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Phase IV Development of a Short-Radius Guardrail for Intersecting Roadways

Submitted by

Cody S. Stolle
Undergraduate Research Assistant

Karla A. Polivka, M.S.M.E., E.I.T.
Research Associate Engineer

Robert W. Bielenberg, M.S.M.E., E.I.T.
Research Associate Engineer

John D. Reid, Ph.D.
Professor

Ronald K. Faller, Ph.D., P.E.
Research Assistant Professor

John R. Rohde, Ph.D., P.E.
Associate Professor

Dean L. Sicking, Ph.D., P.E.
Professor and MwRSF Director

MIDWEST ROADSIDE SAFETY FACILITY
University of Nebraska-Lincoln
527 Nebraska Hall
Lincoln, Nebraska 68588-0529
(402) 472-0965

Submitted to

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Nebraska Department of Roads
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

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16. Abstract (Limit: 200 words)

This research study consisted of the development and testing of a short-radius guardrail system for protection of hazards near intersecting roadways and capable of meeting the Test Level 3 (TL-3) impact conditions of the Update to NCHRP Report No. 350 criteria. A short-radius system was designed and consisted of a curved and slotted thrie beam nose section with two adjacent slotted thrie beam sections supported by breakaway posts. One side of the system was attached to a TL-3 steel post approach transition while the other attached to a TL-2 end terminal.

Two full-scale crash tests were conducted on the short-radius guardrail system. Both tests were conducted at the proposed Update to NCHRP Report No. 350 Test Designation 3-33. As such, the impacts were oriented at an angle of 15 degrees to the roadway, and were to occur at the center of the short-radius nose section. In test SR-7, a 2,263-kg (4,989-lb) pickup truck impacted the short-radius with its center aligned with the centerpoint of the nose section at a speed of 100.3 km/h (62.8 mph) and at an angle of 18.1 degrees. The pickup truck was captured by the short-radius system, but the vehicle overrode the thrie beam guardrail and subsequently rolled over. This test was judged unacceptable according to the Update to NCHRP Report No. 350 criteria due to vehicle rollover.

Following the failure the short-radius system was modified by increasing the size of the transverse holes in post nos. 1S, 2S, and 1P, adding washers to post nos. 1S, 2S, 1P, 2P, 3P and 4P, redesigning the cable anchor bracket on post no. 1P, and reducing the width of the outer slot tabs in the nose section. In test SR-8, a 2,268-kg (5,000-lb) pickup truck impacted the short-radius guardrail with its center aligned with the centerpoint of the nose section at a speed of 101.3 km/h (62.8 mph) and at an angle of 17.9 degrees. Once again the pickup truck was captured by the system, but the vehicle overrode the thrie beam guardrail. This test was judged to be unacceptable according to the proposed Update to NCHRP Report No. 350 criteria due to vehicle override of the guardrail.

After review of the full-scale tests, it was evident that the short-radius guardrail system showed significant improvement over the original system developed by the Midwest Roadside Safety Facility, but further development is required.

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DISCLAIMER STATEMENT

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<u>Midwest Roadside Safety Facility</u>

J.C. Holloway, Research Manager
C.L. Meyer, Research Engineer II
S.K. Rosenbaugh, M.S.C.E., E.I.T., Research Associate Engineer
A.T. Russell, Laboratory Mechanic II
K.L. Krenk, Field Operations Manager
A.T. McMaster, Laboratory Mechanic I
Undergraduate and Graduate Assistants

California Department of Transportation

Wes Lum, P.E., Office Chief National Liaison

Connecticut Department of Transportation

Dionysia Oliveira, Transportation Engineer 3

Illinois Department of Transportation

David Piper, P.E., Highway Policy Engineer

Iowa Department of Transportation

David Little, P.E., Assistant District Engineer
Deanna Maifield, Methods Engineer
Chris Poole, Transportation Engineer Specialist

Kansas Department of Transportation

Ron Seitz, P.E., Bureau Chief
Rod Lacy, P.E., Road Design Leader
Scott W. King, P.E., Road Design Leader

Minnesota Department of Transportation

Mohammad Dehdashti, P.E., Design Standard Engineer
Michael Elle, P.E., Design Standard Engineer

Missouri Department of Transportation

Joseph G. Jones, Technical Support Engineer

Nebraska Department of Roads

Amy Starr, Research Engineer
Phil TenHulzen, P.E., Design Standards Engineer
Jodi Gibson, Research Coordinator

New Jersey Department of Transportation

Kiran Patel, P.E., P.M.P, C.P.M, Deputy State Transportation Engineer

Ohio Department of Transportation

Dean Focke, P.E., Roadway Safety Engineer

South Dakota Department of Transportation

David Huft, Research Engineer
Bernie Clocksin, Lead Project Engineer
Paul Oien, Project Engineer

Wisconsin Department of Transportation

John Bridwell, Standards Development Engineer
Erik Emerson, Standards Development Engineer

Wyoming Department of Transportation

William Wilson, P.E., Standards Engineer

Federal Highway Administration

John Perry, P.E., Nebraska Division Office
Danny Briggs, Nebraska Division Office

Dunlap Photography

James Dunlap, President and Owner

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1 INTRODUCTION

1.1 Problem Statement

A short-radius guardrail is a common safety treatment for situations where driveways or secondary roadways intersect a high-speed roadway near a bridge. Short-radius guardrail systems involve a curved section of guardrail placed around the corner of the intersecting roadway with tangent sections on each end that parallel the respective roadways. The tangent sections of guardrail found along the primary roadway are generally attached to an approach guardrail transition and then anchored to a bridge rail, while the sections found along the secondary roadway are generally attached to a guardrail end terminal. A short-radius guardrail system is intended to perform in a similar manner to a bullnose median barrier or a crash cushion. For example, when a high-angle impact occurs in the curved portion of the system, the vehicle is to be captured and brought to a controlled stop. In addition, the system must be capable of redirecting impacting vehicles along the tangent sections of the guardrail installation.

Recently, the members of the Midwest States' Regional Pooled Fund Program contracted with the Midwest Roadside Safety Facility (MwRSF) to develop a new short-radius guardrail design that would meet the Test Level 3 (TL-3) criteria set forth in the National Cooperative Highway Research Program (NCHRP) Report No. 350 (1). Previously, MwRSF conducted a review of past NCHRP Report No. 230 (2) short-radius designs, identified the important design considerations for such a system, and developed an initial design concept for a TL-3 short-radius system (3-10). Furthermore, MwRSF conducted a series of six full-scale crash tests on this short-radius system (11,12). Phase IV of this research, described herein, consisted of further analysis, design, and full-scale testing of the short-radius system. In addition, the system was tested with newer vehicles to reflect the impending performance criteria updates found in the currently proposed Update to NCHRP Report No. 350 (13).

1.2 Objective

The objective of this research study was to evaluate the safety performance of the short-radius guardrail system through full-scale crash testing and modify the design, as necessary, in order to improve its safety performance. The system's safety performance was evaluated according to the TL-3 criteria set forth in the currently proposed Update to NCHRP Report No. 350.

1.3 Scope

Two full-scale crash tests of the short-radius guardrail system were conducted in order to reach the research objective. The two tests utilized a 1/2-ton, quad-cab pickup trucks weighing approximately 2,270 kg (5,004 lbs). Both tests were conducted according to the test requirements in the currently proposed Update to NCHRP Report No. 350. Test 3-33 is a TL-3 test of a vehicle impacting at a target impact speed of 100 km/h (62.1 mph) and at an angle of 15 degrees on the center of the curved nose of the system. The test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made that pertain to the safety performance of the short-radius guardrail design.

2 UPDATE TO NCHRP 350 TESTING AND EVALUATION CRITERIA

2.1 Test Requirements

Due to the nature of potential impacts into the curved section of a short-radius guardrail system, it was believed necessary to classify the system as either a terminal or crash cushion in order to determine the appropriate crash tests and evaluation criteria found in the currently proposed Update to NCHRP Report No. 350. A short-radius guardrail should be defined as a non-gating device and must fulfill the requirements for non-gating terminals. A non-gating device is designed to contain and redirect a vehicle when impacted downstream from the end of the device. According to the currently proposed Update to NCHRP Report No. 350, all non-gating end terminals and crash cushions must be subjected to nine full-scale vehicle crash tests, five using a 2,270-kg (5,004-lb) pickup truck, three using an 1,100-kg (2,425-lb) small car and one using a 1,500-kg (3,307-lb) intermediate car. The required 2,270-kg (5,004-lb) pickup truck crash tests for a TL-3 device are:

(1) Test Designation 3-31 consisted of a 100 km/h (62.1 mph) impact at a nominal angle of 0 degrees on the tip of the barrier nose.
(2) Test Designation 3-33 consisted of a 100 km/h (62.1 mph) impact at a nominal angle of 15 degrees on the tip of the barrier nose.
(3) Test Designation 3-35 consisted of a 100 km/h (62.1 mph) impact at a nominal angle of 25 degrees on the beginning of the Length-of-Need (LON).
(4) Test Designation 3-36 consisted of a 100 km/h (62.1 mph) impact at a nominal angle of 25 degrees on the Critical Impact Point (CIP) with respect to the transition to the backup structure.
(5) Test Designation 3-37 consisted of a 100 km/h (62.1 mph) reverse direction impact at an angle of 25 degrees on the reverse impact Critical Impact Point (CIP).

The required 1,100-kg (2,425-lb) small car crash tests for a TL-3 device are:

(1) Test Designation 3-30 consisted of a 100 km/h (62.1 mph) impact at a nominal angle of 0 degrees on the tip of the barrier nose with a ¼-point offset.
(2) Test Designation 3-32 consisted of a 100 km/h (62.1 mph) impact at a nominal angle of 15 degrees on the tip of the barrier nose.
(3) Test Designation 3-34 consisted of a 100 km/h (62.1 mph) impact at a nominal impact angle of 15 degrees on the Critical Impact Point (CIP).

The required 1,500-kg (3,307-lb) intermediate car crash test for a TL-3 device is:

(1) Test Designation 3-38 consisted of a 100 km/h (62.1 mph) impact at a nominal angle of 0 degrees on the tip of the barrier nose.

Of the nine recommended compliance tests, it was deemed that only five crash tests were necessary for evaluating the short-radius system's safety performance. The length of need test, 3-35, was not conducted because previous testing has shown that thrie beam guardrail is capable of meeting the length of need requirements found in the safety standards (14, 15). Similarly, the reverse direction impact test was not tested. Test 3-37 calls for a reverse direction impact of a 2,270-kg (5,004-lb) pickup truck at the CIP of a reverse direction impact. Thus, based on previous experience with straight thrie beam guardrail testing, it was believed that test 3-39 was unnecessary. At this time, the stability test utilizing the new 1,500-kg (3,307-lb) vehicle was not conducted because it was believed, due to greater penetration into the system and higher CG heights, that the pickup test would be a more pertinent evaluation of vehicle stability than the mid-size vehicle. Thus, test 3-38 was believed to be unnecessary. In addition, test 3-36 is designed to examine the behavior of terminals when attached to rigid barriers or other very stiff features. Thus, test 3-36 was deemed unnecessary since it would not be attached directly to a stiff barrier. A diagram showing the impact location for the nine crash tests is shown in Figure 1.

2.2 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. The criteria for structural adequacy are intended to evaluate a barrier's ability to contain, redirect, or allow controlled penetration in a predictable manner. Occupant risk criteria evaluate the degree of hazard to which the occupants in the impacting vehicle are affected by impact with the barrier system. Vehicle trajectory after collision is a measure of the potential for the vehicle, upon redirection, to encroach into adjacent traffic lanes and cause subsequent multi-vehicle accidents. This criterion also indicates the potential safety hazard for the occupants of the impacting vehicle associated with secondary collisions with other fixed objects. These three evaluation criteria are defined in Table 1. The full-scale vehicle crash test was conducted and reported in accordance with the evaluation procedures provided in the currently proposed Update to NCHRP Report No. 350.

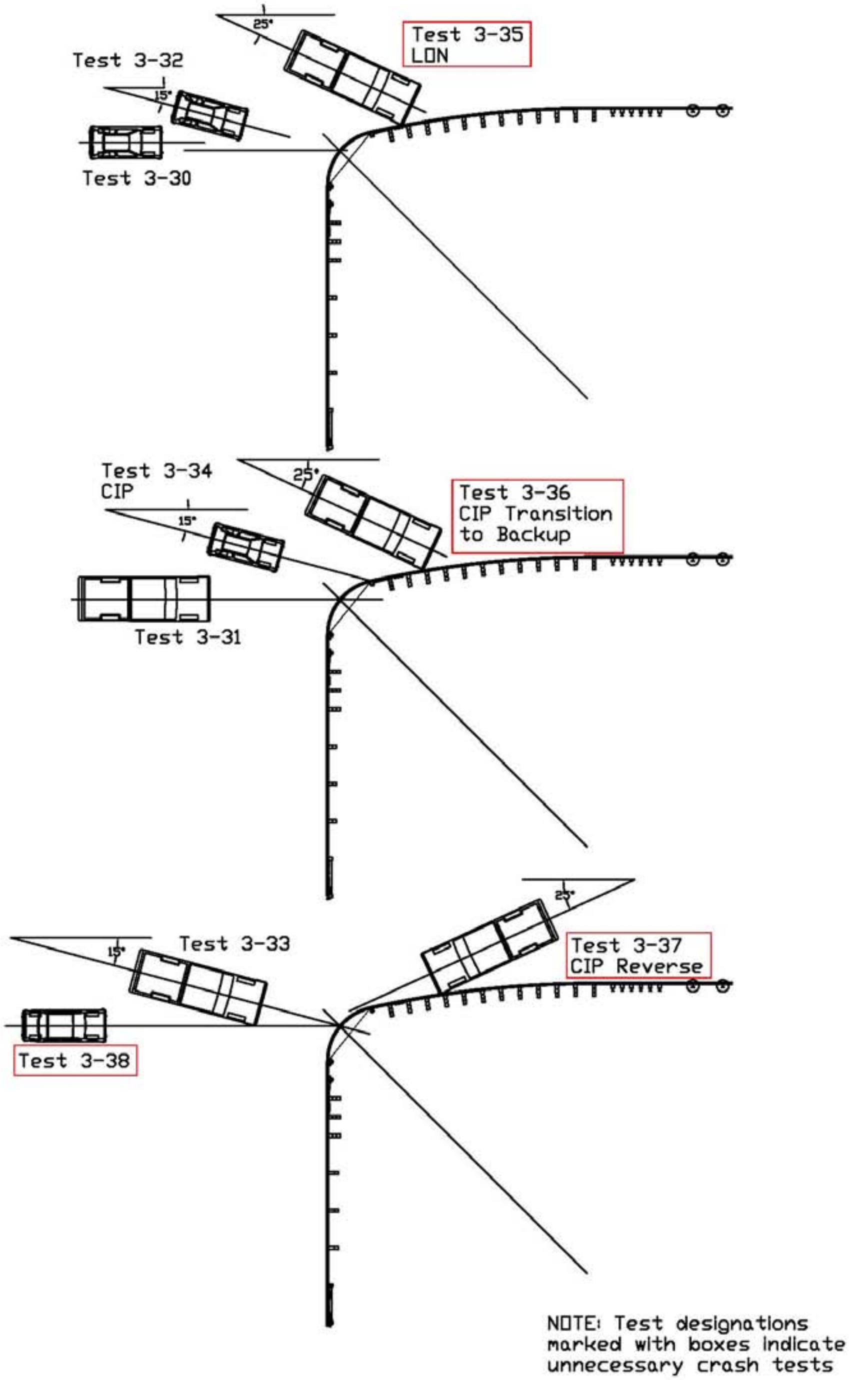


Figure 1. Full-Scale Crash Test Matrix

Table 1. Currently Proposed Update to NCHRP Report No. 350 Evaluation Criteria for Non-Gating Terminal Crash Tests

Evaluation Factors	**Evaluation Criteria**	**Applicable Tests**
Structural Adequacy	A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	ALL
Occupant Risk	D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the passenger compartment should not exceed the limits set forth in Section 5.3 and Appendix E of the currently proposed Update to NCHRP 350.	ALL
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	ALL
	H. Longitudinal and lateral occupant compartment impact velocities should fall below the preferred value of 9.1 m/s (30.0 ft/s), or at least below the maximum allowable value of 12.2 m/s (40.0 ft/s).	ALL
	I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g’s, or at least below the maximum allowable value of 20.49 g’s.	ALL

3 TEST CONDITIONS

3.1 Test Facility

The testing facility is located at the Lincoln Air-Park on the northwest (NW) side of the Lincoln Municipal Airport and is approximately 8.0 km (5.0 miles) NW of the University of Nebraska-Lincoln.

3.2 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 short-radius system. A digital speedometer on the tow vehicle increases the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch (16) was used to steer the test vehicle. A guide-flag, attached to the front-left wheel and the guide cable, was sheared off before impact with the barrier. The 9.5-mm (3/8-in.) diameter guide cable was tensioned to approximately 15.6 kN (3.5 kips), and supported laterally and vertically every 30.48 m (100 ft) 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. The vehicle guidance systems for test nos. SR-7 and SR-8 were approximately 335 m (1,100 ft) long.

3.3 Test Vehicles

For test no. SR-7, a 2002 Dodge Ram 1500 Quad Cab pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,263 kg (4,989 lbs). The test vehicle is shown in Figure 2, and vehicle dimensions are shown in Figure 3.

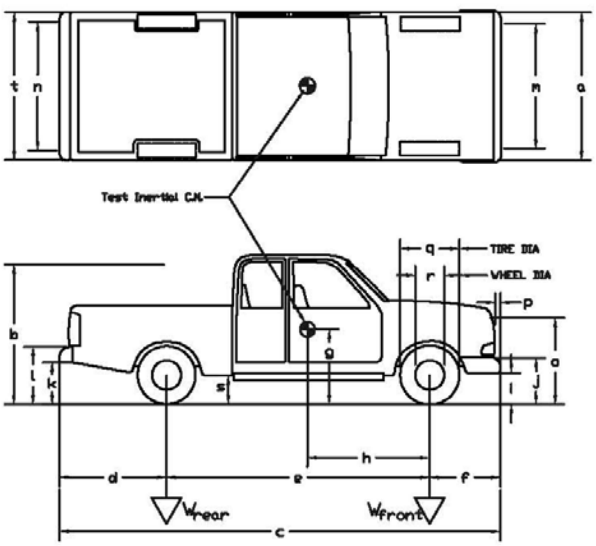
Figure 2. Test Vehicle, Test SR-7

Date: 6/27/06 Test Number: SR-7 Model: RAM 1500 Q.C. 4x2

Make: Dodge Vehicle I.D.#: 3D7HA18N32G183419

Tire Size: 265/70 R17 Year: 2002 Odometer: 139375

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1975 (77.75)	b	1930 (76)
c	5775 (227.375)	d	1194 (47)
e	3562 (140.25)	f	1019 (40.125)
g	711 (28)	h	1595 (62.8)
i	400 (15.75)	j	740 (29.25)
k	533 (21)	l	740 (29.125)
m	1727 (68)	n	1708 (67.25)
o	1118 (44)	p	76 (3)
q	800 (31.5)	r	470 (18.5)
s	425 (16.75)	t	1921 (75.625)

Wheel Center Height Front 384 (15.125)

Wheel Center Height Rear 391 (15.375)

Wheel Well Clearance (FR) 914 (36)

Wheel Well Clearance (RR) 972 (38.25)

Frame Height (FR) 457 (18)

Frame Height (RR) 635 (25)

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	1271 (2801)	1246 (2747)	1246 (2747)
W_{rear}	1007 (2220)	1017 (2242)	1017 (2242)
W_{total}	2277 (5021)	2263 (4989)	2263 (4989)

GVWR Rating

front 3650

rear 3900

total 6650

Engine Type 8 CYL. GAS

Engine Size 4.7 L

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

Note any damage prior to test: Previous LSC-1 Driver Side Repair

Figure 3. Vehicle Dimensions, Test SR-7

For test no. SR-8, a 2003 Dodge Ram Quad Cab pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,268 kg (5,000 lbs). The test vehicle is shown in Figure 4, and vehicle dimensions are shown in Figure 5.

The Suspension Method (17) was used to determine the vertical component of the center of gravity for the pickup trucks. 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 in three positions, and the respective planes containing the cg were established. The longitudinal component of the c.g. was determined using measured axle weights. The location of the final center of gravity is shown in Figures 2 through 5.

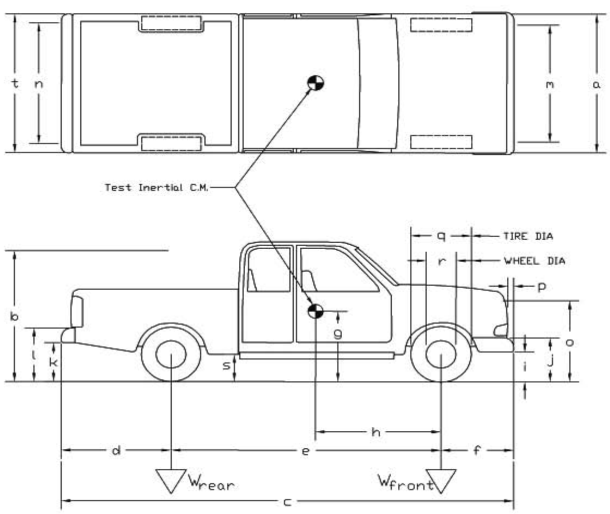
Square black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed digital video, as shown in Figures 6 and 7. Checkered targets were placed on the center of gravity, the left-side door, the right-side door, and the roof of the vehicle. The remaining targets were located for reference so that they could be viewed from the high-speed cameras for video analysis.

The front wheels of the vehicle were aligned for camber, castor, and toe-in values of zero, so that the vehicle would track properly along the guide cable. A 5B flash bulb was mounted on the dashboard of the test vehicles to pinpoint the time of impact with the barrier system on the high-speed videos. The flash bulbs were fired by a pressure tape switch located on the front face of the bumper. A remote-controlled brake system was installed so the test vehicle could be brought to a controlled stop after the test.

Figure 4. Test Vehicle, Test SR-8

Date:	8/1/2007	Test Number:	SR-8	Model:	Ram 1500 Q.C.
Make:	Dodge	Vehicle I.D.#:	1D7HA18N83J526581		
Tire Size:	265/70 R17	Year:	2003	Odometer:	139905

*(All Measurements Refer to Impacting Side)



Vehicle Geometry -- mm (in.)

a	1993.9	(78.5)	b	1917.7	(75.5)
c	5829.3	(229.5)	d	1149.4	(45.25)
e	3562.4	(140.25)	f	1117.6	(44.0)
g	714.38	(28.125)	h	1574.8	(62.0)
i	412.75	(16.25)	j	628.65	(24.75)
k	527.05	(20.75)	l	742.95	(29.25)
m	1727.2	(68.0)	n	1720.9	(67.75)
o	1104.9	(43.5)	p	88.9	(3.5)
q	800.1	(31.5)	r	469.9	(18.5)
s	393.7	(15.5)	t	1968.5	(77.5)

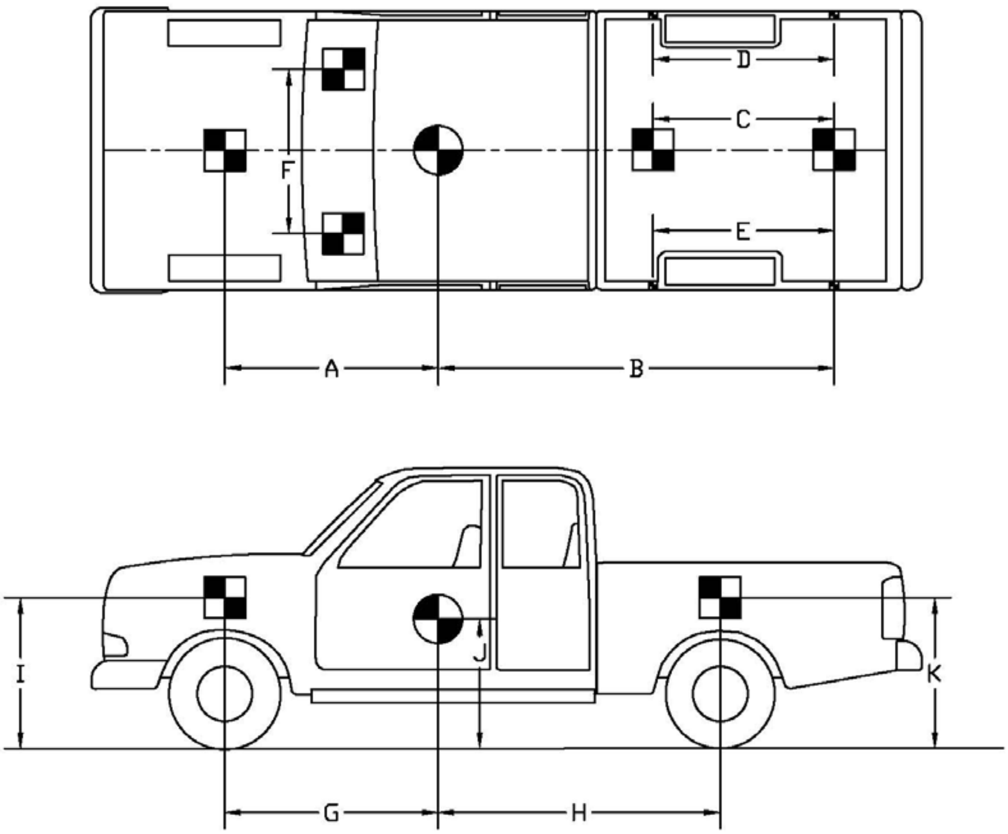
Wheel Center Height Front	374.65	(14.75)
Wheel Center Height Rear	387.35	(15.25)
Wheel Well Clearance (FR)	850.9	(33.5)
Wheel Well Clearance (RR)	965.2	(38.0)
Frame Height (FR)	457.2	(18.0)
Frame Height (RR)	635	(25.0)
Engine Type	8 CYL. GAS	
Engine Size	4.7L	
Transmition Type:	Automatic RWD	

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W-front	1294.6 (2854)	1260.1 (2778)	1033.3 (2278)
W-rear	1041.9 (2297)	1007.9 (2222)	1007.9 (2222)
W-total	2336.5 (5151)	2268 (5000)	2268 (5000)

Front GVWR	3650
Rear GVWR	3900
Total GVWR	6650

Note any damage prior to test: None

Figure 5. Vehicle Dimensions, Test SR-8

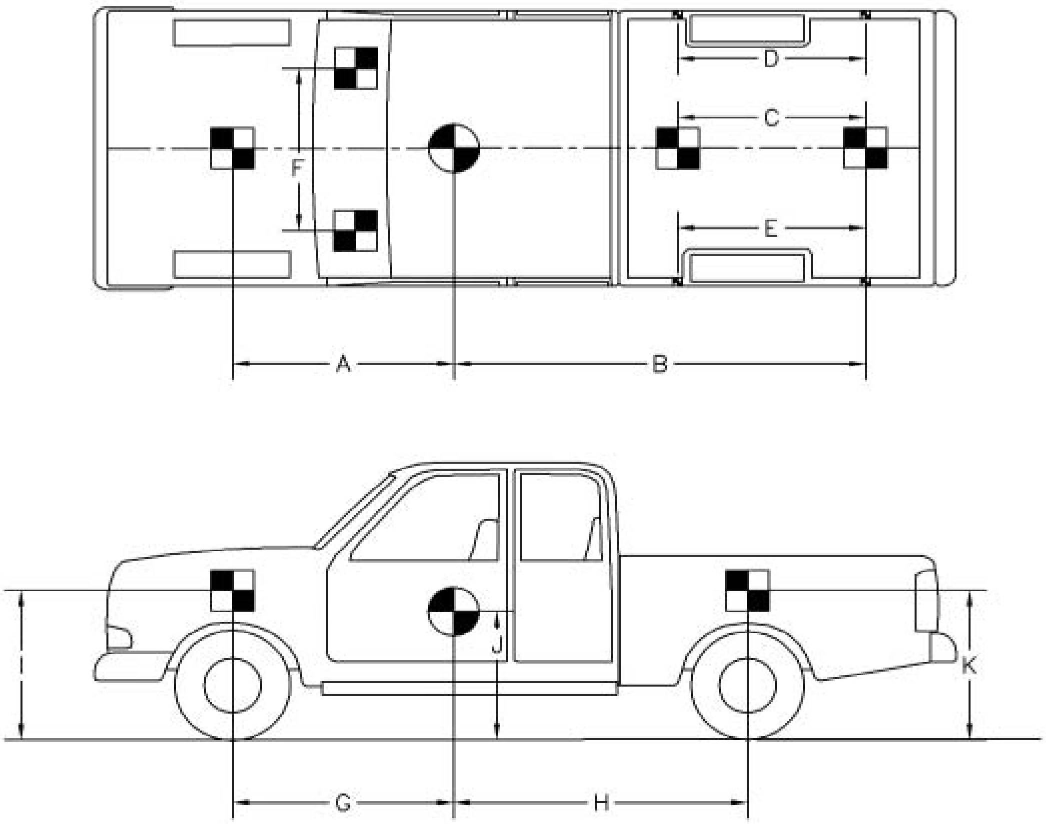


TEST #: SR-7

TARGET GEOMETRY -- mm (in.)

A 1902 (74.875)	D 1622 (63.875)	G 1597 (62.875)	J 711 (28)
B 2619 (103.125)	E 1626 (64)	H 1965 (77.375)	K 1083 (42.625)
C 1283 (50.5)	F 959 (37.75)	I 1026 (40.375)	

Figure 6. Target Locations, Test SR-7



TEST #: SR-8

TARGET GEOMETRY-- mm (in.)

A	1870	(73.625)	E	1626	(64.0)	I	997	(39.25)
B	2718	(107.0)	F	921	(36.25)	J	714	(28.125)
C	1219	(48.0)	G	1575	(62.0)	K	1073	(42.25)
D	1626	(64.0)	H	1988	(78.25)			

Figure 7. Target Locations, Test SR-8

3.4 Data Acquisition Systems

3.4.1 Accelerometers

One triaxial piezoresistive accelerometer system with a range of ±200 g's was used to measure vehicle acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 10,000 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-4M6, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan and includes three differential channels as well as three single-ended channels. The EDR-4 was configured with 6 MB of RAM memory and a 1600 Hz lowpass filter. Computer software, "Dyna-Max 1" (DM-1) and DADiSP, was used to analyze and plot the accelerometer data.

Another triaxial piezoresistive accelerometer system with a range of ±200 g's was also used to measure vehicle acceleration in the longitudinal, lateral and vertical directions at a sample rate of 3,200 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-3M6, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan and includes three differential channels as well as three single-ended channels. The EDR-3 was configured with 256 kB of RAM memory and a 1,120 Hz lowpass filter. Computer software, "Dyna-Max 1" (DM-1) and "DADiSP", was used to analyze and plot the accelerometer data.

3.4.2 Rate Transducer

An Analog Systems 3-axis rate transducer with a range of 1,200 degrees/sec in each of the three directions (pitch, roll, and yaw) was used to measure the rates of motion of the test vehicle. The rate transducer was mounted inside the body of the EDR-4M6 and recorded data at 10,000 Hz to a second data acquisition board inside the EDR-4M6 housing. The raw data measurements were then downloaded, converted to the appropriate Euler angles for analysis, and plotted. Computer software, "DynaMax 1" and "DADiSP," was used to analyze and plot the rate transducer data.

3.4.3 High-Speed Photography

For test no. SR-7, four high-speed AOS VITcam digital video cameras, with operating speeds of 500 frames/sec, were used to film the crash test. Five Canon video cameras and two JVC digital video cameras, with standard operating speeds of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all eleven cameras used in test no. SR-7 is shown in Figure 8.

For test no. SR-8, five high-speed AOS VITcam digital video cameras, with standard operating speeds of 500 frames/sec, were used to film the crash test. Three Canon digital video camerasand four JVC digital video cameras, with standard operating speeds of 29.97 frames/sec, were used to record the crash event. Camera details and a schematic diagram of all twelve camera locations for test no. SR-8 is shown in Figure 9.

The AOS VITcam videos were analyzed using ImageExpress MotionPlus software and RedLake MotionScope software. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos.

3.4.4 Pressure Tape Switches

For test nos. SR-7 and SR-8, five pressure-activated tape switches, spaced at 2-m (6.56-ft) 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 vehicle’s left-front tire passed over it. Test vehicle speed was determined from electronic timing mark data recorded using TestPoint software. 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.

	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	1	Vitcam CTM	500	Fixed 12.5 mm	-
	2	Vitcam CTM	500	Sigma 24-135	45
	3	Vitcam CTM	500	Sigma 24-70	24-28
	4	Vitcam CTM	500	Sigma 70-200	70
High-Speed Video	2	Canon - ZR10	29.97	-	-
	6	Canon - ZR25	29.97	-	-
	4	Canon - ZR30	29.97	-	-
	7	Canon - ZR90	29.97	-	-
	8	Canon - ZR90	29.97	-	-
	1	JVC - GZ-MC500 (Everio)	29.97	-	-
	2	JVC - GZ-MC40u (Everio)	29.97	-	-

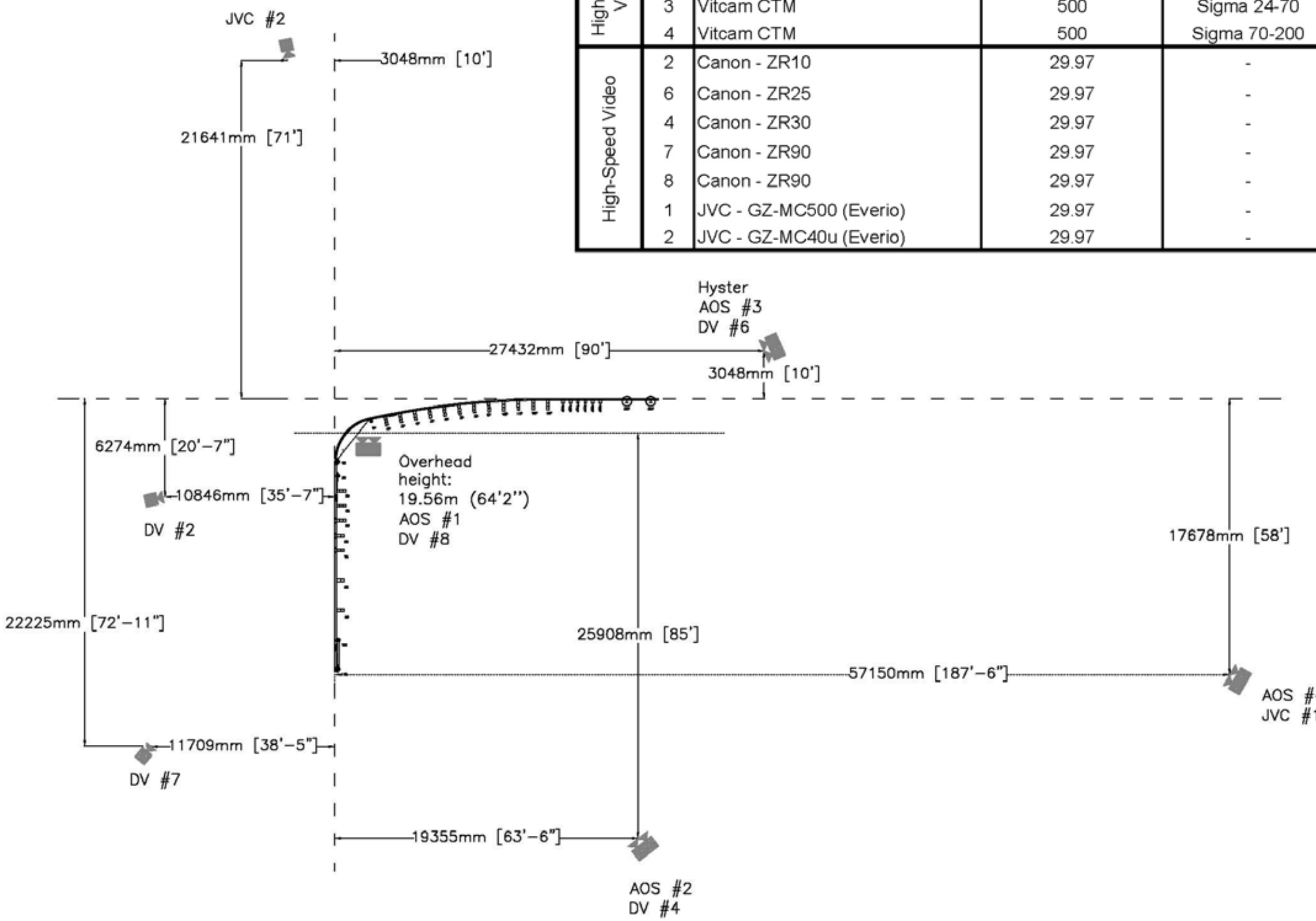


Figure 8. Camera Locations, Test SR-7

	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	1	Vitcam CTM	500	Fixed 12.5 mm	-
	2	Vitcam CTM	500	Fixed 50 mm	-
	3	Vitcam CTM	500	Sigma 24-70 mm	24
	4	Vitcam CTM	500	Sigma 70-200 mm	70
	5	Demo Vitcam CTM	500	-	-
High-Speed Video	1	JVC - GZ-MC500 (Everio)	29.97	-	-
	2	JVC - GZ-MC500 (Everio)	29.97	-	-
	3	JVC - GZ-MC500 (Everio)	29.97	-	-
	4	JVC - GZ-MC500 (Everio)	29.97	-	-
	5	JVC - GZ-MC500 (Everio)	29.97	-	-
	6	Canon - ZR10	29.97	-	-
	7	Canon - ZR90	29.97	-	-
	8	Canon - ZR90	29.97	-	-

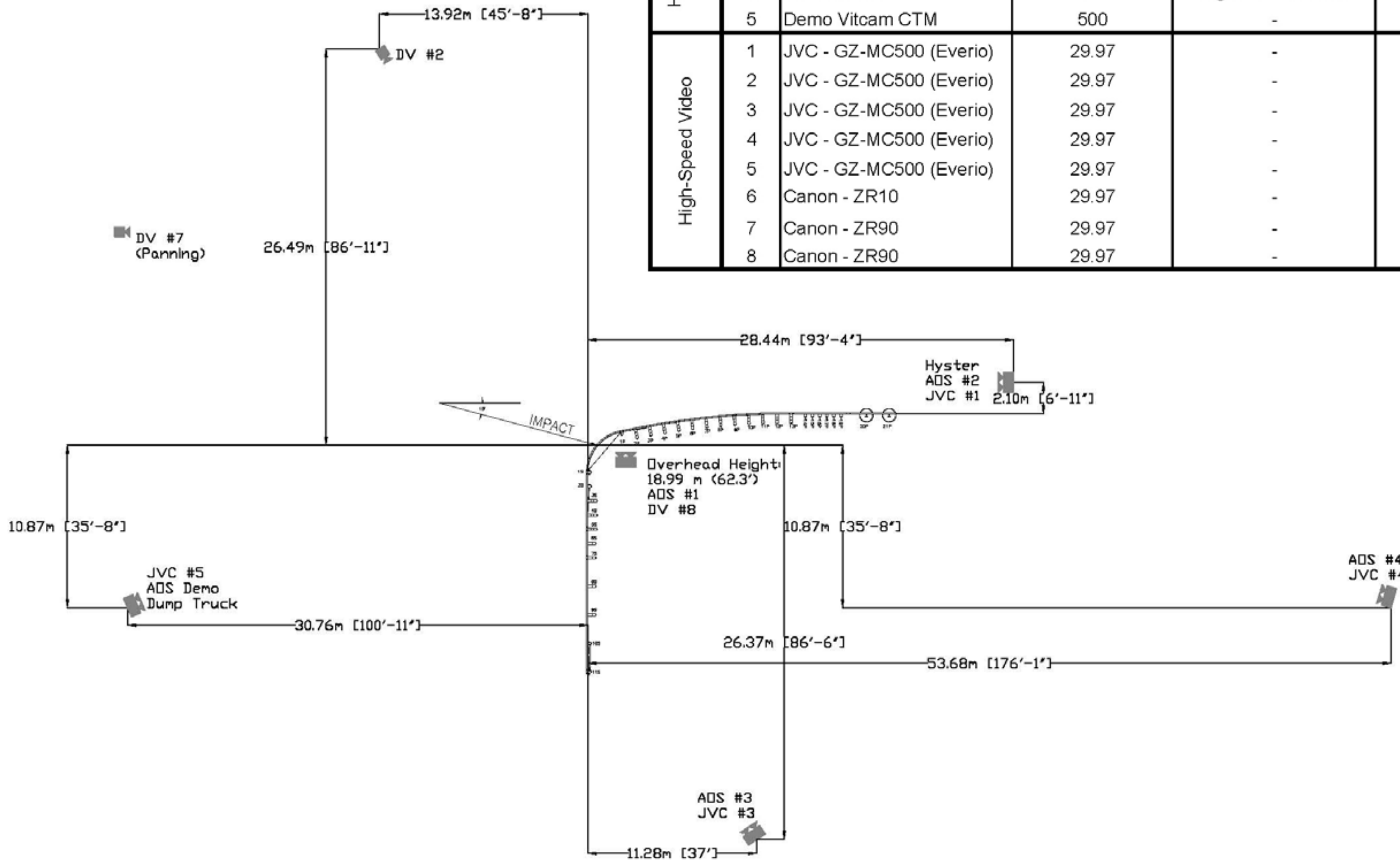


Figure 9. Camera Locations, Test SR-8

4 SHORT-RADIUS DESIGN DETAILS

The design of the short-radius guardrail system for test no. SR-7 was based on previous research conducted on short-radius systems discussed during Phase I, Phase II, and Phase III of this research (10-12). Full details on the considerations and parameters that shaped the design of the short-radius guardrail system can be found in these reports. Experience gained by the MwRSF researchers during the development of the bullnose median barrier system was also applied (20-24).

4.1 Design Details

The short-radius guardrail system was identical to the system tested in SR-6 (12). A 2,769-mm (9-ft 1-in.) radius design was selected for use in the current study. The small radius reduced the overall size of the system and allowed for easier application of the design to a variety of intersections. The nose section was formed using one 3,810-mm (12-ft 6-in.) long, curved section of thrie beam guardrail.

The midsection of the short-radius system was designed without a post at the centerline of the nose since the end post typically rotates backwards after impact, thus creating a potential for the vehicle to vault over the rail. It was determined that a nose section without the centerline post would have sufficient structural strength to maintain the shape of the rail without rail sagging while also reducing the vaulting hazard. Short-radius design details are shown in Figures 10 through 28. The corresponding English-unit drawings are shown in Appendix A. Photographs of the short-radius guardrail system test installation are shown in Figures 29 through 31.

The layout for the short-radius guardrail system is shown in Figures 10 through 14. For the short-radius system, the nose section consists of a 2,769-mm (9-ft 1-in.) radius nose section adjacent to a parabolic flare on the primary side and tangent to the straight section of guardrail on the secondary side. The primary roadway side is 15,240 mm (50 ft) long, and secondary roadway side is 13,335 mm (43 ft - 9 in.) long. After post no. 14P on the primary roadway side of the system, a 3,810-mm (12-ft 6-in.) long approach guardrail transition system was used to adapt the short-radius system to a thrie beam bridge rail. Details on the approach guardrail transition, used in combination with a safety shape bridge rail, can be found in previous publications by MwRSF (25,26). Actual installations of the short-radius guardrail system may use any NCHRP Report No. 350 approved approach guardrail transition. On the downstream end of the secondary roadway side, timber posts measuring 140 mm wide x 190 mm deep x 1,080 mm long (5.5 in. x 7.5 in. x 42.5 in.) were placed in 1,829-mm (6-ft) long steel foundation tubes and were part of an anchor system designed to replicate the capacity of a tangent guardrail terminal.

The system was configured with twenty-one wood posts - thirteen positioned along the primary roadway prior to the transition section and eight placed along the secondary roadway prior to the end terminal. Starting from the radius, the first post on each side of the system was a 140 mm wide by 190 mm deep by 1,187 mm long (5.5 in. x 7.5 in. x 46.75 in.) Breakaway Cable Terminal (BCT) post set in 2,438-mm (8-ft) long foundation tubes. No blockout was used at post no. 1 on either side of the radius. Post nos. 2P through 13P along the primary roadway and post nos. 2S and 5S along the secondary roadway were 1,981-mm (78-in.) long CRT posts. Each of these posts included double 152-mm wide by 203-mm deep by 357-mm long (6-in. x 8-in. x 14-in.) wood blockouts to space the rail away from the post. The front blockouts on the double blockout posts were chamfered at a 25-degree angle from the middle of the front face of the blockout to the bottom. Post spacing along the primary side of the roadway, between posts nos. 2P and 13P, was 952.5 mm (37.5 in.), but followed the parabolic flare, as shown in Figure 12. Post spacing for all posts up to post no. 5S along the secondary roadway was 952.5 mm (37.5 in.). The top mounting height of the rail was 787 mm (31 in.), as measured from the ground surface. Post nos. 2P through 13P along the primary roadway and post nos. 2S through 5S along the secondary roadway had a soil embedment depth of 1,168 mm (46 in.). Post nos. 6S through 8S along the secondary roadway had a soil embedment depth of 1,016 mm (40 in.) Details of these posts are shown in Figures 18 through 20.

A cable anchor system for the secondary side was attached between the thrie beam and post no. 2S on the secondary side of the system in order to develop the tensile strength of the thrie beam guardrail in the secondary side away from the nose section. A cable bracket was located at the ground line of post no. 1P on the primary side which held the cable down and developed the necessary tensile strength. A cable anchor assembly for the primary side was attached to the thrie beam between post nos. 2 and 3 on the primary side, came around the traffic face of the post no. 1P on the primary side, and terminated in post no. 1 on the secondary side. Details of the two cable anchor systems are shown in Figures 13 through 16.

The five guardrail sections used in the short-radius system consisted of 2.67-mm (12-gauge) steel thrie beam. The 3,810-mm (12-ft 6-in.) long sections were spliced together using a standard, bolted lap splice on each interior end. The nose section, rail section nos. 2, 3, and 4 on the primary side, and rail section no. 2 on the secondary side were cut with slots in the valleys. The nose section of the rail (rail section no. 1) consisted of a 3,810-mm (12-ft 6-in.) long beam bent into a 2,769-mm (9-ft 1-in.) radius. The nose section was cut with slots in the valleys to aid in vehicle capture, as shown in Figure 24. There were six primary 699-mm (27.5-in.) long slots centered about the midspan of the rail, three in each valley. The primary slots were divided from one another by 25-mm (1-in.) wide slot tabs. Eight additional smaller 251-mm (9.875-in.) long slots, four on each end of the rail section, were also cut with a 51-mm (2-in.) wide slot tab between them. All slots were 19-mm (0.75-in.) wide. Rail section nos. 2, 3, and 4 were curved along the parabolic flare on the primary roadway side, and rail section no. 2 was straight along the secondary roadway side. These sections were cut with a different pattern of slots, as shown in Figure 25. The slot pattern for these sections consisted of two sets of six 298-mm (11.75-in.) long slots centered between the post slots. The slots were separated by 251-mm (9.875-in.) wide slot tabs, which provided one and one-half slots per valley between posts. The remaining section of thrie beam guardrail along the primary roadway was not slotted.

A 2.67-mm (12-gauge) assymetrical thrie beam to W-beam transition section was placed between post nos. 5S and 6S along the secondary roadway. The transition section was necessary in order to end the guardrail with a simulated tangent MGS W-beam guardrail end terminal.

A set of steel retention cables were attached to the back of the nose section to contain impacting vehicles in the event of rail rupture. A 4.4-m (14-ft 4.75-in.) long by 15.9-mm (0.625-in.) diameter cable was added behind the top and middle humps of the thrie beam nose section. A 6x25 cable was chosen with the intent that one of the two cables would be capable of containing the impacting vehicle. It is noted that the steel cables were only placed behind rail section no. 1. This was done because it was believed that the rail sections beyond the nose section would remain active and intact throughout the impact event. Therefore, the use of longer cable lengths was not deemed necessary. The cables were attached to the guardrail using three 6-mm (0.25-in.) diameter U-bolts per cable to fix the cables behind the top and middle humps of the thrie beam. The ends of each cable were fitted with “Cold Tuff” buttons and clamped between formed steel plates located at the guardrail splice at post no. 1 on each side. The “Cold Tuff” buttons were swaged-grip button ferrules. As such, any similarly sized swaged-grip button ferrule could be substituted into the design. The cable plate and the cable detail are shown in Figure 15, while the assembly details are shown in Figures 13 and 14.

An end anchorage was developed for the primary roadway side of the short-radius system in order to simulate the anchorage provided by a bridge rail in an actual installation, as shown in Figure 12. This anchorage was for test purposes only. The anchorage consisted of a pair of 2,032-mm (80-in.) long, W152x37.2 (W6x25) steel posts embedded 1,245 mm (49 in.) into a reinforced concrete base. The reinforced concrete bases consisted of 914-mm (36-in.) diameter concrete cylinders set in the ground, as shown in Figure 22. Reinforcement of the cylinders consisted of a pre-formed, circular, 864-mm (34-in.) diameter welded wire mesh cage. A 10-gauge section of thrie beam was mounted on the posts and spliced to the end of the bridge transition to complete the anchorage.

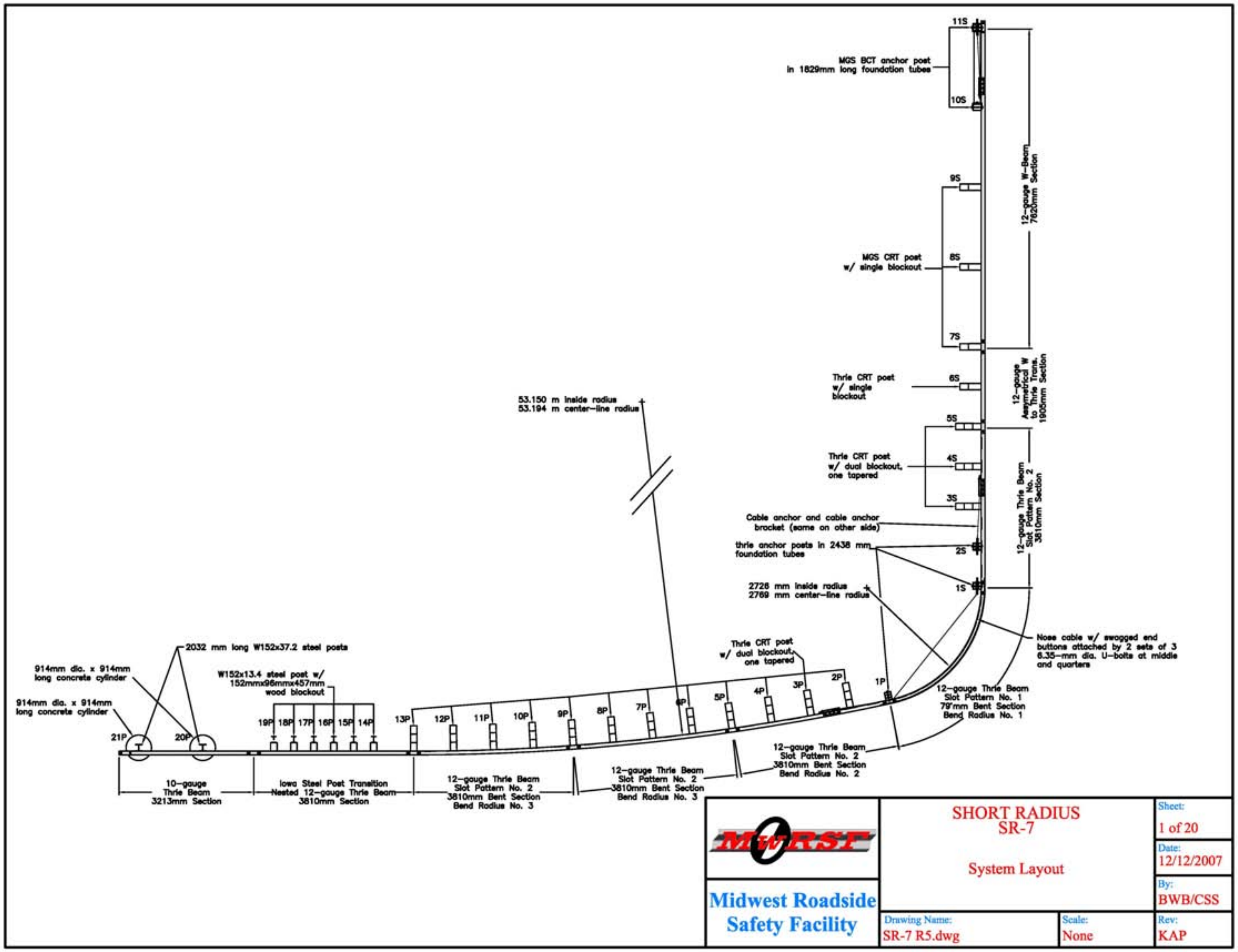


Figure 10. System Layout

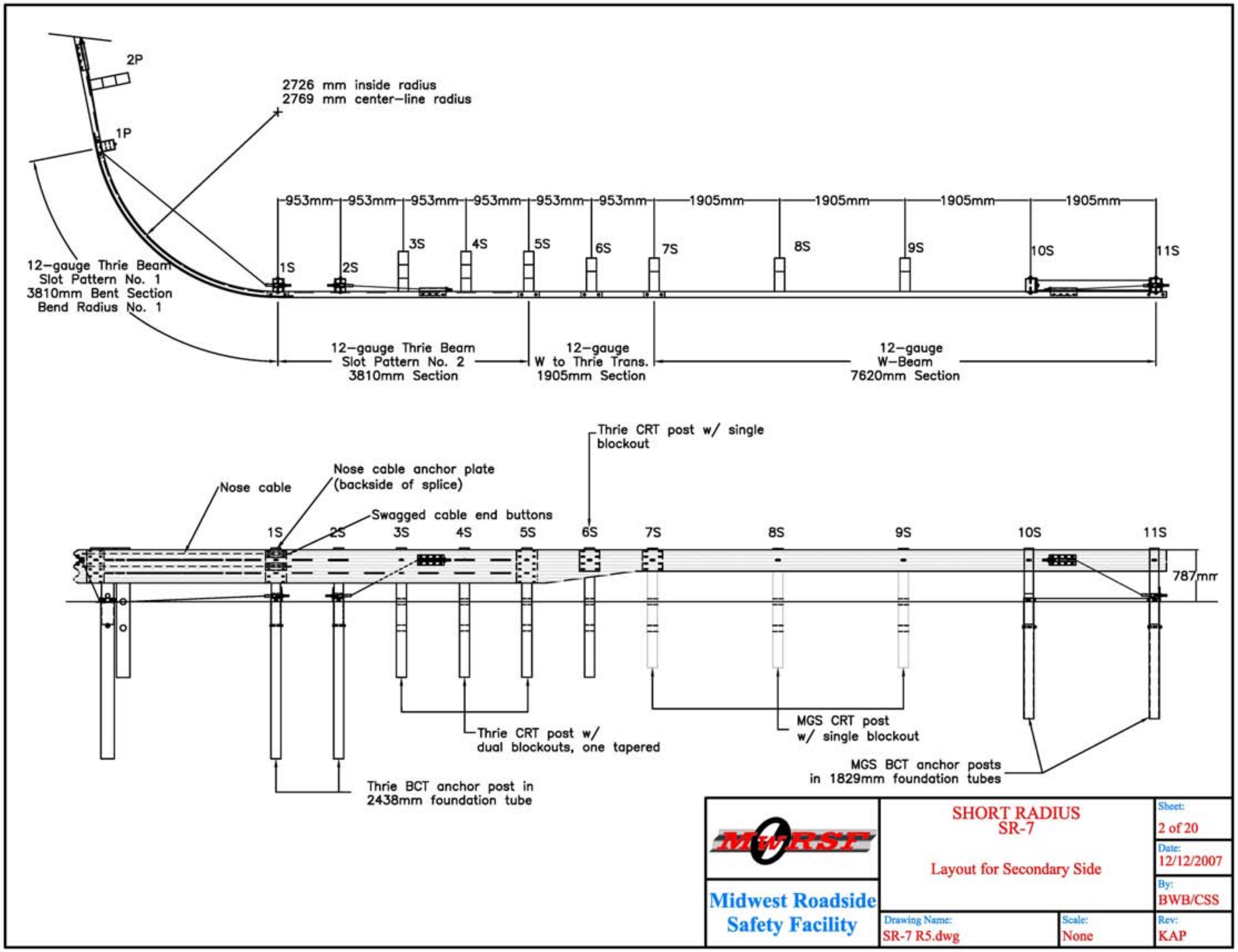
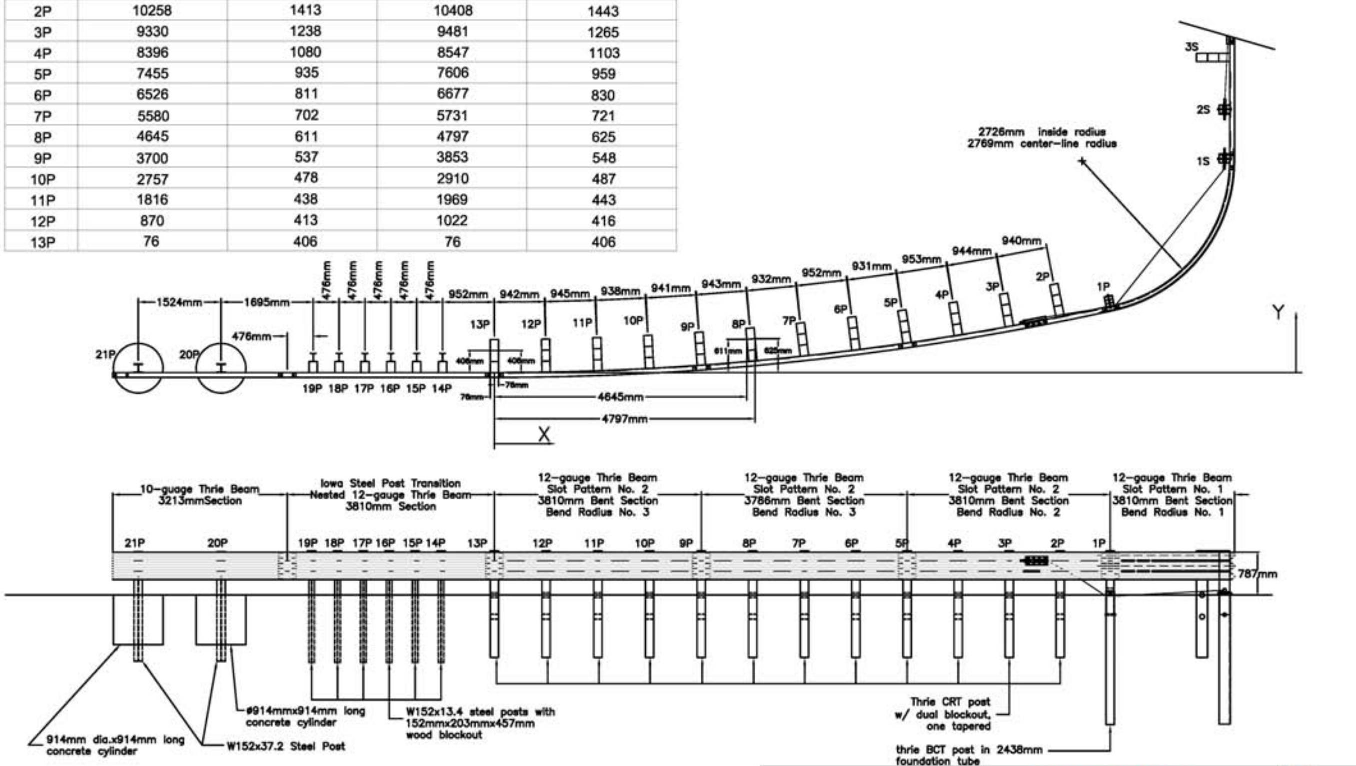


Figure 11. Layout for Secondary Side

X Location with respect to the center of Post no. 13P
Y Location with respect to the backside of the rail at post no. 13P

Post No.	Front Face D.S. Edge		Front Face U.S. Edge	
	X	Y	X	Y
1P	11254	1210	11395	1235
2P	10258	1413	10408	1443
3P	9330	1238	9481	1265
4P	8396	1080	8547	1103
5P	7455	935	7606	959
6P	6526	811	6677	830
7P	5580	702	5731	721
8P	4645	611	4797	625
9P	3700	537	3853	548
10P	2757	478	2910	487
11P	1816	438	1969	443
12P	870	413	1022	416
13P	76	406	76	406



Midwest Roadside Safety Facility	SHORT RADIUS SR-7 Layout for Primary Side & Post Locations		Sheet: 3 of 20
			Date: 12/12/2007
			By: BWB/CSS
	Drawing Name: SR-7 R5.dwg	Scale: 1=100	Rev: KAP

Figure 12. Layout for Primary Side

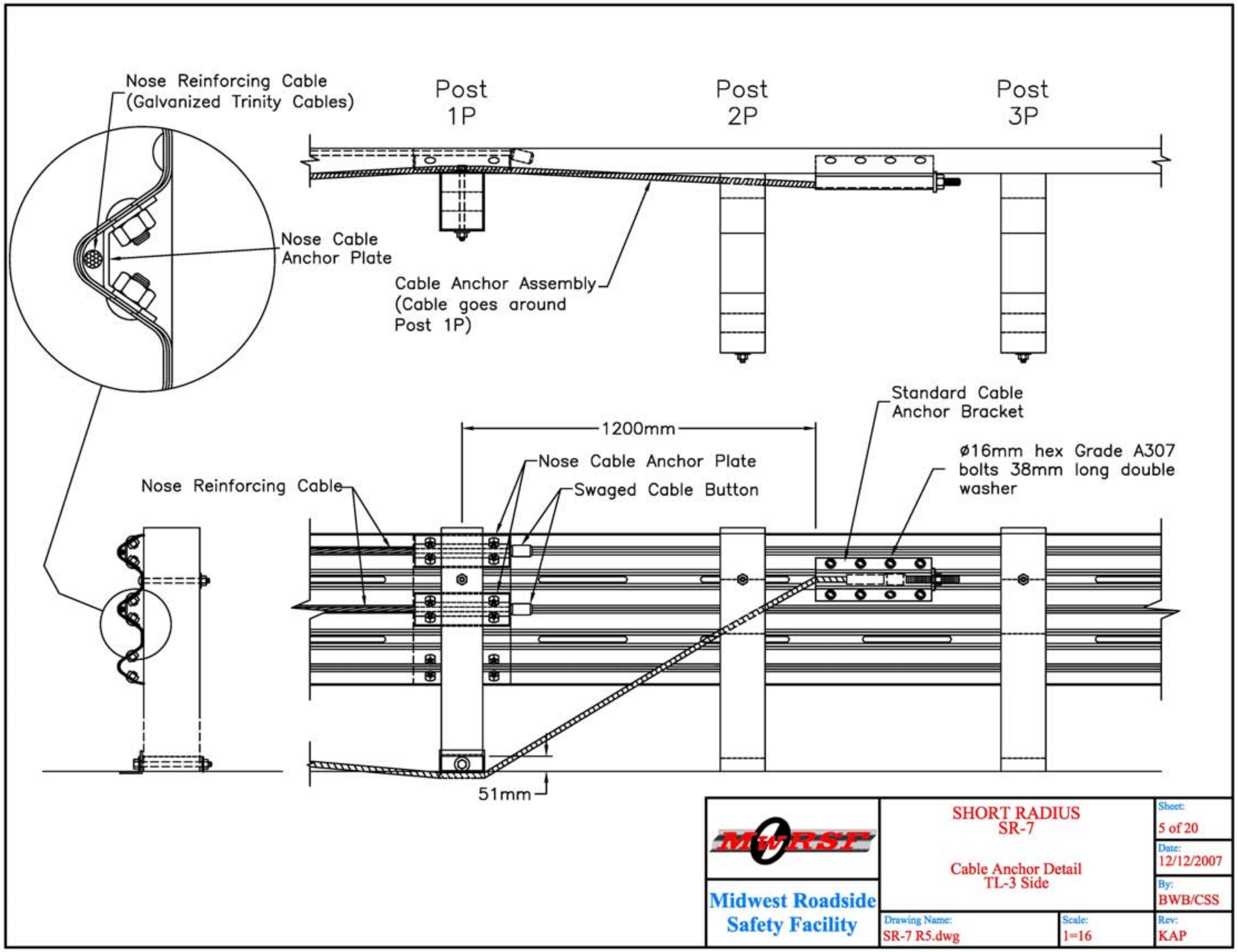


Figure 13. Primary Side Cable Anchor Detail

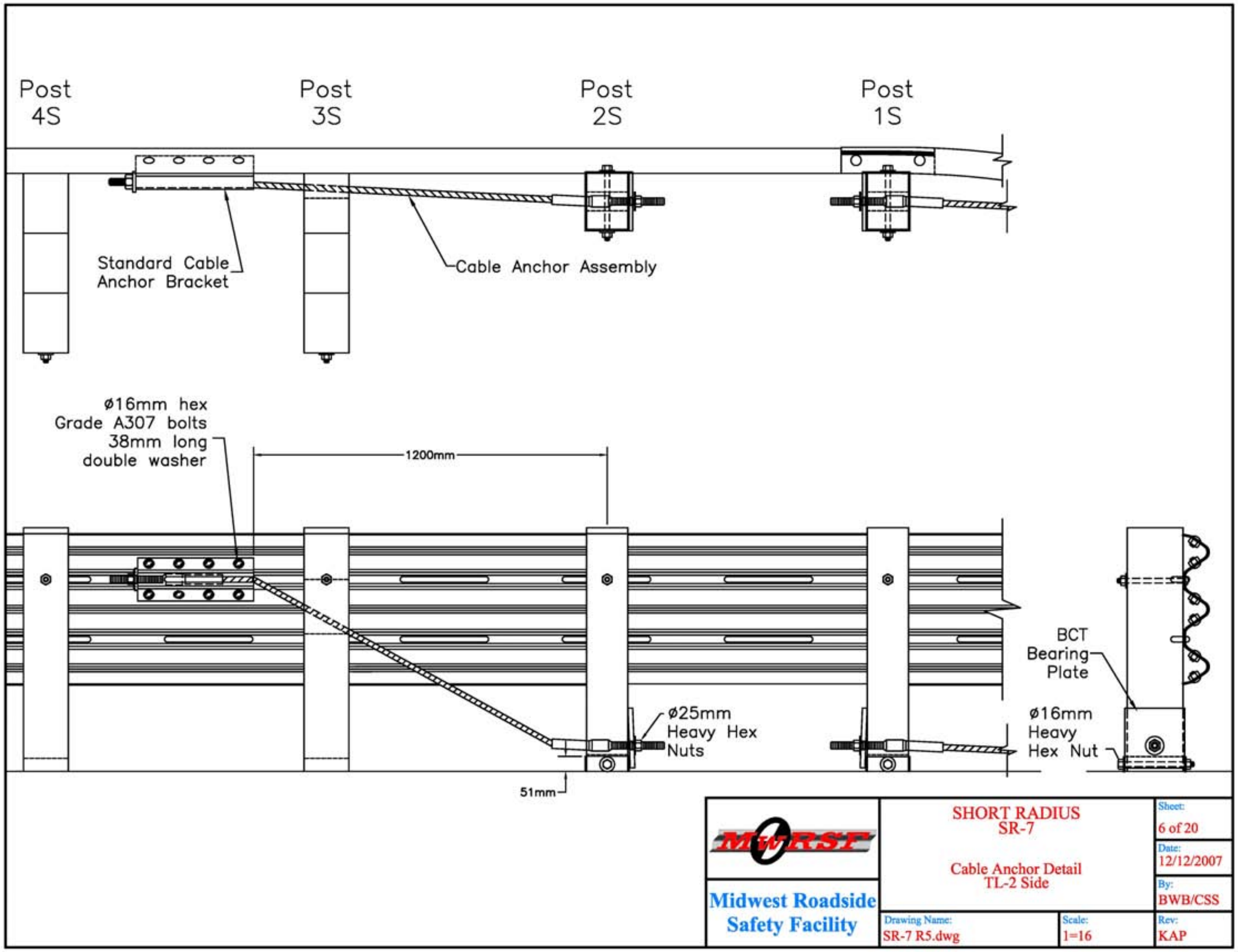


Figure 14. Secondary Side Cable Anchor Detail

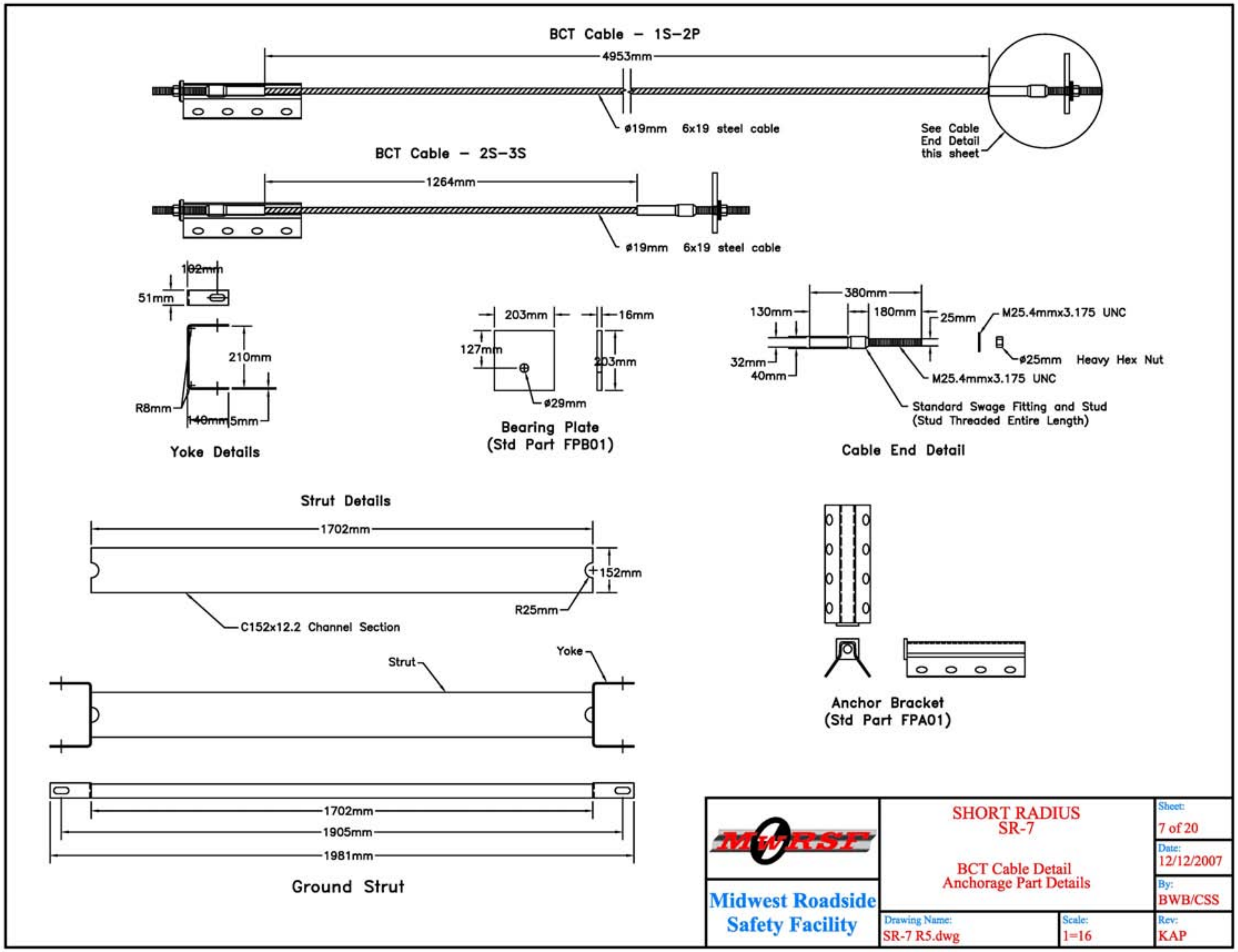


Figure 15. Anchorage Cable Details

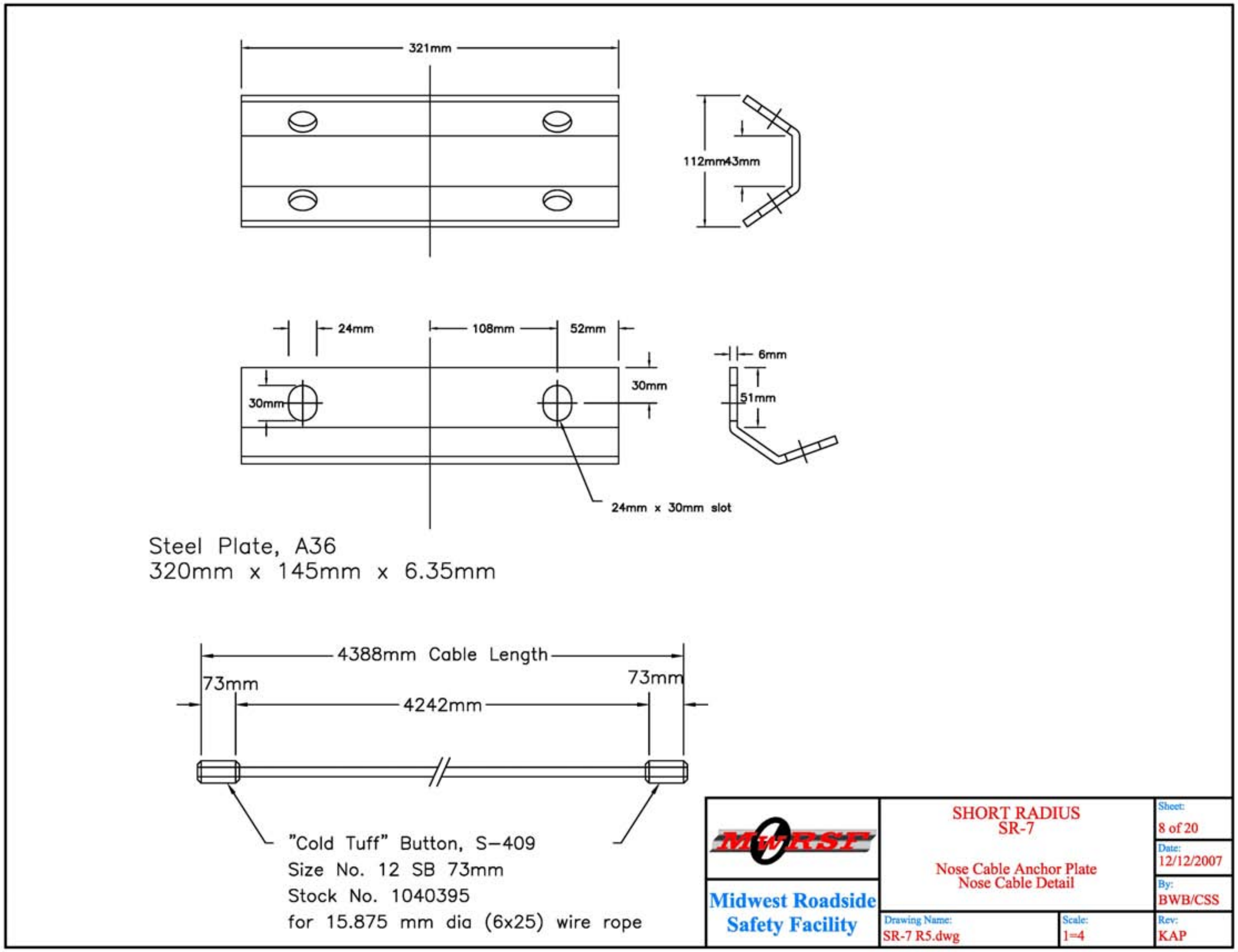


Figure 16. Nose Cable Detail

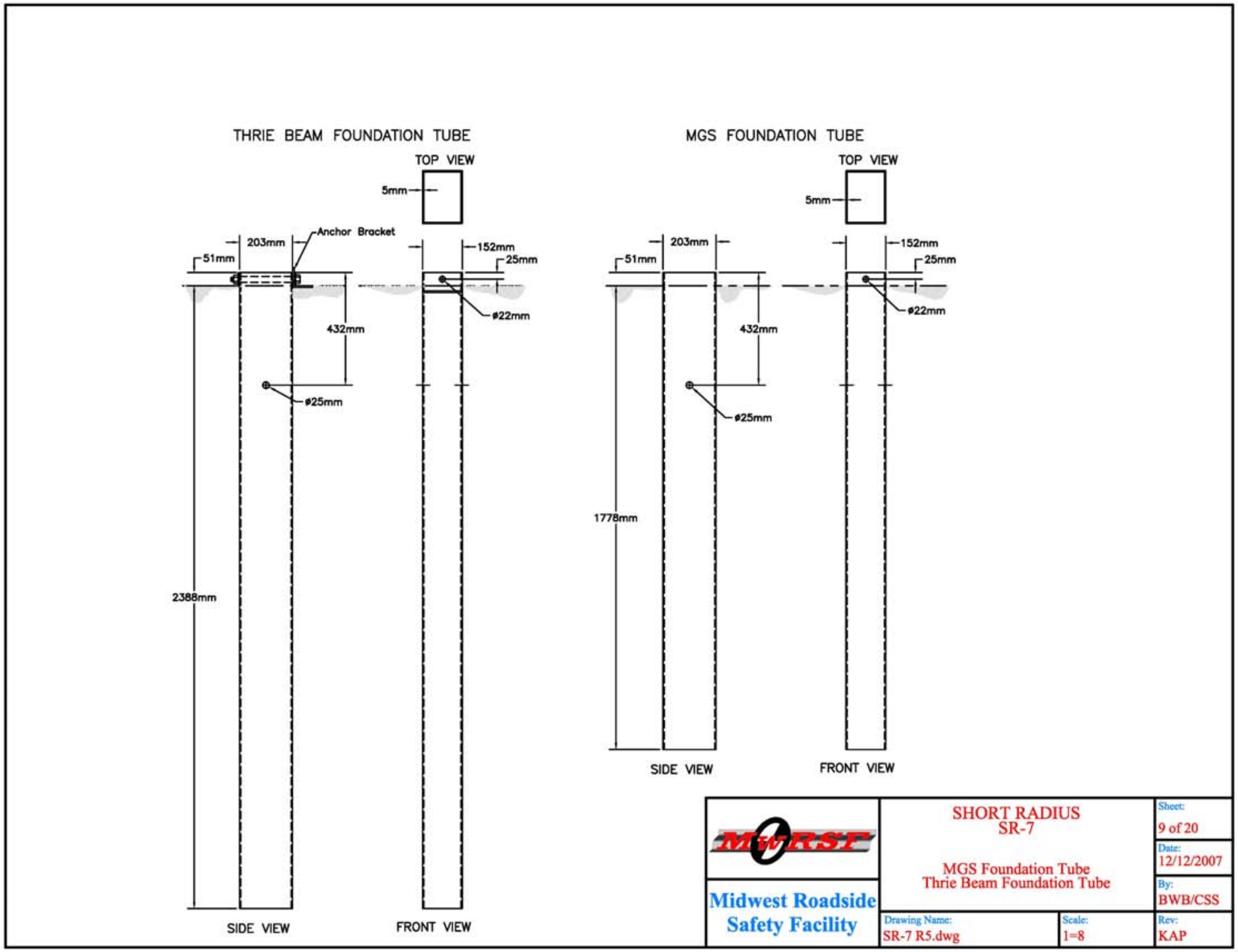


Figure 17. MGS Foundation Tube and Thrie Beam Foundation Tube Details

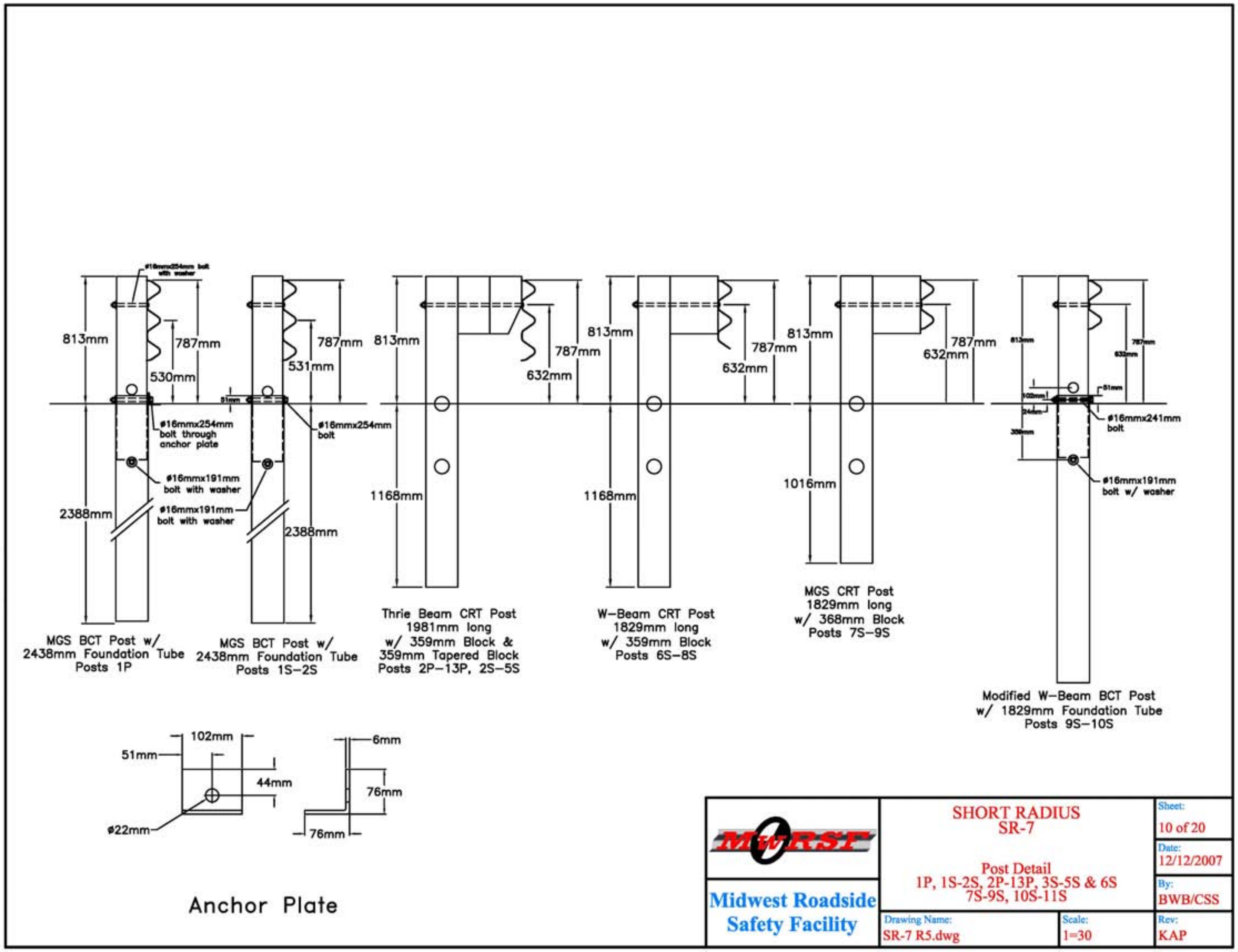


Figure 18. Post Details

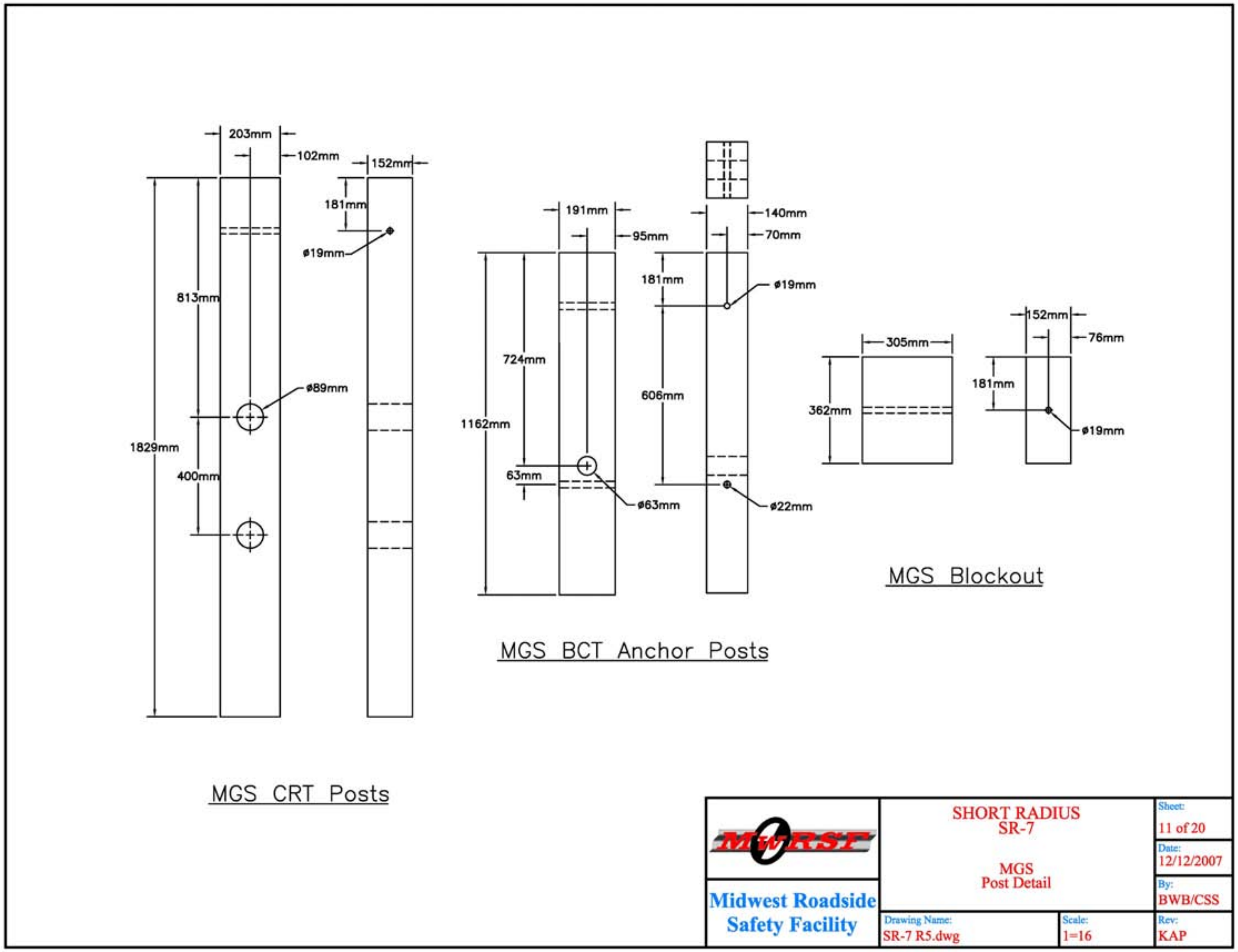


Figure 19. MGS CRT and BCT Post Details

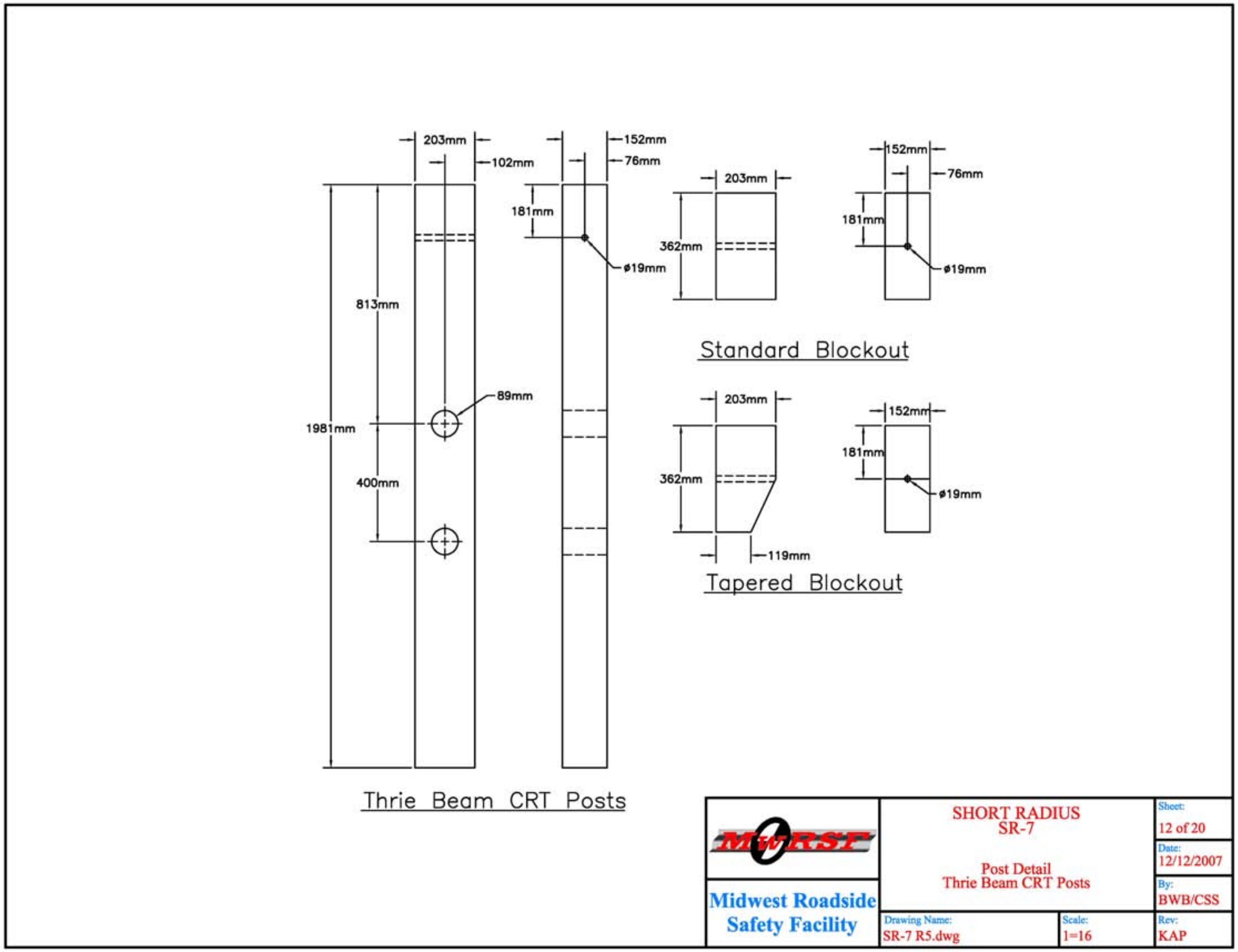


Figure 20. Thrie Beam Anchor Post Details

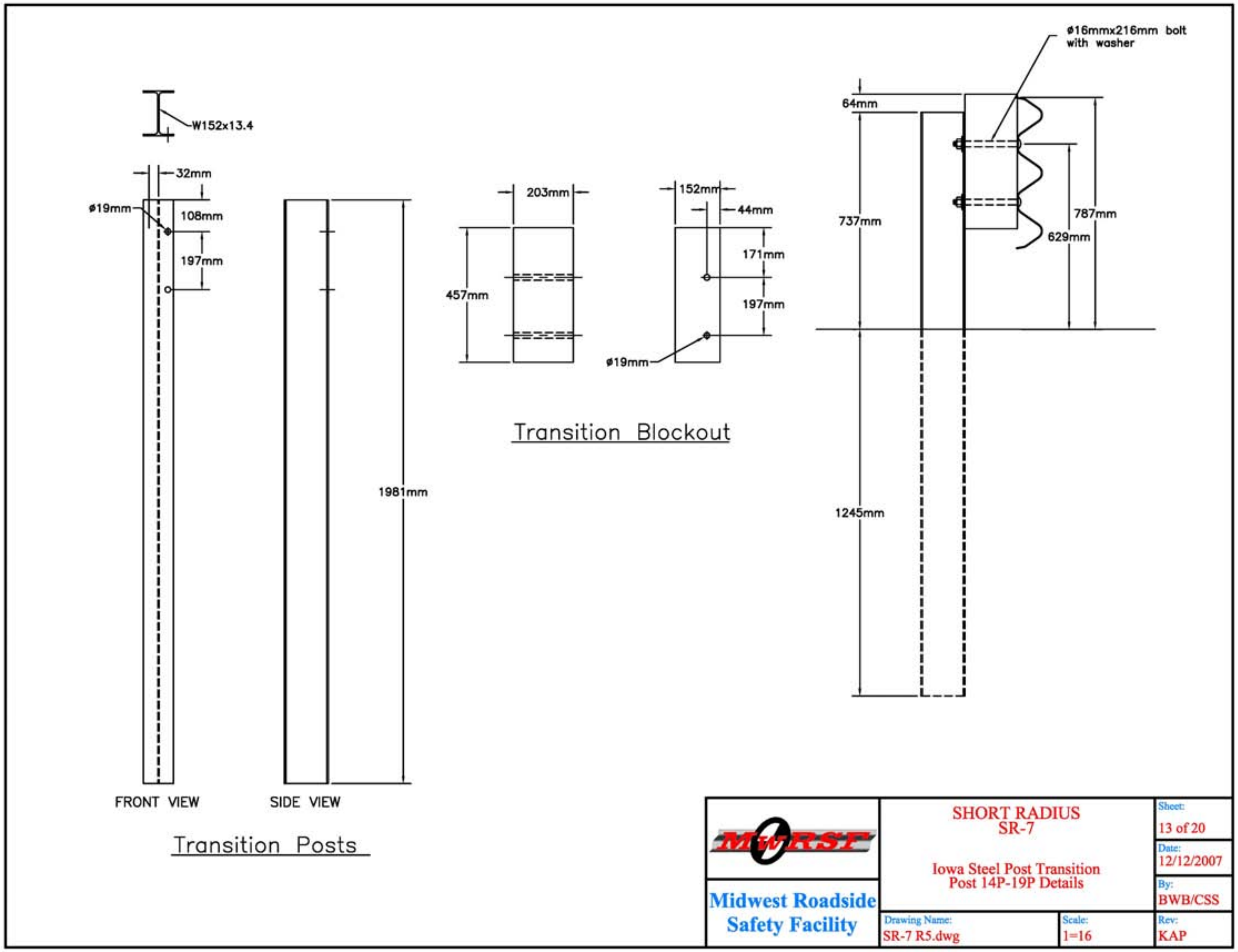


Figure 21. Iowa Steel Post Transition, Post Nos. 14P-19P Details

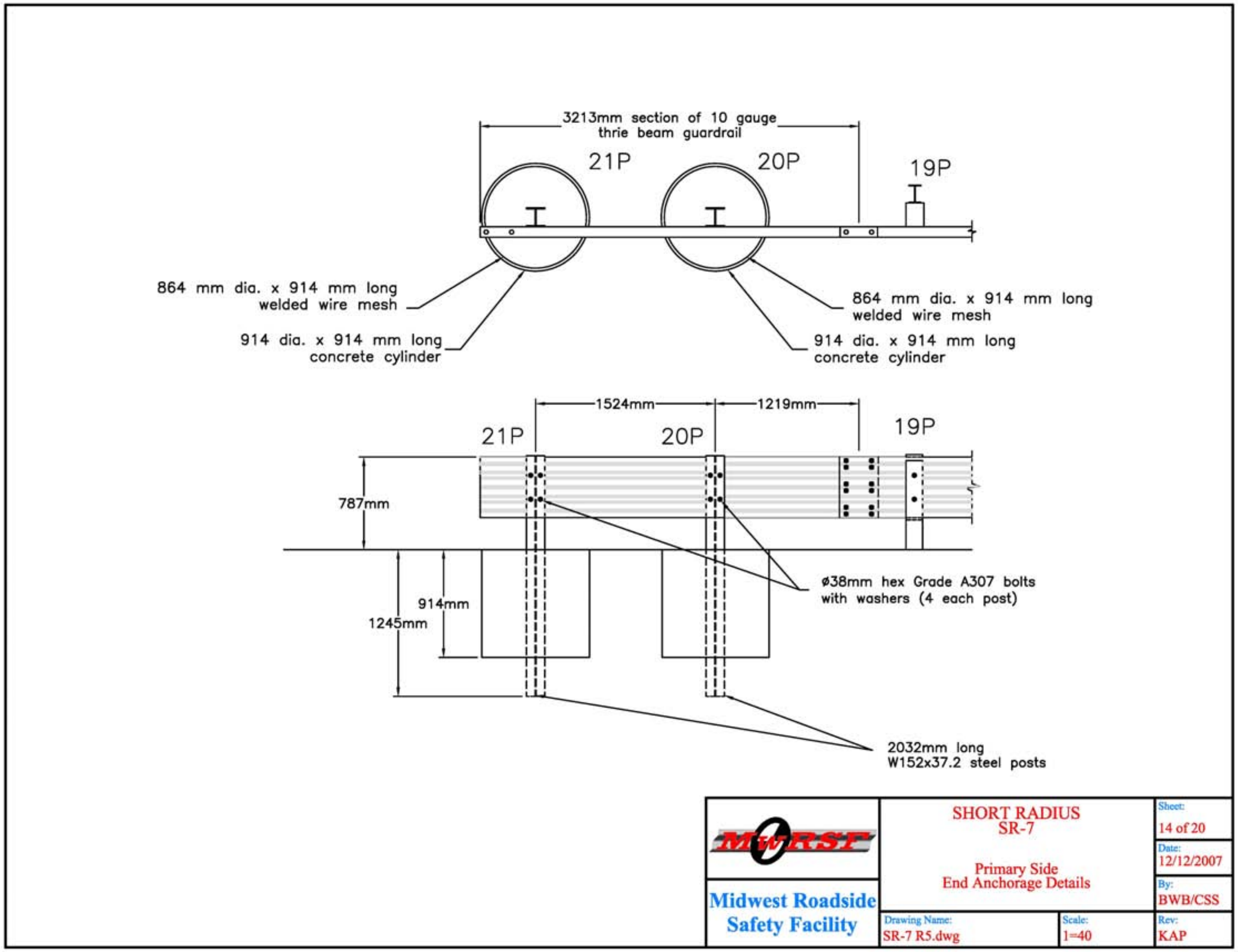


Figure 22. Primary Side End Anchorage Details

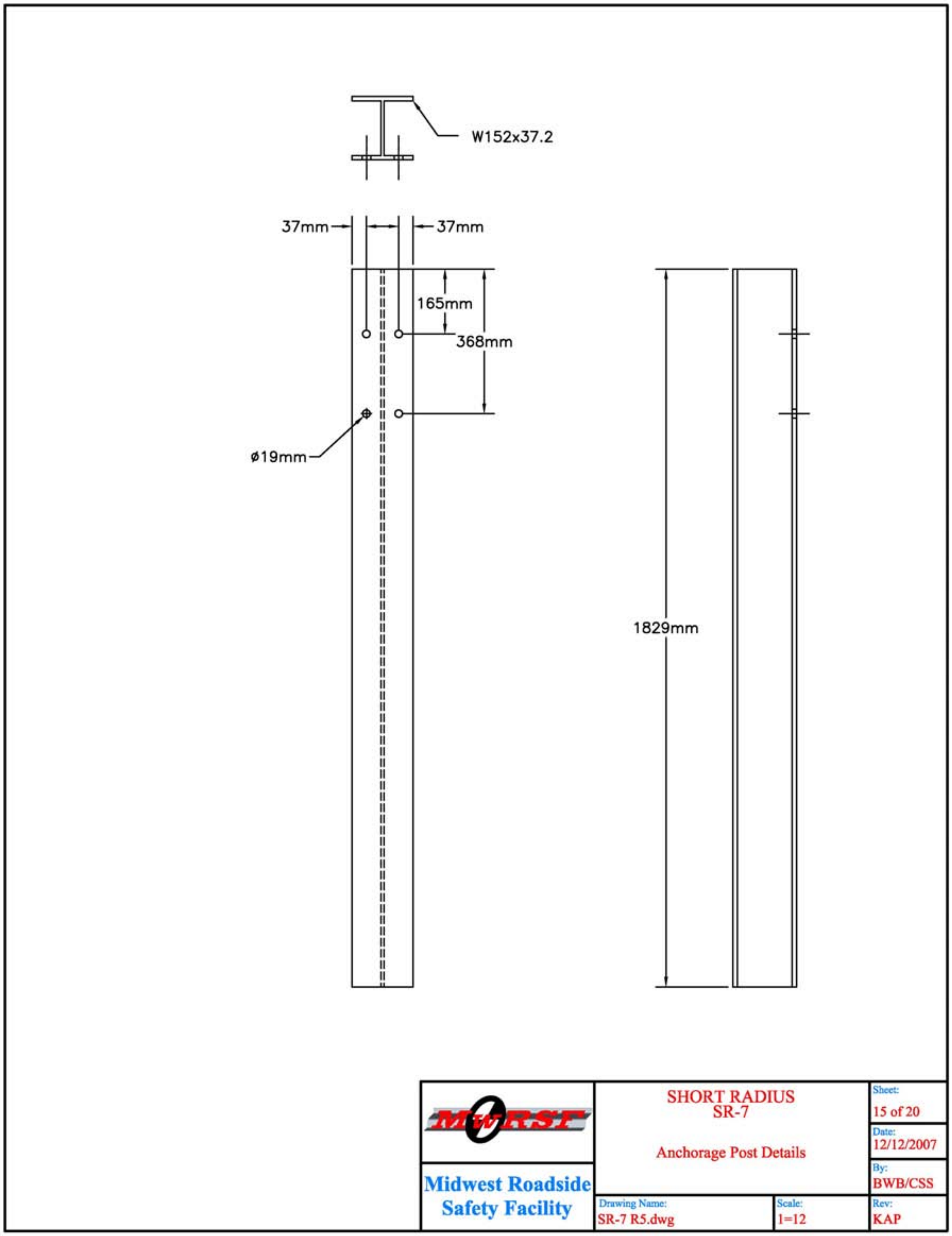


Figure 23. Anchorage Post Details

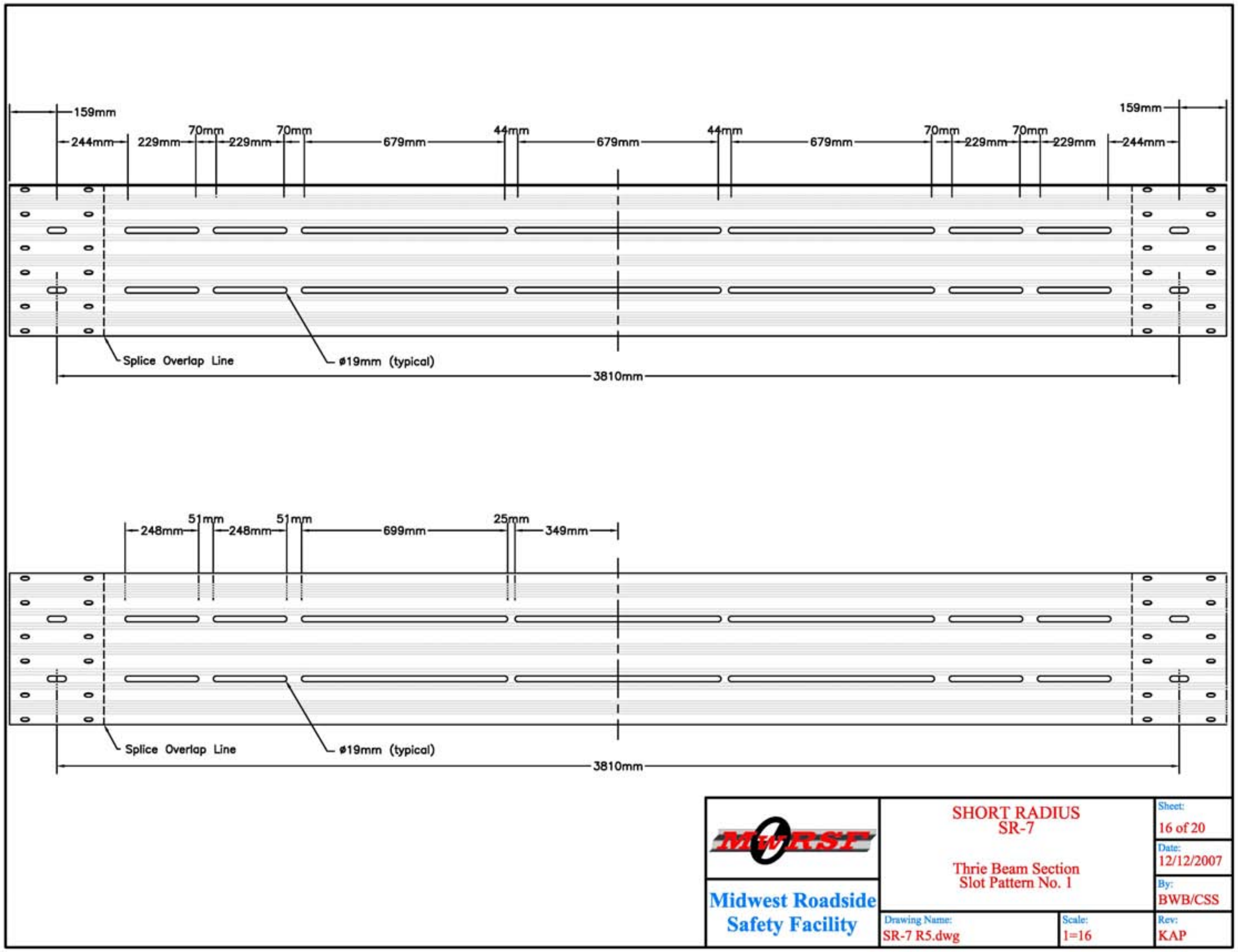


Figure 24. Thrie Beam Slot Pattern No. 1

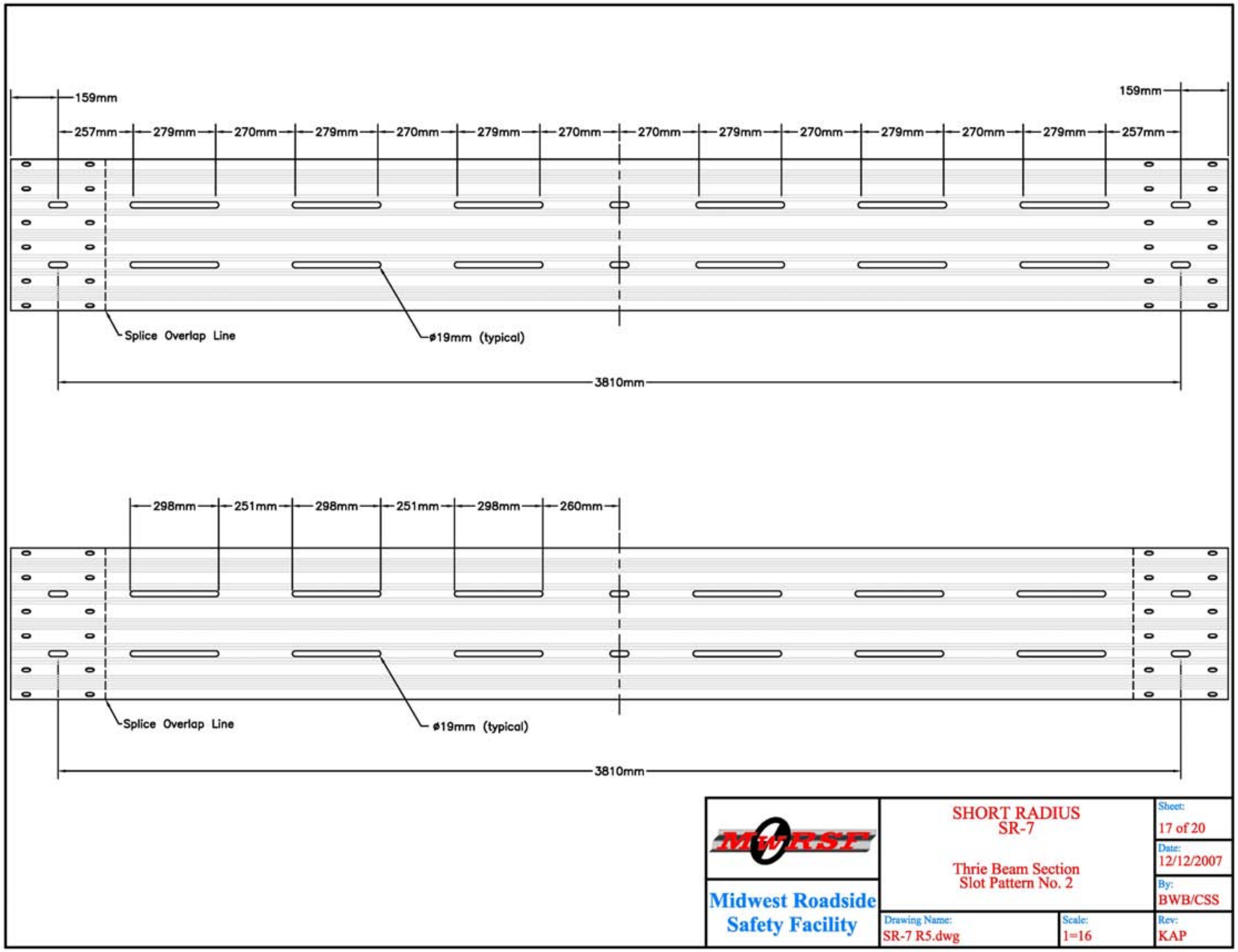


Figure 25. Thrie Beam Slot Pattern No. 2

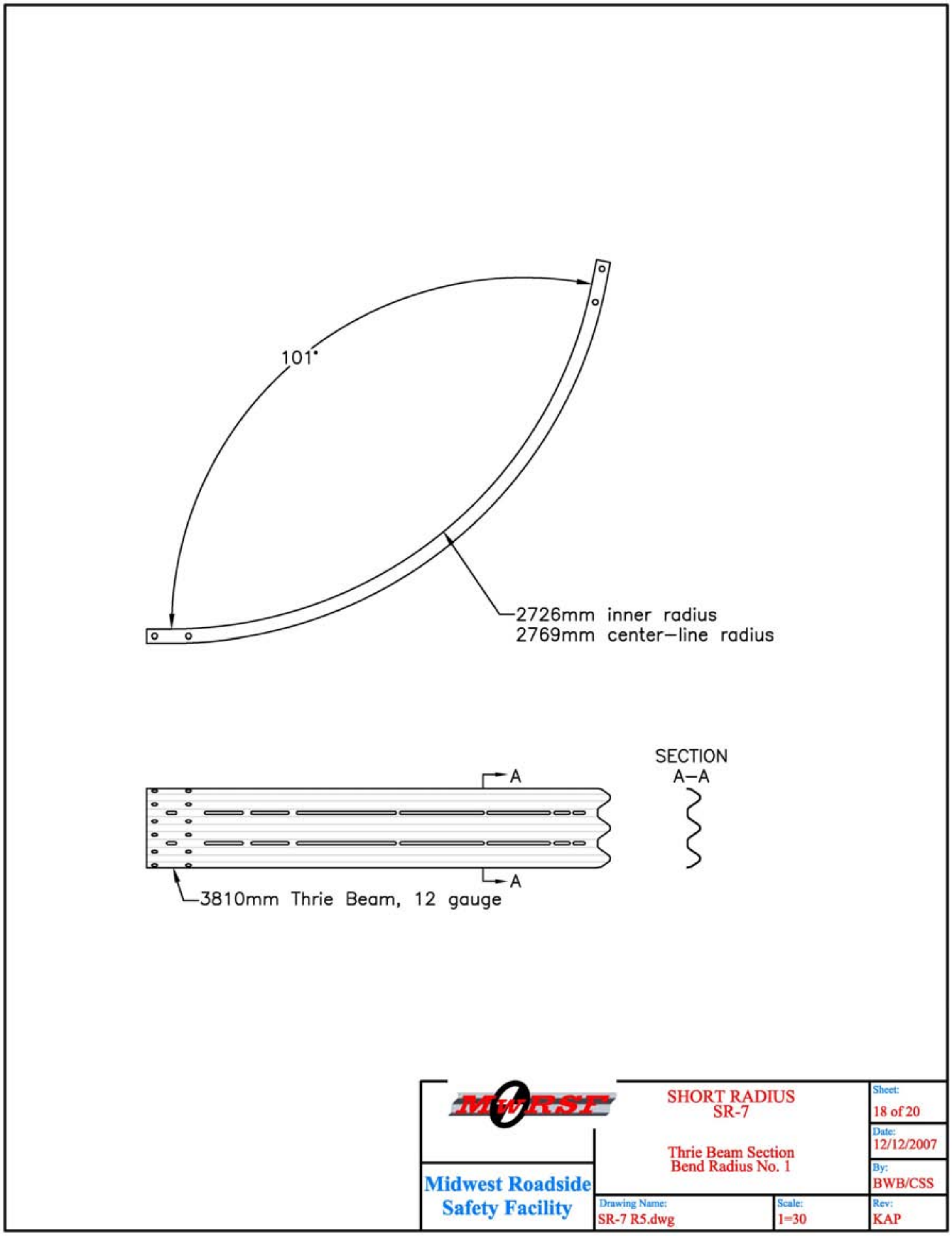


Figure 26. Thrie Beam Bend Radius No. 1

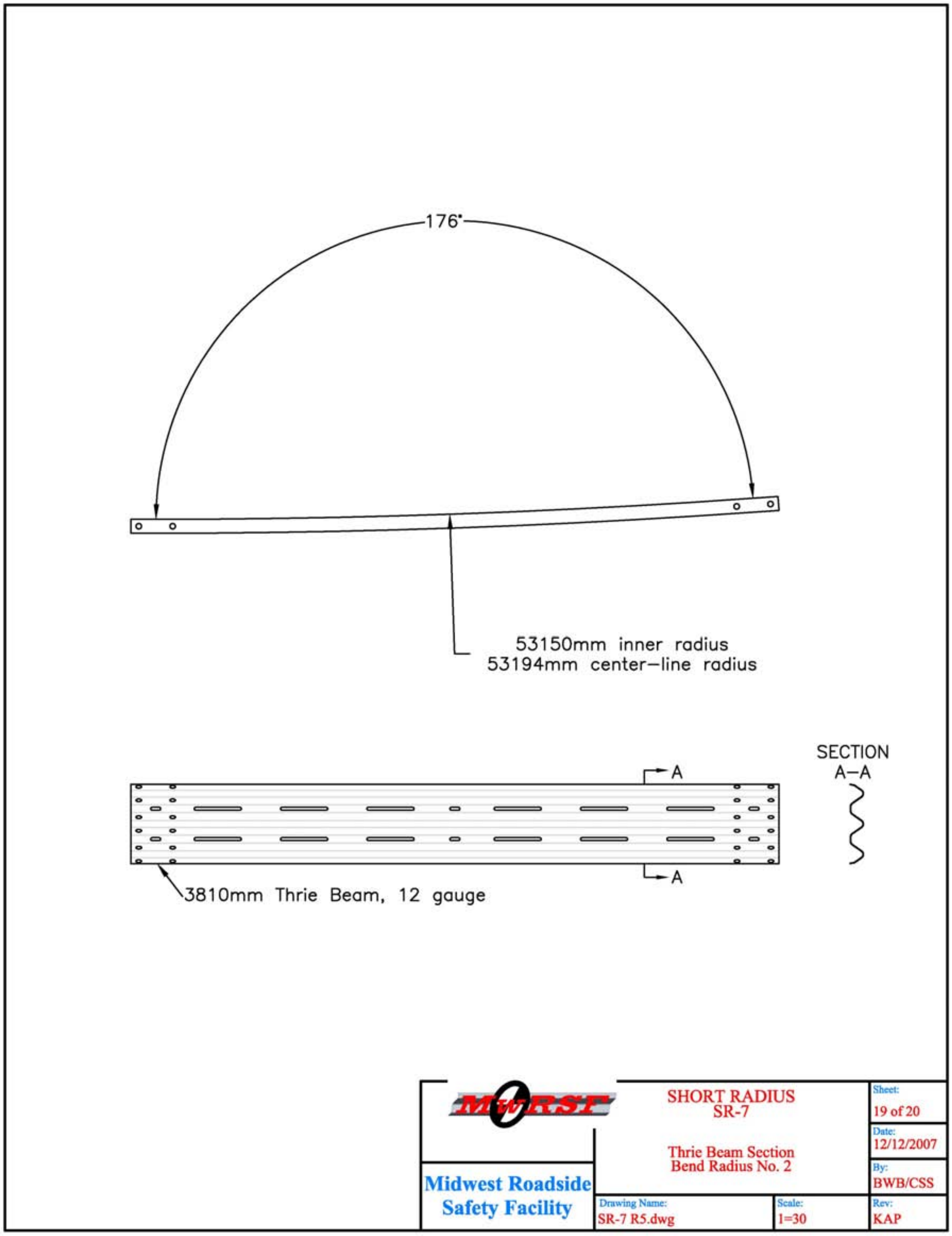


Figure 27.Thrie Beam Bend Radius No. 2

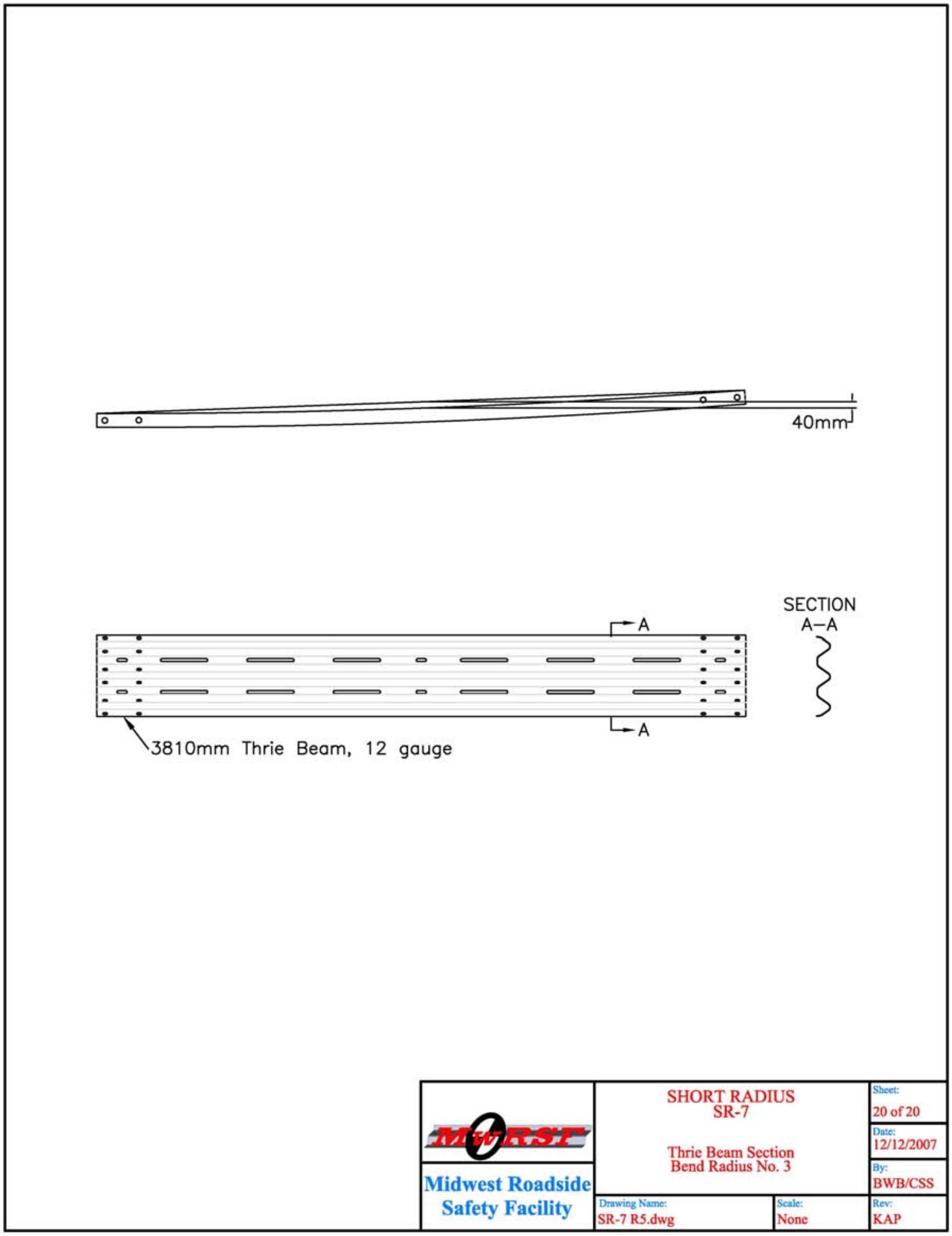


Figure 28. Thrie Beam Bend Radius No. 3

Figure 29. System Details

Figure 30. System Details

Figure 31. System Details

5 CRASH TEST NO. 7

5.1 Test SR-7

The 2,263-kg (4,989-lb) pickup truck impacted the short radius guardrail system at a speed of 100.3 km/h (62.3 mph) and at an angle of 18.1 degrees. A summary of the test results and the sequential photographs are shown in Figure 32. The summary of the test results and sequential photographs in English units are shown in Appendix B. Additional sequential photographs are shown in Figures 33 and 34. Documentary photographs of the crash test are shown in Figures 35 through 38.

5.2 Test Description

Initial impact was to occur with the centerline of the pickup truck aligned with the center of the curved nose section of the system. Actual vehicle impact occurred at the targeted impact point. Immediately following impact, the nose section flattened and deformed. At 0.006 sec, post nos. 1S and 1P deflected toward the back side of the system, and the vehicle's right-front quarter panel dented. At 0.012 sec, a buckle formed in the guardrail between post nos. 2S and 3S. At 0.034 sec, as the rail engaged the front of the vehicle, a buckle formed on the upstream side of post no. 1P. At 0.051 sec, post no. 1S fractured through the BCT hole. At this same time, post no. 2S deflected backward. At 0.076 sec, post no. 3S deflected, and post no. 1P fractured at ground level. At 0.096 sec, the vehicle's front tires contacted the cable between post nos. 1P and 1S. At this same time, the right-front corner of the vehicle's bumper and the trim around the grill deformed, and a gap formed between the hood and the right-front quarter panel. At 0.106 sec, post no. 2S deflected downstream, and a crack initiated at the BCT hole. At 0.118 sec, post no. 2S fractured in the foundation tube, but remained attached to the cable anchor. At 0.122 sec, a buckle formed between post nos. 3S and 4S, and the large buckle at post no. 2S creased the guardrail. At 0.114 sec, post no. 2P deflected downstream and backward as it contacted the vehicle's bumper, and post no. 2S fractured in the foundation tube. At 0.130 sec, post no. 2P fractured. At 0.140 sec, the rear tires traversed over the cable anchor attached to post no. 1S. At 0.154 sec, post no. 1S fractured vertically through the BCT hole, releasing the cable and cable anchor plate. At 0.168 sec, post nos. 3S and 3P fractured, and the guardrail creased and folded around the blockout at post no. 3P. At 0.202 sec, the dual blockout at post no. 3P separated and twisted towards impact on the post bolt. At 0.214 sec, post no. 4S fractured. At this same time, post no. 4P deflected due to contact with post no. 3P, and the blockout at post no. 4P rotated. At 0.236 sec, post no. 5S fractured, and post no. 1S was located under the vehicle. At 0.260 sec, the right-rear tire contacted post no. 1S, and post no. 4P fractured. At 0.314 sec, post no. 7S fractured. At 0.330 sec, post no. 5P fractured and twisted, and the rail buckled on both sides of post no. 5P. At 0.345 sec, the right-rear corner of the vehicle rose upward as the vehicle traversed over post no. 1S. At 0.396 sec, the front of the vehicle pitched downward. At this same time, post nos. 6P through 9P deflected. At 0.404 sec, the guardrail contacted the ground in front of the vehicle, the vehicle yawed clockwise, and the back end continued to rise. At 0.438 sec, post nos. 6P and 6S fractured. At 0.458 sec, post no. 8S fractured, and the rail deformed around the blockout at post no. 8S. At 0.515 sec, post no. 7P fractured, and the blockout twisted on the post bolt. At 0.620 sec, post no. 9S twisted and deflected, and the vehicle's left-rear tire contacted the top corrugation of the thrie beam. At 0.710 sec, the left-rear tire over rode the thrie beam on the primary side of the system, and post nos. 10P and 11P disengaged from the rail. At 0.966 sec, the right-rear tire contacted the guardrail, and post no. 10P fractured. At 1.042 sec, the left-front tire snagged on the deformed guardrail, and the vehicle rotated about this point. At 1.082 sec, the vehicle's left-rear tire contacted the ground, and the vehicle continued pivoting around the left-front tire. At 1.254 sec, the vehicle rolled onto its side. At 1.320 sec, the vehicle came to a stop on its left side at 12.8 m (42 ft) longitudinally and 5.6 m (18 ft-6 in.) laterally away from impact. The vehicle's trajectory and final position are shown in Figures 32, 40 and 42.

5.3 System Damage

Barrier damage was extensive, as shown in Figures 43 through 58. Damage consisted mostly of fractured posts, fractured blockouts, damaged cable anchor hardware, and flattened and deformed guardrail.

Post nos. 1P, 1S and 2S fractured at the foundation tubes. The foundation tube at post no. 2S was dented and bent along the bolt centerline. Post nos. 2P through 10P fractured and disengaged from the rest of the system. Post no. 11P rotated backwards in the soil and cracked at the groundline. Post nos. 12P and 13P rotated backwards in the soil. Post nos. 1S and 2S fractured in the foundation tubes and were disengaged from the rest of the system. Post nos. 3S through 8S fractured at ground level and disengaged from the rest of the system. Post no. 9S rotated backwards in the soil and cracked through the transverse CRT hole, but remained in the ground.

The blockouts at post nos. 2P through 10P deformed and were damaged around the bolt holes. The blockout at post no. 11P twisted on the bolt and the front face was deformed. The blockout at post no. 9S was compressed on the traffic-side face and the upstream top edge of the traffic face was chipped.

Contact marks were found between the nose section of the rail and post no. 8P. The guardrail was flattened and deformed between post nos. 5P and 3S. Rail buckling was observed in the nose section and between post nos. 1P through 13P and 1S through 8S. The post bolts pulled through the rail at post nos. 1P through 13P and 1S through 8S. Rail tearing occurred at post nos. 8S and 9S.

The cable anchor bracket on post no. 1P twisted and scratches were observed on the right side. The threaded rods were stripped and the BCT bearing plate and nut at the groundline anchor were disengaged from the rod. The cable anchor at post no. 2S was disengaged from the system.

5.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 59 through 62. Occupant compartment deformations to the right side and center of the floorboard were judged insufficient to cause serious injury to the vehicle occupants. A maximum longitudinal deflection of 13 mm (0.5 in.) was located in the right-front corner of the right-side floor pan. A maximum lateral deflection of 13 mm (0.5 in.) was located at the center of the right side of the right-side floor pan. Maximum vertical deflections of 6 mm (0.25 in.) were located throughout the right-side floor pan. Complete occupant compartment deformations and the corresponding locations are provided in Appendix C.

The bumper and grill encountered scratches and tears. The right-front corner of the bumper was deformed inwards. The left-side front quarter panel, door, and box of the vehicle sustained dents and scratches. The center of the door panel and above the left-rear wheel well were dented. The left-front tire was deflated and removed from the rim. The left-rear brake light was disengaged from the housing, but remained intact. The left-side mirror was bent upwards. The rear right side, undercarriage, and all window glass remained undamaged.

5.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be -6.14 m/s (-20.16 ft/s) and -2.44 m/s (-7.99 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 9.61 g's and -5.55 g's, respectively. It is noted that the occupant impact velocities (OIVs) and occupant ridedown decelerations (ORDs) were within the suggested limits provided in the currently proposed Update to NCHRP Report No. 350. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 32. Results are shown graphically in Appendix D. Results from the rate transducer are also shown graphically in Appendix D.

5.6 Discussion

Following test SR-7, a safety performance evaluation was conducted, and the short-radius guardrail system did not adequately contain the vehicle due to vehicle override of the system. 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 remain upright after the collision due to it rolling on its side. After collision, the vehicle's trajectory did not intrude into adjacent traffic lanes. The occupant impact velocities and ridedown decelerations were within the suggested limits provided in the currently proposed Update to NCHRP Report No. 350. Therefore, the short-radius guardrail installation was determined to be unacceptable according to the TL-3 safety performance criteria currently found in the proposed Update to NCHRP Report No. 350 due to the vehicle override of the guardrail and subsequent roll of the vehicle.

0.000 sec | 0.104 sec | 0.216 sec | 0.342 sec | 0.484 sec

- Test Agency . . . . MwRSF
- Test Number SR-7
- Date 6/27/2006
- Proposed Update to NCHRP 350 Test Designation . 3-33
- Appurtenance . . . . Short-Radius Guardrail
- Key Elements - Steel Thrie-Beam
  - Thickness . . . . 2.67 mm
  - Top Mounting Height . . . . 787 mm
- Key Elements - Steel Posts
  - Post Nos. 14P-19P . . . . W152 x 13.4 by 1,981 mm long
  - Post Nos. 20P-21P . . . . W152 x 37.2 by 2,032 mm long
- Key Elements - Wood Posts
  - Post Nos. 2P-13P, 3S-6S (Thrie CRT) . . . . 152 mm x 203 mm by 1,981 mm long
  - Post Nos. 7S-9S (MGS CRT) . . . . 152 mm x 203 mm by 1,829 mm long
- Key Elements - Steel Foundation Tube
  - Post Nos. 1P, 1S-2S . . . . 2,438 mm long
  - Post Nos. 10S-11S . . . . 1,829 mm long
- Key Elements - Dual Tapered Wood Spacer Blocks
  - Post Nos. 2P-13P, 3S-5S . . . . two 152 mm x 203 mm by 362 mm long
- Key Elements - MGS Blockouts
  - Post No. 6S-9S . . . . 152 mm x 305 mm by 362 mm long
- Type of Soil . . . . Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model . . . . 2002 Dodge Ram 1500 Quad Cab Pickup Truck
  - Curb . . . . 2,277 kg
  - Test Inertial . . . . 2,263 kg
  - Gross Static . . . . 2,263 kg

- Impact Conditions
  - Speed . . . . 100.3 km/h
  - Angle . . . . 18.1 degrees
  - Impact Location . . . . Centerline of Nose Section with Centerline of Vehicle
- Exit Conditions
  - Speed . . . . N/A
  - Angle . . . . N/A
  - Exit Box Criterion . . . . N/A
- Post-Impact Trajectory
  - Vehicle Stability . . . . Unsatisfactory
  - Stopping Distance . . . . 12.80 m longitudinal, 5.63 m lateral
- Occupant Impact Velocity
  - Longitudinal . . . . 6.14 m/s < 12 m/s
  - Lateral . . . . -2.44 m/s < 12 m/s
- Occupant Ridedown Deceleration
  - Longitudinal . . . . 9.61 Gs < 20 g's
  - Lateral . . . . -5.55 Gs < 20 g's
- THIV (not required) . . . . 6.67 m/s
- PHD (not required) . . . . 9.67 g's
- Test Article Damage . . . . Extensive
- Test Article Deflections
  - Permanent Set . . . . 13.45 m
  - Dynamic . . . . N/A
  - Working Width . . . . 14.21 mlaterally from primary side
- Vehicle Damage . . . . Moderate
  - VDS[18] 1-FD-2
  - CDC[19] 01-FDEW-2
  - Maximum Deformation . . . . 13 mm at right-center door panel
- Angular Displacements
  - Roll . . . . -14 deg
  - Pitch . . . . -12 deg
  - Yaw . . . . 84 deg

Figure 32. Summary of Test Results and Sequential Photographs, Test No. SR-7


0.000 sec

0.224 sec

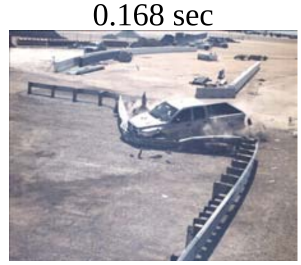
0.464 sec

0.702 sec

1.082 sec

1.320 sec


0.000 sec

0.168 sec

0.398 sec

0.622 sec

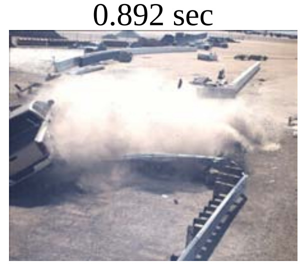
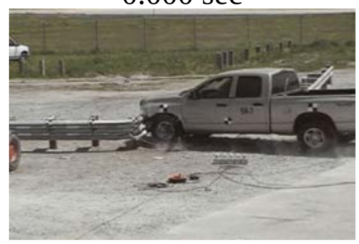
0.892 sec

1.200 sec

Figure 33. Additional Sequential Photographs, Test SR-7


0.000 sec

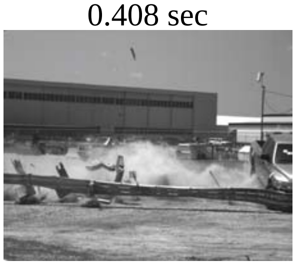
0.000 sec

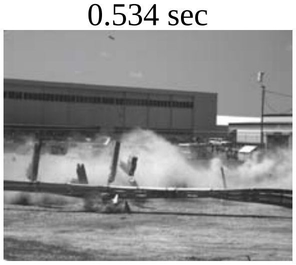
0.142 sec

0.100 sec

0.290 sec

0.234 sec

0.408 sec

0.334 sec

0.534 sec

0.400 sec

0.662 sec

0.501 sec

Figure 34. Additional Sequential Photographs, Test SR-7

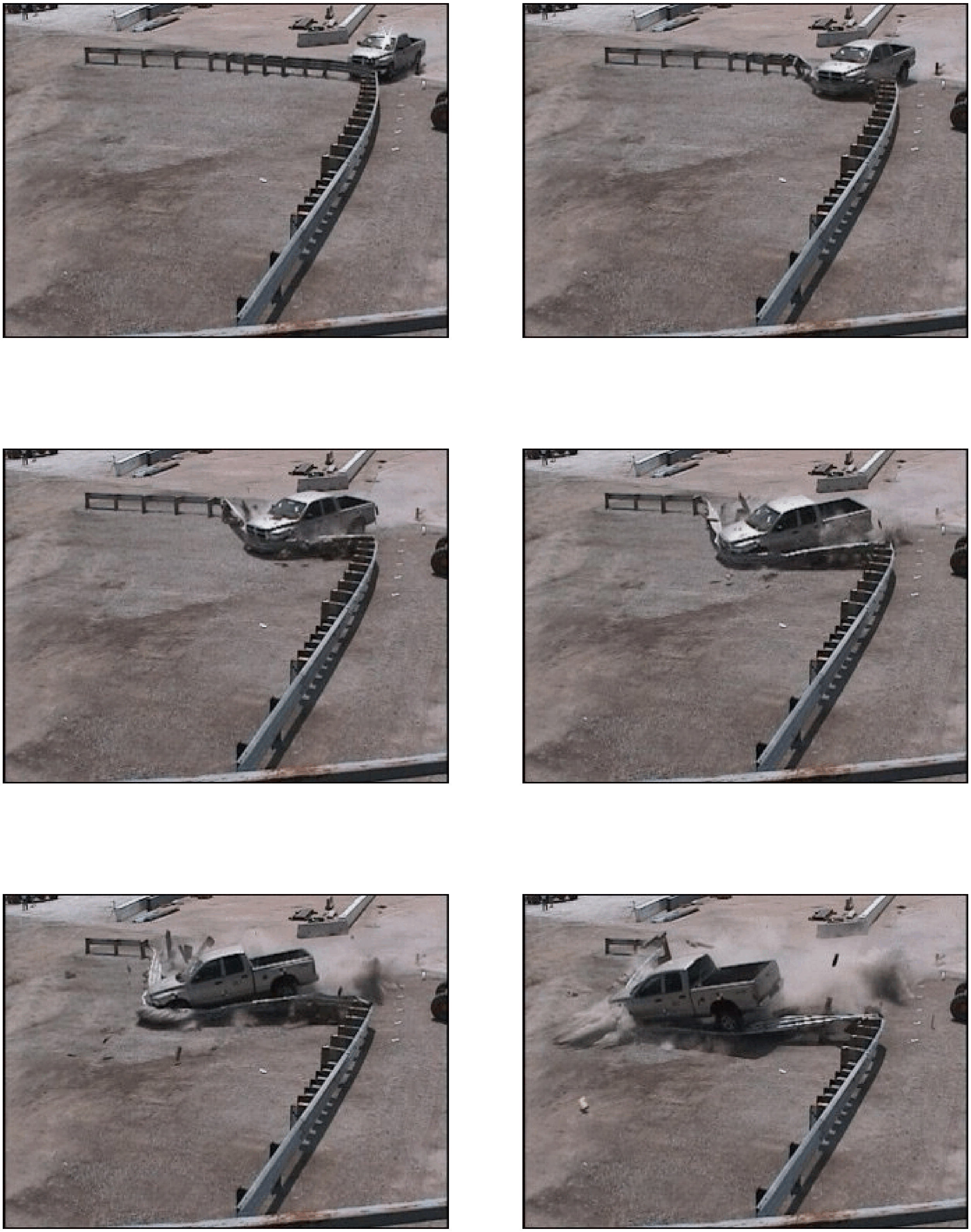


Figure 35. Documentary Photographs, Test SR-7

Figure 36. Documentary Photographs, Test SR-7

Figure 37. Documentary Photographs, Test SR-7

Figure 38. Documentary Photographs, Test SR-7

Figure 39. Impact Location, Test SR-7

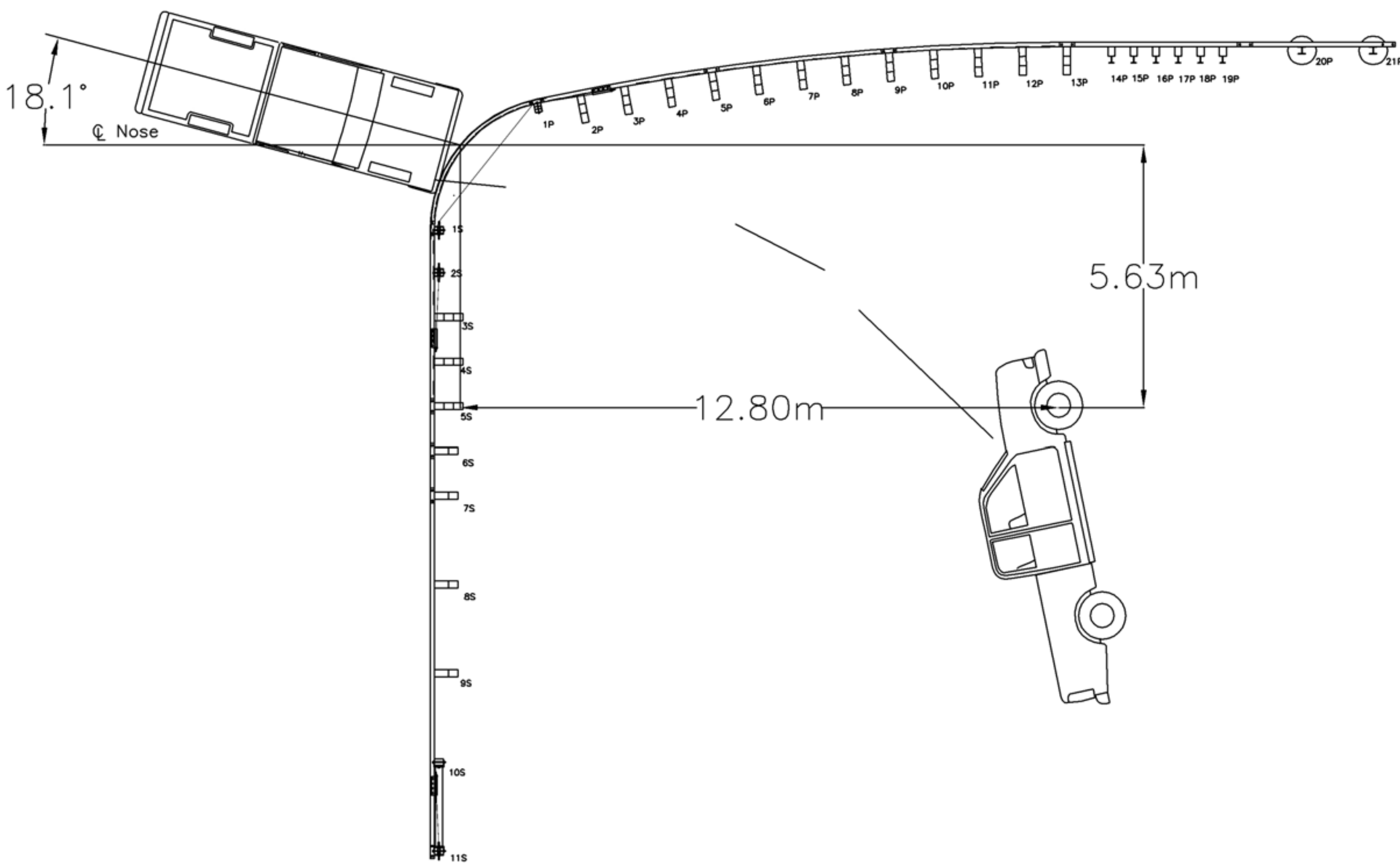


Figure 40. Vehicle Trajectory, Test SR-7

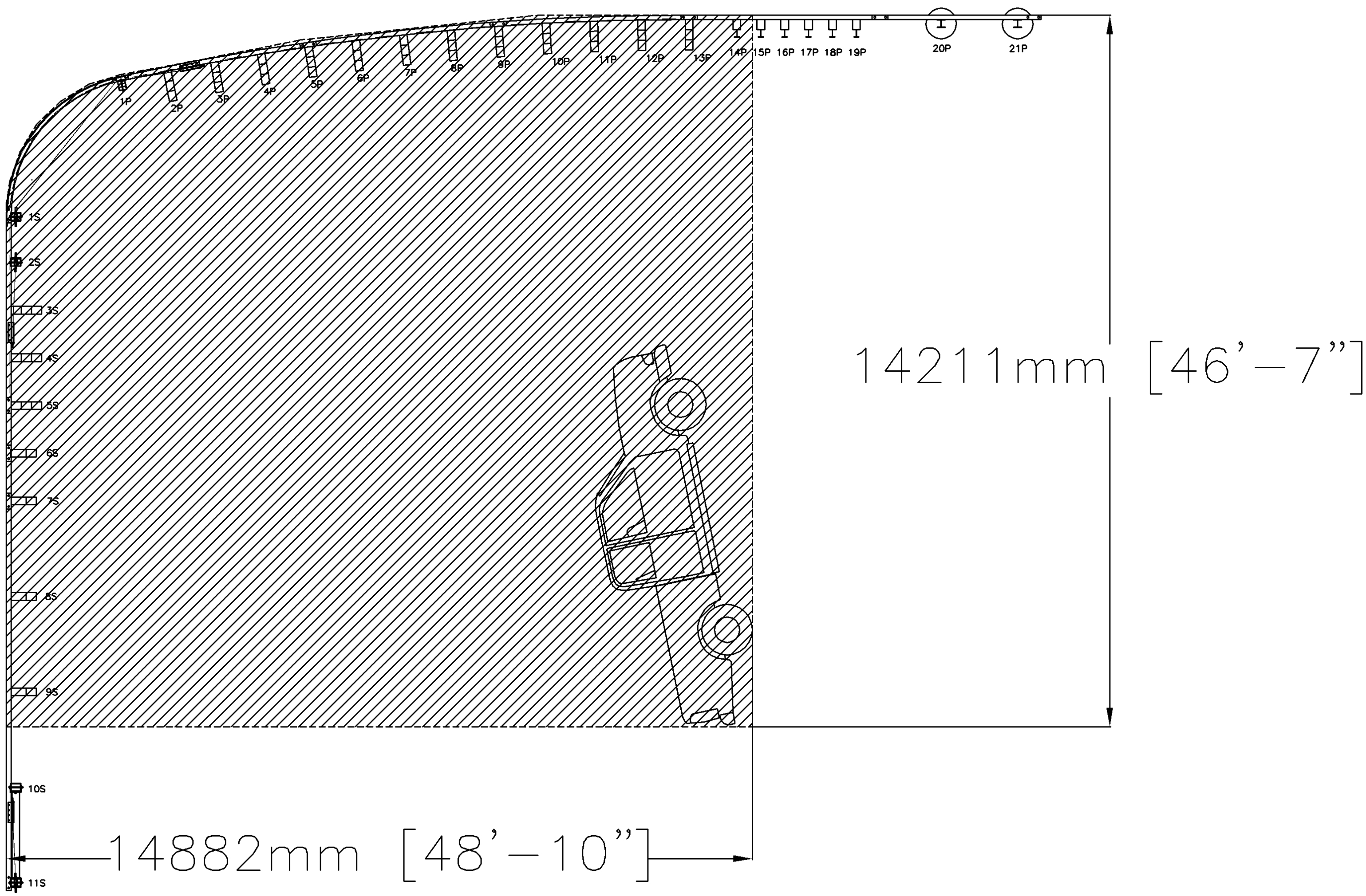


Figure 41. Working Width, Test SR-7

Figure 42. Vehicle Trajectory and Final Position, Test SR-7

Figure 43. System Damage, Test SR-7

Figure 44. System Damage, Test SR-7

Figure 45. System Damage, Test SR-7

Figure 46. System Damage, Test SR-7

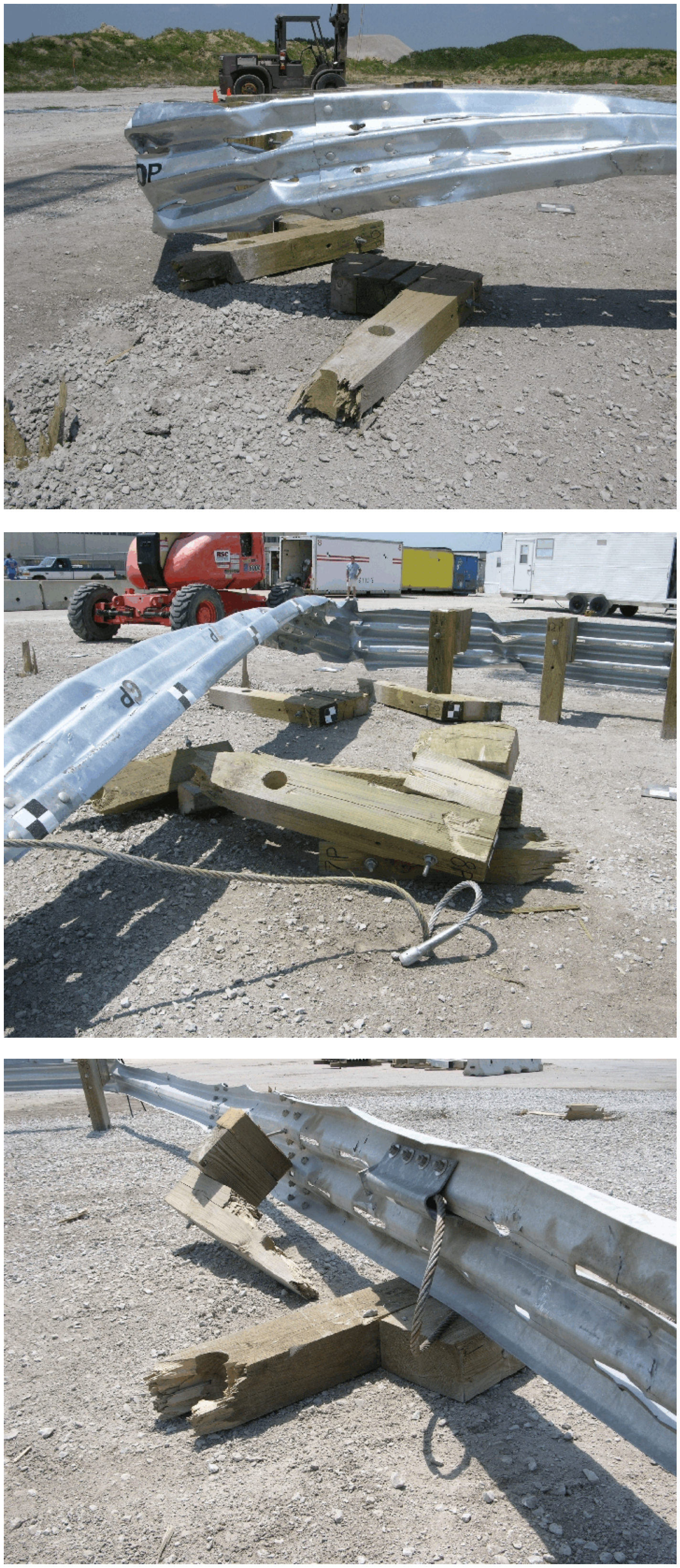


Figure 47. System Damage, Test SR-7

Figure 48. System Damage, Test SR-7

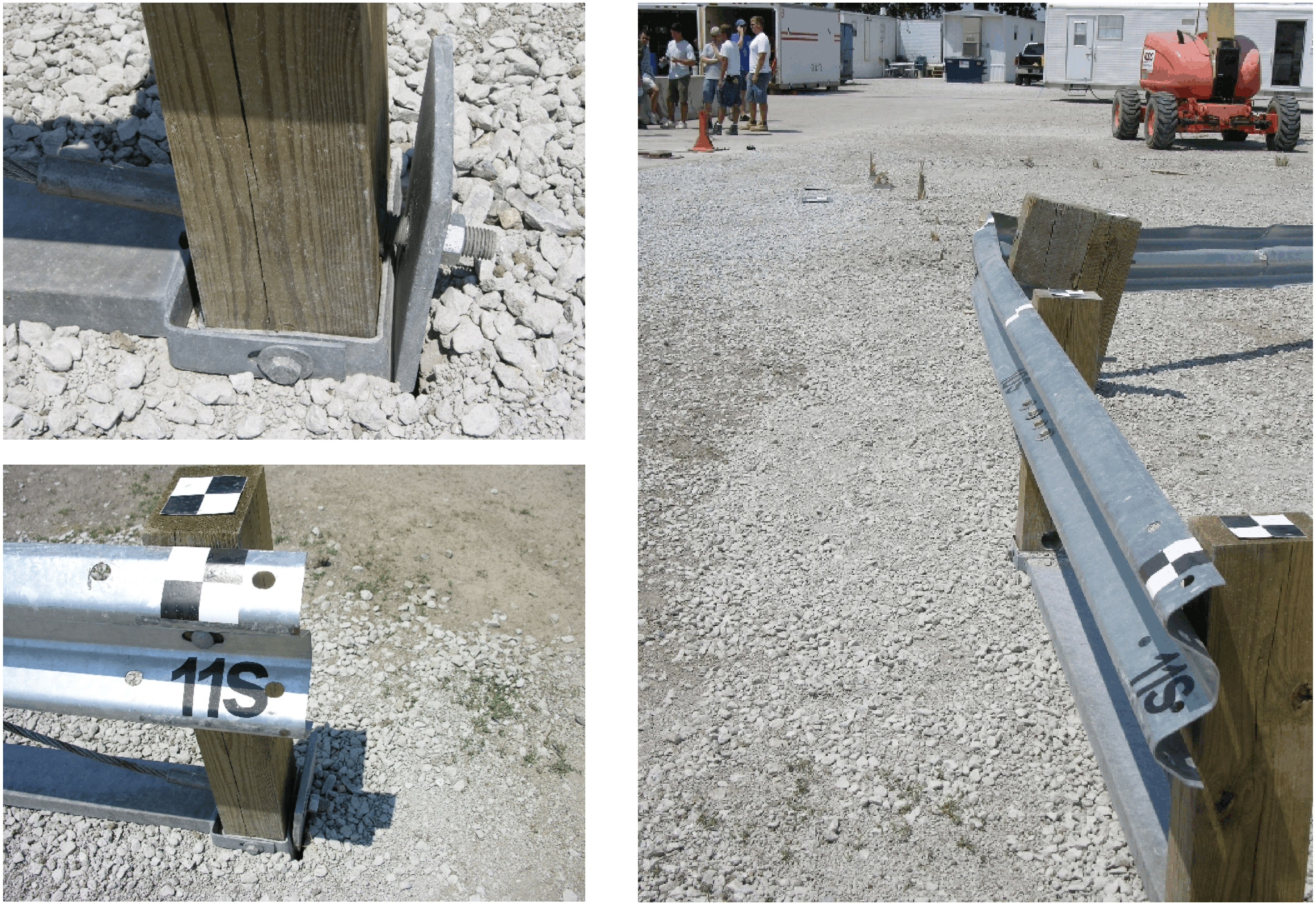


Figure 49. Post Nos. 10 and 11 Damage, Test SR-7

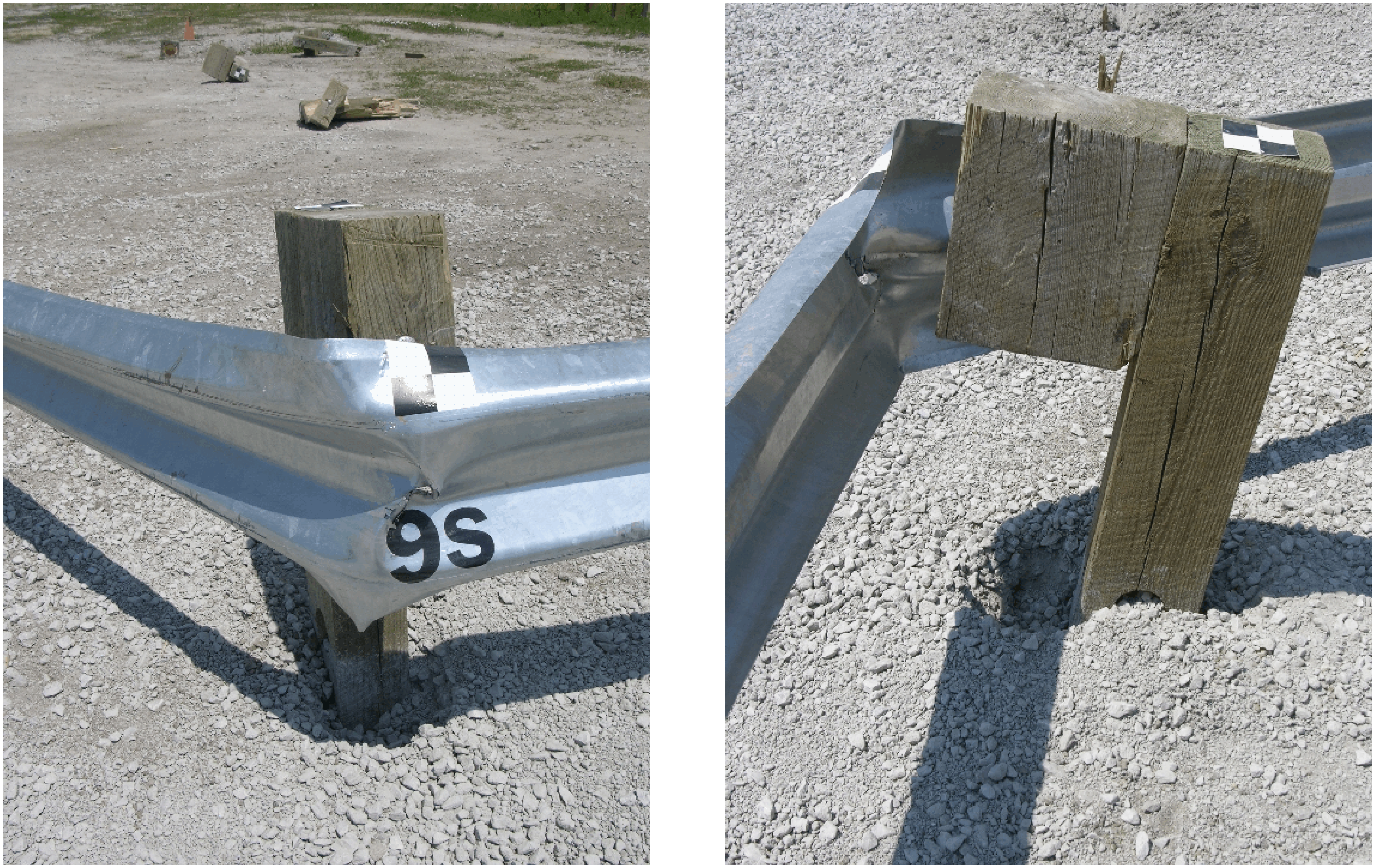


Figure 50. Post No. 9S Damage, Test SR-7

Figure 51. Post Nos. 6S through 8S Damage, Test SR-7

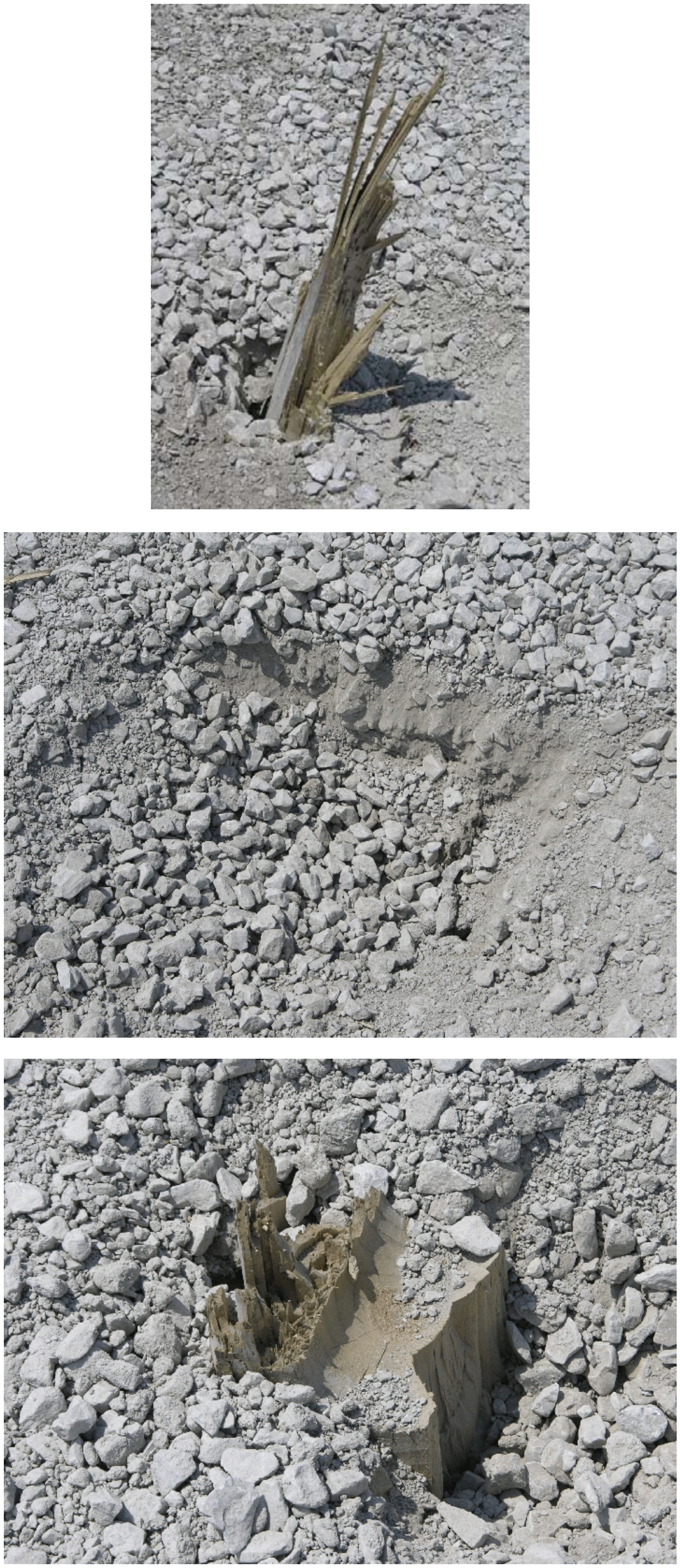


Figure 52. Post Nos. 3S through 5S Damage, Test SR-7

Figure 53. Post Nos. 1P, 1S and 2S Damage, Test SR-7

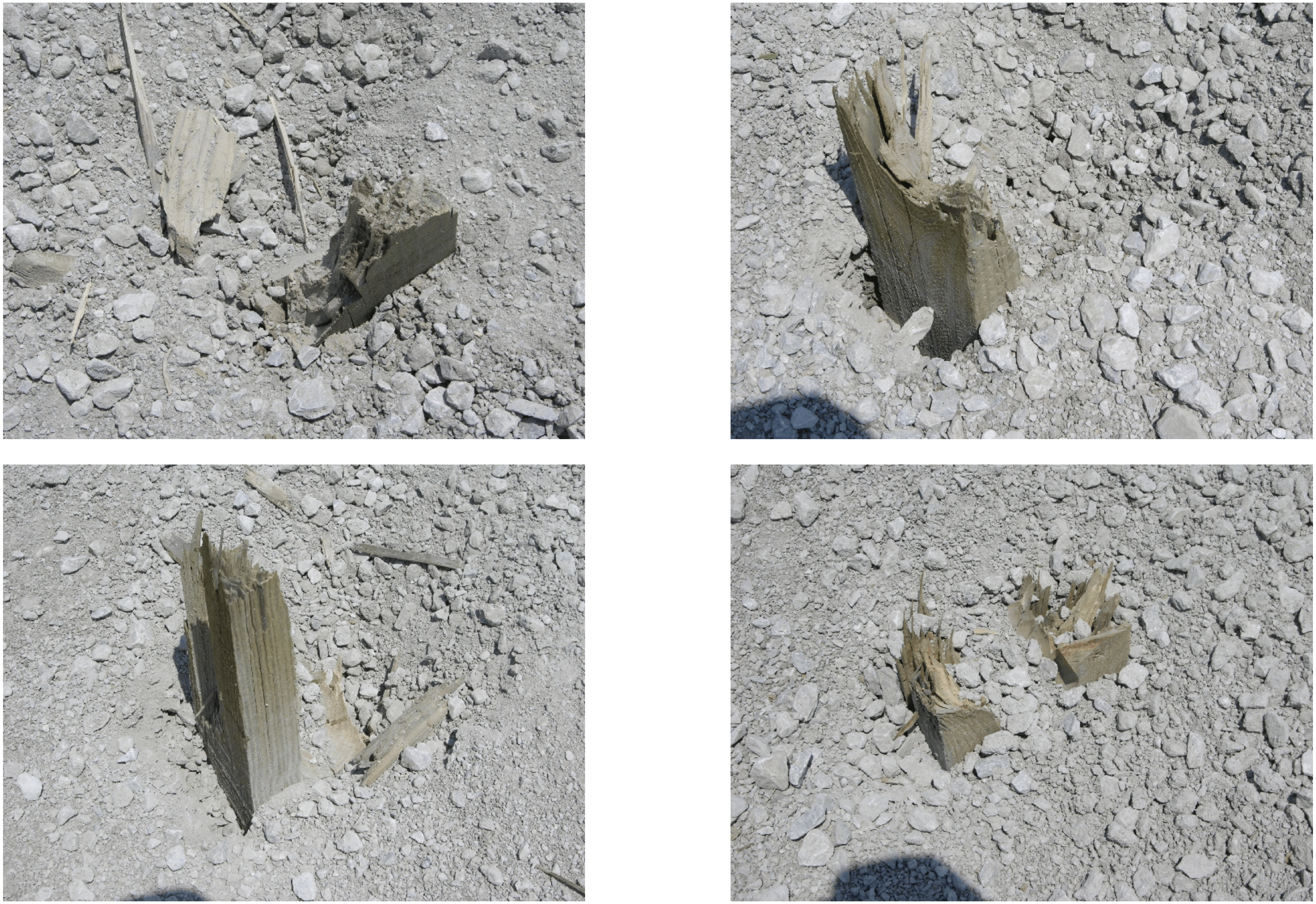


Figure 54. Post Nos. 2P through 4P, Test SR-7

Figure 55. Post Nos. 6P through 9P Damage, Test SR-7

Figure 56. Post Nos. 11P through 13P Damage, Test SR-7

Figure 57. Post Nos. 14P through 19P Damage, Test SR-7

Figure 58. Post Nos. 20 and 21P Damage, Test SR-7

Figure 59. Vehicle Damage, Test SR-7

Figure 60. Vehicle Damage, Test SR-7

Figure 61. Vehicle Damage, Test SR-7

Figure 62. Occupant Compartment Deformation, Test SR-7

6 DESIGN MODIFICATIONS

6.1 Analysis of Test SR-7

Following the unsuccessful performance of the short-radius guardrail system in test no. SR-7, a safety performance evaluation was conducted in order to determine what design changes, if any, could improve the performance of the short-radius guardrail system. A thorough review of the test data revealed four potential causes of vehicle instability observed in the test.

(1) High-speed video from the test showed that debris from the fractured posts and anchorage hardware interacted with the rear wheels of the pickup. The contact with the debris caused the vehicle to pitch and ultimately climb the guardrail, contacting the ground on the rear side of the system.

(2) Post no. 1S did not fracture completely during the crash test. The poor release of the cable at post no. 1S allowed the cable to propel a broken section of post no. 1S under the wheels of the vehicle, adding to the debris under the wheels and the instability of the vehicle.

(3) The groundline cable connected to post no. 1S snagged at the cable anchor bracket located at post no. 1P. As the cable anchor pulled the BCT bearing plate from post no. 1S toward anchorage post no. 1P, the BCT bearing plate became wedged between the foundation tube of post no. 1P and the cable anchor bracket, causing the nut to disengage from the threaded rod. The re-engagement of the groundline cable with the cable anchor bracket on post no. 1P was undesirable, because additional tension in the cable could result in the guardrail being pulled down and twisting in front of the vehicle.

(4) The slot tabs in the nose section and curved thrie beam sections did not tear through

completely. Previous testing with the bullnose median barrier system had shown that the capture of the pickup truck was most effective when the slot tabs in the nose section of the rail tore through allowing the top sections of the rail to slide above the bumper and interlock the truck. Review of the high-speed video revealed that the slot tabs in the nose section during test no. SR-7 did not tear through, which resulted in less effective interlock of the nose section with the front of the pickup truck.

6.2 Design Changes

Following the analysis of test no. SR-7, several design changes were implemented to improve the safety performance of the short radius guardrail system. First, the transverse holes in post nos. 1P, 1S, and 2S were enlarged from 64 mm (2.5 in.) to 76 mm (3 in.) in diameter to facilitate a cleaner release of the cable anchor and improve the breakaway performance of the posts to prevent them from becoming debris that interacted with the vehicle. The modified posts were named BSR posts, or "Breakaway Short Radius" posts, since they were unique to the short radius system. Second, rectangular plate washers were added on the front side of the rail to post nos. 1S, 2S, 1P, 2P, 3P, and 4P. The plate washers were designed to retain the posts on the guardrail to prevent them from becoming debris in the path of the oncoming vehicle. Third, the cable anchor bracket on the front side of post no. 1P was reduced in size to allow the anchor cable to release more easily and prevent the BCT bearing plate and nut from wedging against post no. 1P, as was observed in test no. SR-7. Finally, the outer slot tabs in the nose section of the short-radius system were reduced from 51-mm (2-in.) wide to 25-mm (1-in.) wide. This change was made to allow the slot tabs to tear more easily, thus allowing the rail corrugations to separate and more effectively capture the vehicle. The revised system drawings are shown in Figures 63 through 70. Photographs of the system are shown in Figures 71 through 73. Complete system drawings in English and Metric units are shown in Appendix E and F, respectively.

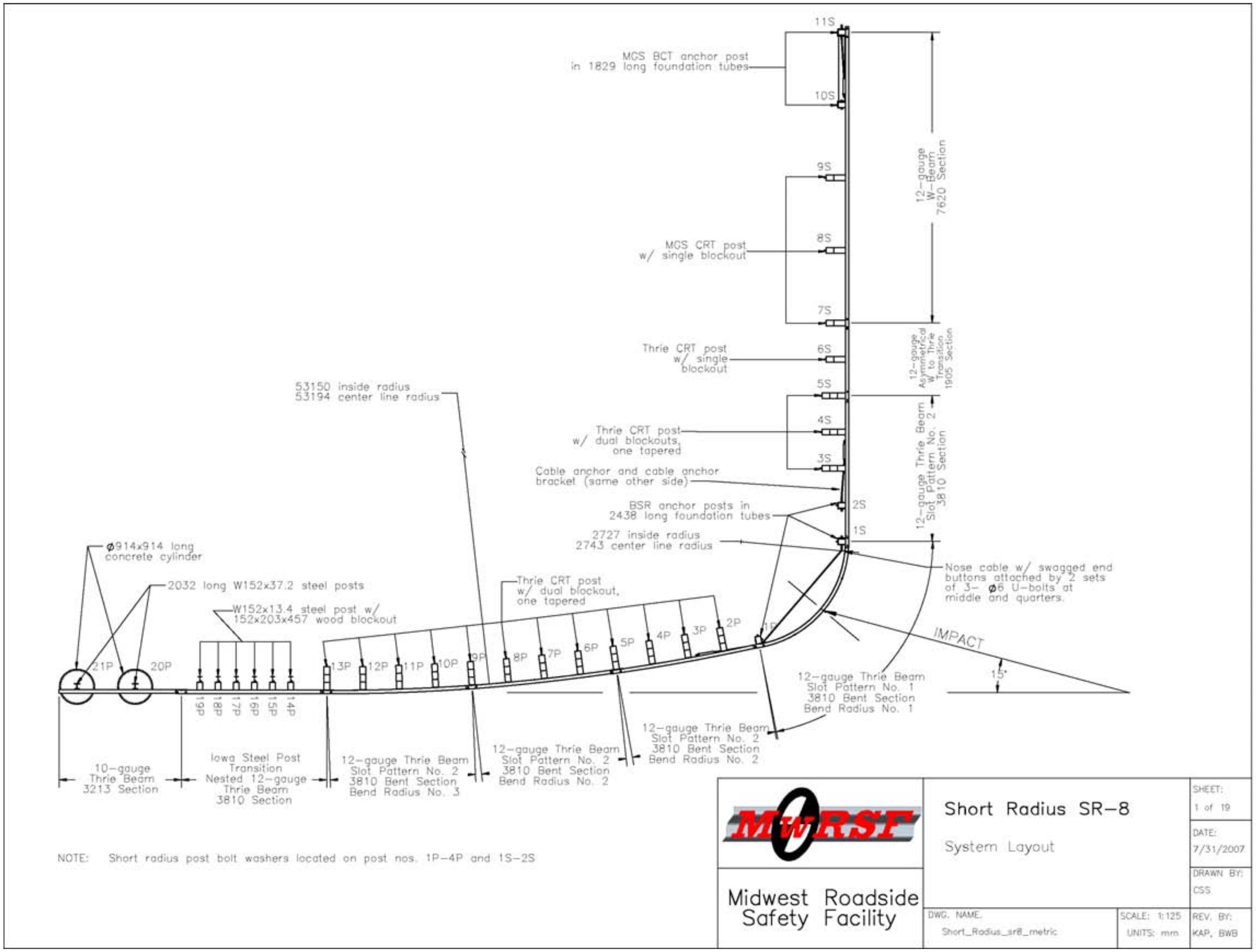


Figure 63. System Layout

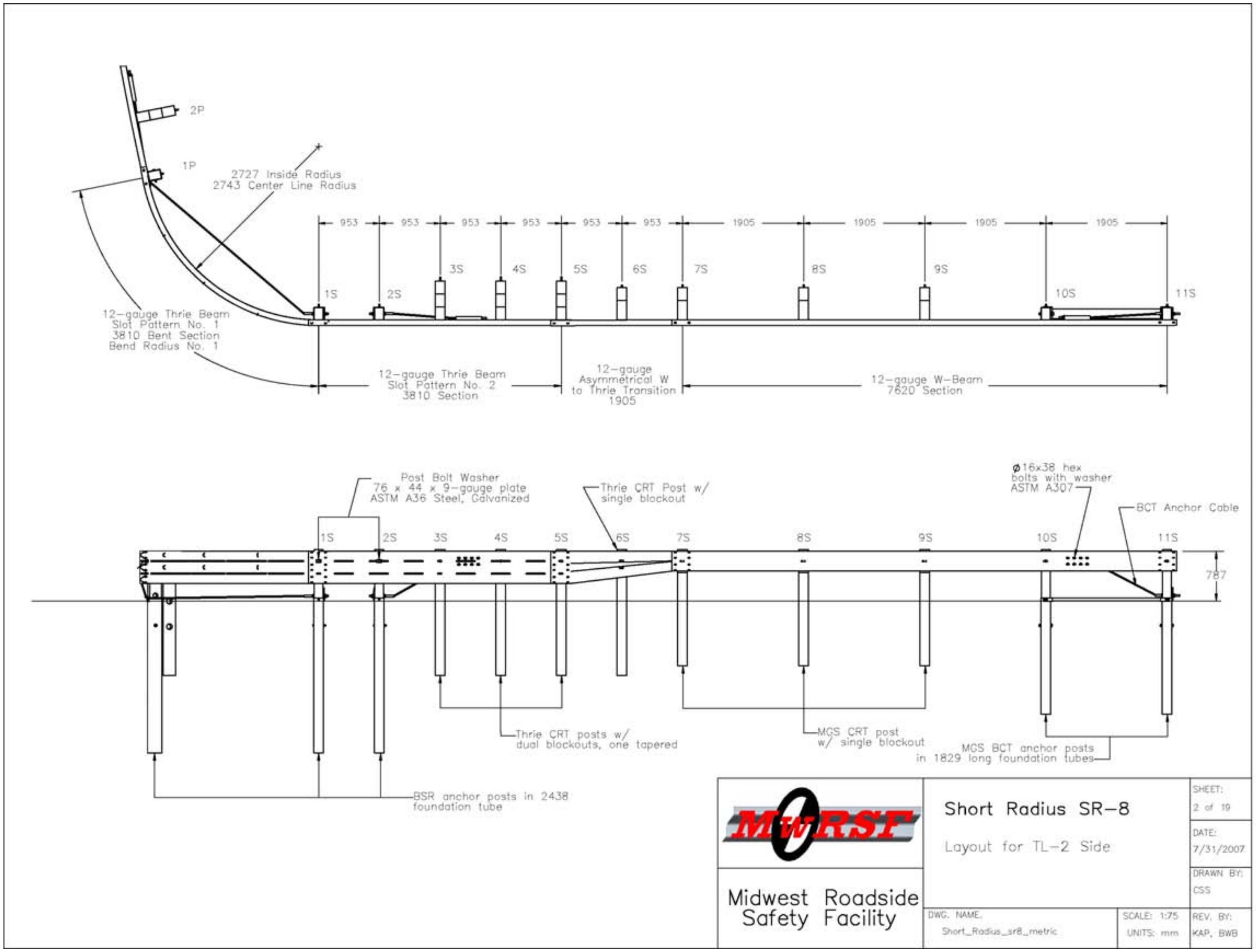


Figure 64. Layout for TL-2 Side

Post No.	Front Face D.S. Edge		Front Face U.S. Edge	
	X	Y	X	Y
1P	11254	1209.675	11395	1235.075
2P	10258	1412.875	10408	1443.0375
3P	9330	1238.25	9481	1265.2375
4P	8396	1079.5	8547	1103.3125
5P	7455	935.0375	7606	958.85
6P	6526	811.2125	6596	830.2625
7P	5580	701.675	5731	720.725
8P	4645	611.1875	4797	625.475
9P	3700	536.575	3853	547.6875
10P	2757	477.8375	2910	487.3625
11P	1816	438.15	1969	442.9125
12P	870	412.75	1022	415.925
13P	−76	406.4	76	406.4

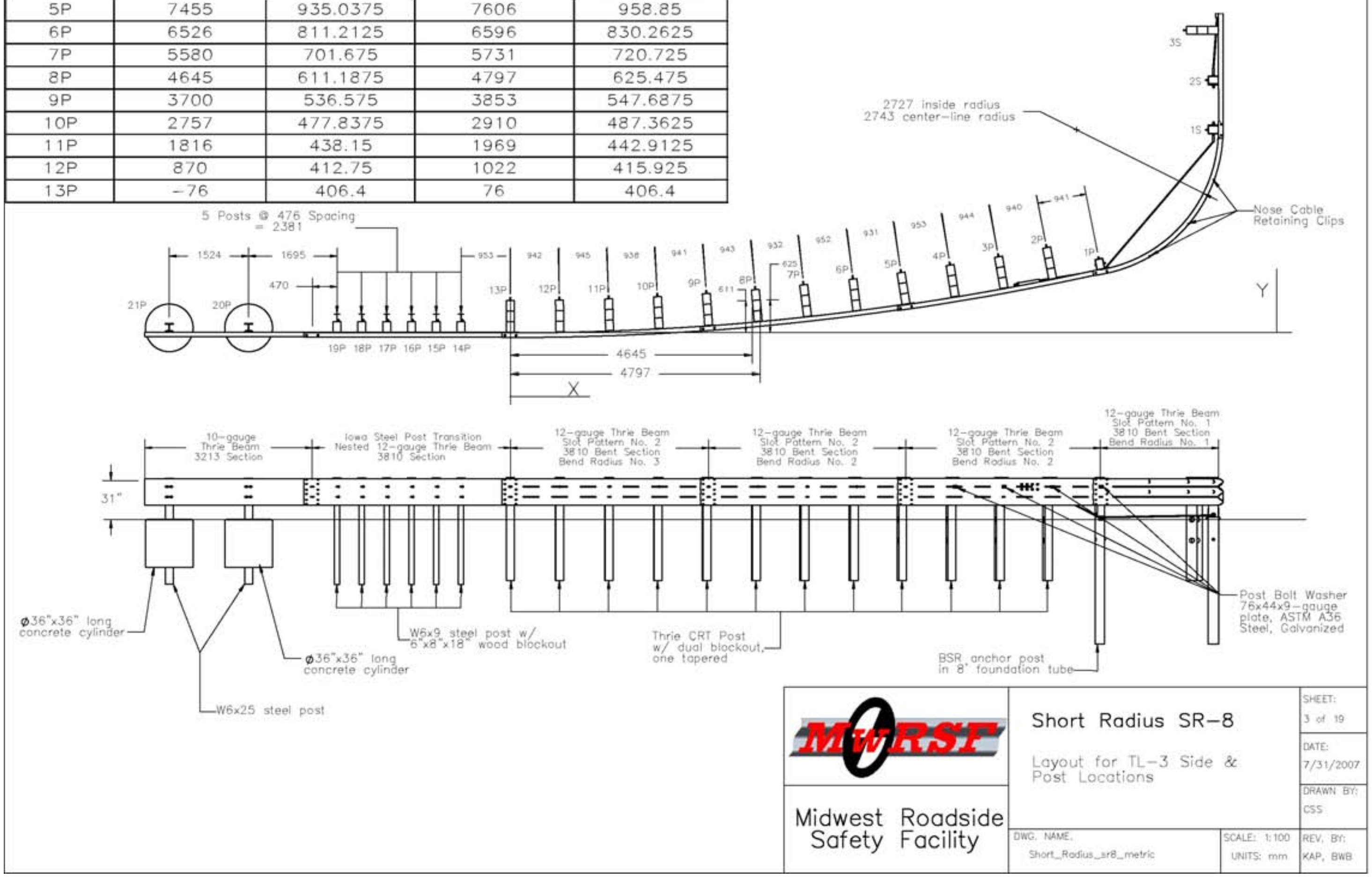


Figure 65. Layout for TL-3 Side

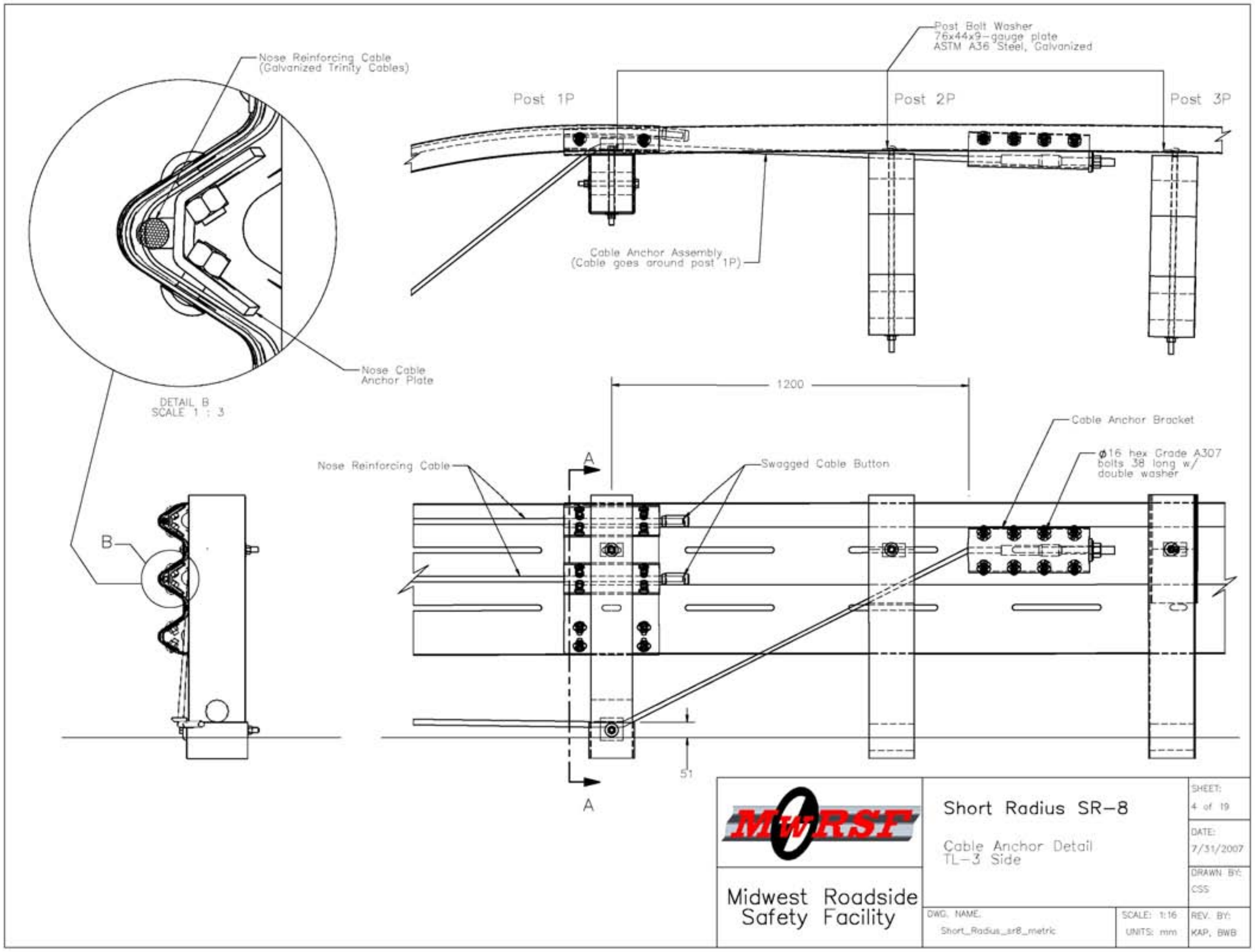


Figure 66. Cable Anchor Detail, TL-3 Side

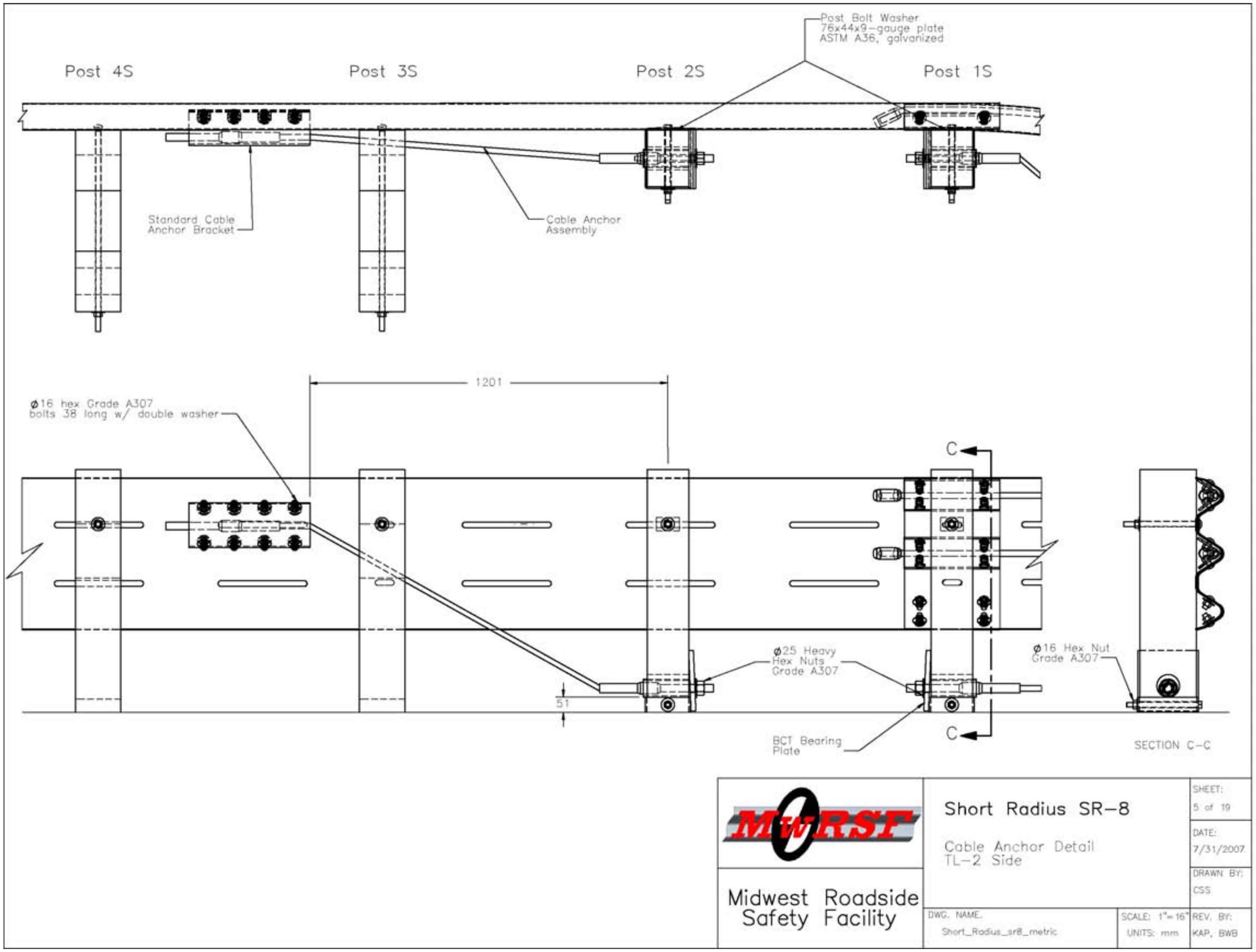


Figure 67. Cable Anchor Detail, TL-2 Side

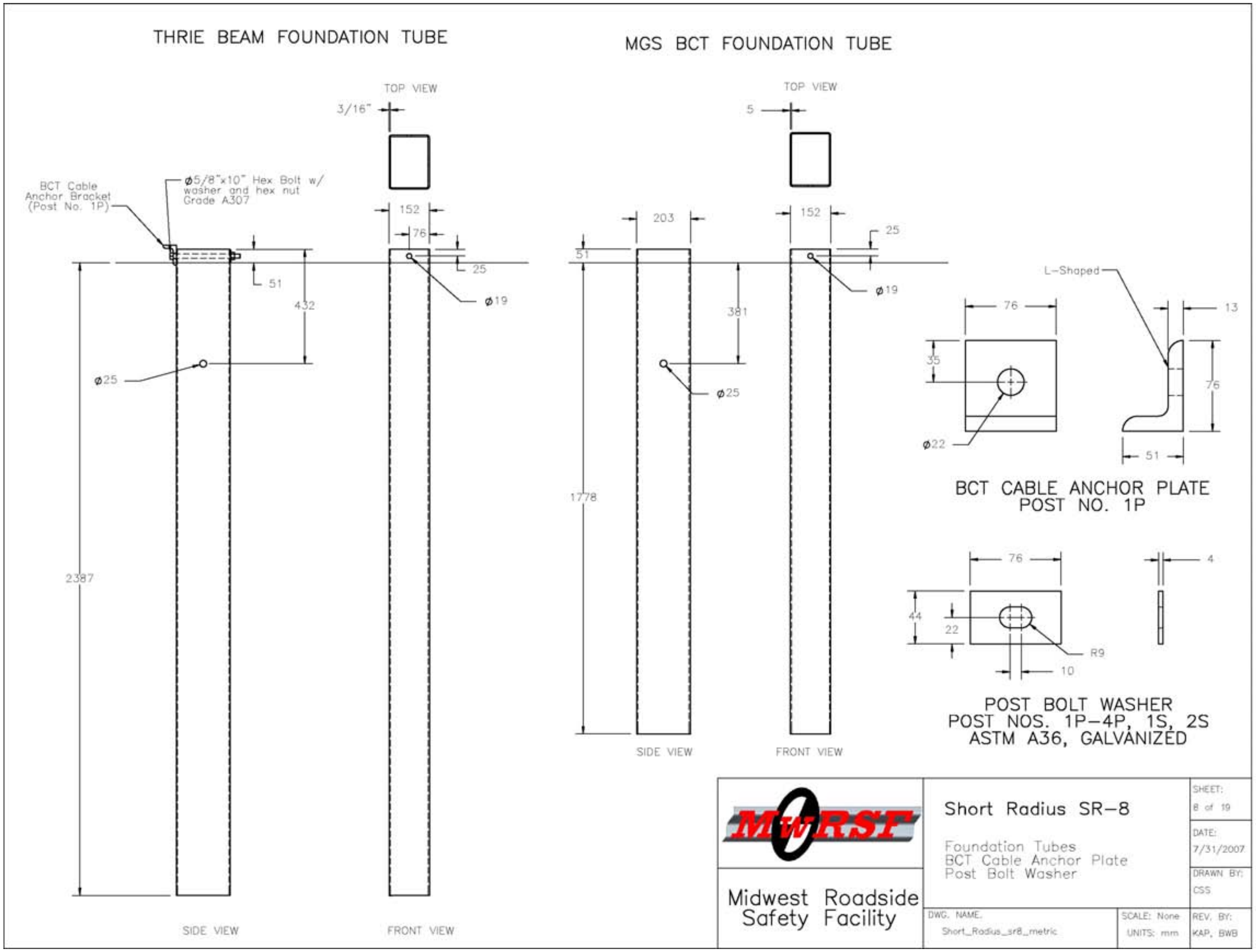


Figure 68. Foundation Tubes, BCT Cable Anchor Plate, and Post Bolt Washer Details

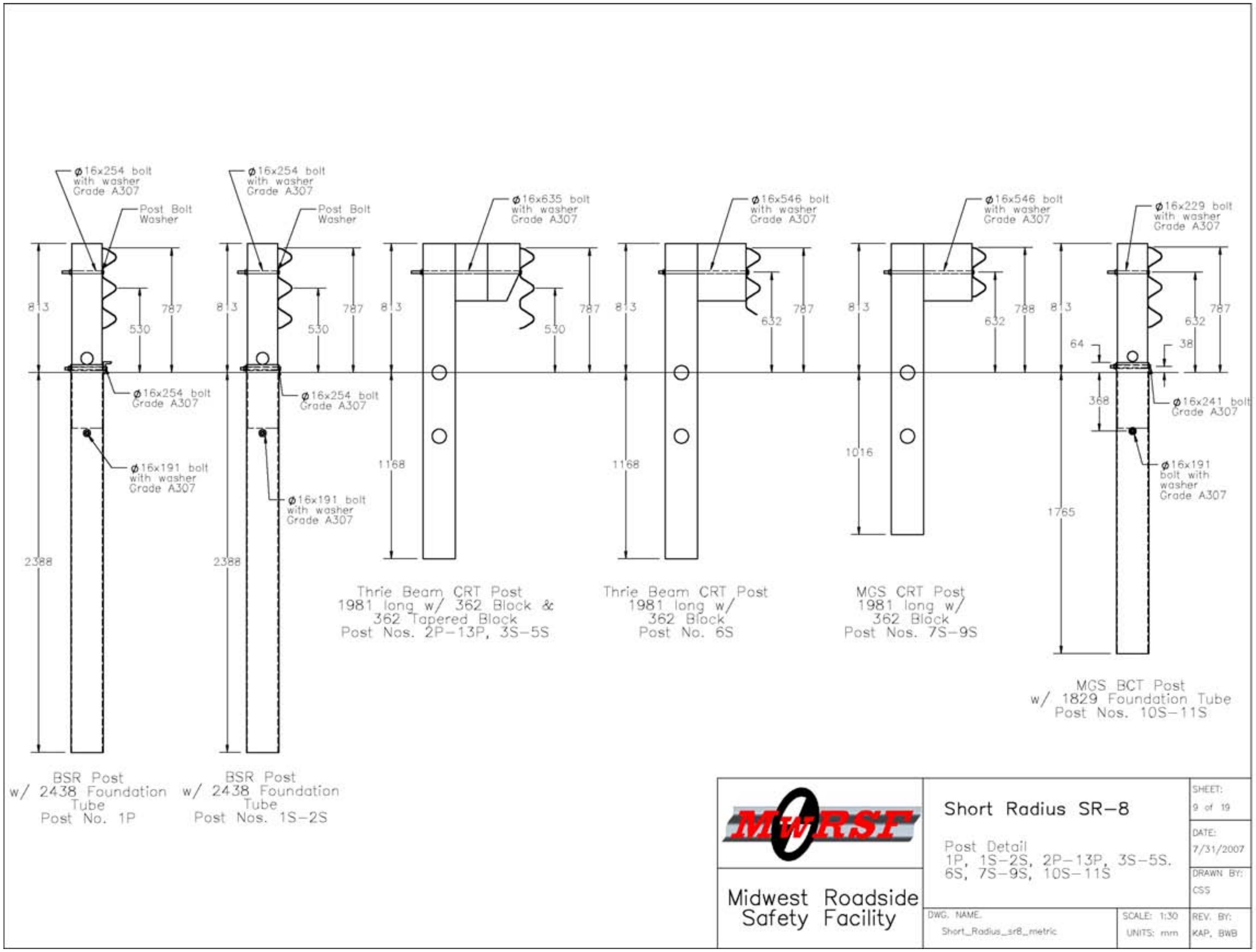


Figure 69. Post Details

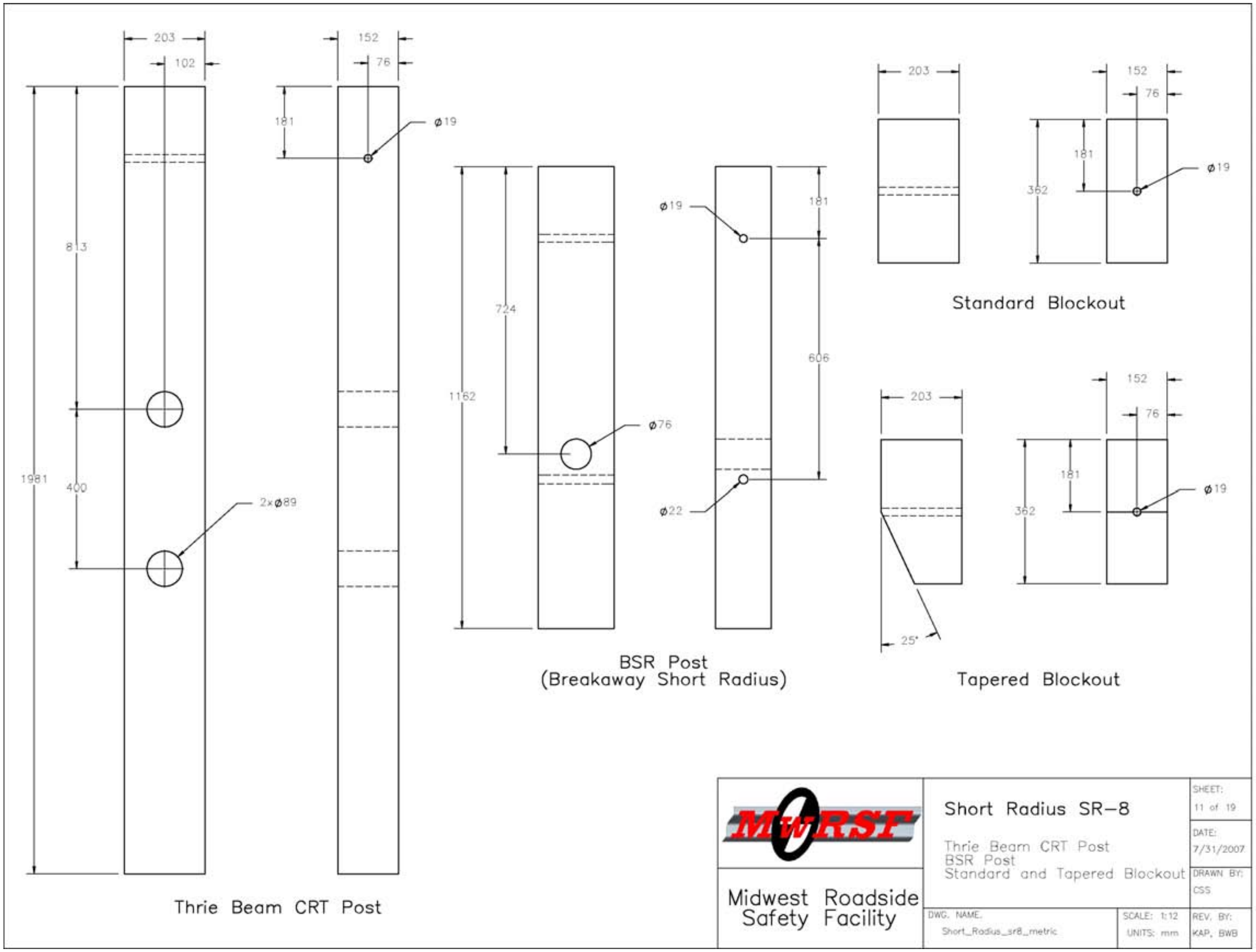


Figure 70. Thrie Beam CRT and BSR Post Details

Figure 71. System Details

Figure 72. Nose and Plate Washer Details

Figure 73. Anchor Bracket Details

7 CRASH TEST NO. 8

7.1 Test SR-8

The 5,000-kg (2,268-lb) pickup truck impacted the revised short-radius guardrail system at a speed of 101.0 km/h (62.8 mph) and at an angle of 17.9 degrees. A summary of the test results and the sequential photographs are shown in Figure 74. The summary of the test results and sequential photographs in English units is shown in Appendix B. Additional sequential photographs are shown in Figures 75 and 76. Documentary photographs of the crash test are shown in Figures 77 through 80.

7.2 Test Description

Impact was to occur with the centerline of the vehicle aligned with the centerline of curved nose section of the system. Actual vehicle impact occurred at the targeted impact. Upon impact, the nose section deformed and crushed in front of the impacting vehicle. At 0.012 sec, post no. 1S deflected backwards. At 0.036 sec, the guardrail deformed around the left-front corner of the vehicle's bumper, post no. 1S twisted clockwise, and the right-front tire overrode the groundline cable. At 0.042 sec, the front of the vehicle pitched downward and post no. 2S deflected backward. At 0.054 sec, post no. 1S fractured and remained attached to the guardrail. At 0.072 sec, post no. 1P fractured at ground level, and post nos. 3P through 5P deflected backwards. At 0.086 sec, post no. 2S fractured and a buckle developed at the downstream front of post no. 3S. At this same time, the cable anchor at post no. 1S was pulled toward the primary side of the system. At 0.100 sec, post no. 2S fractured through the transverse hole and disengaged from the thrie beam. Also at this time, post no. 2P cracked near ground level. At 0.106 sec, the vehicle's right-front tire contacted the bottom corrugation of the thrie beam and tore through the slot tabs in the nose section. At 0.114 sec, the thrie beam deformed around the upstream traffic-side edge of post no. 2P and deformed the post backwards. At 0.120 sec, post no. 2S contacted the ground. At 0.126 sec, the post bolt washer at post no. 2P pulled through the slot in the guardrail and the post fractured at the base. At 0.144 sec, post nos. 3P and 3S fractured. At 0.172 sec, the thrie beam buckled near post no. 2P around the cable anchor bracket, and post no. 4S disengaged from the guardrail. At 0.182 sec, post no. 4S fractured near ground level while rotating backwards. At 0.192 sec, the thrie beam deformed around the upstream front edge of the blockout at post no. 3P. At 0.208 sec, post no. 5S twisted upstream and the dual blockout at post no. 3P separated. At 0.232 sec, post no. 5S fractured. At 0.250 sec, post no. 4P fractured. At 0.290 sec, the guardrail deformed at post no. 4P, post no. 6S twisted clockwise in the soil and the center of the asymmetrical MGS W-beam to thrie beam transition piece buckled. At 0.314 sec, post no. 6S splintered as it twisted. At 0.332 sec, post no. 2P contacted the center of the left-side door. At 0.330 sec, post no. 6S disengaged from the guardrail, post no. 5P fractured at the groundline, and the vehicle’s hood became ajar. At 0.360 sec, post no. 5P disengaged from the rail, and the bottom corrugation of the thrie beam contacted the left-front tire. At this same time, the BCT bearing plate from the groundline anchor impacted the guardrail near post no. 5P, creating a rail tear. At 0.386 sec, post no. 2P contacted the left-rear tire. At 0.404 sec, post no. 7S rotated back in the soil, post no. 6P fractured, and the vehicle yawed about the left-front tire. At 0.476 sec, post no. 2P wedged between the ground and the left-rear tire. At 0.516 sec, post no. 7P fractured. At 0.568 sec, the left-rear tire became airborne due to contact with post no. 2P moving underneath the wheel. At 0.612 sec, post no. 8P fractured and disengaged from the guardrail. At this same time, the left-front tire overrode the guardrail. At 0.688 sec, post no. 9P fractured. At 0.824 sec, the vehicle continued to yaw and post no. 10P fractured. At 1.048 sec, the left-rear tire contacted the deformed thrie beam and a tear propagated in the rail from the upstream side of post no. 5P to the lower slot in the rail, adjacent to the splice location. At 1.202 sec, the left-rear tire overrode the thrie beam rail on the primary side of the system. At 1.522 sec, the right-rear tire overrode the thrie beam rail. At 1.926 sec, the vehicle continued to yaw as the left- and right-front tires overrode the guardrail. At 2.656 sec, the vehicle came to rest at 15.5 m (51 ft) downstream and 1.4 m (4 ft - 6 in.) behind the guardrail system. The vehicle trajectory and final position are shown in Figures 74, 82 and 84.

7.3 Barrier Damage

Barrier damage was extensive, as shown in Figures 85 through 93. Damage consisted mostly of flattened, deformed and torn guardrail, fractured posts, blockouts, and bolts, and deformed cable anchor hardware. System damage occurred between post nos. 8S and post no. 11P. The maximum permanent set of the guardrail was 6,518 mm (21 ft - 4.5 in.) from the primary side and 8,448 mm (27 ft - 9 in.) from the secondary side, measured to the center of the nose.

Contact marks were found on the nose section and on the primary side between post nos. 1P and 13P. Buckling was also found in the rail between post nos. 1S and 8S. Three of the bottom corrugation slot tabs were torn in the nose section. A 152-mm (6-in.) long tear occurred 330 mm (13 in.) downstream of impact on the primary side, and another small tear occurred 1,168 mm (46 in.) downstream of impact on the primary side. A 457-mm (18-in.) long tear occurred at the splice at post no. 5 and extended from the top of the thrie beam to the slot in the lower valley. A small tear occurred in the nose section, downstream of post no. 1. A 152-mm (6 in.) tear was also located between post nos. 1S and 2S. The rail slots at post nos. 2P and 4P opened up, and the post bolt washers pulled through. The lower nose cable was detached from the guardrail.

Post nos. 1S and 2S fractured at the foundation tubes. Post nos. 3S through 5S fractured in the soil. Post nos. 2S through 4S also disengaged from the rest of the system. Post no. 6S split vertically. Post no. 7S was removed from the ground without damaged and remained attached to the system. Post no. 8S rotated backward in the soil. Post nos. 9S and 10S rotated downstream in the soil.

Post nos. 1P through 9P fractured at the ground line. Post nos. 2P through 9 disengaged from the rest of the system. Post no. 10P split vertically through the transverse CRT hole to the top of the post. Post no. 11P rotated backward in the soil. Post no. 12P disengaged from the guardrail but was not damaged.

7.4 Vehicle Damage

Exterior vehicle damage was minimal, as shown in Figures 94 through 96. Occupant compartment deformations to the right side and front of the floorboard were deemed insufficient to cause injury to the vehicle occupants. Maximum longitudinal displacements of 6 mm (0.25 in.) occurred throughout the right side of the floorboard. Maximum lateral displacements of 19 mm (0.75 in.) occurred at the left-front corner of the right-side floorboard. Maximum vertical displacements of 6 mm (0.25 in.) were located throughout the right-side floorpan. Complete occupant compartment deformations and the corresponding locations are provided in Appendix G.

Damage was concentrated on the front of the vehicle. The left-front bumper corner of the bumper was shifted and deformed into the frame and encountered tearing. The grill was crushed and deformed into the engine compartment, and the bumper bowed outward in the center. The vehicle's hood deformed upward approximately 25 mm (1 in.) above the grill. Both right-front and left-front foglights were broken. Contact marks, scrapes, scratches, and kinks occurred throughout the length of the bumper. A 102-mm (4 in.) tear occurred at the bottom of the left-front door. Dents were found on the left corner of the rear bumper and the left-rear quarter panel. The right side, roof, undercarriage, and all window glass remained undamaged as a result of the test.

7.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be -6.40 m/s (-21.00 ft/s) and 3.12 m/s (10.25 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were -6.80 g's and 4.12 g's, respectively. It is noted that the occupant impact velocities (OIVs) and occupant ridedown decelerations (ORDs) were within the suggested limits provided in the currently proposed Update to NCHRP Report No. 350. The THIV and PHD values were determined to be 7.22 m/s (23.69 ft/s) and 7.26 g's, respectively. The results of the occupant risk, determined from the accelerometer data, are summarized in Figure 74. Results are shown graphically in Appendix H. Results from the rate transducer are shown graphically in Appendix H.

7.6 Discussion

The analysis of the test results for test SR-8 showed that the test article did not adequately contain the vehicle due to vehicle override of the system. 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 remained upright during and after collision. After collision, the vehicle's trajectory did not intrude into adjacent traffic lanes. Vehicle roll, pitch and yaw displacements were noted, but they were deemed to be acceptable because they did not adversely influence occupant risk safety criteria. The occupant impact velocities and ridedown decelerations were within the suggested limits provided in the currently proposed Update to NCHRP Report No. 350. Therefore, the short-radius guardrail installation was determined to be unacceptable according to the TL-3 safety performance criteria found in the currently proposed Update to NCHRP Report No. 350, due to the override of the guardrail.

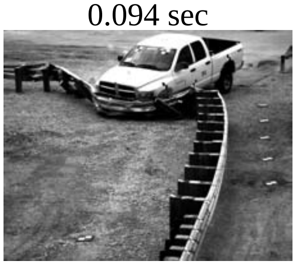
0.000 sec | 0.120 sec | 0.314 sec | 0.556 sec | 0.810 sec

- Test Agency . . . . MwRSF
- Test Number SR-8
- Date 8/1/2007
- Update to NCHRP 350 Test Designation 3-33
- Appurtenance . . . . Short Radius Guardrail
- Key Elements - Steel Thrie-Beam
  - Thickness . . . . 2.67 mm
  - Top Mounting Height . . . . 787 mm
- Key Elements - Steel Posts
  - Post Nos. 14P-19P . . . . W152 x 13.4 by 1,981 mm long
  - Post Nos. 20P-21P . . . . W152 x 37.2 by 2,032 mm long
- Key Elements - Wood Posts
  - Post Nos. 2P-13P, 3S-6S (Thrie CRT) . . . . 152 mm x 203 mm by 1,981 mm long
  - Post Nos. 7S-9S (MGS CRT) . . . . 152 mm x 203 mm by 1,829 mm long
- Key Elements - Steel Foundation Tube
  - Post Nos. 1P, 1S-2S (BSR Posts) . . . . 2,438 mm long
  - Post Nos. 10S-11S . . . . 1,829 mm long
- Key Elements - Dual Tapered Wood Spacer Blocks
  - Post Nos. 2P-13P, 3S-5S . . . . two 152 mm x 203 mm by 362 mm long
- Key Elements - MGS Blockouts
  - Post No. 6S-9S . . . . 152 mm x 305 mm by 362 mm long
- Key Elements - Short Radius Plate Washer
  - Post Nos. 1P-4P, 1S-2S . . . . 44 mm x 76 mm x 3 mm thick
- Type of Soil . . . . Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model . . . . 2002 Dodge Ram 1500 Quad Cab Pickup Truck
  - Curb . . . . 2,336 kg
  - Test Inertial . . . . 2,268 kg
  - Gross Static . . . . 2,268 kg
- Impact Conditions
  - Speed . . . . 101.0 km/h
  - Angle . . . . 17.9 degrees
  - Impact Location . . . . Centerline of Nose Section with Centerline of Vehicle
- Exit Conditions
  - Speed . . . . N/A
  - Angle . . . . N/A
  - Exit Box Criterion . . . . N/A
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 15.5 m longitudinal
1.4 m lateral
- Occupant Impact Velocity
  - Longitudinal . . . . -6.40 m/s < 12 m/s
  - Lateral . . . . 3.12 m/s < 12 m/s
- Occupant Ridedown Deceleration
  - Longitudinal . . . . 6.80 g's < 20 g's
  - Lateral . . . . 4.12 g's < 20 Gs
- THIV (not required) . . . . 7.22 m/s
- PHD (not required) . . . . 7.26 g's
- Test Article Damage . . . . Extensive
- Test Article Deflections
  - Permanent Set . . . . 8,448 mm
  - Dynamic . . . . N/A
  - Working Width . . . . 20.6 m along primary side
11.7 m lateral from primary side
- Vehicle Damage . . . . Minimal
  - VDS[18] 12-FD-1
  - CDC[19] 12-FDEW-1
  - Maximum Deformation . . . . 19 mm at right-side firewall
- Angular Displacements
  - Roll . . . . -8 deg
  - Pitch . . . . -5 deg
  - Yaw . . . . 113 deg

Figure 74. Summary of Test Results and Sequential Photographs, Test No. SR-8

0.000 sec

0.094 sec



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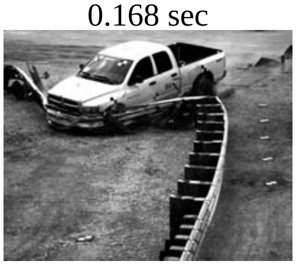

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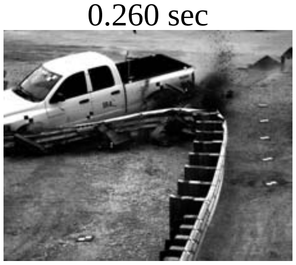

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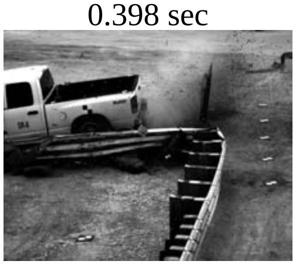

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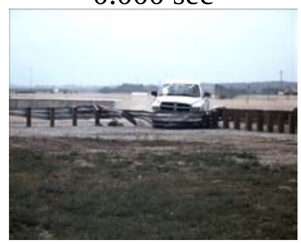

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1.078 sec

1.412 sec

Figure 75. Additional Sequential Photographs, Test SR-8

Figure 76. Additional Sequential Photographs, Test SR-8

Figure 77. Documentary Photographs, Test SR-8

Figure 78. Documentary Photographs, Test SR-8

Figure 79. Documentary Photographs, Test SR-8

Figure 80. Documentary Photographs, Test SR-8

Figure 81. Impact Location, Test SR-8

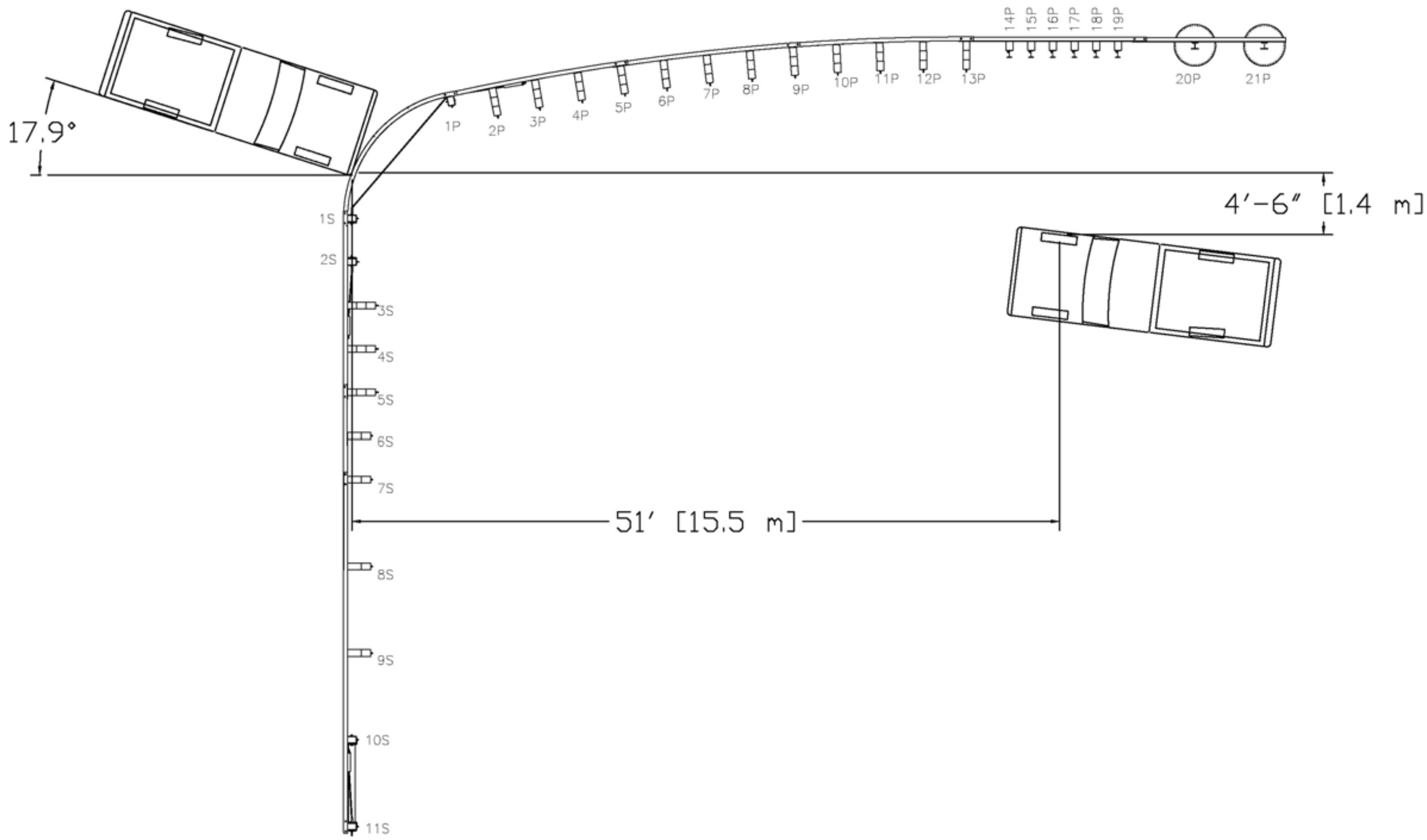

Figure 82. Vehicle Trajectory, Test SR-8

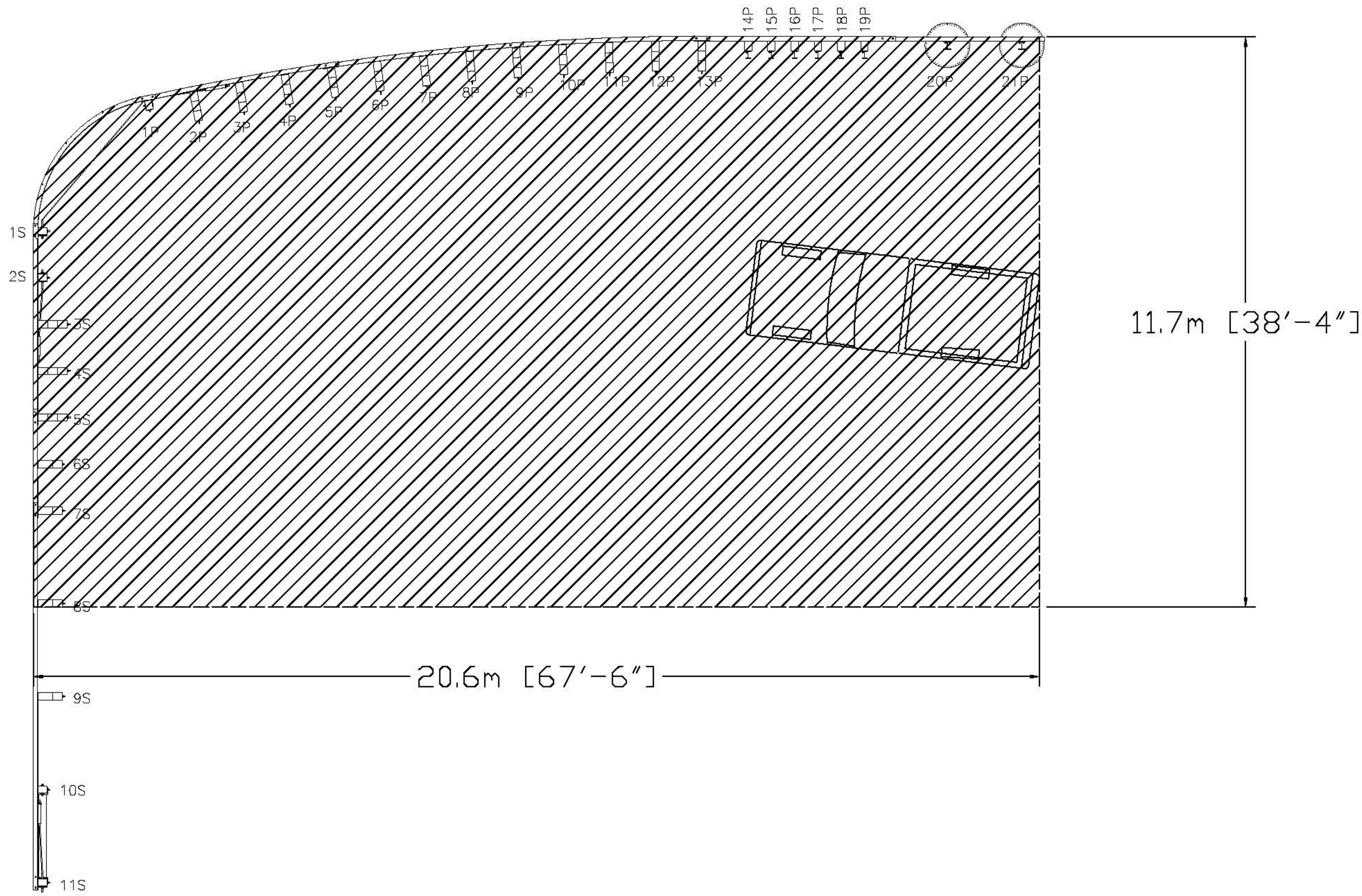

Figure 83. Working Width, Test SR-8

Figure 84. Vehicle Trajectory and Final Position, Test SR-8

Figure 85. System Damage, Test SR-8

Figure 86. System Damage, Test SR-8

Figure 87. System Damage, Test SR-8

Figure 88. Secondary-Side Post Damage, Test SR-8

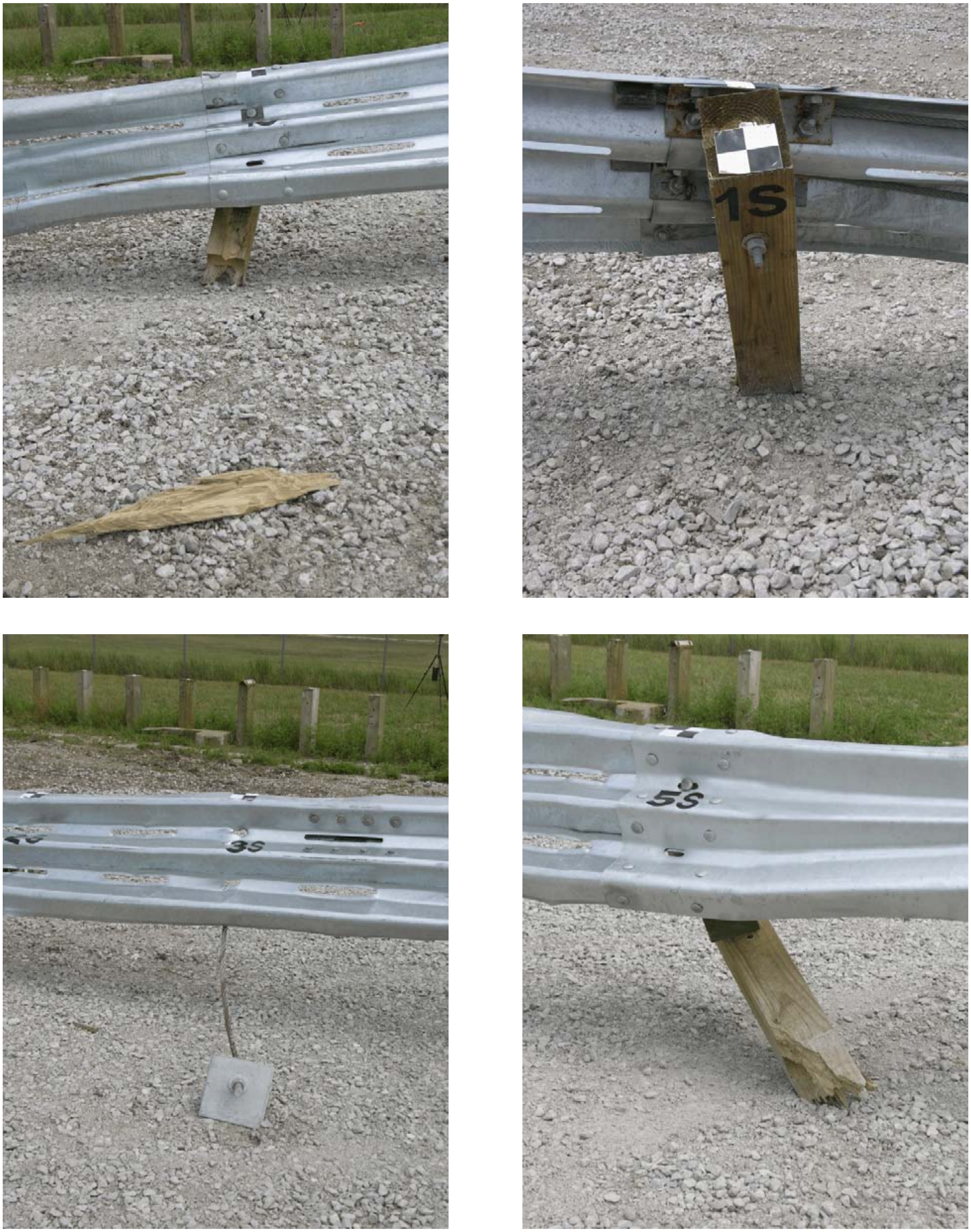

Figure 89. Post Nos. 1S through 5S Damage, Test SR-8

Figure 90. Post Nos. 6S through 8S Damage, Test SR-8

Figure 91. Post Nos. 1P through 12P Damage, Test SR-8

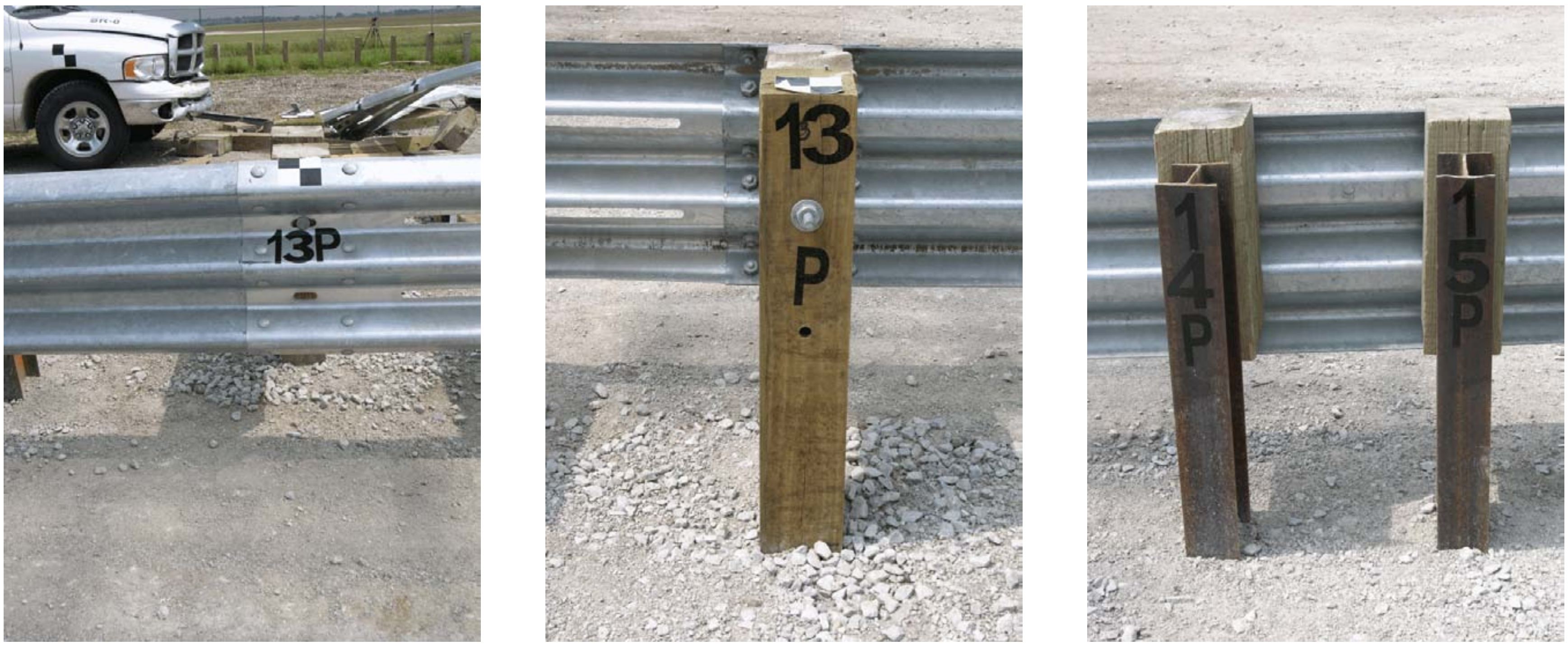

Figure 92. Post Nos. 13P through 15P Damage, Test SR-8

Figure 93. Rail Tear, Test SR-8

Figure 94. Vehicle Damage, Test SR-8

Figure 95. Vehicle Damage, Test SR-8

Figure 96. Undercarriage Damage, Test SR-8

8 ANALYSIS AND DISCUSSION

Following the analysis of test no. SR-8, the test results were reviewed in order to identify potential causes of the failure of the system. Review of the test results demonstrated that the revised short-radius design performed much better than the design used in test no. SR-7. Improvement was observed in the reduction of the debris, release of the cable anchorage, and the capture of the pickup truck. In spite of the improved performance, the test failed due to vehicle override of the guardrail. The cause of the vehicle override of the guardrail was a combination of the yaw motion of the pickup truck and the pitching of the rear of the truck due to interaction of the left-rear wheel with post no. 2P, as mentioned previously. Post no. 2P was attached to the guardrail using a plate washer, but the guardrail bolt at post no. 2P was located in one of the long slots in the valley of the thrie beam on the primary side of the system. As such, the plate washer was not sufficient to keep the post attached to the rail and prevent it from becoming debris that interacted with the pickup truck.

9 SUMMARY AND CONCLUSIONS

Phase IV development of a TL-3 short-radius guardrail system for intersecting roadways began with the construction of a barrier system consisting of a curved and slotted thrie beam nose section, two adjacent curved, slotted thrie beam sections, and breakaway CRT posts. One side of the system attached to a stiff, steel post approach guardrail transition while the other side attached to a simulated W-beam guardrail end terminal. A schematic of the impact conditions for test nos. SR-7 and SR-8 is shown in Figure 97. A summary of the safety performance evaluation is provided in Table 2.

Test SR-7 was conducted according to a modified version of the currently proposed Update to NCHRP Report No. 350 Test Designation 3-33. The short-radius system was identical to the system tested in test SR-6. The impact location for this test aligned the centerline of the vehicle with the centerline of the nose section. In this test, a 2,263-kg (4,849-lb) pickup truck impacted the short-radius guardrail system at a speed of 100.3 km/h (62.8 mph) and at an angle of 18.1 degrees. The results of test SR-7 were deemed unacceptable according to the TL-3 criteria provided in the currently proposed Update to NCHRP Report No. 350 due to vehicle override of the guardrail and subsequent vehicle rollover.

After a thorough review of the results, it was believed that there are four potential causes of vehicle instability and include: (1) vehicle interaction with the system debris causing the rear of the vehicle to pitch upward and over the guardrail as it yawed; (2) poor release of the primary side cable anchor from post no. 1S causing additional debris under the rear wheels of the vehicle; (3) re-engagement of the cable anchor at post no. 1P and (4) nose section slot tabs did not tear through causing less effective interlock of the nose section with the front of the pickup truck. These changes include: (1) modification of the cable anchor bracket on the front side of post no. 1P; (2) enlarged transverse holes in post nos. 1P, 1S and 2S; (3) reduced slot tab size in the nose section of the guardrail; and (4) addition of rectangular plate washers on the front side of the rail at post nos. 1S, 2S, 1P, 2P, 3P, and 4P.

Test no. SR-8 was conducted according to the currently proposed Update to NCHRP Report No. 350 Test Designation 3-33. The impact location for this test aligned the centerline of the pickup truck with the centerline of the nose section. A 2,268-kg (5,000-lb) pickup truck impacted the modified short-radius guardrail system at a speed of 101.3 km/h and at an angle of 17.9 degrees. The results of test no. SR-8 were also deemed unacceptable according to the TL-3 criteria provided in the currently proposed Update to NCHRP Report No. 350 due to the vehicle override of the guardrail. However, the results of test no. SR-8 showed significant improvement in the behavior of the short-radius design.

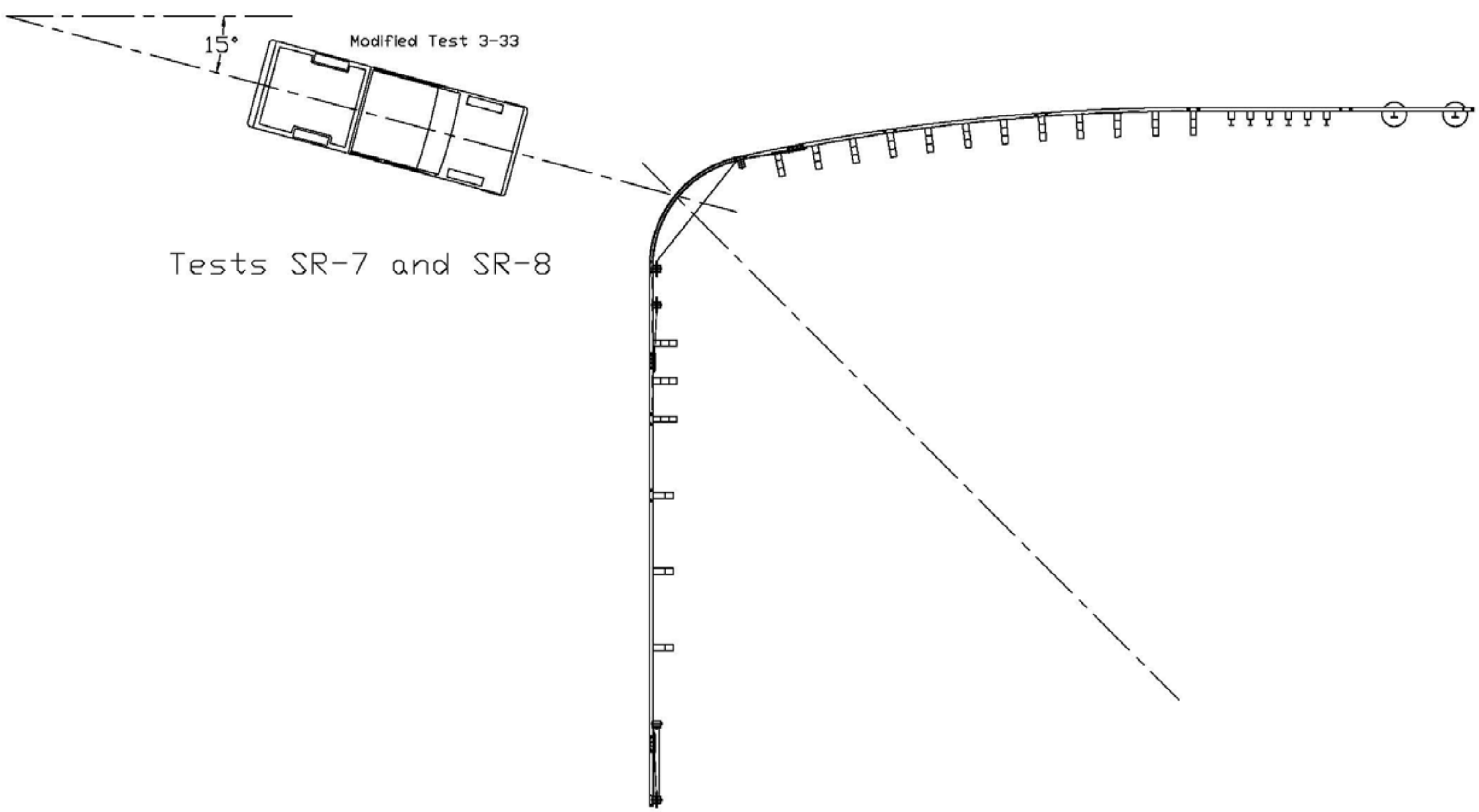

Figure 97. Summary of Short-Radius Guardrail Impacts

Table 2. Summary of Safety Performance Evaluation Results

Evaluation Factors	Evaluation Criteria	Test SR-7	Test SR-8
Structural Adequacy	A	U	U
Occupant Risk	D	S	S
	F	U	S
	H	S	S
	I	S	S

S - Satisfactory
U - Unsatisfactory
NA - Not Available/Not Applicable

10 FUTURE DEVELOPMENT

At this time, the funding for further development and testing of the short radius guardrail system has been exhausted. Currently, there has been only one successful full-scale crash test on the system, test no. SR-5. Test no. SR-5 was a successful test of the short-radius guardrail system conducted as a modified test designation 3-31. This test impacted the short-radius guardrail system with the centerline of a 2,000-kg (4,409-lb) pickup truck aligned with the tangent side of the system at a speed of 100 km/h (62.1 mph) and at a nominal angle of 0 degrees. While this test performed acceptably, design changes to the short-radius system and the switch to testing under the safety requirements of the currently proposed Update to NCHRP Report No. 350 may require that the test be rerun depending on input from the Federal Highway Administration.

MwRSF has reviewed the current state of the short-radius guardrail system and believe that there are several possible options that exist for the future of the short-radius guardrail system. These options include:

1. Continue to develop the short-radius design as a TL-3 system according to the currently proposed Update to NCHRP Report No. 350. Based on the results of test no. SR-8, MwRSF believes that there is potential for the short-radius to be developed into a successful TL-3 system. In order to do so, changes to the design would be necessary to eliminate the override of the guardrail. It has been proposed that a more robust attachment between the post and the guardrail be used in order to prevent posts from becoming debris beneath the truck. This connection would be more robust than the plate washer used in test no. SR-8. A second proposed option would be to mount additional guardrail or a cable element along the primary side of the system to raise the effective

height of that side of the system and reduce the potential for rollover. A total of five tests would need to be completed successfully prior to FHWA approval. There is a potential that some of the tests, such as 3-31, could be waved based on previous testing.

2. Modify the existing short-radius design to meet TL-2 criteria proposed in the currently proposed Update to NCHRP Report No. 350. The Texas Transportation Institute (TTI) is currently conducting research to develop a TL-2 short-radius guardrail system. TTI is using older short-radius guardrail testing in combination with information on the development of the TL-3 short-radius system described herein in their design process. This research could provide a lower test level option that is still better than current short-radius design available for state DOT use.
3. Implement the short-radius guardrail system as the best-available design option. While the current short-radius guardrail system has not met the requirements for TL-3 approval, MwRSF believes that the current system is far better than the older W-beam and thrie beam short-radius designs. As such, it is believed that the Midwest States Regional Pooled Fund Program members could implement the current short radius design and expect an increase in the performance and safety over their current short-radius guardrail designs.
4. Redesign the short-radius guardrail system based on new concepts. The testing and development of the short-radius system to date has shown that the current design using standard post and rail components may not be the most effective form of protection for intersecting roadways. MwRSF has brainstormed several concepts that have the potential to be more cost-effective means of protecting motorists in these situations. These

concepts use a combination of technologies based on crash cushion and end terminal design to attempt to mitigate some of the shortcomings of the current short-radius design. It is possible that these more unconventional designs may prove to be the most effective solution for the problem of protecting intersecting roadways.

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12. APPENDICES

APPENDIX A

System Details in English Units, Test No. SR-7

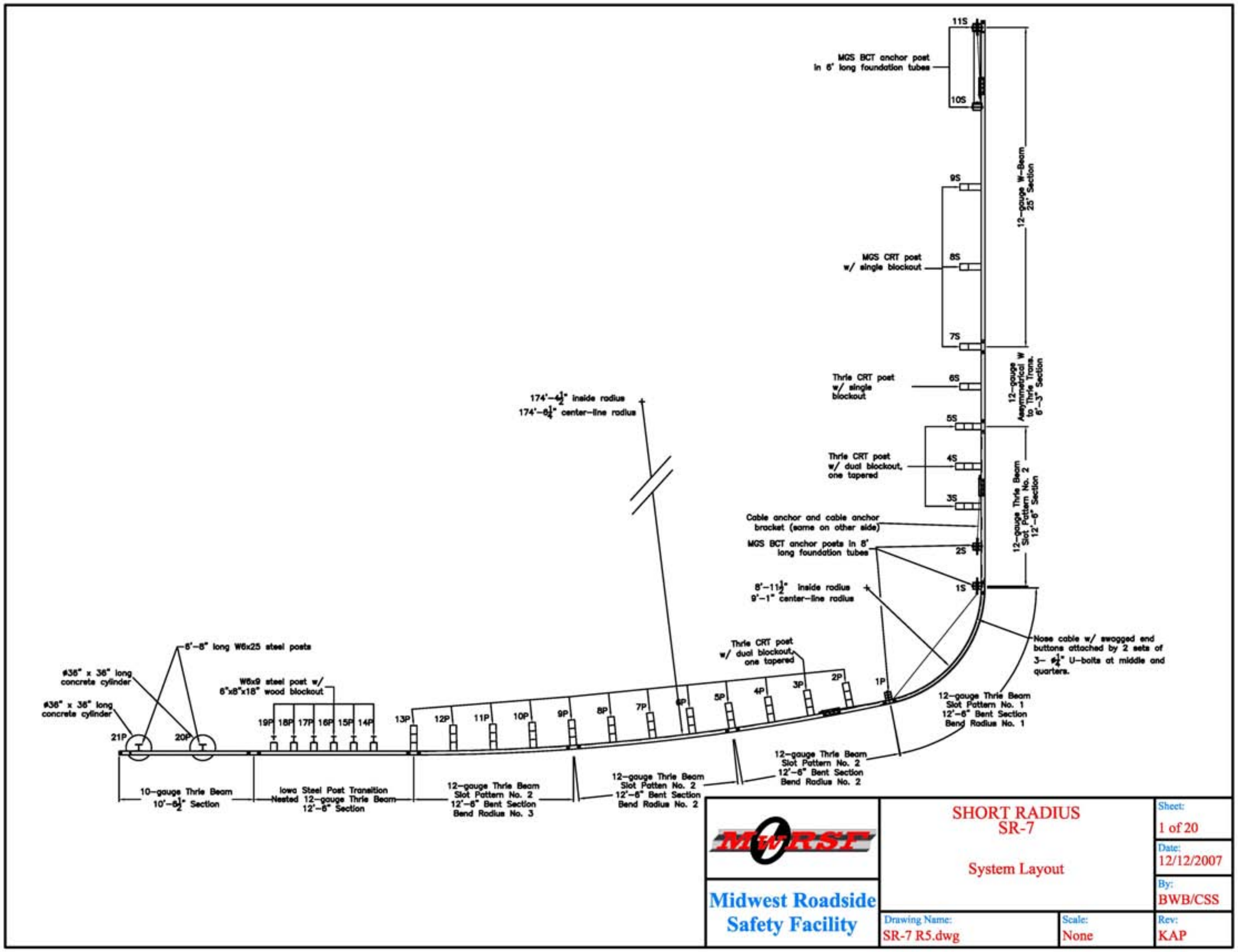


Figure A-1. System Layout (English)

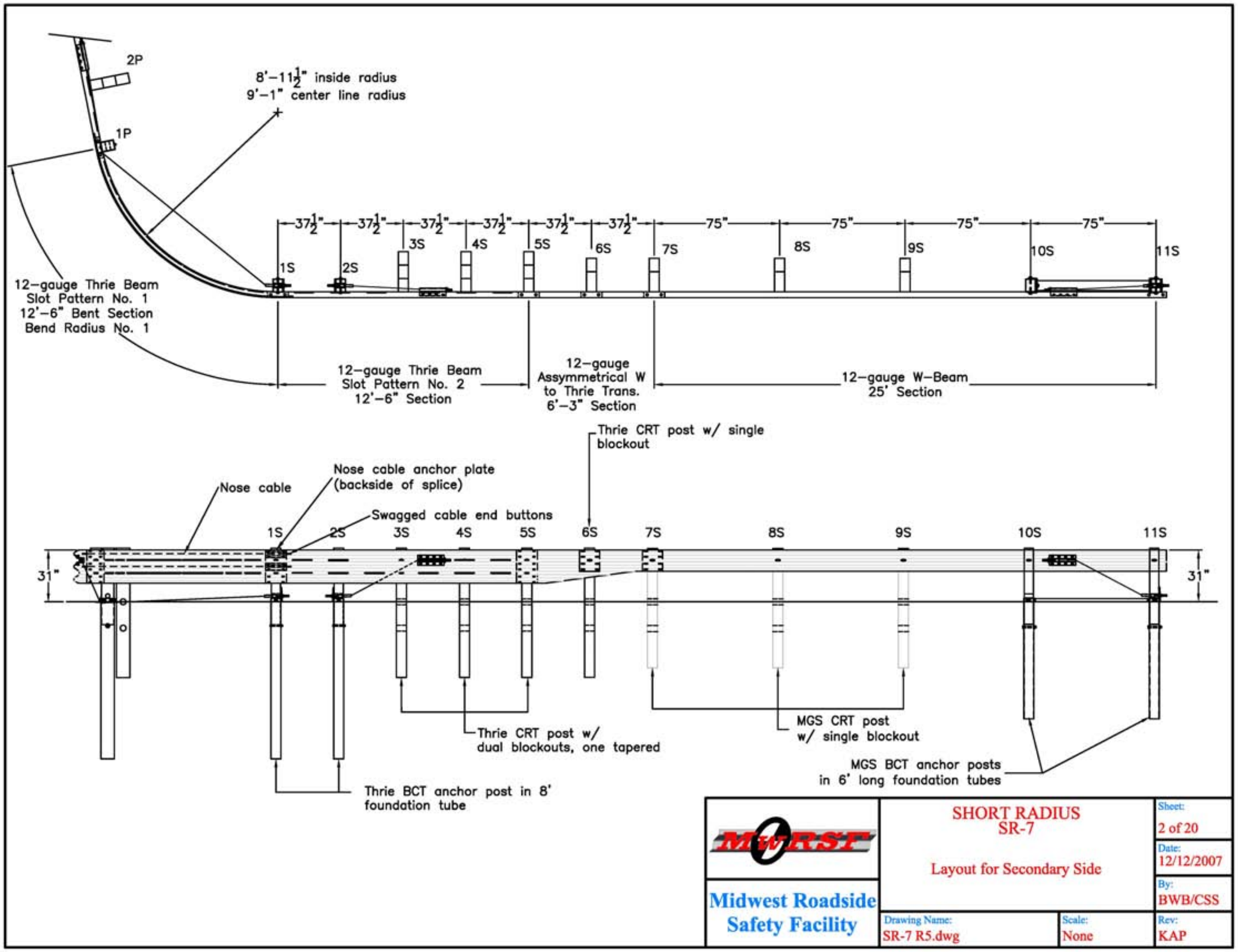


Figure A-2. Layout for Secondary Side (English)

POST LOCATIONS (constant radius = 174' - 6 3/16")
X Location with respect to the center of Post no. 13P
Y Location with respect to the backside of the rail at post no. 13P

Post No.	Front Face D.S. Edge		Front Face U.S. Edge	
	X	Y	X	Y
1P	36' - 11 1/16"	3' - 11 5/8"	37' - 4 5/8"	4' -0 5/8"
2P	33' - 7 7/8"	4' - 7 5/8"	34' - 1 3/4"	4' - 8 13/16"
3P	30' - 7 5/16"	4' - 0 3/4"	31' - 1 1/4"	4' - 1 13/16"
4P	27' - 6 9/16"	3' - 6 1/2"	28' - 0 1/2"	3' - 7 7/16"
5P	24' - 5 1/2"	3' - 0 13/16"	24' - 11 7/16"	3' - 1 3/4"
6P	21' - 4 15/16"	2' - 7 15/16"	21' - 10 7/8"	2' - 8 11/16"
7P	18' - 3 11/16"	2' - 3 5/8"	18' - 9 5/8"	2' - 4 3/8"
8P	15' - 2 7/8"	2' - 0 1/16"	15' - 8 7/8"	2' - 0 5/8"
9P	12' - 1 11/16"	1' - 9 1/8"	12' - 7 11/16"	1' - 9 9/16"
10P	9 '- 0 9/16"	1' - 6 13/16"	9' - 6 9/16"	1' - 7 3/16"
11P	5' - 11 1/2"	1' - 5 1/4"	6' - 5 1/2"	1' - 5 7/16"
12P	2' - 10 1/4"	1' - 4 1/4"	3' - 4 1/4"	1' - 4 3/8"
13P	- 0' - 3"	1' - 4"	0' - 3"	1' - 4"

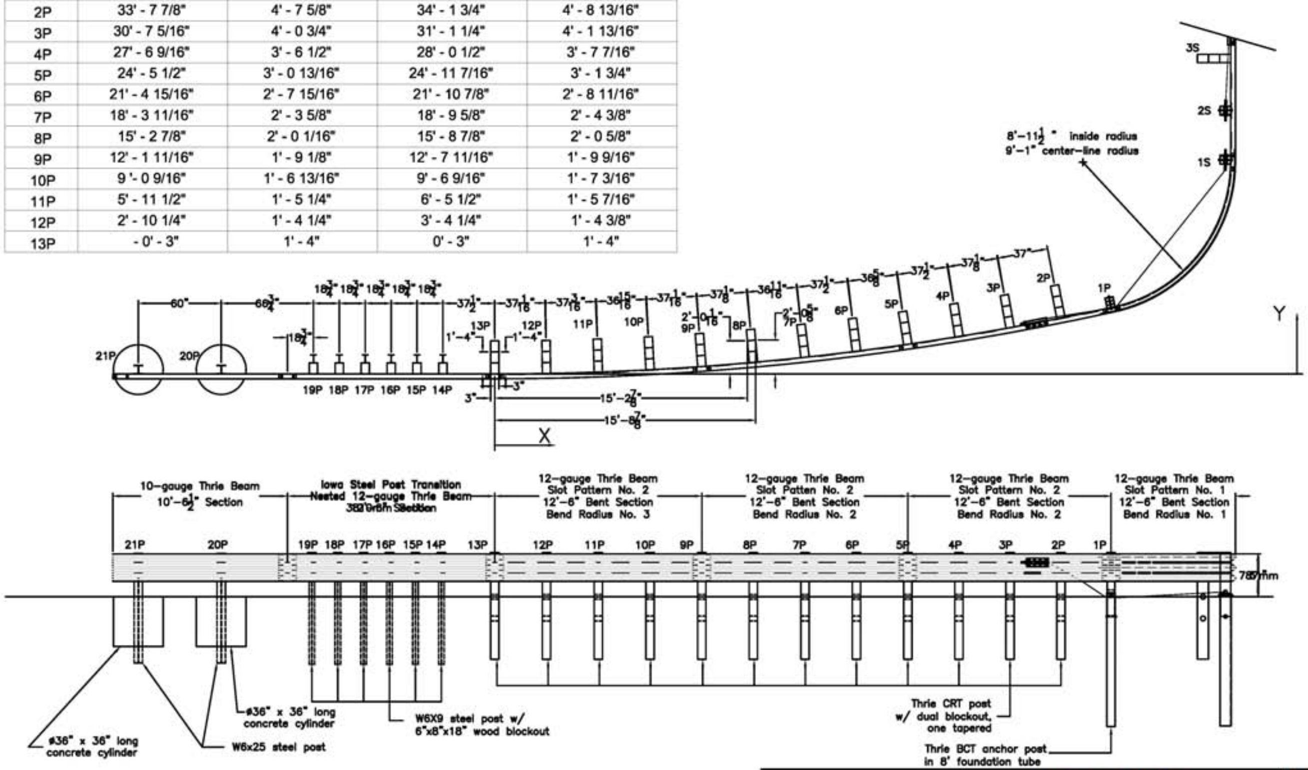


Figure A-3. Layout for Primary Side and Post Locations (English)

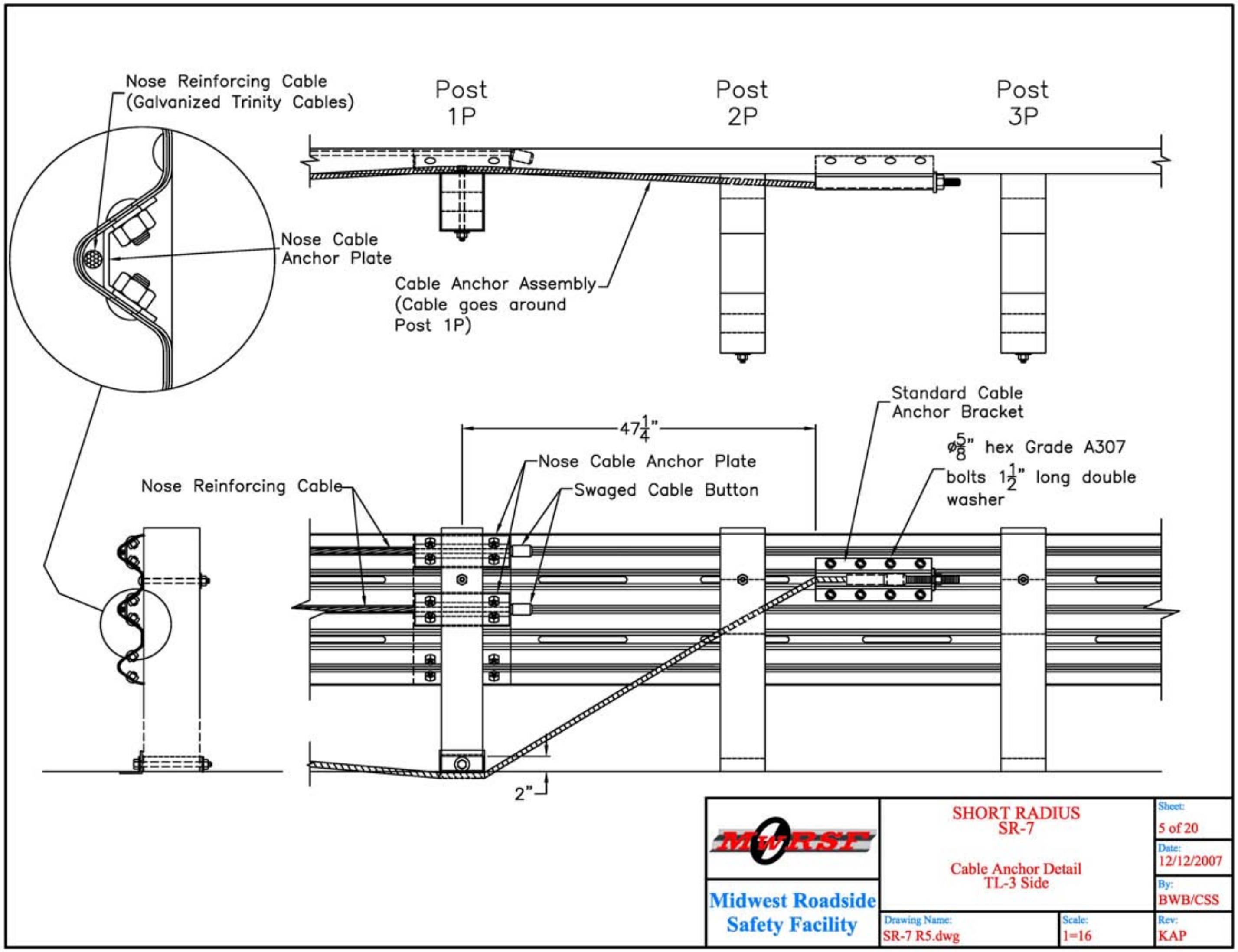


Figure A-4. Cable Anchor Detail, Primary Side (English)

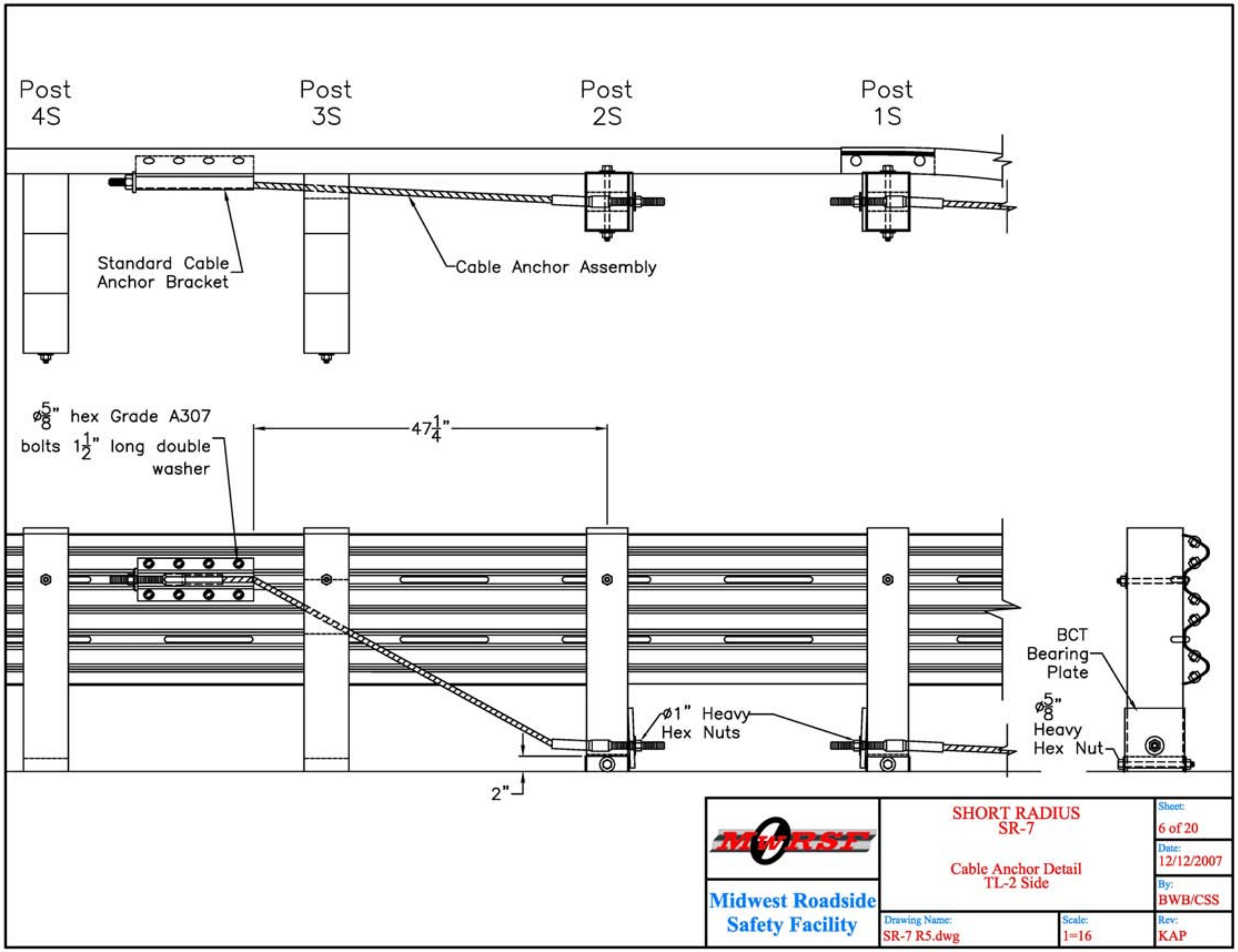


Figure A-5. Cable Anchor Detail, Secondary Side (English)

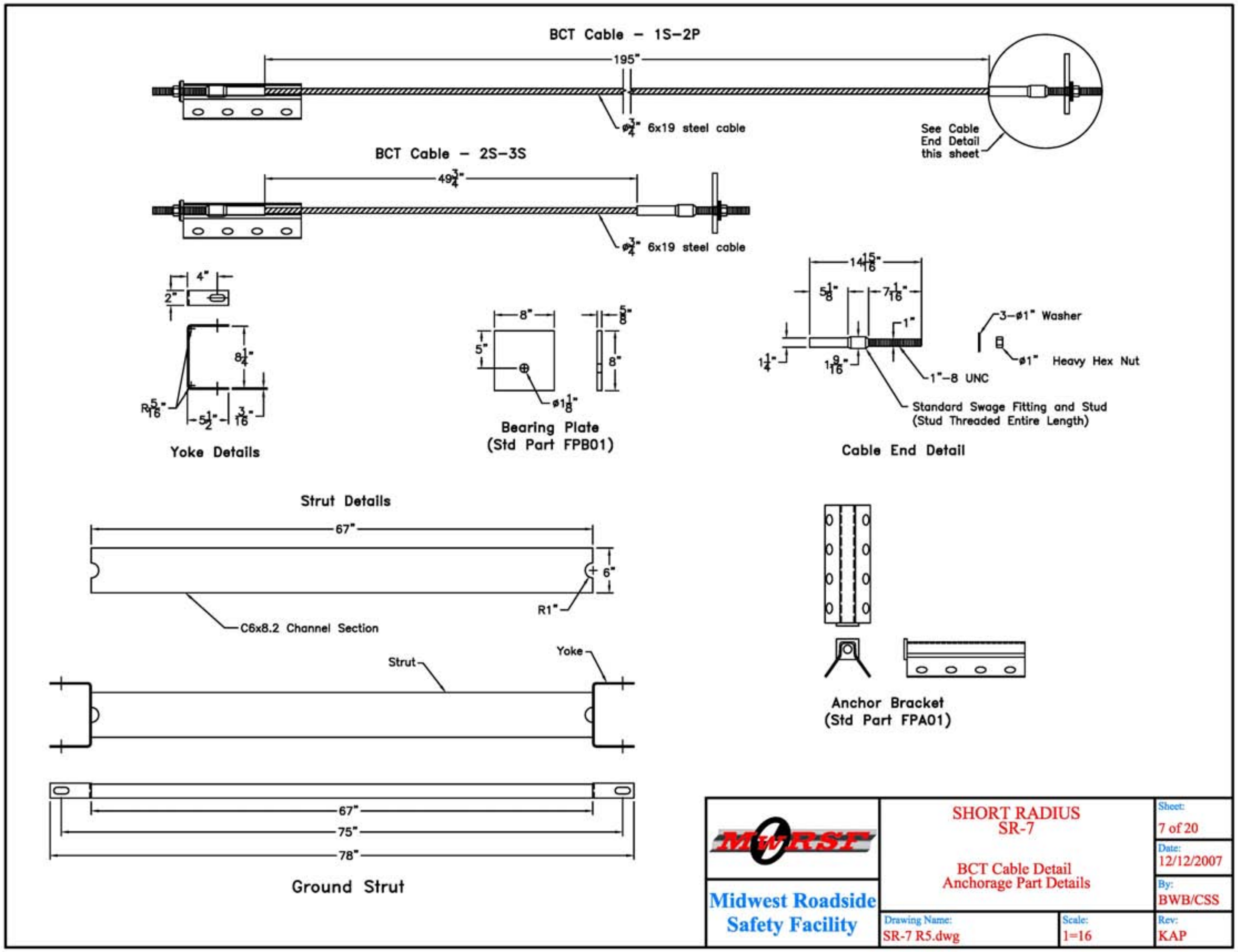


Figure A-6. BCT Cable Detail and Anchorage Part Details (English)

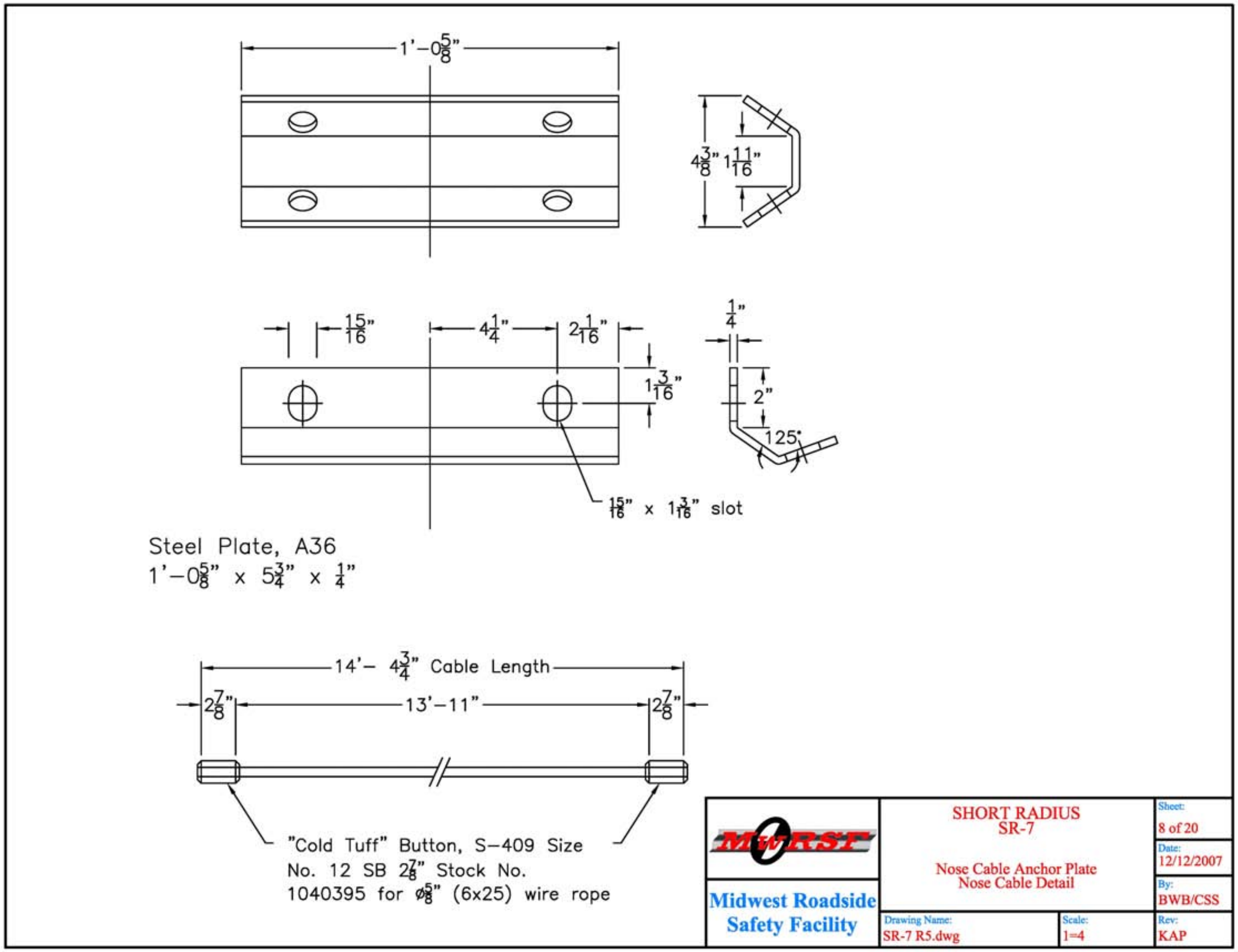


Figure A-7. Nose Cable Anchor Plate and Nose Cable Detail (English)

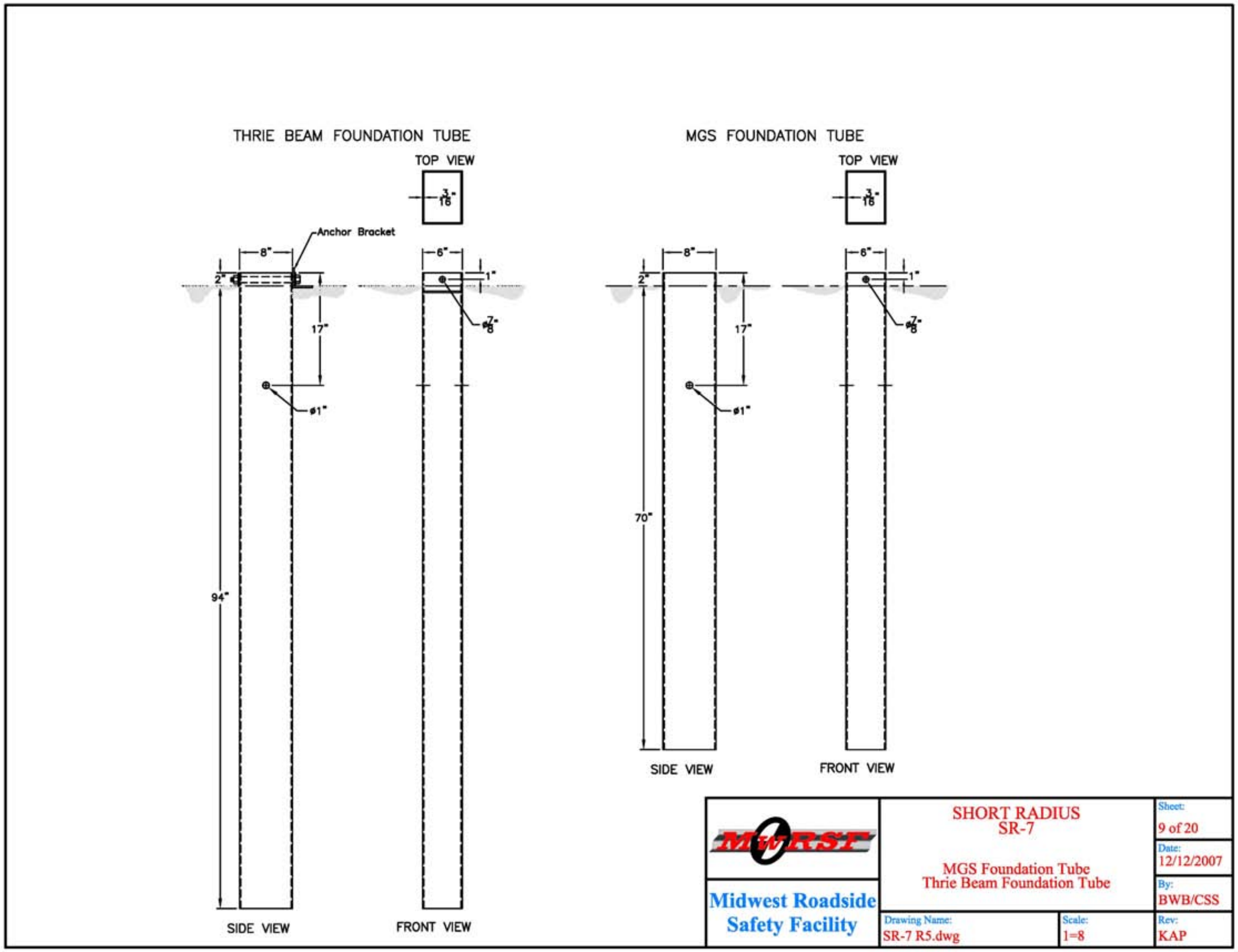


Figure A-8. MGS Foundation Tube and Thrie Beam Foundation Tube Details (English)

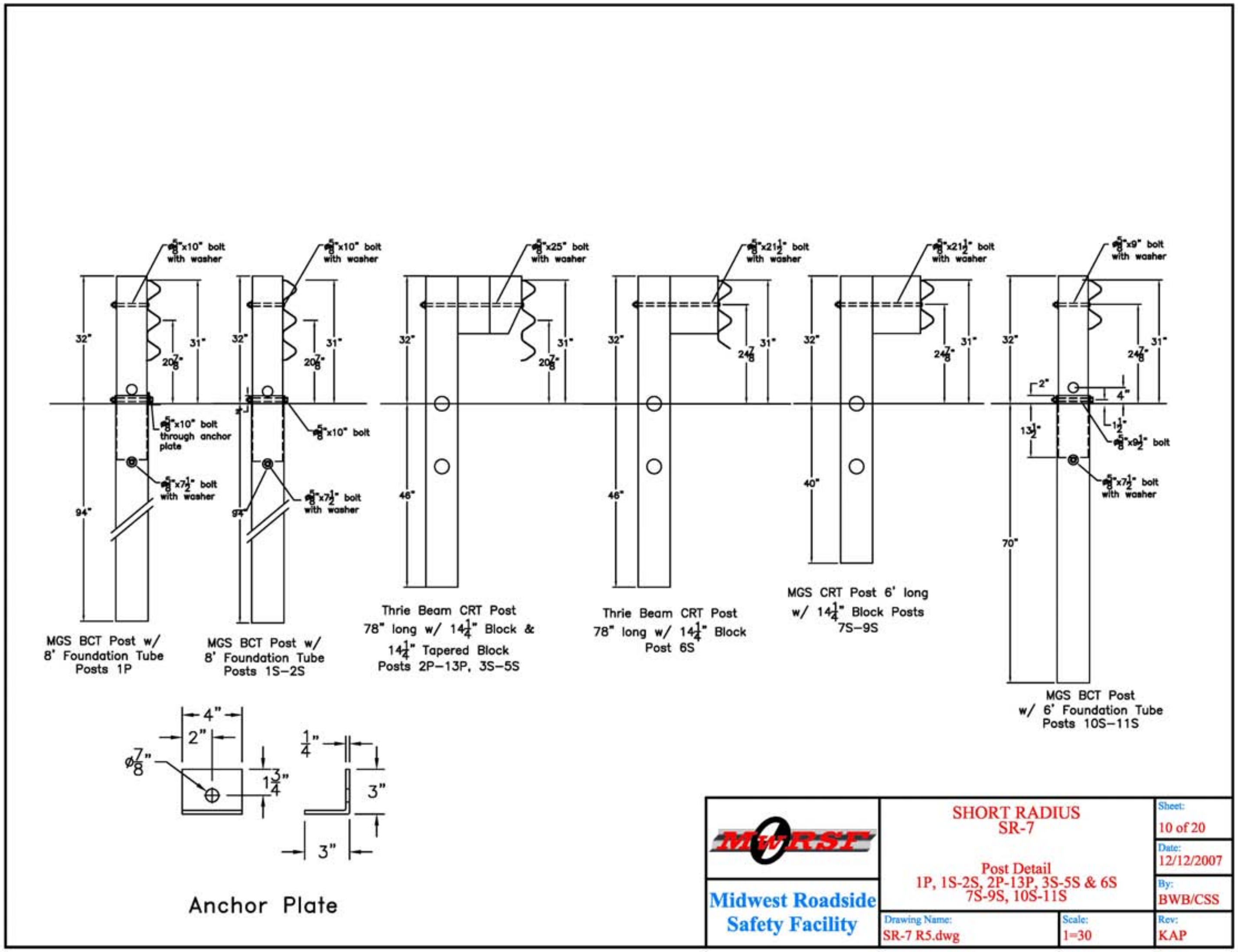


Figure A-9. Post Details (English)

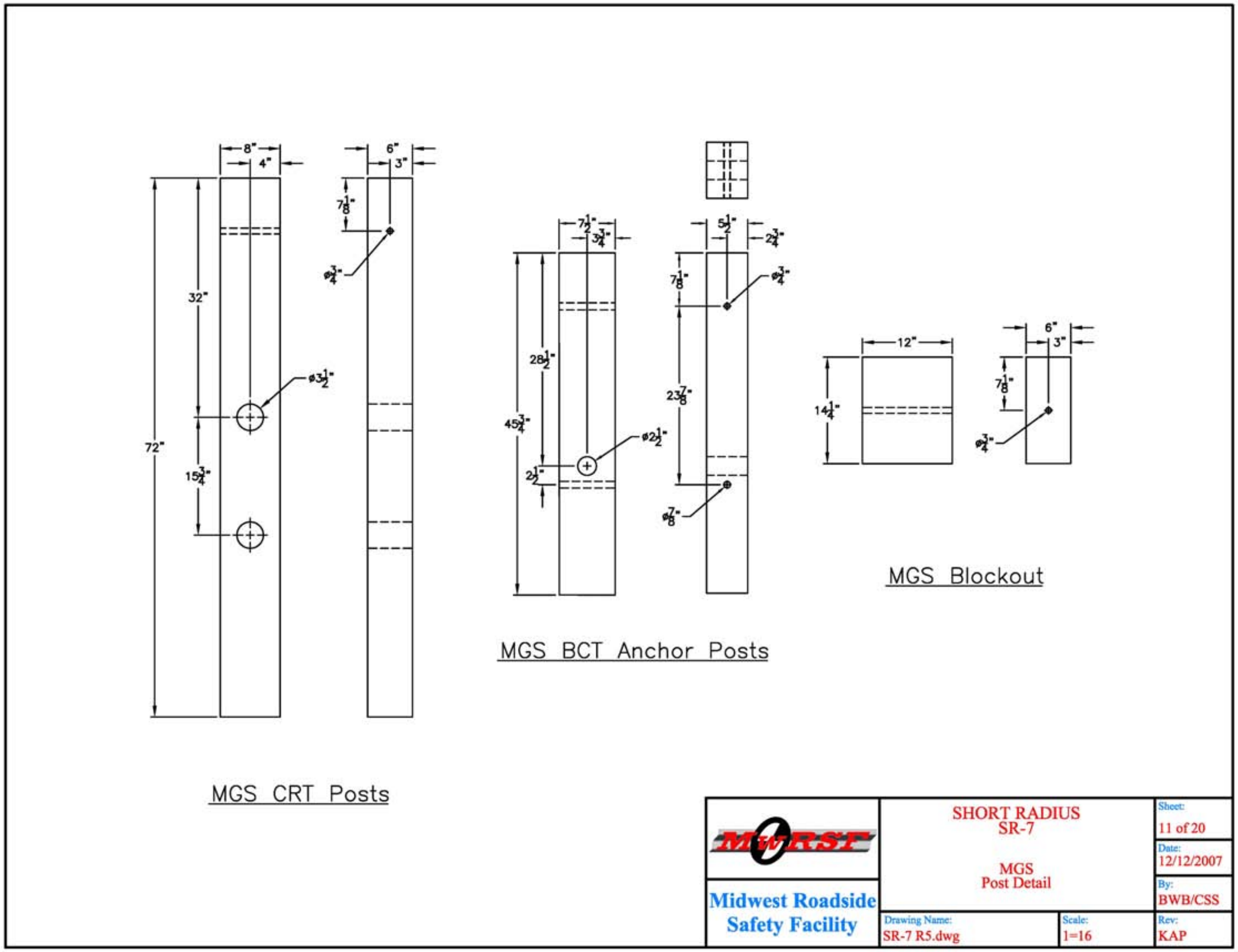


Figure A-10. MGS Post Details (English)

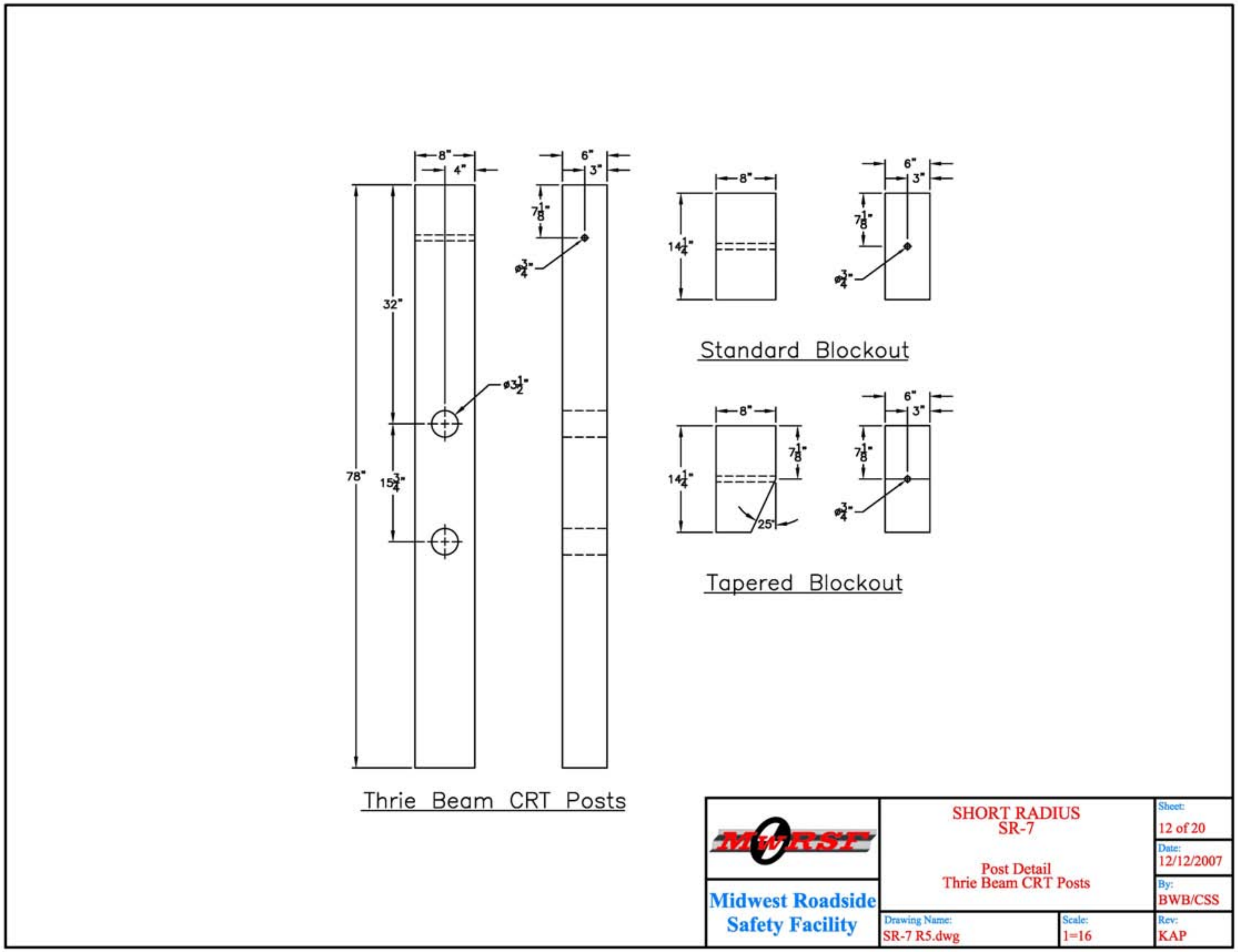


Figure A-11. Thrie Beam Anchor Post Details (English)

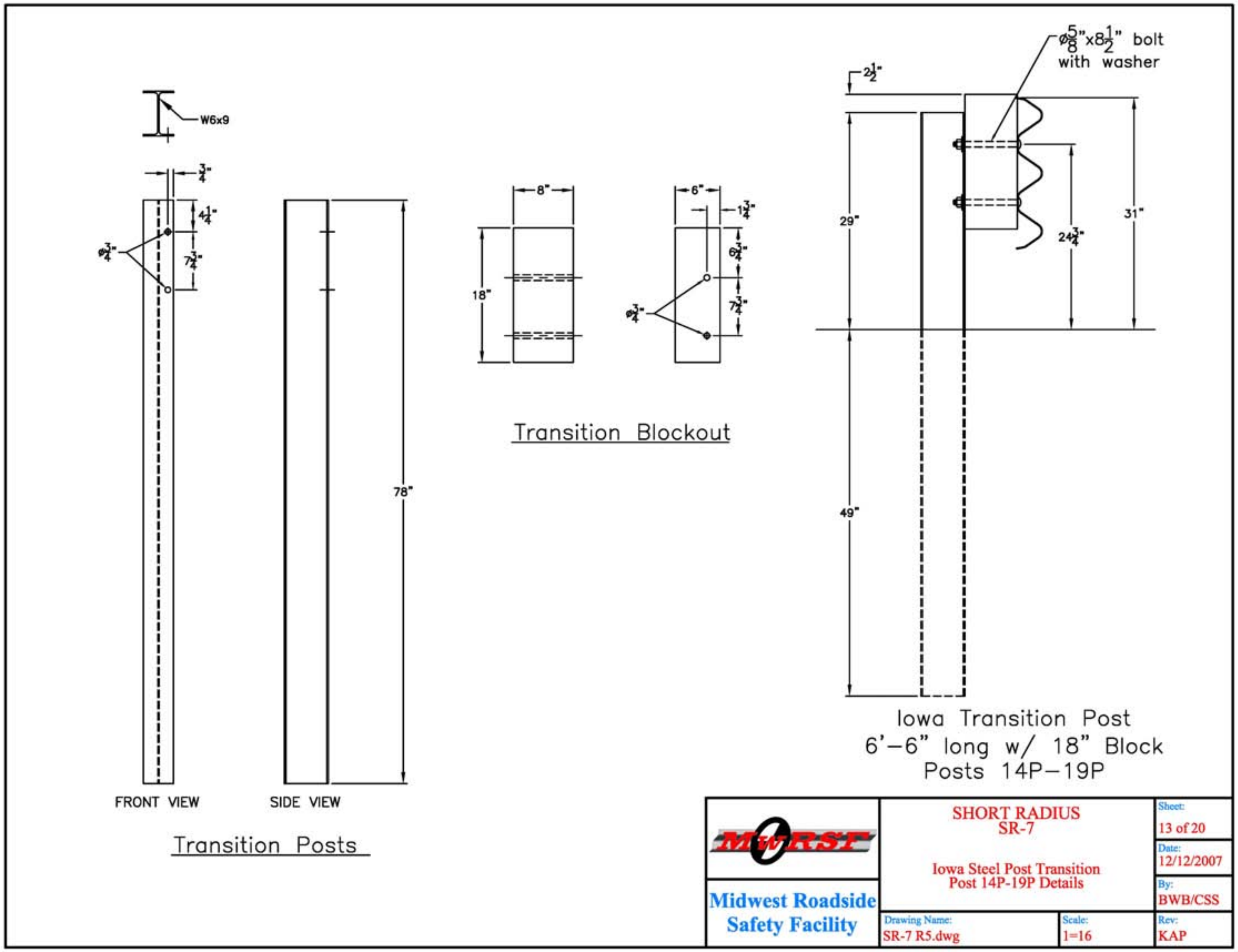


Figure A-12. Iowa Steel Post Transition (English)

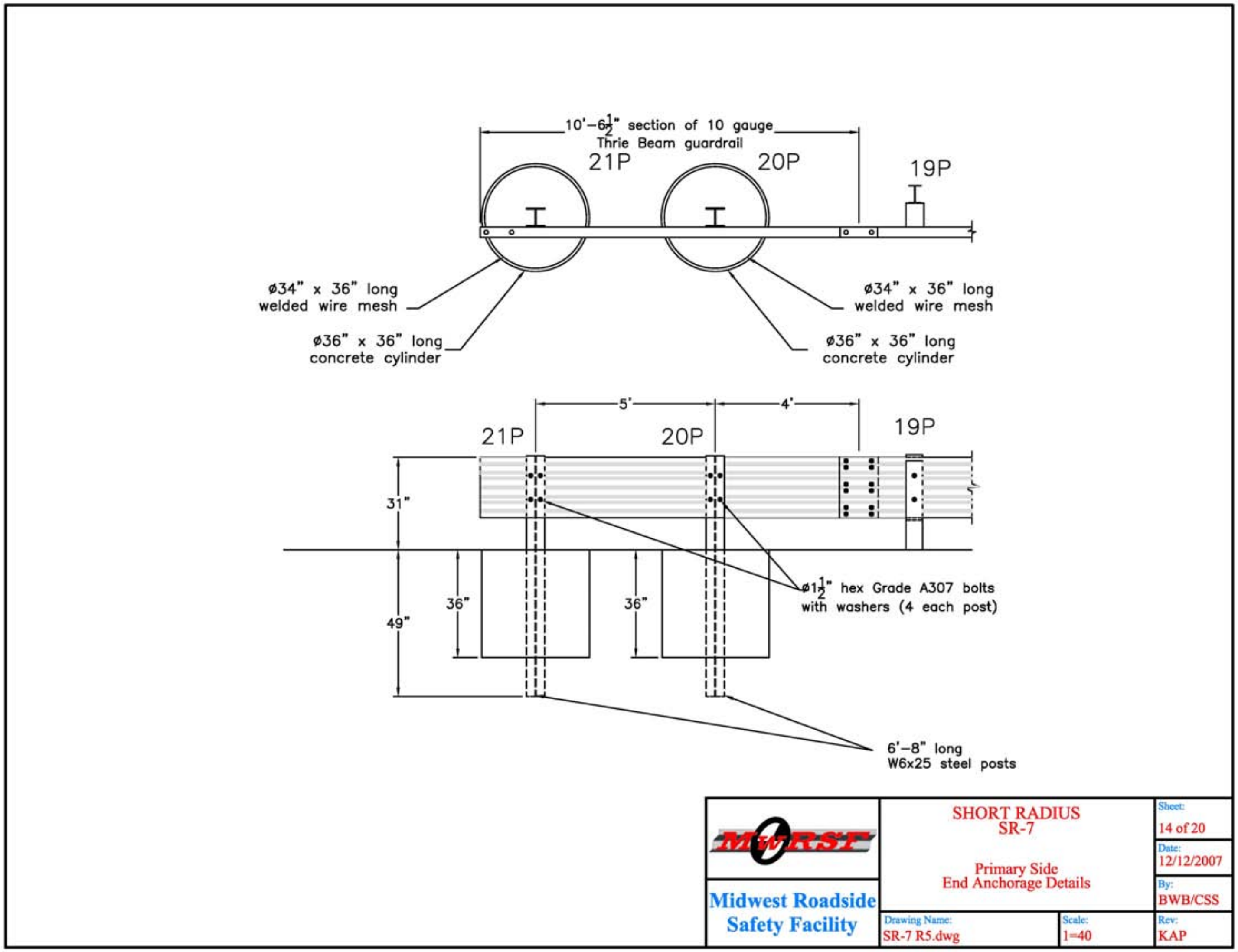


Figure A-13. Primary Side End Anchorage Details (English)

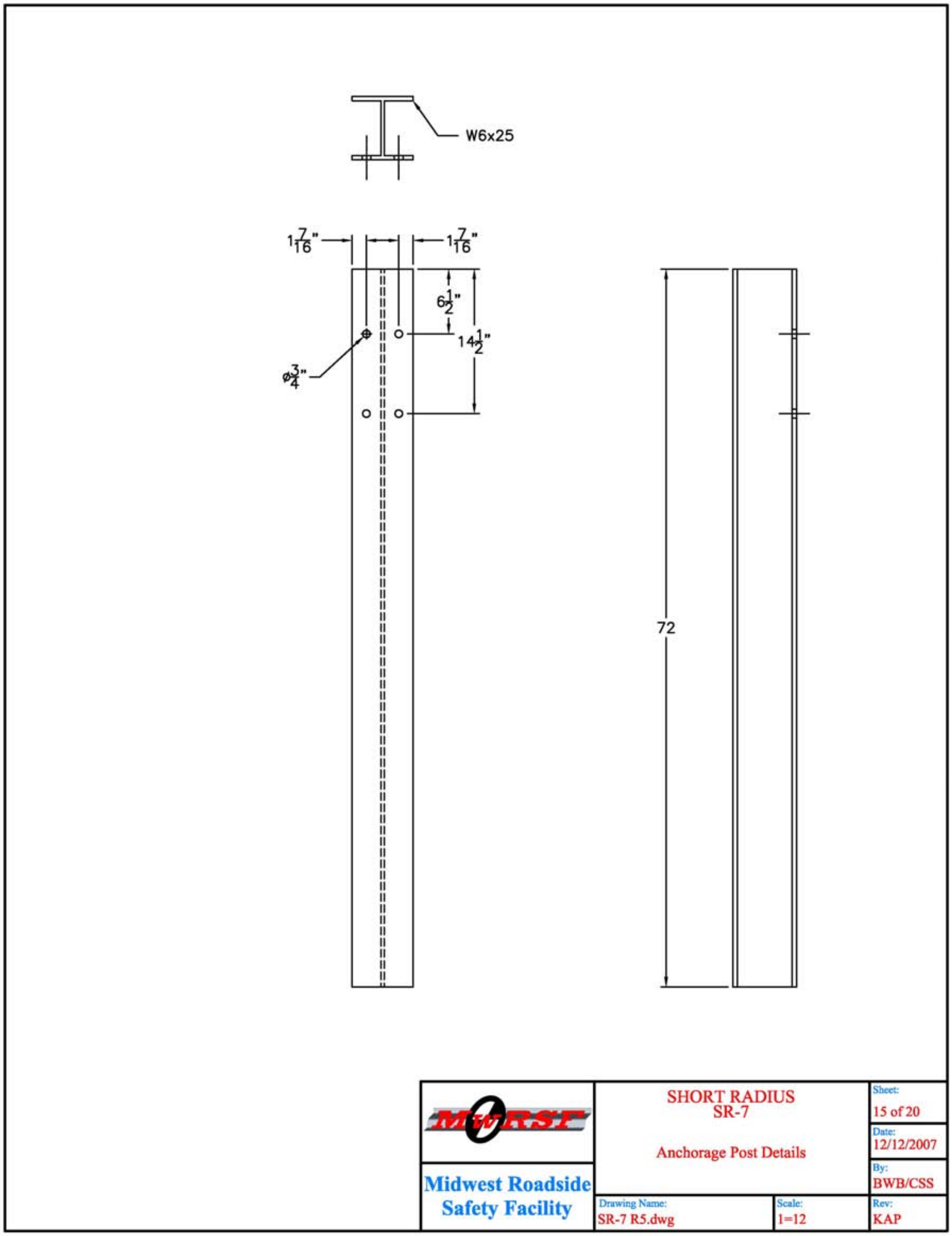


Figure A-14. Anchorage Post Details (English)

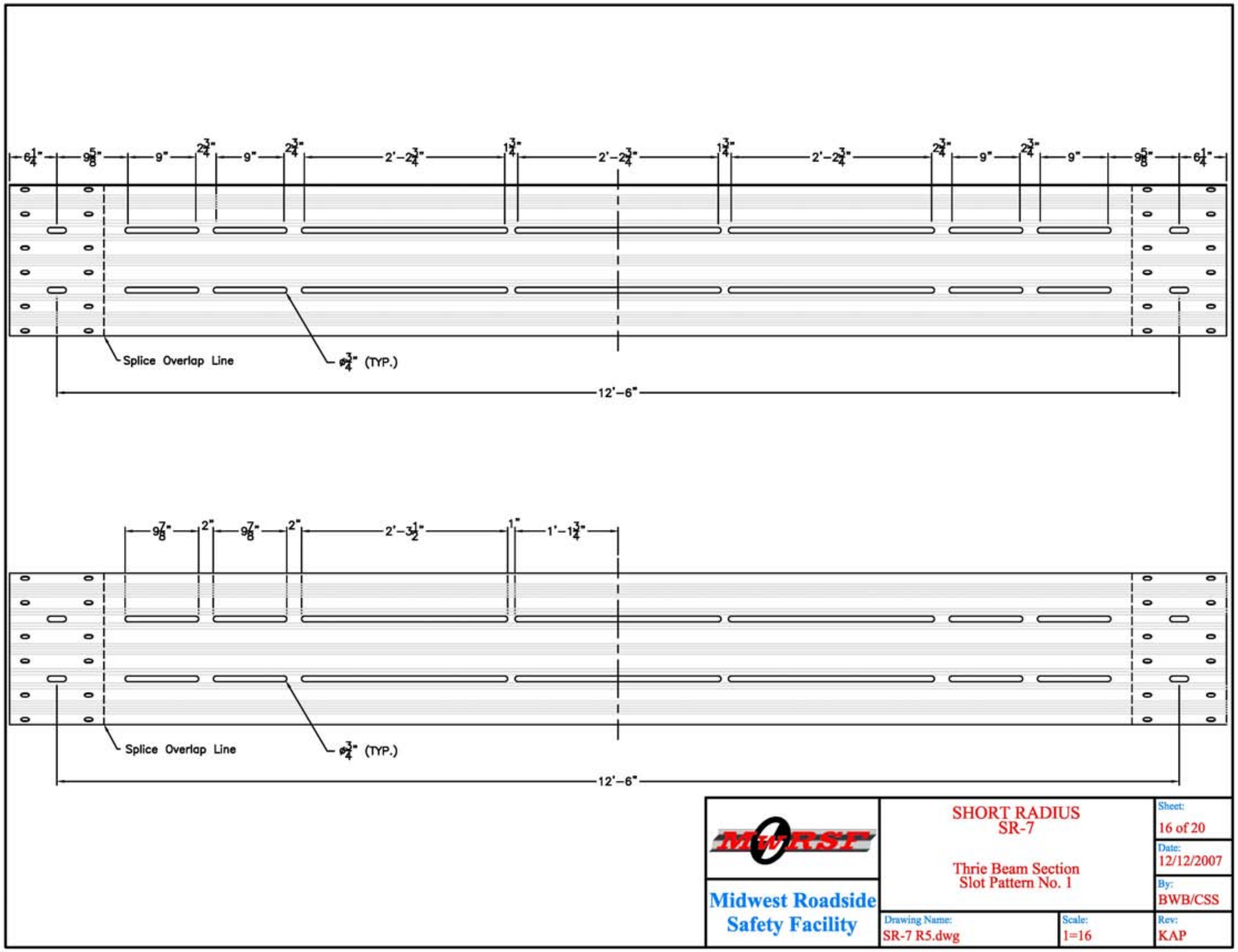


Figure A-15. Thrie Beam Section Slot Pattern No. 1 (English)

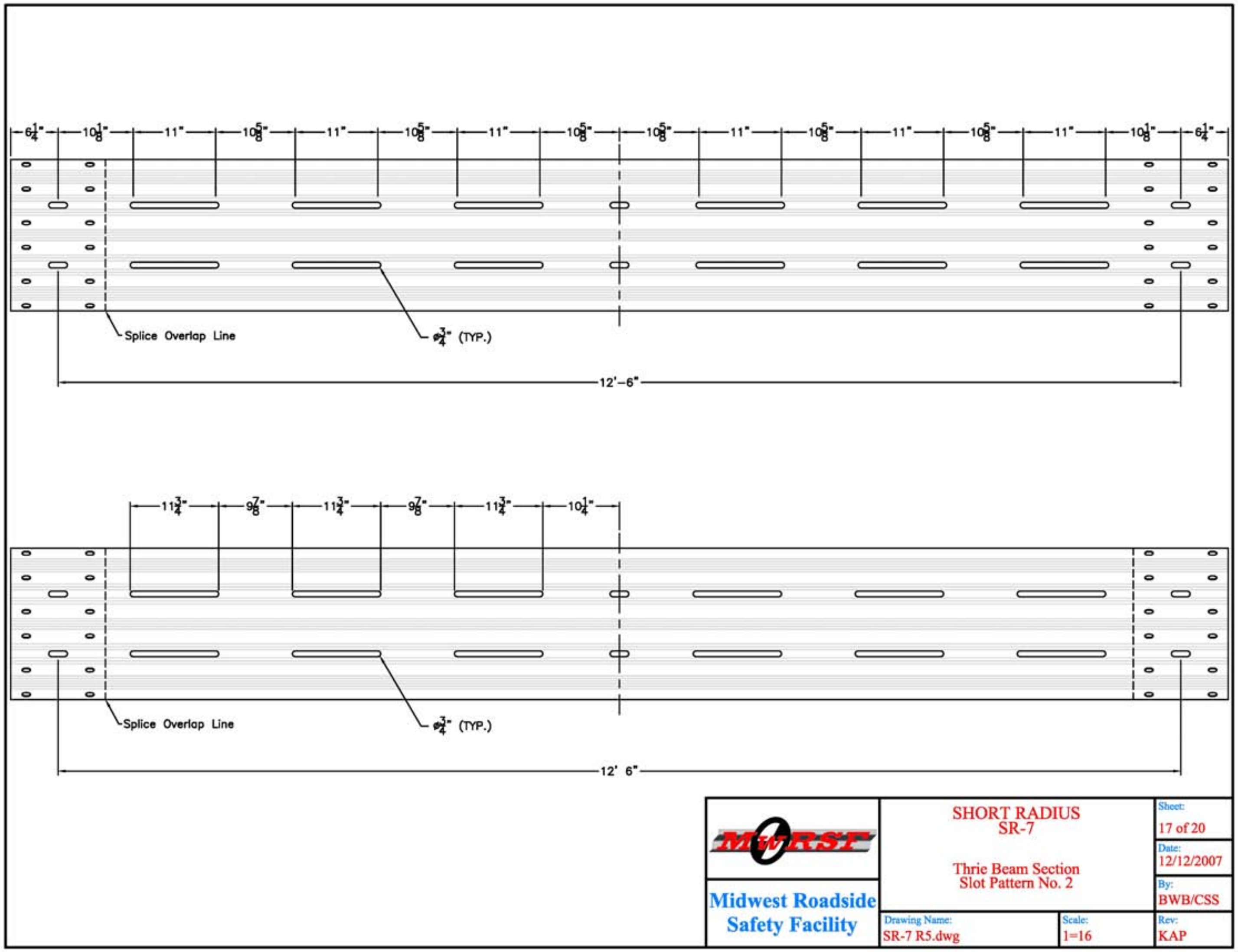


Figure A-16. Thrie Beam Section Slot Pattern No. 2 (English)

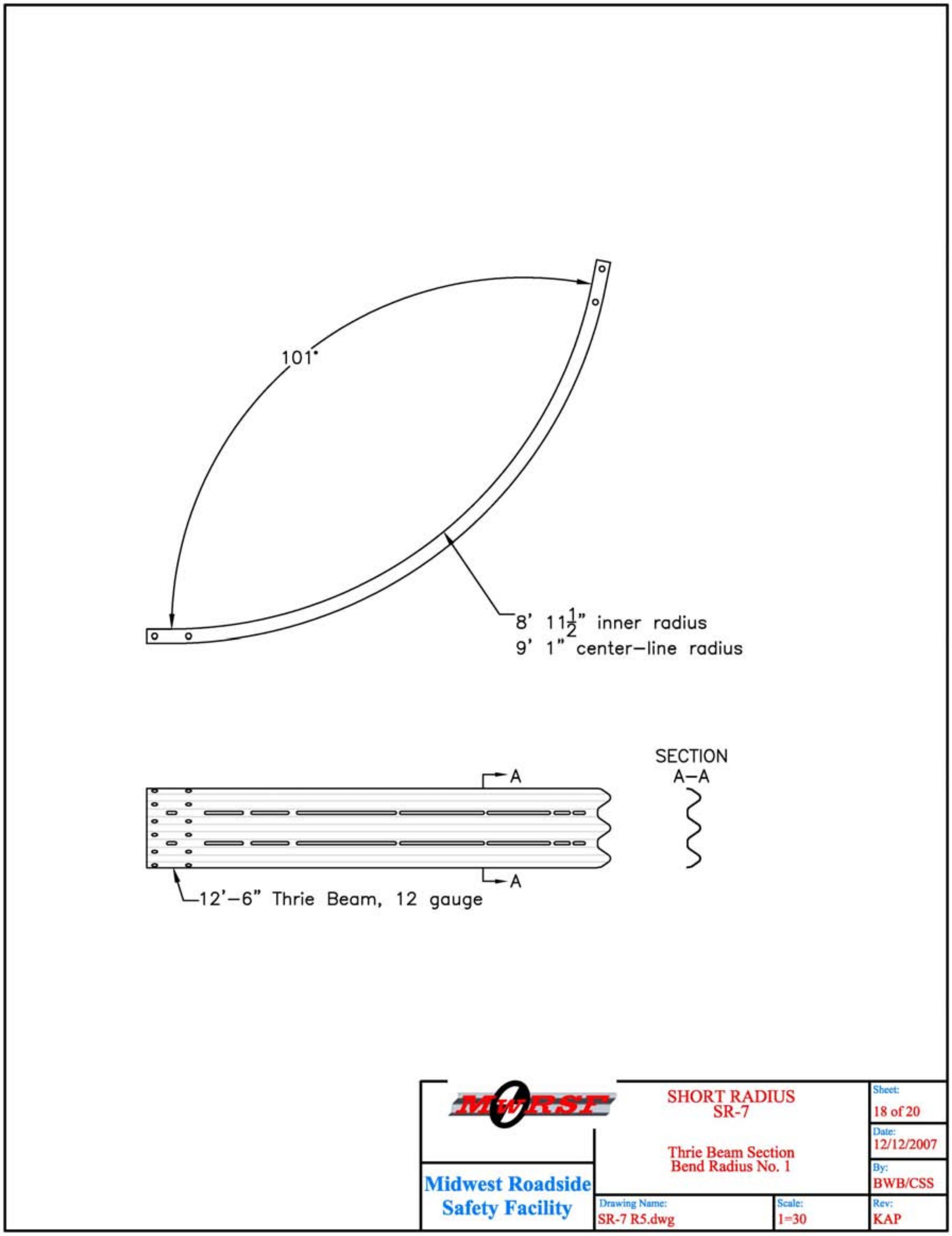


Figure A-17. Thrie Beam Section Bend Radius No. 1 (English)

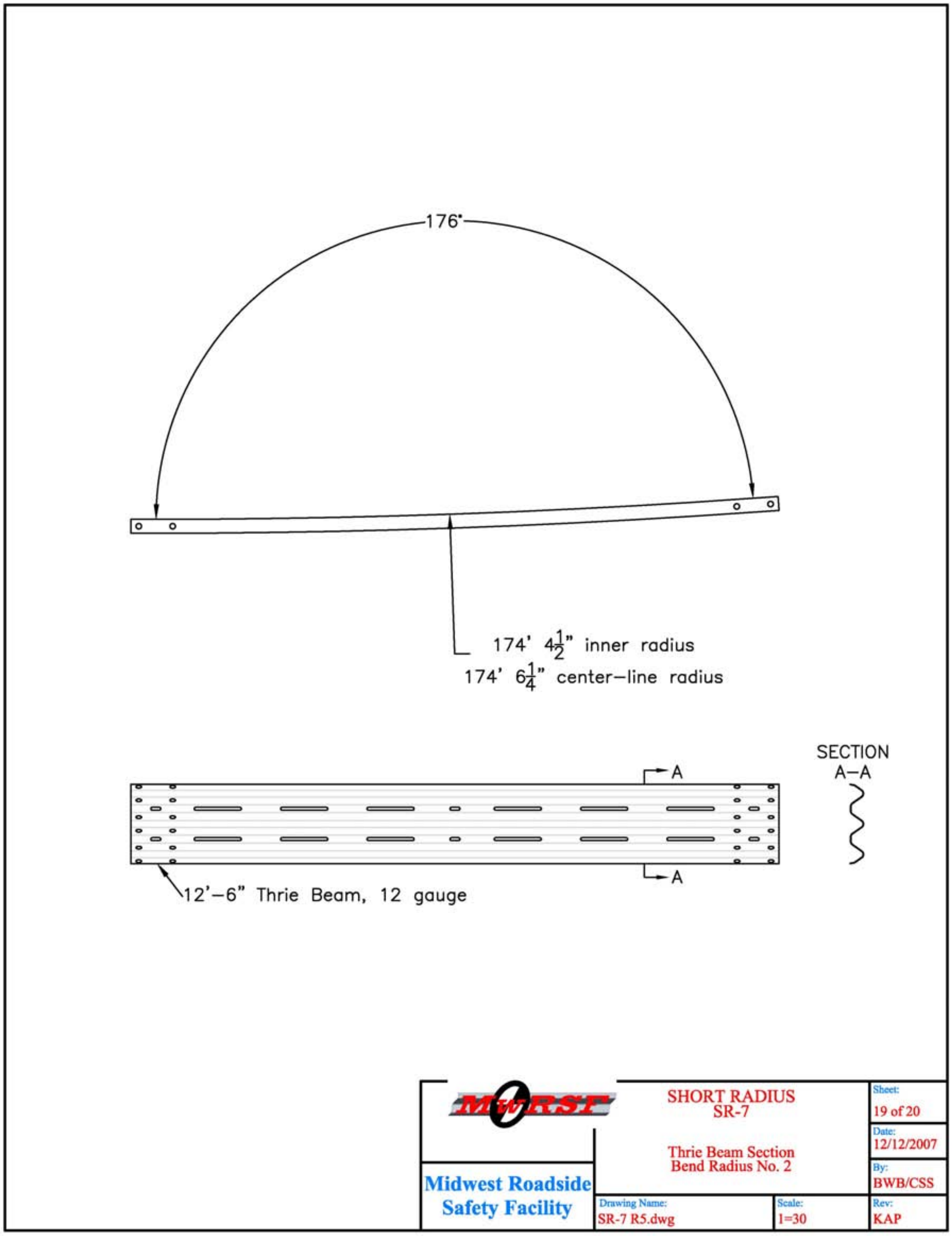


Figure A-18.Thrie Beam Section Bend Radius No. 2 (English)

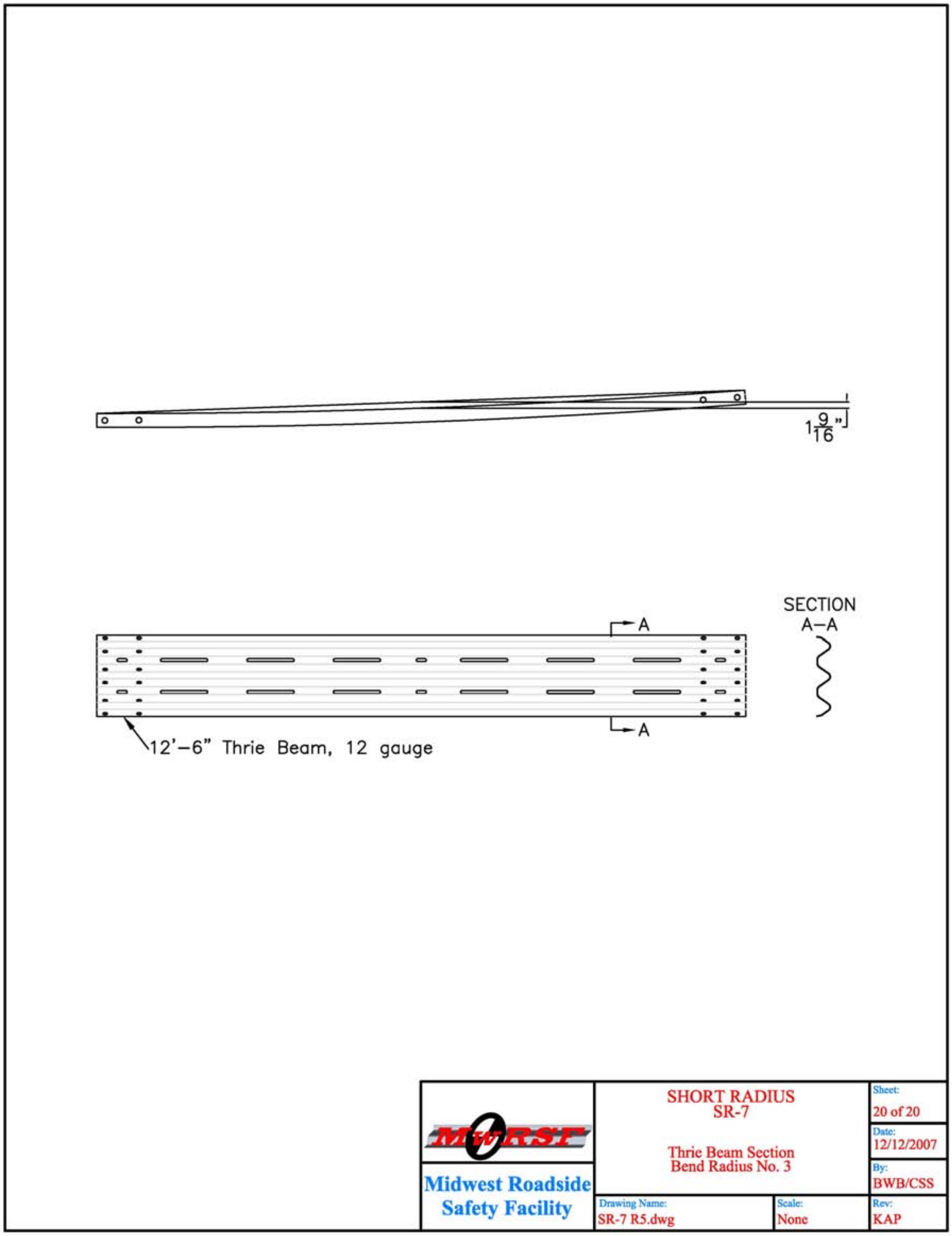


Figure A-19. Thrie Beam Section Bend Radius No. 3 (English)

APPENDIX B

Test Summary Sheets in English Units

0.000 sec | 0.104 sec | 0.216 sec | 0.342 sec | 0.484 sec

• Test Agency	MwRSF
• Test Number	SR-7
• Date	6/27/2006
• Proposed Update to NCHRP 350 Test Designation	3-33
• Appurtenance	Short-Radius Guardrail
• Key Elements - Steel Thrie-Beam	
Thickness	12-gauge
Top Mounting Height	31 in.
• Key Elements - Steel Posts	
Post Nos. 14P-19P	W6 x9 by 78 in. long
Post Nos. 20P-21P	W6 x25 by 80 in. long
• Key Elements - Wood Posts	
Post Nos. 2P-13P, 3S-6S (Thrie CRT)	6 in. x 8 in. by 78 in. long
Post Nos. 7S-9S (MGS CRT)	6 in. x 8 in. by 72 in. long
• Key Elements - Steel Foundation Tube	
Post Nos. 1P, 1S-2S	96 in. long
Post Nos. 10S-11S	72 in. long
• Key Elements - Dual Tapered Wood Spacer Blocks	
Post Nos. 2P-13P, 3S-5S	two 6 in. x 8 in. by 14.25 in. long
• Key Elements - MGS Blockouts	
Post No. 6S-9S	6 in. x 12 in. by 14.25 in. long
• Type of Soil	Grading B - AASHTO M 147-65 (1990)
• Test Vehicle	
Type/Designation	2270P
Make and Model	2002 Dodge Ram 1500 Quad Cab
	Pickup Truck
Curb	5,021 lb
Test Inertial	4,989 lb
Gross Static	4,989 lb

• Impact Conditions	
Speed	62.3 mph
Angle	18.1 degrees
Impact Location	Centerline of Nose Section
	with Centerline of Vehicle
• Exit Conditions	
Speed	N/A
Angle	N/A
Exit Box Criterion	N/A
• Post-Impact Trajectory	
Vehicle Stability	Unsatisfactory
Stopping Distance	42 ft longitudinal
	18 ft - 6 in. lateral
• Occupant Impact Velocity	
Longitudinal	20.03 ft/s < 30 ft/s
Lateral	-7.51 ft/s < 30 ft/s
• Occupant Ridedown Deceleration	
Longitudinal	9.61 Gs < 20 g's
Lateral	-5.55 Gs < 20 g's
• THIV (not required)	21.88 ft/s
• PHD (not required)	9.67 g's
• Test Article Damage	Extensive
• Test Article Deflections	
Permanent Set	44 ft - 2.1 in.
Dynamic	N/A
Working Width	46 ft - 7 in. laterally from primary side
• Vehicle Damage	Moderate
VDS[18]	1-FD-2
CDC[19]	01-FDEW-2
Maximum Deformation	0.5 in. at right-center door panel
• Angular Displacements	
Roll	-14 deg
Pitch	-12 deg
Yaw	84 deg

Figure B-1. Summary of Test Results and Sequential Photographs, Test No. SR-7 (English)

0.000 sec | 0.120 sec | 0.314 sec | 0.556 sec | 0.810 sec

- Test Agency . . . . MwRSF
- Test Number SR-8
- Date 8/1/2007
- Proposed Update to NCHRP 350 Test Designation . 3-33
- Appurtenance . . . . Short-Radius Guardrail
- Key Elements - Steel Thrie-Beam
  - Thickness 12-gauge
  - Top Mounting Height . . . . 31 in.
- Key Elements - Steel Posts
  - Post Nos. 14P-19P . . . . W6 x9 by 78 in. long
  - Post Nos. 20P-21P . . . . W6 x25 by 80 in. long
- Key Elements - Wood Posts
  - Post Nos. 2P-13P, 3S-6S (Thrie CRT) . . . . 6 in. x 8 in. by 78 in. long
  - Post Nos. 7S-9S (MGS CRT) . . . . 6 in. x 8 in. by 72 in. long
- Key Elements - Steel Foundation Tube
  - Post Nos. 1P, 1S-2S . . . . 96 in. long
  - Post Nos. 10S-11S . . . . 72 in. long
- Key Elements - Dual Tapered Wood Spacer Blocks
  - Post Nos. 2P-13P, 3S-5S . . . . two 6 in. x 8 in. by 14.25 in. long
- Key Elements - MGS Blockouts
  - Post No. 6S-9S . . . . 6 in. x 12 in. by 14.25 in. long
- Type of Soil . . . . Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model . . . . 2002 Dodge Ram 1500 Quad Cab Pickup Truck
  - Curb . . . . 5,151 lb
  - Test Inertial . . . . 5,000 lb
  - Gross Static . . . . 5,000 lb
- Impact Conditions
  - Speed . . . . 62.8 mph
  - Angle . . . . 17.9 degrees
  - Impact Location . . . . Centerline of Nose Section with Centerline of Vehicle
- Exit Conditions
  - Speed . . . . N/A
  - Angle . . . . N/A
  - Exit Box Criterion . . . . N/A
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 51 ft longitudinal
    4 ft - 1 in. lateral
- Occupant Impact Velocity
  - Longitudinal . . . . -21.0 ft/s < 30 ft/s
  - Lateral . . . . 10.3 ft/s < 30 ft/s
- Occupant Ridedown Deceleration
  - Longitudinal . . . . 6.80 Gs < 20 g's
  - Lateral . . . . 4.12 Gs < 20 s's
- THIV (not required) . . . . 19.2 ft/s
- PHD (not required) . . . . 7.26 g's
- Test Article Damage . . . . Extensive
- Test Article Deflections
  - Permanent Set . . . . 27 ft - 9 in.
  - Dynamic . . . . N/A
  - Working Width . . . . 38 ft - 4 in. along primary side
    . . . . 67 ft - 6 in. lateral from primary side
- Vehicle Damage . . . . Minimal
  - VDS[18] 12-FD-1
  - CDC[19] 12-FDEW-1
  - Maximum Deformation . . . . 0.75 in. at right-side firewall
- Angular Displacements
  - Roll . . . . -8 deg
  - Pitch . . . . -5 deg
  - Yaw . . . . 113 deg

Figure B-2. Summary of Test Results and Sequential Photographs, Test No. SR-8 (English)

APPENDIX C

Occupant Compartment Deformation, Test No. SR-7

VEHICLE PRE/POST CRUSH INFO
Set-1

TEST: SR-7
VEHICLE: 2002 Ram 1500 Q.C. 4x2

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	24.5	11.5	0.25	24.75	11.25	0.25	0.25	-0.25	0
2	25	15.5	2.25	25	15.5	2.25	0	0	0
3	28	19.75	4.75	28	19.75	4.75	0	0	0
4	27	26.5	3.25	27.5	26.5	3.25	0.5	0	0
5	19.25	7.25	2	19	7.25	2	-0.25	0	0
6	20	12.25	3.75	20	12	3.75	0	-0.25	0
7	21	16.25	6.5	21	16.25	6.5	0	0	0
8	21.75	21.25	7.75	22	21	7.75	0.25	-0.25	0
9	21.75	24.75	7.5	21.75	25	7.25	0	0.25	-0.25
10	21.25	30	7.25	21.5	30.25	7	0.25	0.25	-0.25
11	14.5	2	3.25	14.5	2	3	0	0	-0.25
12	14.5	6	2.75	14.5	6	2.75	0	0	0
13	15	9.75	5	14.75	9.5	5	-0.25	-0.25	0
14	16.5	14	8.75	16.5	13.75	8.75	0	-0.25	0
15	16.5	19.5	8.5	16.5	19.5	8.5	0	0	0
16	16.5	27	7.5	16.25	26.75	7.75	-0.25	-0.25	0.25
17	9.25	2	3.5	9.25	2	3.25	0	0	-0.25
18	8.75	7	3	8.75	7	3	0	0	0
19	10	10.25	8.25	10	10.25	8.25	0	0	0
20	10.5	16	8.25	10.5	16.24	8.5	0	0.24	0.25
21	10.5	23	7.75	10.5	22.75	7.75	0	-0.25	0
22	10.5	28	7.25	10.5	27.5	7.25	0	-0.5	0
23	2.5	5	3.5	2.5	5	3.5	0	0	0
24	3.25	11.75	8	3.25	11.75	8	0	0	0
25	3.25	21.25	7	3.25	21.25	7	0	0	0
26	3.25	27.75	6	3.25	27.5	6.25	0	-0.25	0.25
27	1	14	4.75	1	14	4.5	0	0	-0.25
28	1.75	23	3.5	1.75	23	3.5	0	0	0
29									
30									

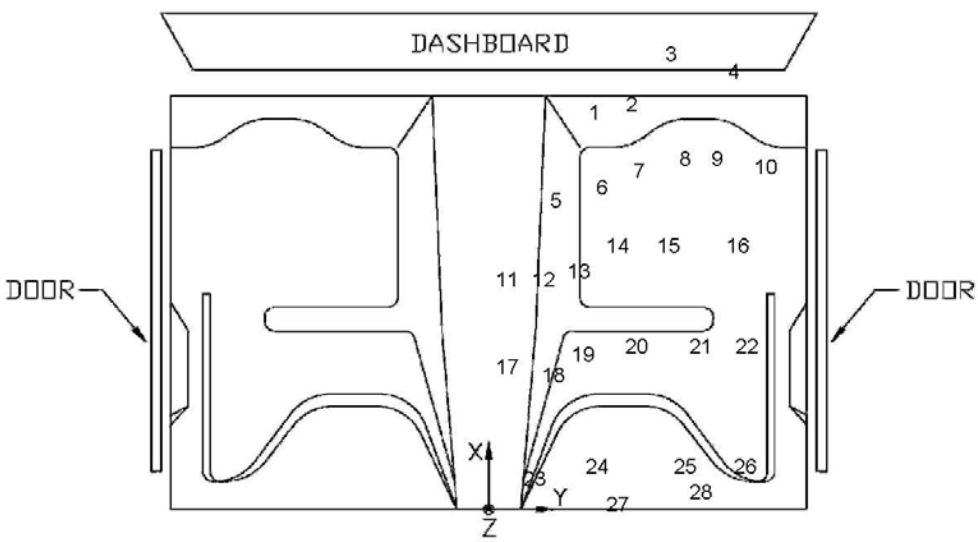


Figure C-1. Occupant Compartment Deformation, Test SR-7

VEHICLE PRE/POST CRUSH INFO
Set-2

TEST: SR-7
VEHICLE: 2002 Ram 1500 Q.C, 4x2

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	47.25	26	0.25	47.5	25.75	0.25	0.25	-0.25	0
2	47.75	30	2.75	47.75	30	2.75	0	0	0
3	50.75	34.25	5.75	50.75	34.25	5.75	0	0	0
4	49.75	41	5	50.25	41	5	0.5	0	0
5	42	21.75	1.25	41.75	21.75	1.25	-0.25	0	0
6	42.75	26.75	4	42.75	26.5	4	0	-0.25	0
7	43.75	30.75	7	43.75	30.75	7	0	0	0
8	44.5	35.75	9	44.75	35.5	9	0.25	-0.25	0
9	44.5	39.25	9	44.5	39.5	9	0	0.25	0
10	44	44.5	9.5	44.25	44.75	9.5	0.25	0.25	0
11	37.25	16.5	1.75	37.25	16.5	1.75	0	0	0
12	37.25	20.5	2	37.25	20.5	2	0	0	0
13	37.75	24.25	4.75	37.5	24	4.75	-0.25	-0.25	0
14	39.25	28.5	9	39.25	28.25	9	0	-0.25	0
15	39.25	34	9.5	39.25	34	9.5	0	0	0
16	39.25	41.5	9.75	39	41.25	9.75	-0.25	-0.25	0
17	32	16.5	2	32	16.5	2	0	0	0
18	31.5	21.5	2.5	31.5	21.5	2.5	0	0	0
19	32.75	24.75	8.25	32.75	24.75	8.25	0	0	0
20	33.25	30.5	9.25	33.25	30.74	9.25	0	0.24	0
21	33.25	37.5	9.25	33.25	37.25	9.5	0	-0.25	0.25
22	33.25	42.5	9.5	33.25	42	9.5	0	-0.5	0
23	25.25	19.5	2.75	25.25	19.5	2.75	0	0	0
24	26	26.25	8.25	26	26.25	8.25	0	0	0
25	26	35.75	8.5	26	35.75	8.75	0	0	0.25
26	26	42.25	8.75	26	42	8.75	0	-0.25	0
27	23.75	28.5	5.25	23.75	28.5	5.25	0	0	0
28	24.5	37.5	5.5	24.5	37.5	5.75	0	0	0.25
29									
30									

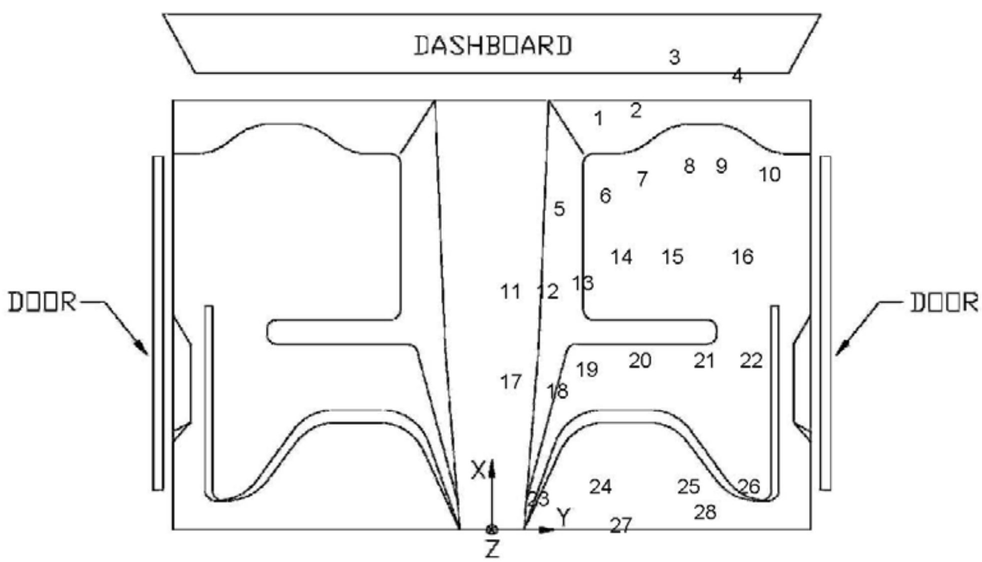


Figure C-2. Occupant Compartment Deformation, Test SR-7

Occupant Compartment Deformation Index (OCDI)

Test No. SR-7
Vehicle Type: 2002 Ram 1500

OCDI = XXABCDEFGHI

XX = location of occupant compartment deformation

A = distance between the dashboard and a reference point at the rear of the occupant compartment, such as the top of the rear seat or the rear of the cab on a pickup

B = distance between the roof and the floor panel

C = distance between a reference point at the rear of the occupant compartment and the motor panel

D = distance between the lower dashboard and the floor panel

E = interior width

F = distance between the lower edge of right window and the upper edge of left window

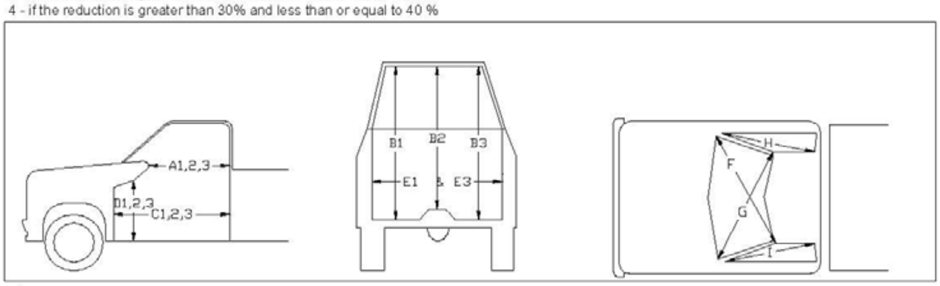
G = distance between the lower edge of left window and the upper edge of right window

H= distance between bottom front corner and top rear corner of the passenger side window

I= distance between bottom front corner and top rear corner of the driver side window

Severity Indices

0 - if the reduction is less than 3%
1 - if the reduction is greater than 3% and less than or equal to 10 %
2 - if the reduction is greater than 10% and less than or equal to 20 %
3 - if the reduction is greater than 20% and less than or equal to 30 %
4 - if the reduction is greater than 30% and less than or equal to 40 %



where,
1 = Passenger Side
2 = Middle
3 = Driver Side

Location:

Measurement	Pre-Test (in.)	Post-Test (in.)	Change (in.)	% Difference	Severity Index
A1	69.25	69.00	-0.25	-0.36	0
A2	70.00	70.25	0.25	0.36	0
A3	71.25	71.00	-0.25	-0.35	0
B1	46.25	46.50	0.25	0.54	0
B2	42.00	41.75	-0.25	-0.60	0
B3	46.50	46.50	0.00	0.00	0
C1	61.00	61.00	0.00	0.00	0
C2	46.25	46.50	0.25	0.54	0
C3	58.50	58.50	0.00	0.00	0
D1	15.75	15.75	0.00	0.00	0
D2	13.50	13.50	0.00	0.00	0
D3	17.00	17.00	0.00	0.00	0
E1	65.00	64.50	-0.50	-0.77	0
E3	64.75	64.50	-0.25	-0.39	0
F	59.75	59.75	0.00	0.00	0
G	59.25	59.50	0.25	0.42	0
H	40.75	41.00	0.25	0.61	0
I	41.00	41.25	0.25	0.61	0

Note: Maximum sevrity index for each variable (A-I) is used for determination of final OCDI value

	XX	A	B	C	D	E	F	G	H	I
Final OCDI:	RF	0	0	0	0	0	0	0	0	0

Figure C-3. Occupant Compartment Deformation Index (OCDI), Test SR-7

APPENDIX D

Occupant Risk, Test No. SR-7

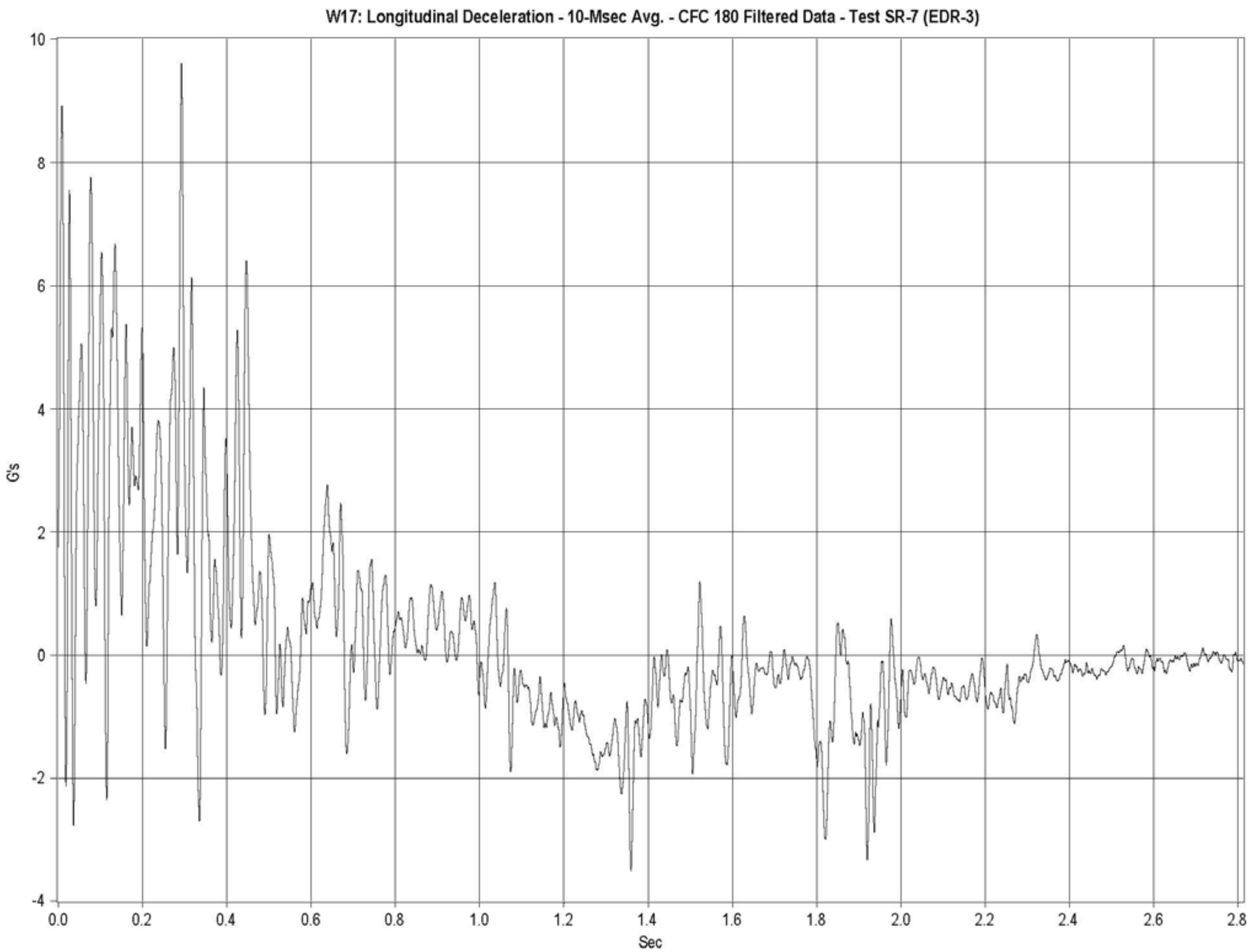


Figure D-1. Longitudinal Occupant Deceleration, Test SR-7

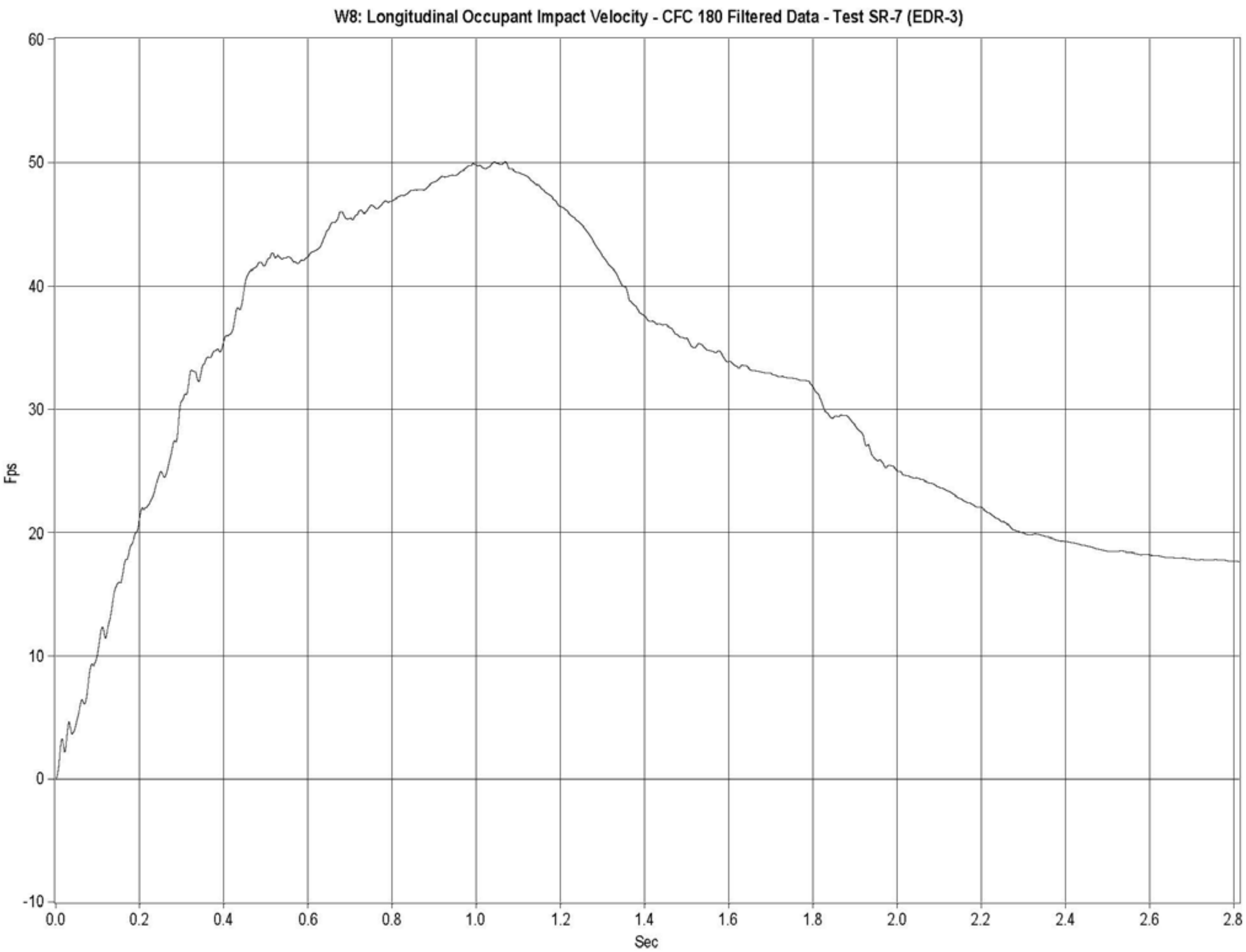


Figure D-2. Longitudinal Occupant Impact Velocity (OIV), Test SR-7

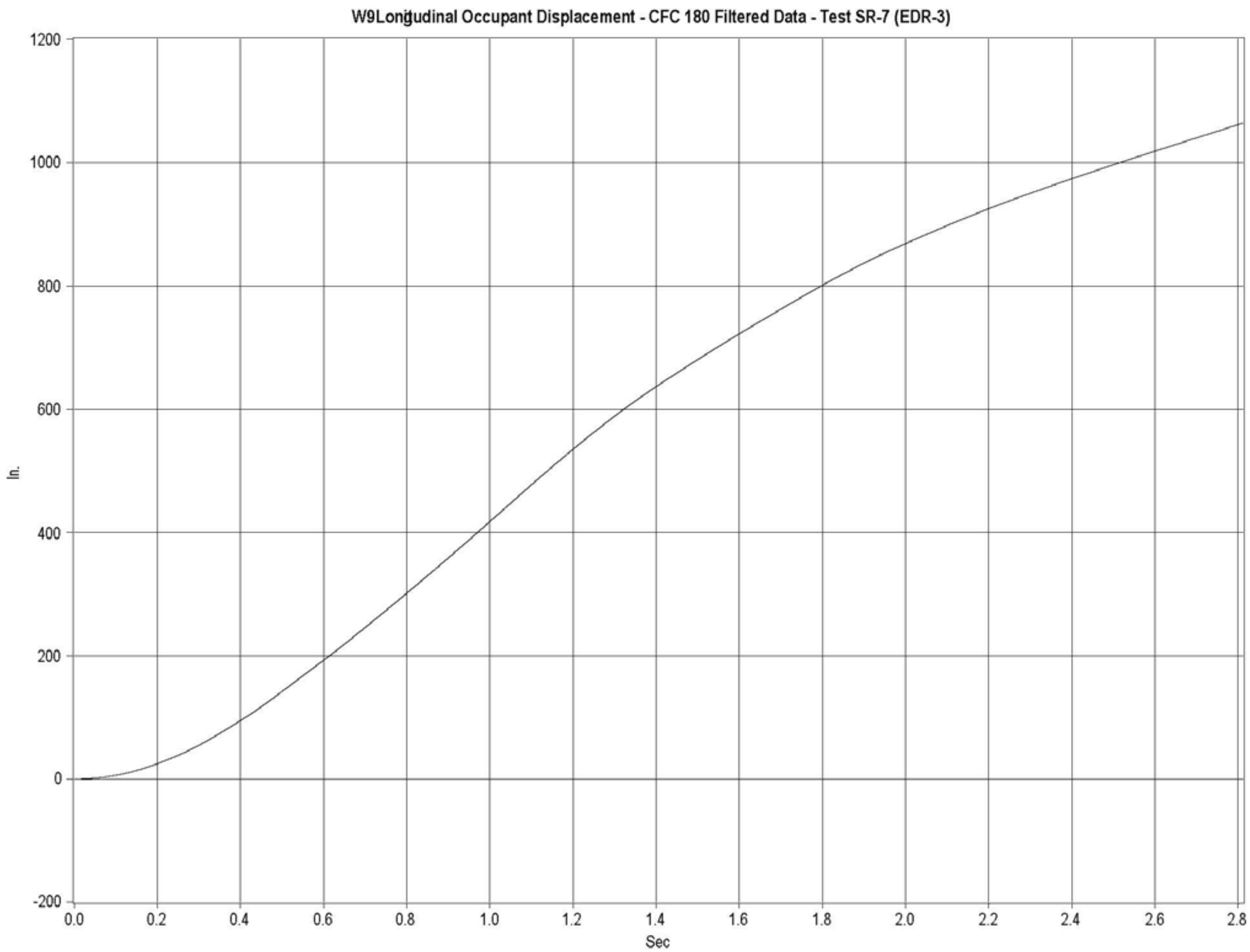


Figure D-3. Longitudinal Occupant Displacement, Test SR-7

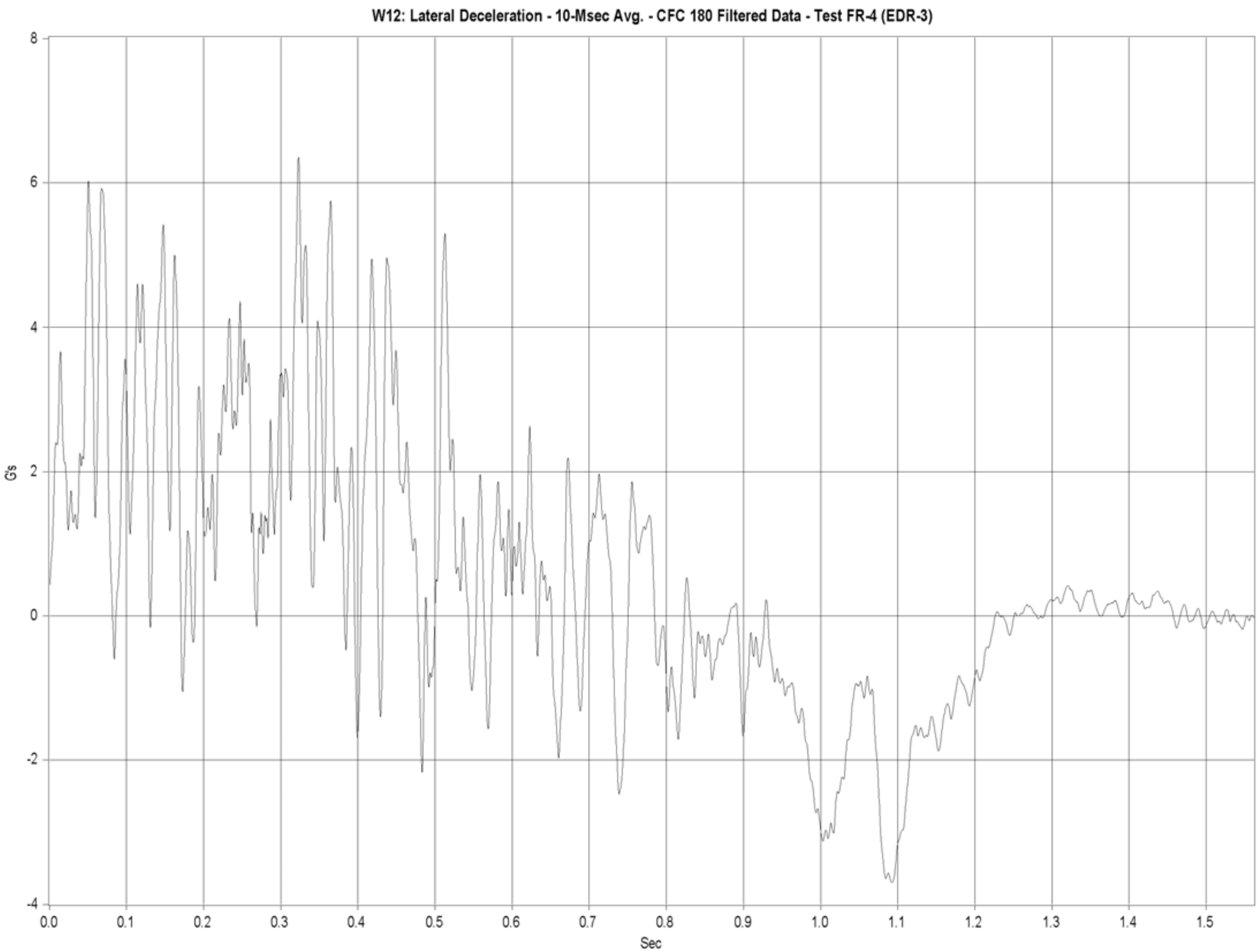


Figure D-4. Lateral Occupant Deceleration, Test SR-7

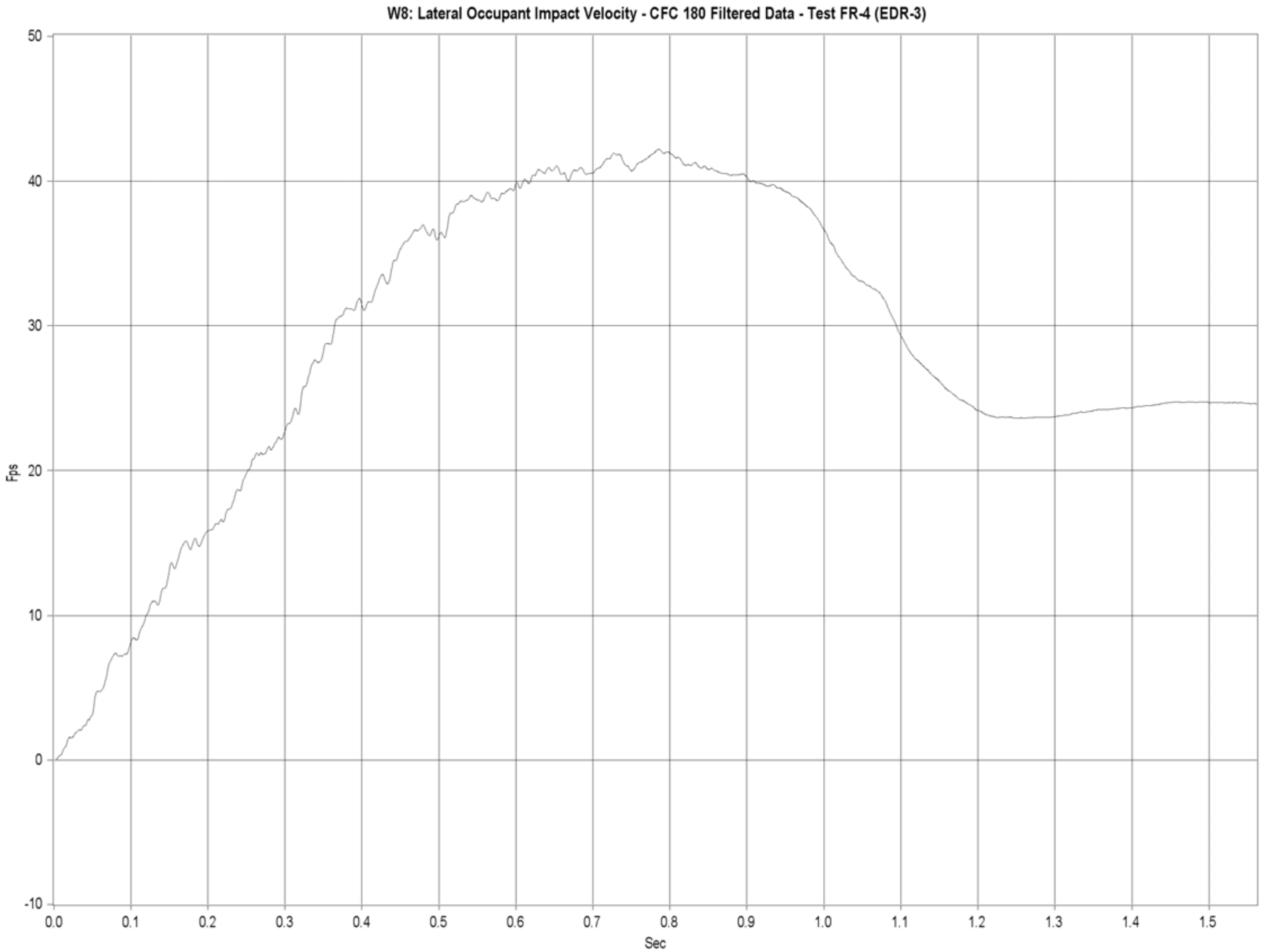


Figure D-5. Lateral Occupant Impact Velocity (OIV), Test SR-7

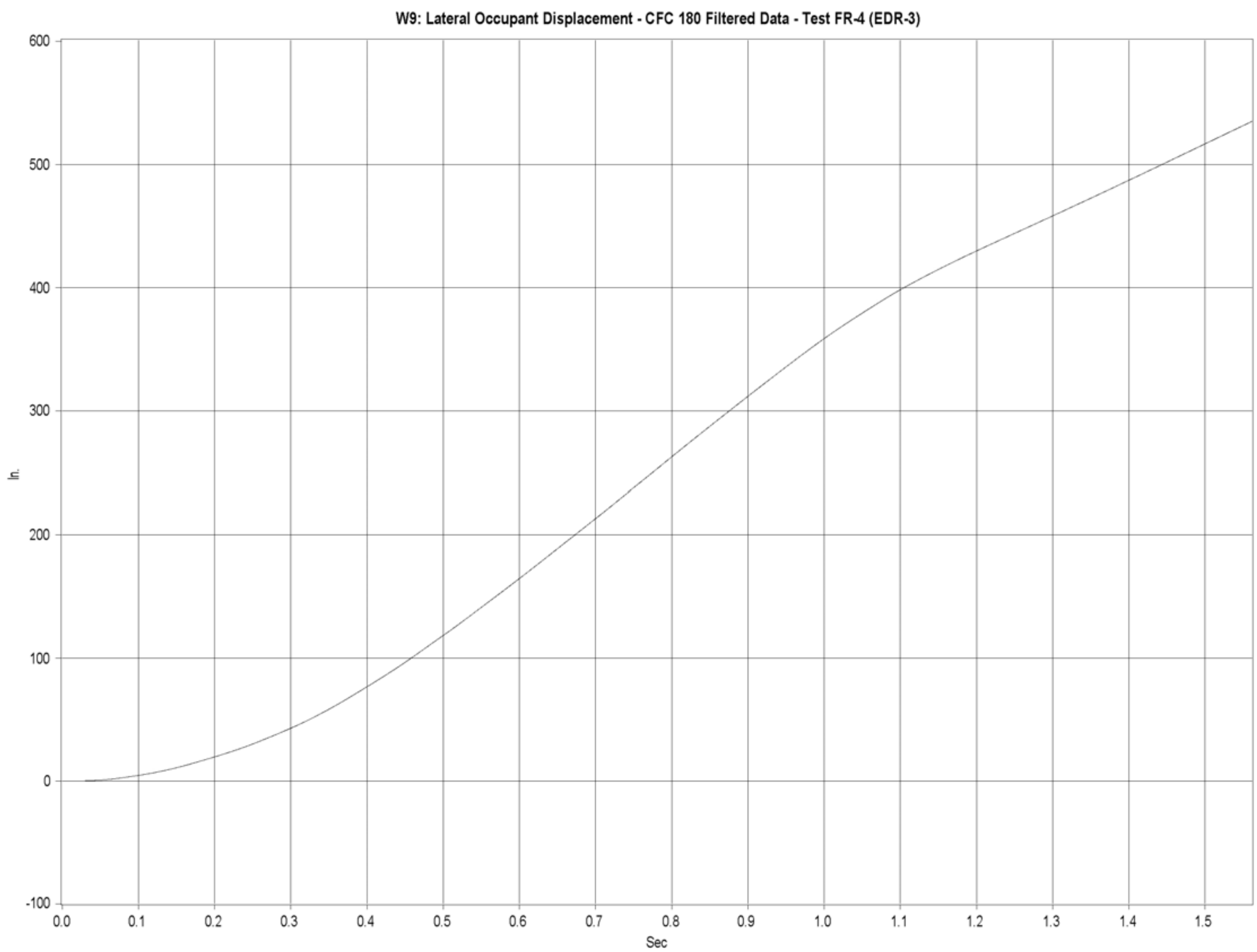


Figure D-6. Lateral Occupant Displacement, Test SR-7

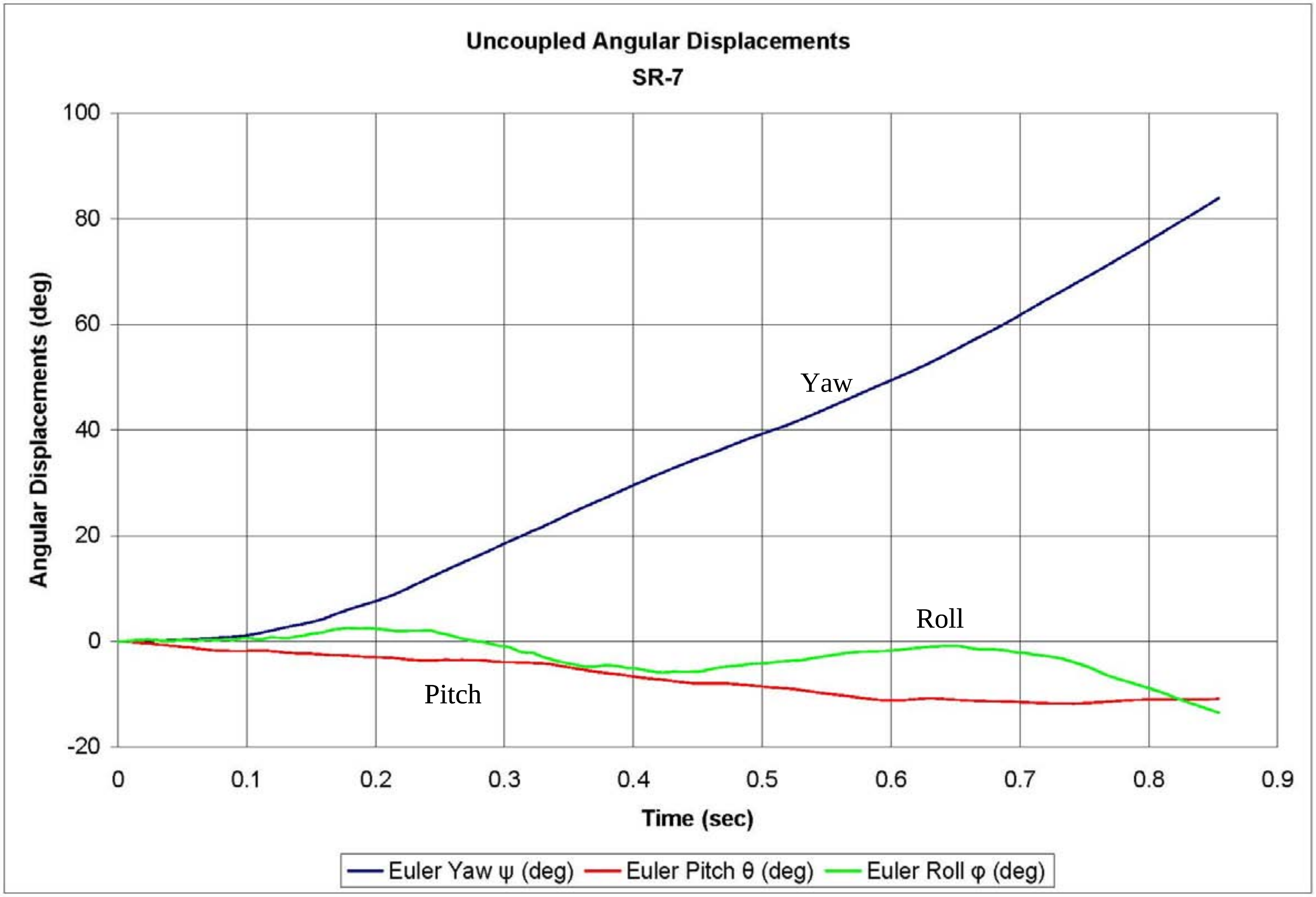


Figure D-7. Angular Displacements, Test SR-7

APPENDIX E

System Details, Test No. SR-8

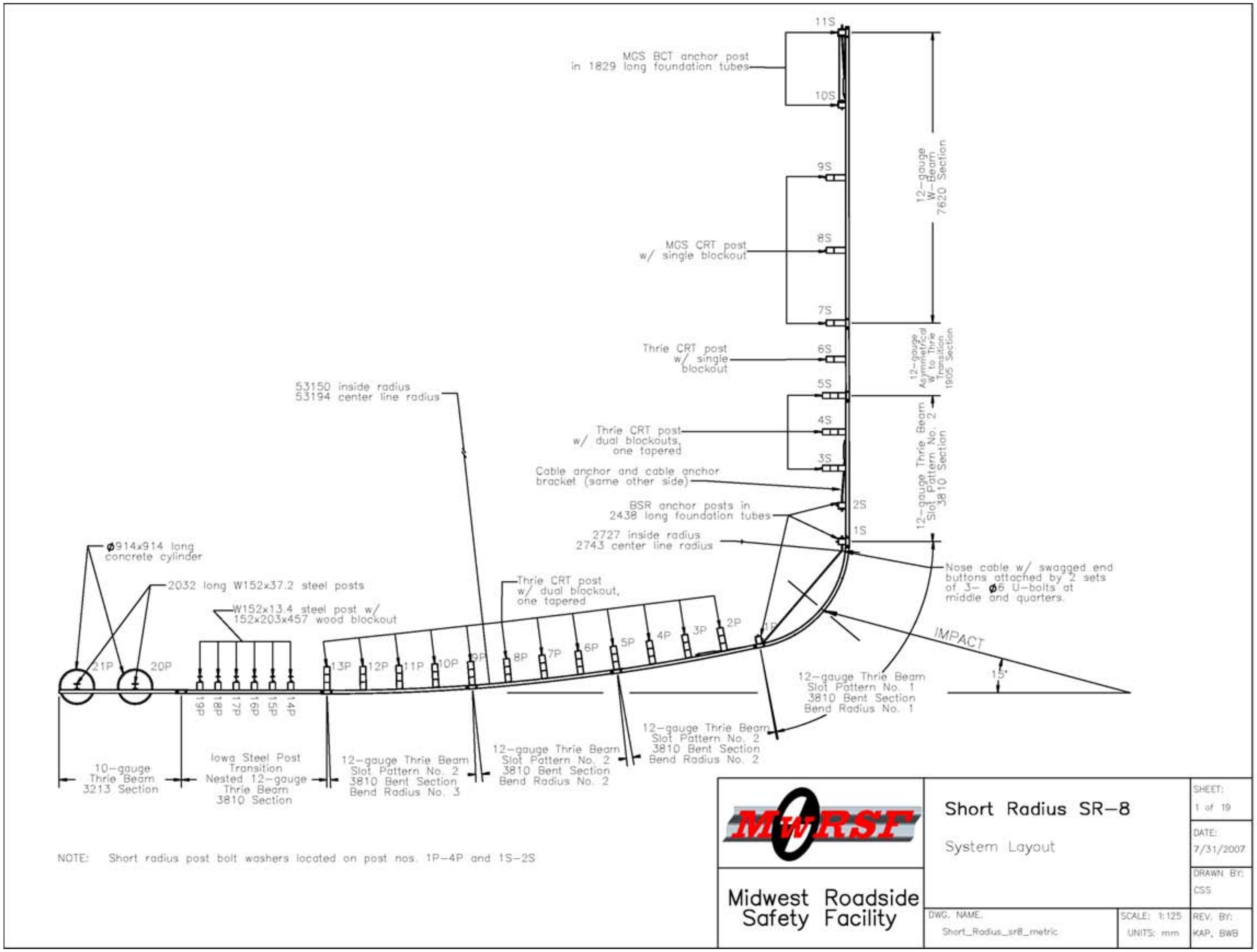


Figure E-1. System Layout

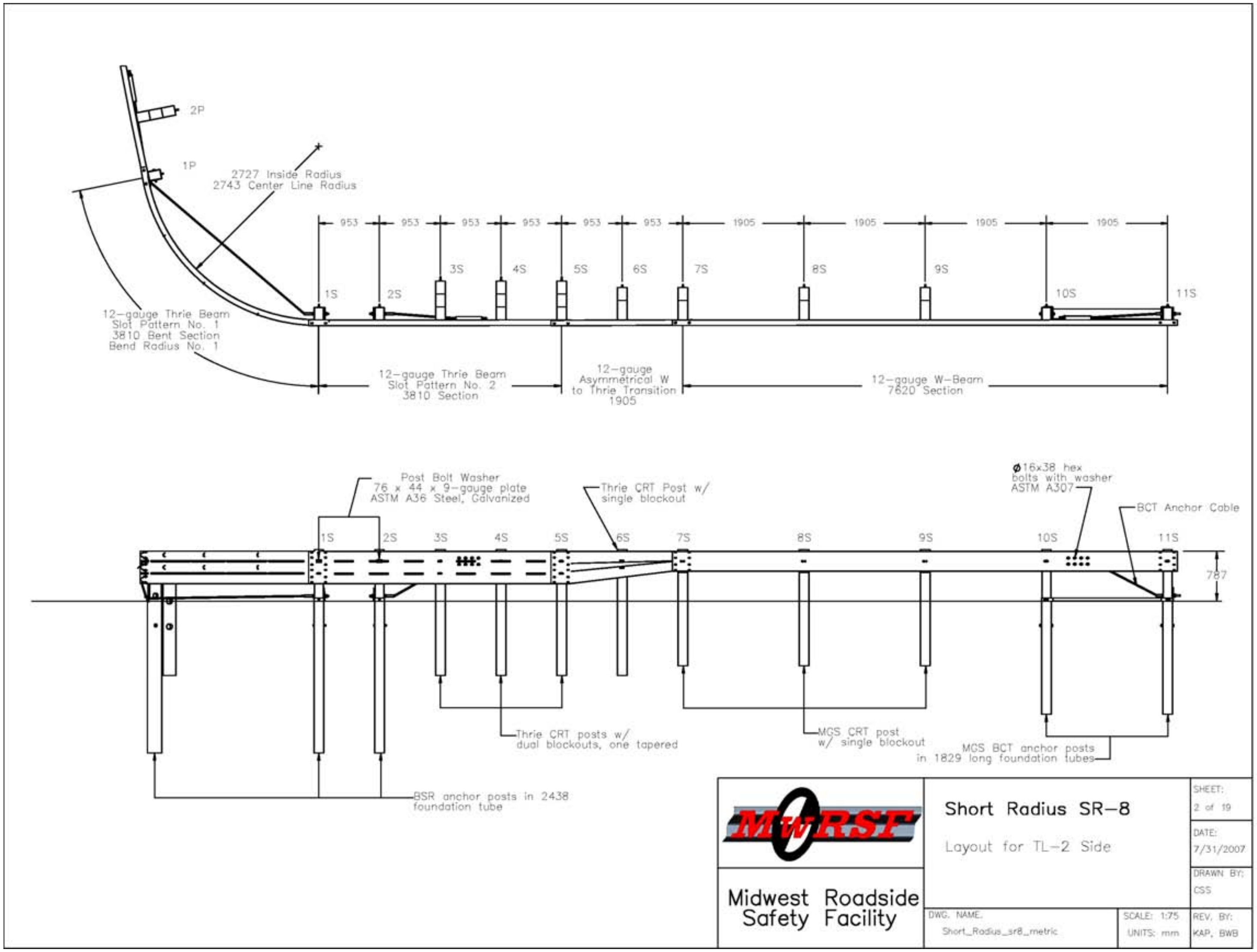


Figure E-2. Layout for Secondary Side

Post No.	Front Face D.S. Edge		Front Face U.S. Edge	
	X	Y	X	Y
1P	11254	1209.675	11395	1235.075
2P	10258	1412.875	10408	1443.0375
3P	9330	1238.25	9481	1265.2375
4P	8396	1079.5	8547	1103.3125
5P	7455	935.0375	7606	958.85
6P	6526	811.2125	6596	830.2625
7P	5580	701.675	5731	720.725
8P	4645	611.1875	4797	625.475
9P	3700	536.575	3853	547.6875
10P	2757	477.8375	2910	487.3625
11P	1816	438.15	1969	442.9125
12P	870	412.75	1022	415.925
13P	-76	406.4	76	406.4

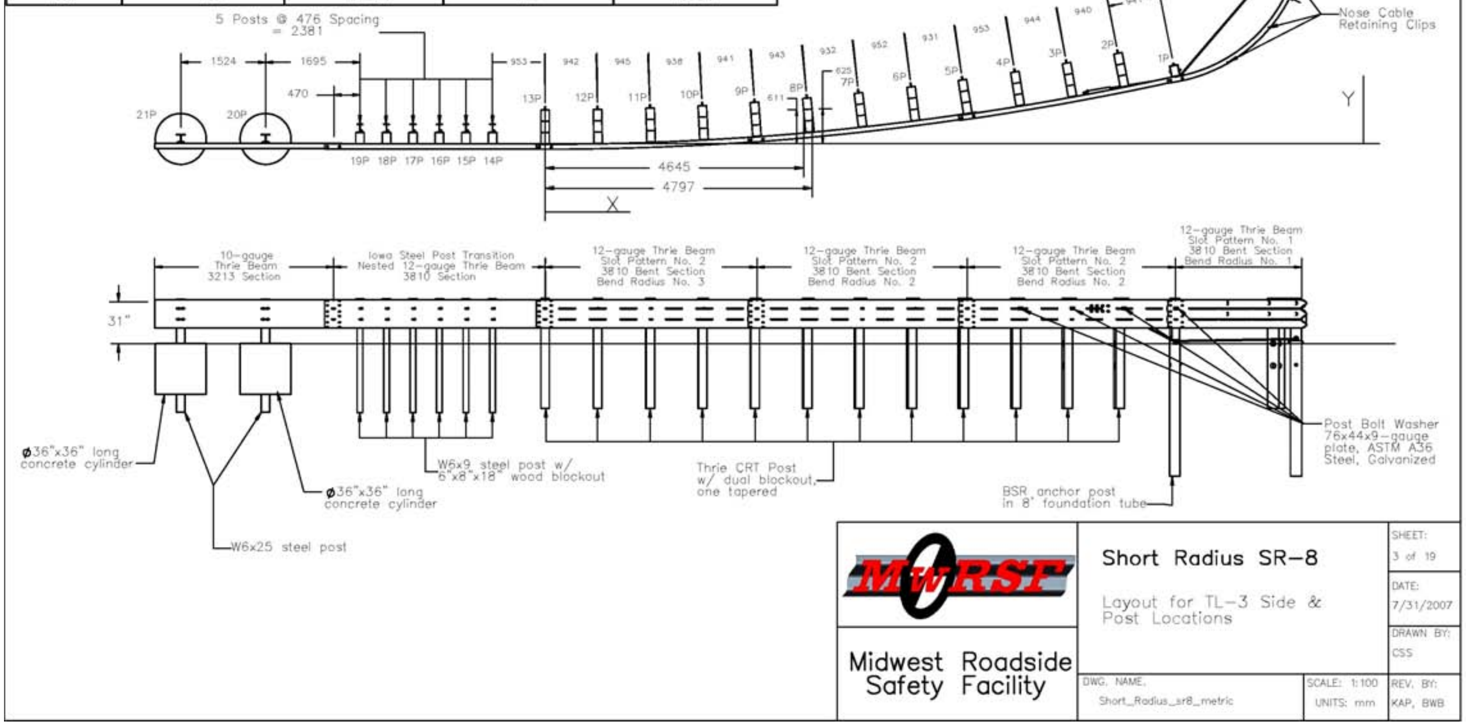


Figure E-3. Layout for Primary Side and Post Locations

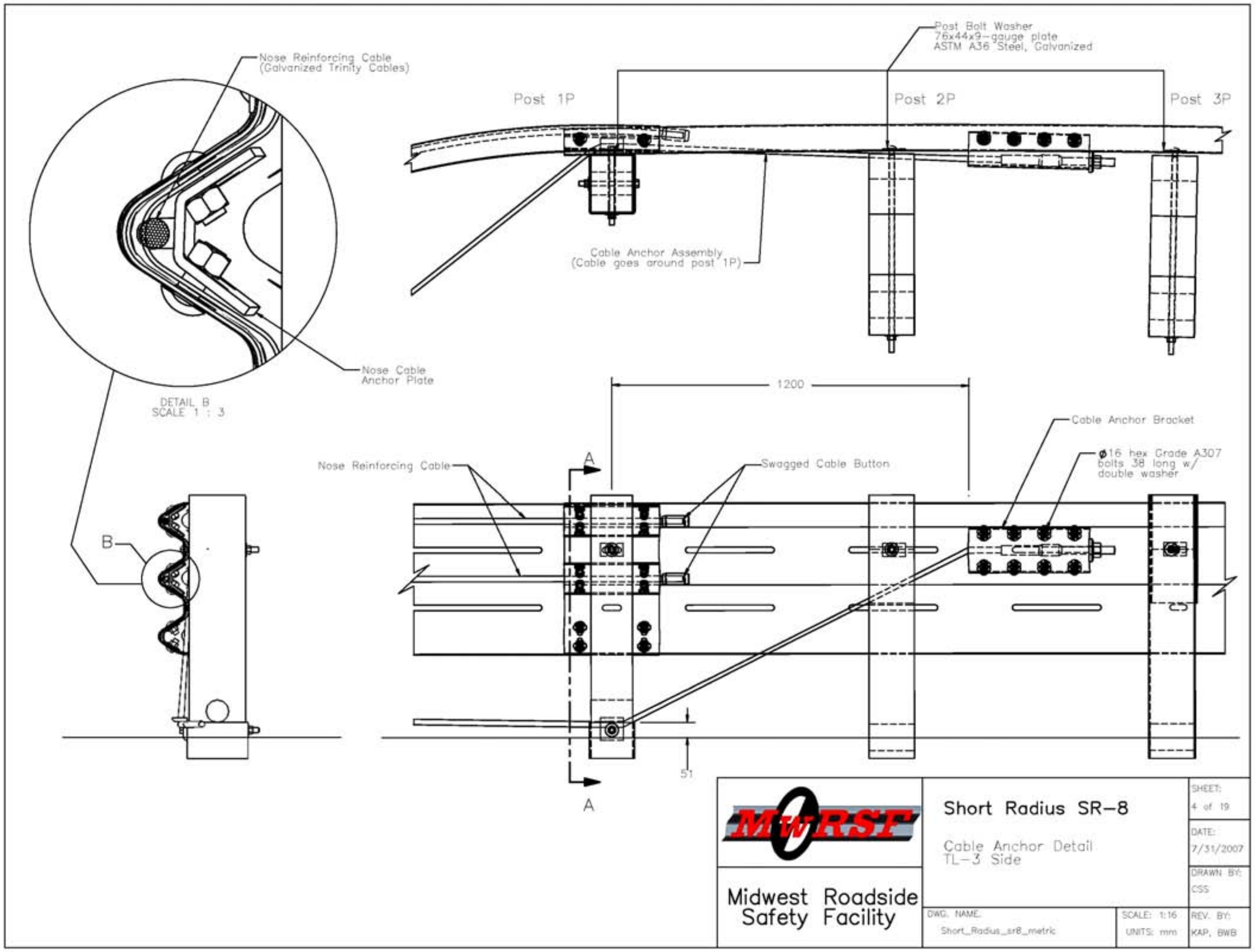


Figure E-4. Cable Anchor Detail, Primary Side

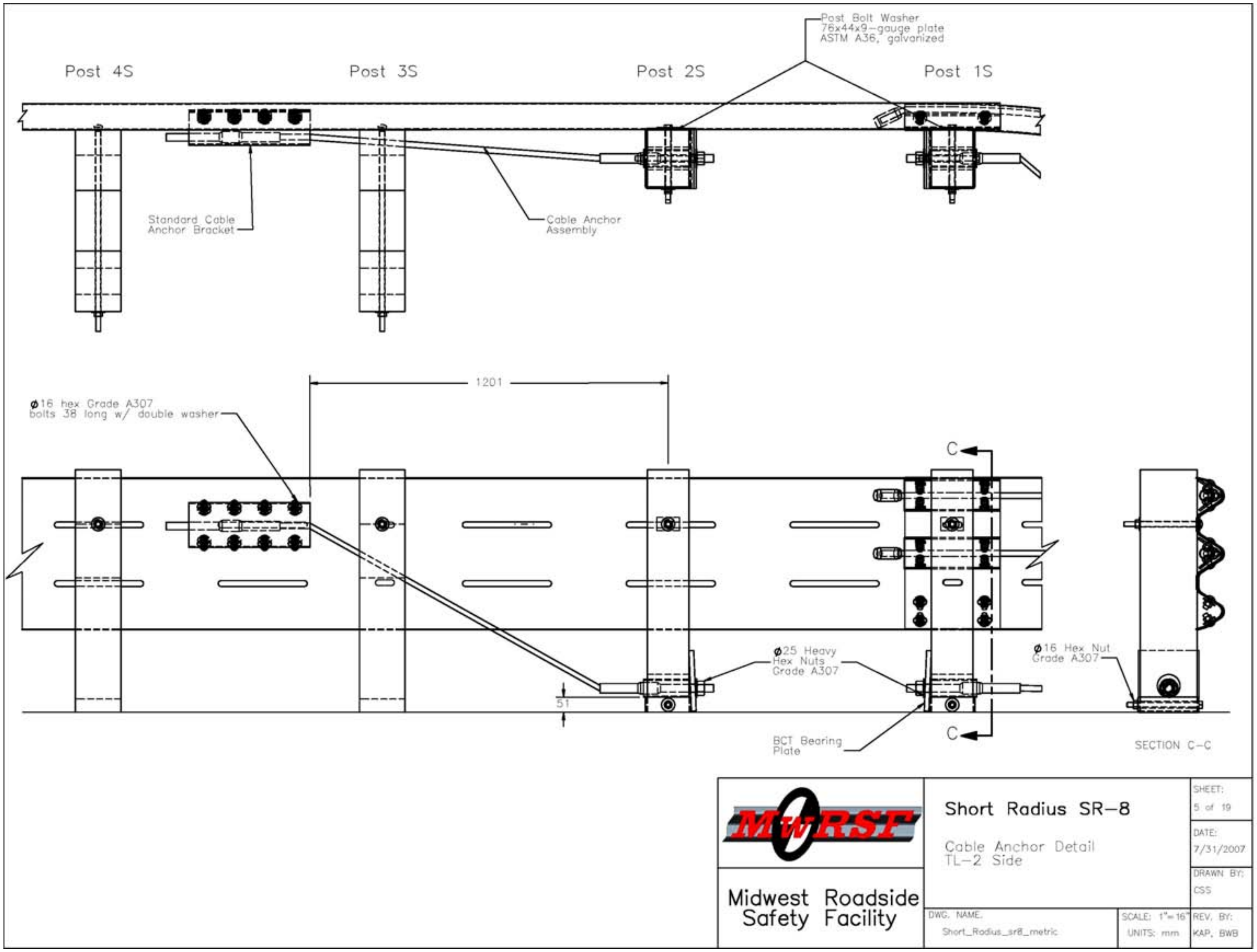


Figure E-5. Cable Anchor Detail, Secondary Side

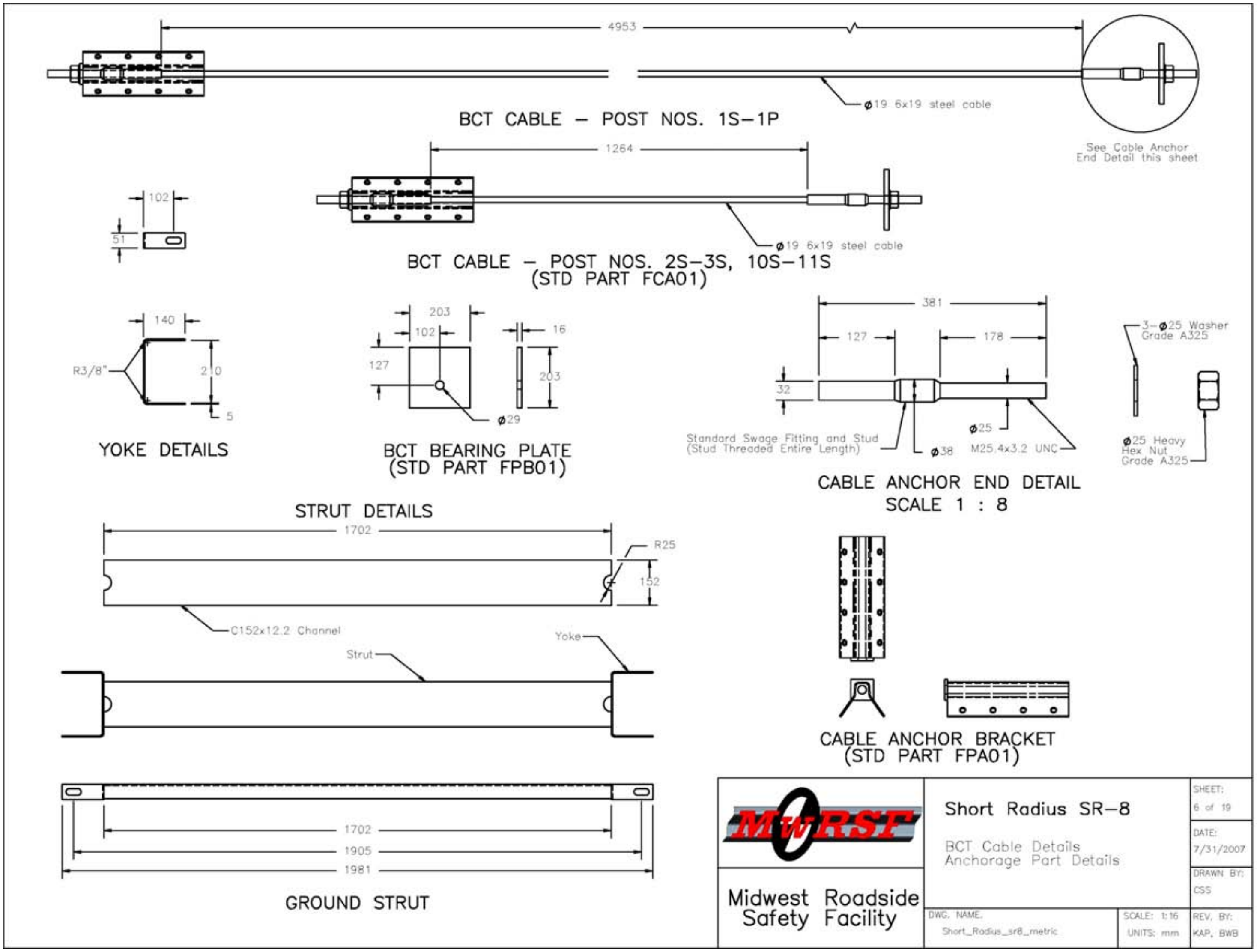


Figure E-6. BCT Cable Detail and Anchorage Part Details

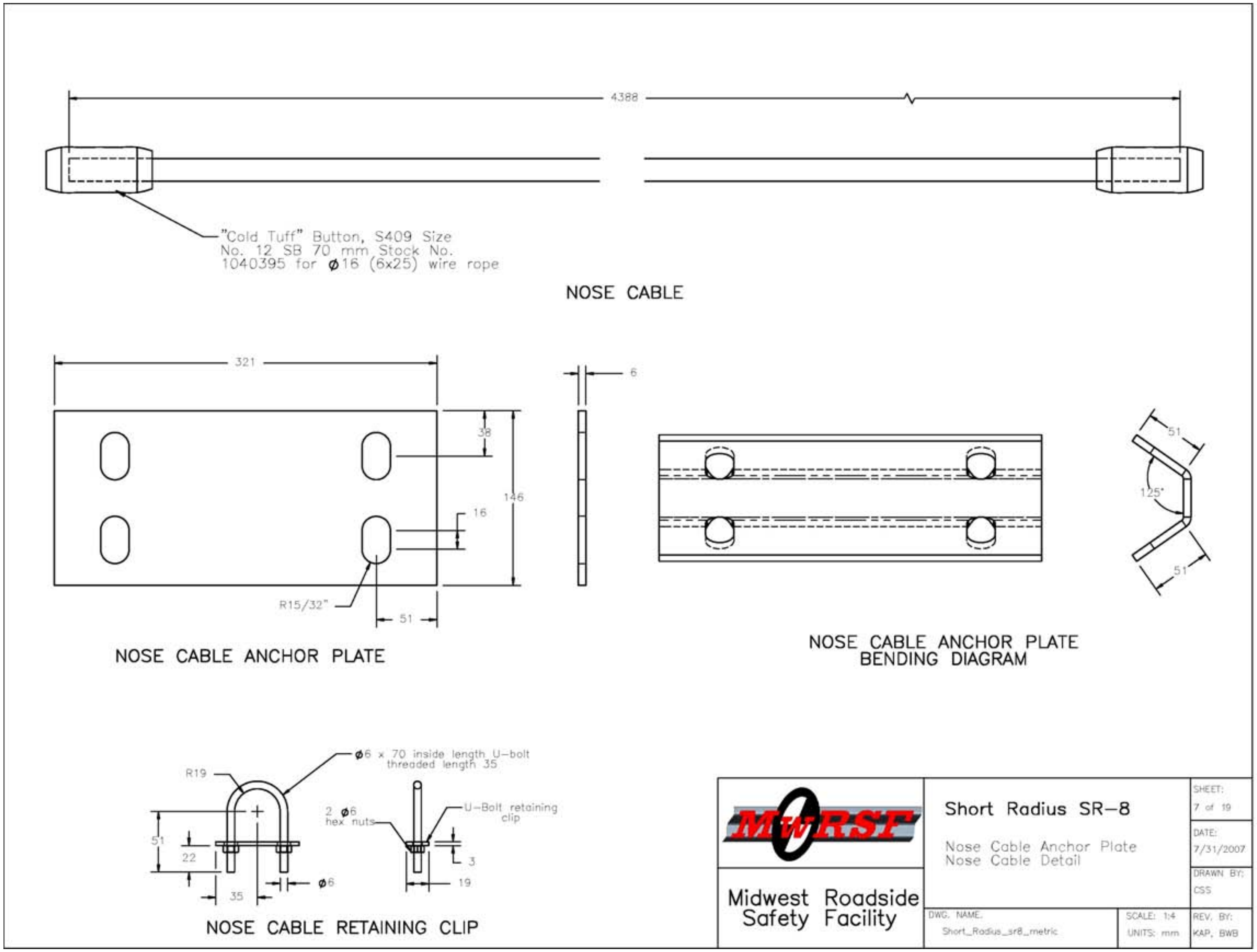


Figure E-7. Nose Cable Anchor Plate and Nose Cable Detail

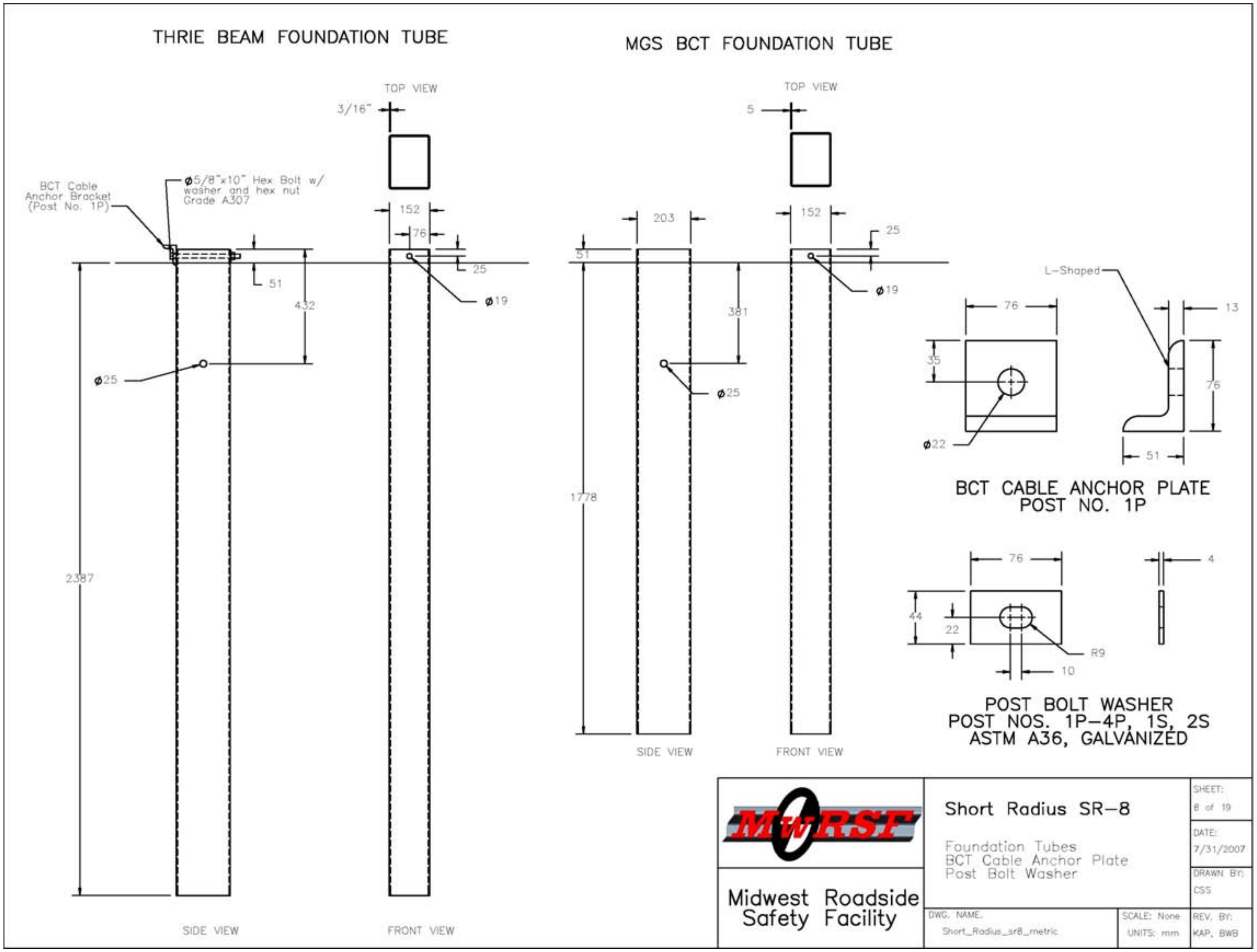


Figure E-8. MGS Foundation Tube and Thrie Beam Foundation Tube Details

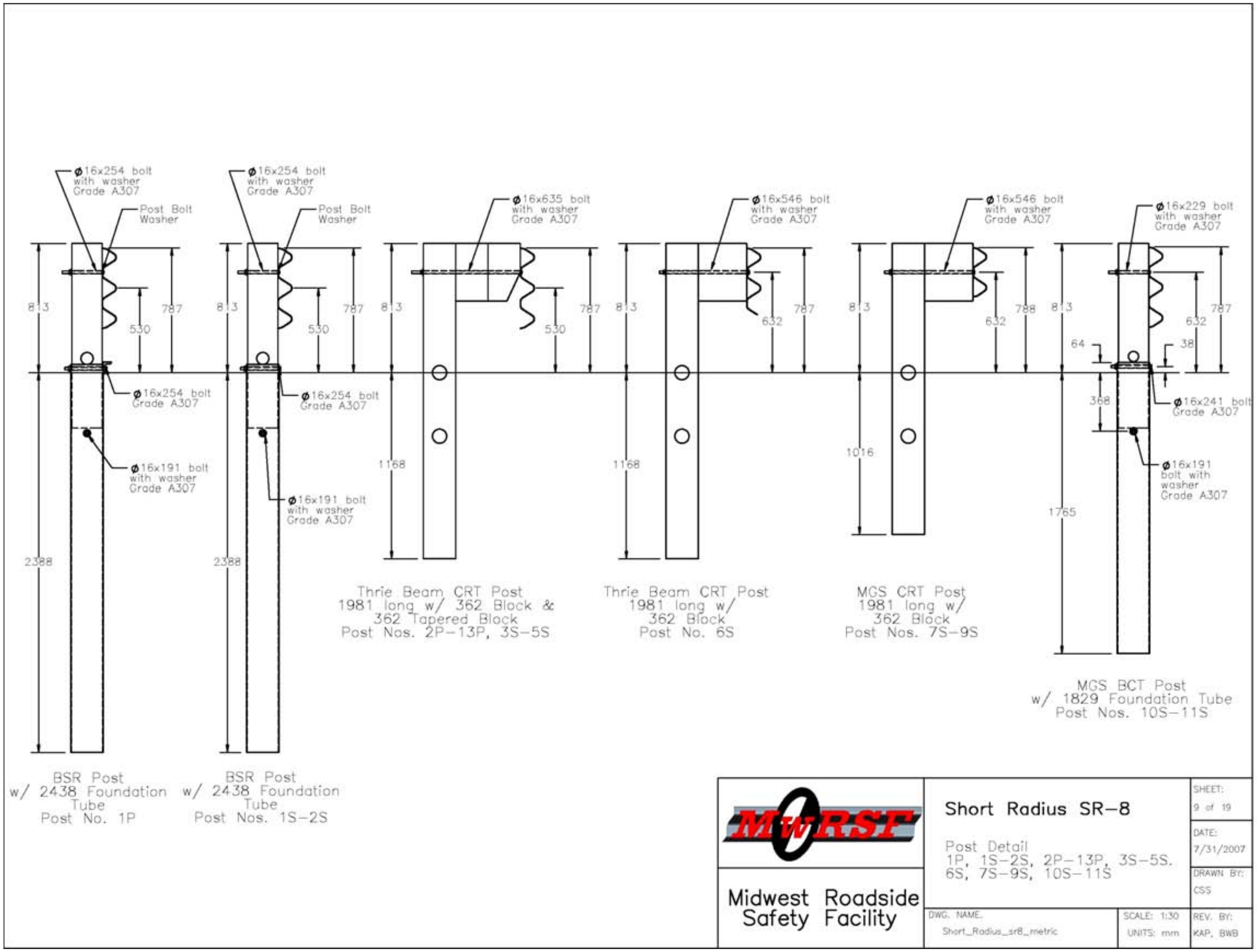


Figure E-9. Post Details

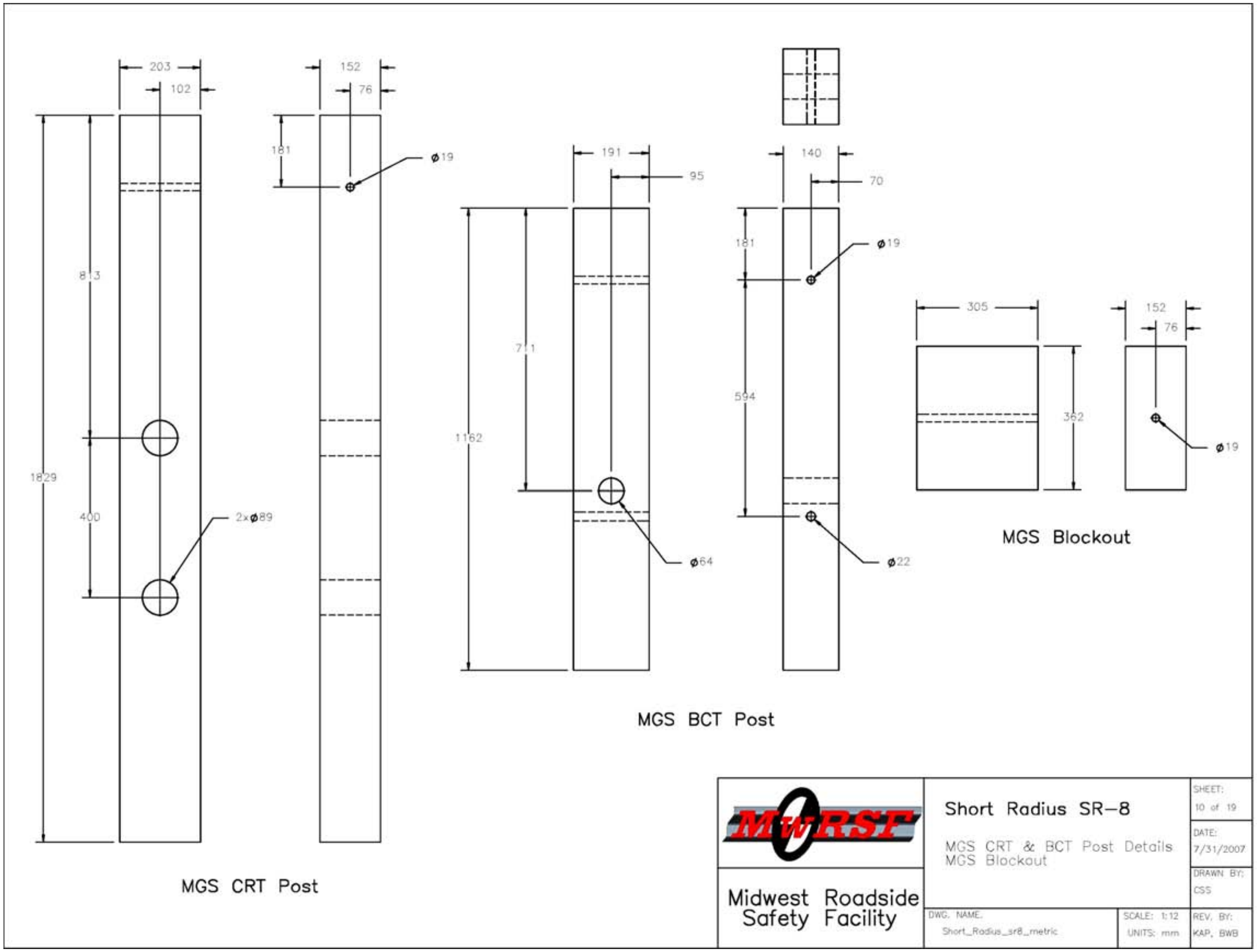


Figure E-10. MGS Post Details

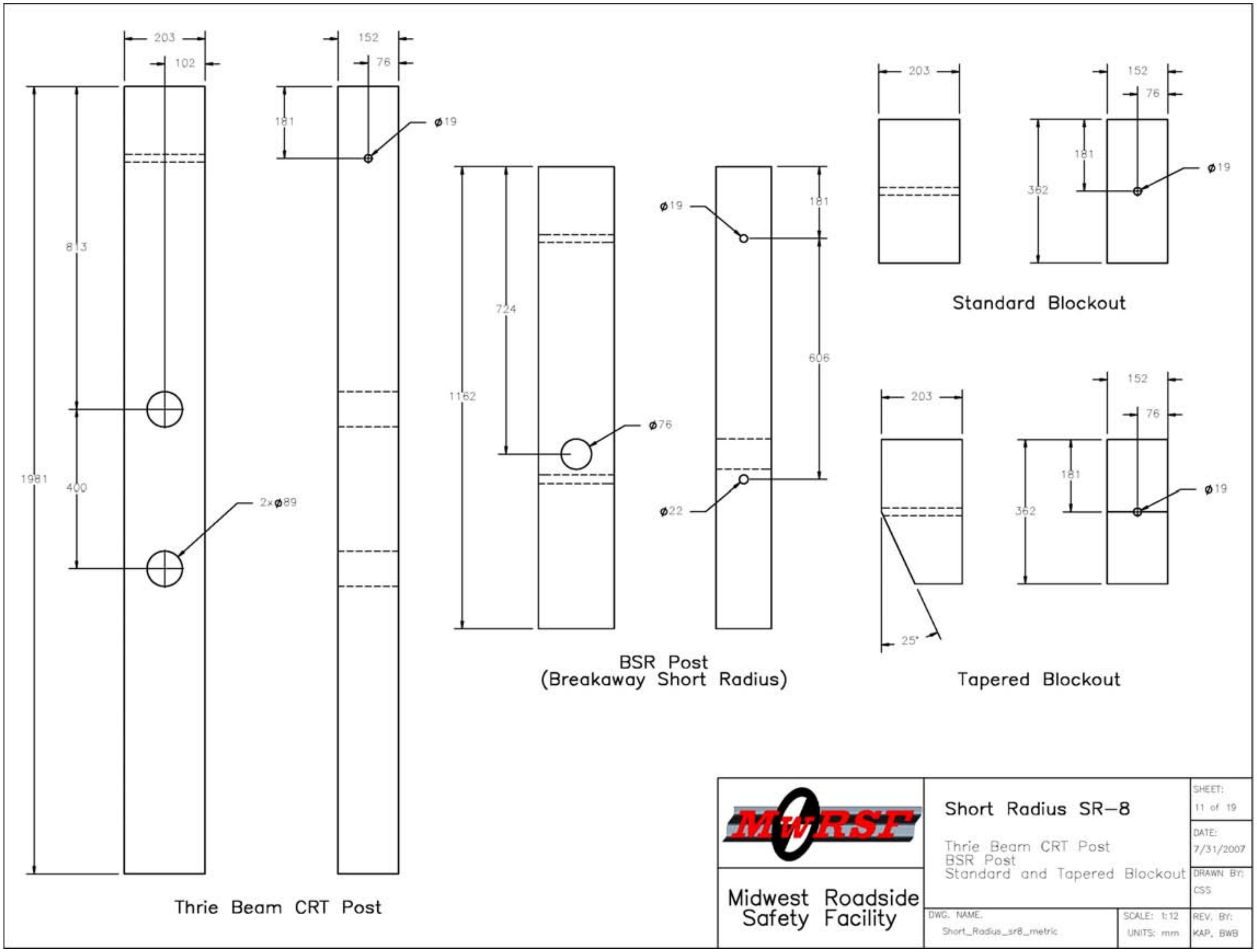


Figure E-11. Thrie Beam CRT Post and BSR Post Details

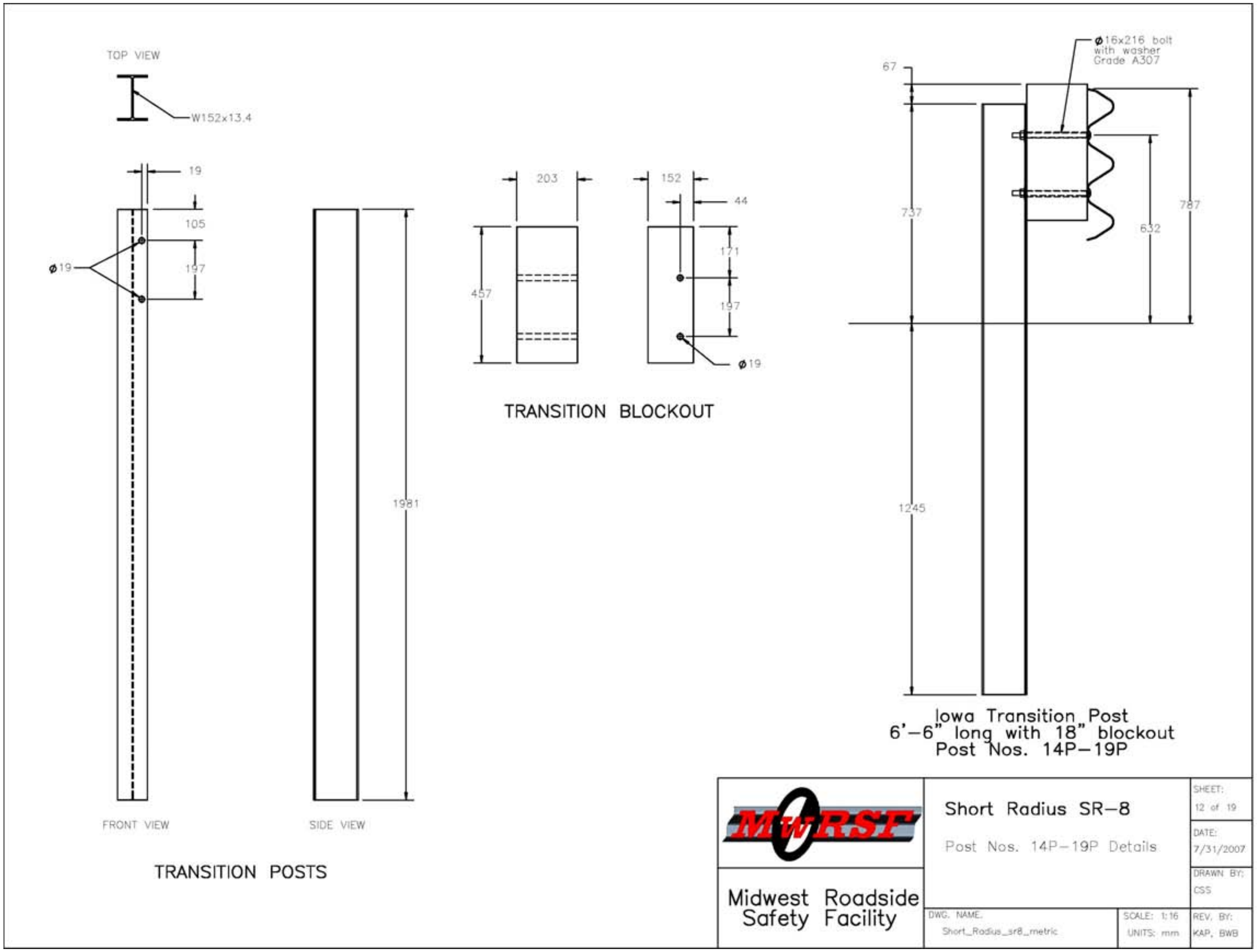


Figure E-12. Iowa Steel Post Transition

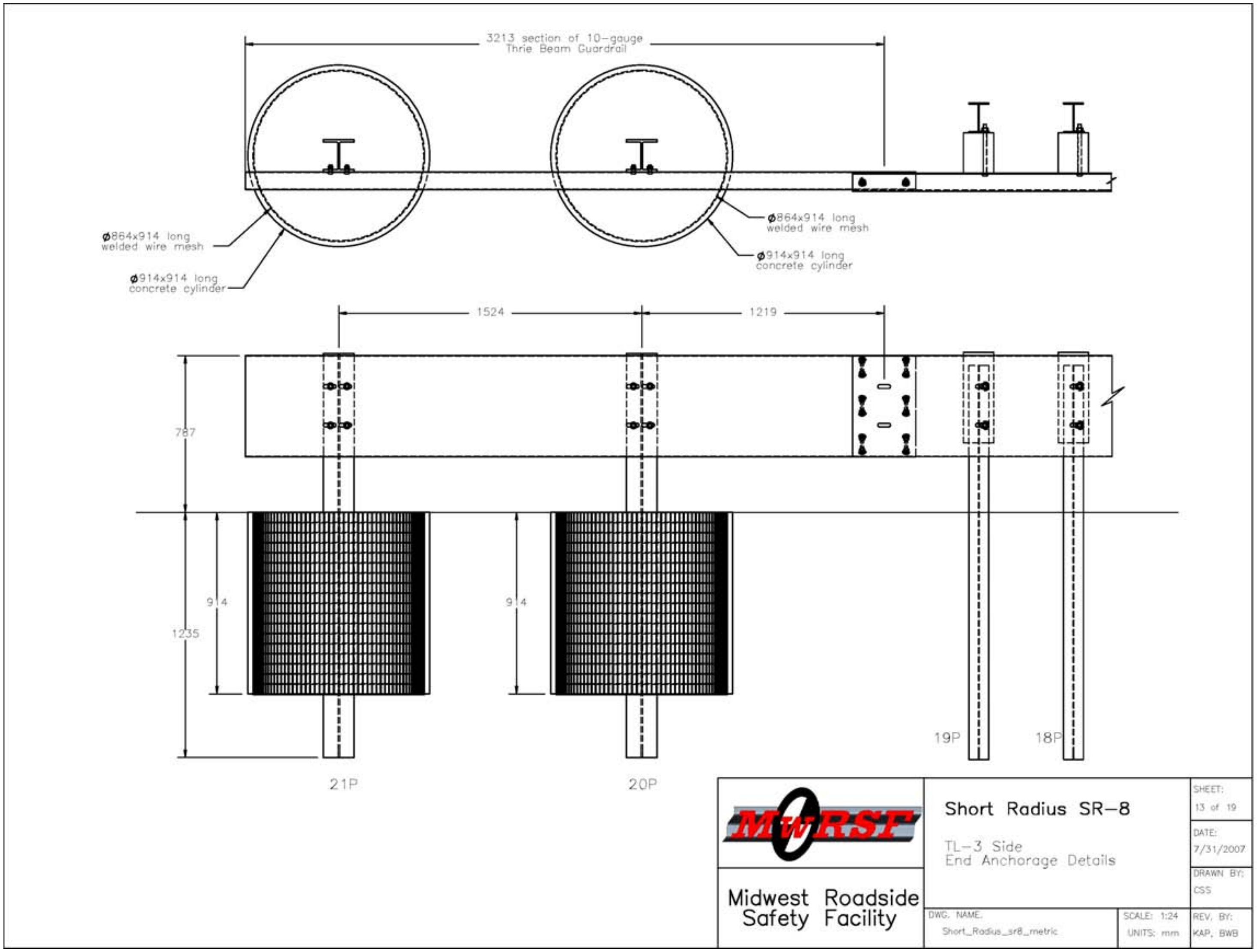


Figure E-13. Primary Side End Anchorage Details

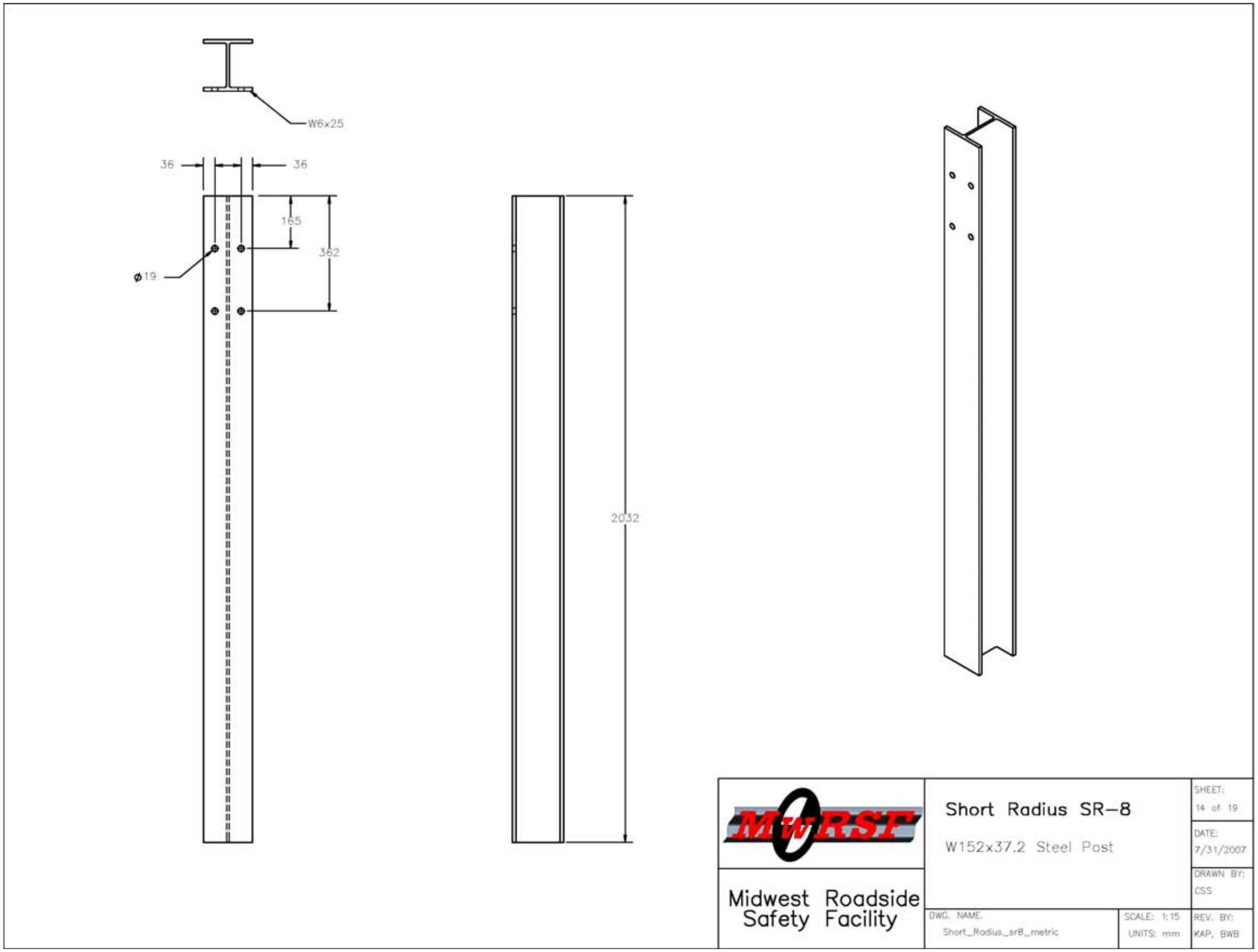


Figure E-14. Anchorage Post Details

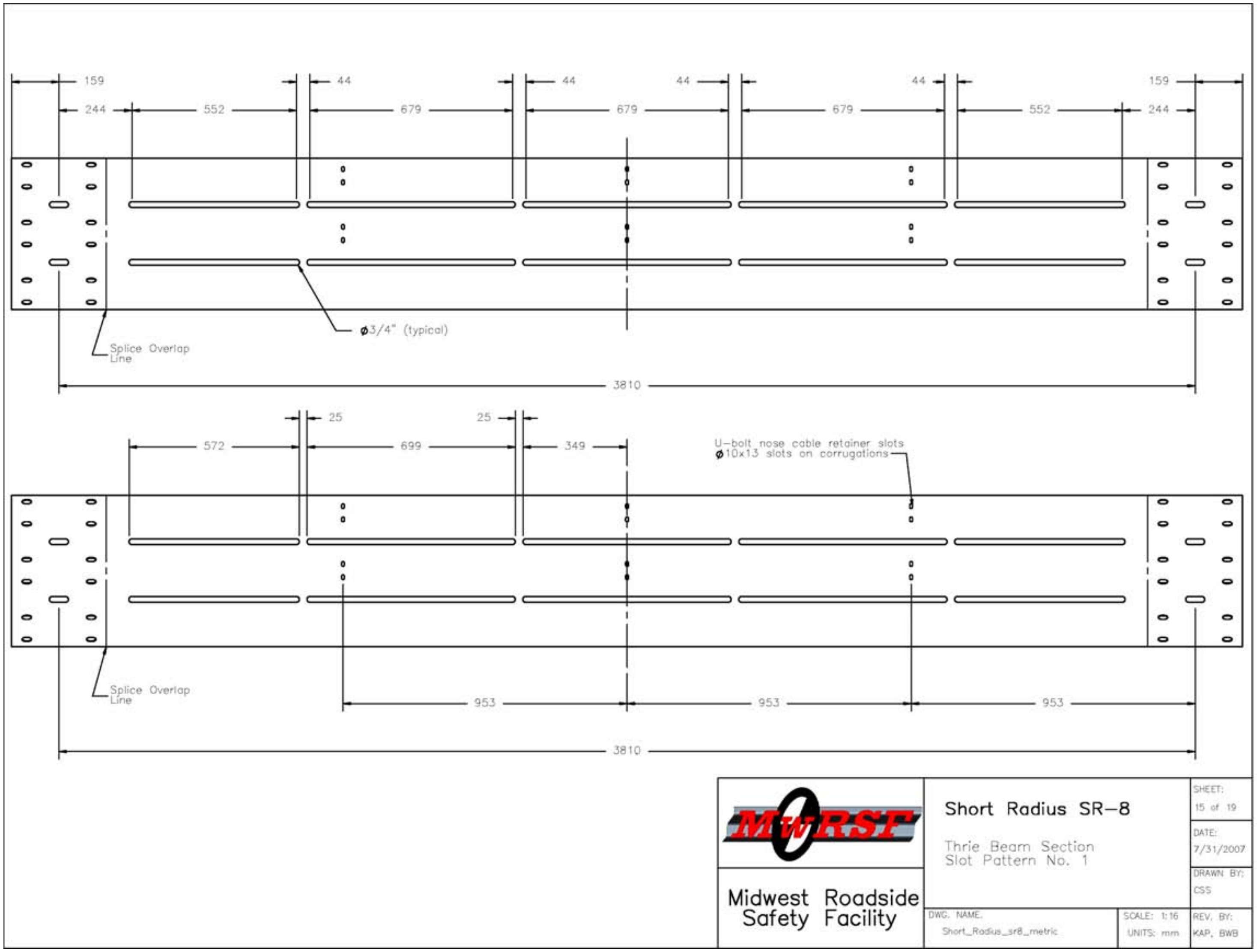


Figure E-15. Thrie Beam Section Slot Pattern No. 1

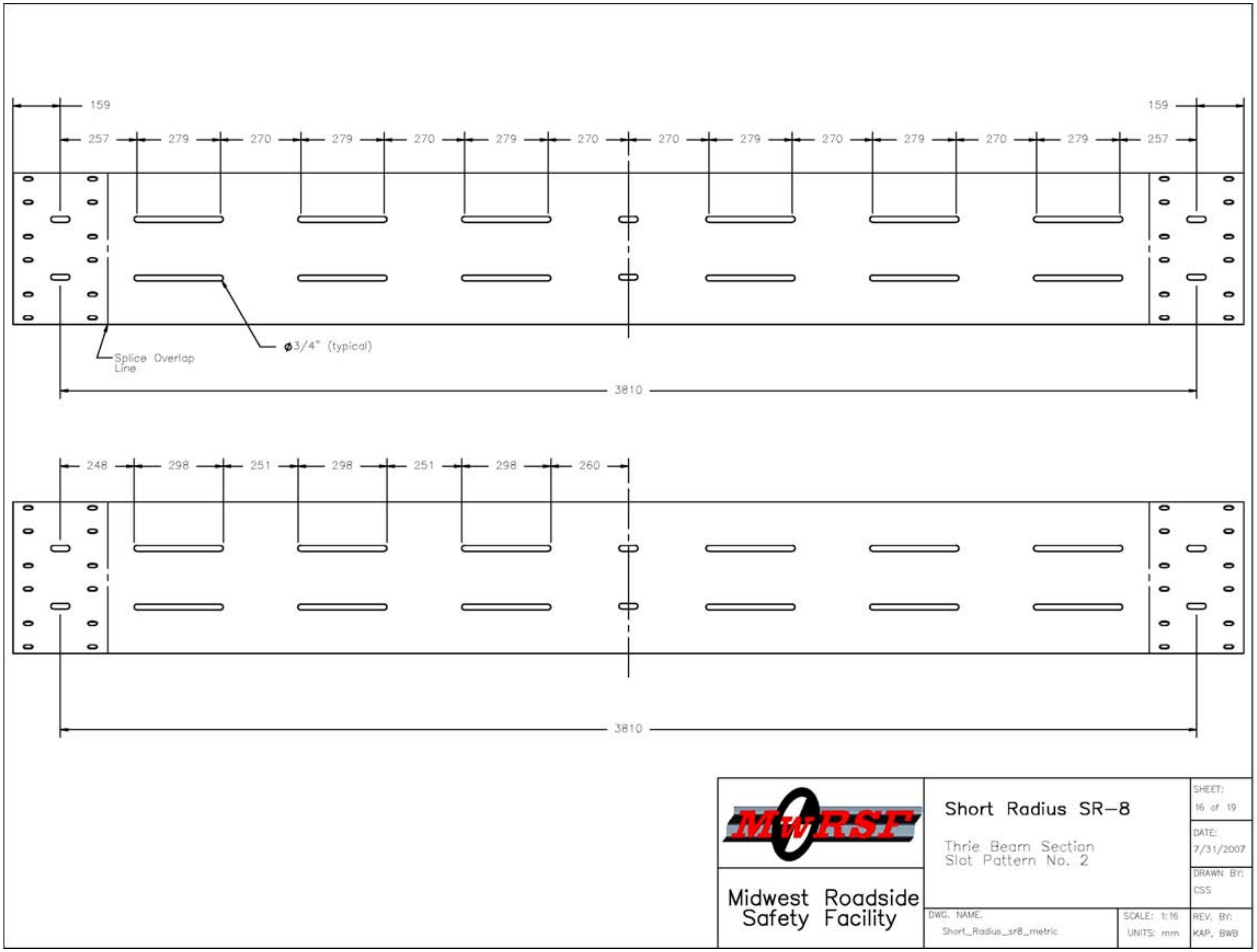


Figure E-16. Thrie Beam Section Slot Pattern No. 2

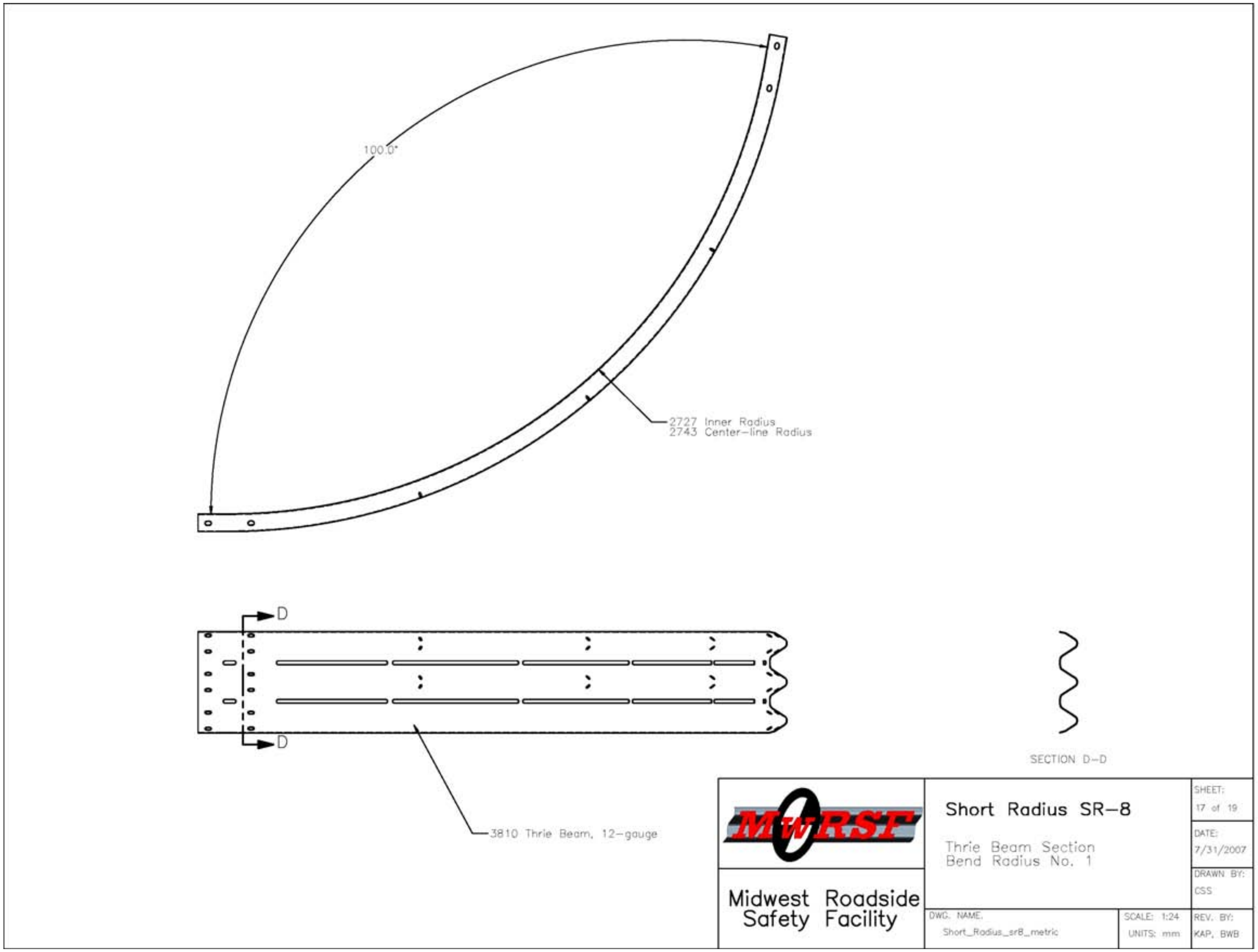


Figure E-17. Thrie Beam Section, Bend Radius No. 1

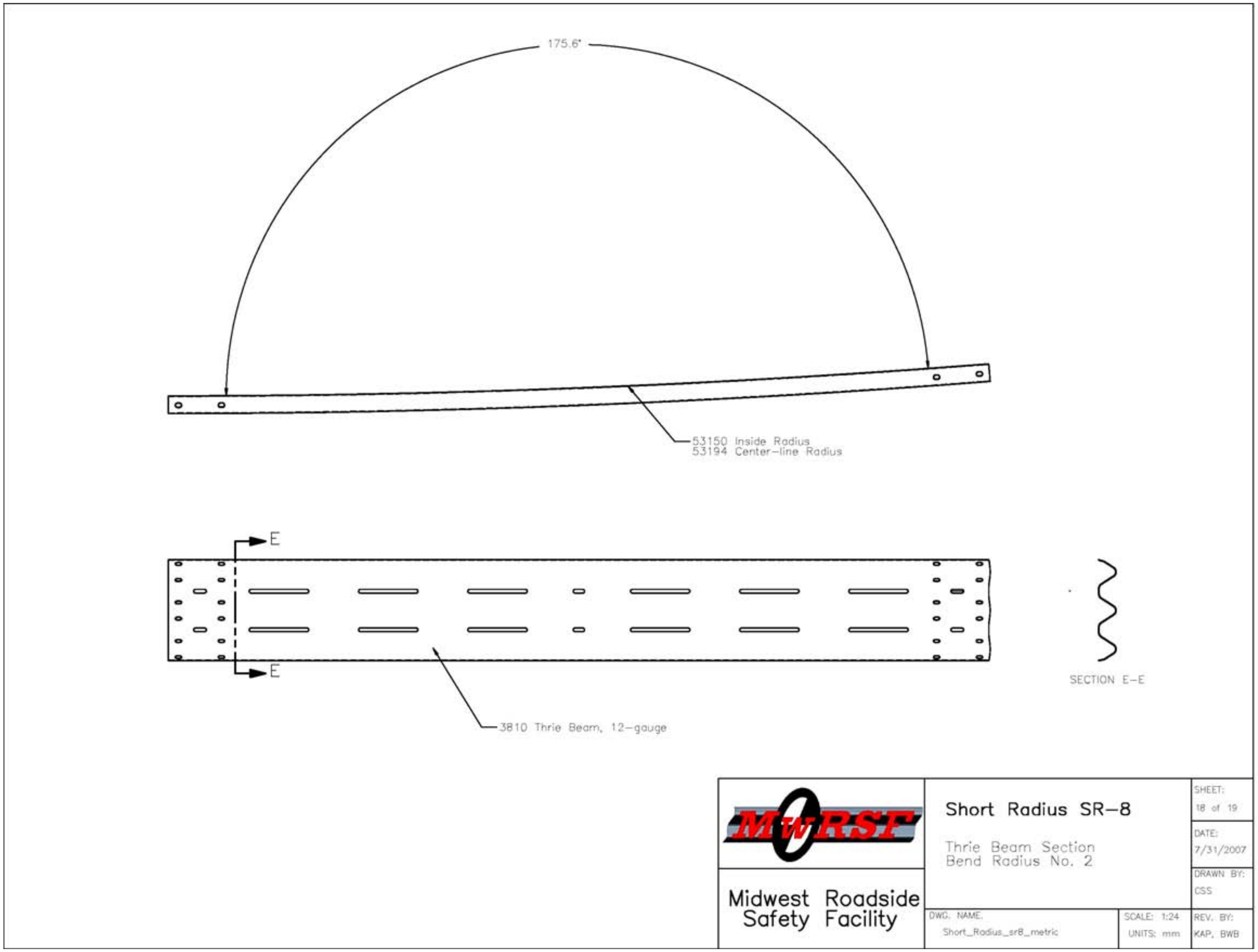


Figure E-18.Thrie Beam Section Bend Radius No. 2

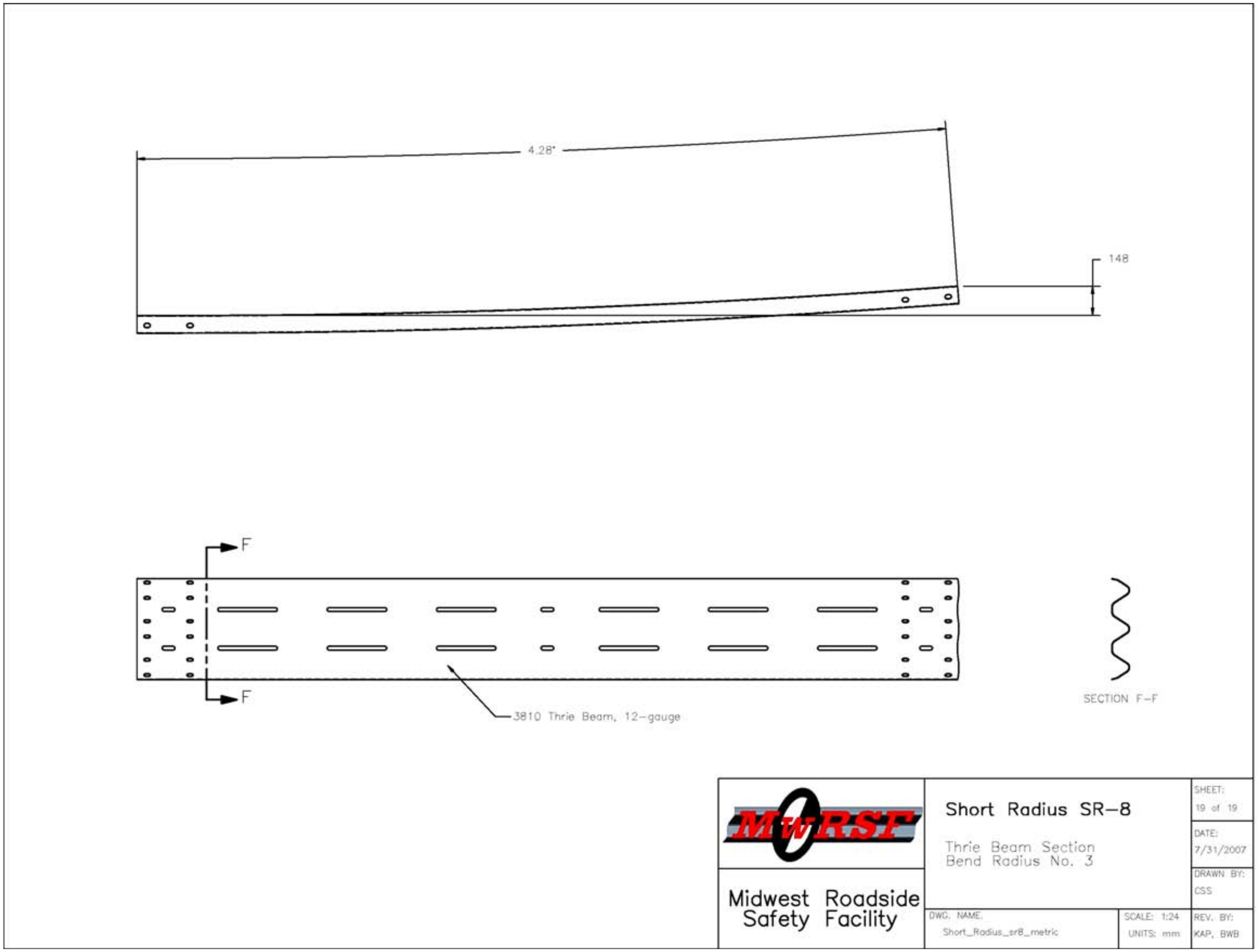


Figure E-19. Thrie Beam Section Bend Radius No. 3

APPENDIX F

System Details in English Units, Test No. SR-8

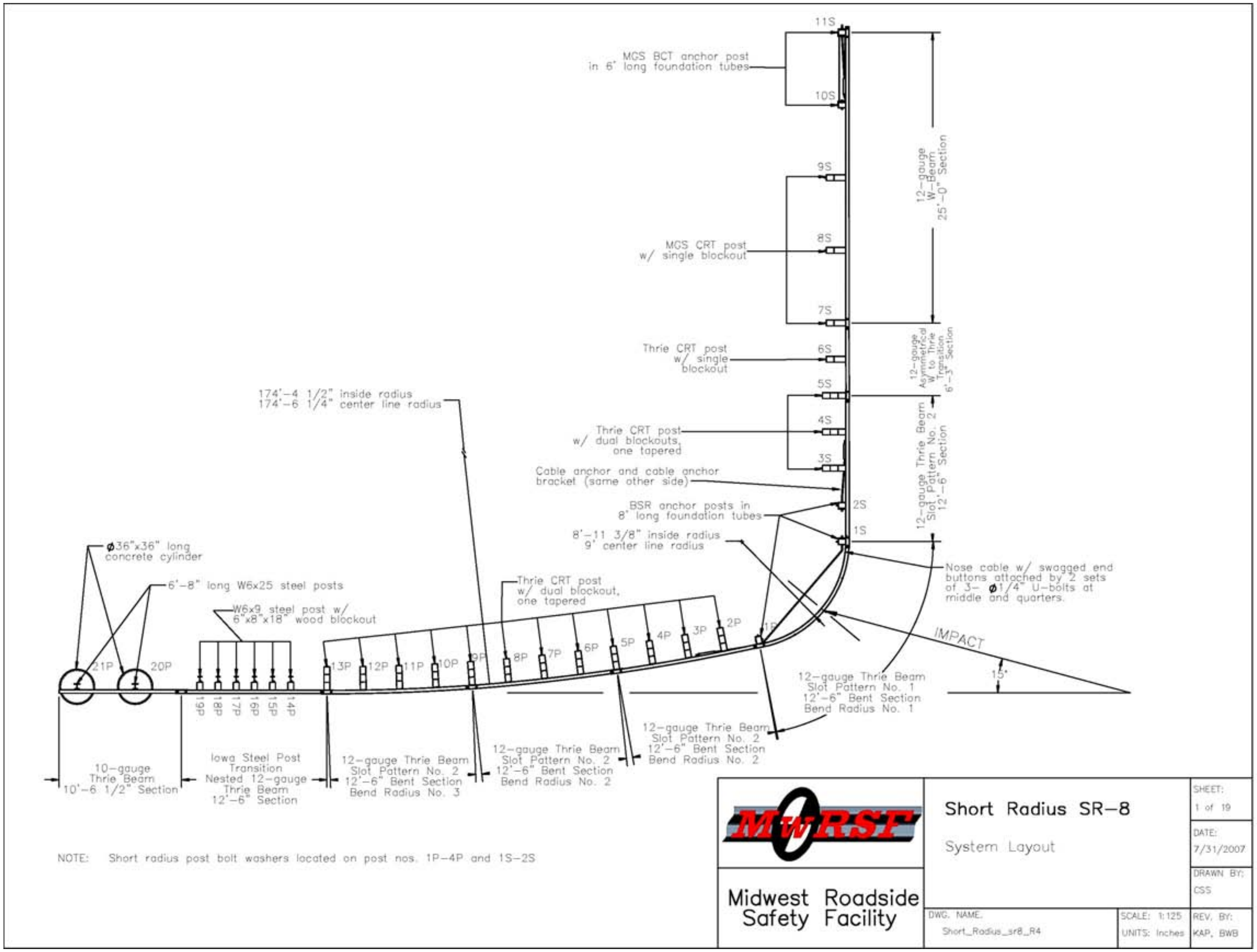


Figure F-1. System Layout (English)

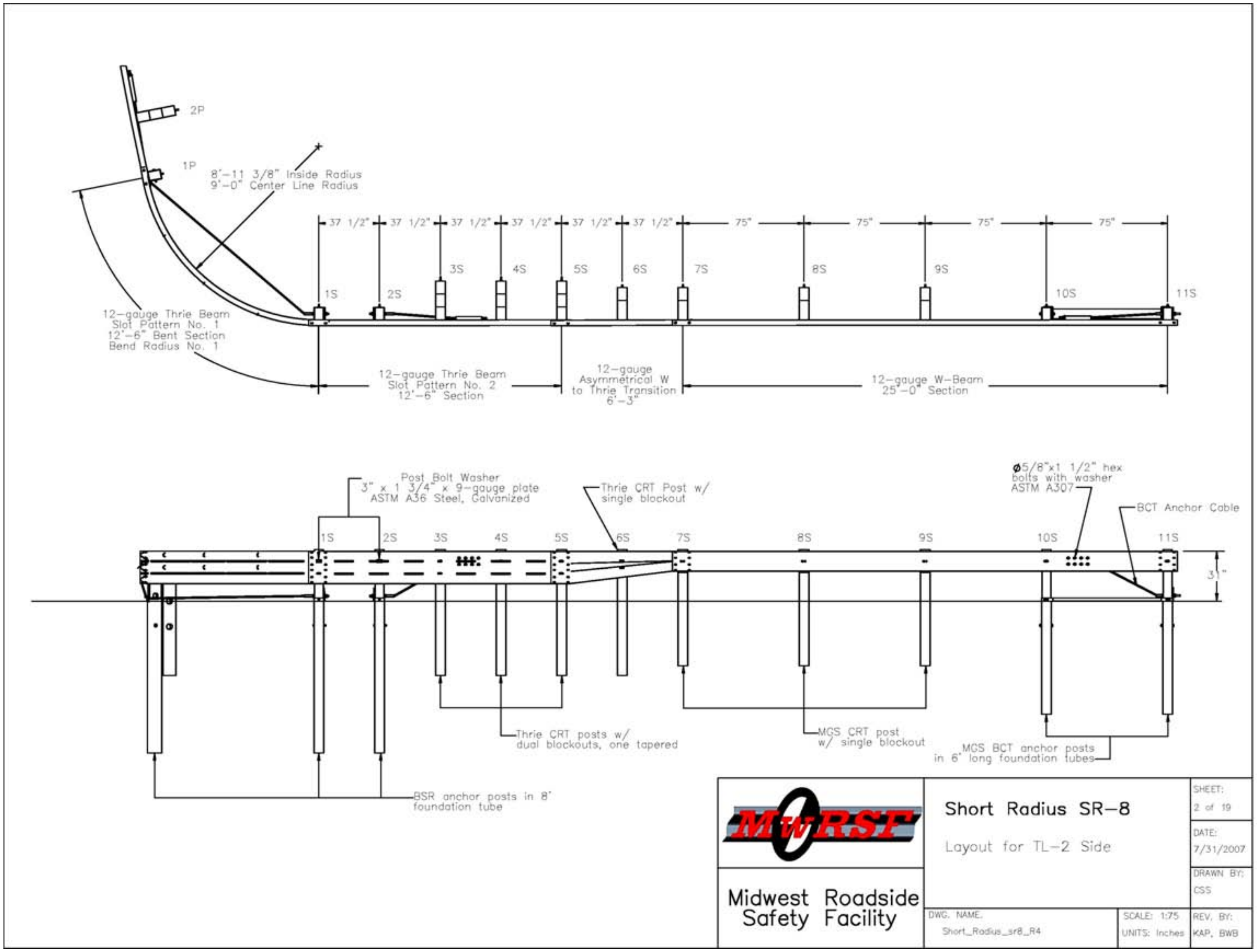


Figure F-2. Layout for Secondary Side (English)

Post No.	Front Face D.S. Edge		Front Face U.S. Edge	
	X	Y	X	Y
1P	36'–11 1/16"	3'–11 5/8"	37'–4 5/8"	4'–0 5/8"
2P	33'–7 7/8"	4'–7 5/8"	34'–1 3/4"	4'–8 13/16"
3P	30'–7 5/16"	4'–0 3/4"	31'–1 1/4"	4'–1 13/16"
4P	27'–6 9/16"	3'–6 1/2"	28'–0 1/2"	3'–7 7/16"
5P	24'–5 1/2"	3'–0 13/16"	24'–11 7/16"	3'–1 3/4"
6P	21'–4 15/16"	2'–7 15/16"	21'–10 7/8"	2'–8 11/16"
7P	18'–3 11/16"	2'–3 5/8"	18'–9 5/8"	2'–4 3/8"
8P	15'–2 7/8"	2'–0 1/16"	15'–8 7/8"	2'–0 5/8"
9P	12'–1 11/16"	1'–9 1/8"	12'–7 11/16"	1'–9 9/16"
10P	9'–0 9/16"	1'–6 13/16"	9'–6 9/16"	1'–7 3/16"
11P	5'–11 1/2"	1'–5 1/4"	6'–5 1/2"	1'–5 7/16"
12P	2'–10 1/4"	1'–4 1/4"	3'–4 1/4"	1'–4 3/8"
13P	–0'–3"	1'–4"	0'–3"	1'–4"

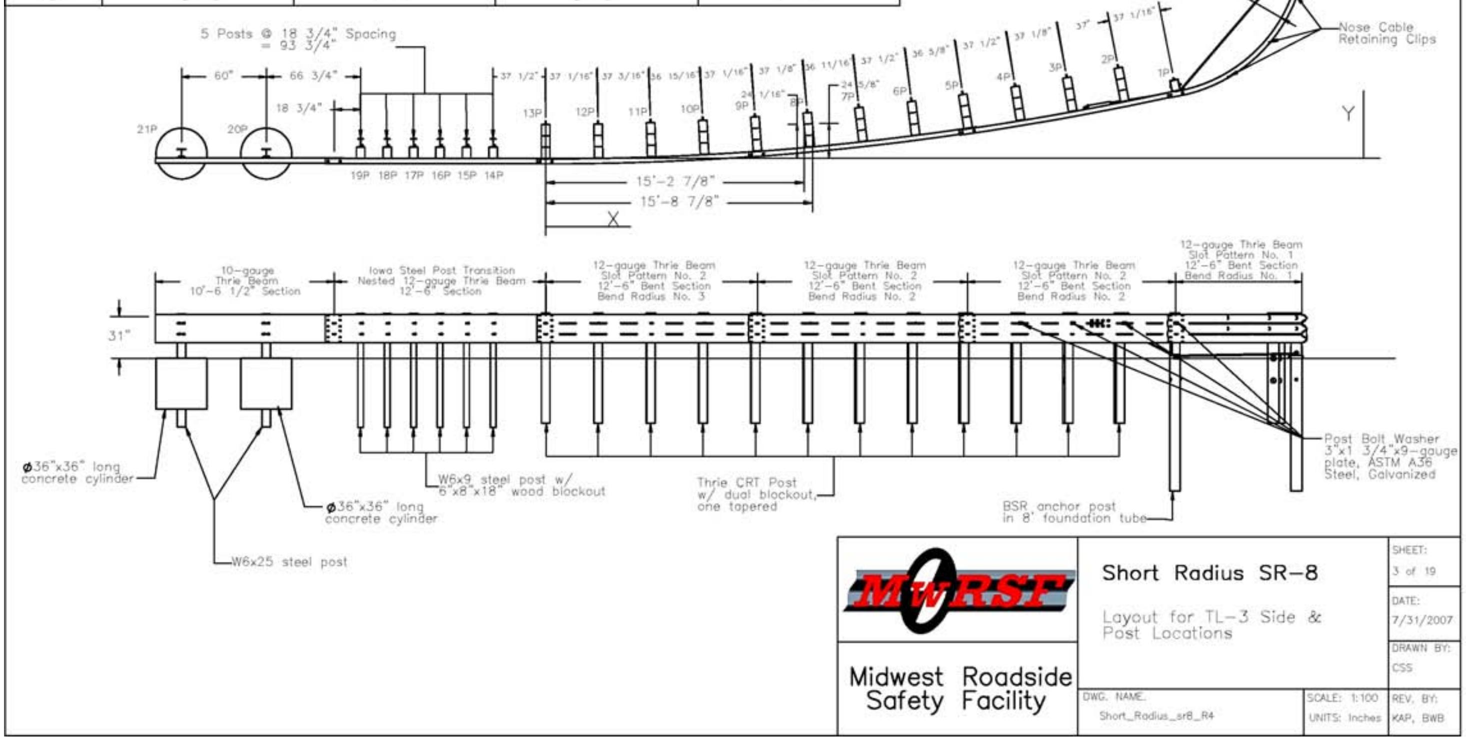


Figure F-3. Layout for Primary Side and Post Locations (English)

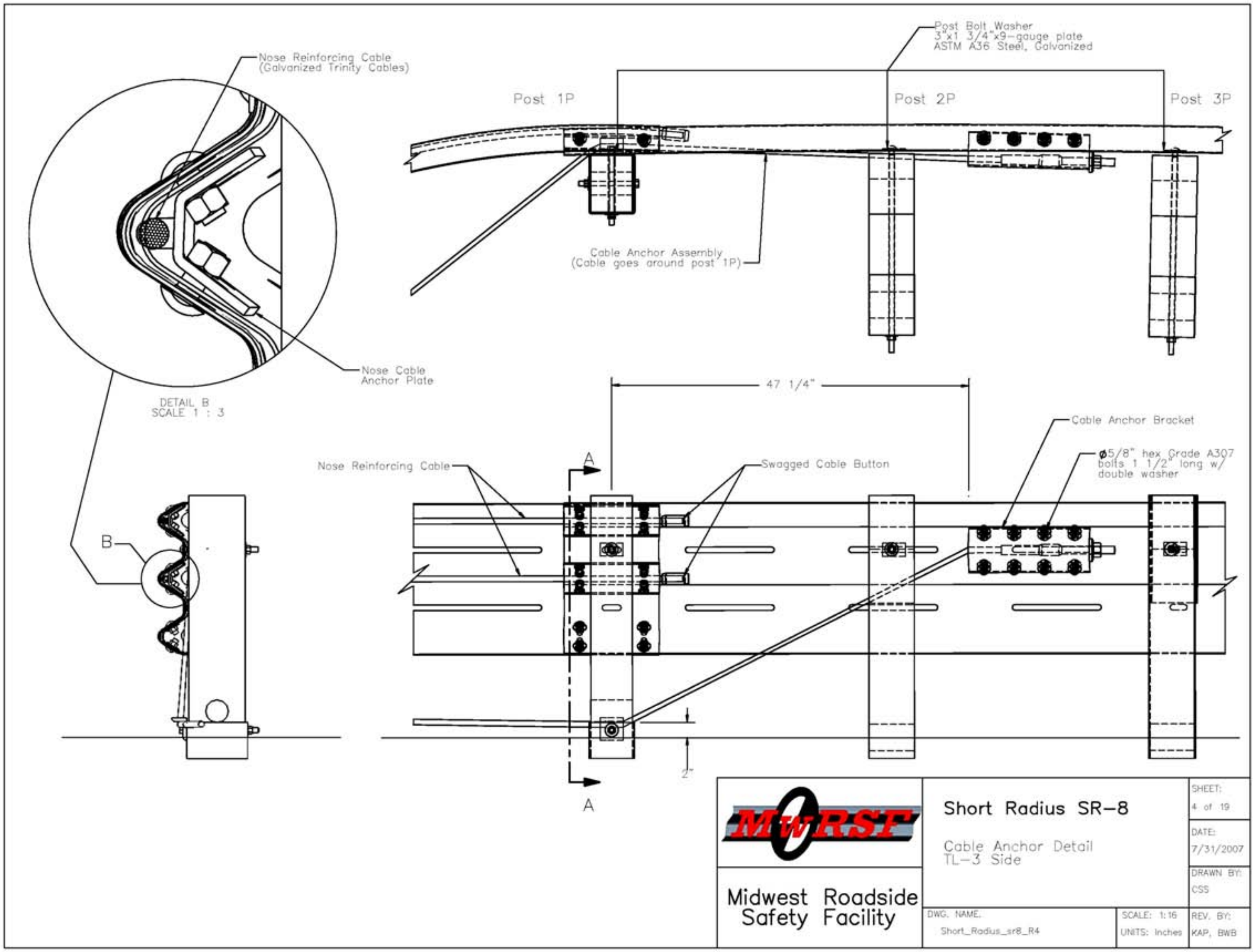


Figure F-4. Cable Anchor Detail, Primary Side (English)

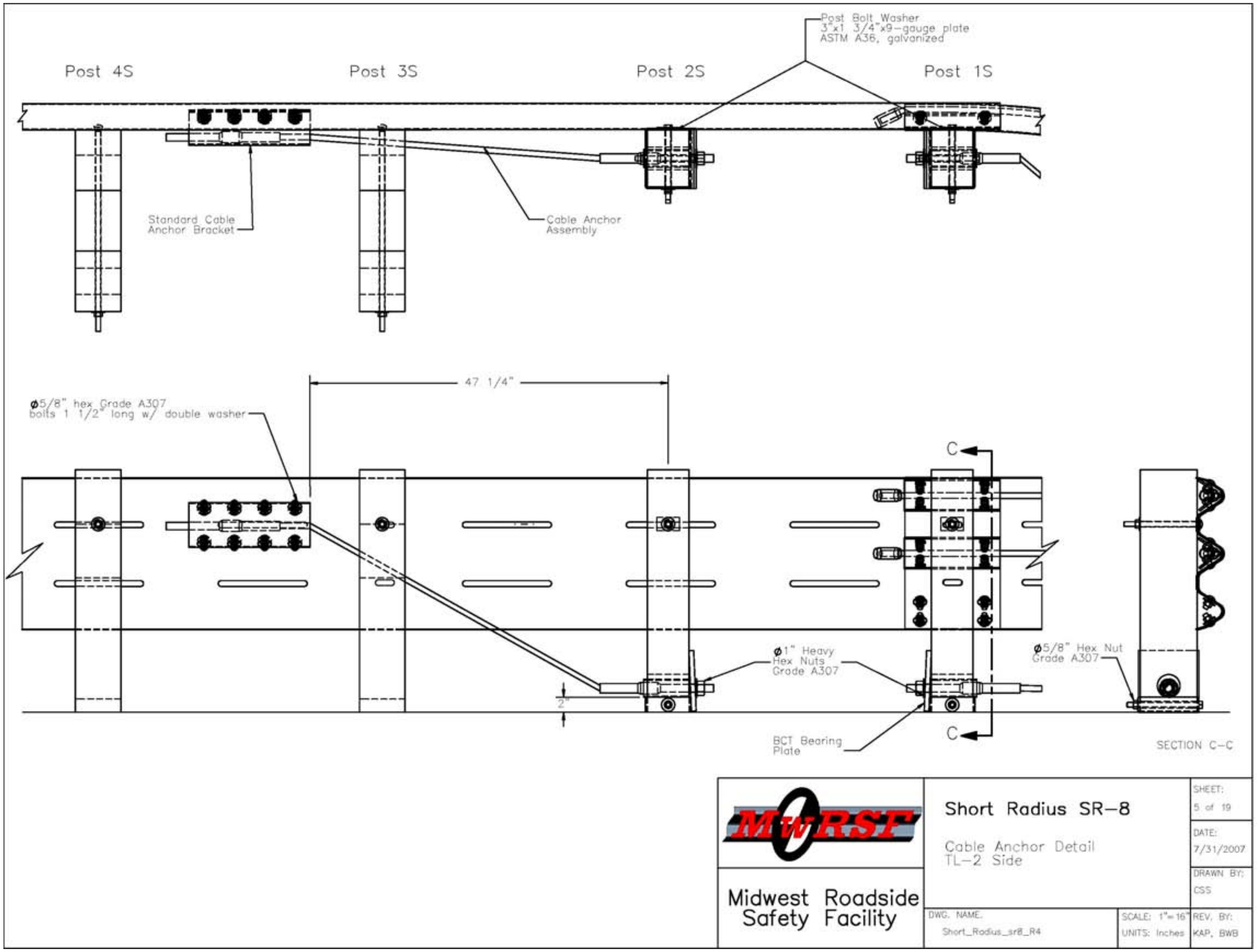


Figure F-5. Cable Anchor Detail, Secondary Side (English)

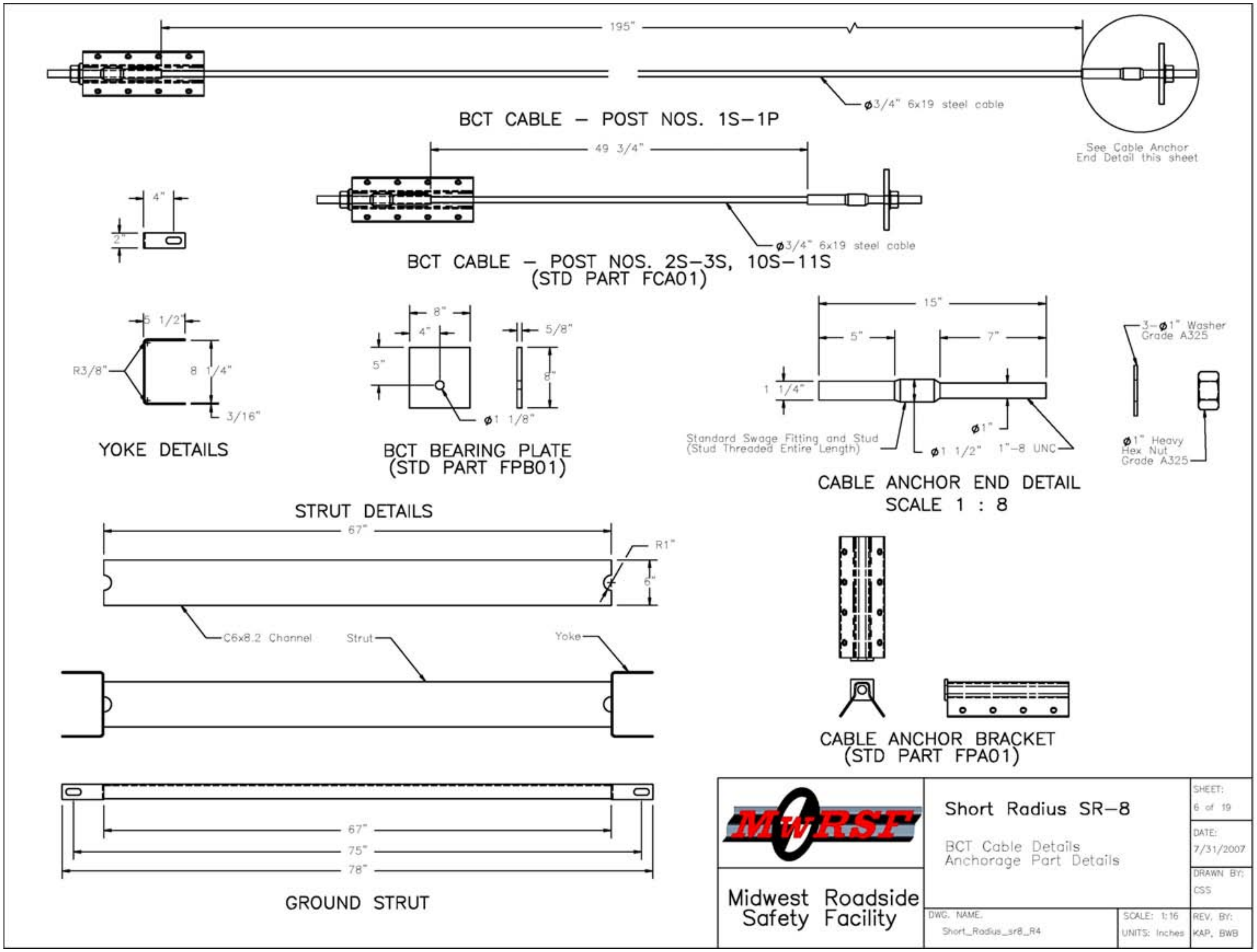


Figure F-6. BCT Cable Detail and Anchorage Part Details (English)

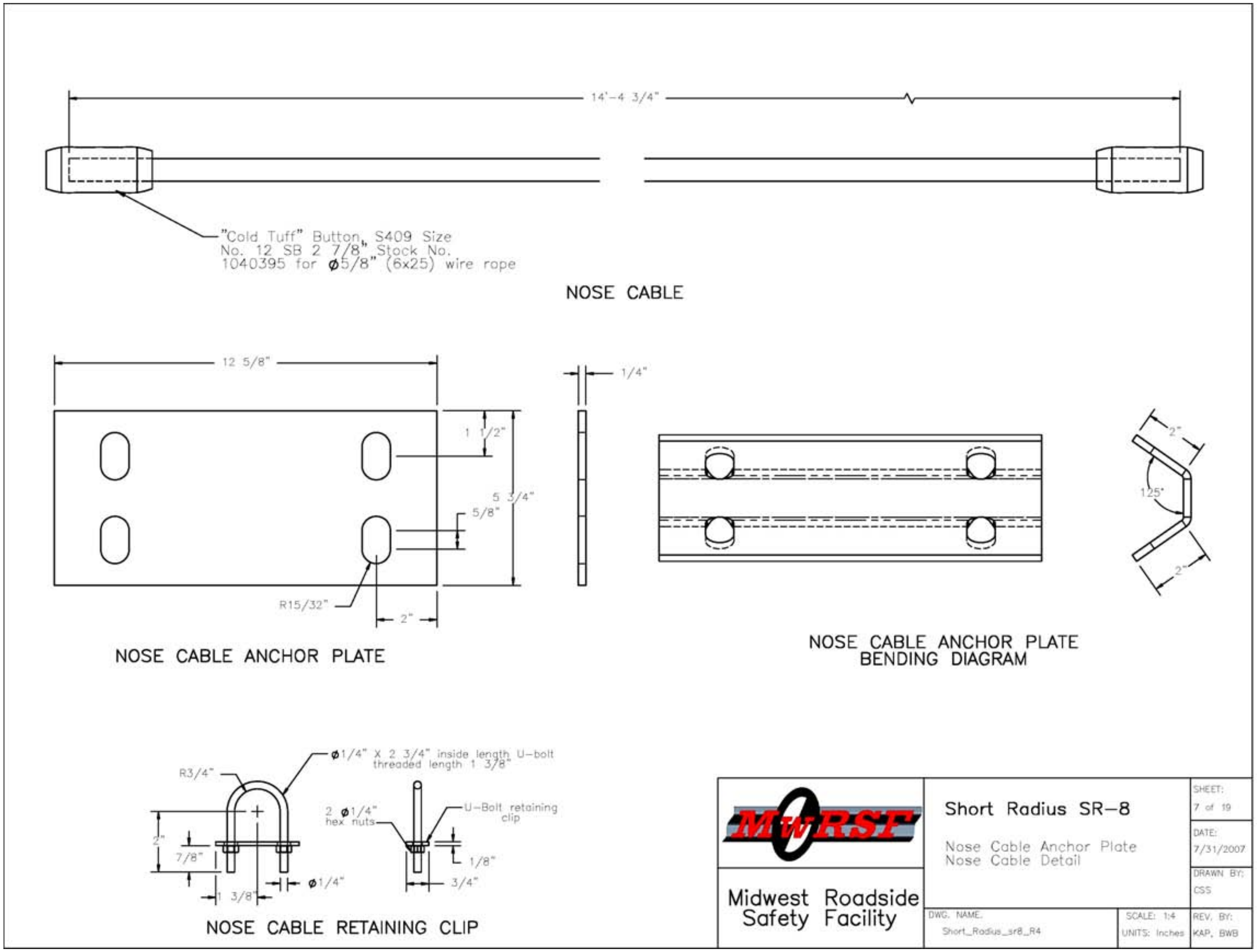


Figure F-7. Nose Cable Anchor Plate and Nose Cable Detail (English)

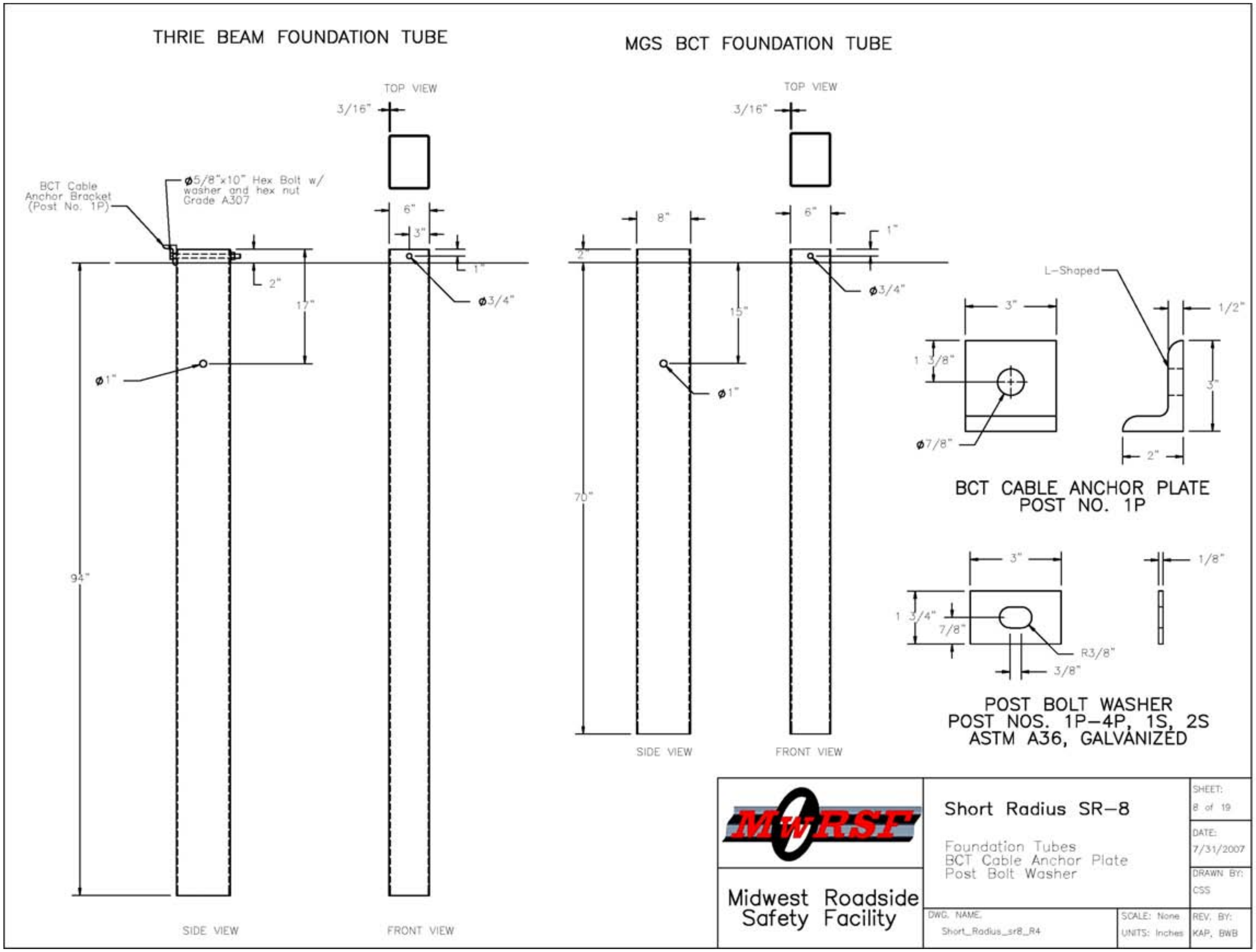


Figure F-8. MGS Foundation Tube and Thrie Beam Foundation Tube Details (English)

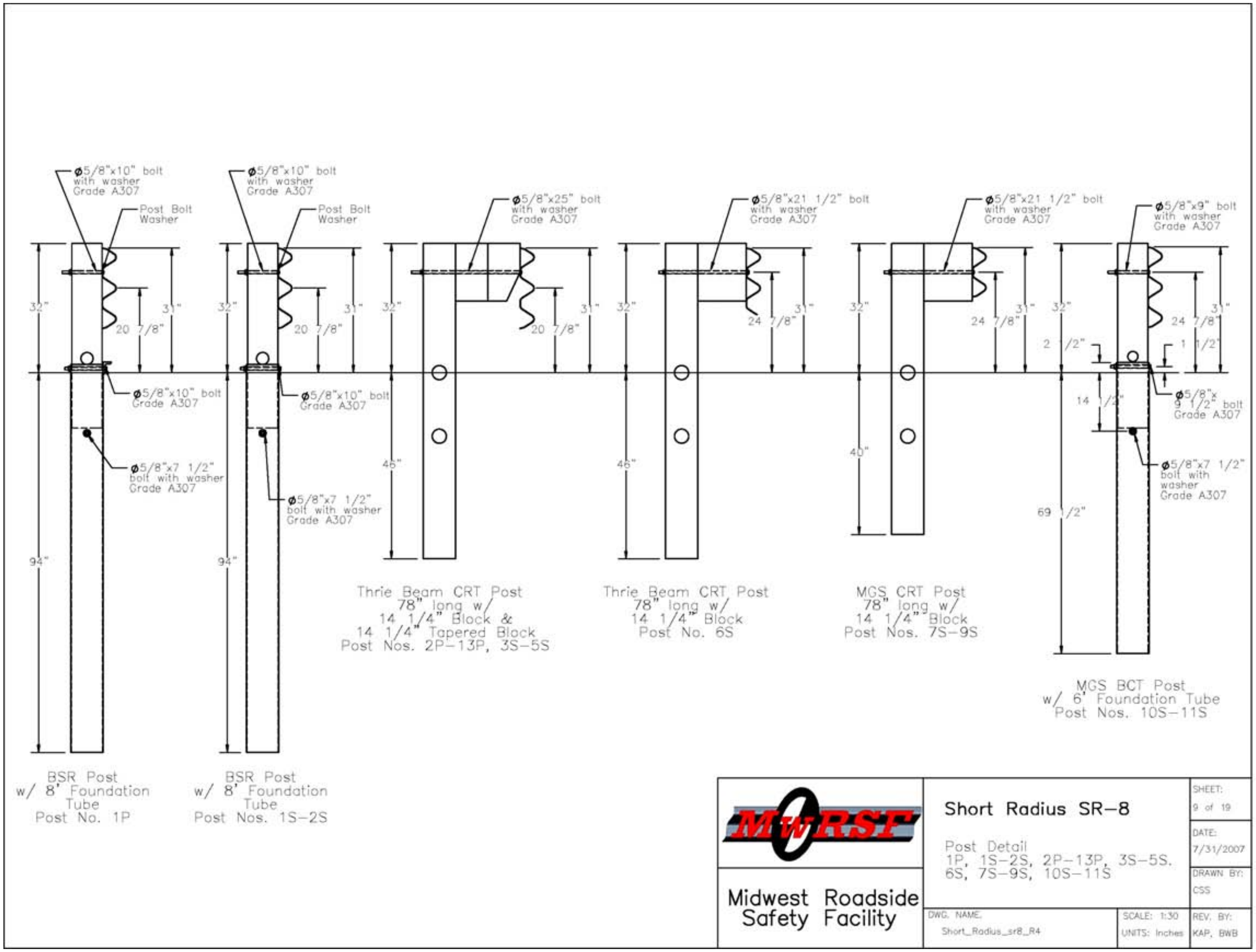


Figure F-9. Post Details (English)

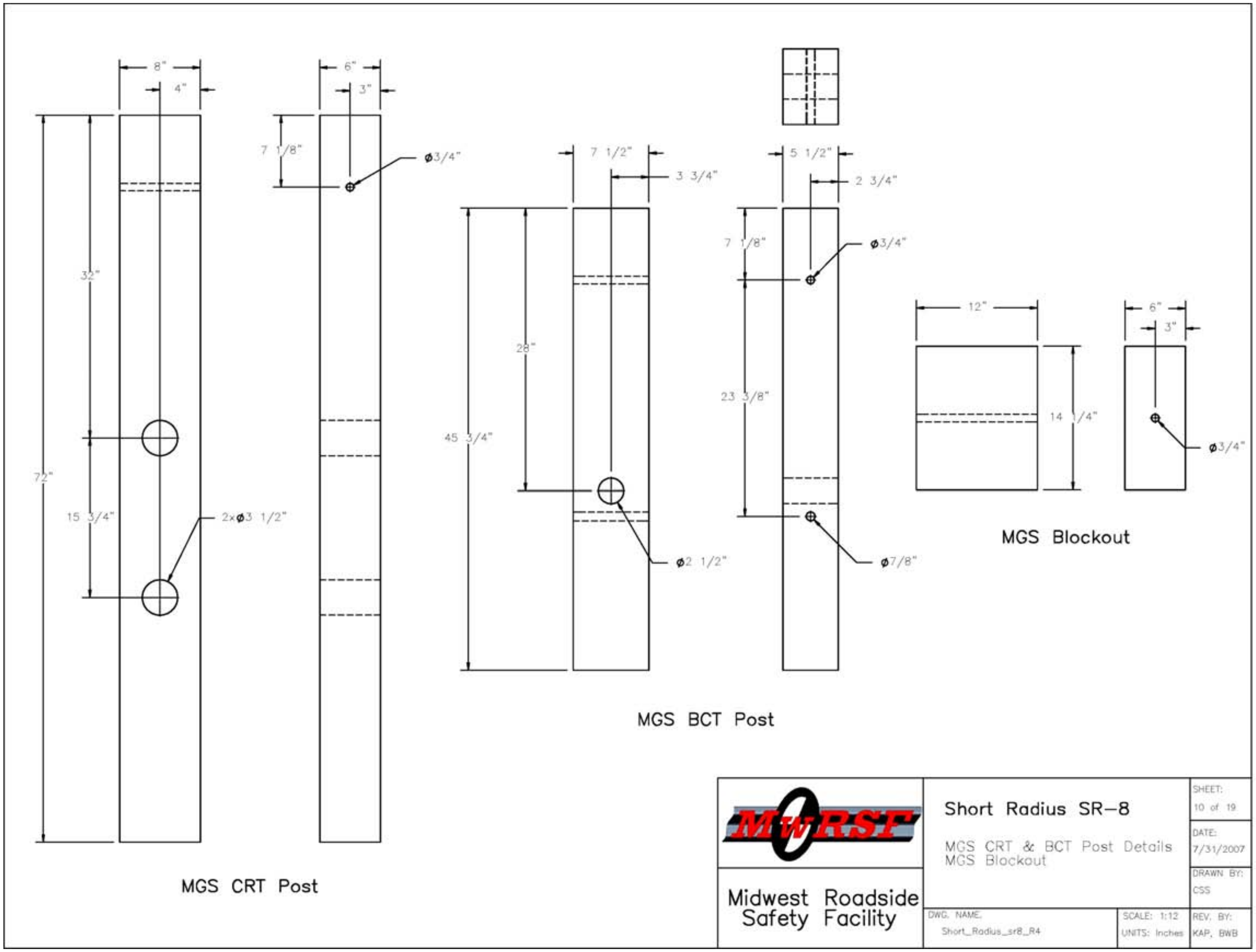


Figure F-10. MGS Post Details (English)

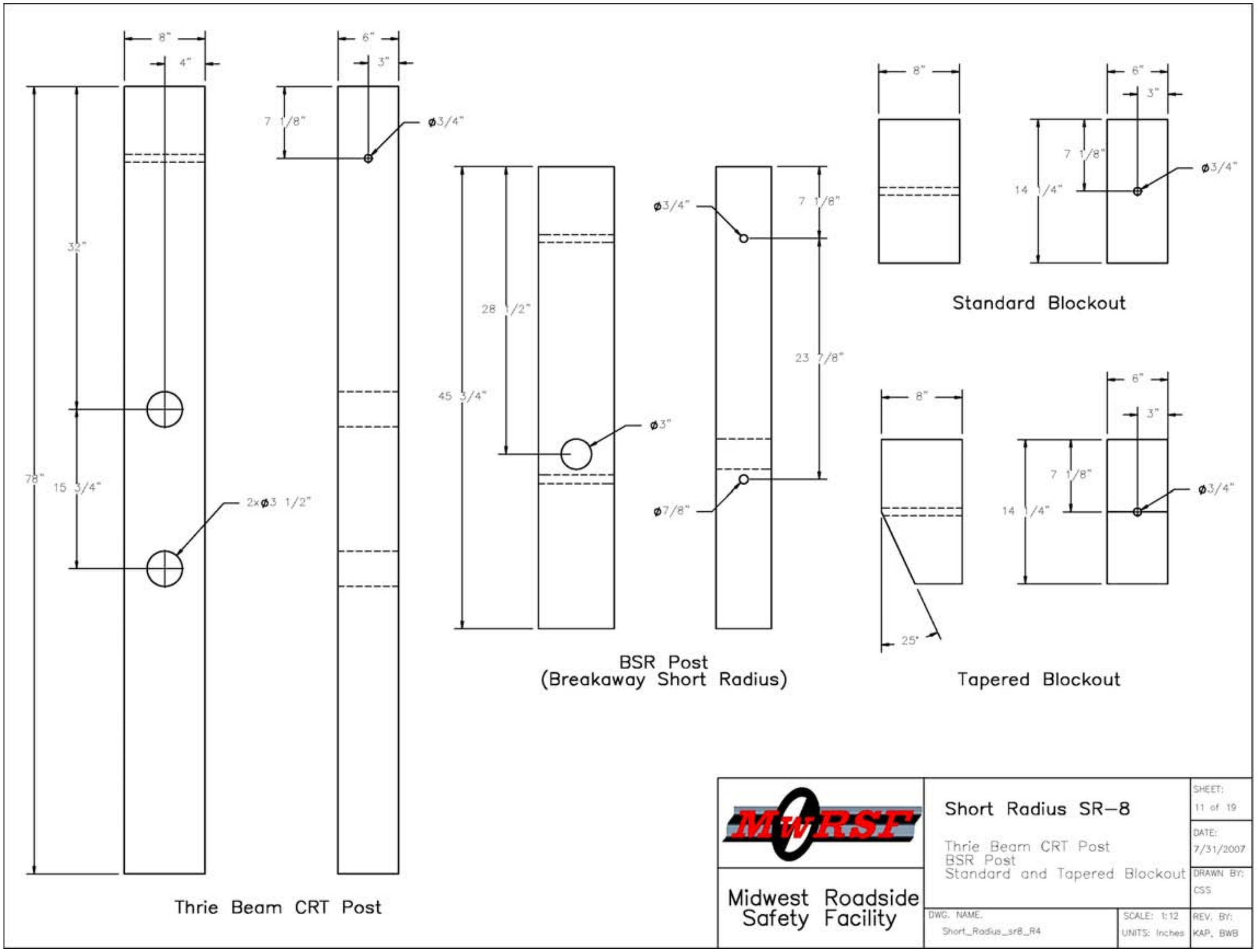


Figure F-11. Thrie Beam CRT and BSR Post Details (English)

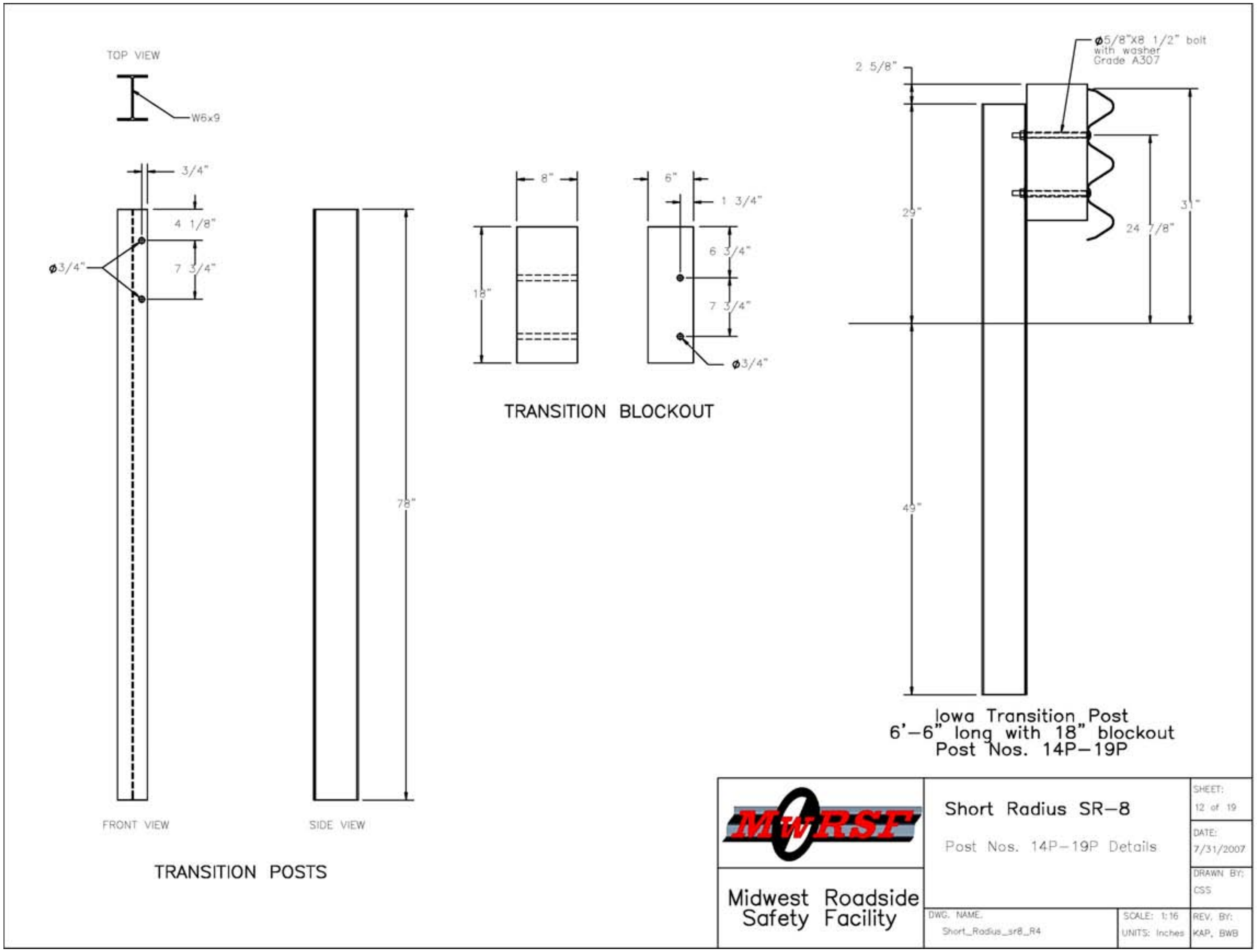


Figure F-12. Iowa Steel Post Transition (English)

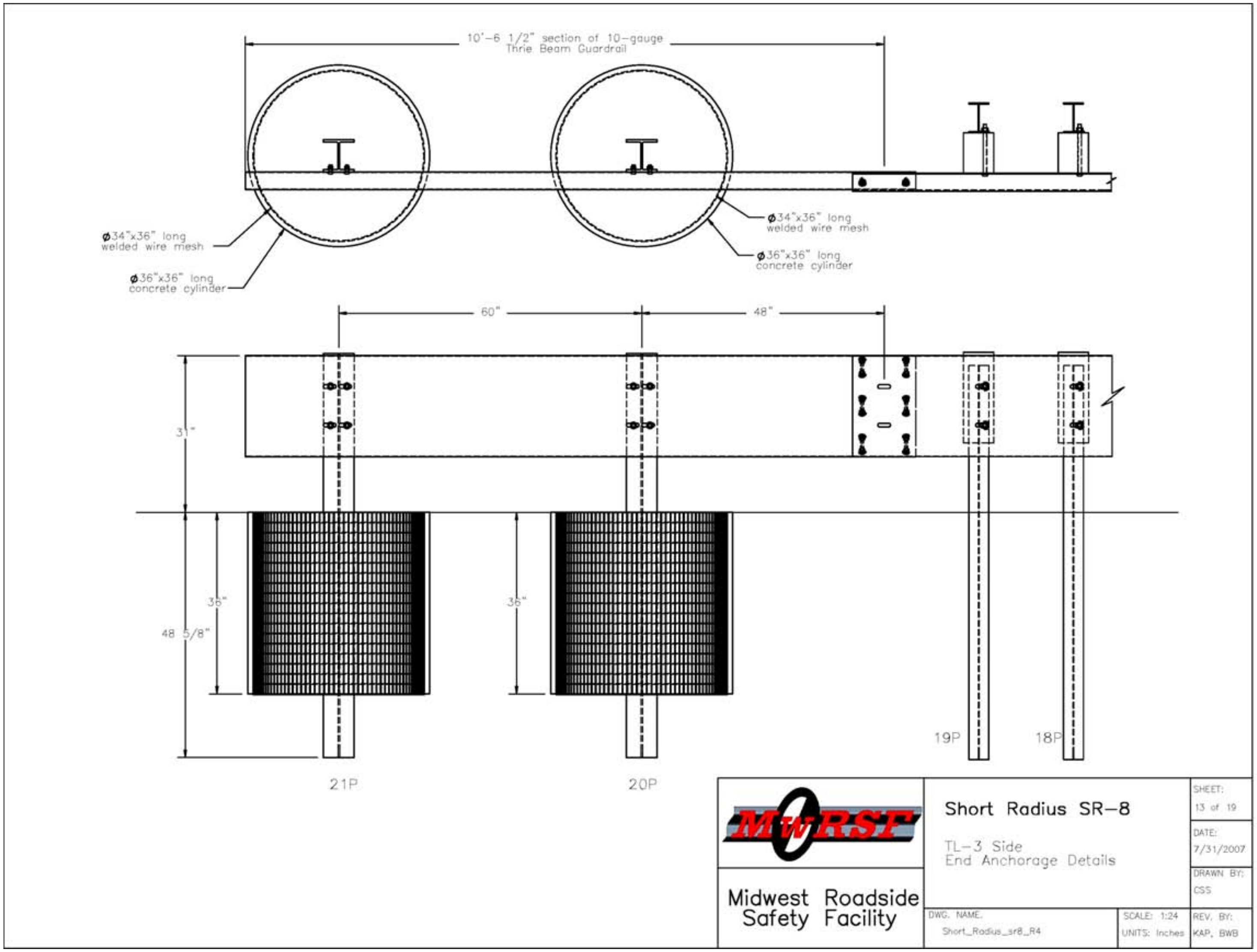


Figure F-13. Primary Side End Anchorage Details (English)

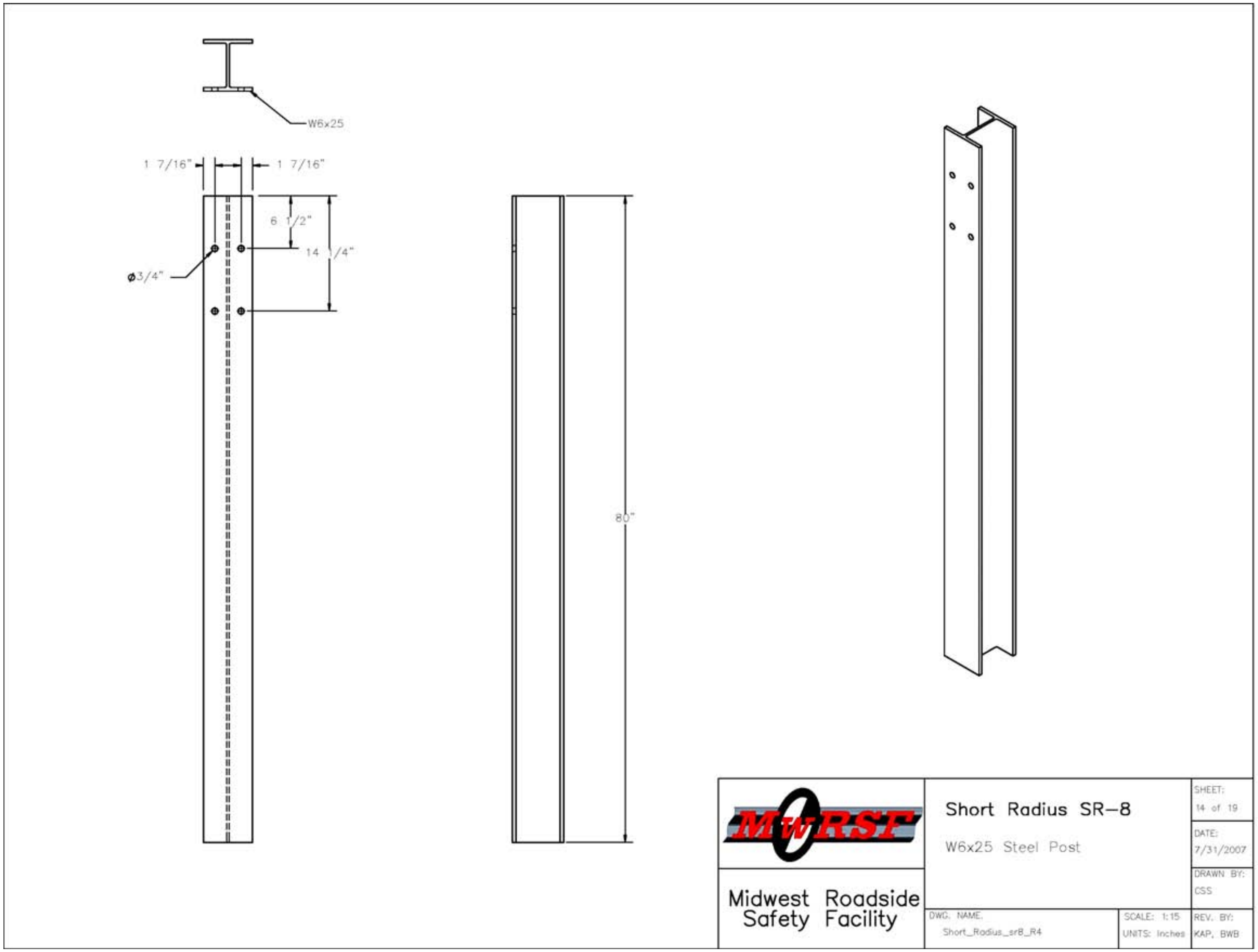


Figure F-14. Anchorage Post Details (English)

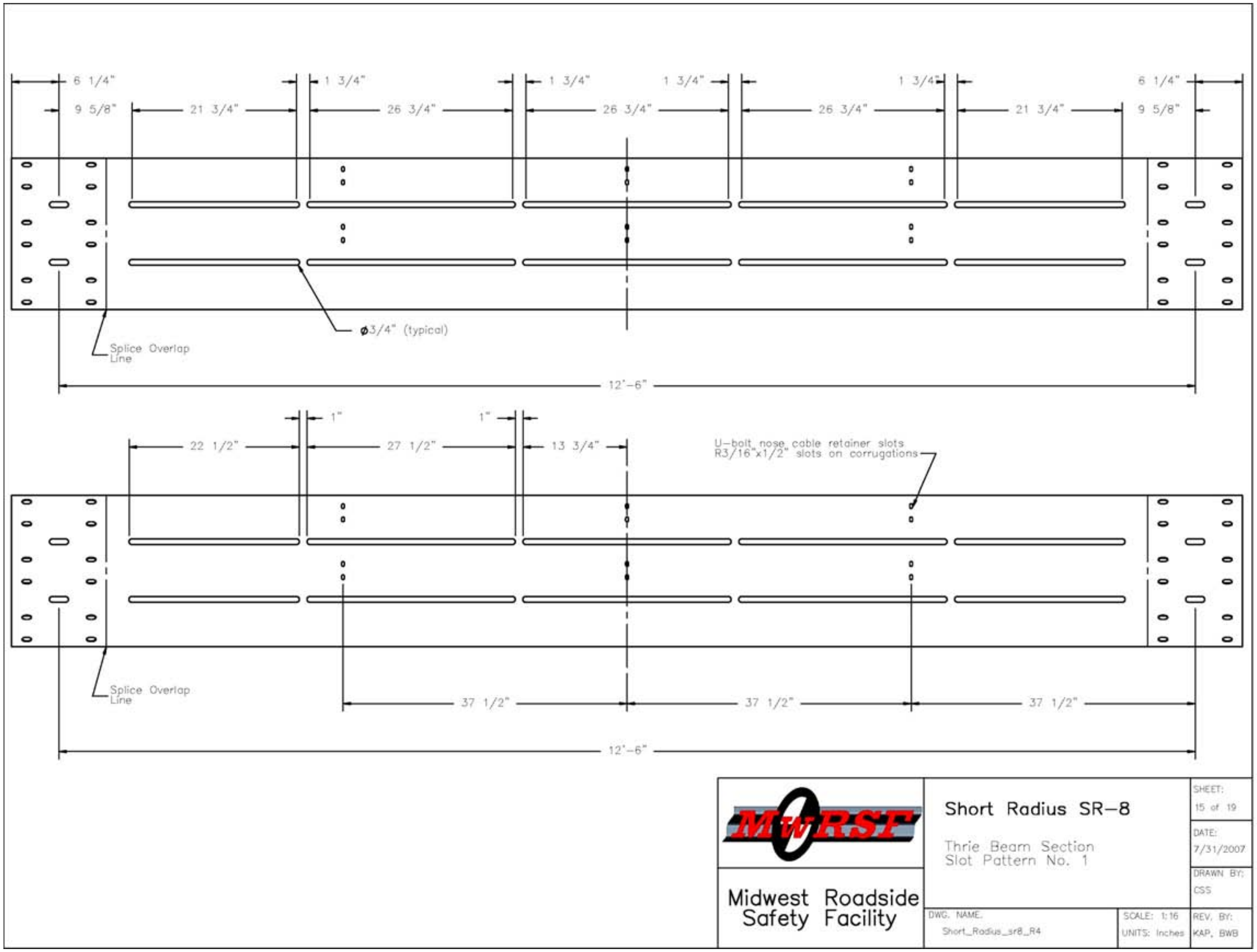


Figure F-15. Thrie Beam Section Slot Pattern No. 1 (English)

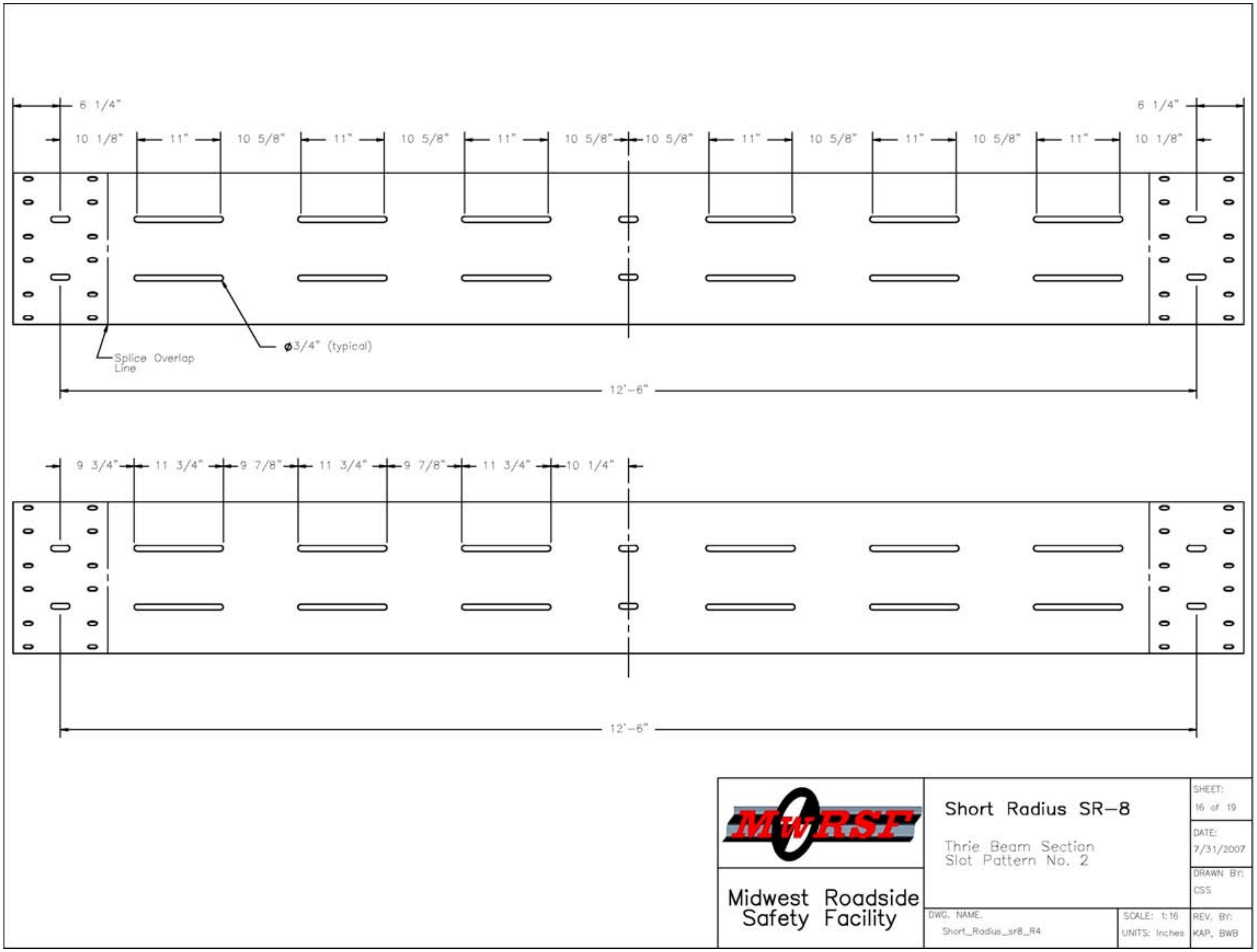


Figure F-16. Thrie Beam Section Slot Pattern No. 2 (English)

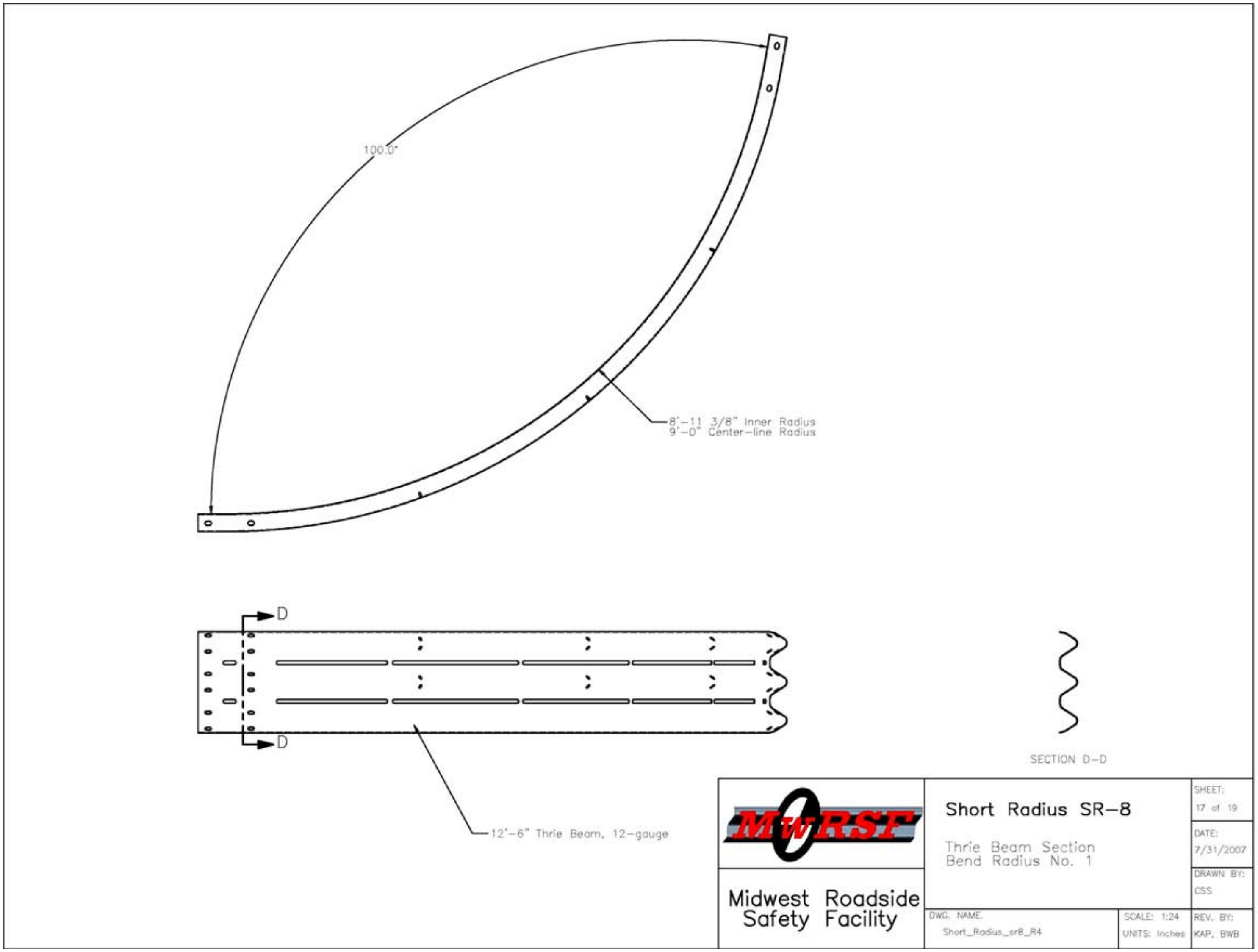


Figure F-17. Thrie Beam Section Bend Radius No. 1 (English)

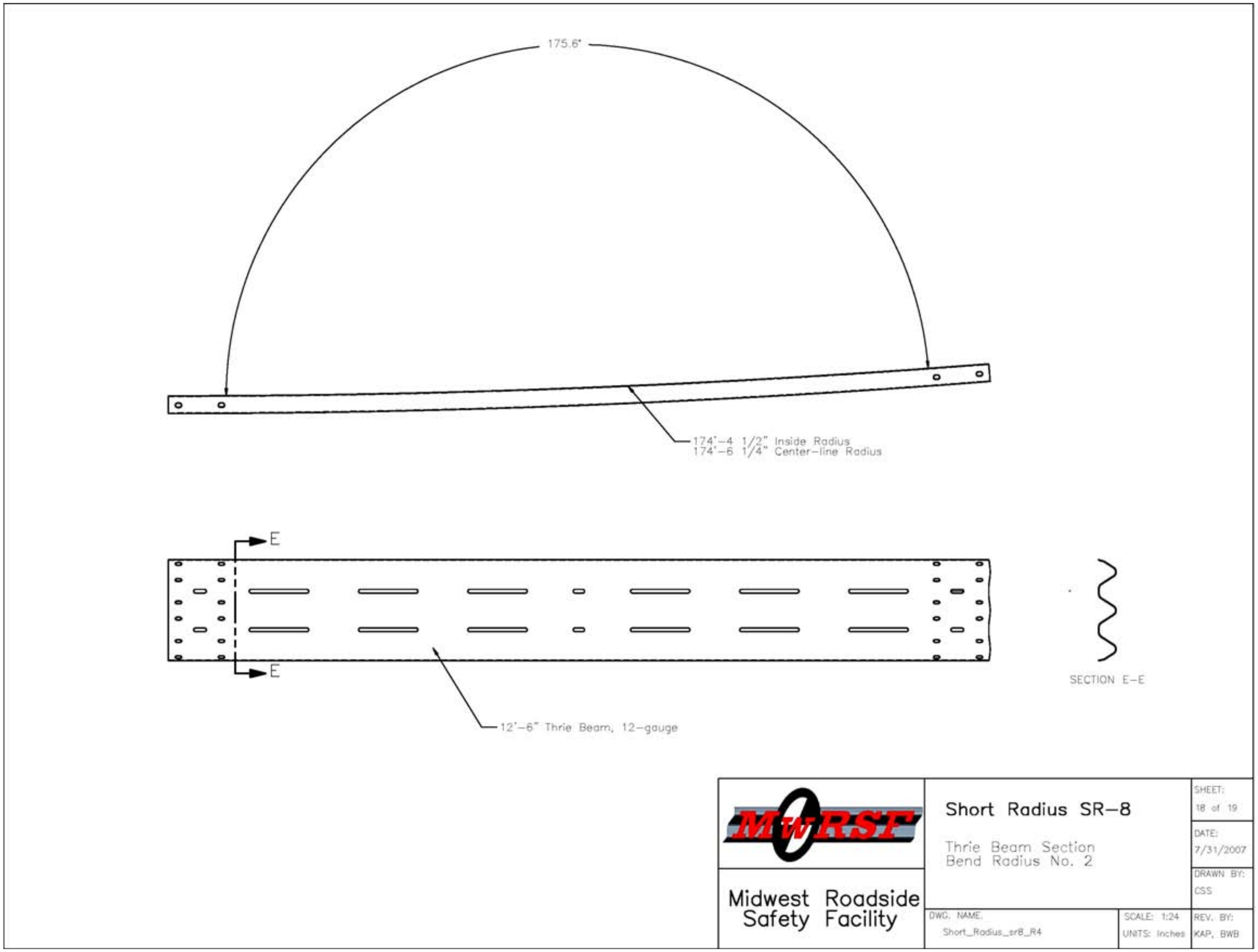


Figure F-18.Thrie Beam Section Bend Radius No. 2 (English)

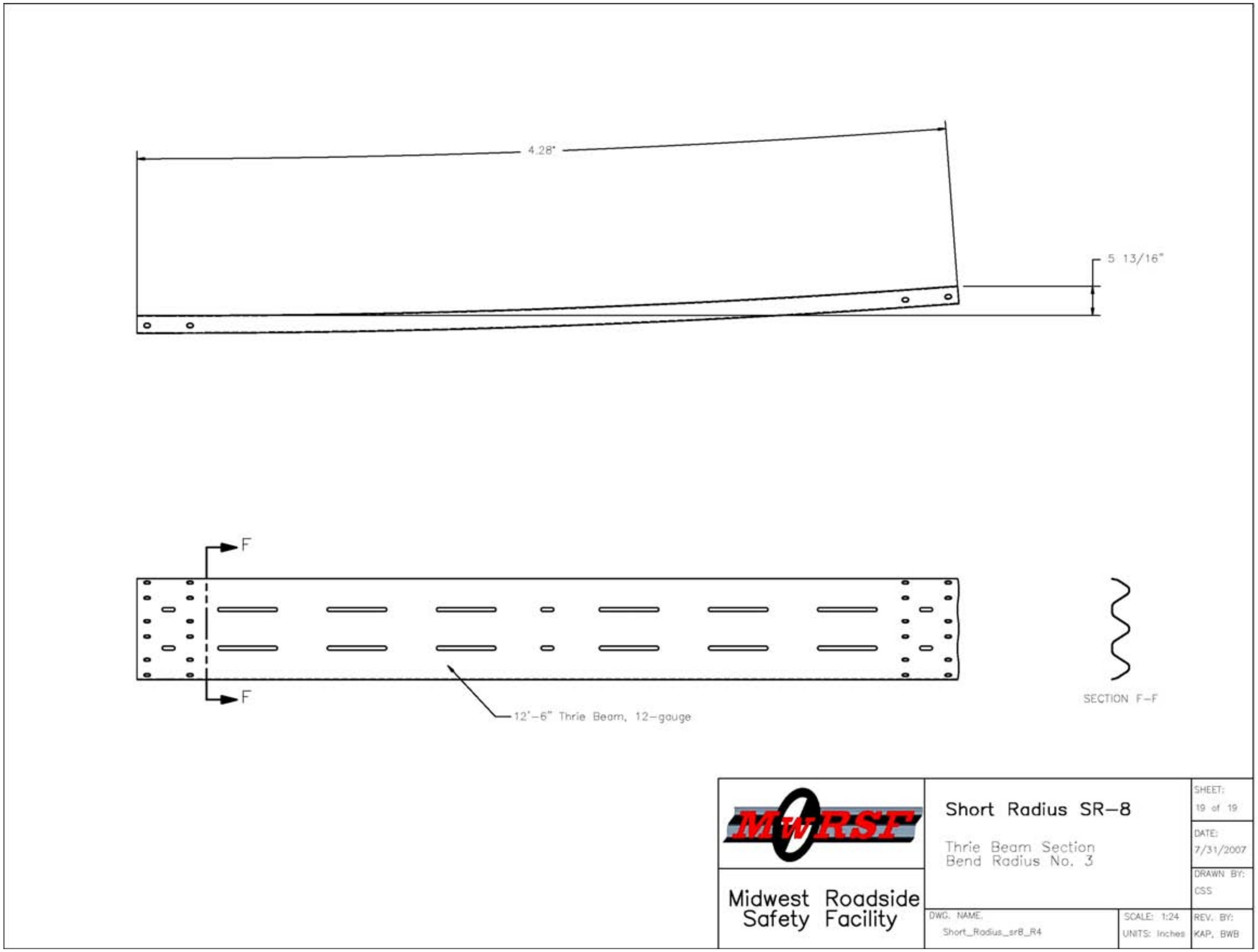


Figure F-19. Thrie Beam Section Bend Radius No. 3

APPENDIX G

Occupant Compartment Deformation, Test No. SR-8

VEHICLE PRE/POST CRUSH INFO
Set-1

TEST: SR-8
VEHICLE: 2003 Ram 1500 Q.C. 4x2

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	28.75	29.25	-0.75	28.75	29.75	-1	0	0.5	-0.25
2	31.5	25.25	-0.75	31.5	25.5	-1	0	0.25	-0.25
3	31.5	19.25	-0.75	31.5	19.25	-0.5	0	0	0.25
4	27.25	10.75	-0.25	27	11	0	-0.25	0.25	0.25
5	27.5	30	-2.75	27.5	30	-2.75	0	0	0
6	28.75	26.5	-3	29	26.5	-3	0.25	0	0
7	30.5	20.5	-4.25	30.25	20.5	-4.25	-0.25	0	0
8	25.75	11	-0.5	25.5	11	-0.75	-0.25	0	-0.25
9	26	30.5	-5	26.25	30.25	-5.25	0.25	-0.25	-0.25
10	26.5	25.25	-5.5	26.5	25.75	-5.5	0	0.5	0
11	26.5	20	-6	26.5	20.25	-6.25	0	0.25	-0.25
12	24.5	11.5	-1.25	24.25	12.25	-1.5	-0.25	0.75	-0.25
13	22.5	8.75	-1.25	22.5	8.5	-1.25	0	-0.25	0
14	20.5	27.5	-8.75	20.5	27.25	-9	0	-0.25	-0.25
15	20.25	22.75	-9.25	20.25	22.5	-9.25	0	-0.25	0
16	19.75	14.25	-5.75	19.75	14.25	-5.75	0	0	0
17	17.5	7.5	-3	17.5	7.5	-3.25	0	0	-0.25
18	15.25	2.5	-3.5	15.5	2.5	-3.75	0.25	0	-0.25
19	13.25	27.75	-9	13.5	27.5	-9	0.25	-0.25	0
20	12.5	21	-9.5	12.5	20.75	-9.5	0	-0.25	0
21	12.5	15.5	-10	12.5	15.25	-10	0	-0.25	0
22	9.5	6.75	-4	9.5	7	-4.25	0	0.25	-0.25
23	9.25	1.75	-4.25	9	1.5	-4.5	-0.25	-0.25	-0.25
24	0.5	28.25	-4.75	0.5	28.5	-4.75	0	0.25	0
25	0.75	21.75	-5.25	1	21.75	-5.5	0.25	0	-0.25
26	1	15	-6	1	15	-6	0	0	0
27	1.25	7.75	-3.75	1.5	8	-3.75	0.25	0.25	0
28	1.25	2	-4	1.5	2	-4	0.25	0	0
29									
30									

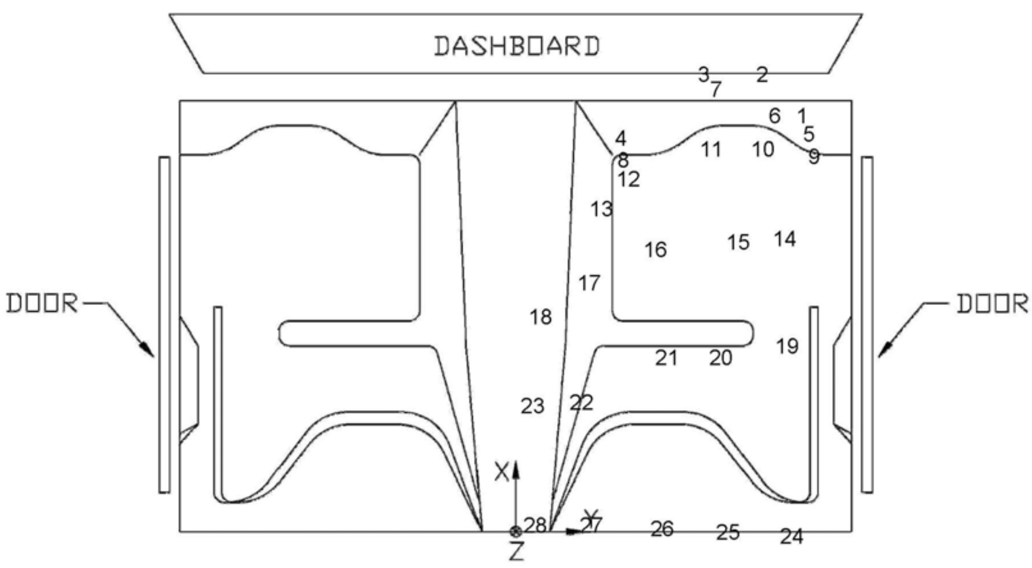


Figure G-1. Occupant Compartment Deformation, Test SR-8

VEHICLE PRE/POST CRUSH INFO
Set-2

TEST: SR-8
VEHICLE: 2003 Ram 1500 Q.C, 4x2

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	51.75	31.75	-1.5	51.75	32.25	-1.5	0	0.5	0
2	54.5	27.75	-1.5	54.5	28	-1.5	0	0.25	0
3	54.5	21.75	-1	54.5	21.75	-1.25	0	0	-0.25
4	50.25	13.25	0.5	50	13.5	0.5	-0.25	0.25	0
5	50.5	32.5	-3.25	50.5	32.5	-3.5	0	0	-0.25
6	51.75	29	-3.5	52	29	-3.5	0.25	0	0
7	53.5	23	-4.5	53.25	23	-4.5	-0.25	0	0
8	48.75	13.5	-0.5	48.5	13.5	-0.5	-0.25	0	0
9	49	33	-5.75	49.25	32.75	-6	0.25	-0.25	-0.25
10	49.5	27.75	-6	49.5	28.25	-6.25	0	0.5	-0.25
11	49.5	22.5	-6.25	49.5	22.75	-6.5	0	0.25	-0.25
12	47.5	14	-1.25	47.25	14.75	-1.25	-0.25	0.75	0
13	45.5	11.25	-1	45.5	11	-1	0	-0.25	0
14	43.5	30	-9	43.5	29.75	-9	0	-0.25	0
15	43.25	25.25	-9.25	43.25	25	-9.25	0	-0.25	0
16	42.75	16.75	-5.75	42.75	16.75	-5.75	0	0	0
17	40.5	10	-2.75	40.5	10	-2.75	0	0	0
18	38.25	5	-3	38.5	5	-3	0.25	0	0
19	36.25	30.25	-9	36.5	30	-9	0.25	-0.25	0
20	35.5	23.5	-9.25	35.5	23.25	-9.5	0	-0.25	-0.25
21	35.5	18	-9.5	35.5	17.75	-9.5	0	-0.25	0
22	32.5	9.25	-3.25	32.5	9.5	-3.5	0	0.25	-0.25
23	32.25	4.25	-3.5	32	4	-3.5	-0.25	-0.25	0
24	23.5	30.75	-4.25	23.5	31	-4.25	0	0.25	0
25	23.75	24.25	-4.5	24	24.25	-4.5	0.25	0	0
26	24	17.5	-5	24	17.5	-5	0	0	0
27	24.25	10.25	-2.75	24.5	10.5	-3	0.25	0.25	-0.25
28	24.25	4.5	-3	24.5	4.5	-3	0.25	0	0
29									
30									

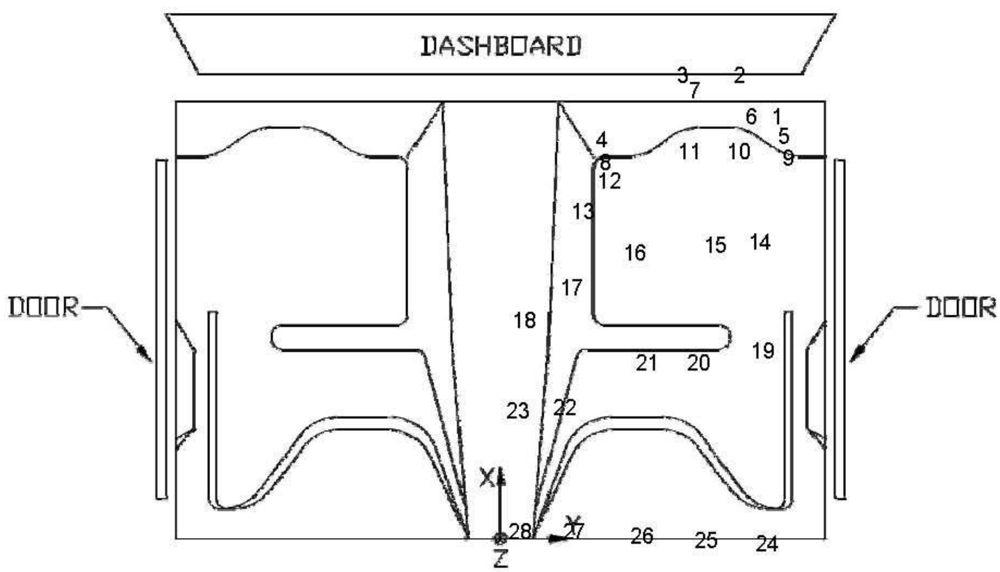


Figure G-2. Occupant Compartment Deformation, Test SR-8

Occupant Compartment Deformation Index (OCDI)

Test No. SR-8
Vehicle Type: 2003 Ram 1500

OCDI = XXABCDEFGHI

XX = location of occupant compartment deformation

A = distance between the dashboard and a reference point at the rear of the occupant compartment, such as the top of the rear seat or the rear of the cab on a pickup

B = distance between the roof and the floor panel

C = distance between a reference point at the rear of the occupant compartment and the motor panel

D = distance between the lower dashboard and the floor panel

E = interior width

F = distance between the lower edge of right window and the upper edge of left window

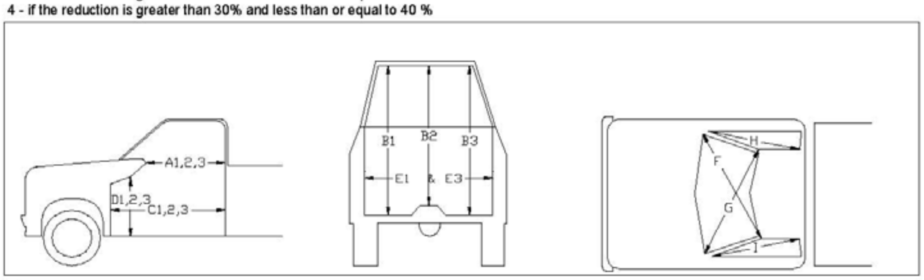
G = distance between the lower edge of left window and the upper edge of right window

H= distance between bottom front corner and top rear corner of the passenger side window

I= distance between bottom front corner and top rear corner of the driver side window

Severity Indices

0 - if the reduction is less than 3%
1 - if the reduction is greater than 3% and less than or equal to 10 %
2 - if the reduction is greater than 10% and less than or equal to 20 %
3 - if the reduction is greater than 20% and less than or equal to 30 %
4 - if the reduction is greater than 30% and less than or equal to 40 %



where,
1 = Passenger Side
2 = Middle
3 = Driver Side

Location:

Measurement	Pre-Test (in.)	Post-Test (in.)	Change (in.)	% Difference	Severity Index
A1	54.75	54.75	0.00	0.00	0
A2	50.50	50.50	0.00	0.00	0
A3	56.50	56.75	0.25	0.44	0
B1	47.25	47.25	0.00	0.00	0
B2	42.25	42.25	0.00	0.00	0
B3	47.00	47.25	0.25	0.53	0
C1	69.50	69.00	-0.50	-0.72	0
C2	46.50	46.75	0.25	0.54	0
C3	66.50	66.50	0.00	0.00	0
D1	23.25	23.50	0.25	1.08	0
D2	13.25	13.25	0.00	0.00	0
D3	23.00	23.00	0.00	0.00	0
E1	66.00	66.00	0.00	0.00	0
E3	64.75	65.00	0.25	0.39	0
F	56.00	56.00	0.00	0.00	0
G	56.25	56.25	0.00	0.00	0
H	37.00	37.00	0.00	0.00	0
I	37.75	37.75	0.00	0.00	0

Note: Maximum sevrity index for each variable (A-I) is used for determination of final OCDI value

	XX	A	B	C	D	E	F	G	H	I
Final OCDI:	RF	0	0	0	0	0	0	0	0	0

Figure G-3. Occupant Compartment Deformation Index (OCDI), Test SR-8

APPENDIX H

Occupant Risk, Test No. SR-8

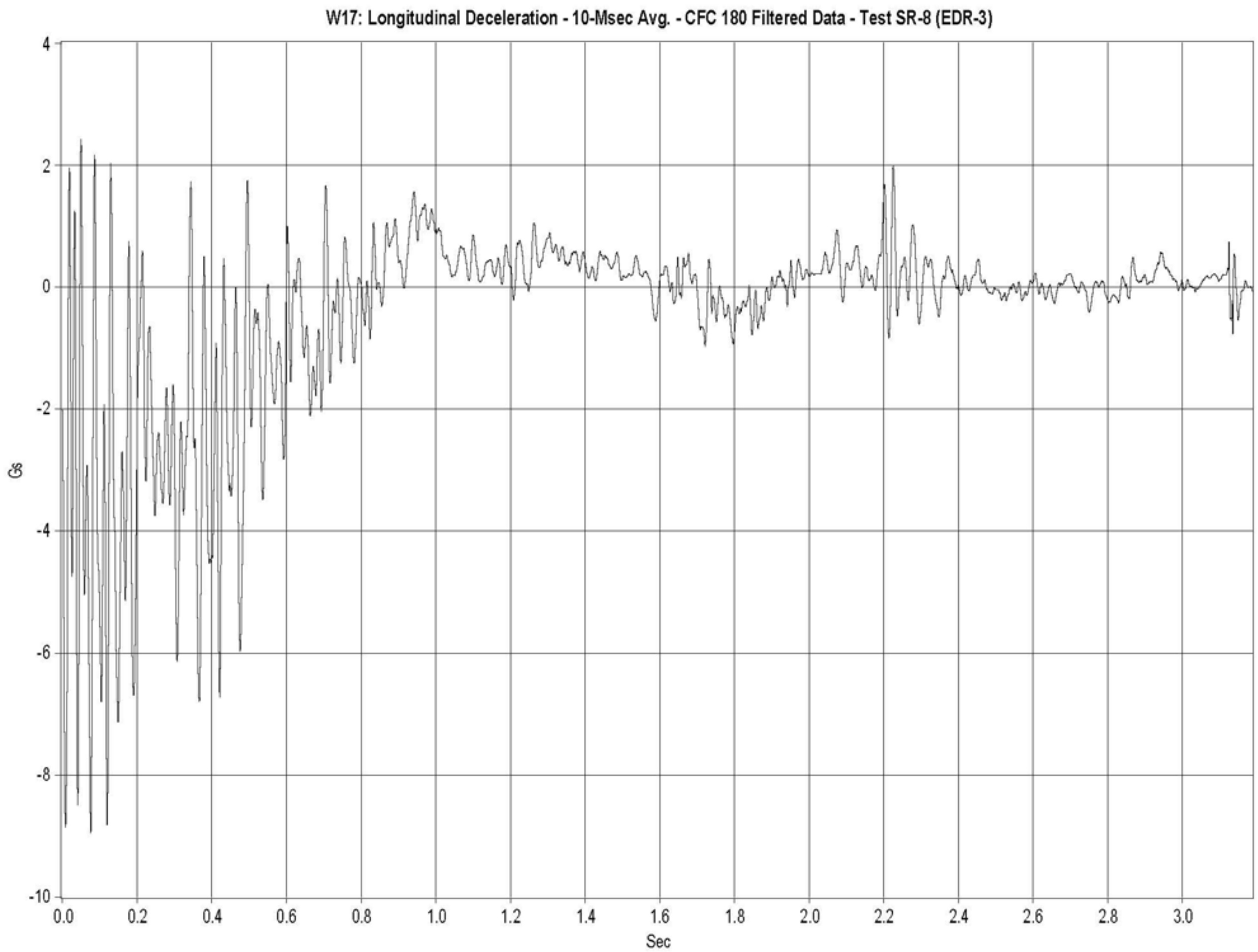


Figure H-1. Longitudinal Occupant Deceleration, Test SR-8

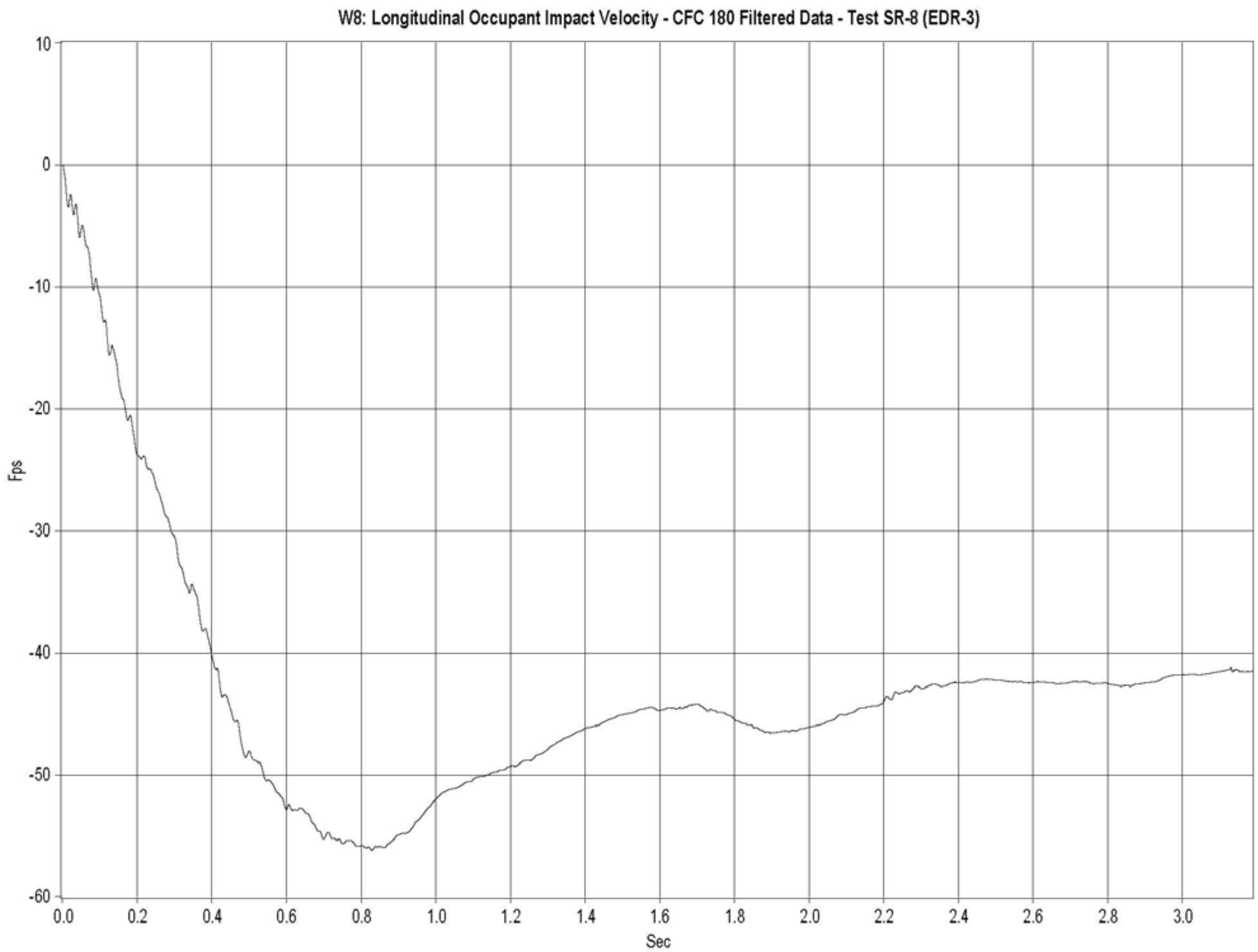


Figure H-2. Longitudinal Occupant Impact Velocity (OIV), Test SR-8

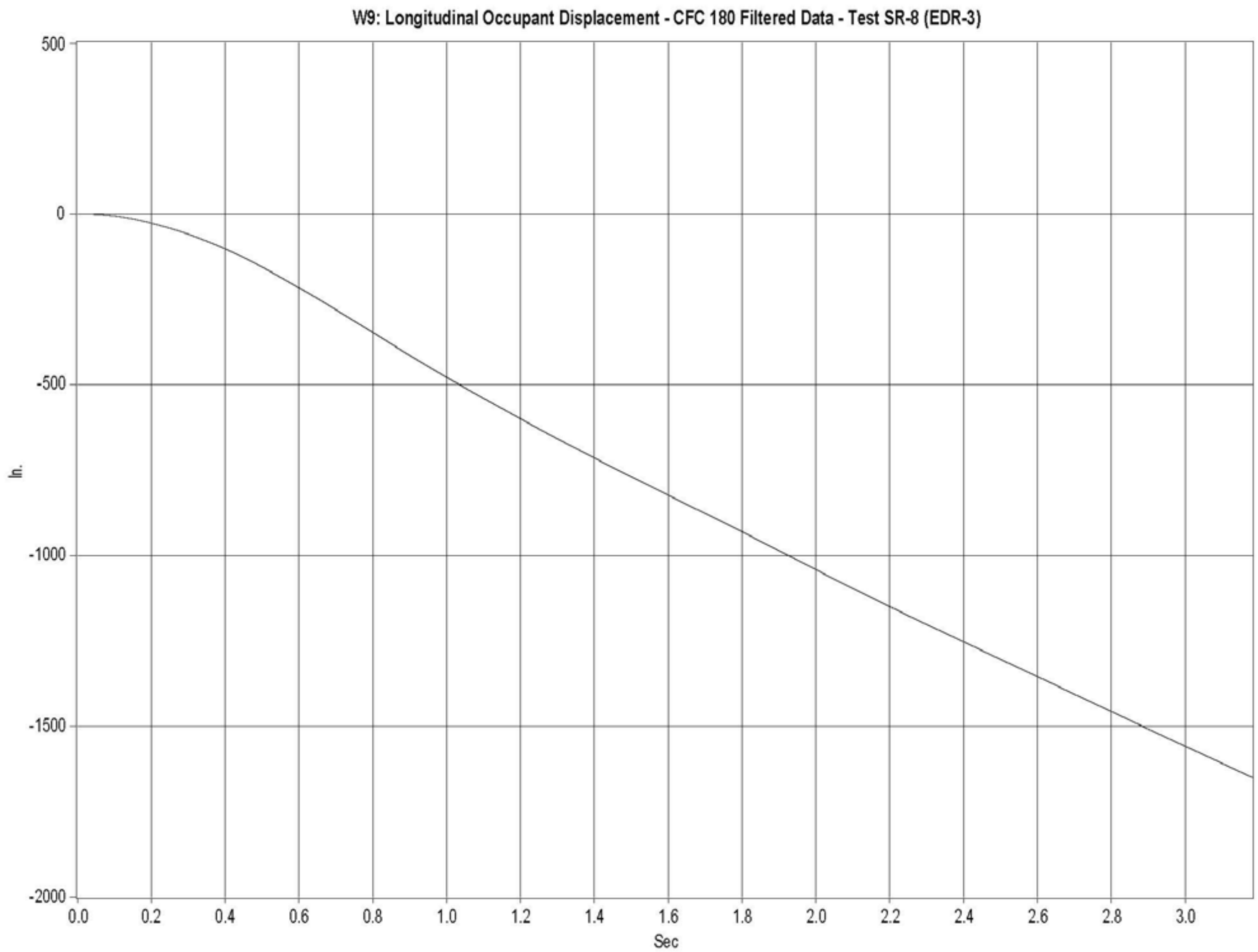


Figure H-3. Longitudinal Occupant Displacement, Test SR-8

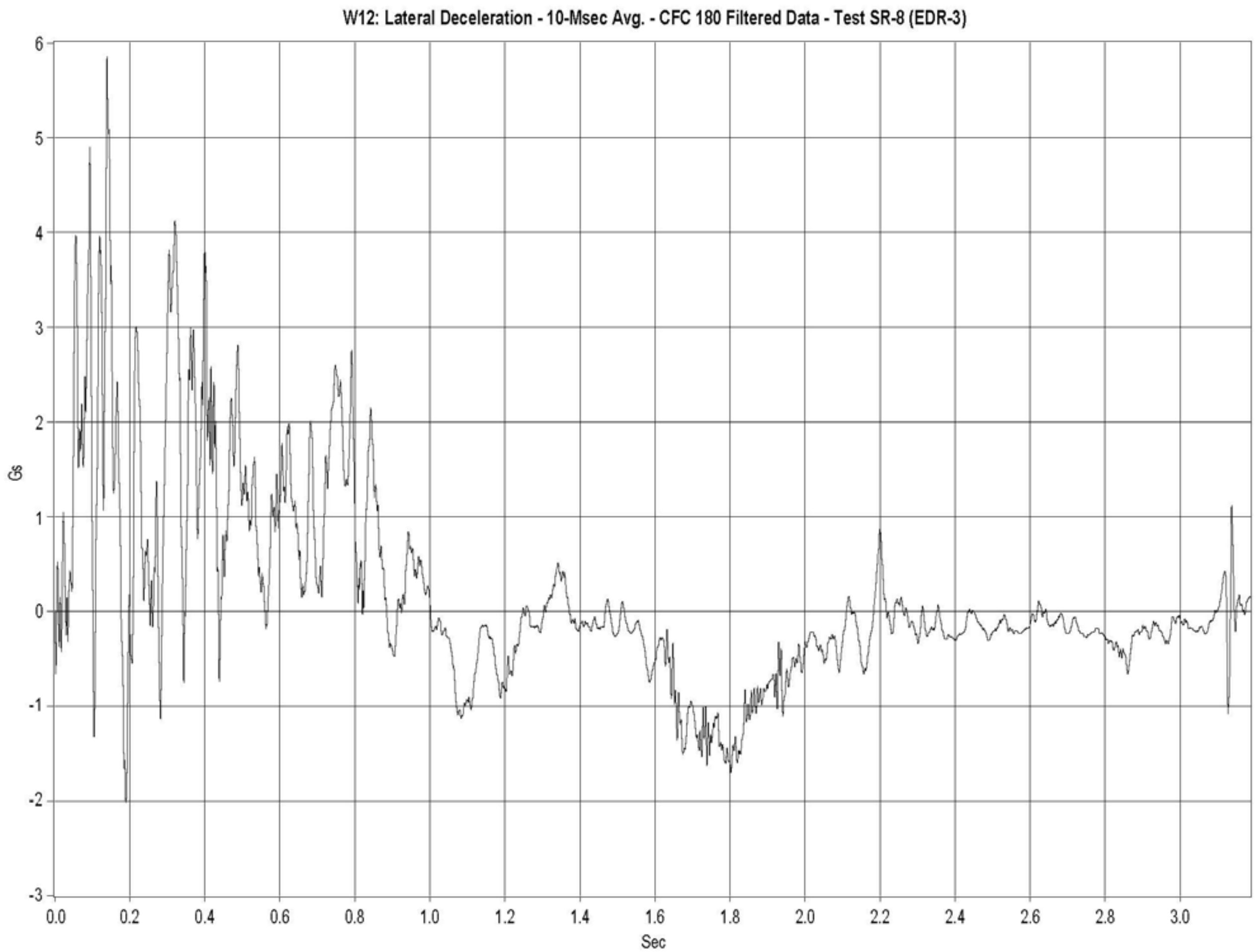


Figure H-4. Lateral Occupant Deceleration, Test SR-8

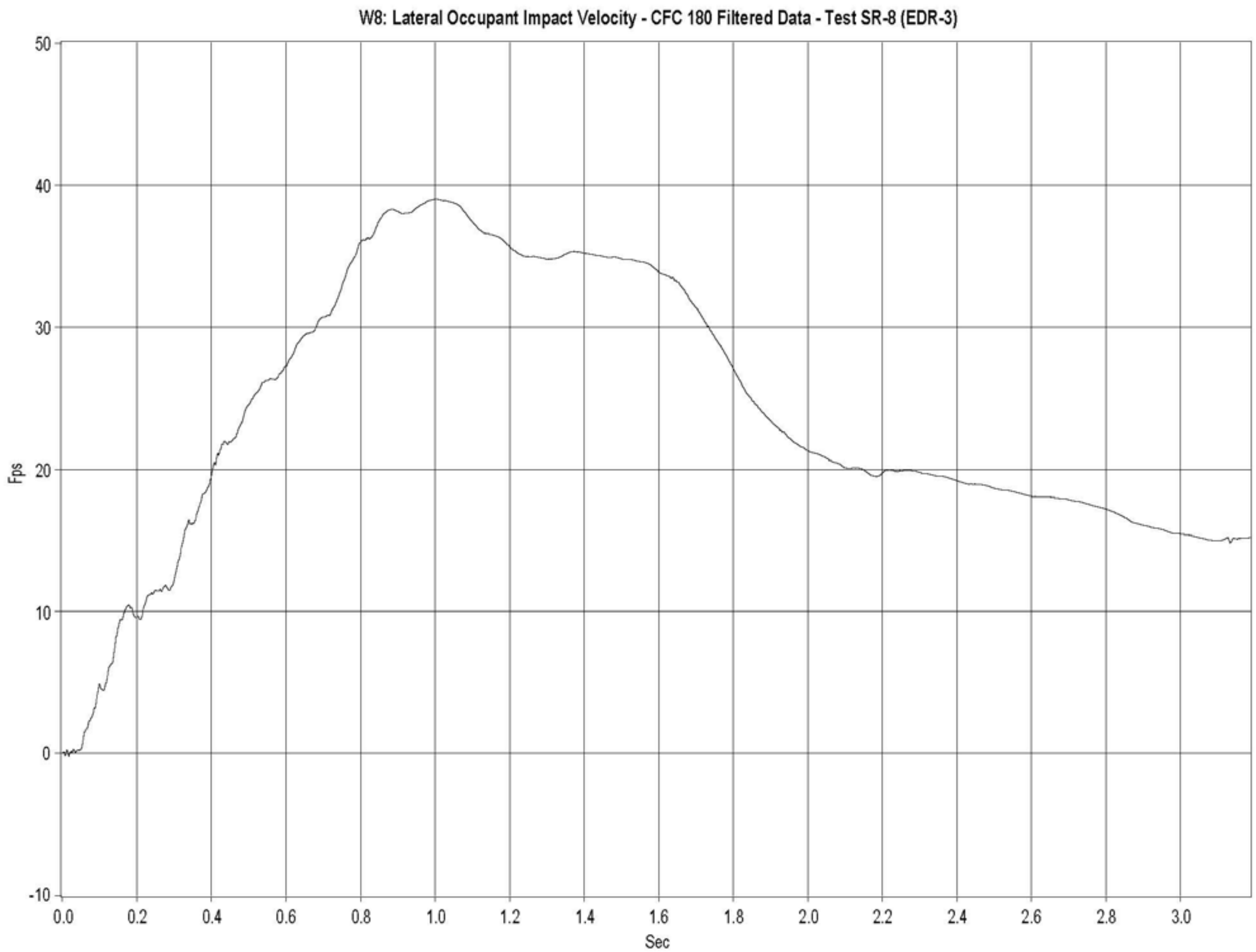


Figure H-5. Lateral Occupant Impact Velocity (OIV), Test SR-8

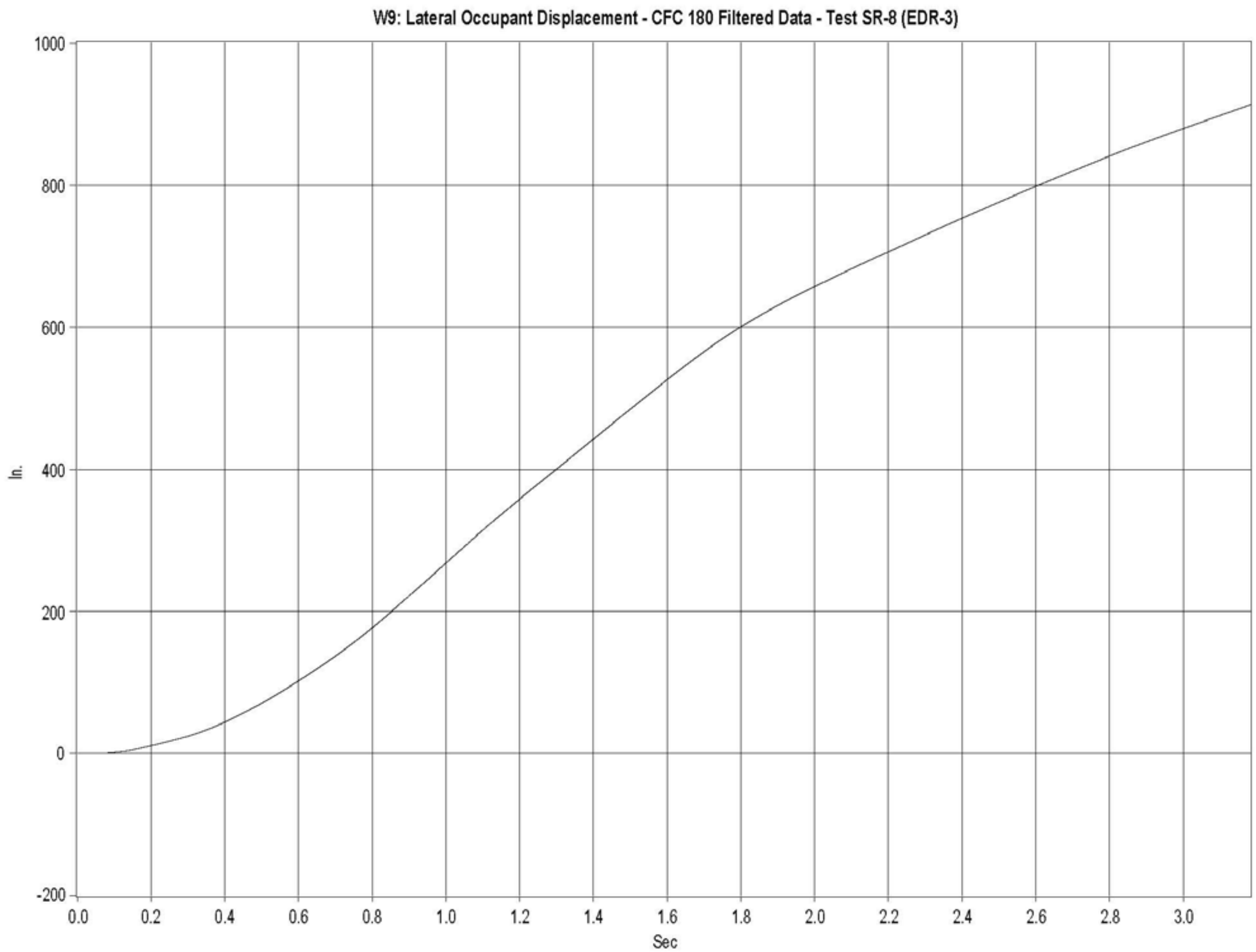


Figure H-6. Lateral Occupant Displacement, Test SR-8

Figure H-7. Roll, Pitch, and Yaw Angular Displacements, Test SR-8

APPENDIX I

MGS Guardrail Specifications

1050 N. Steel Dr. | Huger, SC 29450

METALLURGICAL REPORT

Date: 6/26/07

Customer: Mid Park

Purchase Order: 710515

Type of Steel: .134 x 61.5 x 92.75

Coil Number: 59018859, 59018860
C50034212, C50034213

Heat Number: 842W37420

Grade: 50 Yield

C	MN	P	S	SI	AL	NB	V	Yield	Tensile	Elongation	RB	
.07	.89	.018	.007	.01	.04	.039	.001	53.9	72.7	28.9%		

Figure I-1. Guardrail Metallurgical Report, Test Nos. SR-7 and SR-8

PRODUCT CERTIFICATION

MITTAL

Mittal Burns Harbor

Work Order
3702X

Lot Number
842W37420

Sales Order
EH013-36352

Sold To: JENNMAR CORPORATION
C/O FERROUS METAL PROCESSING CORPORATION
11103 MEMPHIS AVENUE
BROOKLYN, OH 44144

Customer P.O.	Quantity	Lading NO	SHIPMENT DATE
214667-40	58900	805-18340	6/20/2007

SPECIFICATION: Hot Roll Resale
Act Size .1299" X 62-13/16

CERTIFICATION REQUIRMENTS

CHEMICAL

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al
0.07	0.89	0.018	0.007	0.01	0.017	0.01	0.03	0.008	0.001	0.04

V	Cb	N	B	Ti	Sb	Ca
0.001	0.039	0.006	0.0002	0.002	0.002	0.0037

Origin - Made and Melted in USA

MECHANICAL

Coil
321610

I 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 had been approved for conformance to the specifications.

Matthew Kremer
QA Manager

Date: 06/20/2007

Figure I-2. Guardrail Metallurgical Report, Test Nos. SR-7 and SR-8-6

GATEWAY GALVANIZING, INC
1117 Brown Forman Road
Jeffersonville, In 47130
812-284-5241

Certificate of Compliance

Gateway Galvanizing, Inc. certifies that the material referenced below complies in accordance with ASTM A 123/A 123M-97a specifications.

Customer: **Roadway**
Project/Job/PO#:

Processing Dates: **August 2007**

Material covered by the certificate of compliance:

Tracc Parts

Date: August 1, 2007

(Signature) Manager

State of Indiana
County of Clark

Subscribed and sworn before me this 1st day of August 2007.

Notary Public

Resident of Clark County
Commission Expires 6/27/09

CAROL A. COOPER NOTARY STATE OF INDIANA

Figure I-3. Galvanization Certification, Test Nos. SR-7 and SR-8