PERFORMANCE EVALUATION OF THE GUARDRAIL TO CONCRETE BARRIER TRANSITION – UPDATE TO NCHRP 350 TEST NO. 3-21 WITH 28" C.G. HEIGHT (2214T-1)

Submitted by

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

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

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

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

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

John D. Reid, Ph.D.
Associate Professor

Brian A. Coon, Ph.D., P.E.
Research Associate Engineer

MIDWEST ROADSIDE SAFETY FACILITY
University of Nebraska-Lincoln
527 Nebraska Hall
Lincoln, Nebraska 68588-0529
(402) 472-6864

Submitted to

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

MwRSF Research Report No. TRP-03-175-06

October 12, 2006

Technical Report Documentation Page

1. Report No. TRP-03-175-06	2.	3. Recipient's Accession No.
4. Title and Subtitle Performance Evaluation of the Guardrail to Concrete Barrier Transition – Update to NCHRP 350 Test No. 3-21 with 28" C.G. Height (2214T-1)		5. Report Date October 12, 2006
		6.
7. Author(s) Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, B.W., Reid, J.D., and Coon, B.A.		8. Performing Organization Report No. TRP-03-175-06
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) University of Nebraska-Lincoln 527 Nebraska Hall Lincoln, NE 68588-0529		10. Project/Task/Work Unit No.
		11. Contract © or Grant (G) No. NCHRP 22-14(2)
12. Sponsoring Organization Name and Address National Cooperative Highway Research Program Transportation Research Board National Research Council 2101 Constitution Avenue, N.W. Washington, D.C. 20418		13. Type of Report and Period Covered Final Report 2004-2006
		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration

16. Abstract (Limit: 200 words)

Based on the proposed changes to the National Cooperative Highway Research Program (NCHRP) Report No. 350 guidelines, NCHRP Project 22-14(2) researchers deemed it appropriate to evaluate a guardrail to concrete barrier transition system prior to finalizing the new crash testing procedures and guidelines. For this effort, the W-beam guardrail to concrete barrier transition system was selected for evaluation. One full-scale vehicle crash test was performed on the approach guardrail transition system in accordance with the Test Level 3 (TL-3) requirements presented in the Update to NCHRP Report No. 350. For the testing program, a 2270P pickup truck vehicle, which was a ½-ton, four-door vehicle with a 711 mm (28 in.) c.g. height, was used.

The guardrail to concrete barrier transition system provided an acceptable safety performance when impacted by the ½-ton, four-door pickup truck, thus meeting the proposed TL-3 requirements presented in the Update to NCHRP Report No. 350.

17. Document Analysis/Descriptors Highway Safety, Roadside Appurtenances, Longitudinal Barriers, Guardrail, Transition, Crash Test, Compliance Test, NCHRP 350 Update		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 95	22. Price

DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views nor policies of the National Research Council of the Transportation Research Board nor the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the National Research Council of the Transportation Research Board for sponsoring this project; and (2) MwRSF personnel for constructing the barrier and conducting the crash test.

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

Midwest Roadside Safety Facility

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

Transportation Research Board

Charles W. Niessner, Senior Program Officer
NCHRP 22-14(2) Panel Members

Federal Highway Administration

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

Dunlap Photography

James Dunlap, President and Owner

TABLE OF CONTENTS

List of Figures

Page

List of Tables

Page

1 INTRODUCTION

1.1 Problem Statement

In the late 1990s, roadside safety experts, State DOT representatives, Federal government officials, and industry personnel began discussions and preparations for updating the National Cooperative Highway Research Program (NCHRP) Report No. 350 safety performance guidelines (1). The new guidelines would improve upon existing test procedures, consider changes in the vehicle fleet, provide criteria for new roadside hardware categories and re-evaluate the appropriateness of the impact conditions.

In 1997, NCHRP Project 22-14, entitled *Improvement of the Procedures for the Safety Performance Evaluation of Roadside Features*, was initiated with the intent to: (1) evaluate the relevance and efficacy of the crash testing procedures, (2) assess the needs for updating NCHRP Report No. 350, and (3) provide recommended strategies for their implementation. Following the completion of this NCHRP study at the Texas Transportation Institute (TTI) in 2001, a follow-on research study was begun in 2002. NCHRP Project 22-14(2), entitled *Improved Procedures for Safety Performance Evaluation of Roadside Features*, was undertaken by Midwest Roadside Safety Facility (MwRSF) researchers with the objectives to: (1) prepare the revised crash testing guidelines, (2) assess the effects of any proposed guidelines, and (3) identify research needs for future improvements to the procedures.

Consequently, it was anticipated that a number of revisions would be incorporated into the Update of NCHRP Report No. 350 guidelines (2). For example, changes in the vehicle have resulted in the need to reassess the small car and pickup truck test vehicles. Accordingly, new, heavier test vehicles have been selected for both the small car and light truck classes of vehicles. Additionally, during the second study, researchers determined that the 100 km/h (62.1 mph) impact speed and 25 degree impact angle would remain the same as used in NCHRP Report No. 350 for the large passenger vehicle class impacting longitudinal barriers. However, the impact angle for the small car impact condition would increase from 20 to 25 degrees for evaluating longitudinal barriers and the length-of-need for guardrail terminals. The effects of any changes to vehicle specifications or impact conditions must be understood before the safety performance evaluation guidelines are finalized. Therefore, a series of full-scale crash tests on NCHRP Report No. 350 approved systems were to be conducted with the new test vehicles and impact conditions.

1.2 Objective

The objective of this research project was to evaluate the safety performance of a guardrail to concrete barrier transition system when full-scale vehicle crash tested according to the test designation no. 3-21 criteria presented in the Update of NCHRP Report No. 350 guidelines (2).

1.3 Scope

The research objective was achieved through the completion of several tasks. First, a full-scale vehicle crash test was performed on the guardrail to concrete barrier transition system. The crash test utilized a pickup truck, weighing approximately 2,270 kg (5,004 lbs) with a center of gravity (c.g.) height of 711 mm (28 in.). The target impact conditions for the test were an impact speed of 100.0 km/h (62.1 mph) and an impact angle of 25 degrees. Next, the test results were analyzed, evaluated, and documented. Finally, conclusions and recommendations were made that pertain to the safety performance of the guardrail to concrete barrier transition system relative to the test performed.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Historically, longitudinal barriers, such as approach guardrail transitions, have been required to satisfy impact safety standards in order to be accepted by the Federal Highway Administration (FHWA) for use on National Highway System (NHS) construction projects or as a replacement for existing designs not meeting current safety standards. In recent years, these safety standards have consisted of the guidelines and procedures published in NCHRP Report No. 350 (1). However, NCHRP Project 22-14(2) generated revised testing procedures and guidelines for use in the evaluation of roadside safety appurtenances and were presented in the draft report entitled, *NCHRP Report 350 Update* (2). Therefore, according to Test Level 3 (TL-3) of the Update to NCHRP Report No. 350, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests. The two full-scale crash tests are as follows:

1. Test Designation 3-20. An 1,100-kg (2,425-lb) passenger car impacting at a nominal speed and angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively.

2. Test Designation 3-21. A 2,270-kg (5,004-lb) pickup truck impacting at a nominal speed and angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively.

The test conditions for TL-3 longitudinal barriers are summarized in Table 1. Test Designation 3-21 was conducted for the guardrail to concrete barrier transition system described herein.

2.2 Evaluation Criteria

According to the Update to NCHRP Report No. 350, the 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 secondary collisions with other fixed objects. These three evaluation criteria are summarized in Table 2 and defined in greater detail in the Update to NCHRP Report No. 350 report (2). The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in the Update to NCHRP Report No. 350.

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

Test Article	Test Designation	Test Vehicle	Impact Conditions			Evaluation Criteria [1]
			Speed		Angle (degrees)	
			(km/h)	(mph)		
Longitudinal Barrier Transition	3-20	1100C	100	62.1	25	A,D,F,H,I,M
	3-21	2270P	100	62.1	25	A,D,F,H,I,M

[1] Evaluation criteria explained in Table 2.

Table 2. Update to NCHRP Report No. 350 Evaluation Criteria for Crash Tests

Structural Adequacy	A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.
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 should not exceed limits set forth in Section 5.3 and Appendix E of the Update to NCHRP Report No. 350.
	F. The vehicle should remain upright during and after collision.
	H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9.0 m/s (29.5 ft/s), or at least below the maximum allowable value of 12.0 m/s (39.4 ft/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 20.0 Gs.
Vehicle Trajectory	M. After impact, the vehicle shall exit the barrier within the exit box.

3 TEST CONDITIONS

3.1 Test Facility

The testing facility is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 8.0 km (5 mi.) northwest of the University of Nebraska-Lincoln.

3.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch (3) 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 lbf), 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 test 2214T-1, the vehicle guidance system was 297 m (976 ft) long.

3.3 Test Vehicles

For test 2214T-1, a 2002 Chevrolet Crew Cab pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,306 kg (5,083 lbs). The test vehicle is shown in Figure 1, and vehicle dimensions are shown in Figure 2.

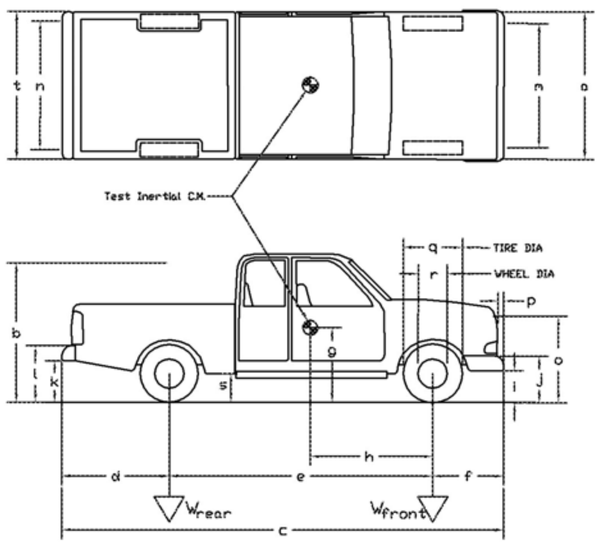
Figure 1. Test Vehicle, Test 2214T-1

Date: 6/22/2005 Test Number: 2214T-1 Model: Crew Cab 2WD Pickup

Make: Chevrolet Vehicle I.D.#: 1GCGC13U12F171883

Tire Size: LT 245/75 R16 Year: 2002 Odometer: 156095

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1930 (76.0)	b	1940 (76.375)
c	6020 (237.0)	d	1194 (47.0)
e	3899 (153.5)	f	927 (36.5)
g	711 (28.0)	h	1676 (66.0)
i	394 (15.375)	j	743 (29.25)
k	594 (23.375)	l	781 (30.75)
m	1724 (67.875)	n	1676 (66.0)
o	1067 (42.0)	p	102 (4.0)
q	775 (30.5)	r	441 (17.375)
s	524 (20.625)	t	1854 (73.0)

Wheel Center Height Front 368 (14.5)

Wheel Center Height Rear 375 (14.75)

Wheel Well Clearance (FR) 959 (37.75)

Wheel Well Clearance (RR) 1000 (39.375)

Frame Height (FR) 435 (17.125)

Frame Height (RR) 673 (26.5)

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	1432 (3156)	1314 (2897)	1314 (2897)
W_{rear}	1090 (2403)	992 (2186)	992 (2186)
W_{total}	5559 (2522)	2306 (5083)	2306 (5083)

Engine Type 8 Cylinder Gas

Engine Size 6.0L/365 c.i.

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

GVWR Ratings

Front 1996 (4400)

Back 2721 (6000)

Total 3901 (8600)

Note any damage prior to test: None

Figure 2. Vehicle Dimensions, Test 2214T-1

The Suspension Method (4) was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the location of the center of gravity. The longitudinal component of the c.g. was determined using the measured axle weights. The location of the final center of gravity is shown in Figures 1 and 2.

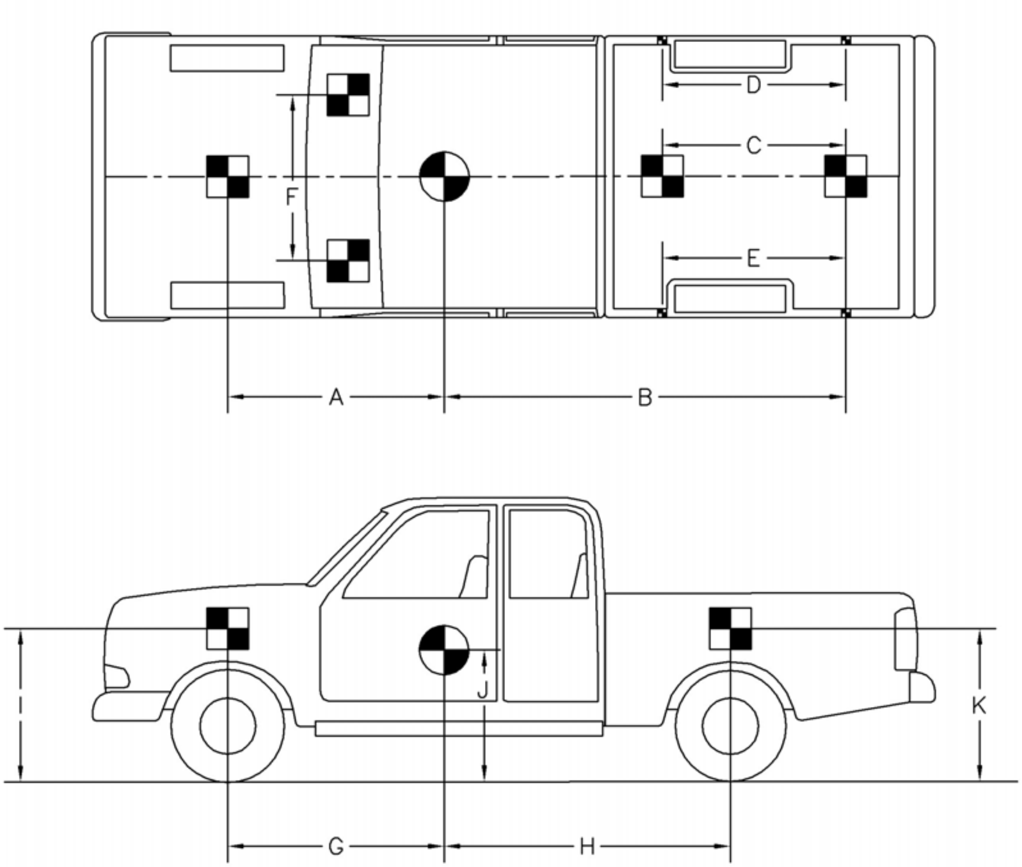
Square black and white-checkered targets were placed on the vehicle to aid in the analysis of the E/cam, Photron, and AOS videos, as shown in Figure 3. Checkered targets were placed on the center of gravity, on the driver's side door, on the passenger's side door, and on the roof of the vehicle. The 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 E/cam video, Photron video, and AOS 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.

3.4 Data Acquisition Systems

3.4.1 Accelerometers

One triaxial piezoresistive accelerometer system with a range of ±200 Gs was used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 10,000



TEST #: 2214T-1

TARGET GEOMETRY -- mm (in.)

A 1832 (72.125)	D 1594 (62.75)	G 1676 (66.0)	J 1206 (47.5)
B 2870 (113.0)	E 1594 (62.75)	H 2222 (87.5)	K 711 (28.0)
C 1111 (43.75)	F 791 (31.125)	I 1210 (47.625)	

Figure 3. Vehicle Target Locations, Test 2214T-1

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 Gs was also used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 3,200 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-3, was developed by Instrumental Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM memory and a 1,120 Hz lowpass filter. Computer software, "DynaMax 1 (DM-1)" and "DADiSP", was used to analyze and plot the accelerometer data.

3.4.2 Rate Transducers

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

3.4.3 High-Speed Photography

For test 2214T-1, two high-speed Photron video cameras, three high-speed AOS VITcam video cameras, and one high-speed Red Lake E/cam video cameras, all with operating speeds of 500 frames/sec, were 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 thirteen camera locations for test 2214T-1 is shown in Figure 4. The Photron and AOS videos and E/cam videos were analyzed using the ImageExpress MotionPlus software and Redlake Motion Scope software, respectively. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

3.4.4 Pressure Tape Switches

For test 2214T-1, 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.

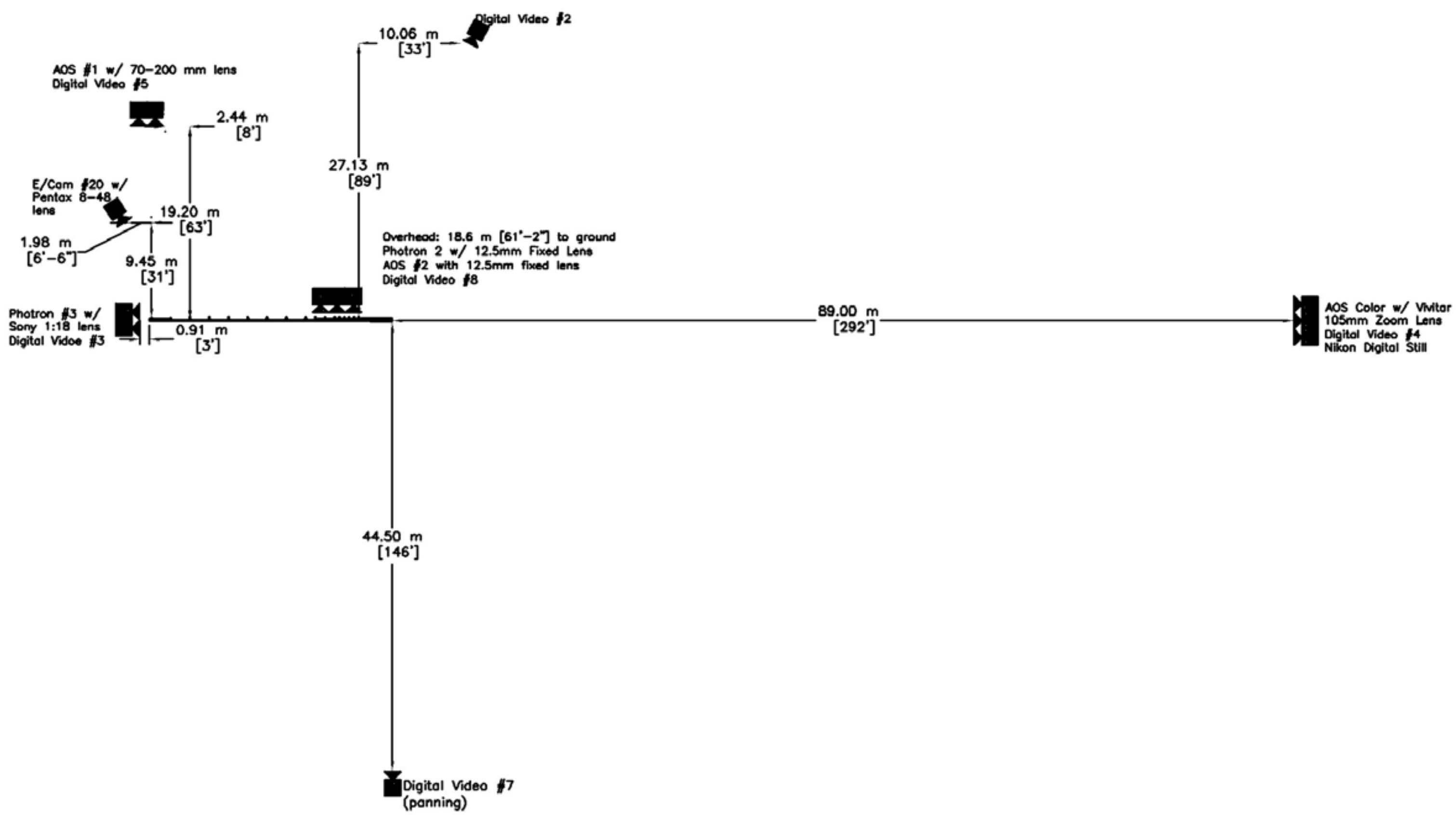


Figure 4. Location of High-Speed Cameras, Test 2214T-1

4 DESIGN DETAILS

The 24.59-m (80.67-ft) long test installation, as shown in Figure 5, consisted of seven major structural components: (1) a 3.66-m (12-ft) long New Jersey safety shape end section; (2) a 4.57-m (15-ft) long x 102-mm (4-in.) high x 178-mm (7-in.) wide lip curb; (3) a 813-mm (32-in.) long steel thrie beam to New Jersey safety shape connector plate (NJ connector plate); (4) a thrie beam terminal connector; (5) 3,810 mm (12 ft - 6 in.) of nested 2.66-mm (12-gauge) thick thrie beam guardrail; (6) a 1,905-mm (6-ft 3-in.) long, 2.66-mm (12-gauge) thick W-beam to thrie beam transition section; and (7) 15.24 m (50 ft) of standard 2.66-mm (12-gauge) thick W-beam guardrail attached to a simulated anchorage device. Design details are shown in Figures 5 through 19. The corresponding English-unit drawings are shown in Appendix A. Photographs of the test installation are shown in Figures 20 through 24.

A NJ connector plate connected the thrie beam rail to the New Jersey safety shape end section, as shown in Figures 5, 20, and 21. The NJ connector plate was fabricated with 4.76-mm and 6.35-mm (3/16-in. and 1/4-in.) thick ASTM A36 steel. External dimensions of the connector plate were 813 mm (32 in.) long by 533 mm (21 in.) deep. A long, sloped section was placed on the end of the connector plate to eliminate any potential for vehicle snagging which may result from a "reverse hit" impact. Five 22-mm (7/8-in.) diameter by 305-mm (12-in.) long ASTM A325 bolts connected the NJ connector plate to the concrete safety shape.

The entire system was constructed with seventeen guardrail posts. Post nos. 3 through 17 were galvanized ASTM A36 steel W152x13.4 (W6x9) sections. Post nos. 3 through 10 measured 1,829 mm (6 ft) long, while post nos. 11 through 17 measured 1,981 mm (6 ft - 6 in.) long. Post nos. 1 and 2 were timber posts measuring 140 mm wide x 190 mm deep x 1,080 mm long (5.5 in. x 7.5

in. x 42.5 in.) and were placed in 1,524-mm (5-ft) long steel foundation tubes with 457-mm wide x 610-mm long x 6-mm thick (18-in. x 24-in. x 0.25-in.) soil plates. The timber posts and foundation tubes were part of anchor systems designed to replicate the capacity of a tangent guardrail terminal.

Post nos. 1 through 9 were spaced 1,905 mm (75 in.) on center while post nos. 9 through 12 were spaced 953 mm (37.5 in.) on center, as shown in Figure 5. Post nos. 12 through 17 were spaced 476 mm (18.75 in.) on center. The spacing from post no. 17 to the New Jersey safety shape end section was 261 mm (10.25 in.). The soil embedment depth for post nos. 3 through 9, 10, and 11 through 17 were 1,114 mm (43.875 in.), 1,080 mm (42.5 in.), and 1,245 mm (49 in.), respectively. The posts were placed in a compacted coarse, crushed limestone material that met Grading B of AASHTO M147-65 (1990) as found in the Update to NCHRP Report No. 350.

For post nos. 3 through 9, 152-mm wide x 203-mm deep x 362-mm long (6-in. x 8-in. x 14.25-in.) wood spacer blockouts were used to block the rail away from the front face of the steel posts. For post no. 10, a 152-mm wide x 203-mm deep x 483-mm long (6-in. x 8-in. x 19-in.) wood spacer blockout was used to block the rail away from the front face of the steel post. For post nos. 11 through 17, a 102-mm wide x 178-mm deep x 445-mm long (4-in. x 7-in. x 17.5-in.) structural tube spacer blockout was used to block the thrie beam guardrail away from the steel posts.

Standard 2.66-mm (12-gauge) thick W-beam rails were placed between post nos. 1 and 9, as shown in Figure 5. The W-beam's top rail height was 689 mm (27.125 in.) with a 533-mm (21-in.) center mounting height. A standard 2.66-mm (12-gauge) thick W-beam to thrie beam transition section was placed between post nos. 9 and 11. Two nested 2.66-mm (12-gauge) thick thrie beam rails were placed between post no. 11 and the thrie beam connector attached to the end of the New Jersey safety shape barrier, as shown in Figure 5. The thrie beam's top rail height was

788 mm (31 in.) with a 533-mm (21-in.) center mounting height. All lap-splice connections between the rail sections were configured to reduce vehicle snag at the splice during the crash test.

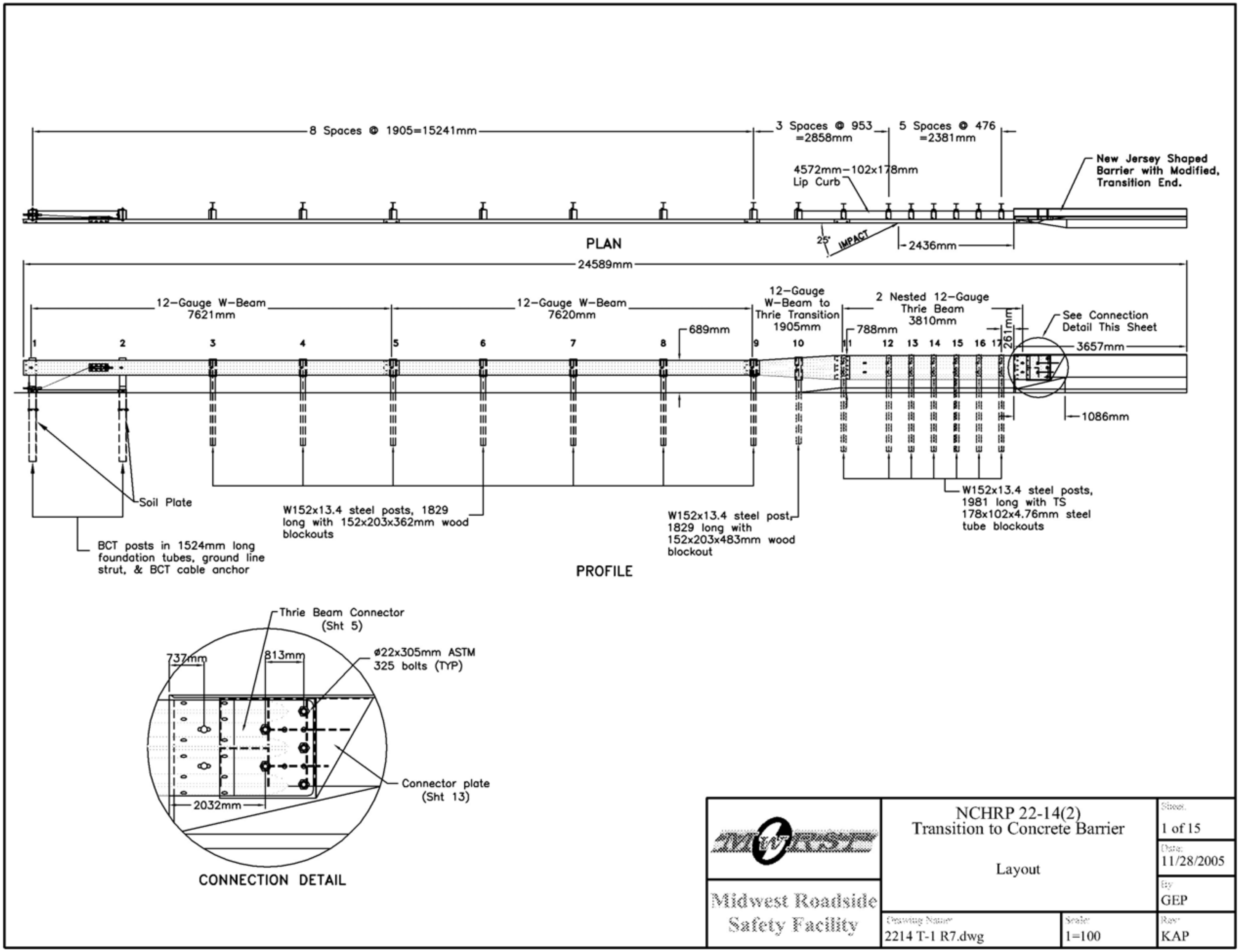


Figure 5. Layout of Approach Guardrail Transition to Concrete Barrier Design

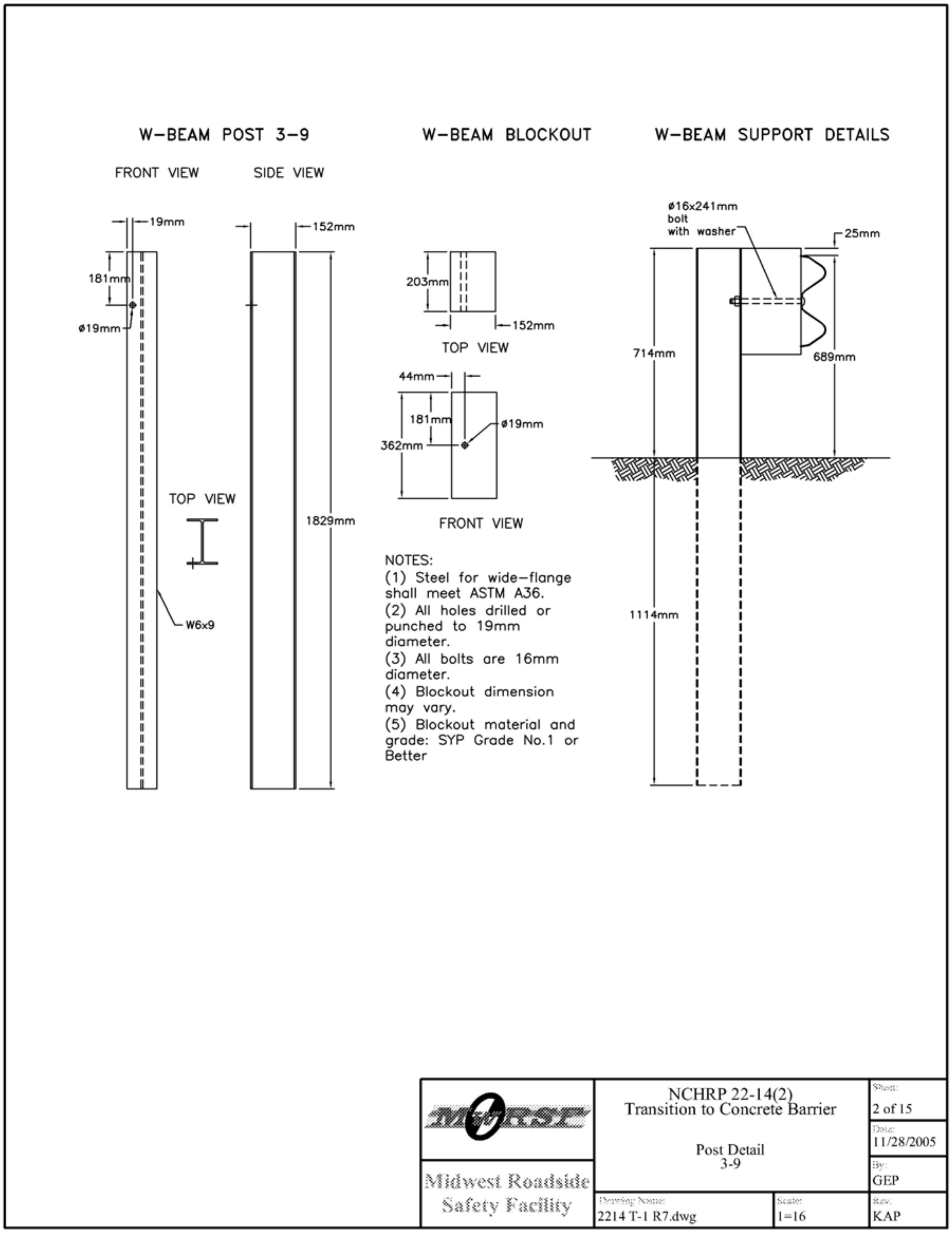


Figure 6. Approach Guardrail Transition to Concrete Barrier Design - Post Details

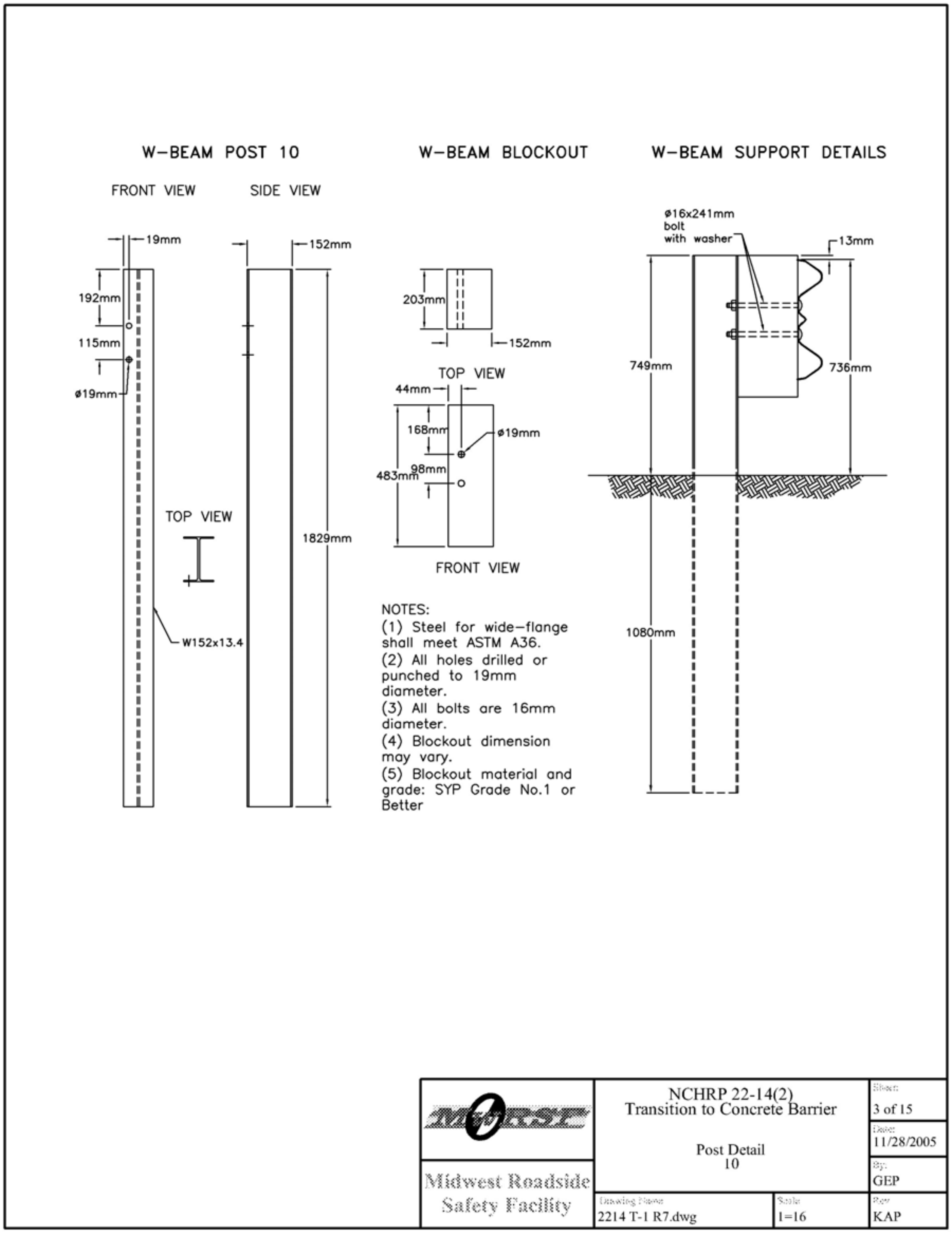


Figure 7. Approach Guardrail Transition to Concrete Barrier Design - Post Details

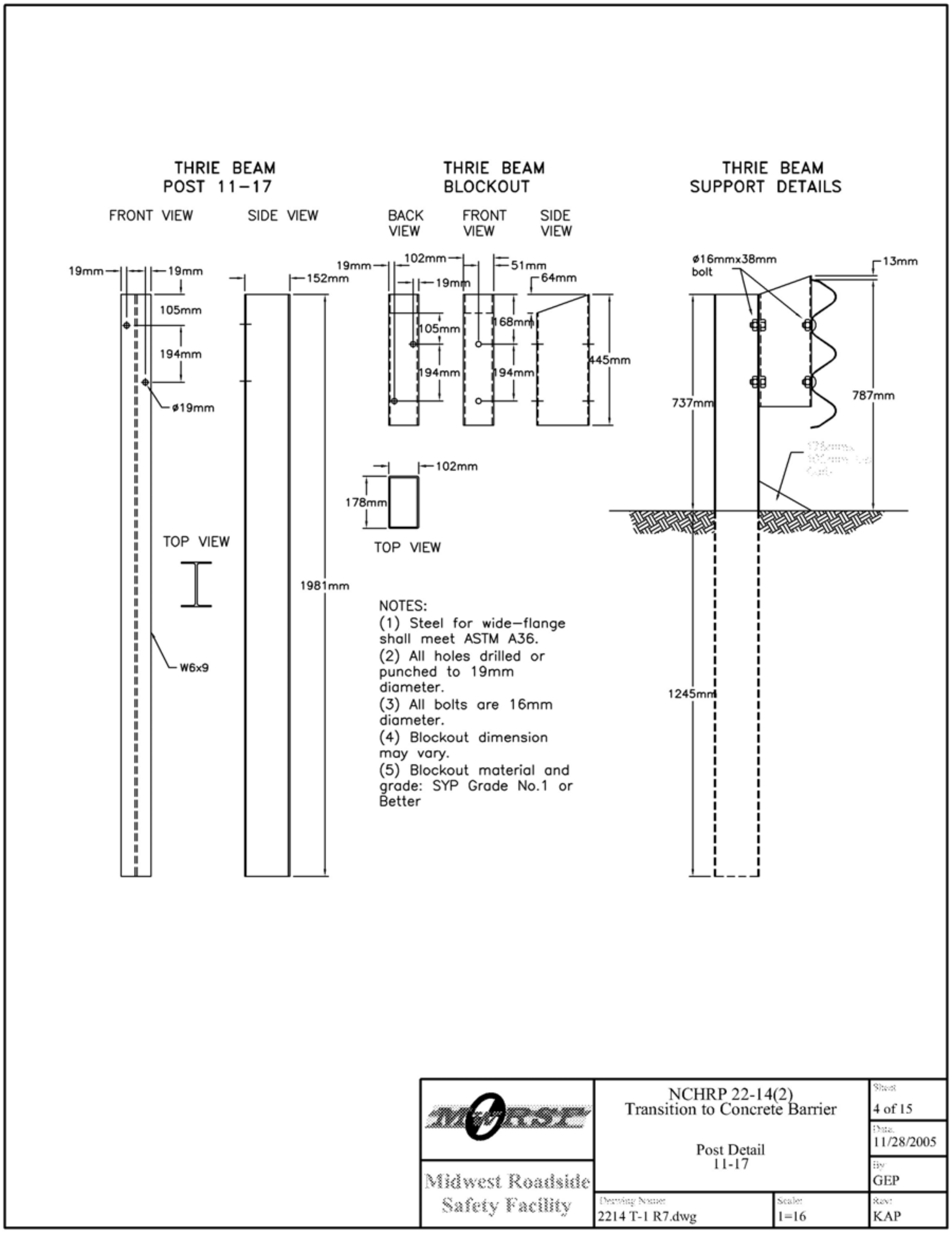


Figure 8. Approach Guardrail Transition to Concrete Barrier Design - Post Details

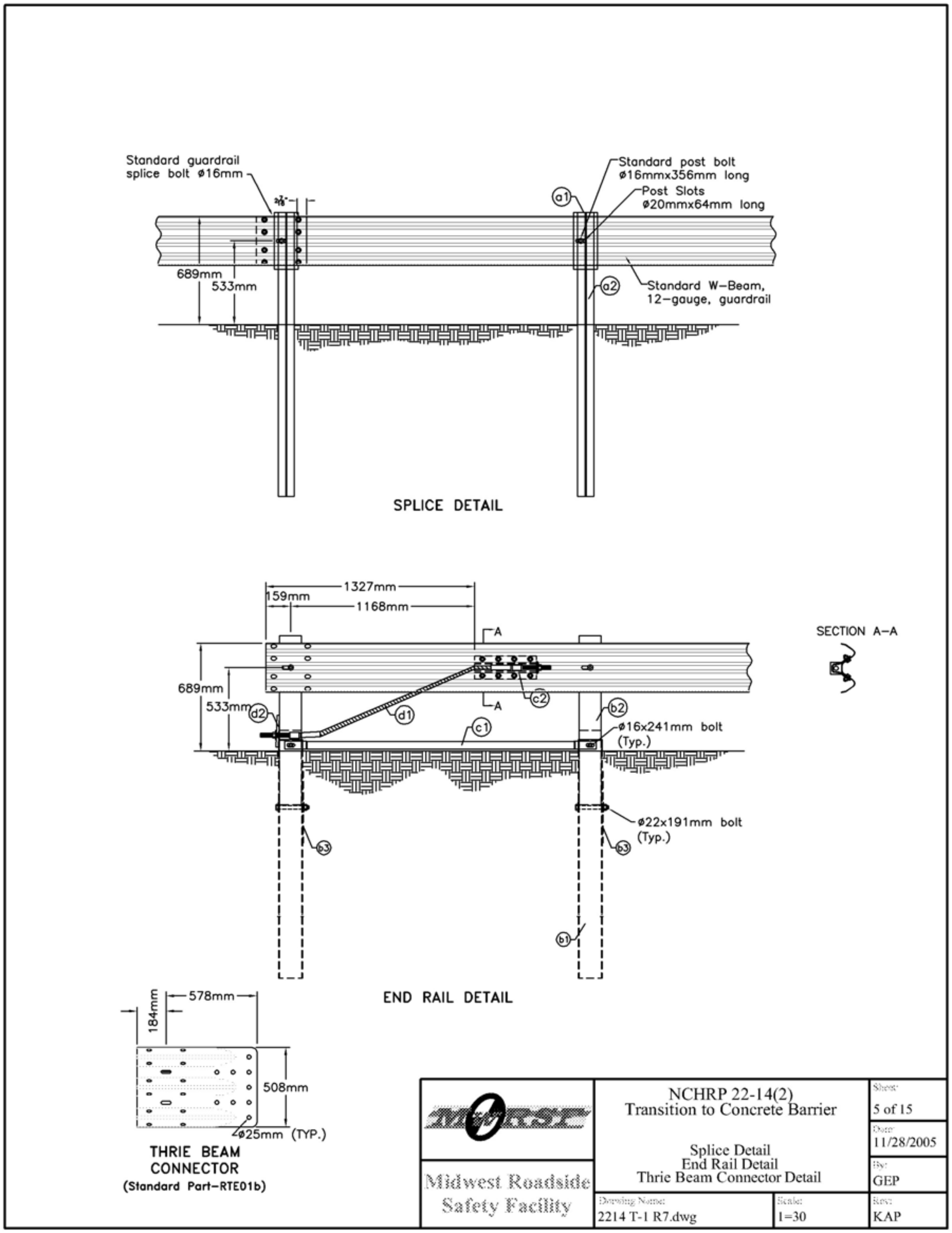


Figure 9. Approach Guardrail Transition to Concrete Barrier Design - Rail Details

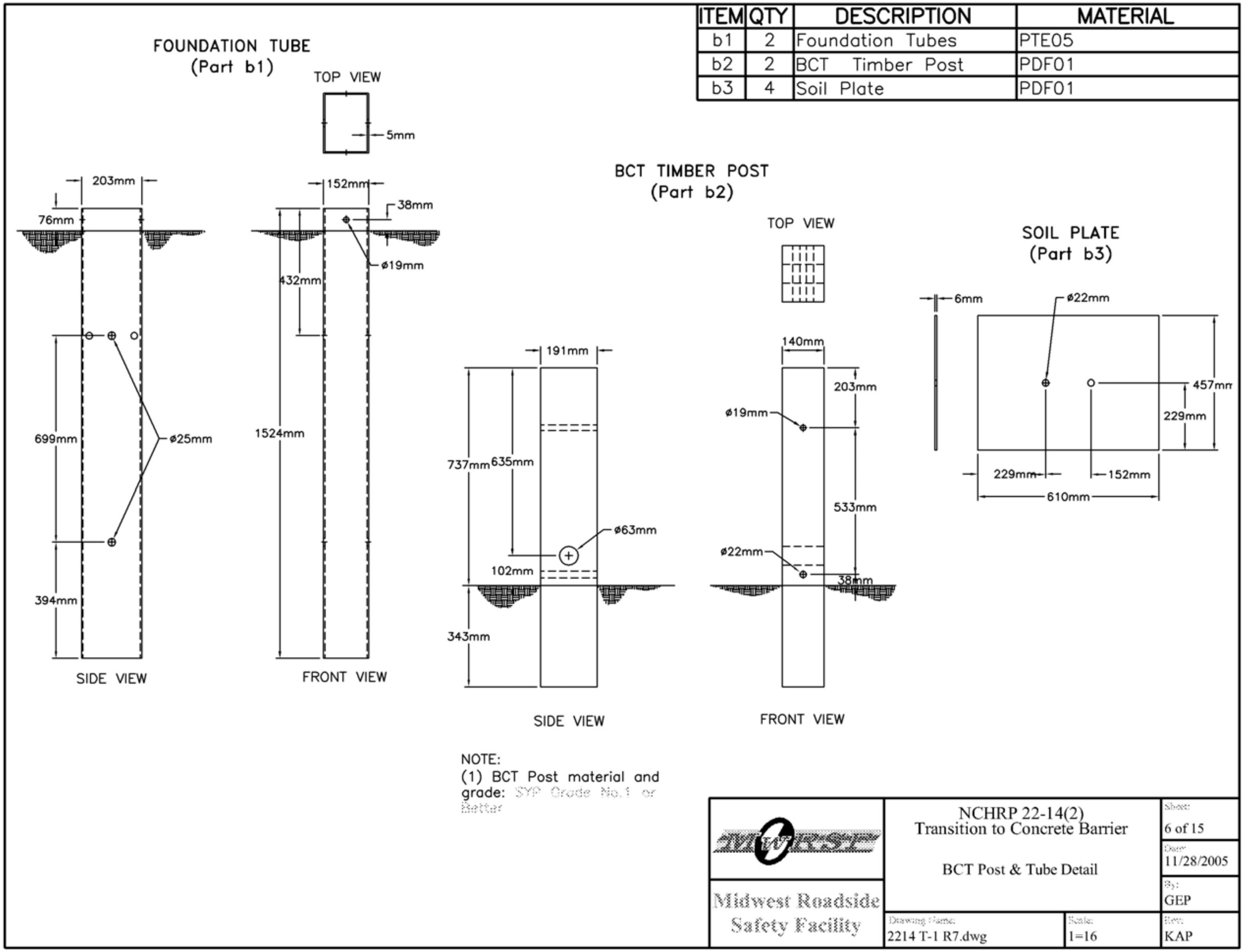


Figure 10. Approach Guardrail Transition to Concrete Barrier Design - Anchorage Details

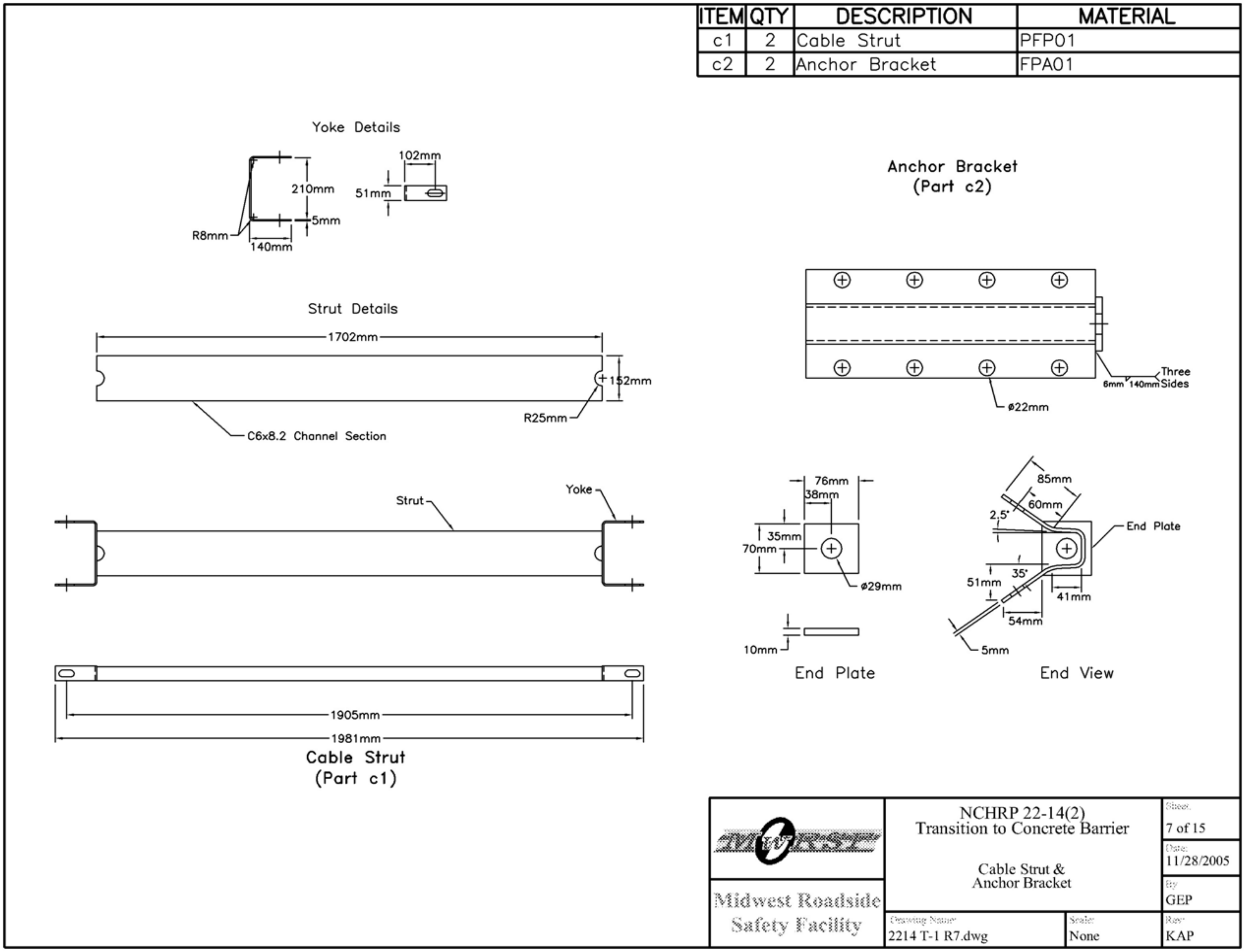


Figure 11. Approach Guardrail Transition to Concrete Barrier Design - Anchorage Details

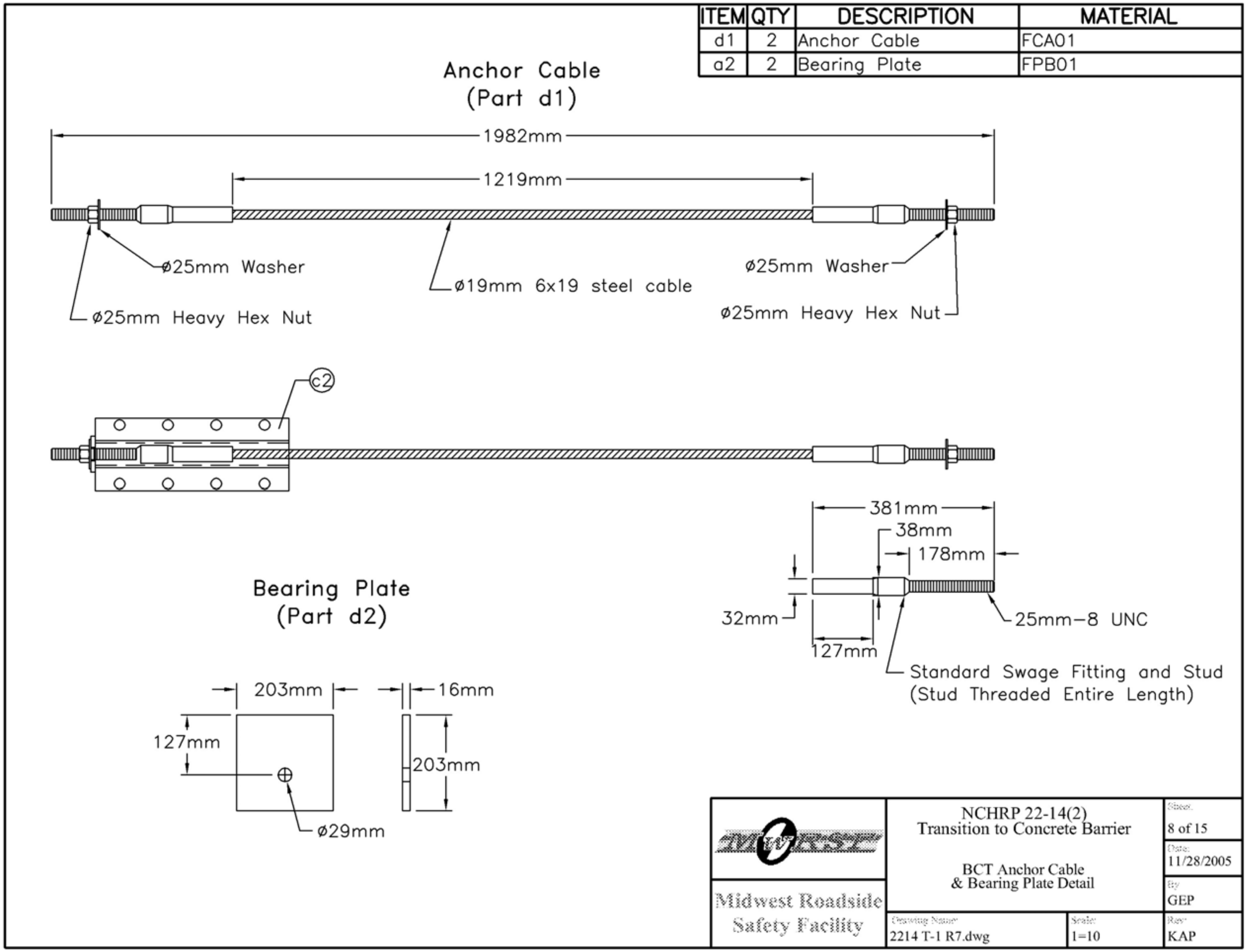


Figure 12. Approach Guardrail Transition to Concrete Barrier Design - Anchorage Details

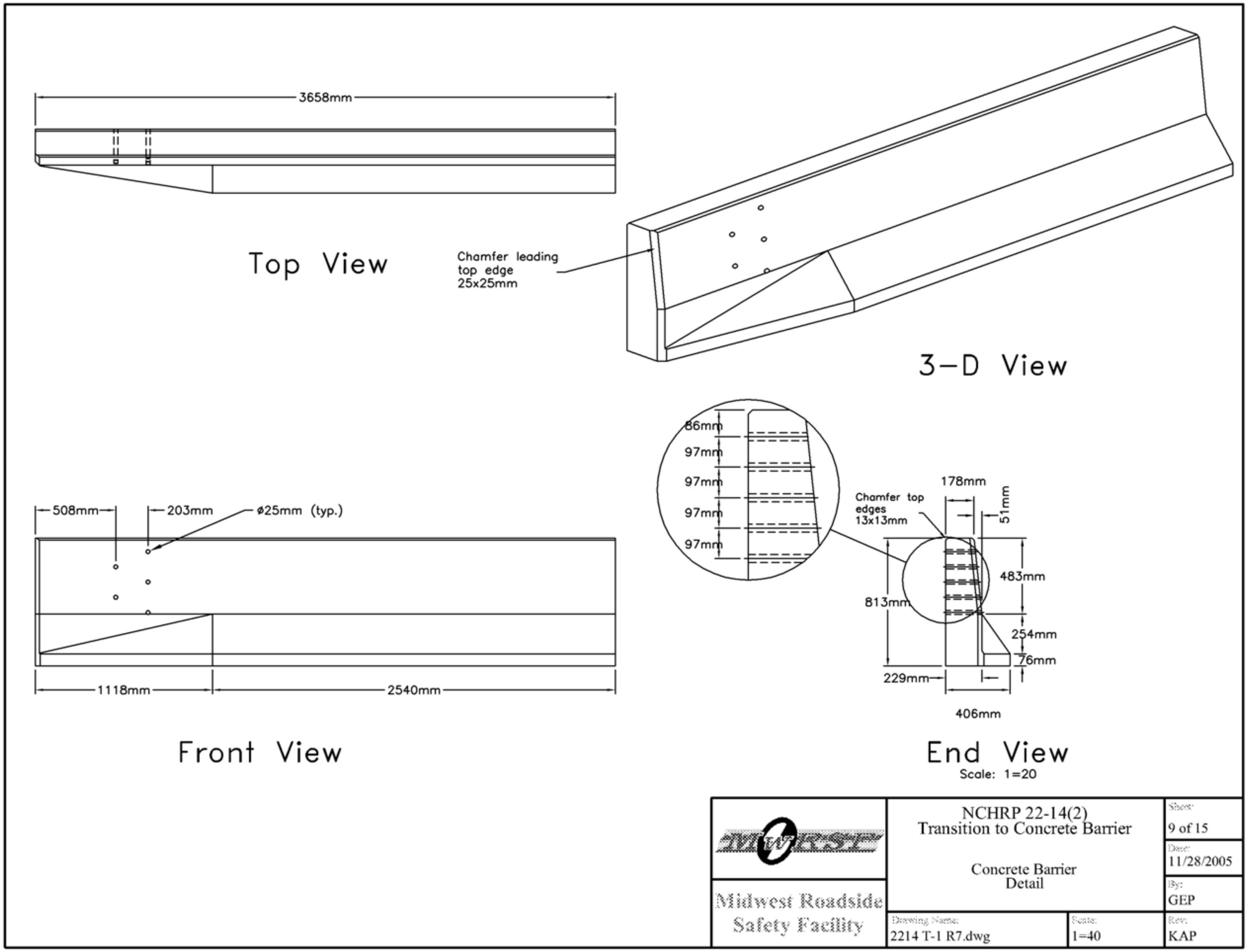


Figure 13. Approach Guardrail Transition to Concrete Barrier Design - Concrete Barrier Details

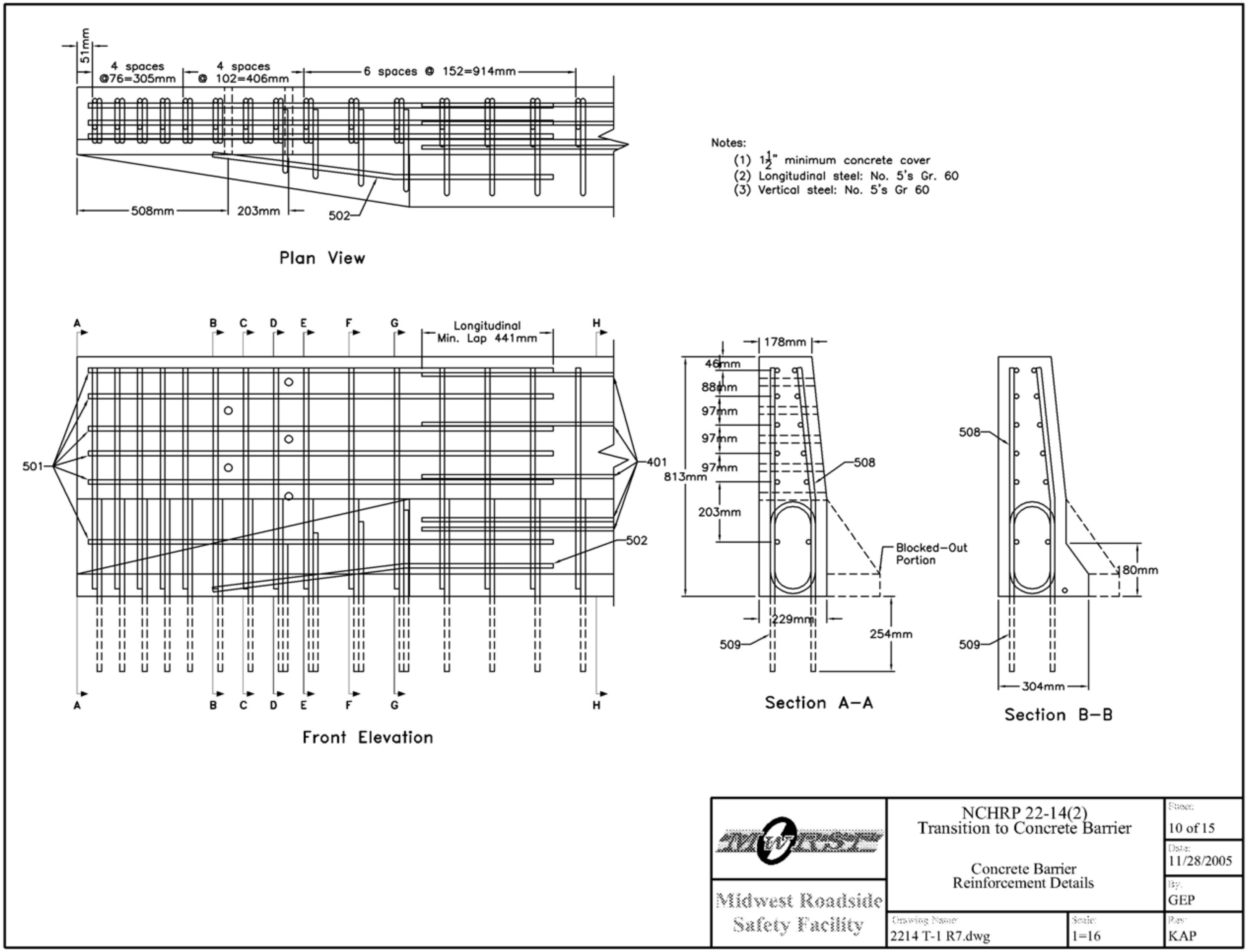


Figure 14. Approach Guardrail Transition to Concrete Barrier Design - Reinforcement Details

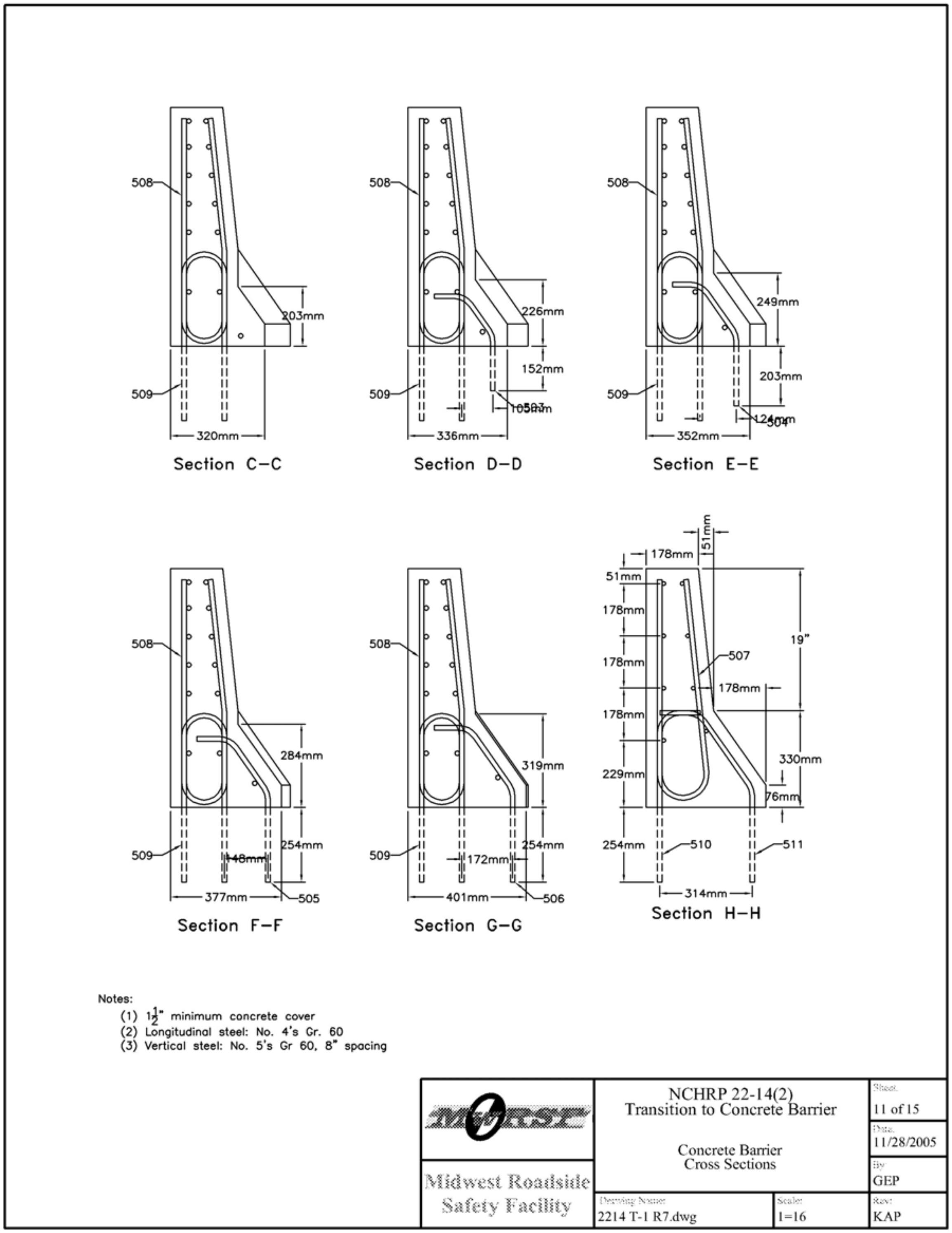
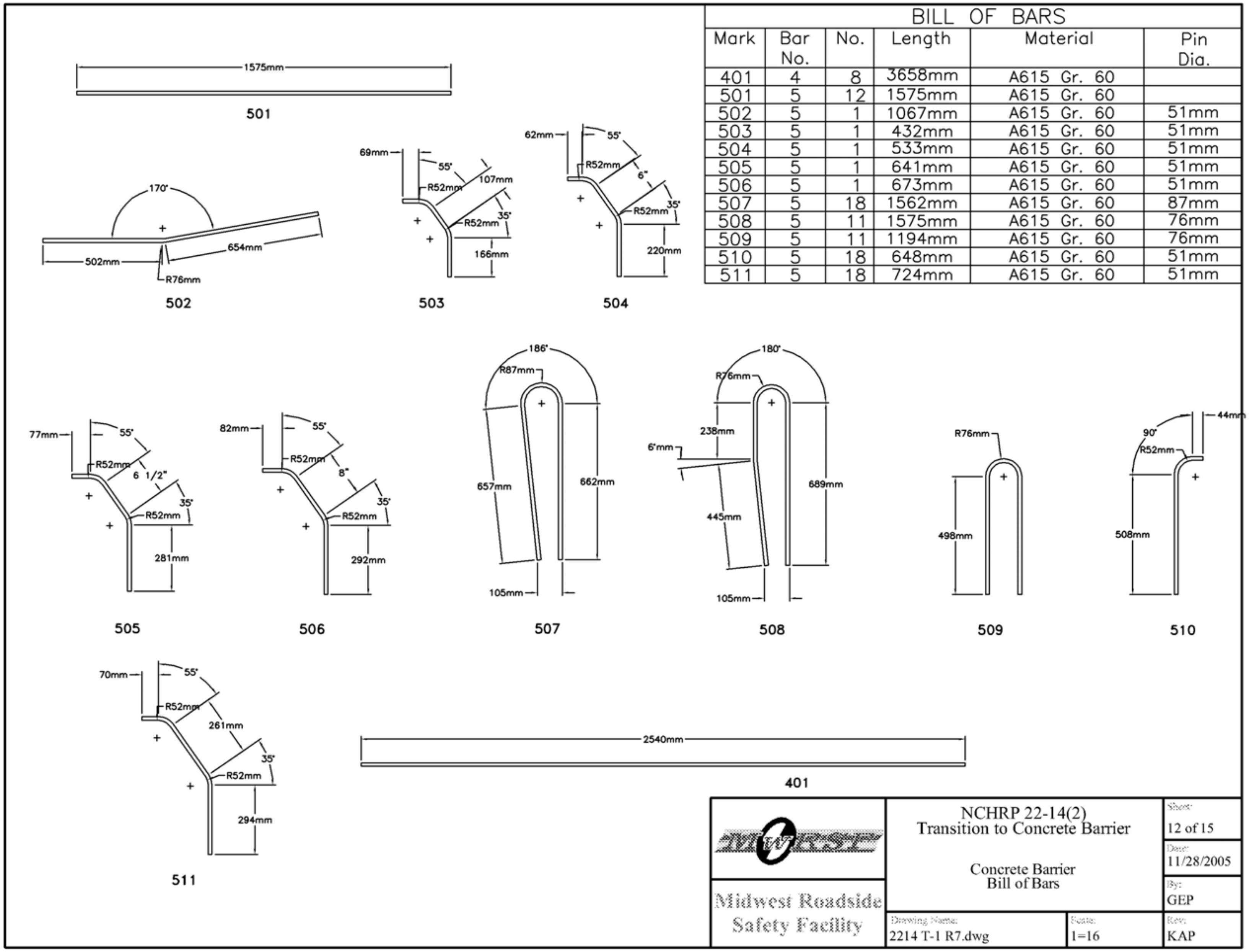


Figure 15. Approach Guardrail Transition to Concrete Barrier - Cross Section Details



BILL OF BARS

Mark	Bar No.	No.	Length	Material	Pin Dia.
401	4	8	3658mm	A615 Gr. 60	
501	5	12	1575mm	A615 Gr. 60	
502	5	1	1067mm	A615 Gr. 60	51mm
503	5	1	432mm	A615 Gr. 60	51mm
504	5	1	533mm	A615 Gr. 60	51mm
505	5	1	641mm	A615 Gr. 60	51mm
506	5	1	673mm	A615 Gr. 60	51mm
507	5	18	1562mm	A615 Gr. 60	87mm
508	5	11	1575mm	A615 Gr. 60	76mm
509	5	11	1194mm	A615 Gr. 60	76mm
510	5	18	648mm	A615 Gr. 60	51mm
511	5	18	724mm	A615 Gr. 60	51mm

Figure 16. Approach Guardrail Transition to Concrete Barrier Design - Bill of Bars

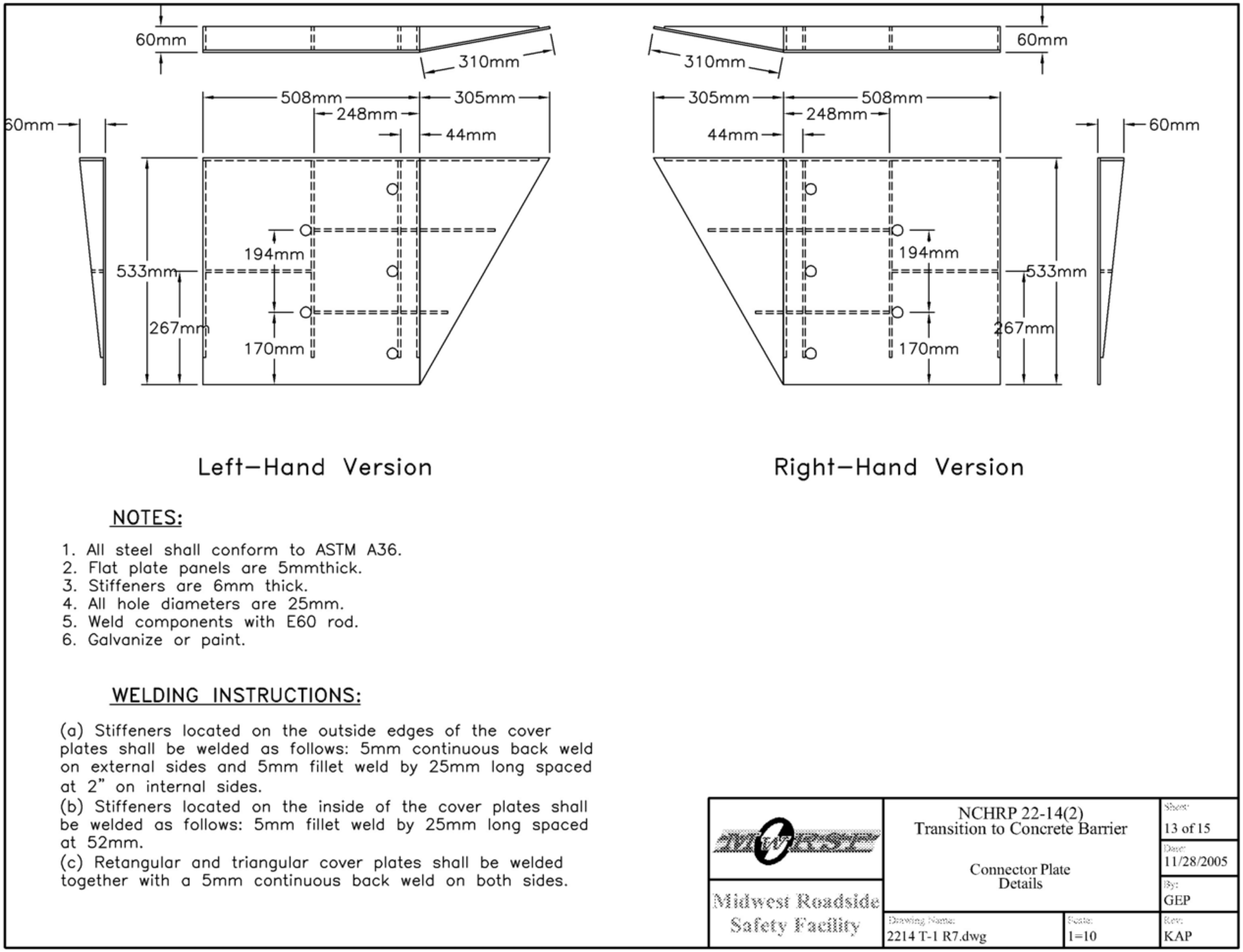
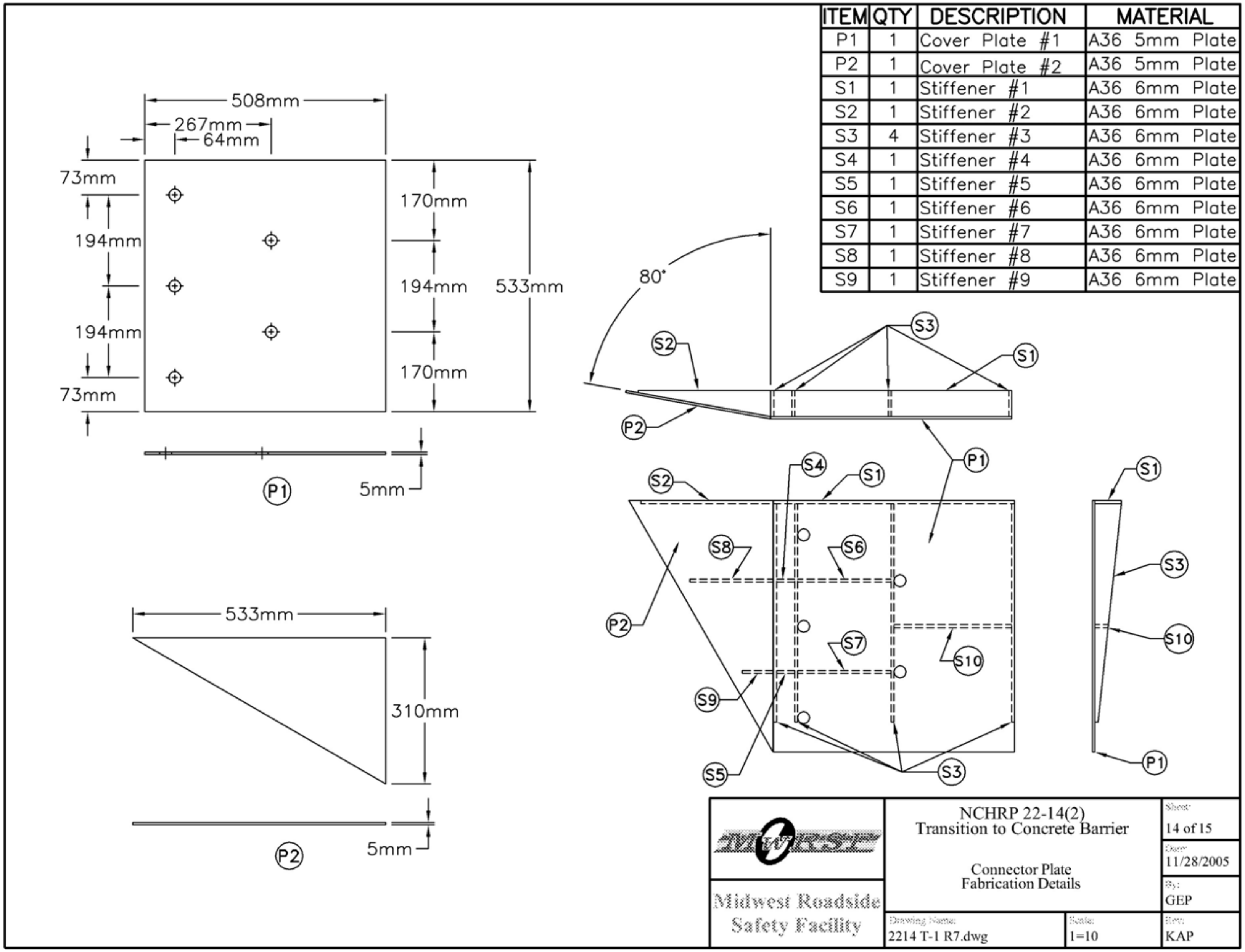


Figure 17. Approach Guardrail Transition to Concrete Barrier Design - Connector Plate Details



ITEM	QTY	DESCRIPTION	MATERIAL
P1	1	Cover Plate #1	A36 5mm Plate
P2	1	Cover Plate #2	A36 5mm Plate
S1	1	Stiffener #1	A36 6mm Plate
S2	1	Stiffener #2	A36 6mm Plate
S3	4	Stiffener #3	A36 6mm Plate
S4	1	Stiffener #4	A36 6mm Plate
S5	1	Stiffener #5	A36 6mm Plate
S6	1	Stiffener #6	A36 6mm Plate
S7	1	Stiffener #7	A36 6mm Plate
S8	1	Stiffener #8	A36 6mm Plate
S9	1	Stiffener #9	A36 6mm Plate

Figure 18. Approach Guardrail Transition to Concrete Barrier Design - Connector Plate Details

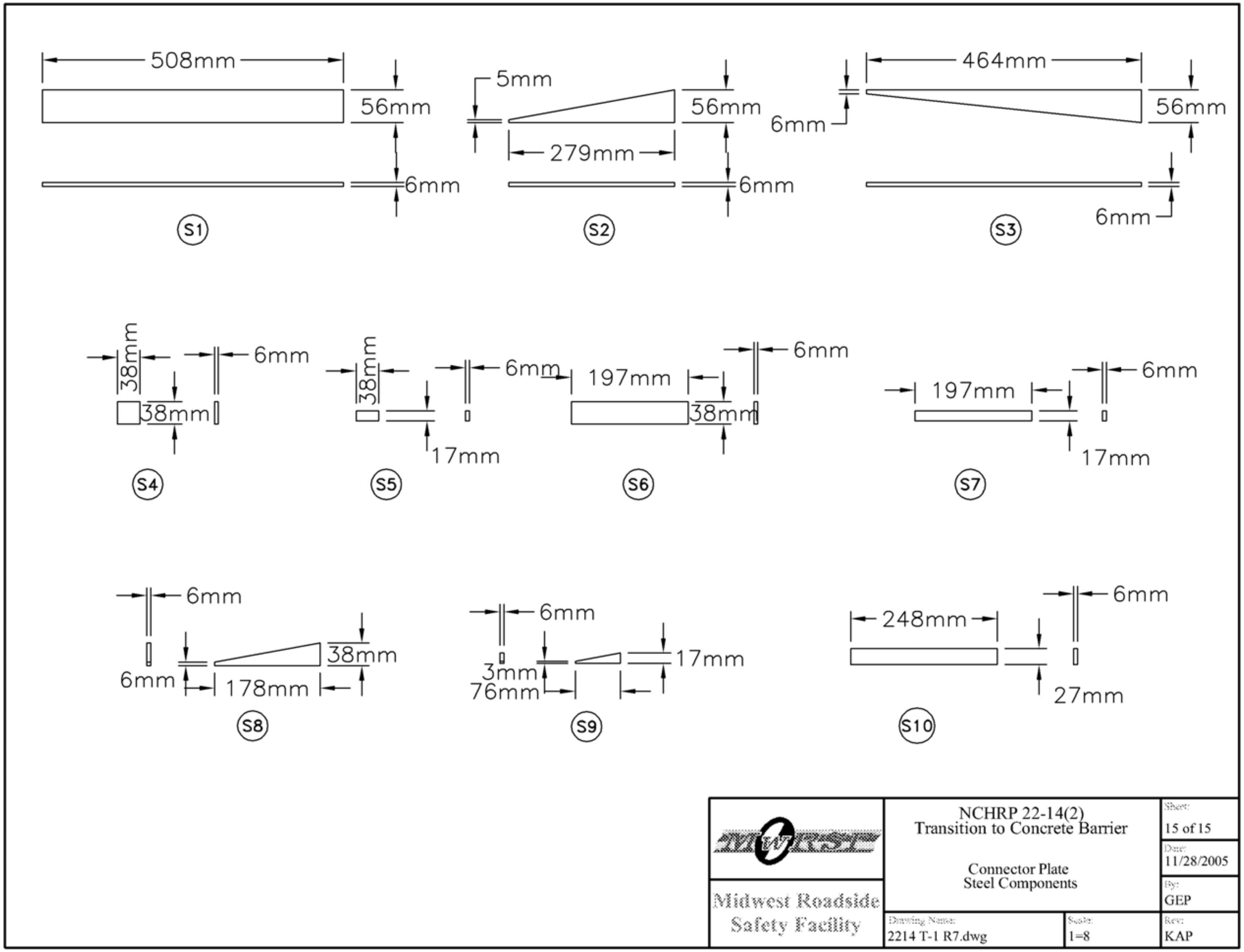


Figure 19. Approach Guardrail Transition to Concrete Barrier Design - Connector Plate Details

Figure 20. Approach Guardrail Transition to Concrete Barrier System

Figure 21. Approach Guardrail Transition to Concrete Barrier System

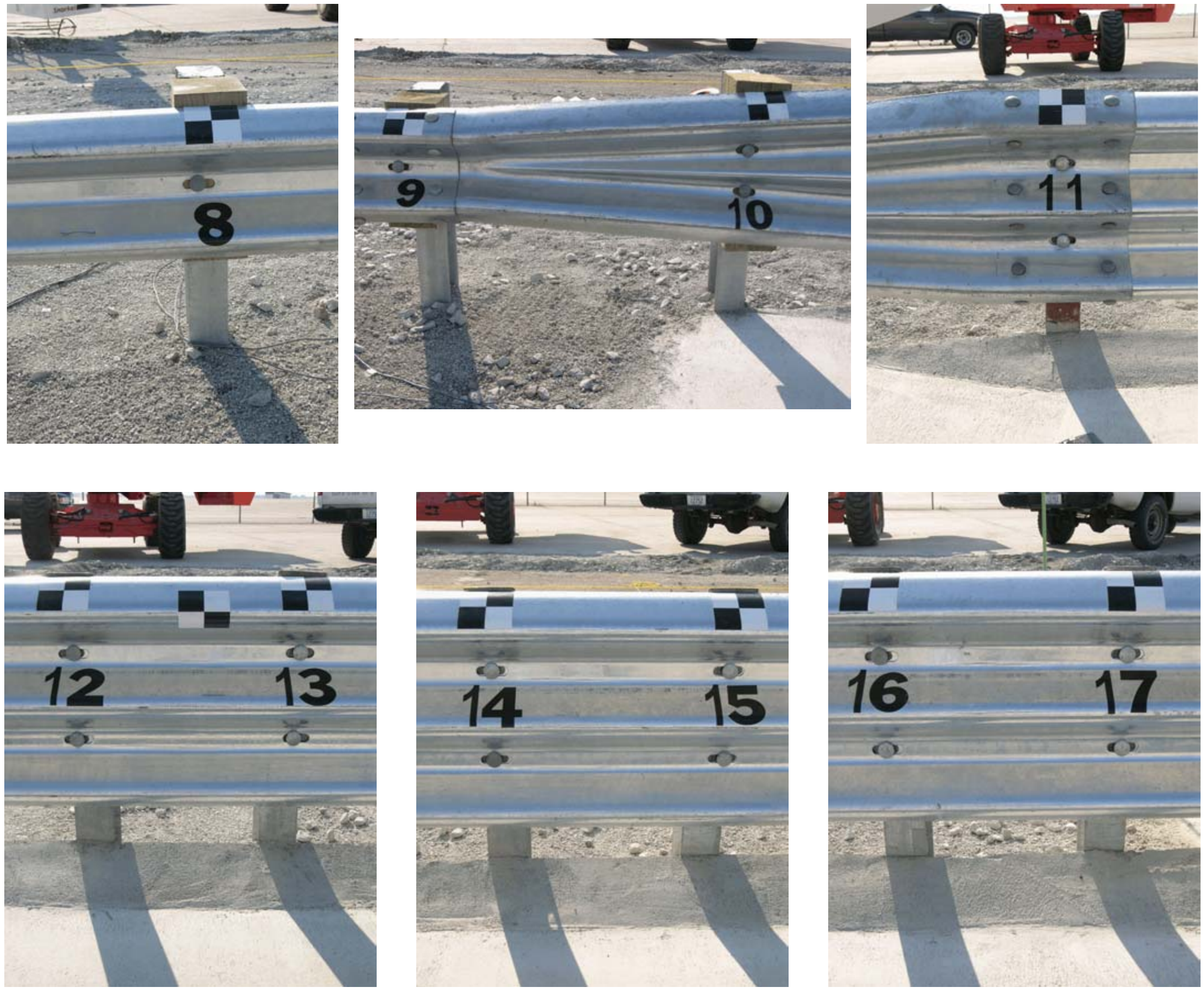


Figure 22. Approach Guardrail Transition to Concrete Barrier System

Figure 23. Approach Guardrail Transition to Concrete Barrier System

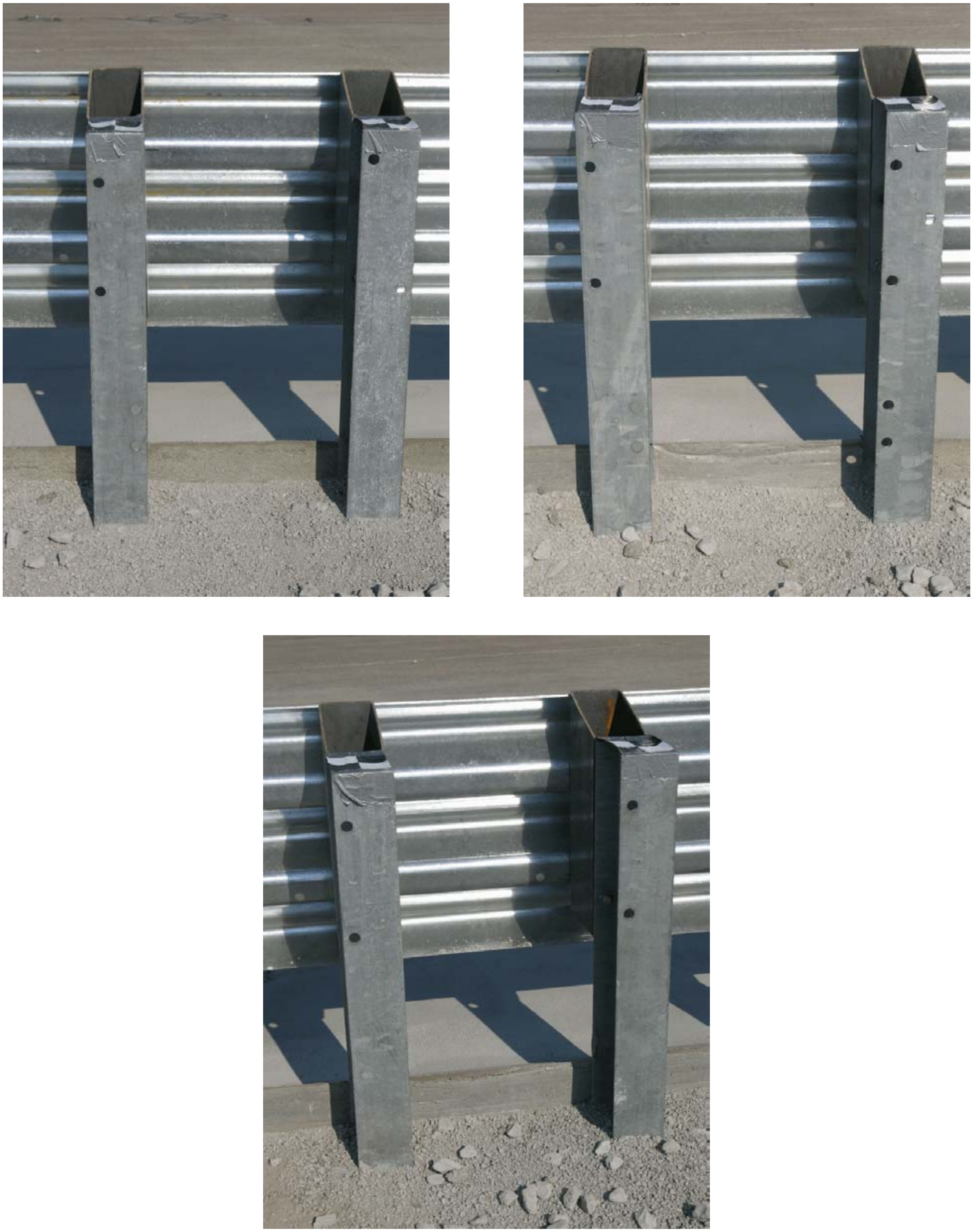


Figure 24. Approach Guardrail Transition to Concrete Barrier System

5 CRASH TEST

5.1 Test 2214T-1

The 2,306-kg (5,083-lb) pickup truck impacted the approach guardrail transition to concrete barrier system at a speed of 97.0 km/h (60.3 mph) and at an angle of 24.8 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 through 28. Documentary photographs of the crash test are shown in Figures 29 and 30.

5.2 Test Description

Initial vehicle impact was to occur between post nos. 12 and 13, or 2.44 m (7 ft - 11.875 in.) upstream from the upstream end of the concrete barrier, as shown in Figure 31. Actual vehicle impact occurred at the targeted impact. At 0.008 sec after initial impact, the left-front bumper contacted the thrie beam and began to deform. At 0.016 sec, the top of the impacted thrie beam deformed while the rail between post nos. 13 and 14 developed a slight buckle point. At this same time the left-front quarter panel deformed inward toward the engine compartment. At 0.024 sec, the hood protruded over the rail near the midspan between post nos. 13 and 14. At this same time, the left-front tire mounted the curb. At 0.032 sec, post nos. 11 through 16 rotated backward as the left-front quarter panel continued to deform. At 0.046 sec, the vehicle began to redirect while the rail near post no. 12 twisted slightly. At 0.056 sec, the protruding hood was positioned over post no. 16 as the rail continued to deform from the vehicle contact. At 0.076 sec, the front of the vehicle was positioned near the upstream end of the concrete barrier. At this same time, the left-front tire was in contact with the rail. At 0.088 sec, the hood extended over the top of the concrete barrier. At this same time, a gap between the hood and the right-quarter panel was apparent. At 0.100 sec, the top of the left-front door was ajar as the vehicle began to experience slight counter-clockwise (CCW) roll toward the system. At 0.120 sec, the right-front tire became airborne. At 0.148 sec, the grill was disengaged on the right side. At this same time, the left-front door was crushing in from contact with the system. At 0.180 sec, the entire left-side door was in contact with the system. At 0.212 sec after impact, the vehicle became parallel to the system with a resultant velocity of 64.4 km/h (40.0 mph). At 0.230 sec, the left rear of the vehicle contacted the system near post no. 12. At this same time, the vehicle continued to roll CCW. At 0.294 sec, the left-rear tire was in contact with the lower portion of the concrete barrier. At this same time, the front of the vehicle pitched downward. At 0.352 sec, the left-rear tire became airborne. At 0.376 sec, the vehicle exited the system at an angle of 7.5 degrees and a resultant velocity of 62.3 km/h (38.7 mph). At this same time, the CCW roll of the vehicle increased significantly. At 0.404 sec, the left-front tire had deformed to parallel with the ground and slid along the ground under the vehicle. At 0.532 sec, the left-front tire deflated as it was positioned under the vehicle. At 0.676 sec, the airborne tires began to descend back toward the ground. At 0.942 sec, the right-front and left-rear tires contact the ground. At 1.058 sec, the right-rear tire contacted the ground. The vehicle came to rest 54.71 m (179 ft - 6 in.) downstream from impact and 1.52 m (5 ft) laterally away from the traffic-side face of the guardrail system. The trajectory and final position of the pickup truck are shown in Figures 25 and 32.

5.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 33 through 35. Barrier damage consisted of contact marks on a guardrail section and deformed thrie beam rail. The length of vehicle contact along the thrie beam guardrail system was approximately 2.4 m (8 ft), which spanned from

206 mm (8.125 in.) downstream from the centerline of post no. 12 through the upstream end of the concrete barrier.

Minor deformation and flattening of the impacted section of thrie beam rail occurred between post nos. 12 and 17. Minor buckling in the lower portion of the rail was found between post nos. 16 and 17. Contact marks were found on the guardrail between post no. 12 and the end of the concrete barrier. The guardrail buckled slightly at the upstream end of the concrete barrier. The head of the second splice bolt from the bottom on the upstream side of the thrie beam connector fractured and was removed, as shown in Figure 35. Steel post nos. 12 through 17 rotated backward slightly, but otherwise remained undamaged. Minor black contact marks were found on the bottom toe of the concrete barrier.

The permanent set of the barrier system is shown in Figure 33. The maximum lateral permanent set rail and post deflections were 194 mm (7.625 in.) at the centerline of post no. 15 and 191 mm (7.5 in.) at the centerline of post no. 15, respectively, as measured in the field. The maximum lateral dynamic rail and post deflections were 289 mm (11.4 in.) at the centerline of post no. 15 and 251 mm (9.9 in.) at the centerline of post no. 15, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 552 mm (21.7 in.).

5.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 36 through 40. Occupant compartment deformations to the left side and front of the floorboard were judged insufficient to cause serious injury to the vehicle occupants. Maximum longitudinal deflections of 102 mm (4 in.) were located near the left-front corner of the left side of the floorboard. Maximum lateral deflections of 44 mm (1.75 in.) were located near the right-front corner of the left-side floorboard. Maximum vertical deflections of 44 mm (1.75 in.) were located near the left-front corner of the left side of the floorboard. Complete occupant compartment deformations and the corresponding locations are provided in Appendix C.

Damage was concentrated on the left-front corner of the vehicle. The left-front quarter panel was deformed inward and downward toward the engine compartment. The left side of the front bumper was flattened and bent back toward the engine compartment. Buckle points at the third points were found on the front bumper. The left-front door encountered deformations and sheet metal tears. The left-rear door encountered scratches and contact marks. The front of the vehicle shifted toward the right while the hood remained in place. The box was dented and deformed along the entire left side. The grill and plastic around the left-side headlight was fractured and removed. The left-front plastic wheel well protection disengaged. The right side of the rear bumper was dented. The tail gate was misaligned. The left side of the frame was bent inward. The drive shaft encountered a dent in the housing. The left-front wheel assembly deformed and crushed inward toward the engine compartment. The left-side tire bearing and ball joint were fractured. The left-side sway bar and control arm connection was bent. The left-front tire disengaged from the rest of the wheel assembly. All hydraulic lines for the left-front wheel were sheared off. The left-rear rim, hub, and tire encountered scratch and scuff marks, and the rim was dented. The exhaust pipe and mount were dented and deformed. The front engine mount was fractured. The windshield encountered cracking in a radial pattern beginning at the lower center of the windshield. All other window glass remained undamaged.

5.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be -7.45 m/s

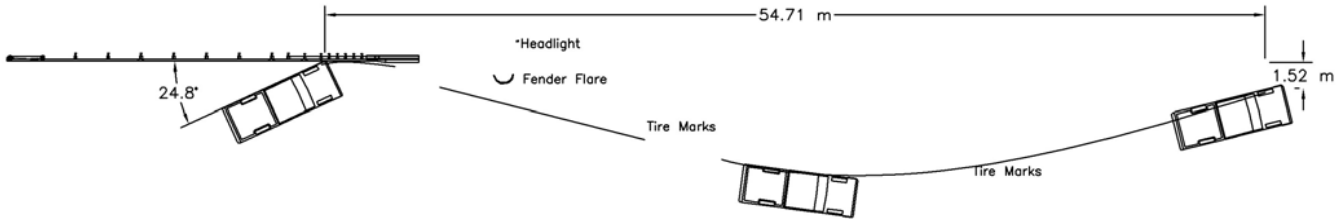
(-24.43 ft/s) and -7.61 m/s (-24.96 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were -12.72 Gs and -8.71 Gs, respectively. It is noted that the occupant impact velocities (OIVs) and occupant ridedown decelerations (ORDs) were within the suggested limits provided in NCHRP Report No. 350. The THIV and PHD values were determined to be 10.07 m/s (33.04 ft/s) and 14.27 Gs, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 25. Results are shown graphically in Appendix D. The results from the rate transducer are shown graphically in Appendix D.

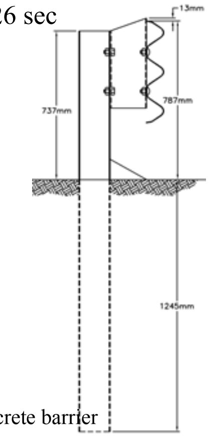
5.6 Discussion

The analysis of the test results for test no. 2214T-1 showed that the approach guardrail transition to a concrete barrier system impacted with the 2270P vehicle of the Update to NCHRP Report No. 350 adequately contained and redirected the 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 revealed minimum intrusion into adjacent traffic lanes. In addition, the vehicle exited the barrier within the exit box. Therefore, test no. 2214T-1 conducted on the approach guardrail transition to a concrete barrier was determined to be acceptable according to the TL-3 safety performance criteria found in the Update to NCHRP

Report No. 350.

0.000 sec | 0.052 sec | 0.136 sec | 0.206 sec | 0.326 sec





- Test Agency . . . . MwRSF
- Test Number 2214T-1
- Date 6/22/05
- NCHRP 350 Update Test Designation 3-21
- Appurtenance . . . . Approach Guardrail Transition to a New Jersey Safety Shape End Section with Curb
- Total Length . . . . 24.59 m
- Key Elements - Steel Thrie Beam (nested)
  - Thickness . . . . 2.66 mm
  - Top Mounting Height . . . . 787 mm
- Key Elements - Steel Posts
  - Post Nos. 3 - 10 . . . . W152 x 13.4 by 1,829 mm long
  - Post Nos. 11 - 17 . . . . W152 x 13.4 by 1,981 mm long
- Key Elements - Post Spacing
  - Post Nos. 3 - 9 . . . . 1,905 mm
  - Post Nos. 9 - 12 . . . . 953 mm
  - Post Nos. 12 - 17 . . . . 476 mm
- Key Elements - Wood Spacer Blocks
  - Post Nos. 3 - 9 . . . . 152 mm x 203 mm by 362 mm long
  - Post No. 10 . . . . 152 mm x 203 mm by 483 mm long
- Key Elements - Steel Spacer Blocks
  - Post Nos. 11 - 17 . . . . TS 178 x 102 x 4.76 by 445 mm long
- Key Element - Curb . . . . 178 mm x 102 mm Lip Curb
- Type of Soil . . . . Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model . . . . 2002 Chevrolet C1500HD Crew Cab Pickup
  - Curb . . . . 2,522 kg
  - Test Inertial . . . . 2,306 kg
  - Gross Static . . . . 2,306 kg
- Impact Conditions
  - Speed . . . . 97.0 km/h
  - Angle . . . . 24.8 degrees
  - Impact Location . . . . 2.44 m upstream of concrete barrier
- Exit Conditions
  - Speed . . . . 62.3 km/h
  - Angle . . . . 7.5 degrees
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 54.71 m downstream
1.52 m traffic-side face
- Occupant Impact Velocity (350 Update)
  - Longitudinal . . . . -7.45 m/s < 12 m/s
  - Lateral . . . . -7.61 m/s < 12 m/s
- Occupant Ridedown Deceleration (350 Update)
  - Longitudinal . . . . -12.72 Gs < 20 Gs
  - Lateral . . . . -8.71 Gs < 20 Gs
- THIV (not required) . . . . 10.07 m/s
- PHD (not required) . . . . 14.27 Gs
- Test Article Damage . . . . Minimal
- Test Article Deflections
  - Permanent Set . . . . 194 mm
  - Dynamic . . . . 289 mm
  - Working Width . . . . 552 mm
- Vehicle Damage . . . . Moderate
  - VDS[5] 11-LFQ-5
  - CDC[6] 11-LYEW7
  - Maximum Deformation . . . . 102 mm at front floorpan

Figure 25. Summary of Test Results and Sequential Photographs, Test 2214T-1

0.000 sec

0.044 sec

0.100 sec

0.144 sec

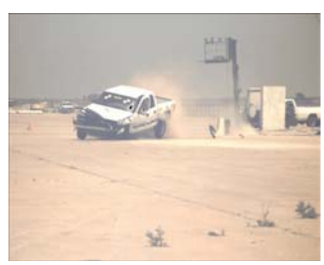
0.196 sec

0.294 sec

0.356 sec

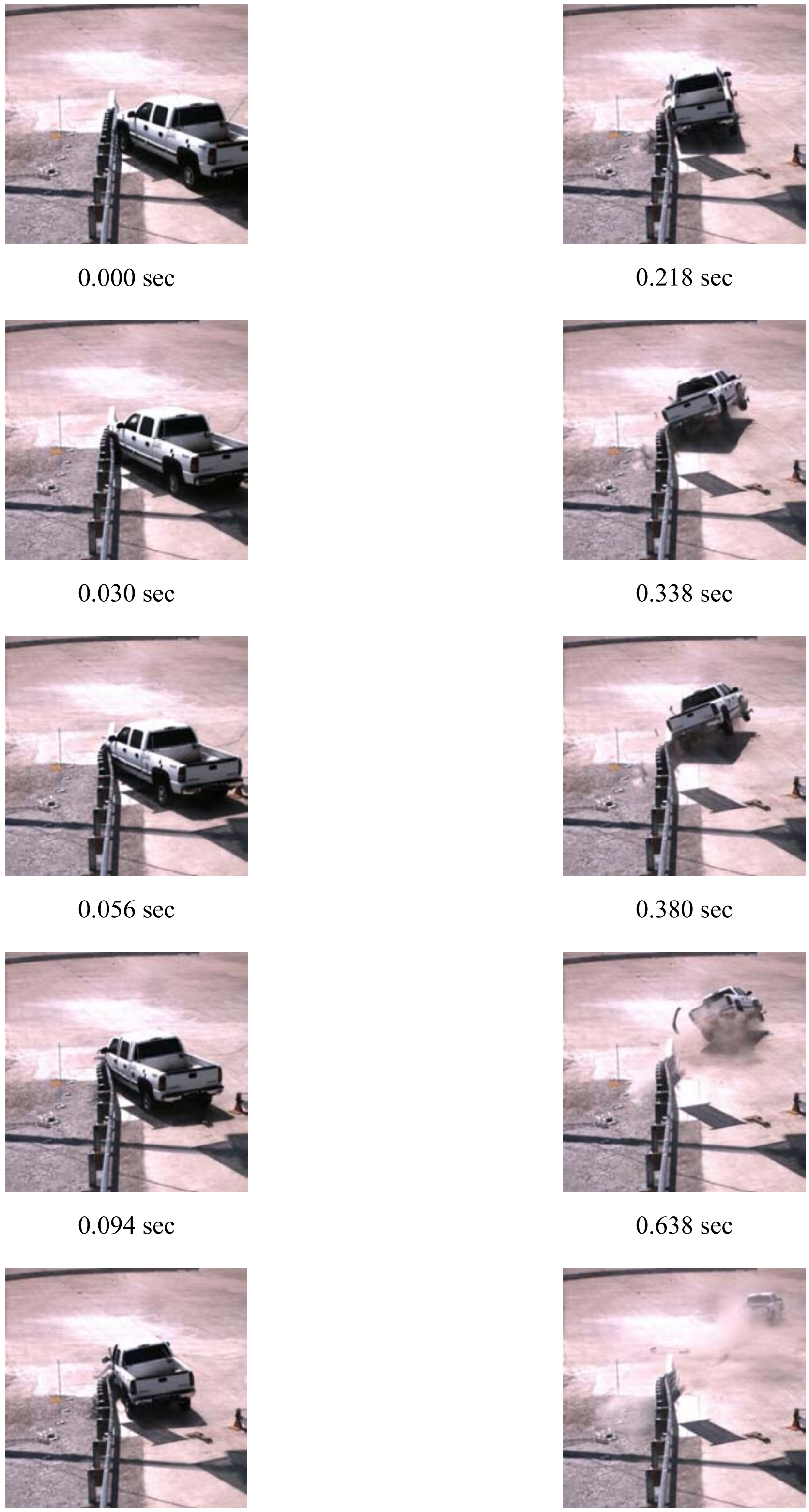
0.452 sec

0.676 sec



0.942 sec

Figure 26. Additional Sequential Photographs, Test 2214T-1



0.000 sec

0.030 sec

0.056 sec

0.094 sec

0.162 sec

0.218 sec

0.338 sec

0.380 sec

0.638 sec

1.408 sec

Figure 27. Additional Sequential Photographs, Test 2214T-1

0.000 sec

0.000 sec

0.028 sec

0.067 sec

0.044 sec

0.200 sec

0.060 sec

0.300 sec

0.082 sec

0.467 sec

Figure 28. Additional Sequential Photographs, Test 2214T-1

Figure 29. Documentary Photographs, Test 2214T-1

Figure 30. Documentary Photographs, Test 2214T-1

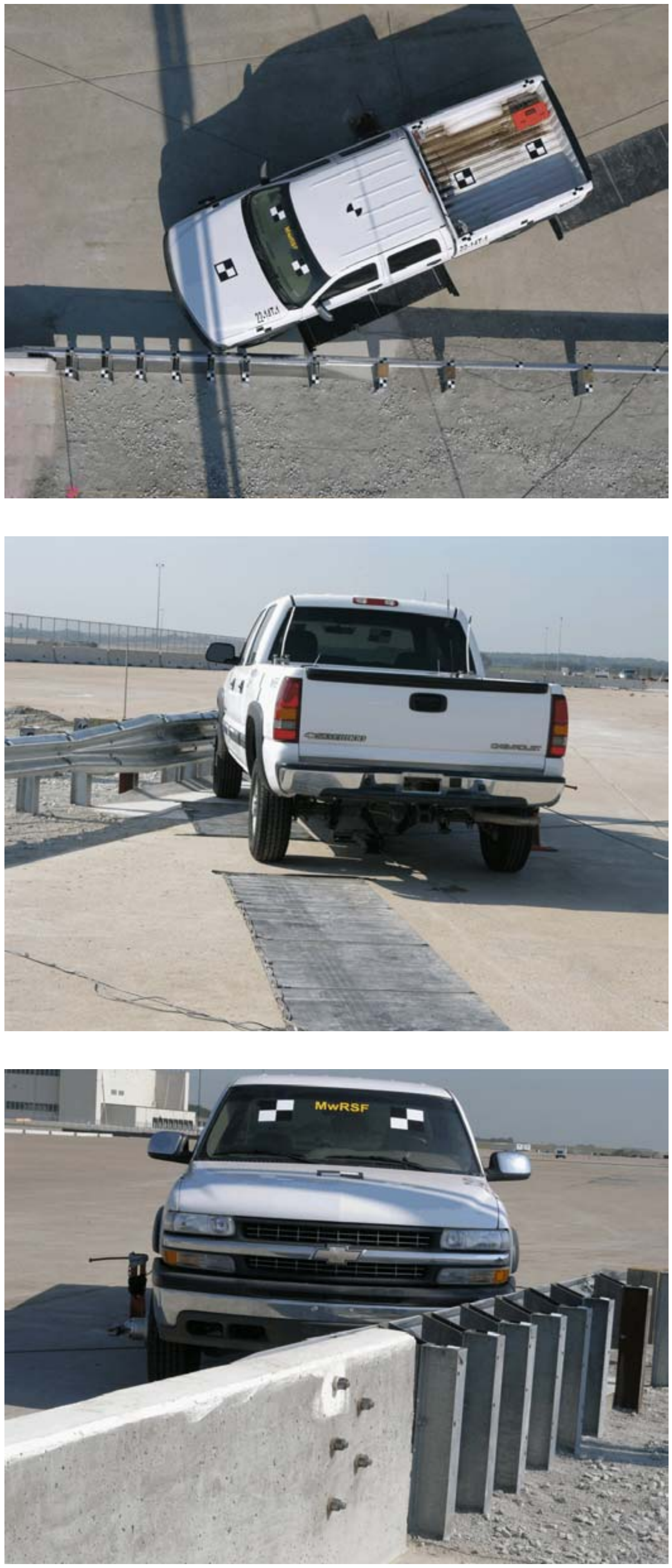


Figure 31. Impact Location, Test 2214T-1

Figure 32. Vehicle Final Position and Trajectory Marks, Test 2214T-1

Figure 33. Approach Guardrail Transition System Damage, Test 2214T-1

Figure 34. Approach Guardrail Transition System Damage, Test 2214T-1

Figure 35. Concrete Barrier System Damage, Test 2214T-1

Figure 36. Vehicle Damage, Test 2214T-1

Figure 37. Vehicle Damage, Test 2214T-1

Figure 38. Vehicle Damage, Test 2214T-1

Figure 39. Vehicle Windshield Damage, Test 2214T-1

Figure 40. Vehicle Undercarriage Damage, Test 2214T-1

6 SUMMARY AND CONCLUSIONS

An approach guardrail transition to a concrete barrier system was constructed and full-scale vehicle crash tested. One full-scale vehicle crash test, using a pickup truck vehicle, was performed on the longitudinal barrier system and was determined to be acceptable according to the TL-3 safety performance criteria presented in the Update to NCHRP Report No. 350. A summary of the safety performance evaluation is provided in Table 3.

Table 3. Summary of Safety Performance Evaluation Results

Evaluation Factors	Evaluation Criteria		Test 2214T-1
Structural Adequacy	A.	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	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 should not exceed limits set forth in Section 5.3 and Appendix E of the Update to NCHRP Report No. 350.	S
	F.	The vehicle should remain upright during and after collision.	S
	H.	Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9.0 m/s (29.5 ft/s), or at least below the maximum allowable value of 12.0 m/s (39.4 ft/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 20.0 Gs.	S
Vehicle Trajectory	M.	After impact, the vehicle shall exit the barrier within the exit box.	S

S - Satisfactory
U - Unsatisfactory
NA - Not Available

7 REFERENCES

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

2. Sicking, D.L., Mak, K.K., and Rohde, J.R., *NCHRP Report No. 350 Update - Chapters 1 through 7, Draft Report*, Presented to the Transportation Research Board, Prepared by the Midwest Roadside Safety Facility, University of Nebraska-Lincoln, July 2005 [Privileged Document].

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

4. *Center of Gravity Test Code - SAE J874 March 1981*, SAE Handbook Vol. 4, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1986.

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

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

8 APPENDICES

APPENDIX A

English-Unit System Drawings

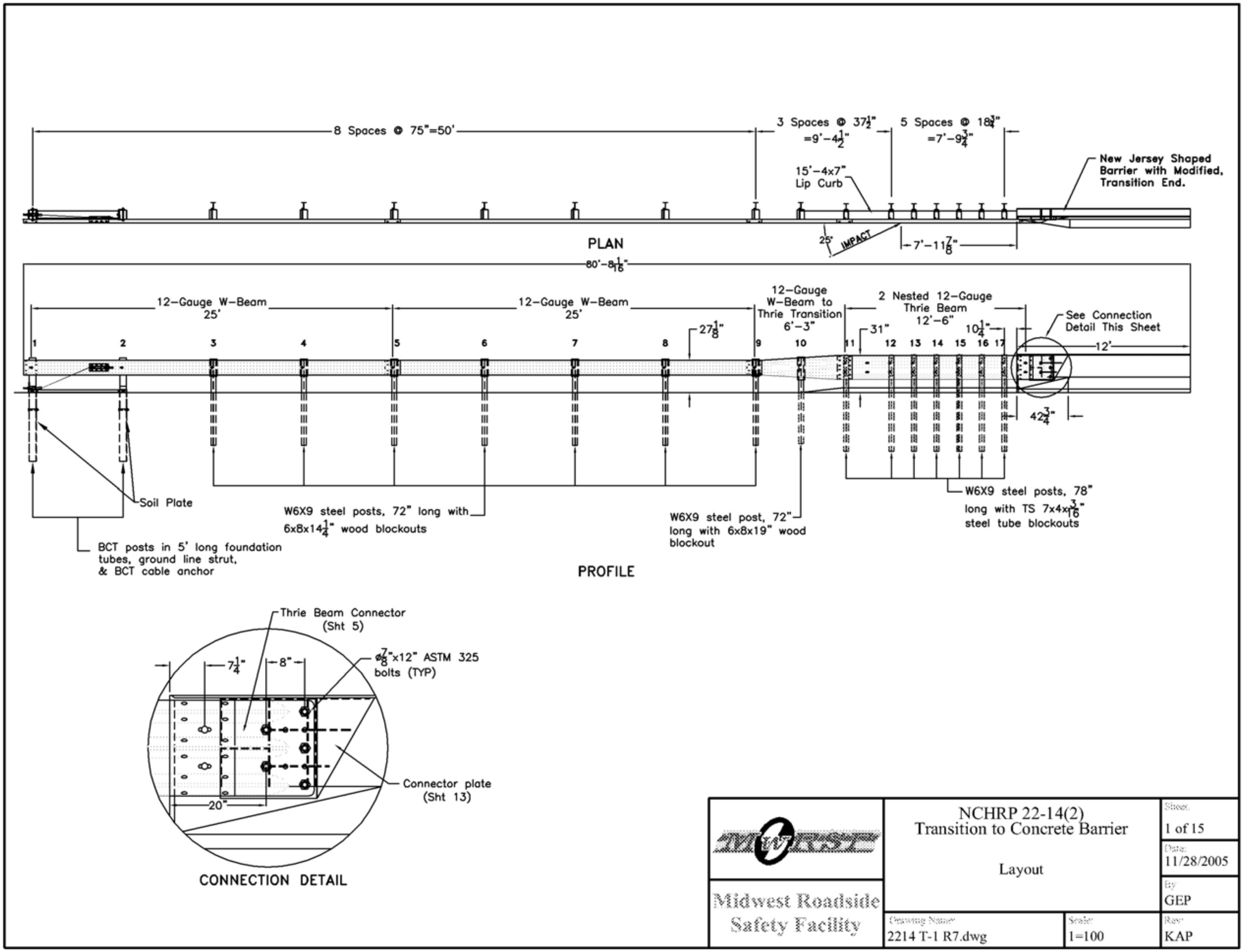


Figure A-1. Layout of Approach Guardrail Transition to Concrete Barrier (English)

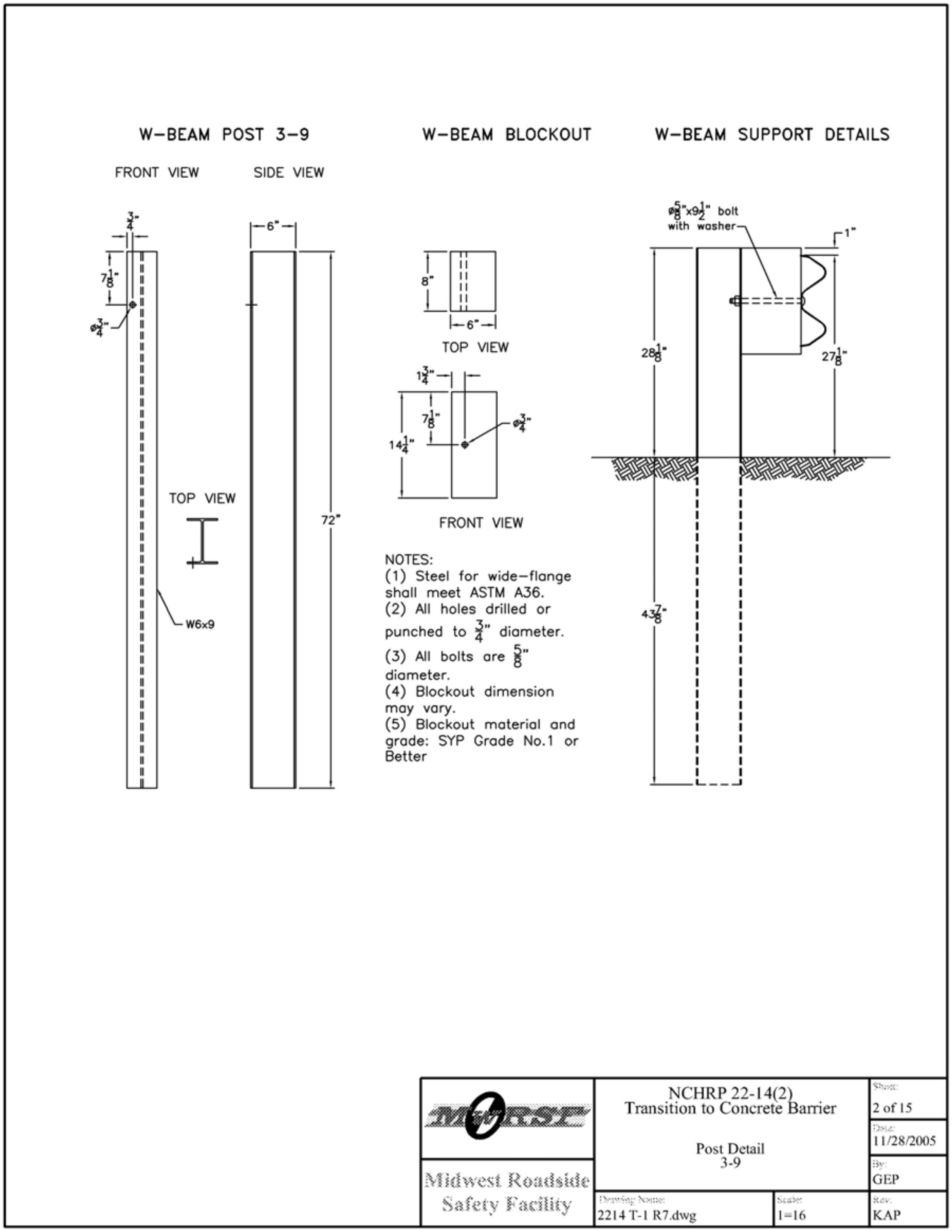


Figure A-2. Approach Guardrail Transition to Concrete Barrier Design - Post Details (English)

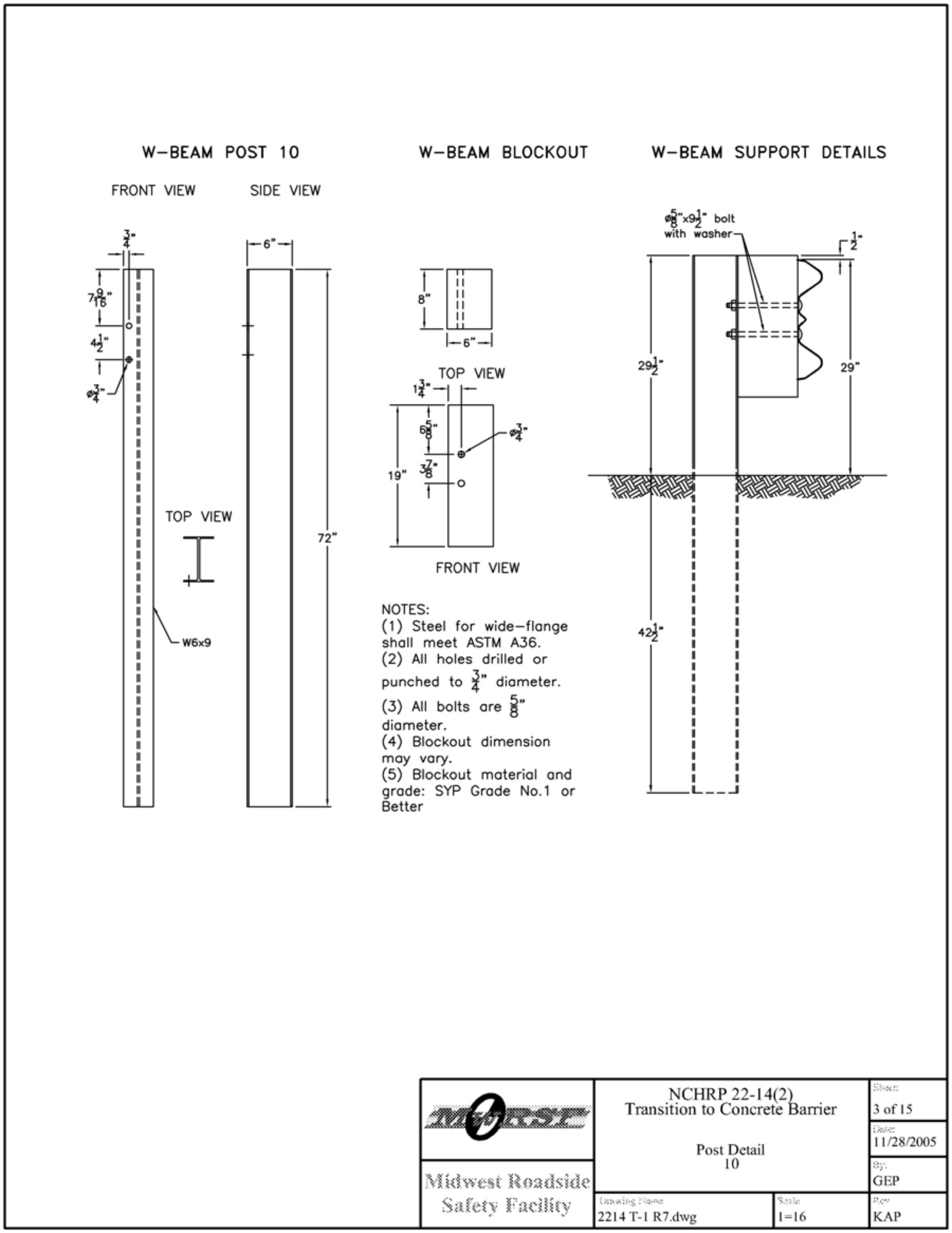


Figure A-3. Approach Guardrail Transition to Concrete Barrier Design - Post Details (English)

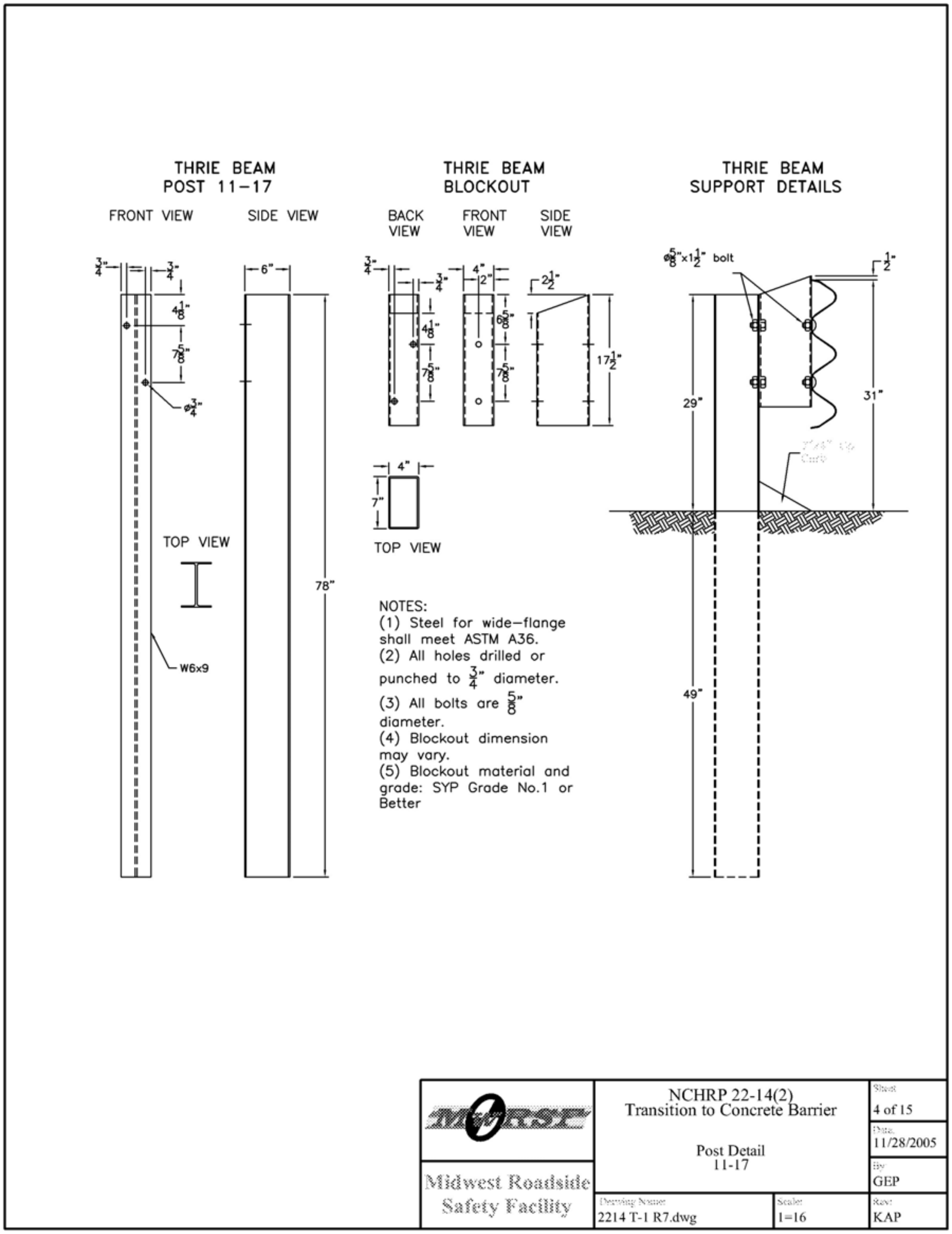


Figure A-4. Approach Guardrail Transition to Concrete Barrier Design - Post Details (English)

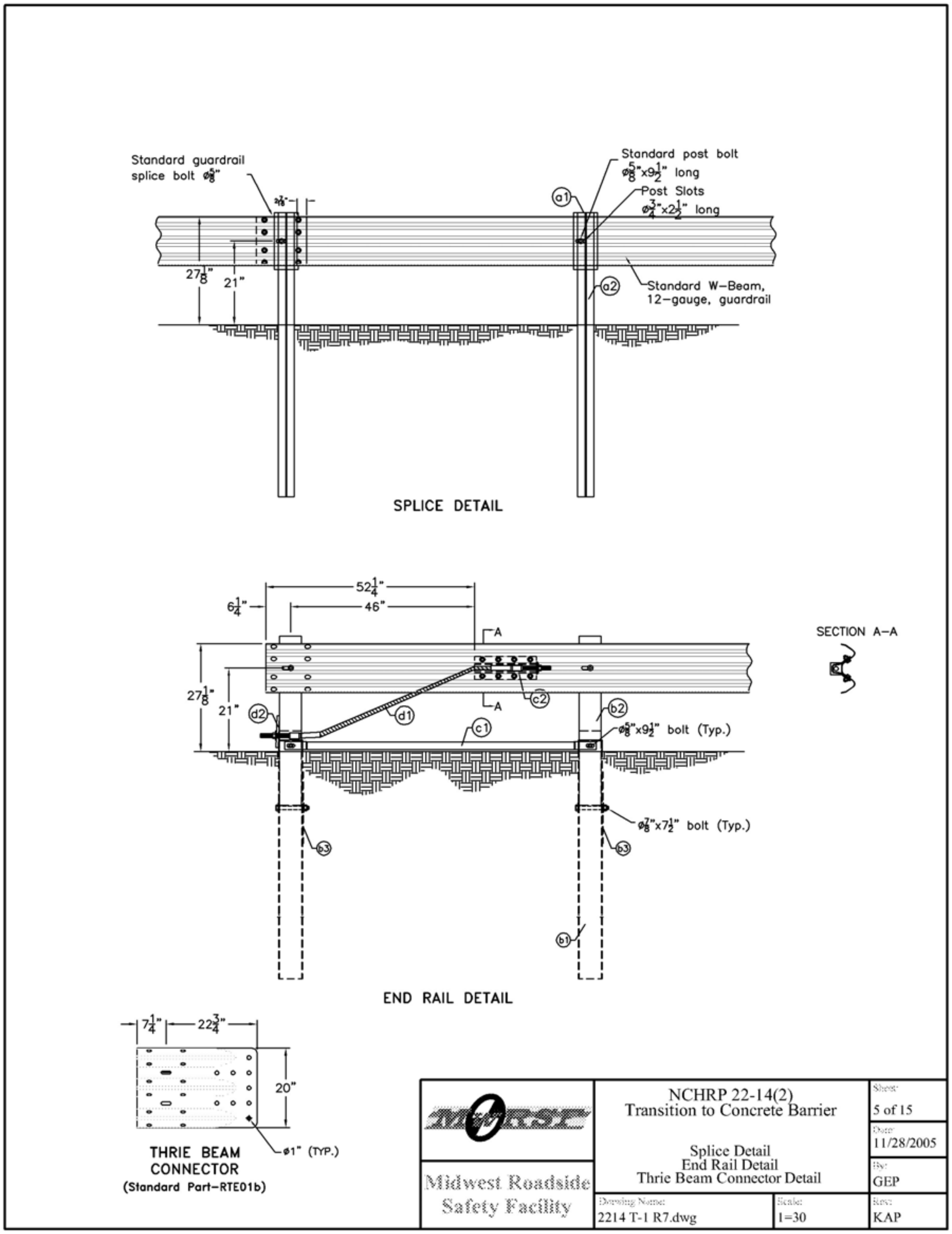


Figure A-5. Approach Guardrail Transition to Concrete Barrier Design - Rail Details (English)

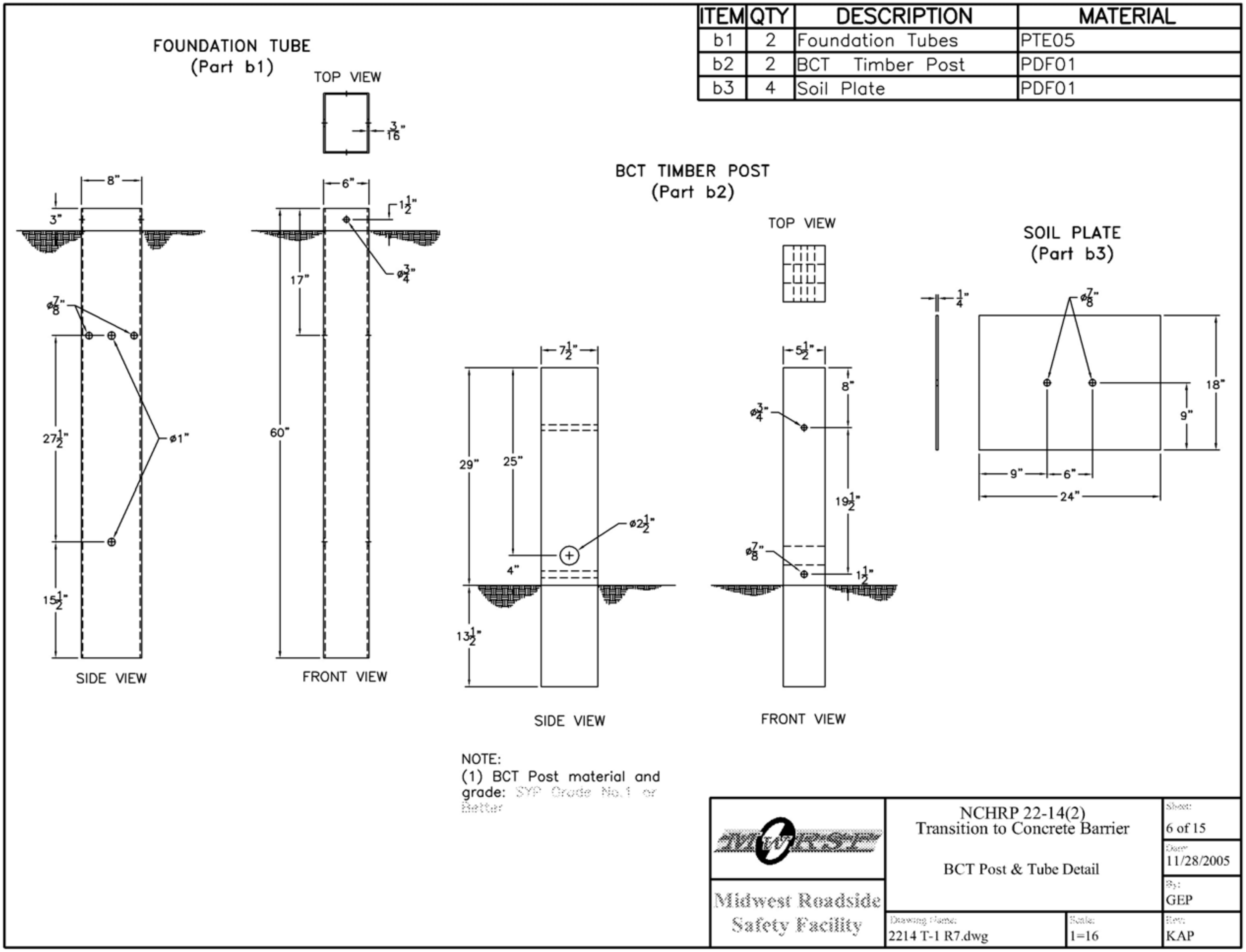


Figure A-6. Approach Guardrail Transition to Concrete Barrier Design - Anchorage Details (English)

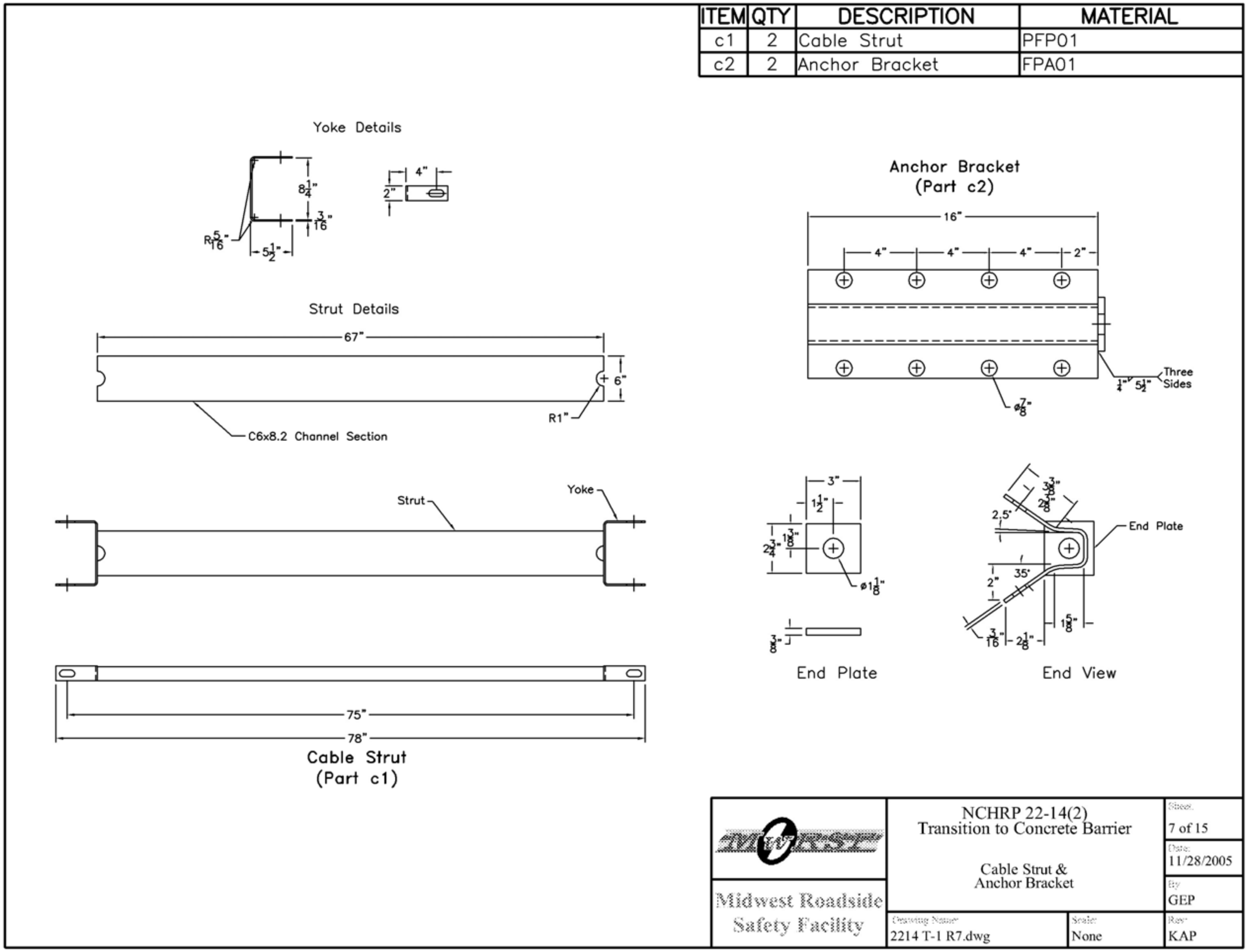


Figure A-7. Approach Guardrail Transition to Concrete Barrier Design - Anchorage Details (English)

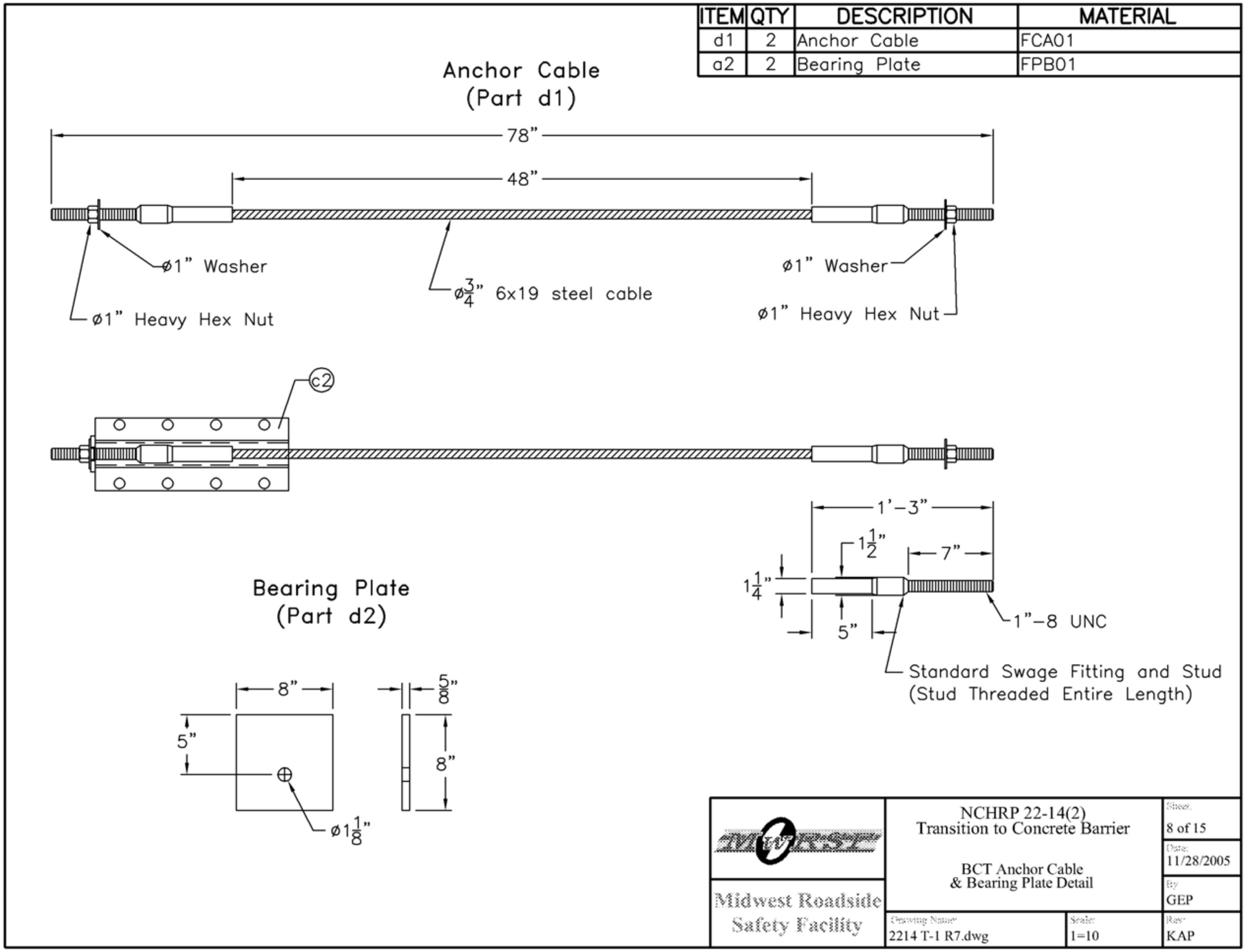


Figure A-8. Approach Guardrail Transition to Concrete Barrier Design - Anchorage Details (English)

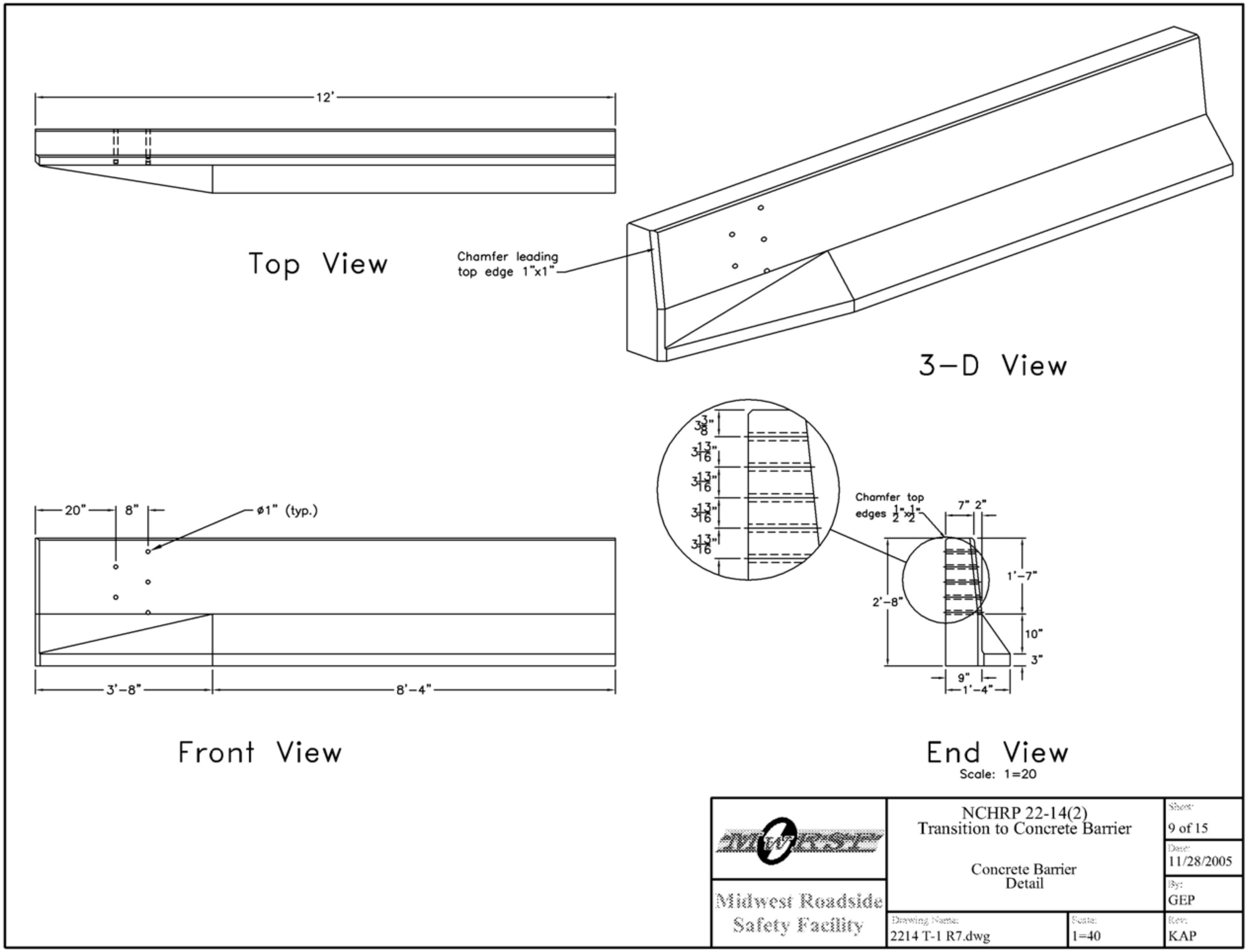


Figure A-9. Approach Guardrail Transition to Concrete Barrier Design - Concrete Barrier Details (English)

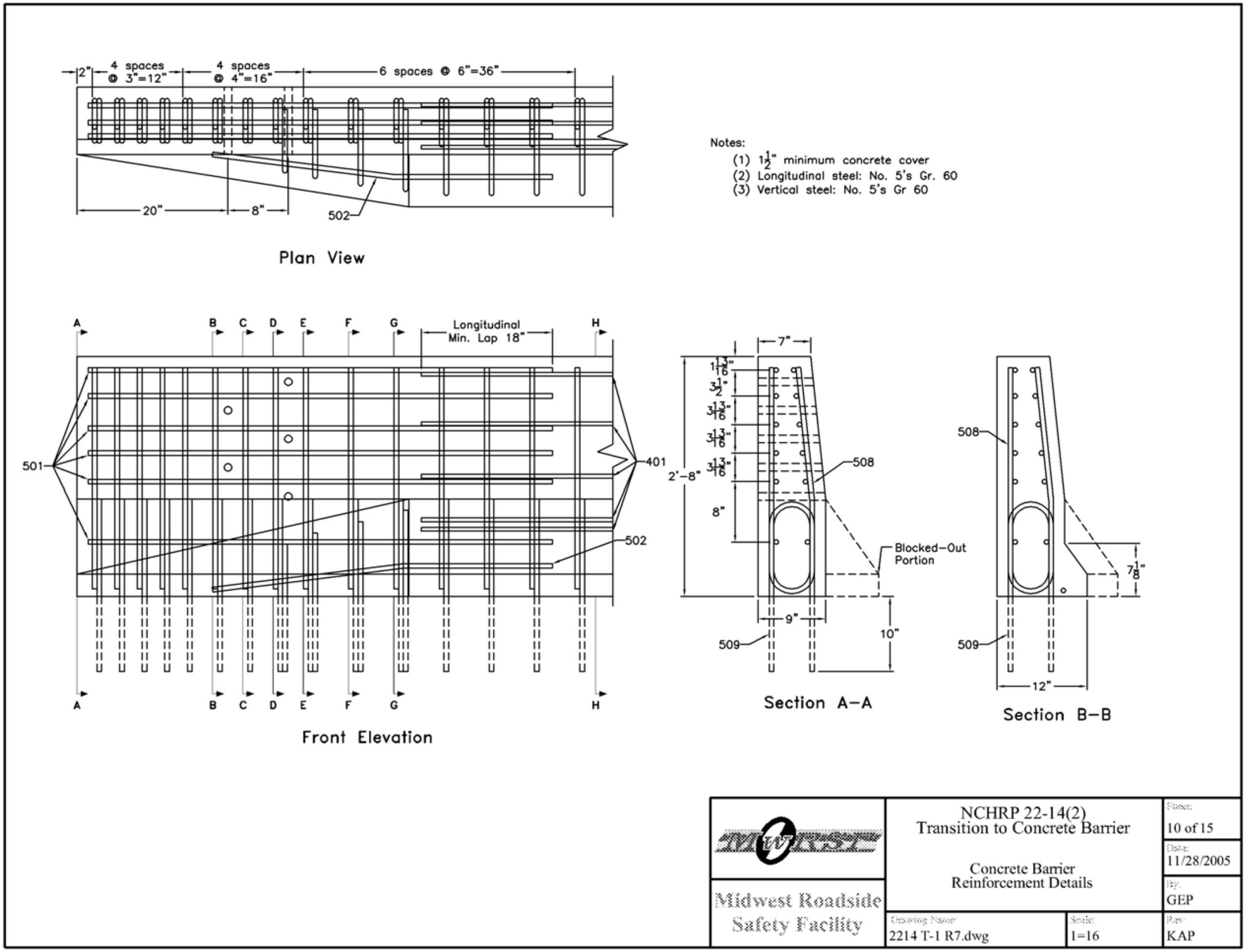


Figure A-10. Approach Guardrail Transition to Concrete Barrier Design - Reinforcement Details (English)

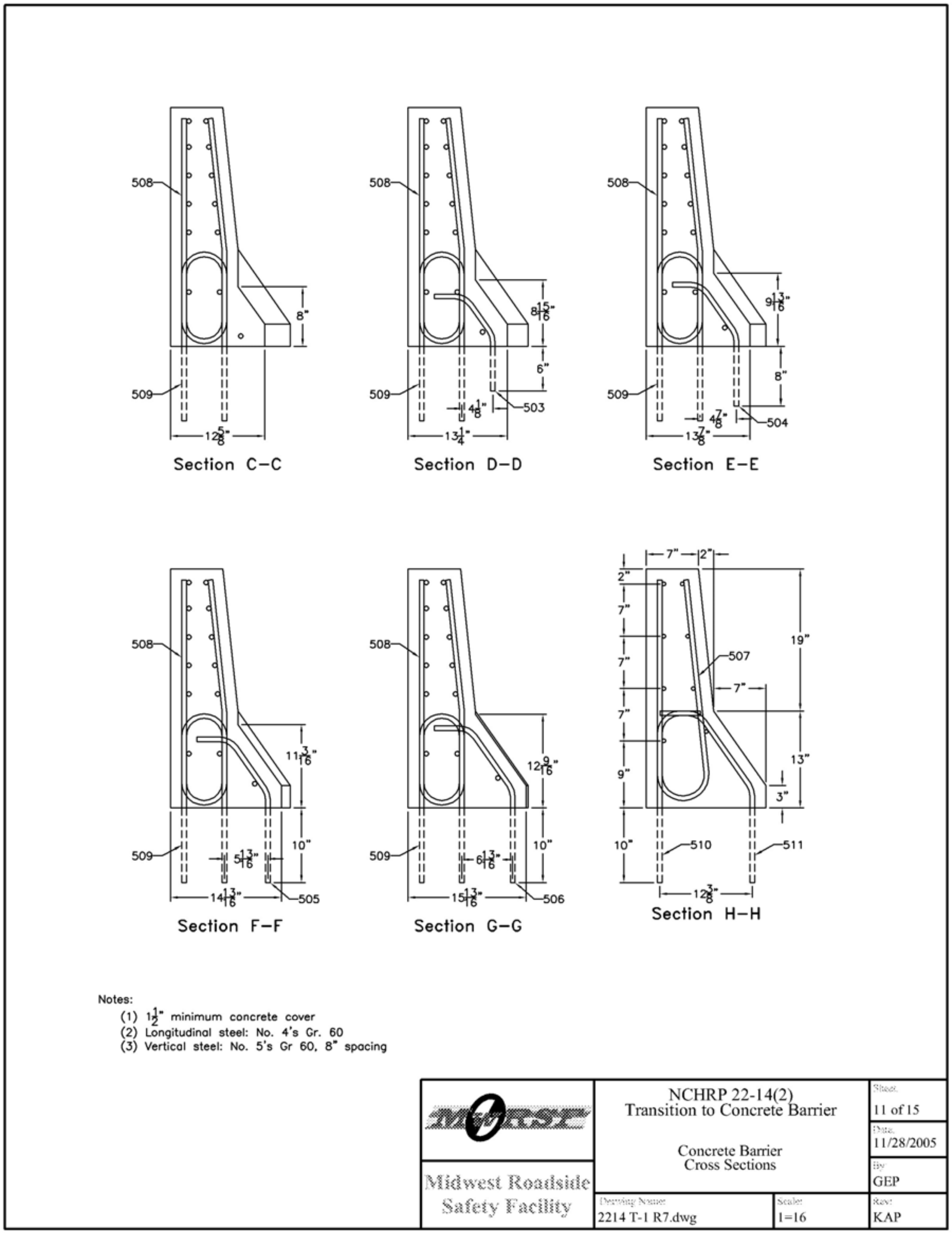
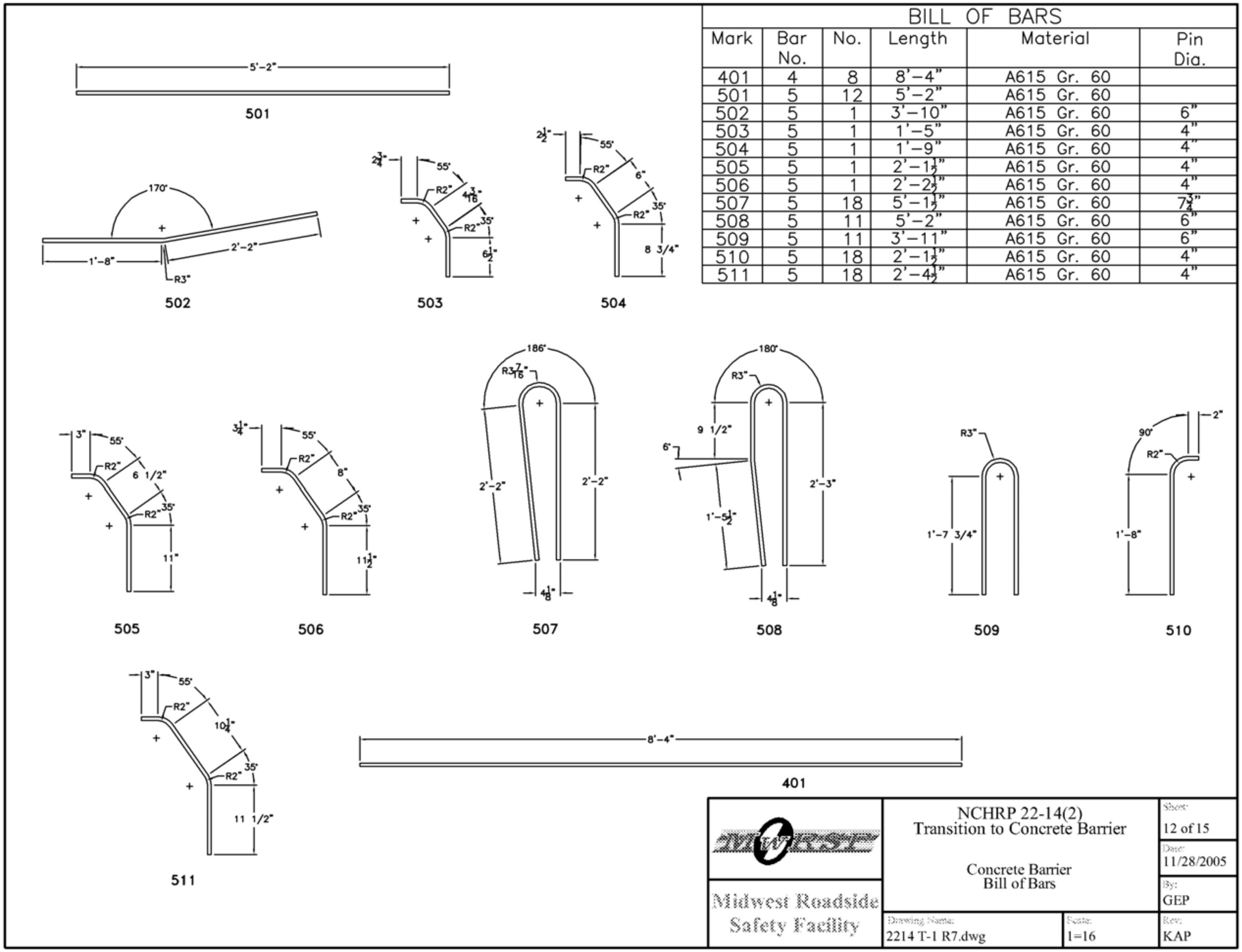


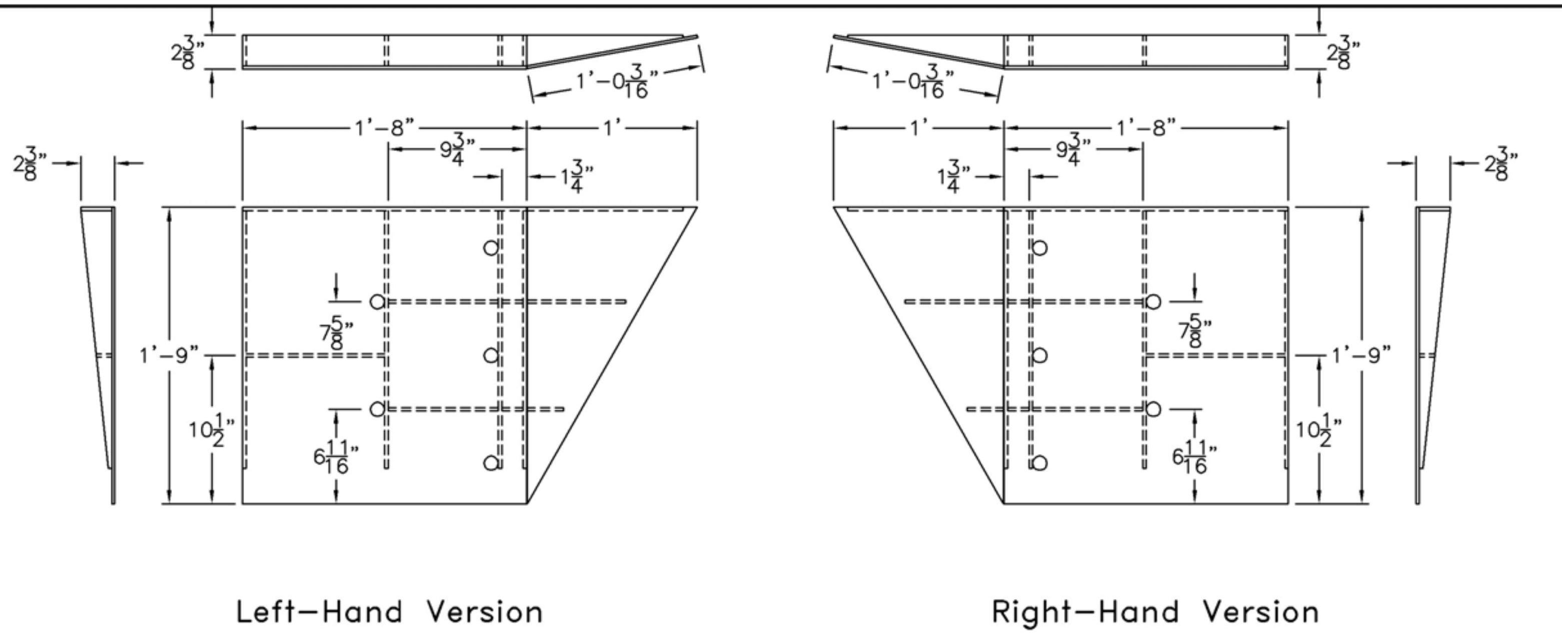
Figure A-11. Approach Guardrail Transition to Concrete Barrier - Cross Section Details (English)



BILL OF BARS

Mark	Bar No.	No.	Length	Material	Pin Dia.
401	4	8	8'-4"	A615 Gr. 60	
501	5	12	5'-2"	A615 Gr. 60	
502	5	1	3'-10"	A615 Gr. 60	6"
503	5	1	1'-5"	A615 Gr. 60	4"
504	5	1	1'-9"	A615 Gr. 60	4"
505	5	1	2'-1½"	A615 Gr. 60	4"
506	5	1	2'-2½"	A615 Gr. 60	4"
507	5	18	5'-1½"	A615 Gr. 60	7½"
508	5	11	5'-2"	A615 Gr. 60	6"
509	5	11	3'-11"	A615 Gr. 60	6"
510	5	18	2'-1½"	A615 Gr. 60	4"
511	5	18	2'-4½"	A615 Gr. 60	4"

Figure A-12. Approach Guardrail Transition to Concrete Barrier Design - Bill of Bars (English)



NOTES:

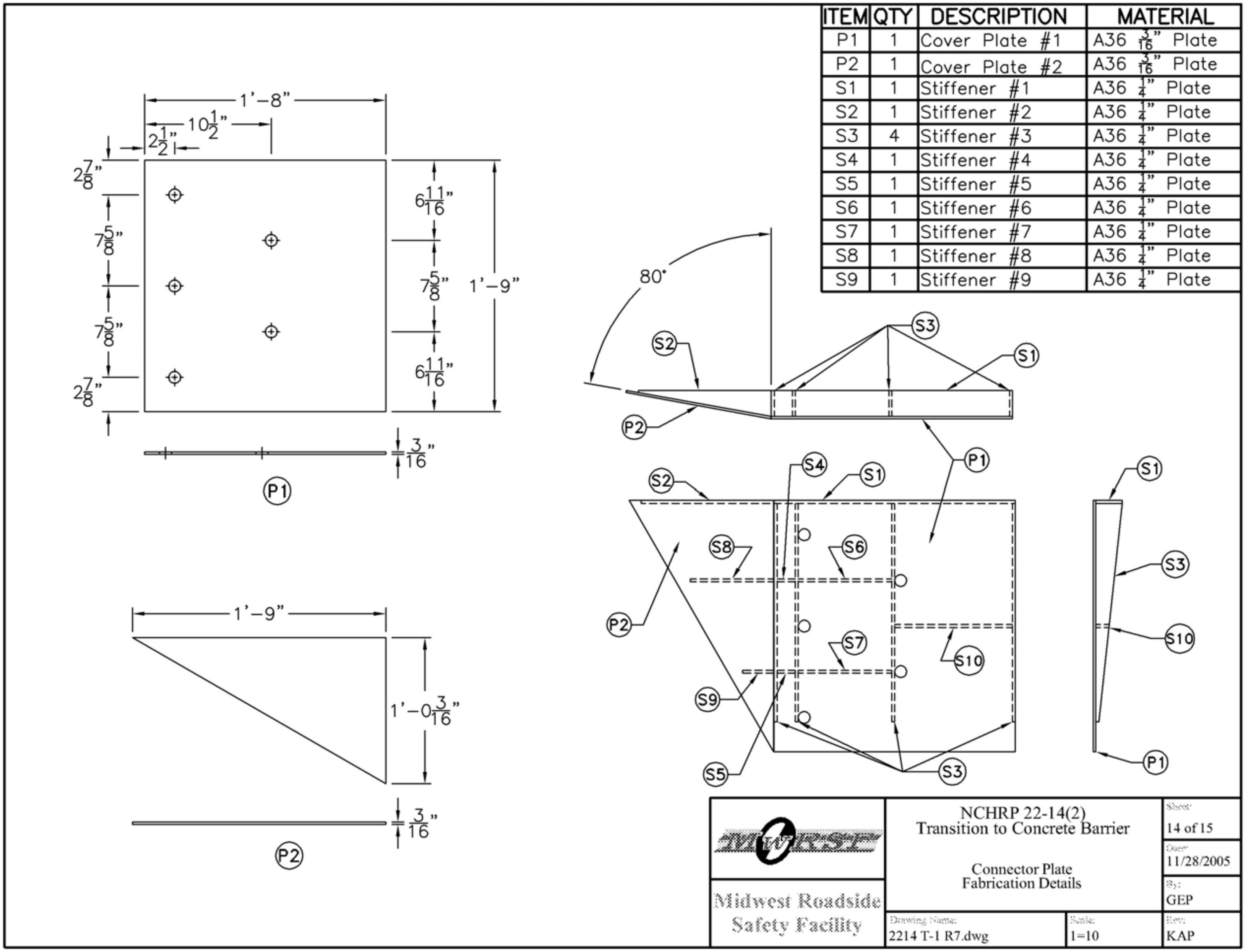
1. All steel shall conform to ASTM A36.
2. Flat plate panels are $\frac{3}{16}$" thick.
3. Stiffeners are $\frac{1}{4}$" thick.
4. All hole diameters are 1".
5. Weld components with E60 rod.
6. Galvanize or paint.

WELDING INSTRUCTIONS:

(a) Stiffeners located on the outside edges of the cover plates shall be welded as follows: $\frac{3}{16}$" continuous back weld on external sides and $\frac{3}{16}$" fillet weld by 1" long spaced at 2" on internal sides.
(b) Stiffeners located on the inside of the cover plates shall be welded as follows: $\frac{3}{16}$" fillet weld by 1" long spaced at 2".
(c) Retangular and triangular cover plates shall be welded together with a $\frac{3}{16}$" continuous back weld on both sides.

Midwest Roadside Safety Facility	NCHRP 22-14(2) Transition to Concrete Barrier Connector Plate Details	Sheet: 13 of 15
		Date: 11/28/2005
		By: GEP
	Drawing Name: 2214 T-1 R7.dwg / Scale: 1=10	Rev: KAP

Figure A-13. Approach Guardrail Transition to Concrete Barrier Design - Connector Plate Details (English)



ITEM	QTY	DESCRIPTION	MATERIAL
P1	1	Cover Plate #1	A36 $\frac{3}{16}$" Plate
P2	1	Cover Plate #2	A36 $\frac{3}{16}$" Plate
S1	1	Stiffener #1	A36 $\frac{1}{4}$" Plate
S2	1	Stiffener #2	A36 $\frac{1}{4}$" Plate
S3	4	Stiffener #3	A36 $\frac{1}{4}$" Plate
S4	1	Stiffener #4	A36 $\frac{1}{4}$" Plate
S5	1	Stiffener #5	A36 $\frac{1}{4}$" Plate
S6	1	Stiffener #6	A36 $\frac{1}{4}$" Plate
S7	1	Stiffener #7	A36 $\frac{1}{4}$" Plate
S8	1	Stiffener #8	A36 $\frac{1}{4}$" Plate
S9	1	Stiffener #9	A36 $\frac{1}{4}$" Plate

Figure A-14. Approach Guardrail Transition to Concrete Barrier Design - Connector Plate Details (English)

78

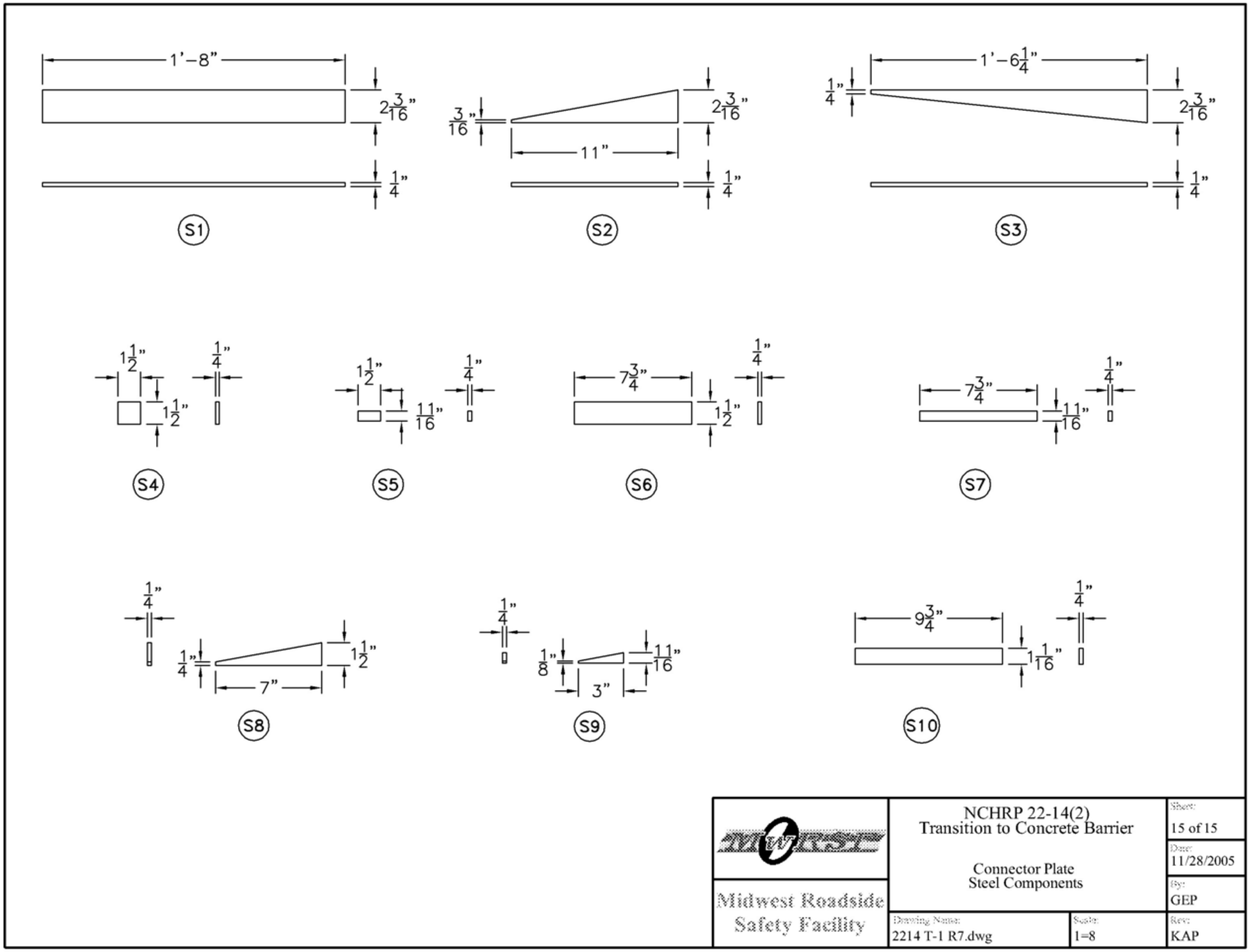


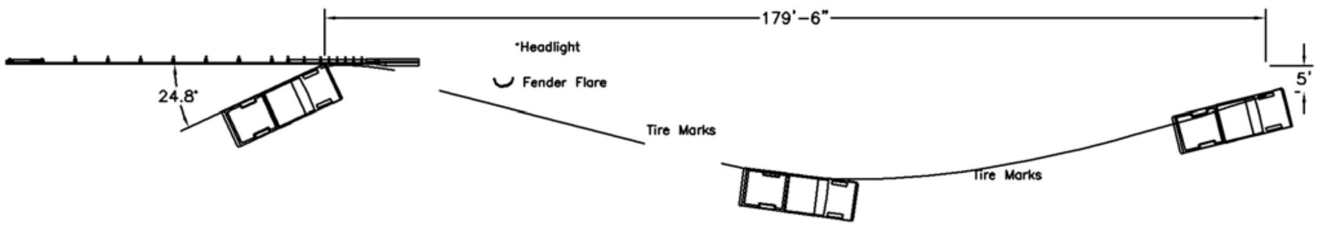
Figure A-15. Approach Guardrail Transition to Concrete Barrier Design - Connector Plate Details (English)

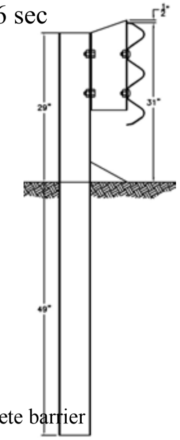
APPENDIX B

Test Summary Sheet in English Units

Figure B-1. Summary of Test Results and Sequential Photographs (English), Test 2214T-1

0.000 sec 0.052 sec 0.136 sec 0.206 sec 0.326 sec





- Test Agency .... MwRSF
- Test Number 2214T-1
- Date 6/22/05
- NCHRP 350 Update Test Designation 3-21
- Appurtenance .... Approach Guardrail Transition to a New Jersey Safety Shape End Section with Curb
- Total Length .... 80.67 ft
- Key Elements - Steel Thrie Beam (nested)
  - Thickness .... 12 gauge
  - Top Mounting Height .... 31 in.
- Key Elements - Steel Posts
  - Post Nos. 3 - 10 .... W6x9 by 6 ft long
  - Post Nos. 11 - 17 .... W6x9 by 6 ft - 6 in. long
- Key Elements - Post Spacing
  - Post Nos. 3 - 9 .... 75 in.
  - Post Nos. 9 - 12 .... 37.5 in.
  - Post Nos. 12 - 17 .... 18.75 in.
- Key Elements - Wood Spacer Blocks
  - Post Nos. 3 - 9 .... 6 in. x 8 in. by 14.25 in. long
  - Post No. 10 .... 6 in. x 8 in. by 19 in. long
- Key Elements - Steel Spacer Blocks
  - Post Nos. 11 - 17 .... TS 7 x 4 x 3/16 in. by 17.5 in. long
- Key Element - Curb .... 7 in. x 4 in. Lip Curb
- Type of Soil .... Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model .... 2002 Chevrolet C1500HD Crew Cab Pickup
  - Curb .... 5,559 lbs
  - Test Inertial .... 5,083 lbs
  - Gross Static .... 5,083 lbs
- Impact Conditions
  - Speed .... 60.3 mph
  - Angle .... 24.8 degrees
  - Impact Location .... 7.99 ft upstream of concrete barrier
- Exit Conditions
  - Speed .... 38.7 mph
  - Angle .... 7.5 degrees
  - Exit Box Criterion .... Pass
- Post-Impact Trajectory
  - Vehicle Stability .... Satisfactory
  - Stopping Distance .... 179 ft - 6 in. downstream 5 ft traffic-side face
- Occupant Impact Velocity (350 Update)
  - Longitudinal .... -24.43 ft/s < 39.4 ft/s
  - Lateral .... -24.96 ft/s < 39.4 ft/s
- Occupant Ridedown Deceleration (350 Update)
  - Longitudinal .... -12.72 Gs < 20 Gs
  - Lateral .... -8.71 Gs < 20 Gs
- THIV (not required) .... 33.04 ft/s
- PHD (not required) .... 14.27 Gs
- Test Article Damage .... Minimal
- Test Article Deflections
  - Permanent Set .... 7.625 in.
  - Dynamic .... 11.4 in.
  - Working Width .... 21.7 in.
- Vehicle Damage .... Moderate
  - VDS[5] 11-LFQ-5
  - CDC[6] 11-LYEW7
  - Maximum Deformation .... 4 in. at front floorpan

Figure B-1. Summary of Test Results and Sequential Photographs (English), Test 2214T-1

APPENDIX C

Occupant Compartment Deformation Data, Test 2214T-1

VEHICLE PRE/POST CRUSH INFO
Set-1

TEST: 2214T-1
VEHICLE: 2270P

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

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	93.25	-28	-0.75	89.25	NA	1	-4	NA	1.75
2	94.25	-23.5	-1.25	90.25	NA	1	-4	NA	2.25
3	95.5	-17.5	-2	92	NA	-0.5	-3.5	NA	1.5
4	94	-12.5	-1.5	91.75	NA	-0.25	-2.25	NA	1.25
5	92.75	-7.5	-1	91.5	NA	-0.25	-1.25	NA	0.75
6	88.75	-28.25	-5.25	87	NA	-4.5	-1.75	NA	0.75
7	88.5	-23.25	-5.5	86.5	NA	-4.75	-2	NA	0.75
8	88.5	-18.5	-5.75	86.5	NA	-4.75	-2	NA	1
9	88.75	-14	-5.75	87	NA	-4.75	-1.75	NA	1
10	88.25	-9.5	-5.75	86.75	NA	-4.5	-1.5	NA	1.25
11	81.5	-28.75	-5.5	80.5	NA	-5.25	-1	NA	0.25
12	81.75	-24	-5.75	80.5	NA	-5	-1.25	NA	0.75
13	82.25	-18.25	-6	80.75	NA	-5	-1.5	NA	1
14	82.5	-13.5	-6	81	NA	-5.25	-1.5	NA	0.75
15	82.75	-9	-6	81.25	NA	-4.75	-1.5	NA	1.25
16	75.5	-29	-5.75	74.5	NA	-4.5	-1	NA	1.25
17	75.75	-23.75	-6	74.5	NA	-5.25	-1.25	NA	0.75
18	75.75	-17.75	-6.25	74.75	NA	-5.5	-1	NA	0.75
19	76	-13.75	-6.25	74.75	NA	-5.25	-1.25	NA	1
20	76.5	-8.5	-6.25	74.75	NA	-4.75	-1.75	NA	1.5
21	69.25	-28.5	-6	69	NA	-6	-0.25	NA	0
22	69.25	-23.75	-6.25	68.75	NA	-6	-0.5	NA	0.25
23	69.5	-18.25	-6.5	68.75	NA	-5.75	-0.75	NA	0.75
24	69.5	-13.5	-6.5	68.25	NA	-5.5	-1.25	NA	1
25	69.75	-9	-6.5	68.25	NA	-4.75	-1.5	NA	1.75
26	63.5	-24.75	-4.5	63.25	NA	-4	-0.25	NA	0.5
27	63.75	-18	-4.75	63.25	NA	-3.75	-0.5	NA	1
28	64	-11.75	-5	63.5	NA	-3.5	-0.5	NA	1.5
29									
30									

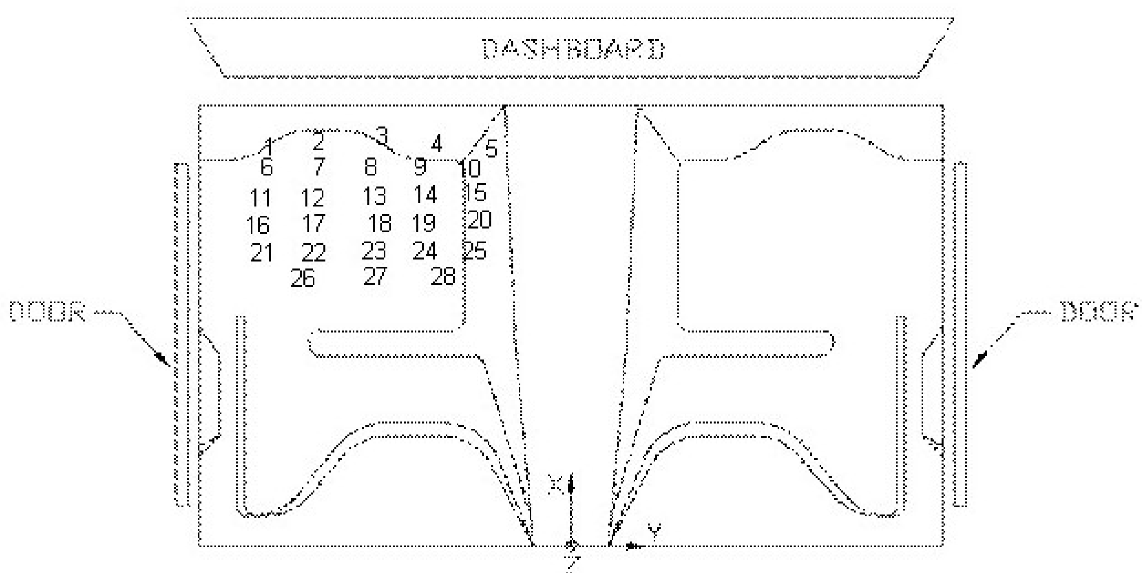


Figure C-1. Occupant Compartment Deformation Data - Set 1, Test 2214T-1

VEHICLE PRE/POST CRUSH INFO
Set-2

TEST: 2214T-1
VEHICLE: 2270P

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

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	53	-33.25	-1.25	49	-31.75	0.25	-4	1.5	1.5
2	54	-28.75	-1.75	50	-27.25	0	-4	1.5	1.75
3	55.25	-22.75	-2.75	51.75	-22.25	-1.5	-3.5	0.5	1.25
4	53.75	-17.75	-2.25	51.5	-16.5	-0.25	-2.25	1.25	2
5	52.5	-12.75	-1.75	51.25	-12	NA	-1.25	0.75	NA
6	48.5	-33.5	-5.5	46.5	-32.5	-5.5	-2	1	0
7	48.25	-28.5	-5.75	46.25	-27.75	-5.75	-2	0.75	0
8	48.25	-23.75	-6.25	46.5	-23	-5.75	-1.75	0.75	0.5
9	48.5	-19.25	-6.5	46.5	-17.5	-6	-2	1.75	0.5
10	48	-14.75	-6.5	46.5	-13.25	-6	-1.5	1.5	0.5
11	41.25	-34	-5.5	40.5	-32.75	-6	-0.75	1.25	-0.5
12	41.5	-29.25	-6	40	-28.75	-5.5	-1.5	0.5	0.5
13	42	-23.5	-6.5	40.25	-22.5	-5.75	-1.75	1	0.75
14	42.25	-18.75	-6.75	41	-18	-6.25	-1.25	0.75	0.5
15	42.5	-14.25	-6.75	41	-14	-6	-1.5	0.25	0.75
16	35.25	-34.25	-5.75	34.5	-34	-6	-0.75	0.25	-0.25
17	35.5	-29	-6.25	34	-29	-6.5	-1.5	0	-0.25
18	35.5	-23	-6.5	34.5	-23.25	-6.25	-1	-0.25	0.25
19	35.75	-19	-6.75	34.25	-19	-6	-1.5	0	0.75
20	36.25	-13.75	-7	34.5	-14	-5.75	-1.75	-0.25	1.25
21	29	-33.75	-5.75	28.75	-35	-6	-0.25	-1.25	-0.25
22	29	-29	-6.25	28.75	-30.25	-6.25	-0.25	-1.25	0
23	29.25	-23.5	-6.5	28.25	-24.5	-6	-1	-1	0.5
24	29.25	-18.75	-6.75	28	-19.75	-6	-1.25	-1	0.75
25	29.5	-14.25	-7	28	-15.5	-5.5	-1.5	-1.25	1.5
26	23.25	-30	-4.25	22.75	-31	-4.25	-0.5	-1	0
27	23.5	-23.25	-4.75	23	-24.5	-4	-0.5	-1.25	0.75
28	23.75	-17	-5.25	23.25	-18.25	-4	-0.5	-1.25	1.25
29									
30									

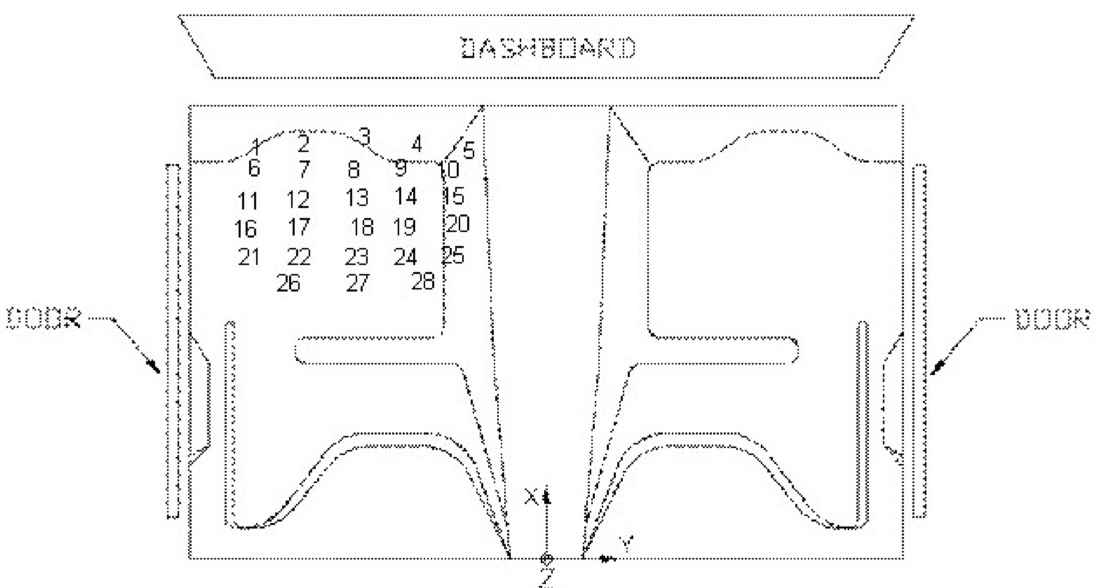


Figure C-2. Occupant Compartment Deformation Data - Set 2, Test 2214T-1

Occupant Compartment Deformation Index (OCDI)

Test No. 2214T-1
Vehicle Type: 2270P

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

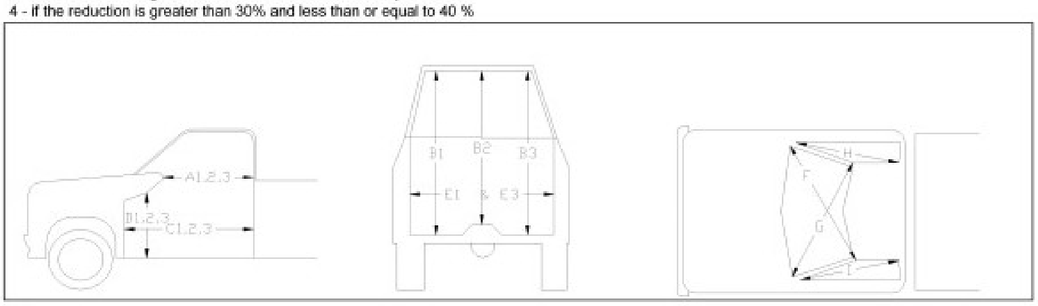
G = distance between the lower edge of left window and the upper edge of right window

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	76.25	76.25	0.00	0.00	0
A2	76.25	76.50	0.25	0.33	0
A3	74.75	74.75	0.00	0.00	0
B1	45.25	45.25	0.00	0.00	0
B2	28.50	28.50	0.00	0.00	0
B3	45.50	45.25	-0.25	-0.55	0
C1	92.50	89.00	-3.50	-3.78	1
C2	88.25	87.00	-1.25	-1.42	0
C3	94.00	94.00	0.00	0.00	0
D1	17.00	17.50	0.50	2.94	0
D2	9.50	9.50	0.00	0.00	0
D3	16.75	17.00	0.25	1.49	0
E1	63.00	59.50	-3.50	-5.56	1
E3	64.00	64.00	0.00	0.00	0
F	58.25	58.50	0.25	0.43	0
G	56.00	55.50	-0.50	-0.89	0
H	36.00	36.25	0.25	0.69	0
I	36.50	36.50	0.00	0.00	0

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

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

Figure C-3. Occupant Compartment Deformation Index (OCDI), Test 2214T-1

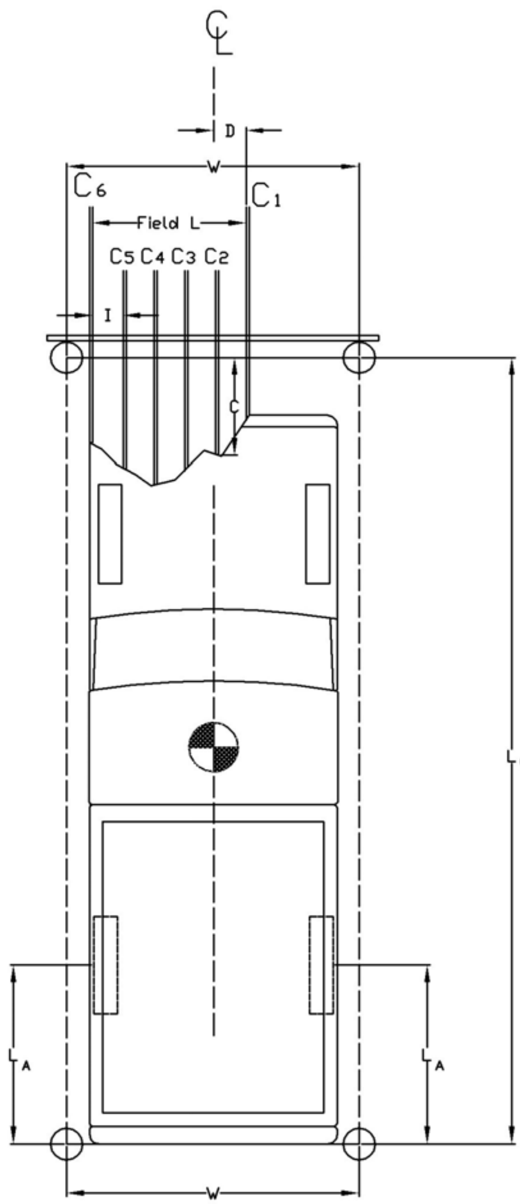
Date: 6/22/05 Test Number: 2214T-1 Model: 2WD Crew Cab

Make: Chevy Vehicle I.D.#: 1GCGC13U12F171883

Tire Size: LT 245/75 R16 Year: 2002 Odometer: 156095

(All Measurements Refer to Impacting Side)
*D is negative on passenger side
*Negative C values are possible

Vehicle Geometry — mm (in.)



L_o 6147 (242)

L_A 1207 (47.5)

W 2280 (89.75)

Field L 1727 (68)

Bumper Height 610 (24)

Field L/5 = I 345 (13.6)

D 708 (27.875)

C_1 470 (18.5)

C_2 140 (5.5)

C_3 143 (5.625)

C_4 187 (7.375)

C_5 318 (12.5)

C_6 1029 (40.5)

Figure C-4. NASS Crush Data, Test 2214T-1

APPENDIX D

Accelerometer and Rate Transducer Data Analysis, Test 2214T-1

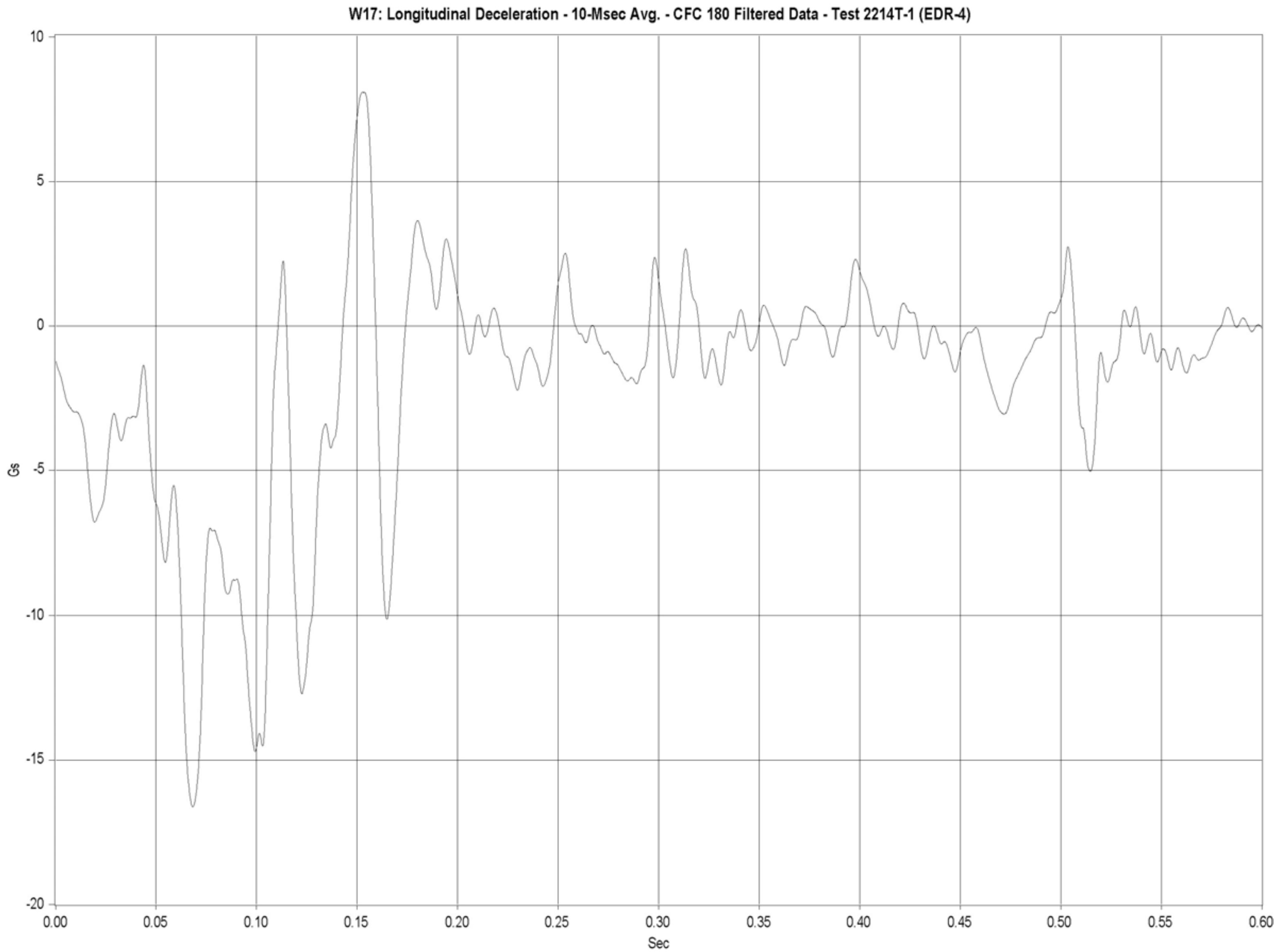


Figure D-1. Graph of Longitudinal Deceleration, Test 2214T-1

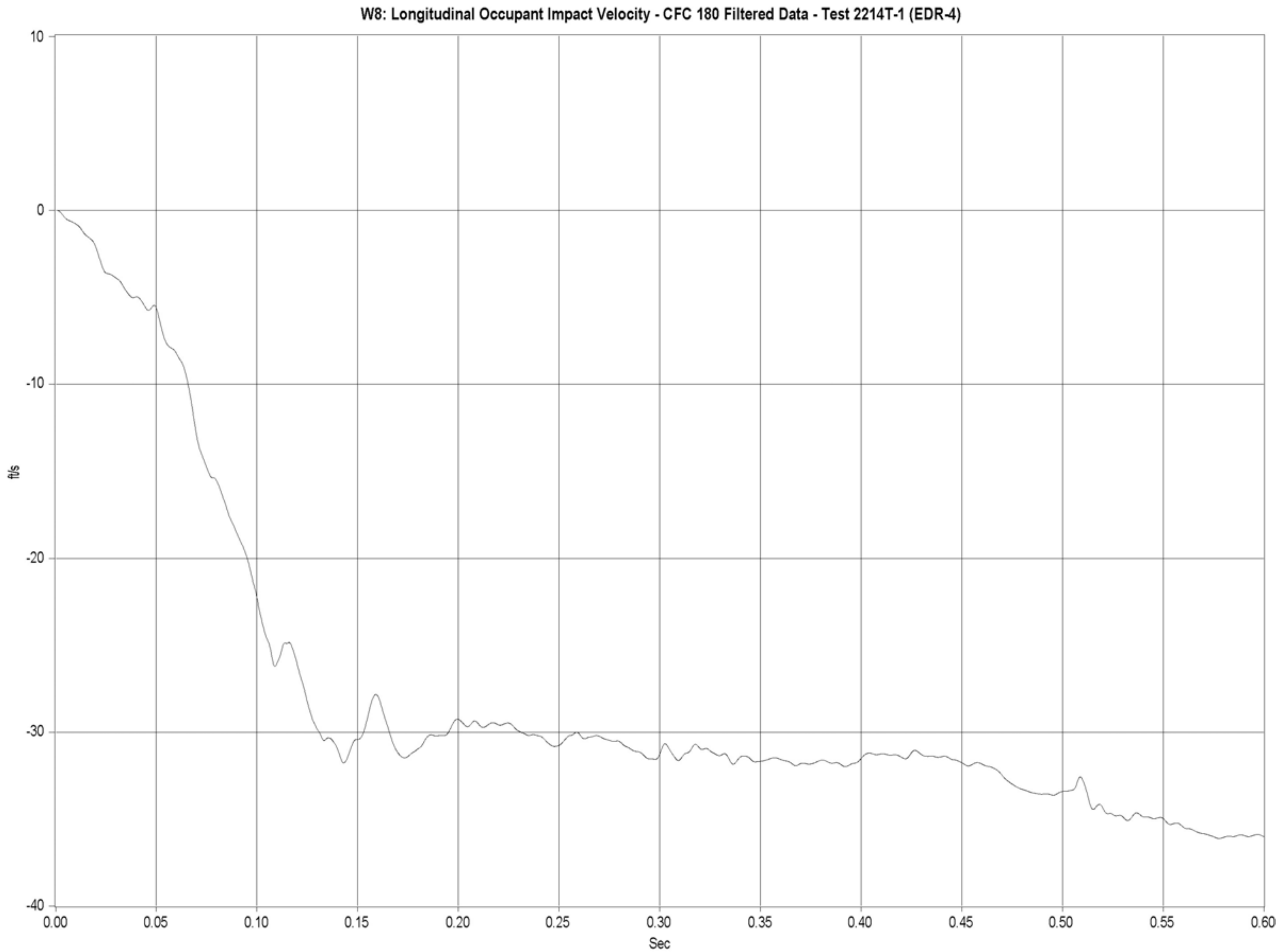


Figure D-2. Graph of Longitudinal Occupant Impact Velocity, Test 2214T-1

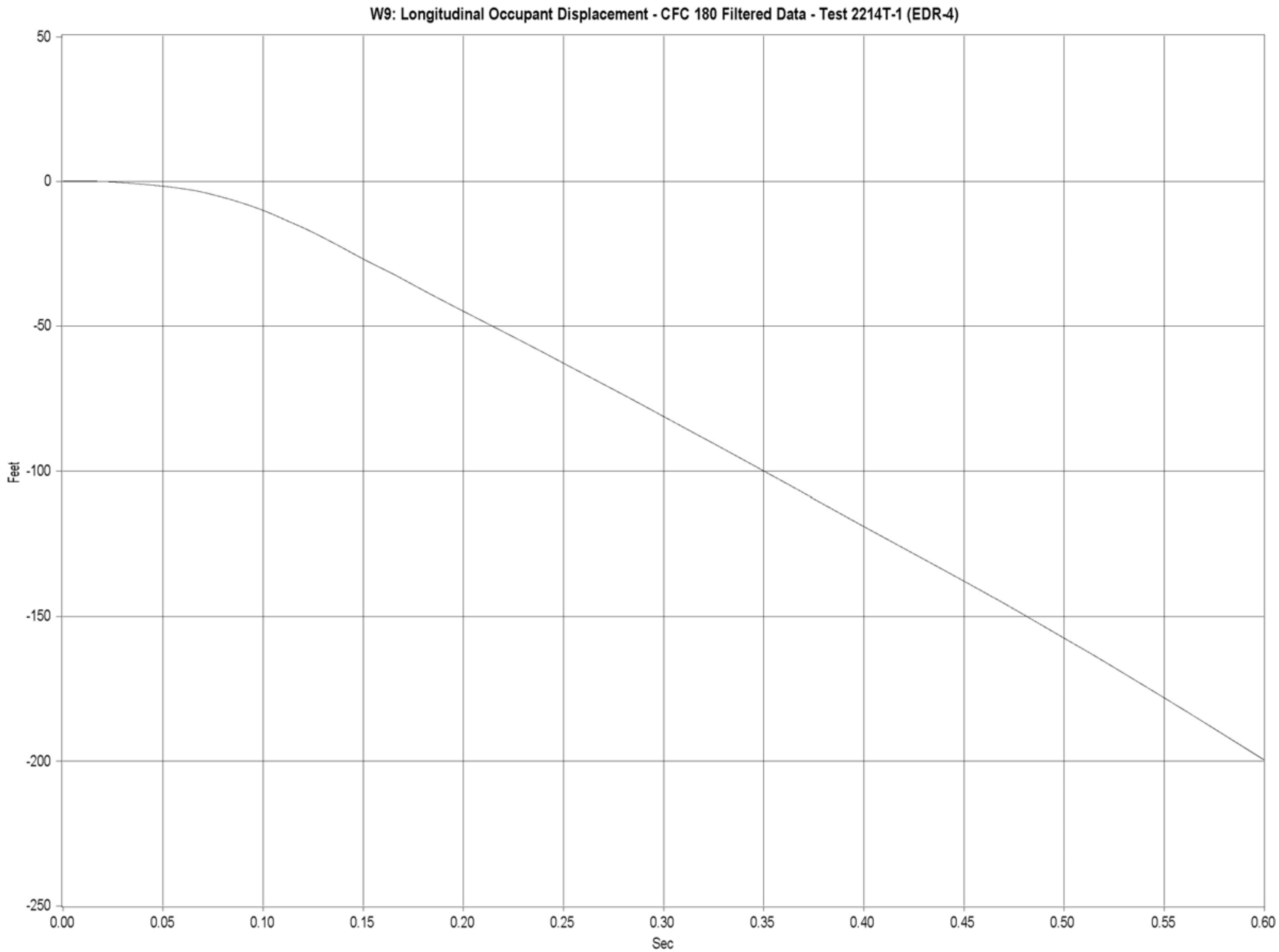


Figure D-3. Graph of Longitudinal Occupant Displacement, Test 2214T-1

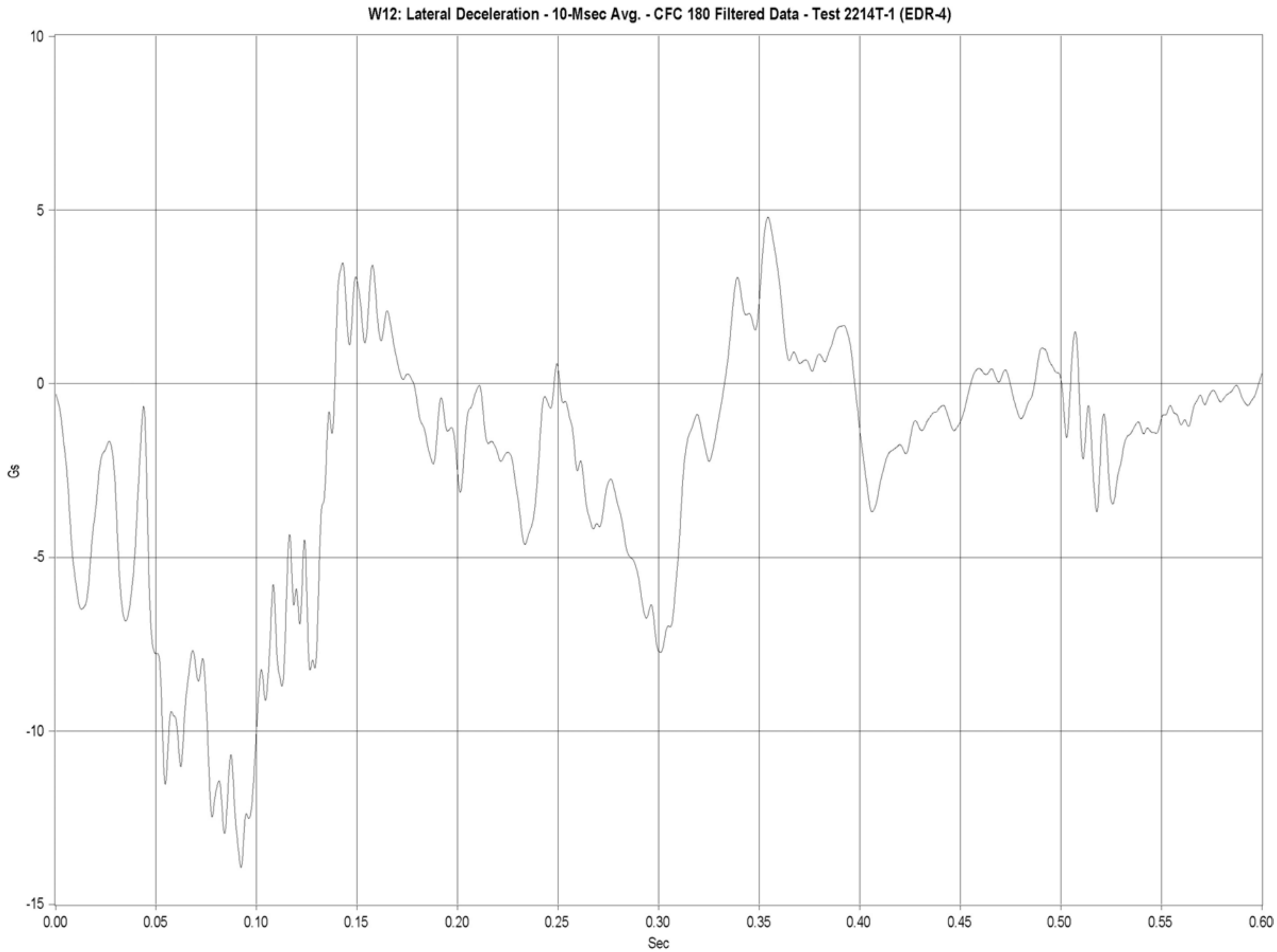


Figure D-4. Graph of Lateral Deceleration, Test 2214T-1

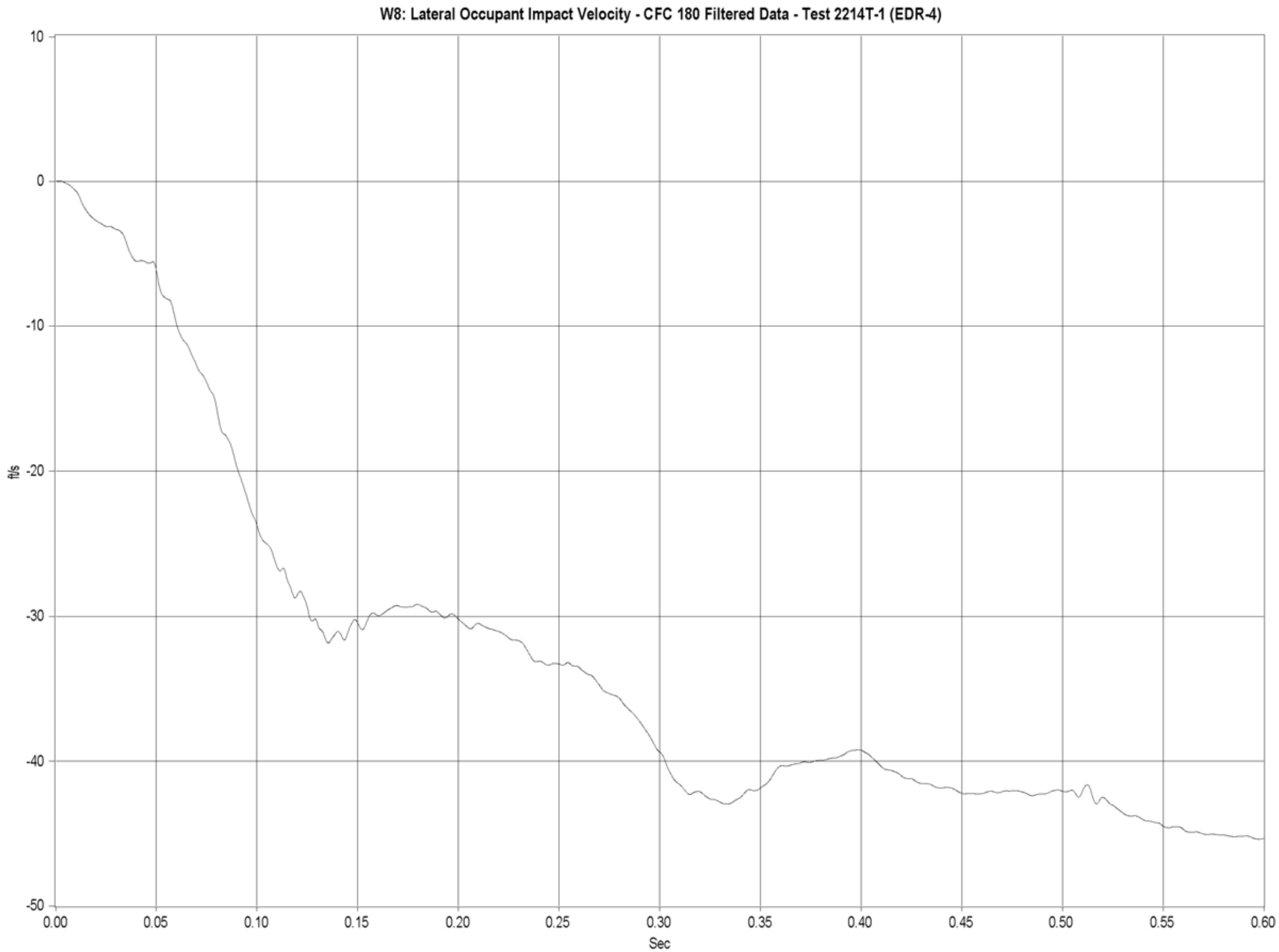


Figure D-5. Graph of Lateral Occupant Impact Velocity, Test 2214T-1

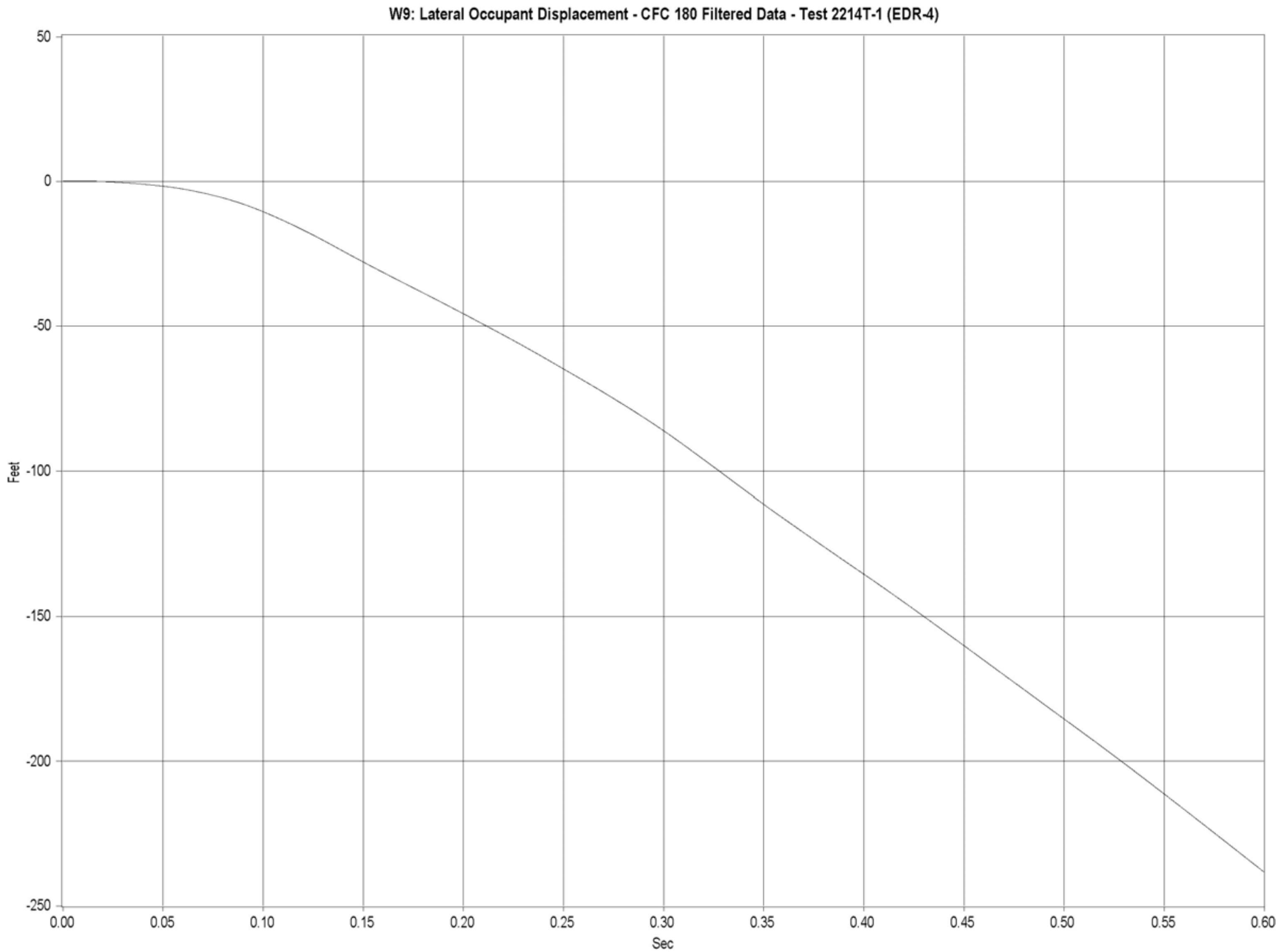


Figure D-6. Graph of Lateral Occupant Displacement, Test 2214T-1

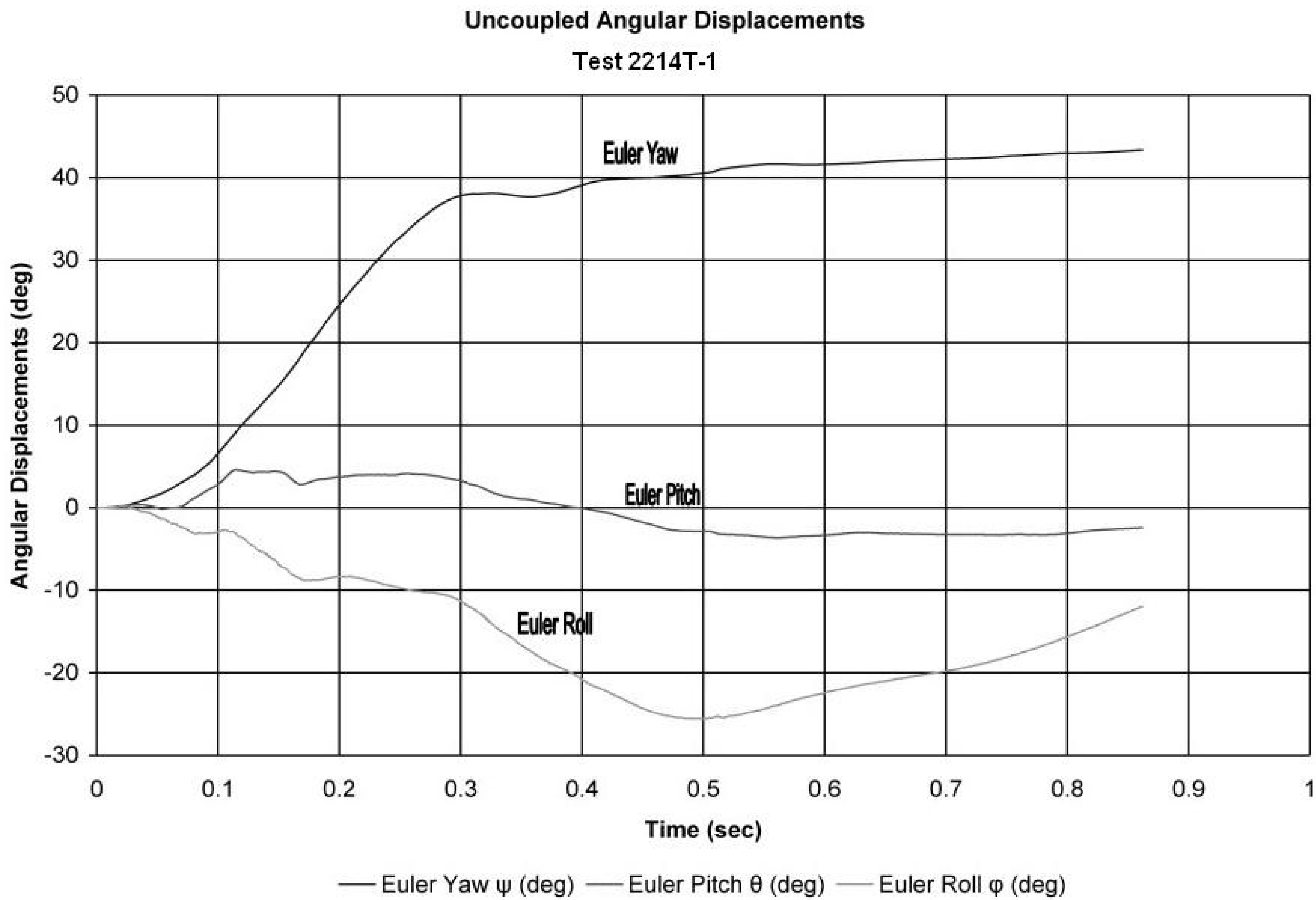


Figure D-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test 2214T-1