PERFORMANCE EVALUATION OF THE MODIFIED G4(1S) GUARDRAIL – UPDATE TO NCHRP 350 TEST NO. 3-11 (2214WB-1)

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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 modified G4(1S) W-beam guardrail system 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 modified G4(1S) W-beam guardrail system, mounted at the metric top rail height of 706 mm (27.75 in.), provided an unacceptable safety performance when impacted by the ¾-ton, two-door pickup truck, thus failing to meet 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.

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TABLE OF CONTENTS

Page

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 modified G4(1S) guardrail system 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 modified G4(1S) guardrail 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 modified G4(1S) guardrail 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 modified G4(1S) guardrail 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 2214WB-1, the vehicle guidance system was 328 m (1,075 ft) long.

3.3 Test Vehicles

For test 2214WB-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.

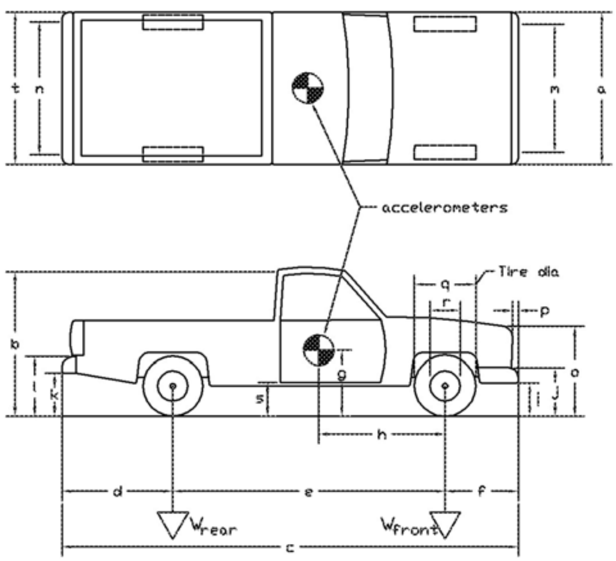
Figure 1. Test Vehicle, Test 2214WB-1

Date: 4/14/04 Test Number: 2214WB-1 Model: 2000P/2500P.V.

Make: GMC Vehicle I.D.#: 1GDGC24U522211218

Tire Size: LT 245/75 R16 Year: 2002 Odometer: 208781

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1911 (75.25)	b	1854 (73.0)
c	5639 (222.0)	d	1302 (51.25)
e	3391 (133.5)	f	946 (37.25)
g	686 (27.0)	h	1457 (57.375)
i	432 (17.0)	j	711 (28.0)
k	610 (24.0)	l	800 (31.5)
m	1740 (68.5)	n	1676 (66.0)
o	1003 (39.5)	p	76 (3.0)
q	749 (29.5)	r	438 (17.25)
s	470 (18.5)	t	1854 (73.0)

Wheel Center Height Front 362 (14.25)

Wheel Center Height Rear 368 (14.5)

Wheel Well Clearance (FR) 902 (35.5)

Wheel Well Clearance (RR) 972 (38.25)

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}	1252 (2761)	1294 (2852)	1294 (2852)
W_{rear}	882 (1945)	974 (2148)	974 (2148)
W_{total}	2135 (4706)	2268 (5000)	2268 (5000)

Note any damage prior to test: None

Figure 2. Vehicle Dimensions, Test 2214WB-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.

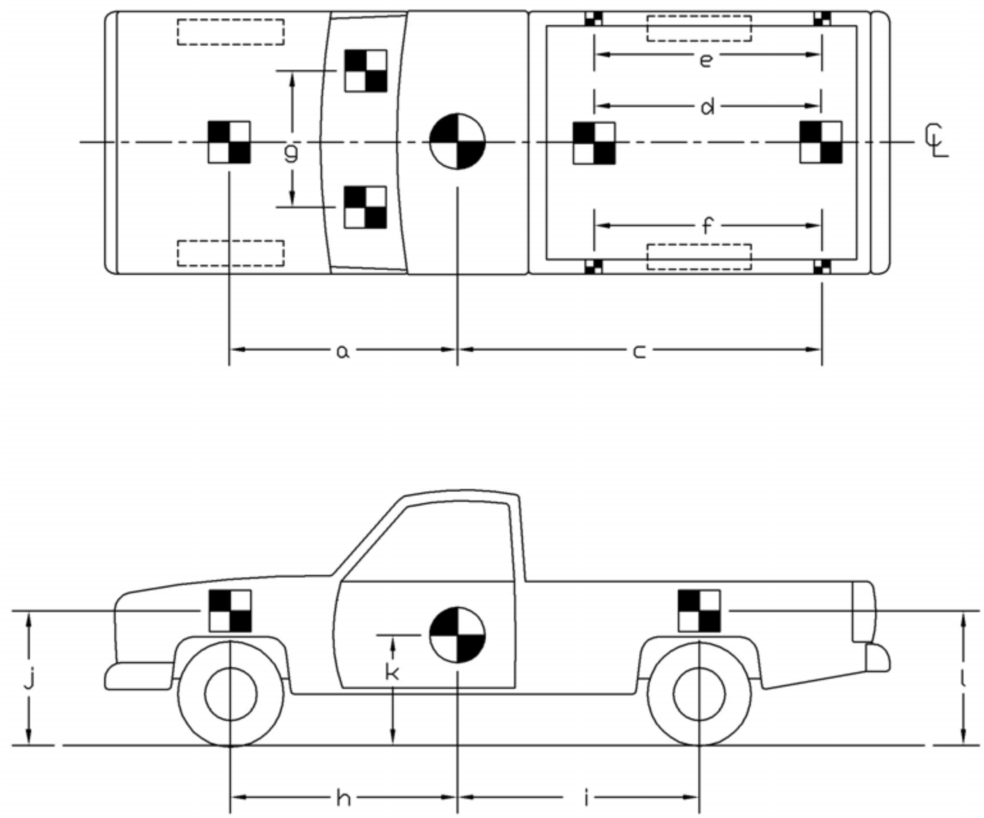
Square black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film and E/cam and Photron video, as shown in Figure 3. Checkered targets were placed on the center of gravity, on the driver's side door, on the passenger's side door, and on the roof of the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

TARGET GEOMETRY -- mm (in.)

a 1870 (73.625)	d 1791 (70.5)	g 1080 (42.5)	j 1099 (43.25)
b –	e 7076 (81.75)	h 1457 (57.375)	k 686 (27.0)
c 2677 (105.375)	f 20732 (81.625)	i 1934 (76.125)	l 1175 (46.25)

Figure 3. Vehicle Target Locations, Test 2214WB-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 2214WB-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 five Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all thirteen camera locations for test 2214WB-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 2214WB-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.

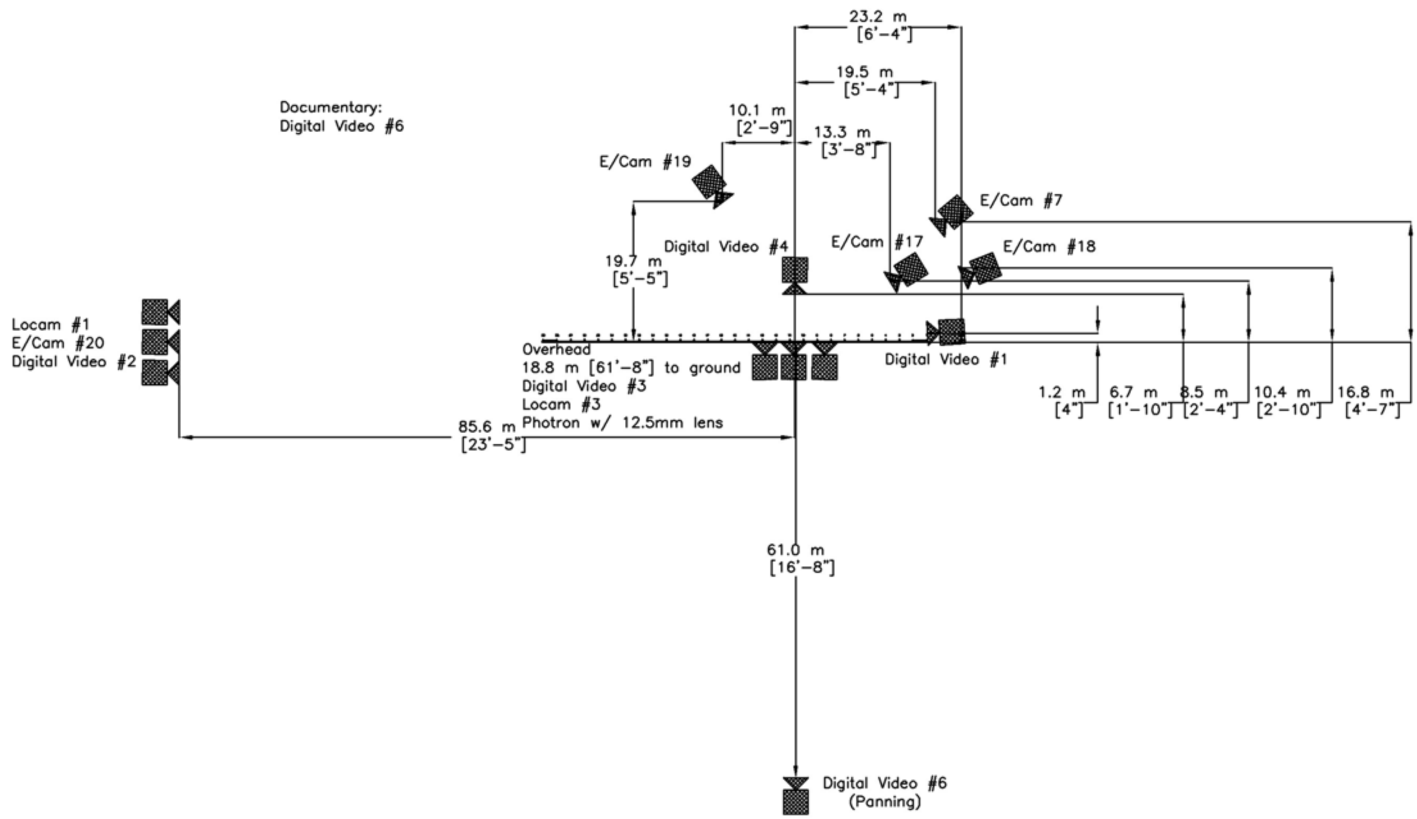


Figure 4. Location of High-Speed Cameras, Test 2214WB-1

4 DESIGN DETAILS

The test installation consisted of 53.34 m (175 ft) 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 as 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 14.

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 1,524-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. 3 through 27 were spaced 1,905 mm (75 in.) on center with a soil embedment depth of 1,098 mm (43.25 in.), as shown in Figures 5 and 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 NCHRP Report No. 350. For post nos. 3 through 27, 152-mm wide x 203-mm deep x 362-mm long (6-in. x 8-in. x 14.25-in.) routed 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 were placed between post nos. 1 and 29, as shown in Figures 5 and 11. The W-beam's top rail height was 706 mm (27.75 in.) with a 550-mm

(21.625-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.

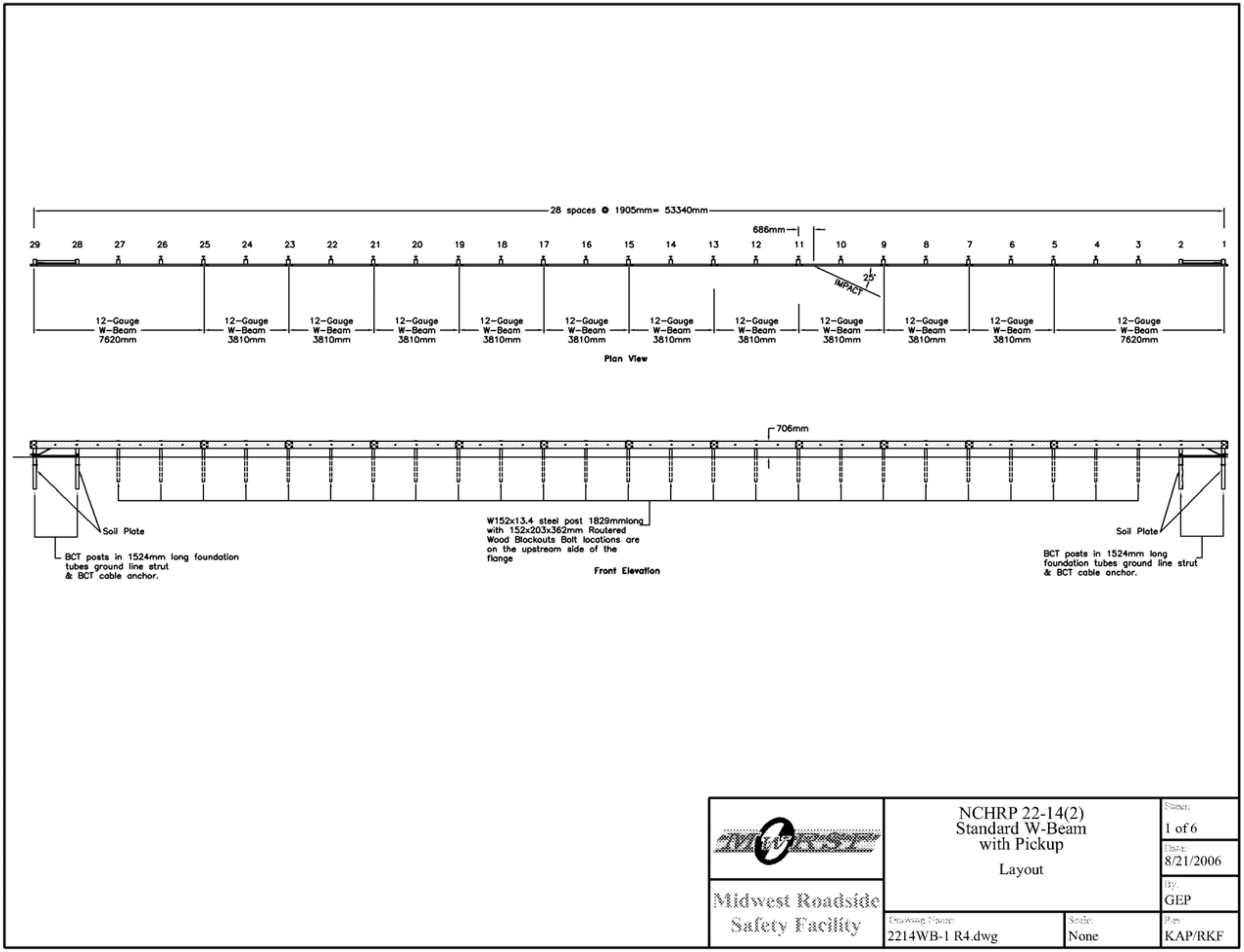


Figure 5. Layout of Standard Height, Strong Post, Wood Blockout W-beam Guardrail Design

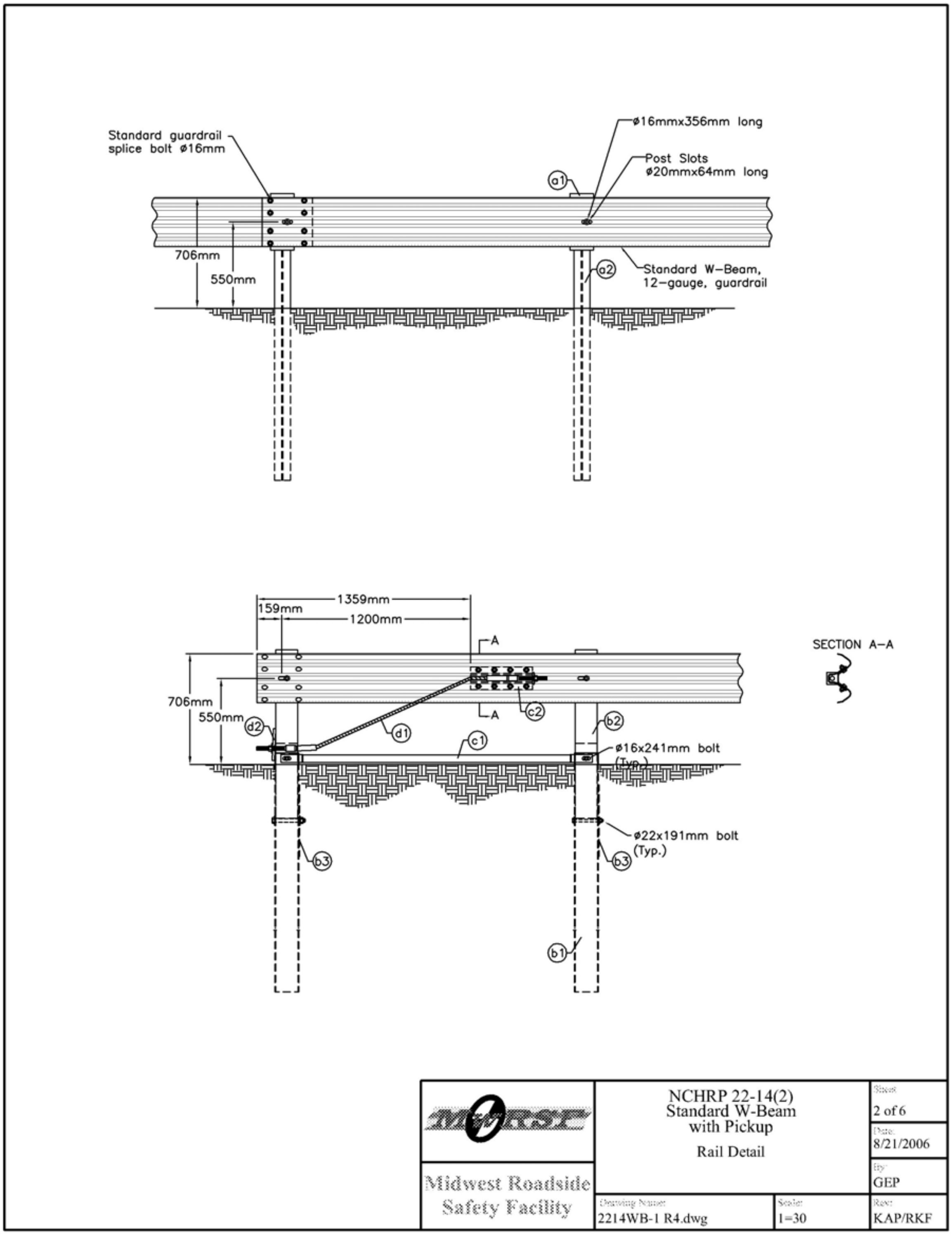


Figure 6. Standard Height, Strong Post, Wood Blockout W-Beam Guardrail Rail Details

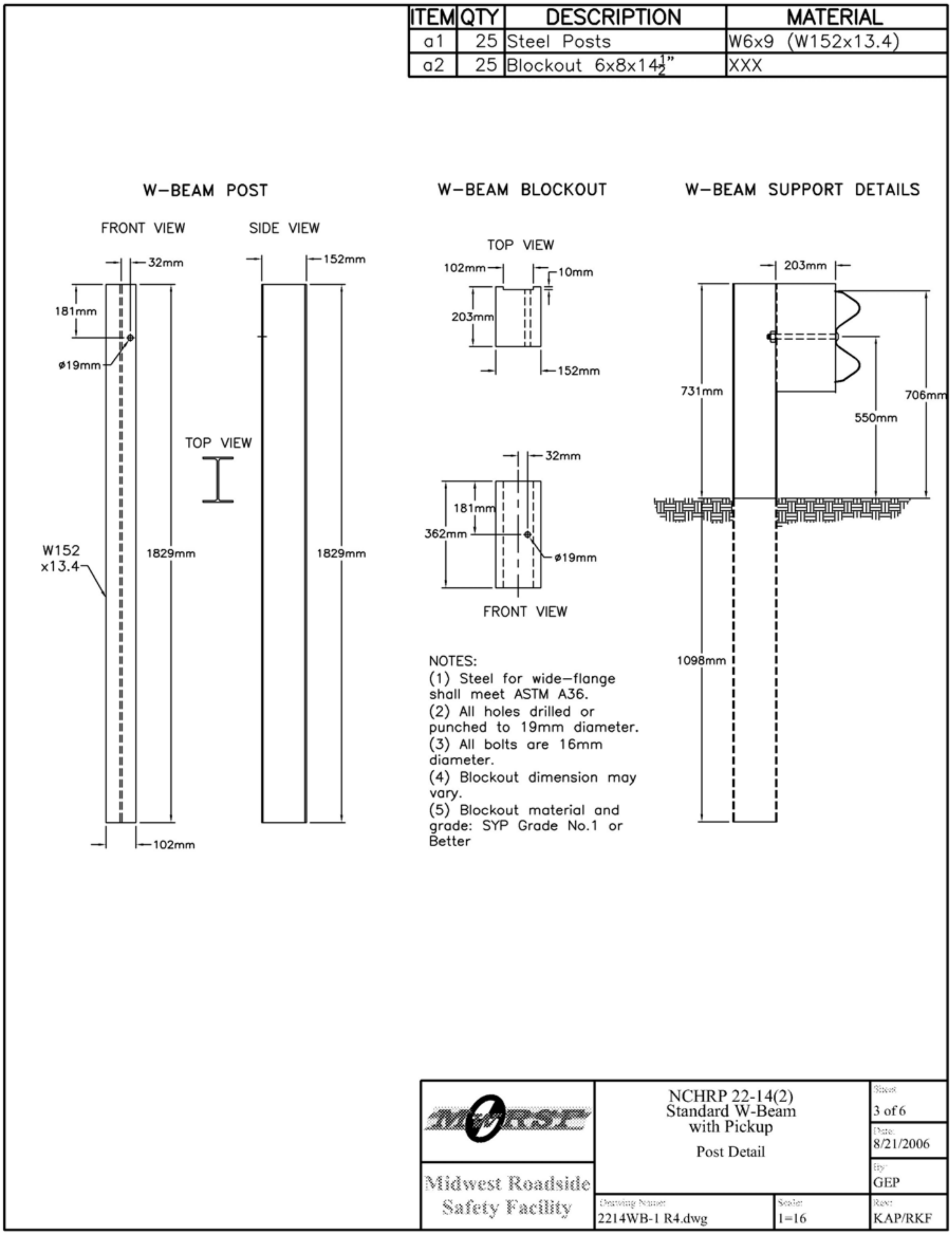


Figure 7. Standard Height, Strong Post, Wood Blockout W-Beam Guardrail Post Details

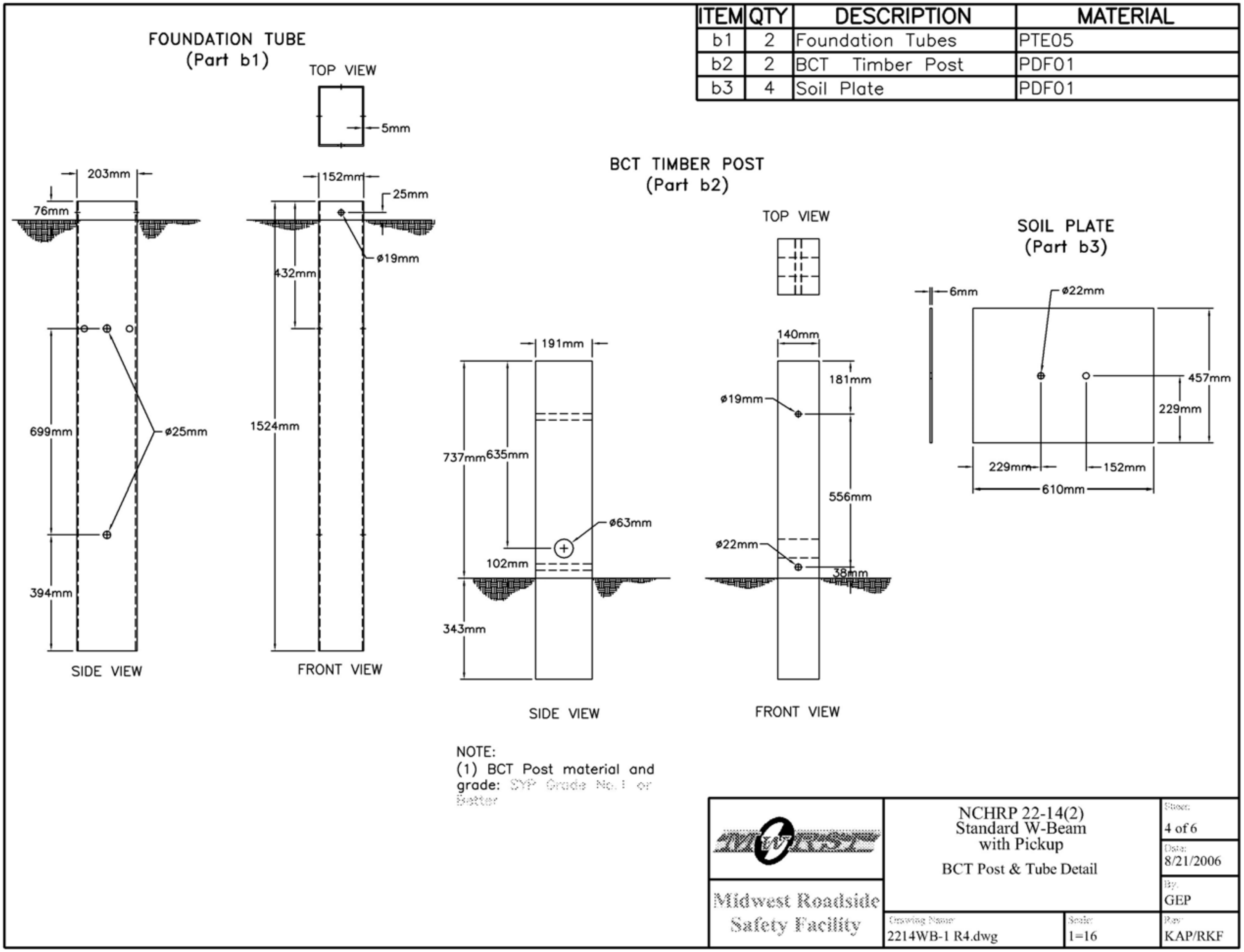


Figure 8. Standard Height, Strong Post, Wood Blockout W-Beam Guardrail Design Anchorage Details

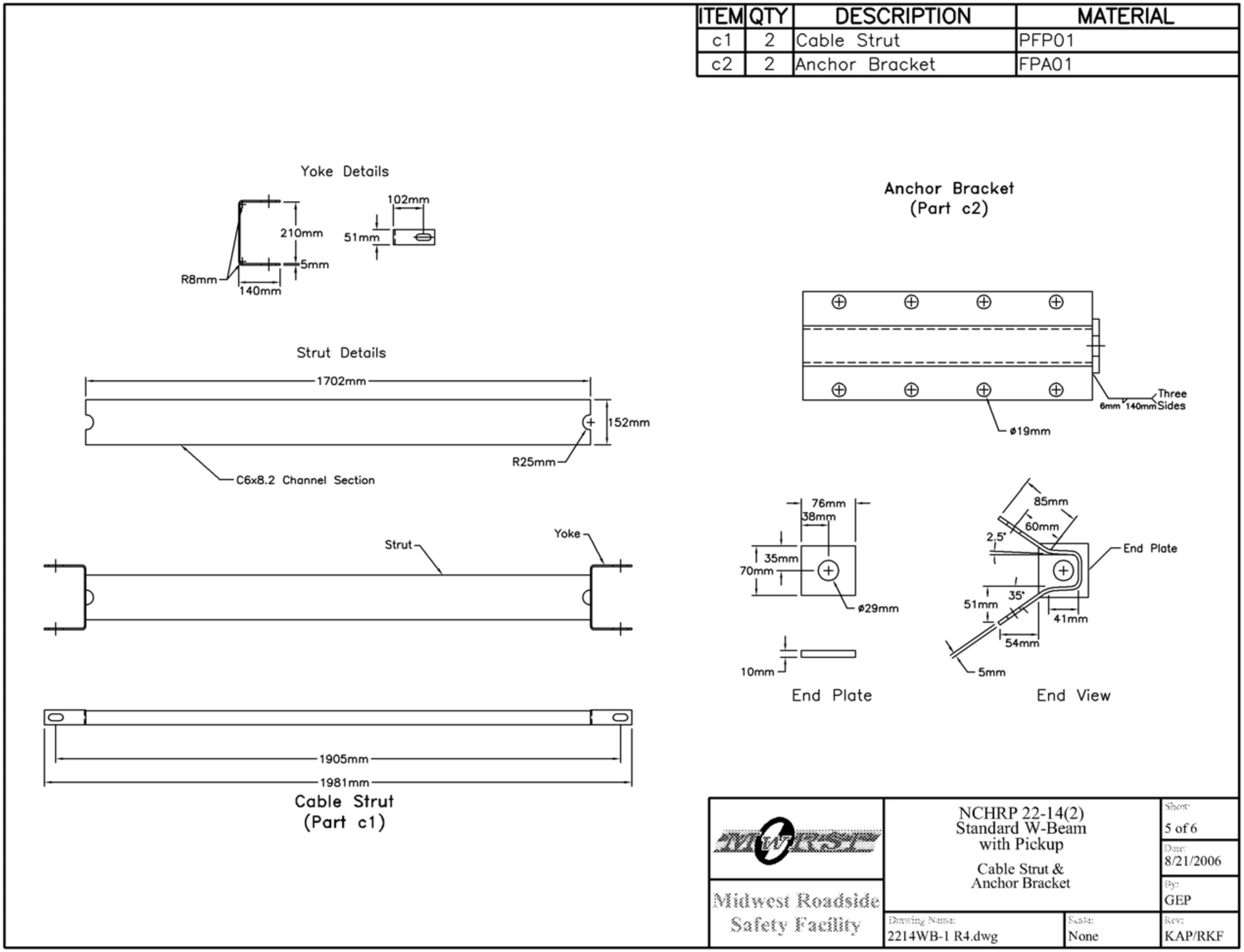


Figure 9. Standard Height, Strong Post, Wood Blockout W-Beam Guardrail Design Anchorage Details

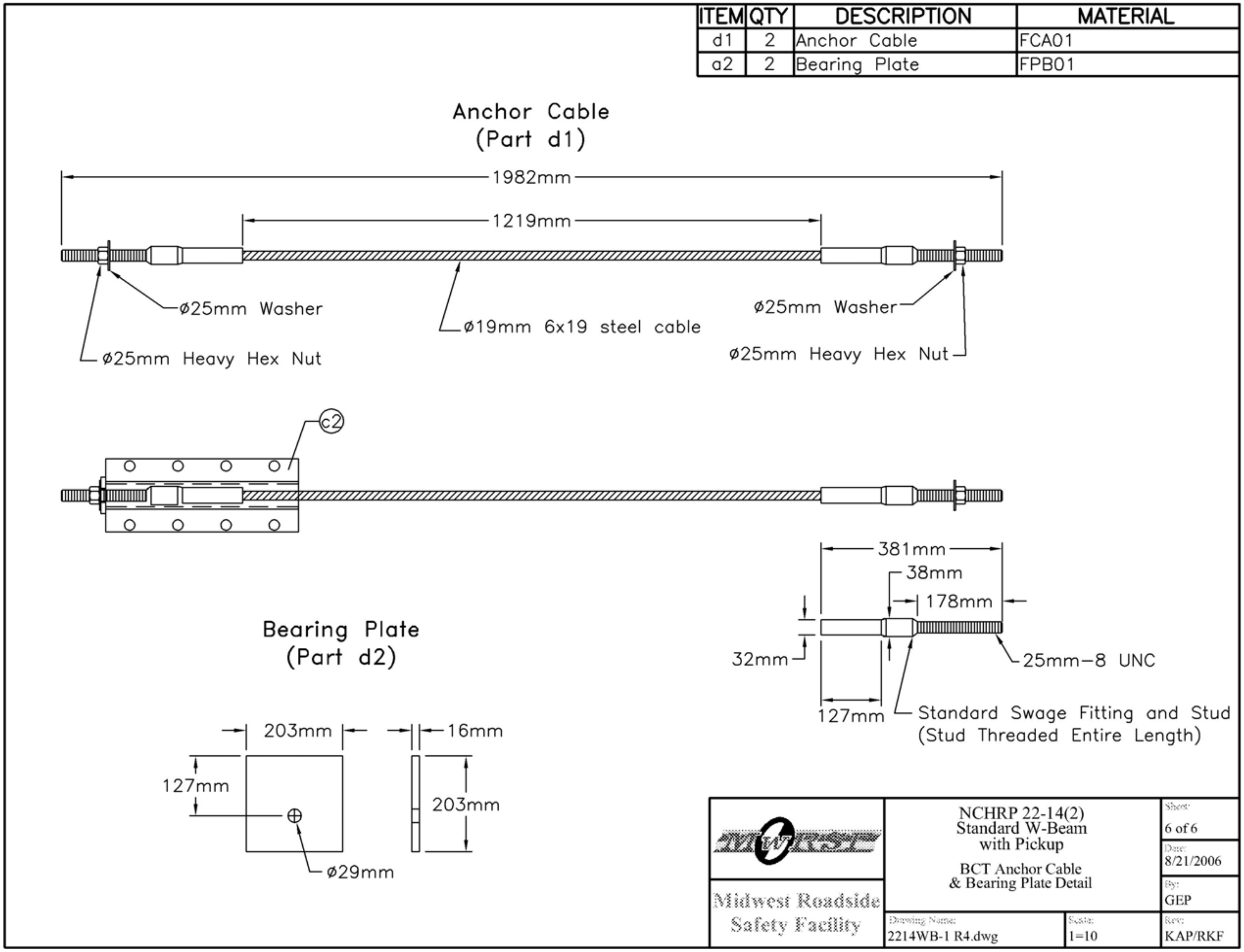


Figure 10. Standard Height, Strong Post, Wood Blockout W-Beam Guardrail Design Anchorage Details

Figure 11. Standard Height, Strong Post, Wood Blockout W-Beam Guardrail System

Figure 12. Standard Height, Strong Post, Wood Blockout W-Beam Guardrail System

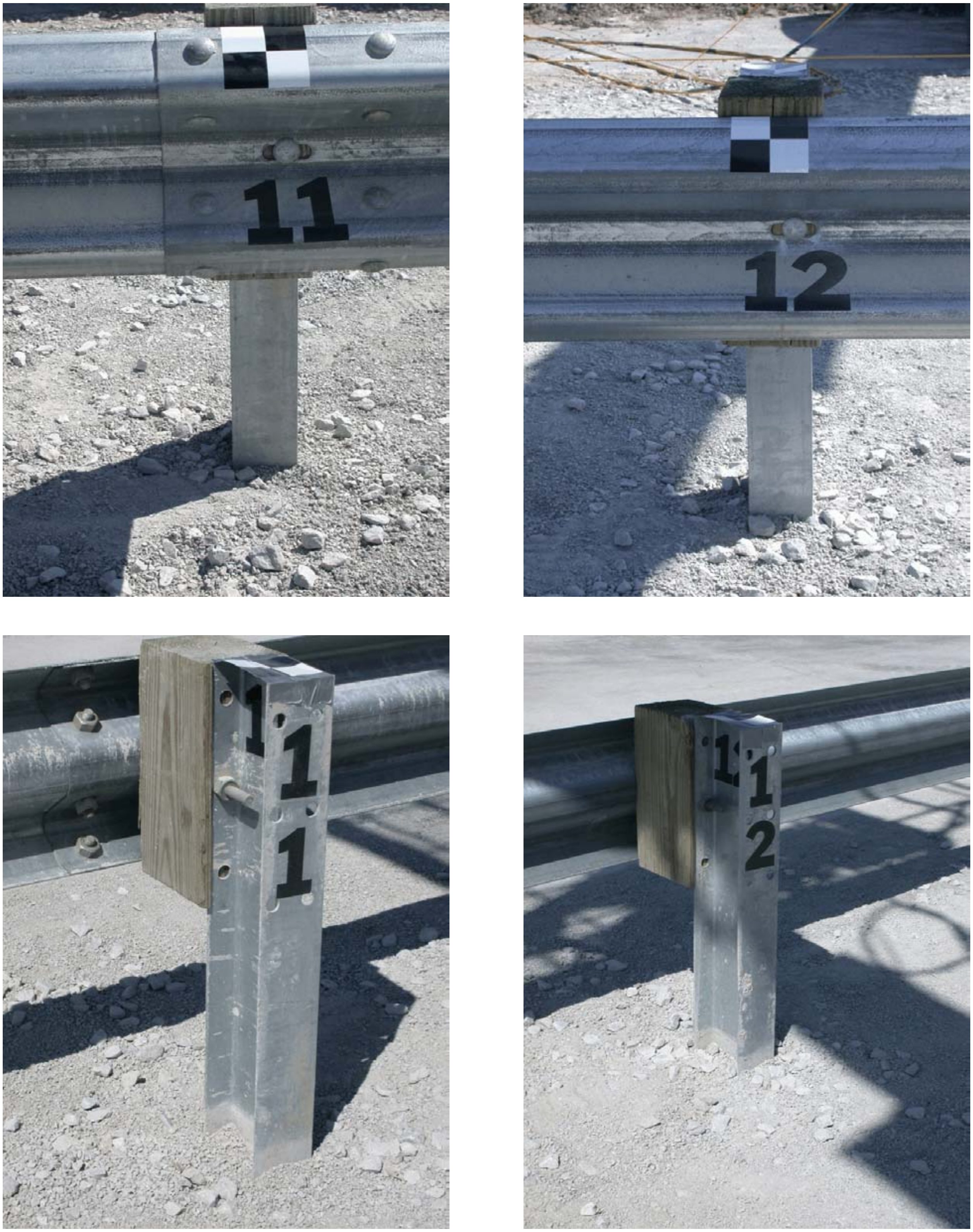


Figure 13. Standard Height, Strong Post, Wood Blockout W-Beam Guardrail System

Figure 14. Standard Height, Strong Post, Wood Blockout W-Beam Guardrail System

5 CRASH TEST

5.1 Test 2214WB-1

The 2,268-kg (5,000-lb) pickup truck impacted the standard height, strong post, wood blockout W-beam guardrail system at a speed of 98.3 km/h (61.1 mph) and at an angle of 25.6 degrees. A summary of the test results and sequential photographs are shown in Figure 15. The summary of the test results and sequential photographs in English units are shown in Appendix B. Additional sequential photographs are shown in Figures 16 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. 10 and 11, or 4.50 m (14 ft - 9 in.) upstream from the center of post no. 13, as shown in Figure 21. Actual vehicle impact occurred 4.57 m (15 ft) upstream from the center of post no. 13. At 0.014 sec after impact, post no. 11 began to deflect backwards. At 0.030 sec, the rail deflected laterally backward with the right-front corner of the vehicle located at post no. 11. At this same time, a separation gap was apparent between the right side of the hood and the right-front quarter panel that was deforming. At 0.060 sec, the right-front corner of the vehicle deformed inward toward the engine compartment and was located at the midspan between post nos. 11 and 12. At this same time, post nos. 9 through 11 twisted clockwise (CW) and the rail flattened between post nos. 11 and 12. At 0.090 sec, the right-front side of the vehicle up to the door was in contact with the system. At this same time, post no. 12 twisted counter-clockwise (CCW) and deflected backward with the right-front tire under the rail. At 0.098 sec, the right-front tire disengaged from the wheel assembly. At 0.102 sec, the rail disengaged from post no. 12. At 0.116 sec, post no. 12 was located under the vehicle and bent downstream to the ground. At

0.140 sec, post no. 13 twisted CCW and deflected backwards. At this same time, the front of the vehicle was located near the midspan between post nos. 12 and 13 with the rail wrapping around the right-front tire. At 0.150 sec, the rail disengaged from post no. 13. At 0.174 sec, the truck was positioned on top of post no. 13. At this same time, the blockout disengaged from post no. 12. At 0.194 sec, the rail fractured as the vehicle began to ramp up the guardrail. At 0.230 sec, the entire right side of the vehicle was in contact with the system with the right-rear corner of the truck position near post no. 11 and the right-front corner of the vehicle protruded over the deformed rail. At this same time, the front of the vehicle was near post no. 14 which twisted CCW and was deflecting backwards. At 0.246, the left-front tire became airborne. At 0.264 sec, the vehicle was positioned over post no. 14 with the rail located underneath the vehicle. At this same time, the vehicle rolled CCW away from the traffic-side face. At 0.292 sec, the front of the vehicle pitched upward. At 0.306 sec, the fractured rail was positioned under the vehicle. At this same time, the front of the vehicle was located near post no. 15 which remained undamaged. At 0.322 sec, the vehicle continued to roll CCW with the fractured rail still positioned under the vehicle and the front of the vehicle was airborne. At 0.334 sec, the vehicle became parallel to the barrier with a resultant velocity of 59.8 km/h (37.1 mph). At 0.454 sec, the vehicle was completely airborne. At 0.460 sec, the vehicle was positioned over post no. 16 and was encountering a CCW roll away from the system. At 0.496 sec, the front of the vehicle began to descent toward the ground. At 0.546 sec, the vehicle redirecting away from the system and was no longer in contact with the first section of fractured rail. At 0.608 sec, the right-front tire was visible positioned under the rail at post no. 11. At 0.614 sec, the right-rear tire traverses over the second section of fractured rail. At 0.664 sec, the vehicle encountered twist between the cab and the box. At 0.704 sec, the vehicle began to roll CW back toward the traffic-side face. At 0.748 sec, the left-front tire contacted the ground. At 0.888 sec, the left-front tire became airborne again. At 0.1324 sec, the left-front tire contact the ground. At 1.434 sec, the vehicle exhibited its maximum CCW roll away from the system and began to roll back toward the system as the left-rear tire contacted the ground. At 1.596 sec, the right-rear tire was contacting the ground behind the system. The vehicle came to rest 24.10 m (79 ft - 1 in.) downstream from impact and 0.53 m (1 ft - 9 in.) laterally away from the traffic-side face of the guardrail system. The trajectory and final position of the pickup truck are shown in Figures 15 and 22.

5.3 Barrier Damage

Damage to the barrier was extensive, as shown in Figures 23 through 27. Barrier damage consisted of deformed guardrail posts, disengaged wooden blockouts, contact marks on a guardrail section, and deformed and fractured W-beam rail. The length of vehicle contact along the W-beam guardrail system was approximately 18.4 m (60.4 ft), which spanned from 1,143 mm (45 in.) downstream from the centerline of post no. 10 through 508 mm (20 in.) downstream from the centerline of post no. 20.

The failure of the W-beam splice at post no. 13 caused significant damage to the posts and the guardrail located downstream. Moderated deformation and flattening of the impacted section of W-beam rail occurred between post nos. 11 and 14. The top corrugation in the rail was deformed downward between post nos. 17 and 19. Contact marks were found on the guardrail between post nos. 10 and 19. The guardrail buckled at post no. 10 and 508 mm (20 in.) downstream of post no. 20. A gouge was found in the lower corrugation at 635 mm (25 in.) upstream of post no. 13 and in the upper corrugation at 203 mm (8 in.) downstream of post no. 14. A small tear was found in the top corrugation 686 mm (27 in.) downstream of post no. 19. The W-beam guardrail was torn through the cross section, beginning at the bottom downstream splice bolt at post no. 13, propagating through the rail section between post nos. 13 and 14, and ending at the top of the W-beam rail 737 mm (29 in.) downstream from post no. 13. A partial tear, measuring 381 mm (15 in.) long, was found near the midspan between post nos. 13 and 14. The W-beam was pulled off of post nos. 14 through 18 and 20. The W-beam rail sustained significant yielding around the post bolt slots at pos nos. 14 through 20.

Steel post nos. 9 and 21 through 27 encountered minor twisting. Post no. 11 rotated backward toward the ground approximately 203 mm (8 in.) at the top. Post no. 12 through 20 encountered significant twisting and were bent toward longitudinally downstream to the ground. The top of post no. 12 also encountered heavy tire contact marks. Post no. 14 also encountered a tear on the front-upstream edge of the flange and a small dent 406 mm (16 in.) from the top of the post. The top of post no. 15 also encountered deformation to the upstream-back corner of the flange. Post nos. 16 through 19 also encountered damage on the upstream-front flange. The upstream and downstream anchorage systems slightly moved longitudinally, however the posts in the downstream anchorage system were fractured at the breakaway hole at ground line.

The wooden blockout at post no. 12 was fractured and a portion of it disengaged from the post. The wooden blockouts at post nos. 13 and 14 were fractured and removed from the post. The wooden blockouts at post no. 15 encountered minor splitting and contact marks on the upstream-top edge. The wooden blockouts at post nos. 16 and 17 were slightly damaged on the top-upstream edge.

5.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 28 through 30. Occupant compartment deformations to the right side and center of the floorboard were judged insufficient to cause serious injury to the vehicle occupants. Maximum longitudinal deflections of 19 mm (0.75 in.) were located near the center of the right side of the floorboard. Maximum lateral deflections of 13 mm (0.5 in.) were located near the left-front corner of the right-side floor pan and the center of the right side of the floorboard. Maximum vertical deflections of 6 mm (0.25 in.) were located throughout the right side of the floorboard. 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 nearly contacting the lower frame rail. The right-side door encountered a deformation and tearing near front quarter panel. The front-right corner of the hood was deformed and dented. The box encountered a tear in front of the left-rear tire. The drive shaft was fractured and disconnected from the vehicle. The rear axle was displaced out of alignment. The right-front wheel assembly deformed and crushed inward toward the engine compartment. The right-side upper ball joint, lower ball joint, and steering linkage were fractured. The right-side sway bar and lower control arm connection was bent approximately 25 degrees. The right-front tire disengaged from the rest of the wheel assembly. The right-rear and left-rear tires were deflated. The left-side rear suspension was fractured. All window glass remained undamaged.

5.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be 5.27 m/s (17.29 ft/s) and 4.93 m/s (16.17 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 19.71 Gs and 8.46 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 7.58 m/s (24.87 ft/s) and 21.22 Gs, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 15. 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. 2214WB-1 showed that the standard height, strong post, wood blockout W-beam guardrail system impacted with the 2270P vehicle of the Update to NCHRP Report No. 350 did not adequately contain the vehicle on the traffic-side face of the barrier system, but redirected the vehicle. Furthermore, it did not behave as would be expected, since the W-beam guardrail fractured and the vehicle contacted the ground behind the system. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or 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. 2214WB-1 conducted on the standard height, strong post, wood blockout W-beam guardrail system was determined to be unacceptable 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.

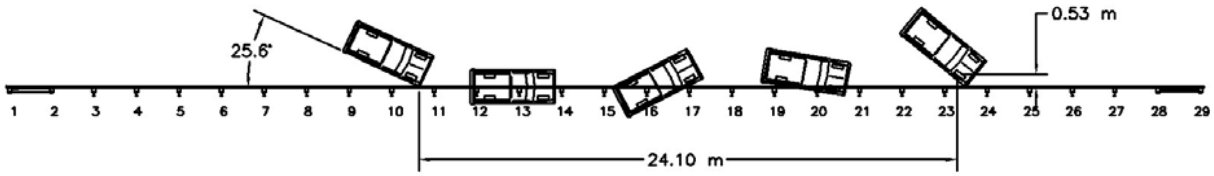

0.000 sec

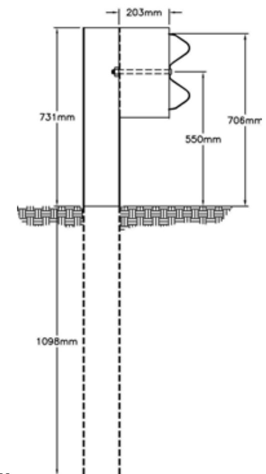

0.116 sec


0.230 sec


0.306 sec


0.470 sec





- Test Agency . . . . MwRSF
- Test Number 2214WB-1
- Date 4/14/04
- NCHRP 350 Update Test Designation . . 3-11
- Appurtenance . . . . Modified G4(1S) Guardrail
- Total Length . . . . 53.34 m
- Key Elements - Steel W-Beam
  - Thickness . . . . 2.66 mm
  - Top Mounting Height . . . . 706 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 . 1,524 mm long with soil plate
- Key Elements - Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 152 mm x 203 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 . . . . 2,278 kg
  - Test Inertial . . . . 2,268 kg
  - Gross Static . . . . 2,268 kg
- Impact Conditions
  - Speed . . . . 98.3 km/h
  - Angle (trajectory) . . . . 25.6 degrees
  - Impact Location . . . . 4.57 m upstream centerline post no. 13
- Exit Conditions
  - Speed . . . . NA
  - Angle . . . . NA
  - Exit Box Criterion . . . . NA
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 24.10 m downstream
0.53 m traffic-side face
- Occupant Impact Velocity (350 Update)
  - Longitudinal . . . . 5.27 m/s < 12 m/s
  - Lateral . . . . 4.93 m/s < 12 m/s
- Occupant Ridedown Deceleration (350 Update)
  - Longitudinal . . . . 19.71 Gs < 20 Gs
  - Lateral . . . . 8.46 Gs < 20 Gs
- THIV (not required) . . . . 7.58 m/s
- PHD (not required) . . . . 21.22 Gs
- Test Article Damage . . . . Extensive (rail fracture)
- Test Article Deflections
  - Permanent Set . . . . NA
  - Dynamic . . . . NA
  - Working Width . . . . NA
- Vehicle Damage . . . . Moderate
  - VDS[5] 1-RFQ-4
  - CDC[6] 1-RFEN3
  - Maximum Deformation . . . . 19 mm at right-center floorpan

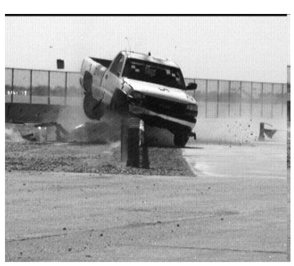
Figure 15. Summary of Test Results and Sequential Photographs, Test 2214WB-1

0.000 sec

0.198 sec

0.332 sec

0.496 sec

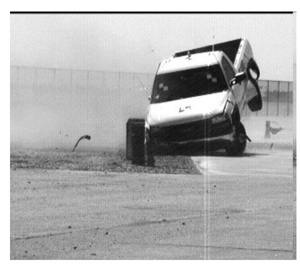


0.748 sec

1.000 sec

1.434 sec

1.770 sec



2.056 sec

2.650 sec

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

0.000 sec

0.000 sec

0.098 sec

0.090 sec

0.194 sec

0.150 sec

0.318 sec

0.204 sec

0.452 sec

0.292 sec

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

0.000 sec 0.000 sec

0.060 sec 0.467 sec

0.102 sec 0.933 sec

0.226 sec 1.800 sec

0.380 sec 2.533 sec

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

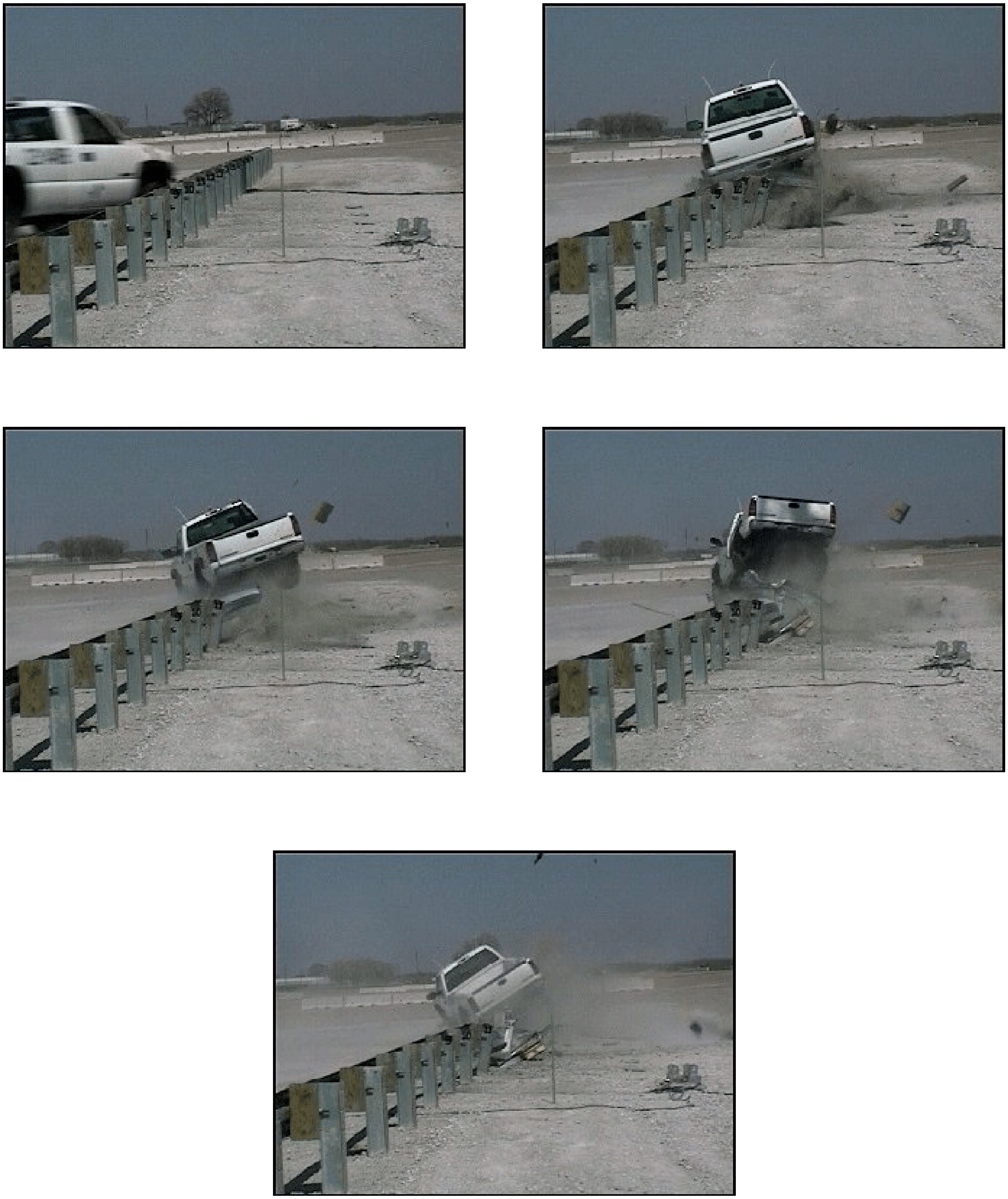


Figure 19. Documentary Photographs, Test 2214WB-1

Figure 20. Documentary Photographs, Test 2214WB-1

Figure 21. Impact Location, Test 2214WB-1

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

Figure 23. Standard Strong-Post, Wood-Blockout, W-beam Guardrail System Damage, Test 2214WB-1

Figure 24. Standard Strong-Post, Wood-Blockout, W-beam Guardrail System Damage, Test 2214WB-1

Figure 25. Standard Strong-Post, Wood-Blockout, W-beam Guardrail System Damage, Test 2214WB-1

Figure 26. Post Nos. 10 through 15 Damage, Test 2214WB-1

Figure 27. Post Nos. 16 through 20 Damage, Test 2214WB-1

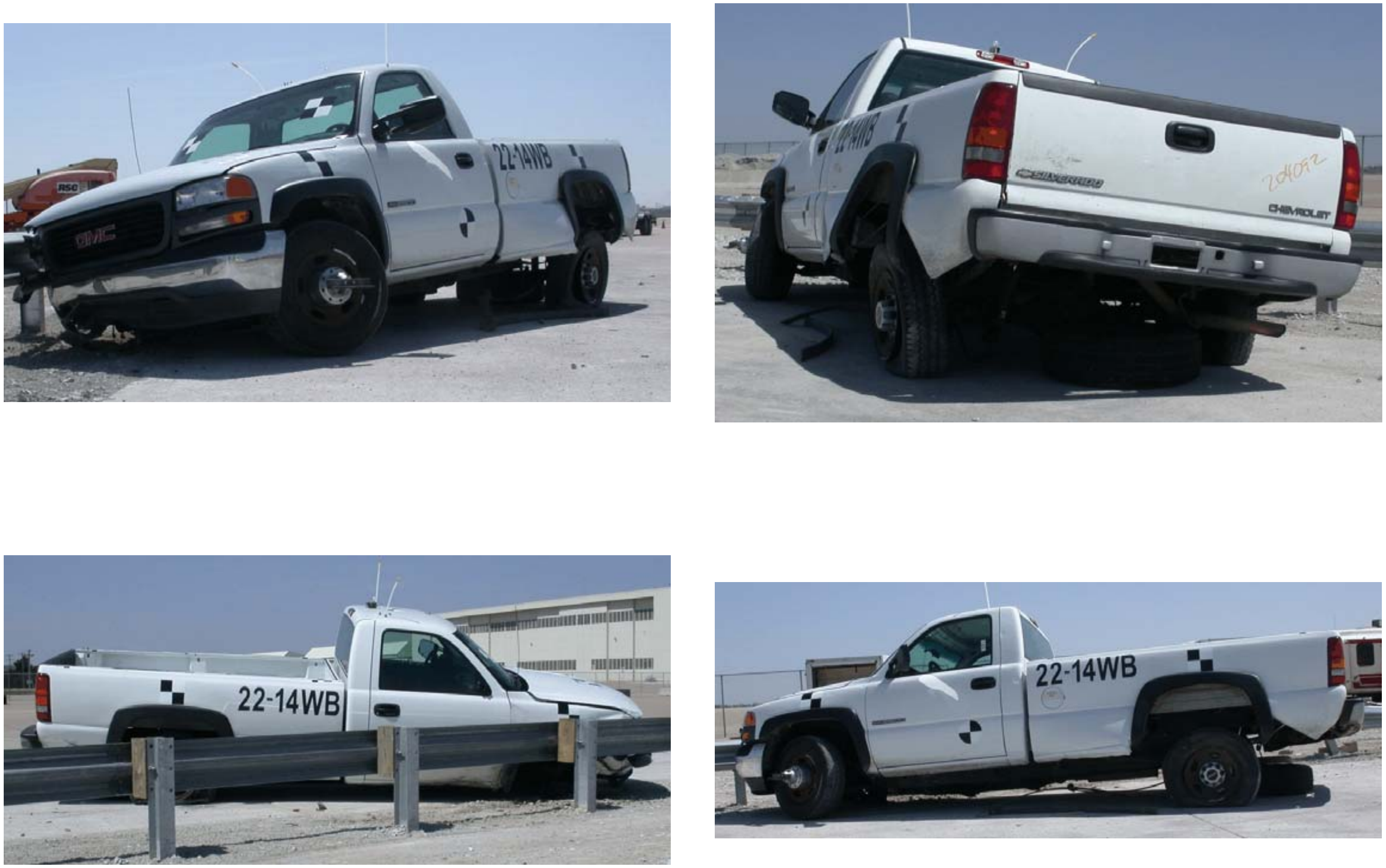


Figure 28. Vehicle Damage, Test 2214WB-1

Figure 29. Vehicle Damage, Test 2214WB-1

Figure 30. Vehicle Damage, Test 2214WB-1

6 SUMMARY AND CONCLUSIONS

A strong-post, W-beam guardrail system, the modified G4(1S) guardrail, 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 unacceptable according to the TL-3 safety performance criteria presented in the Update to NCHRP Report No. 350. During the 2270P crash test, the W-beam rail was completely ruptured and the vehicle contacted the ground located behind the system. 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 2214WB-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.	U
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

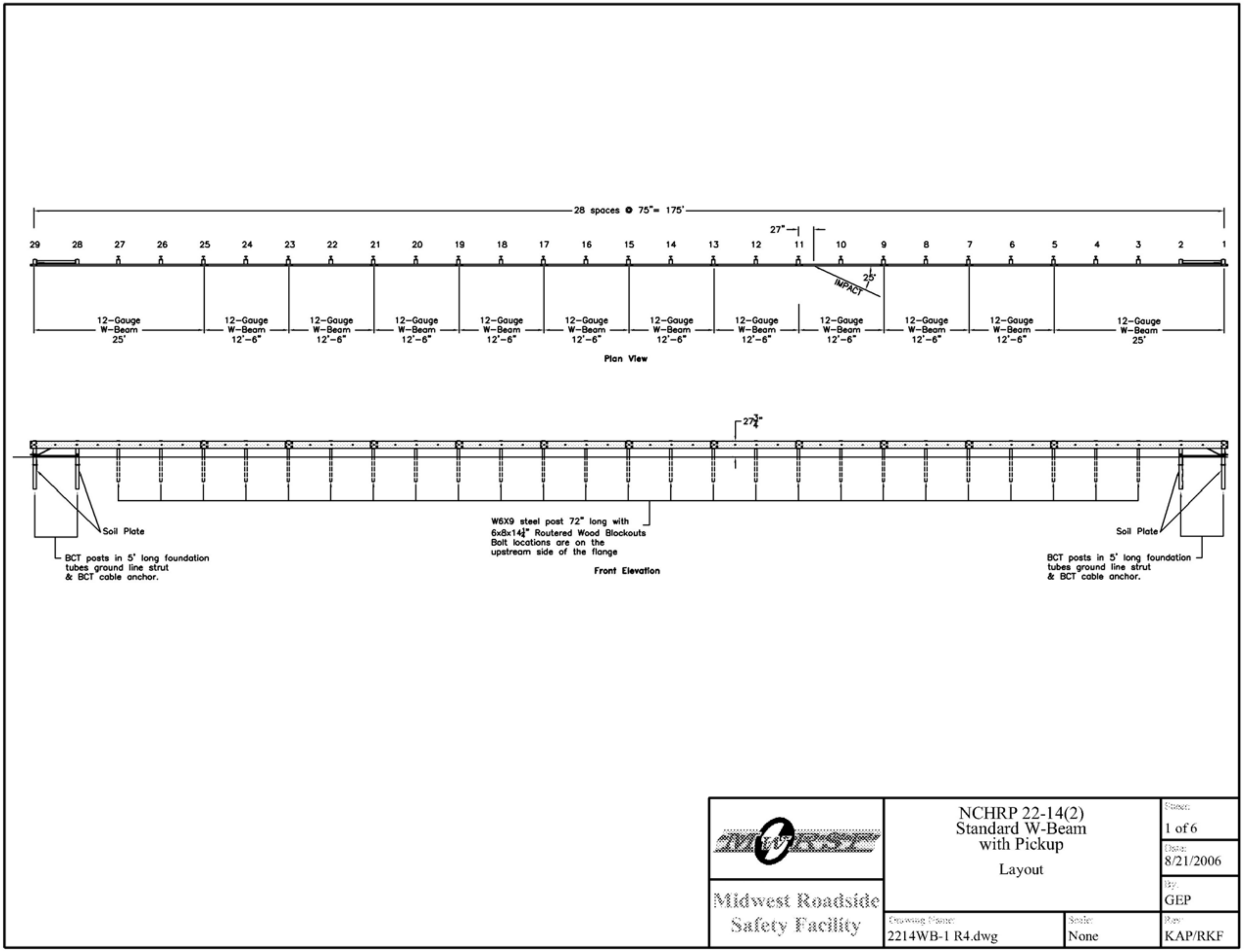


Figure A-1. Layout of Standard Height, Strong Post, Wood Blockout W-beam Guardrail Design (English)

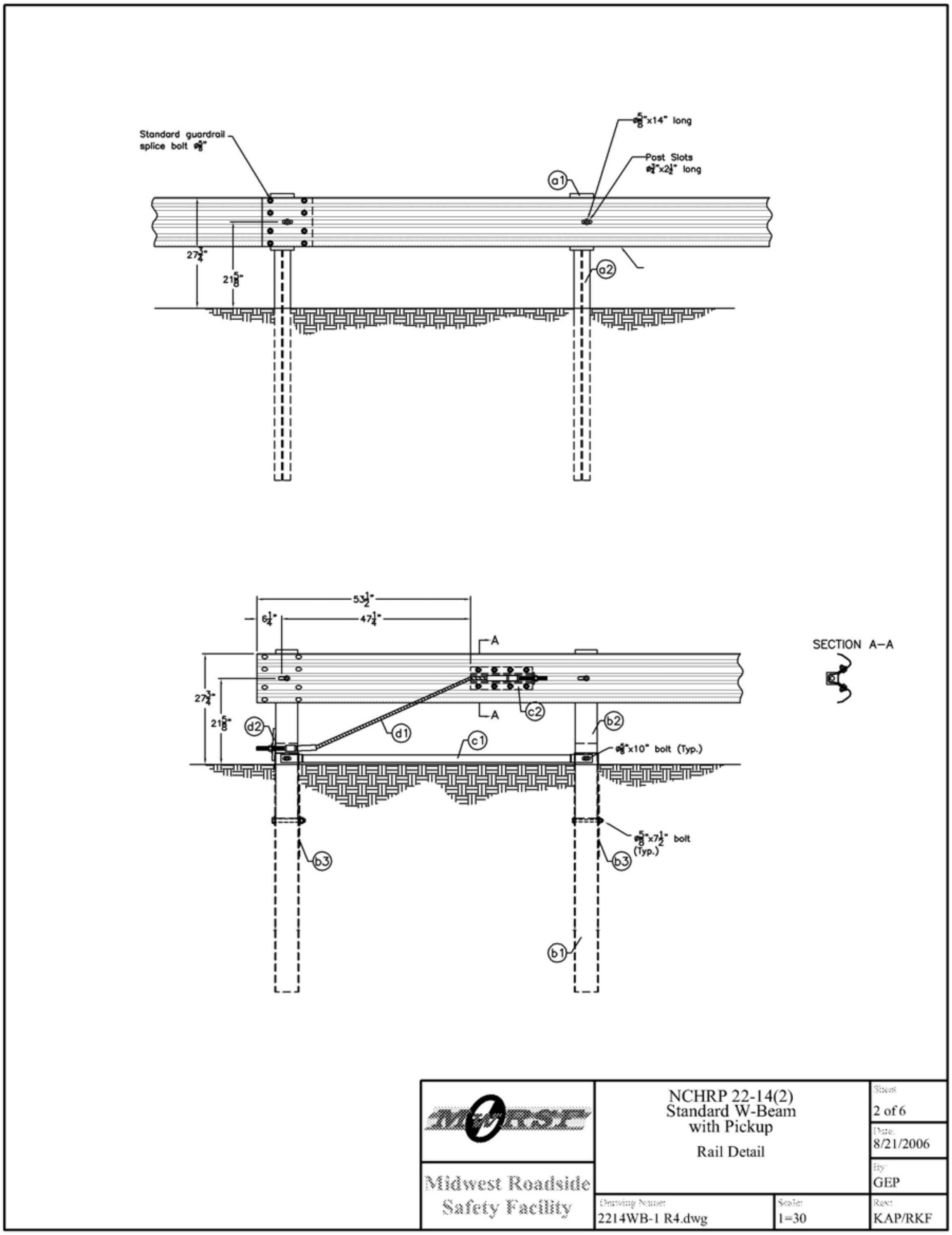
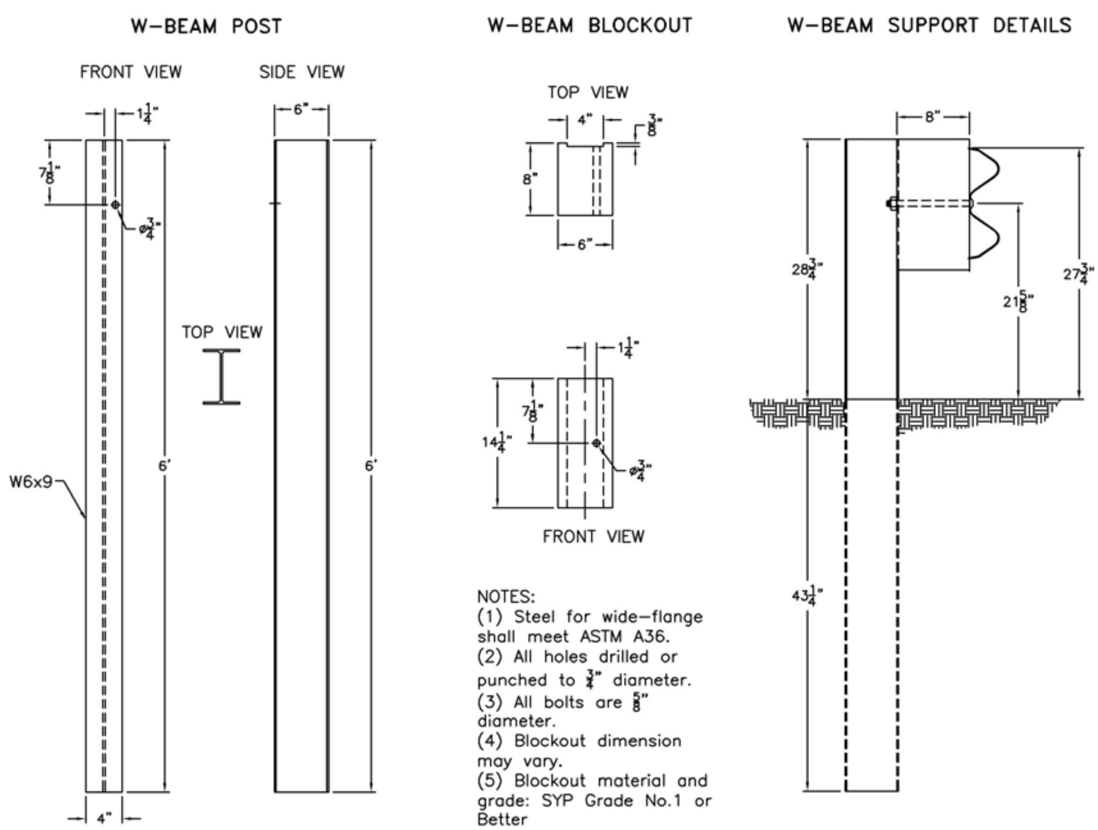


Figure A-2. Standard Height, Strong Post, Wood Blockout W-beam Guardrail Rail Details (English)

ITEM	QTY	DESCRIPTION	MATERIAL
a1	25	Steel Posts	W6x9 (W152x13.4)
a2	25	Blockout 6x8x14½"	XXX



Midwest Roadside Safety Facility
NCHRP 22-14(2) Standard W-Beam with Pickup
Post Detail
Sheet: 3 of 6
Date: 8/21/2006
By: GEP
Drawing Name: 2214WB-1 R4.dwg
Scale: 1=16
Rev: KAP/RKF

Figure A-3. Standard Height, Strong Post, Wood Blockout W-beam Guardrail Post Details (English)

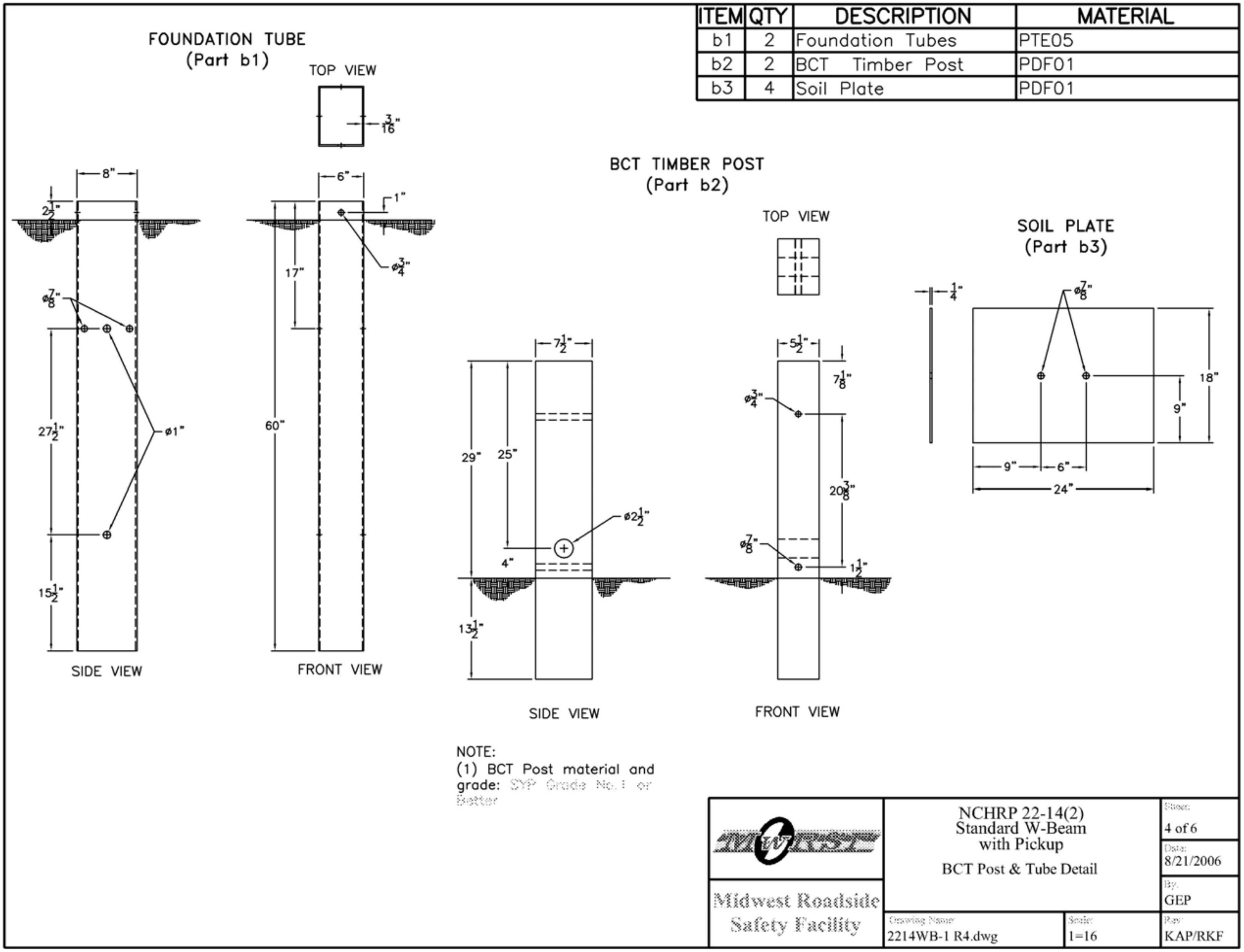


Figure A-4. Standard Height, Strong Post, Wood Blockout W-beam Guardrail Design Anchorage Details (English)

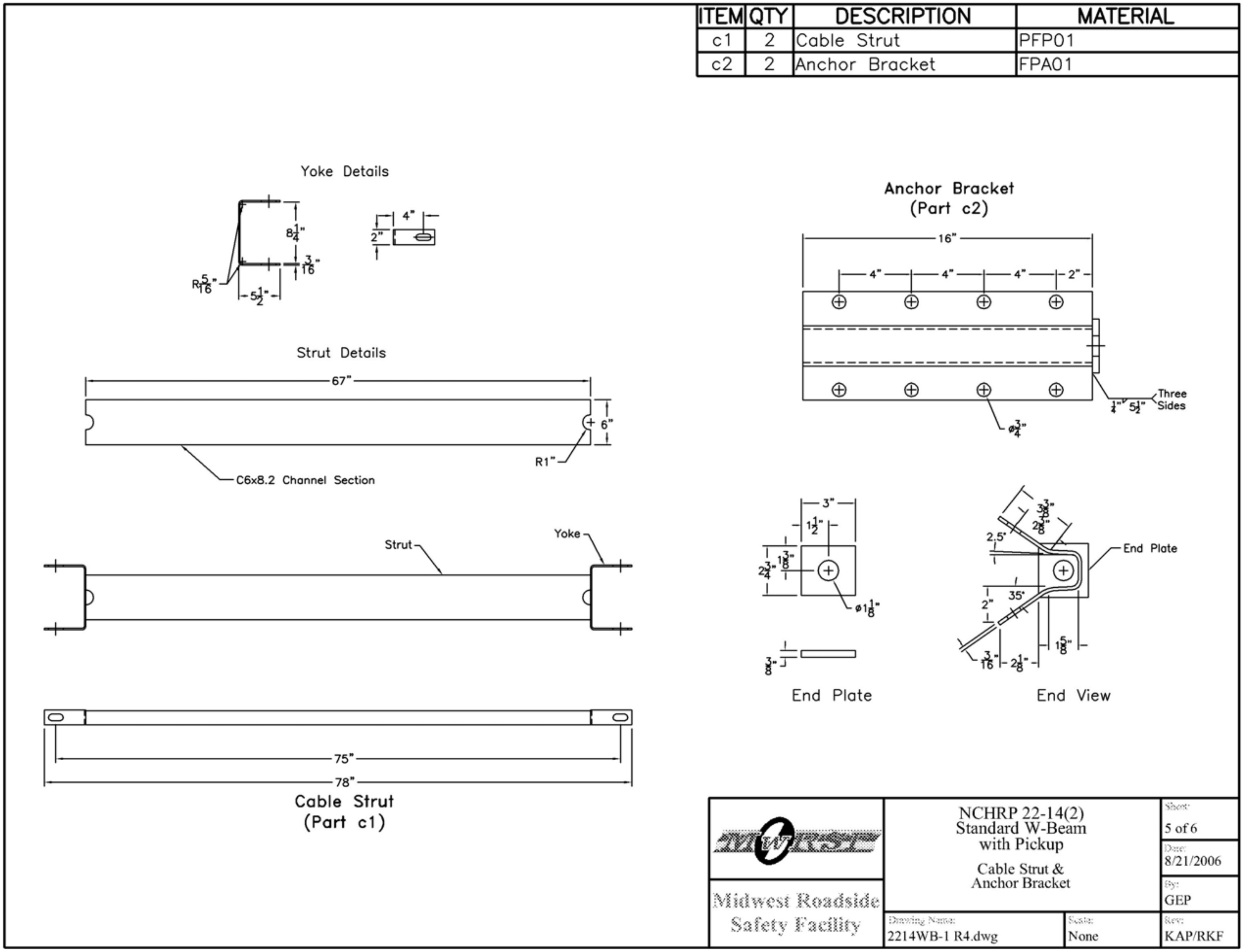


Figure A-5. Standard Height, Strong Post, Wood Blockout W-beam Guardrail Design Anchorage Details (English)

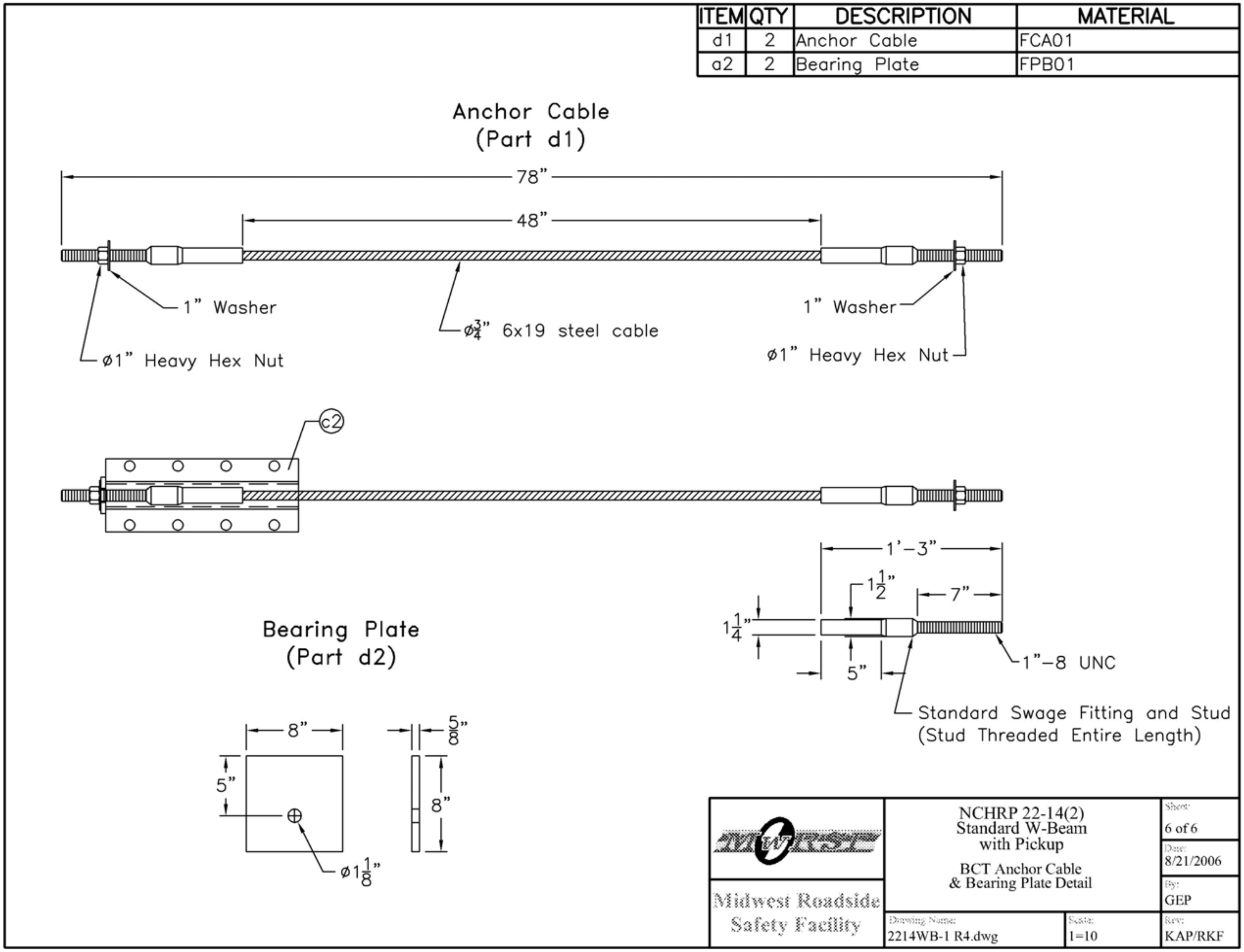


Figure A-6. Standard Height, Strong Post, Wood Blockout W-beam Guardrail Design Anchorage Details (English)

APPENDIX B

Test Summary Sheet in English Units

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

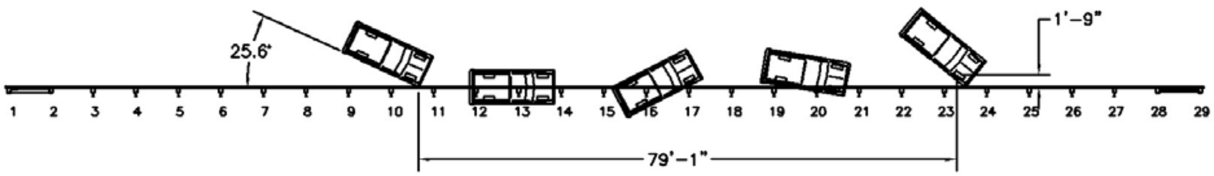
0.000 sec

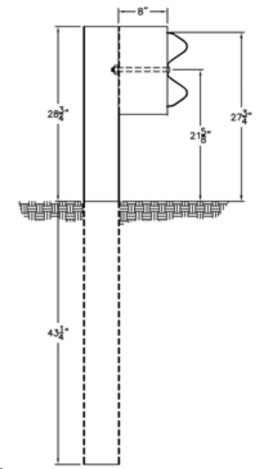
0.116 sec

0.230 sec

0.306 sec

0.470 sec





- Test Agency . . . . MwRSF
- Test Number 2214WB-1
- Date 4/14/04
- NCHRP 350 Update Test Designation . . 3-11
- Appurtenance . . . . Modified G4(1S) Guardrail
- Total Length . . . . 175 ft
- Key Elements - Steel W-Beam
  - Thickness . . . . 12 gauge
  - Top Mounting Height . . . . 27.75 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 . 5-ft long with soil plate
- Key Elements - Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 6 in. x 8 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 . . . . 5,022 lbs
  - Test Inertial . . . . 5,000 lbs
  - Gross Static . . . . 5,000 lbs
- Impact Conditions
  - Speed . . . . 61.1 mph
  - Angle (trajectory) . . . . 25.6 degrees
  - Impact Location . . . . 15 ft upstream centerline post no. 13
- Exit Conditions
  - Speed . . . . NA
  - Angle . . . . NA
  - Exit Box Criterion . . . . NA
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 79 ft - 1 in. downstream; 1 ft - 9 in. traffic-side face
- Occupant Impact Velocity (350 Update)
  - Longitudinal . . . . 17.29 ft/s < 39.4 ft/s
  - Lateral . . . . 16.17 ft/s < 39.4 ft/s
- Occupant Ridedown Deceleration (350 Update)
  - Longitudinal . . . . 19.71 Gs < 20 Gs
  - Lateral . . . . 8.46 Gs < 20 Gs
- THIV (not required) . . . . 24.87 ft/s
- PHD (not required) . . . . 21.22 Gs
- Test Article Damage . . . . Extensive (rail fracture)
- Test Article Deflections
  - Permanent Set . . . . NA
  - Dynamic . . . . NA
  - Working Width . . . . NA
- Vehicle Damage . . . . Moderate
  - VDS[5] 1-RFQ-4
  - CDC[6] 1-RFEN3
  - Maximum Deformation . . . . 0.75 in. at right-center floorpan

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

APPENDIX C

Occupant Compartment Deformation Data, Test 2214WB-1

VEHICLE PRE/POST CRUSH INFO

TEST: 2214WB-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	59.25	10.25	1	59.5	10	0.75	0.25	-0.25	-0.25		1		1		0
2	60.5	14.75	1	60.5	14.25	0.75	0	-0.5	-0.25		0.75		0.75		0
3	62.5	18.25	1	62.75	18	0.75	0.25	-0.25	-0.25		0.5		0.25		0.25
4	62.75	22.75	0.5	63	22.5	0.25	0.25	-0.25	-0.25		0		0		
5	61.75	25.75	0	61.75	25.75	0	0	0	0		0.75		1		-0.25
6	61.5	29.25	0.75	61.75	29	0.75	0.25	-0.25	0		1		1.25		-0.25
7	55.5	9.5	3.5	55.5	9.5	3.25	0	0	-0.25		3.5		3.5		0
8	56.5	14.25	6	56.5	14	5.75	0	-0.25	-0.25		6		5.75		0.25
9	58	20.25	4.75	58	20	4.5	0	-0.25	-0.25		4.5		4.25		0.25
10	56.25	25.25	6.5	56.25	24.75	6.25	0	-0.5	-0.25		6		6		0
11	58	29.75	5.25	57.75	29.75	5.25	-0.25	0	0		4.5		4.5		0
12	48.75	8	4.75	48.75	8	4.5	0	0	-0.25		4.75		4.5		0.25
13	49	13	9	49.25	12.5	9	0.25	-0.5	0		9		9		0
14	49	17.5	9.25	48.25	17	9	-0.75	-0.5	-0.25		9		9		0
15	49	22.25	9.5	48.25	22	9.5	-0.75	-0.25	0		9.25		9		0.25
16	49.25	29.5	9.75	49.25	29.25	9.75	0	-0.25	0		9.25		9		0.25
17	39.5	4	2.5	39.25	4	2.25	-0.25	0	-0.25		2.5		2.75		-0.25
18	40.25	8.5	7	40.25	8.25	7	0	-0.25	0		6.75		7		-0.25
19	40	14.75	9.5	40.25	14.5	9.5	0.25	-0.25	0		9.5		9.5		0
20	41	23.5	10	41	23.5	9.75	0	0	-0.25		9.75		9.5		0.25
21	41.75	29	10	41.5	29	10	-0.25	0	0		9.5		9.5		0
22	32.25	27.25	8.5	32.25	27.25	8.5	0	0	0		8.25		8		0.25
23	31.5	15.5	8	31.5	15.25	8	0	-0.25	0		8		8		0
24	18.25	27	8.5	18.25	26.75	8.75	0	-0.25	0.25		8.75		8.75		0
25	18.25	15	8.5	18.25	15.25	8.5	0	0.25	0		8.5		8.5		0
26	39.5	26.75	19.75	39.5	26.75	20	0	0	0.25		20.25		20.5		-0.25
27	39.75	13	20.5	39.75	13	20.75	0	0	0.25		20.75		21		-0.25
28	43.75	0	24.75	43.75	0	25	0	0	0.25		24.75		24.75		0
29															
30															

ORIENTATION AND REFERENCE INFO

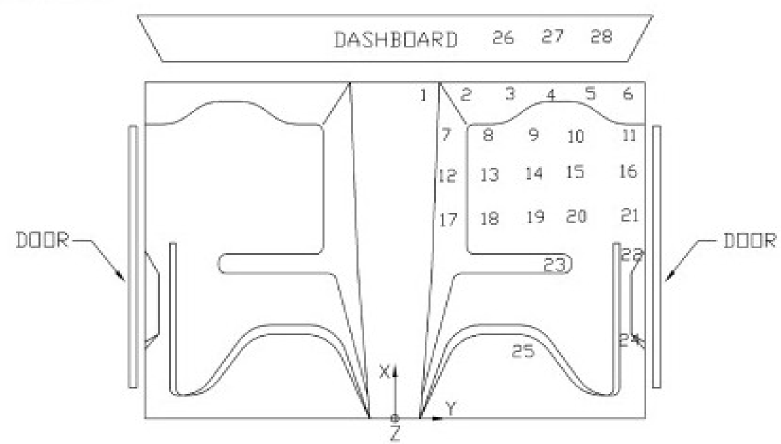


Figure C-1. Occupant Compartment Deformation Data, Test 2214WB-1

Occupant Compartment Deformation Index (OCDI)

Test No. 2214WB-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

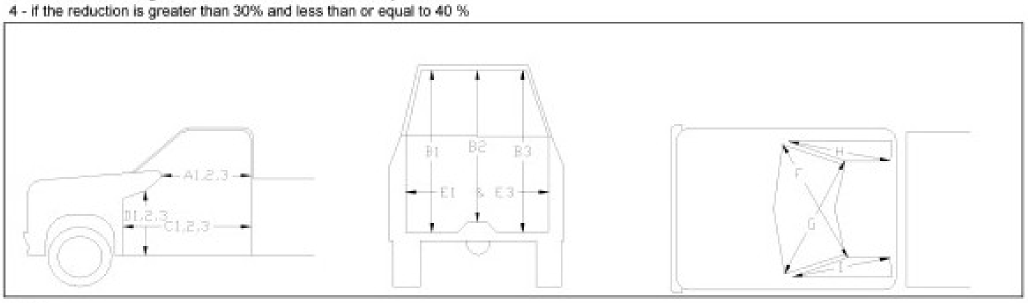
G = distance between the lower edge of left window and the upper edge of right window

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	41.50	41.50	0.00	0.00	0
A2	41.25	41.25	0.00	0.00	0
A3	41.50	41.25	-0.25	-0.60	0
B1	48.00	48.00	0.00	0.00	0
B2	44.50	44.50	0.00	0.00	0
B3	48.00	47.75	-0.25	-0.52	0
C1	59.75	59.75	0.00	0.00	0
C2	54.75	54.50	-0.25	-0.46	0
C3	60.00	60.00	0.00	0.00	0
D1	16.00	16.00	0.00	0.00	0
D2	9.00	9.00	0.00	0.00	0
D3	15.25	15.50	0.25	1.64	0
E1	63.00	62.75	-0.25	-0.40	0
E3	64.25	64.00	-0.25	-0.39	0
F	60.75	61.00	0.25	0.41	0
G	61.25	61.25	0.00	0.00	0
H	37.50	37.00	-0.50	-1.33	0
I	37.00	37.75	0.75	2.03	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 2214WB-1

Date: 4/14/04 Test Number: 2214WB-1 Model: 2000P/2500P.V.

Make: GMC Vehicle I.D.#: 1GDGC24U522211218

Tire Size: LT 245/75 R16 Year: 2002 Odometer: 208781

*(All Measurements Refer to Impacting Side) Vehicle Geometry -- mm (in.)

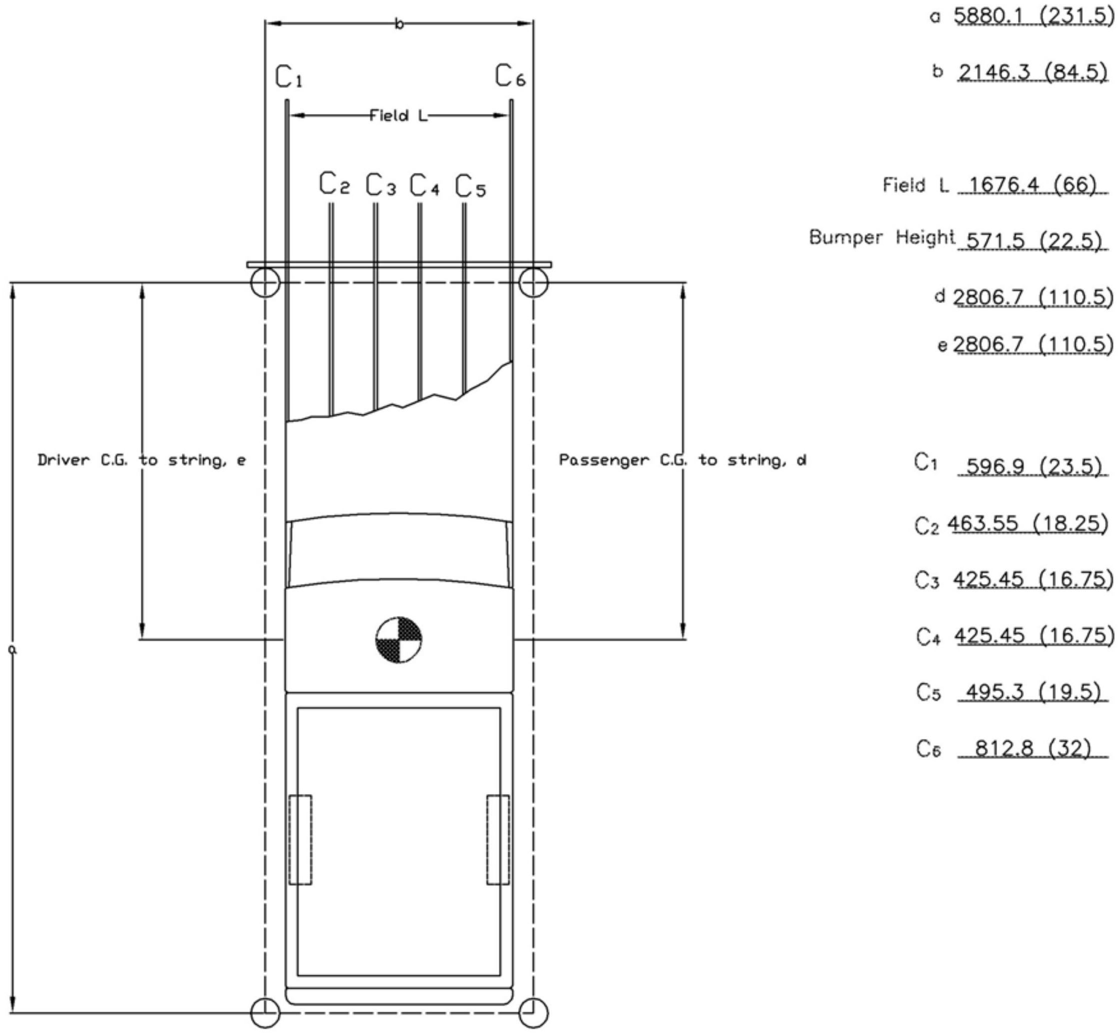


Figure C-3. NASS Crush Data, Test 2214WB-1

APPENDIX D

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

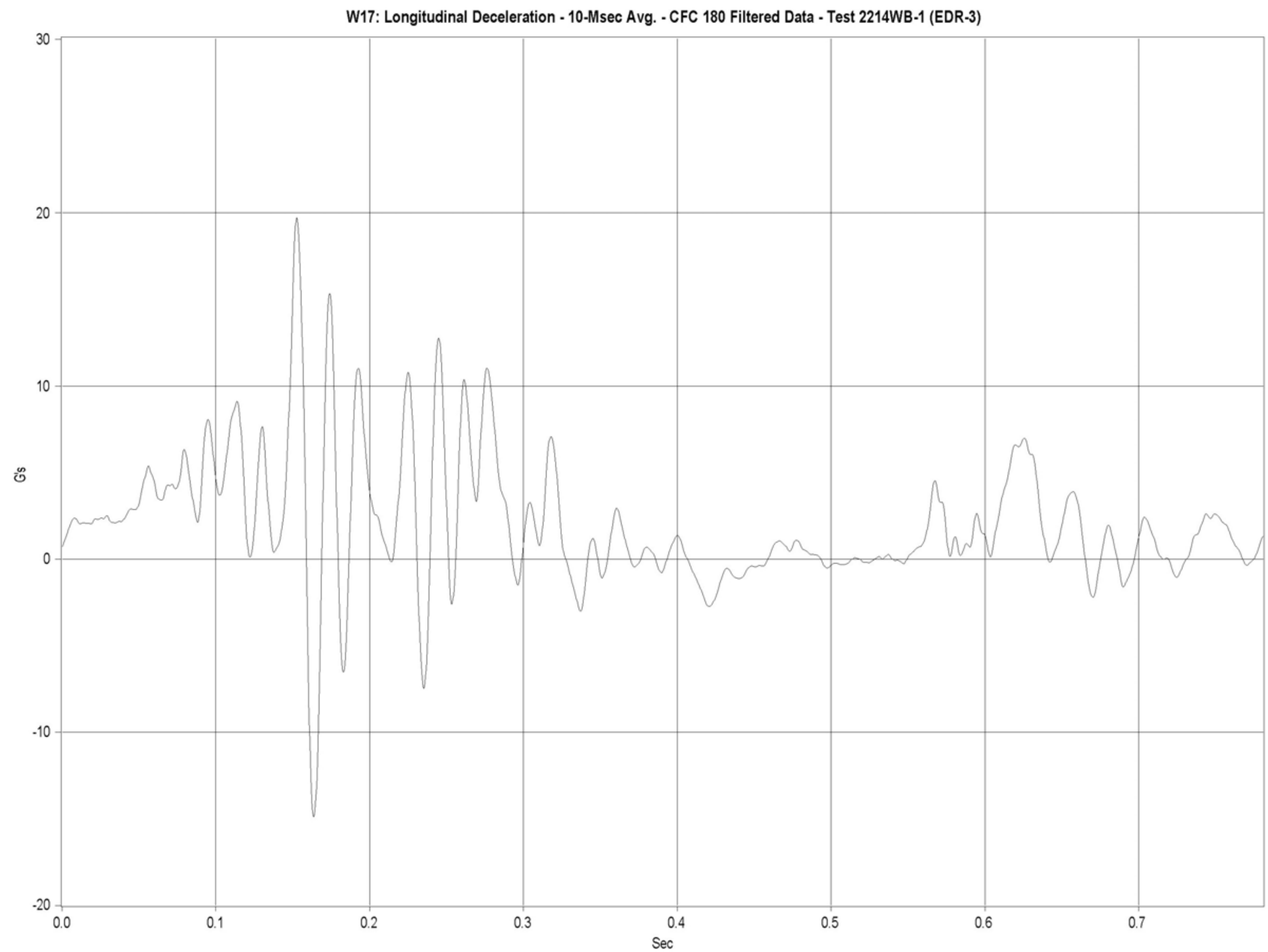


Figure D-1. Graph of Longitudinal Deceleration, Test 2214WB-1

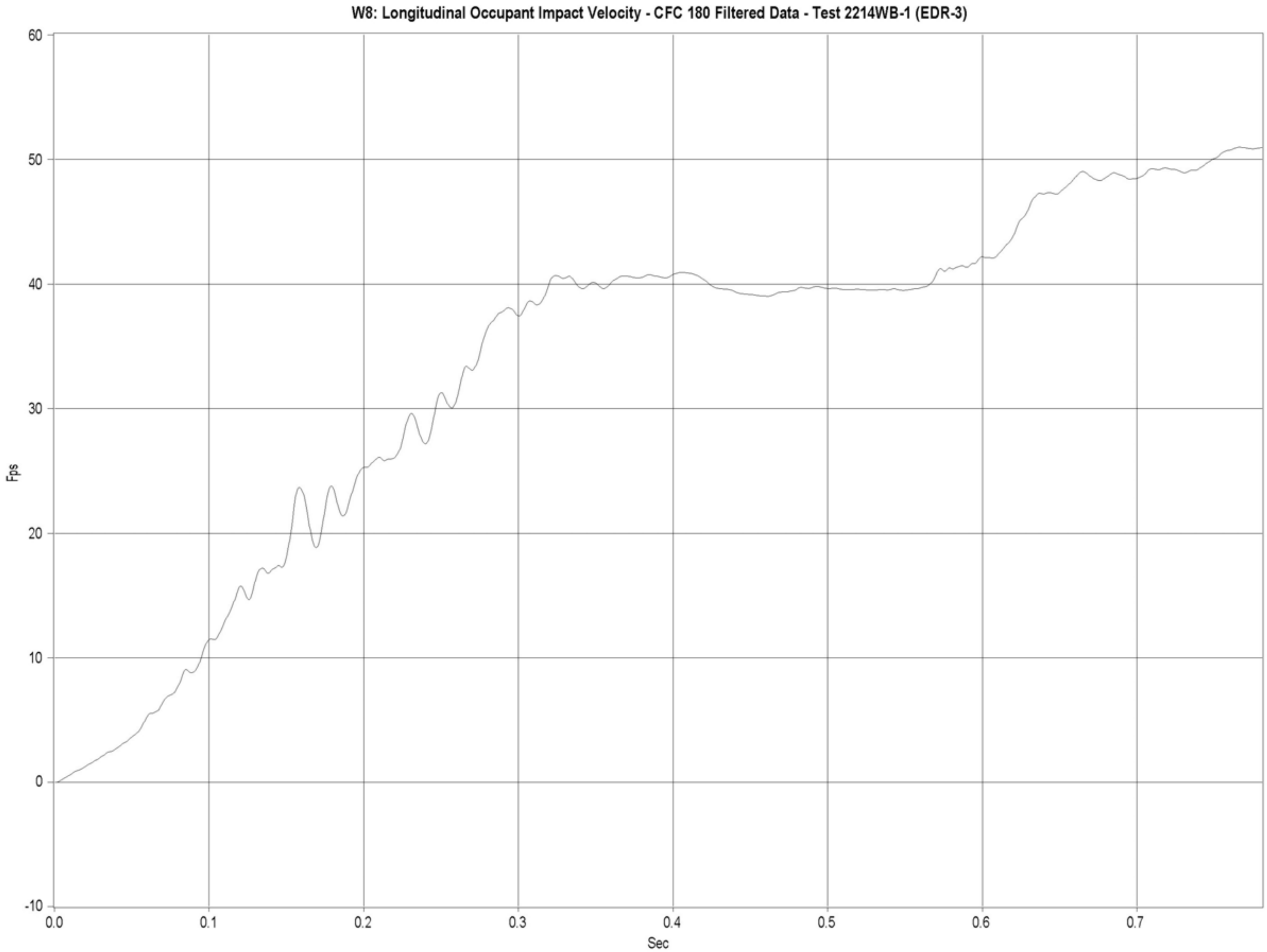


Figure D-2. Graph of Longitudinal Occupant Impact Velocity, Test 2214WB-1

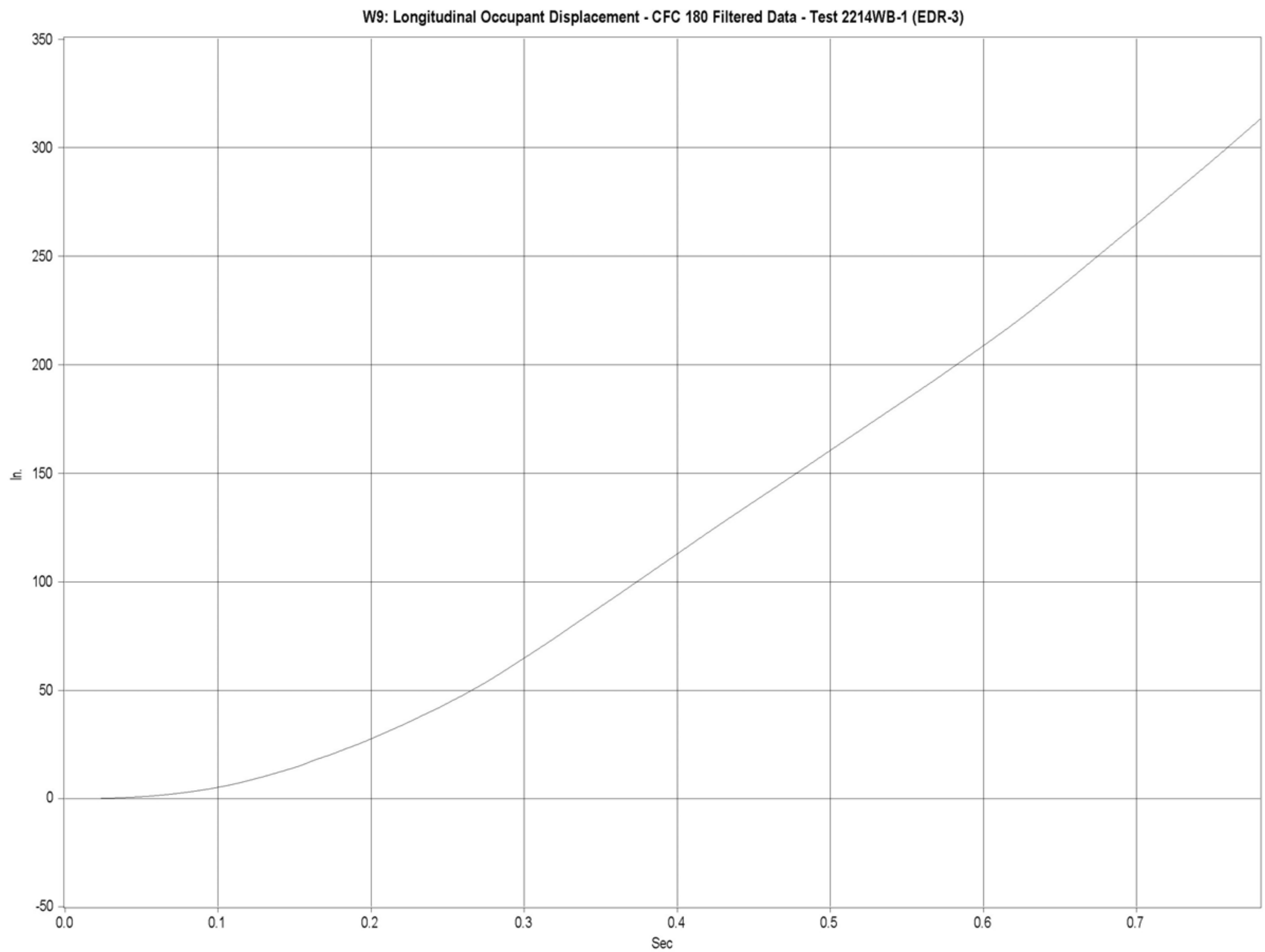


Figure D-3. Graph of Longitudinal Occupant Displacement, Test 2214WB-1

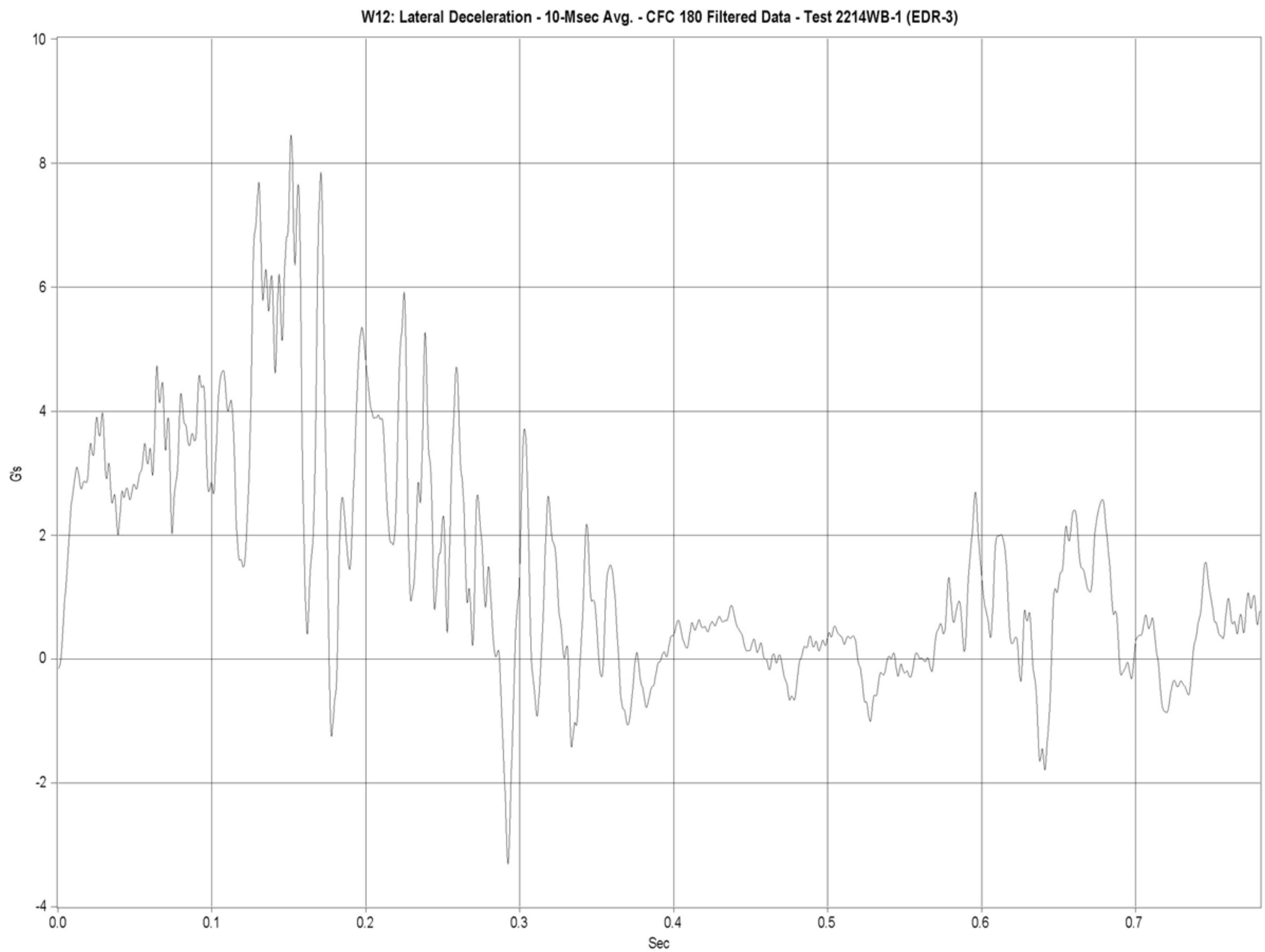


Figure D-4. Graph of Lateral Deceleration, Test 2214WB-1

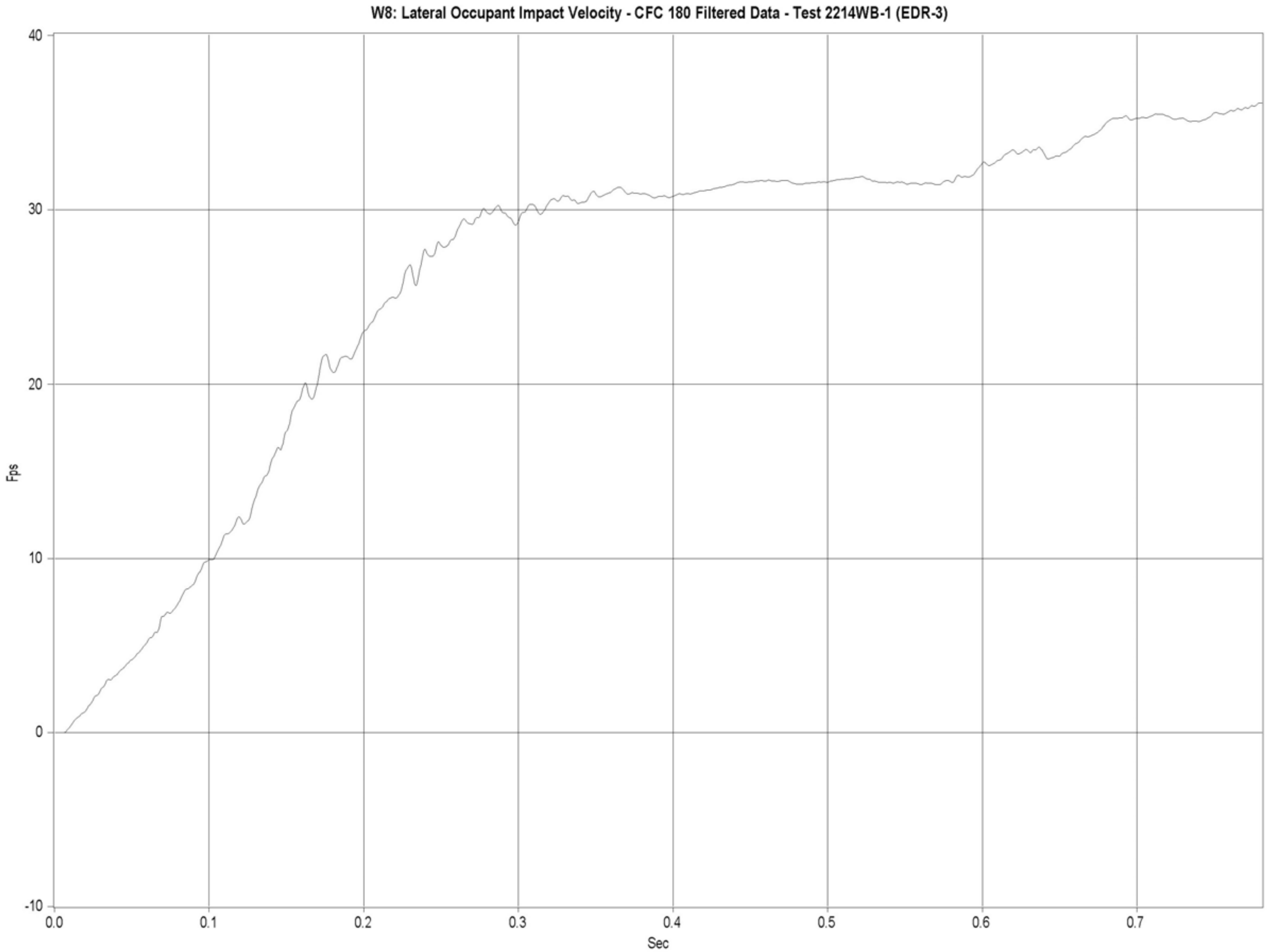


Figure D-5. Graph of Lateral Occupant Impact Velocity, Test 2214WB-1

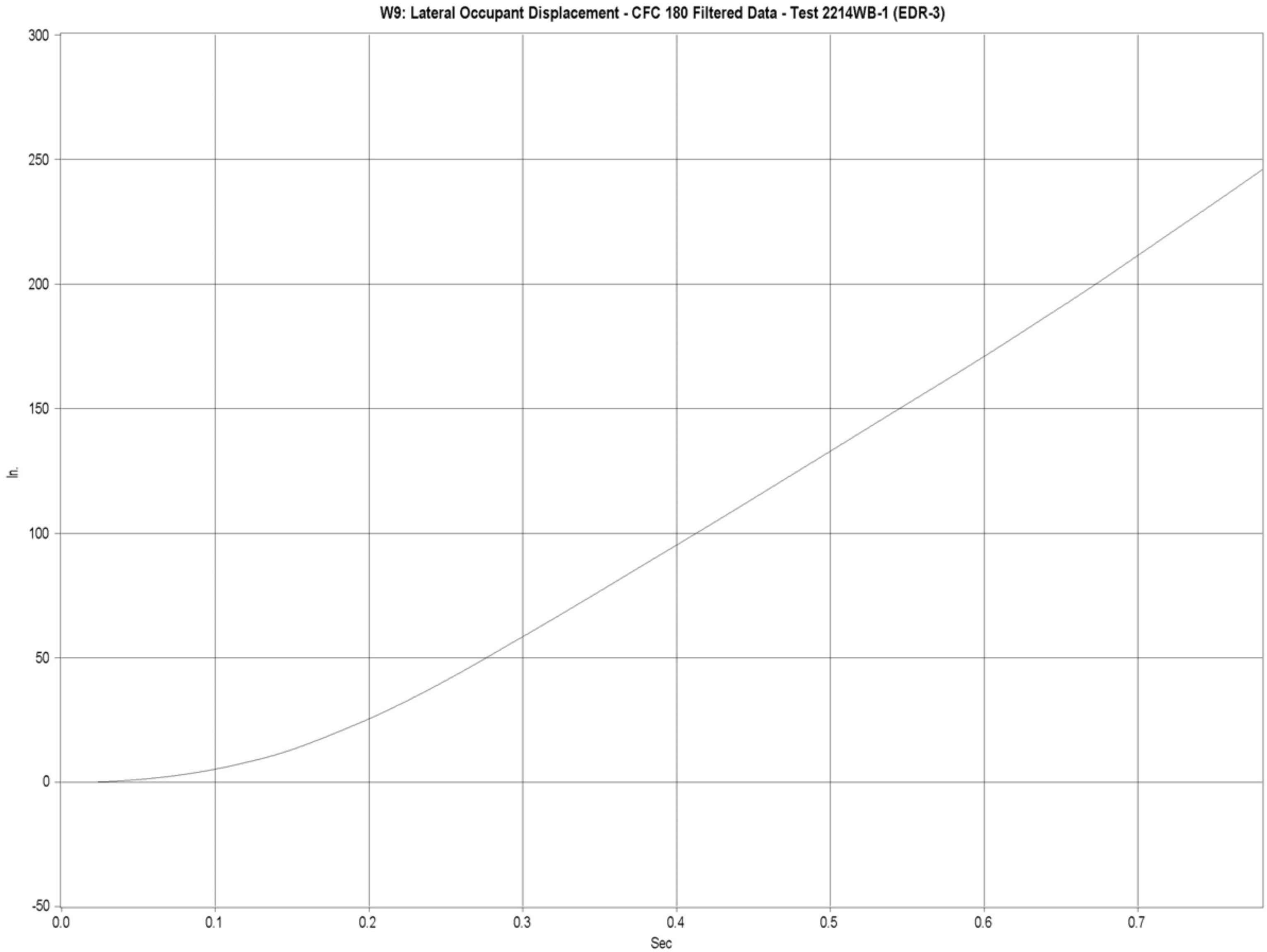


Figure D-6. Graph of Lateral Occupant Displacement, Test 2214WB-1

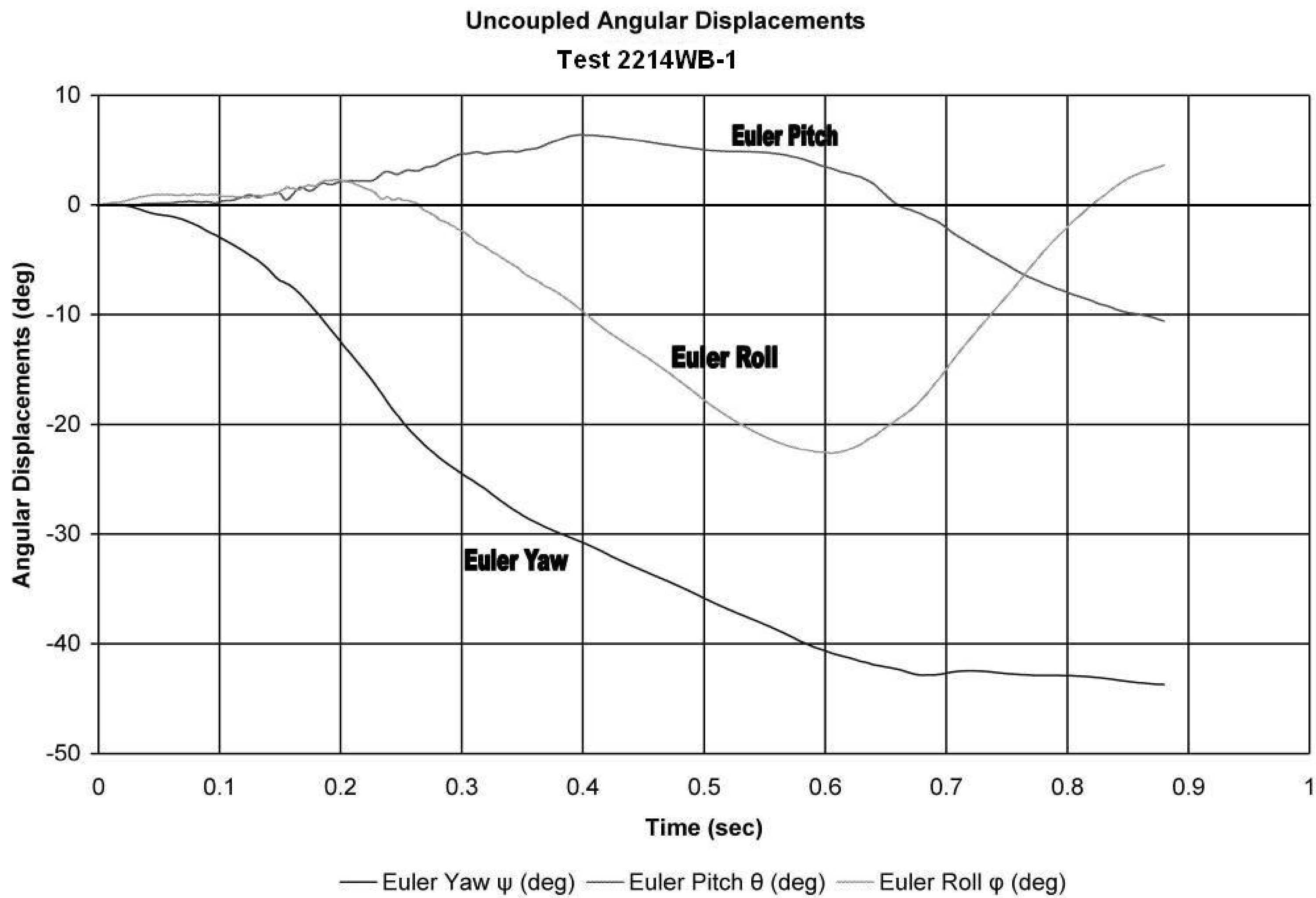


Figure D-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test 2214WB-1