Midwest States' Regional Pooled Fund Research Program
Fiscal Year 2001-2002 (Year 12)
Research Project Number SPR-3(017)
NDOR Sponsoring Agency Code RPFP-01-05

DESIGN AND EVALUATION OF A LOW-TENSION CABLE MEDIAN BARRIER SYSTEM

Submitted by

Kirk J. Molacek, B.S.C.E.
Former Undergraduate Research Assistant

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

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

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

John D. Reid, Ph.D.
Professor

Cale J. Stolle
Undergraduate Research Assistant

Erin A. Johnson
Undergraduate Research Assistant

Cody S. Stolle, B.S.M.E., E.I.T.
Graduate Research Assistant

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

Submitted to

MIDWEST STATES' REGIONAL POOLED FUND PROGRAM
Nebraska Department of Roads
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

MwRSF Research Report No. TRP-03-195-08

December 8, 2008

Technical Report Documentation Page

1. Report No. TRP-03-195-08	2.	3. Recipient's Accession No.
4. Title and Subtitle DESIGN AND EVALUATION OF A LOW-TENSION CABLE MEDIAN BARRIER SYSTEM		5. Report Date December 8, 2008 6.
7. Author(s) Molacek, K.J., Lechtenberg, K.A., Faller, R.K., Rohde, J.R., Sicking, D.L., Bielenberg, R.W., Reid, J.D., Stolle, C.J., Johnson, E.A., and Stolle, C.S.		8. Performing Organization Report No. TRP-03-195-08
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) University of Nebraska-Lincoln 527 Nebraska Hall Lincoln, NE 68588-0529		10. Project/Task/Work Unit No. 11. Contract © or Grant (G) No. SPR-3(017)
12. Sponsoring Organization Name and Address Midwest States' Regional Pooled Fund Program Nebraska Department of Roads 1500 Nebraska Highway 2 Lincoln, Nebraska 68502		13. Type of Report and Period Covered Final Report 2000-2008 14. Sponsoring Agency Code RPFP-01-05
15. Supplementary Notes Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration		

16. Abstract (Limit: 200 words)

Prior full-scale crash testing and accident data analyses have both shown that low-tension, cable median barrier systems are one of the safest roadside barriers in existence. However, existing designs incorporate a relatively small spacing between cables which can allow some vehicles to underride the barrier and can limit the slopes upon which the barrier may be installed. Further, the most widely used design incorporates a wide post spacing of 4,877 mm (192 in.) which allows large lateral deflections. The new cable median barrier design reduces the issues by adding a fourth cable to reduce vehicle penetration over or under the barrier and decreasing the post spacing to reduce lateral deflections.

The new cable median barrier designs were constructed and full-scale crash tested. The first cable median barrier, consisting of M203x9.7 (M8x6.5) posts spaced 1,829-mm (72-in.) on center, standard cable hooks, and woven cables, was impacted with an 820-kg (1,808-lb) small car. This cable median barrier design failed due to vehicle rollover. The redesigned cable median barrier, consisting of S76x8.5 (S3x5.7) posts spaced 2,438-mm (96-in.) on center, welded cable brackets, and non-woven cables, was impacted with an 820-kg (1,808-lb) small car. The vehicle was safely redirected. Following an analysis of the successful small car test, minor system design changes occurred to the cable median barrier system. These changes included lengthening the posts by 25 mm (1 in.) and adding cable retaining bolts at the top of the cable brackets. When impacted with a 2,000-kg (4,409-lb) pickup truck, the modified cable median system safely redirected the pickup truck. All three tests were conducted and reported in accordance with Test Level 3 of NCHRP Report No. 350.

17. Document Analysis/Descriptors Highway Safety, Roadside Appurtenances, Longitudinal Barriers, Cable Guardrail, Crash Test, Compliance Test		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 244	22. Price

DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views nor policies of the State Highway Departments participating in the Midwest States' Regional Pooled Fund Research Program nor the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the Midwest States' Regional Pooled Fund Program funded by the California Department of Transportation, Connecticut Department of Transportation, Illinois Department of Transportation, Iowa Department of Transportation, Kansas Department of Transportation, Minnesota Department of Transportation, Missouri Department of Transportation, Montana Department of Transportation, Nebraska Department of Roads, New Jersey Department of Transportation, Ohio Department of Transportation, South Dakota Department of Transportation, Texas Departments of Transportation, Wisconsin Department of Transportation, and Wyoming Department of Transportation for sponsoring this project; and (2) MwRSF personnel for constructing the barriers and conducting the crash tests.

A special thanks is also given to the following individuals who made a contribution to the completion of this research project.

Midwest Roadside Safety Facility

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

Illinois Department of Transportation

David Piper, P.E., Highway Policy Engineer

Iowa Department of Transportation

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

Kansas Department of Transportation

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

Minnesota Department of Transportation

Michael Elle, P.E., Design Standard Engineer

Missouri Department of Transportation

Joseph G. Jones, P.E., Technical Support Engineer

Nebraska Department of Roads

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

Ohio Department of Transportation

Dean Focke, P.E., Standards Engineer

South Dakota Department of Transportation

David Huft, Research Engineer
Bernie Clocksin, Lead Project Engineer

Texas Department of Transportation

Mark Bloschock, P.E., Former Supervising Design Engineer
Mark Marek, P.E., Design Engineer

Wisconsin Department of Transportation

John Bridwell, P.E., Standards Development Engineer
Erik Emerson, P.E., 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

TABLE OF CONTENTS

Page

List of Figures

List of Tables

Page

1 INTRODUCTION

1.1 Background and Problem Statement

Prior full-scale crash testing and accident data analyses have both shown that low-tension, cable barrier systems are one of the safest roadside barriers in existence. Crash tests of cable barriers installed on slopes have shown that large automobiles can be contained and redirected by only one of the three cables used in current low-tension designs. Further, accident data has shown that cable barriers have the lowest injury rate of any roadside barrier system. However, existing designs incorporate a relatively small spacing between the cables which may allow some vehicles to underride the barrier and can limit the slopes upon which the barrier can be installed. Further, the most widely used designs incorporate wide post spacings which allow large lateral deflections.

1.2 Objective

The overall objective of the research was to significantly improve the design of standard low-tension, cable barrier systems by eliminating operational restrictions and maintenance problems as well as to improve its impact performance. More specifically, the objectives included: (1) a determination of the post spacing required to reduce lateral deflection; (2) a determination of the cable configuration necessary to eliminate or minimize vehicle penetrations under or over the barrier; and (3) an investigation of the post to cable attachments required to simplify and expedite repair of the barrier system. To eliminate vehicle penetrations under or over the barrier, this research examined the use of a four-cable barrier system instead of the typical three-cable barrier system. The cable barrier system was evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth in the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (1).

1.3 Scope

Following the development and construction of the first cable barrier system, three full-scale crash tests were conducted. The first and second test utilized a small car, weighing approximately 820 kg (1,808 lbs), impacting at a speed and angle of 100.0 km/h (62.1 mph) and 20.0 degrees, respectively. The third test was performed using a ¾-ton pickup truck, weighing approximately 2,000 kg (4,409 lbs), impacting at a speed and angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively. Finally, the test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made that pertain to the safety performance of the cable barrier systems.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as cable median barriers, must satisfy the requirements provided in NCHRP Report No. 350 to be accepted for use on National Highway System (NHS) construction projects or as a replacement for existing systems not meeting current safety standards. According to TL-3 of NCHRP Report No. 350, a cable barrier system must be subjected to two full-scale vehicle crash tests. The two required crash tests are noted below.

1. Test Designation 3-10, consisting of an 820-kg (1,808-lb) small car impacting the cable median barrier at a nominal speed and angle of 100.0 km/h (62.1 mph) and 20 degrees, respectively.

2. Test Designation 3-11, consisting of a 2,000-kg (4,409-lb) pickup truck impacting the cable median barrier at a nominal speed and angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively.

The test conditions for TL-3 longitudinal barriers are summarized in Table 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. Criteria for structural adequacy are intended to evaluate the ability of the cable barrier to contain, redirect, or allow controlled vehicle penetration in a predictable manner. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to cause subsequent multi-vehicle accidents. This criterion also indicates the potential safety hazard for the occupants of other vehicles or the occupants of the impacting vehicle when subjected to secondary collisions with other fixed objects. These three evaluation criteria are defined in Table 2. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in NCHRP Report No. 350.

Table 1. NCHRP Report No. 350 Test Level 3 Crash Test Conditions

Test Article	Test Designation	Test Vehicle	Impact Conditions			Evaluation Criteria[1]
			Speed		Angle (degrees)	
			(km/h)	(mph)		
Longitudinal Barriers	3-10	820C	100	62.1	20	A,D,F,H,I,K,M
	3-11	2000P	100	62.1	25	A,D,F,K,L,M

[1] Evaluation criteria explained in Table 2.

Table 2. NCHRP Report No. 350 Evaluation Criteria for Crash 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.
	C.	Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.
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 an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.
	F.	The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.
	H.	Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9 m/s (29.53 ft/s), or at least below the maximum allowable value of 12 m/s (39.37 ft/s).
	I.	Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15 g's, or at least below the maximum allowable value of 20 g's.
Vehicle Trajectory	K.	After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.
	L.	The occupant impact velocity in the longitudinal direction should not exceed 12 m/s (39.37 ft/s), and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.
	M.	The exit angle from the test article preferably should be less than 60 percent of test impact angle measured at time of vehicle loss of contact with test device.
	N.	Vehicle trajectory behind the test article is acceptable.

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 mi.) 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 barrier system. A digital speedometer was located on the tow vehicle to increase the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch (2) was used to steer the test vehicle. A guide-flag, attached to the front-right wheel and the guide cable, was sheared off before impact with the barrier system. The 9.5-mm (0.375-in.) diameter guide cable was tensioned to approximately 15.6 kN (3,500 lbs), 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. For tests CMB-1, CMB-2, and CMB-3, the vehicle guidance systems were 241 m (790 ft), 242 m (795 ft), and 323 m (1,060 ft) long, respectively.

3.3 Test Vehicles

For test CMB-1, a 1997 Geo Metro small car was used as the test vehicle. The test inertial and gross static weights were 818 kg (1,803 lbs) and 893 kg (1,969 lbs), respectively. The test vehicle is shown in Figure 1, and vehicle dimensions are shown in Figure 2.

For test CMB-2, a 1996 Geo Metro was used as the test vehicle. The test inertial and gross static weights were 814 kg (1,794 lbs) and 899 kg (1,960 lbs), respectively. The test vehicle is shown in Figure 3, and vehicle dimensions are shown in Figure 4.

For test CMB-3, a 1999 GMC 3/4-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,023 kg (4,459 lbs). The test vehicle is shown in Figure 5, and vehicle dimensions are shown in Figure 6.

The vertical and longitudinal components of the center of gravity were determined using the measured axle weights. The location of the final centers of gravity are shown in Figures 7 through 9.

Square black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film and E/cam and Photron videos, as shown in Figures 7 through 9. Round, checkered targets were placed on the center of gravity on the driver's side door, on the passenger's side door, and on the roof of the vehicle. The remaining targets were located for reference so that they could be viewed from the high-speed cameras for film analysis.

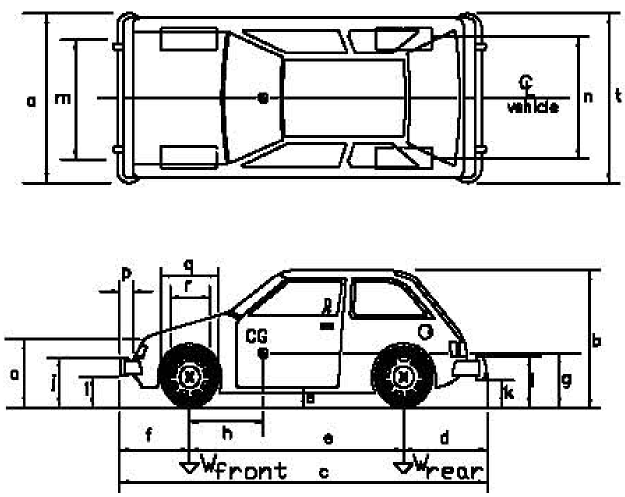
The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable. Two 5B flash bulbs were mounted on both the hood and roof of the vehicle to pinpoint the time of impact with the barrier on the high-speed film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

Figure 1. Test Vehicle, Test CMB-1

Dates: 7/2/03 Test Numbers: CMB-1 Model: Metro

Make: GEO Vehicle I.D.#: 2C1MR2264V6765552

Tire Size: P155/80R13 Year: 1997 Odometer: 117,046



Vehicle Geometry – mm (in.)

a 1556 (61.25)	b 1429 (56.25)
c 3797 (149.5)	d 616 (24.25)
e 2369 (93.25)	f 813 (32.0)
g 540 (21.25)	h 883 (34.75)
i 229 (9.0)	j 572 (22.5)
k 298 (11.75)	l 673 (26.5)
m 1378 (54.25)	n 1346 (53.0)
o 572 (22.5)	p 102 (4.0)
q 584 (23.0)	r 362 (14.25)
s 324 (12.75)	t 1575 (62)

height of wheel center 273

Engine Type 3 cyl. gas

Engine size 1.0 L

Transmission Type:

Automatic or (Manual)

(FWD) or RWD or 4WD

Weight – kg (lb)	Curb	Test Inertial	Gross Static
W_{front}	473 (1043)	513 (1131)	549 (1210)
W_{rear}	271 (597)	305 (672)	344 (758)
W_{total}	744 (1640)	818 (1803)	893 (1969)

Damage prior to test: None

Figure 2. Vehicle Dimensions, Test CMB-1

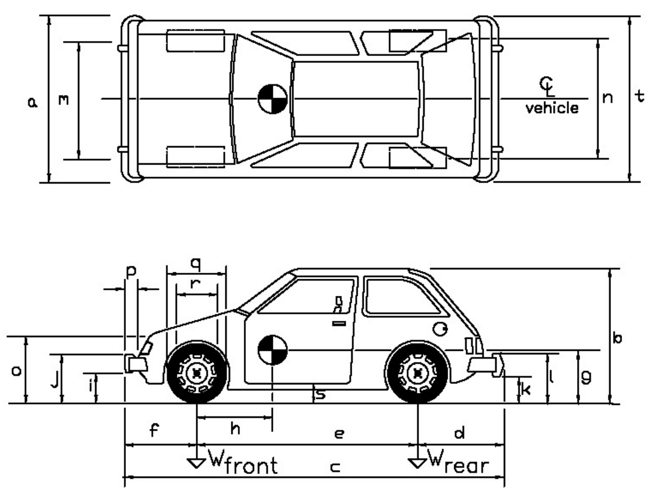
Figure 3. Test Vehicle, Test CMB-2

Date: 11/10/2004 Test Number: CMB-2 Model: 820C Metro

Make: GEO Vehicle I.D.#: 2C1MR2293T6727009

Tire Size: P15580 R13 Year: 1996 Odometer: 177769

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1549 (61.0)	b	1397 (55.0)
c	3797.5 (149.5)	d	584 (23.0)
e	2369 (93.25)	f	838 (33.0)
g	546 (21.5)	h	905 (35.625)
i	419 (16.5)	j	521 (20.5)
k	311 (12.25)	l	622 (24.5)
m	1391 (54.75)	n	1359 (53.5)
o	565 (22.25)	p	108 (4.25)
q	572 (22.5)	r	362 (14.25)
s	311 (12.25)	t	1575 (62.0)

Wheel Center Height 267 (10.5)

Engine Type 4 CYL. GAS

Engine Size 1.3 L

Transmission Type:

(Automatic) or Manual

(FWD) or RWD or 4WD

Weights kg (lbs)	Stripped	Test Inertial	Gross Static
W_{front}	500 (1102)	503 (1108)	539 (1189)
W_{rear}	287 (633)	311 (686)	350 (771)
W_{total}	787 (1735)	814 (1794)	899 (1960)

Note any damage prior to test: Small roof damage

Figure 4. Vehicle Dimensions, Test CMB-2

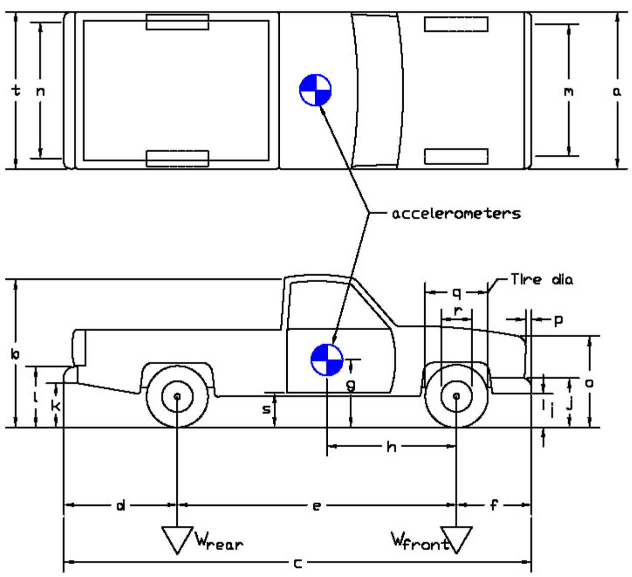
Figure 5. Test Vehicle, Test CMB-3

Date: 03/14/2005 Test Number: CMB-3 Model: 2000P

Make: GMC Vehicle I.D.#: 1GDGC24R6XF046512

Tire Size: LT 245/75 R16 Year: 1999 Odometer: 241559

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1886 (74.25)	b	1848 (72.75)
c	5531 (217.75)	d	1321 (52.0)
e	3334 (131.25)	f	876 (34.5)
g	677 (26.25)	h	1394 (54.9)
i	451 (17.75)	j	660 (26.0)
k	578 (22.75)	l	781 (30.75)
m	1600 (63.0)	n	1626 (64.0)
o	1022 (40.25)	p	83 (3.25)
q	775 (30.5)	r	445 (17.5)
s	508 (20.0)	t	1861 (73.25)

Wheel Center Height Front 368 (14.5)

Wheel Center Height Rear 368 (14.5)

Wheel Well Clearance (FR) 902 (35.5)

Wheel Well Clearance (RR) 711 (28.0)

Engine Type 8 CYL. GAS

Engine Size 5.7 L 350 CID

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	1147 (2529)	1176 (2592)	1176 (2592)
W_{rear}	834 (1839)	847 (1867)	847 (1867)
W_{total}	1981 (4368)	2023 (4459)	2023 (4459)

Note any damage prior to test: None

Figure 6. Vehicle Dimensions, Test CMB-3

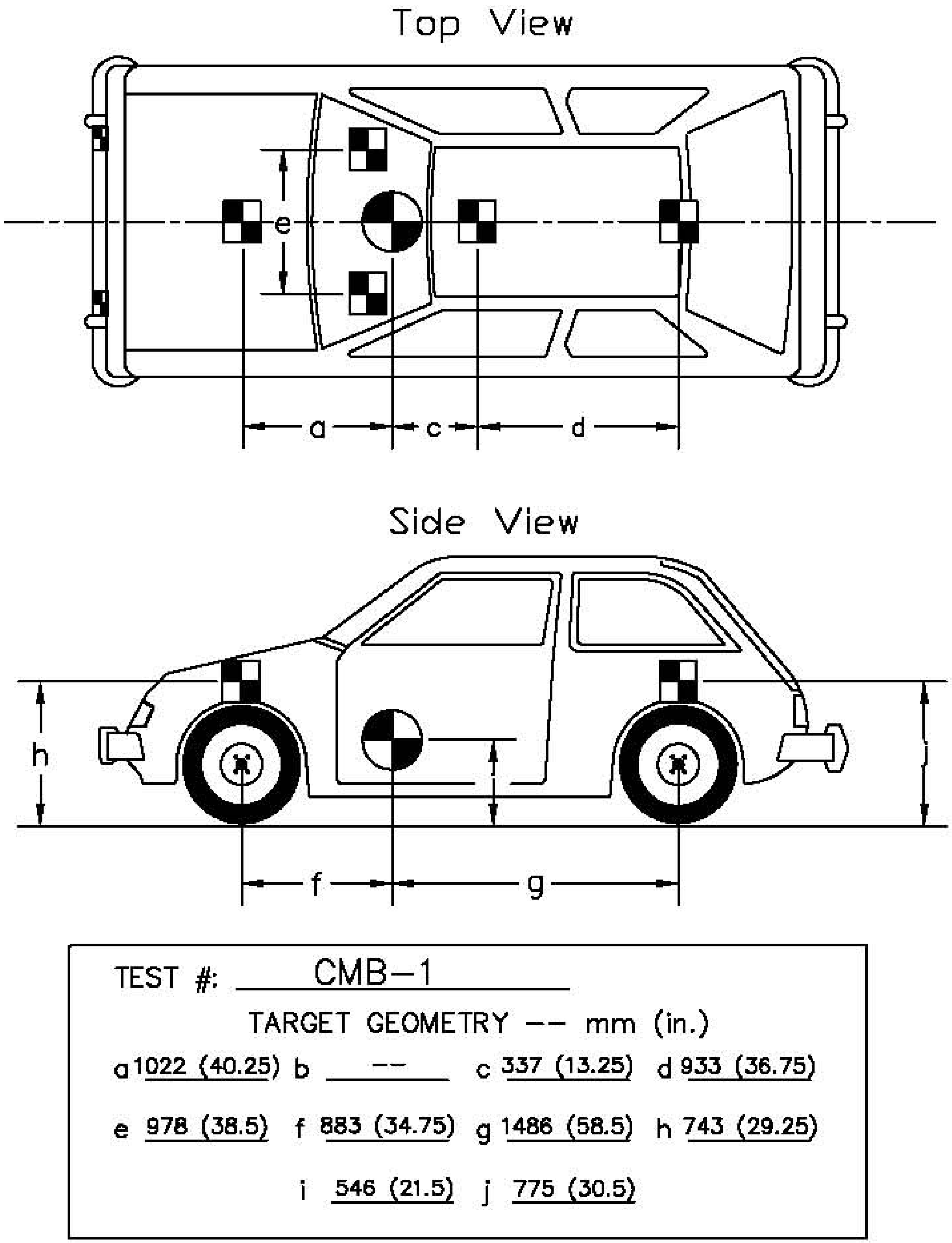
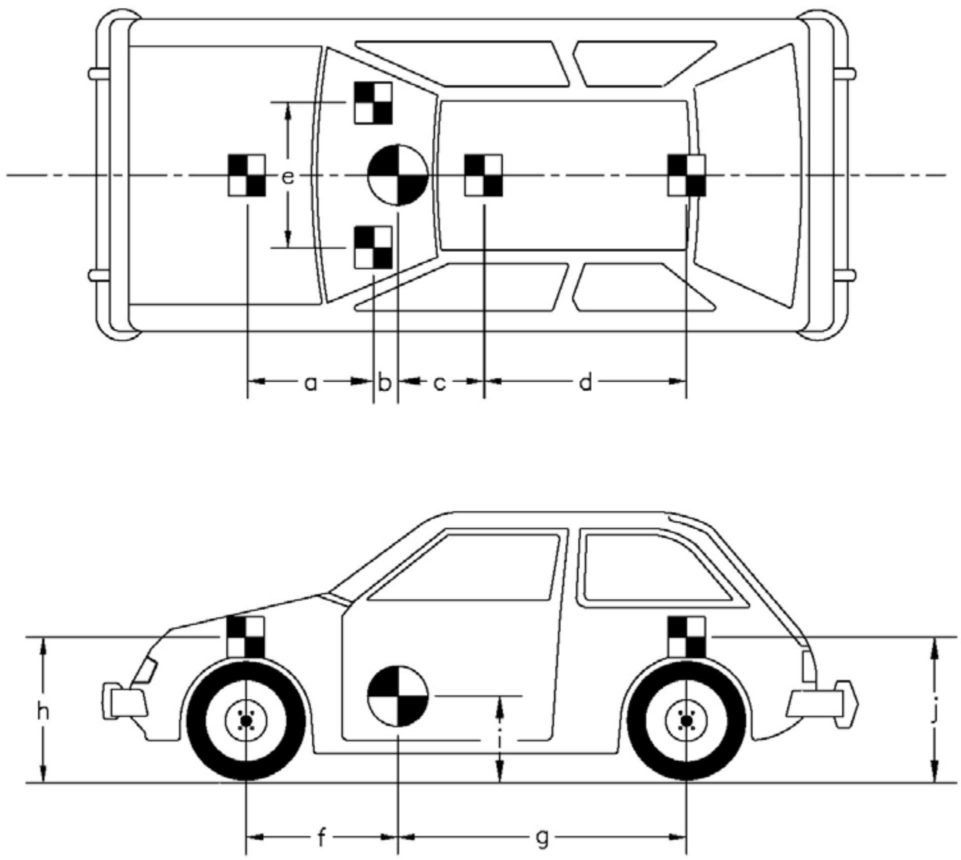


Figure 7. Vehicle Target Locations, Test CMB-1

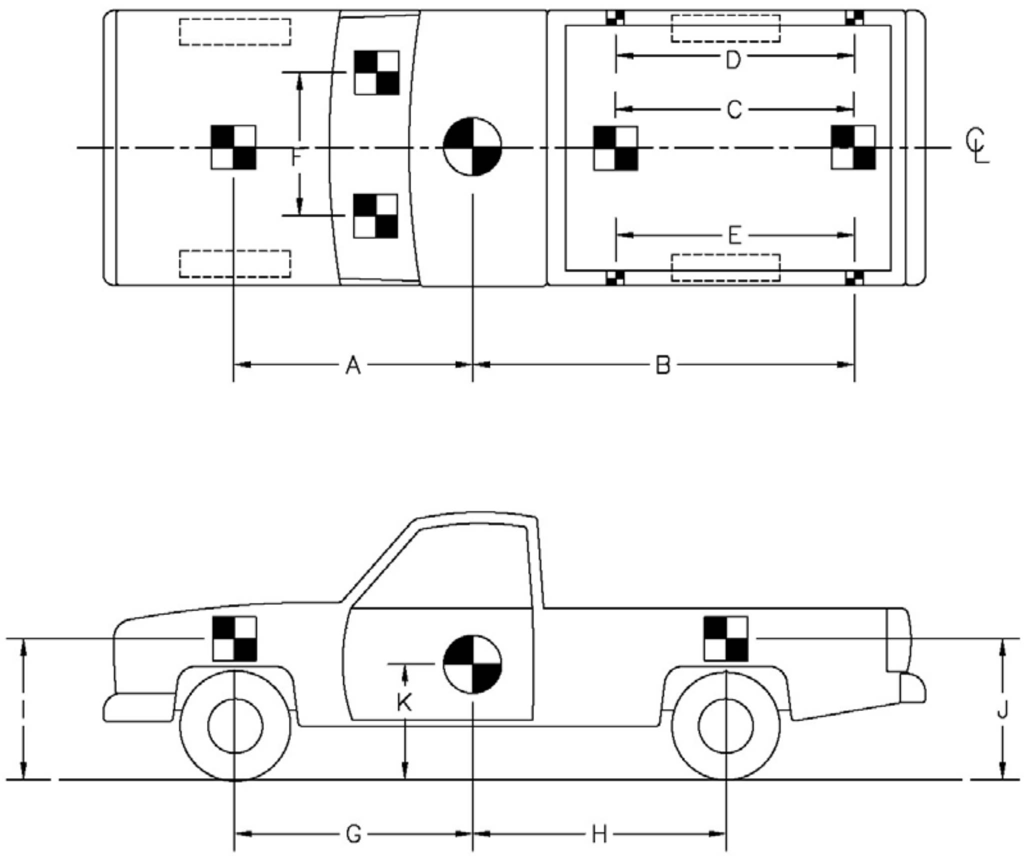


TEST #: CMB-2

TARGET GEOMETRY -- mm (in.)

a 1461 (57.5)	b –	c 295 (11.625)	d 987 (38.875)
e 689 (27.125)	f 905 (35.625)	g 1464 (57.625)	h 613 (24.125)
	i 546 (21.5)	j 756 (29.75)	

Figure 8. Vehicle Target Locations, Test CMB-2



TEST #: CMB-3

TARGET GEOMETRY -- mm (in.)

A 1689 (66.5)	D 2149 (84.625)	G 1394 (54.9)	J 1080 (42.5)
B 2477 (97.5)	E 2153 (84.75)	H 1939 (76.35)	K 667 (26.25)
C 1422 (56.0)	F 889 (35.0)	I 1016 (40.0)	

Figure 9. Vehicle Target Locations, Test CMB-3

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 the 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 1,500 Hz lowpass filter. Computer software, "DynaMax 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 the 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-3, was developed by Instrumental Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM memory and a 1,120 Hz lowpass filter. Computer software, "DynaMax 1 (DM-1)" and "DADiSP", was used to analyze and plot the accelerometer data.

3.4.2 Rate Transducers

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 CMB-1, three high-speed 16-mm Red Lake Locam cameras, with operating speed of approximately 500 frames/sec, were used to film the crash test. Four high-speed Red Lake E/cam video cameras, and one high-speed Photron video camera, all with operating speeds of 500 frames/sec, were also used to film the crash test. Five Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all thirteen camera locations for test no. CMB-1 is shown in Figure 10.

For test CMB-2, three high-speed Red Lake E/cam video cameras, one high-speed AOS VITcam video camera, and two high-speed Photron video cameras, all with operating speeds of 500 frames/sec were used to film the crash test. Five Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all eleven camera locations for test no. CMB-2 is shown in Figure 11.

For test CMB-3, two high-speed Photron video cameras, one high-speed AOS VITcam video camera, and three high-speed Red Lake E/cam video cameras, all with operating speeds of 500 frames/sec, were used to film the crash test. Seven Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all thirteen camera locations for test no. CMB-3 is shown in Figure 12.

The Locam films, Photron and AOS videos, and E/cam videos were analyzed using the Vanguard Motion Analyzer, ImageExpress MotionPlus software, and Redlake Motion Scope software, respectively. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

3.4.4 Pressure Tape Switches

For tests CMB-1, CMB-2, and CMB-3, 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 left-front tire of the test vehicle passed over it. Test vehicle speed was determined from electronic timing mark data recorded using the Test Point software. Strobe lights and high-speed film analysis are used only as a backup in the event that vehicle speed cannot be determined from the electronic data.

3.4.5 Load Cells

Six load cells were installed along the four-cable guardrail system for test CMB-1. Four load cells were positioned in line on each cable on the upstream end. Load cells were attached in line on the middle two cables on the downstream end. The load cell positions is shown in Figure 13.

The load cells were Transducer Techniques TLL-50K load cells with a load range up to 222.4 kN (50,000 lbs). During the test, output voltage signals from the load cells were sent to a Keithly Metrabyte DAS-1802HC data acquisition board, acquired with Test Point, and stored permanently on the computer. The sample rate of the load cells was 10,000 samples per second (10,000 Hz).

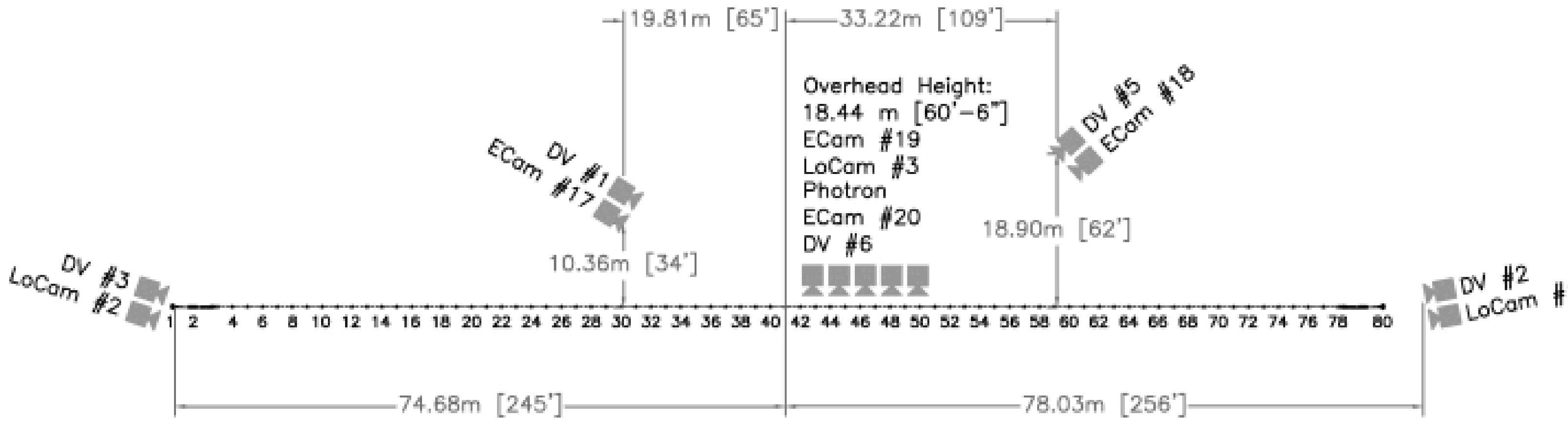


Figure 10. Camera Locations, Test CMB-1

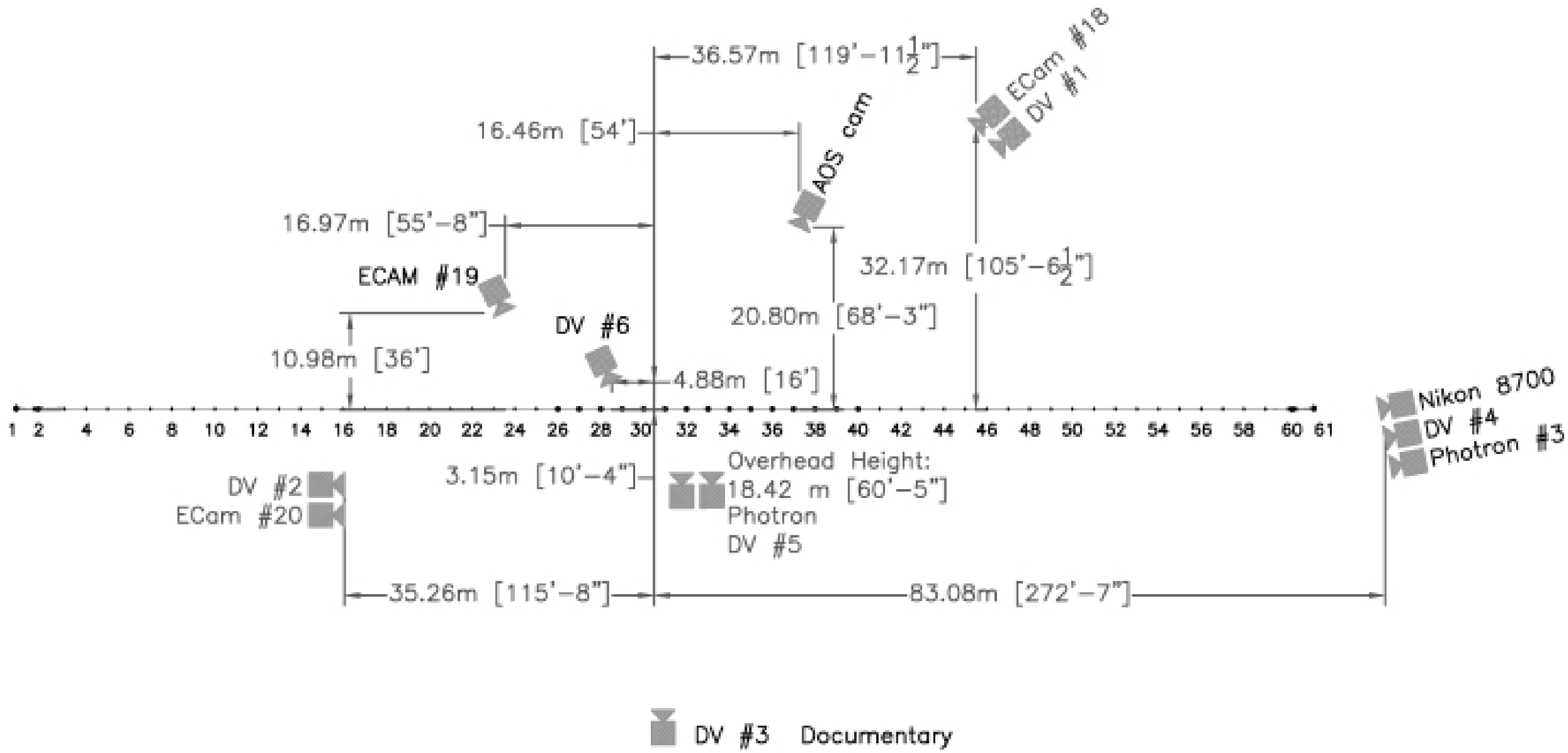


Figure 11. Camera Locations, Test CMB-2

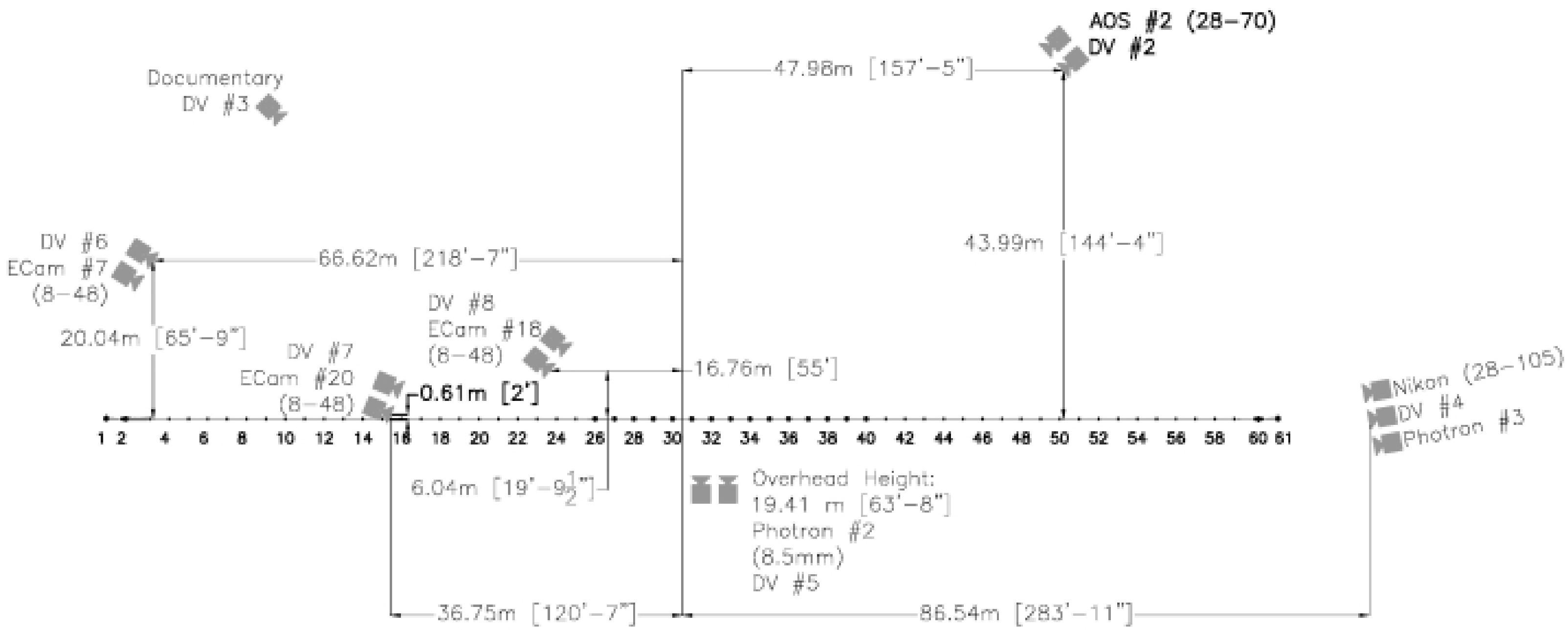


Figure 12. Camera Locations, Test CMB-3

Figure 13. Load Cell Configuration, Test CMB-1

4 CABLE MEDIAN BARRIER - DESIGN NO. 1

The total length of the installation was 148 m (486 ft). The test installation consisted of four major structural components: (1) wire rope; (2) posts; (3) spring compensating cable end assemblies; and (4) anchor assemblies. Design details are shown in Figures 14 through 29. The corresponding English-unit drawings are shown in Appendix A. Photographs of the test installation are shown in Figures 30 through 32.

Four separate lines of 19-mm (0.75-in.) diameter, 3x7 wire rope defined the rail elements. The cable rails were supported by 80 guardrail posts with an uppermost mounting height of 864 mm (34 in.) and with an 178-mm (7-in.) incremental spacing, as shown in Figures 14 and 28. The four cables were pre-tensioned to 2.69 N (0.9 kips). Line post nos. 2 through 79 were spaced 1,829 mm (72 in.) apart, while post nos. 1 and 80 were spaced 2,438 mm (96 in.) away from post nos. 2 and 79, respectively. A spring compensating cable assembly was placed within the 3,048-mm (120-in.) span between post nos. 2 and 3 and post nos. 78 and 79, as shown in Figure 15.

A 2,438-mm (96-in.) long, W152x36.8 (W6x25) steel post was used for each cable anchor base for post nos. 1 and 80. Using the auger and backfill method, these anchor posts were embedded to a depth of 2,438 mm (96 in.) in compacted, course soil that met the criteria for Grading B of AASHTO M147-65 (1990) as found in NCHRP Report No. 350 (1). The cable anchor assembly and parts are shown in Figures 16 through 20 and Figure 31. A 13-mm (0.5-in.) thick by 610-mm (24-in.) square soil plate was welded to the flange of the cable anchor base post by a series of 10-mm (3/8-in.) fillet welds. A 13-mm x 368-mm x 229-mm (0.5-in. x 14.5-in. x 9-in.) anchor base plate was welded to the top of the steel post to complete the cable anchor post. Another 13-mm x 368-mm x 229-mm (0.5-in. x 14.5-in. x 9-in.) steel plate formed the cable anchor bracket, as shown in

Figures 18, 19, and 31. Two 5mm x 32-mm x 32-mm x 495-mm (0.1875-in. x 1.25-in. x 1.25-in. x 19.5-in.) tubes were used to create the cable release lever that was welded to the cable anchor bracket. The cable anchor bracket was bolted to the cable anchor post using 19-mm (0.75-in.) diameter, 64-mm (2.5-in.) long, Grade 5 hex head bolts to complete the cable anchor assembly.

An 1,829-mm (72-in.) long, W152x13.4 (W6x9) steel post and an 863-mm (34 in.) long, S76x8.5 (S3x5.7) steel post were used for the cable support post in post nos. 2 and 79. Using the auger and backfill method, the base posts were embedded to a depth of 1,762 mm (69.375 in.) in compacted, coarse soil that met the criteria for Grading B of AASHTO M147-65 (1990) as found in NCHRP Report No. 350 (1). The breakaway cable support post is shown in Figures 21 through 27 and Figure 32. A 13-mm x 153-mm x 127-mm (0.5-in. x 6-in. x 5-in.) ASTM A36 steel base slip plate was welded onto a W152x13.4 (W6x9) steel post to comprise the cable support post base. A 13-mm x 686-mm x 51-mm (0.5-in. x 27-in. x 2-in.) slotted, ASTM A36 steel plate was welded onto an 863-mm (34-in.) long, S76x8.5 (S3x5.7) steel post, and a 9.5-mm x 102-mm x 127-mm (0.375-in. x 4-in. x 5-in.) steel slip plate was welded onto the base of the steel post to form the upper cable support breakaway post, as shown in Figures 24 and 32. Two 6-mm x 178-mm x 432-mm (0.25-in. x 7-in. x 17-in.) bearing plates were welded onto two 1,016-mm (40-in.) long steel bearing plate braces to form the bearing strut. The bearing strut was bolted onto the cable support base using a 13-mm (0.5-in.) diameter, 203-mm (8-in.) long, ASTM A307 hex head bolt and fastened with a nut. The cable support post base was then bolted to the upper cable support breakaway post using four 13-mm (0.5-in.) diameter, 64-mm (2.5-in.) long, ASTM A307 hex head bolts and fastened with nuts, as shown in Figure 21.

A 1,981-mm (78-in.) long, M203x9.7 (M8x6.5) rolled steel section was used for line post nos. 3 through 78, as was recommended by previous bogie testing (3). Using the auger and backfill method, the section incorporated an 1,067-mm (42-in.) embedment depth in compacted, coarse soil that met the criteria for Grading B of AASHTO M147-65 (1990) as found in NCHRP Report No. 350 (1). The line post is shown in Figures 28 through 30. Four holes were drilled in the left flange of each side of the posts, beginning 64 mm (2.5 in.) from the top of the post with an 178-mm (7-in.) incremental spacing, as shown in Figure 29. Four 16-mm (0.625-in.) diameter, 54-mm (2.125-in.) long, Grade 5 cable hook bolts were placed in the holes such that each flange held two bolts. The top and bottom bolts were attached to one flange, and the lower-middle and upper-middle bolts were attached to the opposite flange. The cable hook bolts were attached to each post with a Grade 2, 16-mm (0.625-in.) diameter nut. The placement of the cable hook bolts on the line posts alternated between the top and bottom holes and the middle two holes to create a weave pattern, as shown in Figures 14 and 30.

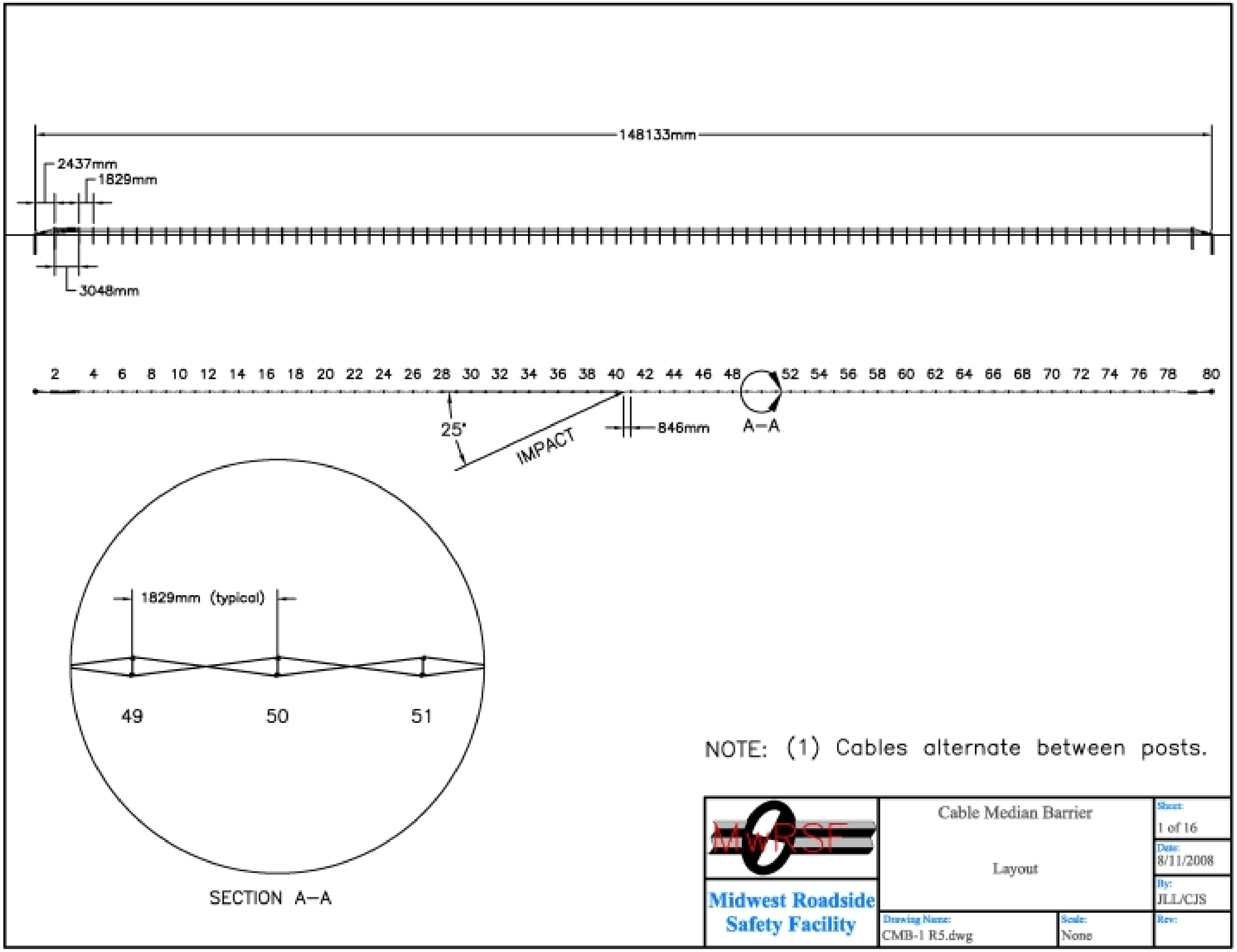


Figure 14. System Layout, Design No. 1

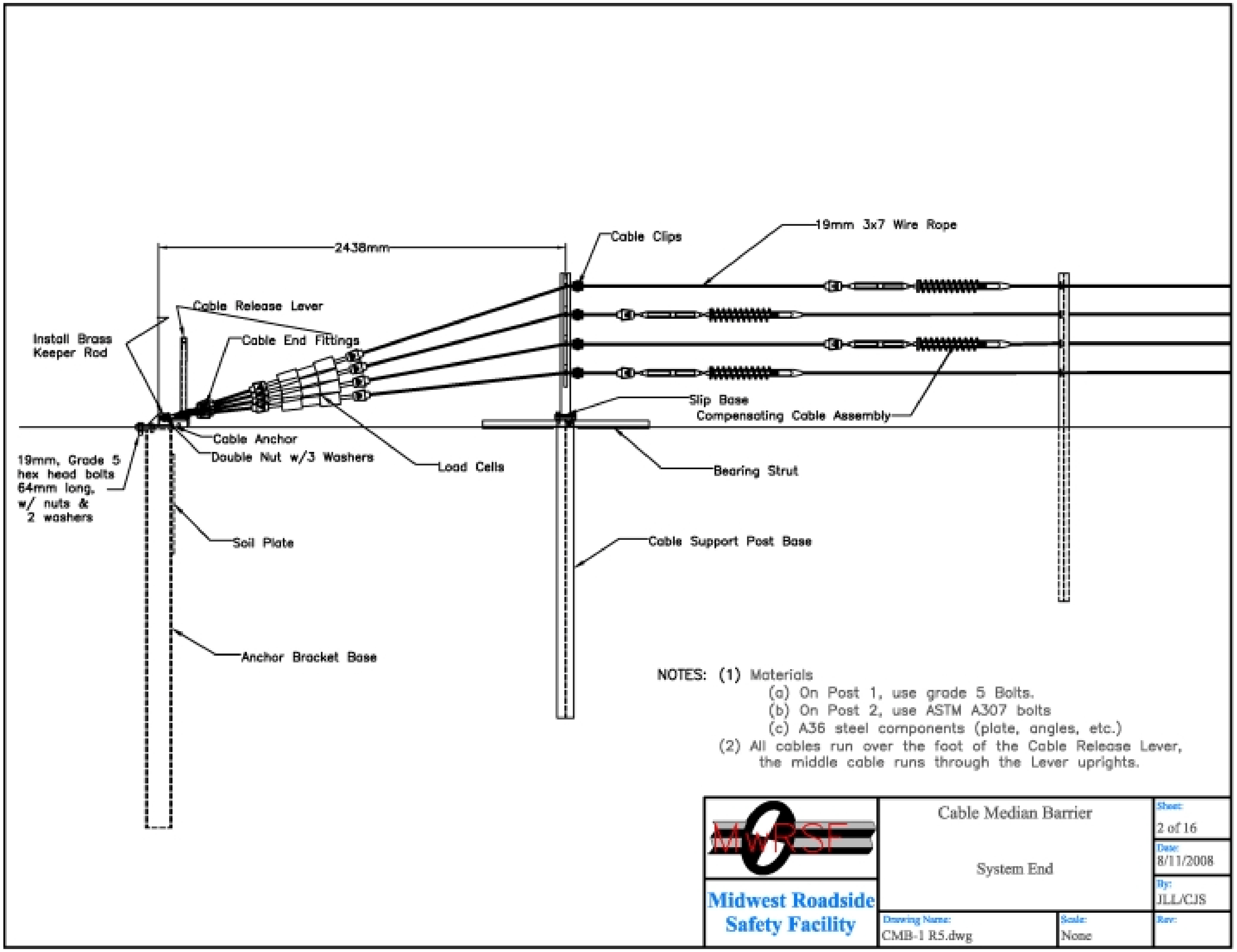


Figure 15. System End, Design No. 1

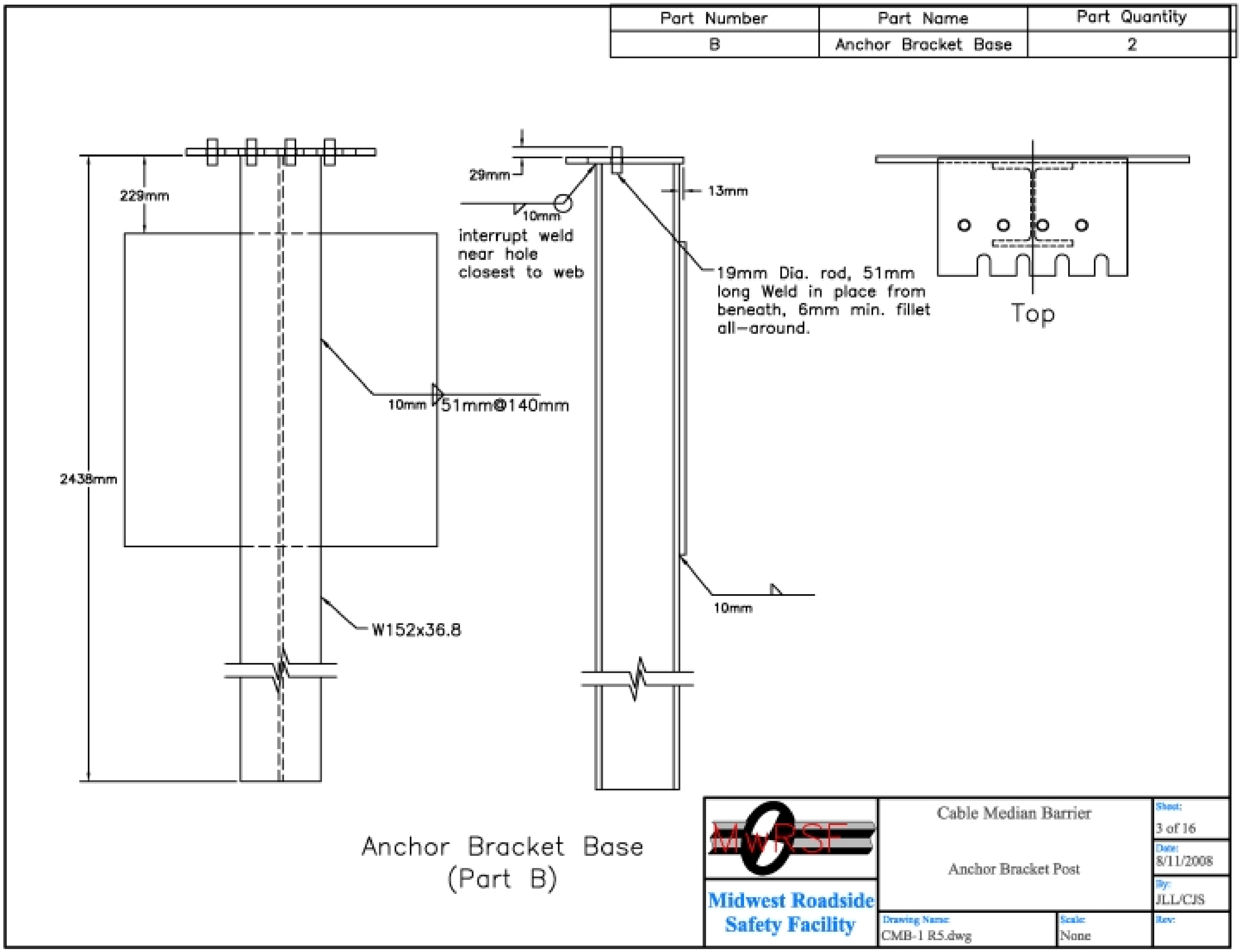
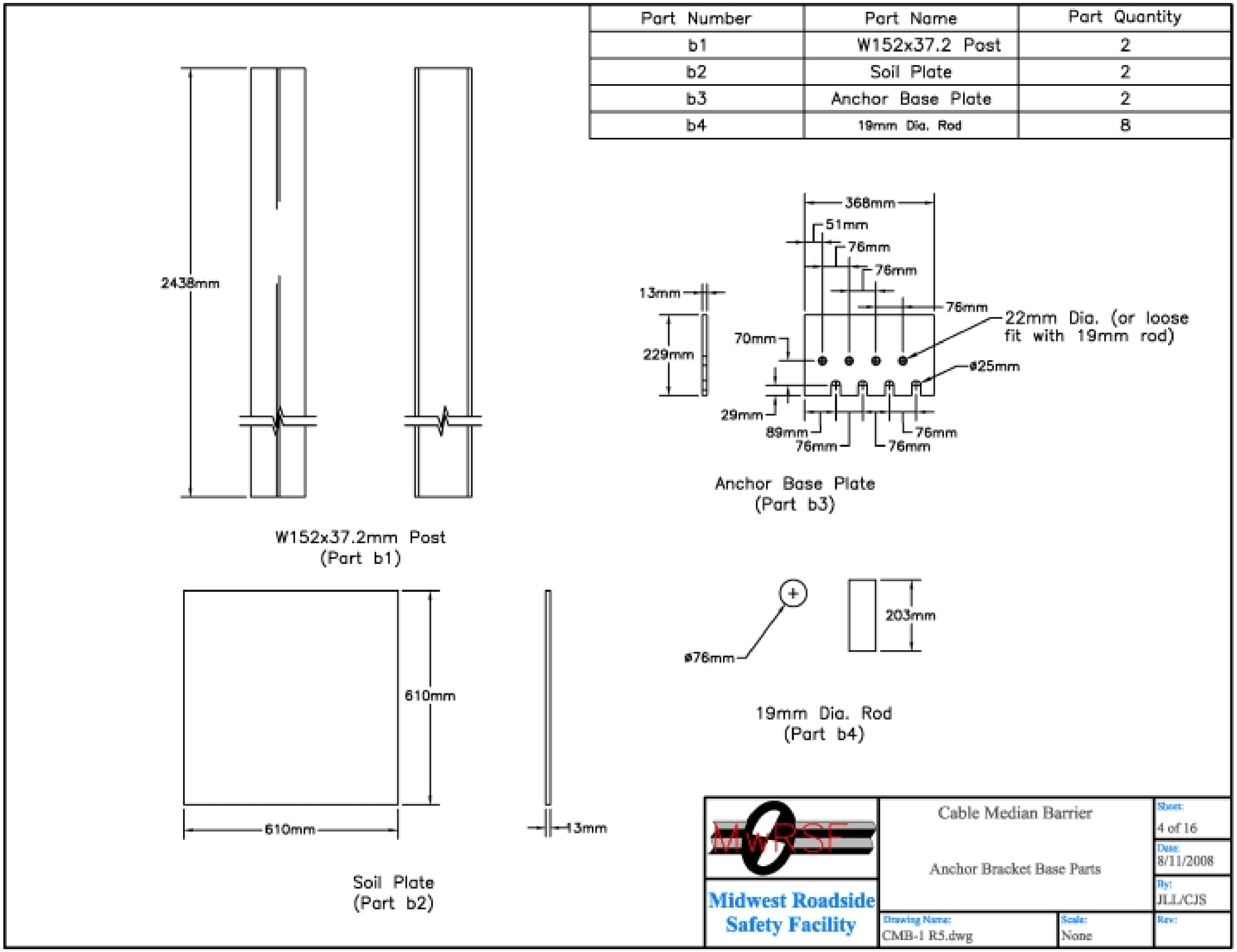


Figure 16. Anchor Bracket Post, Design No. 1



Part Number	Part Name	Part Quantity
b1	W152x37.2 Post	2
b2	Soil Plate	2
b3	Anchor Base Plate	2
b4	19mm Dia. Rod	8

Figure 17. Anchor Bracket Base Parts, Design No. 1

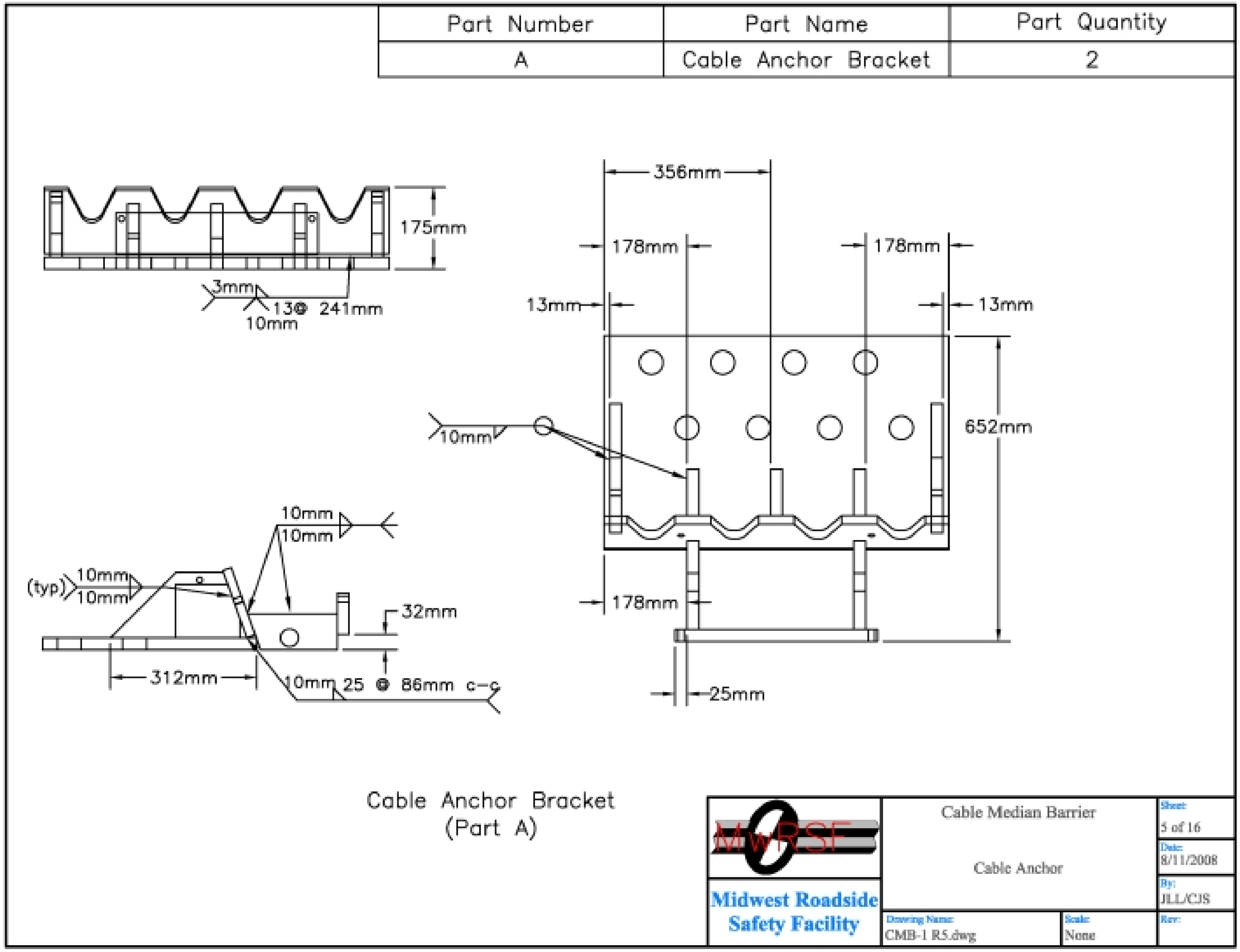
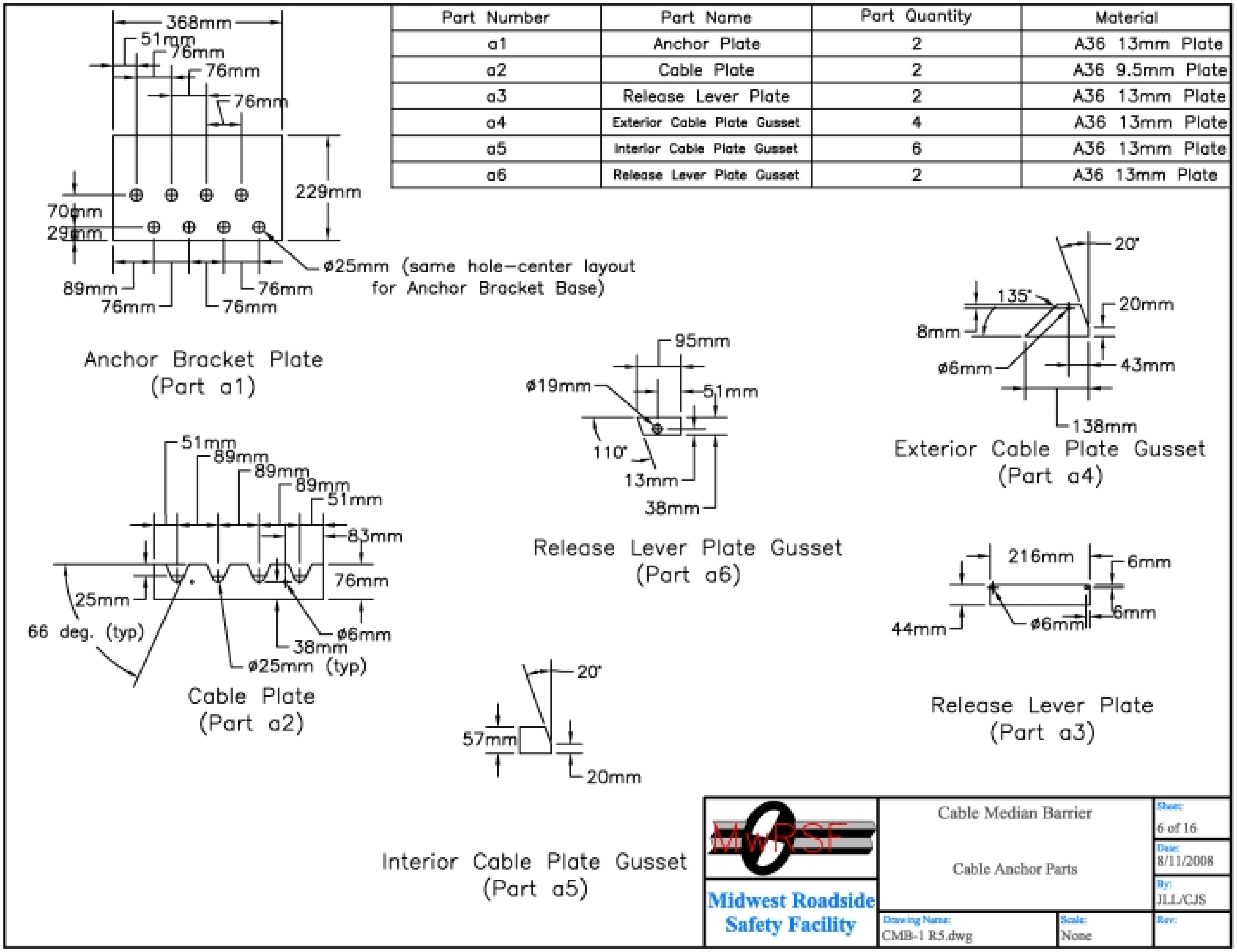


Figure 18. Cable Anchor Bracket, Design No. 1



Part Number	Part Name	Part Quantity	Material
a1	Anchor Plate	2	A36 13mm Plate
a2	Cable Plate	2	A36 9.5mm Plate
a3	Release Lever Plate	2	A36 13mm Plate
a4	Exterior Cable Plate Gusset	4	A36 13mm Plate
a5	Interior Cable Plate Gusset	6	A36 13mm Plate
a6	Release Lever Plate Gusset	2	A36 13mm Plate

Figure 19. Cable Anchor Bracket Parts, Design No. 1

Part Number	Part Name	Part Quantity	Material
F	Cable Release Lever	2	
f1	Kicker Lever	4	A36 32x32x4.8mm tube
f2	Connecting Tube	2	A36 32x32x4.8 mm tube
f3	Kicker Plate Gusset	4	A36 13 mm Plate
f4	Kicker Plate	2	A36 13mm Plate

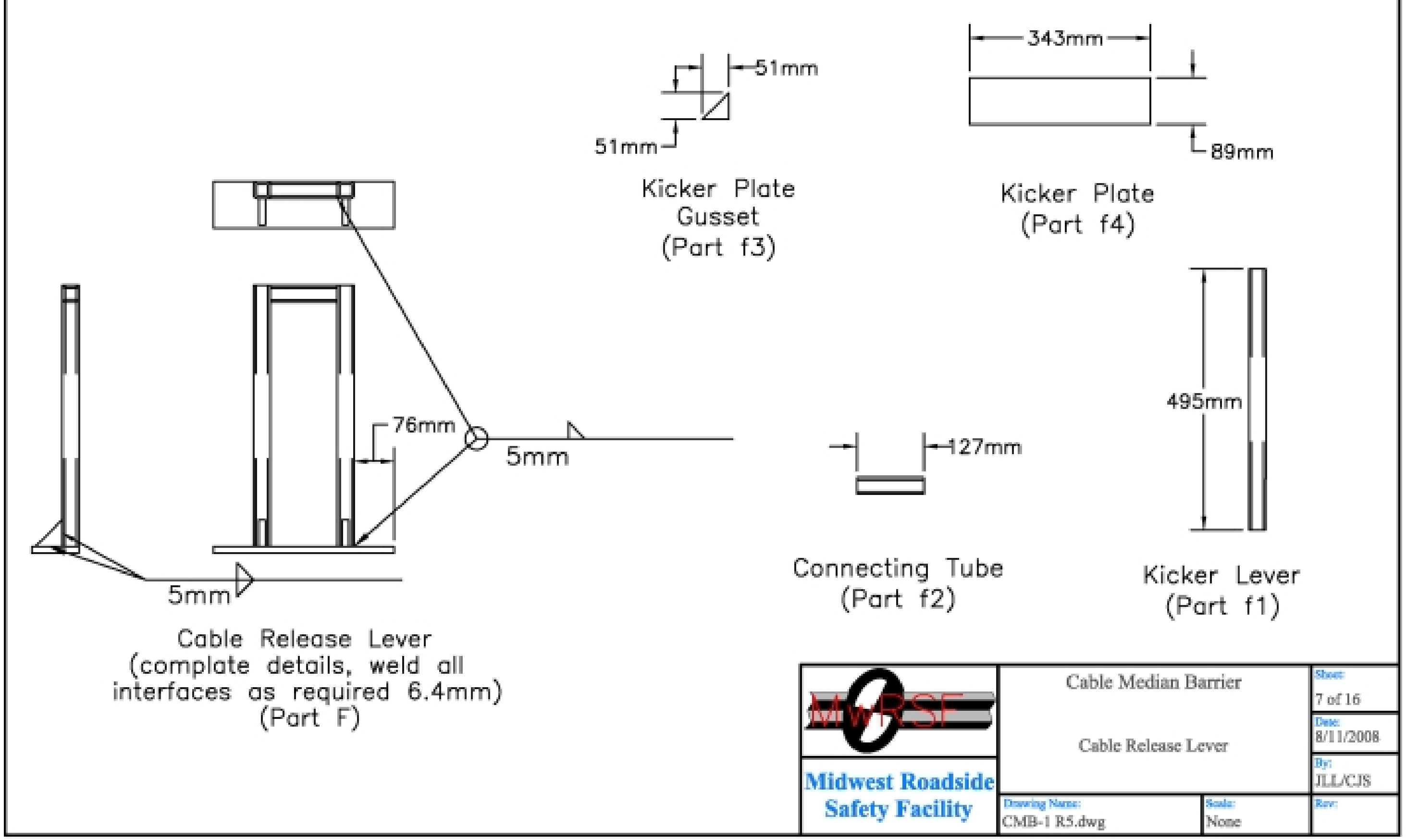


Figure 20. Cable Release Lever, Design No. 1

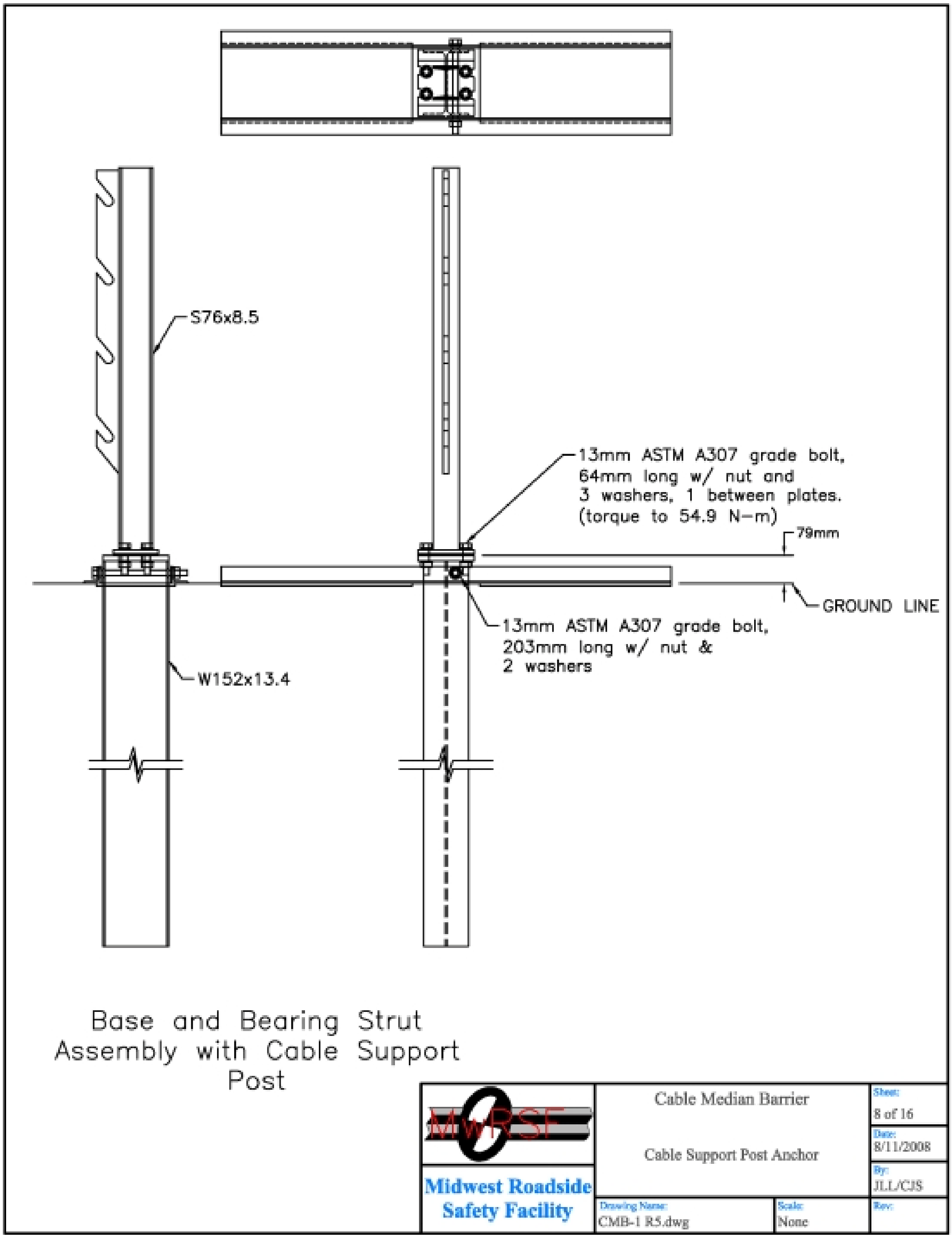


Figure 21. Cable Support Post Anchor, Design No. 1

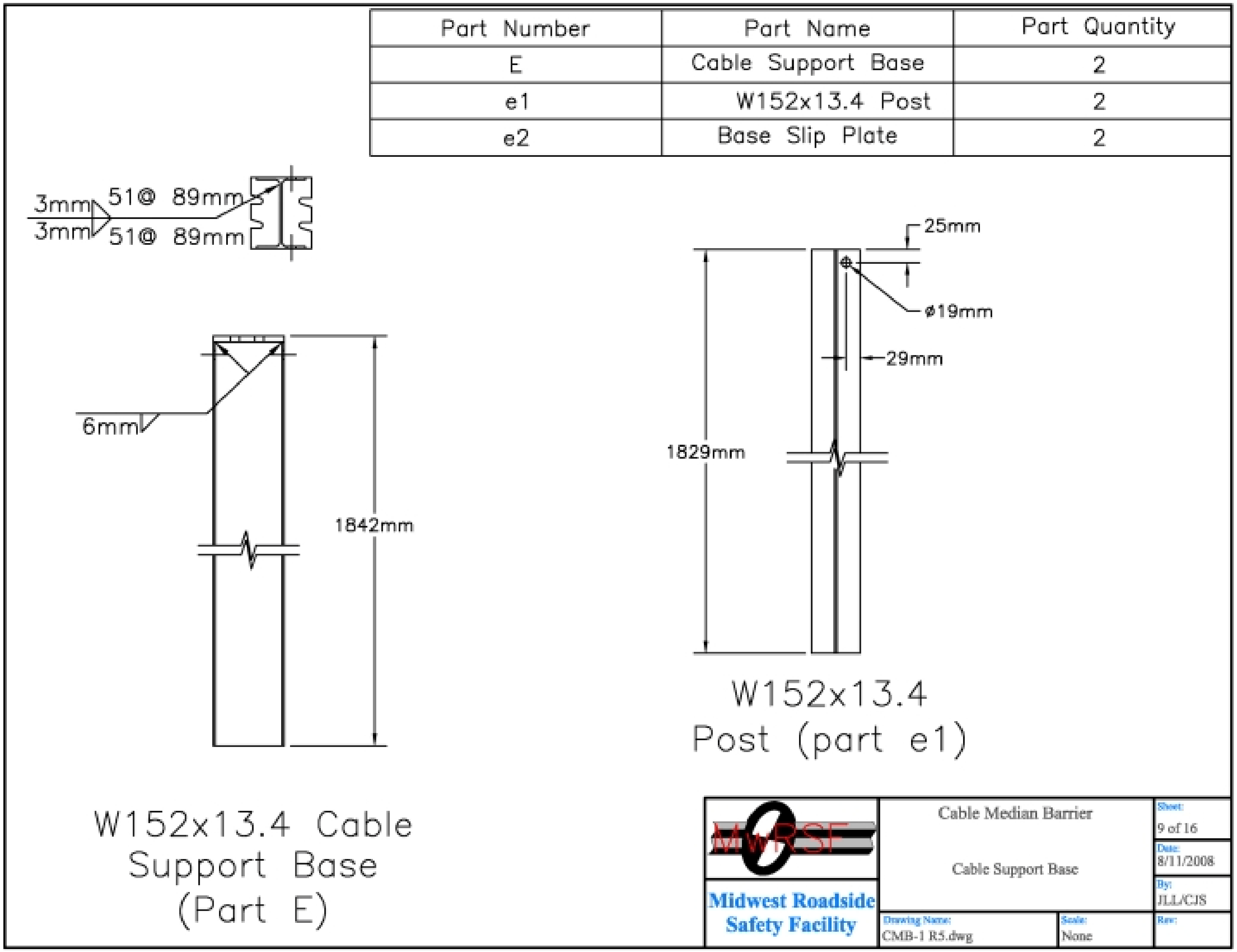


Figure 22. Cable Support Base, Design No. 1

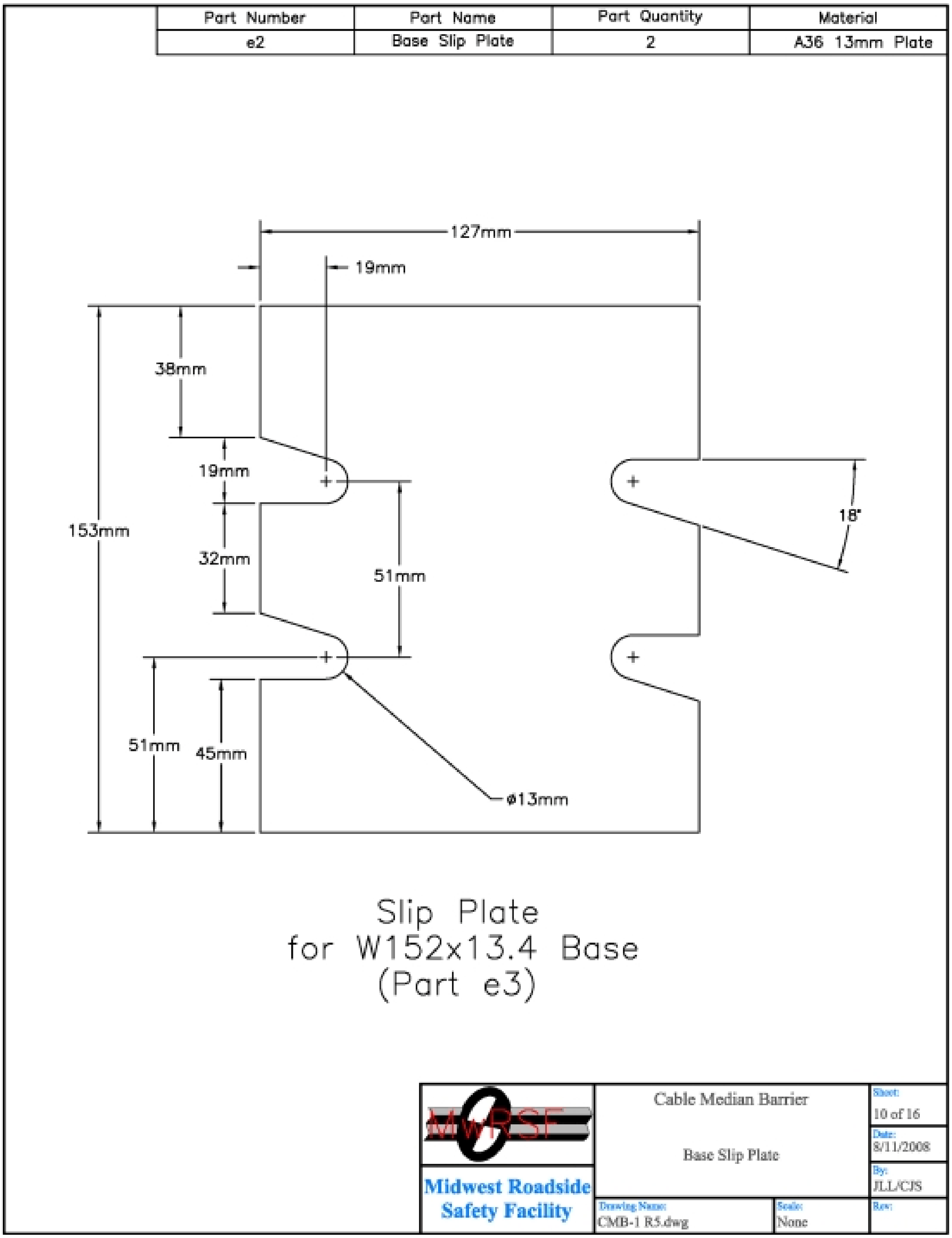


Figure 23. Base Slip Plate, Design No. 1

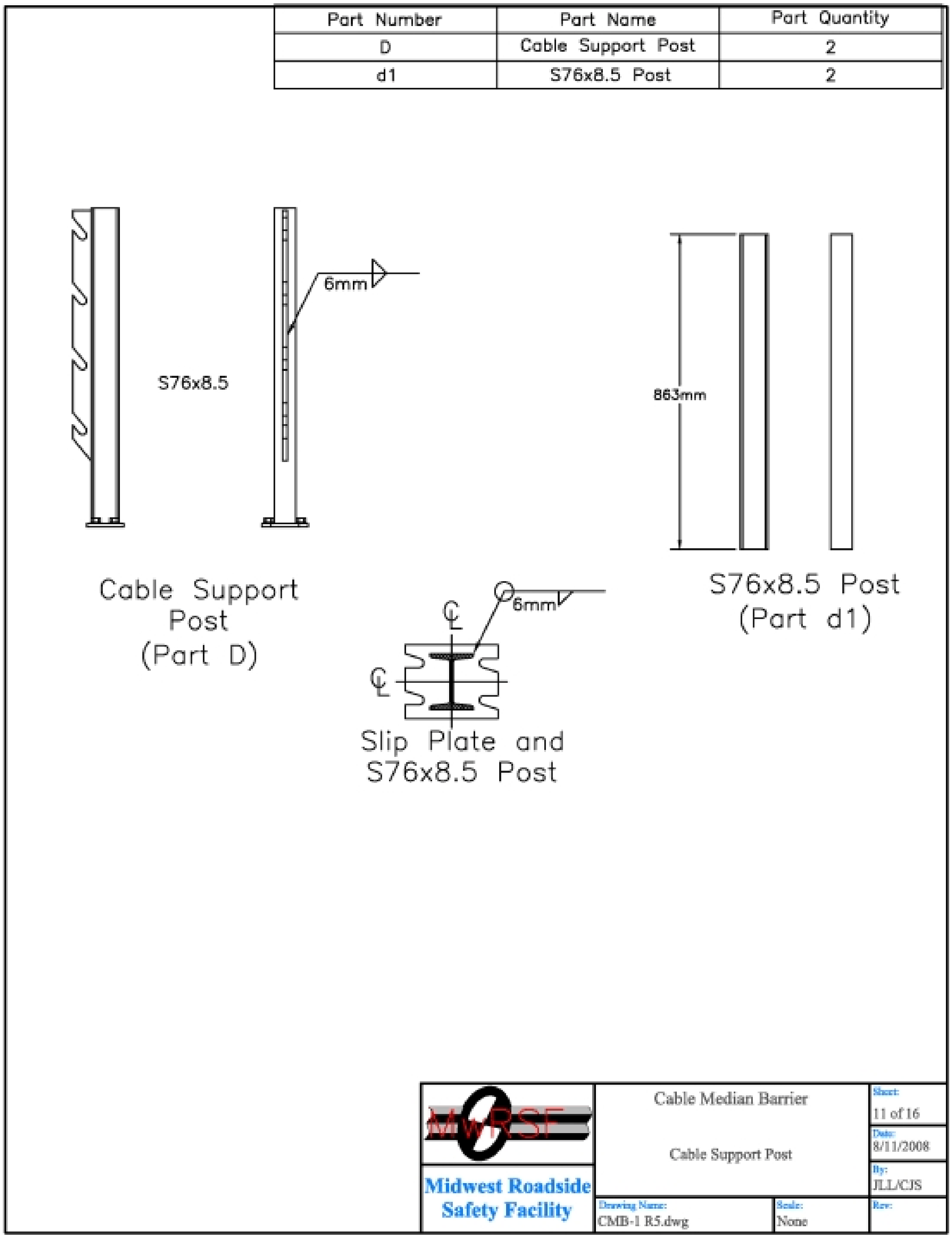


Figure 24. Cable Support Post, Design No. 1

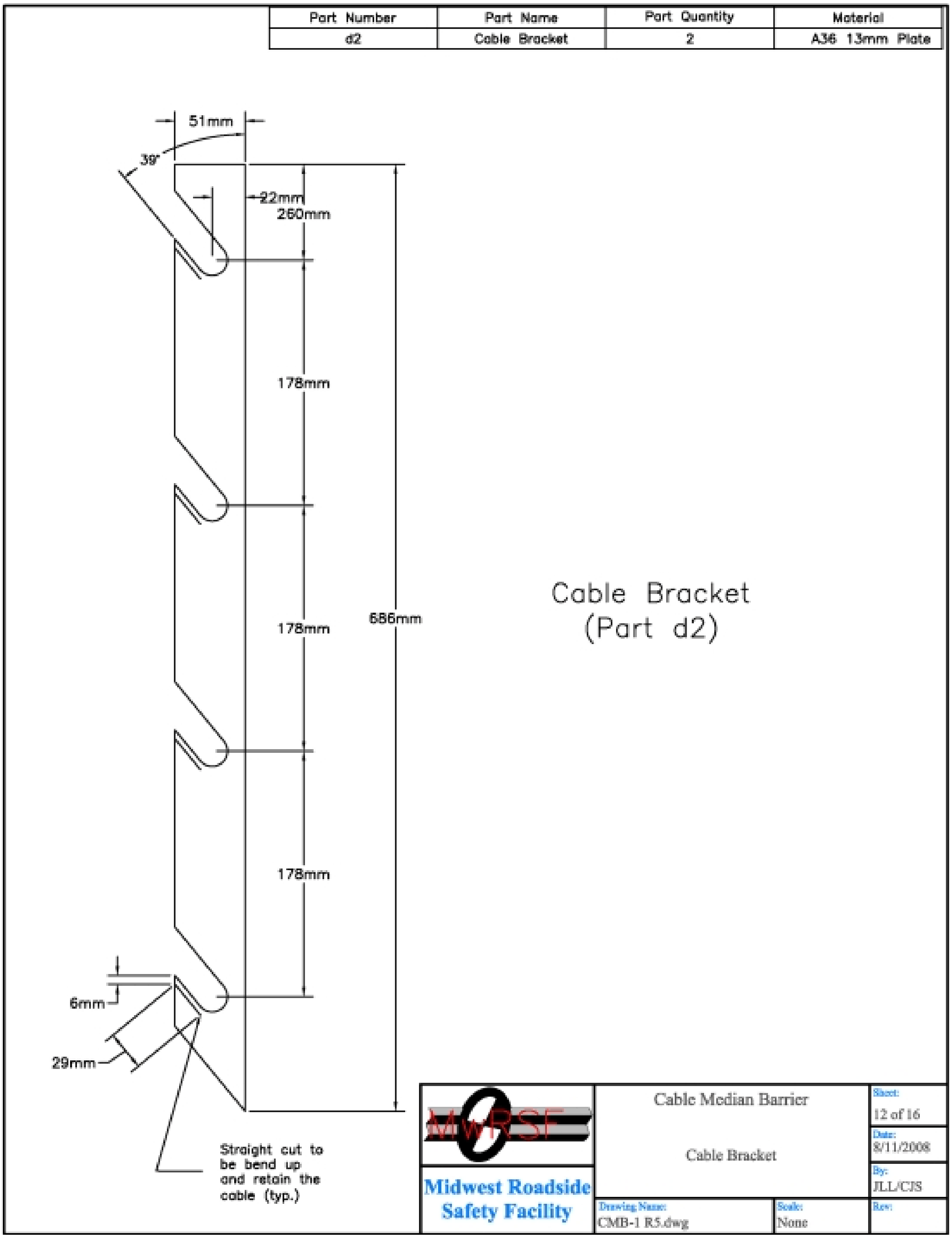


Figure 25. Cable Bracket, Design No. 1

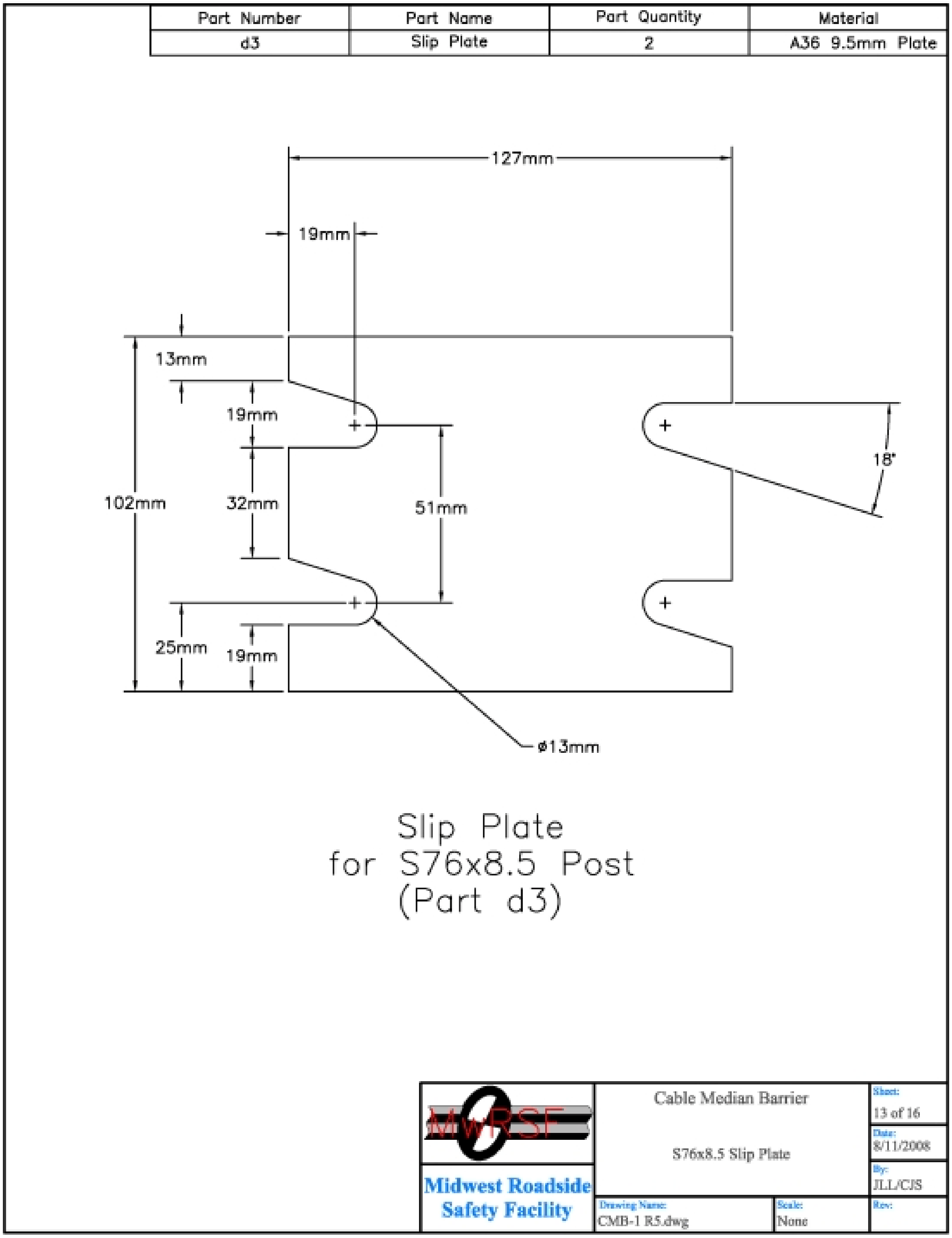


Figure 26. Cable Bracket Slip Plate, Design No. 1

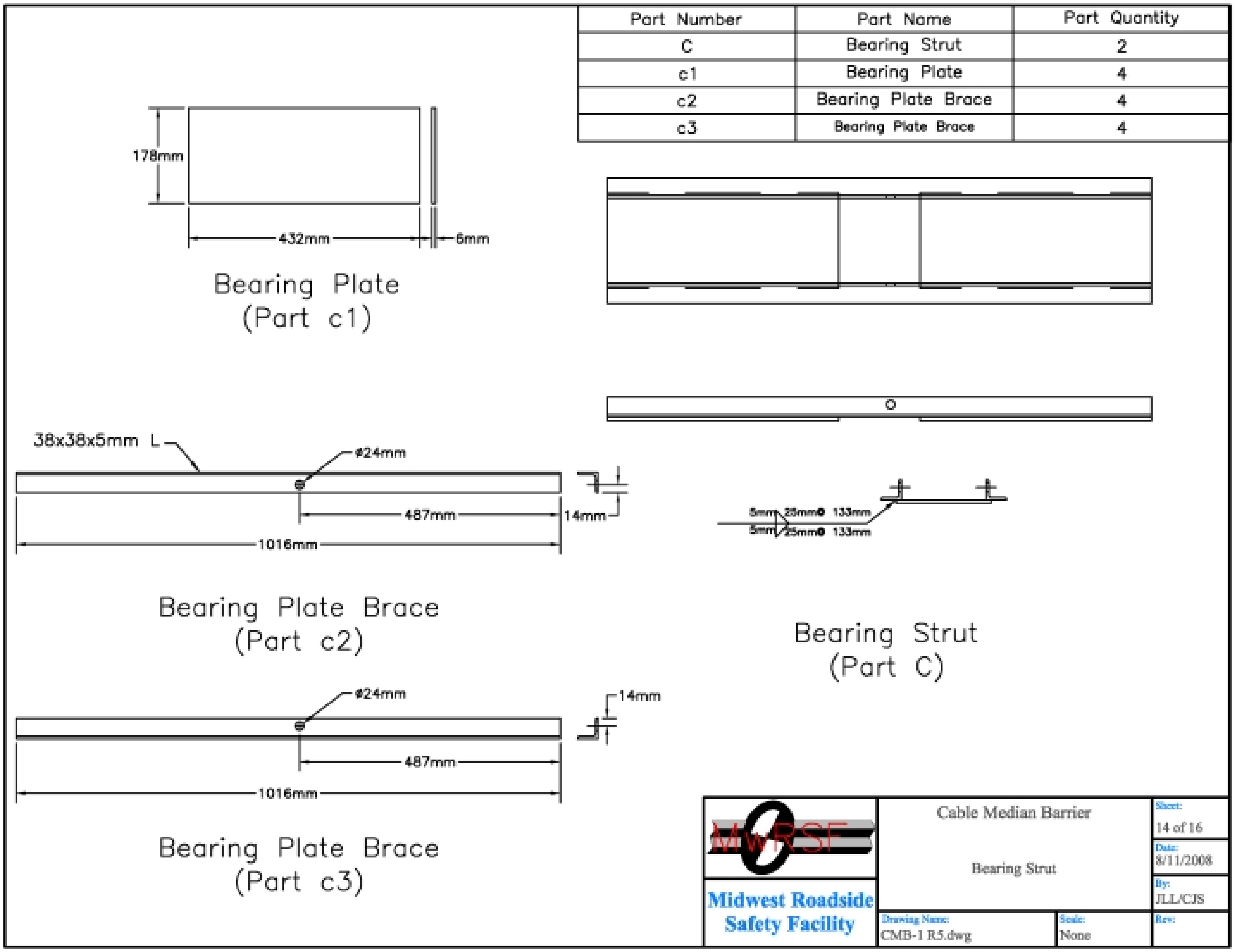


Figure 27. Bearing Strut, Design No. 1

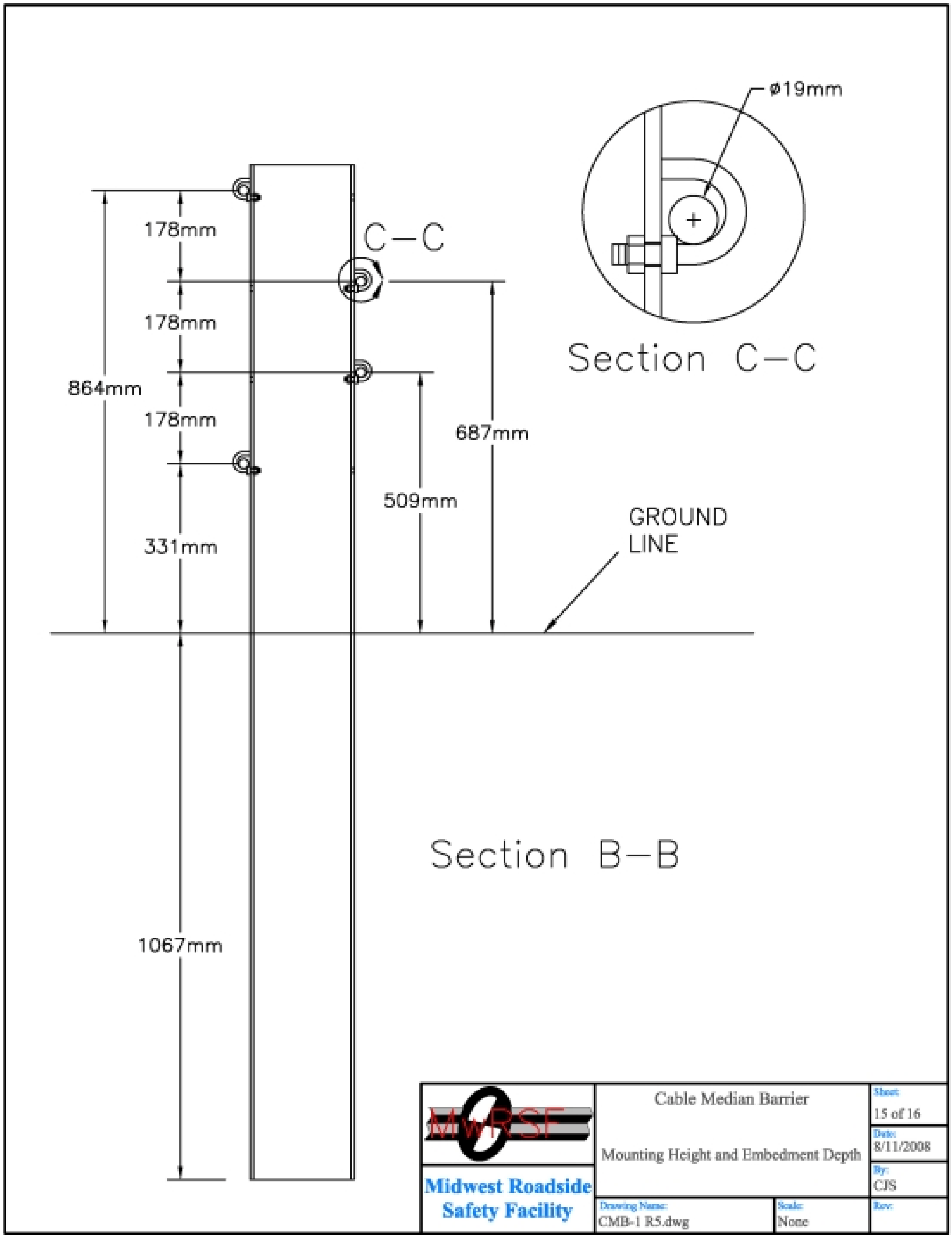


Figure 28. Cable Guardrail Post Assembly, Design No. 1

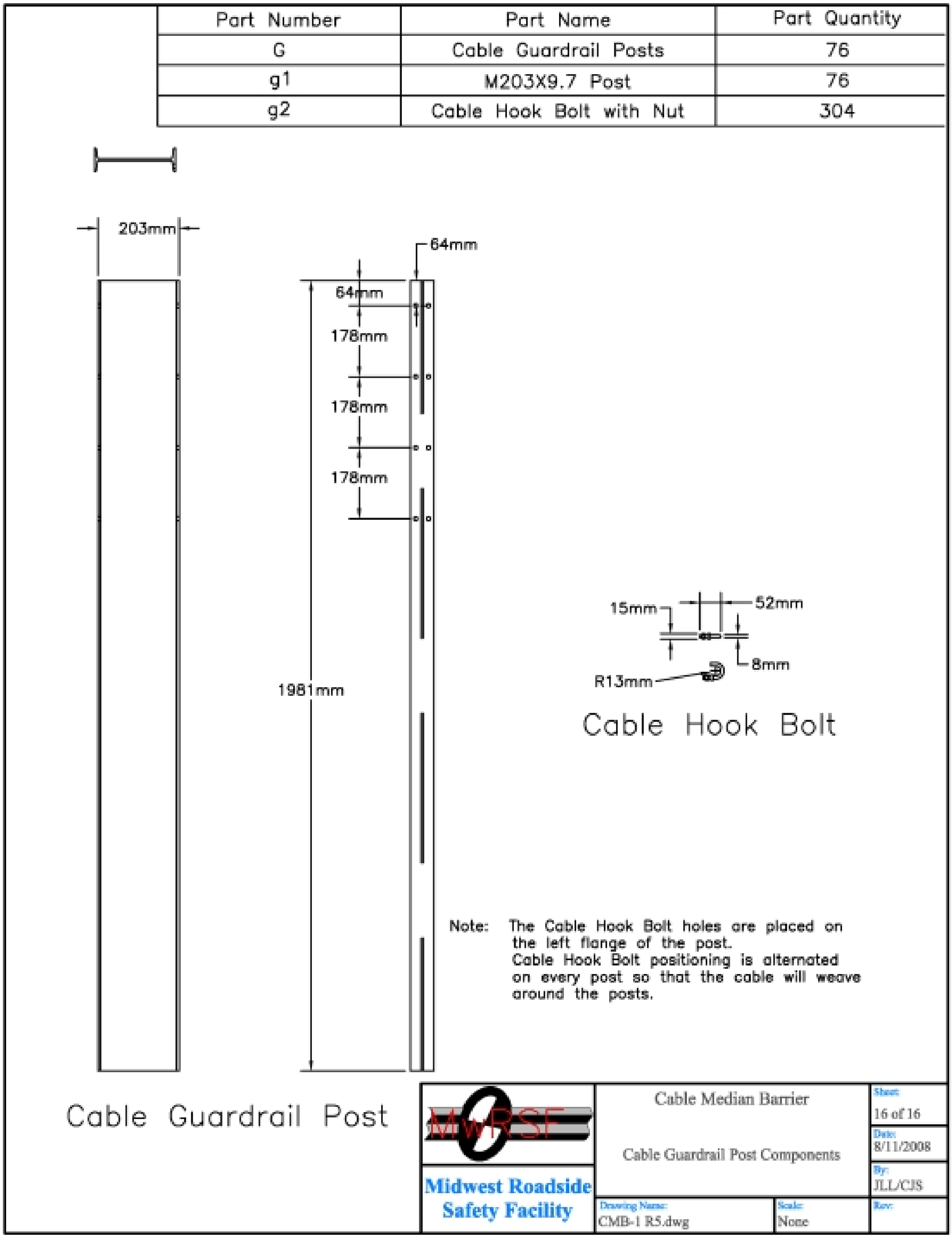


Figure 29. Cable Guardrail Post Components, Design No. 1

Figure 30. Low-Tension Cable Median Barrier, Design No. 1

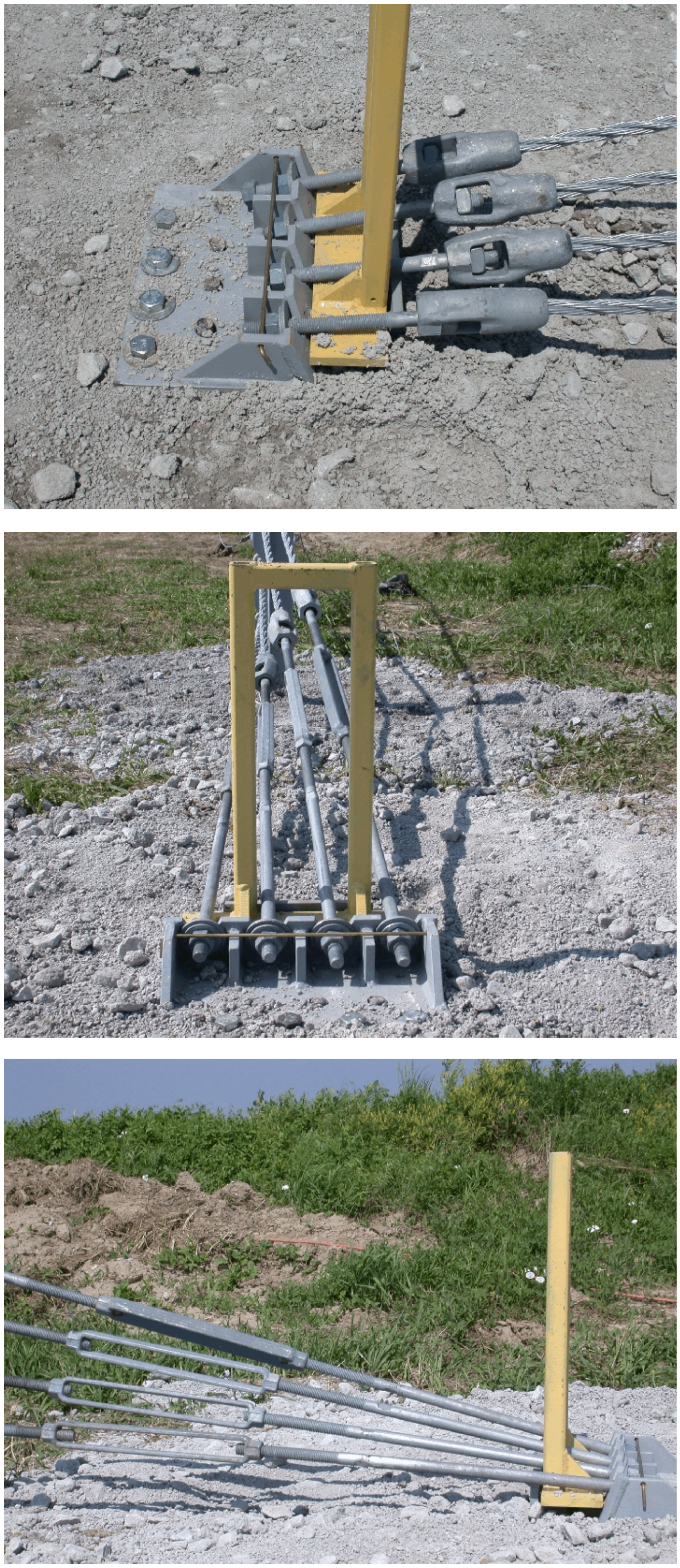


Figure 31. Cable Anchor, Design No. 1

Figure 32. Cable Support Post, Design No. 1

5 CRASH TEST NO. 1 (DESIGN NO. 1)

5.1 Test No. CMB-1

The 893-kg (1,969-lb) small car impacted the cable median barrier (Design No. 1) at a speed of 97.6 km/h (60.6 mph) and at an angle of 19.7 degrees. A summary of the test results and sequential photographs are shown in Figure 33. The summary of the test results and sequential photographs in English units are shown in Appendix B. Additional sequential photographs are shown in Figures 34 and 35. Documentary photographs are shown in Figures 36 through 40**.**

5.2 Test Description

Initial vehicle impact was to occur between post nos. 40 and 41, or 846 mm (33.3 in.) upstream from post no. 41, as shown in Figure 41. At impact, the left-front corner of the bumper protruded between the cables with the top cable above the hood of the vehicle. At 0.016 sec after initial impact, post no. 41 deflected due to contact with front bumper. At 0.030 sec, the left-front tire was located on top of post no. 41, and post no. 40 was bending toward the ground. At 0.062 sec, post no. 40 deflected downstream and buckled as it rotated counter-clockwise. At 0.068 sec, the vehicle impacted post no. 42, while the upper-middle cable was deforming the sheet metal above the left-front wheel well. At 0.156 sec, the vehicle contacted post no. 43, and the left-rear tire lost contact with the ground. At this same time, the driver's-side window was shattered by the contact with the top cable. At 0.212 sec, the vehicle contacted post no. 44. At 0.306 sec, the vehicle had redirected parallel to the barrier with a speed of 78.6 km/h (48.9 mph). At 0.320 sec, the left side of the vehicle was airborne as the car contacted post no. 45. The vehicle impacted post no. 46 at 0.414 sec. At 0.561 sec, the right-rear tire was the only tire touching ground. At 1.110 sec, the car became airborne. At 1.200 sec, the vehicle exited the system at approximately 5 degrees with a velocity of

53.6 km/h (33.3 mph). At 1.674 sec, the car had rolled such that its entire right side was in contact with the ground. At 1.936 sec, the car had rolled completely over and was sliding on its roof. At 2.180 sec, the left-front corner of the car was the only vehicle component still in contact with the ground. At 2.312 sec, the vehicle was completely airborne, and it continued to roll. The final position of the vehicle was determined to be 34.5 m (113.2 ft) downstream from impact and 4.3 m (14.1 ft) laterally from the barrier, as shown in Figure 42.

5.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 43 through 45. Barrier damage consisted of bent and twisted guardrail posts and detached cables. The length of vehicle contact along the cable median barrier system was approximately 12.8 m (42 ft), which spanned from post no. 41 through post no. 48.

Soil gaps less than 3 mm (0.125 in.) wide developed at posts nos. 36 through 39. No other damage was visible to these posts. Post no. 40 had soil gaps of 16 mm (0.625 in.) on the front, 3 mm (0.125 in.) on the back, and 3 mm (0.125 in.) downstream. Post no. 42 had a 51-mm (2-in.) soil gap on the backside of the system. A 38-mm (1.5-in.) soil gap was created on both the front and back sides of post no. 44. A 13-mm (0.5-in.). A soil gap was formed on the upstream side of post no. 45 due to post bending below the ground surface. Post no. 46 had soil gaps of 64 mm (2.5 in.) on the backside and 19 mm (0.75 in.) on the front side. A soil gap of 3 mm (0.125 in.) was created on the front side of post no. 47. Post nos. 49 and 50 had soil gaps due to the post bending beneath the ground surface. Post no. 50 had a 3-mm (0.125-in.) soil gap behind the post. A 25 mm (1-in.) soil gap was formed on the upstream side of post no. 51, while a 3-mm (0.125-in.) gap was found on the backside. A 13-mm (0.5-in.) soil gap was formed on the upstream side of post no. 52.

The top cable was disengaged from the U-bolt and remained on the front face of post no. 40. All four cables were disengaged from their respective U-bolts for post nos. 41 through 43. Cable no. 4 was the only cable still attached to post no. 44. Cable no. 3 was the only cable still attached to post no 45. For post no. 46, cable no. 4 was the only cable still attached. Cable nos. 3 and 4 remained attached to post nos. 47 and 48. Cable no. 4 remained attached to post nos. 49 and 50. Cable no. 1 was the only cable not attached to post no. 51.

Posts no. 41 bent about the weak axis, and localized buckling occurred on the post's front flange. Post no. 41 was twisted 45 degrees counter-clockwise. Post no. 42 was bent toward the ground and was twisted counter-clockwise approximately 5 to 10 degrees. Post no. 43 also bent about its weak axis with minor counter-clockwise twisting. Post no. 44 bent to the ground and underwent significant lateral torsional buckling, beginning at the U-bolt location for cable no. 4. Post no. 44 was twisted counter-clockwise approximately 20 degrees. Post no. 45 was bent about its weak axis with minor twisting. Post no. 46 was bent to the ground, with local buckling of the back-downstream flange at ground level. Post no. 47 was bent slightly below ground level, causing it to appear like it had twisted clockwise. Post no. 48 was bent at the ground about its weak axis and was twisted counter-clockwise less than 5 degrees. Post nos. 49 and 50 were both bent to the ground about their weak axes. Post no. 51 was bent at ground level to approximately 45 degrees and twisted 15 degrees. Post no. 52 was bent approximately 80 degrees from the ground and twisted approximately 5 degrees. Post no. 53 remained vertical but was slightly twisted.

The permanent set of the posts is shown in Figures 43 through 45. The anchor ends encountered slight permanent set deformations, as shown in Figure 46. The maximum lateral permanent set post deflections were not calculated for this test. The maximum lateral dynamic post deflection was 545 mm (21.5 in.) at post no. 44, and the working width was determined to be 1,125 mm (44.3 in.), as determined from the high-speed film analysis.

5.4 Vehicle Damage

Exterior vehicle damage was extensive, as shown in Figures 47 through 49. Occupant compartment deformations occurred, especially to the roof and windshield due to vehicle rollover.

The front-right fender crushed inward. A large gouge extended from the wheel well to the left-side door. Cable contact marks were found along the entire left side of the vehicle. The front bumper cover disengaged from the vehicle. The right-front wheel and tire disengaged from the vehicle. The right-rear tire was deflated. The vehicle's hood sustained severe damage and deformation. The front of the roof crushed inward due to vehicle rollover. The windshield crushed inward and was shattered. The right-side and left-side door window glass shattered and was removed.

5.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be -5.07 m/s (-16.62 ft/s) and 3.91 m/s (12.82 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were -8.11 g's and 6.32 g's, respectively. It is noted that the occupant impact velocities (OIVs) and occupant ridedown decelerations (ORDs) were within the suggested limits provided in NCHRP Report No. 350. The THIV and PHD values were determined to be 6.08 m/s (19.94 ft/s) and 9.84 g's, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 32. Results are shown graphically in Appendix C. The results from the rate transducer are shown graphically in Appendix C.

5.6 Load Cell Results

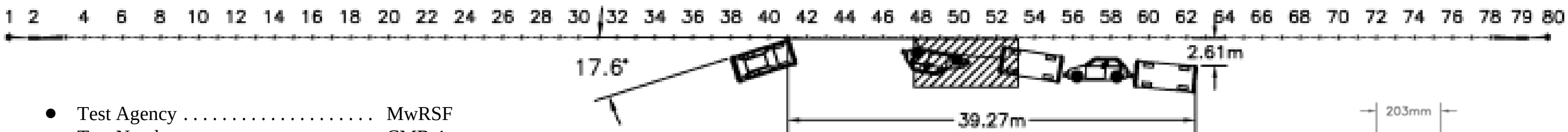
The forces imparted to the upstream end anchor, combined with the corresponding anchor displacements, were used to evaluate the effectiveness of the new driven steel post anchor. As previously discussed, load cells were installed parallel to each cable and at both ends of the barrier system to monitor the loads transferred to the anchor through the cables.

Four load cells were placed on the upstream system end, one on each cable, and two load cells were set on the downstream system end, one on the lower- and upper-middle cables. The total upstream cable load imparted to the upstream cable anchor was determined by summing the observed tension in all four cables on the upstream end and is shown graphically in Figure 50. The maximum force acting on the upstream anchor was determined to be 28.78 kN (6.47 kips). Individual cable loads on the upstream and downstream system ends are depicted graphically in Figures 51 and 52, respectively. The results of the load cell data are summarized in Table 3.

5.7 Discussion

The analysis of the test results for test no. CMB-1 showed that the low-tension, cable median barrier (Design No. 1) adequately contained the 820C vehicle, but it did not safely redirect the vehicle since the vehicle rolled over after collision with the barrier. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did occur with the deformation of the vehicle's windshield and roof. After collision, the vehicle's trajectory appeared to intrude slightly into adjacent traffic lanes. Therefore, test no. CMB-1 (Design No. 1) was determined to be unacceptable according to the TL-3 safety performance criteria for test designation no. 3-10 found in NCHRP Report No. 350.

0.000 sec | 0.110 sec | 0.226 sec | 0.334 sec | 0.450 sec



- Test Agency .... MwRSF
- Test Number CMB-1
- Date 7/02/03
- NCHRP 350 Test Designation 3-10
- Appurtenance .... Low-Tension, Four-Cable Median Barrier
- Total Length .... 148.1 m
- Key Elements - Wire Rope
  - Diameter .... 19 mm
  - Size 7x19
  - Top Cable Mounting Height .. 864 mm
  - Incremental Spacing .... 178 mm
- Key Elements - Steel End Anchor Posts
  - Post No. 1 and 80 .... W152 x 37.2 by 2,438 mm long
  - Post No. 2 and 79 .... S76 x 8.5 by 837 mm long slip post with W152 x 13.4 by 1,829 mm long base post
- Key Elements - Steel Line Posts
  - Post Nos. 3 - 78 .... M203 x 9.7 by 1,981 mm long
  - Spacing .... 1,829 mm
- Type of Soil .... Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 820C
  - Make and Model .... 1997 Geo Metro
  - Curb .... 744 kg
  - Test Inertial .... 818 kg
  - Gross Static .... 893 kg
- Impact Conditions
  - Speed .... 97.6 km/h
  - Angle .... 19.7 degrees
  - Impact Location .... 846 mm upstream from post 41
- Exit Conditions
  - Speed .... 53.6 km/h
  - Angle .... 5 degrees
  - Exit Box Criterion .... Pass
- Post-Impact Trajectory
  - Vehicle Stability .... Unsatisfactory
  - Stopping Distance .... 39.3 m downstream 2.6 m traffic-side face
- Occupant Impact Velocity
  - Longitudinal .... -5.07 m/s < 12 m/s
  - Lateral .... 3.91 m/s < 12 m/s
- Occupant Ridedown Deceleration
  - Longitudinal .... -8.11 g's < 20 g's
  - Lateral .... 6.32 g's < 20 g's
- THIV (not required) .... 6.08 m/s
- PHD (not required) .... 9.84 g's
- Test Article Damage .... Moderate
- Test Article Deflections
  - Post Permanent Set .... NA
  - Post Dynamic .... 545 mm
  - Working Width .... 1,125 mm
- Vehicle Damage .... Extensive
  - VDS[4] 11-FC-6
  - CDC[5] 11-LYA-7
  - Maximum Deformation ... NA

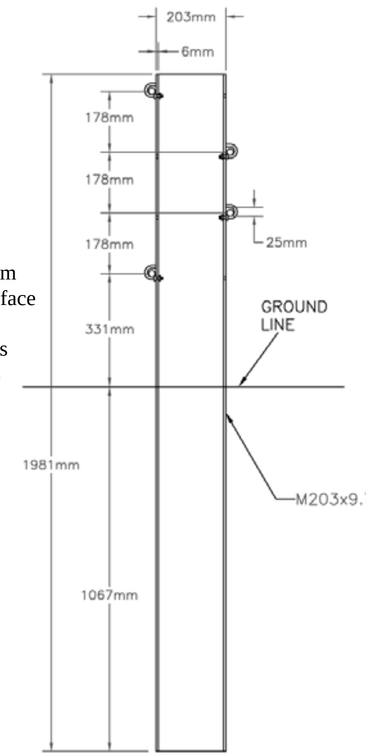


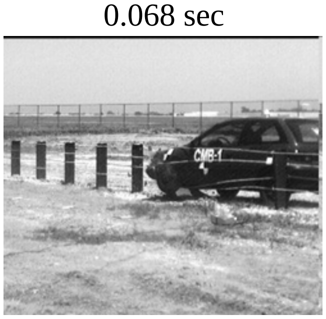
Figure 33. Summary of Test Results and Sequential Photographs, Test CMB-1

0.000 sec

0.022 sec

0.050 sec

0.068 sec



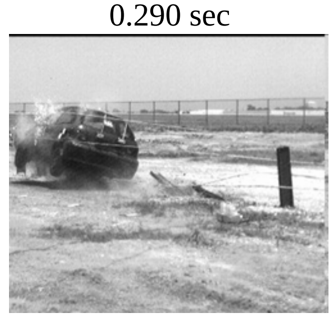
0.094 sec

0.124 sec

0.156 sec

0.242 sec

0.290 sec



0.352 sec

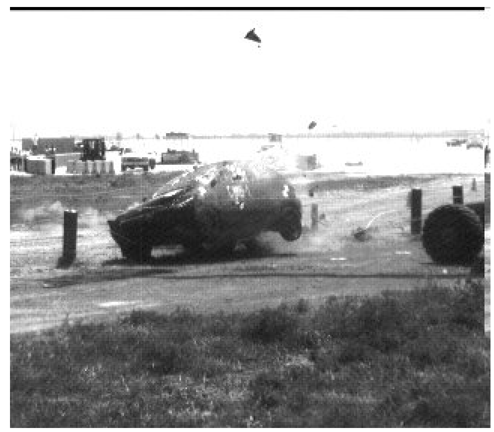
Figure 34. Additional Sequential Photographs, Test CMB-1

0.000 sec

0.078 sec

0.174 sec

0.238 sec



0.344 sec

0.414 sec

Figure 35. Additional Sequential Photographs, Test CMB-1

0.000 sec
0.133 sec
0.234 sec
0.300 sec
0.400 sec
0.501 sec
0.567 sec
0.634 sec
0.801 sec
0.901 sec

Figure 36. Documentary Photographs, Test CMB-1

0.000 sec

0.100 sec

0.200 sec

0.334 sec

0.467 sec

0.634 sec

Figure 37. Documentary Photographs, Test CMB-1

0.000 sec

0.033 sec

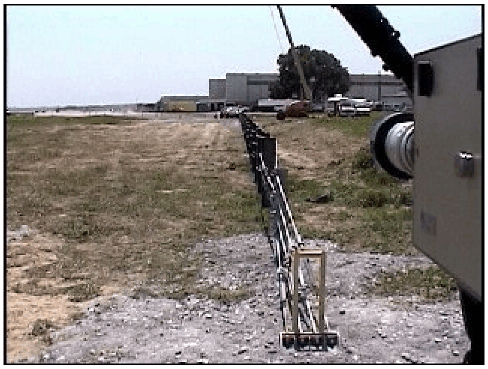
0.100 sec

0.200 sec

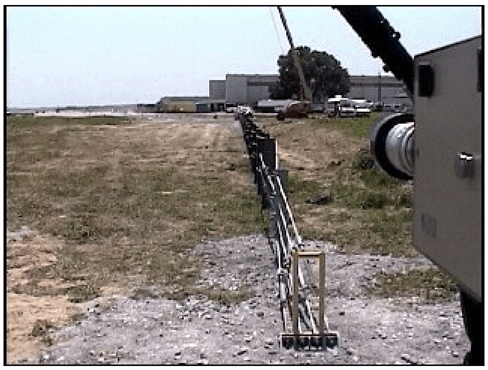
0.334 sec

0.601 sec

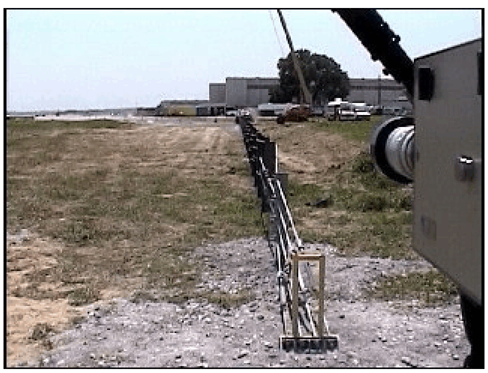
Figure 38. Documentary Photographs, Test CMB-1



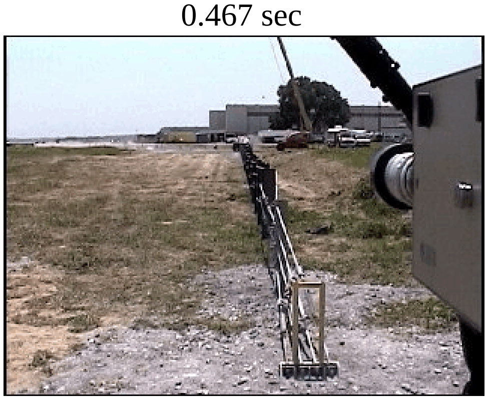
0.000 sec



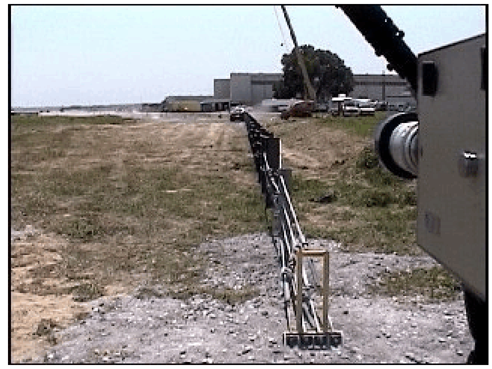
0.234 sec



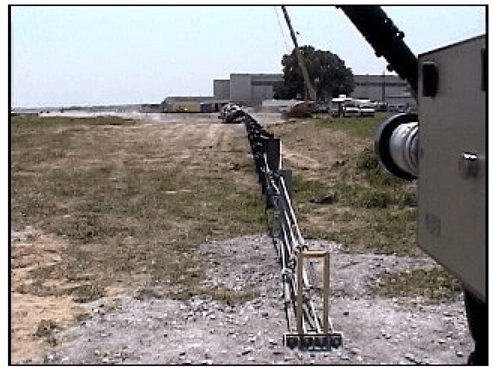
0.467 sec



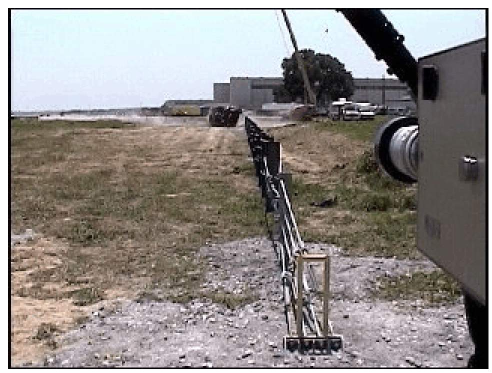
0.567 sec



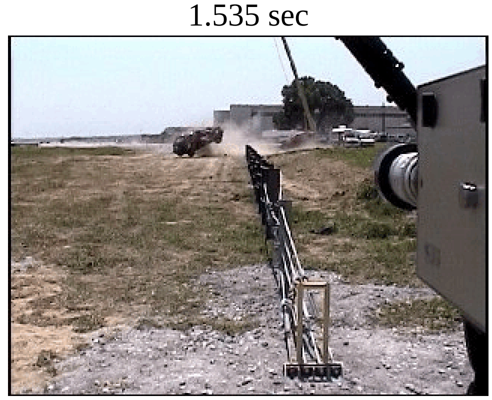
0.868 sec



1.134 sec



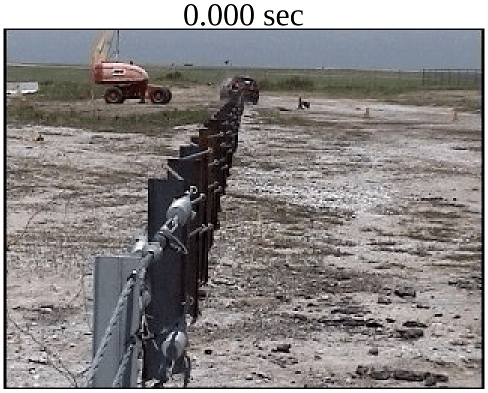
1.535 sec



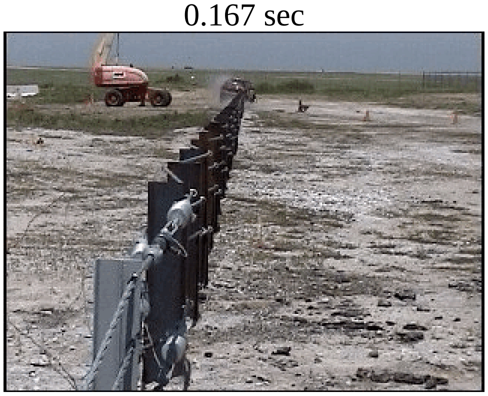
2.503 sec

Figure 39. Documentary Photographs, Test CMB-1

0.000 sec



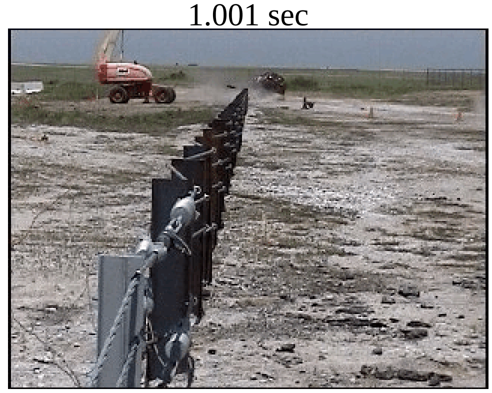
0.167 sec



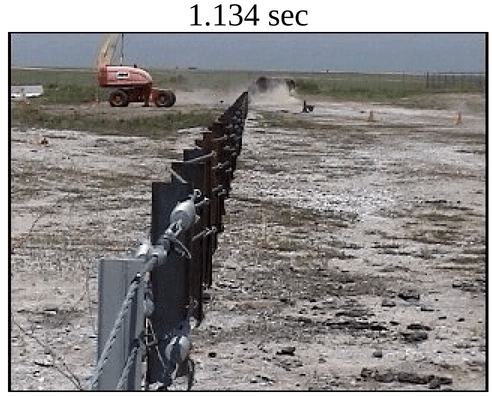
0.467 sec

0.767 sec

1.001 sec



1.134 sec



1.602 sec

3.103 sec

Figure 40. Documentary Photographs, Test CMB-1

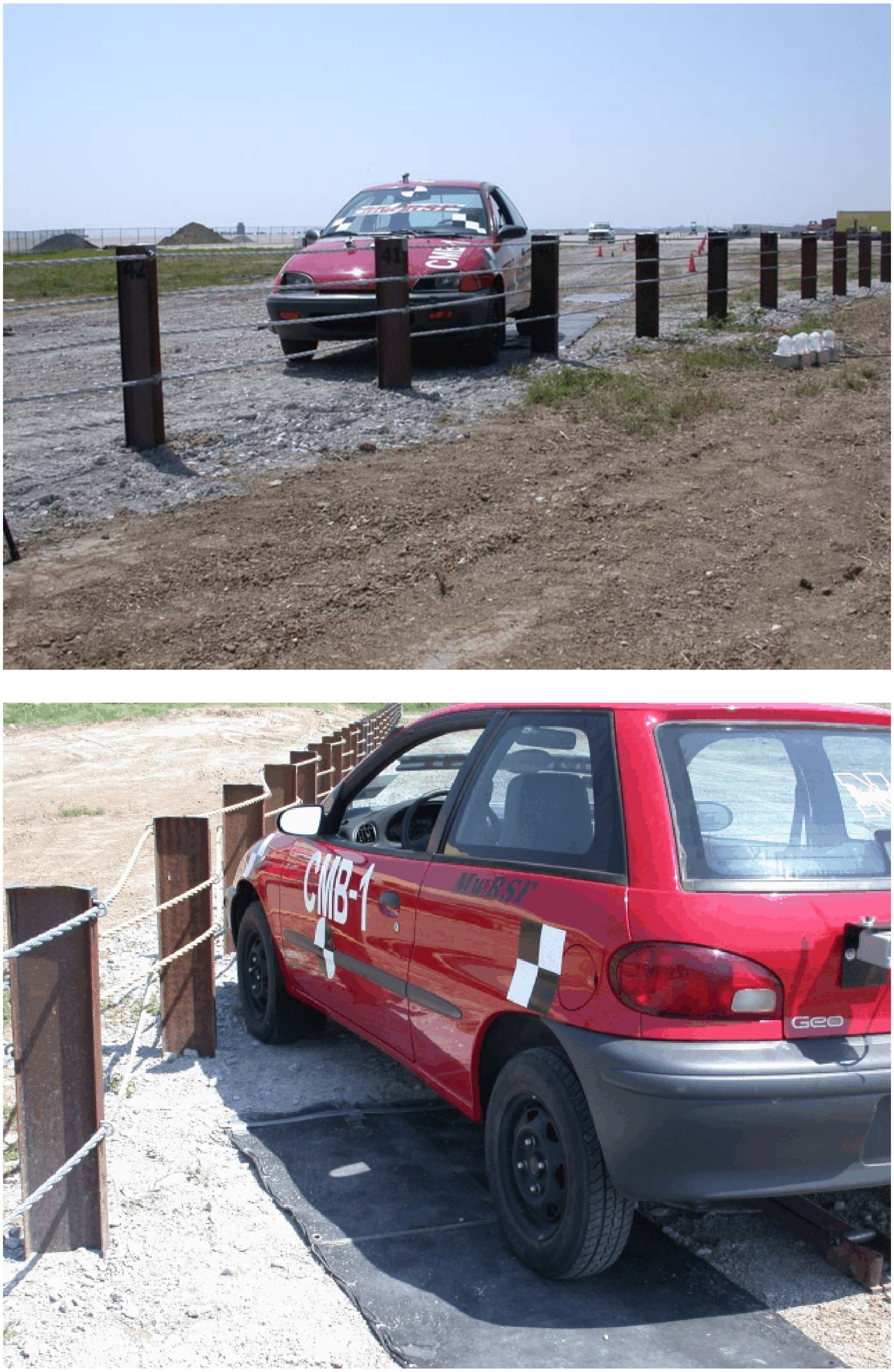


Figure 41. Impact Location, Test CMB-1

Figure 42. Vehicle Final Position and Trajectory Marks, Test CMB-1

Figure 43. System Damage, Test CMB-1

Post No. 41

Post No. 44

Post No. 42

Post No. 45

Post No. 43

Post No. 46

Figure 44. Post Nos. 41 through 46 Damage, Test CMB-1


Post No. 47


Post No. 49


Post No. 48


Post No. 50


Post No. 51

Figure 45. Post Nos. 47 through 51 Damage, Test CMB-1

.

Figure 46. Downstream End Anchorage Damage, Test CMB-1

Figure 47. Vehicle Damage, Test CMB-1

Figure 48. Vehicle Damage, Test CMB-1

Figure 49. Vehicle Damage, Test CMB-1

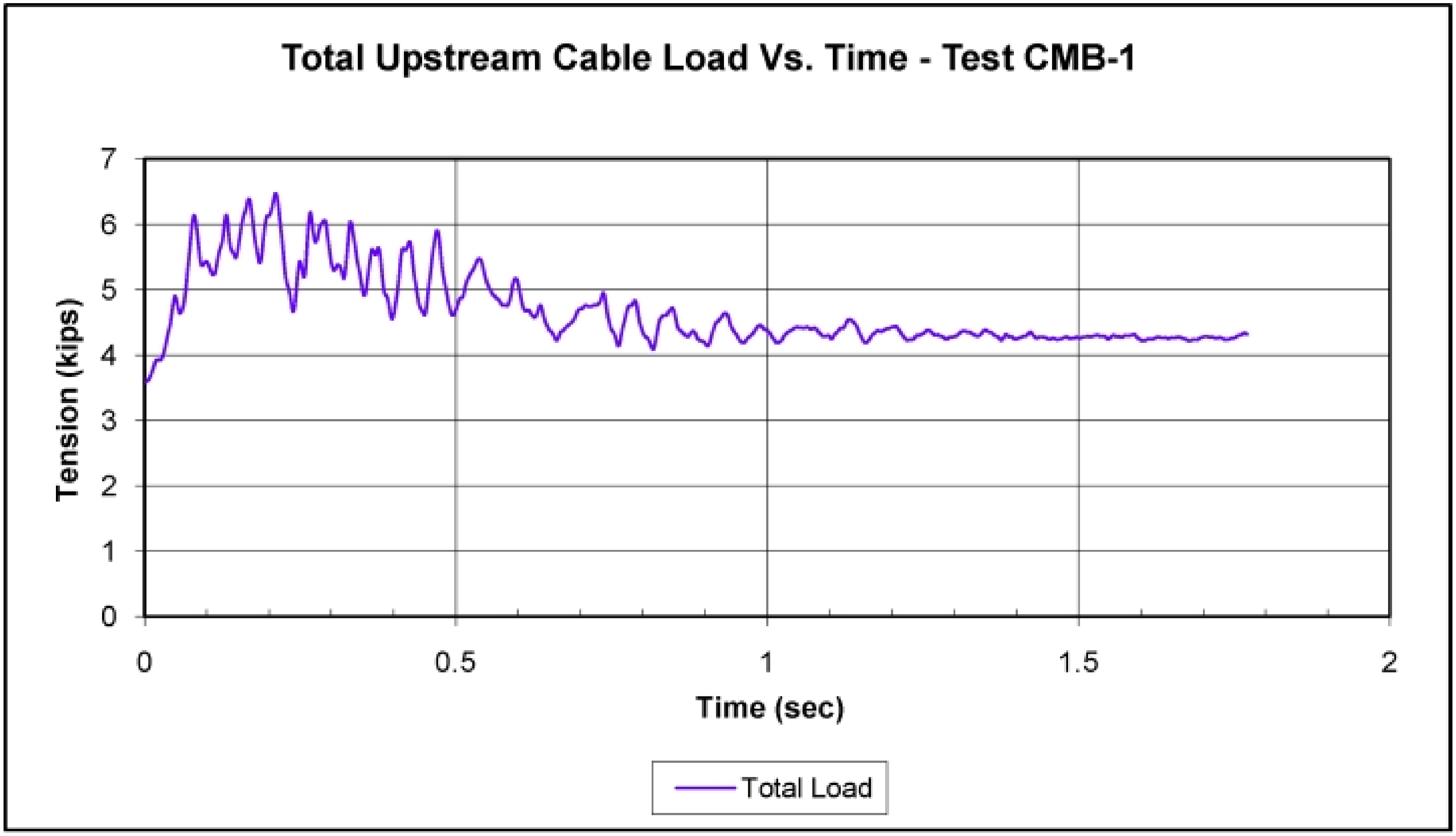


Figure 50. Total Upstream Cable Tension, Test CMB-1

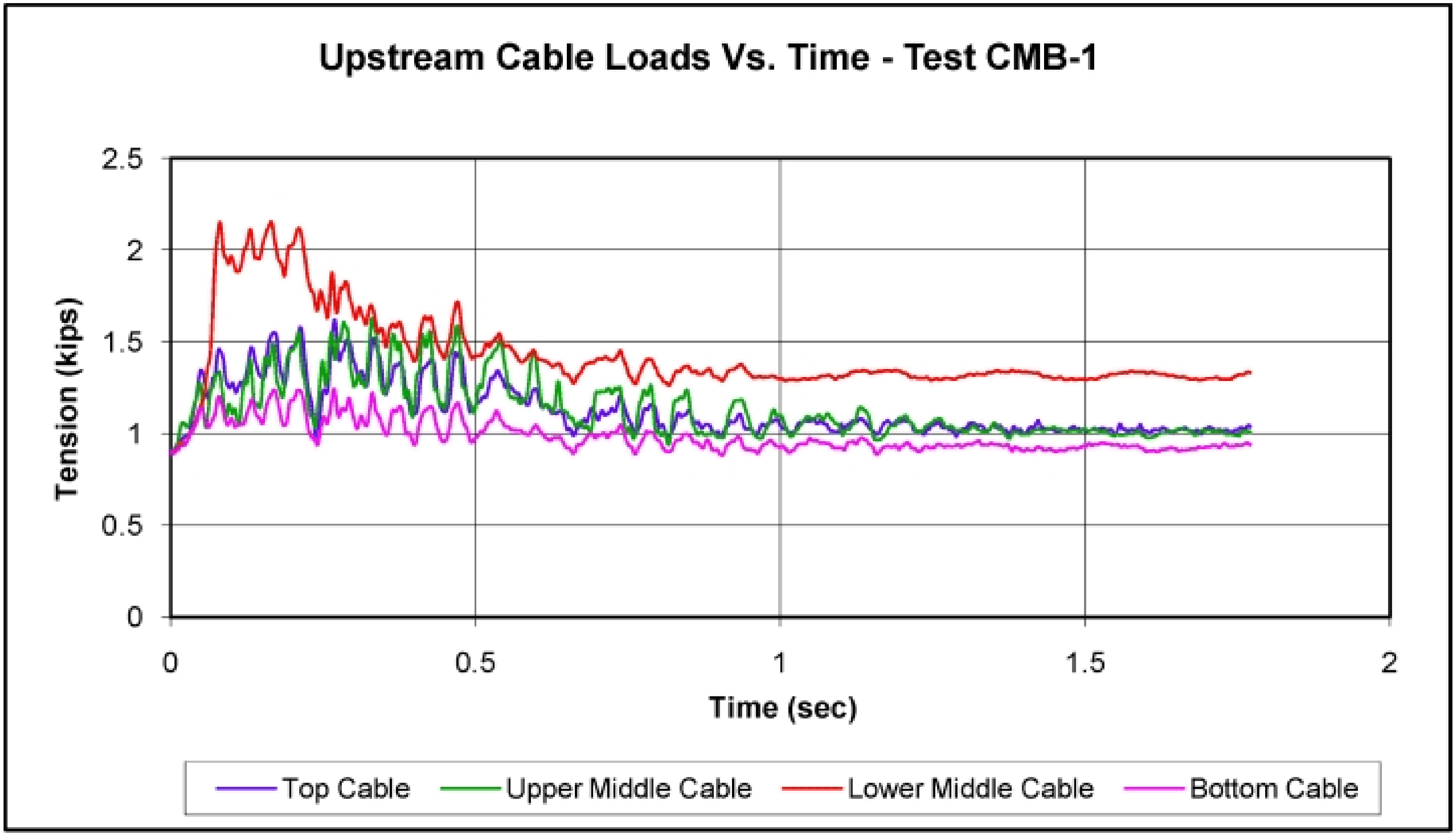


Figure 51. Upstream Cable Loads, Test CMB-1

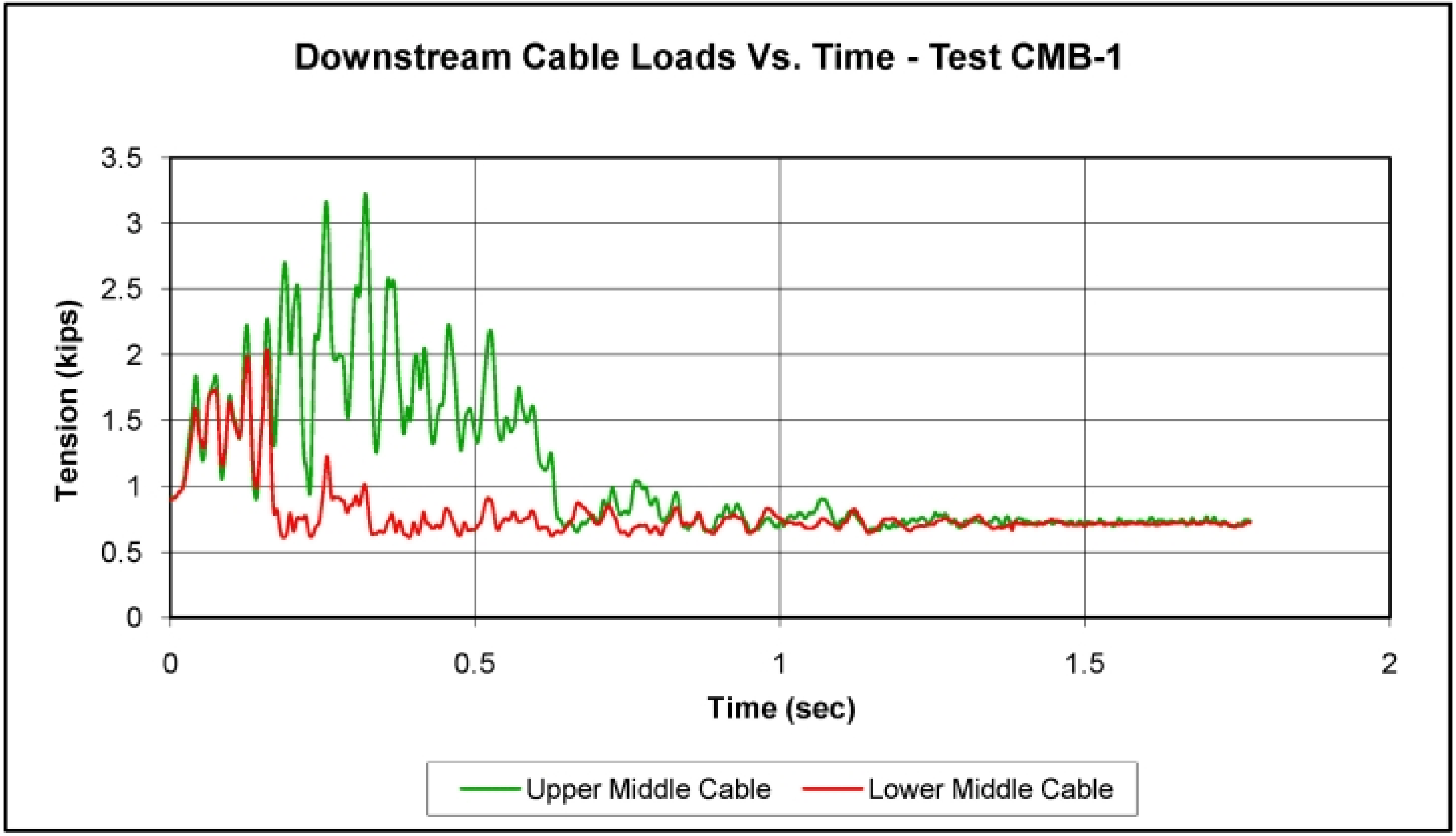


Figure 52. Downstream Cable Loads, Test CMB-1

Table 3. Load Cell Results, Test CMB-1

Location	Loading Cable	Maximum Cable Load		Time
		kN	***kips***	***sec***
Upstream Cable Anchor	Top	7.21	1.62	0.2689
	Upper-Middle	7.25	1.63	0.3308
	Lower-Middle	9.58	2.15	0.1654
	Bottom	5.53	1.24	0.2679
Total Upstream Cable Load Maximum		**28.78**	**6.47**	**0.2108**
Downstream Cable Anchor	Upper-Middle	14.35	3.23	0.3202
	Lower-Middle	9.06	2.04	0.1588
Total Downstream Load Maximum (Only Upper- and Lower-Middle Cables)		**19.45**	**4.38**	**0.2567**

6 CABLE MEDIAN BARRIER DESIGN MODIFICATIONS - DESIGN NO. 2

As stated previously, the small car test was unsuccessful when the vehicle exited the barrier system while entangled in the cables, causing the vehicle to climb a post, and then roll over. Following the unsatisfactory results observed for test no. CMB-1, researchers deemed it necessary to incorporate design modifications that would improve barrier performance.

For the initial barrier design (Design No. 1) [test no. CMB-1], each post consisted of 1,981 mm (78 in.) long, M203x9.7 (M8x6.5) steel sections spaced 1.83 m (6 ft) on centers. Four cables, supported by each post using standard cable hook bolts, alternated on the front and back sides. The top and bottom cables were placed on one flange, while the two middle cables were attached to the opposite flange.

In order to improve barrier performance, several design modifications were implemented into the low-tension, cable guardrail system. First, the post spacing was increased from 1.83 m (6 ft) to 2.44 m (8 ft). Following this modification, the cable guardrail system was altered from an 80 post, 148-m (486-ft) long barrier system to a 61 post, 147.5-m (484-ft) long test installation, which is shown in Figure 53. Second, the M203x9.7 (M8x6.5) posts were replaced with 1,676 mm (66 in.) long, S76x8.5 (S3x5.7) sections. Each post incorporated a welded 6-mm x 203-mm x 610-mm (0.25-in. x 8-in. x 24-in.) soil plate. All cables were attached to the posts using welded 13-mm x 86-mm x 76-mm (0.5-in. x 3.375-in. x 3-in.) rigid cable brackets, as shown in Figures 54 and 55. The new hooks were designed to develop the moment capacity of the line posts. Third, the embedment depth of the post was changed from 1,067 mm (42 in.) to 787 mm (31 in.). Last, the cable mounting heights were altered from Design No. 1 due to the interaction of the vehicle with the cables. The bottom and top cable mounting heights were increased to 343 mm (13.5 in.) and decreased to 838 mm (33 in.) respectively, incorporating an incremental spacing of 165 mm (6.5 in.) between the middle two cables. Once again, four cables were supported by each post but without weaving the cables between the posts. The top and lower-middle cables were placed on one flange, while the bottom and upper-middle cables were attached to the opposite flange. Photographs of the test installation are shown in Figures 56 and 57. Complete system drawings in metric and English units are shown in Appendix D.

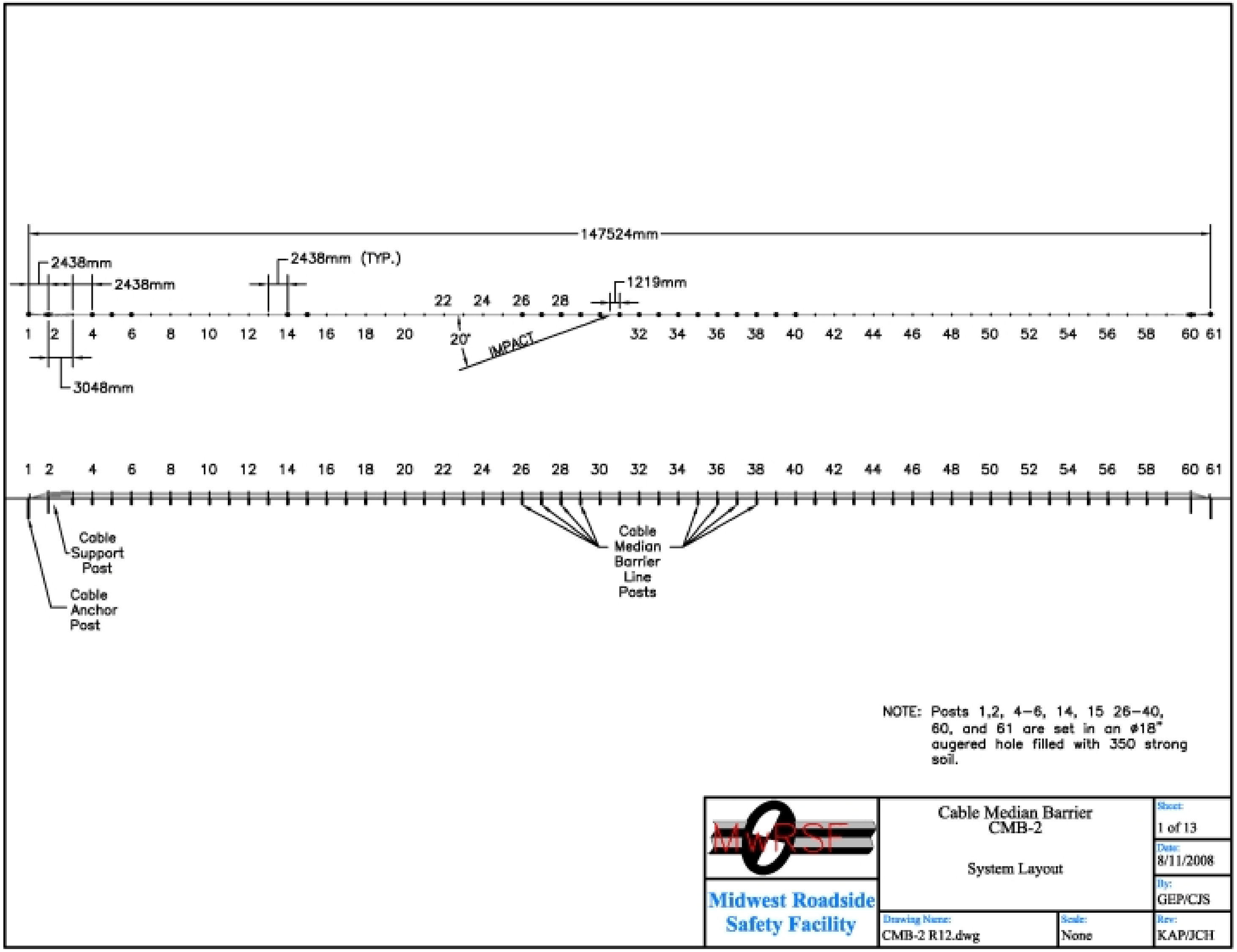


Figure 53. System Layout, Design No. 2

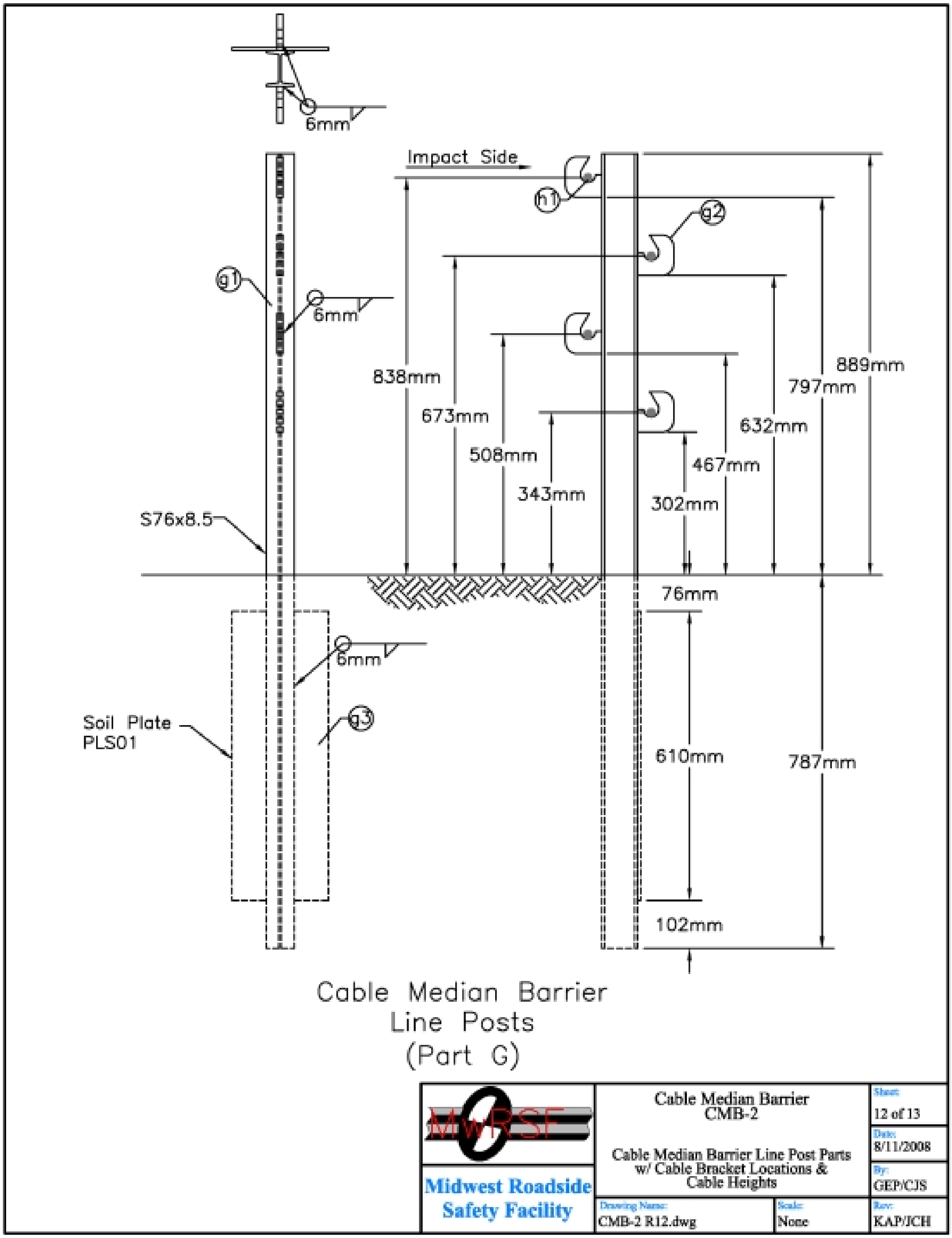


Figure 54. Bracket Locations and Cable Heights, Design No. 2

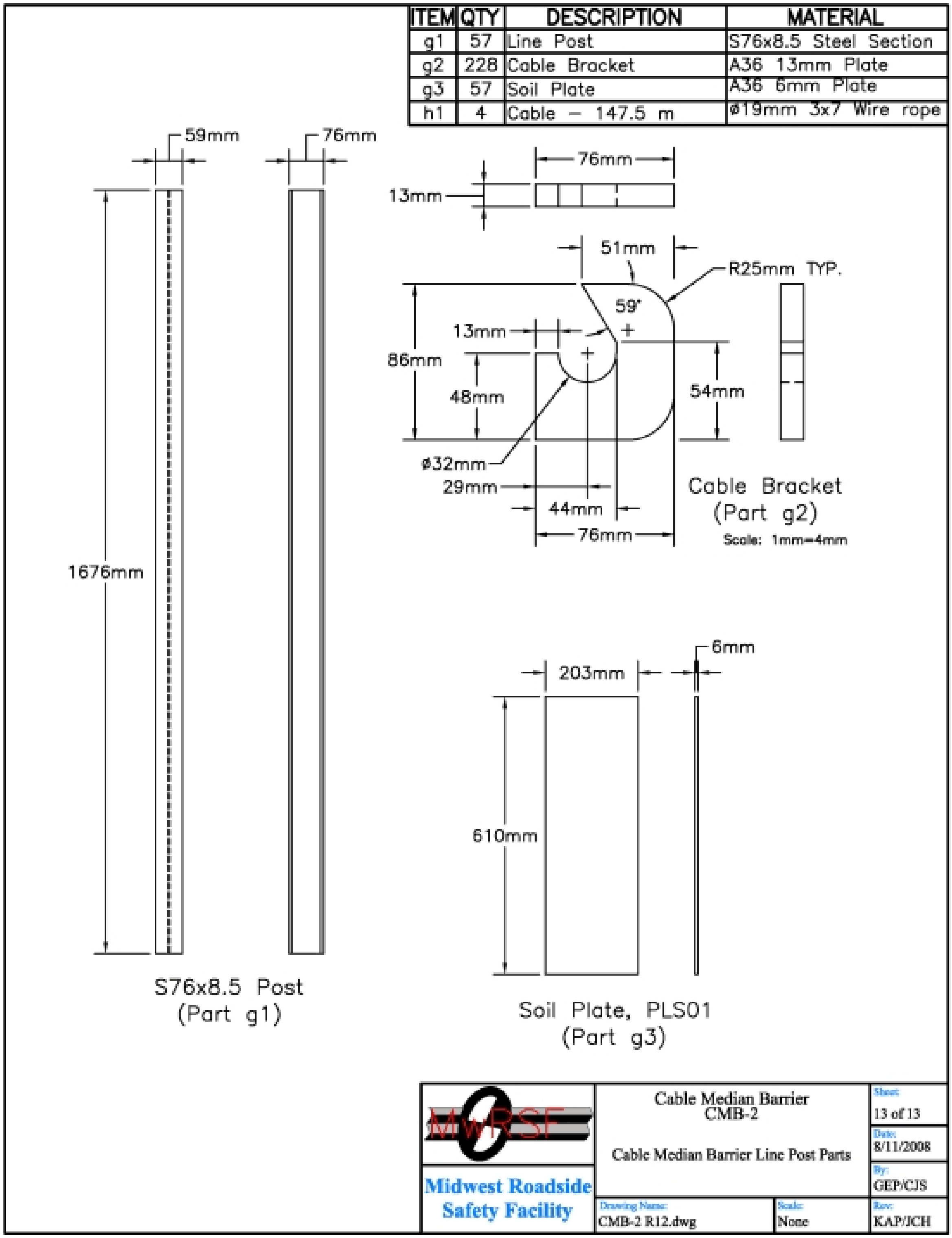


Figure 55. Line Post Parts, Design No. 2

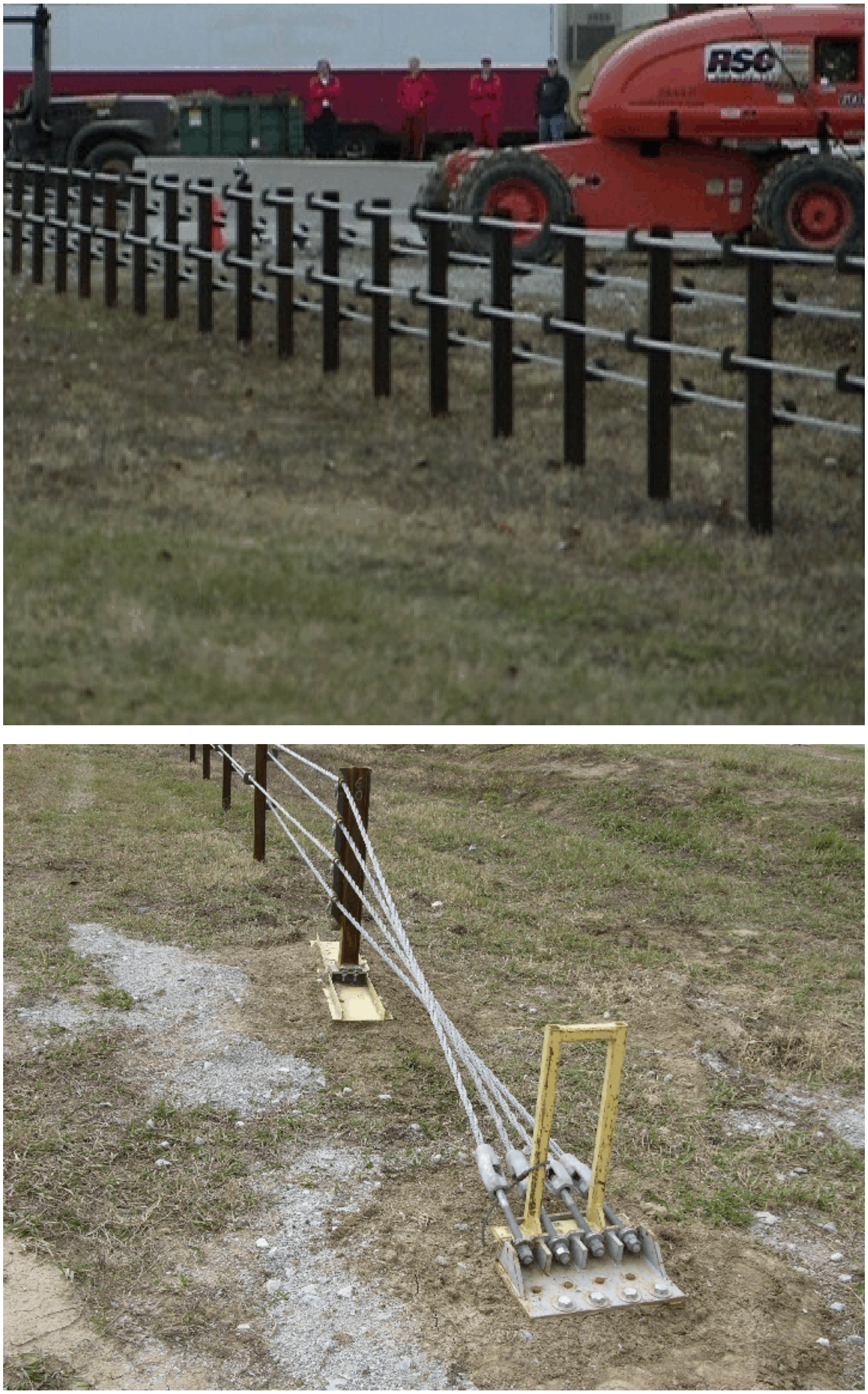


Figure 56. Low-Tension Cable Median Barrier, Design No. 2

Figure 57. Line Posts and Rigid Cable Hooks, Design No. 2

7 CRASH TEST NO. 2 (DESIGN NO. 2)

7.1 Test No. CMB-2

The 889-kg (1,960-lb) small car impacted the cable median barrier (Design No. 2) at a speed of 101.1 km/h (62.8 mph) and at an angle of 19.7 degrees. A summary of the test results and sequential photographs are shown in Figure 58. The summary of the test results and sequential photographs in English units are shown in Appendix B. Additional sequential photographs are shown in Figures 59 through 61. Documentary photographs are shown in Figures 62 through 64.

7.2 Test Description

Initial vehicle impact was to occur between post nos. 30 and 31, or 1,219 mm (4 ft) upstream from the centerline of post no. 31, as shown in Figure 65. At 0.036 sec, post no. 32 was impacted and deflected backward. At 0.082 sec, the left-front corner of the vehicle was crushed inward. At 0.116 sec, the vehicle impacted post no. 33. At 0.178 sec, the top and upper-middle cables rode across the windshield and the bottom and lower-middle cables redirected the vehicle. At 0.258 sec, the vehicle rolled slightly to the passenger's side. At 0.456 sec, the vehicle was redirected parallel to the barrier system with a speed of 58.6 km/h (36.4 mph). At 0.532 sec, the vehicle impacted post no. 34. At 0.660 sec, a large separation was observed between the car and the engine hood. At 0.746 sec, vehicle snag was observed near post no. 37, thus causing the car to rapidly rotate toward the driver's side. At 0.820 sec, the back end of the car became airborne and was yawing counter-clockwise away from the barrier. At 1.004 sec, the car continued to rotate toward the system as the rear wheels dropped to the ground. At 1.356 sec, the car began to roll toward the driver's side as the counter-clockwise yawing motion of the vehicle caused the right-rear tire to slide across the ground. At 1.688 sec, the vehicle came to rest and was nearly perpendicular to the barrier system, with the front side of the car resting on post no. 37. The final position of the vehicle was determined to be 15.4 m (50.5 ft) downstream from impact and 0.0 m (0.0 ft) laterally from the barrier, as shown in Figure 66.

7.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 67 through 69. Barrier damage consisted of bent and twisted guardrail posts and detached cables. The length of vehicle contact along the cable median barrier system was approximately 19.5 m (64 ft), which spanned from post no. 30 through post no. 38.

Post no. 29 had a small crack in its front flange on the downstream edge and a 13 mm (0.5-in.) soil gap on the traffic-side face. Post no. 30 had soil gaps on each face, including gaps of 13 mm (0.5 in.) on the back side, 64 mm (2.5 in) on the traffic side, 127 mm (5 in.) on the downstream side, and 102 mm (4 in.) on the upstream side. Post nos. 31 through 35 sustained significant damage to the soil surrounding the posts. Post no. 36 was pulled out of the ground, and soil was strewn downstream. Post no. 36 created a soil gap of 229 mm (9 in.) front to back and 787 mm (31 in.) upstream to downstream. Post no. 38 had only a 3-mm (0.125-in.) soil gap on its front side.

The top cable was disengaged from post nos. 4 through 52. The upper-middle cable was disengaged from post nos. 24 through 30. All cables were disengaged from post no. 31 and post no. 36. All cables, except the bottom cable, were disengaged from post nos. 32 through 35 and 37. The upper-middle cable was disengaged from post nos. 38 through 44 and post nos. 46 through 50. All of the cables remained attached to post nos. 53 through 61.

Post nos. 27 through 30 had only minor scratches between the top and lower-middle cable hooks. Post no. 31 was bent to the ground and twisted clockwise. The top cable hook was dislodged, and scratches were sustained to the lower-middle cable hook due to contact with the vehicle. Contact marks were found on the bottom cable hook from the cable rubbing against it. Post nos. 32 through 35 were bent to the ground without twisting. Scratches were observed on post nos. 32 and 35 between the top and lower-middle cable hook as well as at the bottom cable hook. Post no. 36 was bent at the ground level, twisted clockwise, and was pulled out of the ground. Severe local bending occurred to the upstream front flange of post no. 36 at the top cable hook. Post no. 37 was bent at the ground level with slight twisting. Following the test, the post remained attached to the vehicle. Post no. 38 had minor scratches on the traffic-side face between the top and lower-middle cable hooks. Post no. 39 had very minor scratches between the top and lower-middle cable hooks.

The permanent set of the posts is shown in Figures 67 through 69. The anchor ends encountered slight permanent set deformations, as shown in Figure 70. The maximum lateral permanent set post deflection was 394 mm (15.5 in.) at post nos. 33 and 34. The maximum lateral dynamic post deflection was 842 mm (33.1 in.) at post no. 33, and the working width was determined to be 1,919 mm (75.6 in.), as determined from the high-speed film analysis.

7.4 Vehicle Damage

Vehicle damage was moderate, as shown in Figures 71 through 73. Minimal damage was observed in the interior occupant compartment of the vehicle. Complete occupant compartment deformations and the corresponding locations are provided in Appendix E.

Damage was concentrated to the front and left sides of the vehicle. The front bumper, grill, and headlights were disengaged. The radiator was severely damaged, and the left-side support was no longer attached. The engine hood buckled. The engine hood, left rear bumper, and roof encountered scratches from cable contact. The left-front quarter panel deformed backward into the engine compartment and windshield trim. The windshield wipers were fractured and disengaged from the vehicle. The left-side mirror was disengaged. The right-front tire was deflated. The left side of the windshield was moderately cracked.

7.5 Occupant Risk Values

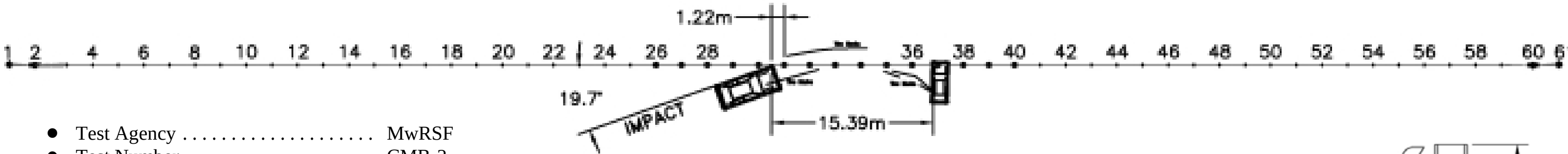
The longitudinal and lateral occupant impact velocities were determined to be -6.12 m/s (-20.08 ft/s) and 1.92 m/s (6.31 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were -8.78 g's and 5.30 g's, respectively. It is noted that the occupant impact velocities (OIVs) and occupant ridedown decelerations (ORDs) were within the suggested limits provided in NCHRP Report No. 350. The THIV and PHD values were determined to be 3.18 m/s (10.43 ft/s) and 8.98 g's, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in 58. Results are shown graphically in Appendix E. The results from the rate transducer are shown graphically in Appendix F.

7.6 Discussion

The analysis of the test results for test no. CMB-2 showed that the low-tension, cable median barrier (Design No. 2) adequately contained and redirected the 820C vehicle with controlled lateral displacements of the barrier 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 penetrate nor ride over the barrier system and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted and were deemed acceptable, because they did not adversely influence occupant risk safety criteria nor lead to vehicle rollover. After collision, the vehicle's trajectory revealed minimum intrusion into adjacent traffic lanes. Therefore, test no. CMB-2 (Design No. 2) was determined to be acceptable according to the TL-3 safety performance criteria for test designation no. 3-10 found in NCHRP Report No. 350.

As noted in the barrier damage discussion, the top and upper-middle cables were released from a significant number of posts beyond the impact region within the barrier system. From a review of the high-speed videos, it was apparent that the cables were released upward and out of the brackets through the propagation of the stress wave traveling through the cables. This premature cable release from the posts was a cause for concern for two reasons. First, the early cable release could potentially result in reduced energy dissipation by the barrier system due to the inability for the cables to fully engage the posts. Second, premature cable release of the upper cables off of the posts could contribute to reduced vehicle containment as well as an increased propensity for the vehicle penetration or override of the barrier system. As a result, the research team investigated methods to prevent premature cable release away from the posts which occurred from the propagation of stress waves in the cables.

0.000 sec 0.103 sec 0.241 sec 0.414 sec 0.601 sec



- Test Agency .... MwRSF
- Test Number CMB-2
- Date 11/10/04
- NCHRP 350 Test Designation 3-10
- Appurtenance .... Low-Tension, Four-Cable Median Barrier
- Total Length .... 147.5 m
- Key Elements - Wire Rope
  - Diameter .... 19 mm
  - Size 7x19
  - Top Cable Mounting Height .. 838 mm
  - Incremental Spacing .... 165 mm
- Key Elements - Steel End Anchor Posts
  - Post No. 1 and 61 .... W152 x 37.2 by 2,438 mm long
  - Post No. 2 and 60 .... S76 x 8 5 by 914 mm long slip post with W152 x 13.4 by 1,829 mm long base post
- Key Elements - Steel Line Posts
  - Post Nos. 3 - 59 .... S76 x 8.5 by 1,776 mm long
  - Spacing .... 2,438 mm
- Type of Soil
  - Posts 4-6, 14, 15, 26-40 ...... Grading B - AASHTO M 147-65 (1990)
  - Posts 3, 7-13, 16-19, 41-59 ... Native soil
- Test Vehicle
  - Type/Designation 820C
  - Make and Model .... 1996 Geo Metro
  - Curb .... 787 kg
  - Test Inertial .... 813 kg
  - Gross Static .... 889 kg

- Impact Conditions
  - Speed .... 101.1 km/h
  - Angle .... 19.7 degrees
  - Impact Location .... 1,219 mm upstream from post 31
- Exit Conditions
  - Speed .... N/A
  - Angle .... N/A
  - Exit Box Criterion .... N/A
- Post-Impact Trajectory
  - Vehicle Stability .... Satisfactory
  - Stopping Distance .... 15.4 m downstream, 0.0 m traffic-side face
- Occupant Impact Velocity
  - Longitudinal .... -6.12 m/s < 12 m/s
  - Lateral .... 1.92 m/s < 12 m/s
- Occupant Ridedown Deceleration
  - Longitudinal .... -8.78 g's < 20 g's
  - Lateral .... 5.30 g's < 20 g's
- THIV (not required) .... 3.18 m/s
- PHD (not required) .... 8.98 g's
- Test Article Damage .... Moderate
- Test Article Deflections
  - Post Permanent Set .... 394 mm
  - Post Dynamic .... 842 mm
  - Working Width .... 1,919 mm
- Vehicle Damage .... Moderate
  - VDS[4] 11-FC-5
  - CDC[5] 11-FEDW-3
  - Maximum Deformation ... N/A

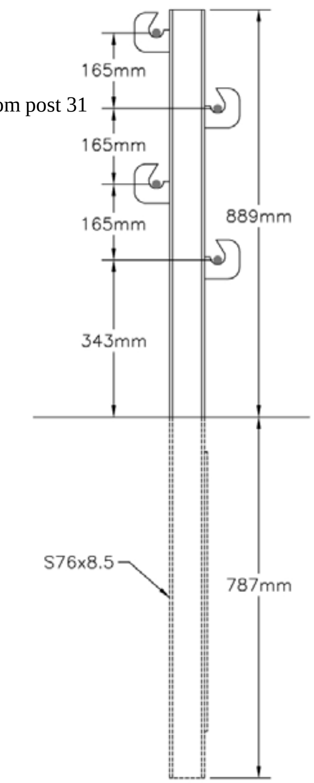


Figure 58. Summary of Test Results and Sequential Photographs, Test CMB-2

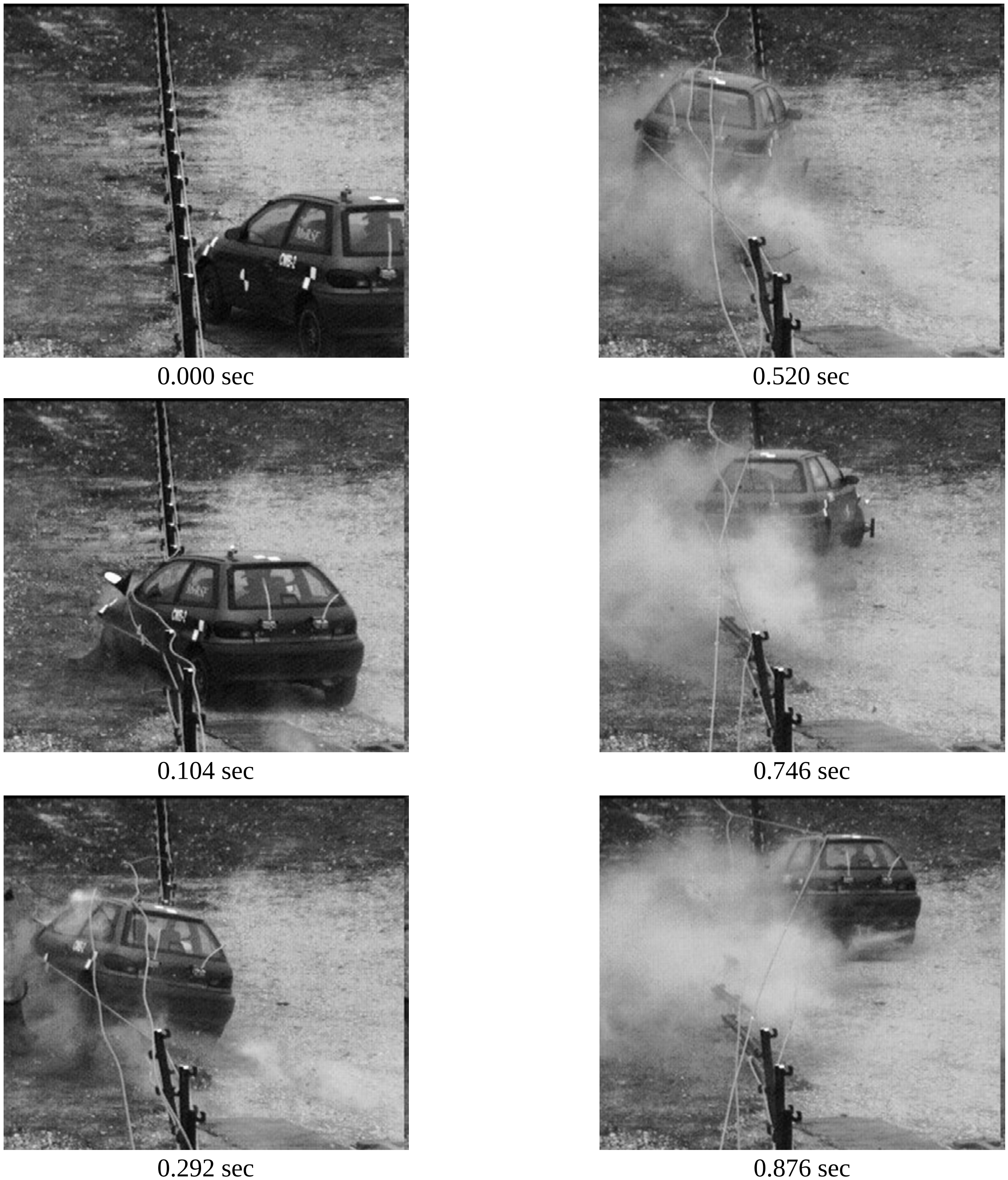


Figure 59. Additional Sequential Photographs, Test CMB-2

0.000 sec

0.036 sec

0.084 sec

0.176 sec

0.296 sec

Figure 60. Additional Sequential Photographs, Test CMB-2

0.194 sec

0.340 sec

0.482 sec

0.560 sec

0.778 sec

0.928 sec

1.044 sec

1.140 sec

1.520 sec

1.772 sec

Figure 61. Additional Sequential Photographs, Test CMB-2

0.000 sec

0.267 sec

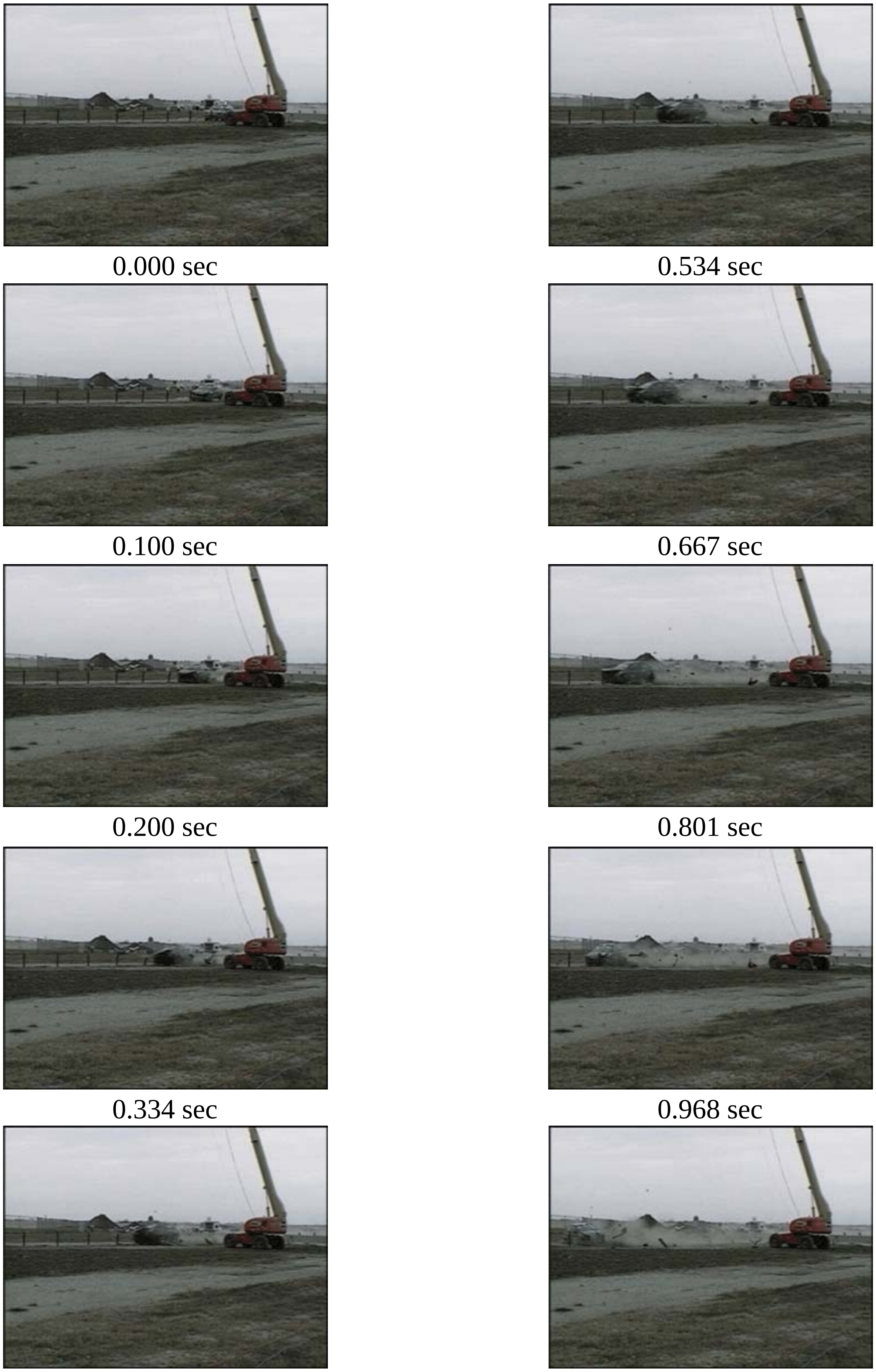
0.067 sec

0.400 sec

0.167 sec

0.567 sec

Figure 62. Documentary Photographs, Test CMB-2



0.000 sec
0.100 sec
0.200 sec
0.334 sec
0.434 sec
0.534 sec
0.667 sec
0.801 sec
0.968 sec
1.235 sec

Figure 63. Documentary Photographs, Test CMB-2

0.000 sec

0.234 sec

0.334 sec

0.501 sec

0.734 sec

0.934 sec

Figure 64. Documentary Photographs, Test CMB-2

Figure 65. Impact Location, Test CMB-2

Figure 66. Vehicle Final Position and Trajectory Marks, Test CMB-2

Figure 67. System Damage, Test CMB-2

Post No. 30

Post No. 31

Post No. 32

Post No. 33

Figure 68. Post Nos. 30 through 33 Damage, Test CMB-2

Post No. 34

Post No. 35

Post No. 36

Post No. 37

Figure 69. Post Nos. 34 through 37 Damage, Test CMB-2

Figure 70. End Anchorage Damage, Test CMB-2

Figure 71. Vehicle Damage, Test CMB-2

Figure 72. Vehicle Damage, Test CMB-2


Figure 73. Occupant Compartment Damage, Test CMB-2

8 CABLE MEDIAN BARRIER - DESIGN NO. 3

The barrier system constructed for test no. CMB-3 was nearly identical to the system used in test no. CMB-2. The 147.5-m (484-ft) long, test installation consisted of two cable anchors, two cable support posts, and 57 line posts. Three changes were instituted from the previous test: (1) the length of line posts was increased; (2) the shape of the cable brackets changed; and (3) retainer bolts were added to the posts above the cable brackets in order to prevent premature cable release away from the posts. The barrier system constructed for test no. CMB-3 is shown in Figures 74 through 78. Photographs of the test installation are shown in Figures 79 and 80. A complete set of system drawings along with the corresponding English-unit drawings, are shown in Appendix G.

Line post nos. 26 through 45 utilized a longer post length in order to farther separate the top bolt away from the top of the post, as shown in Figure 75. The longer line posts were 1,702 mm (67 in.) long. The longer line posts used an embedment depth of 787 mm (31 in.), as used for test no. CMB-2. Line post nos. 3 through 25 and 46 through 59 were the same length as the line posts used in test no. CMB-2.

Holes were drilled in line post nos. 3 through 59 in order to accommodate the placement of cable retainer bolts. Two holes were drilled on the right flange of the line posts on each side. The holes corresponded with the placement of the cable brackets, such that the top and lower-middle hole were drilled in one flange and the bottom and upper-middle hole were drilled on the other flange. The holes were spaced 165 mm (6.5 in.) apart vertically, beginning 32 mm (1.25 in.) down from the top of the post in post nos. 26 through 45 and 13 mm (0.5 in.) down from the top of the post in post nos. 3 through 25 and 46 through 59. The arrangement of the holes on the posts are shown in Figures 76 and 78. A 6.5-mm (0.25-in.) diameter, 25-mm (1-in.) long, Grade 2 retainer bolt was placed in each hole and secured with a nut, as shown in Figures 75 and 77.

Modified cable brackets were used on the line posts in the impacting region, post nos. 26 through 45. Each bracket was constructed using an ASTM A36 steel plate measuring 102-mm x 73-mm x 13-mm (4-in. x 2.875-in. x 0.5-in.), as shown in Figures 76 and 79. The cable brackets were welded to the longer posts beginning 286 mm (11.25 in.) above the ground with an incremental spacing of 165 mm (6.5 in.). The cable mounting heights did not change from Design No. 2, as shown in Figures 75 and 77. The cable bracket dimensions and position on line post nos. 3 through 25 and 46 through 59 were not altered from test no. CMB-2, and the cables did not alternate between posts. The barrier system used identical end anchorage as used in test no. CMB-2, as well as the same cable support posts.

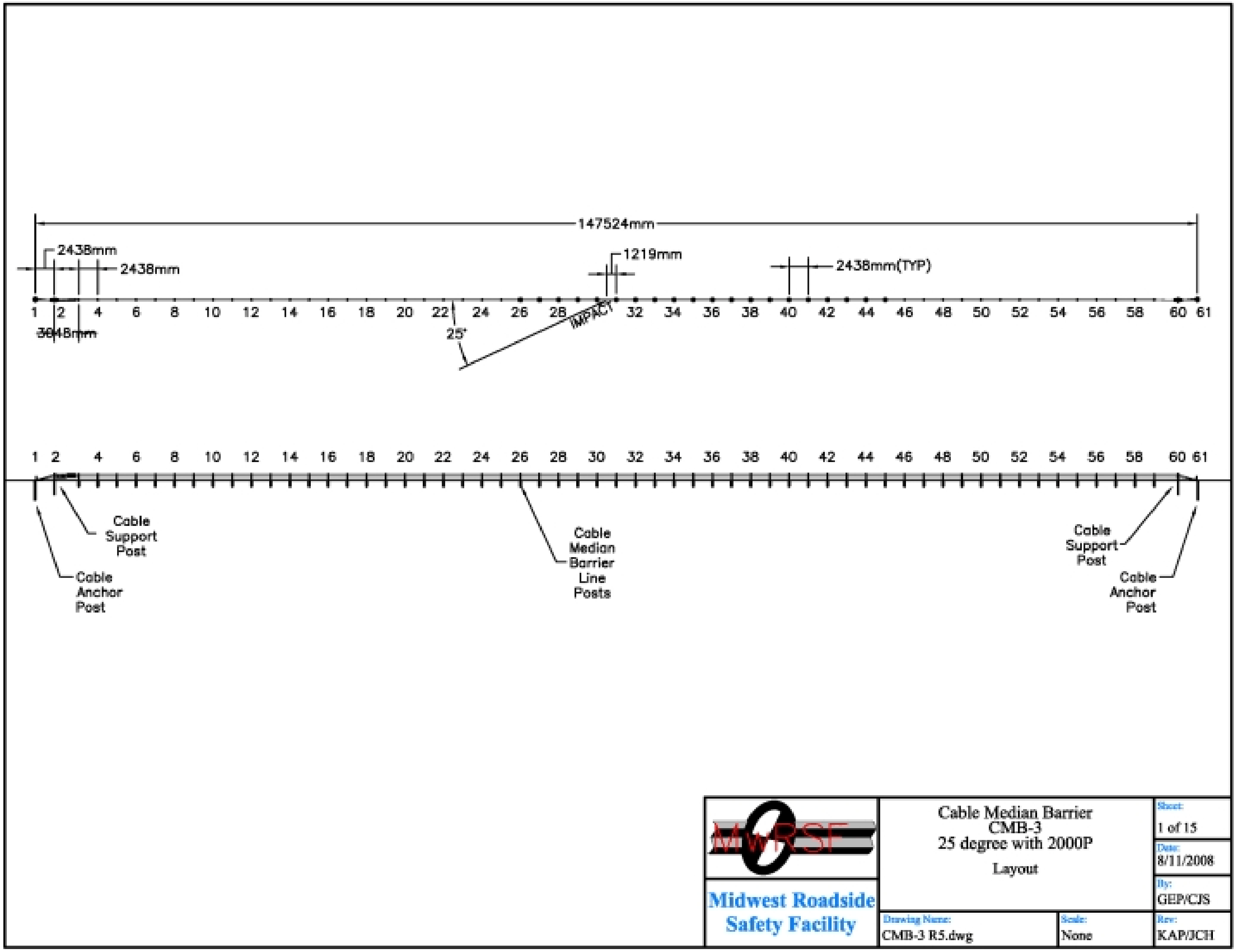


Figure 74. System Layout, Design No. 3

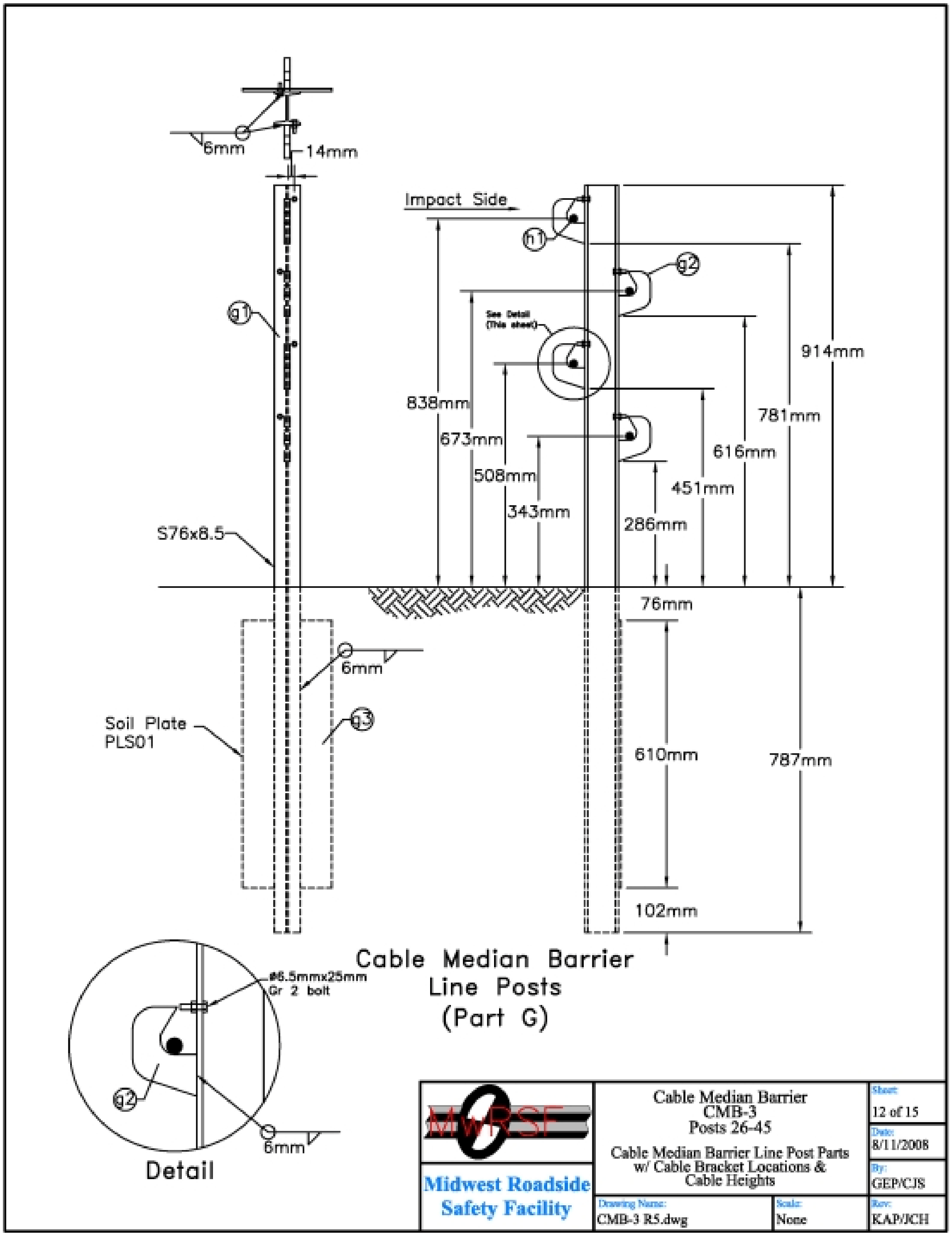


Figure 75. Line Post Nos. 26 through 45, Design No. 3

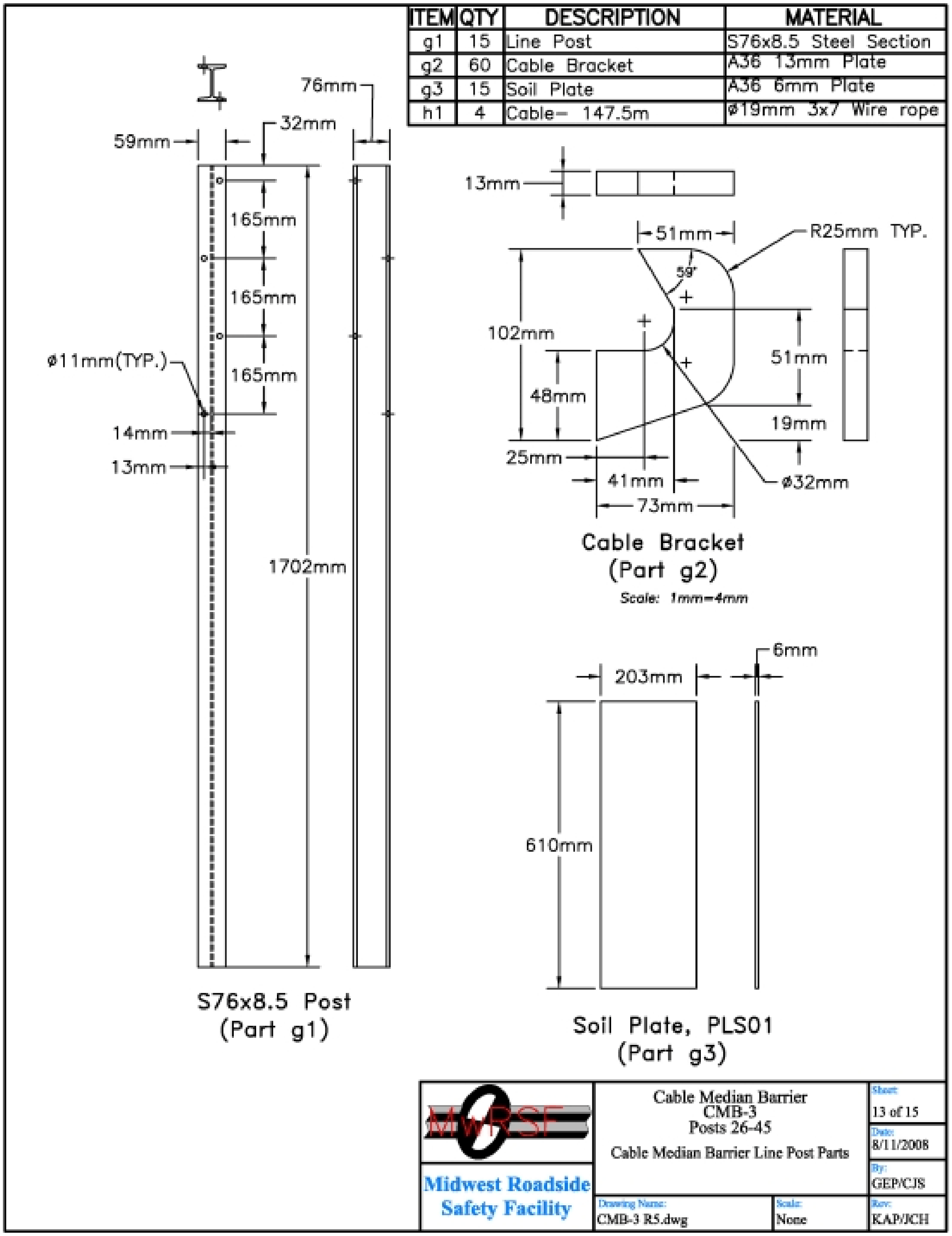


Figure 76. Line Post Nos. 26 through 45 Parts, Design No. 3

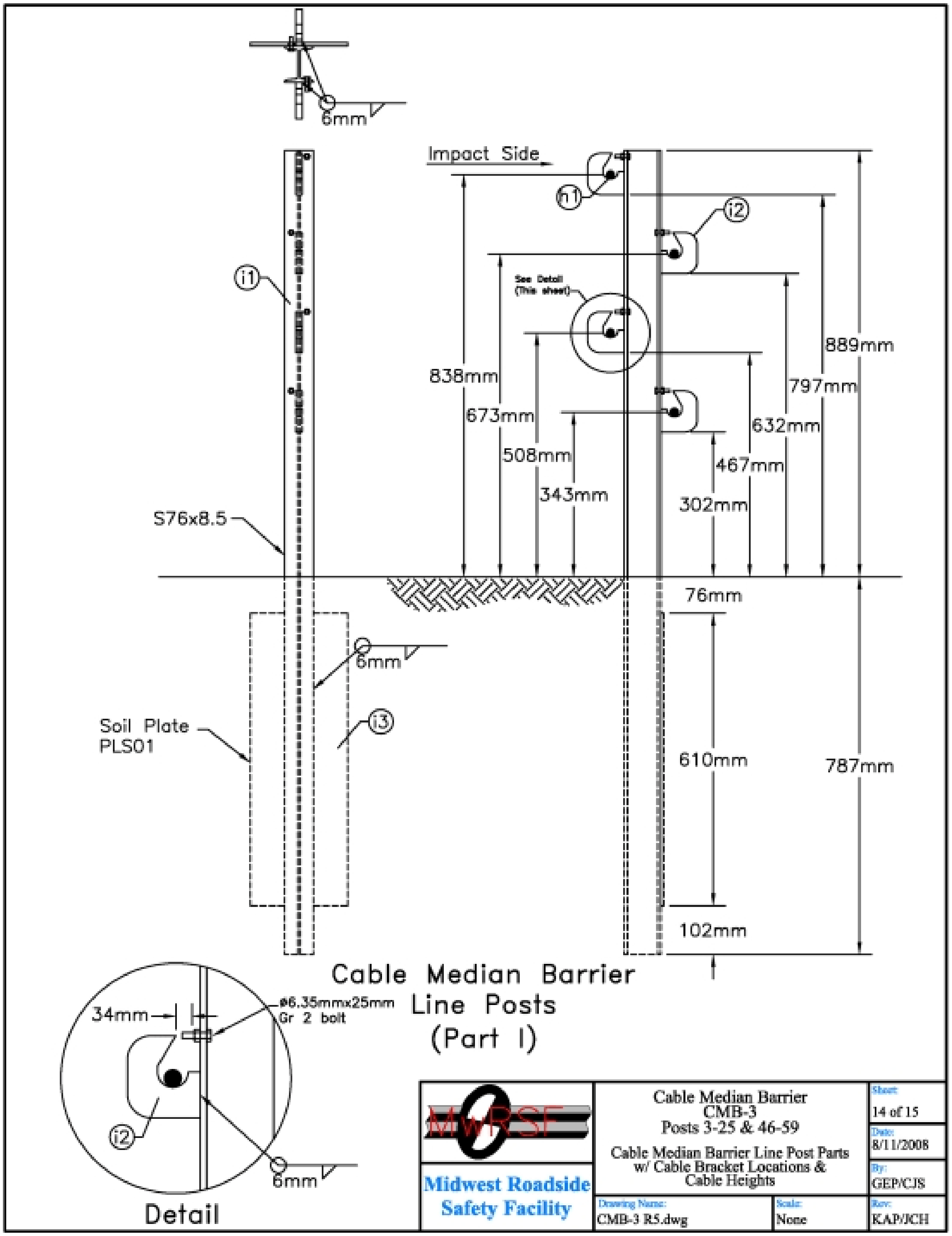


Figure 77. Line Post Nos. 3 through 25 and 46 through 59, Design No. 3

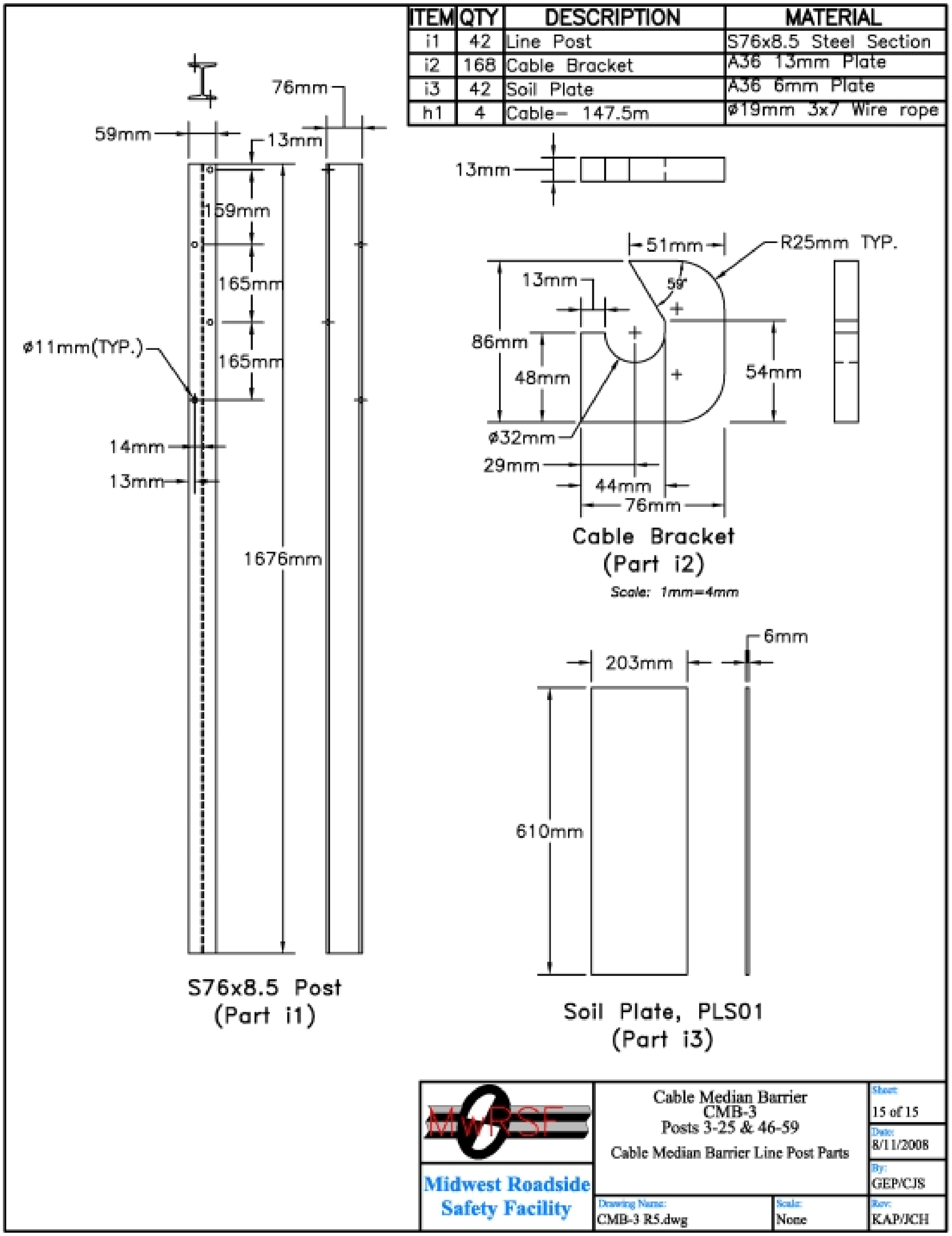


Figure 78. Line Post Nos. 3 through 25 and 46 through 59 Parts, Design No. 3

Figure 79. Line Post Nos. 26 through 45 Cable Brackets, Design No. 3

Figure 80. Line Post Nos. 3 through 25 and 46 through 59 Cable Brackets, Design No. 3

9 CRASH TEST NO. 3 (DESIGN NO. 3)

9.1 Test No. CMB-3

The 2,023-kg (4,459-lb) pickup truck impacted the cable median barrier (Design No. 3) at a speed of 97.8 km/h (60.8 mph) and at an angle of 25.4 degrees. A summary of the test results and sequential photographs are shown in Figure 81. The summary of the test results and sequential photographs in English units are shown in Appendix B. Additional sequential photographs are shown in Figures 82 through 85. Documentary photographs are shown in Figures 86 and 87.

9.2 Test Description

Initial vehicle impact was to occur between post nos. 30 and 31, or 1,219 mm (4 ft) upstream from the centerline of post no. 31, as shown in Figure 88. At 0.010 sec, the left-front bumper impacted post no. 31. At 0.022 sec, the lower-middle and bottom cables were in contact with the left-front tire, and post no. 32 rotated clockwise. At 0.042 sec, the vehicle impacted post no. 32, which caused it to bend downstream. At 0.050 sec, top and upper-middle cables were released from post no. 32, and the left-front tire rolled on top of the lower-middle and bottom cables. At 0.064 sec, the front bumper crushed farther into the engine compartment. At 0.084 sec, the left-front tire was completely airborne. At 0.118 sec, post no. 32 was impacted by the pickup truck. At this time, the rear end of the truck pitched upward slightly, but the tires remained on the ground. Subsequently, the vehicle traveled behind post nos. 33 through 37. At 0.154 sec, post no. 34 deflected backward, and the pickup truck pitched and rolled toward the vehicle's right-front corner. At 0.162 sec, the top and upper-middle cables detached from post no. 34. The left-front door was positioned behind the original barrier face. At 0.208 sec, the right-front wheel passed over the lower-middle and bottom cables, thus causing a jerking motion on post nos. 34 and 35. At this same time, the top two cables continued to damage the left-front side of the vehicle. At 0.274 sec, the rear end of the pickup truck yawed clockwise (CW) toward the barrier system, and the right-rear tire lifted off of the ground. At 0.472 sec, the truck became parallel with the system with a velocity of 78.8 km/h (49.0 mph). At 0.510 sec, the vehicle rolled slightly clockwise, and the left-rear tire lifted off of the ground. At 0.784 sec, the pickup truck impacted post no. 38. At 0.792 sec, the truck began to roll slightly to the passenger's side (clockwise). At 0.922 sec, the right-rear wheel lifted off of the ground, and the pickup truck experienced roll to the driver's side (counter-clockwise) while redirecting away from the barrier system. At 1.03 sec, the left-front tire lifted off of the ground as the truck continued to roll counter-clockwise. At 1.128 sec, the left-front corner impacted post no. 40, and the left-front tire remained airborne as the truck rolled to the passenger's side (clockwise). In addition, the truck bed twisted counter-clockwise with respect to the cab. At 1.426 sec, both left tires were off of the ground. At 1.360 sec, the truck exited the system with a velocity of 67.6 km/h (42.0 mph). At 1.506 sec, the left-rear tire was the only tire airborne. At 1.570 sec, the left-rear tire returned to the ground. At 1.696 sec, the truck rolled clockwise. At 1.840 sec, the vehicle stopped its clockwise roll and moved toward its normal horizontal position. The final position of the pickup truck was determined to be 57.5 m (188.6 ft) downstream from impact and 8.7 m (28.7 ft) laterally from the barrier, as shown in Figure 89.

9.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 90 through 92. Barrier damage consisted of deformed guardrail posts, disengaged cables, and deformed retaining bolts. The length of the vehicle contact along the cable median barrier was approximately 24.0 m (78.7 ft), which spanned from the middle of post nos. 30 and 31 through post no. 40.

A 25-mm (1-in.) soil gap was formed on the front face of post no. 27. At post no. 29, soil damage on the back side occurred with dimensions 229 mm (9 in.) by 279 mm (11 in.). At post no. 30, a soil damage area on the back side was created with dimensions 305 mm (12 in.) by 342 mm (13.5 in.). Post nos. 31 through 41 experienced significant damage to the soil surrounding the post bases.

All cables, except for the lower-middle cable, were disengaged from post no. 31. Only the lower-middle and bottom cables remained attached to post nos. 32, 34 through 36, and 40. The lower-middle cable was the only cable still attached to post nos. 33 and 39. The upper-middle cable was the only cable still attached to post no. 37. All four cables were disengaged from post no. 38. Post nos. 41through 61 had all four cables still attached.

Post nos. 27 through 29 rotated backward 11 degrees about their bases. Post no. 30 rotated backward 16 degrees at its base. The downstream corner of the back side flange was buckled for post nos. 31 through 33. Post no. 31 was pulled upward 25 mm (1 in.), bent back 25 degrees, and bent downstream 60 degrees from a vertical line perpendicular to the ground surface. Post no. 32 was bent back 25 degrees, and upstream 50 degrees from a vertical line perpendicular to the ground surface. Post no. 33 was bent back 15 degrees and downstream 47 degrees. Post no. 34 was rotated back 15 degrees and downstream 47 degrees from a vertical line perpendicular to the ground surface. Post no. 35 was bent back 15 degrees. Post no. 36 was rotated back 5 degrees and bent downstream 50 degrees from a vertical line perpendicular to the ground surface, and twisted 3 degrees at its top. Post no. 37 was twisted back 3 degrees, bent forward 3 degrees at 76 mm (3 in.) above the base, and bent downstream 65 degrees at (5-in.) above the base. Post no. 38 bent downstream 80 degrees and twisted clockwise 4 degrees. Post no. 39 bent downstream 75 degrees and was buckled at the base on the downstream corner of the back side flange. Post no. 40 bent forward 70 degrees, and buckled at the downstream corner of the back side flange. Post 41 was bent forward and downstream slightly from a vertical line perpendicular to the ground surface.

The top and upper-middle bolts were bent upward at post nos. 30 and 31. The bottom bolt was bent on post no. 31. For post nos. 31 and 36 through 38, the lower-middle bolt was sheared off. The top bolt was sheared off of post nos. 32 through 38 and post no. 40. For post no. 32, the lower-middle bolt was bent. The bottom bolt was sheared off of post nos. 33 and 37. Both of the middle bolts were bent on post no. 33. The upper-middle bolt was sheared from post nos. 35, 37, and 40. The upper-middle bolt was bent upward on post no. 36. At post no. 37, the lower-middle cable bracket was sheared off. At post no. 38, noticeable cable scraping was found on the inside of the upper-middle cable bracket. For post no. 39, all four bolts were bent. At post no. 40, the lower-middle bolt was bent, and there was a tear in the post flange located at the bottom bolt.

The permanent set of the posts is shown in Figures 90 through 92. The anchor ends encountered slight permanent set deformations, as shown in Figures 93 and 94. The maximum lateral permanent set post deflection was not calculated for this system. The maximum lateral dynamic post deflection was 665 mm (26.2 in.) at post no. 30, and the working width was determined to be 2,878 mm (113.3 in.), as determined from the high-speed film analysis.

9.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 95 and 96. Minimal damage was observed in the interior occupant compartment of the vehicle. Complete occupant compartment deformations and the corresponding locations are provided in Appendix E.

Damage was concentrated to the left-front corner of the vehicle. The left side of the front bumper was dented near the left-front quarter panel. The left side of the grill was fractured. Contact marks were found on the entire left and right sides of the vehicle as well as on all four tires. The left-front and right-front quarter panels were dented, buckled, and deformed inward toward the engine compartment. The right-side door encountered a large dent in the bottom quarter of the door. The truck bed was buckled inward behind both the left-rear and right-rear wheels. Both front headlight assemblies fractured, and the left-side headlight disengaged from the vehicle. The roof and rear of the vehicle and all window glass remained undamaged.

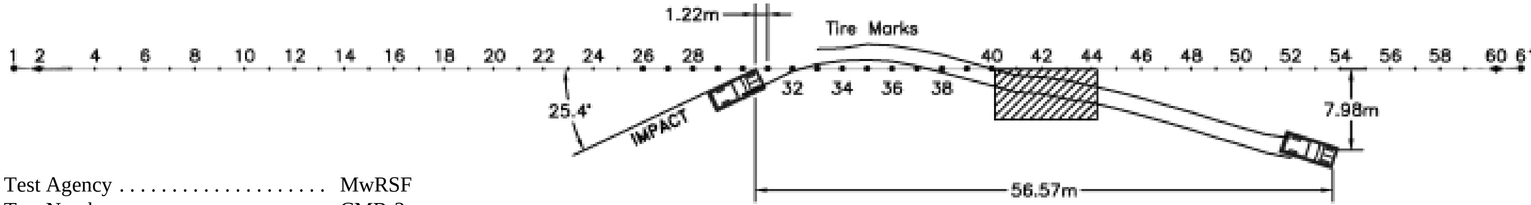
9.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be -3.32 m/s (-10.89 ft/s) and 3.12 m/sec (10.25 ft/sec), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were -3.93 g's and 6.26 g's, respectively. It is noted that the occupant impact velocities (OIVs) and occupant ridedown decelerations (ORDs) were within the suggested limits provided in NCHRP Report No. 350. The THIV and PHD values were determined to be 4.26 m/s (13.98 ft/s) and 6.27 g's, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 81. Results are shown graphically in Appendix E. The results from the rate transducer are shown graphically in Appendix H.

9.6 Discussion

The analysis of the test results for test CMB-3 showed that the low-tension, cable median barrier (Design No. 3) adequately contained and redirected the 2000P vehicle with controlled lateral displacements of the barrier 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 intrusion into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier system and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted and were deemed acceptable, because they did not adversely influence occupant risk safety criteria nor cause rollover. After collision, the vehicle's trajectory did not intrude into adjacent traffic lanes. Therefore, test no. CMB-3 (Design No. 3) was determined to be acceptable according to the TL-3 safety performance criteria for test designation no. 3-11 found in NCHRP Report No. 350.



- Test Agency .... MwRSF
- Test Number CMB-3
- Date 3/14/05
- NCHRP 350 Test Designation 3-11
- Appurtenance .... Low-Tension, Four-Cable Median Barrier
- Total Length .... 147.5 m
- Key Elements - Wire Rope
  - Diameter .... 19 mm
  - Size .... 7 x 19
  - Top Cable Mounting Height .. 838 mm
  - Incremental Spacing .... 165 mm
- Key Elements - Steel End Anchor Posts
  - Post No. 1 and 61 .... W152 x 37.2 by 2,438 mm long
  - Post No. 2 and 60 .... S76 x 8 5 by 914 mm long slip post with W152 x 13.4 by 1,829 mm long base post
- Key Elements - Steel Line Posts
  - Post Nos. 3-25, 46-59 .... S76x8 5 by 1,676 mm long
  - Post Nos. 26-45 .... S76x8 5 by 1,702 mm long
  - Spacing .... 2,438 mm
- Type of Soil .... Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 2000P
  - Make and Model .... 1998 GMC Pickup
  - Curb .... 1,989 kg
  - Test Inertial .... 2,023 kg
  - Gross Static .... 2,023 kg
- Impact Conditions
  - Speed .... 97.8 km/h
  - Angle .... 25.4 degrees
  - Impact Location .... 1,219 mm upstream centerline post no. 31
- Exit Conditions
  - Speed .... 67.6 km/h
  - Angle (estimated) .... 7 degrees
  - Exit Box Criterion .... Pass
- Post-Impact Trajectory
  - Vehicle Stability .... Satisfactory
  - Stopping Distance .... 57.5 m downstream 8.7 m traffic-side face
- Occupant Impact Velocity
  - Longitudinal .... -3.32 m/s < 12 m/s
  - Lateral (not required) ..... 3.12 m/s < 12 m/s
- Occupant Ridedown Deceleration
  - Longitudinal .... -3.93 g's < 20 g's
  - Lateral (not required) ..... 6.26 g's < 20 g's
- THIV (not required) .... 4.26 m/s
- PHD (not required) .... 6.27 g's
- Test Article Damage .... Moderate
- Test Article Deflections
  - Post Permanent Set ...... NA
  - Post Dynamic .... 665 mm
  - Working Width .... 2,878 mm
- Vehicle Damage .... Moderate
  - VDS[4] 11-LFQ-3
  - CDC[5] 11-LFMN-3
  - Maximum Deformation ... 22 mm at center of dashboard

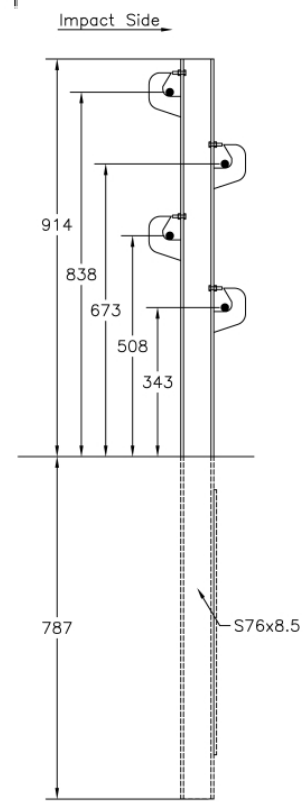
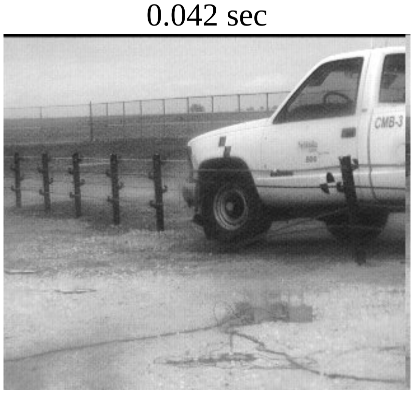


Figure 81. Summary of Test Results and Sequential Photographs, Test CMB-3

0.000 sec

0.016 sec

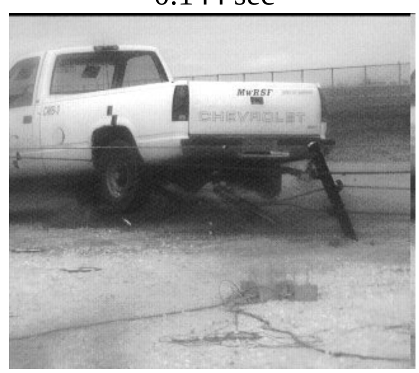
0.042 sec



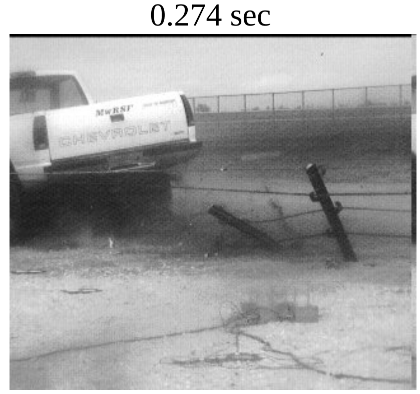
0.064 sec

0.094 sec

0.144 sec

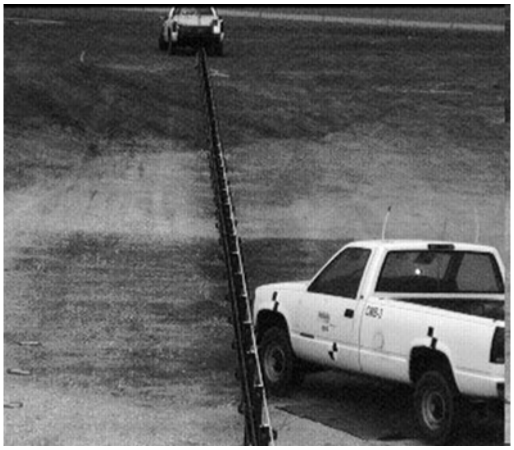


0.274 sec



0.364 sec

Figure 82. Additional Sequential Photographs, Test CMB-3



0.000 sec

0.140 sec

0.270 sec

0.470 sec

0.872 sec

1.390 sec

Figure 83. Additional Sequential Photographs, Test CMB-3

0.000 sec

0.154 sec

0.476 sec

0.716 sec

1.040 sec

1.286 sec

Figure 84. Additional Sequential Photographs, Test CMB-3

0.000 sec

0.260 sec

0.412 sec

0.584 sec

0.826 sec

1.128 sec

Figure 85. Additional Sequential Photographs, Test CMB-3

0.000 sec

0.200 sec

0.501 sec

0.801 sec

1.101 sec

1.401 sec

Figure 86. Documentary Photographs, Test CMB-3


0.000 sec


0.334 sec


0.100 sec


0.434 sec


0.234 sec


0.634 sec

Figure 87. Documentary Photographs, Test CMB-3

Figure 88. Vehicle Impact Location, Test CMB-3

Figure 89. Vehicle Final Position and Trajectory Marks, Test CMB-3

Figure 90. System Damage, Test CMB-3

Post No. 29

Post No. 30

Post No. 31

Post No. 32

Post No. 33

Post No. 35

Figure 91. Post Nos. 29 through 33 and 35 Damage, Test CMB-3

Post No. 36

Post No. 37

Post No. 38

Post No. 39

Post No. 40

Post No. 41

Figure 92. Post Nos. 36 through 41 Damage, Test CMB-3

Figure 93. Upstream Anchorage Damage, Test CMB-3

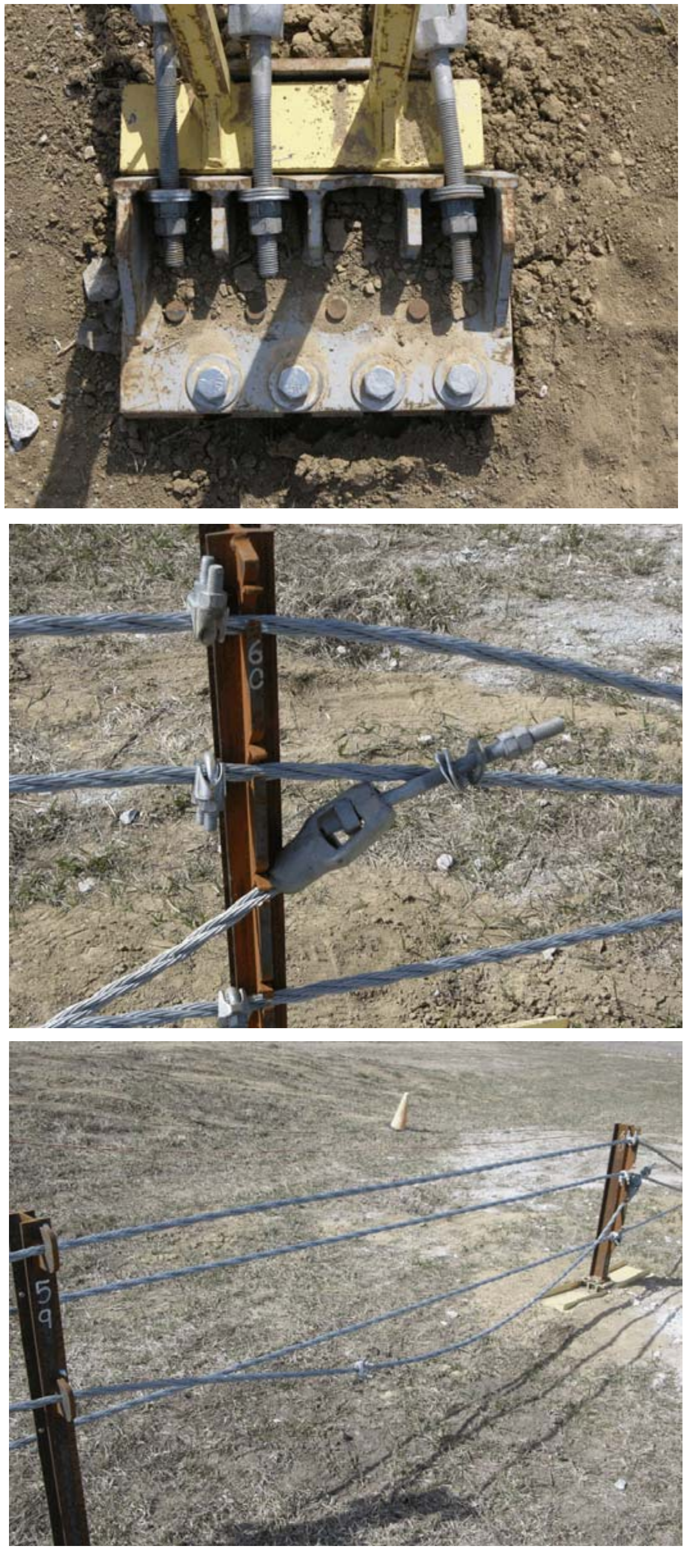


Figure 94. Downstream Anchorage Damage, Test CMB-3

Figure 95. Vehicle Damage, Test CMB-3

Figure 96. Vehicle Damage, Test CMB-3

10 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The main research objective was to develop, test, and evaluate a low-tension cable median barrier system that would improve the field performance of the barrier system over that observed for existing low-tension cable median barrier designs. To accomplish the project objectives, a four-cable barrier design was selected in order to allow for a greater vertical cable spacing, thus resulting in an increased propensity for capturing vehicles and preventing cross-median crashes. Researchers also evaluated several designs with a reduced post spacing as well as improvements in the cable-to-post attachment in an effort to increase energy absorption of the barrier system and further reduce dynamic barrier deflections. A summary of the key design details for each cable median barrier system and the results of the associated full-scale crash tests are provided below.

Three low-tension, cable median barrier systems were subjected to full-scale vehicle crash testing. Three full-scale crash tests were performed on the three different cable systems installed on level terrain. The system tested in the first full-scale crash test, test no. CMB-1, was an 80-post, 148.1-m (486-ft) long, low-tension, cable median barrier with anchored ends (Design No. 1). The system used a shortened post spacing of 1.83 m (6 ft) with cable hooks attached to the flanges of the M203x9.7 (M8x6.5) steel line posts. The cables alternated between posts, creating a weaving pattern. Test no. CMB-1 consisted of an 893-kg (1,969-lb) small car impacting the cable median barrier (Design No. 1) at a speed of 97.6 km/h (60.6 mph) and at an angle of 19.7 degrees. The impact point for this test was 1,219 mm (48 in.) upstream from the centerline of post no. 41. During the test, the vehicle was launched into the air and underwent a significant positive roll. The vehicle experienced rollover, causing considerable crushing of the occupant compartment. Subsequently, the results for test no. CMB-1 were found to fail the TL-3 safety performance criteria for test designation no. 3-10 found in NCHRP Report No. 350 as the vehicle did not remain upright.

The system tested in test no. CMB-2 was a 61-post, 147.5-m (484-ft) long, low-tension, cable median barrier with anchored ends (Design No. 2). The system incorporated the same end anchorage as Design No. 1. Design No. 2 utilized a widened line post spacing with a soil plate welded to each S76x8.5 (S3x5.7) steel line post. The cables were mounted on the posts using welded cable brackets. The cables were not woven between posts. Test no. CMB-2 consisted of an 889-kg (1,960-lb) small car impacting the cable median barrier (Design No. 2) at a speed of 101.1 km/h (62.8 mph) and at an angle of 19.7 degrees. The impact point for this test was 1,219 mm (48 in.) upstream from the centerline of post no. 31. The results for test no. CMB-2 were found to pass the TL-3 safety performance criteria for test designation no. 3-10 found in NCHRP Report No. 350 as the small car was brought to a controlled stop. However, the upper two cables were observed to release prematurely from a significant number of posts, thus warranting the addition of a retainer bolt in the next design.

The system tested in test no. CMB-3 was similar to the previous test in that it was a 61-post, 147.5-m (484-ft) long, low-tension, cable median barrier (Design No. 3). The system utilized the same end anchorage as used in the previous two cable median barrier designs. The line posts consisted of S76x8.5 (S3x5.7) steel sections with soil plates welded to the bases. The line posts were of two different lengths. Line post nos. 26 through 45 were 1,702 mm (67 in.) long, while line post nos. 3 through 25 and 46 through 59 were 1,676 mm (66 in.) long. Line post nos. 26 through 45 used modified welded cable brackets to attach the cables to the posts, while line posts 3 through 25 and 46 through 59 used the same cable brackets used in Design No. 2. On each of the 57 line posts, 6.5-mm (0.25-in.) diameter retainer bolts were attached at the opening of each cable bracket to secure the cables. The cables did not alternate between posts and had a uniform mounting height between the line posts. Test no. CMB-3 consisted of a 2,023-kg (4,459-lb) pickup truck impacting the cable median barrier (Design No. 3) at a speed of 97.8 km/h (60.8 mph) and at an angle of 25.4 degrees. The impact point for this test was 1,219 mm (48 in.) upstream from the centerline of post no. 31. The results for test no. CMB-3 were found to pass the TL-3 safety performance criteria for test designation no. 3-11 found in NCHRP Report No. 350 as the pickup truck was brought to a controlled stop.

As discussed previously, one small car test was successfully performed on Design No. 2, while one pickup truck test achieved satisfactory results on Design No. 3. It should be noted that Design Nos. 2 and 3 were nearly identical to one another, except for the addition of cable retainer bolts utilized in Design No. 3. Based upon the results of test nos. CMB-2 and CMB-3, it is believed that the new, four-cable, low-tension, median barrier system with retainer bolts (Design No. 3) should also perform in an acceptable manner when impacted with an 820-kg (1,808-lb) small car at the TL-3 conditions of NCHRP Report No. 350. However, it is recommended that the new cable median barrier with retainer bolts (Design No. 3) be further evaluated using the TL-3 small car crash test if the barrier system is desired for use.

As noted previously, the cable barrier systems were evaluated when installed on level terrain. Therefore, it is recommended that any future research and development of these median barrier systems should also consider their intended use and placement in medians with sloped versus level terrains.

Table 4. Summary of Safety Performance Evaluation Results

Evaluation Factors	Evaluation Criteria		Test CMB-1 (Design No. 1)	Test CMB-2 (Design No. 2)	Test CMB-3 (Design No. 3)
Structural Adequacy	A.	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflections of the test article is acceptable.	U	S	S
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 an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	S	S	S
	F.	The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	U	S	S
	H.	Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9 m/s (29.53 ft/s) , or at least below the maximum allowable value of 12 m/s (39.37 ft/s).	S	S	NA
	I.	Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15 g's, or at least below the maximum allowable value of 20 g's.	S	S	NA
Vehicle Trajectory	K.	After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	S	S	S
	L.	The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec (39.37 ft/sec), and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	NA	NA	S
	M.	The exit angle from the test article preferably should be less than 60 percent of test impact angle measured at time of vehicle loss of contact with test device.	S	S	S

S - Satisfactory
U - Unsatisfactory
NA - Not Available

11 REFERENCES

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

2. Hinch, J., Yang, T.L., and Owings, R., *Guidance Systems for Vehicle Testing*, ENSCO, Inc., Springfield, VA, 1986.

3. Kuipers, B.D. and Reid, J.D., *Testing of M203.7x9.7 (M8x6.5) and S76x8.5 (S3x5.7) Steel Posts - Post Comparison Study for the Cable Median Barrier*, Final Report to the Midwest State's Regional Pooled Fund Program, Transportation Research Report No. TRP-03-143-03, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, October 24, 2003.

4. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.

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

12 APPENDICES

APPENDIX A

English-Unit System Details, Design No. 1

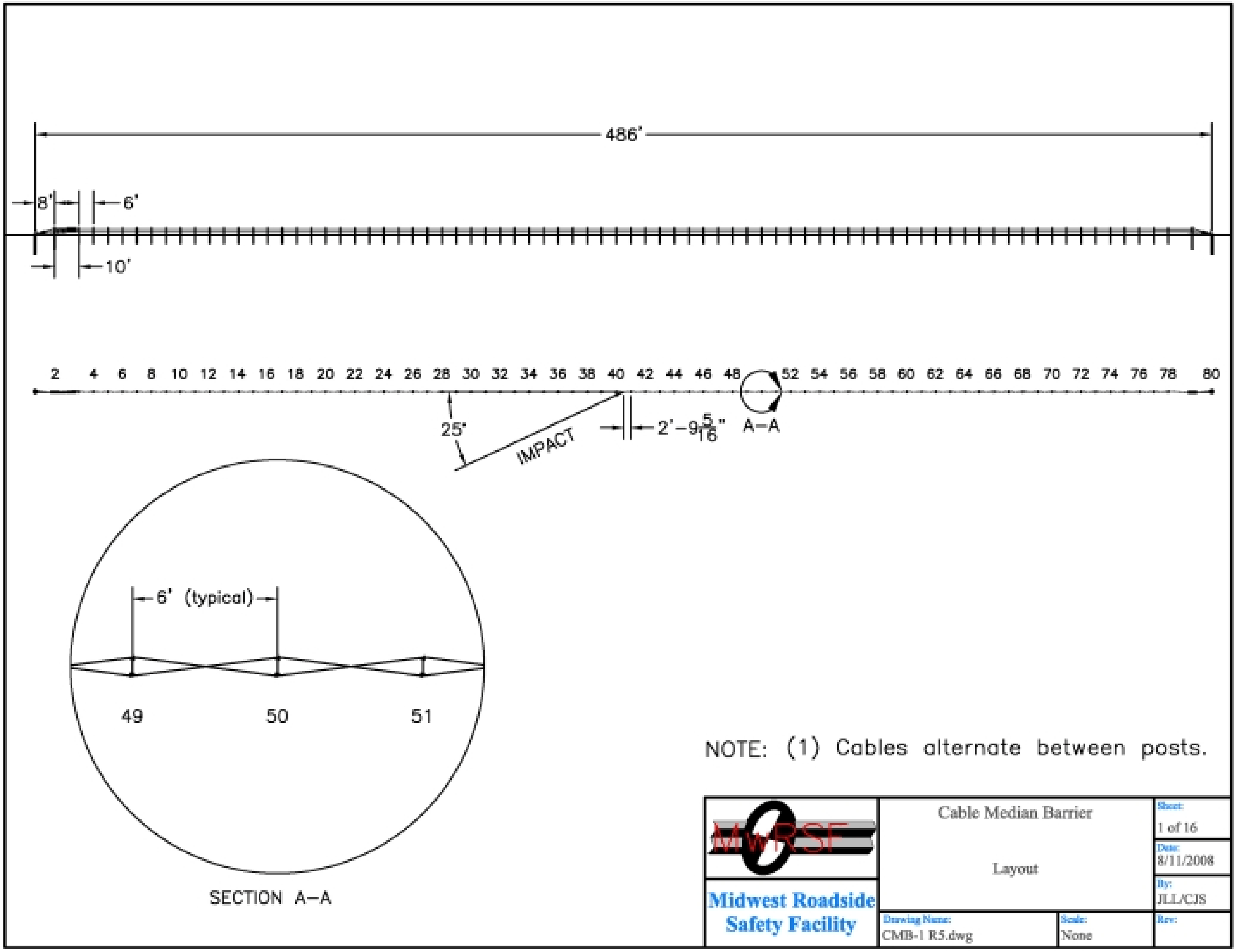


Figure A-1. System Layout (English), Design No. 1

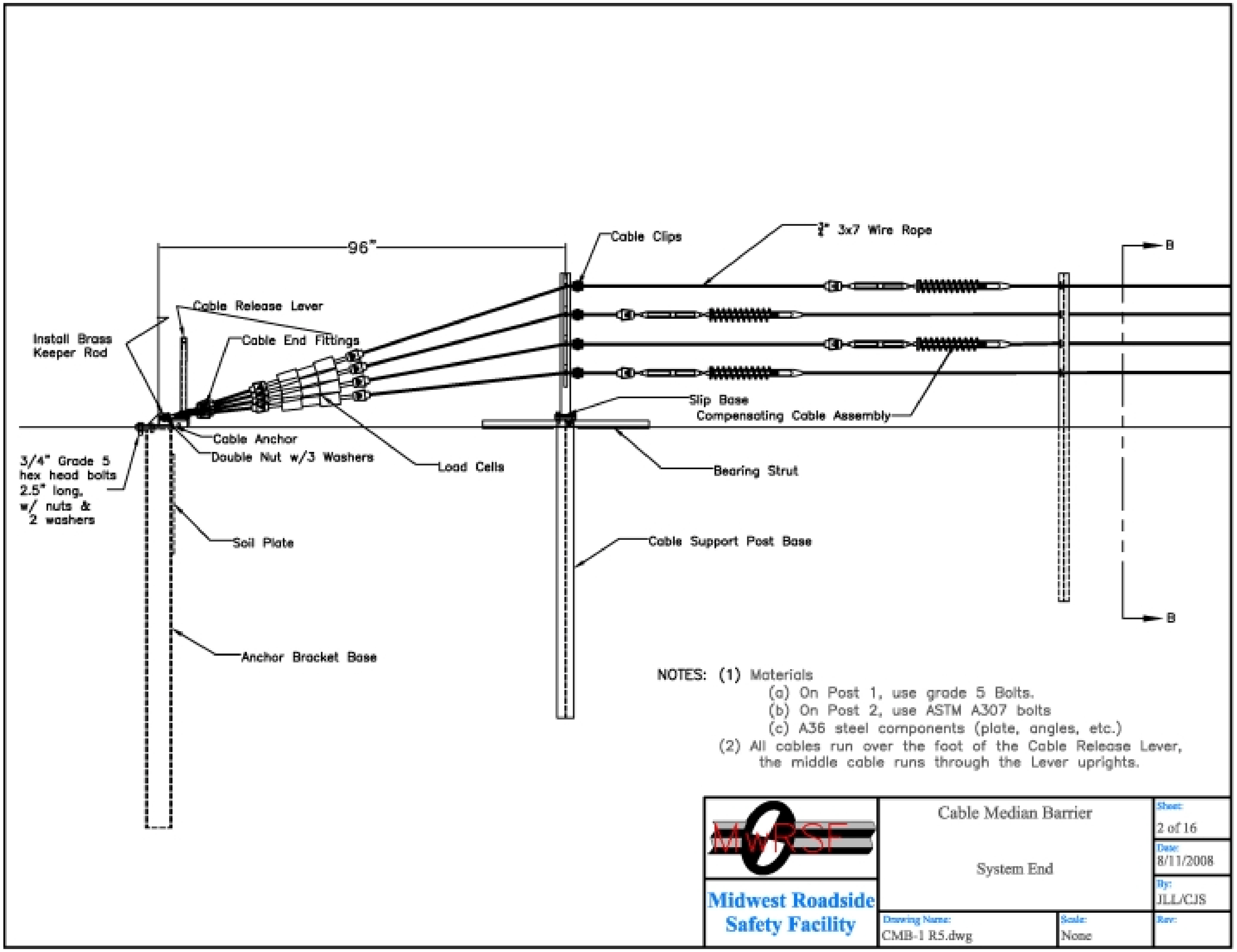


Figure A-2. System End (English), Design No. 1

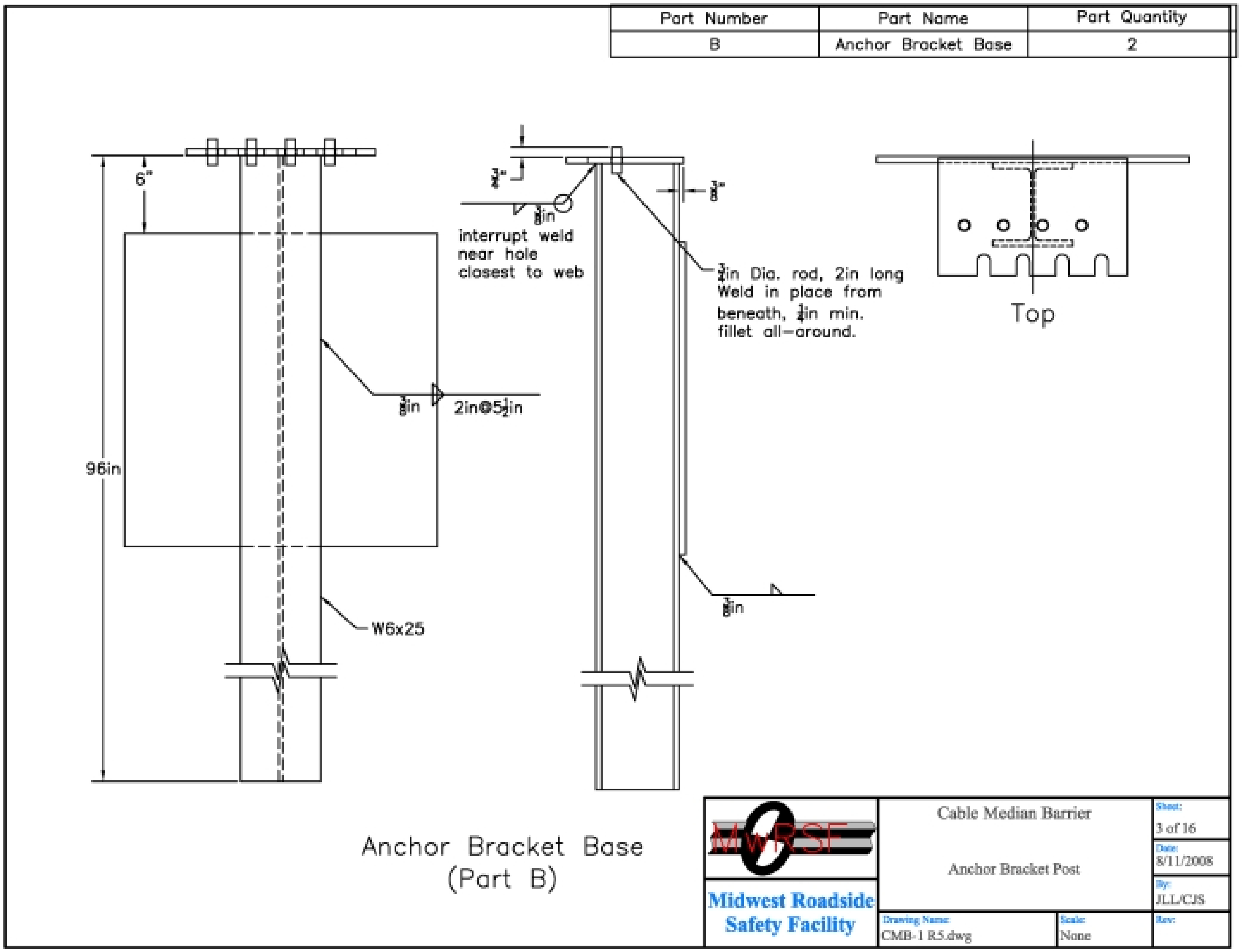
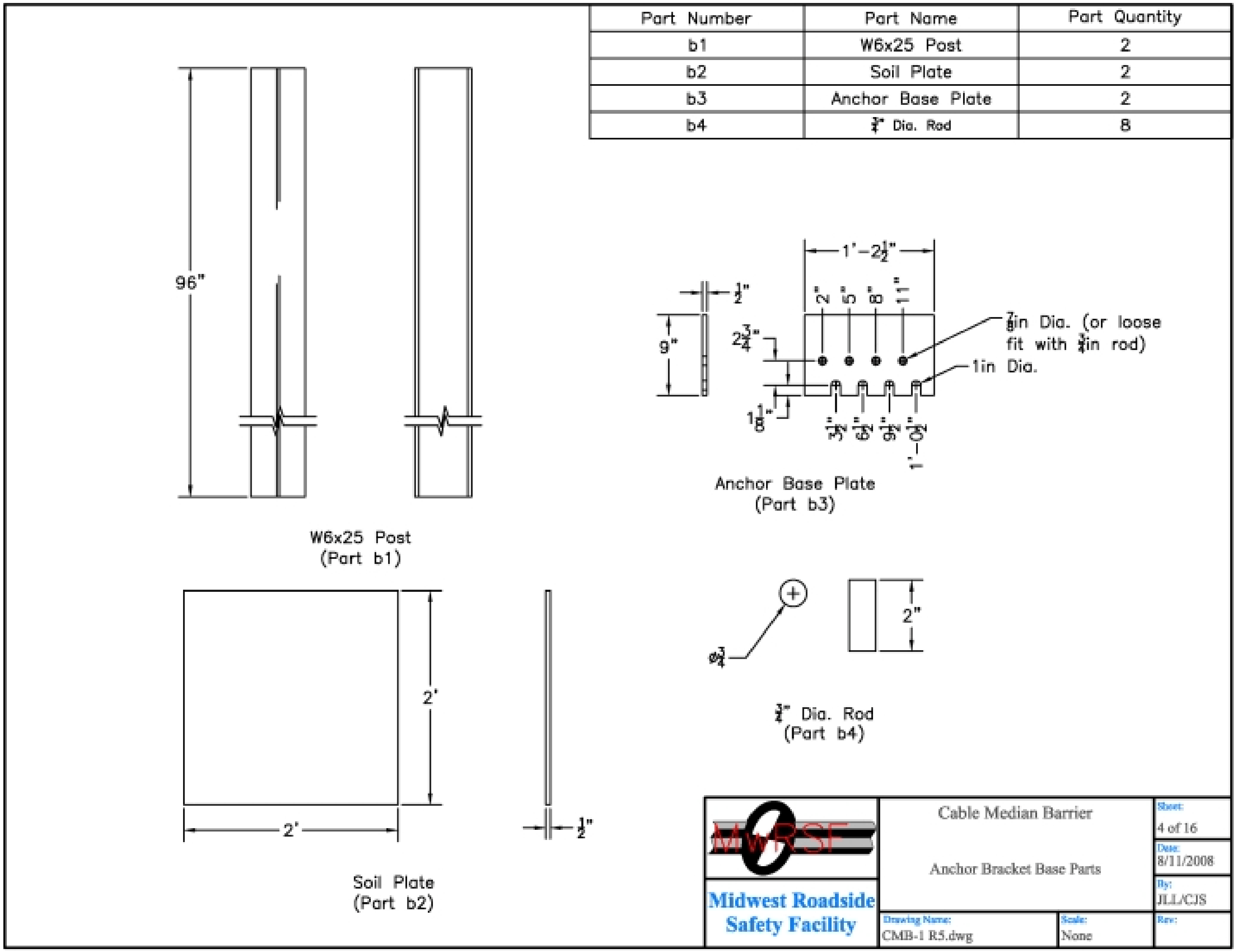


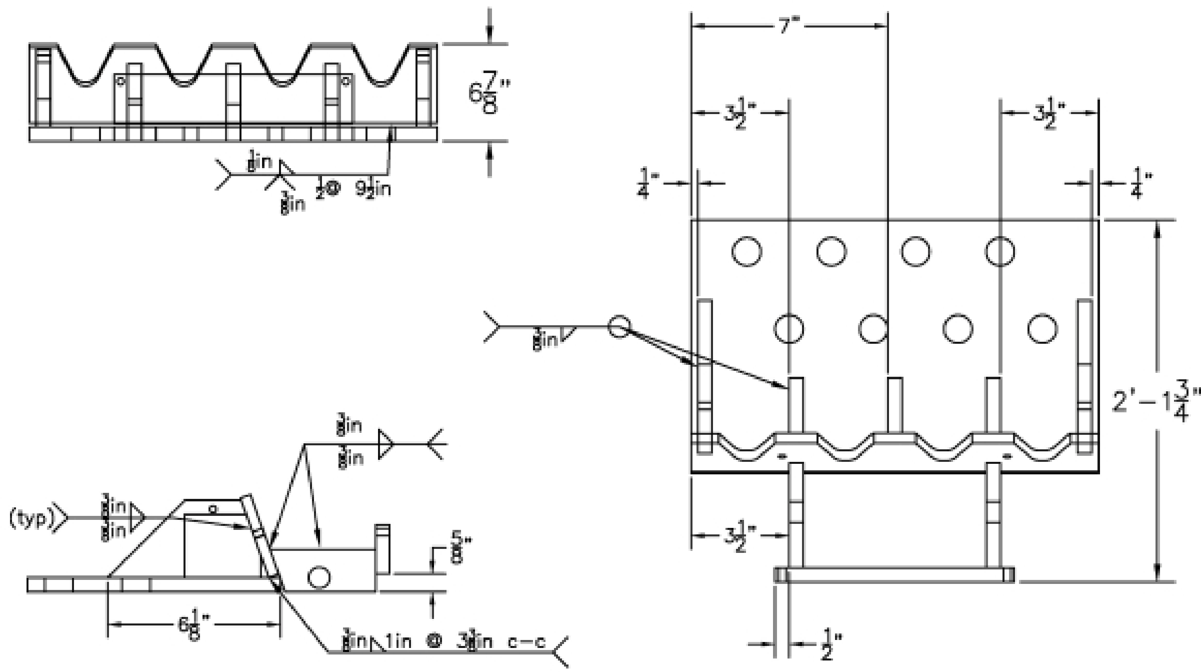
Figure A-3. Anchor Bracket Post (English), Design No. 1



Part Number	Part Name	Part Quantity
b1	W6x25 Post	2
b2	Soil Plate	2
b3	Anchor Base Plate	2
b4	3/4" Dia. Rod	8

Figure A-4. Anchor Bracket Base Parts (English), Design No. 1

Part Number	Part Name	Part Quantity
A	Cable Anchor Bracket	2



Cable Anchor Bracket
(Part A)

MwRSF Midwest Roadside Safety Facility	Cable Median Barrier Cable Anchor		Sheet: 5 of 16 Date: 8/11/2008 By: JLL/CJS
	Drawing Name: CMB-1 R5.dwg	Scale: None	Rev:

Figure A-5. Cable Anchor Bracket (English), Design No. 1

Part Number	Part Name	Part Quantity	Material
a1	Anchor Plate	2	A36 1/2" Plate
a2	Cable Plate	2	A36 3/8" Plate
a3	Release Lever Plate	2	A36 1/2" Plate
a4	Exterior Cable Plate Gusset	4	A36 1/2" Plate
a5	Interior Cable Plate Gusset	6	A36 1/2" Plate
a6	Release Lever Plate Gusset	2	A36 1/2" Plate

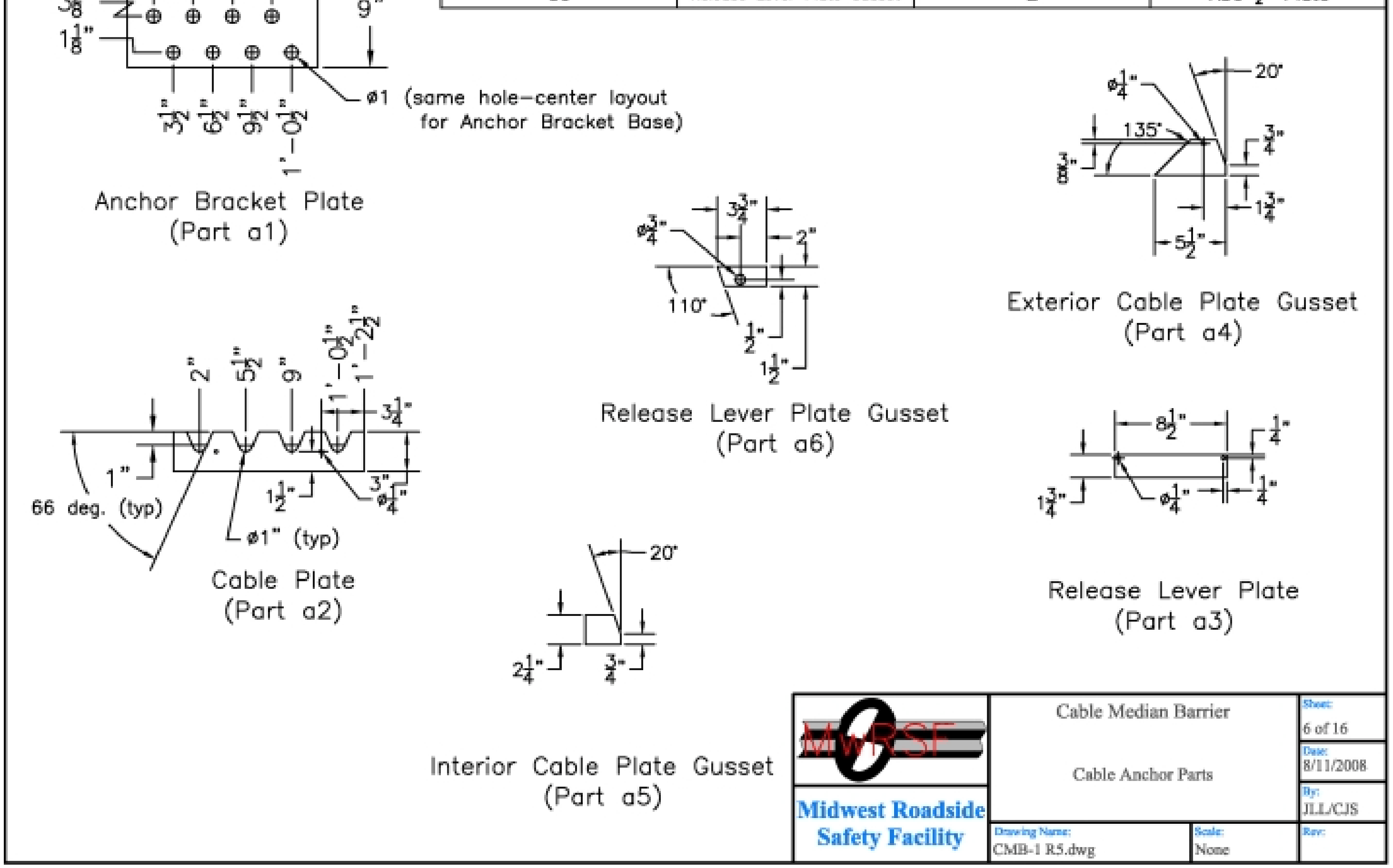


Figure A-6. Cable Anchor Bracket Parts (English), Design No. 1

Part Number	Part Name	Part Quantity	Material
F	Cable Release Lever	2	
f1	Kicker Lever	4	A36 1¼x1¼x3/16in tube
f2	Connecting Tube	2	A36 1¼x1¼x3/16in tube
f3	Kicker Plate Gusset	4	A36 ½" Plate
f4	Kicker Plate	2	A36 1/2" Plate

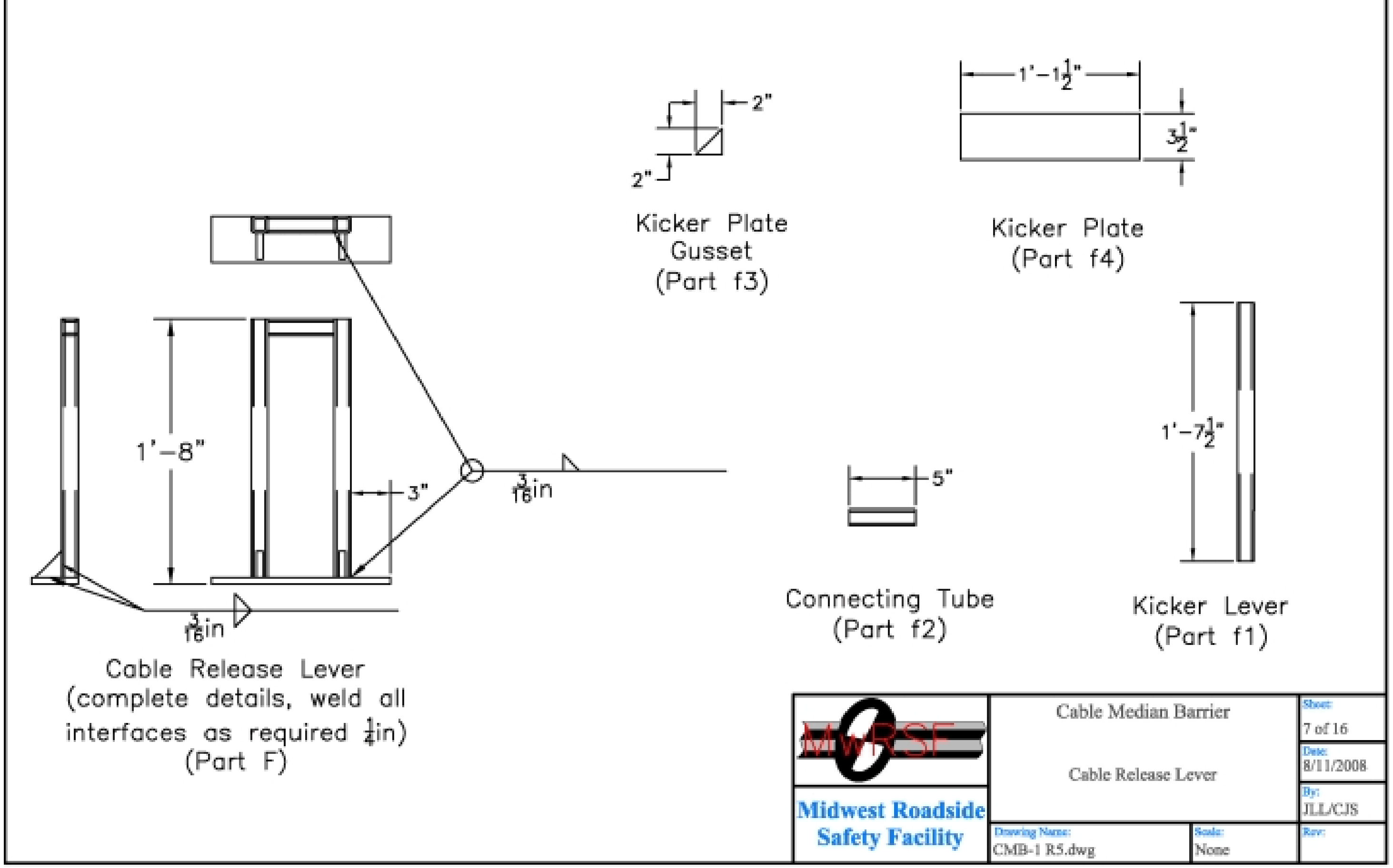


Figure A-7. Cable Release Lever (English), Design No. 1

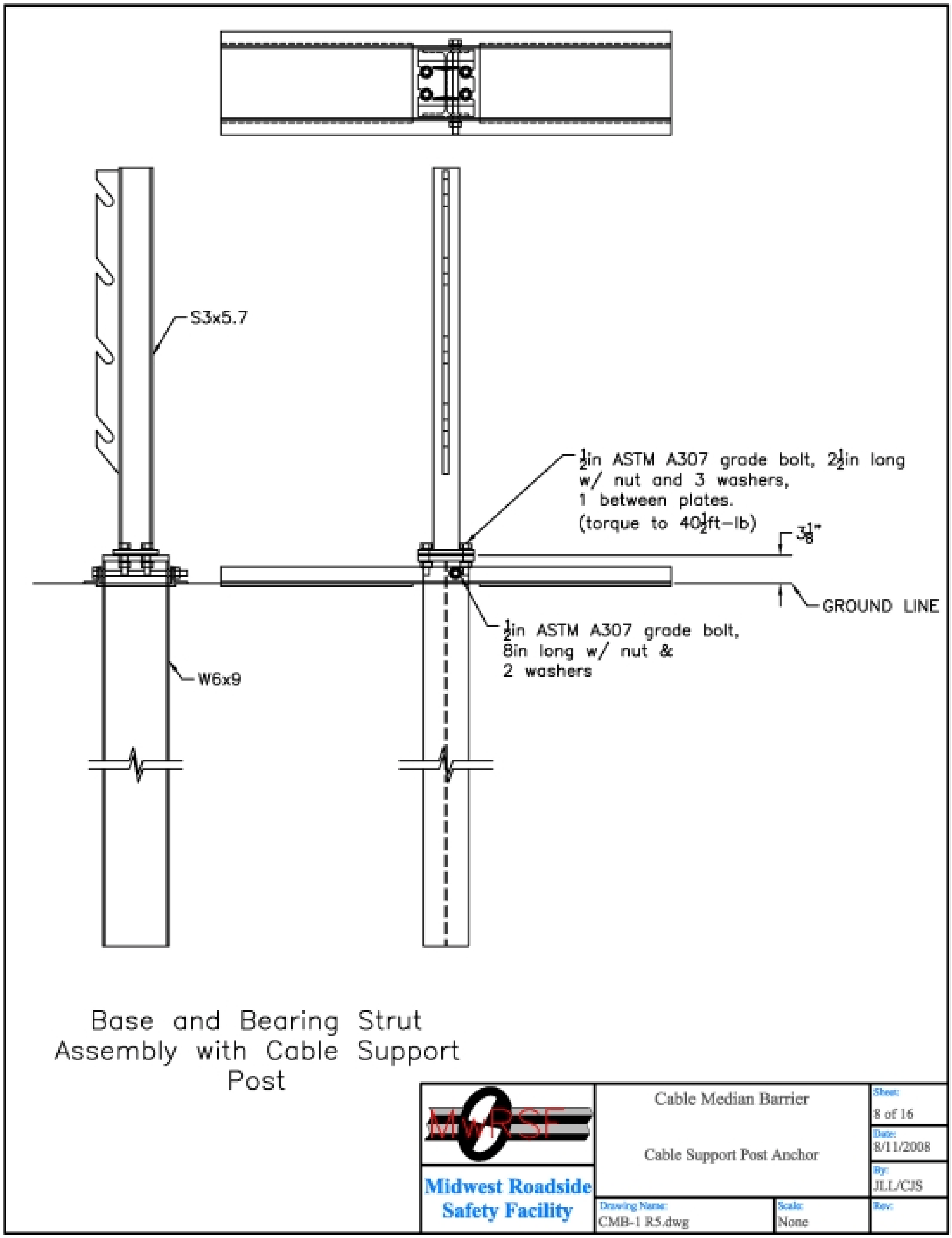


Figure A-8. Cable Support Post Anchor (English), Design No. 1

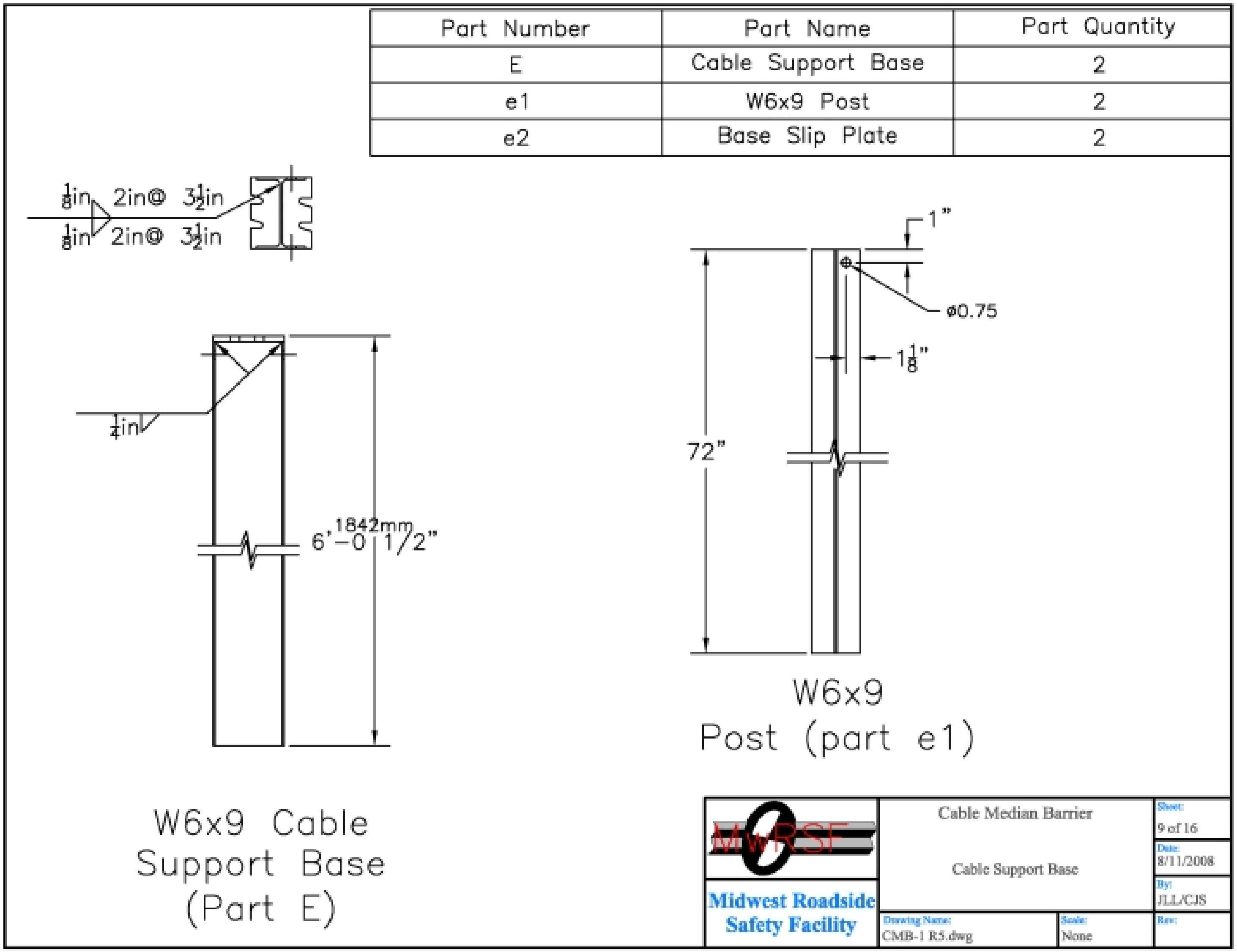
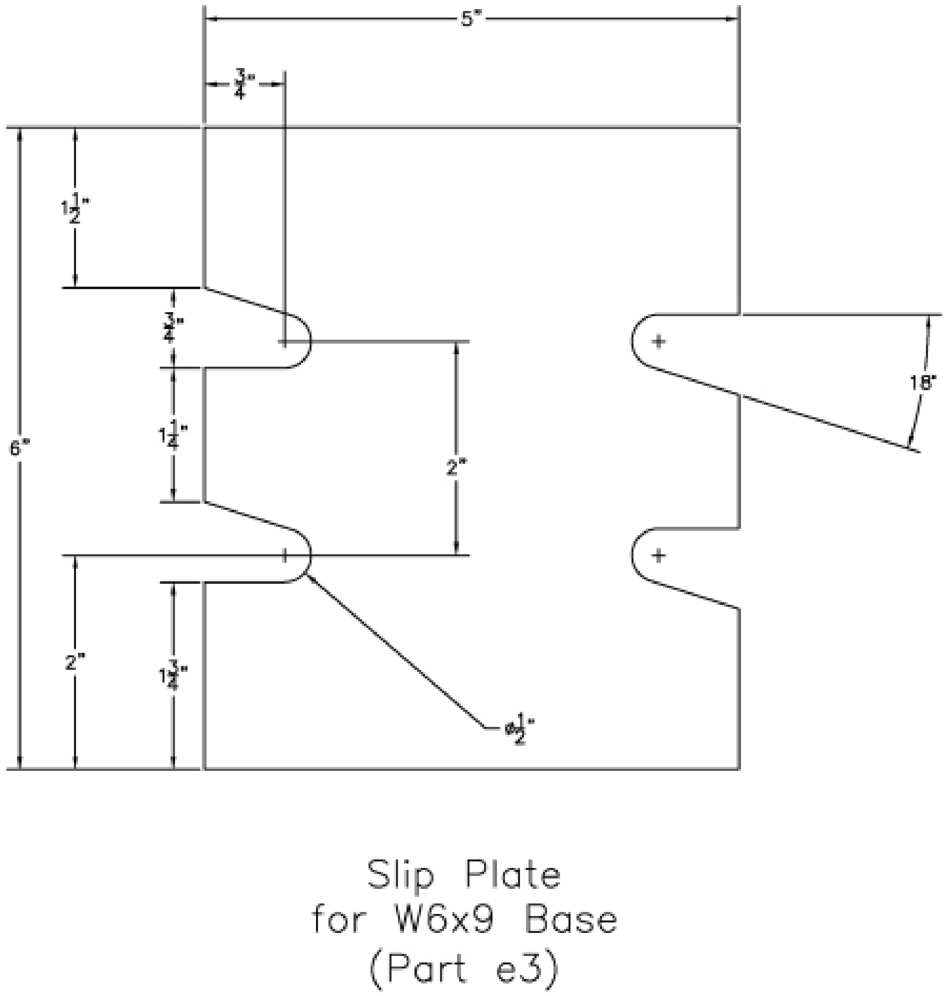


Figure A-9. Cable Support Base (English), Design No. 1

Part Number	Part Name	Part Quantity	Material
e2	Base Slip Plate	2	A36 $\frac{1}{2}$" Plate



Midwest Roadside Safety Facility

Cable Median Barrier

Base Slip Plate

Sheet: 10 of 16

Date: 8/11/2008

By: JLL/CJS

Drawing Name: CMB-1 R5.dwg

Scale: None

Rev:

Figure A-10. Base Slip Plate (English), Design No. 1

Part Number	Part Name	Part Quantity
D	Cable Support Post	2
d1	S3x5.7 Post	2

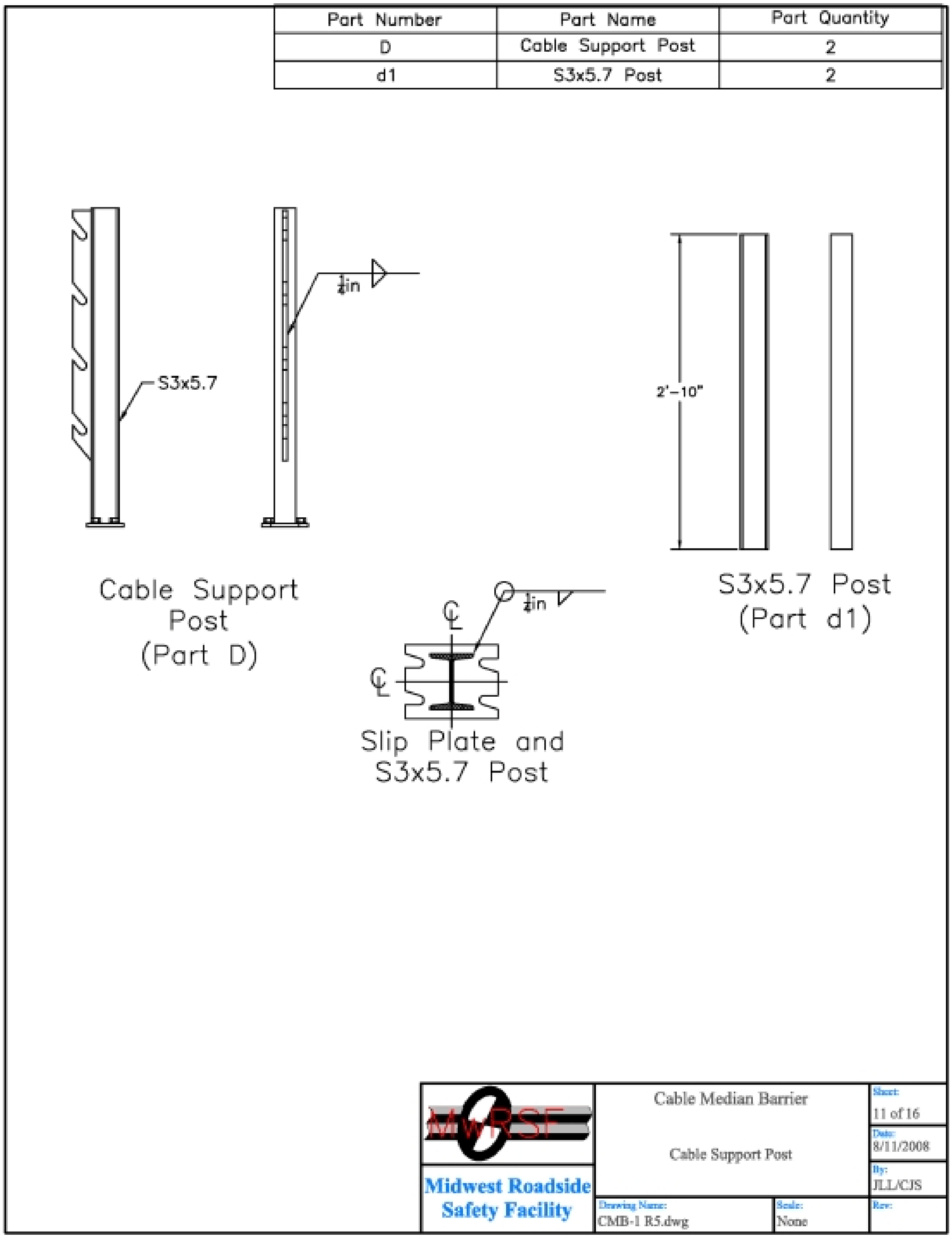


Figure A-11. Cable Support Post (English), Design No. 1

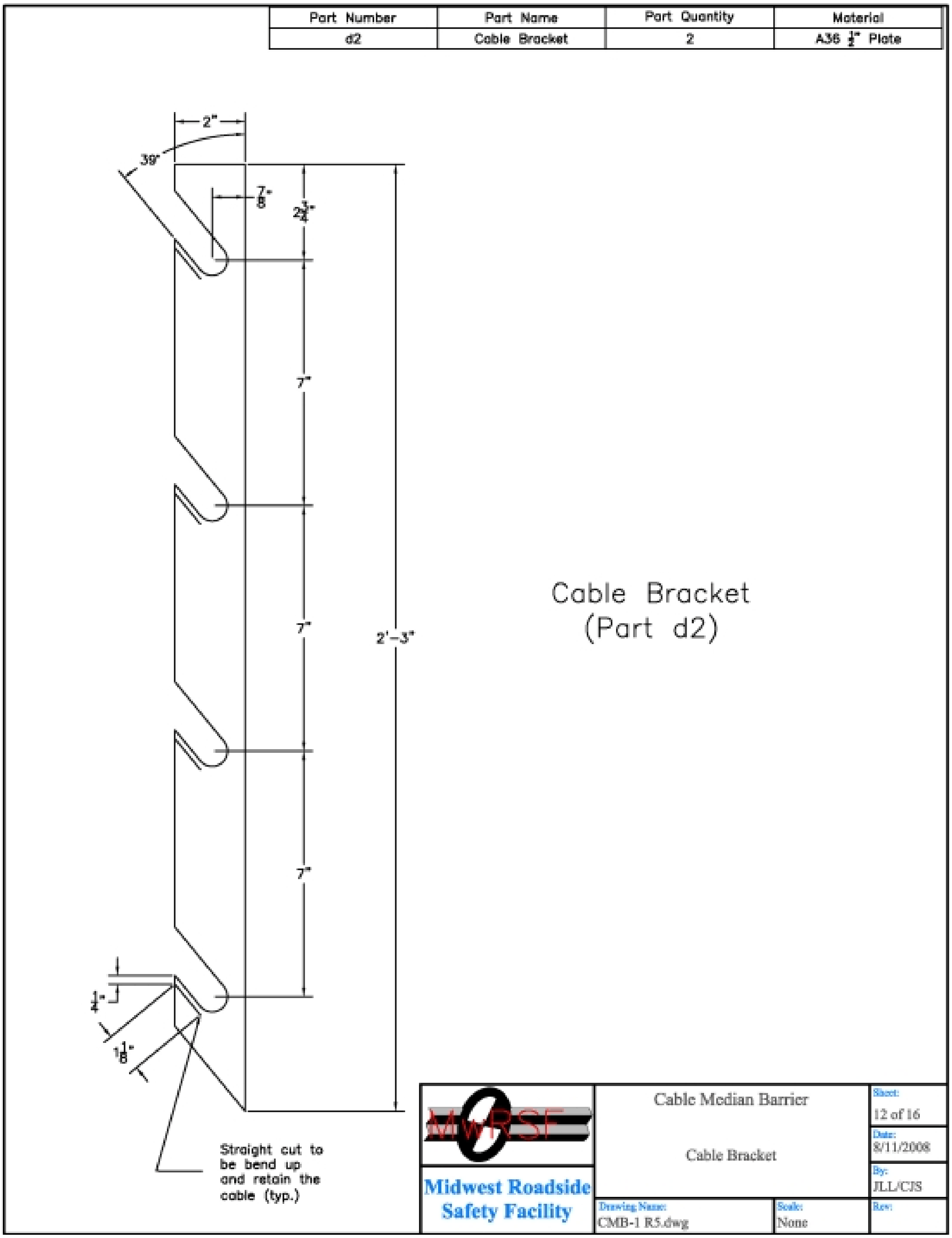


Figure A-12. Cable Bracket (English), Design No. 1

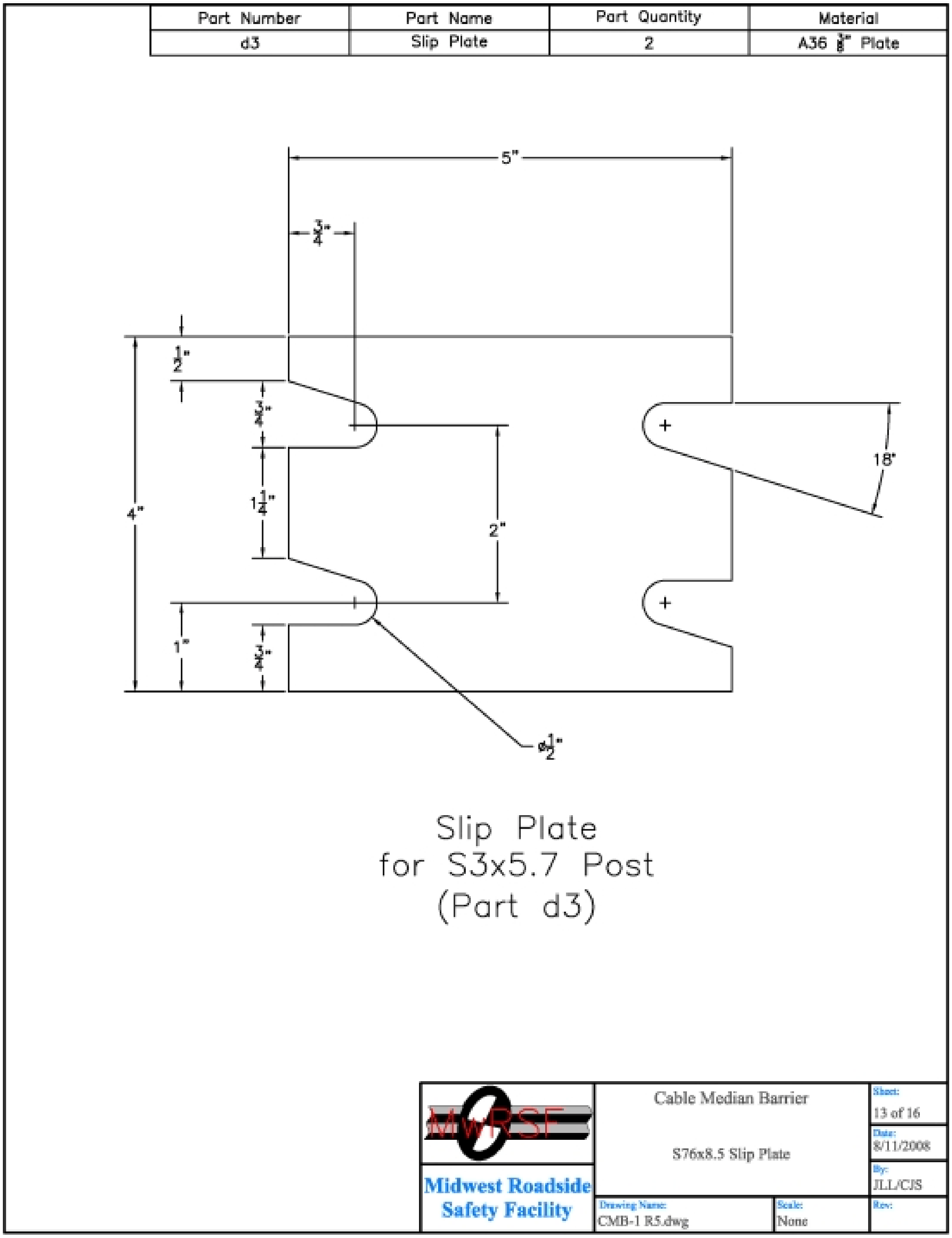


Figure A-13. Cable Bracket Slip Plate (English), Design No. 1

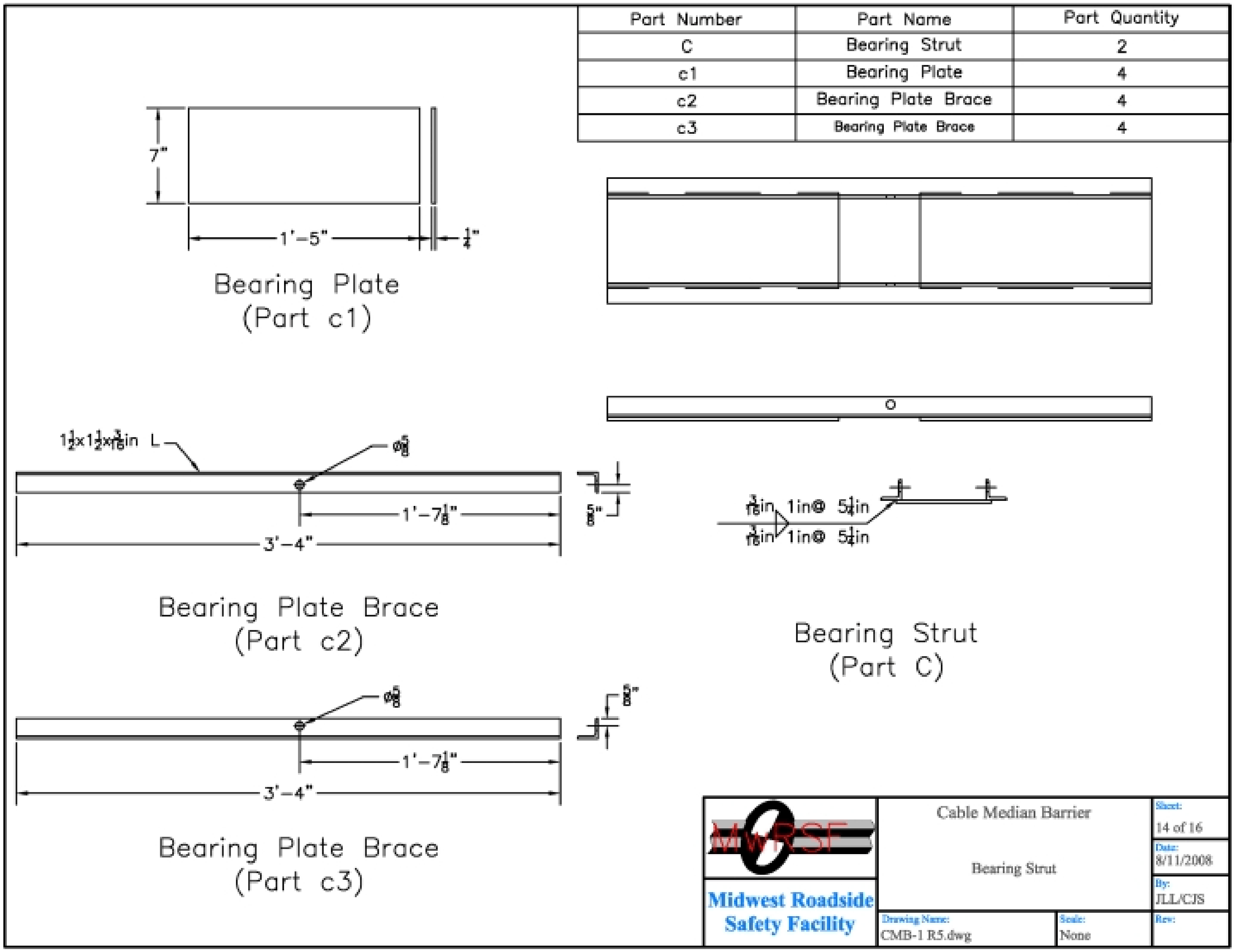


Figure A-14. Bearing Strut (English), Design No. 1

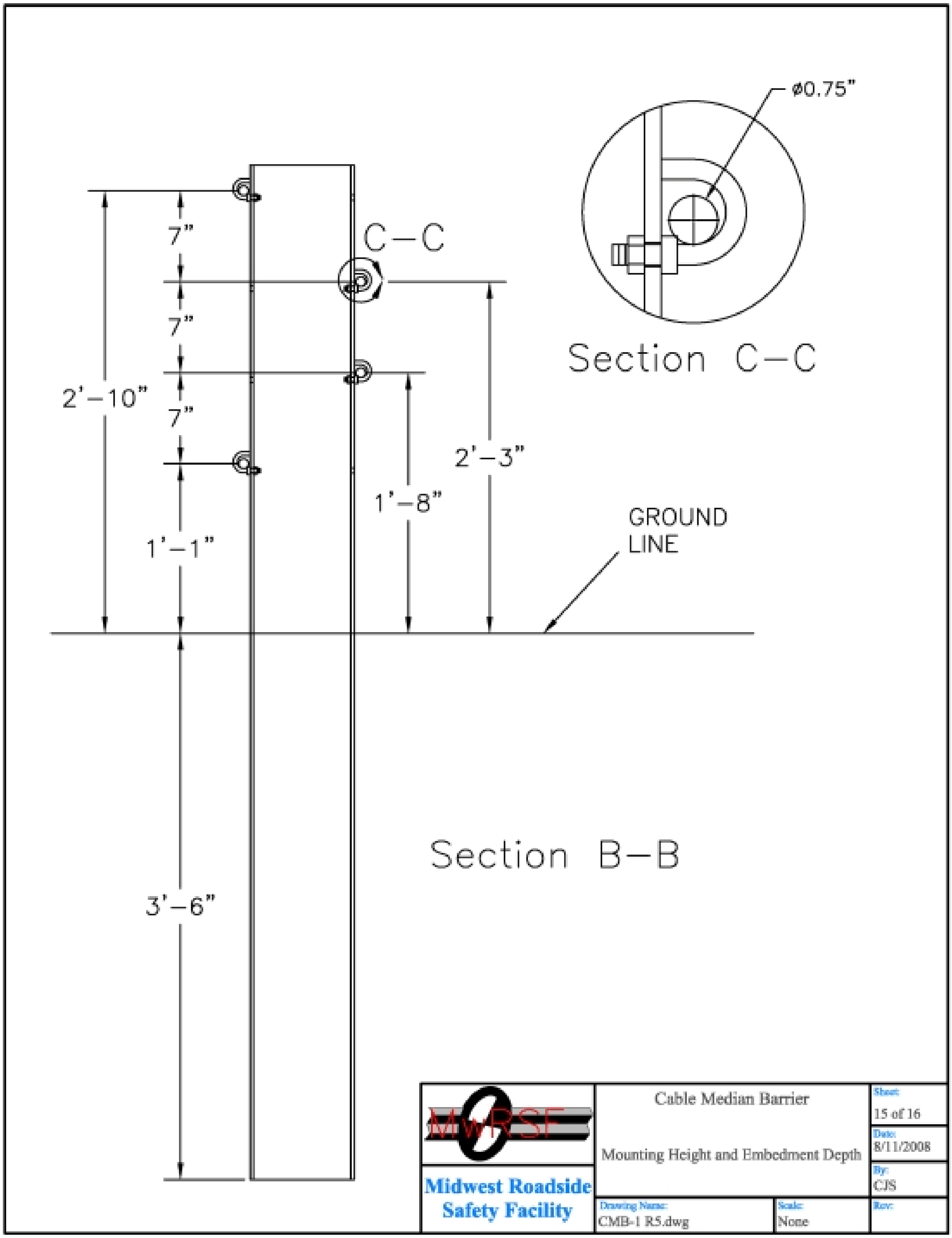


Figure A-15. Cable Guardrail Post Assembly (English), Design No. 1

Part Number	Part Name	Part Quantity
G	Cable Guardrail Posts	76
g1	M8x6.5 Post	76
g2	Cable Hook Bolt with Nut	304

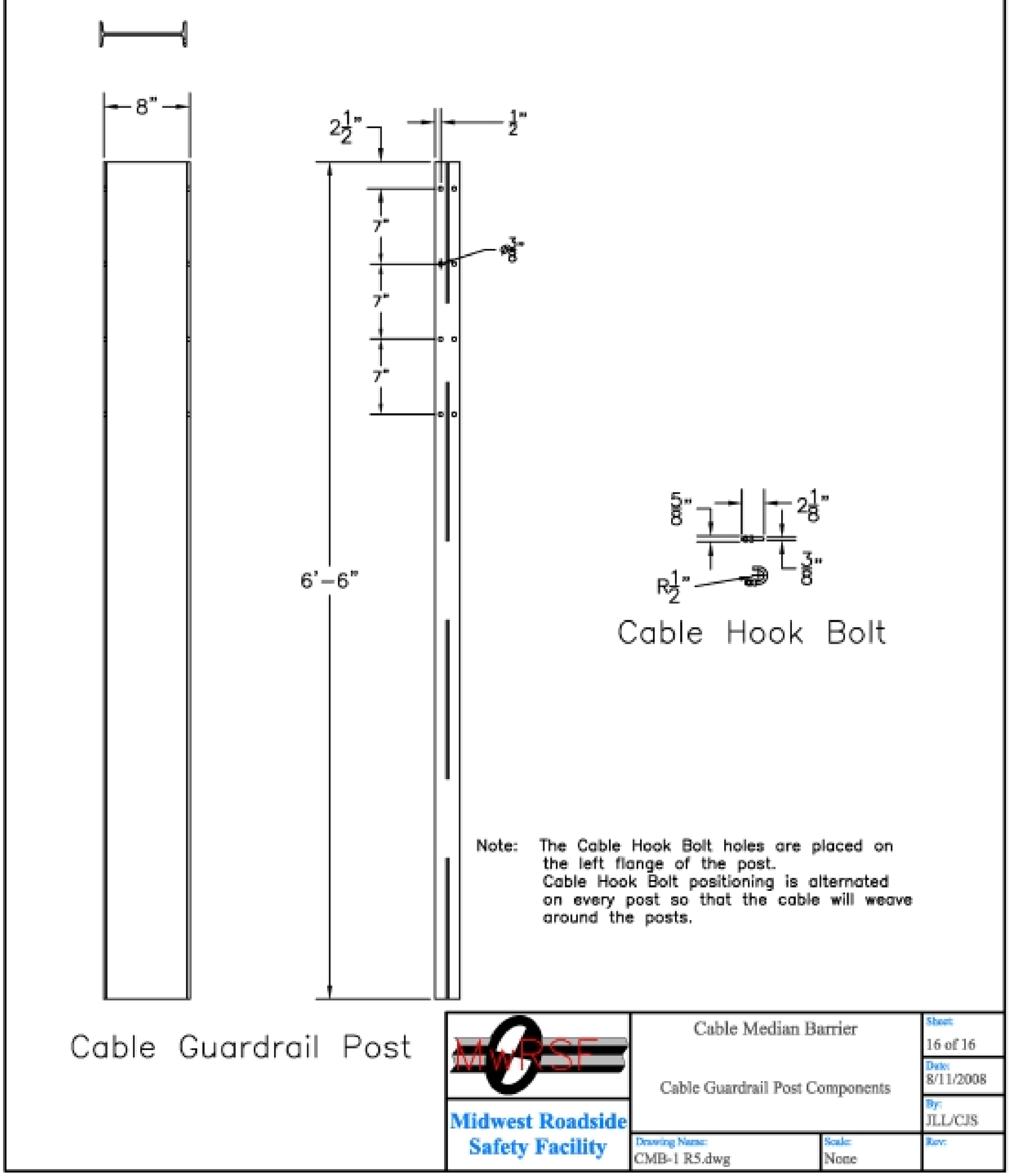
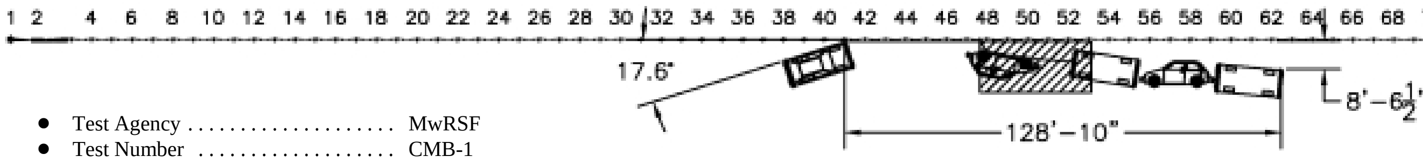


Figure A-16. Cable Guardrail Post Components (English), Design No. 1

APPENDIX B

Test Summary Sheets in English Units

0.000 sec   0.110 sec   0.226 sec   0.334 sec   0.450 sec



- Test Agency .... MwRSF
- Test Number CMB-1
- Date 7/02/03
- NCHRP 350 Test Designation 3-10
- Appurtenance .... Low-Tension, Four-Cable Median Barrier
- Total Length .... 486 ft
- Key Elements - Wire Rope
  - Diameter .... 0.75 in.
  - Size 7x19
  - Top Cable Mounting Height .. 34 in.
  - Incremental Spacing .... 7 in.
- Key Elements - Steel End Anchor Posts
  - Post No. 1 and 80 .... W6x25 by 96 in. long
  - Post No. 2 and 79 .... S3x5.7 by 33 in. long slip post with W6x9 by 72 in. long base post
- Key Elements - Steel Line Posts
  - Post Nos. 3 - 78 .... M8x6.5 by 78 in. long
  - Spacing .... 72 in.
- Type of Soil .... Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 820C
  - Make and Model .... 1997 Geo Metro
  - Curb .... 1,640 lbs
  - Test Inertial .... 1,803 lbs
  - Gross Static .... 1,969 lbs
- Impact Conditions
  - Speed .... 60.6 mph
  - Angle .... 19.7 degrees
  - Impact Location .... 33.3 in. upstream from post 41

- Exit Conditions
  - Speed .... 33.3 mph
  - Angle .... 5 degrees
  - Exit Box Criterion .... Pass
- Post-Impact Trajectory
  - Vehicle Stability .... Unsatisfactory
  - Stopping Distance .... 128.9 ft downstream 8.5 ft traffic-side face
- Occupant Impact Velocity
  - Longitudinal .... -16.6 ft/s < 39.4 ft/s
  - Lateral .... 12.8 ft/s < 39.4 ft/s
- Occupant Ridedown Deceleration
  - Longitudinal .... -8.11 g's < 20 g's
  - Lateral .... 6.32 g's < 20 g's
- THIV (not required) .... 19.9 ft/s
- PHD (not required) .... 9.84 g's
- Test Article Damage .... Moderate
- Test Article Deflections
  - Post Permanent Set .... NA
  - Post Dynamic .... 21.5 in.
  - Working Width .... 44.3 in.
- Vehicle Damage .... Extensive
  - VDS[4] 11-FC-6
  - CDC[5] 11-LYA-7
  - Maximum Deformation ... NA

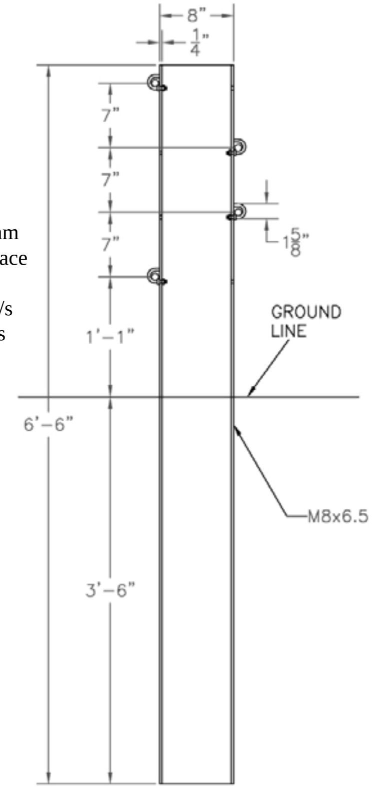


Figure B-1. Summary of Test Results and Sequential Photographs (English), Test CMB-1

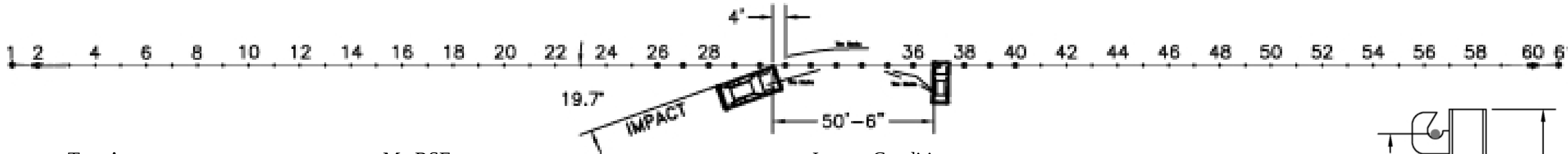

0.000 sec


0.103 sec


0.241 sec


0.414 sec


0.601 sec



- Test Agency .... MwRSF
- Test Number CMB-2
- Date 11/10/04
- NCHRP 350 Test Designation 3-10
- Appurtenance .... Low-Tension, Four-Cable Median Barrier
- Total Length .... 484 ft
- Key Elements - Wire Rope
  - Diameter .... 0.75 in.
  - Size 7x19
  - Top Cable Mounting Height .. 33 in.
  - Incremental Spacing .... 6.5 in.
- Key Elements - Steel End Anchor Posts
  - Post No. 1 and 61 .... W6x25 by 96 in. long
  - Post No. 2 and 60 .... S3x5.7 by 36 in. long slip post with W6x9 by 72 in. long base post
- Key Elements - Steel Line Posts
  - Post Nos. 3 - 59 .... S3x5.7 by 66 in. long
  - Spacing .... 96 in.
- Type of Soil .... Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 820C
  - Make and Model .... 1996 Geo Metro
  - Curb .... 1,735 lbs
  - Test Inertial .... 1,792 lbs
  - Gross Static .... 1,960 lbs
- Impact Conditions
  - Speed .... 62.8 mph
  - Angle .... 19.7 degrees
  - Impact Location .... 48 in. upstream from post 31
- Exit Conditions
  - Speed .... N/A
  - Angle .... N/A
  - Exit Box Criterion .... N/A
- Post-Impact Trajectory
  - Vehicle Stability .... Satisfactory
  - Stopping Distance .... 50.5 ft downstream 0.0 ft traffic-side face
- Occupant Impact Velocity
  - Longitudinal .... -20.1 ft/s < 39.4 ft/s
  - Lateral .... 6.3 ft/s < 39.4 ft/s
- Occupant Ridedown Deceleration
  - Longitudinal .... -8.78 g's < 20 g's
  - Lateral .... 5.30 g's < 20 g's
- THIV (not required) .... 10.4 ft/s
- PHD (not required) .... 8.98 g's
- Test Article Damage .... Moderate
- Test Article Deflections
  - Post Permanent Set .... 15.5 in.
  - Post Dynamic .... 33.1 in.
  - Working Width .... 75.6 in.
- Vehicle Damage .... Moderate
  - VDS[4] 11-FC-5
  - CDC[5] 11-FEDW-3
  - Maximum Deformation ... N/A

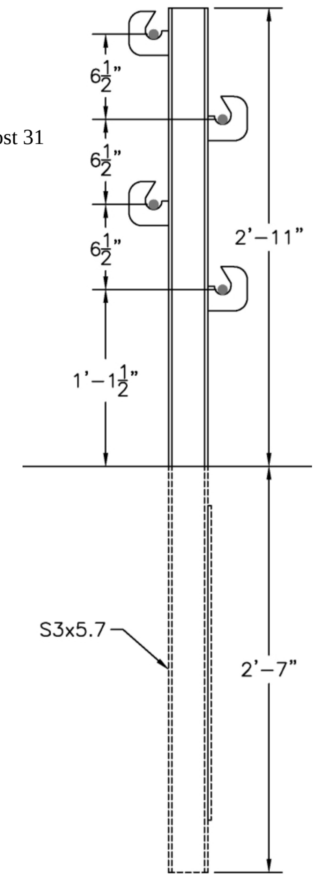
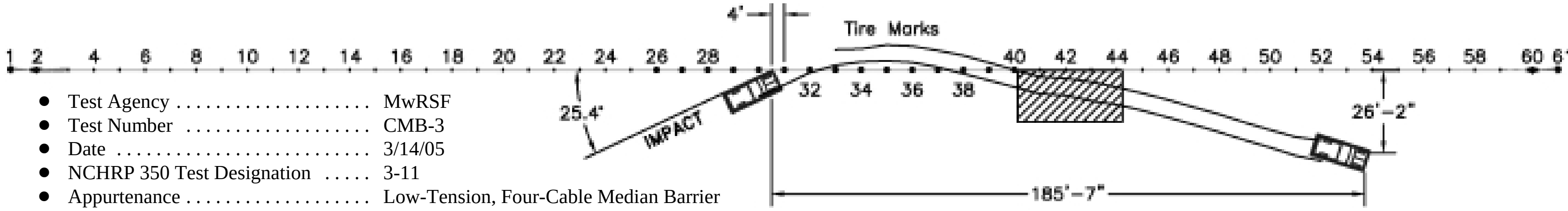


Figure B-2. Summary of Test Results and Sequential Photographs (English), Test CMB-2

0.000 sec | 0.112 sec | 0.276 sec | 0.470 sec | 0.742 sec



- Test Agency .... MwRSF
- Test Number CMB-3
- Date 3/14/05
- NCHRP 350 Test Designation 3-11
- Appurtenance .... Low-Tension, Four-Cable Median Barrier
- Total Length .... 484 ft
- Key Elements - Wire Rope
  - Diameter .... 0.75 in.
  - Size 7x19
  - Top Cable Mounting Height .. 33 in.
  - Incremental Spacing .... 6.5 in.
- Key Elements - Steel End Anchor Posts
  - Post No. 1 and 61 .... W6x25 by 96 in. long
  - Post No. 2 and 60 .... S3x5.7 by 36 in. long slip post with W6x9 by 72 in. long base post
- Key Elements - Steel Line Posts
  - Post Nos. 3-25, 46-59 .... S3x5.7 by 66 in. long
  - Post Nos. 26-45 .... S3x5.7 by 67 in. long
  - Spacing .... 96 in.
- Type of Soil .... Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 2000P
  - Make and Model .... 1998 GMC Pickup
  - Curb .... 4,385 lbs
  - Test Inertial .... 4,460 lbs
  - Gross Static .... 4,460 lbs
- Impact Conditions
  - Speed .... 60.8 mph
  - Angle .... 25.4 degrees
  - Impact Location .... 48 in. upstream centerline post no. 31
- Exit Conditions
  - Speed .... 42.0 mph
  - Angle (estimated) .... 7 degrees
  - Exit Box Criterion .... Pass
- Post-Impact Trajectory
  - Vehicle Stability .... Satisfactory
  - Stopping Distance .... 188.6 ft downstream 28.7 ft traffic-side face
- Occupant Impact Velocity
  - Longitudinal .... -10.9 ft/s <39.4 ft/s
  - Lateral (not required) ..... 10.2 ft/s < 39.4 ft/s
- Occupant Ridedown Deceleration
  - Longitudinal .... -3.93 g's < 20 g's
  - Lateral (not required) ..... 6.26 g's < 20 g's
- THIV (not required) .... 14.0 ft/s
- PHD (not required) .... 6.27 g's
- Test Article Damage .... Moderate
- Test Article Deflections
  - Post Permanent Set ...... NA
  - Post Dynamic .... 26.2 in.
  - Working Width .... 113.3 in.
- Vehicle Damage .... Moderate
  - VDS[4] 11-LFQ-3
  - CDC[5] 11-LFMN-3
  - Maximum Deformation ... 0.875 in. at center of dashboard

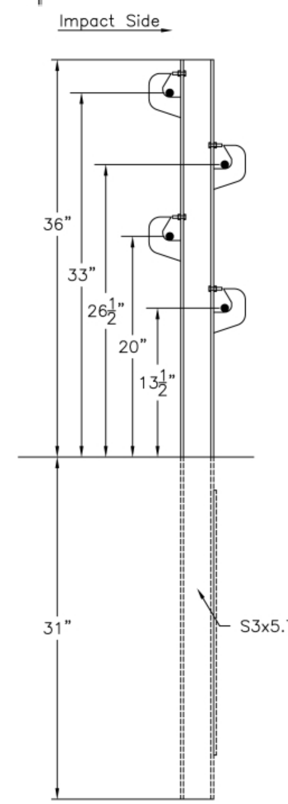


Figure B-3. Summary of Test Results and Sequential Photographs (English), Test CMB-3

APPENDIX C

Accelerometer and Rate Transducer Data Analysis, Test CMB-1

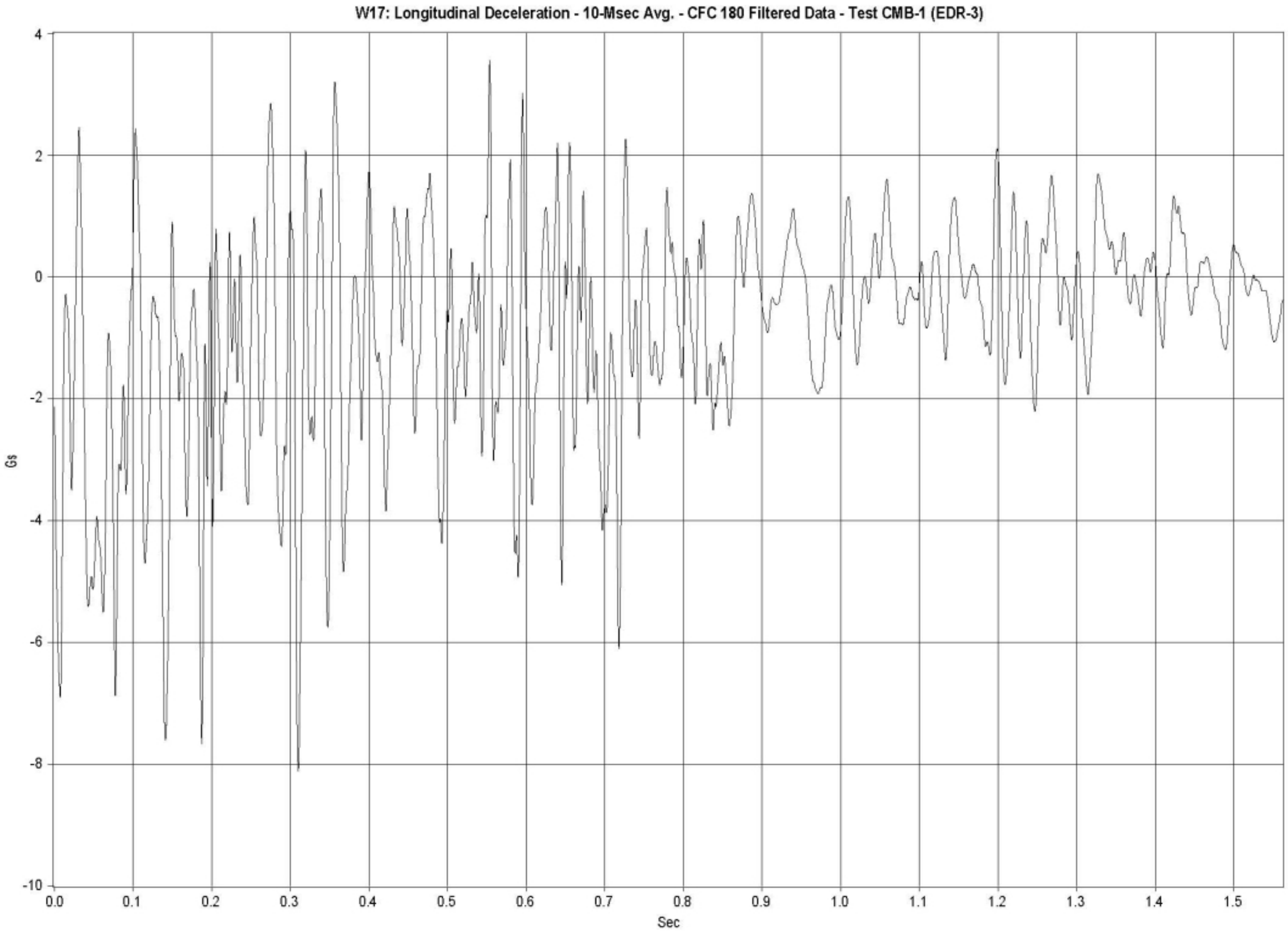


Figure C-1. Graph of Longitudinal Deceleration, Test CMB-1

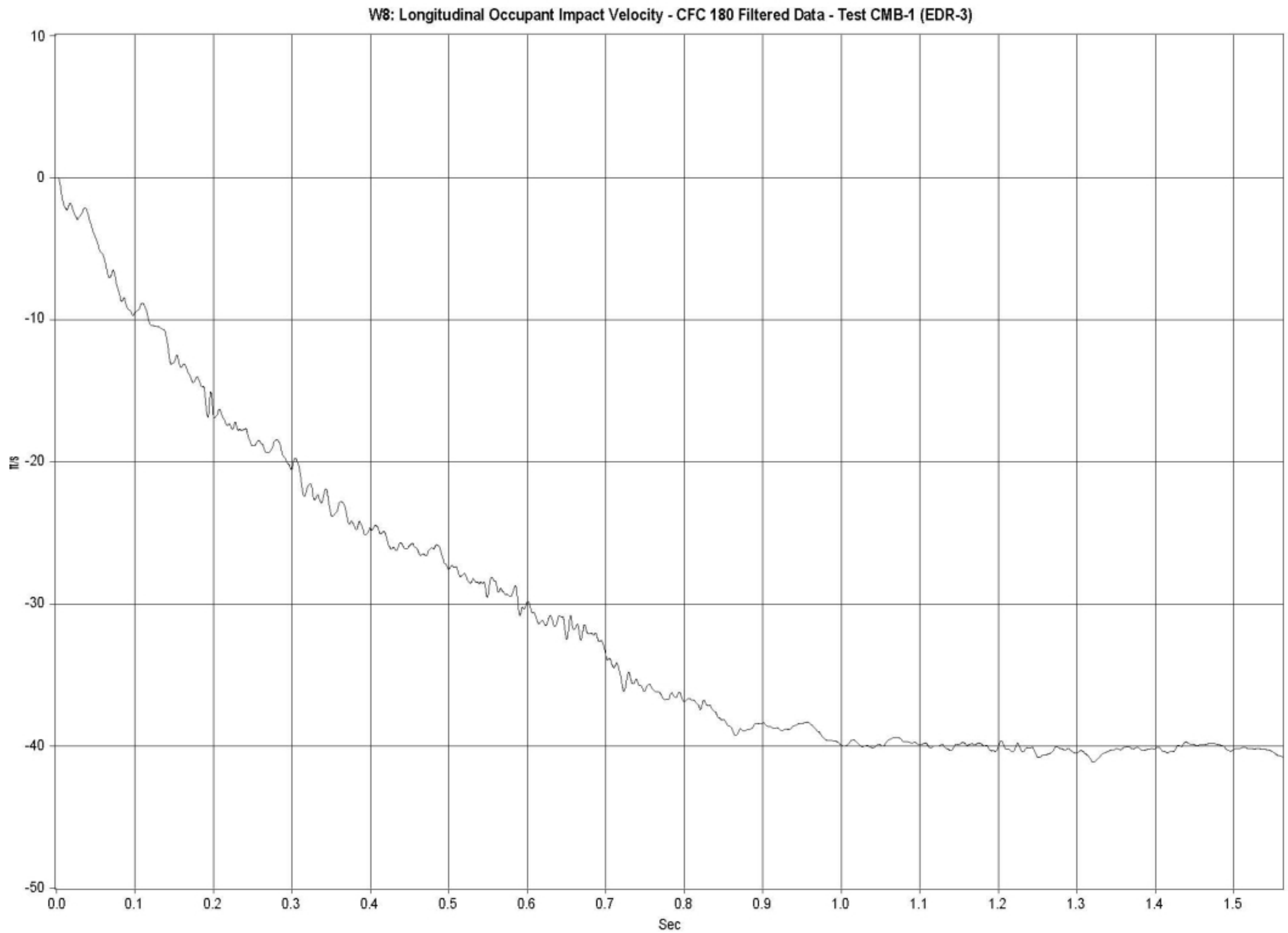


Figure C-2. Graph of Longitudinal Occupant Impact Velocity, Test CMB-1

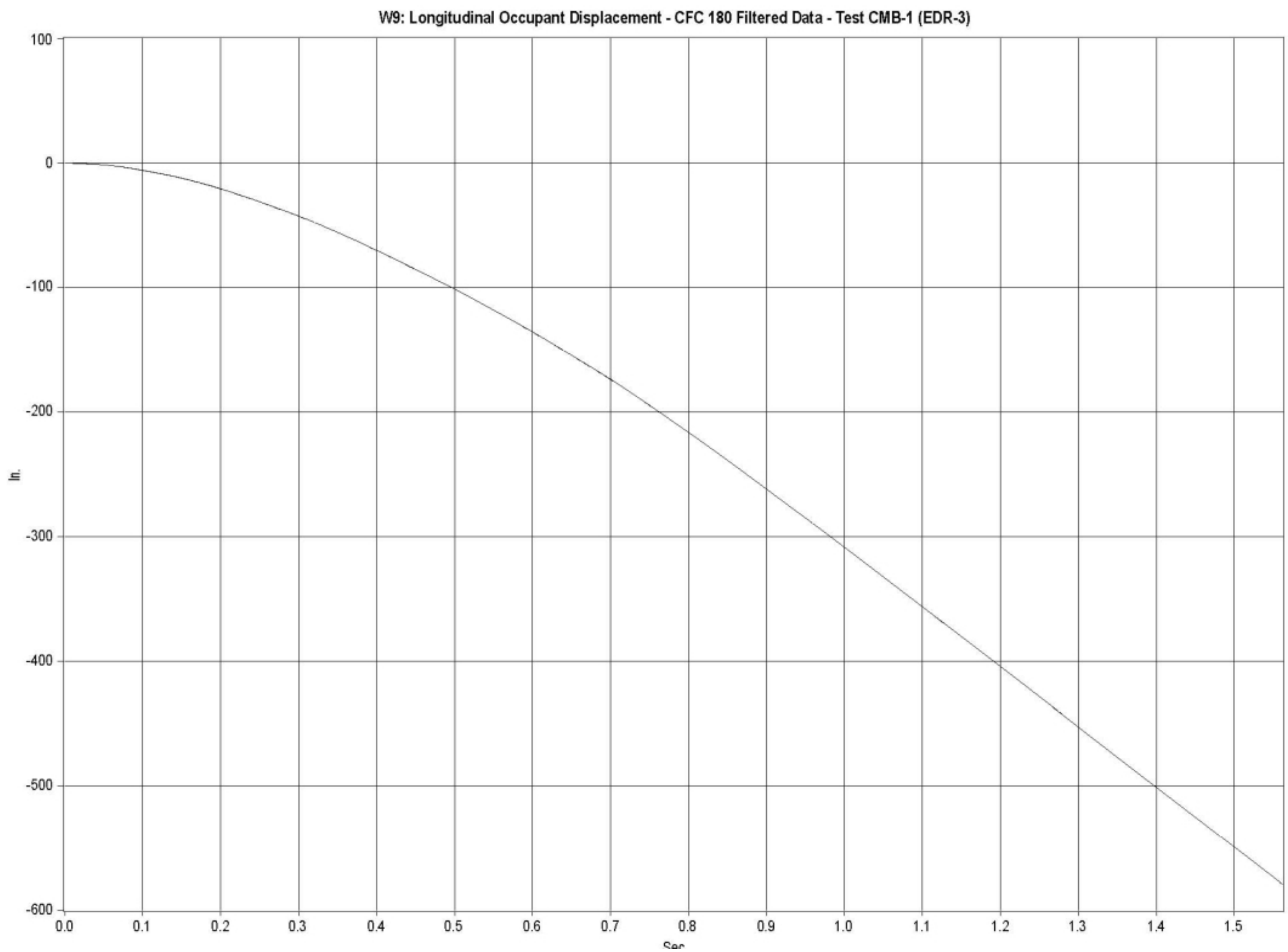


Figure C-3. Graph of Longitudinal Occupant Displacement, Test CMB-1

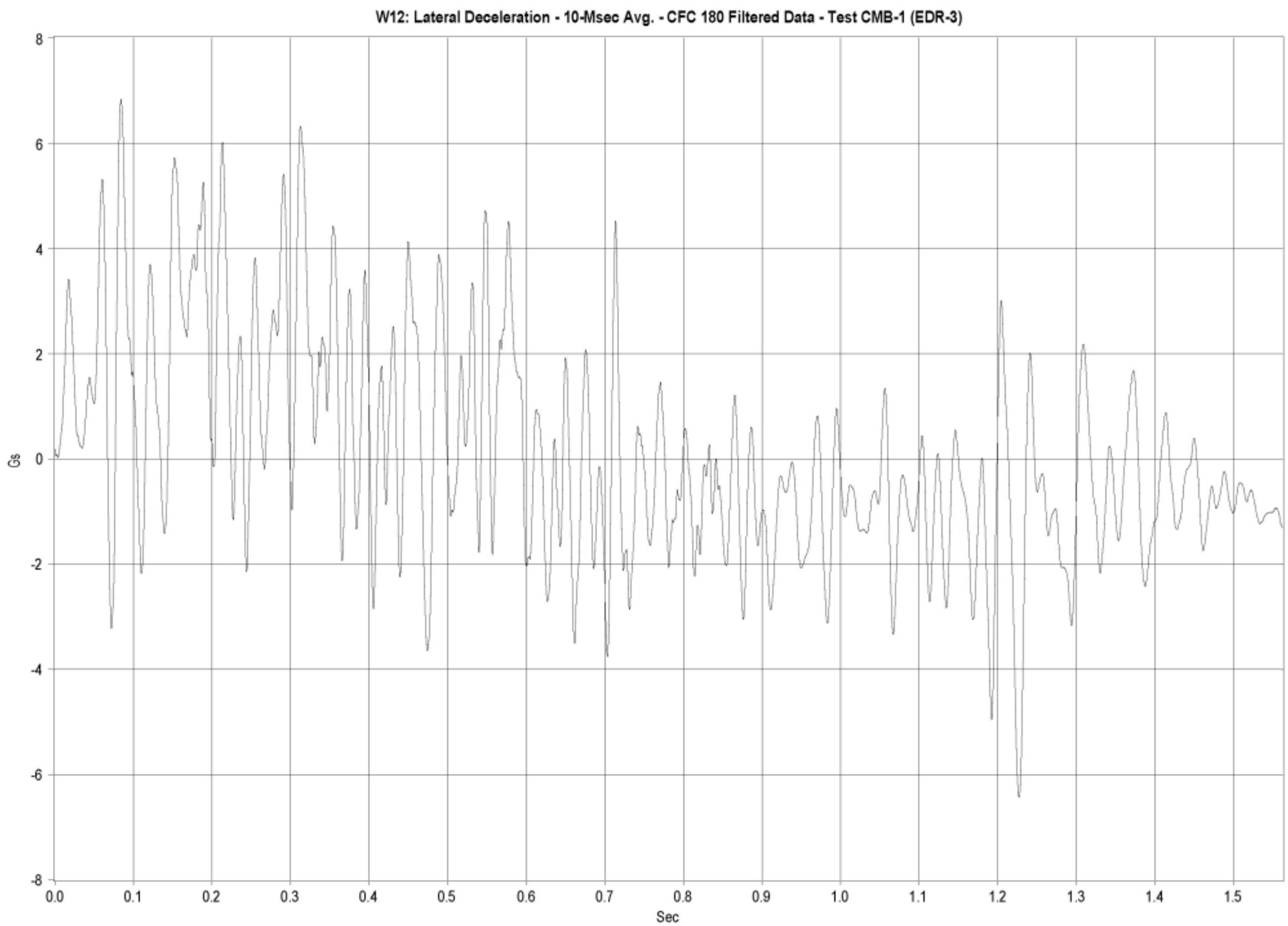


Figure C-4. Graph of Lateral Deceleration, Test CMB-1

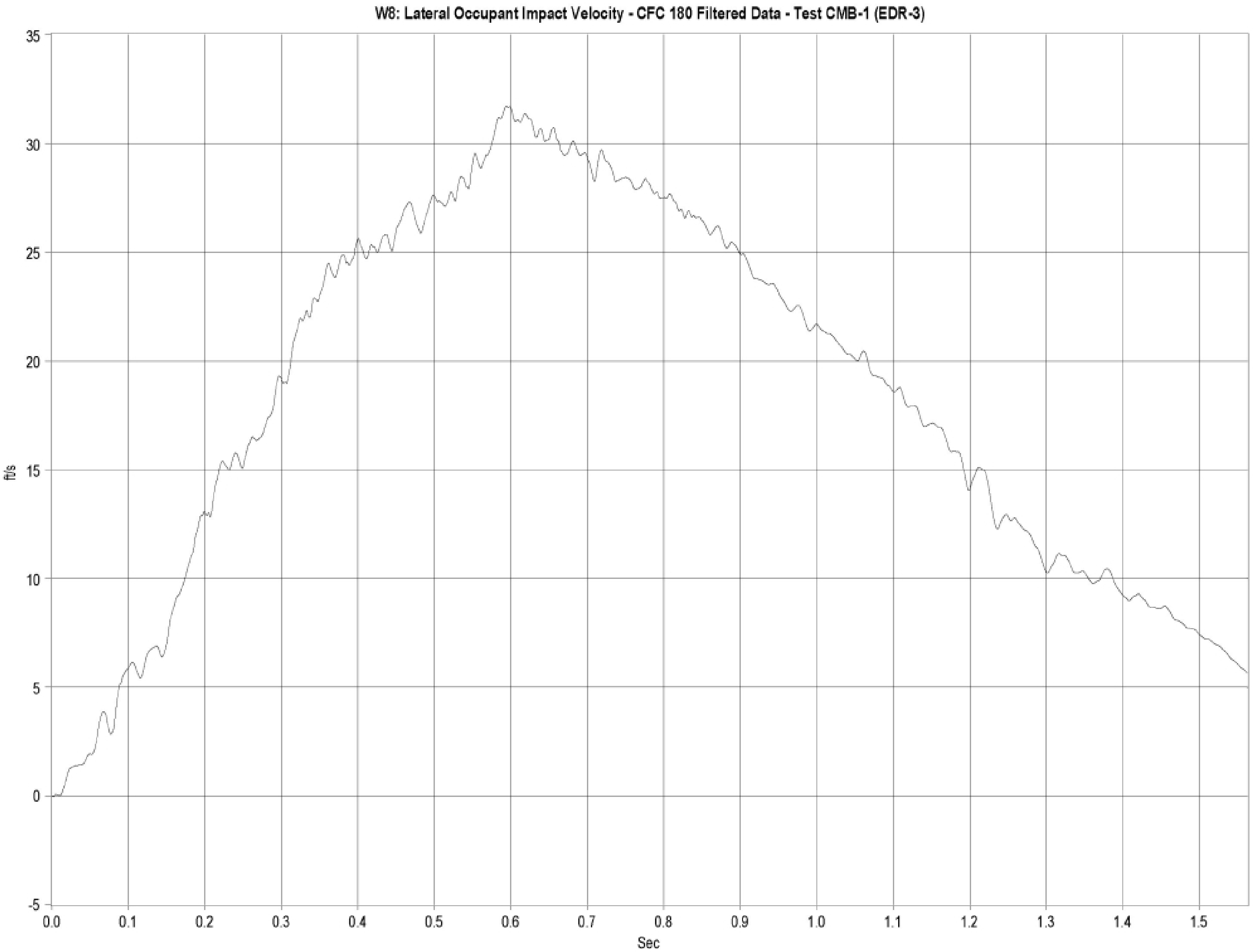


Figure C-5. Graph of Lateral Occupant Impact Velocity, Test CMB-1

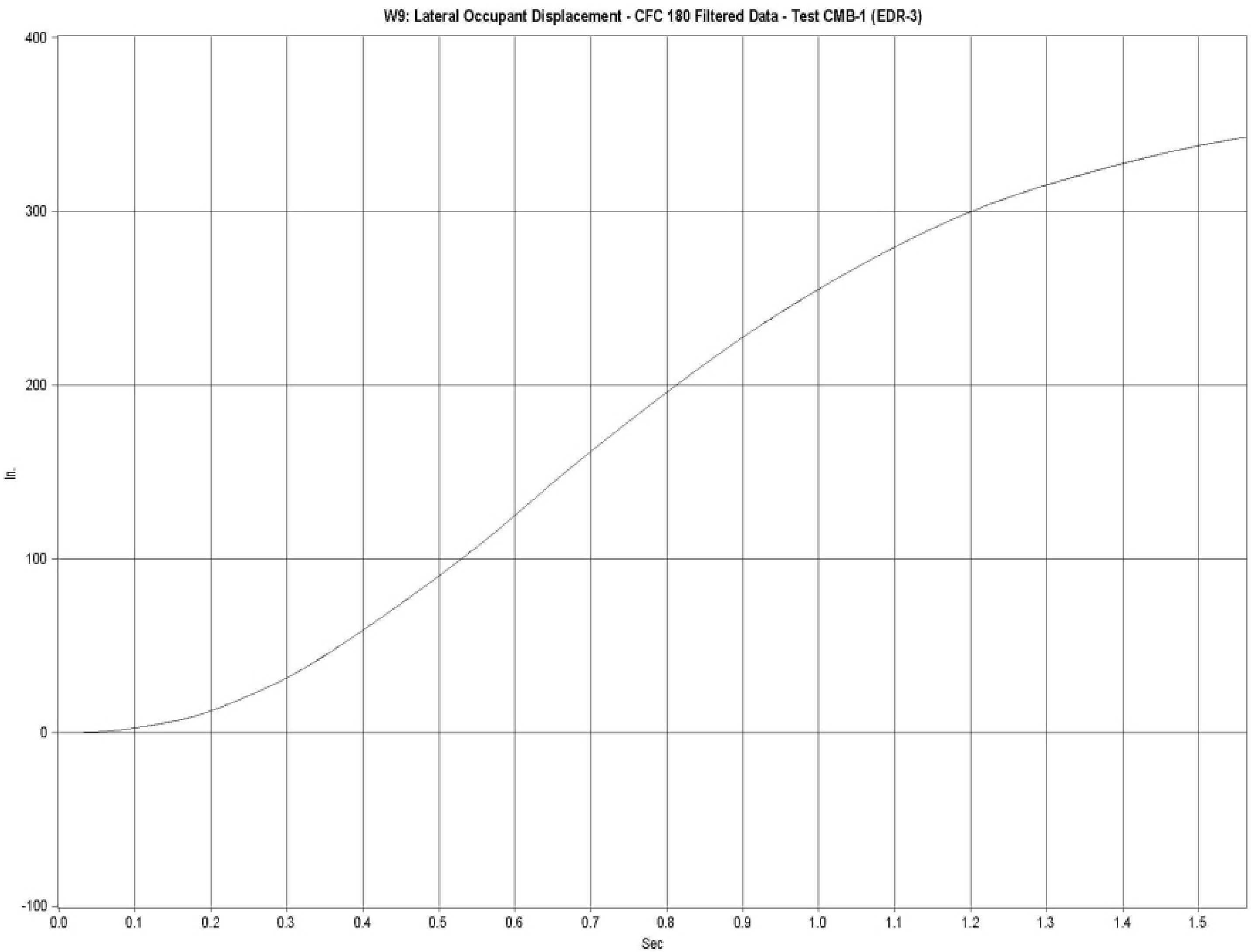


Figure C-6. Graph of Lateral Occupant Displacement, Test CMB-1

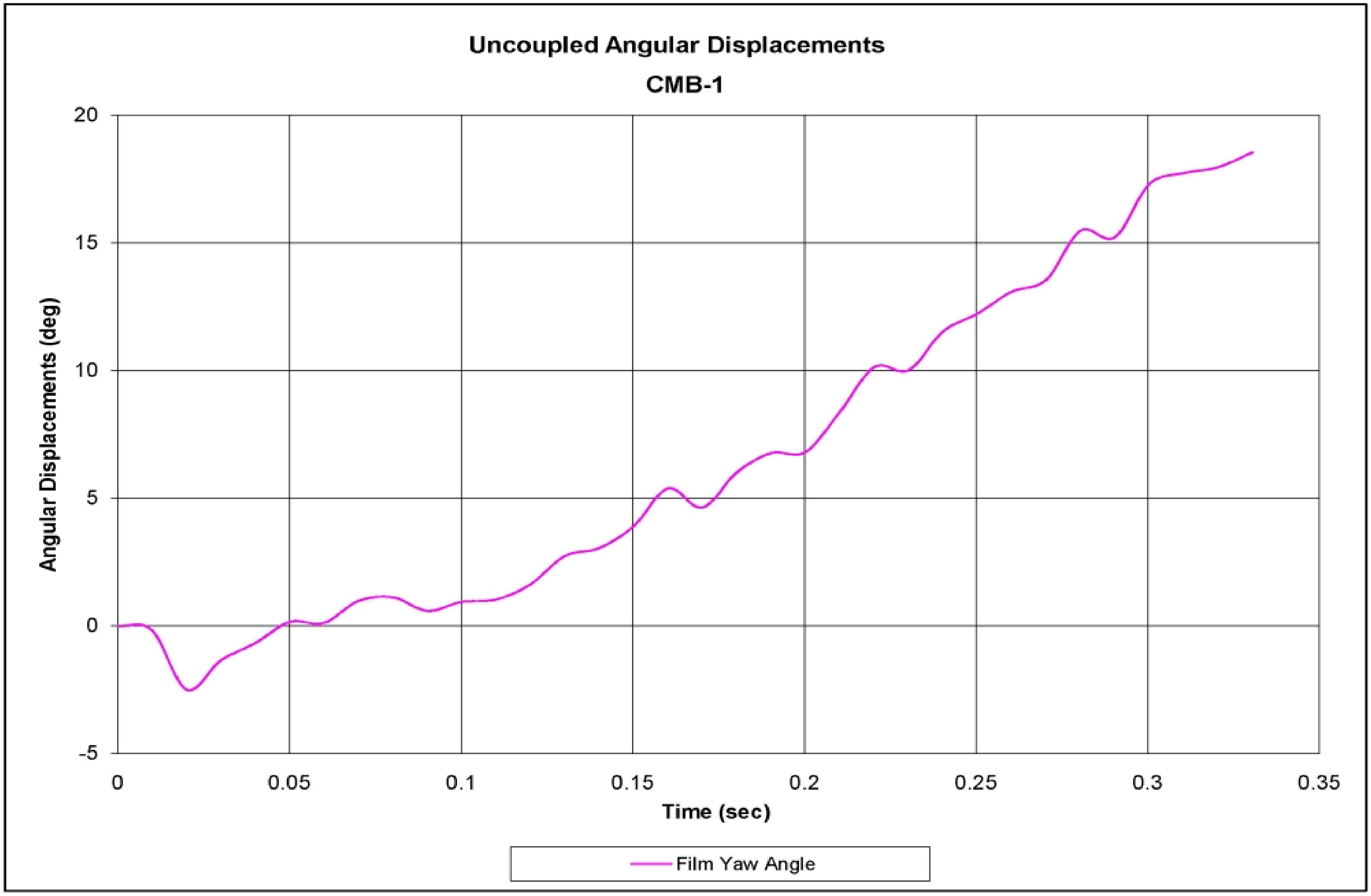


Figure C-7. Graph of Yaw Angular Displacements, Test CMB-1

APPENDIX D

System Details, Design No. 2

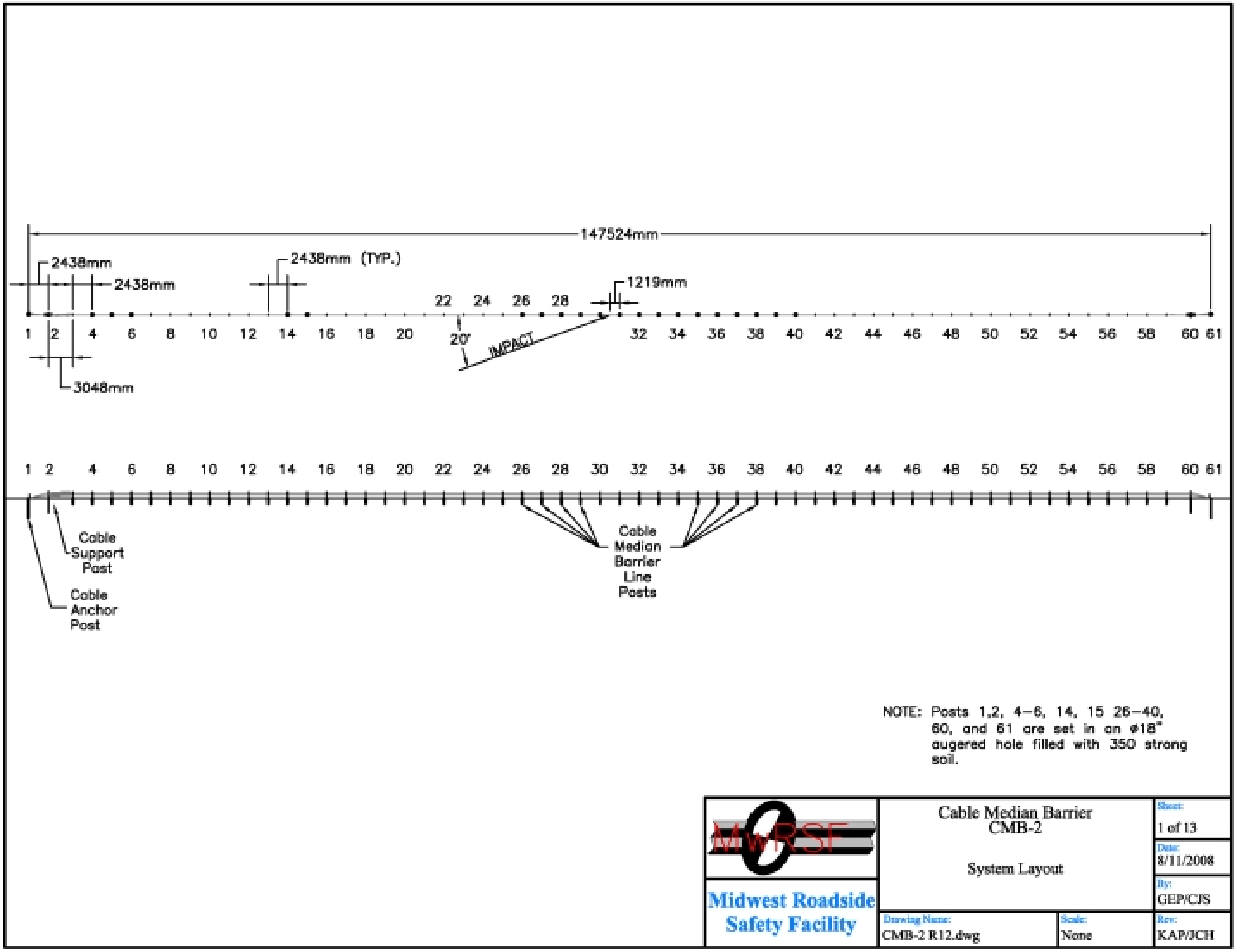


Figure D-1. System Layout (Metric), Design No. 2

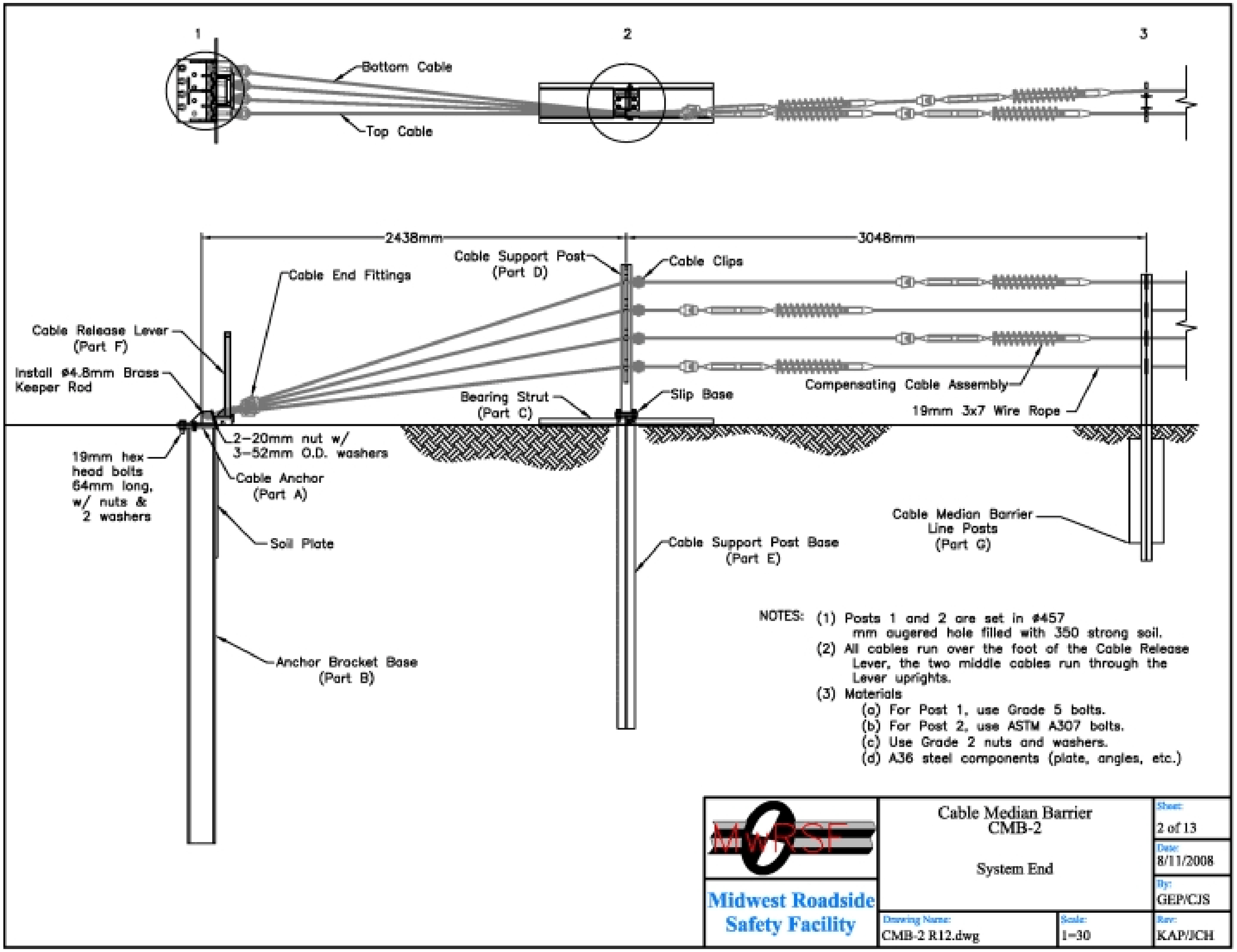


Figure D-2. System End (Metric), Design No. 2

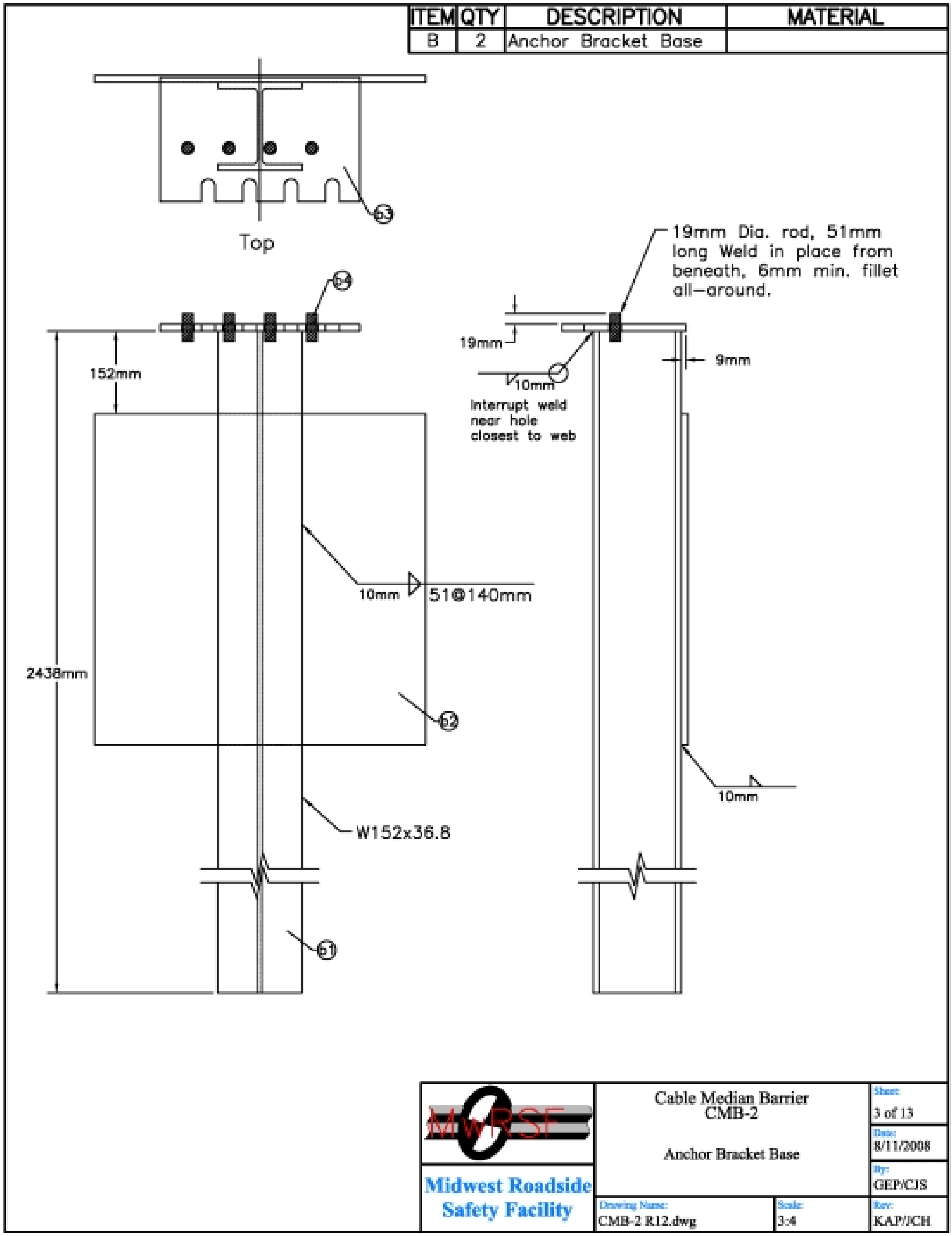


Figure D-3. Anchor Bracket Base (Metric), Design No. 2

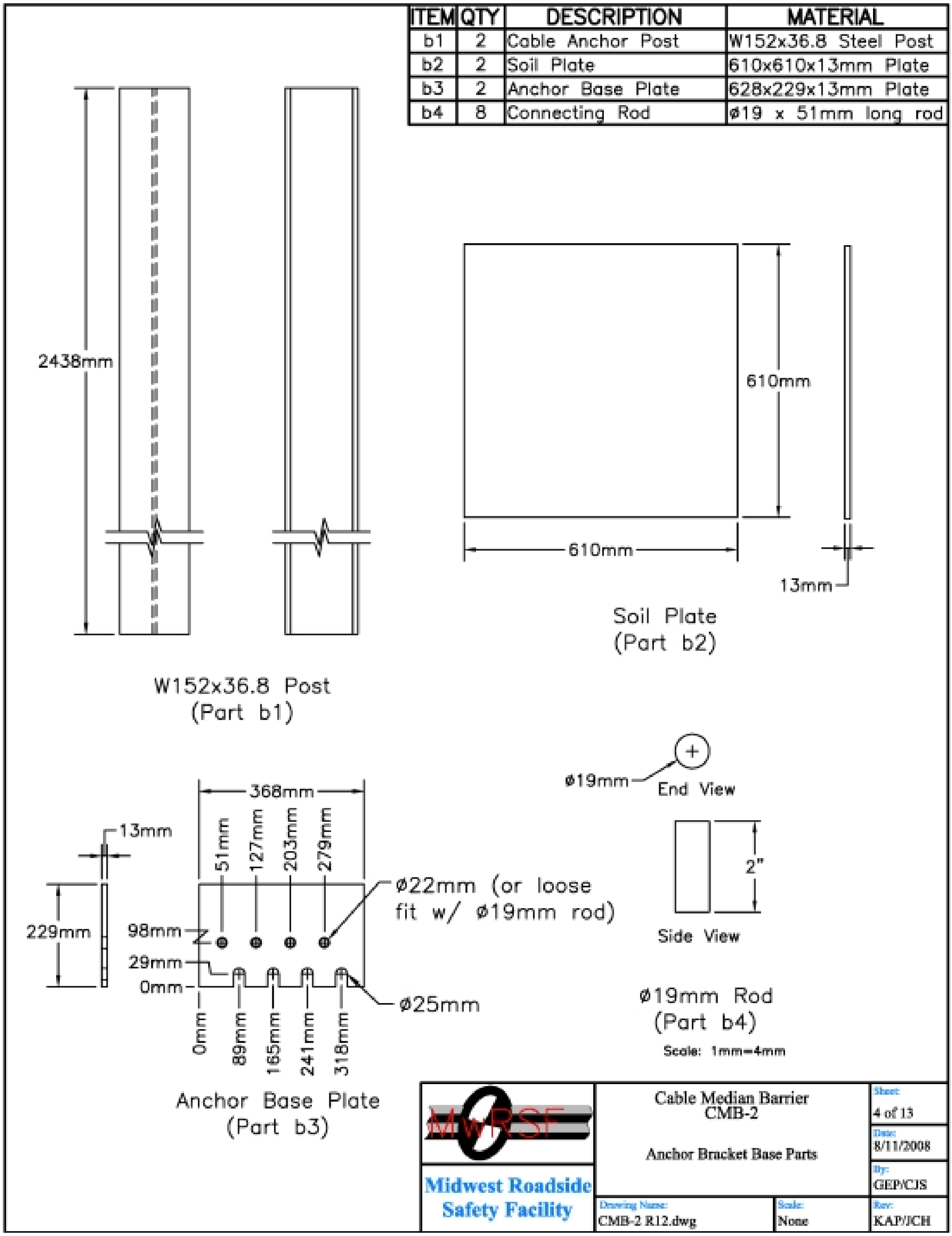


Figure D-4. Anchor Bracket Base Parts (Metric), Design No. 2

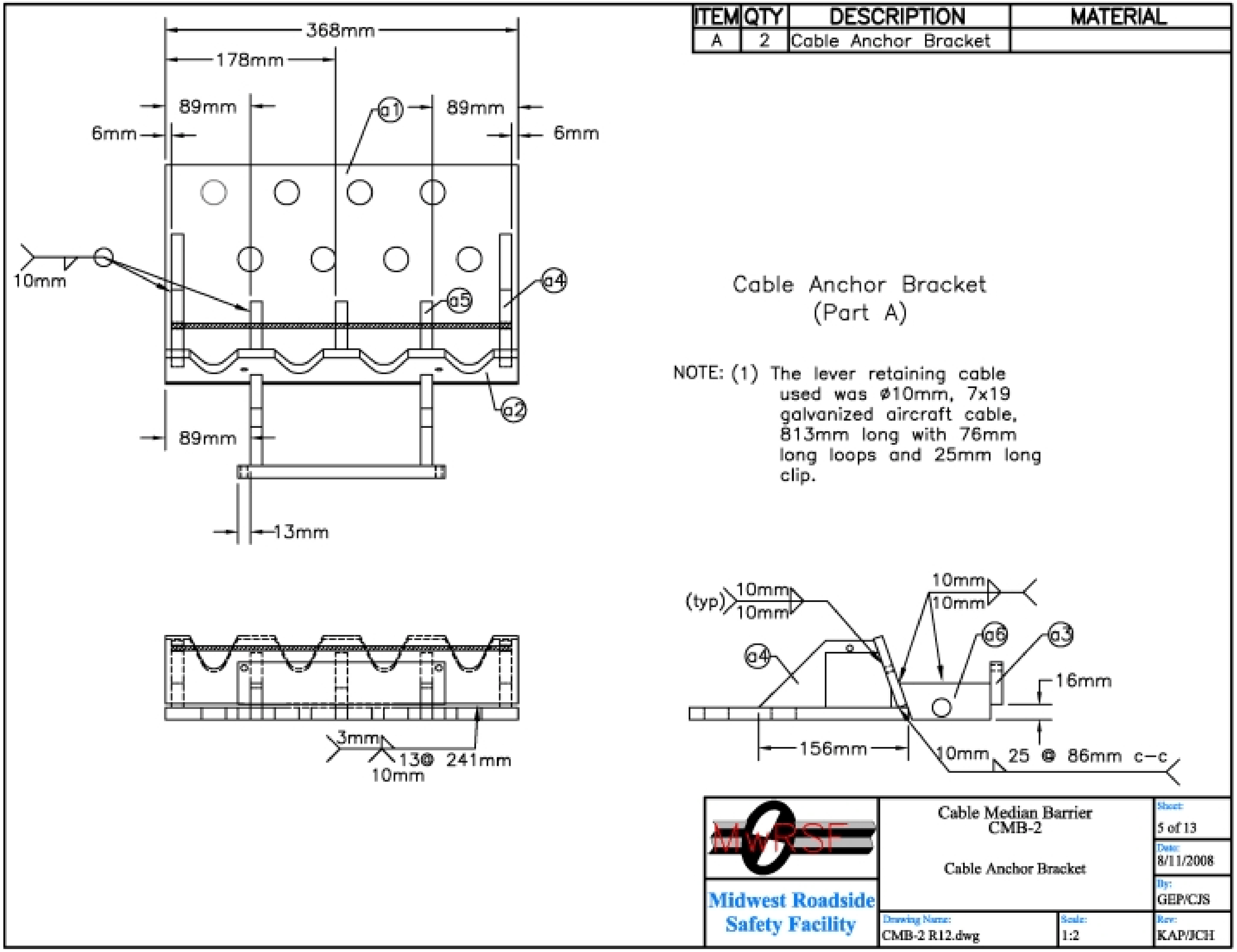


Figure D-5. Cable Anchor Bracket (Metric), Design No. 2

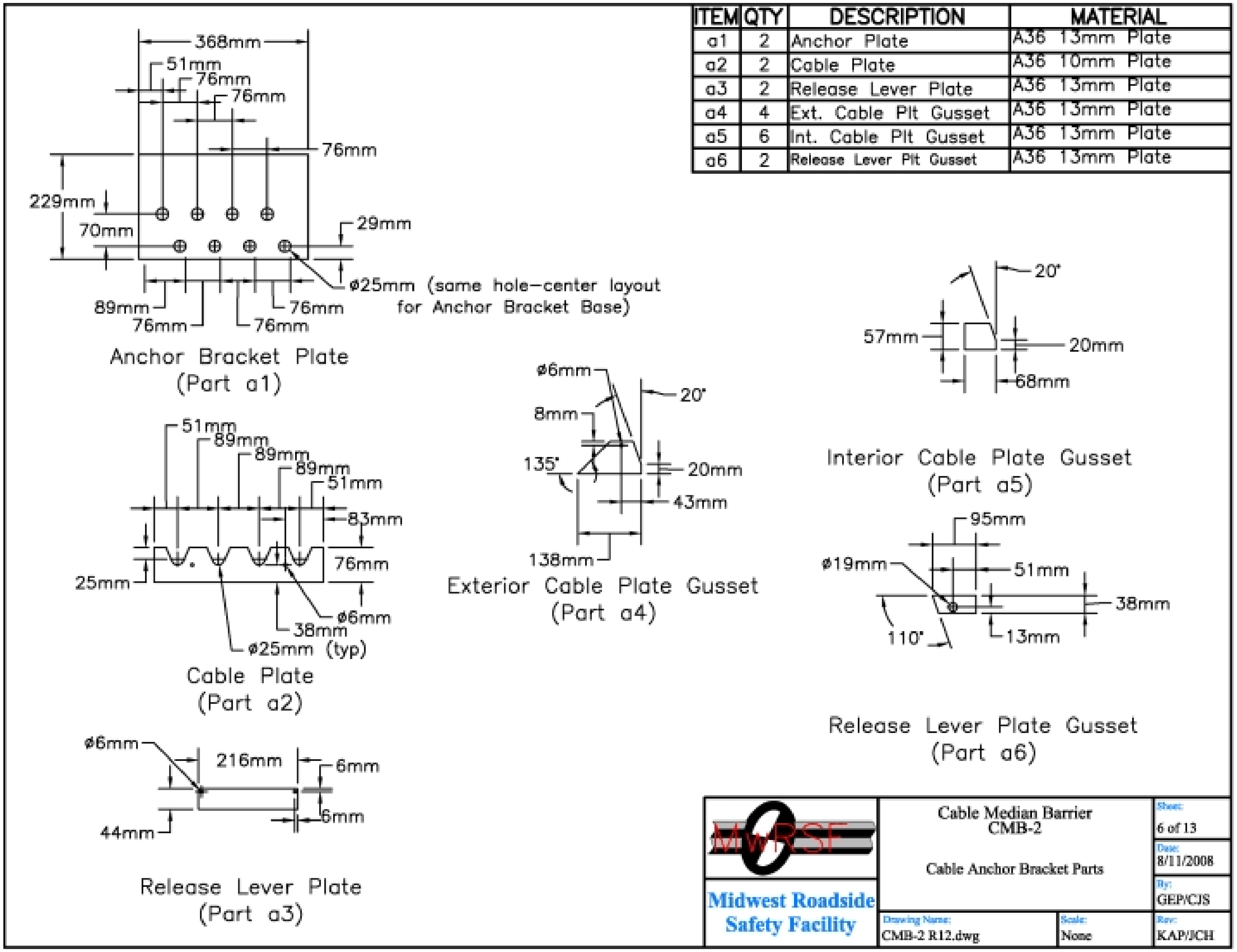


Figure D-6. Cable Anchor Bracket Parts (Metric), Design No. 2

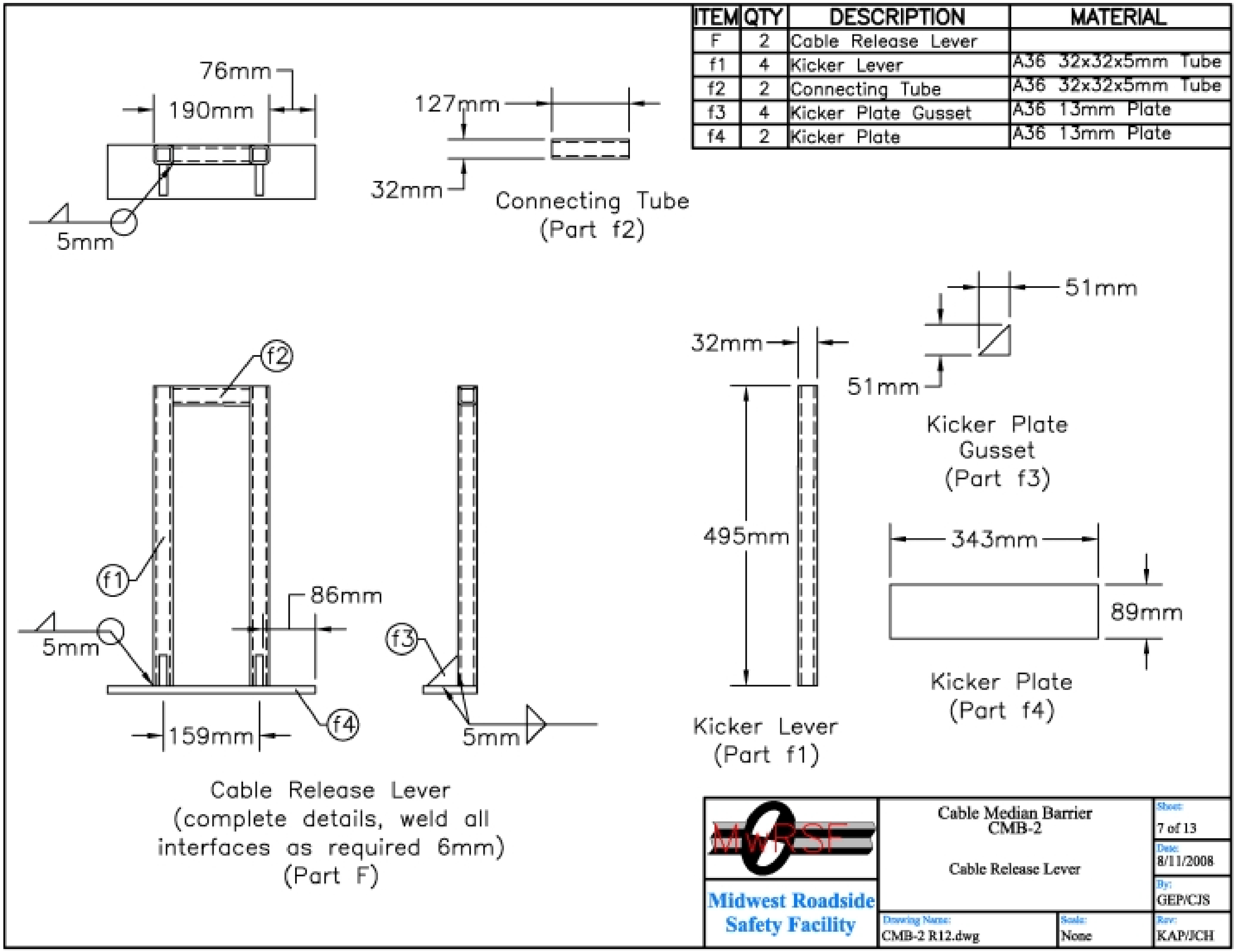


Figure D-7. Cable Release Lever (Metric), Design No. 2

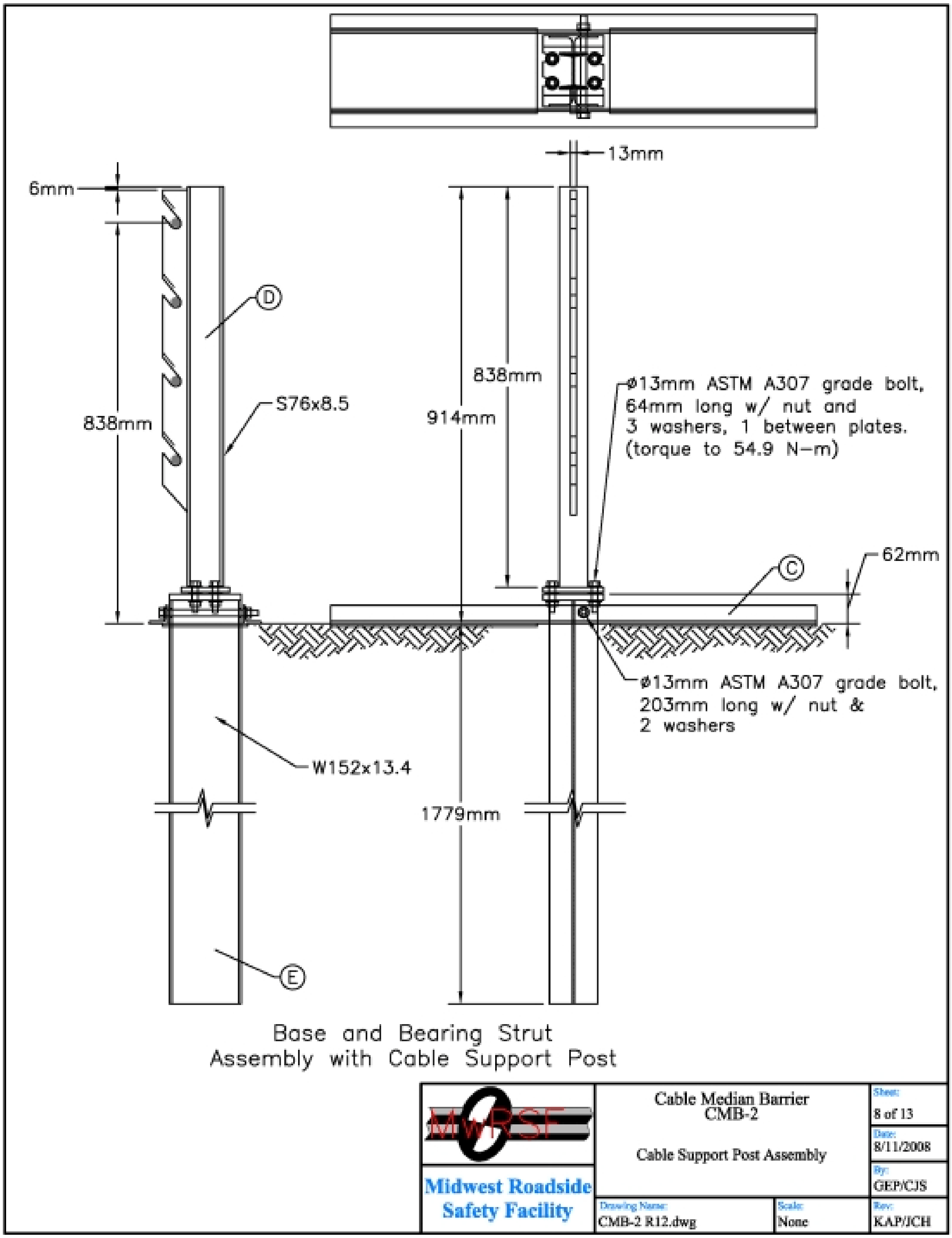


Figure D-8. Cable Support Post Assembly (Metric), Design No. 2

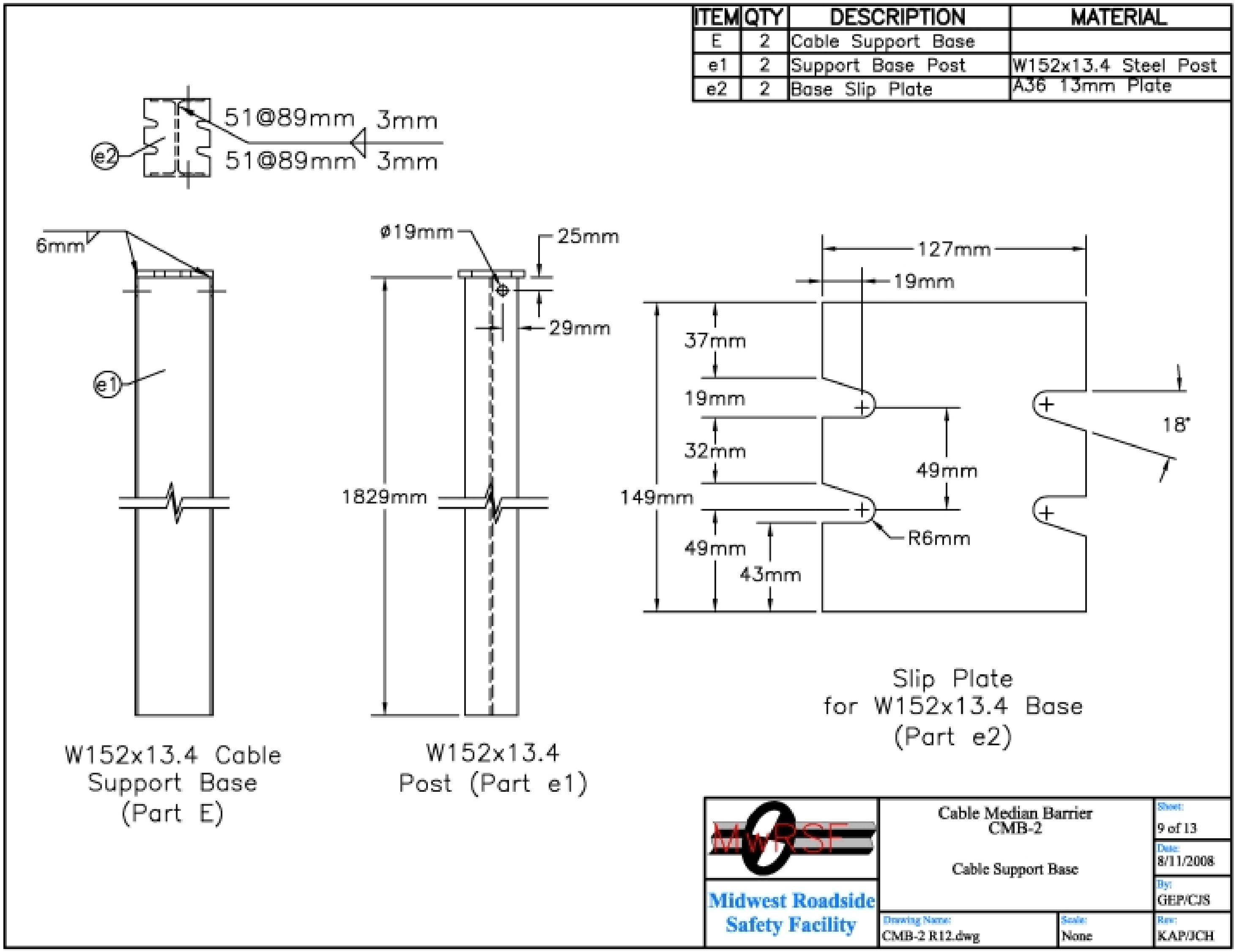


Figure D-9. Cable Support Base (Metric), Design No. 2

ITEM	QTY	DESCRIPTION	MATERIAL
D	2	Cable Support Post	
d1	2	Upper Support Post	S76x8.5 Steel Section
d2	2	Cable Bracket	A36 13mm Plate
d3	2	Slip Plate	A36 10mm Plate

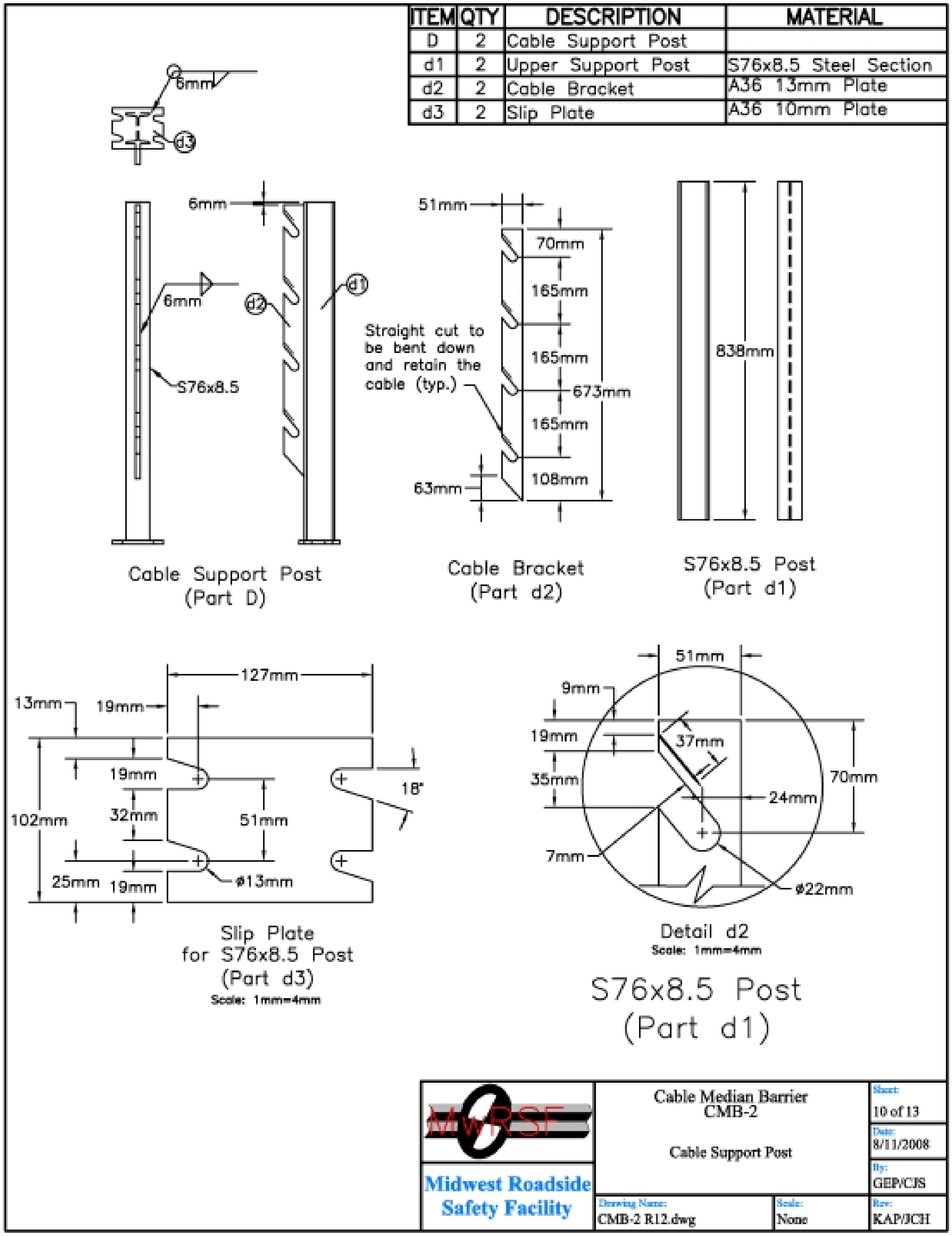


Figure D-10. Cable Support Post (Metric), Design No. 2

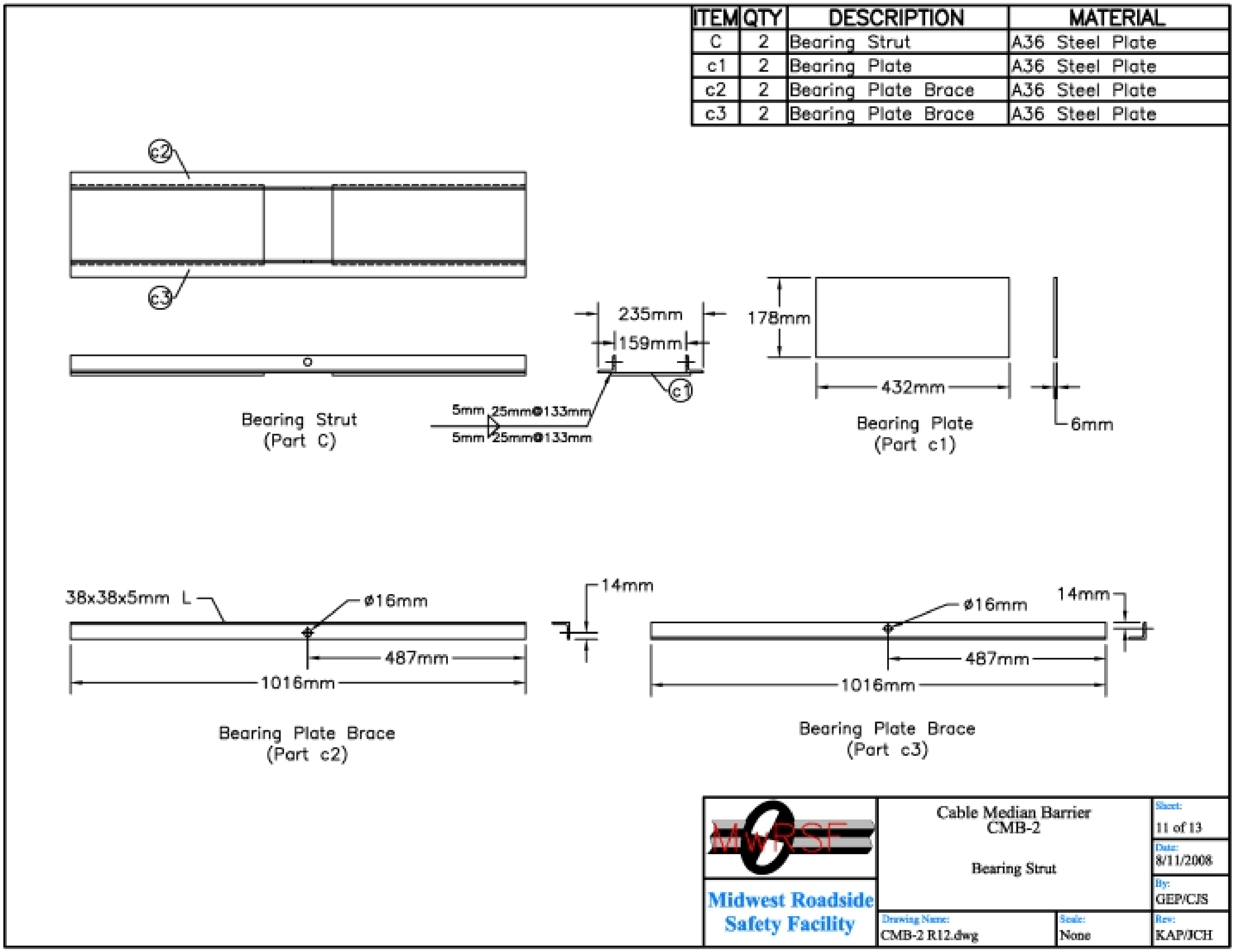


Figure D-11. Bearing Strut (Metric), Design No. 2

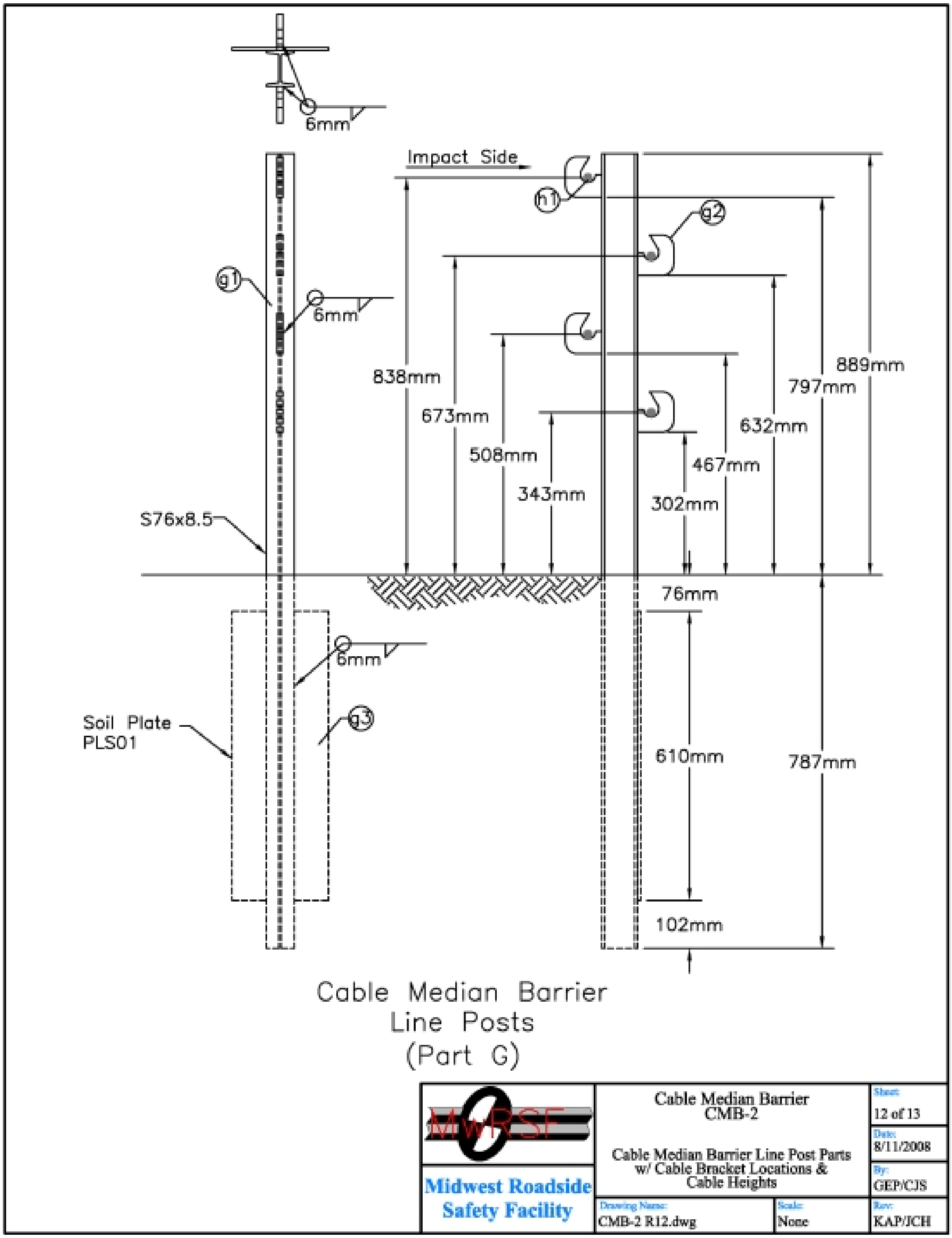


Figure D-12. Bracket Locations and Cable Heights (Metric), Design No. 2

ITEM	QTY	DESCRIPTION	MATERIAL
g1	57	Line Post	S76x8.5 Steel Section
g2	228	Cable Bracket	A36 13mm Plate
g3	57	Soil Plate	A36 6mm Plate
h1	4	Cable – 147.5 m	ø19mm 3x7 Wire rope

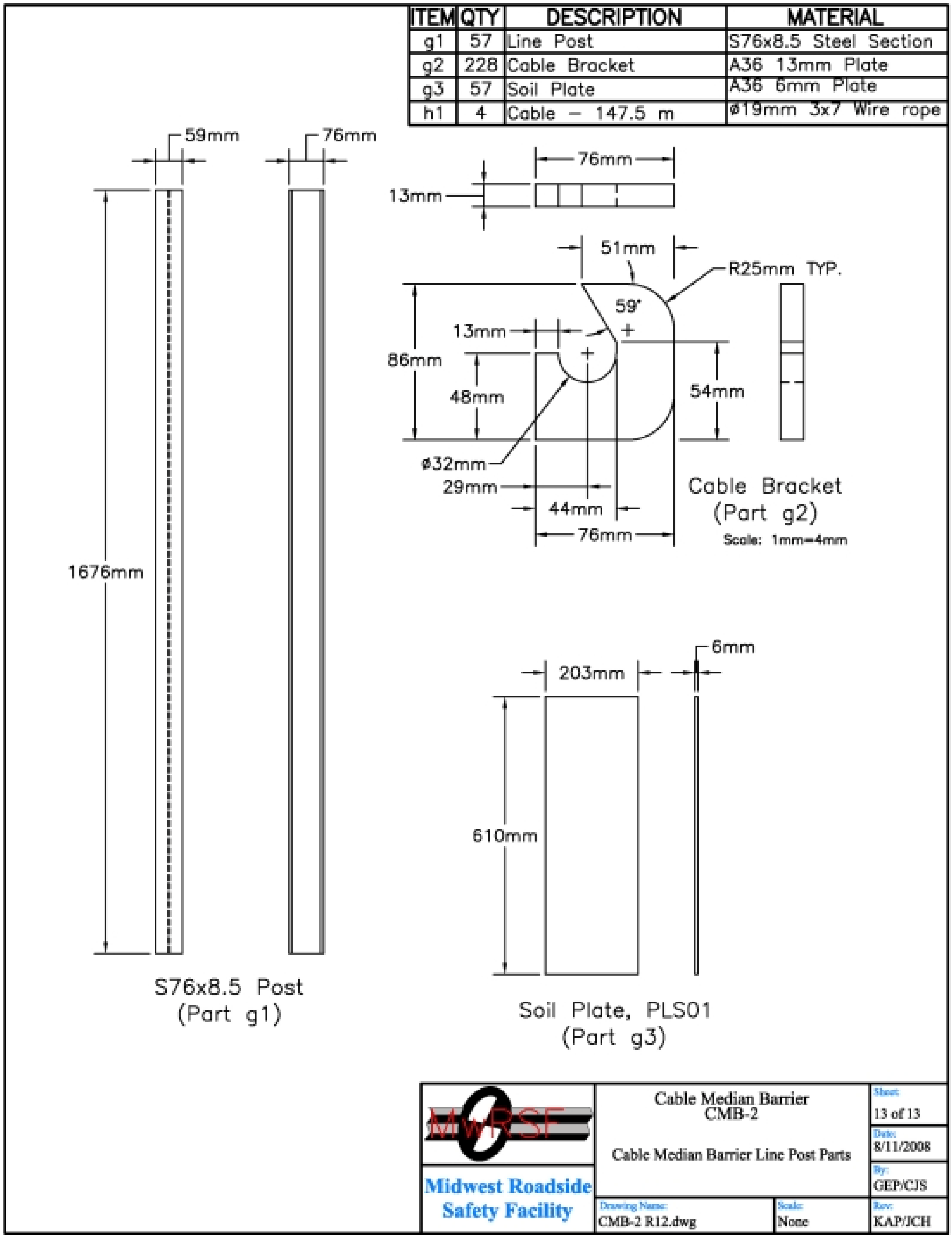


Figure D-13. Line Post Parts (Metric), Design No. 2

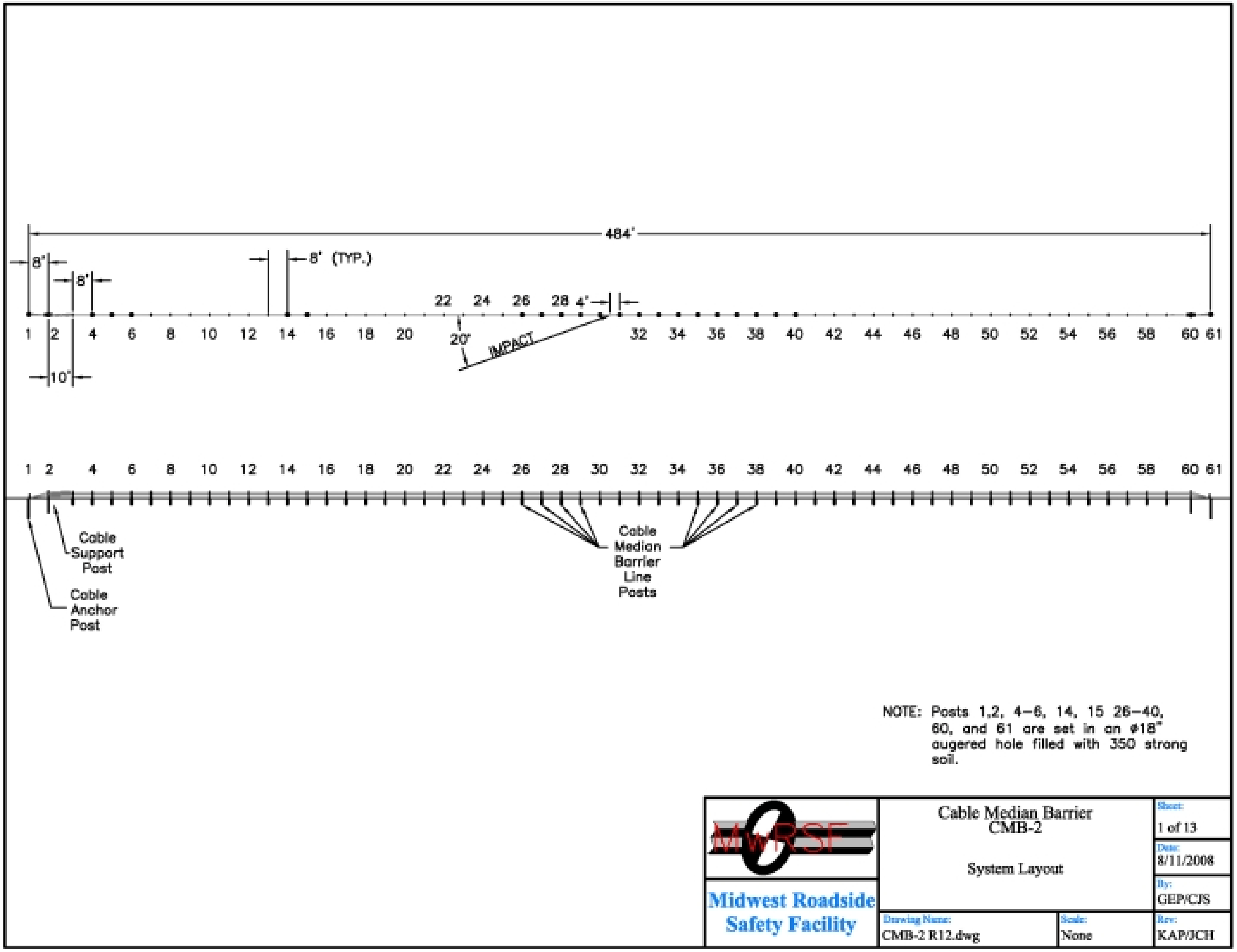


Figure D-14. System Layout (English), Design No. 2

181

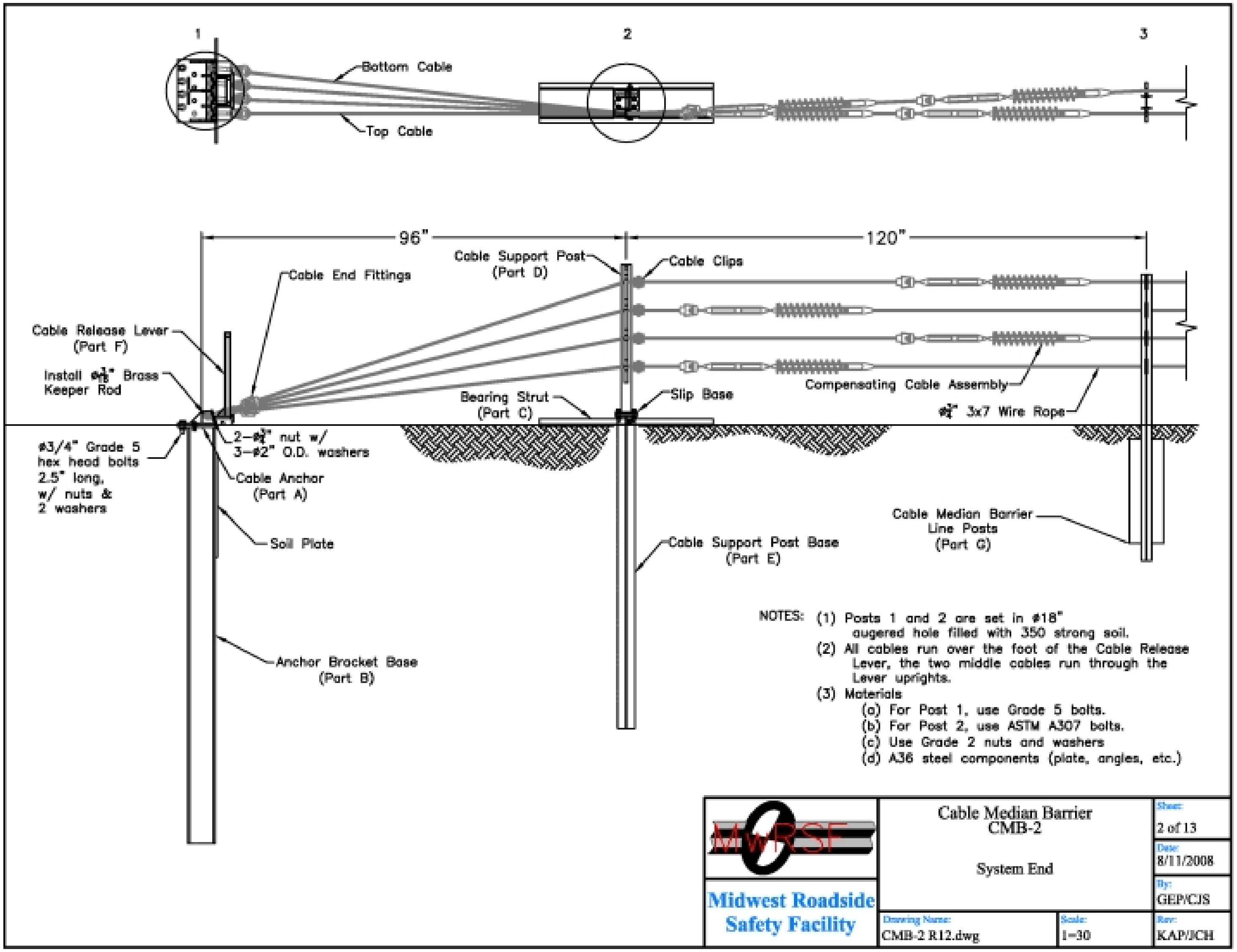


Figure D-15. System End (English), Design No. 2

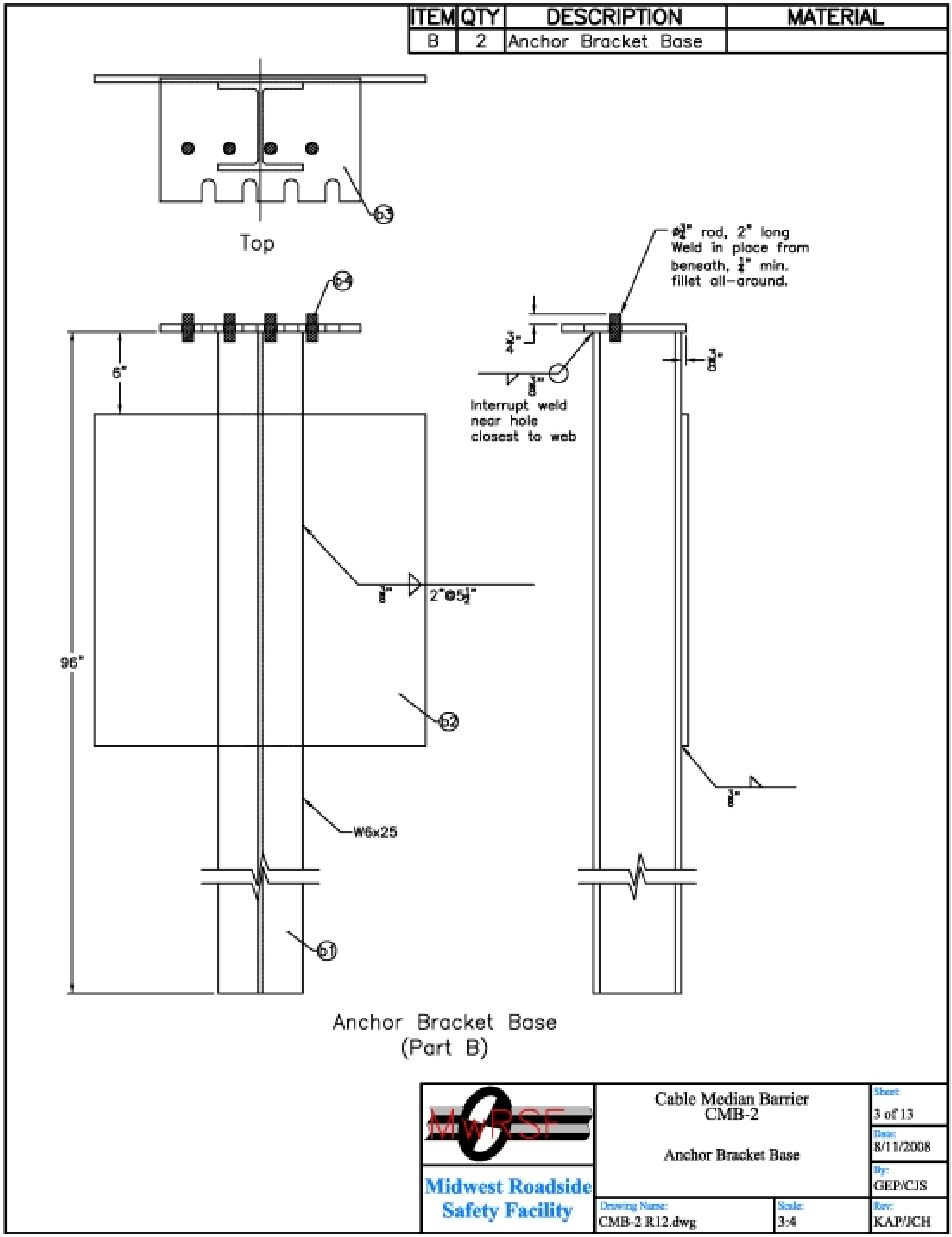


Figure D-16. Anchor Bracket Base (English), Design No. 2

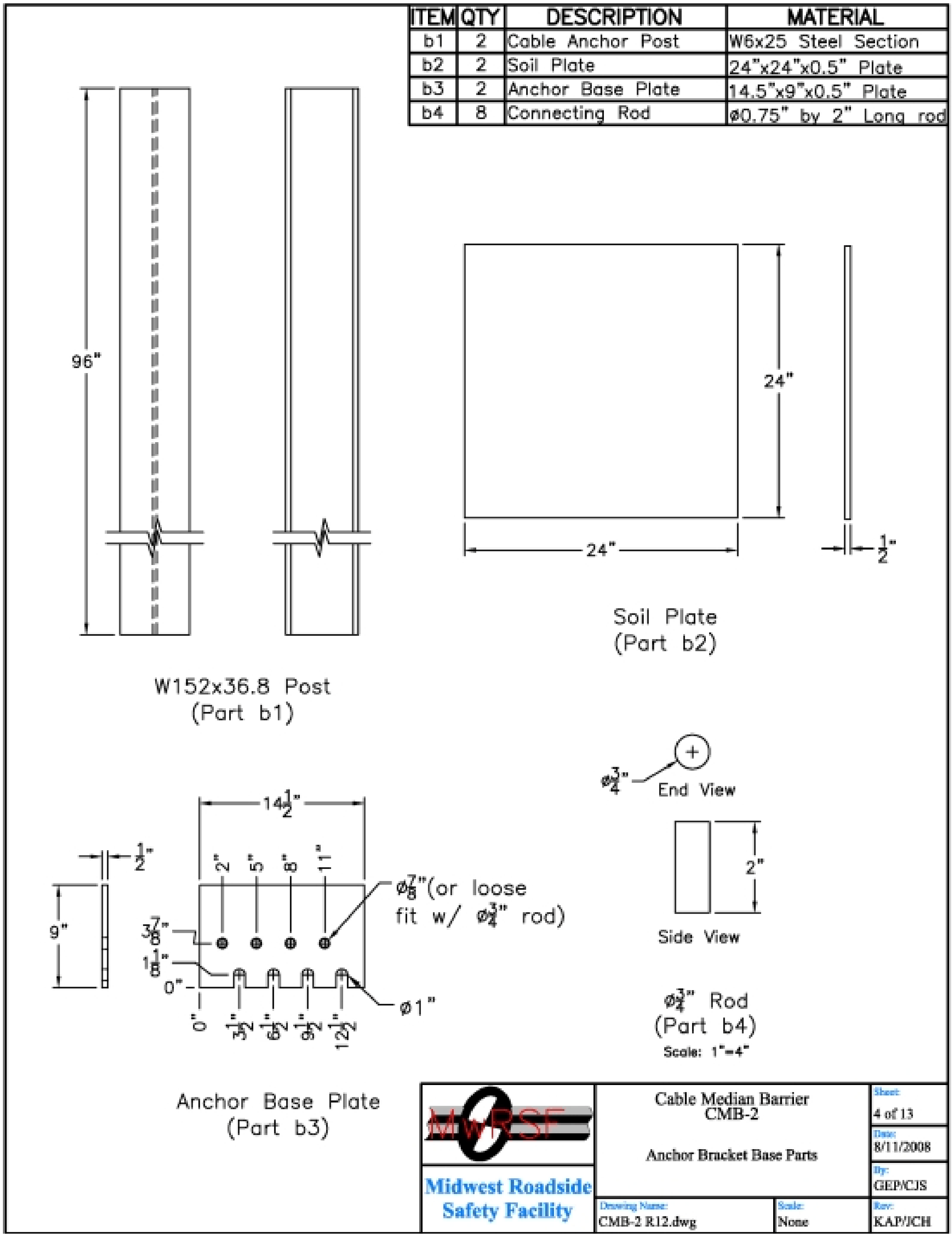


Figure D-17. Anchor Bracket Base Parts (English), Design No. 2

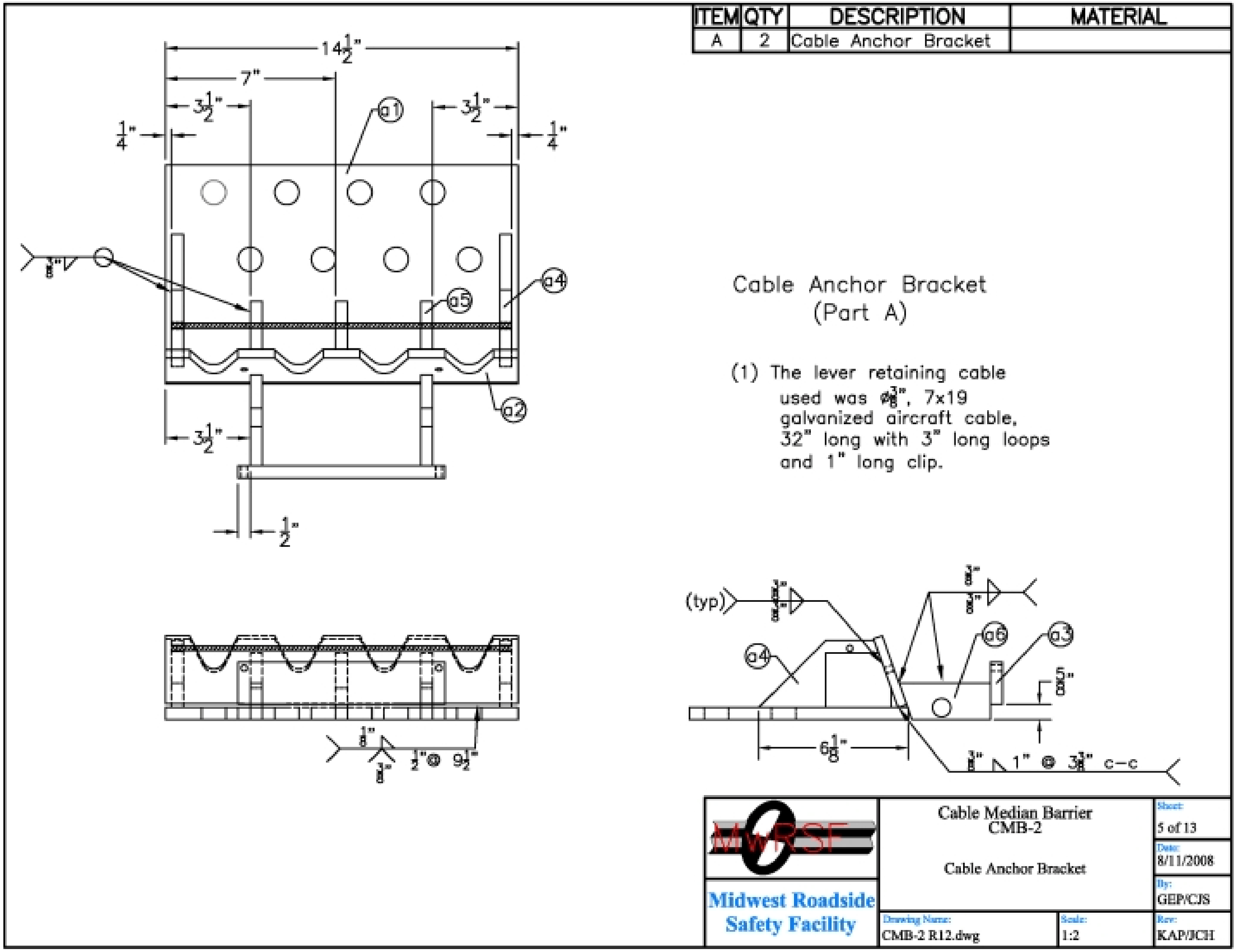
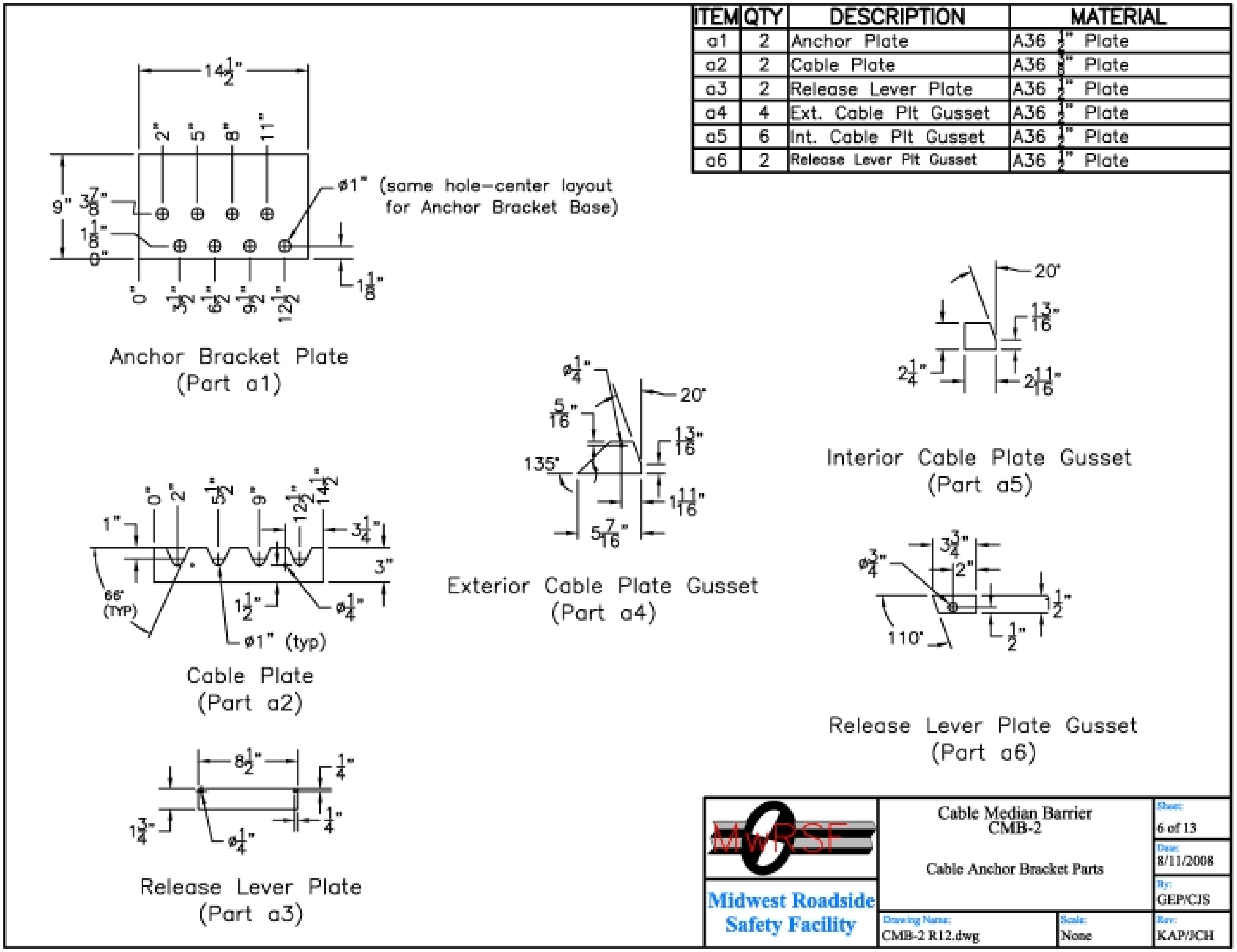
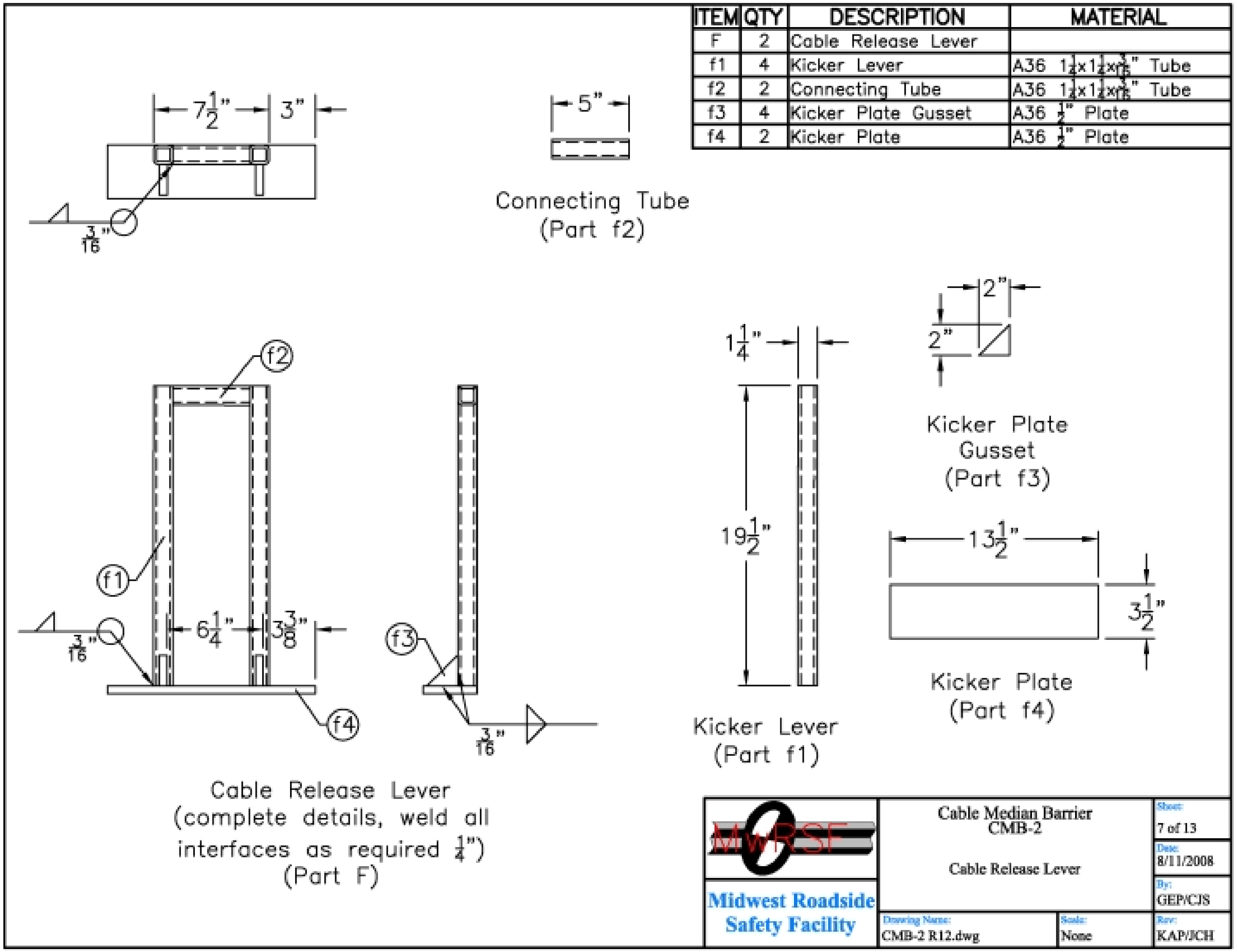


Figure D-18. Cable Anchor Bracket (English), Design No. 2



ITEM	QTY	DESCRIPTION	MATERIAL
a1	2	Anchor Plate	A36 1/2" Plate
a2	2	Cable Plate	A36 3/8" Plate
a3	2	Release Lever Plate	A36 1/2" Plate
a4	4	Ext. Cable Plt Gusset	A36 1/2" Plate
a5	6	Int. Cable Plt Gusset	A36 1/2" Plate
a6	2	Release Lever Plt Gusset	A36 1/2" Plate

Figure D-19. Cable Anchor Bracket Parts (English), Design No. 2



ITEM	QTY	DESCRIPTION	MATERIAL
F	2	Cable Release Lever	
f1	4	Kicker Lever	A36 1 1/2x1 1/2x3/16" Tube
f2	2	Connecting Tube	A36 1 1/2x1 1/2x3/16" Tube
f3	4	Kicker Plate Gusset	A36 1/2" Plate
f4	2	Kicker Plate	A36 1/2" Plate

Figure D-20. Cable Release Lever (English), Design No. 2

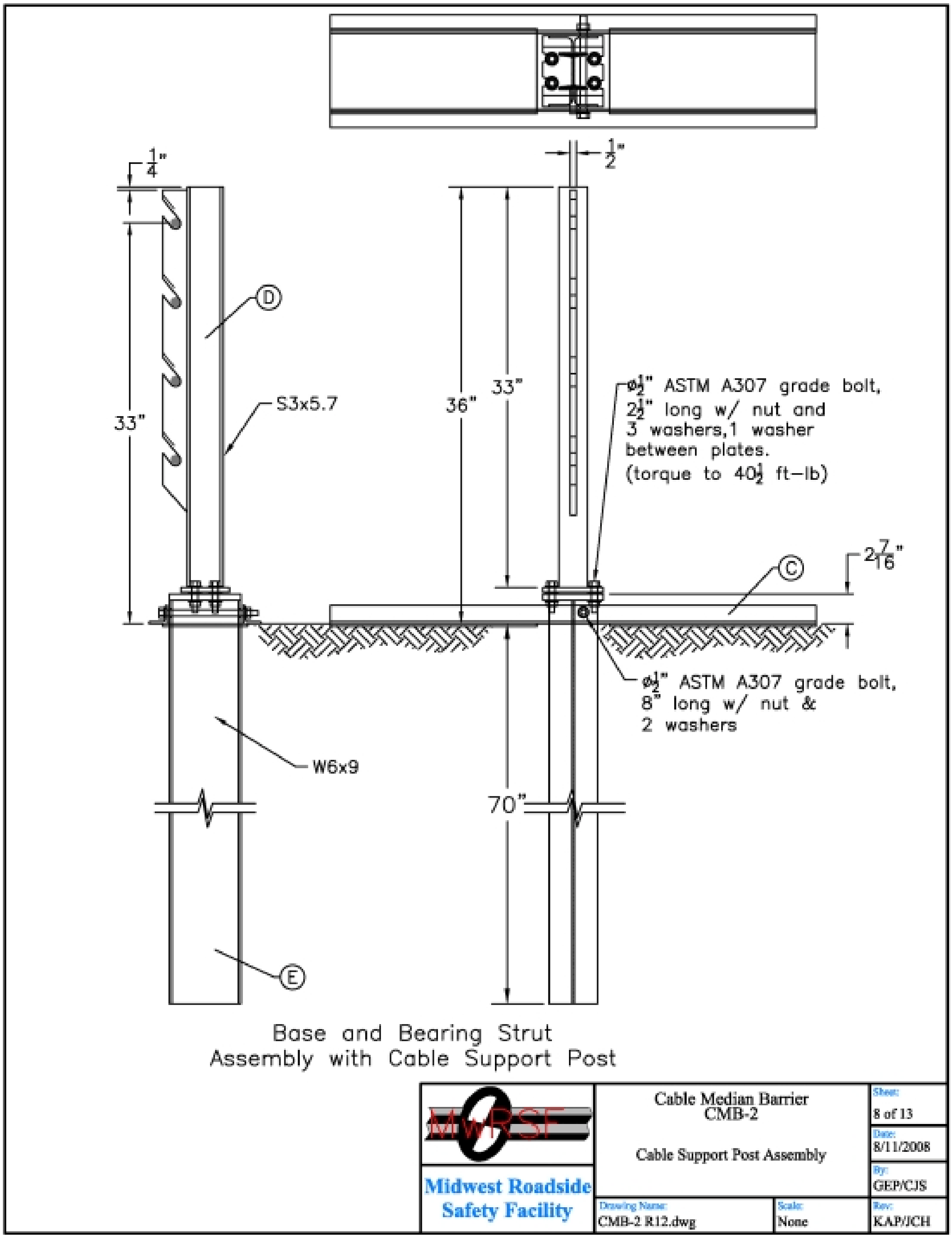


Figure D-21. Cable Support Post Assembly (English), Design No. 2

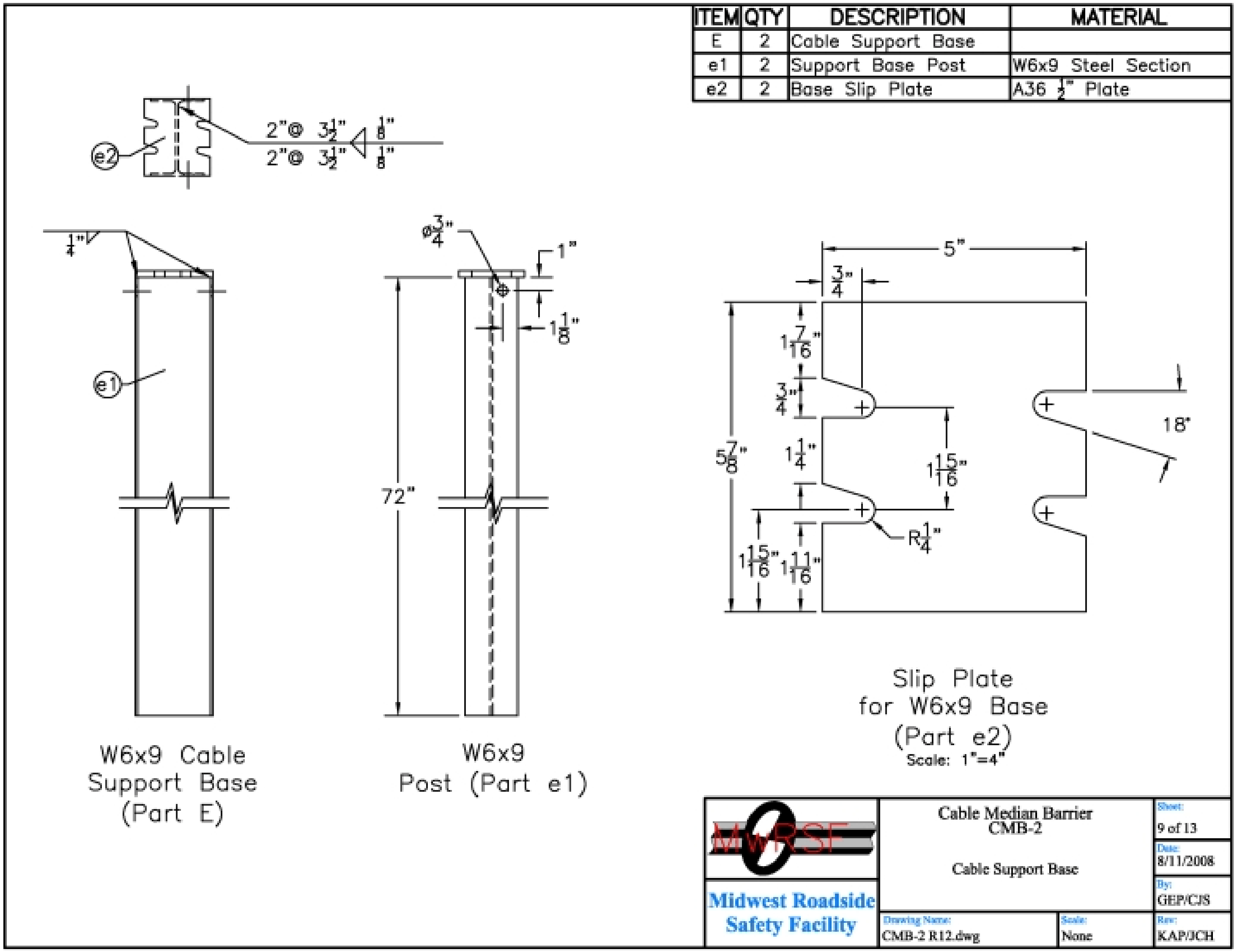


Figure D-22. Cable Support Base (English), Design No. 2

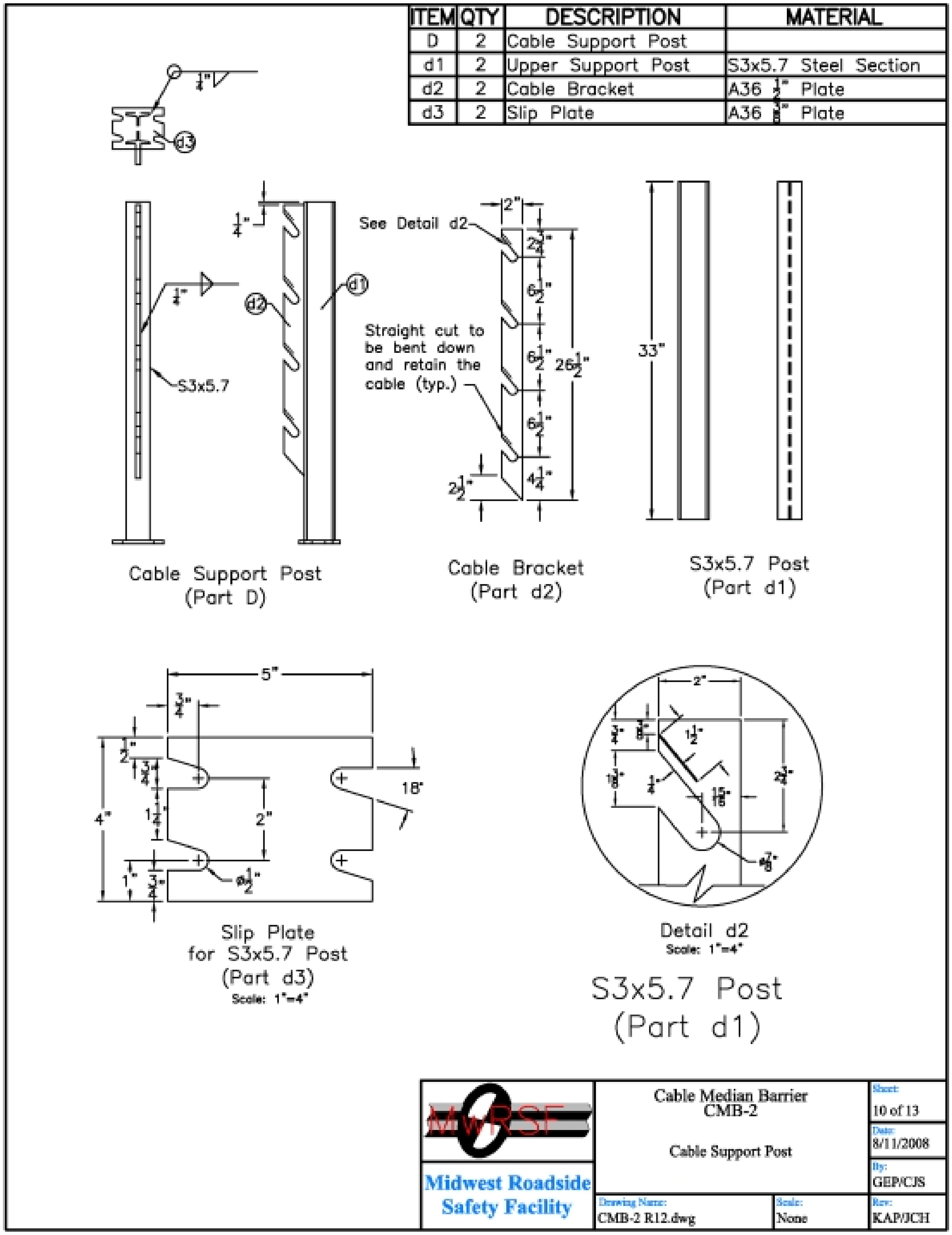
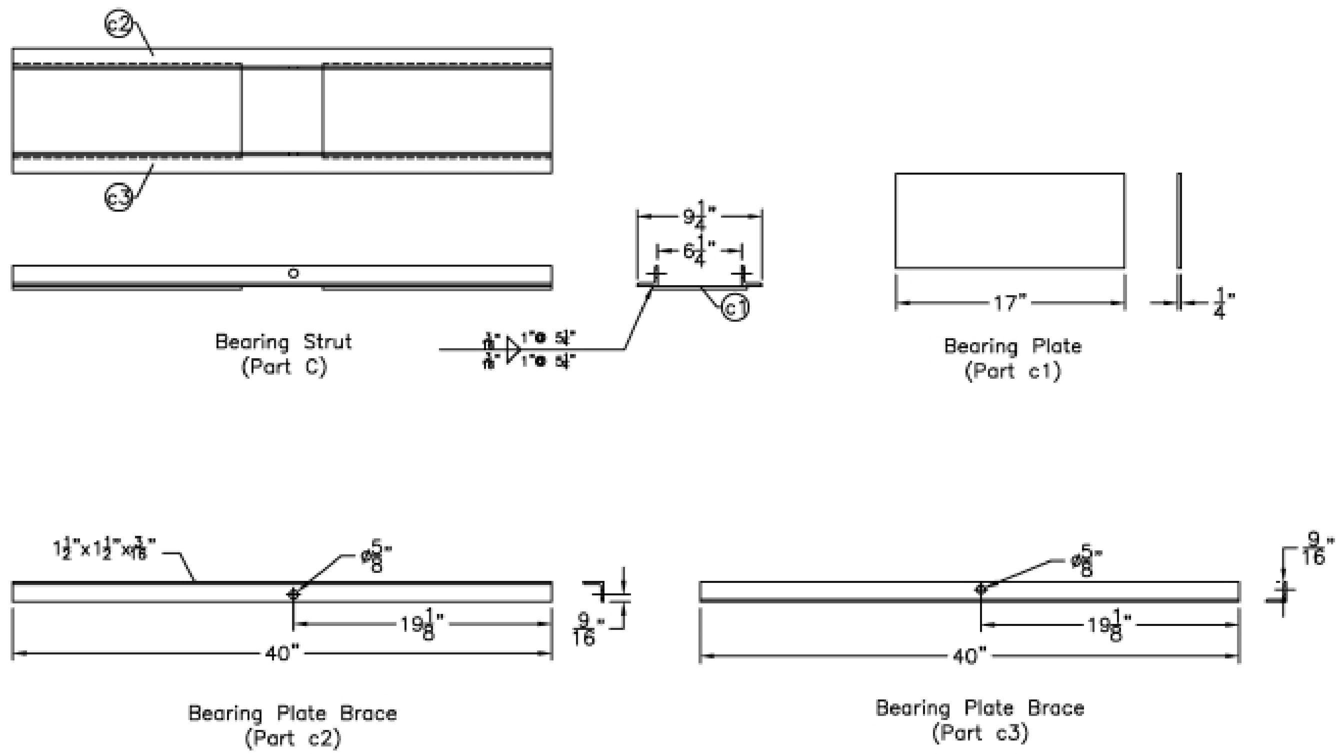


Figure D-23. Cable Support Post (English), Design No. 2

ITEM	QTY	DESCRIPTION	MATERIAL
C	2	Bearing Strut	A36 Steel Plate
c1	2	Bearing Plate	A36 Steel Plate
c2	2	Bearing Plate Brace	A36 Steel Plate
c3	2	Bearing Plate Brace	A36 Steel Plate



Midwest Roadside Safety Facility	Cable Median Barrier CMB-2 Bearing Strut	Sheet: 11 of 13
		Date: 8/11/2008
		By: GEP/CJS
	Drawing Name: CMB-2 R12.dwg / Scale: None	Rev: KAP/JCH

Figure D-24. Bearing Strut (English), Design No. 2

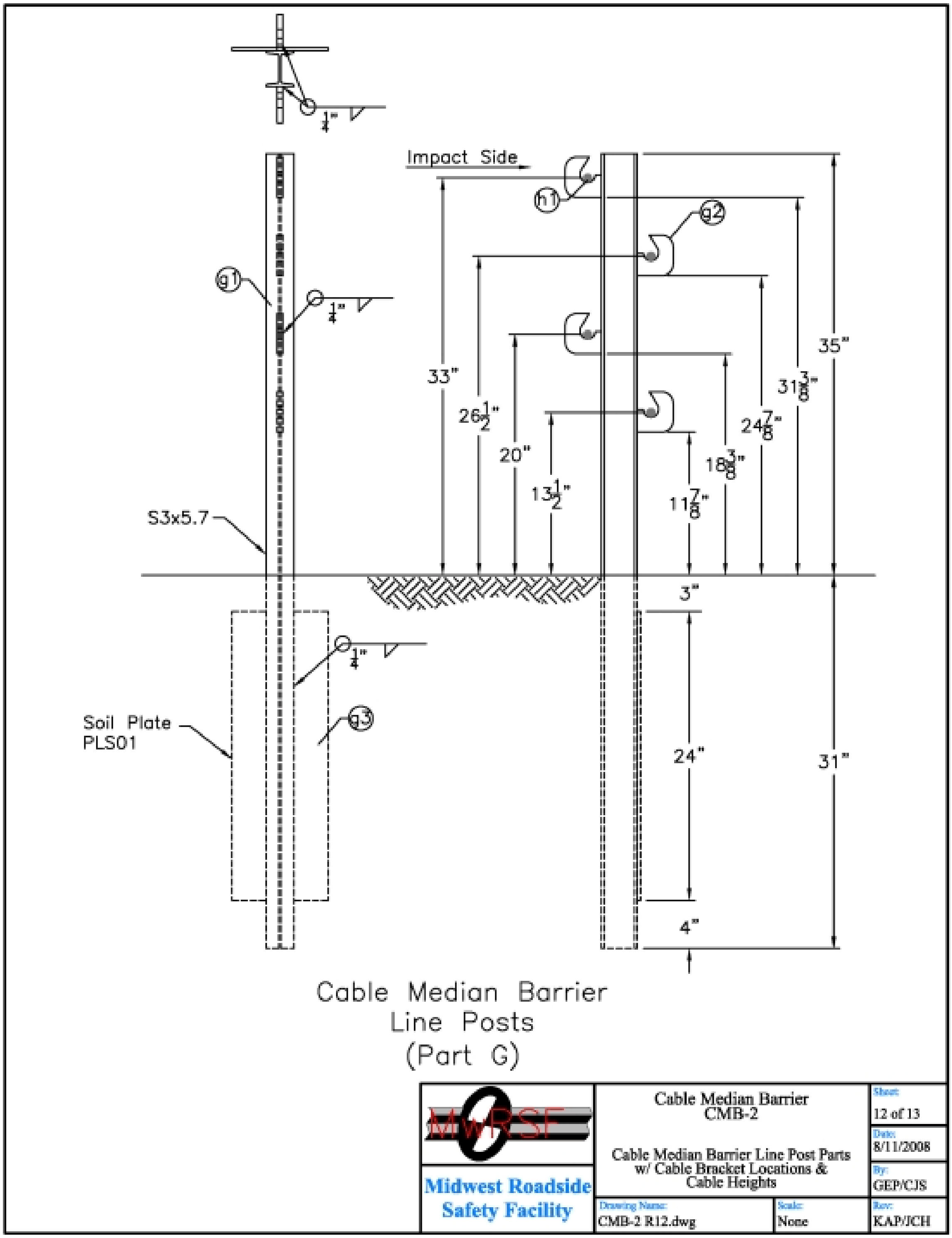


Figure D-25. Bracket Locations and Cable Heights (English), Design No. 2

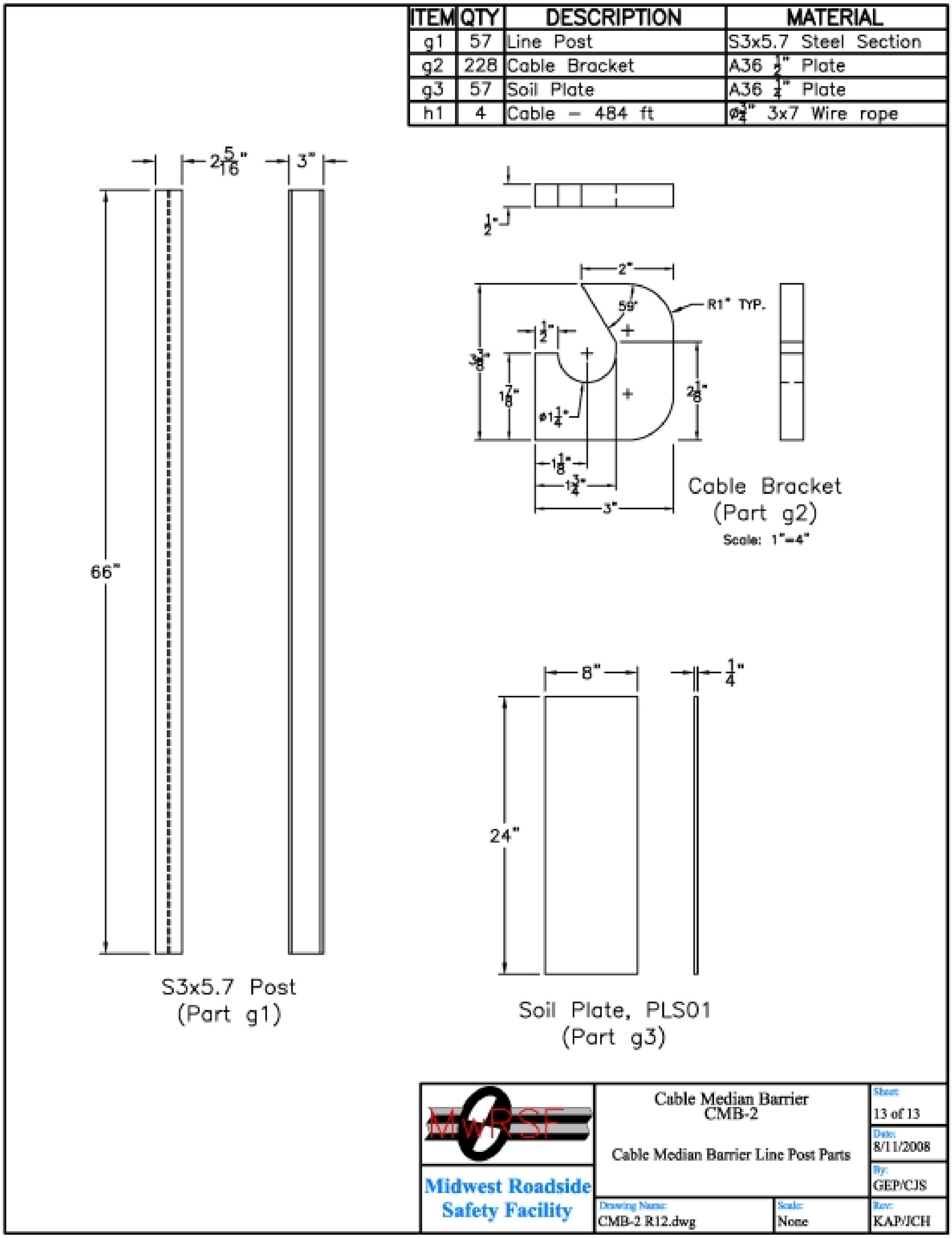


Figure D-26. Line Post Parts (English), Design No. 2

APPENDIX E

Occupant Compartment Deformation Data

Occupant Compartment Deformation Index (OCDI)

Test No. CMB-2
Vehicle Type: 820c

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

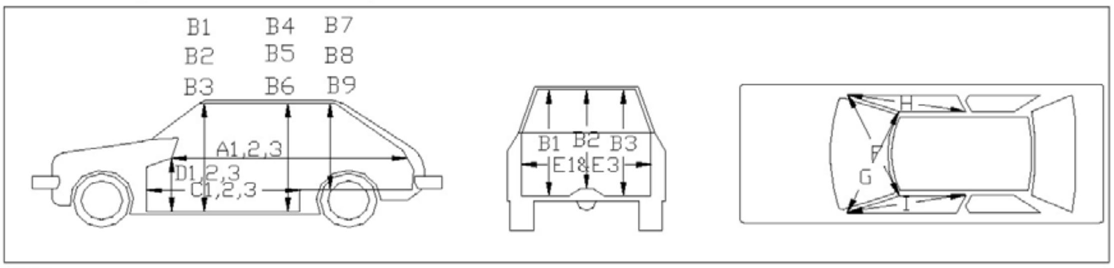
G = distance between the lower edge of left window and the upper edge of right window

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	81.50	81.50	0.00	0.00	0
A2	82.25	82.50	0.25	0.30	0
A3	81.00	81.25	0.25	0.31	0
B1	39.25	39.25	0.00	0.00	0
B2	36.75	36.75	0.00	0.00	0
B3	38.75	38.75	0.00	0.00	0
B4	39.38	37.00	-2.38	-6.03	1
C1	56.25	55.75	-0.50	-0.89	0
C2	40.00	40.00	0.00	0.00	0
C3	56.25	56.25	0.00	0.00	0
D1	16.25	16.50	0.25	1.54	0
D2	16.00	16.00	0.00	0.00	0
D3	13.50	13.75	0.25	1.85	0
E1	49.25	49.25	0.00	0.00	0
E3	49.50	49.50	0.00	0.00	0
F	47.50	47.50	0.00	0.00	0
G	47.00	47.00	0.00	0.00	0
H	39.00	39.25	0.25	0.64	0
I	39.00	39.00	0.00	0.00	0

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

Max roof deformation (B4)

Final OCDI: XX A B C D E F G H I
LF 0 1 0 0 0 0 0 0 0

Figure E-1. Occupant Compartment Deformation Index (OCDI), Test CMB-2

VEHICLE PRE/POST CRUSH INFO
Set-1

TEST: CMB-3
VEHICLE: 1999 GMC C2500

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

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	56.5	-27.5	-5.25	56.5	-27.25	-5.25	0	0.25	0
2	56.5	-22.75	-5.5	56.75	-22.75	-5.5	0.25	0	0
3	56.625	-19.25	-5.5	56.5	-19.25	-5.5	-0.125	0	0
4	56.5	-12.75	-5.5	56.75	-12.75	-5.5	0.25	0	0
5	54.25	-6.25	-3.25	54.25	-6.25	-3.25	0	0	0
6	52.75	-0.372	-1	52.75	0.5	-1	0	0.872	0
7	49.75	-26.75	-9.25	50	-27.25	-9.25	0.25	-0.5	0
8	49	-21.75	-9.5	49.5	-22.25	-9.5	0.5	-0.5	0
9	49	-17.5	-9.5	49.5	-18	-9.5	0.5	-0.5	0
10	48.5	-12.25	-9.25	49	-12.25	-9.25	0.5	0	0
11	47.375	-6.625	-6	47.25	-6.5	-5.75	-0.125	0.125	0.25
12	47	1.375	-3	47	1.25	-3	0	-0.125	0
13	43.125	-27.75	-9.75	43.25	-27.75	-9.75	0.125	0	0
14	42.75	-22.125	-9.75	43	-22	-9.75	0.25	0.125	0
15	42.5	-16.75	-10	42.75	-16.5	-10	0.25	0.25	0
16	42.5	-11.375	-10	42.75	-11.25	-10	0.25	0.125	0
17	42	-6.5	-6	42	-6	-6	0	0.5	0
18	41.75	1.75	-3.75	41.75	1.75	-3.75	0	0	0
19	37.5	-27.875	-10	37.5	-27.75	-10	0	0.125	0
20	37.125	-22	-10	37	-21.75	10	-0.125	0.25	20
21	36.5	-16.25	-10.25	37	-16.25	-10.25	0.5	0	0
22	36.75	-10.5	-10.25	37	-10.75	-10	0.25	-0.25	0.25
23	37.125	-6	-6.25	37	-6	-6	-0.125	0	0.25
24	36.75	2	-4.5	37	2	-4.5	0.25	0	0
25	32	-21.75	-10	32	-21.25	-10	0	0.5	0
26	31.75	-9.75	-10.25	31.75	-10	-10	0	-0.25	0.25
27	23.125	-20.75	-10.25	23	-21	-10.25	-0.125	-0.25	0
28	23	-9.125	-10.5	23.25	-9.5	-10.25	0.25	-0.375	0.25
29									
30									

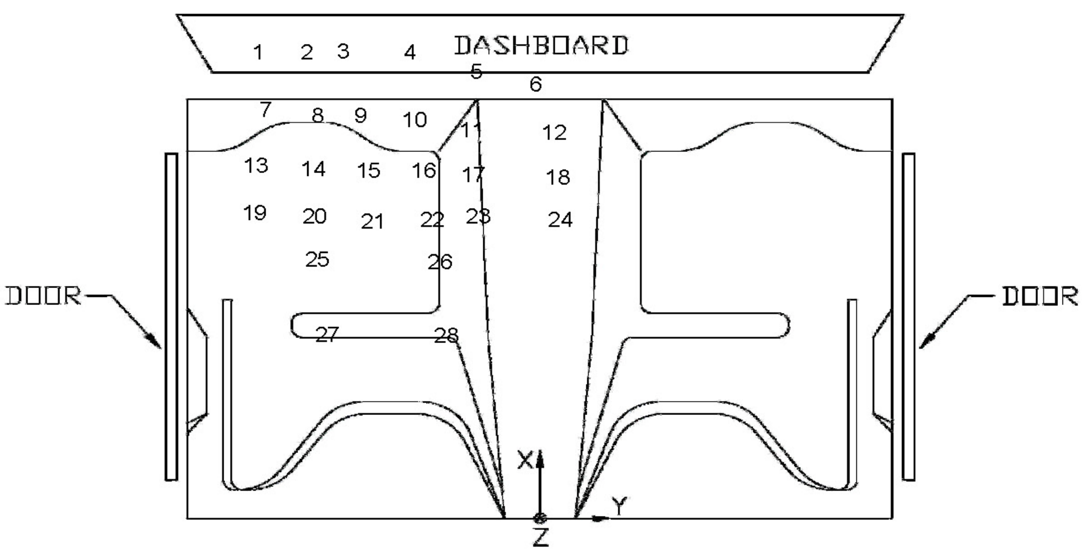


Figure E-2. Occupant Compartment Deformation Data - Set 1, Test CMB-3

VEHICLE PRE/POST CRUSH INFO
Set-2

TEST: CMB-3
VEHICLE: 1999 GMC C2500

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

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	50	-37.25	-3.5	50	-37	-3.5	0	0.25	0
2	50	-32.5	-4	50	-32.5	-3.75	0	0	0.25
3	50.125	-29	-4	50	-29	-3.5	-0.125	0	0.5
4	50	-22.5	-4.5	50	-22.5	-4.5	0	0	0
5	47.75	-16	-2.75	47.5	-15.75	-2.75	-0.25	0.25	0
6	46.25	-10.125	-0.75	46.25	-9.75	-0.75	0	0.375	0
7	43.25	-36.5	-7.5	43.25	-36.75	-7.5	0	-0.25	0
8	42.5	-31.5	-7.75	42.75	-31.25	-8	0.25	0.25	-0.25
9	42.5	-27.25	-8	42.5	-27.25	-8.5	0	0	-0.5
10	42	-22	-8	42	-21.75	-8.25	0	0.25	-0.25
11	40.875	-16.375	-5	41	-16.25	-5	0.125	0.125	0
12	40.5	-8.375	-3	40.25	-8	-3	-0.25	0.375	0
13	36.625	-37.5	-7.75	36.5	-37	-8	-0.125	0.5	-0.25
14	36.25	-31.875	-8	36.25	-31.75	-8.25	0	0.125	-0.25
15	36	-26.5	-8.75	36	-25.75	-8.75	0	0.75	0
16	36	-21.125	-8.75	36	-20.5	-8.75	0	0.625	0
17	35.5	-16.25	-5.25	35	-16	-5.25	-0.5	0.25	0
18	35.25	-8	-3.5	35	-7.5	-3.5	-0.25	0.5	0
19	31	-37.625	-8	31	-37.25	-8	0	0.375	0
20	30.625	-31.75	-8.25	30.75	-31.25	-8.25	0.125	0.5	0
21	30	-26	-8.75	30.5	-26	-9	0.5	0	-0.25
22	30.25	-20.25	-9	30.5	-20.25	-9	0.25	0	0
23	30.625	-15.75	-5.5	30.5	-15.75	-5.5	-0.125	0	0
24	30.25	-7.75	-4.25	30	-7.5	-4.25	-0.25	0.25	0
25	25.5	-31.5	-8.25	25.5	-31.25	-8.5	0	0.25	-0.25
26	25.25	-19.5	-9	25.25	-19.5	-9	0	0	0
27	16.625	-30.5	-8.25	17	-30.5	-8.5	0.375	0	-0.25
28	16.5	-18.875	-9	16.75	-19	-9	0.25	-0.125	0
29									
30									

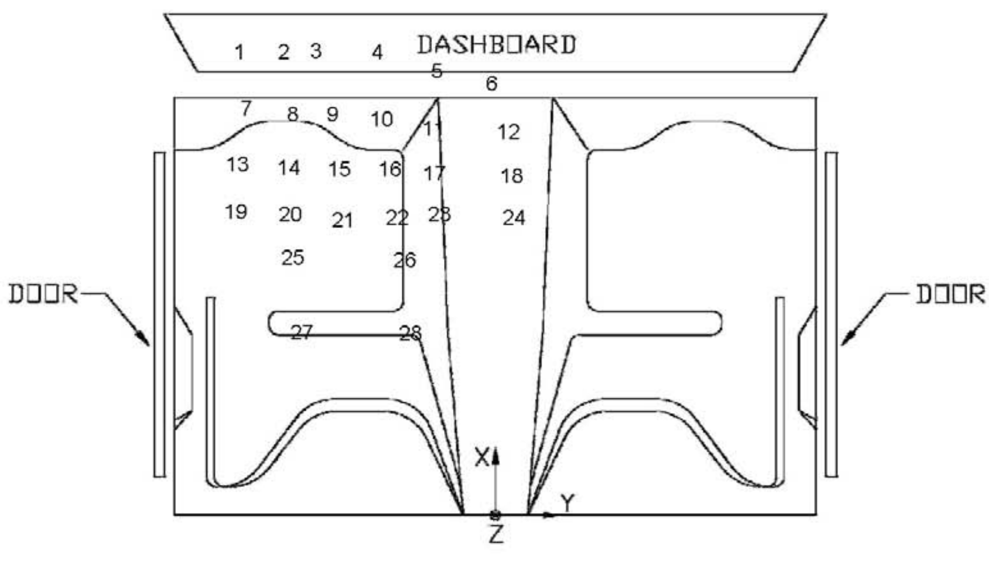


Figure E-3. Occupant Compartment Deformation Data - Set 2, Test CMB-3

Occupant Compartment Deformation Index (OCDI)

Test No. CMB-3
Vehicle Type: 2000p

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

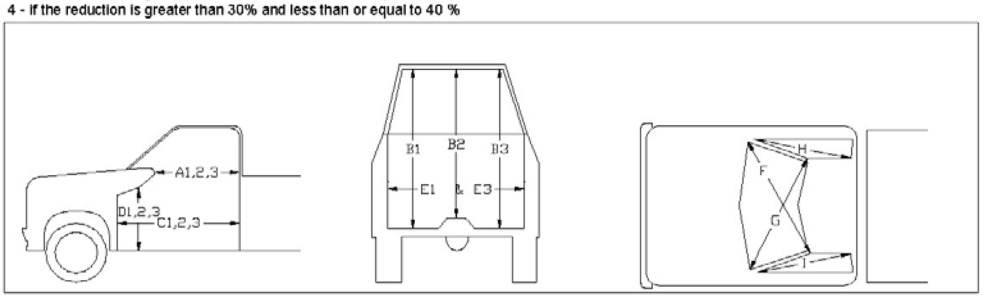
G = distance between the lower edge of left window and the upper edge of right window

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	41.50	41.25	-0.25	-0.60	0
A2	41.75	41.75	0.00	0.00	0
A3	40.75	41.00	0.25	0.61	0
B1	46.00	46.00	0.00	0.00	0
B2	43.25	43.25	0.00	0.00	0
B3	47.25	47.00	-0.25	-0.53	0
C1	56.75	56.75	0.00	0.00	0
C2	52.25	52.25	0.00	0.00	0
C3	57.25	57.25	0.00	0.00	0
D1	15.75	16.00	0.25	1.59	0
D2	15.50	15.50	0.00	0.00	0
D3	17.00	17.25	0.25	1.47	0
E1	62.50	62.50	0.00	0.00	0
E3	63.75	63.50	-0.25	-0.39	0
F	58.00	58.00	0.00	0.00	0
G	58.00	58.00	0.00	0.00	0
H	42.25	42.25	0.00	0.00	0
I	41.75	41.75	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:	LF	0	0	0	0	0	0	0	0	0

Figure E-4. Occupant Compartment Deformation Index (OCDI), Test CMB-3

APPENDIX F

Accelerometer and Rate Transfer Data Analysis, Test CMB-2

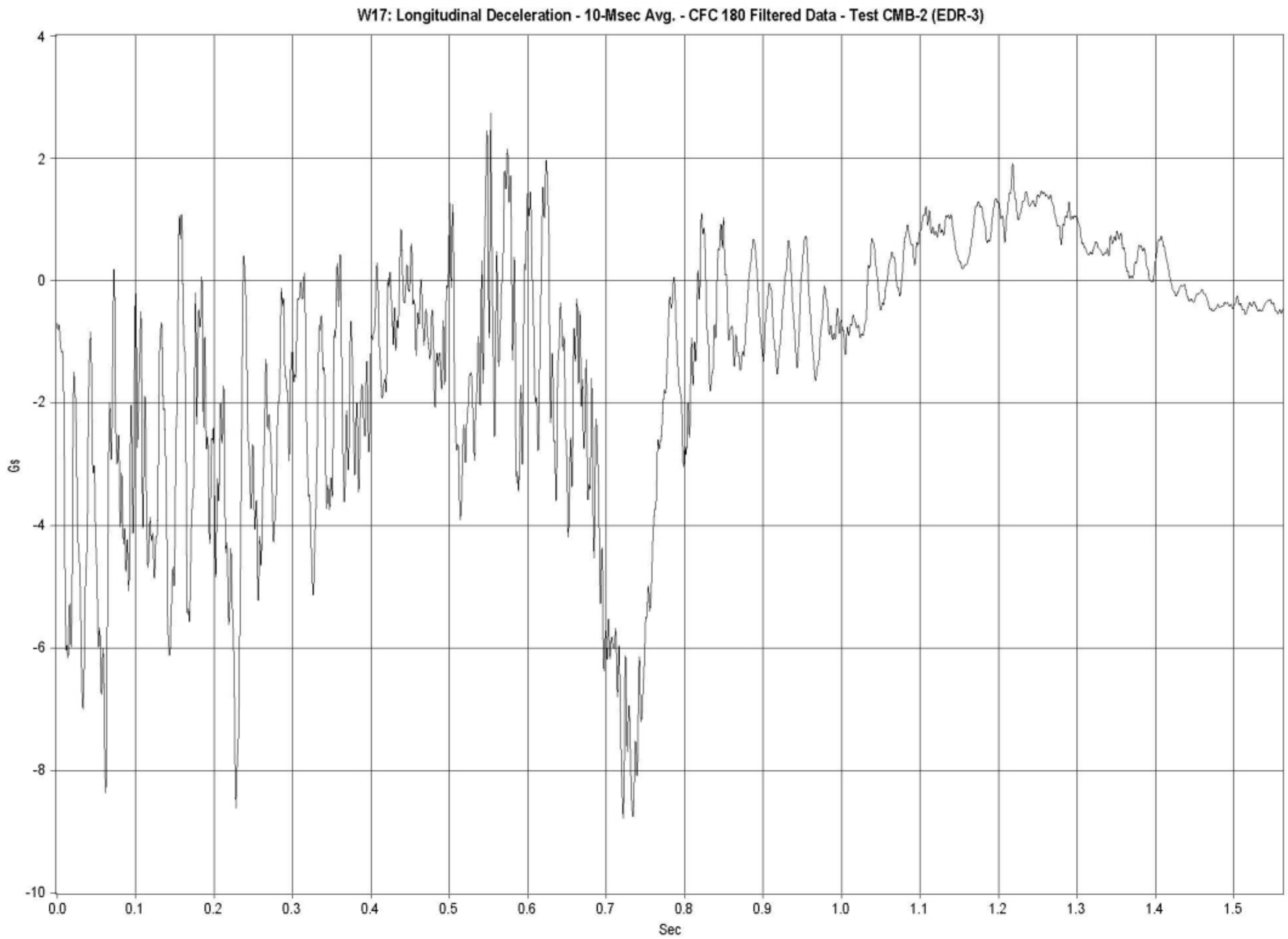


Figure F-1. Graph of Longitudinal Deceleration, Test CMB-2

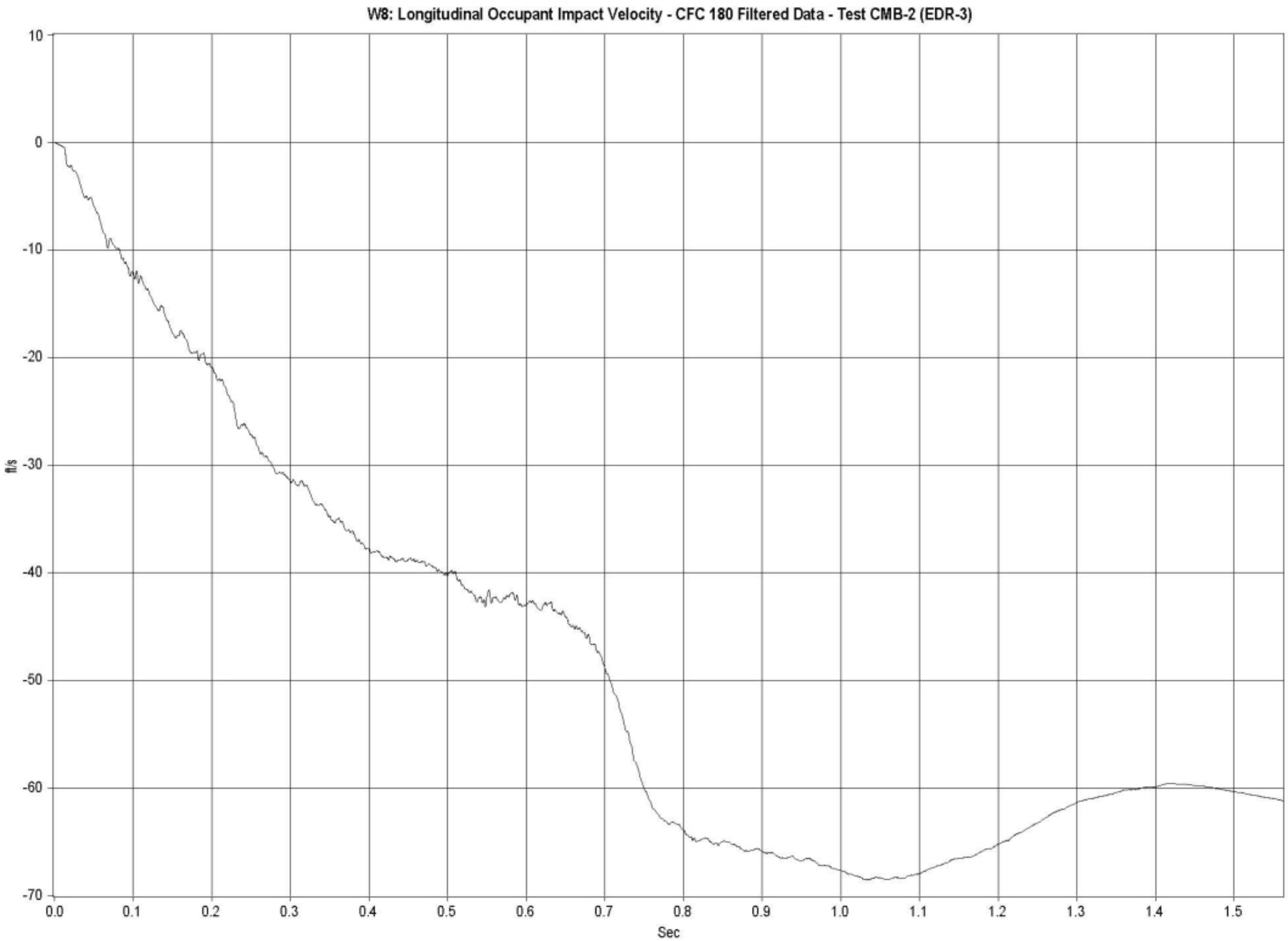


Figure F-2. Graph of Longitudinal Occupant Impact Velocity, Test CMB-2

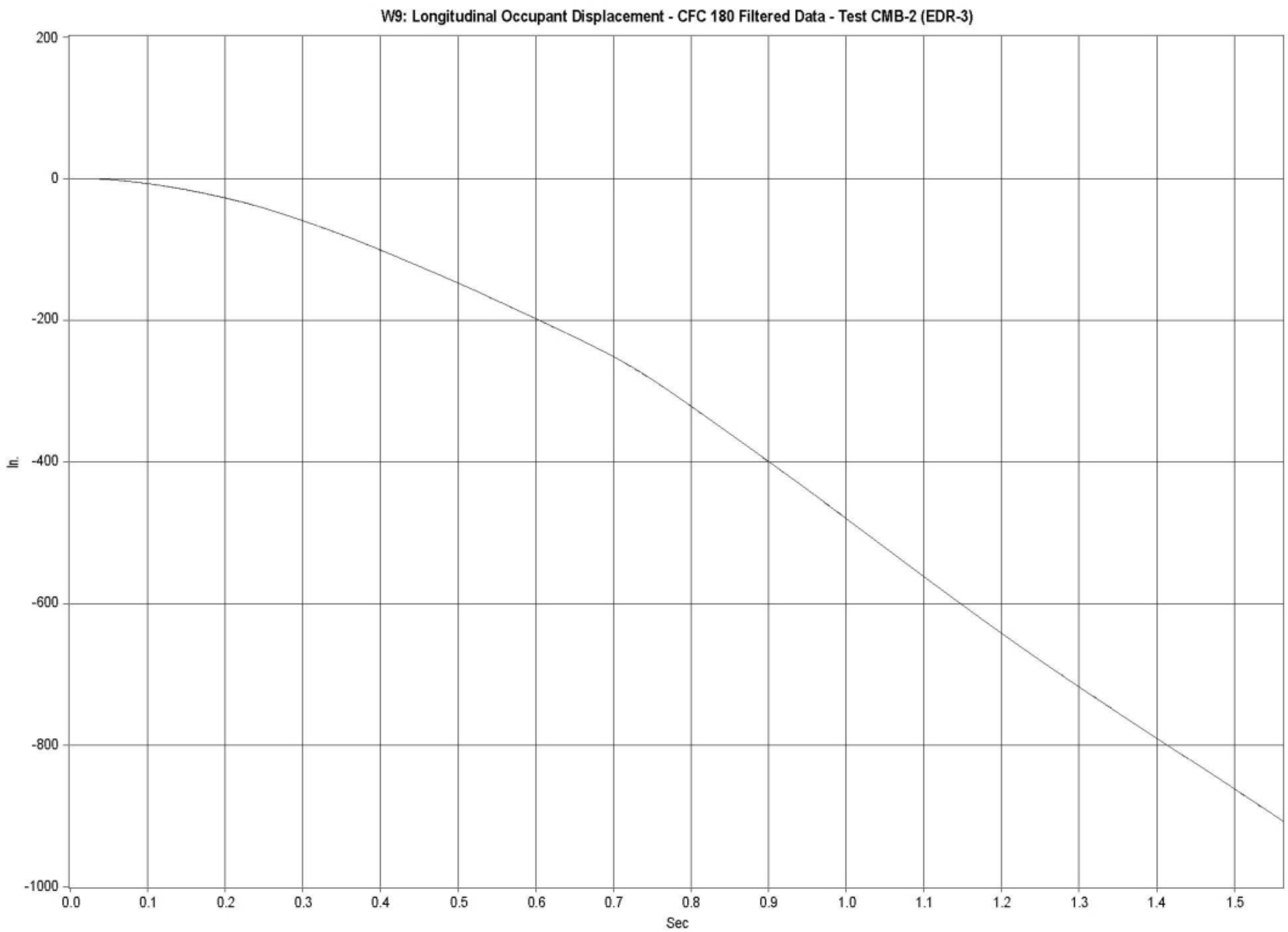


Figure F-3. Graph of Longitudinal Occupant Displacement, Test CMB-2

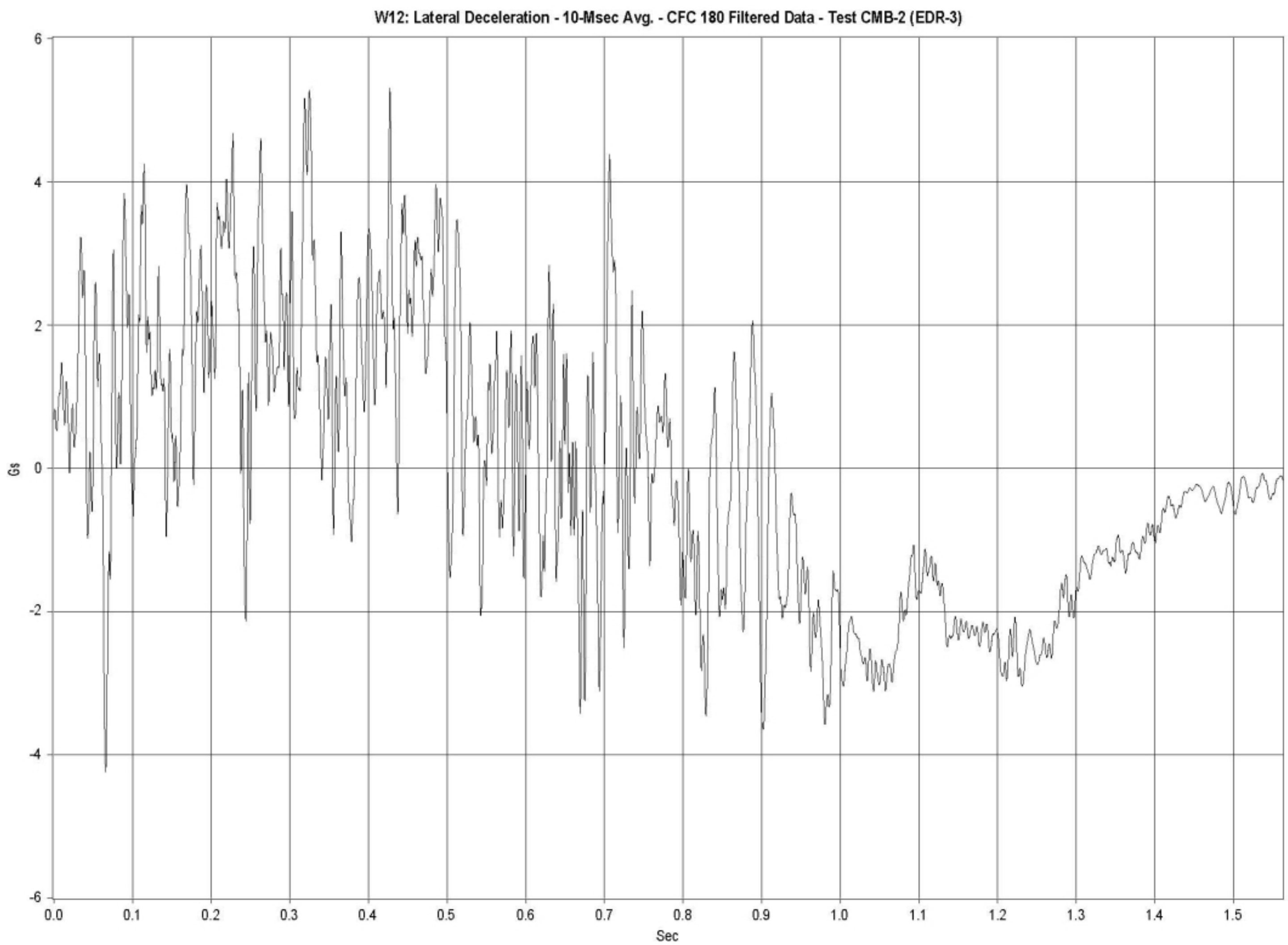


Figure F-4. Graph of Lateral Deceleration, Test CMB-2

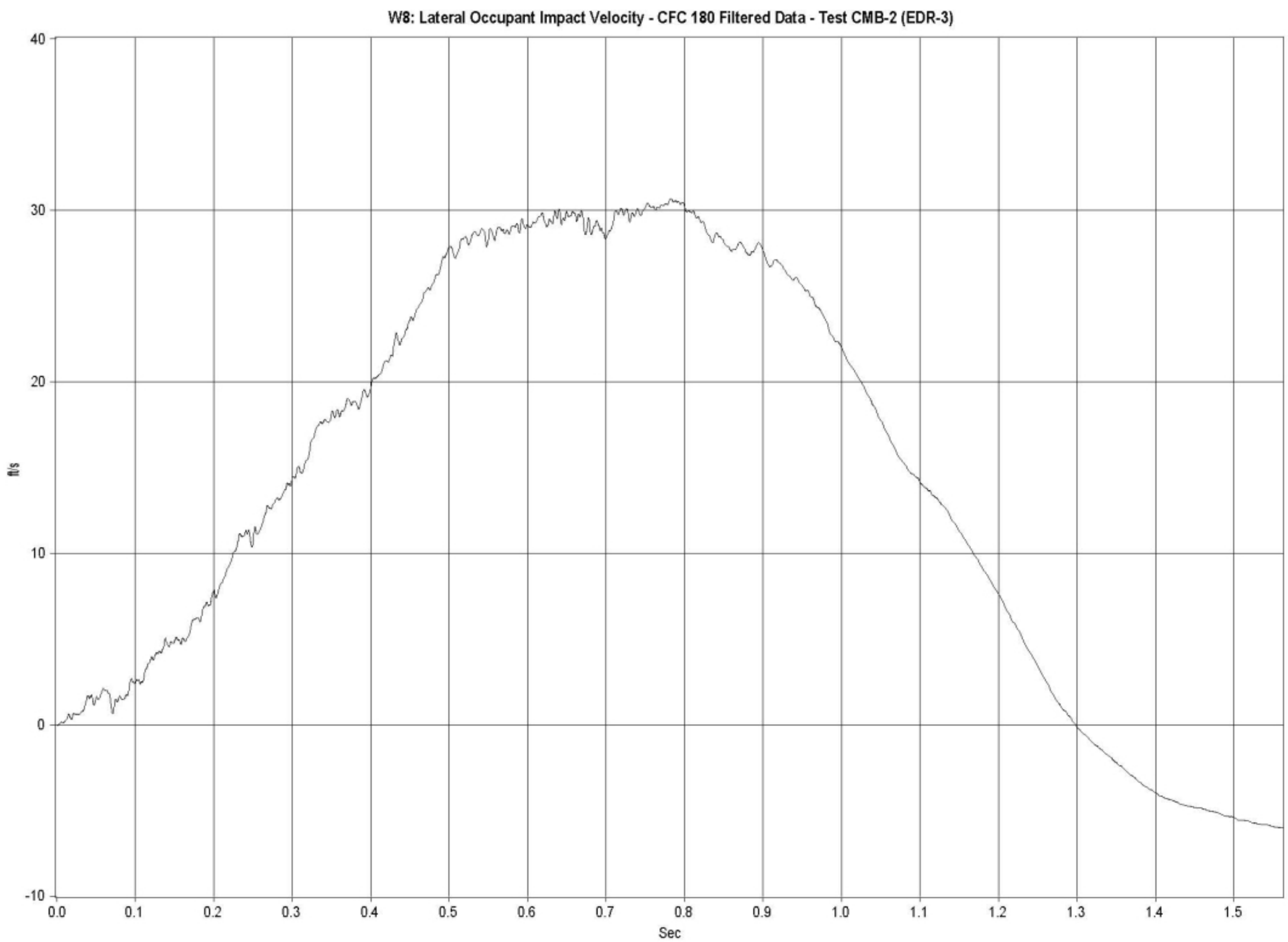


Figure F-5. Graph of Lateral Occupant Impact Velocity, Test CMB-2

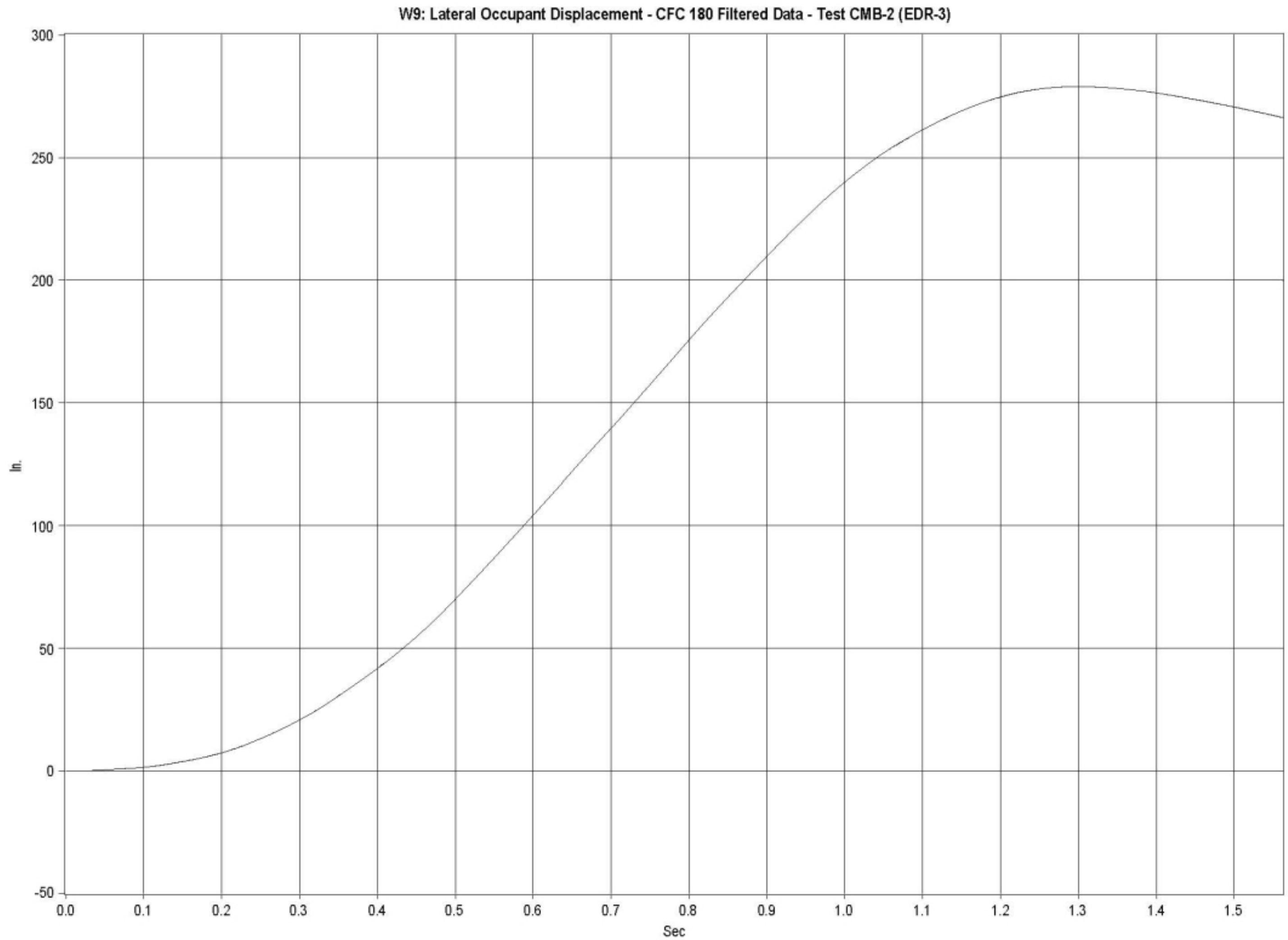


Figure F-6. Graph of Lateral Occupant Displacement, Test CMB-2

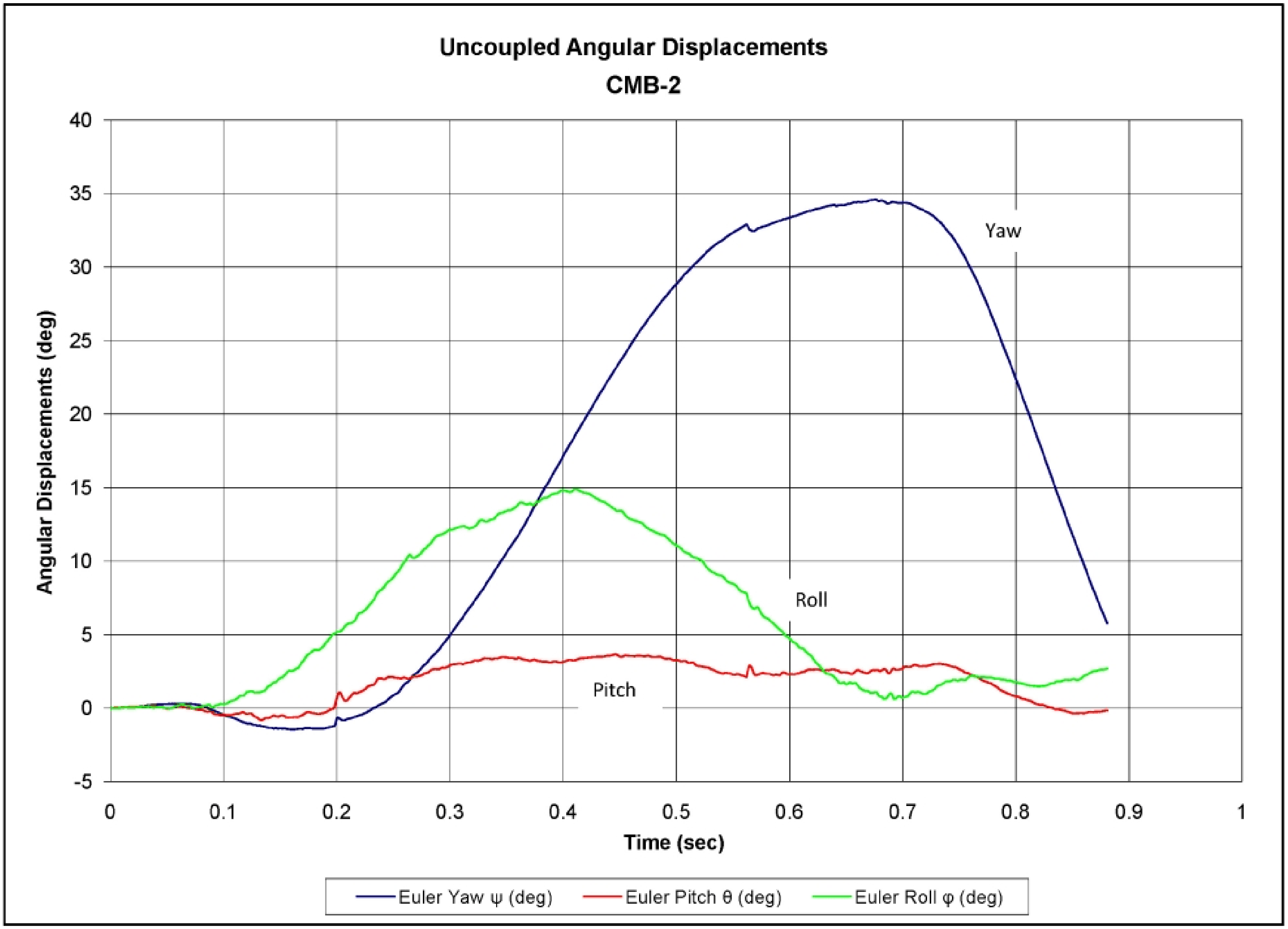


Figure F-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test CMB-2

APPENDIX G

System Details, Design No. 3

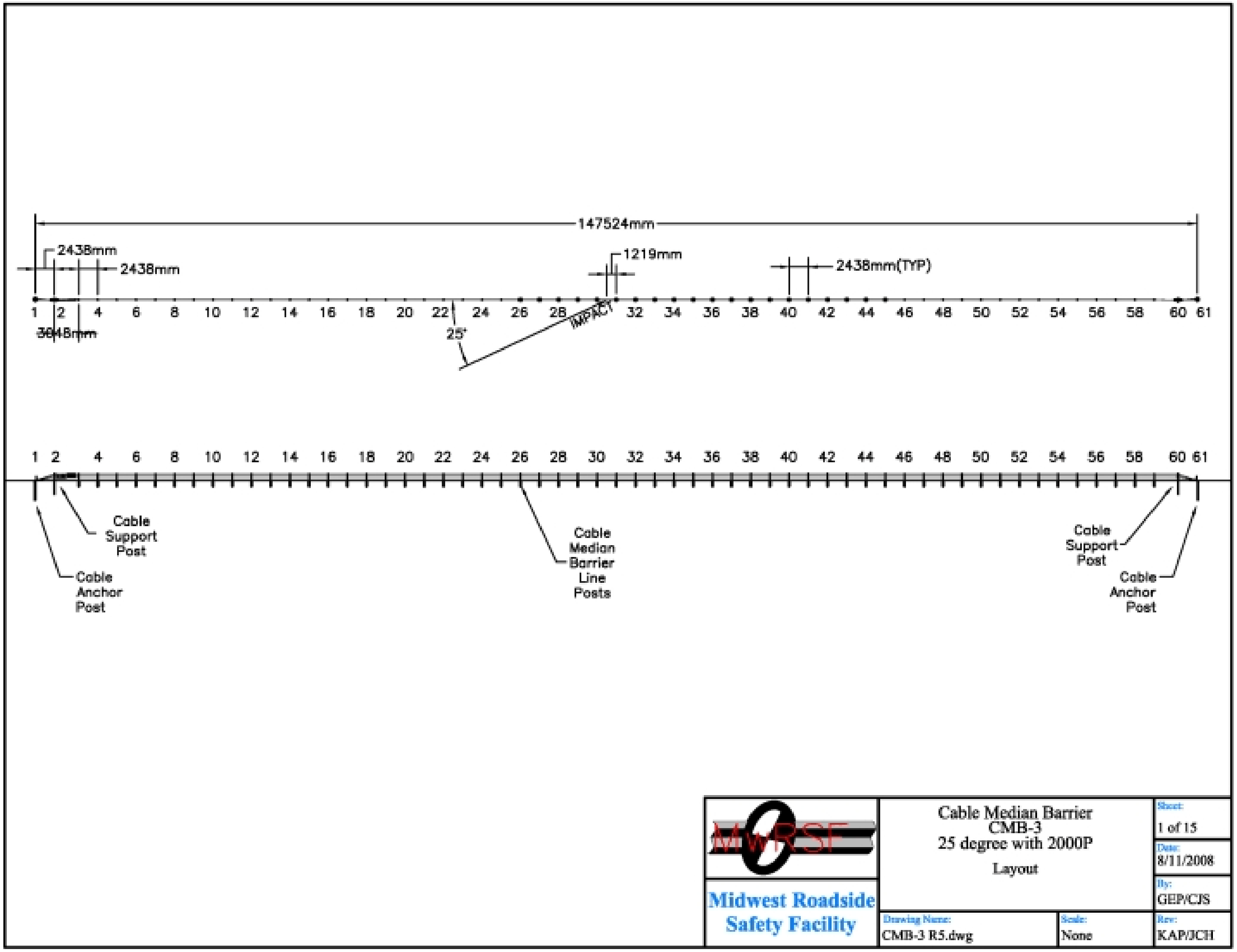


Figure G-1. System Layout (Metric), Design No. 3

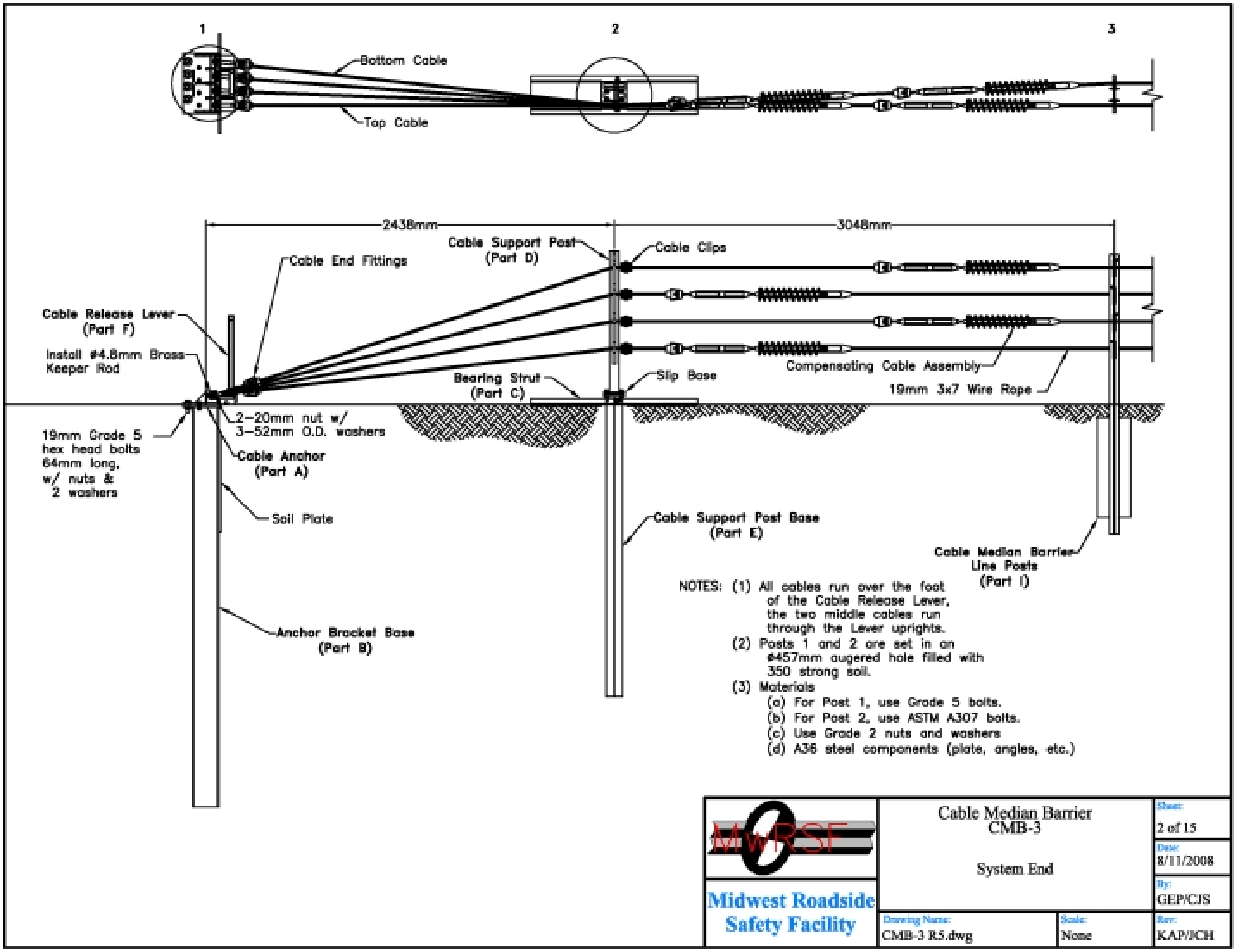


Figure G-2. System End (Metric), Design No. 3

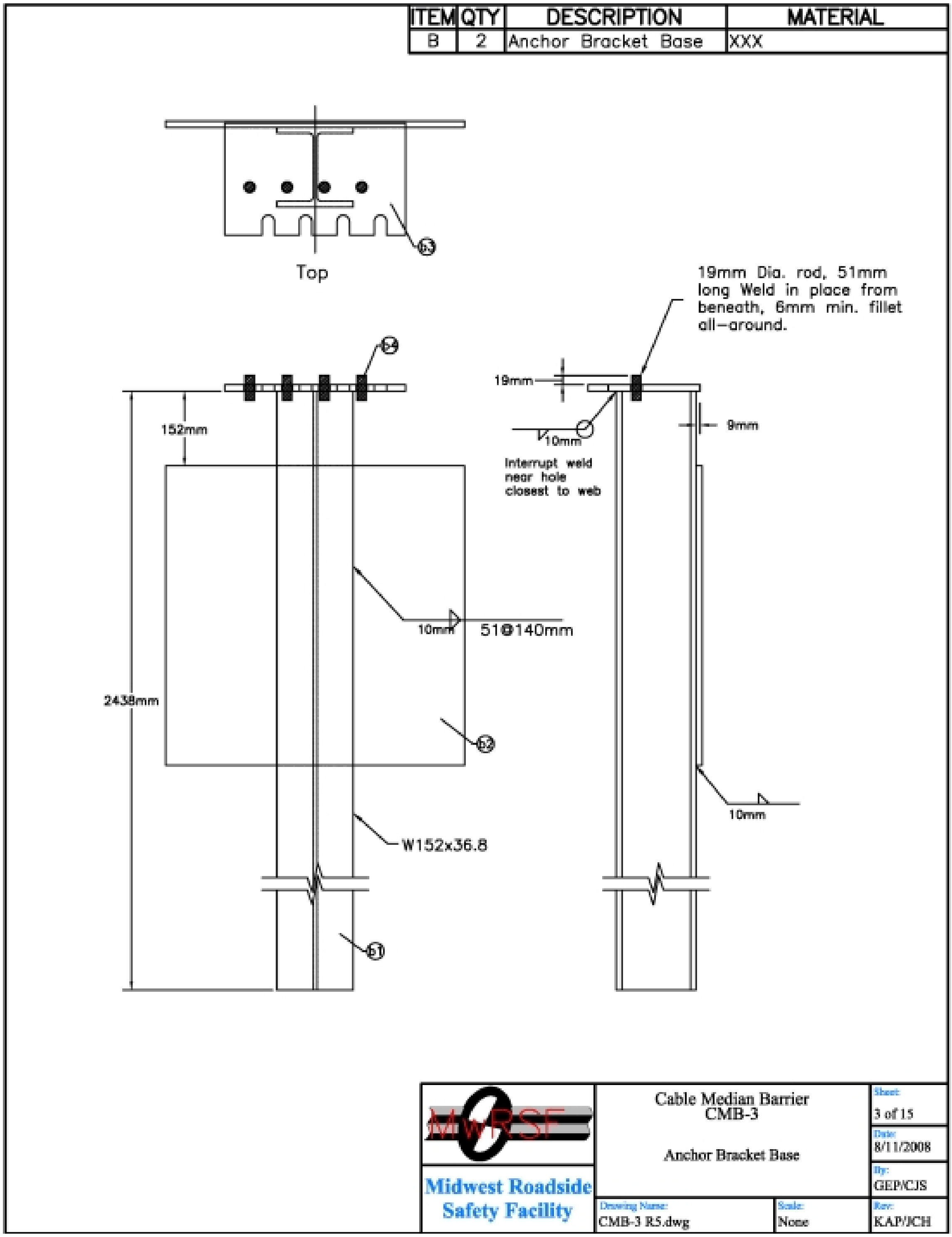


Figure G-3. Anchor Bracket Base (Metric), Design No. 3

ITEM	QTY	DESCRIPTION	MATERIAL
b1	2	Anchor Base Post	W152x36.8 Steel Post
b2	2	Soil Plate	610x610x13mm Plate
b3	2	Anchor Base Plate	628x229x13mm Plate
b4	8	19mm Dia. Rod	ø19 x 51mm long rod

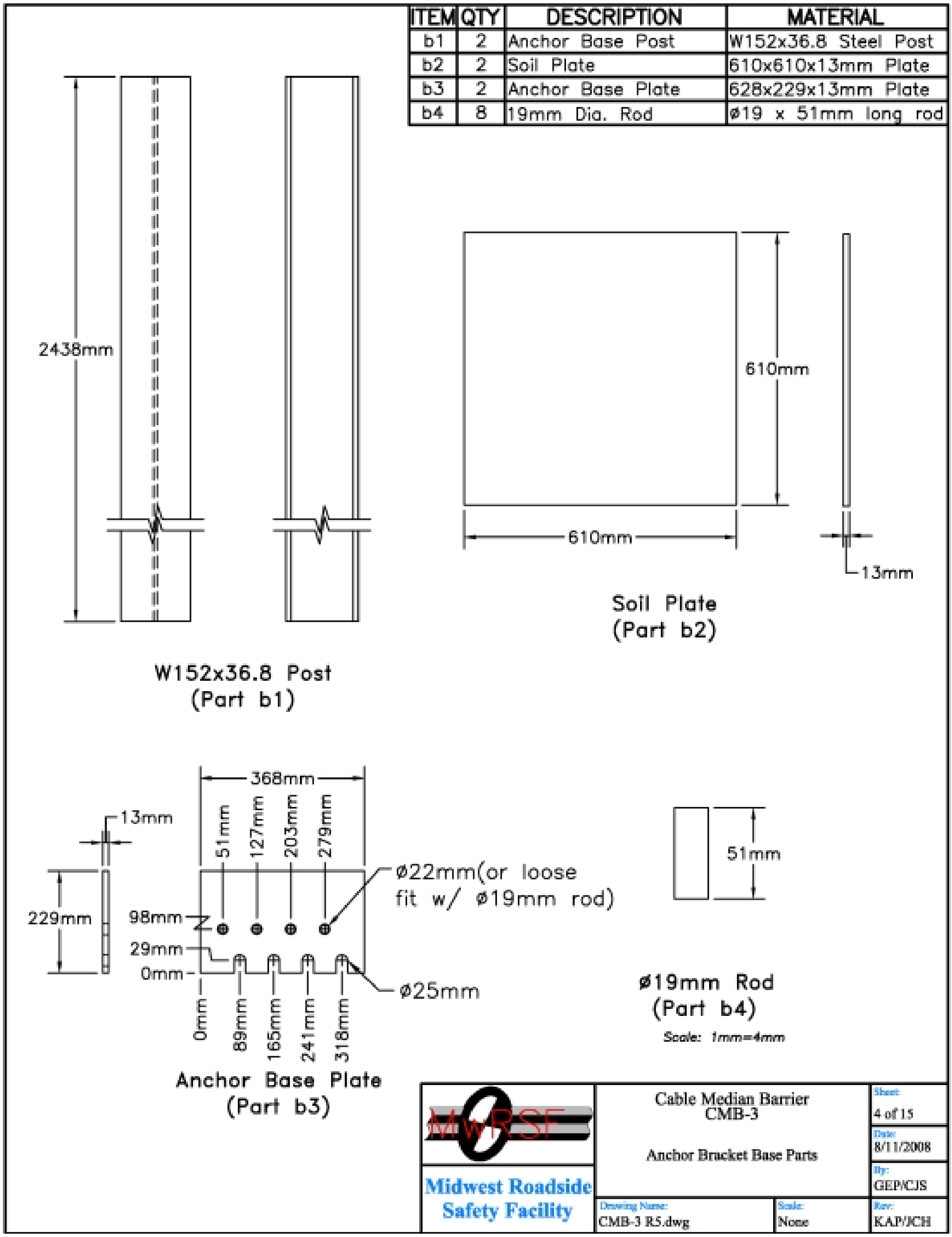


Figure G-4. Anchor Bracket Base Parts (Metric), Design No. 3

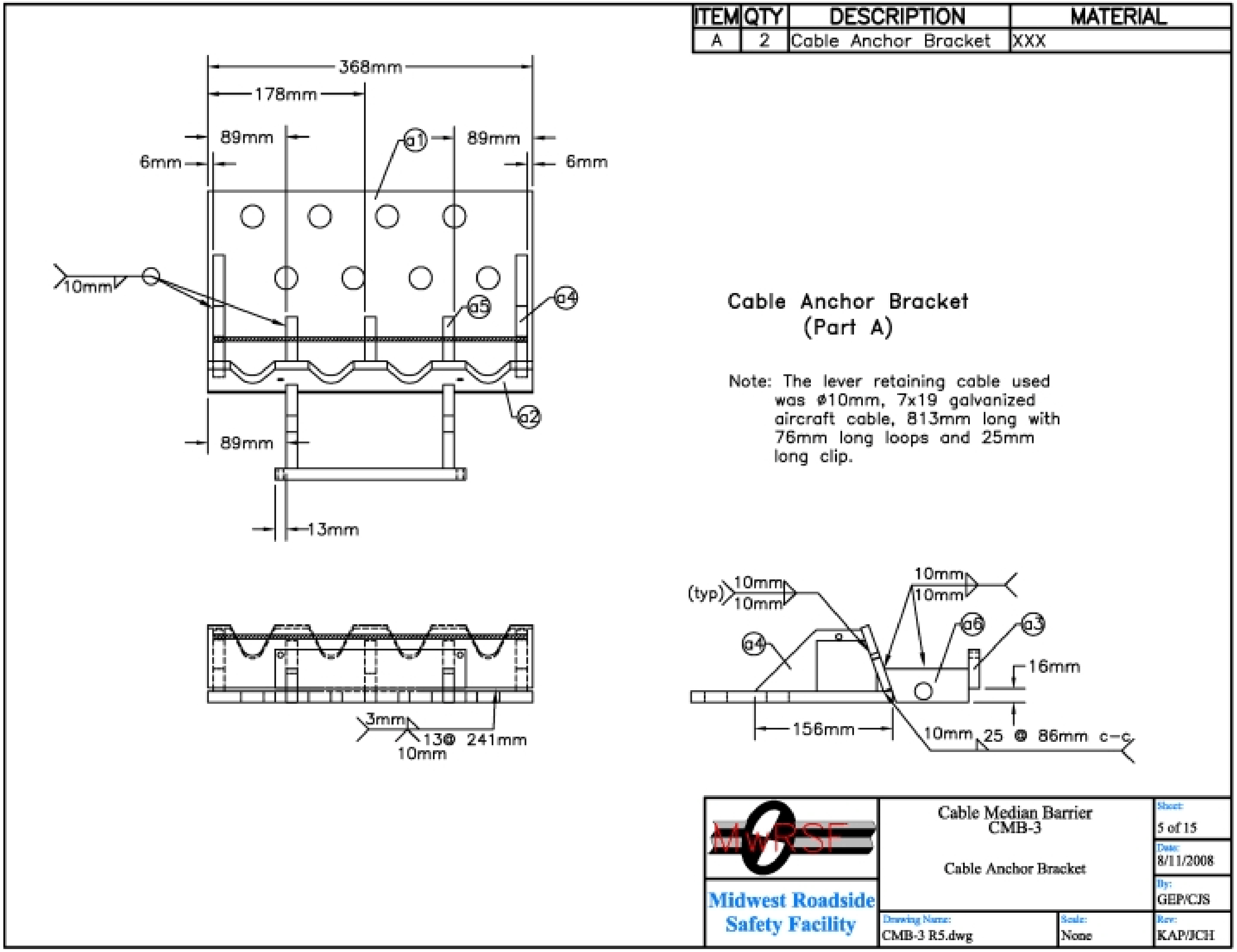
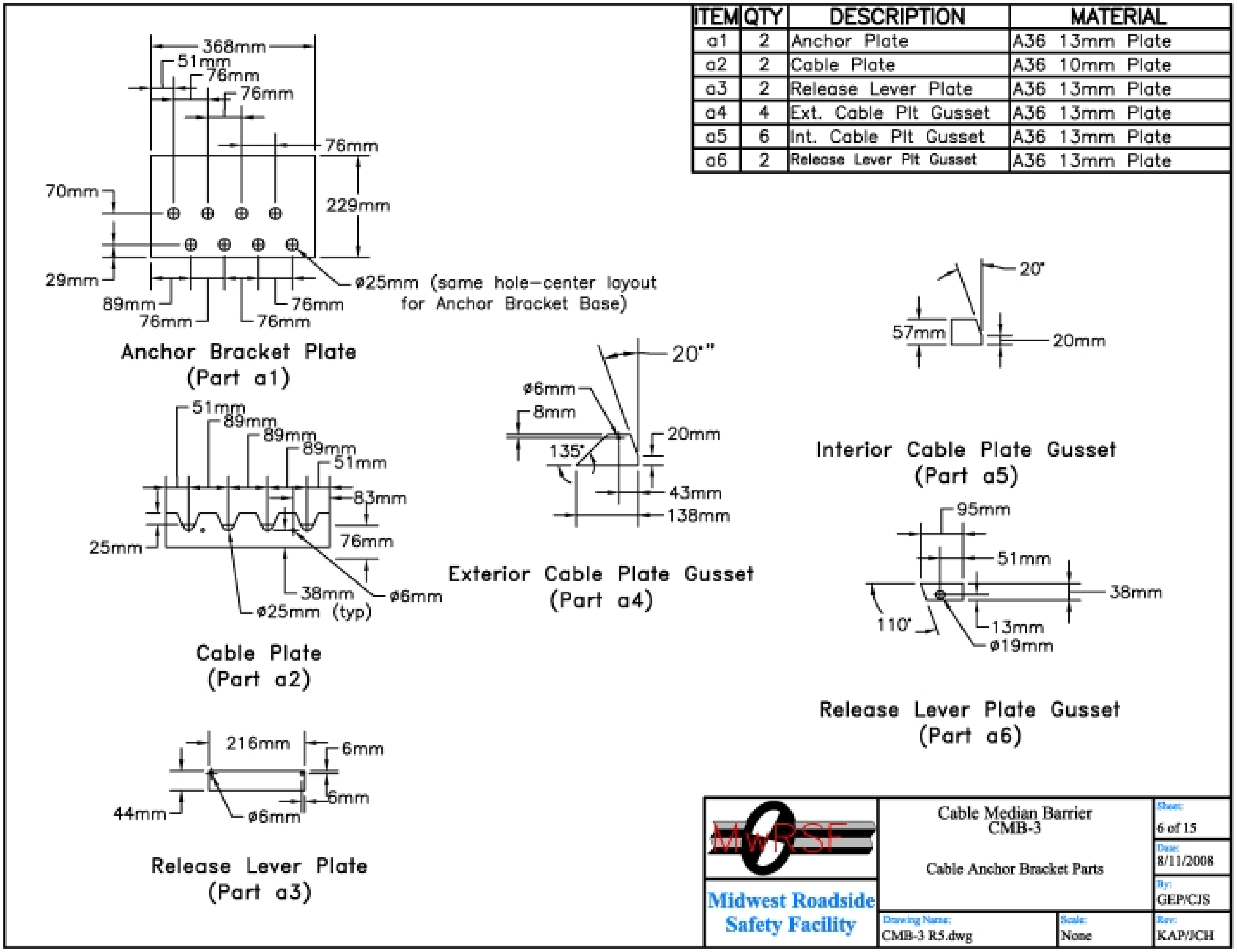


Figure G-5. Cable Anchor Bracket (Metric), Design No. 3



ITEM	QTY	DESCRIPTION	MATERIAL
a1	2	Anchor Plate	A36 13mm Plate
a2	2	Cable Plate	A36 10mm Plate
a3	2	Release Lever Plate	A36 13mm Plate
a4	4	Ext. Cable Plt Gusset	A36 13mm Plate
a5	6	Int. Cable Plt Gusset	A36 13mm Plate
a6	2	Release Lever Plt Gusset	A36 13mm Plate

Figure G-6. Cable Anchor Bracket Parts (Metric), Design No. 3

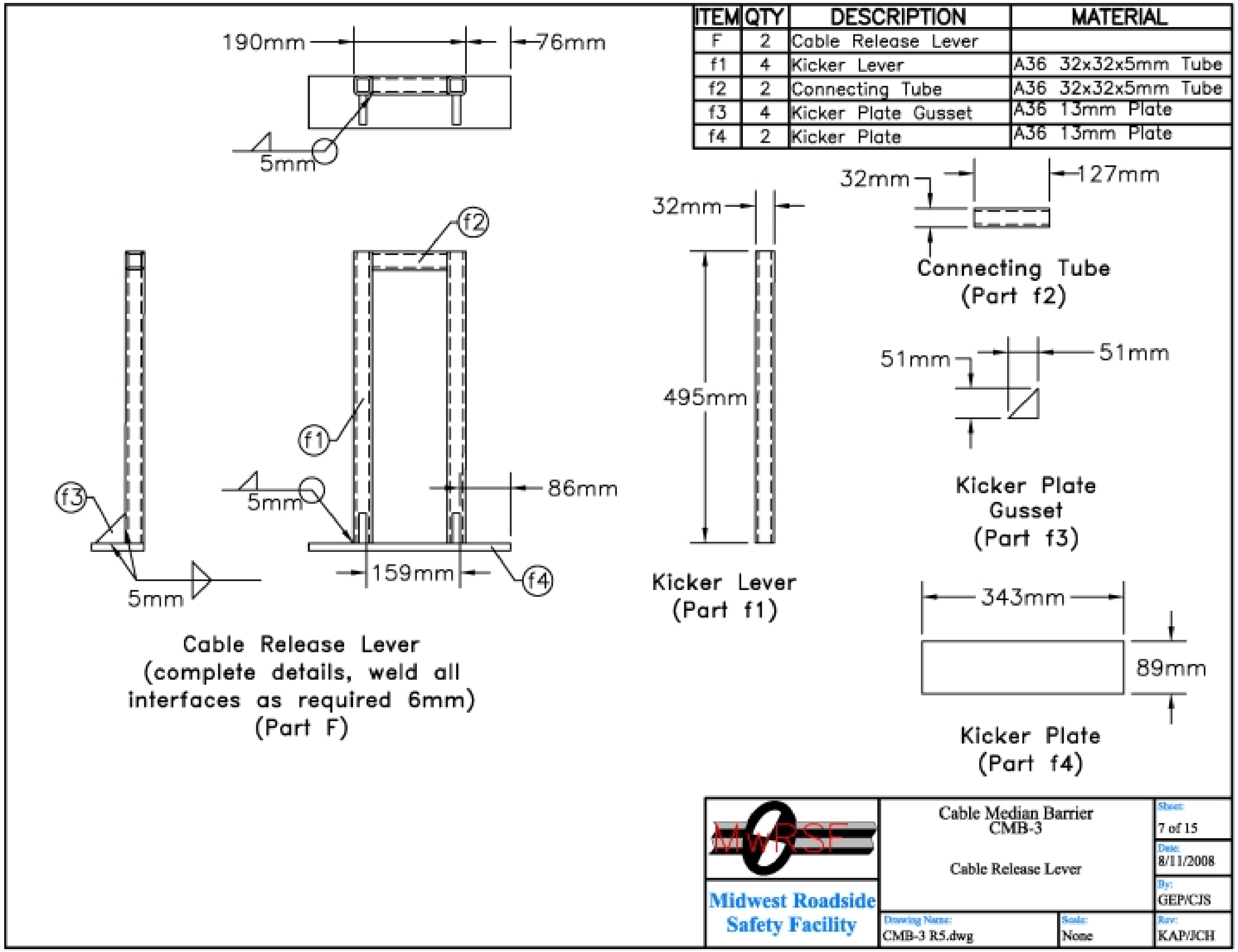


Figure G-7. Cable Release Lever (Metric), Design No. 3

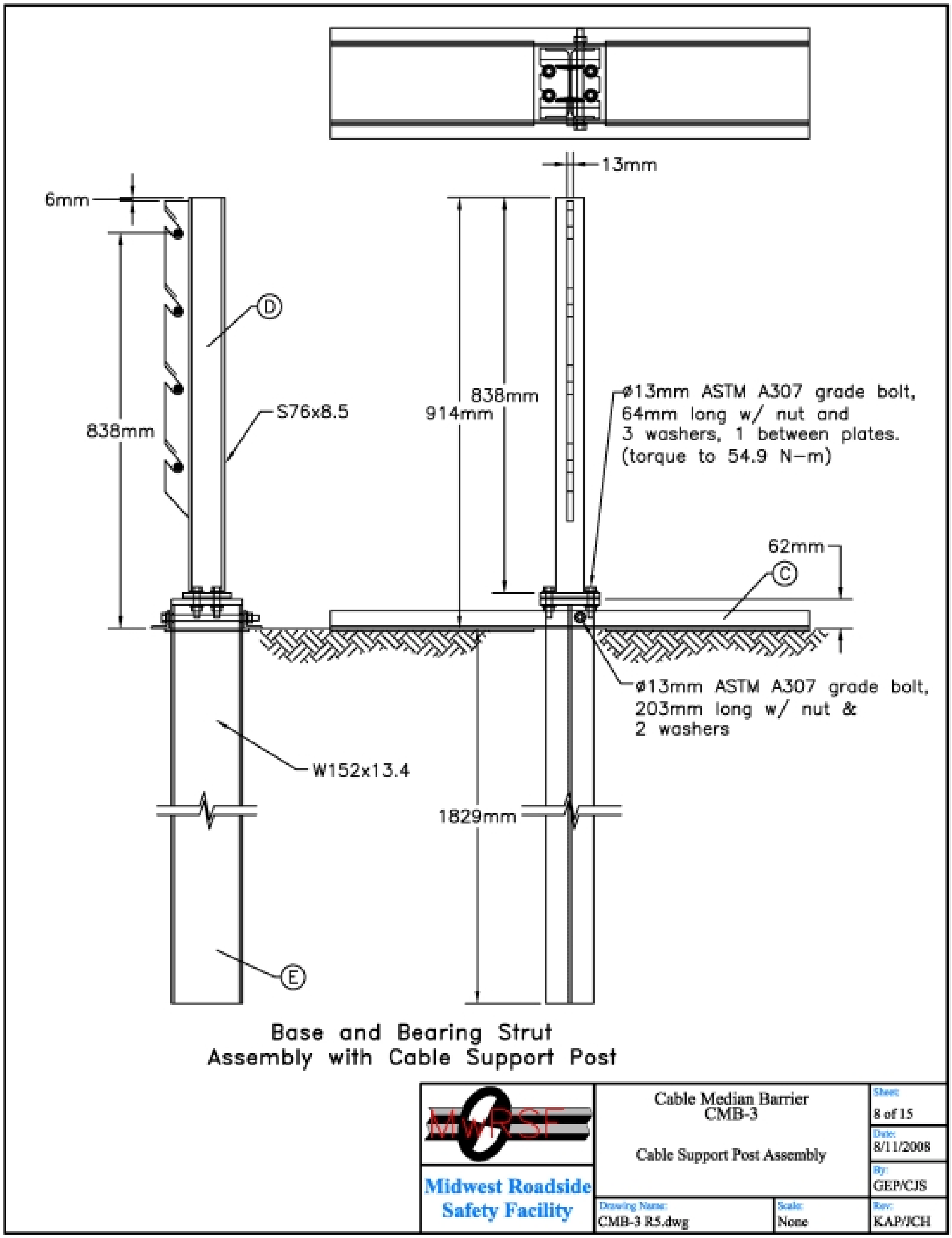


Figure G-8. Cable Support Post Assembly (Metric), Design No. 3

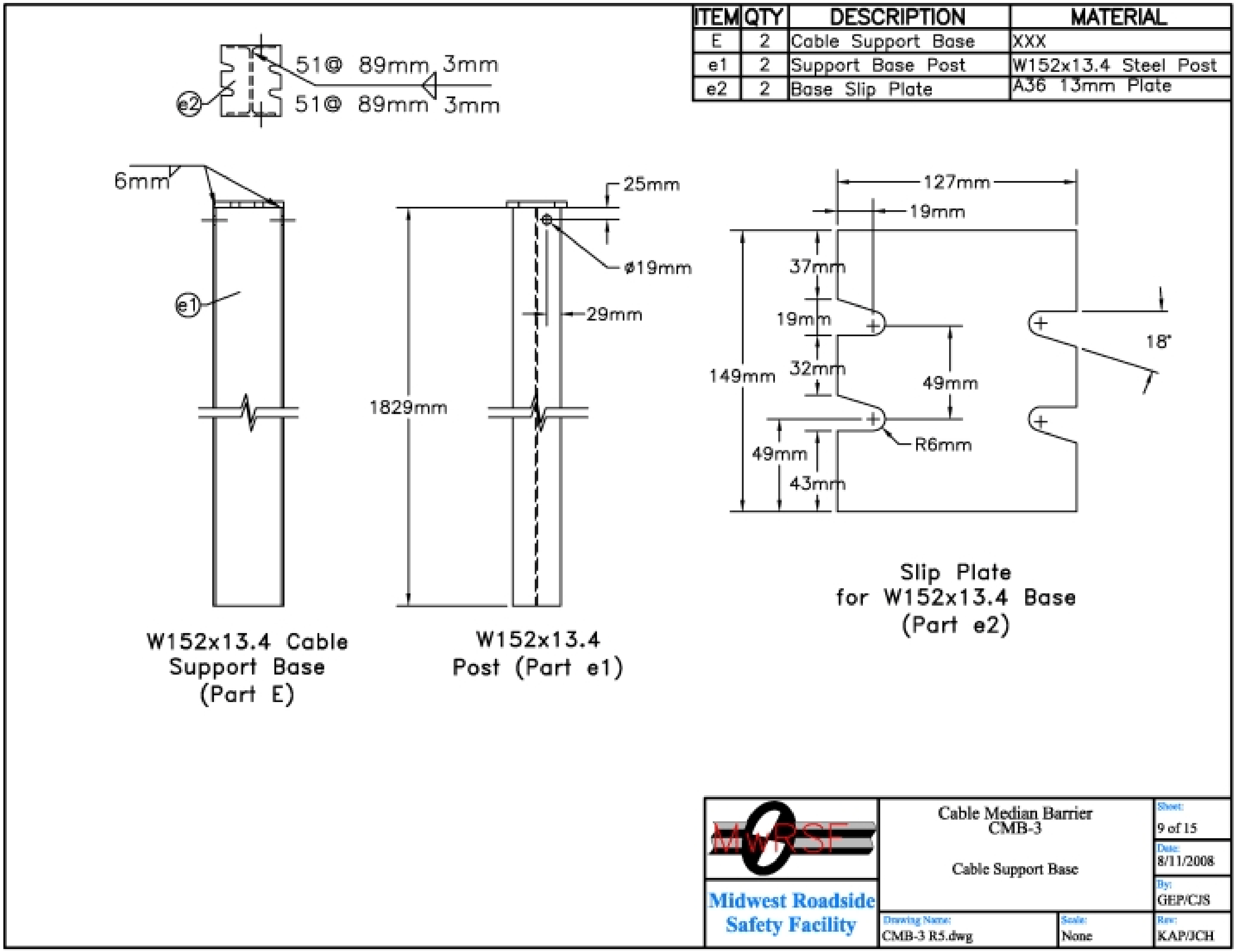


Figure G-9. Cable Support Base (Metric), Design No. 3

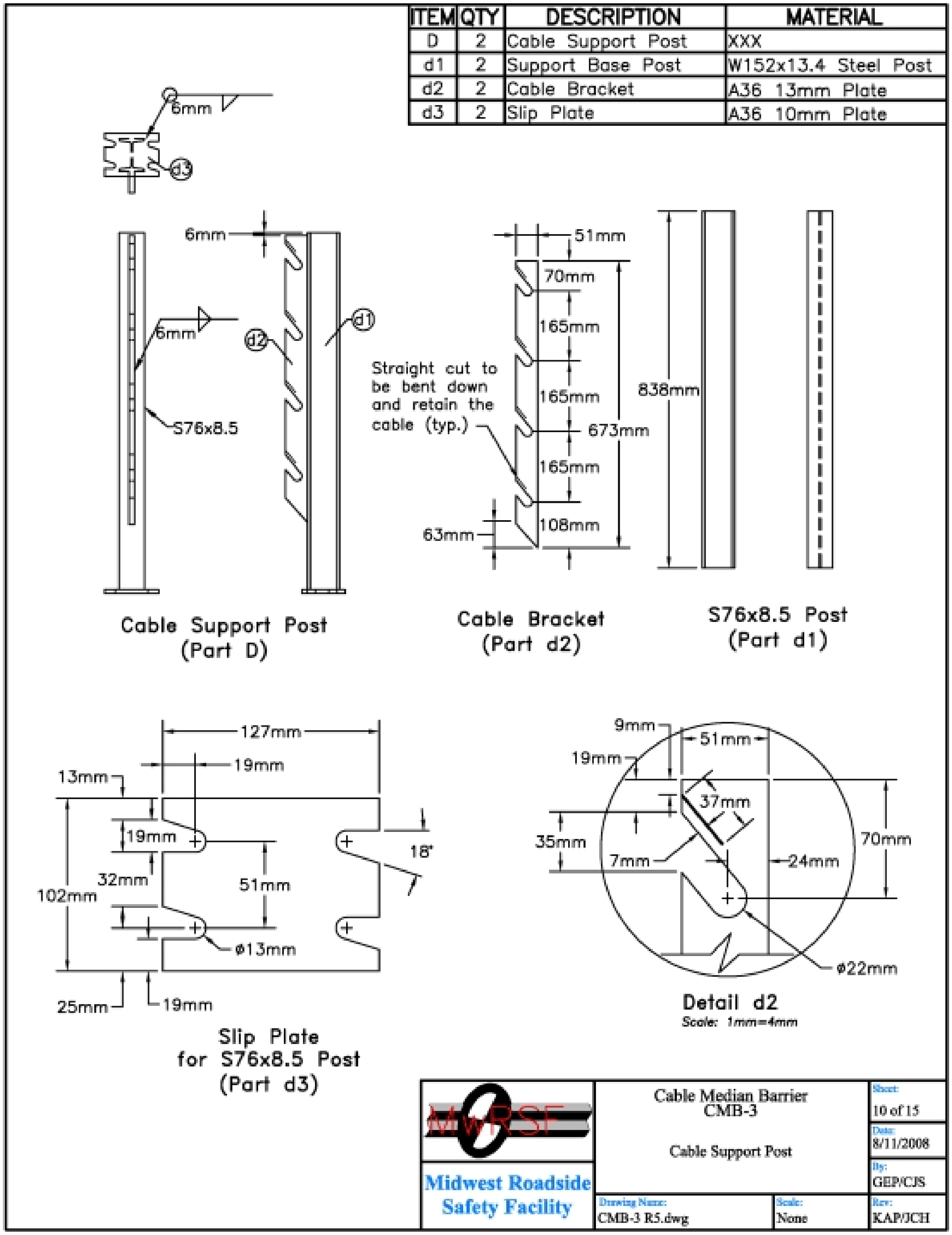


Figure G-10. Cable Support Post (Metric), Design No. 3

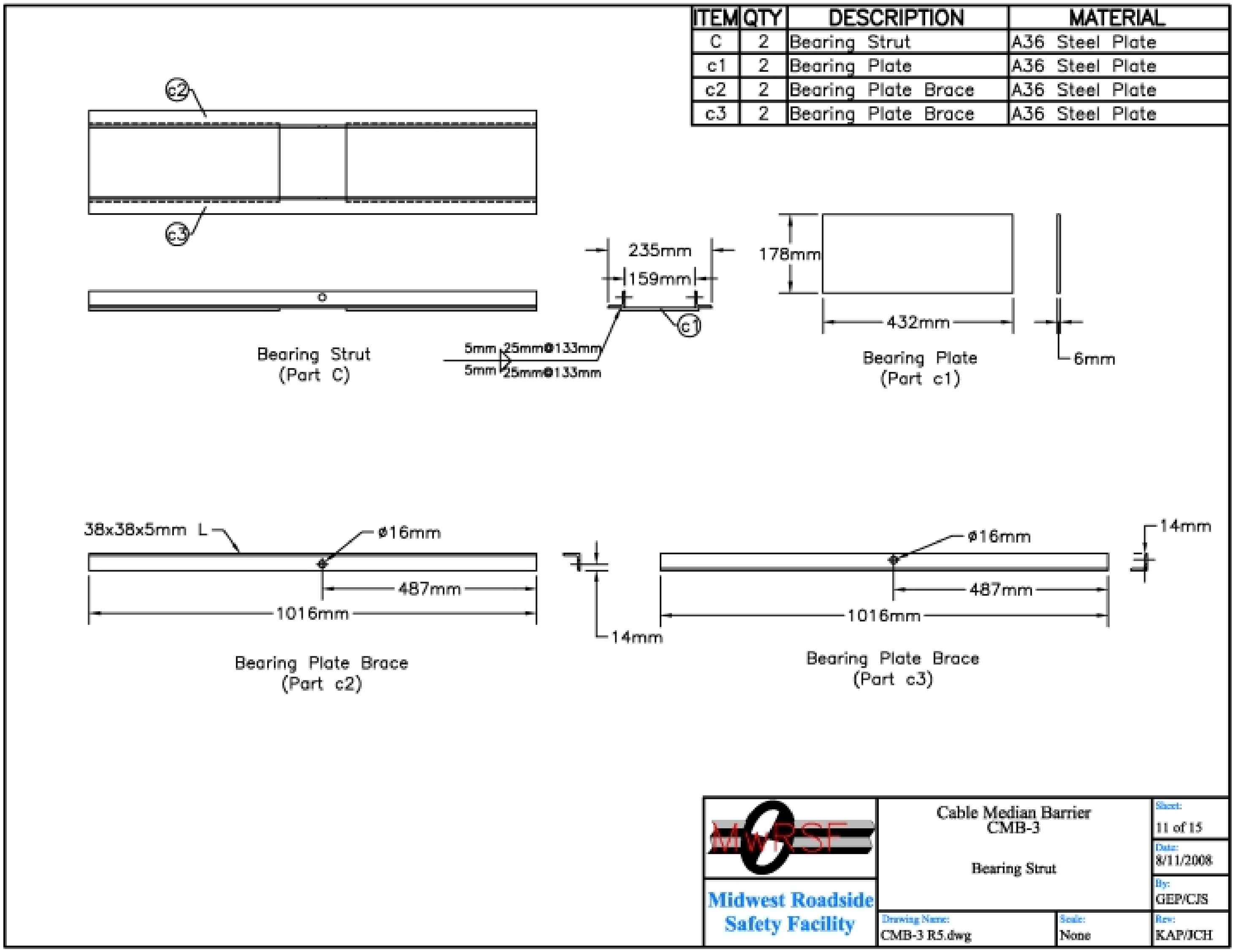


Figure G-11. Bearing Strut (Metric), Design No. 3

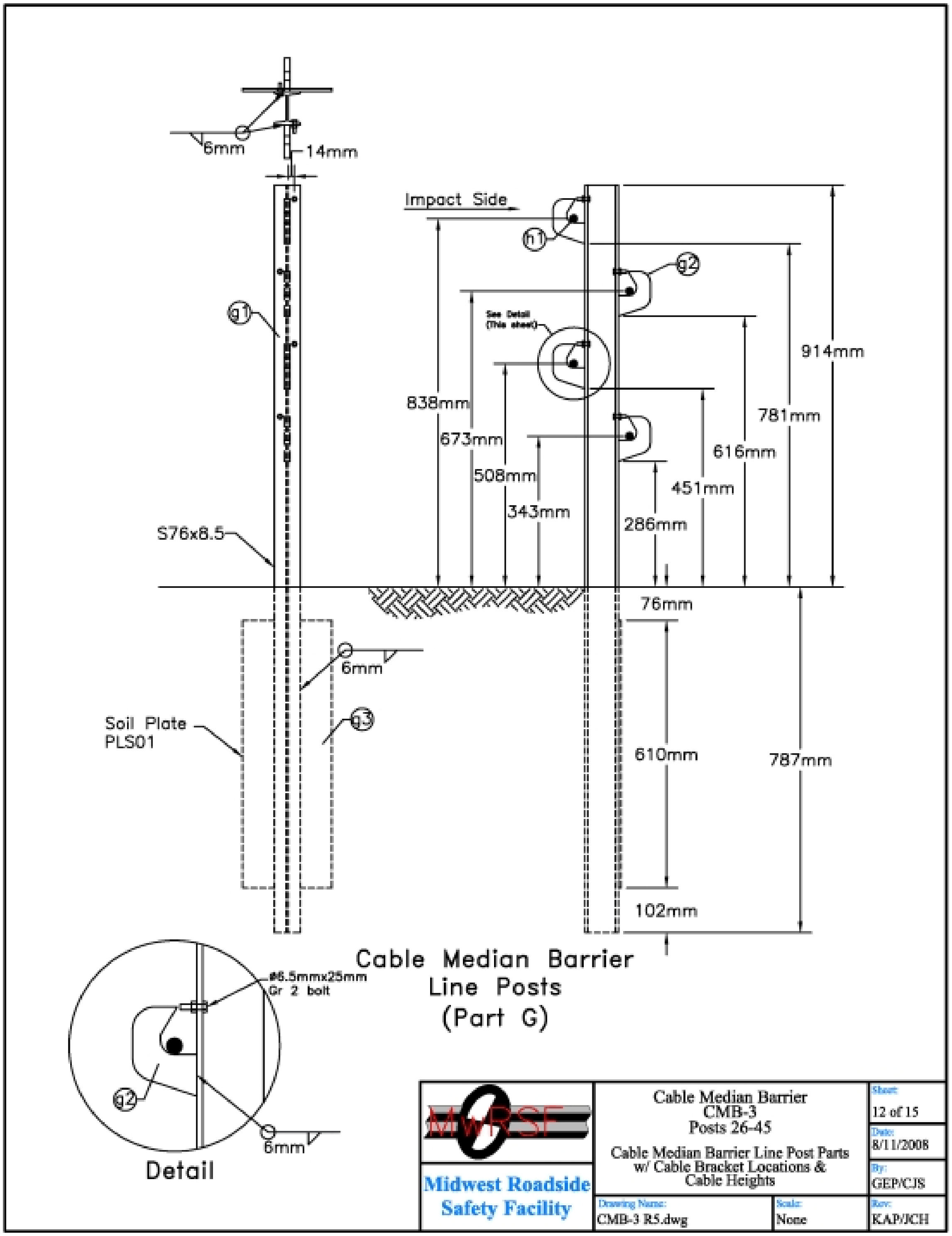


Figure G-12. Line Post Nos. 26 through 45 (Metric), Design No. 3

ITEM	QTY	DESCRIPTION	MATERIAL
g1	15	Line Post	S76x8.5 Steel Section
g2	60	Cable Bracket	A36 13mm Plate
g3	15	Soil Plate	A36 6mm Plate
h1	4	Cable– 147.5m	ø19mm 3x7 Wire rope

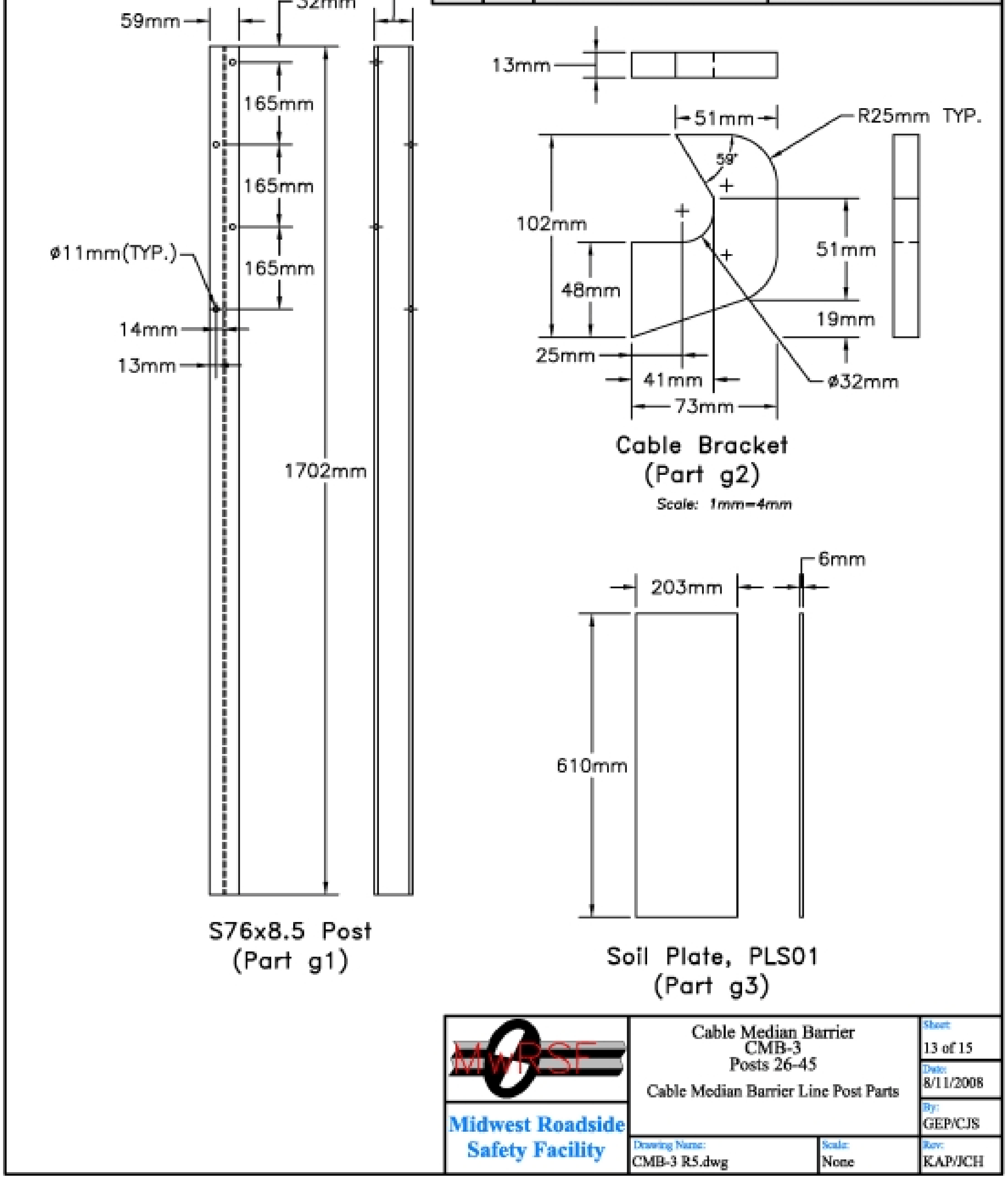


Figure G-13. Line Post Nos. 26 through 45 Parts (Metric), Design No. 3

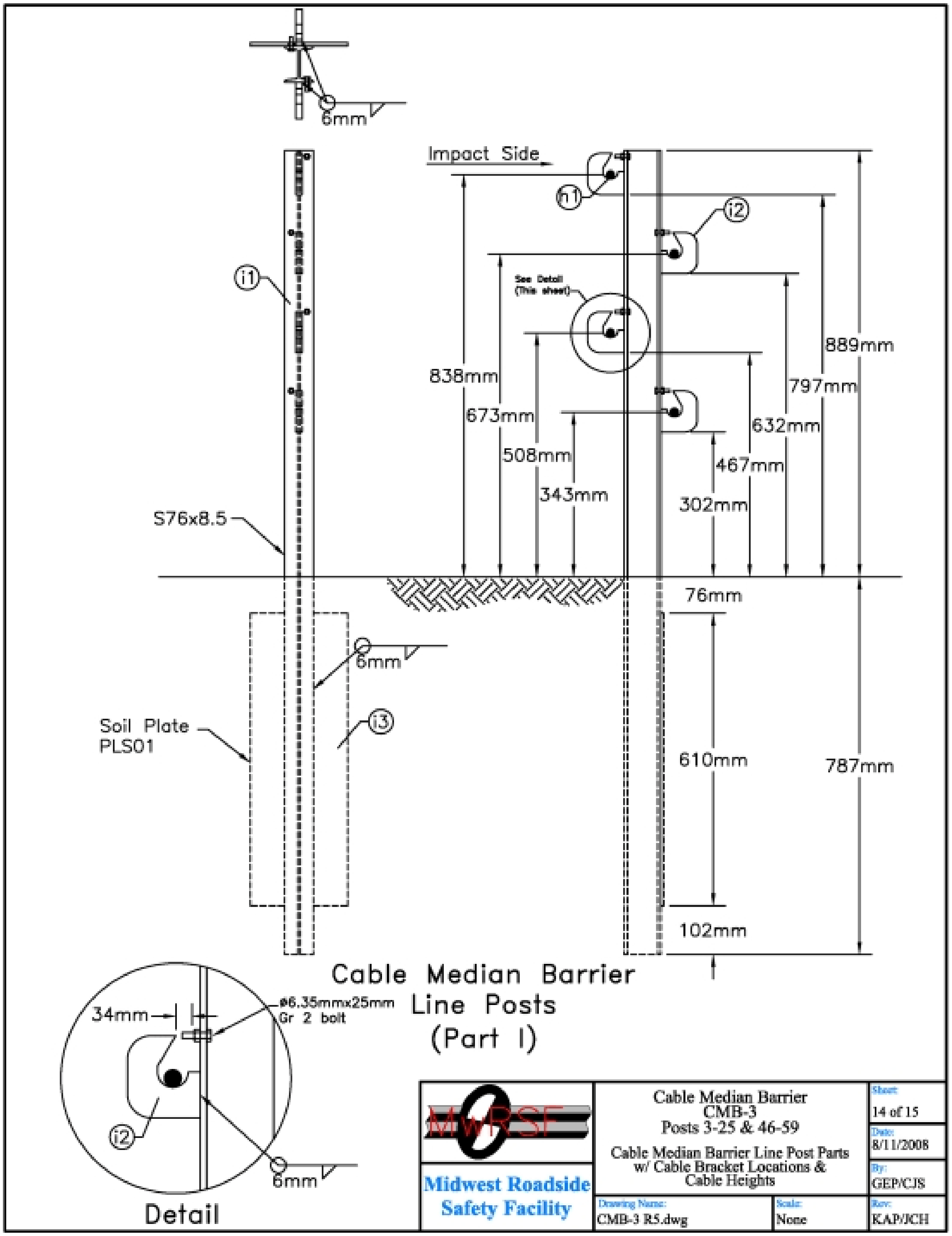


Figure G-14. Line Post Nos. 3 through 25 and 46 through 59 (Metric), Design No. 3

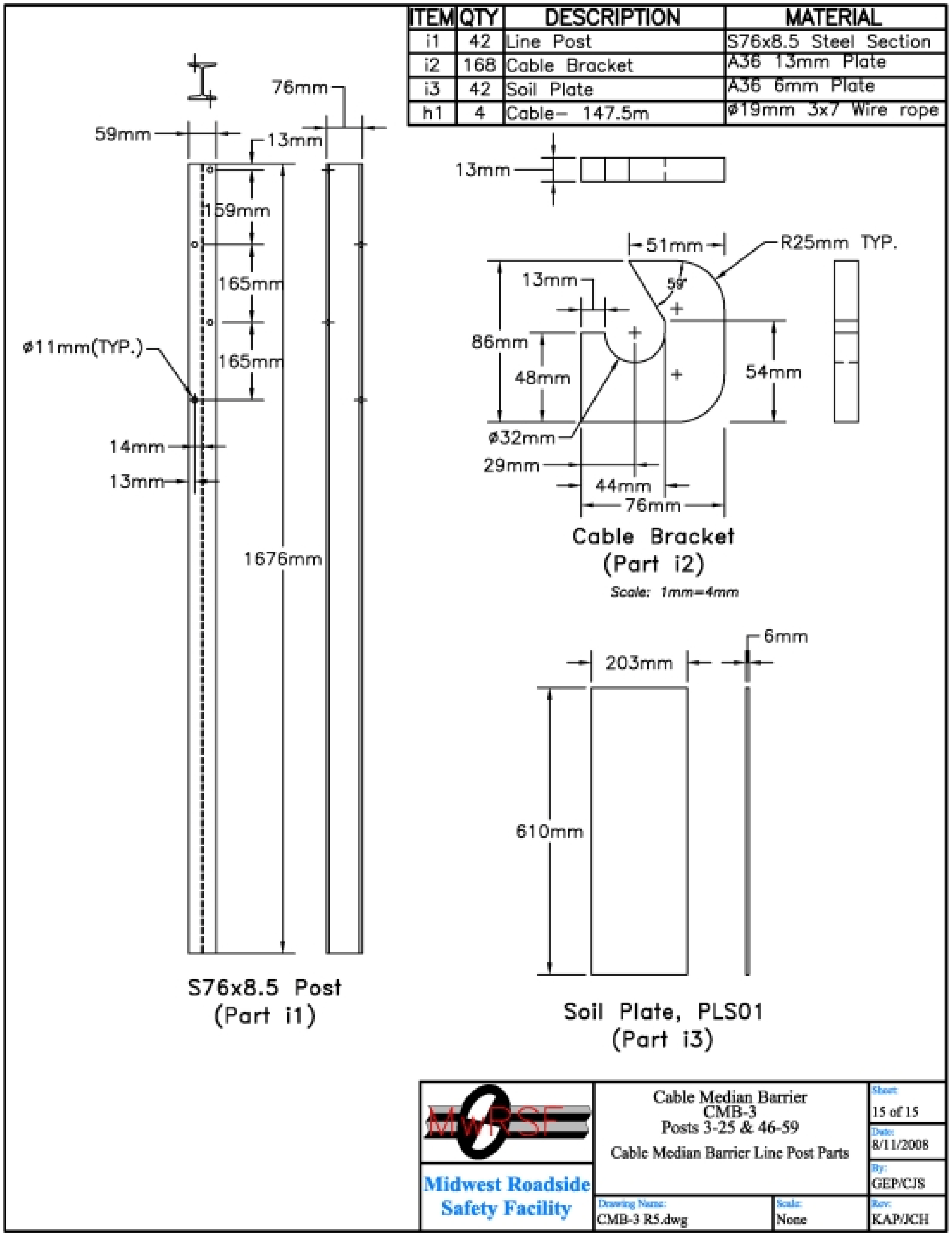


Figure G-15. Line Post Nos. 3 through 25 and 46 through 59 Parts (Metric), Design No. 3

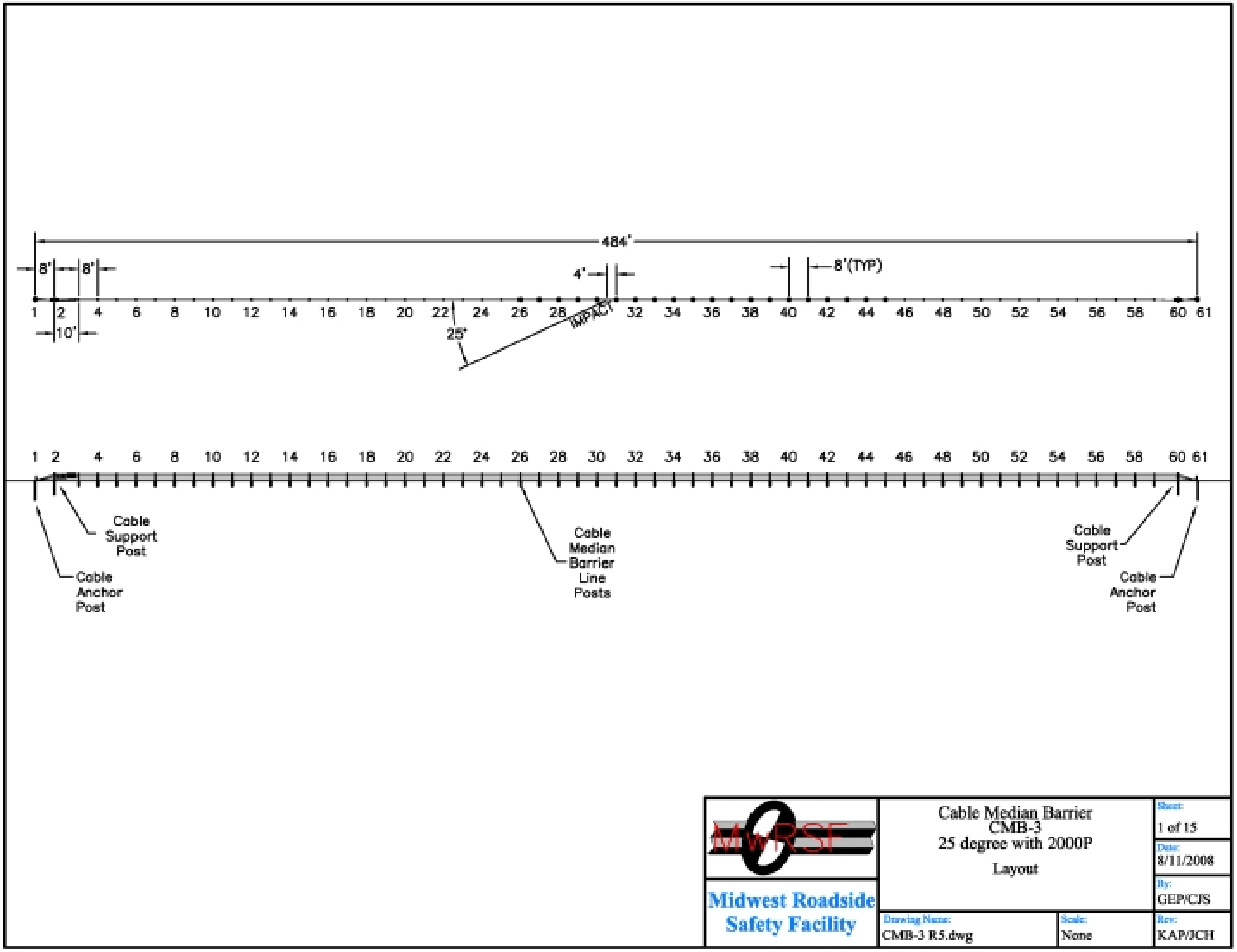


Figure G-16. System Layout (English), Design No. 3

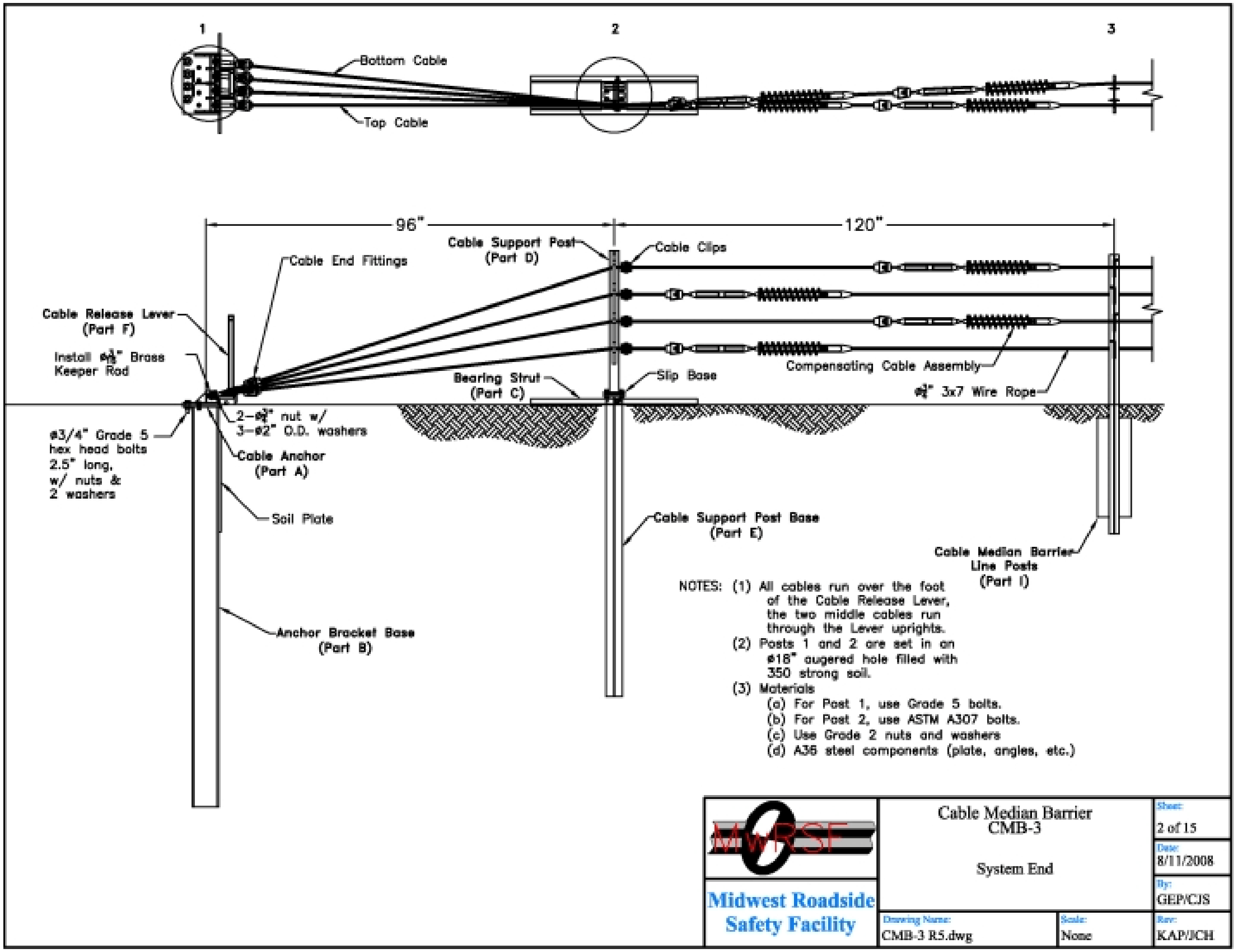


Figure G-17. System End (English), Design No. 3

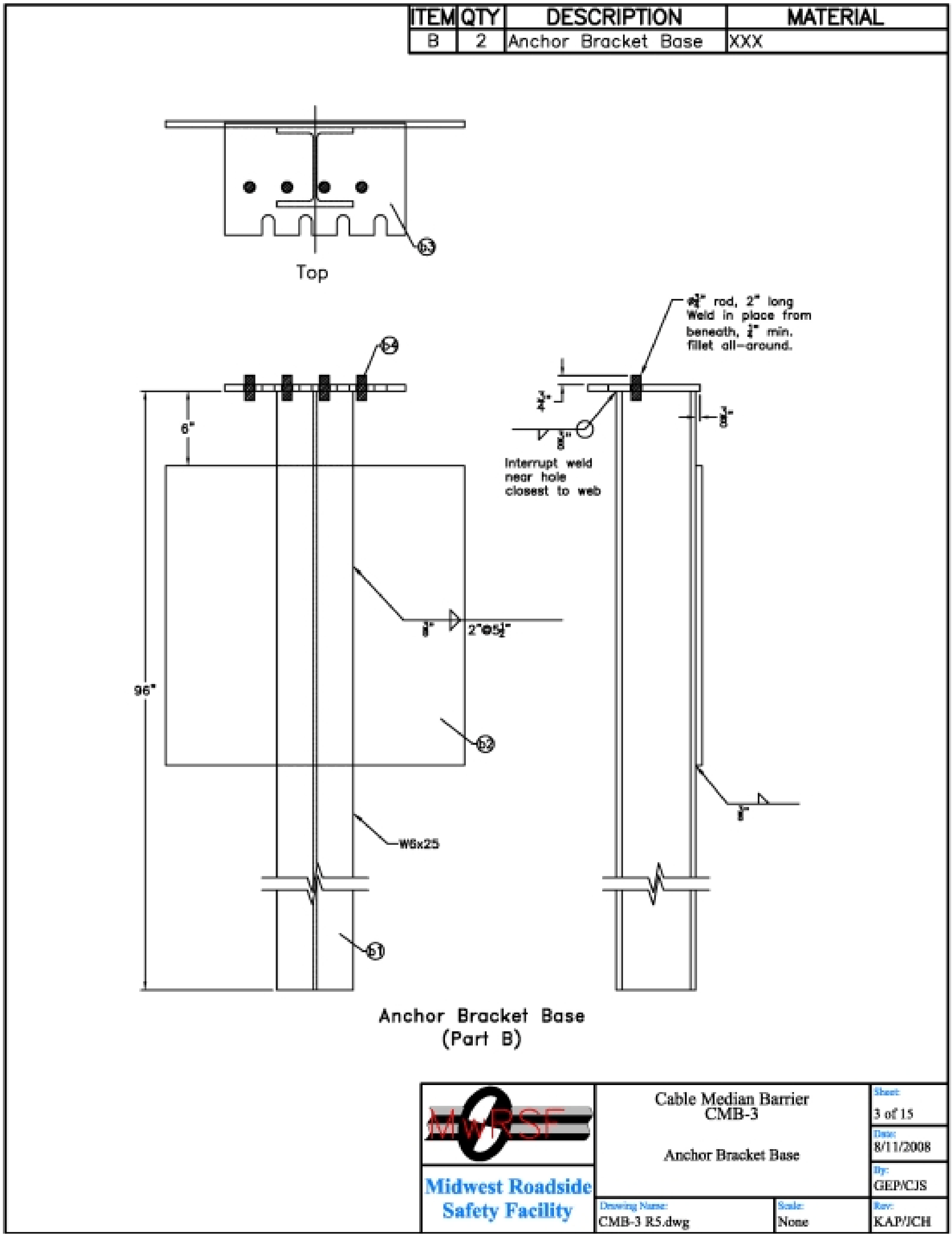


Figure G-18. Anchor Bracket Base (English), Design No. 3

ITEM	QTY	DESCRIPTION	MATERIAL
b1	2	Anchor Base Post	W6x25 Steel Post
b2	2	Soil Plate	24"x24"x1/2" Plate
b3	2	Anchor Base Plate	14 1/2"x9"x1/2" Plate
b4	8	3/4" Dia. Rod	ø3/4" x 2" long rod

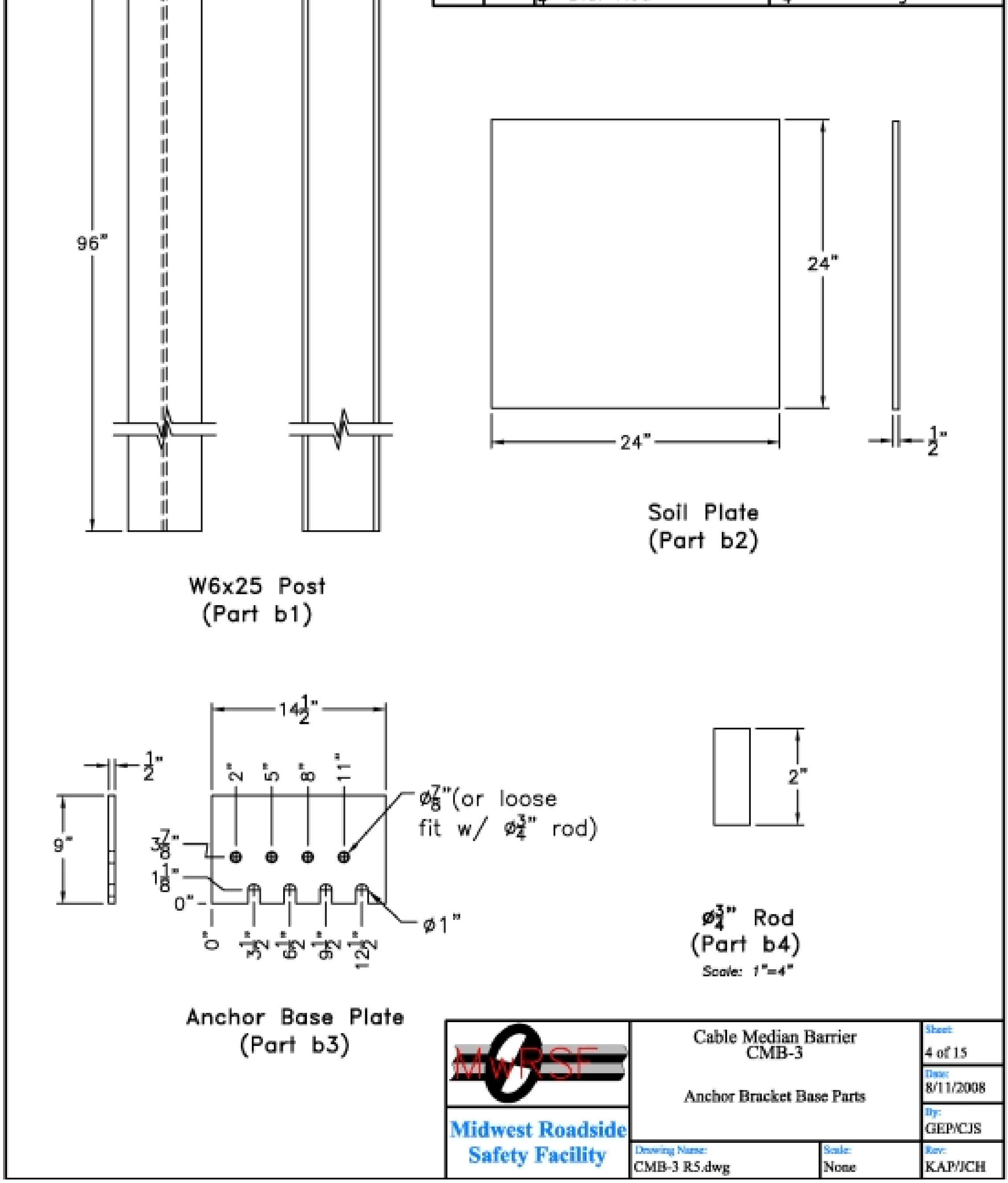


Figure G-19. Anchor Bracket Base Parts (English), Design No. 3

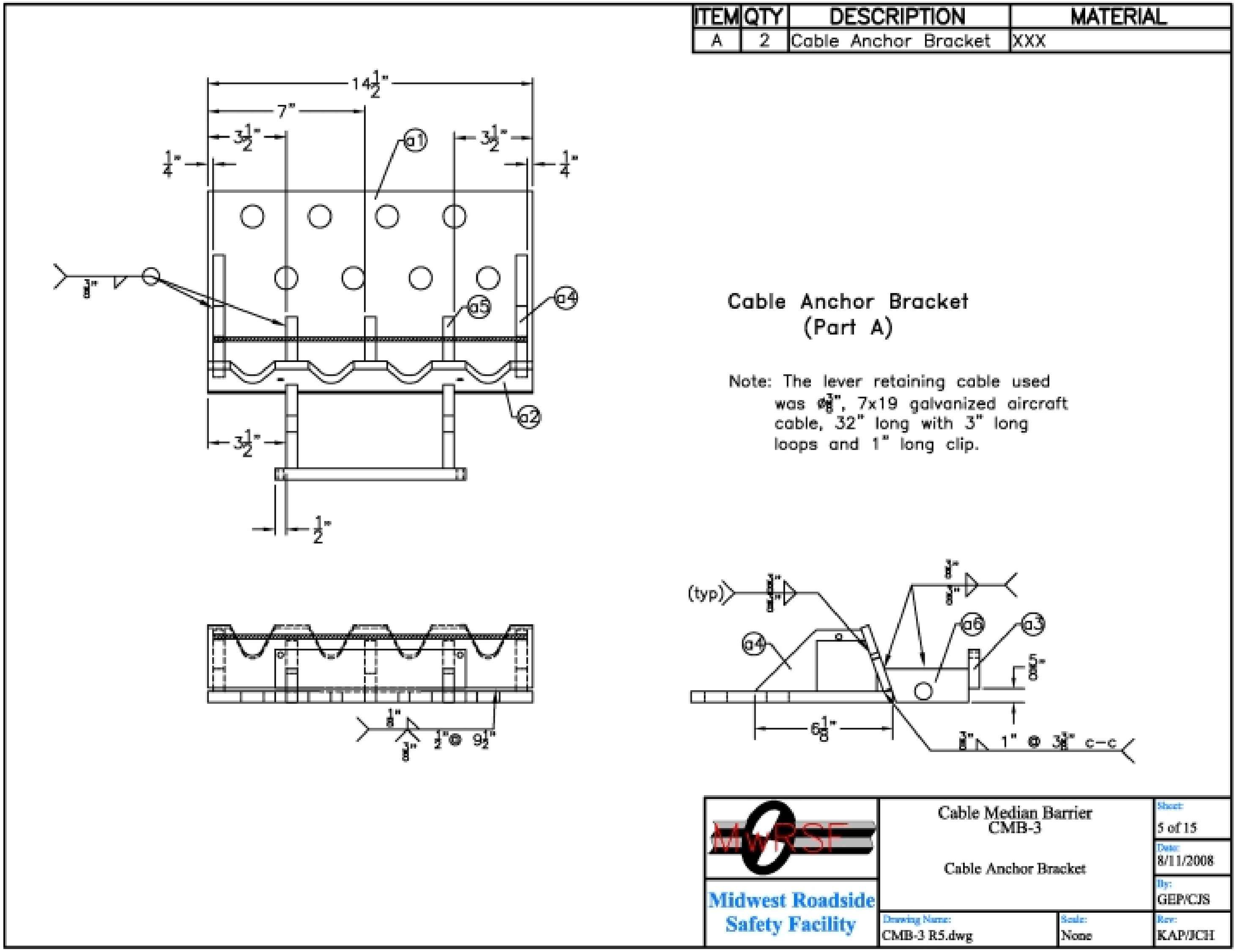


Figure G-20. Cable Anchor Bracket (English), Design No. 3

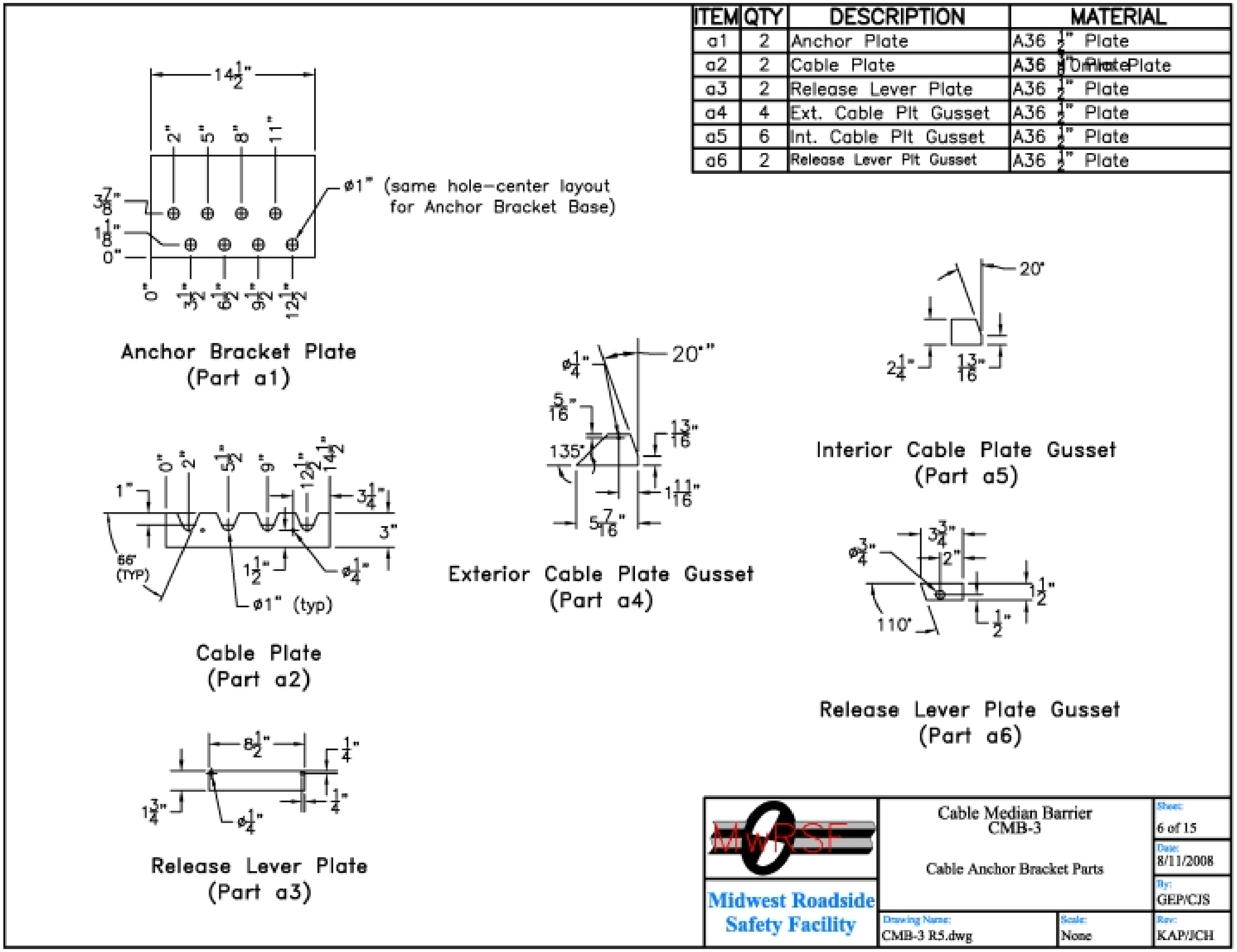
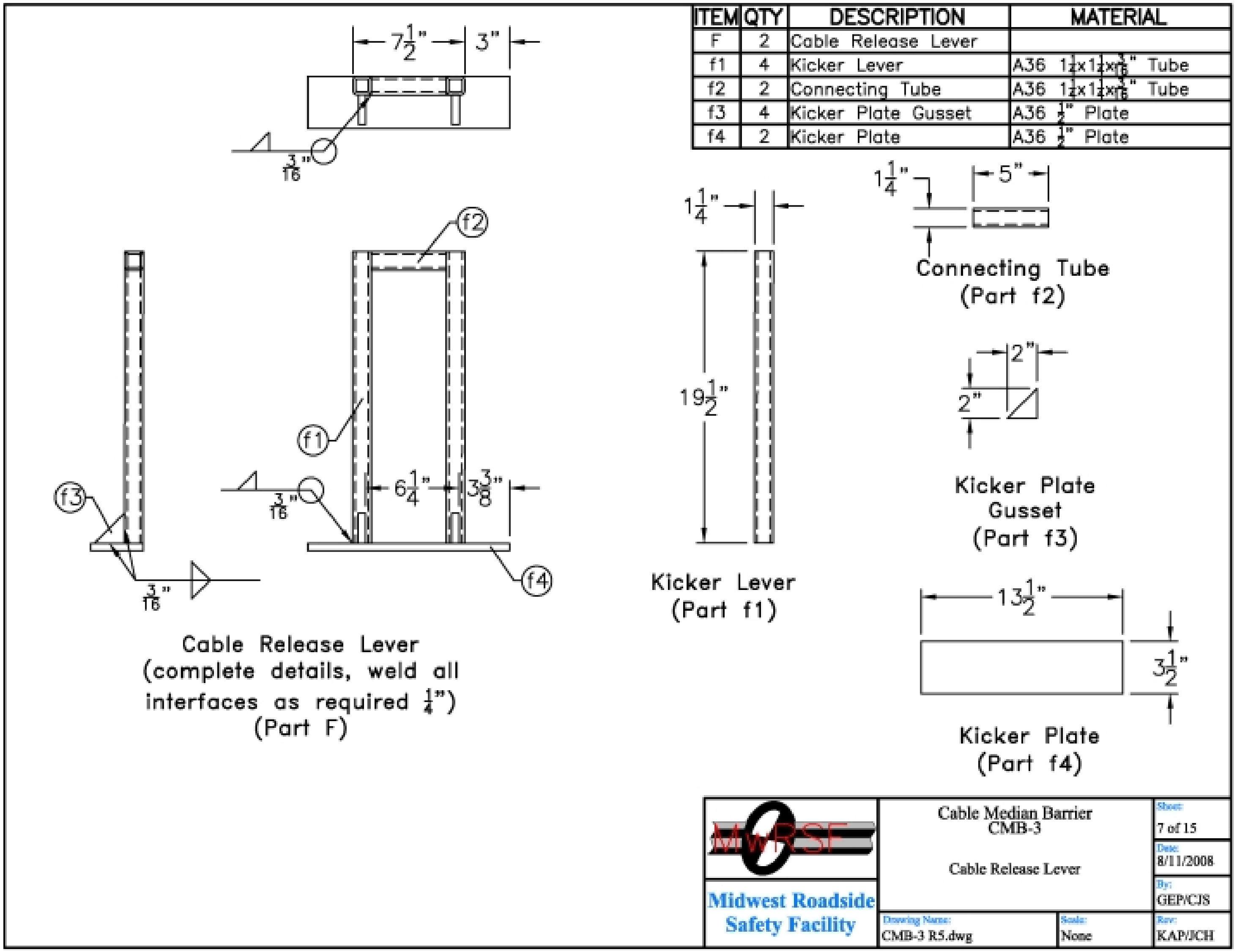


Figure G-21. Cable Anchor Bracket Parts (English), Design No. 3



ITEM	QTY	DESCRIPTION	MATERIAL
F	2	Cable Release Lever	
f1	4	Kicker Lever	A36 1½x1½x3/16" Tube
f2	2	Connecting Tube	A36 1½x1½x3/16" Tube
f3	4	Kicker Plate Gusset	A36 1/2" Plate
f4	2	Kicker Plate	A36 1/2" Plate

Figure G-22. Cable Release Lever (English), Design No. 3

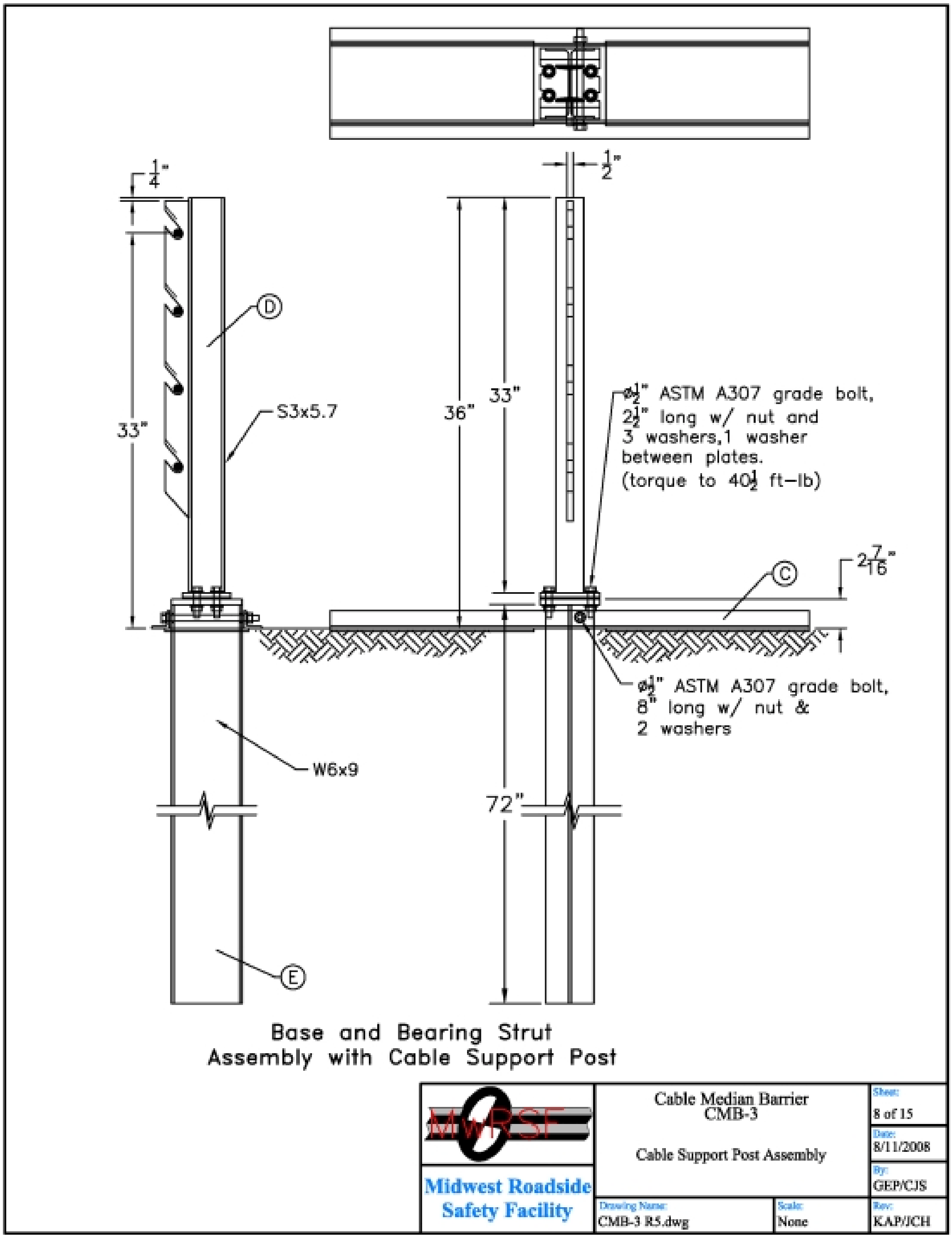


Figure G-23. Cable Support Post Assembly (English), Design No. 3

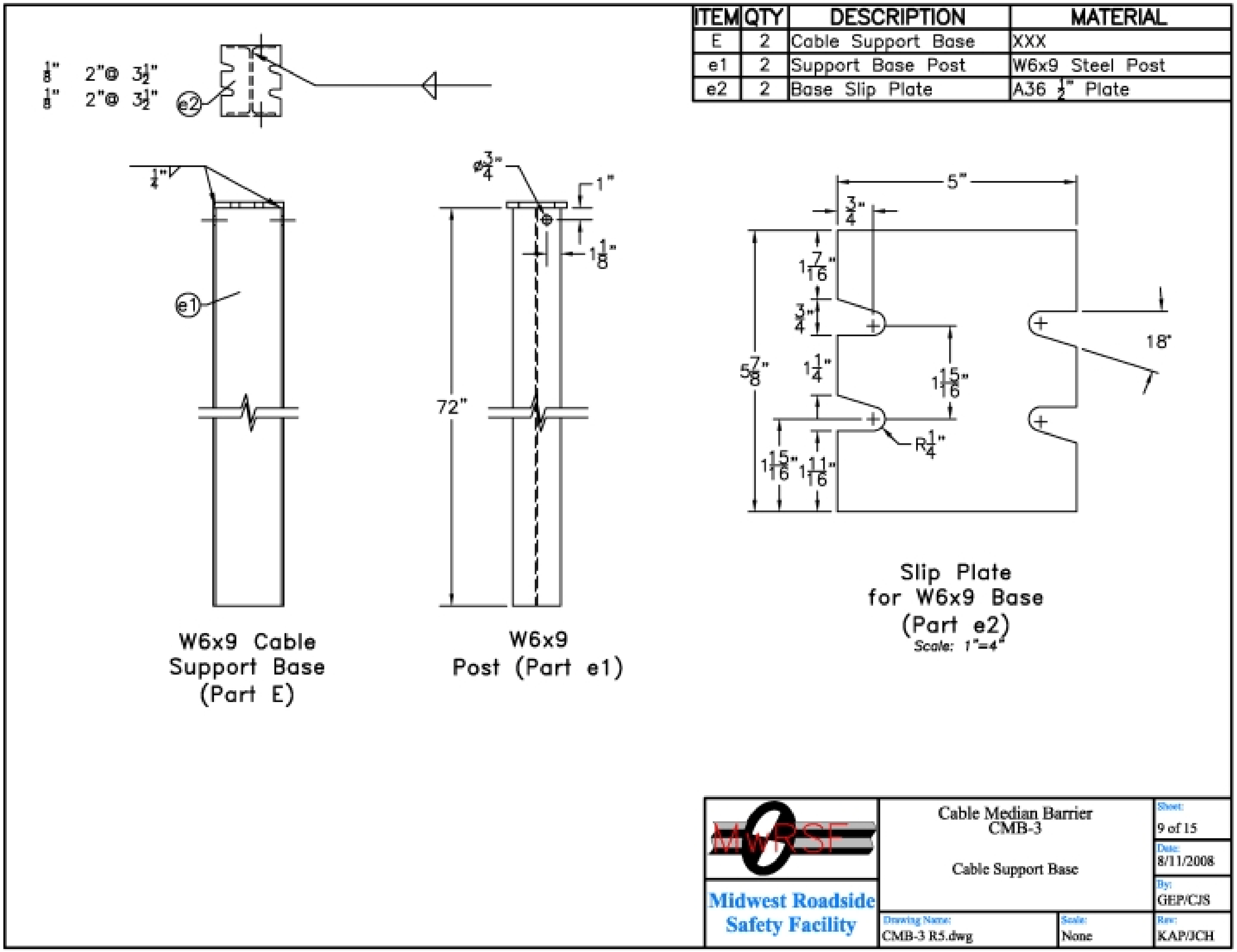


Figure G-24. Cable Support Base (English), Design No. 3

ITEM	QTY	DESCRIPTION	MATERIAL
D	2	Cable Support Post	XXX
d1	2	Support Base Post	W6x9 Steel Post
d2	2	Cable Bracket	A36 1/2" Plate
d3	2	Slip Plate	A36 3/8" Plate

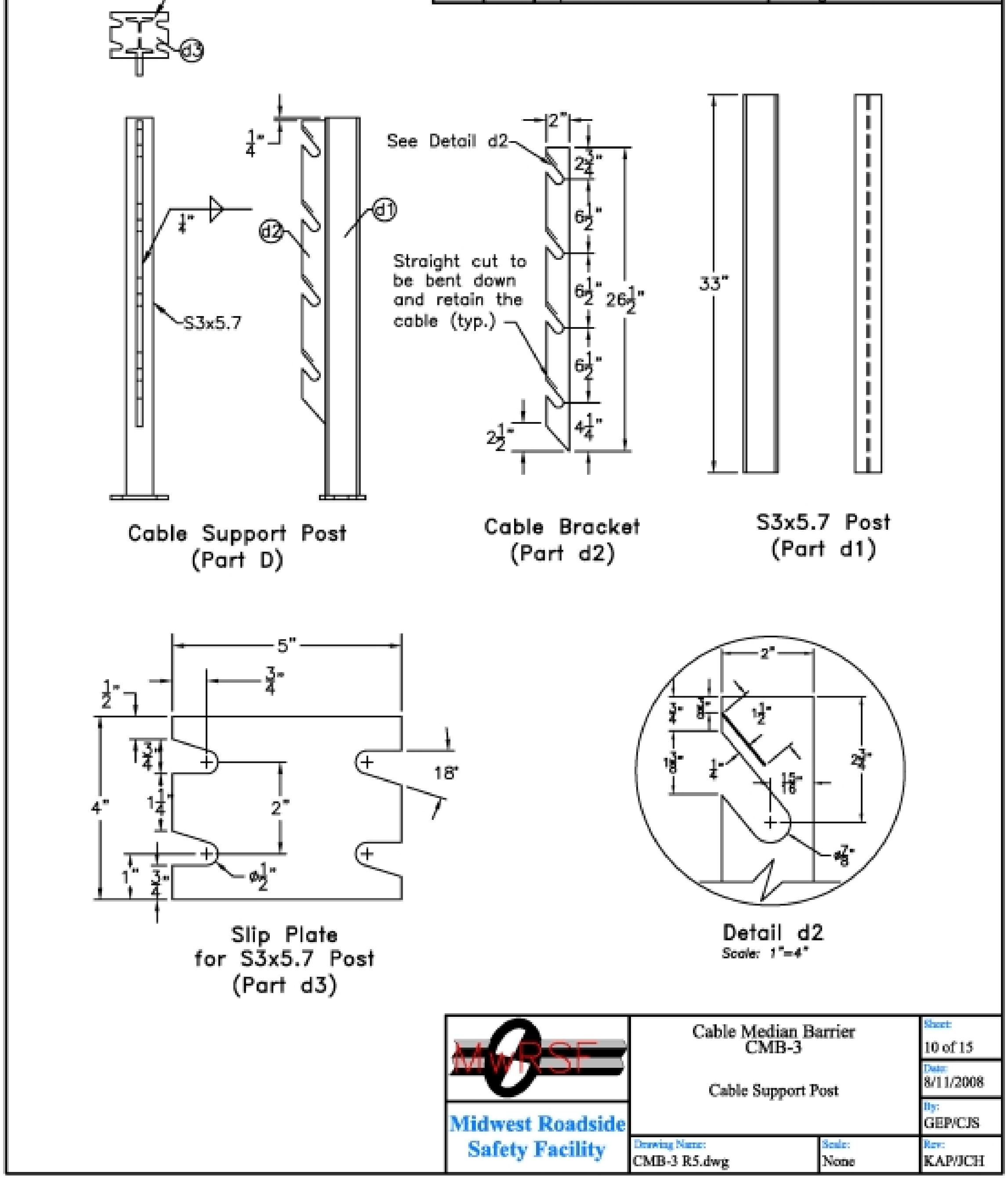
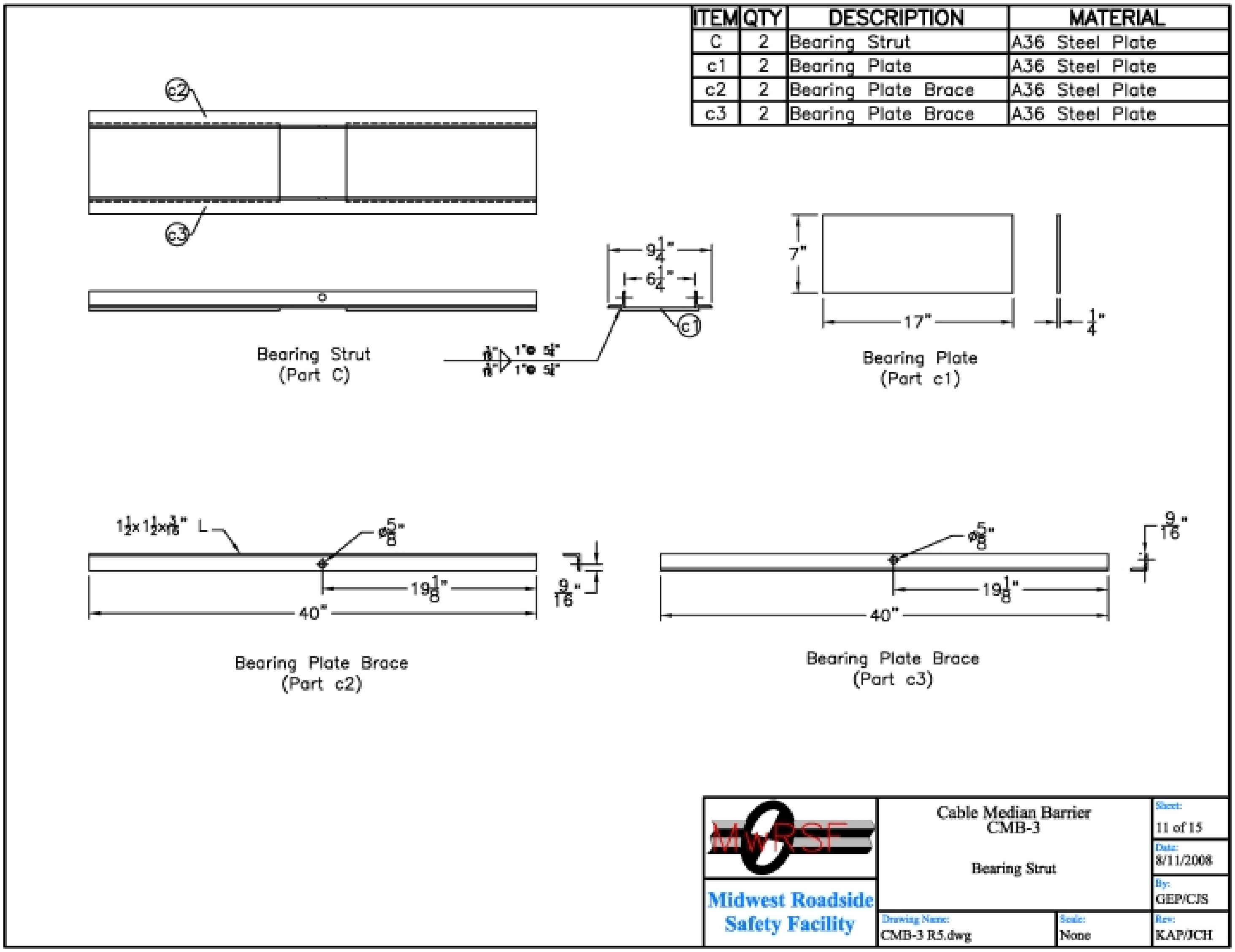


Figure G-25. Cable Support Post (English), Design No. 3



ITEM	QTY	DESCRIPTION	MATERIAL
C	2	Bearing Strut	A36 Steel Plate
c1	2	Bearing Plate	A36 Steel Plate
c2	2	Bearing Plate Brace	A36 Steel Plate
c3	2	Bearing Plate Brace	A36 Steel Plate

Figure G-26. Bearing Strut (English), Design No. 3

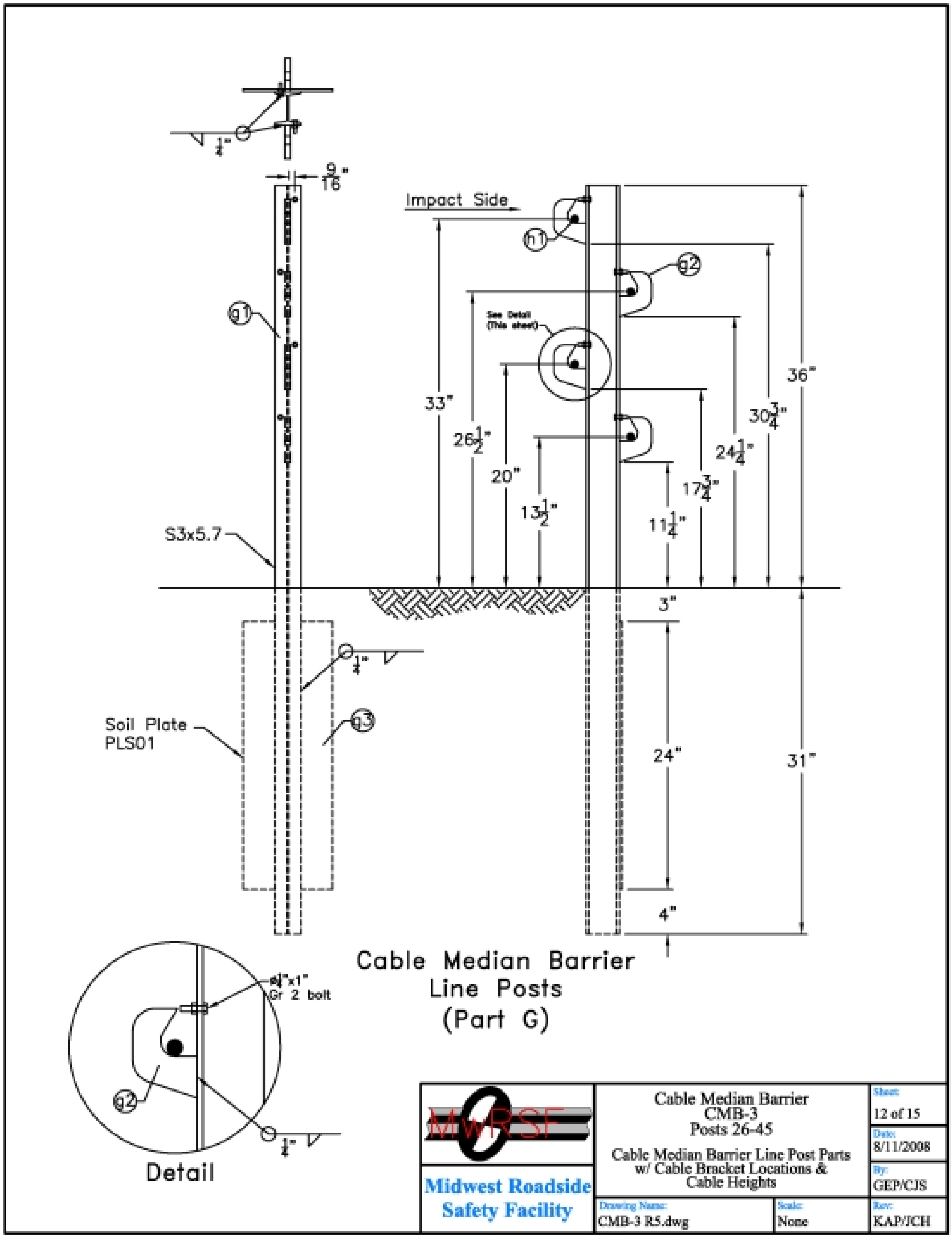


Figure G-27. Line Post Nos. 26-45 (English), Design No. 3

ITEM	QTY	DESCRIPTION	MATERIAL
g1	15	Line Post	S3x5.7 Steel Section
g2	60	Cable Bracket	A36 1/2" Plate
g3	15	Soil Plate	A36 1/4" Plate
h1	4	Cable– 484ft.	ø3/4" 3x7 Wire rope

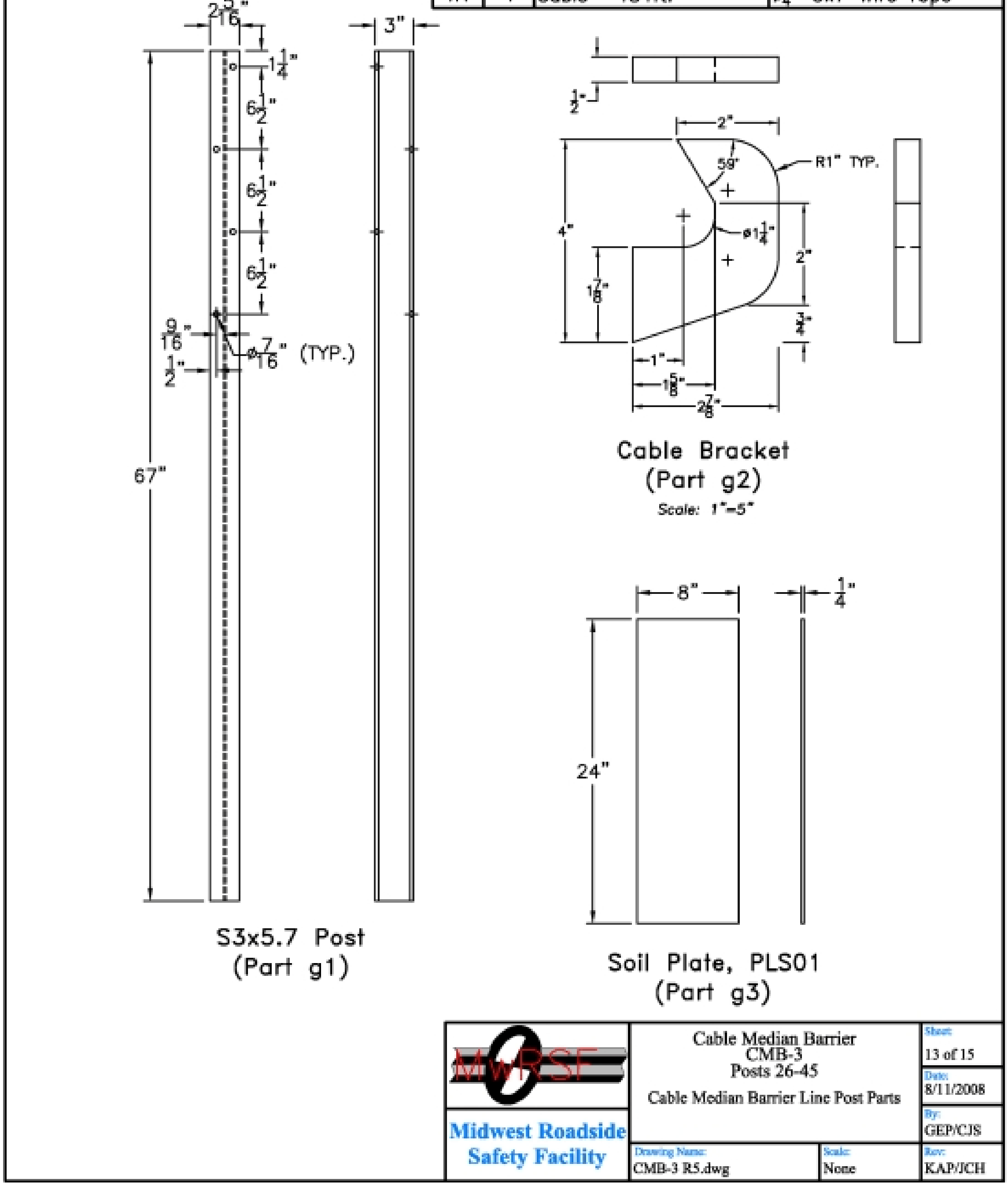


Figure G-28. Line Post Nos. 26-45 Parts (English), Design No. 3

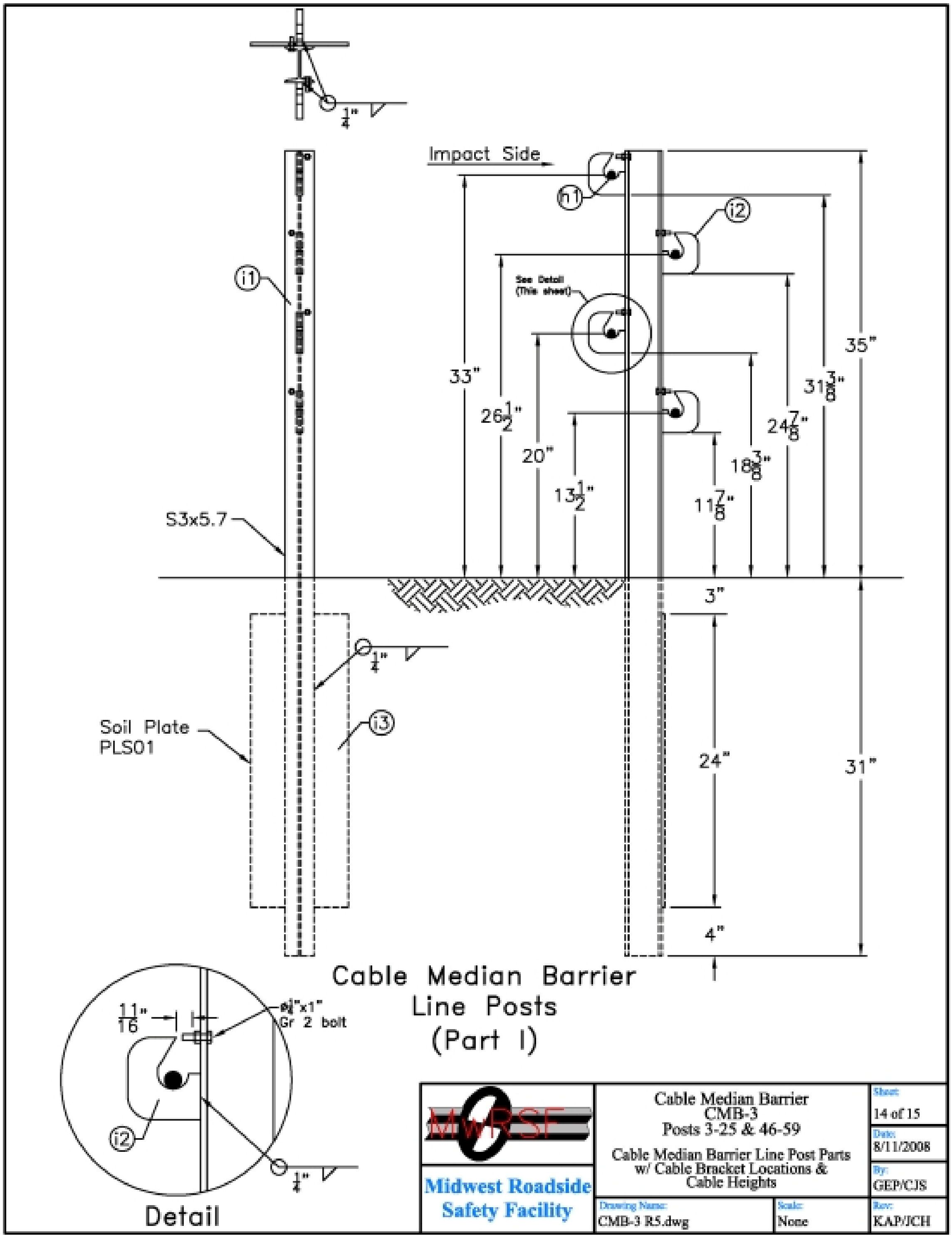


Figure G-29. Line Post Nos. 3 through 25 and 46 through 59 (English), Design No. 3

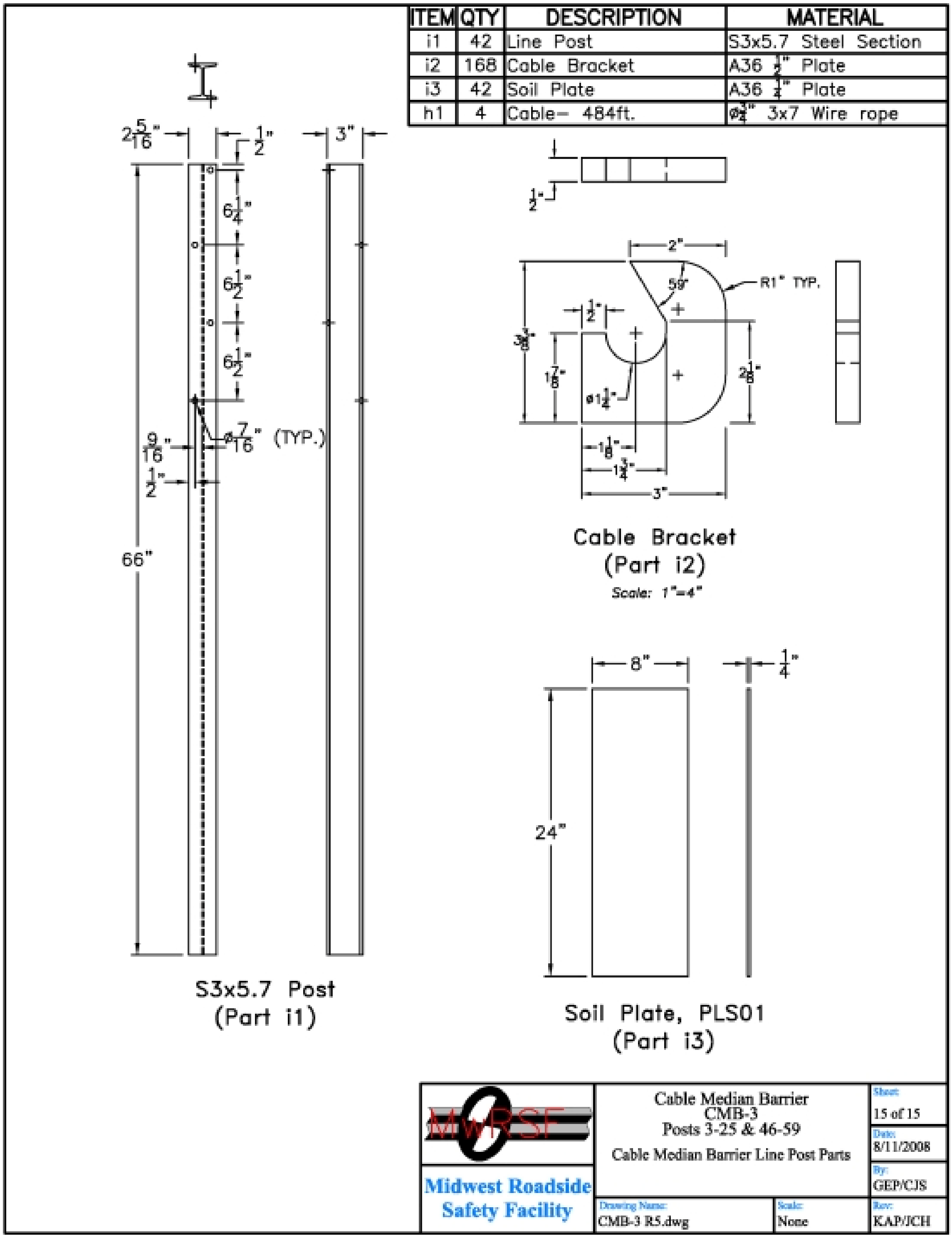


Figure G-30. Line Post Nos. 3 through 25 and 46 through 59 Parts (English), Design No. 3

APPENDIX H

Accelerometer and Rate Transfer Data Analysis, Test CMB-3

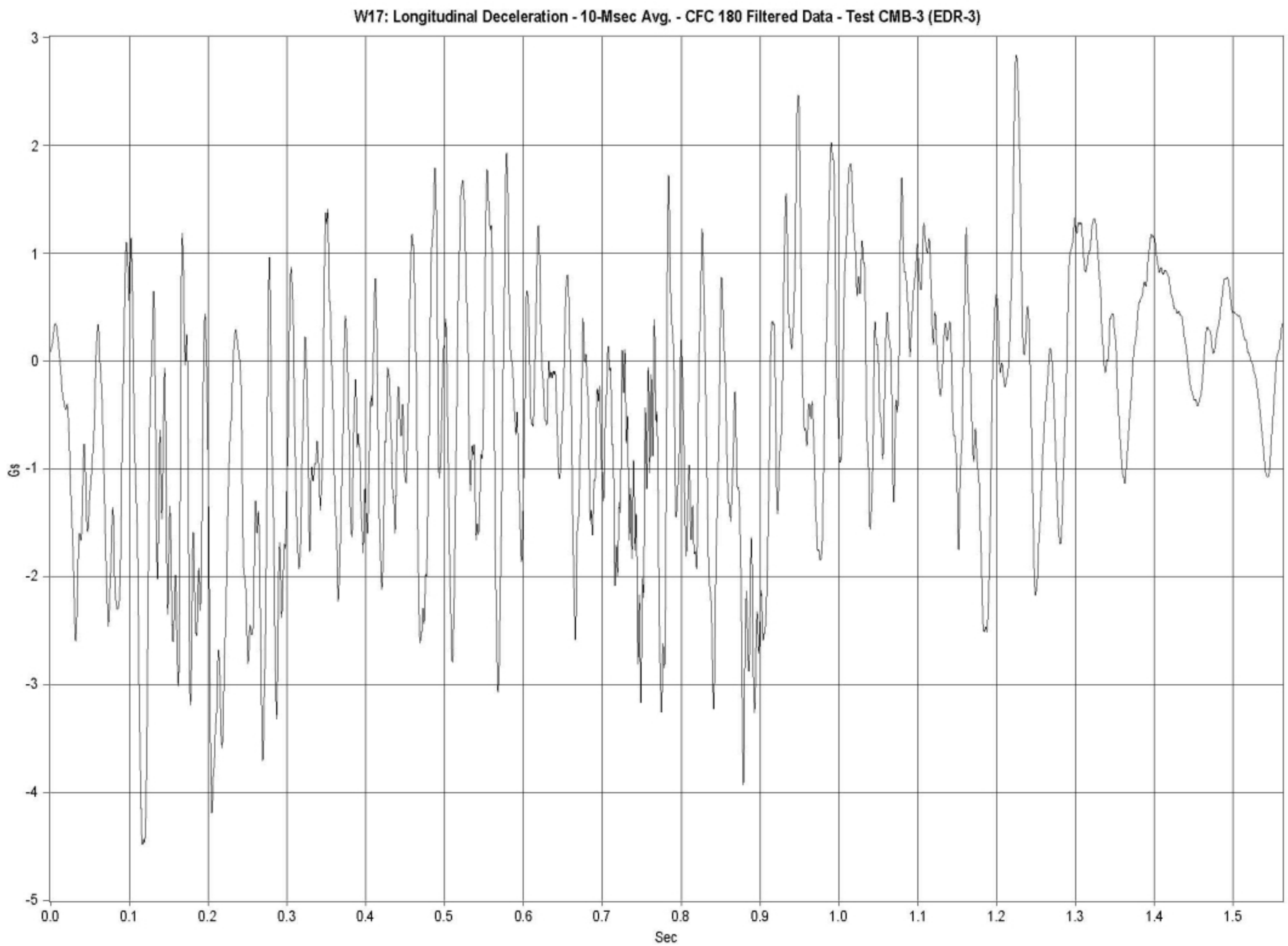


Figure H-1. Graph of Longitudinal Deceleration, Test CMB-3

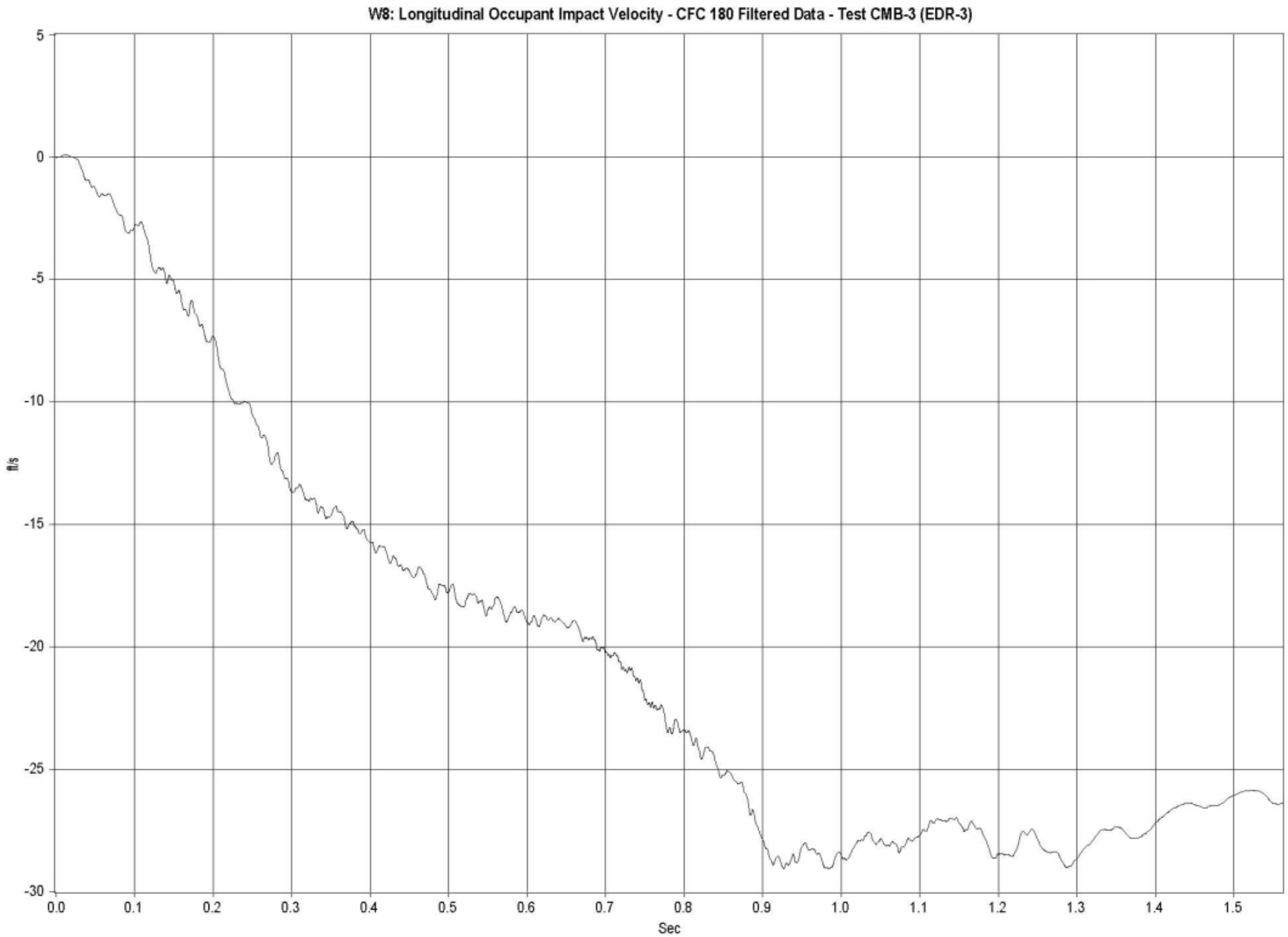


Figure H-2. Graph of Longitudinal Occupant Impact Velocity, Test CMB-3

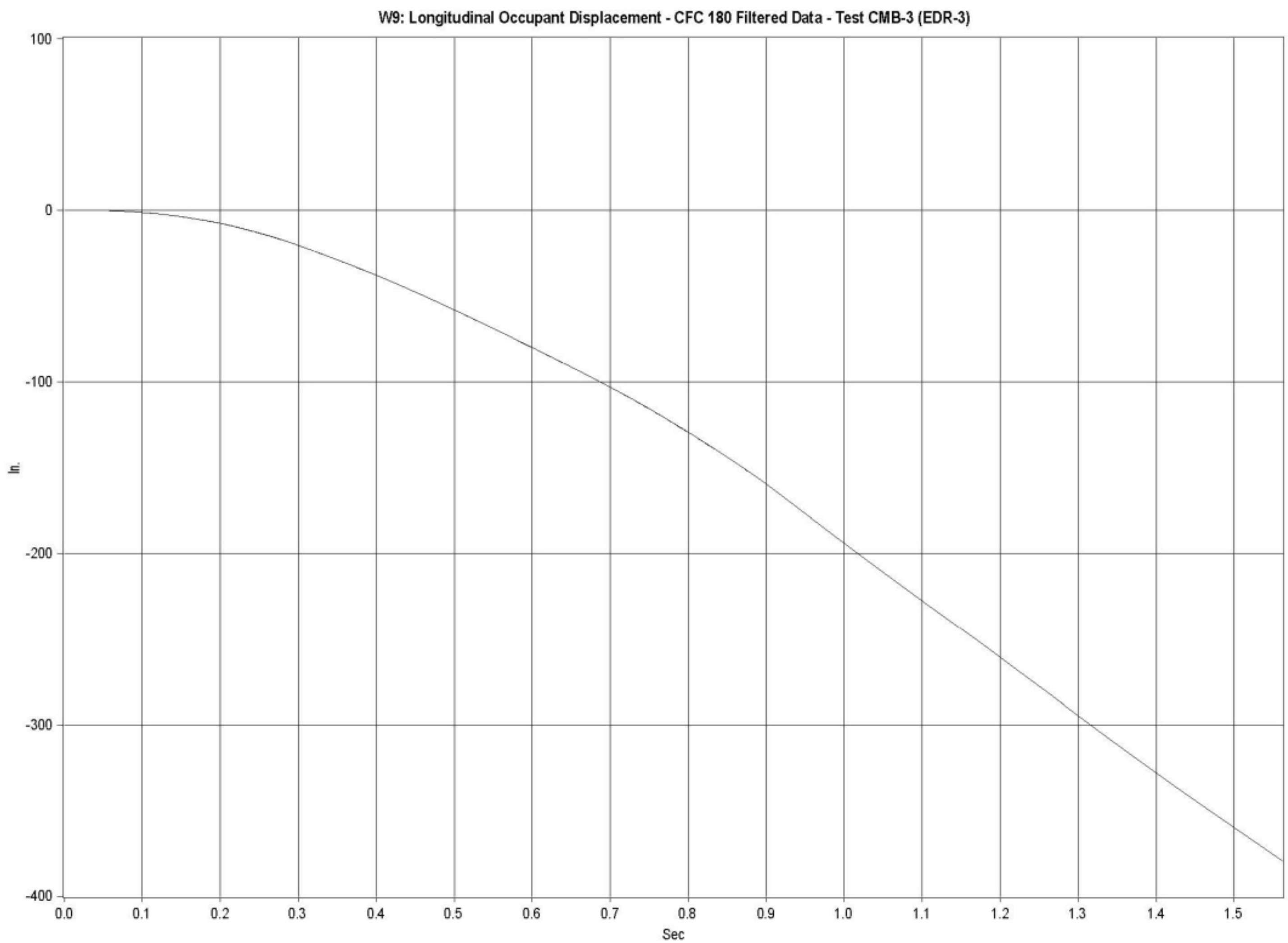


Figure H-3. Graph of Longitudinal Occupant Displacement, Test CMB-3

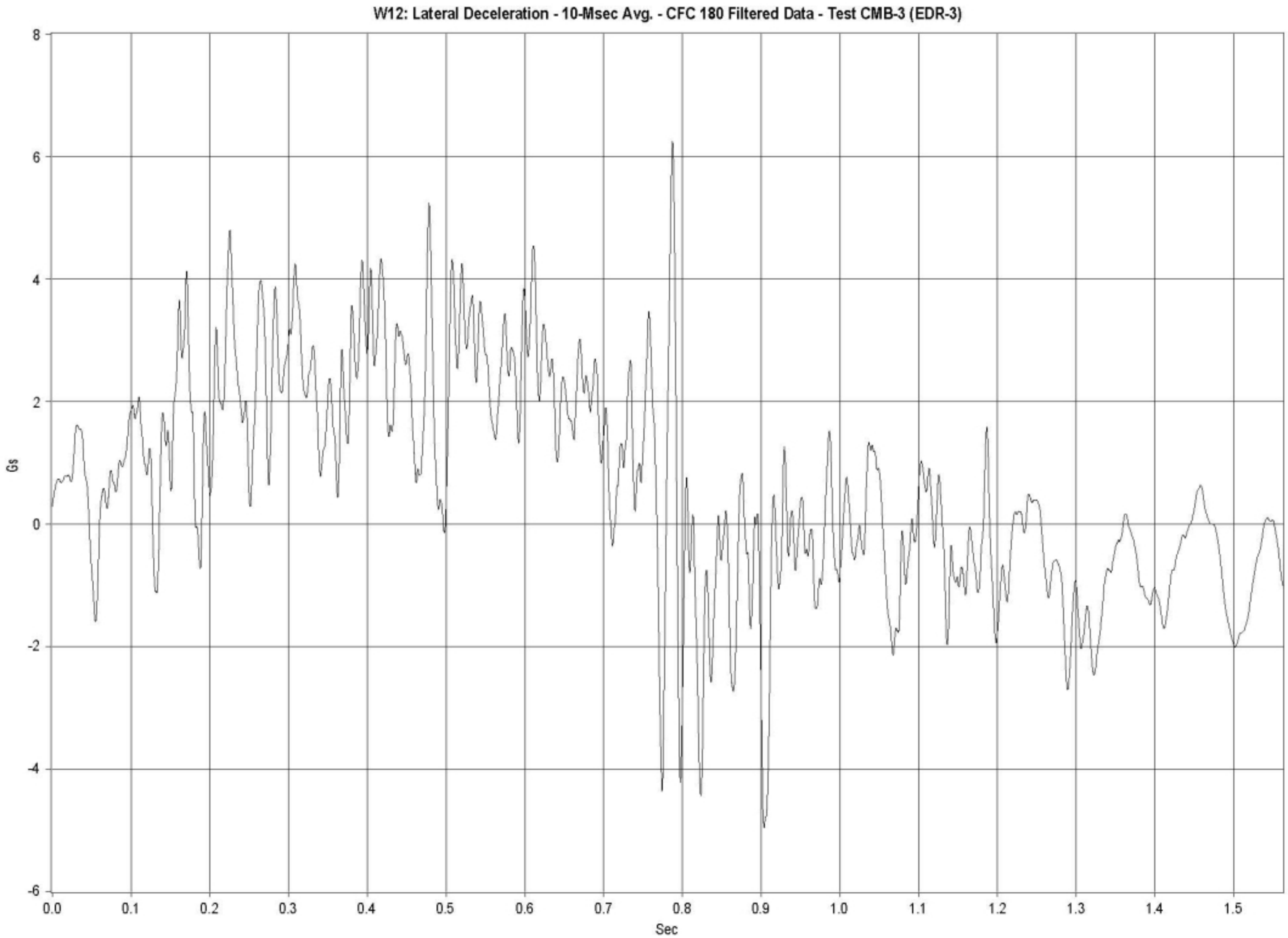


Figure H-4. Graph of Lateral Deceleration, Test CMB-3

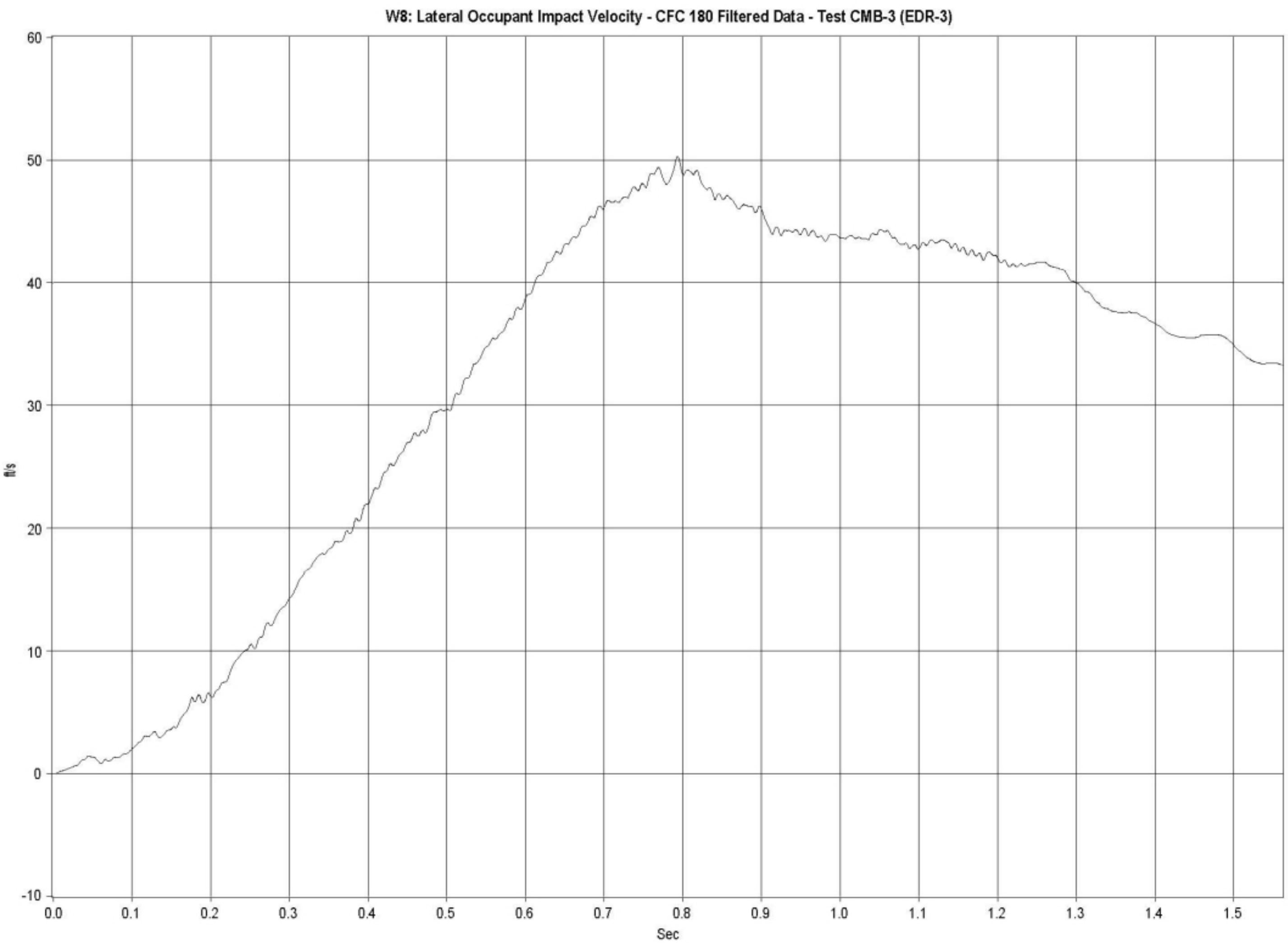


Figure H-5. Graph of Lateral Occupant Impact Velocity, Test CMB-3

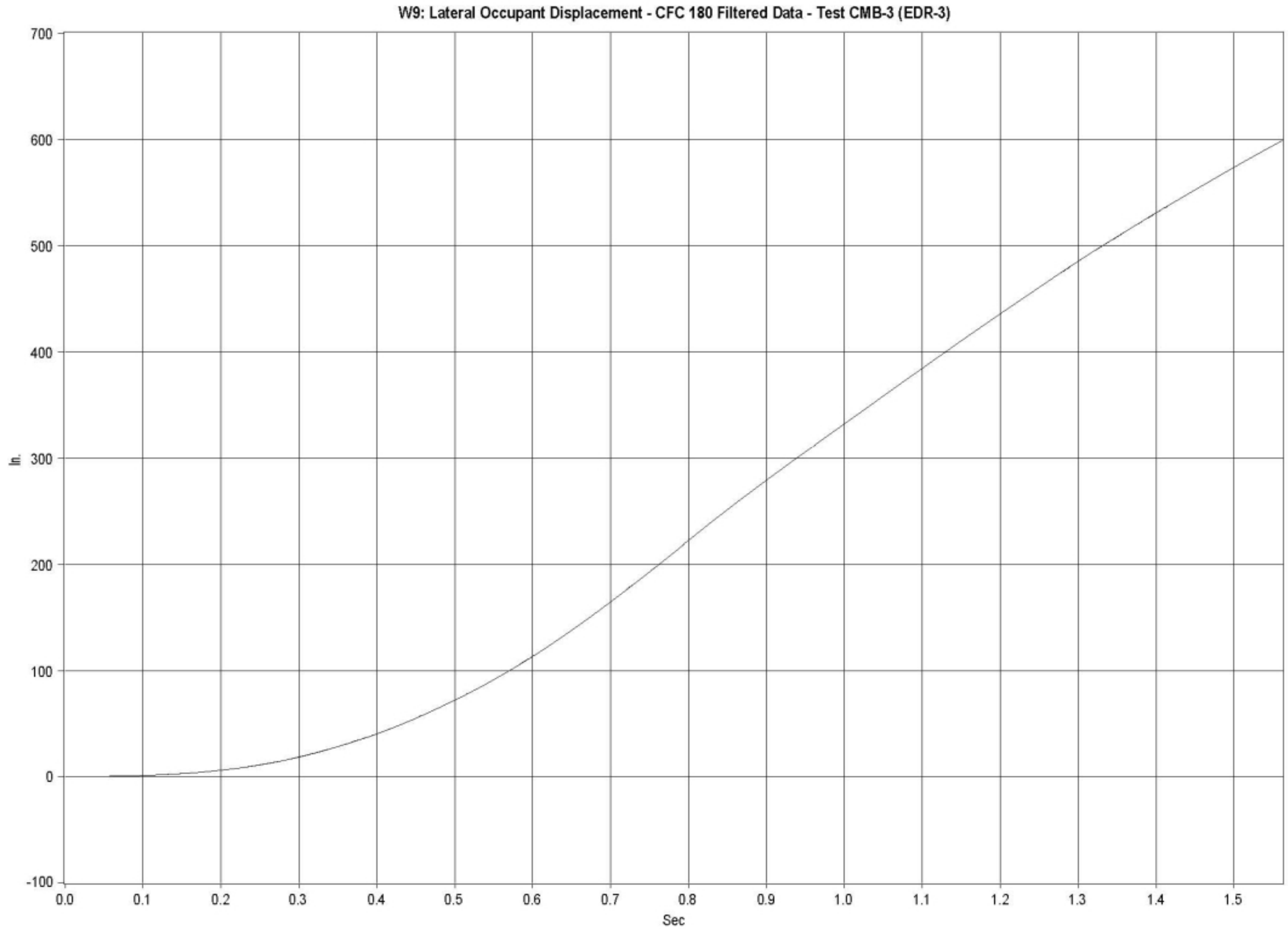


Figure H-6. Graph of Lateral Occupant Displacement, Test CMB-3

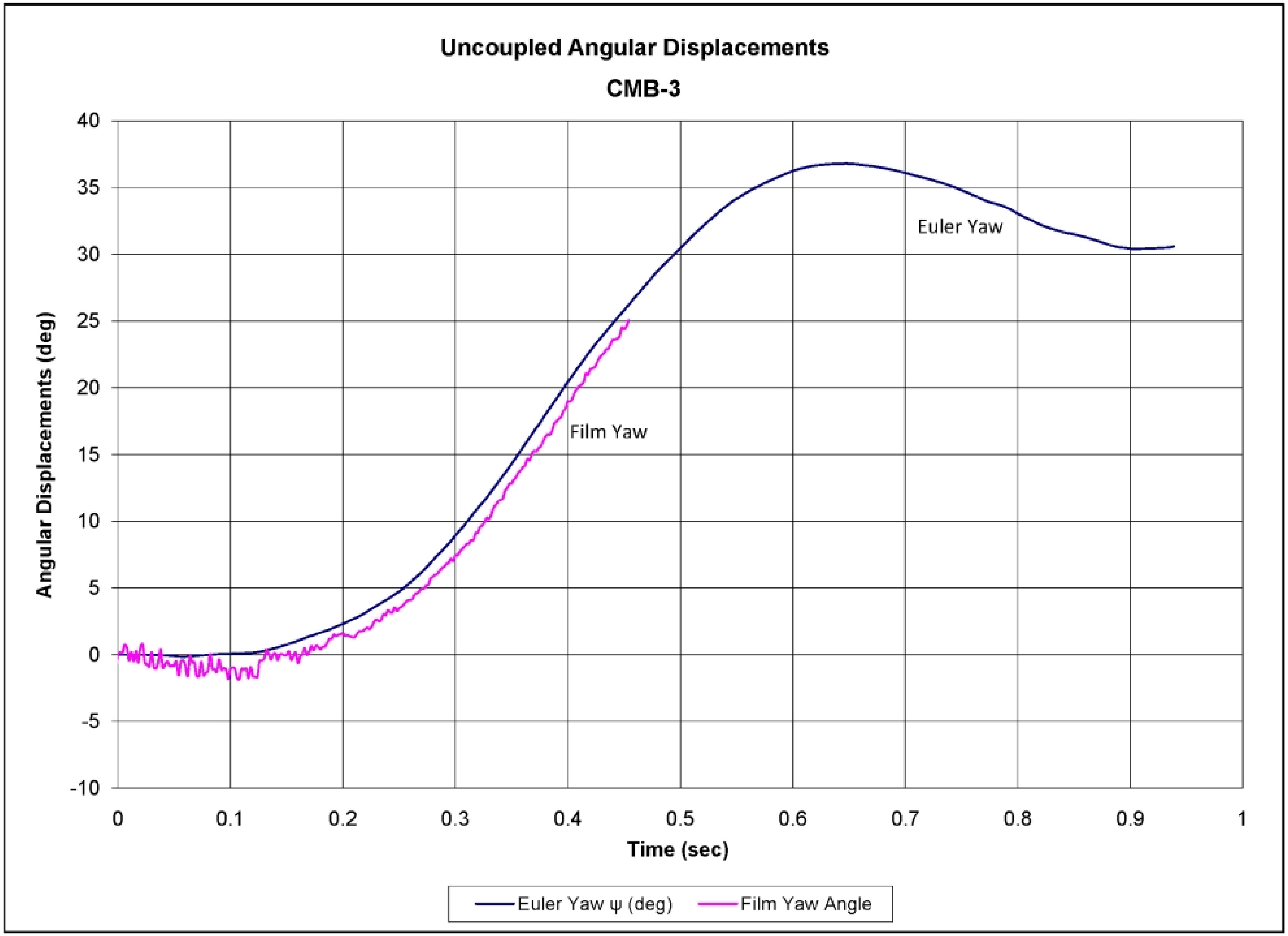


Figure H-7. Graph of Yaw Angular Displacements, Test CMB-3