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Evaluation of Rigid Hazards Placed in the Zone of Intrusion

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EVALUATION OF RIGID HAZARDS PLACED IN THE ZONE OF INTRUSION

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16. Abstract (Limit: 200 words)

The objectives of this research were to evaluate the current practices for the placement of luminaire poles both on top of and behind single-slope concrete barriers and to determine their effects on safety for both the driver and occupants of the impacting vehicle and nearby pedestrians.

Three full-scale crash tests were performed on the barrier system and luminaire poles, with the first two full-scale crash tests evaluating the performance of a luminaire pole placed on top of a single-slope concrete barrier and the third test evaluating the performance of a luminaire pole placed behind the single-slope concrete barrier. The first full-scale crash test, test no. ZOI-1, was performed according to the test designation 4-12 of NCHRP Report No. 350. The test consisted of a 7,985-kg (17,605-lbs) single-unit truck impacting the barrier at a speed of 81.0 km/h (50.4 mph) and at an angle of 15.6 degrees. This test passed all of the NCHRP Report No. 350 safety requirements as the single-unit truck was safely brought to a controlled stop. The second full-scale crash test, test no. ZOI-2, was performed according to test designation 4-11 of NCHRP Report No. 350. The test consisted of a 2,009 (4,430-lbs) pickup truck impacting the barrier at a speed of 99.3 km/h (61.7 mph) and at an angle of 23.4 degrees. This test passed all of the NCHRP Report No. 350 safety requirements as the pickup truck was safely brought to a controlled stop. The third full-scale crash test, test no. ZOI-3, was performed according to test designation 4-12 of NCHRP Report No. 350. The test consisted of a 8,000-kg (17,637-lbs) single-unit truck impacting the barrier at a speed of 80.8 km/h (50.2 mph) and at an angle of 16.4 degrees. This test passed all of the NCHRP Report no. 350 safety requirements as the single-unit truck was safely brought to a controlled stop.

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views nor policies of the State Highway Departments participating in the Midwest States' Regional Pooled Fund Research Program, Valmont Industries, Inc., nor the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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1 INTRODUCTION

1.1 Problem Statement

The work funded under a Year 9 Pooled Fund project developed intrusion zones surrounding barriers tested at various test levels under National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (1). Potential problems with placing rigid attachments on top of or behind commonly used barrier sections were defined through out this study (2). Although moderate concerns were identified under Test Level 3 (TL-3) conditions, the greatest intrusion zones resulted with the Test Level 4 (TL-4) test conditions of the 8000S vehicle.

For this recent pooled fund project, an evaluation of attachments to barriers indicated that single-unit trucks impacting permanent concrete barriers would likely contact many of the attachments placed on rigid barriers. This study demonstrated that current practices with regard to placement of rigid objects on median barriers and bridge rails may have adverse effects on the safety for both the driver and occupants of the impacting vehicle and nearby pedestrians.

In some cases, the vehicle cab would likely impact the barrier attachments, while in other cases, only the cargo box would have the potential to impact the attachments. Both cases have safety concerns and are undesirable, but one case may be far more severe than the other. The differences have not been quantified. Because these relatively rigid hazards are now commonly attached to median barriers and bridge rails in locations where single-unit truck impacts are expected, the magnitude of the safety risk needs to be quantified. Furthermore, the previous study indicated that luminaire poles attached on or near barriers were the most common rigid hazard now in use.

1.2 Objective

The objective of the research project was to quantify the safety hazards posed by placing rigid objects in the zone of intrusion by attaching them to a typical rigid, longitudinal barrier. More specifically, the objective was to evaluate the safety performance of a luminaire pole attached to both the top of and directly behind a single-slope concrete barrier when full-scale vehicle crash tested according to the TL-4 criteria presented in NCHRP Report No. 350.

1.3 Scope

The research objective was achieved by performing several tasks. First, a detailed review of state standards was conducted to identify candidate designs that incorporate the rigid top mounting of the luminaire's support on top of the barrier as well as a rearward placement of the luminaire support behind the barrier. Second, three full-scale vehicle crash tests were performed on the candidate systems. The first test, with the luminaire pole attached to the top of the barrier, utilized a single-unit truck weighing approximately 8,000 kg (17,637 lbs). The target impact conditions for the test were an impact speed of 80 km/h (49.7 mph) and an impact angle of 15 degrees. The second test, with the luminaire pole attached to the top of the barrier, utilized a pickup truck, weighing approximately 2,000 kg (4,409 lbs). The target impact conditions for the test were an impact speed of 100 km/h (62.1 mph) and an impact angle of 25 degrees. The third test, with the luminaire pole placed behind the barrier, utilized a single-unit truck weighing approximately 8,000 kg (17,637 lbs). The target impact conditions for the test were an impact speed of 80 km/h (49.7 mph) and an impact angle of 15 degrees. Next, the test results were analyzed, evaluated, and documented. Finally, conclusions and recommendations were made that pertain to the safety performance of the luminaire pole attached to or behind a rigid barrier.

2 DESIGN CONSIDERATIONS

A review of the Pool Fund State Standards produced designs of the steel luminaire pole, barriers which were used with luminaire poles, and locations for the luminaire poles. The most common and practical system was chosen. The luminaire pole details and standards came from Valmont Industries, Inc., with mounting details coming from the Missouri Department of Transportation (MoDOT) (3). Texas Department of Transportation (TxDOT) had the most practical pole location for on top of and behind the barrier (4). These standards formed the basis for the tests and are found in Appendix A.

3 LUMINAIRE POLE ATTACHED TO THE TOP OF CONCRETE BARRIER

The test installation consisted of a luminaire pole attached to the top of a 36.58-m (120-ft) long, standard single-slope concrete barrier. Design details are shown in Figures 1 through 6. The corresponding English-unit drawings are shown in Appendix C. Photographs of the barrier and luminaire pole installation are shown in Figures 7 through 10.

A 11.43-m (37-ft 6-in.) long, galvanized steel luminaire pole was 254 mm (10 in.) and 121 (4.75 in.) in diameter at the base and the top, respectively. Two 4,572-mm (15-ft) long, galvanized steel butterfly arms were attached to the top of the steel pole. The top arm was placed 203 mm (8 in.) down from the top of the pole. Two 19-mm (0.75-in.) thick by 337-mm (13.25-in.) diameter plates were attached 32 mm (1.25 in.) from the end of the arm with 19 mm (0.75 in.) diameter by 57-mm (2.25-in.) long, Grade 8 bolts. Details for the Valmont Industries, Inc. luminaire pole materials are found in Appendix B.

Four J-bolts, with an ASTM A449 steel specification, were spaced 243 mm (9.5625 in.) on center and extended 152 mm (6 in.) above the top of the barrier and were used to attach the luminaire pole to the top of the concrete pedestal. Eight 32-mm (11.25-in.) diameter heavy hex nuts were used to connect the luminaire pole to the J-bolts embedded in the concrete.

The single-slope concrete barrier was 397 mm (15.625 in.) and 241 mm (9.5 in.) wide at the base and top, respectively, with an overall height of 813 mm (32 in.) from the ground to the top of the barrier. A pedestal extended on the backside of the barrier. The 905-mm (35.625-in.) long pedestal began 21.02 m (68 ft - 11.75 in.) downstream of the upstream end of the barrier. The pedestal extended 168 mm (6.625 in.) backward. The luminaire pole was placed on the pedestal so that there was 76 mm (3 in.) gap from the front face of the pole to the front edge of the barrier.

The concrete used for the barrier consisted of Nebraska 47-BD Mix Type 3, with a minimum 28-day concrete compressive strength of 31.03 MPa (4,500 psi). The 46-day concrete compressive strength for the barrier, as determined from concrete cylinder testing, was found to be approximately 46.93 MPa. (6,807 psi). A minimum concrete cover of 38 mm (1.5 in.) was used along the entire barrier. All the steel reinforcement in the barrier was ASTM Grade 60 rebar. The barrier reinforcement details are shown in Figures 3 through 5.

Barrier reinforcement consisted of No. 5 bars. Each of the eight longitudinal rebar measured 36.50 m (119 ft - 9 in.) long with minimum 610-mm (24-in.) long laps along each bar. The vertical spacings of the lower, lower middle, upper middle, and upper longitudinal bars were 178 mm (7 in.), 368 mm (14.5 in.), 559 mm (22 in.), and 749 mm (29.5 in.) from the ground to their centers, respectively. The vertical stirrups measured 1,676 mm (66 in.) and were bent into a U-shape. Their longitudinal spacings were 203 mm (8 in.) on center, as shown in Figure 3. The barrier-to-tarmac attachment utilized straight bars and angled bars, which were bent into the shape of the front face of the barrier, as shown in Figures 3 through 5. The straight bars utilized on the back face were 1,029 mm (40.5 in.) long, while the angled bars utilized on the front face were 1,346 mm (53 in.) long. The longitudinal spacings of the straight and angled bars were 406 mm (18 in.) and 203 mm (8 in.) on center, respectively, as shown in Figures 3 and 4. The barrier-to-tarmac attachment bars were epoxied into the concrete to an embedment depth of 254 mm (10 in.), as shown in Figure 4. The epoxy consisted of FastSet's Formula Power-Fast's high strength epoxy anchorage system.

For the concrete pedestal, the barrier reinforcement consisted of No. 5 bars. The four longitudinal bars, bent into the shape of the pedestal, were 2,134 mm (84 in.) long, as shown in Figure 5. The vertical spacings of these bars were 178 mm (7 in.), 368 mm (14.5 in.), 559 mm (22 in.), and 749 mm (29.5 in.) from the ground to their centers. Additional barrier-to-tarmac attachment was obtained with three 1,029 mm (40.5 in.) long straight bars spaced 203 mm (8 in.) on centers.

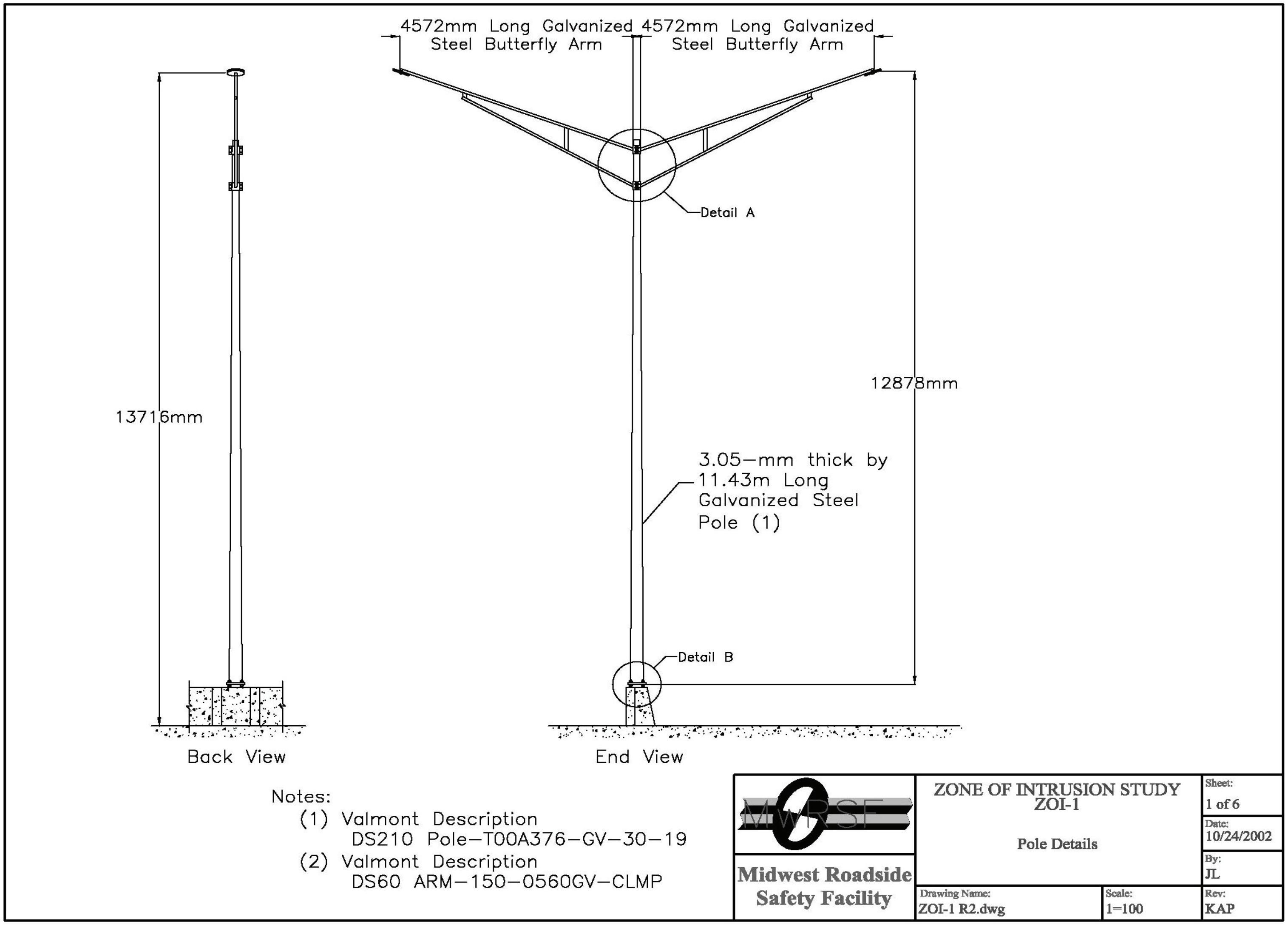


Figure 1. Pole Details, Test Nos. ZOI-1 and ZOI-2

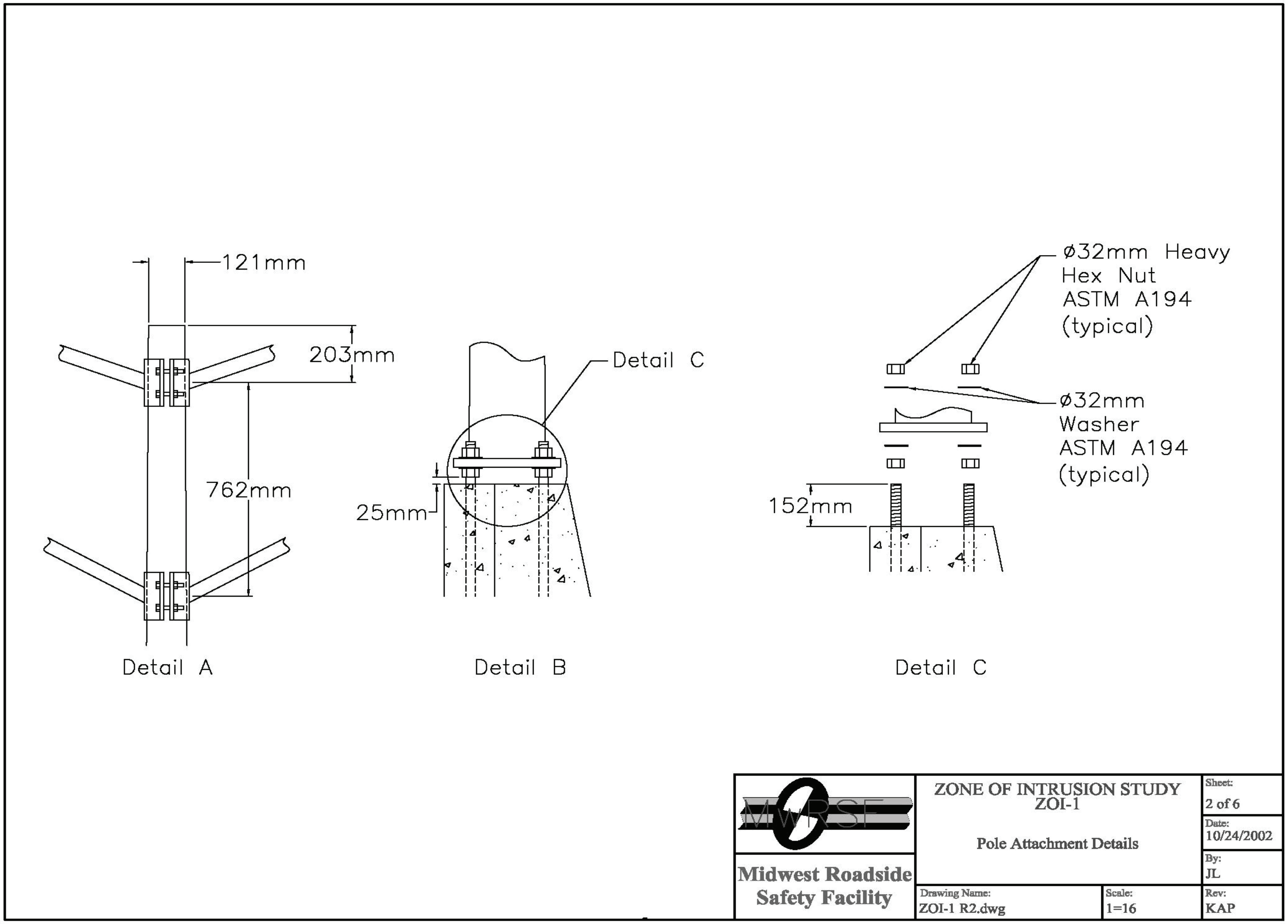


Figure 2. Pole Attachment Details, Test Nos. ZOI-1 and ZOI-2

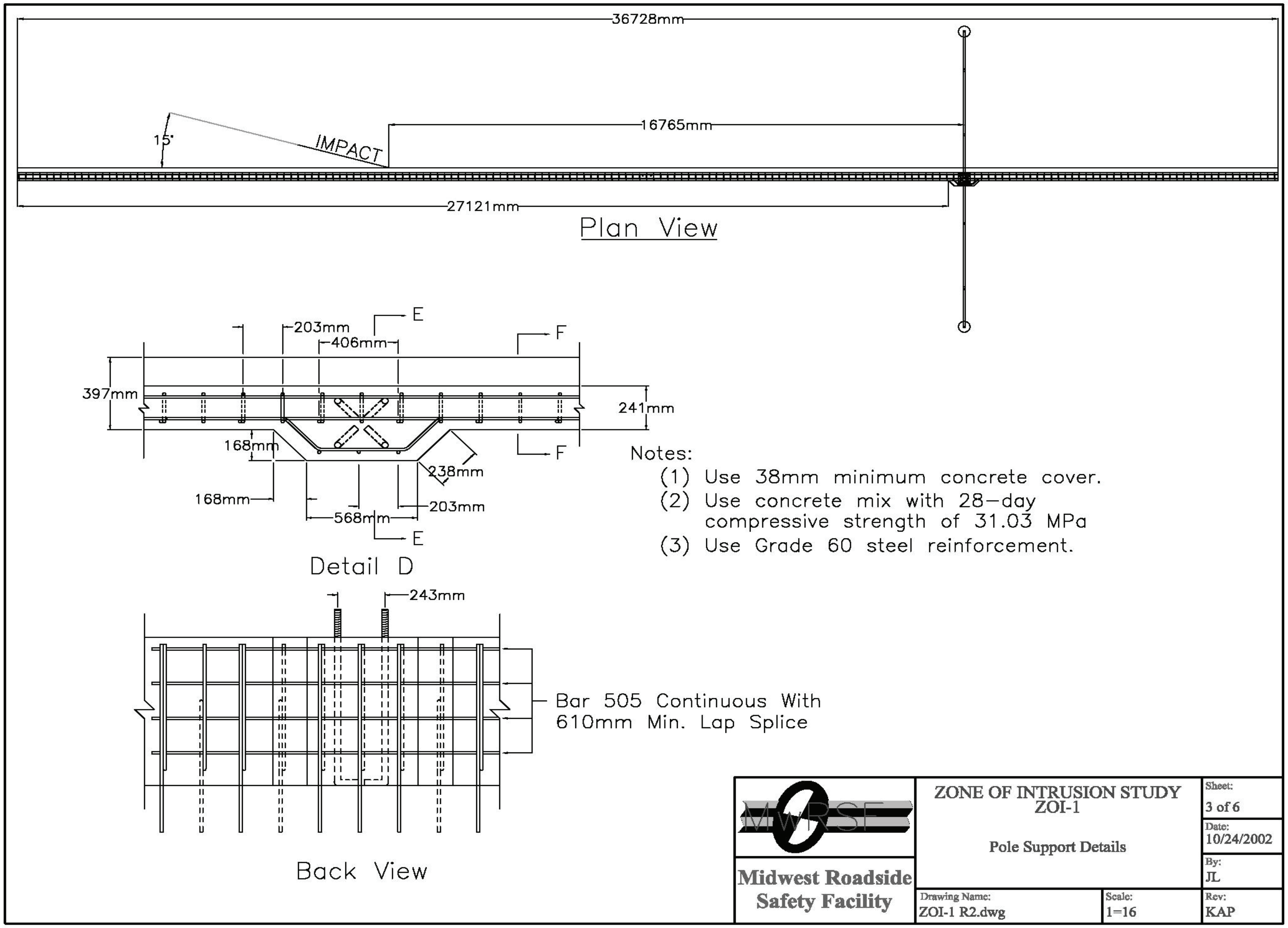


Figure 3. Pole Support Details, Test Nos. ZOI-1 and ZOI-2

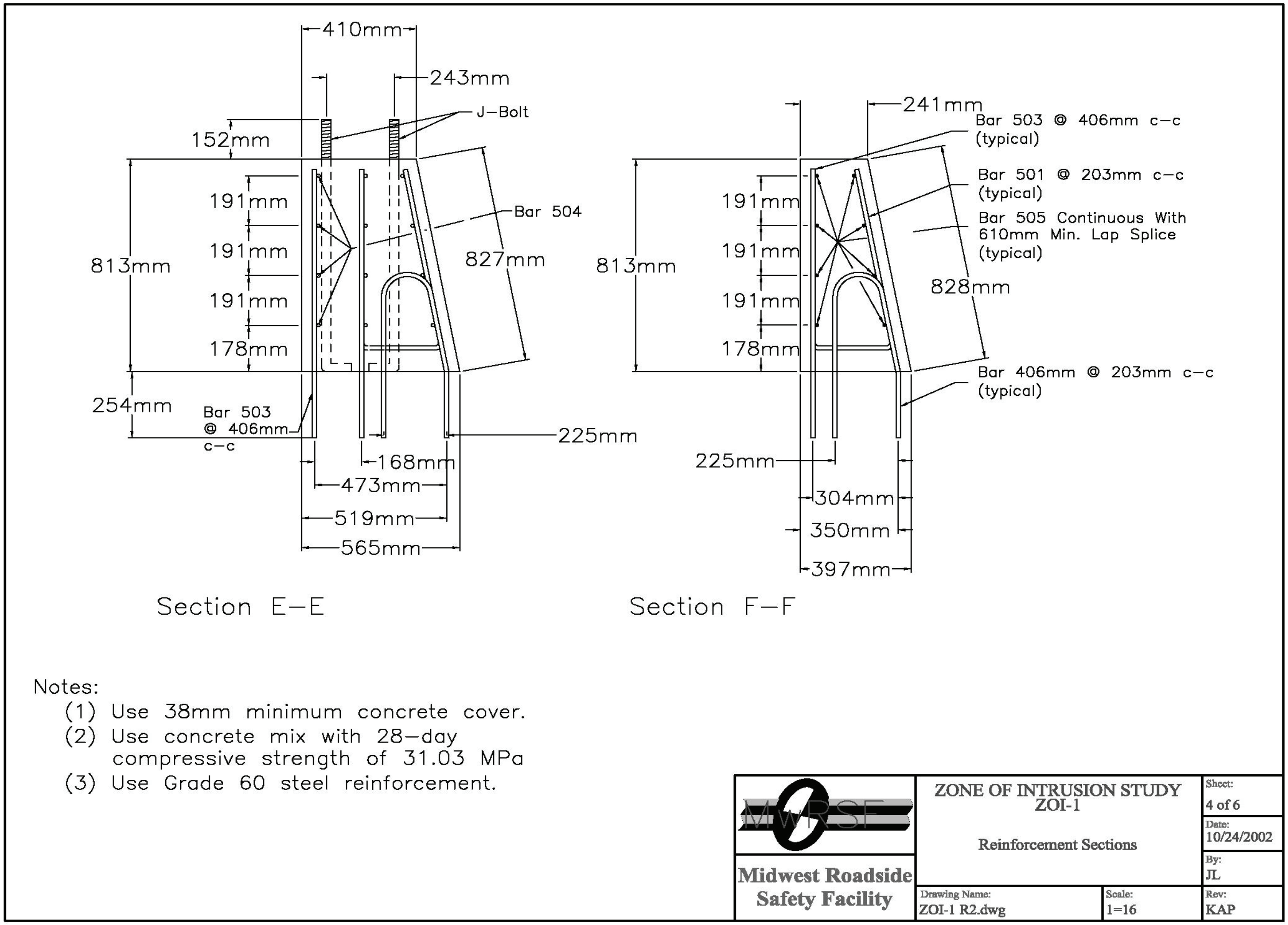
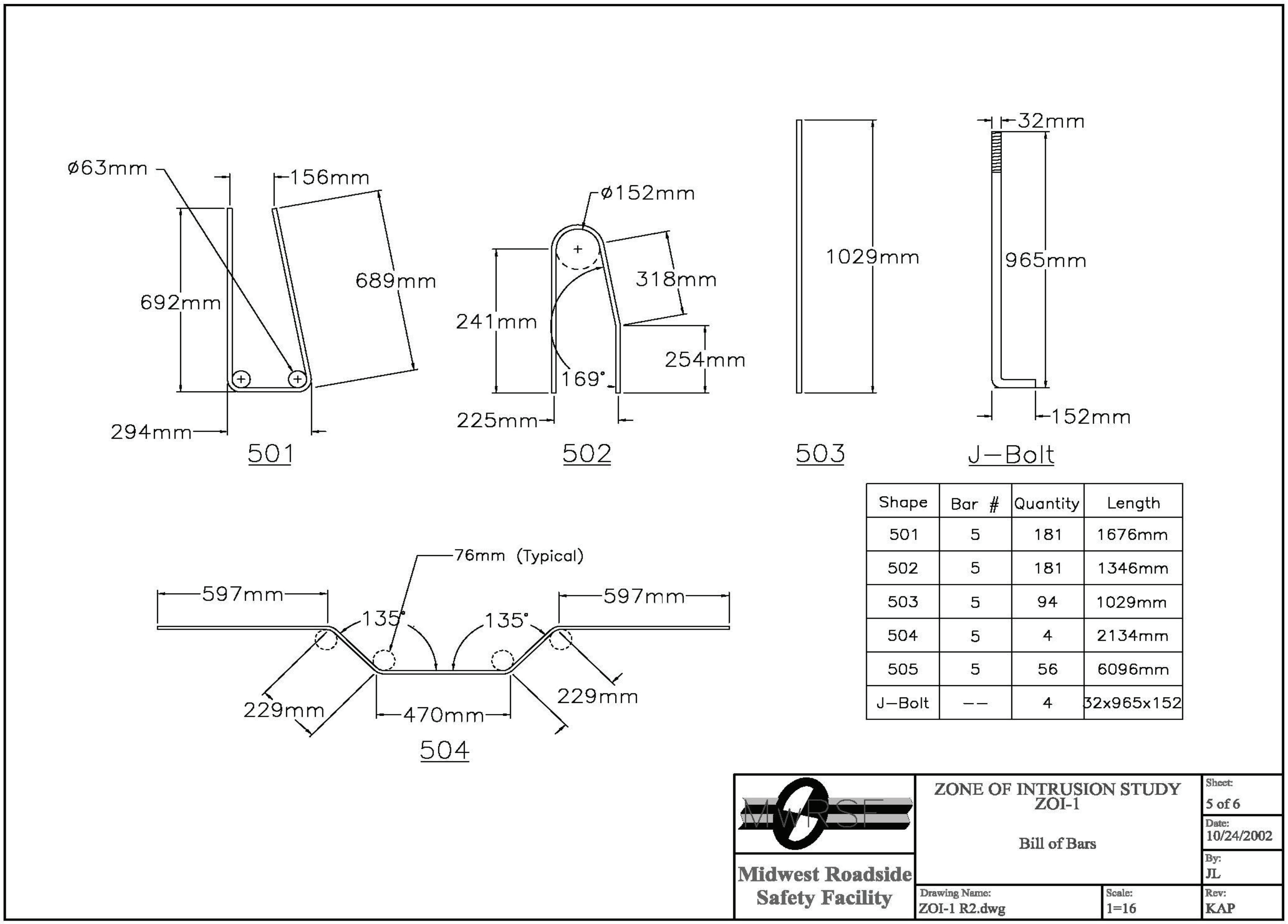


Figure 4. Reinforcement Sections, Test Nos. ZOI-1 and ZOI-2



Shape	Bar #	Quantity	Length
501	5	181	1676mm
502	5	181	1346mm
503	5	94	1029mm
504	5	4	2134mm
505	5	56	6096mm
J–Bolt	––	4	32x965x152

Figure 5. Bill of Bars, Test Nos. ZOI-1 and ZOI-2

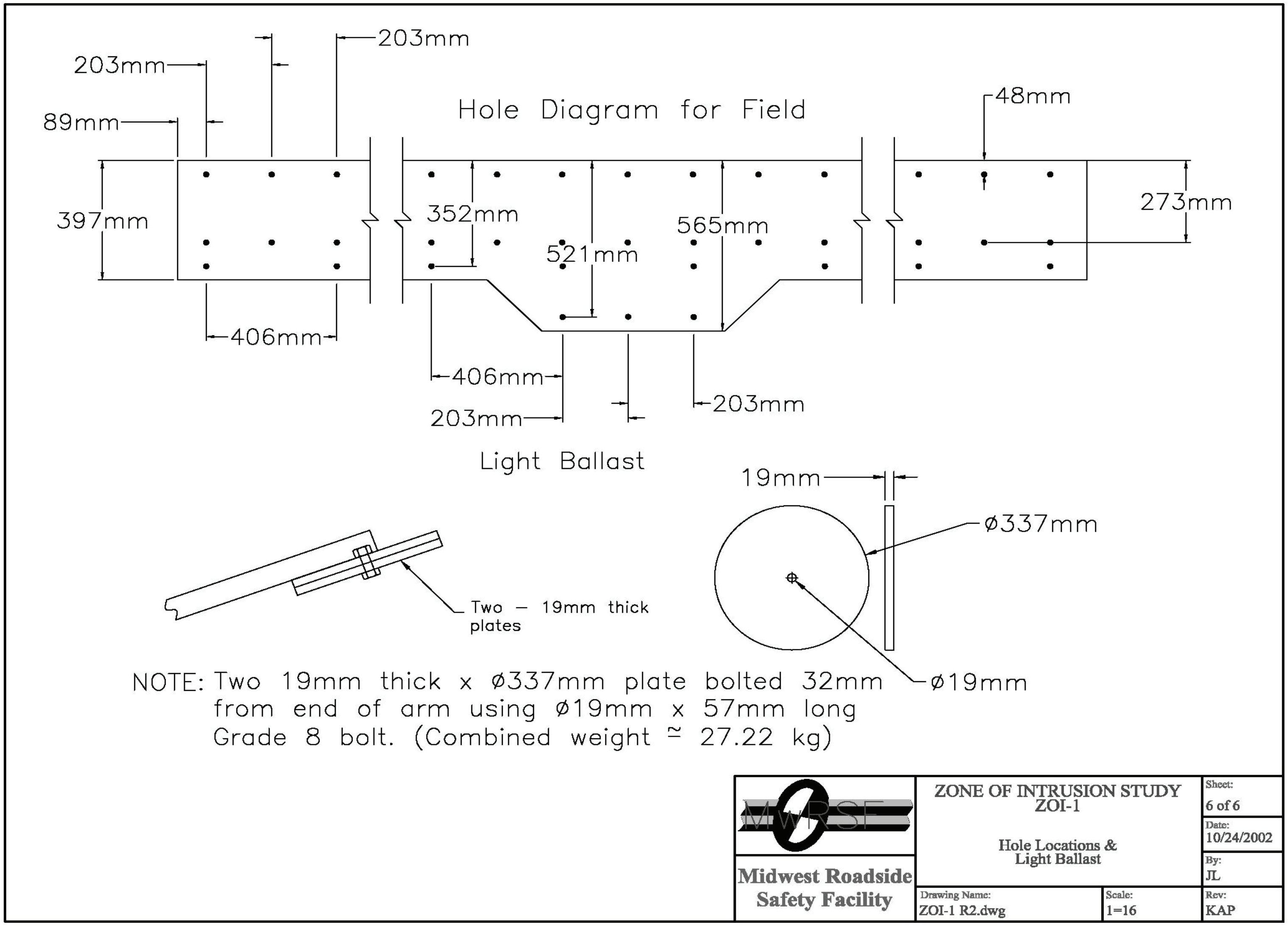


Figure 6. Hole Locations and Light Ballast, Test No. ZOI-1 and ZOI-2

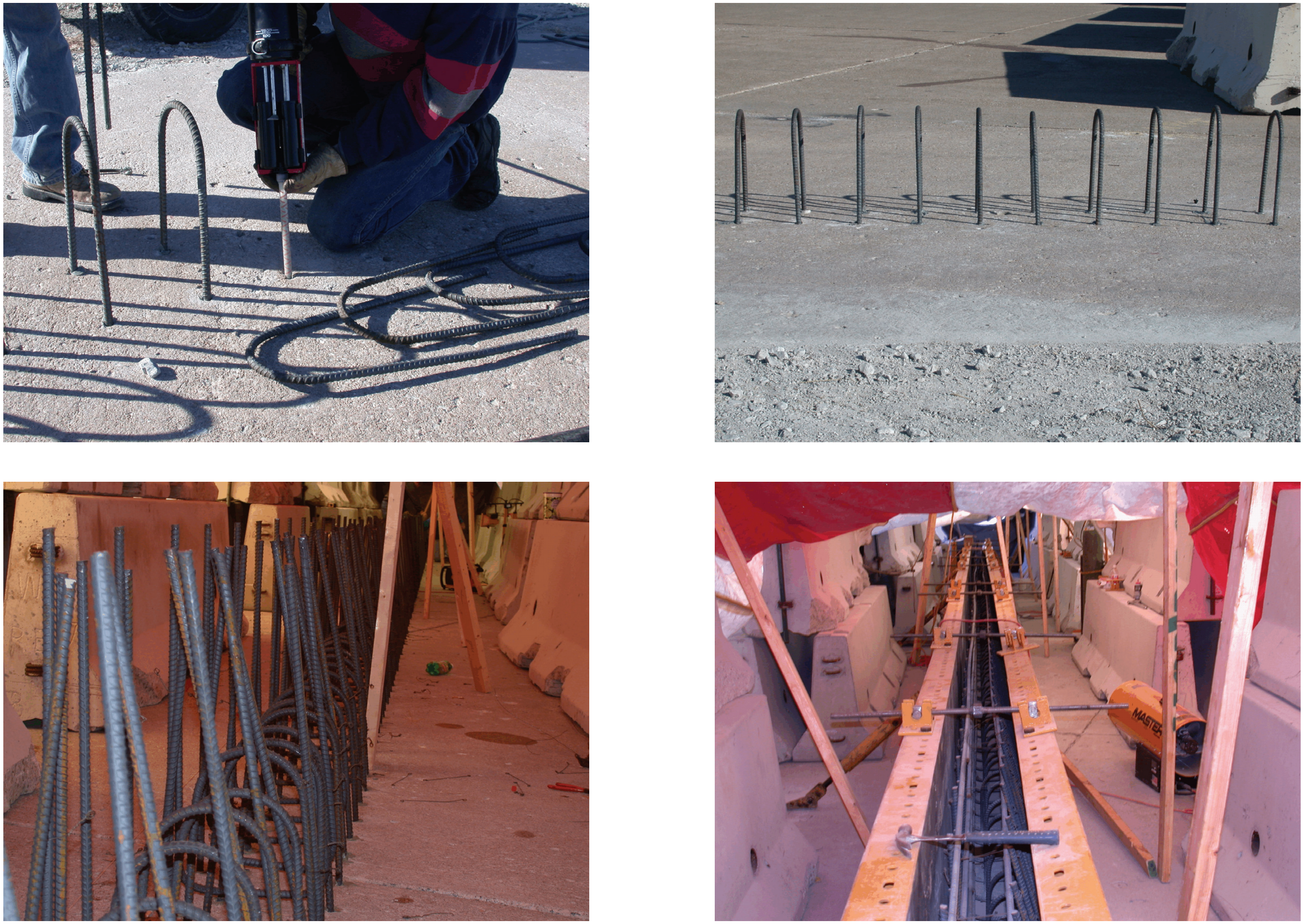


Figure 7. Single-Slope Concrete Barrier Construction

Figure 8. Luminaire Pole Attached to Single-Slope Concrete Barrier, Test No. ZOI-1

Figure 9. Luminaire Pole Attached to Single-Slope Concrete Barrier, Test No. ZOI-2

Figure 10. Luminaire Pole Attach to Single-Slope Concrete Barrier, Test Nos. ZOI-1 and ZOI-2

Figure 11. Luminaire Pole Attached to Single-Slope Concrete Barrier, Connection Details for Test Nos. ZOI-1 and ZOI-2

4 TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 Test Requirements

Longitudinal barriers, such as single-slope concrete barriers with attachments, have been required to satisfy safety requirements provided in NCHRP Report No. 350 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. According to TL-4 of NCHRP Report No. 350, longitudinal barrier systems must be subjected to three full-scale vehicle crash tests. The three full-scale crash tests are as follows:

1. Test Designation 4-10 consisting of an 820-kg (1,808-lbs) passenger car impacting at a nominal speed and angle of 100.0 km/h (62.1 mph) and 20 degrees, respectively.

2. Test Designation 4-11 consisting of a 2,000-kg (4,409-lbs) pickup truck impacting at a nominal speed and angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively.

3. Test Designation 4-12 consisting of an 8,000-kg (17,637-lbs) single-unit truck impacting at a nominal speed and angle of 80.0 km/h (49.7 mph) and 15 degrees, respectively.

Due to the prior successful small car testing on concrete parapets and the placement of the attachment, the 820-kg (1,808-lbs) small car crash test was deemed unnecessary for this project. The test conditions for TL-4 longitudinal barriers are summarized in Table 1.

4.2 Evaluation Criteria

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 hazards 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 NCHRP Report No. 350. The full-scale vehicle crash test were conducted and reported in accordance with the procedures provided in NCHRP Report No. 350.

Table 1. NCHRP Report No. 350 Test Level 4 Crash Test Conditions

Test Designation	Test Vehicle	Impact Conditions			Evaluation Criteria[1]
		Speed		Angle (degrees)	
		(km/h)	(mph)		
4-10	820C	100	62.1	20	A,D,F,H,I,K,M
4-11	2000P	100	62.1	25	A,D,F,K,L,M
4-12	8000S	80	49.7	15	A,D,G,K,M

[1] Evaluation criteria explained in Table 2.

Table 2. NCHRP Report No. 350 Evaluation Criterial for Crash Tests

Structural Adequacy	A.	Test article should contain and redirect the vehicle, 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 that could cause serious injuries should not be permitted.
	F.	The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.
	G.	It is preferable, although not essential, that the vehicle remain upright during and after collision.
	H.	Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9 m/s (29.5 ft/s), or at least below the maximum allowable value of 12 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 Gs.
Vehicle Trajectory	K.	After the collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.
	L.	The occupant impact velocity in the longitudinal direction should not exceed 12 m/s (39.4 ft/s) and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 Gs.
	M.	The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.

5 TEST CONDITIONS

5.1 Test Facility

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

5.2 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 (5) was used to steer the test vehicle. A guide-flag, attached to the front-left 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 tests ZOI-1, ZOI-2, and ZOI-3 the guidance systems were 582.8 m (1,912 ft), 270.7 m (888 ft), and 585.2 m (1,920 ft) long, respectively.

5.3 Test Vehicle

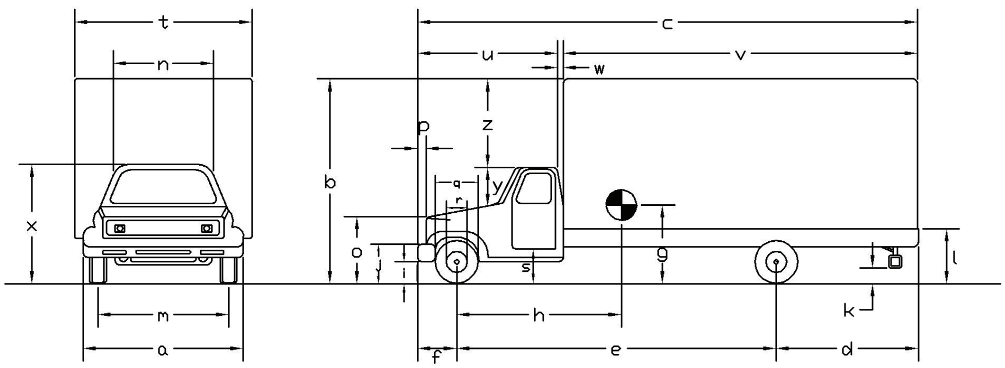
For test no. ZOI-1, a 1989 Ford F-800 single-unit truck was used as the test vehicle. The test inertial and gross static weights were 7,985 kg (17,605 lbs). The test vehicle is shown in Figure 12,

Figure 12. Test Vehicle, Test No. ZOI-1

Date: 4/2/03 Test Number: ZOI-1 Model: F - 800

Tire Sz FR: 11 R 22.5 Odometer: 186,530 Make: Ford

Tire Sz RR: 11 R 22.5 V.I.N. #: 1FDXF82K3JVA3237 Year: 1989



Vehicle Geometry – mm (inches)

a> fr. bump. width	2362 (93.0)	j> fr. bump. top	851 (33.5)	s> bot. door height	940 (37.0)
b> overall height	3556 (140.0)	k> rr. bump. bot.	527 (20.75)	t> overall width	2426 (95.5)
c> overall length	8560 (337.0)	l> rr. frame top	1035 (40.75)	u> cab length	2578 (101.5)
d> rear overhang	2915 (114.75)	m> fr. track width	2013 (79.25)	v> trler/box length	5626 (221.5)
e> wheel base	4807 (189.25)	n> roof width	1543 (60.75)	w> gap width	70 (2.75)
f> front overhang	819 (32.25)	o> hood height	1537 (60.5)	x> overall fr. height	2299 (90.5)
g> C.G. height	1092 (43.0)	p> bump. extension	76 (3.0)	y> roof–hood dist.	508 (20.0)
h> C.G. hor. dist.	3901 (153.6)	q> fr. tire width	1016 (40.0)	z> roof height dif.	1257 (49.5)
i> fr. bump. bot.	546 (21.5)	r> fr. wheel width	597 (23.5)		

wheel center height front 498 (19.625)

wheel center height rear 519 (20.4375)

wheel well clearance (FR) 1194 (47.0)

wheel well clearance (RR) 1130 (44.5)

Engine Type 8 Cyl. Gas

Engine Size 429 ci

Transmission Type:

Automatic or (Manual)

FWD or (RWD) or 4WD

Weights – kg (lbs)

	Curb	Test Inertial	Gross Static
$W_{front\ axel}$	2176 (4797)	2806 (6186)	2806 (6186)
$W_{rear\ axel}$	3345 (7375)	5180 (11419)	5180 (11419)
W_{TOTAL}	5521 (12172)	7985 (17605)	7985 (17605)

Ballast 798 (1760)

Note any damage prior to test: minor scratches, dents, rust

Figure 13. Vehicle Dimensions, Test No. ZOI-1

vehicle dimensions are shown in Figure 13. For test no. ZOI-2, a 1997 GMC 2000P 3/4-ton pickup truck was used as the test vehicle. The test inertial gross static weights were 2,009 kg (4,430 lbs). The test vehicle is shown in Figure 14, and vehicle dimensions are shown in Figure 15.

For test no. ZOI-3, a 1989 Ford 8000S single-unit truck was used as the test vehicle. The test inertial and gross static weight were 8,000 kg (17,637 lbs). The test vehicle is shown in Figure 16, and vehicle dimensions are shown in Figure 17.

The Suspension Method (6) was used to determine the vertical component of the center of gravity (c.g.) for the 2000P test vehicle. 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 Elevated Axle Method (7) was used to determine the vertical component of the center of gravity for the 8000S test vehicles. This method converts measured wheel weights at different elevations to the location of the vertical component of the center of gravity. The longitudinal component of the c.g. for all three test vehicles, and the vertical component of the two 8000S test vehicles, were determined using measured axle weights. The location of the final centers of gravity is shown in Figures 18 through 20.

Black and white, checkered targets were placed on the vehicles to aid in the analysis of the high-speed film and high-speed digital video, as shown in Figures 18 through 20. Round 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.

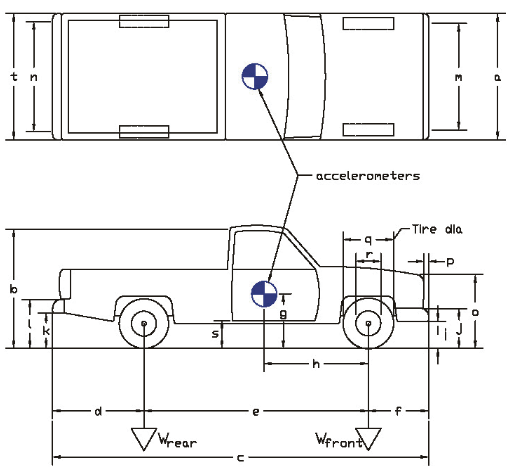
Figure 14. Test Vehicle, Test No. ZOI-2

Date: 7/25/03 Test Number: ZOI-2 Model: 2000D

Make: GMC Vehicle I.D.#: 1GDGC24R9WZ531370

Tire Size: LT 245/75 R16 Year: 1997 Odometer: 280392

*(All Measurements Refer to Impacting Side)



Vehicle Geometry — mm (in.)

a	1930 (76.0)	b	1975 (77.75)
c	5563 (219)	d	1321 (52.0)
e	3327 (131.0)	f	889 (35.0)
g	641 (20.25)	h	1372 (54.0)
i	445 (17.5)	j	664 (26.125)
k	673 (26.5)	l	787 (31.0)
m	1581 (62.25)	n	1613 (63.5)
o	1025 (40.365)	p	83 (3.25)
q	743 (29.25)	r	445 (17.5)
s	413 (16.25)	t	1867 (73.5)

Wheel Center Height Front 365 (14.365)

Wheel Center Height Rear 378 (15.25)

Wheel Well Clearance (FR) 902 (35.5)

Wheel Well Clearance (RR) 968 (38.125)

Engine Type 8 CYL. GAS

Engine Size 5.7 L 350 CID

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	1172 (2583)	1183 (2609)	1183 (2609)
W_{rear}	855 (1885)	826 (1821)	826 (1821)
W_{total}	2027 (4468)	2009 (4430)	2009 (4430)

Note any damage prior to test: None

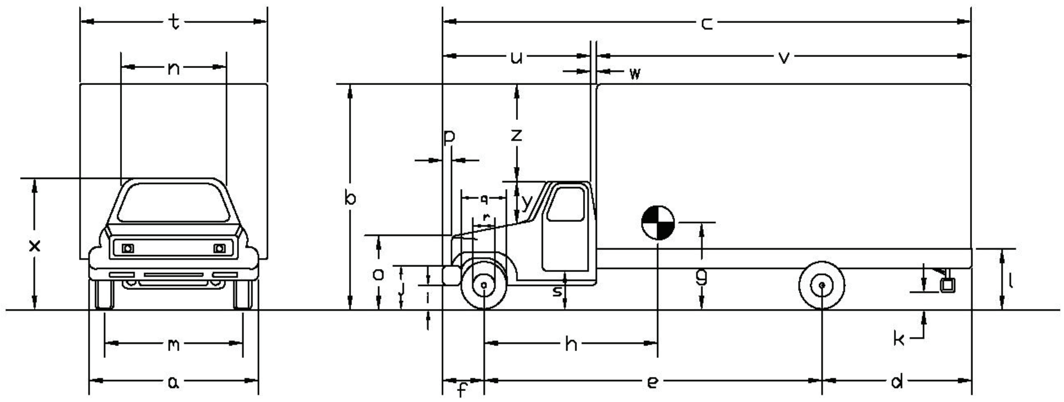
Figure 15. Vehicle Dimensions, Test No. ZOI-2

Figure 16. Test Vehicle, Test No. ZOI-3

Date: 03/02/2005 Test Number: ZOI–3 Model: F–800

Tire Sz FR: 11 R 22.5 Odometer: 168294 Make: Ford

Tire Sz RR: 11 R 22.5 V.I.N. #: 1FDFX82K6JVA31151 Year: 1989



Vehicle Geometry – mm (inches)

a> fr. bump. width	2350 (92.5)	j> fr. bump. top	864 (34.0)	s> bot. door height	940 (37.0)
b> overall height	3613 (142.25)	k> rr. bump. bot.	565 (22.25)	t> overall width	2423 (95.375)
c> overall length	8553 (336.75)	l> rr. frame top	1048 (41.25)	u> cab length	2597 (102.25)
d> rear overhang	2883 (113.5)	m> fr. track width	2010 (79.125)	v> trler/box length	5886 (231.75)
e> wheel base	4807 (189.25)	n> roof width	1537 (60.5)	w> gap width	57 (2.25)
f> front overhang	845 (33.25)	o> hood height	1556 (61.25)	x> overall fr. height	2299 (90.5)
g> C.G. height	1259 (49.58)	p> bump. extension	70 (2.75)	y> roof–hood dist.	514 (20.25)
h> C.G. hor. dist.	3137 (123.5)	q> fr. tire width	1029 (40.5)	z> roof height dif.	1270 (50.0)
i> fr. bump. bot.	565 (22.25)	r> fr. wheel width	597 (23.5)	wheel center height front	502 (19.75)
				wheel center height rear	508 (20.0)
				wheel well clearance (FR)	1216 (47.875)
				wheel well clearance (RR)	1213 (47.75)
				Engine Type	8 Cyl. Gas
				Engine Size	429 ci

Weights – kg (lbs)

	Curb	Test Inertial	Gross Static
$W_{front\ axel}$	2116 (4666)	2361 (5205)	2361 (5205)
$W_{rear\ axel}$	3323 (7327)	5639 (12432)	5639 (12432)
W_{TOTAL}	5440 (11993)	8000 (17637)	8000 (17637)

Ballast 2521 (5558)

Transmission Type:

Automatic or (Manual)

FWD or (RWD) or 4WD

Note any damage prior to test: Rusty – no major damage

Figure 17. Vehicle Dimensions, Test No. ZOI-3

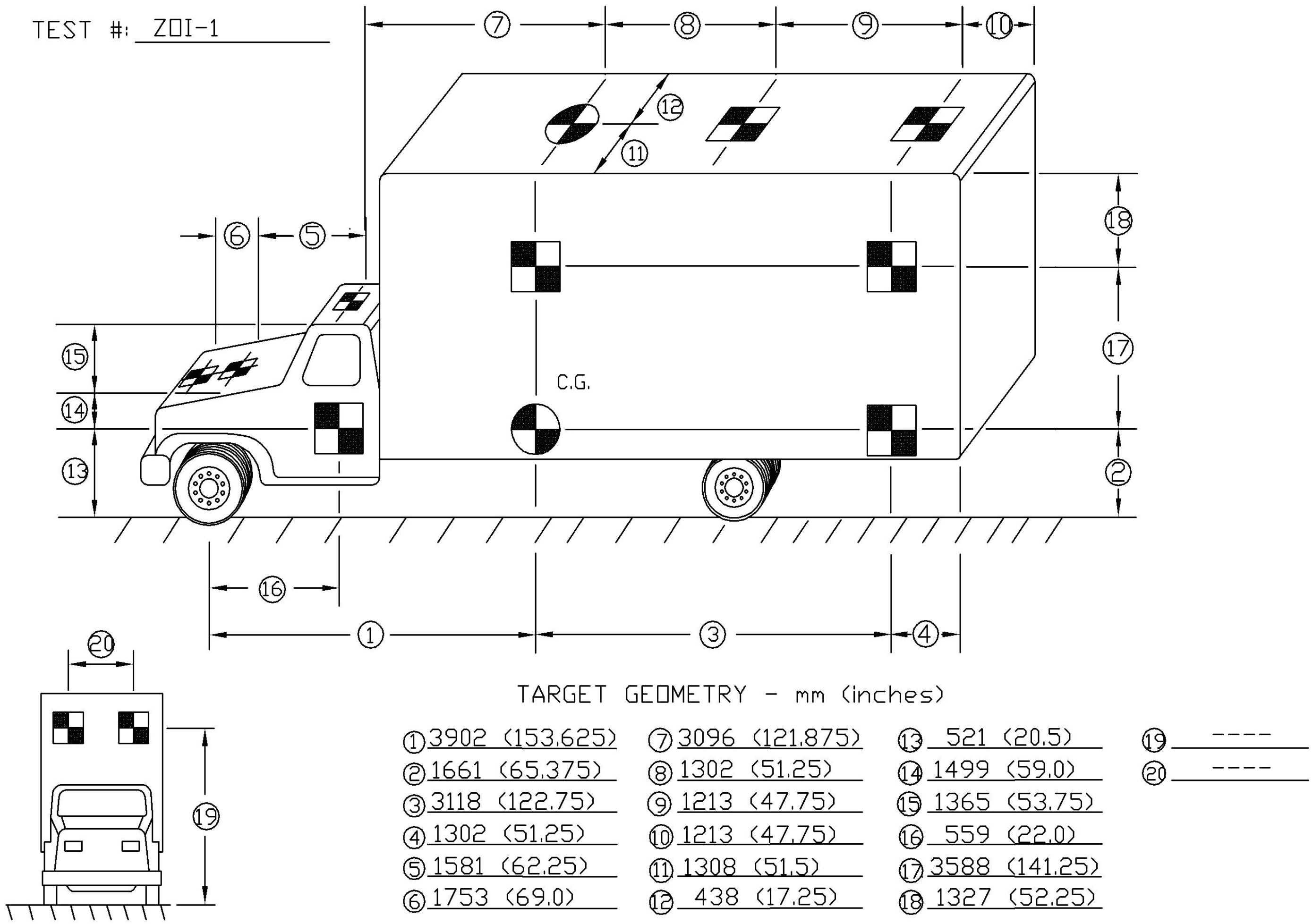
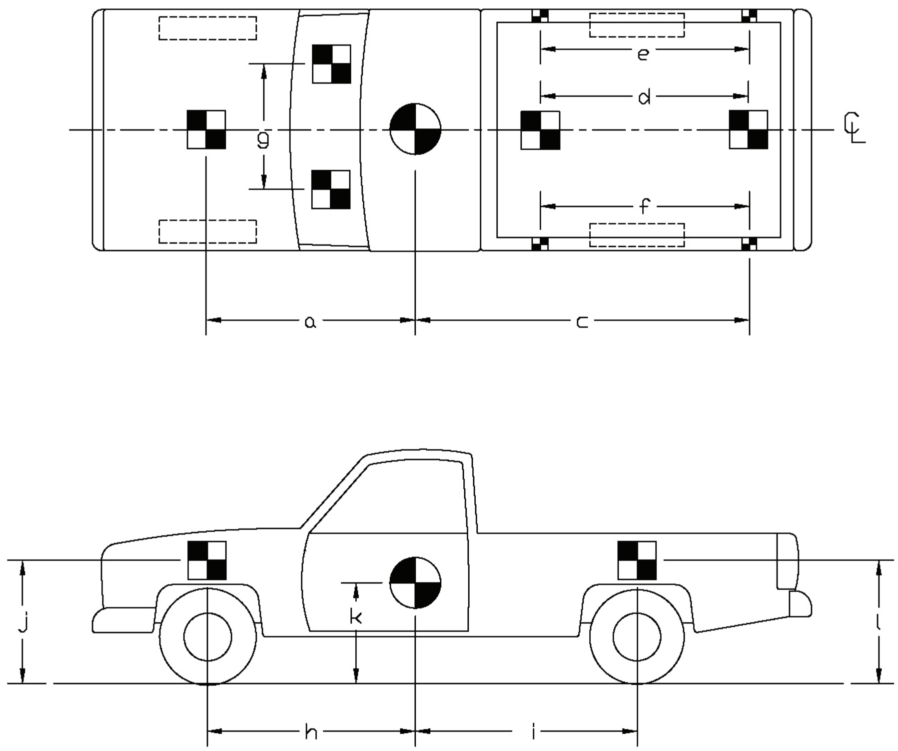


Figure 18. Vehicle Target Locations, Test No. ZOI-1



TEST #: ZOI-2

TARGET GEOMETRY -- mm (in.)

a 1654 (65.125)	d 1937 (76.25)	g 1251 (49.25)	j 1010 (39.75)
b -----	e 2153 (84.75)	h 1499 (59.0)	k 667 (26.25)
c 2794 (110.0)	f 2153 (84.75)	i 1829 (72.0)	l 1086 (42.75)

Figure 19. Vehicle Target Locations, Test No. ZOI-2

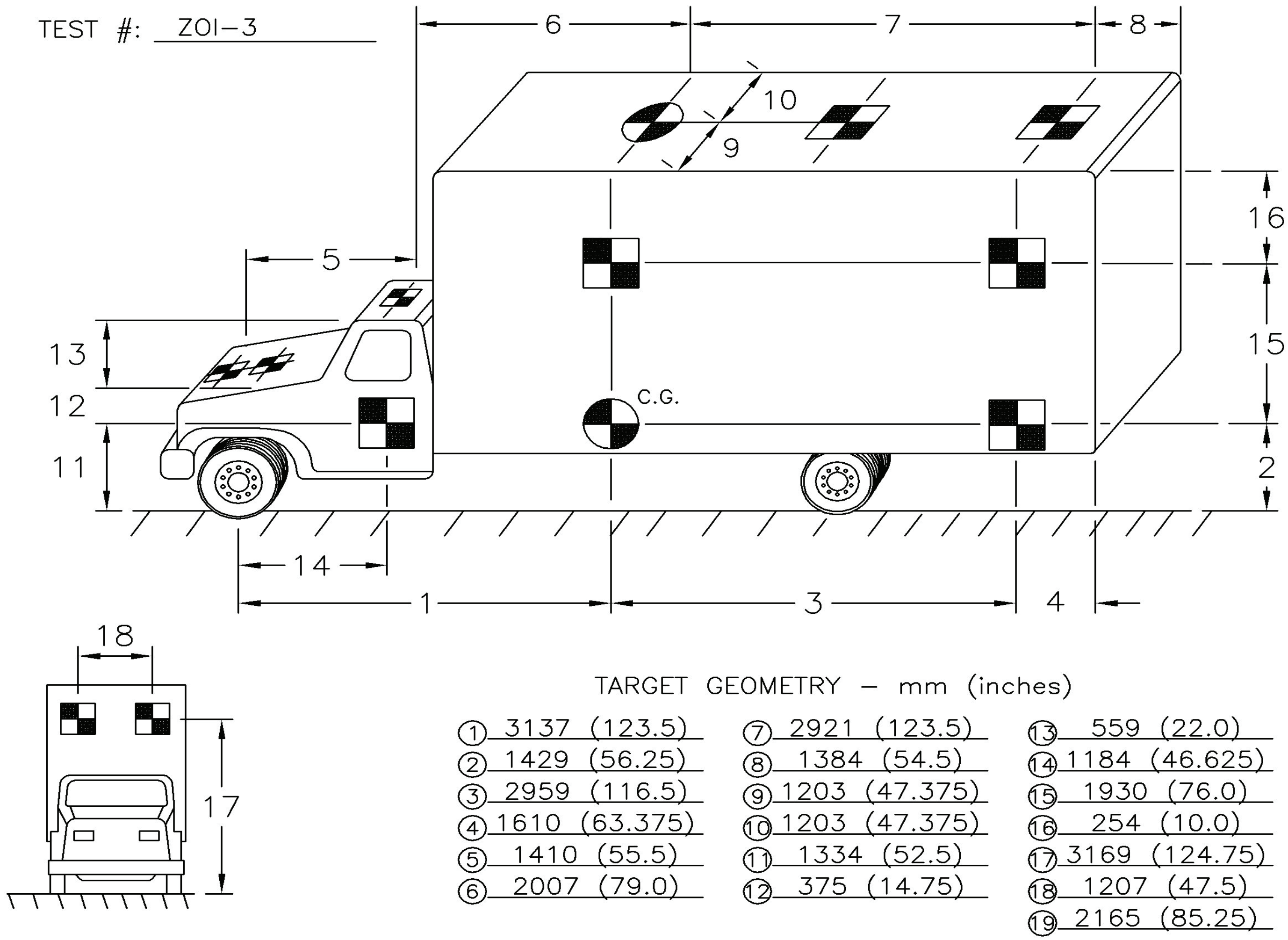


Figure 20. Vehicle Target Locations, Test No. ZOI-3

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 and E/cam 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.

5.4 Data Acquisition Systems

5.4.1 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.

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 Instrumented 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.

5.4.2 Rate Transducers

An Analog Systems 3-axis rate transducer with range of 1,200 degree/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.

5.4.3 High-Speed Photography

For test ZOI-1, three high-speed 16-mm Redlake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. Four high-speed Red Lake E/cam video cameras, with operating speeds of 500 frames/sec, were also used to film the crash test. Six Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all thirteen camera locations for test ZOI-1 are shown in Figure 21.

For test ZOI-2, two high-speed 16-mm Red Lake Locam cameras, with operating speed of approximately 500 frames/sec, were used to film the crash test. A high-speed Photron video camera and five high-speed Redlake E/cam video cameras, all with operating speeds of 500 frames/sec, were also used to film the crash test. Six Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all fourteen camera locations for test ZOI-2 are shown in Figure 22.

For test ZOI-3, two high-speed Photron video cameras, two high-speed Redlake E/cam video cameras, and one high-speed AOS VITcam video camera, all with operating speeds of 500 frames/sec, were used to film the crash test. Five Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all ten camera locations for test ZOI-3 are shown in Figure 23.

The Locam films, Photron and AOS videos, and E/cam videos were analyzed using the Vanguard Motion Analyzer, ImageExpress MotionPlus software and Redlake MotionScope software, respectively. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film and video.

5.4.4 Pressure Tape Switches

For all three tests, 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.

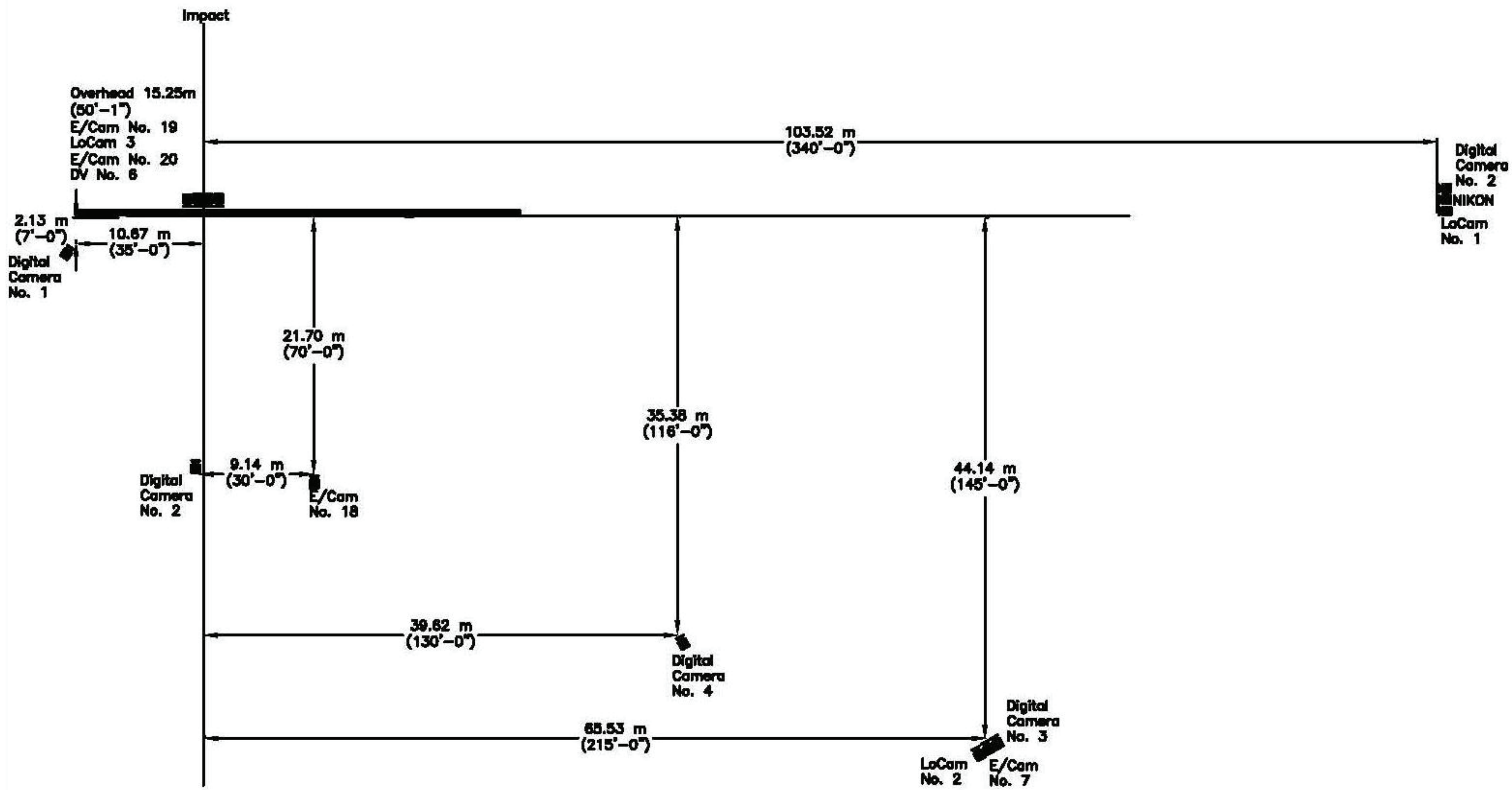


Figure 21. Location of Cameras, Test No. ZOI-1

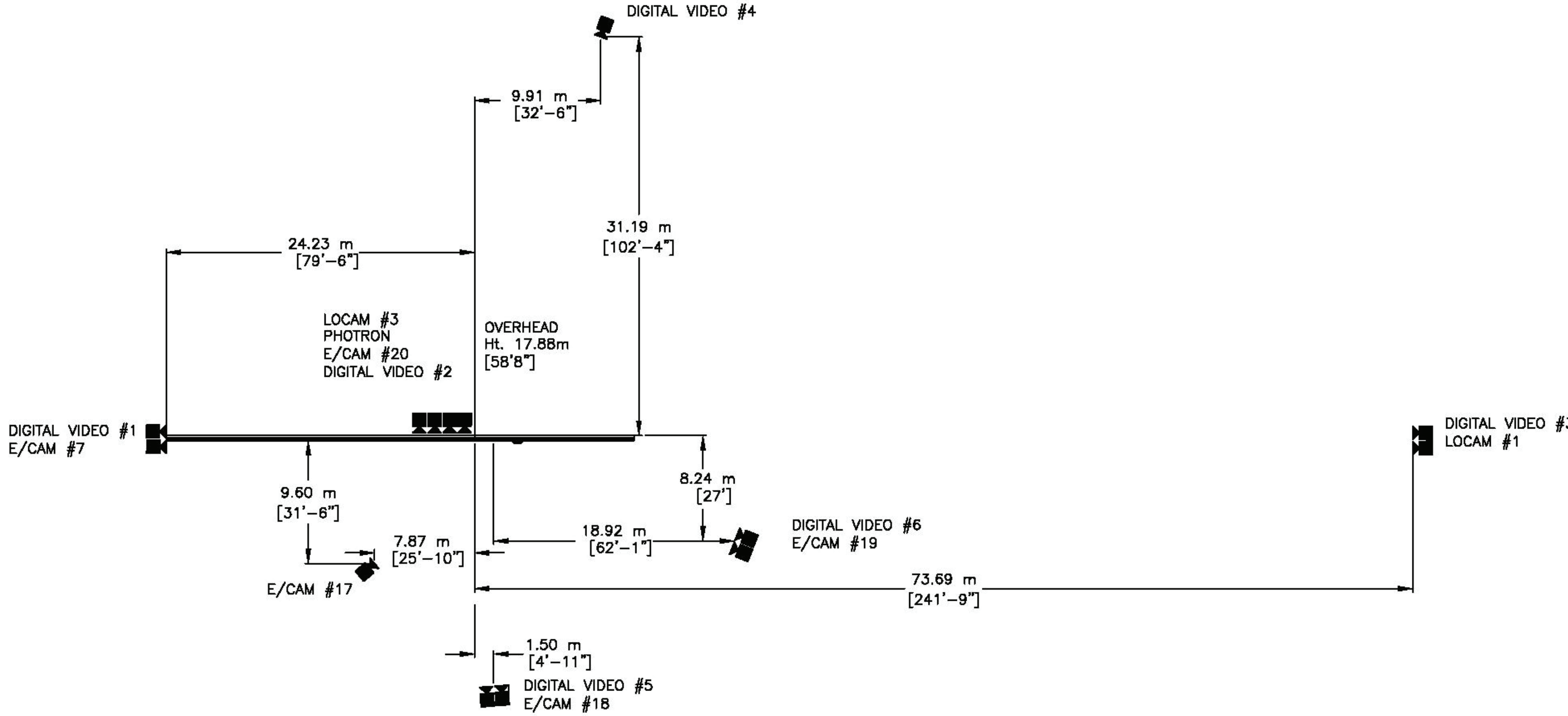


Figure 22. Location of Cameras, Test No. ZOI-2

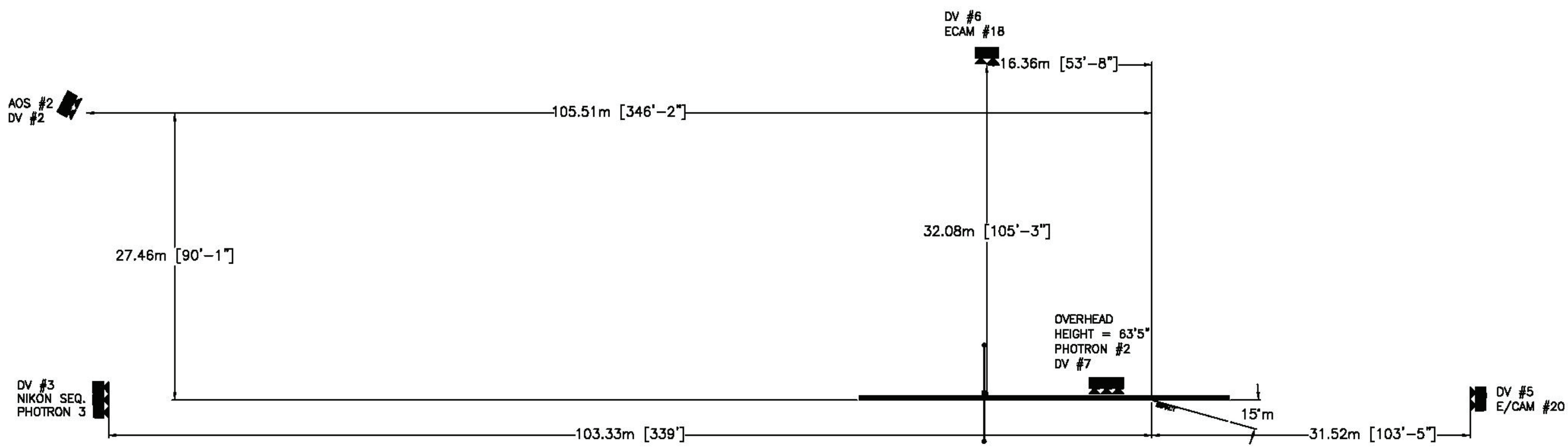


Figure 23. Location of Cameras, Test No. ZOI-3

6 CRASH TEST NO. ZOI-1

6.1 Test No. ZOI-1

A 7,985-kg (17,605-lbs) single-unit truck impacted the single-slope concrete barrier with a luminaire pole attached to the top of the barrier at a speed of 80.8 km/h (50.4 mph) and at an angle of 15.6 degrees. A summary of the test results and sequential photographs are shown in Figure 24. The summary of the test results and sequential photographs in English units are shown in Appendix D. Additional sequential photographs are shown in Figures 25 and 26. Documentary photographs of the crash test are shown in Figures 27 through 32.

6.2 Test Description

Initial vehicle impact was to occur 16.8 m (55 ft) upstream of the centerline of the luminaire pole, as shown in Figure 33. Actual vehicle impact occurred 356 mm (14 in.) upstream of the targeted impact. At 0.078 sec after impact, the right-front corner of the cab rose upward. At 0.133 sec, the truck began to redirect. At 0.191 sec, the front of the truck continued to rise upward and rolled clockwise. At 0.311 sec, the truck became parallel to the barrier at a speed of 63.4 km/h (39.4 mph). At 0.320 sec, the truck rolled counter-clockwise. At this same time, the rear of the truck rose up, and the left-front tire disengaged. At 0.394 sec, the left-rear tire became airborne. At 0.830 sec, the front of the truck contacted the pole. At 0.880 sec, the pole disengaged from the barrier and rotated downward toward the truck. At 1.135 sec, the cab rolled counter-clockwise, and the box continued to roll clockwise. At this same time, the pole descended down and traversed the truck. At 1.204 sec, the cab rolled clockwise. At 1.411 sec, the pole was no longer in contact with the truck. At 1.984 sec, the truck rolled to a 40 degree angle, and the left-front corner of the truck contacted the ground. At 2.050 sec, the truck rolled counter-clockwise as it exited the end of the system. The vehicle came to rest 63.28 m (207 ft - 7 in.) downstream from impact and inline with the concrete barrier. The trajectory and final position of the single unit-truck are shown in Figures 24 and 34.

6.3 System Damage

Damage to the barrier and pole was moderate, as shown in Figures 35 through 37. Barrier damage consisted of gouge marks and tire marks. The length of vehicle contact along the concrete barrier system was approximately 26.26 m (86 ft - 2 in.), which spanned from 17.12 m (56 ft - 2 in.) upstream of the centerline of the pole through the downstream end of the system.

A 25-mm (1-in.) deep wheel gouge began 17.12 m (56 ft - 2 in.) upstream of the centerline of the pole at a height of 256 mm (14 in.) to 559 mm (22 in.) from the ground and continued for a length of 4.88 m (16 ft). A 5.16-m (16-ft 11-in.) long tire mark began 76 mm (3 in.) downstream from the beginning of the first gouge. Tire marks and minor gouges were found on the top and back edges and front face from the barrier upstream of the centerline of the pole. Tire marks and gouges also began 305 mm (12 in.) downstream of the centerline of the pole and continued through the end of the barrier. Hairline cracks and surface chipping was found on the top of the barrier and extended diagonally from three of the bolts.

The pole fractured above the weld line on the impact-side face. Contact marks were found on the upstream edge of the pole plate and on one of the bolts and nuts. The pole buckled 610 mm (2 ft) above the ripped pole surface. The arms of the pole were bent due to contact with the ground and the barrier. One set of the ballest plates disengaged from the pole. After disengaging from the barrier and landing on the ground, the top of the pole was located 3.51 m (11ft - 6 in.) downstream from its original position and 1.02 m (3 ft - 4 in.) behind the barrier and the bottom of the pole was located

5.33 m (17 ft - 6 in.) downstream from the downstream end of the barrier and 1.22 m (4 ft) behind the barrier.

6.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 38 through 40. Occupant compartment deformations did not occur. Damage was concentrated on the front and right sides of the vehicle. The outer rim of the right-rear was severely bent, and the tire deflated. The front face of the right-side fuel tank was deformed and dented. The left-side fuel tank was bent upward and lodged into the bottom of the door causing the door to not open. The front bumper bent backward around the frame support on both sides. Minimal separation was found between the fender, the hood, and the right-side door. The right-front shear plate on both sides was bent. All three U-bolts in front of both the right and left leaf spring attachments were bent, but remained attached. The right leaf spring attachment fractured. The additional U-bolt behind the leaf spring attachment on both sides fractured. The front axle disengaged. All four U-bolts for the front axle fractured. All window glass, the rear, and the box remained undamaged.

6.5 Occupant Risk Values

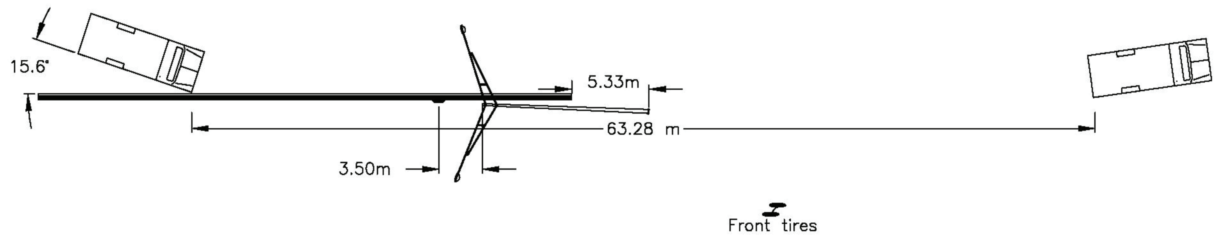
The longitudinal and lateral occupant impact velocities were determined to be -2.57 m/s (-8.84 ft/s) and -2.05 m/s (-6.37 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were -4.14 Gs and -6.54 Gs, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 24. Results are shown graphically in Appendix D. The results from the rate transducer are shown graphically in Appendix D.

6.6 Discussion

The analysis of the test results for test no. ZOI-1 showed that the single-slope concrete barrier with an attached luminaire pole impacted with the 8000S vehicle 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 as the pole landed behind the barrier and parallel to it. Deformations, or intrusion, into the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier system and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After the collision, the vehicle's trajectory did not intrude into adjacent traffic lanes. In addition, the vehicle's exit angle was less than 60 percent of the impact angle. Therefore, test no. ZOI-1 conducted on the single-slope concrete barrier with an attached luminaire pole was determined to be acceptable according to the TL-4 safety performance criteria of test designation no. 4-12 found in NCHRP Report No. 350.

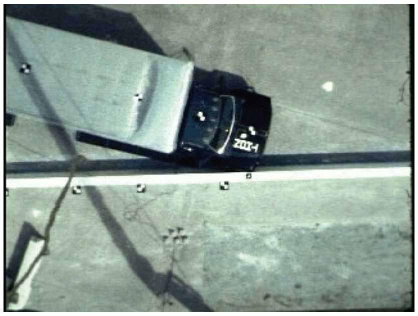
This test demonstrated that luminaire poles placed on top of barriers can become dislodged by large trucks and be propelled behind the barrier. For this test, the luminaire pole landed directly behind the barrier and parallel to it. For median barrier applications, these results would not pose significant concerns as the pole would likely be within the shoulder and edge of the lane regions. For bridge railing applications, a flailing pole would only pose safety concerns if vehicular and/or pedestrians are found below.

0.000 sec　0.320 sec　0.830 sec　1.411 sec　1.984 sec

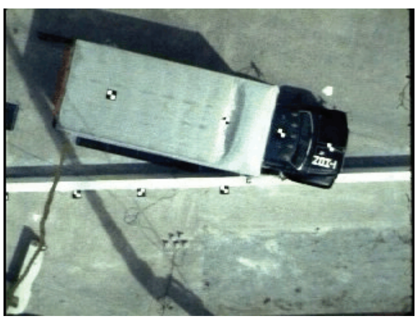


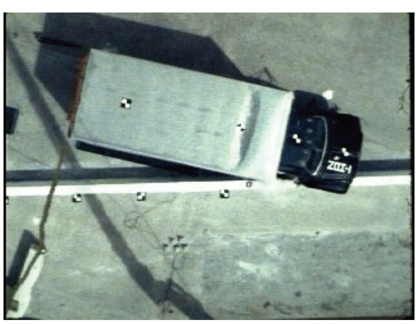
- Test Agency . . . . . MwRSF
- Test Number ZOI-1
- Date 4/02/03
- NCHRP 350 Test Designation 4-12
- Appurtenance . . . . . Single-Slope Concrete Barrier with an Attached Luminaire Pole
- Total Length . . . . . 36.58 m
- Overall Height . . . . . 13,716 mm
- Key Elements - Barrier
  - Description . . . . . Single-Slope Concrete Barrier
  - Base Width . . . . . 397 mm
  - Top Width . . . . . 241 mm
  - Base Width (at pedestal) . . . . . 565 mm
  - Top Width (at pedestal) . . . . . 410 mm
  - Height . . . . . 813 mm
  - Concrete Material . . . . . Nebraska 47-BD Mix
  - Reinforcing Steel Material . . . . . Grade 60 Rebar
- Key Elements - Luminaire Pole
  - Pole Description . . . . . TOOA376-GV30-19 DS210 Pole
  - Arm Description . . . . . DS60 Arm 150-0560GV-CLMP
  - Size . . . . . 3.05 mm thick by 11.43 m long
  - Material . . . . . Galvanized Steel
- Type of Soil . . . . . NA
- Test Vehicle
  - Type/Designation 8000S
  - Make and Model . . . . . 1989 Ford F-800
  - Curb . . . . . 5,521 kg
  - Test Inertial . . . . . 7,985 kg
  - Gross Static . . . . . 7,985 kg
- Impact Conditions
  - Speed . . . . . 81.0 km/h
  - Angle . . . . . 15.6 degrees
  - Impact Location . . . . . 16.8 m upstream of Pole centerline
- Exit Conditions
  - Speed . . . . . NA
  - Angle . . . . . NA
  - Exit Box Criterion . . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . . Satisfactory
  - Stopping Distance . . . . . 63.28 m downstream
- Occupant Impact Velocity
  - Longitudinal (not required) . . . . . -2.57 m/s
  - Lateral (not required) . . . . . -2.05 m/s
- Occupant Ridedown Deceleration
  - Longitudinal (not required) . . . . . -4.14 Gs
  - Lateral (not required) . . . . . -6.54 Gs
- THIV (not required) . . . . . NA
- PHD (not required) . . . . . NA
- Test Article Damage . . . . . Pole disengaged
- Test Article Deflections
  - Permanent Set . . . . . NA
  - Dynamic . . . . . NA
  - Working Width . . . . . 1,711 mm
- Vehicle Damage . . . . . Moderate
  - VDS[5] I-RFQ-3
  - CDC[6] I-RFEW-4
  - Maximum Deformation . . . . . NA

Figure 24. Summary of Test Results and Sequential Photographs, Test No. ZOI-1


0.000 sec


0.106 sec


0.133 sec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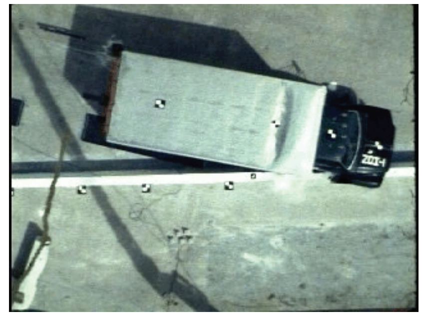
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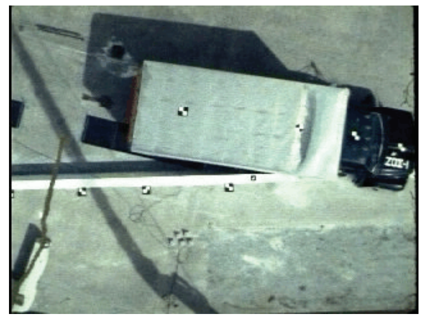
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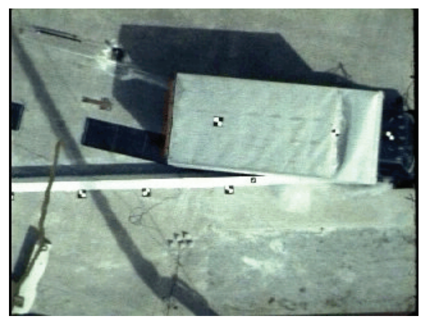

0.311 sec

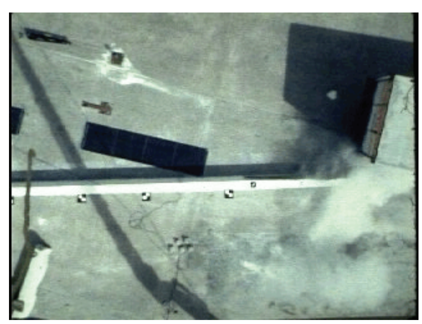
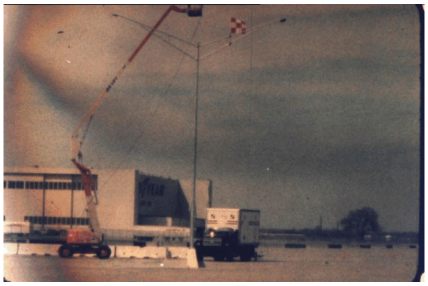

0.697 sec

Figure 25. Additional Sequential Photographs, Test No. ZOI-1



0.000 sec

0.078 sec

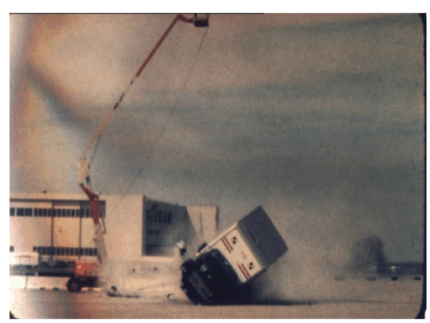
0.320 sec

0.394 sec

0.830 sec

1.411sec

1.984 sec



2.050 sec

Figure 26. Additional Sequential Photographs, Test No. ZOI-1

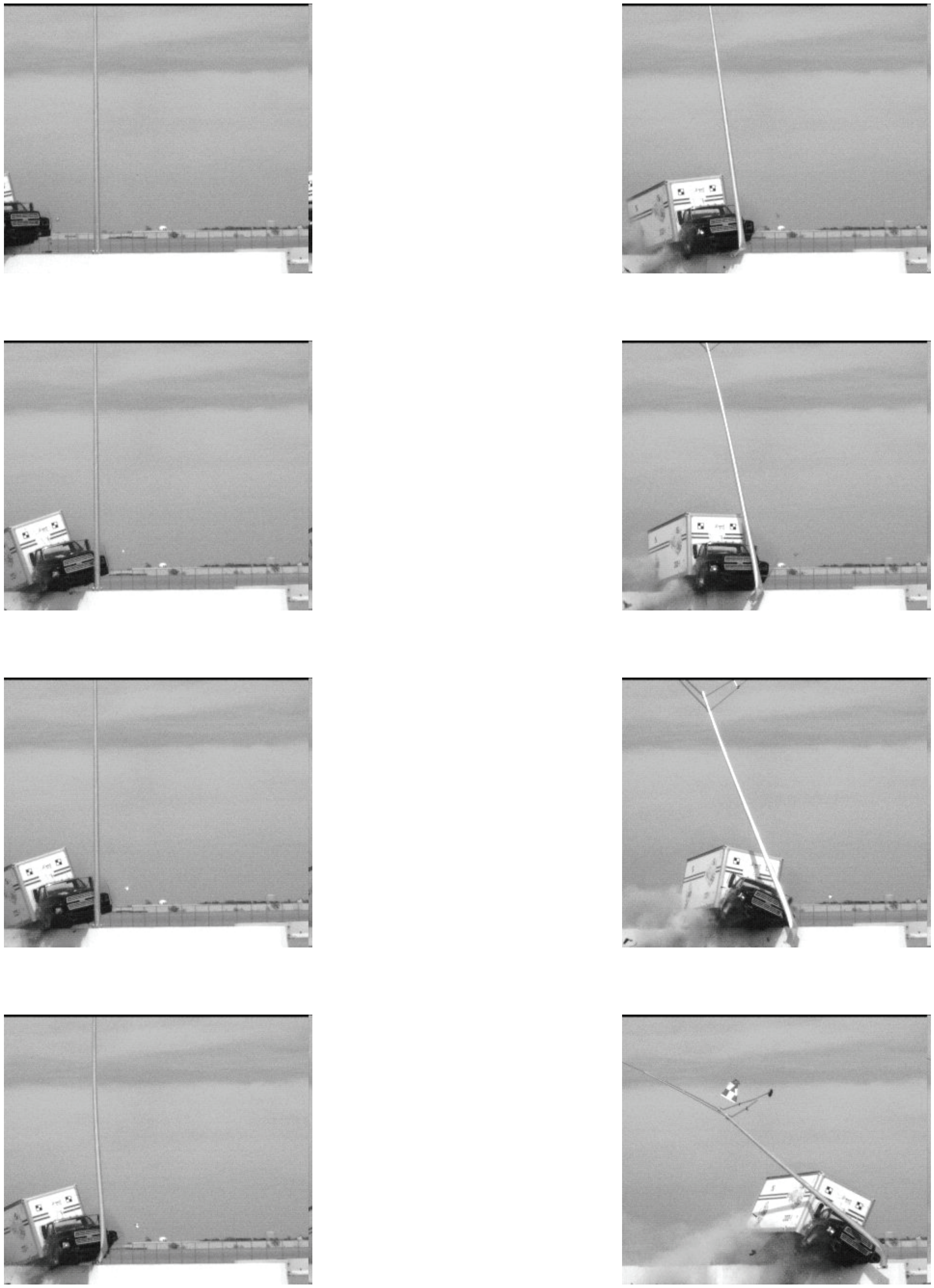


Figure 27. Documentary Photographs, Test No. ZOI-1

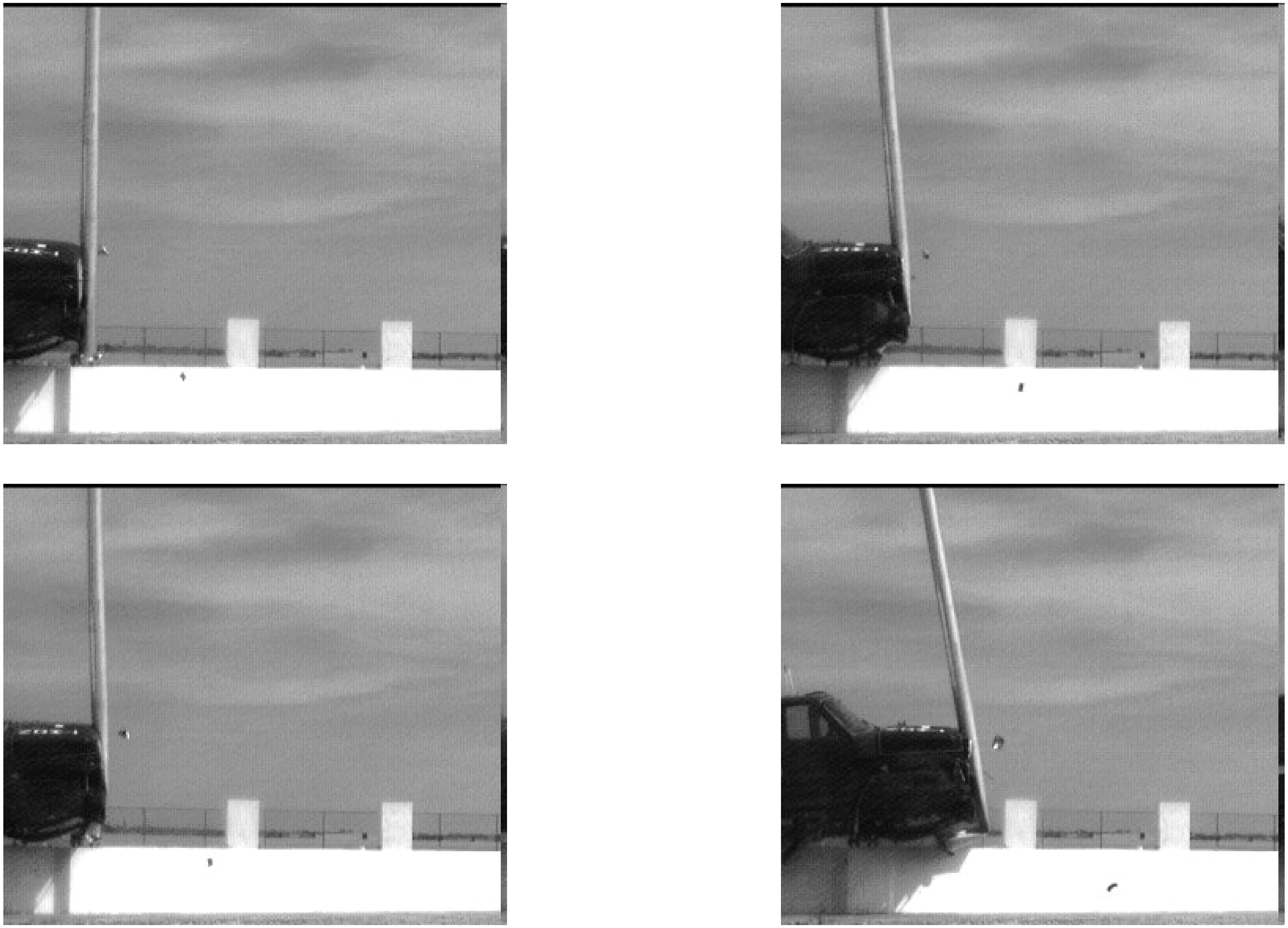


Figure 28. Documentary Photographs, Test No. ZOI-1

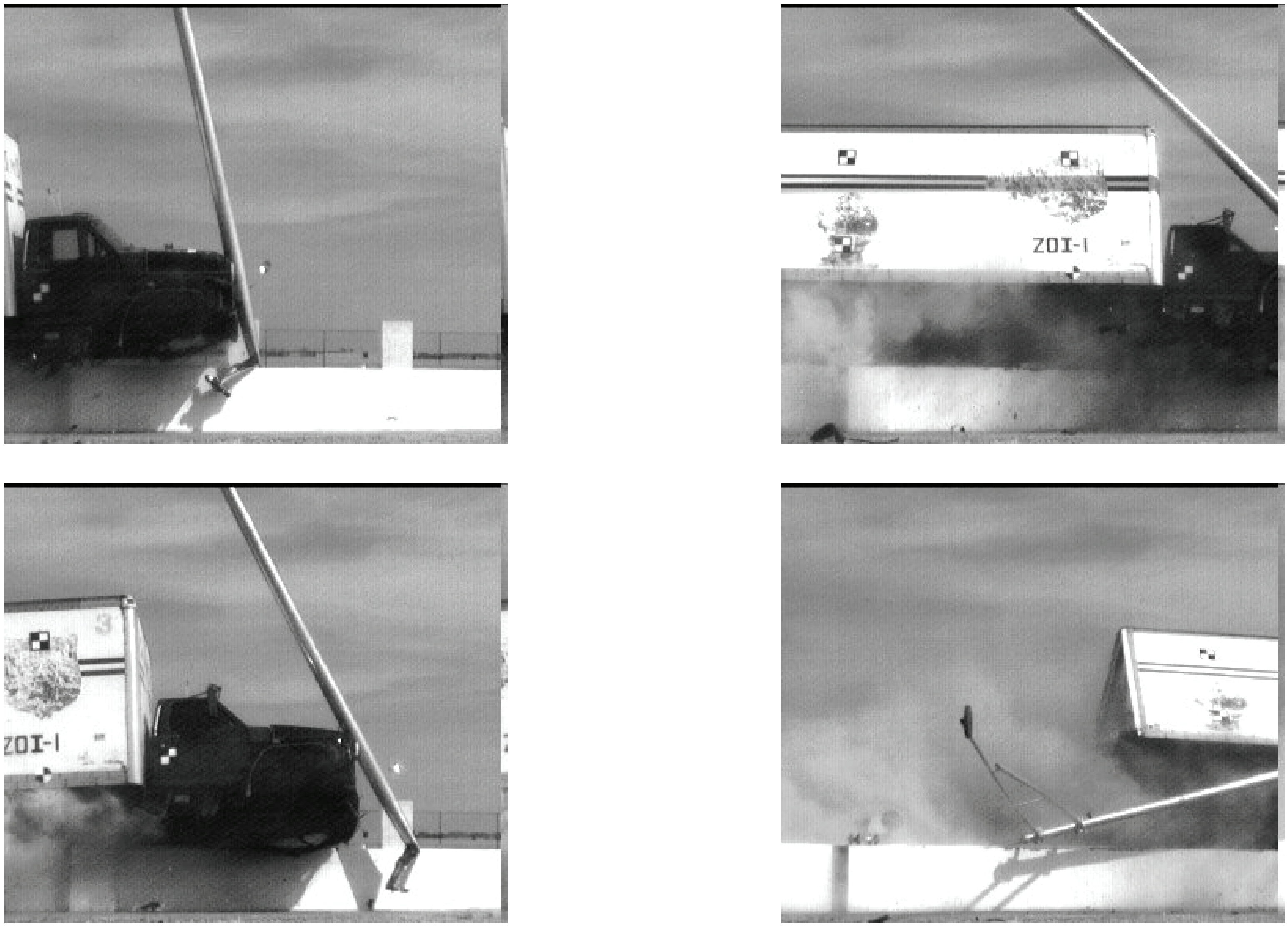


Figure 29. Documentary Photographs, Test No. ZOI-1

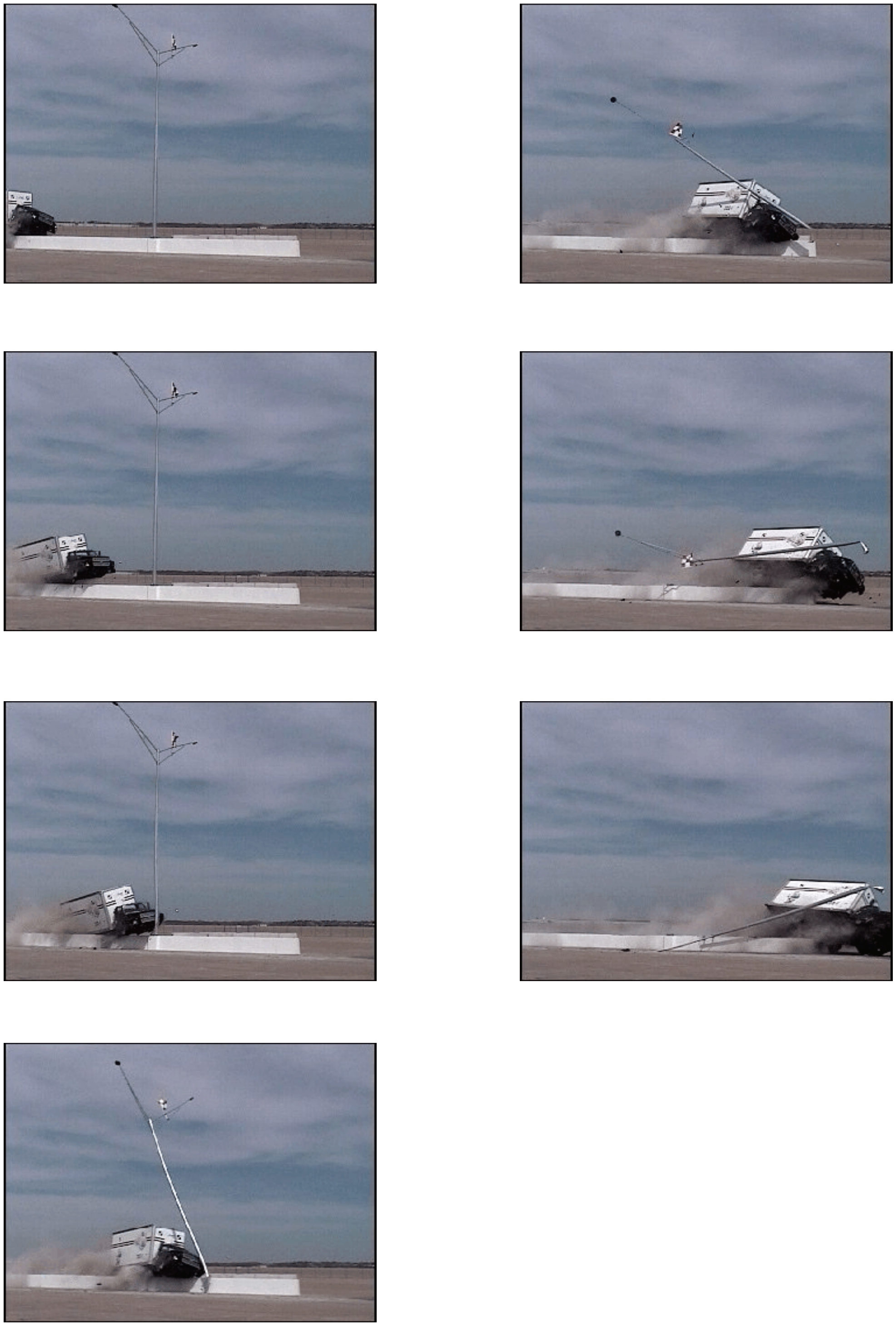


Figure 30. Documentary Photographs, Test No. ZOI-1

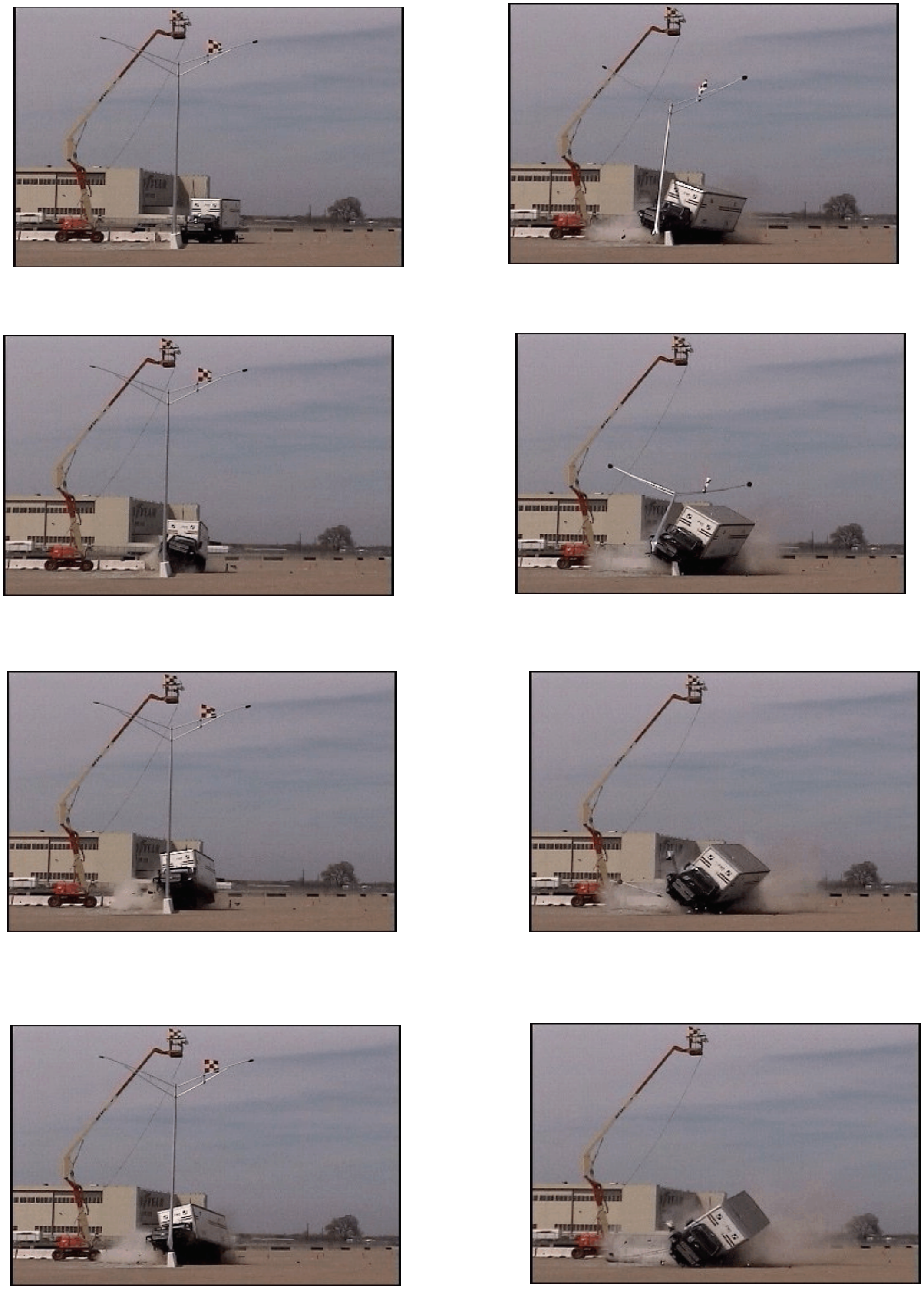


Figure 31. Documentary Photographs, Test No. ZOI-1

Figure 32. Documentary Photographs, Test No. ZOI-1

Figure 33. Impact Location, Test No. ZOI-1

Figure 34. Vehicle Final Position and Trajectory Marks, Test ZOI-1

Figure 35. System Damage, Test No. ZOI-1

Figure 36. System Damage, Test No. ZOI-1

Figure 37. System Damage, Test No. ZOI-1

Figure 38. Vehicle Damage, Test No. ZOI-1

Figure 39. Vehicle Damage, Test No. ZOI-1

Figure 40. Undercarriage Damage, Test No. ZOI-1

7 CRASH TEST NO. ZOI-2

7.1 Test No. ZOI-2

A 2,009-kg (4,430-lbs) pickup truck impacted the single-slope concrete barrier with a luminaire pole attached to the top of the barrier at a speed of 99.3 km/h (61.7 mph) and at an angle of 23.4 degrees. A summary of the test results and sequential photographs are shown in Figure 41. The summary of the test results and sequential photographs in English units are shown in Appendix D. Additional sequential photographs are shown in Figures 42 through 44. Documentary photographs of the crash test are shown in Figures 45 through 47.

7.2 Test Description

Initial vehicle impact was to occur 3.4 m (11 ft) upstream of the upstream side of the luminaire pole, as shown in Figure 48. Actual vehicle impact occurred 457 mm (18 in.) downstream of the targeted impact. At 0.028 sec after impact, the lower right-front corner of truck crushed inward. At 0.048 sec, the truck hood protruded over the top of the barrier. At 0.066 sec, the top of the right-side door became ajar. At 0.072 sec, the truck yawed counter-clockwise, and the front end of the truck pitched upward. At 0.084 sec, the right-front corner of the hood contacted the pole. At 0.094 sec, the left-front tire became airborne. At 0.104 sec, the right-front corner of truck continued to crush inward. At 0.124 sec, the truck's hood buckled and the front of the truck continued to pitch upward. At 0.140 sec, the front end of the truck became airborne. At 0.186 sec, the grill detached from the left side, but remained attached on the right. At 0.202 sec, the box of the truck impacted the pole. At 0.248, the truck became parallel to the barrier with a resultant velocity of 84.2 km/h (52.3 mph). At this same time, the truck rolled toward the right. At 0.258, the truck exited the bridge rail at a speed of 83.7 km/h (52.0 mph) and at an angle of 8.3 degrees. At 0.288 sec, the hood opened and blocked the view from the front windshield. At 0.356 sec, the front of the truck descended toward the ground. At 0.414 sec, all tires, except for the right-rear tire, were airborne. At 0.630 sec, the truck continued to descend toward the ground. At 0.736 sec, the right-rear tire contacted the ground. At 0.802 sec, the left-front tire contacted the ground. At 0.906 sec, the front of the truck pitched downward. At 0.982 sec, the right side of the truck bed became detached. At 1.148 sec, the truck had regained contact with the ground. The vehicle came to rest 77.16 m (253 ft - 2 in.) downstream from impact and 3.05 m (10 ft) laterally away from the traffic-side face of the system. The trajectory and final position of the pickup truck are shown in Figures 41 and 49.

7.3 System Damage

Damage to the barrier and pole was minimal, as shown in Figures 50 through 51. Barrier damage consisted of gouge marks and tire marks. The length of vehicle contact along the concrete barrier system was approximately 3.33 m (10 ft - 11 in.), which spanned from 2.90 m (114 in.) upstream from the centerline of the pole through 432 mm (17 in.) downstream from the centerline of the pole.

Tire marks on the front face of the barrier began 2.90 m (114 in.) upstream from the centerline of the luminaire pole and continue to 432 mm (17 in.) downstream from the centerline of the pole. Minor concrete gouges occurred at the front edge of the concrete barrier's top face throughout the tire mark region. Major gouges were found on the front-top edge of the barrier between 1,346 mm (53 in.) and 1,600 mm (63 in.) upstream from the centerline of the luminaire pole. A 254-mm (10-in.) long by 76-mm (3-in.) wide wheel gouge began 2,362 mm (93 in.) upstream from the centerline pole and 381 mm (15 in.) above the ground on the front face of the concrete barrier. Another 919-mm (7.5-in.) long by 32-mm (1.25-in.) wide wheel gouge on the front face of the wall began 1,842 mm (72.5 in.) upstream from the centerline of the pole and 476 mm (18.75 in.) up above the ground. Another major gouge on the front face of the concrete barrier was located 2,654 mm (104.5 in.) upstream from the centerline of the pole and 330 mm (13 in.) up above the ground. Another 114-mm (4.5-in.) long by 121-mm (4.75-in.) wide gouge surrounded the bolt on the upstream-front corner of the pole. Another major gouge occurred on the downstream edge of the bolt on the upstream-back corner of the pole. Paint scratches were found at 2,769 mm (109 in.) upstream from the centerline of the pole and 178 mm (7 in.) above the ground through 622 mm (24.5 in.) above the ground. Another major region of paint scratches occurred from 584 mm (23 in.) through 1,905 mm (75 in.) upstream of the centerline of the pole and was 152 mm (6 in.) to 254 mm (10 in.) above the ground. The luminaire pole connection bolts were slightly bent.

7.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 52 through 54. Occupant compartment deformations to the right-side floorboard were judged insufficient to cause serious injury to the vehicle occupants, as shown in Figure 55. Maximum longitudinal deflections of 60 mm (2.375 in.) were located near the right-front corner of the right-side floorboard. Maximum lateral deflections of 70 mm (2.75 in.) were located near the right-front corner of the right-side floorboard. Maximum vertical deflections of 98 mm (3.875 in.) were located near the right center of the right-side floorboard. Complete occupant compartment deformations and their corresponding locations are provided in Appendix F.

Damage was concentrated on the front and right sides of the vehicle. The right-front quarter-panel, wheel well, and hood were deformed and dented. The bumper and bumper connections were deformed and damaged. The front bumper encountered two major buckle points. The hood buckled.

The right-front top corner of the box was dented. Light scrapes and deformations were found along the entire right side. One heavy contact mark was found on the right side near the rear of the truck. The top of the right-side door was ajar with a 127 mm (5 in.) gap. The drive shaft disengaged between the rear end and the middle joint. The lower right-side A-frame was deformed upward. The right-side frame horn encountered heavy contact marks and was crushed inward. The right-front wheel fractured but remained attached to the truck. The lower-right side of the windshield shattered. The right-side window glass was fractured and removed. The left side, rear end, and all other window glass remained undamaged.

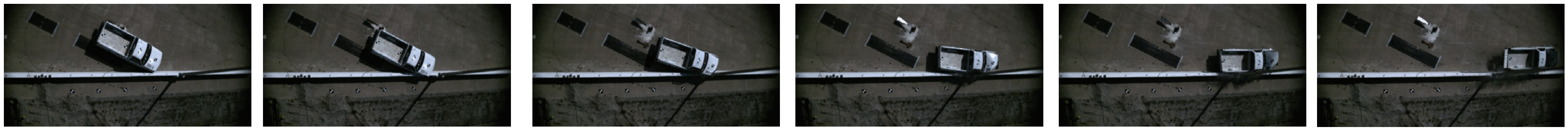
7.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be -5.92 m/s (-19.41 ft/s) and 8.61 m/s (28.25 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were -5.90 Gs and 12.48 Gs, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 41. Results are shown graphically in Appendix G. The results from the rate transducer are shown graphically in Appendix G.

7.6 Discussion

The analysis of the test results for test no. ZOI-2 showed that the single-slope concrete barrier with an attached luminaire pole impacted with the 2000P vehicle 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, or intrusion, into the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier system and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After the collision, the vehicle's trajectory did not intrude into adjacent traffic lanes. In addition, the vehicle's exit angle was less than 60 percent of the impact angle. Therefore, test no. ZOI-2 conducted on the single-slope concrete barrier with an attached luminaire pole was determined to be acceptable according to the TL-4 safety performance criteria of test designation no. 4-11 found in NCHRP Report No. 350.

Since it was not required by NCHRP Report No. 350, test no. ZOI-2 was performed without the use of a non-instrumented dummy positioned in the right-side passenger seat. As such, the results from this test do not demonstrate whether or not a belted passenger would be partially ejected outside of the occupant compartment, thereby allowing the head to contact the pole attached to the top of the barrier. In the future, it is recommended that the crash testing and evaluation of attachments to rigid parapets utilize dummies placed in both small cars and pickup trucks in order to observe the potential for head ejection and contact with the attachment being studied.



0.000 sec | 0.048 sec | 0.104sec | 0.170 sec | 0.248 sec | 0.378 sec

- Test Agency . . . . . . MwRSF
- Test Number ZOI-2
- Date 7/25/03
- NCHRP 35 Test Designation 4-11
- Appurtenance . . . . . . Single-Slope Concrete Barrier With Attached Luminaire Pole
- Total Length . . . . . . 36.58 m
- Overall Height . . . . . . 13,716 mm
- Key Elements - Barrier
  - Description . . . . . . Single-Slope Concrete Barrier
  - Base Width . . . . . . 397 mm
  - Top Width . . . . . . 241 mm
  - Base Width (at pedestal) . . . . . . 565 mm
  - Top Width (at pedestal) . . . . . . 410 mm
  - Height . . . . . . 813 mm
  - Concrete Material . . . . . . Nebraska 47-BD Mix
  - Reinforcing Steel Material . . . . . . Grade 60 Rebar
- Key Elements - Luminaire Pole
  - Pole Description . . . . . . TOOA376-GV30-19 DS210 Pole
  - Arm Description . . . . . . DS60 Arm 150-0560GV-CLMP
  - Size . . . . . . 3.05 mm thick by 11.43 m long
  - Material . . . . . . Galvanized Steel
- Type of Soil . . . . . . NA
- Test Vehicle
  - Type/Designation 2000P
  - Make and Model . . . . . . 1997 GMC 3/4-ton Pickup Truck
  - Curb . . . . . . 2,027 kg
  - Test Inertial . . . . . . 2,009 kg
  - Gross Static . . . . . . 2,009 kg
- Impact Conditions
  - Speed . . . . . . 99.3 km/h
  - Angle . . . . . . 23.4 degrees
  - Impact Location . . . . . . 3,352 mm upstream of pole centerline
- Exit Conditions
  - Speed . . . . . . 83.7 km/h
  - Angle . . . . . . 8.3 degrees
  - Exit Box Criterion . . . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . . . Satisfactory
  - Stopping Distance . . . . . . 77.2 m downstream 3.1 m traffic-side face
- Occupant Impact Velocity
  - Longitudinal . . . . . . -5.92 m/s
  - Lateral (not required) . . . . . . 8.61 m/s
- Occupant Ridedown Deceleration
  - Longitudinal . . . . . . -5.90 Gs
  - Lateral (not required) . . . . . . 12.48 Gs
- THIV (not required) . . . . . . NA
- PHD (not required) . . . . . . NA
- Test Article Damage . . . . . . Minimal
- Test Article Deflections
  - Permanent Set . . . . . . NA
  - Dynamic . . . . . . NA
  - Working Width . . . . . . 664 mm
- Vehicle Damage . . . . . . Moderate
  - VDS[5] 1-RFQ-6
  - CDC[6] 1-RYEW-7
  - Maximum Deformation . . . . . . 98 mm

Figure 41. Summary of Test Results and Sequential Photographs, Test No. ZOI-2

0.000 sec.

0.094 sec.

0.124 sec.

0.148 sec.

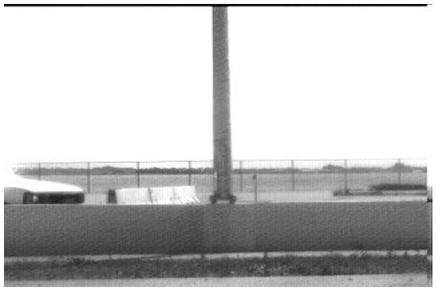
0.234 sec.

0.402 sec.

0.630 sec.

0.906 sec.

Figure 42. Additional Sequential Photographs, Test No. ZOI-2



0.000 sec.

0.044 sec.

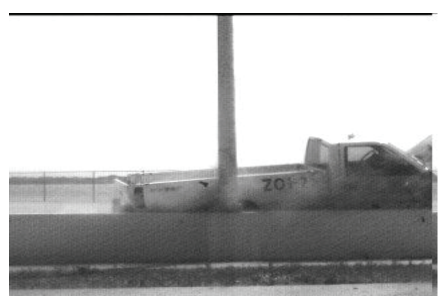
0.080 sec.

0.104 sec.

0.128 sec.

0.172 sec.

0.204 sec.



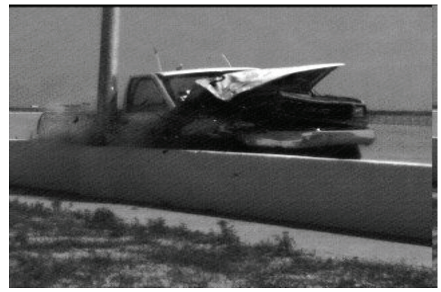
0.262 sec.

Figure 43. Additional Sequential Photographs, Test No. ZOI-2

0.000 sec.

0.170 sec.

0.074 sec.



0.202 sec.

0.114 sec.

0.274 sec.

0.136 sec.

0.356 sec.

Figure 44. Additional Sequential Photographs, Test No. ZOI-2

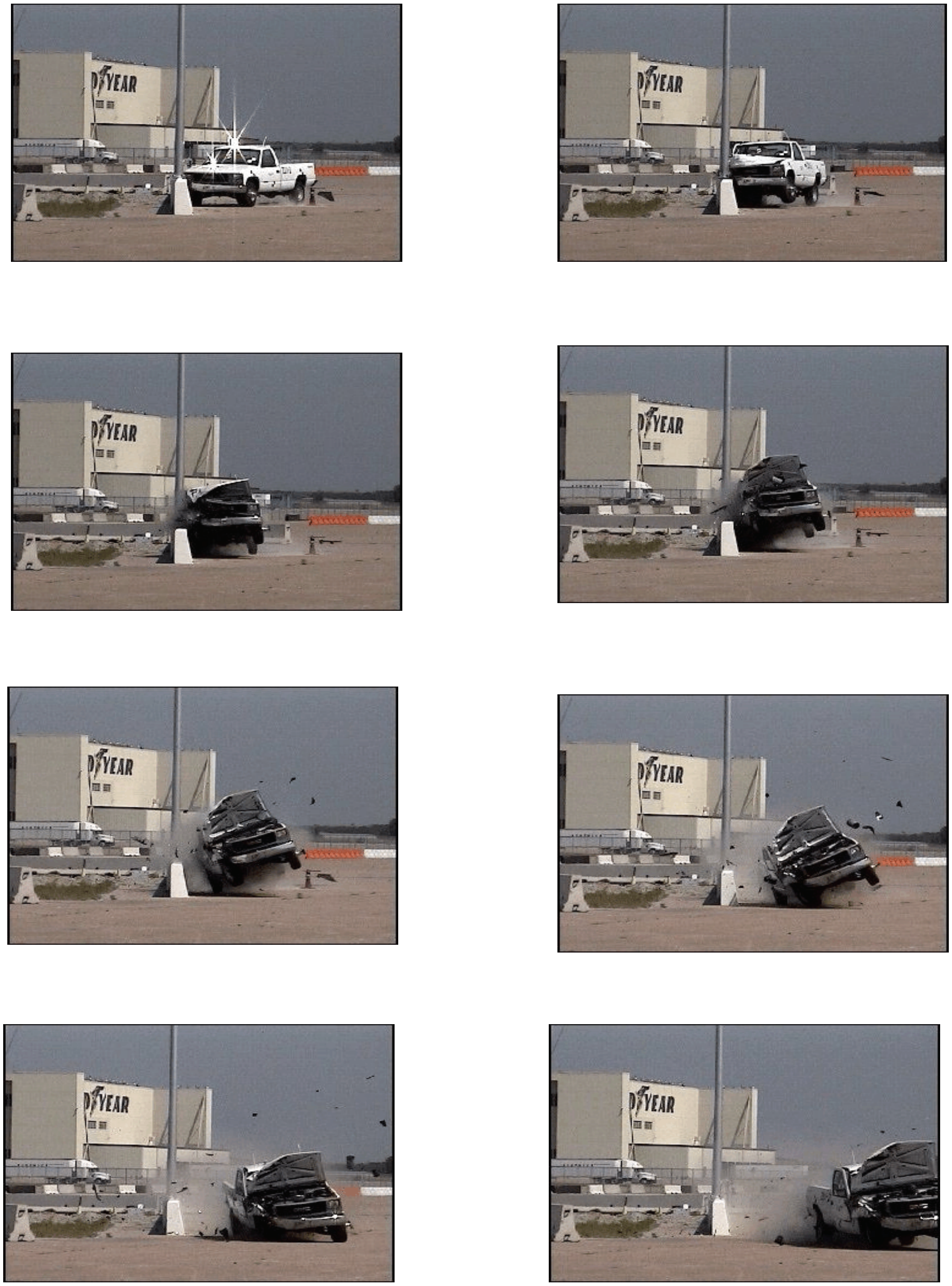


Figure 45. Documentary Photographs, Test No. ZOI-2

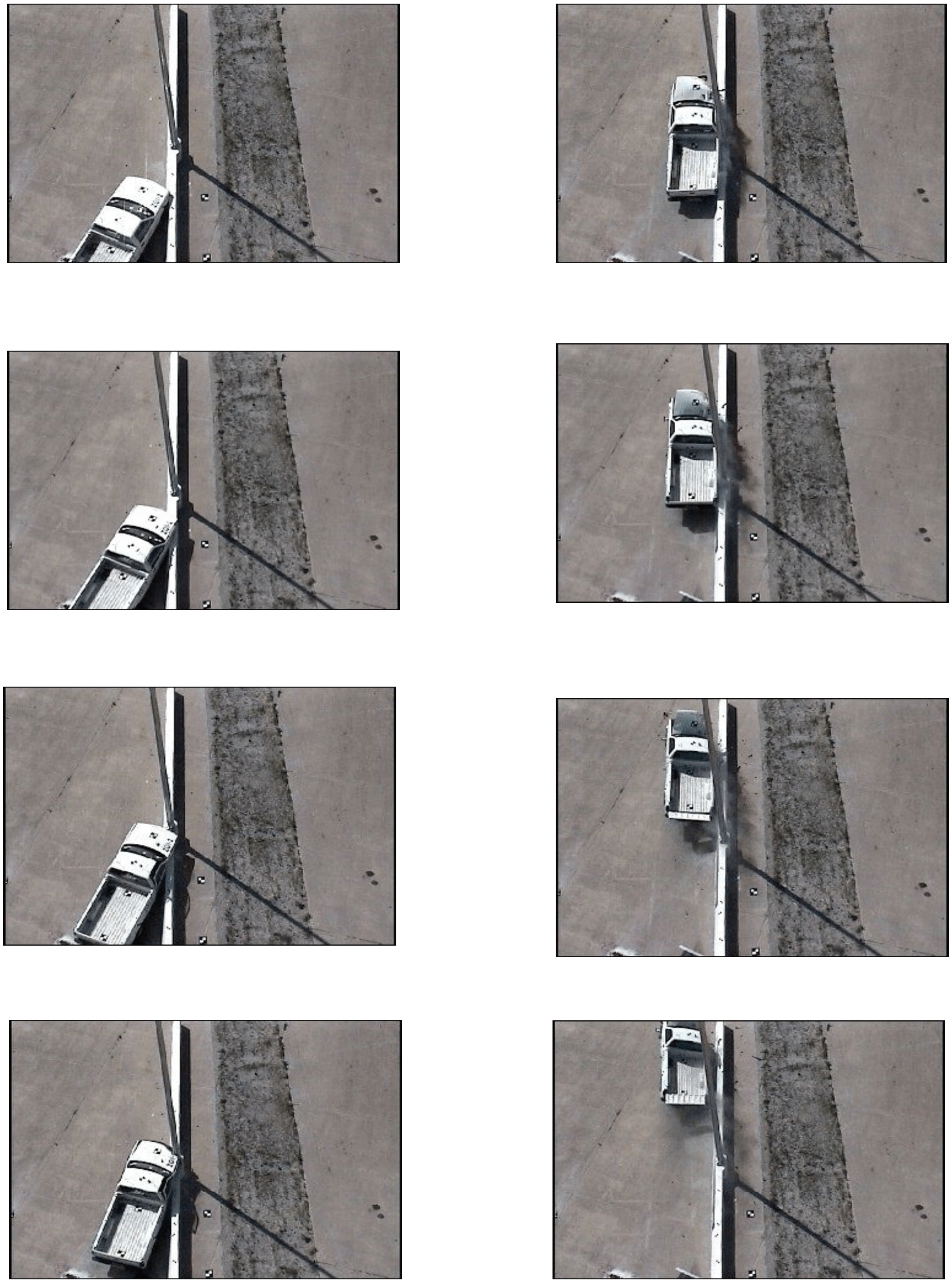


Figure 46. Documentary Photographs, Test No. ZOI-2

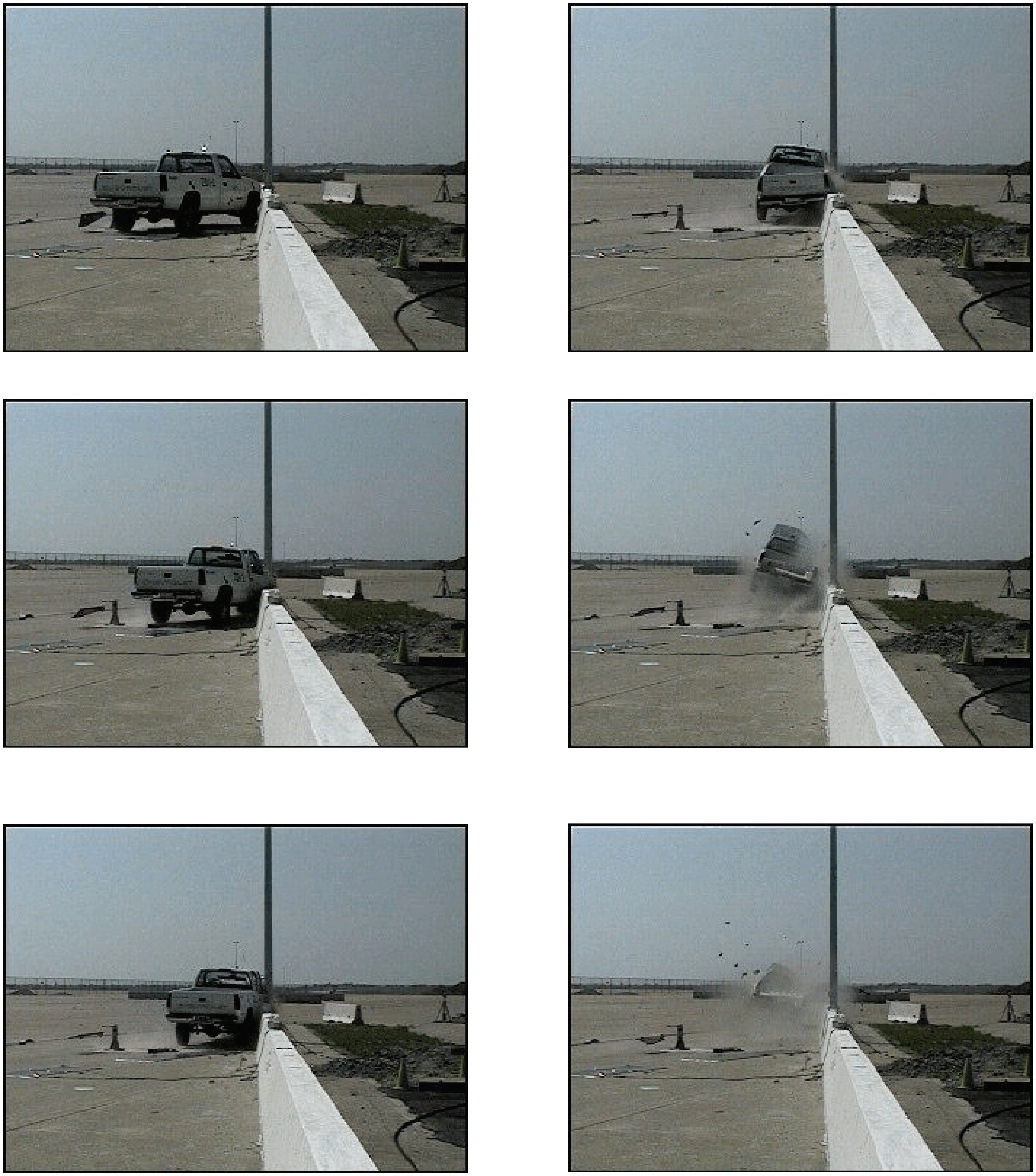


Figure 47. Documentary Photographs, Test No. ZOI-2

Figure 48. Impact Location, Test No. ZOI-2

Figure 49. Vehicle Trajectory and Final Position, Test No. ZOI-2

Figure 50. System Damage, Test No. ZOI-2

Figure 51. System Damage, Test No. ZOI-2

Figure 52. Vehicle Damage, Test No. ZOI-2

Figure 53. Vehicle Damage, Test No. ZOI-2

Figure 54. Undercarriage Damage, Test No. ZOI-2

Figure 55. Occupant Compartment Deformation, Test No. ZOI-2

8 LUMINAIRE POLE LOCATED BEHIND CONCRETE BARRIER

The test installation was identical to the previous system except for the mounting position of the luminaire pole. The luminaire poles used in test nos. ZOI-1 and ZOI-2 were mounted to the top of the single-slope concrete barrier. For the second installation and test no. ZOI-3, the luminaire pole was mounted behind the single-slope concrete barrier and on the concrete surface, as shown in Figures 56 through 60.

Once again, the test installation consisted of a 36.58-m (120-ft) long, standard single-slope concrete barrier. The single-slope concrete barrier was 398 mm (15.625 in.) and 241 mm (9.5 in.) wide at the base and at the top, respectively, with an overall height of 813 mm (32 in.) from the ground to the top of the barrier. In addition, a 11.43-m (37-ft 6-in.) long, galvanized steel luminaire pole, which was identical to that used in the previous system, was placed 267 mm (10.5 in.) behind the barrier to the centerline of the pole. The pole was attached with four 32-mm (1.25-in.) diameter by 470-mm (18.5-in.) long B7 alloy anchors epoxied in the concrete behind the barrier. The corresponding English-unit drawings are shown in Appendix H. Photographs of the barrier and luminaire pole installation are shown in Figures 61 and 62.

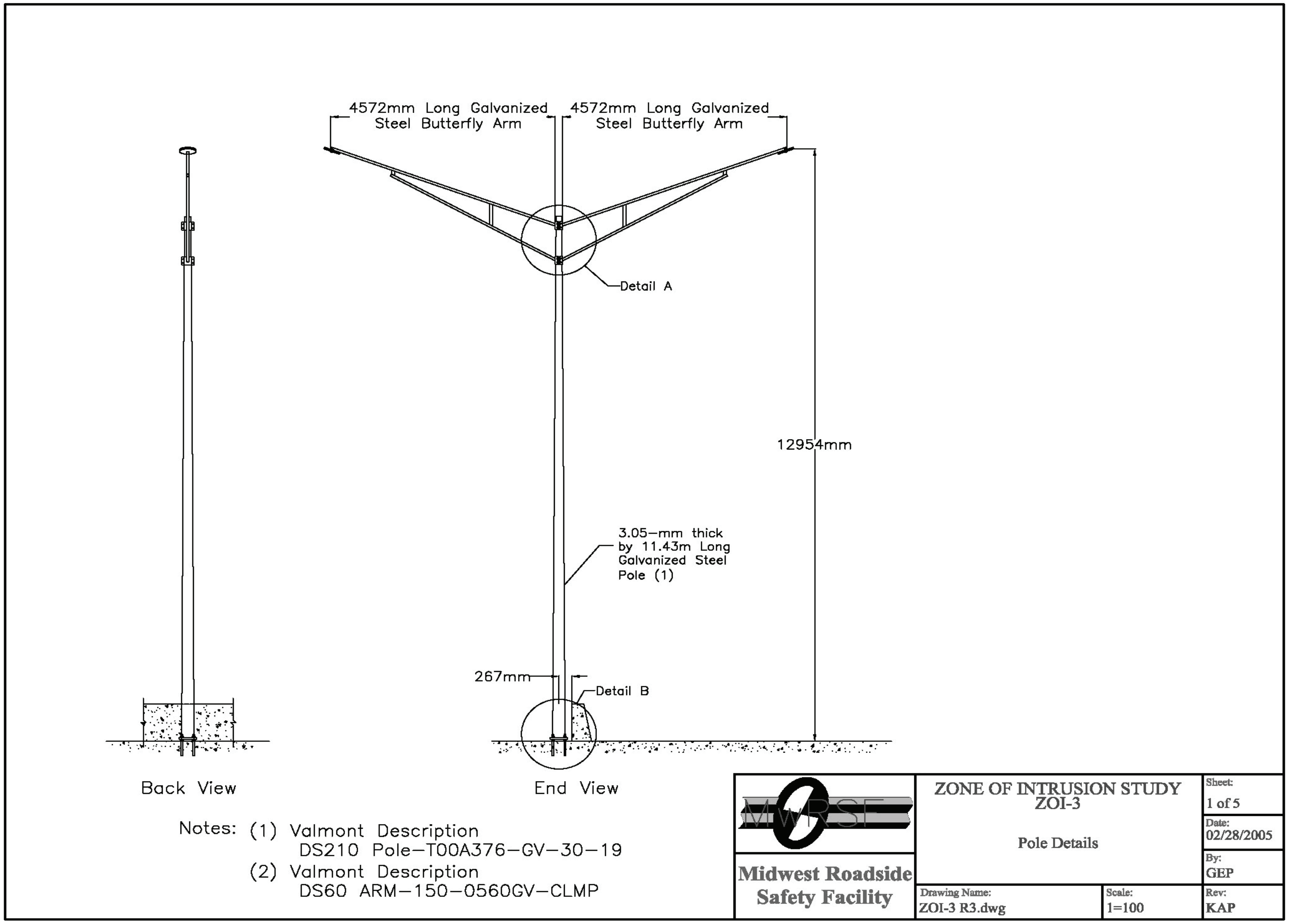


Figure 56. Pole Details, Test No. ZOI-3

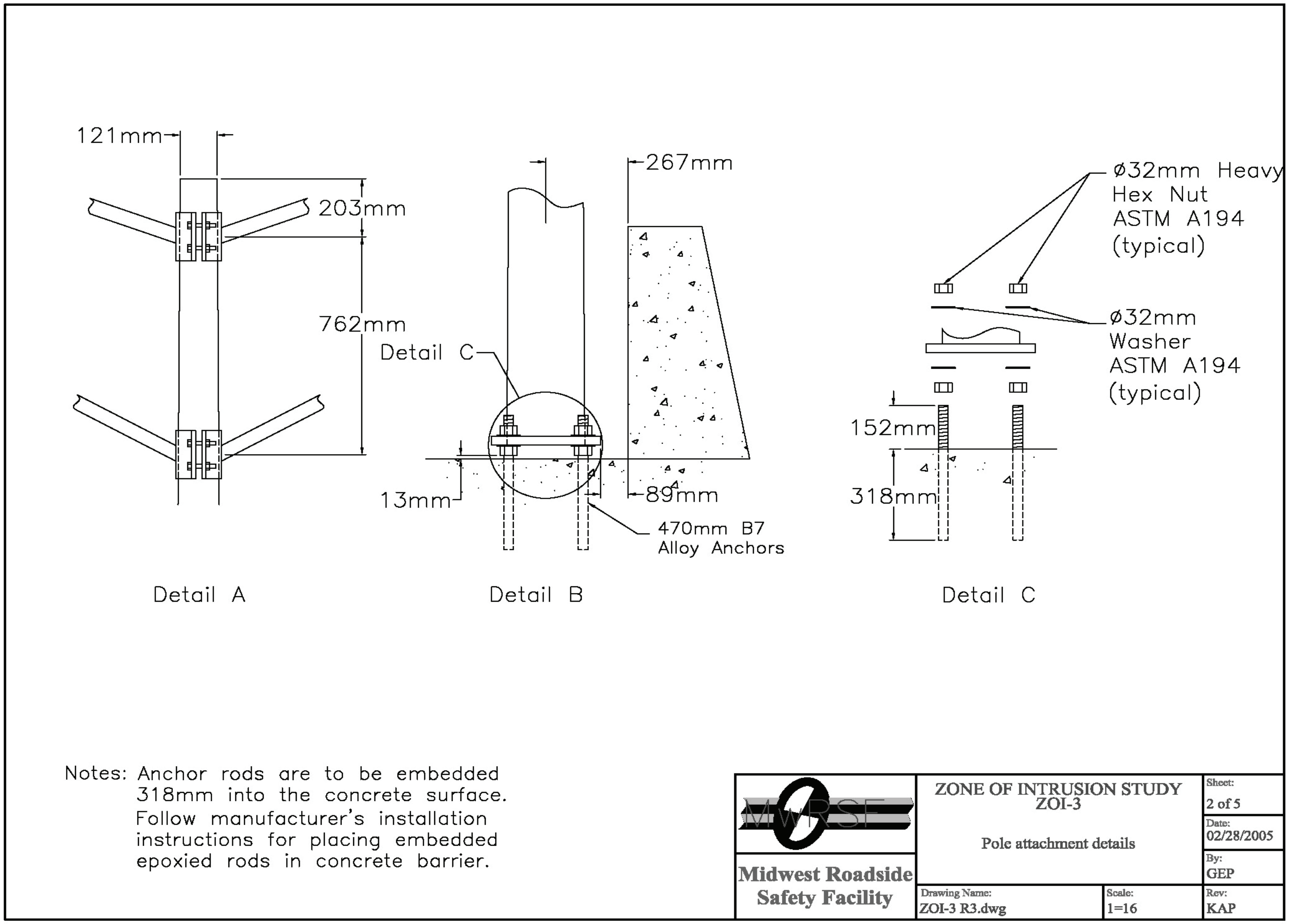


Figure 57. Pole Attachment Details, Test No. ZOI-3

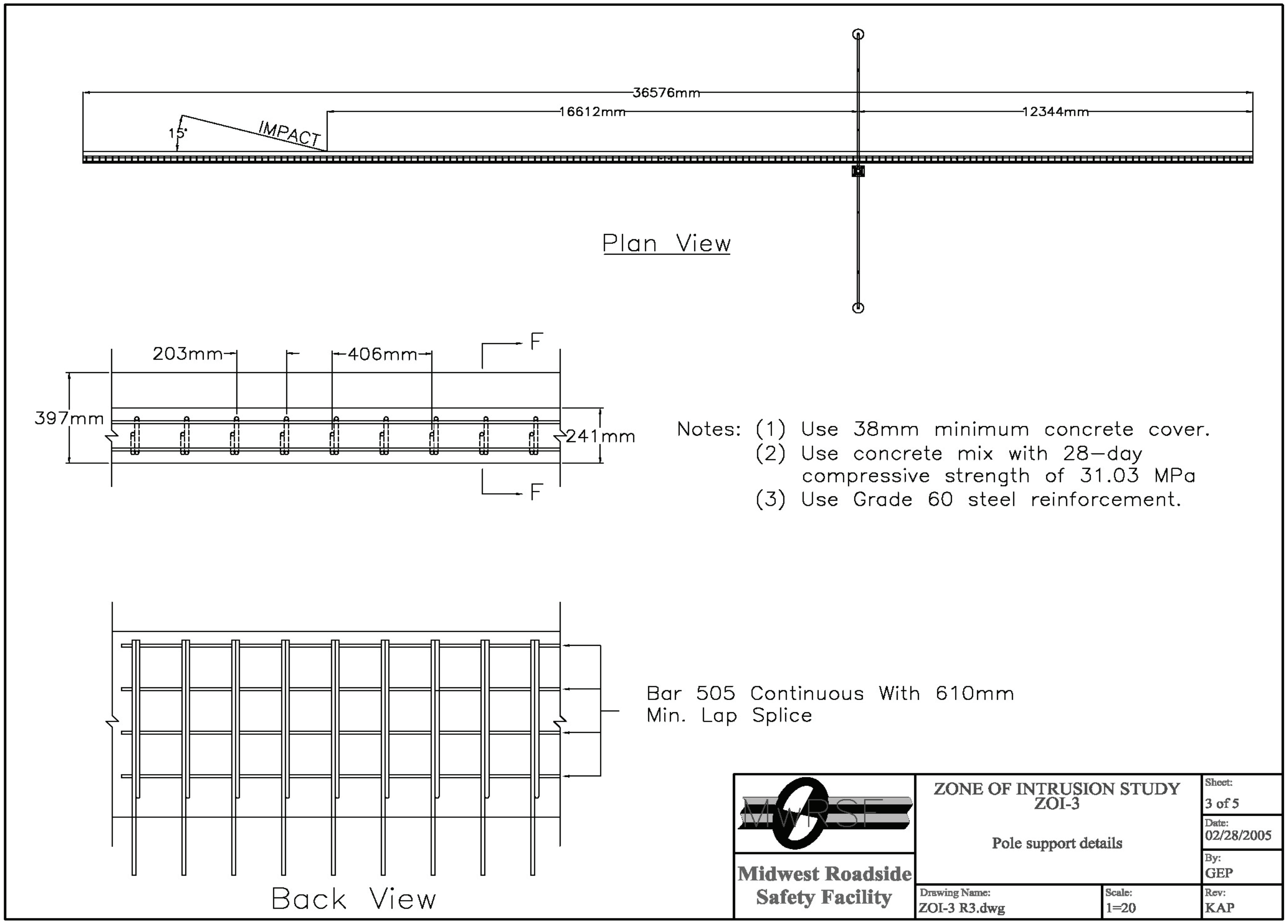


Figure 58. Pole Support Details, Test No. ZOI-3

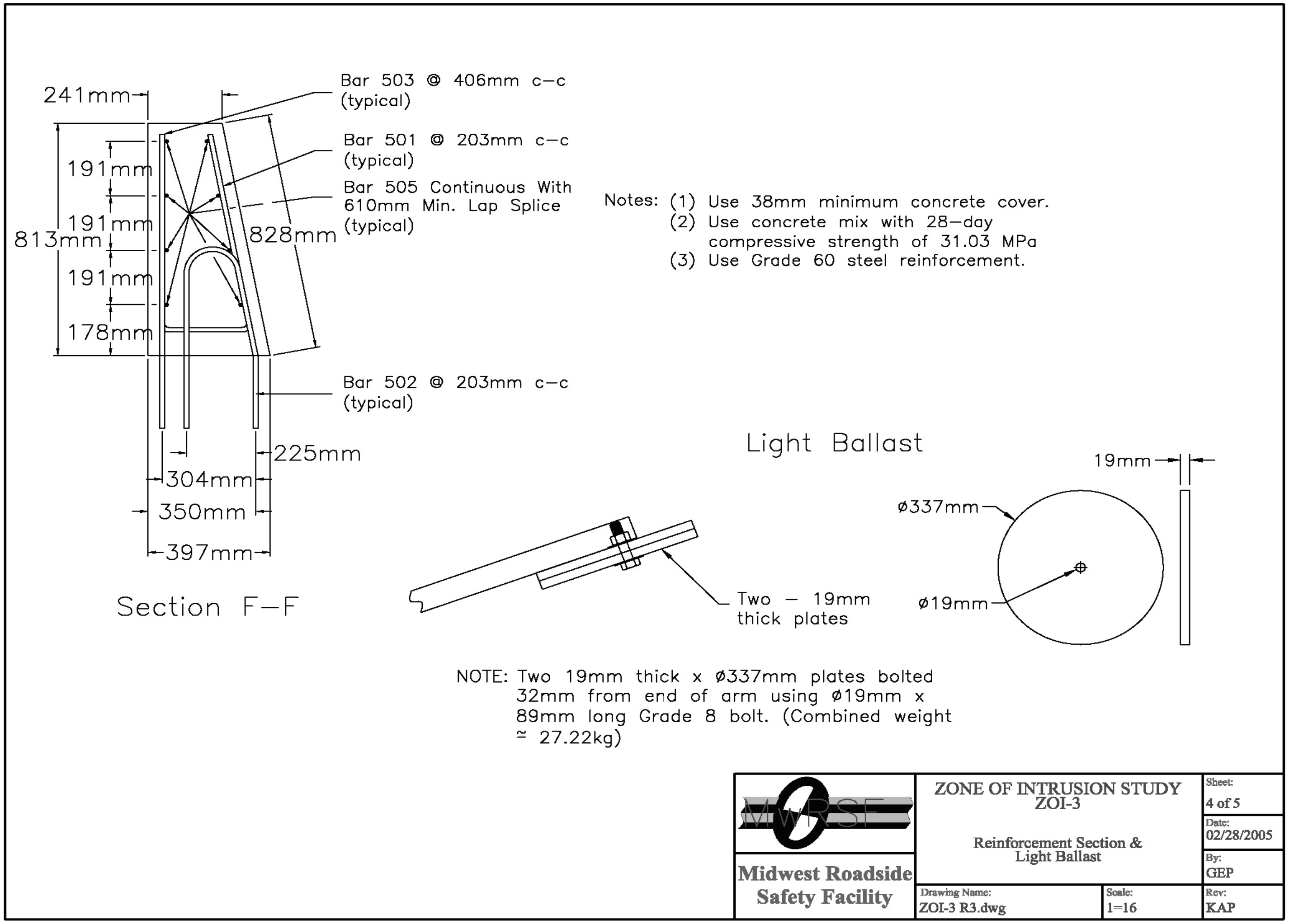
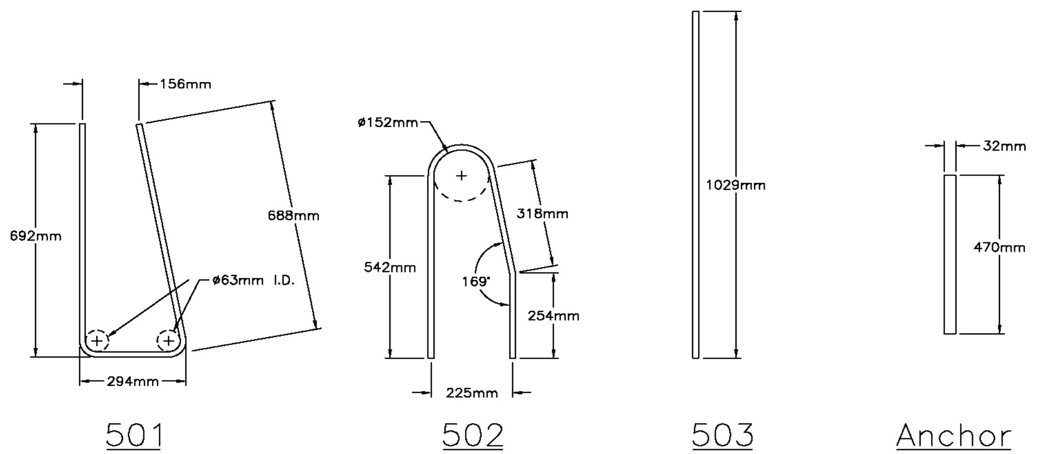


Figure 59. Reinforcement Section and Light Ballast, Test No. ZOI-3



Shape	Bar #	Quantity	Length
501	5	181	1676mm
502	5	181	1346mm
503	5	94	1029mm
Anchor	–	4	470mm – B7 Alloy
505	5	56	609mm

Midwest Roadside Safety Facility	ZONE OF INTRUSION STUDY ZOI-3 Bill of Bars		Sheet: 5 of 5
			Date: 02/28/2005
			By: GEP
	Drawing Name: ZOI-3 R3.dwg	Scale: 1=16	Rev: KAP

Figure 60. Bill of Bars, Test No. ZOI-3

Figure 61. Luminaire Pole Mounted Behind Single-Slope Concrete Barrier, Test No. ZOI-3

Figure 62. Luminaire Pole Mounted Behind Single-Slope Concrete Barrier, Test No. ZOI-3

9 CRASH TEST NO. ZOI-3

9.1 Test No. ZOI-3

An 8,000-kg (17,637-lbs) single-unit truck impacted the single-slope concrete barrier with a luminaire pole placed behind the barrier and mounted to the lower concrete surface at a speed of 80.8 km/h (50.2 mph) and at an angle of 16.4 degrees. A summary of the test results and sequential photographs are shown in Figure 63. The summary of the test results and sequential photographs in English units are shown in Appendix D. Additional sequential photographs are shown in Figure 64 through 67. Documentary photographs of the crash test are shown in Figures 68 and 69.

9.2 Test Description

Initial vehicle impact was to occur 16.61 m (54 ft - 6 in.) upstream of the centerline of the luminaire pole, as shown in Figure 70. Actual vehicle impact occurred 178 mm (7 in.) downstream of the targeted impact. At 0.042 sec after impact, the right-front corner of vehicle crushed inward. At 0.052 sec, the vehicle began to redirect with the right-front corner protruding over the top of the system. At 0.082 sec, the front end of vehicle pitched upward. At 0.130 sec, the box rolled toward the system. At this same time, the box and cab twisted. At 0.180 sec, the right-front corner of the box protruded over the top of the system, and the front of the box lifted upward. At 0.192 sec, the right side of the cab protruded over the top of the system. At 0.210 sec, the front of the box pitched upward. At 0.292 sec, the box rolled toward the system again. At 0.360 sec, the cab rolled toward the system. At this same time, the left side of the vehicle rose into the air. At 0.400 sec, the left-rear tire became airborne. At 0.510 sec, the box reached its maximum intrusion of 906 mm (35.6875 in.) over the system. At 0.582 sec, the vehicle slid along the top of the barrier. At 0.732 sec, the left side of the vehicle descended toward the ground. At 0.858 sec, the pole moved due to vehicle impact but remained in place. At 0.920 sec, the vehicle rolled toward the left side with minor debris disengaging from the vehicle. At 1.040 sec, the rear of the vehicle pitched upward. At 1.270 sec, the vehicle and the box twisted.. At 1.470 sec, the vehicle rolled toward the right. At 1.506 sec, the right-front wheel contacted and scraped the barrier. At 1.570 sec, the vehicle redirected away from the system. At 2.104 sec, the rear of the vehicle yawed toward the system. At 3.272 sec, the vehicle reached the end of the system. At this same time, the left-rear corner of the box pitched upward, and the vehicle rolled toward the system. The vehicle never became parallel to the system before it exited the end of the barrier. The vehicle came to rest 52.81 m (173 ft - 3 in.) downstream from impact and inline with the concrete barrier. The trajectory and final position of the single-unit truck are shown in Figures 63 and 71.

9.3 System Damage

Damage to the barrier was moderate, as shown in Figure 72. Barrier damage consisted of gouge and tire marks. The length of vehicle contact along the concrete barrier system was approximately 28.78 m (94 ft - 5 in.), which spanned from 16.43 m (53 ft - 11 in.) upstream of the centerline of the pole through the downstream end of the system.

A 356-mm (14-in.) long by 114-mm (4.5-in.) wide gouge began 17.03 m (55 ft - 10.5 in.) upstream from the centerline of the pole. A 349-mm (13.75-in.) long gouge began 16.88 m (55 ft - 4.5 in.) upstream from the centerline of the pole. A 349-mm (13.75-in.) long by 25-mm (1-in.) wide gouge began 16.43 m (553 ft - 11 in.) upstream from the centerline of the pole. A 876-mm (34.5-in.) long by 229-mm (9-in.) wide gouge began 16.29 m (53 ft - 55 in.) upstream from the centerline of the pole. A 1,054-mm (41.5-in.) long by 305-mm (12-in.) wide gouge began 15.93 m (52 ft - 3 in.) upstream from the centerline of the pole. A 1,080-mm (42.5-in.) long by 102-mm (4-in.) wide gouge began 15.56 m (51 ft - 0.75 in.) upstream from the centerline of the pole. A 622-mm (24.5-in.) long by 121-mm (4.75-in.) wide gouge began 15.09 m (49 ft - 6.25 in.) upstream from the centerline of the pole. A 699-mm (27.5-in.) long by 203-mm (8-in.) wide gouge began 15.15 m (49 ft - 8.5 in) upstream from centerline of the pole. A 686-mm (27-in.) long by 51-mm (2-in.) wide gouge began 14.82 m (48 ft - 7.5 in.) upstream from the centerline of the pole. A 394-mm (15.5-in.) long by 95-mm (3.75-in.) wide gouge began 14.62 m (47 ft - 11.5 in.) upstream from the centerline of the pole. A 495-mm (19.5-in.) long by 64-mm (2.5-in.) wide gouge began 14.19 m (46 ft - 6.5 in.) upstream from the centerline of the pole. A 457-mm (18-in.) long by 95-mm (3.75-in.) wide gouge began 14.17 m (46 ft - 6 in.) upstream from the centerline of the pole. A 159-mm (6.25-in.) long by 25-mm (1-in.) wide gouge began 14.14m (46 ft - 4.5 in.) upstream from the centerline of the pole. A 419-mm (16.5-in.) long by 32-mm (1.25-in.) wide gouge began 6.82 m (22 ft - 4.5 in.) upstream from the centerline of the pole. A 229-mm (9-in.) long by 57-mm (2.25-in.) wide gouge began 5.09 m (16 ft - 8.5 in.) upstream from the centerline of the pole. The upper-front edge of concrete barrier encountered spalling from 9.22 m (30 ft - 3 in.) upstream from the centerline of the pole through the end of the barrier. Minor contact marks were found on top of the concrete barrier from 10.16 m (33 ft - 4 in.) upstream from the centerline of the pole through 3.66 m (12 ft) upstream from the centerline of the pole.

Major concrete gouging was found on the front face of the concrete barrier. One large area of gouging began 83 mm (3.25 in.) above the ground and 16.90 m (55 ft - 5.5 in.) upstream from the centerline of the pole and encompassed the majority of the front face through 11.26 m (36 ft -11.5 in.) upstream from the centerline of the pole. Another large area of gouging with an average width of 381 mm (15 in.), spanned from 7.77 m (25 ft - 6 in.) upstream from the centerline of the pole and

76 mm (3 in.) above the ground to 902 mm (35.5 in.) downstream from the centerline of the pole and 457 mm (18 in.) above the ground. A 178-mm (7-in.) wide major gouge spanned from 2.43 m (7 ft - 11.5 in.) downstream from the centerline of the pole and 470 mm (18.5 in.) above the ground to 4.64 m (15 ft - 2.5 in.) downstream from the centerline of the pole and 470 mm (18.5 in.) and 648 m (25.5 in.) above the ground. One last major gouge, with an average width of 381 mm (15 in.), spanned from 6.81m (22 ft - 4.25 in.) downstream from the centerline of the pole and 749 mm (29.5 in.) above the ground through 10.86 m (33 ft - 7.5 in.) downstream from the centerline of the pole and 368 mm (14.5 in.) above the ground.

The pole encountered minor scuff and scrape marks on the upstream face. The pole remained attached to the concrete. No deformations or damage occurred to the attachment mechanism, as shown in Figure 72.

9.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 73 through 75. Occupant compartment deformations did not occur. Complete occupant compartment deformations and their corresponding locations are provided in Appendix I.

Damage was concentrated on the right-front corner of the vehicle. The right side of the front bumper deformed inward. The plastic headlight housing fractured on both the left and right sides. The left-side fender was bent and deformed inward. The metal straps for the left-side and right-side fuel tanks fractured. The right-side fuel tank was dented. The box frame on the right side was severely bent above the tire. The wood supports fractured, and the box shifted. The U-bolts deformed. The right-side trim was deformed. The right-side mirror was severely damaged. The right-side suspension springs broke. The right-front fender disengaged. The front axle detached and was rotated 90 degrees. The left-front tire bead broke, and the tire was deflated. The right-front wheel hub encountered scrapes and dents. The right-front tire was deflated. The right-rear steel rim was damaged, and the outside tire was deflated. The right-side door window shattered. The left side, rear, and all other window glass remained undamaged.

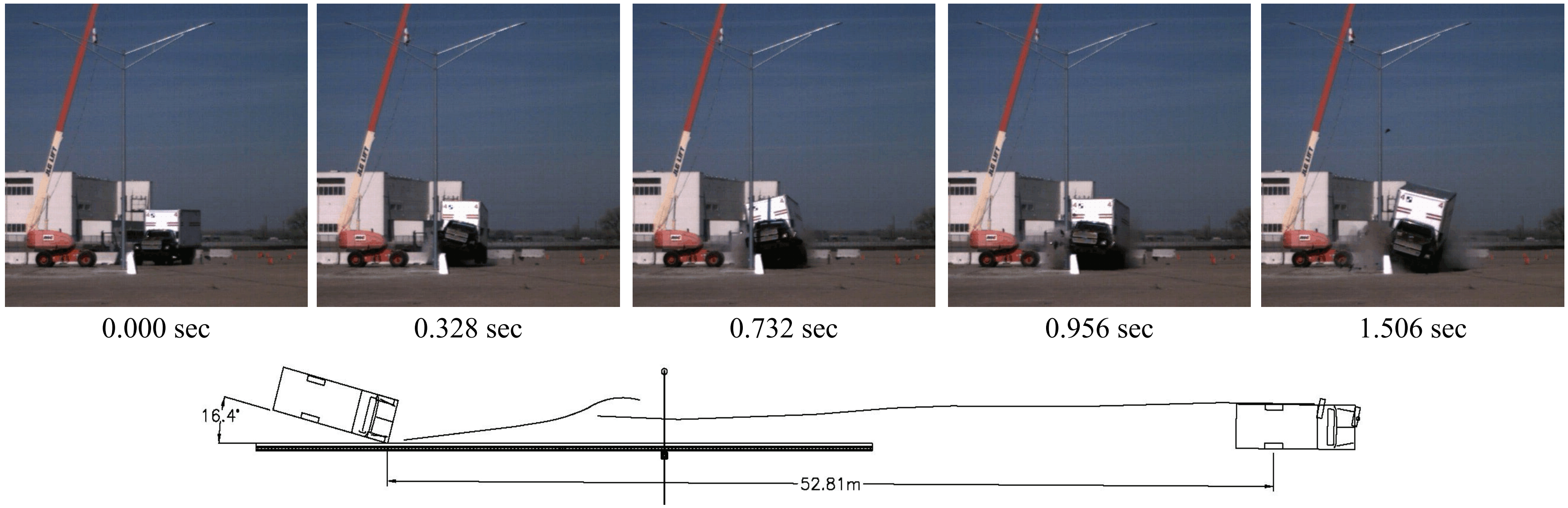
9.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be 2.59 m/s (8.51 ft/s) and 2.24 m/s (7.36 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 3.13 Gs and 6.43 Gs, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 63. Results are shown graphically in Appendix J. The results from the rate transducer are shown graphically in Appendix J.

9.6 Discussion

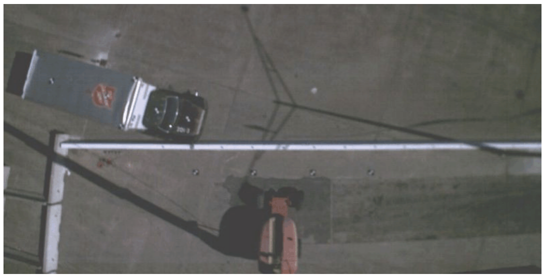
The analysis of the test results for test no. ZOI-3 showed that the single-slope concrete barrier with a luminaire pole placed behind it adequately contained and redirected the 8000S vehicle with controlled lateral displacements of the barrier system. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations, or intrusion, into the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier system and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After the collision, the vehicle's trajectory did not intrude into adjacent traffic lanes. In addition, the vehicle's exit angle was less than 60 percent of the impact angle. Therefore, test no. ZOI-3 conducted on the single-slope concrete barrier with a ground-mounted luminaire behind it was determined to be acceptable according to the TL-4 safety performance criteria of test designation no. 4-12 found in NCHRP Report No. 350.

For test no. ZOI-3, the impact location was determined from an analysis of prior 8000S vehicle impacts into single-slope barrier systems. The 16.61 m (54 ft - 6 in.) impact location was selected in order to maximize the vehicle penetration over the top of the barrier at the same time at which vehicle contact with the pole was believed to occur. Unfortunately, during the test no. ZOI-3, the 8000S vehicle reached its maximum extent over the barrier prior to striking the pole, and actually was rolling away from the pole at the time of contact with it. In addition, a different truck behavior was observed as compared to test no. ZOI-1 and other 8000S vehicle impacts into single-slope barriers. As such, MwRSF researchers recommend caution with the use of these test results as a worst-case impact scenario was not observed between the 8000S vehicle and the ground-mounted luminaire pole.



● Test Agency	MwRSF	● Impact Conditions	
● Test Number	ZOI-3	Speed	80.8 km/h
● Date	3/2/05	Angle	16.4 degrees
● NCHRP 350 Test Designation	4-12	Impact Location	16.6 m upstream of pole centerline
● Appurtenance	Single-Slope Barrier with Luminaire Pole Behind Barrier	● Exit Conditions	
● Total Length	36.58 m	Speed	NA
● Overall Height	12,954 mm	Angle	NA
● Key Elements - Barrier		Exit Box Criterion	Pass
Description	Single-Slope Concrete Barrier	● Post-Impact Trajectory	
Base Width	397 mm	Vehicle Stability	Satisfactory
Top Width	241 mm	Stopping Distanve	52.80 m downstream
Height	813 mm	● Occupant Impact Velocity	
Concrete Material	Nebraska 47-BD Mix	Longitudinal (not required)	2.59 m/s
Reinforcing Steel Material	Grade 60 Rebar	Lateral (not required)	2.24 m/s
● Key Elements - Luminaire Pole		● Occupant Ride Down Deceleration	
Pole Description	TOOA376-GV30-19 DS210 Pole	Longitudinal (not required)	3.13 Gs
Arm Description	DS60 Arm 150-0560GV-CLMP	Lateral (not required)	6.43 Gs
Size	3.05 mm thick by 11.43 m long	● THIV (not required)	NA
Material	Galvanized Steel	● PHD (not required)	NA
● Type of Soil	NA	● Test Article Damage	Moderate
● Test Vehicle		● Test Article Deflections	
Type/Designation	8000S	Permanent Set	NA
Make and Model	1989 Ford F800	Dynamic	NA
Curb	5,440 kg	Working Width	906 mm
Test Inertial	8,000 kg	● Vehicle Damage	Moderate
Gross Static	8,000 kg	VDS[5]	I-RFQ-3
		CDC[6]	I-FREW-4
		Maximum Deformation	NA

Figure 63. Summary of Test Results and Sequential Photographs, Test No. ZOI-3



0.000 sec

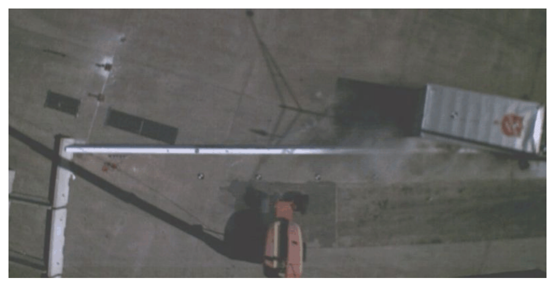
0.132 sec

0.192 sec

0.422 sec

0.582 sec

0.762 sec



0.948 sec

1.108 sec

Figure 64. Additional Sequential Photographs, Test No. ZOI-3

0.000 sec.

0.170 sec.

0.360 sec.

0.460 sec.

0.710 sec.

0.920 sec.

1.270 sec.

1.670 sec.

Figure 65. Additional Sequential Photographs, Test No. ZOI-3

0.000 sec.

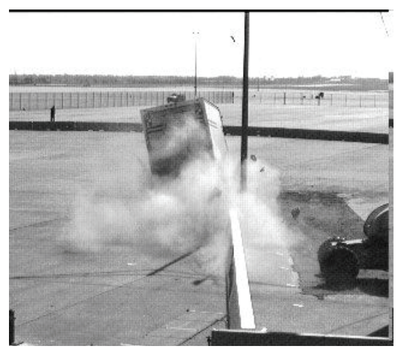
0.180 sec.

0.400 sec.

0.858 sec.

1.040 sec.

1.096 sec.



1.470 sec.

1.910 sec.

Figure 66. Additional Sequential Photographs, Test No. ZOI-3

0.000 sec.

0.328 sec.

0.428 sec.

0.732 sec.

0.956 sec.

1.506 sec.

1.936 sec.

3.272 sec.

Figure 67. Additional Sequential Photographs, Test No. ZOI-3

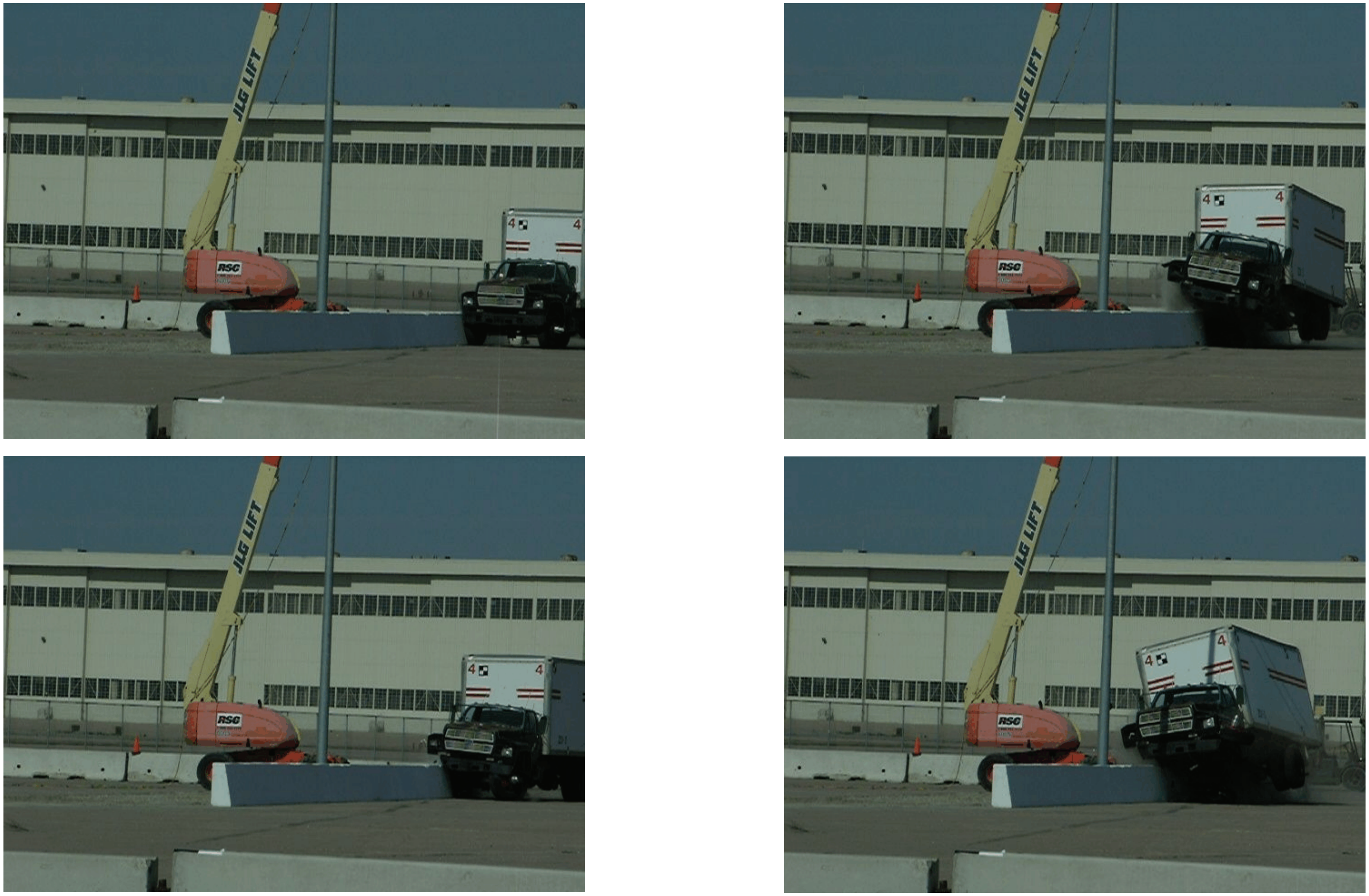


Figure 68. Documentary Photographs, Test No. ZOI-3

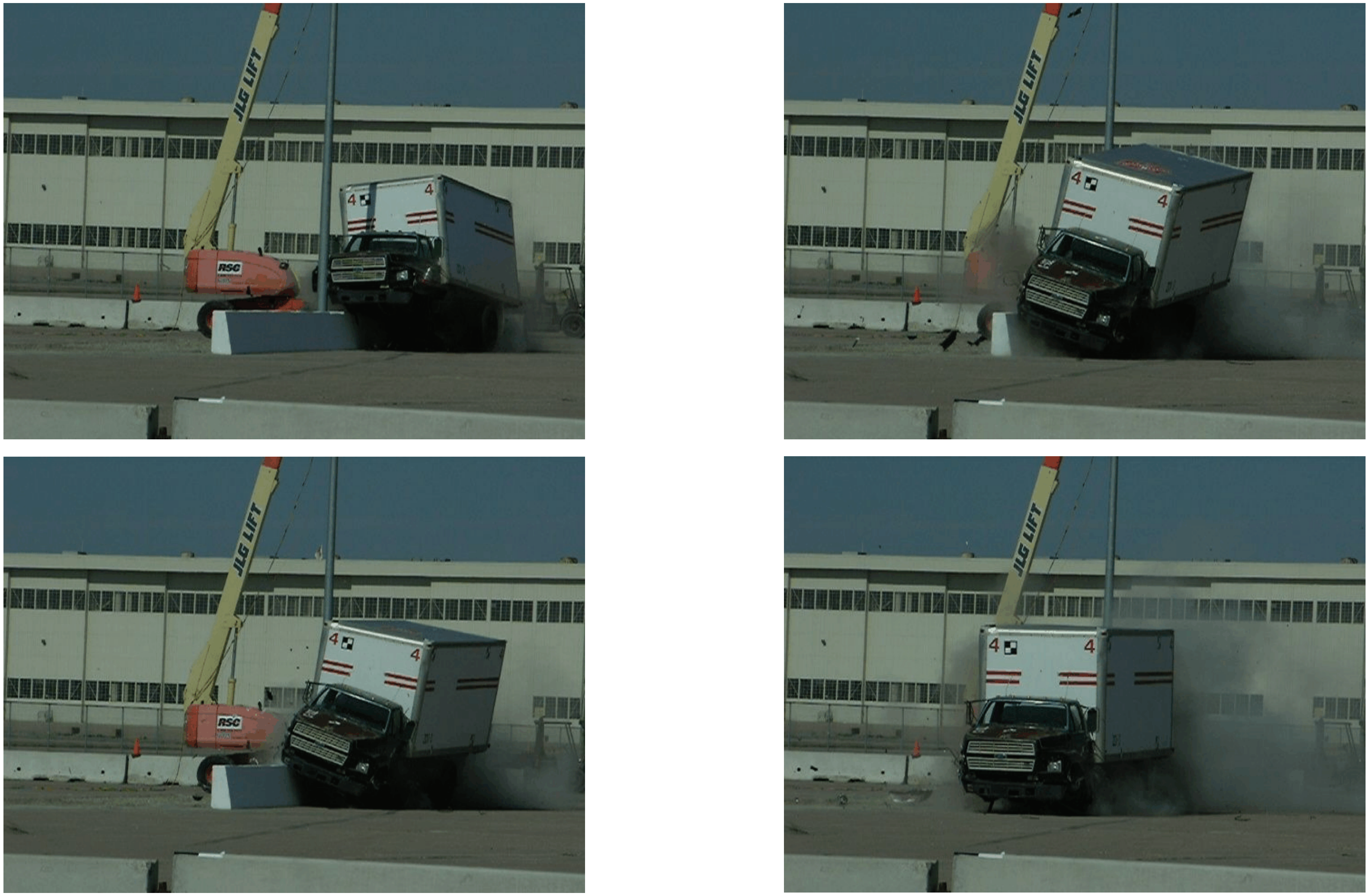


Figure 69. Documentary Photographs, Test No. ZOI-3

Figure 70. Impact Location, Test No. ZOI-3

Figure 71. Vehicle Final Position and Trajectory Marks, Test ZOI-3

Figure 72. System Damage, Test No. ZOI-3

Figure 73. Vehicle Damage, Test No. ZOI-3

Figure 74. Vehicle Damage, Test No. ZOI-3

Figure 75. Undercarriage Damage, Test No. ZOI-3

10 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A galvanized steel luminaire pole was placed both on top of and behind a standard rigid single-slope concrete barrier and subjected to full-scale vehicle crash testing. Three full-scale crash tests were performed on the combination luminaire pole and barrier systems.

The first full-scale crash test, test no. ZOI-1, was performed according to test designation 4-12 of NCHRP Report No. 350 with the luminaire pole attached to the top of the concrete barrier. The test consisted of a 7,985-kg (17,605-lb) single-unit truck impacting the single-slope barrier at a speed of 81.0 km/h (50.4 mph) and at an angle of 15.6 degrees. The impact point for this test was 16.8 m (55 ft) upstream from the centerline of the pole. During the test, the luminaire pole detached from the barrier and landed behind and parallel to the barrier. This result would not pose significant concerns for median barrier applications as the dislodged pole landed within the shoulder and edge of lane regions. For bridge railing applications, a flailing pole would only pose safety concerns if vehicular traffic and/or pedestrians are found below. Subsequently, the test results were found to meet all of the NCHRP Report No. 350 safety requirements as the single-unit truck was safely brought to a controlled stop.

The second full-scale crash test, test no. ZOI-2, was performed according to test designation 4-11 of NCHRP Report No. 350 with the luminaire pole attached to the top of the concrete barrier. The test consisted of a 2,009-kg (4,430-lb) pickup truck impacting the single-slope barrier at a speed of 99.3 km/h (61.7 mph) and at an angle of 23.4 degrees. The impact point for this test was 3.4 m (11 ft) upstream from the centerline of the pole. Once again, the test results were found to meet all of the NCHRP Report No. 350 safety requirements as the pickup truck was safely brought to a controlled stop. Since it was not required by NCHRP Report No. 350, test no. ZOI-2 was performed without the use of an instrumented dummy positioned in the right-side driver seat. As such, the results from this test do not demonstrate whether or not a belted passenger would be partially ejected outside of the occupant compartment, thereby allowing the head to contact the pole attached to the top of the barrier. In the future, it is recommended that the crash testing and evaluation of attachments to rigid parapets utilize dummies placed in both small cars and pickup trucks in order to observe the potential for head ejection and contact with the attachment being studied.

The third full-scale crash test, test no. ZOI-3, was performed according to test designation 4-12 of NCHRP Report No. 350 with the luminaire pole placed behind the concrete barrier. The test consisted of a 8,000-kg (17,637-lb) single-unit truck impacting the single-slope barrier at a speed of 80.8 km/h (50.2 mph) and at an angle of 16.4 degrees. The impact point for this test was 16.6 m (54 ft - 6 in.) upstream from the centerline of the pole. The test results were again found to meet all of the NCHRP Report No. 350 safety requirements as the single-unit truck was safely brought to a controlled stop. During the test no. ZOI-3, the 8000S vehicle reached its maximum extent over the barrier prior to striking the pole, and actually was rolling away from the pole at the time of contact with it. In addition, a different truck behavior was observed as compared to ZOI-1 and other 8000S vehicle impacts into single-slope barriers. As such, MwRSF researchers recommend caution with the use of these test results as a worst-case impact scenario was not observed between the 8000S vehicle and the ground-mounted luminaire pole.

It should be noted that the intrusion zone exhibited by the two single-unit truck test fell within the intrusion zone for TL-4 barriers specified in the results of the year 9 Pool Fund Study. On the other hand the intrusion zone of the pickup truck test was 51 mm (2 in.) outside of the intrusion zone of the previous study (2). Furthermore, the test results indicate that this luminaire pole attached to the top of a concrete median barrier or a bridge railing, one that is free from vehicular traffic and/or pedestrians below, is suitable for use on Federal aid highways. In addition, these results indicate that a luminaire pole placed both behind and below a concrete barrier may also provide a safe alternative. However, further full-scale crash testing with 8000S vehicles is recommended in order to properly evaluate the varying behaviors observed during truck-to-barrier impacts. Finally, any significant modifications to the attachment mechanism or pole placement would require additional analysis and can only be verified through the use of full-scale crash testing. A summary of the safety performance evaluation of the three test is provided in Table 3.

Table 3. Summery of Safety Performance Evaluation Results

	Evaluation Criteria	Test ZOI-1	Test ZOI-2	Test ZOI-3
A.	Test article should contain and redirect the vehicle, the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	S	S	S
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 that could cause serious injuries should not be permitted.	S	S	S
F.	The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	NA	S	NA
G.	It is preferable, although not essential, that the vehicle remain upright during and after collision.	S	NA	S
K.	After the collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	S	S	S
L.	The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 Gs.	NA	S	NA
M.	The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	S	S	S

S- Satisfactory
M- Marginal
U- Unsatisfactory
NA- Not Applicable

11 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. Keller, E.A., Sicking, D.L., Faller, R.K., Polivka, K.A., and Rohde, J.R., *Guidelines for Attachments to Bridge Rails and Median Barriers*, Final Report to the Midwest State's Regional Pooled Fund Program, Transportation Record No. TRP-03-98-03, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, February 26, 2003.

3. *Missouri Highway and Transportation Commission*, Standard M90101Z, Missouri Department of Roads, January 1, 2002.

4. *Single Slope Concrete Barrier*," Bride and Roadway with Illumination, Texas Department of Transportation, May 1992

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

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

7. Taborck, J.J., *Mechanics of Vehicle - 7*, Machine Design Journal, May 30, 1957.

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

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

12 APPENDICES

APPENDIX A

Design Considerations State Standards

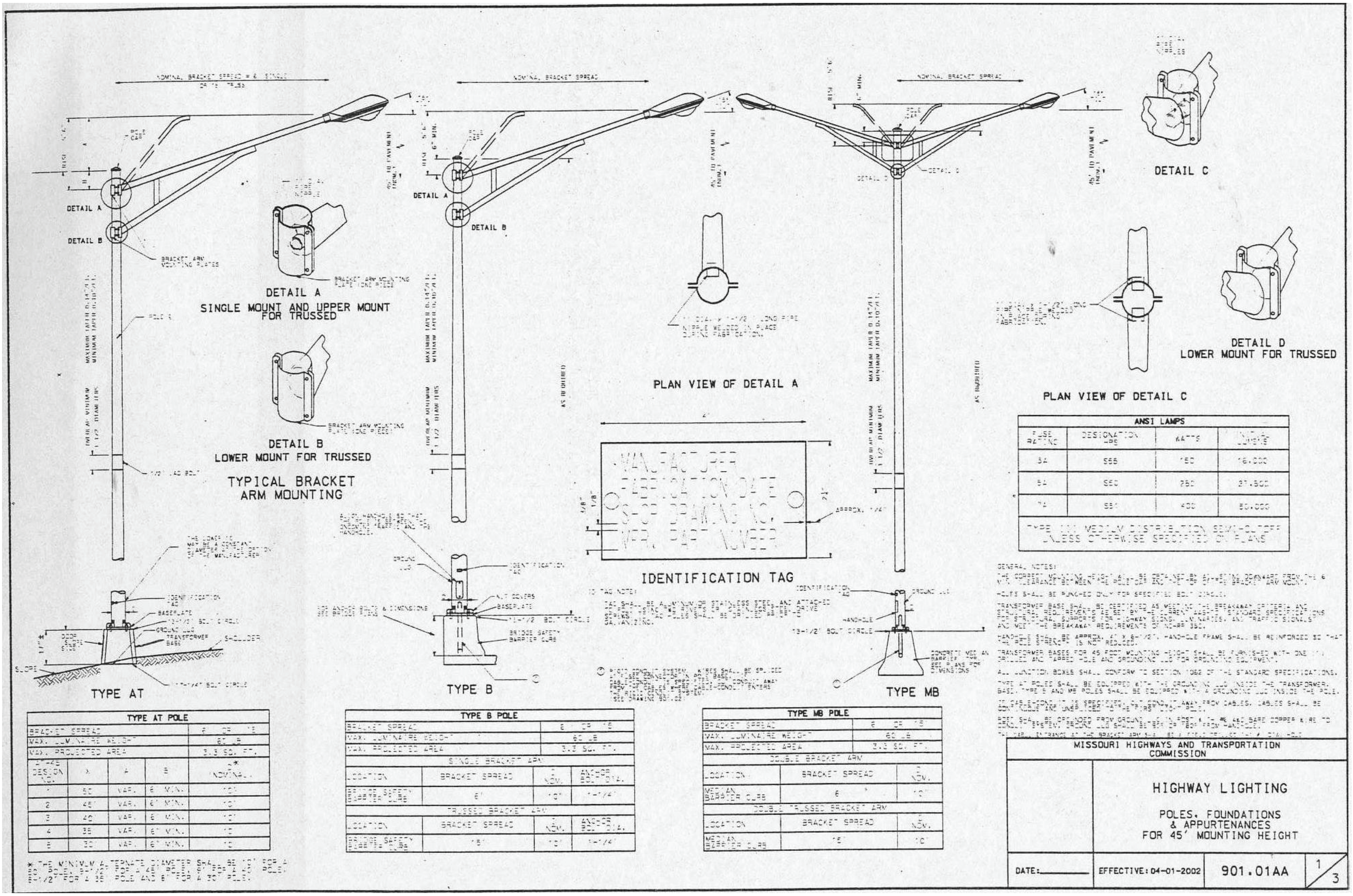


Figure A-1. MoDOT Highway Lighting Design Details (Page 1)

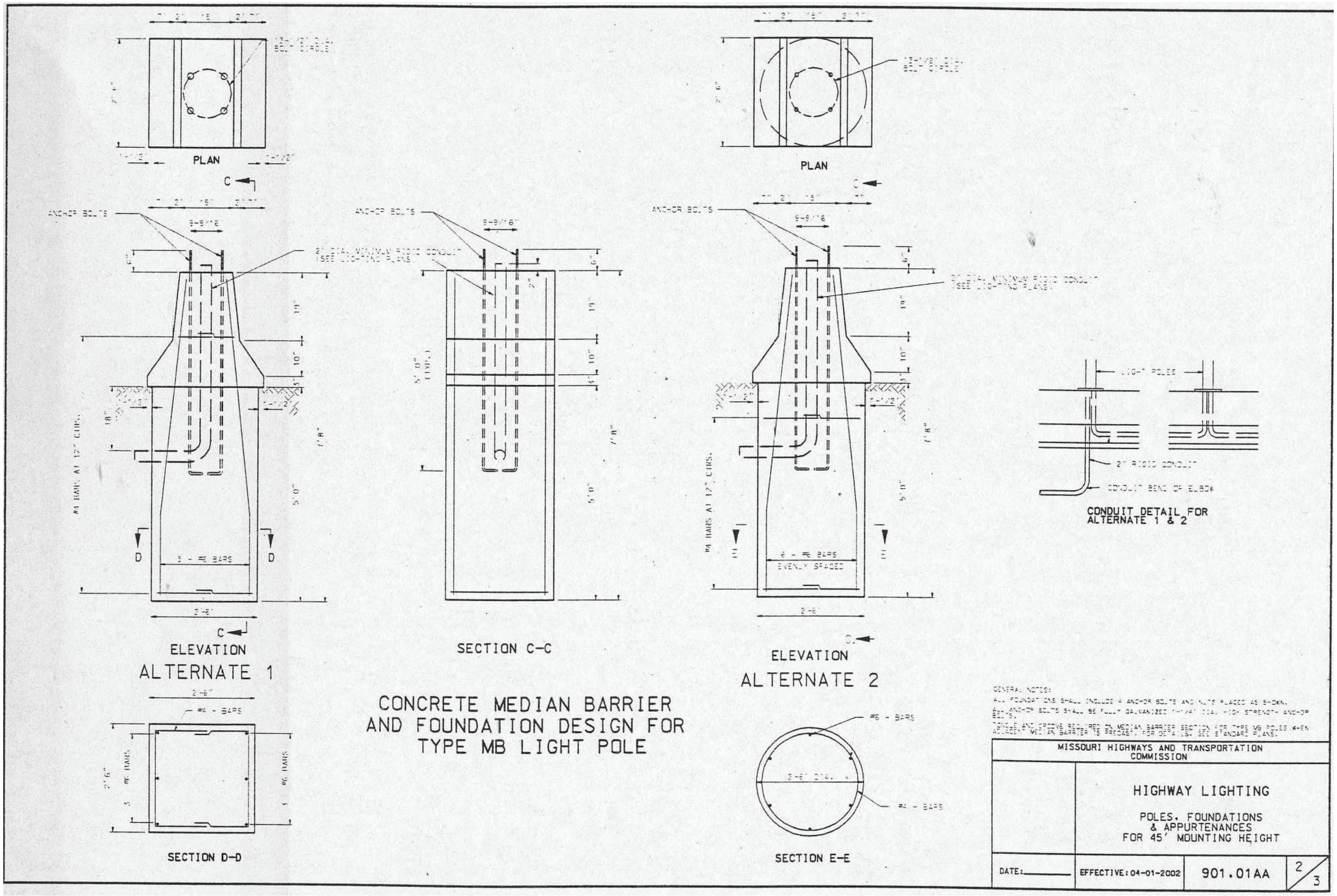


Figure A-2. MoDOT Highway Lighting Design Details (Page 2)

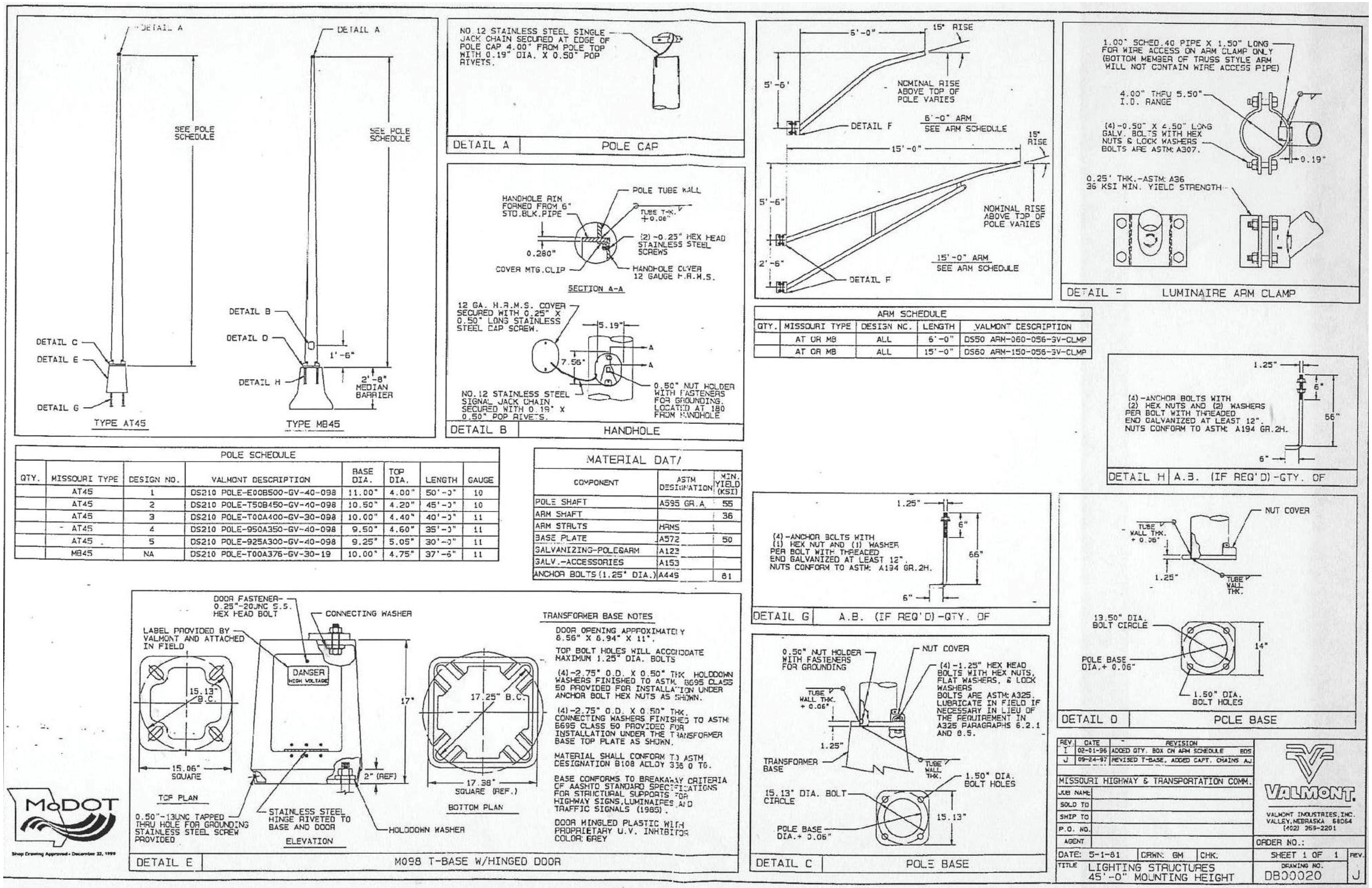


Figure A-3. MoDOT Valmont Lighting Structure 45 ft Mounting Height

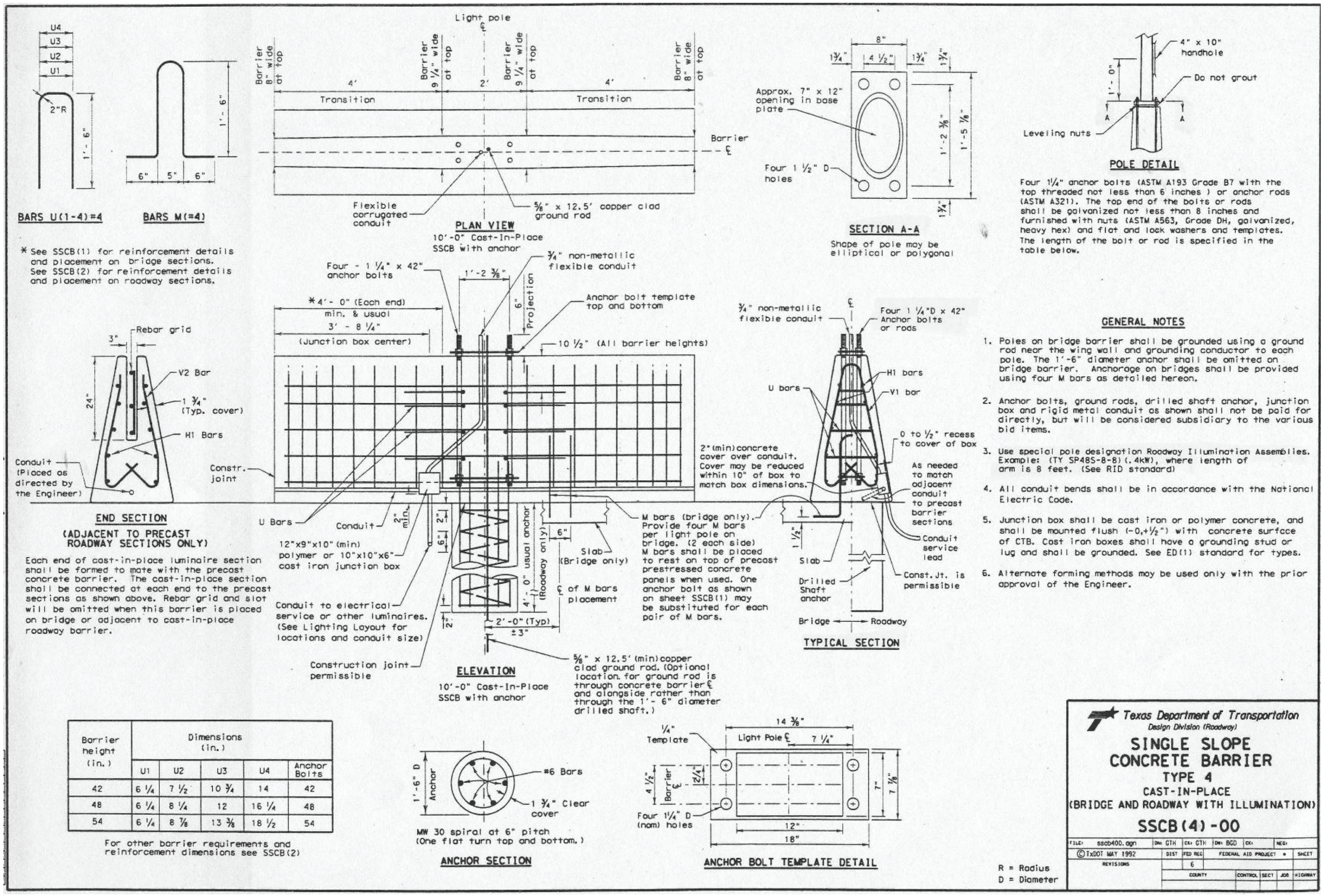


Figure A-4. TxDOT Single-Slope Concrete Barrier with Illumination

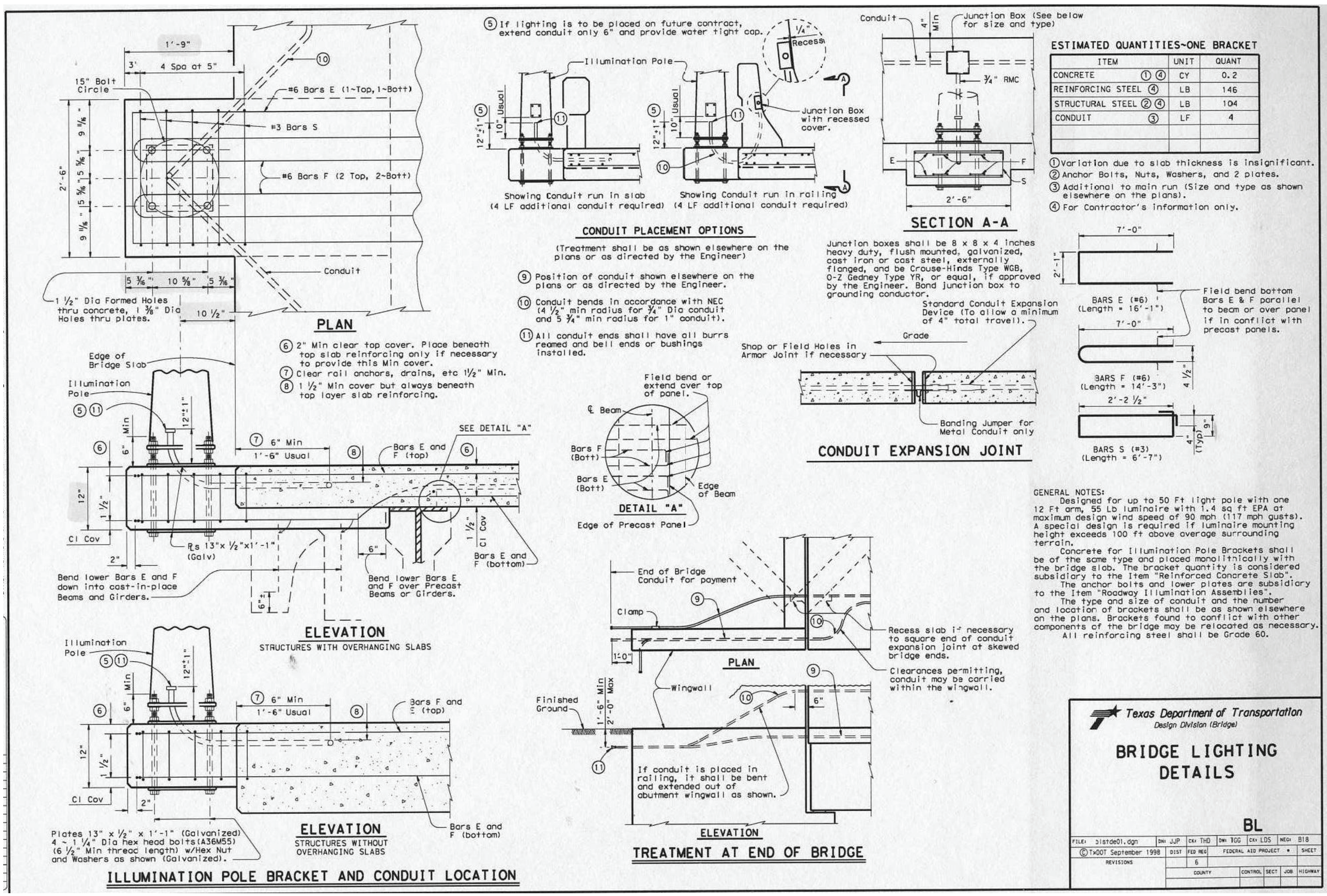


Figure A-5. TxDOT Bridge Lighting Details

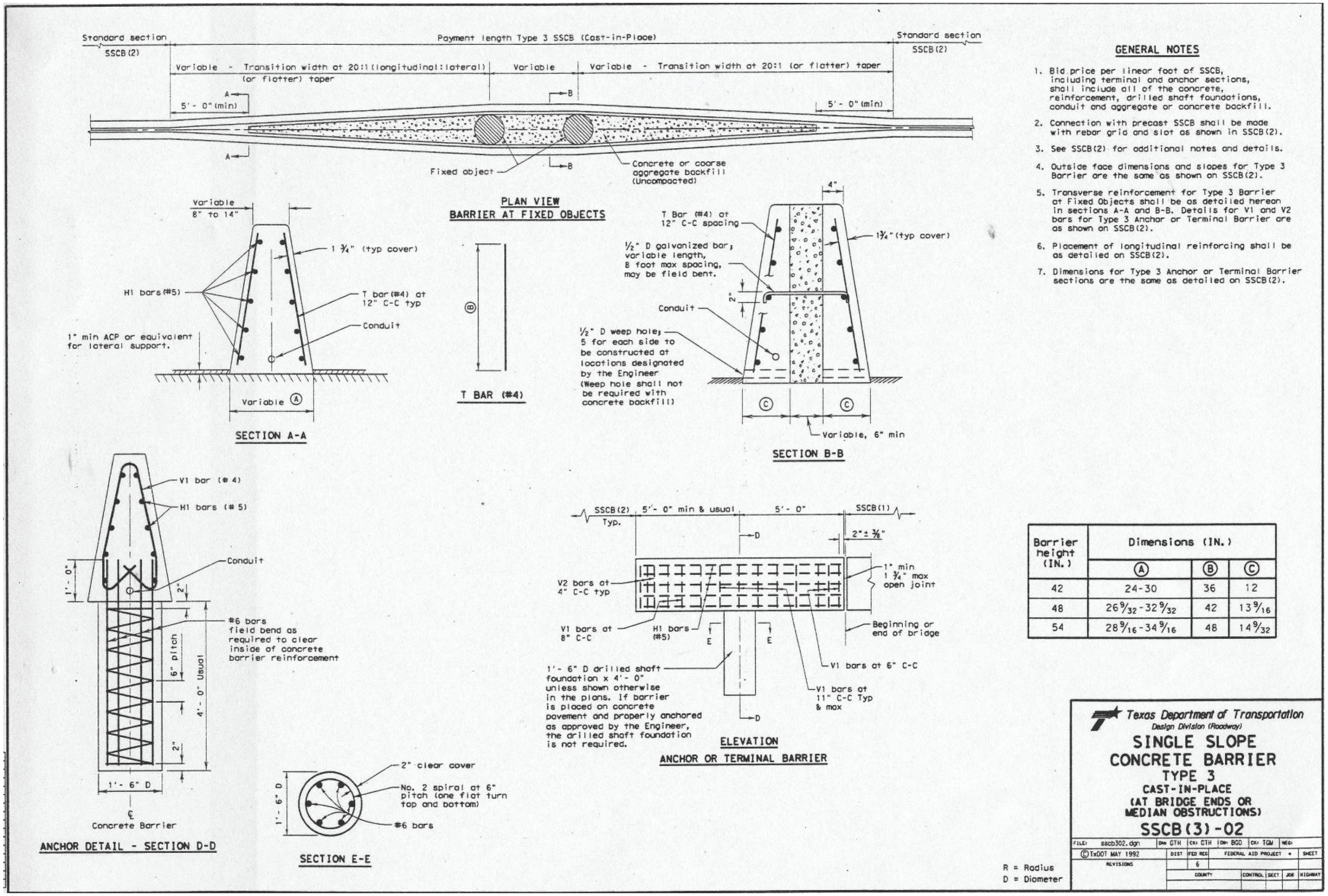


Figure A-6. TxDOT Single-Slope Concrete Barrier

APPENDIX B

Valmont Industries, Inc. Luminaire Pole Material Details

valmont POLES

April 7, 2003

University of Nebraska-Lincoln
Administration Building Room 401
Lincoln, NE 68588

Certification: Lighting Standards
University of Nebraska-Lincoln Purchase Order No.: 4500087849
Valmont Industries, Inc. Order No.: 43522-03

The attached material fabricator's statement covers the material furnished for the subject Order/Project. The galvanizing was done in accordance with ASTM A123. This material does conform to the Buy America requirements of the Surface Transportation Assistance Act of 1982. (S.T.A.A.).

I certify that the reports are a true and correct copy as contained in the records of the company.

Sincerely,

VALMONT INDUSTRIES, INC.

Amy Betzinger
Amy Betzinger
Certification Specialist
Poles Division

cc: Electrical Products
Steve Krohn
Scott Sare

Poles Division, Valmont Industries, Inc.
7002 North 288th Street P.O. Box 358 Valley, Nebraska 68064-0358 USA
402-359-2201 800-825-6668 www.valmont.com

Figure B-1. Valmont Luminaire Pole Materials' Details

FABRICATOR'S MATERIAL STATEMENT

FORM NO : 914(REV. 2/23/90)
CUSTOMER : UNIV. OF NEBRASKA-LINCOLN
SITE :
PROJECT :
PURCHASE ORDER : 4500087849

DATE : 4/7/2003
VALMONT INDUSTRIES, INC.
P.O. BOX 358
VALLEY, NE 68064
ORDER NO : 4352203

MATERIAL INFORMATION

P.O. No.	QTY	MATERIAL DESCRIPTION	VENDOR	HEAT NUMBER	MATERIAL USE	ASTM SPEC/GR
D1662	2	10" OD TUBE	NUCOR STEEL	126378	POLE SHFT	A595/A
E2459	2	1.25" PLATE	CITISTEEL USA	1K204	BS PLT	A572/50
38731	4	2.375" OD PIPE	VALMONT INDUSTRIES	D38224	PIPE ARM	A500/B
E3839	16	.25" PLATE	METRON STEEL	831Z13820	ARM CLMP	A36

THIS STATEMENT CERTIFIES THAT MATERIALS BEARING THE ABOVE LISTED DESCRIPTIONS WERE USED IN THIS PROJECT/ORDER. THE ATTACHED "MILL TEST REPORTS" ARE TYPICAL FOR MATERIALS OF THOSE DESIGNATIONS. ALTERNATIVELY, THROUGH "CERTFICATION", VALMONT ATTESTS THAT THE MATERIALS ARE OF PROPER DESIGNATION. THIS PRODUCT DOES CONFORM TO THE "BUY AMERICA" REQUIREMENTS OF THE SURFACE TRANSPORTATION ACT OF 1982.(S.T.A.A.)

SUBSCRIBED IN MY PRESENCE, SWORN TO, AND ACKNOWLEDGED BEFORE ME AT VALLEY, NEBRASKA, THIS 7 DAY OF APRIL 2003 BY THE SUBSCRIBER WHO IS TO ME PERSONALLY KNOWN.

NOTARY PUBLIC: Roberta J. Cody

AMY BETZINGER
CERTIFICATION SPECIALIST
POLES DIVISION

GENERAL NOTARY - State of Nebraska
ROBERTA J. CODY
My Comm. Exp. Sept. 26, 2006

Page : 1 of 2

Figure B-2. Fabricator's Material Statement

VALMONT INDUSTRIES INC. POLES DIVISION FORM 914A

CERTIFIED TEST REPORT : A595 TAPERED TUBE(S) DATE : 4/7/2003

CUSTOMER ORDER NO : 4500087849 VALMONT ORDER NO : 4352203

VENDORS : NS-NATIONAL, US-USS, LT-LTV, GE-GENEVA, NU-NUCOR *WEATHERING ASTM A595 GRADE(S):A-MIN 55KSI, B-MIN 60 KSI, WEATHERING(A606/4) MIN 60 KSI THE CHEMISTRY IS TRANSCRIBED FROM MILL REPORTS MAINTAINED IN VALMONT FILES

QTY	GA	DIAM	HEAT	VE	C	YIELD PSI	TENSL PSI	EL%	C	MN	P	S	SI	CU	CR	NI
2	11	10.00	126378	NU	N	64500	77200	31	0.24	0.71	0.01	0.00	0.03	0.09	0.06	0.04

SUBSCRIBED IN MY PRESENCE, SWORN TO, AND ACKNOWLEDGED BEFORE ME AT VALLEY, NEBRASKA, THIS 7 DAY OF APRIL 2003 BY THE SUBSCRIBER WHO IS TO ME PERSONALLY KNOWN.

NOTARY PUBLIC: Roberta J. Cody

GENERAL NOTARY - State of Nebraska
ROBERTA J. CODY
My Comm. Exp. Sept. 26, 2006

Amy Betzinger
AMY BETZINGER
CERTIFICATION SPECIALIST
POLES DIVISION

Page : 2 of 2

Figure B-3. Poles Division

CitiSteel USA
INCORPORATED
4001 PHILADELPHIA PIKE
CLAYMONT, DELAWARE 19703 U.S.A.

MATERIAL TEST REPORT

SOLD TO:
VALMONT INDUSTRIES, INC.
P.O. BOX 358

VALLEY, NE

SPECIFICATION
ASTM A572-00 GRADE 50 with .05% max Si / Valmont Specification S-11 Rev. 3

L ORDER	BILL OF LADING	CUSTOMER P.O. NO.	DATE
151590	181356	E2459	01/08/03

Unless otherwise specified, the following conditions apply: 1. Material is 100% melted and manufactured in the USA. 2. Mercury, radium or alpha source materials have not been used. 3. Test piece serial # represents actual plate tested, not necessarily plate shipped (except PVQ where every plate is tested).

CHEMICAL ANALYSIS

HEAT	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	V	Nb	N	Acid Soluble Al	Ti
1K204	0.08	1.30	0.016	0.030	0.03	0.35	0.20	0.15	0.067	0.022	0.013	0.118	0.002	0.011	0.011	

EAT	NO PCS	GAUGE (IN)	WIDTH (IN)	LENGTH (IN)	TEST PIECE SERIAL #	NORM	TENSILE (KSI)	YIELD (KSI)	ELONG % IN	BEND	TEST TEMP (F)	FT-LBS 1	FT-LBS 2	FT-LBS 3	MILS LAT EXP 1	MILS LAT EXP 2	MILS LAT EXP 3	% SHEAR 1	% SHEAR 2	% SHEAR 3
1K204	2	1.2500	84.0000	132.0000	0617661		78.0	56.0	24	2										
	Part	Number:	0072448																	
1K204	-	1.2500	84.0000	132.0000	0633470		76.0	63.0	22	3										
1K204	-	1.2500	84.0000	132.0000	0627610						-20	86.0	72.0	43.0	67.0	58.0	39.0	60.0	40.0	20.0

(DIMENSION: NO PCS through NORM; TENSILE TESTS: TENSILE through BEND; IMPACT TESTS: TEST TEMP through % SHEAR)

NOTARY SEAL

NAME: Ann Marie Deininger

OTHER TESTS / INFORMATION

I CERTIFY THE ABOVE RESULTS TO BE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION

D. J. Cernava
DAVID J. CERNAVA
CHIEF METALLURGIST
Page: 3 (Tot Pgs: 7)

Figure B-4. Material Test Report

VALMONT Industrial Products Division
CERTIFICATION OF CHEMICAL AND/OR MECHANICAL PROPERTIES FOR TUBULAR PRODUCTS

Customer Name: VALMONT / NEBRASKA
Customer Address: IPD ACCOUNTS PAYABLE
VALLEY , NE 68064

CUSTOMER ORDER: JW LIGHT POLE
VALMONT ORDER: 3873195
DATE: 12/11/2002

CHEMISTRY IS TRANSCRIBED FROM MILL TEST REPORTS AVAILABLE UPON REQUEST. TENSION TEST SPECIMENS ARE MACHINED/TESTED PER ASTM A370 (E.U.L.). FLATTENING, FLARING ,REVERSE FLATTENING, CRUSH, HARDNESS, CHARPY, OR TENSION TESTS ARE PER A370 AND/OR PRODUCT SPECIFICATION. EDDY CURRENT IS PER ASTM E309. PRODUCT IS MANUFACTURED TO NATIONAL STANDARDS AND CONFORMS TO THE REVISION IN EFFECT AT MANUFACTURE.

Material :	1015	1015	1015
Tubing Size :	2.375	2.375	2.375
Gauge :	.156	.156	.156
Heat :	D38218	D38224	C39130
Carbon :	.14	.14	.18
Manganese :	.41	.45	.42
Phosphorus :	.01	.015	.007
Sulphur :	.007	.009	.008
Silicon :	.009	.008	.011
Chromium :	.04	.04	.03
Nickel: :	.01		.01
Molybdenum :	.01		.02
Copper :		.01	.02
Aluminum :	.029	.034	.044
Vanadium :			
Columbium :			
Titanium :			.001
ASTM Spec :	A500 / B	A500 / B	A500 / B
Long Yield :	61500	60800	60800
Long Tensile :	71300	70100	71900
Elong(2-IN%) :	26	29	29
Hardness RB :	83	84	83
Trnv Tensile :			
Weld Tensile :			
Hydrostatic :			
Flattening :			
Flare :			
Eddy :			
Anneal :			
Other Specs :			
Finish :	HR	HR	HR
Chrpy :			
Part No :	41010	41010	41010
Comments :			

MATERIAL MELTED AND MANUFACTURED IN THE U.S.A.

Mark Seebohm

MARK SEEBOHM
SENIOR QUALITY ENGINEER
INDUSTRIAL PRODUCTS GROUP

FORM 2044 (09/09/97)

Figure B-5. Properties for Tubular Products

Feb 12 03 02:04p Metron Steel 773 646 5445 p.4

12Feb03 13:29 T E S T C E R T I F I C A T E No: CHI 139489

Sold By:
METRON STEEL DIVISION
OF PRIMARY STEEL INC
12900 S METRON DRIVE
CHICAGO, IL 60633
Tel: 800 638-7661 Fax: 773 646-4102

P/O No E3839
Rel
S/O No CHI 140913-001
B/L No CHI 82513-001 Shp 12Feb03
Inv No Inv

Sold To: (8034)
VALMONT IND INC NE
ATTENTION:ACCOUNTS PAYABLE -POLES
P O BOX 358
VALLEY, NE 68064-0358

Ship To: (001)
VALMONT IND INC NE
WEST HWY 275 ATT.EVE/PURC
PO BOX 358
VALLEY, NE 68064

Tel: 402 359-2201 Fax: 402 359-6056

CERTIFICATE of ANALYSIS and TESTS Cert. No: CHI 139489
12Feb03

Part No 0030006 S70
PLATE ASTM A36 / ASME SA36
1/4" X 48.0000" X 120.0000"

Heat Number	Tag No	Mill Tag	Pcs	Wgt
			50	420
831Z13820	295268	284169	25	210
	YLDH=43900/TENH=68400/ELGH=33.0/YLDM=39000/TENM=62600 ELGM=38.0			
831Z13820	295269	284169	25	10,210
	YLDH=43900/TENH=68400/ELGH=33.0/YLDM=39000/TENM=62600 ELGM=38.0			

Heat Number *** Chemical Analysis ***
831Z13820 C=0.16 MN=1.03 P=0.02 S=0.007 SI=0.018 CU=0.008 NI=0.01 CR=0.04
MO=0.005 V=0.003 TI=0.002 Al=0.033 CB=0.02 N=0.004

We certify that the above information is correct
as contained in the records of the company.

Page: 1 .... Last

Figure B-6. Test Certificate

Feb 12 03 02:04p Metron Steel 773 846 5445 .5

Doc No. 31201

Burns Harbor Test Report

Page 1 of 2

Bethlehem

PRIMARY STEEL INC

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Vendor		Sold To		Ship To
BETHLEHEM STEEL CORPORATION BURNS HARBOR PLANT BOX 248 CHESTERTON, INDIANA 46304		PRIMARY STEEL INC METRON STEEL DIV 12900 S METRON DR CHICAGO IL 60633		PRIMARY STEEL INC METRON STEEL DIV THEIR SIDING 12900 S METRON DR CHICAGO IL 60633
Shipment No 0805-91268	Date Shipped 2003-01-12	Mill Order YH828-39349B	Car or Vehicle 43048 CSS	Purchase Order CHI-29695 2002-11-27
Gauge .2360 IN M	Width 48 IN	Length COIL IN	Customer Application CONVERSION TO A36 PLATE / ASME SA36	

Specifications

HOT ROLLED STRUCTURAL STEEL DRY
COILS-ME---ASTM A1018-01A-GR 36 MODIFIED
TENSILE 58-80 KSI

MELTED AND MANUFACTURED IN THE U.S.A.

Item Test Results | **Notes**

COIL/LIFT/SERIAL	PCS	WEIGHT	HEAT	L	YLD PT TRANS	TENSILE KSI-T	ELONG-T IN	ELONG-T PCT	BEND TRAN.
284169	1	49420	831Z13820	F	43.9	68.4	2	33	OK
284172	1	51180	841Z13820	F	43.9	68.4	2	33	OK
284173	1	48280	841Z13820	F	43.9	68.4	2	33	OK

Chemical Analysis

HEAT	C	MN	P	S	SI	CU	NI	CR	MO	V	TI	AL	CB	N
831Z13820	0.16	1.03	.020	.007	0.018	.008	0.01	0.04	.005	.003	.002	.033	.002	.004
841Z13820	0.16	1.03	.020	.007	0.018	.008	0.01	0.04	.005	.003	.002	.033	.002	.004

https://e-commerce.bethsteel.com/App/WosApp/WebOrderStatus/pgShipmentQuery

B265884
B265885
B265886

1/13/03

METRON STEEL DIVISION

PART NO.

PO/Ref

Certificate of Mill Test Results

Figure B-7. Burns Harbor Test Report

APPENDIX C

English-Unit System Drawings - Test Nos. ZOI-1 and ZOI-2

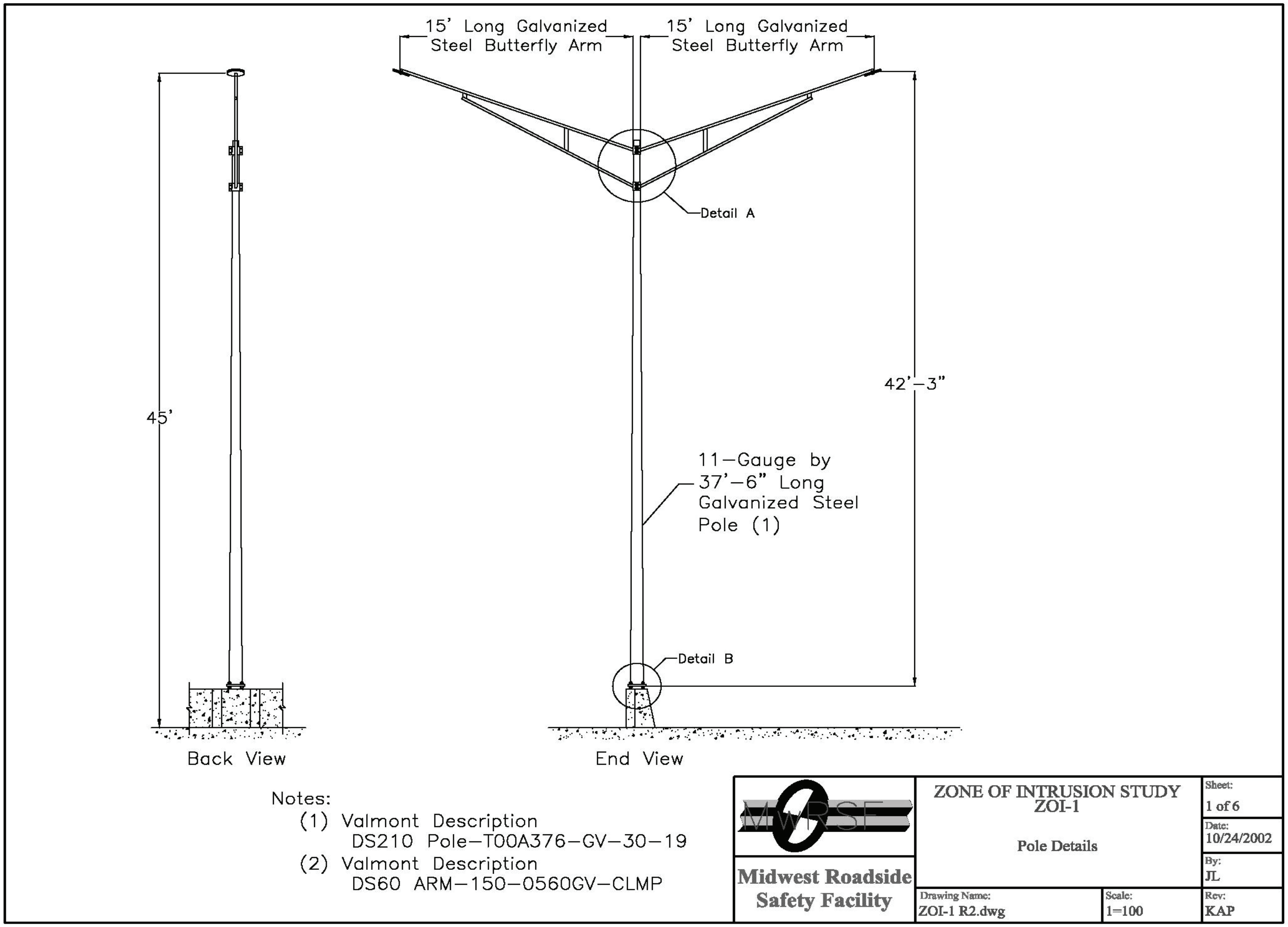


Figure C-1. Pole Details, Test Nos. ZOI-1 and ZOI-2 (English)

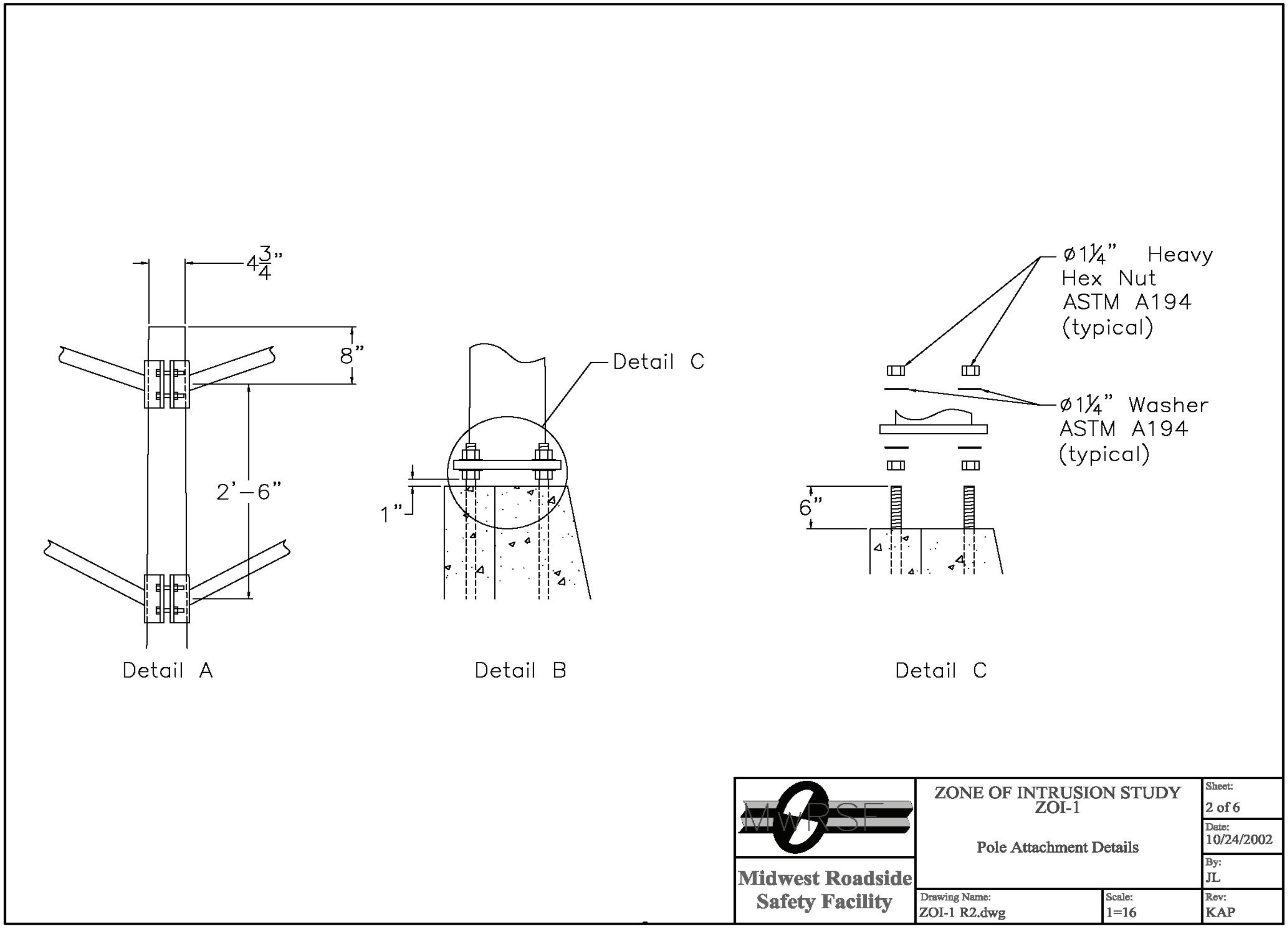


Figure C-2. Pole Attachment Details, Test Nos. ZOI-1 and ZOI-2 (English)

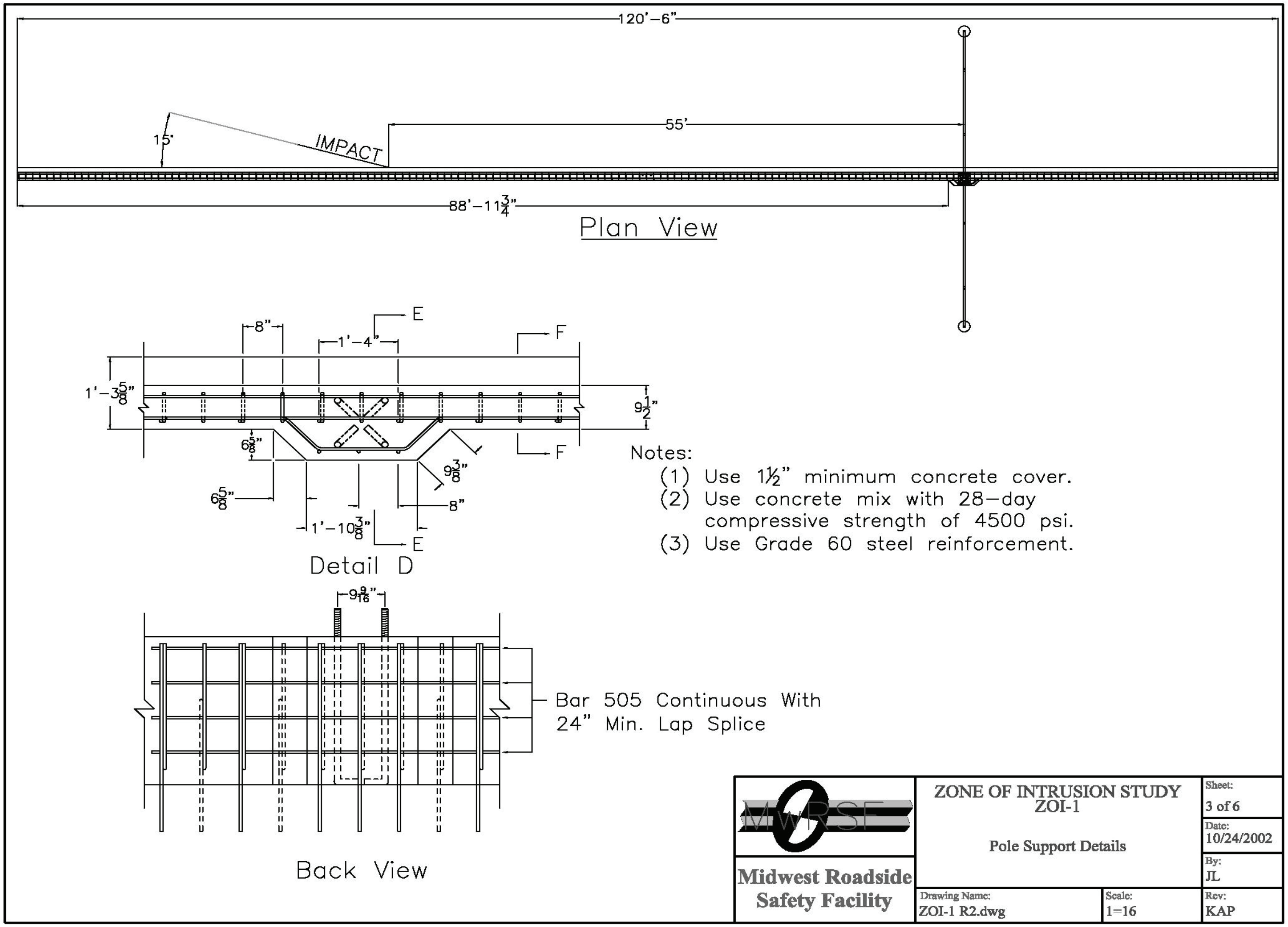


Figure C-3. Pole Support Details, Test Nos. ZOI-1 and ZOI-2 (English)

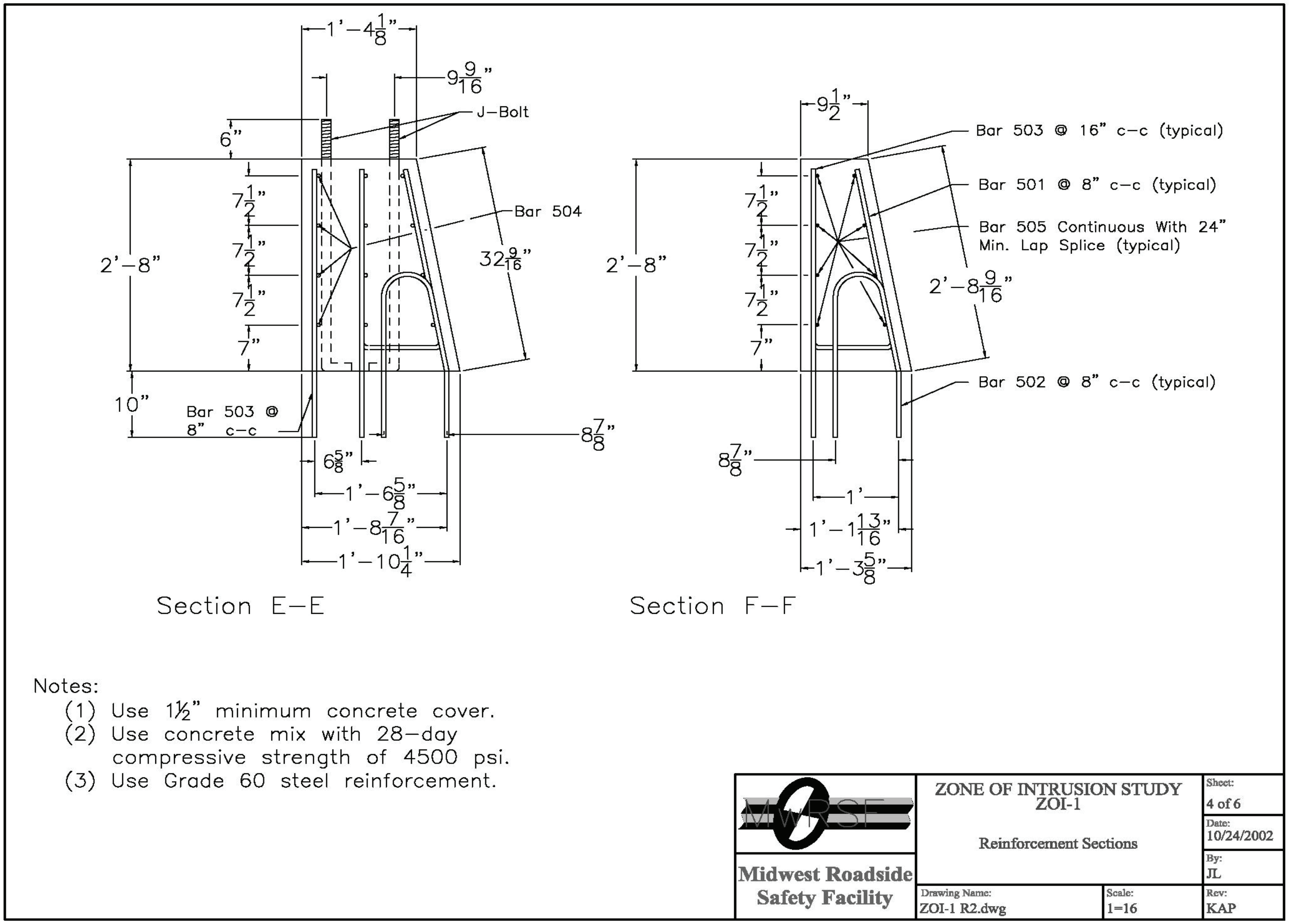
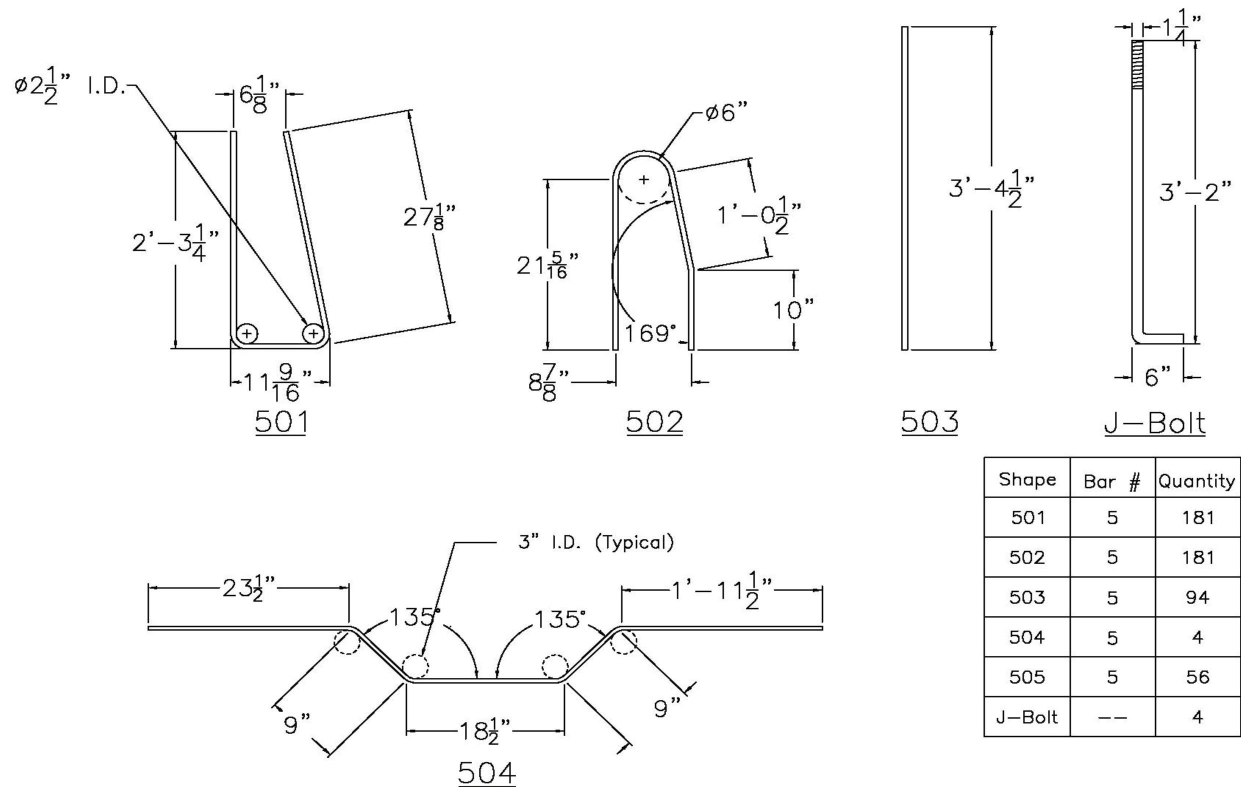


Figure C-4. Reinforcement Sections, Test Nos. ZOI-1 and ZOI-2 (English)



Shape	Bar #	Quantity	Length
501	5	181	5'–6"
502	5	181	4'–6"
503	5	94	3'–4½"
504	5	4	7'
505	5	56	20'
J–Bolt	––	4	1¼"x38"x6"

Figure C-5. Bill of Bars, Test Nos. ZOI-1 and ZOI-2 (English)

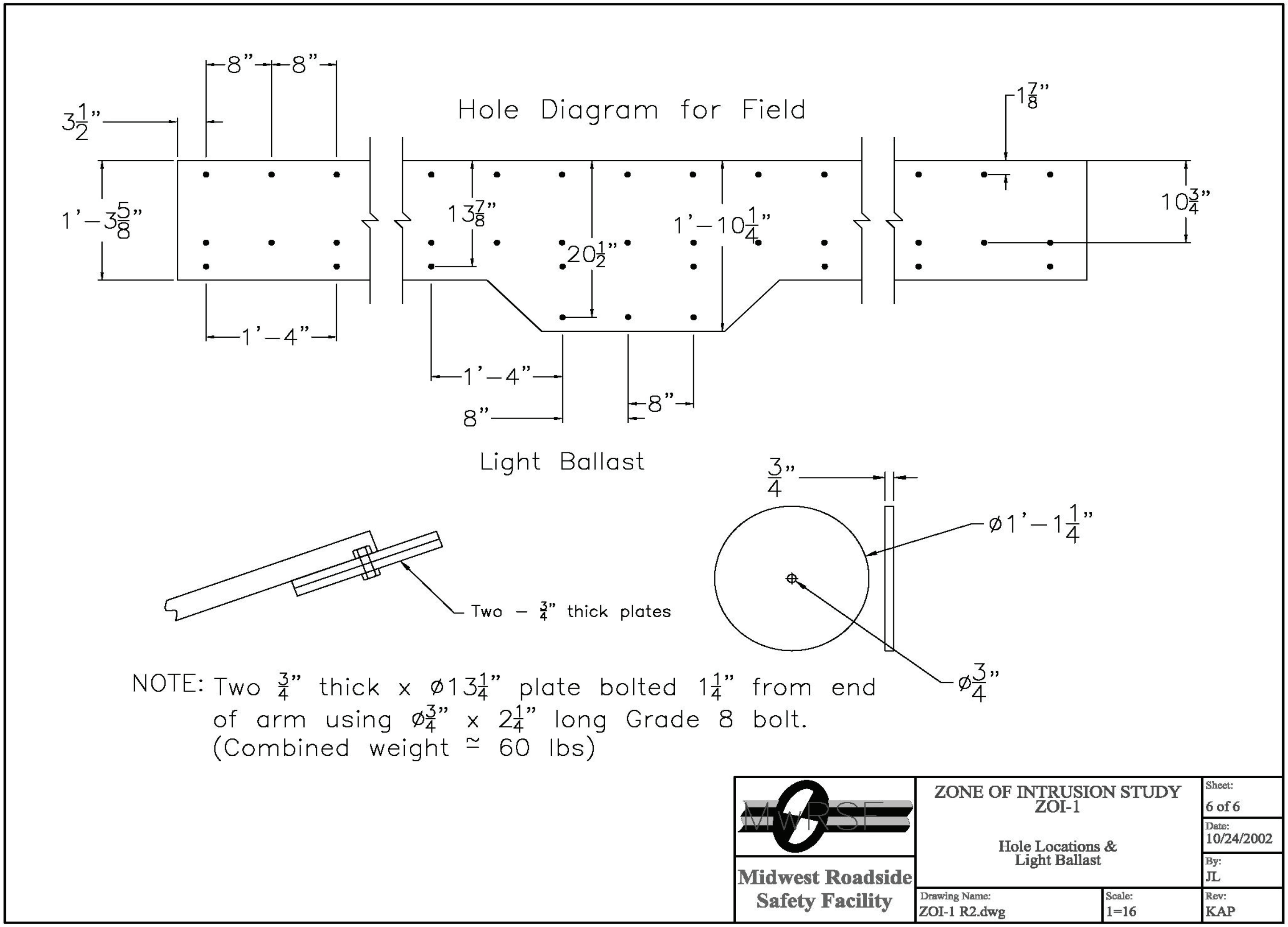
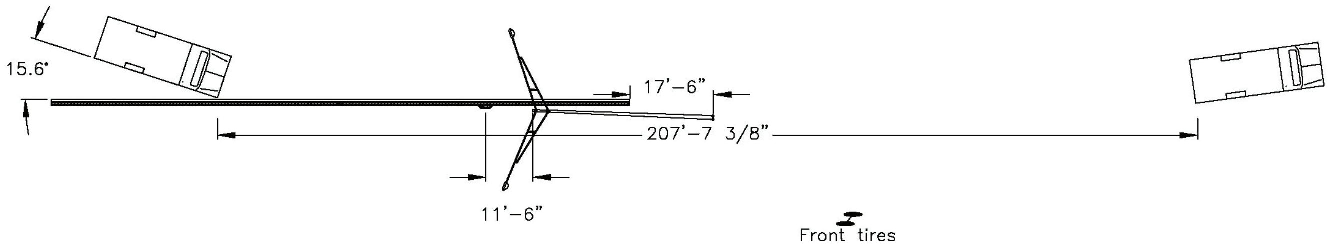


Figure C-6. Hole Locations and Light Ballast, Test No. ZOI-1 and ZOI-2 (English)

APPENDIX D

Test Summary Sheets in English Units

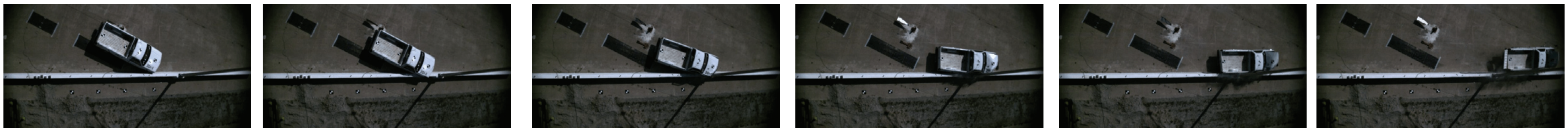
0.000 sec   0.320 sec   0.830 sec   1.411 sec   1.984 sec



● Test Agency	MwRSF
● Test Number	ZOI-1
● Date	4/02/03
● NCHRP 350 Test Designation	4-12
● Appurtenance	Single-Slope Concrete Barrier with an Attached Luminaire Pole
● Total Length	120 ft
● Overall Height	45 ft
● Key Elements - Barrier	
Description	Single-Slope Concrete Barrier
Base Width	15.625 in.
Top Width	9.5 in.
Base Width (at pedestal)	22.25 in.
Top Width (at pedestal)	16.175 in.
Height	32 in.
Concrete Material	Nebraska 47-BD Mix
Reinforcing Steel Material	Grade 60 Rebar
● Key Elements - Luminaire Pole	
Pole Description	TOOA376-GV30-19 DS210 Pole
Arm Description	DS60 Arm 150-0560GV-CLMP
Size	11 Gauge thick by 37 ft - 6 in. long
Material	Galvanized Steel
● Type of Soil	NA
● Test Vehicle	
Type/Designation	8000S
Make and Model	1989 Ford F-800
Curb	12,172 lbs
Test Inertial	17,605 lbs
Gross Static	17,605 lbs

● Impact Conditions	
Speed	50.4 mph
Angle	15.6 degrees
Impact Location	55 ft upstream of pole centerline
● Exit Conditions	
Speed	NA
Angle	NA
Exit Box Criterion	Pass
● Post-Impact Trajectory	
Vehicle Stability	Satisfactory
Stopping Distance	207 ft - 7.375 in. downstream
● Occupant Impact Velocity	
Longitudinal (not required)	-8.44 ft/s
Lateral (not required)	6.73 ft/s
● Occupant Ridedown Deceleration	
Longitudinal (not required)	-4.14 Gs
Lateral (not required)	-6.54 Gs
● THIV (not required)	NA
● PHD (not required)	NA
● Test Article Damage	Pole disengaged
● Test Article Deflections	
Permanent Set	NA
Dynamic	NA
Working Width	67.375 in.
● Vehicle Damage	Moderate
VDS[5]	I-RFQ-3
CDC[6]	I-RFEW-4
Maximum Deformation	NA

Figure D-1. Summary of Test Results and Sequential Photographs, Test No. ZOI-1 (English)



0.000 sec | 0.048 sec | 0.104sec | 0.170 sec | 0.248 sec | 0.378 sec

- Test Agency ... MwRSF
- Test Number ... ZOI-2
- Date ... 7/25/03
- NCHRP 35 Test Designation ... 4-11
- Appurtenance ... Single-Slope Concrete Barrier With Attached Luminaire Pole
- Total Length ... 120 ft
- Overall Height ... 45 ft
- Key Elements - Barrier
  - Description ... Single-Slope Concrete Barrier
  - Base Width ... 15.625 in.
  - Top Width ... 9.5 in.
  - Base Width (at pedestal) ... 22.25 in.
  - Top Width (at pedestal) ... 16.175 in.
  - Height ... 32 in.
  - Concrete Material ... Nebraska 47-BD Mix
  - Reinforcing Steel Material ... Grade 60 Rebar
- Key Elements - Luminaire Pole
  - Pole Description ... TOOA376-GV30-19 DS210 Pole
  - Arm Description ... DS60 Arm 150-0560GV-CLMP
  - Size ... 11 Gauge thick by 37 ft - 6 in. long
  - Material ... Galvanized Steel
- Type of Soil ... NA
- Test Vehicle
  - Type/Designation ... 2000P
  - Make and Model ... 1997 GMC 3/4-ton Pickup Truck
  - Curb ... 4,468 lbs
  - Test Inertial ... 4,430 lbs
  - Gross Static ... 4,430 lbs
- Impact Conditions
  - Speed ... 61.7 mph
  - Angle ... 23.4 degrees
  - Impact Location ... 11 ft upstream of pole centerline
- Exit Conditions
  - Speed ... 52.0 mph
  - Angle ... 8.3 degrees
  - Exit Box Criterion ... Pass
- Post-Impact Trajectory
  - Vehicle Stability ... Satisfactory
  - Stopping Distance ... 253 ft -2 in. downstream 10 ft traffic-side face
- Occupant Impact Velocity
  - Longitudinal ... -19.41 ft/s
  - Lateral (not required) ... 28.25 ft/s
- Occupant Ridedown Deceleration
  - Longitudinal ... -5.90 Gs
  - Lateral (not required) ... 12.48 Gs
- THIV (not required) ... NA
- PHD (not required) ... NA
- Test Article Damage ... Minimal
- Test Article Deflections
  - Permanent Set ... NA
  - Dynamic ... NA
  - Working Width ... 26.125 in.
- Vehicle Damage ... Moderate
  - VDS[5] ... 1-RFQ-6
  - CDC[6] ... 1-RYEW-7
  - Maximum Deformation ... 3.875 in.

Figure D-2. Summary of Test Results and Sequential Photographs, Test No. ZOI-2 (English)

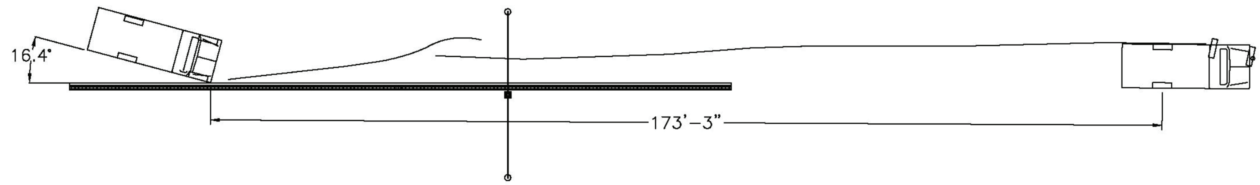

0.000 sec


0.000 sec


0.000 sec


0.000 sec


0.000 sec



- Test Agency . . . . MwRSF
- Test Number ZOI-3
- Date 3/2/05
- NCHRP 350 Test Designation 4-12
- Appurtenance . . . . Single-Slope Barrier with Luminaire Pole Behind Barrier
- Total Length . . . . 120 ft
- Overall Height . . . . 42 ft - 6 in.
- Key Elements - Barrier
  - Description . . . . Single-Slope Concrete Barrier
  - Base Width . . . . 15.625 in.
  - Top Width . . . . 9.5 in.
  - Height . . . . 32 in.
  - Concrete Material . . . . Nebraska 47-BD Mix
  - Reinforcing Steel Material . . . . Grade 60 Rebar
- Key Elements - Luminaire Pole
  - Pole Description . . . . TOOA376-GV30-19 DS210 Pole
  - Arm Description . . . . DS60 Arm 150-0560GV-CLMP
  - Size . . . . 11 Gauge thick by 37ft - 6 in. long
  - Material . . . . Galvanized Steel
- Type of Soil . . . . NA
- Test Vehicle
  - Type/Designation 8000S
  - Make and Model . . . . 1989 Ford F800
  - Curb . . . . 11,993 lbs
  - Test Inertial . . . . 17,637 lbs
  - Gross Static . . . . 17,637 lbs
- Impact Conditions
  - Speed . . . . 50.2 mph
  - Angle . . . . 16.4 degrees
  - Impact Location . . . . 54 ft - 6 in. upstream of pole centerline
- Exit Conditions
  - Speed . . . . NA
  - Angle . . . . NA
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping . . . . 173 ft - 3 in. downstream
- Occupant Impact Velocity
  - Longitudinal (not required) . . . . 6.96 ft/s
  - Lateral (not required) . . . . 8.03 ft/s
- Occupant Ride Down Deceleration
  - Longitudinal (not required) . . . . 3.13 Gs
  - Lateral (not required) . . . . 6.43 Gs
- THIV (not required) . . . . NA
- PHD (not required) . . . . NA
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . NA
  - Dynamic . . . . NA
  - Working Width . . . . 35.6875 in.
- Vehicle Damage . . . . Moderate
  - VDS[5] I-RFQ-3
  - CDC[6] I-FREW-4
  - Maximum Deformation . . . . NA

Figure D-3. Summary of Test Results and Sequential Photographs, Test No. ZOI-3 (English)

APPENDIX E

Accelerometer and Rate Transducer Data Analysis, Test ZOI-1

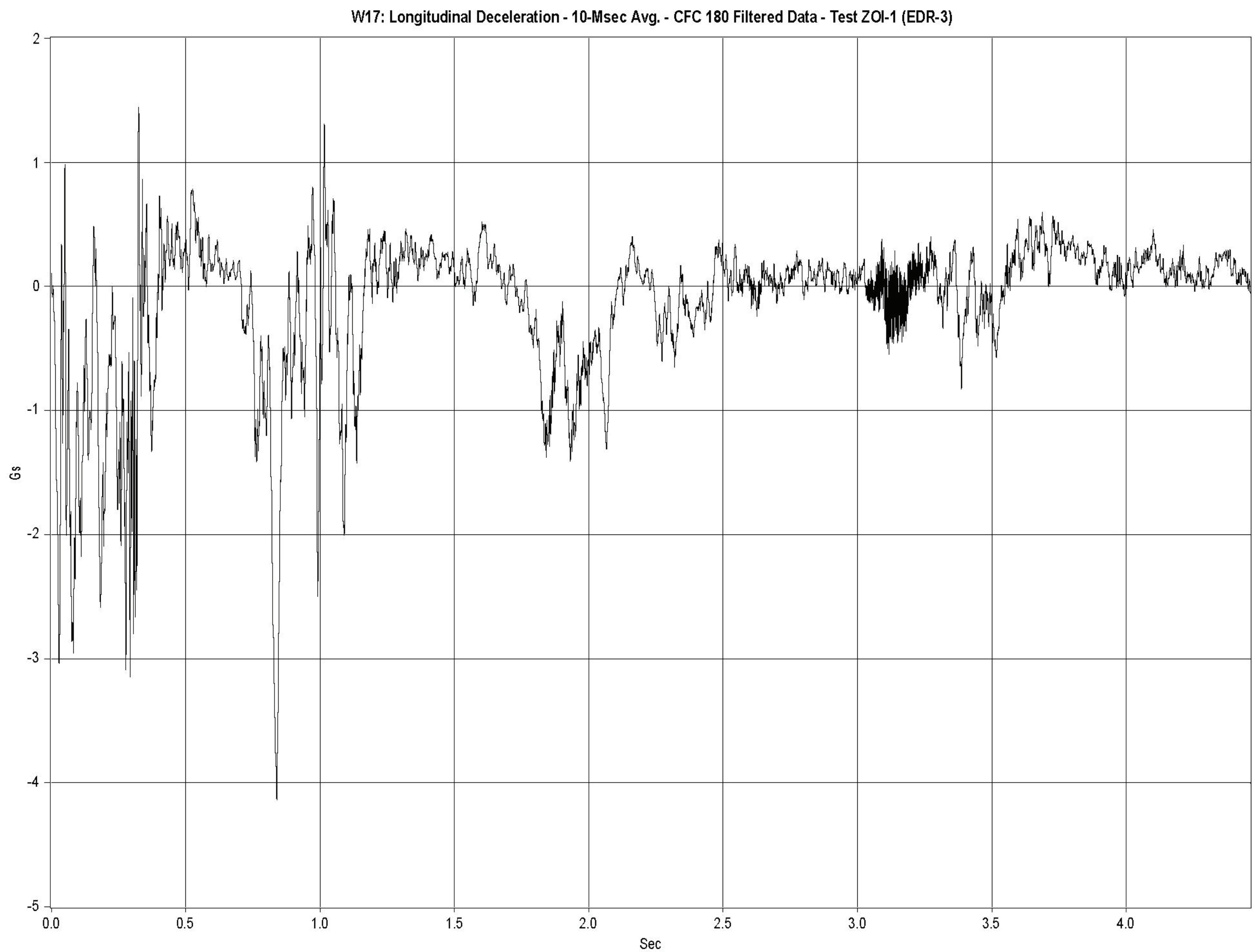


Figure E-1. Graph of Longitudinal Deceleration, Test ZOI-1

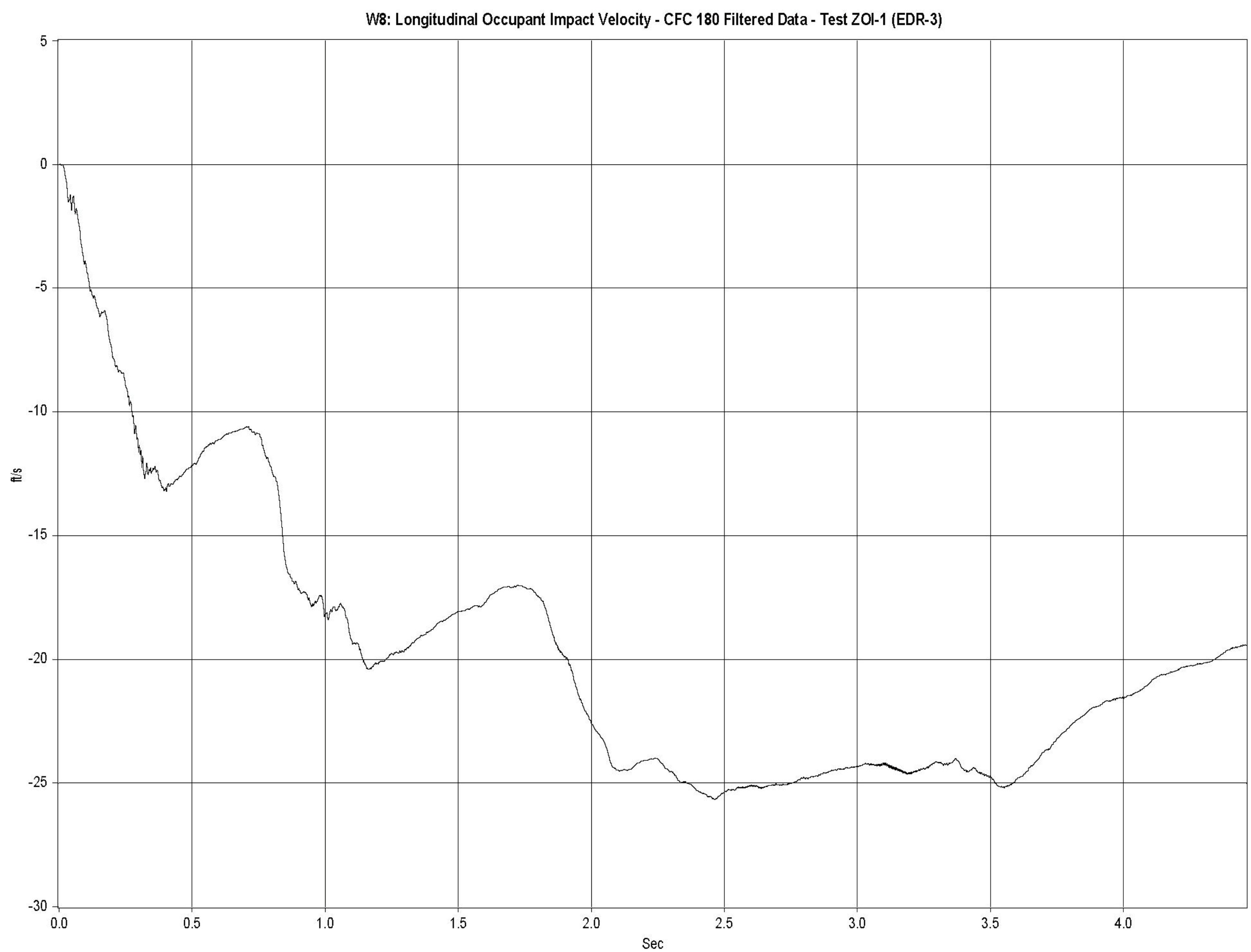


Figure E-2. Graph of Longitudinal Occupant Impact Velocity, Test ZOI-1

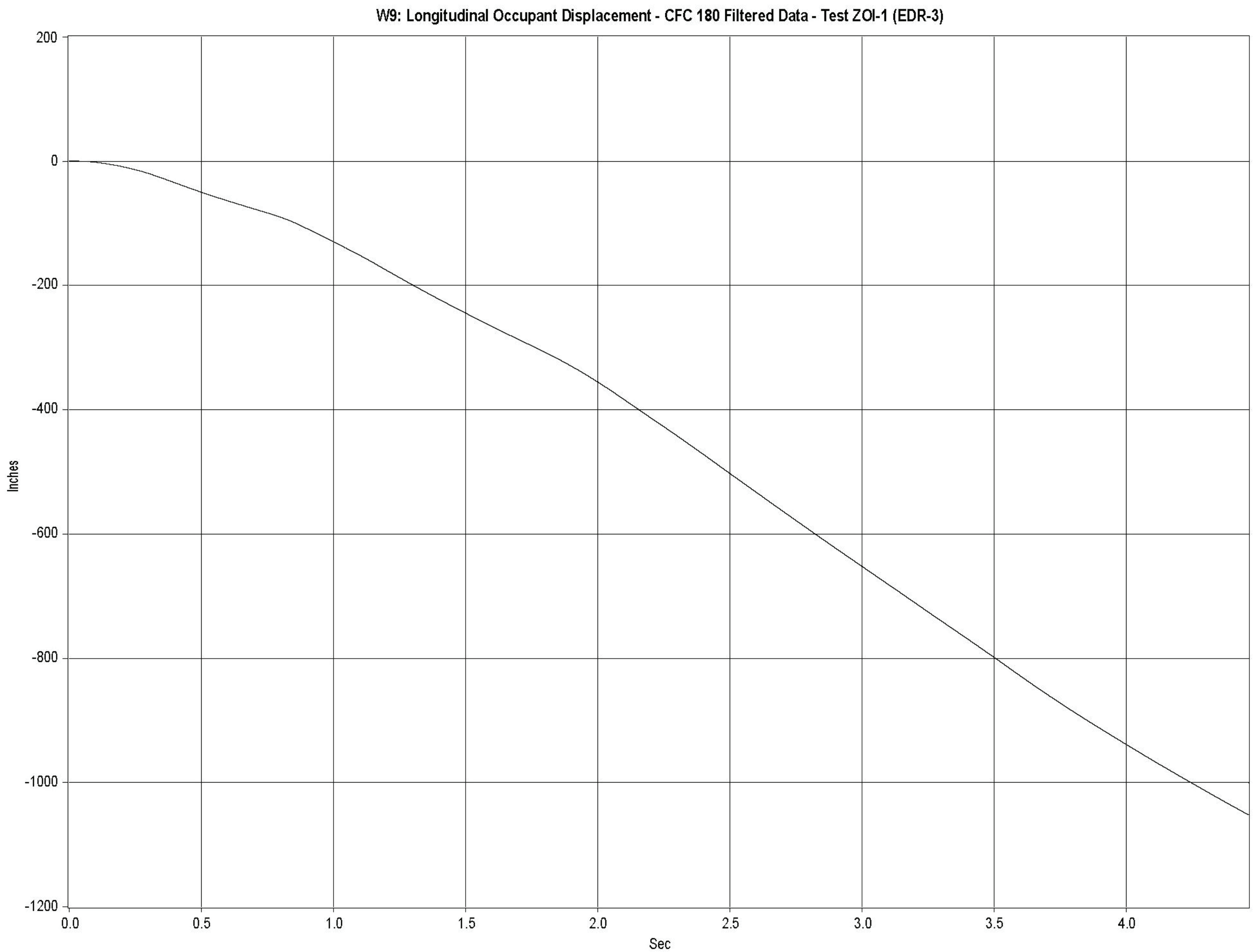


Figure E-3. Graph of Longitudinal Occupant Displacement, Test ZOI-1

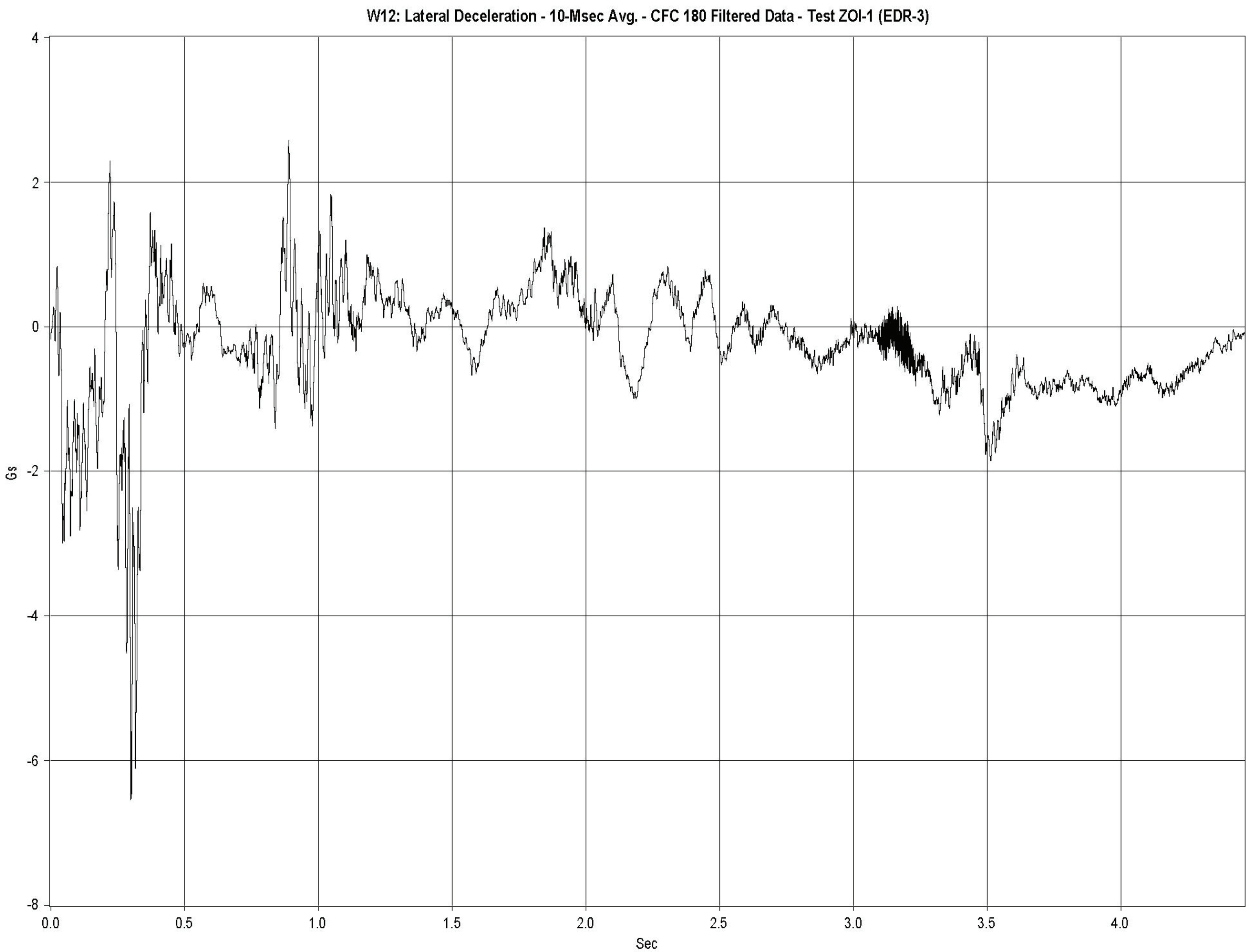


Figure E-4. Graph of Lateral Deceleration, Test ZOI-1

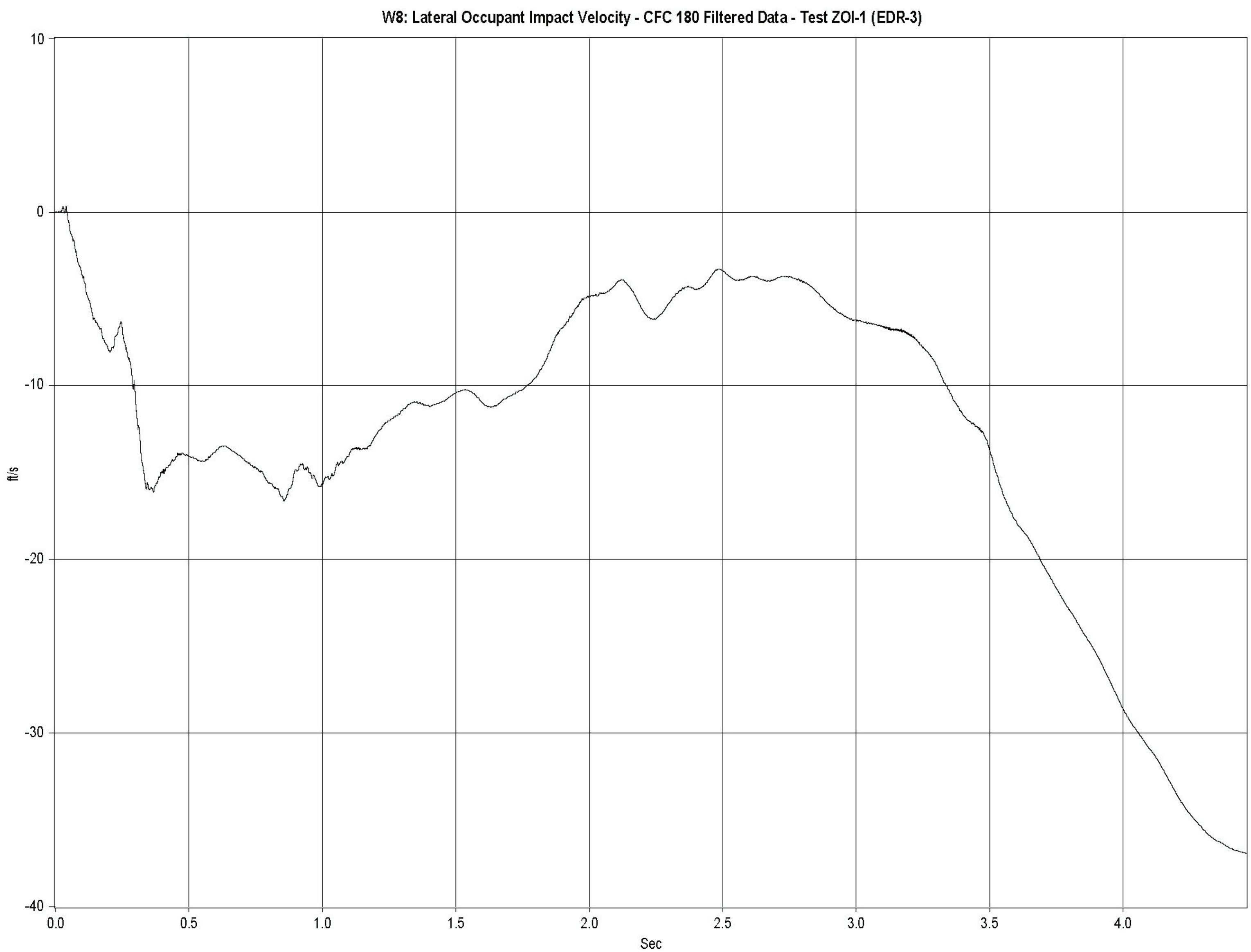


Figure E-5. Graph of Lateral Occupant Impact Velocity, Test ZOI-1

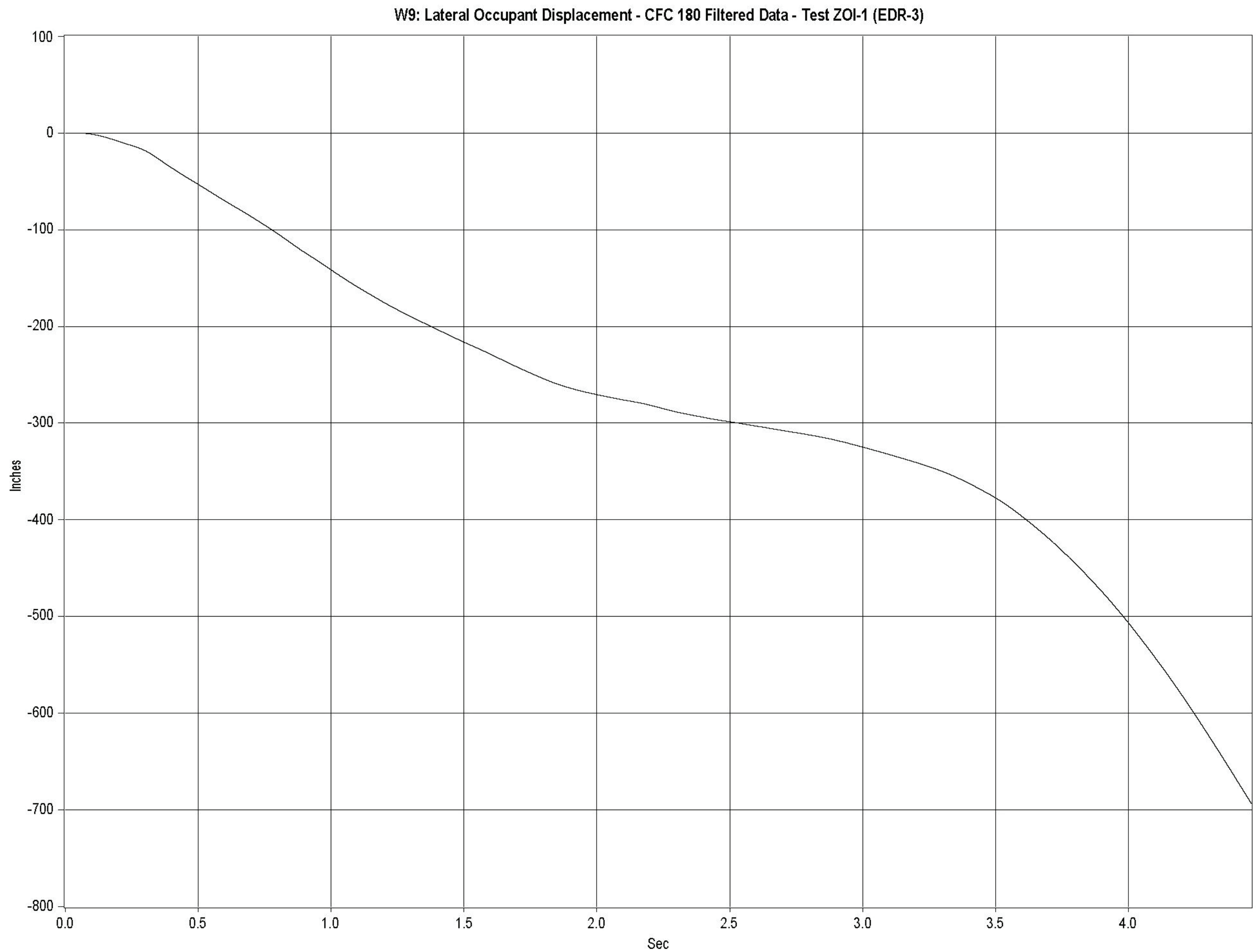


Figure E-6. Graph of Lateral Occupant Displacement, Test ZOI-1

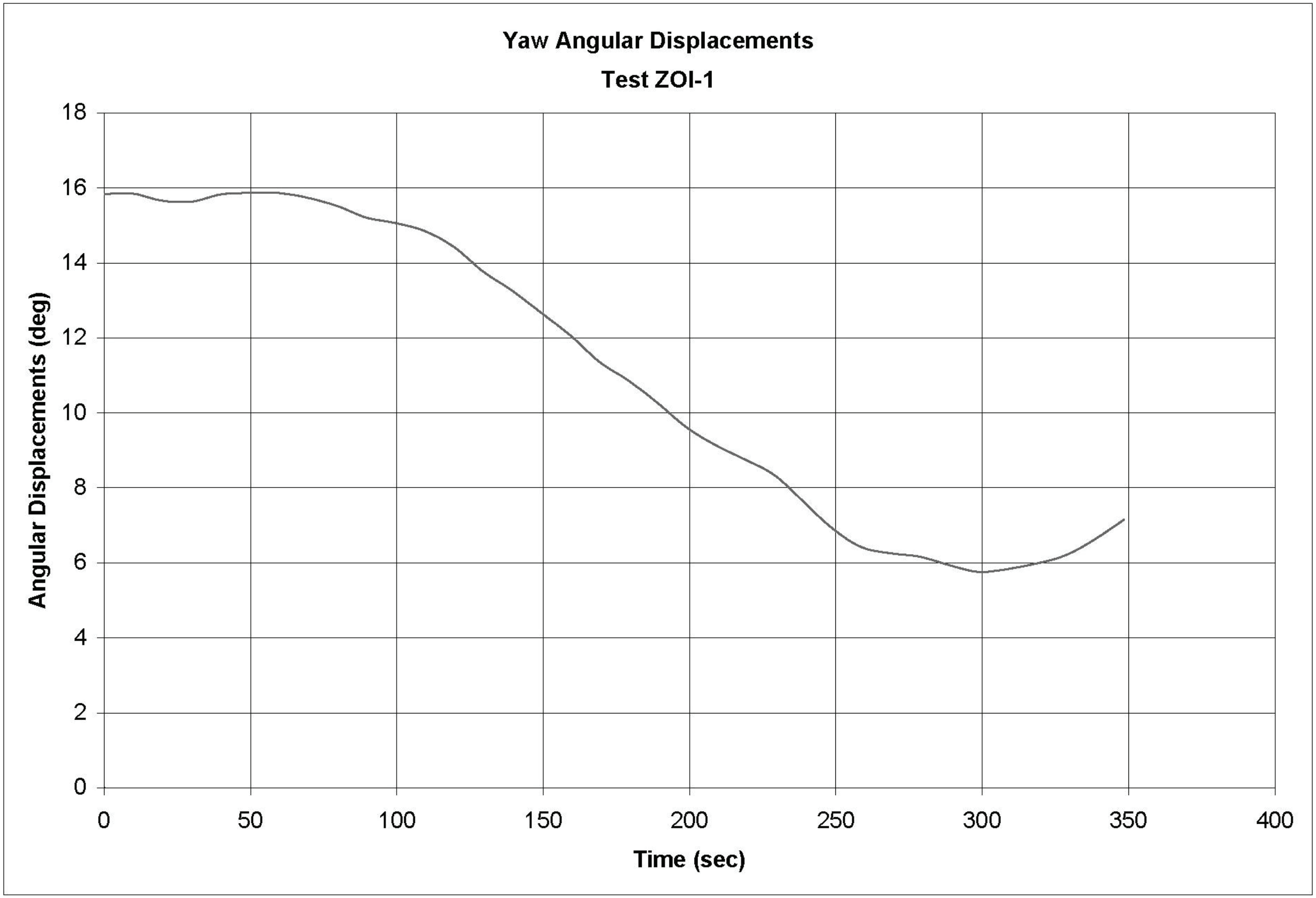


Figure E-7. Yaw Angular Displacements, Test ZOI-1

APPENDIX F

Occupant Compartment Deformation Data, Test ZO1-2

Figure F-1. Occupant Compartment Deformation Data, Test ZOI-2

VEHICLE PRE/POST CRUSH INFO

TEST: ZOI-2
VEHICLE: 1998/GMC/white

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z	Secondary points: Y2	Z2	Y2'	Z2'	Del Y2	Del Z2
1	54.25	6	-1.375	53.25	6.25		-1	0.25	1.375	21.5	-1.75	21.5	-1.25	0	-0.5
2	56.5	10.5	1	55.5	10.25		-1	-0.25	-1	26	0.75	25	1.5	1	-0.75
3	57	13.25	0.75	57	12.75		0	-0.5	-0.75	28.75	0.25	28	1.75	0.75	-1.5
4	57	19.375	4	55.5	17.25		-1.5	-2.125	-4	34.875	3	33	4	1.875	-1
5	58.75	24	2.25	55.25	22		-3.5	-2	-2.25	39.5	1.25	37.5	1.25	2	0
6	57.375	31.25	1.25	55	29.25		-2.375	-2	-1.25	46.75	0.5	45	1.75	1.75	-1.25
7	51.5	8.125	1.875	50.25	8		-1.25	-0.125	-1.875	23.625	1.5	23.75	2	-0.125	-0.5
8	53	12.375	6.75	52.25	11.25		-0.75	-1.125	-6.75	27.875	6.25	27	7	0.875	-0.75
9	53.25	17.5	6.5	53.25	16.25		0	-1.25	-6.5	33	6.25	32.25	7.5	0.75	-1.25
10	53.25	23.5	6.75	52	20.75		-1.25	-2.75	-6.75	39	6	36.75	7	2.25	-1
11	53	31.25	6	51.75	28.5		-1.25	-2.75	-6	46.75	5	44.25	6.75	2.5	-1.75
12	45.5	8.25	3	45	8.5		-0.5	0.25	-3	23.75	2.75	24	3.25	-0.25	-0.5
13	47.25	12	7.5	46.75	11.75		-0.5	-0.25	-7.5	27.5	7.25	26.5	6.75	1	0.5
14	47.75	18.5	7.75	47	17		-0.75	-1.5	-7.75	34	7.5	33	8.25	1	-0.75
15	47.75	24	8	47.25	22.25		-0.5	-1.75	-8	39.5	7.25	37.75	9.5	1.75	-2.25
16	47	29	8.25	46.5	26.5		-0.5	-2.5	-8.25	44.5	7.375	43.5	11	1	-3.625
17	34.75	8.5	4	33	8.25		-1.75	-0.25	-4	24	4	24	4.25	0	-0.25
18	34.75	12.25	6.875	34.25	12		-0.5	-0.25	-6.875	27.75	6.875	28	7.5	-0.25	-0.625
19	38	17.25	7.375	37.5	16.75		-0.5	-0.5	-7.375	32.75	7.125	32.25	7	0.5	0.125
20	34.25	21.25	7.125	34.25	20.75		0	-0.5	-7.125	36.75	6.75	36.5	6.75	0.25	0
21	35	29.5	8.25	35.5	28		0.5	-1.5	-8.25	45	7.75	44	11	1	-3.25
22	29.5	30.5	4.25	29.5	28.5		0	-2	-4.25	46	8.75	44.25	10.5	1.75	-1.75
23	26	19.25	6.5	26	19.5		0	0.25	-6.5	34.75	6.5	35.25	6.75	-0.5	-0.25
24	18.25	30.5	9	18.25	30.5		0	0	-9	46	8.375	44.5	4.5	1.5	3.875
25	10.25	16.75	3	10.5	17.5		0.25	0.75	-3	32.25	3.25	32.5	3	-0.25	0.25
26	41.75	10.5	-24	41.75	10.5		0	0	24	10.5	-24.25	10.5	-23.75	0	-0.5
27	40.375	18.25	-24.25	40.25	18.25		-0.125	0	24.25	18.25	-24.25	18.25	-23.75	0	-0.5
28	40.25	26.25	-23.75	39.75	26.25		-0.5	0	23.75	26.25	-23.75	26.25	-23.25	0	-0.5
29															
30															

ORIENTATION AND REFERENCE INFO

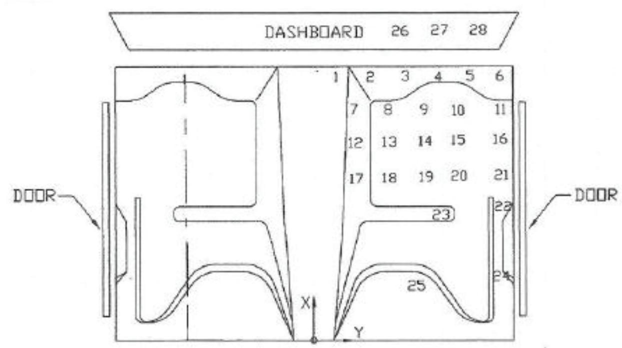


Figure F-1. Occupant Compartment Deformation Data, Test ZOI-2

APPENDIX G

Accelerometer and Rate Transducer Data Analysis, Test ZOI-2

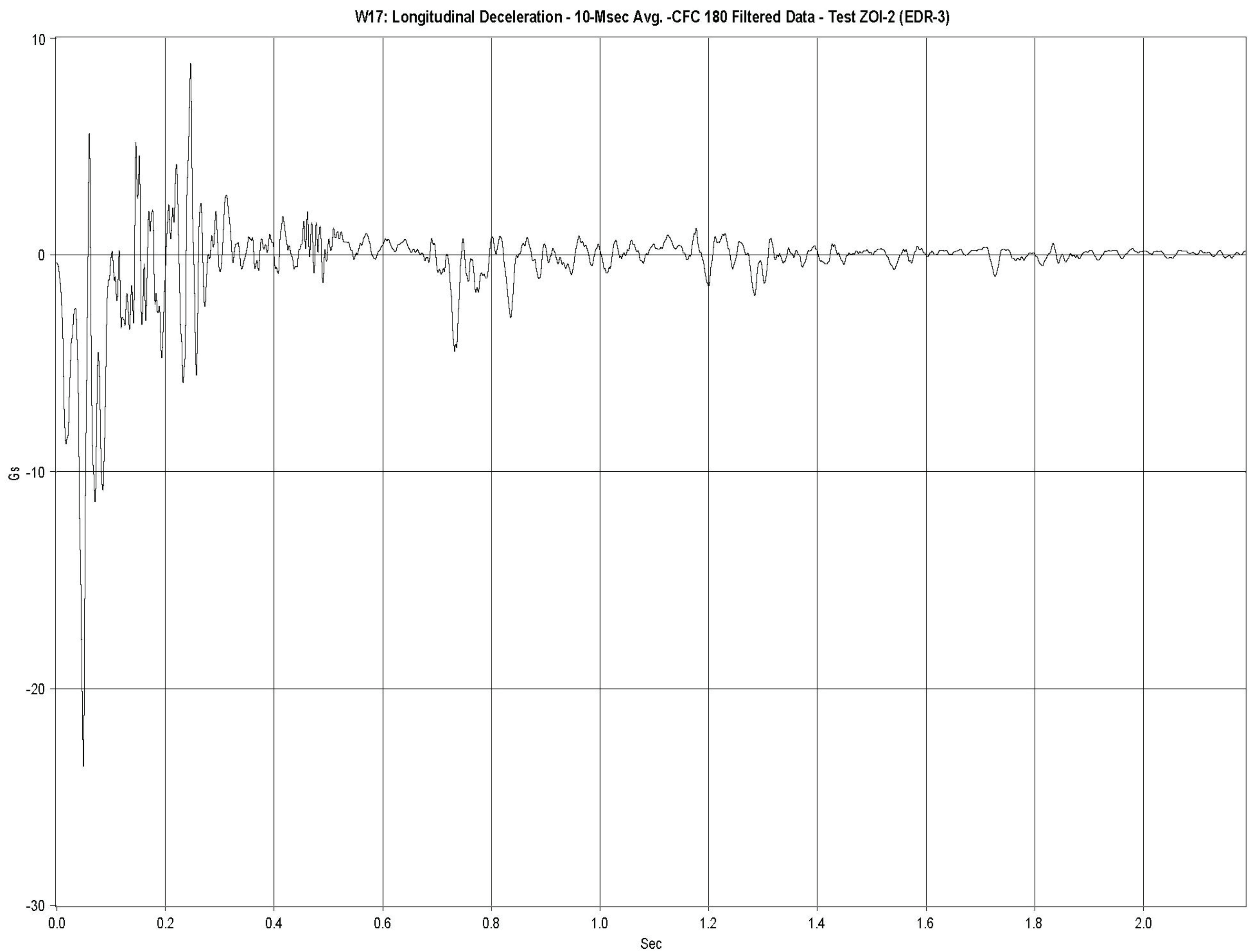


Figure G-1. Graph of Longitudinal Deceleration, Test ZOI-2

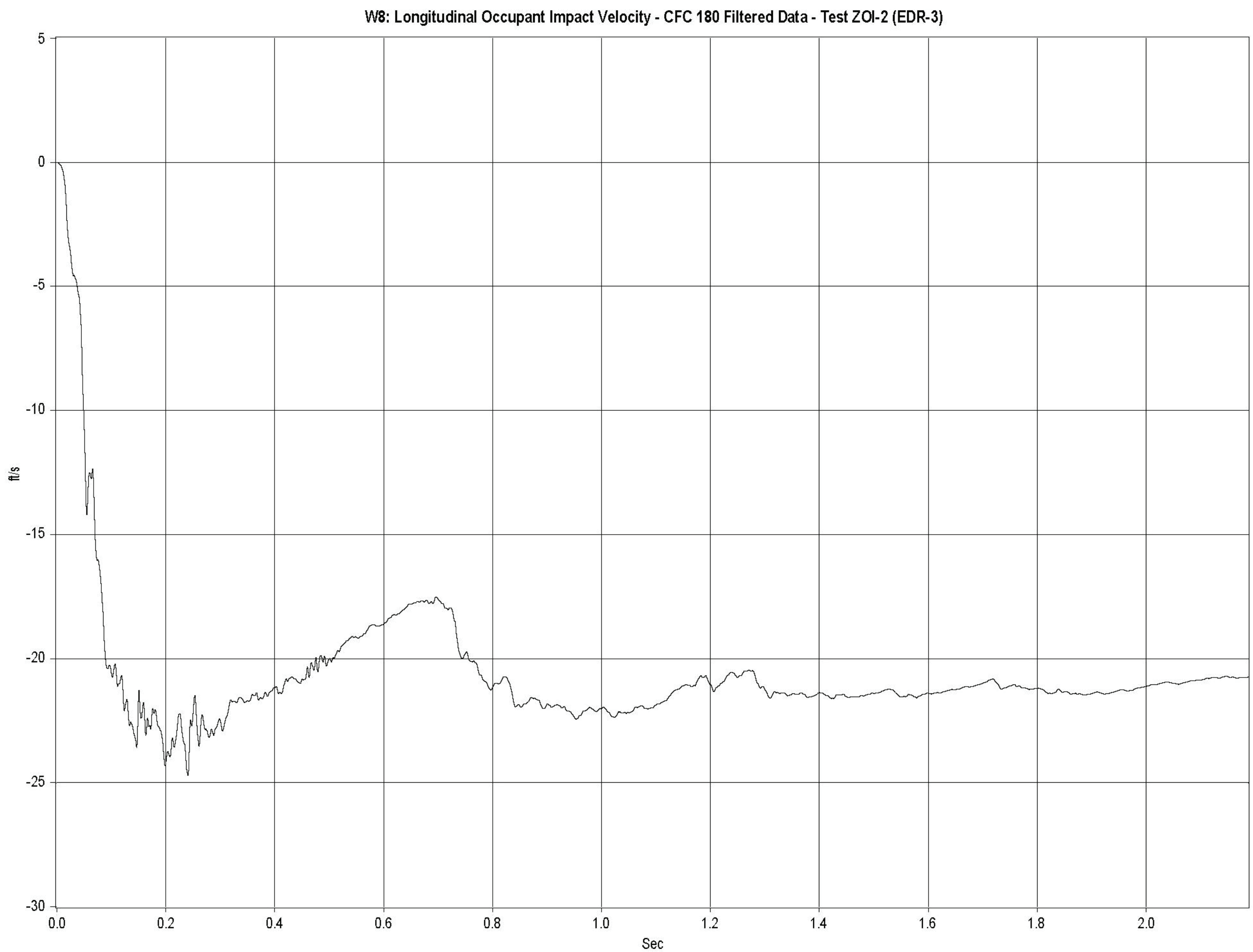


Figure G-2. Graph of Longitudinal Occupant Impact Velocity, Test ZOI-2

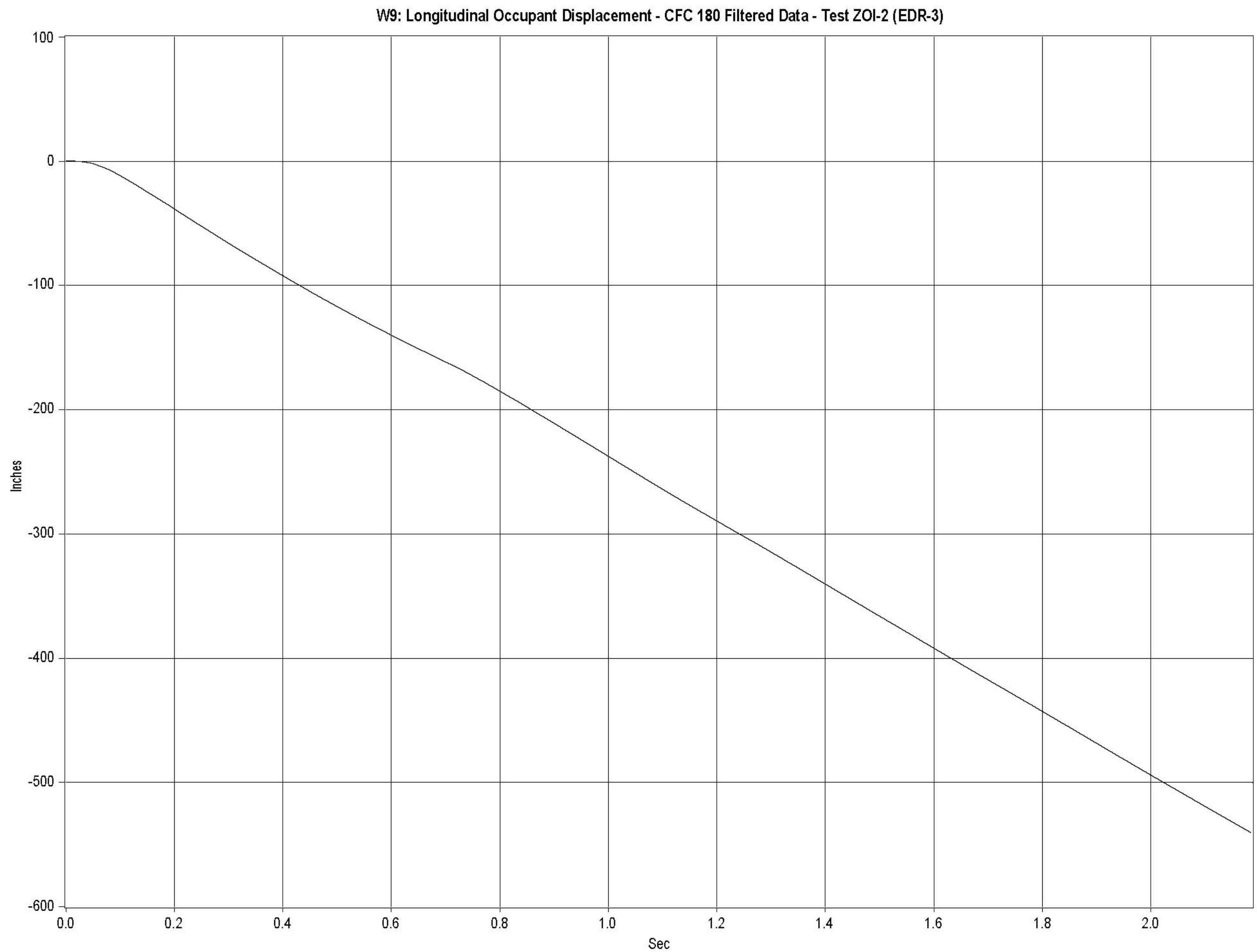


Figure G-3. Graph of Longitudinal Occupant Displacement, Test ZOI-2

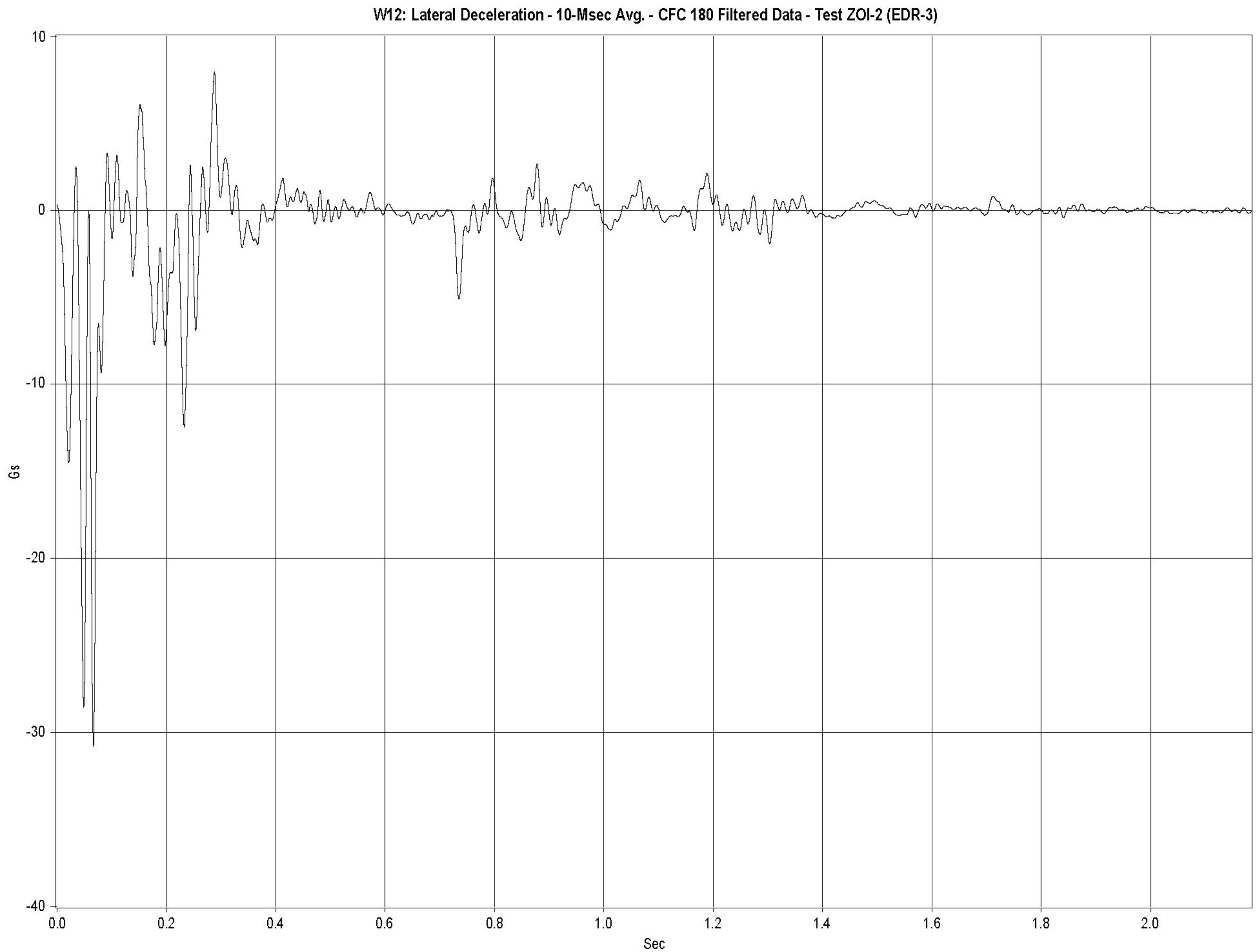


Figure G-4. Graph of Lateral Deceleration, Test ZOI-2

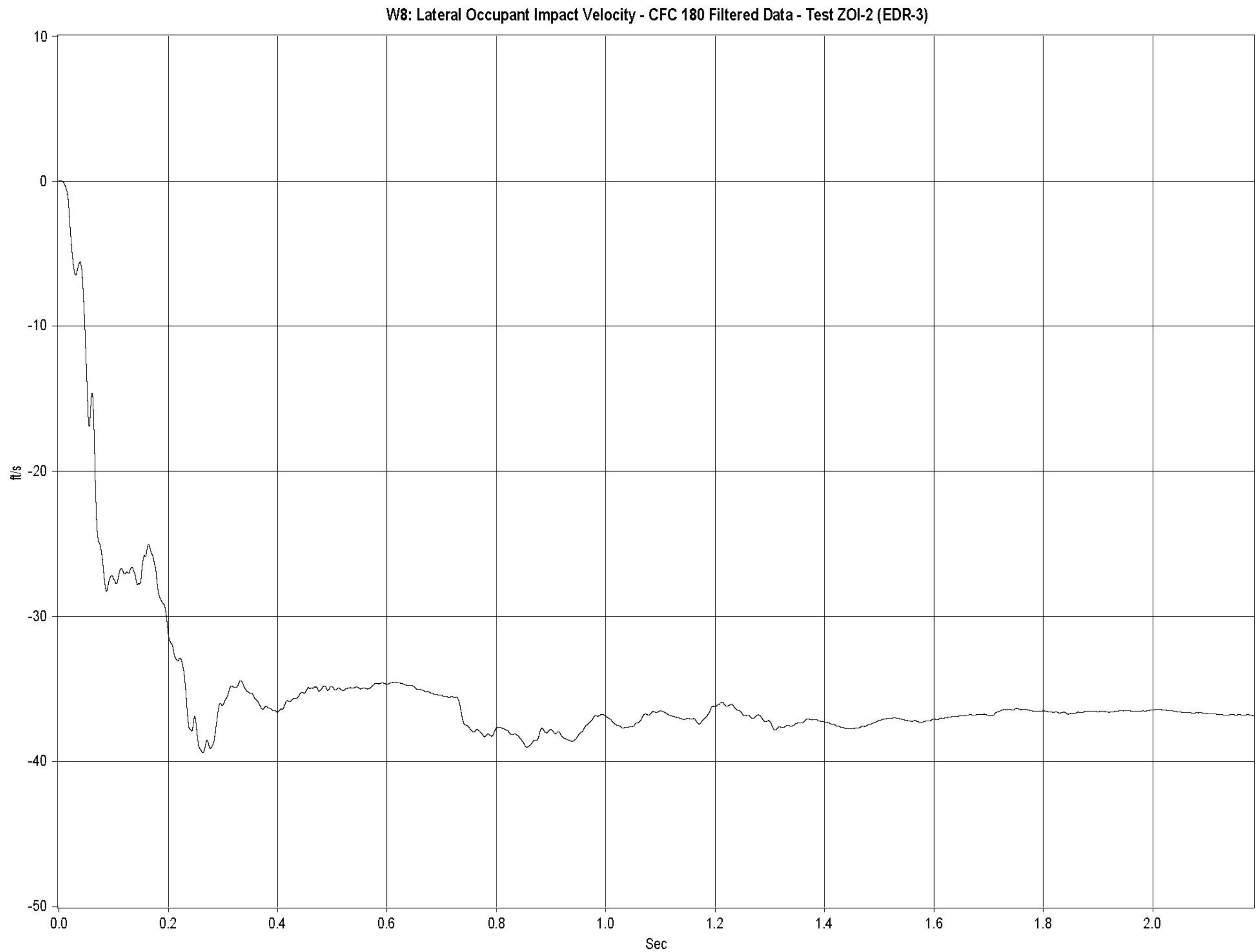


Figure G-5. Graph of Lateral Occupant Impact Velocity, Test ZOI-2

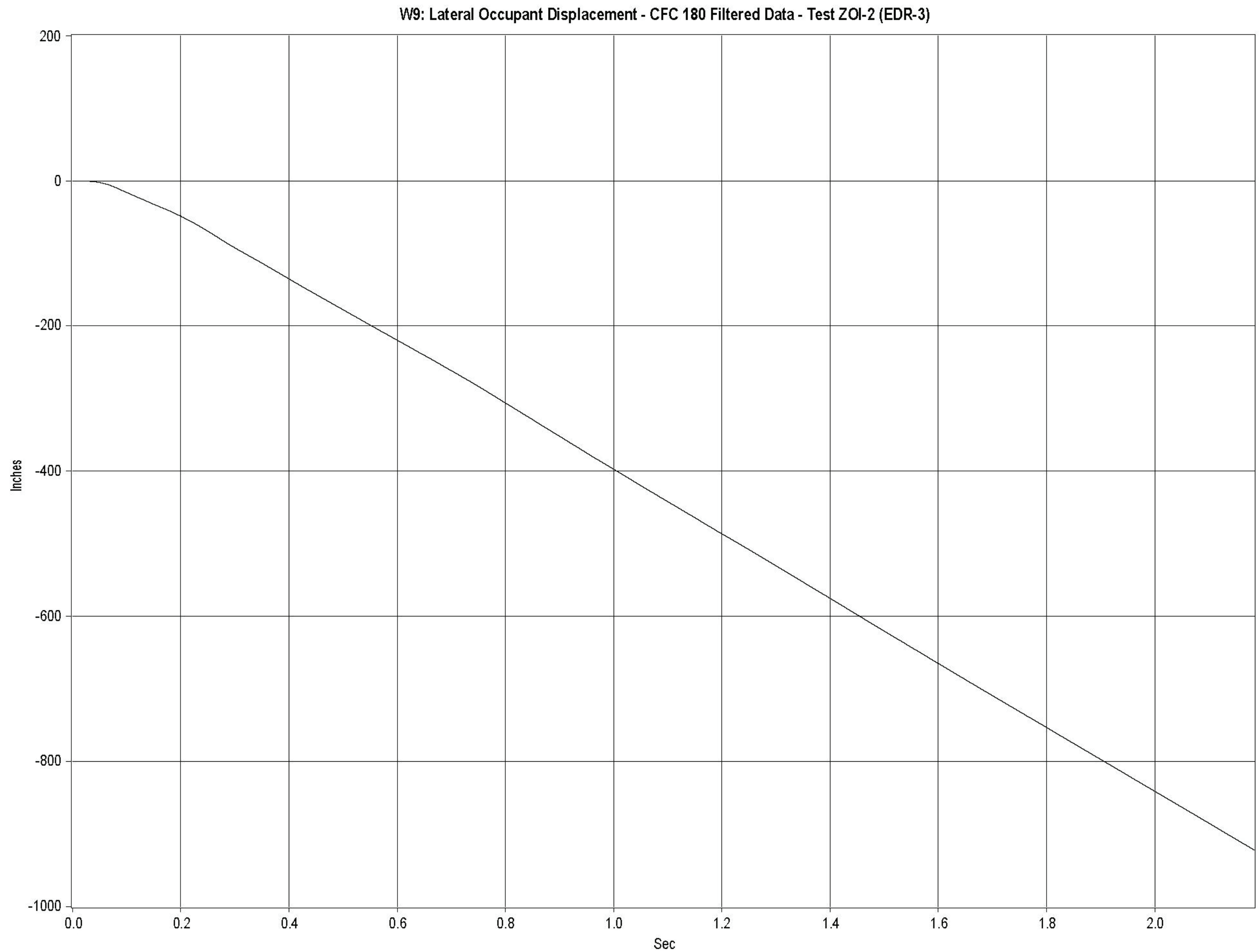


Figure G-6. Graph of Lateral Occupant Displacement, Test ZOI-2

APPENDIX H

English-Unit System Drawings, Test ZOI-3

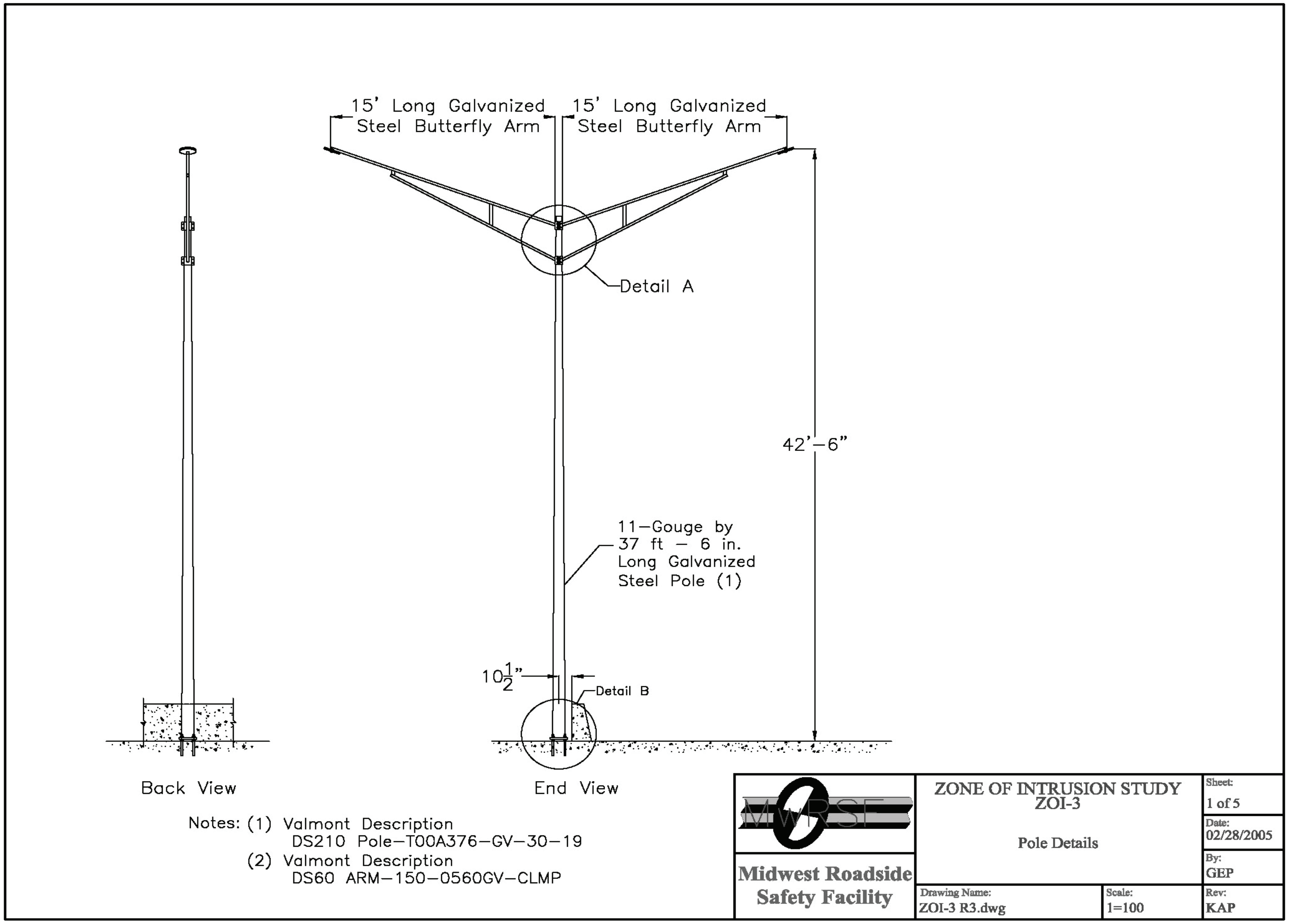


Figure H-1. Pole Details, Test No. ZOI-3 (English)

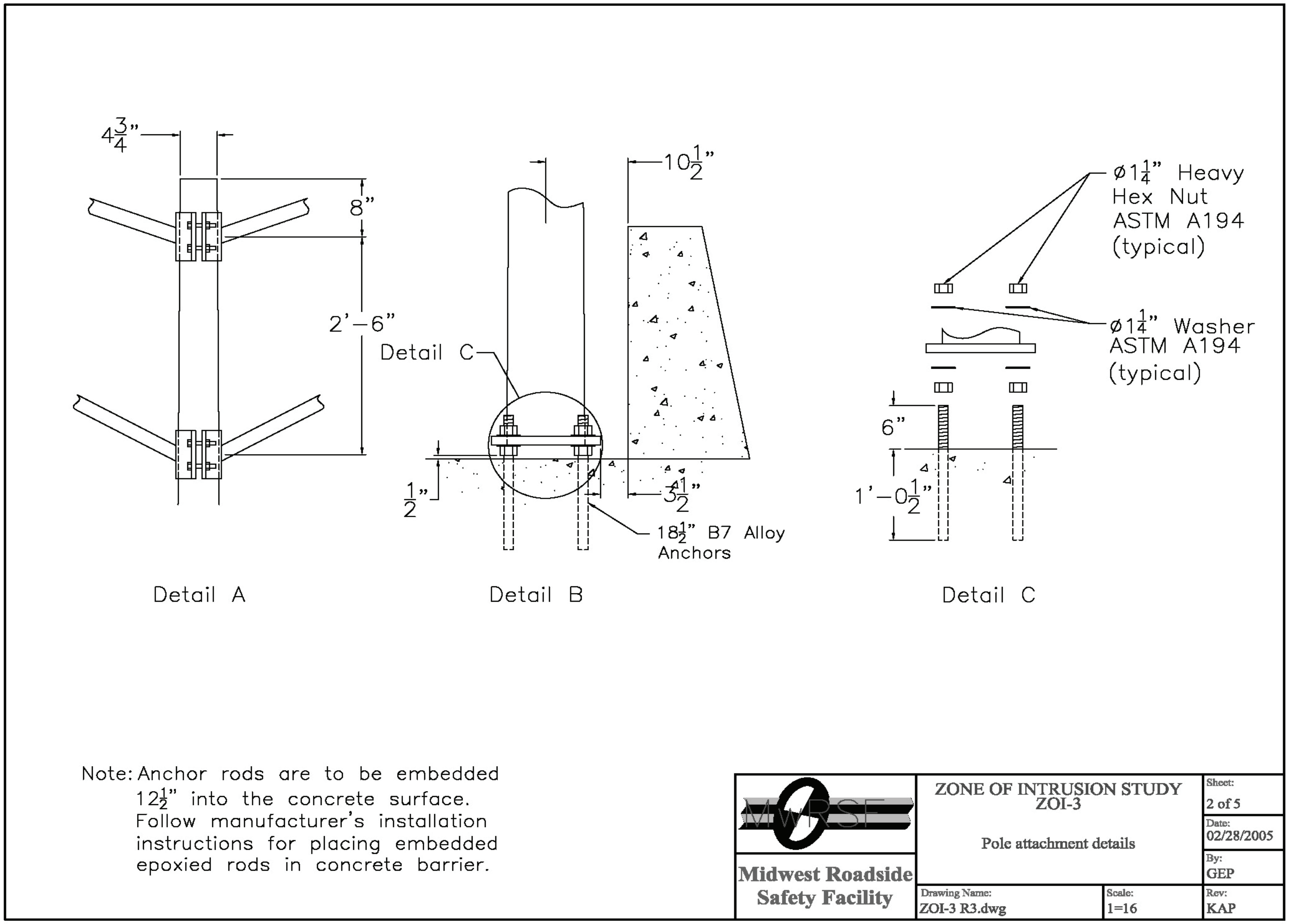


Figure H-2. Pole Attachment Details, Test No. ZOI-3 (English)

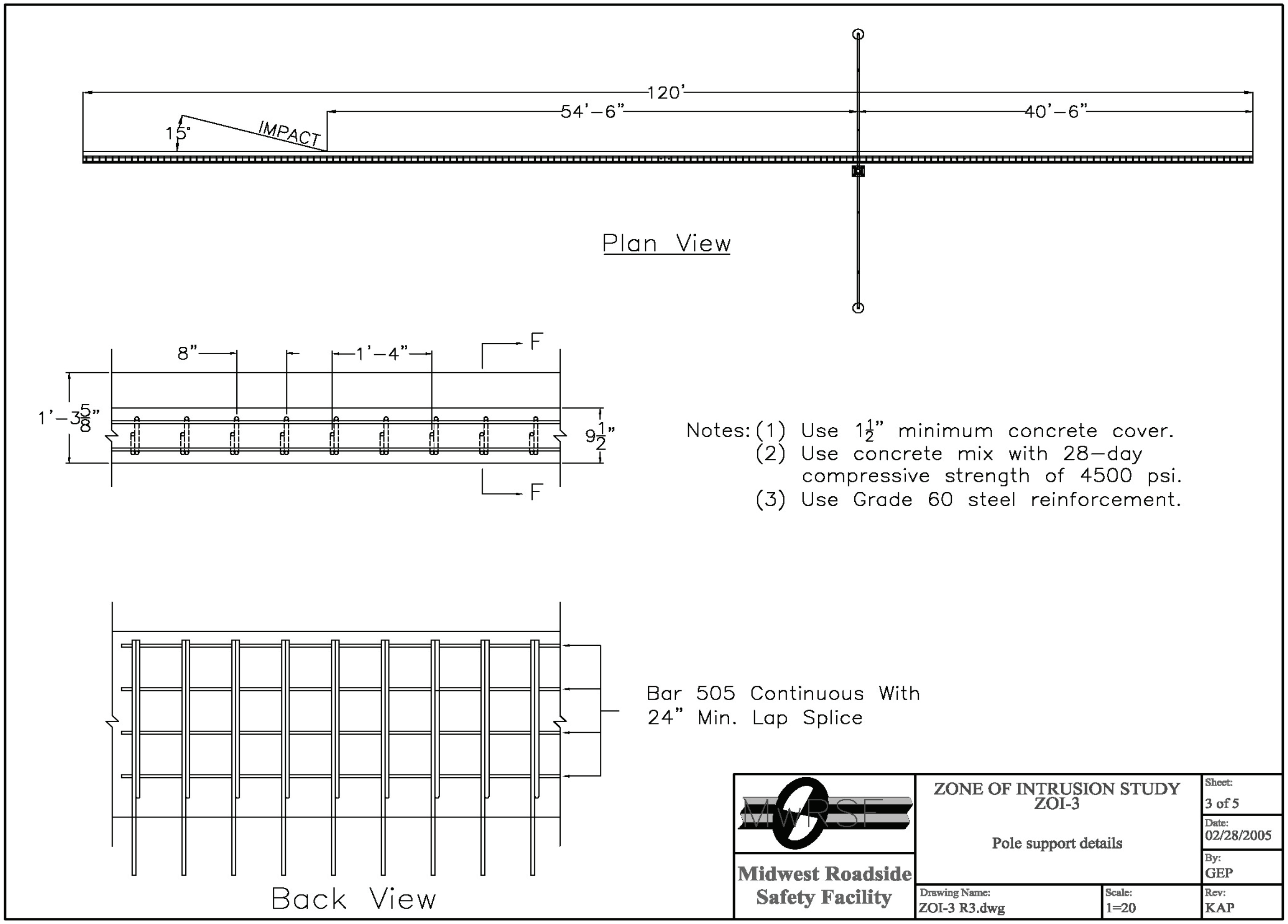


Figure H-3. Pole Support Details, Test No. ZOI-3 (English)

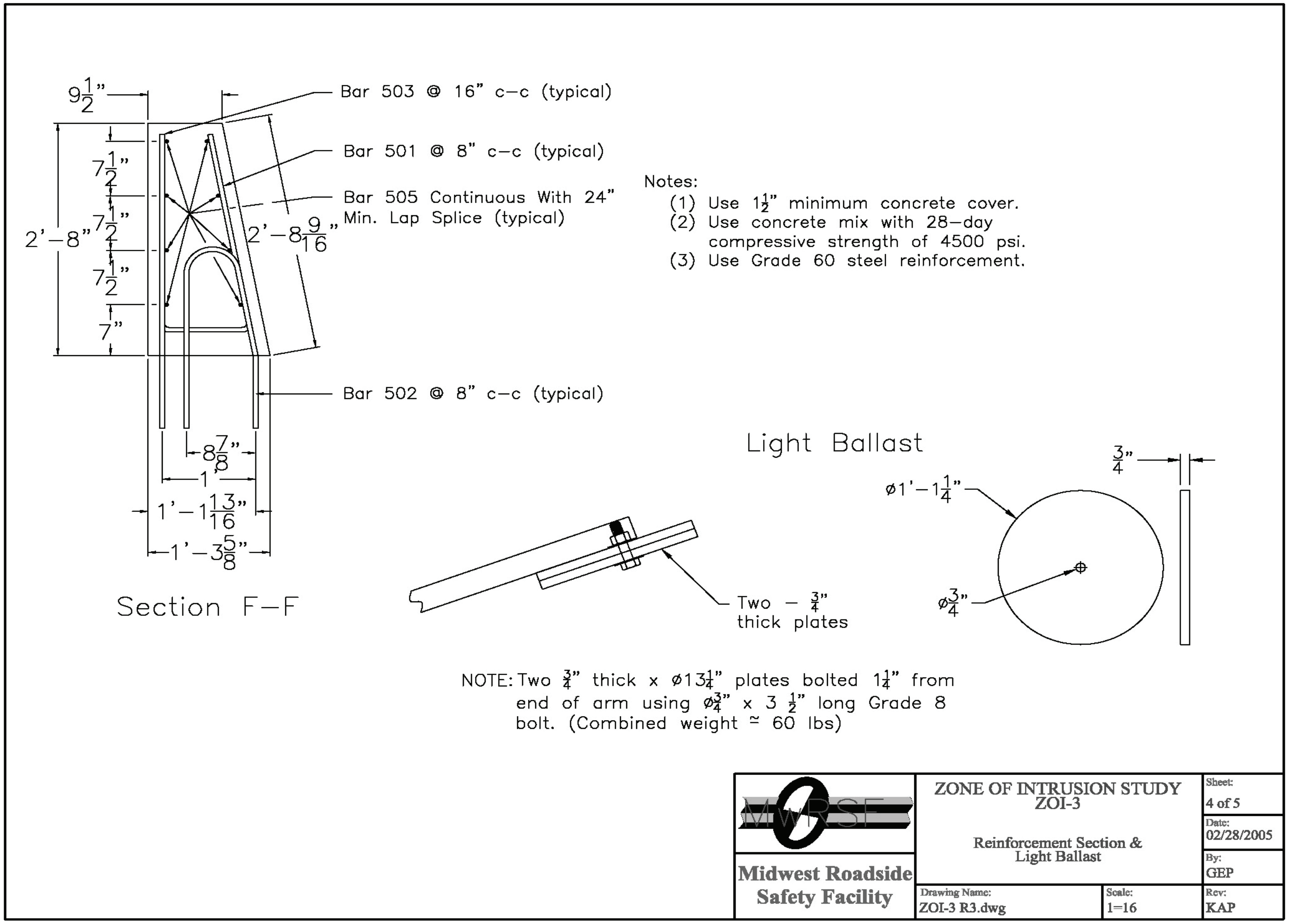
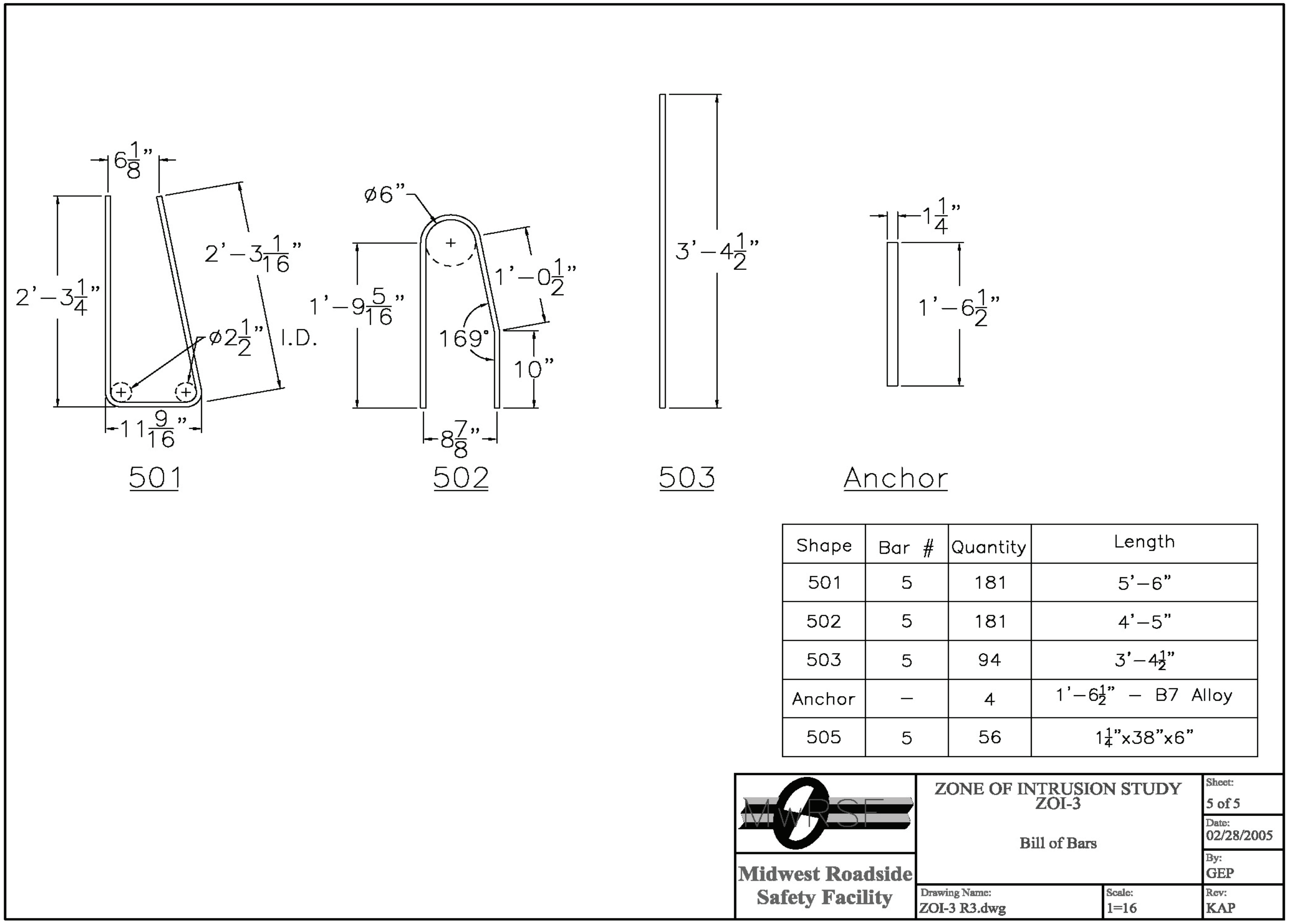


Figure H-4. Reinforcement Section and Light Ballast, Test No. ZOI-3 (English)



Shape	Bar #	Quantity	Length
501	5	181	5'-6"
502	5	181	4'-5"
503	5	94	3'-4 1/2"
Anchor	–	4	1'-6 1/2" – B7 Alloy
505	5	56	1 1/4"x38"x6"

Figure H-5. Bill of Bars, Test No. ZOI-3 (English)

APPENDIX I

Occupant Compartment Deformation Data, Test ZOI-3

Figure I-1. Occupant Compartment Deformation Index (OCDI), Test ZOI-3

Occupant Compartment Deformation Index (OCDI)

Test No. ZOI-3
Vehicle Type: 8000s

OCDI = XXABCDEFGHI

XX = location of occupant compartment deformation

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

B = distance between the roof and the floor panel

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

D = distance between the lower dashboard and the floor panel

E = interior width

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

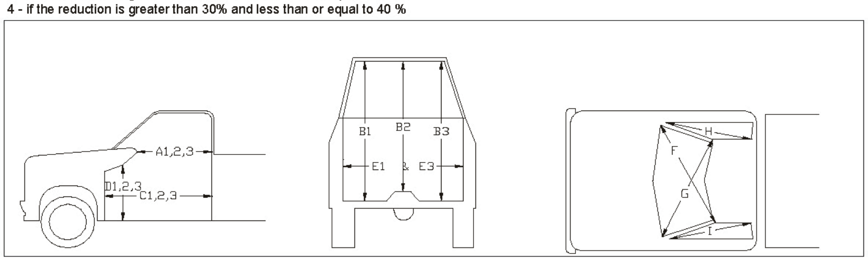
G = distance between the lower edge of left window and the upper edge of right window

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

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

Severity Indices

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



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

Location:

Measurement	Pre-Test (in.)	Post-Test (in.)	Change (in.)	% Difference	Severity Index
A1	41.00	41.00	0.00	0.00	0
A2	41.25	41.25	0.00	0.00	0
A3	43.00	43.00	0.00	0.00	0
B1	48.00	48.00	0.00	0.00	0
B2	44.75	45.00	0.25	0.56	0
B3	48.00	48.00	0.00	0.00	0
C1	58.25	58.25	0.00	0.00	0
C2	47.50	47.25	-0.25	-0.53	0
C3	56.25	56.25	0.00	0.00	0
D1	18.25	18.25	0.00	0.00	0
D2	11.50	11.50	0.00	0.00	0
D3	18.25	18.50	0.25	1.37	0
E1	65.50	65.00	-0.50	-0.76	0
E3	65.50	65.50	0.00	0.00	0
F	60.75	60.25	-0.50	-0.82	0
G	59.75	59.75	0.00	0.00	0
H	37.50	37.25	-0.25	-0.67	0
I	38.00	37.75	-0.25	-0.66	0

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

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

Figure I-1. Occupant Compartment Deformation Index (OCDI), Test ZOI-3

APPENDIX J

Accelerometer and Rate Transducer Data Analysis, Test ZOI-3

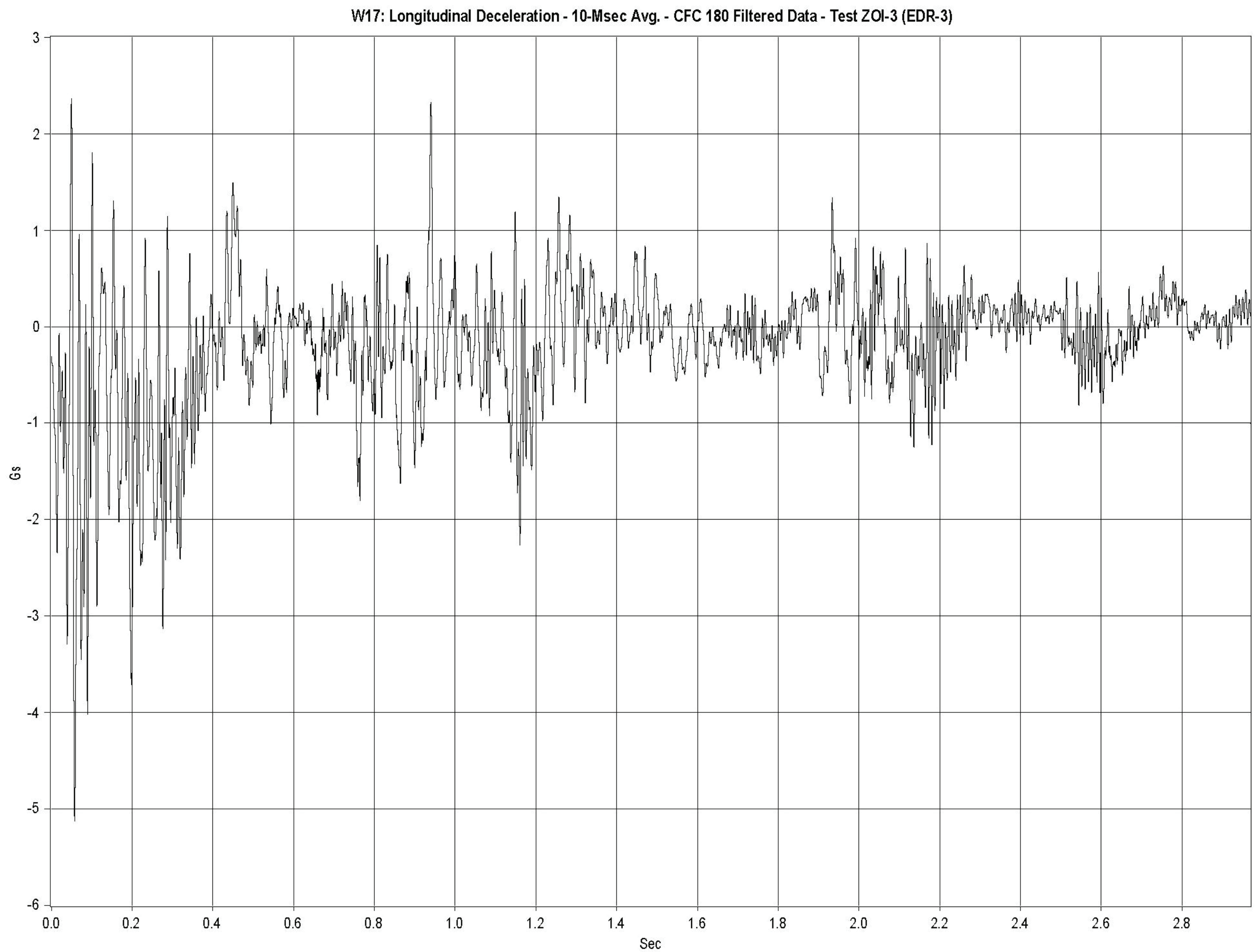


Figure J-1. Graph of Longitudinal Deceleration, Test ZOI-3

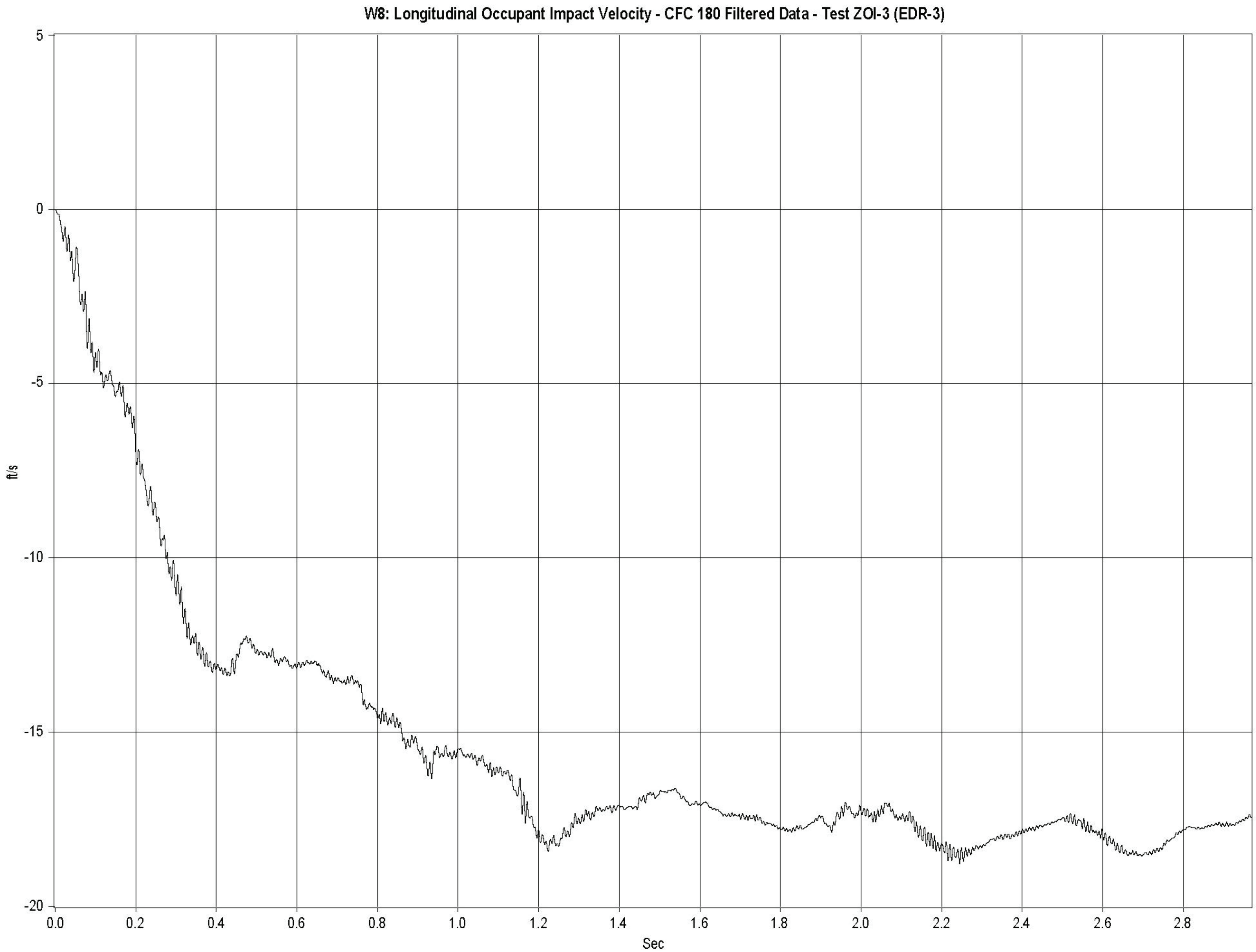


Figure J-2. Graph of Longitudinal Occupant Impact Velocity, Test ZOI-3

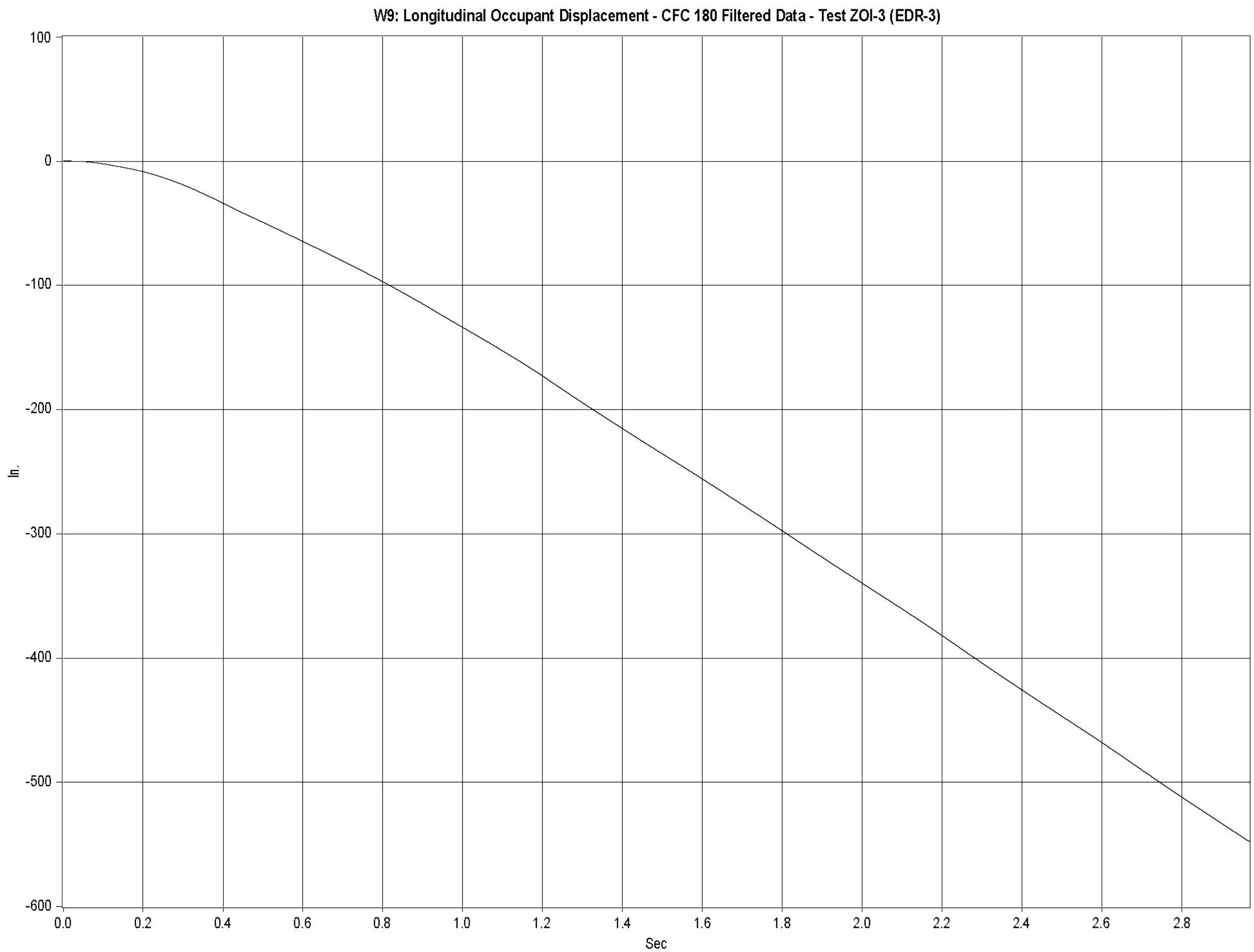


Figure J-3. Graph of Longitudinal Occupant Displacement, Test ZOI-3

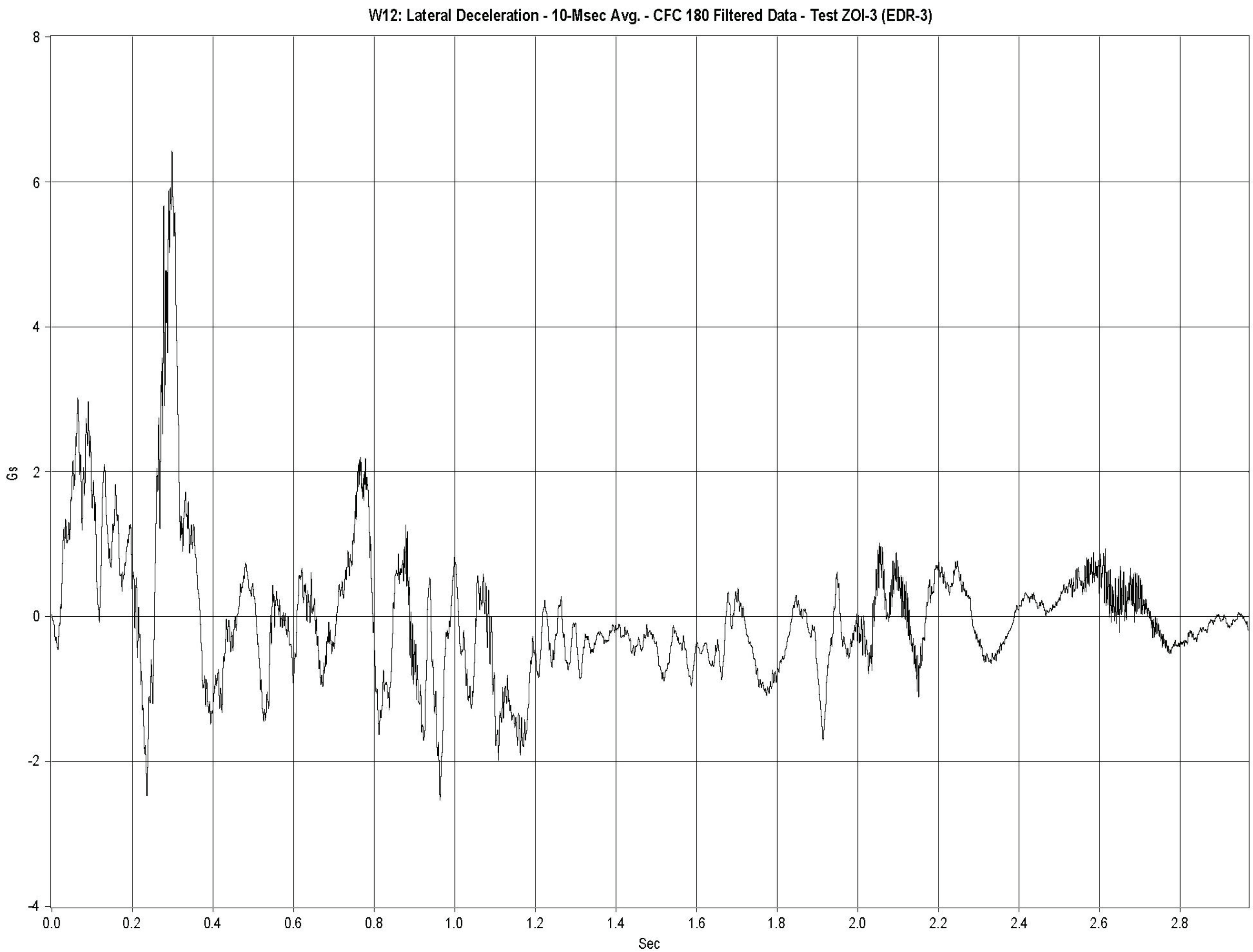


Figure J-4. Graph of Lateral Deceleration, Test ZOI-3

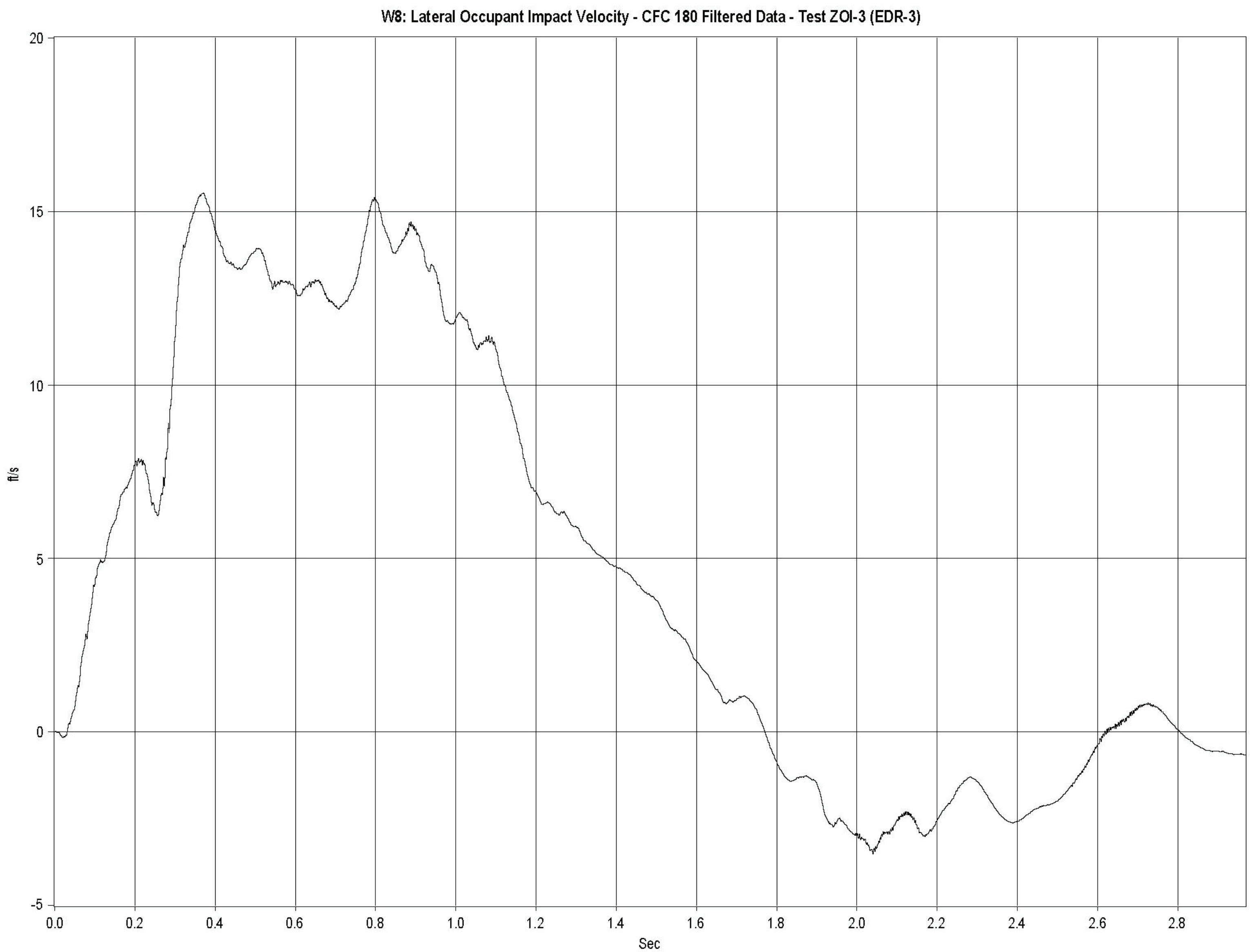


Figure J-5. Graph of Lateral Occupant Impact Velocity, Test ZOI-3

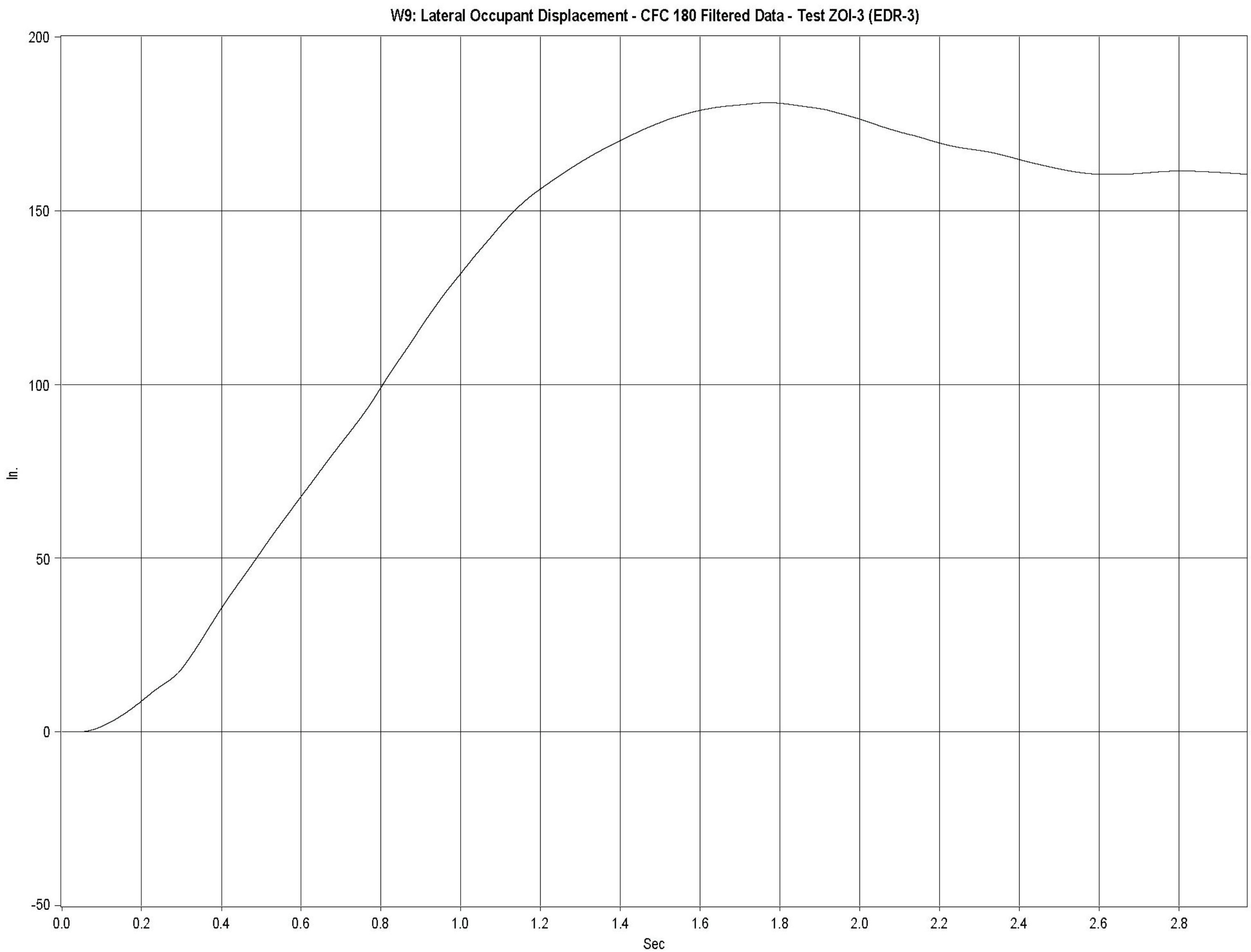


Figure J-6. Graph of Lateral Occupant Displacement, Test ZOI-3

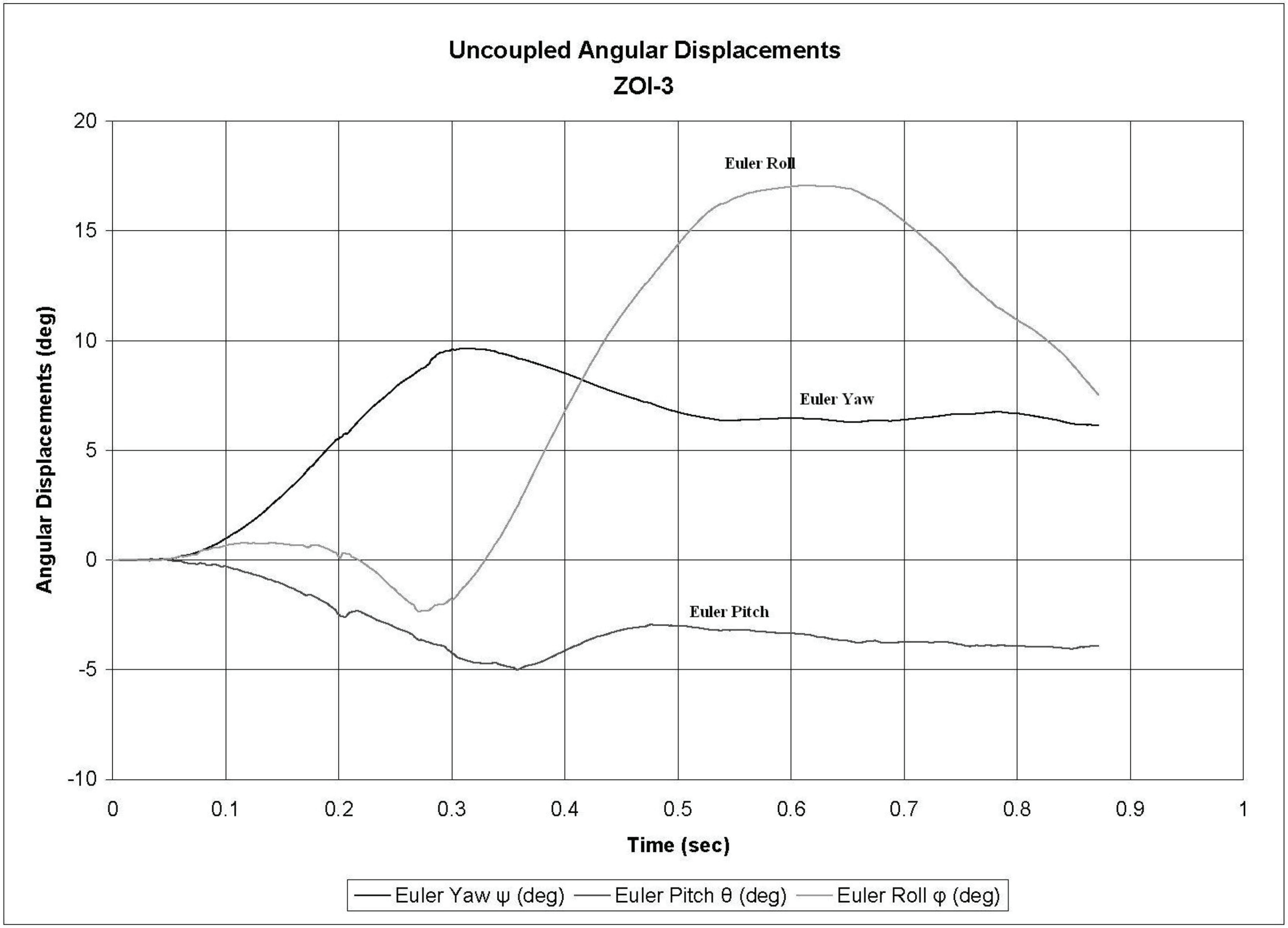


Figure J-7. Graph of Roll, Pitch and Yaw Angular Displacements, Test ZOI-3