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DESIGN AND EVALUATION OF A LOW-TENSION CABLE GUARDRAIL END TERMINAL SYSTEM

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16. Abstract (Limit: 200 words)

Cable guardrail systems are utilized due to the ease of construction, low vehicle damage, low occupant risk, and low initial installation cost. However, a cable guardrail system must be terminated in an acceptable manner that does not pose a significant risk to errant motorists. A cable guardrail system, developed by the New York State Department of Transportation (NYDOT), was successfully crash tested to the recommendations provided in National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Roadside Features*, but the terminal incorporated a large cable anchor system and a flared end that limited the use of the cable guardrail system adjacent to slopes. In order to reduce the size of the cable anchorage system and increase the versatility of a low-tension cable guardrail system, a tangent cable terminal, similar to the design developed by the NYDOT, was developed and full-scale vehicle crash tested for use with low-tension, three cable guardrail systems.

Four full-scale crash tests were performed on the cable terminal system. The first test utilized a 2,000-kg (4,409-lb) pickup truck, impacting the cable terminal system at 20 degrees. The other three impacts utilized an 820-kg (1,808-lb) small car, impacting the tangent cable terminal head-on and at a 1/4 point offset. It was determined that the cable terminal system was acceptable according to the criteria provided in NCHRP Report No. 350 for the tests performed and discussed herein.

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.

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1 INTRODUCTION

1.1 Background and Problem Statement

The low-tension, three cable barrier is a versatile and economical guardrail system which is often used in conjunction with relatively low traffic volumes in order to shield non-recoverable slopes and hazards, and where a large dynamic deflection is acceptable. These systems consist of steel cables supported by weak posts. When an errant vehicle impacts the cable system, sufficient tension is developed within the cables in order to redirect the vehicle, effectively shield the motorist from roadside hazards. Due to the likelihood of a longitudinal impact with the end of the cable guardrail system, a crashworthy end terminal is required. For this purpose, various crashworthy cable guardrail end terminal designs have been designed using the breakaway feature of the slip base mechanism. Currently, only one end terminal and anchorage system for the low tension, three-cable barrier has met the criteria of the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Roadside Features* (1). The terminal, developed by the New York Department of Transportation (NYDOT), is a flared end terminal with a large anchor block (2). This flared design has limitations when used along steep slopes and in combination with a W-beam guardrail, especially at bridges. Maintenance workers also have difficulty working with the anchor size.

As currently approved, the length of need (LON) for the NY Cable Terminal design begins approximately 12 m (39 ft - 4 in.) downstream from the concrete anchor block. The reason for such a long development length is to reduce the loads on the anchors. In addition, the existing design used 1.64 m^3 (57.9 ft^3) of concrete in the 1,448-mm x 1,143-mm x 991-mm (57-in. x 45-in. x 39-in.) anchor block. Therefore, the need exists to develop a tangent anchor with a smaller anchor block which meets the NCHRP Report No. 350 criteria.

1.2 Objective

The objective of the research project was to redesign the New York low-tension, three-cable terminal to be used as a tangent system and with a reduced the size of the anchor block. The cable terminal system was to be evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth in NCHRP Report No. 350.

1.3 Scope

The research objective was achieved by performing several tasks. Following the design and construction of the cable terminal system, four full-scale crash tests were performed on the cable terminal system. The first test utilized a ¾-ton pickup truck weighing approximately 2,000 kg (4,409 lbs), with a target impact speed and angle of 100.0 km/h (62.1 mph) and 20 degrees, respectively. The last three tests were performed using a small car, weighing approximately 820 kg (1,808 lbs), with a target impact speed and angle of 100.0 km/h (62.1 mph) and 0 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 terminal system.

2 LITERATURE REVIEW

The first three-strand cable terminal system to be full-scale vehicle crash tested according to NCHRP Report Nos. 230 (3) and 350 (1) was developed by the NYDOT (2, 4). This system consists of standard cable posts with S76x8.5(S3x5.7) sections and soil plates, three 19-mm (0.75-in.) diameter cables with a top mounting height of 762 mm (30 in.), and a rectangular concrete anchor block located 1,219 mm (48 in.) laterally behind the tangent posts. The end terminal has a flared section extending 12.8 m (48 ft). This requires that the anchor be placed on the fill slope.

The reverse direction test, test no. 96 (2), involved a small car weighing approximately 816 kg (1,800 lb) impacting 10.44 m (34 ft-3 in.) upstream of the anchor at a speed and angle of 94.3 km/h (58.3 mph) and 14 degrees, respectively. Due to vehicle rollover, this test was deemed a failure. To improve the performance of the cable guardrail end terminal, the system was redesigned by utilizing V-notches in the cable anchor bracket tension plate and teflon-coated washers. The modified system was impacted in the reverse direction. This test, test no. 97 (2), consisted of an 816 kg (1,800 lb) small car, impacting 10.06 m (33 ft) upstream of the anchor, at a speed and angle of 92.9 km/h (57.7 mph) and 13 degrees, respectively. Similarly, test no. 97 was deemed a failure due to vehicle rollover.

Following the unsuccessful test nos. 96 and 97, researchers determined that friction and angle of impact were critical in the reverse-direction impact on the cable guardrail end terminal. Thus, the design was modified to include a cable guide post with a steel sleeve anchored in concrete in order to guide the cables into the cable anchor bracket. The reverse direction test, test no. 98, was conducted on the modified system using an 816-kg (1,800-lb) small car impacting 12 m (39.4 ft) upstream of the anchor at a speed and angle of 89.8 km/h (55.8 mph) and 11 deg, respectively, and was deemed acceptable. Test no. 99, consisted of a 2,041-kg (4,500-lb) sedan impacting 23.2 m (76 ft) downstream of the anchor at a speed and angle of 92.4 km/h (57.4 mph) and 24 degrees, respectively. The vehicle penetrated and underrode the cables, resulting in excessive roof crush and windshield deformation of the vehicle. During this test, the cable bracket disengaged and was thrown into adjacent traffic lanes. Test no. 99 was deemed unacceptable.

To reduce the risk of the cable underride, the top mounting height of the top cable was lowered to 686 mm (27 in.) with cable spacing of 76 mm (3 in.) between the others. Additionally, since the detached bracket posed a significant threat to other motorists, the design was modified by welding the brackets to the posts. Test no. 100 consisted of a 2,168-kg (4,780-lb) sedan impacting the modified system 24.7 m (81 ft) downstream of the anchor at a speed and angle of 92.9 km/h (57.7 mph) and 23 deg, respectively, and was determined to be successful according to the criteria presented in NCHRP Report No. 230 (3).

The next test was performed head-on with the centerline of the vehicle aligned with the centerline of the cable anchor bracket. Test no. 101 consisted of an 816-kg (1,800-lb) small car impacting the system with the centerline of the vehicle aligned with the centerline of the cable anchor bracket at a speed and angle of 93.5 km/h (58.1 mph) and 0 degrees, respectively. The vehicle rolled over due to vehicle contact with the first post in the system. Thus, the cable guardrail end terminal was modified to include a slip-base post as the first post in the system. The retest, test no. 102, conducted on the modified system, consisted of an 816-kg (1,800-lb) small car impacting the system at a speed and angle of 116.5 km/h (72.4 mph) and 0 degrees with respect to the centerline of the cable anchor bracket, respectively, also resulted in rollover and subsequent test failure.

The system was then modified, reducing the angle between the anchor rods and the cable anchor bracket by running the cables over shelf brackets on post no. 1 and moving post no. 2 to 4.88 m (16 ft) downstream of the anchor. The retest, test no. 103, consisted of an 816-kg (1,800-lb) small car impacting at 109.4 km/h (68.0 mph) and 5 degrees with respect to the tangent section at a quarter point offset. The test was determined to be successful according to the criteria presented in NCHRP Report No. 230. The next test, test no. 104, consisting of an 816-kg (1,800-lb) small car impacting the cable anchor terminal at 98.7 km/h (61.3 mph) and 15 degrees, respectively, was determined to be acceptable. The next test, test no. 105, consisted of an 816-kg (1,800-lb) small car impacting 7.2 m (23.5 ft) downstream of the anchor at a speed and angle of 88.2 km/h (54.8 mph) and 10 degrees, respectively, was determined to be acceptable.

The next test, test no. 106, consisting of a 2,041-kg (4,500-lb) sedan impacting 11.6 m (38 ft) downstream of the anchor at an angle of 10 degrees relative to the tangent section, resulted in vehicle penetration of the three-cable guardrail and subsequent failure of the test. The system was modified by adding an additional washer to the anchor rods. The retest, test no. 107, consisting of a 2,200-kg (4,850-lb) sedan impacting 11.6 m (38 ft) downstream of the anchor at a speed and angle of 91.1 km/h (56.6 mph) and 25 degrees relative to the tangent section, respectively, was determined to be acceptable according to NCHRP Report No. 230.

In order to meet the standards of NCHRP Report 350, NYDOT was required to perform an additional test, test designation 3-35 of NCHRP Report 350 (1 _). This test, test no. 404211-6, consisted of an 896-kg (1,975-lb) small car at the critical impact point (CIP) of the system in a reverse direction impact, such that the centerline of the vehicle was aligned with the centerline of the cable anchor bracket, at a speed and angle of 99.3 km/h (61.7 mph) and 14.7 degrees relative to the tangent section, respectively (5). The test was determined to be acceptable according to the NCHRP Report No. 350 criteria.

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Cable guardrail end terminals 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 gating terminal system must be subjected to seven full-scale vehicle crash tests. The crash test designations are as follows:

1. Test Designation 3-30 consisting of an 820-kg (1,808-lb) small car impacting the cable end terminal at a nominal speed and angle of 100.0 km/h (62.1 mph) and 0 degrees, respectively, on the nose of the end terminal with a 1/4-point offset.

2. Test Designation 3-31 consisting of a 2,000-kg (4,409-lb) pickup truck impacting the cable end terminal at a nominal speed and angle of 100.0 km/h (62.1 mph) and 0 degrees, respectively, on the nose of the end terminal.

3. Test Designation 3-32 consisting of an 820-kg (1,808-lb) small car impacting the cable end terminal at a nominal speed and angle of 100.0 km /h (62.1 mph) and 15 degrees to the tangent section, respectively, on the nose of the end terminal.

4. Test Designation 3-33 consisting of a 2,000-kg (4,409-lb) pickup truck impacting the cable end terminal at a nominal speed and angle of 100.0 km/h (62.1 mph) and 15 degrees, respectively, on the nose of the end terminal.

5. Test Designation 3-34 consisting of an 820-kg (1,808-lb) small car impacting the cable end terminal at a nominal speed and angle of 100.0 km/h (62.1 mph) and 15 degrees, respectively, and at the Critical Impact Point (CIP) on the end terminal.

6. Test Designation 3-35 consisting of a 2,000-kg (4,409-lb) pickup truck impacting the cable end terminal at a nominal speed and angle of 100.0 km/h (62.1 mph) and 20 degrees, respectively, and at the beginning of the Length-of-Need (LON) on the end terminal.

7. Test Designation 3-39 consisting of a 2,000-kg (4,409-lb) pickup truck impacting the cable end terminal at a nominal speed and angle of 100.0 km/h

(62.1 mph) and 20 degrees, respectively, and at the midpoint of the end terminal length for reverse direction impacts on the end terminal.

The test conditions for TL-3 gating terminals are summarized in Table 1. However, due to the similarity between the modified cable guardrail end terminal and the NYDOT terminal design, several crash tests were deemed unnecessary. Test no. 3-30 was considered a critical test, thus requiring it to be performed on the modified cable guardrail terminal even though test no. 103 was found to be acceptable on the NYDOT terminal design. It should be noted that test no. 103 was conducted at 5 degrees versus the 0-degree impact angle specified in NCHRP Report No. 350. Test nos. 3-31 and 3-33 were not performed on the terminal end at 0 and 15 degrees, respectively, since the heavier pickup truck vehicle would not be critical as compared to the small car impact on the nose at 0 degrees and with a 1/4-point offset. In addition, the pickup truck would not become unstable as the cable posts would be easily bent over as the vehicle passed over them Test no. 3-32 was not performed on the nose at 15 degrees due to the success of test no. 104 on the NYDOT terminal design and the similarities between the two cable barrier systems. In addition, it was believed that the small car test at 0 degrees on the nose using a 1/4-point offset was more critical than the small car test at 15 degrees on the nose aligned with the vehicle's centerline.

Test no. 3-34 with a small car was deemed unnecessary due to prior testing with small cars on the nose of the NYDOT terminal design at 15 degrees and with the understanding that small cars impacting at 20 degrees downstream from the terminal end would be safely redirected. Test no. 3-35, a Length-of-Need test (LON) with a 2000P vehicle impacting at 20 degrees, was considered a critical test for evaluating the optimized anchor designs and imparting a maximum loading into the foundations. This test was believed critical even though the NYDOT terminal anchor design was successfully evaluated with test no. 107 using a heavy sedan vehicle. Finally, test no. 3-39 was not performed due to similarities between the between the two cable barrier systems and the successful performance of two small car tests (test nos. 98 and 404211-6) performed in the reverse direction on the NYDOT design. In addition, the reverse direction 2000P crash test was not deemed critical.

In summary, test designation nos. 3-30 and 3-35 were determined to be necessary to prove the crashworthiness of the new, cable guardrail end terminal system.

3.2 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 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)		
Gating End Terminals	3-30	820C	100	62.1	0	C,D,F,H,I,K,N
	3-31	2000P	100	62.1	0	C,D,F,H,I,K,N
	3-32	820C	100	62.1	15	C,D,F,H,I,K,N
	3-33	2000P	100	62.1	15	C,D,F,H,I,K,N
	3-34	820C	100	62.1	15	C,D,F,H,I,K,N
	3-35	2000P	100	62.1	20	A,D,F,K,L,M
	3-39	2000P	100	62.1	20	C,D,F,K,L,M,N

[1] Evaluation criteria explained in Table 2.

Table 2. NCHRP Report No. 350 Evaluation Criteria for Crash Tests (1)

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.

4 TEST CONDITIONS

4.1 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.

4.2 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 (6) 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 CT-1, CT-2, CT-3, and CT-4, the vehicle guidance systems were 304.8-m (1000-ft), 243.8-m (800-ft), 241-m (790-ft), and 240-m (788-ft) long, respectively.

4.3 Test Vehicles

For test CT-1, a 1996 GMC ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,018 kg (4,449 lbs). The test vehicle is shown in Figure 1, and vehicle dimensions are shown in Figure 2 .

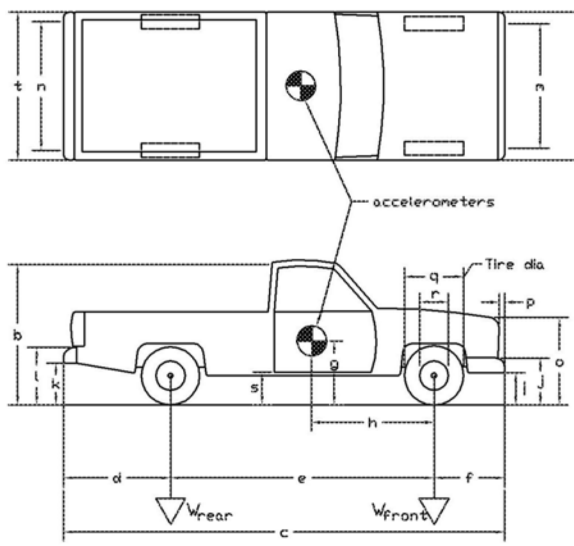
Figure 1. Test Vehicle, Test CT-1

Date: 7/3/02 Test Number: CT-1 Model: 2500

Make: GMC Vehicle I.D.#: 1GDGC24R6TZ544461

Tire Size: LT 245/75 R16 Year: 1996 Odometer: 214552

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1892 (74.5)	b	1835 (42.25)
c	5537 (71.8)	d	1327 (52.25)
e	3327 (131.0)	f	908 (35.75)
g	540 (21.25)	h	1394 (54.875)
i	438 (17.25)	j	660 (26.0)
k	597 (23.5)	l	794 (31.25)
m	1594 (62.75)	n	1613 (12.5)
o	1041 (41.0)	p	83 (3.25)
q	762 (30.0)	r	445 (17.5)
s	483 (19.0)	t	1867 (73.5)

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) 962 (37.875)

Engine Type 8 CYL. GAS

Engine Size 5.7 L 350 GI

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	1133 (2498)	1173 (2586)	1173 (2586)
W_{rear}	846 (1865)	844 (1861)	844 (1861)
W_{total}	1979 (4363)	2018 (4449)	2018 (4449)

Note any damage prior to test: none

Figure 2. Vehicle Dimensions, Test CT-1

For test CT-2, a 1995 Geo Metro was used as the test vehicle. The test inertial and gross static weights were 816 kg (1,799 lb) and 891 kg (1,965 lbs), respectively. The test vehicle is shown in Figure 3, and vehicle dimensions are shown in Figure 4.

For test CT-3, a 1998 Geo Metro was used as the test vehicle. The test inertial and gross static weights were 810 kg (1,786 lb) and 885 kg (1,952 lbs), respectively. The test vehicle is shown in Figure 5, and vehicle dimensions are shown in Figure 6.

For test CT-4, a 1997 Geo Metro was used as the test vehicle. The test inertial and gross static weights were 814 kg (1,795 lb) and 889 kg (1,961 lb), respectively. The test vehicle is shown in Figure 7, and vehicle dimensions are shown in Figure 8.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The location of the final centers of gravity are shown in Figures 1 through 8.

Square black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film and E/cam, Photron, and AOS videos, as shown in Figures 9 through 12. 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.

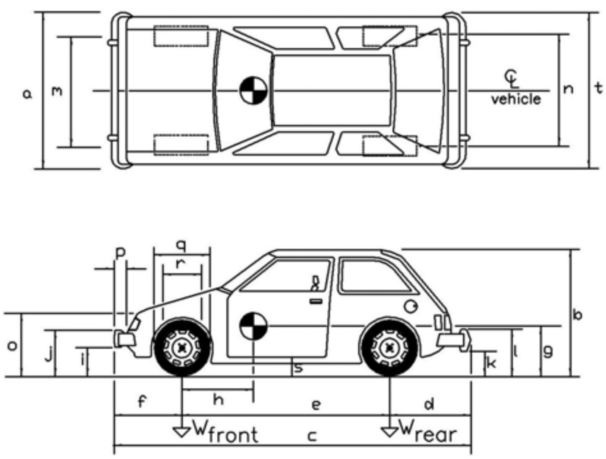
The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable. Two 5B flash bulbs were mounted on both the hood and roof of the vehicle to pinpoint the time of impact with the barrier on the high-speed film and video. The flash bulbs were 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 3. Test Vehicle, Test CT-2

Date: 7-16-02 Test Number: CT-2 Model: 820c

Make: Geo Metro 2Dr. Vehicle I.D.#: 2C1MR226656725470

Tire Size: 155/80 R13 Year: 1995 Odometer: 101,105



Vehicle Geometry – mm (in)

a	1537 (60.5)	b	1416 (55.75)
c	3797 (149.5)	d	597 (23.5)
e	2369 (93.25)	f	838 (33.0)
g	546 (21.5)	h	870 (34.25)
i	216 (8.5)	j	540 (21.25)
k	330 (13.0)	l	679 (26.75)
m	1372 (54.0)	n	1365 (53.25)
o	559 (22.0)	p	121 (4.25)
q	572 (22.5)	r	362 (14.25)
s	273 (10.75)	t	1562 (61.5)

height of wheel center: 270 (10.625)

Engine Type: 3 cyl. Gas

Engine size: 1.0 L

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Weight kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	444 (979)	516 (1138)	552 (1218)
W_{rear}	260 (574)	300 (661)	339 (747)
W_{total}	704 (1553)	816 (1799)	891 (1965)

Damage prior to test: None

Figure 4. Vehicle Dimensions, Test CT-2

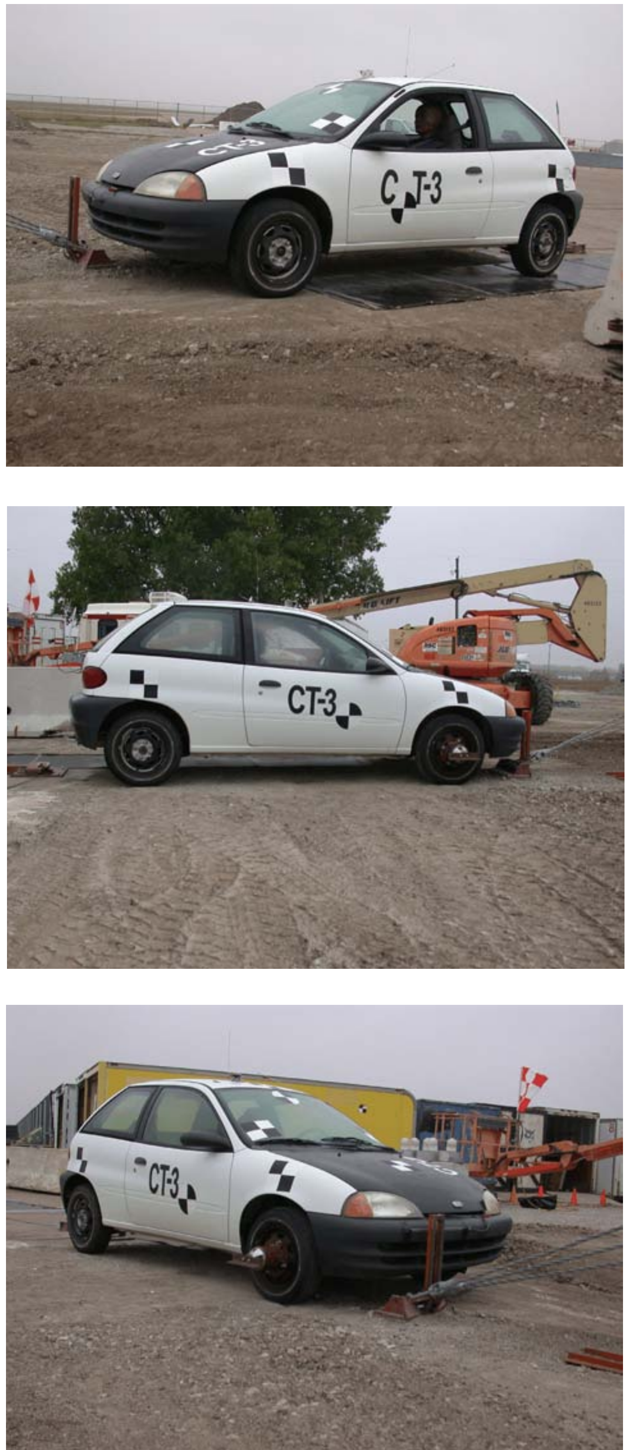


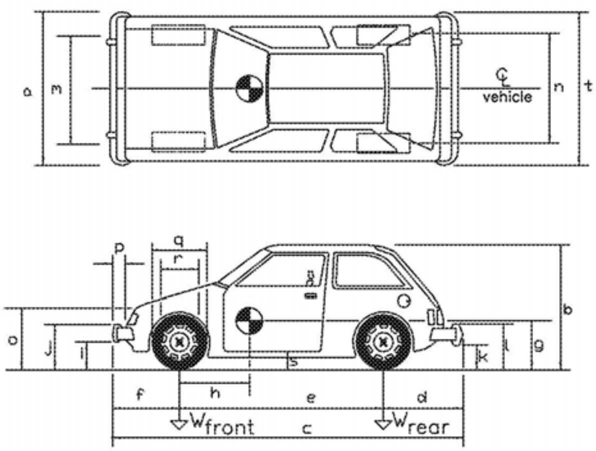
Figure 5. Test Vehicle, Test CT-3

Date: 10/10/03 Test Number: CT-3 Model: GEO METRO

Make: CHEVY Vehicle I.D.#: 2C1MR2265W6700937

Tire Size: 155/80R19 Year: 1998 Odometer: 92,631

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1562 (61.5)	b	1435 (56.5)
c	3785 (149.0)	d	584 (23.0)
e	2369 (93.25)	f	832 (32.75)
g	546 (21.5)	h	851 (33.5)
i	64 (2.5)	j	552 (21.75)
k	2794 (110)	l	673 (26.5)
m	1505 (59.25)	n	1340 (53.75)
o	572 (22.5)	p	229 (9.0)
q	572 (22.5)	r	375 (14.75)
s	672 (10.5)	t	1600 (63.0)

Wheel Center Height 261 (10.265)

Engine Type 3 CYL. GAS

Engine Size 1.0 L

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	437 (437)	200 (442)	555 (1223)
W_{rear}	258 (568)	292 (644)	331 (729)
W_{total}	695 (1532)	810 (1786)	885 (1952)

Note any damage prior to test: NONE

Figure 6. Vehicle Dimensions, Test CT-3

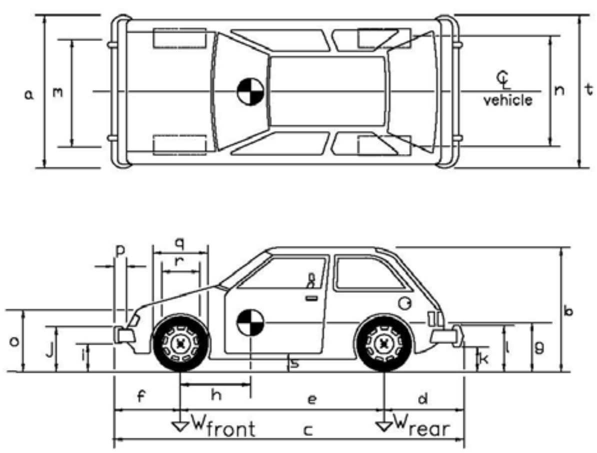
Figure 7. Test Vehicle, Test CT-4

Date: 6/8/05 Test Number: CT-4 Model: 820L - METRO

Make: Geo Vehicle I.D.#: 2C1MR2290v6728119

Tire Size: P150/80R13 Year: 1997 Odometer: 187,358

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1543 (60.75)	b	1394 (54.875)
c	3797 (149.5)	d	603 (23.75)
e	2362 (93.0)	f	864 (34.0)
g	546 (21.5)	h	864 (34.0)
i	432 (17.0)	j	527 (20.75)
k	318 (12.5)	l	635 (25.0)
m	1375 (54.125)	n	1356 (53.375)
o	581 (22.875)	p	105 (4.125)
q	572 (22.5)	r	365 (14.375)
s	308 (12.125)	t	1549 (61.0)

Wheel Center Height 267 (10.5)

Engine Type 4 CYL. GAS

Engine Size 1.3 L

Transmission Type:

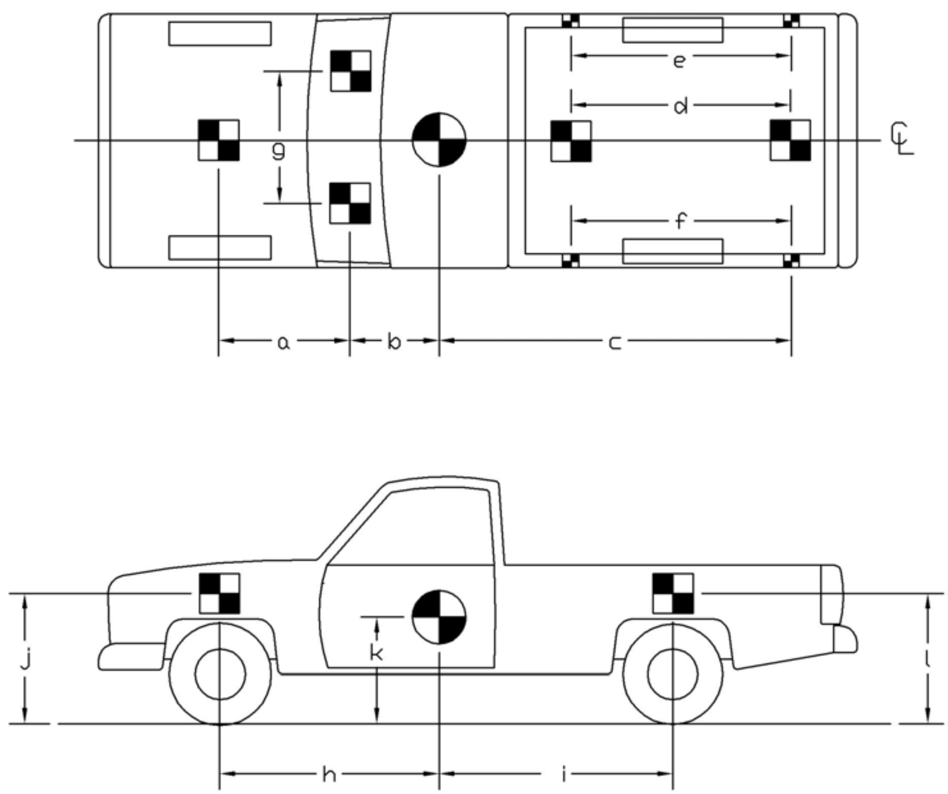
Automatic or Manual

FWD or RWD or 4WD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	492 (1085)	517 (1140)	554 (1221)
W_{rear}	288 (635)	297 (635)	297 (655)
W_{total}	780 (1720)	814 (1795)	889 (1961)

Note any damage prior to test: NONE

Figure 8. Vehicle Dimensions, Test CT-4

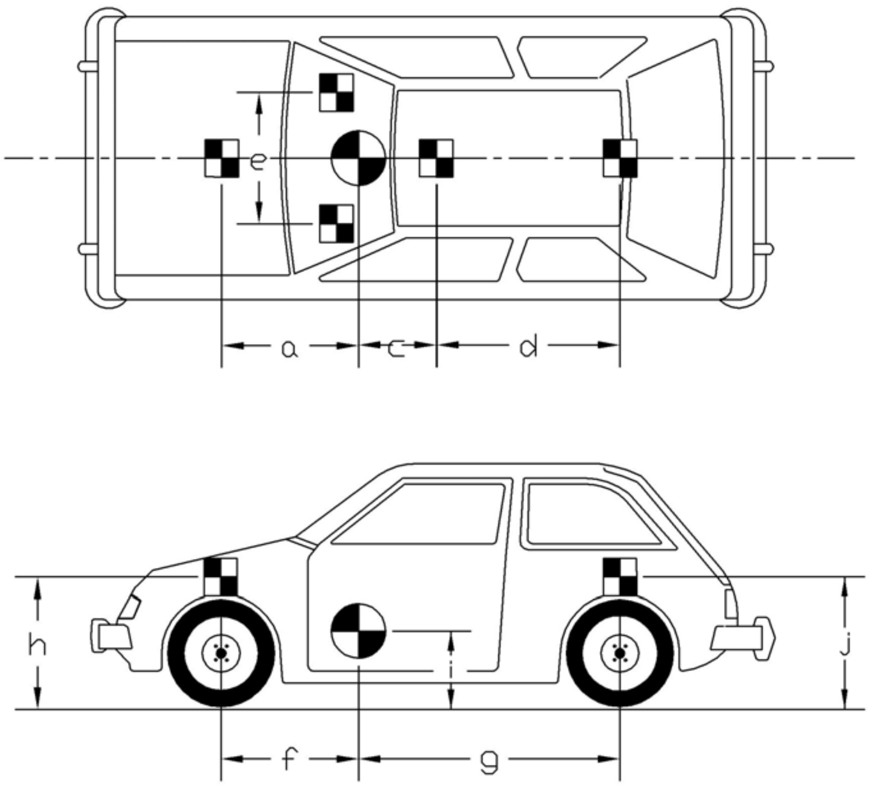


TEST #: CT-1

TARGET GEOMETRY -- mm (in.)

a 921 (36.25)	d 1664 (65.5)	g 1264 (49.75)	j 997 (34.25)
b 705 (27.25)	e 2153 (84.75)	h 1394 (54.875)	k 667 (26.25)
c 2604 (102.5)	f 2153 (84.75)	i 1200 (47.25)	l 1067 (42.0)

Figure 9. Vehicle Target Locations, Test CT-1

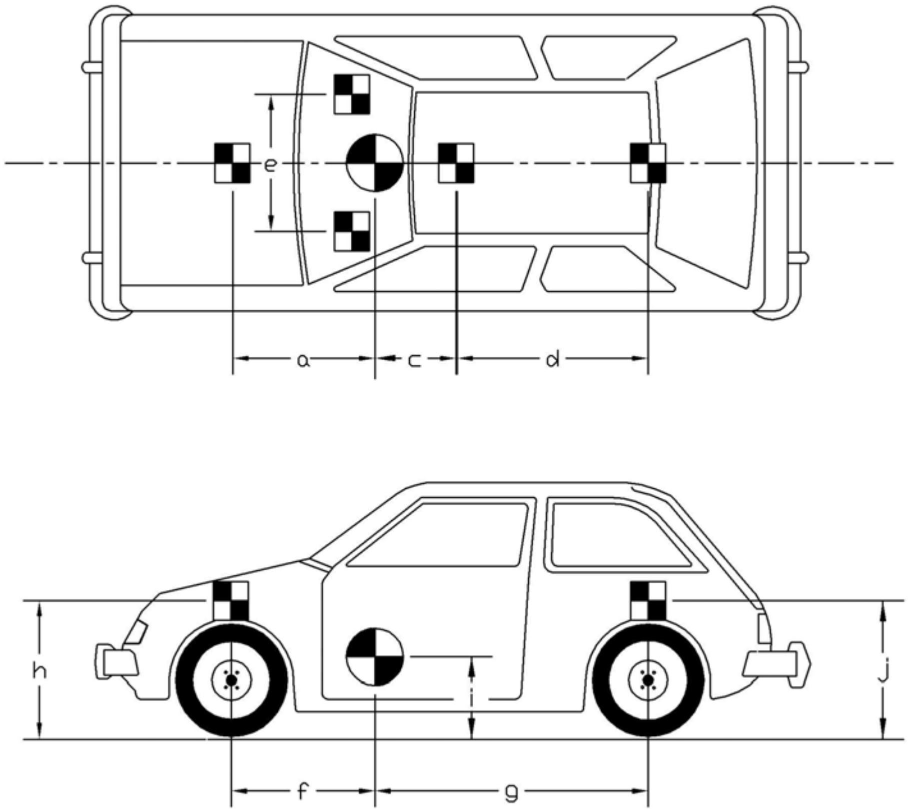


TEST #: CT-2

TARGET GEOMETRY -- mm (in.)

a 1105 (43.5)	b ——	c 248 (9.75)	d 930 (36.625)
e 1029 (40.5)	f 870 (34.25)	g 1499 (59.0)	h 749 (29.5)
	i 546 (21.5)	j 978 (30.5)	

Figure 10. Vehicle Target Locations, Test CT-2

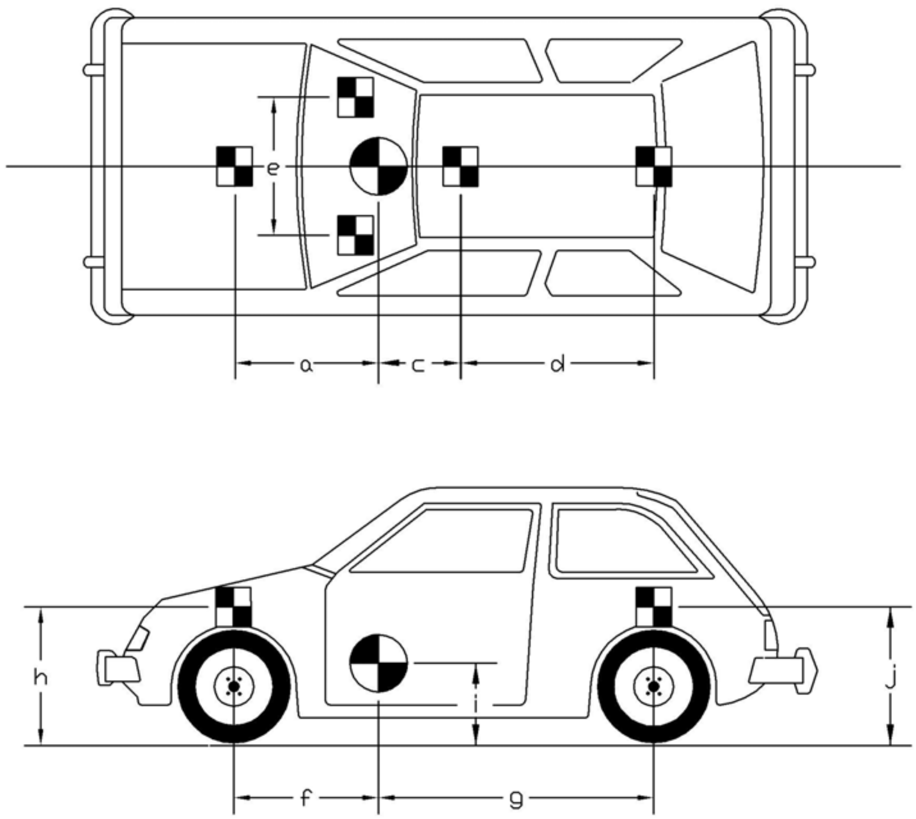


TEST #: CT-3

TARGET GEOMETRY -- mm (in.)

a	1594 (62.75)	b	----	c	235 (9.25)	d	2381 (93.75)
e	1041 (41.0)	f	851 (33.5)	g	1492 (58.75)	h	756 (29.75)
		i	546 (21.5)	j	787 (31.0)		

Figure 11. Vehicle Target Locations, Test CT-3



TEST #: CT-4

TARGET GEOMETRY -- mm (in.)

a 952 (37.5)	b ----	c 283 (11.125)	d 1032 (40.625)
e 578 (22.75)	f 864 (34.0)	g 1499 (59.0)	h 733 (28.875)
	i 546 (21.5)	j 743 (29.25)	

Figure 12. Vehicle Target Locations, Test CT-4

4.4 Data Acquisition Systems

4.4.1 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.

4.4.2 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.

4.4.3 High-Speed Photography

For test CT-1, two high-speed 16-mm Red Lake Locam cameras, with operating speed of approximately 500 frames/sec, were used to film the crash test. Five high-speed Red Lake E/cam video cameras, 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 twelve camera locations for test CT-1 is shown in Figure 13.

For test CT-2, three high-speed 16-mm Red Lake Locam cameras, with operating speed of approximately 500 frames/sec, were used to film the crash test. Five high-speed Red Lake E/cam video cameras, 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 CT-2 is shown in Figure 14.

For test CT-3, two high-speed 16-mm Red Lake Locam cameras, with operating speed of approximately 500 frames/sec, were used to film the crash test. One high-speed Photron video camera and three high-speed Red Lake E/cam video cameras, all with operating speeds of 500 frames/sec, were also used to film the crash test. Six 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 twelve camera locations for test CT-3 is shown in Figure 15.

For test CT-4, two high-speed Photron video cameras, two high-speed AOS VITcam video cameras, and two 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 CT-4 is shown in Figure 16. 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 and videos.

4.4.4 Pressure Tape Switches

For tests CT-1, CT-2, CT-3 and CT-4, 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 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.

4.4.5 End Terminal Instrumentation

Electronic sensors were places near the terminal anchor of the three-cable guardrail system for test CT-1 only. The types of sensors used for the crash test were load cells are described following.

4.4.5.1 Load Cells

Six load cells were installed along the three-cable guardrail system. The load cells were positioned in line and at both ends of the three individual cables to measure the forces transferred to the end terminal anchors. The positioning of the load cells is shown in Figure 17.

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 string potentiometers 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).

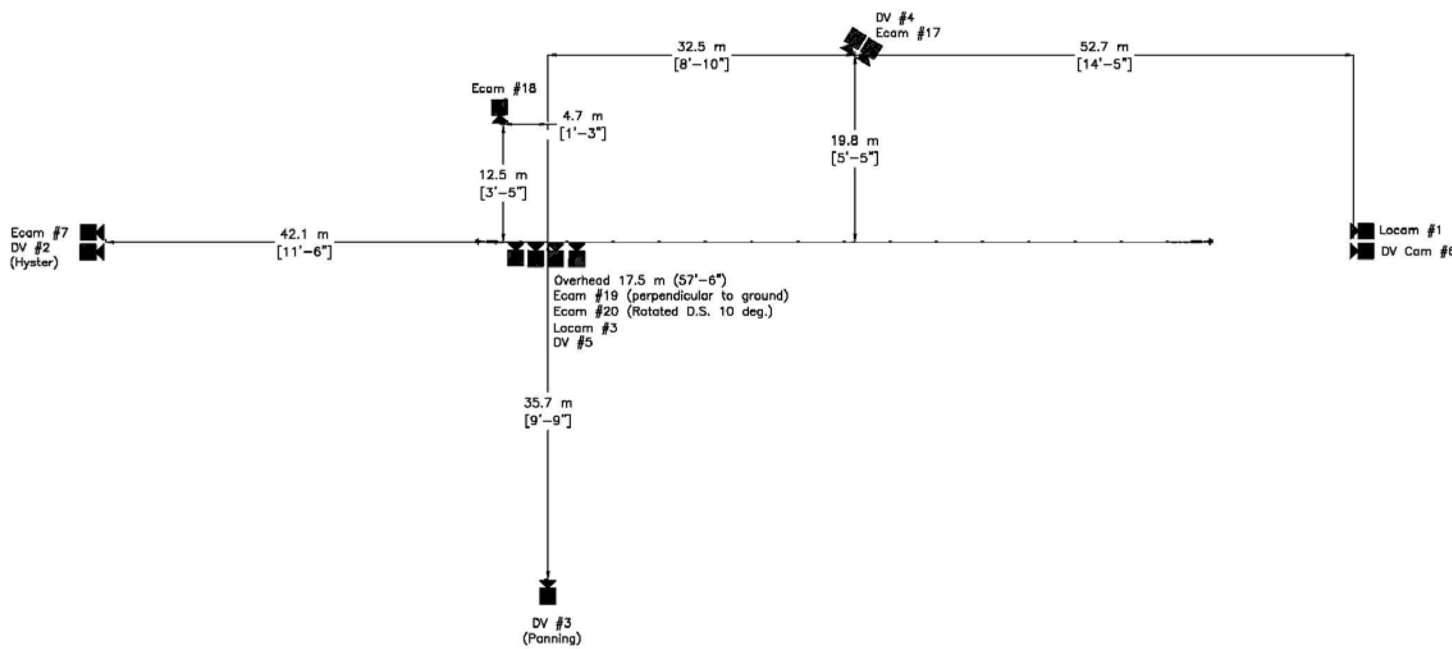


Figure 13. Location of Cameras, Test CT-1

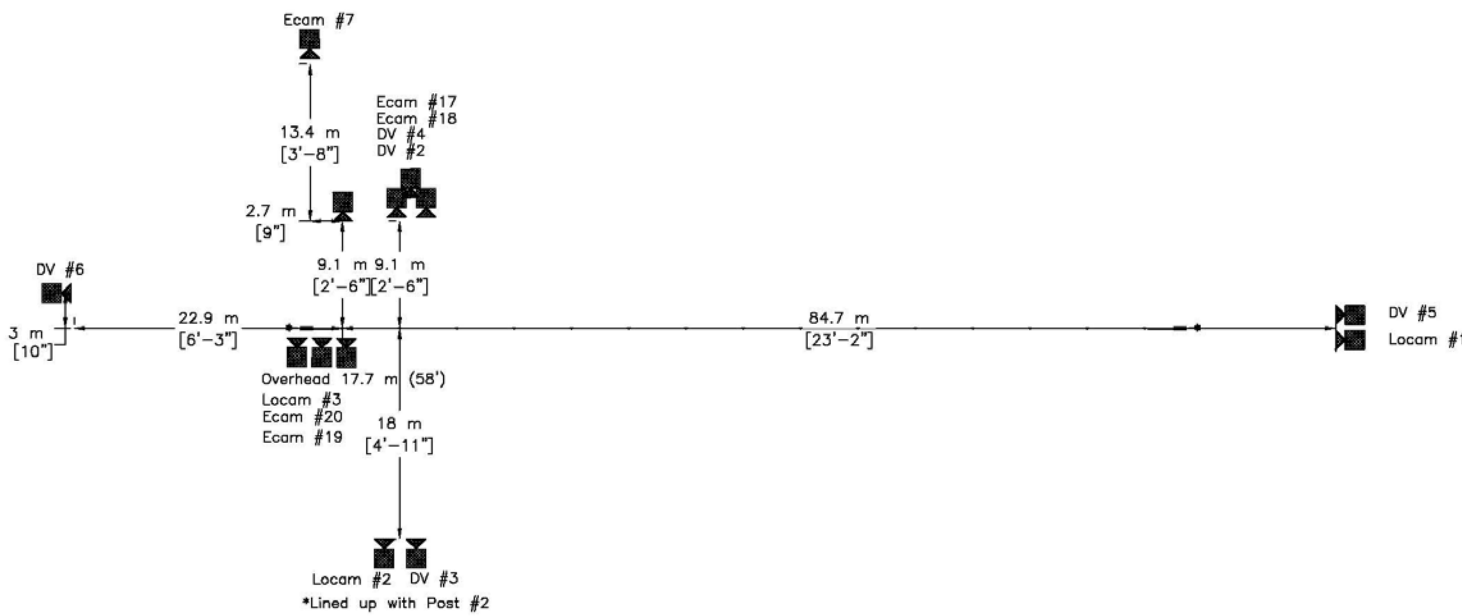


Figure 14. Location of Cameras, Test CT-2

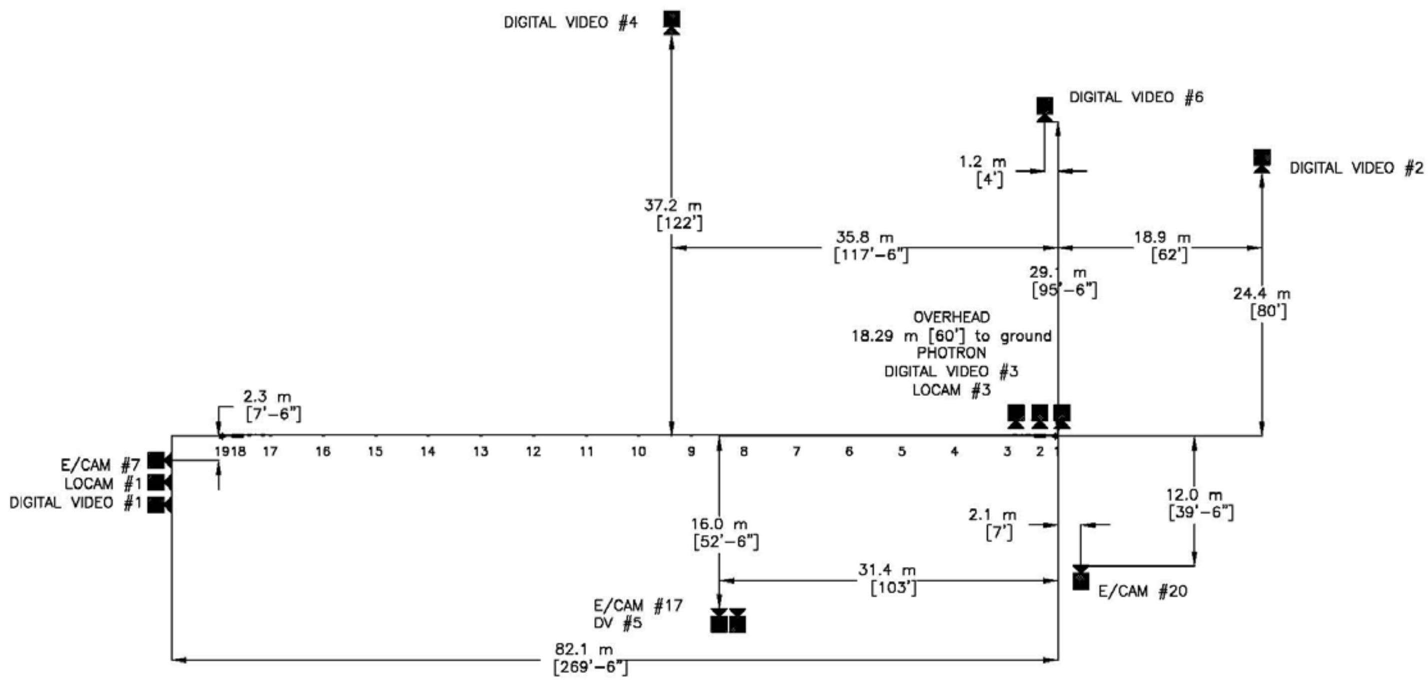


Figure 15. Location of Cameras, Test CT-3

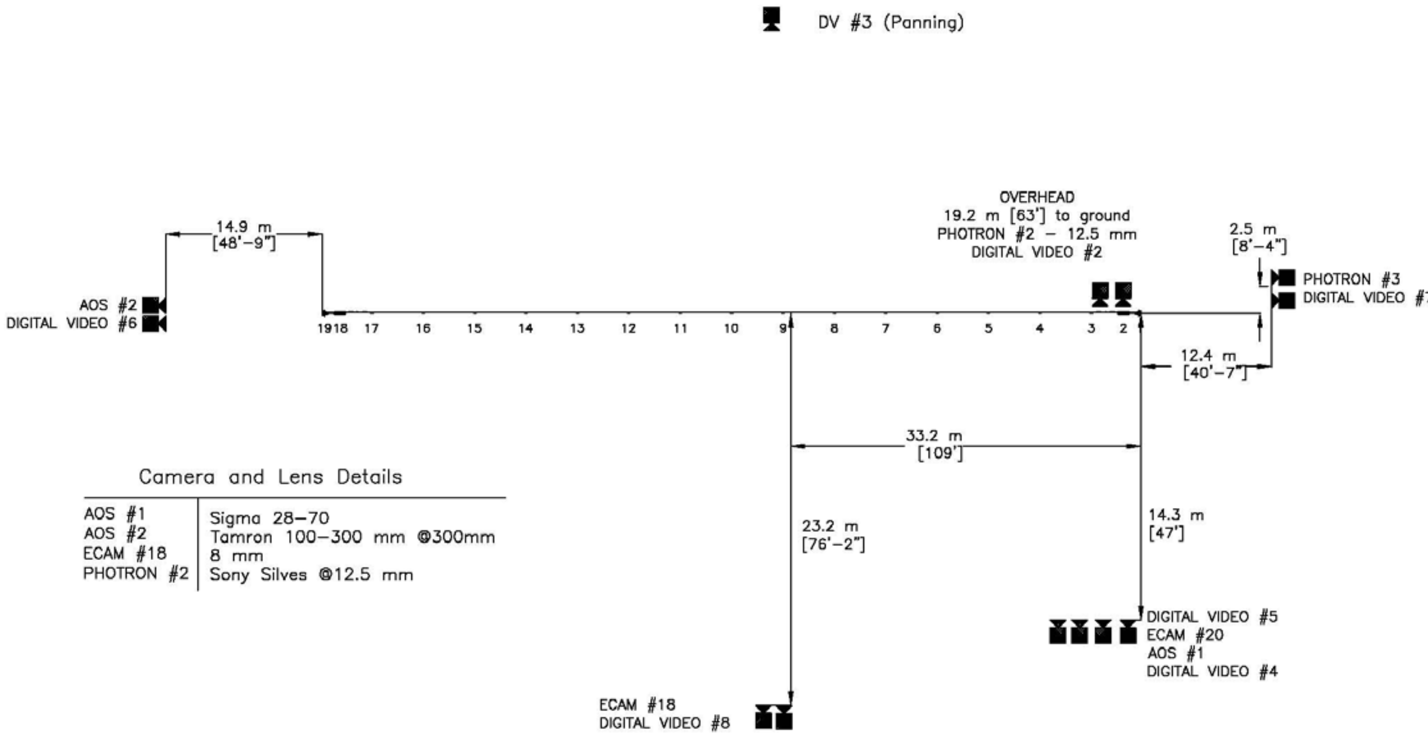


Figure 16. Location of Cameras, Test CT-4

Figure 17. Load Cell Configuration, Test CT-1

5 DESIGN DETAILS - DESIGN NO. 1

The total length of the installation was 77.42 m (254 ft) and consisted of four major structural components: (1) wire rope; (2) posts; (3) cable compensator assemblies, and (4) anchor assemblies. Design details are shown in Figures 17 through 21. The corresponding English-unit drawings are shown in Appendix A. Photographs of the test installation are shown in Figures 22 through 24.

Three 19-mm (3/4-in.) diameter cables comprised of 3x7 wire rope were used for the rail elements. The cable rails were supported by nineteen posts with an upper cable mounting height of 762 mm (30 in.), a middle mounting height of 686 mm (27 in.), and a lower mounting height of 610 mm (24 in.), as shown in Figures 18, 20, and 22. The cables were tightened through the use of cable compensators, as shown in Figure 24. The ends of the cable were threaded rods that terminated in the cable anchor. The threaded rods were attached to the cable anchor by three 51-mm (2-in.) diameter galvanized washers and two 19-mm (0.75-in.) diameter galvanized Grade 5 heavy hex nuts.

The anchor bracket posts, post nos. 1 and 19, were 2,438-mm (96-in.) long W152x37.2 (W6x25) sections with a 610-mm x 610-mm (24-in. x 24-in.) soil plate welded along the downstream flange of the post. The anchor post was embedded to a depth of 2,438 mm (96 in.), as shown in Figures 18 and 20. A 368-mm x 229-mm x 13-mm (14.5-in. x 9-in. x 0.5-in.) plate was welded to the top of the anchor post to which the cable anchor bracket was bolted with four 19-mm diameter x 64 -mm long (0.75-in. x 2.5-in.) Grade 5 hex head bolts.

Post nos. 2 and 18 were configured with S76x8.5 (S3x5.7) sections measuring 838 mm (33 in.) long for the slip post and W152x13.4 (W6x9) sections measuring 1,829 mm (72 in.) long for the foundation posts. The foundation post was embedded to a depth of 1,778 mm (70 in.). A slip base plate was welded to the bottom of the slip post and the top of the foundation post, as shown in Figure

23. Four 13-mm diameter x 51-mm long (0.5-in. x 2-in.) ASTM A307 bolts with nuts and washers were used to form the slip base configuration.

The line posts, post nos. 3 through 17, consisted of 1,600-mm (63-in.) long, S76x8.5 (S3x5.7) sections, with a 762-mm (30-in.) embedment depth and a 203-mm x 610-mm x 6-mm (8-in. x 24-in. x 1/4-in.) soil plate welded along the back flange of the post, as shown in Figure 19. These line posts were spaced 4,877 mm (16 ft) on center with a soil embedment depth of 762 mm (30 in.). The top cable hook was located 89 mm (3.5 in.) down from the top of the post with the middle and lower cable hooks 165 mm and 241 mm (6.5 in. and 9.5 in.) from the top of the post, respectively.

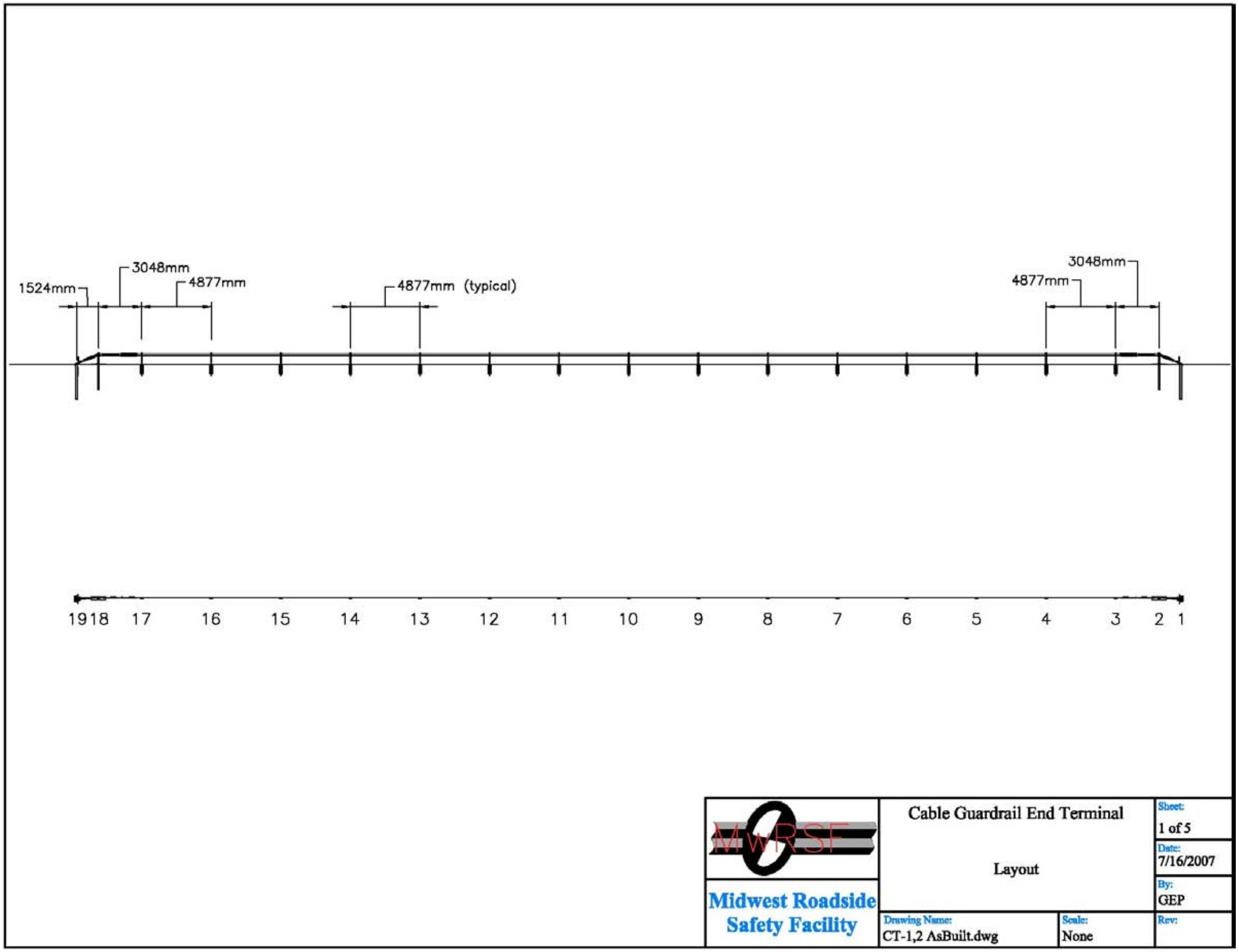


Figure 17. System Details, Design No. 1

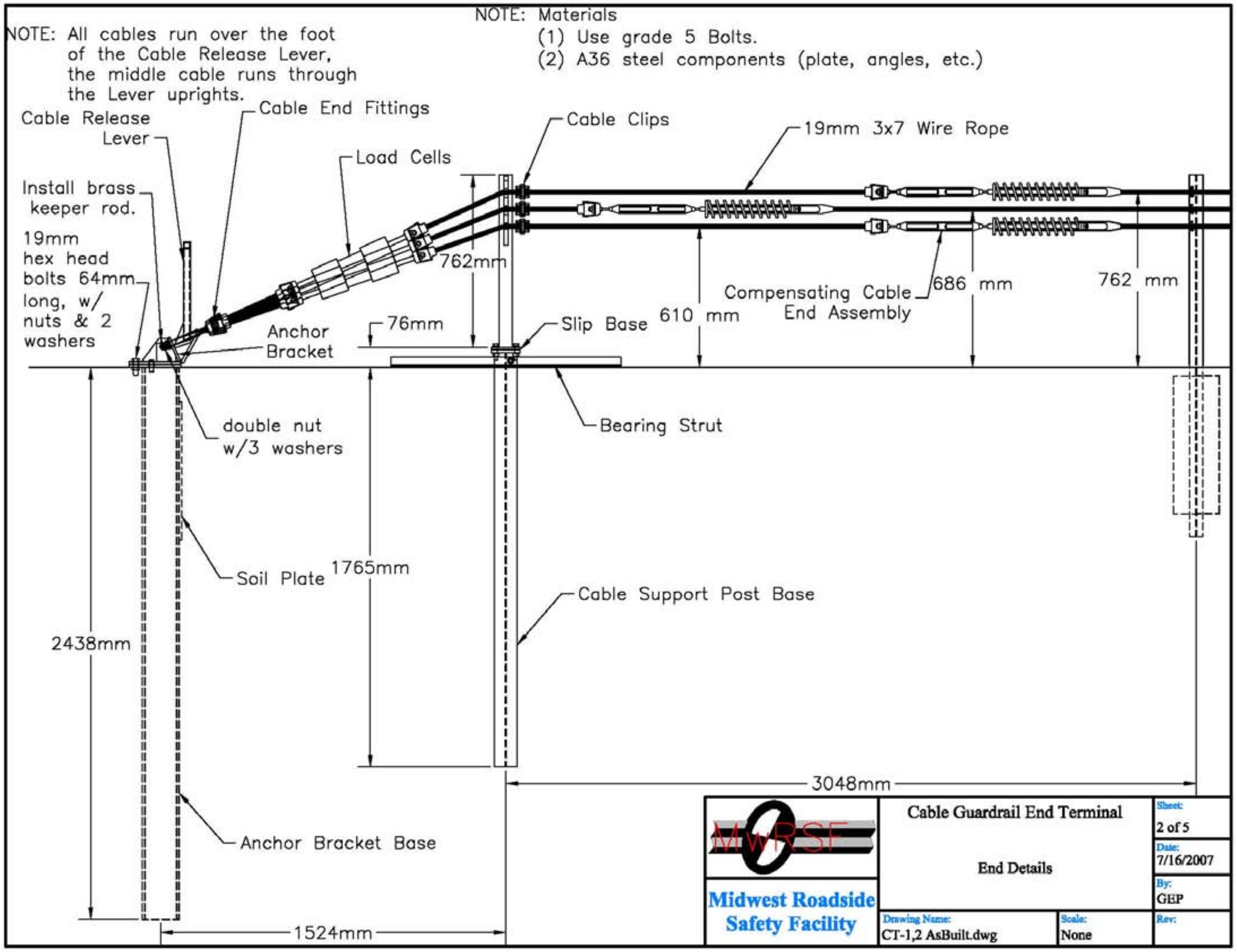


Figure 18. End Anchorage Details, Design No. 1

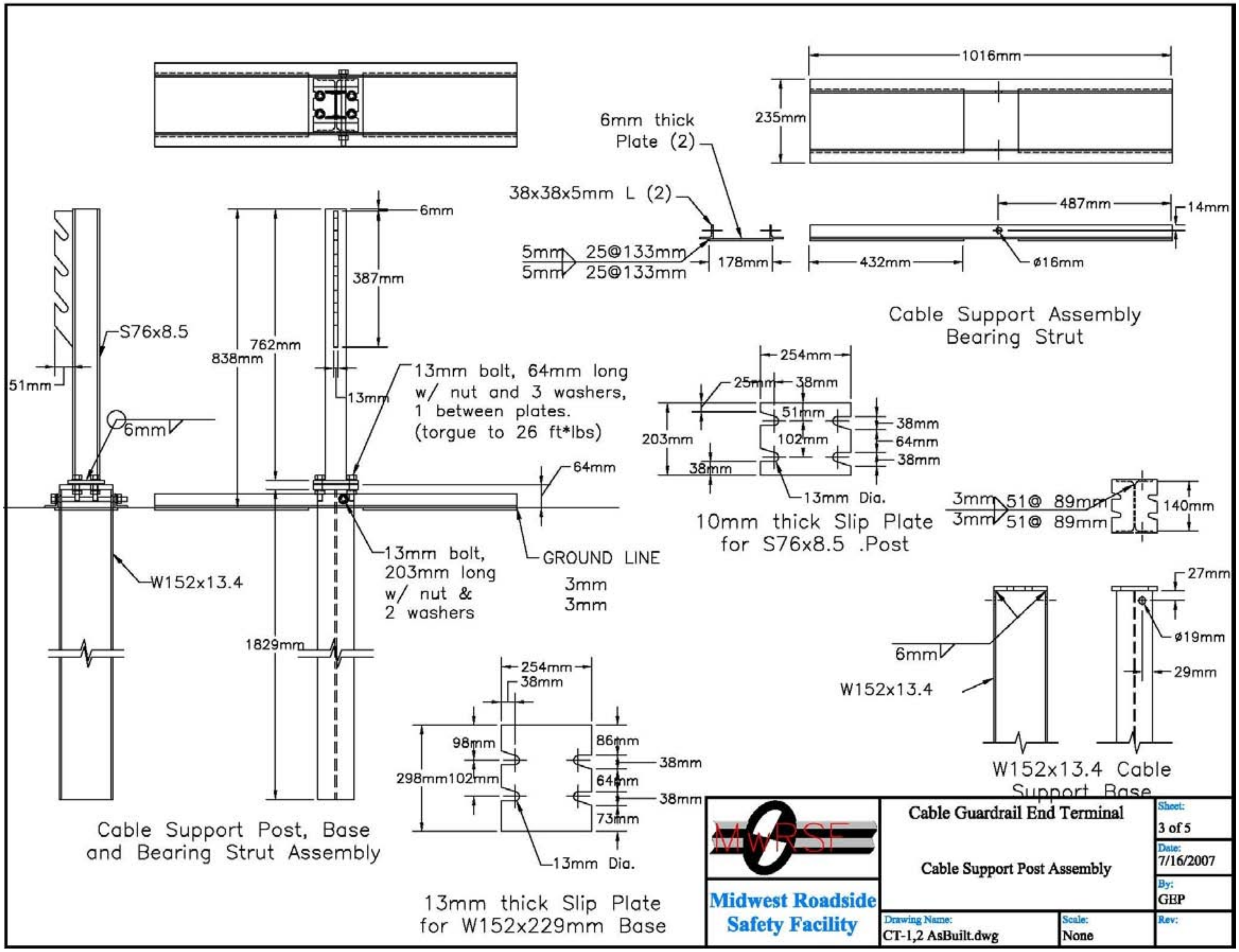


Figure 19. Support Post Assembly Details, Design No. 1

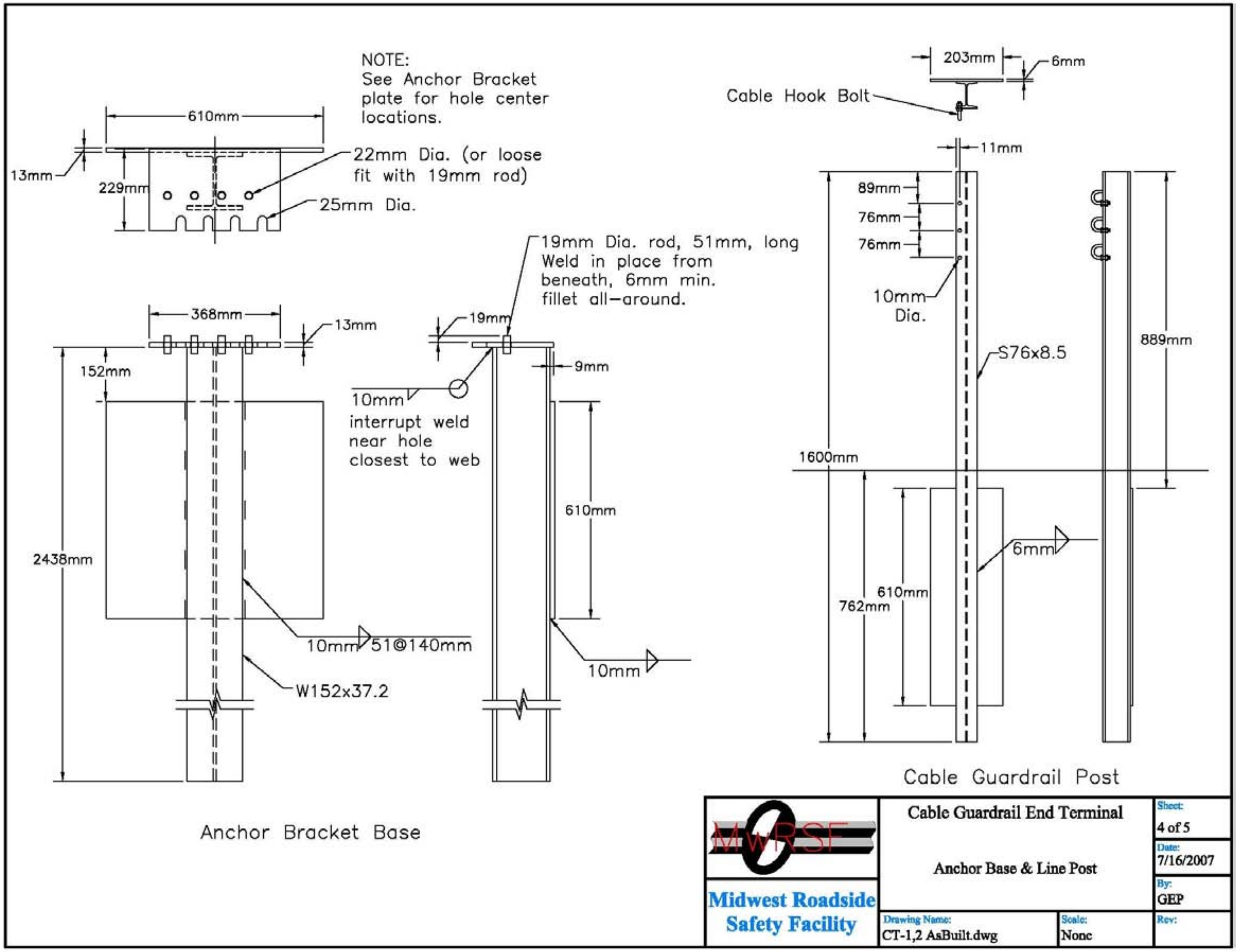


Figure 20. Anchor Bracket and Line Post Detail, Design No. 1

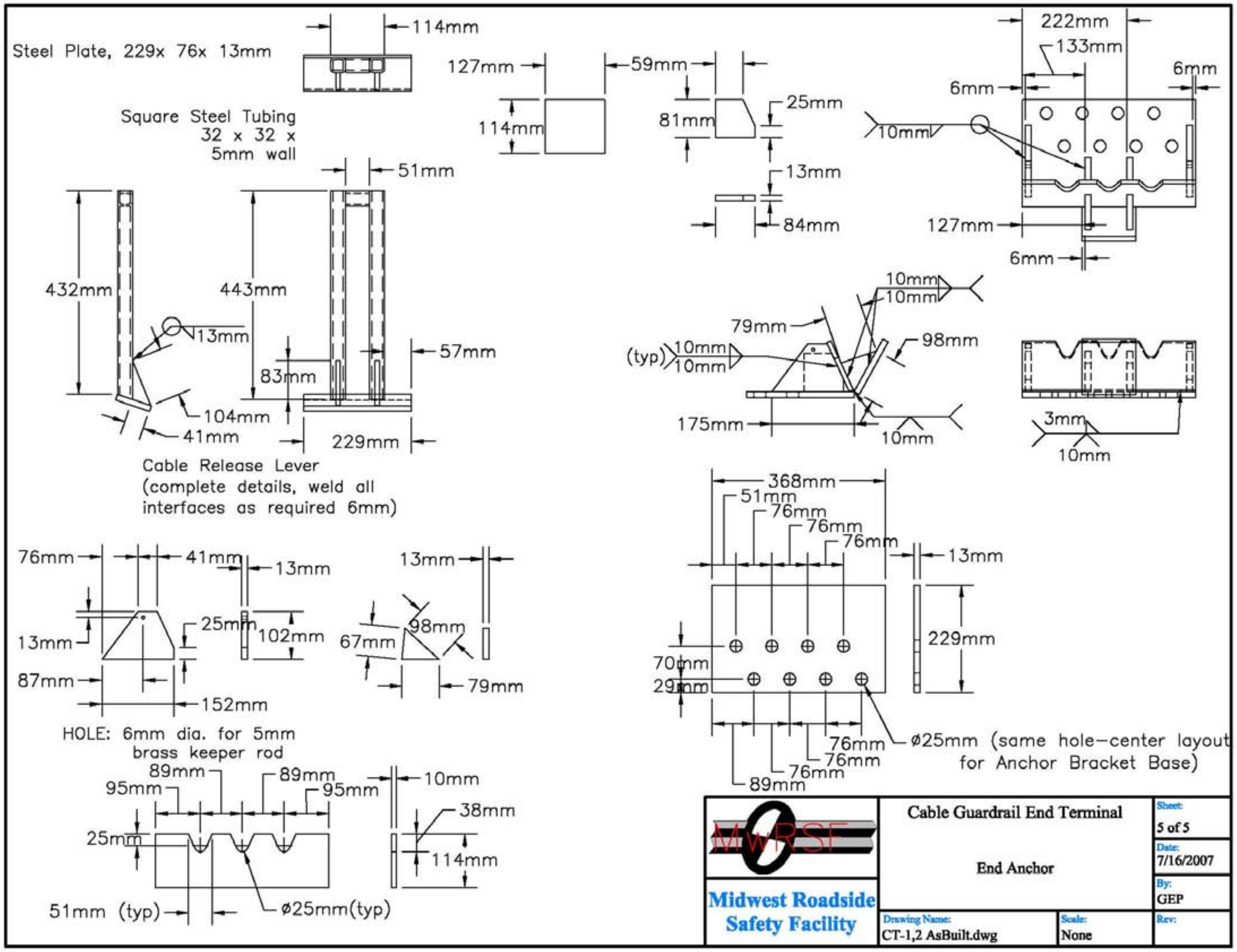


Figure 21. End Anchor Details, Design No. 1

Figure 22. System Layout, Design No. 1

Figure 22. Line Post Details, Design No. 1

Figure 23. Slip-Base Post Details, Design No. 1

Figure 24. End Anchor, Load Cell, and Spring Compensator Details, Design No. 1

6 CRASH TEST NO. 1

6.1 Test CT-1 (Test Designation 3-35)

The 2,017-kg (4,448-lb) pickup truck impacted the cable guardrail end terminal system at post no. 3 with a speed of 101.8 km/h (63.3 mph) and at an angle of 20.7 degrees. A summary of the test results and sequential photographs are shown in Figure 25. The summary of the test results and sequential photographs in English units are shown in Appendix B. Additional sequential photographs are shown in Figures 26 and 27. Documentary photographs of the crash test are shown in Figures 28 and 29.

6.2 Test Description

Impact occurred at post no. 3, as shown in Figure 30. At 0.062 sec after impact, the top and middle cables deformed the left-front corner of the hood. At 0.084 sec, the bottom cable was positioned above the bumper. At 0.154 sec, the truck contacted post no. 4. At 0.192 sec, the truck began to redirect. At 0.270 sec, the left-front fender deformed downward from the cable tension. At 0.338 sec, the truck contacted post no. 5. At 0.378 sec, the right end of the bumper contacted post no. 6. By 0.450 sec, the entire truck was positioned behind the line of posts. At this same time, the middle and bottom cables were positioned under the rear bumper, and the right-rear tire contacted the top of post no. 4. At 0.509 sec, the truck became parallel to the system with a resultant velocity of 93.6 km/h (58.2 mph). At 0.570 sec, the truck rolled slightly towards the right side. At 0.673 sec, the right side of the bumper contacted post no. 7, and the truck exhibited roll toward the left side. At this same time, the right-rear tire traversed over the top of post no. 5, and the left-side headlight housing fractured. At 0.798 sec, the right-front tire traversed over post no. 7. At 0.989 sec, the truck contacted post no. 8. At 1.331 sec, the front of the truck exited the system. The truck exited the system at 1.630 sec, with a resultant velocity of 96.0 km/h (59.6 mph) and at an angle of 4 degrees. The vehicle came to rest 141.5 m (464 ft - 1 in.) downstream from impact and 10.0 m (32 ft - 9 in.) laterally from the traffic-side face of the barrier. The trajectory and final position of the pickup truck are shown in Figures 25 and 31.

6.3 Barrier Damage

Damage to the cable guardrail end terminal was moderate, as shown in Figures 32 through 36. Barrier damage consisted of contact marks on posts, deformed line posts, disengaged cable, and deformed cable hooks. The length of vehicle contact along the cable system was approximately 39.3 m (128 ft - 11 in.), which spanned from post no. 3 through post no. 8.

Post no. 1 rotated and deflected downstream. However, the cable anchor bracket, cable release lever, and cable fittings were undamaged. The center of the soil plate on post no. 2 was bent. Post no. 2 rotated causing damage to the upstream traffic-side slip bolt and washer. The slip plate welds on the traffic and back sides of post no. 2 were torn. Post no. 3 bent downstream and twisted in the soil. Post no. 4 also bent but twisted at the ground line. Heavy contact marks were found on the upstream-back flange which were 51 mm (2 in.) long and 32 mm (1.2-in.) long. Post no. 4 had contact marks on the front flange and gouges along the top 203 mm (8 in.) of the post. Post no. 5 bent and twisted 90 degrees with contact marks on the front face. Post no. 6 twisted slightly and bent downstream with cable marks on the front face of the post. Post nos. 7 through 9 bent downstream about the weak axis. Post no. 8 encountered heavy contact marks on the upstream front flange. Minor contact marks were evident on post no. 9. Post nos. 10 through 17 remained undamaged, but rotated slightly upstream towards impact. Post no. 18 encountered slight bending at the base and damage to the soil plate, as shown in Figure 36.

The top and middle hook bolts disengaged from post no. 4. All three hook bolts on post nos. 5 through 9 were deformed and damaged, but remained attached to the posts. The hook bolts on post nos. 3 and 10 through 17 remained undamaged and attached to the posts. The cables disengaged from post nos. 4 through 9.

The maximum lateral permanent post deflection was 622 mm (24.5 in.) at the centerline of the top of post no. 4, as measured in the field. The maximum lateral dynamic post deflection was 651 mm (25.625 in.) at the centerline of post no. 5, as determined from high-speed digital video analysis. The working width of the system was 2,136 mm (84.1 in.).

6.4 Vehicle Damage

Exterior vehicle damage was minimal, as shown in Figures 37 through 40. Occupant compartment deformations to the left side and center of the floorboard were judged insufficient to cause serious injury to the vehicle occupants. The maximum lateral deformation was measured to be 13 mm (0.5 in.) at the center of the left-side dashboard. The maximum longitudinal and vertical deformations were measured to be 6 mm (0.25 in.) distributed throughout the floor pan. Complete occupant compartment deformations and the corresponding locations are provided in Appendix C.

Damage was concentrated on the left-front corner and left and right sides of the truck. Scrapes, gouges, and contact marks were found along the entire right and left sides of the vehicle. Contact marks were found on all four tires, and the right-front tire was deflated. The right-rear quarter panel was dented and scraped. A dent was found on the left side of the bumper. The grill and headlights were broken. The back side, roof, undercarriage, and all window glass remained undamaged.

6.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be 1.84 m/s (6.04

ft/s) and 2.88 m/s (9.46 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 4.55 g's and 7.00 g's, respectively. It is noted that the occupant impact velocities (OIV) and occupant ridedown decelerations (ORD) were well within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 25 and are shown graphically in Appendix D. The results from the rate transducer are also shown graphically in Appendix D.

6.6 Load Cell and String Potentiometer Results

The forces transferred to the upstream end anchor as well as and the corresponding anchor displacements provided a measure for the effectiveness of the driven steel post anchor. As previously discussed, load cells were installed parallel to each cable and at both ends of the system to monitor the loads transferred to the anchor through the cables. The results of the load cell data is summarized in Table 3.

The recorded data for both sensor types is shown in Figures 41 through 45. The total cable load was summed and plotted, as shown in Figures 41 and 42. As expected, the upstream anchor experienced a larger load than the downstream anchor, due to vehicle friction with the cables during impact. The maximum forces acting on the upstream and downstream anchors were 127.2 kN (28.60 kips) and 100.3 kN (22.55 kips), respectively. The dissection of the total cable loading to the contribution of each individual cable is shown in Figures 43 through 45. The load pattern for the top cable mimics that of the total load. The upstream anchor experienced a maximum load of 53.1 kN (11.93 kips) and the downstream anchor experienced a maximum load of 40.0 kN (9.00 kips) by the top cable. The middle cable also followed the expected pattern, with the upstream anchor sustaining a higher force than the downstream anchor. The maximum forces acting on the upstream and downstream anchors by the middle cable were 42.7 kN (9.60 kips) and 34.2 kN (7.68 kips), respectively. The bottom cable also illustrated the expected behavior, resulting in a higher force at the upstream anchor. The resultant force applied to the upstream and downstream anchors by the bottom cable were determined to be 37.4 kN (8.42 kips) and 33.1 kN (7.44 kips), respectively.

Table 3. Load Cell Results, Test CT-1

Load Type	Location	Maximum Cable Load		Time
		kN	kips	sec
Maximum Combined Cable Load	Upstream	127.2	28.60	0.48
	Downstream	100.3	22.55	0.49
Maximum Load in Top Cable	Upstream	53.1	11.93	0.61
	Downstream	40.0	9.00	0.49
Maximum Load in Middle Cable	Upstream	42.7	9.60	0.48
	Downstream	34.2	7.68	0.47
Maximum Load in Bottom Cable	Upstream	37.4	8.42	0.48
	Downstream	33.1	7.44	0.47

6.7 Discussion

The analysis of the test results for test no. CT-1 showed that the cable guardrail end terminal adequately contained and redirected a 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, but they 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. In addition, the vehicle's exit angle was less than 60 percent of the impact angle. Therefore, test no. CT-1 conducted on the cable guardrail end terminal system was determined to be acceptable according to the TL-3 safety performance criteria of test designation no. 3-35 found in NCHRP Report No. 350.

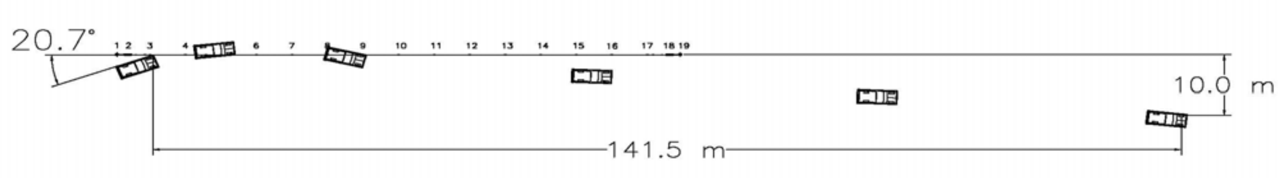
0.000 sec

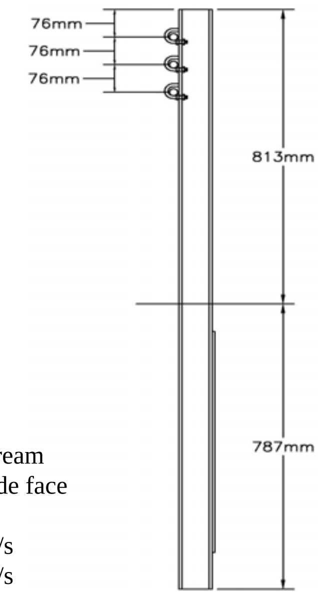
0.154 sec

0.241 sec

0.337 sec

0.509 sec

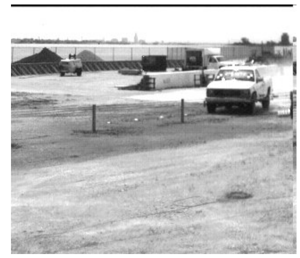




- Test Agency . . . . MwRSF
- Test Number CT-1
- Date 7/3/2002
- NCHRP 350 Test Designation 3-35
- Appurtenance . . . . Cable Guardrail End Terminal
- Total Length . . . . 77.42 m
- Key Elements - Wire Rope
  - Diameter . . . . 19 mm
  - Specifications 7x19
  - Top Mounting Height . . . . 762 mm
  - Spacing . . . . 76 mm
- Key Elements - End Anchor Posts
  - Post Nos. 1 and 19 . . . . W152x37.2 by 2,438 mm long
  - Post Nos. 2 and 18 . . . . S76x8.5 by 762 mm long with W152x13.4 by 1,829 mm long
- Key Elements - Line Post
  - Post Nos. 3-17 . . . . S76x8.5 by 1,600 mm long
  - Post Spacing . . . . 4,877 mm
- Test Vehicle
  - Type/Designation 2000P
  - Make and Model . . . . 1996 GMC 2500 3/4-ton pickup
  - Curb . . . . 1,979 kg
  - Test Inertial . . . . 2,018 kg
  - Gross Static . . . . 2,018 kg
- Impact Conditions
  - Speed . . . . 101.8 km/h
  - Angle . . . . 20.7 degrees
  - Impact Location . . . . Centerline of Post No. 3
- Exit Conditions
  - Speed . . . . 96.0 km/h
  - Angle . . . . 4 degrees
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 141.5 m downstream 10.0 m traffic-side face
- Occupant Impact Velocity
  - Longitudinal . . . . 1.84 m/s < 12 m/s
  - Lateral (not required) . . . . 2.88 m/s < 12 m/s
- Occupant Ridedown Deceleration
  - Longitudinal . . . . 4.55 g's < 20 g's
  - Lateral (not required) . . . . 7.00 g's < 20 g's
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . 584 mm
  - Dynamic . . . . 654 mm
  - Working Width . . . . 2,136 mm
- Vehicle Damage . . . . Minimal
  - VDS[7] 11-LFQ-2/11-LD-2
  - CDC[8] 11-LDES3
  - Maximum Deformation . . . . . . 6 mm

Figure 25. Summary of Test Results and Sequential Photographs, Test No. CT-1

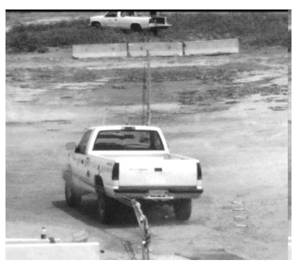
0.000 sec



0.000 sec

0.084 sec

0.156 sec



0.254 sec

0.270 sec

0.450 sec

0.368 sec

0.824 sec

0.498 sec

Figure 26. Additional Sequential Photographs, Test CT-1

0.000 sec

0.100 sec

0.234 sec

0.334 sec

0.434 sec

0.000 sec

0.167 sec

0.334 sec

0.601 sec

0.801 sec

0.934 sec

Figure 27. Additional Sequential Photographs, Test CT-1

Figure 28. Documentary Photographs, Test CT-1

Figure 29. Documentary Photographs, Test CT-1

Figure 30. Impact Location, Test CT-1

Figure 31. Vehicle Trajectory and Final Position, Test CT-1

Figure 32. System Damage, Test CT-1

Figure 33. Upstream Anchor Post Damage, Test CT-1

Figure 32. Post Nos. 2 and 3 Damage, Test CT-1

Figure 33. Post Nos. 4 and 5 Damage, Test CT-1

Figure 34. Post Nos. 6 and 7 Damage, Test CT-1

Figure 35. Post Nos. 8 and 9 Damage, Test CT-1

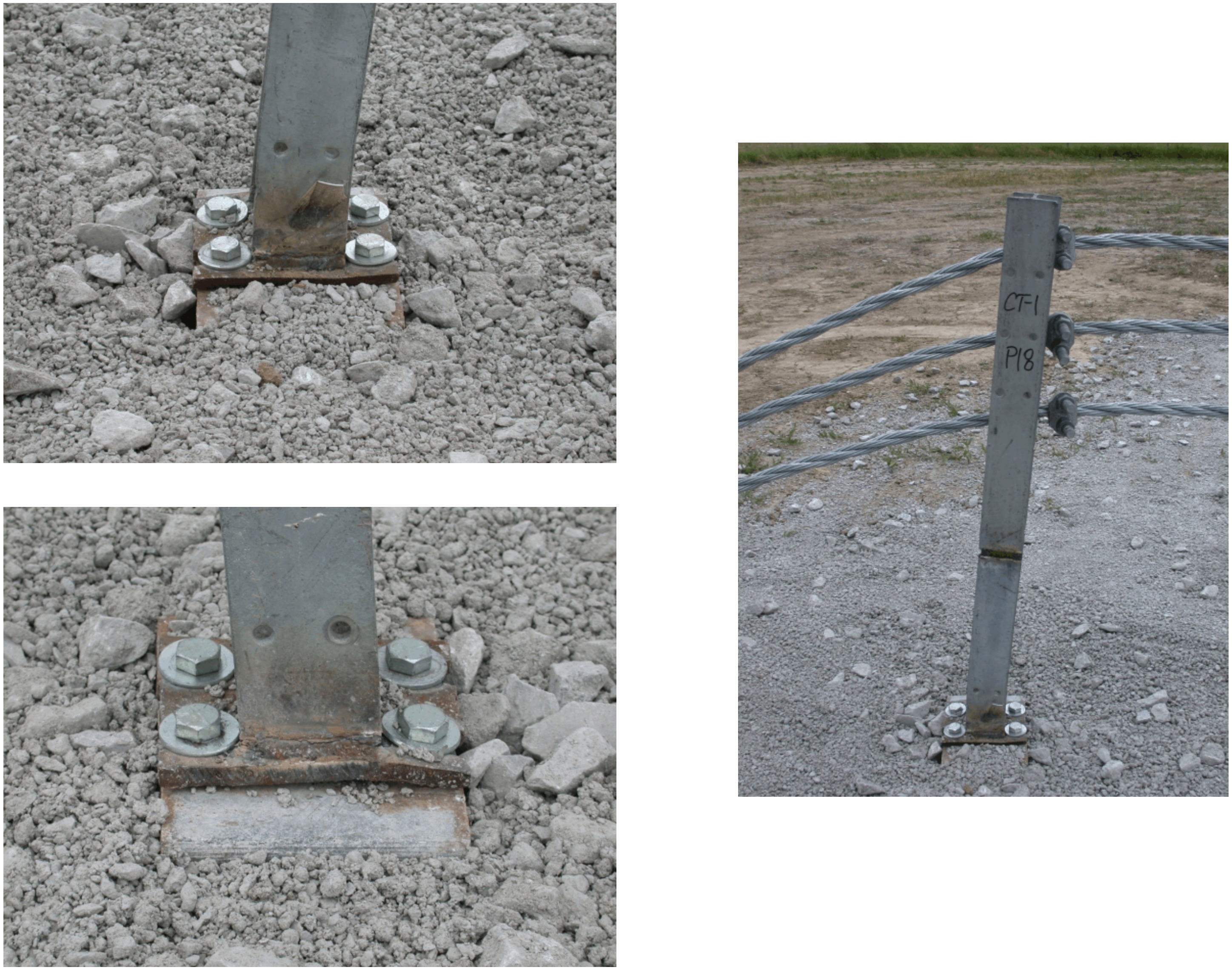


Figure 36. Post No. 18 Damage, Test CT-1

Figure 37. Vehicle Damage, Test CT-1

Figure 38. Vehicle Damage, Test CT-1

Figure 39. Right-Rear and Right-Front Tire Damage, Test CT-1

Figure 40. Occupant Compartment Damage, Test CT-1

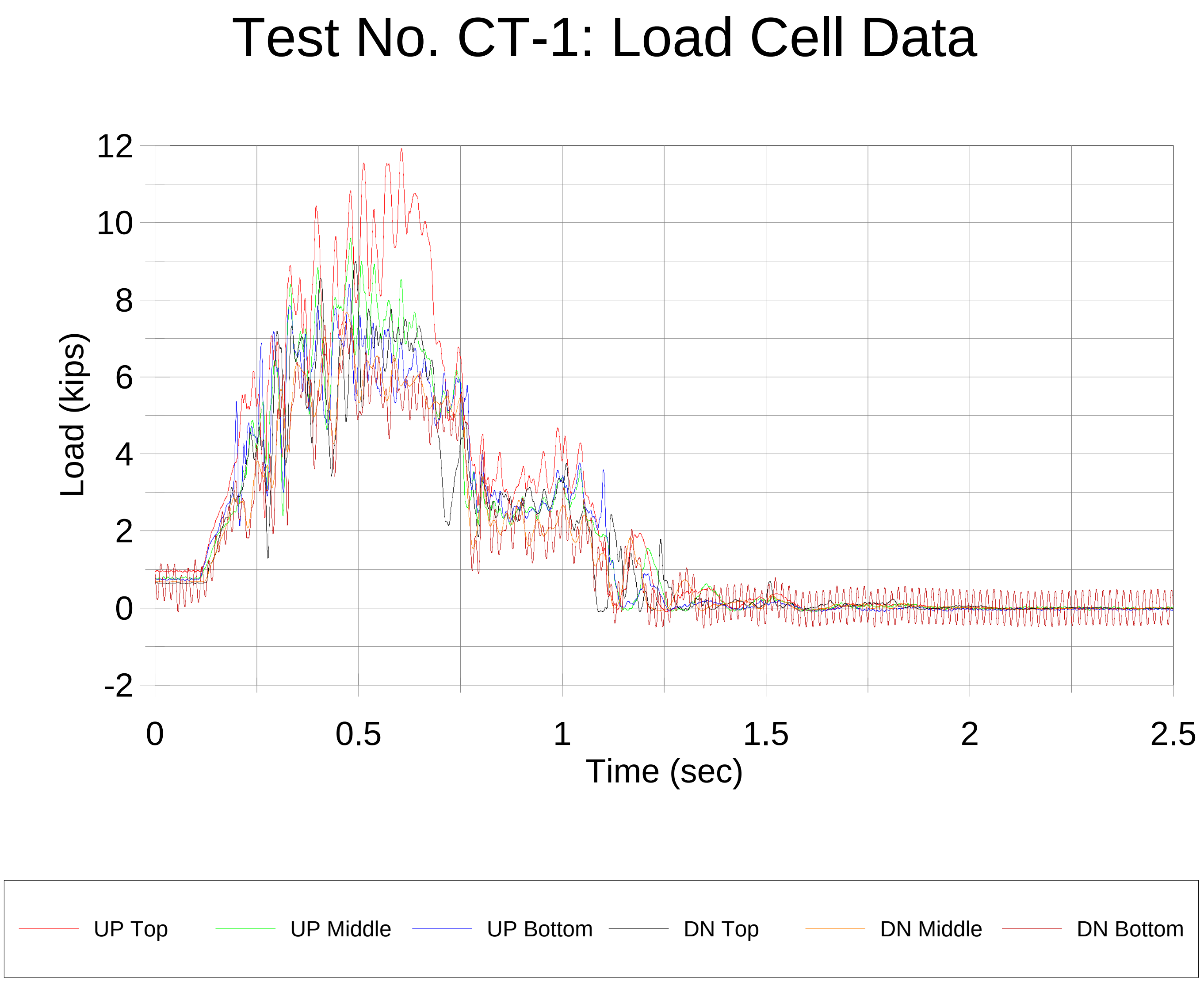


Figure 41. Force - Time History for All Cables, Test CT-1

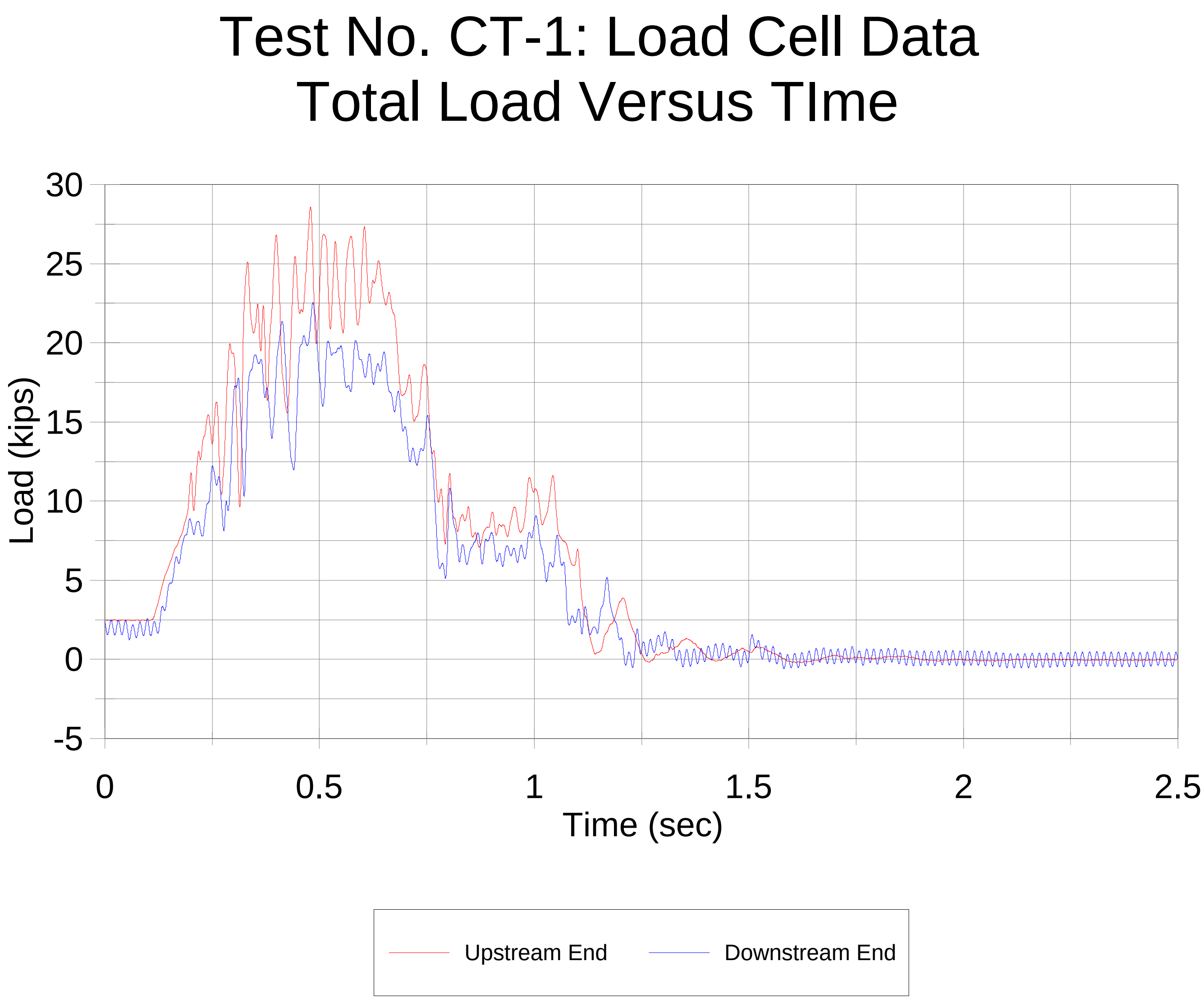


Figure 42. Force - Time History for Combined Cable Loading, Test CT-1

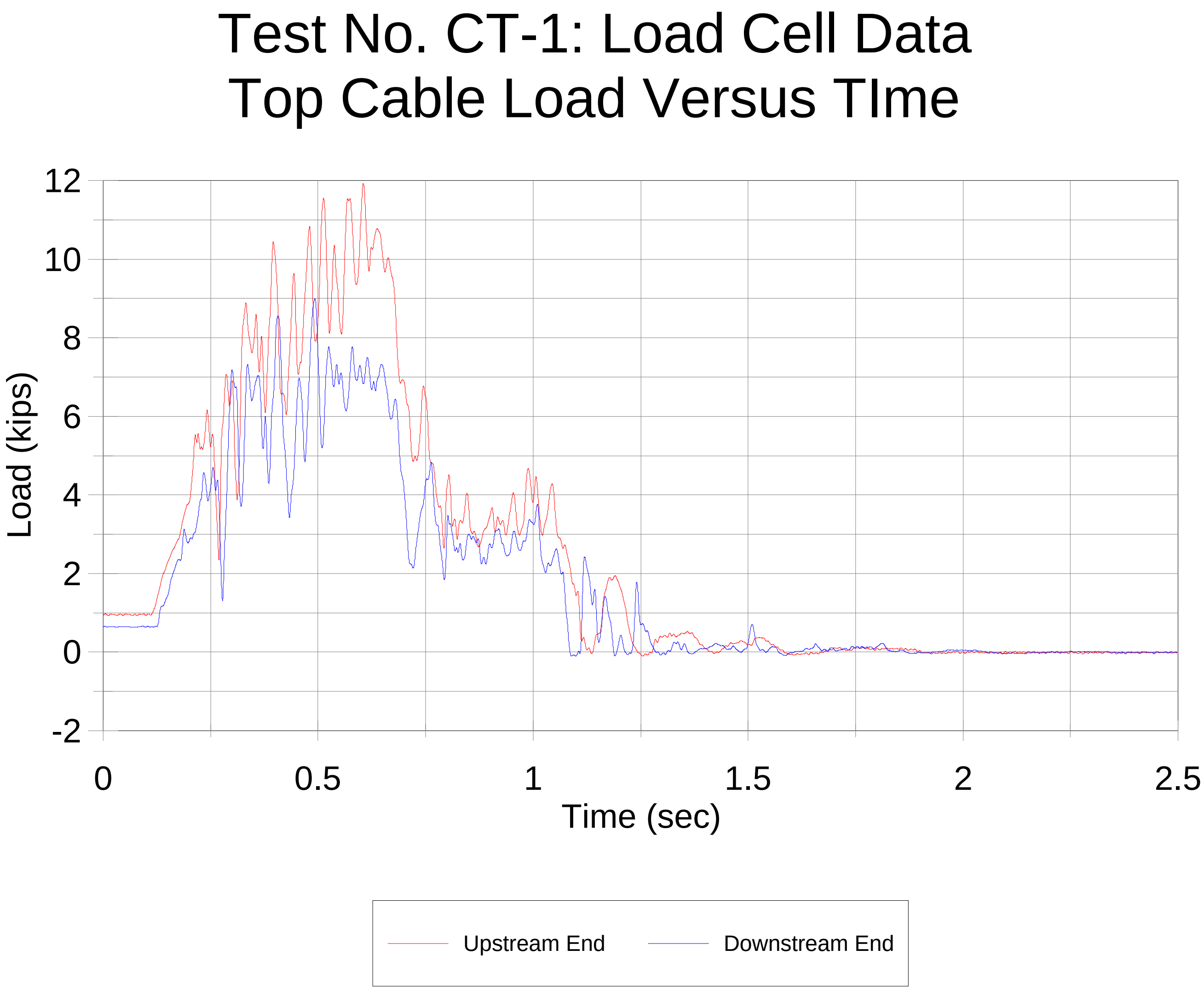


Figure 43. Force - Time History for Top Cable, Test CT-1

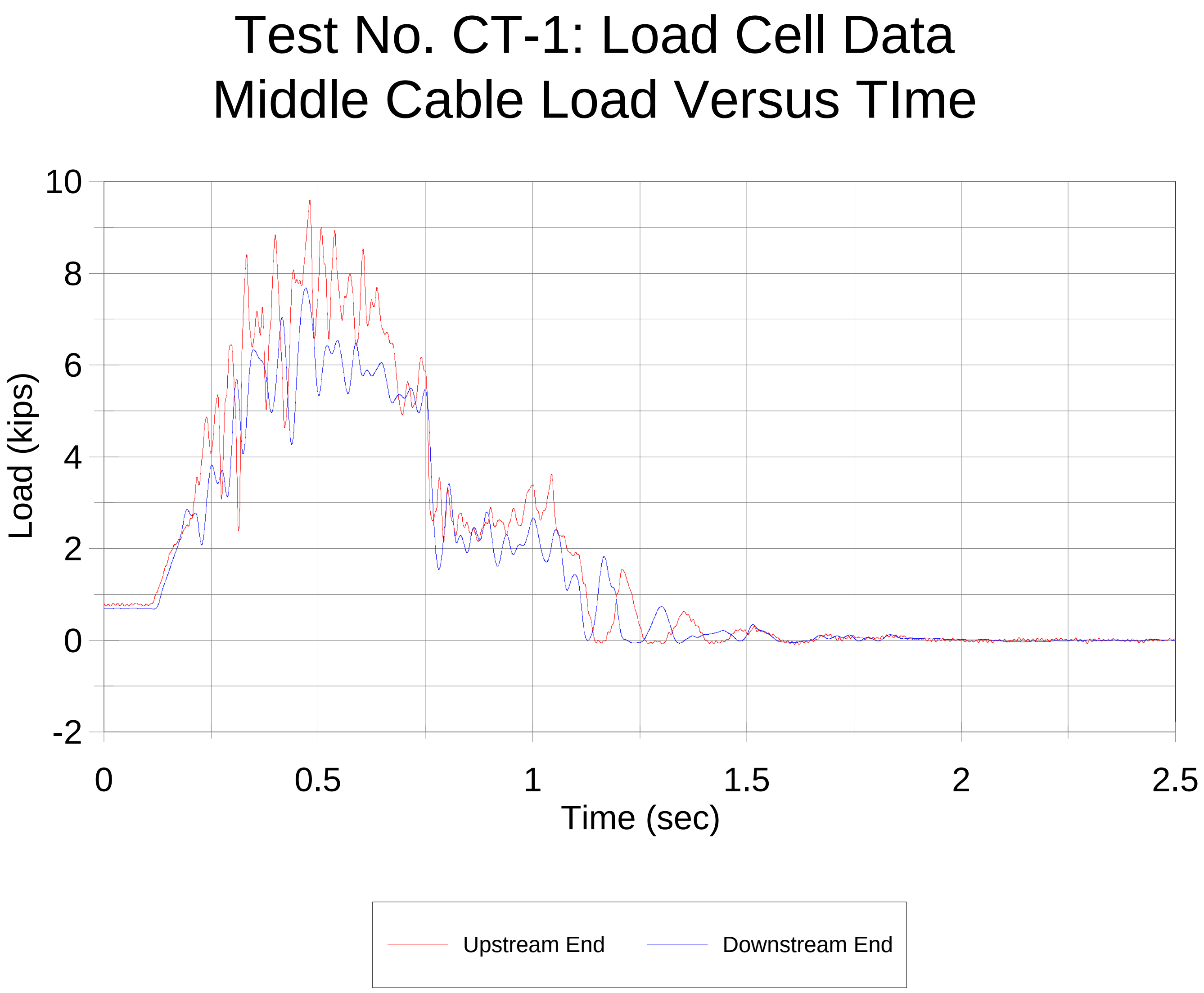


Figure 44. Force - Time History for Middle Cable, Test CT-1

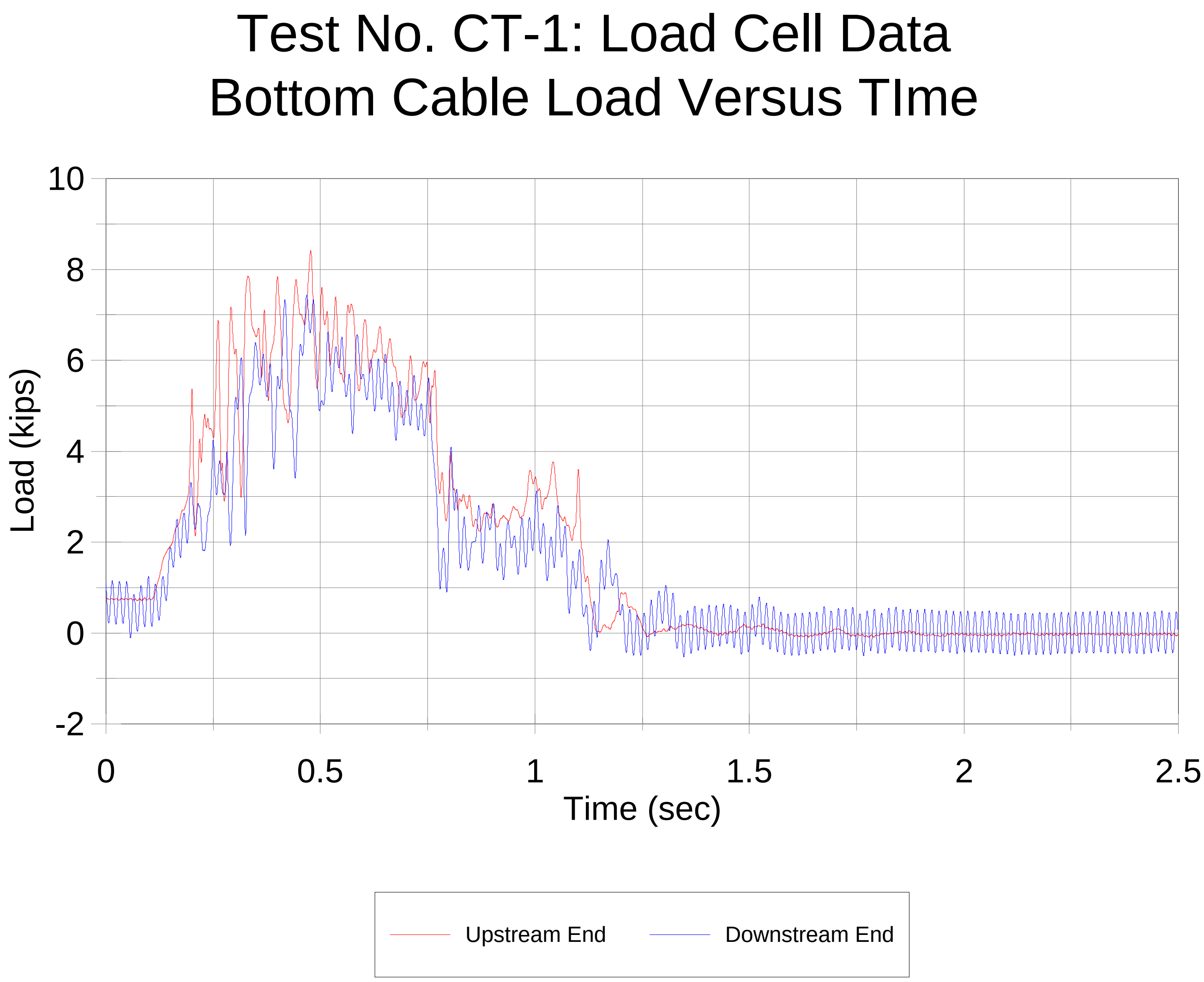


Figure 45. Force-Time History for Bottom Cable, Test CT-1

7 CRASH TEST NO. 2

7.1 Test CT-2 (Test Designation No. 3-30)

The 891-kg (1,965-lb) small car impacted the end of the cable guardrail end terminal system at a speed of 100.0 km/h (62.1 mph) and at an angle of 1.5 degrees. A summary of the test results and sequential photographs are shown in Figure 46. The summary of the test results and sequential photographs in English units are shown in Appendix B. Additional sequential photographs are shown in Figures 47 and 48. Documentary photographs of the crash test are shown in Figures 49 and 50.

7.2 Test Description

Impact occurred head-on with the right-side quarter point of the vehicle impacting at the centerline of post no. 1, as shown in Figure 58. At 0.008 sec, the cable release lever rotated downstream and released the three cables. At 0.030 sec, the front tires of the vehicle passed over the cable anchor bracket. At 0.054 sec, the front bumper of the vehicle contacted post no. 2. At 0.060 sec, the slip base of post no. 2 engaged. At 0.074 sec, the front tires passed the original position of post no. 2. At 0.118 sec, the vehicle pitched forward, and the vehicle's undercarriage contacted the foundation post of post no. 2. At 0.132 sec, post no. 2 moved toward the right side of the vehicle while in contact with the front bumper. At 0.166 sec, the vehicle contacted post no. 3 and yawed counterclockwise. At this same time, the cable release lever dug into the ground and was forced under the vehicle. At 0.184 sec, the vehicle rolled counter-clockwise toward the left side. At 0.195 sec, the vehicle traversed over post no. 3. Post no. 2 remained positioned on the bumper until approximately 0.223 sec. At this same time, the cables accumulated on the right side of the vehicle as the vehicle yawed clockwise, and the right-front tire became airborne. At 0.300 sec, the right-rear tire became airborne, and the vehicle continued rolling counter-clockwise toward the left side. At 0.755 sec, all tires became airborne. At 1.101 sec, the vehicle rolled onto its left side and contacted the ground with the left-front corner of the roof. At 1.312 sec, the vehicle rolled over such that the hood and the front of the roof contacted the ground. At 1.518 sec, the vehicle became airborne again. At 1.879 sec, the left-rear corner of the vehicle contacted the ground, and the windshield disengaged from the vehicle. The vehicle continued to roll end-over-end until it came to rest at 5.960 sec. The vehicle came to rest 64.2 m (210 ft - 8in.) downstream and 1.7 m (5 ft - 7in.) laterally behind the traffic-side face of the barrier. The trajectory and final position of the small car are shown in Figure 46 and 52.

7.3 Barrier Damage

Damage to the cable guardrail end terminal was moderate, as shown in Figures 53 through 61. Barrier damage consisted of contact marks on posts, deformed line posts, disengaged cable, and deformed cable hooks. The length of vehicle contact along the cable system was approximately 28.9 m (94 ft - 10 in.) downstream, which spanned from post no. 1 through post no. 8.

The cable release lever at post no. 1 was dented, scratched, and disengaged from the system. The cable release lever was located 3.05 m (10 ft) downstream of post no. 8 and 3.35 m (11 ft) laterally away from the traffic-side face of the system. Minor scratching and scraping around the bolt locations was found on post no. 2. Minor buckling and flange twisting was found on the top section of post no. 2. The top section of post no. 2 was located 0.91 m (3 ft) upstream from post no. 8 and 6.10 m (20 ft) laterally away from the traffic-side face of the system. Post nos. 3 through 8 rotated downstream in the soil and bent about the weak axis. However, post nos. 6 and 7 were bent nearly to the ground. Heavy contact marks were visible on the upstream flanges of post nos. 3 through 7.

The remainder of the downstream posts showed no evidence of movement nor damage.

All of the hook bolts on post nos. 3 through 8 were deformed, but remained attached to the posts. All three cables disengaged from post nos. 3 through 7, except the bottom cable remained attached to post no. 5. The threaded cable end fittings were fractured at the nut locations.

7.4 Vehicle Damage

Exterior and interior damage was extensive, as shown in Figures 62 and 63. Most of the damage that occurred was due to the multiple rollovers of the vehicle. It should be noted that it was impossible to distinguish the damage due to the impact from that due to the rollover.

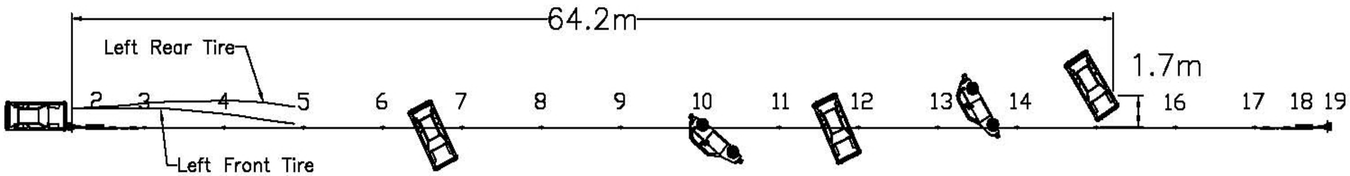
7.5 Occupant Risk Values

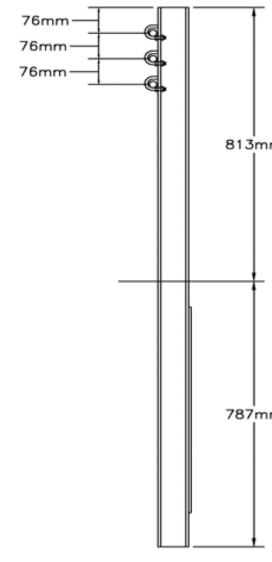
The longitudinal and lateral occupant impact velocities were determined to be 2.99 m/s (9.80 ft/s) and -0.12 m/sec (-0.39 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 5.37 g's and 3.99 g's, respectively. It is noted that the occupant impact velocities (OIVs) and occupant ridedown decelerations (ORDs) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 46, and results are shown graphically in Appendix E. The results from the rate transducer are also shown graphically in Appendix E.

7.6 Discussion

The analysis of the test results for test no. CT-2 showed that the cable guardrail end terminal system did not contain nor redirect the 820C vehicle, since the vehicle did not remain upright after collision with the barrier. There were detached elements which showed potential for penetrating the occupant compartment. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did occur with the deformation of the vehicle's roof and penetration of the floorboard. After collision, the vehicle's trajectory did not intrude into adjacent traffic lanes. Test no. CT-2 was determined to be unacceptable according to the TL-3 safety performance criteria of test designation no. 3-30 found in NCHRP Report No. 350 due to vehicle rollover.

0.000 sec | 0.054 sec | 0.132 sec | 0.166 sec | 0.259 sec





- Test Agency . . . . MwRSF
- Test Number CT-2
- Date 7/16/2002
- NCHRP 350 Test Designation 3-30
- Appurtenance . . . . Cable Guardrail End Terminal
- Total Length . . . . 77.42 m
- Key Elements - Wire Rope
  - Diameter . . . . 19 mm
  - Size 7x19
  - Top Mounting Height . . . . 762 mm
  - Spacing . . . . 76 mm
- Key Elements - End Anchor Posts
  - Post Nos. 1 and 19 . . . . W152x37.2 by 2,438 mm long
  - Post Nos. 2 and 18 . . . . S76x8.5 by 762 mm long with W152x13.4 by 1,829 mm long
- Key Elements - Line Post
  - Post Nos. 3-17 . . . . S76x8.5 by 1,600 mm long
  - Post Spacing . . . . 4,877 mm long
- Test Vehicle
  - Type/Designation 820C
  - Make and Model . . . . 1995 Geo Metro
  - Curb . . . . 704 kg
  - Test Inertial . . . . 816 kg
  - Gross Static . . . . 891 kg
- Impact Conditions
  - Speed . . . . 100.0 km/h
  - Angle . . . . 1.5 degrees
  - Impact Location . . . . Centerline of Post No. 1
- Exit Conditions
  - Speed . . . . N/A
  - Angle . . . . N/A
  - Exit Box Criterion . . . . N/A
- Post-Impact Trajectory
  - Vehicle Stability . . . . Unsatisfactory
  - Stopping Distance . . . . 64.2 m downstream; 1.7 m behind
- Occupant Impact Velocity
  - Longitudinal . . . . 2.99 m/s < 12 m/s
  - Lateral . . . . -0.12 m/s < 12 m/s
- Occupant Ridedown Deceleration
  - Longitudinal . . . . 5.37 Gs < 20 g's
  - Lateral . . . . 3.99 Gs < 20 g's
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . N/A
  - Dynamic . . . . N/A
  - Working Width . . . . N/A
- Vehicle Damage . . . . Extensive
  - VDS[7] . . . . 12-L&D-6
  - CDC[8] 12-TDD08
  - Maximum Deformation . . . . N/A

Figure 46. Summary of Test Results and Sequential Photographs, Test No. CT-2

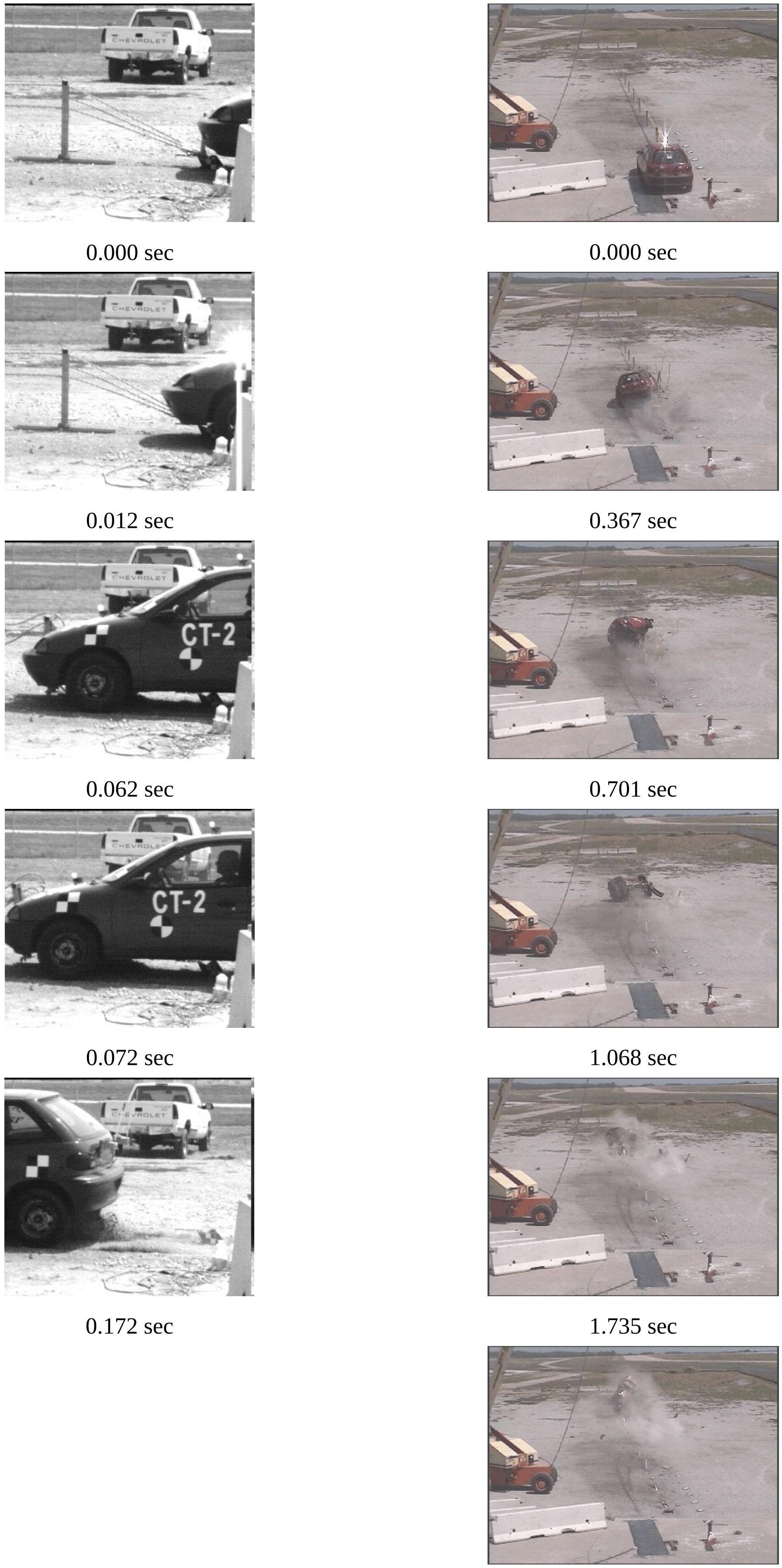


Figure 47. Additional Sequential Photographs, Test CT-2

0.000 sec

0.000 sec

0.033 sec

0.067 sec

0.167 sec

0.100 sec

0.300 sec

0.133 sec

0.434 sec

0.167 sec

Figure 48. Additional Sequential Photographs, Test CT-2

Figure 49. Documentary Photographs, Test CT-2

Figure 50. Documentary Photographs, Test CT-2

Figure 51. Impact Location, Test CT-2

Figure 52. Vehicle Final Position and Trajectory Marks, Test CT-2

Figure 53. System Damage, Test CT-2

Figure 54. Post Nos. 1 and 2 Damage, Test CT-2

Figure 55. Post Nos. 3 and 4 Damage, Test CT-2

Figure 56. Post Nos. 5 and 6 Damage, Test CT-2

Figure 57. Post Nos. 7 and 8 Damage, Test CT-2

Figure 58. Cable Release Lever Damage, Test CT-2

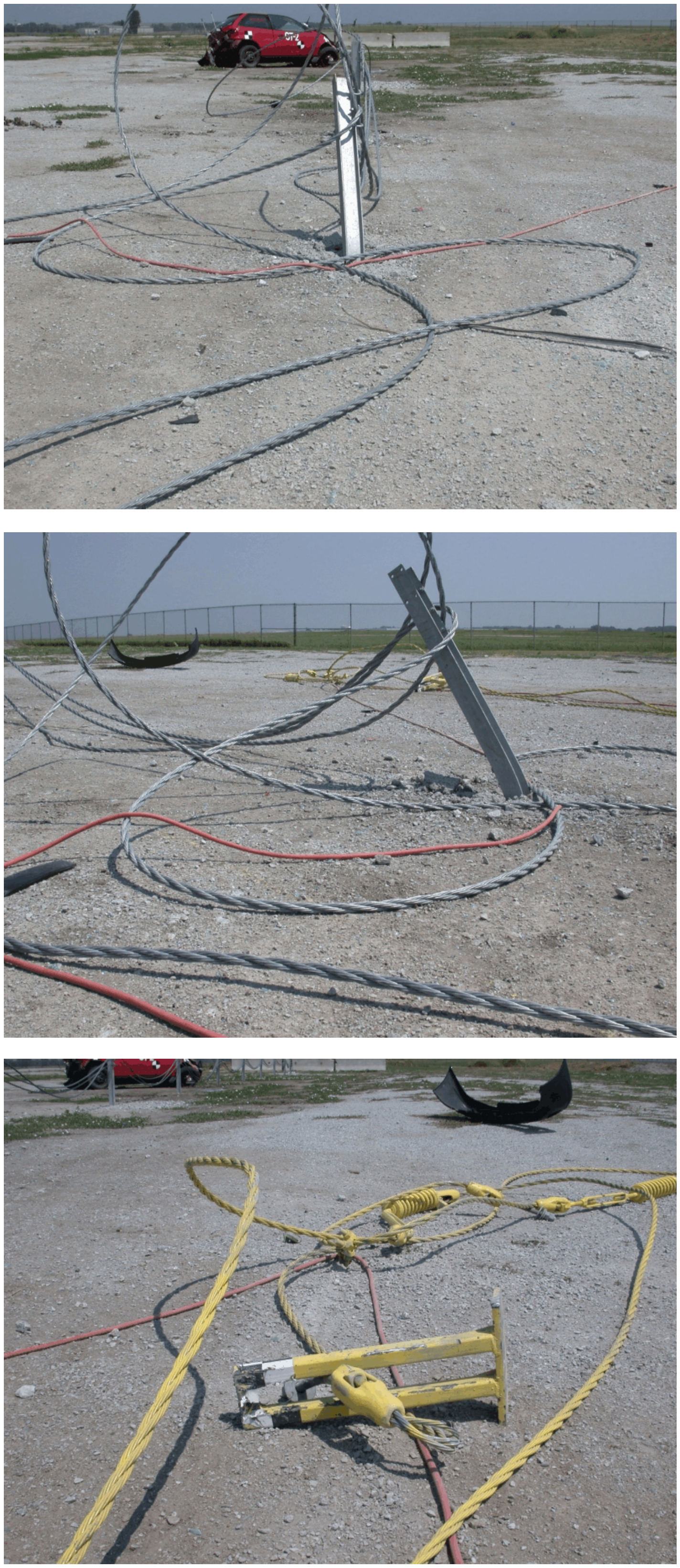


Figure 59. Cable Damage, Test CT-2

Figure 60. Threaded Rod Damage, Test CT-2

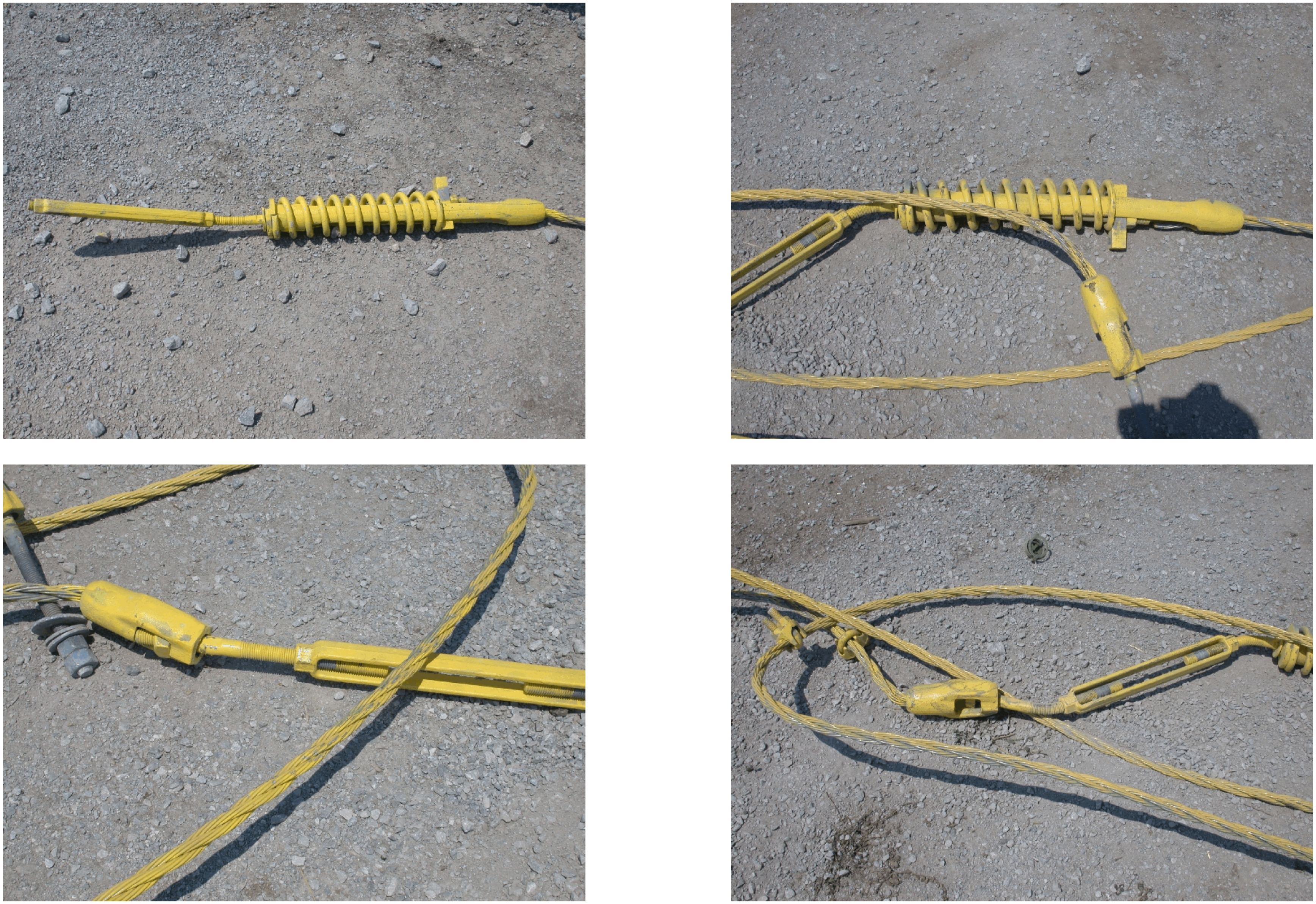


Figure 61. Cable Turnbuckle and Compensator Damage, Test CT-2

Figure 62. Vehicle Damage, Test CT-2

Figure 63. Occupant Compartment Deformation, Test CT-2

8 DESIGN MODIFICATION DETAILS - DESIGN NO. 2

Following the unsuccessful performance of test no. CT-2, modifications were made to the system in an attempt to improve impact performance. After reviewing the high-speed videos and photographs, the cable release lever was determined to be responsible for the occupant compartment penetration in the floorpan and rear. As the vehicle passed over the cable release lever it became lodged between the ground and the floorpan of the vehicle, causing the vehicle to be propelled upward, and subsequently rolling over. It was then determined that retaining the cable release lever would be prudent, and therefore, in the modified system, a cable was used to retain the cable release lever attached to the anchor bracket. The 9.5-mm (0.375-in.) diameter, 7x19 galvanized aircraft cable was 813 mm (32 in.) long.

System design no. 2 was 77.42 m (254 ft) and consisted of four major structural components: (1) wire rope; (2) posts; (3) cable compensator assemblies; and (4) anchor assemblies. The design details of the modified cable terminal system are shown in Figure 64. The complete sets of system drawings, along with the corresponding English-unit drawings, are shown in Appendix F. Photographs of the modifications are shown in Figure 65.

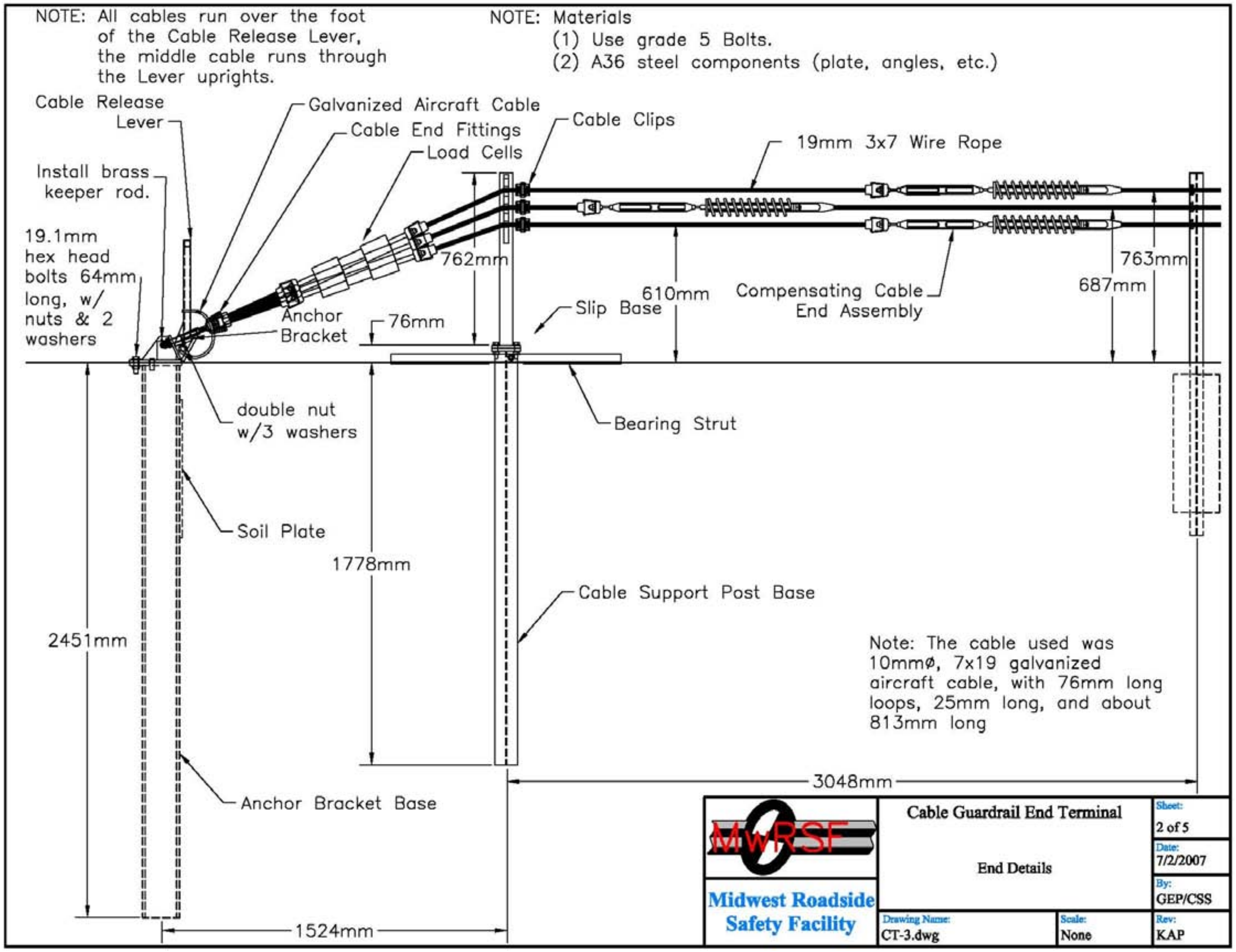


Figure 64. End Anchor Details, Design No. 2

Figure 65. Cable to Keep Cable Release Lever Attached to System, Design No. 2

9 CRASH TEST NO. 3

9.1 Test CT-3 (Test Designation No. 3-30)

The 885-kg (1,952-lb) small car impacted the end of the cable guardrail end terminal system at a speed of 98.8 km/h (61.4 mph) and at an angle of 0.1 degrees. A summary of the test results and sequential photographs are shown in Figure 66. The summary of the test results and sequential photographs in English units are shown in Appendix B. Additional sequential photographs are shown in Figures 67 through 69. Documentary photographs of the crash test are shown in Figures 70 and 71.

9.2 Test Description

Vehicle impact occurred head-on with the right-side quarter-point of the vehicle impacting the centerline of post no. 1, as shown in Figure 87. Immediately after impact, the cables released from the cable anchor bracket. At 0.038 sec after impact, post no. 2 deflected downstream with the cables. At 0.054 sec, the right-front side of the bumper contacted post no. 2. At 0.066 sec, post no. 2 disengaged from the slip base, but remained in contact with the vehicle. At 0.112 sec, post no. 2 rotated over the bumper of the vehicle and slid along the hood. At 0.148 sec, the cables accumulated around the front bumper. At 0.159 sec, post no. 3 deflected and deformed toward the right side of the vehicle. At 0.176 sec, the vehicle contacted post no. 3, and the top cable slid over the hood and onto the windshield. At 0.220 sec, the cable compensator contacted the right side of the windshield. At 0.260 sec, spider-web cracking and an indentation appeared in the windshield. At this same time, the vehicle yawed due to contact with post no. 3. At 0.376 sec, the vehicle contacted post no. 4 near the center of the front bumper and rolled towards its left side. At 0.408 sec, post no. 4 deflected downstream while in contact with the bumper. At 0.560 sec, the vehicle continued to roll towards its left side, and the right side tires were airborne. At 0.574 sec, the vehicle contacted post no. 5. At 0.844 sec, the left-front corner of the bumper contacted post no. 6. At 1.186 sec, the vehicle rolled onto its left side as it yawed clockwise. At 1.608 sec, the vehicle had rolled onto its hood and roof. At 2.026 sec, the right-rear corner of the bumper contacted the ground as the vehicle pitched forward. At 2.236 sec, the vehicle became airborne and subsequently rolled three complete revolutions and came to rest at approximately 4.200 sec. The vehicle came to rest 47.36 m (157 ft - 3 in.) downstream from impact and 5.72 m (18 ft - 9 in.) laterally from the traffic-side face of the barrier. The trajectory and final position of the small car are shown in Figures 66 and 73.

9.3 Barrier Damage

Damage to the cable guardrail end terminal was moderate, as shown in Figures 74 through 81. Barrier damage consisted of contact marks on posts, deformed line posts, disengaged cable and deformed cable hooks. The length of vehicle contact along the cable system was approximately 24.0 m (78 ft - 8 in.), which spanned from post no. 1 through post no. 7.

Minor scrapes were found around the edge of the anchor bracket keeper plate. The brass keeper rod was deformed. The cable release lever disengaged from the system. The upstream and traffic-side edges of the bearing strut of post no. 2 was damaged. The top portion of post no. 2 disengaged from the system, and contact marks were found on this portion of the post. Post no. 3 was bent downstream with very little rotation and twisting. Contact marks and scrapes were found on the upstream edge of the traffic-side and backside flanges. Post no. 4 bent downstream and encountered contact marks and gouges along the upstream edges of the traffic-side and backside flanges. Post no. 5 was bent downstream with little twisting and rotation. Post no. 6 bent to almost in contact with the ground and rotated backwards in the soil slightly. Post no. 7 was bent downstream, although not as severe as post nos. 3 through 6. The remainder of the downstream posts showed no evidence of movement nor damage.

All twelve hook bolts on post nos. 3 through 6 were deformed but remained attached to the posts. All three cables disengaged from post nos. 3 through 6, except the bottom cable remained attached to post no. 5.

9.4 Vehicle Damage

Exterior and interior vehicle damage was extensive, as shown in Figures 82 through 84. It should be noted that it was almost impossible to distinguish the damage due to impact from that due to the rollovers.

The oil pan was deformed and gouged with one rectangular mark 51 mm (2 in.) wide which extended for the entire length of the pan and one circular contact mark on the right-side edge of the pan. Additional contact marks and deformations occurred beginning at the oil pan and continuing to the lower face of the right-side control arm. Lighter contact marks were found 305 mm (12 in.) behind the marks on the right-side control arm.

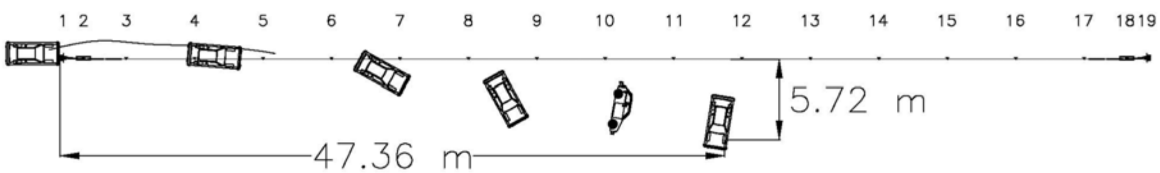
9.5 Occupant Risk Values

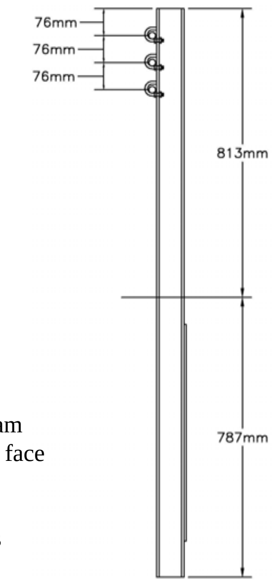
The longitudinal and lateral occupant impact velocities were determined to be 3.36 m/s (11.03 ft/s) and -0.22 m/s (-0.71 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 9.56 g’s and -13.72 g’s, respectively. It is noted that the occupant impact velocities (OIVs) and occupant ridedown decelerations (ORDs) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 66. Results are shown graphically in Appendix G. The results from the rate transducer are shown graphically in Appendix G.

9.6 Discussion

Interaction with the cable release lever which detached from the system and penetrated the floorpan is believed to have induced vehicle rollover. Therefore, test no. CT-3 was determined to be unacceptable according to the TL-3 safety performance criteria of test designation no. 3-30 found in NCHRP Report No. 350 due to vehicle rollover.

0.000 sec | 0.096 sec | 0.190 sec | 0.274 sec | 0.434 sec

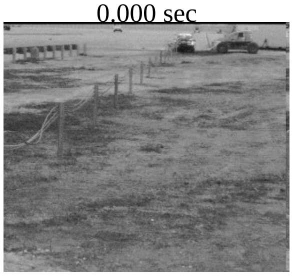




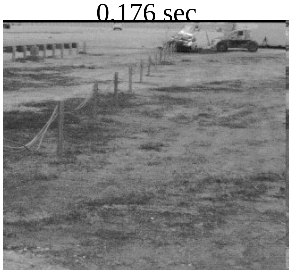
- Test Agency . . . . MwRSF
- Test Number CT-3
- Date 10/10/2003
- NCHRP 350 Test Designation 3-30
- Appurtenance . . . . Cable Guardrail End Terminal
- Total Length . . . . 77.42 m
- Key Elements - Wire Rope
  - Diameter . . . . 19 mm
  - Size 7x19
  - Top Mounting Height . . . . 762 mm
  - Spacing . . . . 76 mm
- Key Elements - End Anchor Post
  - Post Nos. 1 and 19 . . . . W152x37.2 by 2,438 mm long
  - Post Nos. 2 and 18 . . . . S76x8.5 by 762 mm long with W152x13.4 by 1,829 mm long
- Key Elements - Line Post
  - Post Nos. 3-17 . . . . S76x8.5 by 1,600 mm long
  - Spacing . . . . 4,877 mm
- Test Vehicle
  - Type/Designation 820C
  - Make and Model . . . . 1998 Geo Metro
  - Curb . . . . 695 kg
  - Test Inertial . . . . 810 kg
  - Gross Static . . . . 885 kg
- Impact Conditions
  - Speed . . . . 98.8 km/h
  - Angle . . . . 0.1 degrees
  - Impact Location . . . . Centerline of post no. 1
- Exit Conditions
  - Speed . . . . N/A
  - Angle . . . . N/A
  - Exit Box Criterion . . . . N/A
- Post-Impact Trajectory
  - Vehicle Stability . . . . Unsatisfactory
  - Stopping Distance . . . . 47.36 m downstream
    5.72 m traffic-side face
- Occupant Impact Velocity
  - Longitudinal . . . . 3.36 m/s < 12 m/s
  - Lateral . . . . -0.22 m/s < 12 m/s
- Occupant Ridedown Deceleration
  - Longitudinal . . . . 9.56 g's < 20 g's
  - Lateral . . . . -13.72 g's < 20 g's
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . N/A
  - Dynamic . . . . N/A
  - Working Width . . . . N/A
- Vehicle Damage . . . . Extensive
  - VDS[7] . . . . 12-L&T-6
  - CDC[8] 12-TDD08
  - Maximum Deformation . . . . N/A

Figure 66. Summary of Test Results and Sequential Photographs, Test No. CT-3

0.000 sec



0.176 sec



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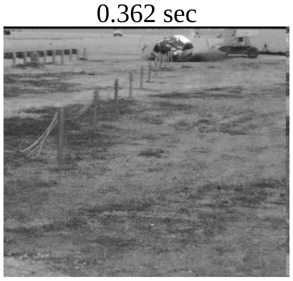
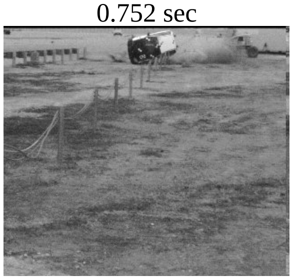
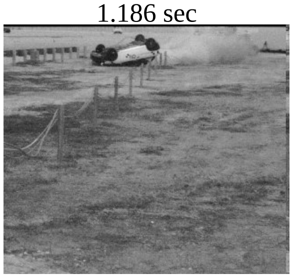


0.752 sec

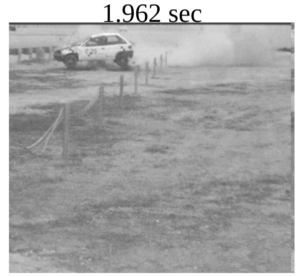


1.186 sec

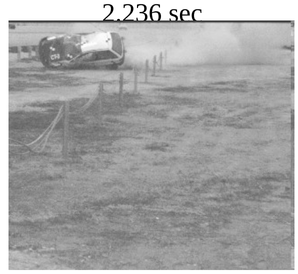


1.608 sec

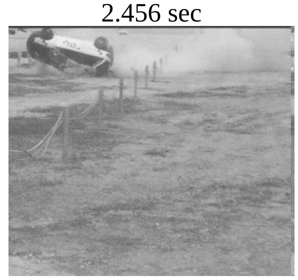
1.962 sec



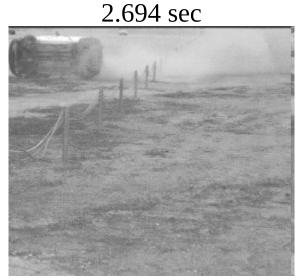
2.236 sec



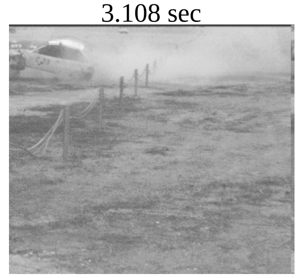
2.456 sec



2.694 sec



3.108 sec



3.478 sec

Figure 67. Additional Sequential Photographs, Test CT-3

0.000 sec

0.000 sec

0.167 sec

0.167 sec

0.367 sec

0.567 sec

0.601 sec

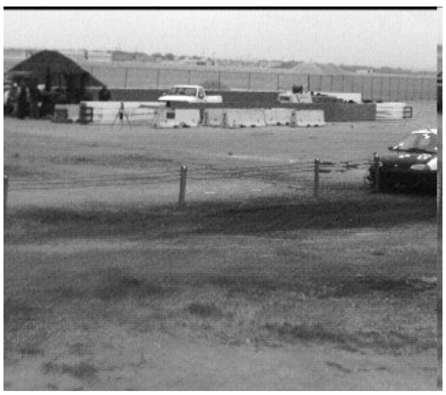
1.101 sec

0.701 sec

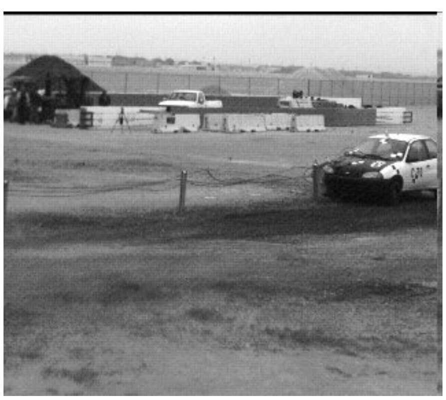
1.268 sec

Figure 68. Additional Sequential Photographs, Test CT-3

0.000 sec

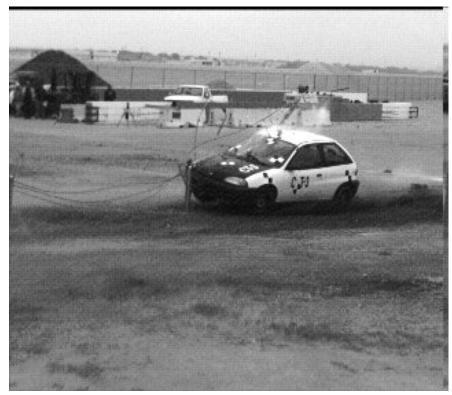


0.072 sec

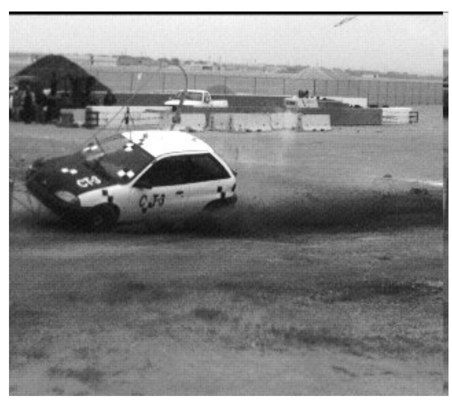


0.158 sec

0.240 sec



0.368 sec



0.560 sec

Figure 69. Additional Sequential Photographs, Test CT-3

Figure 70. Documentary Photographs, Test CT-3

Figure 71. Documentary Photographs, Test CT-3

Figure 72. Impact Location, Test CT-3

Figure 73. Vehicle Trajectory and Final Position, Test CT-3

Figure 74. System Damage, Test CT-3

Figure 75. System Damage, Test CT-3

Figure 76. Post No. 1 and Cable Release Lever Damage, Test CT-3

Figure 77. Post No. 2 Damage, Test CT-3

Figure 78. Post No. 3 Damage, Test CT-3

Figure 79. Post Nos. 4 and 5 Damage, Test CT-3

Figure 80. Post Nos. 6 and 7 Damage, Test CT-3

Figure 81. Downstream Anchorage Damage, Test CT-3

Figure 82. Vehicle Damage, Test CT-3

Figure 83. Vehicle Damage, Test CT-3

Figure 84. Occupant Compartment Damage, Test CT-3

10 DESIGN MODIFICATION DETAILS - DESIGN NO. 3

Following the unsuccessful performance of test no. CT-3, modifications were made to the system in an attempt to improve the impact performance. After reviewing the high-speed videos, the cable release mechanism performed just as designed by releasing the cables. However, after the vehicle engaged the S76x8.5 (S3x5.7) posts downstream of the anchor, the front corner of the vehicle became elevated, resulting in vehicle rollover.

Based on the unsatisfactory performance of the cable terminal and cable median systems, an investigation into the weak axis performance of both the S-posts and M-posts was undertaken (9). This investigation proved the capability of the S76x8.5 (S3x5.7) post to induce rollover. It was determined that modifying the posts in the region of the terminal would potentially reduce the observed vehicle instability.

Therefore, in the modified system, five of the line posts, post nos. 3 through 7, were changed from standard S-posts to slip-base posts. System details are shown in Figures 85 through 91. The complete set of system drawings along with the corresponding English-unit drawings are shown in Appendix H. Photographs of the modified system are shown in Figures 92 through 93.

The slip base posts were configured with S76x8.5 (S3x5.7) sections measuring 762 mm (30 in.) long for the slip posts. The slip posts were mounted on foundation posts with W152x13.4 (W6x9) sections measuring 1,829 mm (72 in.) long. The foundation post was embedded to a depth of 1,778 mm (70 in.). A slip base plate was welded to the bottom of the slip post and the top of the foundation post, as shown in Figure 87. Four 13-mm diameter x 51-mm long (0.5-in. x 2-in.) ASTM A307 bolts with nuts and washers were used to form the slip base configuration. The top cable hook was located 89 mm (3.5 in.) down from the top of the post with the middle and lower cable hooks

166 mm and 242 mm (6.5 in. and 9.5 in.) from the top of the post, respectively.

Once again, the system was 77.42 m (254 ft) and consisted of four major structural components: (1) wire rope; (2) slip-base posts; (3) standard cable posts; (4) cable compensator assemblies; and (5) anchor assemblies. The upper, middle, and lower cables were located 762 mm, 686 mm, and 610 mm (30 in., 27 in., and 24 in.) from the ground, respectively. The line posts were spaced 4,877 mm (16 ft) on center.

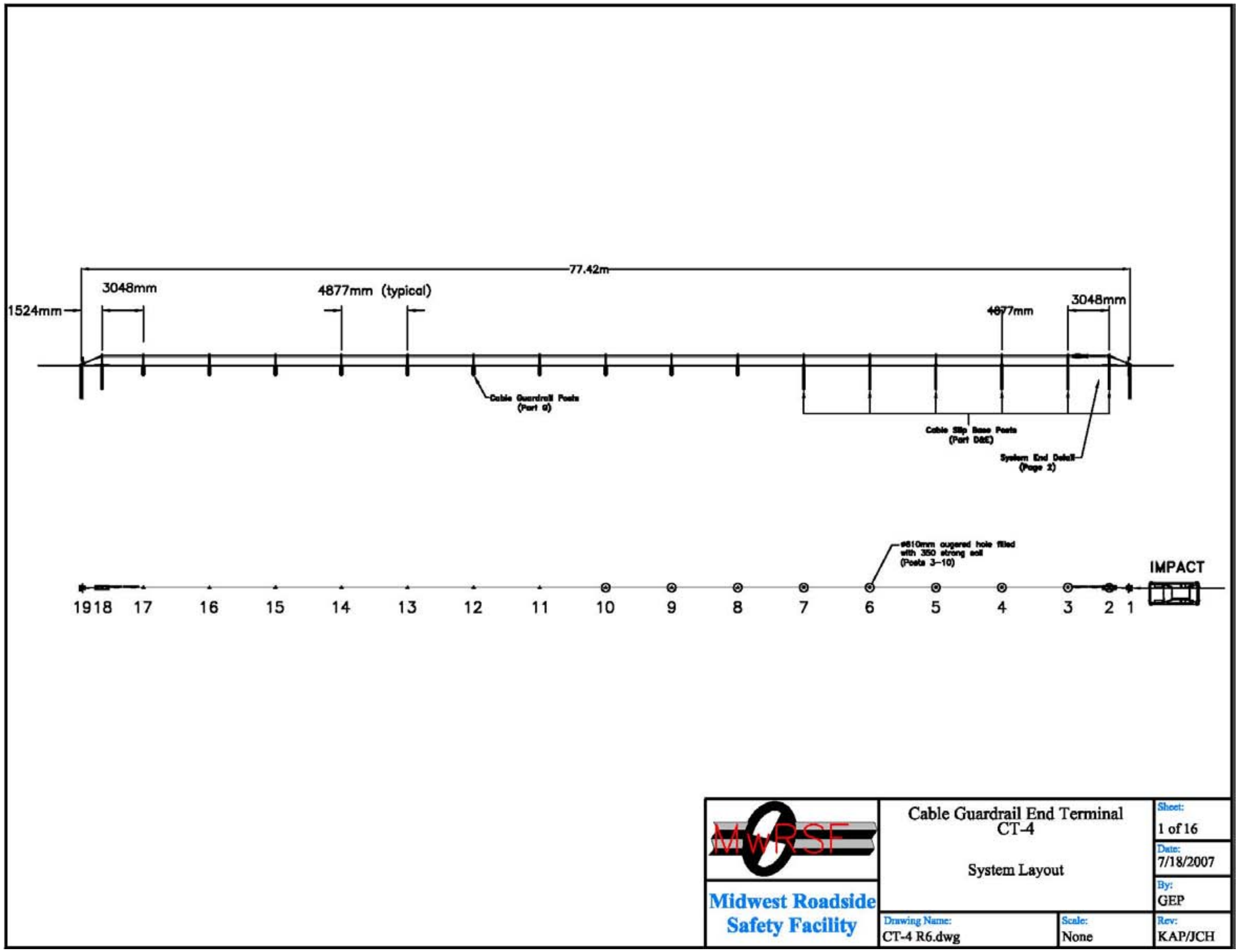


Figure 85. System Details, Design No. 3

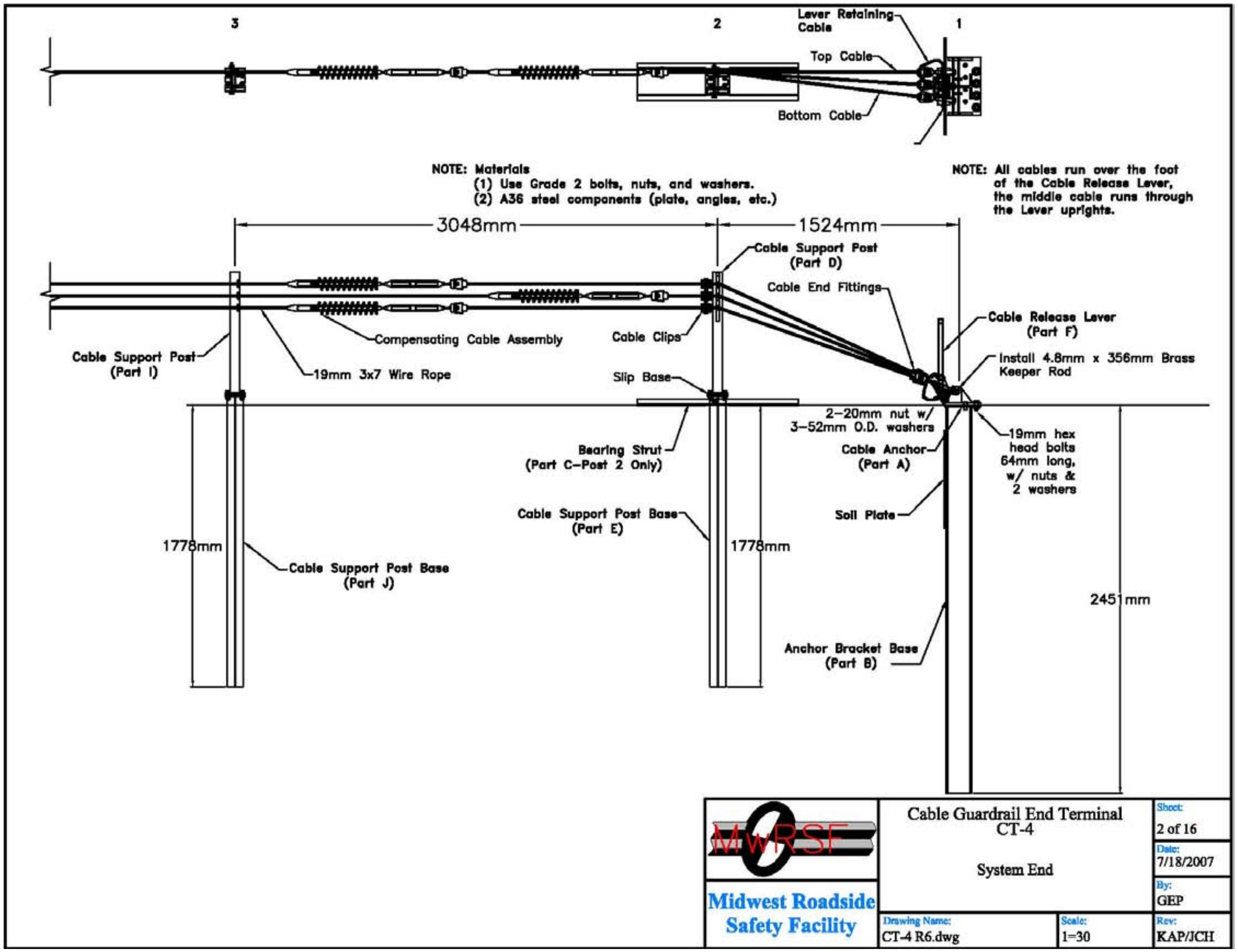


Figure 86. End Details, Design No. 3

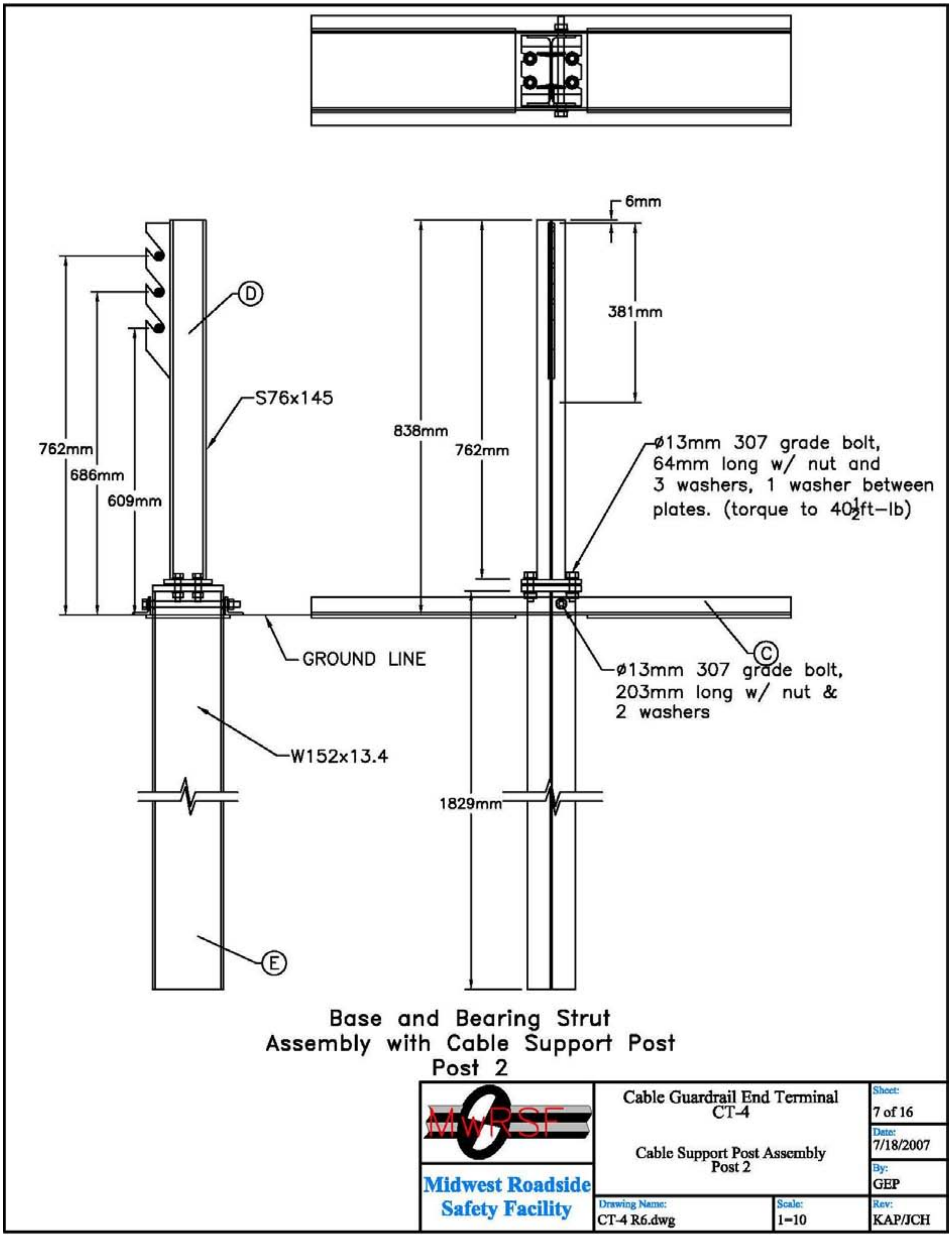


Figure 87. End Terminal Line Post Details, Post Nos. 3 through 7, Design No. 3

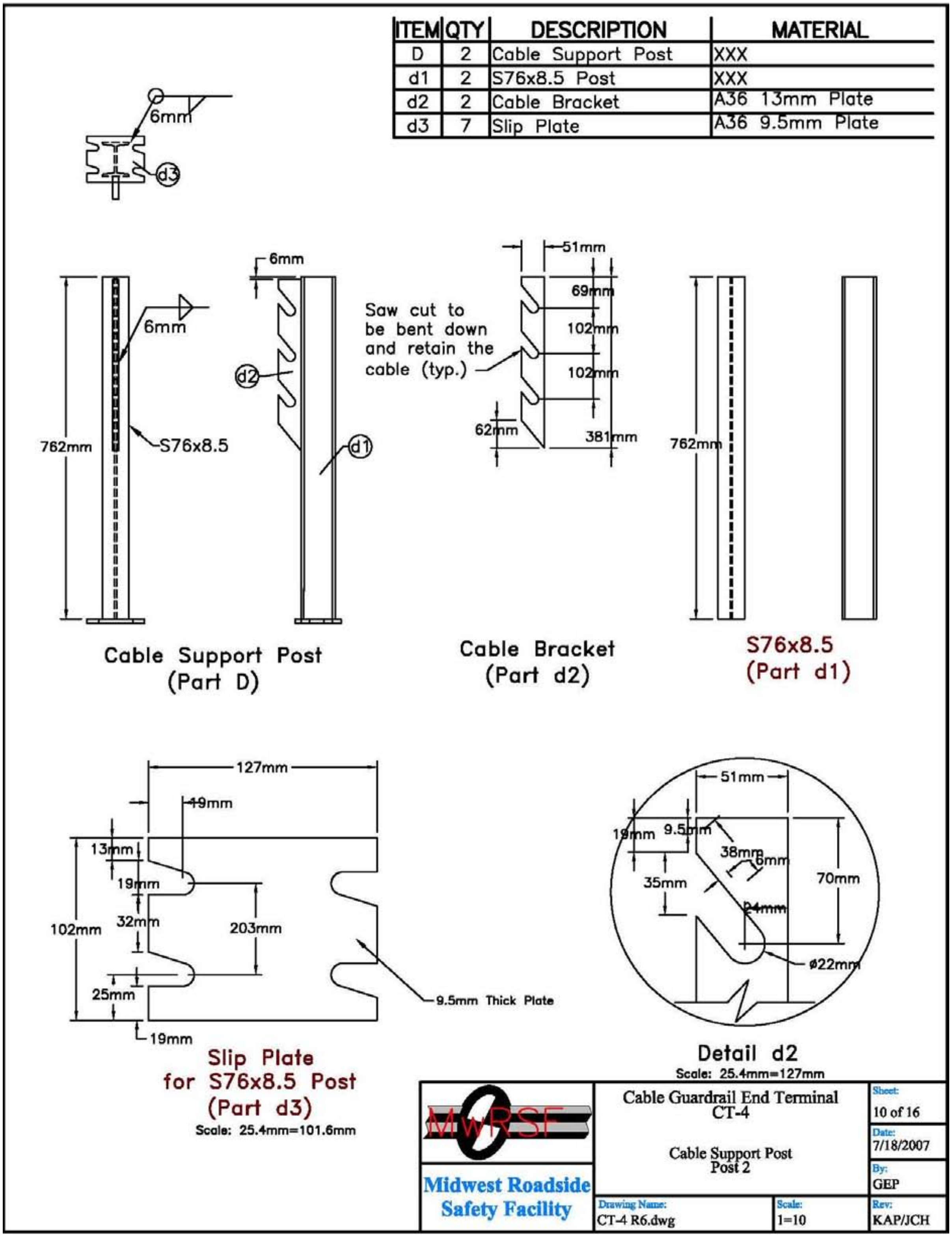


Figure 88. Support Post Assembly, Design No. 3

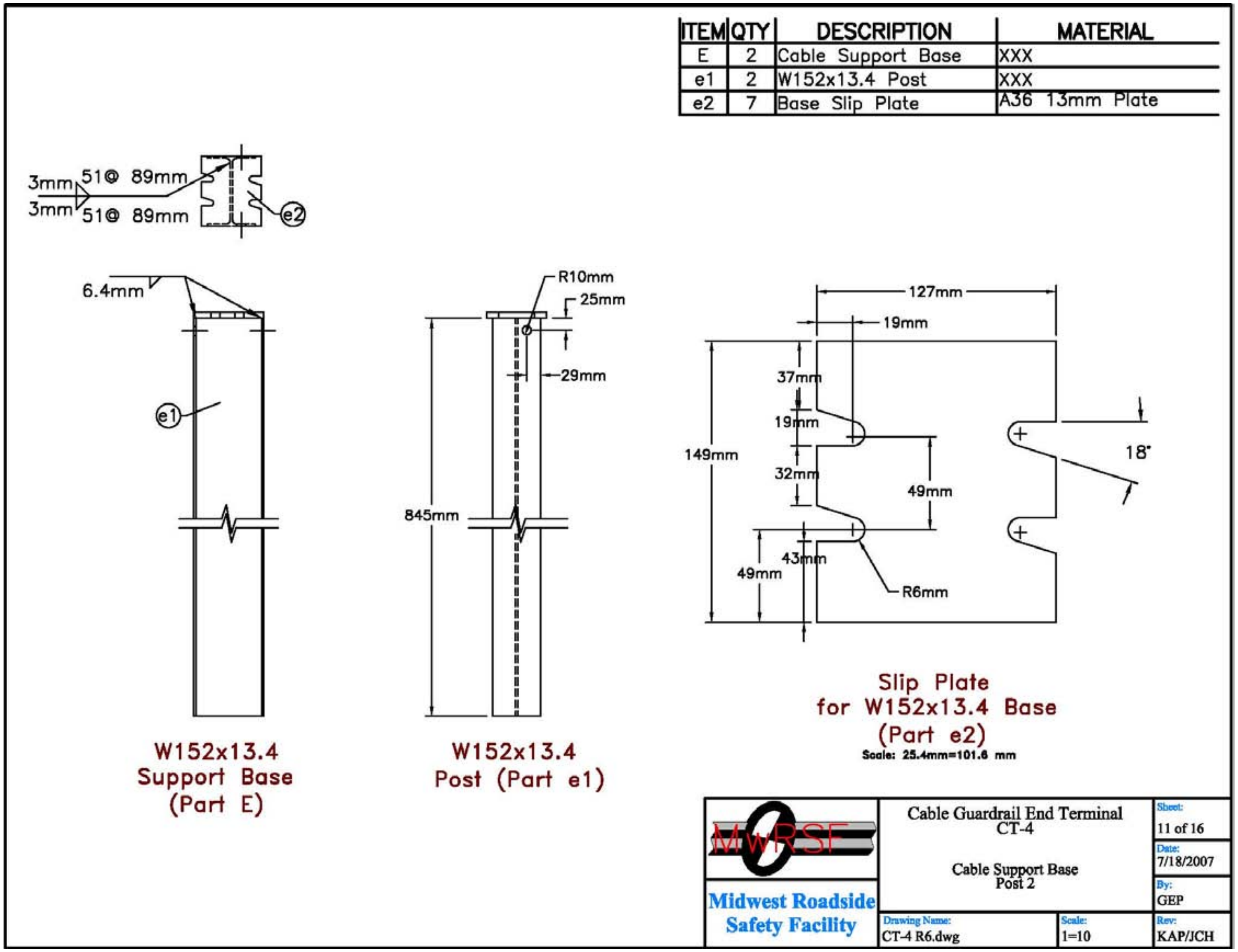


Figure 89. Cable Support Base and Base Plate Details, Design No. 3

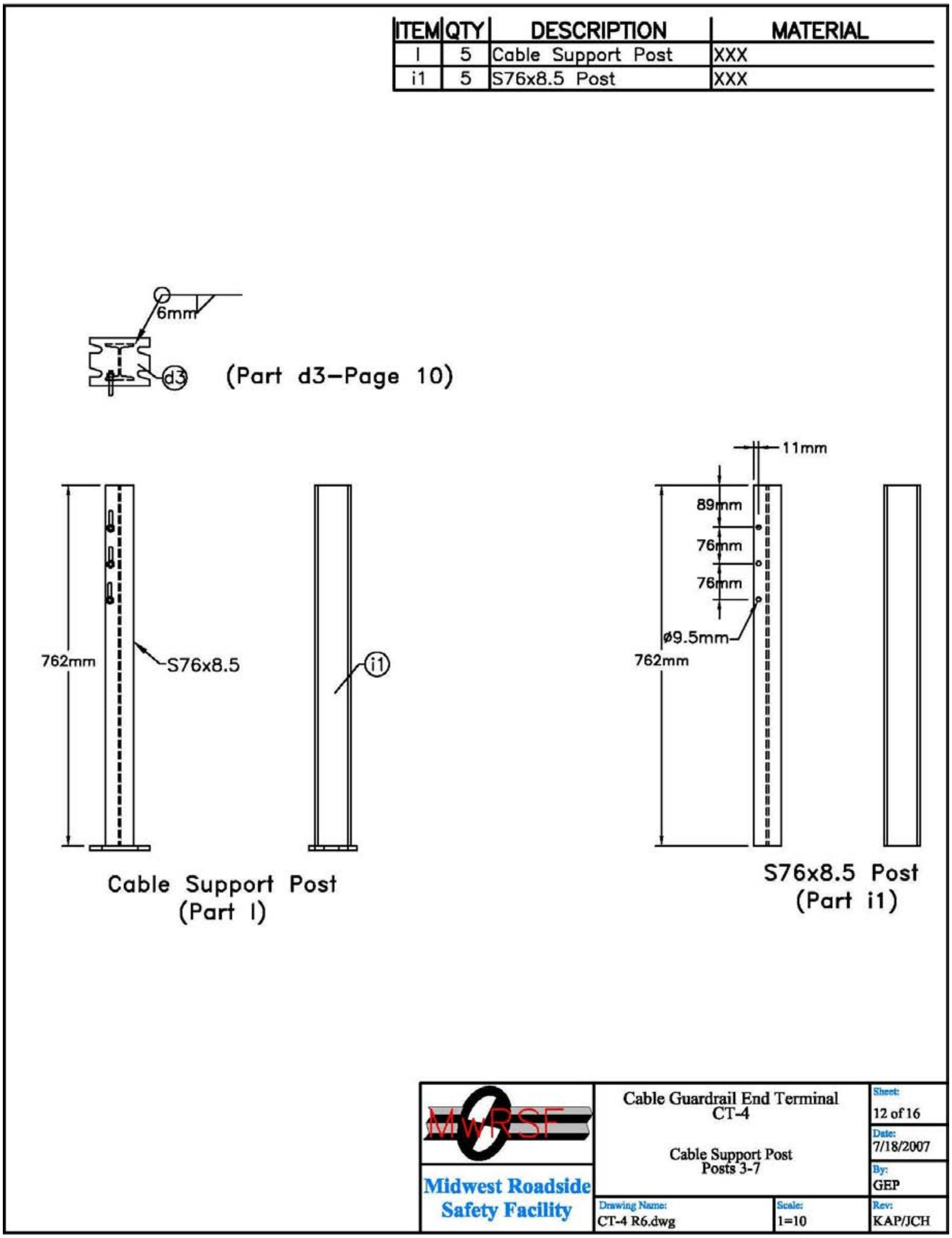


Figure 90. End Terminal Line Post Details, Design No. 3

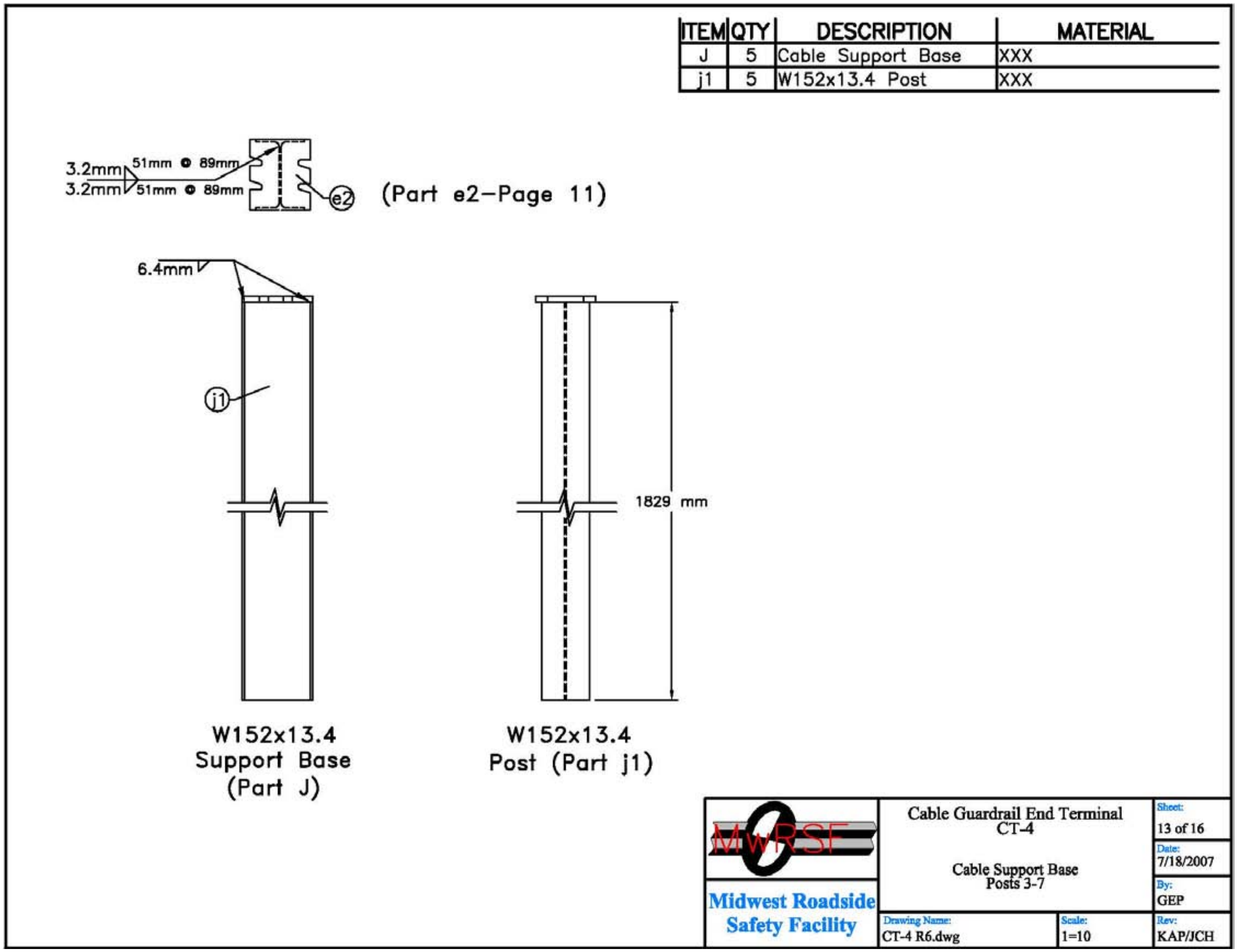


Figure 91. End Terminal Line Post Foundation Details, Design No. 3

Figure 92. System Layout, Design No. 3

Figure 93. End Terminal Line Post Details, Design No. 3

11 CRASH TEST NO. 4

11.1 Test CT-4 (Test Designation 3-30)

The 890-kg (1,961-lb) small car impacted the cable guardrail end terminal system at a speed of 98.3 km/h (61.1 mph) and at an angle of 0.1 degrees. A summary of the test results and sequential photographs are shown in Figure 94. The summary of the test results and sequential photographs in English units are shown in Appendix B. Additional sequential photographs are shown in Figures 95 through 97. Documentary photographs of the crash test are shown in Figures 98 and 99.

11.2 Test Description

Vehicle impact occurred head-on with the right-side quarter-point of the vehicle impacting post no. 1, as shown in Figure 100. At 0.016 sec after impact, the cable release lever rotated downstream with the cables deformed around the front edge of the hood. At 0.046 sec, the vehicle contacted post no. 2 with the cables deformed around the front of the vehicle. At 0.072 sec, post no. 2 released from the slip base. At 0.114 sec, the vehicle yawed clockwise as the vehicle continued forward. At this same time, the top cable wrapped around the top of the hood. At 0.168 sec, the vehicle contacted post no. 3. At 0.230 sec, the cable compensators slid along the vehicle's hood. At this same time, post no. 3 released from the slip base. At 0.250 sec, the right-rear corner of the vehicle pitched upward. At 0.320 sec, the top cable rose to a height above the vehicle. At 0.342 sec, the top cable compensator was positioned over the roof of the vehicle, and the cables accumulated at the front of the vehicle. At this same time, the right-rear tire became airborne. At 0.372 sec, the vehicle contacted post no. 4, and the cable release lever dug into the ground behind the test vehicle. At 0.388 sec, post no. 4 released from the slip base. At 0.402 sec, the grill disengaged. At 0.420 sec, the cables continued to accumulate in front of the vehicle with the top cable compensator positioned near the right-side window. At 0.548 sec, the vehicle yawed clockwise to approximately 45 degrees relative to the system and continued downstream. At 0.600 sec, the vehicle contacted post no. 5, which released. At 0.658 sec, the top cable contacted the roof and the top of the windshield. At 0.784 sec, the car yawed to a position nearly perpendicular to the system and slid downstream. At this same time, the vehicle contacted post no. 6. At 0.944 sec, the vehicle impacted post no. 7. At 0.980 sec, the top cable compensator impacted the windshield. At 1.022 sec, the vehicle rolled counter-clockwise, thus causing the right-rear tire to become airborne. At 1.054 sec, the right-front tire became airborne, and the top cable rebounded off of the windshield. At 1.324 sec, the vehicle exited system at a trajectory angle of 13 degrees and at a velocity of 74.6 km/h (46.4 mph). At 1.394 sec, the top cable compensator slid down the hood of the vehicle. At 1.638 sec, the right-front quarter panel contacted the ground. At 2.742 sec, the vehicle yawed again counter-clockwise such that the front of the vehicle faced the traffic side of the barrier. At 3.088 sec, the right-side tires contacted the ground. The vehicle came to rest 44.30 m (145 ft - 4 in.) downstream from impact and 8.23 m (27 ft) laterally away from the traffic-side face of the barrier. The trajectory and final position of the small car are shown in Figures 94 and 101.

11.3 Barrier Damage

Damage to the cable guardrail end terminal system was moderate, as shown in Figures 102 through 106. Barrier damage consisted of contact marks on posts, deformed and disengaged line posts, disengaged cables, and deformed cable hooks. The length of vehicle contact along the cable system was approximately 24.0 m (78 ft - 8 in.), which spanned from post no. 1 through post no. 7.

Minor scratches occurred around the washer locations on the cable anchor bracket and the slip base plates of post nos. 3 through 6. The cable release lever disengaged from the system. The cable release lever’s retaining cable was fractured, thus allowing the cable release lever to be removed from the anchor post. Deformation and chipping occurred around the upstream slots and the top of the base plate at post no. 6.

Post nos. 3 through 5 were bent. The welds between post no. 7 and the slip plate fractured. The slip plate of post no. 7 remained attached to the foundation portion of the post and was deformed on the upstream edge. Post no. 2 came to rest 8.66 m (28 ft - 5 in.) downstream from its original position and 0.89 m (2 ft - 11 in.) laterally away from the traffic-side face of the barrier. Post no. 3 came to rest 22.83 m (74 ft - 11 in.) downstream from its original position and 76 mm (3 in.) laterally behind the barrier. Post no. 4 came to rest 17.35 m (56 ft - 11 in.) downstream from its original position and 1.68 m (5 ft - 6 in.) laterally behind the barrier. Post no. 5 came to rest 10.90 m (35 ft - 9 in.) downstream from its original position and 1,092 mm (3 ft - 7 in.). Post no. 6 came to rest 4.88 m (16 ft) downstream from its original position and 1,194 mm (3 ft - 11 in.) laterally behind the barrier. Post no. 7 came to rest 940 mm (3 ft - 1 in.) downstream from its original position and 762 mm (30 in.) laterally behind the barrier. The remainder of the downstream posts showed no evidence of movement nor damage.

All the cable hooks on post nos. 3 through 7 were deformed but remained attached to the posts. All three cables disengaged from post nos. 2 and 3. All three cables remained attached to post no. 4 and all posts downstream of post no. 8. The top and middle cables remained attached to post nos. 5 and 7, while the middle and bottom cables remained attached to post no. 6.

11.4 Vehicle Damage

Exterior vehicle damage was minimal, as shown in Figures 107 through 111. Occupant compartment deformations to the right side and center of the floorboard were judged insufficient to cause serious injury to the vehicle occupants. Complete occupant compartment deformations and the corresponding locations are provided in Appendix C.

Damage was concentrated on the front and left side of the vehicle. Minor cuts, scratches and dents occurred to the front of the vehicle, the hood, the left-front door, and left-rear quarter panel. The lower portion of the bumper and the right-side parking light were fractured. The hood was dented inward towards the engine compartment. The right-side headlight protruded out from under the hood. The left corner of the hood was deformed upward. The left-front quarter panel was severely dented above and behind the left-front tire. The left-front door frame was bent such that the upper-rear corner was separated from the vehicle. The beads of the left-front and right-front tires were broken, and the tires deflated. The left-front and right-front steel rims were deformed. Dents were found on the right-rear quarter panel and the right-side A-pillar. The right-front corner of the quarter-panel was deformed inward.

The oil pan was punctured and gouged. The engine frame was dented and bent at the bumper fracture. The alternator was pushed backward. Scratches and scrapes were found on the left-front control arm. The left side of the steering control was bent and in contact with the sway bar. The lower-left control arm was dented, and the sway bar was in contact with the exhaust pipe behind the catalytic converter. Spider-web cracking occurred to the right side of the windshield. All door window glass, the rear of the vehicle, the rear tires, and the roof remained undamaged.

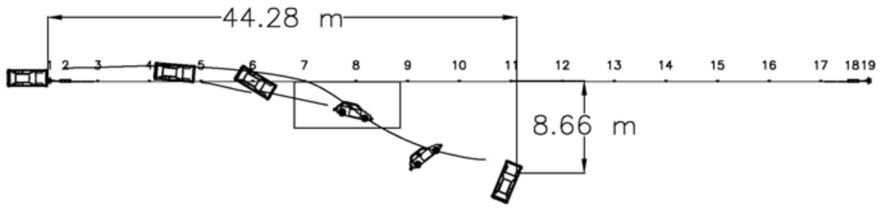
11.5 Occupant Risk Values

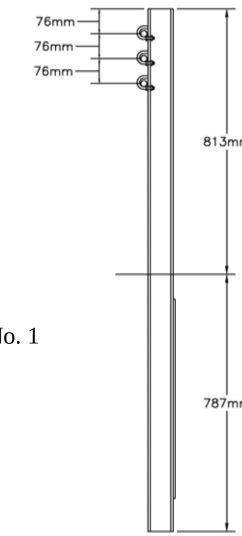
The longitudinal and lateral occupant impact velocities were determined to be 3.48 m/s (11.42 ft/s) and -0.77 m/s (-2.54 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 7.85 g's and -3.48 g's, respectively. It is noted that the occupant impact velocities (OIVs) and occupant ridedown decelerations (ORDs) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 94, and are shown graphically in Appendix I. The results from the rate transducer are also shown graphically in Appendix I.

11.6 Discussion

The analysis of the test results for test no. CT-4 showed that the 820C vehicle was brought to a safe stop. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. It should be noted that the vehicle achieved a significant roll angle prior to coming to rest on its tires. After collision, the vehicle’s trajectory intruded minimally into adjacent traffic lanes. Therefore, test no. CT-4 was determined to be acceptable according to the TL-3 safety performance criteria of test designation no. 3-30 found in NCHRP Report No. 350.

0.000 sec | 0.046 sec | 0.168 sec | 0.388 sec | 0.600 sec





- Test Agency .... MwRSF
- Test Number CT-4
- Date 6/8/2005
- NCHRP 350 Test Designation 3-30
- Appurtenance .... Cable Guardrail End Terminal
- Total Length .... 77.42 m
- Key Elements - Wire Rope
  - Diameter .... 19 mm
  - Size 7x19
  - Top Mounting Height .... 762 mm
  - Spacing .... 76 mm
- Key Elements - End Anchor Posts
  - Post Nos. 1 and 19 .... W152x37.2 by 2,438 mm long
  - Post Nos. 2 and 18 .... S76x8.5 by 762 mm long with W152x13.4 by 1,829-mm long
- Key Elements - Line Posts
  - Post Nos. 3-10 .... S76x8.5 by 762 mm long with W152x13.4 by 1,829 support post
  - Post Nos. 11-17 .... S76x8.5 by 1,600 mm long
  - Post Spacing .... 4,877 mm
- Test Vehicle
  - Type/Designation 820C
  - Make and Model .... 1998 Geo Metro
  - Curb .... 780 kg
  - Test Inertial .... 814 kg
  - Gross Static .... 889 kg
- Impact Conditions
  - Speed .... 94.8 km/h
  - Angle .... 0.1 degrees
  - Impact Location .... Centerline of Post No. 1
- Exit Conditions
  - Speed .... 74.6 km/h
  - Angle .... 13 degrees
- Exit Box Criterion .... Fail
- Post-Impact Trajectory
  - Vehicle Stability .... Satisfactory
  - Stopping Distance .... 44.3 m downstream
    8.7 m traffic-side face
- Occupant Impact Velocity
  - Longitudinal .... 3.48 m/s < 12 m/s
  - Lateral .... -0.77 m/s < 12 m/s
- Occupant Ridedown Deceleration
  - Longitudinal .... 7.85 g’s < 20 g’s
  - Lateral .... -3.48 g’s < 20 g’s
- Test Article Damage .... Moderate
- Test Article Deflections
  - Permanent Set .... N/A
  - Dynamic .... N/A
  - Working Width .... N/A
- Vehicle Damage .... Minimal
  - VDS[7] 12-FD-1
  - CDC[8] 12-FDEN-9
  - Maximum Deformation .... 6 mm

Figure 94. Summary of Test Results and Sequential Photographs, Test No. CT-4

0.000 sec

0.192 sec

0.268 sec

0.402 sec

0.500 sec

0.658 sec

1.022 sec

1.196 sec

1.394 sec

1.638 sec

Figure 95. Additional Sequential Photographs, Test CT-4

0.000 sec

0.200 sec

0.400 sec

0.601 sec

0.901 sec

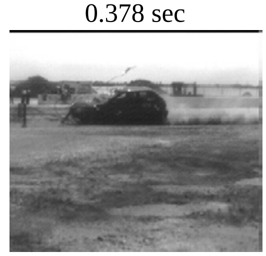
1.001 sec

0.000 sec

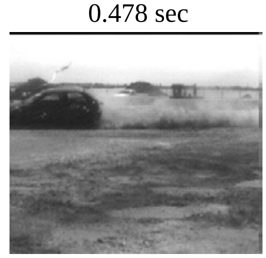
0.080 sec

0.178 sec

0.378 sec



0.478 sec



0.634 sec

Figure 96. Additional Sequential Photographs, Test CT-4

0.000 sec

0.128 sec

0.238 sec

0.422 sec

0.608 sec

0.944 sec

1.492 sec

3.088 sec

Figure 97. Additional Sequential Photographs, Test CT-4

Figure 98. Documentary Photographs, Test CT-4

Figure 99. Documentary Photographs, Test CT-4

Figure 100. Impact Location, Test CT-4

Figure 101. Vehicle Trajectory and Final Position, Test CT-4

Figure 102. System Damage, Test CT-4

Figure 103. System Damage, Test CT-4

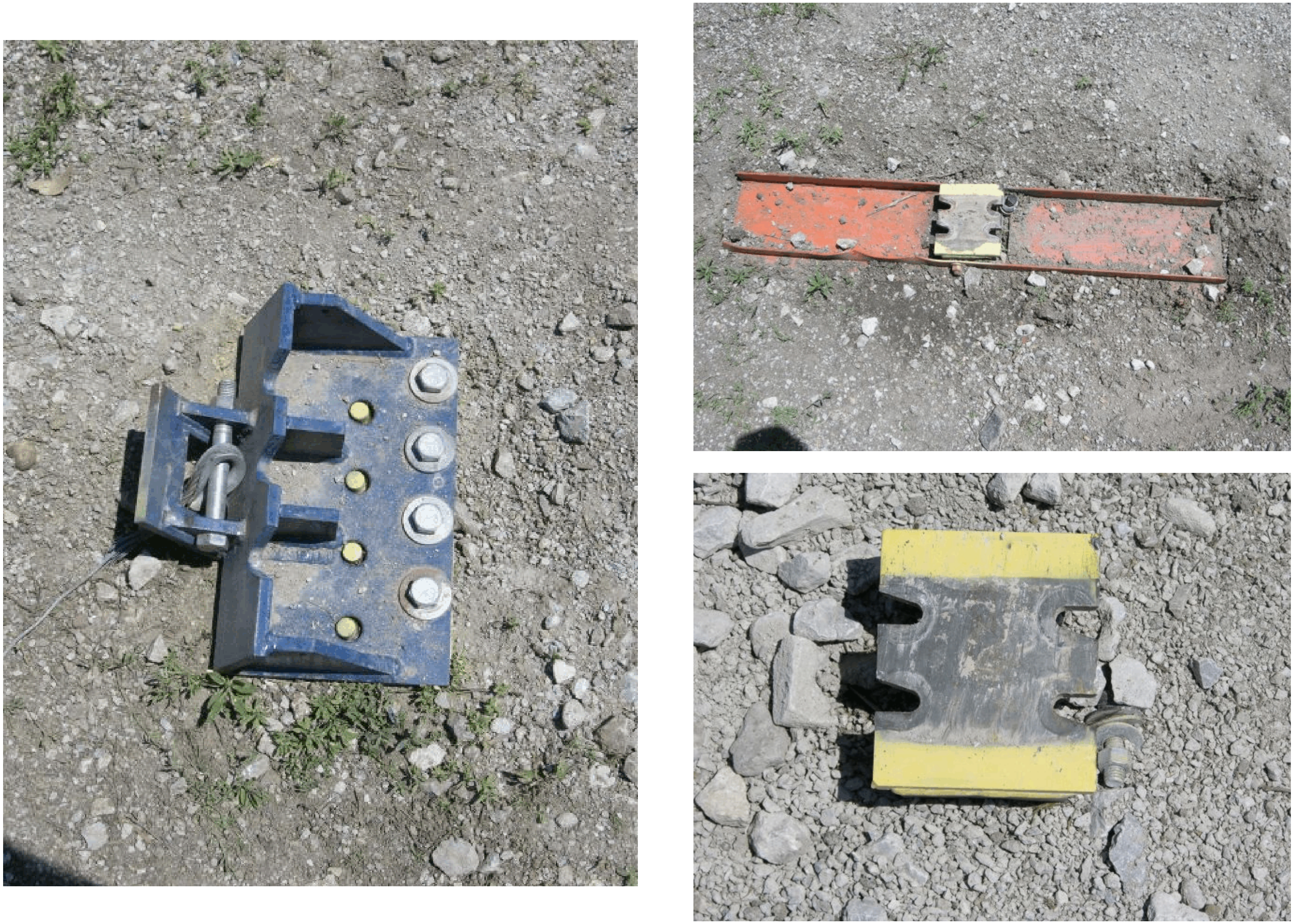


Figure 104. Post Nos. 1 through 3 Base Plate Damage, Test CT-4

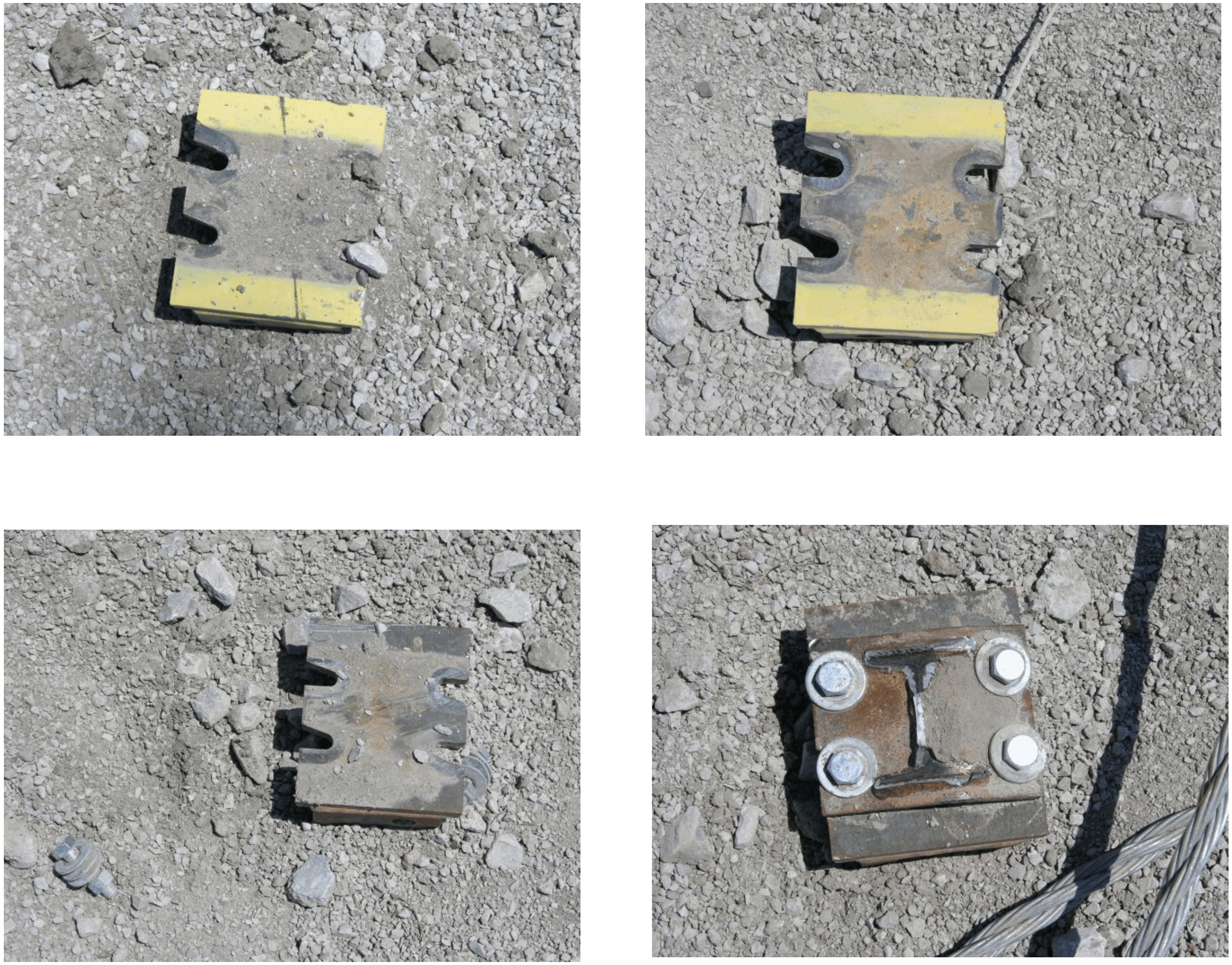


Figure 105. Post Nos. 4 through 7 Base Plate Damage, Test CT-4

Figure 106. Post Nos. 3 through 7 Damage, Test CT-4

Figure 107. Vehicle Damage, Test CT-4

Figure 108. Vehicle Damage, Test CT-4

Figure 109. Windshield Damage, Test CT-4

Figure 110. Undercarriage Damage, Test CT-4

Figure 111. Occupant Compartment Damage, Test CT-4

12 SUMMARY AND CONCLUSIONS

A cable guardrail end terminal for use with low-tension, cable guardrail systems was developed and full-scale vehicle crash tested. The full-scale crash tests were performed according to the TL-3 criteria found in NCHRP Report No. 350. The cable guardrail end terminal was designed to be used as a tangent system and reduce the size and cost of the anchor block. A summary of the safety performance evaluation is provided in Table 4.

The first crash test, test no. CT-1, a length-of-need test, was performed on the cable terminal with a ¾-ton pickup truck. During the test, the pickup was safely contained and redirected. Therefore, test no. CT-1 was determined to be acceptable according to test designation 3-35 of the TL-3 safety performance criteria presented in NCHRP Report No. 350.

The second crash test, test no. CT-2, was performed with a small car impacting head-on into the cable guardrail end terminal. The vehicle engaged the cable release lever which caused the vehicle to pitch upward and subsequently rollover. Furthermore, the cable release lever penetrated the occupant compartment. Therefore, test no. CT-2 was determined to be unacceptable according to test designation 3-30 of the TL-3 safety performance criteria presented in NCHRP Report 350.

Following the unsuccessful performance, the system was modified to retain the cable release lever to the anchor bracket. The third crash test, test no. CT-3, was performed with a small car impacting head-on into the cable guardrail end terminal. After the vehicle engaged the S76x8.5 (S3x5.7) posts downstream of the anchor, the front corner of the vehicle became elevated, resulting in vehicle rollover. Therefore, test no. CT-3 was also determined to be unacceptable according to test designation 3-30 of the TL-3 safety performance criteria presented in NCHRP Report 350.

Following the unsatisfactory performance of the cable guardrail end terminal in test no.

CT-3, an investigation determined that the S76x8.5 (S3x5.7) posts possess the capability to induce vehicular rollover. Thus, the system was modified to include slip-base posts instead of the standard S-posts for the line posts, post nos. 3 through 7. The fourth crash test, test no. CT-4, was performed with a small car impacting head-on into the cable guardrail end terminal. Although the vehicle exhibited a significant roll angle, the vehicle was safely redirected and brought to a controlled stop. Test no. CT-4 was determined to be acceptable according to test designation 3-30 of the TL-3 safety performance criteria presented in NCHRP Report No. 350.

Therefore, the cable guardrail end terminal system for use with low-tension, three-strand cable guardrail has been determined to meet the TL-3 safety guidelines provided in NCHRP Report No. 350.

It should be noted that the cable guardrail end terminal anchor used in test nos. CT-1 through CT-4 incorporated the driven steel-post anchor design recommended in a previous cable anchor evaluation study (10). All three cable anchors described in the study, a reduced-size reinforced concrete block to replace the New York anchor block, a reinforced concrete shaft post, and a driven steel post with soil plate, were deemed suitable for low-tension, cable guardrail applications. The steel post design was implemented in the cable guardrail end terminal design, because previous testing had shown that the steel post option was the weakest of the three anchor designs. It performed acceptably when full-scale vehicle crash tested and significantly reduced the overall size and cost of the anchor utilized in the cable guardrail end terminal design. Therefore, it was believed that the other cable anchor designs would be acceptable for use in cable guardrail end terminal systems. Details of the cable anchor designs are contained in the referenced report.

Table 4. Summary of Safety Performance Evaluation Results

Evaluation Factors	Evaluation Criteria	Test CT-1	Test CT-2	Test CT-3	Test CT-4
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.	S	NA	NA	NA
	C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	S	U	U	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	U	U	S
	F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	S	U	U	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).	NA	S	S	S
	I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15 Gs, or at least below the maximum allowable value of 20 Gs.	NA	S	S	S
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	S	S	S	S
	L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec (39.37 ft/s), and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 Gs.	S	NA	NA	NA
	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	NA	NA	NA
	N. Vehicle trajectory behind the test article is acceptable.	NA	S	S	S
NCHRP Report No. 350 Test Designation		3-34	3-30	3-30	3-30

S - Satisfactory
U - Unsatisfactory
M - Marginal
NA - Not Available

13 REFERENCES

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4. *New York Terminal for 3-Cable Barrier: NCHRP Report 350 Test No. 3-34*, Presented to the New York State Department of Transportation, Conducted by the Texas Transportation Institute, 2001.

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

9. Kuipers, B.D., and Reid, J.D., *Testing of M203x9.7 (M8x6.5) and S76x8.5 (S3x5.7) Steel Posts - Post Comparison Study for the Cable Median Barrier*, Performed for the Midwest States’ Regional Pooled Fund Program, Transportation Research Report TRP-03-143-03, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, 2003.

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14 APPENDICES

APPENDIX A

English-Unit System Details, Design No. 1

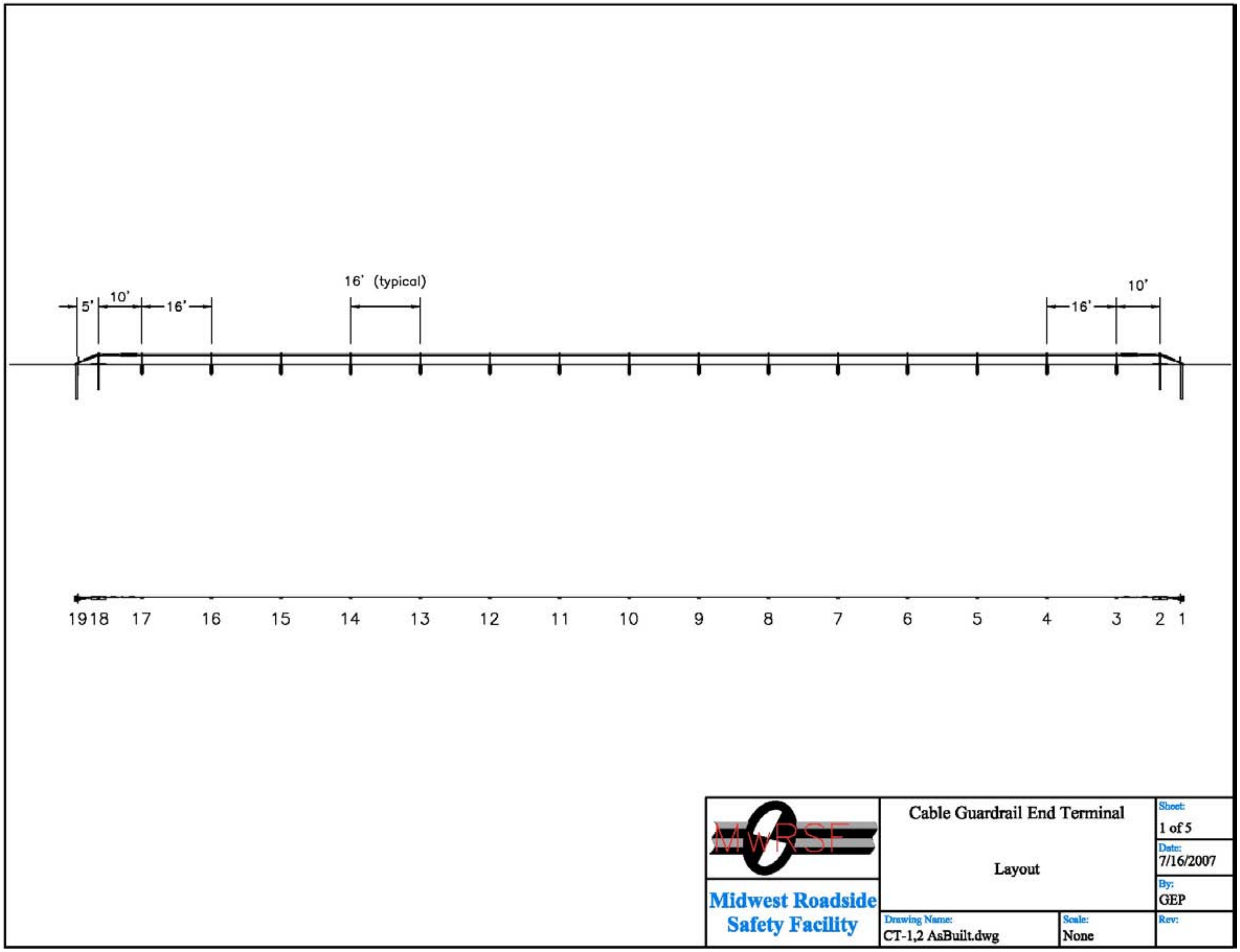


Figure A-1. System Details (English), Design No. 1

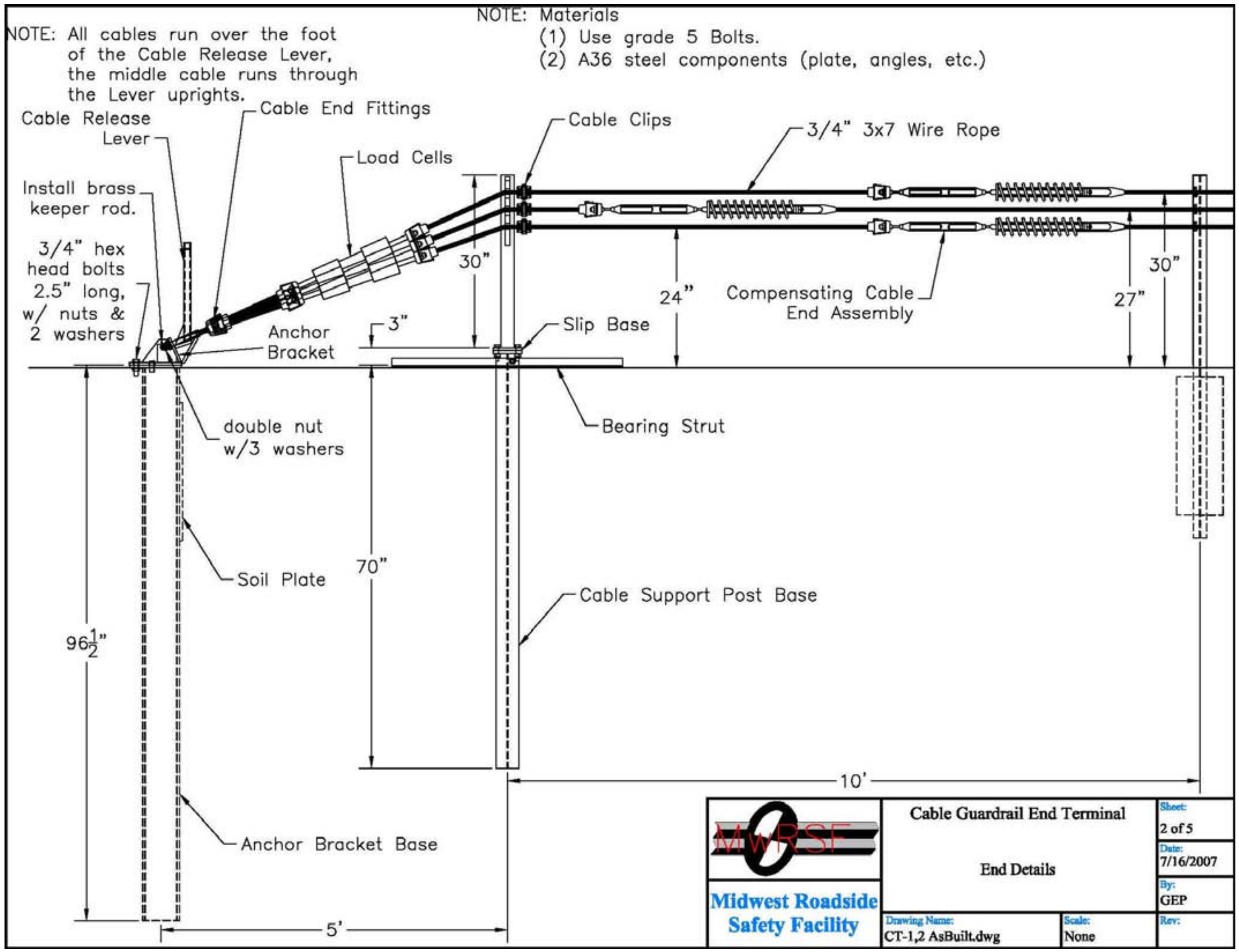


Figure A-2. End Anchorage Details (English), Design No. 1

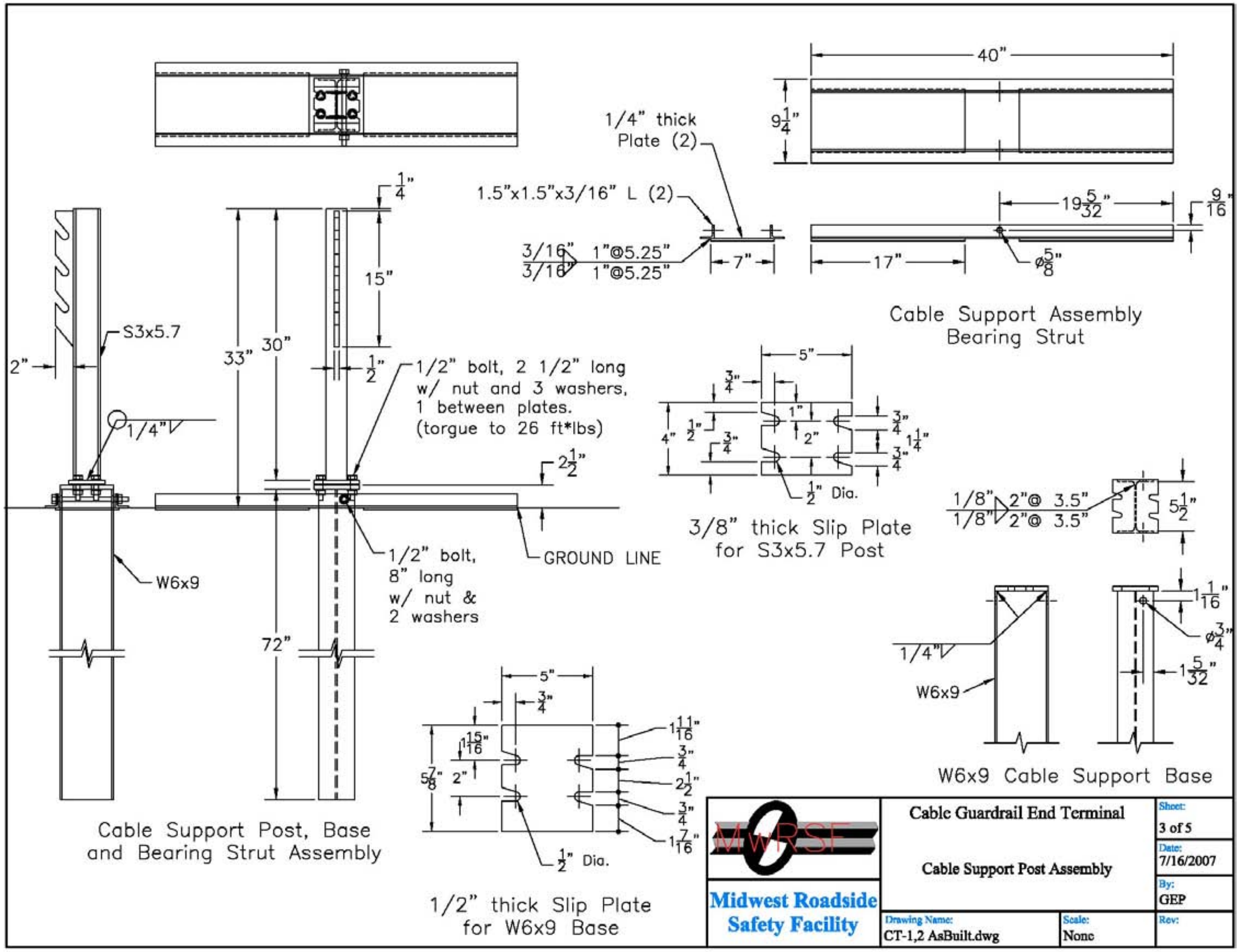


Figure A-3. Support Post Assembly Details (English), Design No. 1

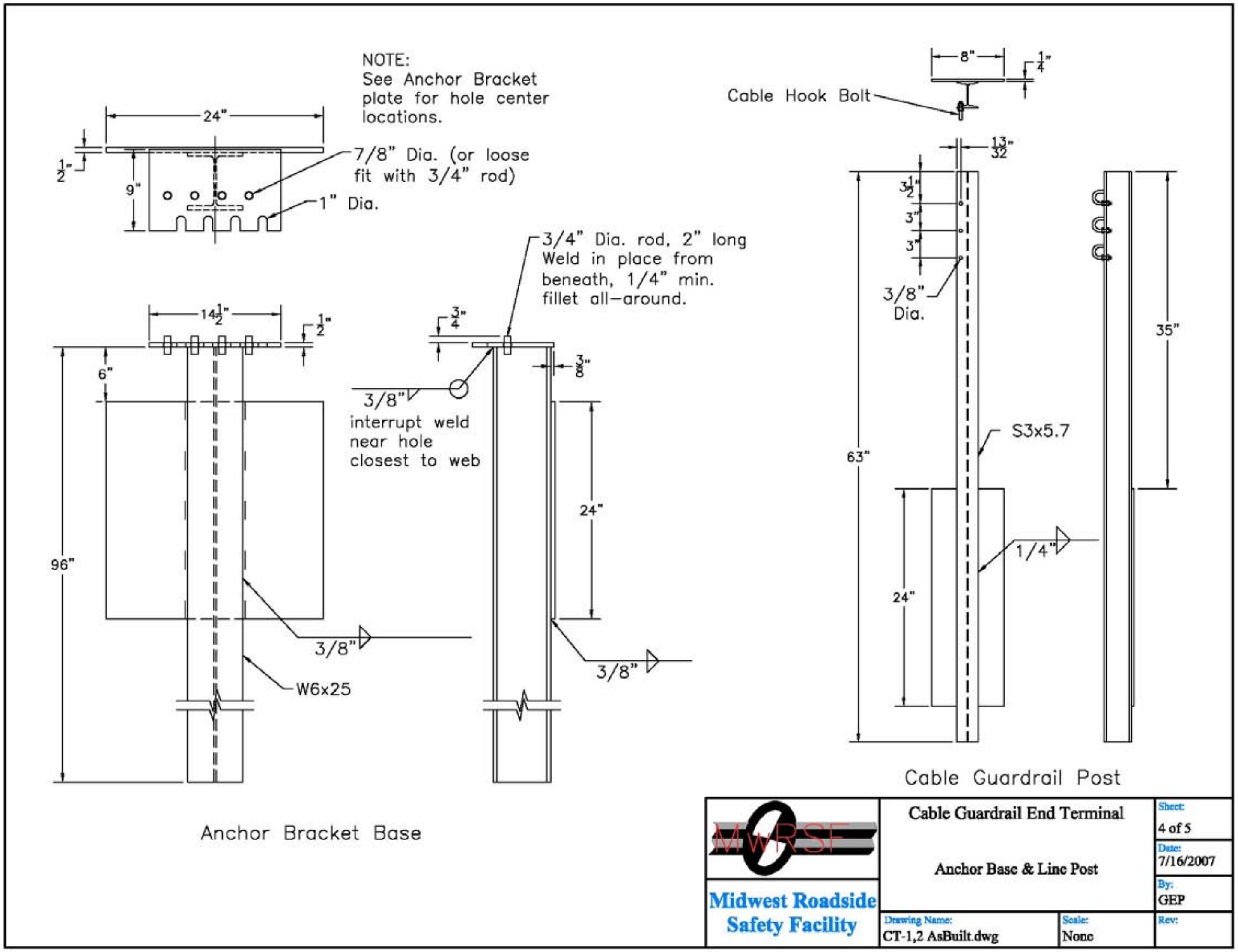


Figure A-4. Anchor Bracket and Line Post Details (English), Design No. 1

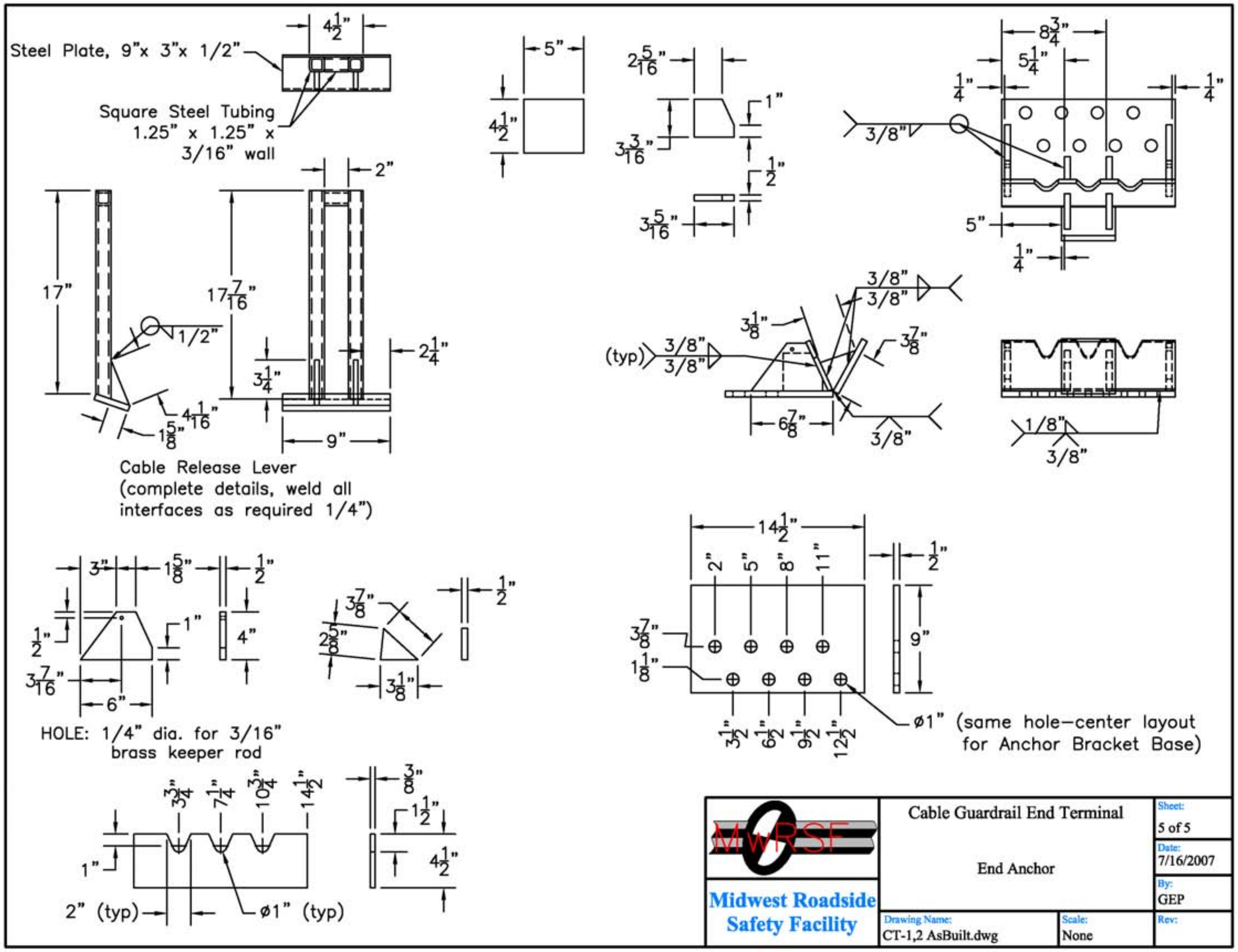
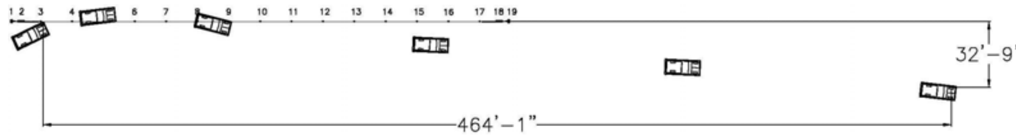


Figure A-5. Anchor Bracket and Line Post Details (English), Design No. 1

APPENDIX B
Test Summary Sheets in English Units

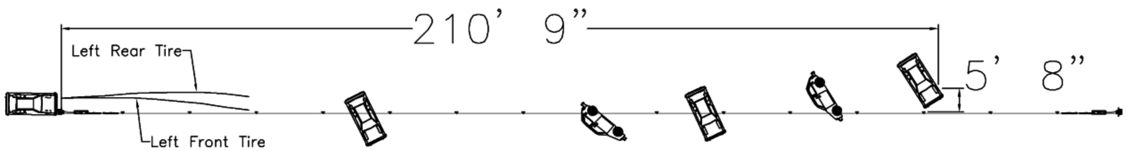
0.000 sec   0.154 sec   0.241 sec   0.337 sec   0.509 se



- Test Agency . . . . MwRSF
- Test Number CT-1
- Date 7/3/2002
- NCHRP 350 Test Designation 3-35
- Appurtenance . . . . Cable Guardrail End Terminal System
- Total Length . . . . 254 ft
- Key Elements - Wire Rope
  - Diameter . . . . 0.75 in.
  - Size 7x19
  - Top Mounting Height . . . . 30 in.
  - Spacing . . . . 3 in.
- Key Elements - Cable Anchor Post
  - Post Nos. 1 and 19 . . . . W6x25 by 96 in. long
  - Post Nos. 2 and 18 . . . . S3x5.7 by 30 in. long with W6x9 by 72 in. long
- Key Elements - Line Post
  - Post Nos. 3-17 . . . . S3x5.7 by 63 in. long
  - Post Spacing . . . . 16 ft
- Test Vehicle
  - Type/Designation 2000P
  - Make and Model . . . . 1996 GMC 2500 ¾-ton pickup
  - Curb . . . . 4,363 lb
  - Test Inertial . . . . 4,448 lb
  - Gross Static . . . . 4,448 lb
- Impact Conditions
  - Speed . . . . 63.3 mph
  - Angle . . . . 20.7 degrees
  - Impact Location . . . . Centerline of Post No. 2
- Exit Conditions
  - Speed . . . . 59.6 mph
  - Angle . . . . 4 degrees
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 464 ft-1 in. downstream 32 ft-9 in. traffic-side face
- Occupant Impact Velocity
  - Longitudinal . . . . 6.04 ft/s < 39.37 ft/s
  - Lateral (not requried) . . . . 9.45 ft/s < 39.37 ft/s
- Occupant Ridedown Deceleration
  - Longitudinal . . . . 4.55 Gs < 20 Gs
  - Lateral (not required) . . . . 7.00 Gs < 20 Gs
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . 23.0 in.
  - Dynamic . . . . 25.8 in.
  - Working Width . . . . 84.1 in.
- Vehicle Damage . . . . Minimal
  - VDS[7] 11-LFQ-2/11-LD-2
  - CDC[8] 11-LDES3
  - Maximum Deformation . . . . 0.25 in.

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

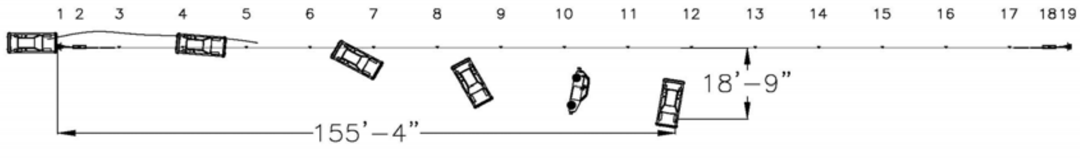
0.000 sec 0.054 sec 0.132 sec 0.166 sec 0.259 sec

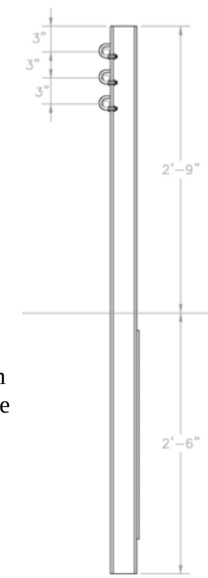


- Test Agency . . . . MwRSF
- Test Number CT-2
- Date 7/16/2002
- NCHRP 350 Test Designation 3-30
- Appurtenance . . . . Cable Guardrail End Terminal
- Total Length . . . . 254 ft
- Key Elements - Wire Rope
  - Diameter . . . . 0.75 in.
  - Size 7x19
  - Top Mounting Height . . . . 30 in.
  - Spacing . . . . 3 in.
- Key Elements - Cable Anchor Post
  - Post Nos. 1 and 19 . . . . W6x25 by 96 in. long
  - Post Nos. 2 and 18 . . . . S3x5.7 by 30 in. long with W6x9 by 72 in. long
- Key Elements - Line Post
  - Post Nos. 3-17 . . . . S3x5.7 by 63 in. long
  - Post Spacing . . . . 16 ft
- Test Vehicle
  - Type/Designation 820C
  - Make and Model . . . . 1995 Geo Metro
  - Curb . . . . 1,553 lb
  - Test Inertial . . . . 1,799 lb
  - Gross Static . . . . 1,965 lb
- Impact Conditions
  - Speed . . . . 62.1 mph
  - Angle . . . . 1.5 degrees
  - Impact Location . . . . Centerline of Post No. 1
- Exit Conditions
  - Speed . . . . N/A
  - Angle . . . . N/A
  - Exit Box Criterion . . . . N/A
- Post-Impact Trajectory
  - Vehicle Stability . . . . Unsatisfactory
  - Stopping Distance . . . . 210 ft - 9 in. downstream
    5 ft - 8 in. traffic-side face
- Occupant Impact Velocity
  - Longitudinal . . . . 9.81 ft/s < 39.37 ft/s
  - Lateral . . . . -0.39 ft/s < 39.37 ft/s
- Occupant Ridedown Deceleration
  - Longitudinal . . . . 5.37 Gs < 20 Gs
  - Lateral . . . . 3.99 Gs < 20 Gs
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . N/A
  - Dynamic . . . . N/A
  - Working Width . . . . N/A
- Vehicle Damage . . . . Extensive
  - VDS[7] . . . . 12-L&D-6
  - CDC[8] 12-TDD08
  - Maximum Deformation . . . . N/A

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

0.000 sec | 0.096 sec | 0.190 sec | 0.274 sec | 0.434 sec

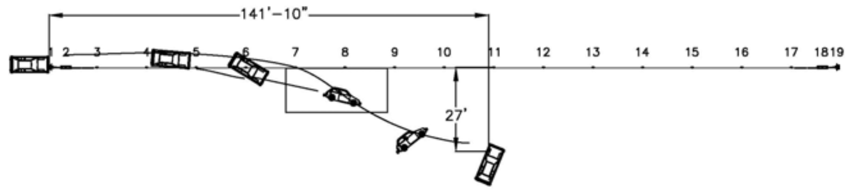




- Test Agency .... MwRSF
- Test Number CT-3
- Date 10/10/2003
- NCHRP 350 Test Designation 3-30
- Appurtenance .... Cable Guardrail End Terminal
- Total Length .... 254 ft
- Key Elements - Wire Rope
  - Diameter .... 0.75 in.
  - Size 7x19
  - Top Mounting Height .... 30 in.
  - Spacing .... 3 in.
- Key Elements - Cable Anchor Post
  - Post Nos. 1 and 19 .... W6x25 by 96 in. long
  - Post Nos. 2 and 18 .... S3x5.7 by 30 in. long with W6x9 by 72 in. long
- Key Elements - Line Post
  - Post Nos. 3-17 .... S3x5.7 by 63 in. long
  - Post Spacing .... 16 ft
- Test Vehicle
  - Type/Designation 820C
  - Make and Model .... 1998 Geo Metro
  - Curb .... 1,532 lb
  - Test Inertial .... 1,786 lb
  - Gross Static .... 1,952 lb
- Impact Conditions
  - Speed .... 58.9 mph
  - Angle .... 0.1 degrees
  - Impact Location .... Centerline of Post No. 1
- Exit Conditions
  - Speed .... N/A
  - Angle .... N/A
  - Exit Box Criterion .... N/A
- Post-Impact Trajectory
  - Vehicle Stability .... Unsatisfactory
  - Stopping Distance .... 154 ft-10.5 in. downstream, 18 ft-10 in. traffic-side face
- Occupant Impact Velocity
  - Longitudinal .... 11.03 ft/s < 39.37 ft/s
  - Lateral .... -0.71 m/s < 39.37 ft/s
- Occupant Ridedown Deceleration
  - Longitudinal .... 9.56 Gs < 20 Gs
  - Lateral .... -13.72 Gs < 20 Gs
- Test Article Damage .... Moderate
- Test Article Deflections
  - Permanent Set .... N/A
  - Dynamic .... N/A
  - Working Width .... N/A
- Vehicle Damage .... Extensive
  - VDS[7] .... 12-L&T-6
  - CDC[8] 12-TDD08
  - Maximum Deformation .... N/A

Figure B-3. Summary of Test Results and Sequential Photographs, Test No. CT-3

0.000 sec | 0.046 sec | 0.168 sec | 0.388 sec | 0.600 sec



- Test Agency .... MwRSF
- Test Number CT-4
- Date 6/8/2005
- NCHRP 350 Test Designation 3-30
- Appurtenance .... Cable Guardrail End Terminal
- Total Length .... 254 ft
- Key Elements - Wire Rope
  - Diameter .... 0.75 in.
  - Size 7x19
  - Top Mounting Height .... 30 in.
  - Spacing .... 3 in.
- Key Elements - Cable Anchor Post
  - Post Nos. 1 and 19 .... W6x25 by 96 in. long
  - Post Nos. 2 and 18 .... S3x5.7 by 30 in. long with W6x9 by 96 in. long
- Key Elements - Line Post
  - Post Nos. 11-17 .... S3x5.7 by 63 in. long
  - Post Spacing .... 16 ft
- Test Vehicle
  - Type/Designation 820C
  - Make and Model .... 1998 Geo Metro
  - Curb .... 1,720 lb
  - Test Inertial .... 1,795 lb
  - Gross Static .... 1,961 lb
- Impact Conditions
  - Speed .... 61.1 mph
  - Angle .... 0.1 degrees
  - Impact Location .... Centerline of Post No. 1
- Exit Conditions
  - Speed .... 46.4 mph
  - Angle .... 13 degrees
  - Exit Box Criterion .... Fail
- Post-Impact Trajectory
  - Vehicle Stability .... Satisfactory
  - Stopping Distance .... 141 ft - 10 in. downstream, 27 ft traffic-side face
- Occupant Impact Velocity
  - Longitudinal .... 11.41 ft/s < 39.37 ft/s
  - Lateral .... -2.54 ft/s < 39.37 ft/s
- Occupant Ridedown Deceleration
  - Longitudinal .... 7.85 Gs < 20 Gs
  - Lateral .... -3.48 Gs < 20 Gs
- Test Article Damage .... Moderate
- Test Article Deflections
  - Permanent Set .... N/A
  - Dynamic .... N/A
  - Working Width .... 254.8 in.
- Vehicle Damage .... Minimal
  - VDS[7] 12-FD-1
  - CDC[8] 12-FDEN-9
  - Maximum Deformation .... 0.25 in.

Figure B-4. Summary of Test Results and Sequential Photographs (English), Test No. CT-4

APPENDIX C
Occupant Compartment Deformation Data

VEHICLE PRE/POST CRUSH INFO

TEST: CT-1
VEHICLE: 1996/GMC/WHITE

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	57.25	-27.5	0	57.5	-27.5	0	0.25	0	
2	57.5	-21	1.75	57.5	-21	1.5	0	0	-0.25
3	57.25	-13.5	2.5	57	-13.25	2.25	-0.25	0.25	-0.25
4	53.25	-4.5	1.25	53.25	-4.25	1.5	0	0.25	0.25
5	53.25	0.5	-1.5	53.25	0.5	-1.5	0	0	0
6	51.25	-27	5	51.5	-27	5	0.25	0	0
7	52.25	-20.25	5.5	52.5	-20	5.25	0.25	0.25	-0.25
8	51	-13.75	6.25	51	-13.5	6.5	0	0.25	0.25
9	48	-4.75	0.75	48.25	-4.75	0.75	0.25	0	0
10	45	-27.75	5.75	45	-27.75	5.5	0	0	-0.25
11	45.25	-19.5	6	45	-19.25	6	-0.25	0.25	0
12	44.5	-10.5	6.5	44.25	-10.5	6.25	-0.25	0	-0.25
13	44.5	-1.25	1	44.5	-1.25	1	0	0	0
14	36.5	-26.5	5.5	36.25	-26.25	5.25	-0.25	0.25	-0.25
15	37.75	-20.5	5.75	37.5	-20.75	5.75	-0.25	-0.25	0
16	38.25	-14.25	6.5	38.25	-14.25	6.25	0	0	-0.25
17	38.5	-6	2.25	38.5	-6	2	0	0	-0.25
18	38.5	0.5	1.5	38.5	0.5	1.25	0	0	-0.25
19	28	-29.25	5.75	28.25	-29	5.75	0.25	0.25	0
20	28.25	-16.5	5.5	28.25	-16.5	5.25	0	0	-0.25
21	28.5	-1.5	2	28.5	-1.5	2	0	0	0
22	20.5	-27	4.75	20.25	-27	4.5	-0.25	0	-0.25
23	18.25	-15.25	5.75	18.25	-15.5	5.5	0	-0.25	-0.25
24	20.25	-5.25	3.25	20	-5.25	3	-0.25	0	-0.25
25	26.75	-31.25	-9.5	26.5	-31.25	-9.25	-0.25	0	0.25
26	43.75	-26	25.75	43.75	-26	25.75	0	0	0
27	44.75	-10.75	25.75	44.75	-10.25	25.75	0	0.5	0
28	44	1.75	25	44	1.5	25	0	-0.25	0
29									
30									

ORIENTATION AND REFERENCE INFO

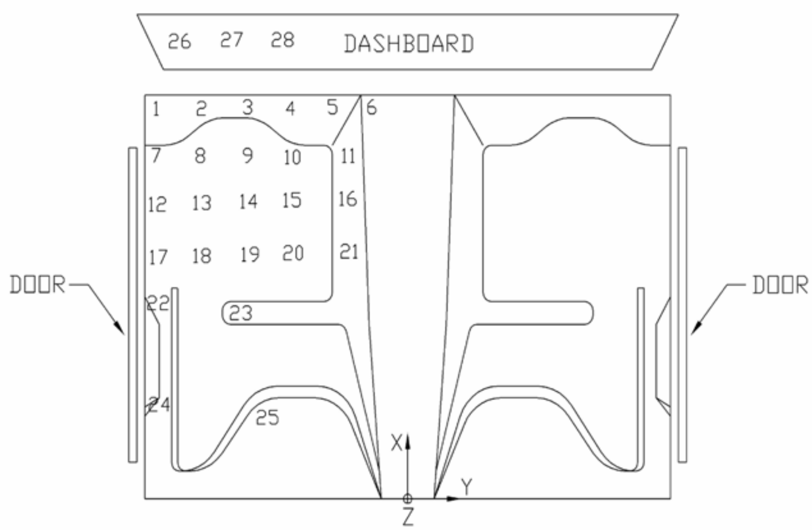


Figure C-1. Occupant Compartment Deformation Data, Test CT-1

Occupant Compartment Deformation Index (OCDI)

Test No. CT-4
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

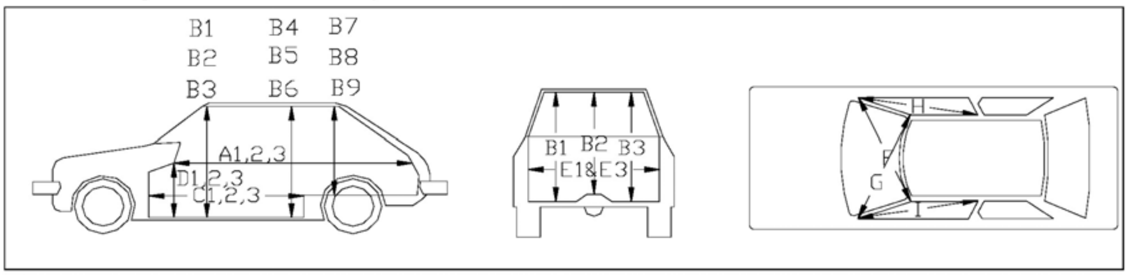
G = distance between the lower edge of left window and the upper edge of right window

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	84.25	84.25	0.00	0.00	0
A2	85.75	86.00	0.25	0.29	0
A3	86.50	86.50	0.00	0.00	0
B1	40.50	40.25	-0.25	-0.62	0
B2	38.25	38.25	0.00	0.00	0
B3	40.25	40.25	0.00	0.00	0
C1	55.50	55.50	0.00	0.00	0
C2	59.75	59.50	-0.25	-0.42	0
C3	55.75	55.75	0.00	0.00	0
D1	14.75	14.75	0.00	0.00	0
D2	19.75	19.75	0.00	0.00	0
D3	23.25	23.25	0.00	0.00	0
E1	52.00	52.00	0.00	0.00	0
E3	49.00	49.00	0.00	0.00	0
F	49.25	50.00	0.75	1.52	0
G	49.25	49.25	0.00	0.00	0
H	40.75	40.75	0.00	0.00	0
I	40.50	40.75	0.25	0.62	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:		0	0	0	0	0	0	0	0	0

Figure C-2. Occupant Compartment Deformation Index (OCDI), Test CT-4

APPENDIX D

Accelerometer and Rate Transducer Data Analysis, Test CT-1

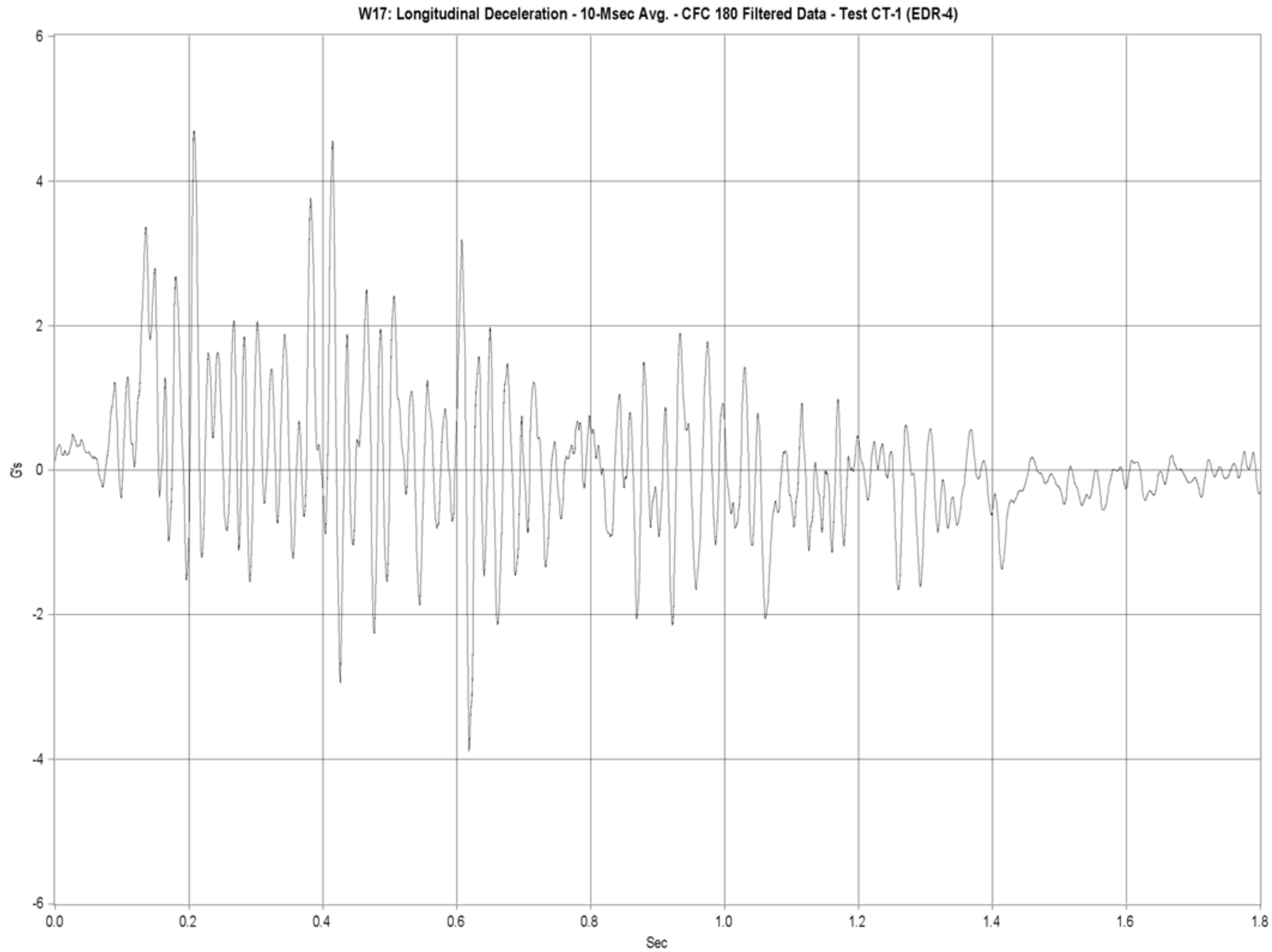


Figure D-1. Graph of Longitudinal Deceleration, Test CT-1

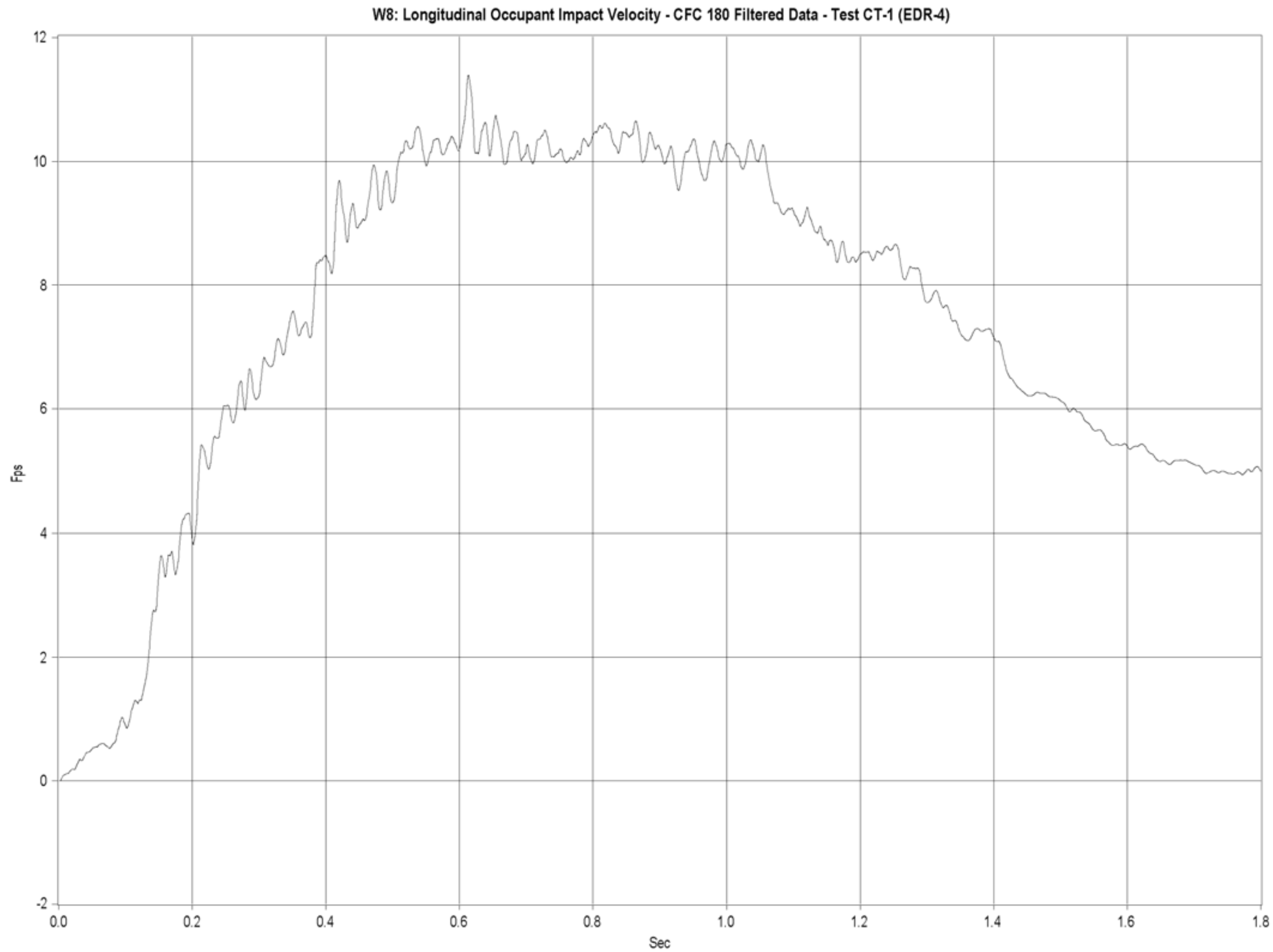


Figure D-2. Graph of Longitudinal Occupant Impact Velocity, Test CT-1

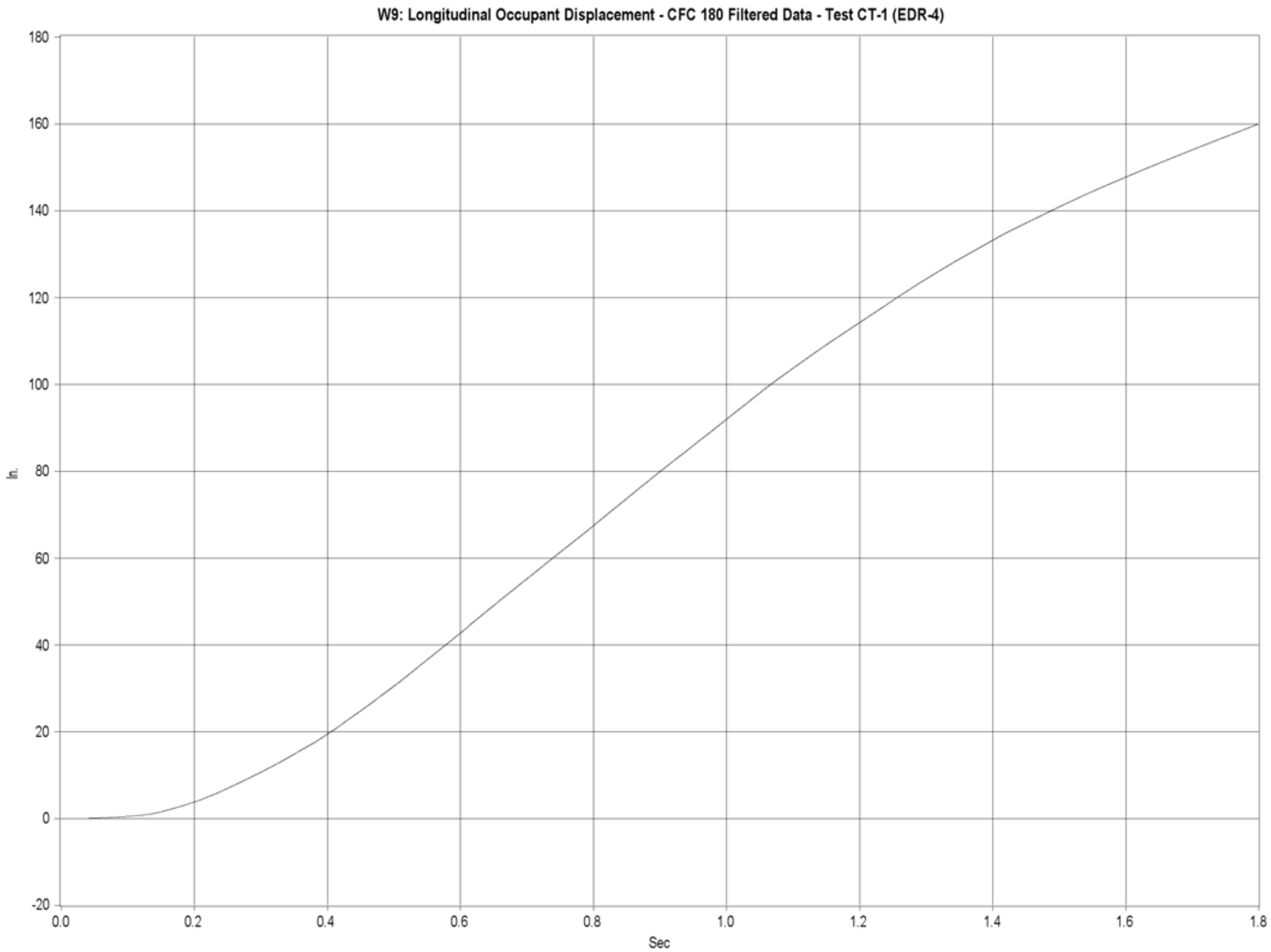


Figure D-3. Graph of Longitudinal Occupant Displacement, Test CT-1

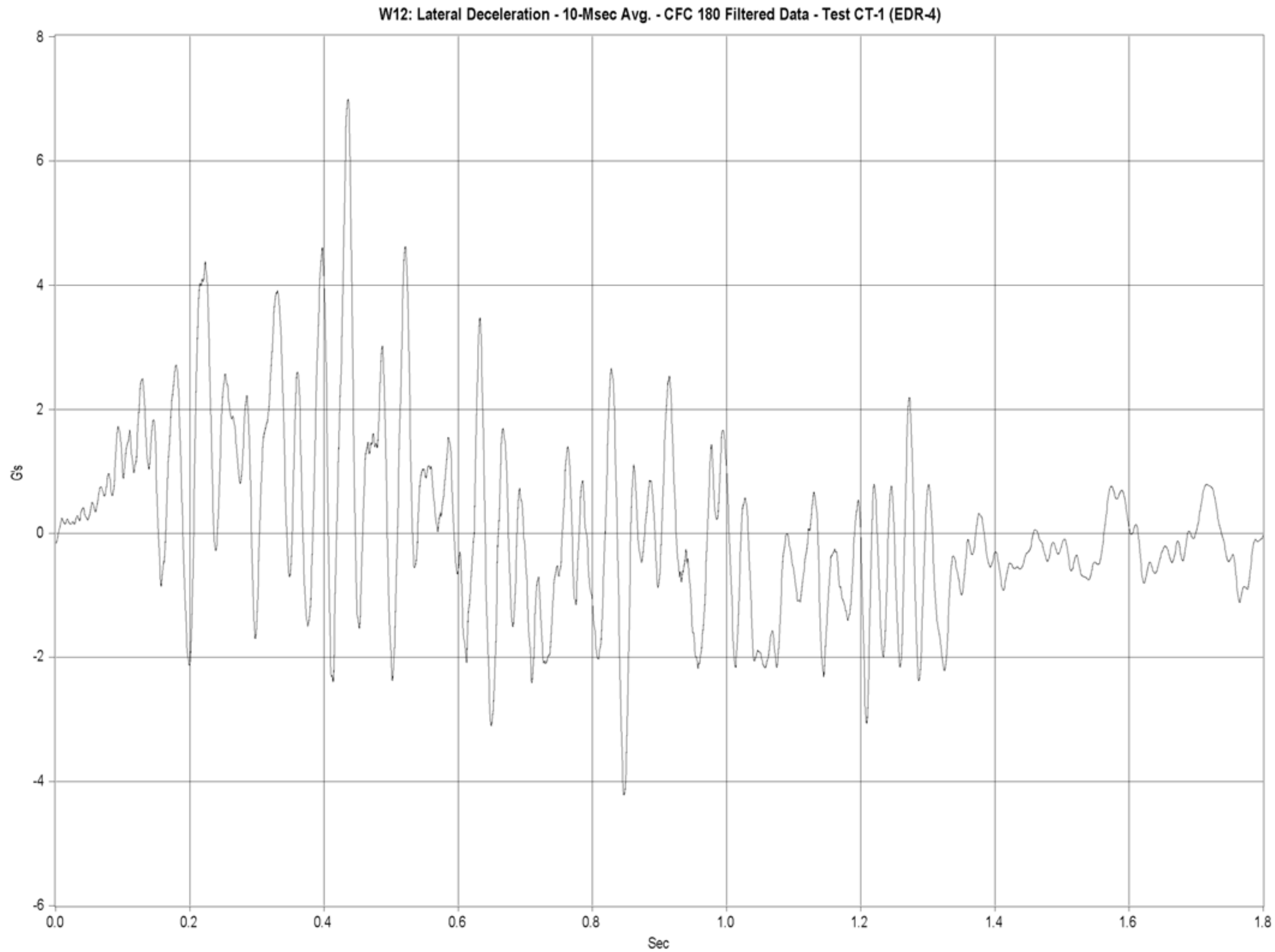


Figure D-4. Graph of Lateral Deceleration, Test CT-1

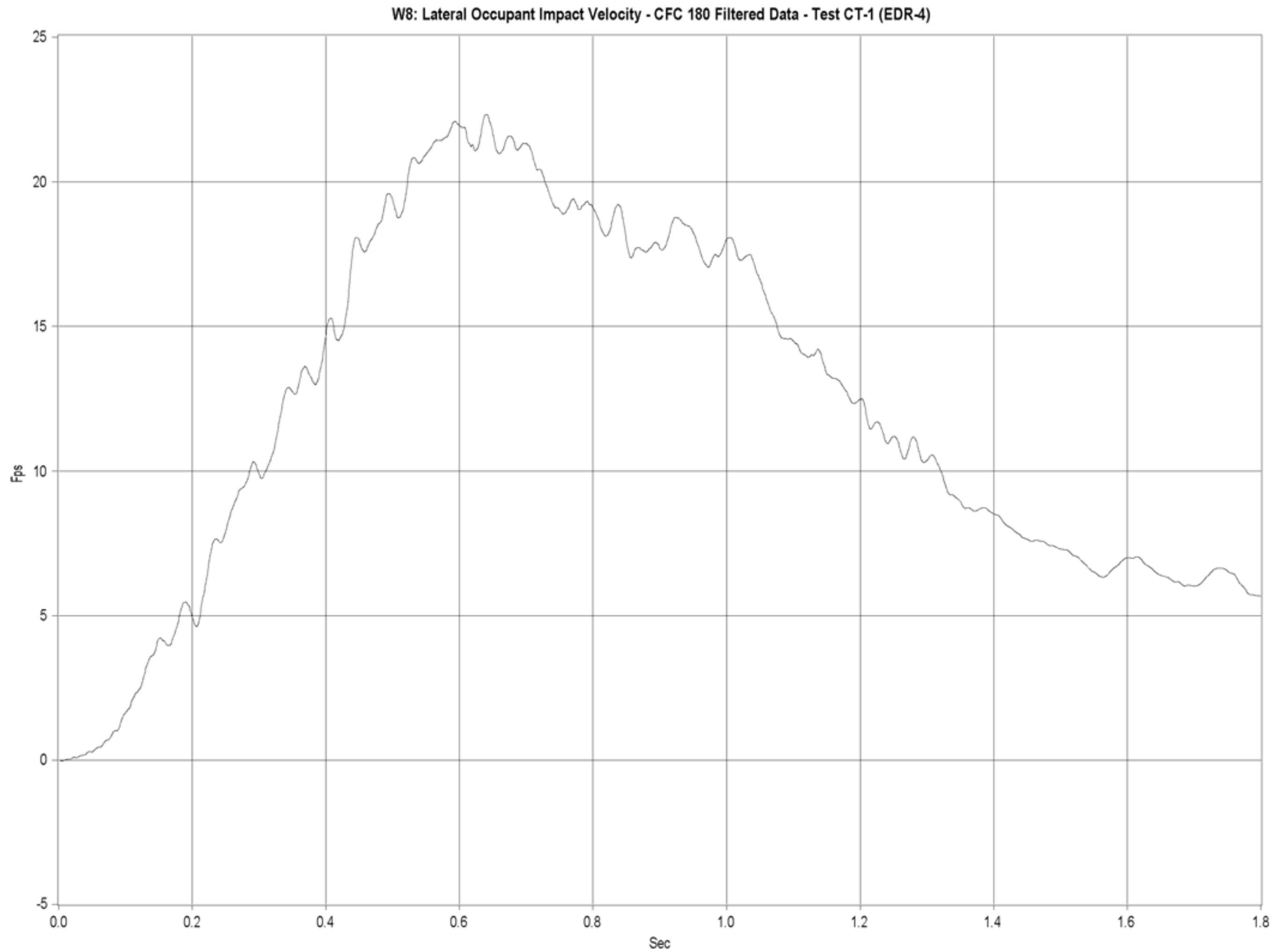


Figure D-5. Graph of Lateral Occupant Impact Velocity, Test CT-1

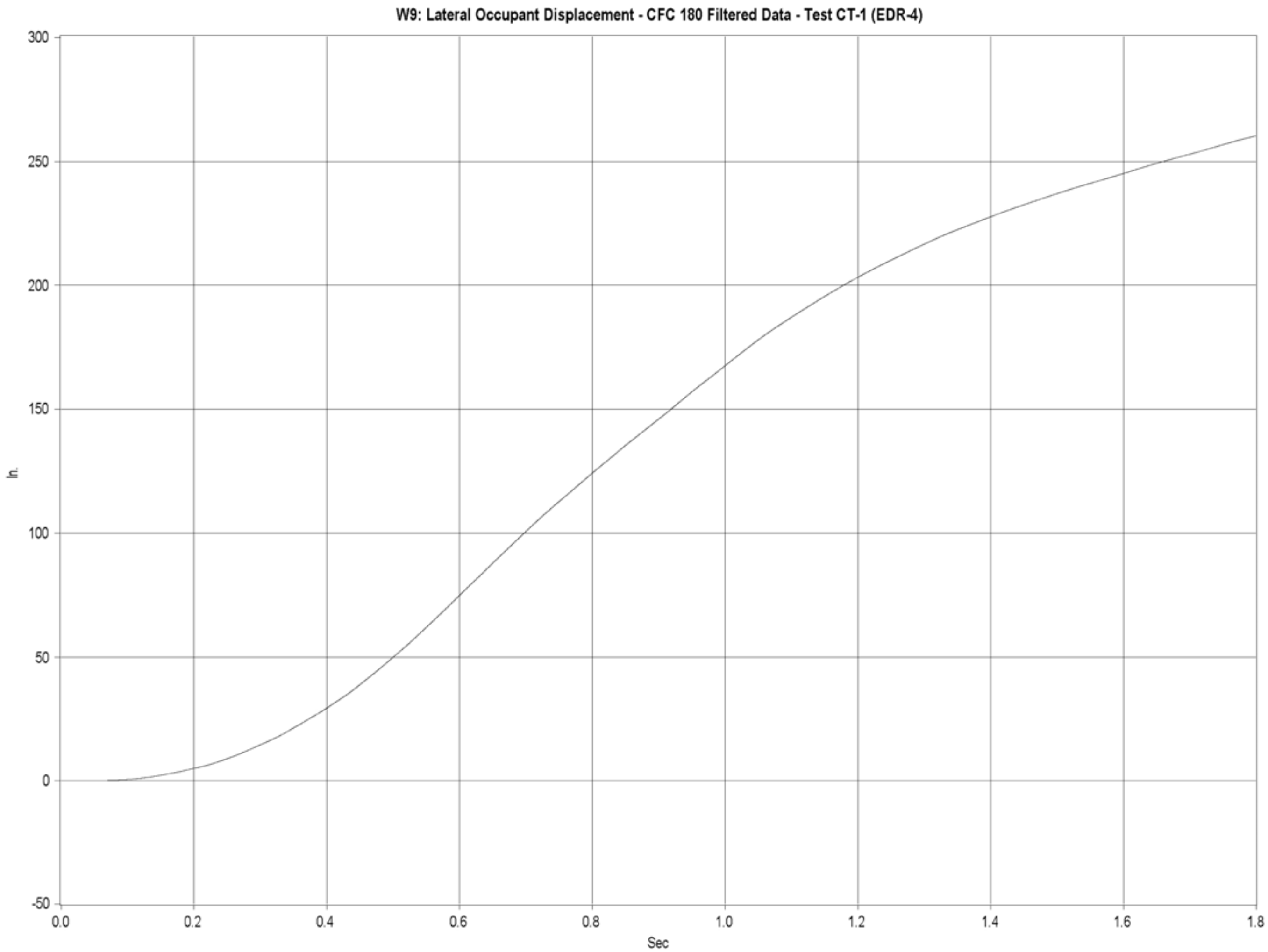


Figure D-6. Graph of Lateral Occupant Displacement, Test CT-1

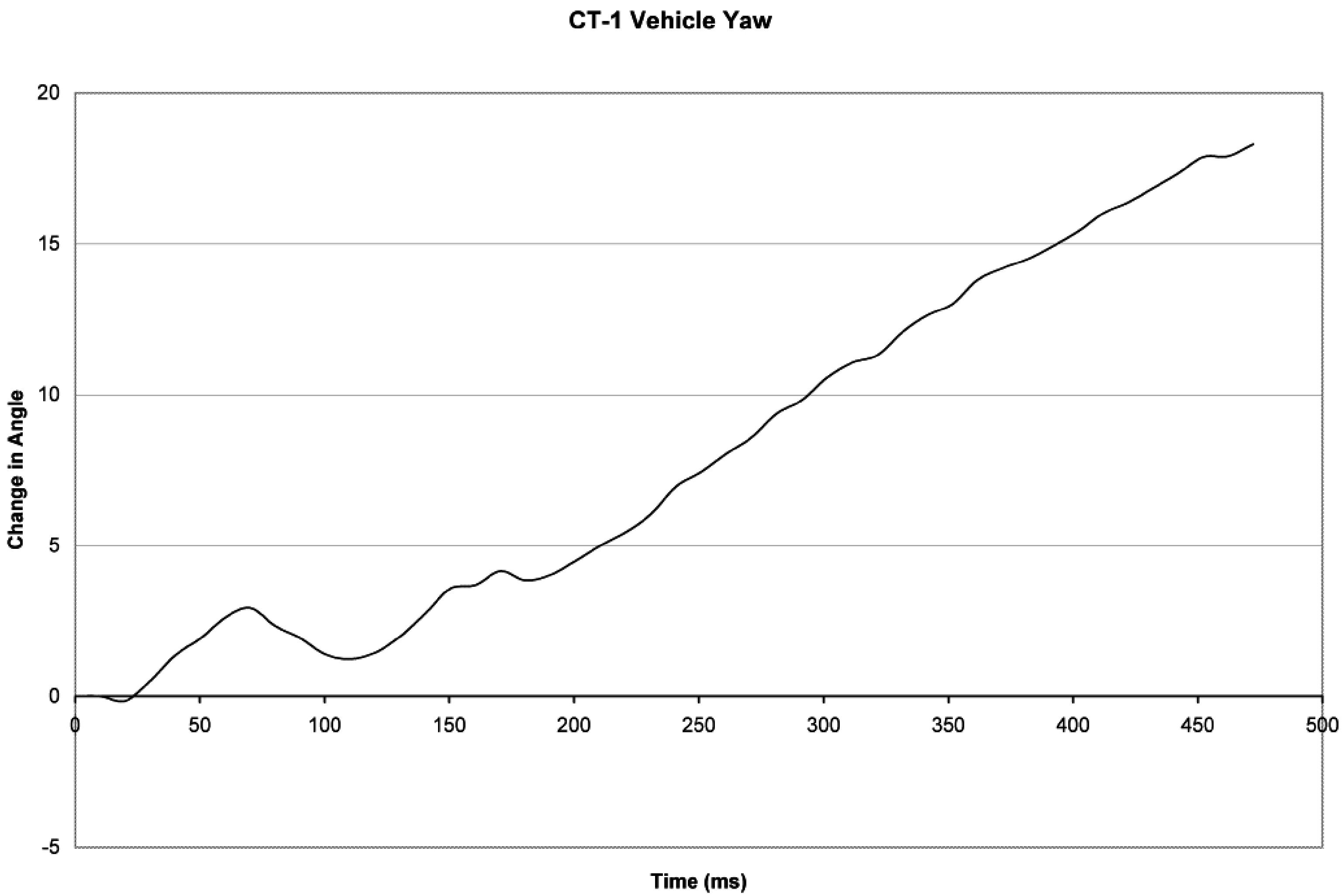


Figure -7. Graph of Yaw Angular Displacement, Test CT-1

APPENDIX E

Accelerometer and Rate Transducer Data Analysis, Test CT-2

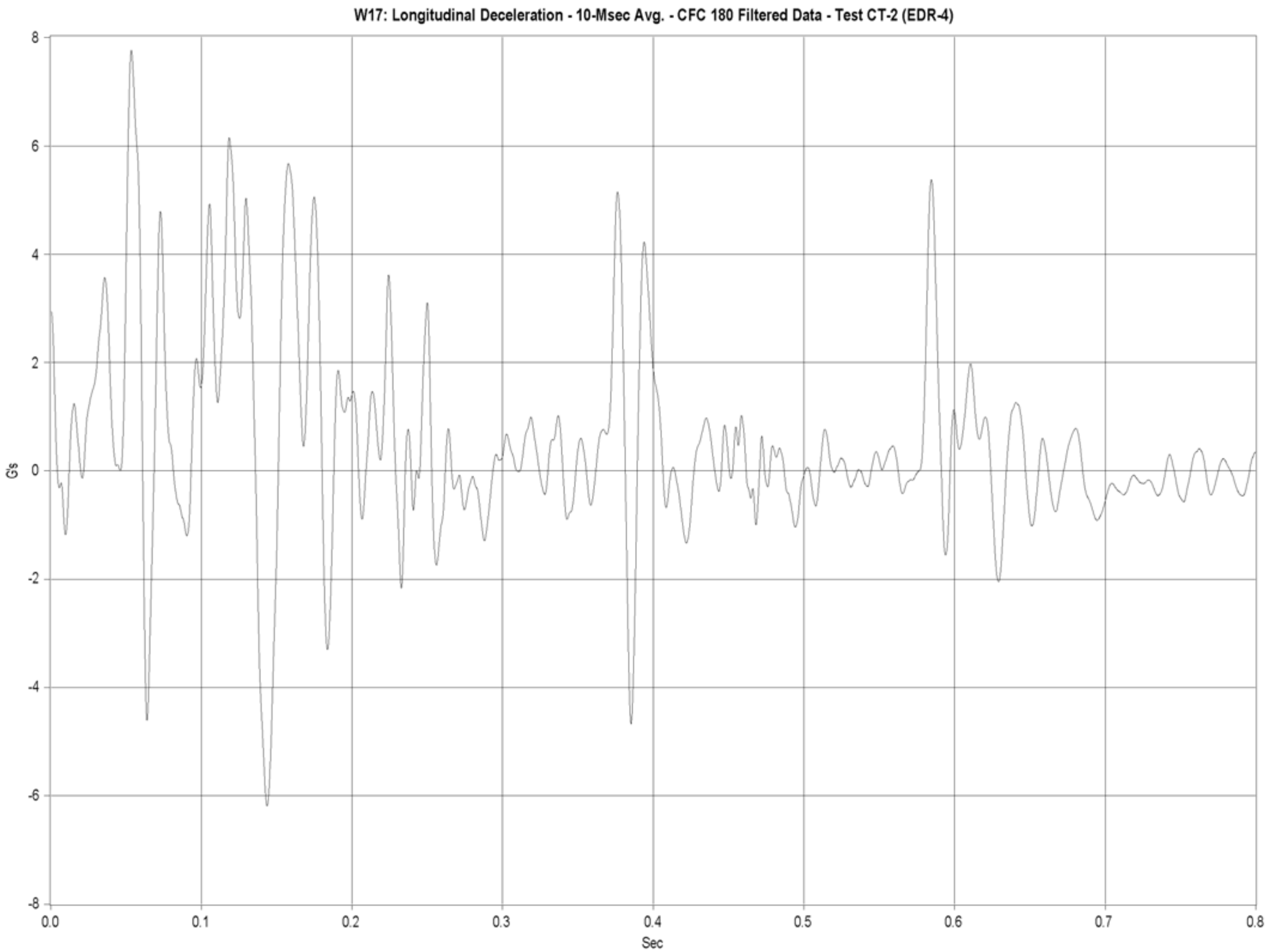


Figure E-1. Graph of Longitudinal Deceleration, Test CT-2

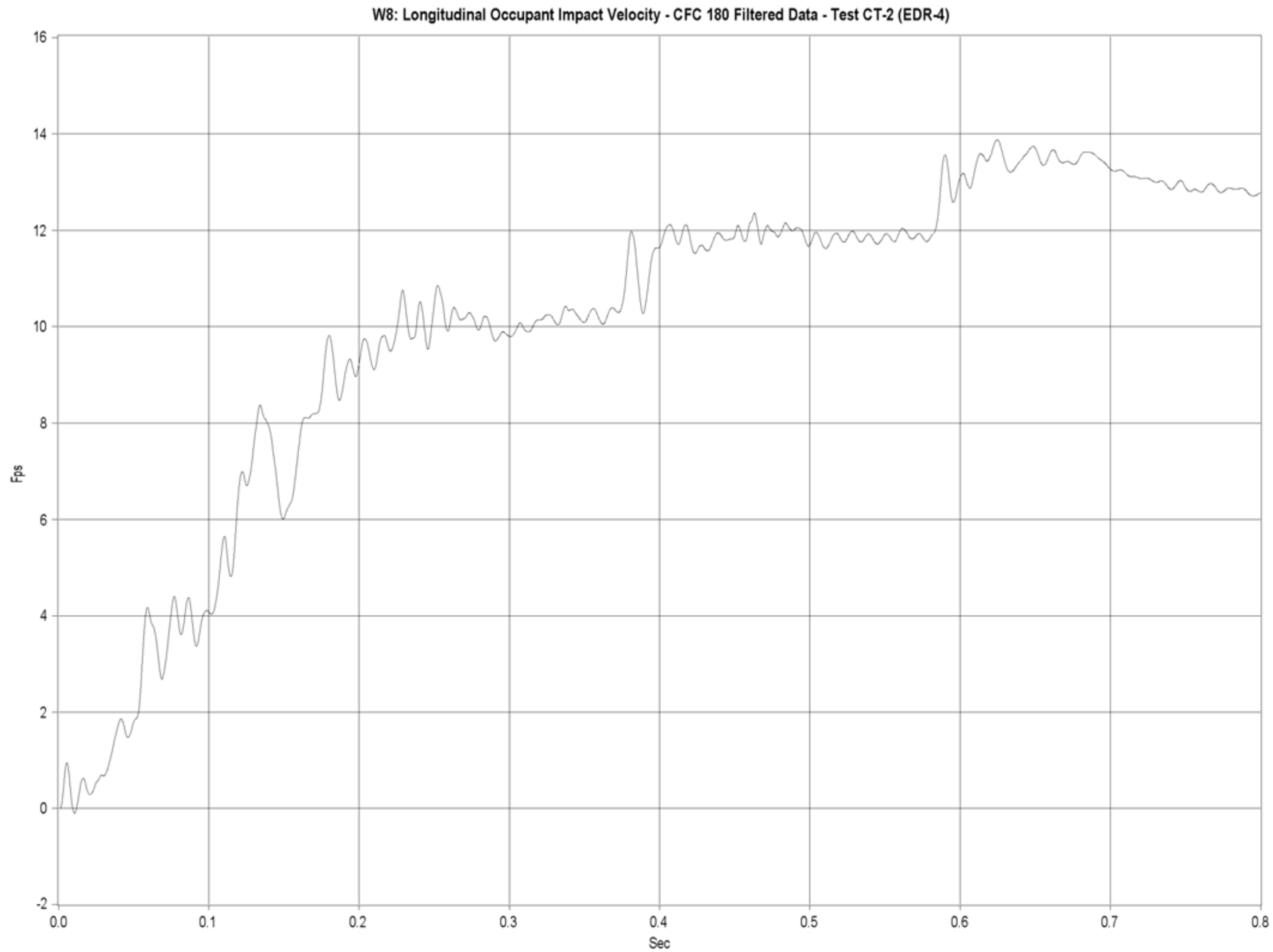


Figure E-2. Graph of Longitudinal Occupant Impact Velocity, Test CT-2

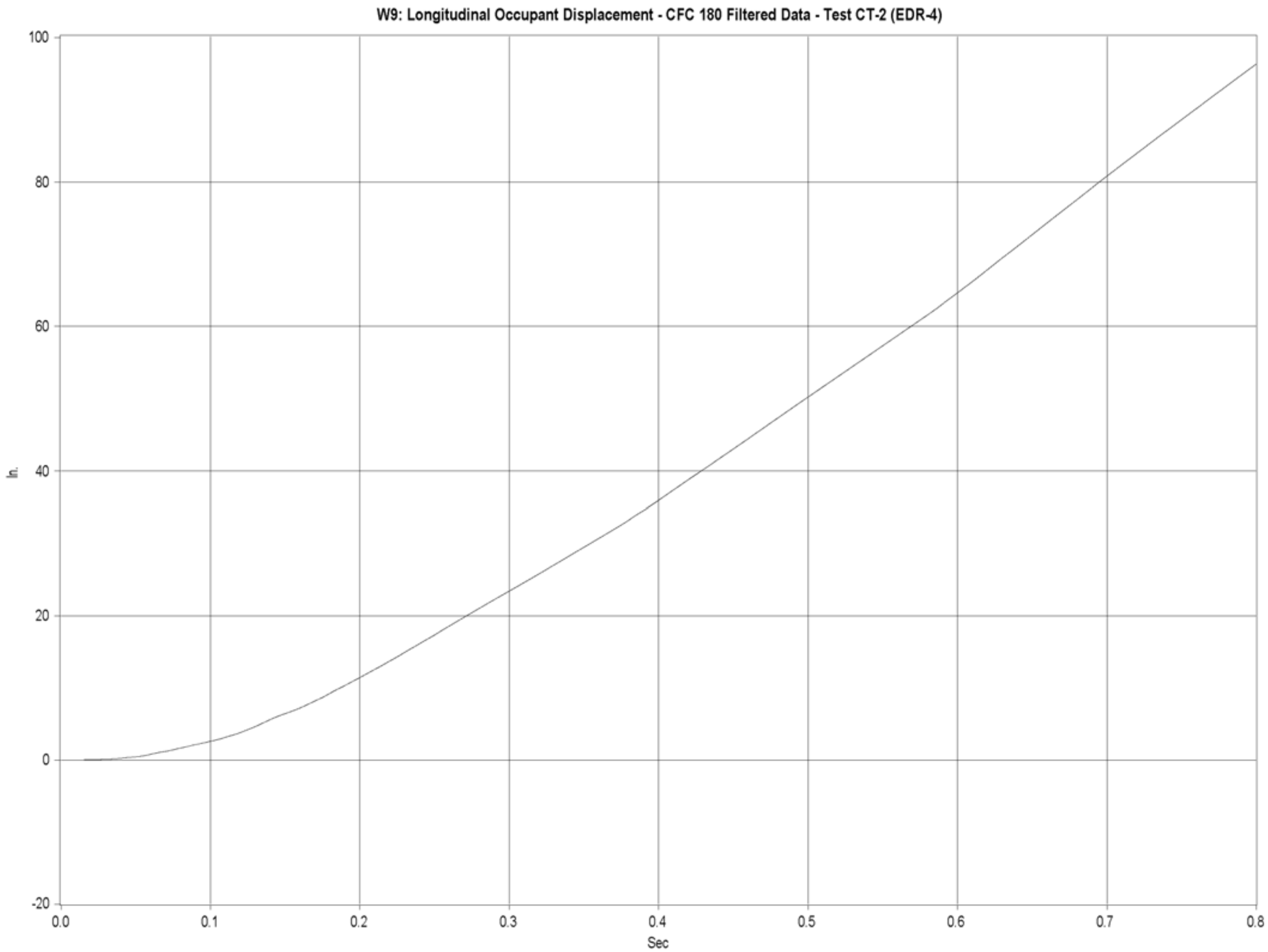


Figure E-3. Graph of Longitudinal Occupant Displacement, Test CT-2

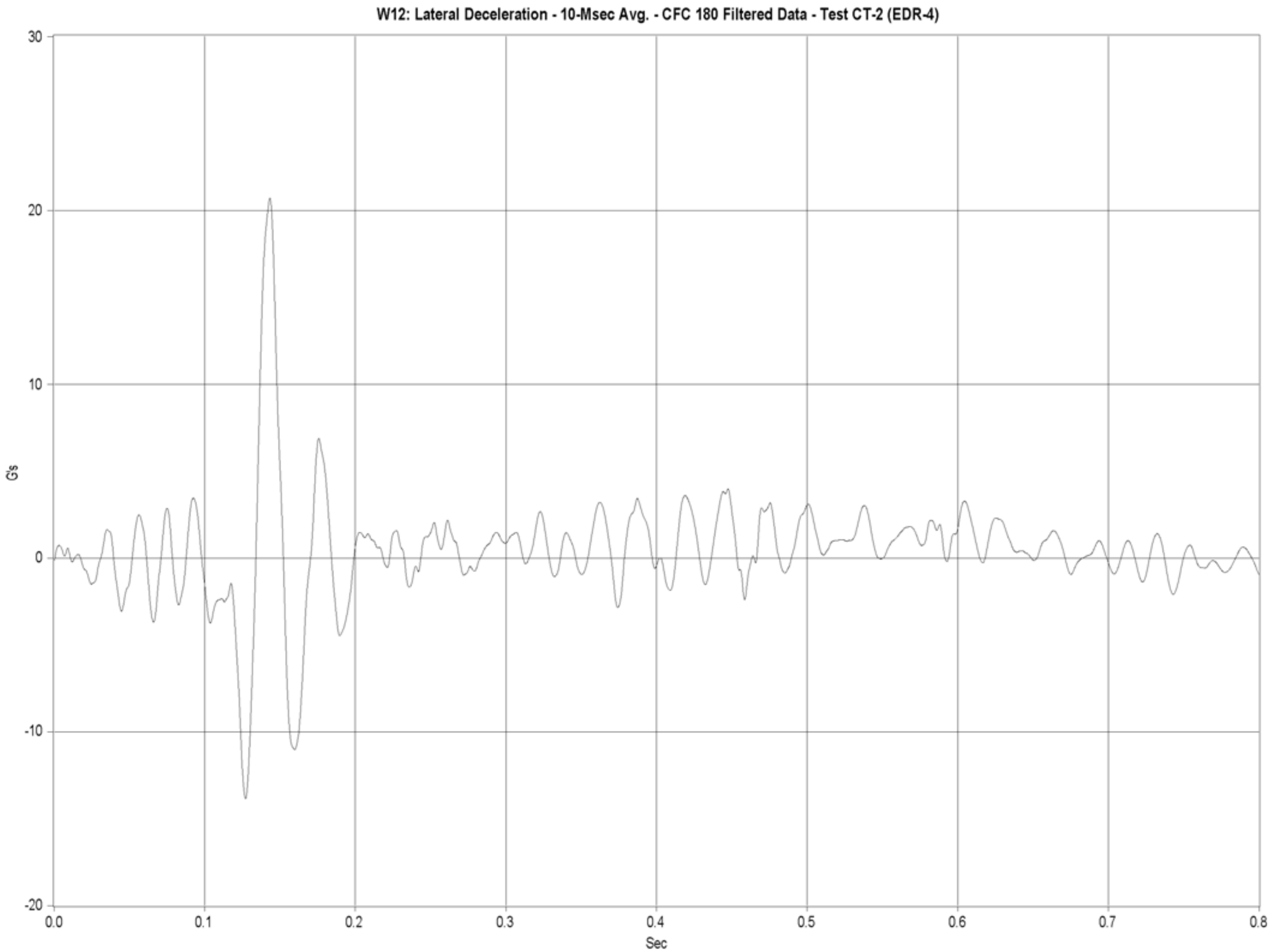


Figure E-4. Graph of Lateral Deceleration, Test CT-2

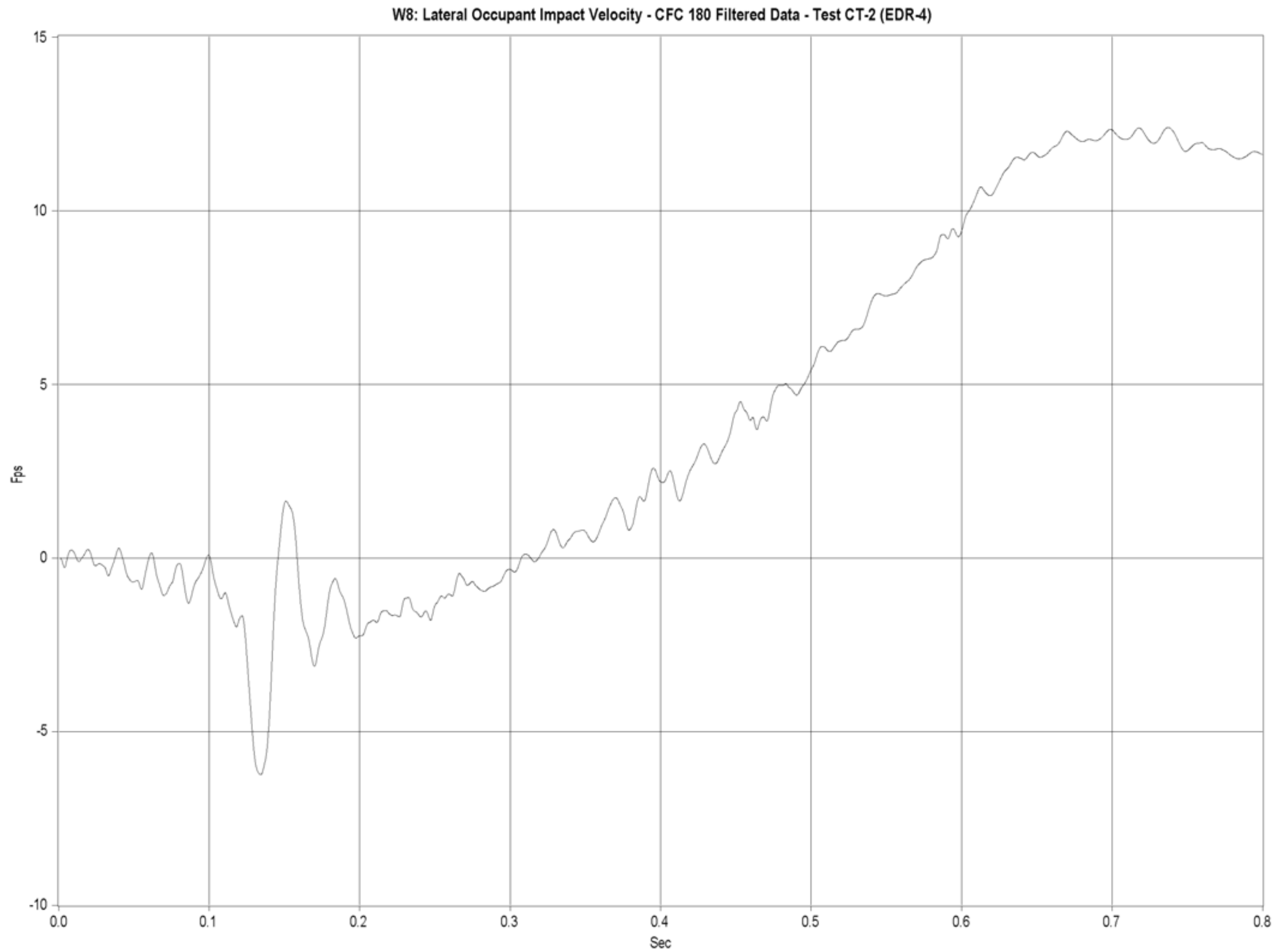


Figure E-5. Graph of Lateral Occupant Impact Velocity, Test CT-2

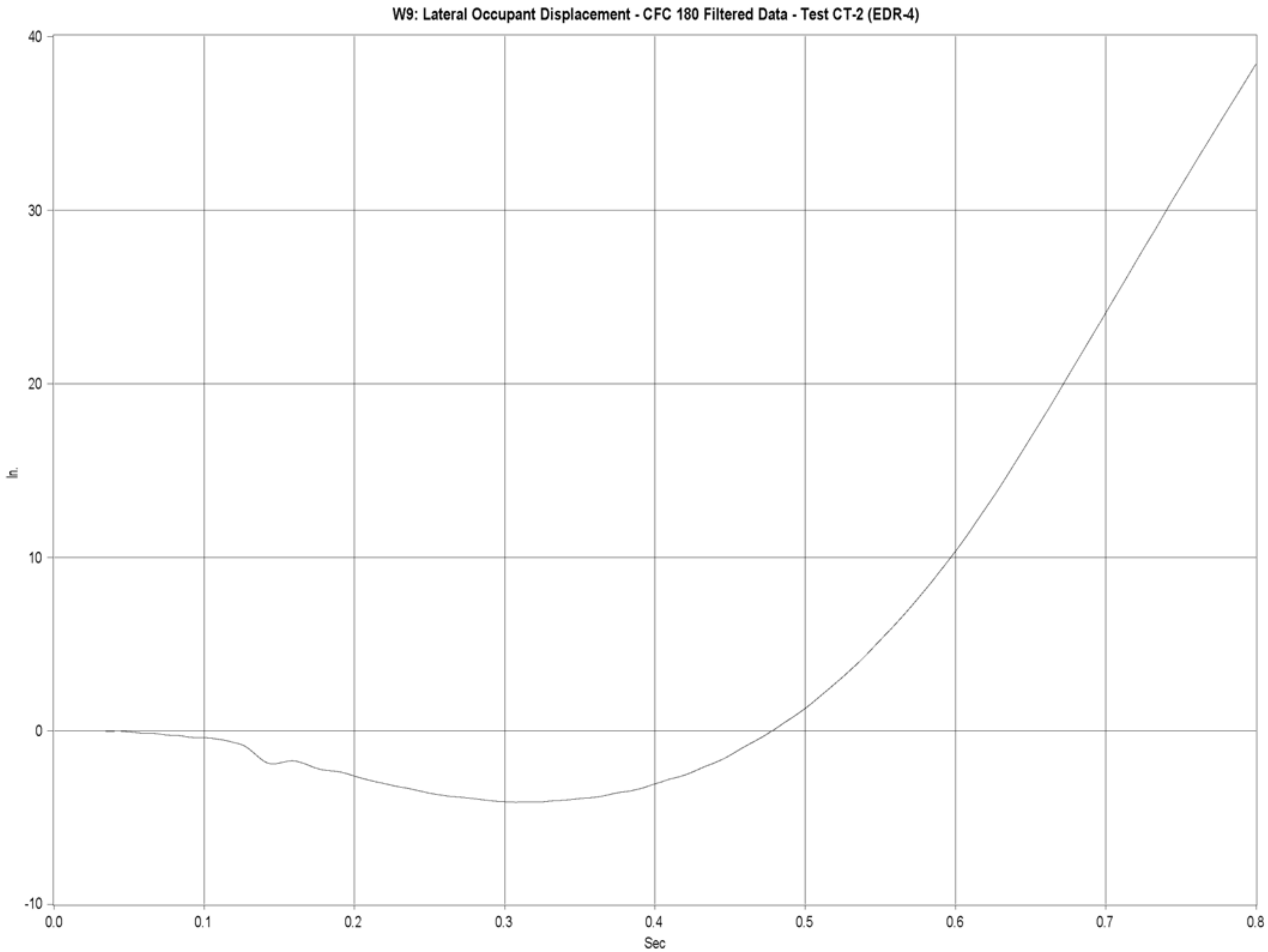


Figure E-6. Graph of Lateral Occupant Displacement, Test CT-2

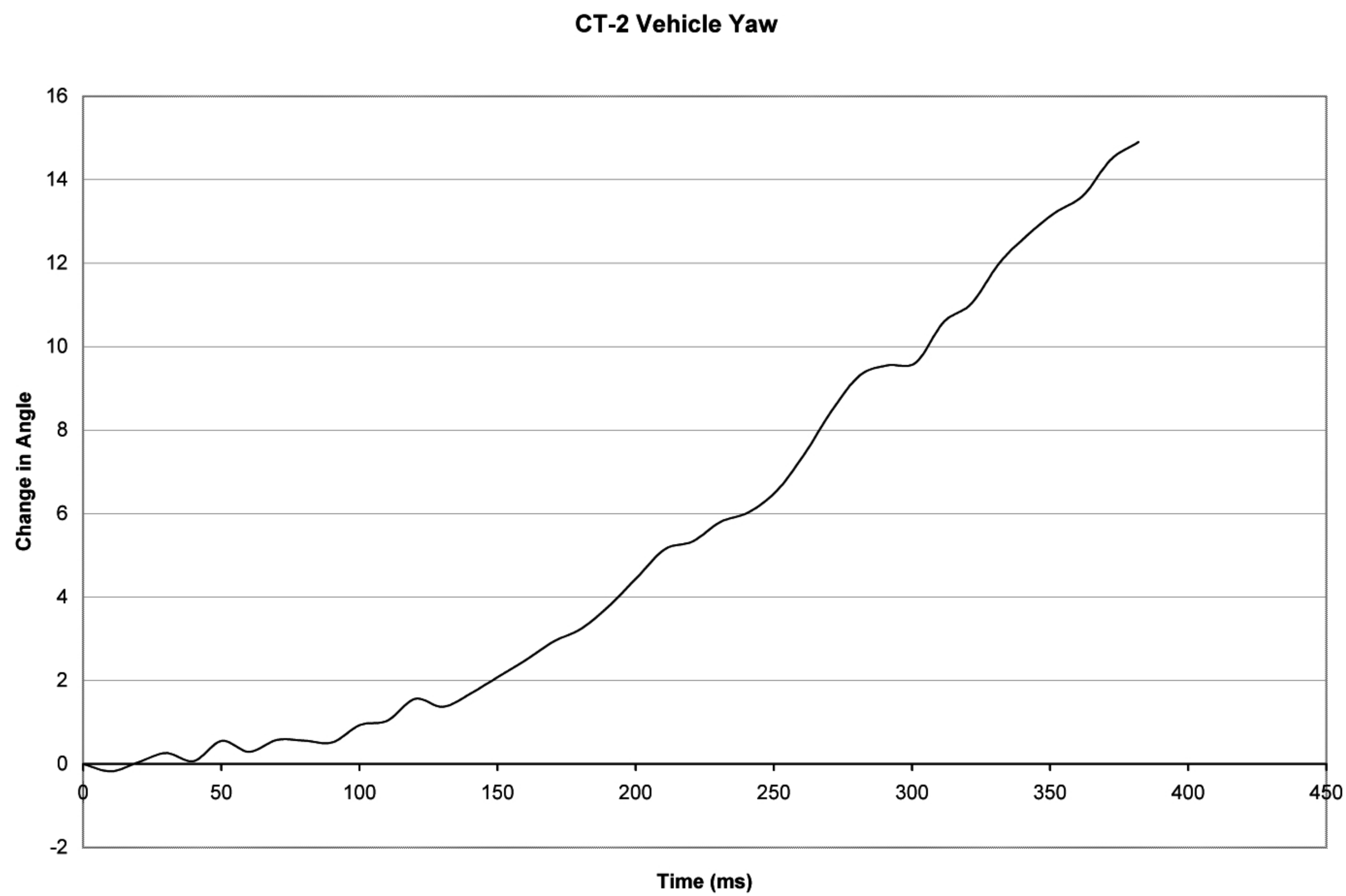


Figure E-7. Graph of Yaw Angular Displacement, Test CT-2

APPENDIX F

System Details, Design No. 2

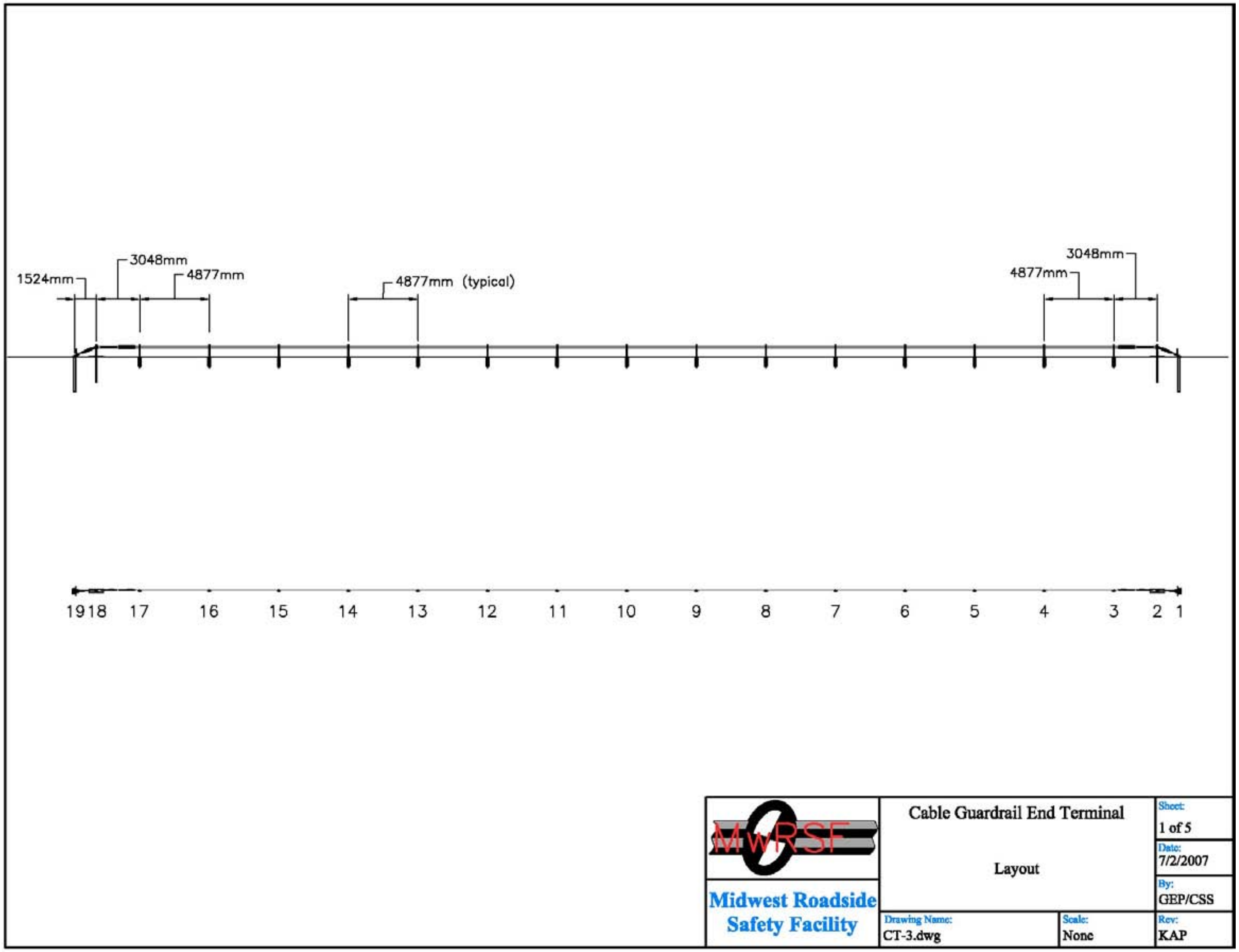


Figure F-1. System Details, Design No. 2

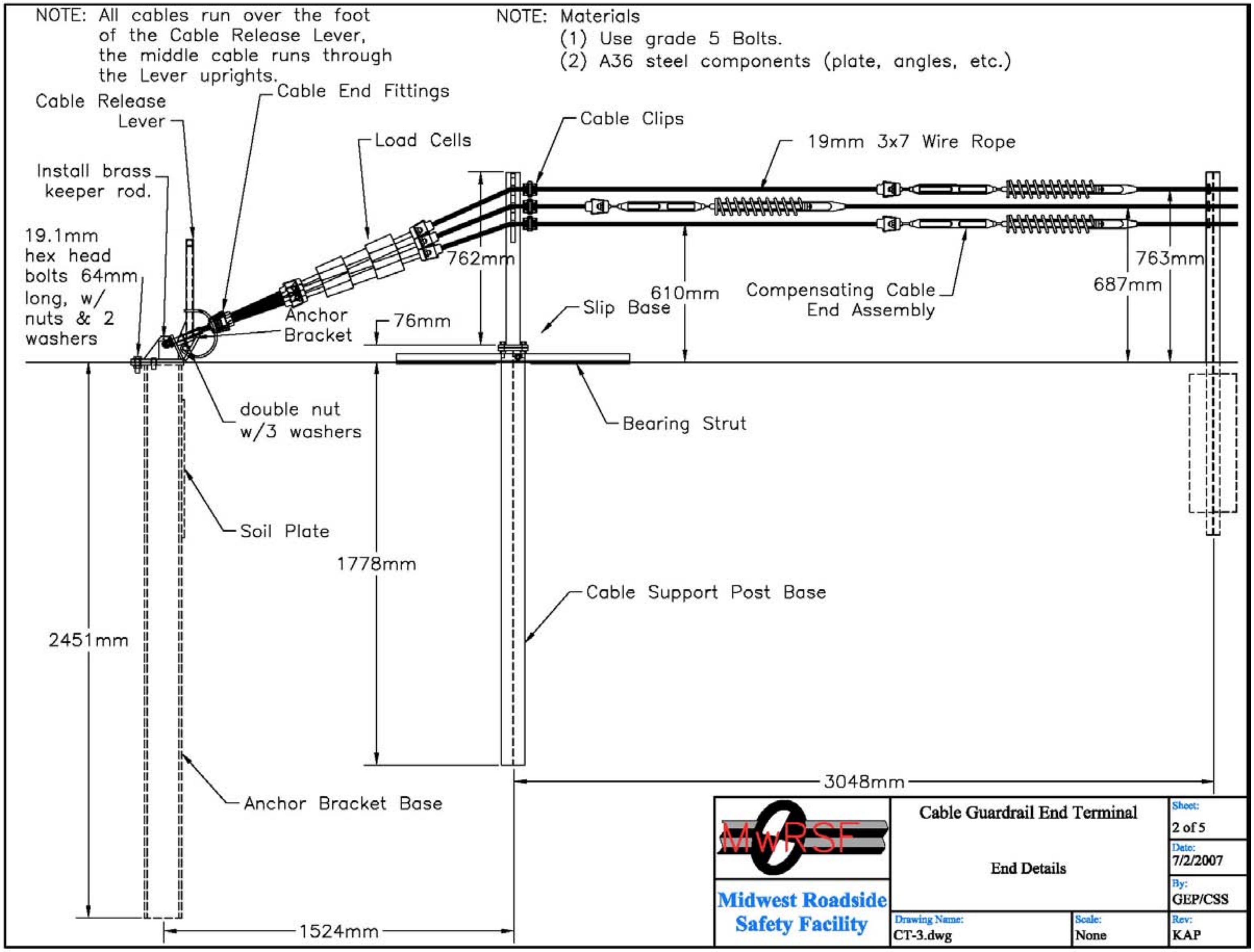


Figure F-2. End Anchorage Details, Design No. 2

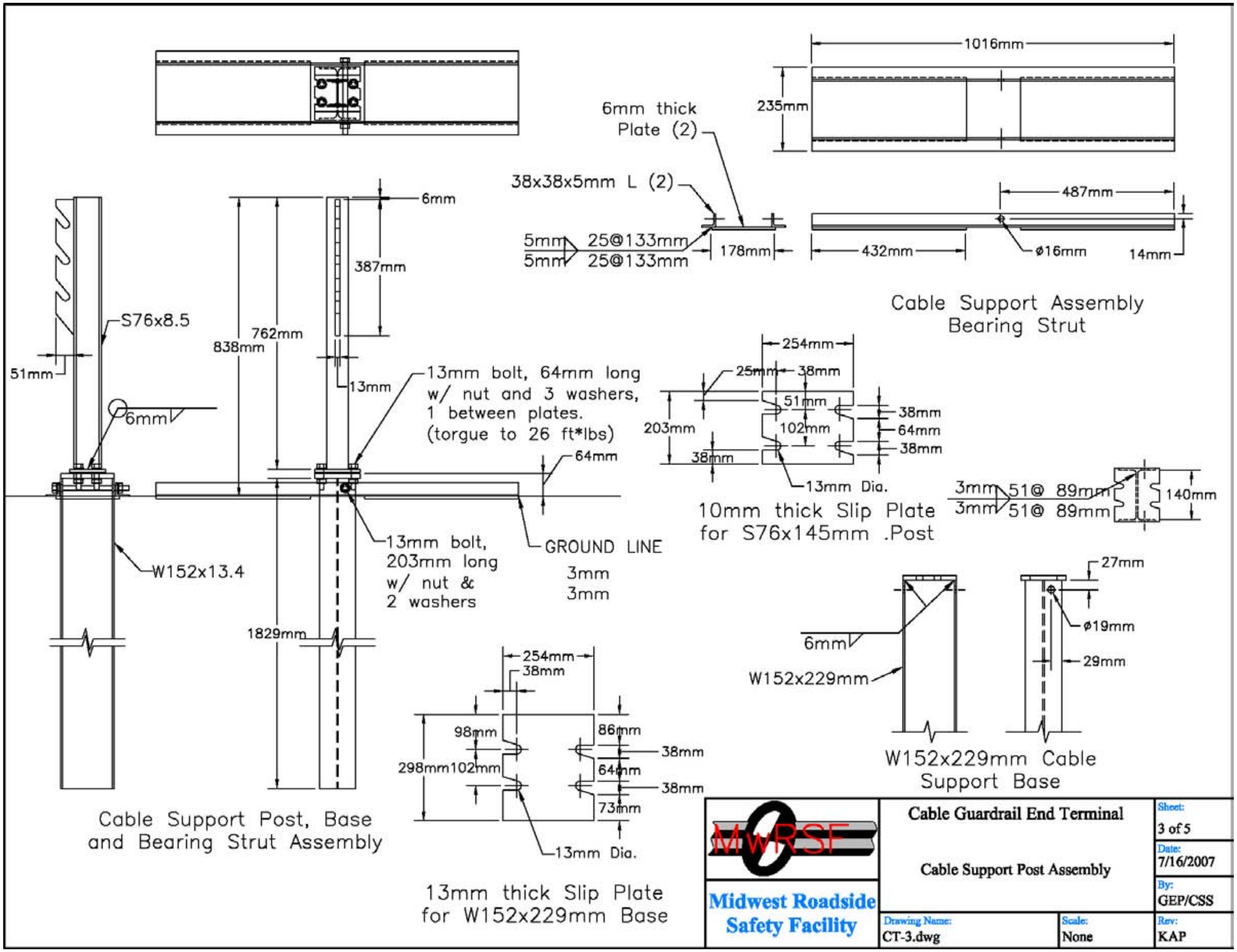


Figure F-3. Support Post Assembly Details, Design No. 2

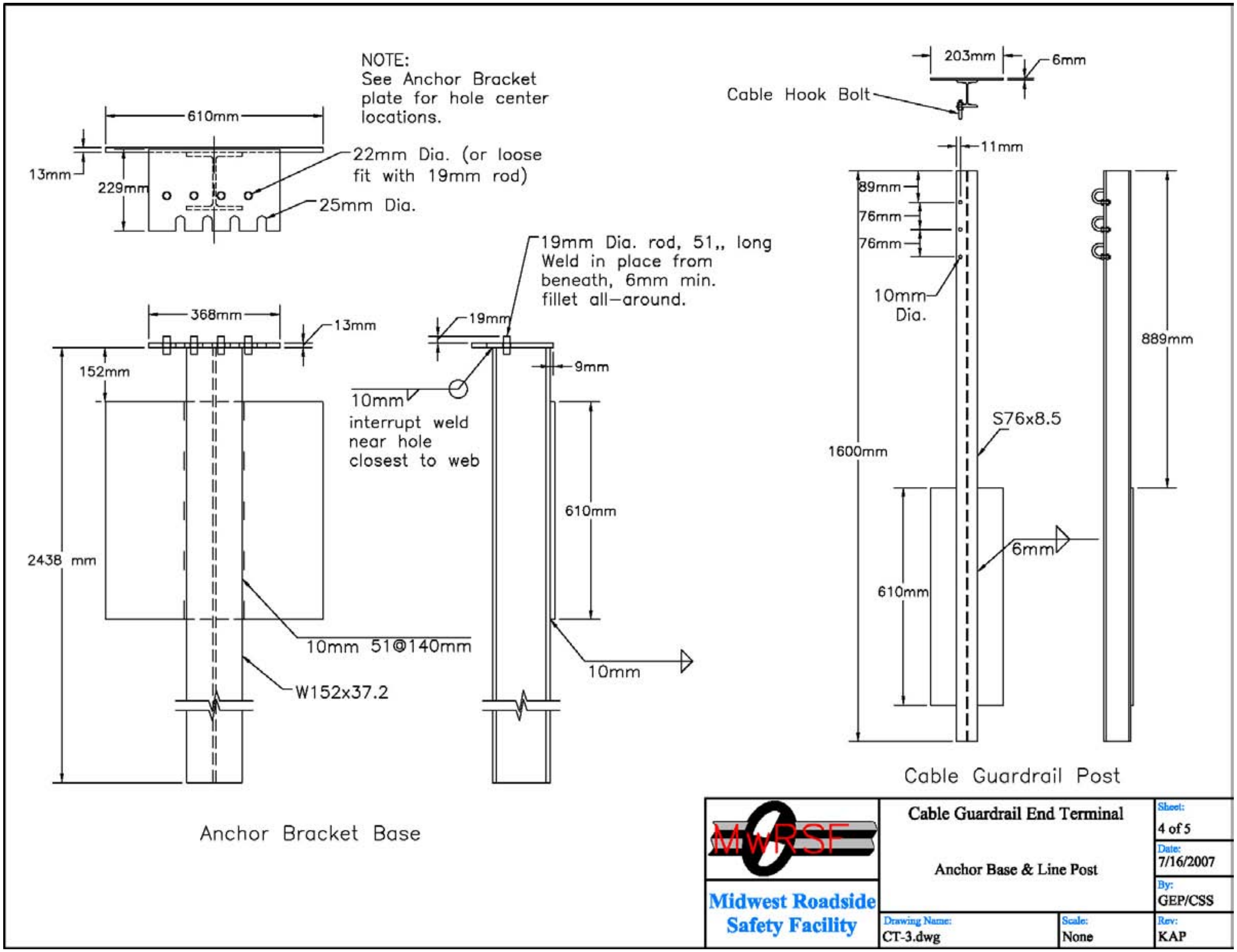


Figure F-4. Anchor Bracket and Line Post Details, Design No. 2

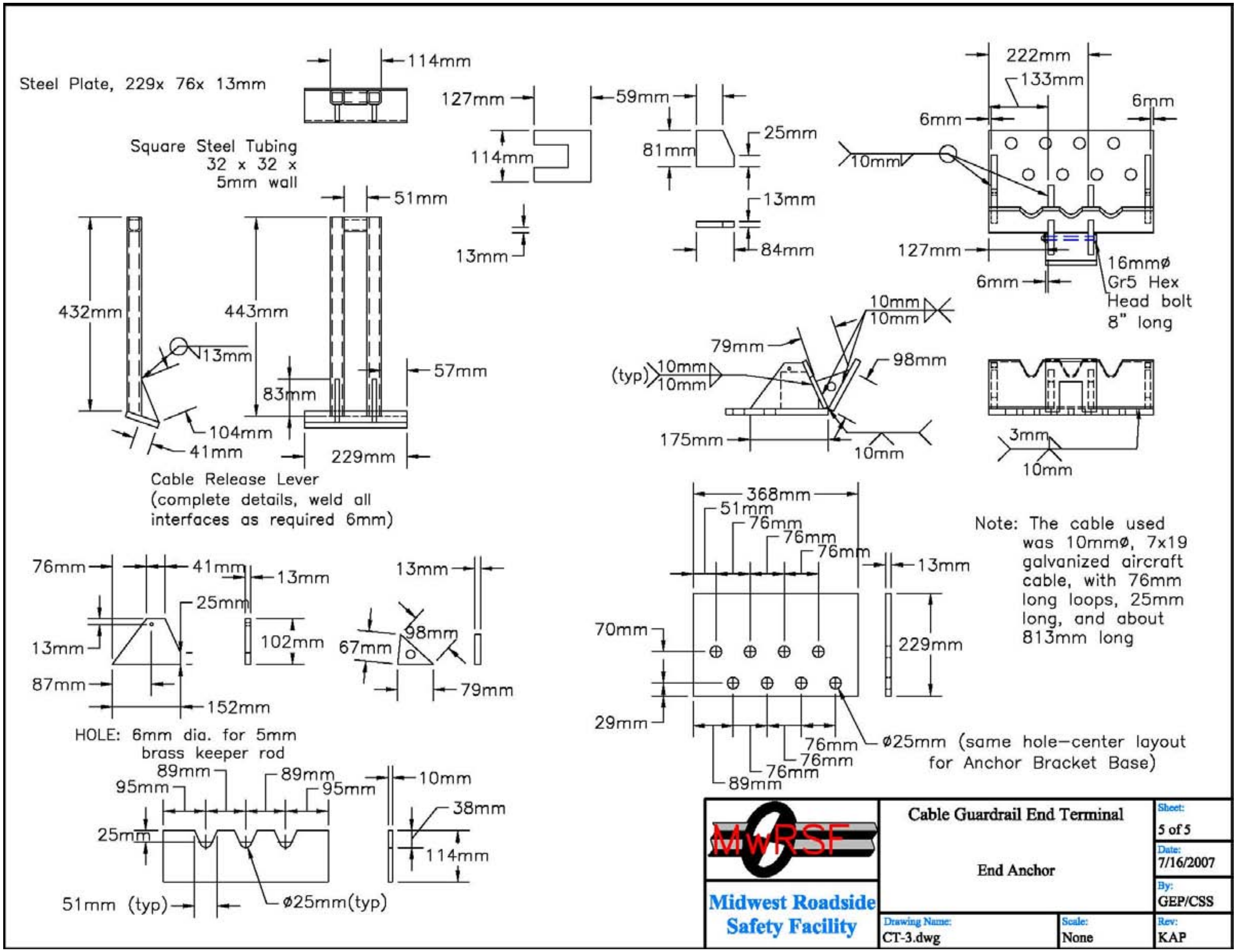


Figure F-5. End Anchor Details, Design No. 2

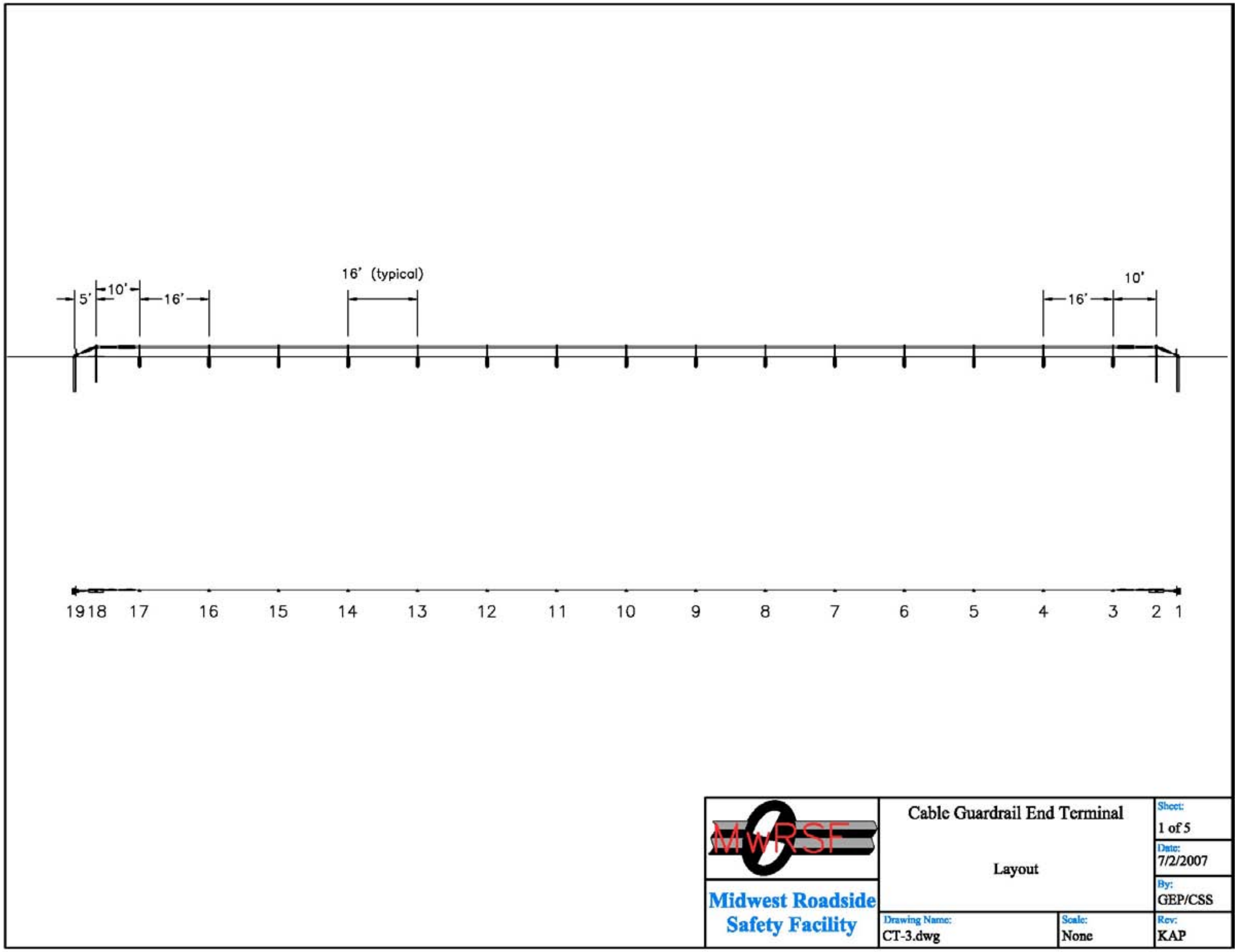


Figure F-6. System Details (English), Design No. 2

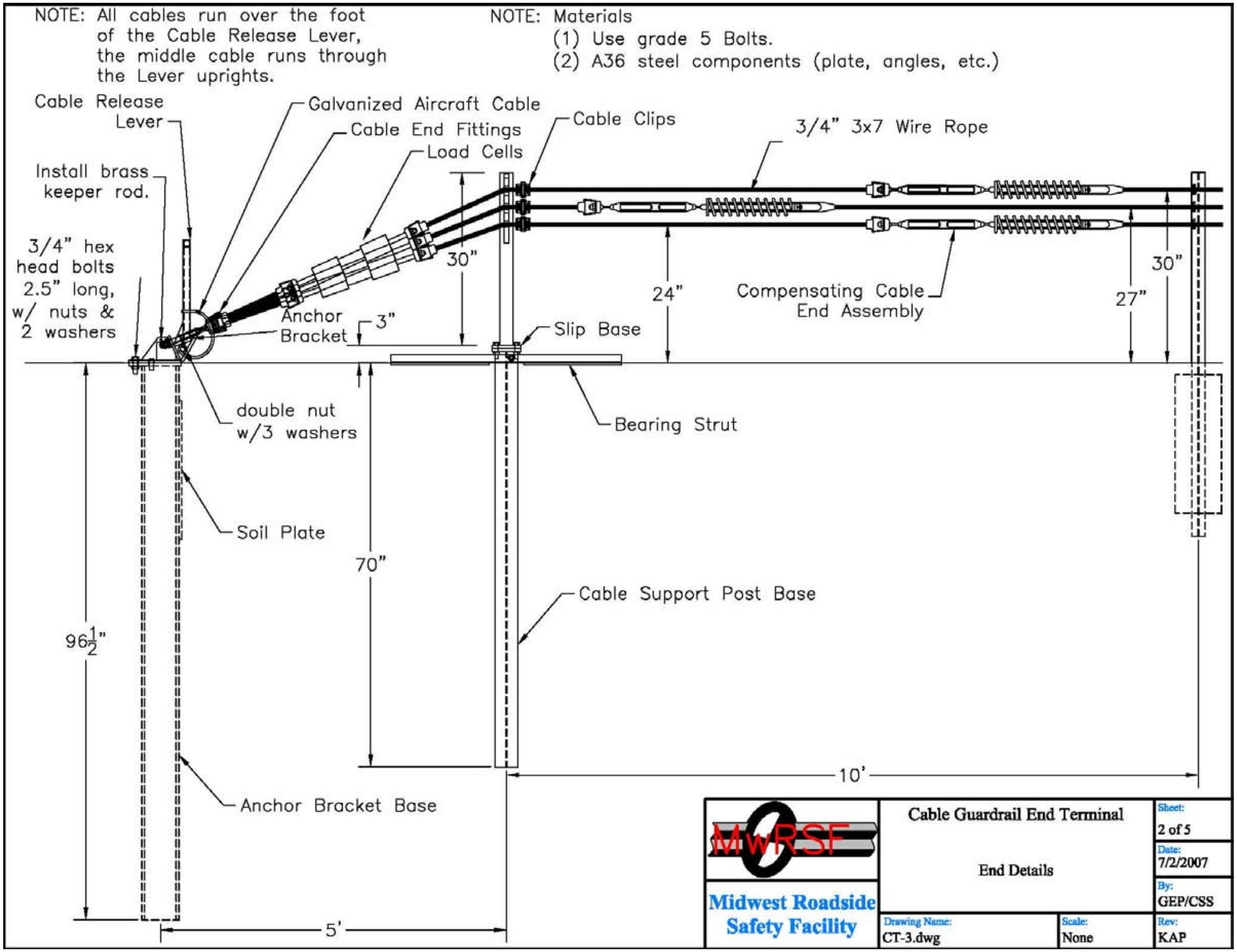


Figure F-7. End Anchorage Details (English), Design No. 2

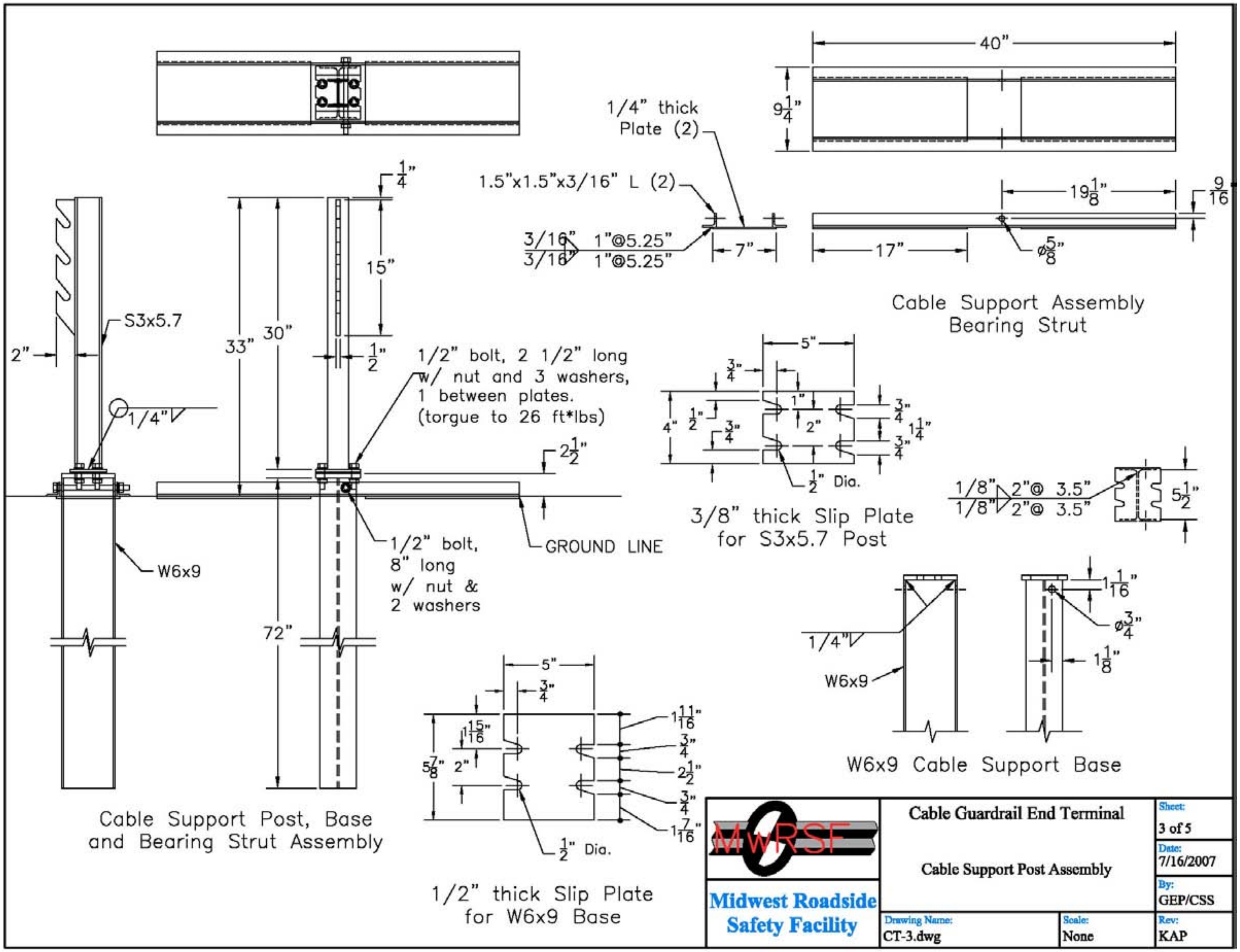


Figure F-8. Support Post Assembly Details (English), Design No. 2

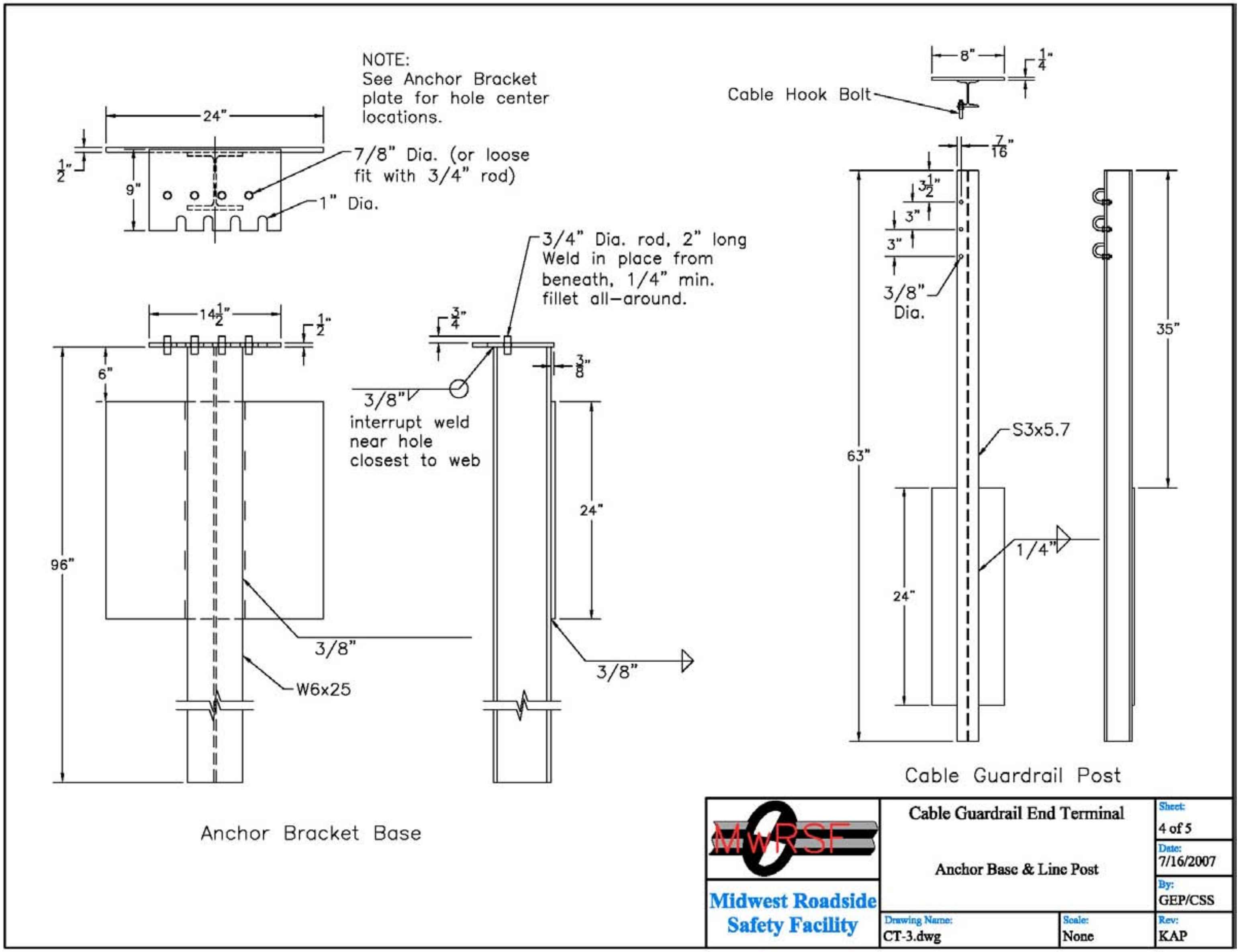


Figure F-9. Anchor Bracket and Line Post Details (English), Test CT-3

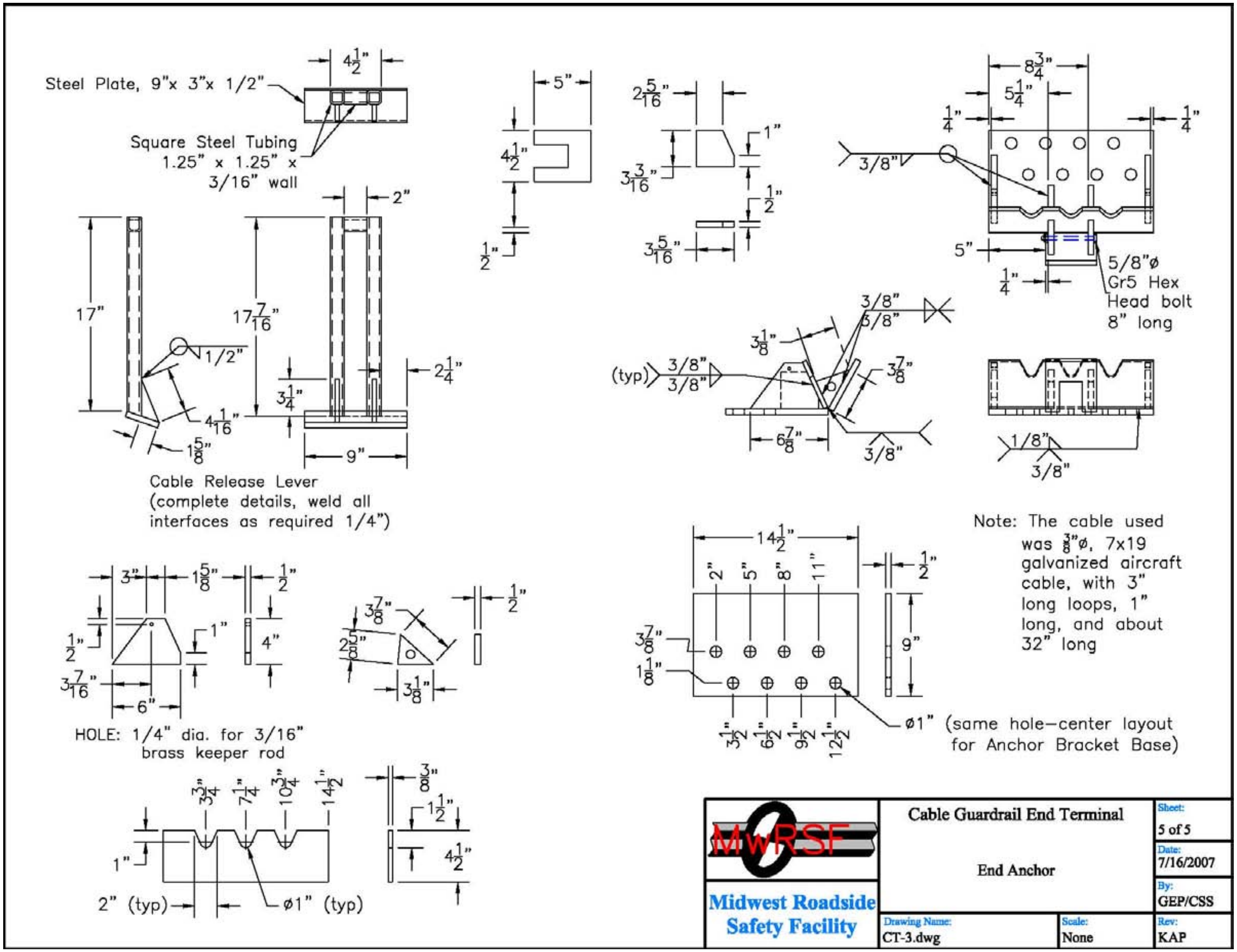


Figure F-10. End Anchor Details (English), Test CT-3

APPENDIX G

Accelerometer and Rate Transducer Data Analysis, Test CT-3

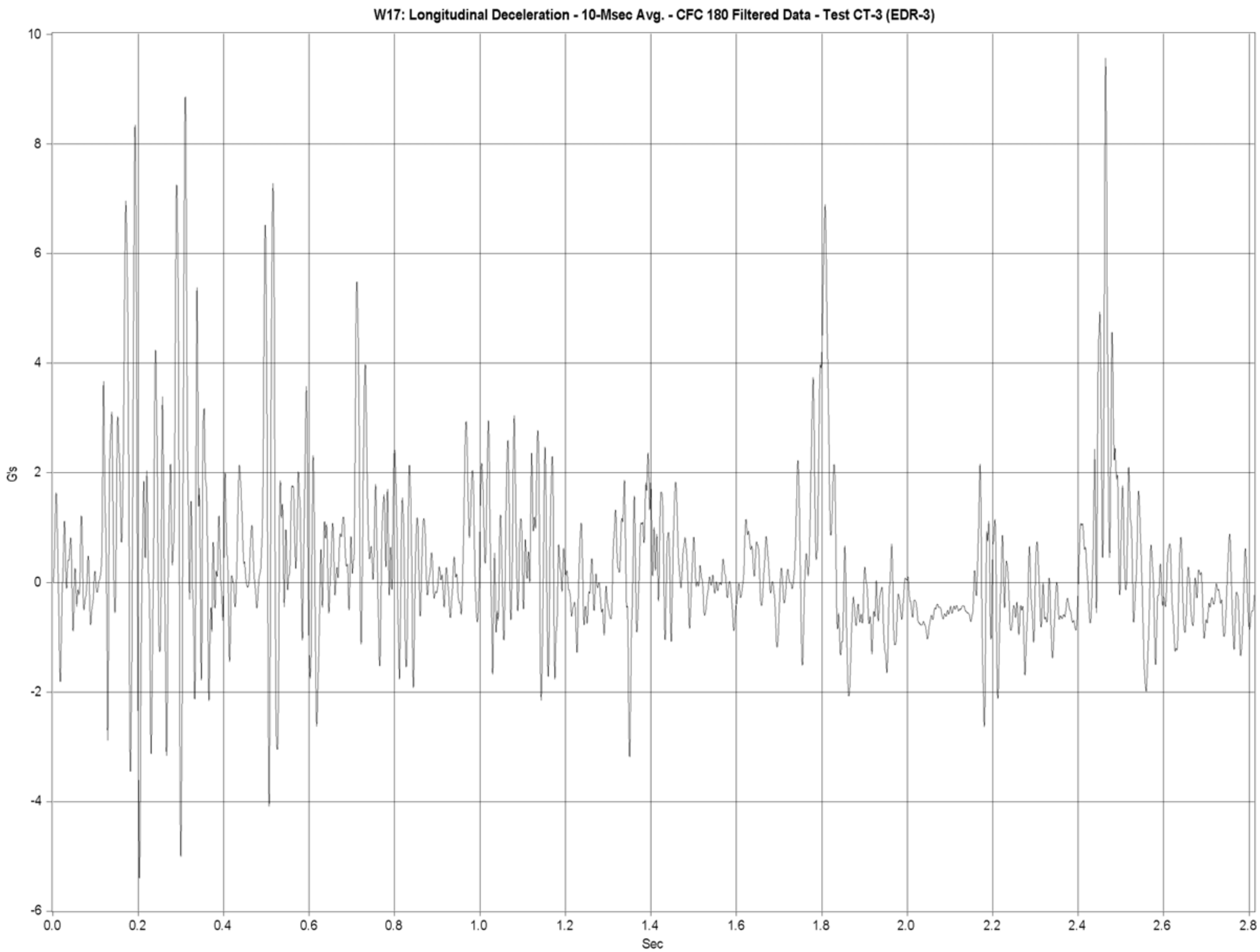


Figure G-1. Graph of Longitudinal Deceleration, Test CT-3

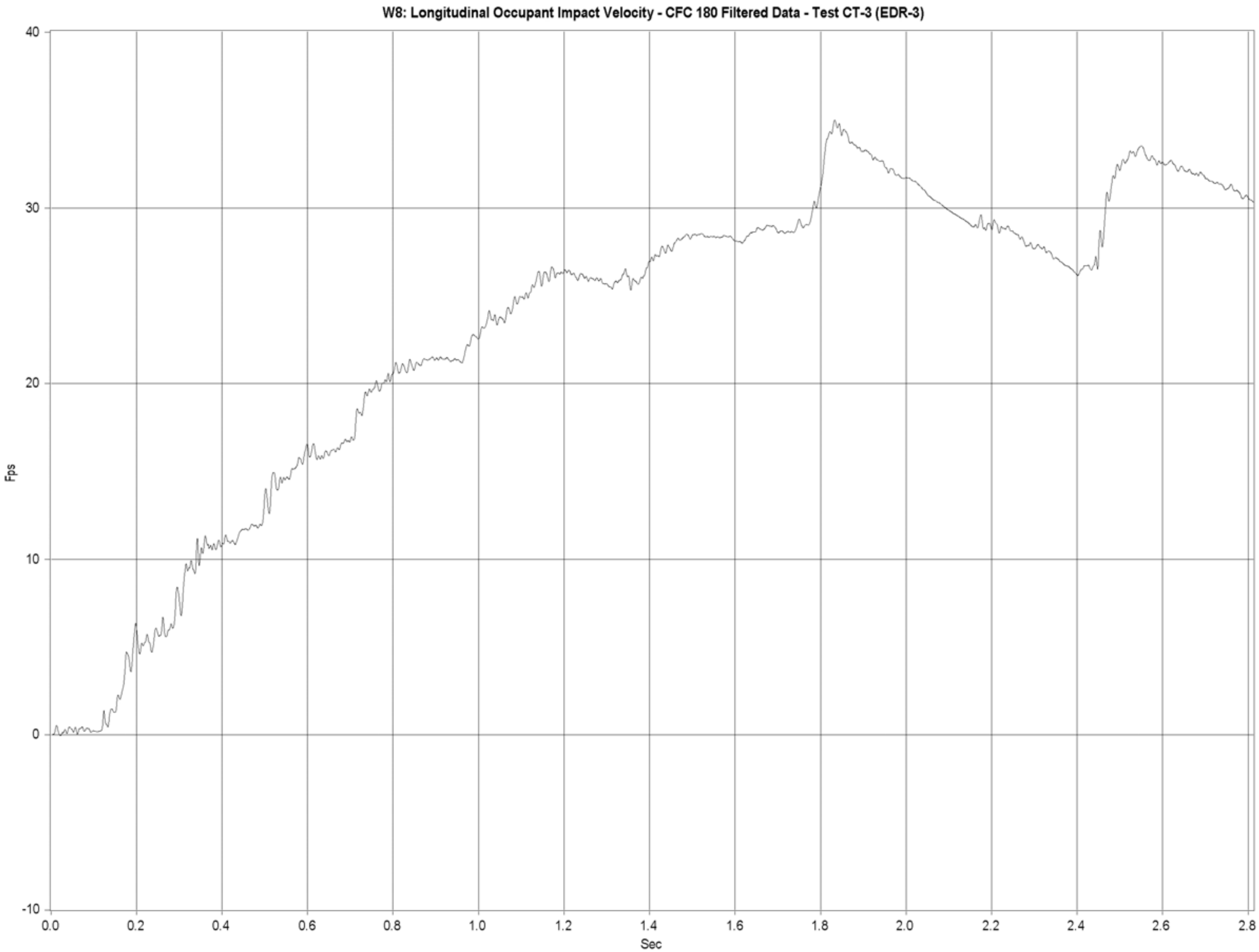


Figure G-2. Graph of Longitudinal Occupant Impact Velocity, Test CT-3

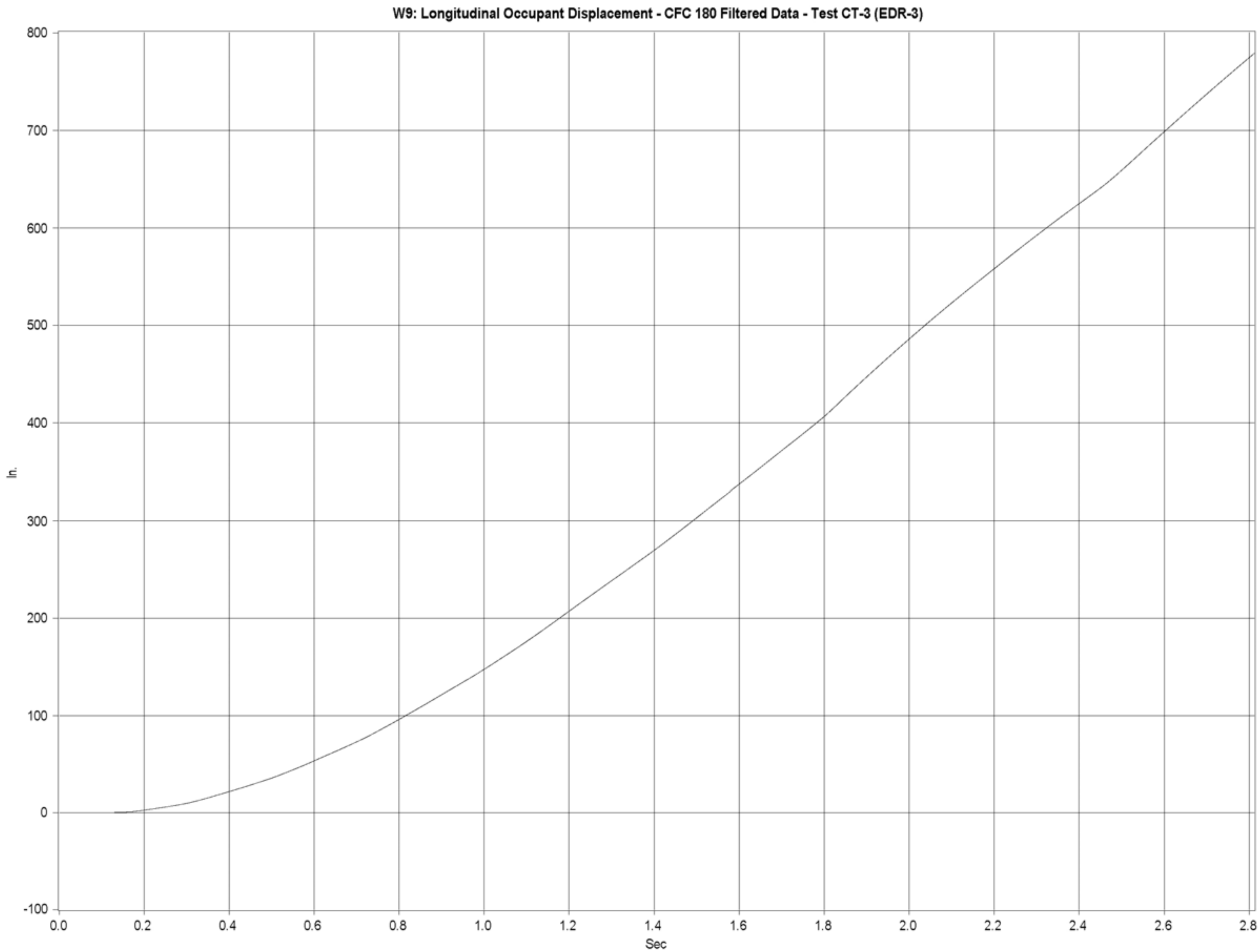


Figure G-3. Graph of Longitudinal Occupant Displacement, Test CT-3

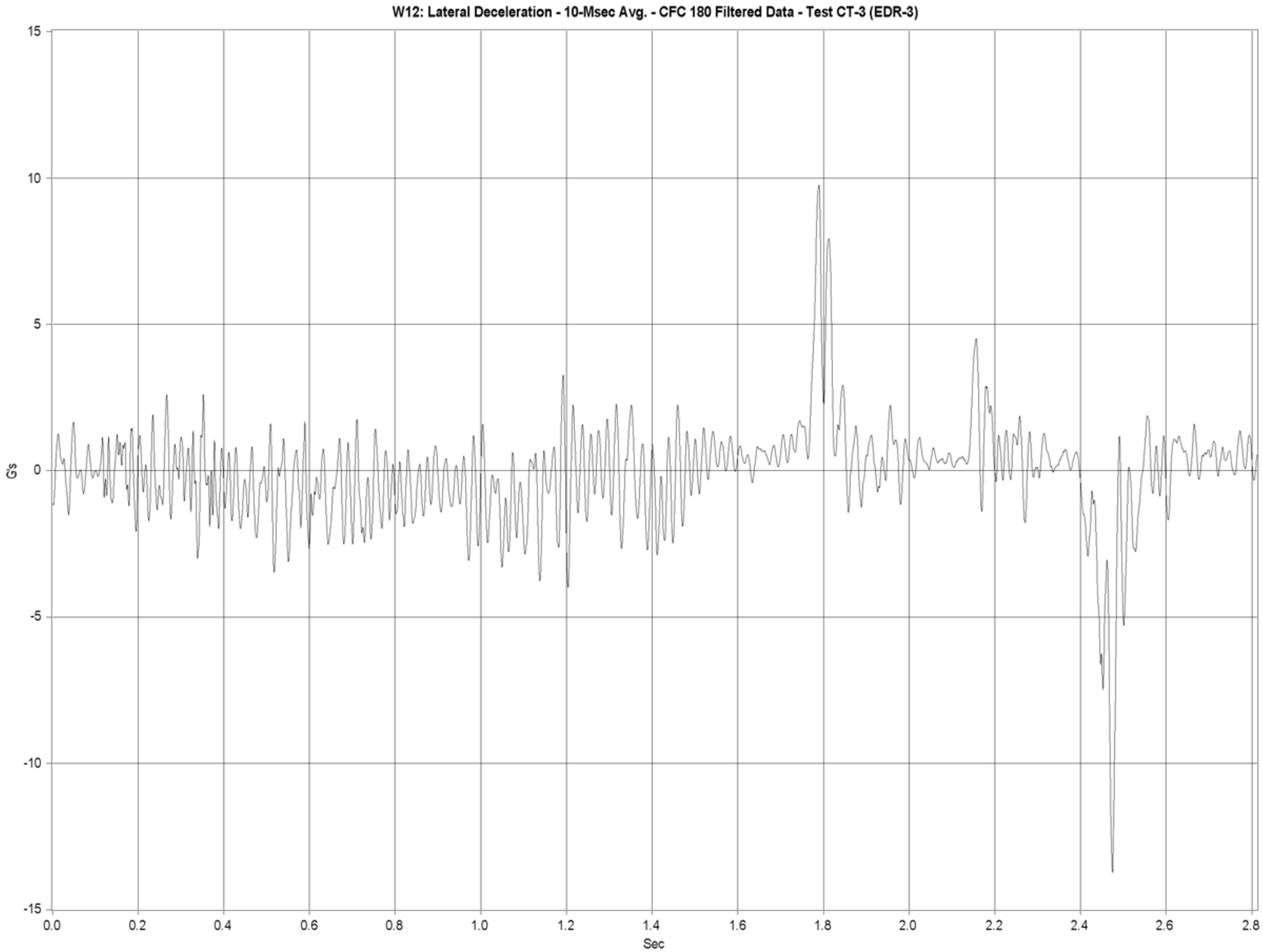


Figure G-4. Graph of Lateral Deceleration, Test CT-3

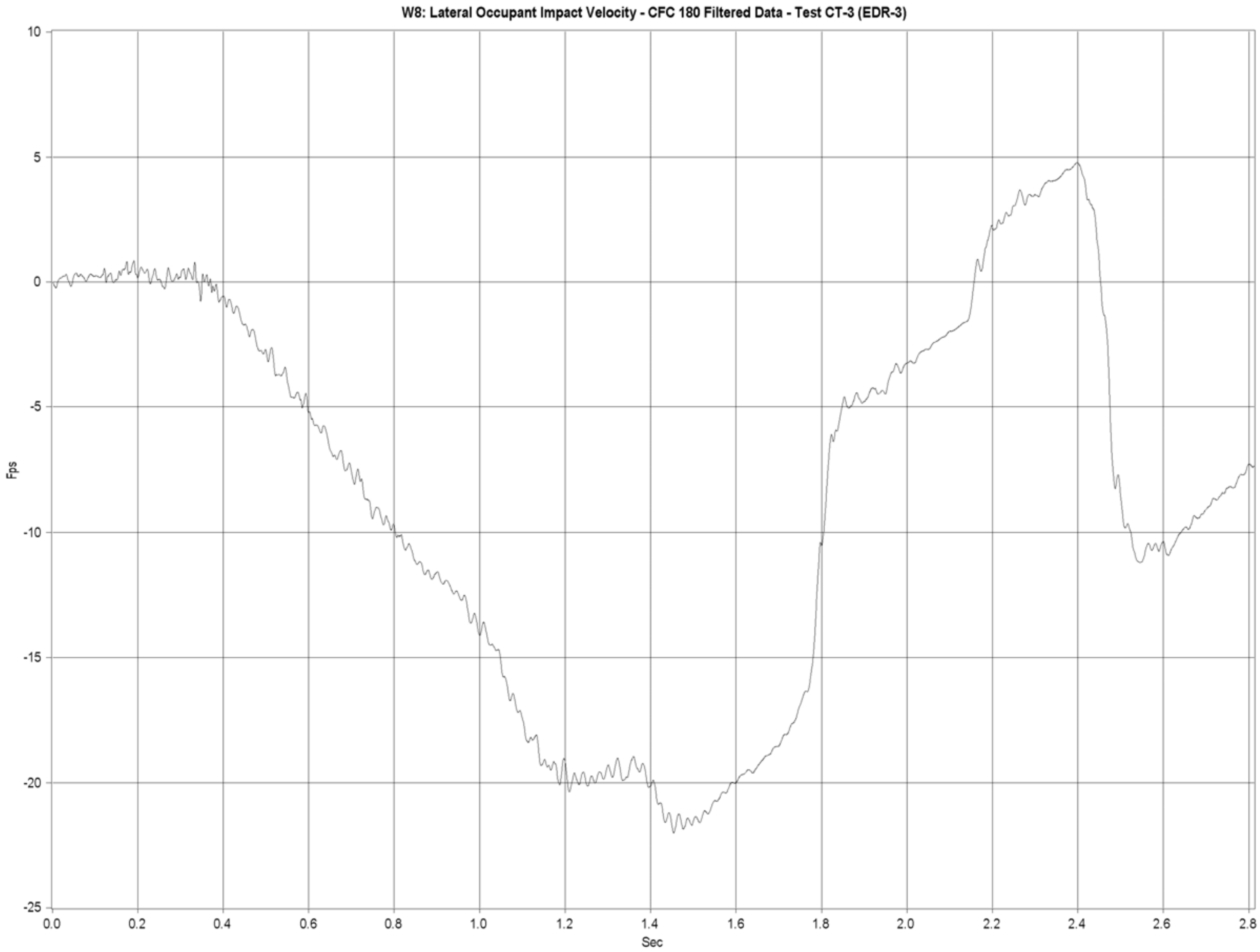


Figure G-5. Graph of Lateral Occupant Impact Velocity, Test CT-3

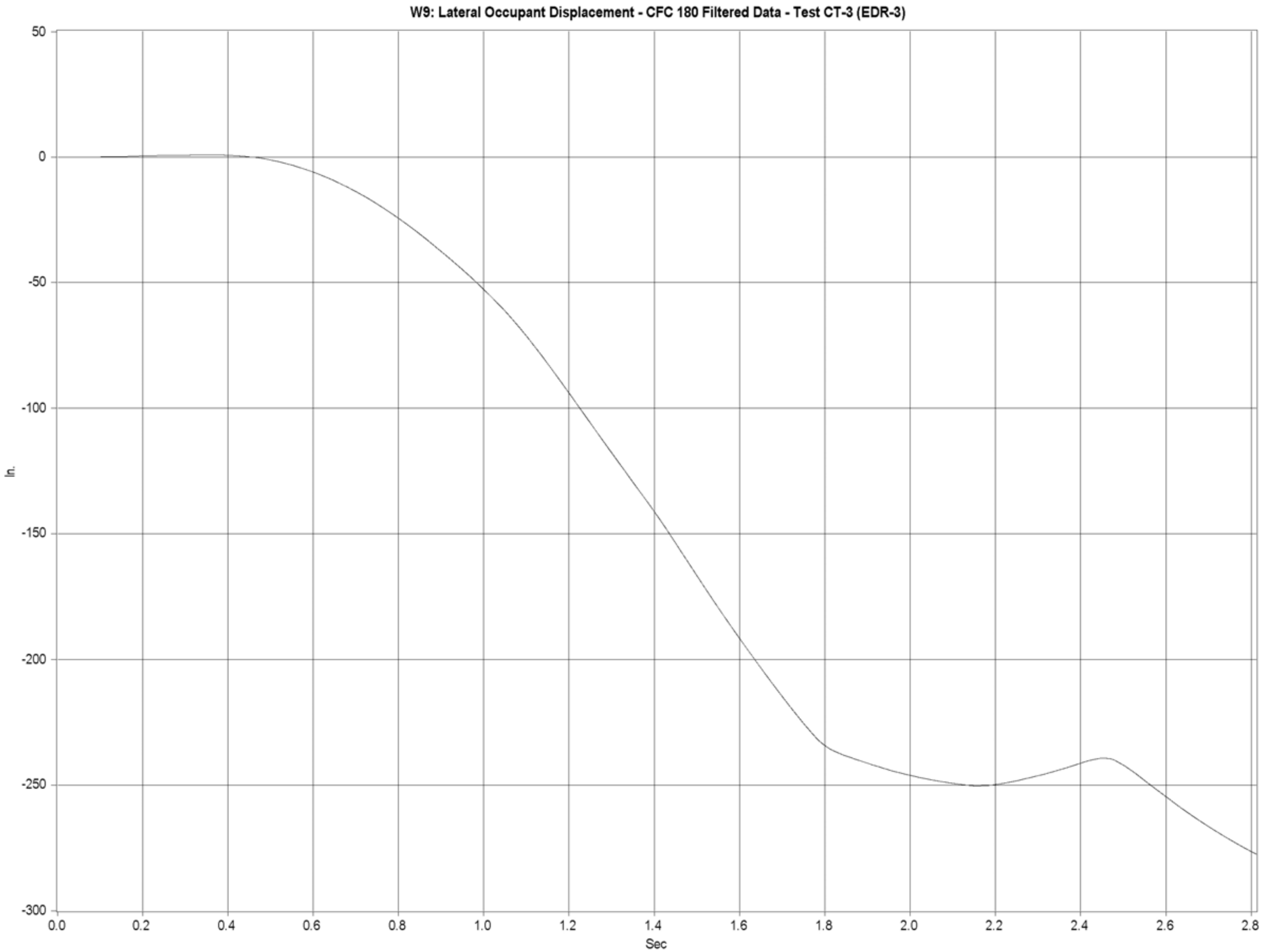


Figure G-6. Graph of Lateral Occupant Displacement, Test CT-3

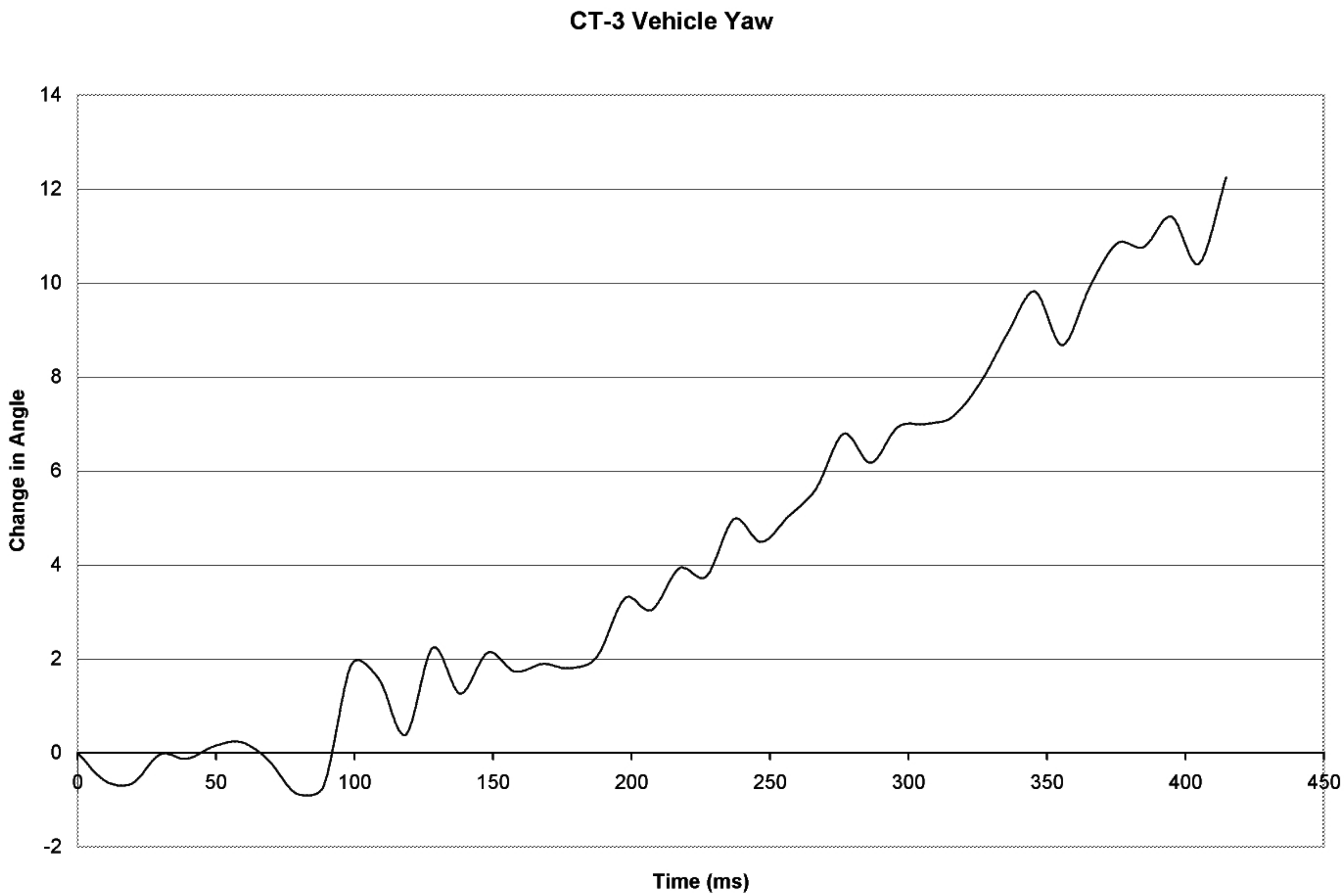


Figure G-7. Graph of Yaw Angular Displacement, Test CT-3

APPENDIX H

System Details, Design No. 3

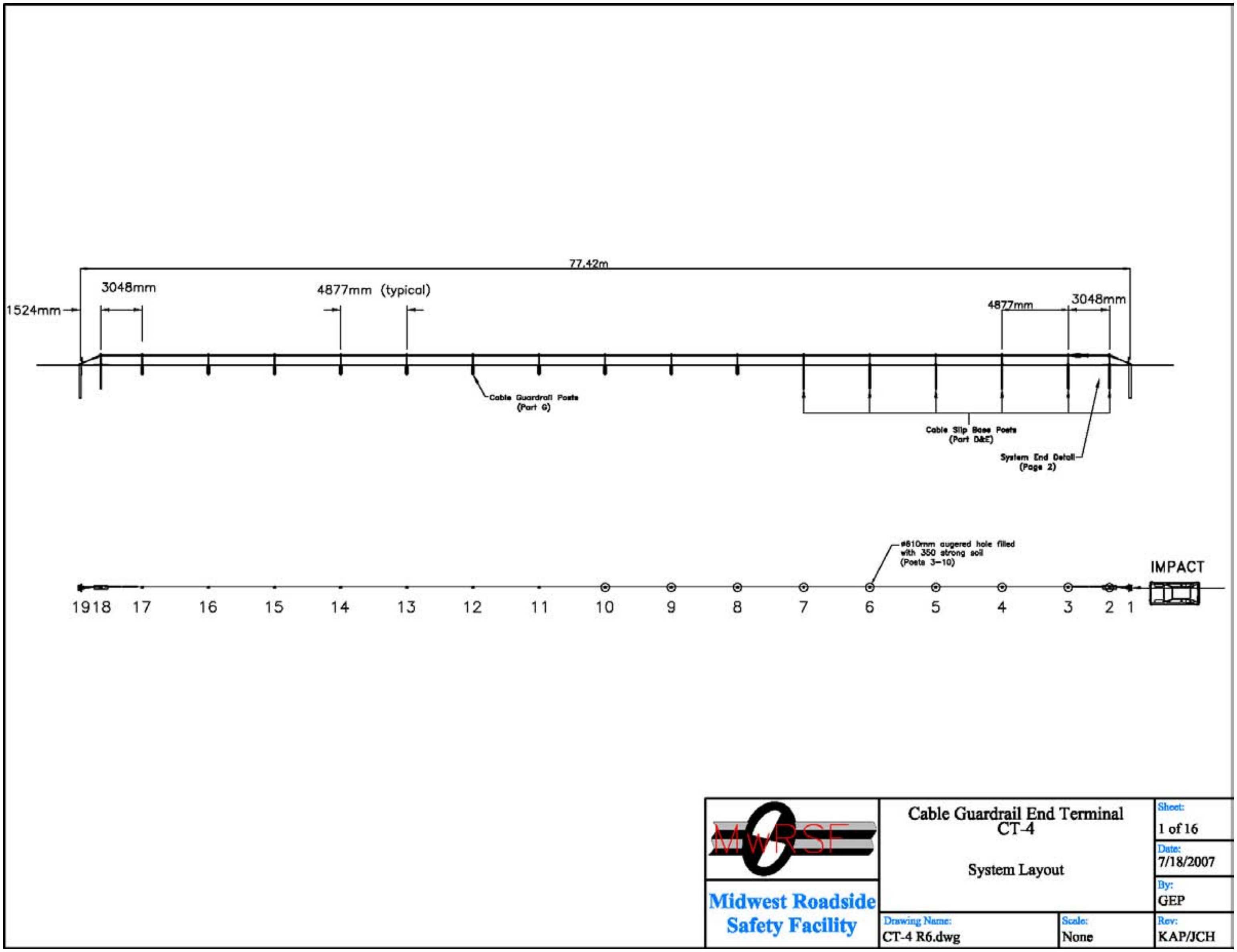


Figure H-1. System Details (Metric), Design 3

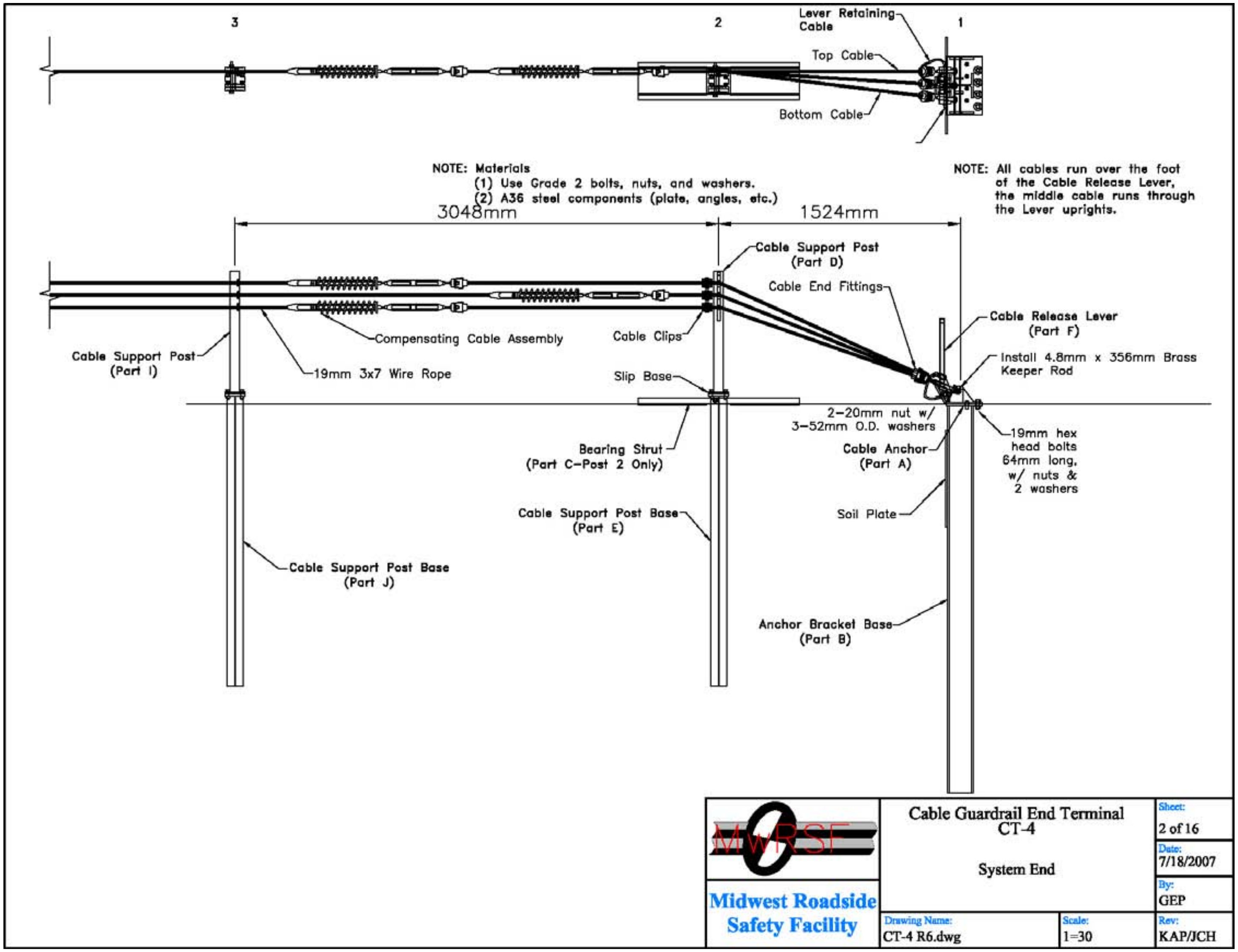


Figure H-2. End Anchorage Details (Metric), Design No. 3

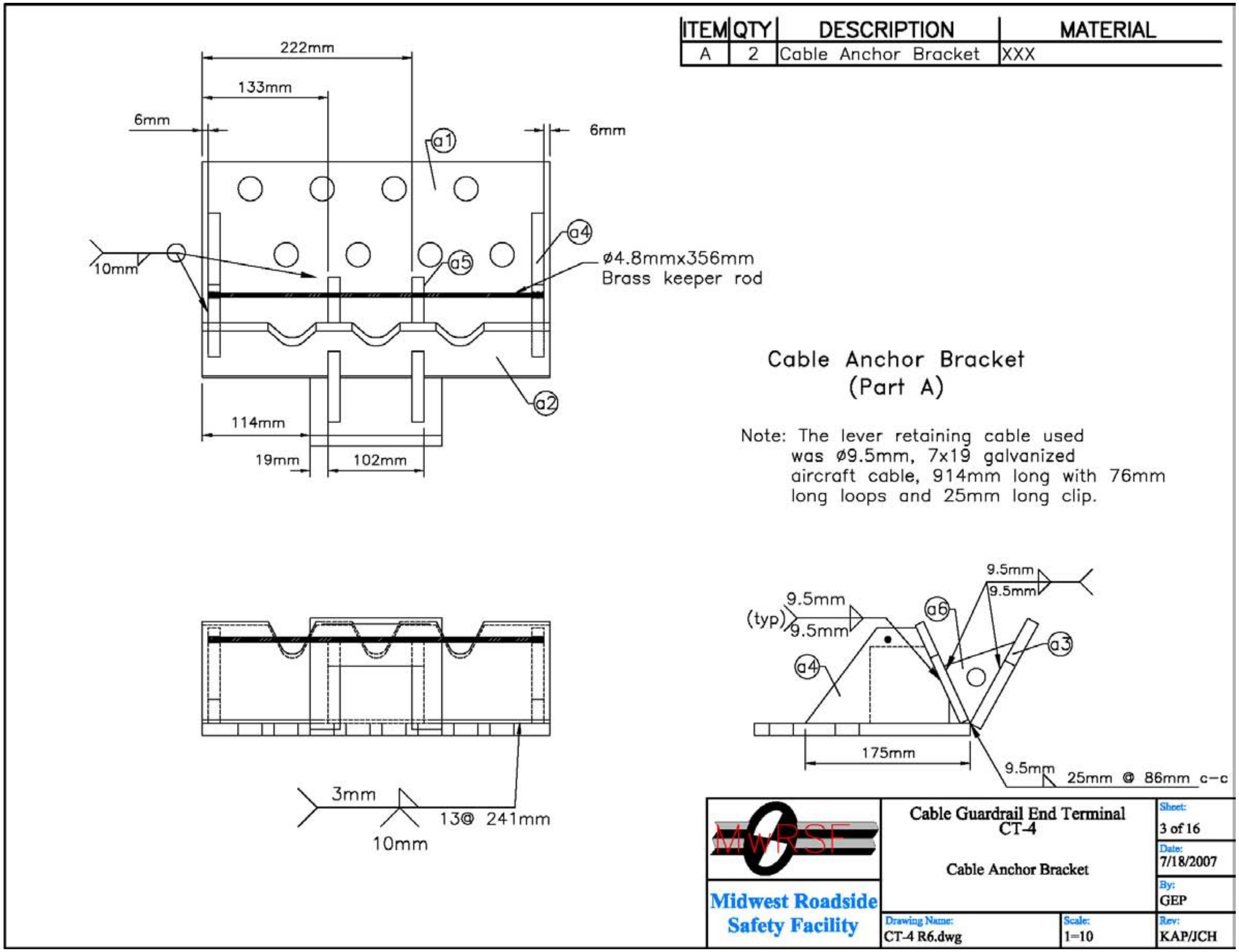
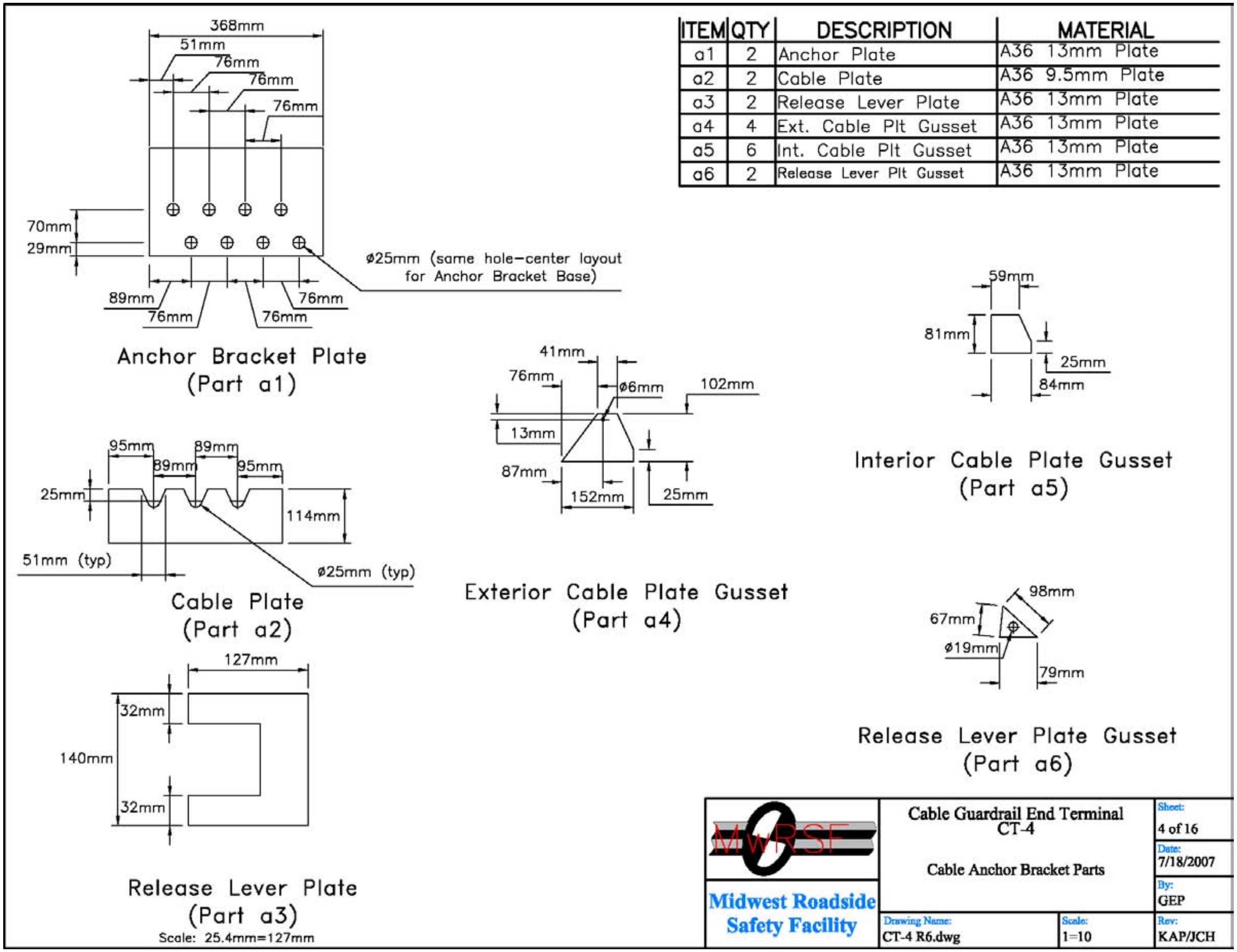


Figure H-3. Anchor Bracket Details (Metric), Design No. 3



ITEM	QTY	DESCRIPTION	MATERIAL
a1	2	Anchor Plate	A36 13mm Plate
a2	2	Cable Plate	A36 9.5mm 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 H-4. Anchor Bracket Details (Metric), Design No. 3

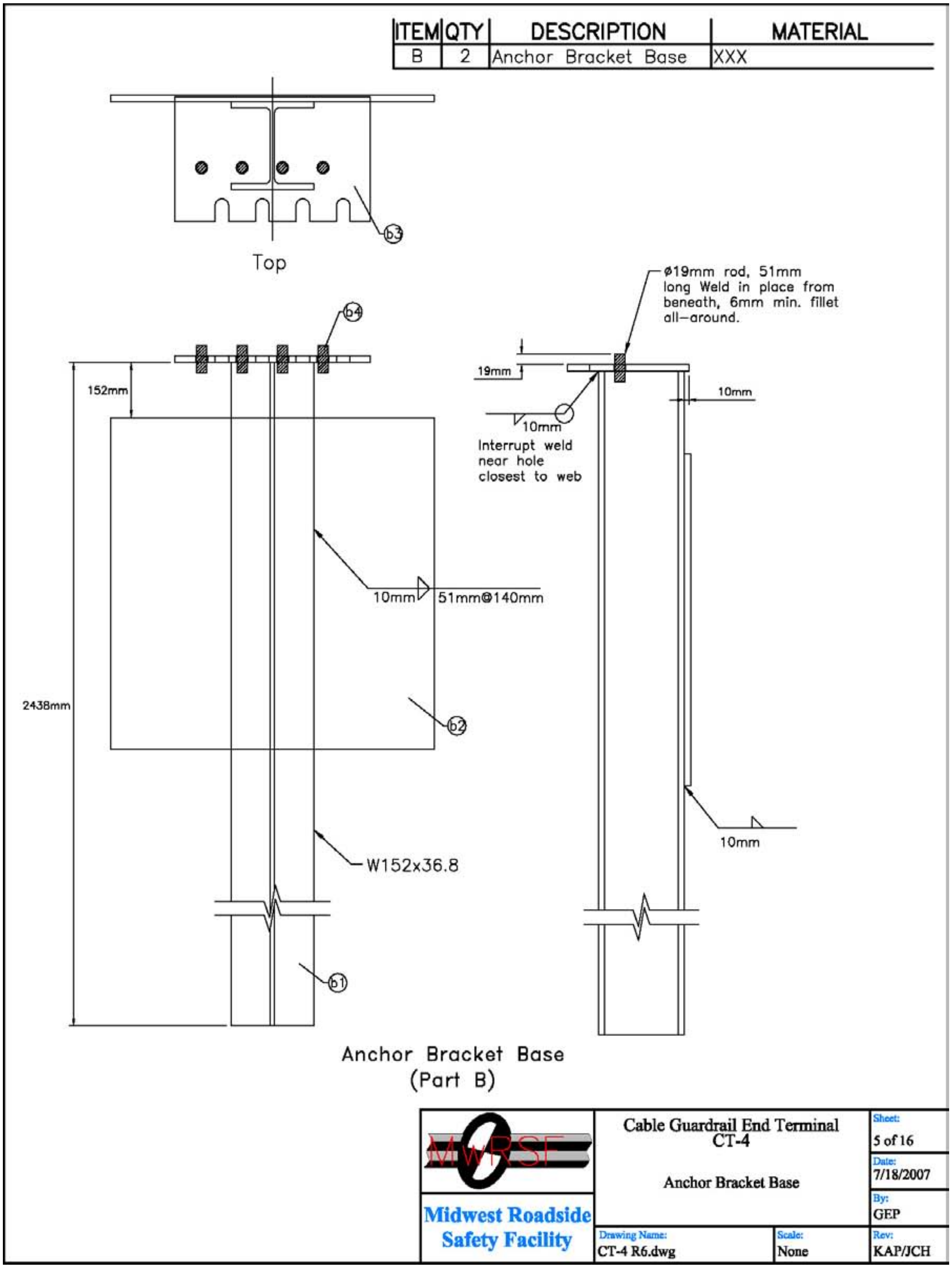


Figure H-5. Anchor Bracket Base Details (Metric), Design No. 3

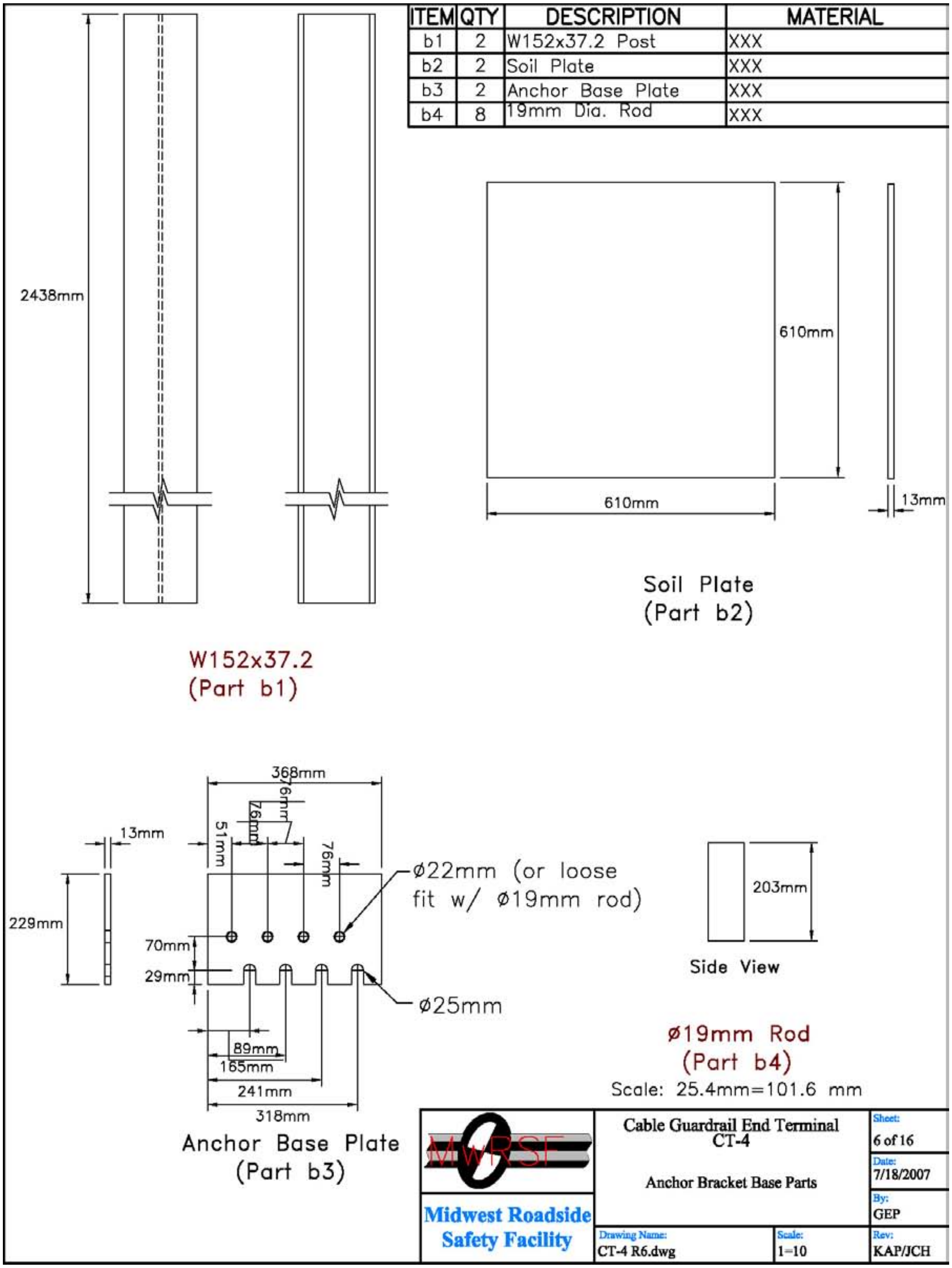


Figure H-6. Anchor Bracket Base Details (Metric), Design No. 3

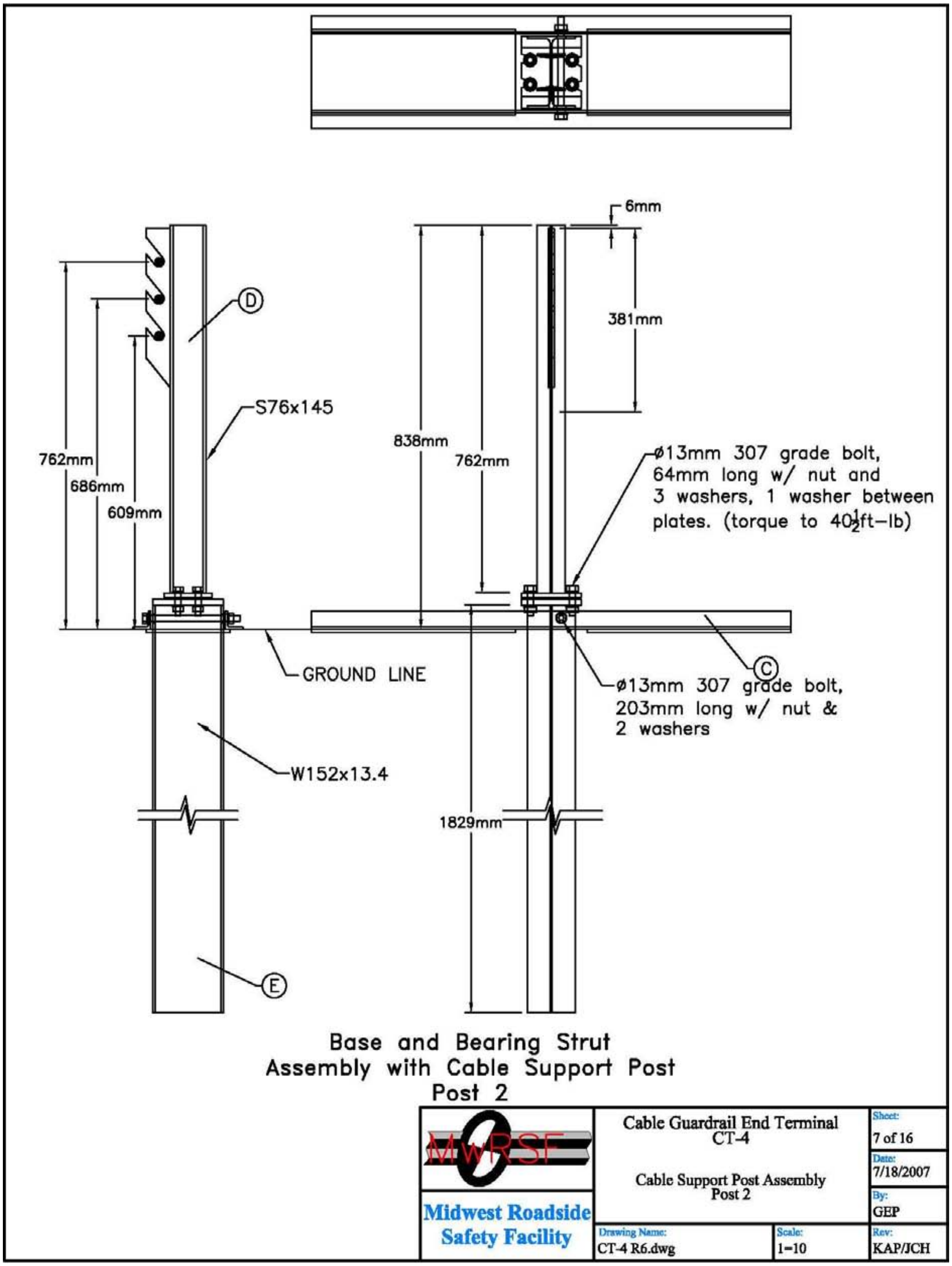


Figure H-7. Support Post Assembly (Metric), Design No. 3

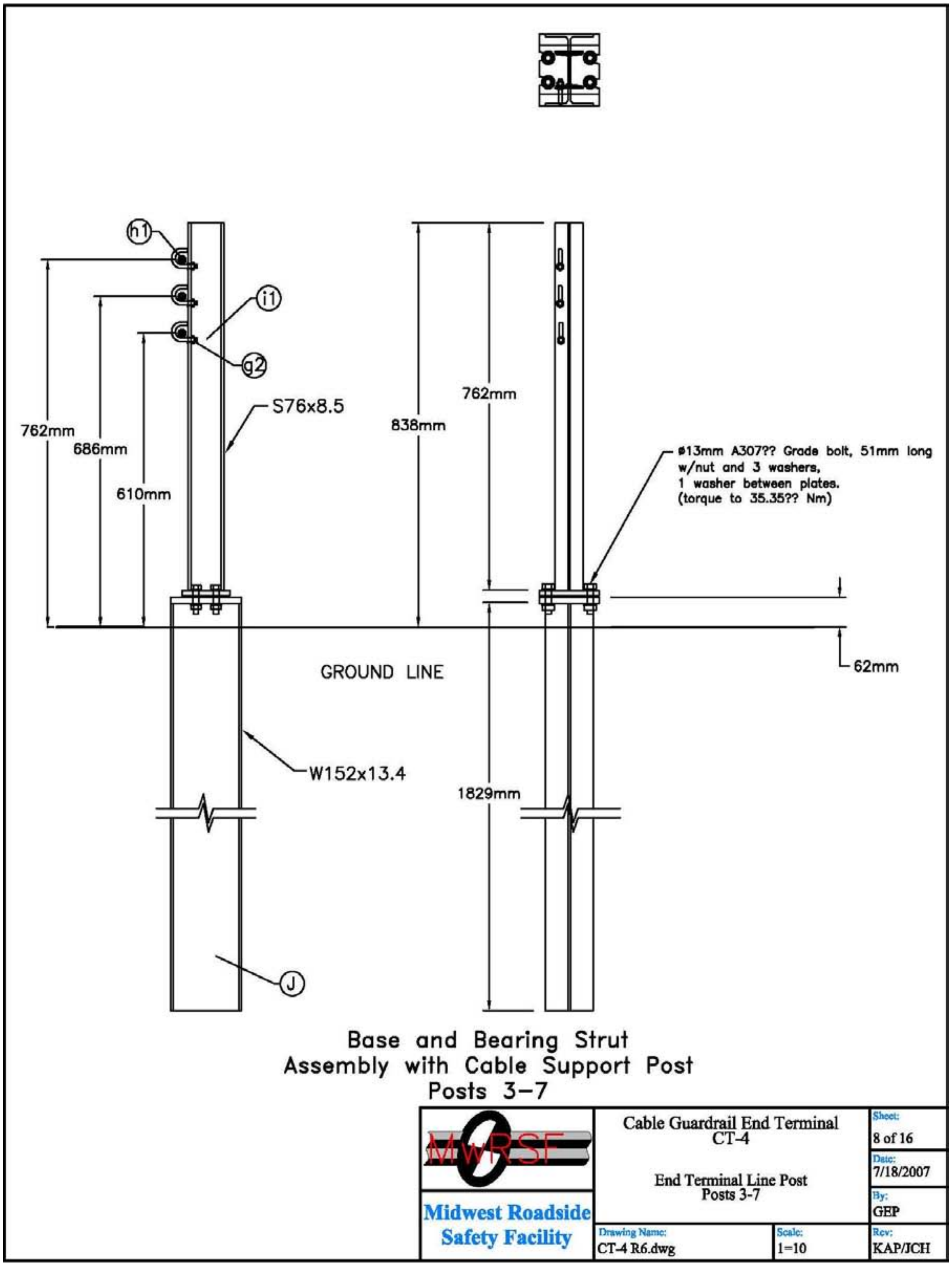


Figure H-8. Line Post Nos. 3 through 7 Details (Metric), Design No. 3

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

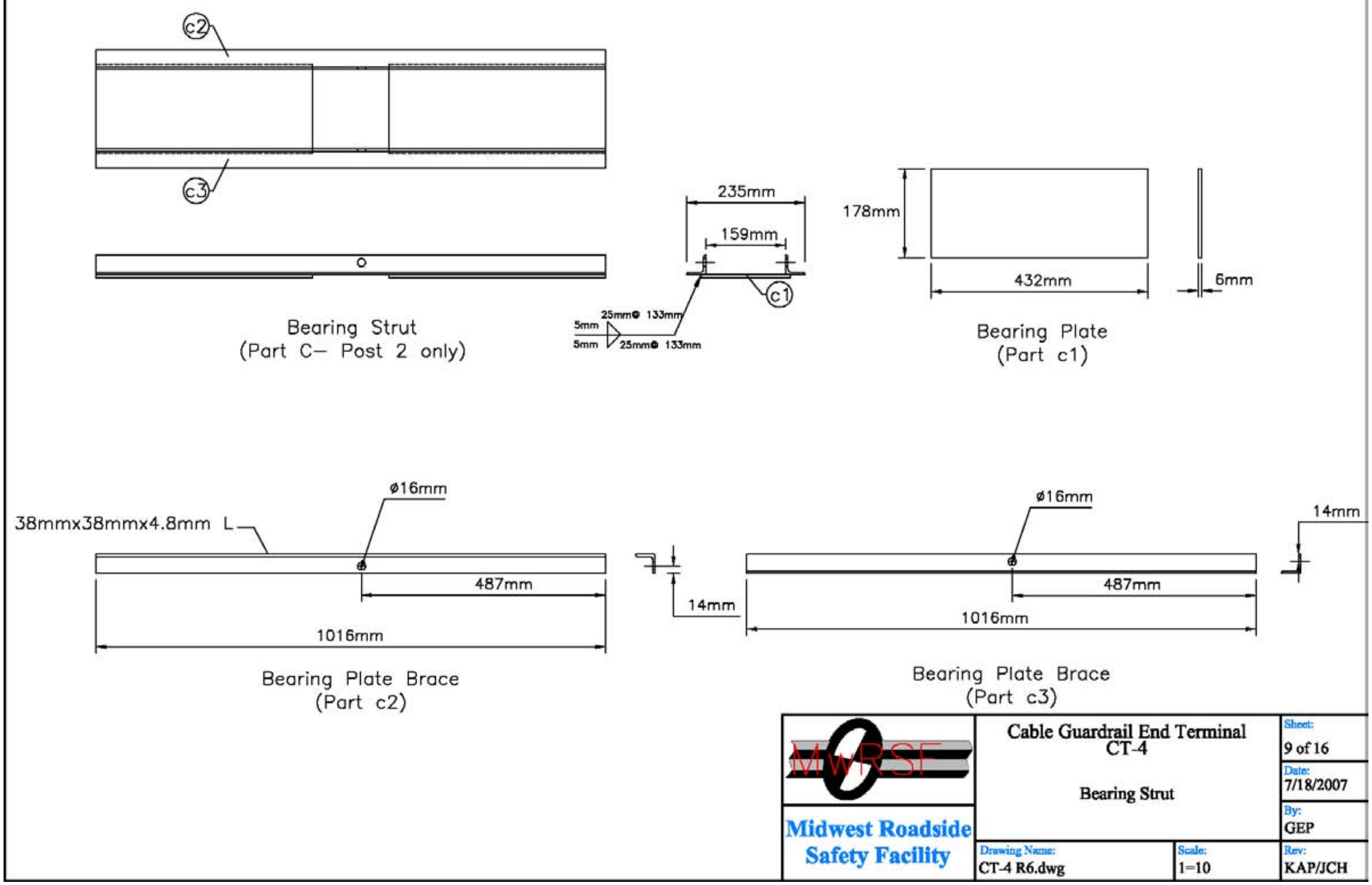


Figure H-9. Bearing Strut Details (Metric), Design No. 3

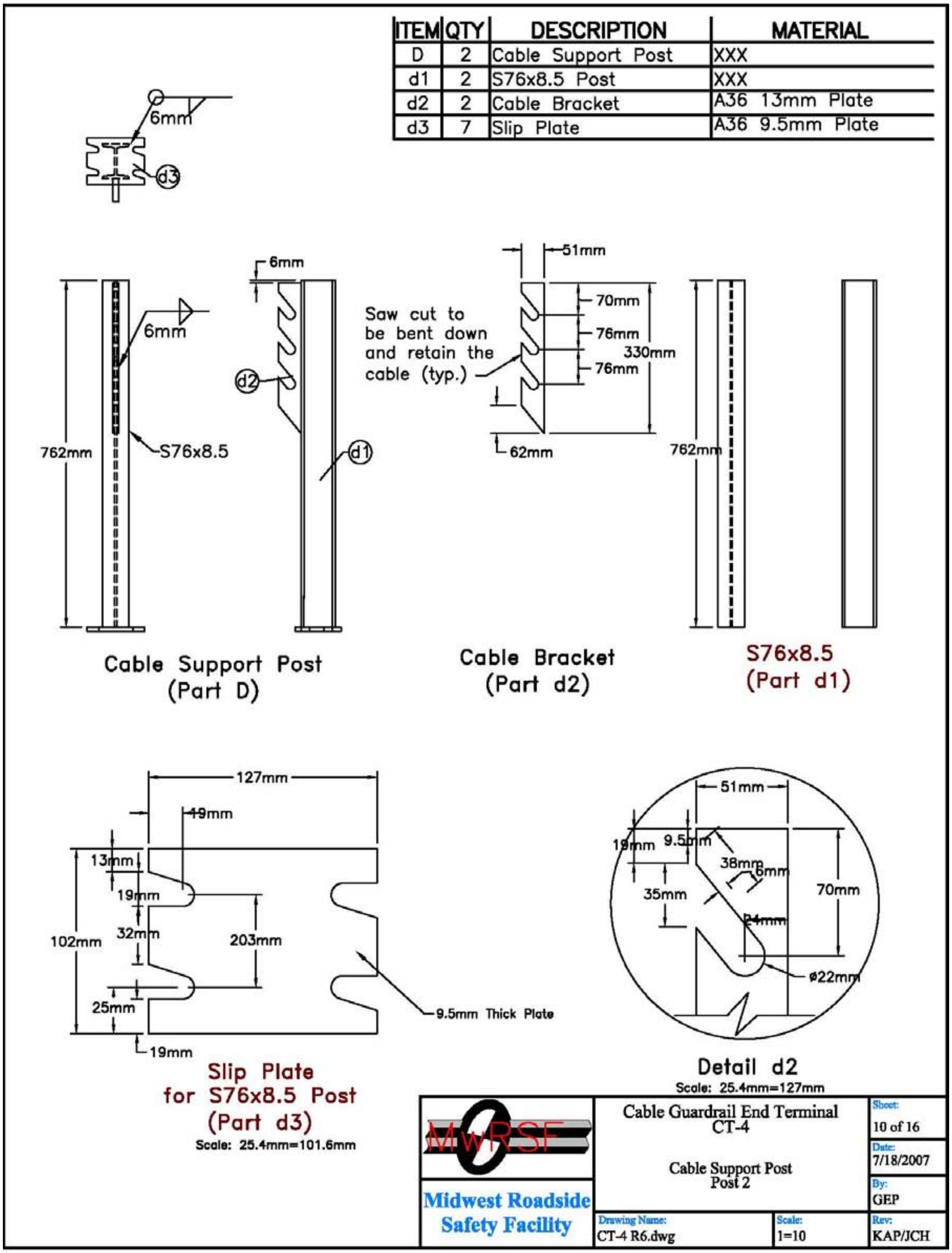


Figure H-10. Support Post Details (Metric), Design No. 3

ITEM	QTY	DESCRIPTION	MATERIAL
E	2	Cable Support Base	XXX
e1	2	W152x13.4 Post	XXX
e2	7	Base Slip Plate	A36 13mm Plate

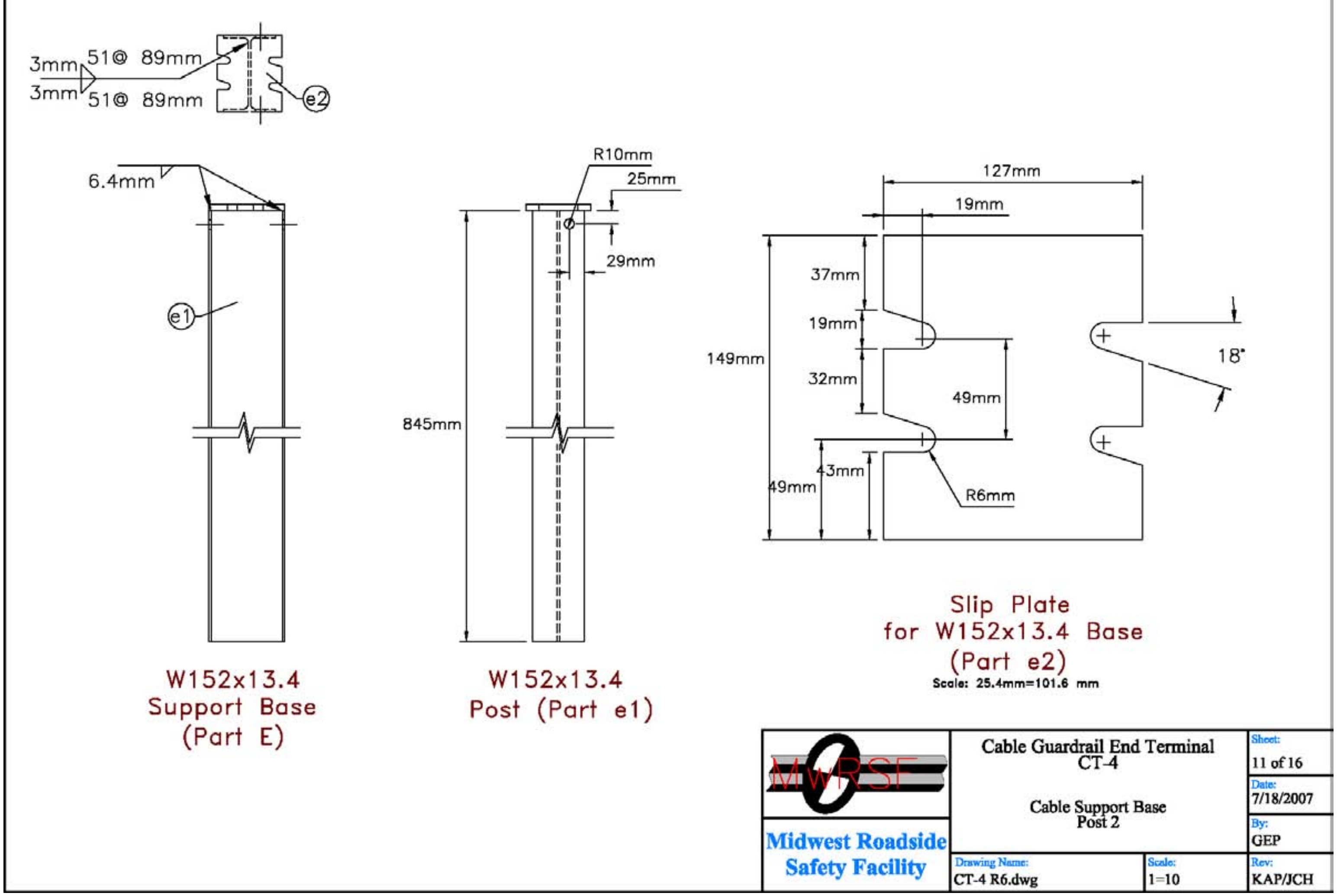


Figure H-11. Support Post Base Details (Metric), Design No. 3

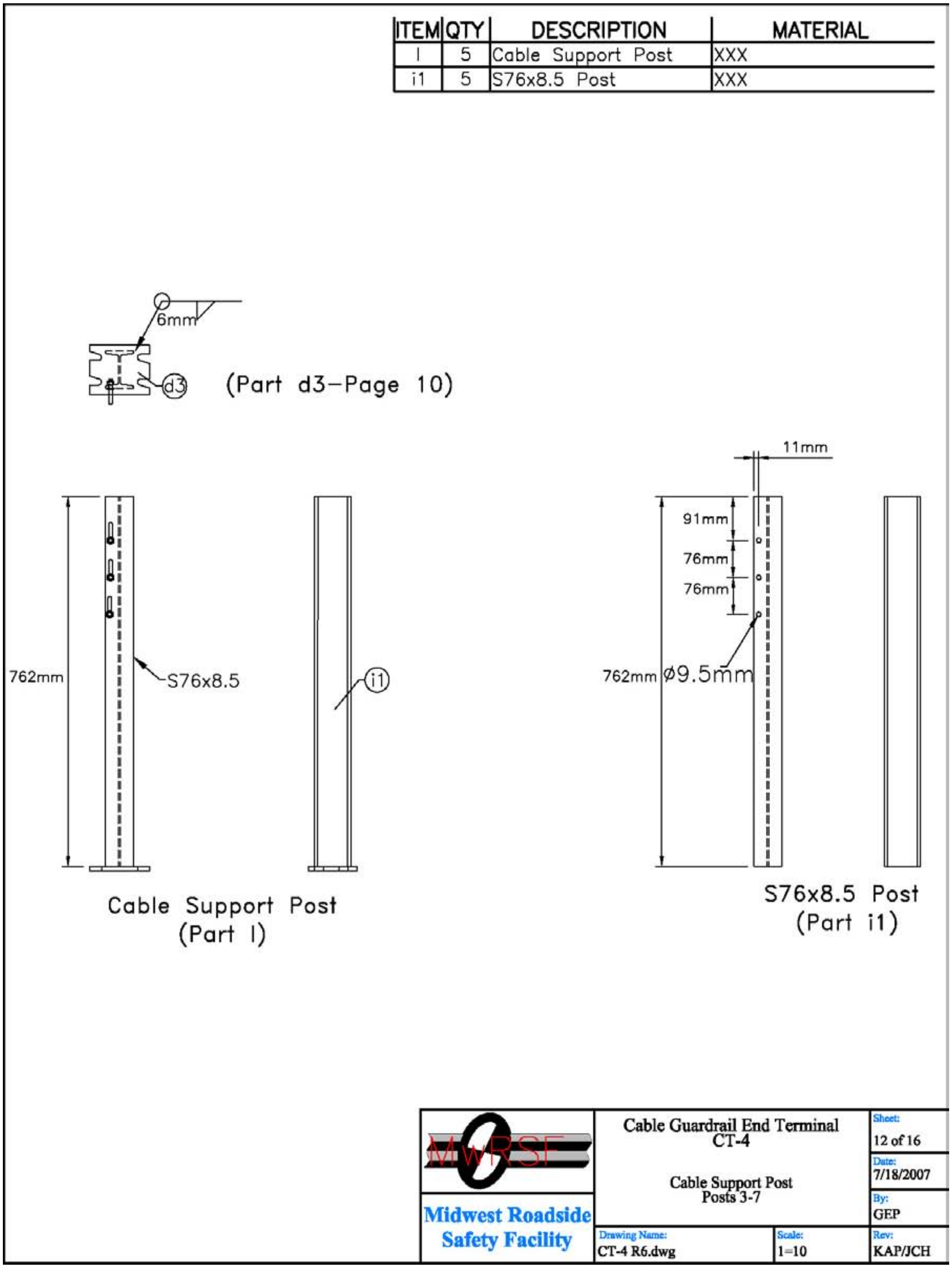
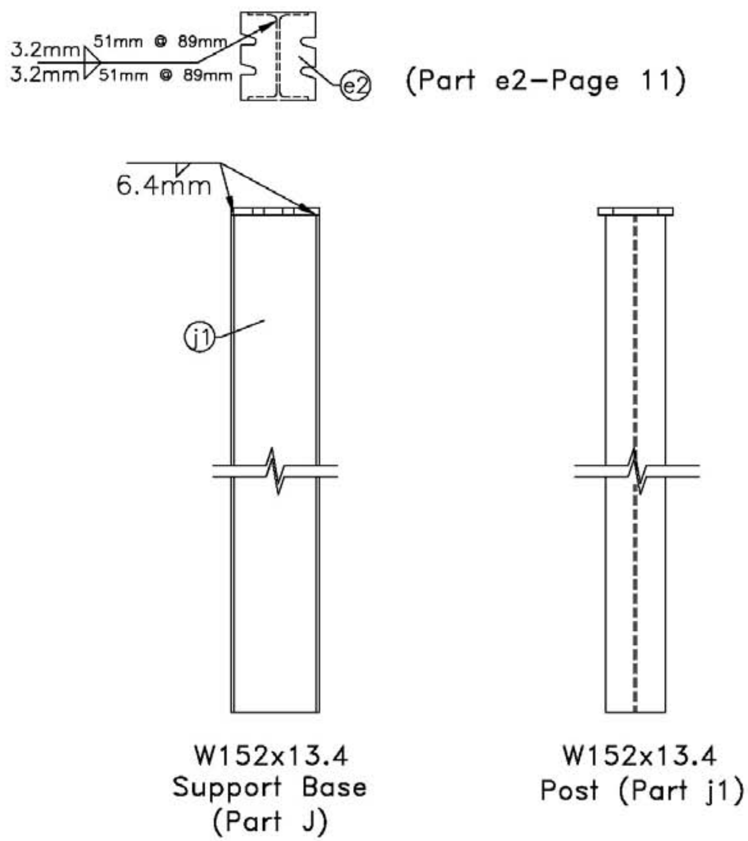


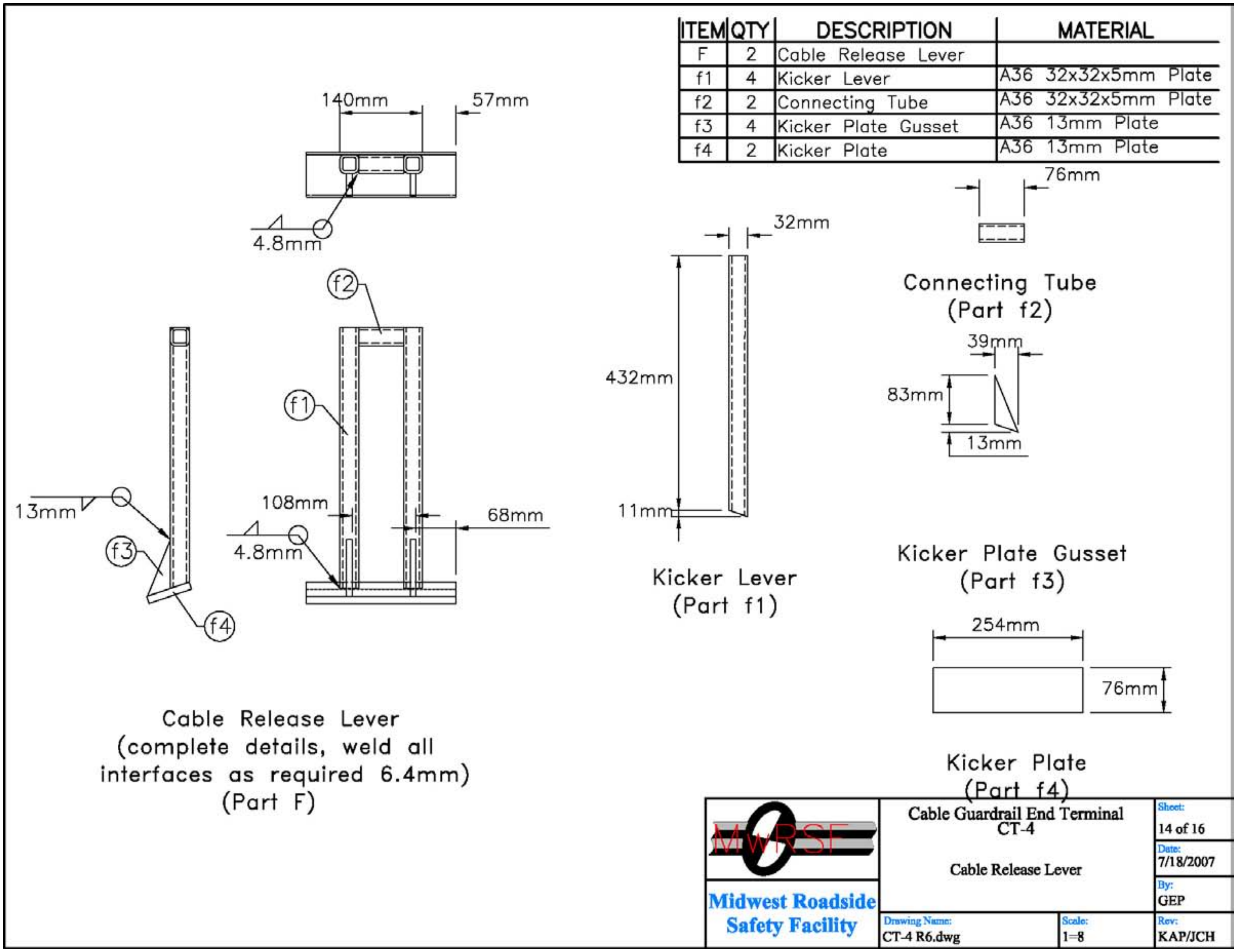
Figure H-12. Line Post Nos. 3 through 7 Details (Metric), Design No. 3

ITEM	QTY	DESCRIPTION	MATERIAL
J	5	Cable Support Base	XXX
j1	5	W152x13.4 Post	XXX



Midwest Roadside Safety Facility	Cable Guardrail End Terminal CT-4 Cable Support Base Posts 3-7	Sheet: 13 of 16 Date: 7/18/2007 By: GEP
	Drawing Name: CT-4 R6.dwg | Scale: 1=10	Rev: KAP/JCH

Figure H-13. Line Post Nos. 3 through 17 Details (Metric), Design No. 3



ITEM	QTY	DESCRIPTION	MATERIAL
F	2	Cable Release Lever	
f1	4	Kicker Lever	A36 32x32x5mm Plate
f2	2	Connecting Tube	A36 32x32x5mm Plate
f3	4	Kicker Plate Gusset	A36 13mm Plate
f4	2	Kicker Plate	A36 13mm Plate

Figure H-14. Cable Release Lever Details (Metric), Design No. 3

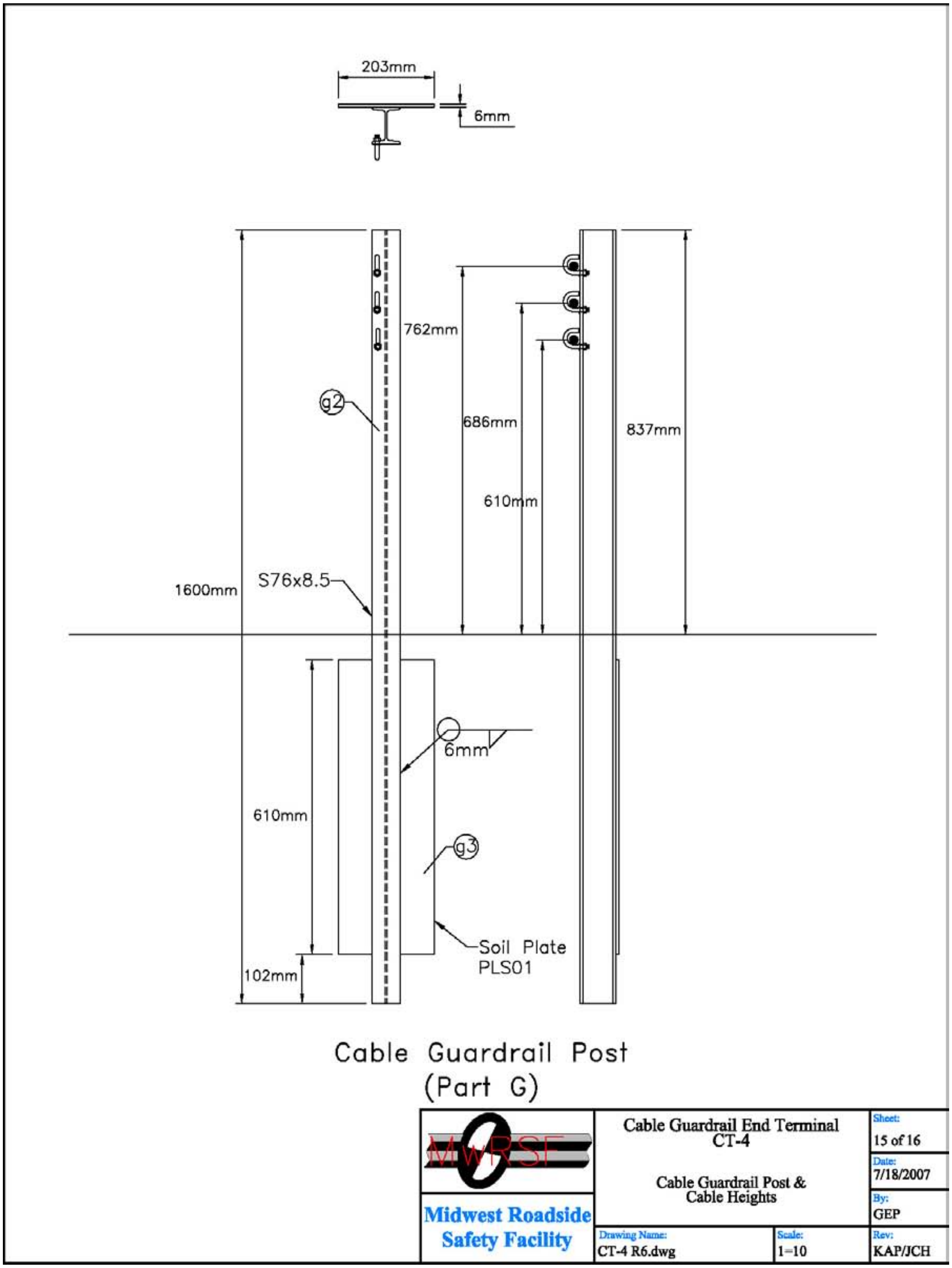


Figure H-15. Line Post Nos. 8 through 17 Details (Metric), Design No. 3

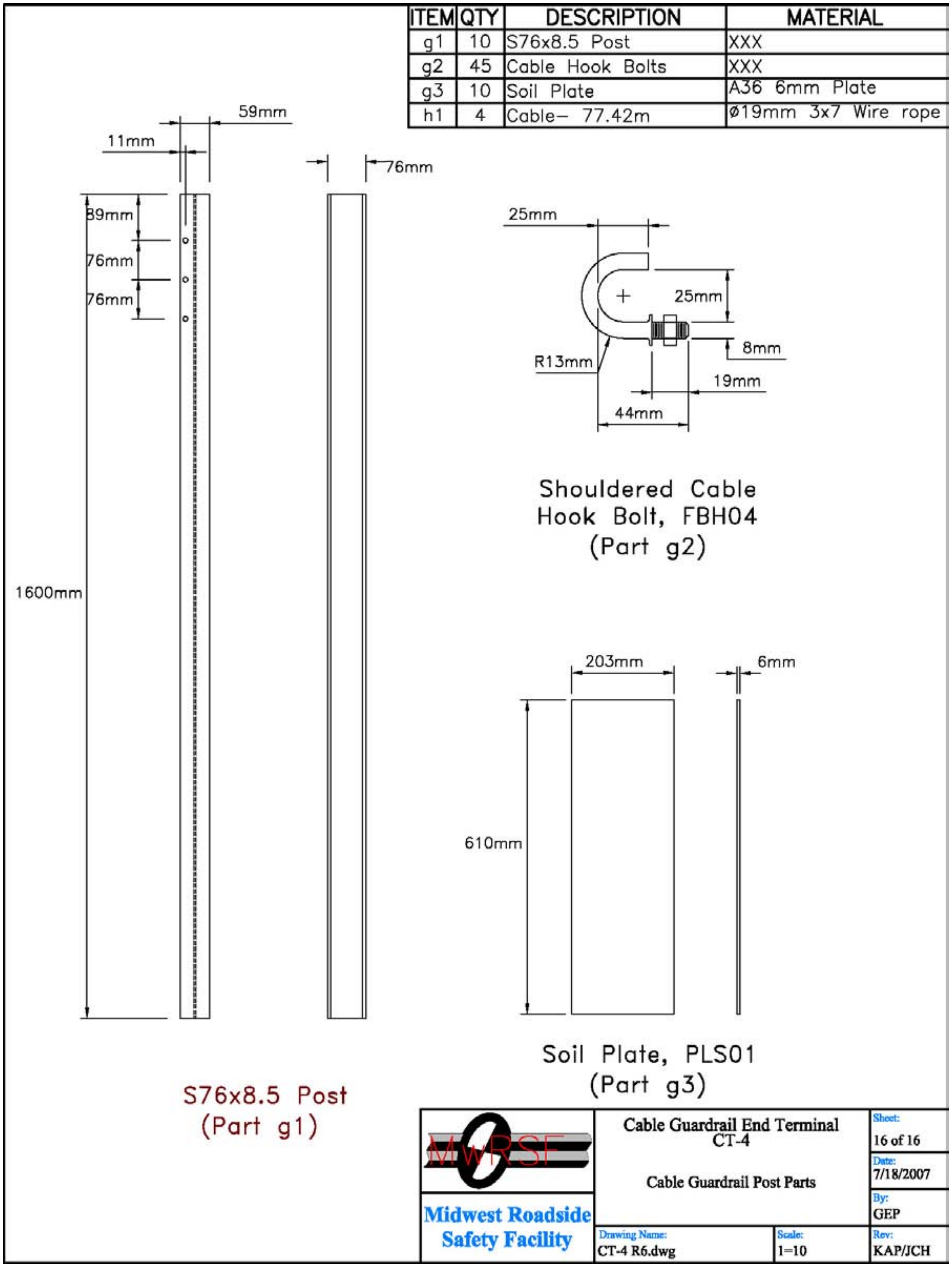


Figure H-16. Line Post Nos. 8 through 17 Details (Metric), Design No. 3

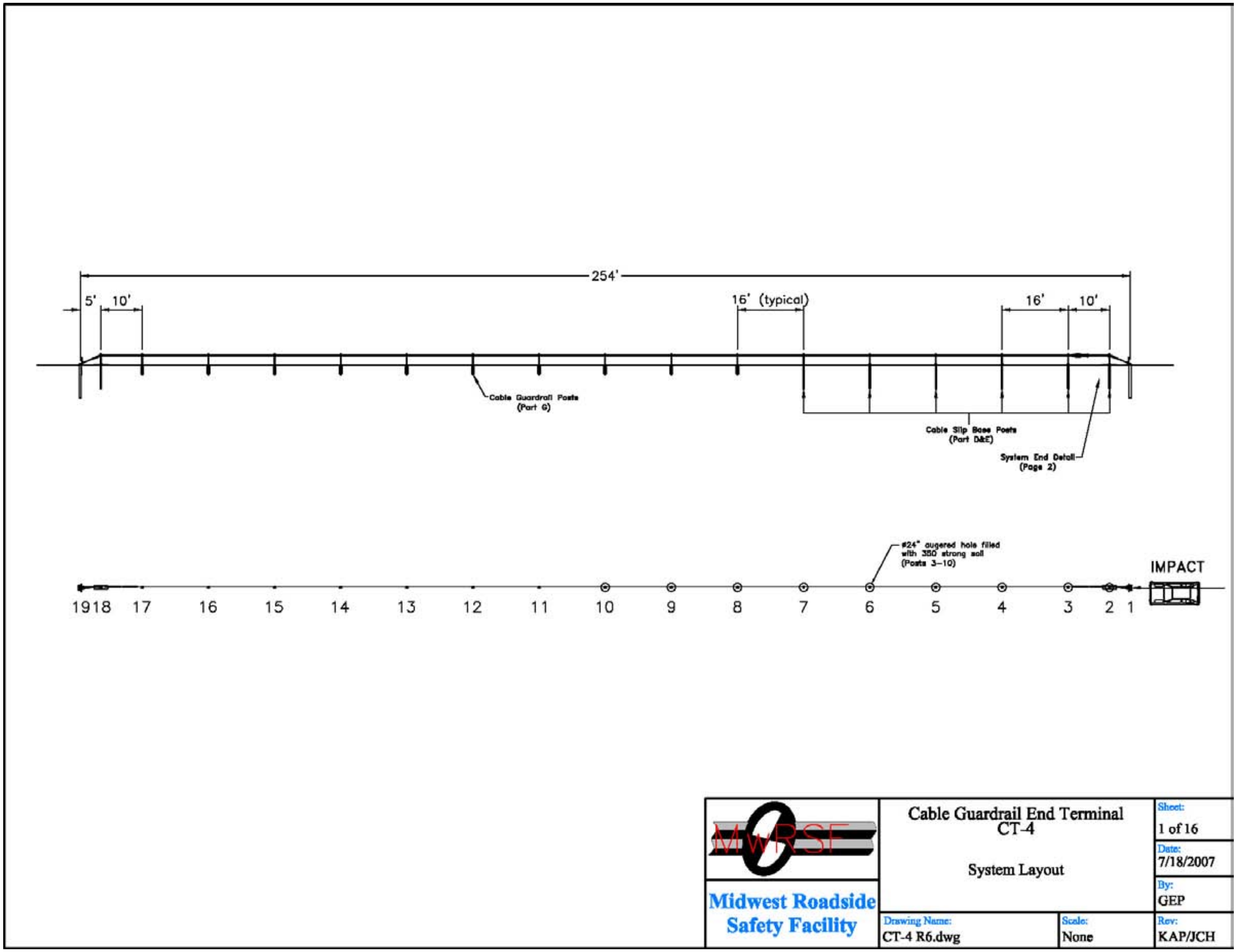


Figure H-17. System Details (English), Design No. 3

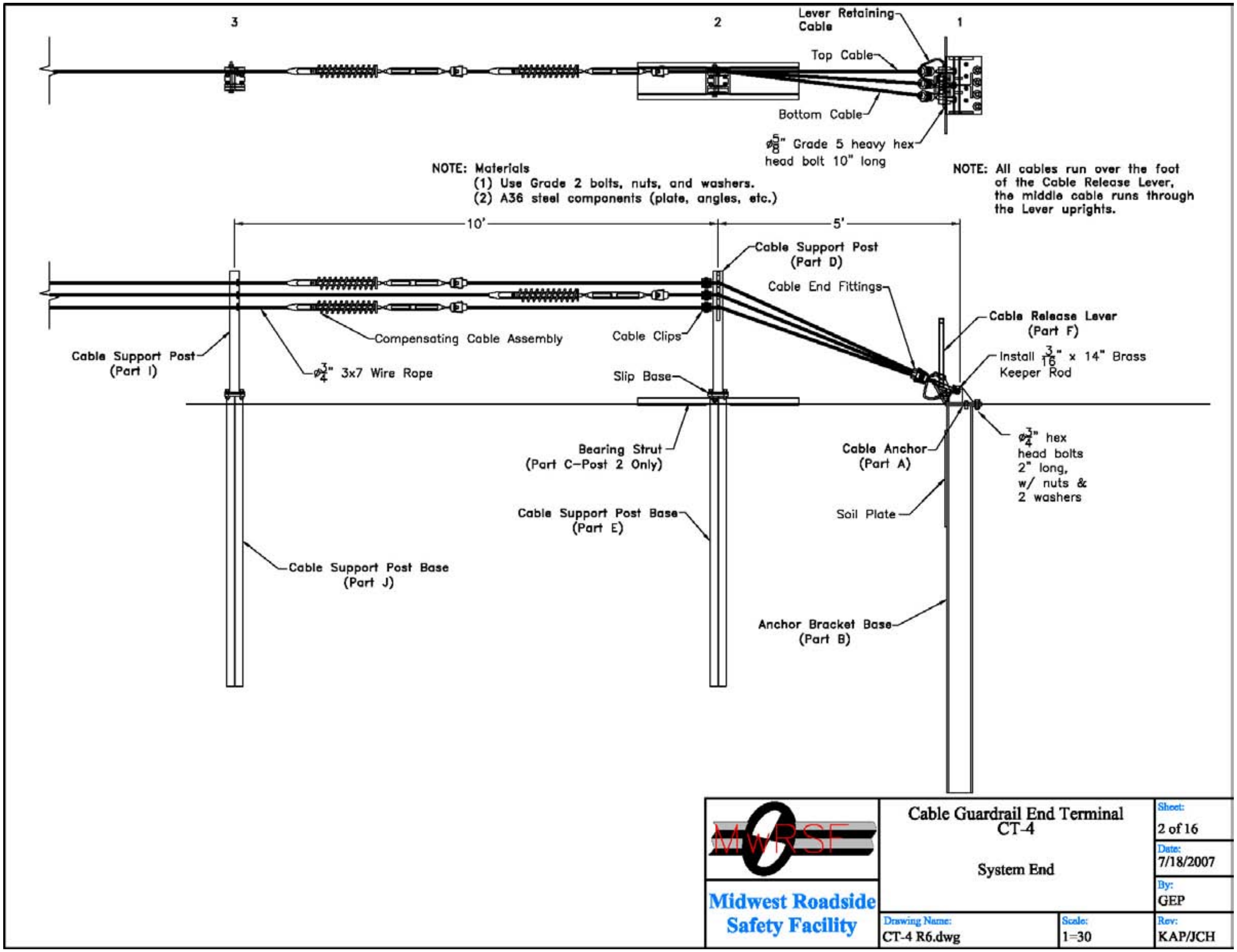


Figure H-18. End Anchorage Details (English), Design No. 3

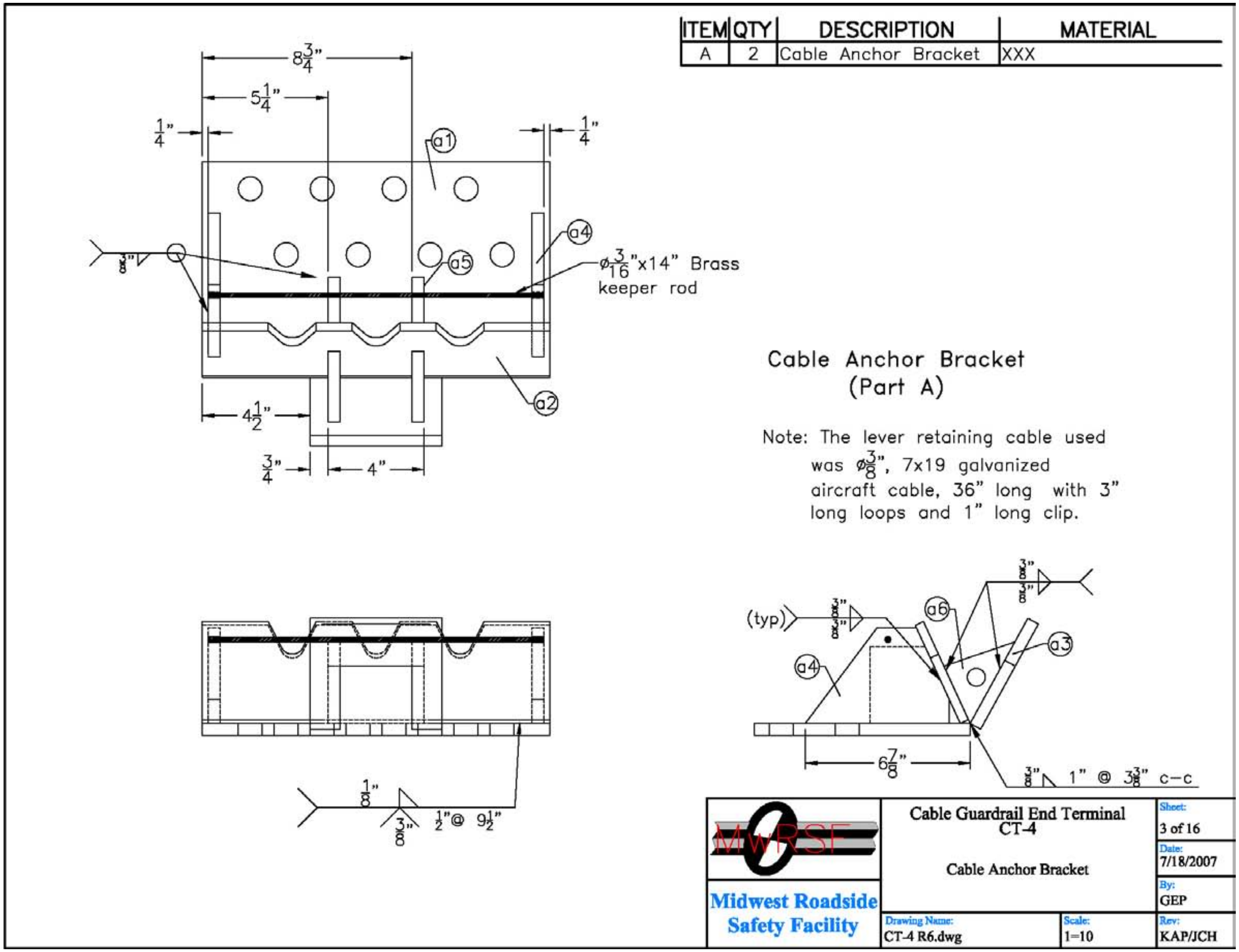


Figure H-19. Anchor Bracket Details (English), Design No. 3

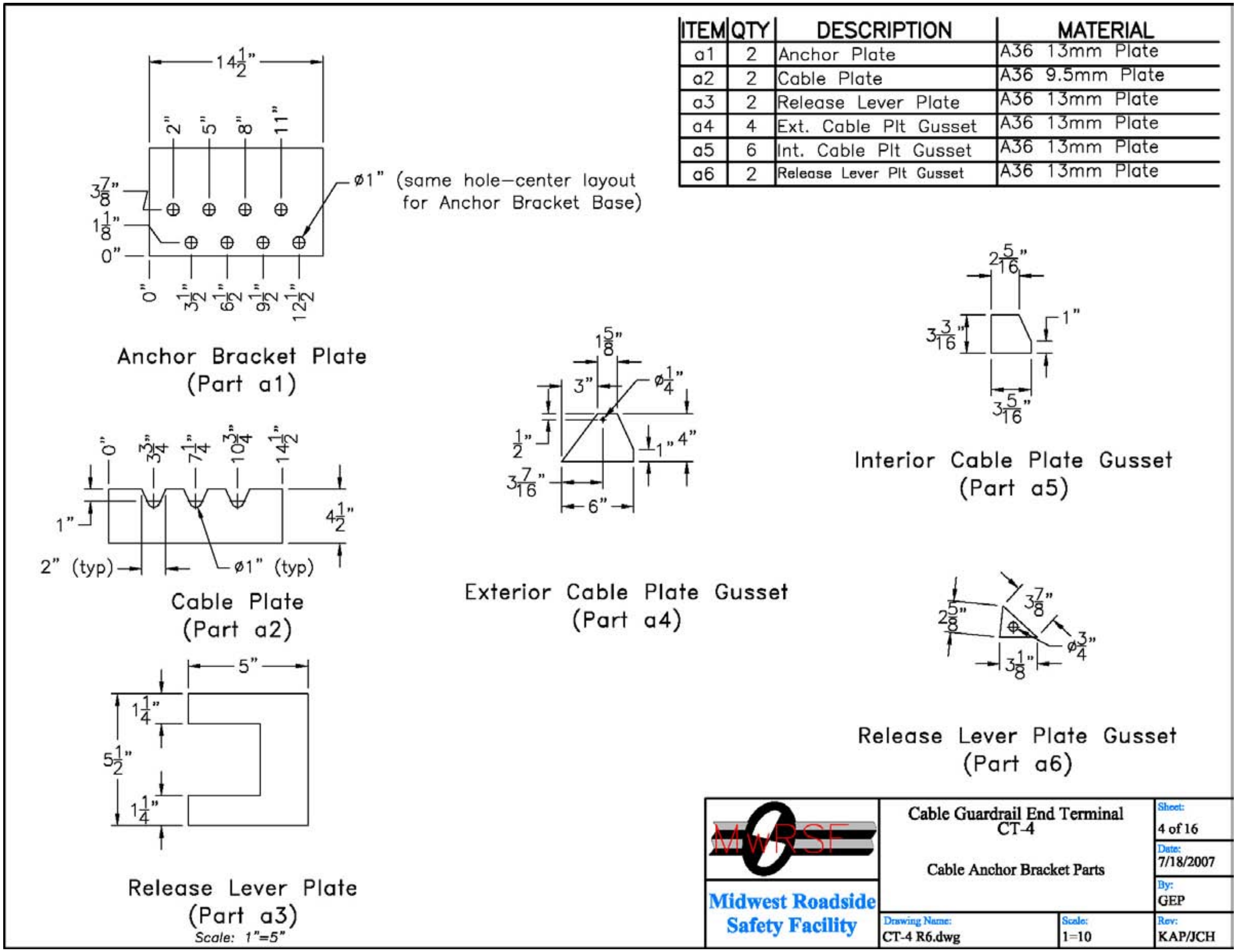


Figure H-20. Anchor Bracket Details (English), Design No. 3

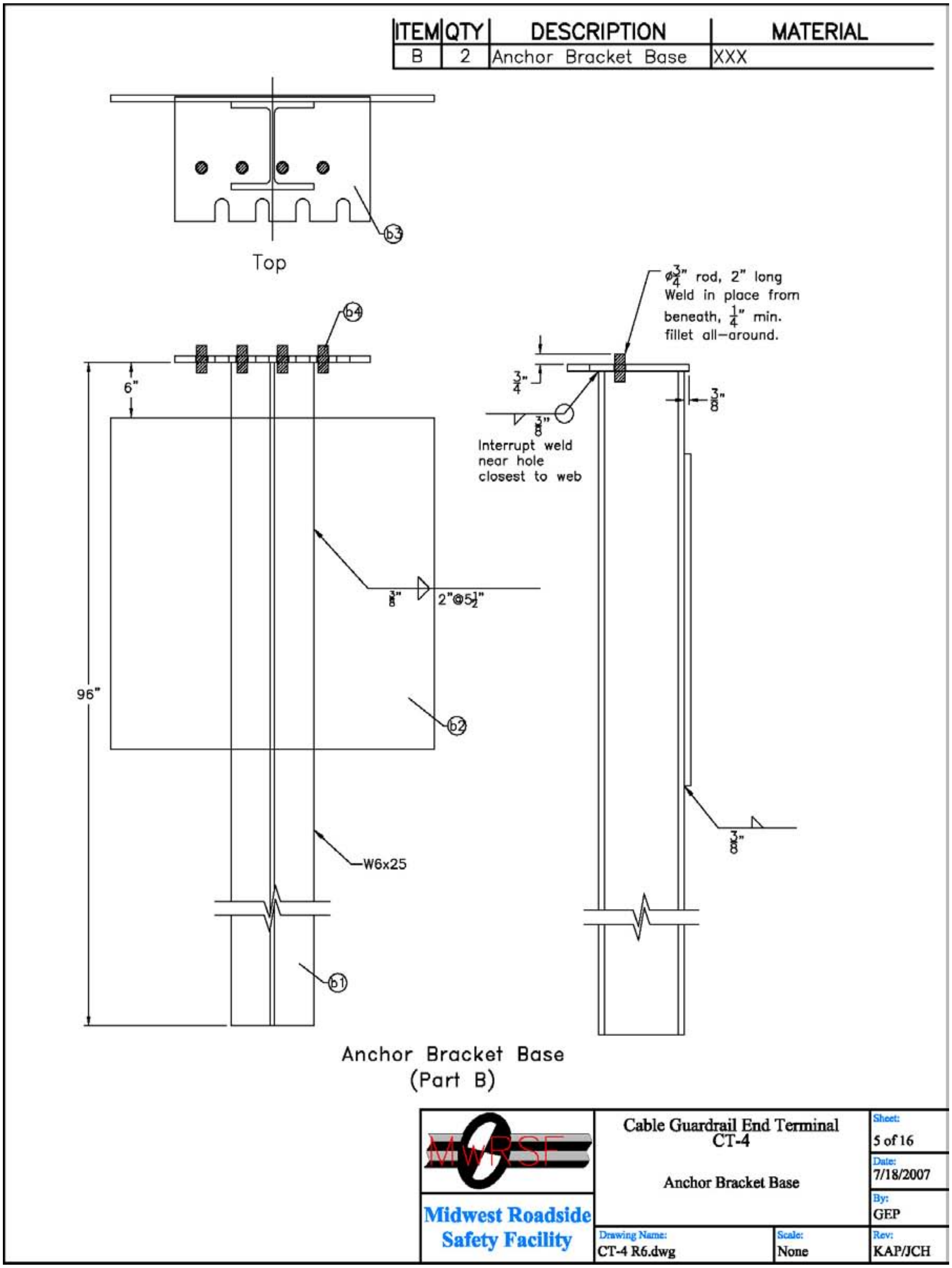


Figure H-21. Anchor Bracket Base Details (English), Design No. 3

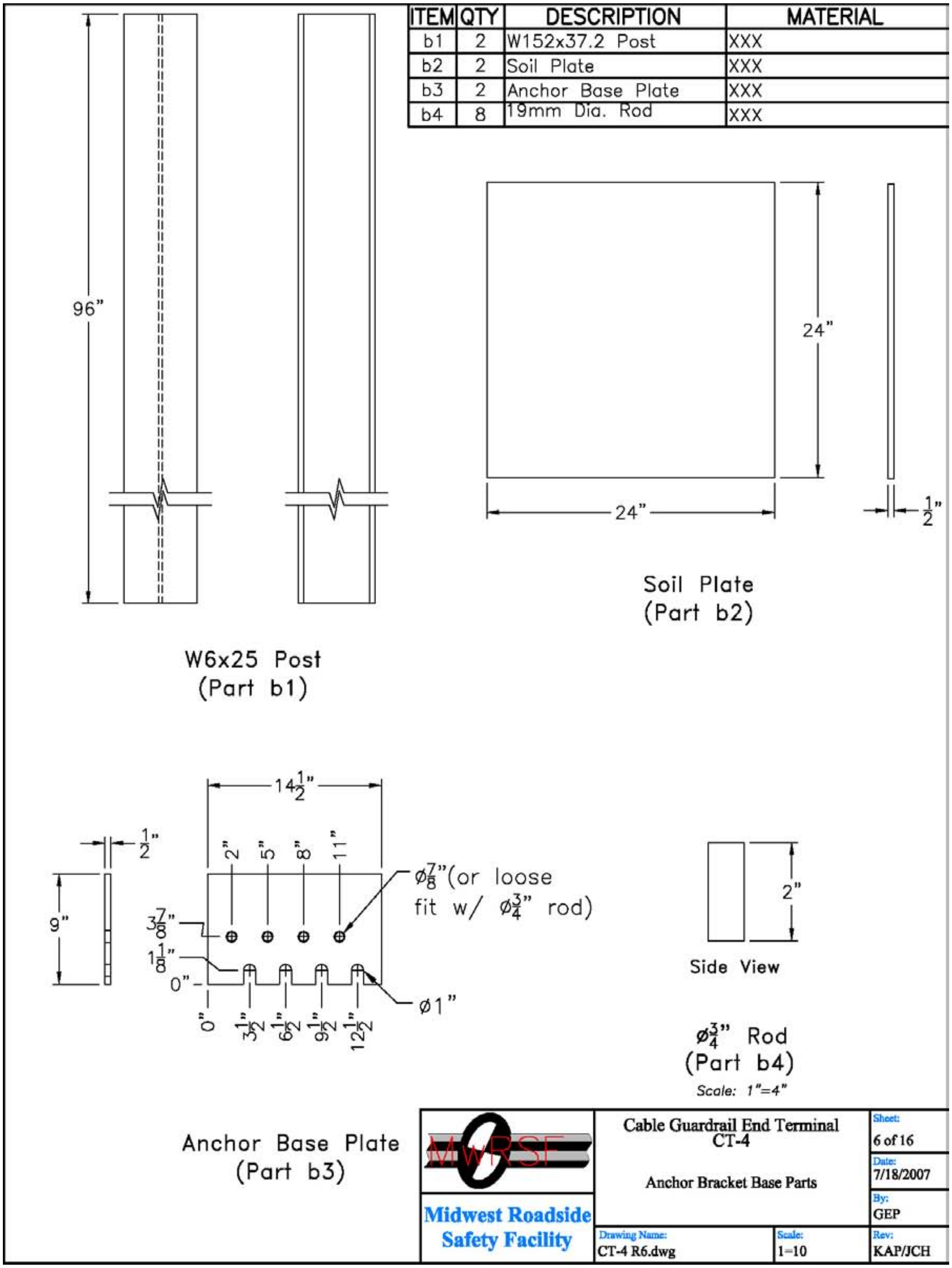


Figure H-22. Anchor Bracket Base Details (English), Test CT-4

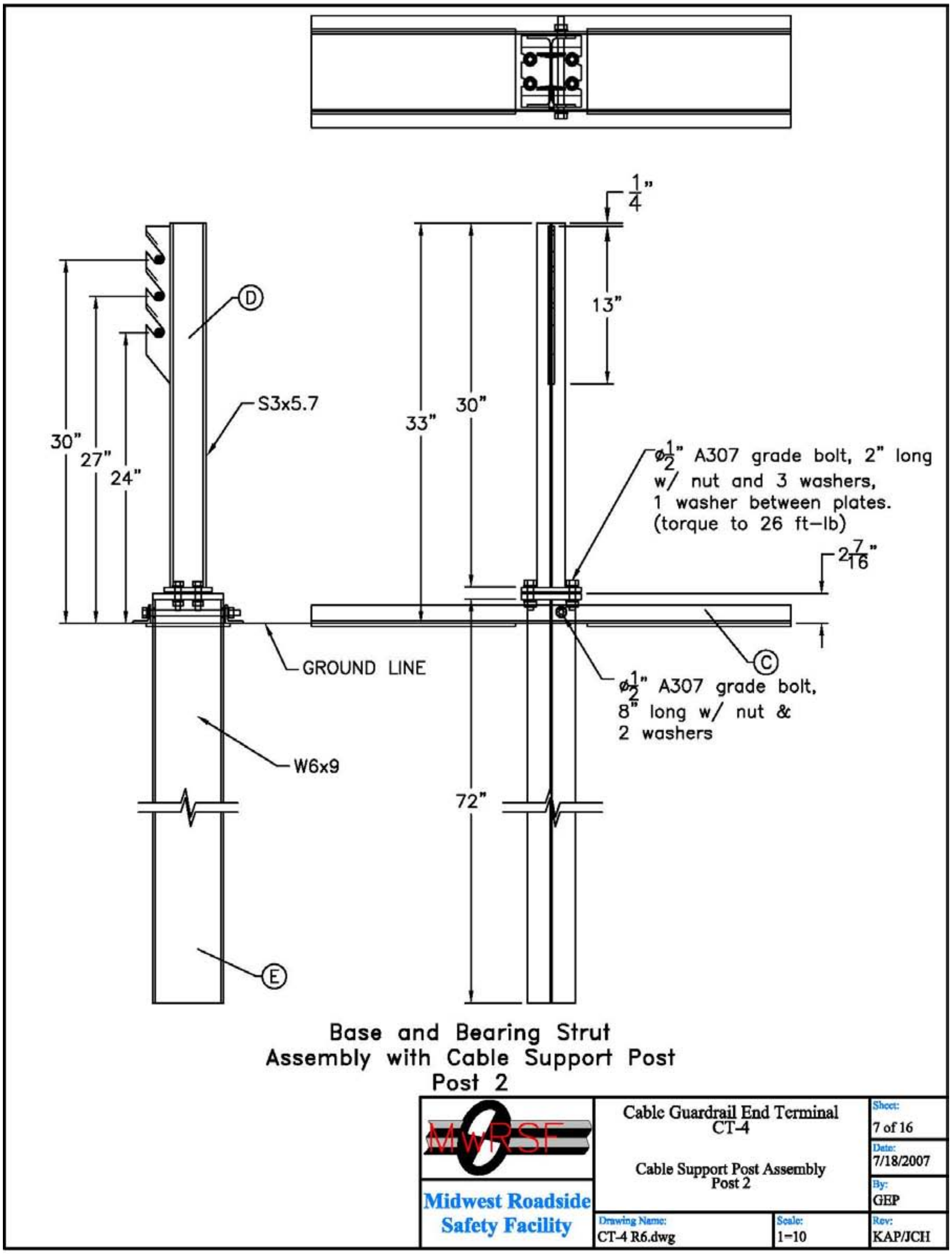


Figure H-23. Support Post Assembly (English), Design No. 3

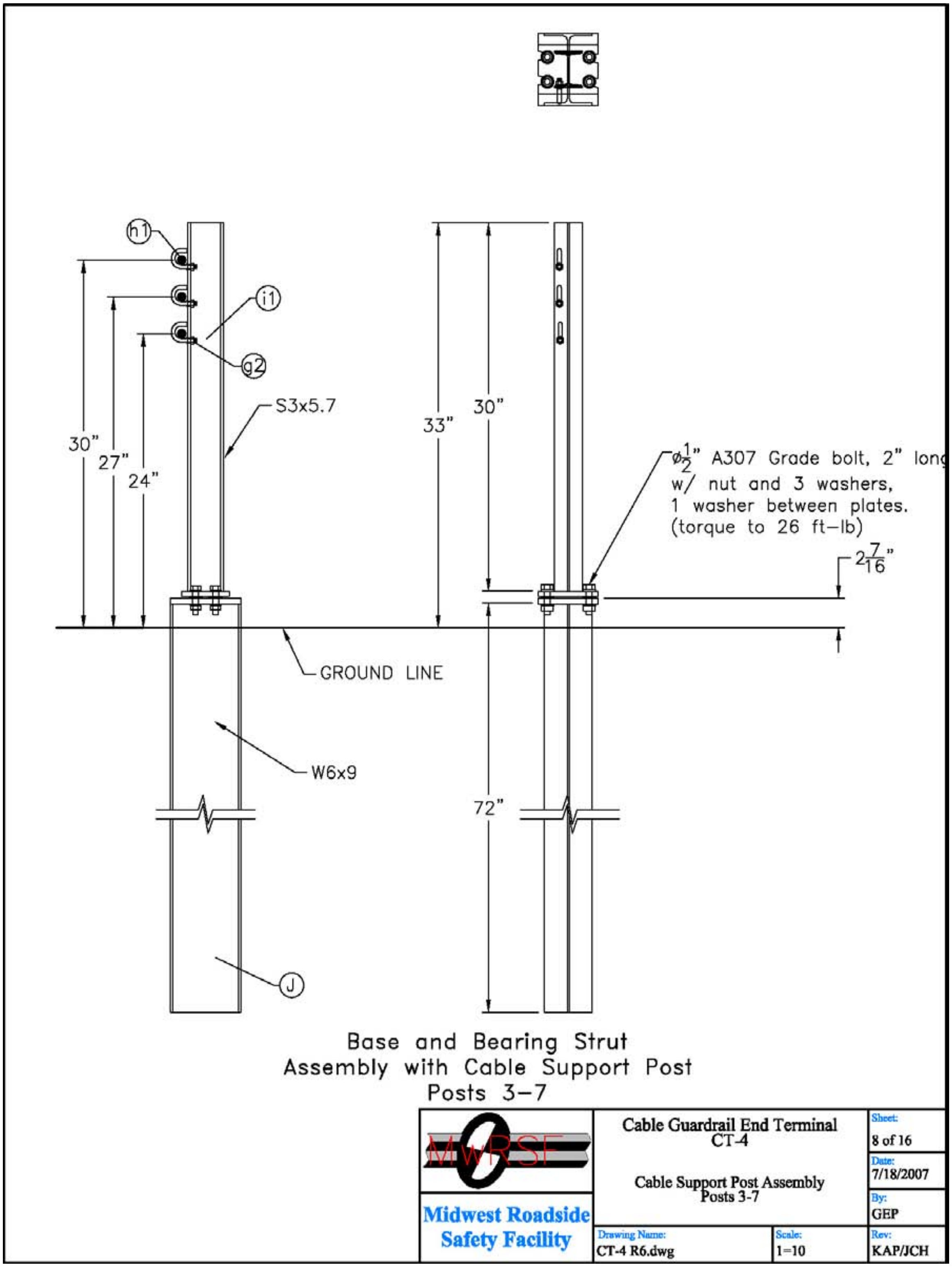


Figure H-24. Line Post Nos. 3 through 7 Details (English), Design No. 3

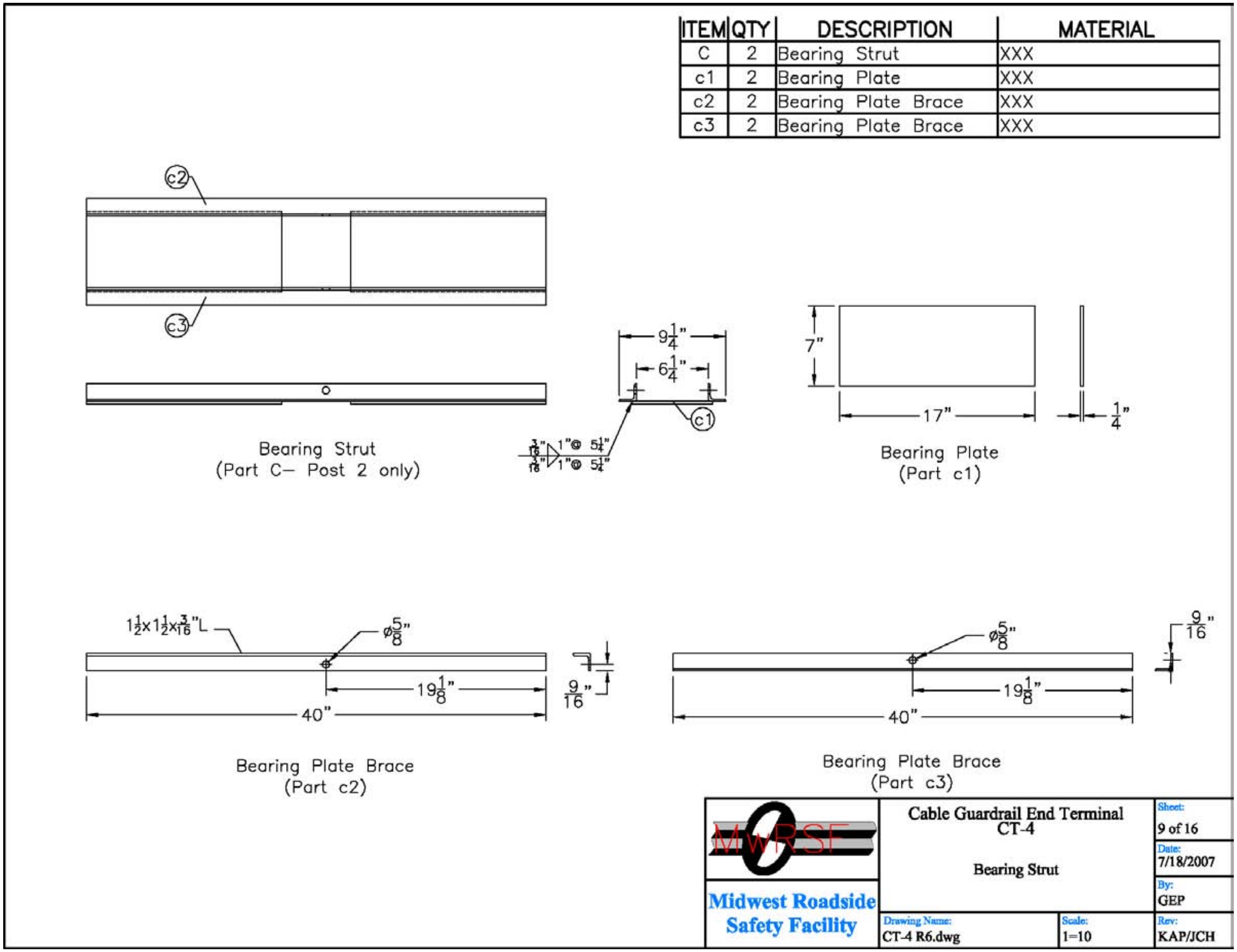


Figure H-25. Bearing Strut Details (English), Design No. 3

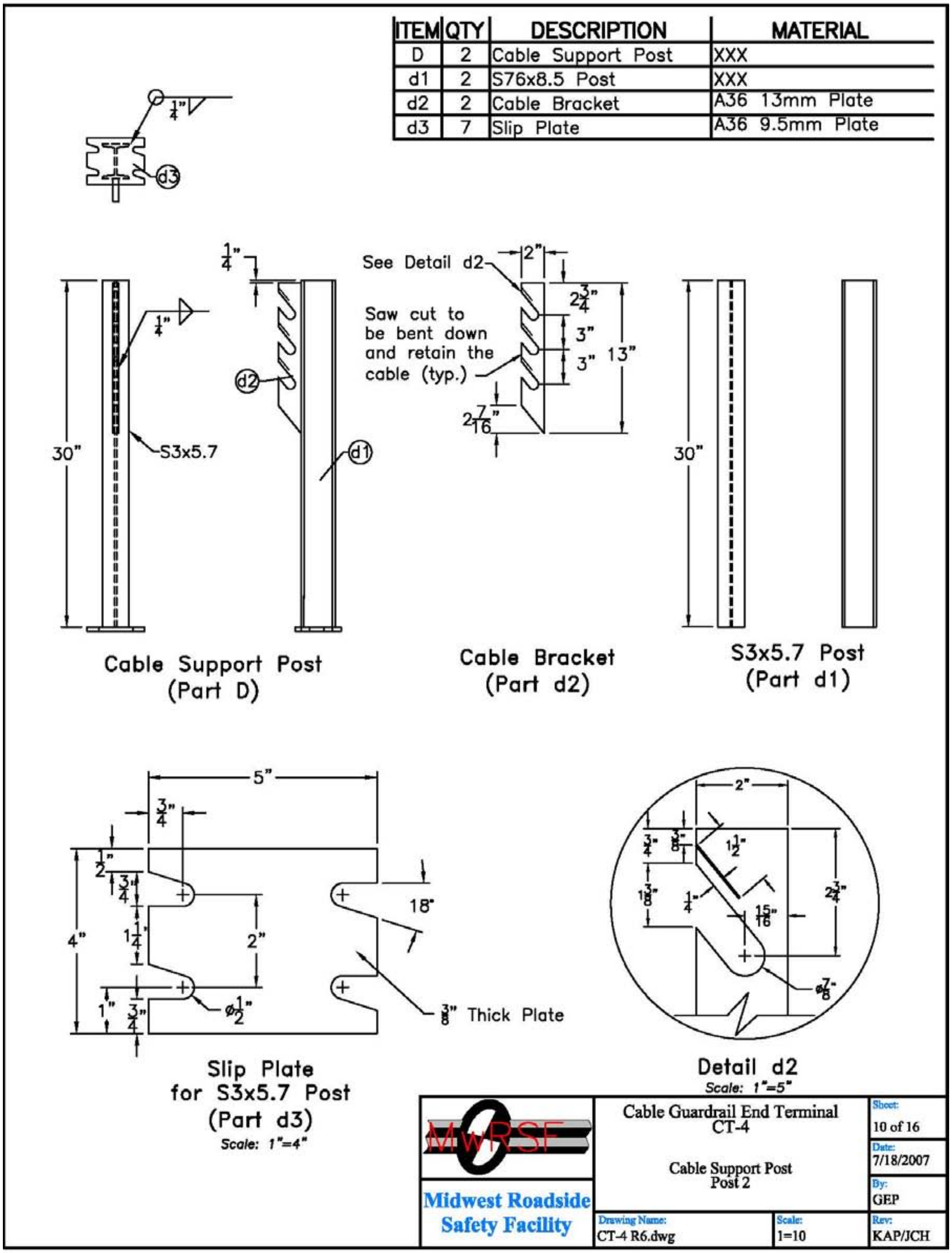


Figure H-26. Support Post Details (English), Design No. 3

ITEM	QTY	DESCRIPTION	MATERIAL
E	2	Cable Support Base	XXX
e1	2	W152x13.4 Post	XXX
e2	7	Base Slip Plate	A36 13mm Plate

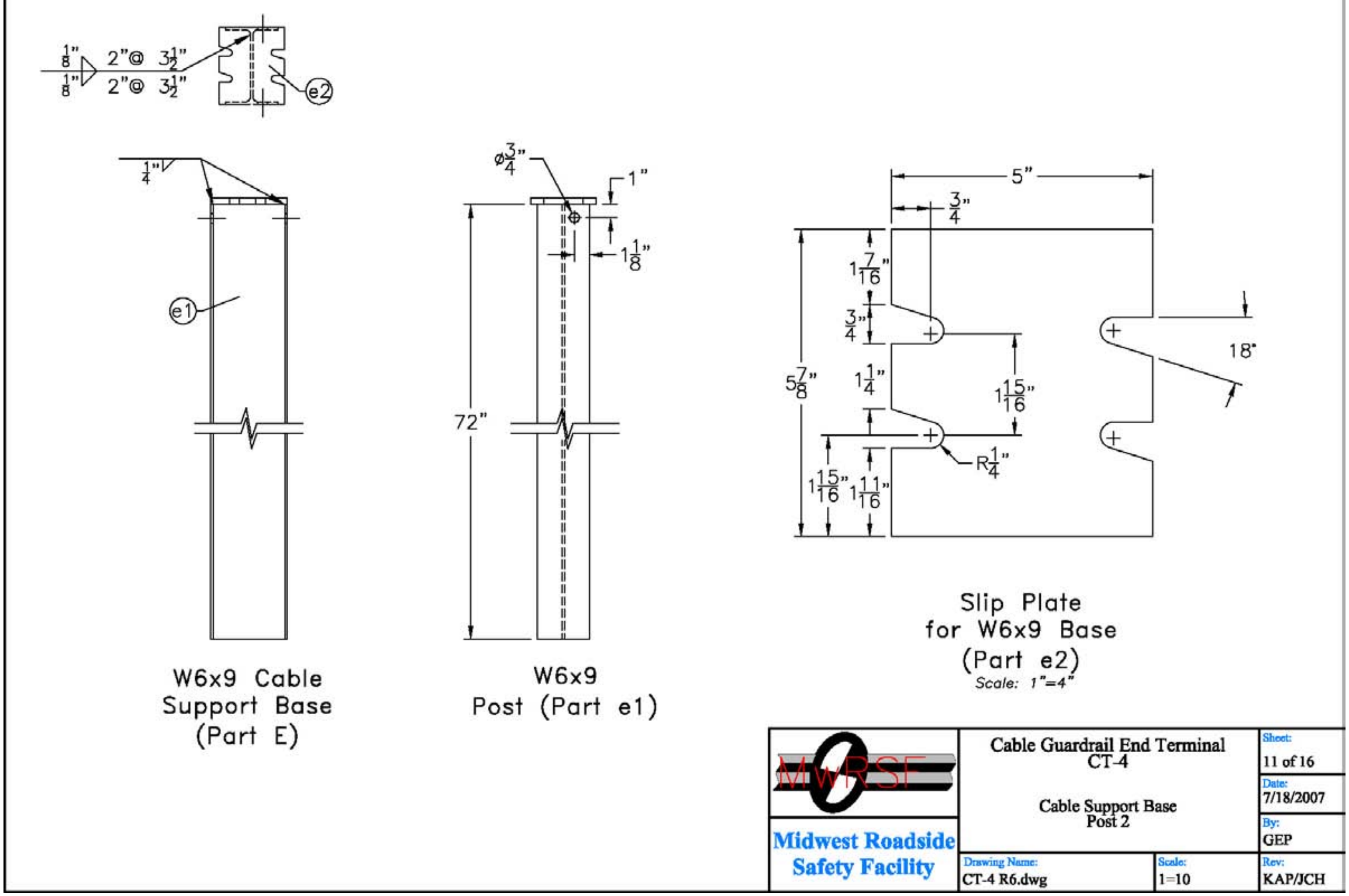


Figure H-27. Support Post Base Details (English), Design No. 3

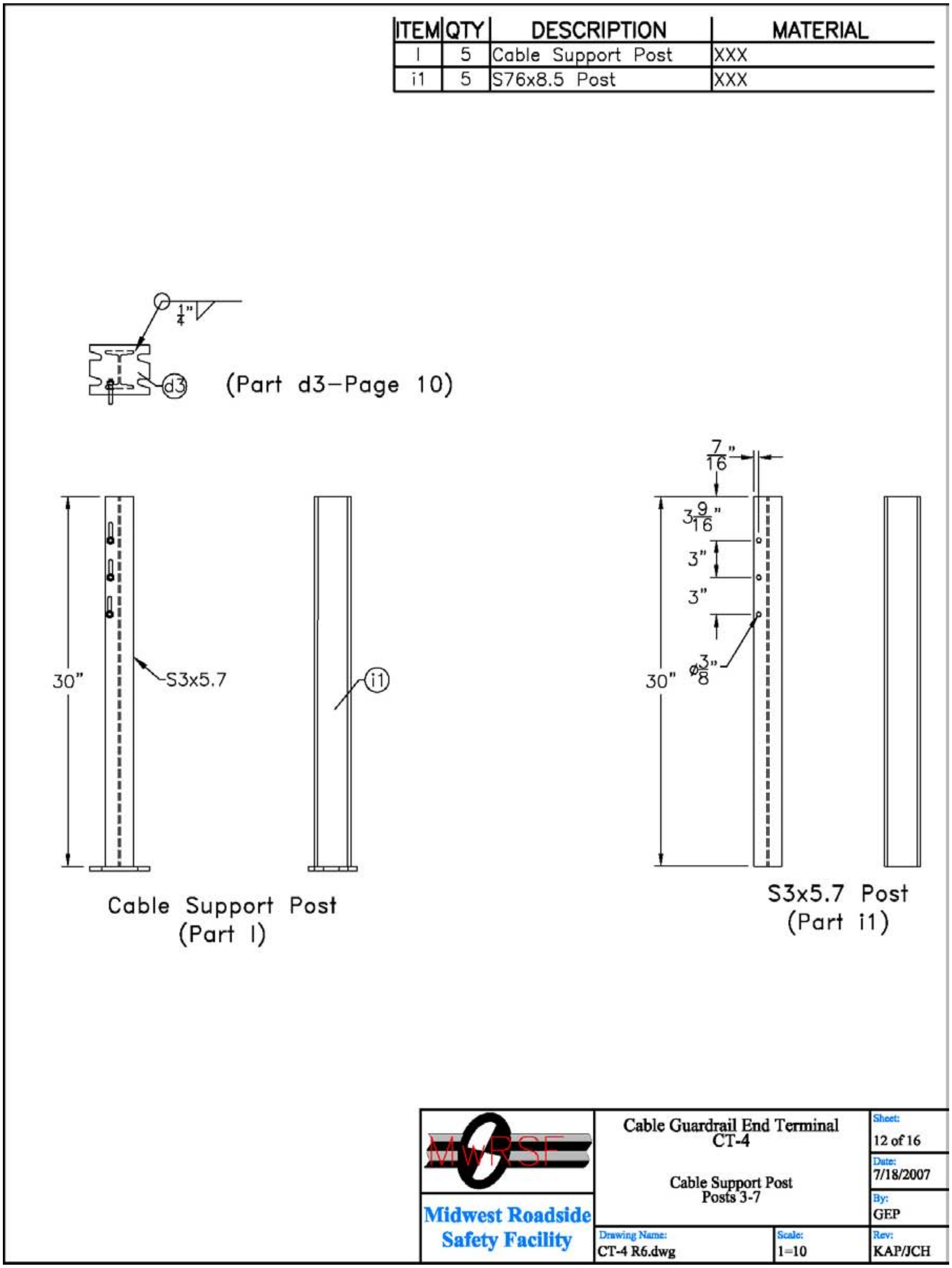


Figure H-28.Line Post Nos. 3 through 7 Details (English), Design No. 3

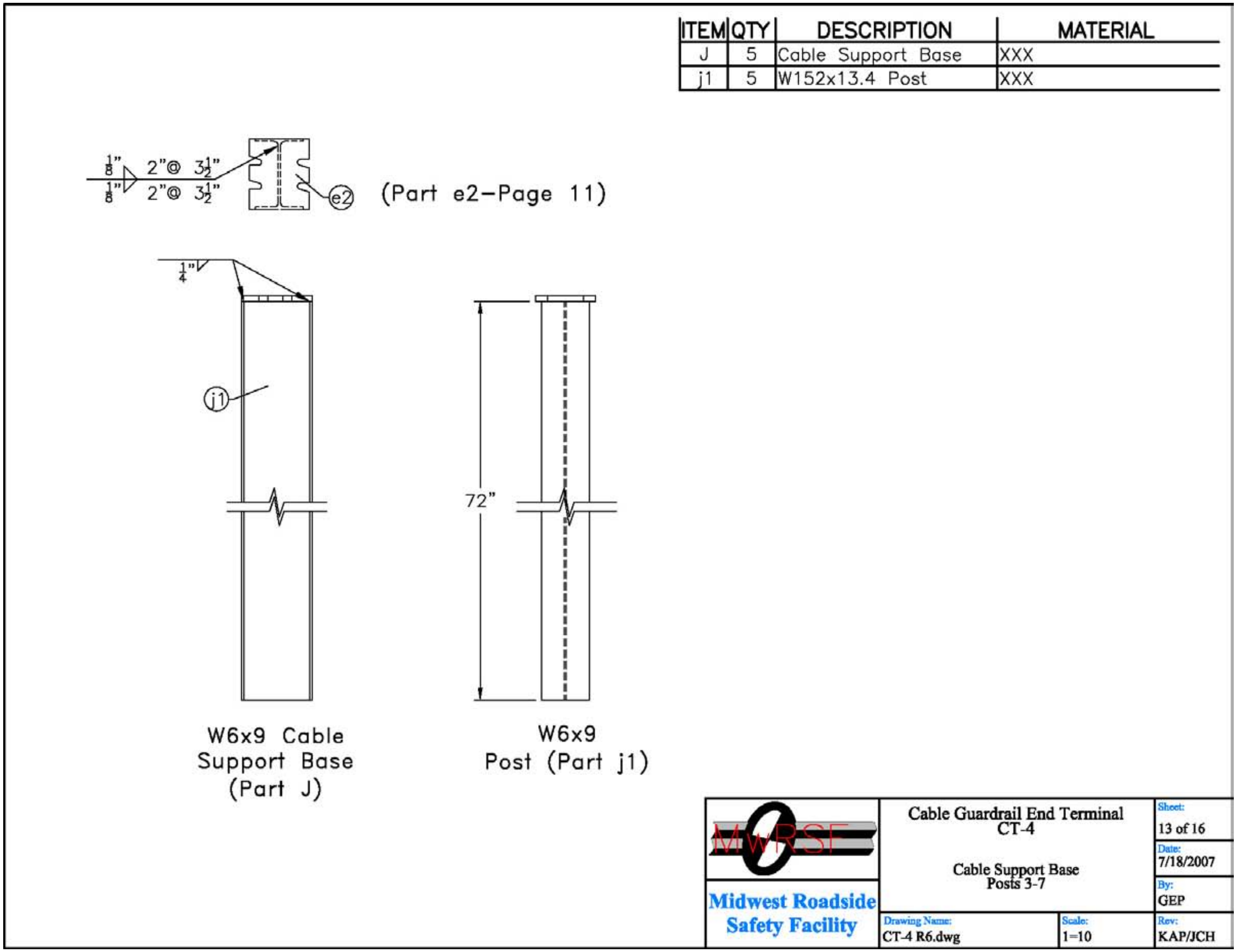


Figure H-29. Line Post Nos. 3 through 7 Base Details (English), Design No. 3

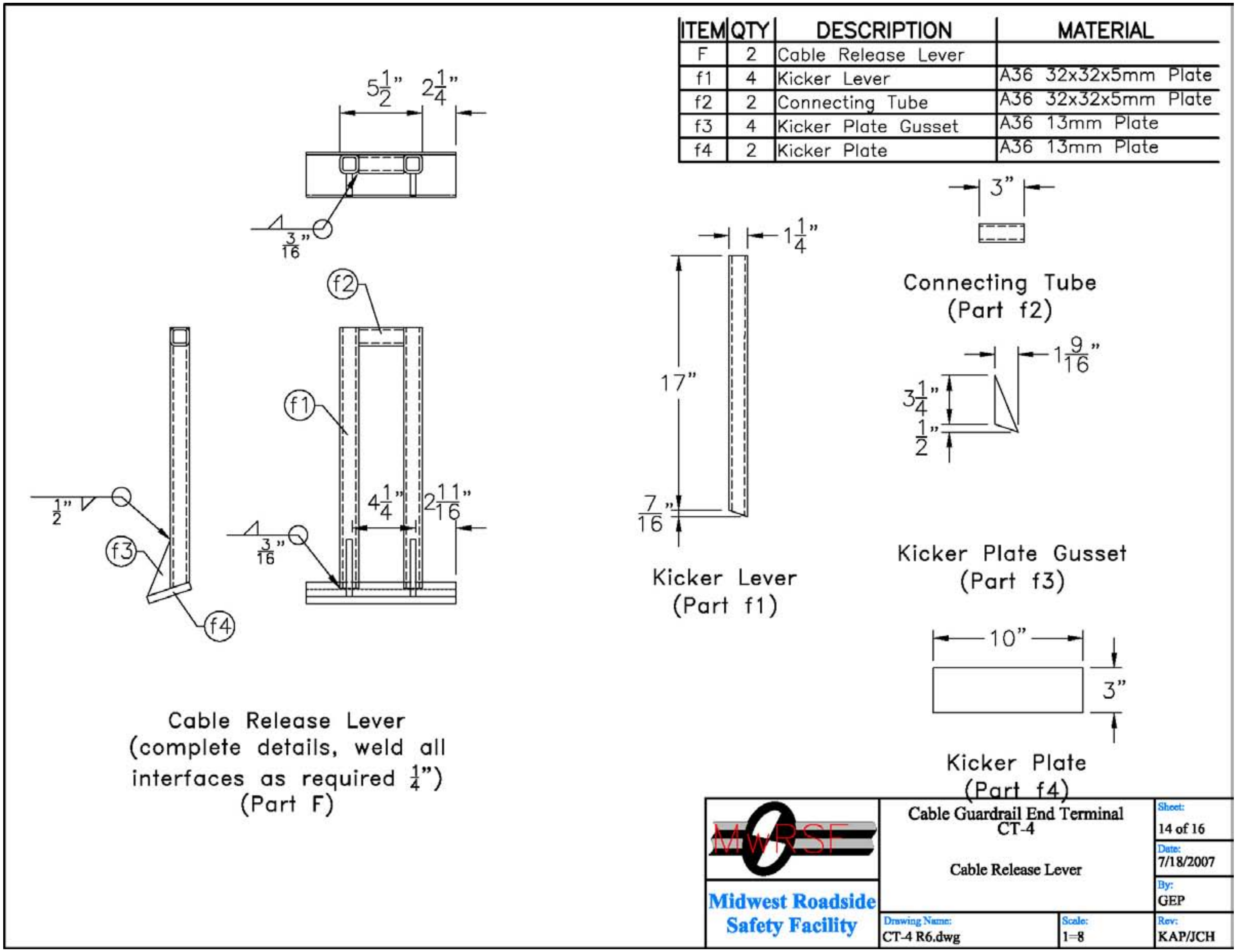


Figure H-30. Cable Release Lever Details (English), Design No. 3

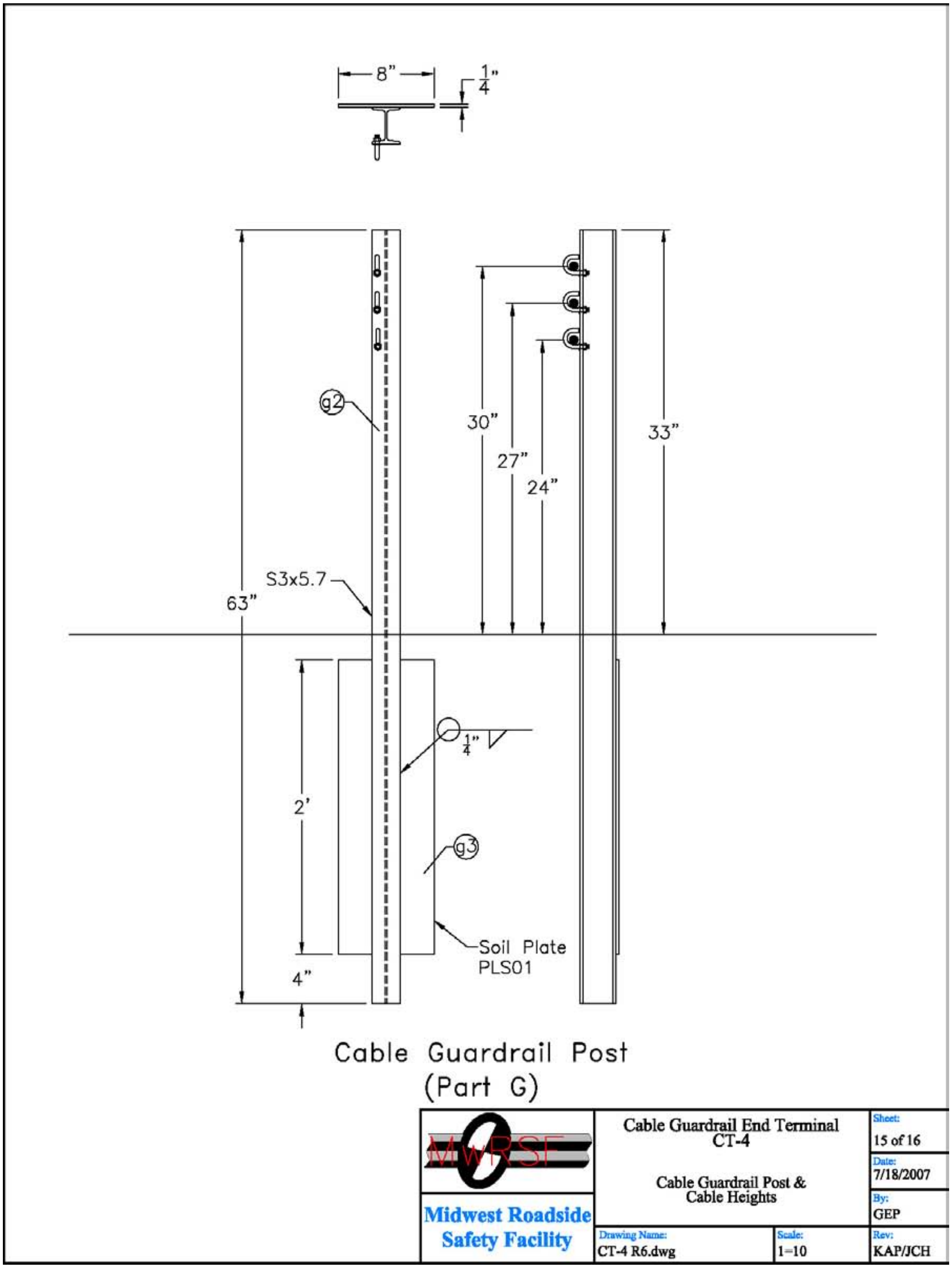
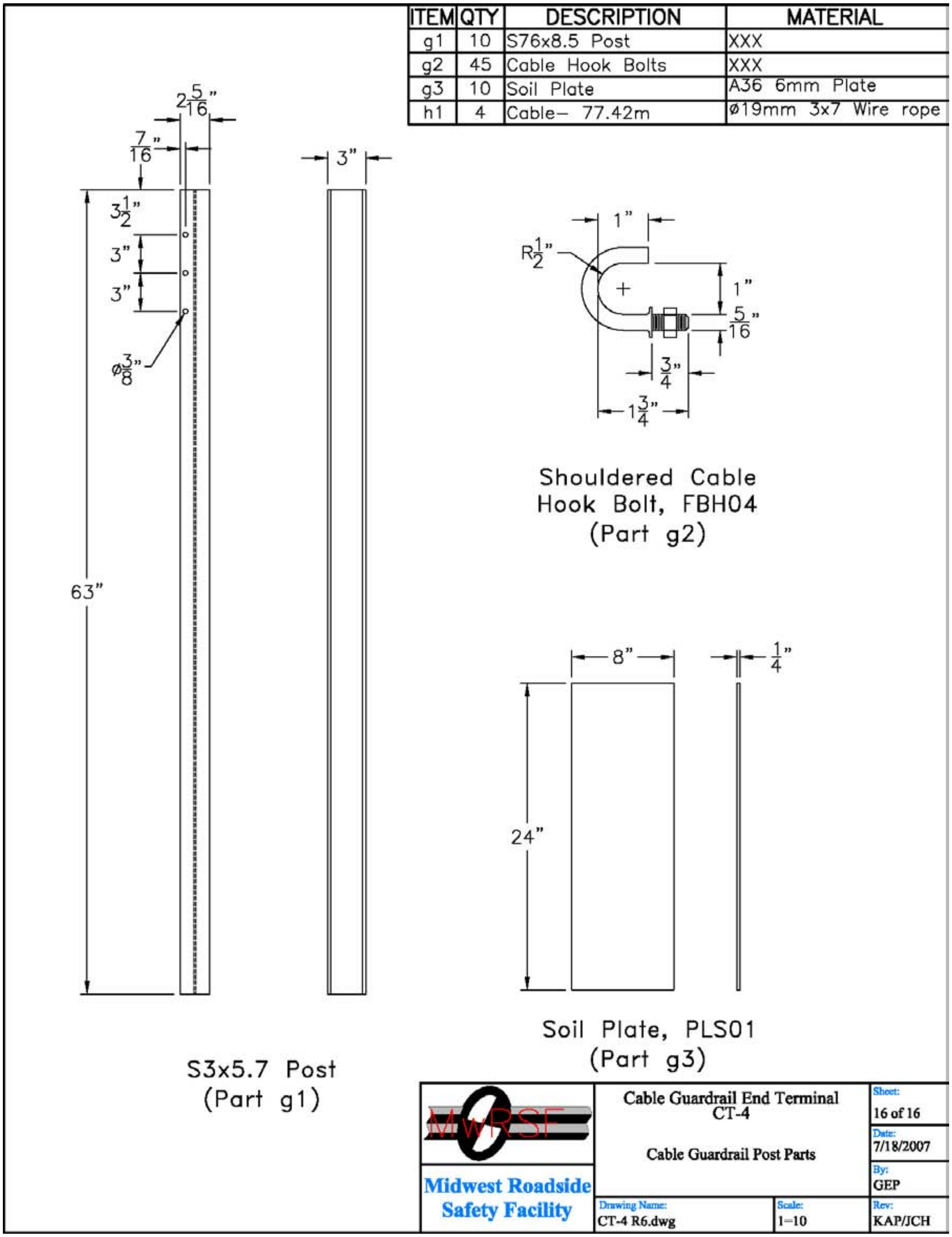


Figure H-31. Line Post Nos. 8 through 17 Details (English), Design No. 3



ITEM	QTY	DESCRIPTION	MATERIAL
g1	10	S76x8.5 Post	XXX
g2	45	Cable Hook Bolts	XXX
g3	10	Soil Plate	A36 6mm Plate
h1	4	Cable– 77.42m	ø19mm 3x7 Wire rope

Figure H-32. Line Post Nos. 8 through 17 Details (English), Design No. 3

APPENDIX I

Accelerometer and Rate Transducer Data Analysis, Test CT-4

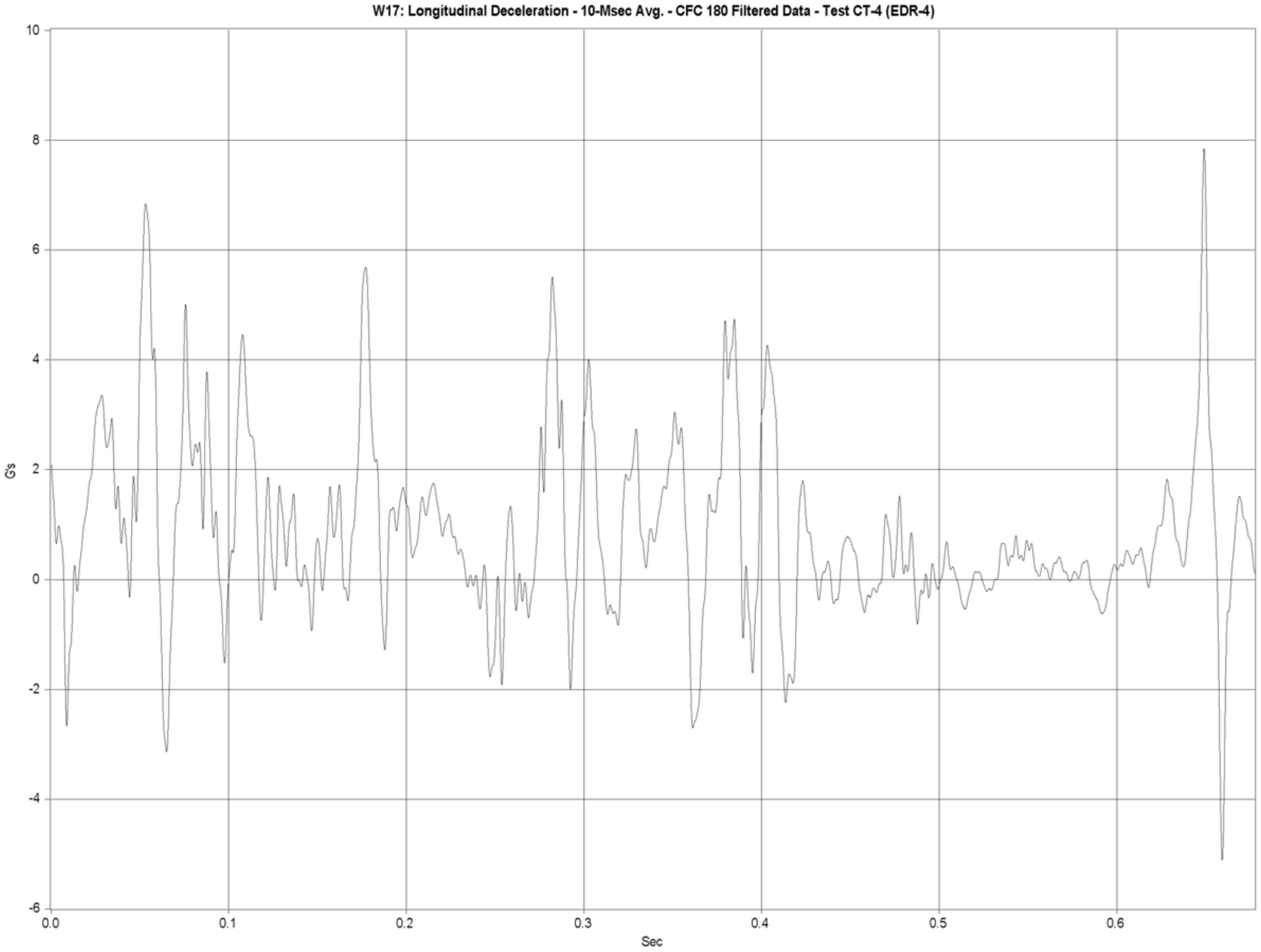


Figure I-1. Graph of Longitudinal Deceleration, Test CT-4

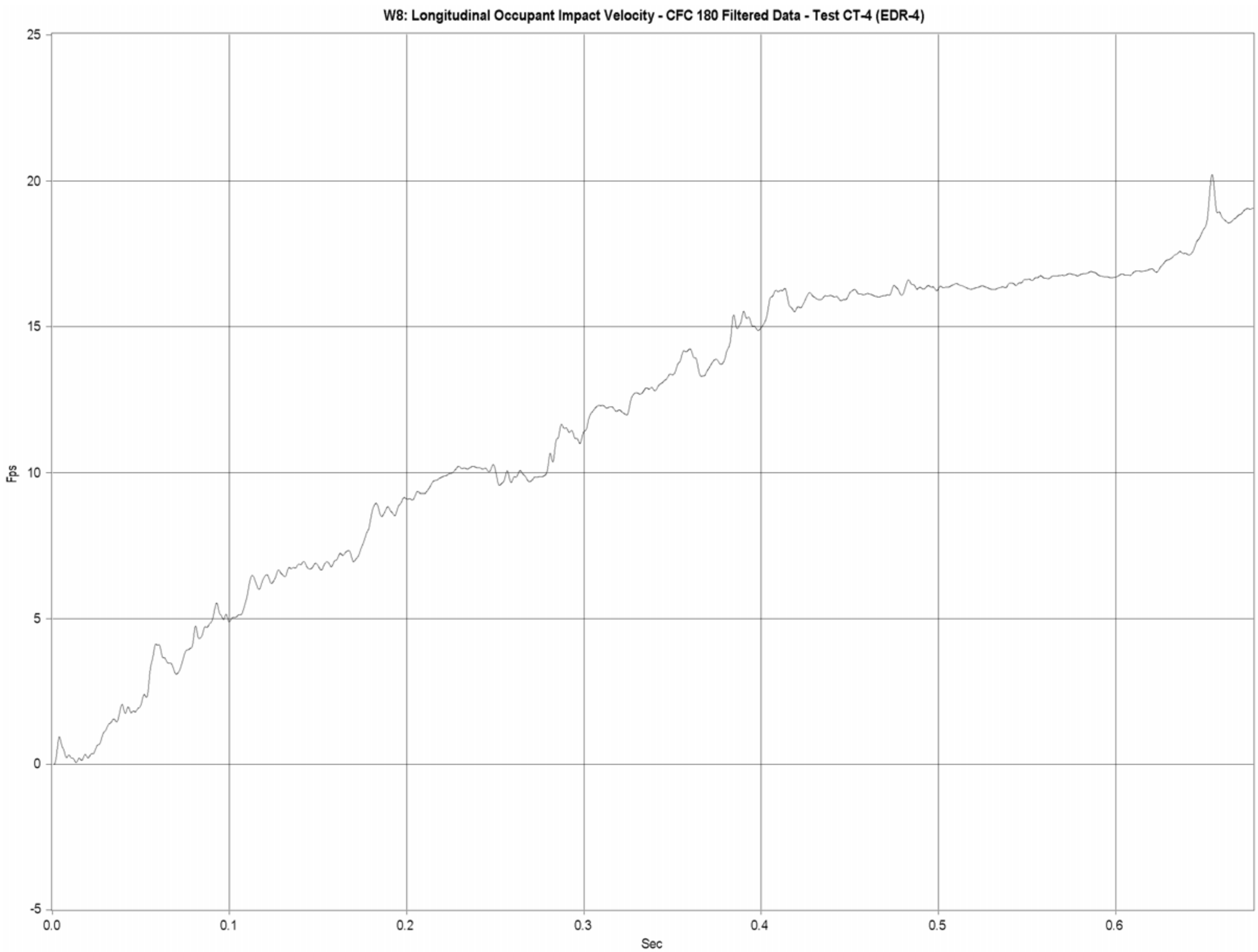


Figure I-2. Graph of Longitudinal Occupant Impact Velocity, Test CT-4

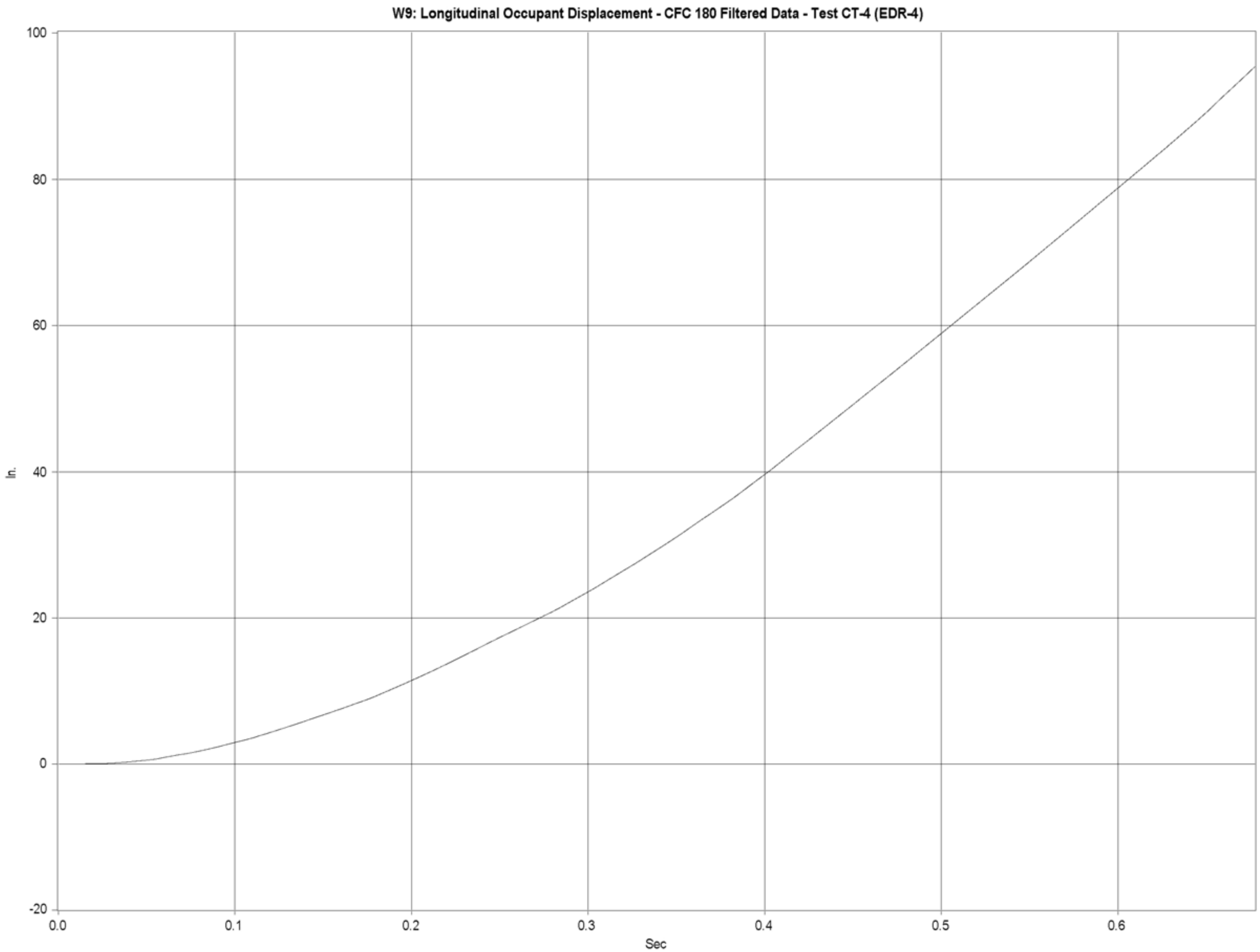


Figure I-3. Graph of Longitudinal Occupant Displacement, Test CT-4

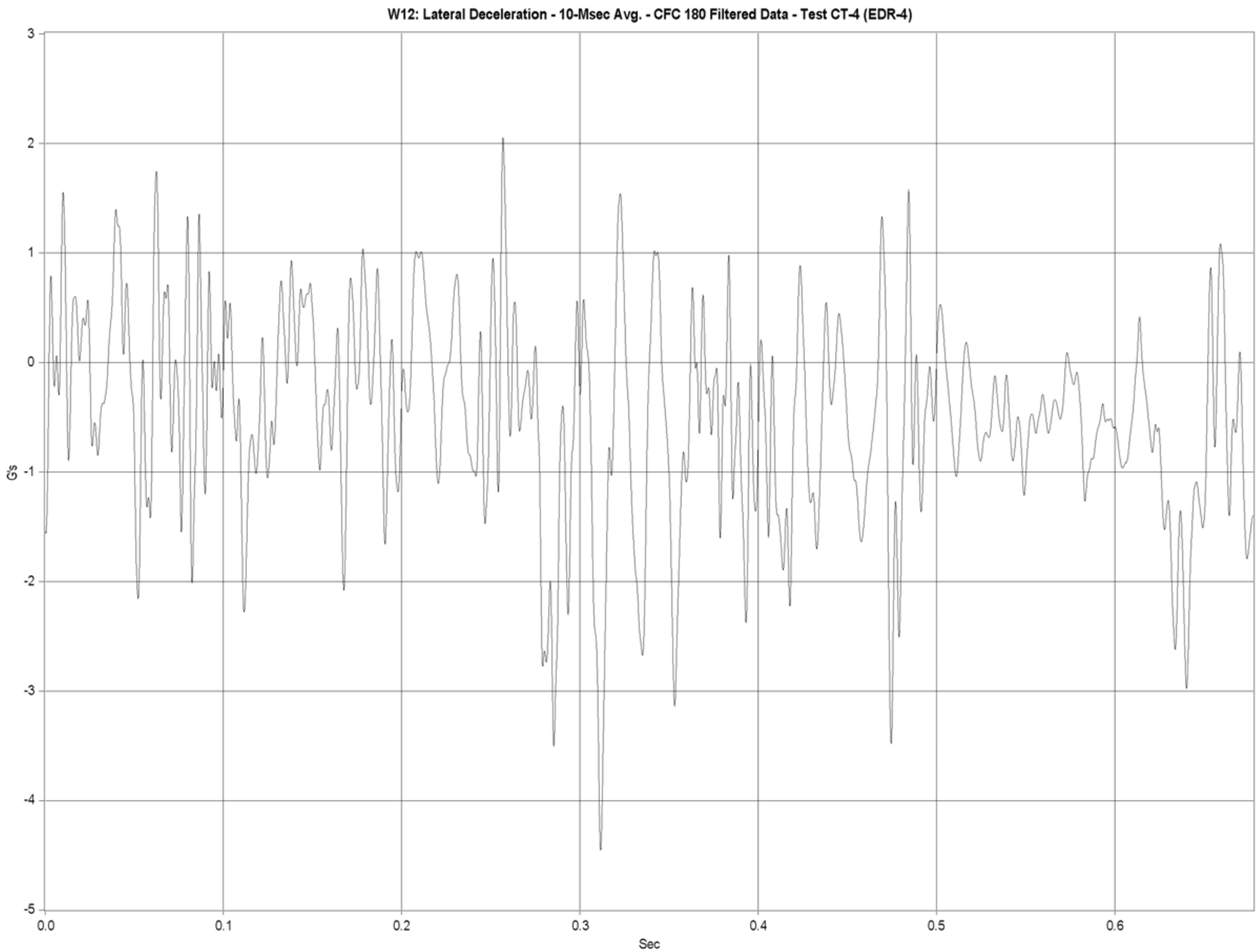


Figure I-4. Graph of Lateral Deceleration, Test CT-4

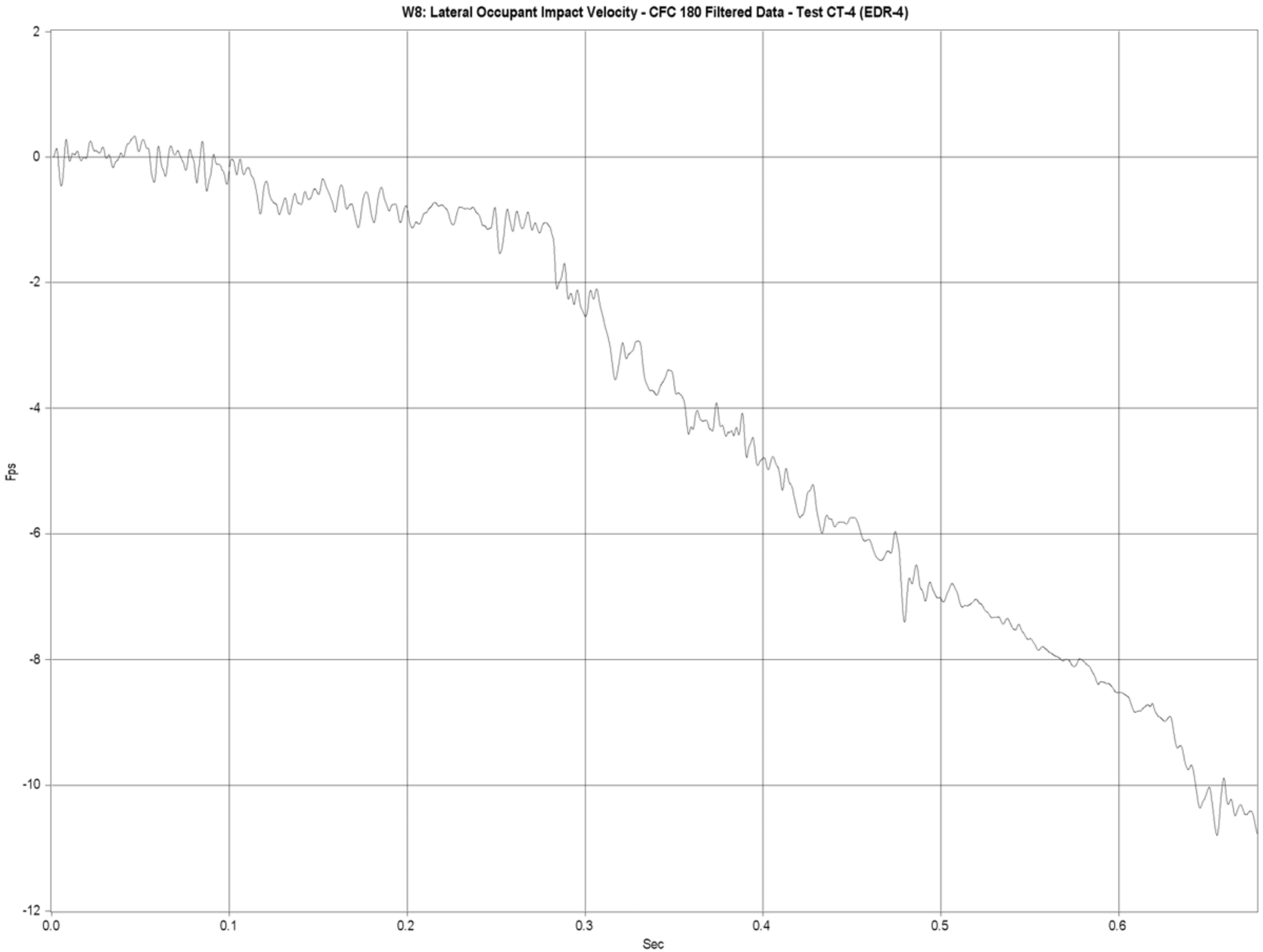


Figure I-5. Graph of Lateral Occupant Impact Velocity, Test CT-4

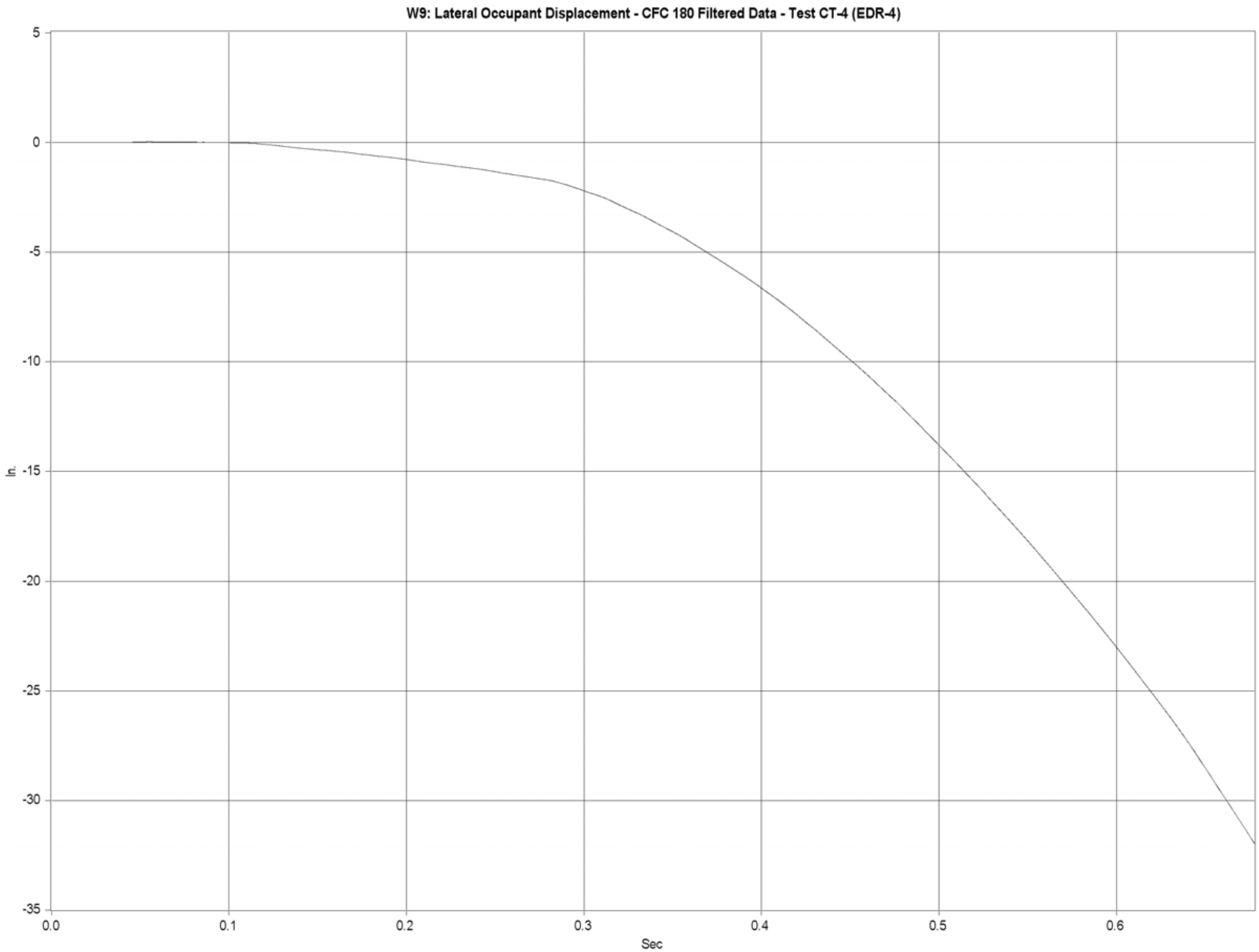


Figure I-6. Graph of Lateral Occupant Displacement, Test CT-4

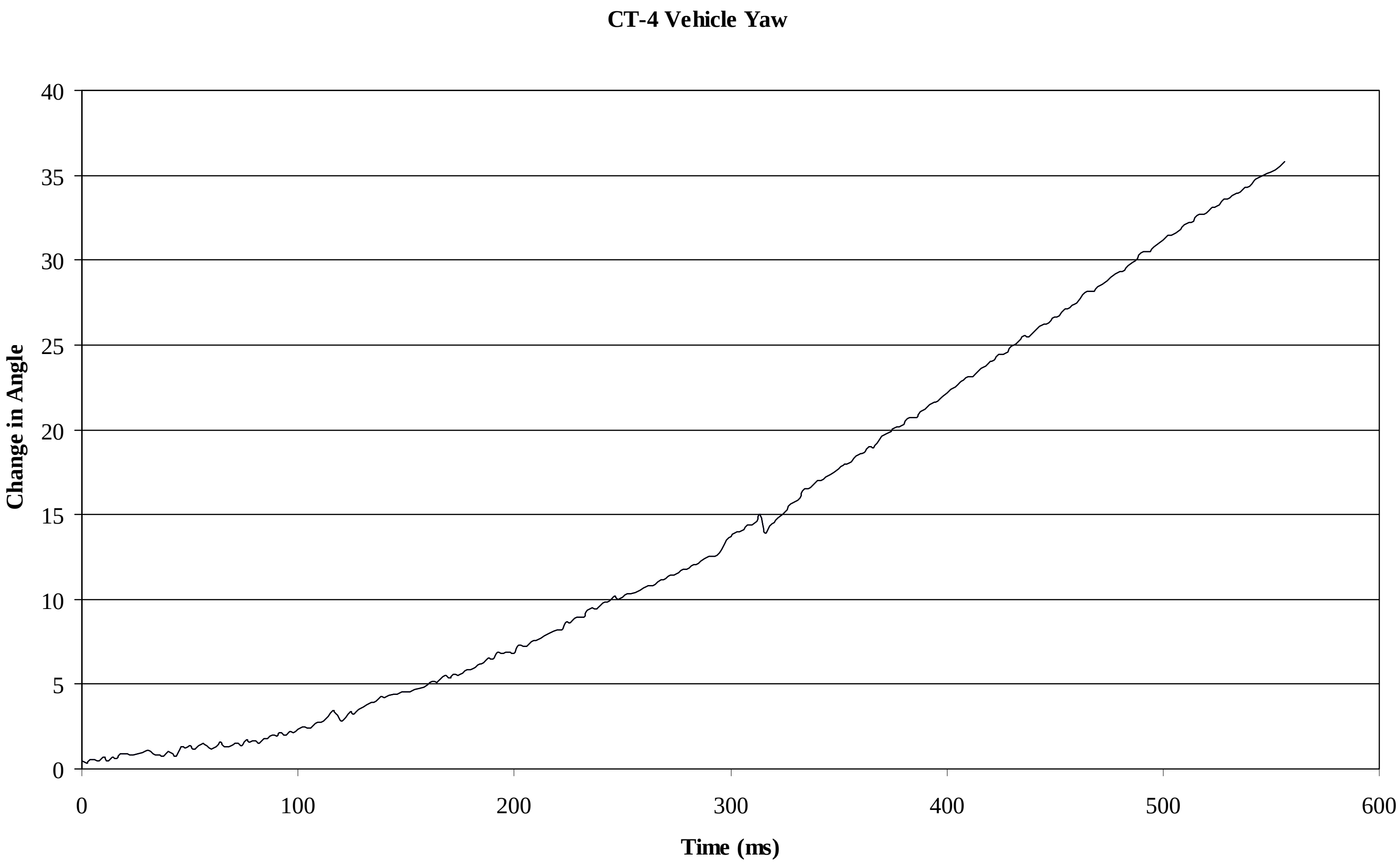


Figure I-7. Graph of Yaw Angular Displacement, Test CT-4