PERFORMANCE EVALUATION OF THE MIDWEST GUARDRAIL SYSTEM – UPDATE TO NCHRP 350 TEST NO. 3-10 (2214MG-3)

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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 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, an 1100C small car vehicle was used.

The MGS system, mounted at the metric top rail height of 813 mm (32.0 in.), provided an acceptable safety performance when impacted by the small car, thus meeting the proposed TL-3 requirements presented in the Update to NCHRP Report No. 350.

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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. 3-10 criteria presented in the Update of NCHRP Report No. 350 guidelines (2).

1.3 Scope

The research objective was achieved by performing several tasks. First, a full-scale vehicle crash test was performed on the MGS system. The crash test utilized a small car, weighing approximately 1,100 kg (2,425 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 3-10 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-3, the vehicle guidance system was 268 m (879 ft) long.

3.3 Test Vehicles

For test 2214MG-3, a 2002 Kia Rio was used as the test vehicle. The test inertial and gross static weights were 1,099 kg (2,423 lbs) and 1,174 kg (2,588 lbs). The test vehicle is shown in Figure 1, and vehicle dimensions are shown in Figure 2.

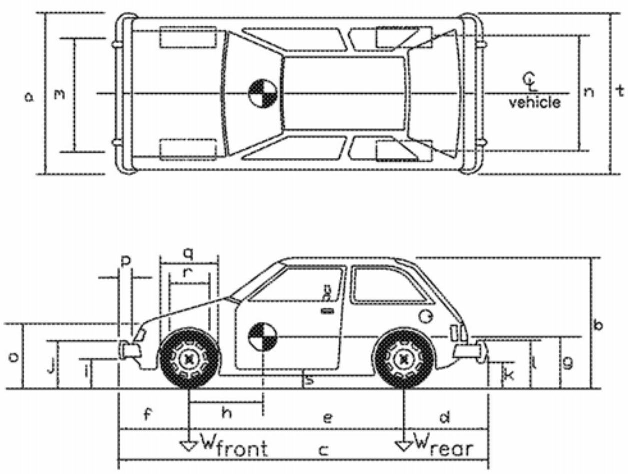
Figure 1. Test Vehicle, Test 2214MG-3

Date: 11/8/2004 Test Number: 2214MG-3 Model: 820C Rio Sadan

Make: Kia Vehicle I.D.#: KNADC123426148283

Tire Size: P175/65 R14 Year: 2002 Odometer: 37133

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1638 (64.5)	b	1918 (75.5)
c	4216 (166.0)	d	953 (37.5)
e	2426 (95.5)	f	838 (33.0)
g	546 (21.5)	h	925 (36.4)
i	216 (8.5)	j	540 (21.25)
k	235 (9.25)	l	552 (21.75)
m	1394 (54.875)	n	1445 (56.875)
o	559 (22.0)	p	76 (3.0)
q	578 (22.75)	r	391 (15.375)
s	279 (11.0)	t	1664 (65.5)

Wheel Center Height 267 (10.5)

Engine Type 4 CYL. GAS

Engine Size 1.5 L

Transmission Type:

(Automatic) or Manual

(FWD) or RWD or 4WD

Weights kg (lbs)	Stripped	Test Inertial	Gross Static
W_{front}	648 (1428)	679 (1498)	717 (1581)
W_{rear}	378 (833)	419 (924)	457 (1007)
W_{total}	1025 (2261)	1099 (2422)	1174 (2588)

Note any damage prior to test: None

Figure 2. Vehicle Dimensions, Test 2214MG-3

The longitudinal component of the center of gravity was determined using the measured axle weights. The location of the final centers of gravity are shown in Figures 1 and 2.

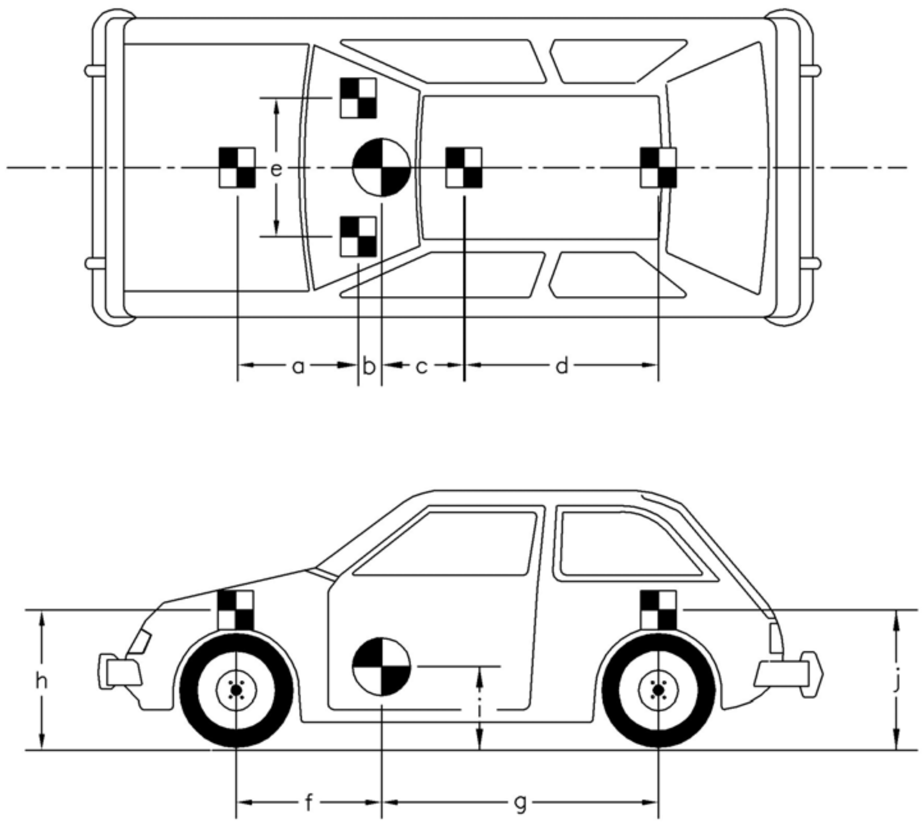
Square black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film and E/cam and Photron video, as shown in Figure 3. Checkered targets were placed on the center of gravity, on the driver's side door, on the passenger's side door, and on the roof of the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



TEST #: 2214MG-3

TARGET GEOMETRY -- mm (in.)

a 1181 (46.5)	b –	c 1035 (40.75)	d 1197 (47.125)
e 673 (26.5)	f 925 (36.4)	g 1502 (59.125)	h 737 (29.0)
	i 546 (21.5)	j 711 (28.0)	

Figure 3. Vehicle Target Locations, Test 2214MG-3

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-3, one high-speed 16-mm Red Lake Locam camera, with operating speed of approximately 500 frames/sec, was used to film the crash test. Two high-speed Photron video camera and three 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-3 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-3, five pressure-activated tape switches, spaced at 2-m (6.56-ft) intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the 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.

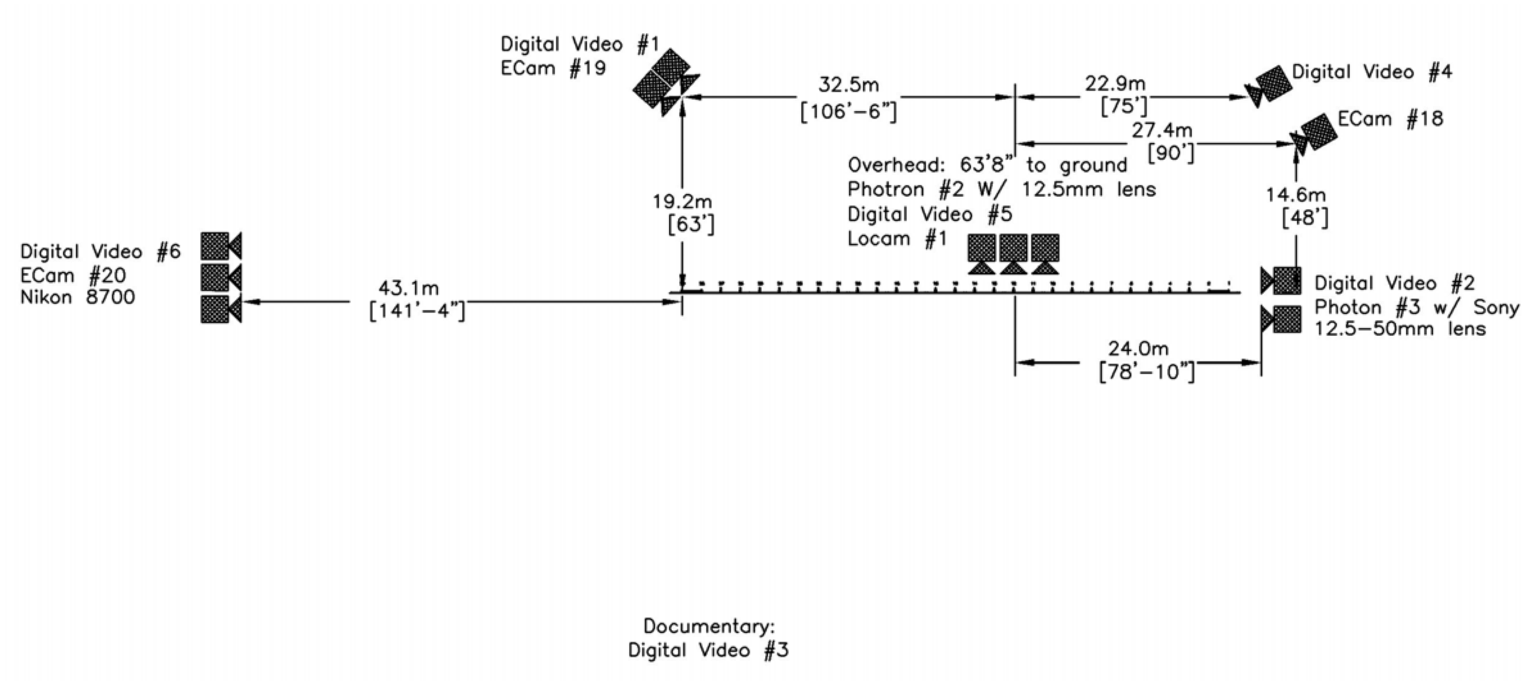


Figure 4. Location of High-Speed Cameras, Test 2214MG-3

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 and 12.

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 991 mm (39 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 NCHRP 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 813 mm (32 in.) with a 657-mm (25 ⅞-in.) center mounting height. This guardrail height corresponds to the maximum tolerance of the design's nominal top rail height of 787 mm (31 in.) and center mounting height of 632 mm (24 ⅞ in.). 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.

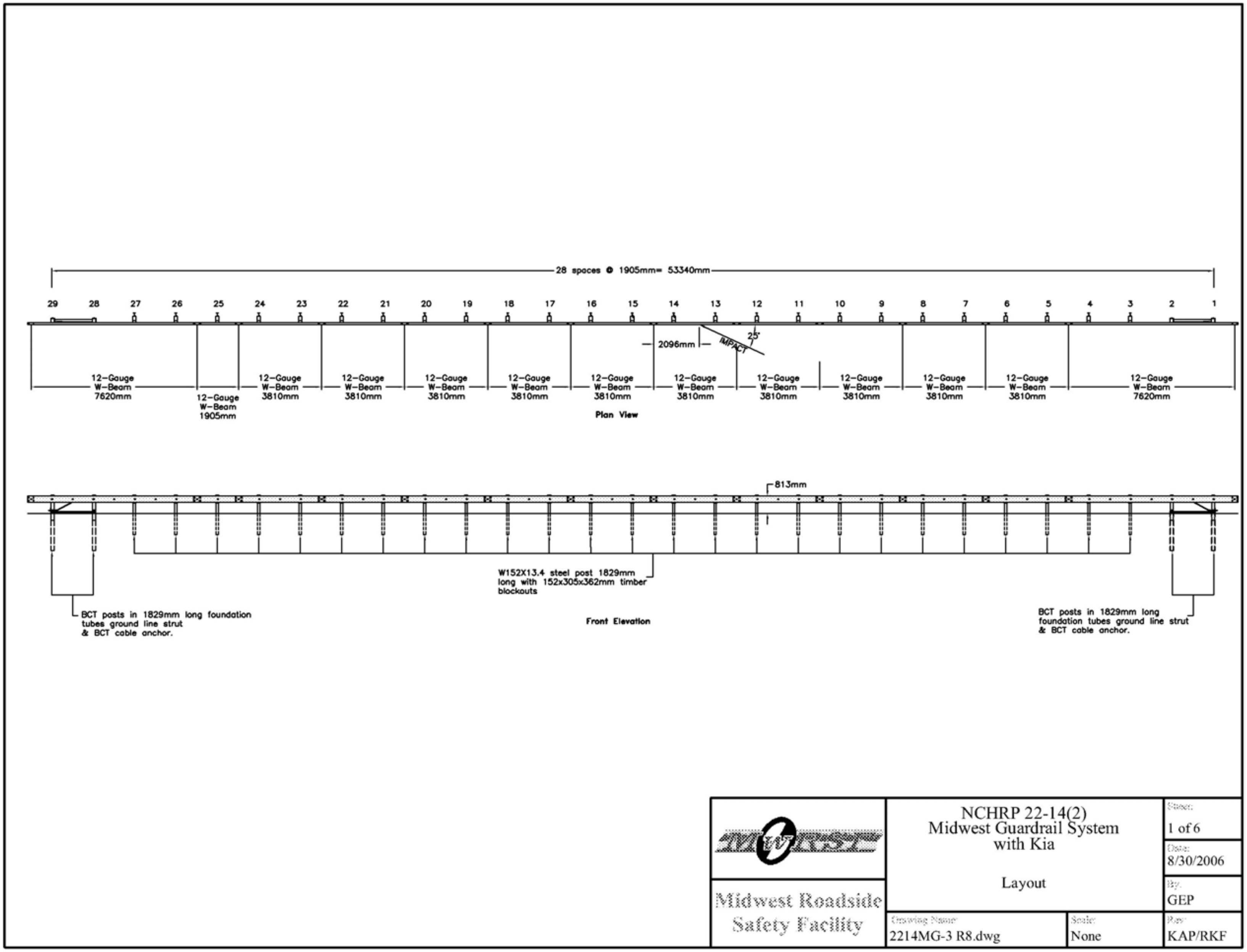


Figure 5. Layout of Midwest Guardrail System Design - Maximum Height Tolerance

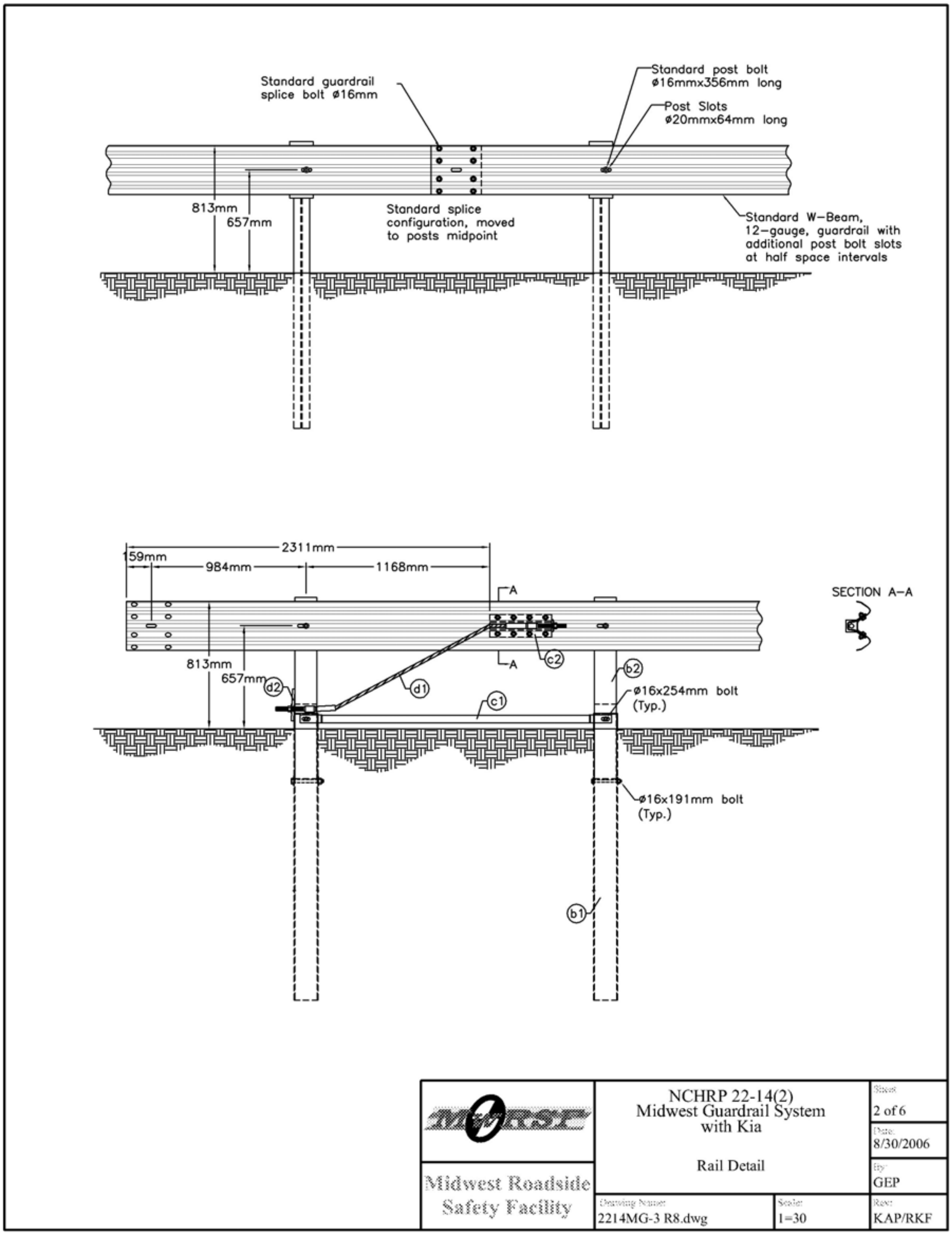


Figure 6. Midwest Guardrail System Rail Details - Maximum Height Tolerance

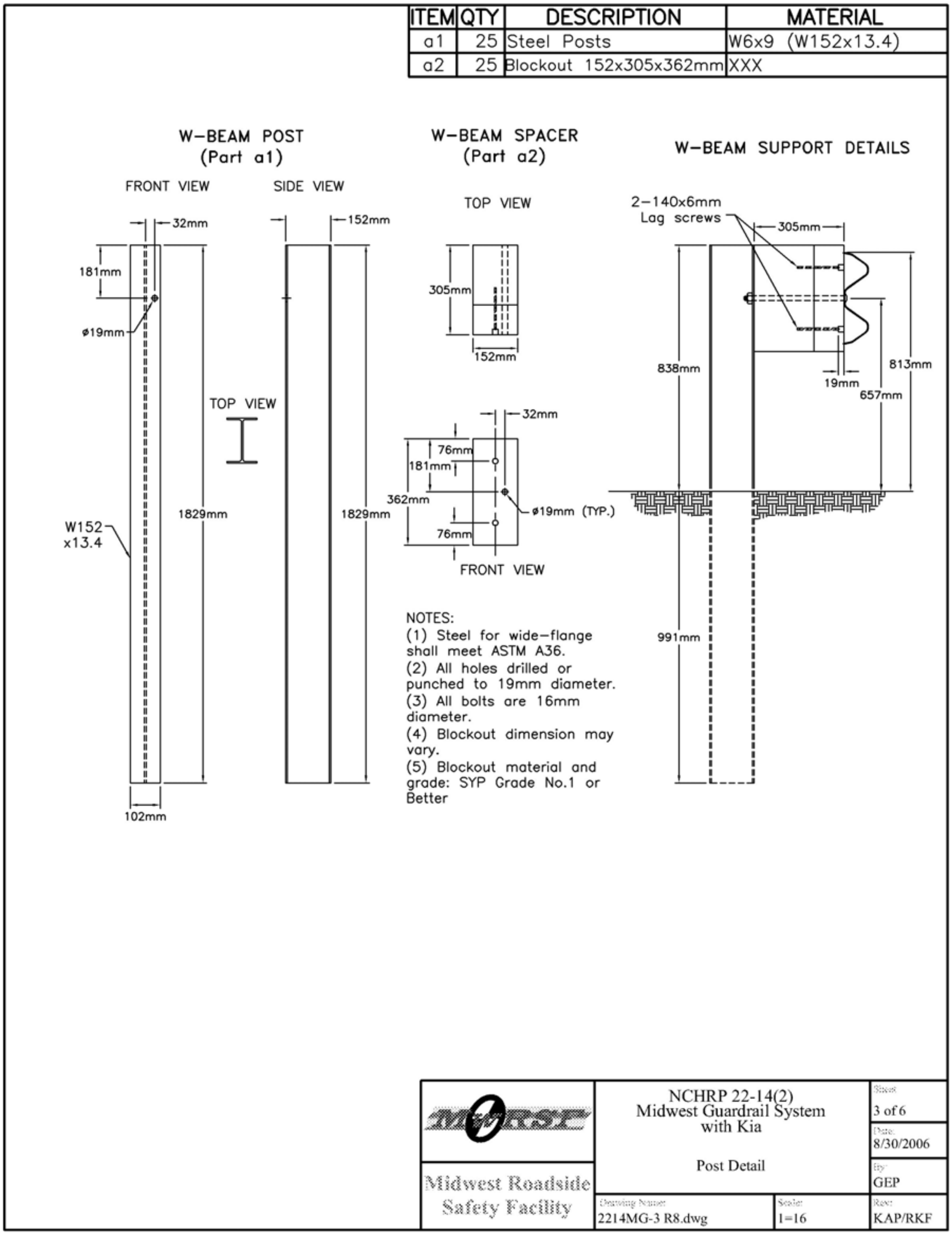


Figure 7. Midwest Guardrail System Post Details - Maximum Height Tolerance

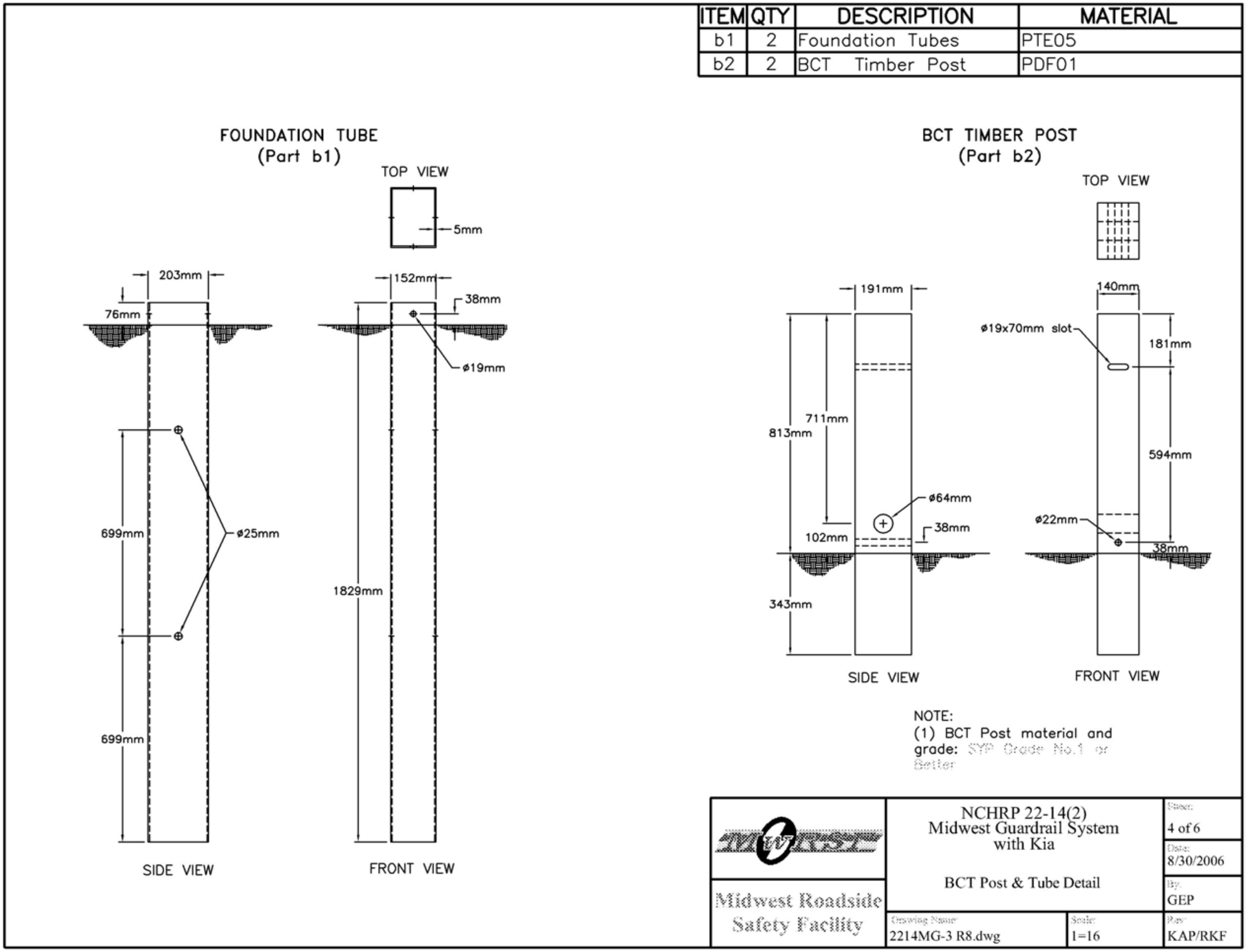


Figure 8. Midwest Guardrail System Anchorage Details - Maximum Height Tolerance

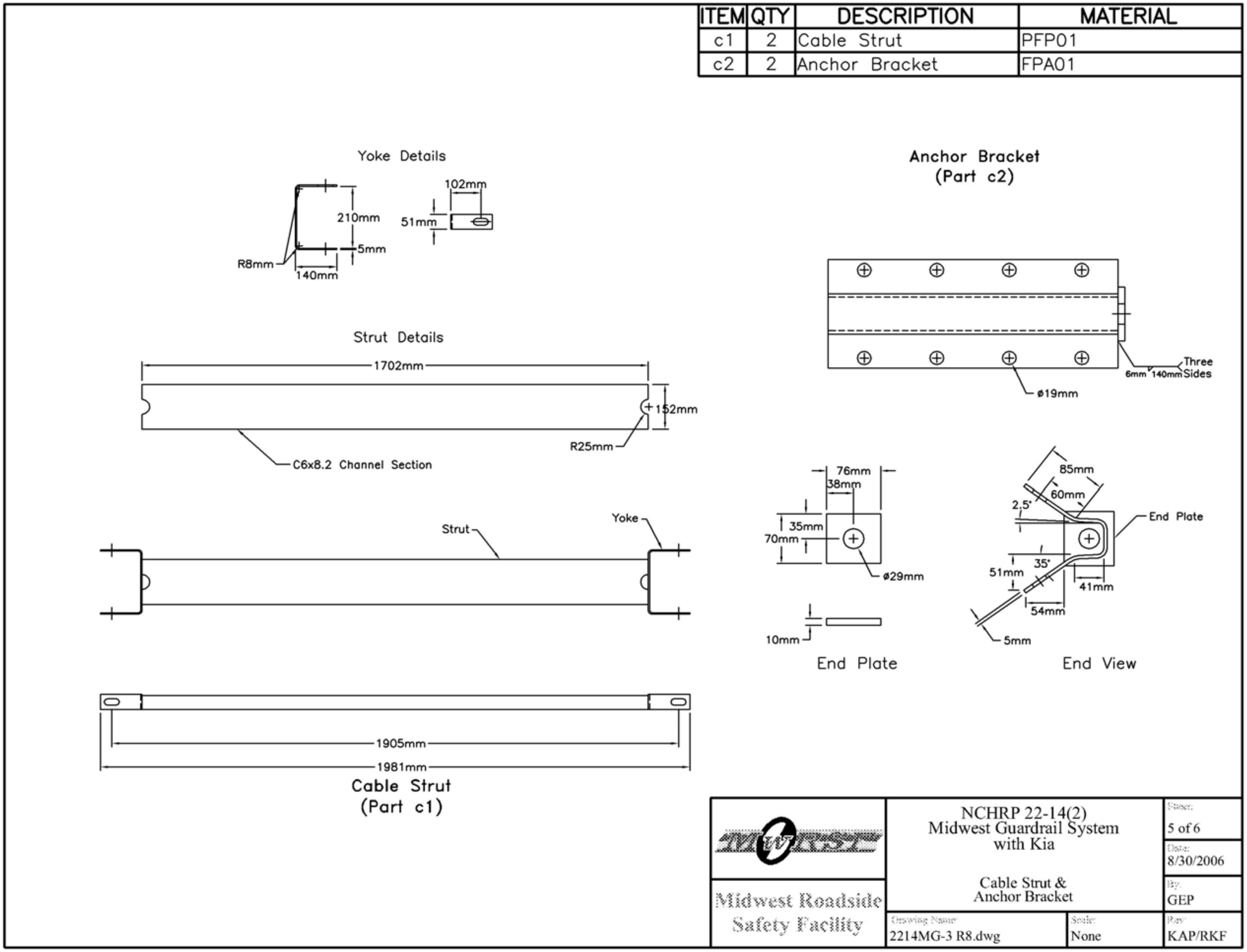


Figure 9. Midwest Guardrail System Anchorage Details - Maximum Height Tolerance

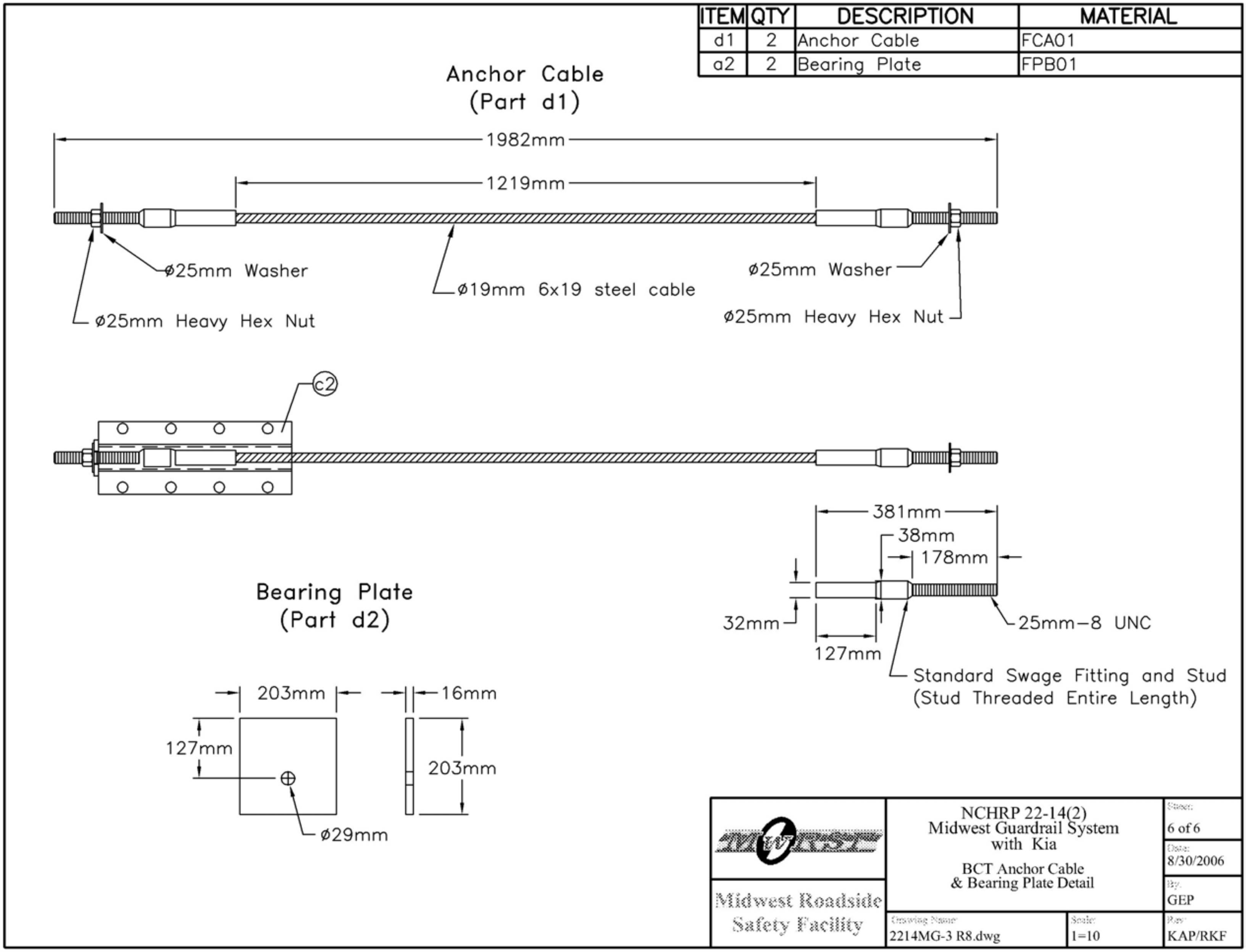


Figure 10. Midwest Guardrail System Anchorage Details - Maximum Height Tolerance

Figure 11. Midwest Guardrail System - Maximum Height Tolerance

Figure 12. Midwest Guardrail System - Maximum Height Tolerance

5 CRASH TEST

5.1 Test 2214MG-3

The 1,174-kg (2,588-lb) small car impacted the Midwest Guardrail System (MGS) with maximum height tolerance at a speed of 97.8 km/h (60.8 mph) and at an angle of 25.4 degrees. A summary of the test results and sequential photographs are shown in Figure 13. The summary of the test results and sequential photographs in English units are shown in Appendix B. Additional sequential photographs are shown in Figures 14 through 16. Documentary photographs of the crash test are shown in Figures 17 and 18.

5.2 Test Description

Initial vehicle impact was to occur between post nos. 13 and 14, or 2.10 m (6 ft - 10.5 in.) upstream from the center of the splice at the midspan between post nos. 14 and 15, as shown in Figure 19. Actual vehicle impact occurred 2.11 m (6 ft - 11 in.) upstream from the center of the splice at the midspan between post nos. 14 and 15. At 0.022 sec, the right-front corner of the hood protrudes over the top of the rail, and the rail deflected backwards. At 0.054 sec, post no. 14 deflected backward and the blockout at post no. 14 split and disengaged from the system. At 0.106 sec, post no. 15 deflected backward and the blockout at post no. 15 split and disengaged from the system. At 0.120 sec, the right-front corner of the vehicle was located at post no. 15 and the right-front tire rides up post no. 15. At this same time, the vehicle rolled clockwise (CW) away from the rail. At 0.166 sec, the right-front corner of the vehicle continued to protrude over the top of the rail. At 0.188 sec, the right-front corner of the vehicle was located at post no. 16 and the blockout at post no. 16 split and disengaged from the system. At 0.216 sec, the vehicle became parallel to the barrier with a resultant velocity of 72.4 km/h (45.0 mph). At 0.294 sec, the right-front corner of the vehicle was located at post no. 17 which was deflecting backwards. At this same time, the vehicle rolled CCW back toward the system. At 0.332 sec, the blockout at post no. 17 split and disengaged from the system. At 0.374 sec, the rear of the vehicle pitched upward. At 0.404 sec, the vehicle yawed back toward the system with the rear of the vehicle airborne. At 0.530 sec, the vehicle exited the barrier at a trajectory angle of 14.1 degrees and at a resultant velocity of 48.4 km/h (30.1 mph). At 0.636 sec, the vehicle continued to yaw back toward the system as it continued downstream. At 0.886 sec, the vehicle yawed to approximately perpendicular with the system. At 1.738 sec, the vehicle impacted the system again in a near perpendicular orientation. At 1.890 sec, the front of the vehicle crushed inward from the secondary impact. The vehicle came to rest with the front of the vehicle against and perpendicular to the rail at 22.46 m (73 ft - 8 in.) downstream from impact and 0.83 m (2 ft - 9 in.) away from the traffic-side face of the guardrail system. The trajectory and final position of the small car are shown in Figures 13 and 20.

5.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 21 through 25. 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 8.3 m (27 ft), which spanned from 749 mm (29.5 in.) downstream from the centerline of post no. 13 through 1,822 mm (71.75 in.) downstream from the centerline of post no. 17.

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. 13 and 18. The guardrail buckled at 105 mm (4.125 in.) upstream of post no. 13 and 254 mm (10 in.) upstream of the post no. 19. Major buckling of the guardrail occurred at the downstream edge of the blockout at post no. 18 and at post no. 15. The W-beam was pulled off post nos. 15 through 17. The W-beam rail sustained yielding around the post bolt slots at post nos. 14 through 18. No significant guardrail damage occurred downstream of post no. 18, except for slight rail deflection and minor contact marks between post nos. 24 and 26 due to secondary vehicle contact with the system before coming to rest.

Steel post nos. 3 through14 encountered minor twisting. Post no. 13 also rotated backward. Post no. 14 also rotated backward and downstream slightly. Post no. 15 rotated slightly backward and bent longitudinally downstream. Post no. 16 bent longitudinally downstream toward the ground and encountered major buckling and damage on the flanges. Post no. 17 rotated backward and bent longitudinally downstream. Post no. 18 also rotated backward slightly and bent slightly longitudinally downstream. Contact marks were found on the front and back flanges of post nos. 14 through 16. The post bolt at post no. 17 sheared off. The wooden blockouts at post nos. 14 through 17 were fractured and removed from the posts. 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 permanent set of the barrier system is shown in Figure 21. The maximum lateral permanent set rail and post deflections were 505 mm (19.875 in.) at the centerline of post no. 16 and 502 mm (19.75 in.) at post no. 15, as measured in the field. The maximum lateral dynamic rail and post deflections were 913 mm (35.9 in.) at the midspan between post nos. 15 and 16 and 687 mm (27.0 in.) at post no. 16, as determined from high-speed digital video analysis. The working width of the system was found to be 1,227 mm (48.3 in.).

5.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 26 through 28. 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 6 mm (0.25 in.) were located throughout the right-side floor pan. Maximum lateral deflections of 6 mm (0.25 in.) were located throughout the right-side floor pan. Maximum vertical deflections of 6 mm (0.25 in.) were located near the center of the right-side floor pan. 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 crushed inward toward the frame. The front frame was bent about the centerline and the right side was bent backward and downward. The right-side frame with the connection to the wheel was bent backward also. The right-side of the hood buckled upward and crushed inward. The protective plastic molding in the right-front wheel well was fractured. The right-front wheel assembly deformed and crushed inward toward the engine compartment. The right-front steel rim was bent on both the interior and exterior sides. The right-front tire was pulled off the rim and deflated. The right-front door encountered dents and scratches and was ajar at the top. The right rear door also encountered contact marks from system interaction. The right-rear quarter panel sustained minor contact marks and denting. The right-rear bumper was scratched and dislodged slightly. The right-side headlight, park light, and brake light fractured and disengaged from the vehicle. The left-side headlight was dislodged out of its socket. All window glass remained undamaged.

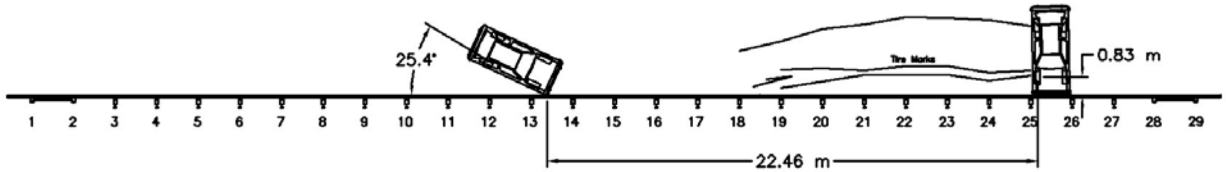
5.5 Occupant Risk Values

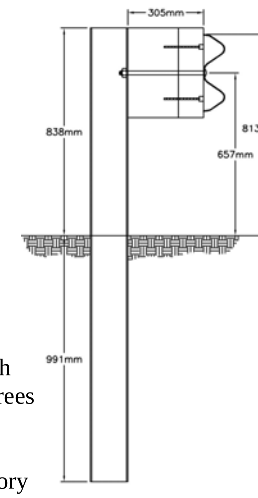
The longitudinal and lateral occupant impact velocities were determined t be 4.52 m/s (14.83 ft/s) and 5.22 m/s (17.13 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 16.14 Gs and 8.37 Gs, respectively. It is noted that 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 7.26 m/s (23.82 ft/s) and 16.20 Gs, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 13. 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-3 showed that the Midwest Guardrail System with maximum height tolerance impacted with the 1100C 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-3 conducted on the Midwest Guardrail System with maximum height tolerance was determined to be acceptable according to the TL-3 safety performance criteria found in the Update to NCHRP Report No. 350.

0.000 sec | 0.166 sec | 0.236 sec | 0.404 sec | 0.574 sec



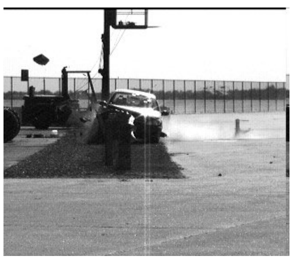


- Test Agency . . . . MwRSF
- Test Number 2214MG-3
- Date 11/8/04
- NCHRP 350 Update Test Designation . . 3-10
- Appurtenance . . . . Midwest Guardrail System
- Total Length . . . . 55.25 m
- Key Elements - Steel W-Beam
  - Thickness . . . . 2.66 mm
  - Top Mounting Height . . . . 813 mm
- Key Elements - 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 1100C
  - Make and Model . . . . 2002 Kia Rio
  - Curb . . . . 1,026 kg
  - Test Inertial . . . . 1,099 kg
  - Gross Static . . . . 1,174 kg
- Impact Conditions
  - Speed . . . . 97.8 km/h
  - Angle . . . . 25.4 degrees
  - Impact Location . . . . 2.11 m upstream splice between posts 14 & 15
- Exit Conditions
  - Speed . . . . 48.4 km/h
  - Angle . . . . 14.1 degrees
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 22.46 m downstream
0.83 m traffic-side face
- Occupant Impact Velocity (350 Update)
  - Longitudinal . . . . 4.52 m/s < 12 m/s
  - Lateral . . . . 5.22 m/s < 12 m/s
- Occupant Ridedown Deceleration (350 Update)
  - Longitudinal . . . . 16.14 Gs < 20 Gs
  - Lateral . . . . 8.37 Gs < 20 Gs
- THIV (not required) . . . . 7.26 m/s
- PHD (not required) . . . . 16.20 Gs
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . 505 mm
  - Dynamic . . . . 913 mm
  - Working Width . . . . 1,227 mm
- Vehicle Damage . . . . Moderate
  - VDS[4] 1-RFQ-6
  - CDC[5] 1-RYEW6
  - Maximum Deformation . . . . 6 mm at right-front floorpan

Figure 13. Summary of Test Results and Sequential Photographs, Test 2214MG-3

0.000 sec

0.124 sec



0.274 sec

0.402 sec

0.636 sec

0.886 sec

1.250 sec

1.738 sec

2.250 sec

Figure 14. Additional Sequential Photographs, Test 2214MG-3

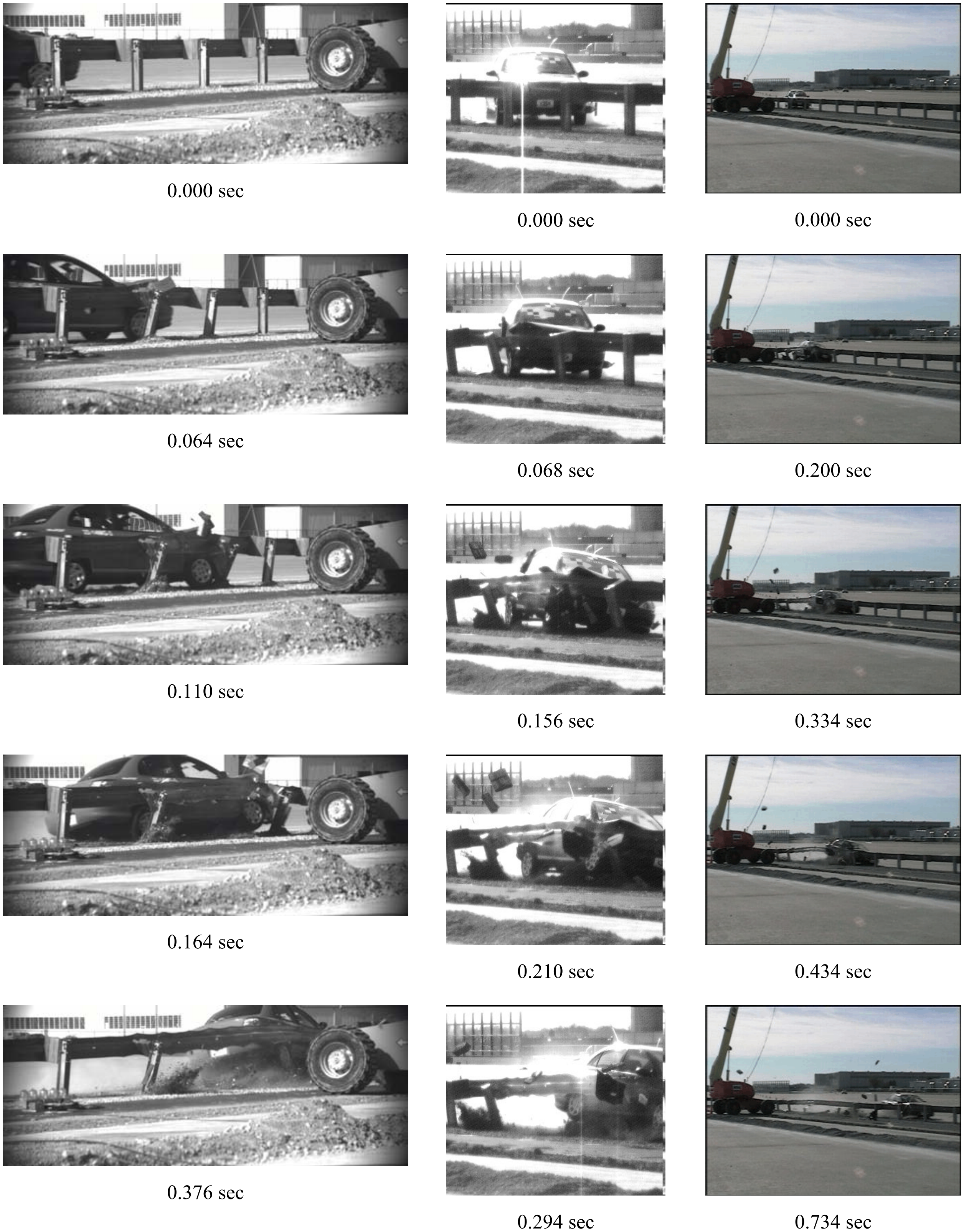
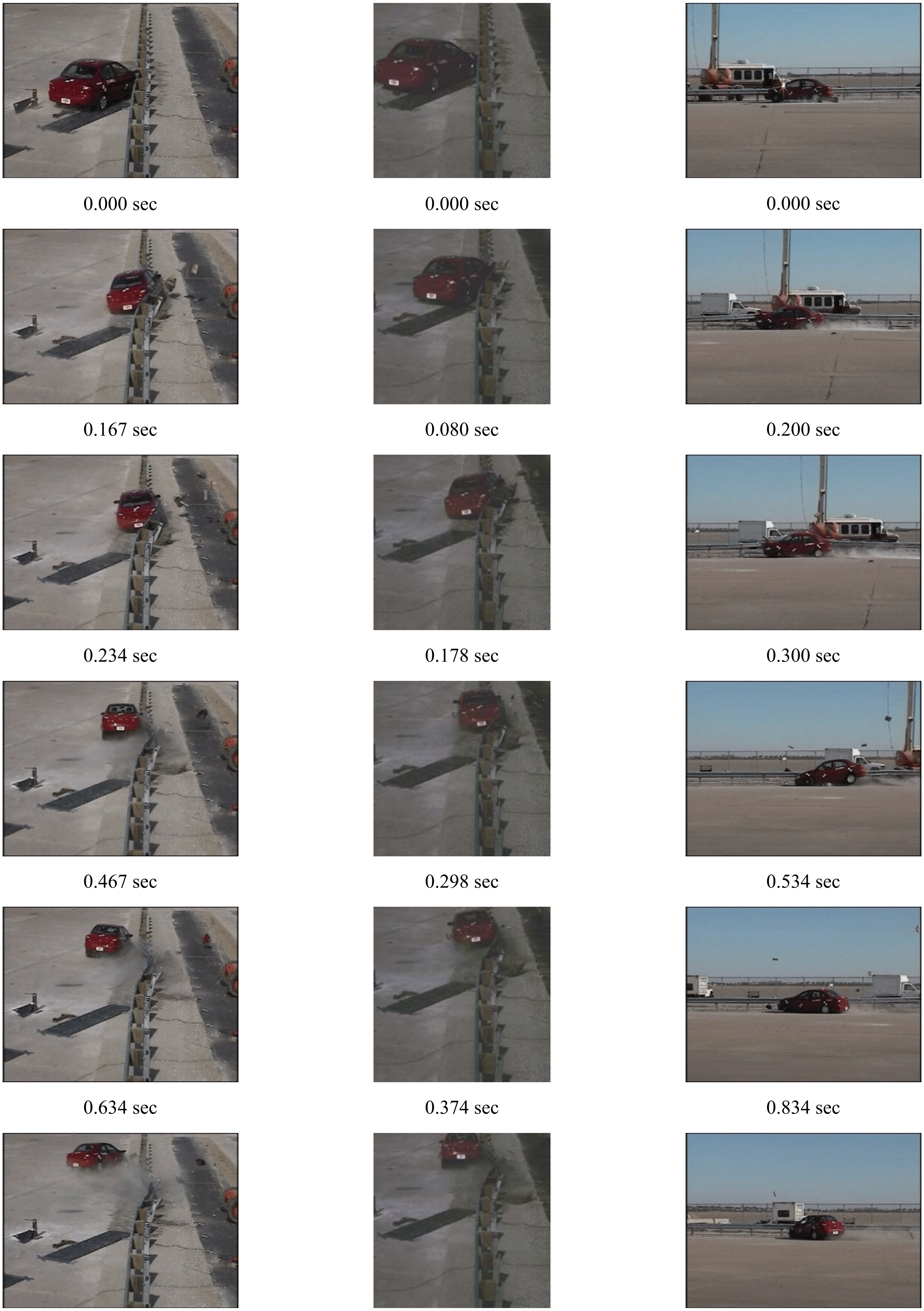


Figure 15. Additional Sequential Photographs, Test 2214MG-3



0.000 sec | 0.000 sec | 0.000 sec

0.167 sec | 0.080 sec | 0.200 sec

0.234 sec | 0.178 sec | 0.300 sec

0.467 sec | 0.298 sec | 0.534 sec

0.634 sec | 0.374 sec | 0.834 sec

0.968 sec | 0.492 sec | 1.535 sec

Figure 16. Additional Sequential Photographs, Test 2214MG-3

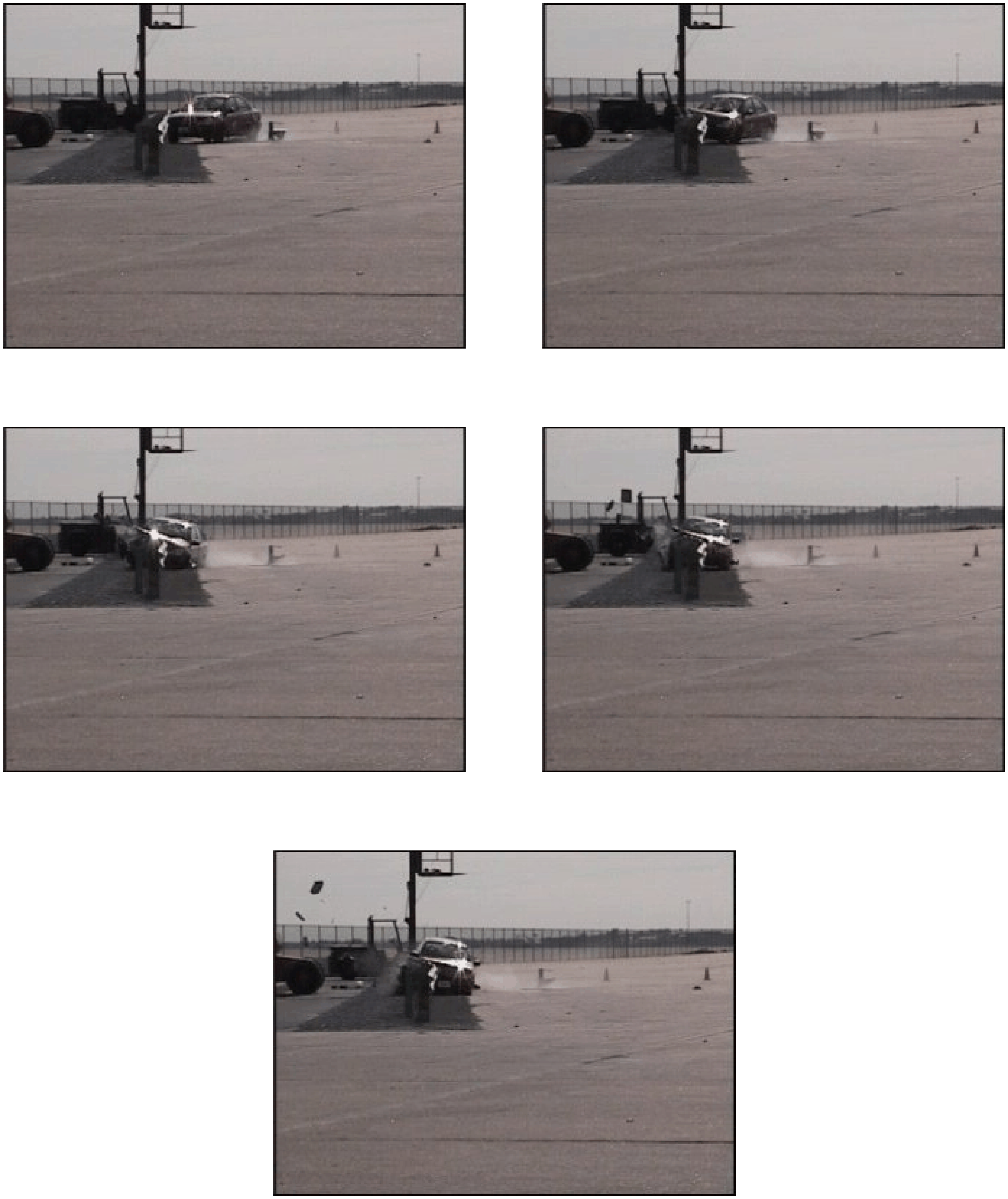


Figure 17. Documentary Photographs, Test 2214MG-3

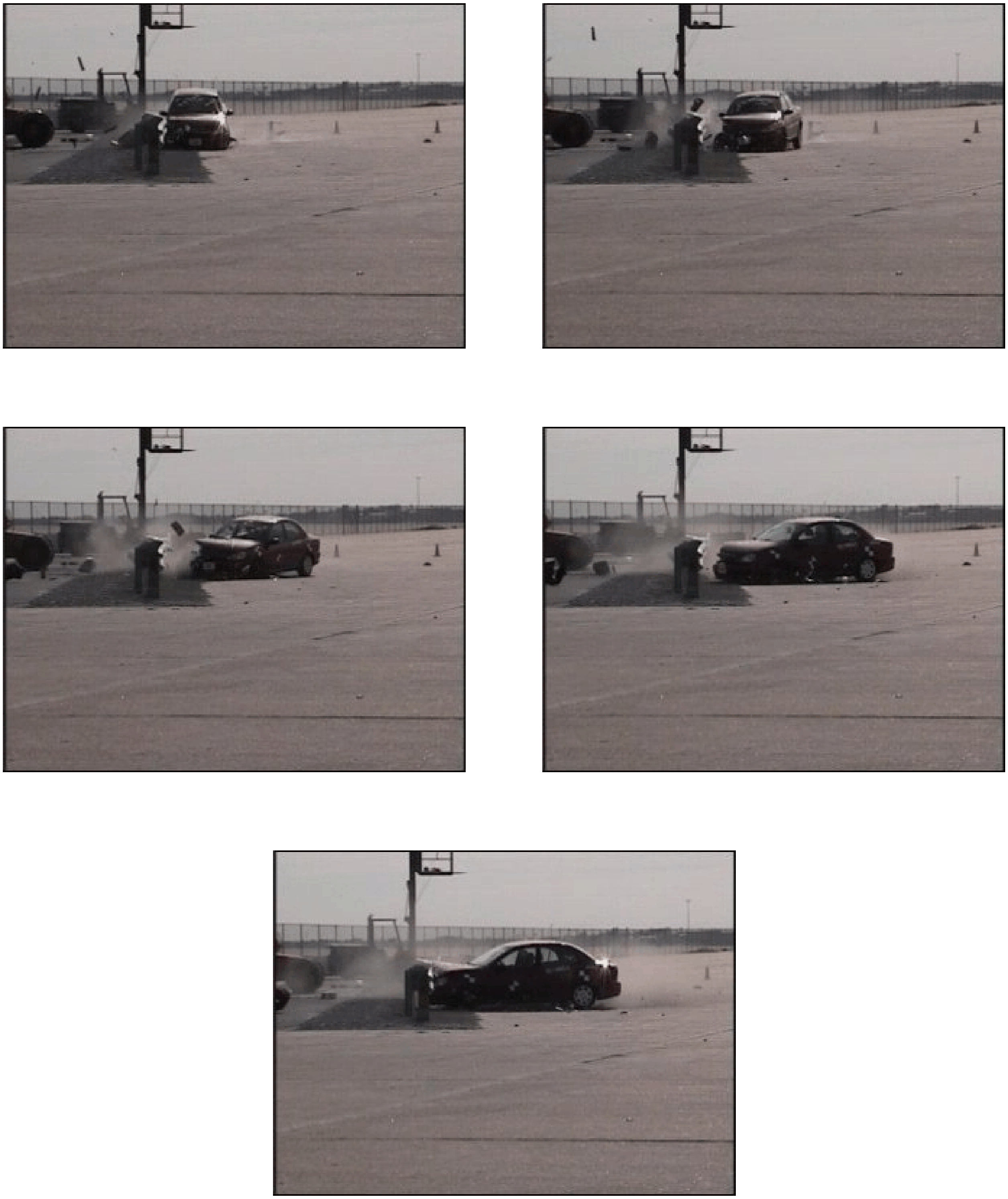


Figure 18. Documentary Photographs, Test 2214MG-3

Figure 19. Impact Location, Test 2214MG-3

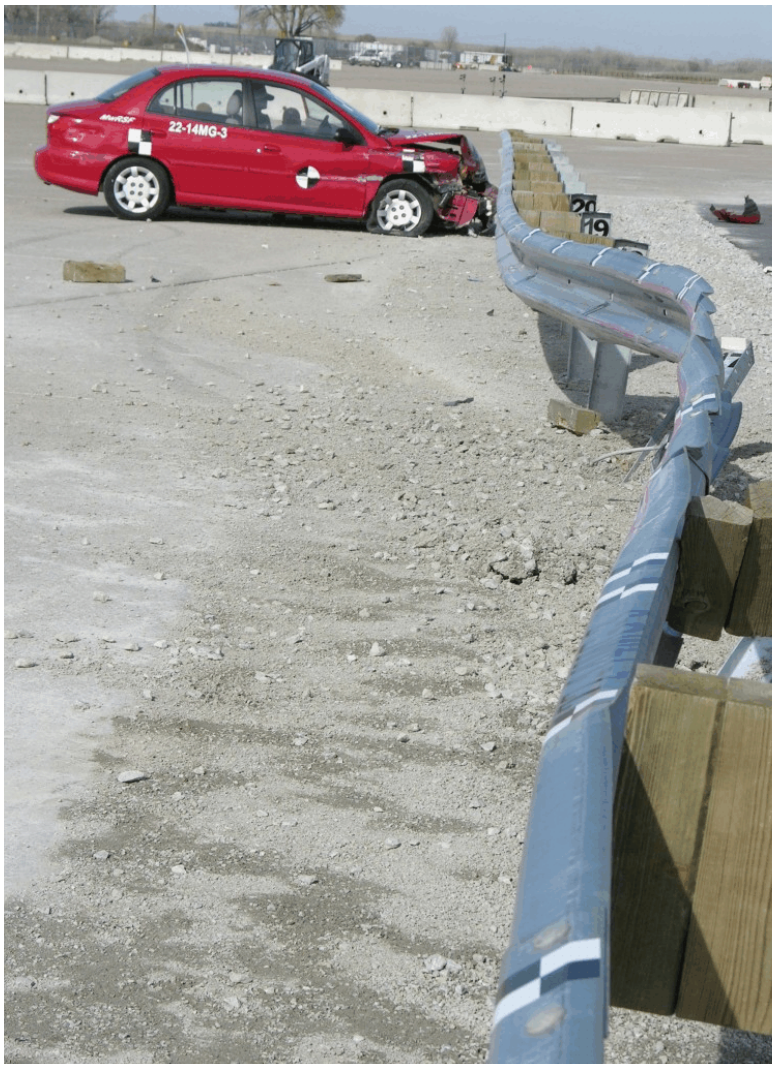


Figure 20. Vehicle Final Position and Trajectory Marks, Test 2214MG-3

Figure 21. Midwest Guardrail System Damage, Test 2214MG-3

Figure 22. System Damage - Post Nos. 13 and 14, Test 2214MG-3

Figure 23. System Damage - Post Nos. 14 through 18, Test 2214MG-3

Figure 24. System Damage - Post Nos. 18 through 20, Test 2214MG-3

Figure 25. Upstream and Downstream Anchorage Damage, Test 2214MG-3

Figure 26. Vehicle Damage, Test 2214MG-3

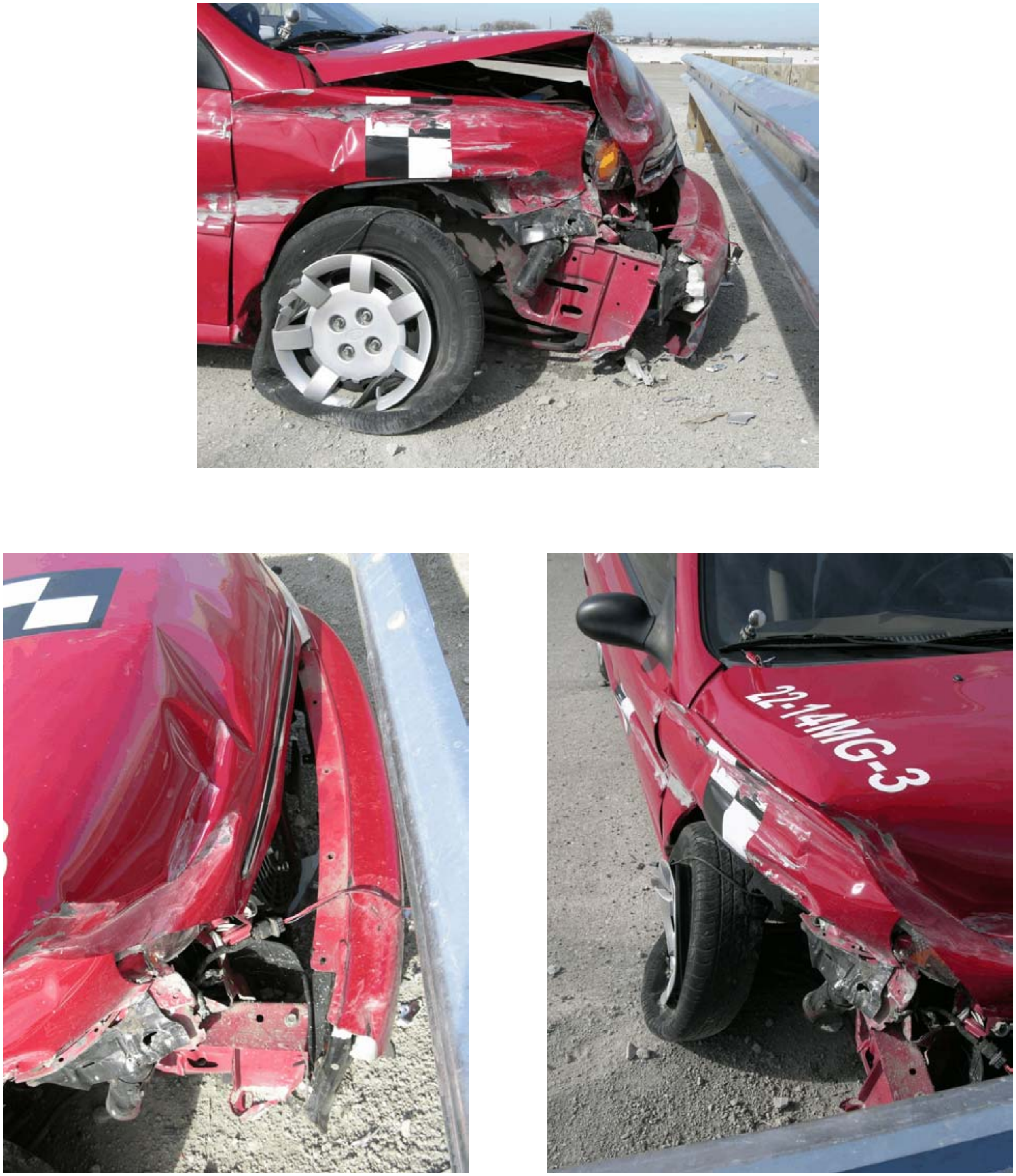


Figure 27. Vehicle Damage, Test 2214MG-3

Figure 28. Vehicle Damage, Test 2214MG-3

6 SUMMARY AND CONCLUSIONS

A strong-post, W-beam guardrail system, the MGS system, was constructed at the maximum top rail height tolerance of 813 mm (32 in.) corresponding to a nominal top rail height of 787 mm (31 in.) and full-scale vehicle crash tested. One full-scale vehicle crash test, using a small car vehicle, was performed on the longitudinal barrier system and was determined to be acceptable according to the TL-3 safety performance criteria presented in the Update to NCHRP Report No. 350. A summary of the safety performance evaluation is provided in Table 3.

Table 3. Summary of Safety Performance Evaluation Results

Evaluation Factors		Evaluation Criteria	Test 2214MG-3
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. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.

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

8 APPENDICES

APPENDIX A

English-Unit System Drawings

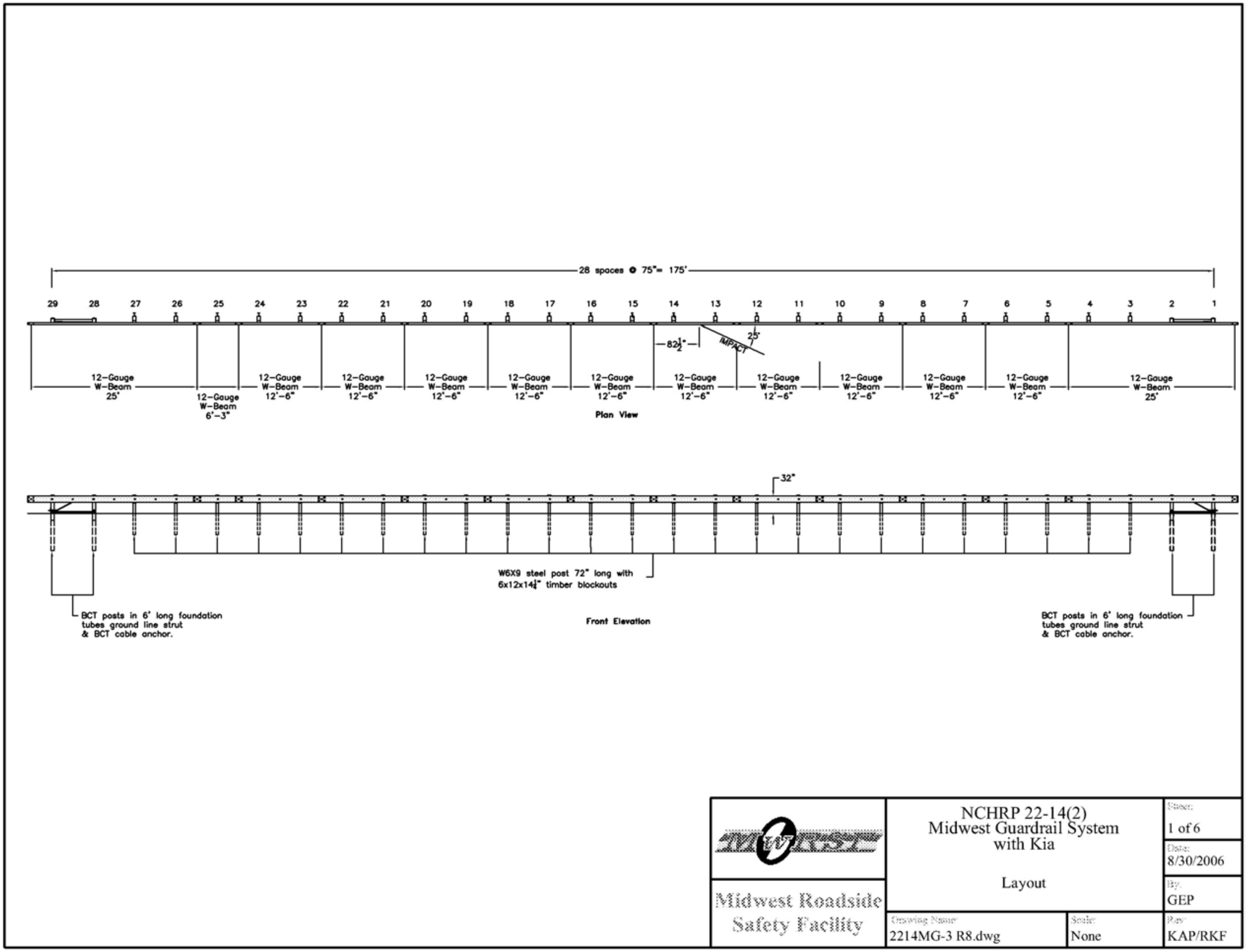


Figure A-1. Layout of Midwest Guardrail System Design - Maximum Height Tolerance (English)

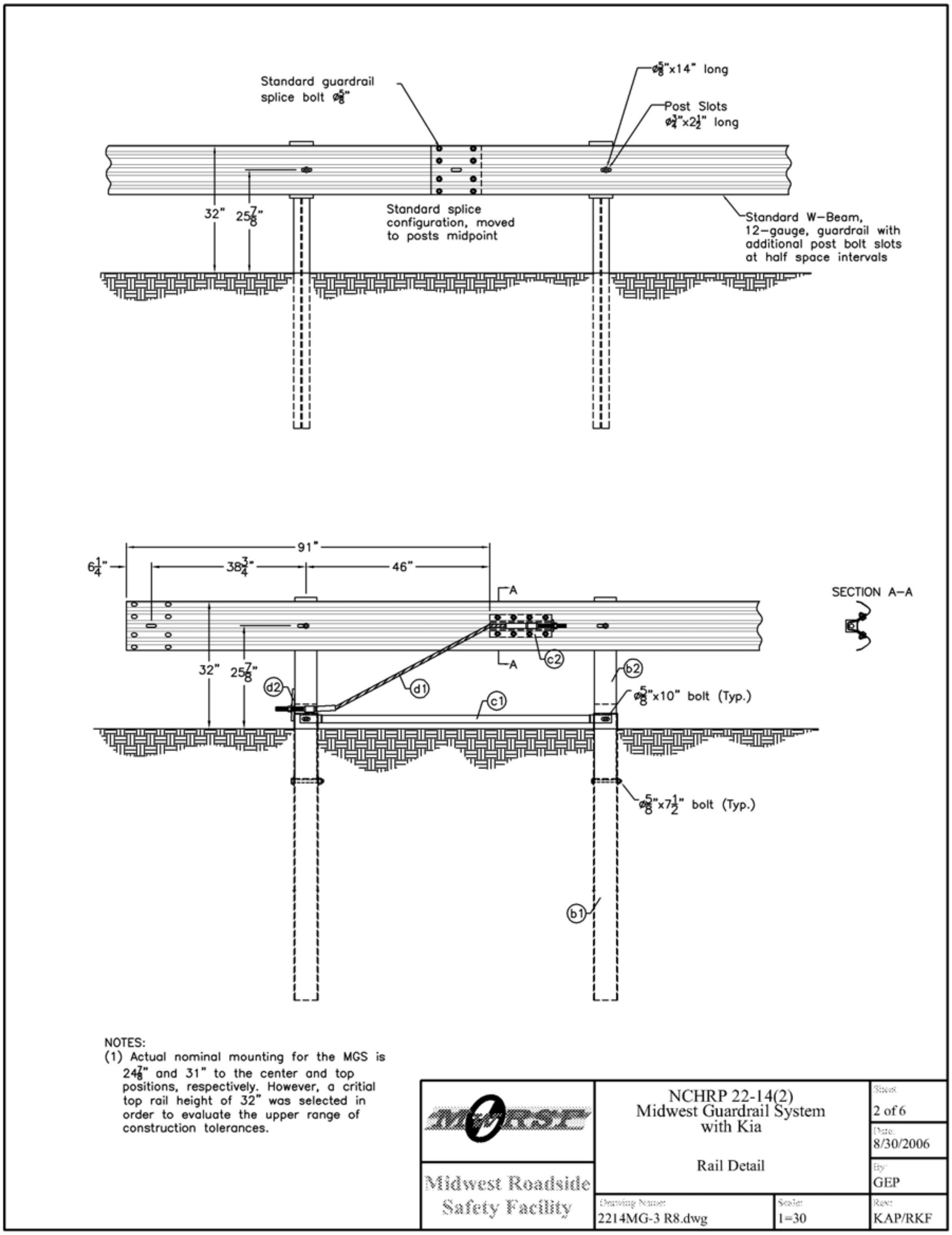


Figure A-2. Midwest Guardrail System Rail Details - Maximum Height Tolerance (English)

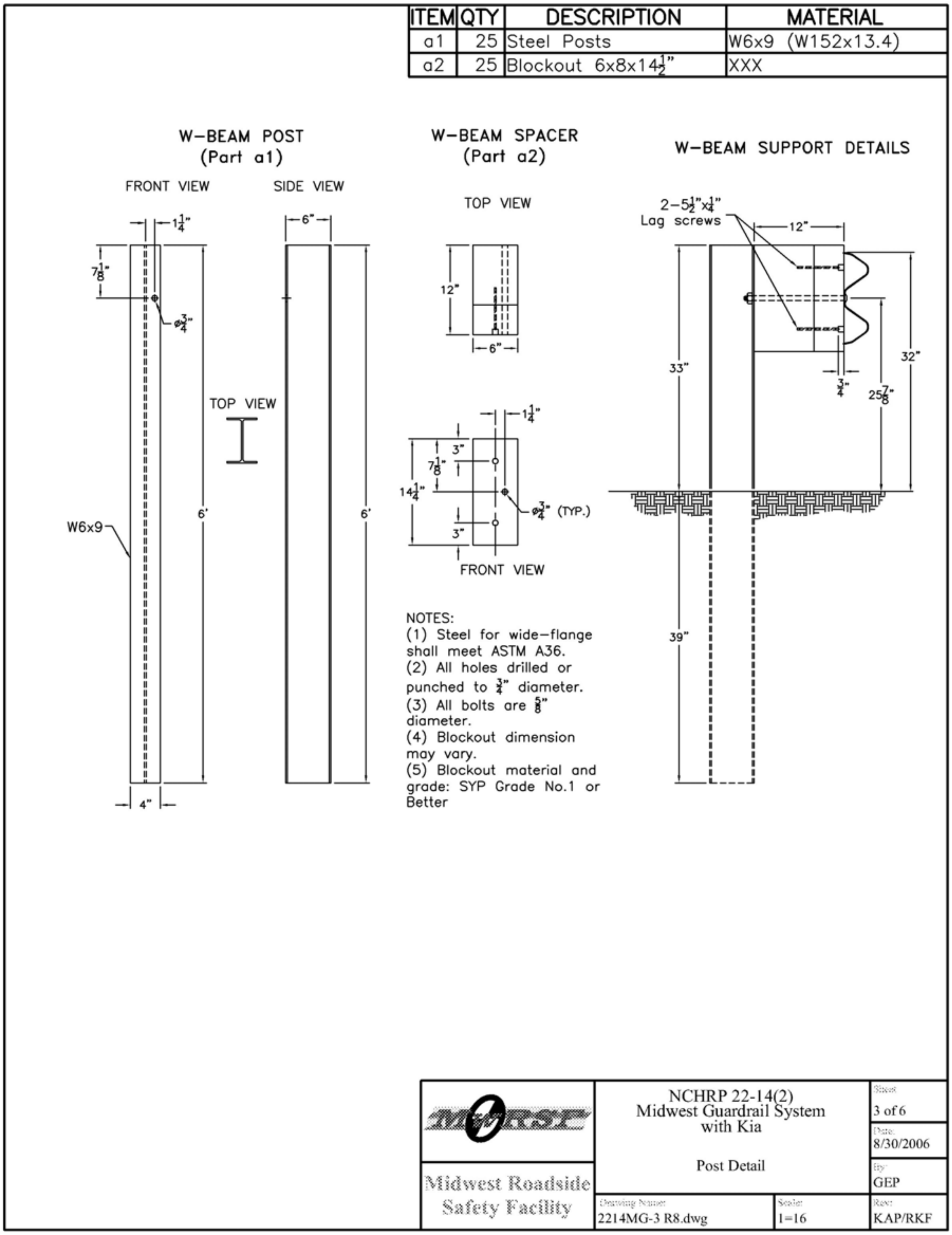


Figure A-3. Midwest Guardrail System Post Details - Maximum Height Tolerance (English)

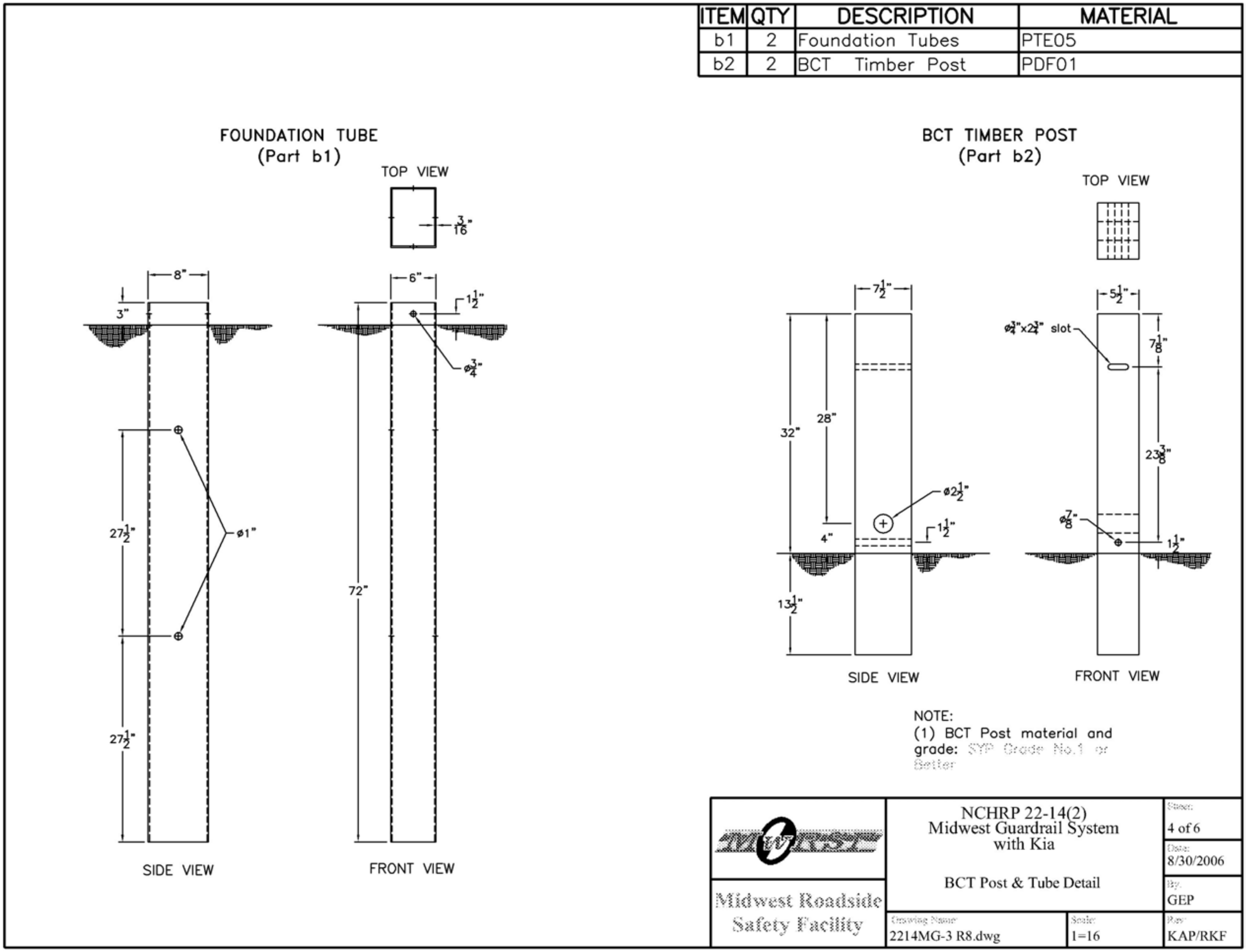


Figure A-4. Midwest Guardrail System Anchorage Details - Maximum Height Tolerance (English)

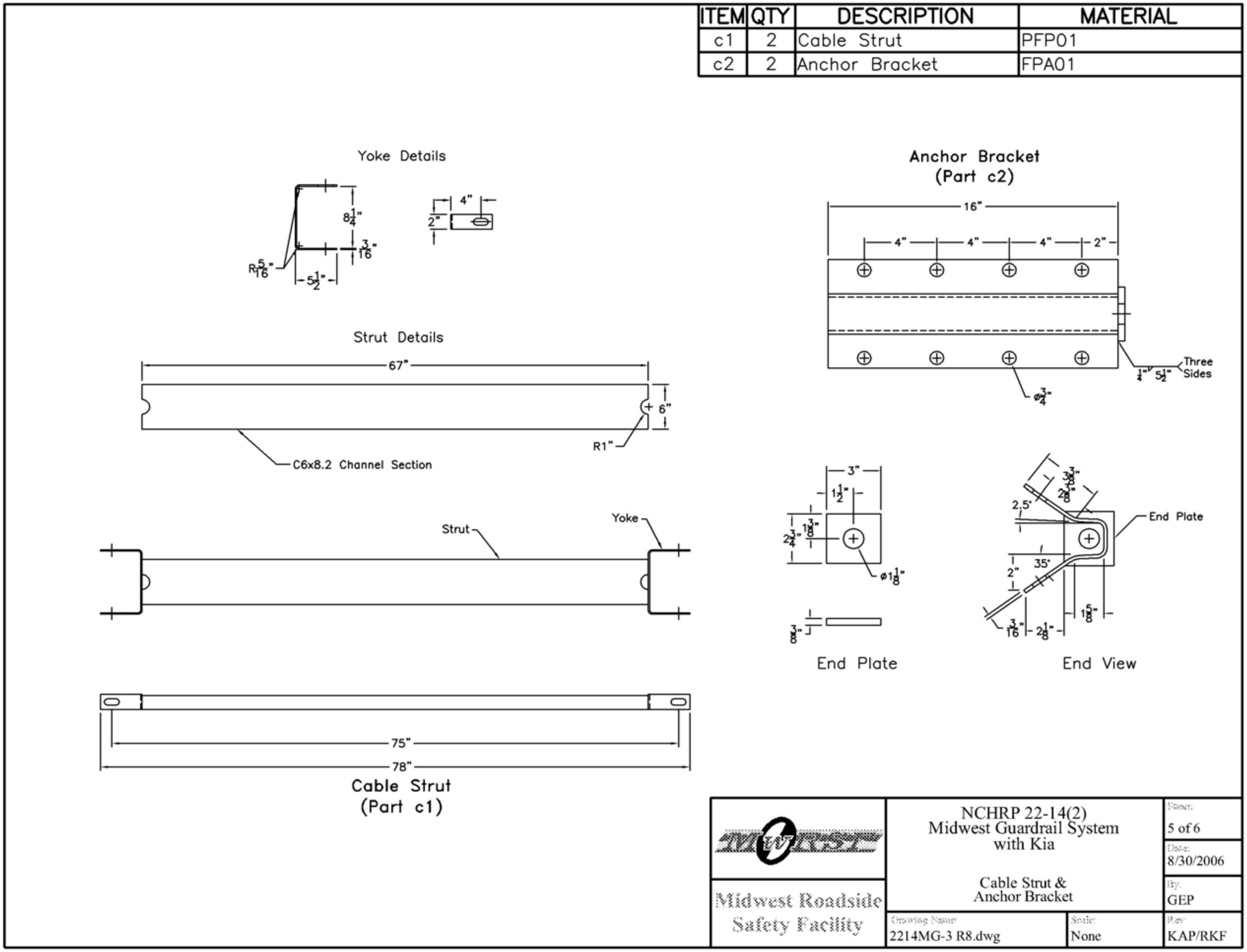


Figure A-5. Midwest Guardrail System Anchorage Details - Maximum Height Tolerance (English)

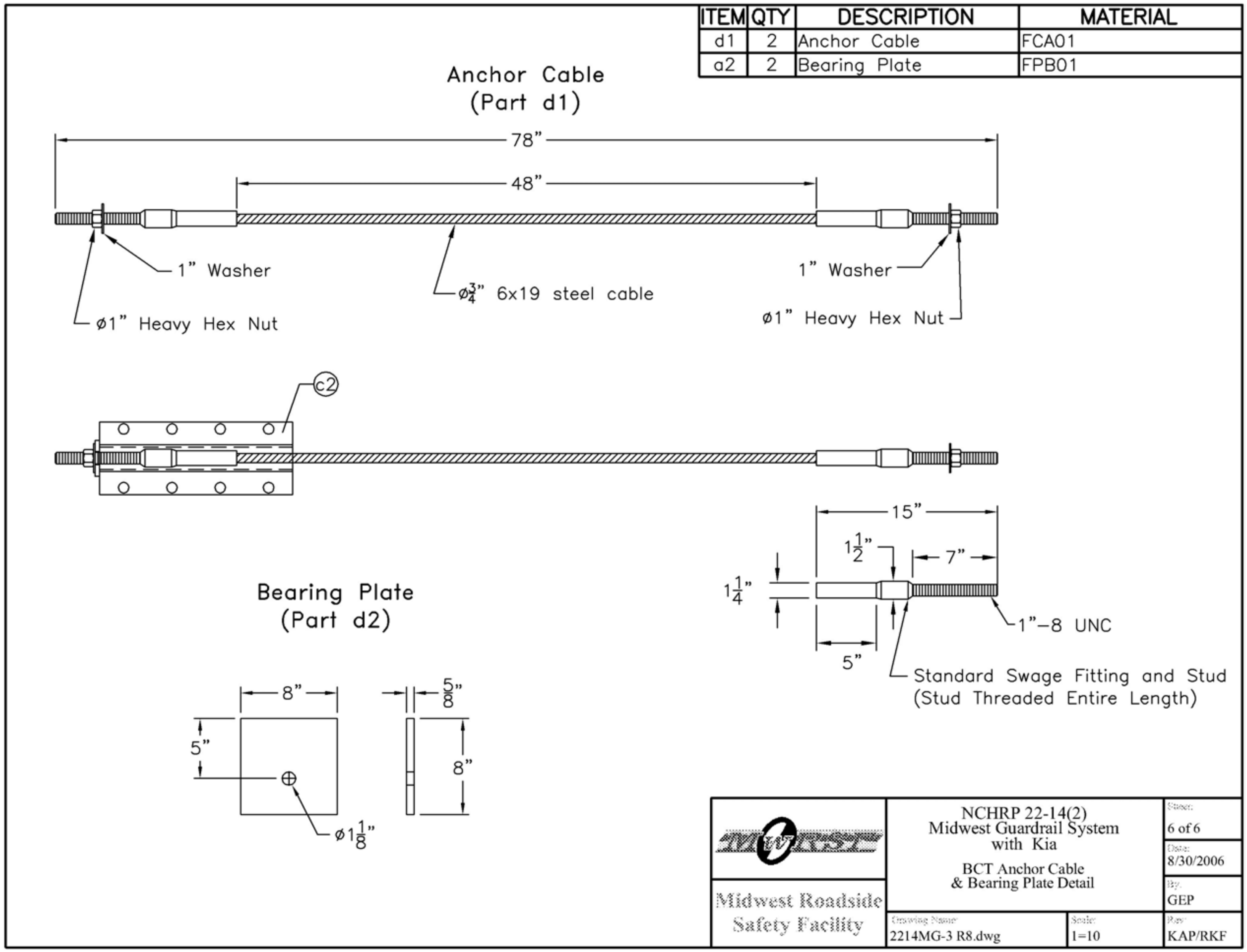
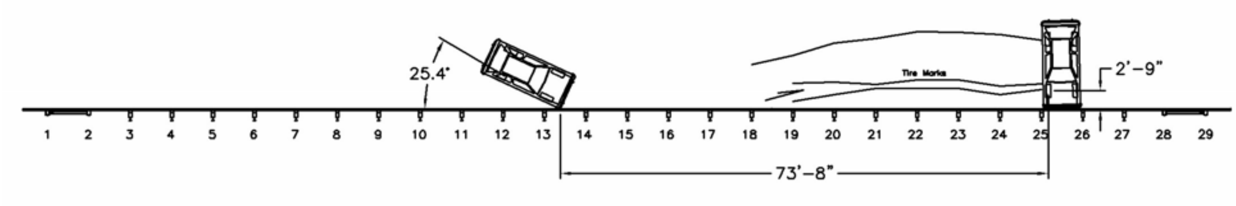


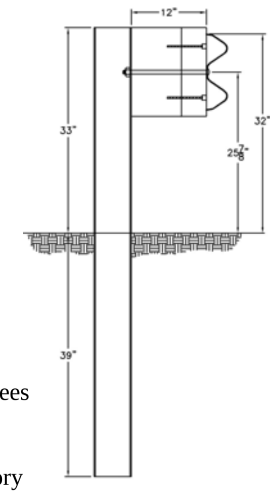
Figure A-6. Midwest Guardrail System Anchorage Details - Maximum Height Tolerance (English)

APPENDIX B

Test Summary Sheet in English Units

Figure B-1. Summary of Test Results and Sequential Photographs (English), Test 2214MG-3





- Test Agency . . . . MwRSF
- Test Number 2214MG-3
- Date 11/8/04
- NCHRP 350 Update Test Designation . . 3-10
- Appurtenance . . . . Midwest Guardrail System
- Total Length . . . . 181 ft - 3 in.
- Key Elements - Steel W-Beam
  - Thickness . . . . 12 gauge
  - Top Mounting Height . . . . . . 32 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 1100C
  - Make and Model . . . . 2002 Kia Rio
  - Curb . . . . 2,261 lbs
  - Test Inertial . . . . 2,422 lbs
  - Gross Static . . . . 2,588 lbs
- Impact Conditions
  - Speed . . . . 60.8 mph
  - Angle . . . . 25.4 degrees
  - Impact Location . . . . 6 ft - ll in. upstream splice between posts 14 & 15
- Exit Conditions
  - Speed . . . . 30.1 mph
  - Angle . . . . 14.1 degrees
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 73 ft - 8 in. downstream
2 ft - 9 in. traffic-side face
- Occupant Impact Velocity (350 Update)
  - Longitudinal . . . . 14.83 ft/s < 39.4 ft/s
  - Lateral . . . . 17.13 ft/s < 39.4 ft/s
- Occupant Ridedown Deceleration (350 Update)
  - Longitudinal . . . . 16.14 Gs < 20 Gs
  - Lateral . . . . 8.37 Gs < 20 Gs
- THIV (not required) . . . . 23.82 ft/s
- PHD (not required) . . . . 16.20 Gs
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . 19.875 in.
  - Dynamic . . . . 35.9 in.
  - Working Width . . . . 48.3 in.
- Vehicle Damage . . . . Moderate
  - VDS[4] 1-RFQ-6
  - CDC[5] 1-RYEW6
  - Maximum Deformation . . . . . 0.25 in. at right-front floorpan

Figure B-1. Summary of Test Results and Sequential Photographs (English), Test 2214MG-3

APPENDIX C

Occupant Compartment Deformation Data, Test 2214MG-3

VEHICLE PRE/POST CRUSH INFO

TEST: 2214MG-3
VEHICLE: 2002/Kia/Rio/Red

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

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	56.25	1.5	0.75	56.25	1.25	0.75	0	-0.25	0
2	57	6	1.75	57.25	6	1.75	0.25	0	0
3	57.5	9.5	1.75	57.5	9.5	1.75	0	0	0
4	57.25	13	2	57.5	13	2	0.25	0	0
5	55.25	16	1.75	55	16	1.75	-0.25	0	0
6	53.75	19	1.5	53.75	19	1.5	0	0	0
7	51	0.75	4.75	51	1	5	0	0.25	0.25
8	51.25	5.5	5.5	51.25	5.25	5.5	0	-0.25	0
9	51.5	9.75	5	51.5	9.5	5.25	0	-0.25	0.25
10	51.5	13	5.5	51.75	13	5.5	0.25	0	0
11	52	16.25	6	52	16.25	6	0	0	0
12	51	19.25	6.25	51	19.5	6.5	0	0.25	0.25
13	45.75	1.25	4.75	46	1	5	0.25	-0.25	0.25
14	45.75	5	5.5	45.75	5	5.5	0	0	0
15	46	9.5	5.5	46	9.25	5.5	0	-0.25	0
16	46.5	13.25	6	46.5	13	6	0	-0.25	0
17	46.5	16.5	6.25	46.5	16.25	6.25	0	-0.25	0
18	46.5	19.5	6.5	46.25	19.5	6.5	-0.25	0	0
19	40	0.5	4.75	40	0.5	4.75	0	0	0
20	40	5	5.25	40	5	5.25	0	0	0
21	40.25	9.75	5.25	40.25	9.75	5.25	0	0	0
22	40.25	13.75	6	40.25	13.5	6	0	-0.25	0
23	39.75	19.75	6.5	39.5	19.5	6.5	-0.25	-0.25	0
24	34.5	0.5	4.5	34.75	0.5	4.5	0.25	0	0
25	35.5	5.25	5.25	35.5	5.5	5.25	0	0.25	0
26	36.25	10	5.25	36.25	10	5.5	0	0	0.25
27	36.25	14.25	5.75	36.25	14.25	5.75	0	0	0
28	36	18.75	6	36	19	6	0	0.25	0
29									
30									

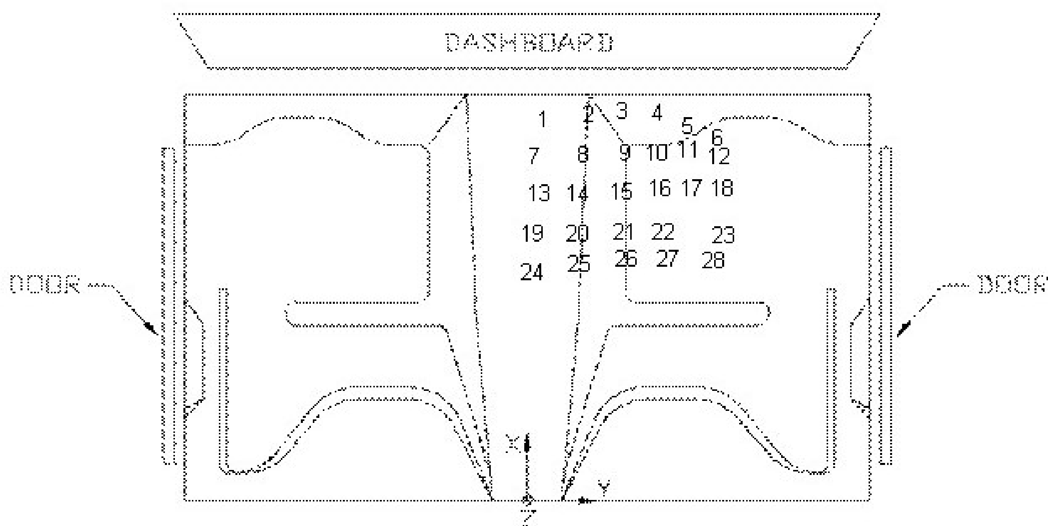


Figure C-1. Occupant Compartment Deformation Data, Test 2214MG-3

Occupant Compartment Deformation Index (OCDI)

Test No. 2214MG-3
Vehicle Type: 2002 Kia Rio

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

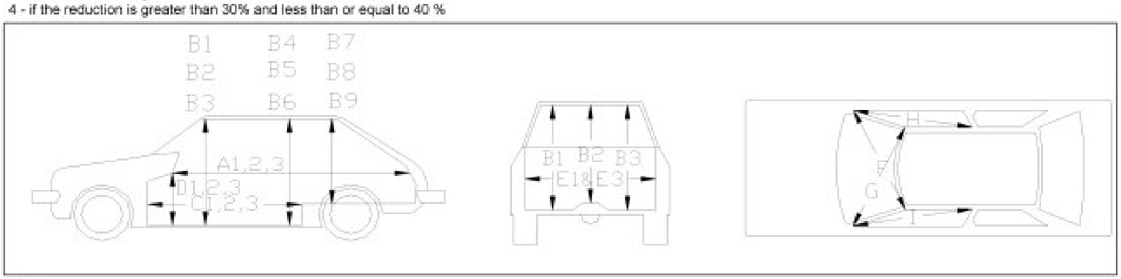
G = distance between the lower edge of left window and the upper edge of right window

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	48.50	48.50	0.00	0.00	0
A2	47.25	47.25	0.00	0.00	0
A3	47.50	47.75	0.25	0.53	0
B1	38.25	38.25	0.00	0.00	0
B2	37.25	37.25	0.00	0.00	0
B3	38.25	38.25	0.00	0.00	0
C1	56.25	55.75	-0.50	-0.89	0
C2	57.50	57.50	0.00	0.00	0
C3	55.00	54.75	-0.25	-0.45	0
D1	15.00	15.00	0.00	0.00	0
D2	13.75	13.75	0.00	0.00	0
D3	13.50	13.50	0.00	0.00	0
E1	53.50	53.75	0.25	0.47	0
E3	51.25	51.25	0.00	0.00	0
F	46.25	46.50	0.25	0.54	0
G	46.50	46.50	0.00	0.00	0
H	38.50	39.00	0.50	1.30	0
I	38.75	38.50	-0.25	-0.65	0

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

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

Figure C-2. Occupant Compartment Deformation Index (OCDI), Test 2214MG-3

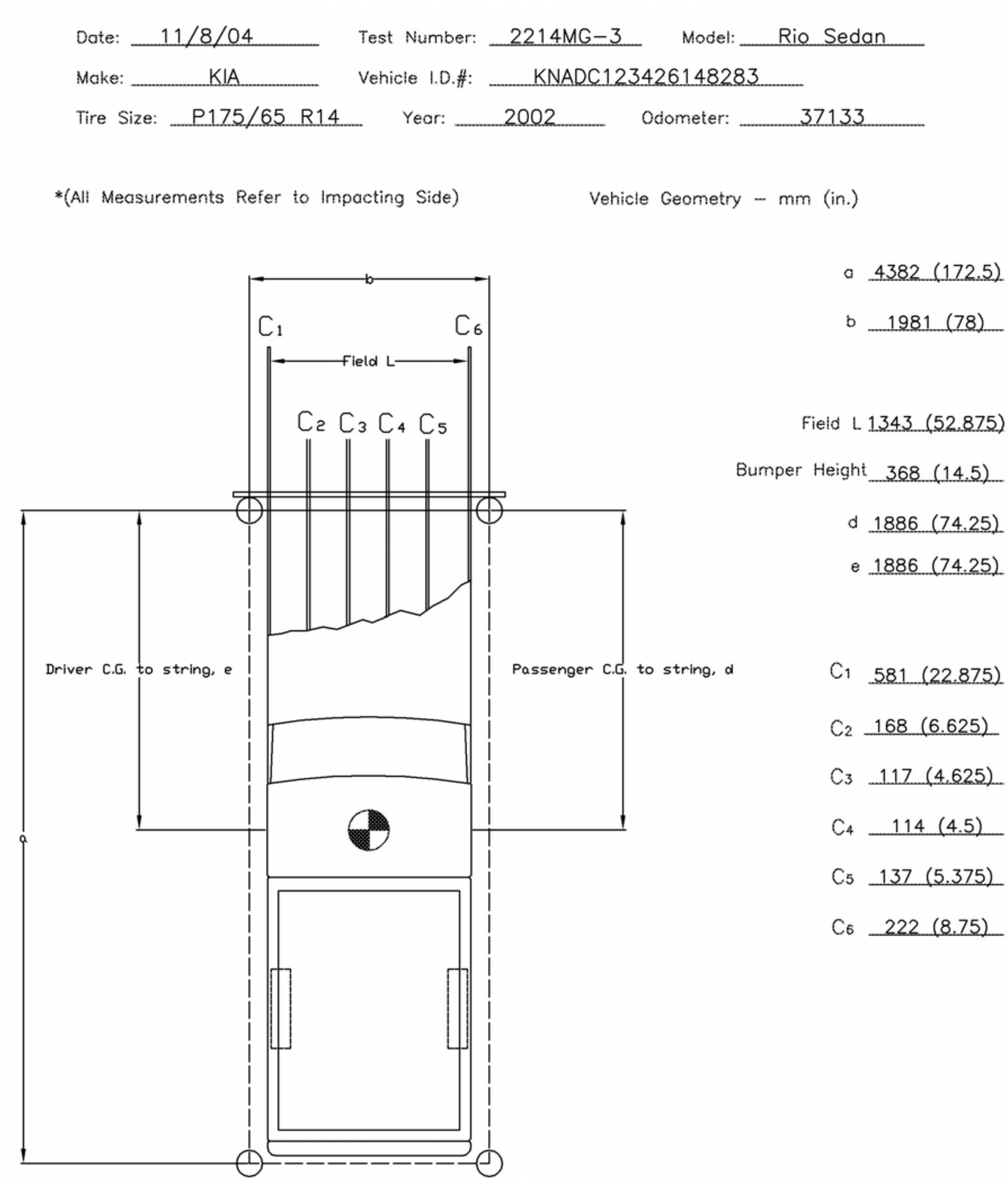


Figure C-3. NASS Crush Data, Test 2214MG-3

APPENDIX D

Accelerometer and Rate Transducer Data Analysis, Test 2214MG-3

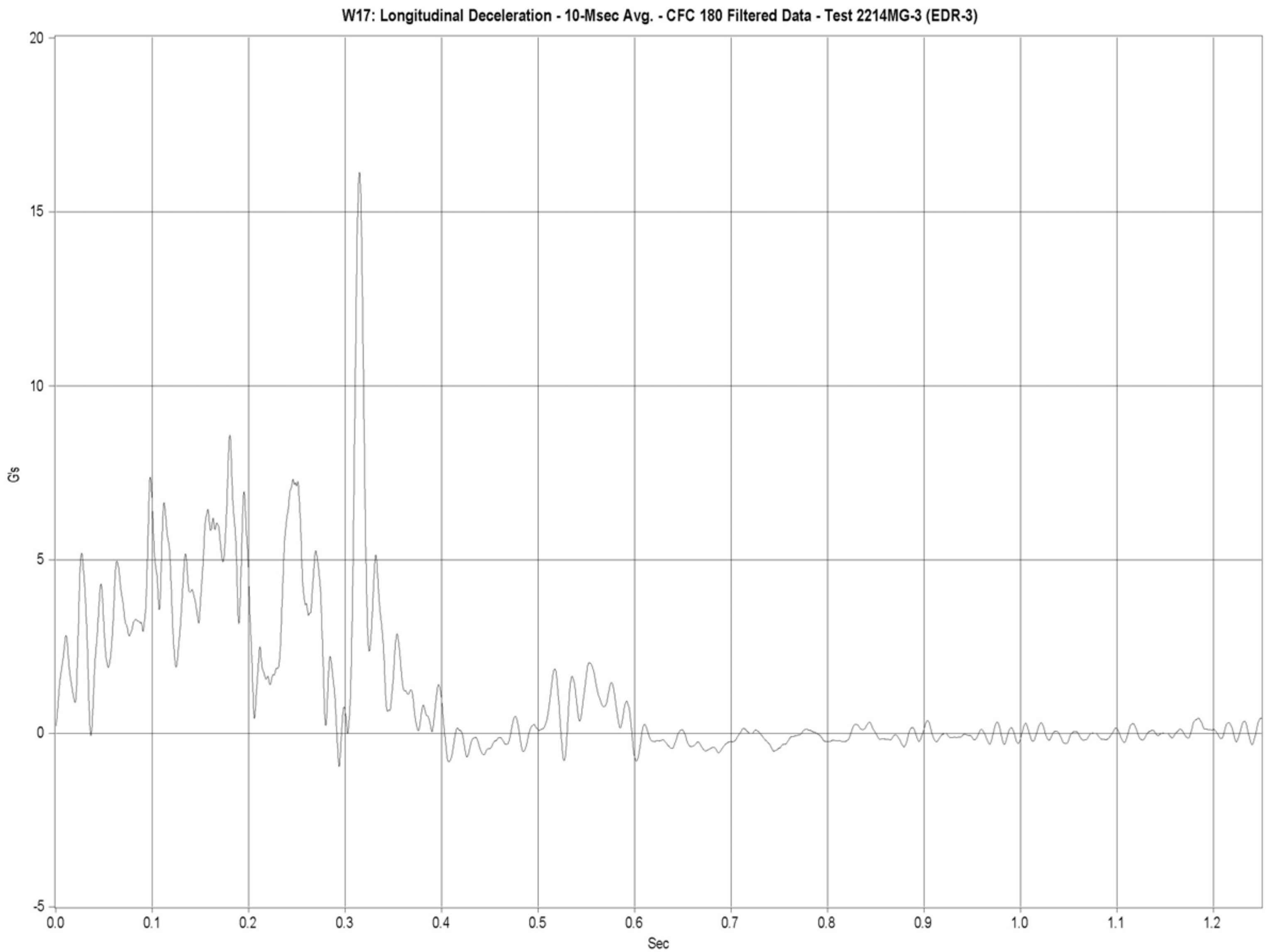


Figure D-1. Graph of Longitudinal Deceleration, Test 2214MG-3

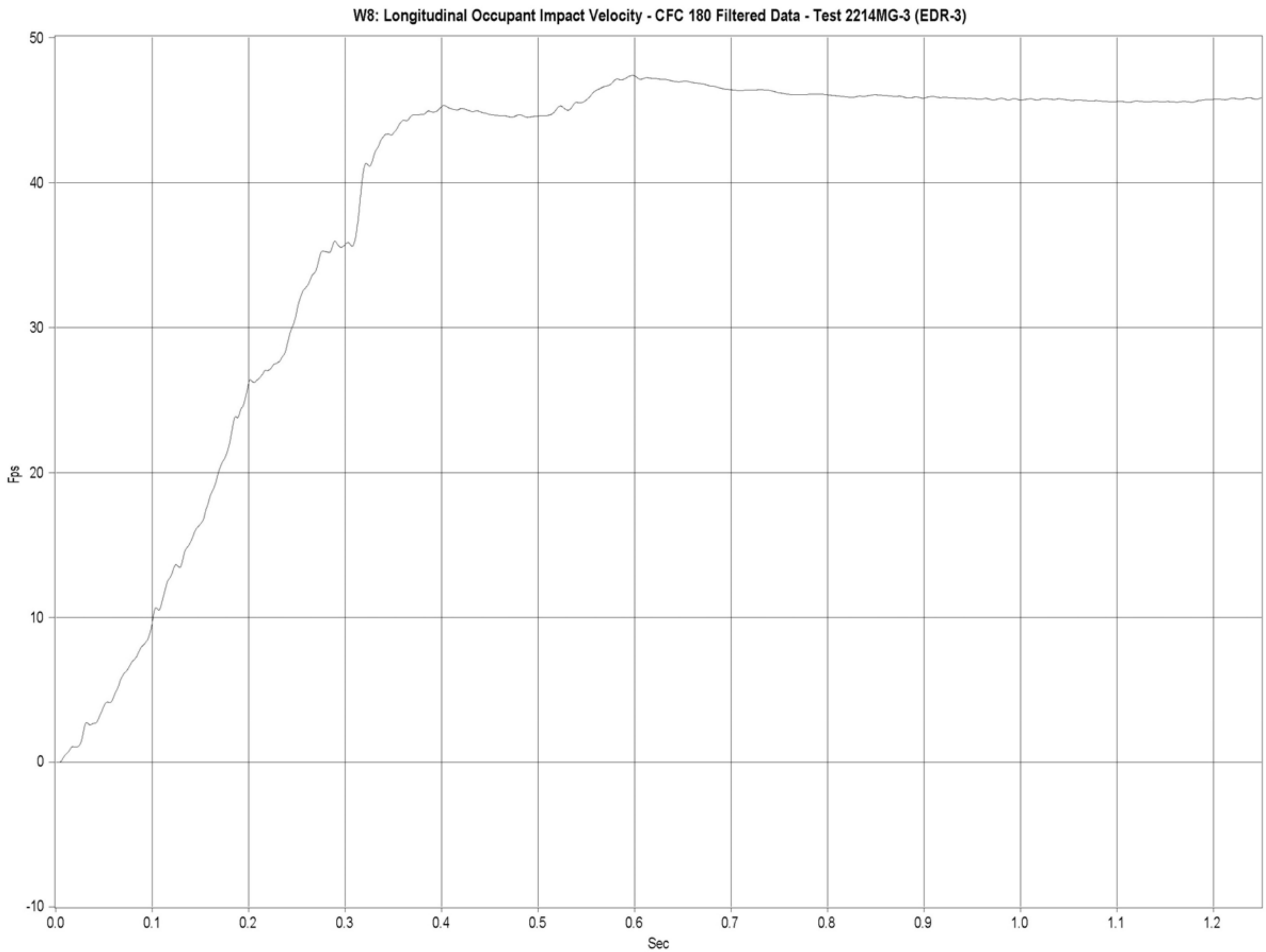


Figure D-2. Graph of Longitudinal Occupant Impact Velocity, Test 2214MG-3

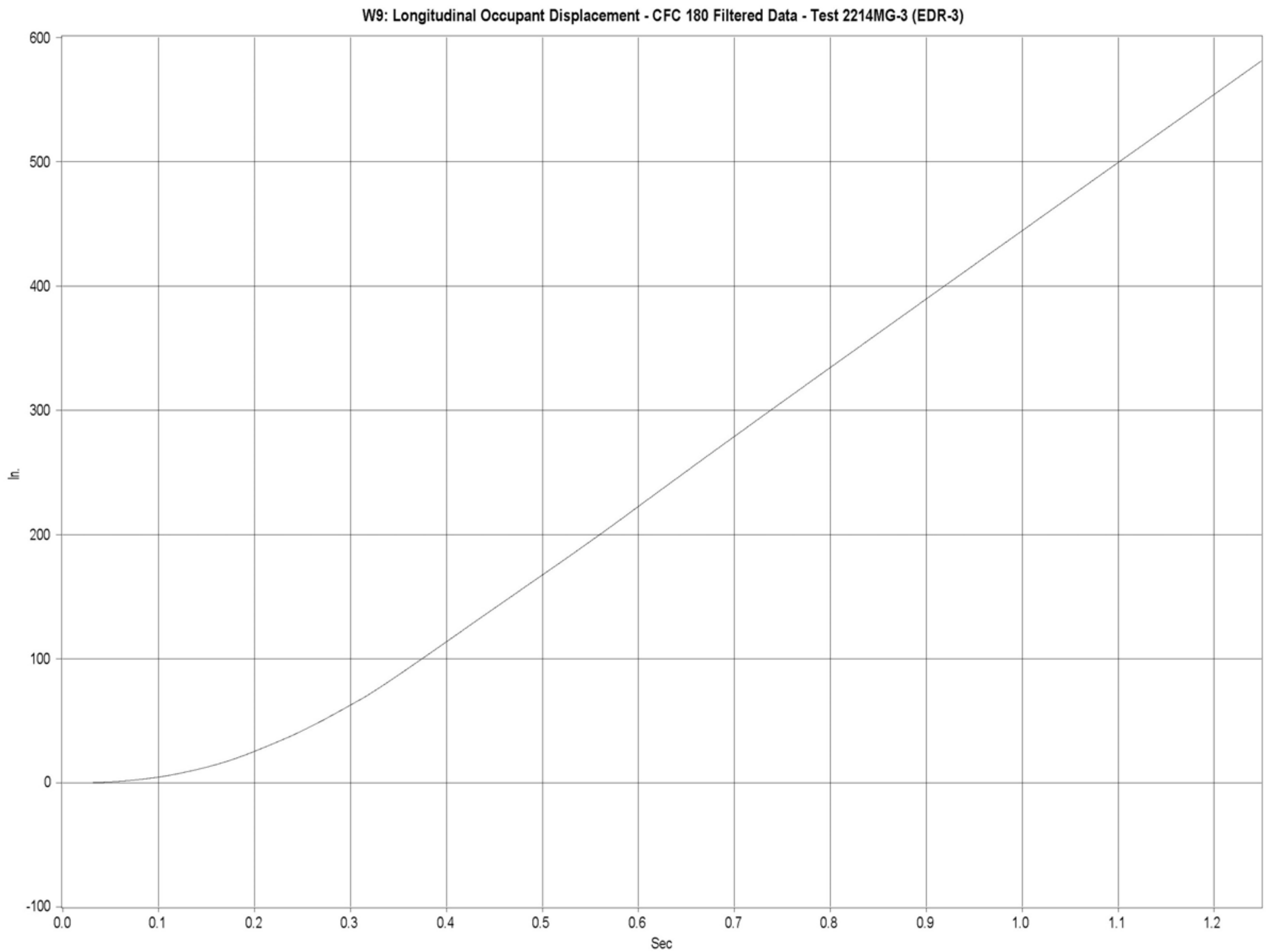


Figure D-3. Graph of Longitudinal Occupant Displacement, Test 2214MG-3

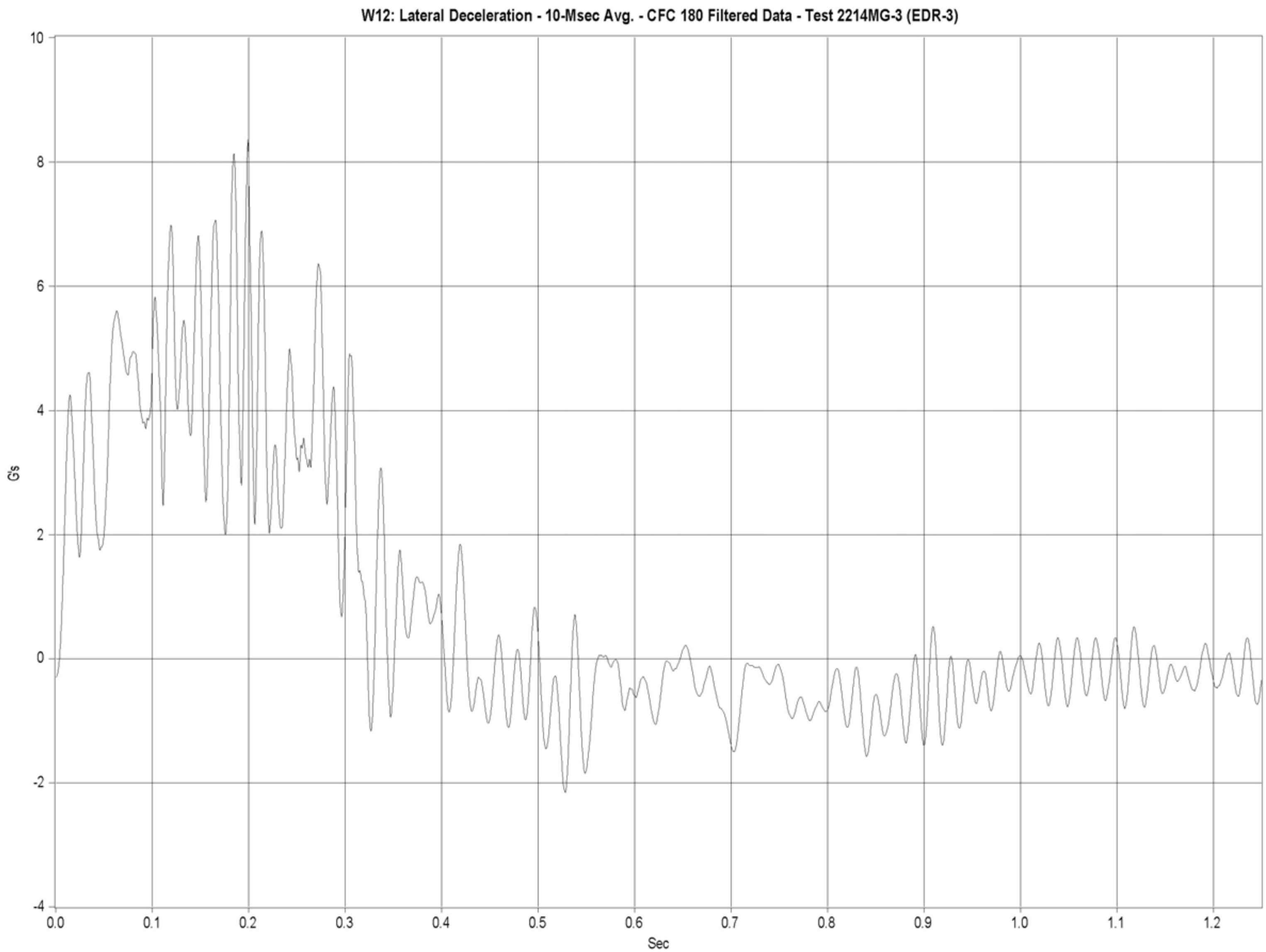


Figure D-4. Graph of Lateral Deceleration, Test 2214MG-3

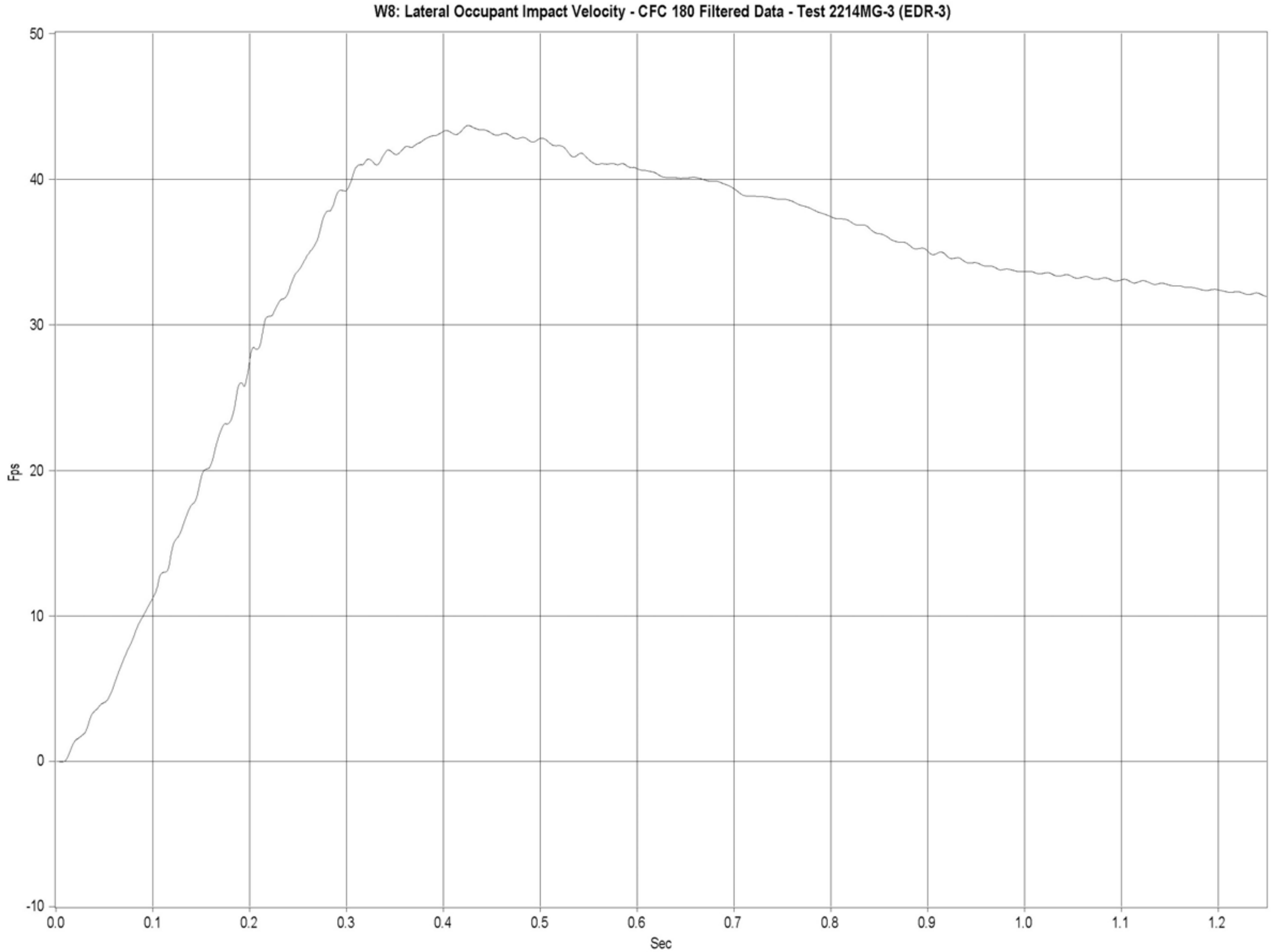


Figure D-5. Graph of Lateral Occupant Impact Velocity, Test 2214MG-3

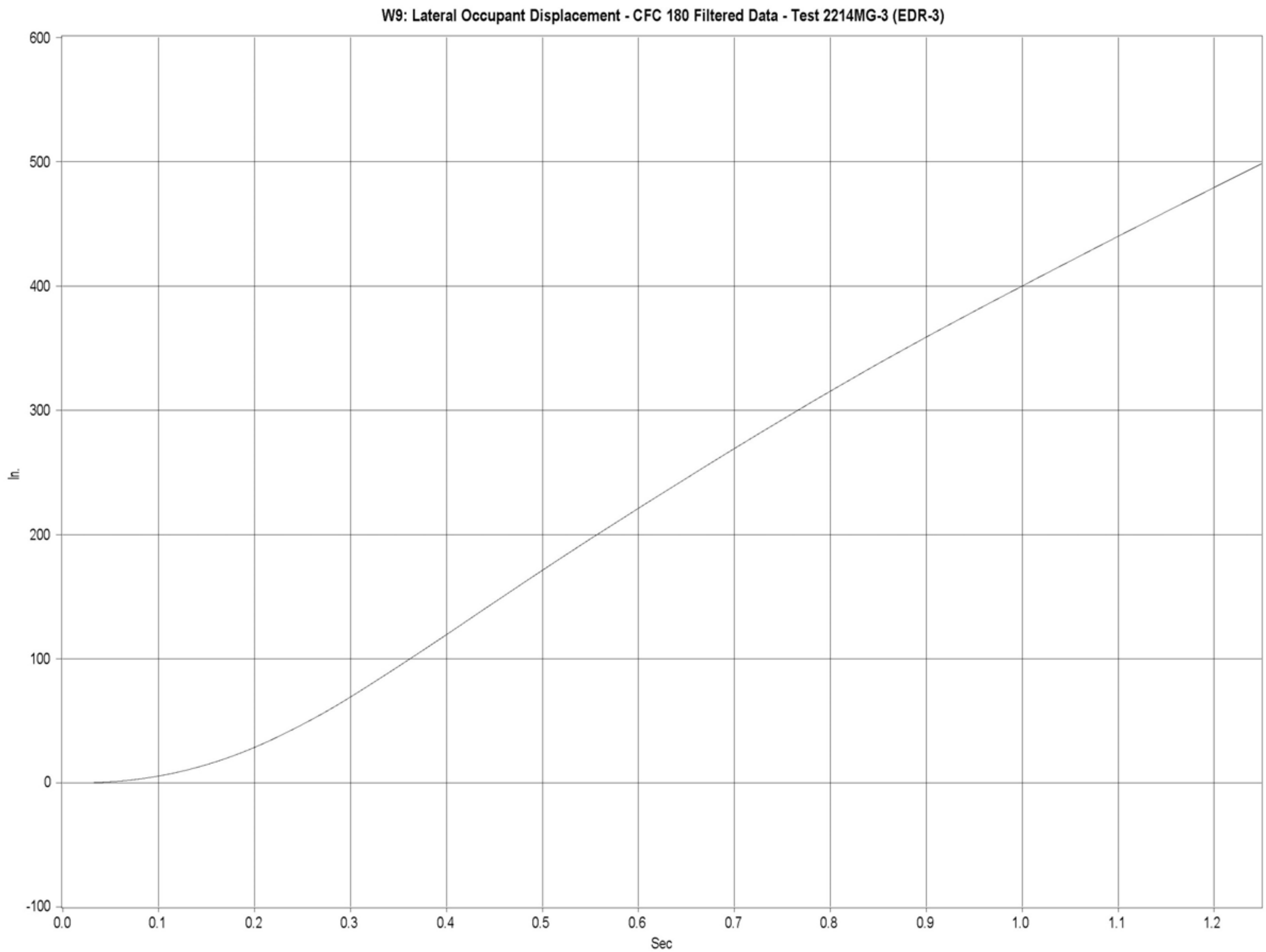


Figure D-6. Graph of Lateral Occupant Displacement, Test 2214MG-3

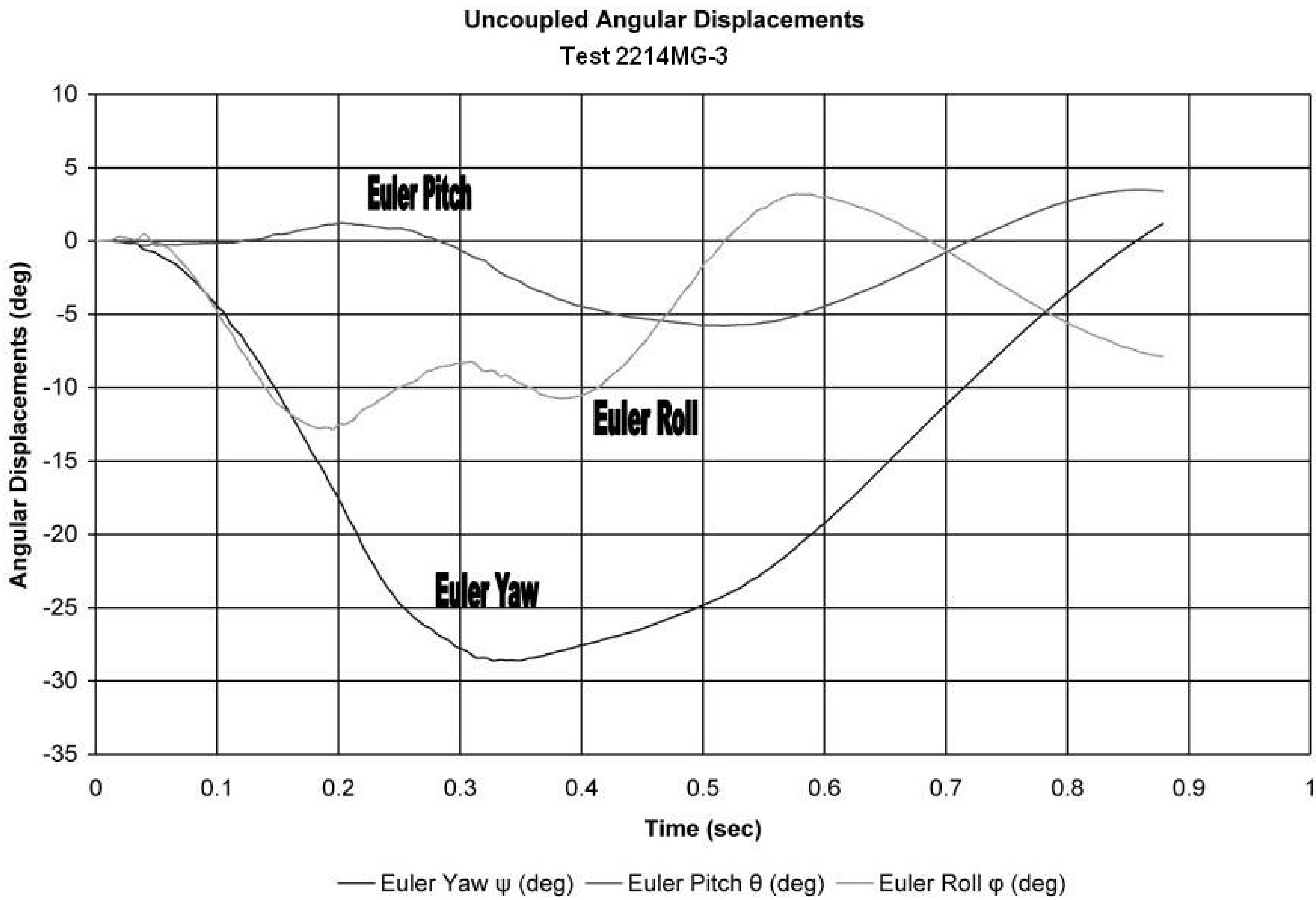


Figure D-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test 2214MG-3