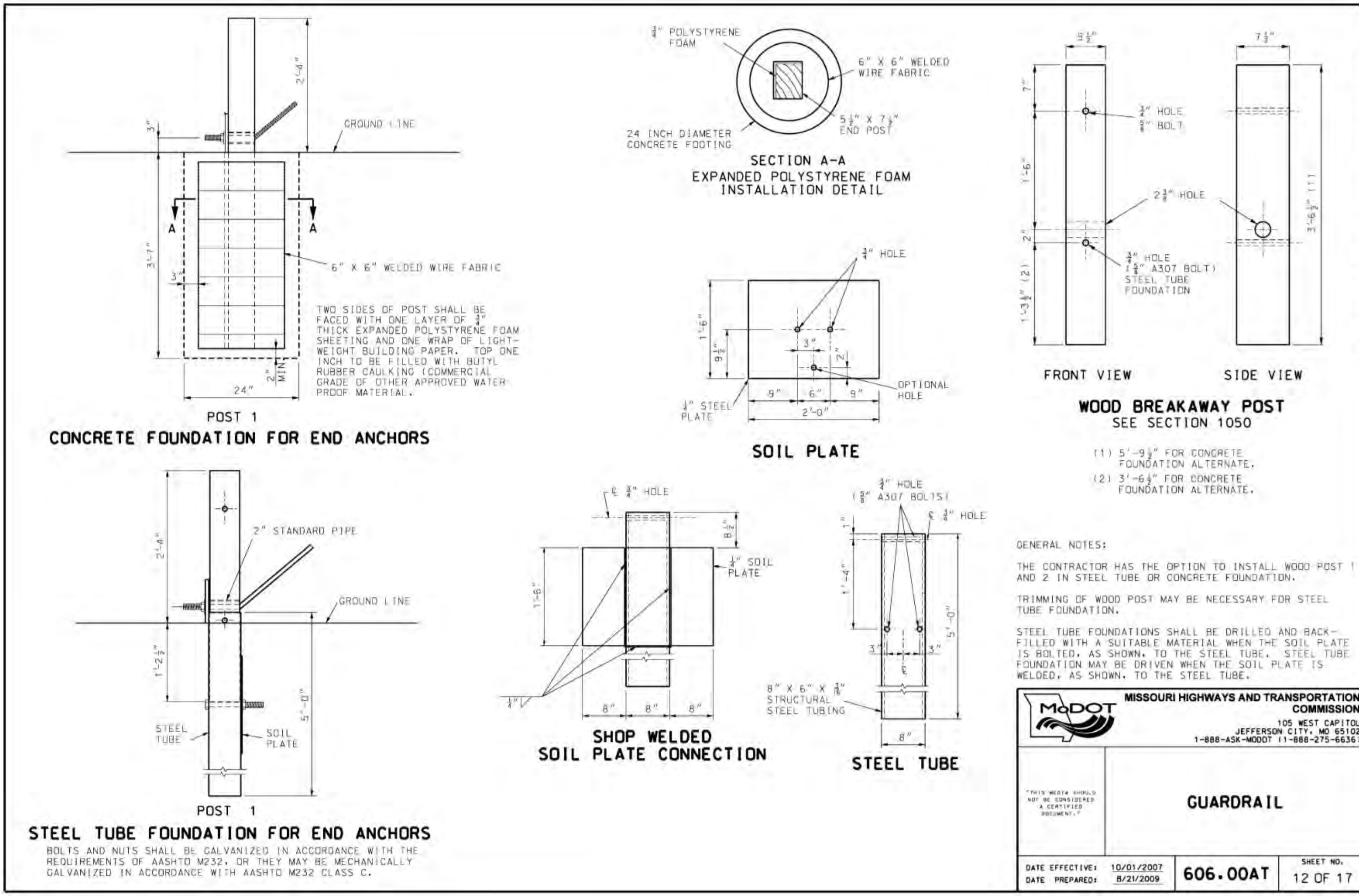


Figure A-16. Missouri DOT Drawing 606.00AT

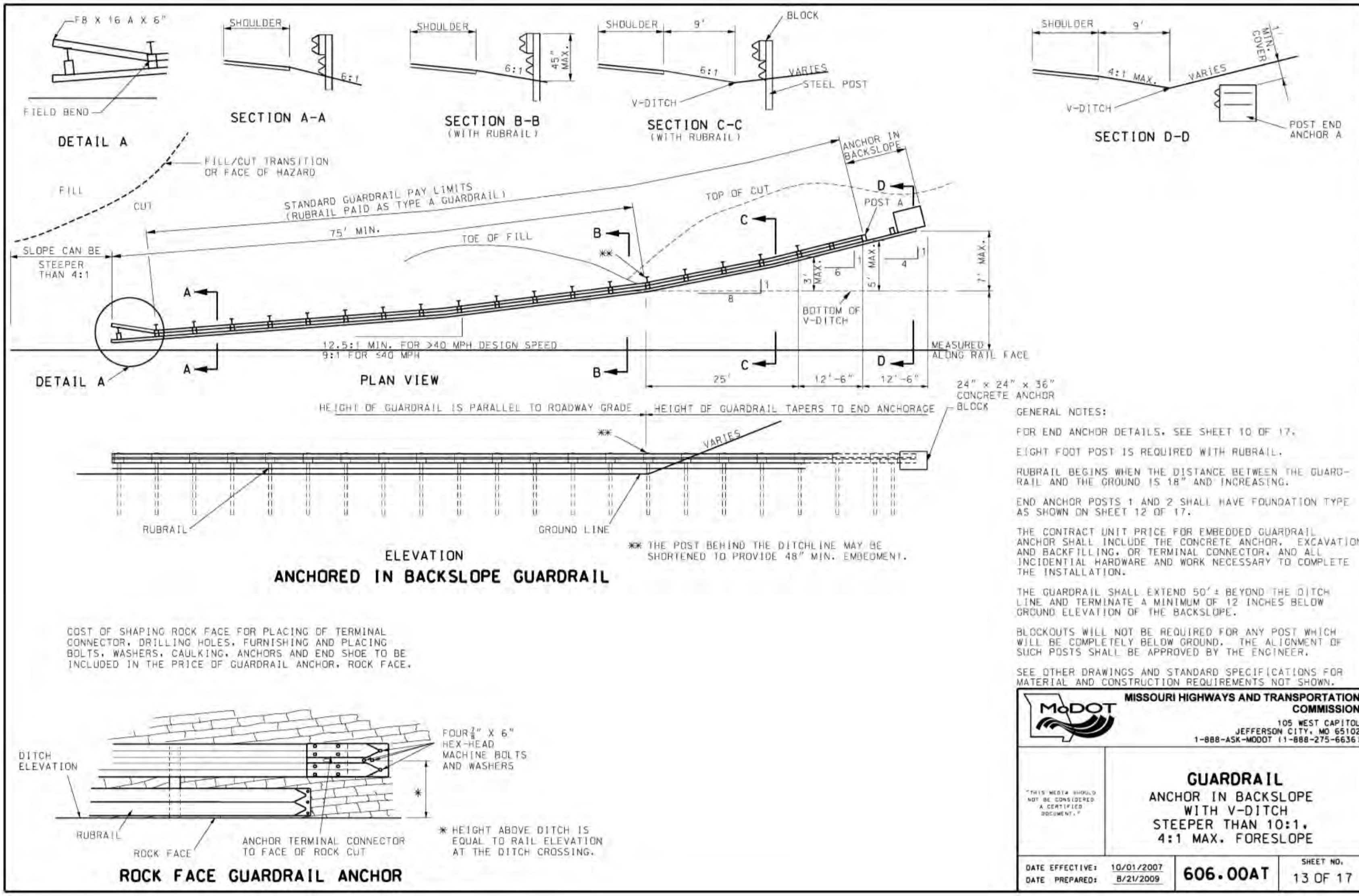


Figure A-17. Missouri DOT Drawing 606.00AT

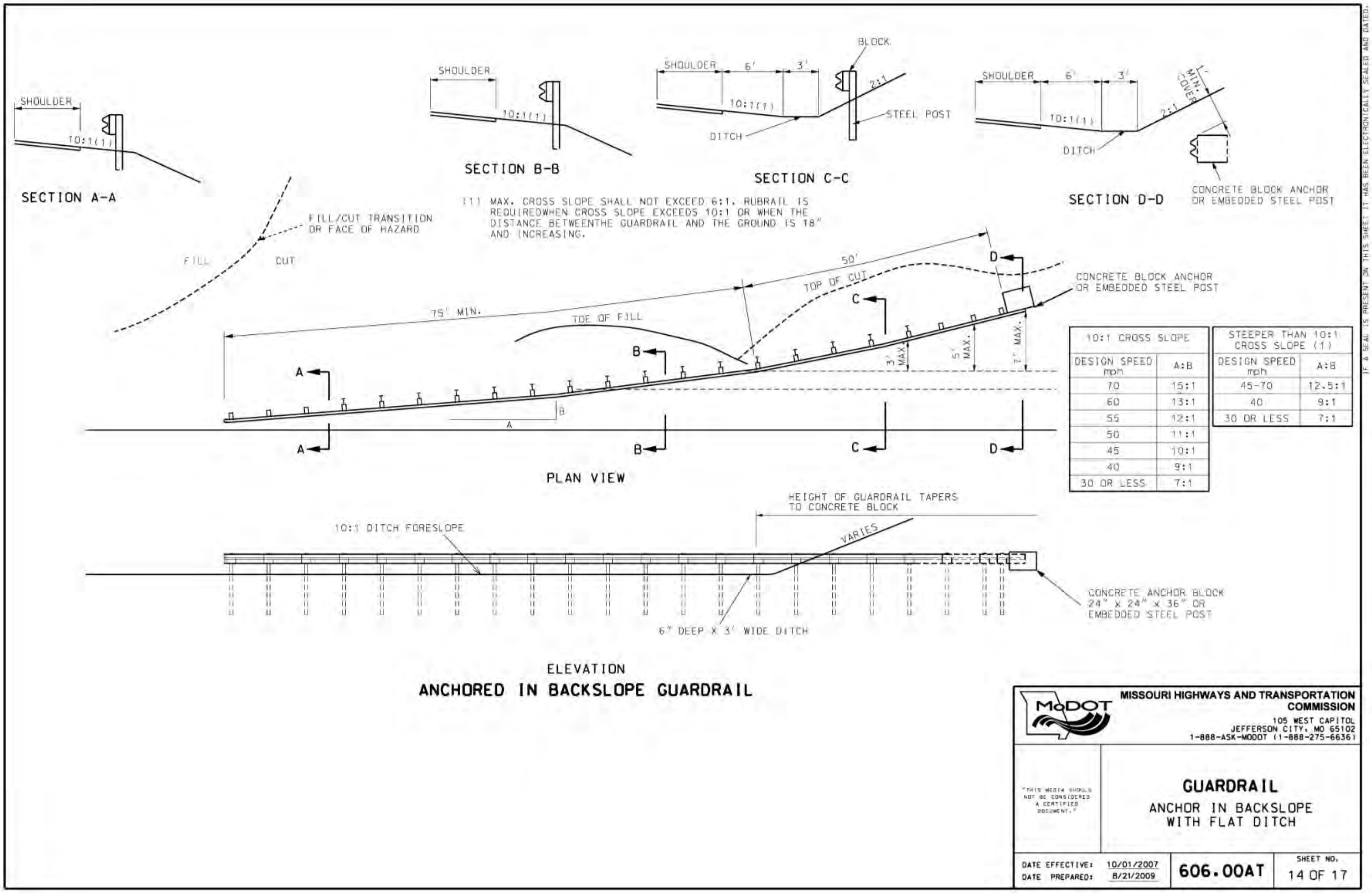


Figure A-18. Missouri DOT Drawing 606.00AT

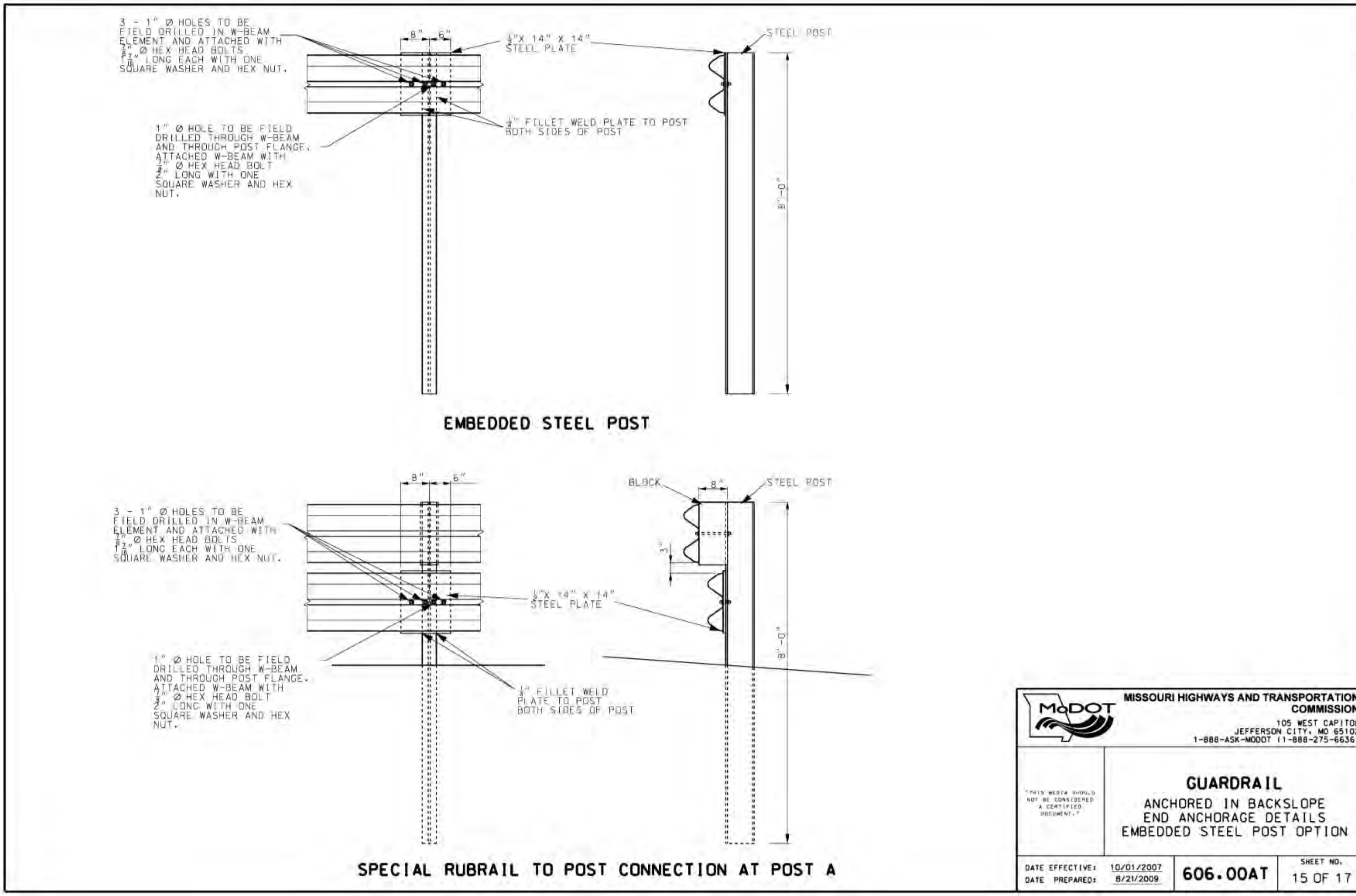


Figure A-19. Missouri DOT Drawing 606.00AT

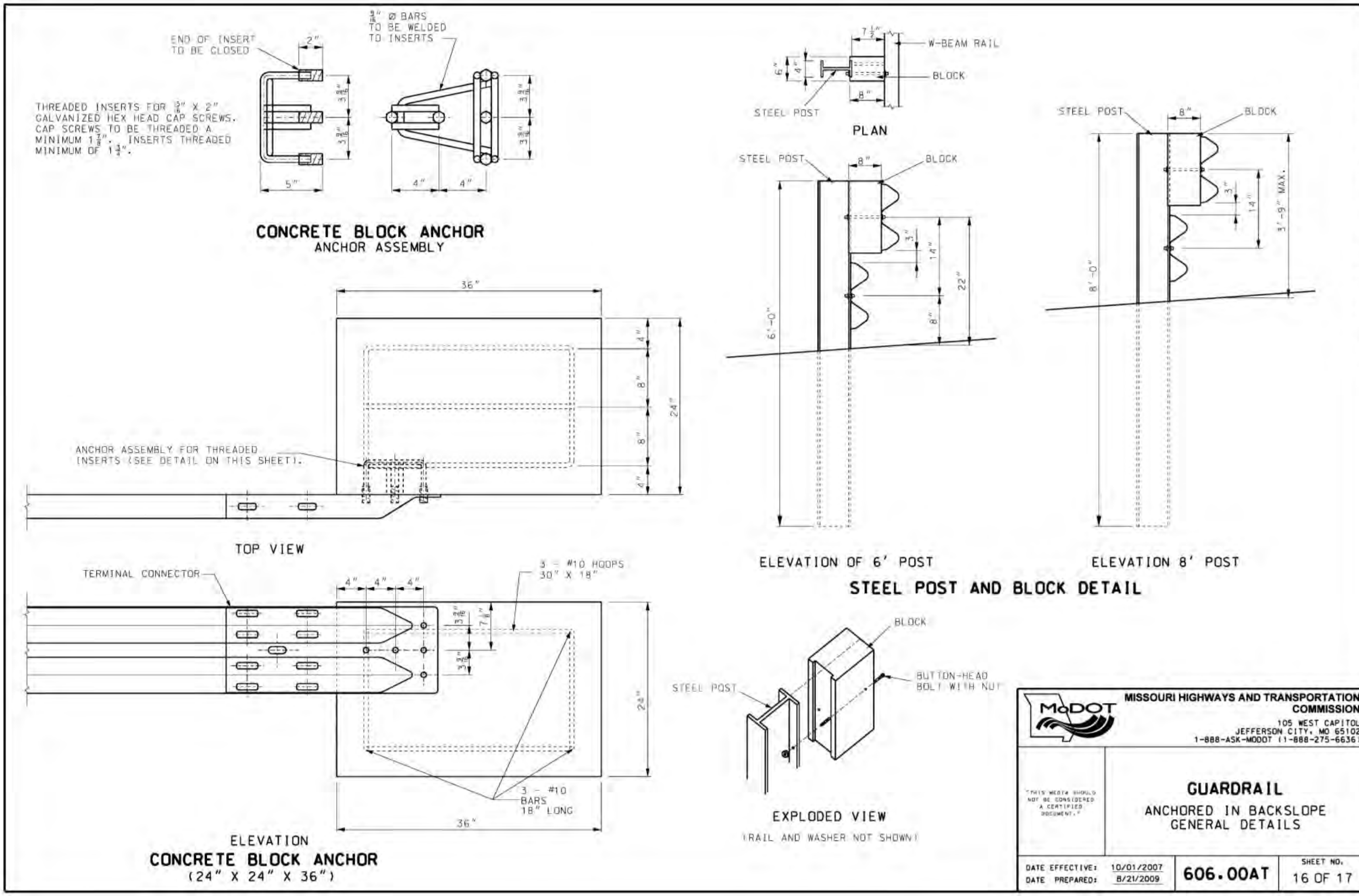


Figure A-20. Missouri DOT Drawing 606.00AT

Nebraska

1) Special Plan C

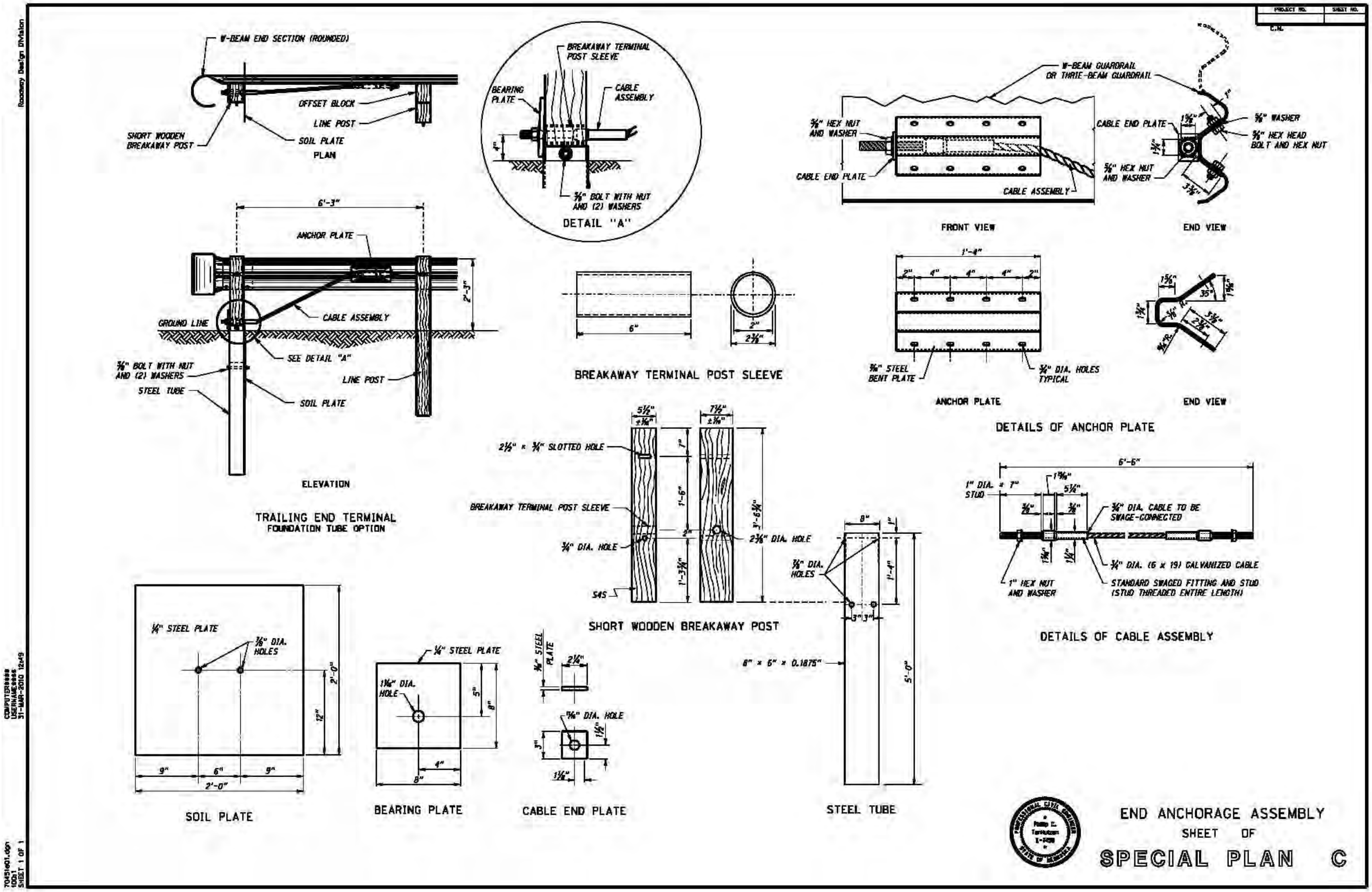


Figure A-21. Nebraska DOT Special Plan C

Ohio

1) Type T (Drawing GR-4.2)

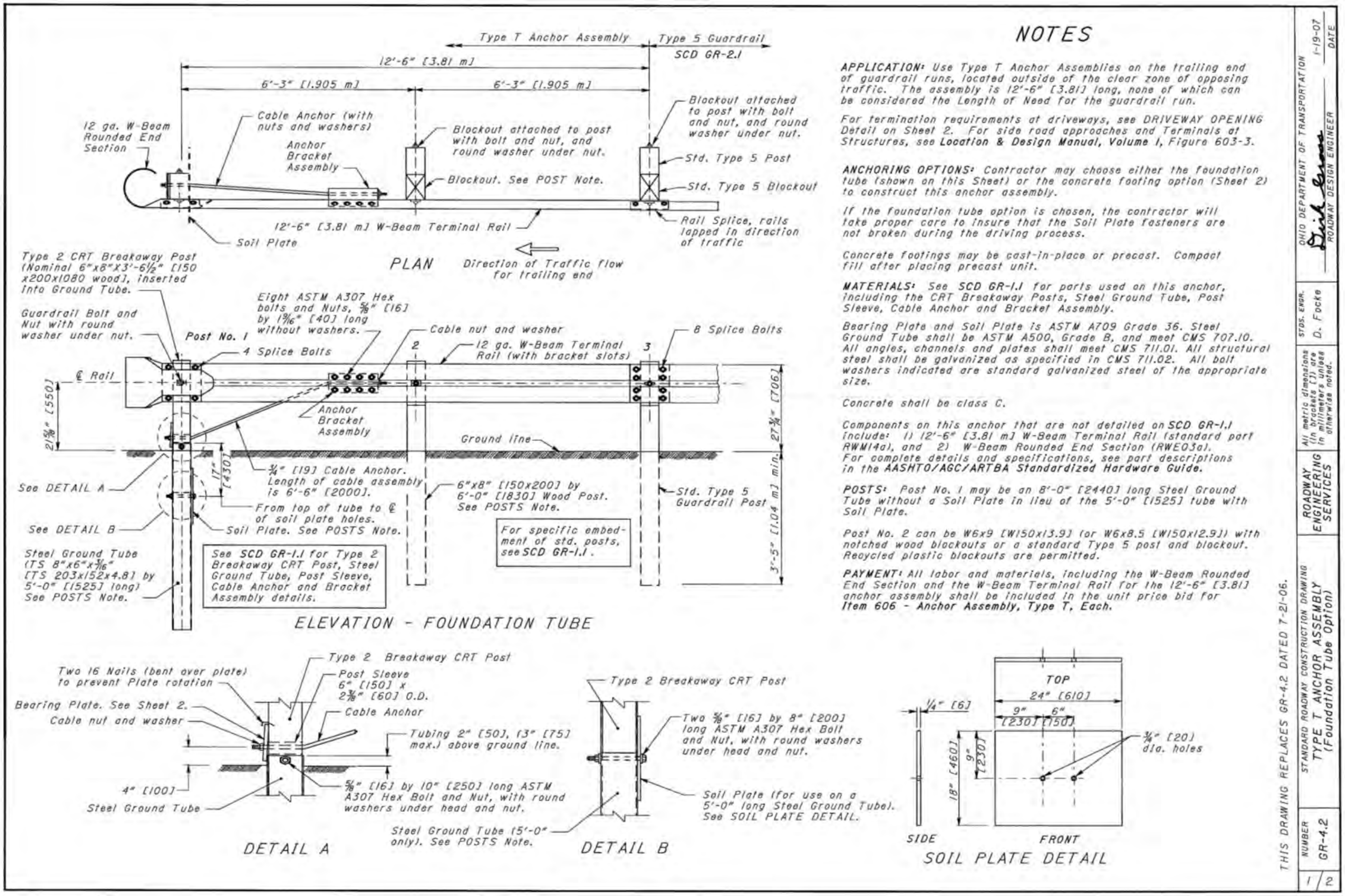


Figure A-22. Ohio DOT Terminal Type T

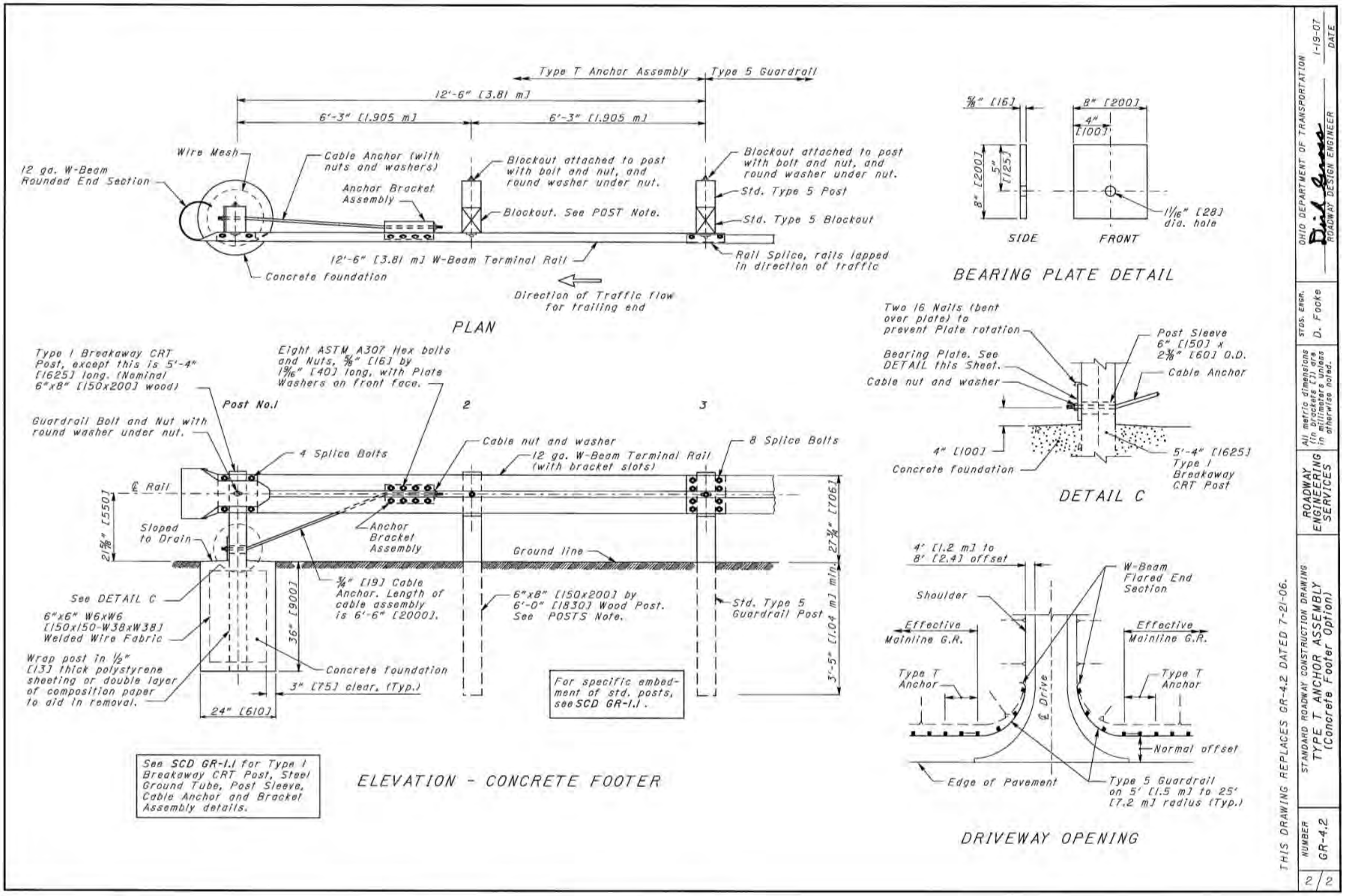
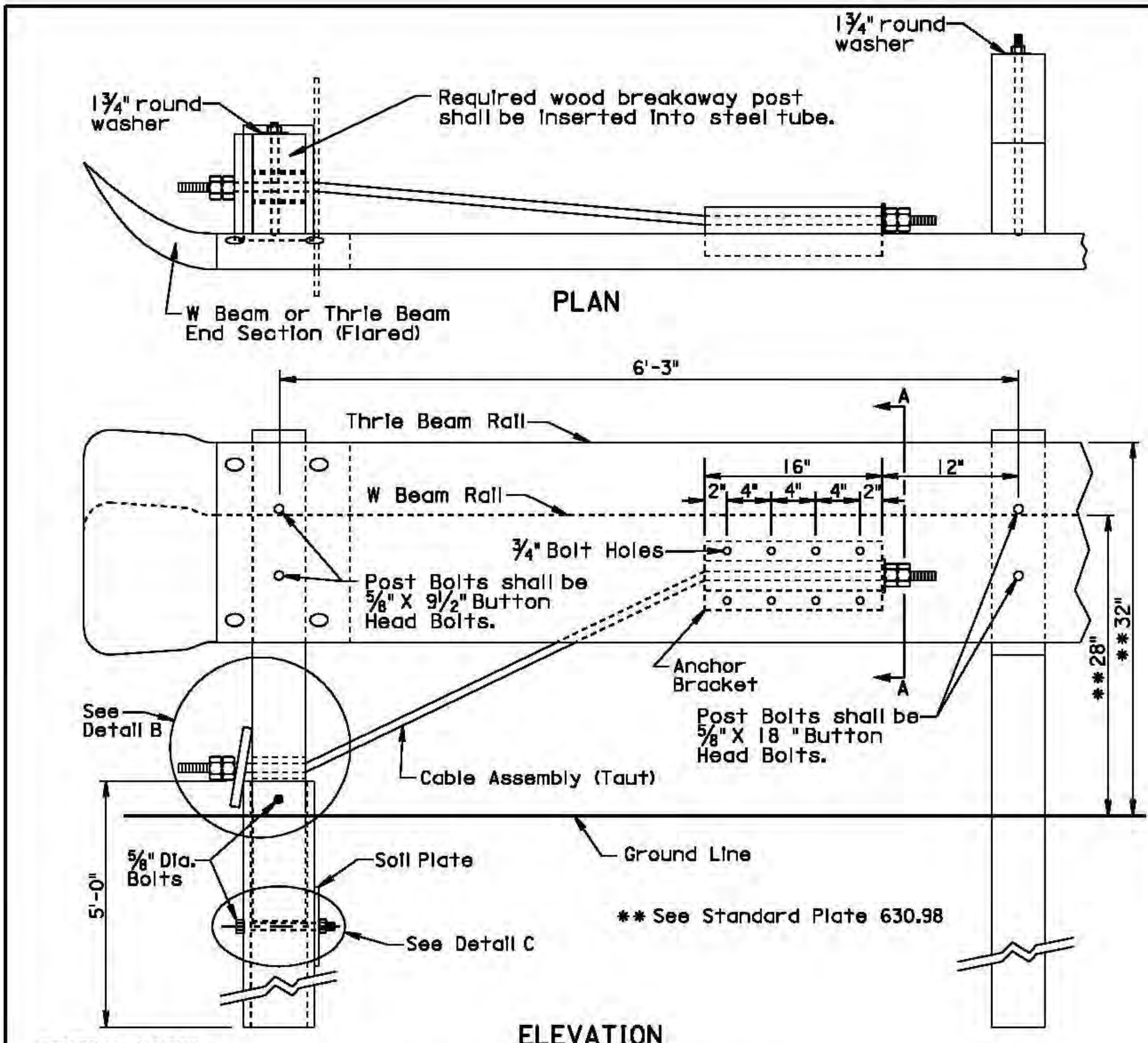


Figure A-23. Ohio DOT Terminal Type T

South Dakota

1) Drawing 630.80
2) Drawing 630.32
3) Drawing 630.02



GENERAL NOTES:

All hardware shall be galvanized in accordance with ASTM A153.

The cable shall be ¾", Type II, with Class A coating in conformance with AASHTO M30.

The steel tube shall meet the requirements of ASTM Specification A500, Grade B, and shall be galvanized after fabrication in accordance with the requirements of AASHTO Specification M111.

The anchor bracket, soil plate, and bearing plate shall be fabricated from steel that meets ASTM A36 Specifications. They shall be galvanized after fabrication in accordance with ASTM A123.

Costs for constructing the beam guardrail trailing end terminal and furnishing the anchor bracket, cable assembly, steel tube, soil plate, bearing plate, pipe sleeve, wood breakaway post, and all hardware necessary to attach anchor bracket, cable assembly, steel tube, soil plate, bearing plate, pipe sleeve, and wood breakaway post shall be incidental to the contract unit price per each for "Beam Guardrail Trailing End Terminal".

Costs for the thrie beam or W beam guardrail and the thrie beam or W beam end sections (Flared) shall be incidental to the contract unit price per foot for the respective "Thrie Beam Guardrail" or "W Beam Guardrail" bid items.

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Figure A-24. South Dakota DOT Drawing 630.80

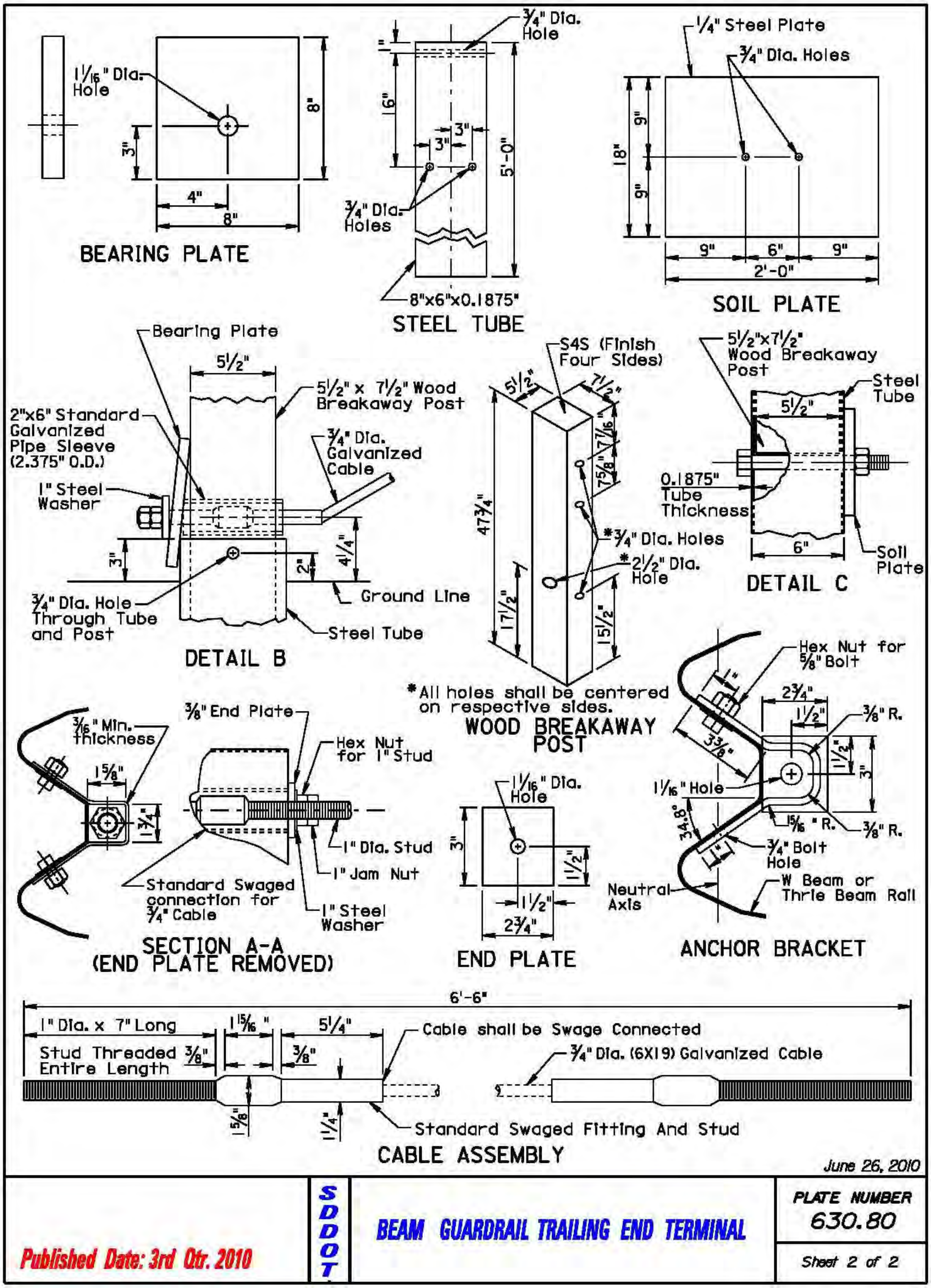
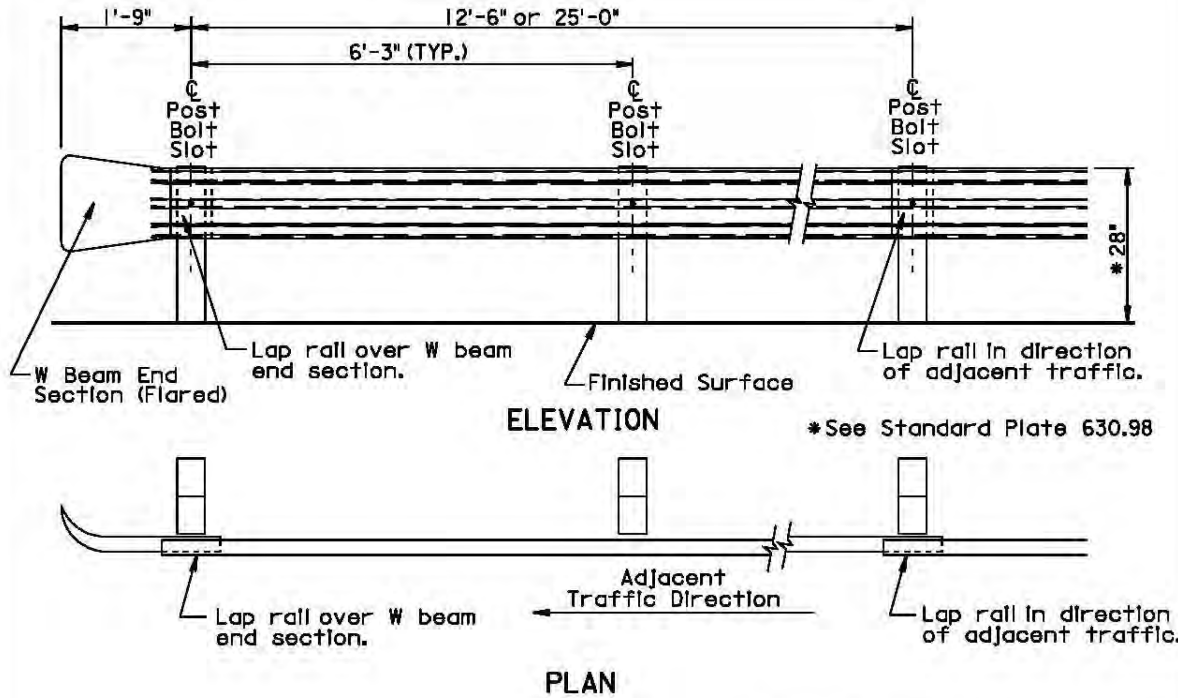


Figure A-25. South Dakota DOT Drawing 630.80



W BEAM GUARDRAIL DEFLECTION CRITERIA	
POST SPACING	MAXIMUM DEFLECTION
6'-3"	3'-3"
3'-1½"	2'-0"

For Informational Purposes Only

GENERAL NOTES:

All W beam rail shall be Type I.

There will be no separate payment for furnishing and installing W Beam End Sections (Flared) and W Beam Terminal Connectors. All costs for the W Beam End Sections (Flared) and W Beam Terminal Connectors shall be incidental to the contract unit price per foot for the respective "W Beam Guardrail" bid item.

W beam rail section lengths may be 12'-6" and/or 25'-0". The combination of section lengths used shall be compatible with the total length of rail per site as shown in the plans.

W Beam End Sections (Flared) shall only be used in a one way traffic situation. See Standard Plate 630.80 for W Beam End Section (Flared) in the Beam Guardrail Trailing End Terminal.

All costs for constructing W beam guardrail including labor, equipment, and materials including all posts, blocks, steel beam rail, and hardware shall be incidental to the contract unit price per foot for the respective "W Beam Guardrail" bid item.

Surfacing and embankment quantities will be paid for separately and will NOT be incidental to the "W Beam Guardrail" bid item.

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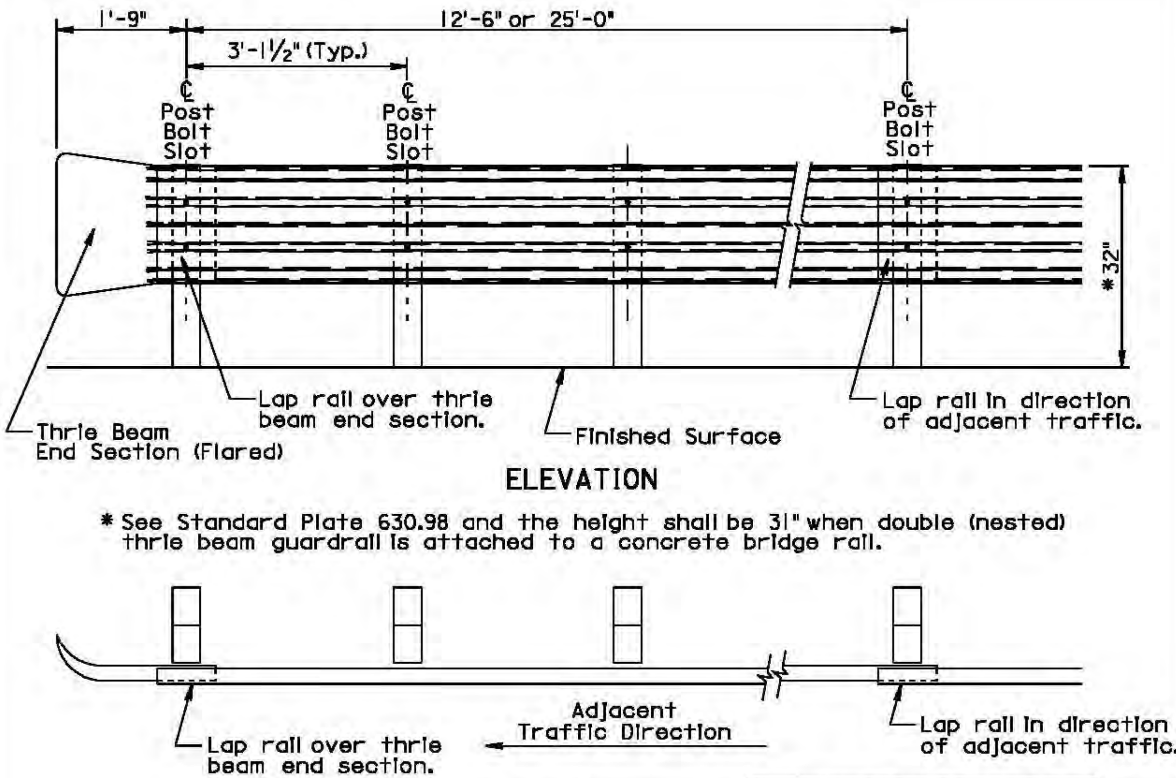
Figure A-26. South Dakota DOT Drawing 630.32



* See Standard Plate 630.98 and the height shall be 31" when double (nested) thrie beam guardrail is attached to a concrete bridge rail.

THRIE BEAM GUARDRAIL DEFLECTION CRITERIA	
POST SPACING	MAXIMUM DEFLECTION
6'-3"	2'-6"
3'-1½"	1'-9"

For Informational Purposes Only

GENERAL NOTES:

All thrie beam rail shall be Type I.

There will be no separate payment for furnishing and installing Thrie Beam End Sections (Flared) and Thrie Beam Terminal Connectors. All costs for the Thrie Beam End Sections (Flared) and Thrie Beam Terminal Connectors shall be incidental to the contract unit price per foot for the respective "Thrie Beam Guardrail" bid item.

Thrie beam rail section lengths may be 12'-6" and/or 25'-0". The combination of section lengths used shall be compatible with the total length of rail per site as shown in the plans.

Thrie Beam End Sections (Flared) shall only be used in a one way traffic situation. See Standard Plate 630.80 for Thrie Beam End Section (Flared) in the Beam Guardrail Trailing End Terminal.

All costs for constructing thrie beam guardrail including labor, equipment, and materials including all posts, blocks, steel beam rail, and hardware shall be incidental to the contract unit price per foot for the respective "Thrie Beam Guardrail" bid item.

Surfacing and embankment quantities will be paid for separately and will NOT be incidental to the "Thrie Beam Guardrail" bid item.

June 26, 2010

Published Date: 3rd Qtr. 2010

SDDOT

THRIE BEAM GUARDRAIL INSTALLATION

PLATE NUMBER
630.02

Sheet 1 of 1

Figure A-27. South Dakota DOT Drawing 630.02

Wisconsin

1) Type 2 (Drawing S.D.D. 14 B 16-4a)
2) Rounded End Section Class B (Drawing S.D.D. 14 B 3-2)

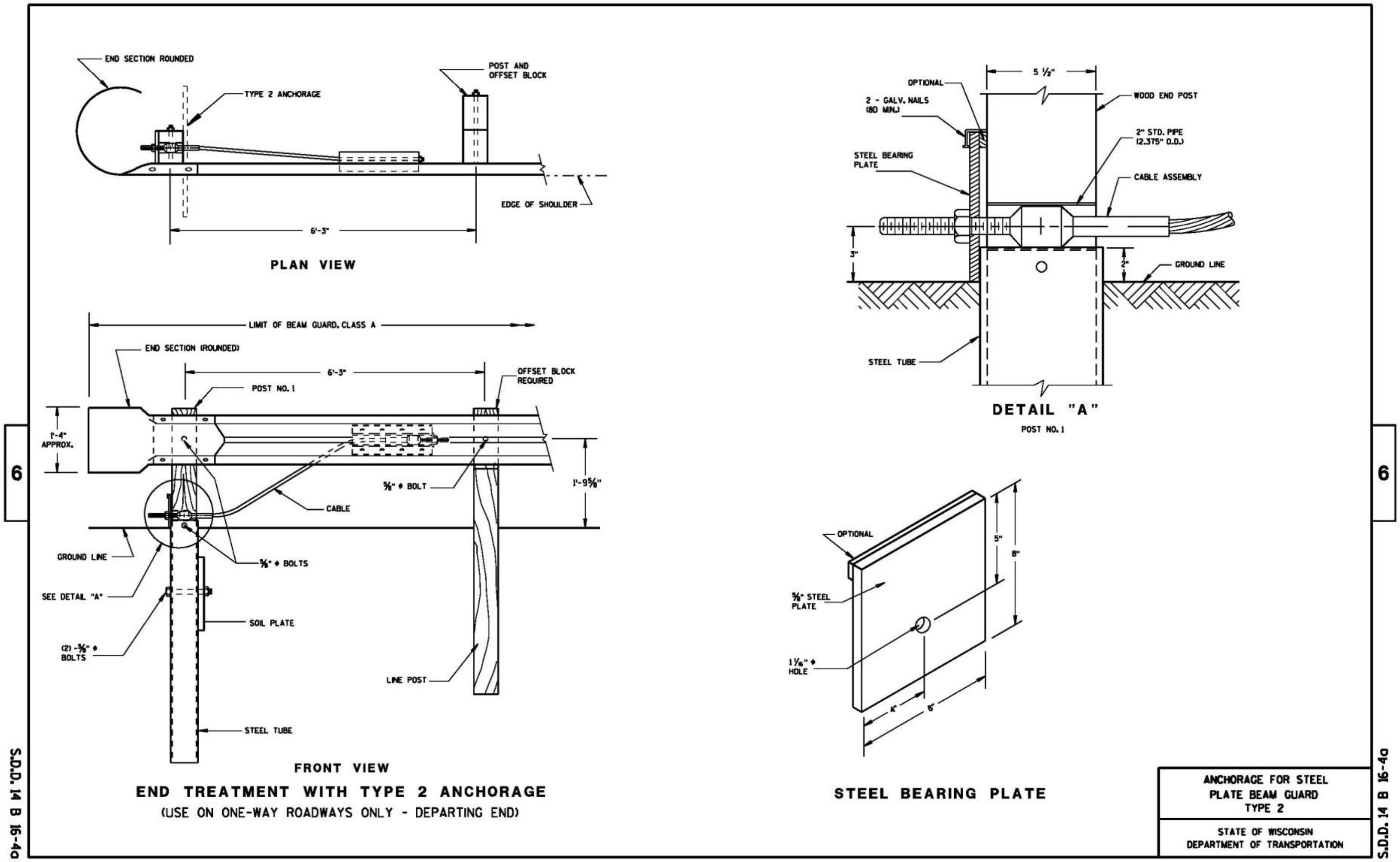


Figure A-28. Wisconsin DOT Terminal Type 2

Standard Detail Drawing 14B16-4a

References: FDM Procedure 11-45-1
AASHTO Roadside Design Guide

Bid items associated with this drawing:

Item #	Title
614.0305	Steel Plate Beam Guard Class A (LF)
614.0115	Anchorages for Steel Plate Beam Guard Type 2 (each)

Standardized Special Provisions associated with this drawing:

STSP #	Title

Other SDD's associated with this drawing: 14B15 and 14B18 - 14B16-4b & 14B18-5a is required when this drawing is called for in the plans.

Design Notes:

A Type 2 anchor shall only be used on the departing end of beam guard located along one-way roadways.

Contact Person: Erik Emerson (608) 266 – 2842

September 7, 2007

Figure A-29. Wisconsin DOT Terminal Type 2

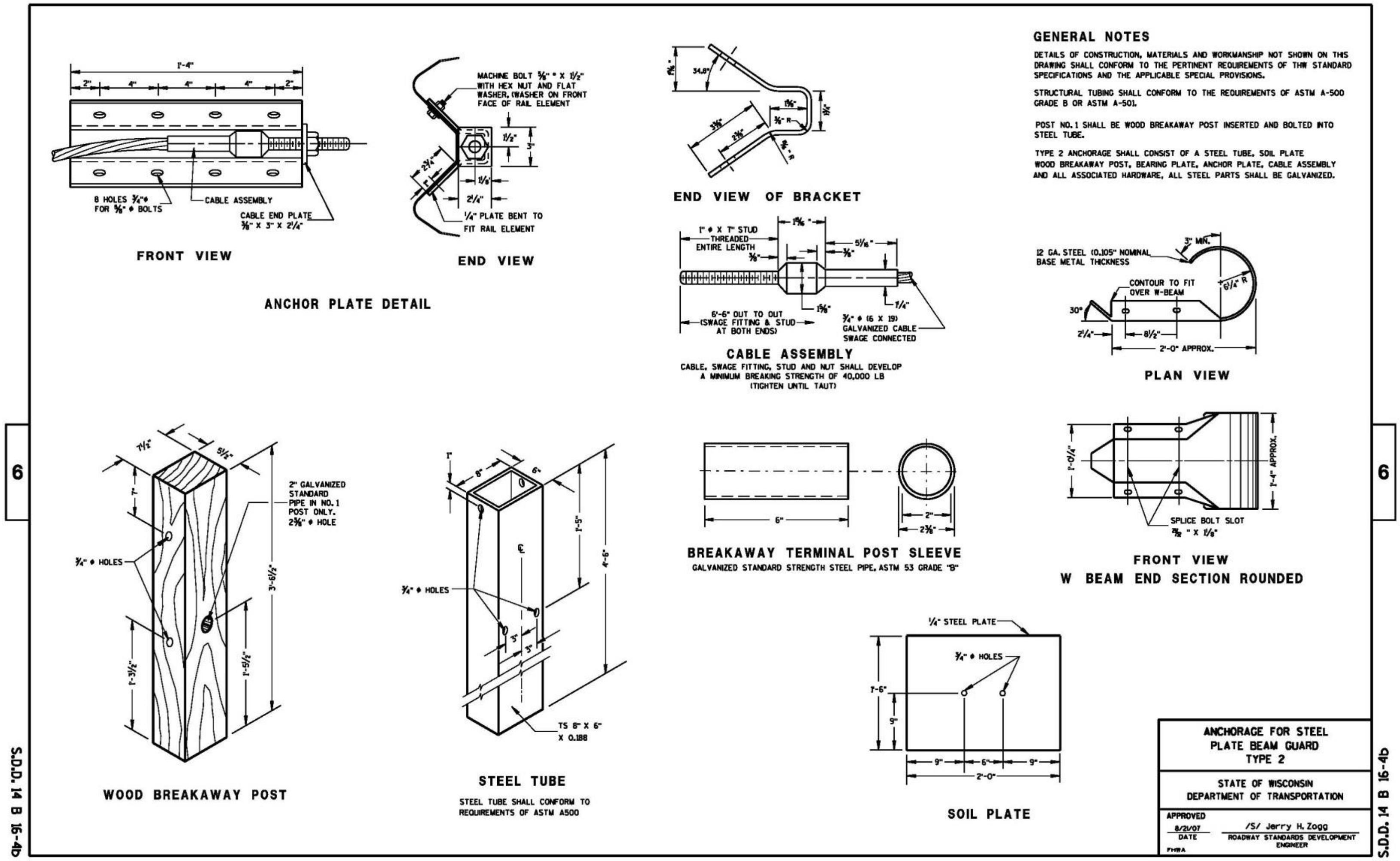


Figure A-30. Wisconsin DOT Terminal Type 2

Standard Detail Drawing 14B16-4b

References: FDM Procedure 11-45-1
AASHTO Roadside Design Guide

Bid items associated with this drawing:

Item #	Title
614.0305	Steel Plate Beam Guard Class A (LF)
614.0115	Anchorages for Steel Plate Beam Guard, Type 2 (each)
205.9006.S	Grading, Shaping, and Finishing for Barrier Terminals, Item 205.9006.S (each)

Standardized Special Provisions associated with this drawing:

STSP #	Title
205.009	Grading, Shaping and Finishing for Barrier Terminals, Item 205.9006.S

Other SDD's associated with this drawing: 14B15 & 14B18
14B16-4a and 14B18-6a are required when this drawing is called for in the plans.

Design Notes: For Non-Grading Type Projects with Beam Guard - (Resurfacing plus Beam Guard or Separate Beam Guard Project)

Item #	Title
205.9005.S	Grading, Shaping and Finishing for Beam Guard Anchorage

List all items of work and round up the quantities for individual items and note them as "For Bid Information Only." Following is suggested table format for use on the Miscellaneous Quantities Sheet:

GRADIING, SHAPING AND FINISHING FOR BARRIER TERMINALS, ITEM 205.9006.S

Station Location (Anchorage Post # 1)	* Fill	* Borrow Exc.	* Salv. Topsoil	* Fert. Type ---	* Seeding	* Mulching	Each
	C.Y.	C.Y.	S.Y.	CWT.	L.B.	S.Y.	
STA.							
Totals							

* Items & Quantities listed for Bid Information Only. For quantities shown be very clear how many units Each are included in the table.
Options to use in displaying quantities:

1. Show items and quantities for 1 Each, typical location.
2. List each anchor location separately with respective quantities.
3. Show items and quantities for all anchors inclusive, and indicate the quantity of anchors these totals are for.

Contact Person: Erik Emerson (608) 266–2842

September 7, 2007

Figure A-31. Wisconsin DOT Terminal Type 2

Standard Detail Drawing 14B3 - 2

References:

Bid items associated with this drawing:

Item # Title

Standardized Special Provisions associated with this drawing:

STSP # Title

Other SDD's associated with this drawing:

Design Notes:

Contact Person: Peter Amakobe (608) 266-2842

April 18, 2003

Figure A-32. Wisconsin DOT Terminal Steel Plate Beam Guard Class B

Wyoming

1) Type C (Drawing 606-1 (sheet 10))
2) Type D - low speed terminal (Drawing 606-1 (sheet 11))

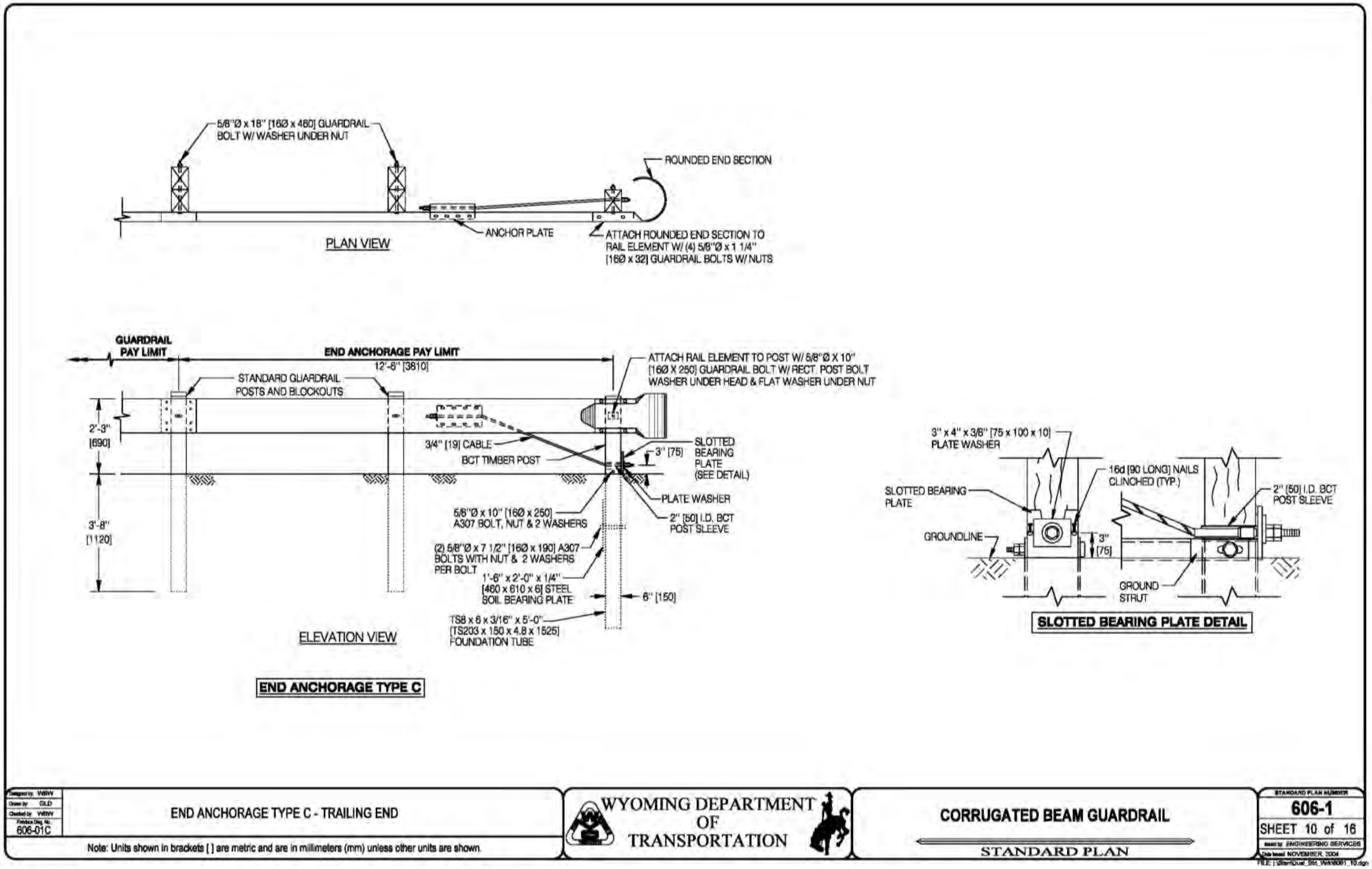


Figure A-33. Wyoming DOT Terminal Type C

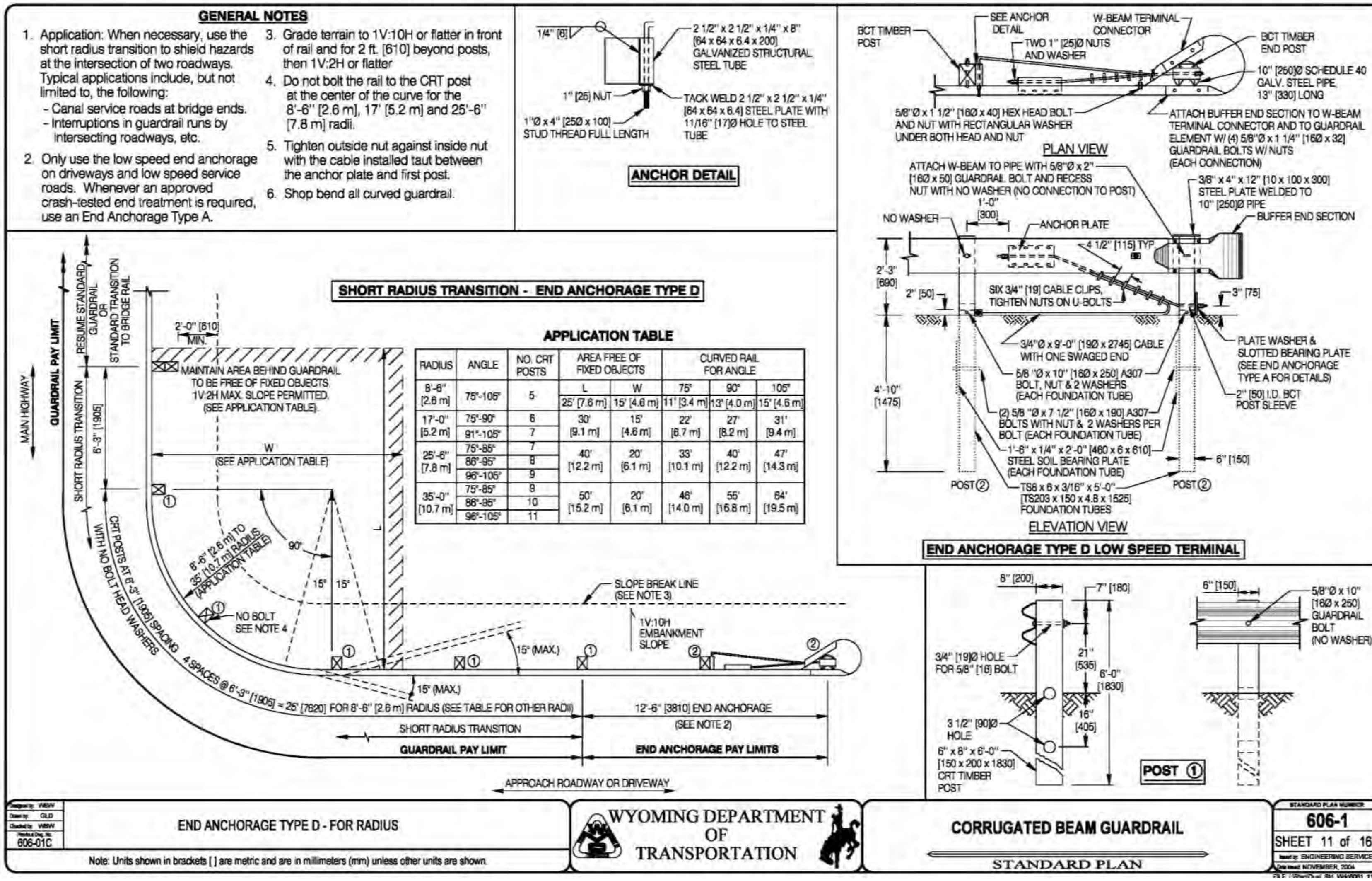


Figure A-34. Wyoming DOT Terminal Type D

Texas

1) Texas DOT Metal Beam Guard Fence Downstream Anchor Terminal

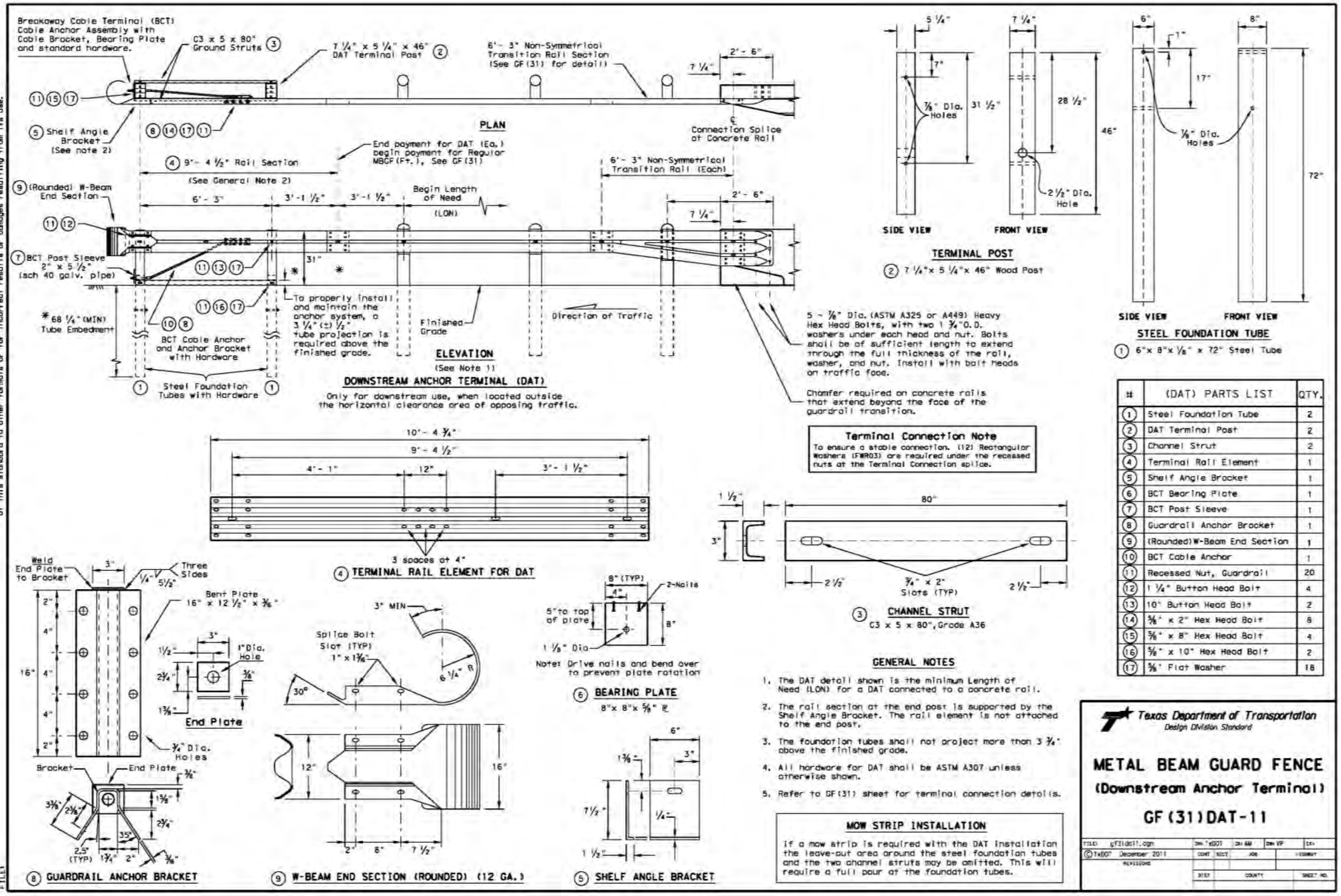


Figure A-35. Texas DOT Metal Beam Guard Fence Downstream Anchor Terminal

California

1) Type SFT
2) Single thrie beam barrier end anchor
3) Anchored in backslope rail

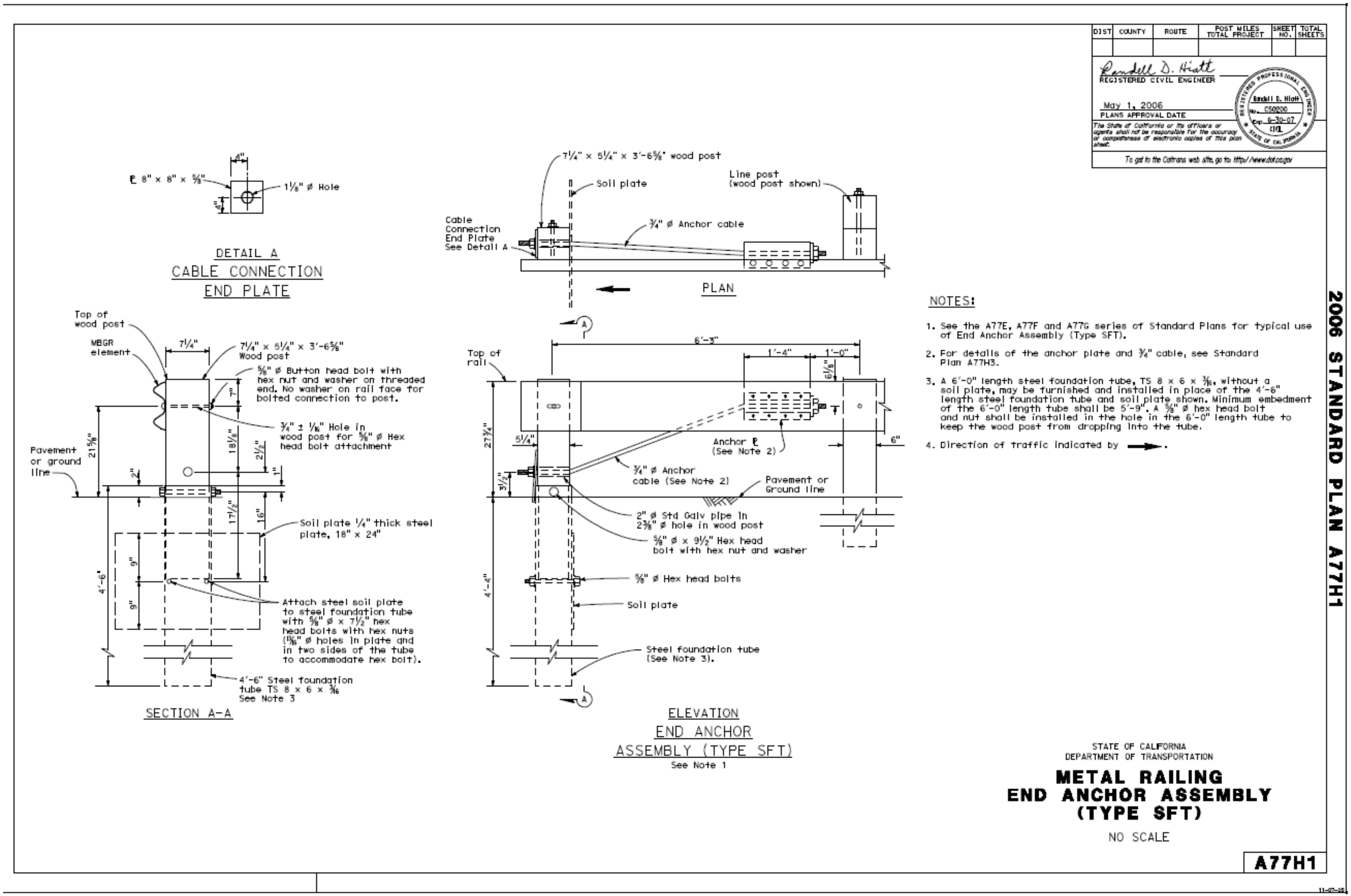


Figure A-36. Type SFT

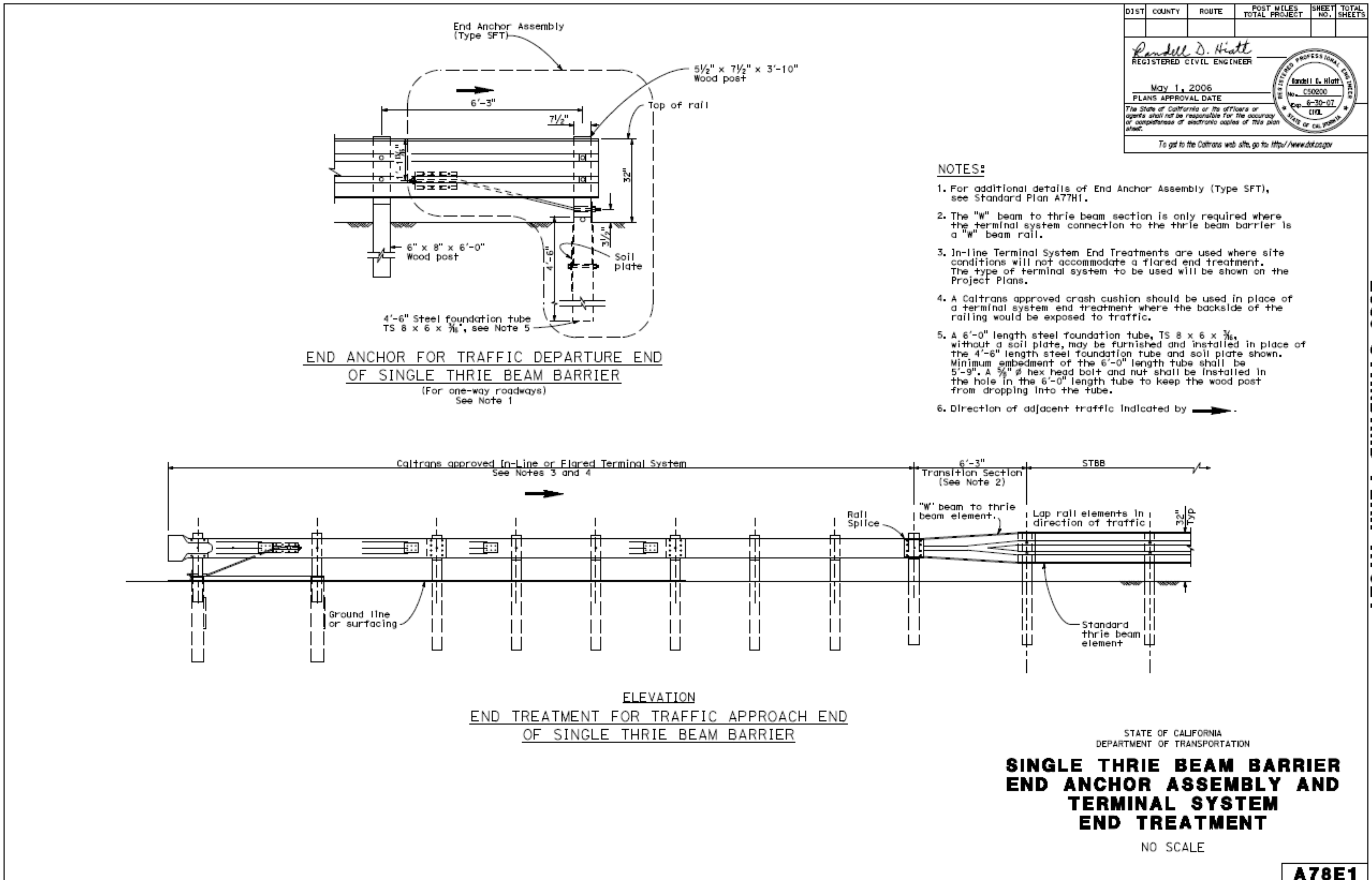


Figure A-37. Single Thrie-Beam Barrier End Aanchor

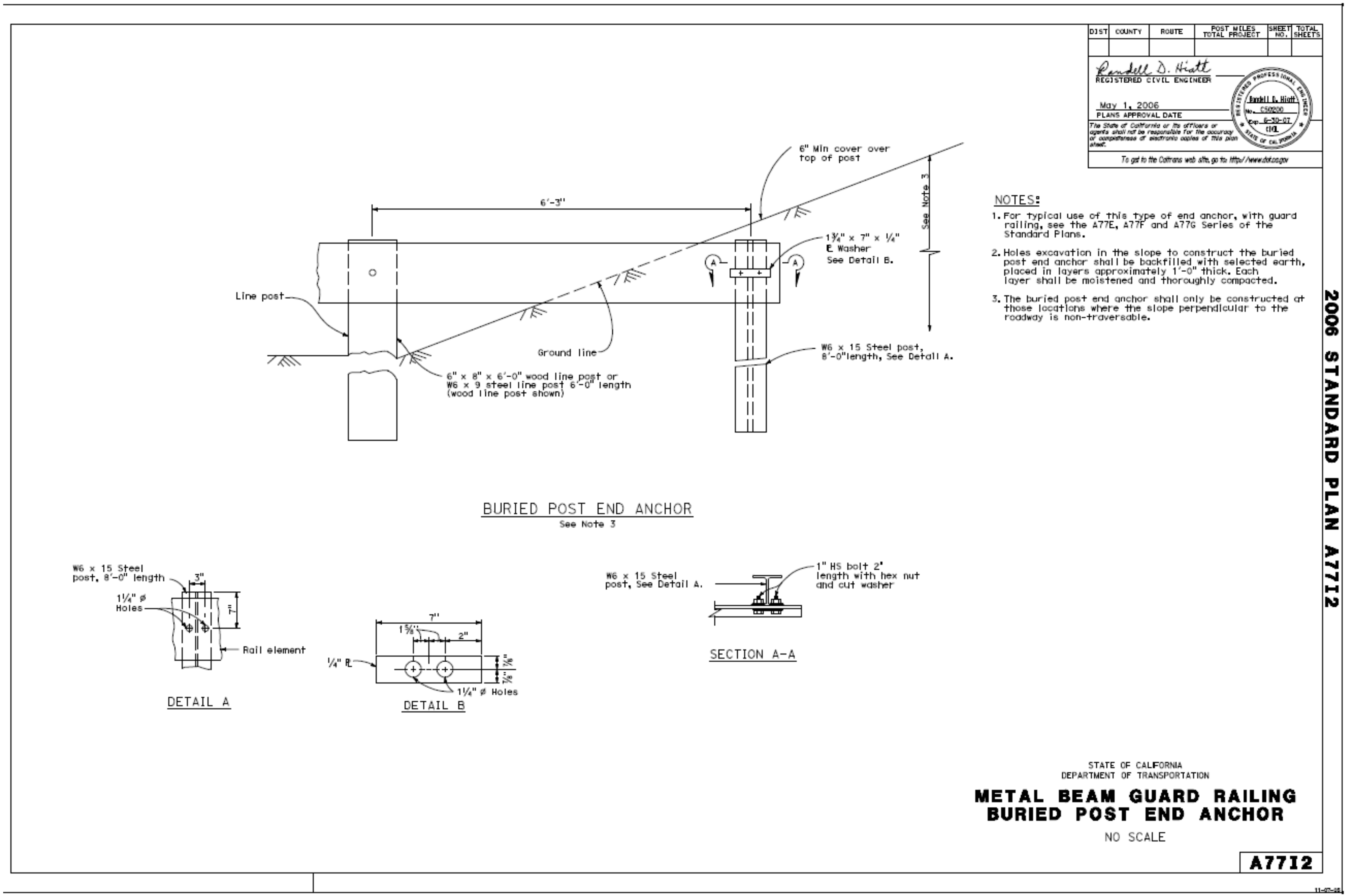


Figure A-38. Anchored-in-Backslope Rail

Appendix B. Material Specifications and Mill Certifications

3500G

TRINITY HIGHWAY PRODUCTS, LLC.
Plant #55
425 E. O' CONNOR AVENUE
Lima, OH 45801
419-227-1296

MATERIAL CERTIFICATION

CUSTOMER: STOCK	DATE: MAY 05, 2011 INVOICE # LOT NUMBER: 110325L
PART NUMBER 3500G	QUANTITY: 16,659
DESCRIPTION: 5/8"x 10" GR BOLT	DATE SHIPPED:
SPECIFICATIONS: ASTM A307-A /A153	HEAT# 20134300 & 20134310

MATERIAL CHEMISTRY

C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
.08	.34	.009	.004	.05	.04	.04	.01	.09	.009	.001	.030	.008	.0002	.001	.001
.09	.35	.009	.004	.06	.04	.04	.01	.08	.008	.001	.024	.007	.0001	.001	.001

PLATING AND/OR PROTECTIVE COATING

HOT DIP GALVANIZED (OZ. PER SQ. FT.)		2.59 Avg.

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

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

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

TRINITY HIGHWAY PRODUCTS, LLC.

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME
THIS 5TH DAY OF MAY, 2011

Sherri L. Dnofz/uMann NOTARY PUBLIC

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

Figure B-1. 0.625-in. (16-mm) Post Bolts, Test Nos. DSAP-1 and DSAP-2

CHARTER STEEL

A Division of Charter Manufacturing Company, Inc.

FILE

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Trinity Industries Inc.
425 E. O Conner Ave
Sue Henline
Lima,OH-45801
Kind Attn :Sue Henline

Cust P.O.	139855M-3
Customer Part #	100941B
Charter Sales Order	70016981
Heat #	20134300
Ship Lot #	2011626
Grade	1010 R AK FG RHQ 41/64
Process	HR
Finish Size	41/64

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 20134300

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.08	.34	.009	.004	.05	.04	.04	.01	.09	.009	.001

AL	N	B	TI	NB
.030	.0080	.0002	.001	.001

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 2011626

REDUCTION RATIO = 152:1

=

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29-05 Revision = 05 Dated =

Additional Comments: Fax Number - 222-7398

RECEIVED
MAR 17 2011
TRINITY HWY PRODUCTS, LLC
Lima, Ohio Plant 55

Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load1,Fax1,Mail0

ACCREDITED Testing Laboratory
Page 1 of 1

Janice Barnard
Manager of Quality Assurance
03/17/2011

Figure B-2. 0.625-in. (16-mm) Post Bolts, Test Nos. DSAP-1 and DSAP-2

USED 3-22-11

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

FILE

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Trinity Industries Inc.
425 E. O Conner Ave
Sue Henline
Lima,OH-45801
Kind Attn :Sue Henline

Cust P.O.	139855M-3
Customer Part #	100941B
Charter Sales Order	70016981
Heat #	20134310
Ship Lot #	2011625
Grade	1010 R AK FG RHQ 41/64
Process	HR
Finish Size	41/64

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 20134310

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.09	.35	.009	.004	.06	.04	.04	.01	.03	.008	.001

AL	N	B	TI	NB
.024	.0070	.0001	.001	.001

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 2011625

REDUCTION RATIO = 152:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29-05 Revision = 05 Dated =

Additional Comments: Fax Number - 222-7398

RECEIVED
MAR 15 2011
TRINITY HWY PRODUCTS, LLC
Lima, Ohio Plant 55

Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load1,Fax1,Mail0

Page 1 of 1

Janice Barnard
Manager of Quality Assurance
03/15/2011

Figure B-3. 0.625-in. (16-mm) Post Bolts, Test Nos. DSAP-1 and DSAP-2

3346

TRINITY HIGHWAY PRODUCTS, LLC.
425 E. O'CONNOR AVENUE
LIMA, OHIO 45801
419-227-1296

MATERIAL CERTIFICATION

CUSTOMER: STOCK	DATE: MARCH 31, 2011
	INVOICE #:
	LOT #: 110318N2
PART NUMBER: 3340G	QUANTITY: 106,000
DESCRIPTION: 5/8" GR NUT	DATE SHIPPED
SPECIFICATIONS: ASTM A563-A/A153	HEAT # 20131470 & 20131460

MATERIAL CHEMISTY

C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
.08	.35	.007	.004	.07	.05	.05	.02	.09	.007	.004	.023	.008	.0001	.001	.001
.09	.36	.008	.004	.05	.04	.06	.01	.09	.006	.004	.025	.006	.0002	.001	.001

PLATING AND/OR PROTECTIVE COATING

HOT DIP GALVANIZING (OZ. PER SQ. FT.)	2.52 AVG.

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

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

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

TRINITY HIGHWAY PRODUCTS, LLC.

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME
THIS 31ST DAY OF MARCH, 2011

Sheri L. Dondi/Mann NOTARY PUBLIC

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

Figure B-4. 0.625-in. (16-mm) Post Bolt Nuts, Test Nos. DSAP-1 and DSAP-2

Trinity Metals Laboratory
A DIVISION OF TRINITY INDUSTRIES
4001 IRVING BLVD. 75247 - P.O. BOX 568887
DALLAS, TX 75356-8887
Phone: 214.589.7591 FAX: 214.589.7594

NVLAP LAB CODE 200654-0

Lab No: 11040021F
KEITH HAMBURG
TRINITY HWY PRODUCTS, LLC #55
ROLLFORM
LIMA, OH 45801

Received Date: 04/04/2011
Heat Code:
Heat Number: 20131460 & 20131470
PO or Work Order: 110318N2
Test Spec: F606 ASTM METHODS
Other Information: 55-61597

Completion Date: 04/04/2011
Weld Spec:
Material Type: A 563 A
Material Size: 5/8" GR Nuts

HARDNESS TEST:

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: Surface of Wrench Flat A
Hardness Average: 86.5

Measured Value	Measured Amt
Measured Value	86
Measured Value	87

PASSED

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: Surface of Wrench Flat B
Hardness Average: 84

Measured Value	Measured Amt
Measured Value	84
Measured Value	84

PASSED

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: Surface of Wrench Flat C
Hardness Average: 87

Measured Value	Measured Amt
Measured Value	87
Measured Value	87

PASSED

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: Surface of Wrench Flat D
Hardness Average: 87.5

Measured Value	Measured Amt
Measured Value	87
Measured Value	88

PASSED

4-04-11 CG

We certify the above results to be a true and accurate representation of the sample(s) submitted. Alteration or partial reproduction of this report will void certification. NVLAP Certificate of Accreditation effective through 12-31-11.This report may not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

Lab Director, Michael S. Beaton, PE

Page 1 of 2

Figure B-5. 0.625-in. (16-mm) Post Bolt Nuts, Test Nos. DSAP-1 and DSAP-2

Trinity Metals Laboratory
A DIVISION OF TRINITY INDUSTRIES
4001 IRVING BLVD. 75247 - P.O. BOX 568887
DALLAS, TX 75356-8887
Phone: 214.589.7591 FAX: 214.589.7594

NVLAP LAB CODE 200654-0

Lab No: 11040021F

KEITH HAMBURG
TRINITY HWY PRODUCTS, LLC #55
ROLLFORM
LIMA, OH 45801

Received Date: 04/04/2011
Heat Code:
Heat Number: 20131460 & 20131470
PO or Work Order: 110318N2
Test Spec: F606 ASTM METHODS
Other Information: 55-61597

Completion Date: 04/04/2011
Weld Spec:
Material Type: A 563 A
Material Size: 5/8" GR Nuts

PASSED

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: Surface of Wrench Flat E
Hardness Average: 86.5

Measured Value	Measured Amt
Measured Value	87
Measured Value	86

OTHER TEST:

Type: NUT PROOF LOAD (to 30K)
Samples PASSED proof loads of 16,950 lbs.

Quantity amount: 5

Type: HEAD MARKINGS
TRN N

Quantity amount: 1

We certify the above results to be a true and accurate representation of the sample(s) submitted. Alteration or partial reproduction of this report will void certification. NVLAP Certificate of Accreditation effective through 12-31-11. This report may not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

Lab Director, Michael S. Beaton, PE

Page 2 of 2

Figure B-6. 0.625-in. (16-mm) Post Bolt Nuts, Test Nos. DSAP-1 and DSAP-2

FILE

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

Trinity Industries Inc.
425 E. O Conner Ave
Sue Henline
Lima,OH-45801
Kind Attn :Sue Henline

[redacted]	
	139854M-4
	100944B
	70017174
	20131480
	2010864
	1010 R AK FG RHQ 1-7/32
	HR
	1-7/32

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 20131480

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.09	.36	.008	.004	.05	.04	.06	.01	.09	.006	.004

AL	N	B	TI	NB
.025	.0080	.0002	.001	.001

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 2010884

REDUCTION RATIO = 42:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29-05 Revision = 05 Dated =

Additional Comments: Fax Number - 222-7398

RECEIVED
MAR 11 2011
TRINITY HWY PRODUCTS, LLC
Lima, Ohio Plant 55

Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load1,Fax1,Mail0

Page 1 of 1

Janice Barnard
Manager of Quality Assurance
03/11/2011

Figure B-7. 0.625-in. (16-mm) Post Bolt Nuts, Test Nos. DSAP-1 and DSAP-2

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

FILE

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Trinity Industries Inc.
425 E. O Conner Ave
Sue Henline
Lima,OH-45801
Kind Attn :Sue Henline

Cust P.O.	139854M-4
Customer Part #	100944B
Charter Sales Order	70017174
Heat #	20131470
Ship Lot #	2010863
Grade	1010 R AK FG RHQ 1-7/32
Process	HR
Finish Size	1-7/32

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 20131470

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.08	.35	.007	.004	.07	.05	.05	.02	.09	.007	.004

AL	N	B	TI	NB
.023	.0080	.0001	.001	.001

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 2010863

REDUCTION RATIO = 42:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29-05 Revision = 05 Dated =

Additional Comments: Fax Number - 222-7398

RECEIVED
MAR 15 2011
TRINITY HWY PRODUCTS, LLC
Lima, Ohio Plant 55

Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load1,Fax1,Mail0

Page 1 of 1

Janice Barnard
Manager of Quality Assurance
03/15/2011

Figure B-8. 0.625-in. (16-mm) Post Bolt Nuts, Test Nos. DSAP-1 and DSAP-2

425 E. O'Connor
Lima, OH

Customer:	MIDWEST MACH.& SUPPLY CO.	Sales Order:	1093497	Print Date:	6/30/08
	P. O. BOX 81097	Customer PO:	2030	Project:	RESALE
		BOL #	43073	Shipped To:	NE
		Document #	1	Use State:	KS
	LINCOLN, NE 68501-1097				

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

Pieces	Description
64	5/8"X10" GR BOLT A307
192	5/8"X18" GR BOLT A307
32	1" ROUND WASHER F844
64	1" HEX NUT A563
192	WD 6'0 POST 6X8 CRT
192	WD BLK 6X8X14 DR
64	NAIL 16d SRT
64	WD 3'9 POST 5.5X7.5 BAND
32	STRUT & YOKE ASSY
128	SLOT GUARD '98
32	3/8 X 3 X 4 PL WASHER

MGSBR

Ground Strut

090453-8

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

402-761-3288 15:36 06/04/2009

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

State of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public: [signature]
Commission Expires 6/26/2012

Trinity Highway Products, LLC
Certified By: [signature]

2 of 4

Figure B-9. Groundline Strut and Yoke, Test Nos.DSAP-1 and DSAP-2

Table B-1. Bill of Materials for Test No. WIDA-1

Item No.	QTY	Description	Material Specifications	Reference
a1	25	W6x8.5 6' [W152x12.6 1,829 mm] Long Steel Post	ASTM A992 Min 50 ksi [345 MPa] (W6x9 ASTM A36 Min 36 ksi [248 MPa])	NAVY BLUE TAGS 12-0348
a2	25	6x12x14 1/4" [152x305x362 mm] blockout	SYP Grade No. 1 or better	NAVY BLUE TAGS 12-0356, 11-0025
a3	1	6'-3" [1,905 mm] W-Beam MGS Section	12 gauge [2.7 mm] AASHTO M180	"WB1" w/GREEN 12-0034
a4	12	12'-6" [3,810 mm] W-Beam MGS Section	12 gauge [2.7 mm] AASHTO M180	HEAT #4614 12-6_4614
a5	2	12'-6" [3,810 mm] W-Beam MGS End Section	12 gauge [2.7 mm] AASHTO M180	HEAT #4614 12-6_4614
a6	1	W-Beam Rounded End Section	12 gauge [2.7 mm] AASHTO M180	BLUE PAINT 12-0358
b1	25	5/8" Dia. x 14" [M16x356 mm] Long Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM 563 DH	BOLT: RED 12-0368 / NAVY BLUE 12-0348 NUT: 12-0204
b2	25	16D Double Head Nail	-	16D-1
b3	4	5/8" Dia. x 10" [M16x254 mm] Long Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM 563 DH	BOLT: NAVY BLUE 12-0098 NUT: 12-0204
b4	116	5/8" Dia. x 1 1/4" [M16x32 mm] Long Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM 563 DH	BOLT AND NUT: 12-0204
b5	44	5/8" [16 mm] Dia. Flat Washer	ASTM A153	PLAIN 090453 / BLACK 12-0019, BLUE 12-0098(*)
c1	4	BCT Timber Post - MGS Height	SYP Grade No. 1 or better	BLUE TAGS 11-0025
c2	4	72" [1,829 mm] Long Foundation Tube	ASTM A53 Grade B	REQ: 090453-7 AND 090458
c3	2	Strut and Yoke Assembly	ASTM A36 Steel Galvanized	090453-8
c4	2	8x8x5/8" [127x203x16 mm] Anchor Cable Bearing Plate	ASTM A36 Steel	BLACK PAINT, STAMPED WITH "A3", HEATS V911470 AND 18486
c5	2	BCT Anchor Cable Assembly	3/4-in. [19-mm] 6x19 IWRC IPS Galvanized Wire Rope	RED PAINT, REEL # 428-277631-1-2-3
c6	2	Anchor Bracket Assembly	ASTM A36 Steel	BLACK PAINT, STAMPED WITH "A2", HEATS V911470 AND 18486
c7	2	2 3/8" [60 mm] O.D. x 6" [152 mm] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40	REQUISITION: 09-0458 HEAT # 280638
c8	4	5/8" Dia. x 10" [M16x254 mm] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM 563 DH	BOLT: NAVY BLUE 12-0098 NUT: 12-0203
c9	16	5/8" Dia. x 1 1/2" [M16x38 mm] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM 563 DH	BOLT: 11-0006-3 NUT: 12-0203
c10	4	7/8" Dia. x 7 1/2" [M16x191 mm] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM 563 DH	12-0037
c11	8	7/8" [22 mm] Dia. Flat Washer	ASTM A153	12-0037

(*) Mill Certification not provided

Table B-2. Bill of Materials for Test No. WIDA-2

Item No.	QTY	Description	Material Specifications	Reference
a1	25	W6x8.5 6' [W152x12.6 1,829 mm] Long Steel Post	ASTM A992 Min 50 ksi [345 MPa] (W6x9 ASTM A36 Min 36 ksi [248 MPa])	NAVY BLUE TAGS 12-0348
a2	25	6x12x14 1/4" [152x305x362 mm] blockout	SYP Grade No. 1 or better	NAVY BLUE TAGS 12-0356, 11-0025
a3	1	6'-3" [1,905 mm] W-Beam MGS Section	12 gauge [2.7 mm] AASHTO M180	"WB1" w/GREEN 12-0034
a4	12	12'-6" [3,810 mm] W-Beam MGS Section	12 gauge [2.7 mm] AASHTO M180	HEAT #4614 12-6_4614
a5	2	12'-6" [3,810 mm] W-Beam MGS End Section	12 gauge [2.7 mm] AASHTO M180	HEAT #4614 12-6_4614
a6	1	W-Beam Rounded End Section	12 gauge [2.7 mm] AASHTO M180	BLUE PAINT 12-0358
b1	25	5/8" Dia. x 14" [M16x356 mm] Long Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM 563 DH	BOLT: RED 12-0368 / NAVY BLUE 12-0348 NUT: 12-0204
b2	25	16D Double Head Nail	-	16D-1
b3	4	5/8" Dia. x 10" [M16x254 mm] Long Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM 563 DH	BOLT: NAVY BLUE 12-0098 NUT: 12-0204
b4	116	5/8" Dia. x 1 1/4" [M16x32 mm] Long Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM 563 DH	BOLT AND NUT: 12-0204
b5	44	5/8" [16 mm] Dia. Flat Washer	ASTM A153	PLAIN 090453 / BLACK 12-0019, BLUE 12-0098(*)
c1	4	BCT Timber Post - MGS Height	SYP Grade No. 1 or better	BLUE TAGS 11-0025
c2	4	72" [1,829 mm] Long Foundation Tube	ASTM A53 Grade B	REQ: 090453-7 AND 090458
c3	2	Strut and Yoke Assembly	ASTM A36 Steel Galvanized	090453-8
c4	2	8x8x5/8" [127x203x16 mm] Anchor Cable Bearing Plate	ASTM A36 Steel	BLACK PAINT, STAMPED WITH "A3", HEATS V911470 AND 18486
c5	2	BCT Anchor Cable Assembly	3/4-in. [19-mm] 6x19 IWRC IPS Galvanized Wire Rope	RED PAINT, REEL # 428-277631-1-2-3
c6	2	Anchor Bracket Assembly	ASTM A36 Steel	BLACK PAINT, STAMPED WITH "A2", HEATS V911470 AND 18486
c7	2	2 3/8" [60 mm] O.D. x 6" [152 mm] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40	REQUISITION: 09-0458 HEAT # 280638
c8	4	5/8" Dia. x 10" [M16x254 mm] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM 563 DH	BOLT: NAVY BLUE 12-0098 NUT: 12-0203
c9	16	5/8" Dia. x 1 1/2" [M16x38 mm] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM 563 DH	BOLT: 11-0006-3 NUT: 12-0203
c10	4	7/8" Dia. x 7 1/2" [M16x191 mm] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM 563 DH	12-0037
c11	8	7/8" [22 mm] Dia. Flat Washer	ASTM A153	12-0037

(*) Mill Certification not provided

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

Test Report
DATE SHIPPED: 02/29/12

Customer: MIDWEST MACHINERY & SUPPLY CO.
2200 Y STREET

LINCOLN,NE,68501

B.O.L. # 5239AA-1
Customer P.O.: 2551
Shipped to: MIDWEST MACHINERY & SUPPLY CO.
Project: STOCK
GHP Order No. 5239AA

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
L81665	0.1	0.8	0.01	0.025	0.19	63000	53300	20	200		2	6IN WF AT 8.5 X 6FT 0IN GR POST
L83827	0.09	0.94	0.013	0.031	0.23	70400	56300	24	200		2	6IN WF AT 8.5 X 6FT 0IN GR POST
L83786	0.09	0.85	0.011	0.038	0.23	66500	52300	20	200		2	6IN WF AT 8.5 X 6FT 0IN GR POST
L83766	0.09	0.88	0.011	0.036	0.19	67200	53300	21	200		2	6IN WF AT 8.5 X 6FT 0IN GR POST
L81670	0.09	0.92	0.014	0.028	0.2	62000	47400	21	50		2	6IN WF AT 8.5 X 6FT 0IN GR POST

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-653
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4

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

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 1 st day of March, 2012

Notary Public, State of Ohio

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2014

Figure B-10. W6x8.5 6' (W152x12.6 1,829 mm) Long Steel Post,, Part a1, Test Nos. WIDA-1 and WIDA-2

Certifiec Analysis

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

MILFORD, NE 68405
Project: RESALE

Order Number: 1150595
Customer PO: 2483
BOL Number: 63165
Document #: 1
Shipped To: NE
Use State: KS

W BEAM - 6'3"
12-0034

As of: 6/27/11

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
40	6G	12/6'3/S	M-180	A	2	144794	59,920	76,860	28.7	0.190	0.740	0.011	0.003	0.020	0.130	0.00	0.050	0.002	4
			M-180	A	2	144790	62,490	79,560	26.7	0.190	0.730	0.014	0.000	0.030	0.130	0.000	0.050	0.001	4
			M-180	A	2	144791	60,790	77,800	26.7	0.200	0.730	0.013	0.004	0.010	0.130	0.000	0.060	0.002	4
			M-180	A	2	144793	63,330	78,900	28.4	0.190	0.730	0.012	0.002	0.020	0.120	0.000	0.050	0.002	4
	6G		M-180	A	2	95601	60,950	78,720	28.1	0.180	0.740	0.013	0.001	0.020	0.130	0.00	0.060	0.002	4
			M-180	A	2	144789	61,990	78,810	29.3	0.190	0.730	0.013	0.002	0.030	0.130	0.000	0.050	0.002	4
			M-180	A	2	144791	60,790	77,800	26.7	0.200	0.730	0.013	0.004	0.010	0.130	0.000	0.060	0.002	4
			M-180	A	2	144794	59,920	76,860	28.7	0.190	0.740	0.011	0.003	0.020	0.130	0.000	0.050	0.002	4
			M-180	A	2	144795	59,070	76,940	28.7	0.200	0.730	0.014	0.001	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	144800	60,890	78,640	27.0	0.190	0.730	0.015	0.002	0.020	0.120	0.000	0.060	0.002	4
			M-180	A	2	145135	61,550	79,710	25.5	0.190	0.730	0.012	0.002	0.020	0.120	0.000	0.050	0.001	4
			M-180	A	2	145136	61,410	79,430	25.6	0.190	0.730	0.011	0.003	0.020	0.120	0.000	0.050	0.002	4
			M-180	A	2	145137	59,910	77,480	29.4	0.190	0.720	0.011	0.003	0.010	0.120	0.000	0.050	0.001	4
25	211G	T12/12'6/3'1.5/S	M-180	A	2	144302	59,460	78,950	25.8	0.190	0.720	0.010	0.004	0.020	0.140	0.00	0.060	0.001	4
			M-180	A	2	143214	64,690	82,970	24.9	0.200	0.740	0.012	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	144300	53,230	72,710	32.2	0.190	0.730	0.012	0.004	0.020	0.140	0.000	0.060	0.001	4
			M-180	A	2	144301	61,670	78,930	25.5	0.180	0.720	0.013	0.003	0.020	0.140	0.000	0.050	0.002	4
			M-180	A	2	144303	59,490	78,080	27.1	0.190	0.740	0.013	0.003	0.020	0.140	0.000	0.050	0.000	4
			M-180	A	2	144304	57,100	75,130	27.1	0.190	0.730	0.012	0.004	0.020	0.140	0.000	0.060	0.001	4
			M-180	A	2	144305	57,590	76,090	27.6	0.190	0.740	0.013	0.003	0.010	0.140	0.000	0.050	0.002	4
20	260G	T12/25/6'3/S	M-180	A	2	144301	61,670	78,930	25.5	0.180	0.720	0.013	0.003	0.020	0.140	0.00	0.050	0.002	4
			M-180	A	2	144300	53,230	72,710	32.2	0.190	0.730	0.012	0.004	0.020	0.140	0.000	0.060	0.001	4
			M-180	A	2	144303	59,490	78,080	27.1	0.190	0.740	0.013	0.003	0.020	0.140	0.000	0.050	0.000	4
			M-180	A	2	144304	57,100	75,130	27.1	0.190	0.730	0.012	0.004	0.020	0.140	0.000	0.060	0.001	4
			M-180	A	2	144305	57,590	76,090	27.6	0.190	0.740	0.013	0.003	0.010	0.140	0.000	0.050	0.002	4
			M-180	A	2	144306	57,890	77,170	29.9	0.190	0.730	0.011	0.004	0.020	0.100	0.000	0.050	0.001	4

Figure B-11. 6 ft-3 in. (1,905 mm) W-Beam MGS Section, Part a3, Test Nos. WIDA-1 and WIDA-2

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

MAY 14 2009

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

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

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

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

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

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

Notary Public, State of Ohio

NOTARIAL SEAL STATE OF OHIO

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

Figure B-12. 12'-6" (3,810 mm) W-Beam MGS Section, Part a4, Test Nos. WIDA-1 and WIDA-2

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

MAY 14 2009

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

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

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

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

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

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

NOTARIAL SEAL STATE OF OHIO

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

Figure B-13. 12'-6" (3,810 mm) W-Beam MGS End Section, Part a5, Test Nos. WIDA-1 and WIDA-2

Certified Analysis

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

MILFORD, NE 68405
Project: RESALE

Order Number: 1168756
Customer PO: 2581
BOL Number: 68287
Document #: 1
Shipped To: NE
Use State: KS

As of: 3/9/12

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
30	260G	T12/25/6'3/S	M-180	A	2	151877	58,680	77,470	26.0	0.190	0.720	0.013	0.004	0.010	0.120	0.00	0.050	0.002	4
			M-180	A	2	152774	59,060	77,140	29.2	0.190	0.720	0.011	0.004	0.010	0.011	0.000	0.050	0.001	4
			M-180	A	2	152775	60,650	79,300	25.1	0.190	0.730	0.014	0.004	0.020	0.120	0.000	0.060	0.001	4
			M-180	A	2	152777	59,110	76,570	30.4	0.190	0.730	0.012	0.004	0.020	0.120	0.000	0.050	0.001	4
			M-180	A	2	152779	58,850	76,750	25.7	0.180	0.710	0.010	0.004	0.010	0.120	0.000	0.050	0.001	4
			M-180	A	2	152780	61,020	78,750	26.6	0.190	0.730	0.009	0.001	0.030	0.110	0.000	0.040	0.001	4
50	901G	12/FLARE/8 HOLE	M-180	A	2	149776	54,950	71,300	29.5	0.190	0.730	0.013	0.004	0.020	0.110	0.00	0.050	0.001	4
10	907G	12/BUFFER/ROLLED	M-180	A	2	515699	67,600	76,100	28.0	0.063	0.780	0.014	0.008	0.009	0.031	0.04	0.029	0.000	4

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.

BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH -- 49100 LB

1 of 2

Figure B-14. W-Beam Rounded End Section, Part a6, Test Nos. WIDA-1 and WIDA-2

Certified Analysis

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

MILFORD, NE 68405
Project: RESALE

Order Number: 1168756
Customer PO: 2581
BOL Number: 68287
Document #: 1
Shipped To: NE
Use State: KS

As of: 3/9/12

State of Ohio, County of Allen. Sworn and subscribed before me this 9th day of March, 2012

Notary Public:
Commission Expires 1/23/2016

STATE OF OHIO
ANGELA COUNTS
NOTARY PUBLIC
ID# 2011NT0014
Commission Expires
January 23, 2016
AUGLAIZE COUNTY

Trinity Highway Products , LLC
Certified By:
Quality Assurance

2 of 2

Figure B-15. W-Beam Rounded End Section, Part a6, Test Nos. WIDA-1 and WIDA-2

3540G

INSPECTION CERTIFICATE

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

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER P.O. : 143227

INVOICE #: 946256 **DATE SHIPPED:** 6/20/11

LOT #: 22191

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

	SPECIFICATION	ACTUAL		
TENSILE RESULTS:	60,000 min.	81,460	70,642	76,898
		81,389	70,341	76,623
HARDNESS RESULTS:	SPECIFICATION	80.63	83.90	84.00
	100 MAX	86.33	77.90	85.00

COATING: ASTM SPECIFICATION F2329 HOT DIP GALVANIZE

STEEL SUPPLIER: NUCOR, CHARTER, NUCOR

HEAT NO. NF11101335, 10132120, NF11101336

QUANTITY AND DESCRIPTION:

18,900 PCS 5/8" X 14" GUARD RAIL BOLT
P/N 3540G

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

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS 21 DAY OF June 20 11
Diane Rasmussen

Linda McComas 6/21/11
APPROVED SIGNATORY DATE

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

Figure B-16. 5/8 in. Diameter x 14 in. (M16x356 mm) Long Guardrail Bolt and Nut, Part b1, Test Nos. WIDA-1 and WIDA-2

Mill Certification Details

NUCOR
NUCOR CORPORATION
NUCOR STEEL NEBRASKA

Mill Certification Details - 4/11/2011 10:10 AM

Customer: KRUEGER & CO - ELMHURST
Bill of Lading #: 197576
Chief Metallurgist : Jim Hill **Date :** 4/4/2011
Heat # : NF1110133502 **Tag # :** NF1111050255
Product : RDC **Size :** .594-19/32 Wire Rod
Grade: 1010 **Division :** Norfolk, NE
Comments : **Billet Heat #:** NF11101335

Chemical Properties -Wt.%

[illegible]
0.13 0.57 0.17 0.020 0.014 0.23 0.13 0.09 0.03 0.001 0.000 0.000 0.000 0.006 0.0002
[illegible]
0.0000 0.001

Physical Properties

[illegible]
Tensile: 64127
Yield: 46541
Elongation (in 8 inches):
Elongation (in 2 inches):

The testing was conducted in accordance with the requirements of this specification. All melting and manufacturing processes were performed in the United States of America.

[illegible signature]
Jim Hill
Division Metallurgist

Figure B-17. 5/8 in. Diameter x 14 in. (M16x356 mm) Long Guardrail Bolt and Nut, Part b1, Test Nos. WIDA-1 and WIDA-2

Apr 11 11 12:49p KruegerCo 630-833-5652 p.5

Krueger Steel & Wire

PRODUCT CERTIFICATION

WORK ORDER 027544
LOT NUMBER NF11101335
SALES ORDER / RLS 028704 / 1

SOLD TO

Rockford Bolt & Steel
126 Mill St.
Rockford, IL 61101
United States
Attn: Diana Rasmussen

CUSTOMER P.O.	CUSTOMER PART	QUANTITY	COILS	LADING NO	SHIPMENT DATE
P32693	100094	8,160 lb	2	00020419	?

SPECIFICATION 593R1010IQCL
19/32" Diameter 1010 Industrial Quality, Clean and Lime

CERTIFICATION REQUIREMENTS

Chemical

C	Mn	P	S	Si	Pb	Cr	Cu	Ni	Mo	Nitr
.13	.57	.014	.020	.17	.00	.13	.23	.09	.03	.0000

Al
.001

Physical

Melt Country
USA

End of Certification

I certify that the results are a true and correct copy of the records prepared and maintained by Krueger Steel & Wire in compliance with the requirements of the cited specification. Chemistry is as reported by the rod / bar supplier. This test report cannot be reproduced or distributed except in full without the written permission of Krueger Steel & Wire.

(C) AXIS Computer Systems - qtc302 (v1 1) Page 1 Date Printed 04/07/2011

APR-11-2011 13:11 630 833 5652 96% P.05

Figure B-18. 5/8 in. Diameter x 14 in. (M16x356 mm) Long Guardrail Bolt and Nut, Part b1, Test Nos. WIDA-1 and WIDA-2

LOAD

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Rockford Bolt & Steel
126 Mill St.
Lynn McComas
Rockford,IL-61101
Kind Attn :Lynn McComas

Cust P.O.	P32628
Customer Part #	100094
Charter Sales Order	70019230
Heat #	10132120
Ship Lot #	4080465
Grade	1010 A SK FG IQ 19/32
Process	HRCC
Finish Size	19/32

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 10132120

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.11	.37	.007	.014	.18	.04	.07	.02	.09	.006	.001

AL	N	B	TI	NB
.024	.0070	.0001	.001	.001

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 1039920

REDUCTION RATIO = 109:1

=

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29-05 Revision = 05 Dated =

Additional Comments: "MELTED & ROLLED IN USA".

Charter Steel
Saukville, WI, USA

Rem: Load1,Fax0,Mail0

ACCREDITED
Testing Laboratory

Page 1 of 1

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
05/31/2011

Figure B-19. 5/8 in. Diameter x 14 in. (M16x356 mm) Long Guardrail Bolt and Nut, Part b1, Test Nos. WIDA-1 and WIDA-2

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFARS compliance.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	CSSM	Charter Steel Melting Division	1653 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSSR/ CSSP	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	CSFP	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	CSCM/ CSCR	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
•	•	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Possible Laboratory	Specification
Chemistry Analysis	CSSM, CSCM/CSCR	ASTM E415; ASTM E1019
X-ray Fluorescence Stainless and Alloy Steel	CSCM/CSCR	ASTM E572
Macroetch	CSSM, CSCM/CSCR	ASTM E381
Hardenability (Jominy)	CSSM, CSCM/CSCR	ASTM A255; SAE J406; JIS G0561
Grain Size	CSSM	ASTM E112
Tensile Test	CSSR/CSSP, CSFP, CSCM/CSCR	ASTM E8; ASTM A370
Rockwell Hardness	All labs	ASTM E18; ASTM A370
Microstructure (spheroidization)	CSSR/CSSP, CSFP	ASTM A892
Inclusion Content (Methods A, E)	CSSR/CSSP, CSCM/CSCR	ASTM E45

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/13.

All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specifiction, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

ACCREDITED
Testing Laboratory

Figure B-20. 5/8 in. Diameter x 14 in. (M16x356 mm) Long Guardrail Bolt and Nut, Part b1, Test Nos. WIDA-1 and WIDA-2

Page 2 of 4

King Steel Corporation

King Steel
5225 East Cook Rd.
Grand Blanc, MI 48439
Tel 810-953-7637
Fax 810-953-1718

Bill of Lading

Ship To : Rockford Bolt & Steel Co.
126-T Mill St.
Rockford, IL 61101
USA

Bill To: Rockford Bolt & Steel Co.
126-T Mill St.
Rockford, IL 61101
USA

Bol No: 129216

Invoice No: 0037531
Ship Date : 5/10/11
Carrier: Valente Trucking Inc
Freight Terms: PrePaid
Class or Rate: 50

Load coils "eyes to the rear"
COIL VANS ONLY - NO REGULAR FLATBEDS ALLOWED
certs must accompany truck

0.593 1010 IQ HR RD PLI ROD

Cust PO	Customer Item	Lot No	Heat No	Ship Qty	Ship Weight	Net Weight	Gross Weight
P32696	-	S088223	NF11101336	1	4,045	4,045 lbs	4,045 lbs
P32696	-	S088224	NF11101336	1	4,039	4,039 lbs	4,039 lbs
P32696	-	S088227	NF11101336	1	4,075	4,075 lbs	4,075 lbs
P32696	-	S088238	NF11101336	1	4,082	4,082 lbs	4,082 lbs
P32696	-	S088239	NF11101336	1	4,085	4,085 lbs	4,085 lbs
P32696	-	S088240	NF11101336	1	4,047	4,047 lbs	4,047 lbs
P32696	-	S091240	NF11201343	5	20,369	20,369 lbs	20,369 lbs
			Part Total:	11 Lots	44,742	44,742 lbs	44,742 lbs
			Shipment Total:	11 Lots	44,742	44,742 lbs	44,742 lbs

Heat	Material Specification
NF11101336	C: 0.13 % Mn: 0.56 % P: 0.013 % S: 0.033 % Si: 0.19 % Ni: .14 % Cr: .12 % Mo: .02 % Cu: .29 % Sn: .009 % Ca: .0002 %
NF11201343	C: .12 % Mn: .53 % P: .008 % S: .032 % Si: .18 % Ni: .07 % Cr: .08 % Mo: .02 % AL: .001 % Cu: .21 % Ti: .001 % Nb: .002 % Sn: .009 %

Payment to any intermediary or arranger of freight constitutes payment to the carrier and the carrier therefore has no claim against the consignee of the material.

Signature Date/Time Consignee Date/Time

Office

Plex Online 6/21/11 5:08 PM dsutherland Page 1

file://C:\Documents%20and%20Settings\drasmussen\Local%20Settings\Temporary%20Int... 6/21/2011

Figure B-21. 5/8 in. Diameter x 14 in. (M16x356 mm) Long Guardrail Bolt and Nut, Part b1, Test Nos. WIDA-1 and WIDA-2

THIS MEMORANDUM is an acknowledgment that a bill of lading has been issued and is not the Original Bill of Lading, nor a copy or duplicate, covering the property named herein, and is intended solely for filing or record.

BILL OF LADING NO. 2887790

from **TAUBENSEE STEEL & WIRE CO.**

the property described below, in apparent good order, except as noted (contents and conditions of contents of packages unknown), marked, consigned, and destined as indicated below, which said carrier (the word carrier being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its route, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the terms and conditions of the Uniform Domestic Straight Bill of Lading set forth (1) in Official, Southern, Western and Illinois Freight Classifications in effect on the date hereof, if this is a rail or rail-water shipment, or (2) in the applicable motor carrier classification or tariff if this is a motor carrier shipment.

Shipper hereby certifies that he is familiar with all the terms and conditions of the said bill of lading, set forth in the classification of tariff which governs the transportation of this shipment, and the said terms and conditions are hereby agreed to by the shipper and accepted for himself and his assigns.

SOLD TO:
KING STEEL, INC
5225 E. COOK RD
GRAND BLANC, MI 48439
123817 10B

R45856

SHIP TO:
KING STEEL, INC
5225 E. COOK RD
GRAND BLANC, MI 48439
(810) 953-7657

CUSTOMER ORDER NO.	DATED	DELIVERY REQUESTED	F.O.B.	CARRIER
03-691	04/05/11	05/13/11	WHEELING	JUST ARRG [illegible]

UNITS SHIPPED	KIND OF PACKAGES DESCRIPTION OF ARTICLES SPECIAL MARKS AND EXCEPTIONS	WEIGHT	CLASS OR RATE	CHK. COL.
	CUSTOMER'S MATERIAL TO BE CONVERTED AS PICKLE AND LIME COAT			
	Pounds Ordered X 5000# COIL ON CARRIER			
11	(45,000) (.5930) +-.0150 1010	44,742	50	
	PART NUMBER: 10100553 0-001			
	Heat no. Wght Heat no. Wght			
	11201343 4,05[illegible] ✓ 11101336 4,039 ✓			
	11201343 4,079 ✓ 11101336 4,075 ✓			
	11201343 4,080 ✓ 11101336 4,047 ✓			
	11201343 4,070 ✓ 11101336 4,085 ✓			
	11201343 4,073 ✓ 11101336 4,082 ✓			
	11101336 4,045 ✓			
	2887790 Total Gross Weight:	44,742		
	MATERIAL SHIPPED ON FLATBEDS MUST BE TARPED. Carriers and Drivers are Responsible for Securing All Loads and for Weights of Loaded Vehicles Leaving the Premises. Drivers will display all Product Identification signs in accordance with DOT regulations.			

101336

P32696
19/32 - 1010
PO/100094
HT#11201343 (5)
HT#11101336 (6)

INSP. MAY 13 2011 QC 5/11/11

MATERIAL MUST BE PROTECTED FROM DAMAGE AND MOISTURE IN TRANSIT AND ARRIVE IN LIKE CONDITION.

Pursuant to the non-recourse provision of Section 7 of the bill of lading the carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

TAUBENSEE STEEL & WIRE CO.

If charges are to be prepaid, write or stamp here. "To Be Prepaid."

COLLECT

Received $.............. to apply in prepayment of the charges on the property described hereon.

AGENT OR CASHIER

Per...... (THE SIGNATURE HERE ACKNOWLEDGES ONLY THE AMOUNT PREPAID)

Charges Advanced:

$..............

SHIPPERS ORDER NO.

CARRIER: FOR PAYMENT, SIGNED DELIVERY RECEIPT MUST BE RETURNED WITH B/L #'S ON YOUR INVOICE

Fibre Boxes used for this shipment conform to the specifications set forth in the box maker's certificate thereon and all other requirements of Consolidated Freight Classification. Shipper's imprint in lieu of stamp; not a part of bill of lading approved by the Department of Transportation.

TAUBENSEE STEEL & WIRE CO., Shipper

Per

Agent

Per

Permanent post-office address shipper - 600 Diens Dr., Wheeling, Illinois

Figure B-22. 5/8 in. Diameter x 14 in. (M16x356 mm) Long Guardrail Bolt and Nut, Part b1, Test Nos. WIDA-1 and WIDA-2

Mill Certification Details

NUCOR

NUCOR CORPORATION
NUCOR STEEL NEBRASKA

Mill Certification Details - 5/10/2011 11:13 AM

Customer: KING STEEL CORP - GRAND BLANC
Bill of Lading #: 197610
Chief Metallurgist : Jim Hill **Date :** 4/4/2011
Heat # : NF1110133601 **Tag # :** NF1111050147
Product : RDC **Size :** .594-19/32 Wire Rod
Grade: 1010 **Division :** Norfolk, NE
Comments : **Billet Heat #:** NF11101336

Chemical Properties -Wt.%

[illegible]
0.13 0.58 0.19 0.033 0.013 0.29 0.12 0.14 0.02 0.000 0.000 0.000 0.000 0.009 0.0002
[illegible]
0.0000 0.000

Physical Properties

[illegible]
Tensile: 66213
Yield: 50184
Elongation (in 8 inches):
Elongation (in 2 inches):

The testing was conducted in accordance with the requirements of this specification. All melting and manufacturing processes were performed in the United States of America.

Jim Hill
Division Metallurgist

Figure B-23. 5/8 in. Diameter x 14 in. (M16x356 mm) Long Guardrail Bolt and Nut, Part b1, Test Nos. WIDA-1 and WIDA-2

ROGERS BROTHERS GALVANIZING

HOT DIP GALVANIZING
1925 KISHWAUKEE STREET
ROCKFORD, IL 61104-5197
PHONE: 815/965-5132
FAX: 815/965-3765

ORDER NO. 76302
06/13/11
Page 1

SOLD TO: RKB
ROCKFORD BOLT & STEEL COMPANY
126 MILL STREET
ROCKFORD, IL 61101

SHIP TO: ROCKFORD BOLT & STEEL COMPANY
126 MILL STREET
ROCKFORD, IL 61101

TERMS:	SHIPPED VIA	COLLECT	PREPAID	CUSTOMER ORD. NO.	INVOICE DATE	INVOICE NO.
1/2% 10-N30	OUR TRUCK		X	069112		

QUANTITY	DESCRIPTION	WEIGHT	PRICE CWT / EA	AMOUNT
~~12574~~ 12512	5/8 X 14 GUARD RAIL BOLT 9 TUBS +2 RB BX #0001-466168 JOB#22191 BLK WT 13411#	13730		
12511 1	AVG. COATING WEIGHT: 523 MILS.	13733		
1	WE CERTIFY THE ABOVE SIZES & LOT#'S COMPLY W/ THE COATING, WORKMANSHIP, FINISH & APPEARANCE OF ASTM F2329.			
1	THE GALVANIZING PROCESS WAS CONDUCTED IN A TEMPERATURE RANGE OF 830F TO 850F			
	WE CERTIFY THAT THE ABOVE SIZES AND LOT NUMBERS THAT WERE GALVANIZED IN OUR PLANT MEET SPECS ASTM A153 CLASS C or ASTM A123. ROHS COMPLIANT AS IT PERTAINS TO HDG. DATE: 06-15-11 Q. C. DEPT. TC Request Date: 06/24/11			
	9 tubs + 2 RBOX galv OK 6/15/11 JM			

Seller represents that with respect to the production of the articles and/or the performance of the services covered by this invoice, it has fully complied with Section 12 (a) of the Fair Labor Standards Act of 1938 as amended.
ALL AGREEMENTS CONTINGENT UPON STRIKES, ACCIDENTS OR OTHER CAUSES BEYOND OUR CONTROL.
NOTICE—CLAIMS FOR LOSS OR DAMAGE MUST BE MADE WITHIN FIVE DAYS. ALL PRICES SUBJECT TO CHANGE WITHOUT NOTICE.

DUPLICATE DELIVERY RECEIPT

Figure B-24. 5/8 in. Diameter x 14 in. (M16x356 mm) Long Guardrail Bolt and Nut, Part b1, Test Nos. WIDA-1 and WIDA-2

ROGERS BROTHERS GALVANIZING

HOT DIP GALVANIZING
1925 KISHWAUKEE STREET
ROCKFORD, IL 61104-5197
PHONE: 815/965-5132
FAX: 815/965-3765

ORDER NO. 76327
06/14/11
Page 1

SOLD TO: RKB
ROCKFORD BOLT & STEEL COMPANY
126 MILL STREET
ROCKFORD, IL 61101

SHIP TO: ROCKFORD BOLT & STEEL COMPANY
126 MILL STREET
ROCKFORD, IL 61101

TERMS	SHIPPED VIA	COLLECT	PREPAID	CUSTOMER ORD. NO.	INVOICE DATE	INVOICE NO.
1/2% 10-N30	OUR TRUCK		X	069114		

QUANTITY	DESCRIPTION	WEIGHT	PRICE CWT / EA	AMOUNT
~~8351~~ 8316	5/8 X 14 GUARD RAIL BOLT #0001-466168 JOB#22191-B BLK WT 9024# ~~8 TUBS~~ 6RbBx	9186 9175		
8319 1	AVG. COATING WEIGHT: 539 MILS.			
1	WE CERTIFY THE ABOVE SIZES & LOT#'S COMPLY W/ THE COATING, WORKMANSHIP, FINISH & APPEARANCE OF ASTM F2329.			
1	THE GALVANIZING PROCESS WAS CONDUCTED IN A TEMPERATURE RANGE OF 830F TO 850F			
	WE CERTIFY THAT THE ABOVE SIZES AND LOT NUMBERS THAT WERE GALVANIZED IN OUR PLANT MEET SPECS ASTM A153 CLASS C or ASTM A123. ROHS COMPLIANT AS IT PERTAINS TO HDG.			
	DATE: 06-14-11			
	Q. C. DEPT.			
	Request Date: 06/27/11			
	8RB Bx galv OK 6/15/11			

Seller represents that with respect to the production of the articles and/or the performance of the services covered by this invoice, it has fully complied with Section 12 (a) of the Fair Labor Standards Act of 1938 as amended.
ALL AGREEMENTS CONTINGENT UPON STRIKES, ACCIDENTS OR OTHER CAUSES BEYOND OUR CONTROL.
NOTICE—CLAIMS FOR LOSS OR DAMAGE MUST BE MADE WITHIN FIVE DAYS. ALL PRICES SUBJECT TO CHANGE WITHOUT NOTICE.

DUPLICATE DELIVERY RECEIPT

Figure B-25. 5/8 in. Diameter x 14 in. (M16x356 mm) Long Guardrail Bolt and Nut, Part b1, Test Nos. WIDA-1 and WIDA-2

ROGERS BROTHERS GALVANIZING

HOT DIP GALVANIZING
1925 KISHWAUKEE STREET
ROCKFORD, IL 61104-5197
PHONE: 815/965-5132
FAX: 815/965-3765

ORDER NO. 76326
06/14/11
Page 1

SOLD TO: RKB
ROCKFORD BOLT & STEEL COMPANY
126 MILL STREET
ROCKFORD, IL 61101

SHIP TO: ROCKFORD BOLT & STEEL COMPANY
126 MILL STREET
ROCKFORD, IL 61101

TERMS	SHIPPED VIA	COLLECT	PREPAID	CUSTOMER ORD. NO.	INVOICE DATE	INVOICE NO.
1/2% 10-N30	OUR TRUCK		X	069113		

QUANTITY	DESCRIPTION	WEIGHT	PRICE CWT / EA	AMOUNT
8814 8752 8746	5/8 X 14 GUARD RAIL BOLT #0001-466168 JOB#22191 BLK WT 9402# +7RbBY	9586 9569		
1	AVG. COATING WEIGHT: 509 MILS.			
1	WE CERTIFY THE ABOVE SIZES & LOT#'S COMPLY W/ THE COATING, WORKMANSHIP, FINISH & APPEARANCE OF ASTM F2329.			
1	THE GALVANIZING PROCESS WAS CONDUCTED IN A TEMPERATURE RANGE OF 830F TO 850F			
	WE CERTIFY THAT THE ABOVE SIZES AND LOT NUMBERS THAT WERE GALVANIZED IN OUR PLANT MEET SPECS ASTM A153 CLASS C or ASTM A123. ROHS COMPLIANT AS IT PERTAINS TO HDG. DATE: 06-11-11 Q. C. DEPT. TC Request Date: 06/27/11			
	5 RB BX +2 tubs galv OK 6/16/11 Jm			

Seller represents that with respect to the production of the articles and/or the performance of the services covered by this Invoice, it has fully complied with Section 12 (a) of the Fair Labor Standards Act of 1938 as amended.
ALL AGREEMENTS CONTINGENT UPON STRIKES, ACCIDENTS OR OTHER CAUSES BEYOND OUR CONTROL.
NOTICE—CLAIMS FOR LOSS OR DAMAGE MUST BE MADE WITHIN FIVE DAYS. ALL PRICES SUBJECT TO CHANGE WITHOUT NOTICE.

DUPLICATE DELIVERY RECEIPT

Figure B-26. 5/8 in. Diameter x 14 in. (M16x356 mm) Long Guardrail Bolt and Nut, Part b1, Test Nos. WIDA-1 and WIDA-2

ROGERS BROTHERS GALVANIZING

HOT DIP GALVANIZING
1925 KISHWAUKEE ST., ROCKFORD IL 61104-5197
PHONE: 815/965-5132
FAX: 815/965-3765

ORDER NO.

SOLD TO RKFOBOLT

SHIP TO RKFOBOLT

TERMS	SHIPPED VIA	COLLECT	PREPAID	CUSTOMER ORD. NO.	INVOICE DATE	INVOICE NO.
	OT			66926	091 20-	

QUANTITY	DESCRIPTION	WEIGHT	PRICE CWT/EA	AMOUNT
11560 11540	5/8x14 gib 22191-P 0001-466168 11 tubs 2 RBBX	11680 12689		
	Avg coating wt 482 mills			
	11 tubs + 2 RBBX galv OK 6/16/11			

WE CERTIFY THAT THE ABOVE SIZES AND LOT NUMBERS THAT WERE GALVANIZED IN OUR PLANT MEET SPECS ASTM A153 CLASS C OR ASTM 123. ROHS COMPLIANT AS IT PERTAINS TO HDG.
DATE: 06-16-11
Q.C. DEPT. ________

Seller represents that with respect to the production of the articles and/or the performance of the services covered by this invoice, it has fully complied with Section 12 (a) of the Fair Labor Standards Act of 1938 as amended.
ALL AGREEMENTS CONTINGENT UPON STRIKES, ACCIDENTS OR OTHER CAUSES BEYOND OUR CONTROL.
NOTICE—CLAIMS FOR LOSS OR DAMAGE MUST BE MADE WITHIN FIVE DAYS. ALL PRICES SUBJECT TO CHANGE WITHOUT NOTICE.

DUPLICATE DELIVERY RECEIPT

Figure B-27. 5/8 in. Diameter x 14 in. (M16x356 mm) Long Guardrail Bolt and Nut, Part b1, Test Nos. WIDA-1 and WIDA-2

Figure B-28. 16D Double Head Nail, Part b2, Test Nos. WIDA-1 and WIDA-2

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

MATERIAL CERTIFICATION

Customer: Stock
Date: November 21,2011
Invoice Number:
Lot Number: DECKER 1135055
Part Number: 3340G
Quantity: 239,000
Description: 5/8" GUARD RAIL NUT +.031
Heat Number(s): 20163550 20166280 20158820

Specification: ASTM 563-A / A153 / F2329 as described

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
20163550	.08	.32	.010	.003	.08	.04	.05	.01	.10	.008	.001	.040	.008	.0003	.001	.001
20158820	.10	.39	.009	.002	.06	.04	.05	.01	.08	.009	.001	.040	.007	.0003	.001	.001
20166280	.08	.35	.009	.004	.08	.03	.03	.01	.07	.006	.001	.039	.008	.0002	.001	.001

PLATING AND/OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.52 (2.0 Mils Minimum)

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

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

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

TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 21st DAY OF NOVEMBER, 2011

NOTARY PUBLIC

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

Figure B-29. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Guardrail Bolt and Nut, Part b3, Test Nos. WIDA-1 and WIDA-2

Trinity Metals Laboratory
A DIVISION OF TRINITY INDUSTRIES
4001 IRVING BLVD. 75247 - P.O. BOX 568887
DALLAS, TX 75356-8887
Phone: 214.589.7591 FAX: 214.589.7594

NVLAP LAB CODE 200654-0

Lab No: 11110270F
KEITH HAMBURG
TRINITY HWY PRODUCTS, LLC #55
ROLLFORM
LIMA, OH 45801

Received Date: 11/28/2011
Heat Code:
Heat Number: 20163550, 20158820
PO or Work Order: Decker 1135055
Test Spec: F606 ASTM METHODS
Other Information: 55-66379

Completion Date: 11/29/2011
Weld Spec:
Material Type: A 563 A
Material Size: 5/8" GR Nuts

HARDNESS TEST:

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: Surface of Wrench Flat A
Hardness Average: 85

Measured Value	Measured Amt
Measured Value	84
Measured Value	86

PASSED

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: Surface of Wrench Flat B
Hardness Average: 86

Measured Value	Measured Amt
Measured Value	86
Measured Value	86

PASSED

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: Surface of Wrench Flat C
Hardness Average: 84.5

Measured Value	Measured Amt
Measured Value	83
Measured Value	86

PASSED

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: Surface of Wrench Flat D
Hardness Average: 84

Measured Value	Measured Amt
Measured Value	84
Measured Value	84

PASSED

We certify the above results to be a true and accurate representation of the sample(s) submitted. Alteration or partial reproduction of this report will void certification. NVLAP Certificate of Accreditation effective through 12-31-11. This report may not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

Lab Director, Michael S. Beaton, PE

Figure B-30. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Guardrail Bolt and Nut, Part b3, Test Nos. WIDA-1 and WIDA-2

Trinity Metals Laboratory
A DIVISION OF TRINITY INDUSTRIES
4001 IRVING BLVD. 75247 - P.O. BOX 568887
DALLAS, TX 75356-8887
Phone: 214.589.7591 FAX: 214.589.7594

NVLAP LAB CODE 200654-0

Lab No: 11110270F

KEITH HAMBURG
TRINITY HWY PRODUCTS, LLC #55
ROLLFORM
LIMA, OH 45801

Received Date: 11/28/2011
Heat Code:
Heat Number: 20163550, 20158820
PO or Work Order: Decker 1135055
Test Spec: F606 ASTM METHODS
Other Information: 55-66379

Completion Date: 11/29/2011
Weld Spec:
Material Type: A 563 A
Material Size: 5/8" GR Nuts

PASSED

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: Surface of Wrench Flat E
Hardness Average: 84

Measured Value	Measured Amt
Measured Value	84
Measured Value	84

OTHER TEST:

Type: NUT PROOF LOAD (to 30K) Quantity amount: 5
Samples PASSED proof loads of 16,950 lbs.

Type: Notes Quantity amount: 1
Additional heat number: 20166280

We certify the above results to be a true and accurate representation of the sample(s) submitted. Alteration or partial reproduction of this report will void certification. NVLAP Certificate of Accreditation effective through 12-31-11.This report may not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

Lab Director, Michael S. Beaton, PE

Figure B-31. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Guardrail Bolt and Nut, Part b3, Test Nos. WIDA-1 and WIDA-2

FAX

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Decker Manufacturing Corp.
703 N. Clark St.
Steve Konkle
Albion, MI-49224
Kind Attn :Steve Konkle

Cust P.O.	45917-1109
Customer Part #	1.125 1010
Charter Sales Order	30032649
Heat #	20163550
Ship Lot #	3053824
Grade	1010 A AK FG RHQ 1-1/8'
Process	HRCC
Finish Size	1-1/8

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side, and that it satisfies these requirements.

Test Results of Heat Lot# 20163550

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.08	.32	.010	.003	.08	.04	.05	.01	.10	.008	.001

AL	N	B	TI	NB
.040	.0080	.0003	.001	.001

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 2018925

	# of Tests	Min Value	Max Value	Mean Value	
ROCKWELL B	6	54	57	55	RB LAB = 0358-04
ROD SIZE	12	1.123	1.130	1.127	
ROD OUT OF ROUND	3	.005	.007	.006	

REDUCTION RATIO = 49:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-08
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M-11 Revision = Dated = 01-APR-11

Additional Comments: Fax Number - 517-629-3535

cc: DU ✓ 9-7-11

1.125
20163550

Charter Steel
Cuyahoga Heights, OH, USA

Rsm: Load0, Fax1, Mail0

ACCREDITED

Page 1 of 1

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance

Figure B-32. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Guardrail Bolt and Nut, Part b3, Test Nos. WIDA-1 and WIDA-2

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFARS compliance.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	CSSM	Charter Steel Melting Division	1653 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSSR/ CSSP	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	CSFP	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	CSCM/ CSCR	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
*	*	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Possible Laboratory	Specification
Chemistry Analysis	CSSM, CSCM/CSCR	ASTM E415; ASTM E1019
X-ray Fluorescence Stainless and Alloy Steel	CSCM/CSCR	ASTM E572
Macroetch	CSSM, CSCM/CSCR	ASTM E381
Hardenability (Jominy)	CSSM, CSCM/CSCR	ASTM A255; SAE J406; JIS G0561
Grain Size	CSSM	ASTM E112
Tensile Test	CSSR/CSSP, CSFP, CSCM/CSCR	ASTM E8; ASTM A370
Rockwell Hardness	All labs	ASTM E18; ASTM A370
Microstructure (spheroidization)	CSSR/CSSP, CSFP	ASTM A892
Inclusion Content (Methods A, E)	CSSR/CSSP, CSCM/CSCR	ASTM E45

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/13.

All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specification, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

ACCREDITED
Testing Laboratory

Figure B-33. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Guardrail Bolt and Nut, Part b3, Test Nos. WIDA-1 and WIDA-2

FAX

CHARTER STEEL

A Division of Charter Manufacturing Company, Inc.

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Decker Manufacturing Corp.
703 N. Clark St.
Steve Konkle
Albion,MI-49224
Kind Attn :Steve Konkle

Cust P.O.	45917-1109
Customer Part #	1.125 1010
Charter Sales Order	30032649
Heat #	20158820
Ship Lot #	3053821
Grade	1010 A AK FG RHQ 1-1/8
Process	HRCC
Finish Size	1-1/8

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 20158820

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.10	.39	.009	.002	.06	.04	.05	.01	.08	.009	.001

	AL	N	B	TI	NB
	.040	.0070	.0003	.001	.001

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 2018923

	# of Tests	Min Value	Max Value	Mean Value	
ROCKWELL B	3	57	61	59	RB LAB = 0358-04
ROD SIZE	8	1.123	1.132	1.128	
ROD OUT OF ROUND	2	.008	.008	.008	

REDUCTION RATIO = 49:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 9.08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M-11 Revision = Dated = 01-APR-11

Additional Comments: Fax Number - 517-629-3535

1 1/25 20158820

cc DJ 9-7-11

Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load0,Fax1,Mail0

ACCREDITED

Page 1 of 1

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance

Figure B-34. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Guardrail Bolt and Nut, Part b3, Test Nos. WIDA-1 and WIDA-2

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFARS compliance.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	CSSM	Charter Steel Melting Division	1653 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSSR/ CSSP	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	CSFP	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	CSCM/ CSCR	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
-	-	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Possible Laboratory	Specification
Chemistry Analysis	CSSM, CSCM/CSCR	ASTM E415; ASTM E1019
X-ray Fluorescence Stainless and Alloy Steel	CSCM/CSCR	ASTM E572
Macroetch	CSSM, CSCM/CSCR	ASTM E381
Hardenability (Jominy)	CSSM, CSCM/CSCR	ASTM A255; SAE J406; JIS G0561
Grain Size	CSSM	ASTM E112
Tensile Test	CSSR/CSSP, CSFP, CSCM/CSCR	ASTM E8; ASTM A370
Rockwell Hardness	All labs	ASTM E18; ASTM A370
Microstructure (spheroidization)	CSSR/CSSP, CSFP	ASTM A892
Inclusion Content (Methods A, E)	CSSR/CSSP, CSCM/CSCR	ASTM E45

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/13.

All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specification, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

A2LA ACCREDITED Testing Laboratory

Figure B-35. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Guardrail Bolt and Nut, Part b3, Test Nos. WIDA-1 and WIDA-2

10-10-2011 05:02AM FROM-PROCESSING QC +1-262-268-2569 T-306 P.002/003 F-474

FAX

CHARTER STEEL

CHARTER STEEL
A Division of
Charter Manufacturing Company, Inc.

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Decker Manufacturing Corp.
703 N. Clark St.
Steve Konkle
Albion, MI-49224
Kind Attn :Steve Konkle

Cust P.O.	45917-1110
Customer Part #	1.125 1010
Charter Sales Order	30034370
Heat #	20166280
Ship Lot #	4101595
Grade	1010 A AK FG RHQ 1-1/8
Process	HRCC
Finish Size	1-1/8

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side, and that it satisfies these requirements.

Test Results of Heat Lot# 20166280

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.08	.35	.009	.004	.08	.03	.03	.01	.07	.006	.001

AL	N	B	TI	NB
.039	.0080	.0002	.001	.001

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 2013951

	# of Tests	Min Value	Max Value	Mean Value	
ROCKWELL B	6	54	55	54	RB LAB = 0358-04
ROD SIZE	16	1.119	1.135	1.127	
ROD OUT OF ROUND	4	.011	.012	.012	

REDUCTION RATIO = 49:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M-11 Revision = Dated = 01-APR-11

Additional Comments: Fax Number - 517-629-3535

20166280
1.125

Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load0,Fax1,Mail0

ACCREDITED
Testing Laboratory
Page 1 of 1

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
10/09/2011

Figure B-36. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Guardrail Bolt and Nut, Part b3, Test Nos. WIDA-1 and WIDA-2

December 7, 2011
5/8" Guardrail Nut Req# 12-0204

Figure B-37. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Guardrail Bolt and Nut, Part b3, Test Nos. WIDA-1 and WIDA-2

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFARS compliance.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	CSSM	Charter Steel Melting Division	1658 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSSR/ CSSP	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	CSFP	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	CSCM/ CSCR	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
*	*	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Possible Laboratory	Specification
Chemistry Analysis	CSSM, CSCM/CSCR	ASTM E415; ASTM E1019
X-ray Fluorescence Stainless and Alloy Steel	CSCM/CSCR	ASTM E572
Macroetch	CSSM, CSCM/CSCR	ASTM E381
Hardenability (Jominy)	CSSM, CSCM/CSCR	ASTM A255; SAE J406; JIS G0561
Grain Size	CSSM	ASTM E112
Tensile Test	CSSR/CSSP, CSFP, CSCM/CSCR	ASTM E8; ASTM A370
Rockwell Hardness	All labs	ASTM E18; ASTM A370
Microstructure (spheroidization)	CSSR/CSSP, CSFP	ASTM A892
Inclusion Content (Methods A, E)	CSSR/CSSP, CSCM/CSCR	ASTM E45

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/13.

All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
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   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specification, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

ACCREDITED
Testing Laboratory

Figure B-38. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Guardrail Bolt and Nut, Part b3, Test Nos. WIDA-1 and WIDA-2

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

MATERIAL CERTIFICATION

Customer: Stock

Date: OCT 18,2011

Invoice Number:

Lot Number: 110930B2

Part Number: 3360G

Quantity: 116,239

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

Heat Number(s): 20156640 | 20161540 | 20161530

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
20156640	.09	.34	.011	.004	.04	.05	.06	.01	.08	.007	.001	.027	.007	.0002	.001	.001
20161530	.09	.33	.007	.005	.03	.04	.06	.01	.10	.003	.001	.025	.008	.0001	.001	.001
20161540	.08	.34	.007	.001	.06	.04	.06	.01	.08	003	.001	.028	.006	.0002	.001	.001

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.32 (2.0 Mils Minimum)

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

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A
WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 18th DAY OF OCTOBER, 2011

NOTARY PUBLIC

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

Figure B-39. 5/8 in. Diameter x 1 ¼ in. (M16x32 mm) Long Guardrail Bolt and Nut, Part b4, Test Nos. WIDA-1 and WIDA-2

Trinity Metals Laboratory
A DIVISION OF TRINITY INDUSTRIES
4001 IRVING BLVD. 75247 - P.O. BOX 568887
DALLAS, TX 75356-8887
Phone: 214.589.7591 FAX: 214.589.7594

Trinity MSB Metals Lab

NVLAP LAB CODE 200654-0

Lab No: 11100124F
KEITH HAMBURG
TRINITY HWY PRODUCTS, LLC #55
ROLLFORM
LIMA, OH 45801

Received Date: 10/14/2011
Heat Code:
Heat Number: 20156640, 20161530
PO or Work Order: 110930B2
Test Spec: F606 ASTM METHODS
Other Information: SO#: 55-65321

Completion Date: 10/21/2011
Weld Spec:
Material Type: A 307 A
Material Size: 5/8" x 1-1/4" GR BOLT

OTHER TEST:

Type: HARDNESS ROCKWELL BW — Quantity amount: 20

Bolt "A": 88 - 87 - 87 - 87
Bolt "B": 85 - 87 - 87 - 87
Bolt "C": 84 - 87 - 87 - 87
Bolt "D": 88 - 89 - 88 - 88
Bolt "E": 87 - 88 - 88 - 88

Type: Notes — Quantity amount: 1
Additional heat #: 20161540

Type: HEAD MARKINGS — Quantity amount: 1
TRN USA 307A O

CG- 10-21-11

We certify the above results to be a true and accurate representation of the sample(s) submitted. Alteration or partial reproduction of this report will void certification. NVLAP Certificate of Accreditation effective through 12-31-11. This report may not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

Lab Director, Michael S. Beaton, PE

Page 1 of 1

Figure B-40. 5/8 in. Diameter x 1 ¼ in. (M16x32 mm) Long Guardrail Bolt and Nut, Part b4, Test Nos. WIDA-1 and WIDA-2

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

FILE

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Trinity Industries Inc.
425 E. O Conner Ave
Sue Henline
Lima,OH-45801
Kind Attn :Sue Henline

[illegible]	142496M-2
Customer Part	100941B
Charter Sales Order	70023317
[illegible]	20156640
[illegible]	2017253
[illegible]	1010 R AK FG RHQ 41/64
[illegible]	HR
[illegible] Size	41/64

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 20156640

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.09	.34	.011	.004	.04	.05	.06	.01	.08	.007	.001

AL	N	B	TI	NB
.027	.0070	.0002	.001	.001

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 2017253

REDUCTION RATIO = 152:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M-11 Revision = Dated = 01-APR-11

Additional Comments: Fax Number - 222-7398

RECEIVED
SEP 14 2011
TRINITY HWY PRODUCTS, LLC
Lima, Ohio Plant 55

Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load1,Fax1,Mail0

Page 1 of 1

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
09/14/2011

Figure B-41. 5/8 in. Diameter x 1 ¼ in. (M16x32 mm) Long Guardrail Bolt and Nut, Part b4, Test Nos. WIDA-1 and WIDA-2

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFAR's compliance.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	CSSM	Charter Steel Melting Division	1653 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSSR/ CSSP	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	CSFP	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	CSCM/ CSCR	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
*	*	---	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Specification	CSSM	CSSR/CSSP	CSFP	CSCM/CSCR
Chemistry Analysis	ASTM E415; ASTM E1019	X			X
Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwell Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
Inclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/13.
All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

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   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specifiction, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

Figure B-42. 5/8 in. Diameter x 1 ¼ in. (M16x32 mm) Long Guardrail Bolt and Nut, Part b4, Test Nos. WIDA-1 and WIDA-2

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFAR's compliance.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	CSSM	Charter Steel Melting Division	1653 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSSR/ CSSP	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	CSFP	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	CSCM/ CSCR	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
•	•	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Specification	CSSM	CSSR/CSSP	CSFP	CSCM/CSCR
Chemistry Analysis	ASTM E415; ASTM E1019	X			X
Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwell Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
Inclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/13.
All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specifiction, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

Figure B-43. 5/8 in. Diameter x 1 ¼ in. (M16x32 mm) Long Guardrail Bolt and Nut, Part b4, Test Nos. WIDA-1 and WIDA-2

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

FILE

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Trinity Industries Inc.
425 E. O Conner Ave
Sue Henline
Lima,OH-45801
Kind Attn :Sue Henline

[illegible]	142496M-1
[illegible]	100941B
[illegible]	70023316
[illegible]	20181540
[illegible]	2018475
Grade	1010 R AK FG RHQ 41/64
Process	HR
Finish Size	41/64

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 20181540

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.05	.34	.007	.001	.05	.04	.06	.01	.08	.003	.001

AL	N	B	TI	NB
.028	.0060	.0002	.001	.001

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 2018475

REDUCTION RATIO = 152:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 0,00-01-00
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M-11 Revision = Dated = 01-APR-11

Additional Comments: Fax Number - 222-7390

RECEIVED
SEP 14 2011
TRINITY HWY PRODUCTS, LLC
Lima, Ohio Plant 55

Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load1,Fax1,Mail0

Page 1 of 1

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
09/14/2011

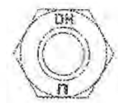
Figure B-44. 5/8 in. Diameter x 1 ¼ in. (M16x32 mm) Long Guardrail Bolt and Nut, Part b4, Test Nos. WIDA-1 and WIDA-2

NUCOR
FASTENER DIVISION

LOT NO.
289716A

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

CUSTOMER NO/NAME
8061 STRUCTURAL BOLT CO LLC — NUCOR ORDER # 755201
TEST REPORT SERIAL# FB365324 — CUST PART #
TEST REPORT ISSUE DATE 7/01/11
DATE SHIPPED 7/21/11 — CUSTOMER P.O. # 12052
NAME OF LAB SAMPLER: Jeff Hoering, LAB TECHNICIAN



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

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175647	3600	289716A	1-8 GR DH HV H.D.G. HEX NUT H.D.G.

MANUFACTURE DATE 5/06/11

--CHEMISTRY — MATERIAL GRADE -1045L
**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER — NUCOR STEEL - NEBRASKA

MATERIAL NUMBER	HEAT NUMBER		C	MN	P	S	SI
RM026568	NF11201550		.43	.68	.015	.016	.20
		MIN	.20	.60			
		MAX	.55		.040	.050	

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

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 90900 LBS	TENSILE STRENGTH DEG-WEDGE (LBS)	STRESS (PSI)
N/A	27.4	PASS	N/A	N/A
N/A	30.1	PASS	N/A	N/A
N/A	26.7	PASS	N/A	N/A
N/A	32.9	PASS	N/A	N/A
N/A	28.6	PASS	N/A	N/A

AVERAGE VALUES FROM TESTS 29.1 — PRODUCTION LOT SIZE 90000 PCS

ROTATIONAL CAPACITY TESTED IN ACCORDANCE WITH A325-09, A563-07a AND F606-09 TO 360 DEGREES OF ROTATION.
SAMPLE #1 PASSED SAMPLE #2 PASSED

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-07a — 80 PCS. SAMPLED — LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-05
1. 0.00228 2. 0.00523 3. 0.00583 4. 0.00849 5. 0.00952 6. 0.00656 7. 0.00754
8. 0.00272 9. 0.00720 10. 0.00622 11. 0.00349 12. 0.00397 13. 0.00532 14. 0.00430
15. 0.00583
AVERAGE THICKNESS FROM 15 TESTS .00563
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2006

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.8240	1.8290
Thickness	32	0.9750	0.9950

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

ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/11

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

BOB HAYWOOD
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

Figure B-45. 5/8 in. Diameter x 1 ¼ in. (M16x32 mm) Long Guardrail Bolt and Nut, Part b4, Test Nos. WIDA-1 and WIDA-2

Nucor Steel 4/27/2011 12:54:39 PM PAGE 1/001 Fax Server

26568

NUCOR
NUCOR CORPORATION
NUCOR STEEL NEBRASKA

Mill Certification
4/27/2011

2911 East Nucor Road
NORFOLK, NE 68701
(402) 644-0200
Fax: (402) 644-0329

Sold To: NUCOR FASTENER INDIANA
PO BOX 6100
6730 COUNTY RD 60
ST JOE, IN 46785-0000
(260) 337-1600
Fax: (435) 734-4581

Ship To: NUCOR FASTENER INDIANA
COUNTY RD 60
ST JOE, IN 46785-0000

Customer P.O.	123394	Sales Order	114818.13
Product Group	Special Bar Quality	Part Number	30001281480V780
Grade	1045L	Lot ID	NF1120155051
Size	1-9/32" (1.2813) Round	Heat ID	NF11201550
Product	1-9/32" (1.2813) Round 40' 1045L	B.L. Number	N1-199010
Description	1045L	Load Number	N1-147886
Customer Spec		Customer Part #	025016

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

* - Test outside scope of L-A-B accreditation

C	Mn	V	Si	S	P	Cu	Cr	Ni	Mo	Al	Cb
0.43%	0.68%	0.000%	0.20%	0.016%	0.015%	0.15%	0.10%	0.06%	0.02%	0.002%	0.001%
Pb	Sn	Ca	B	Ti	*NICUMO						
0.000%	0.007%	0.0002%	0.0000%	0.001%	0.23						

*NICUMO: Cu + Ni + Mo

*Reduction Ratio 34 :1

Specification Comments: Coarse Grain Practice

Sellenium,Tellurium,Lead,Bismuth or Boron were not intentionally added to this heat.

1. All manufacturing processes of the steel materials in this product, including melting, have been performed in the United States.
2. All products produced are weld free.
3. Mercury, in any form, has not been used in the production or testing of this material.
4. L.A.B Accredited Chemical Testing, Certificate L-2232 Expires 12-16-2012
5. Test conform to ASTM A29-05, ASTM E415 and ASTM E1019-resulphurized grades or applicable customer requirements.
6. All material melted at Nucor Steel Nebraska is produced in an Electric Arc Furnace

Chemistry Verification Checks

Part # 25016 RM # 26568

	Checked By	Date
Receiving OK:	AB 020	4/27/11
Certifications OK:	375	4-28-11

LABORATORY ACCREDITATION BUREAU
Cert# L-2232 Testing - Chemical

Jim Hill
Division Metallurgist

NBMG-10 May 12, 2009

Page 1 of 1

December 7, 2011
5/8 x 1 1/4" Splice Bolt Req: 12-0204

Figure B-46. 5/8 in. Diameter x 1 ¼ in. (M16x32 mm) Long Guardrail Bolt and Nut, Part b4, Test Nos. WIDA-1 and WIDA-2

Figure B-47. 5/8 in. (16 mm) Diameter Flat Washer, Part b5, Test Nos. WIDA-1 and WIDA-2

S.I. Storey
LUMBER COMPANY, INC.

CERTIFICATE OF COMPLIANCE

AUGUST 4, 2009

MIDWEST MACHINERY & SUPPLY
PO BOX 81097
LINCOLN, NE 68501

THE FOLLOWING MATERIAL DELIVERED ON 8/3/09 ON BILL OF LADING NUMBER 19477 HAS BEEN INSPECTED BEFORE AND AFTER TREATMENT AND IS IN FULL COMPLIANCE WITH APPLICABLE NEBRASKA DEPARTMENT OF ROADS REQUIREMENTS FOR SOUTHERN YELLOW PINE TIMBER GUARDRAIL COMPONENTS, PRESERVATIVE TREATED WITH CHROMATED-COPPER-ARSENATE (CCA-C) TO A MINIMUM RETENTION OF .60 LBS/CU.FT. THE ACCEPTANCE OF EACH PIECE BY COMPANY QUALITY CONTROL IS INDICATED BY A HAMMER BRAND ON THE END OF EACH PIECE.

MATERIAL		CHARGE #	DATE	RETENTION	QUANTITY
6x8x14"	Blockout (CD)	09-283	7/29/09	0.67	70
6x8x6'	Line Post	09-283	7/29/09	0.67	175
51/2x71/2-46"	TB Bullnose	09-283	7/29/09	0.67	48
6x6x8"	Blockout	09-283	7/29/09	0.67	100
6x8x22"	Blockout	09-283	7/29/09	0.67	70

THIS CERTIFICATE APPLIES TO MATERIAL ORDERED FOR your order no.: 2191

FOR ANY INQUIRIES, PLEASE RETAIN THIS DOCUMENT FOR FUTURE REFERENCE.

THANK YOU FOR YOUR ORDER.

SINCERELY,

Karen Storey

SIGNED BEFORE ME THIS 4 DAY OF AUGUST 2009.

Notary: Notary Public Floyd County Georgia
My Commission Expires Oct. 19, 2010

WILLIAM S. HOUSTON NOTARY PUBLIC EXP. OCT. 19, 2010 FLOYD COUNTY, GA

Phone: 706-234-1605 P.O. Box 99, Armuchee, GA 30105 Fax: 706-235-8132

Figure B-48. BCT Timber Post - MGS Height, Part c1, Test Nos. WIDA-1 and WIDA-2

Charge Report

Plant No. : 1

Address

S.I. Storey Lumber Co.
285 Sike Storey Rd.
Armuchee, GA 30105
PH: 706 234-1605
Fax:706 235-8132

EPA Reg. No. 3008-36

Charge : 283
Treatment : Guardrail Type 1
Date : 7/29/09 12:42:23PM
Chemical : CCA
Target Retention : .60
Cylinder : 1 (9,090)
Tank : 3
Operator : Richard
Total Time : 2:06:43
Turn Around Time (min) : 2,676
Time/Date Off Drip Pad :

Total Board Ft : 6,037
Total Cubic Ft : 491
Total Treatable Cubic Ft : 491
Displaced Volume In : 502
Displaced Volume Out : 535
Volume Start : 8,616
Volume Finish : 7,598
Volume Used : 1,018
Penetration Sampled : 0
Penetration Failed : 0
Treat By Tally : True

Step	Time			Pressure			Injection			Retention			Flow Rate			Time			Volume	Reason
	Min	Max	Act	Min	Max	Act	Min	Max	Act	Min	Max	Act	Min	Max	Act	Ramp	Start	End	End	
Initial Vacuum	0	17	17	0	-23	-23	0.00	0.00	0.00	.00	.00	.00	0.00	0.00	0.00	0	12:42:23	12:59:25	8,616	Time
Fill	0	10	7	0	-23	10	0.00	0.00	0.00	.00	.00	.00	0.00	0.00	0.00	0	12:59:25	13:06:05	3,281	Full
Raise Press	0	2	0	0	75	78	0.00	0.00	0.08	.00	.00	.01	0.00	0.00	0.00	0	13:06:06	13:06:26	3,159	PSI
Pressure	1	45	45	75	140	128	0.00	3.20	1.97	.00	.00	.32	0.00	0.00	0.01	1	13:06:26	13:51:27	2,229	Time
Press Relief	0	1	1	0	25	13	0.00	0.00	1.93	.00	.00	.31	0.00	0.00	0.00	1	13:51:27	13:52:15	2,249	PSI
Empty	0	10	9	0	0	0	0.00	0.00	2.61	.00	.00	.42	0.00	0.00	0.00	0	13:52:15	14:00:55	7,334	Empty
Final Vacuum	0	45	45	0	-29	-26	0.00	1.75	2.10	.00	.00	.34	0.00	0.00	0.01	0	14:00:55	14:45:57	7,588	Time
Final Empty	0	1	2	-1	-1	-1	0.00	0.00	2.09	.00	.00	.34	0.00	0.00	0.00	0	14:45:57	14:48:02	7,593	Empty
Finish	0	1	1	0	-1	0	0.00	0.00	2.07	.00	.00	.34	0.00	0.00	0.00	0	14:48:03	14:49:06	7,598	Time

	Solution Percent		Lbs. Per Gallon			Total Lbs.		Retention		Assay	
Chemical	Start	Finish	Start	Finish	Absorbed	Gauge	Absorbed	Gauge	Absorbed	Min Reten	Wood
CCA	1.90 %	1.90 %	.1624	.1624	.1624	165	165	.337	.337	-	-
Totals :	1.90 %	1.90 %	.1624	.1624	.1624	165	165	.337	.337	.60	-

Additive List

Additives	Solution %

Automatic Mix Information

Chemical	Current Value	Target Value	Required	Actual	Difference
Water	- Gals.	- Gals.	1,319 Gals.	1,311 Gals.	-8 Gals.
CCA	1.88 %	1.90 %	25 Gals.	25 Gals.	- Gals.

1 021.001021.60 Pieces: 175 Packs/Size : 5 @ 35 Desc: 6 x 8 x 6 Line Post Rough Nebraska #1 Dense BF: 4,200 CF: 350 HW: - % Moist. Cont.: - %
Std.: .60 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP Rem1: None

2 021.001008.60 Pieces: 70 Packs/Size : 1 @ 70 Desc: 6 x 8 x 0-14 Blockout Rough BF: 329 CF: 27 HW: - % Moist. Cont.: - %
Std.: .60 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP Rem1: None

3 9999 Pieces: 48 Packs/Size : 1 @ 48 Desc: 5-1/2 x 7-1/2 x 0-46 TB Bullnose Post BF: 720 CF:
Std.: .60 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP

4 9999 Pieces: 70 Packs/Size : 1 @ 70 Desc: 6 x 8 x 0-22" Rough Blockout BF: 513 CF:
Std.: .60 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP

5 9999 Pieces: 100 Packs/Size : 1 @ 100 Desc: 6 x 6 x 8" Post Block CCA .60 BF: 275 CF:
Std.: .40 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP

ANALYSIS REPORT
****

RETENTION
CRO3 = 0.32 PCF
CUO = 0.12 PCF
AS2O5 = 0.23 PCF

TOTAL RETENTION
0.67 PCF
****

P..ted on: 8/4/09 9:34:53AM Plant Number : 1 Charge Number : 283 Page 1 of 1

Figure B-49. BCT Timber Post - MGS Height, Part c1, Test Nos. WIDA-1 and WIDA-2

MATERIAL TEST REPORT

(\TE: 09/25/07
PAGE: 1
BILL OF LADING: 164358

LEAVIT(UBE COMPANY, LLC

LEAVITT
The Tube People
Leavitt Tube Co., LLC
1717 W. 115th St.
Chicago, IL 60643
Phone: 773-239-7700
Phone: 1-800-LEAVITT
Fax: 773-239-1023
www.leavitt-tube.com
QA1002-0003 Rev. 0

CUST: STEEL & PIPE SUPPLY - CATOOSA OK
1050 FORT GIBSON ROAD
CATOOSA OK 74015

TUBING MANUFACTURED IN USA

ATTN: * Test Report Desk

106201 8027185

ITEM NO.	PIECES	SIZE, GAUGE, LENGTH	QTY. SHIPPED	CUSTOMER P.O.	ORDER NUMBER	CUSTOMER PART NBR	ASTM SPECIFICATION	GRADE
1	7	8.625-322HRB 252	147	4500088611	1015580 1.000		A500-03b	B
2	6	12X2-188HRB 480	240	4500088813	1016034 1.000		A500-03b	B
3.- 4	28	8.625-322HRB 504	1,176	4500091471	1025579 1.000		A500-03b	B
5	9	8X6-188HRB 480	360	4500092386	1029189 1.000		A500-03b	B

ITEM NO.	1	2	3	4	5
COIL NO.	395453	395532	395813	395460	391232
HEAT NO.	722562	722551	722564	722564	A13386
CORRECTED COIL					
CARBON	.210	.210	.210	.210	.220
MANGANESE	.820	.860	.820	.820	.700
PHOSPHORUS	.004	.006	.004	.004	.006
SULFUR	.006	.004	.006	.006	.003
ALUMINUM	.047	.050	.047	.047	.024
SILICON	.020	.030	.020	.020	.030
WELD TESTING	FLATTEN	FLARE	FLATTEN	FLATTEN	FLARE
YIELD STRENGTH (PSI)	47,297			52,000	55,056
TENSILE STRENGTH (PSI)	62,162			70,666	70,787
ELONGATION IN 2" (%)	29.0			31.0	27.0

Item(s)- 1 2 3 4 5 Are
Made and Melted
In The U.S.A.

I HEREBY CERTIFY THAT THE ABOVE IS CORRECT AS CONTAINED IN THE RECORDS OF THE COMPANY.

Figure B-50. 72 in. (1,829 mm) Long Foundation Tube, Part c2, Test Nos. WIDA-1 and WIDA-2

Certified Analysis

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

LINCOLN, NE 68501-1097

Project: STOCK

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

As of: 5/22/09

MIDWEST MACHINERY

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

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

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

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

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

Trinity Highway Products , LLC
Certified By: [signature]
Quality Assurance

4 of 7

06/04/2009 16:36 402-761-3288

Figure B-51. 72 in. (1,829 mm) Long Foundation Tube, Part c2, Test Nos. WIDA-1 and WIDA-2

425 E. O'Connor
Lima, OH

PAGE 44/52

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

LINCOLN, NE 68501-1097

Sales Order: 1093497
Customer PO: 2030
BOL # 43073
Document # 1

Print Date: 6/30/08
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

MIDWEST MACHINERY

Pieces	Description
32	12/12'6/S SRT-1
32	12/25'0/SPEC/S SRT-2
32	3/16X12.5X16 CAB ANC BRKT
32	2" X 5 1/2" PIPE (LONG)
64	6'0 TUBE SL/.188X8X6
32	5/8 X 6 X 8 BEARING PLATE
32	12/BUFFER/ROLLED
32	CBL 3/4X6'6/DBL SWG/NOHWD
640	5/8" RD WASHER 1 3/4 OD
1,728	5/8" GR HEX NUT
1,152	5/8"X1.25" GR BOLT
256	5/8"X1.5" HEX BOLT A307
64	5/8"X9.5" HEX BOLT A307

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB
State of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public:
Commission Expires

Trinity Highway Products, LLC
Certified By:

Figure B-52. Strut and Yoke Assembly, Part c3, Test Nos. WIDA-1 and WIDA-2

Certified Analysis

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

MILFORD, NE 68405
Project: RESALE

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

As of: 4/15/11

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

Figure B-53. 8x8x5/8 in. (127x203x16 mm) Anchor Cable Bearing Plate, Part c4, Test Nos. WIDA-1 and WIDA-2

COMMERCIAL GROUP LIFTING PRODUCTS
2427 East Judd Rd., Burton, MI 48529 • Phone (810) 744-4540 • Fax (810) 744-1588

NOVEMBER 15TH 2011

TRINITY INDUSTRIES-DALLAS
TRINITY INDUSTRIES-LLC-55
550 EAST ROBB AVE.
LIMA, OHIO 45801

ATTN: MR. KEITH HAMBURG

ENCLOSED ARE THE NECESSARY COMPLIANCE CERTIFICATES FOR YOUR PURCHASE ORDER# 146071. THESE CERTIFICATES ARE FOR YOUR PART # 003000G (750) PCS 3/4" X 6FT 6IN DOUBLE SWAGE GUARD RAIL ASSEMBLIES, YOUR PART # 003011G (20) PCS 3/4" X 11FT 3IN SINGLE SWAGE GUARDRAIL ASSEMBLIES, YOUR PART # 003012G (150) PCS 3/4" X 8FT DOUBLE SWAGE GUARDRAIL ASSEMBLIES, THEY SHOW THE DOMESTICITY OF ALL MATERIAL USED, MELTED AND MANUFACTURED IN THE USA.

VERY TRULY YOURS

Joe Carpenter

JOE CARPENTER
OFFICE / CUSTOMER SERVICE MGR

RECEIVED
NOV 18 2011
TRINITY HWY PRODUCTS, LLC
Lima, Ohio Plant 55

Figure B-54. BCT Anchor Cable Assembly, Part c5, Test Nos. WIDA-1 and WIDA-2

24150 Oak Grove Lane
PO Box 844
Sedalia, MO 65302

660.829.6721
Fax 660.829.6780

WireCo WorldGroup

November 9th, 2011

Order No. 81156

CERTIFICATION OF COMPLIANCE

This is to certify that the diameter, strand construction, minimum breaking strength, and wire coating weights for RP122260 3/4 6x19W RR A741 CL-A SC -US produced on 428-277631 are in accordance with ASTM A741-98 (2003) titled "Standard Specification for Zinc Coated Steel Wire Rope and Fittings for Highway Guard Rail".

All rope manufacturing processes occurred in the United States.
All steel used was melted and manufactured in the United States.

ACTUAL TEST DATA

MEASURED ROPE DIAMETER:	**0.7560**		
STRAND CONSTRUCTION:	**19 WARRINGTON 1-6-(6+6)**		
BREAKING STRENGTH:	**51,885 pounds**		**Req'd. 42,800 pounds**
ZINC COATING WEIGHTS (Class A):	**Wire Dia.**	**Min. Oz/ft^2**	**Avg. Oz/ft^2**
	.0395"	**N/A**	**0.429**
	.0460"	**0.40**	**0.454**
	.0540"	**0.40**	**0.444**
	.0610"	**0.40**	**0.463**

WIRECO WORLD GROUP

Michele Johnson
Quality Process Administrative Assistant
Michele Johnson

Page 1

3

Figure B-55. BCT Anchor Cable Assembly, Part c5, Test Nos. WIDA-1 and WIDA-2

Certificate of Compliance

Report of Chemical Analysis and Physical Tests

Customer: Commercial Group
G-2427 E Judd Group
Burton, MI 48529

Date November 9th, 2011

Order 81156 **Reel numbers 428-277631-1-2-3** **Rope Description** 3/4 6x19W RR A741 CLA SC

Item No.	Description	Tensile Strength Lbs.	Lbs. per sq. in.	Wt. Coat	Torsion Test 8"	Heat No.	C	MN	P	S	Si
001	.0395" Galvanized Wire										
	0.0395	344	281,000	0.413	87	11R541721	0.81	0.59	0.018	0.007	0.20
						11R541722	0.80	0.56	0.011	0.008	0.23
	0.0395	344	281,000	0.411	86	10R534925	0.79	0.60	0.012	0.003	0.22
						10R536303	0.79	0.54	0.008	0.006	0.23
	0.0395	329	268,000	0.416	69	10R532013	0.81	0.56	0.013	0.007	0.21
						10R532996	0.80	0.55	0.011	0.004	0.24
	0.0395	348	284,000	0.415	86	9R525608	0.79	0.56	0.019	0.010	0.24
	0.0395	359	293,000	0.446	81	10R536602	0.83	0.59	0.014	0.004	0.21
					81	11R530539	0.74	0.67	0.012	0.007	0.22
	0.0395	331	270,000	0.446	94	10R532996	0.80	0.55	0.011	0.004	0.24
	0.0395	349	285,000	0.349	79	10R539802	0.81	0.56	0.009	0.008	0.25
002	.0460" Galvanized Wire										
	0.0460	417	251,000	0.478	69	10R533656	0.79	0.53	0.008	0.009	0.23
						10R534943	0.58	0.70	0.012	0.004	0.23
	0.0460	431	259,000	0.431	78	08R521550	0.79	0.57	0.017	0.005	0.22
						08R520728	0.80	0.56	0.012	0.013	0.19
	0.0460	429	258,000	0.458	67	10R538434	0.79	0.58	0.009	0.006	0.22
	0.0460	425	256,000	0.450	69	07R514031	0.79	0.59	0.014	0.014	0.22
003	.0540" Galvanized Wire										
	0.054	661	289,000	0.418	56	10R538434	0.79	0.58	0.009	0.006	0.22
						10R536258	0.81	0.57	0.010	0.006	0.24
						10R534277	0.83	0.56	0.006	0.001	0.24
	0.054	651	284,000	0.467	58	09R527474	0.80	0.57	0.011	0.014	0.20
						09R529653	0.80	0.58	0.010	0.011	0.25
	0.054	671	293,000	0.477	53	11R530541	0.79	0.51	0.013	0.008	0.22
						11R528609	0.79	0.65	0.001	0.006	0.27
	0.054	649	283,000	0.428	62	09R531038	0.80	0.58	0.010	0.009	0.23
	0.054	658	287,000	0.431	59	10R531471	0.80	0.57	0.012	0.011	0.24
	0.054	622	272,000	0.443	58	10R532995	0.81	0.56	0.008	0.005	0.23
004	.0610" Galvanized Wire										
	0.061	741	254,000	0.411	58	08R519995	0.80	0.57	0.013	0.11	0.21
	0.061	781	267,000	0.504	46	11R528609	0.79	0.65	0.011	0.006	0.27
						11R530541	0.79	0.51	0.013	0.008	0.22
	0.061	775	265,000	0.478	58	09R531038	0.80	0.58	0.010	0.009	0.23

The material covered by this certification was manufactured and tested in accordance with specifications as listed above. We certify that representative samples of the material have been tested and the results conform to the requirements outlined in these specifications.

The chemical, physical, or mechanical tests reported above are correct as contained in the records of the corporation.

Signed: Michele Johnson
Michele Johnson

Page 2

4

Figure B-56. BCT Anchor Cable Assembly, Part c5, Test Nos. WIDA-1 and WIDA-2

Sep.08.2011 10:37 AM PAGE. 2/ 16

Mar. 24. 2011 3:18PM NEW DIMENSION METALS No. 5031 P. 1/1

MATERIAL CERTIFICATION

Date: 3/24/2011

NEW DIMENSION METALS

3050 Dryden Rd.
Dayton, Ohio 45439
(937) 299-2233

Bill To:
REMLINGER MANUFACTURING
P.O. BOX 299
KALIDA, OH45853

Ship To:
REMLINGER MANUFACTURING
16394 U.S. 224
KALIDA, OH 45853

Customer PO#: 007748-00

Order Date: 12/6/2010

NDM SO: 30504 - 7

Item code: H1625RCH2000MOD2

Customer Part#:

Item Description
HR 1-5/8 RD 1035 X 20 FT
AL FG / VAC-DEGAS
AIM .35-.38 CARBON / ASTM A576

MATERIAL TEST RESULTS

Heat #: M39998

	C	Mn	P	S	Si	Ni	Cu	Cr	Mo	B	Pb	Al
Chemical Composition %	0.330	0.760	0.018	0.024	0.250	0.060	0.150	0.110	0.020	0.000	0.000	0.035
Material Grade: 1035												
Grade Min:	0.320	0.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max:	0.360	0.900	0.040	0.050	0.350	0.350	0.350	0.350	0.350	0.350	0.000	0.350

Material conforms to ASTM A-576.

I certify that the above information is true and accurate as contained in the records of the company.

New Dimension Metals Corp.

Daniel M. Wilson

Daniel M. Wilson
Director of Quality & Technical Services

New Dimension Metals ISO 9001:2008 certificate# 3600

Form: NDMQ200-R (10/08)

Page 1 of 1

Figure B-57. BCT Anchor Cable Assembly, Part c5, Test Nos. WIDA-1 and WIDA-2

Sep.08.2011 10:37 AM PAGE. 3/ 16

GERDAU MACSTEEL

Page: 1

MASTER B/L NUMBER		DATE SHIPPED	3/04/11
B/L NUMBER	476231	LOADER	CHOGBERG
CUSTOMER P.O.	19508		
ORDER NUMBER	251840		
CUSTOMER NUMBER	140351		

This Memorandum ...

RECEIVED, subject to classifications and tariffs in effect on the date of the receipt by the carrier of the property described in the Original Bill of Lading ...

SOLD TO
NEW DIMENSION METALS CORP
ATTN: PHIL HUSTON
3050 DRYDEN RD
DAYTON OH 45439

SHIP TO (CONSIGNED TO)
NEW DIMENSION METALS CORP
3050 DRYDEN ROAD
DAYTON OH 45439

CARRIER NAME			
CT	PVJ4216 OH		
T MONROE, MI	MONROE	COLLECT	23591
AL FG; VAC DEGAS; "AIM CARBON .35 / .38"; ASTM A576-90B		H1625RCH2000MOD2	
NONE			YES

HEAT NUMBER	GRADE		SIZE / LENGTH				WEIGHT
M39997	1035		1 05/08" 20' "	1	60	60	8509.80LB
			Bundle #: 0001488522				
			HEAT TOTALS	1		60	8509.80LB
			8509.80LBS OF 8509LBS SHIPPED				
M39998 DUE DATE:	1035 3/07/11		1 05/08" 20' "	4	60	240	34020.00LB
			Bundle #: 0001488523 0001488524 0001488525 0001488526				
			Bundle Weight= 8505.00 LBS				
			HEAT TOTALS	4		240	34020.00LB
			34020.00LBS OF 83774LBS SHIPPED				
CONTINUED ON PAGE 2			SHIPMENT TOTALS	5		300	42529.80LB

Gerdau MACSTEEL Shipper, Per
Permanent post office address of shipper
3000 East Front Street
MONROE, MI 48161

GOODS COVERED BY THIS B/L HAVE BEEN PLACED ON TRUCK SPECIFICALLY UNDER DRIVER'S INSTRUCTIONS AND LOADED TO HIS SATISFACTION. THIS B/L MAY BE EXECUTED BY ELECTRONIC OR FACSIMILE SIGNATURE AND IN ANY NUMBER OF COUNTERPARTS, EACH SUCH COUNTERPART TO BE DEEMED AN ORIGINAL INSTRUMENT.

CUSTOMER

3

Figure B-58. BCT Anchor Cable Assembly, Part c5, Test Nos. WIDA-1 and WIDA-2

Certified Analysis

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

MILFORD, NE 68405
Project: RESALE

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

As of: 4/15/11

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

1 of 2

Figure B-59. Anchor Bracket Assembly, Part c6, Test Nos. WIDA-1 and WIDA-2

EXLTUBE

905 ATLANTIC STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

CERTIFIED TEST REPORT

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

Heat No	Yield P.S.I.	Tensile P.S.I.	Elongation % 2 inch
280638	61,500	66,400	23.00

SLEEVE MAT CRT

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
280638	0.040	0.330	0.010	0.000	0.034	0.088	0.039	0.042	0.015	0.003

We hereby certify that the above material was manufactured in the U.S.A and that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade tiles above.

BNT=Grade B not tested - meets tensile properties ONLY

STEEL VENTURES, LLC dba EXLTUBE

Steve Frerichs
Quality Assurance Manager

104158

Figure B-60. 2 3/8 in. (60 mm) O.D. x 6 in. (152 mm) Long BCT Post Sleeve, Part c7, Test Nos.WIDA-1 and WIDA-2

Figure B-61. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Hex Head Bolt and Nut, Part c8, Test Nos.WIDA-1 and WIDA-2

Birmingham Fastener Manufacturing

P.O. Box 10323
Birmingham, Alabama 35202
(205) 595-3512

Pg 1 of 1

Certificate of Compliance

Customer : MIDWEST MACHINE
P.O. # : 2430
BFM # : 100325-00
Date Shipped : 3/21/2011

Item	*Quantity*	*Description*	*Lot#*	*Heat #*	*Specification*	*Finish*
2	100	5/8"-11 x 10" HEX BOLT	154572	780337	ASTM A307 GR A	HDG
3	156	5/8"-11 x 12" HEX BOLT	156402	DL1010223101	ASTM F1554-36	HDG
4	504	5/8"-11 x 19" HEX BOLT	156403	DL1010223101	ASTM F1554-36	HDG
5	102	3/4"-10 x 8" HEX BOLT	156404	JK1110044101	ASTM A36	HDG
6	513	7/8"-9 x 14" HEX BOLT	156405	11907740	ASTM F1554-55	HDG
7	208	7/8"-9 x 16" HEX BOLT	156406	11907740	ASTM F1554-55	HDG
8	48	1"-8 x 24" HEX BOLT	156407	109218	ASTM F1554-55	HDG
9	102	3/4"-10 x 16" HEX BOLT	143841	DL0910629104	ASTM A36	HDG

Birmingham Fastener Manufacturing. hereby certifies that the material furnished in reference to the above purchase order number will meet or exceed the above assigned specifications.

Signed: [signature] ***Brian Hughes*** ***Date:*** ***03/21/2011***

4

Figure B-62. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Hex Head Bolt and Nut, Part c8, Test Nos.WIDA-1 and WIDA-2

Certificate of Compliance

Birmingham Fastener Manufacturing
PO Box 10323
Birmingham, AL 35202
(205) 595-3512

Customer MIDWEST MACHINERY   Date Shipped 03/21/2011

Customer Order Number 2430   BFM Order Number 100325-00

Item Description

Description 5/8"-11 x 10" HEX BOLT   Qty 100

Lot # 154572   Specification ASTM A307-07b Gr A   Finish F2329

Raw Material Analysis

Heat# 780337

Chemical Composition (wt% Heat Analysis) By Material Supplier

C	Mn	P	S	Si	Cu	Ni	Cr	Mo
0.16	0.54	0.009	0.04	0.18	0.36	0.09	0.13	0.020

Mechanical Properties

Sample #	Hardness	Tensile Strength (lbs)	Tensile Strength (psi)
1	80 HRB	16,700	73,900
2	80 HRB	16,600	73,400
3			
4			
5			

This information represents the most recent analysis of the product supplied on the stated customer order. The samples tested conform to the ASTM standard listed above.
All steel melted and manufactured in the U.S.A.

Authorized Signature: [signature]   Date: 3/21/2011

Brian Hughes
Quality Assurance

Figure B-63. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Hex Head Bolt and Nut, Part c8, Test Nos.WIDA-1 and WIDA-2

5/8 x 10

NUCOR
NUCOR CORPORATION
NUCOR STEEL SOUTH CAROLINA

Mill Certification
1/26/2010

300 Steel Mill Road
DARLINGTON, SC 29540
(843) 393-5841
Fax: (843) 395-8701

Sold To: BIRMINGHAM FASTENER & SUPPLY
PO BOX 10323
BIRMINGHAM, AL 35202-0323
(205) 595-3511
Fax: (205) 591-0244

Ship To: BIRMINGHAM FASTENER & SUPPLY
931 AVE W
PO BOX 10323
BIRMINGHAM, AL 35202-0000
(205) 595-3511
Fax: (205) 591-0244

Customer P.O.	m52300	Sales Order	100312.4
Product Group	Merchant Bar Quality	Part Number	300005634803600
Grade	ASTM A36/A36M-08, A709/A709M-07 GR36, ASME SA36-07	Heat #	780337
Size	9/16" (.5625) Round	Heat ID	DL0810033701
Product	9/16" (.5625) Round 40' A36	B.L. Number	C1-522429
Description	A36	Load Number	C1-210596
Customer Spec		Customer Part #	

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.

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb
0.16%	0.54%	0.009%	0.04%	0.18%	0.36%	0.09%	0.13%	0.020%	0.004%	0.003%

Yield 1: 50000psi (345MPa) Tensile 1: 69000psi (476MPa) Elongation: 25% in 8"(% in 203.3mm)
Yield 2: 51000psi (352MPa) Tensile 2: 69000psi (476MPa) Elongation 27% in 8"(% in 203.3mm)

1. WELDING OR WELD REPAIR WAS NOT PERFORMED ON THIS MATERIAL
2. MELTED AND MANUFACTURED IN THE USA
3. MERCURY, RADIUM, OR ALPHA SOURCE MATERIALS IN ANY FORM HAVE NOT BEEN USED IN THE PRODUCTION OF THIS MATERIAL

James H. Blew
Division Metallurgist

NBAR0 10 May 12, 2009 Page 3 of 3

Figure B-64. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Hex Head Bolt and Nut, Part c8, Test Nos.WIDA-1 and WIDA-2

From: 2055914659 Page: 9/10 Date: 3/22/2011 9:52:39 AM

5/8 X 10

BIRMINGHAM | ATLANTA | JACKSONVILLE | HOUSTON

Metalplate Galvanizing, L.P.

MARCH 22, 2011

Birmingham Fastener
P.O. Box 10323
Birmingham, Alabama 35202

Purchase Order # M58420 Lot# 154572

We certify that the material on your above order was galvanized with 2-1/2 oz. of zinc per square foot of surface areas in accordance with specifications set forth in ASTM Standard Specification Designation F2329.

METALPLATE GALVANIZING, L.P.

Gilbert O. Fredrick, Plant Manager

I certify the above to be correct.

Rhonda D.Newton, Notary Public
Rhonda D. Newton

RHONDA D. NEWTON NOTARY PUBLIC ALABAMA STATE AT LARGE

Corporate Office	Plant 1	Plant 2	Atlanta Plant	Jacksonville Plant	Houston West	Houston East
P.O. Box 968 1120 39th Street North Birmingham, AL 35201 Phone (205) 595-4700 Fax (205) 595-7800	757 44th Street North Birmingham, AL 35212 Phone (205) 595-1108 Fax (205) 591-4659	1120 39th Street North Birmingham, AL 35234 Phone (205) 595-7103 Fax (205) 595-2955	605 Selig Drive, S.W. Atlanta, GA 30336 Phone (404) 691-0600 Fax (404) 699-2270	7123 Moncrief Road, West Jacksonville, FL 32219 Phone (904) 768-6330 Fax (904) 764-3948	10625 Needham Street Houston, TX 77013 Phone (713) 671-2454 Fax (713) 671-2957	10635 Needham Street Houston, TX 77013 Phone (713) 672-9480 Fax (713) 672-9892

This fax was received by GFI FAXmaker fax server. For more information, visit: http://www.gfi.com

Figure B-65. 5/8 in. Diameter x 10 in. (M16x254 mm) Long Hex Head Bolt and Nut, Part c8, Test Nos.WIDA-1 and WIDA-2

TRINITY HIGHWAY PRODUCTS, LLC.
425 E. O'CONNOR AVENUE
LIMA, OHIO 45801
419-227-1296

MATERIAL CERTIFICATION

CUSTOMER: STOCK	DATE: SEPTEMBER 29, 2009
	INVOICE #:
	LOT #: 090123B
PART NUMBER: 3380G	QUANTITY: 119,201
DESCRIPTION: 5/8" X 1 ½ HH BOLT	DATE SHIPPED:
SPECIFICATIONS: ASTM A307-A/A153	HEAT #: 7367052, 7366484,7368369

MATERIAL CHEMISTY

C	MN	P	S	SI	CU	NI	CR	MO	AL	V	N	CB	SN	B	TI	NB
.15	.49	.008	.002	.06	.03	.02	.05	.01	.029	.002	.005	.001	.001	.000	.000	.000
.13	.38	.007	.002	.10	.03	.04	.06	.02	.037	.002	.004	.001	.001	.000	.000	.000
.14	.43	.006	.008	.06	.04	.02	.06	.02	.034	.002	.005	.001	.001	.000	.000	.000

PLATING AND/OR PROTECTIVE COATING

HOT DIP GALVANIZING (OZ. PER SQ. FT.)	2.74 AVG.

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

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

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

TRINITY HIGHWAY PRODUCTS, LLC.

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME
THIS 29TH DAY SEPTEMBER, 2009

NOTARY PUBLIC

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

Figure B-66. 5/8 in. Diameter x 1 ½ in. (M16x38 mm) Long Hex Head Bolt and Nut, Part c9, Test Nos.WIDA-1 and WIDA-2

Trinity Metals Laboratory
A DIVISION OF TRINITY INDUSTRIES
4001 IRVING BLVD. 75247 - P.O. BOX 568887
DALLAS, TX 75356-8887
Phone: 214.589.7591 FAX: 214.589.7594

MSB

NVLAP LAB CODE 200654-0

Lab No: 9010250F

SUE HENLINE
TRINITY HWY PRODUCTS, LLC #55
ROLLFORM
LIMA, OH 45801

Received Date: 01/27/2009
Heat Code:
Heat Number: 7367052, 7366484, and 7368369
PO or Work Order: Lot#: 090123B
Test Spec: F606 ASTM METHODS
Other Information: SO#: 55-46502

Completion Date: 01/29/2009
Weld Spec:
Material Type: A 307 A
Material Size: 5/8" x 1-1/2" HHB

OTHER TEST:

Type: HARDNESS ROCKWELL BW — Quantity amount: 20

A) 90-91-90-89

B) 88-90-91-91

C) 89-91-91-91

D) 89-89-91-91

E) 91-91-90-88

Type: HEAD MARKINGS — Quantity amount: 0

TRN 307A USA

We certify the above results to be a true and accurate representation of the sample(s) submitted. Alteration or partial reproduction of this report will void certification. NVLAP Certificate of Accreditation effective through 12-31-09.This report may not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

Lab Director, Michael S. Beaton, PE

Page 1 of 1

Figure B-67. 5/8 in. Diameter x 1 ½ in. (M16x38 mm) Long Hex Head Bolt and Nut, Part c9, Test Nos.WIDA-1 and WIDA-2

07/18/2008 11:19 330-670-3198 REPUBLIC ENGINEER PAGE 03/04

Attn Carlina Smith

Republic ENGINEERED PRODUCTS 1807 EAST 28TH ST. PHONE: 330-438-5694 LORAIN, OH 4405 FAX: 330-438-569

CERTIFICATE OF TESTS REPUBLIC ENGINEERED PRODUCTS July 9, 2008
PAGE 1
OF 2

PURCHASE ORD:	127595M	PURCHASE ORDER DATE:	4/14/2008
PART NUMBER:	1009418	ACCOUNT NUMBER:	5550-3007-01
ORDER NUMBER:	1379747 - 01	SCHEDULE:	4116-85
HEAT:	7366484	REVISION:	1

CHARGE ADDRESS / SHIP TO

TRINITY INDUSTRIES INC
HIGHWAY SAGETY PRODUCTS INC
P O BOX 568887 4TH FLOOR
DALLAS, TX 75356-8887

TRINITY INDUSTRIES INC
C/O BCS METALS PREP
5800 STERLING AVE
MAPLE HTS, OH 44137

MATERIAL DESCRIPTION

HOT ROLLED STEEL COILS CARBON AISI-1015 AK AL KILLED FINE GRAIN COLD WORKING QUALITY TEST REPORTS OF MECHANICAL PROPERTIES FOR INFO ONLY EXTRA TESTING
SIZE: RDS .6390 DIAM X COIL
RDS 16.2306MM DIAM X COIL

LADLE CHEMISTRY %

C	MN	P	S	SI	CU	NI	CR
0.13	0.38	0.007	0.002	0.10	0.03	0.04	0.06
V	MO	SN	AL	CB	N		
0.002	0.02	0.001	0.037	0.001	0.0040		

CALCULATED TESTS

REDUCTION RATIO 112.3 TO 1

AUSTENITIC GRAIN SIZE 5 OR FINER BASED ON A TOTAL ALUMINUM CONTENT EQUAL TO OR GREATER THAN .020% PER ASTM A29.

SEMI - FINISHED RESULTS

FINISHED SIZE RESULTS

TENSILE TEST STANDARD FORMAT

	TENSILE PSI	YIELD(0.2%) PSI	RA %	E %
PCE 10427	59700	422000	72.4	49.0

HARDNESS TEST ASTM E10/ASTM A370 HBW AS-RLD/CD HBW
MID-RADIUS
PCE 10428 107

NOTES

CHEMICAL ANALYSIS CONFORMS TO APPLICABLE SPECS: ASTM E415, LBL10129, LBL10130, ASTM E1019, LBL10158, LBL10114, AND ASTM E1085, LBL10184, LBL10188.

REPUBLIC ENGINEERED PRODUCTS HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

CERTIFICATE OF TESTS SHALL NOT BE REPRODUCED EXCEPT IN FULL.

ALL TESTING HAS BEEN PERFORMED USING THE CURRENT REVISION OF THE TESTING SPECIFICATIONS.

RECORDING OF FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELONY UNDER FED STATUES TITLE 18 CHAPTER 47.

THE MATERIAL WAS NOT EXPOSED TO MERCURY OR ANY METAL ALLOY THAT IS LIQUID AT AMBIENT TEMPERATURE DURING PROCESSING OR WHILE IN OUR POSSESSION.

NO WELD OR WELD REPAIR WAS PERFORMED ON THIS MATERIAL.

R. A. SZELIGA
MANAGER TECH. SERVICES
R. A. Szeliga

BY JANET K. HARTLINE

Figure B-68. 5/8 in. Diameter x 1 ½ in. (M16x38 mm) Long Hex Head Bolt and Nut, Part c9, Test Nos.WIDA-1 and WIDA-2

07/10/2008 11:19 330-670-3198 REPUBLIC ENGINEER PAGE 04/04

Republic ENGINEERED PRODUCTS 1807 EAST 28TH ST. PHONE: 330-438-5694 LORAIN, OH 4405 FAX: 330-438-569

CERTIFICATE OF TESTS REPUBLIC ENGINEERED PRODUCTS July 9, 2008

PAGE 2 OF 2

PURCHASE ORD:	127595M	PURCHASE ORDER DATE:	4/14/2008
PART NUMBER:	100941B	ACCOUNT NUMBER:	5550-3007-01
ORDER NUMBER:	1379747 - 01	SCHEDULE:	4116-85
HEAT:	7366484	REVISION:	1

NOTES (CONTINUED)

THE RESULTS REPORTED RELATE ONLY TO THE ITEMS TESTED

MELTED AND MANUFACTURED IN THE U.S.A.

SOURCE INFORMATION

MELT SOURCE: LORAIN BILLET MELT COUNTRY: U.S.A HOT ROLL SOURCE: LORAIN 9/10, U.S.A

MELT METHOD: BOF BILLET RED. RATIO: 112.3

END OF DATA ---- CC ---- END OF DATA

FILE 1 COPY

R. A. SZELIGA
MANAGER TECH. SERVICES
R. A. Szeliga

BY JANET K. HARTLINE

Figure B-69. 5/8 in. Diameter x 1 ½ in. (M16x38 mm) Long Hex Head Bolt and Nut, Part c9, Test Nos.WIDA-1 and WIDA-2

Republic 1807 EAST 28TH ST. LORAIN, OH 44055
PHONE: 330-438-5694 FAX: 330-438-5695
CERTIFICATE OF TESTS REPUBLIC ENGINEERED PRODUCTS September 12, 2008
PAGE 1
OF 2

PURCHASE ORD: I27595M PURCHASE ORDER DATE: 4/14/2008
PART NUMBER: 100941B ACCOUNT NUMBER: 5550-3007-01
ORDER NUMBER: 1379747 - 01 SCHEDULE: 7327-85
HEAT: 7367052 REVISION: 1

CHARGE ADDRESS — SHIP TO

TRINITY INDUSTRIES INC
HIGHWAY SAGETY PRODUCTS INC
P O BOX 568887 4TH FLOOR
DALLAS, TX 75356-8887

TRINITY INDUSTRIES INC
C/O BCS METALS PREP
5800 STERLING AVE
MAPLE HEIGHTS, OH 44137

MATERIAL DESCRIPTION

HOT ROLLED STEEL COILS CARBON AISI-1015 AK AL KILLED FINE GRAIN COLD WORKING QUALITY TEST REPORTS OF MECHANICAL PROPERTIES FOR INFO ONLY EXTRA TESTING
SIZE: RDS .6390 DIAM X COIL
RDS 16.2306MM DIAM X COIL

LADLE CHEMISTRY %

C	MN	P	S	SI	CU	NI	CR
0.15	0.49	0.008	0.002	0.06	0.03	0.02	0.05
V	MO	SN	AL	CB	N		
0.002	0.01	0.001	0.029	0.001	0.0050		

CALCULATED TESTS

REDUCTION RATIO 112.3 TO 1

AUSTENITIC GRAIN SIZE 5 OR FINER BASED ON A TOTAL ALUMINUM CONTENT EQUAL TO OR GREATER THAN .020% PER ASTM A29.

SEMI - FINISHED RESULTS

FINISHED SIZE RESULTS

TENSILE TEST STANDARD FORMAT

	TENSILE PSI	YIELD (0.2%) PSI	RA %	E %
PCE 14133	60850	45000	64.4	44.0

HARDNESS TEST ASTM E10/ASTM A370 HBW AS-RLD/CD HBW

	MID-RADIUS
PCE 14134	116

NOTES

CHEMICAL ANALYSIS CONFORMS TO APPLICABLE SPECS: ASTM E415, LBL10129, LBL10130, ASTM E1019, LBL10158, LBL10114, AND ASTM E1085, LBL10184, LBL10188.

REPUBLIC ENGINEERED PRODUCTS HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

CERTIFICATE OF TESTS SHALL NOT BE REPRODUCED EXCEPT IN FULL.

ALL TESTING HAS BEEN PERFORMED USING THE CURRENT REVISION OF THE TESTING SPECIFICATIONS.

RECORDING OF FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELONY UNDER FED STATUES TITLE 18 CHAPTER 47.

THE MATERIAL WAS NOT EXPOSED TO MERCURY OR ANY METAL ALLOY THAT IS LIQUID AT AMBIENT TEMPERATURE DURING PROCESSING OR WHILE IN OUR POSSESSION.

NO WELD OR WELD REPAIR WAS PERFORMED ON THIS MATERIAL.

R. A. SZELICA BY JANET K. HARTLINE
MANAGER TECH. SERVICES
R. A. Szelica

Figure B-70. 5/8 in. Diameter x 1 ½ in. (M16x38 mm) Long Hex Head Bolt and Nut, Part c9, Test Nos.WIDA-1 and WIDA-2

Republic 1807 EAST 28TH ST. PHONE: 330-438-5694 LORAIN, OH 44055 FAX: 330-438-5695

CERTIFICATE OF TESTS REPUBLIC ENGINEERED PRODUCTS September 12, 2008

PAGE 2 OF 2

PURCHASE ORD:	127595M	PURCHASE ORDER DATE:	4/14/2008
PART NUMBER:	100941B	ACCOUNT NUMBER:	5550-3007-01
ORDER NUMBER:	1379747 - 01	SCHEDULE:	7327-85
HEAT:	7367052	REVISION:	1

NOTES (CONTINUED)

THE RESULTS REPORTED RELATE ONLY TO THE ITEMS TESTED

MELTED AND MANUFACTURED IN THE U.S.A.

SOURCE INFORMATION

MELT SOURCE: LORAIN BILLET MELT COUNTRY: U.S.A HOT ROLL SOURCE: LORAIN 9/10, U.S.A

MELT METHOD: BOF BILLET RED. RATIO: 112.3

END OF DATA ---- CC ---- END OF DATA

FILE 1 COPY

R. A. SZELIGA
MANAGER TECH. SERVICES
R. A. Szeliga

BY JANET K. HARTLINE

Figure B-71. 5/8 in. Diameter x 1 ½ in. (M16x38 mm) Long Hex Head Bolt and Nut, Part c9, Test Nos.WIDA-1 and WIDA-2

Republic 1807 EAST 28TH ST. PHONE: 330-438-5694 LORAIN, OH 44055 FAX: 330-438-5695

CERTIFICATE OF TESTS REPUBLIC ENGINEERED PRODUCTS October 31, 2008 PAGE 1 OF 2

PURCHASE ORD: 129120M PURCHASE ORDER DATE: 8/27/2008
PART NUMBER: 100941B ACCOUNT NUMBER: 5550-3007-01
ORDER NUMBER: 1396203 - 01 SCHEDULE: 9510-85
HEAT: 7368369 REVISION: 1

CHARGE ADDRESS / SHIP TO

TRINITY INDUSTRIES INC
HIGHWAY SAGETY PRODUCTS INC
P O BOX 568887 4TH FLOOR
DALLAS, TX 75356-8887

TRINITY INDUSTRIES INC
C/O BCS METALS PREP
5800 STERLING AVE
MAPLE HEIGHTS, OH 44137

MATERIAL DESCRIPTION

HOT ROLLED STEEL COILS CARBON AISI-1015 AK AL KILLED FINE GRAIN COLD WORKING QUALITY TEST REPORTS OF MECHANICAL PROPERTIES FOR INFO ONLY EXTRA TESTING
SIZE: RDS .6390 DIAM X COIL
RDS 16.2306MM DIAM X COIL

LADLE CHEMISTRY %

C	MN	P	S	SI	CU	NI	CR
0.14	0.43	0.006	0.008	0.06	0.04	0.02	0.06
V	MO	SN	AL	CB	N		
0.002	0.02	0.001	0.034	0.001	0.0050		

CALCULATED TESTS

REDUCTION RATIO 112.3 TO 1

AUSTENITIC GRAIN SIZE 5 OR FINER BASED ON A TOTAL ALUMINUM CONTENT EQUAL TO OR GREATER THAN .020% PER ASTM A29.

SEMI - FINISHED RESULTS

FINISHED SIZE RESULTS

TENSILE TEST STANDARD FORMAT

	TENSILE PSI	YIELD(0.2%) PSI	RA %	E %
PCE 15910	58600	43200	63.9	47.0

HARDNESS TEST ASTM E10/ASTM A370 HBW AS-RLD/CD HBW

	MID-RADIUS
PCE 15911	111

NOTES

CHEMICAL ANALYSIS CONFORMS TO APPLICABLE SPECS: ASTM E415, LBL10129, LBL10130, ASTM E1019, LBL10158, LBL10114, AND ASTM E1085, LBL10184, LBL10188.

REPUBLIC ENGINEERED PRODUCTS HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

CERTIFICATE OF TESTS SHALL NOT BE REPRODUCED EXCEPT IN FULL.

ALL TESTING HAS BEEN PERFORMED USING THE CURRENT REVISION OF THE TESTING SPECIFICATIONS.

RECORDING OF FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELONY UNDER FED STATUES TITLE 18 CHAPTER 47.

THE MATERIAL WAS NOT EXPOSED TO MERCURY OR ANY METAL ALLOY THAT IS LIQUID AT AMBIENT TEMPERATURE DURING PROCESSING OR WHILE IN OUR POSSESSION.

NO WELD OR WELD REPAIR WAS PERFORMED ON THIS MATERIAL.

R. A. SZELIGA BY JANET K. HARTLINE
MANAGER TECH. SERVICES
R. A. Szeliga

Figure B-72. 5/8 in. Diameter x 1 ½ in. (M16x38 mm) Long Hex Head Bolt and Nut, Part c9, Test Nos.WIDA-1 and WIDA-2

Republic 1807 EAST 28TH ST. PHONE: 330-438-5694 LORAIN, OH 44055 FAX: 330-438-5695

CERTIFICATE OF TESTS REPUBLIC ENGINEERED PRODUCTS October 31, 2008

PAGE 2 OF 2

PURCHASE ORD:	129120M	PURCHASE ORDER DATE:	8/27/2008
PART NUMBER:	100941B	ACCOUNT NUMBER:	5550-3007-01
ORDER NUMBER:	1396203 - 01	SCHEDULE:	9510-85
HEAT:	7368369	REVISION:	1

---------- NOTES (CONTINUED) ----------

THE RESULTS REPORTED RELATE ONLY TO THE ITEMS TESTED

MELTED AND MANUFACTURED IN THE U.S.A.

---------- SOURCE INFORMATION ----------

MELT SOURCE: LORAIN BILLET MELT COUNTRY: U.S.A HOT ROLL SOURCE: LORAIN 9/10, U.S.A

MELT METHOD: BOF BILLET RED. RATIO: 112.3

---------- END OF DATA ---------- CC ---------- END OF DATA ----------

FILE 1 COPY

R. A. SZELIGA
MANAGER TECH. SERVICES
R. A. Szeliga

BY JANET K. HARTLINE

Figure B-73. 5/8 in. Diameter x 1 ½ in. (M16x38 mm) Long Hex Head Bolt and Nut, Part c9, Test Nos.WIDA-1 and WIDA-2

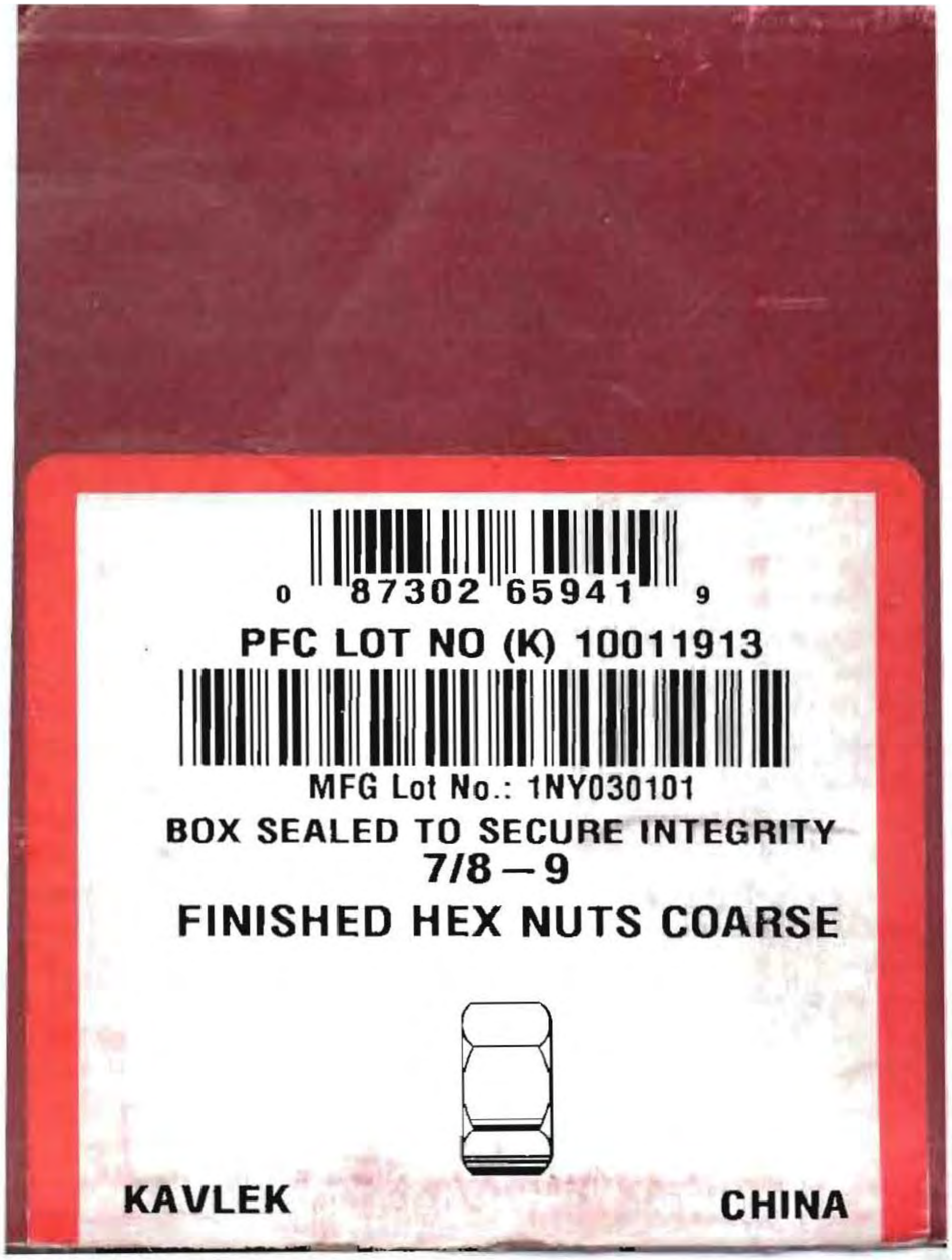


Figure B-74. 7/8 in. Diameter x 7 ½ in. (M16x191 mm) Long Hex Head Bolt and Nut, Part c10, Test Nos.WIDA-1 and WIDA-2

Figure B-75. 7/8 in. Diameter x 7 ½ in. (M16x191 mm) Long Hex Head Bolt and Nut, Part c10, Test Nos.WIDA-1 and WIDA-2

Figure B-76. 7/8" [22 mm] Dia. Flat Washer, Part c11, Test Nos.WIDA-1 and WIDA-2

Appendix C. Bogie Test Results

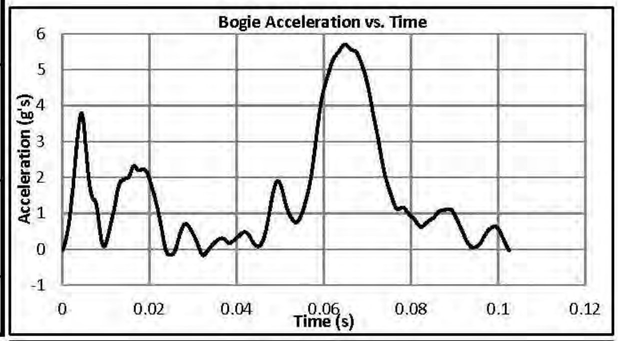
The results of the recorded data from each accelerometer for every dynamic bogie test are provided in the summary sheets found in this appendix. Summary sheets include acceleration, velocity, deflection versus time plots, force versus deflection plots, and energy versus deflection plots. For those bogie tests for which load cells were used, the corresponding measured data are provided as well.

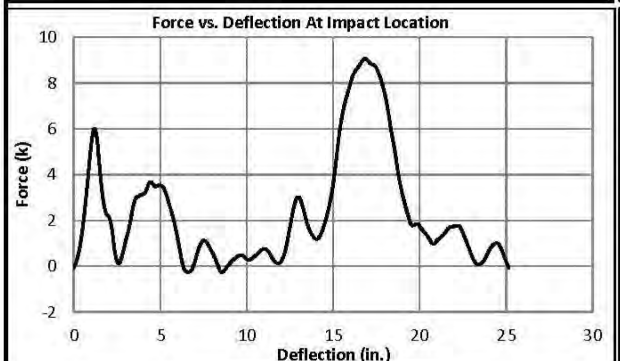
MIDWEST ROADSIDE SAFETY FACILITY

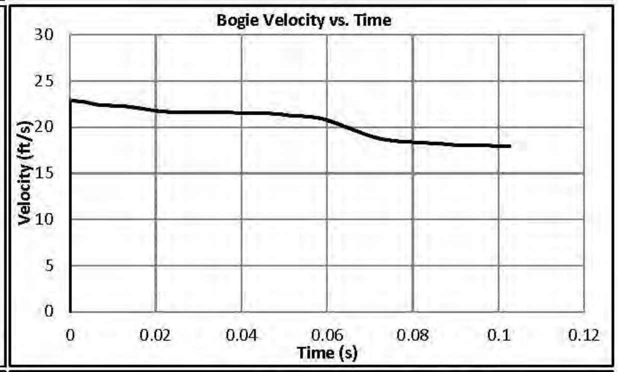
Bogie Test Summary

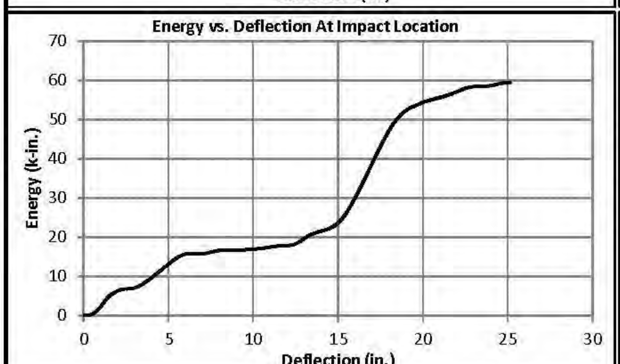
Test Information	Dynamic Test vs. Post in Rigid Sleeve	
Test Number:	BCTRS-1	
Test Date:	16-Aug-2011	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Wood BCT	
Post Size:	5.5" x 7.5" (BCT)	140 mm x 191 mm
Post Length:	45.625 in.	115.9 cm
Embedment Depth:	13.625 in.	34.6 cm
Orientation:	Weak Axis	
Soil Properties		
Gradation:	Rigid Sleeve	
Moisture Content:	NA	
Compaction Method:	Installed with wood shims	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	15.57 mph (22.8 fps)	6.96 m/s
Impact Height:	25 in.	63.5 cm
Bogie Mass:	1589.5 lbs	721 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular -155"	

Test Results Summary		
Max. Deflection:	25.2	in.
Peak Force:	9.1	k
Initial Linear Stiffness:	5.0	k/in.
Total Energy:	59.4	k-in.









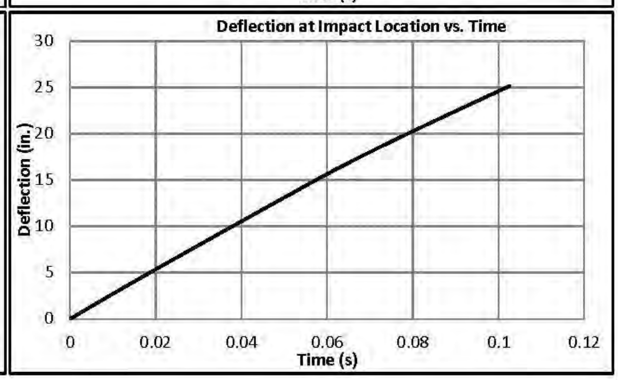


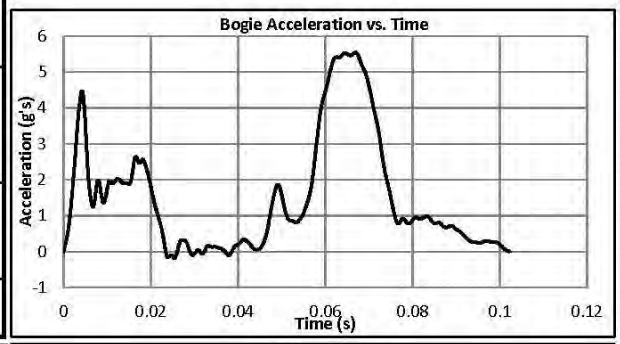
Figure C-1. Test No. BCTRS-1 Results (EDR-3)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Dynamic Test vs. Post in Rigid Sleeve	
Test Number:	BCTRS-1	
Test Date:	16-Aug-2011	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Wood BCT	
Post Size:	5.5" x 7.5" (BCT)	140 mm x 191 mm
Post Length:	45.625 in.	115.9 cm
Embedment Depth:	13.625 in.	34.6 cm
Orientation:	Weak Axis	
Soil Properties		
Gradation:	Rigid Sleeve	
Moisture Content:	NA	
Compaction Method:	Installed with wood shims	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	15.57 mph (22.8 fps)	6.96 m/s
Impact Height:	25 in.	63.5 cm
Bogie Mass:	1589.5 lbs	721 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS-5 Perpendicular - 155"	

Test Results Summary		
Max. Deflection:	24.9	in.
Peak Force:	8.8	k
Initial Linear Stiffness:	6.2	k/in.
Total Energy:	59.9	k-in.



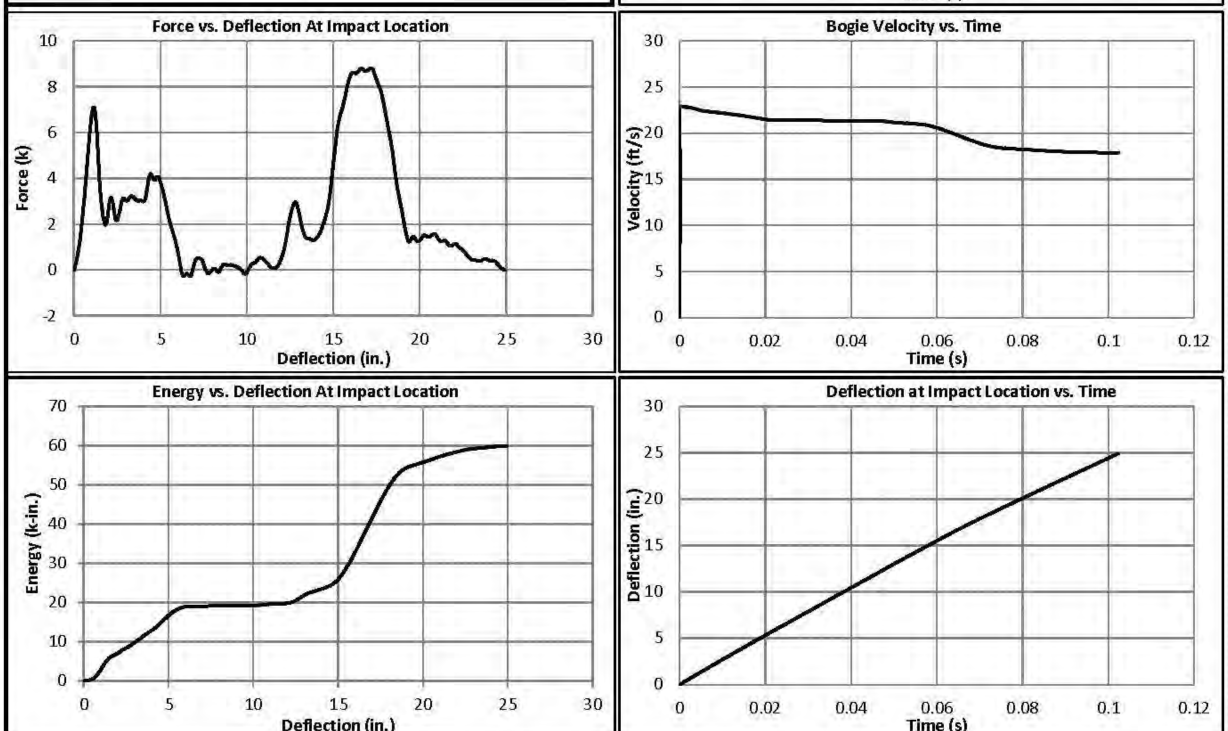


Figure C-2. Test No. BCTRS-1 Results (DTS)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information — Dynamic Test vs. Post in Rigid Sleeve

Test Number:	BCTRS-2	
Test Date:	16-Aug-2011	
Failure Type:	Post Fracture	

Post Properties

Post Type:	Wood BCT	
Post Size:	5.5" x 7.5" (BCT)	140 mm x 191 mm
Post Length:	45.125 in.	114.6 cm
Embedment Depth:	13.125 in.	33.3 cm
Orientation:	Weak Axis	

Soil Properties

Gradation:	Rigid Sleeve
Moisture Content:	NA
Compaction Method:	Installed with wood shims
Soil Density, γd:	NA

Bogie Properties

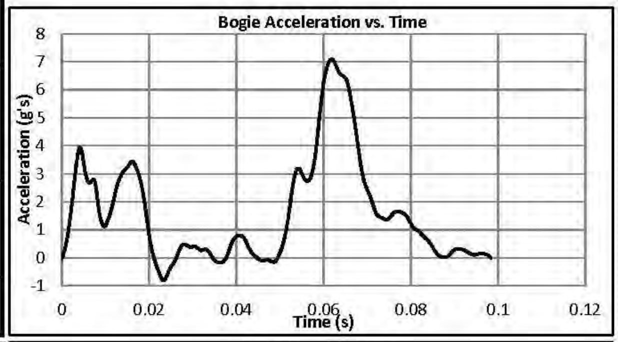
Impact Velocity:	15.28 mph (22.4 fps)	6.83 m/s
Impact Height:	25 in.	63.5 cm
Bogie Mass:	1589.5 lbs	721 kg

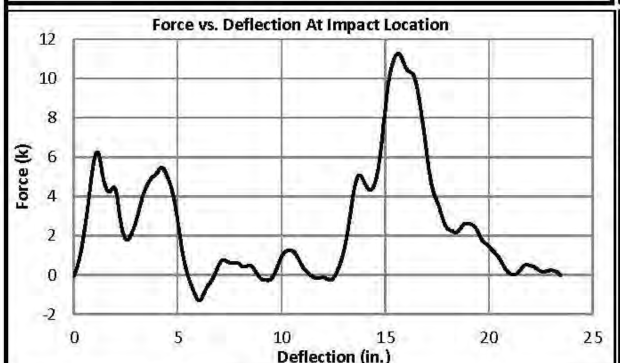
Data Acquired

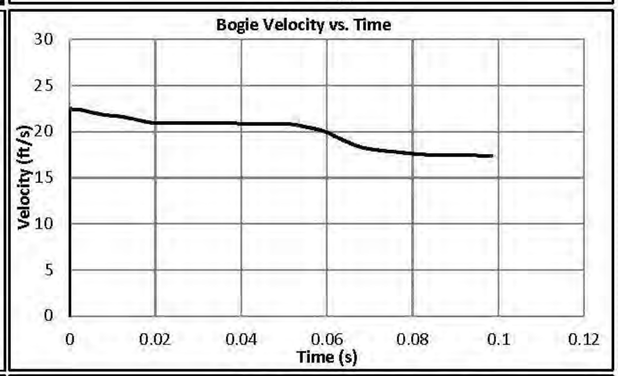
Acceleration Data:	EDR-3
Camera Data:	AOS-5 Perpendicular -155"

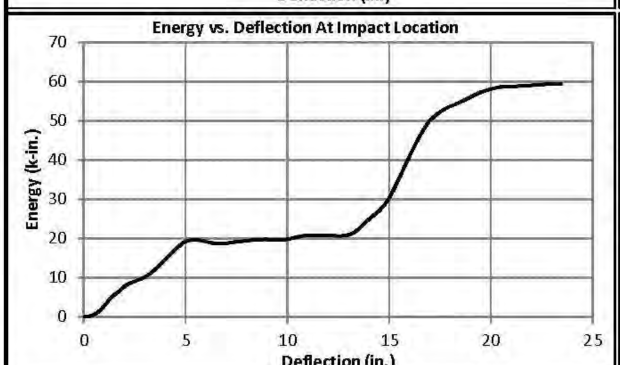
Test Results Summary

Max. Deflection:	23.4	in.
Peak Force:	11.3	k
Initial Linear Stiffness:	5.7	k/in.
Total Energy:	59.4	k-in.









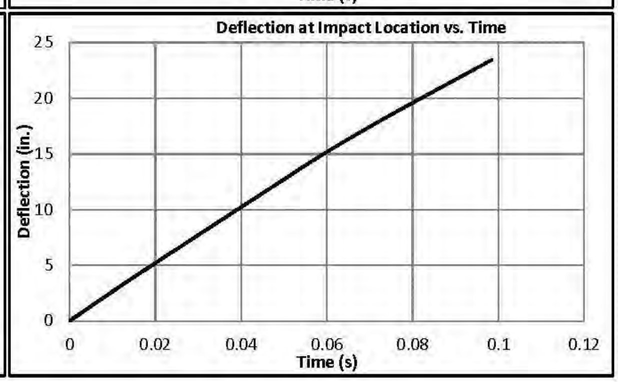


Figure C-3. Test No. BCTRS-2 Results (EDR-3)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information Dynamic Test vs. Post in Rigid Sleeve

Test Number:	BCTRS-2	
Test Date:	16-Aug-2011	
Failure Type:	Post Fracture	

Post Properties

Post Type:	Wood BCT	
Post Size:	5.5" x 7.5" (BCT)	140 mm x 191 mm
Post Length:	45.125 in.	114.6 cm
Embedment Depth:	13.125 in.	33.3 cm
Orientation:	Weak Axis	

Soil Properties

Gradation:	Rigid Sleeve
Moisture Content:	NA
Compaction Method:	Installed with wood shims
Soil Density, γd:	NA

Bogie Properties

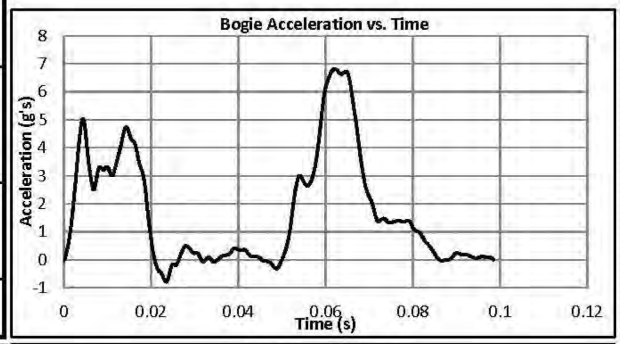
Impact Velocity:	15.28 mph (22.4 fps)	6.83 m/s
Impact Height:	25 in.	63.5 cm
Bogie Mass:	1589.5 lbs	721 kg

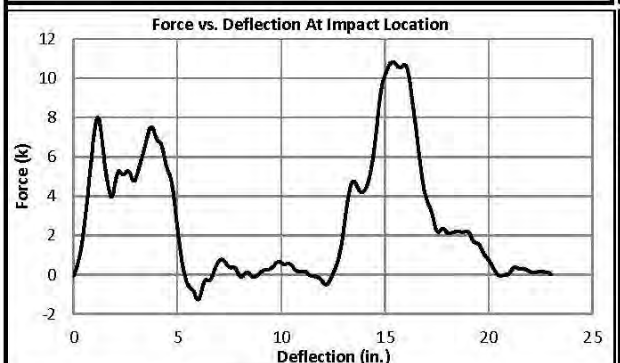
Data Acquired

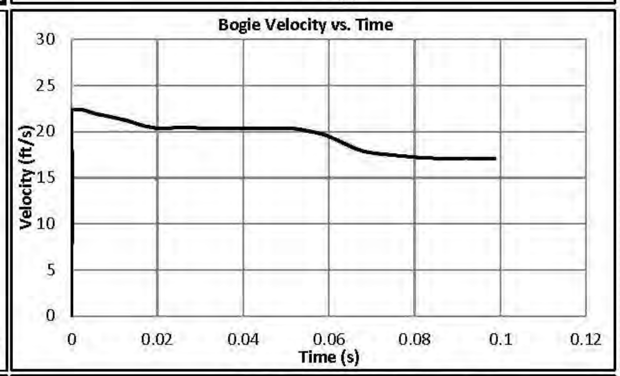
Acceleration Data:	DTS
Camera Data:	AOS-5 Perpendicular - 155"

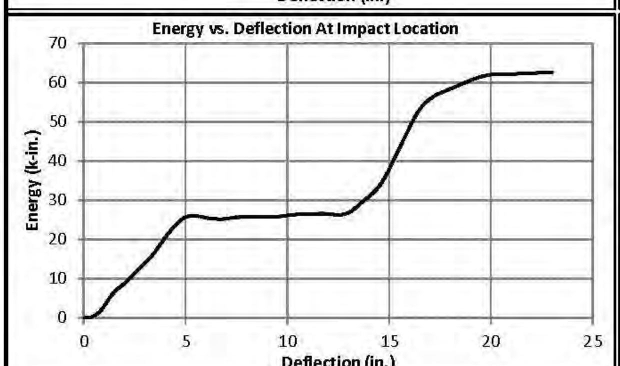
Test Results Summary

Max. Deflection:	23.0	in.
Peak Force:	10.8	k
Initial Linear Stiffness:	6.8	k/in.
Total Energy:	62.6	k-in.









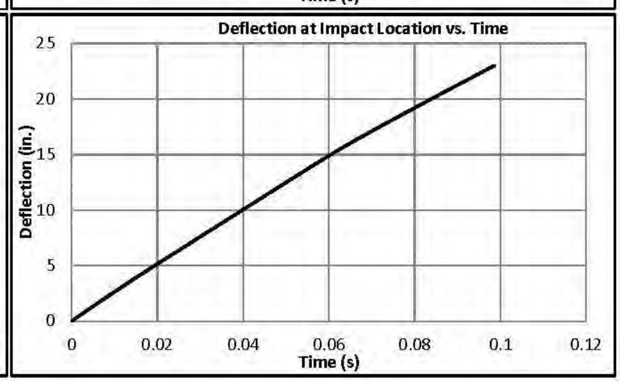


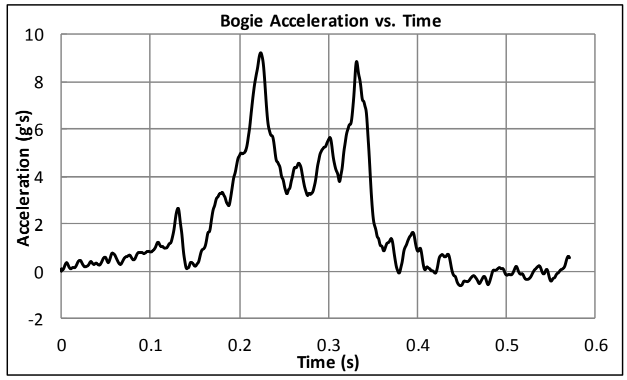
Figure C-4. Test No. BCTRS-2 Results (DTS)

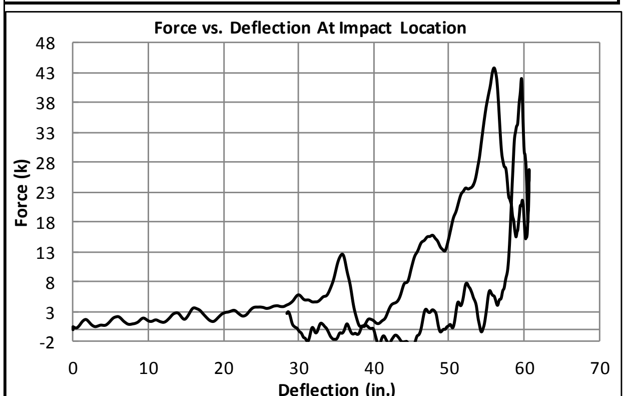
MIDWEST ROADSIDE SAFETY FACILITY

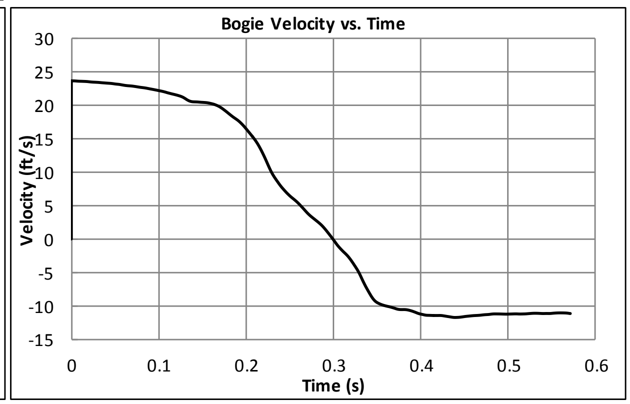
Bogie Test Summary

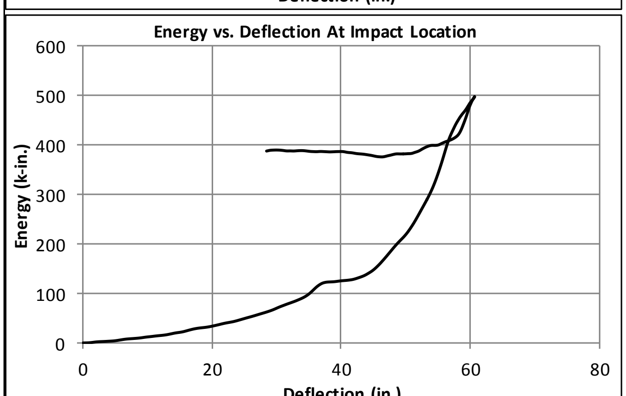
Test Information	Bogie Jerk Test on anchorage cable	
Test Number:	MGSEA-1	
Test Date:	11-May-2012	
Failure Type:	Movement in soil	
Post Properties		
Post Type:	Anchorage - Steel Foundation Tube	
Post Size:	CRT	0
Post Length:	72 in.	182.9 cm
Embedment Depth:	70 in.	177.8 cm
Orientation:	longitudinal	
Soil Properties		
Gradation:	40927	
Moisture Content:	0.0328	
Compaction Method:	H.E. - 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	16.13 mph (23.7 fps)	7.21 m/s
Impact Height:	4 in.	10.2 cm
Bogie Mass:	4753 lbs	2155.9 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-7 Perpendicular - 260"	

Test Results Summary		
Max. Deflection:	60.7	in.
Peak Force:	43.8	k
Initial Linear Stiffness:	0.8	k/in.
Total Energy:	497.4	k-in.









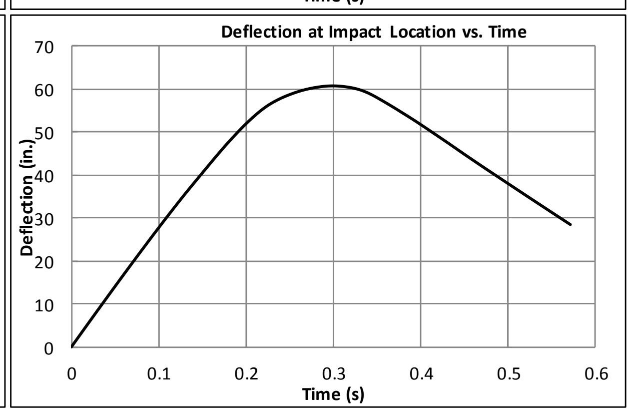


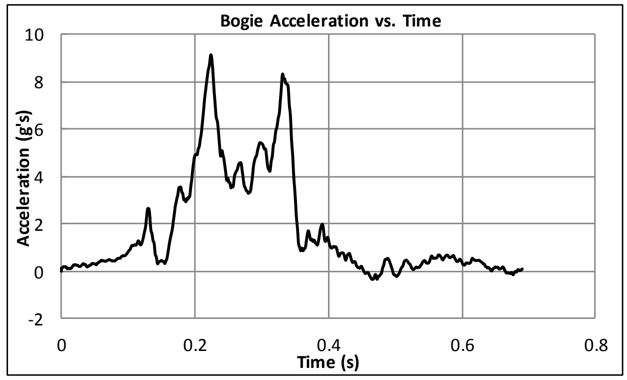
Figure C-5. Test No. MGSEA-1 Results (EDR-3)

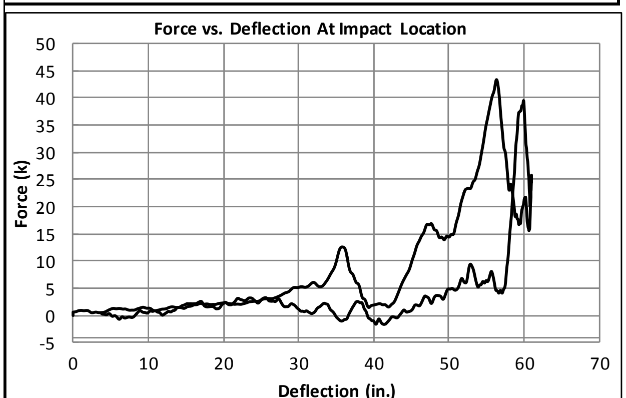
MIDWEST ROADSIDE SAFETY FACILITY

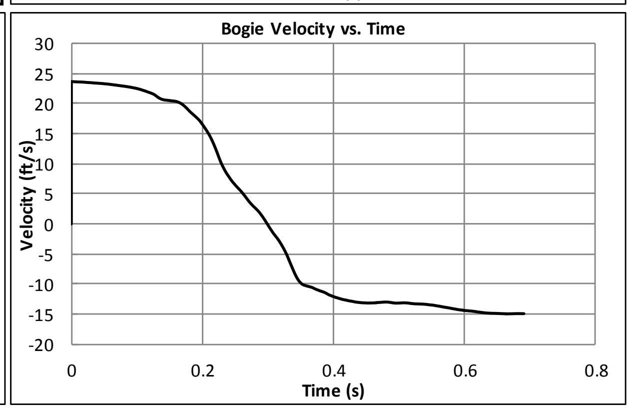
Bogie Test Summary

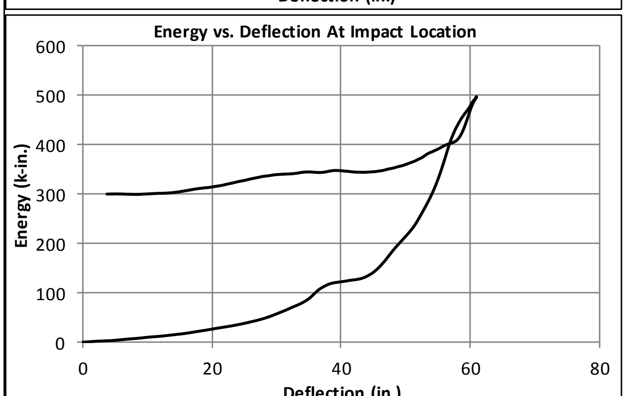
Test Information	Bogie Jerk Test on anchorage cable	
Test Number:	MGSEA-1	
Test Date:	11-May-2012	
Failure Type:	movement in soil	
Post Properties		
Post Type:	Anchorage - Steel Foundation Tube	
Post Size:	CRT	0
Post Length:	72 in.	182.9 cm
Embedment Depth:	70 in.	177.8 cm
Orientation:	longitudinal	
Soil Properties		
Gradation:	40927	
Moisture Content:	0.0328	
Compaction Method:	H.E. - 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	16.13 mph (23.7 fps)	7.21 m/s
Impact Height:	4 in.	10.2 cm
Bogie Mass:	4753 lbs	2155.9 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-7 Perpendicular - 260"	

Test Results Summary		
Max. Deflection:	61.0	in.
Peak Force:	43.4	k
Initial Linear Stiffness:	NA	k/in.
Total Energy:	496.7	k-in.









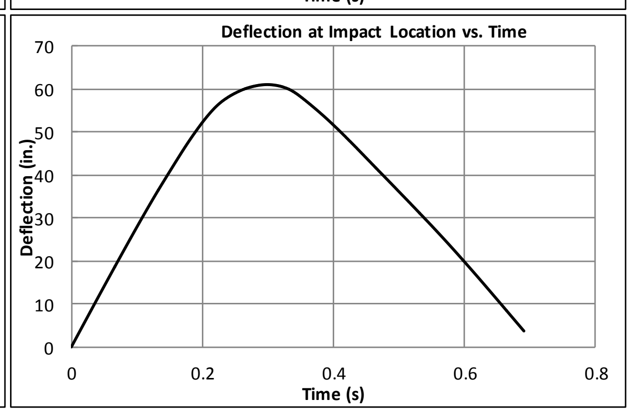


Figure C-6. Test No. MGSEA-1 Results (DTS-SLICE)

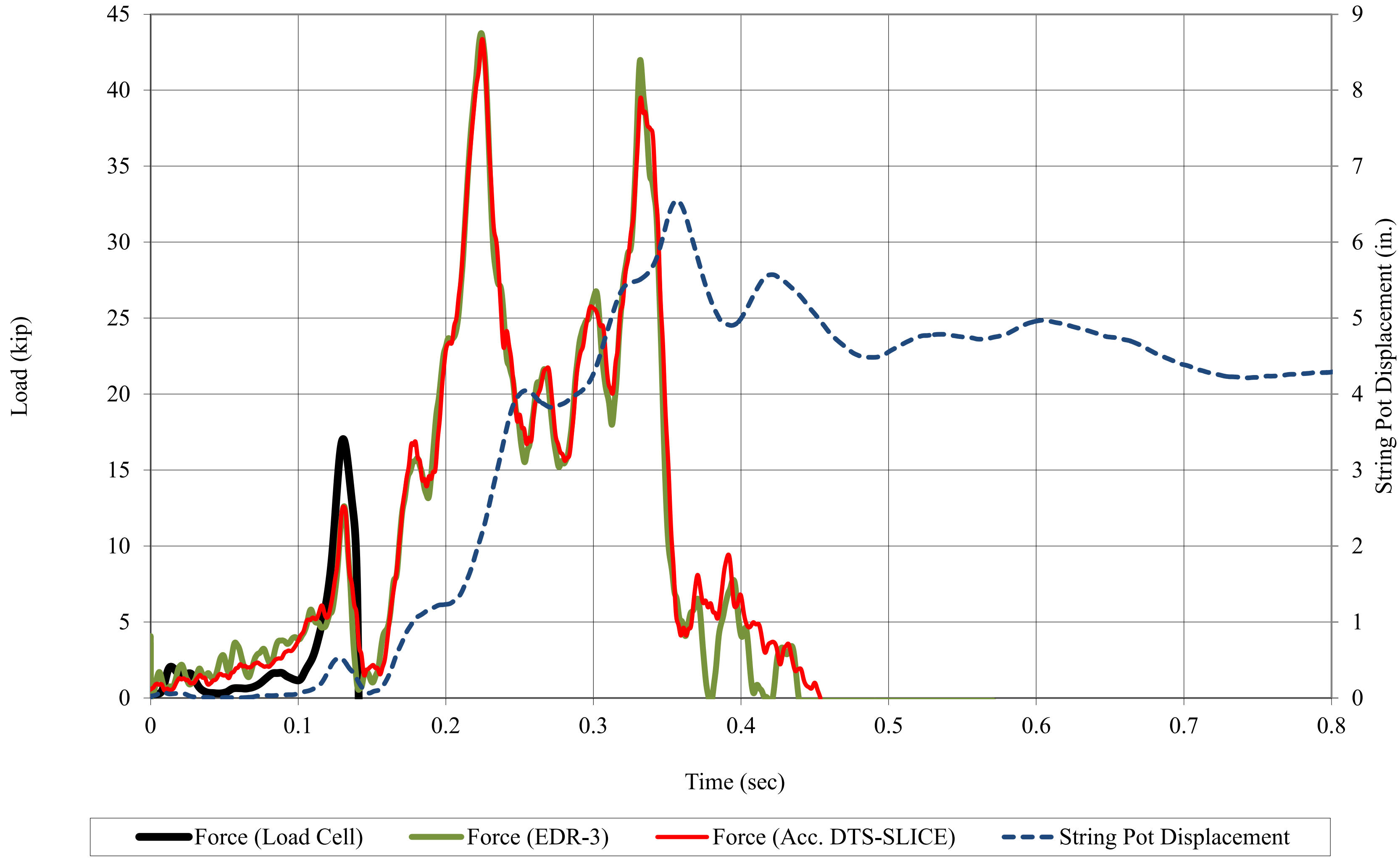


Figure C-7. Test No. MGSEA-1 Results (Load Cell, DTS-SLICE, and EDR-3)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information Bogie Jerk Test

Test Number:	DSAP-1	
Test Date:	23-Nov-2011	
Failure Type:	Strap Failure on pull cable	

Post Properties

Post Type:	Gaurdrail anchorage	
Post Size:	0	0
Post Length:	in.	0 cm
Embedment Depth:	in.	0 cm
Orientation:	longitudinal Jerk	

Soil Properties

Gradation:	40709
Moisture Content:	0
Compaction Method:	H.E. 8
Soil Density, γd:	NA

Bogie Properties

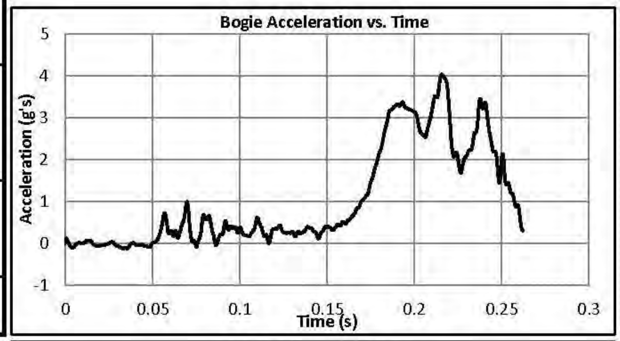
Impact Velocity:	27.18 mph (39.9 fps)	12.15 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	5086 lbs	2307 kg

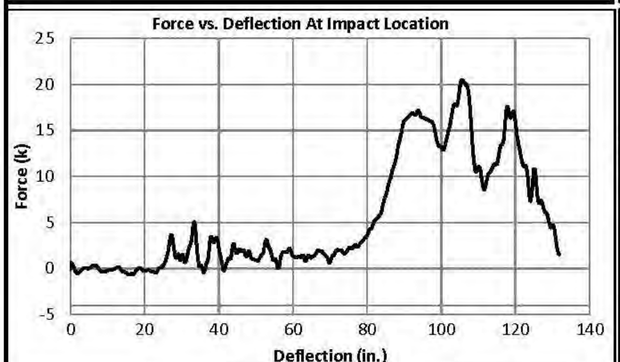
Data Acquired

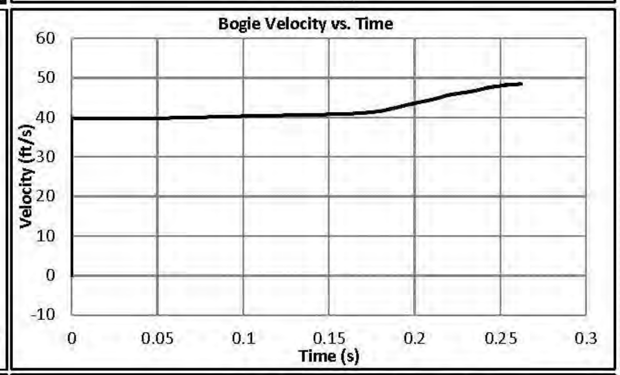
Acceleration Data:	0
Camera Data:	0

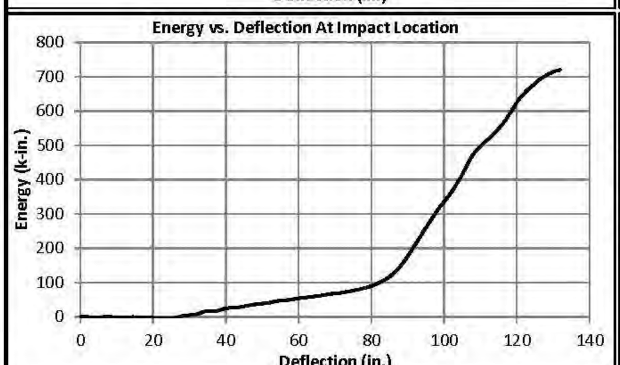
Test Results Summary

Max. Deflection:	131.9	in.
Peak Force:	20.5	k
Initial Linear Stiffness:	#DIV/0!	k/in.
Total Energy:	720.0	k-in.









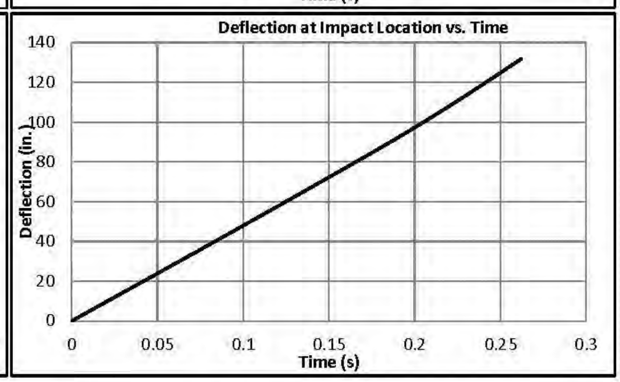


Figure C-8. Test No. DSAP-1 Results (DTS)

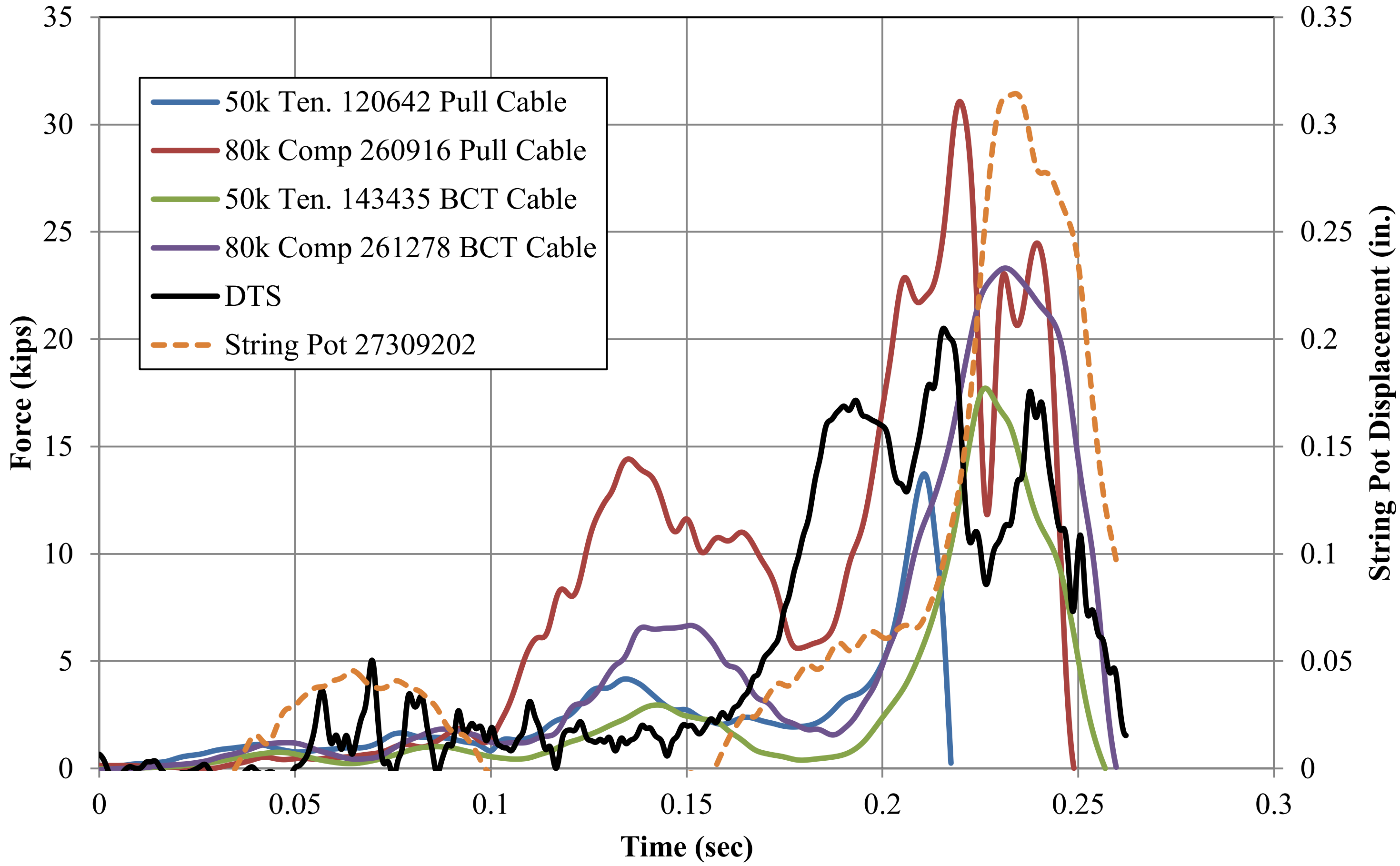


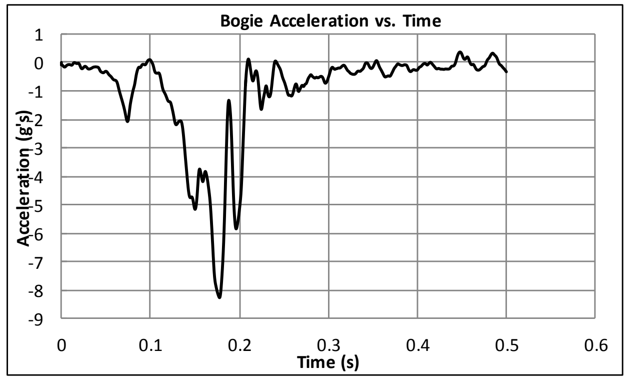
Figure C-9. Test No. DSAP-1 Results (Load Cells and DTS)

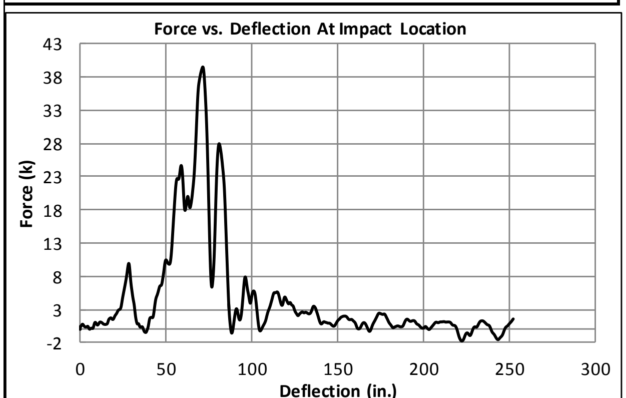
MIDWEST ROADSIDE SAFETY FACILITY

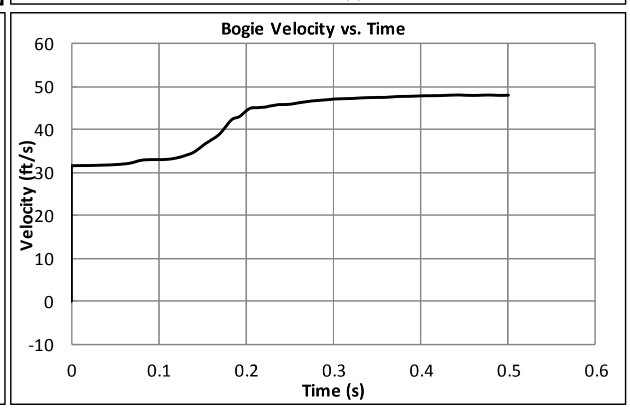
Bogie Test Summary

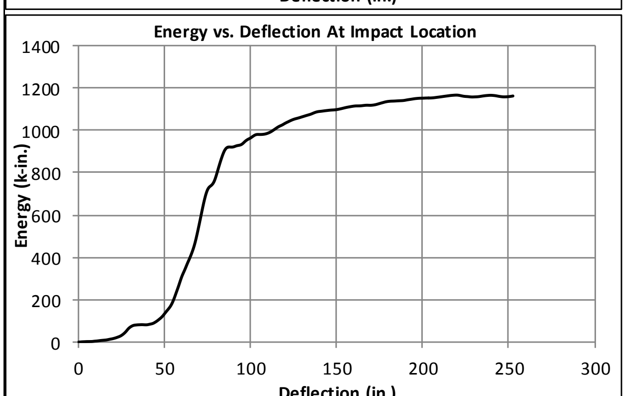
Test Information	Bogie jerk test	
Test Number:	DSAP-2	
Test Date:	10-Jan-2012	
Failure Type:	Post Failure	
Post Properties		
Post Type:	D.S. Anchorage	
Post Size:	BCT (2)	BCT (2)
Post Length:	in.	0 cm
Embedment Depth:	in.	0 cm
Orientation:	Loaded longitudinally through w-beam	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.52 mph (31.6 fps)	9.62 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	4779.5 lbs	2167.9 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	Multiple	

Test Results Summary		
Max. Deflection:	252.5	in.
Peak Force:	39.5	k
Initial Linear Stiffness:	0.6	k/in.
Total Energy:	1166.9	k-in.









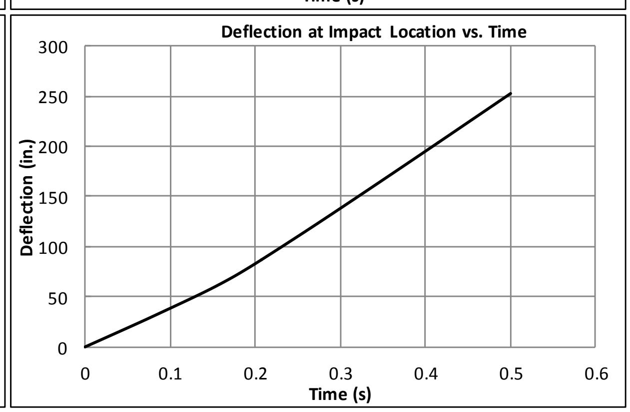


Figure C-10. Test No. DSAP-2 Results (EDR-3)

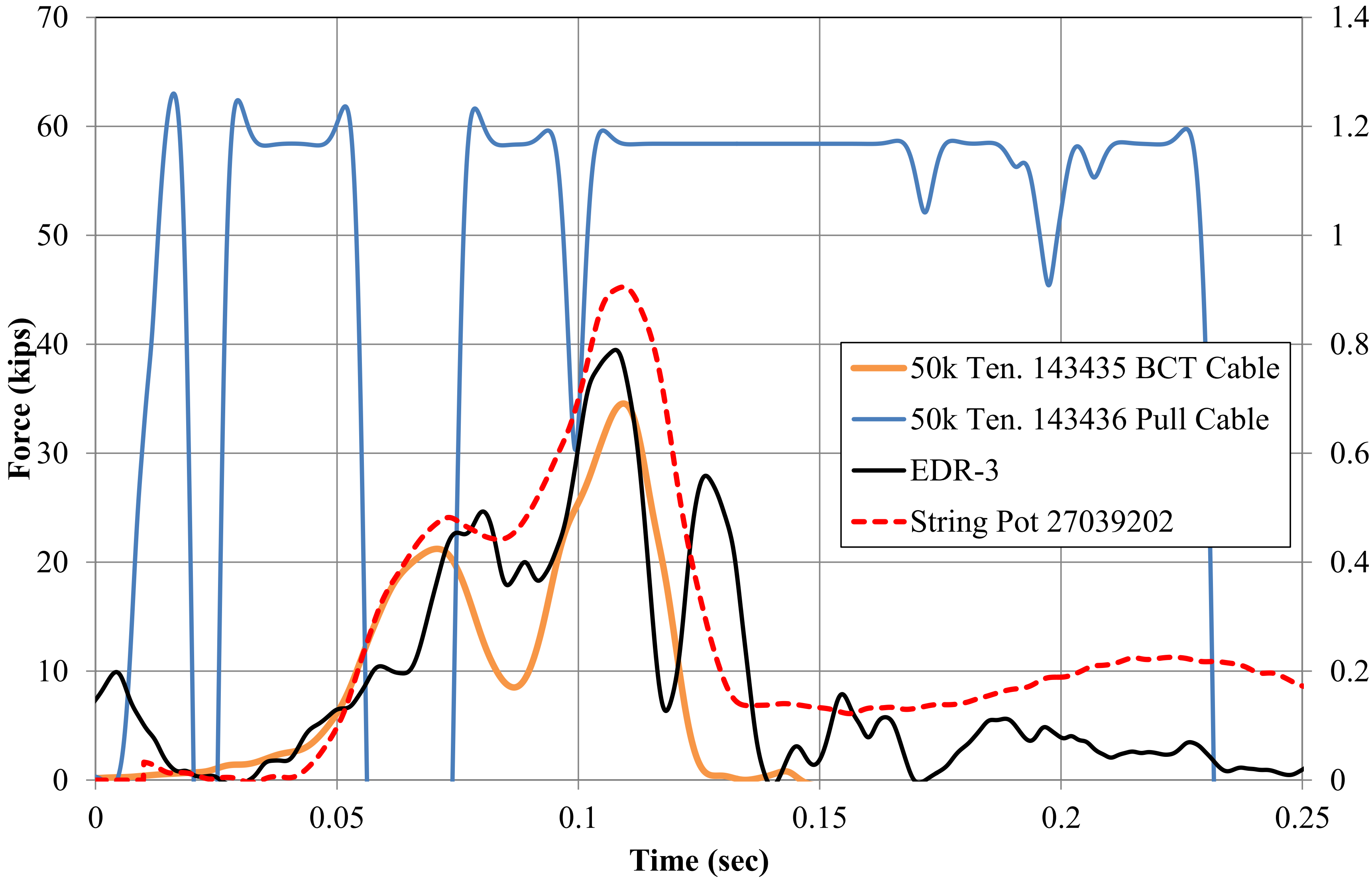


Figure C-11. Test No. DSAP-2 Results (Load Cells and EDR-3)

Appendix D. Vehicle Center of Gravity Determination

Test: WIDA-1 Vehicle: 2270P

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vert CG (in.)	Vert M (lb-in.)
+	Unbalasted Truck (Curb)	5016	28.30313	141968.5
+	Brake receivers/wires	6	52	312
+	Brake Frame	6	26	156
+	Brake Cylinder (Nitrogen)	22	27.5	605
+	Strobe/Brake Battery	6	32	192
+	Hub	27	15	405
+	CG Plate (EDRs)	8	33.5	268
-	Battery	-42	41.5	-1743
-	Oil	-5	15.5	-77.5
-	Interior	-64	24	-1536
-	Fuel	-152	18	-2736
-	Coolant	-13	36	-468
-	Washer fluid	-2	40	-80
BALLAST	Water	181	18	3258
	DTS Rack	17	30	510
	Misc.			0
				141034

Estimated Total Weight (lb)	5011
Vertical CG Location (in.)	28.14488

wheel base (in.) 140.5

MASH Targets	Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	5002	2.0
Long CG (in.)	63 ± 4	64.58	1.57607
Lat CG (in.)	NA	-0.63425	NA
Vert CG (in.)	28	28.14	0.14488

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb)

	Left	Right
Front	1437	1316
Rear	1144	1119

FRONT	2753 lb
REAR	2263 lb
TOTAL	5016 lb

TEST INERTIAL WEIGHT (lb)
(from scales)

	Left	Right
Front	1402	1301
Rear	1146	1153

FRONT	2703 lb
REAR	2299 lb
TOTAL	5002 lb

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

Test: WIDA-2 Vehicle: 1100C

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)
+	Unbalasted Car (curb)	2491
+	Brake receivers/wires	6
+	Brake Frame	6
+	Brake Cylinder	22
+	Strobe Battery	6
+	Hub	20
+	CG Plate (EDRs)	8
+	DTS	17
-	Battery	-35
-	Oil	-5
-	Interior	-33
-	Fuel	-20
-	Coolant	-5
-	Washer fluid	-7
BALLAST	Water	
	Spare tire	-23
	Misc.	

Estimated Total Weight 2448 lb

wheel base 98.625 in.

MASH targets		**Test Inertial**	**Difference**
Test Inertial Wt (lb)	2420 (+/-)55	2449	29.0
Long CG (in.)	39 (+/-)4	35.88	-3.11806
Lateral CG (in.)	N/A	-0.38572	NA

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb)

	Left	Right
Front	822	788
Rear	448	433

FRONT	1610 lb
REAR	881 lb
TOTAL	2491 lb

Dummy = 166lbs.

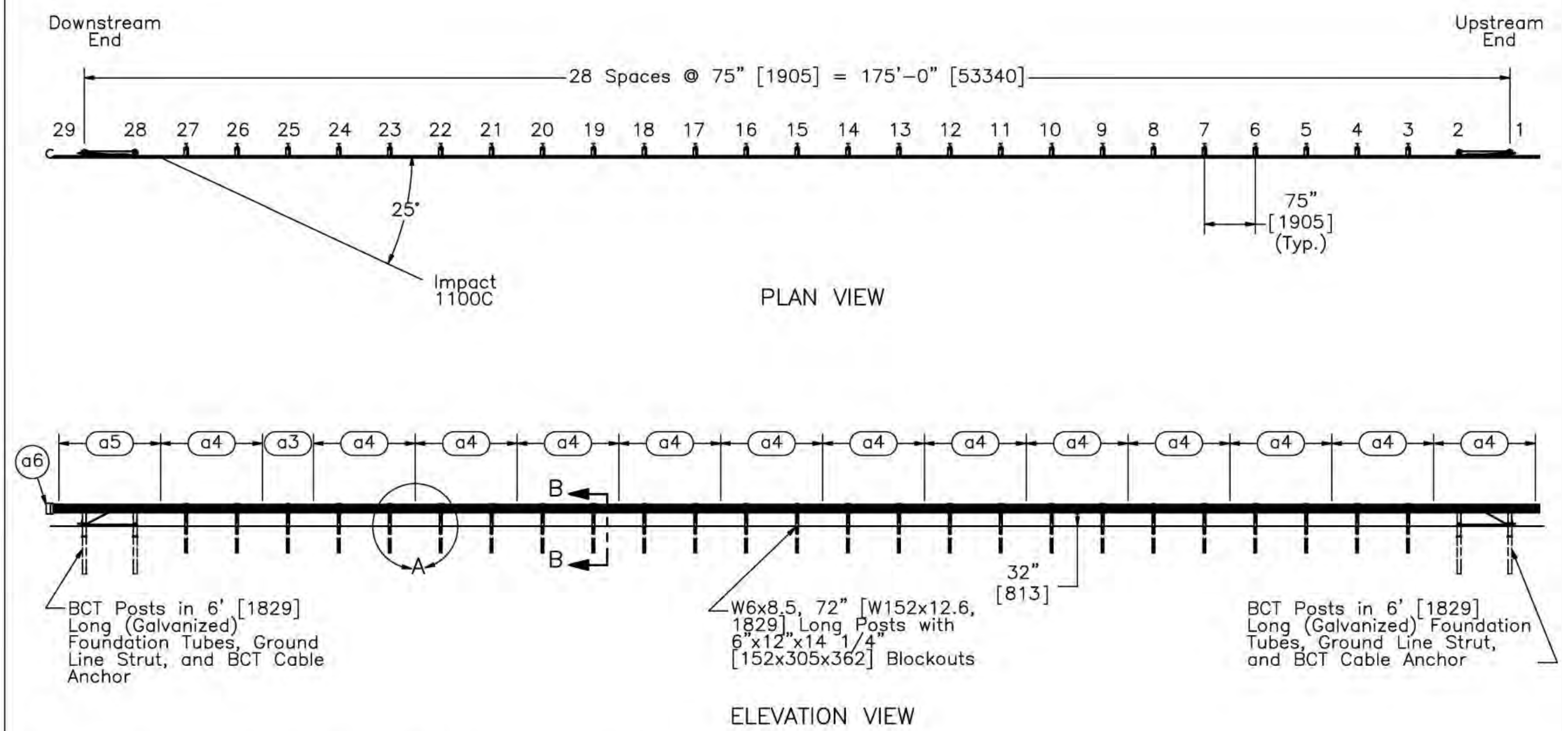
TEST INERTIAL WEIGHT (lb)
(from scales)

	Left	Right
Front	787	771
Rear	454	437

FRONT	1558 lb
REAR	891 lb
TOTAL	2449 lb

Figure D-2. Vehicle Mass Distribution, Test No. WIDA-2

Appendix E. System Details, Test No. WIDA-2



Notes: (1) Impact location for the 1100C is the midspan of post nos. 27 and 28.

(2) The BCT anchor posts are placed in ⌀3' [914] holes.

(3) Critical region located between post nos. 21 and 29.

(4) A high-speed digital video camera shall be placed perpendicular to downstream anchor.

(5) Vehicle is expected to gate through.

(6) Avoid activating vehicle brakes in the first 100' [30480] downstream of post no. 29.

(7) Allow for a minimum lateral clearance of 30' [9144] behind the system in the first 75' [22860] downstream of post no. 29.

(8) Paint the downstream bearing plate and BCT cable two different colors.

(9) Put marks on foundation tube bolts.

Midwest Roadside Safety Facility	Wisconsin DOT Project MGS with Standard Downstream Anchorage System System Layout	SHEET: 1 of 11 DATE: 5/25/2012 DRAWN BY: CWP
	DWG. NAME. DS-Anchorage-32in_R3	SCALE: 1:225 UNITS: in.[mm]
		REV. BY: KAL/RKF

Figure E-1. Test Installation Layout, Test No. WIDA-2

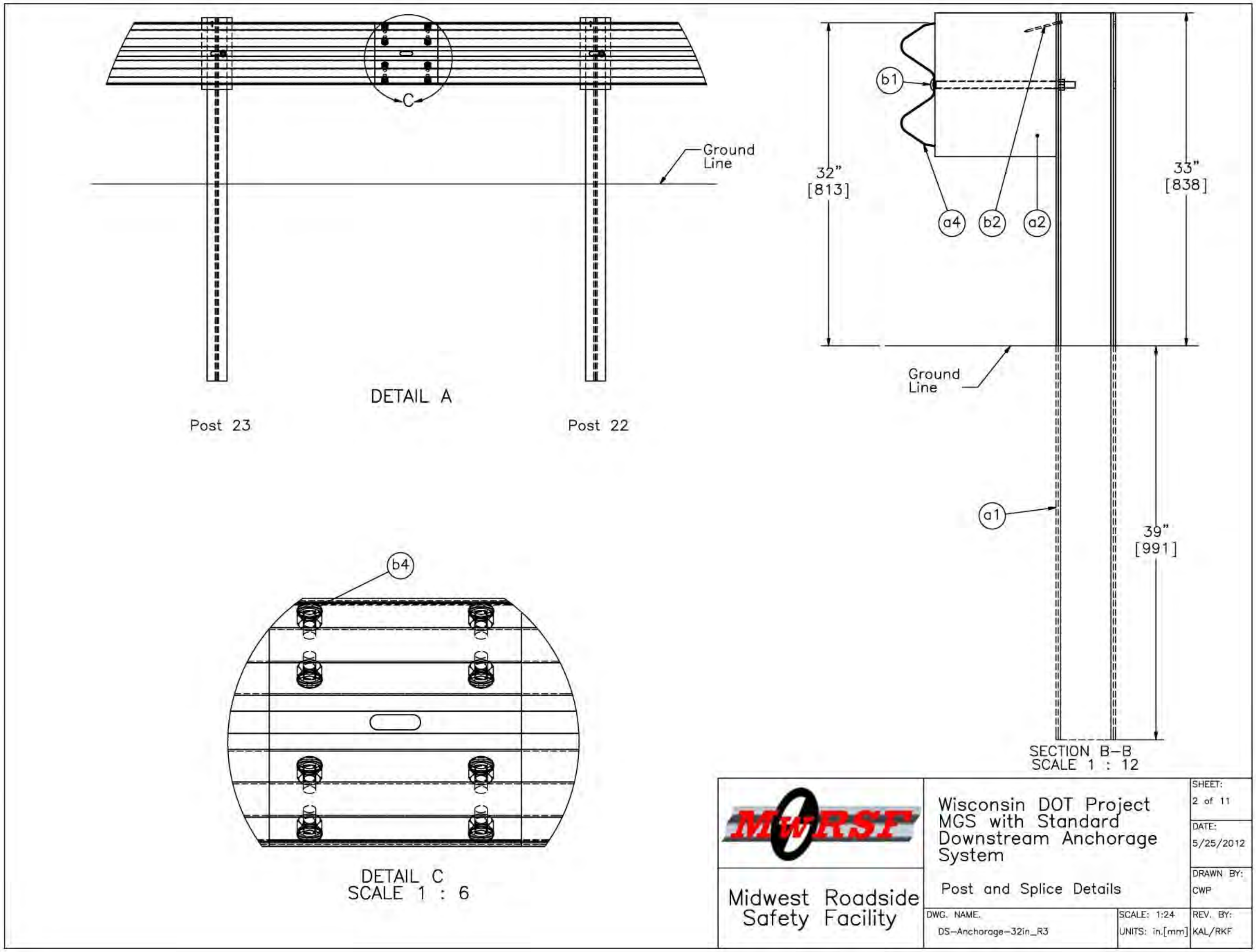


Figure E-2. Post and Splice Details, Test No. WIDA-2

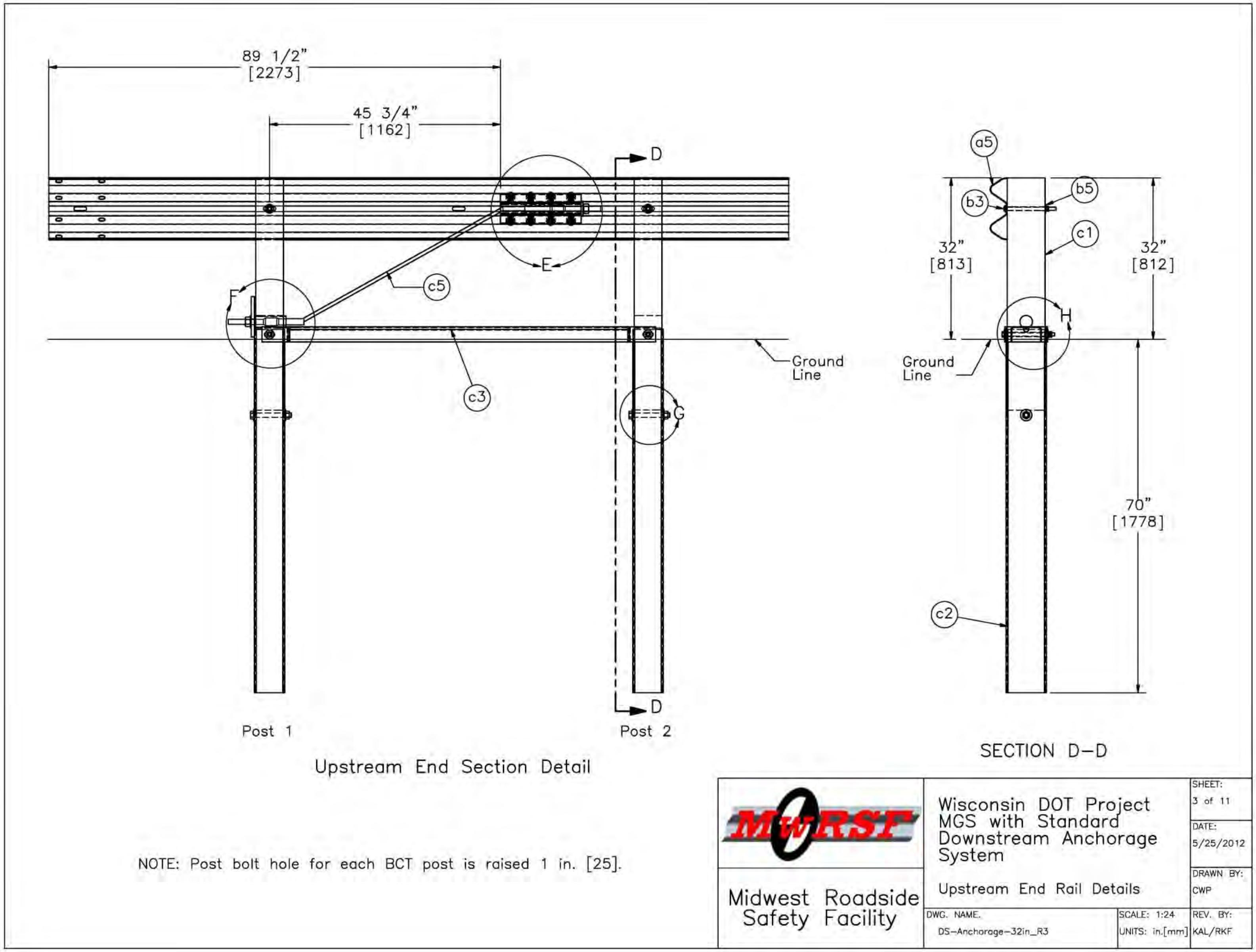


Figure E-3. Upstream End Anchor Details, Test No. WIDA-2

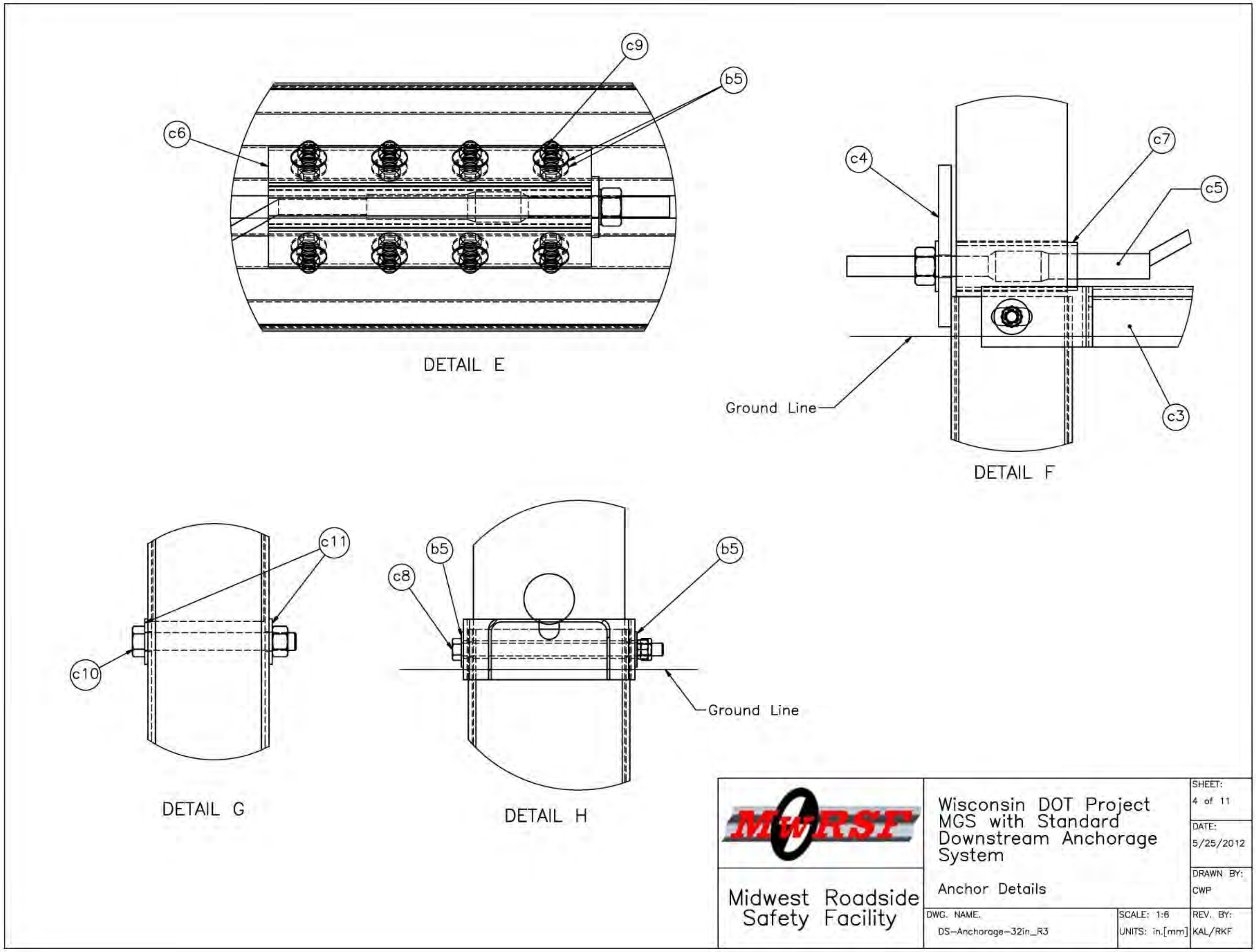


Figure E-4. Anchor Details, Test No. WIDA-2

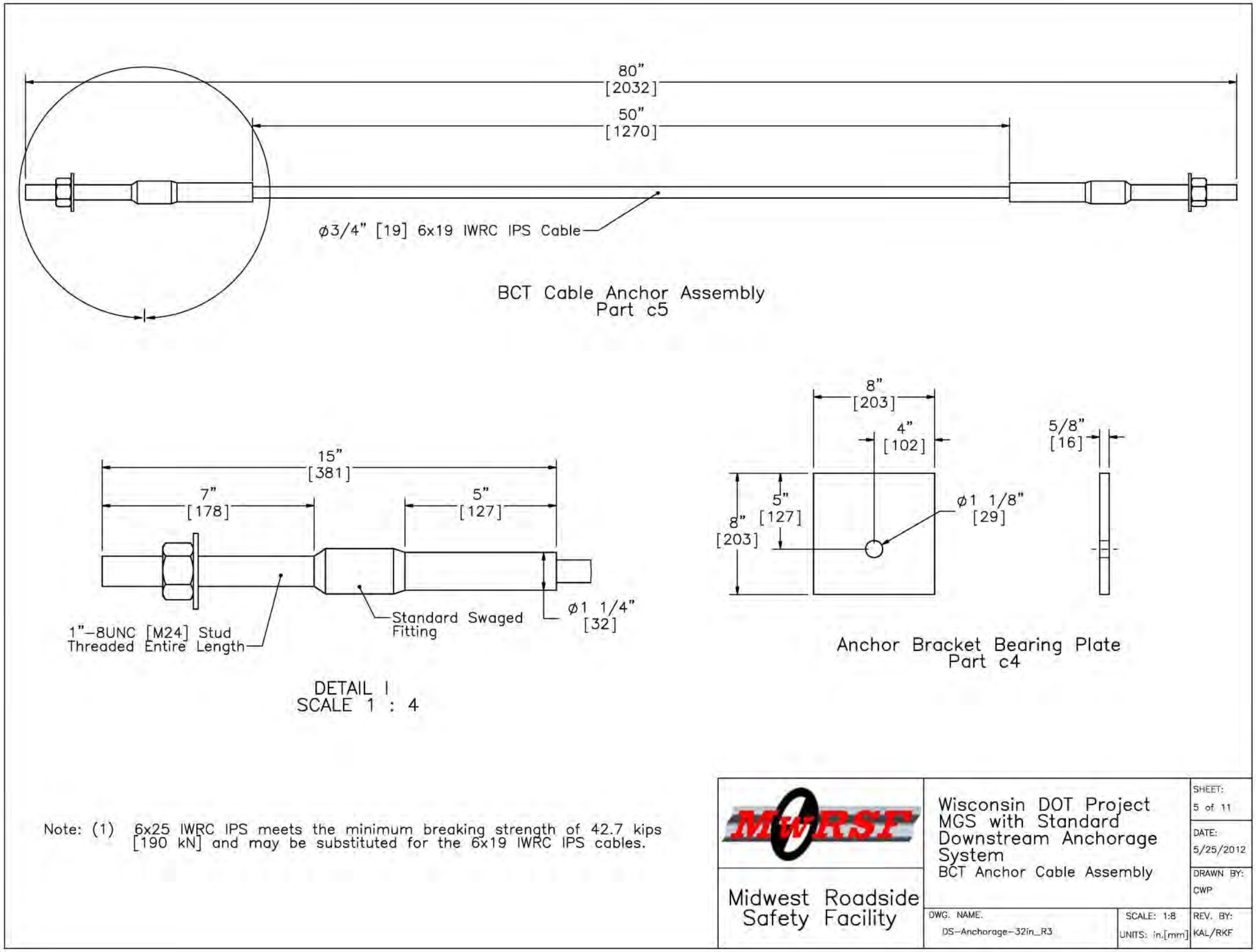
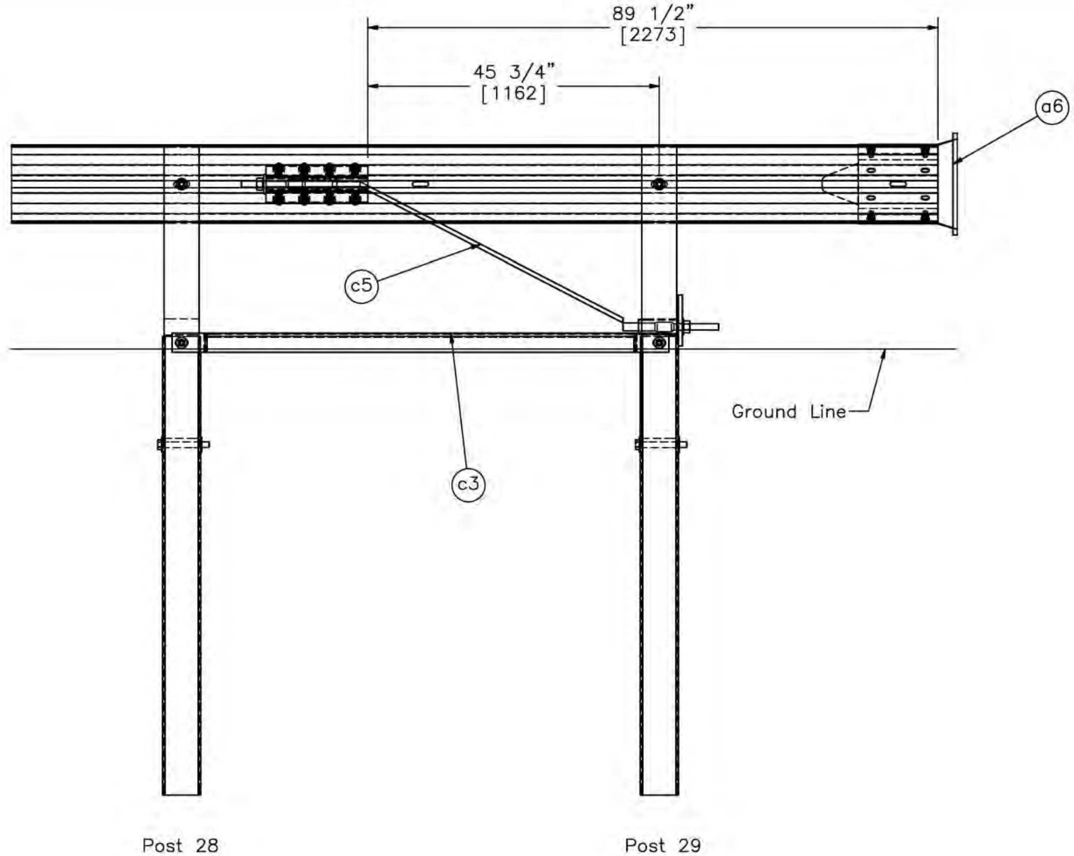


Figure E-5. BCT Anchor Cable Details, Test No. WIDA-2



Downstream End Section Detail

NOTE: Post bolt hole for each BCT post is raised 1 in. [25].

MwRSF

Midwest Roadside Safety Facility

Wisconsin DOT Project
MGS with Standard Downstream Anchorage System

Downstream End Rail Details

SHEET:	6 of 11
DATE:	5/25/2012
DRAWN BY:	CWP
DWG. NAME.	DS-Anchorage-32in_R3
SCALE:	1:24
UNITS:	in.[mm]
REV. BY:	KAL/RKF

Figure E-6. Downstream End Anchor Details, Test No. WIDA-2

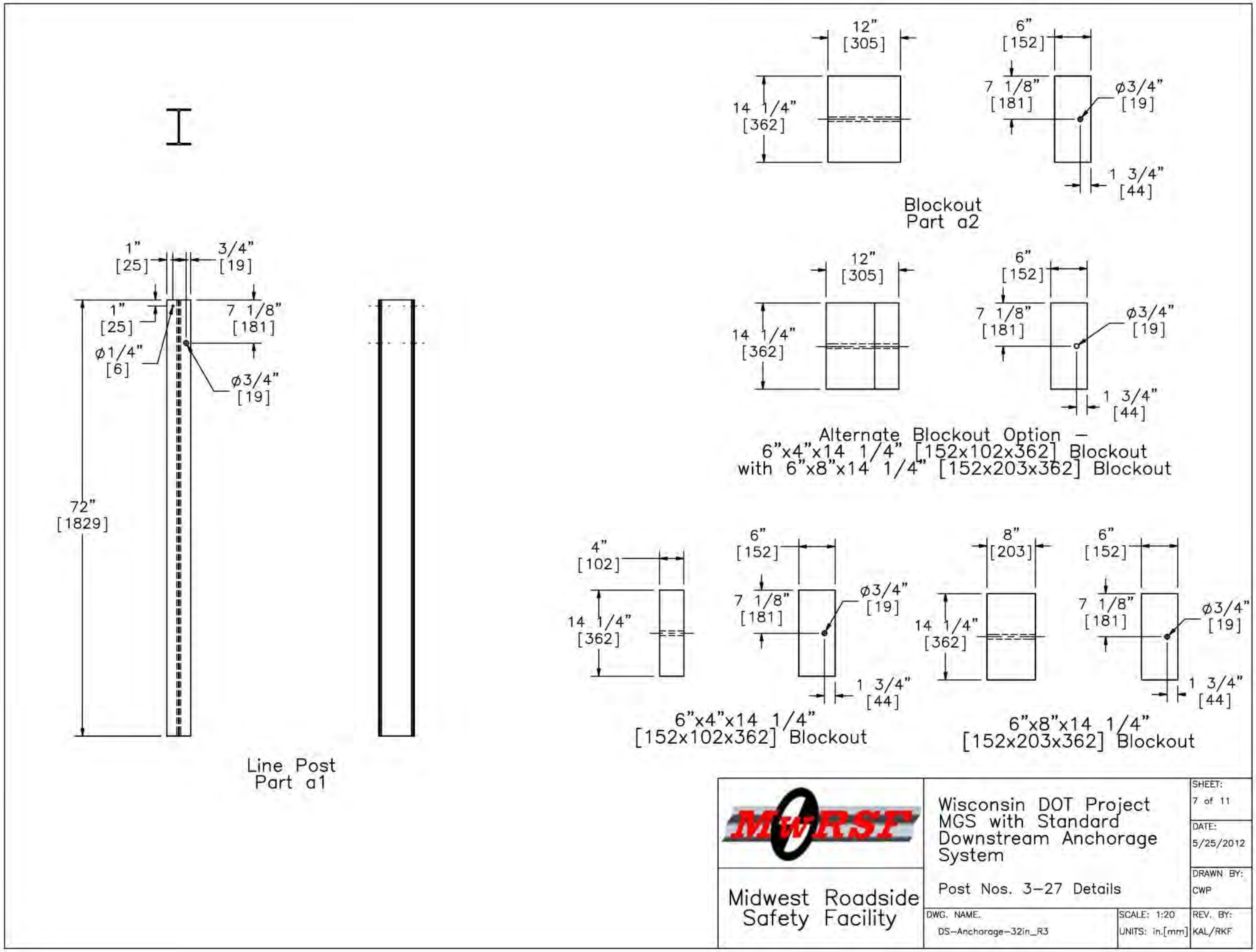


Figure E-7. Line Post Details, Test No. WIDA-2

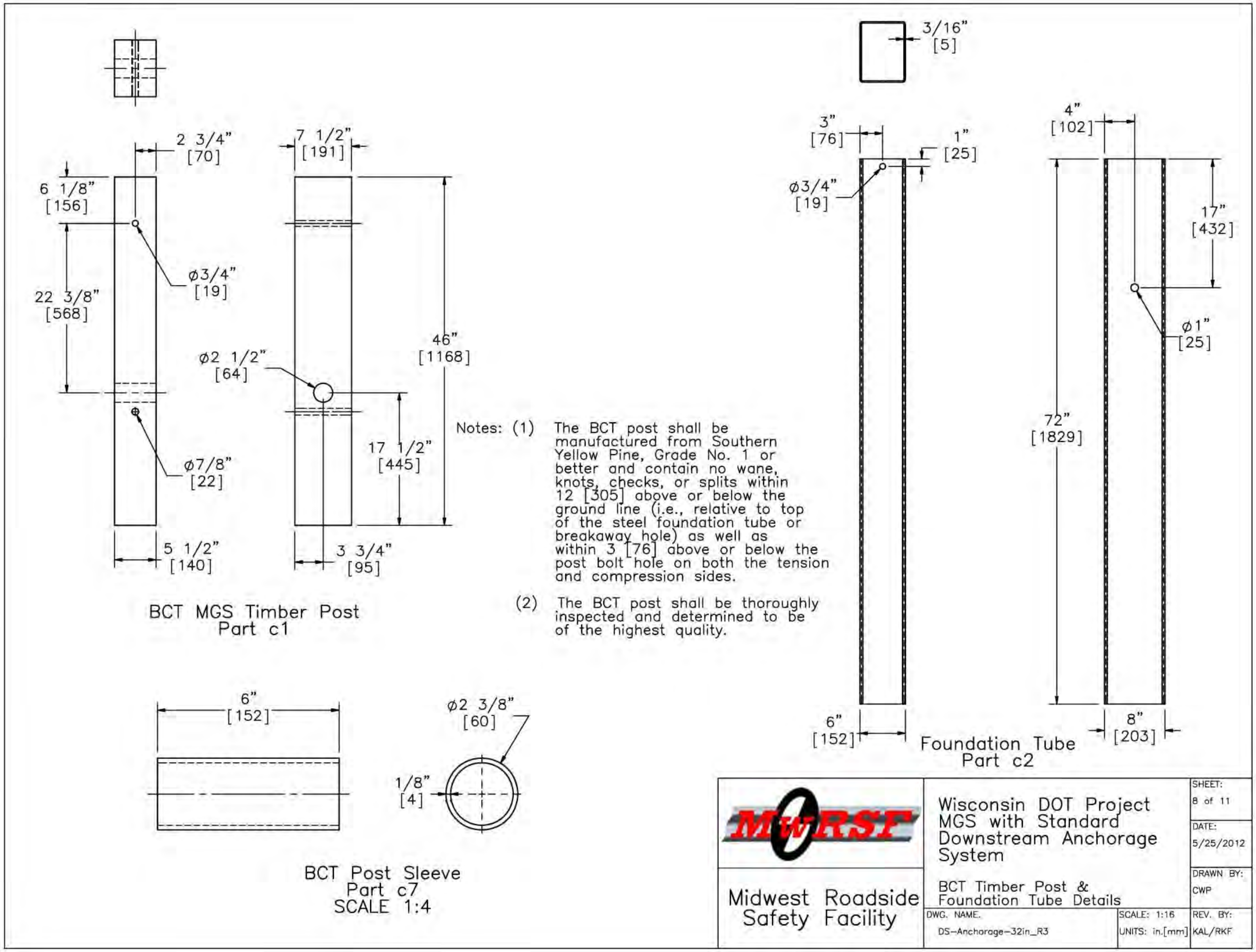


Figure E-8. BCT Timber Post and Foudation Details, Test No. WIDA-2

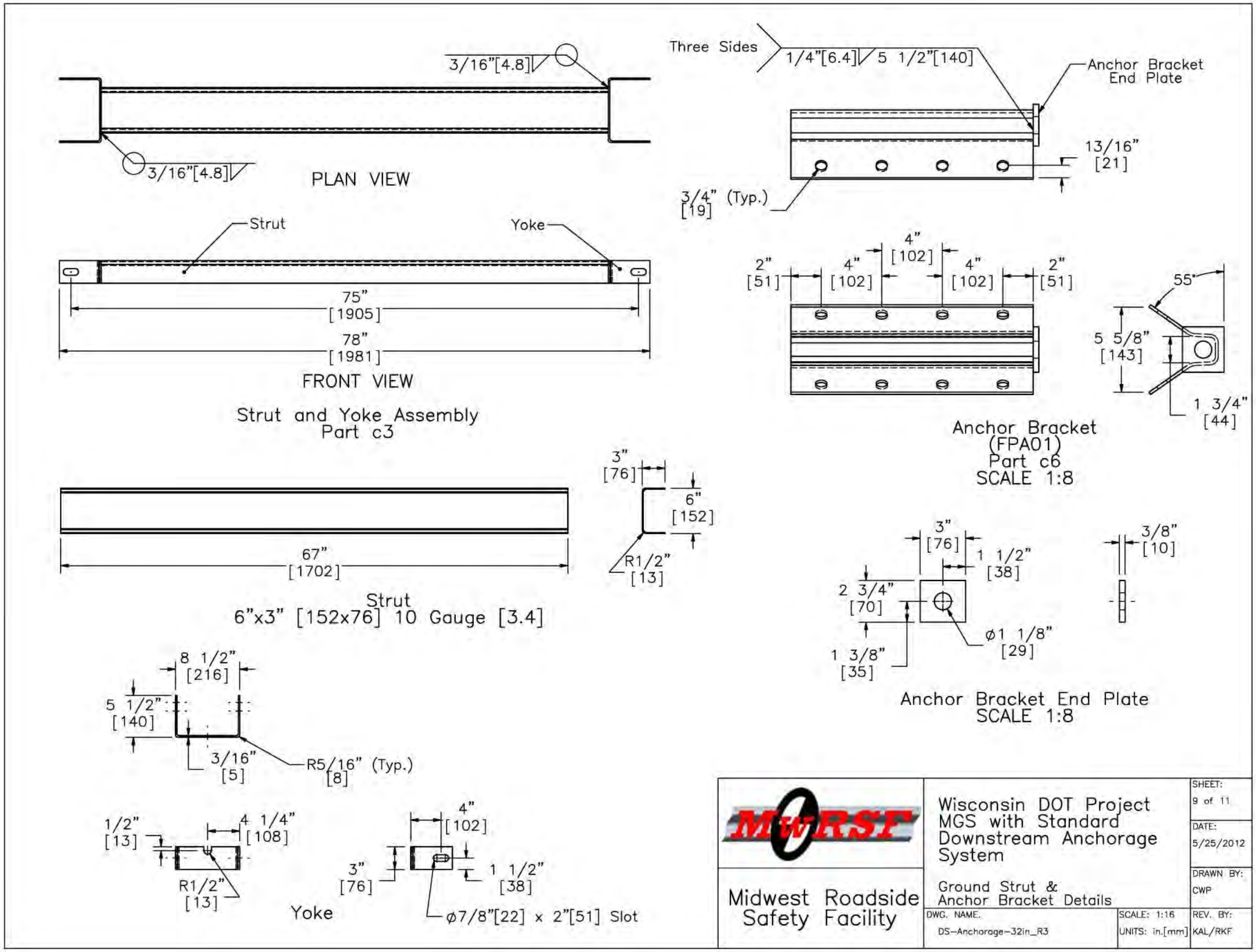


Figure E-9. Ground Strut and Anchor Bracket Details, Test No. WIDA-2

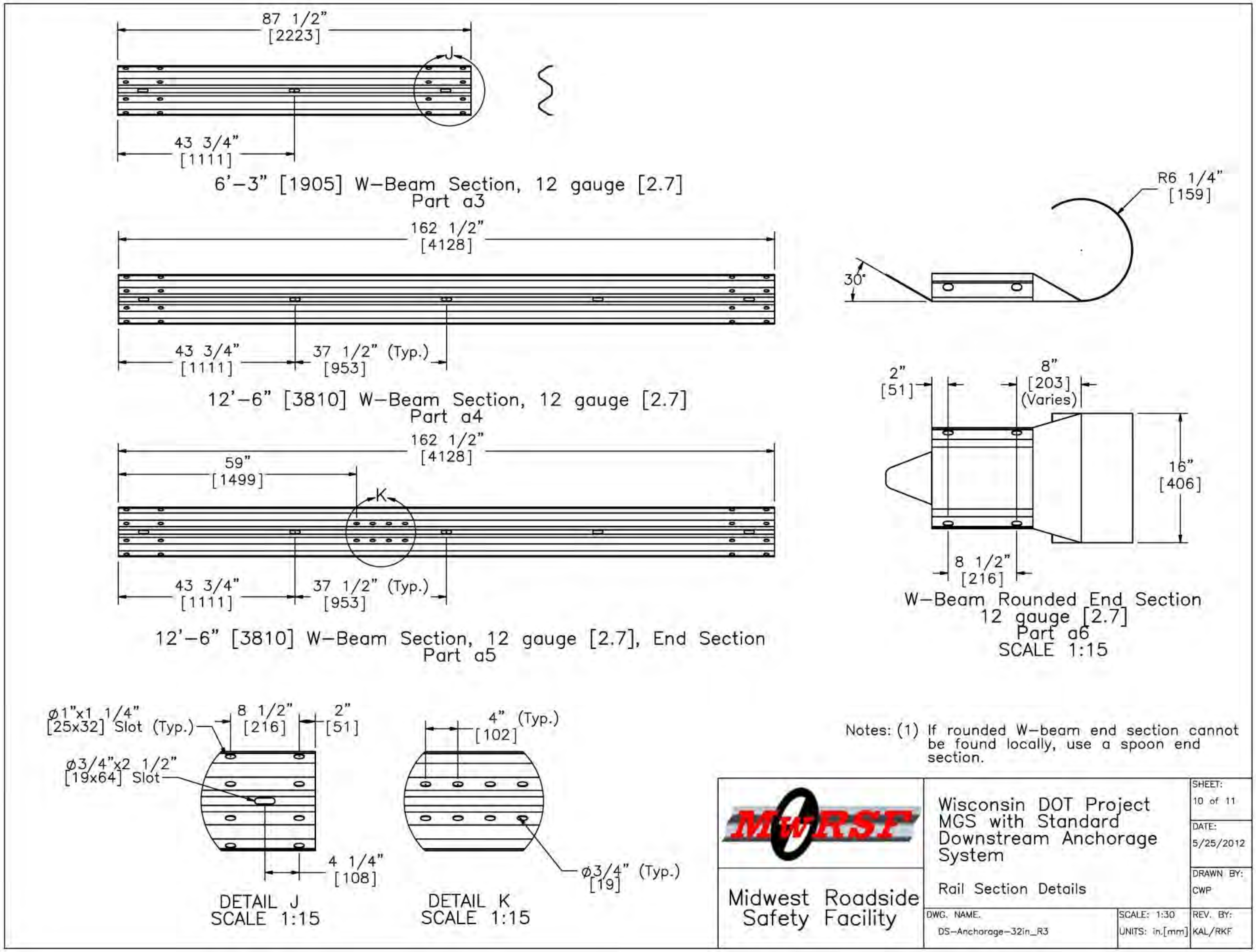


Figure E-10. W-Beam Guardrail Details, Test No. WIDA-2

ItemNo.	QTY.	Description	Material Specification	Hardware Guide
a1	25	W6x8.5 6' Long [W152x12.6 1829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa] (W6x9 ASTM A36 Min. 36 ksi [248 MPa])	PWE06
a2	25	6x12x14 1/4" [152x305x362] Blockout	SYP Grade No. 1 or better	PDB10a-b
a3	1	6'-3" [1905] W-Beam MGS Section	12 gauge [2.7] AASHTO M180	RWM01a
a4	12	12'-6" [3810] W-Beam MGS Section	12 gauge [2.7] AASHTO M180	RWM04a
a5	2	12'-6" [3810] W-Beam MGS End Section	12 gauge [2.7] AASHTO M180	RWM14a
a6	1	W-Beam Rounded End Section	12 gauge [2.7] AASHTO M180	RWE03a
b1	25	5/8" Dia. x 14" Long [M16x356] Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM A563A	FBB06
b2	25	16D Double Head Nail	–	–
b3	4	5/8" Dia. x 10" [M16x254] Long Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM A563A	FBB03
b4	116	5/8" Dia. x 1 1/2" Long [M16x38] Guardrail Bolt and Nut	Bolt ASTM A307, Nut ASTM A563A	FBB01
b5	46	5/8" [16] Dia. Flat Washer	ASTM F844 or Grade 2 Steel	FWC16a
c1	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (high quality)	PDF01
c2	4	72" [1829] Long Foundation Tube	ASTM A53 Grade B	PTE06
c3	2	Strut and Yoke Assembly	ASTM A36 Steel Galvanized	–
c4	2	8x8x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel	FPB01
c5	2	BCT Anchor Cable Assembly	ø3/4" [19] 6x19 IWRC IPS Galvanized Wire Rope	FCA01
c6	2	Anchor Bracket Assembly	ASTM A36 Steel	FPA01
c7	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40	FMM02
c8	4	5/8" Dia. x 10" [M16x254] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM A563A	FBX16a
c9	16	5/8" Dia. x 1 1/2" Long [M16x38] Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM A563A	FBX16a
c10	4	7/8" Dia. x 7 1/2" [M22x191] Long Hex Head Bolt and Nut	Bolt ASTM A307, Nut ASTM A563A	FBX22a
c11	8	7/8" [22] Dia. Flat Washer	SAE Grade 2	FWC22a

Midwest Roadside Safety Facility

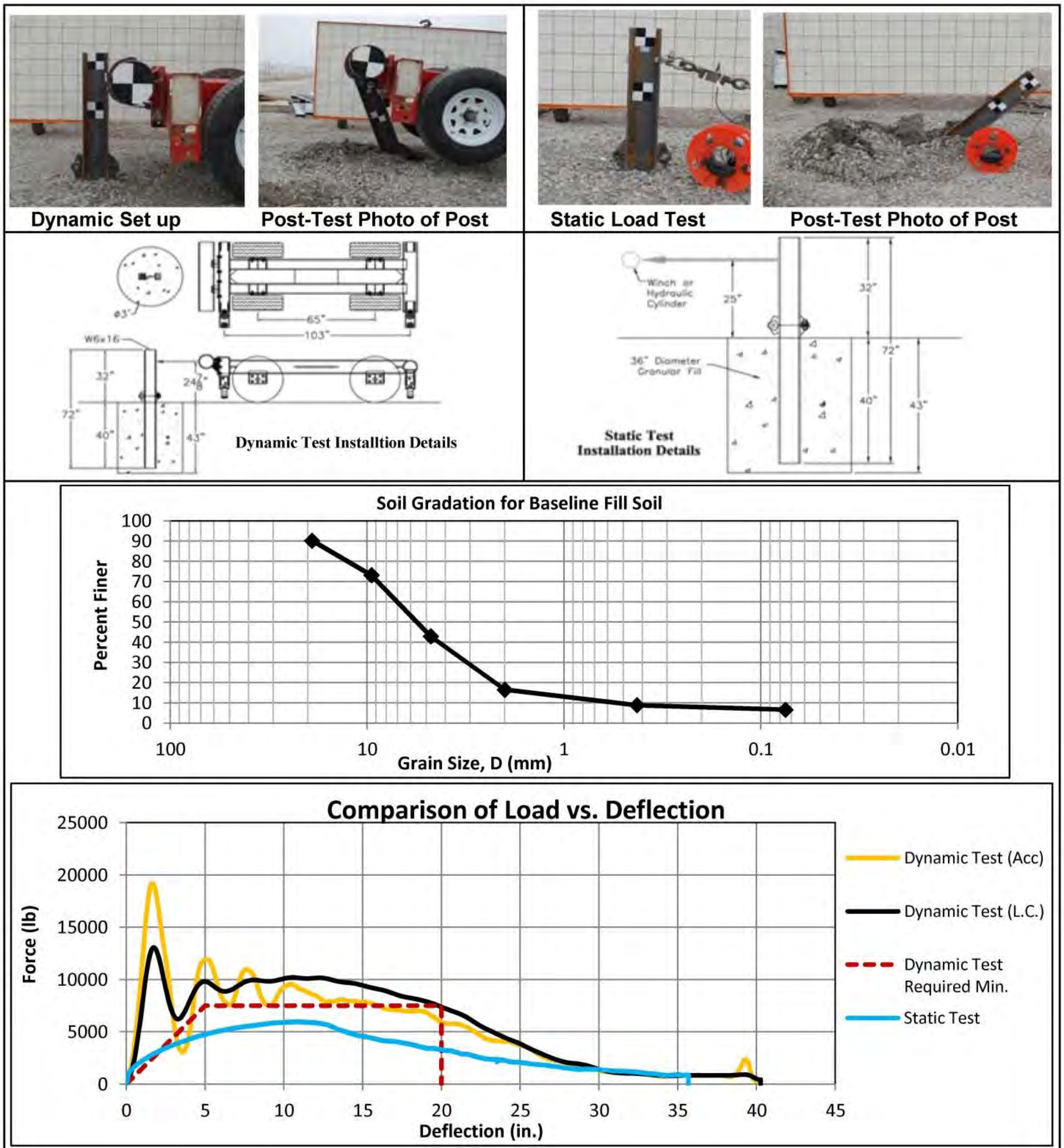
Wisconsin DOT Project MGS with Standard Downstream Anchorage System

Bill of Materials

SHEET: 11 of 11
DATE: 5/25/2012
DRAWN BY: CWP
DWG. NAME. DS-Anchorage-32in_R3
SCALE: NONE UNITS: in.[mm]
REV. BY: KAL/RKF

Figure E-11. Bill of Materials, Test No. WIDA-2

Appendix F. Soil Tests

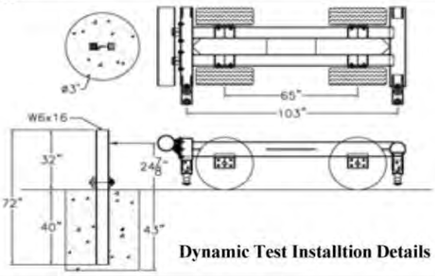


Date	3/20/2012
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well Graded Gravel (GW)
Fill material description (ASTM D2487)	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	8" lift 3-4 passes
Bogie Weight	1,843 lb
Impact Velocity	20.02 mph

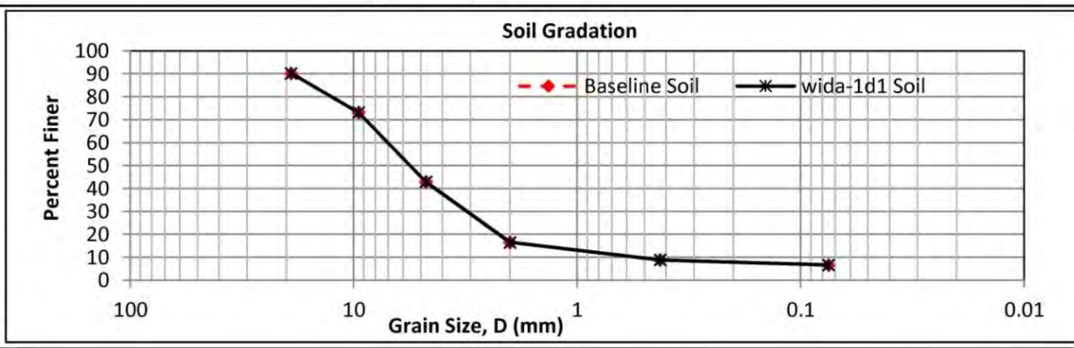
Figure F-1. Summary Sheet for Strong Soil Test Results, Test No. DSAP-2

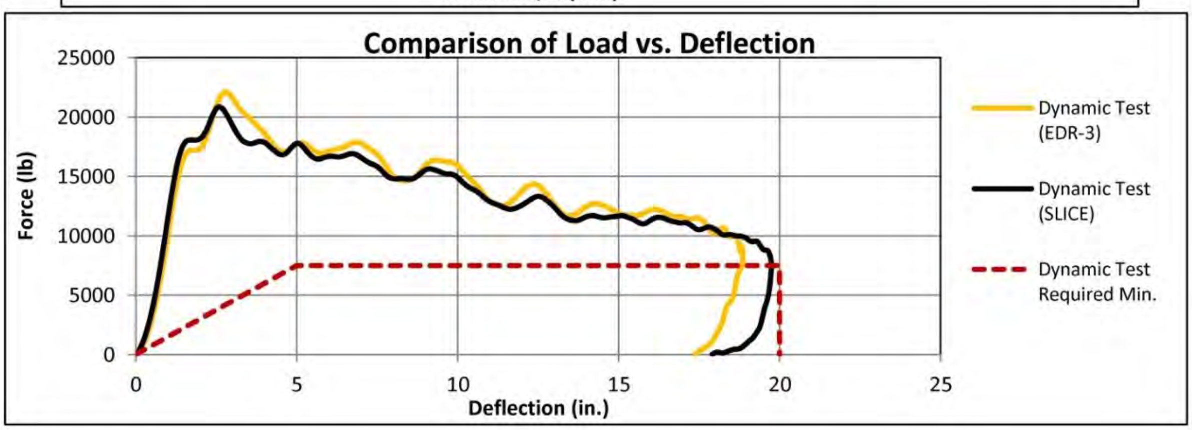
Dynamic Set up

Post-Test Photo of Post



Dynamic Test Installtion Details



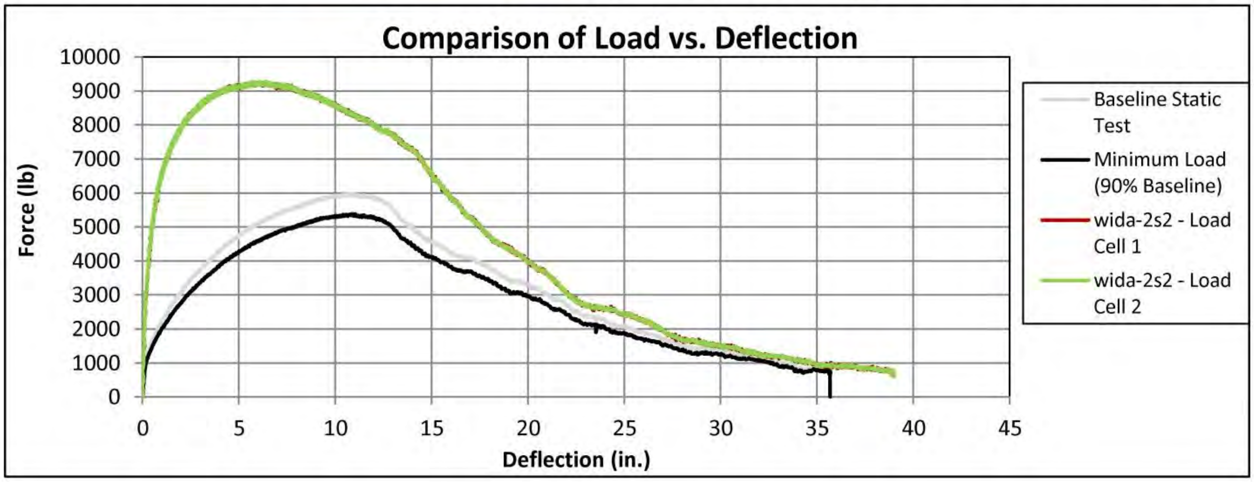


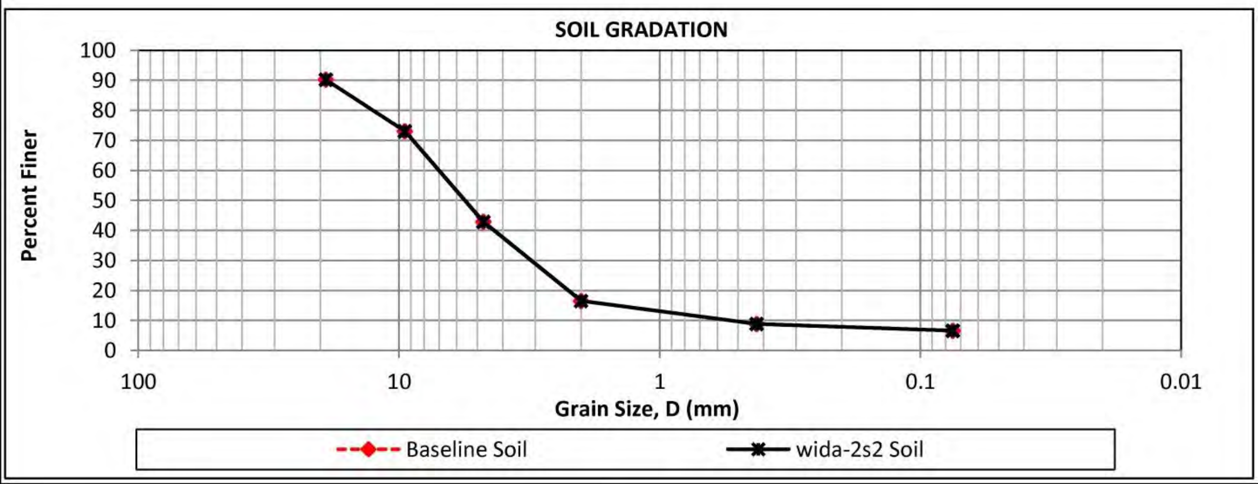
Date..	5/17/2012
Test Facility & Site Location......................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)..........	Well Graded Gravel (GW)
Fill material description (ASTM D2487)........	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure.......	8-inch lifts tamped with a pneumatic compactor
Bogie Weight..	1,744.6 lb
Impact Velocity.......................................	19.6 mph

NOTE: Although the end of the force-deflection curve dropped below the mnimum load defined in MASH for a dynamic soil test, the soil resistance was still deemed satisfactory. In fact, for the first 10 in. (254 mm) of deflection, the soil was clearly capable of sustaining a force double the minimum required. Between 10 and 18 in. (254 and 457 mm), the soil still sustained a force above 10 kip (44 kN), which is 25 percent greater than the minimum required. By this time, there was no more energy to be dissipated, thus the sharp drop-off in force.

Figure F-2. Test Day Dynamic Soil Strength, Test No. WIDA-1

Static Load Test Setup	Post-Test Photo of Post
	





Date………	6/5/2012
Test Facility & Site Location………	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)………	Well Graded Gravel (GW)
Fill material description (ASTM D2487)………	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure………	8-inch lifts tamped with a pneumatic compactor

Figure F-3. Test Day Static Soil Strength, Test No. WIDA-2

Appendix G. Permanent Splice Displacements

Table G-1. Permanent Separation of Splice Connections and Bolt Slippage, Test No. WIDA-1

Splice Movement (in.)	Splice Location																											
	Post Nos. 2&3		Post Nos. 4&5		Post Nos. 6&7		Post Nos. 8&9		Post Nos. 10&11		Post Nos.12 &13		Post Nos. 14&15		Post Nos. 16&17		Post Nos. 18&19		Post Nos. 20&21		Post Nos. 22&23		Post Nos. 24&25		Post Nos. 25&26		Post Nos. 27&28	
	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back
Rail	⅜	⅜	⅜	⅜	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅜	⅜	¼	¼	⅜	⅜	0	0
Bolt No. 1	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0
Bolt No. 2	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0
Bolt No. 3	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0
Bolt No. 4	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0
Bolt No. 5	⅛	⅛	⅛	⅛	⅛	⅛	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0
Bolt No. 6	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0
Bolt No. 7	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0
Bolt No. 8	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0	⅛	⅛	⅛	⅛	⅛	⅛	⅛	⅛	0	0

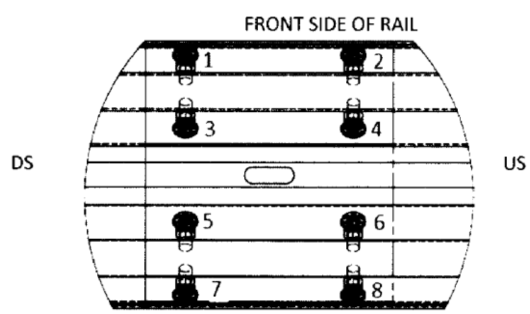
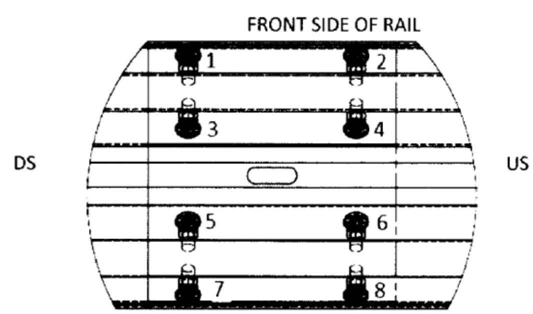


Table G-2. Permanent Separation of Splice Connections and Bolt Slippage, Test No. WIDA-2

Splice Movement (in.)	Splice Location									
	Post Nos. 20&21		Post Nos. 22&23		Post Nos. 24&25		Post Nos. 25&26		Post Nos. 27&28	
	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back
Rail	½	½	⅜	⅜	⅛	⅛	¼	¼	¼	¼
Bolt No. 1	¼	0	⅛	⅛	0	0	⅛	1/16	⅛	⅛
Bolt No. 2	¼	⅛	¼	¼	0	0	⅛	0	⅛	⅛
Bolt No. 3	¼	¼	¼	¼	⅛	0	⅛	⅛	⅛	⅛
Bolt No. 4	¼	¼	⅛	¼	⅛	0	⅛	0	⅛	⅛
Bolt No. 5	⅜	⅛	¼	⅛	⅛	0	⅛	1/16	0	0
Bolt No. 6	⅛	¼	¼	⅛	1/16	0	¼	0	1/16	0
Bolt No. 7	⅛	¼	⅛	¼	⅛	⅛	0	⅛	⅛	0
Bolt No. 8	¼	¼	⅜	⅛	0	0	⅛	⅛	⅛	0



Appendix H. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: WIDA-1
VEHICLE: 2270P

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

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

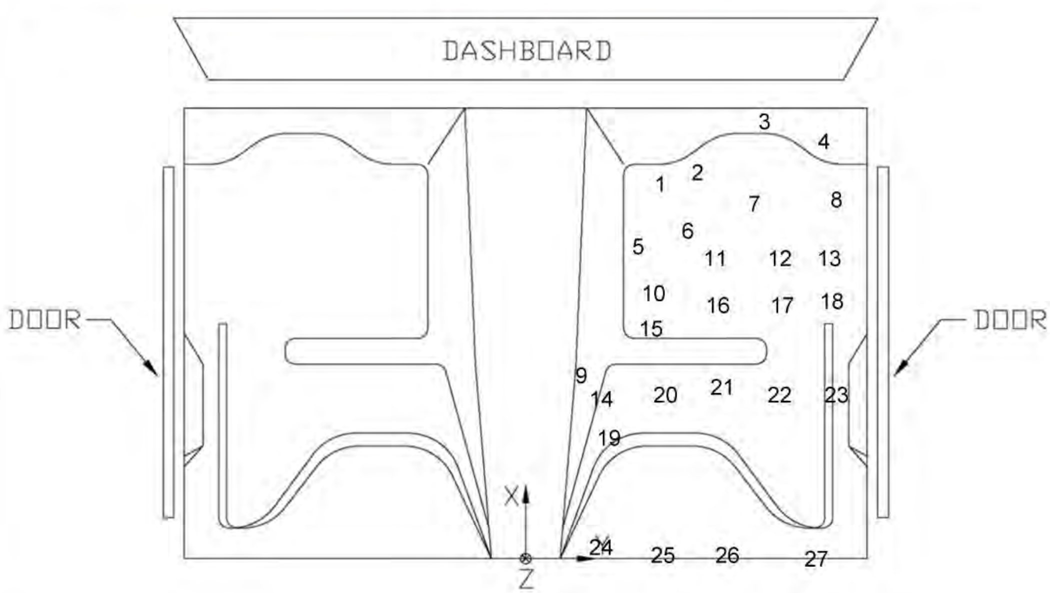


Figure H-1. Floor Pan Deformation Data – Set 1, Test No. WIDA-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: WIDA-1
VEHICLE: 2270P

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

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	40 1/2	18 1/2	0	40 3/4	19	0	1/4	1/2	0
2	41 1/2	22 1/4	-2 1/4	41 1/2	22 3/4	-2 1/4	0	1/2	0
3	44 3/4	28 3/4	-4 3/4	44 3/4	29	-4 3/4	0	1/4	0
4	43 3/4	34 1/2	-3 1/2	43 1/2	34 3/4	-3 1/2	- 1/4	1/4	0
5	37	16 1/4	-1	37	17	-1	0	3/4	0
6	38 1/4	21 1/2	-4	38	21 1/4	-4	- 1/4	- 1/4	0
7	40	28	-7 1/4	39 3/4	27 3/4	-7	- 1/4	- 1/4	1/4
8	40	36 1/4	-7 1/4	40	36 1/2	-7 1/4	0	1/4	0
9	29	10 1/2	-1 3/4	29	10 3/4	-2	0	1/4	- 1/4
10	34	18	-4	34	18	-4	0	0	0
11	36 1/4	23 1/4	-8 3/4	36 1/4	23 3/4	-8 3/4	0	1/2	0
12	36 1/4	30	-9	36 1/4	30 1/2	-9	0	1/2	0
13	36 1/2	35 1/4	-9	36 1/4	35 1/4	-9	- 1/4	0	0
14	27 1/4	12 3/4	-2 1/4	27 1/4	13	-2 1/4	0	1/4	0
15	32	17 1/2	-6 1/4	32	17 1/4	-6 1/4	0	- 1/4	0
16	33 1/4	24 1/2	-8 3/4	33 1/4	24 1/4	-9	0	- 1/4	- 1/4
17	33 1/4	30 3/4	-9	33 1/4	30 3/4	-9	0	0	0
18	33 1/2	35 3/4	-9	33 1/4	35 1/2	-9	- 1/4	- 1/4	0
19	24 3/4	13 1/2	-2 1/2	24 3/4	13 3/4	-2 1/2	0	1/4	0
20	27 1/2	19 1/4	-8 3/4	27 1/2	19 1/4	-8 3/4	0	0	0
21	28	25	-8 3/4	28	25	-8 3/4	0	0	0
22	27 1/2	30 1/2	-8 3/4	27 1/2	30 3/4	-8 3/4	0	1/4	0
23	27 1/2	36 1/4	-9	27 1/2	36 1/4	-9	0	0	0
24	17 3/4	13	-2 1/4	18	13 1/4	-2 1/4	1/4	1/4	0
25	17 1/4	19	-5	17 1/4	19 1/4	-4 3/4	0	1/4	1/4
26	17 1/4	25 1/4	-5	17 1/4	25 1/4	-5	0	0	0
27	17	34 1/4	-5	17	34 1/4	-5	0	0	0
28							0	0	0
29							0	0	0
30							0	0	0
31							0	0	0

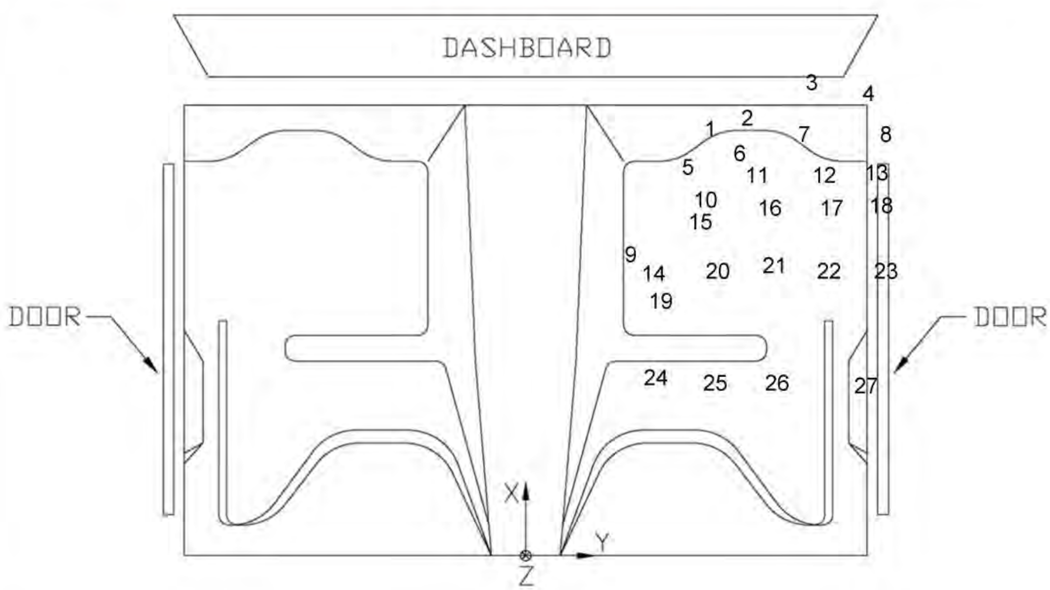


Figure H-2. Floor Pan Deformation Data – Set 2, Test No. WIDA-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: WIDA-1
VEHICLE: 2270P

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

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	39 3/4	40 1/2	23 1/2	40	40 1/2	23 1/4	1/4	0	- 1/4
	A2	39 1/2	47	23	39 1/2	47	23	0	0	0
	A3	39 1/4	55 1/2	22	39 1/2	55 1/2	22	1/4	0	0
	A4	32 1/2	43 1/2	15	32 1/2	43 1/2	14 3/4	0	0	- 1/4
	A5	32 3/4	50 1/2	15	32 1/2	50 1/2	14 3/4	- 1/4	0	- 1/4
	A6	33	58 1/2	14 3/4	32 3/4	58 1/2	14 1/2	- 1/4	0	- 1/4
SIDE PANEL	B1	21 3/4	27 1/4	- 1/4	21 1/2	27 1/4	- 1/2	- 1/4	0	- 1/4
	B2	21	27 1/2	-4 1/4	21	27 1/2	-4 1/4	0	0	0
	B3	25	28	-2 1/2	25	28	-2 1/2	0	0	0
IMPACT SIDE DOOR	C1	26 3/4	40 3/4	17	26 3/4	41	17	0	1/4	0
	C2	20	40 1/4	17	19 3/4	40	17	- 1/4	- 1/4	0
	C3	8 1/4	40 1/4	17 1/2	8	40 1/4	17 1/4	- 1/4	-0	- 1/4
	C4	24 1/4	35 3/4	2 1/2	24	36	2 1/2	- 1/4	1/4	0
	C5	18 1/4	35	3 1/4	18	35	3 1/4	- 1/4	0	0
	C6	7	34 3/4	3	6 3/4	34 3/4	3	- 1/4	0	0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

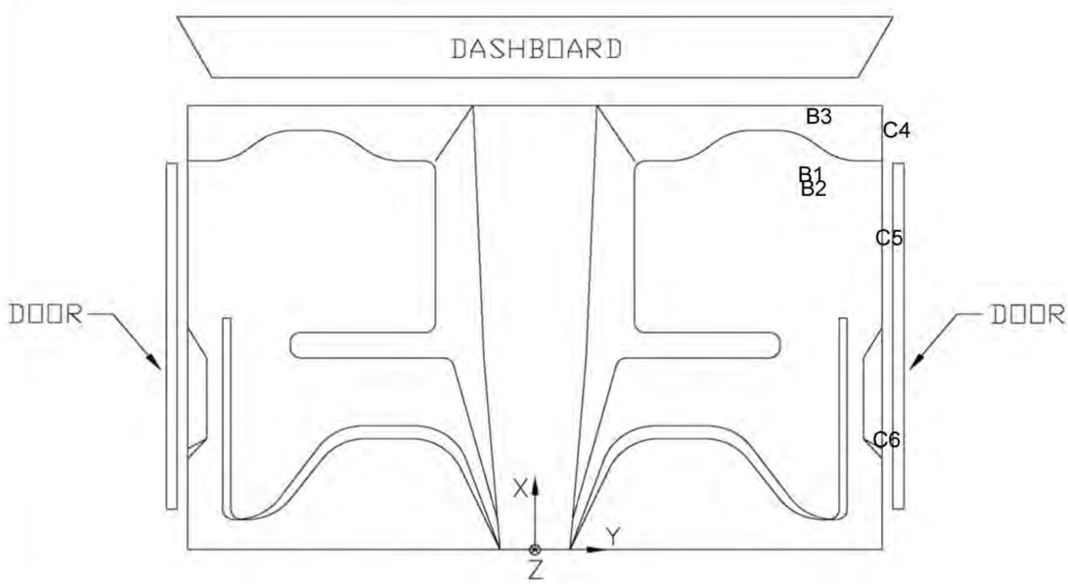


Figure H-3. Occupant Compartment Deformation Data – Set 1, Test No. WIDA-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: WIDA-1
VEHICLE: 2270P

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

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	52 1/2	40 3/4	23	53	40 3/4	23 1/4	1/2	0	1/4
	A2	52 1/2	47 1/4	22 3/4	52 3/4	47	22 3/4	1/4	- 1/4	0
	A3	55 1/4	55 3/4	22	55 1/4	55 1/2	22	0	- 1/4	0
	A4	47	44 1/4	14 3/4	46 3/4	44 1/4	14 1/2	- 1/4	0	- 1/4
	A5	47	51	14 3/4	47	51	14 3/4	0	0	0
	A6	50 1/4	59	14 1/2	50 1/2	58 1/2	14 1/2	1/4	- 1/2	0
SIDE PANEL	B1	37 1/4	30	- 1/2	37	30	- 1/2	- 1/4	0	0
	B2	37	30	-4 1/4	36 3/4	30	-4 1/2	- 1/4	0	- 1/4
	B3	41	30 1/4	-2 1/2	40 3/4	30 1/4	-2 1/2	- 1/4	0	0
IMPACT SIDE DOOR	C1	30 1/4	45 1/2	17	30	45 3/4	16 3/4	- 1/4	1/4	- 1/4
	C2	23 1/4	45 3/4	17	23 1/4	46	17	0	1/4	0
	C3	11 1/2	46 1/4	17 1/4	11 1/4	46 3/4	17 1/4	- 1/4	1/2	0
	C4	29 1/2	41 1/4	2 1/2	29 1/2	41 1/2	2 1/2	0	1/4	0
	C5	23 1/2	41 1/2	3	23 1/2	41 3/4	3	0	1/4	0
	C6	12	42	2 3/4	12	42 1/4	3	0	1/4	1/4
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

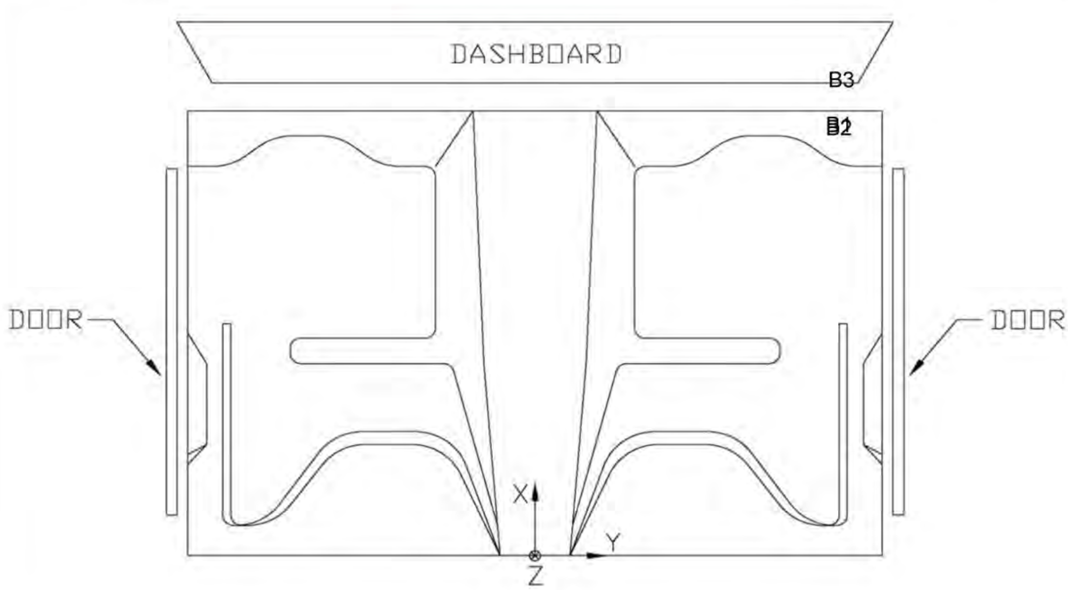
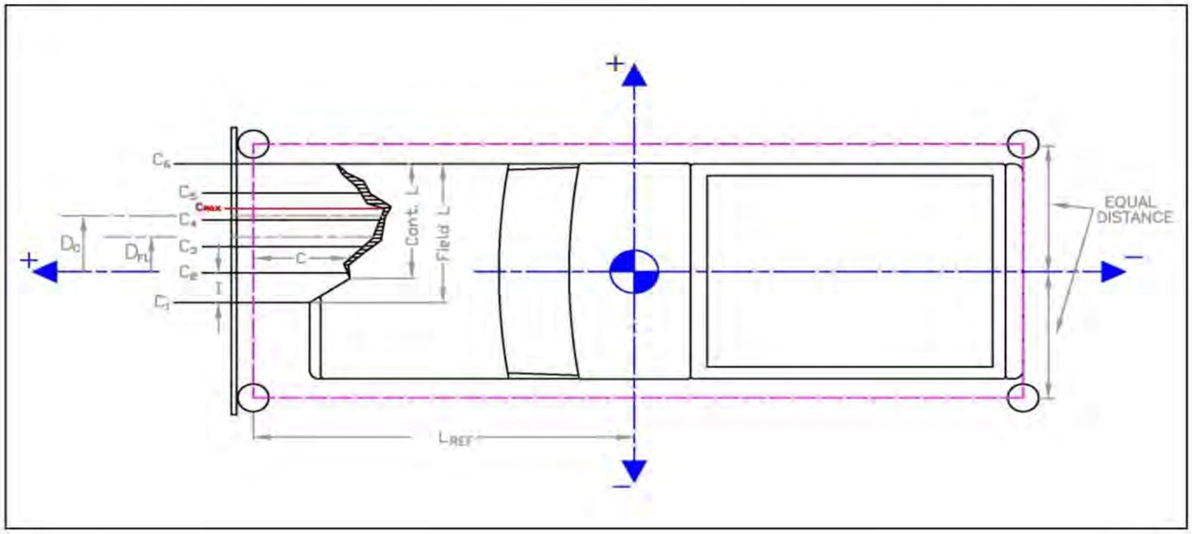


Figure H-4. Occupant Compartment Deformation Data – Set 2, Test No. WIDA-1

Date: 8/22/2012 | Test Number: WIDA-1

Make: Dodge Ram 1500 | Model: 2270P | Year: 2007



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	118 7/8	(3019)
Width of contact and induced crush - Field L:	78	(1981)
Crush measurement spacing interval (L/5) - I:	15.6	(396)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	78	(1981)
Distance from center of vehicle to center of contect damage - D_C:	0	()

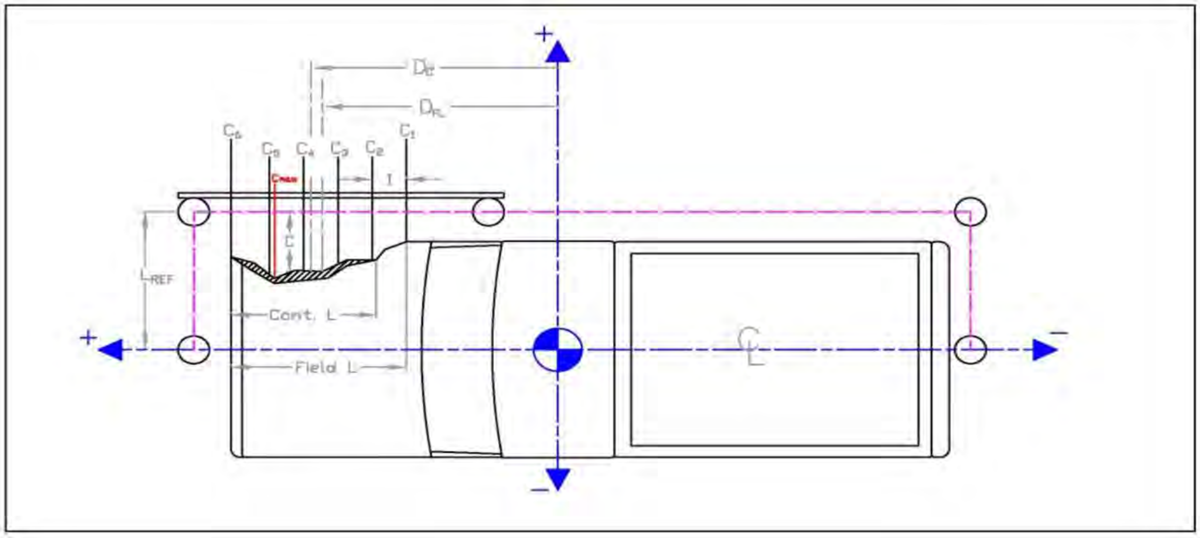
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-39	-(991)	29	(737)	4 4/5	(122)	NA	NA
C_2	19 1/4	(489)	-23 2/5	-(594)	13 1/2	(342)			1	(25)
C_3	16 1/2	(419)	-7 4/5	-(198)	10 1/2	(267)			1 1/5	(31)
C_4	15 1/4	(387)	7 4/5	(198)	10 1/2	(266)			-0	-(1)
C_5	22 1/2	(572)	23 2/5	(594)	13 2/5	(340)			4 1/3	(109)
C_6	na	NA	39	(991)	29	(737)			NA	NA
C_{MAX}	22 1/2	(572)	23 2/5	(594)	13 2/5	(340)			4 1/3	(109)

Figure H-5. Exterior Vehicle Crush (NASS) - Front, Test No. WIDA-1

Date: 8/22/2012 **Test Number:** WIDA-1

Make: Dodge Ram 1500 **Model:** 2270P **Year:** 2007



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	52	(1321)
Width of contact and induced crush - Field L:	228	(5791)
Crush measurement spacing interval (L/5) - I:	45.6	(1158)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-9.37	-(238)
Width of Contact Damage:	228	(5791)
Distance from vehicle c.g. to center of contect damage - D_C:	9 3/7	(239)

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

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-123 3/8	-(3134)	16	(406)	2	(51)	NA	NA
C_2	13	(330)	-77 7/9	-(1975)	10 1/2	(267)			1/2	(13)
C_3	13	(330)	-32 1/6	-(817)	11 5/8	(295)			- 5/8	-(16)
C_4	12 3/4	(324)	13 3/7	(341)	11 1/4	(286)			- 1/2	-(13)
C_5	14	(356)	59	(1499)	10 1/2	(267)			1 1/2	(38)
C_6	na	NA	104 5/8	(2658)	37	(940)			NA	NA
C_{MAX}	20	(508)	81	(2057)	11 1/4	(286)			6 3/4	(171)

Figure H-6. Exterior Vehicle Crush (NASS) - Side, Test No. WIDA-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: WIDA-2
VEHICLE: 1100C

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

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
F1	27	4 3/4	-2 1/4	26 3/4	4 1/2	-1 3/4	- 1/4	- 1/4	1/2
2	28	11	-1 3/4	27 3/4	10 1/4	-1	- 1/4	- 3/4	3/4
3	29	15 1/4	-1	28 3/4	15 1/4	- 1/2	- 1/4	0	1/2
4	26 1/4	19 1/2	- 1/2	25 3/4	19 3/4	- 1/4	- 1/2	1/4	1/4
5	24 1/2	4 1/2	-4	24 1/2	4	-3 1/2	0	- 1/2	1/2
6	25	9 3/4	-3 3/4	24 1/2	9 1/2	-3	- 1/2	- 1/4	3/4
7	25 1/4	13 3/4	-3	25	13 1/4	-2 1/2	- 1/4	- 1/2	1/2
8	24 3/4	19 1/4	-3 1/2	24 1/2	18 1/2	-3 1/2	- 1/4	- 3/4	0
9	20 1/4	3 1/2	-4 1/2	20 1/4	3	-4 1/2	0	- 1/2	0
10	20 3/4	8	-4 3/4	20 3/4	8	-4 1/2	0	0	1/4
11	20 1/2	12	-4 1/2	20 1/4	12	-4	- 1/4	0	1/2
12	21 3/4	20	-4 1/2	21 3/4	19 1/4	-4 1/4	0	- 3/4	1/4
13	16	4	-5 1/4	16	4	-5 1/4	0	0	0
14	16 3/4	9 3/4	-4 3/4	16 1/2	9 3/4	-4 1/2	- 1/4	0	1/4
15	17 1/4	15 3/4	-4 3/4	17	15 3/4	-4 1/2	- 1/4	0	1/4
16	18 3/4	20 3/4	-4 1/2	18 3/4	20 1/2	-4 1/2	0	- 1/4	0
17	14	4 1/4	-5 1/2	13 1/4	4	-5 1/2	- 3/4	- 1/4	0
18	14	10 1/2	-4 3/4	14	10	-4 1/2	0	- 1/2	1/4
19	15	15	-4 1/2	14 3/4	14 3/4	-4 1/2	- 1/4	- 1/4	0
20	14 3/4	21 1/2	-4 3/4	14 3/4	21	-5	0	- 1/2	- 1/4
21	8 1/2	4 3/4	-5 1/4	8 1/2	4 1/2	-5 1/4	0	- 1/4	0
22	9	10	-4 3/4	9	9 1/2	-4 1/2	0	- 1/2	1/4
23	10	16	-4 1/2	10	15 1/4	-4 1/2	0	- 3/4	0
24	9 1/4	22	-4 3/4	9 1/4	21 1/4	-4 3/4	0	- 3/4	0
25	1 1/2	5 1/4	-1 1/4	1 1/2	5 1/2	-1 1/2	0	1/4	- 1/4
26	1 1/2	10 1/4	-1 1/4	1 1/2	10 1/4	-1 1/4	0	0	0
27	1 1/2	18 1/4	-1	1 1/2	18 1/4	-1	0	0	0
28							0	0	0
29							0	0	0
30							0	0	0
31							0	0	0

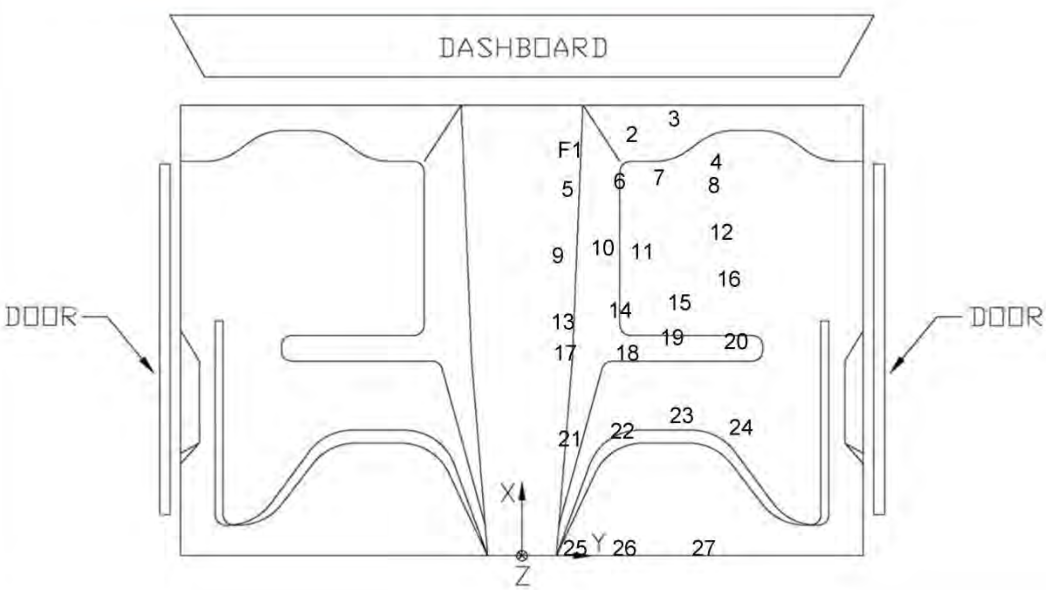


Figure H-7. Floor Pan Deformation Data – Set 1, Test No. WIDA-2

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: WIDA-2
VEHICLE: 1100C

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

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	36	10 1/4	-1 3/4	36	10	-1	0	- 1/4	3/4
2	37	16 1/2	-1 1/4	36 3/4	15 3/4	- 1/4	- 1/4	- 3/4	1
3	37 3/4	21	- 3/4	37 3/4	21	0	0	0	3/4
4	35	25 1/2	- 1/4	34 1/2	25 1/2	0	- 1/2	0	1/4
5	33 1/2	10 1/2	-3 1/2	33 1/2	10 1/4	-2 3/4	0	- 1/4	3/4
6	33 3/4	15 1/2	-3 1/4	33 1/2	15 1/4	-2 1/4	- 1/4	- 1/4	1
7	34 1/4	19 3/4	-2 1/2	34	19 1/4	-2	- 1/4	- 1/2	1/2
8	33 3/4	25	-3 1/4	33 1/2	24 1/2	-3	- 1/4	- 1/2	1/4
9	29 1/4	10 1/2	-4	29 1/4	9 3/4	-3 3/4	0	- 3/4	1/4
10	29 3/4	13 3/4	-4 1/4	29 3/4	13	-4	0	- 3/4	1/4
11	29 1/4	17 3/4	-4	29 1/4	17 1/4	-3 1/2	0	- 1/2	1/2
12	30 3/4	25 1/2	-4	30 1/2	25	-4	- 1/4	- 1/2	0
13	25	9 3/4	-4 3/4	25	9 1/4	-4 1/2	0	- 1/2	1/4
14	25 1/2	15 1/2	-4 1/4	25 1/2	14 3/4	-3 3/4	0	- 3/4	1/2
15	26	21 3/4	-4 1/4	26	21	-4	0	- 3/4	1/4
16	27 1/2	27 1/4	-4 1/4	27 1/2	27 1/4	-4 1/2	0	0	- 1/4
17	22	10 1/4	-5	22	9 1/2	-4 3/4	0	- 3/4	1/4
18	23	16 1/4	-4 1/4	23	16	-4	0	- 1/4	1/4
19	23 3/4	20 3/4	-4 1/4	23 1/2	20	-4	- 1/4	- 3/4	1/4
20	23 3/4	27 1/2	-4 3/4	23 3/4	26 3/4	-4 3/4	0	- 3/4	0
21	17 1/2	10 1/2	-5	17 1/4	9 3/4	-4 3/4	- 1/4	- 3/4	1/4
22	18	15 3/4	-4 1/4	17 3/4	15	-4	- 1/4	- 3/4	1/4
23	19	21 3/4	-4 1/4	18 1/2	21	-4 1/4	- 1/2	- 3/4	0
24	18	27 3/4	-4 1/2	18	27	-4 3/4	0	- 3/4	- 1/4
25	10 1/2	11	-1	10 1/2	11 3/4	-1	0	3/4	0
26	10 1/2	16	-1	10 1/2	16 1/2	-1	0	1/2	0
27	10 1/4	24	-1	10 1/2	24 1/2	-1	1/4	1/2	0
28							0	0	0
29							0	0	0
30							0	0	0
31							0	0	0

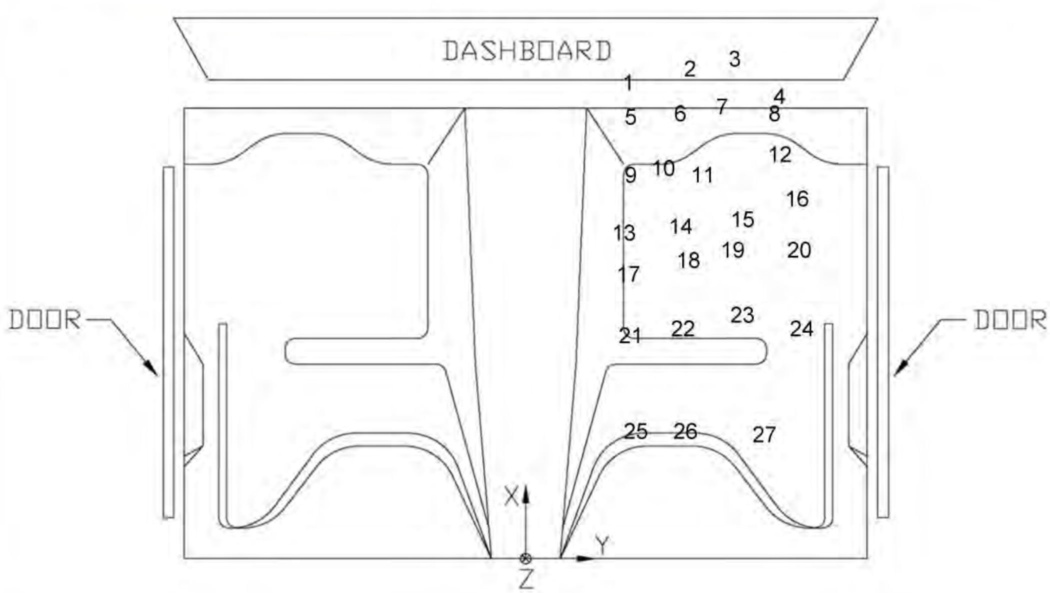


Figure H-8. Floor Pan Deformation Data – Set 2, Test No. WIDA-2

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: WIDA-2
VEHICLE: 1100C

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

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	33	35 1/2	22 3/4	33	35 3/4	22 3/4	0	1/4	0
	A2	33 1/2	41 1/4	22 3/4	33 1/2	41 1/4	22 3/4	0	0	0
	A3	33 1/4	45 1/2	22 1/2	33	45 1/2	22 1/2	- 1/4	0	0
	A4	27 3/4	38	16 1/2	27 3/4	38	16 1/2	0	0	0
	A5	28	42	16 3/4	28	42 1/4	16 3/4	0	1/4	0
	A6	27 3/4	47 1/4	17	27 3/4	47 1/4	17	0	0	0
SIDE PANEL	B1	20 1/2	23 3/4	4	19 1/2	23 1/2	4 1/4	-1	- 1/4	1/4
	B2	20	23 3/4	2	19	23 1/2	2	-1	- 1/4	0
	B3	23	23 1/2	1 3/4	22 1/4	23 1/2	1 3/4	- 3/4	0	0
IMPACT SIDE DOOR	C1	25 1/2	33 1/2	22 1/4	25 1/2	33	22 1/4	0	- 1/2	0
	C2	15 1/2	34 3/4	23 1/4	15 1/2	34 3/4	23 1/4	0	0	0
	C3	4	35 3/4	23 3/4	4	35 1/2	23 3/4	0	- 1/4	0
	C4	20	28 1/2	12 1/2	20	28 1/2	13	0	0	1/2
	C5	13	29 1/2	13	12 3/4	29 1/2	13	- 1/4	0	0
	C6	6 3/4	29 3/4	13 1/4	6 3/4	29 3/4	13 1/4	0	0	0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

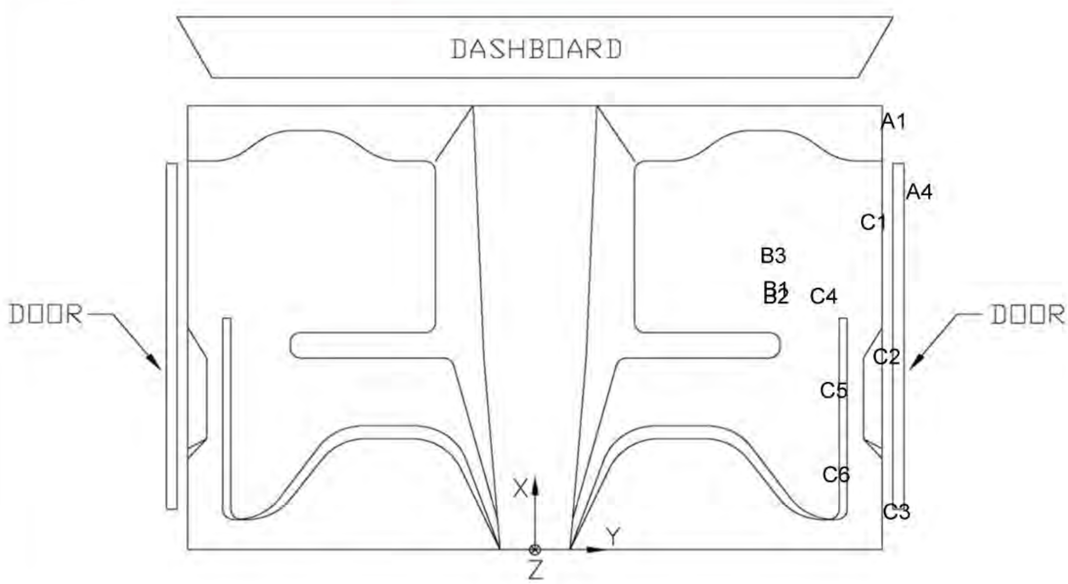


Figure H-9. Occupant Compartment Deformation Data – Set 1, Test No. WIDA-2

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: WIDA-2
VEHICLE: 1100C

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

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	47 3/4	37	23 1/4	48	37	23 1/4	1/4	0	0
	A2	48 3/4	42 1/4	23	48 1/2	42 1/2	23	- 1/4	1/4	0
	A3	48 3/4	46 1/4	22 3/4	48 3/4	46 1/2	22 3/4	0	1/4	0
	A4	44	39 1/4	17	43 1/2	39 1/4	17 1/4	- 1/2	0	1/4
	A5	44 1/4	43 1/2	17	44	43 1/2	17 1/4	- 1/4	0	1/4
	A6	44 1/2	48	17 1/4	44 1/4	48 1/4	17 1/4	- 1/4	1/4	0
SIDE PANEL	B1	29	24 1/4	4 1/2	28 3/4	24 1/4	4 1/4	- 1/4	0	- 1/4
	B2	28 3/4	24 1/4	2	28 3/4	24 1/4	2 1/4	0	0	1/4
	B3	32	25 1/4	2	31 3/4	25	2	- 1/4	- 1/4	0
IMPACT SIDE DOOR	C1	30 1/4	36 1/2	22 1/4	30 1/4	36 3/4	22 1/4	0	1/4	0
	C2	20 1/4	37 1/2	23 1/4	20 1/4	37 1/2	23 1/2	0	0	1/4
	C3	8 3/4	38 1/2	23 1/2	8 3/4	38 1/2	23 1/4	0	0	- 1/4
	C4	24 3/4	32 3/4	12 1/2	24 3/4	33	12 1/2	0	1/4	0
	C5	17 3/4	33 1/4	12 3/4	18 1/2	33 1/2	13	3/4	1/4	1/4
	C6	11 1/2	33 1/2	13	11 1/2	34	12 3/4	0	1/2	- 1/4
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

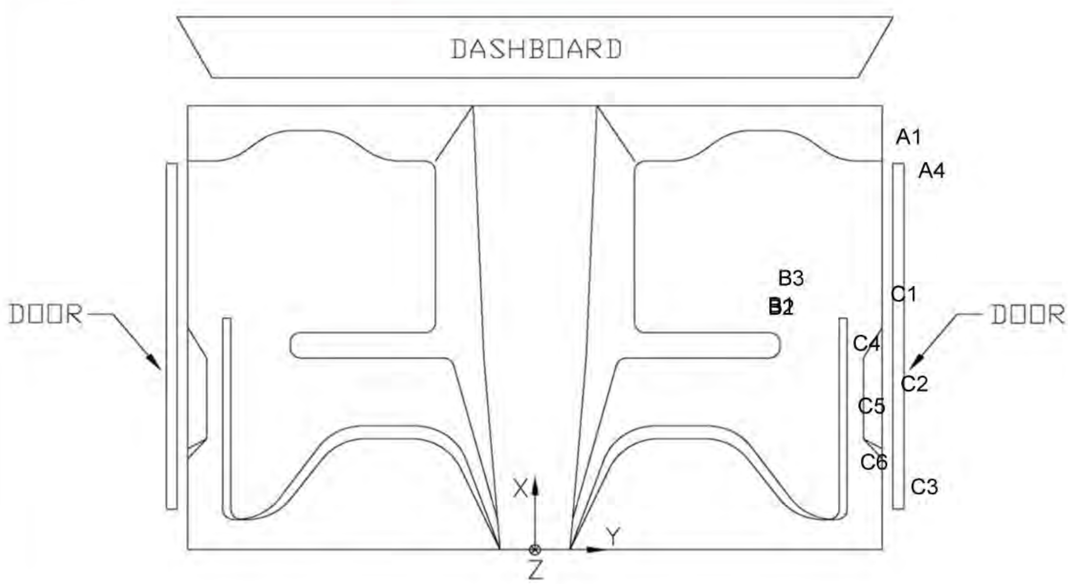
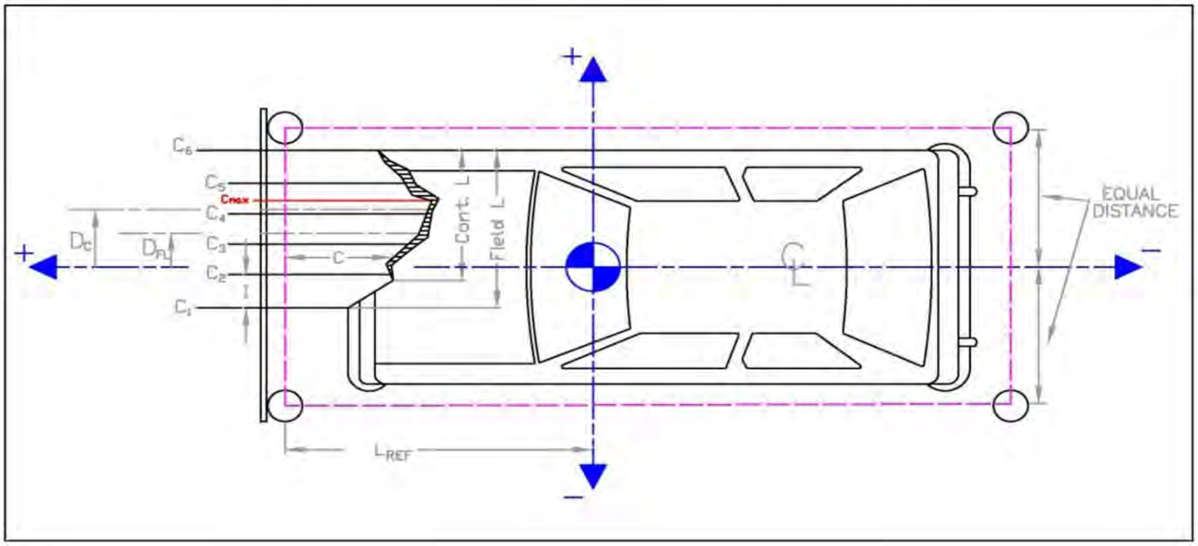


Figure H-10. Occupant Compartment Deformation Data – Set 2, Test No. WIDA-2

Date: 8/22/2012 **Test Number:** WIDA-2

Make: Kia Rio **Model:** 1100C **Year:** 2006



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	70 1/2	(1791)
Width of contact and induced crush - Field L:	61 3/4	(1568)
Crush measurement spacing interval (L/5) - I:	12 1/3	(314)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	61 3/4	(1568)
Distance from center of vehicle to center of contect damage - D_C:	0	()

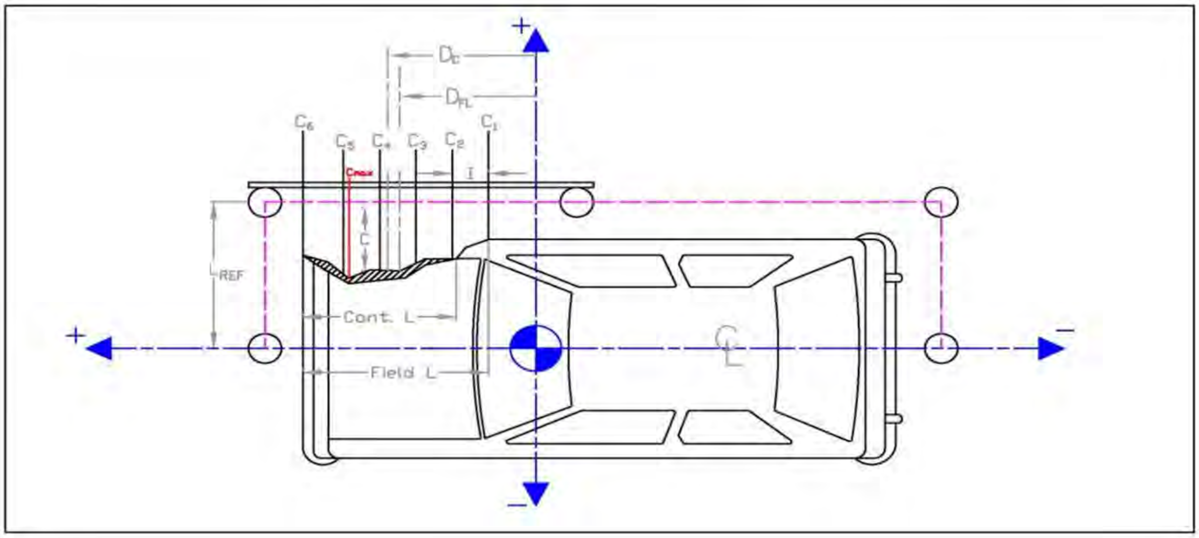
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	Crush Measurement in.	Crush Measurement (mm)	Lateral Location in.	Lateral Location (mm)	Original Profile Measurement in.	Original Profile Measurement (mm)	Dist. Between Ref. Lines in.	Dist. Between Ref. Lines (mm)	Actual Crush in.	Actual Crush (mm)
C_1	na	NA	-30 7/8	-(784)	24 1/3	(618)	-4 1/4	-(108)	NA	NA
C_2	4 1/2	(114)	-18 1/2	-(471)	11 1/3	(289)			-2 3/5	-(66)
C_3	9	(229)	-6 1/6	-(157)	9 2/5	(239)			3 6/7	(98)
C_4	19	(483)	6 1/6	(157)	9 3/8	(238)			13 7/8	(353)
C_5	22 1/2	(572)	18 1/2	(471)	11 2/7	(287)			15 1/2	(393)
C_6	na	NA	30 7/8	(784)	23	(585)			NA	NA
C_{MAX}	22 3/4	(578)	12 1/2	(318)	10	(253)			17	(433)

Figure H-11. Exterior Vehicle Crush (NASS) - Front, Test No. WIDA-2

Date: 8/22/2012 **Test Number:** WIDA-2

Make: Kia Rio **Model:** 1100C **Year:** 2006



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	40.25	(1022)
Width of contact and induced crush - Field L:	68	(1727)
Crush measurement spacing interval (L/5) - I:	13.6	(345)
Distance from vehicle c.g. to center of Field L - D_{FL}:	34	(864)
Width of Contact Damage:	68	(1727)
Distance from vehicle c.g. to center of contect damage - D_C:	34	(864)

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

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	7.25	(184)	0	()	3.13	(79)	4.25	(108)	-0.1	-(3)
C_2	7.75	(197)	13.6	(345)	3.13	(79)			0.4	(10)
C_3	8	(203)	27.2	(691)	4.38	(111)			-0.6	-(16)
C_4	17	(432)	40.8	(1036)	4.00	(102)			8.8	(222)
C_5	na	NA	54.4	(1382)	4.75	(121)			NA	NA
C_6	na	NA	68	(1727)	23.50	(597)			NA	NA
C_{MAX}	17	(432)	40.8	(1036)	4.00	(102)			8.8	(222)

Figure H-12. Exterior Vehicle Crush (NASS) - Side, Test No. WIDA-2

Appendix I. Accelerometer and Rate Transducer Data Plots, Test No. WIDA-1

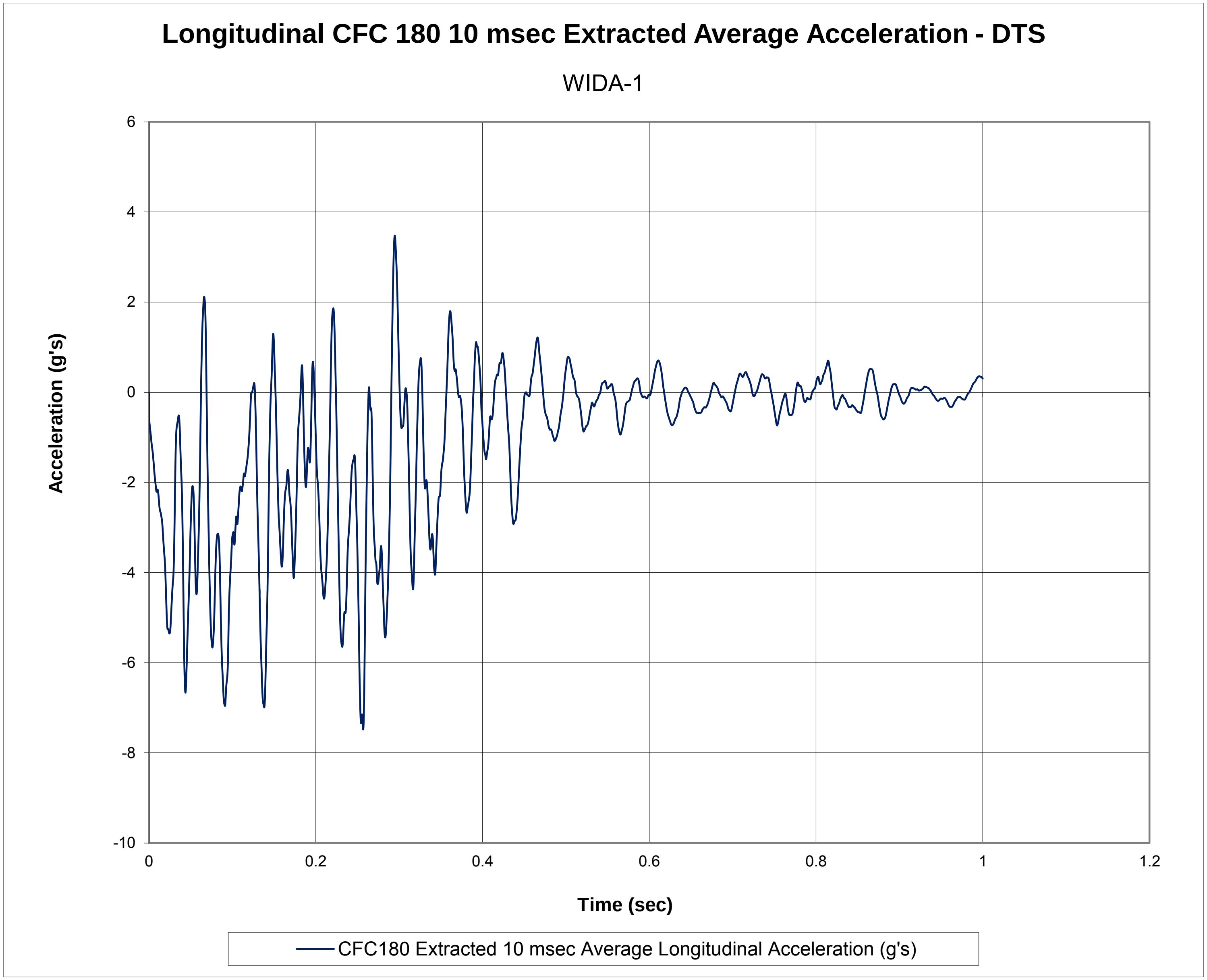


Figure I-1. 10-ms Average Longitudinal Deceleration (DTS), Test No. WIDA-1

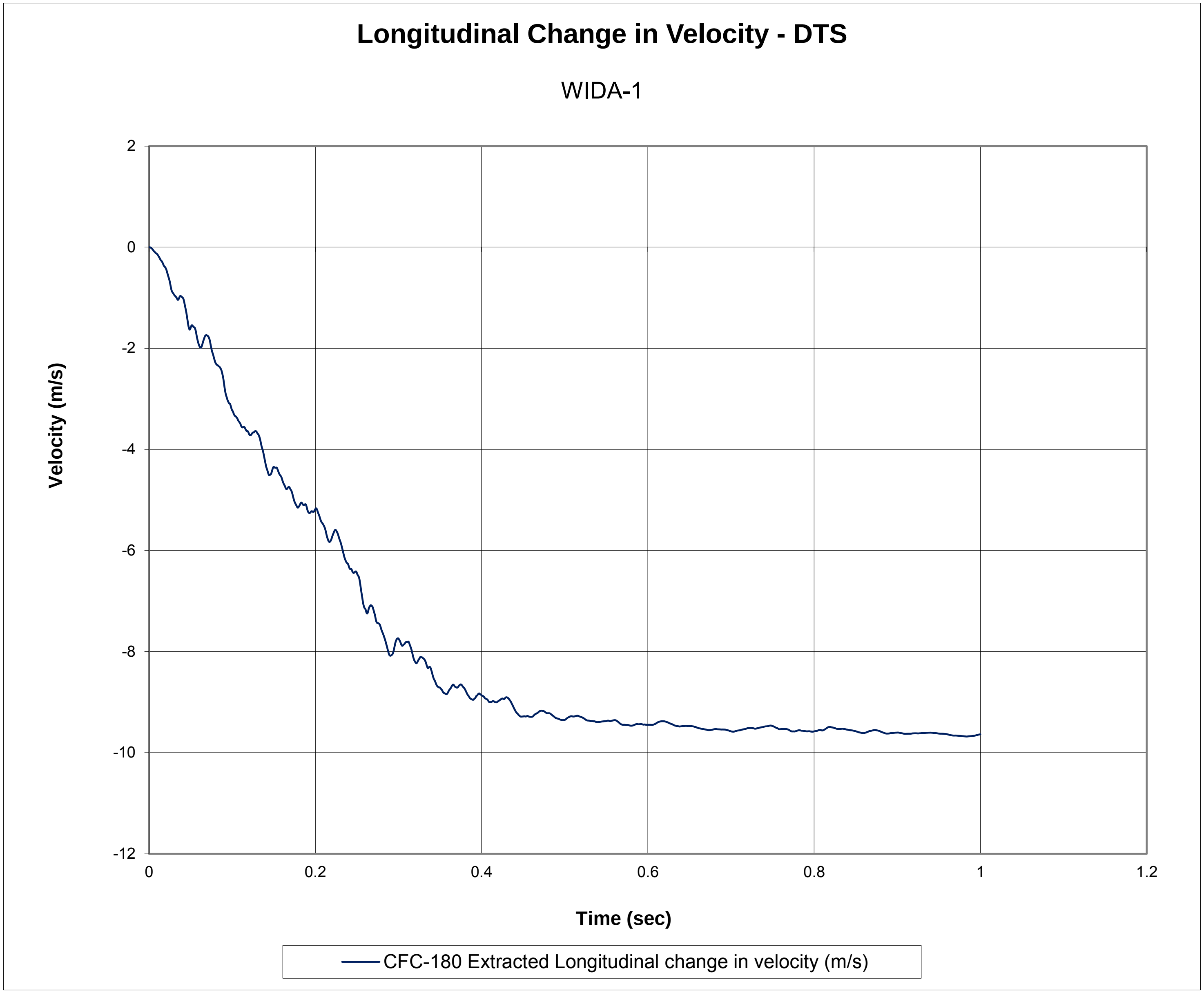


Figure I-2. Longitudinal Occupant Impact Velocity (DTS), Test No. WIDA-1

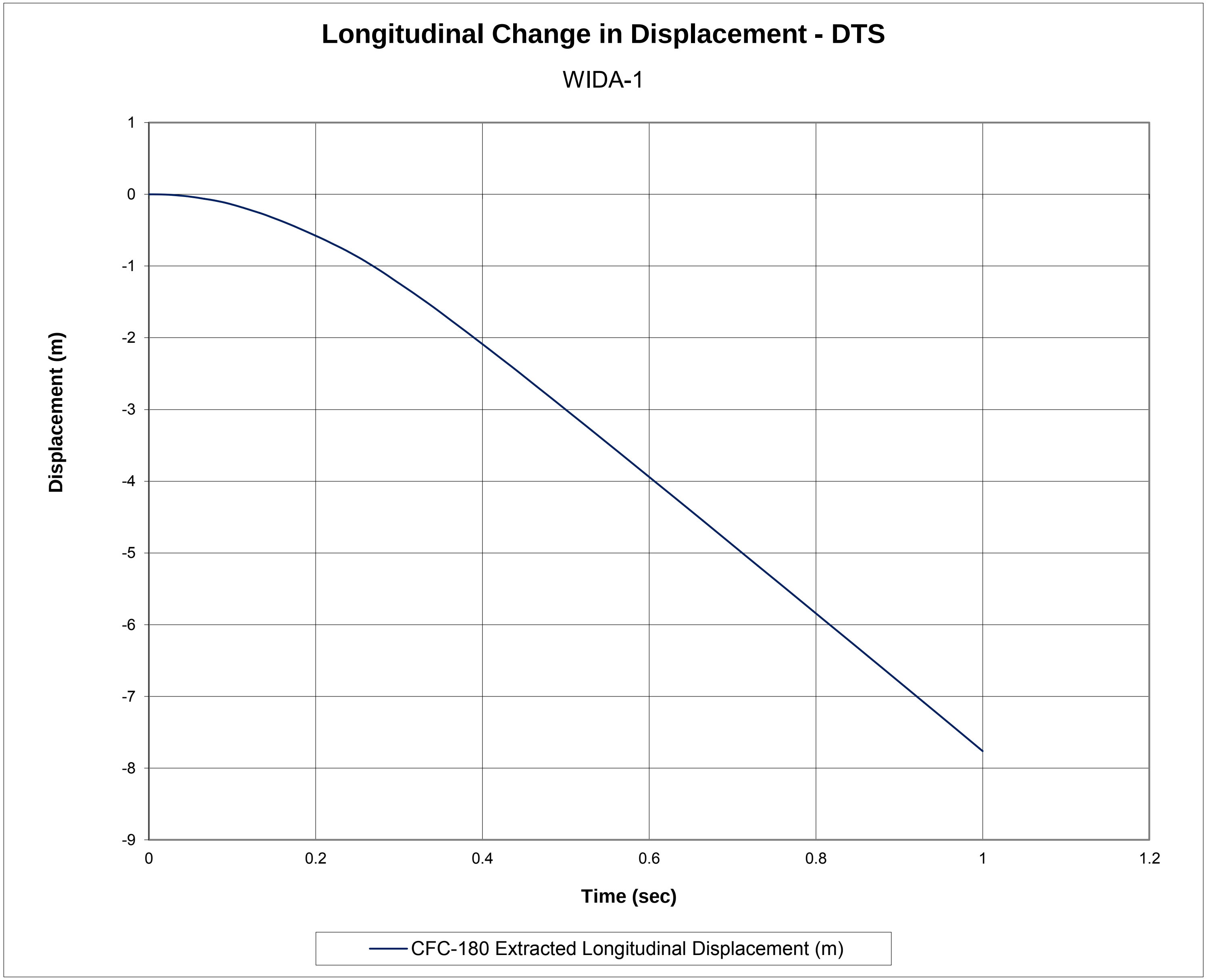


Figure I-3. Longitudinal Occupant Displacement (DTS), Test No. WIDA-1

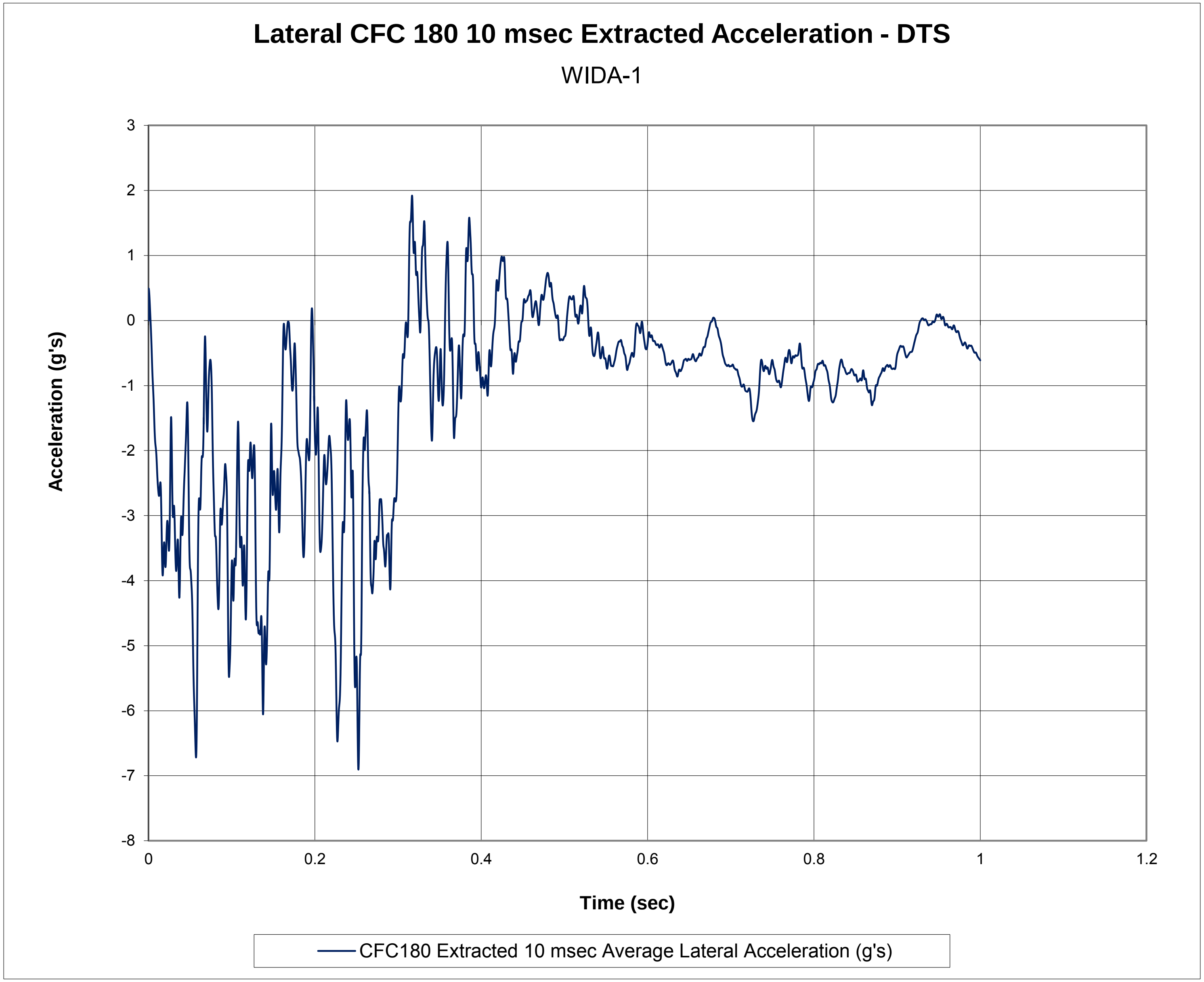


Figure I-4. 10-ms Average Lateral Deceleration (DTS), Test No. WIDA-1

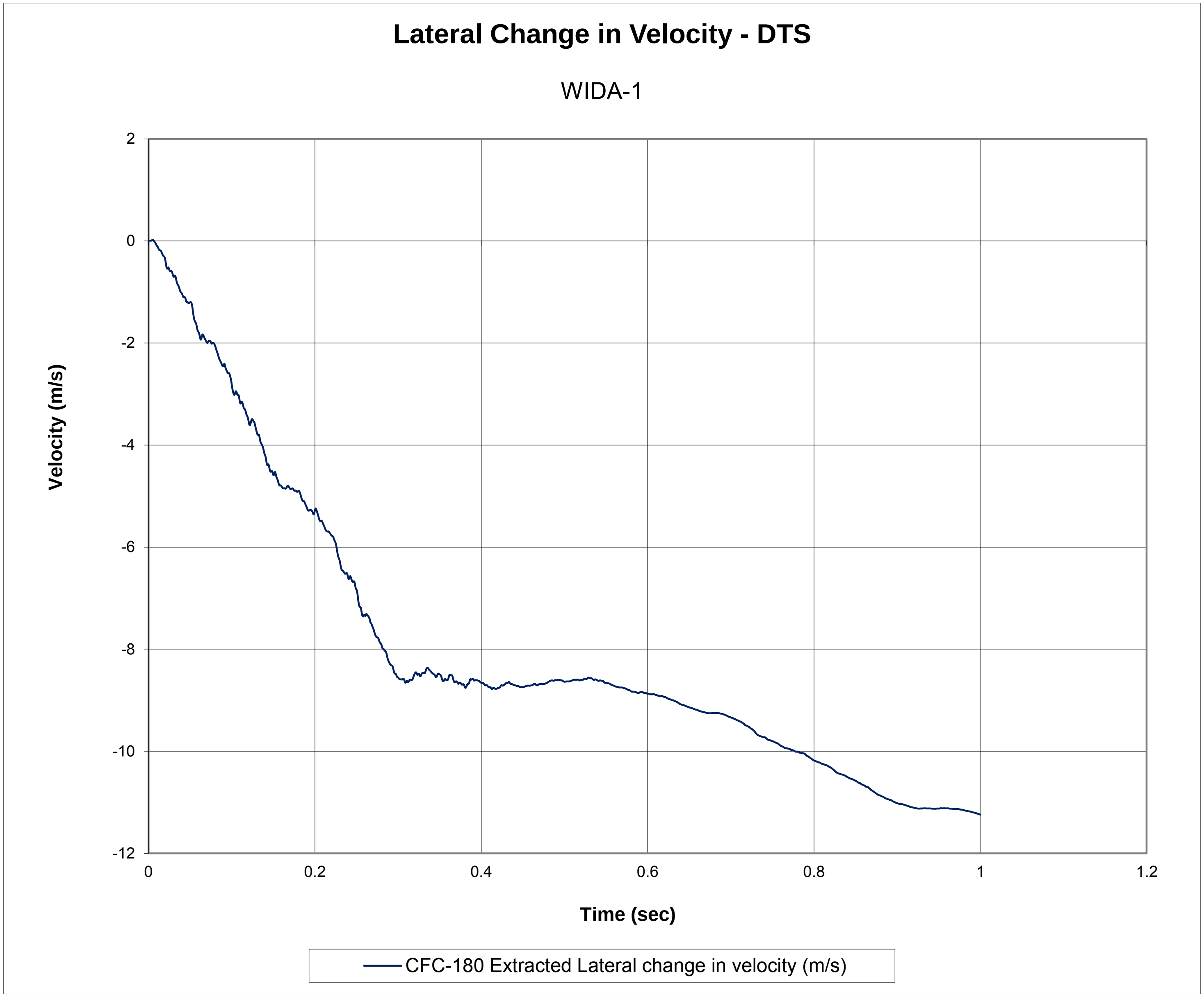


Figure I-5. Lateral Occupant Impact Velocity (DTS), Test No. WIDA-1

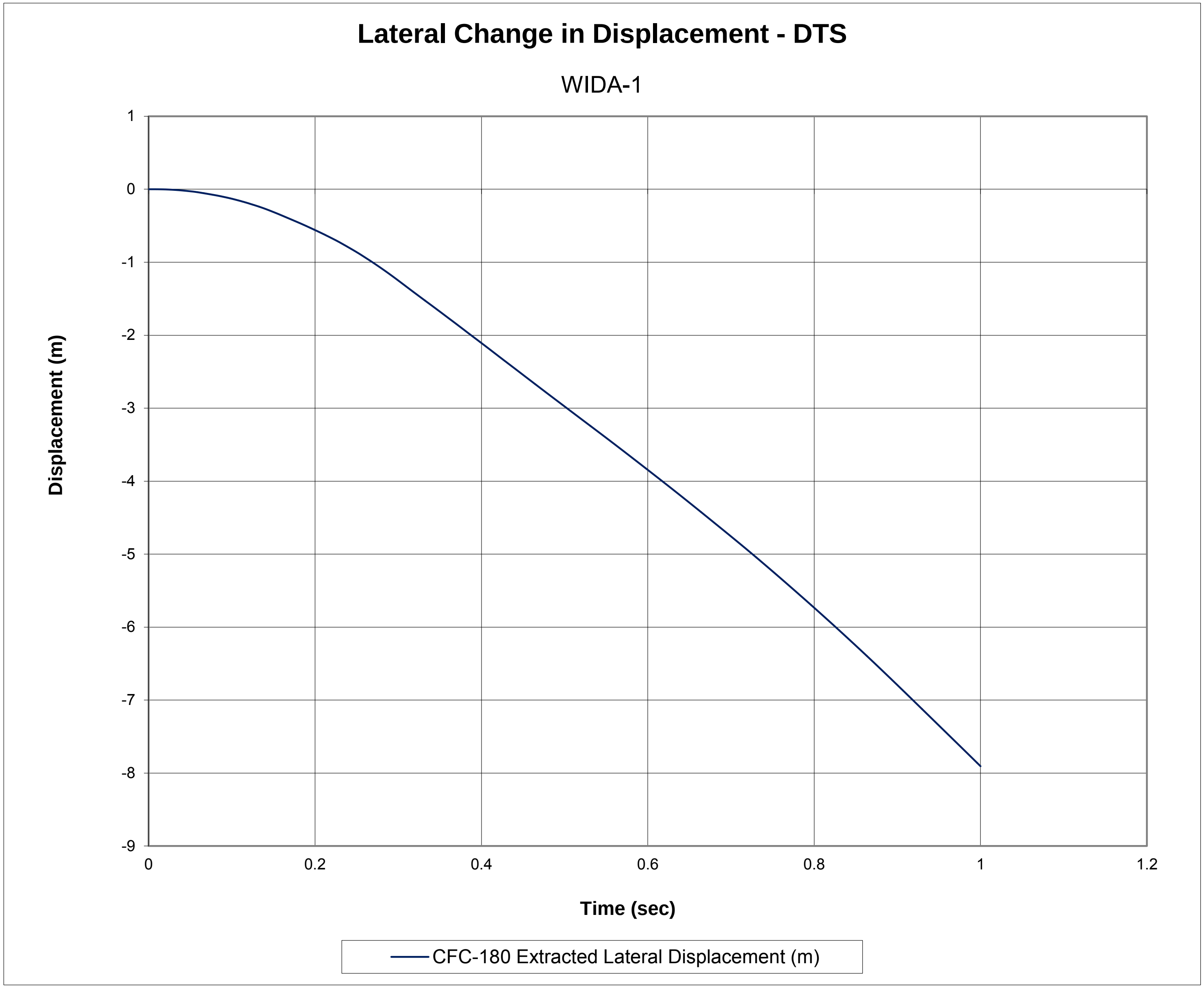


Figure I-6. Lateral Occupant Displacement (DTS), Test No. WIDA-1

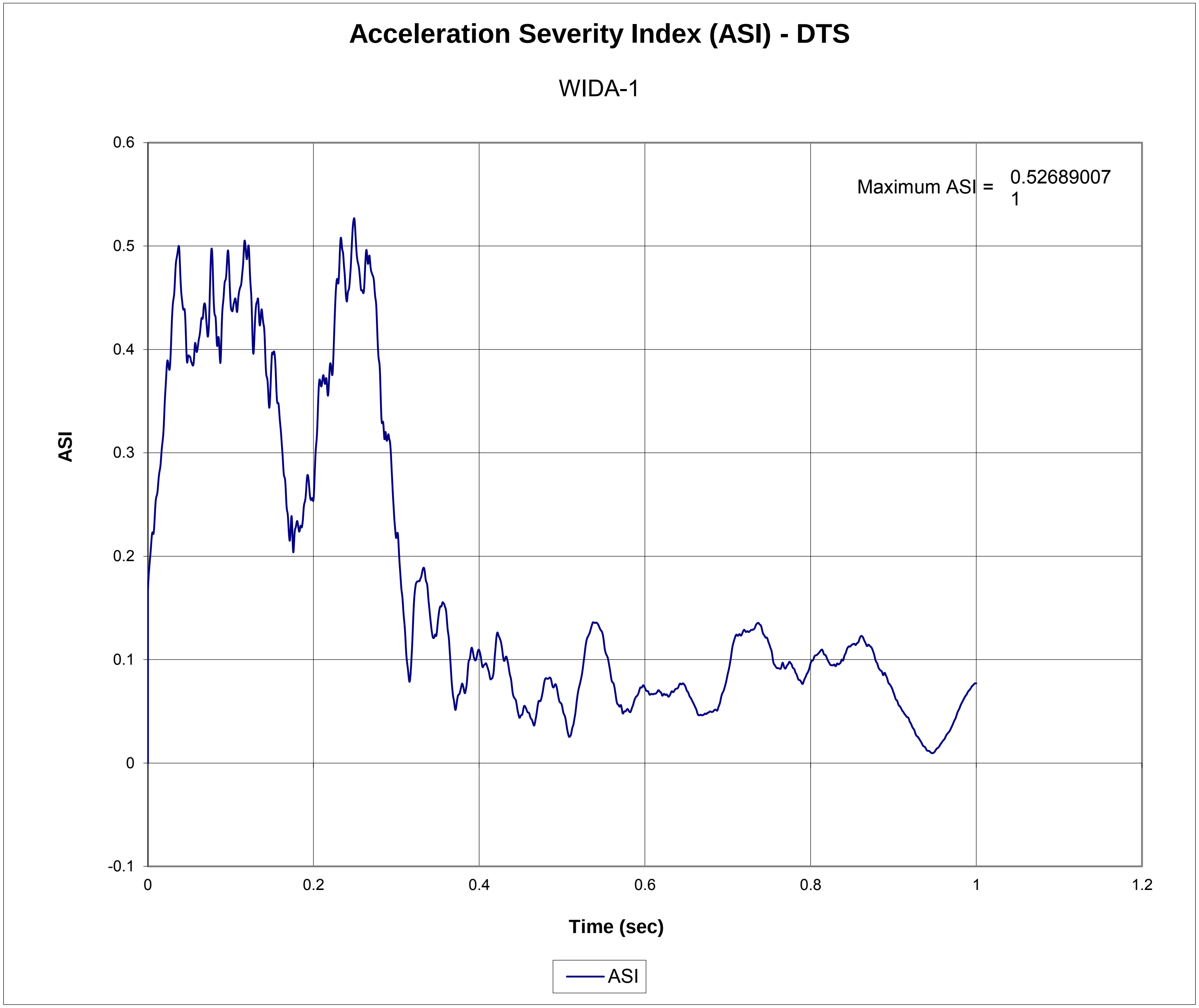


Figure I-7. Acceleration Severity Index (DTS), Test No. WIDA-1

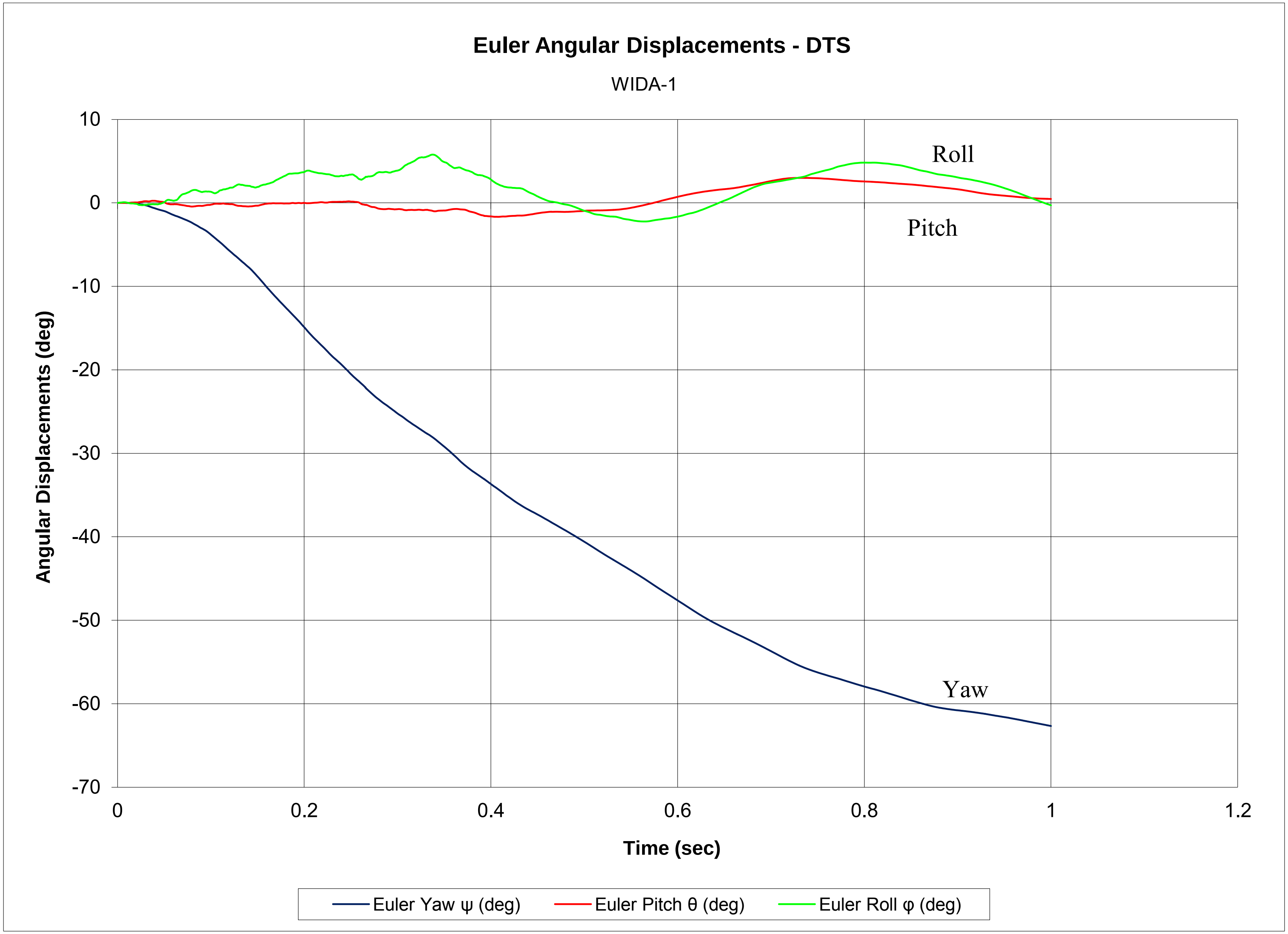


Figure I-8. Vehicle Angular Displacements (DTS), Test No. WIDA-1

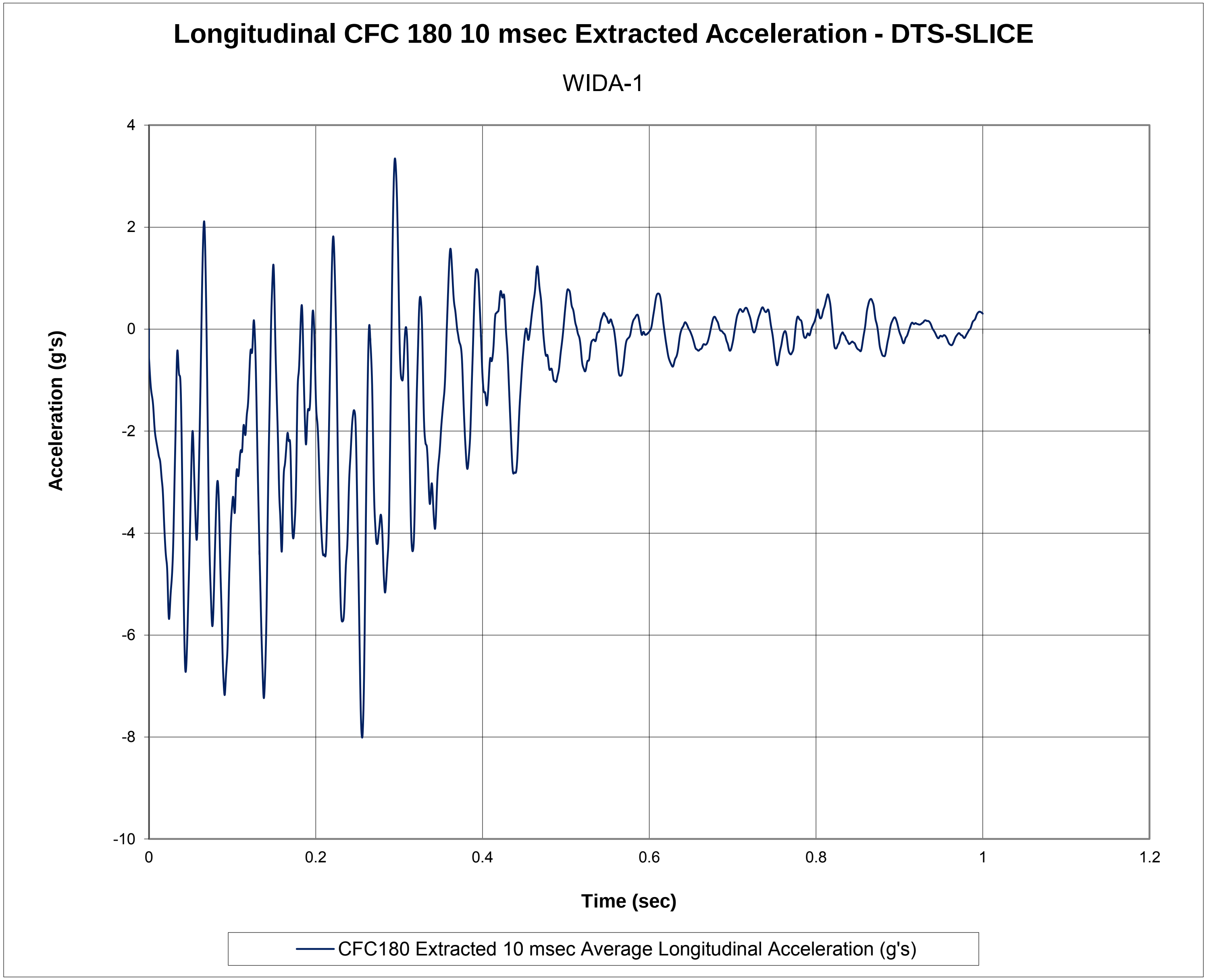


Figure I-9. 10-ms Average Longitudinal Deceleration (DTS - SLICE), Test No. WIDA-1

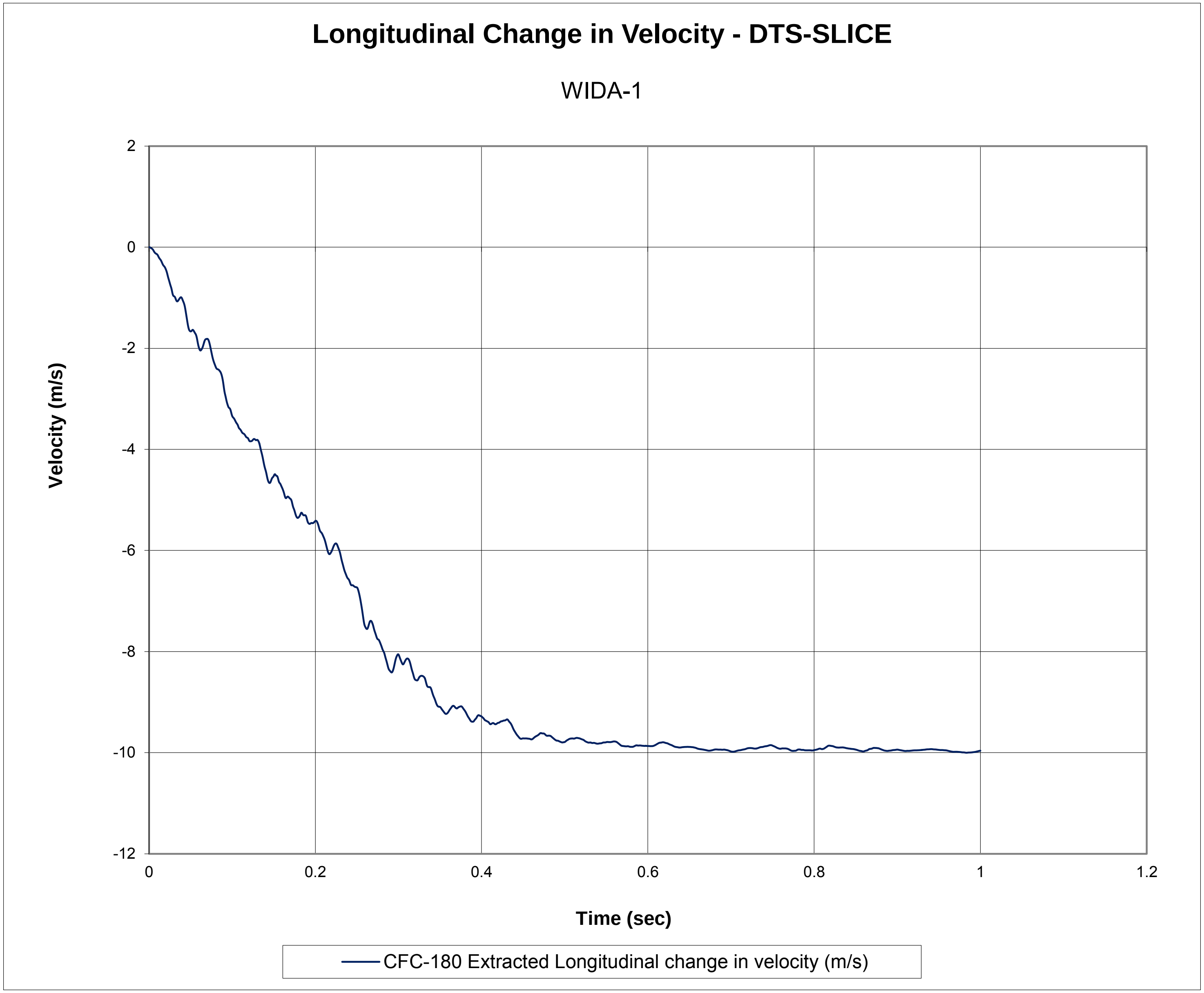


Figure I-10. Longitudinal Occupant Impact Velocity (DTS - SLICE), Test No. WIDA-1

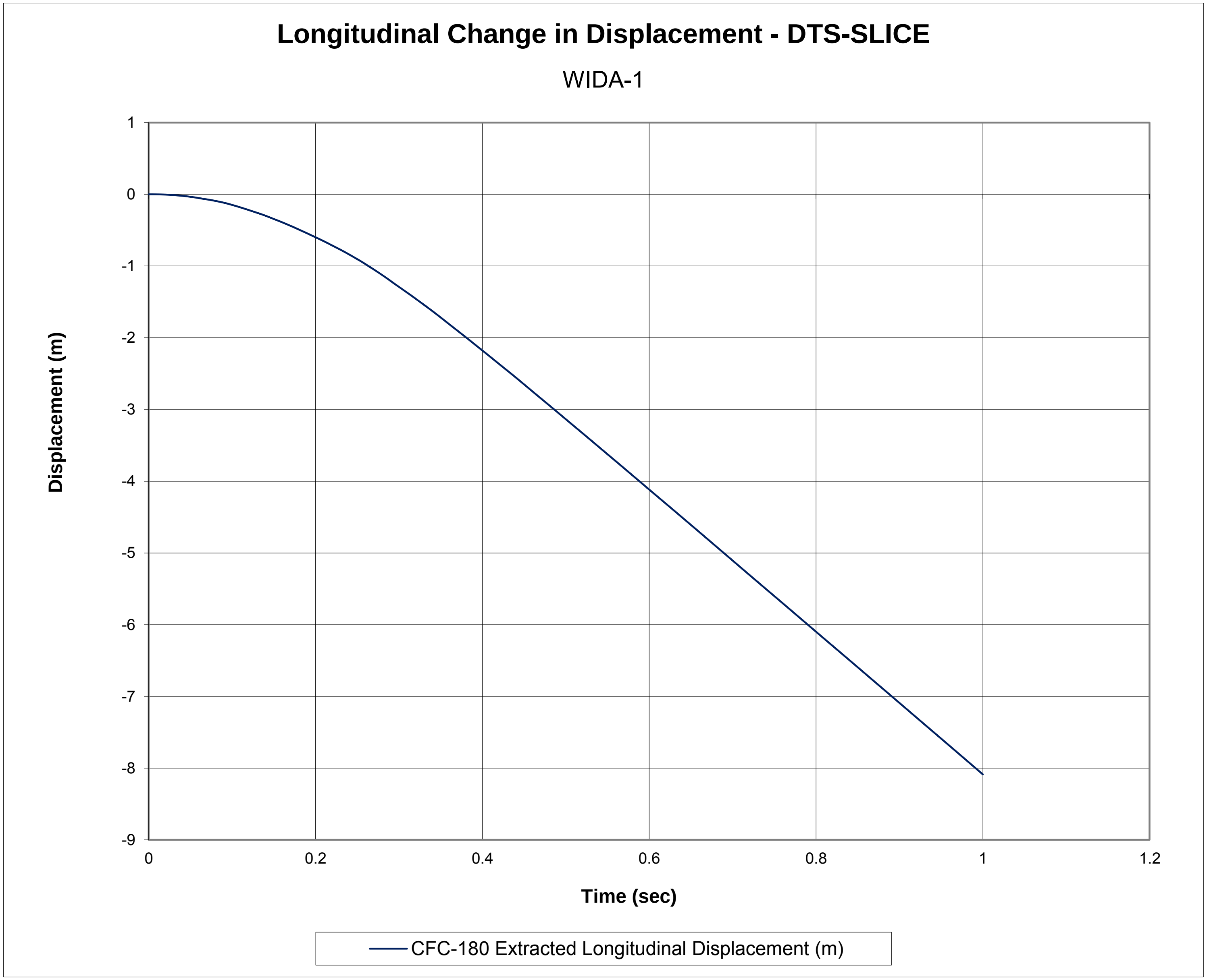


Figure I-11. Longitudinal Occupant Displacement (DTS - SLICE), Test No. WIDA-1

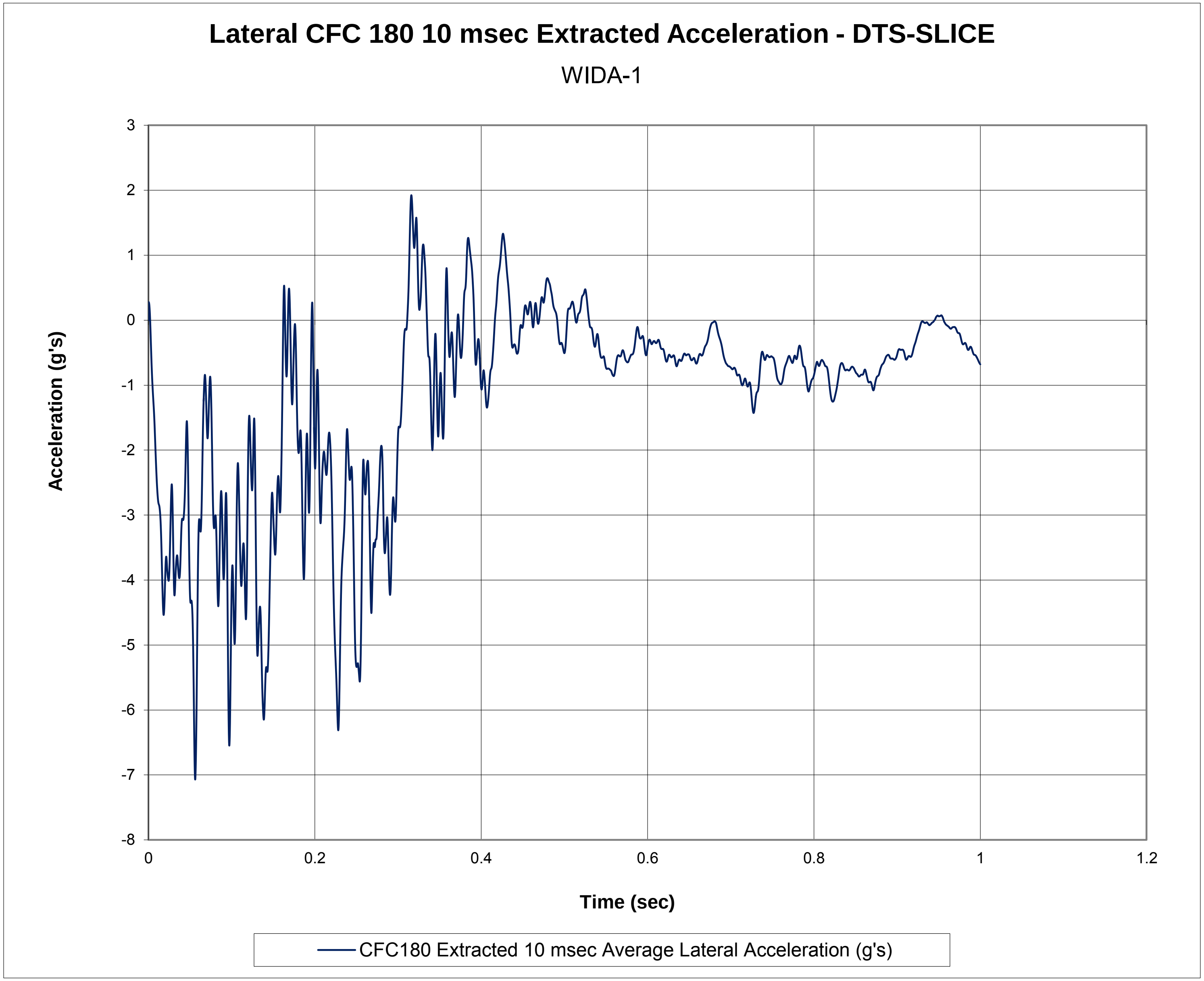


Figure I-12. 10-ms Average Lateral Deceleration (DTS - SLICE), Test No. WIDA-1

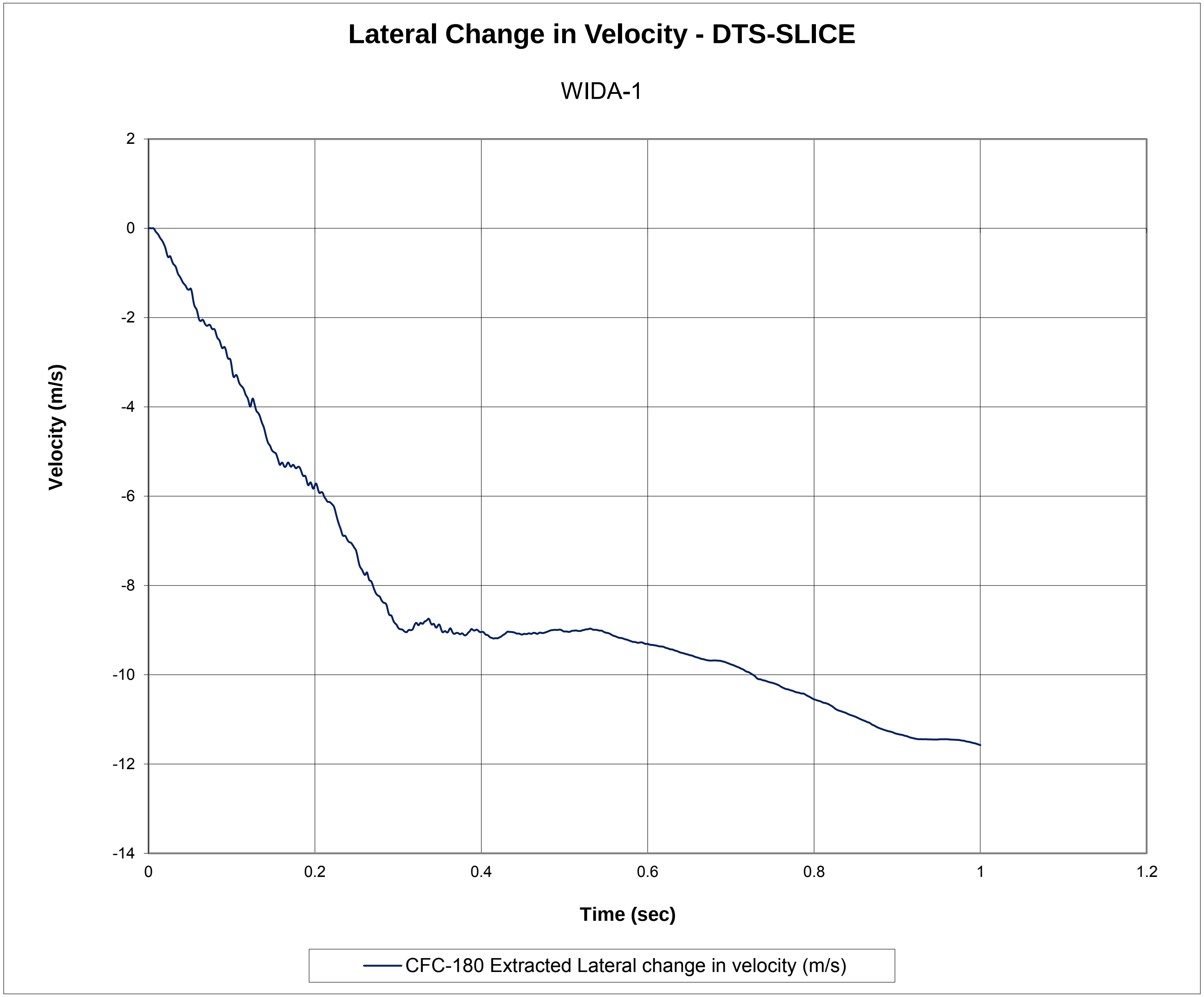


Figure I-13. Lateral Occupant Impact Velocity (DTS - SLICE), Test No. WIDA-1

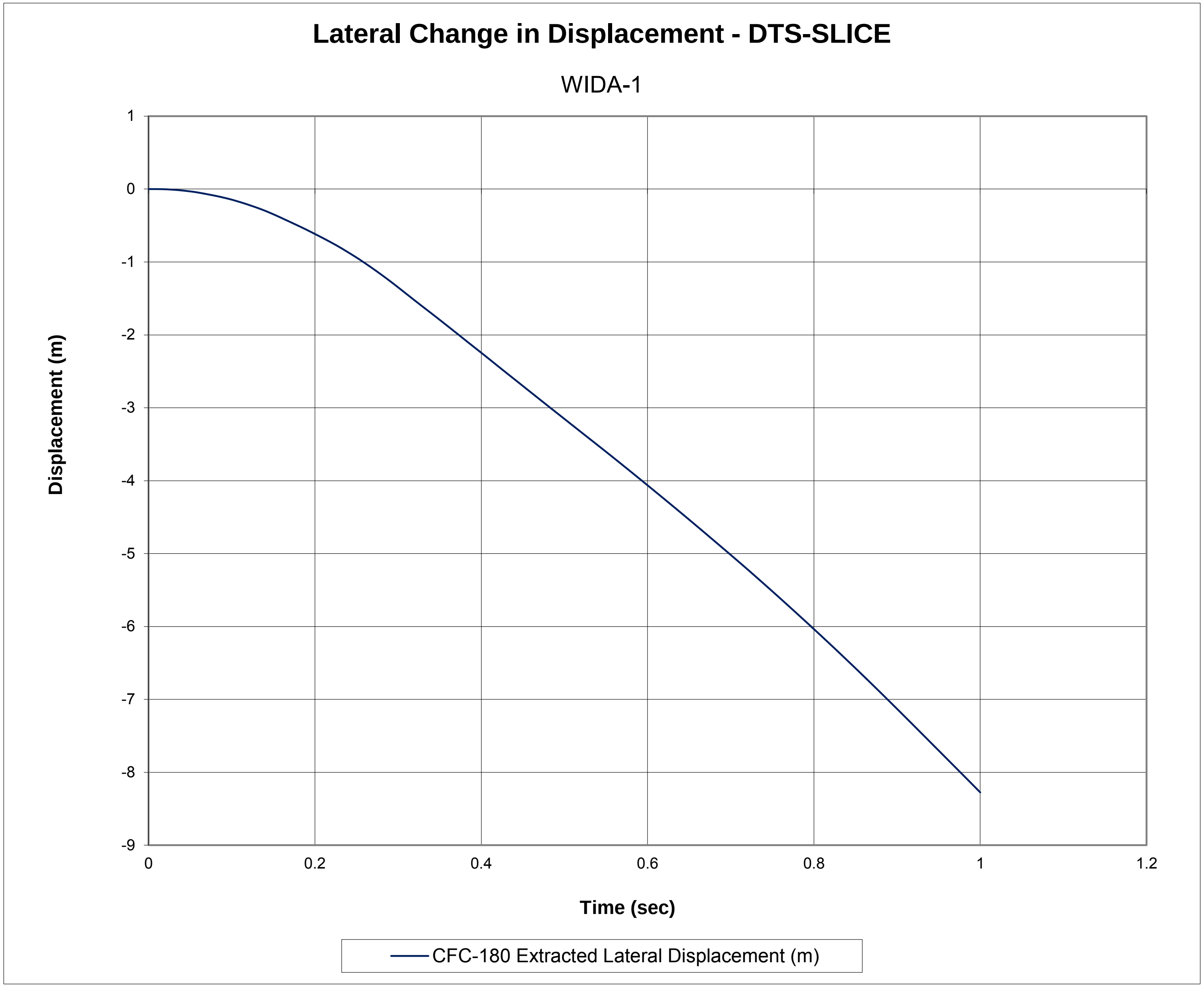


Figure I-14. Lateral Occupant Displacement (DTS - SLICE), Test No. WIDA-1

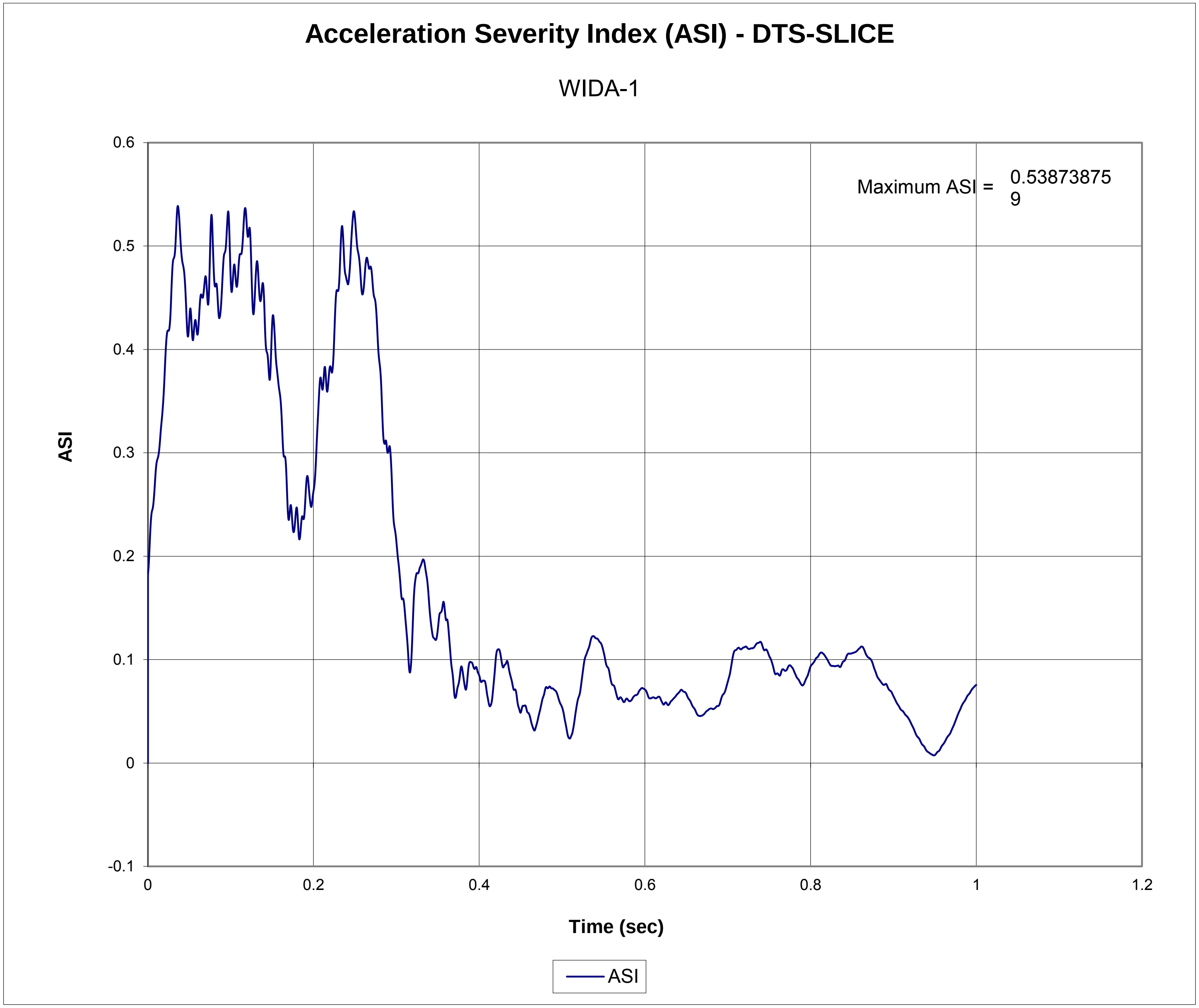


Figure I-15. Acceleration Severity Index (DTS - SLICE), Test No. WIDA-1

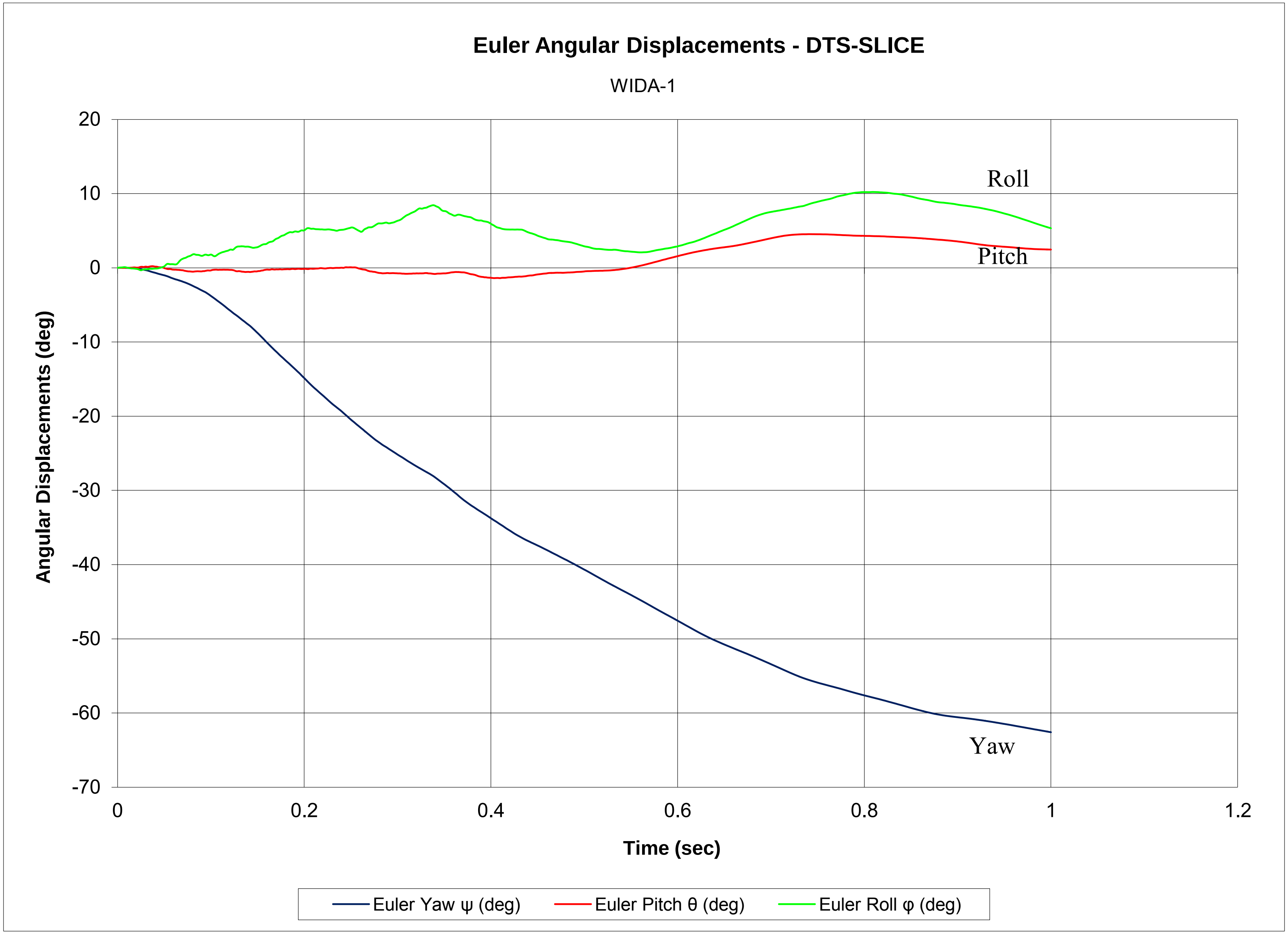


Figure I-16. Vehicle Angular Displacements (DTS - SLICE), Test No. WIDA-1

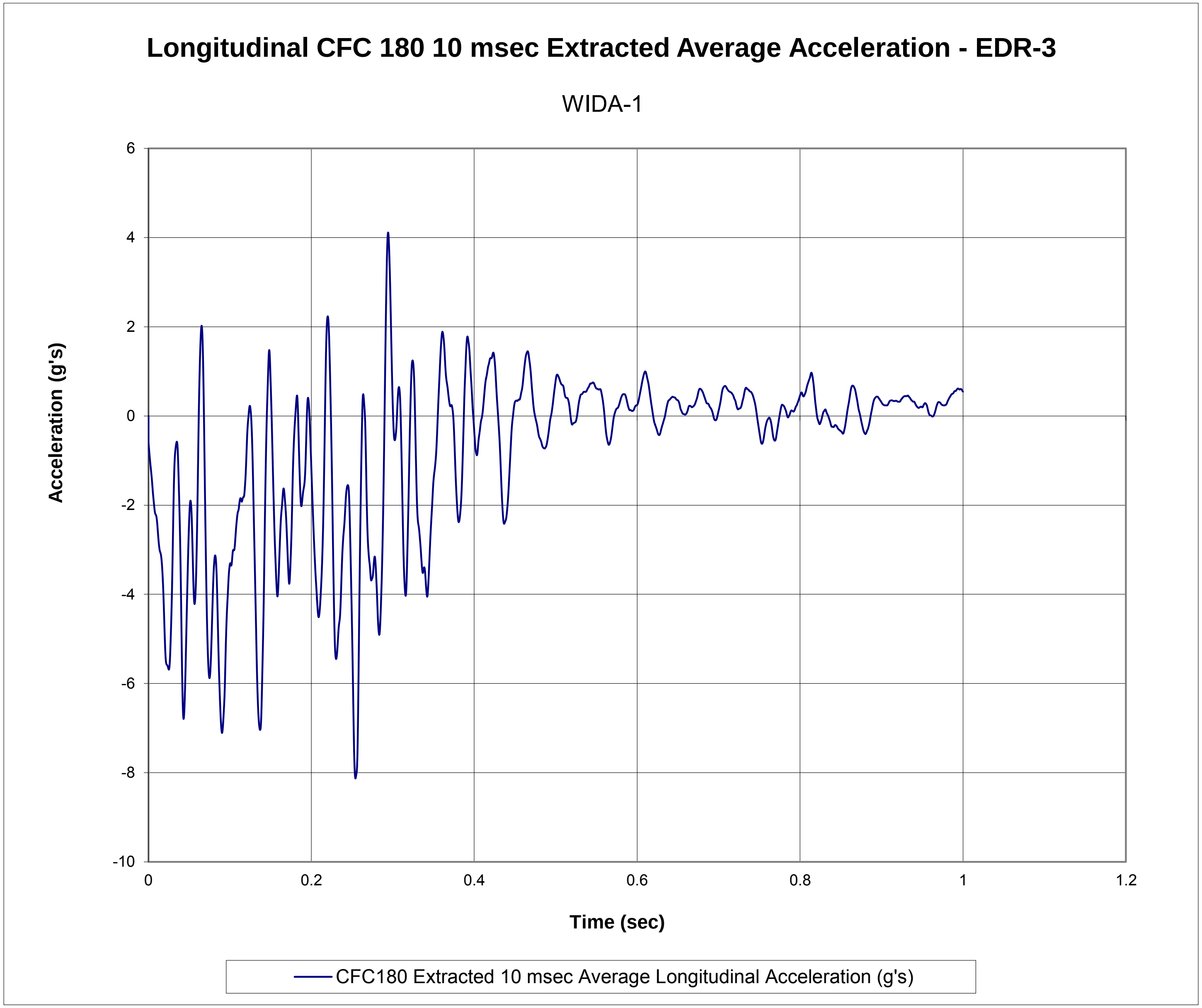


Figure I-17. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. WIDA-1

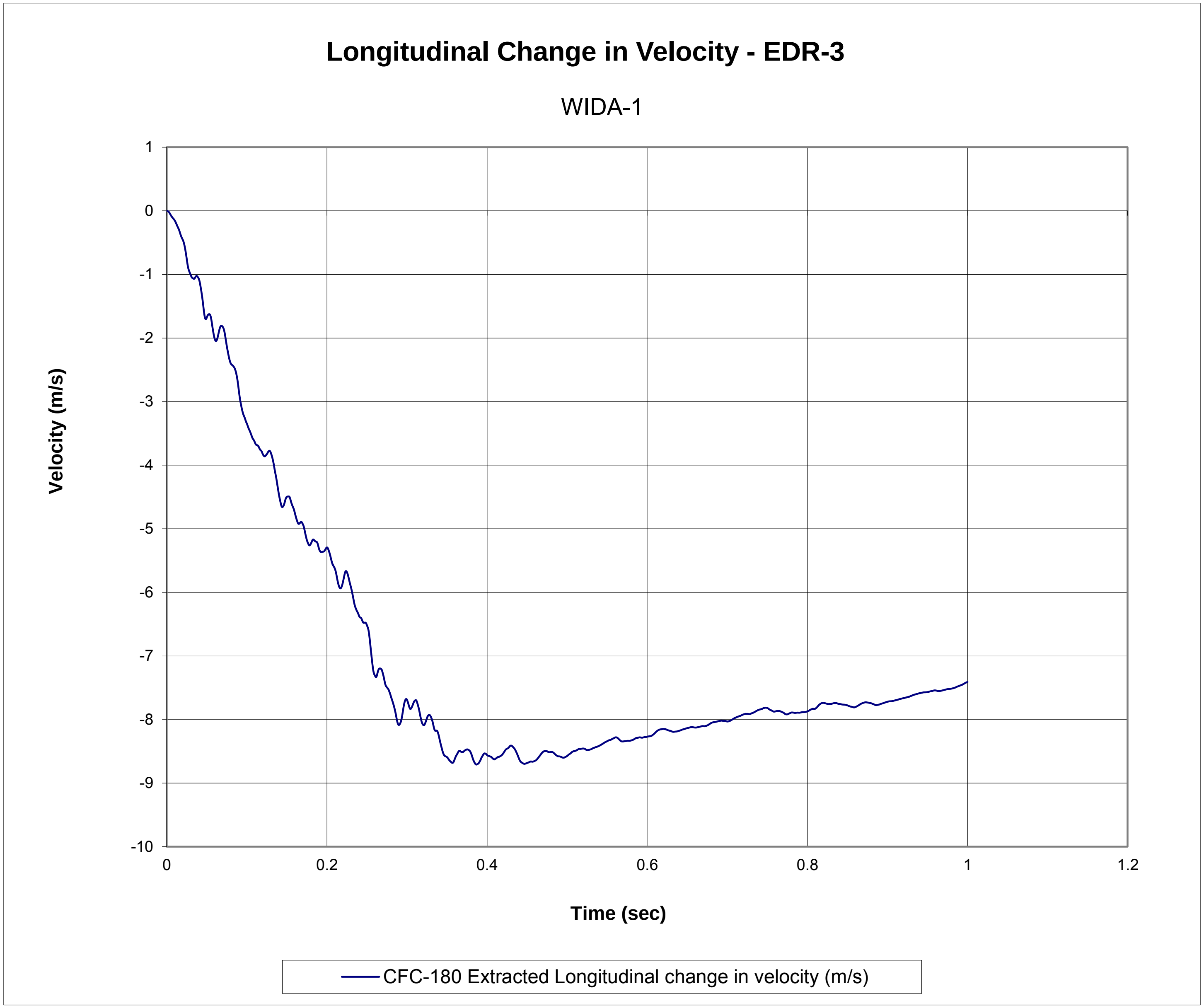


Figure I-18. Longitudinal Occupant Impact Velocity (EDR-3), Test No. WIDA-1

Figure I-19. Longitudinal Occupant Displacement (EDR-3), Test No. WIDA-1

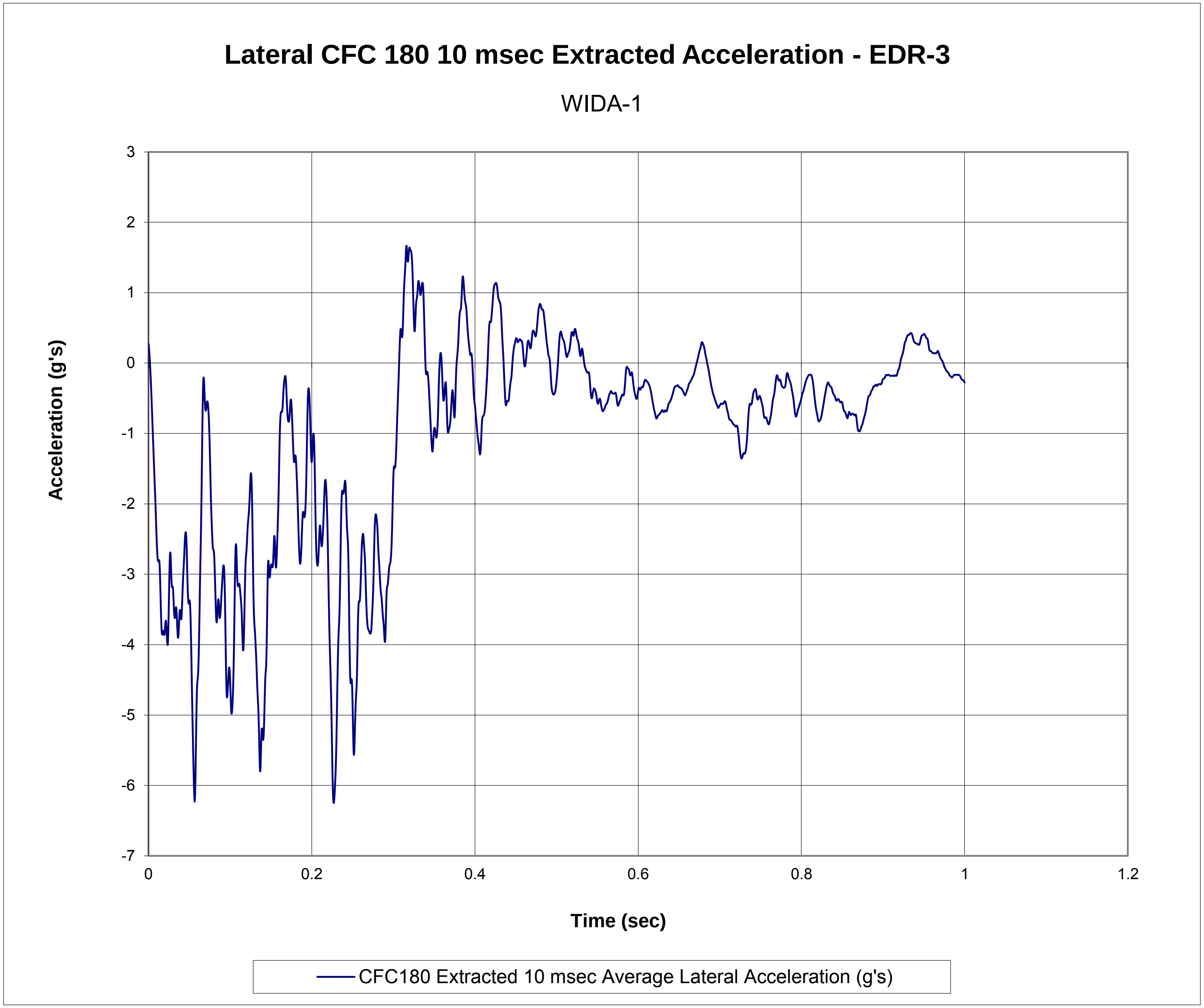


Figure I-20. 10-ms Average Lateral Deceleration (EDR-3), Test No. WIDA-1

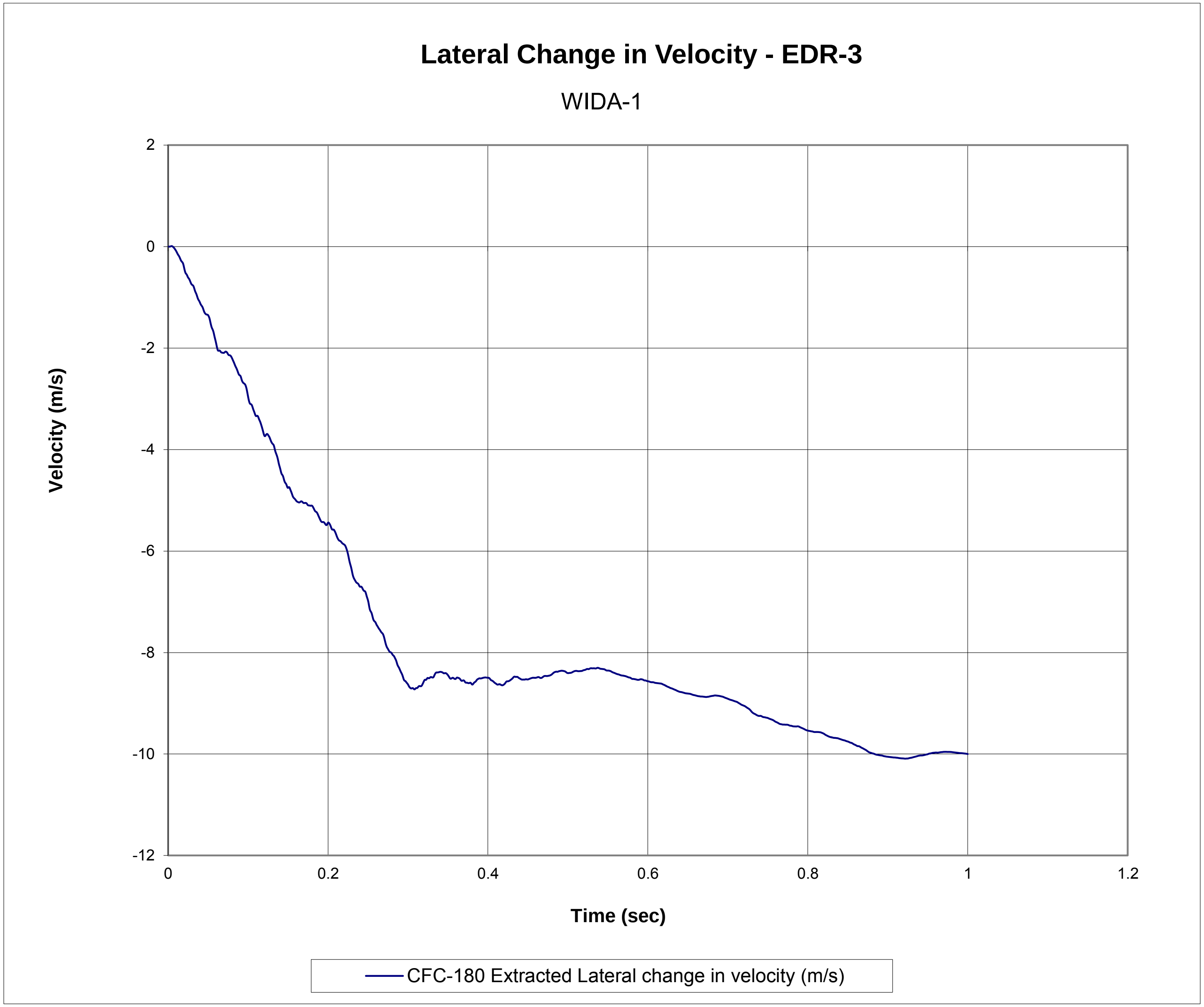


Figure I-21. Lateral Occupant Impact Velocity (EDR-3), Test No. WIDA-1

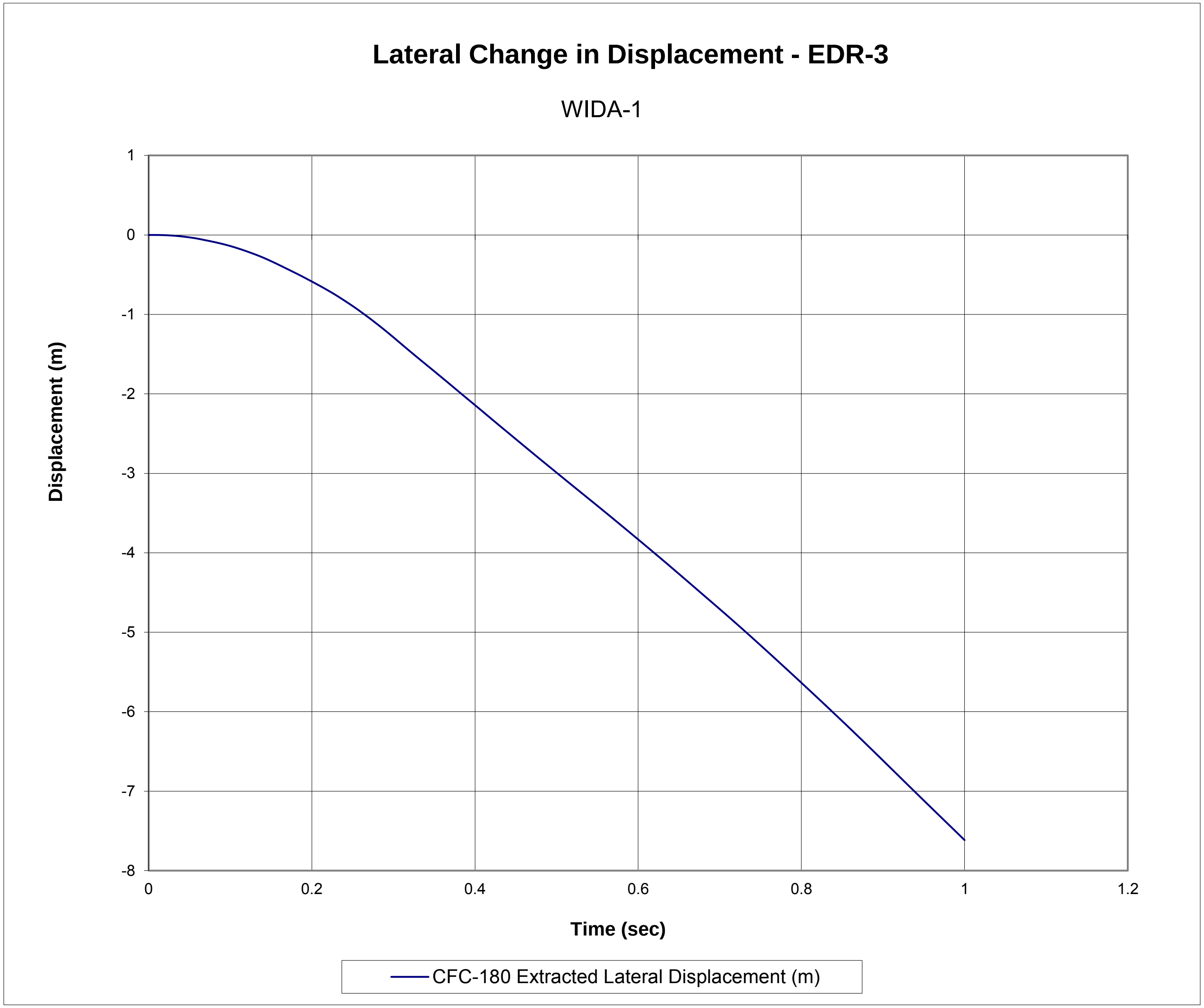


Figure I-22. Lateral Occupant Displacement (EDR-3), Test No. WIDA-1

Appendix J. Accelerometer and Rate Transducer Data Plots, Test No. WIDA-2

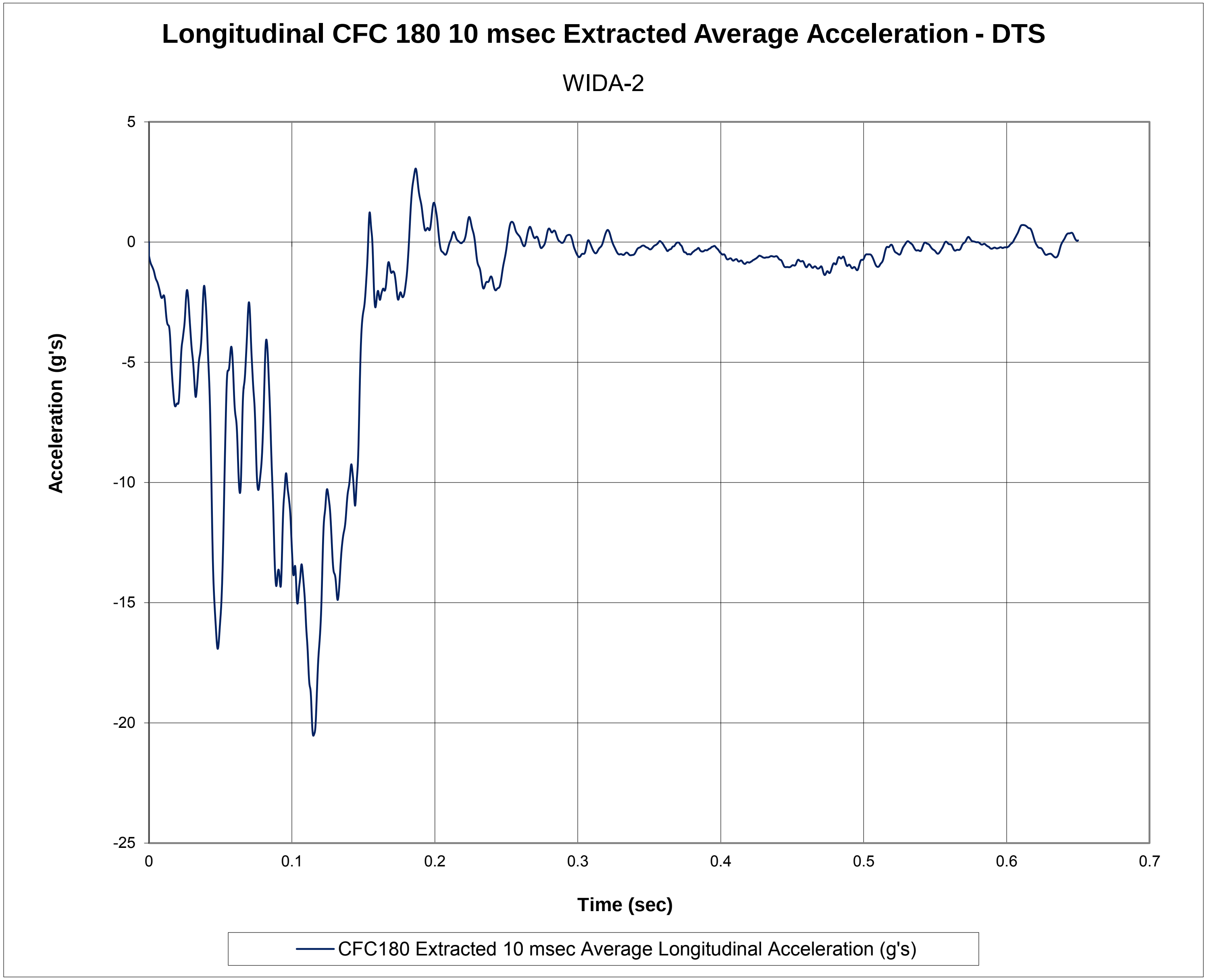


Figure J-1. 10-ms Average Longitudinal Deceleration (DTS), Test No. WIDA-2

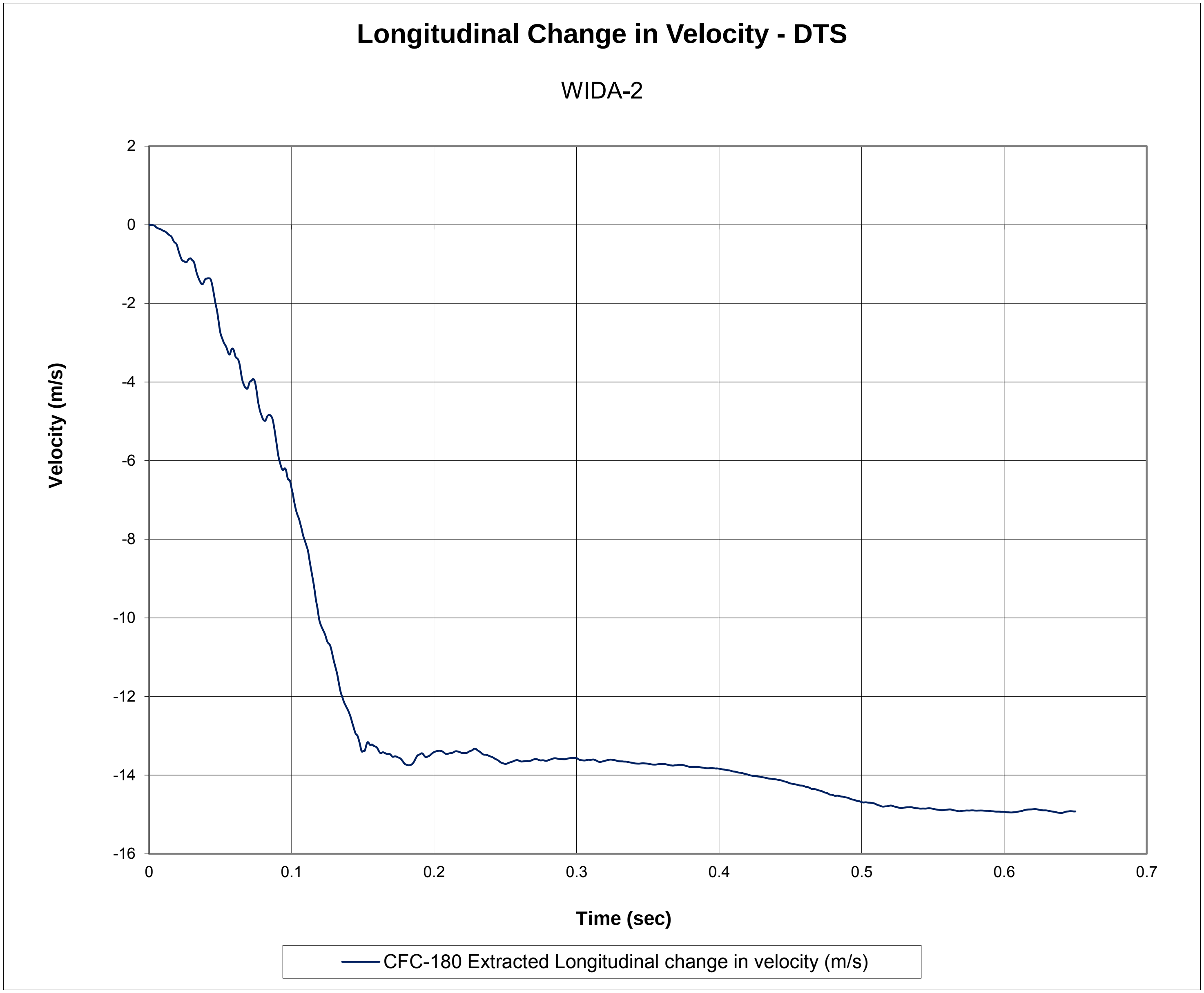


Figure J-2. Longitudinal Occupant Impact Velocity (DTS), Test No. WIDA-2

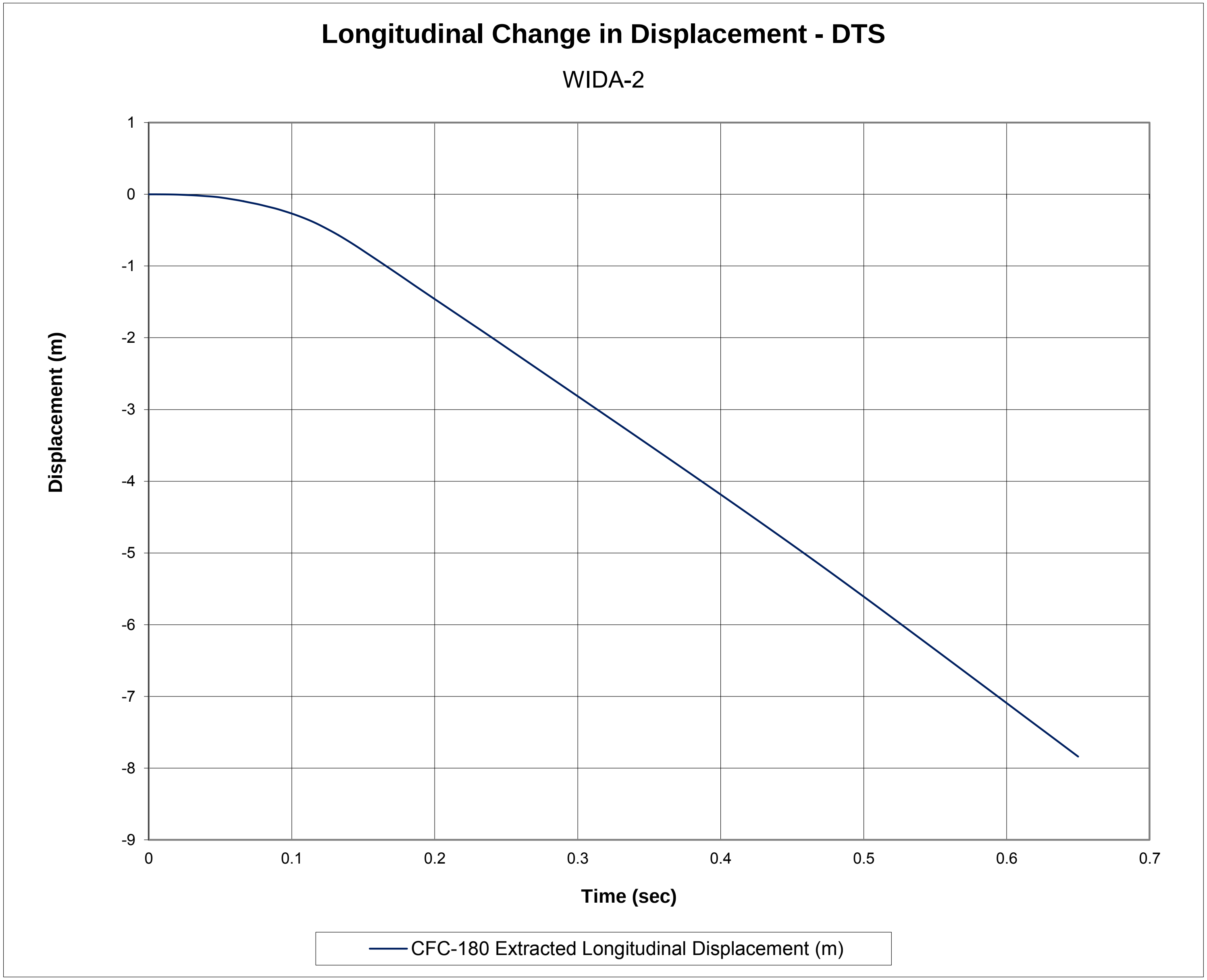


Figure J-3. Longitudinal Occupant Displacement (DTS), Test No. WIDA-2

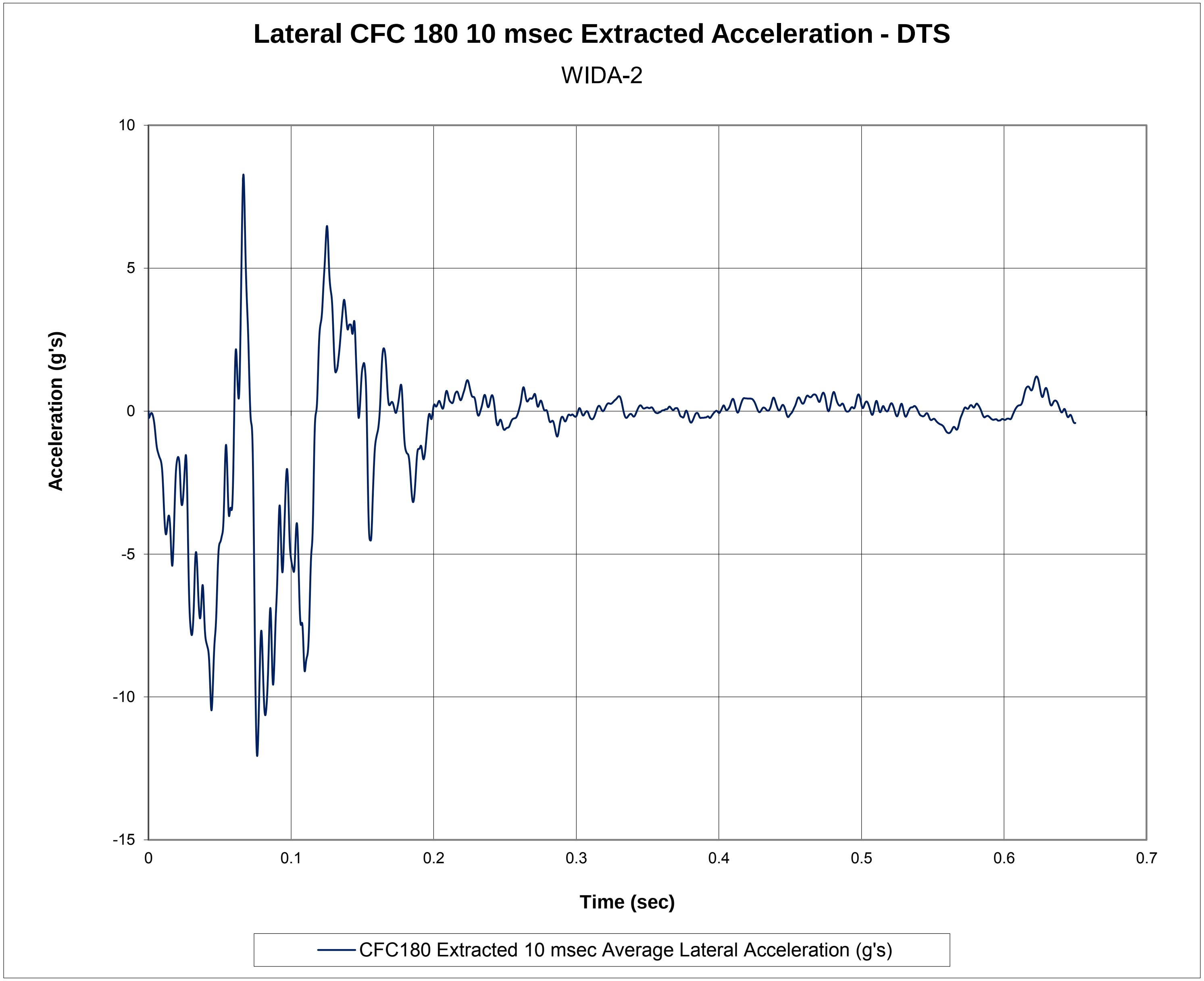


Figure J-4. 10-ms Average Lateral Deceleration (DTS), Test No. WIDA-2

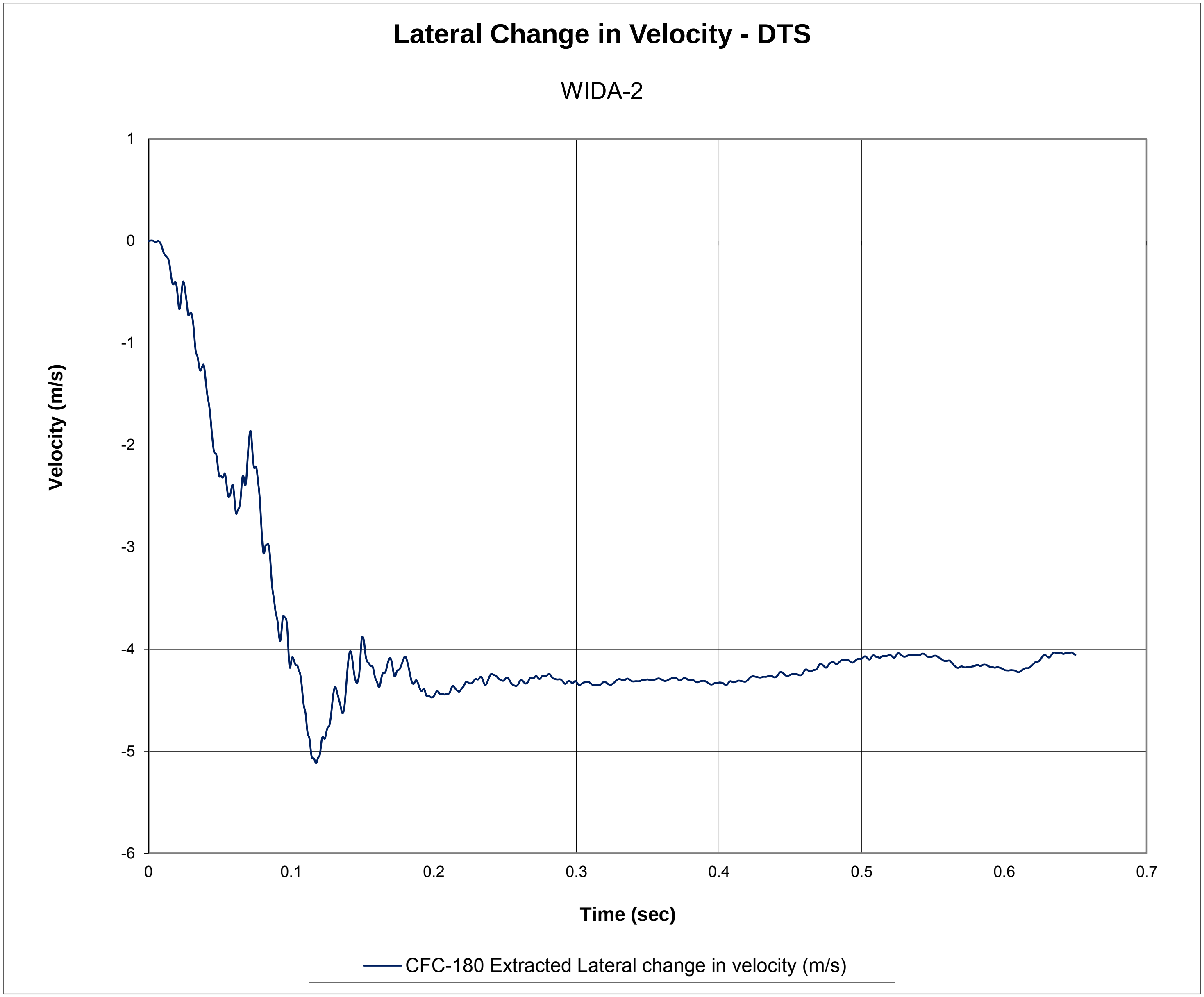


Figure J-5. Lateral Occupant Impact Velocity (DTS), Test No. WIDA-2

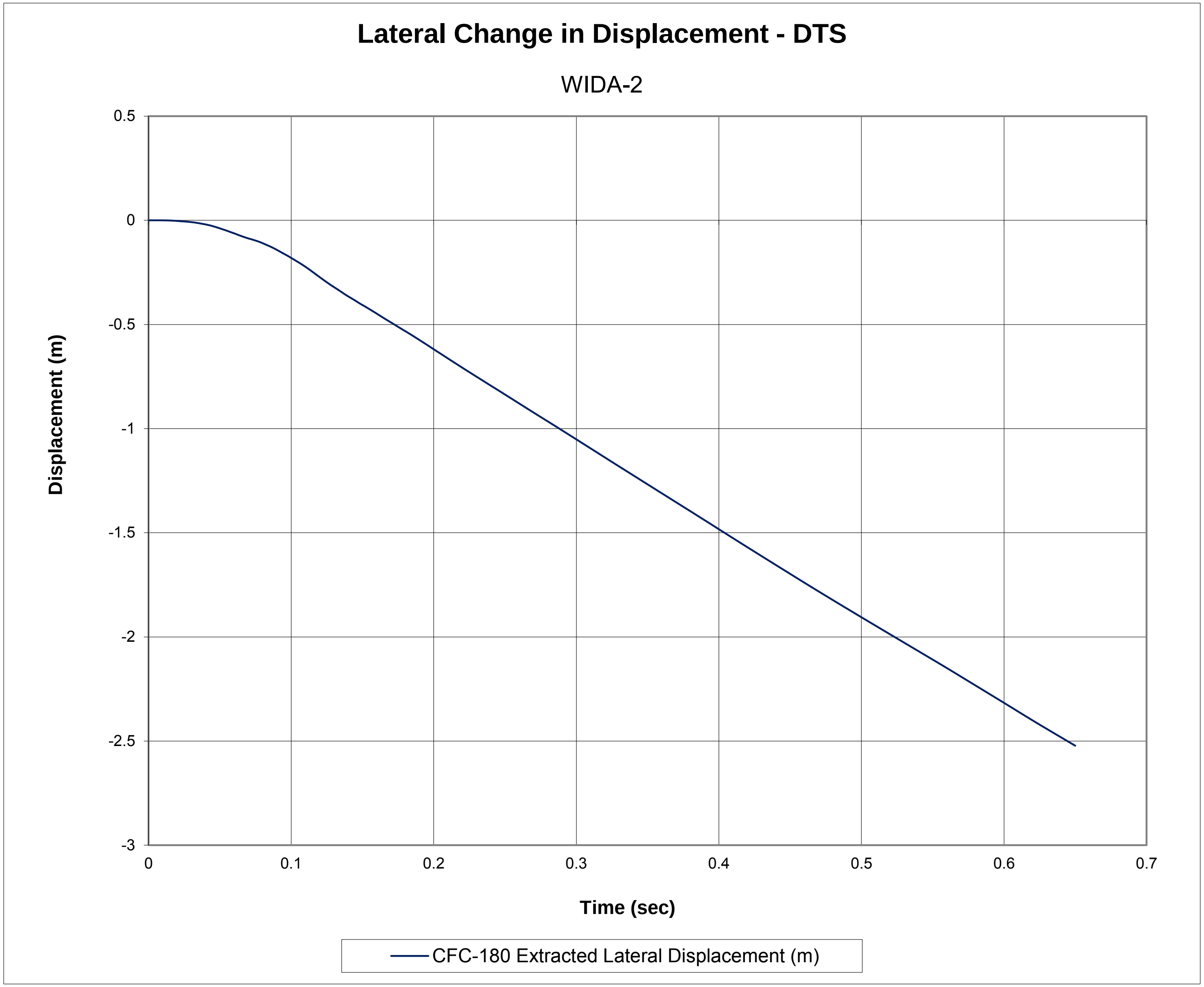


Figure J-6. Lateral Occupant Displacement (DTS), Test No. WIDA-2

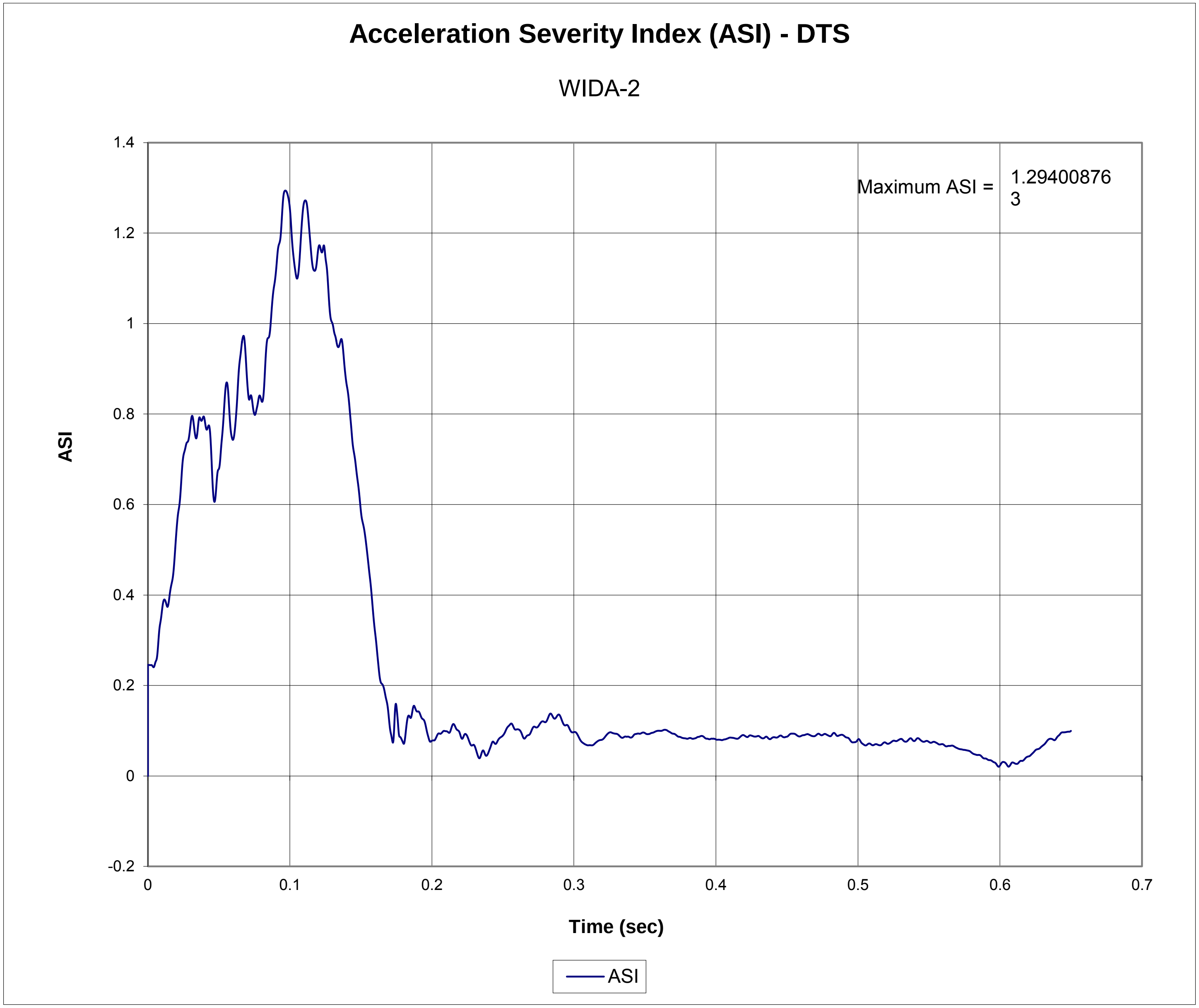


Figure J-7. Acceleration Severity Index (DTS), Test No. WIDA-2

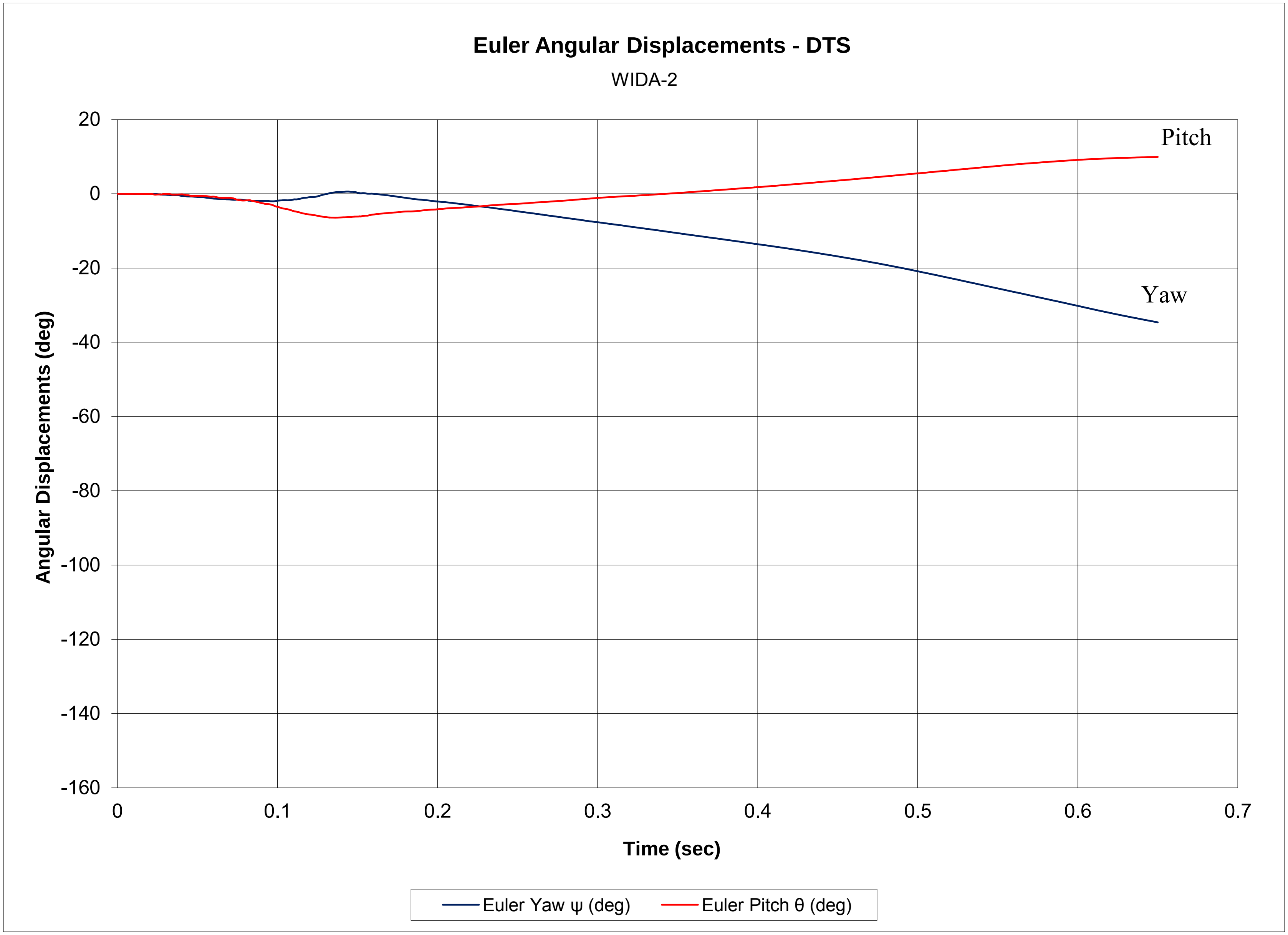


Figure J-8. Vehicle Angular Displacements (DTS), Test No. WIDA-2

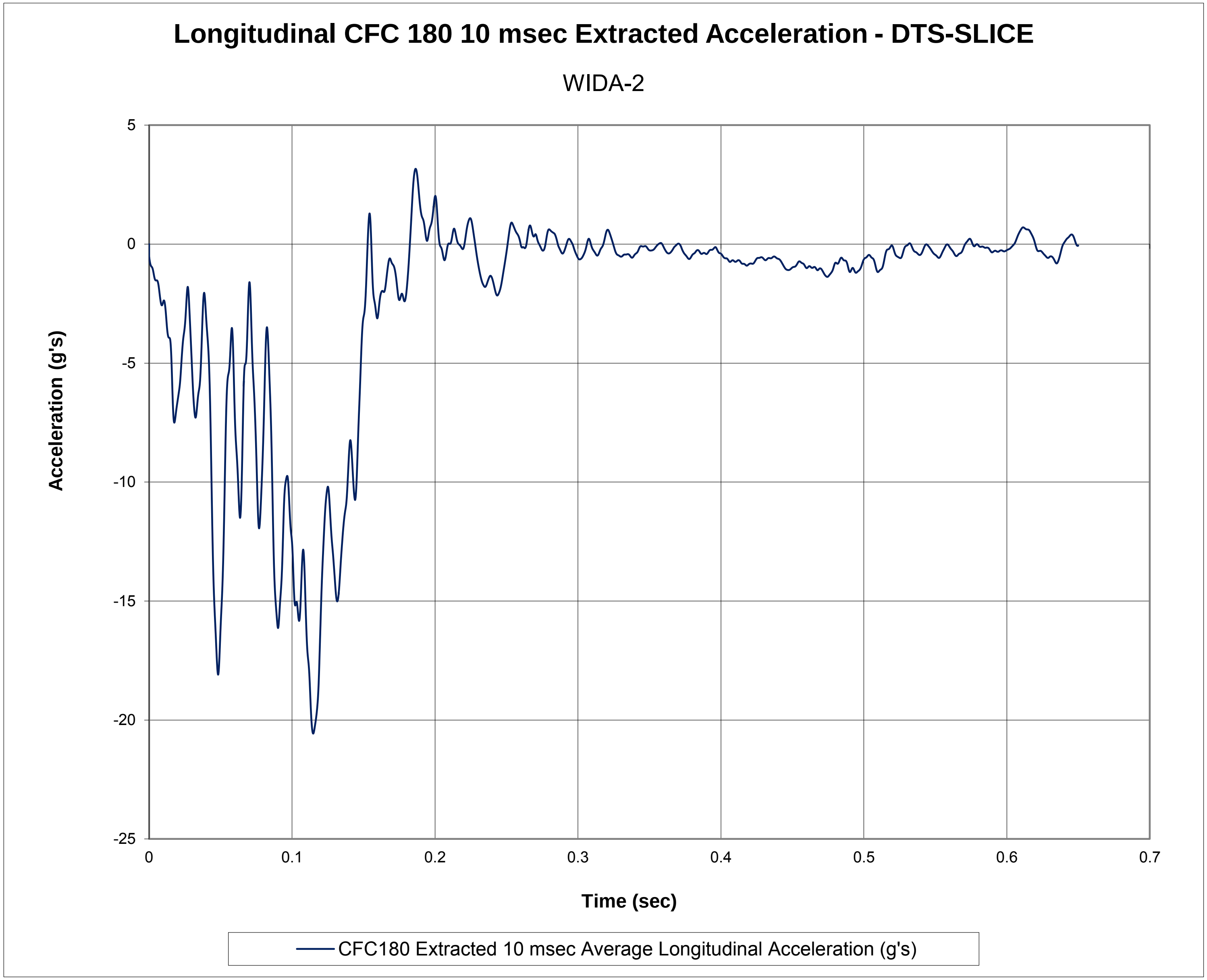


Figure J-9. 10-ms Average Longitudinal Deceleration (DTS - SLICE), Test No. WIDA-2

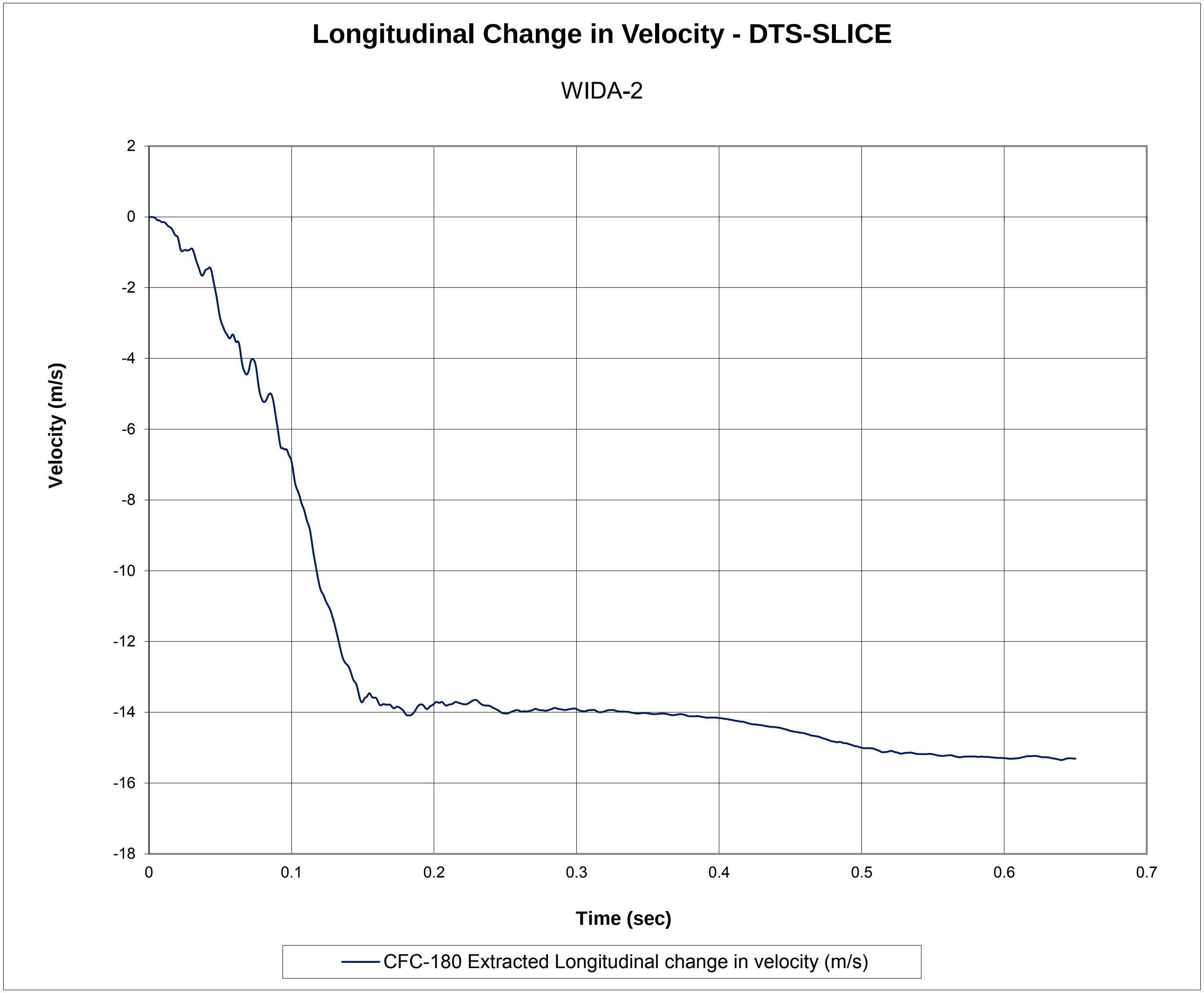


Figure J-10. Longitudinal Occupant Impact Velocity (DTS - SLICE), Test No. WIDA-2

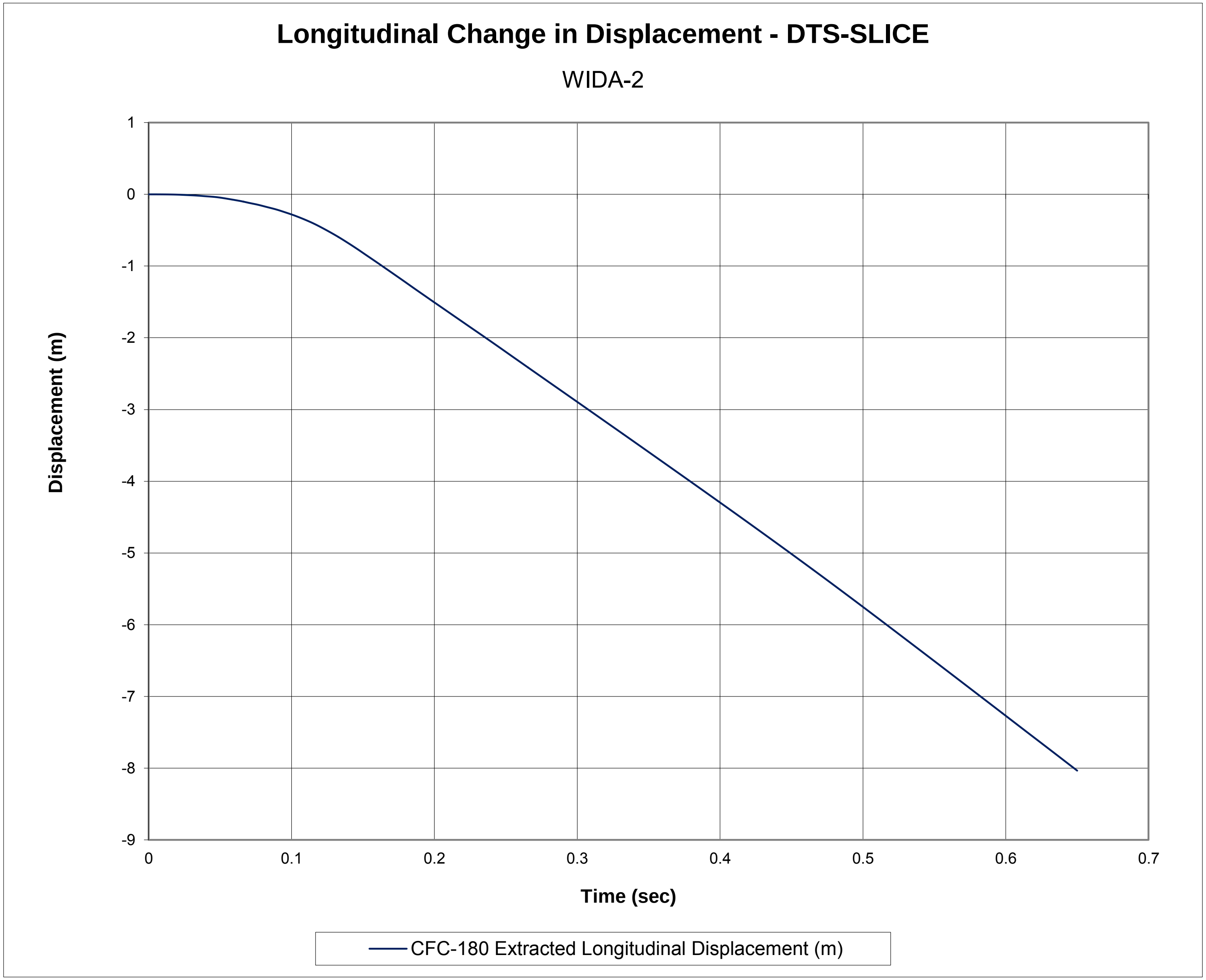


Figure J-11. Longitudinal Occupant Displacement (DTS - SLICE), Test No. WIDA-2

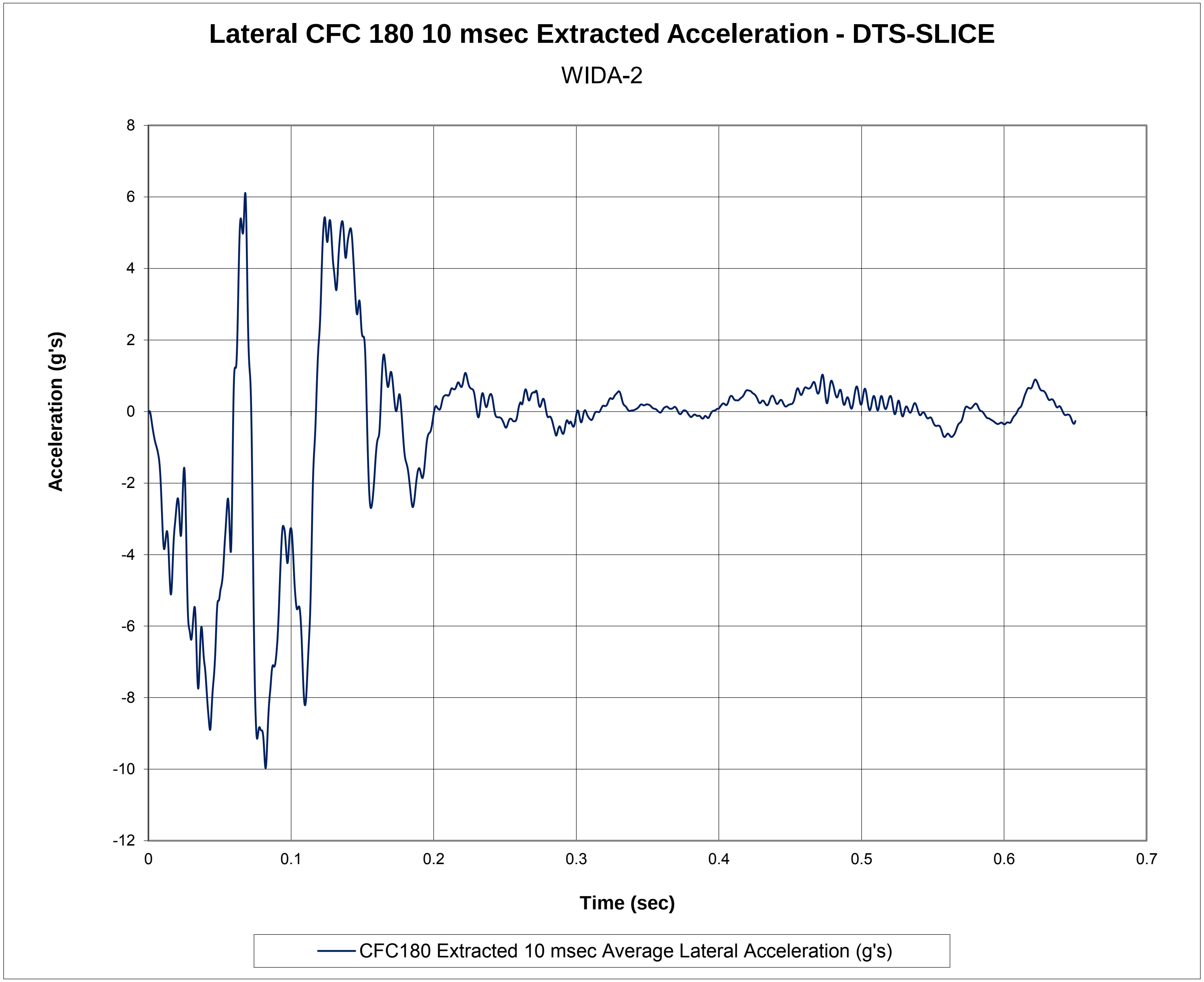


Figure J-12. 10-ms Average Lateral Deceleration (DTS - SLICE), Test No. WIDA-2

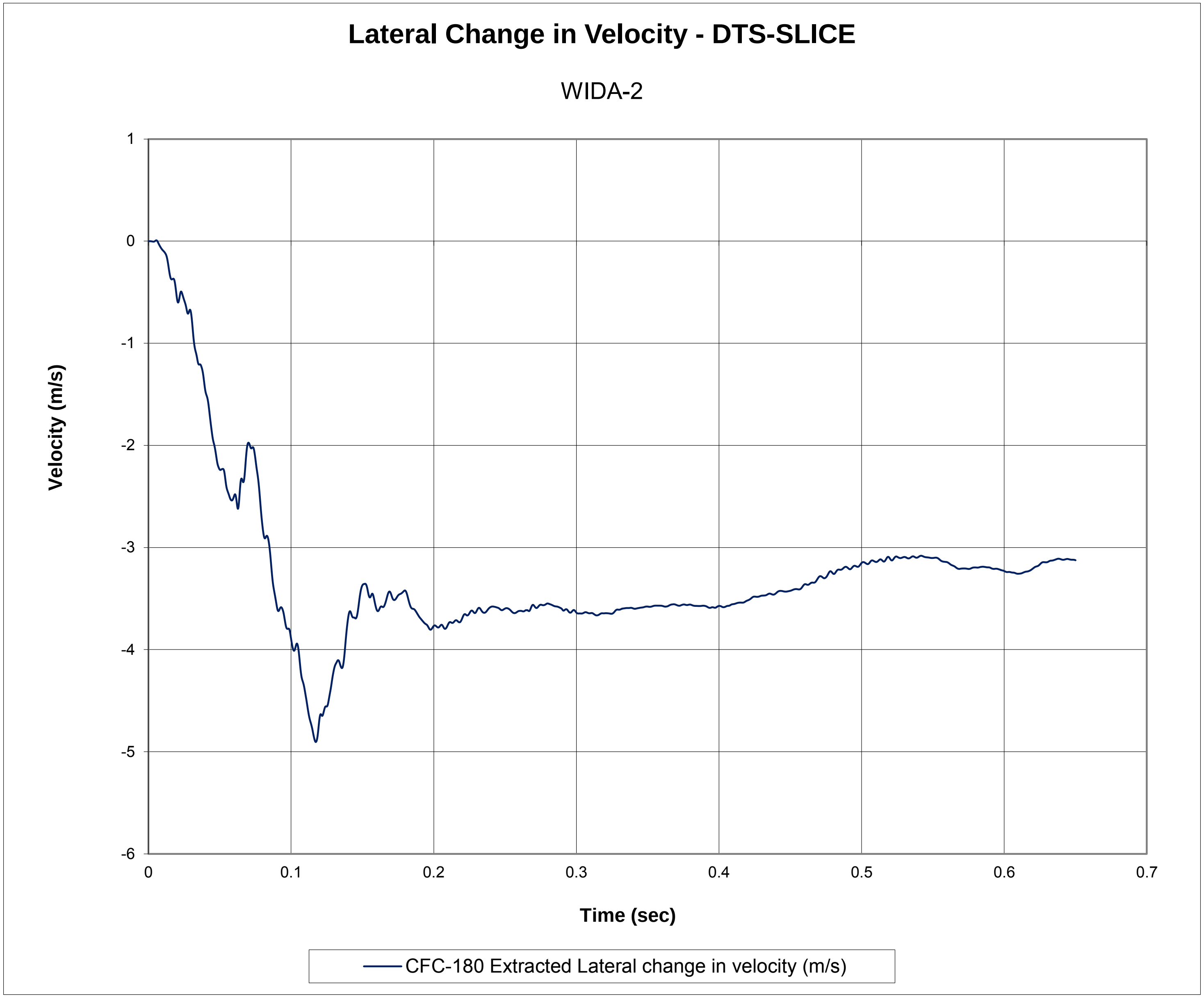


Figure J-13. Lateral Occupant Impact Velocity (DTS - SLICE), Test No. WIDA-2

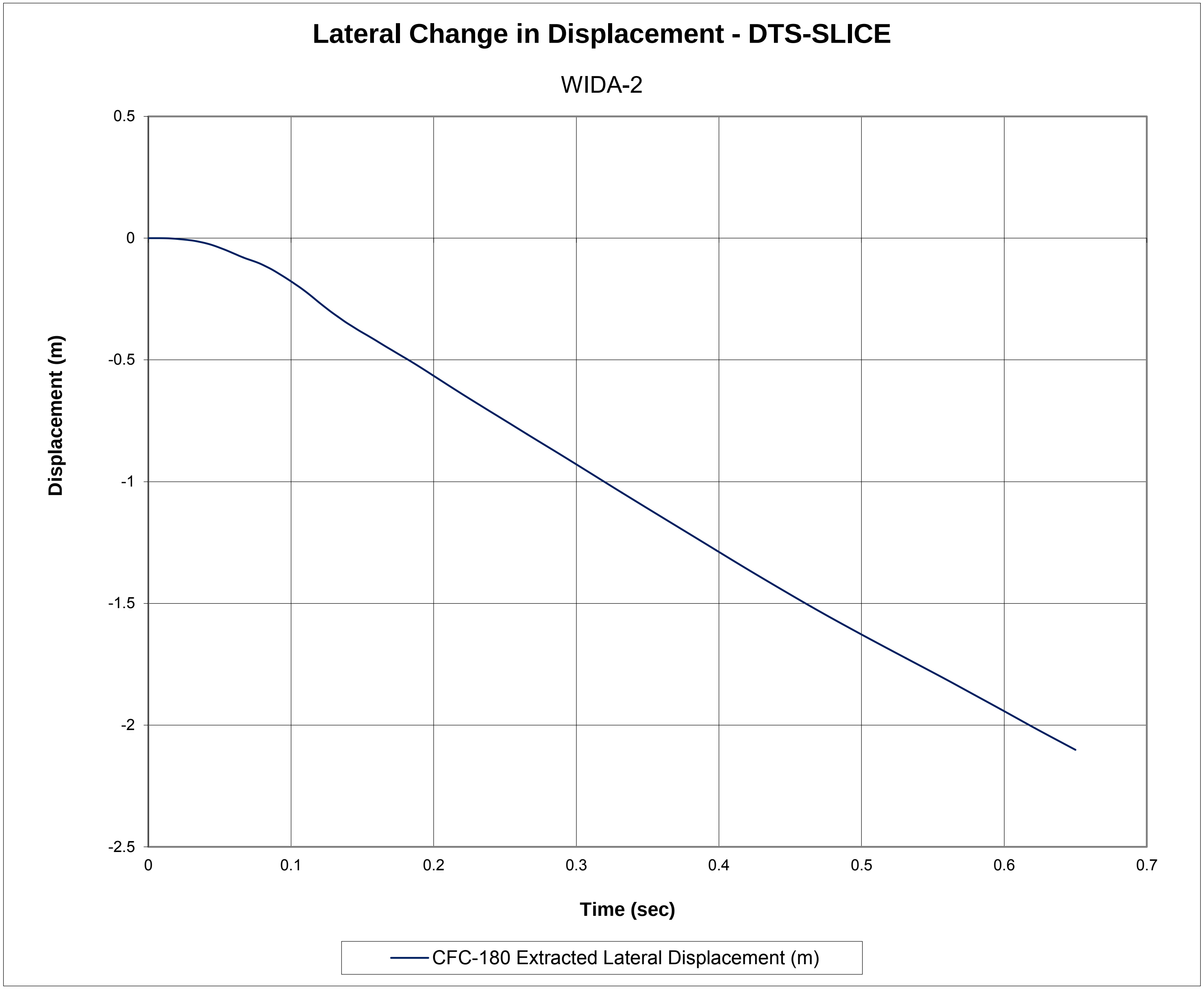


Figure J-14. Lateral Occupant Displacement (DTS - SLICE), Test No. WIDA-2

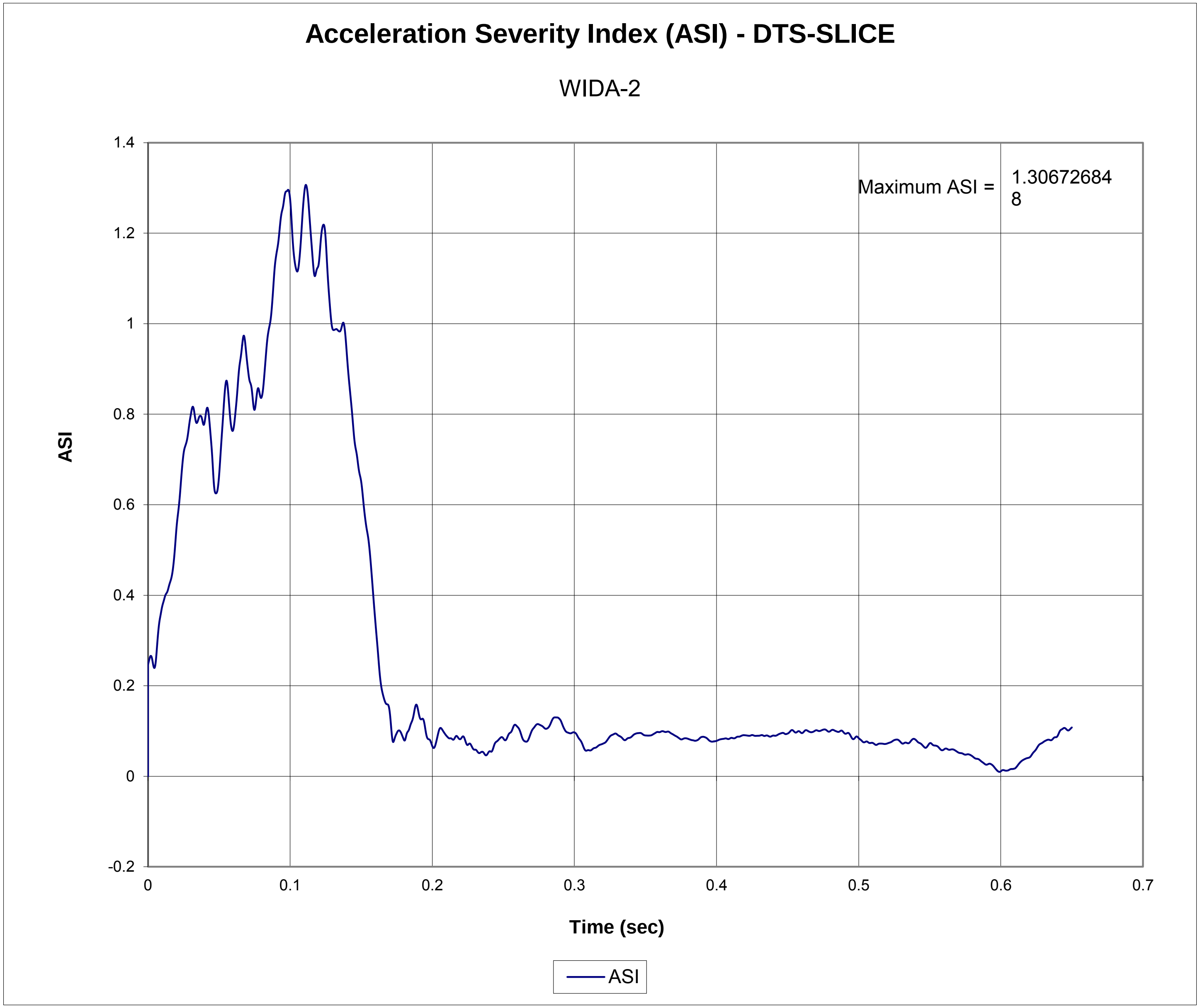


Figure J-15. Acceleration Severity Index (DTS - SLICE), Test No. WIDA-2

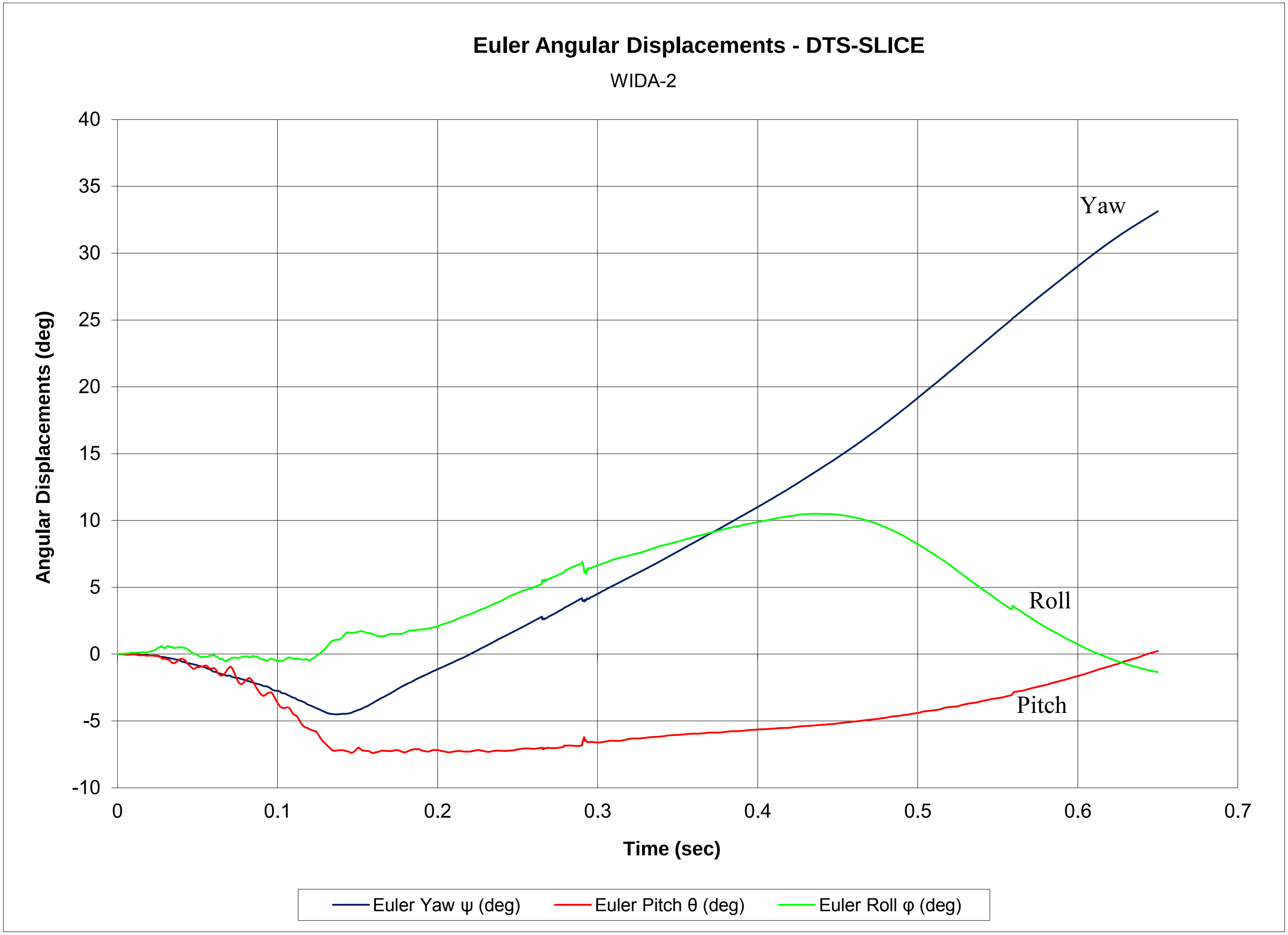


Figure J-16. Vehicle Angular Displacements (DTS - SLICE), Test No. WIDA-2

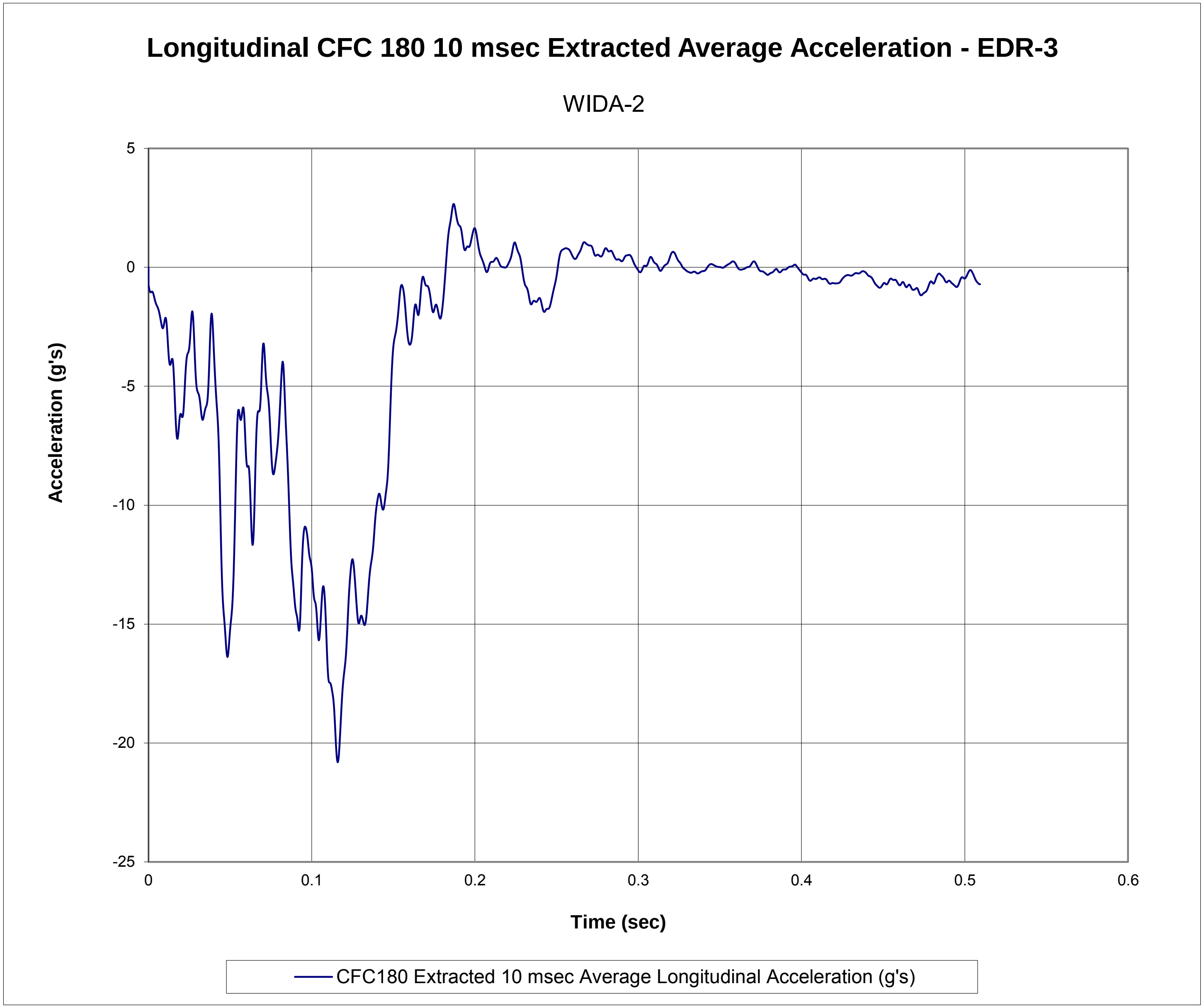


Figure J-17. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. WIDA-2

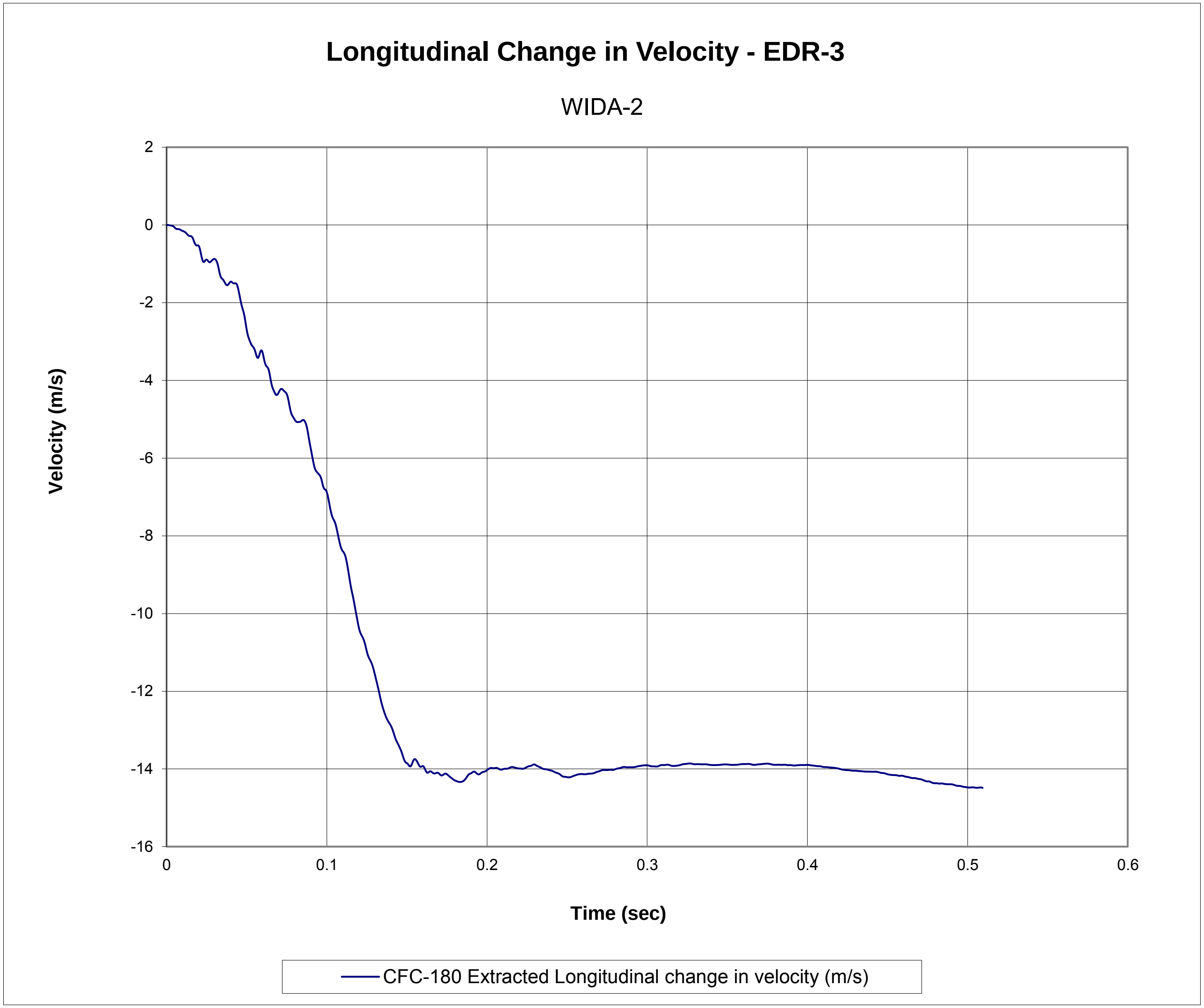


Figure J-18. Longitudinal Occupant Impact Velocity (EDR-3), Test No. WIDA-2

Figure J-19. Longitudinal Occupant Displacement (EDR-3), Test No. WIDA-2

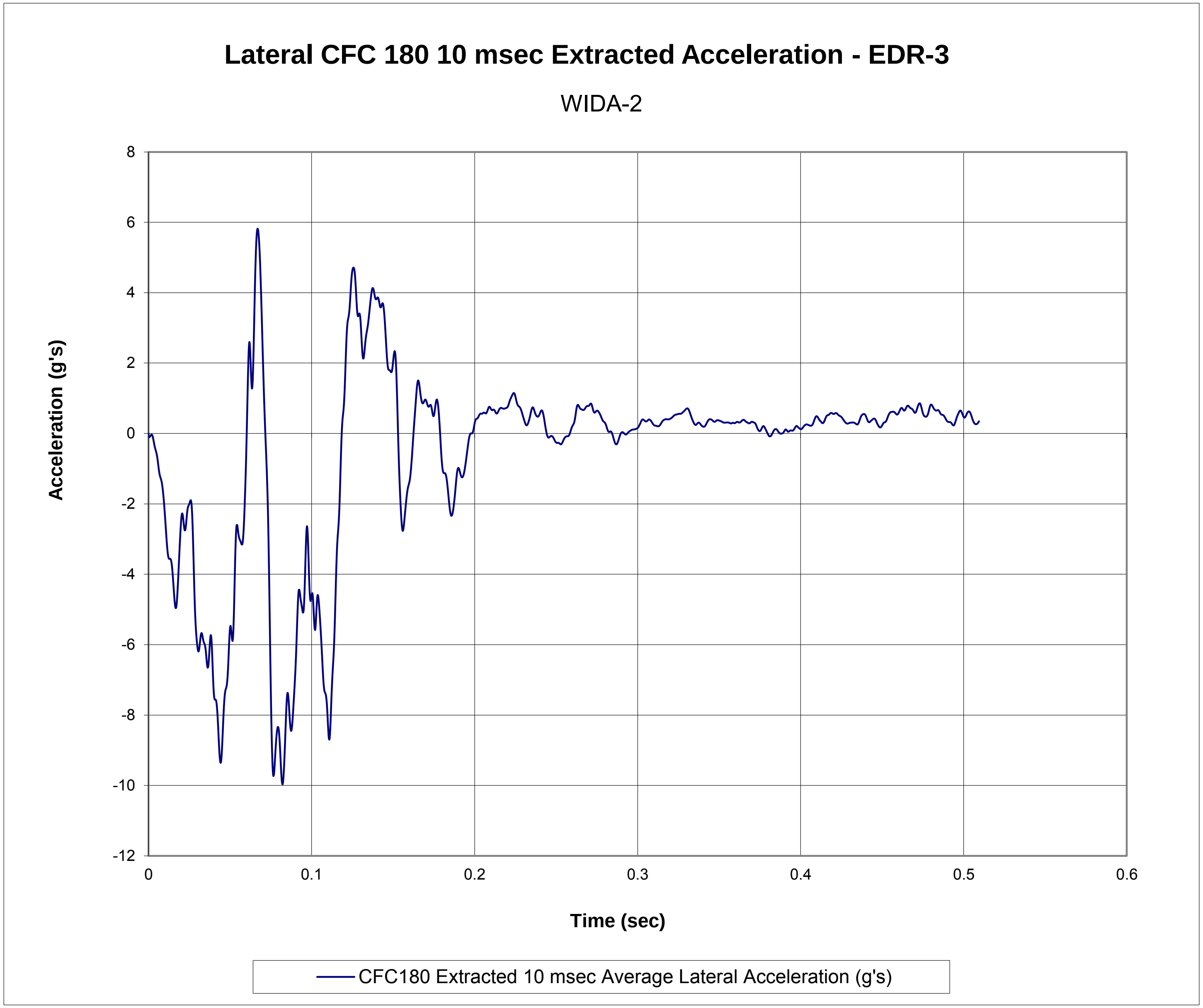


Figure J-20. 10-ms Average Lateral Deceleration (EDR-3), Test No. WIDA-2

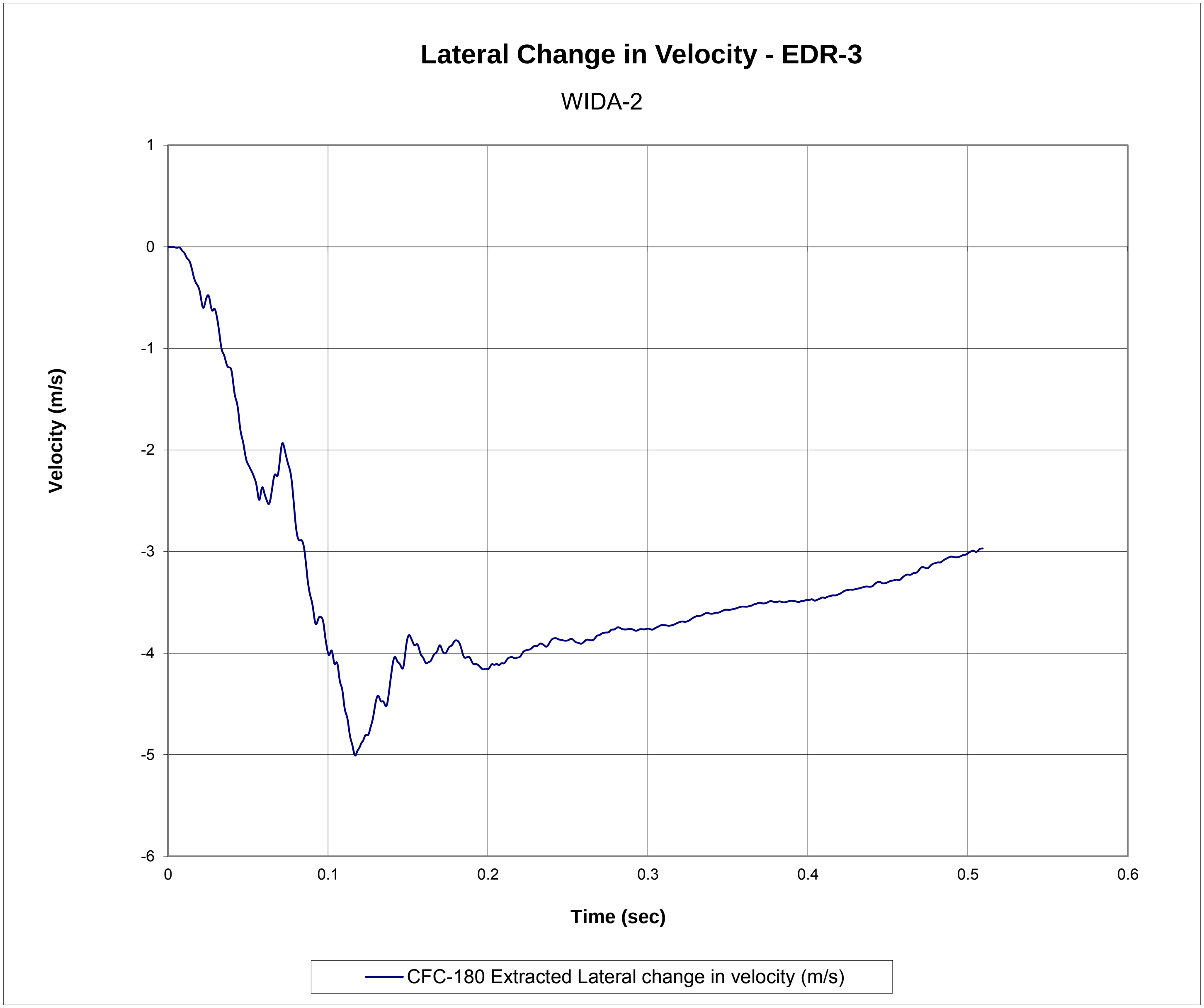


Figure J-21. Lateral Occupant Impact Velocity (EDR-3), Test No. WIDA-2

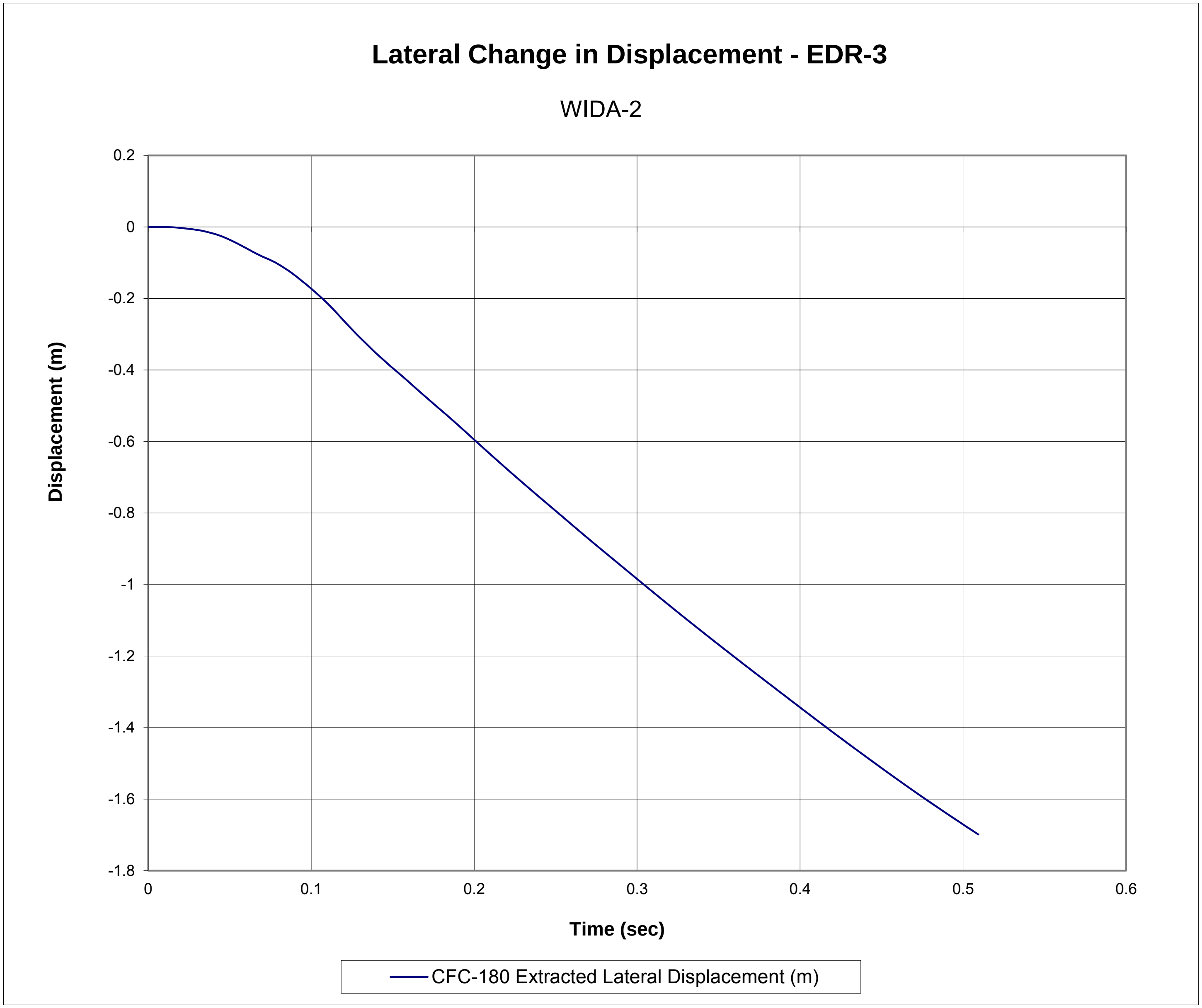


Figure J-22. Lateral Occupant Displacement (EDR-3), Test No. WIDA-2

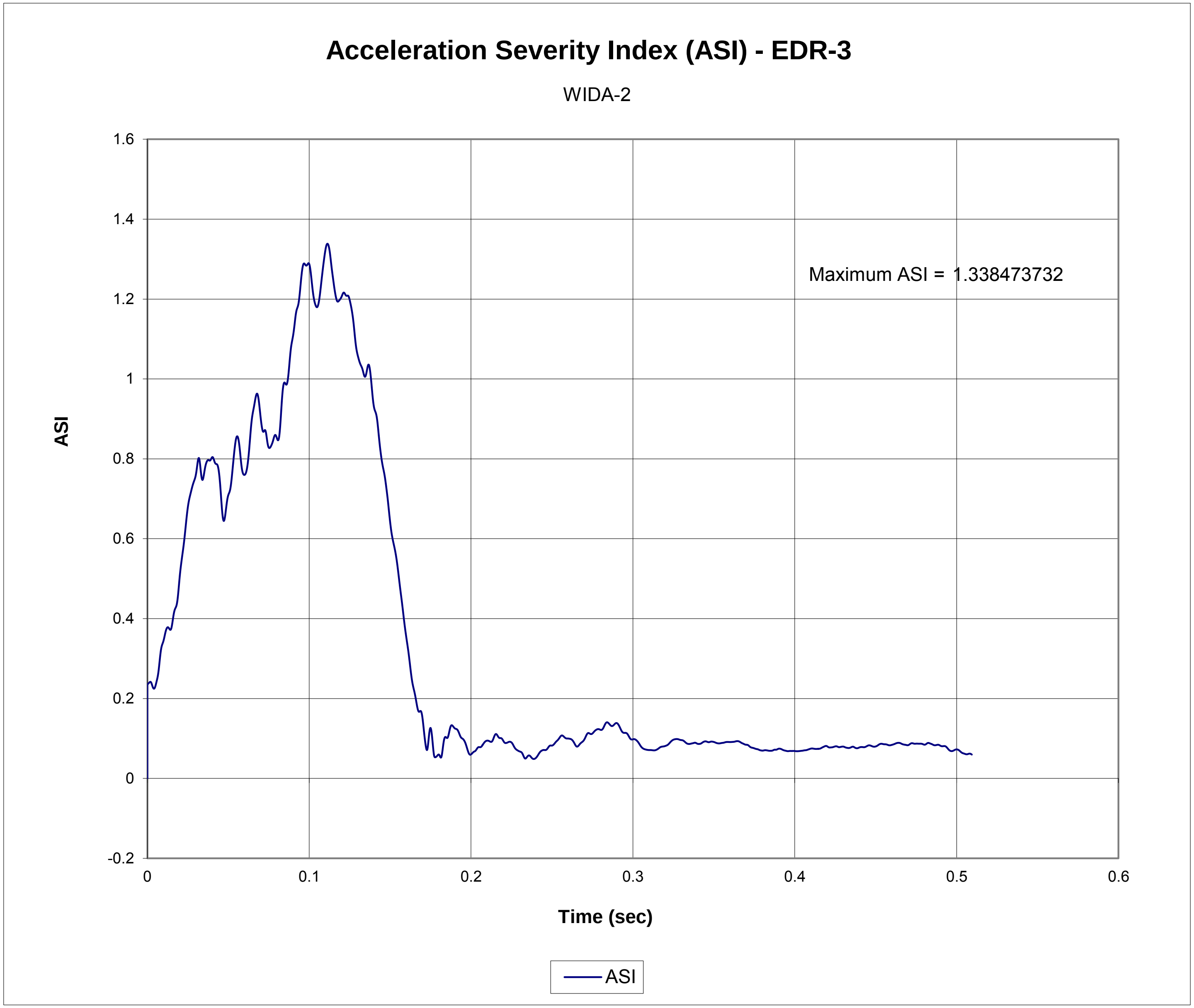


Figure J-23. Acceleration Severity Index (EDR-3), Test No. WIDA-2

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