PERFORMANCE EVALUATION OF THE MIDWEST GUARDRAIL SYSTEM – UPDATE TO NCHRP 350 TEST NO. 3-11 (2214MG-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

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-03-170-06

October 10, 2006

Technical Report Documentation Page

1. Report No.	2.	3. Recipient's Accession No.
TRP-03-170-06		

4. Title and Subtitle	5. Report Date
Performance Evaluation of the Midwest Guardrail System – Update to NCHRP 350 Test No. 3-11 (2214MG-1)	October 10, 2006
	6.
7. Author(s)	8. Performing Organization Report No.
Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, B.W., and Reid, J.D.	TRP-03-170-06
9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
Midwest Roadside Safety Facility (MwRSF) University of Nebraska-Lincoln 527 Nebraska Hall Lincoln, NE 68588-0529	11. Contract © or Grant (G) No. NCHRP 22-14(2)
12. Sponsoring Organization Name and Address	13. Type of Report and Period Covered
National Cooperative Highway Research Program Transportation Research Board National Research Council 2101 Constitution Avenue, N.W. Washington, D.C. 20418	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 strong-post W-beam guardrail systems prior to finalizing the new crash testing procedures and guidelines. For this effort, the Midwest Guardrail System (MGS) was selected for evaluation. One full-scale vehicle crash test was performed on the longitudinal barrier system in accordance with the Test Level 3 (TL-3) requirements presented in the Update to NCHRP Report No. 350. For this test, a 2270P pickup truck vehicle, which was a ¾-ton, two-door vehicle, was used.

The MGS system, mounted at the metric top rail height of 787 mm (31.0 in.), provided an acceptable safety performance when impacted by the ¾-ton, two-door pickup truck, thus meeting the proposed TL-3 requirements presented in the Update to NCHRP Report No. 350. This test vehicle was not ultimately recommended for inclusion in the Update to NCHRP Report No. 350.

17. Document Analysis/Descriptors	18. Availability Statement
Highway Safety, Roadside Appurtenances, Longitudinal Barriers, Guardrail, Crash Test, Compliance Test, NCHRP 350 Update	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	75	

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 fleet 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 the Midwest Guardrail System (MGS) when full-scale vehicle crash tested according to the test designation no. 3-11 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 MGS system. The crash test utilized a pickup truck, weighing approximately 2,270 kg (5,004 lbs). 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 MGS system relative to the test performed.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Historically, longitudinal barriers, such as W-beam guardrail systems, 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 3-10. 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 3-11. 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 3-11 was conducted for the MGS 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	3-10	1100C	100	62.1	25	A,D,F,H,I,M
	3-11	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 2214MG-1, the vehicle guidance system was 322 m (1,055 ft) long.

3.3 Test Vehicles

For test 2214MG-1, a 2002 GMC 2500 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,268 kg (5,000 lbs). The test vehicle is shown in Figure 1, and vehicle dimensions are shown in Figure 2.

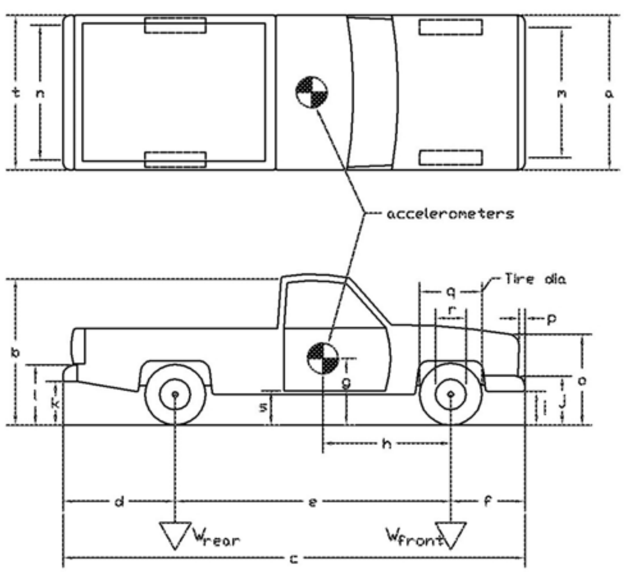
Figure 1. Test Vehicle, Test 2214MG-1

Date: 5/7/04 Test Number: 2214MG-1 Model: 2500P.U.

Make: GMC Vehicle I.D.#: 1GDGC24U622256121

Tire Size: LT 245/75 R16 Year: 2002 Odometer: 197661

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1930 (76.0)	b	1886 (74.25)
c	5639 (222.0)	d	1302 (51.25)
e	3391 (133.5)	f	946 (37.25)
g	691 (27.20)	h	1451 (57.125)
i	457 (18.0)	j	756 (29.75)
k	591 (23.25)	l	781 (30.75)
m	1419 (55.875)	n	1676 (66.0)
o	1029 (40.5)	p	102 (4.0)
q	762 (30.0)	r	438 (17.25)
s	489 (19.25)	t	1854 (73.0)

Wheel Center Height Front 365 (14.375)

Wheel Center Height Rear 368 (14.5)

Wheel Well Clearance (FR) 921 (36.25)

Wheel Well Clearance (RR) 979 (38.5)

Engine Type 8 CYL. GAS

Engine Size 6.0 L

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

Weights kg (lbs)	Stripped	Test Inertial	Gross Static
W_{front}	1255 (2766)	1298 (2862)	1298 (2862)
W_{rear}	877 (1934)	970 (2138)	970 (2138)
W_{total}	2132 (4700)	2268 (5000)	2268 (5000)

Note any damage prior to test: None

Figure 2. Vehicle Dimensions, Test 2214MG-1

The Suspension Method (4) was used to determine the vertical component of the center of gravity (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.

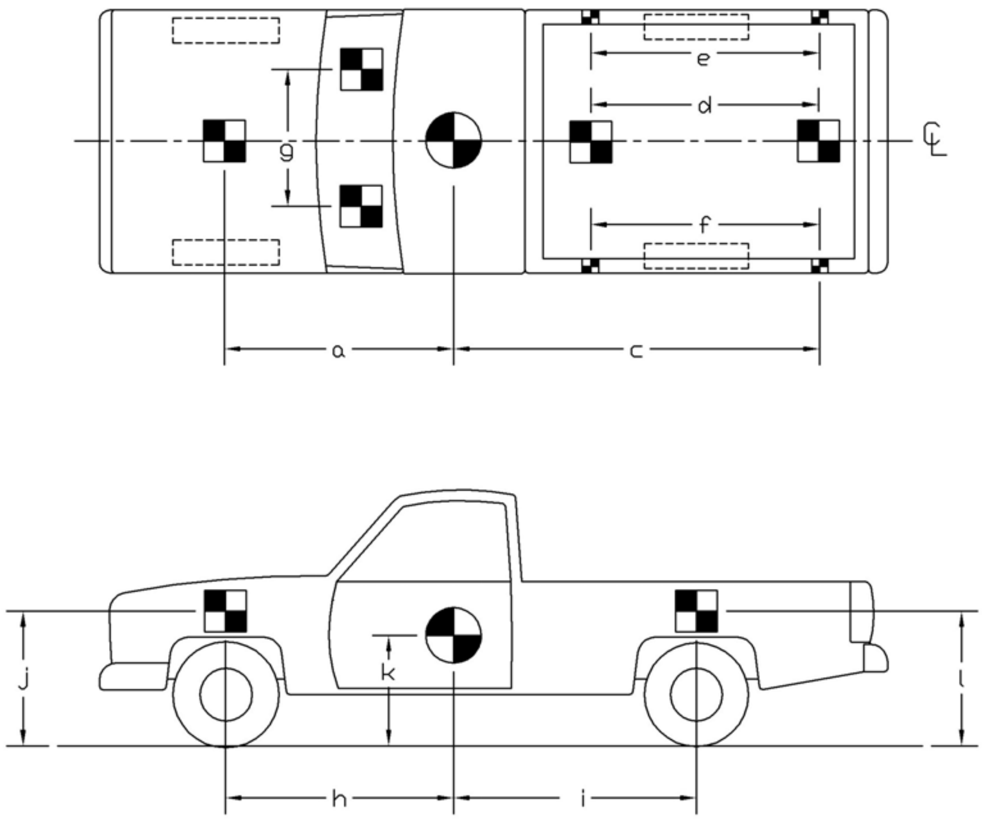
Square black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film and E/cam and Photron video, as shown in Figure 3. Checkered targets were placed on the center of gravity, on the driver's side door, on the passenger's side door, and on the roof of the 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 the high-speed film, E/cam video, and Photron 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 #: 2214MG-1

TARGET GEOMETRY -- mm (in.)

a 1702 (67.0)	d 1746 (68.75)	g 1124 (44.25)	j 1121 (44.125)
b –	e 7076 (81.75)	h 1451 (57.125)	k 691 (27.20)
c 2638 (103.875)	f 7076 (81.75)	i 1915 (75.375)	l 1184 (46.625)

Figure 3. Vehicle Target Locations, Test 2214MG-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 2214MG-1, two high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. One high-speed Photron video camera and five high-speed Red Lake E/cam video cameras, all with operating speeds of 500 frames/sec, and 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 fourteen camera locations for test 2214MG-1 is shown in Figure 4. The Locam films, Photron video, and E/cam videos were analyzed using the Vanguard Motion Analyzer, ImageExpress MotionPlus software, and Redlake Motion Scope software, respectively. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

3.4.4 Pressure Tape Switches

For test 2214MG-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 right-front tire of the test vehicle passed over it. Test vehicle speed was determined from electronic timing mark data recorded using TestPoint 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.

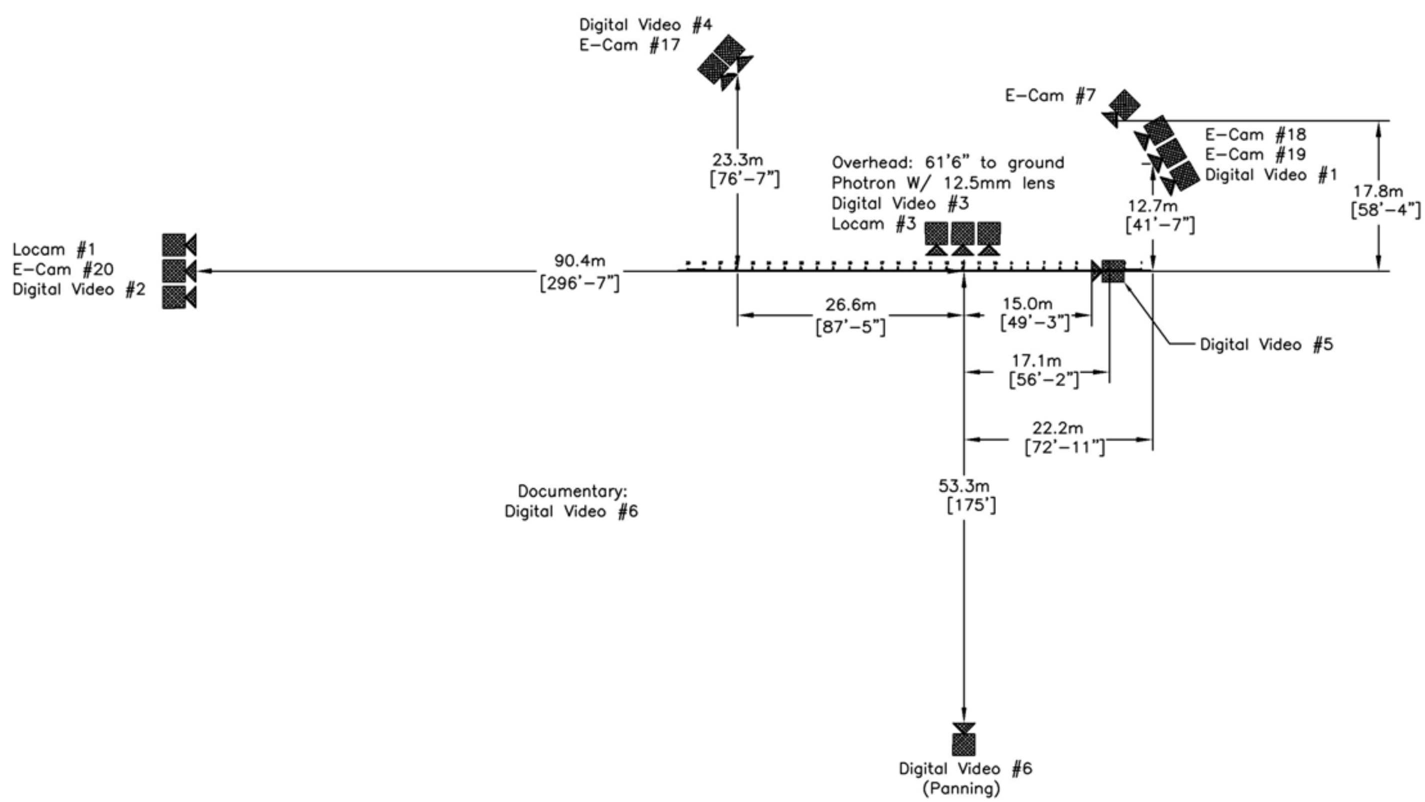


Figure 4. Location of High-Speed Cameras, Test 2214MG-1

4 DESIGN DETAILS

The test installation consisted of 55.25 m (181 ft - 3 in.) of standard 2.66-mm (12-gauge) thick W-beam guardrail supported by steel posts, as shown in Figure 5. Anchorage systems similar to those used on tangent guardrail terminals were utilized on both the upstream and downstream ends of the guardrail system. Design details are shown in Figures 5 through 10. The corresponding English-unit drawings are shown in Appendix A. Photographs of the test installation are shown in Figures 11 through 13.

The entire system was constructed with twenty-nine guardrail posts. Post nos. 3 through 27 were galvanized ASTM A36 steel W152x13.4 (W6x9) sections measuring 1,829 mm (6 ft) long. Post nos. 1, 2, 28, and 29 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 1,829-mm (6-ft) long steel foundation tubes, as shown in Figures 6 and 8. 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 29 were spaced 1,905 mm (75 in.) on center with a soil embedment depth of 1,016 mm (40 in.), as shown in Figure 7. 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 Report No. 350. For post nos. 3 through 27, 152-mm wide x 305-mm deep x 362-mm long (6-in. x 12-in. x 14.25-in.) wood spacer blockouts were used to block the rail away from the front face of the steel posts.

Standard 2.66-mm (12-gauge) thick W-beam rails with additional post bolt slots at half post spacing intervals were placed between post nos. 1 and 29, as shown in Figures 5 and 6. The W-beam's top rail height was 787 mm (31 in.) with a 632-mm (24 ⅞-in.) center mounting height. The rail splices have been moved to the center of the span location, as shown in Figures 5 and 6. All lap-splice connections between the rail sections were configured to reduce vehicle snag at the splice during the crash test.

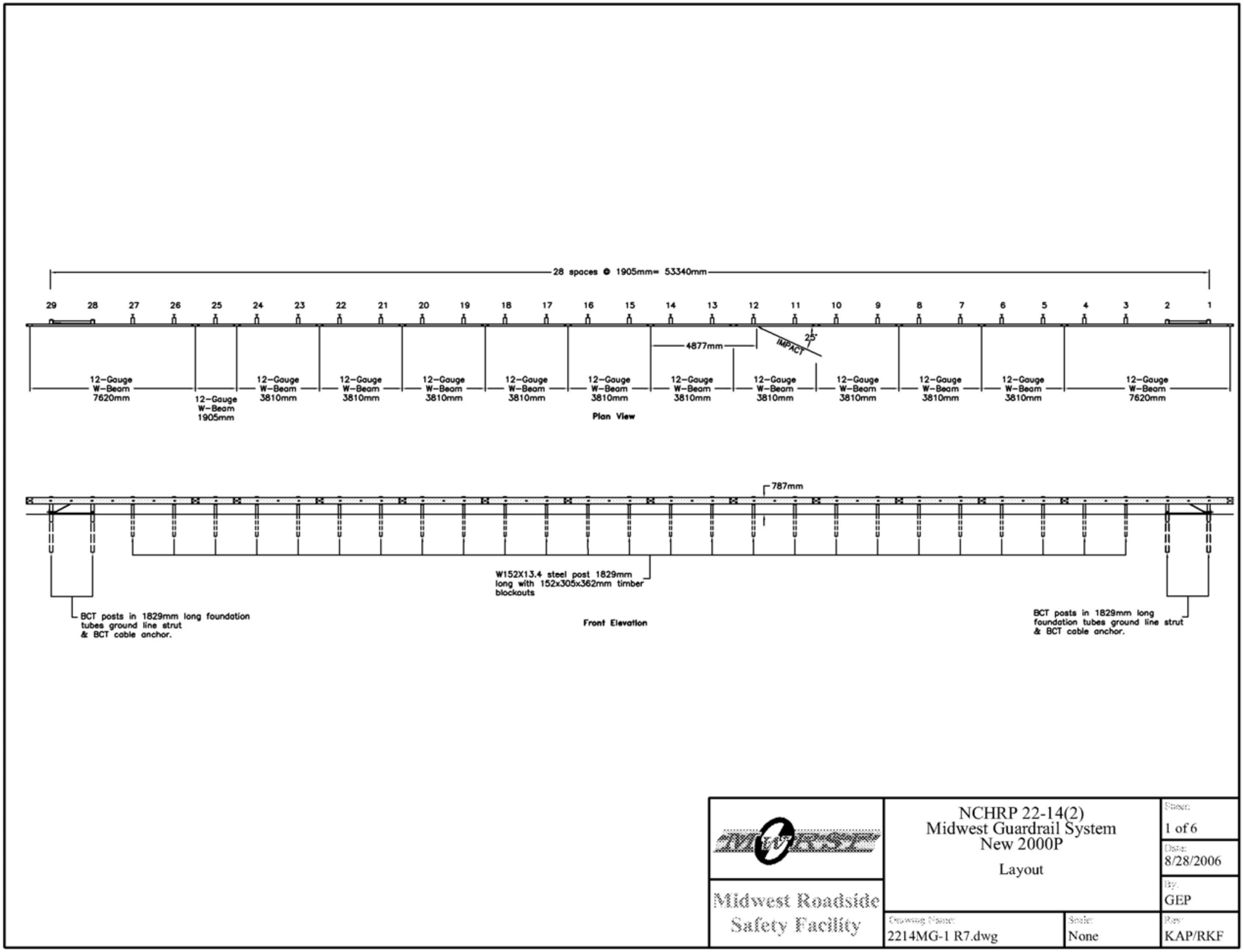


Figure 5. Layout for Midwest Guardrail System

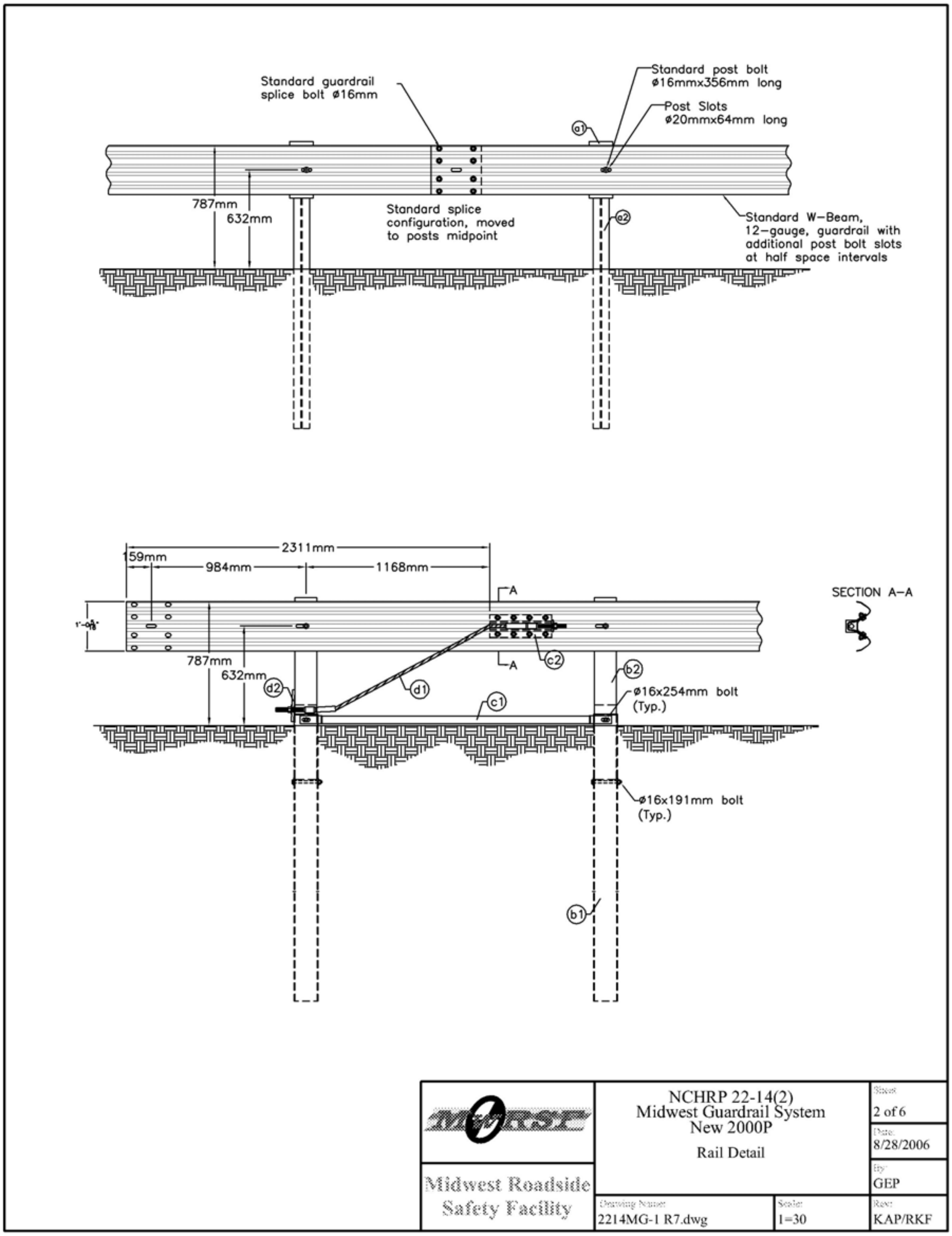


Figure 6. Midwest Guardrail System Rail Details

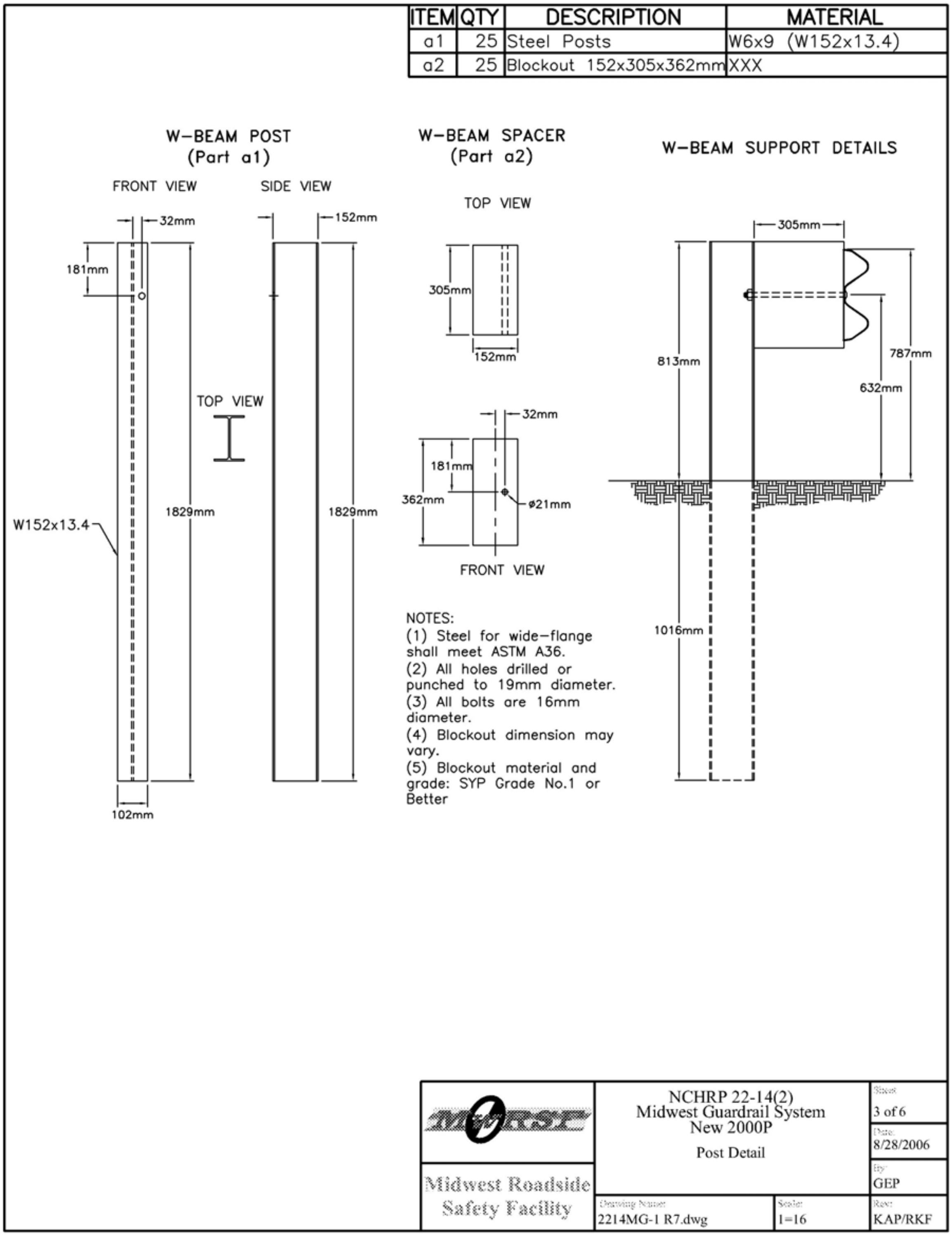


Figure 7. Midwest Guardrail System Post Details

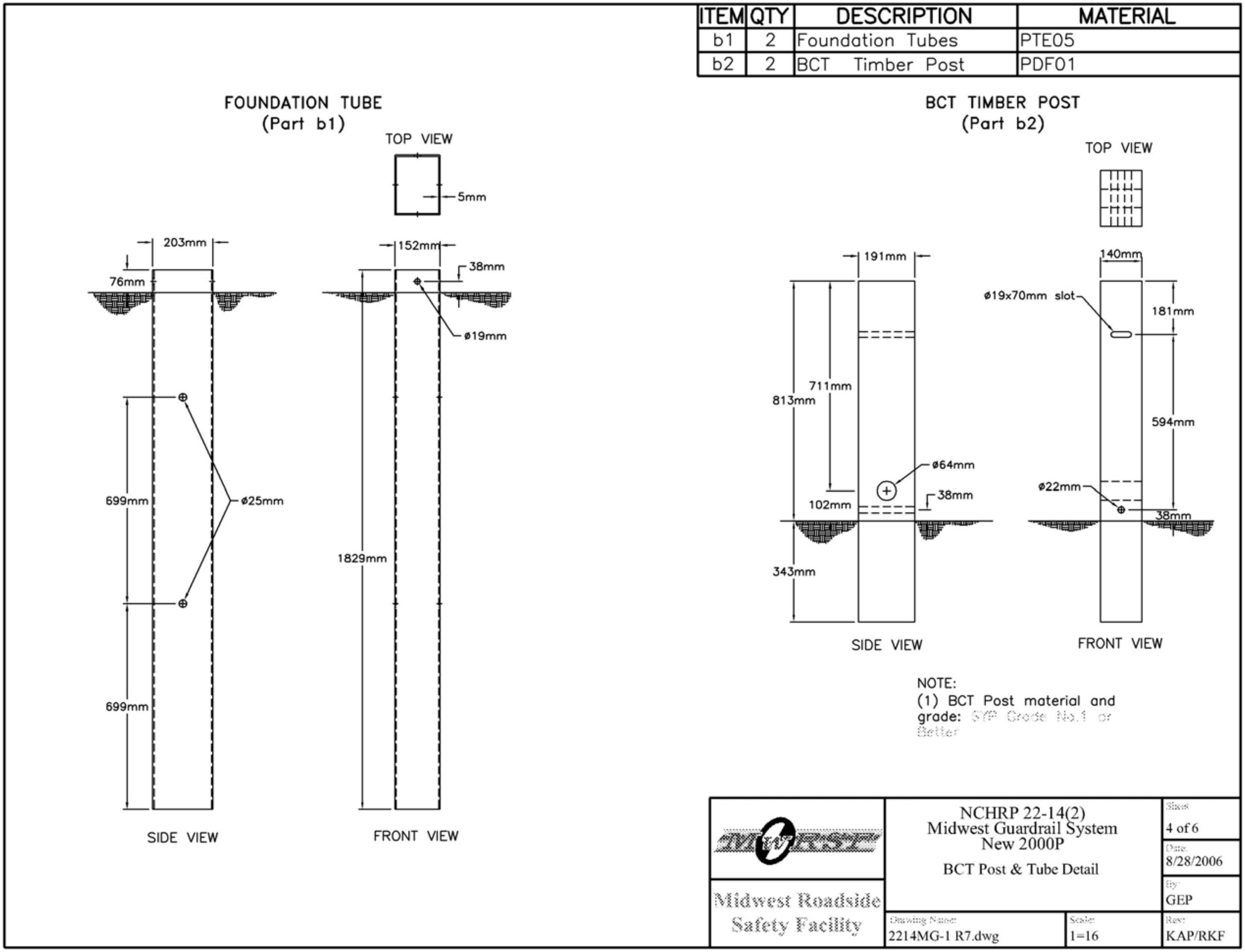


Figure 8. Midwest Guardrail System Anchorage Details

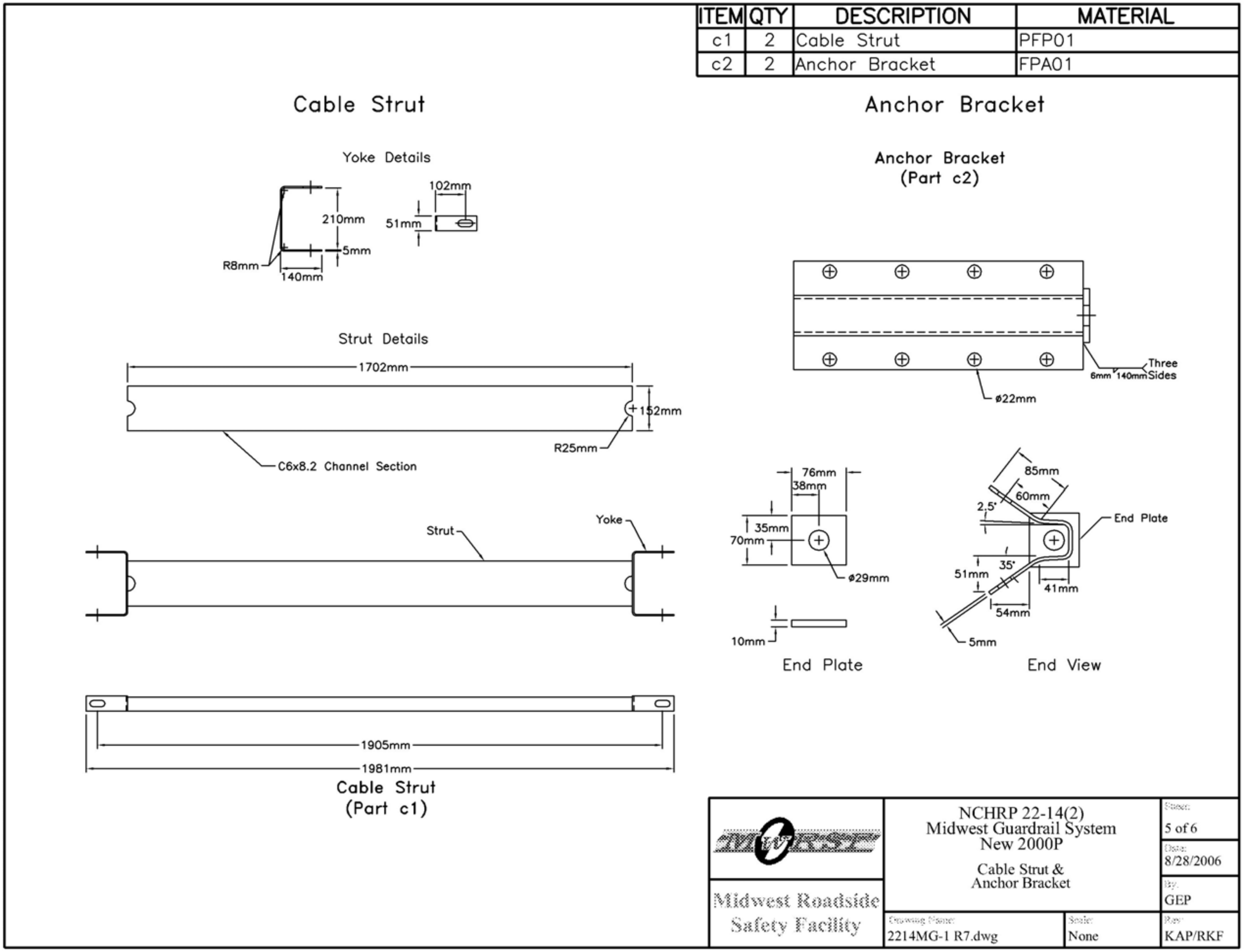


Figure 9. Midwest Guardrail System Anchorage Details

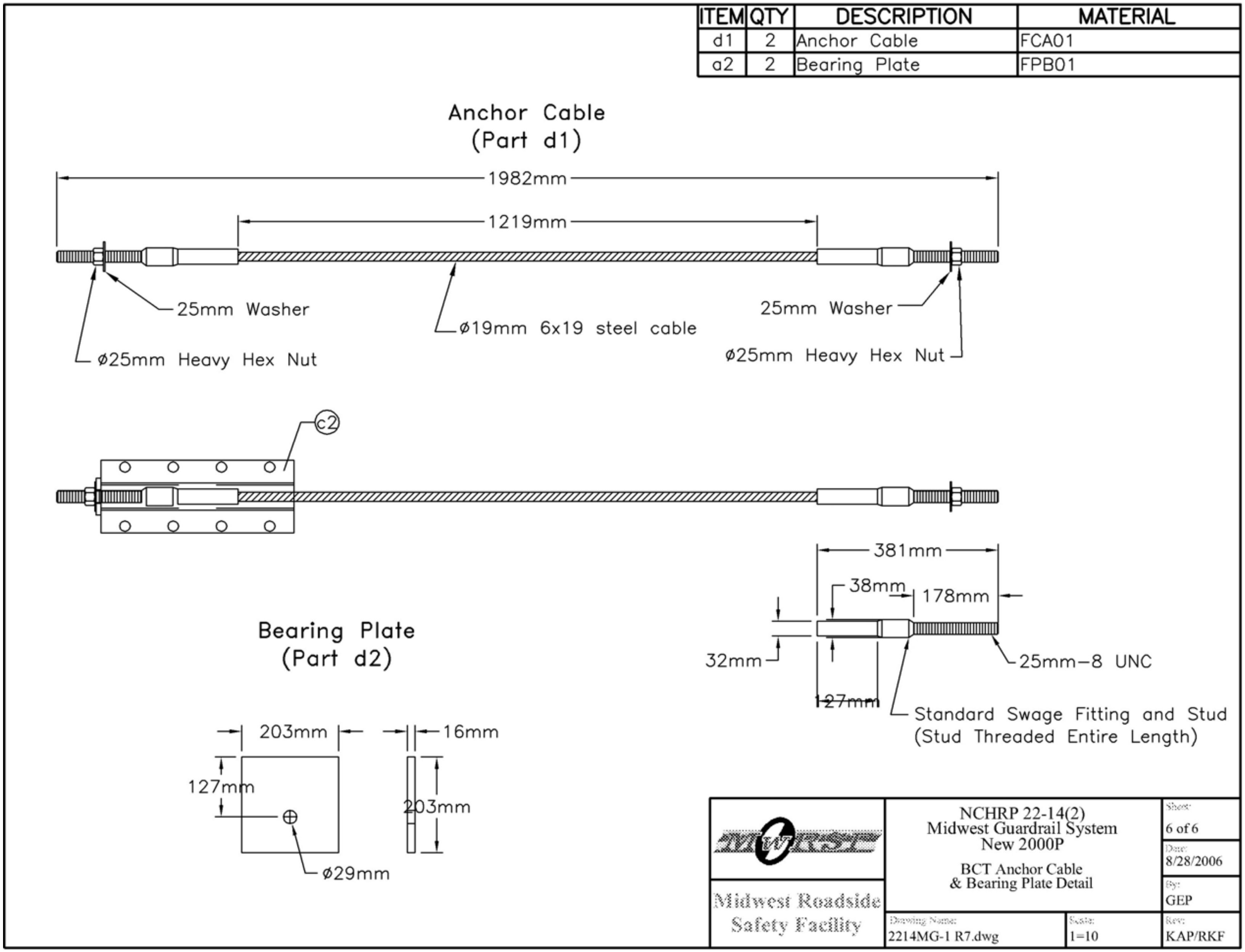


Figure 10. Midwest Guardrail System Anchorage Details

Figure 11. Midwest Guardrail System

Figure 12. Midwest Guardrail System

Figure 13. Midwest Guardrail System

5 CRASH TEST

5.1 Test 2214MG-1

The 2,268-kg (5,000-lb) pickup truck impacted the Midwest Guardrail System (MGS) at a speed of 100.7 km/h (62.6 mph) and at an angle of 25.2 degrees. A summary of the test results and sequential photographs are shown in Figure 14. The summary of the test results and sequential photographs in English units are shown in Appendix B. Additional sequential photographs are shown in Figures 15 through 18. Documentary photographs of the crash test are shown in Figures 19 and 20.

5.2 Test Description

Initial vehicle impact was to occur between post nos. 11 and 12, or 4.88 m (16 ft) upstream from the center of the splice at the midspan between post nos. 14 and 15, as shown in Figure 21. Actual vehicle impact occurred 4.84 m (15 ft - 10.5 in.) upstream from the center of the splice at the midspan between post nos. 14 and 15. At 0.024 sec after impact, post no. 12 deflected as the rail deformed. At 0.038 sec, the right-front corner of the hood deformed and protruded over the rail. At 0.064 sec, the front of the vehicle was located at post no. 13 which had deflected significantly. At this same time, the right-front quarter panel was in contact with the rail and post no. 14 began to deflect. At 0.070 sec, post no. 13 disengaged from the rail. At 0.088 sec, post no. 13 was deformed out of the way of the vehicle as the right-front tire was in contact with post no. 13 near the ground. At this same time, the rail was positioned under the wheel well and was in contact with the tire. At 0.118 sec, post no. 14 had deflected and the right-side door was in contact with the rail. At 0.128 sec, post no. 14 disengaged from the rail. At 0.138 sec, the vehicle redirected as the right-front quarter panel continued to crush inward and the right-front wheel assembly was deformed outward. At this same time, post no. 14 deflected significantly toward the ground, and post no. 15 began to deflect. At 0.170 sec, post no. 15 disengaged from the rail. At 0.188 sec, the right side of the vehicle was in contact with the system. At this same time, post no. 16 began to deflect. At 0.222 sec, the right corner of the rear bumper contacted the system. At this same time, the right-front tire ran over post no. 15, and post no. 16 disengaged from the rail. At 0.262 sec, the right-rear quarter panel deforming from contact with the rail. At 0.282 sec, post no. 16 deflected significantly toward the ground and post no. 17 began to deflect. At 0.364 sec, the vehicle became parallel to the guardrail with a resultant velocity of 68.0 km/h (42.3 mph). At 0.424 sec, post no. 17 deflected significantly backward and downstream as it disengaged from the rail. At 0.436 sec, the front of the vehicle pitched downward as the rear pitched upward. At 0.488 sec, a noticeable reduction in vehicle velocity was apparent. At 0.534 sec, the right side of the vehicle remained in contact with the rail. At 0.612 sec, the W-beam twisted counter-clockwise. At 0.874 sec, the vehicle exited the guardrail at an orientation angle of approximately 7 degrees and at a resultant velocity of 68.4 km/h (42.5 mph). At 1.040 sec, the vehicle redirected back toward the system. At 1.812 sec, the vehicle contacted the system again. At 1.900 sec, the hood deformed upward due to contact with the rail. At 2.192 sec, the vehicle continued to slide along the rail. The vehicle came to rest 23.45 m (76 ft - 11 in.) downstream from impact and against the traffic-side face of the guardrail system. The trajectory and final position of the pickup truck are shown in Figures 14 and 22.

5.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 23 through 28. Barrier damage consisted of deformed guardrail posts, disengaged wooden blockouts, contact marks on a guardrail section and posts, and deformed W-beam rail. The length of vehicle contact along the MGS system was approximately 12.5 m (41 ft), which spanned from 76 mm (3 in.) upstream from the centerline of post no. 12 through 953 mm (37.5 in.) downstream from the centerline of post no. 18.

Moderate deformation and flattening of the impacted section W-beam rail occurred between post nos. 13 and 18. Contact marks were found on the guardrail between post nos. 12 and 19. A small tear was found in the top corrugation 6 mm (0.25 in.) upstream of post no. 14. The guardrail buckled at 216 mm (8.5 in.) upstream of post no. 11, 64 mm (2.5 in.) downstream of the midspan between post nos. 11 and 12, and at post no. 12. The guardrail also buckled at the upstream side of splice between post nos. 12 and 13, at the post bolt hole of post no. 14, and 368 mm (14.5 in.) downstream from the midspan between post nos. 13 and 14. Other guardrail buckle points were found at 267 mm (10.5 in.) upstream of post no. 15 and 1,276 mm (50.25 in.) downstream of post no. 15. The guardrail encountered numerous buckle points at post no. 16. Major buckling of the guardrail occurred at 533 mm (21 in.) downstream of post no. 16. The guardrail also buckled at 51 mm (2 in.) upstream of post no. 18, 254 mm (10 in.) downstream of post no. 18, at post no. 19, and 279 mm (11 in.) downstream of post no. 19. The W-beam was pulled off post nos. 3 through 10 and 13 through 18. The W-beam rail sustained tearing and significant yielding around the post bolt slots at post nos. 14 through 19, while only minor yielding occurred around the post bolt slots at post nos. 11 through 13. No significant guardrail damage occurred downstream of post no. 20, except for slight rail deflection and minor contact marks between post nos. 22 and 25 due to secondary vehicle contact with the system before coming to rest.

Steel post nos. 3 through11, 13, and 20 encountered minor twisting. The flanges of post nos. 7 and 11 were bent at the bolt attachment. Post nos. 10 also rotated backwards slightly. Post nos. 11 and 13 yielded at the top of the post. Post no. 12 encountered significant twisting and was bent slightly downstream. Post nos. 13 and 19 rotated backwards slightly, while post no. 19 also encountered minor buckling of the web. Post nos. 14 through 18 were bent longitudinally downstream toward the ground. Post no. 14 encountered significant buckling of the downstream front flange. Post no. 15 and 17 were severely buckled, while the bolt hole of post no. 17 was torn out. The right flange of post no. 16 and the web of post no. 18 buckled. Contact marks were found on the upstream edge of the back flange of post no. 16 and toward the top of the upstream edge of the back flange of post no. 17. Small gouges were found in the web of post no. 17 from the post bolt. The post bolts at post nos. 13 and 15 sheared off. The upstream and downstream anchorage systems moved longitudinally and the ground struts encountered plastic deformations on both ends. The upstream anchorage posts deflected downstream, while the downstream anchorage posts deflected upstream, but all four wood BCT posts remained undamaged.

The wooden blockouts at post nos. 5 through 7 and 10 rotated slightly while still attached to the post. The wooden blockout at post no. 11 encountered slight damage to the upstream front corners due to contact from the W-beam rail. The wooden blockout at post no. 12 rotated to approximately a 45 degree angle and remained attached to the post. The wooden blockouts at post nos. 14 through 17 were fractured and removed from the post.

The permanent set of the barrier system is shown in Figure 23. The maximum lateral permanent set rail and post deflections were 1,089 mm (42.875 in.) at the centerline of post no. 16 and 648 mm (25.5 in.) at post no. 13, as measured in the field. The maximum lateral dynamic rail and post deflections were 1,447 mm (57.0 in.) at the midspan between post nos. 14 and 15 and 764 mm (30.1 in.) at post no. 13, as determined from high-speed digital video analysis. The working width of the system was found to be 1,456 mm (57.3 in.).

5.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 29 through 32. Occupant compartment deformations to the right side and center of the floorboard, as shown in Figure 32, were judged insufficient to cause serious injury to the vehicle occupants. Maximum longitudinal deflections of 13 mm (0.5 in.) were located near the center of the right-side floor pan. Maximum lateral deflections of 25 mm (1.0 in.) were located near the center of the right-side floor pan. Maximum vertical deflections of 13 mm (0.5 in.) were located near the firewall at the right-front corner and center of the right side. Complete occupant compartment deformations and the corresponding locations are provided in Appendix C.

Damage was concentrated on the right-front corner of the vehicle. The right-front quarter panel was deformed inward and downward toward the engine compartment. The right side of the front bumper was flattened and bent back toward the engine compartment and contacted the lower frame rail. The box was bent upward and inward behind the right-rear wheel. The right side of the hood was bent slightly. The right-front wheel assembly deformed and crushed inward toward the engine compartment. The right-side ball joints and steering linkage were fractured. The upper control arm was bent. The right-front tire disengaged from the rest of the wheel assembly. The right-rear tire deflated. The right-side headlight and park light fractured and disengaged from the vehicle. All window glass remained undamaged. The left side and rear of the vehicle remained undamaged.

5.5 Occupant Risk Values

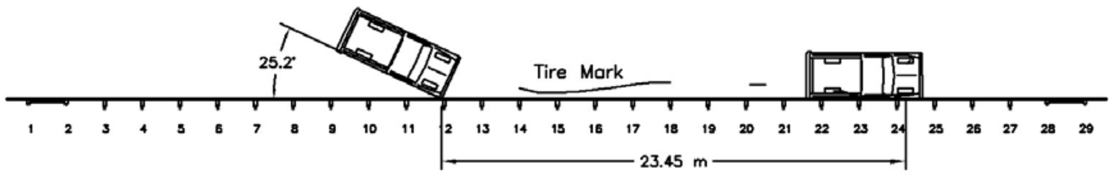
The longitudinal and lateral occupant impact velocities were determined to be 5.20 m/s (17.06 ft/s) and 4.51 m/s (14.80 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 8.77 Gs and 5.34 Gs, respectively. It is noted that the occupant impact velocities (OIVs) and occupant ridedown decelerations (ORDs) were within the suggested limits provided in the Update to NCHRP Report No. 350. The THIV and PHD values were determined to be 7.17 m/s (23.52 ft/s) and 9.41 Gs, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 14. Results are shown graphically in Appendix D. The results from the rate transducer are shown graphically in Appendix D.

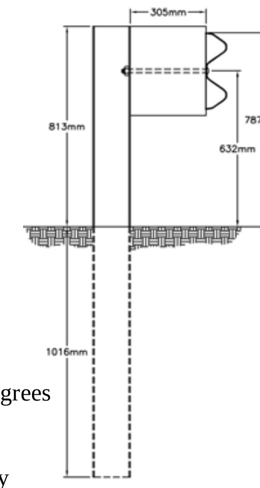
5.6 Discussion

The analysis of the test results for test no. 2214MG-1 showed that the Midwest Guardrail 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 guardrail 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. 2214MG-1 conducted on the Midwest Guardrail System was determined to be acceptable according to the TL-3 safety performance criteria found in the Update to NCHRP Report No. 350.

It should be noted that the center of gravity of 686 mm (27 in.) of the pickup tested was determined to be at the low end of the c.g. height range of the large passenger vehicle class (i.e., light trucks) currently on the roadways. Consequently, this vehicle was judged to not be an accurate representation of the light trucks on the roadways, which accounts for approximately half of all vehicles sold in this country. Since it was desired that the test vehicle represented the taller vehicles in this class, a minimum c.g. height of 710 mm (28 in.) was set.

0.000 sec | 0.118 sec | 0.222 sec | 0.378 sec | 0.466 sec





- Test Agency . . . . MwRSF
- Test Number 2214MG-1
- Date 5/7/04
- NCHRP 350 Update Test Designation . . 3-11
- Appurtenance . . . . Midwest Guardrail System
- Total Length . . . . 55.25 m
- Key Elements - Steel W-Beam
  - Thickness . . . . 2.66 mm
  - Top Mounting Height . . . . 787 mm
- Key Elements - Steel Posts
  - Post Nos. 3 - 27 . . . . W152x13.4 by 1,829 mm long
  - Spacing . . . . 1,905 mm
- Key Elements - Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) . . . . 140 mm x 190 mm by 1,080 mm long
- Key Elements - Steel Foundation Tube . 1,829 mm long
- Key Elements - Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 152 mm x 305 mm by 362 mm long
- Type of Soil . . . . Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model . . . . 2002 GMC 2500 ¾-ton Pickup
  - Curb . . . . 2,132 kg
  - Test Inertial . . . . 2,268 kg
  - Gross Static . . . . 2,268 kg
- Impact Conditions
  - Speed . . . . 100.7 km/h
  - Angle . . . . 25.2 degrees
  - Impact Location . . . . 4.84 m upstream splice between posts 14 & 15
- Exit Conditions
  - Speed . . . . 68.4 km/h
  - Angle . . . . Appx. 7 degrees
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 23.45 m downstream Against traffic-side face
- Occupant Impact Velocity (350 Update)
  - Longitudinal . . . . 5.20 m/s < 12 m/s
  - Lateral . . . . 4.51 m/s < 12 m/s
- Occupant Ridedown Deceleration (350 Update)
  - Longitudinal . . . . 8.77 Gs < 20 Gs
  - Lateral . . . . 5.34 Gs < 20 Gs
- THIV (not required) . . . . 7.17 m/s
- PHD (not required) . . . . 9.41 Gs
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . 1,089 mm
  - Dynamic . . . . 1,447 mm
  - Working Width . . . . 1,456 mm
- Vehicle Damage . . . . Moderate
  - VDS[5] 1-RFQ-4
  - CDC[6] 1-RYEN3
  - Maximum Deformation . . . . 25 mm at right-center floorpan

Figure 14. Summary of Test Results and Sequential Photographs, Test 2214MG-1

0.000 sec

0.106 sec

0.210 sec

0.296 sec

0.422 sec

0.598 sec

0.732 sec

1.104 sec

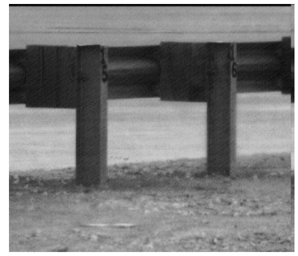
1.812 sec

2.800 sec

Figure 15. Additional Sequential Photographs, Test 2214MG-1

Figure 16. Additional Sequential Photographs, Test 2214MG-1

0.004 sec



0.004 sec

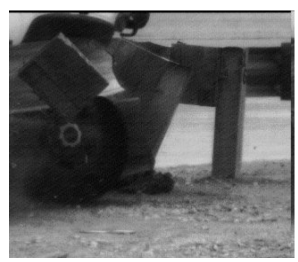
0.060 sec

0.062 sec

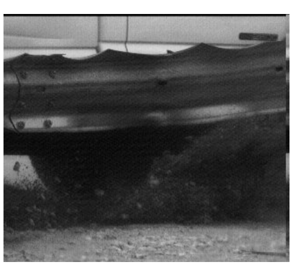
0.088 sec

0.084 sec

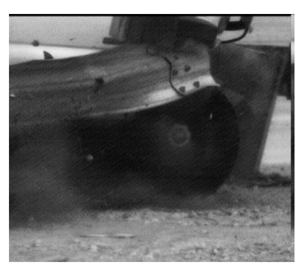
0.132 sec



0.116 sec



0.162 sec



0.168 sec

Figure 17. Additional Sequential Photographs, Test 2214MG-1

0.000 sec

0.000 sec

0.300 sec

0.133 sec

0.467 sec

0.333 sec

0.667 sec

0.467 sec

1.200 sec

0.733 sec

2.600 sec

1.167 sec

Figure 18. Additional Sequential Photographs, Test 2214MG-1

Figure 19. Documentary Photographs, Test 2214MG-1

Figure 20. Documentary Photographs, Test 2214MG-1

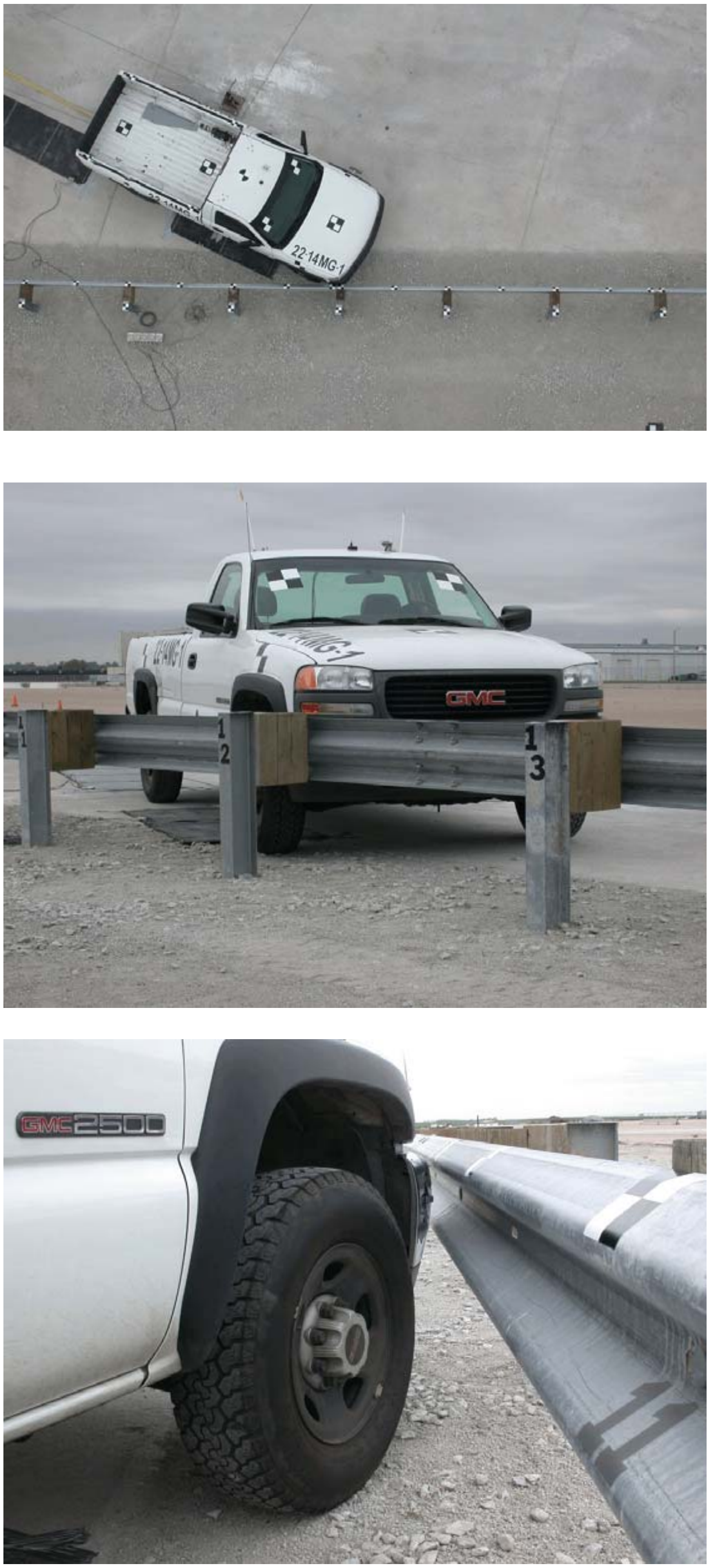


Figure 21. Impact Location, Test 2214MG-1

Figure 22. Vehicle Final Position and Trajectory Marks, Test 2214MG-1

Figure 23. Midwest Guardrail System Barrier Damage, Test 2214MG-1

Figure 24. Midwest Guardrail System Post Nos. 12 through 15 Damage, Test 2214MG-1

Figure 25. Midwest Guardrail System Post Nos. 16 through 19 Damage, Test 2214MG-1

Figure 26. Post Nos. 9, 10, and 12 through 14 Guardrail Damage, Test 2214MG-1

Figure 27. Post Nos. 15 through 18 Guardrail Damage, Test 2214MG-1

Figure 28. Upstream Anchorage Damage, Test 2214MG-1

Figure 29. Vehicle Damage, Test 2214MG-1

Figure 30. Vehicle Damage, Test 2214MG-1

Figure 31. Vehicle Damage, Test 2214MG-1

Figure 32. Occupant Compartment Deformation, Test 2214MG-1

6 SUMMARY AND CONCLUSIONS

A strong-post, W-beam guardrail system, the MGS 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. While the vehicle mass and impact conditions are included in the proposed Update to NCHRP Report No. 350, the ¾-ton 2-door pickup truck utilized in this test was ultimately not recommended in the Update to NCHRP Report No. 350.

Table 3. Summary of Safety Performance Evaluation Results

Evaluation Factors		Evaluation Criteria	Test 2214MG-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

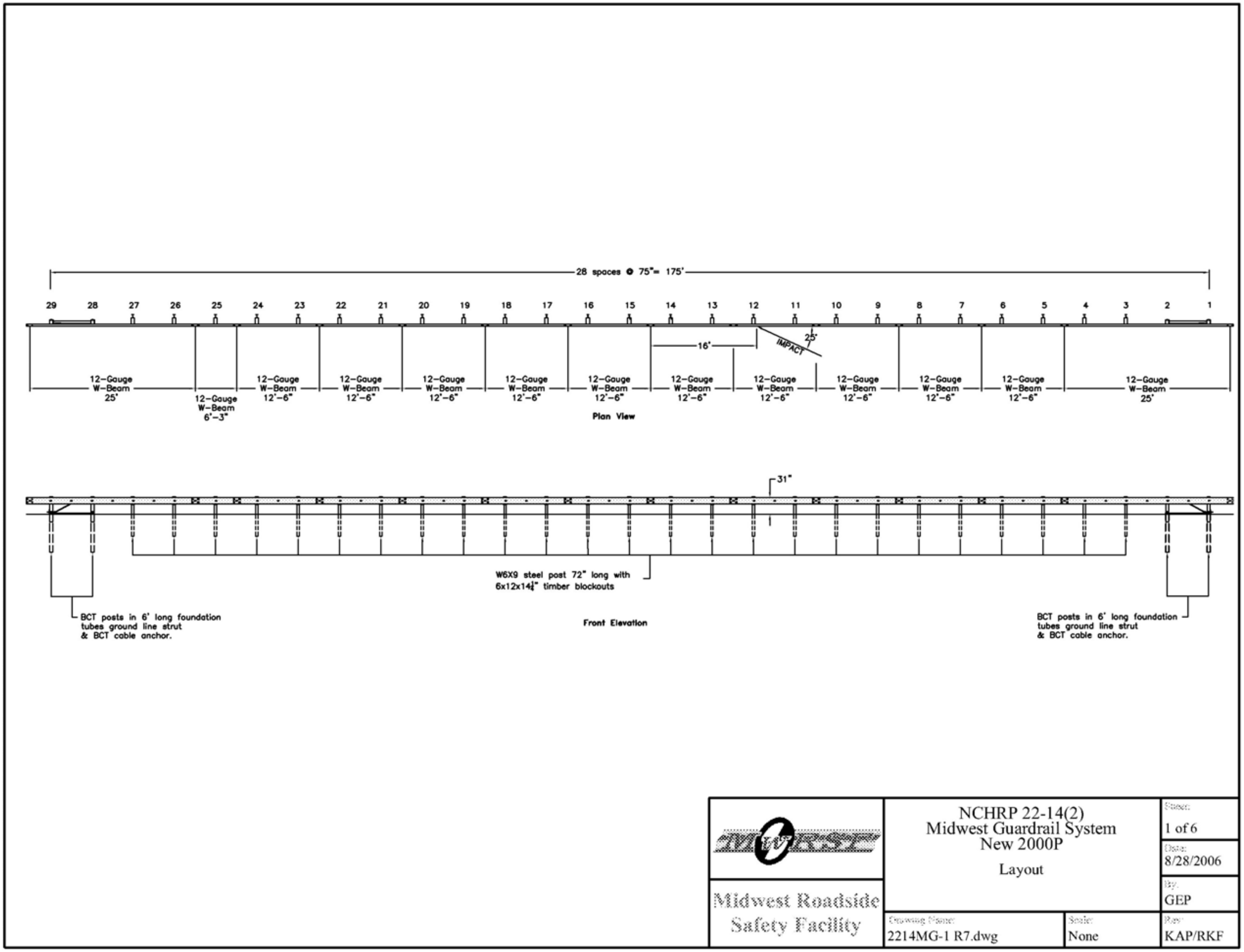


Figure A-1. Layout of Midwest Guardrail System Design (English)

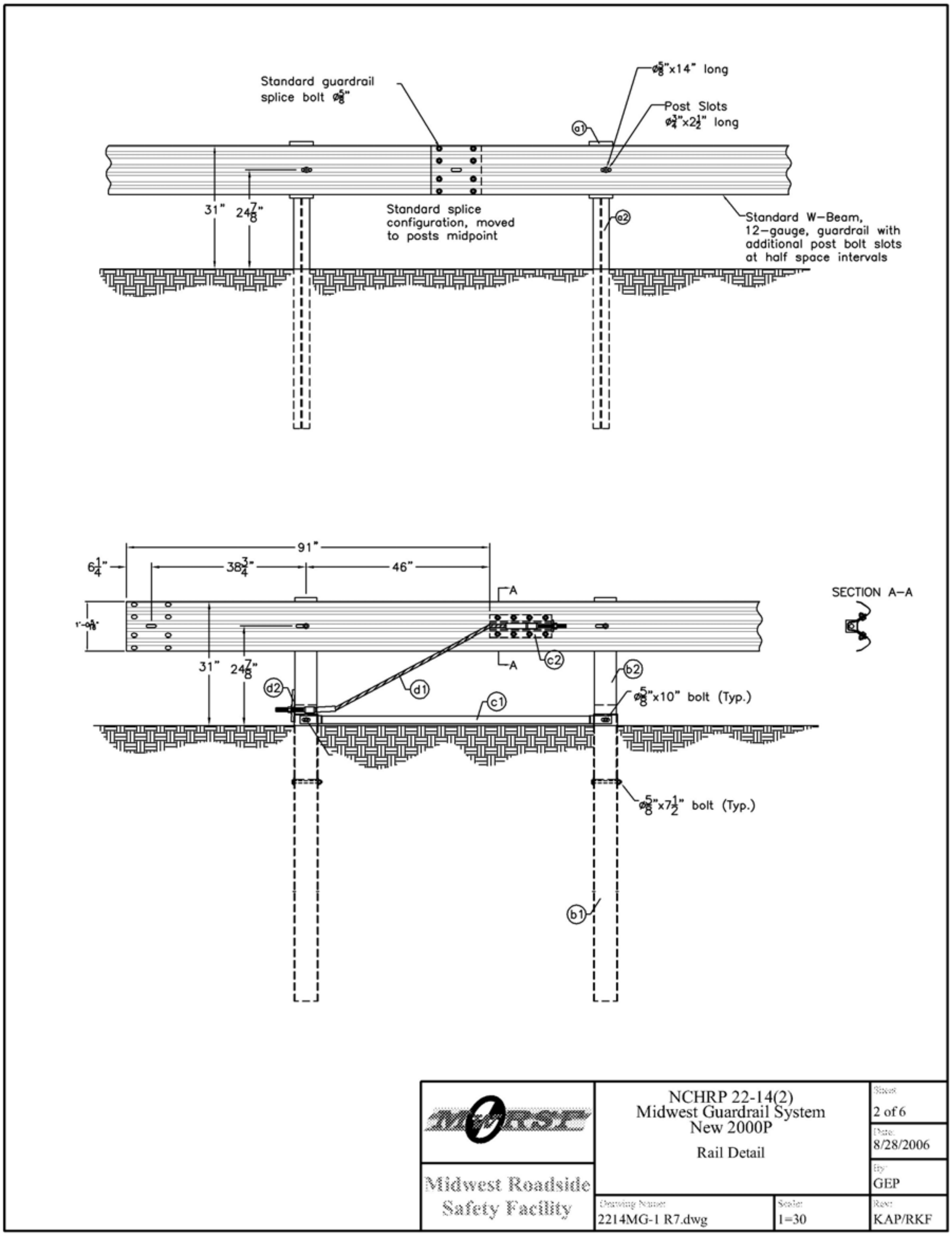


Figure A-2. Midwest Guardrail System Rail Details (English)

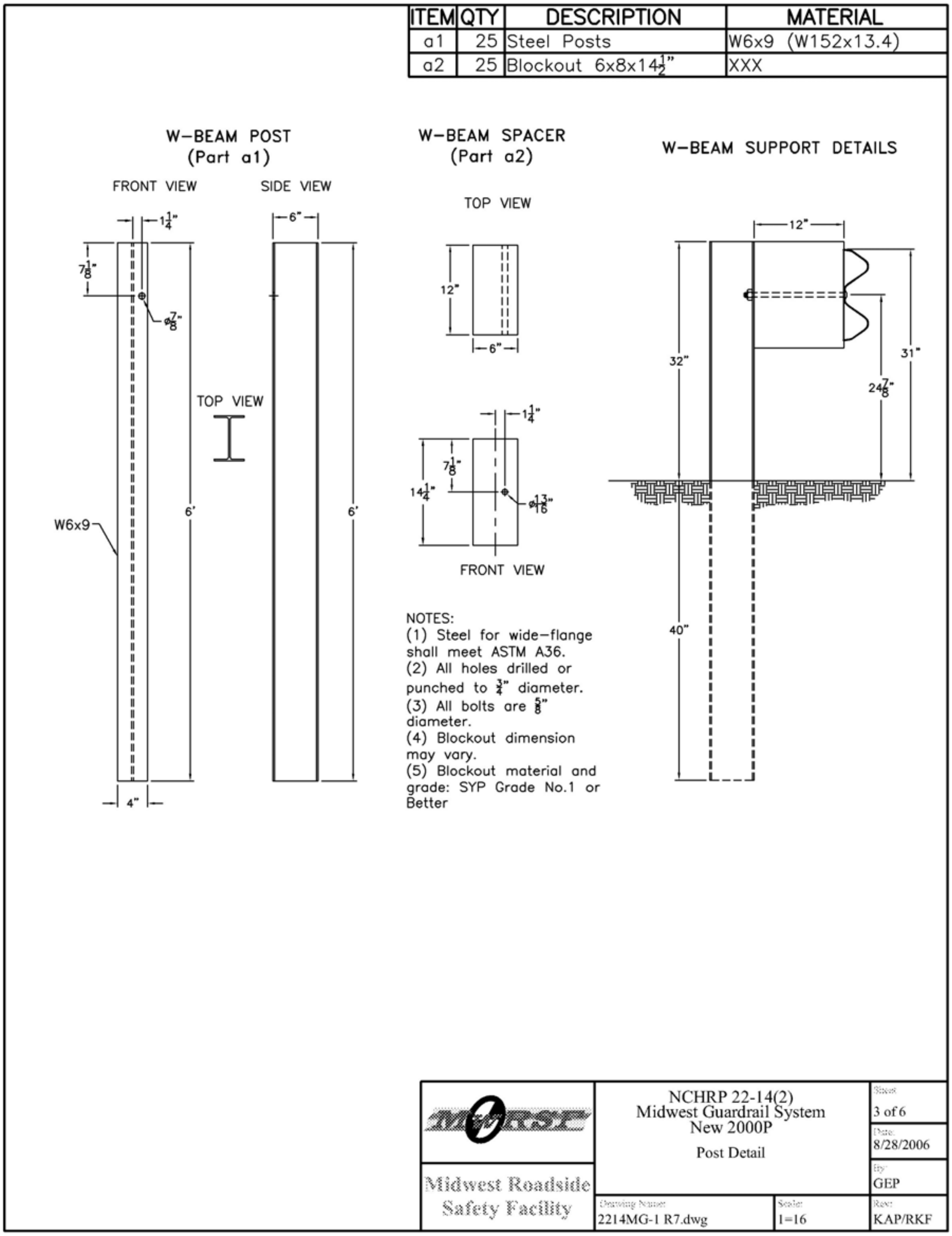


Figure A-3. Midwest Guardrail System Post Details (English)

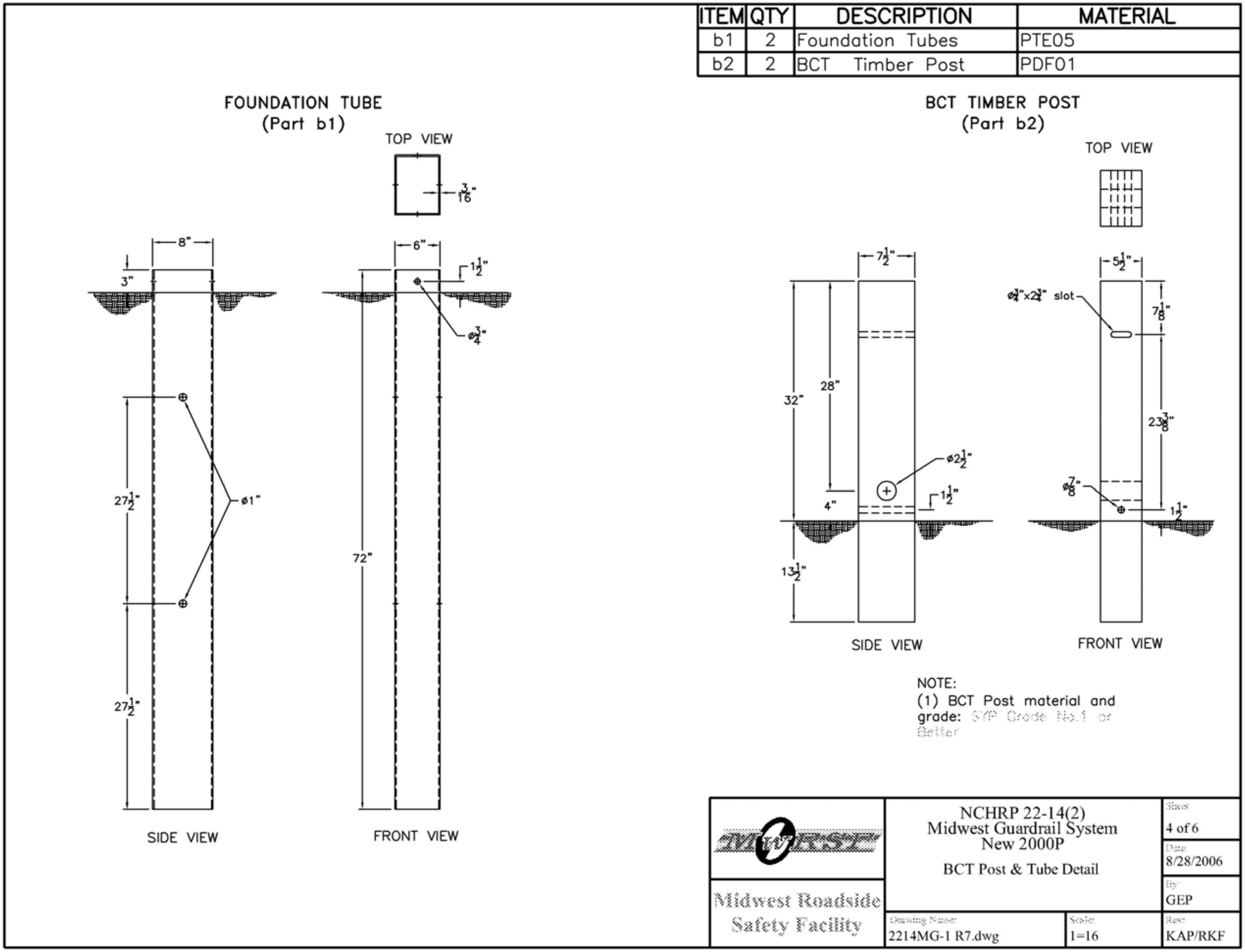


Figure A-4. Midwest Guardrail System Anchorage Details (English)

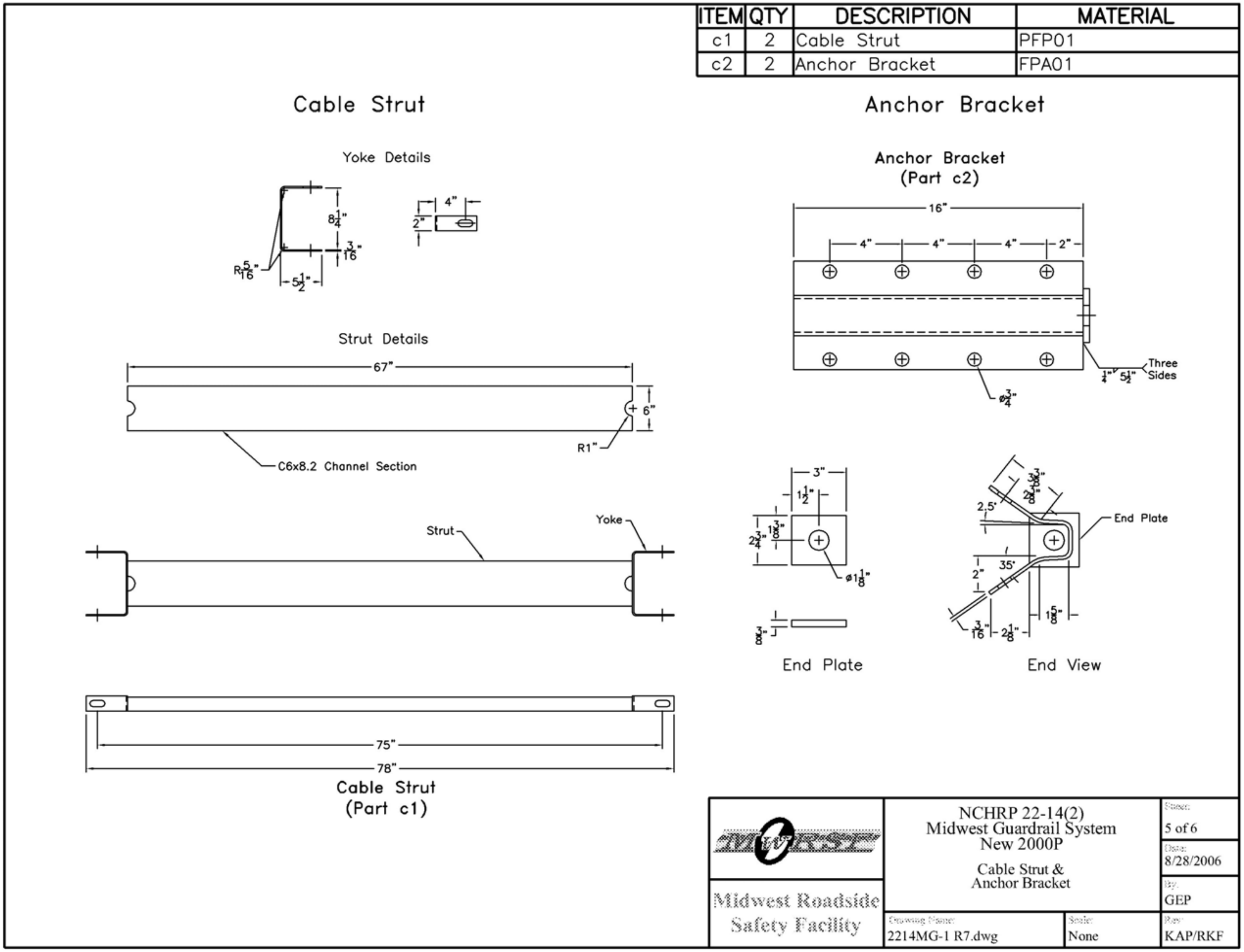


Figure A-5. Midwest Guardrail System Anchorage Details (English)

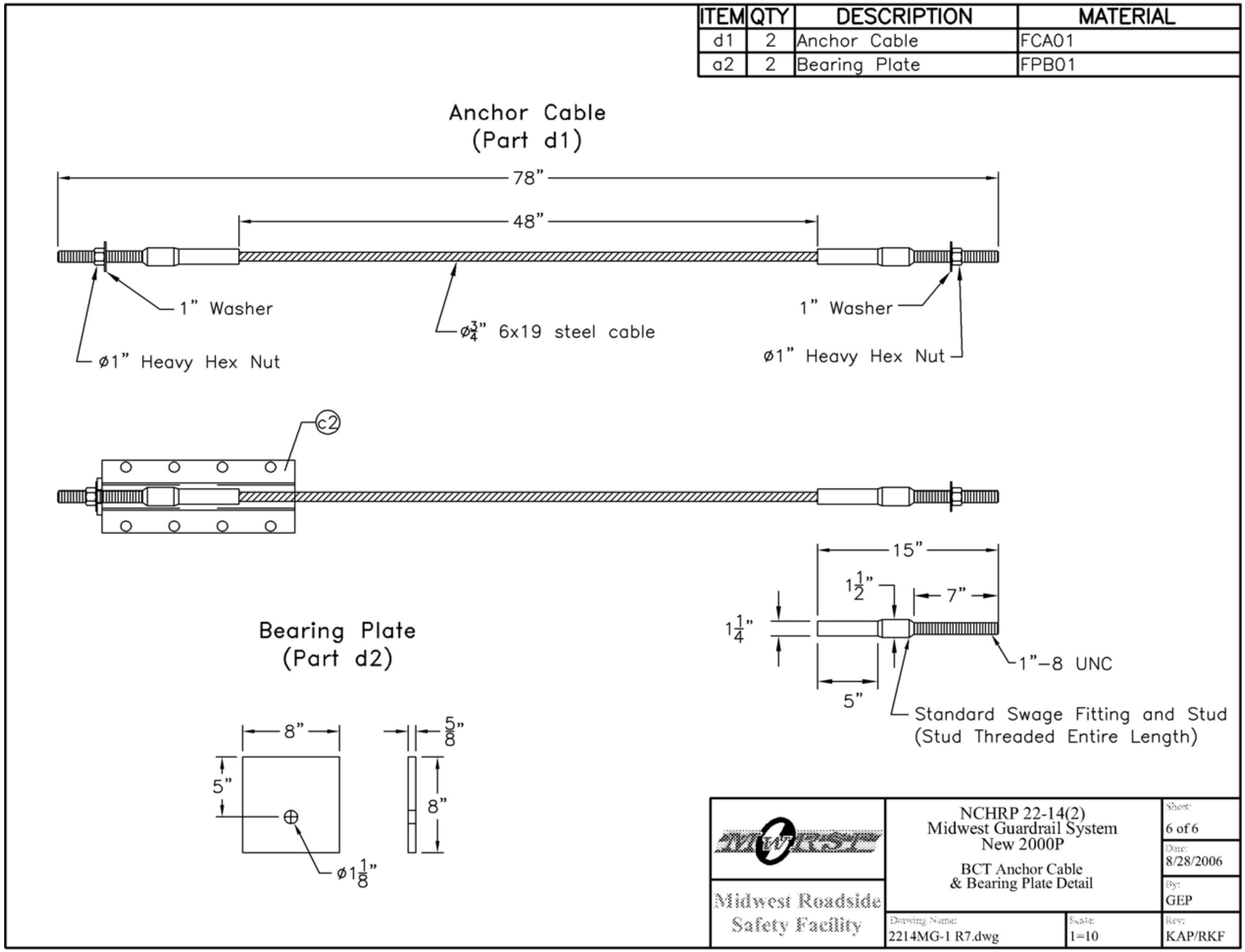


Figure A-6. Midwest Guardrail System Anchorage Details (English)

APPENDIX B

Test Summary Sheet in English Units

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

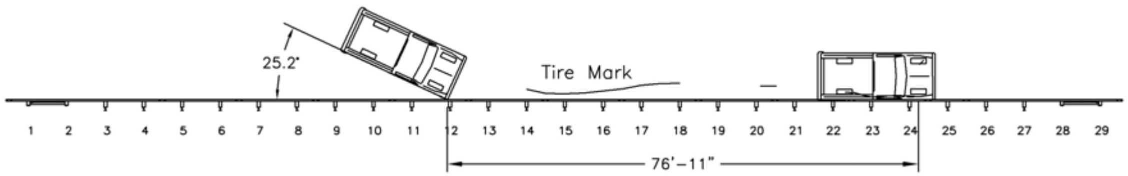

0.000 sec

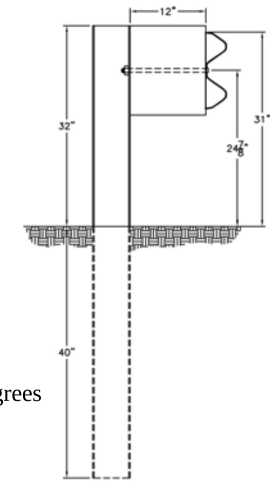

0.118 sec


0.222 sec


0.378 sec


0.466 sec





- Test Agency . . . . MwRSF
- Test Number 2214MG-1
- Date 5/7/04
- NCHRP 350 Update Test Designation . . 3-11
- Appurtenance . . . . Midwest Guardrail System
- Total Length . . . . 181 ft - 3 in.
- Key Elements - Steel W-Beam
  - Thickness . . . . 12 gauge
  - Top Mounting Height . . . . . . 31 in.
- Key Elements - Steel Posts
  - Post Nos. 3 - 27 . . . . W6x9 by 6 ft long
  - Spacing . . . . 75 in.
- Key Elements - Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) . . . . 5.5 in. x 7.5 in. by 42.5 in. long
- Key Elements - Steel Foundation Tube . 6-ft long
- Key Elements - Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 6 in. x 12 in. by 14.25 in. long
- Type of Soil . . . . Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model . . . . 2002 GMC 2500 ¾-ton Pickup
  - Curb . . . . 4,700 lbs
  - Test Inertial . . . . 5,000 lbs
  - Gross Static . . . . 5,000 lbs
- Impact Conditions
  - Speed . . . . 62.6 mph
  - Angle . . . . 25.2 degrees
  - Impact Location . . . . 15 ft - 10.5 in. upstream splice btwn posts 14 & 15
- Exit Conditions
  - Speed . . . . 42.5 mph
  - Angle . . . . Appx. 7 degrees
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 76 ft - 11 in. downstream
    Against traffic-side face
- Occupant Impact Velocity (350 Update)
  - Longitudinal . . . . 17.06 ft/s < 39.4 ft/s
  - Lateral . . . . 14.80 ft/s < 39.4 ft/s
- Occupant Ridedown Deceleration (350 Update)
  - Longitudinal . . . . 8.77 Gs < 20 Gs
  - Lateral . . . . 5.34 Gs < 20 Gs
- THIV (not required) . . . . 23.52 ft/s
- PHD (not required) . . . . 9.41 Gs
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . 42.875 in.
  - Dynamic . . . . 57.0 in.
  - Working Width . . . . 57.3 in.
- Vehicle Damage . . . . Moderate
  - VDS[5] 1-RFQ-4
  - CDC[6] 1-RYEN3
  - Maximum Deformation . . . . . 1 in. at right-center floorpan

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

APPENDIX C

Occupant Compartment Deformation Data, Test 2214MG-1

VEHICLE PRE/POST CRUSH INFO

TEST: 2214MG-1
VEHICLE: 2002/GMC/white

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z	Secondary points					
										Y2	Z2	Y2'	Z2'	Del Y2	Del Z2
1	54.75	3.25	0	54.75	3.25	0	0	0	0		0		0.25		-0.25
2	59.5	9.75	1	59.25	10	0.75	-0.25	0.25	-0.25		1		1		0
3	61.75	17.25	1.5	61.75	17	2	0	-0.25	0.5		1.75		2		-0.25
4	62	22.5	1.25	62.25	22.25	1.25	0.25	-0.25	0		1.5		1.25		0.25
5	61	26	0.75	61.25	25.75	1	0.25	-0.25	0.25		1.25		1		0.25
6	60.75	29.5	0.5	60.75	29.5	0.25	0	0	-0.25		1		0.5		0.5
7	53.25	8.25	2.75	53.25	8	2.75	0	-0.25	0		3		2.75		0.25
8	56.5	12.25	6.25	56.5	11.75	6.25	0	-0.5	0		6.25		6.5		-0.25
9	58	17.5	5	58	17.25	4.75	0	-0.25	-0.25		5		5		0
10	56	23.25	6.75	56	23	6.75	0	-0.25	0		7		7		0
11	56.5	30	6.5	56.5	30	6.25	0	0	-0.25		7		7		0
12	44.75	3.5	2.25	44.5	3.5	2.25	-0.25	0	0		2.5		2.25		0.25
13	45.75	9	7.25	45.75	8.75	7.25	0	-0.25	0		7.5		7.25		0.25
14	46.5	15.25	9.5	46.5	15	9.5	0	-0.25	0		10		9.75		0.25
15	49.25	20.25	9.75	49.25	21.25	9.75	0	1	0		10		9.75		0.25
16	48	29.25	9.75	48	29.25	9.5	0	0	-0.25		10		10		0
17	35.75	5.25	4	35.75	5.75	4	0	0.5	0		4.5		4.25		0.25
18	37.75	11	9.75	37.75	10.5	9.75	0	-0.5	0		10		10		0
19	39.5	20	10	40	19.75	10	0.5	-0.25	0		10.25		10.25		0
20	39.5	25.25	10.25	39.5	25.25	10	0	0	-0.25		10.25		10.25		0
21	39	29.25	10.25	39	29.25	10	0	0	-0.25		10.25		10.25		0
22	32.25	27.25	8.5	32.25	27.25	8.5	0	0	0		8.5		8.5		0
23	31.5	15	8.5	31.75	14.75	8.5	0.25	-0.25	0		8.5		8.5		0
24	23	27.25	9.25	23	27.25	9.25	0	0	0		9		9		0
25	20	16.5	9	20	16.25	9	0	-0.25	0		8.75		9		-0.25
26	43.25	0.75	24.25	43.5	0.75	24.25	0.25	0	0		24		24.25		-0.25
27	39.75	13.75	20.5	40	13.75	20.75	0.25	0	0.25		20.25		20.25		0
28	39.75	28	20	39.5	28	19.75	-0.25	0	-0.25		19.5		19.75		-0.25
29															
30															

ORIENTATION AND REFERENCE INFO

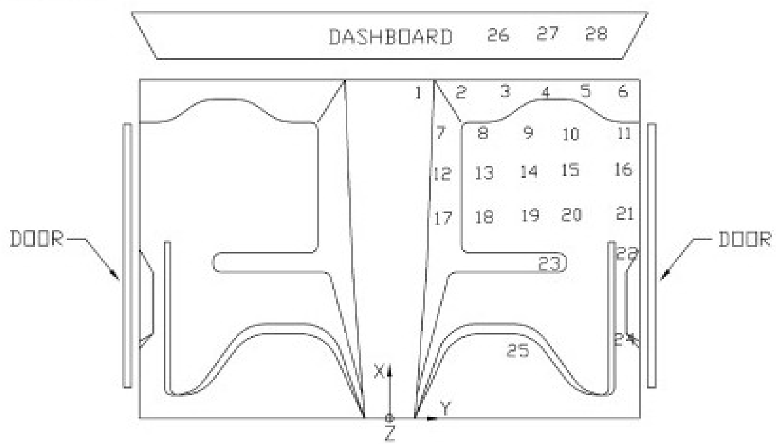


Figure C-1. Occupant Compartment Deformation Data, Test 2214MG-1

Occupant Compartment Deformation Index (OCDI)

Test No. 2214MG-1
Vehicle Type: 2002 GMC 2500

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

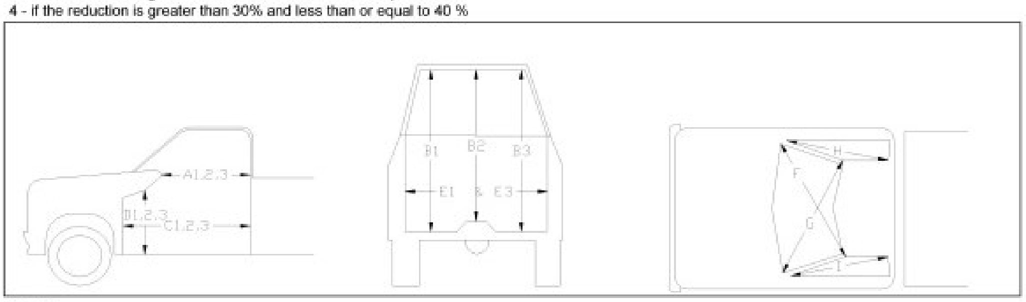
G = distance between the lower edge of left window and the upper edge of right window

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	43.25	43.25	0.00	0.00	0
A2	42.50	42.50	0.00	0.00	0
A3	42.50	42.50	0.00	0.00	0
B1	48.00	48.00	0.00	0.00	0
B2	45.25	45.25	0.00	0.00	0
B3	48.50	48.25	-0.25	-0.52	0
C1	59.00	59.00	0.00	0.00	0
C2	54.75	55.25	0.50	0.91	0
C3	61.50	61.50	0.00	0.00	0
D1	16.00	16.00	0.00	0.00	0
D2	8.75	9.00	0.25	2.86	0
D3	15.75	15.75	0.00	0.00	0
E1	62.75	62.75	0.00	0.00	0
E3	64.25	64.25	0.00	0.00	0
F	60.75	60.75	0.00	0.00	0
G	60.75	60.75	0.00	0.00	0
H	37.00	37.00	0.00	0.00	0
I	37.00	37.00	0.00	0.00	0

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

	RF	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 2214MG-1

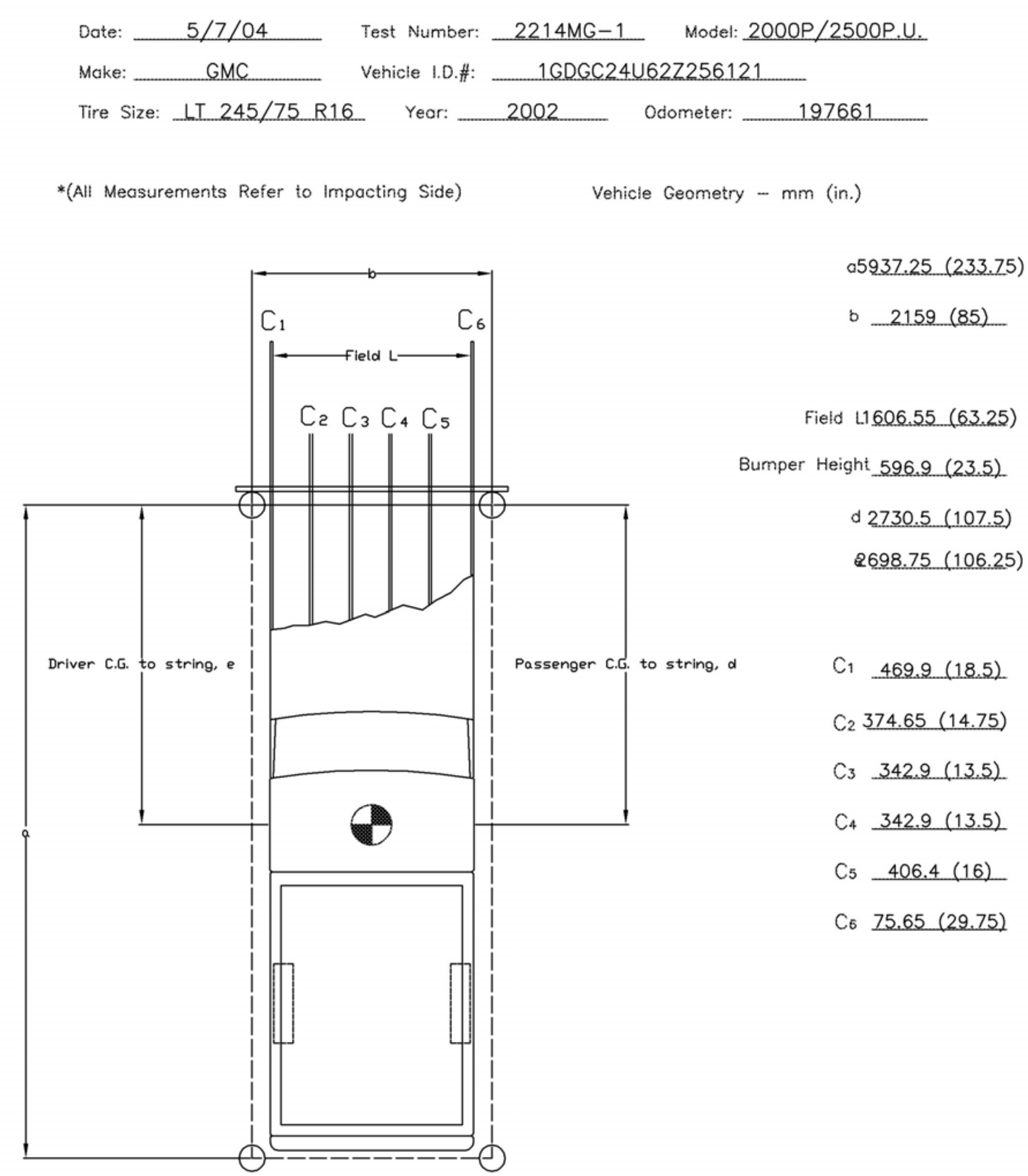


Figure C-3. NASS Crush Data, Test 2214MG-1

APPENDIX D

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

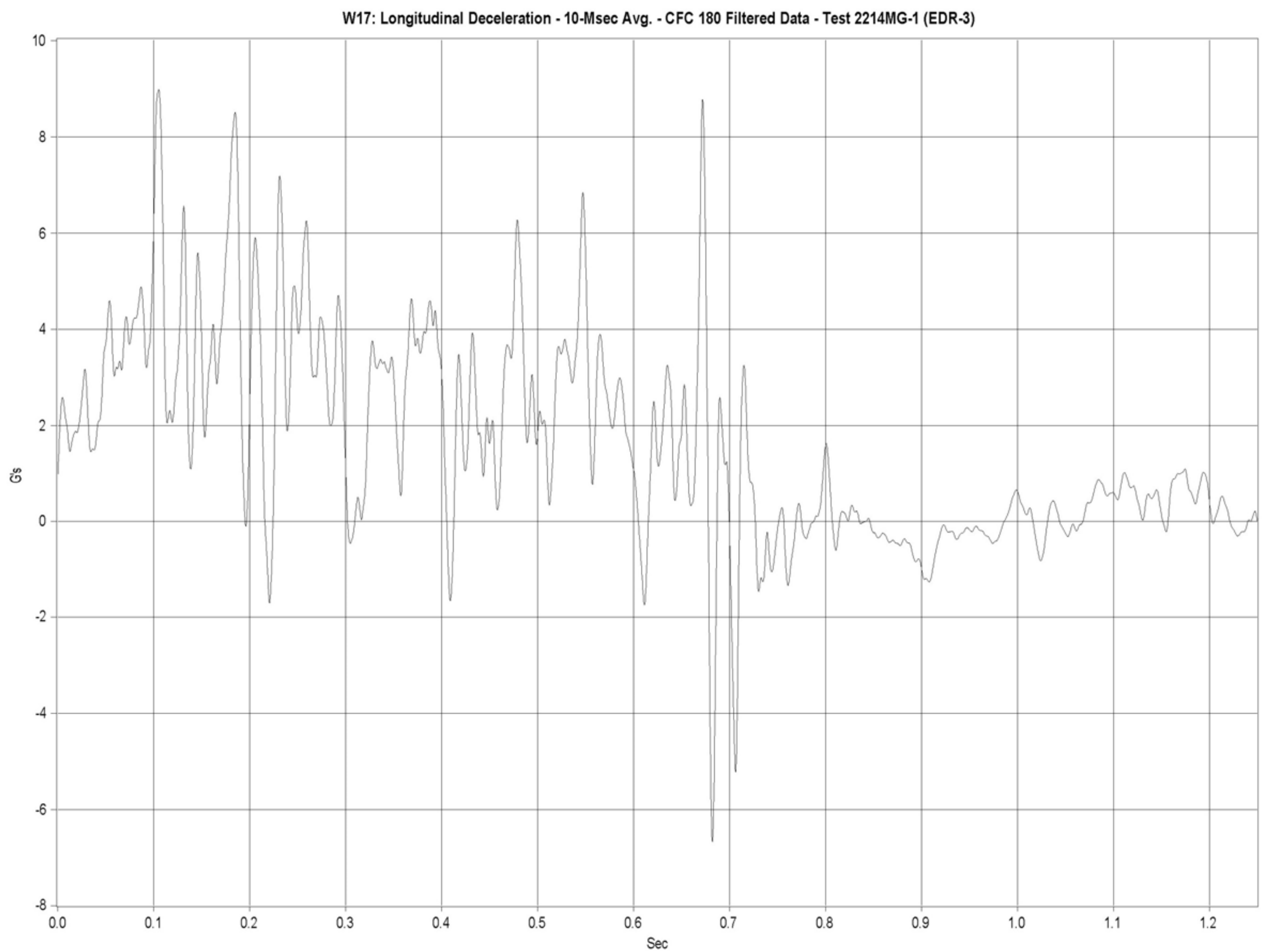


Figure D-1. Graph of Longitudinal Deceleration, Test 2214MG-1

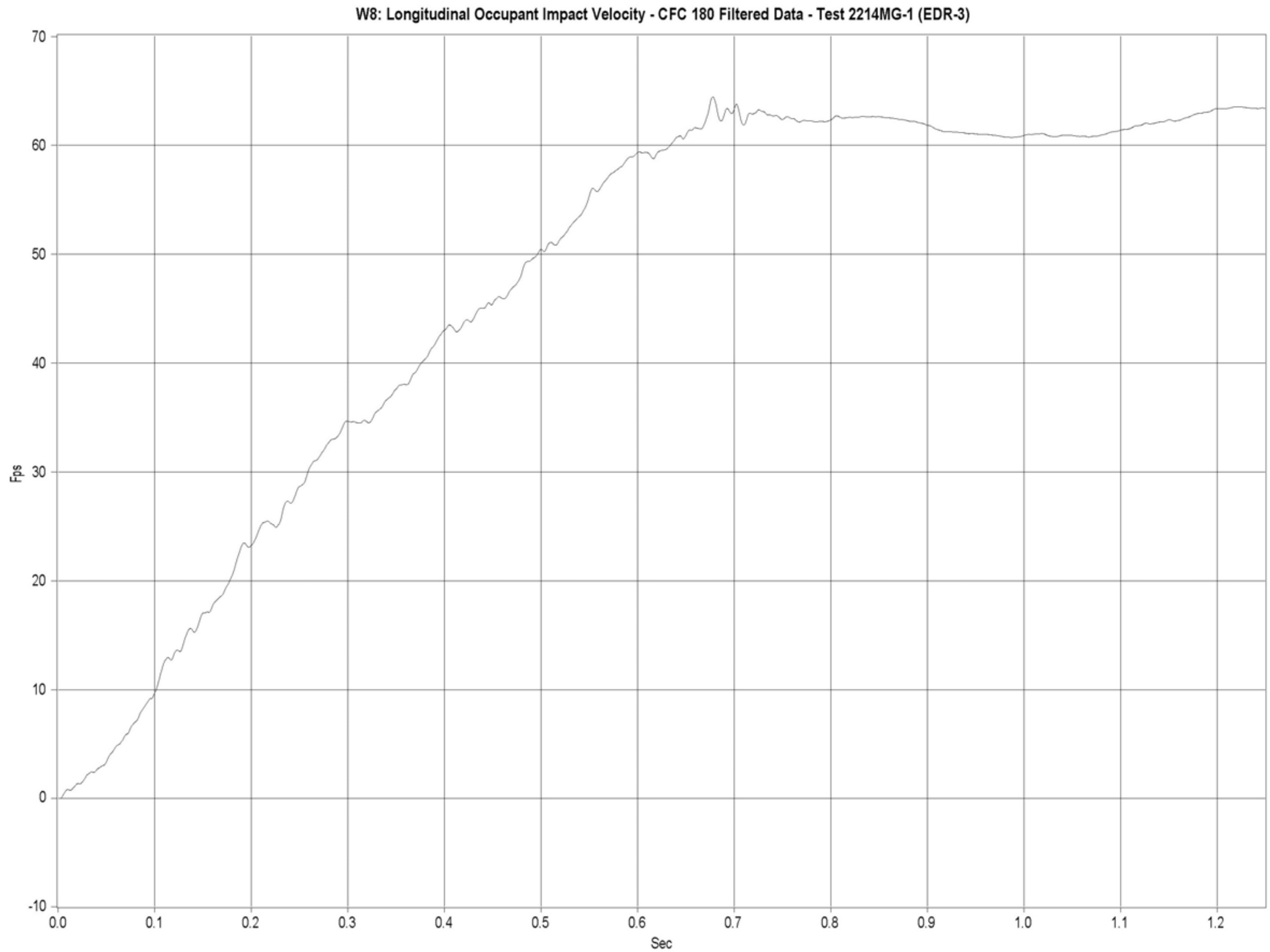


Figure D-2. Graph of Longitudinal Occupant Impact Velocity, Test 2214MG-1

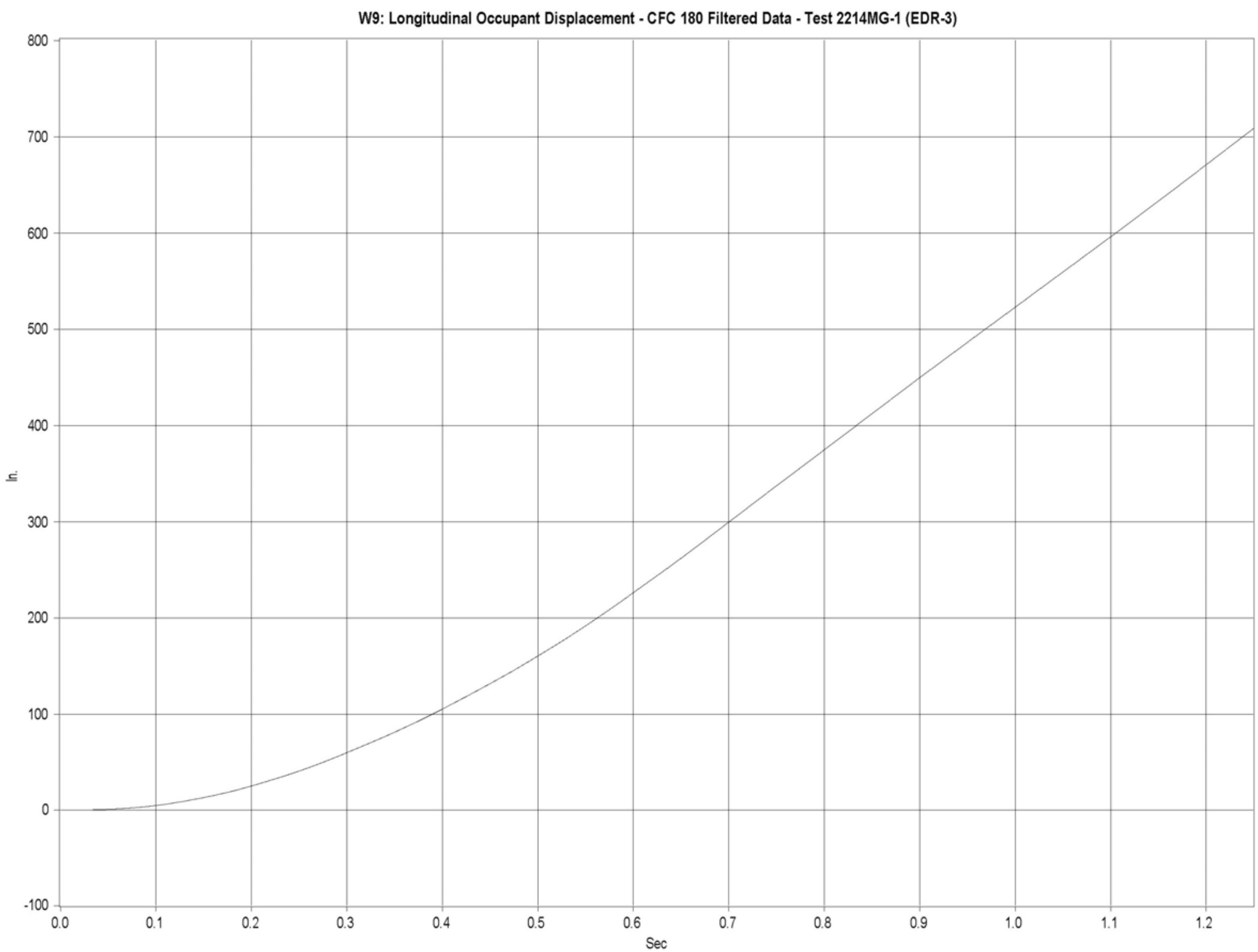


Figure D-3. Graph of Longitudinal Occupant Displacement, Test 2214MG-1

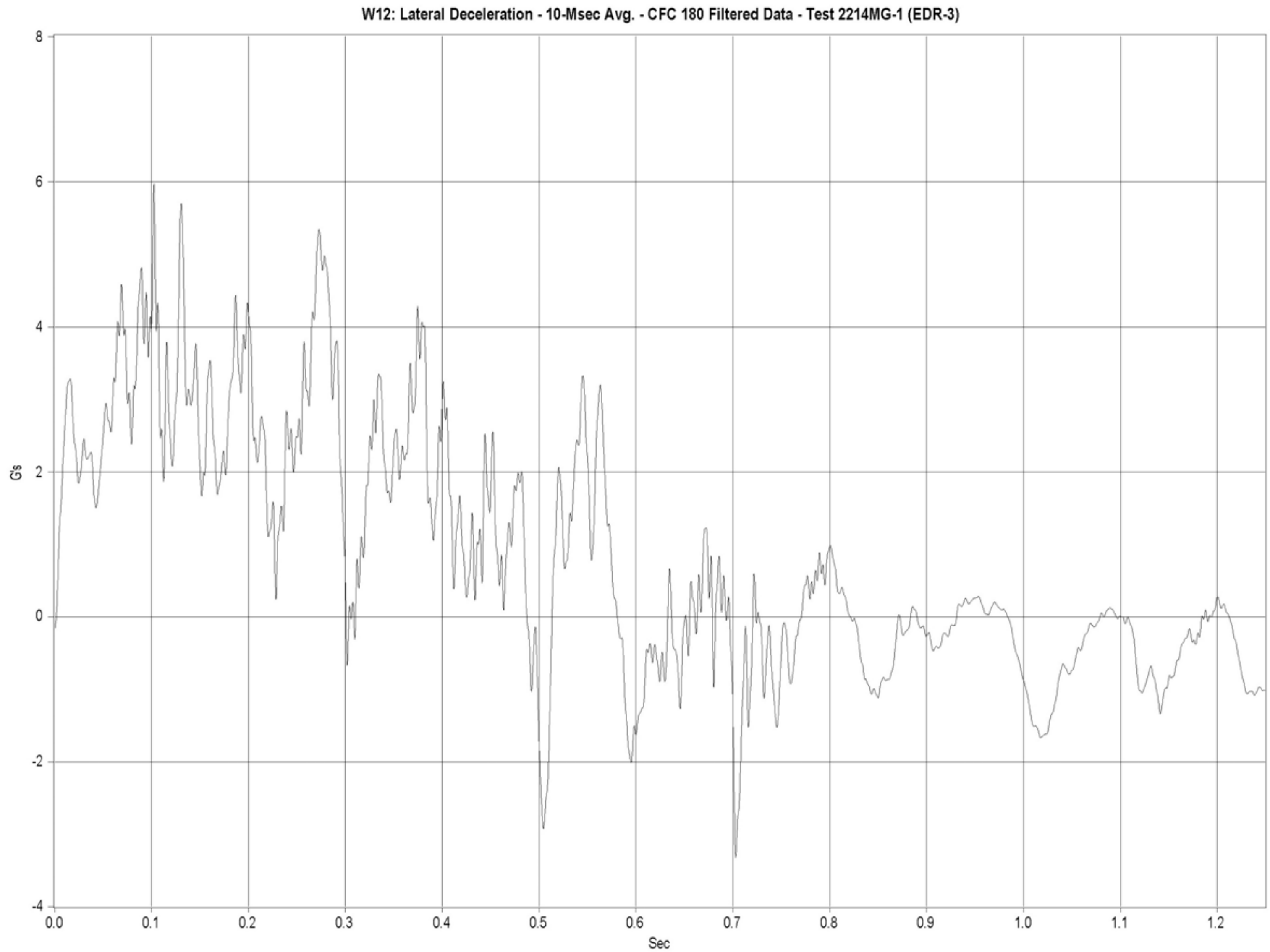


Figure D-4. Graph of Lateral Deceleration, Test 2214MG-1

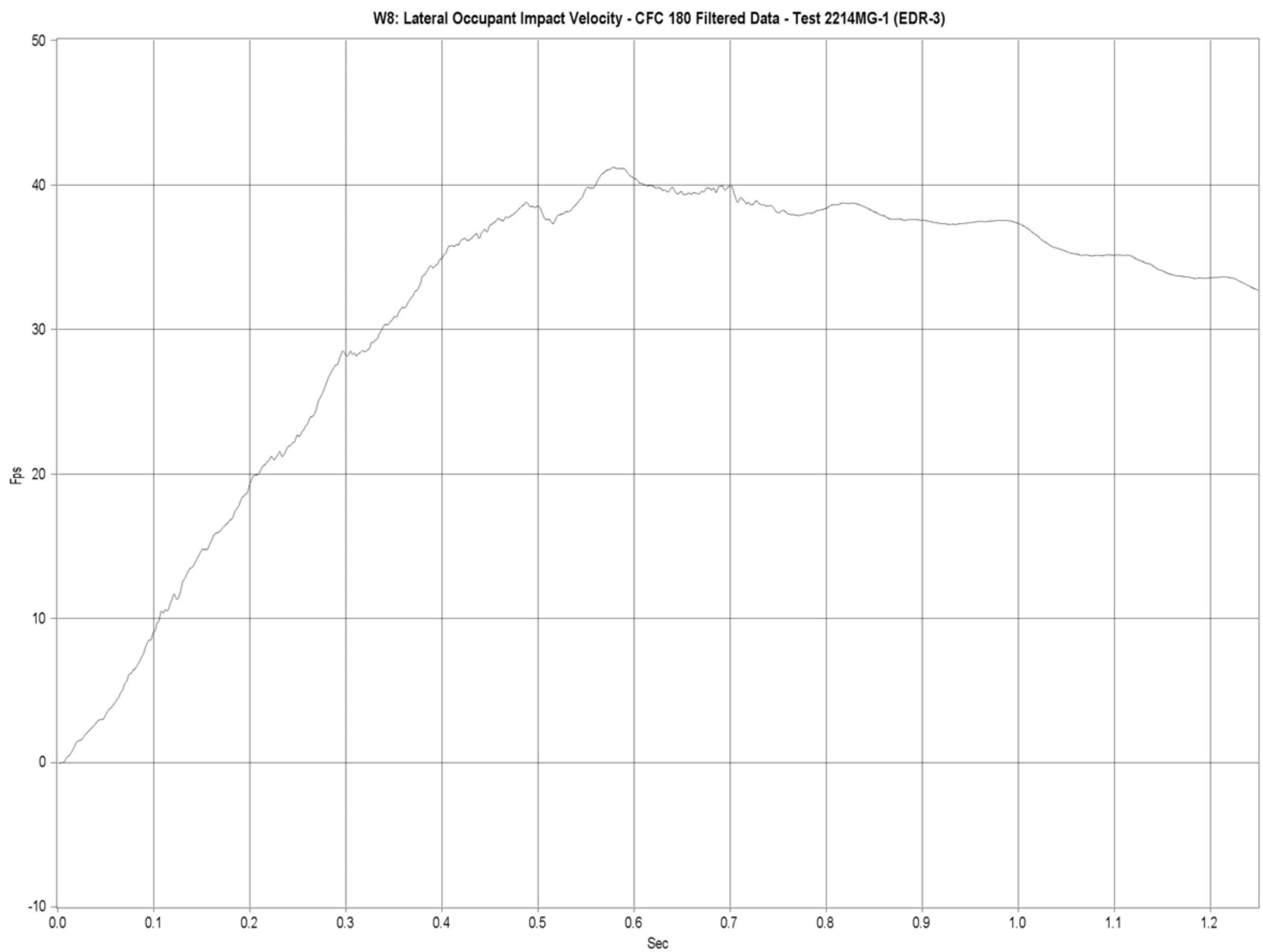


Figure D-5. Graph of Lateral Occupant Impact Velocity, Test 2214MG-1

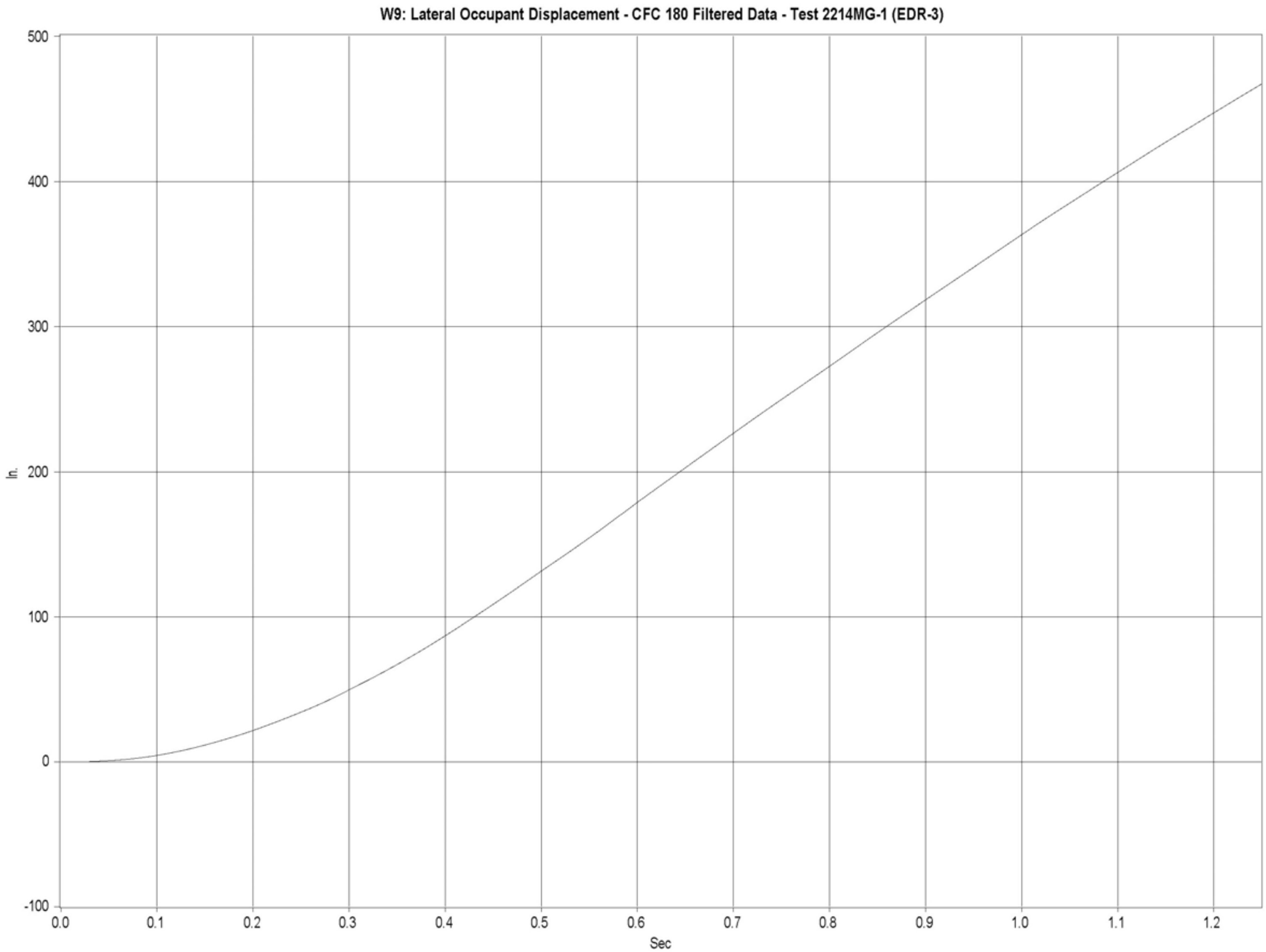


Figure D-6. Graph of Lateral Occupant Displacement, Test 2214MG-1

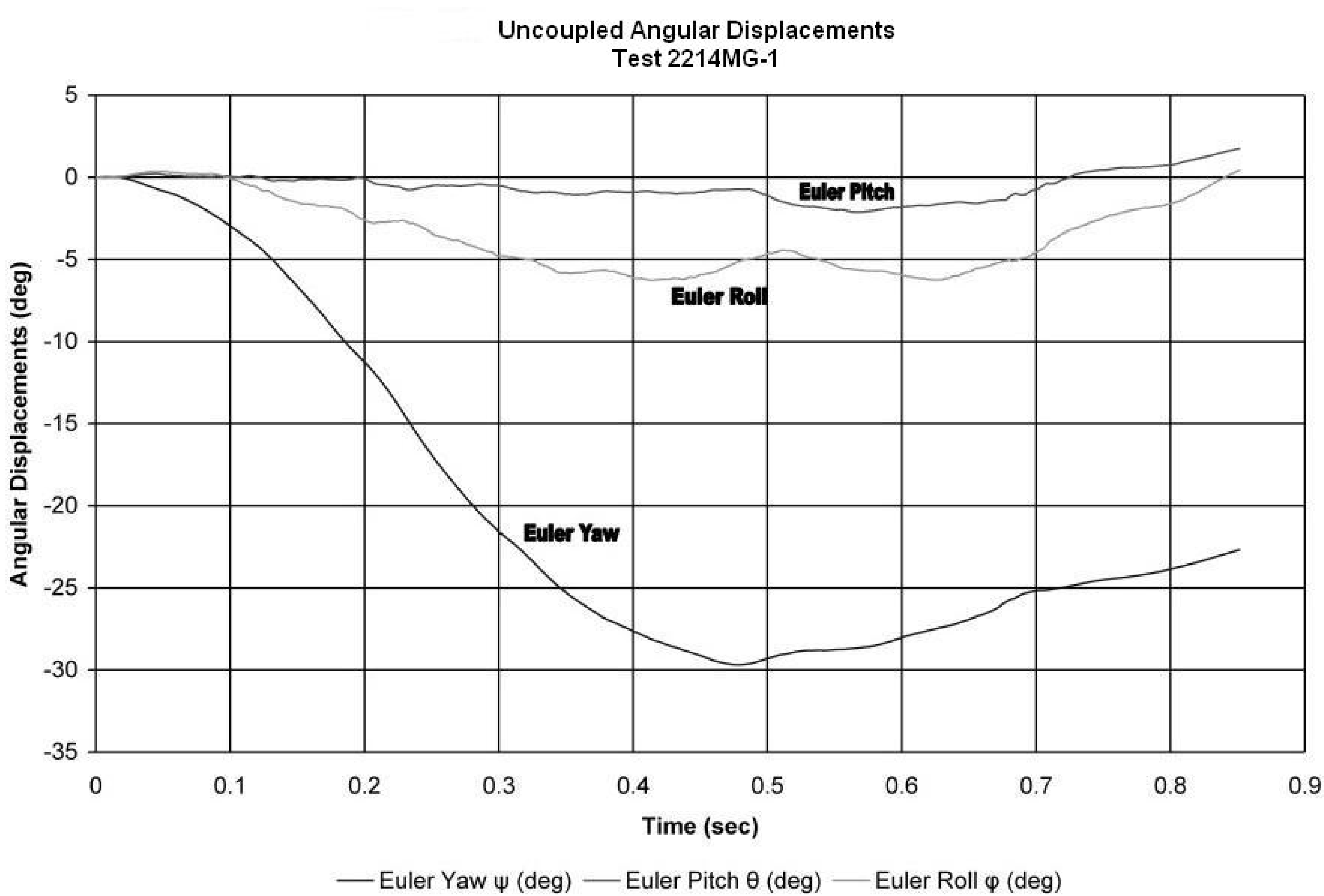


Figure D-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test 2214MG-1