PERFORMANCE EVALUATION OF THE FREE-STANDING TEMPORARY BARRIER – UPDATE TO NCHRP 350 TEST NO. 3-11 WITH 28" C.G. HEIGHT (2214TB-2)

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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 free-standing temporary concrete barrier system prior to finalizing the new crash testing procedures and guidelines. For this effort, the free-standing temporary barrier 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 the testing program, a 2270P pickup truck vehicle, which was a ½-ton, four-door vehicle with a 711 mm (28 in.) c.g. height, was used.

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

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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 free-standing temporary barrier 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 free-standing temporary barrier system. The crash test utilized a pickup truck, weighing approximately 2,270 kg (5,004 lbs) with a center of gravity (c.g.) height of 711 mm (28 in.). The target impact conditions for the test were an impact speed of 100.0 km/h (62.1 mph) and an impact angle of 25 degrees. Next, the test results were analyzed, evaluated, and documented. Finally, conclusions and recommendations were made that pertain to the safety performance of the free-standing temporary barrier system relative to the test performed.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Historically, longitudinal barriers, such as temporary barrier 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 free-standing temporary barrier 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 2214TB-2, the vehicle guidance system was 311 m (1,019 ft) long.

3.3 Test Vehicles

For test 2214TB-2, a 2002 Dodge Ram 1500 Quad Cab 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.

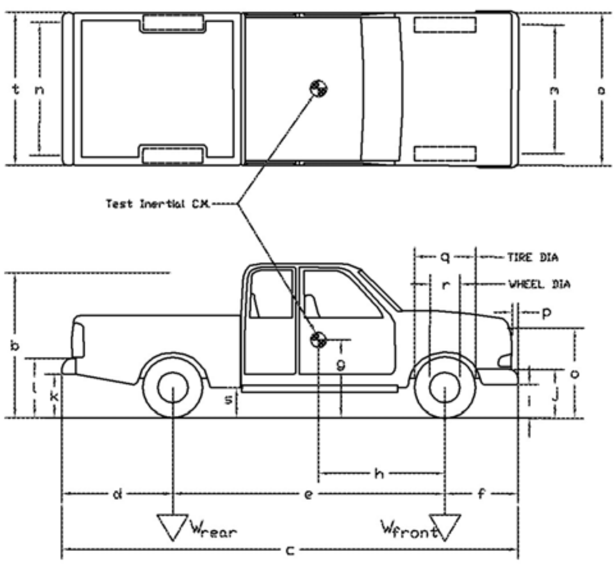
Figure 1. Test Vehicle, Test 2214TB-2

Date: 10/12/04 Test Number: 2214TB-2 Model: Ram 1500 Quad Cab

Make: Dodge Vehicle I.D.#: 3B7GA18NX2G106086

Tire Size: P265/70 R16 Year: 2002 Odometer: 45152

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1981 (78.0)	b	1892 (74.5)
c	5785 (227.75)	d	1219 (48.0)
e	3562 (140.25)	f	1054 (41.5)
g	721 (28.4)	h	1578 (62.125)
i	270 (10.625)	j	676 (26.625)
k	524 (20.625)	l	740 (29.125)
m	705 (67.75)	n	1715 (67.5)
o	1092 (43.0)	p	79 (3.125)
q	787 (31.0)	r	470 (18.5)
s	403 (15.875)	t	1911 (75.25)

Wheel Center Height Front 378 (14.875)

Wheel Center Height Rear 384 (15.125)

Wheel Well Clearance (FR) 902 (35.5)

Wheel Well Clearance (RR) 962 (37.875)

Frame Height (FR) 444 (17.5)

Frame Height (RR) 635 (25.0)

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	1285 (2833)	1263 (2784)	1263 (2784)
W_{rear}	999 (2202)	1005 (2216)	1005 (2216)
W_{total}	2284 (5035)	2268 (5000)	2268 (5000)

Engine Type 8 CYL. GAS

Engine Size 4.7 L

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

Note any damage prior to test: None

Figure 2. Vehicle Dimensions, Test 2214TB-2

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.

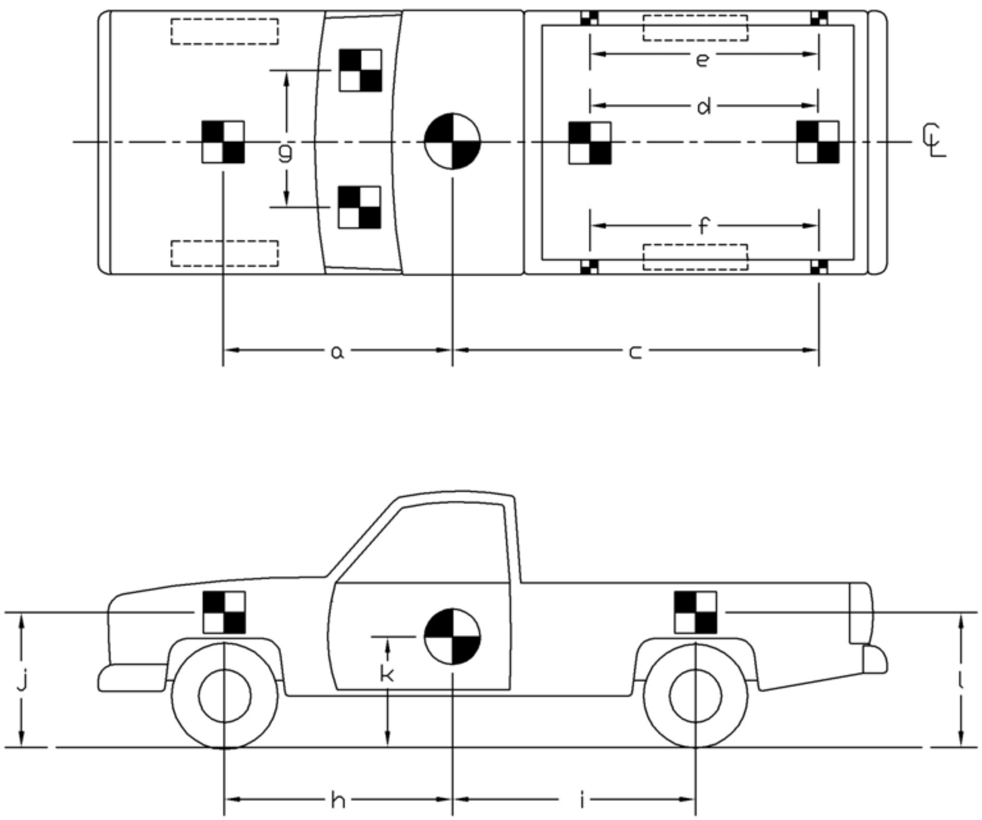
Square black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film and E/cam and Photron video, as shown in Figure 3. Checkered targets were placed on the center of gravity, on the driver's side door, on the passenger's side door, and on the roof of the 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 #: 2214TB-2

TARGET GEOMETRY -- mm (in.)

a 1886 (74.25)	d 1969 (77.5)	g 841 (33.125)	j 1010 (39.75)
b –	e 1622 (63.875)	h 1578 (62.125)	k 721 (28.4)
c 2724 (107.25)	f 1662 (63.875)	i 1984 (78.125)	l 1073 (42.25)

Figure 3. Vehicle Target Locations, Test 2214TB-2

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 2214TB-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. Two high-speed Photron video cameras and four 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 thirteen camera locations for test 2214TB-2 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 2214TB-2, 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 theleft-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.

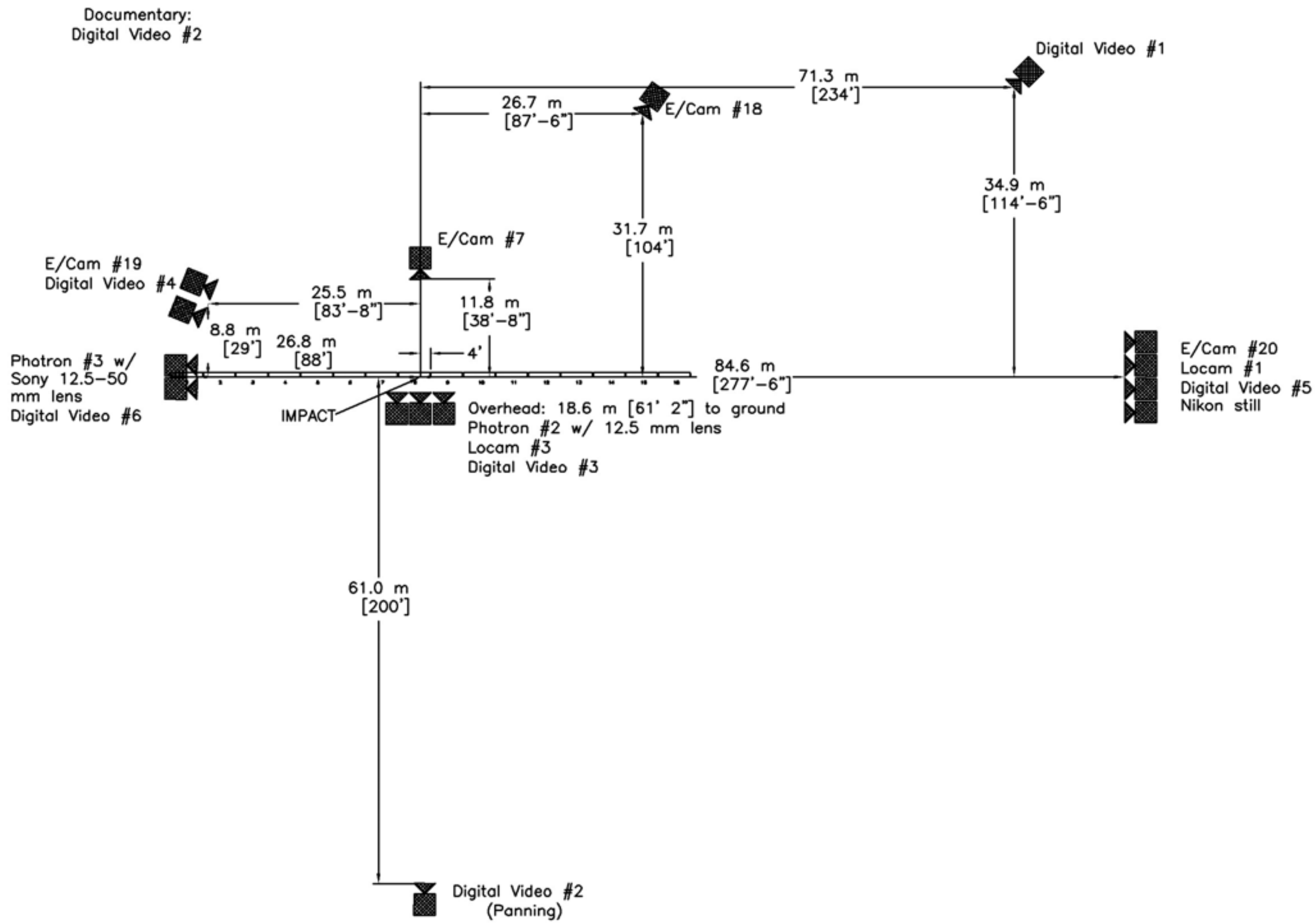


Figure 4. Location of High-Speed Cameras, Test 2214TB-2

4 DESIGN DETAILS

The 62.34-m (204.5-ft) long test installation consisted of temporary concrete barriers in a free-standing configuration, as shown in Figures 5 through 9. The sixteen 3,810-mm (12-ft 6-in.) long, F-shaped temporary concrete barriers were placed on the concrete tarmac without any attachment between the barriers and the tarmac. The corresponding English-unit drawings are shown in Appendix A. Photographs of the test installation are shown in Figures 10 through 12.

The concrete used for the barriers consisted of Iowa's Barrier Mix, with a minimum 28-day concrete compressive strength of 34.5 MPa (5,000 psi). The minimum concrete cover varied at different positions of rebar in the barrier. A minimum concrete cover of 51 mm (2 in.) was used along the top of the vertical stirrup rebar and the bottom longitudinal rebar. Minimum concrete cover of 44 mmm (1.75 in.) and 25 mm (1 in.) were used along the sides of the vertical stirrup rebar and at the rebar around the anchor bolt block, respectively. All the steel reinforcement in the barier was ASTM A615 Grade 60 rebar, except for the loop bars which were ASTM A706 Grade 60 rebar. The barrier reinforcement details are shown in Figures 5 through 9.

Barrier reinforcement consisted of three No. 5 and two No. 4 longitudinal bars, twelve No. 4 bars for the vertical stirrups, and six No. 6 bars for the anchor bolt block reinforcement loops. Each of the five longitudinal rebar was 3.71 m (12 ft - 2 in.) long. The vertical spacings of the lower, middle, and upper longitudinal bars were 165 mm (6.5 in.), 368 mm (14.5 in.), and 780 mm (29.125 in.) from the ground to their centers, respectively. The 1,829-mm (72-in.) long, vertical stirrups were bent into the shape of the barrier. Their spacings varied longitudinally, as shown in Figure 6. The 889-mm (35-in.) long, anchor bolt block loops were bent into a U-shape and were used to reinforce the anchor bolt area, as shown in Figures 6 through 8.

The barriers used a pin and loop type connection comprised of two sets of rebar loops on each barrier interconnection. Each loop assembly was configured with three ASTM A706 Grade 60 No. 6 bars that were bent into a loop shape, as shown in Figure 8. The vertical pin used in the connection consisted of a 32-mm (1.25 in.) diameter x 711-mm (28-in.) long round bar composed of ASTM, A36 steel, as shown in Figure 9. The pin was held in place using one 64-mm wide x 102-mm long x 13-mm thick (2.5-in. x 4-in. x 0.5-in.) ASTM A36 steel plate with a 35-mm (1.375-in.) diameter hole centered on it. The plate was welded 64 mm (2.5 in.) below the top of the pin. A gap of 92 mm (3.625 in.) between the ends of two consecutive barriers was formed from the result of pulling the connection taut.

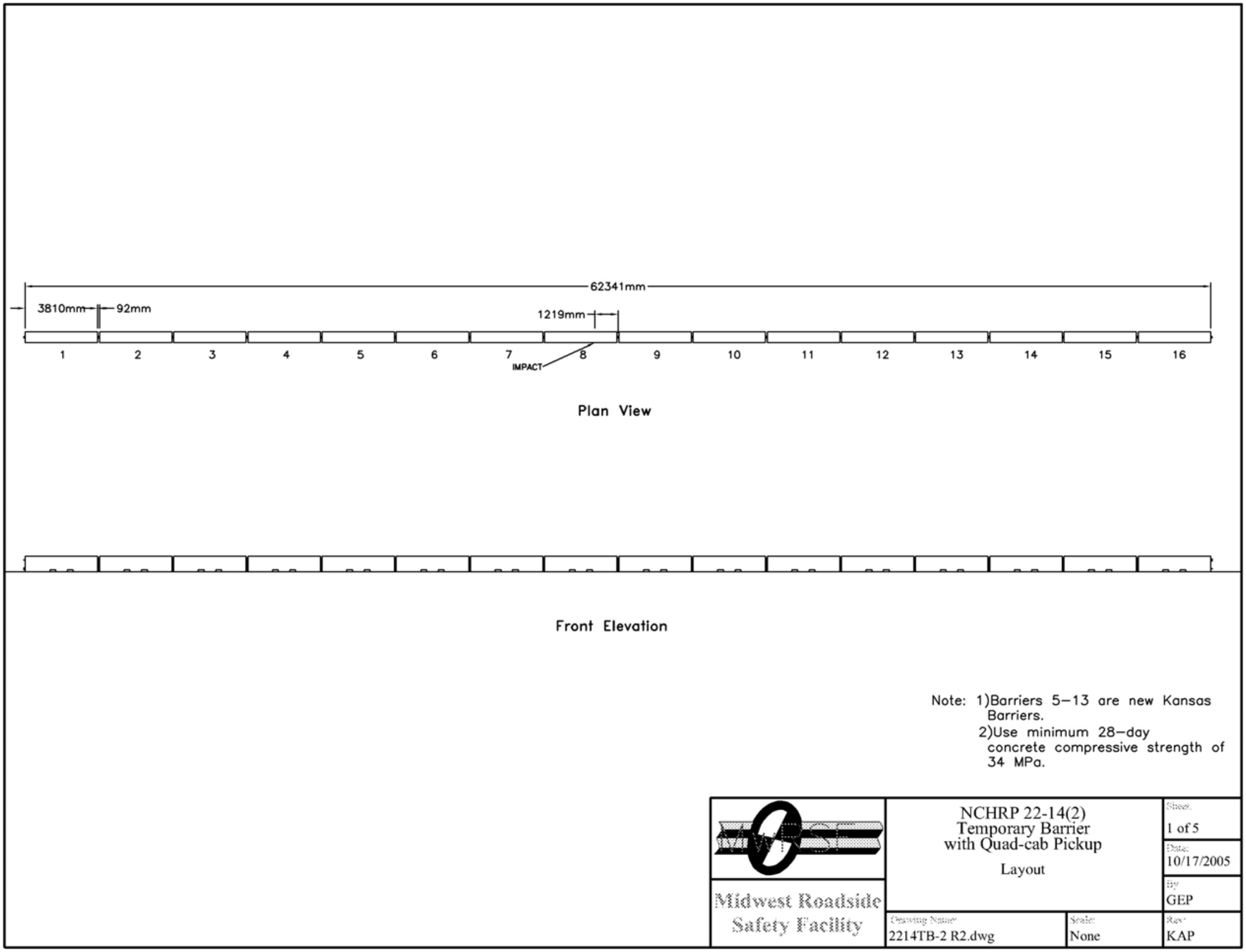


Figure 5. Layout for Free-Standing Temporary Barriers

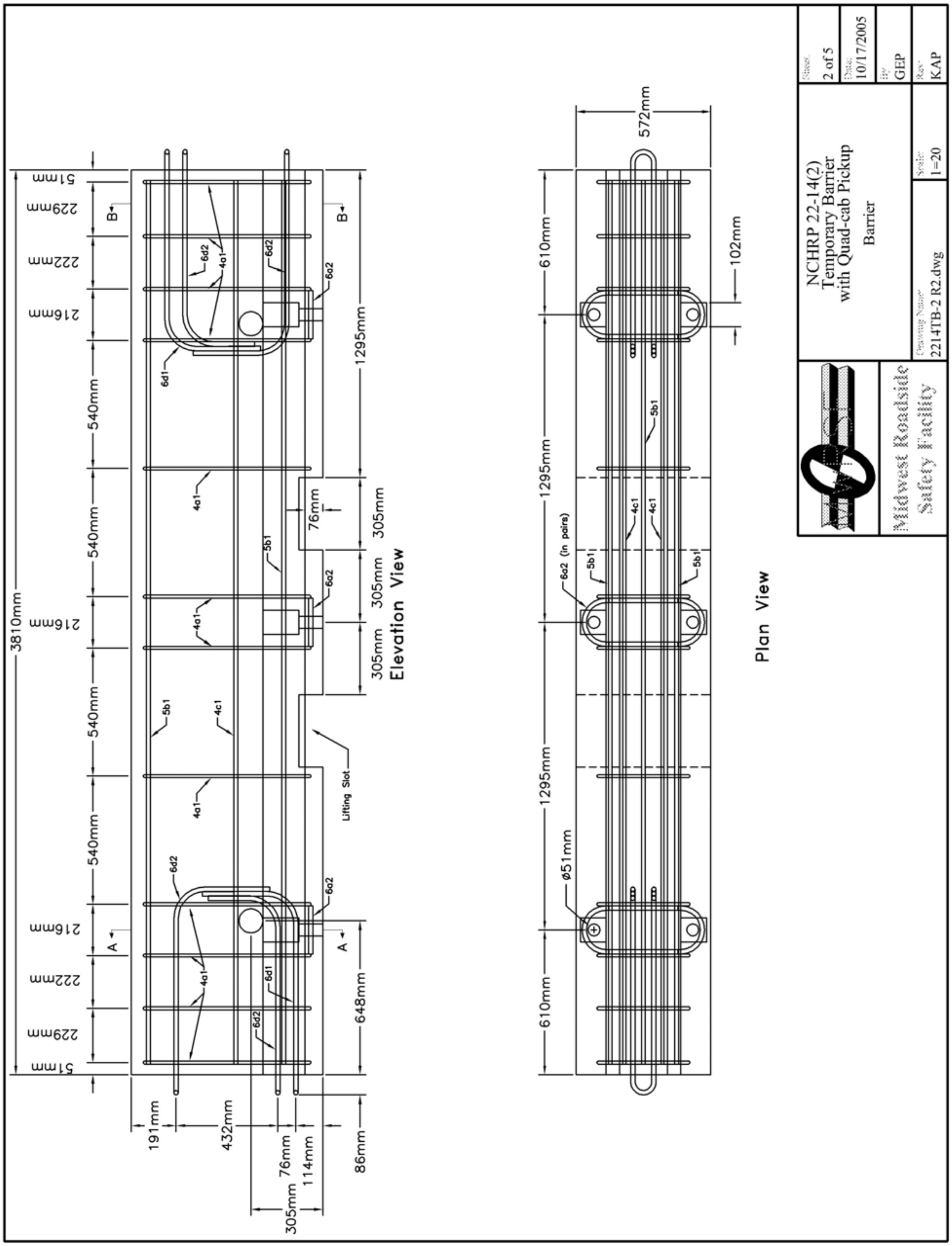


Figure 6. Temporary Barrier Design Details

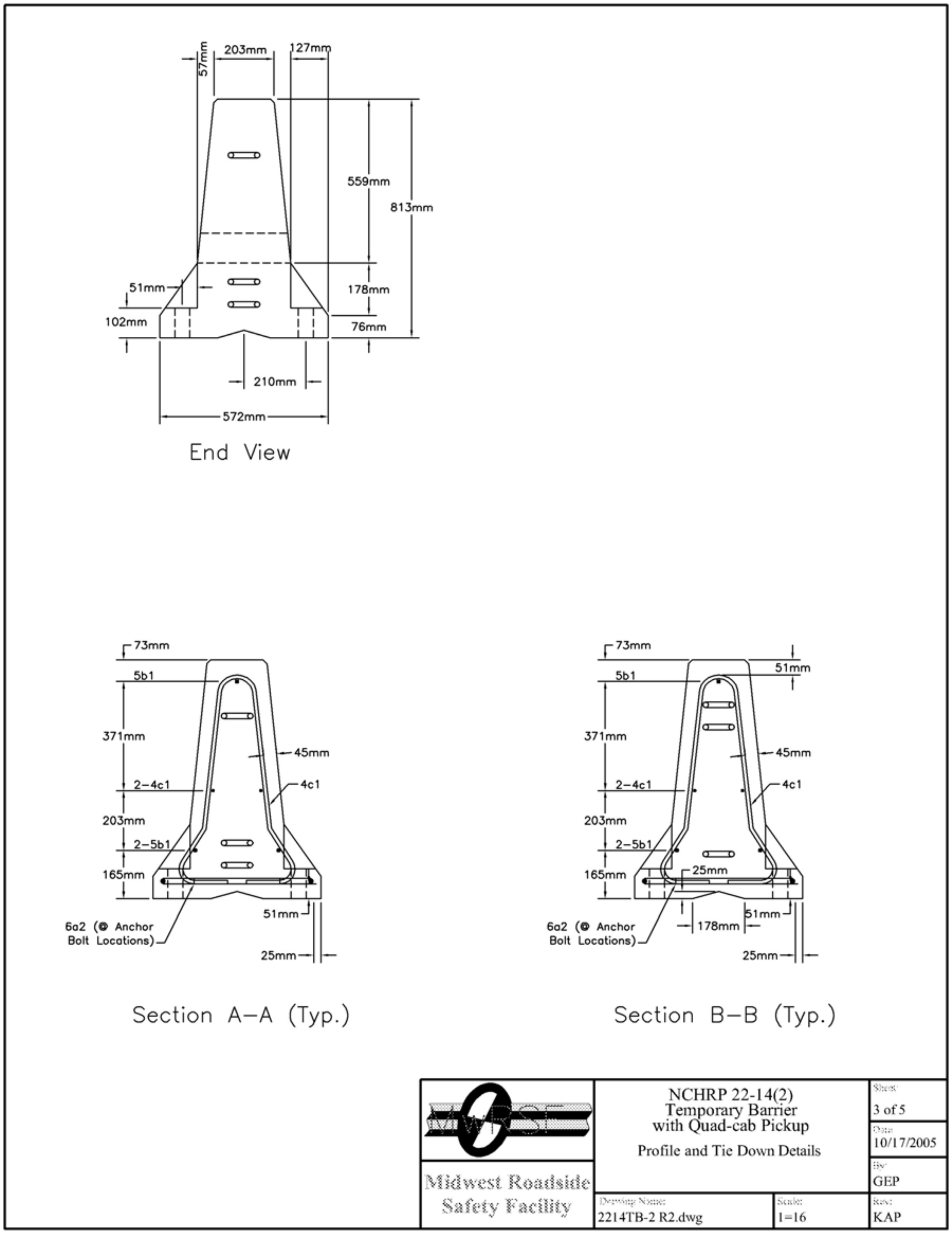
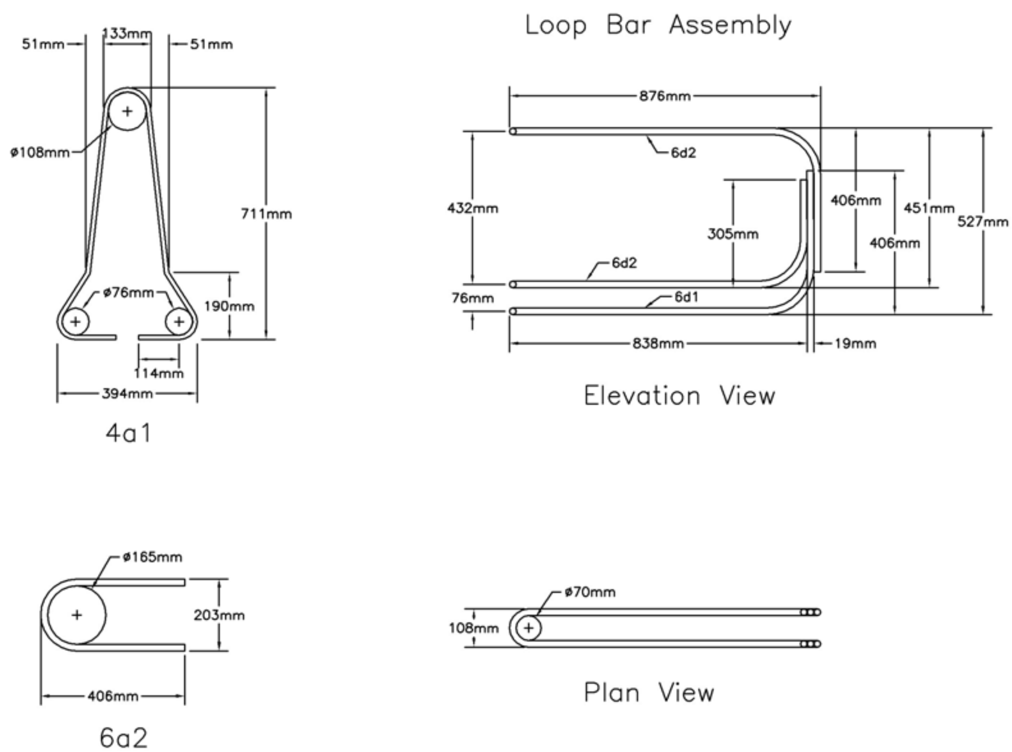


Figure 7. Temporary Barrier Profile Details



BILL OF BARS					
Mark	Bar No.	No.	Length	Material	Pin Dia.
4a1	4	12	1829mm	A615 Gr. 60	76&108mm
6a2	6	6	889mm	A615 Gr. 60	165mm
5b1	5	3	3708mm	A615 Gr. 60	
4c1	4	2	3708mm	A615 Gr. 60	
6d1	6	2	2565mm	A706 Gr. 60	
6d2	6	2	2311mm	A706 Gr. 60	
6d3	6	2	2591mm	A706 Gr. 60	

Midwest Roadside Safety Facility

NCHRP 22-14(2)
Temporary Barrier
with Quad-cab Pickup

Bill of Bars

Sheet: 4 of 5
Date: 10/17/2005
By: GEP
Drawing Name: 2214TB-2 R2.dwg
Scale: 1=16
Rev: KAP

Figure 8. Temporary Barrier Bill of Bars

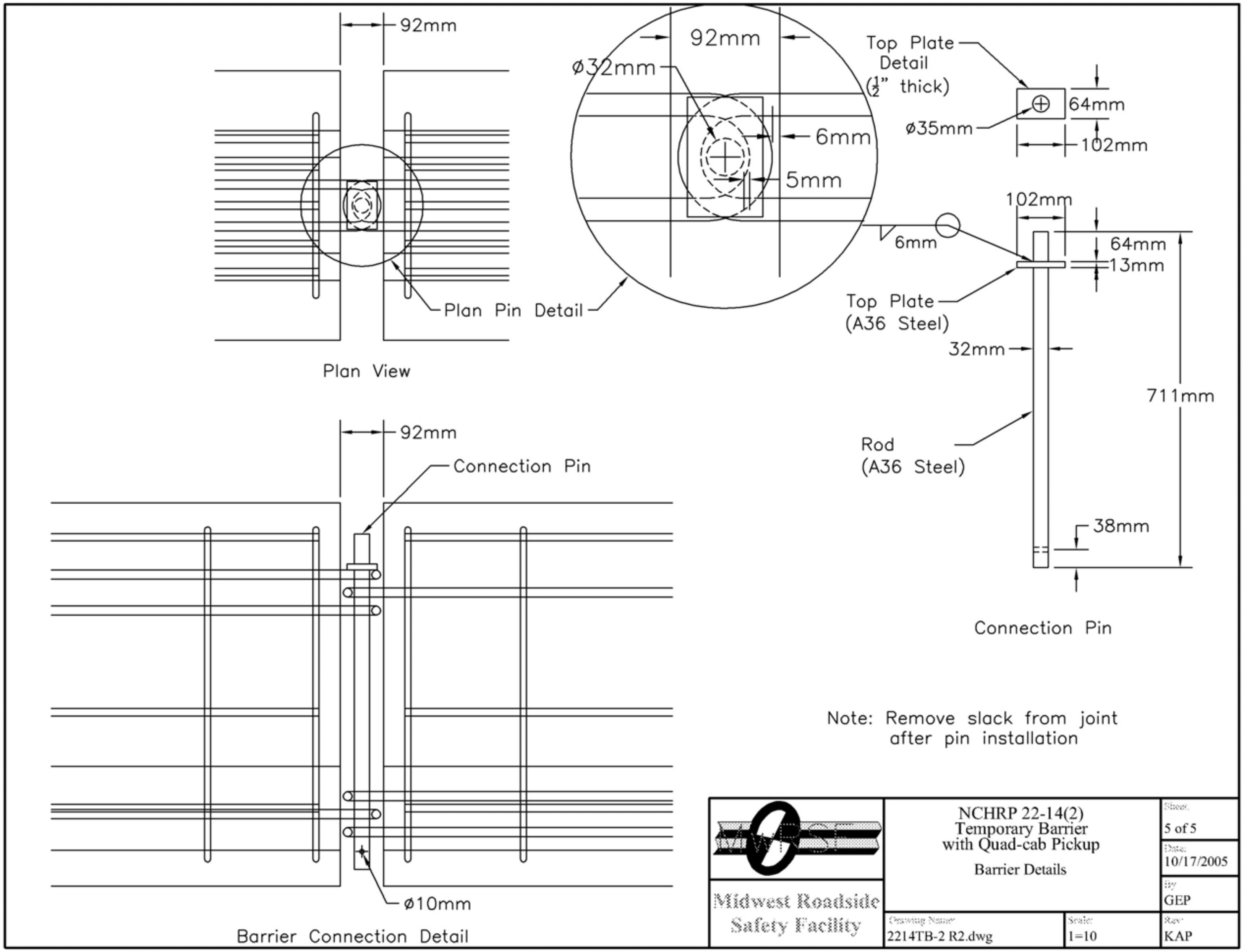


Figure 9. Temporary Barrier Connection Details

Figure 10. Temporary Barrier System

Figure 11. Temporary Barrier System

Figure 12. Barrier Connection Joints

5 CRASH TEST

5.1 Test 2214TB-2

The 2,268-kg (5,000-lb) pickup truck impacted the free-standing temporary barrier system at a speed of 99.7 km/h (61.9 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 17. Documentary photographs of the crash test are shown in Figures 18 and 19.

5.2 Test Description

Initial vehicle impact was to occur 1,219 mm (48 in.) upstream from the center of the gap between barrier nos. 8 and 9, as shown in Figure 20. Actual vehicle impact occurred 1,201 mm (47.3125 in.) upstream from the center of the gap between barrier nos. 8 and 9. At 0.020 sec after impact, the left-front tire rolled up the bottom of barrier no. 8. At 0.036 sec, the left-front corner of the vehicle crushed inward as the front of the vehicle was located near the joint between barrier no. 8 and 9. At 0.056, barrier nos. 8 and 9 deflected backward. At 0.070 sec, the top of the left-side door was ajar. At 0.078 sec, barrier nos. 8 and 9 continued to deflect backward and the front of the vehicle was located near the middle of barrier no. 9. At 0.122 sec, the vehicle began to redirect. At 0.126 sec, the right-front tire became airborne. At 0.156 sec, the vehicle began to redirect quickly. At 0.170 sec, the vehicle began to roll slightly CCW toward the barrier. At 0.220 sec after impact, the vehicle became parallel to the system with a resultant velocity of 75.6 km/h (47.0 mph). At 0.246 sec, the front of the vehicle pitched upward as the left-front corner rode along the top of the barrier system. At 0.282 sec, the entire left side of the vehicle was in contact with the system. At this same time, the right-side tires were airborne. At 0.370 sec, the vehicle was completely airborne but the left side of the vehicle remained in contact with the barrier. At 0.400 sec, the vehicle rolled CCW toward the system. At 0.440 sec, the barriers slid downstream. At 0.452 sec, the front of the vehicle pitched downward as it continued to roll CCW. At 0.498 sec, the vehicle continued to roll CCW. At 0.548 sec, the vehicle encountered increased roll CCW. Prior to 0.554 sec after impact, the left-front tire disengaged from the vehicle. At 0.644 sec, the vehicle exited the system at an angle of 7.9 degrees and a resultant velocity of 72.2 km/h (44.9 mph). At this same, the left-front corner of the vehicle contacted the ground. At 0.774 sec, the vehicle recovered from CCW roll due to the ground contact. At 0.822, the right-front tire contacted the ground. At 1.214 sec, the rear tires contacted the ground. At 1.350 sec, the tailgate partially separated from the rest of the vehicle. At 1.664 sec, the vehicle yawed back toward the system. At 2.260 sec, the right-front tire deflated. The vehicle came to rest 74.63 m (244 ft - 10 in.) downstream from impact and 1.23 m (4 ft - 0.5 in.) laterally behind a line projected parallel to the traffic-side face of the temporary barrier system. The trajectory and final position of the pickup truck are shown in Figures 13 and 21.

5.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 22 through 25. Barrier damage consisted of contact and gouge marks, concrete barrier cracking, and spalling of the concrete. The length of vehicle contact along the temporary concrete barrier system was approximately 10 m (34 ft), which spanned from 1,156 mm (45.5 in.) upstream from the downstream end of barrier no. 8 through 1,626 mm (64 in.) downstream from the upstream end of barrier no. 11.

Tire marks from the left-front tire were visible on the front face of barrier nos. 8 through 11. Tire marks from the left-rear tire were visible on the front face of barrier nos. 9 through 11 and began at about the middle of barrier no. 9. A 171-mm (6.75-in.) wide scratch, beginning 749 mm (29.5 in.) upstream from the downstream end, was found on barrier no. 8. Minor random scratches were found on barrier no. 9.

Cracking was found on the front face of barrier no. 8 beginning at the upper corners of the lifting slots and propagated up to the top of the barrier. Major cracking was found throughout barrier no. 9.

The downstream end of barrier no. 8 encountered concrete spalling located 241 mm (9.5 in.) from the top of the barrier and was 191 mm (7.5 in.) long. Concrete spalling, 127 mm (5 in.) in length, was found 102 mm (4 in.) from the top of the barrier on the upstream end of barrier no. 9. Concrete spalling occurred on the lower-front face of barrier no. 9 from 1,270 mm (50 in.) to 2,216 mm (87.25 in.) downstream from the barrier's upstream end. Minor concrete spalling was also found on the lower-front corner of the upstream and downstream ends of barrier no. 9 and the upstream end of barrier no. 10.

The permanent set of the barrier system is shown in Figure 22. Barrier nos. 6 through 12 encountered longitudinal and lateral movement while barrier nos. 5 and 13 through 16 only moved longitudinally. The maximum lateral permanent set barrier deflection was 1,854 mm (73 in.) at the downstream end of barrier no. 9 and upstream end of barrier no. 10, as measured in the field. The maximum lateral dynamic barrier deflection was 2,023 mm (79.65 in.) at the downstream end of barrier no. 9, as determined from high-speed digital video analysis. The working width of the system was found to be 2,595 mm (102.2 in.).

5.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 26 through 28. Occupant compartment deformations to the left side and center of the floorboard, as shown in Figure 29, were judged insufficient to cause serious injury to the vehicle occupants. Maximum longitudinal deflections of 108 mm (4.25 in.) were located near the left-front corner of the left-side floor pan. Maximum lateral deflections of 32 mm (1.25 in.) were located near the left-front corner of the left-side floor pan. Maximum vertical deflections of 102 mm (4 in.) were located near the left-front corner of the left-side floor pan. Complete occupant compartment deformations and the corresponding locations are provided in Appendix C.

Damage was concentrated on the left-front corner of the vehicle. The hood, front bumper, grill, and the left-side and right-side front-quarter panels shifted toward the right. The left-front quarter panel was deformed inward and downward toward the engine compartment. The left side of the front bumper was flattened and bent back toward the engine compartment. A buckle point was located near the center of the front bumper. The left side of the grill fractured and was deformed inward toward the engine compartment. The radiator and air conditioning units were deformed into the engine. Minor paint scratches were observed on the front of the hood and on the tailgate. The top of the left door was ajar. The vehicle encountered numerous sheet metal scratches and tears along its left side. The left-front side of the frame and engine mount were bent inward toward the center of the vehicle. The left-front upper A-arm was bent. The left-side lower ball joint was fractured and removed from the lower A-arm. The left-side tie rod disengaged from the rest of the wheel assembly. The left-side bump stop bracket was deformed upward and the brake line was severed. The left-front and left-rear steel rims were deformed and dented. The left-front tire's lug nuts were scratched. The left-rear tire's hub cap was bent and deformed. The left-front and left-rear tires' side walls were torn, and the tires deflated. The rear bumper was dented on the left side. The right-side tailgate connection fractured, but the tailgate remained attached to the vehicle. The left-front wheel assembly disengaged from the vehicle. The left-side headlight and park light were fractured. The left-side tail light was detached from the vehicle. All window glass remained undamaged.

5.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be 5.18 m/s (17.00 ft/s) and 5.27 m/sec (17.28 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 7.17 Gs and 11.37 Gs, respectively. It is noted that the occupant impact velocities (OIVs) and occupant ridedown decelerations (ORDs) were within the suggested limits provided in NCHRP Report No. 350. The THIV and PHD values were determined to be 6.89 m/s (22.60 ft/s) and 11.52 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. 2214TB-2 showed that the free-standing temporary concrete barrier system impacted with the 2270P vehicle of the Update to NCHRP Report No. 350 adequately contained and redirected the vehicle with controlled lateral displacements of the barrier system. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the temporary concrete 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. 2214TB-2 conducted on the free-standing temporary concrete barrier system was determined to be acceptable according to the TL-3 safety performance criteria found in the Update to NCHRP Report No. 350.

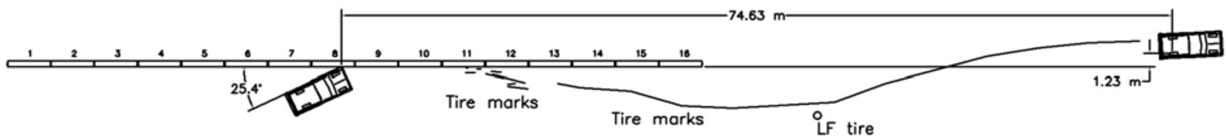
0.000 sec

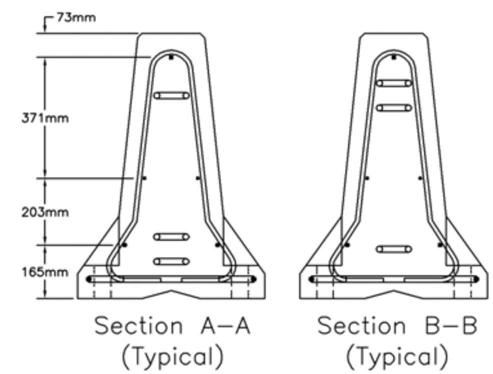
0.122 sec

0.216 sec

0.400 sec

0.498 sec





- Test Agency . . . . MwRSF
- Test Number 2214TB-2
- Date 10/12/04
- NCHRP 350 Update Test Designation . . 3-11
- Appurtenance . . . . Free-Standing Temporary Barrier
- Total Length . . . . 62.34 m
- Key Elements - Barrier
  - Description . . . . F-Shape Barrier
  - Length . . . . 3,810 mm
  - Base Width . . . . 572 mm
  - Height . . . . 813 mm
- Type of Soil . . . . NA
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model . . . . 2002 Dodge Ram 1500 Quad Cab Pickup
  - Curb . . . . 2,284 kg
  - Test Inertial . . . . 2,268 kg
  - Gross Static . . . . 2,268 kg
- Impact Conditions
  - Speed . . . . 99.7 km/h
  - Angle . . . . 25.4 degrees
  - Impact Location . . . . 1.2 m upstream barriers 8 & 9 joint
- Exit Conditions
  - Speed . . . . 72.2 km/h
  - Angle . . . . 7.9 degrees
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 74.63 m downstream
    1.23 m laterally behind
- Occupant Impact Velocity (350 Update)
  - Longitudinal . . . . 5.18 m/s < 12 m/s
  - Lateral . . . . 5.27 m/s < 12 m/s
- Occupant Ridedown Deceleration (350 Update)
  - Longitudinal . . . . 7.17 Gs < 20 Gs
  - Lateral . . . . 11.37 Gs < 20 Gs
- THIV (not required) . . . . 6.89 m/s
- PHD (not required) . . . . 11.52 Gs
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . 1,854 mm
  - Dynamic . . . . 2,023 mm
  - Working Width . . . . 2,595 mm
- Vehicle Damage . . . . Moderate
  - VDS[5] 11-LFQ-3
  - CDC[6] 11-LYES4
  - Maximum Deformation . . . . 108 mm at front floorpan

Figure 13. Summary of Test Results and Sequential Photographs, Test 2214TB-2

0.000 sec

0.126 sec

0.202 sec

0.388 sec

0.554 sec

0.782 sec

0.976 sec

1.376 sec

Figure 14. Additional Sequential Photographs, Test 2214TB-2


0.000 sec


0.070 sec


0.170 sec


0.292 sec


0.452 sec


0.642 sec


0.822 sec

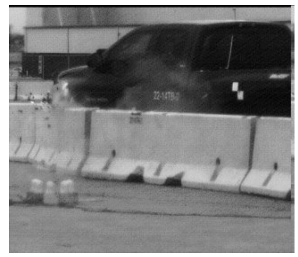

1.350 sec

Figure 15. Additional Sequential Photographs, Test 2214TB-2

0.000 sec

0.000 sec

0.116 sec

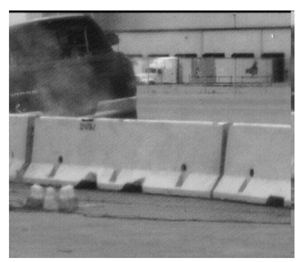


0.116 sec

0.246 sec

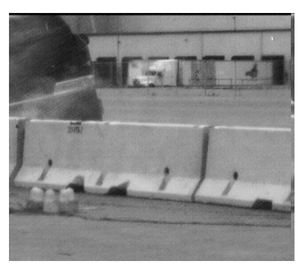
0.220 sec

0.340 sec



0.348 sec

0.580 sec



0.440 sec

Figure 16. Additional Sequential Photographs, Test 2214TB-2

0.000 sec

0.000 sec

0.200 sec

0.167 sec

0.434 sec

0.367 sec

0.634 sec

0.501 sec

0.968 sec

0.667 sec

1.468 sec

1.068 sec

Figure 17. Additional Sequential Photographs, Test 2214TB-2

Figure 18. Documentary Photographs, Test 2214TB-2

Figure 19. Documentary Photographs, Test 2214TB-2

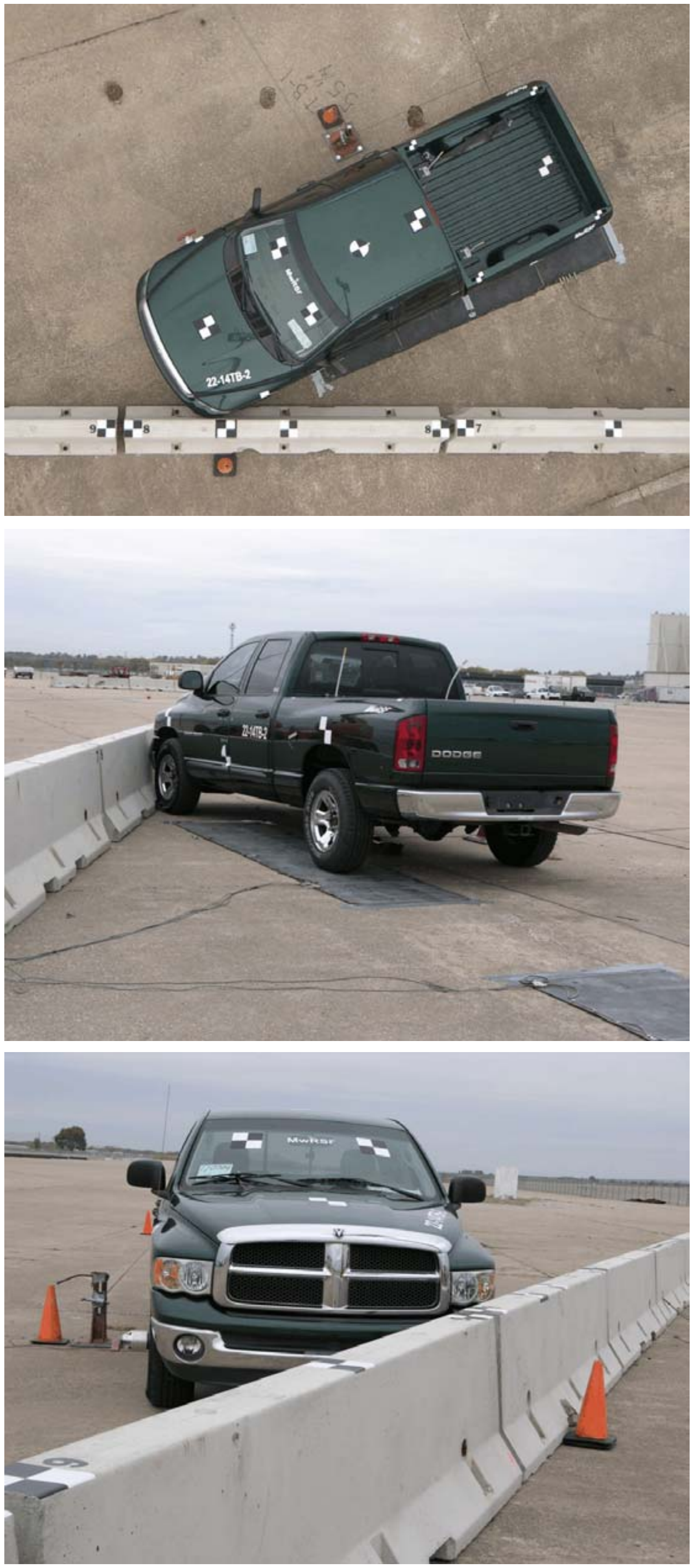


Figure 20. Impact Location, Test 2214TB-2

Figure 21. Vehicle Final Position and Trajectory Marks, Test 2214TB-2

Figure 22. Temporary Barrier Damage, Test 2214TB-2

Figure 23. Temporary Barrier Damage, Test 2214TB-2

Figure 24. Temporary Barrier Damage, Test 2214TB-2

Figure 25. Temporary Barrier Damage, Test 2214TB-2

Figure 26. Vehicle Damage, Test 2214TB-2

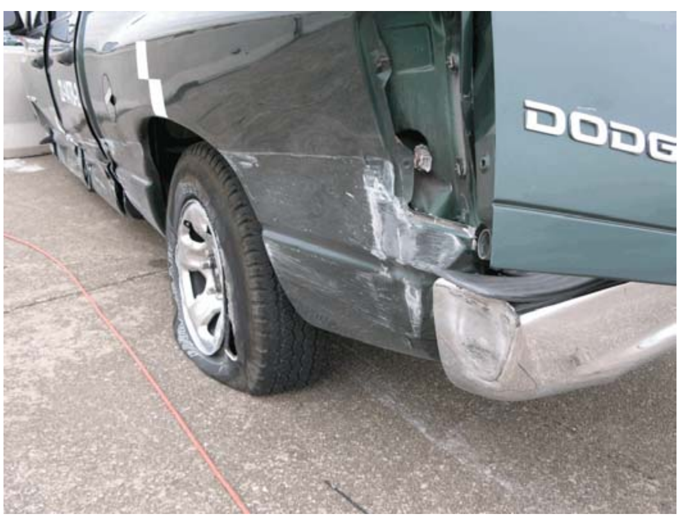


Figure 27. Vehicle Damage, Test 2214TB-2

Figure 28. Vehicle Damage, Test 2214TB-2

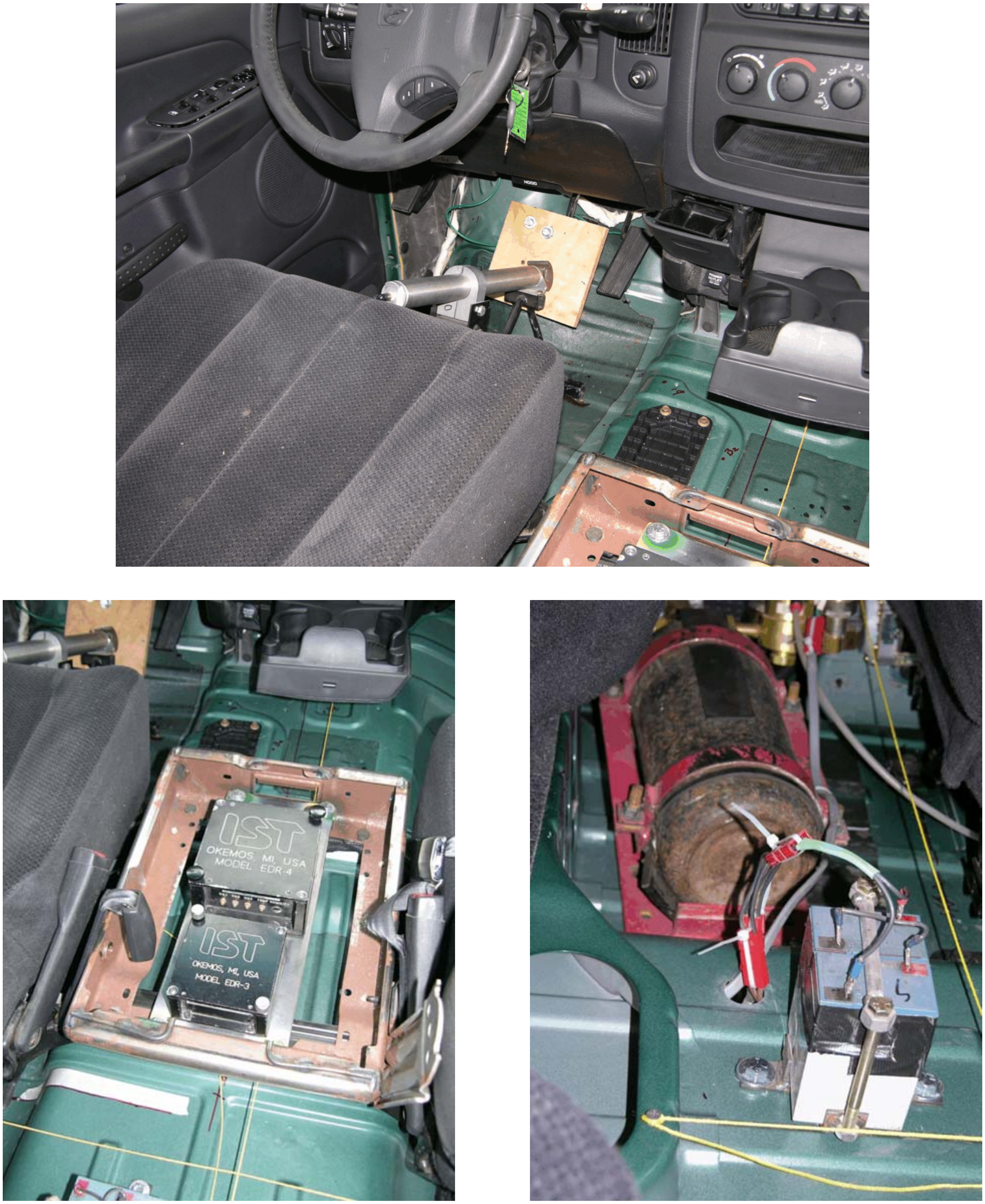


Figure 29. Occupant Compartment Deformation, Test 2214TB-2

6 SUMMARY AND CONCLUSIONS

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

Table 3. Summary of Safety Performance Evaluation Results

Evaluation Factors		Evaluation Criteria	Test 2214TB-2
Structural Adequacy	A.	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	S
Occupant Risk	D.	Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of the Update to NCHRP Report No. 350.	S
	F.	The vehicle should remain upright during and after collision.	S
	H.	Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9.0 m/s (29.5 ft/s), or at least below the maximum allowable value of 12.0 m/s (39.4 ft/s).	S
	I.	Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15 Gs, or at least below the maximum allowable value of 20.0 Gs.	S
Vehicle Trajectory	M.	After impact, the vehicle shall exit the barrier within the exit box.	S

S - Satisfactory
U - Unsatisfactory
NA - Not Available

7 REFERENCES

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

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

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

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

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

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

8 APPENDICES

APPENDIX A

English-Unit System Drawings

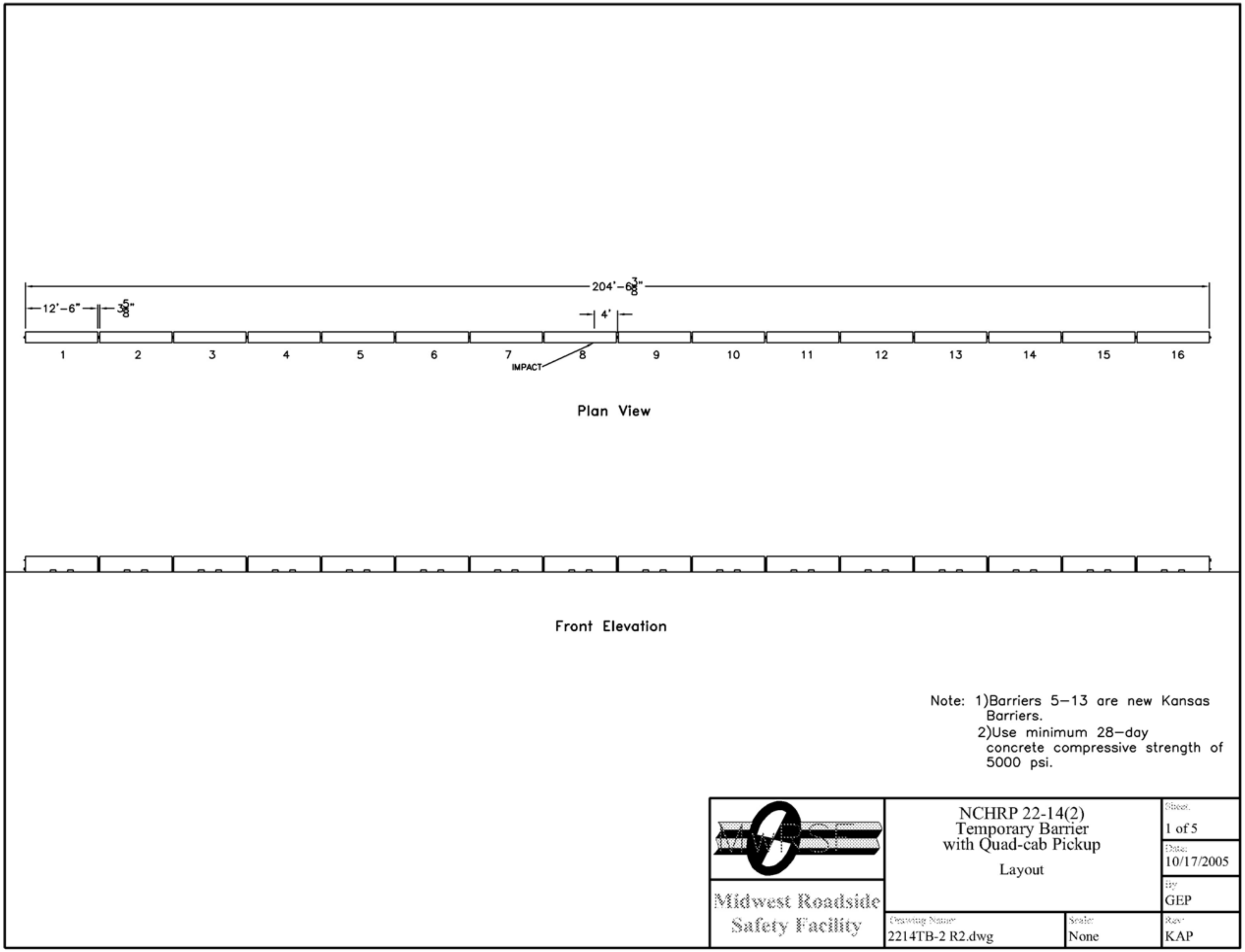


Figure A-1. Layout for Free-Standing Temporary Barriers (English)

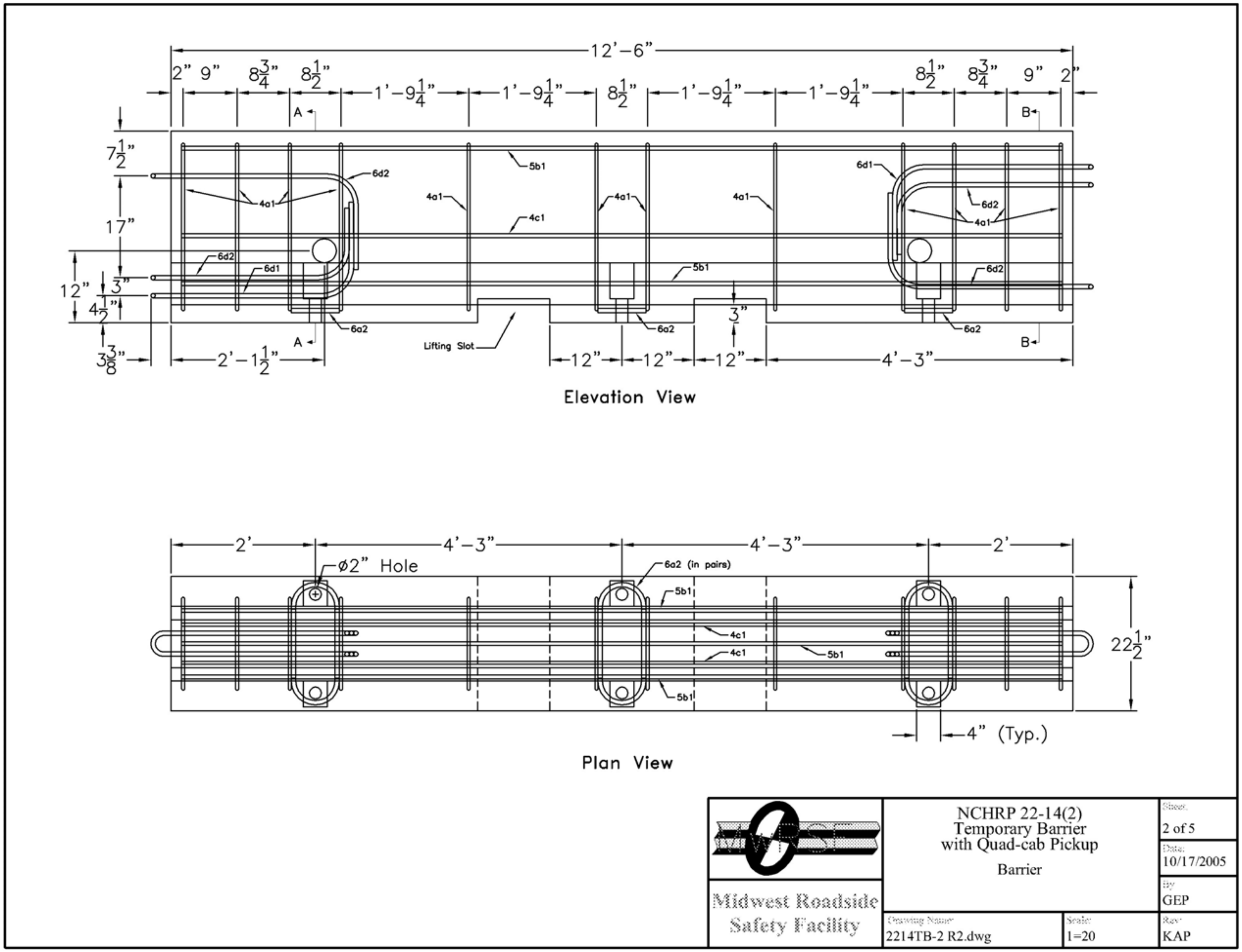


Figure A-2. Temporary Barrier Design Details (English)

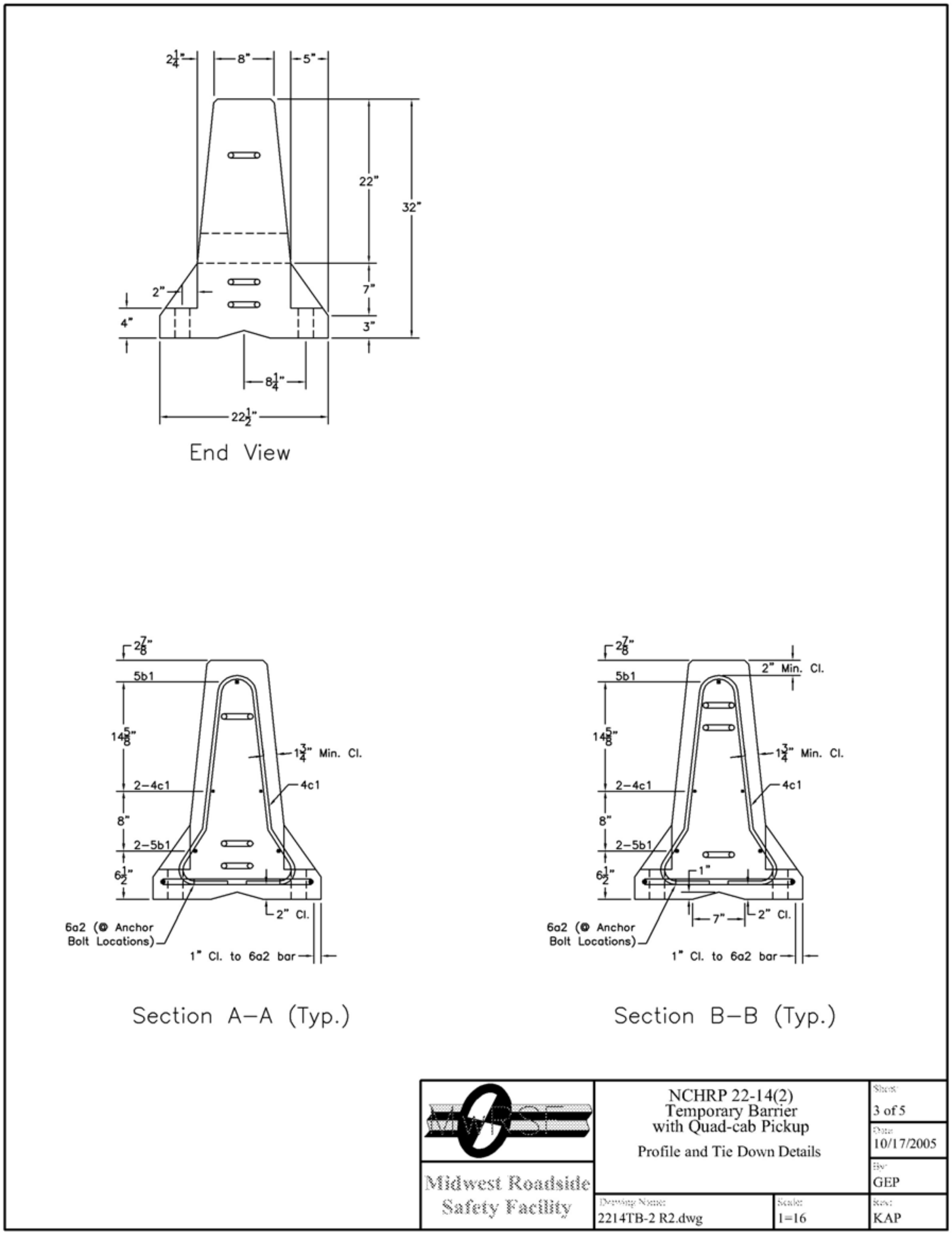
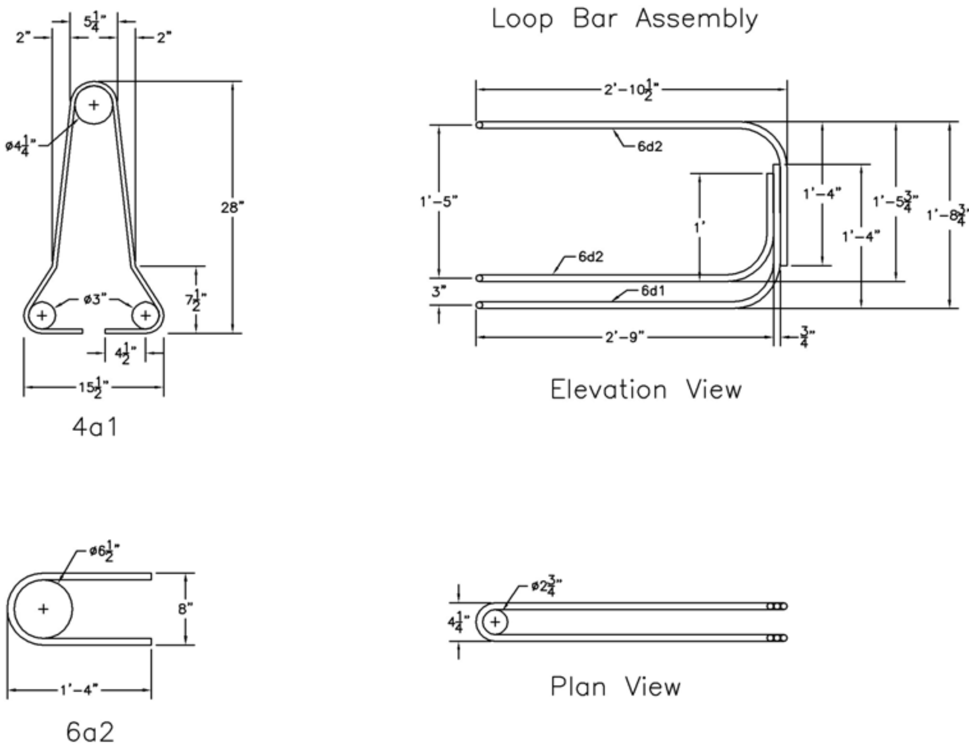


Figure A-3. Temporary Barrier Profile Details (English)



BILL OF BARS					
Mark	Bar No.	No.	Length	Material	Pin Dia.
4a1	4	12	6'–0"	A615 Gr. 60	3" & 4¼"
6a2	6	6	2'–11"	A615 Gr. 60	6½"
5b1	5	3	12'–2"	A615 Gr. 60	
4c1	4	2	12'–2"	A615 Gr. 60	
6d1	6	2	8'–5"	A706 Gr. 60	
6d2	6	2	7'–7"	A706 Gr. 60	
6d3	6	2	8'–6"	A706 Gr. 60	

Midwest Roadside Safety Facility	NCHRP 22-14(2) Temporary Barrier with Quad-cab Pickup Bill of Bars		Sheet: 4 of 5 Date: 10/17/2005 By: GEP
	Drawing Name: 2214TB-2 R2.dwg	Scale: 1=16	Rev: KAP

Figure A-4. Temporary Barrier Bill of Bars (English)

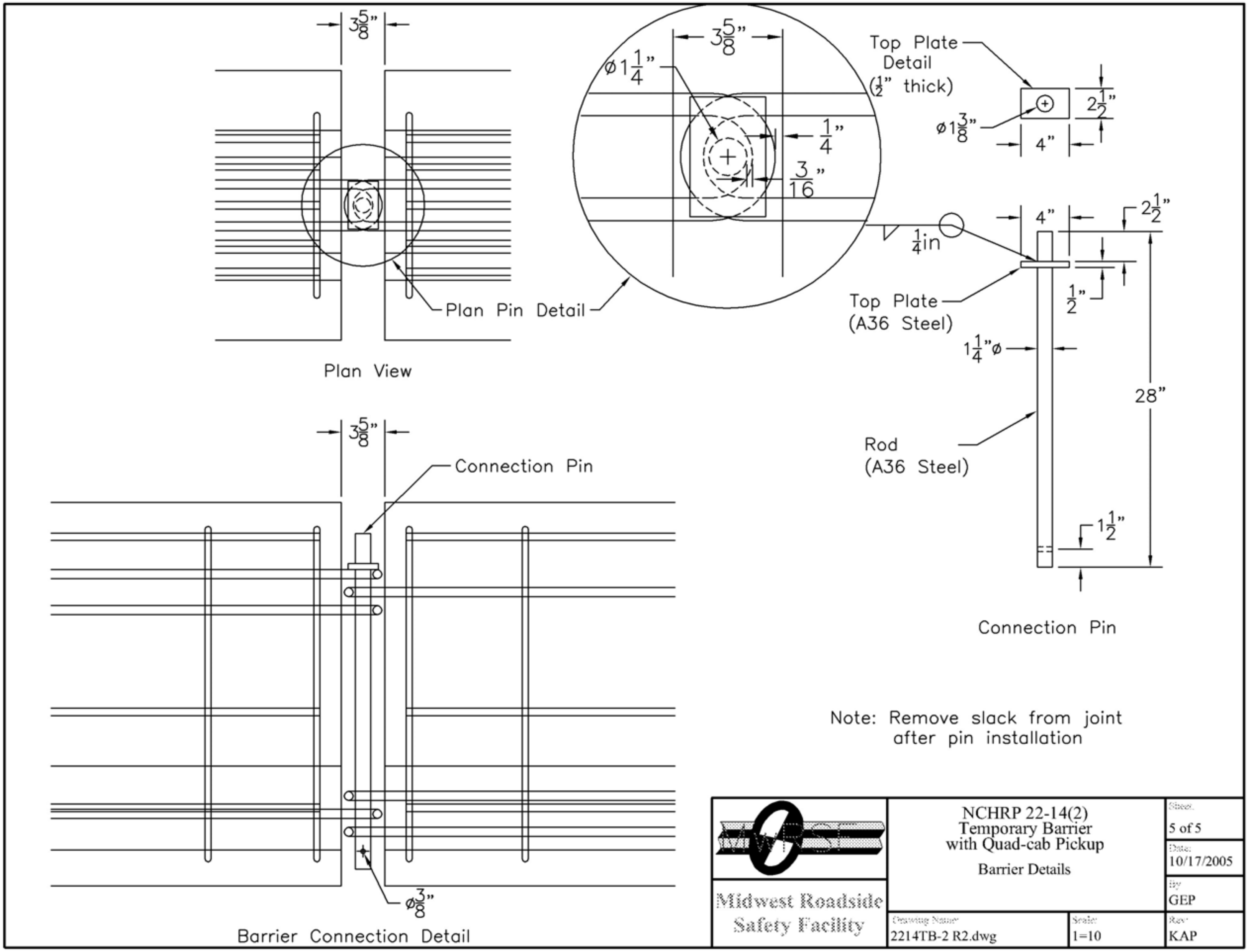


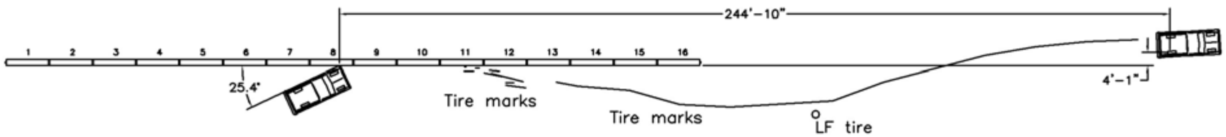
Figure A-5. Temporary Barrier Connection Details (English)

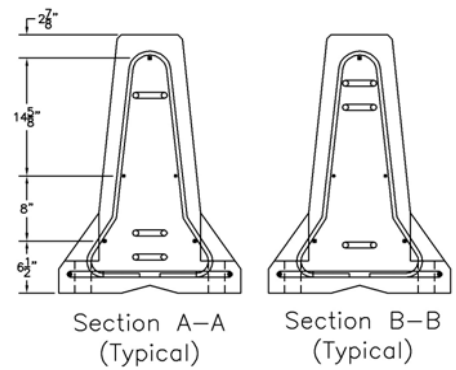
APPENDIX B

Test Summary Sheet in English Units

Figure B-1. Summary of Test Results and Sequential Photographs (English), Test 2214TB-2

0.000 sec 0.122 sec 0.216 sec 0.400 sec 0.498 sec





- Test Agency . . . . MwRSF
- Test Number 2214TB-2
- Date 10/12/04
- NCHRP 350 Update Test Designation . . 3-11
- Appurtenance . . . . Free-Standing Temporary Barrier
- Total Length . . . . 204 ft - 6 in.
- Key Elements - Barrier
  - Description . . . . F-Shape Barrier
  - Length . . . . 12 ft - 6 in.
  - Base Width . . . . 22.5 in.
  - Height . . . . 32 in.
- Type of Soil . . . . NA
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model . . . . 2002 Dodge Ram 1500 Quad Cab Pickup
  - Curb . . . . 5,035 lbs
  - Test Inertial . . . . 5,000 lbs
  - Gross Static . . . . 5,000 lbs
- Impact Conditions
  - Speed . . . . 61.9 mph
  - Angle . . . . 25.4 degrees
  - Impact Location . . . . 3 ft - ll.3125 in. upstream barriers 8 & 9 joint
- Exit Conditions
  - Speed . . . . 44.9 mph
  - Angle . . . . 7.9 degrees
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 244 ft - 10 in. downstream
    4 ft - 0.5 in. laterally behind
- Occupant Impact Velocity (350 Update)
  - Longitudinal . . . . 17.00 ft/s < 39.4 ft/s
  - Lateral . . . . 17.28 ft/s < 39.4 ft/s
- Occupant Ridedown Deceleration (350 Update)
  - Longitudinal . . . . 7.17 Gs < 20 Gs
  - Lateral . . . . 11.37 Gs < 20 Gs
- THIV (not required) . . . . 22.60 ft/s
- PHD (not required) . . . . 11.52 Gs
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . 73 in.
  - Dynamic . . . . 79.65 in.
  - Working Width . . . . 102.2 in.
- Vehicle Damage . . . . Moderate
  - VDS[5] 11-LFQ-3
  - CDC[6] 11-LYES4
  - Maximum Deformation . . . . 4.25 in. at front floorpan

Figure B-1. Summary of Test Results and Sequential Photographs (English), Test 2214TB-2

APPENDIX C

Occupant Compartment Deformation Data, Test 2214TB-2

VEHICLE PRE/POST CRUSH INFO
Set-1

TEST: 2214TB-2
VEHICLE: 2002/DodgeRam1500/QuadCab

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	46.75	-27.75	6.25	43.25	-26.75	2.5	-3.5	1	-3.75
2	47.25	-23.5	7	43	-22.25	3	-4.25	1.25	-4
3	47.25	-18.25	6.75	44.5	-17.25	4.5	-2.75	1	-2.25
4	44	-9.5	6.75	43.75	-9.25	6.5	-0.25	0.25	-0.25
5	44	-28	8.5	41	-27	5.5	-3	1	-3
6	43.5	-23.25	8.5	40	-22.25	6	-3.5	1	-2.5
7	42.75	-17.5	8.75	41.25	-16.5	7.75	-1.5	1	-1
8	41.5	-12.75	9.75	41.25	-12.25	9.5	-0.25	0.5	-0.25
9	40.5	-9	6.25	40.5	-8.5	6.25	0	0.5	0
10	39.5	-28.25	10	38.75	-27.25	9.25	-0.75	1	-0.75
11	39.5	-23.25	10.25	38	-22.5	9.5	-1.5	0.75	-0.75
12	39.25	-18	10.25	39	-17.75	10.75	-0.25	0.25	0.5
13	39.25	-12	10.25	39	-12	10.5	-0.25	0	0.25
14	36.5	-8.75	5.5	36.5	-8.5	5.5	0	0.25	0
15	34.25	-28.5	10	34.5	-28.25	10.25	0.25	0.25	0.25
16	33.75	-23.5	10	34	-23.25	10.5	0.25	0.25	0.5
17	33.75	-17.5	10	33.75	-17.25	10.25	0	0.25	0.25
18	33.75	-11.5	10.25	33.75	-11.25	10.25	0	0.25	0
19	30.75	-6.5	3.25	30.75	-6.5	3	0	0	-0.25
20	26.5	-29	9.5	26.25	-28.75	9.75	-0.25	0.25	0.25
21	26.5	-23.75	9.5	26.75	-23.5	9.75	0.25	0.25	0.25
22	26.75	-17.25	9.75	26.5	-17	10	-0.25	0.25	0.25
23	26.25	-11	9.75	26.25	-10.5	9.5	0	0.5	-0.25
24	24.75	-8	4.25	24.75	-7.75	4.25	0	0.25	0
25	19.5	-27	5	19.5	-26.75	5	0	0.25	0
26	19.5	-14.75	5.5	19.25	-14.25	5.5	-0.25	0.5	0
27	12.75	-27.75	7.5	12.5	-27	7.5	-0.25	0.75	0
28	12	-13.75	8.25	12	-13	8.5	0	0.75	0.25
29									
30									

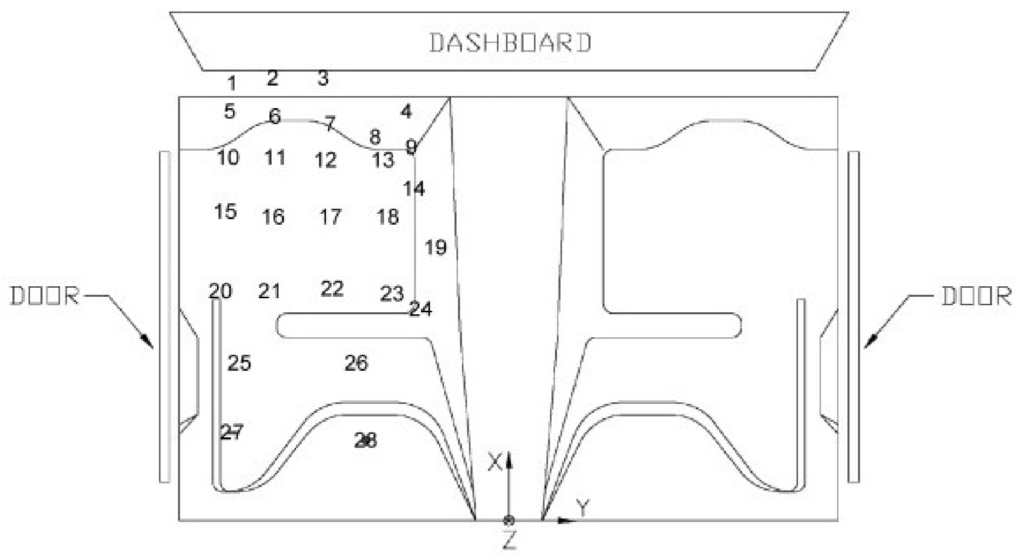


Figure C-1. Occupant Compartment Deformation Data - Set 1, Test 2214TB-2

VEHICLE PRE/POST CRUSH INFO
Set-2

TEST: 2214TB-2
VEHICLE: 2002/DodgeRam1500/QuadCab

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	49.75	-25.75	3.25	46.25	-24.75	0	-3.5	1	-3.25
2	50.25	-21.5	4.5	46	-20.25	0.5	-4.25	1.25	-4
3	50.25	-16.25	4.75	47.5	-15.25	2.5	-2.75	1	-2.25
4	47	-7.5	5	46.75	-7.25	5	-0.25	0.25	0
5	47	-26	5.75	44	-25	3	-3	1	-2.75
6	46.5	-21.25	6.25	43	-20.25	3.75	-3.5	1	-2.5
7	45.75	-15.5	6.75	44.25	-14.5	5.75	-1.5	1	-1
8	44.5	-10.75	7.75	44.25	-10.25	8	-0.25	0.5	0.25
9	43.5	-7	4.5	43.5	-6.5	4.5	0	0.5	0
10	42.5	-26.25	7.5	41.75	-25.25	7	-0.75	1	-0.5
11	42.5	-21.25	8	41	-20.5	7.25	-1.5	0.75	-0.75
12	42.25	-16	8.25	42	-15.75	8.75	-0.25	0.25	0.5
13	42.25	-10	8.5	42	-10	8.75	-0.25	0	0.25
14	39.5	-6.75	4	39.5	-6.5	4	0	0.25	0
15	37.25	-26.5	7.75	37.5	-26.25	8	0.25	0.25	0.25
16	36.75	-21.5	8	37	-21.25	8.5	0.25	0.25	0.5
17	36.75	-15.5	8.25	36.75	-15.25	8.5	0	0.25	0.25
18	36.75	-9.5	8.75	36.75	-9.25	8.75	0	0.25	0
19	33.75	-4.5	2	33.75	-4.5	2	0	0	0
20	29.5	-27	7.5	29.25	-26.75	8	-0.25	0.25	0.5
21	29.5	-21.75	7.75	29.75	-21.5	8	0.25	0.25	0.25
22	29.75	-15.25	8.25	29.5	-15	8.5	-0.25	0.25	0.25
23	29.25	-9	8.25	29.25	-8.5	8.5	0	0.5	0.25
24	27.75	-6	3	27.75	-5.75	3	0	0.25	0
25	22.5	-25	3.75	22.5	-24.75	3.25	0	0.25	-0.5
26	22.5	-12.75	4.25	22.25	-12.25	4.25	-0.25	0.5	0
27	15.75	-25.75	6	15.5	-25	6	-0.25	0.75	0
28	15	-11.75	7.25	15	-11	7.5	0	0.75	0.25
29									
30									

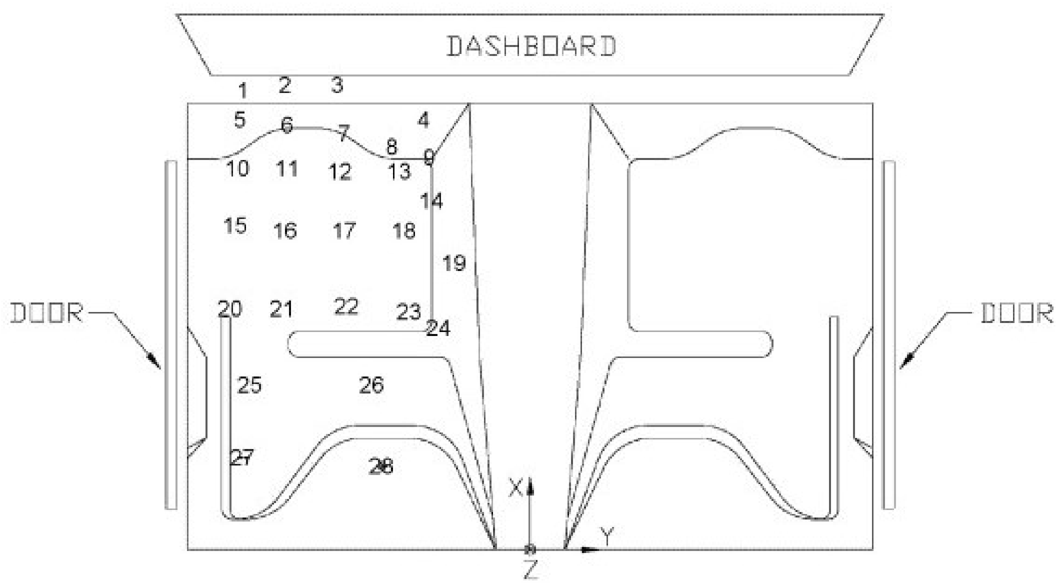


Figure C-2. Occupant Compartment Deformation Data - Set 2, Test 2214TB-2

Occupant Compartment Deformation Index (OCDI)

Test No. 2214TB-2
Vehicle Type: 2270P

OCDI = XXABCDEFGHI

XX = location of occupant compartment deformation

A = distance between the dashboard and a reference point at the rear of the occupant compartment, such as the top of the rear seat or the rear of the cab on a pickup

B = distance between the roof and the floor panel

C = distance between a reference point at the rear of the occupant compartment and the motor panel

D = distance between the lower dashboard and the floor panel

E = interior width

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

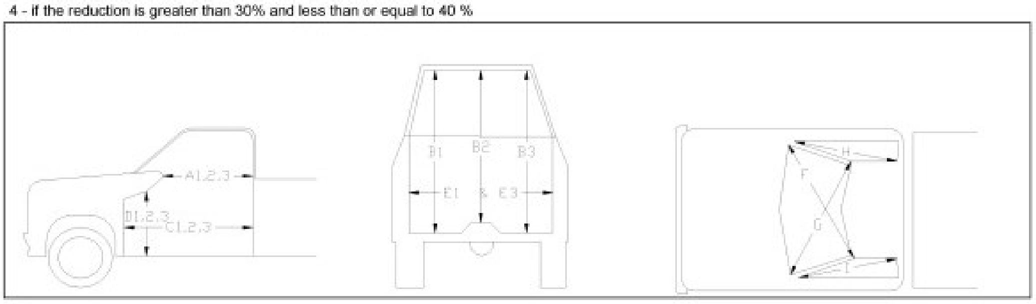
G = distance between the lower edge of left window and the upper edge of right window

H= distance between bottom front corner and top rear corner of the passenger side window

I= distance between bottom front corner and top rear corner of the driver side window

Severity Indices

0 - if the reduction is less than 3%
1 - if the reduction is greater than 3% and less than or equal to 10 %
2 - if the reduction is greater than 10% and less than or equal to 20 %
3 - if the reduction is greater than 20% and less than or equal to 30 %
4 - if the reduction is greater than 30% and less than or equal to 40 %



where,
1 = Passenger Side
2 = Middle
3 = Driver Side

Location:

Measurement	Pre-Test (in.)	Post-Test (in.)	Change (in.)	% Difference	Severity Index
A1	69.00	69.00	0.00	0.00	0
A2	69.63	69.75	0.13	0.18	0
A3	71.13	71.00	-0.13	-0.18	0
B1	46.75	47.00	0.25	0.53	0
B2	41.50	41.50	0.00	0.00	0
B3	47.13	47.00	-0.13	-0.27	0
C1	63.38	60.50	-2.88	-4.54	1
C2	47.50	47.50	0.00	0.00	0
C3	62.13	62.00	-0.13	-0.20	0
D1	15.25	16.50	1.25	8.20	0
D2	7.50	7.75	0.25	3.33	0
D3	15.63	15.63	0.00	0.00	0
E1	66.00	66.00	0.00	0.00	0
E3	64.88	64.38	-0.50	-0.77	0
F	59.00	59.13	0.13	0.21	0
G	59.13	59.00	-0.13	-0.21	0
H	39.13	39.00	-0.13	-0.32	0
I	38.00	38.00	0.00	0.00	0

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

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

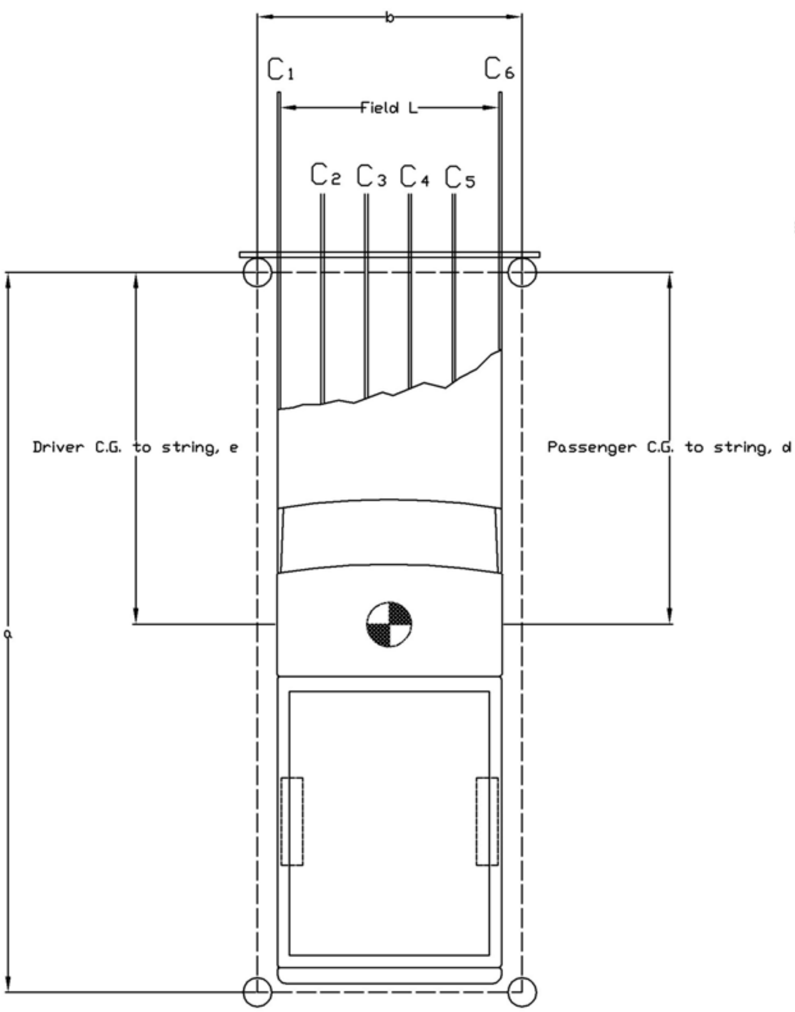
Figure C-3. Occupant Compartment Deformation Index (OCDI), Test 2214TB-2

Date: 10/14/04 Test Number: 2214TB-2 Model: Ram 1500 Quad Cab 4x2

Make: Dodge Vehicle I.D.#: 3B7HA18NX2G106086

Tire Size: lt265/70 R16 Year: 2002 Odometer: 45152

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



a 6096 (240)

b 2343 (92.25)

Field L 1765 (69.5)

Bumper Height 483 (19)

d 2896 (114)

e 2870 (113)

C_1 883 (34.75)

C_2 432 (17)

C_3 356 (14)

C_4 343 (13.5)

C_5 381 (15)

C_6 756 (29.75)

Figure C-4. NASS Crush Data, Test 2214TB-2

APPENDIX D

Accelerometer and Rate Transducer Data Analysis, Test 2214TB-2

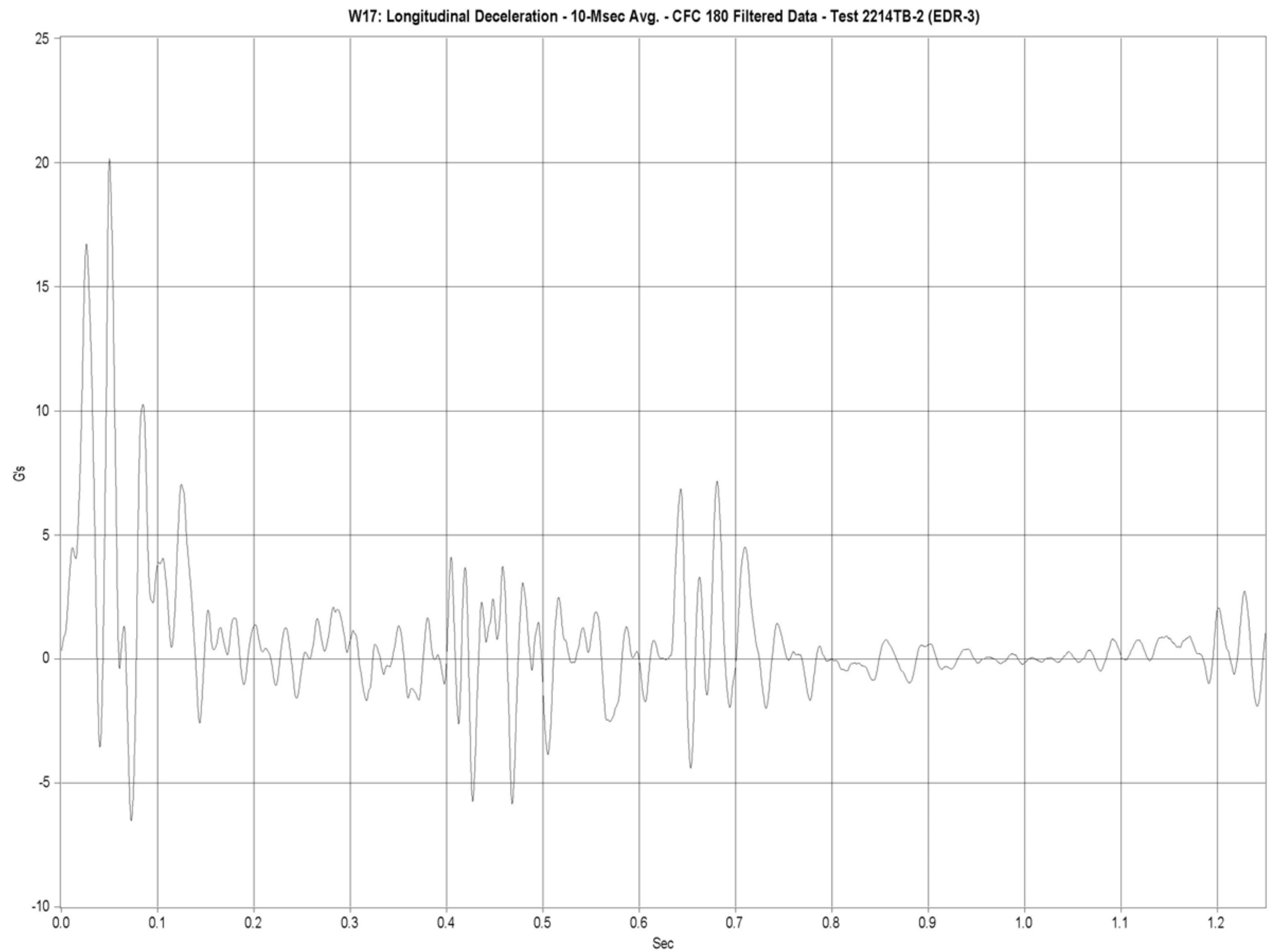


Figure D-1. Graph of Longitudinal Deceleration, Test 2214TB-2

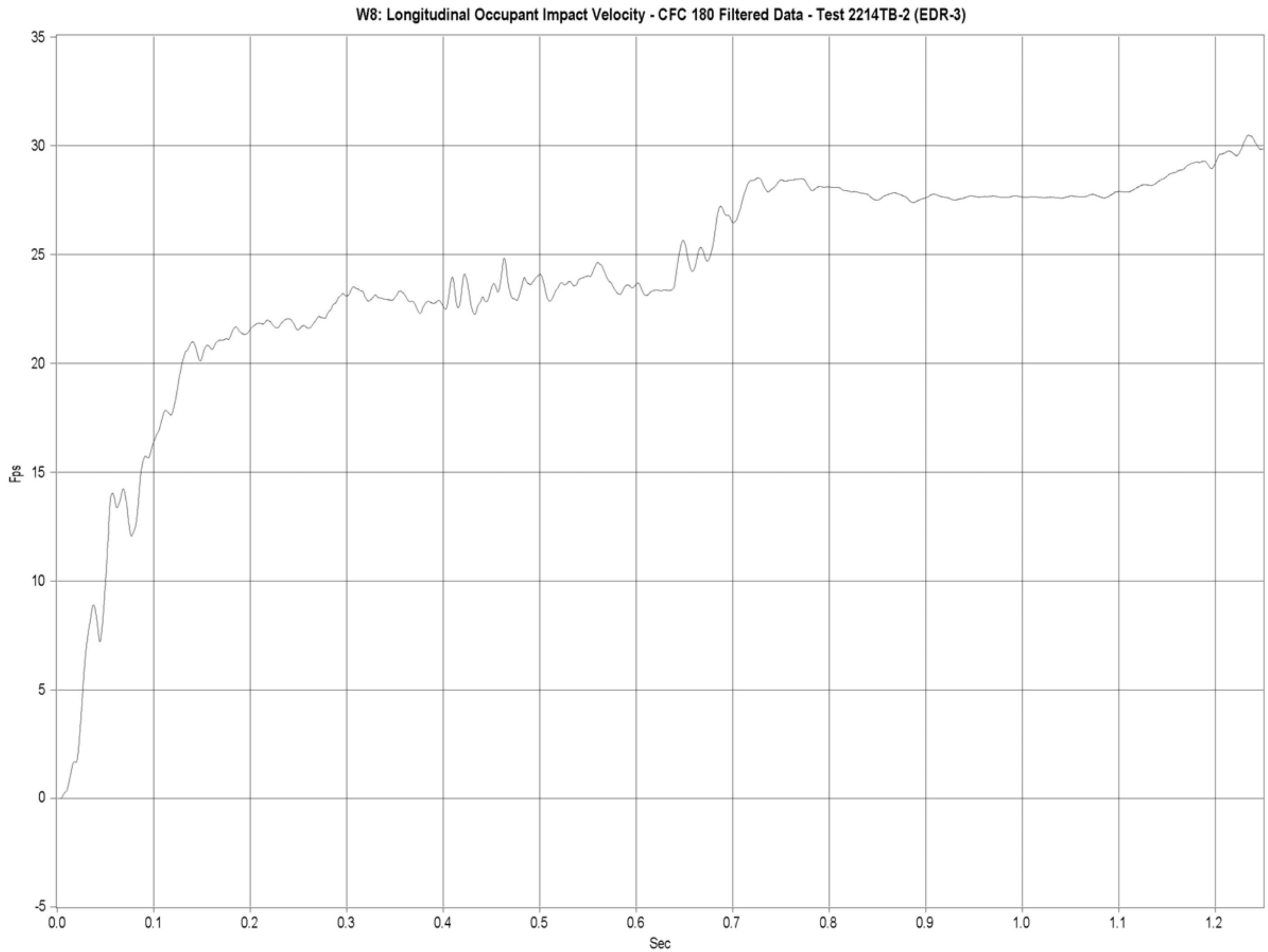


Figure D-2. Graph of Longitudinal Occupant Impact Velocity, Test 2214TB-2

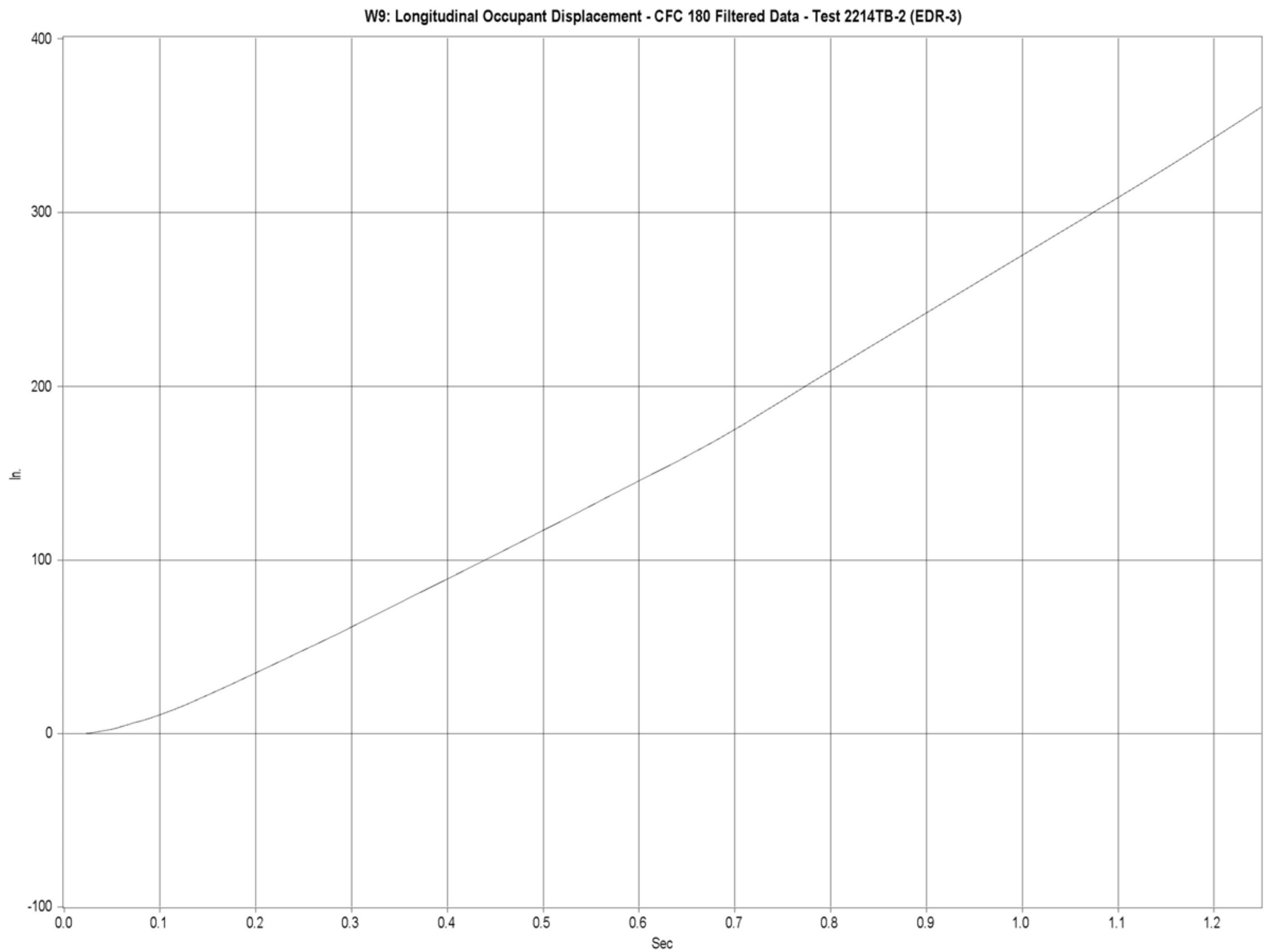


Figure D-3. Graph of Longitudinal Occupant Displacement, Test 2214TB-2

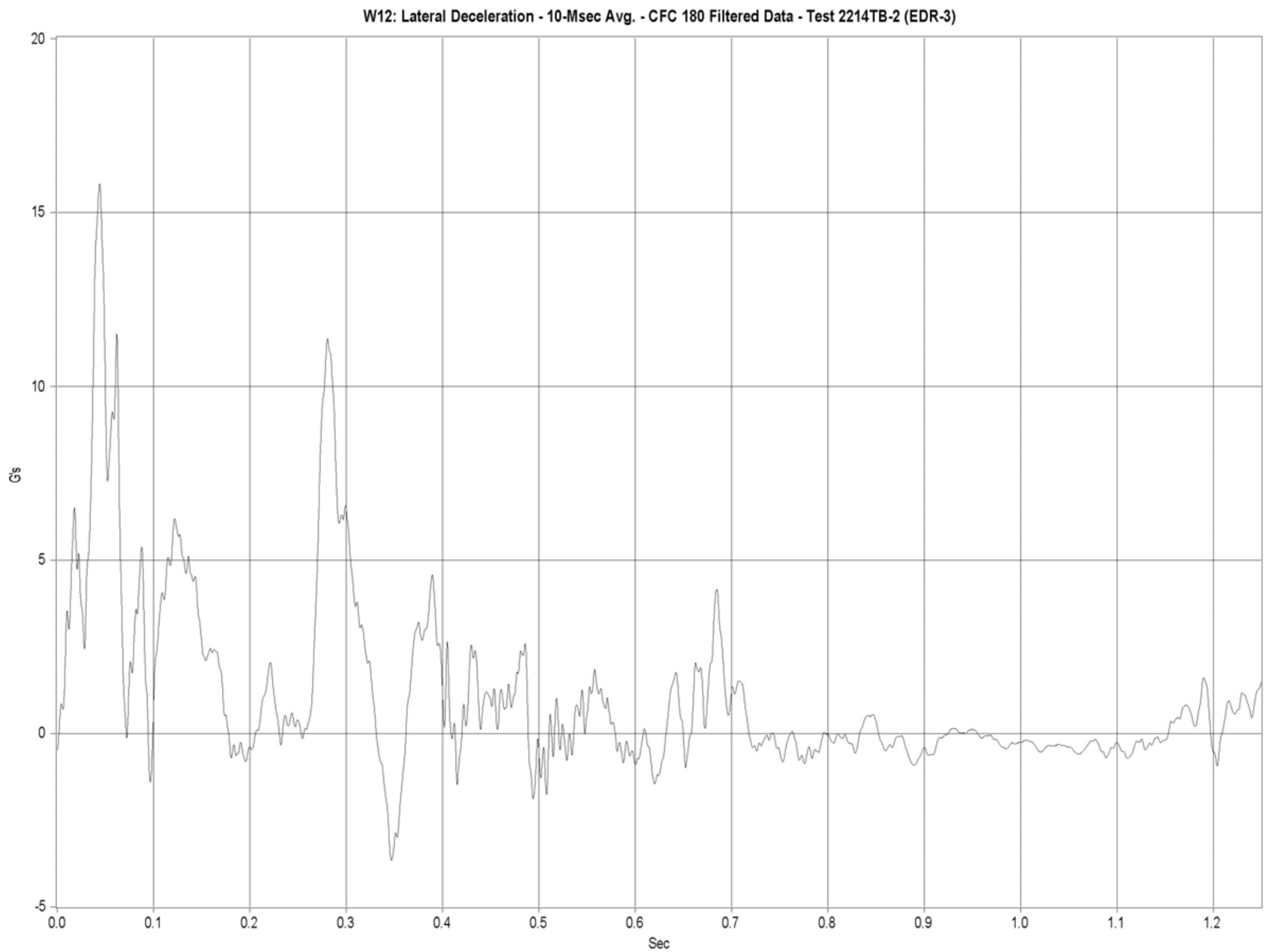


Figure D-4. Graph of Lateral Deceleration, Test 2214TB-2

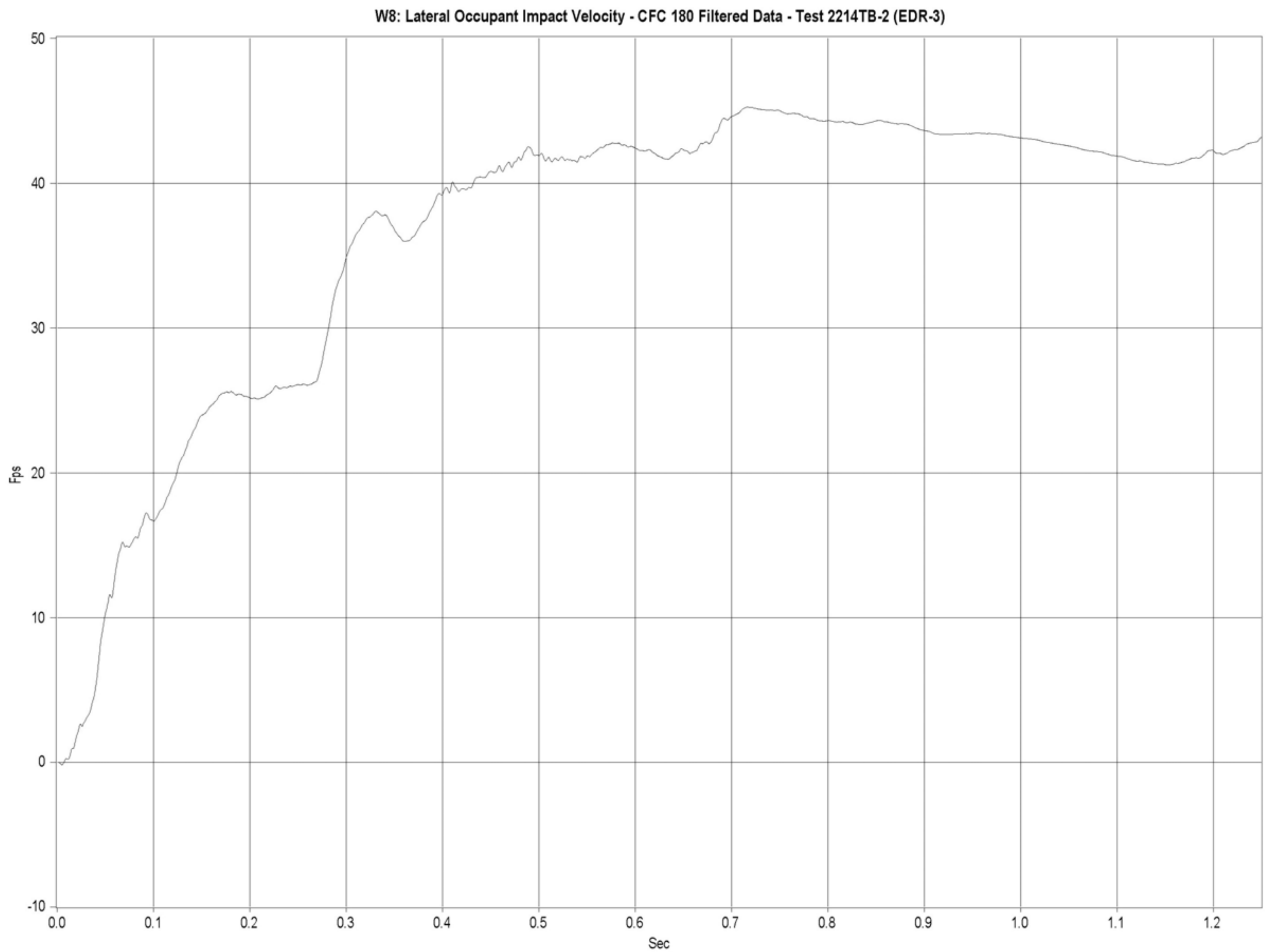


Figure D-5. Graph of Lateral Occupant Impact Velocity, Test 2214TB-2

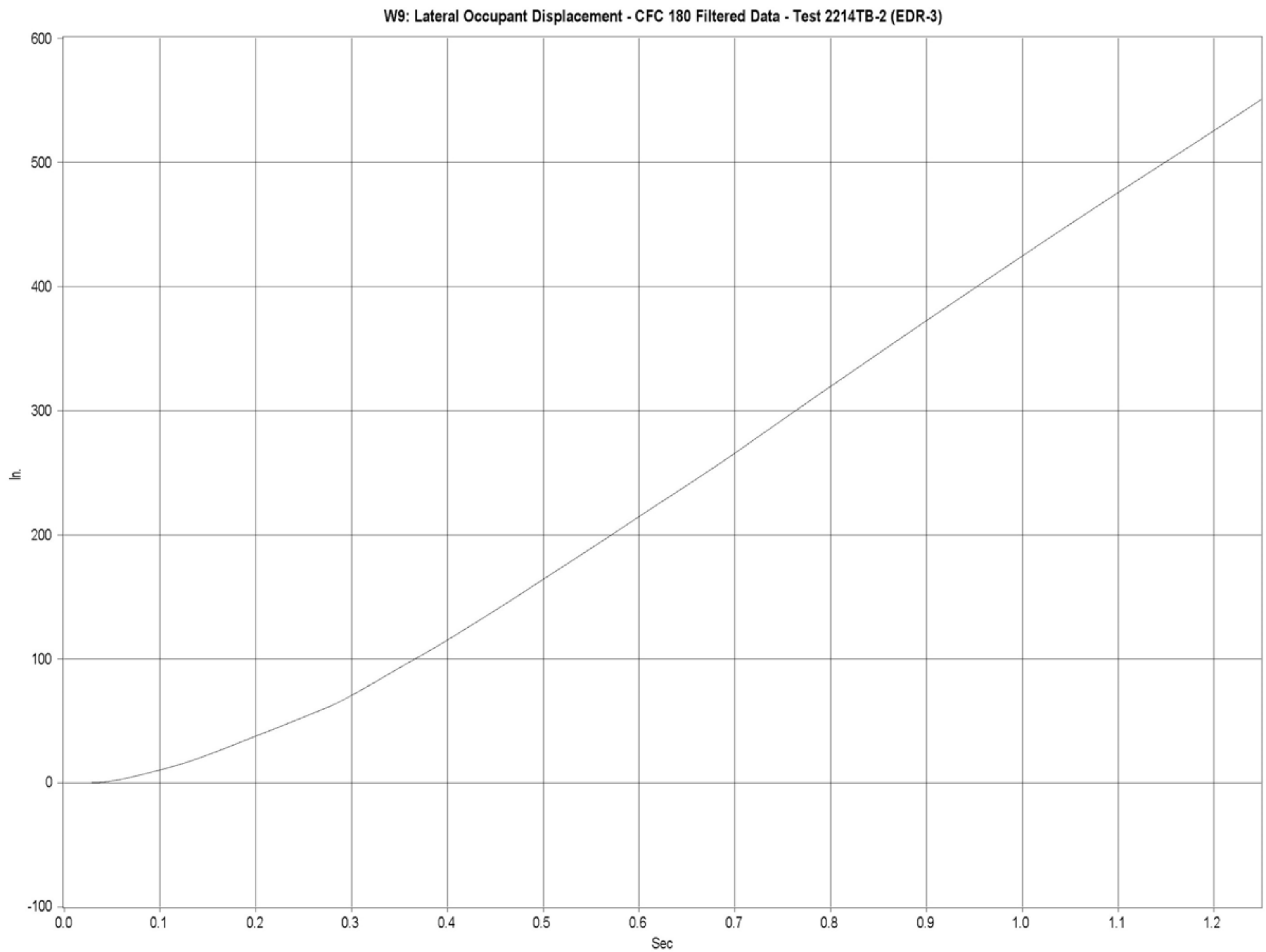


Figure D-6. Graph of Lateral Occupant Displacement, Test 2214TB-2

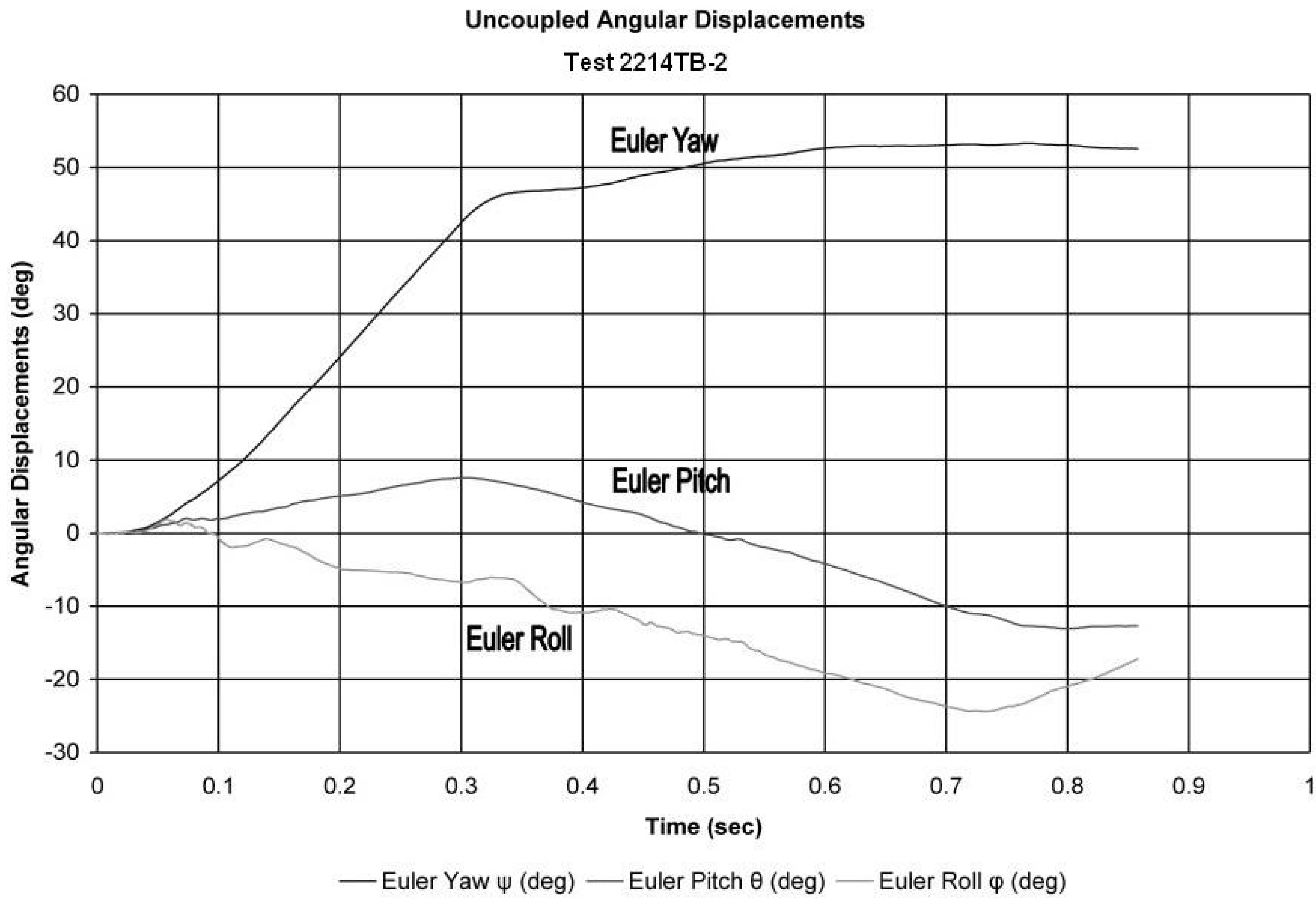


Figure D-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test 2214TB-2