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DEVELOPMENT OF THE *MIDWEST GUARDRAIL SYSTEM* (MGS) FOR STANDARD AND REDUCED POST SPACING AND IN COMBINATION WITH CURBS

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16. Abstract (Limit: 200 words)

A new strong-post W-beam guardrail system called the *Midwest Guardrail System* (MGS) was developed, tested, evaluated, and provides increased safety for impacts with higher center-of-mass vehicles. The new barrier utilizes W-beam guardrail and standard W6x9 steel posts. Design differences between the MGS and standard W-beam systems include a new W-beam rail top mounting height of 787 mm (31 in.), a reduced guardrail post embedment depth, an increased blockout depth from 203 mm (8 in.) to 305 mm (12 in.), and a repositioning of the guardrail splice from a post to a midspan location. Additional design variations of the new MGS included a standard guardrail design configured with a 152-mm (6-in.) high concrete curb as well as stiffened versions using reduced (half and quarter) post spacings.

All six full-scale vehicle crash tests were conducted and reported in accordance with the Test Level 3 (TL-3) requirements specified in the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. One of the full-scale crash tests was conducted to verify that the guardrail performs adequately with mini-size automobiles when raised to an 813 mm (32 in.) top mounting heights. This test proved that the barrier can provide satisfactory performance when mounted at heights ranging from standard guardrail height of 706 mm (27.78 in.) to 813 mm (32 in.). Hence, the safety performance of the *Midwest Guardrail System* (MGS) was determined to be acceptable according to the TL-3 evaluation criteria specified in NCHRP Report No. 350 and provides approximately 107 mm (4.2 in.) of mounting height tolerance.

The research study also included computer simulation modeling with LS-DYNA to study guardrail design parameters, dynamic bogie testing on steel posts placed at various embedment depths, and computer simulation modeling with BARRIER VII to analyze and predict dynamic guardrail performance. Recommendations for the placement of the original *Midwest Guardrail System* (MGS) as well as its stiffened variations were also made.

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DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views nor policies of the State Highway Departments participating in the Midwest States' Regional Pooled Fund Research Program 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

Significant changes in the vehicle fleet over the past 10 years have led to changes in performance criteria for roadside safety hardware. In particular the replacement of the large sedan with a ¾-ton pickup has caused the re-evaluation of much of the existing roadside safety hardware. One of the key questions in this re-evaluation has been the performance of the W-beam guardrail. Several recent tests of W-beam guardrails have demonstrated that successful capture and redirection of the ¾-ton pickup vehicle is very sensitive to vehicle size, soil conditions, and type and design of posts. W-beam guardrail relies on the capture of the pickup's front wheel under the rail element. The capture mechanism must function over a wide range of wheel sizes, vehicle configurations, soil conditions, and post types. Unfortunately, these requirements do not appear to be satisfied by either standard W-beam rail systems nor the more costly thrie-beam systems.

In a recent project, funded by a guardrail manufacturer, the Midwest Roadside Safety Facility (MwRSF) developed a new proprietary guardrail shape intended to address these issues (1). The result of this project was a proprietary guardrail section that was slightly less costly than existing W-beam system and utilized a deeper section and increased post spacing. This system met the Test Level 3 (TL-3) criteria of the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (2), and demonstrated the capacity to contain and redirect high center-of-gravity light truck vehicles. However, experience with a number of crash tests has led researchers to believe that there may be several new concepts that may achieve further improvements in barrier performance without significant cost increases. Therefore, a need exists to develop a strong-post, W-beam guardrail system that is capable of containing and redirecting high center-of-gravity vehicles and that can accommodate some reasonable reduction in height from the design standards.

In addition, W-beam guardrail is occasionally installed over curbs located along the roadways. Although W-beam guardrail systems installed over curbs have adequately met the NCHRP Report No. 350 criteria, it is believed that systems with a curb taller than 102-mm (4-in.) would not be capable of meeting current safety standards. Furthermore, the placement of 102-mm (4-in.) high curbs further away from the front face of existing W-beam barrier systems may not be capable of meeting the pickup truck crash testing requirements. Therefore, a need also exists to develop a W-beam guardrail over curb system that accommodates increased curb heights and increased lateral curb placement in front of the guardrail system.

Similarly, W-beam guardrail may be installed in situations where limited space is available between the edge of the traveled way and the front of hazards. In these instances, it may be necessary for roadway designers to use stiffened variations of the standard W-beam guardrail system. In the past, computer simulation studies and full-scale crash testing programs have been utilized to better understand guardrail stiffening techniques, such as guardrail nesting and reduced post spacing, as well as to formulate guardrail placement guidelines (3-7). Therefore, it seems necessary for researchers and roadway designers to better understand the dynamic performance of the new barrier system for both the standard and stiffened configurations. As a result, there also exists a need to develop appropriate guardrail placement guidelines for the standard, half-post, and quarter-post spacing designs.

1.2 Objective

In recognition of the potential for improving guardrail performance for high center-of-gravity vehicles and the need to re-establish reasonable barrier height tolerances, the objectives of the research project were to: (1) examine the performance of W-beam guardrail and make any design changes, including the rail shape that would provide increased safety for higher center-of-mass vehicles, provide reasonable barrier height tolerances, maintain acceptable safety performance for small vehicles, and reduce the potential for W-beam rupture; (2) develop a guardrail-to-curb barrier combination that provides increased hydraulic capacity and placement farther in front of the rail face to reduce the frequency of snow plow damage to guardrails; and (3) evaluate guardrail stiffening and determine appropriate guardrail placement guidelines for shielding rigid hazards using full-, half-, and quarter-post spacing designs. The guardrail systems were to be developed and evaluated according to the TL-3 safety performance criteria set fourth in the NCHRP Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (2).

1.3 Scope

The research objective was achieved by performing several tasks. First, a careful review of the research program that led to the development of the Buffalo Rail was undertaken (1). Next, a literature review was performed on previously crash tested W-beam guardrail systems as well as guardrail systems over curbs and stiffened W-beam guardrail systems. Subsequently, a parametric study of guardrail design parameters was undertaken using LS-DYNA computer simulation modeling (8). Following the parametric study, ten dynamic bogie tests were performed on steel posts in soil in order to evaluate alternative embedment depths as well as to determine the associated force-deflection behaviors. Based on the findings of the simulation and bogie testing efforts, a new W-beam guardrail system, called the *Midwest Guardrail System* (MGS), was developed. Six full-scale vehicle crash tests were conducted. The first test utilized a small compact car weighing approximately 820 kg (1,808 lbs) with a target impact speed and angle of 100.0 km/h (62.1 mph) and 20 degrees, respectively. The second test was a developmental test which was performed, using a non-compliant 4x4 pickup truck, with a target impact speed and angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively. The last four tests were performed using ¾-ton pickup trucks, weighing approximately 2,000 kg (4,409 lbs), at target impact speeds and angles of 100.0 km/h (62.1 mph) and 25 degrees, respectively. Finally, the test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made that pertain to the safety performance of the standard *Midwest Guardrail System* (MGS) with and without a curb. In addition, guardrail placement guidelines were presented for the standard *Midwest Guardrail System* (MGS) as well as the stiffened variations.

2 LITERATURE REVIEW

2.1 Standard W-beam Guardrail Systems

For more than 50 years, strong-post W-beam guardrail systems have been placed along our highways and roadways in order to prevent errant motorists from striking dangerous hazards located beyond the roadway edge. The design of strong-post W-beam guardrail has not changed significantly since the early 1960's when the California Department of Transportation (CALTRANS) first tested a blocked-out W-beam guardrail system (9). In general and based on the CALTRANS research, these systems have consisted of a single, 2.66-mm (12-gauge) thick W-beam rail supported by steel or wood posts spaced 1,905-mm (75-in.) on center. Although several rail spacer variations have existed throughout the United States, one common W-beam guardrail system incorporated a 203-mm (8-in.) deep wood blockout in conjunction with 530-mm (20 ⅞-in.) and 686-mm (27-in.) center and top rail mounting heights, respectively. This guardrail design in particular has provided excellent safety performance for many years.

Although these original W-beam guardrail designs were successfully developed to contain and safely redirect full-size sedans and later small cars when the vehicle fleet was downsized during the 1970's, one research study indicated a performance weakness for standard guardrail designs. In 1983, the Texas Transportation Institute (TTI) conducted a large research study to determine the performance limits of the G4(1S), the modified G4(2W), and the modified G4(1S) longitudinal barrier systems (10). For this effort, seven crash tests were performed into strong-post, W-beam guardrail systems using several types of vehicles, including a sedan, small cars, pickup trucks, and a van. Several important conclusions could be made from these tests. First, a standard wood-post W-beam guardrail system installed to a 762-mm (30-in.) top mounting height could safely contain and redirect small cars with only limited wheel snag on the wood posts. The standard steel-post W-beam guardrail system was evaluated using small and ½-ton full-size pickup trucks and a van. Although this W-beam guardrail system has the capability of safely containing and redirecting small and ½-ton full-size pickup trucks, testing also revealed a tendency for the front wheel to severely snag on the posts, resulting in heavy damage to the front quarter and wheel assembly regions and a potential for a moderate vehicle roll angles while exiting the barrier. Furthermore, full-scale testing indicated that the steel-post W-beam guardrail system was incapable of safely redirecting a full-size van as the vehicle violently rolled over after exiting the barrier.

In 1993, the implementation of the NCHRP Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features,* provided new and revised crash testing guidelines and introduced the ¾-ton pickup truck as a replacement to the full-size passenger sedan vehicle used previously (2). Following the implementation of these new impact safety standards, several crash testing studies were conducted in order to determine whether existing strong steel-post and wood-post W-beam guardrail systems with a 686-mm (27-in.) top mounting height would meet the new NCHRP Report No. 350 requirements (11-14). The results from these research studies revealed differing levels of safety performance and consequently potential room for improvement in the barrier's performance during impacts. The wood-post, wood blockout guardrail system adequately contained and redirected the pickup truck, while the steel-post with steel and wood blockout guardrail systems both resulted in vehicle rollover. Similarly, statistical analysis of W-beam guardrail accidents has also revealed that light trucks are much more likely to rollover when striking W-beam guardrail than conventional automobiles (14).

During this same period, metrication of roadside safety hardware occurred and resulted in a repositioning of the W-beam rail center height to 550 mm (21.65 in.). Subsequently, several research studies were performed in order to investigate the safety performance of 706-mm (27.78-in.) high strong-post, W-beam guardrail systems when subjected to ¾-ton pickup truck impacts at the target conditions of 100 km/h (62.14 mph) and 25 degrees (12,15-19). Although most of these crash tests resulted in satisfactory barrier performance, there were indications that these W-beam guardrail systems may not have sufficient reserve capacity to safely contain and redirect higher center-of-mass vehicles during high-speed and high-angle collisions.

On a similar note, the effective height of standard W-beam guardrail has the potential to be below the height at which crash testing has been conducted. Even though all successful crash testing conducted to date incorporated a center height of 550 mm (21.65 in.), most state standard plans continue to specify that W-beam guardrails be installed at a height of 530 mm (20 ⅞ in.) to the center of the rail. Although this 20 mm (0.78 in.) difference is not considered to be a major problem, one full-scale crash test has indicated that even this small change can significantly affect the performance of W-beam guardrail during light truck impacts (13-15). In addition, significant variations exist in the actual constructed height of a guardrail, both above and below its design height. Finally, when pavement overlays are applied to a roadway, the effective height of most of the guardrails installed near the roadway is significantly reduced. Currently, there appears to be no tolerance for low height guardrail below the nominal 530 mm (20 ⅞ in.) design center height specified in most state plans. Consequently, guardrails on every pavement overlay project would have to be raised in order to meet the design's minimum height requirements.

2.2 W-beam Guardrail Over Curb Systems

Curbs are often utilized along the roadway edge to provide drainage control, roadway edge delineation and support, right-of-way reduction, and sidewalk separation, as well as to perform several other functions. Since hazards are often found along roadways with curbs, W-beam guardrail systems are frequently installed over curbs.

In recent years, two research studies were conducted to test and evaluate standard W-beam guardrail systems installed over 102-mm (4-in.) high curbs according to the NCHRP Report No. 350 guidelines (20-22). In 2000, TTI researchers performed a study that showed that the G4(2W) guardrail system, when installed over a 102-mm (4-in.) high asphaltic curb, would adequately contain and redirect ¾-ton pickup trucks (20). However, in a separate study, MwRSF engineers tested and evaluated the modified G4(1S) guardrail system when installed over a concrete curb and encountered unsatisfactory results (21-22). The W-beam guardrail ruptured at a splice location, allowing the vehicle to penetrate behind the system. Several alternatives were considered, including guardrail nesting, utilizing a single 3.42-mm (10-gauge) W-beam rail, and relocating the rail splice away from a post location. Researchers modified the guardrail system to use two nested 2.66-mm (12-gauge) W-beam rails. Pickup truck testing on this nested, modified G4(1S) guardrail system was met with satisfactory results. However, the vehicle was redirected into the air and landed on the barrier downstream. Both guardrail-to-curb combinations were constructed with the toe of the curb either at or within 25 mm (1 in.) of the rail face because past research has shown that curbs placed in front of W-beam guardrails can lead to the vehicle's climbing and vaulting over the barriers (21).

Although these two W-beam guardrail systems installed over curbs adequately met the NCHRP Report No. 350 requirements, it is generally believed that W-beam guardrail systems with curbs higher than 102-mm (4-in.) tall, would not be capable of meeting current safety standards. In addition, placement of curbs at a greater distance away from the guardrail face reduces the propensity for snow plows to gouge and/or damage the W-beam rail sections. However, placement of the 102-mm (4-in.) high curbs farther away from the front face of the existing W-beam barrier systems also may not be capable of meeting current pickup truck crash testing requirements.

2.3 Limited Deflection W-beam Guardrail Systems

As previously mentioned, longitudinal barrier systems are used for shielding roadside hazards. However, there often exists situations where limited space is available between the edge of the traveled way and the front of the hazard, such as when concrete bridge piers are found near the roadway shoulder. In these instances, it may be necessary for roadway designers to use stiffened variations of the standard W-beam guardrail system in order to reduce dynamic deflections and allow for a closer placement of the barrier to the hazard. In the past, computer simulation studies and full-scale crash testing programs have been utilized to better understand guardrail stiffening techniques, such as guardrail nesting and reduced post spacing, as well as to formulate guardrail placement guidelines (3-7).

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as W-beam guardrail systems, must satisfy the requirements provided in NCHRP Report No. 350 to be accepted for use on National Highway System (NHS) construction projects or as a replacement for existing systems not meeting current safety standards. According to TL-3 of NCHRP Report No. 350, the longitudinal barriers must be subjected to two full-scale vehicle crash tests. The two crash tests are as follows:

1. Test Designation 3-10. An 820-kg (1,808-lb) small car impacting the guardrail system at a nominal speed and angle of 100.0 km/h (62.1 mph) and 20 degrees, respectively.

2. Test Designation 3-11. A 2,000-kg (4,409-lb) pickup truck impacting the guardrail system at a nominal speed and angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively.

Prior research has shown successful safety performance for small cars impacting guardrail-to-curb barrier combinations using a 152-mm (6-in.) high asphalt dike (23). When impacted by a small car, this barrier system, like other strong-post W-beam barriers, remained essentially rigid with only modest deflection. In addition, the small car tests resulted in no significant potential for occupant risk problems arising from vehicle pocketing, severe wheel snagging on the guardrail posts, nor potential for rail rupture, nor vehicular instabilities due to vaulting or climbing the rail (10, 24-25). Therefore, the 820-kg (1,808-lb) small car test was deemed unnecessary for the evaluation of the guardrail-to-curb barrier combination of the new *Midwest Guardrail System* (MGS). In addition, following the satisfactory results of the small car test on the standard full-post spacing *Midwest Guardrail System* design, MwRSF researchers believed that additional small car testing was also unnecessary for the reduced post spacing designs. The test conditions for TL-3 longitudinal barriers are summarized in Table 1.

3.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the barrier to contain, redirect, or allow controlled vehicle penetration in a predictable manner. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to cause subsequent multi-vehicle accidents. This criterion also indicates the potential safety hazard for the occupants of other vehicles or the occupants of the impacting vehicle when subjected to secondary collisions with other fixed objects. These three evaluation criteria are defined in Table 2. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in NCHRP Report No. 350.

Table 1. NCHRP Report No. 350 Test Level 3 Crash Test Conditions

Test Article	Test Designation	Test Vehicle	Impact Conditions			Evaluation Criteria [1]
			Speed		Angle (degrees)	
			(km/h)	(mph)		
Longitudinal Barrier	3-10	820C	100	62.1	20	A,D,F,H,I,K,M
	3-11	2000P	100	62.1	25	A,D,F,K,L,M

[1] Evaluation criteria explained in Table 2.

Table 2. NCHRP Report No. 350 Evaluation Criteria for Crash Tests (2)

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.
	H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9 m/s (29.53 ft/s), or at least below the maximum allowable value of 12 m/s (39.37 ft/s).
	I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15 g's, or at least below the maximum allowable value of 20 g's.
Vehicle Trajectory	K. After 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/sec (39.37 ft/sec), and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.
	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.

4 TEST CONDITIONS

4.1 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.

4.2 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 guardrail 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 (26) was used to steer the test vehicle. A guide-flag, attached to the front-right wheel and the guide cable, was sheared off before impact with the guardrail 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 NPG-1 and NPG-3, the vehicle guidance systems were approximately 229-m and 290-m (750-ft and 950-ft) long, respectively. For tests NPG-2, NPG-4, NPG-5, and NPG-6, the vehicle guidance system was approximately 305-m (1000-ft) long.

4.3 Test Vehicles

For test NPG-1, a 1994 Geo Metro was used as the test vehicle. The test inertial and gross static weights were 812 kg (1,790 lbs) and 887 kg (1,956 lbs), respectively. The test vehicle is shown in Figure 1, and vehicle dimensions are shown in Figure 2.

For test NPG-2, a 1995 Chevrolet 2500 ¾-ton 4-wheel drive pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,241 kg (4,941 lbs). The test vehicle is shown in Figure 3, and vehicle dimensions are shown in Figure 4.

For test NPG-3, a 1995 Chevrolet 2500 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,037 kg (4,491 lbs). The test vehicle is shown in Figure 5, and vehicle dimensions are shown in Figure 6.

For test NPG-4, a 1995 GMC 2500 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 1,986 kg (4,378 lbs). The test vehicle is shown in Figure 7, and vehicle dimensions are shown in Figure 8.

For test NPG-5, a 1997 Chevrolet 2500 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 1,991 kg (4,389 lbs). The test vehicle is shown in Figure 9, and vehicle dimensions are shown in Figure 10.

For test NPG-6, a 1997 GMC 2500 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,001 kg (4,411 lbs). The test vehicle is shown in Figure 11, and vehicle dimensions are shown in Figure 12.

The longitudinal component of the center of gravity was determined using the measured axle weights. The location of the final centers of gravity are shown in Figures 1 through 12.

Square black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film and E/cam video, as shown in Figures 13 through 18. Round, checkered targets were placed on the center of gravity, on the driver's side door, on the passenger's side door,

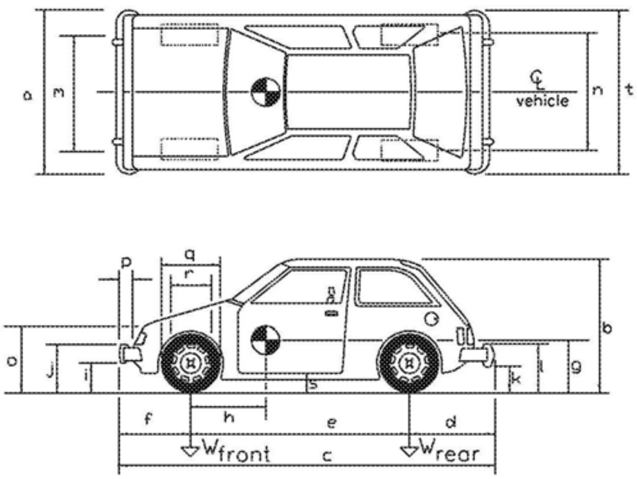
Figure 1. Test Vehicle, Test NPG-1

Date: 6/1/01 Test Number: NPG-1 Model: 820C

Make: Geo Metro 2Dr. Vehicle I.D.#: 2C1MR2461R6771926

Tire Size: 145/80 R12 Year: 1994 Odometer: 83315

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1549 (61.0)	b	1353 (53.25)
c	3747 (147.5)	d	692 (27.25)
e	2267 (89.25)	f	787 (31.0)
g	546 (21.5)	h	867 (34.15)
i	203 (8)	j	451 (17.75)
k	267 (10.5)	l	584 (23)
m	1368 (53.875)	n	1337 (52.625)
o	521 (20.5)	p	95 (3.75)
q	527 (20.75)	r	333 (13.125)
s	276 (10.875)	t	1575 (62.0)

Wheel Center Height 248 (9.75)

Engine Type 3 CYL. GAS

Engine Size 1.0 L

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	488 (1077)	515 (1136)	552 (1217)
W_{rear}	258 (568)	297 (654)	335 (739)
W_{total}	746 (1645)	812 (1790)	887 (1956)

Note any damage prior to test: Minor dents: hood & rear hatch

Figure 2. Vehicle Dimensions, Test NPG-1

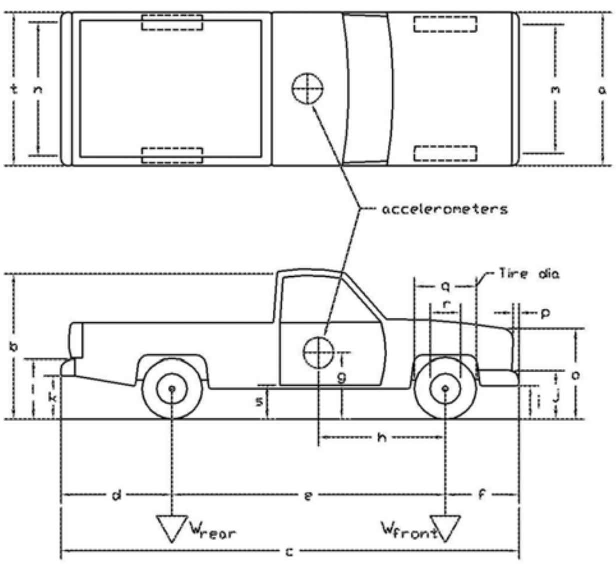
Figure 3. Test Vehicle, Test NPG-2

Date: 8/9/01 Test Number: NPG-2 Model: 2500

Make: Chevrolet Vehicle I.D.#: 1GCGK24K25E103796

Tire Size: 255/85 R16 Year: 1995 Odometer: 127172

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1883 (74.125)	b	1905 (75.0)
c	5537 (218.0)	d	1289 (50.75)
e	3327 (131.0)	f	921 (36.25)
g	733 (28.875)	h	1343 (52.875)
i	562 (22.125)	j	781 (30.75)
k	603 (23.75)	l	797 (31.375)
m	1708 (67.25)	n	1622 (63.875)
o	1137 (44.75)	p	95 (3.75)
q	838 (33.0)	r	445 (17.5)
s	549 (21.625)	t	1848 (72.75)

Wheel Center Height Front 406 (16.0)

Wheel Center Height Rear 406 (16.0)

Wheel Well Clearance (FR) 994 (39.125)

Wheel Well Clearance (RR) 978 (38.5)

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}	1274 (2808)	1337 (2949)	1337 (2949)
W_{rear}	881 (1942)	904 (1992)	904 (1992)
W_{total}	2155 (4750)	2241 (4941)	2241 (4941)

Note any damage prior to test: None

Figure 4. Vehicle Dimensions, Test NPG-2

Figure 5. Test Vehicle, Test NPG-3

Date: 8/20/01 Test Number: NPG-3 Model: 2500

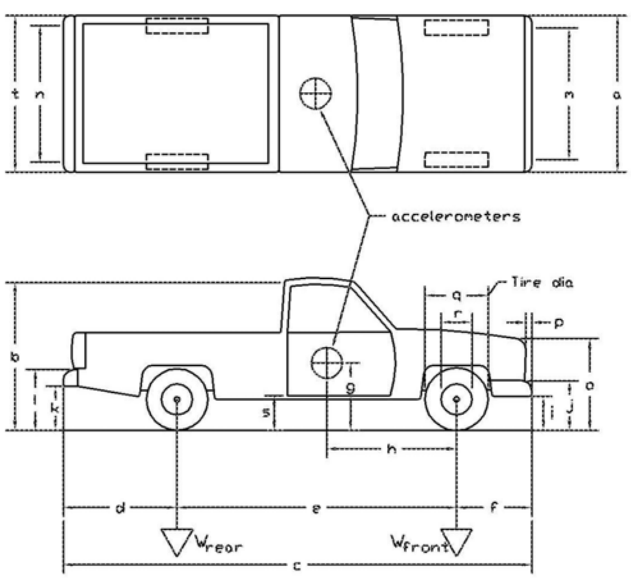
Make: Chevrolet Vehicle I.D.#: 1GCGC24K35E148680

Tire Size: 245/75 R16 Year: 1995 Odometer: 213433

*(All Measurements Refer to Impacting Side)

Vehicle Geometry – mm (in.)

a	1899 (74.75)	b	1835 (72.25)
c	5537 (218.0)	d	1308 (51.5)
e	3327 (131.0)	f	902 (35.5)
g	667 (26.25)	h	1387 (54.625)
i	451 (17.75)	j	660 (26.0)
k	597 (23.5)	l	787 (31.0)
m	1591 (62.625)	n	1619 (63.75)
o	1029 (40.5)	p	102 (4.0)
q	756 (29.75)	r	445 (17.5)
s	483 (19.0)	t	1867 (73.5)



Wheel Center Height Front 368 (14.5)

Wheel Center Height Rear 375 (14.75)

Wheel Well Clearance (FR) 908 (35.75)

Wheel Well Clearance (RR) 962 (37.875)

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}	1122 (2474)	1187 (2617)	1187 (2617)
W_{rear}	824 (1816)	850 (1874)	850 (1874)
W_{total}	1946 (4290)	2017 (4491)	2017 (4491)

Note any damage prior to test: None (Incorrect grill – pre-1994)

Figure 6. Vehicle Dimensions, Test NPG-3

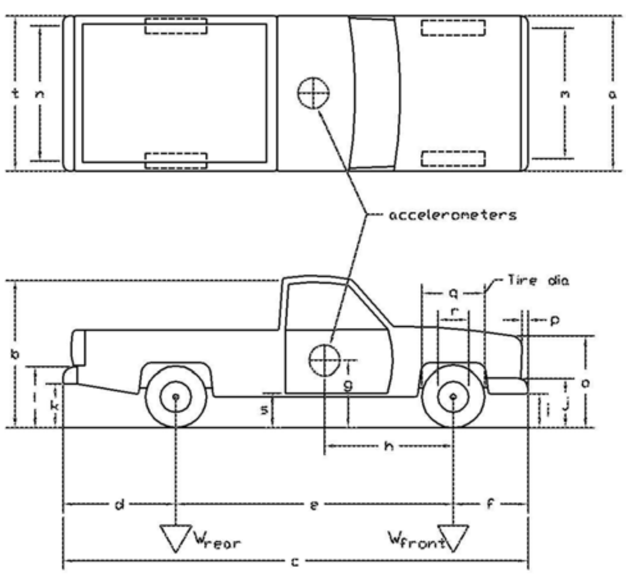
Figure 7. Test Vehicle, Test NPG-4

Date: 6/14/02 Test Number: NPG-4 Model: C/K 2500

Make: GMC Vehicle I.D.#: 1GDGC24K15Z538097

Tire Size: 245/75 R16 Year: 1995 Odometer: 253138

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1892 (74.5)	b	1829 (72.0)
c	5537 (218.0)	d	1283 (50.5)
e	3353 (132.0)	f	902 (35.5)
g	667 (26.25)	h	1448 (57.0)
i	467 (18.375)	j	705 (27.75)
k	552 (21.75)	l	749 (29.5)
m	1588 (62.5)	n	1626 (64.0)
o	1041 (41.0)	p	83 (3.25)
q	756 (29.75)	r	445 (17.5)
s	479 (18.875)	t	1867 (73.5)

Wheel Center Height Front 368 (14.5)

Wheel Center Height Rear 375 (14.75)

Wheel Well Clearance (FR) 914 (36.0)

Wheel Well Clearance (RR) 933 (36.75)

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}	1072 (2363)	1125 (2480)	1125 (2480)
W_{rear}	841 (1855)	861 (1898)	861 (1898)
W_{total}	1913 (4218)	1986 (4378)	1986 (4378)

Note any damage prior to test: None

Figure 8. Vehicle Dimensions, Test NPG-4

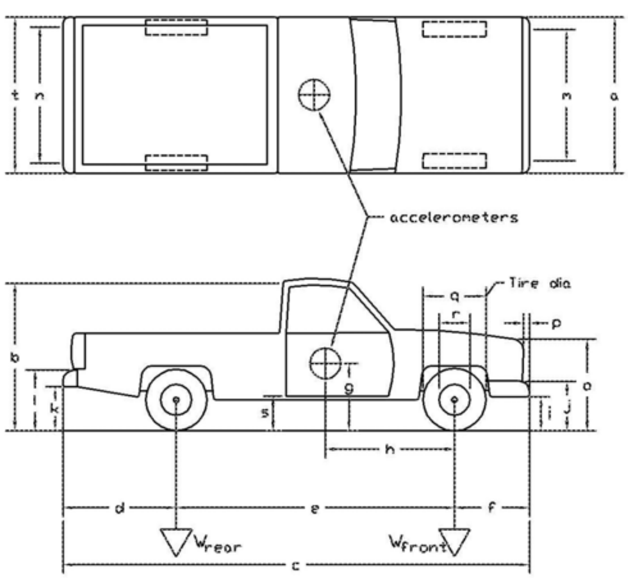
Figure 9. Test Vehicle, Test NPG-5

Date: 8/4/02 Test Number: NPG-5 Model: 2500

Make: Chevrolet Vehicle I.D.#: 1GCFC24M9VZ164862

Tire Size: LT225/75 R16 Year: 1997 Odometer: 144400

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1880 (74.0)	b	1803 (71.0)
c	5537 (218.0)	d	1327 (52.25)
e	3353 (132.0)	f	857 (33.75)
g	667 (26.25)	h	1416 (55.75)
i	394 (15.5)	j	603 (23.75)
k	546 (21.5)	l	730 (28.75)
m	1588 (62.5)	n	1613 (63.5)
o	959 (37.75)	p	95 (3.75)
q	724 (28.5)	r	445 (17.5)
s	419 (16.5)	t	1842 (72.5)

Wheel Center Height Front 356 (14.0)

Wheel Center Height Rear 362 (14.25)

Wheel Well Clearance (FR) 845 (33.25)

Wheel Well Clearance (RR) 914 (36.0)

Engine Type 8 CYL. GAS

Engine Size 5.0 L 305 CID

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	1063 (2344)	1143 (2520)	1143 (2520)
W_{rear}	750 (1653)	848 (1869)	848 (1869)
W_{total}	1813 (3997)	1991 (4389)	1991 (4389)

Note any damage prior to test: Small dent in center of front bumper

Figure 10. Vehicle Dimensions, Test NPG-5

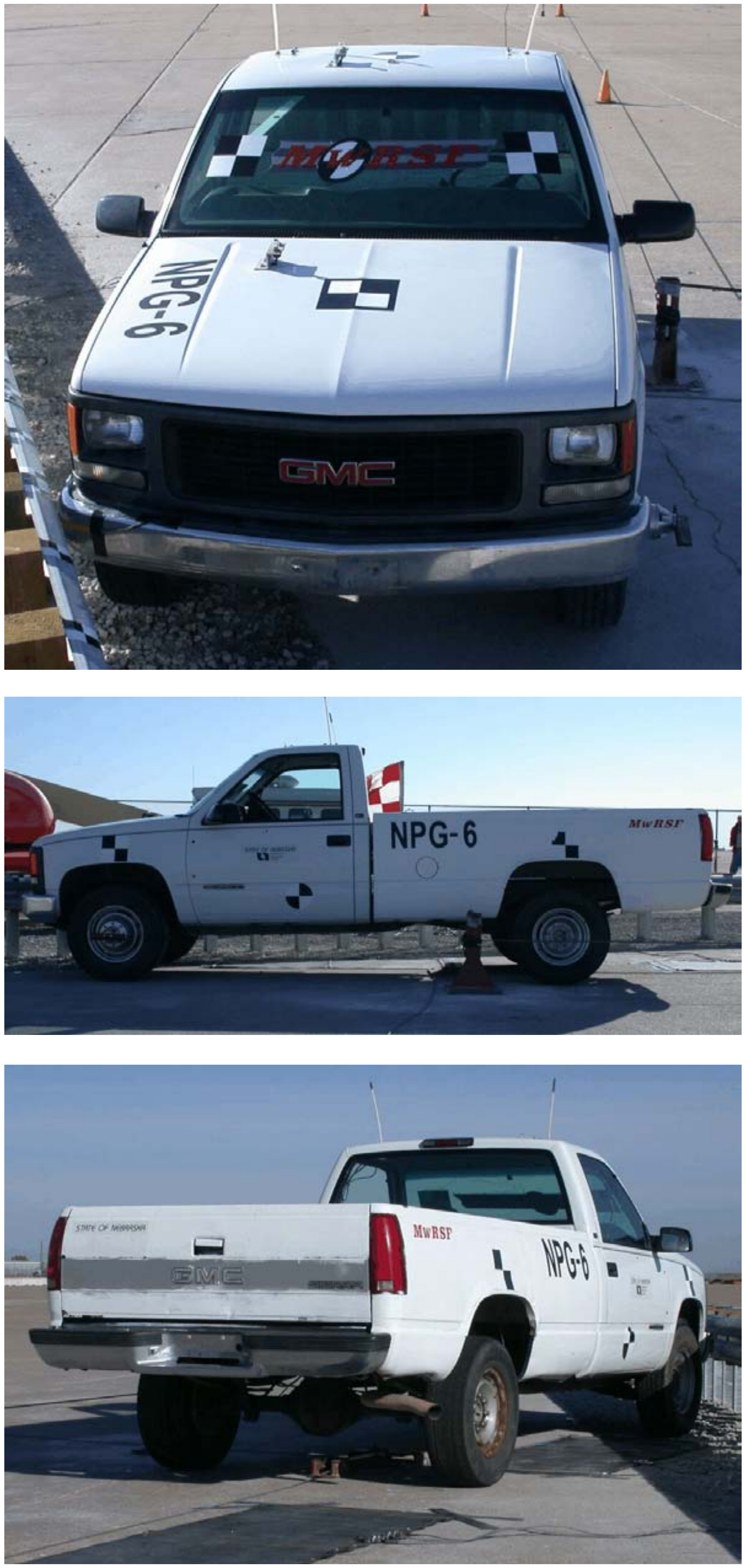


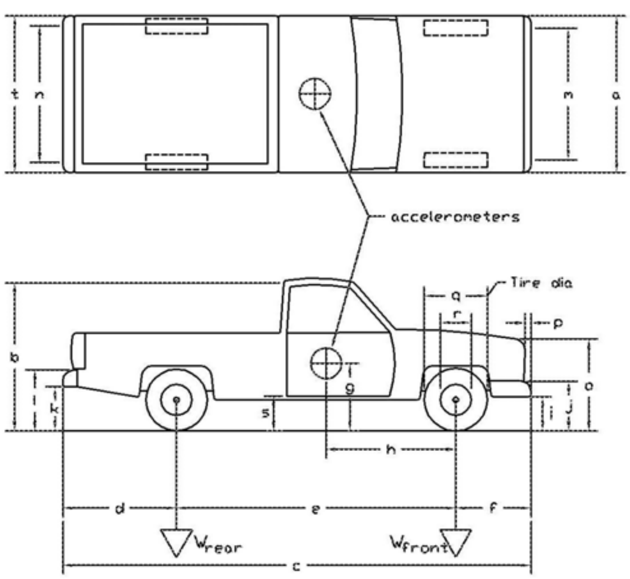
Figure 11. Test Vehicle, Test NPG-6

Date: 10/18/02 Test Number: NPG-6 Model: 2500

Make: GMC Vehicle I.D.#: 1GDGC24R4VZ535003

Tire Size: 245/75 R16 Year: 1997 Odometer: 268475

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1886 (74.25)	b	1835 (72.25)
c	5537 (218.0)	d	1340 (52.75)
e	3327 (131.0)	f	870 (34.25)
g	667 (26.25)	h	1378 (54.25)
i	457 (18.0)	j	667 (26.25)
k	565 (22.25)	l	768 (30.25)
m	1591 (62.625)	n	1619 (63.75)
o	1029 (40.5)	p	95 (3.75)
q	762 (30.0)	r	445 (17.5)
s	489 (19.25)	t	1867 (73.5)

Wheel Center Height Front 362 (14.25)

Wheel Center Height Rear 362 (14.25)

Wheel Well Clearance (FR) 914 (36.0)

Wheel Well Clearance (RR) 946 (37.25)

Engine Type 8 CYL. GAS

Engine Size 5.7 L 350 CID

Transmission Type:

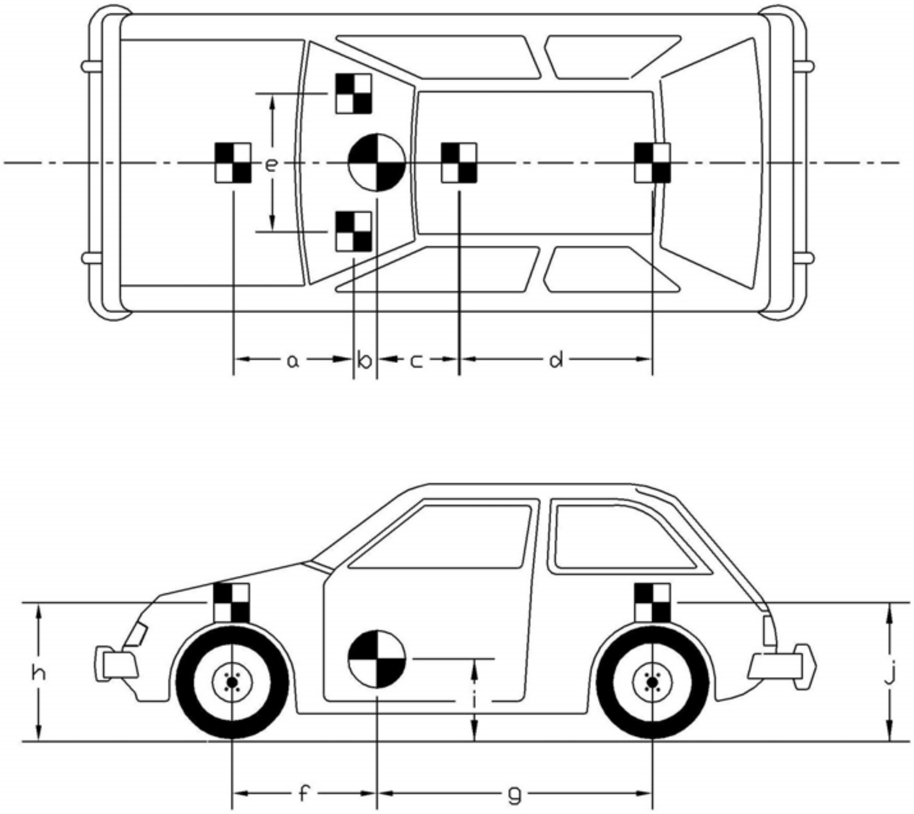
Automatic or Manual

FWD or RWD or 4WD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	1134 (2499)	1171 (2582)	1171 (2582)
W_{rear}	837 (1846)	830 (1829)	830 (1829)
W_{total}	1971 (4345)	2001 (4411)	2001 (4411)

Note any damage prior to test: None

Figure 12. Vehicle Dimensions, Test NPG-6

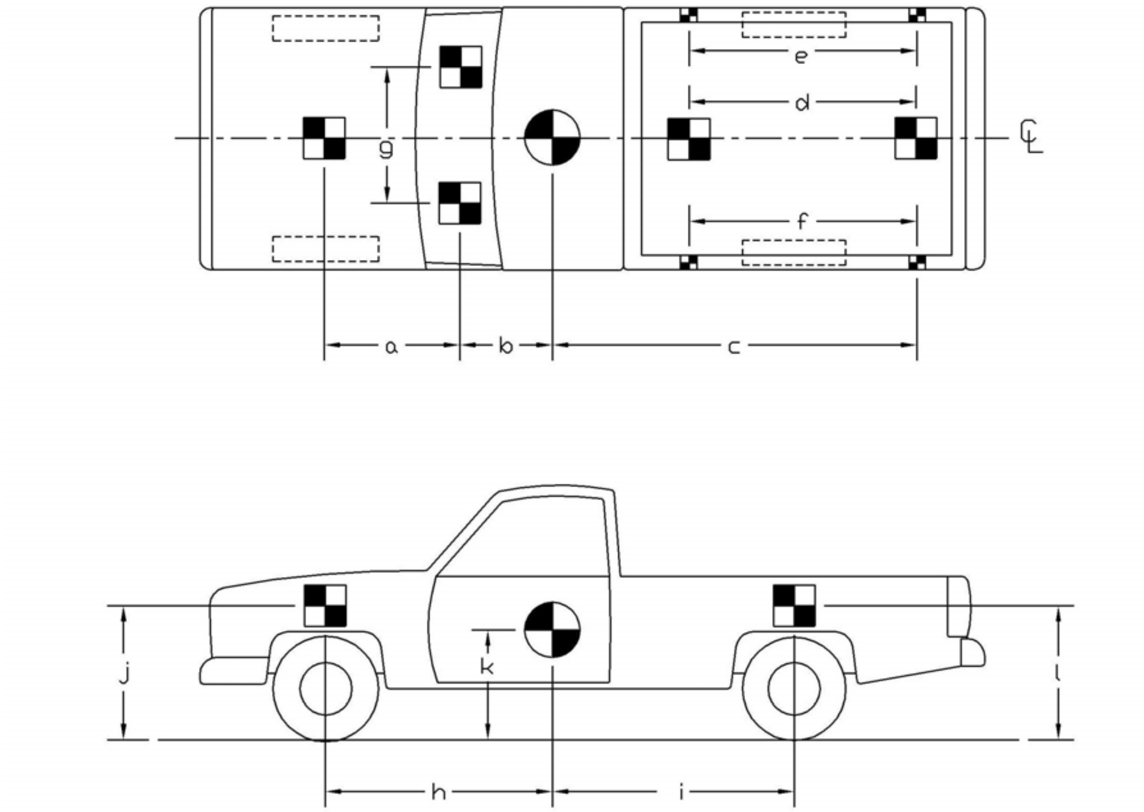


TEST #: NPG-1

TARGET GEOMETRY -- mm (in.)

a 831 (32.75)	b 213 (8.375)	c 546 (21.5)	d 743 (29.75)
e 949 (37.375)	f 867 (34.125)	g 1356 (53.375)	h 673 (26.5)
	i 546 (21.5)	j 711 (28.0)	

Figure 13. Vehicle Target Locations, Test NPG-1

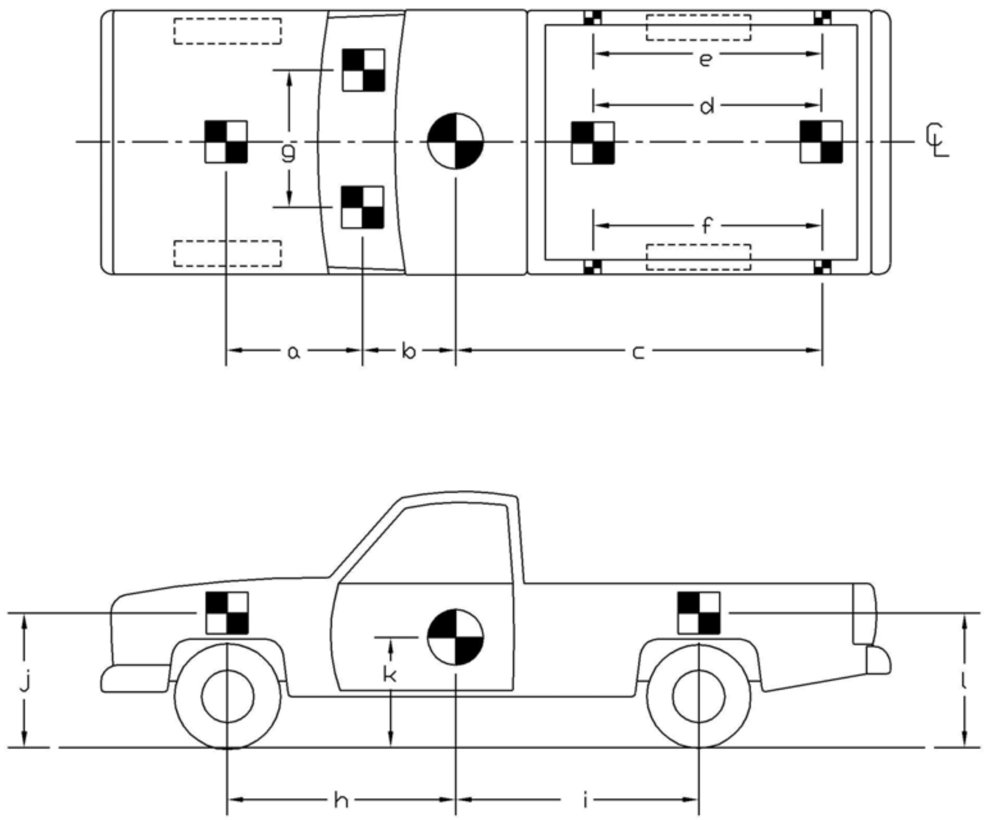


TEST #: NPG-2

TARGET GEOMETRY -- mm (in.)

a 832 (32.75)	d 2153 (84.75)	g 1175 (46.25)	j 1105 (43.5)
b 654 (25.75)	e 2153 (84.75)	h 1343 (52.875)	k 733 (28.875)
c 2889 (113.75)	f 2153 (84.75)	i 1984 (78.125)	l 1073 (42.25)

Figure 14. Vehicle Target Locations, Test NPG-2

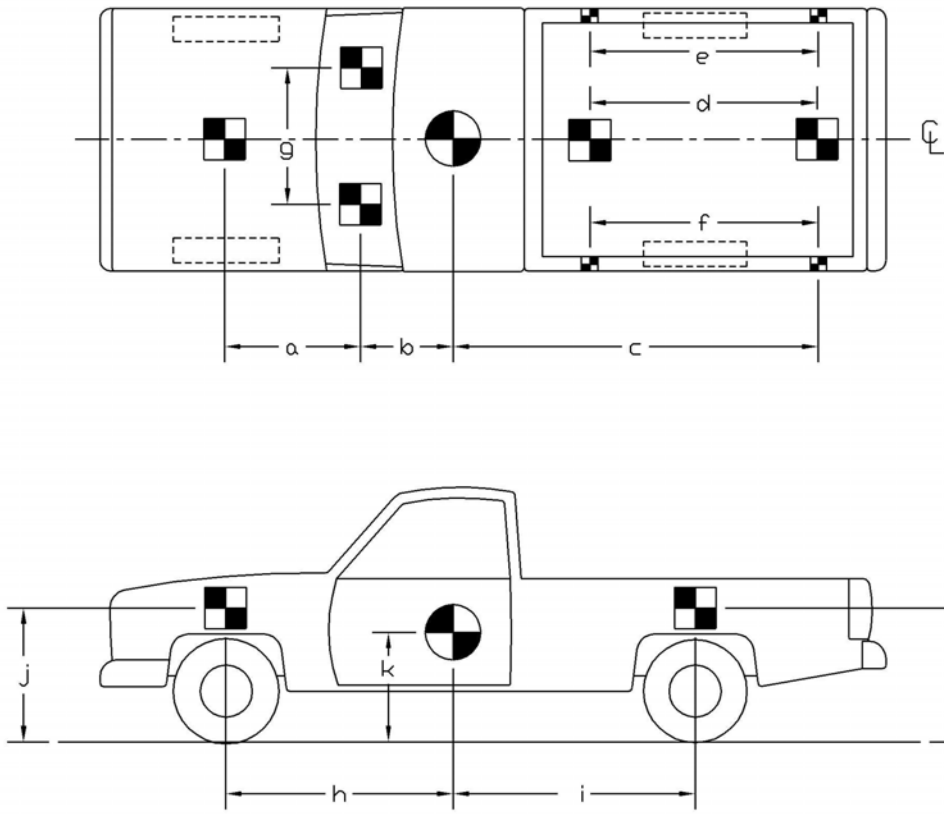


TEST #: NPG-3

TARGET GEOMETRY -- mm (in.)

a	902 (35.5)	d	1943 (76.5)	g	1118 (44.0)	j	1010 (39.75)
b	699 (27.5)	e	2153 (84.75)	h	1387 (54.625)	k	667 (26.25)
c	2769 (109.0)	f	2153 (84.75)	i	1939 (76.325)	l	1080 (42.5)

Figure 15. Vehicle Target Locations, Test NPG-3

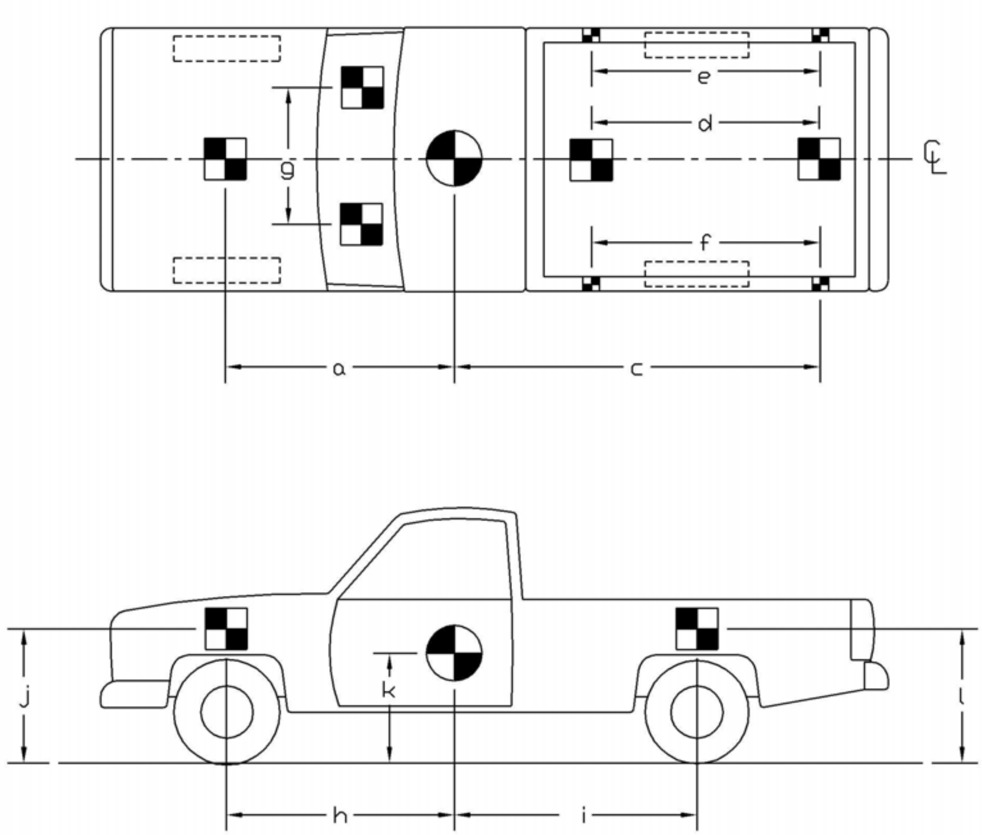


TEST #: NPG-4

TARGET GEOMETRY -- mm (in.)

a 895 (35.25)	d 1962 (77.25)	g 1476 (58.125)	j 1022 (40.25)
b 803 (31.625)	e 2153 (84.75)	h 1435 (56.5)	k 667 (26.25)
c 2750 (108.25)	f 2153 (84.75)	i 1918 (75.5)	l 1060 (41.75)

Figure 16. Vehicle Target Locations, Test NPG-4

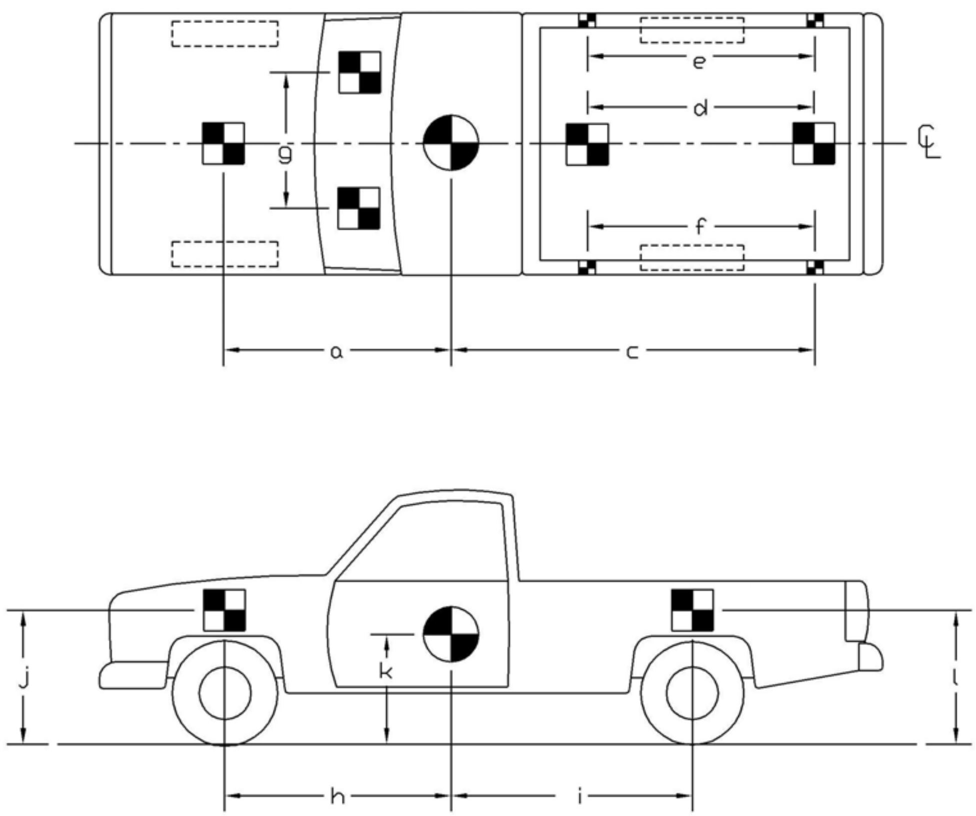


TEST #: NPG-5

TARGET GEOMETRY -- mm (in.)

a	1619 (63.75)	d	1689 (66.5)	g	1111 (43.75)	j	953 (37.5)
b	NA	e	2115 (83.25)	h	1416 (55.75)	k	667 (26.25)
c	2642 (104.0)	f	2115 (83.25)	i	1937 (76.25)	l	1022 (40.25)

Figure 17. Vehicle Target Locations, Test NPG-5



TEST #: NPG-6

TARGET GEOMETRY -- mm (in.)

a	1562 (61.5)	d	1816 (71.5)	g	1137 (44.75)	j	1022 (40.25)
b	NA	e	2153 (84.75)	h	1378 (54.25)	k	667 (26.25)
c	2711 (106.75)	f	2153 (84.75)	i	1949 (76.75)	l	1067 (42.0)

Figure 18. Vehicle Target Locations, Test NPG-6

and on the roof of the vehicle. The remaining targets were located for reference so that they could be viewed from the high-speed cameras for film analysis.

The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable. Two 5B flash bulbs were mounted on both the hood and roof of the vehicle to pinpoint the time of impact with the barrier on the high-speed film and E/cam 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.

4.4 Data Acquisition Systems

4.4.1 Accelerometers

One triaxial piezoresistive accelerometer system with a range of ±200 G's 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.

A backup triaxial piezoresistive accelerometer system with a range of ±200 G's was also used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 3,200 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-3, was developed by Instrumental Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 Kb of RAM memory and a 1,120 Hz lowpass filter. Computer software, “DynaMax 1 (DM-1)” and “DADiSP”, was used to analyze and plot the accelerometer data.

4.4.2 Rate Transducers

A Humphrey 3-axis rate transducer with a range of 360 deg/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 rigidly attached to the vehicle near the center of gravity of the test vehicle. Rate transducer signals, excited by a 28-volt DC power source, were received through the three single-ended channels located externally on the EDR-4M6 and stored in the internal memory. The raw data measurements were then downloaded for analysis and plotted. Computer software, “DynaMax 1 (DM-1)” and “DADiSP”, was used to analyze and plot the rate transducer data.

4.4.3 High-Speed Photography

For test NPG-1, three high-speed 16-mm Red Lake 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. Three Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. A Locam, with a wide-angle 12.5-mm lens, and two high-speed E/cam video cameras were placed above the test installation to provide a field of view perpendicular to the ground. A Locam, an SVHS video camera, and a Nikon 35-mm still camera were placed downstream from the impact point and had a field of view parallel to the barrier. A high-speed E/cam video camera and a Canon digital video camera were placed downstream from the impact point and behind the barrier. A high-speed E/cam video camera and a Canon digital video camera were placed upstream from the impact point and behind the barrier. A SHVS video camera was placed upstream from the impact point and behind the barrier, but closer to the impact point. A Locam and a Canon digital video camera, with a panning view, were placed on the traffic side of the barrier and had a field of view perpendicular to the barrier. A schematic of all thirteen camera locations for test NPG-1 is shown in Figure 19.

For test NPG-2, three high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. Five high-speed Red Lake E/cam video cameras, with operating speeds of 500 frames/sec, were also used to film the crash test. Three Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. A Locam, with a wide-angle 12.5-mm lens, and two high-speed E/cam video cameras were placed above the test installation to provide a field of view perpendicular to the ground. A Locam, a Canon digital video camera, and a Nikon 35-mm still camera were placed downstream from the impact point and had a field of view parallel to the barrier. A Locam, a high-speed E/cam video camera, and a Canon digital video camera were placed downstream from the impact point and behind the barrier. A high-speed E/cam video camera was placed upstream from the impact point and behind the barrier. A high-speed E/cam video camera and a Nikon 995 digital camera were placed upstream from the impact point and on the traffic side of the barrier. A Canon digital video camera was placed downstream from the impact point and on the traffic side of the barrier. A schematic of all thirteen camera locations for test NPG-2 is shown in Figure 20.

For test NPG-3, two high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. Five high-speed Red Lake E/cam video cameras, with operating speeds of 500 frames/sec, were also used to film the crash test. Four Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used

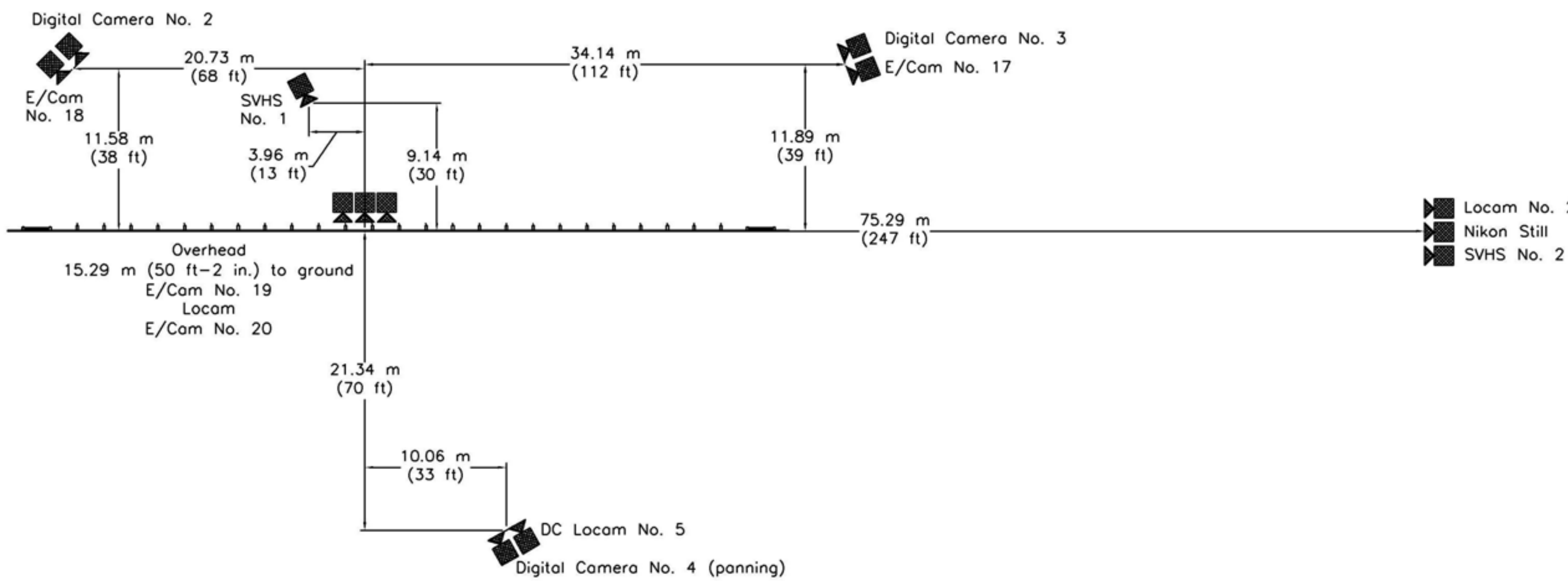


Figure 19. Location of High-Speed Cameras, Test NPG-1

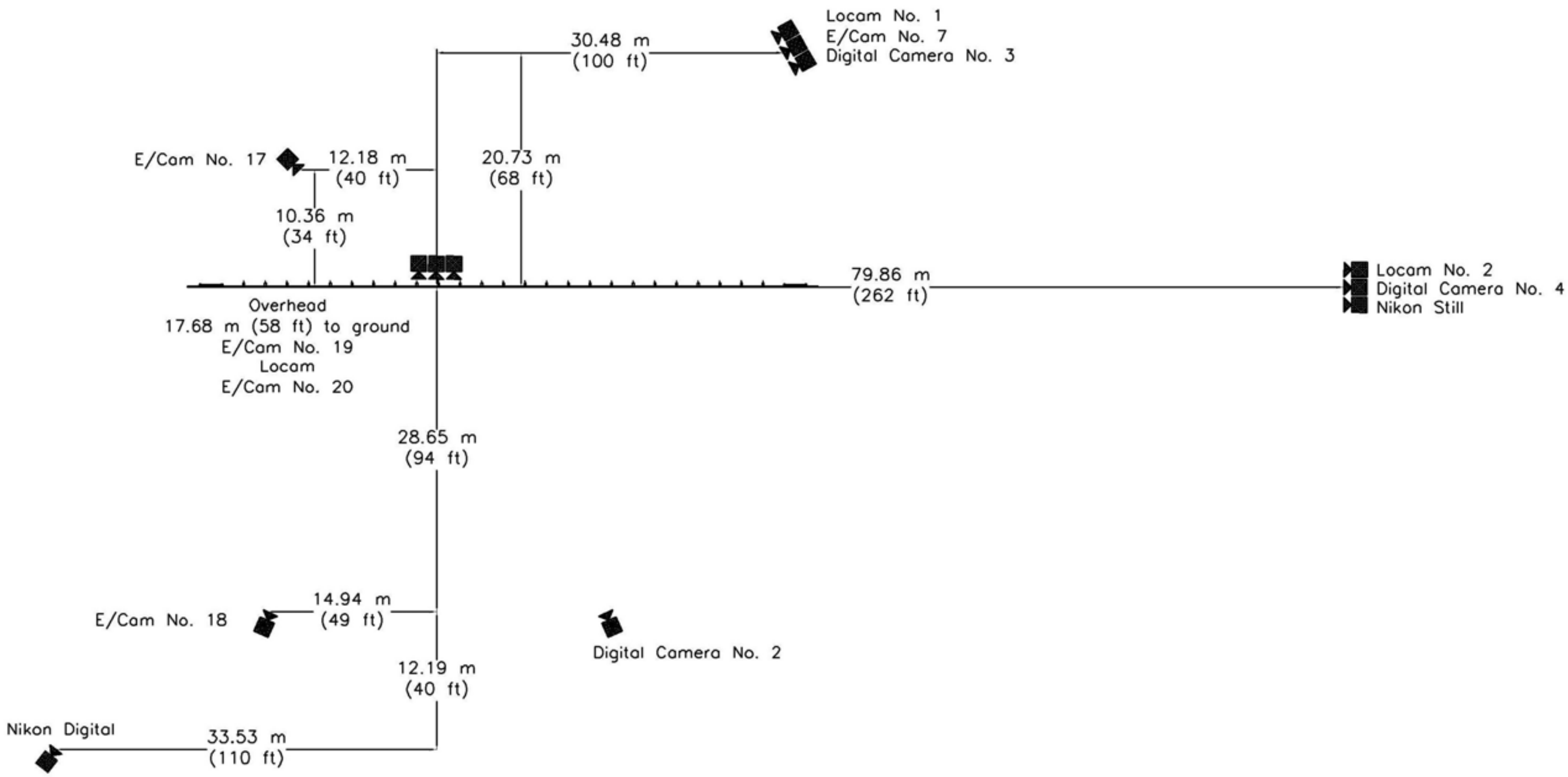


Figure 20. Location of High-Speed Cameras, Test NPG-2

to film the crash test. A Locam, with a wide-angle 12.5-mm lens, and two high-speed E/cam video cameras were placed above the test installation to provide a field of view perpendicular to the ground. A Locam, a Canon digital video camera, and a Nikon F5 35-mm still camera were placed downstream from the impact point and had a field of view parallel to the barrier. A high-speed E/cam video camera and a Canon digital video camera were placed downstream from the impact point and behind the barrier. Another high-speed E/cam video camera was placed downstream from the impact point and behind the barrier, but closer to the impact point. A high-speed E/cam video camera and a Canon digital video camera were placed upstream from the impact point and behind the barrier. A Canon digital camera was placed downstream from the impact point and on the traffic side of the barrier. A Nikon 995 digital camera was placed upstream from the impact point and on the traffic side of the barrier. A schematic of all thirteen camera locations for test NPG-3 is shown in Figure 21.

For test NPG-4, two high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. Five 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. A Locam, with a wide-angle 12.5-mm lens, and two high-speed E/cam video cameras were placed above the test installation to provide a field of view perpendicular to the ground. A Locam and a Canon digital video camera were placed downstream from the impact point and had a field of view parallel to the barrier. A high-speed E/cam video camera and a Canon digital video camera were placed downstream from the impact point and behind the barrier. A high-speed E/cam video camera and a Canon digital video camera were placed upstream from the impact point

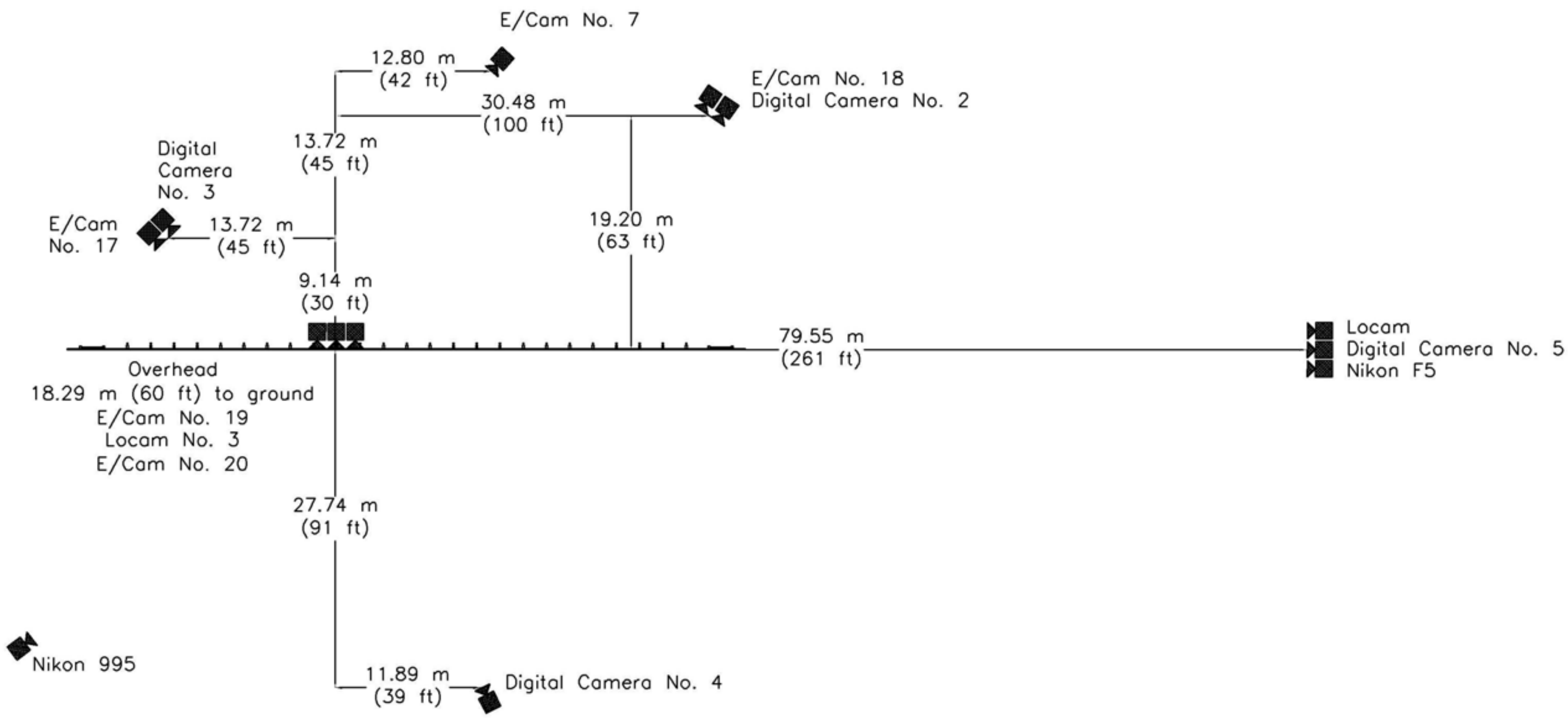


Figure 21. Location of High-Speed Cameras, Test NPG-3

and had a field of view parallel to the barrier. Another high-speed E/cam video camera and another Canon digital video camera were placed upstream from the impact point and behind the barrier. A Canon digital video camera, with a panning view, was placed on the traffic side of the barrier and had a field of view perpendicular to the barrier. A Canon digital video camera was placed upstream from the impact point and on the traffic side of the barrier. A schematic of all thirteen camera locations for test NPG-4 is shown in Figure 22.

For test NPG-5, two high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. Five high-speed Red Lake E/cam video cameras, with operating speeds of 500 frames/sec, were also used to film the crash test. Four Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. A Locam, with a wide-angle 12.5-mm lens, and two high-speed E/cam video cameras were placed above the test installation to provide a field of view perpendicular to the ground. A Locam, a high-speed E/cam video camera, and a Canon digital video camera were placed downstream from the impact point and had a field of view parallel to the barrier. A high-speed E/cam video camera and a Canon digital video camera were placed downstream from the impact point and behind the barrier. A high-speed E/cam video camera and a Canon digital video camera were placed upstream from the impact point and behind the barrier. A Canon digital video camera, with a panning view, was placed on the traffic side of the barrier and had a field of view perpendicular to the barrier. A schematic of all eleven camera locations for test NPG-5 is shown in Figure 23.

For test NPG-6, two high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. Four high-speed Red Lake E/cam

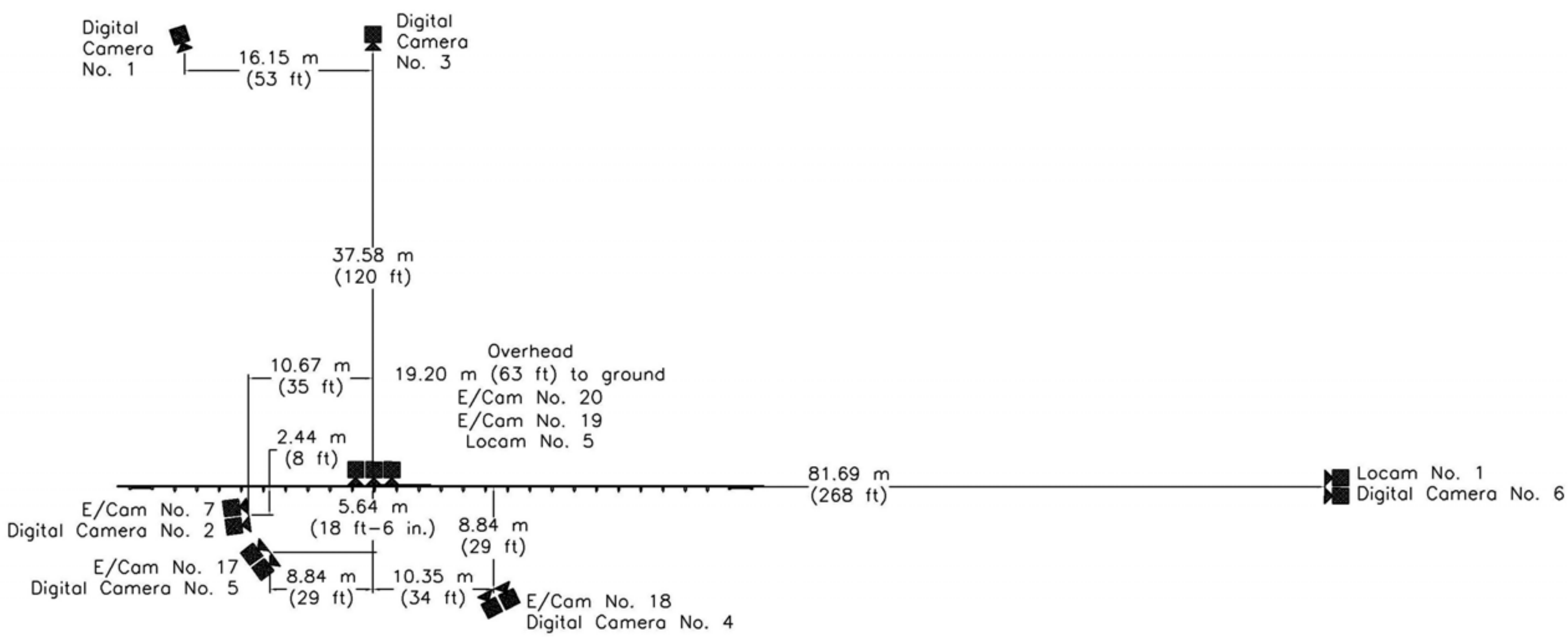


Figure 22. Location of High-Speed Cameras, Test NPG-4

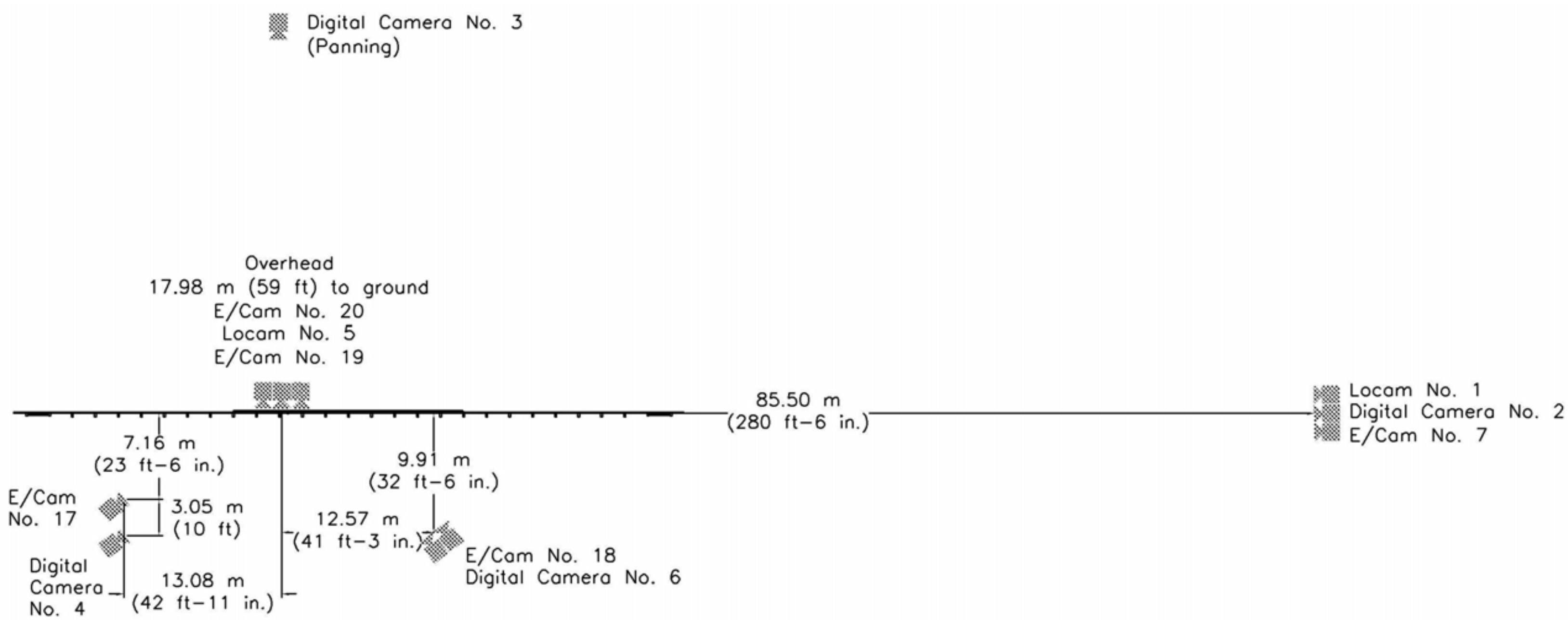


Figure 23. Location of High-Speed Cameras, Test NPG-5

video cameras, with operating speeds of 500 frames/sec, were also 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. A Locam, with a wide-angle 12.5-mm lens, and two high-speed E/cam video cameras were placed above the test installation to provide a field of view perpendicular to the ground. A Locam and a Canon digital video camera were placed downstream from the impact point and had a field of view parallel to the barrier. A high-speed E/cam video camera and a Canon digital video camera were placed downstream from the impact point and behind the barrier. A high-speed E/cam video camera and a Canon digital video camera were placed upstream from the impact point and behind the barrier. Another Canon digital video camera was placed upstream from the impact point and behind the barrier. A Canon digital video camera, with a panning view, was placed on the traffic side of the barrier and had a field of view perpendicular to the barrier. A schematic of all eleven camera locations for test NPG-6 is shown in Figure 24.

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

4.4.4 Pressure Tape Switches

For test NPG-1, NPG-2, NPG-3, NPG-4, NPG-5, and NPG-6, five pressure-activated tape switches, spaced at 2-m (6-ft 6 ¾-in.) 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 vehicle's front tire passed over it. For tests NPG-1 through NPG-3, the left-front tire of the vehicle passed over the tape switches. For tests NPG-4 through NPG-6, the right-front tire of the vehicle passed over the tape switches. Test vehicle speed was determined from electronic timing mark data recorded using the "Test Point" 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.

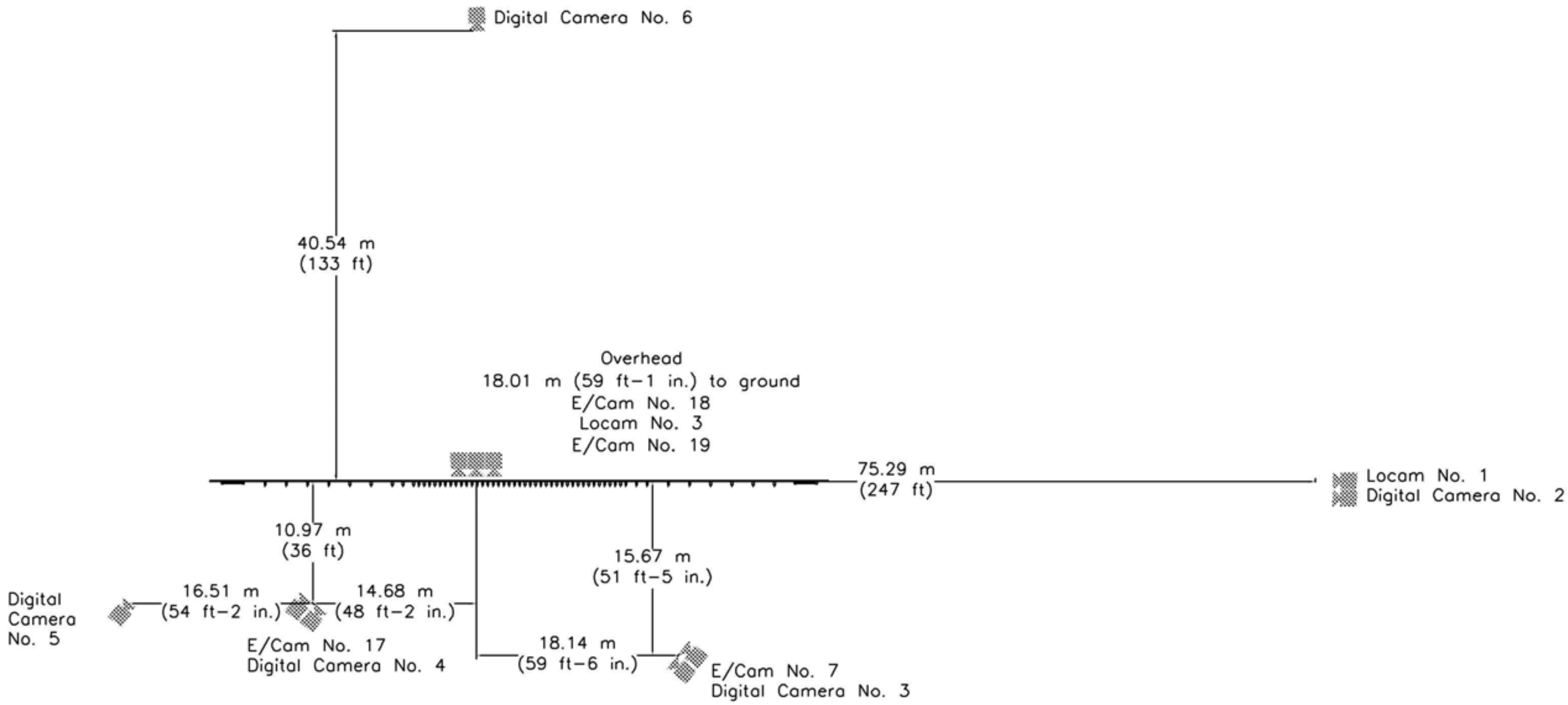


Figure 24. Location of High-Speed Cameras, Test NPG-6

5 PARAMETRIC STUDY USING LS-DYNA

As mentioned previously, a great deal of effort was devoted to improving the shape of the W-beam guardrail under a prior research study (1). After careful review of this prior research, it was concluded that much of the improved performance observed with the Buffalo Rail could be attributed to other changes in the guardrail design, such as increased blockout depth, increased mounting height, and reduced post embedment. Therefore, it was decided to examine the possibility of improving guardrail performance by altering other design parameters, without changing the guardrail shape. This effort explored the effects of various guardrail design parameters, such as guardrail mounting height, blockout depth, post embedment, post spacing, and method for attaching the rail to the post, on the barrier's safety performance.

5.1 Barrier Height

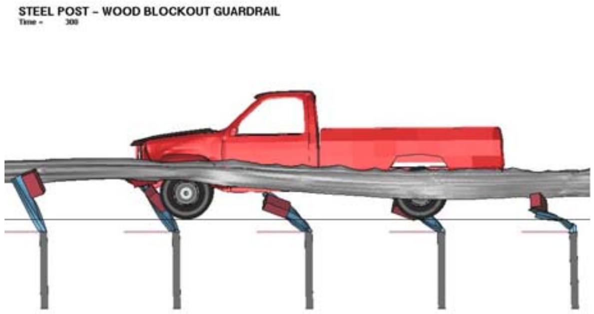
W-beam guardrails capture light trucks by allowing the front tire to become wedged under the rail element. Frequently, when the tire does not become captured under the rail, the wheel ultimately climbs up the face of the barrier and the vehicle either vaults over the barrier or rolls over on the traffic side of the barrier. LS-DYNA (8) simulations clearly demonstrated that raising the height of the W-beam barrier will improve the barrier's ability to capture the vehicle's tire and reduce the propensity for high center-of-gravity vehicles to vault or rollover. However, raising the rail also increases the possibility that small cars will become wedged under the barrier and snag severely on the guardrail posts. Full-scale crash testing has shown that standard W-beam guardrails can provide adequate performance for small cars when mounted as high as 610 mm (24 in.) to the center (14).

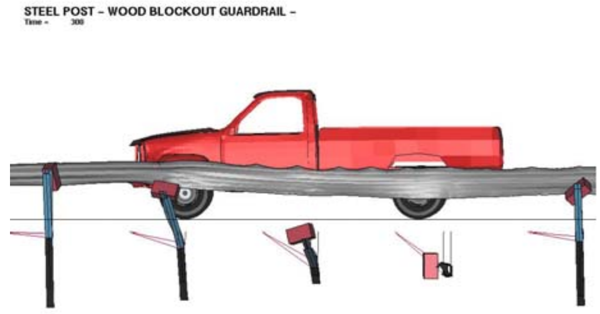
5.2 Post Configuration

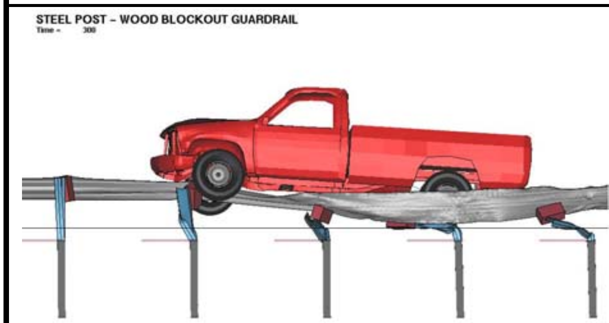
The capability for a guardrail to contain and redirect light trucks has been shown to be strongly correlated to the stiffness of the guardrail posts (1). For strong post guardrail systems, post stiffness is primarily controlled by the soil forces. Therefore, post embedment depth becomes the primary consideration. LS-DYNA modeling seemed to indicate that for conventional strong post W-beam guardrail, barrier performance begins to degrade when soil yield forces reach 50 kN (11 kips). Although soil yield forces from field installations are generally believed to be below this level, a soil yield force of 50 kN (11 kips) is certainly within the expected range for 1829-mm (6-ft) long posts embedded into strong soils. Note that optimum soil force levels were found to be somewhat dependent on other guardrail design parameters, including height and the strength of the rail attachment to the post. As mentioned previously, higher guardrail mounting heights improve the ability of the barrier to capture light trucks and sport utility vehicles (SUV's) and as a result the barrier has greater tolerance for higher soil yield forces. As shown in Figure 25, the strength of the rail/post attachment was also found to affect the system's tolerance for high post forces. Based on this analysis, it was concluded that keeping soil yield forces and post-to-rail attachment strengths low would improve the ability of W-beam guardrails to safely contain and redirect light trucks.

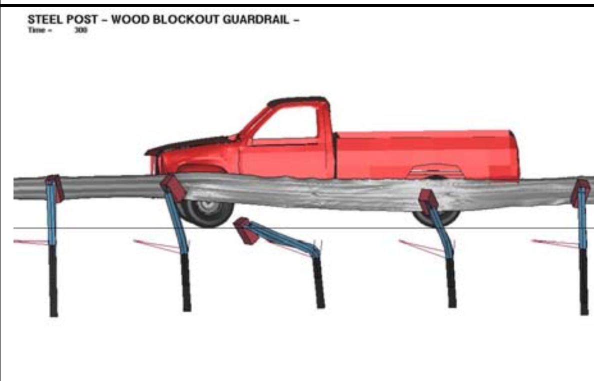
5.3 Blockout Size

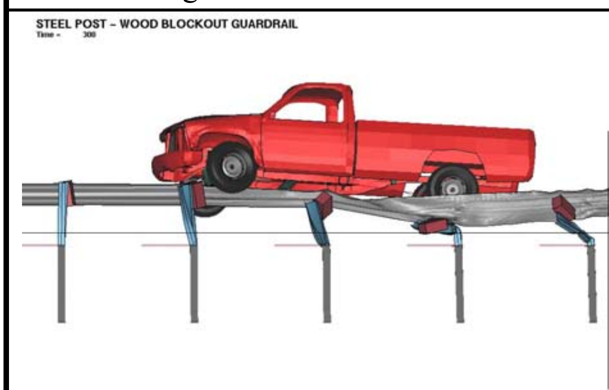
The primary concern with raising the height of W-beam guardrail is that small cars may extend under the rail and snag severely on the guardrail posts. One mechanism for preventing this behavior is to increase the blockout size to offset the posts farther from the face of the guardrail. LS-DYNA simulations indicated that increasing the blockout size also minimizes wheel snagging with light trucks, as shown in Figure 26. LS-DYNA modeling indicated that a 305 mm (12 in.) blockout would provide adequate safety performance for mini-size automobiles with guardrail mounting heights up to 657 mm (25 ⅞ in.) and 813 mm (32 in.) to the center and top of the rail,

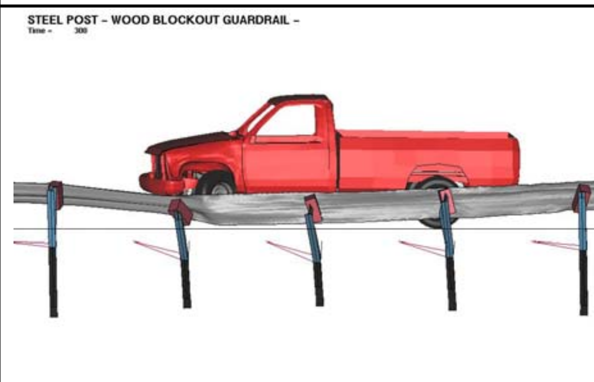
<table>
<tr><th>Strong Soil</th><th>Soft Soil</th></tr>
<tr><td>

Regular Rail-to-Post Connection</td><td>

Regular Rail-to-Post Connection</td></tr>
<tr><td>

Strong Rail-to-Post Connection</td><td>

Strong Rail-to-Post Connection</td></tr>
<tr><td>

Very Strong Rail-to-Post Connection</td><td>

Very Strong Rail-to-Post Connection</td></tr>
</table>

Figure 25. Effects of Post Attachment and Soil Yield Force on Guardrail Performance

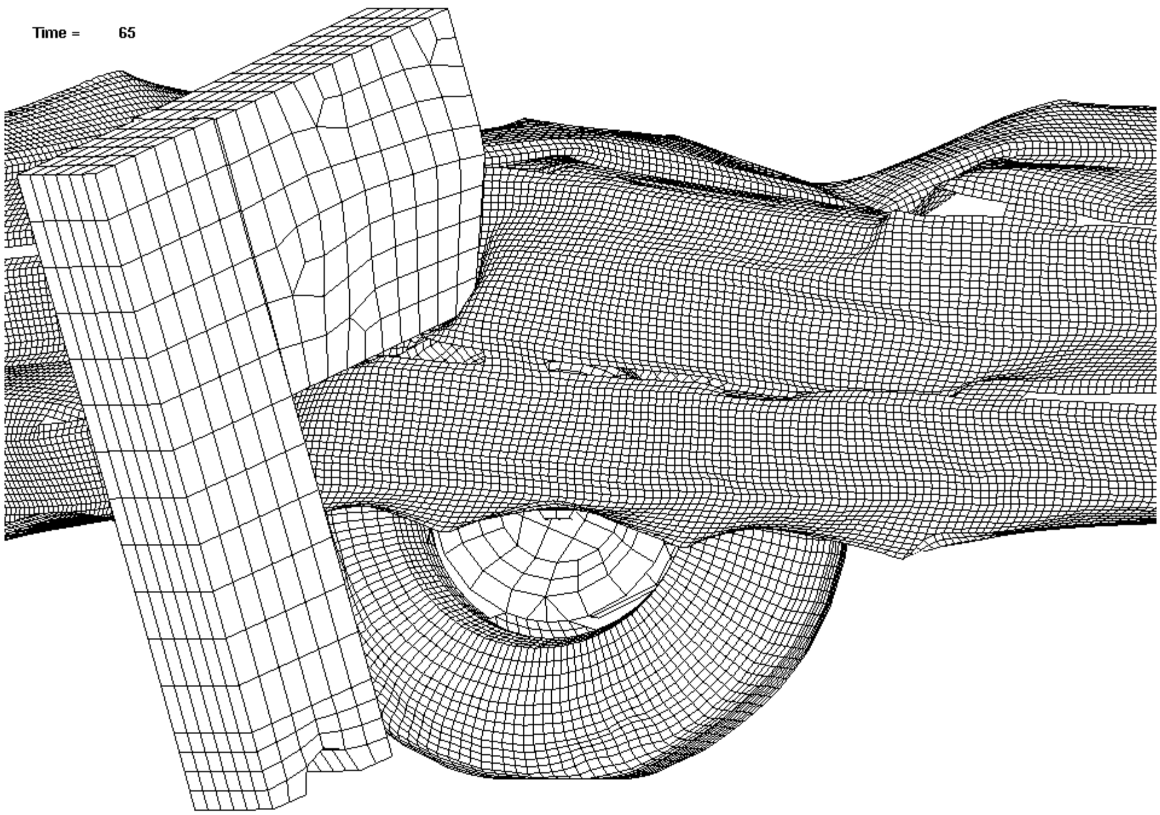


Figure 26. Wheel Snag Reduction with Increased Blockout Depth

respectively. Higher mounting heights would require deeper blockouts to minimize the chances for severe snagging on the guardrail posts. As shown in Figure 27, increasing the height of the guardrail above 657 mm (25 ⅞ in.) to the center would become a major concern for bullet-nosed vehicles that might dive under the rail.

5.4 Splice Configuration

Crash testing has shown that whenever the W-beam guardrail is installed in critical situations, such as over a curb (21) or at a terminal end (27), the rail element can rupture at a splice. MwRSF researchers observed that not only is the guardrail splice the weakest point in the rail element, the bolt holes cause stress risers that can become crack initiators (21). Further, it was observed that the maximum stress on a rail element occurs at the post. Therefore, MwRSF researchers first proposed moving the weakest part of the rail, the splice, away from the maximum stress location, at the post, as a remedy for a rail failure during testing of guardrail over curb (21). The benefits of moving the splice away from the post were later demonstrated both through simulation (28) and full-scale crash testing with weak post W-beam guardrail (29).

Another problem with placing the rail splice at the post is that the post bolt pull-out forces increase dramatically since the bolt must pull through two rail elements instead of just one. As summarized previously, LS-DYNA modeling indicates that reducing the post bolt pull-out forces improves W-beam guardrail performance during light truck impacts. Hence, moving the splice away from the post adds another benefit by dramatically lowering post bolt pull-out forces.

Figure 27. Front of Vehicle vs. Guardrail Height

6 DEVELOPMENTAL TESTING – DYNAMIC POST TESTING

It is widely know that guardrail posts are an integral part of the design on semi-rigid barriers. Post performance greatly influences the guardrail system's ability to safely contain and redirect the impacting vehicle as well as allows for the dissipation of a portion of the vehicle's kinetic energy through post rotation in the soil. Since post-soil forces are approximately proportional to the square of the post embedment depth, determination of an appropriate post length, post embedment depth, and rail mounting height are all critical elements to be determined for the new guardrail design. This fact is more important since the preliminary numerical analysis showed that higher post-soil forces may degrade guardrail performance.

Dynamic testing of steel posts placed in soil was conducted in order to evaluate alternative embedment depths as well as to determine the associated force-deflection behaviors. The steel posts were embedded in soil material conforming to AASHTO M147-65 Gradation B specifications (NCHRP Report No. 350 strong soil). The posts used in the *Midwest Guardrail System* (MGS) consisted of W152x13.4 (W6x9) steel sections. However, the dynamic bogie testing performed for this study utilized W152x23.8 (W6x16) sections for the alternative embedment depths in order to isolate soil failure with only minimal post yielding. Since the W152x23.8 (W6x16) post has a similar flange width and overall depth to that of the W152x13.4 (W6x9) post, it was believed that the posts would exhibit similar post-soil behavior. A 1,014-kg (2,237-lb) rigid-frame bogie vehicle was used to impact the steel guardrail posts at a target speed of 32.2 km/h (20 mph). An impact head, fabricated from a 203-mm (8-in.) diameter concrete-filled steel pipe and used to strike the posts, was mounted to the front end of the bogie vehicle at a height of 632 mm (24 ⅞ in.) above the ground surface. Additional details related to the bogie vehicle and the test setup are provided in the referenced MwRSF research report (30).

A total of ten dynamic bogie tests were performed on the embedded steel posts. Actual impact conditions, post embedment depths, and test results for the tests are provided in Table 3. All steel posts were impacted perpendicular to the front face of the posts or about the post's strong axis of bending, as shown in Figure 28. Typical post and soil deformations following two bogie tests are provided in Figure 28. Typical force-deflection curves for the steel posts embedded 1,016 mm (40 in.) into the soil are provided in Figure 29.

Failure of the posts was found to be dependent upon embedment depth. For post embedment depths of 1,016 mm (40 in.) or greater, soil failure was observed with occasions of slight yielding within the post. For post embedment depths of 940 mm (37 in.) or less, the posts were pulled out of the ground after rotating in the soil for some distance. In addition, there were measurable differences in the impact forces observed for the two modes of failure. As a result of these differing impact forces, the amount of energy dissipated also varied. Posts that failed by rotating in the soil dissipated more energy than posts that initially rotated but eventually pulled out of the ground. Additional discussion of the post testing results is provided in the referenced MwRSF research report (30).

Based on the results of the dynamic post testing program, researchers determined that the 1,016-mm (40-in.) embedment depth was a reasonable choice for use in the *Midwest Guardrail System* (MGS). This embedment depth, when combined with a 1,829-mm (6-ft) long post and a 787-mm (31-in.) rail top mounting height, provides acceptable post-soil forces and energy dissipation.

One purpose for analyzing the force-deflection curve and energy dissipated during a post test is to quantify post-soil interaction parameters. These parameters are of great interest to those studying vehicular impacts into longitudinal barrier systems, such as the *Midwest Guardrail System* (MGS), through the use of dynamic computer simulation modeling. Relevant results from this study for use in these analytical investigations are the estimated initial post stiffness and the estimated average force for the first 381 to 597 mm (15 to 23.5 in.) of dynamic displacement after the initial slope of the impact force. Over this distance, the guardrail post is typically being separated from the W-beam rail based on observations from full-scale crash tests. Therefore, calculated parameters for estimated average force and estimated initial stiffness are also provided in Table 3.

Table 3. Steel Post Bogie Test Matrix and Results

Bogie Test No.	Impact Speed (m/s)	Embedment Depth (mm)	Initial Peak Force		Estimated Average Force[1]		Estimated Initial Stiffness[2] (kN/mm)	Total Energy		Failure Mode
			Deflection (cm)	Force (kN)	Measured @ 381 mm dynamic deflection (kN)	Measured @ 597 mm dynamic deflection (kN)		Deflection (cm)	Energy (kJ)	
NPGB-1[3]	8.94	1092	6.12	47.91	28.98	30.63	0.783	104.53	29.82	Post Rotation, Slight Yielding
NPGB-3[3]	8.94	1092	5.29	43.00	25.57	26.35	0.813	124.17	28.45	Post Rotation, Slight Yielding
Average	**8.9**	**1092**	**5.7**	**45.5**	**27.3**	**28.5**	**0.798**	**114.4**	**29.1**	
NPGB-2[3]	9.39	1016	5.56	36.76	27.27	29.93	0.661	115.29	29.15	Post Rotation
NPGB-4	8.94	1016	5.56	52.83	28.73	29.30	0.950	109.23	29.14	Post Rotation
NPGB-9	9.28	1016	5.48	58.04	28.14	28.31	1.059	122.15	29.16	Post Rotation, Slight Yielding
NPGB-10	9.61	1016	5.97	62.89	29.99	31.47	1.053	118.56	31.78	Post Rotation, Slight Yielding
Average	**9.3**	**1016**	**5.6**	**52.6**	**28.5**	**29.8**	**0.931**	**116.3**	**29.8**	
NPGB-5	8.94	940	7.24	52.39	24.85	26.95	0.724	136.50	27.37	Post Pulled Out of Ground
NPGB-7	8.81	940	4.93	57.23	23.13	24.04	1.161	132.63	22.50	Post Pulled Out of Ground
NPGB-8	9.25	940	7.19	72.34	26.38	27.01	1.006	116.41	24.83	Post Pulled Out of Ground
Average	**9.0**	**940**	**6.5**	**60.7**	**24.8**	**26.0**	**0.964**	**128.5**	**24.9**	
NPGB-6	9.16	864	4.56	55.44	24.63	24.79	1.216	134.01	24.20	Post Pulled Out of Ground

[1] – Determined after initial slope
[2] – Determined using initial peak force and deflection
[3] – Results may have been affected by wet soil conditions

(a)

(b)

Figure 28. (a) Typical Installed Post for Bogie Tests, (b) Typical Post-Soil Behavior

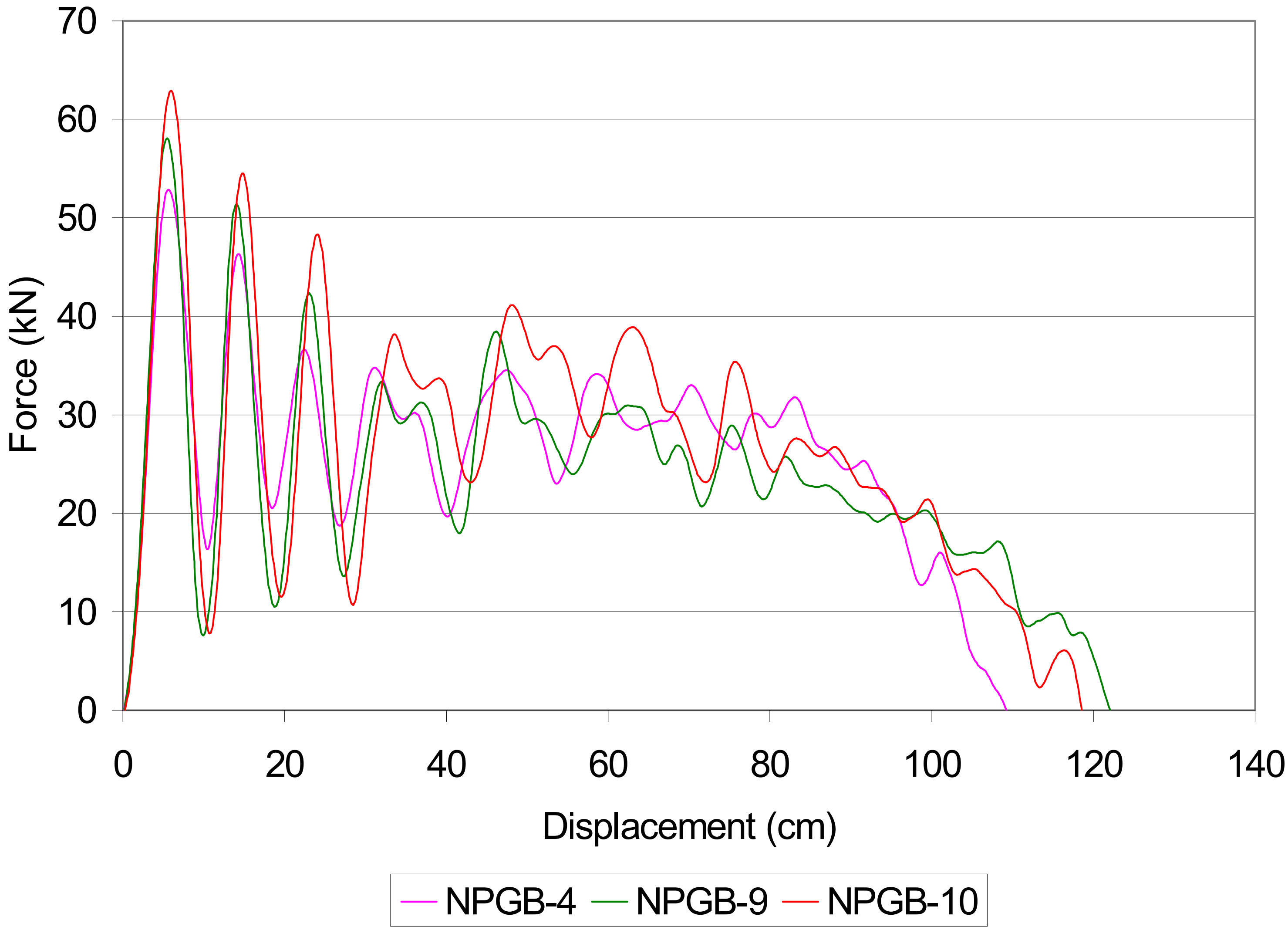


Figure 29. Force-Displacement Curves for 1,016-mm (40-in.) Embedment Depth

7 *MIDWEST GUARDRAIL SYSTEM* DESIGN DETAILS – MAXIMUM HEIGHT

The test installation consisted of 55.25 m (181 ft - 3 in.) of standard 2.66-mm (12-gauge) thick W-beam guardrail supported by steel posts, as shown in Figure 30. Anchorage systems similar to those used on tangent guardrail terminals were utilized on both the upstream and downstream ends of the guardrail system. Design details are shown in Figures 30 through 34. Photographs of the test installation are shown in Figures 35 and 36.

The entire system was constructed with twenty-nine guardrail posts. Post nos. 3 through 27 were galvanized ASTM A36 steel W152x13.4 (W6x9) sections measuring 1,829-mm (6-ft) long. Post nos. 1, 2, 28, and 29 were timber posts measuring 140-mm wide x 190-mm deep x 1,080-mm long (5 ½-in. x 7 ½-in. x 42 ½-in.) and were placed in 1,524-mm (5-ft) long steel foundation tubes with soil plates. The timber posts and foundation tubes were part of anchor systems designed to replicate the capacity of a tangent guardrail terminal.

Post nos. 1 through 29 were spaced 1,905 mm (75 in.) on center with a soil embedment depth of 994 mm (39 in.), as shown in Figure 30. The posts were placed in a compacted course, crushed limestone material that met Grading B of AASHTO M147-65 (1990) as found in NCHRP Report No. 350. For post nos. 3 through 27, 152-mm wide x 305-mm deep x 356-mm long (6-in. x 12-in. x 14-in.) wood spacer blockouts were used to block the rail away from the front face of the steel posts.

Standard 2.66-mm (12-gauge) thick W-beam rails with additional post bolt slots at half post spacing intervals were placed between post nos. 1 and 29, as shown in Figures 30 and 31. The W-beam's top rail height was 813 mm (32 in.) with a 657-mm (25 ⅞-in.) center mounting height. This guardrail height corresponds to the maximum tolerance of the design's nominal top rail height of

787 mm (31 in.) and center mounting height of 632 mm (24 ⅞ in.). The rail splices have been moved to the center of the span location, as shown in Figures 30, 35, and 36. In order to reduce rail/post attachment forces, the post bolt slots were increased to 102 mm (4 in.) in length. All lap-splice connections between the rail sections were configured to reduce vehicle snag at the splice during the crash test.

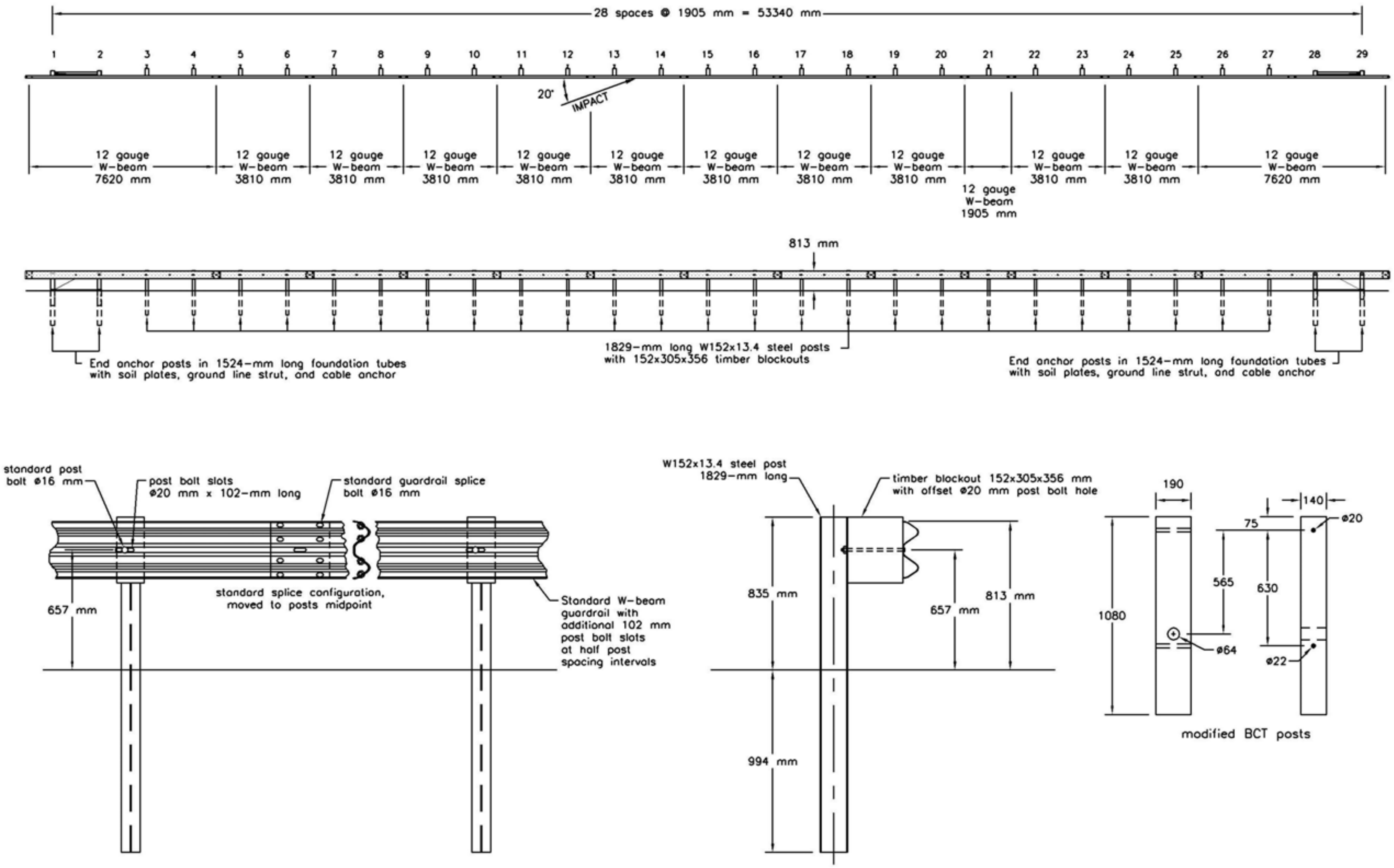


Figure 30. *Midwest Guardrail System* Maximum Height Tolerance Design Details

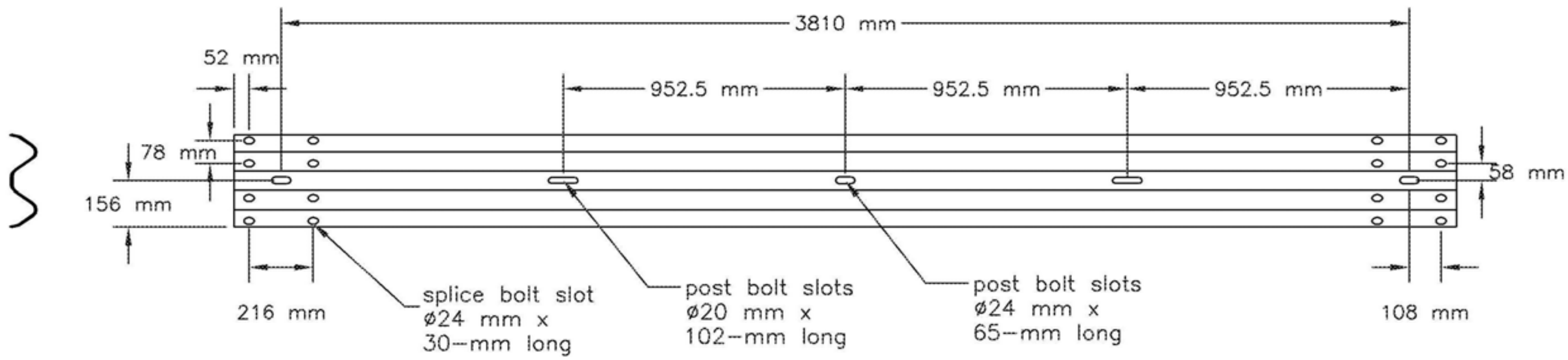


Figure 31. *Midwest Guardrail System* Rail Design Details

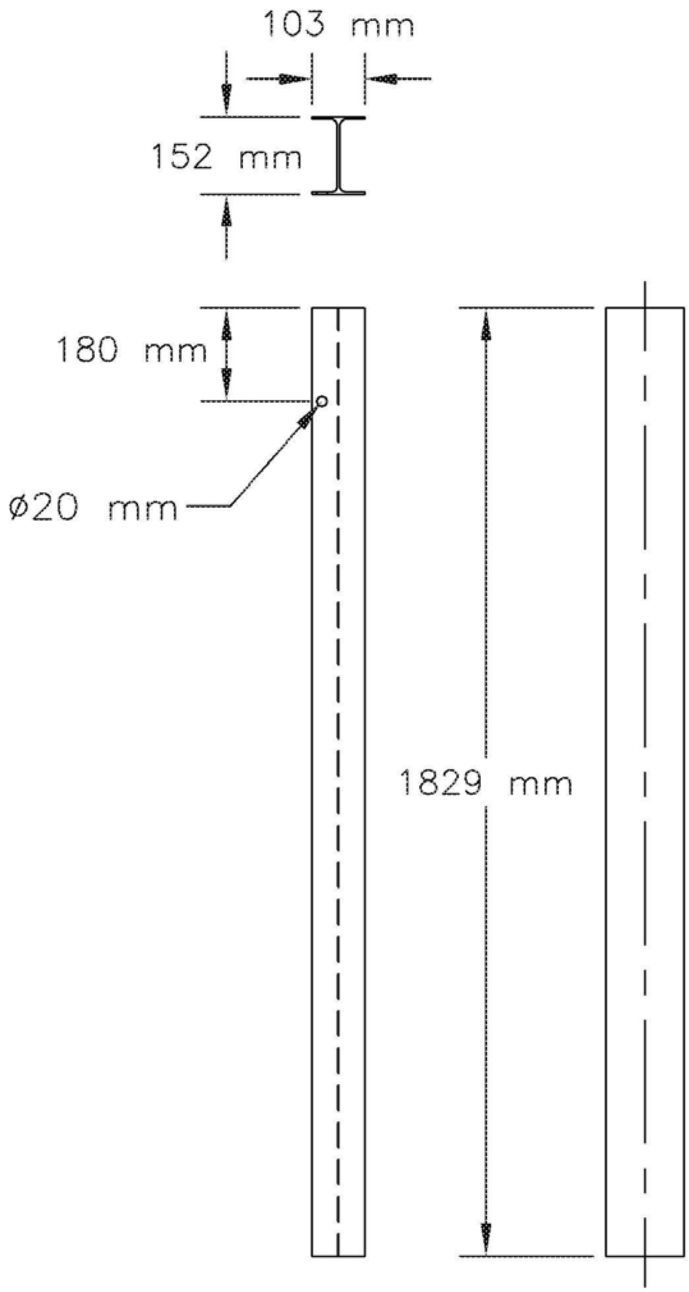


Figure 32. *Midwest Guardrail System* Steel Post Details – Post Nos. 3 through 27

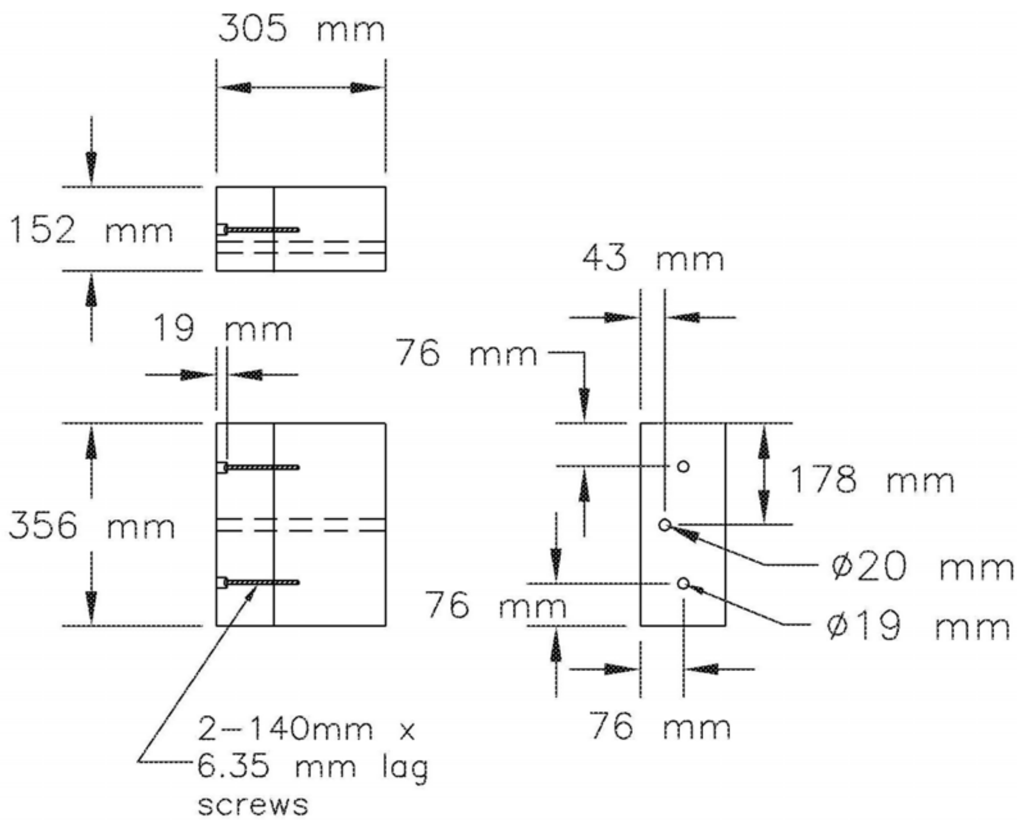


Figure 33. *Midwest Guardrail System* Wood Blockout Details – Post Nos. 3 through 27

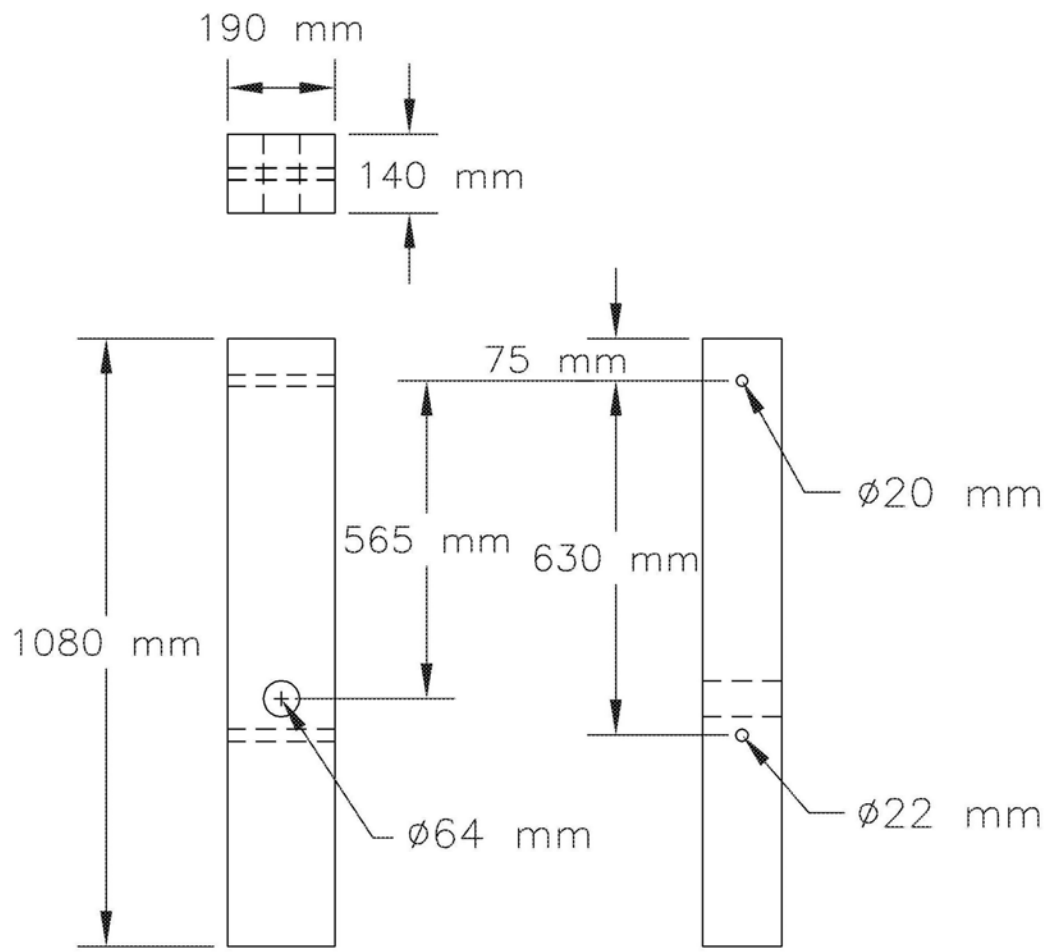


Figure 34. *Midwest Guardrail System* End Anchor Post Details – Post Nos. 1, 2, 28, and 29

Figure 35. *Midwest Guardrail System* Maximum Height Tolerance

Figure 36. *Midwest Guardrail System* Maximum Height Tolerance

8 CRASH TEST NO. 1

8.1 Test NPG-1

The *Midwest Guardrail System* (MGS) with standard post spacing was installed with the top guardrail height set to the design's maximum rail height tolerance. The 887-kg (1,956-lb) small car impacted the *Midwest Guardrail System* (MGS) with maximum height tolerance at a speed of 102.9 km/h (63.9 mph) and at an angle of 20.0 degrees. A summary of the test results and the sequential photographs are shown in Figure 37. The summary of the test results and sequential photographs in English units are shown in Appendix A. Additional sequential photographs are shown in Figure 38. Documentary photographs of the crash test are shown in Figures 39 and 40.

8.2 Test Description

Initial impact was to occur between post nos. 13 and 14 or 1,461-mm (57 ½-in.) upstream from the centerline of the splice between post nos.14 and 15, as shown in Figure 41. Actual vehicle impact occurred 1,562-mm (61 ½-in.) upstream from the centerline of the splice between post nos. 14 and 15. At 0.012 sec after initial impact, post no. 14 began to rotate backward. At 0.026 sec, post nos. 13, 15, and 16 began to rotate backward as the left-front corner of the vehicle protruded under the bottom of the guardrail. At 0.052 sec, the left-front corner of the vehicle crushed inward toward the engine compartment as post nos. 13 through 15 continued to rotate backward. At 0.080 sec, the left-front corner of the vehicle rolled away from the barrier system and contacted the wood blockout at post no. 15, causing it to rotate clockwise (CW) about the post bolt. At this same time, post no. 14 deflected downstream as it continued to rotate backward and post no. 17 began to rotate backward. At 0.106 sec, the guardrail released away from post no. 15. At 0.120 sec, the left-front corner of the vehicle contacted the wood blockout at post no. 16, causing it to rotate CW about the post bolt. At 0.138 sec, the left-rear corner of the vehicle was located at post no. 14 and post nos. 13 and 14 ceased deflection movement. At 0.152 sec, the guardrail released away from post no. 16. At this same time, the disengaged bumper cover contacted post no. 16. At 0.198 sec, the left-front corner of the vehicle was located at post no. 17 as post nos. 17 and 18 ceased deflection movement. At 0.201 sec, the vehicle became parallel to the barrier with a resultant velocity of 88.5 km/h (55.0 mph). At 0.208 sec, the front end of the vehicle was no longer located under the bottom of the guardrail. At 0.262 sec, the left-front corner of the vehicle was no longer in contact with the barrier system. At 0.298 sec, the vehicle was redirecting in a stable state without any rolling, pitching, or yawing. At 0.314 sec, post no. 17 and the guardrail began to rebound back toward the traffic side as the left-rear corner of the vehicle was in contact with the guardrail system. At 0.379 sec, the vehicle exited the barrier at a trajectory angle of 9 degrees and at a resultant velocity of 92.3 km/h (57.4 mph). At 0.414 sec, post no. 14 began to rebound back toward the traffic side. At 0.466 sec, the deformed barrier system ceased all movement. The vehicle came to rest 41.53-m (136-ft 3-in.) downstream from impact and 0.71-m (2-ft 4-in.) laterally away from the traffic-side face of the rail, as shown in Figures 37 and 42.

8.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 43 through 45. Barrier damage consisted of deformed W-beam and guardrail posts, contact marks on a guardrail section, and damaged wooden blockouts.

The guardrail damage consisted of moderate deformation and flattening of the impacted section of W-beam rail between post nos. 13 and 17. Contact marks were found on the guardrail between post nos. 13 and 17. A small tear was found on the downstream side of the post bolt slot at post no. 15. The W-beam was pulled off of post nos. 15 and 16. No significant guardrail damage occurred upstream of post no. 13 nor downstream of post no. 18.

Steel post nos. 3 through 12 were slightly twisted but did not encounter any rotational deflections. Post nos. 13, 14, 17, and 18 rotated backward slightly in the soil. Post nos. 15 and 16 rotated in the soil and bent laterally toward the ground. Contact marks were found on the front face of post nos. 15 and 16. Longitudinal splitting through the bolt holes was found on the wooden blockouts at post nos. 15 and 16. No significant post damage or movement occurred to post nos. 19 through 28, and the blockouts at post nos. 3 through 14 and 17 through 28 remained undamaged. The upstream and downstream anchorage systems slightly moved longitudinally, but the posts in both the upstream and downstream anchorage systems were not damaged.

The permanent set of the guardrail and posts is shown in Figures 43 through 45. The maximum lateral permanent set rail and post deflections were 238 mm (9 ⅜ in.) at the centerline of post no. 15 and 432 mm (17 in.) at post no. 15, respectively, as measured in the field. It should be noted that the rail was removed from this post. The maximum lateral dynamic rail deflection was 443 mm (17 ⅜ in.) at the centerline of post no. 15, as determined from the high-speed film analysis.

8.4 Vehicle Damage

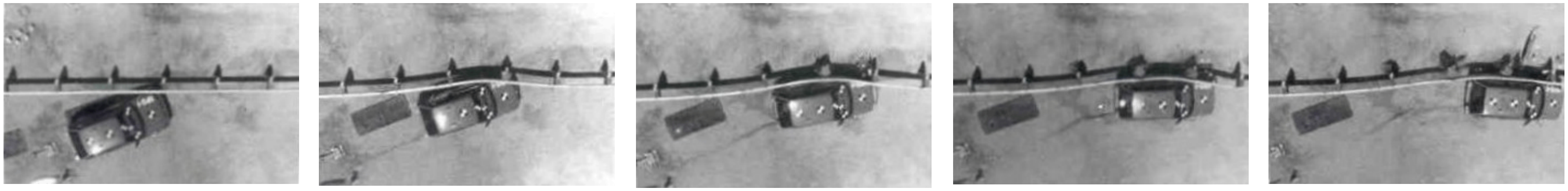
Exterior vehicle damage was moderate, as shown in Figures 46 and 47. Minimal occupant compartment deformations occurred with only slight deformation of the forward floorpan area and the left-side rocker panel. Damage was concentrated on the left-front corner and left side of the vehicle. The left-front corner of the vehicle was crushed inward, including the fender, bumper, hood, and wheel assembly. The outer plastic cover was removed from the bumper, while the bumper's inner steel reinforcement was deformed slightly inward on the left end. The left-front wheel assembly was deformed inward toward the engine compartment. The lower control arm along with the shock and spring assembly were bent and deformed back toward the occupant compartment but remained attached. The wheel assembly joint connected to the transfer case was disengaged. The left-front tire disengaged from the rim and the side wall was torn. The right-front tire also disengaged from the rim. Scrape marks and deformations were found along the middle portion of the entire left side of the vehicle from contact with the W-beam guardrail. The left-side headlight region was damaged and crushed inward toward the engine compartment. The top of the left-side door was jarred open. The lower-left side of the windshield sustained minor spider cracking with several of the cracks extending across the entire windshield. The roof, the right side and rear of the vehicle as well as the left-side, right-side, and rear window glass remained undamaged.

8.5 Occupant Risk Values

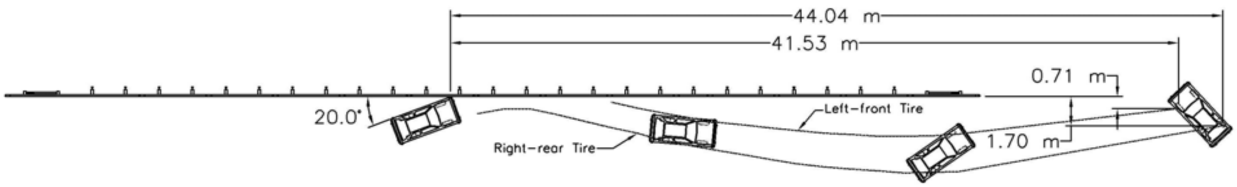
The longitudinal and lateral occupant impact velocities were determined to be 3.52 m/sec (11.55 ft/sec) and 5.68 m/sec (18.63 ft/sec), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 6.13 g's and 7.97 g's, respectively. It is noted that the occupant impact velocities (OIV's) and occupant ridedown decelerations (ORD's) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from the accelerometer data, are summarized in Figure 37. Results are shown graphically in Appendix B. The results from the rate transducer are shown graphically in Appendix B.

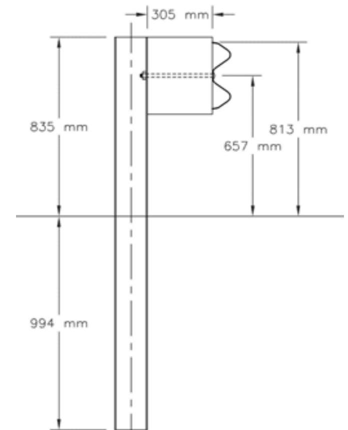
8.6 Discussion

The analysis of the test results for test NPG-1 showed that the W-beam guardrail with increased rail height adequately contained and redirected the vehicle with controlled lateral displacements of the guardrail. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the W-beam guardrail and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After collision, the vehicle's trajectory revealed minimum intrusion into adjacent traffic lanes. In addition, the vehicle's exit angle was less than 60 percent of the impact angle. Therefore, test NPG-1 conducted on the new W-beam guardrail system, known as the *Midwest Guardrail System* (MGS), at its maximum height tolerance was determined to be acceptable according to the TL-3 safety performance criteria found in NCHRP Report No. 350.



0.000 sec 0.088 sec 0.147 sec 0.189 sec 0.251 sec





- Test Number NPG-1
- Date 6/29/01
- Appurtenance . . . . *Midwest Guardrail System*
  - Key Elements . . . . increased mounting height, blockout depth, and bolt slot length, mid-span splices
- Total Length . . . . 55.25 m
- Steel W-beam
  - Thickness . . . . 2.66 mm
  - Top Mounting Height . . . . 813 mm
  - Bolt Slot Length . . . . 102 mm
- Steel Posts
  - Post Nos. 3 - 27 . . . . W152 x 13.4 by 1,829-mm long
  - Spacing . . . . 1,905 mm
- Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) . . 140 mm x 190 mm by 1,080-mm long
- Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 152 mm x 305 mm by 356-mm long
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1994 Geo Metro
  - Curb . . . . 746 kg
  - Test Inertial . . . . 812 kg
  - Gross Static . . . . 887 kg
- Vehicle Speed
  - Impact . . . . 102.9 km/h
  - Exit (resultant) . . . . 92.3 km/h
- Vehicle Angle
  - Impact (trajectory) . . . . 20.0 deg
  - Exit (trajectory) . . . . 9 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 6.13 g's < 20 g's
  - Lateral (not required) . . . . 7.97 g's
- Occupant Impact Velocity
  - Longitudinal . . . . 3.52 m/s < 12 m/s
  - Lateral (not required) . . . . 5.68 m/s
- Vehicle Damage . . . . Moderate
  - TAD[31] 11-LFQ-3
  - SAE[32] 11LFEW3
- Vehicle Stopping Distance . . . . 41.53 m downstream
  0.71 m traffic-side face
- Barrier Damage . . . . Moderate
- Maximum Rail Deflections
  - Permanent Set . . . . 238 mm
  - Dynamic . . . . 443 mm
- Working Width . . . . 1,023 mm

Figure 37. Summary of Test Results and Sequential Photographs, Test NPG-1

Figure 38. Additional Sequential Photographs, Test NPG-1

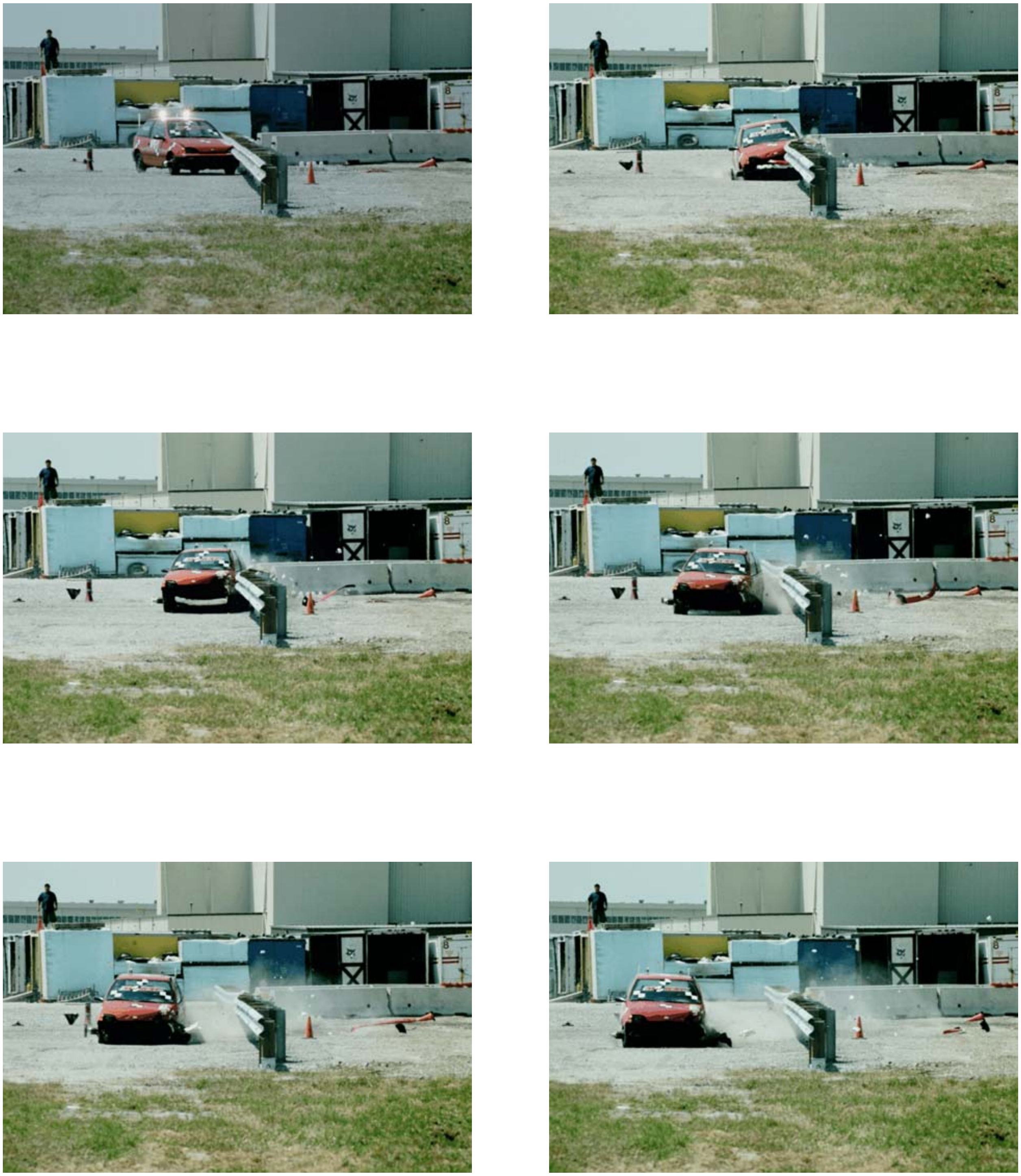


Figure 39. Documentary Photographs, Test NPG-1

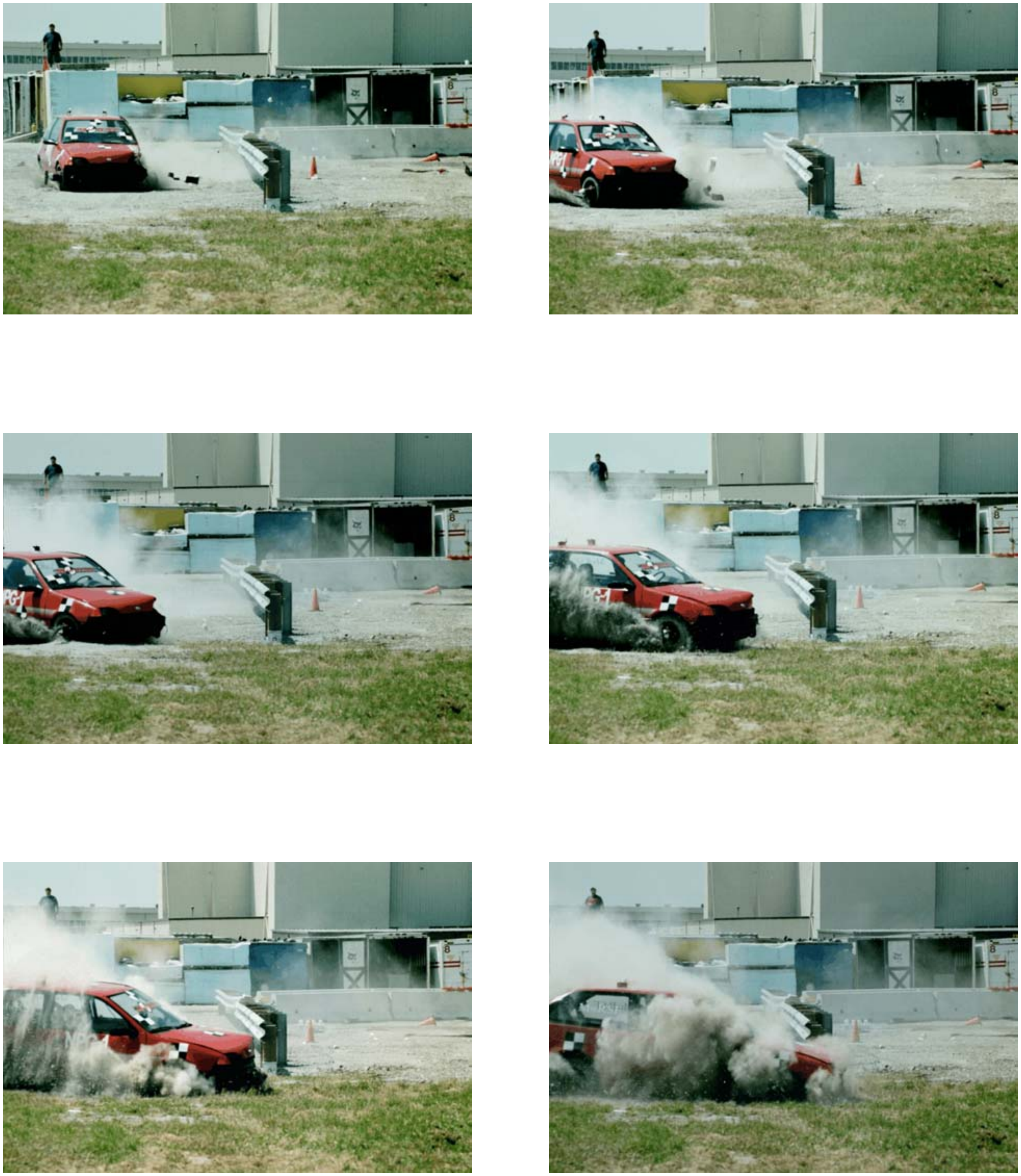


Figure 40. Documentary Photographs, Test NPG-1

Figure 41. Impact Location, Test NPG-1

Figure 42. Vehicle Final Position and Trajectory Marks, Test NPG-1

Figure 43. System Damage, Test NPG-1

Figure 44. Post Nos. 15 and 16 Damage, Test NPG-1

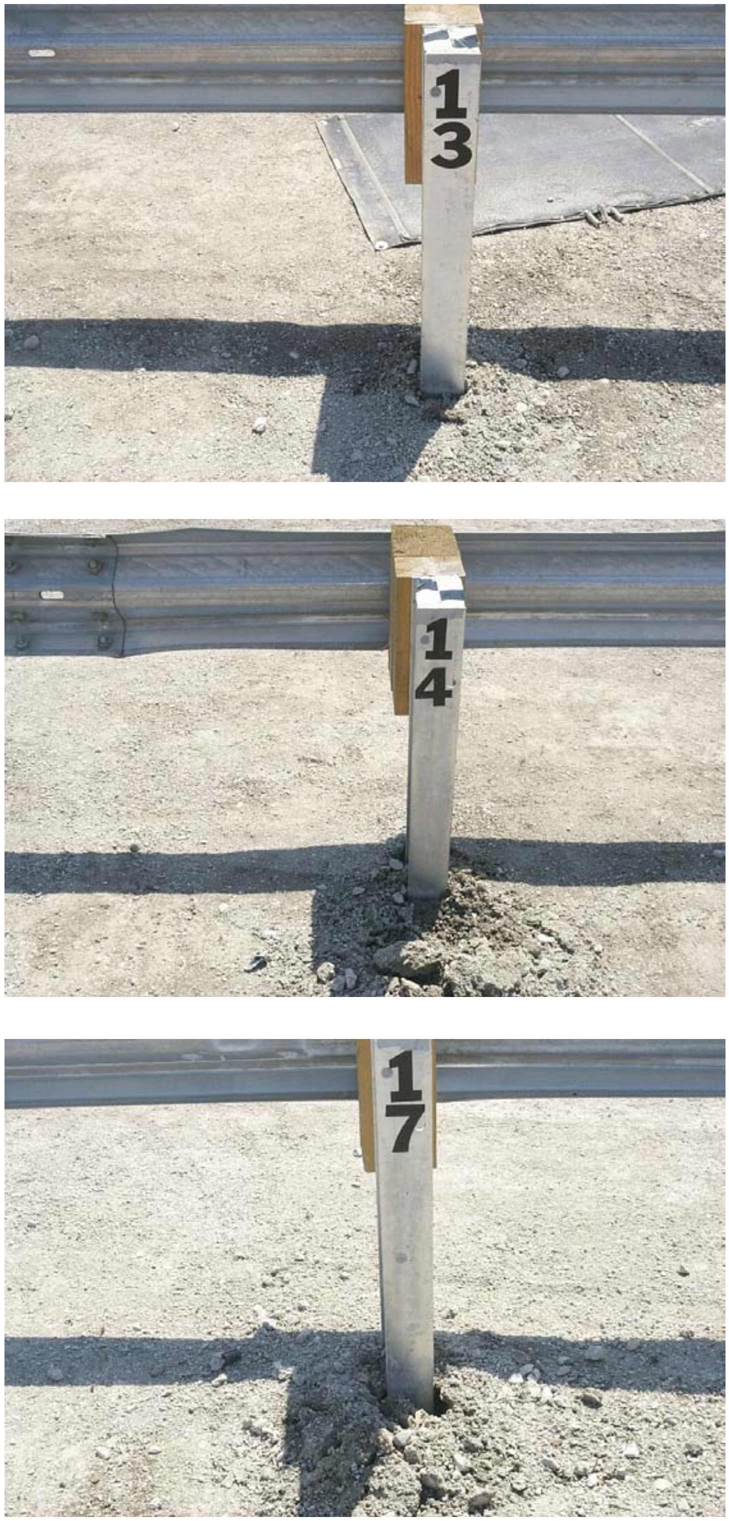


Figure 45. Post Nos. 13, 14, and 17 Damage, Test NPG-1

Figure 46. Vehicle Damage, Test NPG-1

Figure 47. Vehicle Damage, Test NPG-1

9 *MIDWEST GUARDRAIL SYSTEM* DESIGN DETAILS – NOMINAL HEIGHT

The second test installation of the *Midwest Guardrail System* (MGS) was identical to the previous system except for the guardrail's top mounting height. The first installation's height was set at the design's maximum height tolerance of 813 mm (32 in.). For the second installation, the nominal height design, the top W-beam guardrail height was 787 mm (31 in.) with a 632-mm (24 ⅞-in.) center mounting height. Additionally, post nos. 1 through 29 were still spaced 1,905 mm (75 in.) on center, but were embedded to a depth of 1,019 mm (40 in.) in the soil, as shown in Figures 48 through 56.

Once again, the test installation consisted of 55.25 m (181 ft-3 in.) of standard 2.66-mm (12-gauge) thick W-beam guardrail supported by steel posts, as shown in Figures 48, 53, and 54. Also, anchorage systems similar to those used on tangent guardrail terminals were utilized on both the upstream and downstream ends of the guardrail system, as shown in Figures 48, 52, 53, and 56. As done previously in the maximum height tolerance system, the rail splices were moved to the center of the span location, and the post bolt slots were increased to 102 mm (4 in.) in length, as shown in Figures 48, 49, and 55. Furthermore, all lap-splice connections between the rail sections were configured to reduce vehicle snag at the splice during the crash test. Photograph of the test installation are shown in Figures 53 through 56.

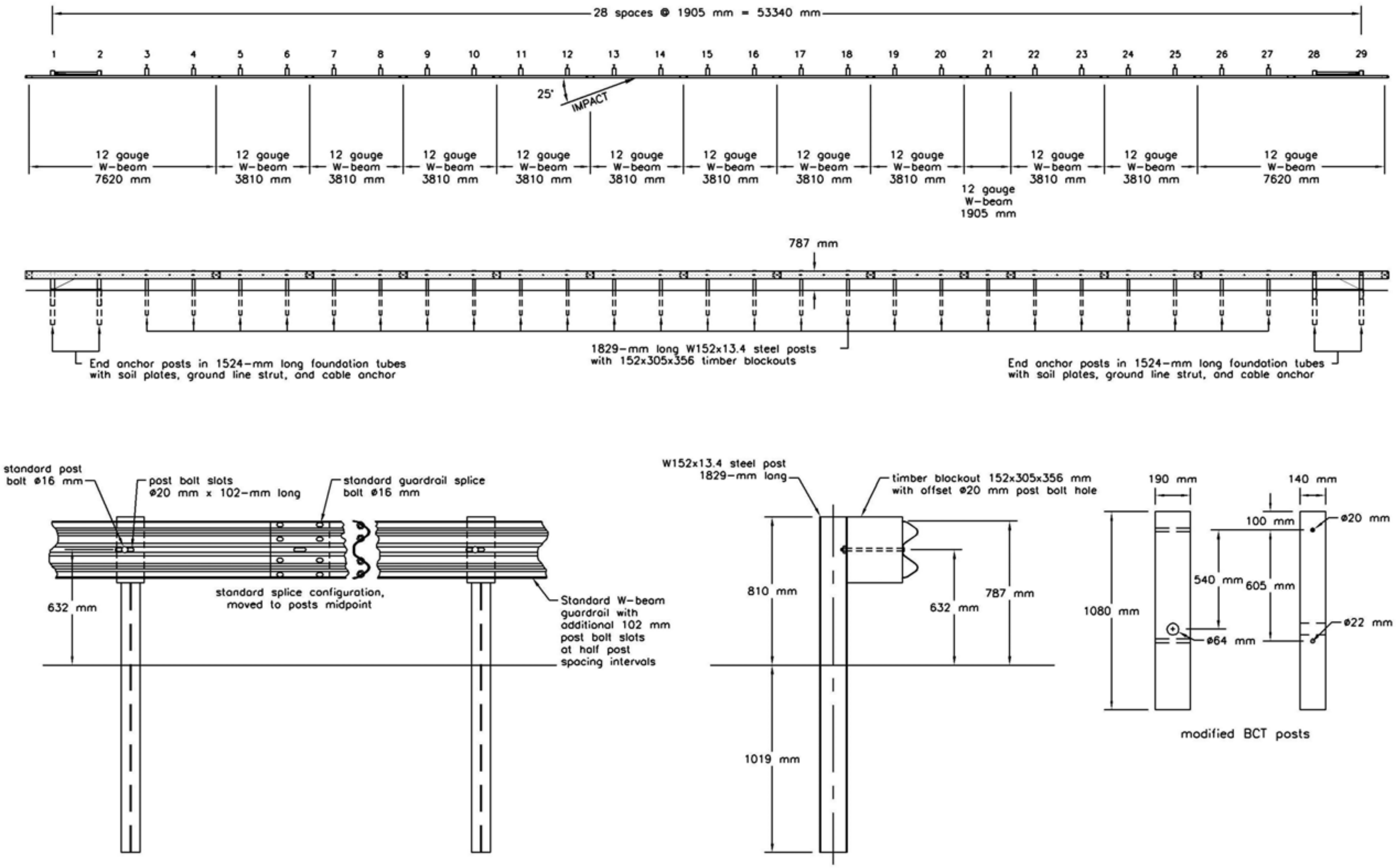


Figure 48. *Midwest Guardrail System* Nominal Height Test Installation

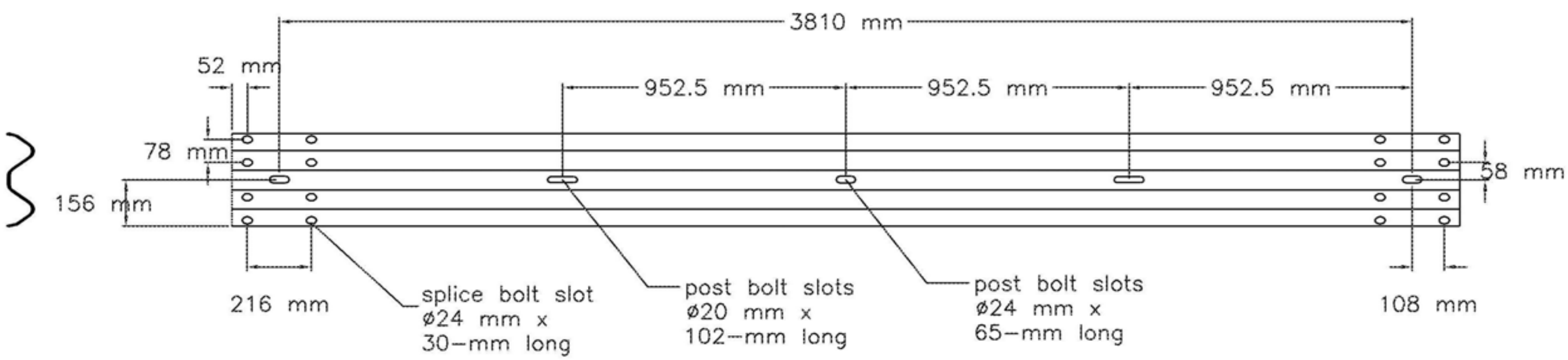


Figure 49. *Midwest Guardrail System* Rail Design Details

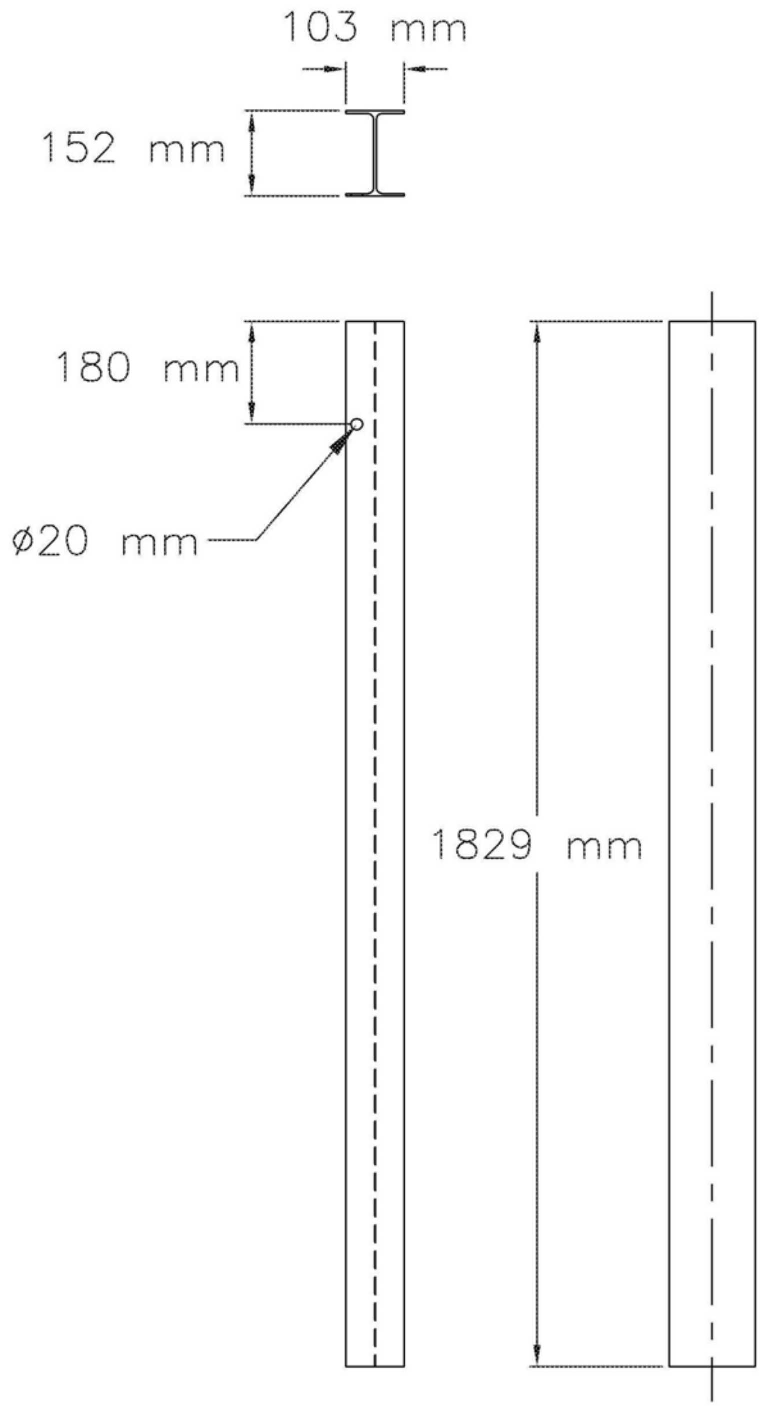


Figure 50. *Midwest Guardrail System* Nominal Height Steel Post Details – Post Nos. 3 through 27

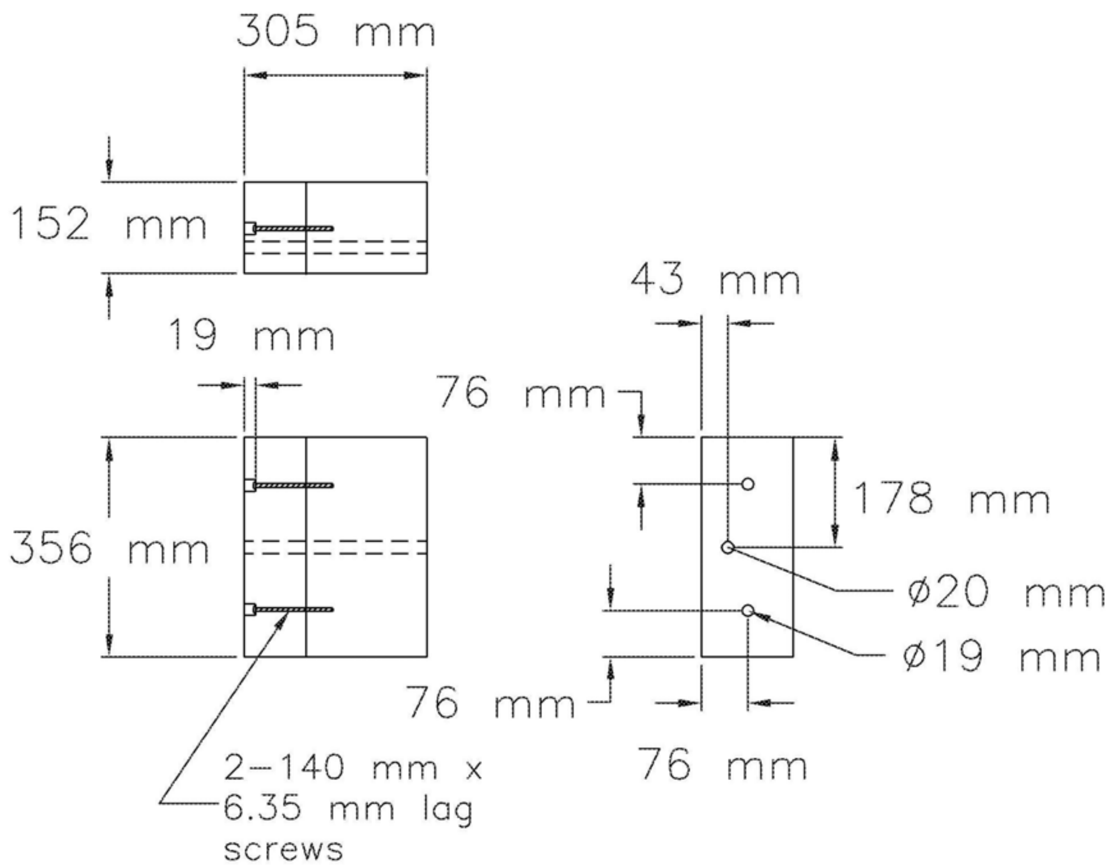


Figure 51. *Midwest Guardrail System* Wood Blockout Details – Post Nos. 3 through 27

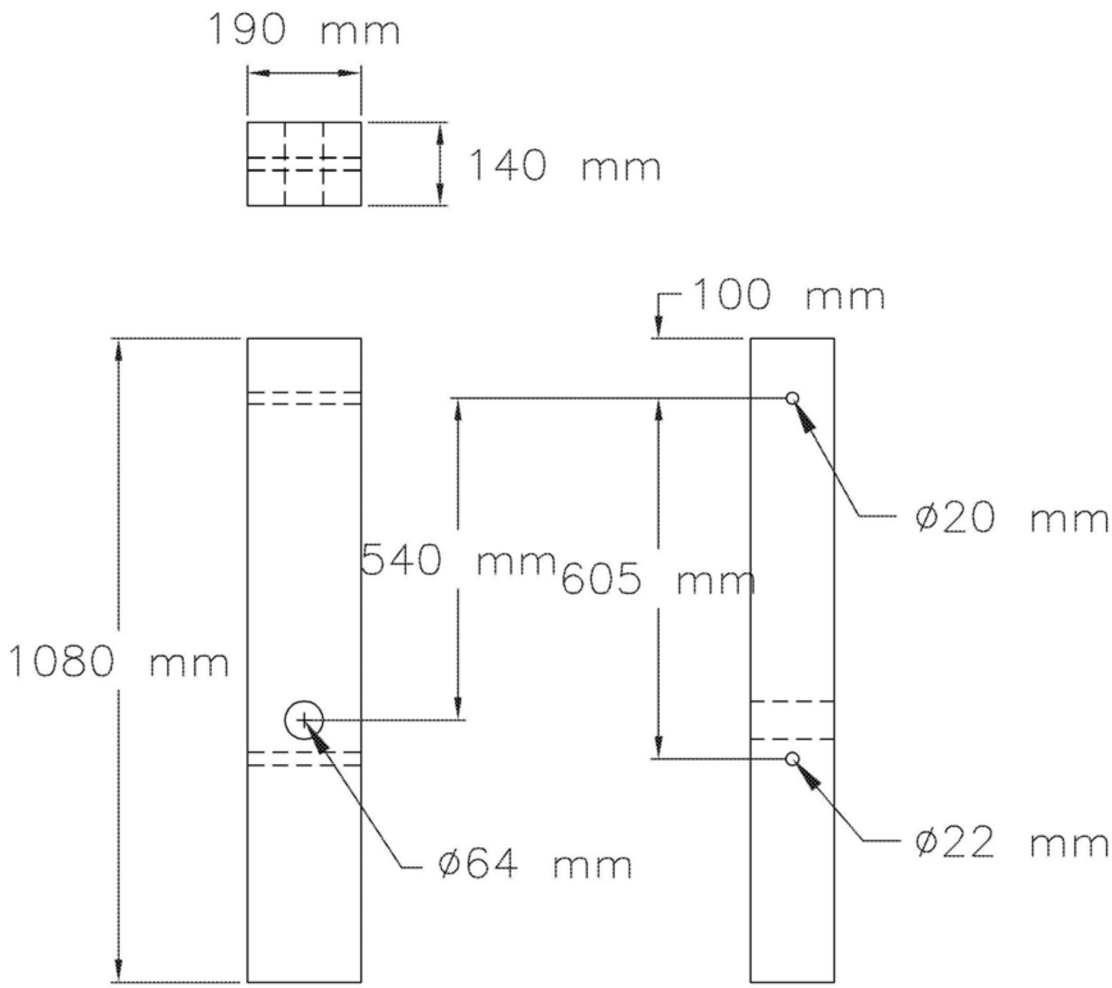


Figure 52. *Midwest Guardrail System* Nominal Height End Anchor Post Details – Post Nos. 1, 2, 28, and 29

Figure 53. *Midwest Guardrail System* Nominal Height

Figure 54. *Midwest Guardrail System* Nominal Height

Figure 55. *Midwest Guardrail System* Nominal Height

Figure 56. *Midwest Guardrail System* Nominal Height

10 CRASH TEST NO. 2 (DEVELOPMENTAL, NON-COMPLIANT TEST)

10.1 Test NPG-2

Although standard W-beam guardrails have been shown to meet NCHRP Report No. 350 testing standards, accident data analysis (14) has shown that light trucks and sport-utility vehicles (SUV's) are much more likely to roll over during a collision with a guardrail than are automobiles. Further, occupant injury rates during guardrail crashes involving light trucks and SUV's were found to be higher than those for large automobiles. The primary purpose for developing the *Midwest Guardrail System* (MGS) was to improve the safety performance of W-beam guardrails during crashes involving light truck and SUV's. In order to demonstrate that the new guardrail was capable of safely accommodating light trucks and SUV's, the original proposal for this study included a provision for utilizing test vehicles with higher mass and higher center of gravity (c.g.) than recommended by NCHRP Report No. 350. Therefore, 4-wheel drive pickups were chosen as the candidate test vehicle evaluating the new barrier's capacity for safely redirecting light trucks and SUV's.

The *Midwest Guardrail System* (MGS) with standard post spacing was installed with the top guardrail height set to the design's nominal rail height. The developmental, non-compliant 2,241-kg (4,941-lb) 4x4 pickup truck impacted the *Midwest Guardrail System* (MGS) with nominal rail height at a speed of 99.0 km/h (61.5 mph) and at an angle of 24.7 degrees. A summary of the test results and the sequential photographs are shown in Figure 57. The summary of the test results and sequential photographs in English units are shown in Appendix A. Additional sequential photographs are shown in Figures 58 and 59. Documentary photographs of the crash test are shown in Figures 60 and 61.

10.2 Test Description

Initial impact was to occur between post nos. 11 and 12 or 4,877-mm (16-ft) upstream from the centerline of the splice between post nos. 14 and 15, as shown in Figure 62. Actual vehicle impact occurred 1,715-mm (67.5-in.) downstream from the center of post no. 11. At 0.006 sec after impact, post no. 12 began to rotate backward. At 0.020 sec, post nos. 13 and 14 began to rotate backward. At 0.042 sec, post no. 12 twisted as the front of the vehicle deformed and deflected the rail spanning between post nos. 12 and 13. At 0.066 sec, the left-front corner of the vehicle was located at post no. 13 with the guardrail pushing against the left-front tire. At 0.088 sec, the guardrail released from post no. 13. At 0.139 sec, the front of the vehicle was located at post no. 14 as the vehicle began to redirect. At 0.160 sec, the guardrail released from post no. 14. At this same time, the left-front tire disengaged from the vehicle as it contacted post no. 13. At 0.227 sec, the front of the vehicle was located at post no. 15 as the vehicle began to ride up on the guardrail. At this same time, the guardrail released from post no. 15. At 0.240 sec, the vehicle began to roll toward its right side, and post no. 14 was bent toward the ground. At this same time, the left-rear tire contacted post no. 13, and post no. 12 began to rotate back toward the traffic side. At 0.303 sec, the front of the vehicle was located at post no. 16, and post nos. 11 and 12 twisted back toward their original positions. At this same time, the rail near post no. 15 began to tear as a result of the interaction between the guardrail and the exposed suspension components due to the left-front tire's previous disengagement. At 0.352 sec, the front of the vehicle began to become airborne on top of the guardrail. At 0.388 sec, the rail near post no. 15 ruptured completely through. At 0.406 sec, the guardrail released from post no. 12. At 0.464 sec, the vehicle began to roll back toward the left. At 0.510 sec, the vehicle appeared to be parallel to the barrier with a resultant velocity of 71.6 km/h

(44.5 mph). At 0.546 sec, the vehicle became airborne and continued to travel over the rail toward the back side of the barrier system. At 0.652 sec, the rear of the vehicle contacted the ground. At 0.742 sec after impact, the vehicle rolled toward its left side with the front end still airborne. At 1.004 sec, the front of the vehicle contact the ground as the vehicle continued to roll toward its left side. At 1.354 sec, the vehicle rolled onto its left side, but with the vehicle airborne. At 1.712 sec, the vehicle rolled over onto its roof. At 1.886 sec, the vehicle continued to roll as the roof crushed inward toward the occupant compartment. At 2.358 sec, the vehicle continued to roll toward the left and was now positioned on its right side. At 3.110 sec, the vehicle continued to roll toward the left as it rolled back over to its upright position. The vehicle came to rest 26.82-m (88-ft) downstream from impact and 1.52-m (5-ft) laterally behind the traffic-side face of the barrier, as shown in Figures 57 and 63.

10.3 Barrier Damage

Damage to the barrier was extensive, as shown in Figures 64 through 67. Barrier damage consisted of deformed W-beam and guardrail posts, contact marks on a guardrail section, and disengaged wooden blockouts.

The guardrail damage consisted of moderate deformation and flattening of the impacted section of W-beam rail between post nos. 13 and 17. Contact marks were found on the guardrail between post nos. 12 and 18. The guardrail buckled at post nos. 11, 12, and 17. The W-beam guardrail was torn through the cross section, beginning at the bottom of the W-beam rail 254-mm (10-in.) downstream of the centerline of the splice between post nos. 14 and 15, propagating up through the post bolt slot at post no. 15, and ending at the top of the W-beam rail 203-mm (8-in.) downstream of the centerline of post no. 15. The W-beam was pulled off of post nos. 1 through 5, 12 through 17, and 20 through 24. The W-beam rail sustained significant yielding around the post bolt slots at post nos. 3 through 5. No significant guardrail damage occurred downstream of post no. 25.

Steel posts nos. 11 and 12 rotated backward slightly in the soil. Post no. 13 rotated backward toward the ground. Post nos. 14 and 15 encountered significant twisting and were bent toward the ground. Post no. 16 bent toward the ground and the top of the post was bent severely, torn, and encountered heavy contact marks 152 mm (6 in.) from the top. Post nos. 17 and 20 through 24 rotated and bent longitudinally downstream. Post no. 20 also encountered heavy contact marks at the top. The upstream and downstream anchorage systems slightly moved longitudinally, but the posts in both the upstream and downstream anchorage systems were not damaged.

The wooden blockouts at post nos. 13, 14, 15, 17, 21, and 22 fractured, but remained attached to the post. The wooden blockouts at post nos. 18 through 20 encountered only minor deformations. The wooden blockout at post no. 16 disengaged from the system. The blockout bolt at post nos. 13, 14, 15, and 17 bent and subsequently rotated the blockout toward the downstream side of the post. The blockouts at post nos. 3 through 12 and 23 through 27 remained undamaged.

10.4 Vehicle Damage

Exterior vehicle damage was extensive, as shown in Figures 68 and 69. Extensive occupant compartment deformations occurred due to vehicle rollover. The left-front quarter panel was crushed inward. The front bumper was flattened from the centerline out toward the left side as the left side of the bumper was bent back toward the engine compartment. The frame of the vehicle was bent near the left-front tire. The left-front tire's tie rods as well as the upper and lower ball joints disengaged, causing the wheel to be removed from the vehicle. The four-wheel drive shaft disengaged from the vehicle. The left side of the hood was creased and sustained cuts. The roof, the A- and B-pillars on both sides, and both the left- and right-side doors were crushed and deformed due to vehicle rollover. The windshield was cracked and deformed. Both the left- and right-side door windows as well as the rear window were shattered. The box portion of the vehicle remained undamaged.

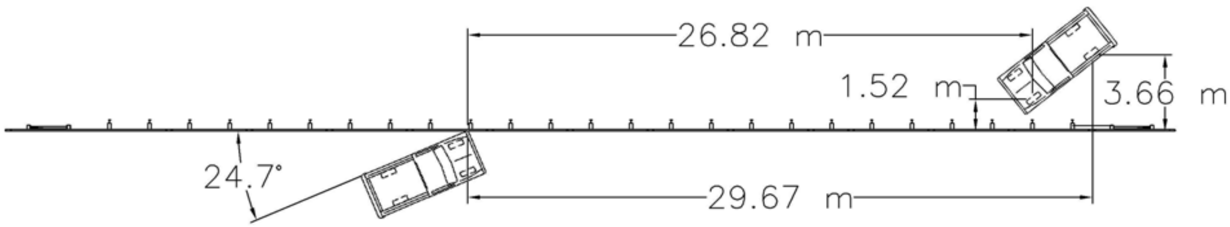
10.5 Occupant Risk Values

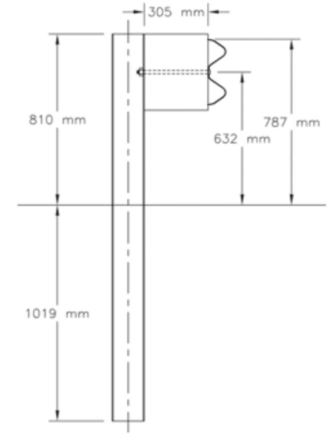
The longitudinal and lateral occupant impact velocities were determined to be 4.98 m/sec (16.33 ft/sec) and 3.15 m/sec (10.32 ft/sec), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 6.51 g's and 8.19 g's, respectively. It is noted that the occupant impact velocities (OIV's) and occupant ridedown decelerations (ORD's) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from the accelerometer data, are summarized in Figure 57. Results are shown graphically in Appendix C. The results from the rate transducer are shown graphically in Appendix C.

10.6 Discussion

The analysis of the test results of the non-compliant NCHRP Report 350 test, test NPG-2, showed that the W-beam guardrail with increased rail height did not contain nor redirect the vehicle since the vehicle penetrated the system and did not remain upright after collision with the guardrail. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did occur with the deformation of the vehicle's roof. The test vehicle rode over and penetrated the guardrail system. The vehicle's trajectory did not intrude into adjacent traffic lanes, but the penetration of the vehicle through the system was unacceptable. Therefore, test NPG-2 conducted on the *Midwest Guardrail System* (MGS) with a non-compliant, 4x4, ¾-ton pickup truck at its nominal height, was determined to be unacceptable due to vehicle rollover and penetration behind the system.

0.042 sec 0.102 sec 0.227 sec 0.303 sec 0.464 sec





- Test Number NPG-2
- Date 8/9/01
- Appurtenance . . . . *Midwest Guardrail System*
  - Key Elements . . . . increased mounting height, blockout depth, and bolt slot length, mid-span splices
- Total Length . . . . 55.25 m
- Steel W-beam
  - Thickness . . . . 2.66 mm
  - Top Mounting Height . . . . 787 mm
  - Bolt Slot Length . . . . 102 mm
- Steel Posts
  - Post Nos. 3 - 27 . . . . W152 x 13.4 by 1,829-mm long
  - Spacing . . . . 1,905 mm
- Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) . . 140 mm x 190 mm by 1,080-mm long
- Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 152 mm x 305 mm by 356-mm long
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1995 Chevrolet 2500 4x4 pickup
  - Curb . . . . 2,155 kg
  - Test Inertial . . . . 2,241 kg
  - Gross Static . . . . 2,241 kg
- Vehicle Speed
  - Impact . . . . 99.0 km/h
  - Exit (resultant) . . . . NA
- Vehicle Angle
  - Impact (trajectory) . . . . 24.7 deg
  - Exit (trajectory) . . . . NA
- Vehicle Stability . . . . Unsatisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 6.51 g’s < 20 g’s
  - Lateral (not required) . . . . 8.19 g’s
- Occupant Impact Velocity
  - Longitudinal . . . . 4.98 m/s < 12 m/s
  - Lateral (not required) . . . . 3.15 m/s
- Vehicle Damage . . . . Extensive
  - TAD[31] . . . . 11-FFQ-3, L&T-4
  - SAE[32] 11LFEW3, 00TDDO6
- Vehicle Stopping Distance . . . . 24.80 m downstream, 1.52 m laterally behind
- Barrier Damage . . . . Extensive
- Maximum Deflections
  - Permanent Set . . . . NA
  - Dynamic . . . . NA
- Working Width . . . . NA

Figure 57. Summary of Test Results and Sequential Photographs, Test NPG-2

0.000 sec

0.000 sec

0.167 sec

0.158 sec

0.300 sec

0.242 sec

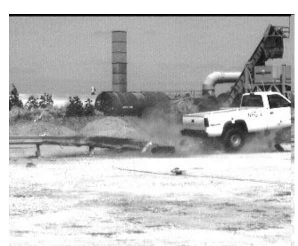
0.400 sec

0.334 sec

0.534 sec

0.458 sec

0.667 sec



0.564 sec

Figure 58. Additional Sequential Photographs, Test NPG-2

0.000 sec

0.000 sec

0.067 sec

0.200 sec

0.133 sec

0.300 sec

0.234 sec

0.434 sec

0.400 sec

0.567 sec

0.567 sec

0.701 sec

Figure 59. Additional Sequential Photographs, Test NPG-2

Figure 60. Documentary Photographs, Test NPG-2

Figure 61. Documentary Photographs, Test NPG-2

Figure 62. Impact Location, Test NPG-2

Figure 63. Vehicle Final Position and Trajectory Marks, Test NPG-2

Figure 64. System Damage, Test NPG-2

Figure 65. System Damage, Test NPG-2

Figure 66. System Damage, Test NPG-2

Figure 67. System Damage, Test NPG-2

Figure 68. Vehicle Damage, Test NPG-2

Figure 69. Vehicle Damage, Test NPG-2

11 CRASH TEST NO. 3

11.1 Test NPG-3

The *Midwest Guardrail System* (MGS) with standard post spacing was installed with the top guardrail height set at the design's nominal rail height. The 2,037-kg (4,491-lb) pickup truck impacted the *Midwest Guardrail System* (MGS)with nominal rail height at a speed of 102.0 km/h (63.3 mph) and at an angle of 25.2 degrees. A summary of the test results and the sequential photographs are shown in Figure 70. The summary of the test results and sequential photographs in English units are shown in Appendix A. Additional sequential photographs are shown in Figure 71. Documentary photographs of the crash test are shown in Figures 72 and 73.

11.2 Test Description

Initial impact occurred between post nos. 11 and 12 or 4,877-mm (16-ft) upstream from the centerline of the splice between post nos. 14 and 15, as shown in Figure 74. At 0.026 sec after impact, the rail between post nos. 12 and 13 deflected toward the back side, and the front bumper was deformed. At 0.069 sec, the left-front corner of the vehicle was located at post no. 13. At 0.084 sec, the grill and front bumper encountered extensive deformations. At this same time, the guardrail released from post no. 13. At 0.109 sec, post no. 13 was bent over to the ground. At this same time, the hood of the vehicle protruded over the rail as it began to redirect. At 0.135 sec, the front of the vehicle was located at post no. 14. At 0.146 sec, the guardrail released from post no. 14. At 0.167 sec, post no. 14 continued to deflect. At 0.180 sec, the right-front tire bent under the vehicle. At 0.210 sec, the guardrail released from post no. 15. At 0.302 sec, the front of the vehicle was located at post no. 16. At 0.352 sec, the rear-end of the vehicle pitched upward as the vehicle rolled away from the rail. At this same time, the guardrail released from post no. 16. At 0.384 sec, the rail moved downstream with the vehicle. At 0.430 sec, the vehicle appeared to be parallel to the barrier with a resultant velocity of 63.5 km/h (39.5 mph). At 0.466 sec, the guardrail released from post no. 17. At 0.526 sec, the guardrail released from post no. 18. At 0.687 sec, the left side of the vehicle was airborne with the front of the vehicle near post no. 18. At 1.157 sec, the vehicle was back in contact with the ground as it continued to travel forward. At 1.407 sec, the left side of the vehicle was airborne again. At 1.798 sec, the vehicle came to rest 14.44-m (47-ft 5-in.) downstream from impact and centered over the original position of the rail, as shown in Figures 70 and 75.

11.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 76 through 80. Barrier damage consisted mostly of deformed W-beam and guardrail posts, contact marks on a guardrail section, deformed guardrail posts, uprooted guardrail and anchor posts, and failure of the upstream cable anchor system. The increased length of the bolt slots in the guardrail caused the guardrail to release from the posts too early, thereby absorbing less energy. In addition to the early release of the posts, the increased guardrail height increased the moment on the anchorage tubes on the upstream end, causing failure of the upstream anchor system. The failure of the BCT cable anchor system caused significant damage to the posts and guardrail, as shown in Figures 76 through 80.

Steel post nos. 3 through 10 encountered very little movement. Post no. 11 twisted with a large soil gap around the post. Post no. 12 rotated backward and also twisted slightly. Post nos. 13 and 14 bent about the ground line and laid on the ground. Post nos. 15 and 16 pulled completely out of the ground. Post nos. 17 through 19 were bent and rotated downstream due to the vehicle being positioned on top of the posts. Major soil failure occurred around post nos. 13 through 16. Steel post nos. 20 through 27 did not encounter significant damage or movement. The first wooden post in the upstream anchor, post no. 1, pulled completely out of the ground and was found downstream between post nos. 3 and 4. The other wooden post in the upstream anchor, post no. 2, encountered deformations on the upstream edge and moved downstream in the soil. The wooden posts in the downstream anchor, post nos. 28 and 29, split and were severely deformed. Damage to both the upstream and downstream anchor systems is shown in Figure 80.

The W-beam was pulled off of all of the posts in the system. All the post bolt slots were deformed, as shown in Figures 77 through 79. Contact marks were found on the guardrail between post nos. 12 and 17. The guardrail between post nos. 12 and 17 was also flattened. Major guardrail buckling occurred at post no. 17.

11.4 Vehicle Damage

Exterior vehicle damage was minimal, as shown in Figure 81. Occupant compartment deformation was negligible. Occupant compartment deformation and the corresponding locations are provided in Appendix D. The vehicle experienced frontal crush, as shown in Figure 81. The radiator was crushed inward toward the engine. The front bumper was flattened, and the left-front frame horn was bent and encountered heavy contact marks. Deformation occurred to the left-front quarter panel. The left-side tie rod disengaged, while the rest of the suspension components remained attached. The hood popped open but remained undamaged. The roof, right side and rear of the vehicle, the rims and tires, and all window glass remained undamaged.

11.5 Occupant Risk Values

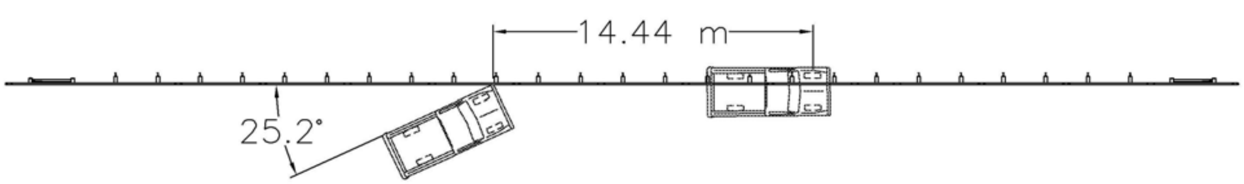
The longitudinal and lateral occupant impact velocities were determined to be 5.04 m/sec (16.55 ft/sec) and 3.65 m/sec (11.97 ft/sec), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 6.49 g's and 8.31 g's, respectively. It is noted that the occupant impact velocities (OIV's) and occupant ridedown decelerations (ORD's) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from the accelerometer data, are summarized in Figure 70. Results are shown graphically in Appendix E. The results from the rate transducer are shown graphically in Appendix E.

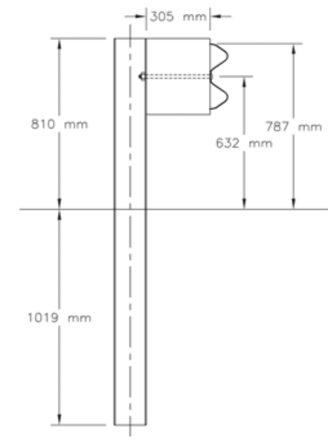
11.6 Discussion

The analysis of the test results for test NPG-3 showed that the W-beam guardrail with increased rail height adequately contained the vehicle on the traffic-side face of the guardrail. However, it did not behave as would be expected since the anchor tube pulled out of the ground, and the W-beam rail was released off of the posts with the post bolt head pulling through the longer rail slots. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The test vehicle remained upright during and after the collision. After collision, the vehicle's trajectory did not intrude into adjacent traffic lanes. Therefore, test NPG-3 conducted on the *Midwest Guardrail System* (MGS) at its nominal height was determined to be marginally acceptable according to the TL-3 safety performance criteria found in NCHRP Report No. 350.

As shown in the system details, the barrier in this test incorporated an increased post bolt slot length equal to 102 mm (4 in.). This longer slot was used in order to reduce the guardrail-post attachment force, thus decreasing the potential for the W-beam rail to be pulled down during post rotation. In this test, the rail released from the posts in an acceptable manner throughout the impact region. However, this test also showed a propensity for the guardrail to release prematurely from the posts near the upstream end of the barrier installation.

0.000 sec | 0.052 sec | 0.135 sec | 0.167 sec | 0.227 sec





- Test Number NPG-3
- Date 8/20/01
- Appurtenance . . . . *Midwest Guardrail System*
  - Key Elements . . . . increased mounting height, blockout depth, and bolt slot length, mid-span splices
- Total Length . . . . 55.25 m
- Steel W-beam
  - Thickness . . . . 2.66 mm
  - Top Mounting Height . . . . 787 mm
  - Bolt Slot Length . . . . 102 mm
- Steel Posts
  - Post Nos. 3 - 27 . . . . W152 x 13.4 by 1,829-mm long
  - Spacing . . . . 1,905 mm
- Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) . 140 mm x 190 mm by 1,080-mm long
- Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 152 mm x 305 mm by 356-mm long
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1995 Chevrolet 2500 ¾-ton pickup
  - Curb . . . . 1,946 kg
  - Test Inertial . . . . 2,037 kg
  - Gross Static . . . . 2,037 kg
- Vehicle Speed
  - Impact . . . . 102.0 km/h
  - Exit (resultant) . . . . NA
- Vehicle Angle
  - Impact (trajectory) . . . . 25.2 deg
  - Exit (trajectory) . . . . NA
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 6.49 g's < 20 g's
  - Lateral (not required) . . . . 8.31 g's
- Occupant Impact Velocity
  - Longitudinal . . . . 5.04 m/s < 12 m/s
  - Lateral (not required) . . . . 3.65 m/s
- Vehicle Damage . . . . Minimal
  - TAD[31] 11-LFQ-4, 11-FL-3
  - SAE[32] 11LFEW4
- Vehicle Stopping Distance . . . . 14.44 m downstream, 0 m lateral
- Barrier Damage . . . . Moderate
- Maximum Deflections
  - Permanent Set . . . . NA
  - Dynamic . . . . NA
- Working Width . . . . NA

Figure 70. Summary of Test Results and Sequential Photographs, Test NPG-3


0.000 sec

0.000 sec

0.000 sec

0.100 sec


0.100 sec

0.167 sec

0.267 sec


0.267 sec

0.300 sec

0.434 sec

0.501 sec

0.467 sec

0.601 sec

0.868 sec

0.801 sec

0.968 sec

1.301 sec

2.669 sec

Figure 71. Additional Sequential Photographs, Test NPG-3

Figure 72. Documentary Photographs, Test NPG-3

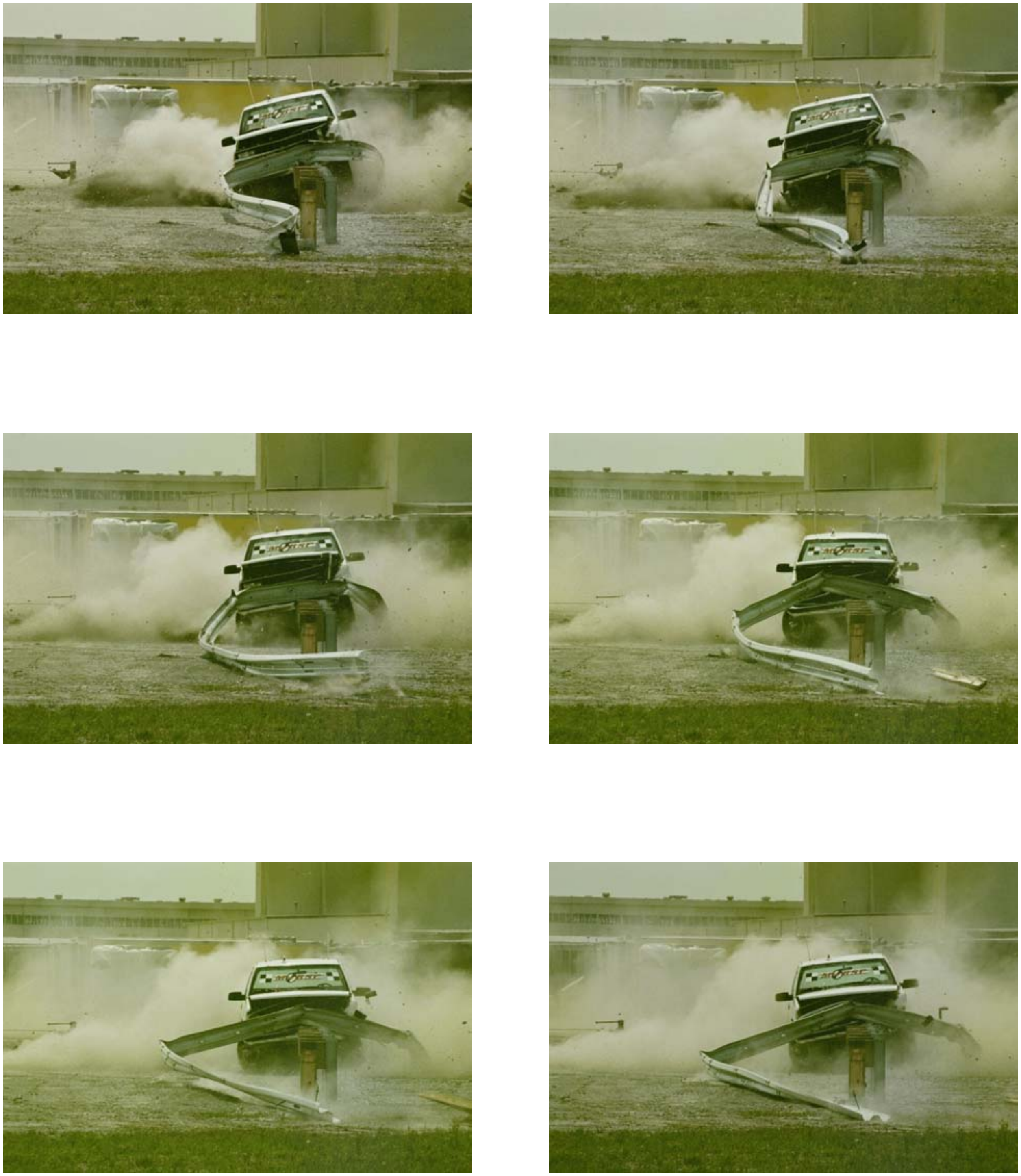


Figure 73. Documentary Photographs, Test NPG-3

Figure 74. Impact Location, Test NPG-3

Figure 75. Vehicle Final Position and Trajectory Marks, Test NPG-3

Figure 76. System Damage, Test NPG-3

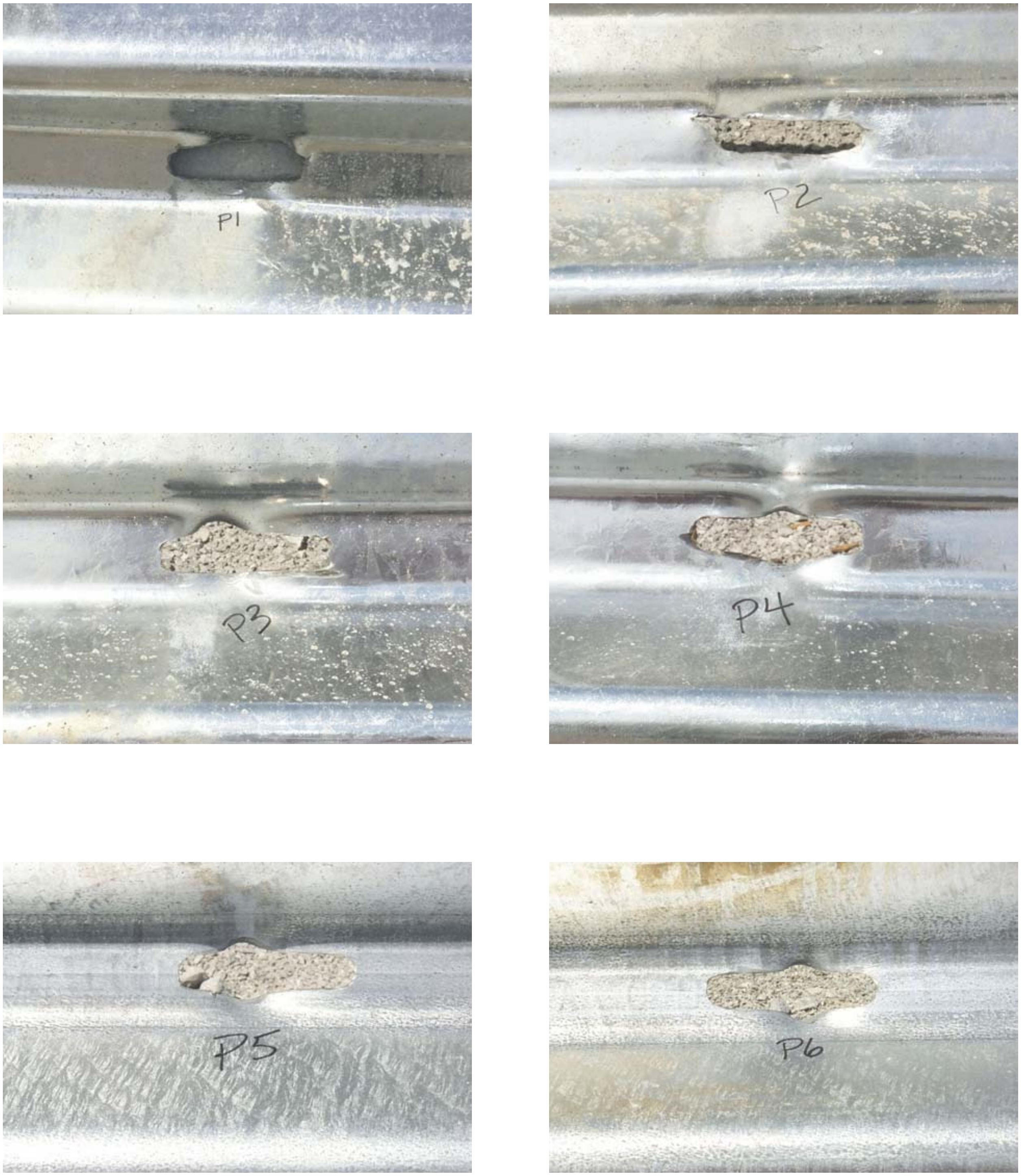


Figure 77. System Damage, Test NPG-3

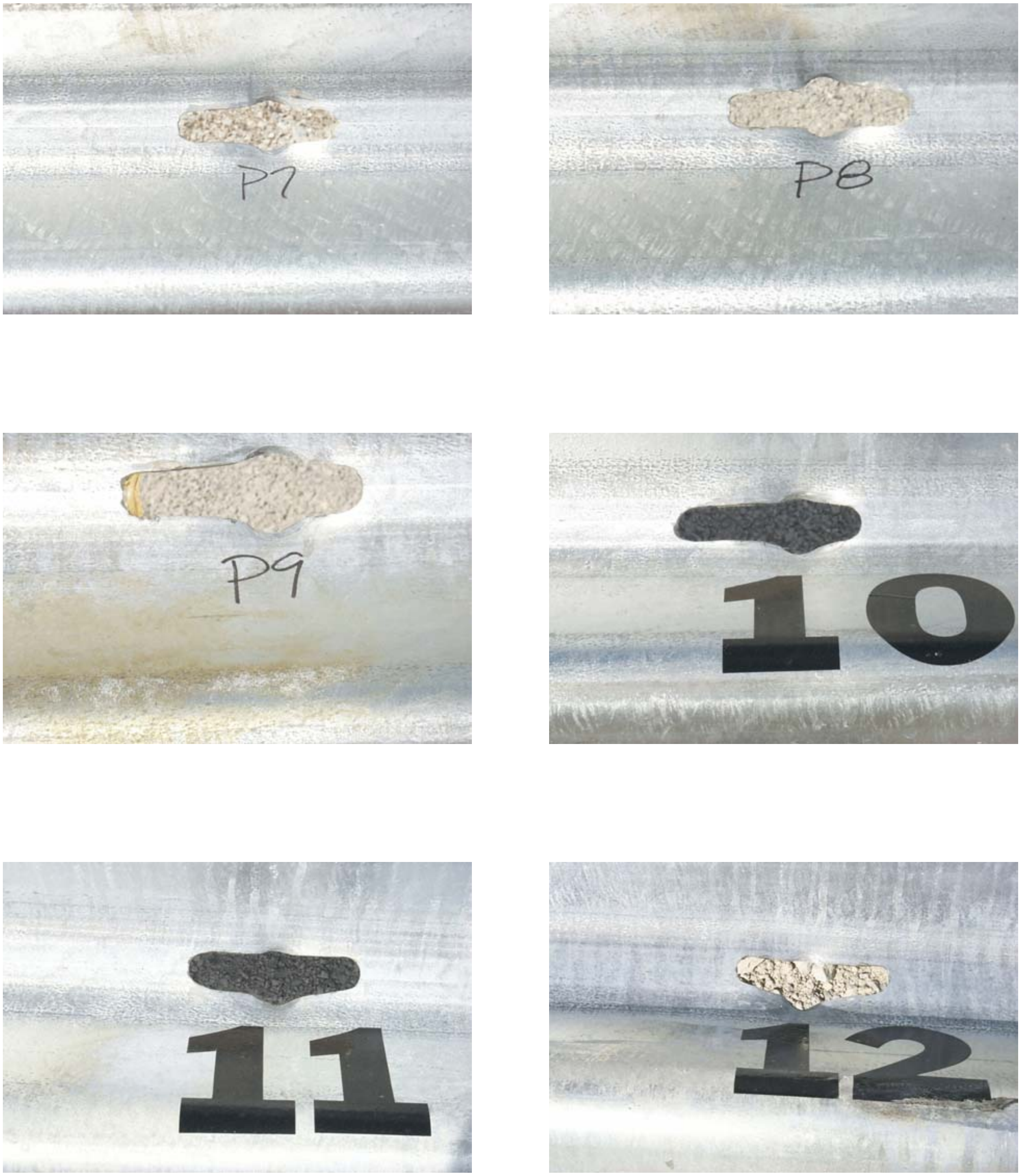


Figure 78. System Damage, Test NPG-3

Figure 79. System Damage, Test NPG-3

Figure 80. System Damage, Test NPG-3

Figure 81. Vehicle Damage, Test NPG-3

12 DISCUSSION AND DESIGN MODIFICATIONS (STANDARD POST SPACING)

12.1 Results of Test Nos. NPG-1 through NPG-3

Crash test nos. NPG-1 through NPG-3 were conducted on the *Midwest Guardrail System* (MGS) prototype that incorporated an increased length of the post bolt slot equal to 102 mm (4 in.). This longer slot length was used in order to reduce the guardrail-post attachment force, thus decreasing the potential for the W-beam rail to be pulled down during post rotation. The first crash test, test no. NPG-1 that was conducted with a small car, resulted in an acceptable performance of the original guardrail design that used an increased slot length. It should be noted that this system's guardrail height was set at its maximum height tolerance. The other two crash tests, test nos. NPG-2 and NPG-3, showed that the rail would release from the posts in an acceptable manner throughout the impact region. However, these tests also showed a propensity for the rail to release prematurely from the post near the upstream end of the barrier installation. As a result of these findings, the post bolt slot length was reduced back to the standard 64-mm (2 ½-in.) length, as shown in Figure 82. In addition, the upstream anchor in test no. NPG-3 pulled completely out of the ground due to the increase load on the anchors. Therefore, the length of the steel foundation tube was increased by 305 mm (12 in.) for a total length of 1,829 mm (6 ft), as shown in Figure 83.

12.2 *Midwest Guardrail System* – Standard Post Spacing Design Details

The test installation consisted of 55.25 m (181 ft-3 in.) of standard 2.66-mm (12-gauge) thick W-beam guardrail supported by steel posts. Anchorage systems similar to those used on tangent guardrail terminals were utilized on both the upstream and downstream ends of the guardrail system. Photographs of the test installation are shown in Figures 84 through 86. The complete set of system drawings along with the corresponding English-unit drawings are shown in Appendix F.

The entire system was constructed with twenty-nine guardrail posts. Post nos. 3 through 27 were galvanized ASTM A36 steel W152x13.4 (W6x9) sections measuring 1,829-mm (6-ft) long. Post nos. 1, 2, 28, and 29 were timber posts measuring 140-mm wide x 190-mm deep x 1,080-mm long (5 ½-in. x 7 ½-in. x 42 ½-in.) and were placed in 1,829-mm (6-ft) long steel foundation tubes, as shown in Figure 83. The timber posts and foundation tubes were part of anchor systems designed to replicate the capacity of a tangent guardrail terminal.

Post nos. 1 through 29 were spaced 1,905 mm (75 in.) on center with a soil embedment depth of 1,019 mm (40 in.). The posts were placed in a compacted course, crushed limestone material that met Grading B of AASHTO M147-65 (1990) as found in NCHRP Report No. 350. For post nos. 3 through 27, 152-mm wide x 305-mm deep x 356-mm long (6-in. x 12-in. x 14-in.) wood spacer blockouts were used to block the rail away from the front face of the steel posts.

Standard 2.66-mm (12-gauge) thick W-beam rails with additional 64-mm (2 ½-in.) long post bolt slots at half post spacing intervals were placed between post nos. 1 and 29, as shown in Figure 82. The nominal top W-beam rail height was 787 mm (31 in.) with a 632-mm (24 ⅞-in.) center mounting height. The rail splices have been moved to the center of the span location, as shown in Figures 82 through 85. All lap-splice connections between the rail sections were configured to reduce vehicle snag at the splice during the crash test.

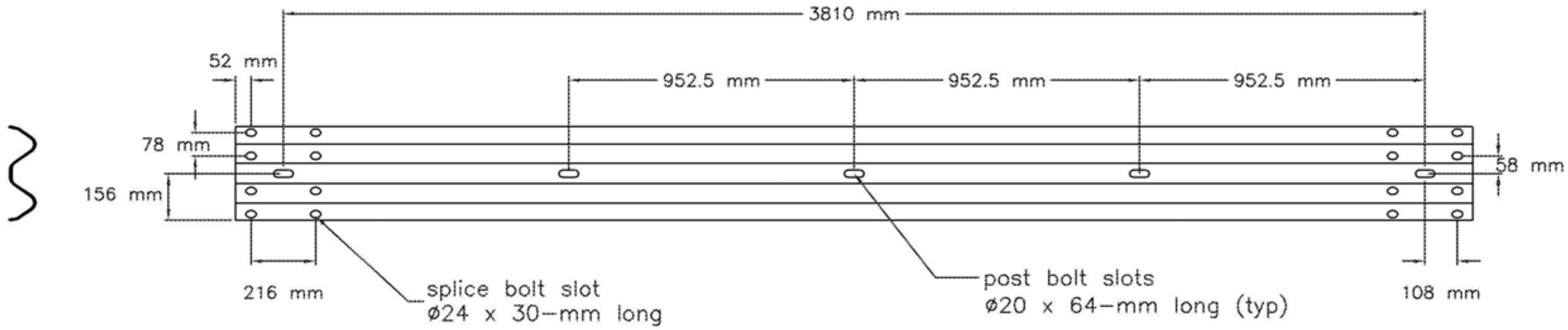


Figure 82. *Midwest Guardrail System* Rail Design Details

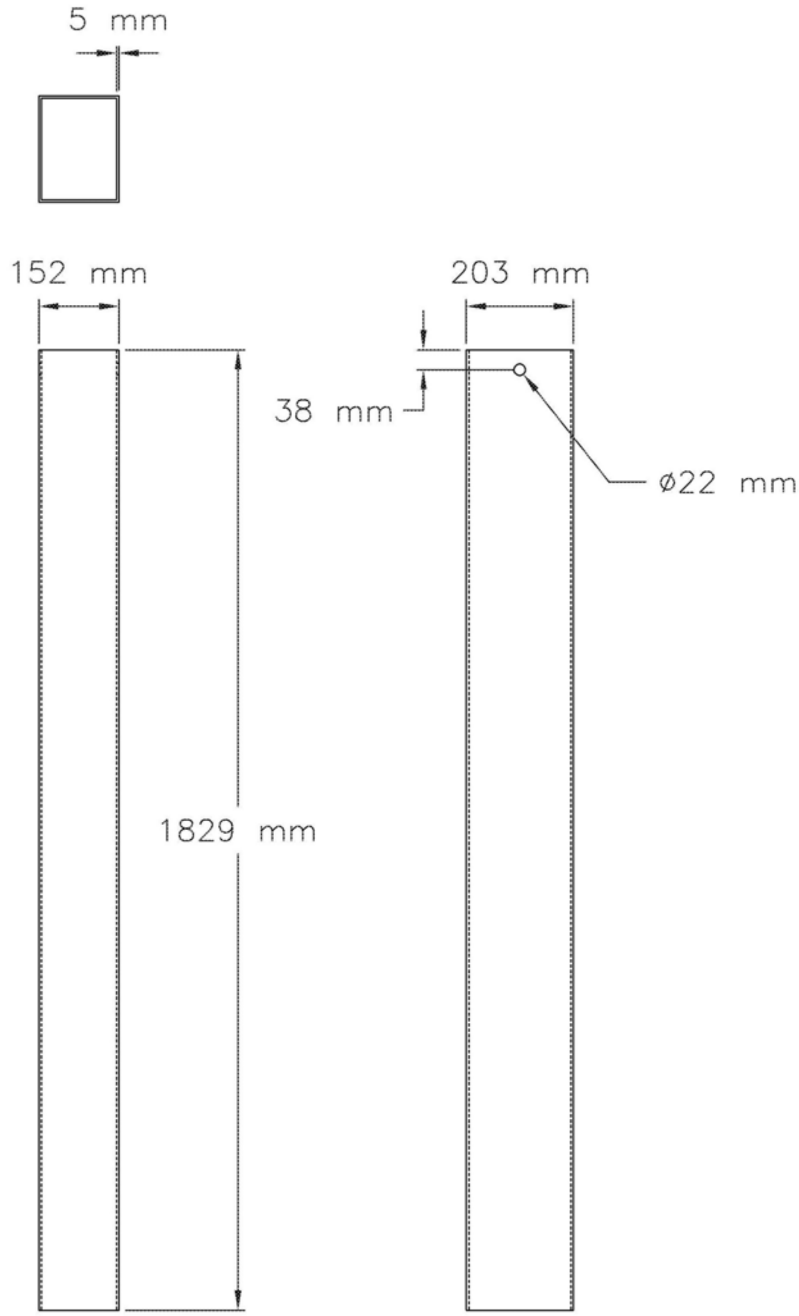


Figure 83. *Midwest Guardrail System* Anchorage – Increased Foundation Tube Length

Figure 84. *Midwest Guardrail System* – Standard Post Spacing

Figure 85. *Midwest Guardrail System* – Standard Post Spacing

Figure 86. *Midwest Guardrail System* – Standard Post Spacing

13 CRASH TEST NO. 4

13.1 Test NPG-4

The *Midwest Guardrail System* (MGS) with standard post spacing was installed with the top guardrail height set at the design's nominal rail height. The 1,986-kg (4,378-lb) pickup truck impacted the *Midwest Guardrail System* (MGS) with standard post spacing at a speed of 98.1 km/h (61.0 mph) and at an angle of 25.6 degrees. A summary of the test results and the sequential photographs are shown in Figure 87. The summary of the test results and sequential photographs in English units are shown in Appendix A. Additional sequential photographs are shown in Figures 88 and 89. Documentary photographs of the crash test are shown in Figures 90 and 91.

13.2 Test Description

Initial impact was to occur between post nos. 11 and 12 or 4,877-mm (192-in.) upstream from the centerline of the splice between post nos.14 and 15, as shown in Figure 92. Actual vehicle impact occurred 4,826-mm (190-in.) upstream from the centerline of the splice between post nos. 14 and 15. At 0.042 sec after initial impact, post no. 11 twisted CW. At this same time, post no. 13 deflected backward while post no. 12 deflected backward and rotated CW. At 0.052 sec, the right-front corner of the vehicle crushed inward. At 0.069 sec, the front of the vehicle was located at post no. 13, which deflected downstream. At this same time, post no. 10 twisted CW. At 0.101 sec, the right-front tire snagged on post no. 13, and post no. 15 rotated backward. At 0.125 sec, the truck began to redirect, and post no. 16 rotated backward. At 0.149 sec, the wooden blockout at post no. 13 disengaged from the system. At 0.157 sec, the front of the vehicle was located at post no. 14. At this same time, post no. 15 rotated counter clockwise (CCW). At 0.190 sec, the right-front tire began to ride up post no. 14, and the wooden blockout disengaged from post no. 14. At 0.232 sec, the front of the vehicle was at post no. 15, and post no. 14 bent and contacted the ground. At 0.252 sec, the right-rear corner of the vehicle contacted the guardrail. At 0.281 sec, the right-rear corner protruded over the guardrail as the rear of the vehicle rose into the air. At 0.323 sec, the front of the vehicle was located at post no. 16. At 0.396 sec, the vehicle became parallel to the guardrail with a resultant velocity of 61.2 km/h (38.0 mph). At 0.446 sec, the front of the vehicle was located at post no. 17 which encountered minimal movement. At this same time, post nos. 10 through 12 began to twist CCW. At 0.521 sec, the right-rear corner of the vehicle lost contact with the rail. At 0.571 sec, the vehicle rolled slightly CCW. At 0.597 sec, the vehicle exited the guardrail at a trajectory angle of 19.3 degrees and at a resultant velocity of 55.1 km/h (34.2 mph). At 0.683 sec, the rear of the vehicle pitched downward. At 0.909 sec, the vehicle encountered moderate pitching. At 1.209 sec, the vehicle encountered a slight rolling motion back and forth. At 1.491 sec, the vehicle yawed back toward the system. At 2.344 sec, the vehicle contacted the system again. At 2.552 sec, the vehicle ceased its forward motion and rebounded off of the system in a CW yawing motion. At 3.029 sec, the vehicle came to rest 23.31-m (76-ft 6-in.) downstream from impact and 0.51-m (1-ft 8-in.) laterally away from the traffic-side face of the rail, as shown in Figures 87 and 93.

13.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 94 through 97. Barrier damage consisted of deformed W-beam and guardrail posts, contact marks on a guardrail section, and disengaged wooden blockouts.

The guardrail damage consisted of moderate deformation and flattening of the impacted section of W-beam rail between post nos. 12 and 17. Contact marks were found on the guardrail between post nos. 11 and 18. The guardrail buckled at post nos. 11 and 12. The W-beam was pulled off of post nos. 13 through 16. The guardrail post bolt slots for post nos. 12, 13, 14, and 16 were deformed, while the post bolt slot for post no. 15 encountered a tear approximately 19-mm (¾-in.) long. No significant guardrail damage occurred upstream of post no. 11 nor downstream of post no. 18, except for slight rail deflection and minor contact marks between post nos. 24 and 25 due to vehicle contact with the system before coming to rest.

Steel post nos. 3 through 11 twisted approximately 5 degrees CCW at the top, while post no. 12 rotated backward slightly. Post no. 13 rotated and bent toward the ground with a 610-mm (24-in.) radius of soil failure. Steel post nos. 14 and 15 bent to a 90 degree angle with a buckle point at groundline and soil failure around the posts. Post nos. 16 and 17 rotated backward with slight twisting and a 305-mm (12-in.) radius of soil failure around post no. 16. The upstream and downstream anchorage systems slightly moved longitudinally, but the posts in both anchorage systems were not damaged.

A 305-mm (12-in.) long tire contact mark was found along the upstream side of the front face of post no. 13. Contact marks were found along the upstream side of both the front and back faces of post nos. 14 and 15 above the groundline. Post nos. 3 through 13 also encountered local deformations at the front face's bolt hole. The post bolt hole was torn through to the upstream edge of post nos. 14 and 15. The wooden blockout at post no. 13 split longitudinally and only a 76-mm wide by 356-mm long (3-in. x 14-in.) piece of the blockout remained attached to the post. The wooden blockouts at post nos. 14 and 15 disengaged from the system. The rest of the blockouts remained undamaged.

The permanent set of the guardrail and posts is shown in Figures 94 and 95. The upstream and downstream cable anchor ends encountered slight permanent set deformations, as shown in

Figure 97. The maximum lateral permanent set barrier deflection was 652 mm (26 in.) at the midspan between post nos. 14 and 15, as determined from high-speed film analysis. The maximum lateral dynamic barrier deflection was 1,094 mm (43 in.) at the midspan between post nos. 14 and 15, as determined from the high-speed film analysis.

13.4 Vehicle Damage

Exterior vehicle damage was minimal, as shown in Figures 98 through 100. Occupant compartment deformation was negligible, as shown in Figure 100. Occupant compartment deformations and the corresponding locations are provided in Appendix D. The minor damage was concentrated on the right-front corner of the vehicle. The right-front quarter panel was crushed inward, and the right side of the front bumper was also bent back toward the engine compartment. The joint between the lower-front portion of the right-side door and the right-front quarter panel was crushed and deformed, but the door could be opened. The right-front wheel assembly was deformed slightly with disengagement of the tie rod which resulted in outward rotation of the right-front tire. The grill was broken and deformed around the right-side headlight assembly, and the right-side headlight was fractured. The windshield encountered minor cracks approximately 203-mm (8-in.) long. The roof, hood, left side, and rear of the vehicle, the rims and tires, and all window glass remained undamaged.

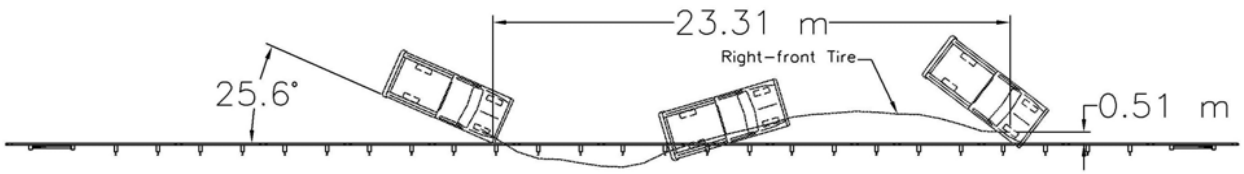
13.5 Occupant Risk Values

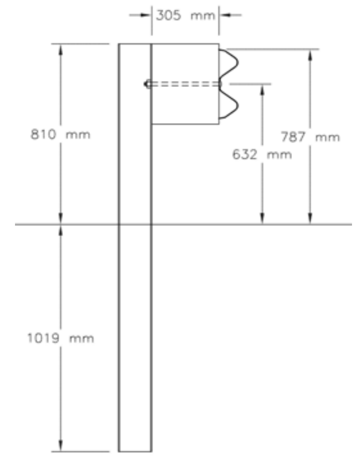
The longitudinal and lateral occupant impact velocities were determined to be 5.58 m/sec (18.32 ft/sec) and 3.89 m/sec (12.78 ft/sec), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 9.50 g's and 6.94 g's, respectively. It is noted that the occupant impact velocities (OIV's) and occupant ridedown decelerations (ORD's) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from the accelerometer data, are summarized in Figure 87. Results are shown graphically in Appendix G. Roll and yaw data were collected from film analysis and are shown graphically in Appendix G.

13.6 Discussion

The analysis of the test results for test NPG-4 showed that the W-beam guardrail with increased rail height adequately contained and redirected the vehicle with controlled lateral displacements of the guardrail. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the W-beam guardrail and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After collision, the vehicle's trajectory revealed minimum intrusion into adjacent traffic lanes. In addition, the vehicle's exit angle of 19.3 degrees was greater than 60 percent of the impact angle of 25.6 degrees. However, it should be noted that this evaluation criterion is only preferred and not required. Therefore, test NPG-4 conducted on the *Midwest Guardrail System* (MGS) at its nominal height was determined to be acceptable according to the TL-3 safety performance criteria found in NCHRP Report No. 350.

0.000 sec 0.101 sec 0.190 sec 0.323 sec 0.446 sec





- Test Number NPG-4
- Date 6/14/02
- Appurtenance . . . . *Midwest Guardrail System*
  - Key Elements . . . . increased mounting height, blockout depth, and foundation tube length, mid-span splices
- Total Length . . . . 55.25 m
- Steel W-beam
  - Thickness . . . . 2.66 mm
  - Top Mounting Height . . . . 787 mm
  - Bolt Slot Length . . . . 64 mm
- Steel Posts
  - Post Nos. 3 - 27 . . . . W152 x 13.4 by 1,829-mm long
  - Spacing . . . . 1,905 mm
- Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) . 140 mm x 190 mm by 1,080-mm long
- Steel Foundation Tube Length . . . . . 1,829 mm
- Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 152 mm x 305 mm by 356-mm long
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1995 GMC 2500 ¾-ton pickup
  - Curb . . . . 1,913 kg
  - Test Inertial . . . . 1,986 kg
  - Gross Static . . . . 1,986 kg
- Vehicle Speed
  - Impact . . . . 98.1 km/h
  - Exit (resultant) . . . . 55.1 km/h
- Vehicle Angle
  - Impact (trajectory) . . . . 25.6 deg
  - Exit (trajectory) . . . . 19.3 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 9.50 g's < 20 g's
  - Lateral (not required) . . . . 6.94 g's
- Occupant Impact Velocity
  - Longitudinal . . . . 5.58 m/s < 12 m/s
  - Lateral (not required) . . . . 3.89 m/s
- Vehicle Damage . . . . Minimal
  - TAD[31] 1-RFQ-4
  - SAE[32] 01RFEW5
- Vehicle Stopping Distance . . . . 23.31 m downstream, 0.51 m traffic-side face
- Barrier Damage . . . . Moderate
- Maximum Deflections
  - Permanent Set . . . . 652 mm
  - Dynamic . . . . 1,094 mm
- Working Width . . . . 1,260 mm

Figure 87. Summary of Test Results and Sequential Photographs, Test NPG-4

0.000 sec

0.000 sec

0.167 sec

0.100 sec

0.334 sec

0.234 sec

0.567 sec

0.367 sec

0.834 sec

0.467 sec

2.236 sec

0.634 sec

Figure 88. Additional Sequential Photographs, Test NPG-4

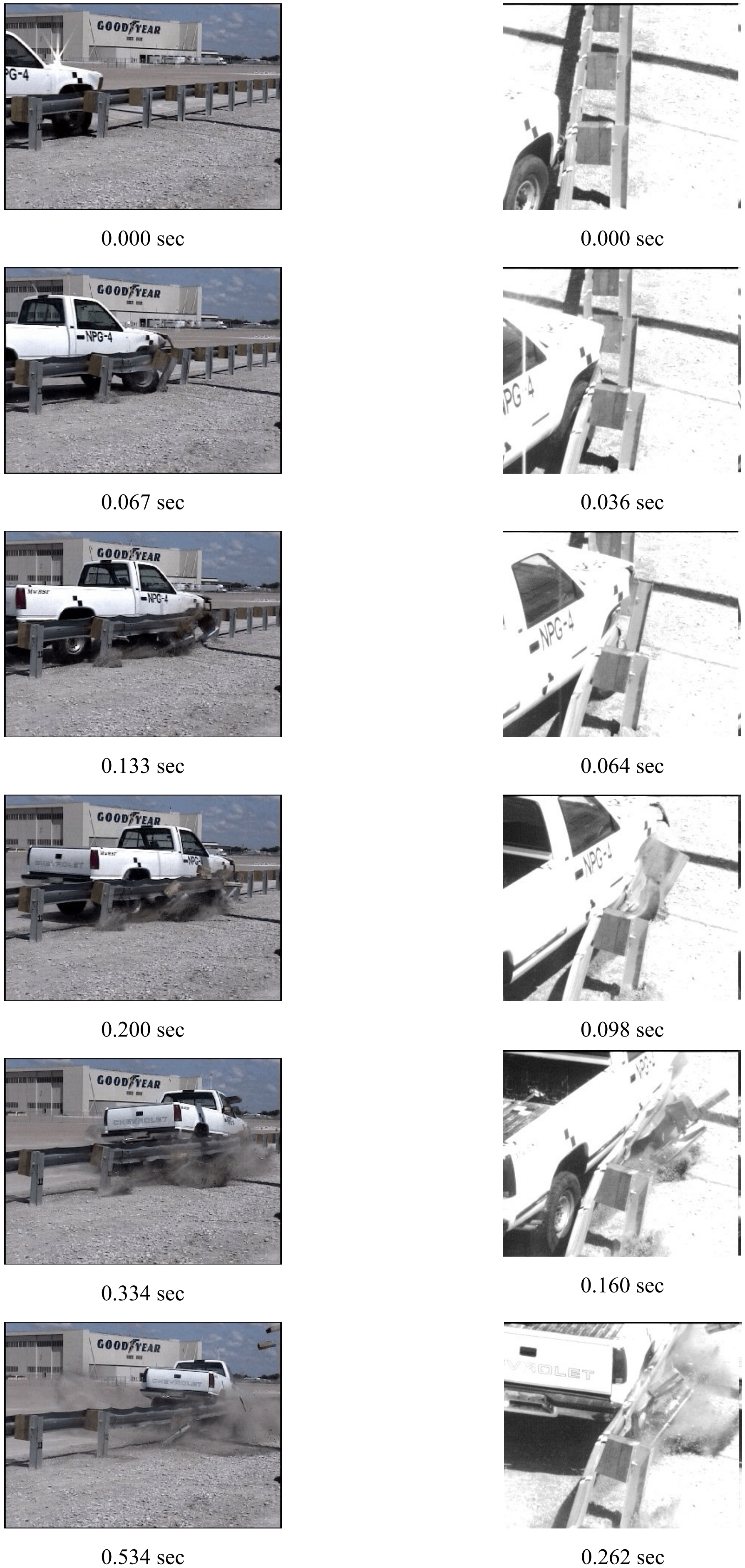


Figure 89. Additional Sequential Photographs, Test NPG-4

Figure 90. Documentary Photographs, Test NPG-4

Figure 91. Documentary Photographs, Test NPG-4

Figure 92. Impact Location, Test NPG-4

Figure 93. Vehicle Final Position and Trajectory Marks, Test NPG-4

Figure 94. System Damage, Test NPG-4

Figure 95. System Damage, Test NPG-4

Figure 96. System Damage, Test NPG-4

Figure 97. System Damage, Test NPG-4

Figure 98. Vehicle Damage, Test NPG-4

Figure 99. Vehicle Damage, Test NPG-4

Figure 100. Occupant Compartment Damage, Test NPG-4

14 STANDARD POST SPACING SYSTEM WITH CURB DESIGN DETAILS

This installation was identical to the standard *Midwest Guardrail System* (MGS) except that the guardrail system was installed over a 152-mm (6-in.) tall, American Association of State Highway and Transportation Officials (AASHTO) Type "B" concrete curb. A 152-mm (6-in.) versus a 102-mm (4-in.) high concrete curb was selected for testing since increased hydraulic drainage is often required at the roadway edge, and the taller curb is believed to provide a "worst case" impact scenario for the guardrail-to-curb barrier combination. Therefore, if the test results are found to be satisfactory, then shorter curb heights would also be acceptable and not require additional testing. The curb located beneath the W-beam guardrail was 19.05-m (62-ft 6-in.) long, spanning between post nos. 10 and 20. The curb was constructed such that the center of the curb's front face was placed 152 mm (6 in.) in front of the front face of the guardrail, as shown in Figure 101. It should be noted that the top mounting height of the guardrail remained at 787 mm (31 in.), which was measured from the gutter line to the top of the W-beam rail. It should be noted that the length of the steel foundation tubes remained at the increased length of 1,829 mm (6 ft) as used in the standard *Midwest Guardrail System* design (test no. NPG-4). Photographs of the test installation are shown in Figures 102 through 104. The complete set of system drawings along with the corresponding English-unit drawings are shown in Appendix H.

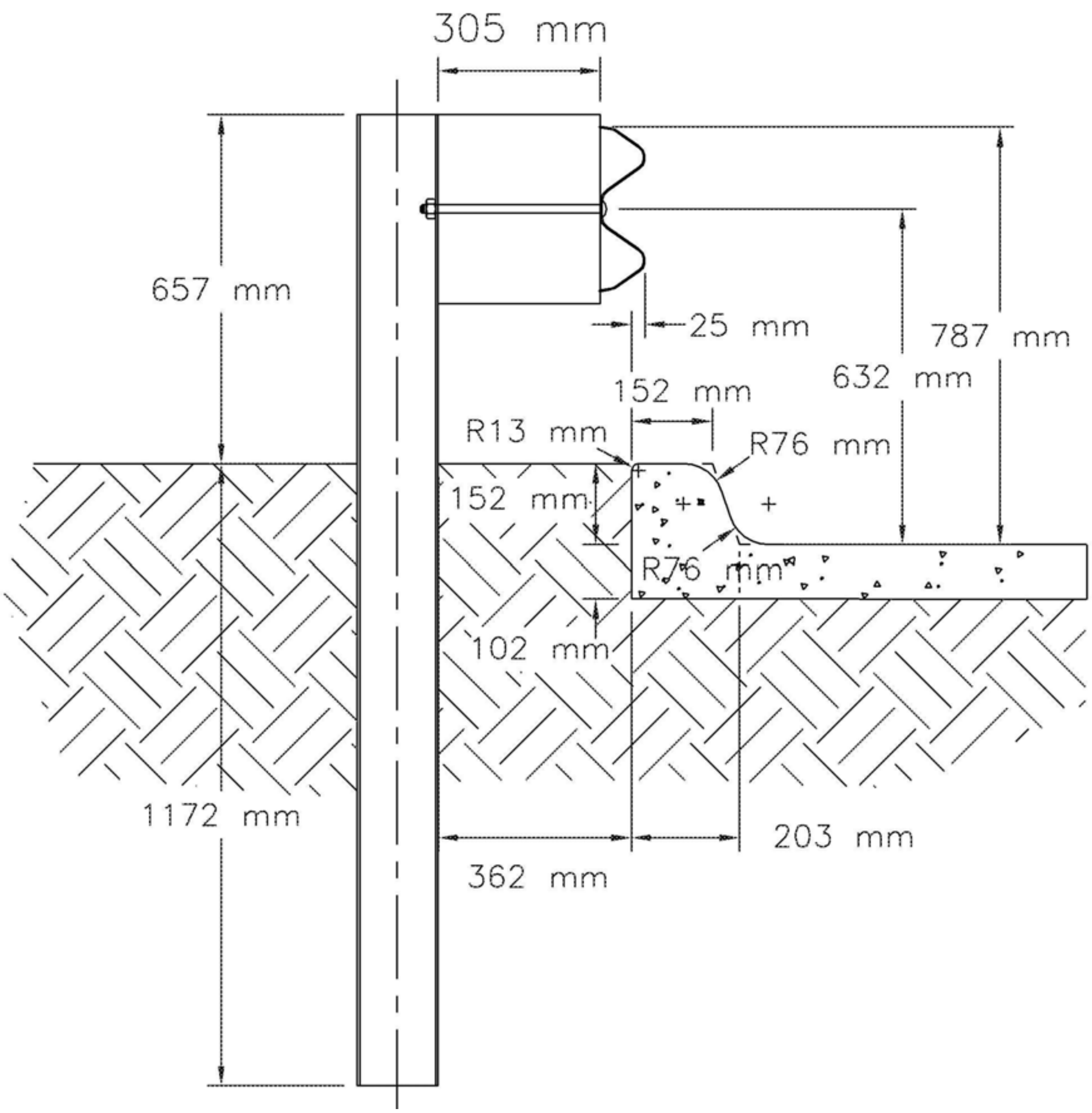


Figure 101. Standard Post Spacing *Midwest Guardrail System* with Curb Test Installation

Figure 102. Standard Post Spacing *Midwest Guardrail System* with Curb

Figure 103. Standard Post Spacing *Midwest Guardrail System* with Curb

Figure 104. Standard Post Spacing *Midwest Guardrail System* with Curb

15 CRASH TEST NO. 5

15.1 Test NPG-5

The test installation consisted of the standard post spacing *Midwest Guardrail System* (MGS) installed over an AASHTO Type "B" concrete curb. The 1,986-kg (4,378-lb) pickup truck impacted the *Midwest Guardrail System* (MGS) installed over a concrete curb at a speed of 96.6 km/h (60.1 mph) and at an angle of 25.8 degrees. A summary of the test results and the sequential photographs are shown in Figure 105. The summary of the test results and sequential photographs in English units are shown in Appendix A. Additional sequential photographs are shown in Figure 106. Documentary photographs of the crash test are shown in Figures 107 and 108.

15.2 Test Description

Initial impact was to occur between post nos. 12 and 13 or 4,597-mm (15-ft 1-in.) upstream from the centerline of the splice between post nos. 14 and 15, as shown in Figure 109. Actual vehicle impact occurred 4,547-mm (14-ft 11-in.) upstream from the centerline of the splice between post nos. 14 and 15. At 0.018 sec after impact, post no. 13 began to deflect. At 0.038 sec, the right-front corner of the vehicle crushed inward as the right-front tire became airborne. At 0.066 sec, the front of the vehicle was located at post no. 13 as post nos. 10 through 12 rotated backward. At 0.080 sec, the wooden blockout at post no. 13 disengaged from the system, and post no. 14 deflected. At this same time, the vehicle began to redirect as the right-front tire contacted the ground, and the hood's left-side opened up. At 0.102 sec, post no. 14 rotated CCW. At 0.130 sec, the wooden blockout at post no. 14 disengaged from the system, post no. 14 continued to deflect, and post no. 15 rotated CCW. At this same time, the vehicle rolled CW away from the rail. At 0.151 sec, the right-front tire rolled up on top of post no. 14 which had previously bent over toward the ground. At 0.179 sec, the right-front wheel snagged on post no. 14, and the right-rear tire became airborne. At 0.205 sec, the wooden blockout at post no. 15 disengaged from the system, and post no. 16 rotated CCW. At this same time, the left-rear tire became slightly airborne. At 0.237 sec, the front of the vehicle contacted post no. 15. At this same time, the rear of the vehicle pitched upward. At 0.317 sec, the wooden blockout at post no. 16 disengaged from the system. At 0.345 sec, the right-front corner of the vehicle was located at post no. 16. At 0.403 sec, the vehicle began to roll CCW toward the guardrail. At 0.518 sec, the vehicle became parallel to the guardrail with a resultant velocity of 52.3 km/h (32.5 mph). At 0.552 sec, the vehicle ceased forward motion, the rear of the vehicle yawed CW away from the guardrail, and the vehicle began to slide toward the left. At 0.718 sec, the vehicle exited the guardrail at a trajectory angle of 6.7 degrees and at a resultant velocity of 48.0 km/h (29.8 mph). At 0.845 sec, the rear end of the vehicle continued to yaw CW away from the guardrail. At 0.956 sec, the right-front corner of the vehicle, which rolled slightly CW, contacted the system again as the rear of the vehicle continued to yaw CW away from the system. At 1.442 sec, the vehicle lost contact with the system again and rolled back to a neutral position. The vehicle came to rest 14.15-m (46-ft 5-in.) downstream from impact and 4.47-m (14-ft 8-in.) laterally away from the traffic-side face of the rail, as shown in Figures 105 and 110.

15.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 111 through 116. Barrier damage consisted of deformed W-beam and guardrail posts, an uprooted post, contact marks on a guardrail section and a curb section, and disengaged wooden blockouts. A 483-mm (19-in.) long black tire mark was found on the front and top faces of the curb beginning 76-mm (3-in.) upstream of post no.

12. The curb's top face also encountered a 1,397-mm (55-in.) long scrape mark beginning 152-mm (6-in.) upstream of post no. 18.

The guardrail damage consisted of moderate deformation and flattening of the impacted section of W-beam rail between post nos. 12 and 19. Contact marks were found on the guardrail between post nos. 11 and 19. The guardrail buckled at 51 mm (2 in.) downstream of post no. 12, at the bolt slot for post no. 18, and at 305 mm (12 in.) downstream of post no. 18. The W-beam was pulled off of post nos. 13 through 17. The guardrail post bolt slots for post nos. 14 and 17 were deformed severely, while the bolt slots for post nos. 13, 15, and 16 encountered tears in addition to the severe deformations. No significant guardrail damage occurred upstream of post no. 12 nor downstream of post no. 19.

Steel post nos. 3 through 10 and 19 through 27 twisted slightly. Post nos. 11 and 12 twisted and rotated backward slightly. Post no. 13 rotated and bent backward with a 254-mm (10-in.) radius of soil failure. Post no. 14 twisted and bent over lying flat on the ground. The front face of post no. 14 was torn and twisted at the top. Post no. 15 was bent downstream toward the ground. Post no. 16 pulled completely out of the ground and encountered a buckle point 813 mm (32 in.) from the bottom of the post. Post no. 17 rotated backward and downstream slightly with major soil disturbance. The webs of post nos. 13, 15, and 17 were also deformed. Post no. 18 also rotated slightly backward. The upstream and downstream anchorage systems slightly moved longitudinally, but the posts in both anchorage systems were not damaged.

A 152-mm (6-in.) long contact mark was found on the front face of post no.13. Light contact marks were found near the top of post no. 15. Contact marks were found along the upstream side of both the front and back faces of post no. 16. Tire contact marks were found near the groundline on the front face of post no. 17. The post bolt hole of post no. 14 was torn through to the downstream side of the front face, and the unused lower post bolt hole on the back face was also torn through. The wooden blockouts at post nos. 12, 13, 15, 17, and 18 were damaged from the W-beam cutting into them. However, the damage to the blockouts at post no. 15 and 17 was more significant due to vehicle and W-beam contact. The wooden blockouts at post nos. 14 and 16 split longitudinally and disengaged from the system.

The permanent set of the barrier system is shown in Figures 111 through 114. The upstream and downstream cable anchor ends encountered slight permanent set deformations, as shown in Figure 116. The maximum lateral permanent set post deflection was 611 mm (24 in.) at the centerline of post no. 13, as determined from high-speed film analysis. The maximum lateral dynamic rail and post deflections were 1,024 mm (40 in.) at the midspan between post nos. 14 and 15 and 611 mm (24 in.) at post no. 13, respectively, as determined from the high-speed film analysis.

15.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 117 through 119. Occupant compartment deformations were negligible, as shown in Figure 119. Occupant compartment deformations and the corresponding locations are provided in Appendix D. Damage was concentrated on the right-front corner of the vehicle. The right-front quarter panel was crushed inward and downward. The right side of the front bumper was bent back toward the engine compartment. The joint between the lower-front portion of the right-side door and the right-front quarter panel was crushed and deformed. Light contact marks from vehicle-rail interlock were observed along the entire right side of the vehicle. The right side of the grill was fractured and deformed. The right-side headlight was fractured. The right-side wheel assembly's upper A-frame crushed both inward and downward and encountered heavy contact marks. The outer right-front tie rod disengaged. A 51-mm (2-in.) dent was found on the right-front steel rim. The side wall of the right-front tire was torn, and the tire deflated. The roof, the hood, the left side and the rear of the vehicle, and all the window glass remained undamaged.

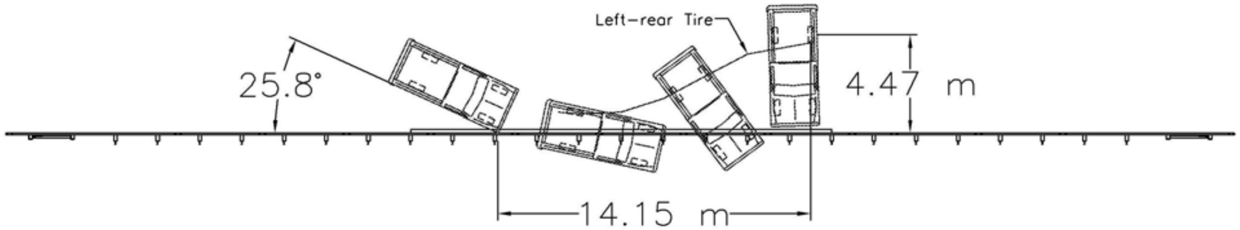
15.5 Occupant Risk Values

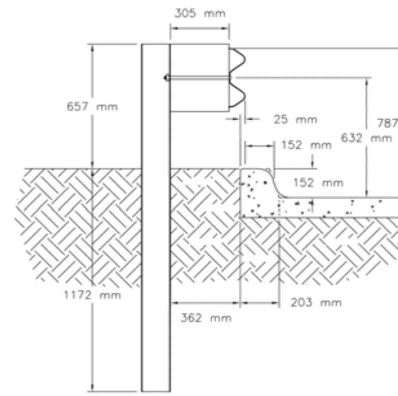
The longitudinal and lateral occupant impact velocities were determined to be 5.23 m/sec (17.16 ft/sec) and 3.93 m/sec (12.91 ft/sec), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 10.50 g's and 8.66 g's, respectively. It is noted that the occupant impact velocities (OIV's) and occupant ridedown decelerations (ORD's) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from the accelerometer data, are summarized in Figure 105. Results are shown graphically in Appendix I. Roll and yaw data were collected from film analysis and are shown graphically in Appendix I.

15.6 Discussion

The analysis of the test results for test NPG-5 showed that the W-beam guardrail with increased rail height installed over a concrete curb adequately contained and redirected the vehicle with controlled lateral displacements of the guardrail. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the guardrail and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After collision, the vehicle's trajectory revealed minimum intrusion into adjacent traffic lanes. In addition, the vehicle's exit angle was less than 60 percent of the impact angle. Therefore, test NPG-5 conducted on the *Midwest Guardrail System* (MGS) installed over a concrete curb was determined to be acceptable according to the TL-3 safety performance criteria found in NCHRP Report No. 350.

0.000 sec 0.080 sec 0.151 sec 0.237 sec 0.504 sec





- Test Number NPG-5
- Date 9/4/02
- Appurtenance . . . . *Midwest Guardrail System* with Curb
  - Key Elements . . . . increased mounting height, blockout depth, and foundation tube length, mid-span splices, and curb
- Total Length . . . . 55.25 m
- Steel W-beam
  - Thickness . . . . 2.66 mm
  - Top Mounting Height . . . . 787 mm
  - Bolt Slot Length . . . . 64 mm
- Steel Posts
  - Post Nos. 3 - 27 . . . . W152 x 13.4 by 1,829-mm long
  - Spacing . . . . 1,905 mm
- Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) . . 140 mm x 190 mm by 1,080-mm long
- Steel Foundation Tube Length . . . . . 1,829 mm
- Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 152 mm x 305 mm by 356-mm long
- Curb . . . . 152-mm tall Type B mounted 152 mm . . in front of guardrail face
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1997 Chevrolet C2500 ¾-ton pickup
  - Curb . . . . 1,813 kg
  - Test Inertial . . . . 1,991 kg
  - Gross Static . . . . 1,991 kg
- Vehicle Speed
  - Impact . . . . 96.6 km/h
  - Exit (resultant) . . . . 48.0 km/h
- Vehicle Angle
  - Impact (trajectory) . . . . 25.8 deg
  - Exit (trajectory) . . . . 6.7 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 10.50 g's < 20 g's
  - Lateral (not required) . . . . 8.66 g's
- Occupant Impact Velocity
  - Longitudinal . . . . 5.23 m/s < 12 m/s
  - Lateral (not required) . . . . 3.93 m/s
- Vehicle Damage . . . . Moderate
  - TAD[31] 1-RFQ-4
  - SAE[32] 01RFEW5
- Vehicle Stopping Distance . . . . 14.15 m downstream 4.47 m traffic-side face
- Barrier Damage . . . . Moderate
- Maximum Deflections
  - Permanent Set . . . . 611 mm
  - Dynamic . . . . 1,024 mm
- Working Width . . . . 1,453 mm

Figure 105. Summary of Test Results and Sequential Photographs, Test NPG-5

0.000 sec

0.000 sec

0.000 sec

0.100 sec

0.067 sec

0.267 sec

0.234 sec

0.133 sec

0.434 sec

0.334 sec

0.234 sec

0.667 sec

0.467 sec

0.367 sec

1.134 sec

0.667 sec

0.601 sec

2.135 sec

Figure 106. Additional Sequential Photographs, Test NPG-5

Figure 107. Documentary Photographs, Test NPG-5

Figure 108. Documentary Photographs, Test NPG-5

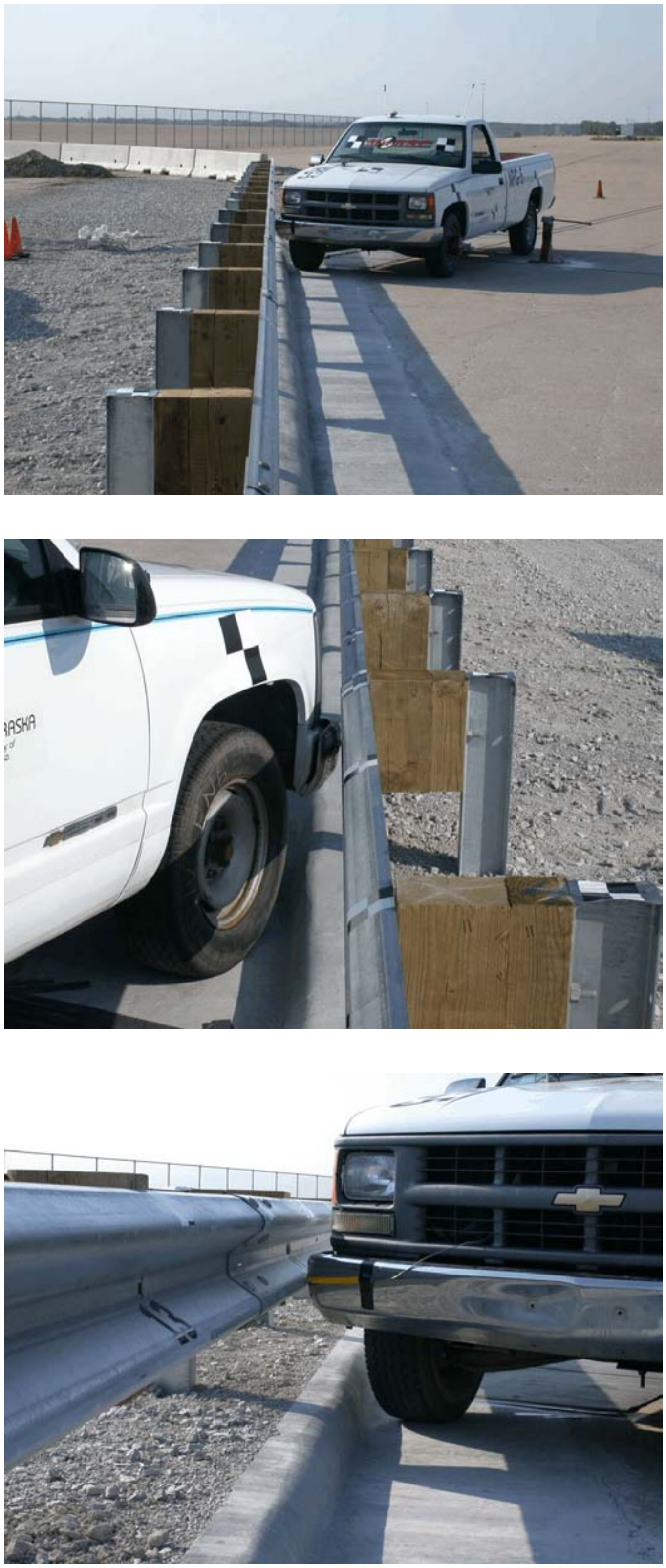


Figure 109. Impact Location, Test NPG-5

Figure 110. Vehicle Final Position and Trajectory Marks, Test NPG-5

Figure 111. System Damage, Test NPG-5

Figure 112. System Damage, Test NPG-5

Figure 113. System Damage, Test NPG-5

Figure 114. System Damage, Test NPG-5

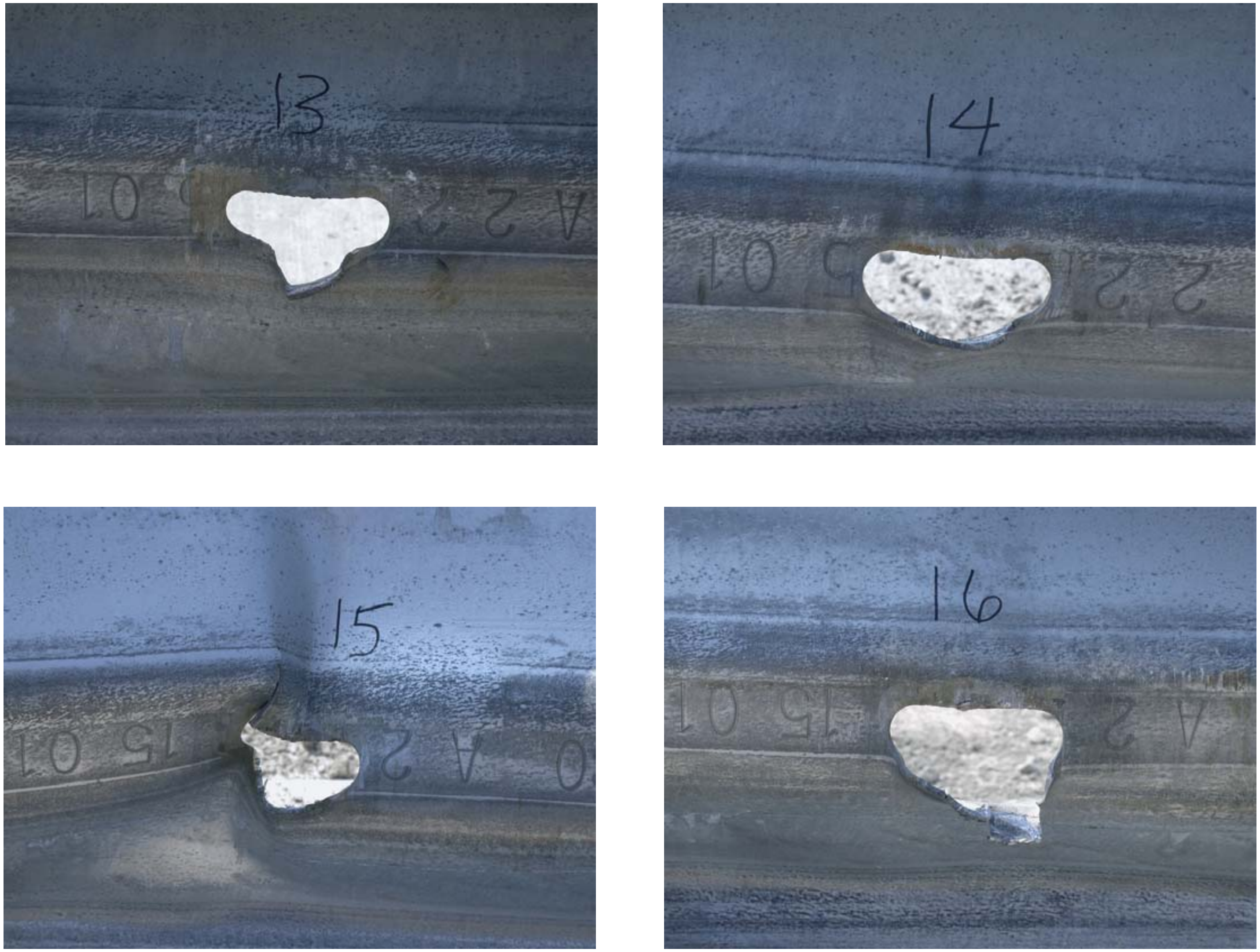


Figure 115. System Damage, Test NPG-5

Figure 116. System Damage, Test NPG-5

Figure 117. Vehicle Damage, Test NPG-5

Figure 118. Vehicle Damage, Test NPG-5

Figure 119. Occupant Compartment Damage, Test NPG-5

16 REDUCED POST SPACING *MIDWEST GUARDRAIL SYSTEM* DESIGN

The reduced post spacing test installation was identical to the standard *Midwest Guardrail System* (MGS) except that the original guardrail system was stiffened through the use of a reduced post spacing. Post nos. 9 through 11 and 51 through 53 were spaced 952.5 mm (37 ½ in.) on center while post nos. 11 through 51 were spaced 476.25 mm (18 ¾ in.) on center. The standard 2.66-mm (12-gauge) thick W-beam rails located between post nos. 9 and 53 were modified to include additional post bolt slots at the half-post and quarter-post spacing intervals, as shown in Figure 120. It should be noted that the length of the steel foundation tubes remained at the increased length of 1,829 mm (6 ft) as used in the standard *Midwest Guardrail System* design (test no. 4). Photographs of the test installation are shown in Figures 121 through 123. The complete set of system drawings along with the corresponding English-unit drawings are shown in Appendix J.

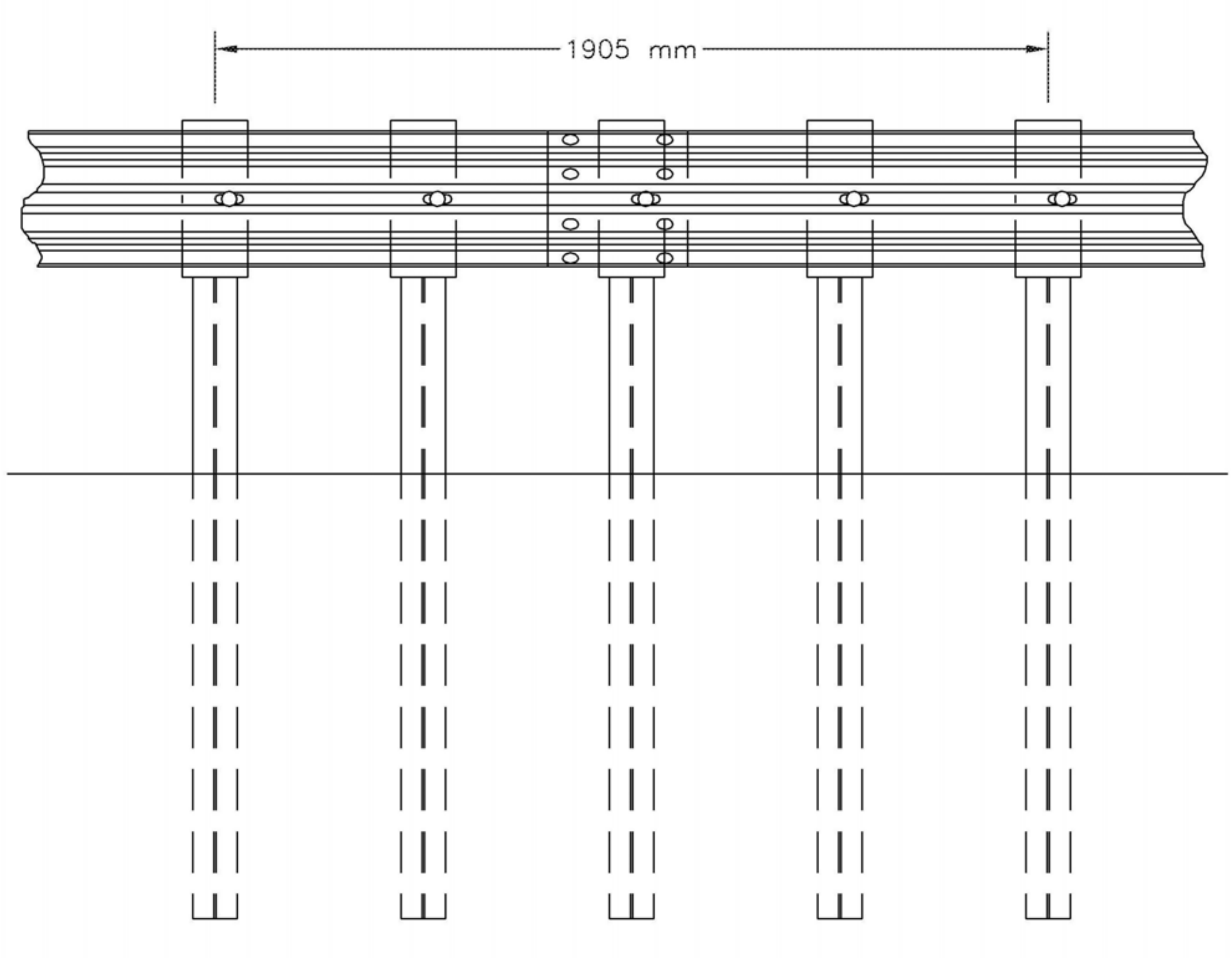


Figure 120. Reduced Post Spacing Midwest Guardrail System Test Installation

Figure 121. Reduced Post Spacing *Midwest Guardrail System*

Figure 122. Reduced Post Spacing *Midwest Guardrail System*

Figure 123. Reduced Post Spacing *Midwest Guardrail System*

17 CRASH TEST NO. 6

17.1 Test NPG-6

The test installation consisted of the *Midwest Guardrail System* (MGS) stiffened with reduced post spacings. The 1,986-kg (4,378-lb) pickup truck impacted the *Midwest Guardrail System* (MGS) with reduced post spacing at a speed of 96.8 km/h (60.2 mph) and at an angle of 25.6 degrees. A summary of the test results and the sequential photographs are shown in Figure 124. The summary of the test results and sequential photographs in English units are shown in Appendix A. Additional sequential photographs are shown in Figures 125 and 126. Documentary photographs of the crash test are shown in Figures 127 and 128.

17.2 Test Description

Initial impact was to occur between post nos. 22 and 23 or 2,920-mm (9-ft 7-in.) upstream from the centerline of post no.29, as shown in Figure 129. Actual vehicle impact occurred 2,946-mm (9-ft 8-in.) upstream from the centerline of post no. 29 or 89-mm (3.5-in.) upstream from the center of post no. 23. At 0.020 sec after initial impact, the front of the vehicle was located at post no. 24. By this same time, post nos. 22 through 25 deflected. At 0.038 sec, the front of the vehicle was located at post no. 25. At this same time, the left side of the hood popped open as the right side was crushed inward. At 0.057 sec, the front of the vehicle was located at post no. 26, and post nos. 12 through 21 rotated CW. At this same time, the top of the right-side door jarred open. At 0.077 sec, the vehicle was located at post no. 27 and began to redirect. At this same time, post no. 26 deflected downstream. At 0.101 sec, the front of the vehicle was located at post no. 28 with the left-front tire rotated inward to approximately perpendicular to the rail. At this same time, post no. 31 began to deflect. At 0.123 sec, the front of the vehicle was located at post no. 29, and post nos. 32 and 33 deflected. At 0.144 sec, the front of the vehicle was located at post no. 30. At 0.164 sec, the front of the vehicle was located at post no. 31 as the rear of the vehicle pitched upward. At this same time, post nos. 27 and 28 rebounded back toward the traffic side. At 0.192 sec, the front of the vehicle was located at post no. 32, and post nos. 29 and 30 rebounded back toward the traffic side. At 0.212 sec, the front of the vehicle was located at post no. 33. At 0.235 sec, the front of the vehicle was located at post no. 34. At 0.246 sec, the left-front tire became airborne as post nos. 31 rebounded back toward the traffic side. At 0.258 sec, post nos. 32 and 33 rebounded back toward the traffic side. At 0.285 sec, the right-front corner lost contact with the rail. At 0.297 sec, the vehicle became parallel to the guardrail with a resultant velocity of 59.5 km/h (37.0 mph). At 0.342 sec, the right-rear corner of the vehicle protruded over the top of the rail. At 0.491 sec, the vehicle exited the guardrail at a trajectory angle of 12.9 degrees and at a resultant velocity of 59.5 km/h (37.0 mph). At 0.508 sec, the rear of the vehicle began to descend back toward the ground. At 0.814 sec, the vehicle yawed back toward the rail. At 2.498 sec, the right-front corner of the vehicle contacted the system again. At 2.623 sec, the right-front tire protruded under the rail as the vehicle redirected again. At 3.556 sec, the vehicle traveled down the rail with the right-front corner of the vehicle still in contact with the system. The vehicle came to rest 28.30-m (92-ft 10-in.) downstream from impact and 0.61-m (2-ft) laterally away from the traffic-side face of the barrier, as shown in Figures 124 and 130.

17.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 131 through 133. Barrier damage consisted of deformed W-beam and guardrail posts, contact marks on a guardrail section, and disengaged wooden blockouts. The guardrail damage consisted of moderate deformation, flattening, and buckling of the impacted section of W-beam rail between post nos. 23 and 34. Contact marks were found on the guardrail between post nos. 22 and 34. The W-beam was pulled off of post no. 27. No significant guardrail damage occurred upstream of post no. 20 nor downstream of post no. 35, except for slight post movement of steel post no. 59 as well as to anchor post nos. 60 and 61 due to vehicle contact with the system before coming to rest.

Steel post nos. 21 through 34 rotated backward. Tire contact marks, 165-mm (6.5-in.) and 216-mm (8.5-in.) long, were found on the front faces of post nos. 25 and 26, respectively. Light contact marks were also found along the upstream side of the front face of post no. 27. The front face of the wooden blockout at post no. 25 was damaged above the rail line. The upstream edge of the wooden blockout at post no. 26 encountered major contact damage and subsequently split longitudinally. The corner between the upstream and front faces of the wooden blockout at post nos. 27, 28, and 31 encountered contact damage, but the damage on the blockout at post no. 31 was more extensive. The corner of the wooden blockout at post no. 32 was removed between the upstream and front faces.

The permanent set of the barrier system is shown in Figures 131 and 132. The maximum lateral permanent set rail and post deflections were 305 mm (12 in.) at the centerline of post no. 28 and 286 mm (11¼ in.) at post no. 27, respectively, as measured in the field. The maximum lateral dynamic rail and post deflections were 447 mm (17½ in.) at the centerline of post no. 27 and 424 mm (16 ⅝ in.) at post no. 28, respectively, as determined from the high-speed film analysis.

17.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 134 through 137. Damage was concentrated on the right-front corner of the vehicle and below the hood line. The right-front quarter panel and wheel well were crushed inward. The right side of the front bumper and bumper supports were flattened and deformed and bent back toward the engine compartment. The front bumper also buckled at its centerline. The joint between the lower-front portion of the right-side door and the right-front quarter panel was crushed and deformed. The right side of the radiator was crushed inward. The right side of the plastic grill was fractured around the headlight region. Heavy wheel assembly damage occurred to the right-front tire, including disengagement of the outer tie rod, heavy rim damage and deformation into the lower frame rail, and tire removal from the rim. The left-front quarter panel also sustained a small buckle point near the front of the left-side door. The lower-right side of the truck's box was crushed inward. The right-rear steel rim also was deformed, and the tire's side wall was scuffed. The windshield encountered minor cracks. The roof, the hood, and the rear and side window glass remained undamaged.

Minor occupant compartment deformations occurred with slight deformations to the right-side floorboard, as shown in Figure 137. Occupant compartment deformations and the corresponding locations are provided in Appendix D. A maximum vertical deflection of 44 mm (1.75 in.) was found near the firewall at the center of the right side. Maximum longitudinal and lateral deflections of the floor pan were measured as 44 mm (1.75 in.) and 13 mm (0.5 in.), respectively. Maximum dash deflection was found to be approximately 64 mm (2.5 in.).

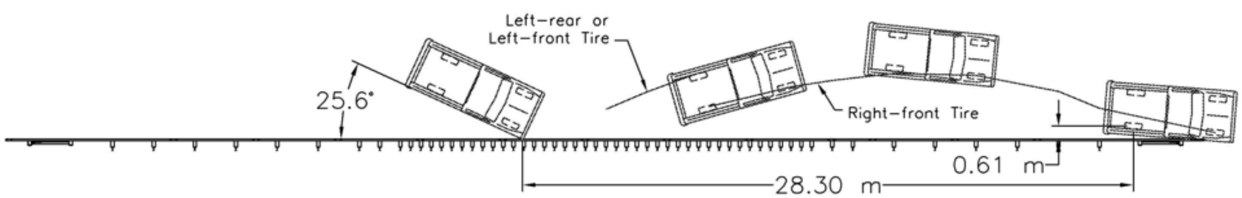
17.5 Occupant Risk Values

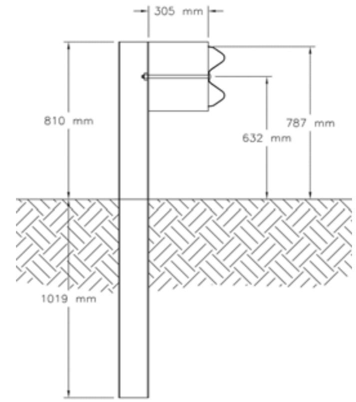
The longitudinal and lateral occupant impact velocities were determined to be 7.62 m/sec (25.00 ft/sec) and 5.61 m/sec (18.42 ft/sec), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 10.67 g's and 8.97 g's, respectively. It is noted that the occupant impact velocities (OIV's) and occupant ridedown decelerations (ORD's) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from the accelerometer data, are summarized in Figure 124. Results are shown graphically in Appendix K. Roll and yaw data were collected from film analysis and are shown graphically in Appendix K.

17.6 Discussion

The analysis of the test results for test NPG-6 showed that the stiffened W-beam guardrail with increased rail height and reduced post spacing adequately contained and redirected the vehicle with controlled lateral displacements of the guardrail. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the guardrail and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After collision, the vehicle’s trajectory revealed minimum intrusion into adjacent traffic lanes. In addition, the vehicle’s exit angle was less than 60 percent of the impact angle. Therefore, test NPG-6 conducted on the stiffened *Midwest Guardrail System* (MGS) was determined to be acceptable according to the TL-3 safety performance criteria found in NCHRP Report No. 350.

0.000 sec | 0.077 sec | 0.164 sec | 0.295 sec | 0.625 sec





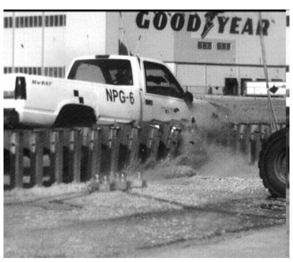
- Test Number NPG-6
- Date 10/18/02
- Appurtenance . . . . *Midwest Guardrail System* with reduced post spacing
  - Key Elements . . . . reduced post spacing, increased mounting height, blockout depth, and foundation tube length
- Total Length . . . . 55.25 m
- Steel W-beam
  - Thickness . . . . 2.66 mm
  - Top Mounting Height . . . . 787 mm
  - Bolt Slot Length . . . . 64 mm
- Steel Posts
  - Post Nos. 3 - 59 . . . . W152 x 13.4 by 1,829-mm long
- Steel Post Spacing
  - Post Nos. 3 - 8, 54 - 59 . . . . 1,905 mm
  - Post Nos. 9 - 10, 52 - 53 . . . . . . 953 mm
  - Post Nos. 11 - 51 . . . . 476 mm
- Wood Posts
  - Post Nos. 1 -2, 60 - 61 (BCT) . . 140 mm x 190 mm by 1,080-mm long
- Steel Foundation Tube Length . . . . . 1,829 mm
- Wood Spacer Blocks
  - Post Nos. 3 - 59 . . . . 152 mm x 305 mm by 356-mm long
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1997 GMC C2500 ¾-ton pickup
  - Curb . . . . 1,971 kg
  - Test Inertial . . . . 2,001 kg
  - Gross Static . . . . 2,001 kg
- Vehicle Speed
  - Impact . . . . 96.8 km/h
  - Exit (resultant) . . . . 59.5 km/h
- Vehicle Angle
  - Impact (trajectory) . . . . 25.6 deg
  - Exit (trajectory) . . . . 12.9 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 10.67 g's < 20 g's
  - Lateral (not required) . . . . 8.97 g's
- Occupant Impact Velocity
  - Longitudinal . . . . 7.62 m/s < 12 m/s
  - Lateral (not required) . . . . 5.61 m/s
- Vehicle Damage . . . . Moderate
  - TAD[31] 1-RFQ-5
  - SAE[32] 01RYEW7
- Vehicle Stopping Distance . . . . 30.86 m downstream 0.61 m laterally
- Barrier Damage . . . . Moderate
- Maximum Deflections
  - Permanent Set . . . . 305 mm
  - Dynamic . . . . 447 mm
- Working Width . . . . 931 mm

Figure 124. Summary of Test Results and Sequential Photographs, Test NPG-6

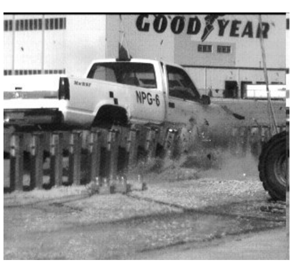
0.000 sec

0.076 sec

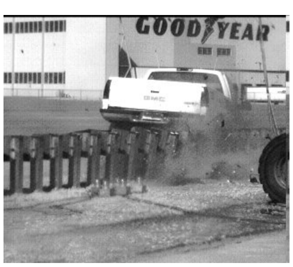
0.110 sec



0.198 sec



0.248 sec



0.460 sec

0.000 sec

0.100 sec

0.200 sec

0.367 sec

0.567 sec

Figure 125. Additional Sequential Photographs, Test NPG-6

0.000 sec

0.000 sec

0.056 sec

0.133 sec

0.114 sec

0.267 sec

0.426 sec

0.400 sec

Figure 126. Additional Sequential Photographs, Test NPG-6

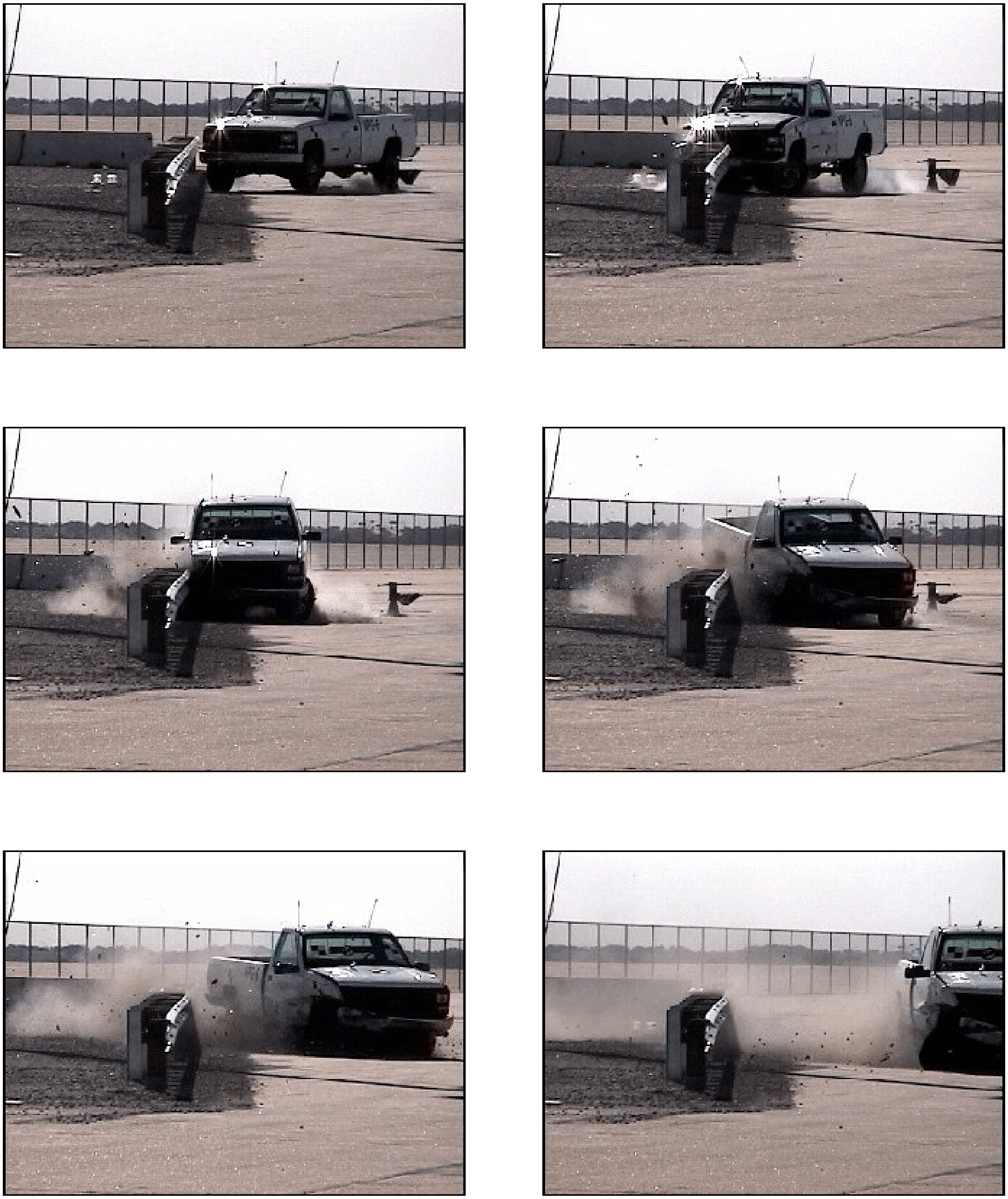


Figure 127. Documentary Photographs, Test NPG-6

Figure 128. Documentary Photographs, Test NPG-6

Figure 129. Impact Location, Test NPG-6

Figure 130. Vehicle Final Position and Trajectory Marks, Test NPG-6

Figure 131. System Damage, Test NPG-6

Figure 132. System Damage, Test NPG-6

Figure 133. System Damage, Test NPG-6

Figure 134. Vehicle Damage, Test NPG-6

Figure 135. Vehicle Damage, Test NPG-6

Figure 136. Vehicle Damage, Test NPG-6

Figure 137. Occupant Compartment Damage, Test NPG-6

18 COMPUTER SIMULATION MODELING

Non-linear, 2-dimensional (2-D) computer simulation modeling with BARRIER VII (33) was used to analyze and predict the dynamic performance of the *Midwest Guardrail System* (MGS). This impact analysis included a calibration and validation of the pickup truck crash tests performed on both the standard-post (test no. NPG-4) and quarter-post (test no. NPG-6) spacing designs. For the validation effort, several simulations were performed at the impact conditions of the two crash tests in order to calibrate selected BARRIER VII input parameters. For the posts, initial parameters were obtained from the dynamic post testing. Other parameters worth noting include: post failure displacement based on guardrail release, vehicle-to-barrier dynamic coefficient of friction, and yaw mass moment of inertia for the pickup truck, as provided in Table 3. The data acquired from the overhead high-speed film, onboard vehicle accelerometers, and speed traps were used to calibrate vehicle simulations to the two physical tests.

Table 3. Initial BARRIER VII Simulation Parameters

BARRIER VII Parameters		**Initial Input Values**
K_B - Post Stiffness Along B (strong axis)	kN/mm (kip/in.)	1.021 (5.83)
K_A - Post Stiffness Along A (weak axis)	kN/mm (kip/in.)	0.701 (4.00)
M_A - Moment About A (weak axis)	kN*mm (kip*in.)	18549 (164.17)
M_B - Moment About B (strong axis)	kN*mm (kip*in.)	10494 (92.88)
δ_F - Failure Displacement Along B	mm (in.)	381 (15)
μ_k - Kinetic Friction Coefficient	Vehicle to Barrier	0.350
Im_Z - 2000P Mass Moment of Inertia - Yaw	$N*m*s^2$ ($lb*ft*s^2$)	4971 (44000)

The calibration effort began with the development of a finite element model for the standard-post spacing design (MGS Standard Post Spacing Design). Using a parametric technique, initial simulations showed a need to tune input parameters for posts located both in the impact region as well as at the ends. It was also necessary to adjust the vehicle-to-rail friction coefficient and the vehicle's yaw mass moment of inertia in order to more accurately predict vehicle behavior at the parallel and exit conditions. The final validated BARRIER VII input parameters for test no. NPG-4 are provided in Table 4. A graphical comparison of the simulated and actual barrier displacements for test no. NPG-4 is provided in Figure 138 through 140. The BARRIER VII input deck can be seen in Appendix L.

Table 4. Final Validated BARRIER VII Input Parameters for NPG-4 Simulation

BARRIER VII Parameters		**NPG-4 Final Validation Run Input Values**
K_B - Post Stiffness Along B (strong axis)	kN/mm (kip/in.)	1.056 (6.03)
K_A - Post Stiffness Along A (weak axis)	kN/mm (kip/in.)	0.701 (4.00)
M_A - Moment About A (weak axis)	kN*mm (kip*in.)	16230 (143.65)
M_B - Moment About B (strong axis)	kN*mm (kip*in.)	10494 (92.88)
δ_F - Failure Displacement Along B	mm (in.)	381 (15)
μ_k - Kinetic Friction Coefficient	Vehicle to Barrier	0.350
Im_Z - 2000P Mass Moment of Inertia - Yaw	$N*m*s^2$ ($lb*ft*s^2$)	5356 (47400)

BARRIER VII had some difficulty fully reproducing the guardrail shape near the upstream end of the deformed region, as shown in Figures 138 through 140. However, it should be noted that during the actual test, the vehicle's rear end pitched upward and protruded over the rail during

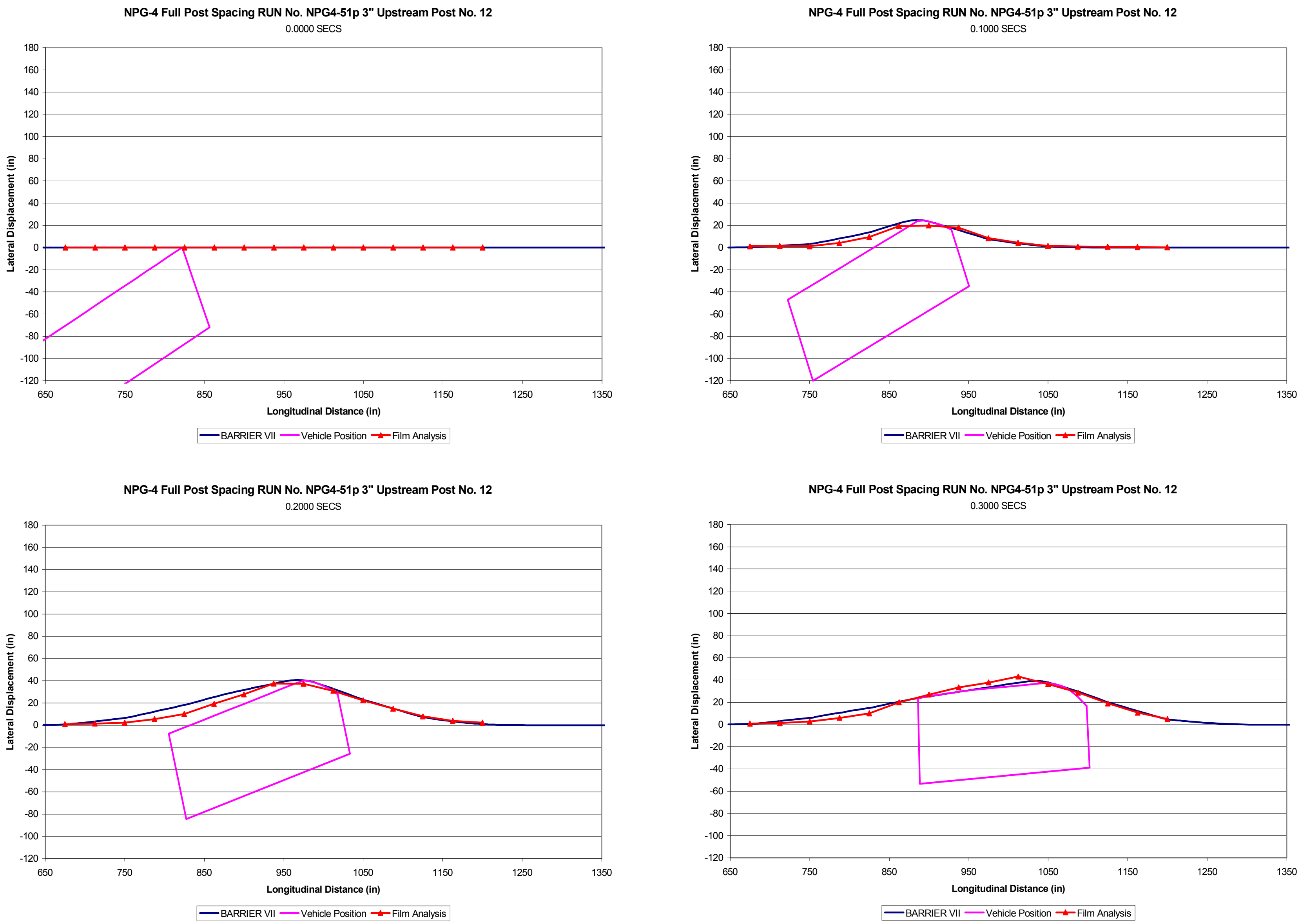


Figure 138. Sequential Figures from BARRIER VII Simulation of NPG-4

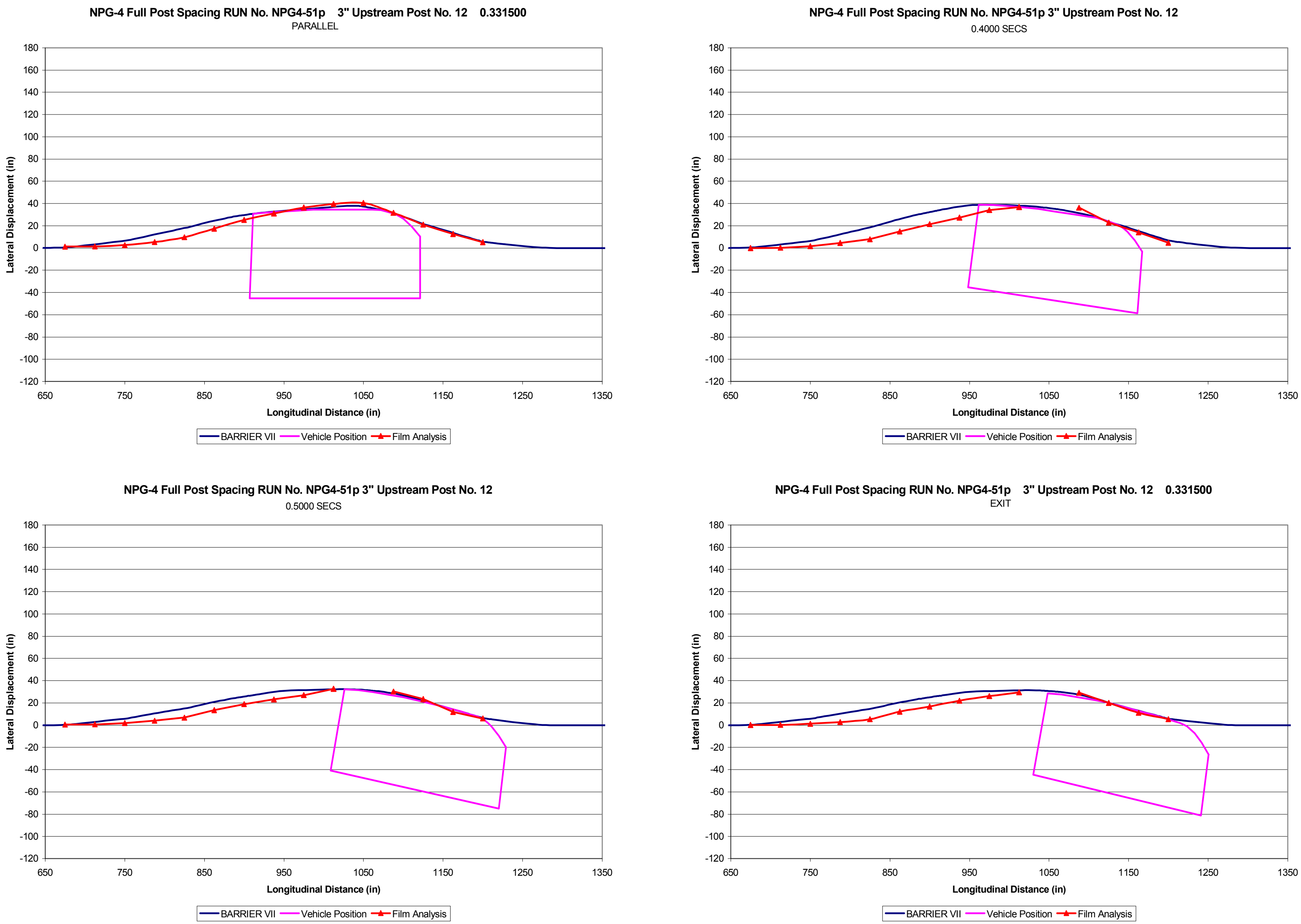
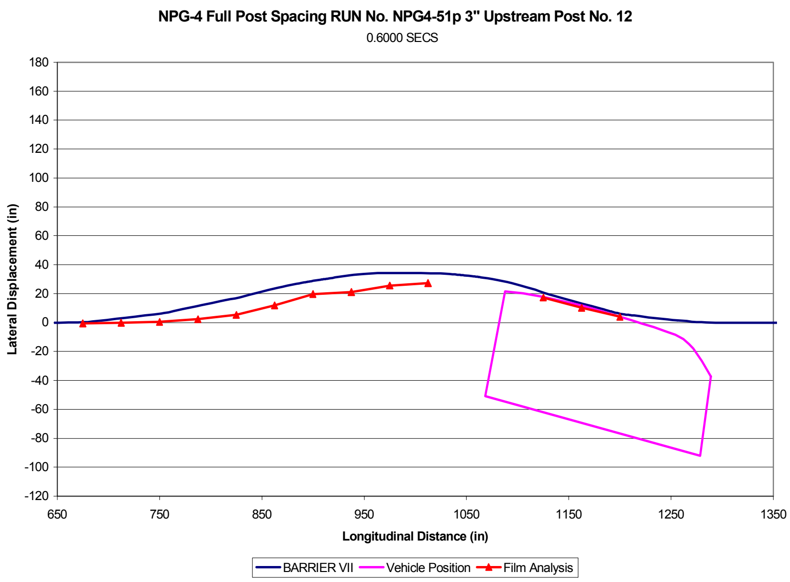


Figure 139. Sequential Figures from BARRIER VII Simulation of NPG-4 (continued)



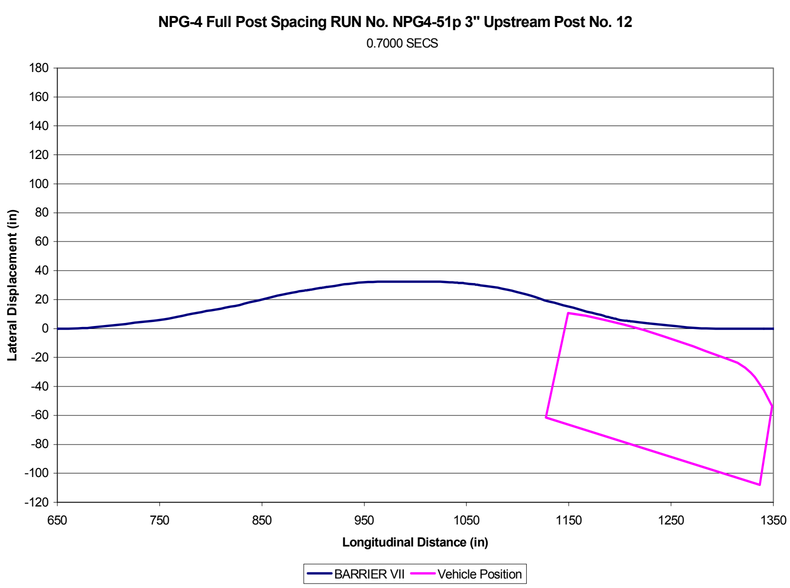


Figure 140. Sequential Figures from BARRIER VII Simulation of NPG-4 (continued)

redirection. Since BARRIER VII is limited to planar motion, it is unable to reproduce roll and pitch angular motions. Therefore, it would calculate vehicle tail slap into the barrier, thus potentially increasing the predicted barrier displacements in this region. Tabulated validation results for vehicle behavior, barrier displacements, and working width for test no. NPG-4 are shown in Table 5. From this effort, researchers determined that the final simulation accurately predicted barrier performance and vehicle behavior for the standard post spacing configuration.

Table 5. Working Width, Vehicle Behavior, and Barrier Displacements for NPG-4

Evaluation Parameters		Results Comparison 1905-mm (75-in.) Post Spacing	
		Test No. NPG-4	Simulation
Parallel Time	ms	396.4	331.5
Dynamic Rail Deflection	mm (in.)	1094 (43)	1054 (41.5)
Working Width	mm (in.)	1260 (50)	1391 (55) *
Working Width Indicator		Hood Corner	Post *
Exit Time	ms	596.6	536.1
Exit Angle	degrees	8.8	9.9
Exit Velocity Vector	degrees	19.4	13.2
Resultant Velocity at Exit	km/h (mph)	55.1 (34.2)	56.26 (35.0)

*Although the post was the working width indicator, it is unlikely that the post would remain attached to the rail for that displacement. If the working width is governed by the engine/hood corner intrusion, the estimated working width would be 1235 mm (49 in.).

Once the calibration effort was completed for test no. NPG-4, simulations commenced on the quarter-post spacing design (Reduced Post Spacing MGS Design), which was evaluated by test no. NPG-6. Using the same parametric evaluation, researchers determined that the final post properties used in the NPG-4 validation effort were appropriate for the NPG-6 simulations as well.

However, it was necessary to increase the vehicle-to-rail friction coefficient from 0.400 to 0.475 in order to more accurately predict vehicle behavior. Initially, it may seem unreasonable to adjust the vehicle-to-barrier friction coefficient since it should be the same for comparable guardrail tests. However, one must understand that wheel contact and snag on additional posts effectively caused additional vehicle drag and energy loss in the actual system that BARRIER VII cannot predict. Therefore, adjustment of the effective coefficient of friction was deemed appropriate. The final validated BARRIER VII input parameters for test no. NPG-6 are provided in Table 6. A graphical comparison of the simulated and actual barrier displacements for test no. NPG-6 is provided in Figures 141 through 143. Tabulated validation results for vehicle behavior, barrier displacements, and working width for test no. NPG-6 are shown in Table 7. The BARRIER VII input deck can be seen in Appendix L. Once again, researchers determined that the final simulation accurately predicted barrier performance and vehicle behavior for the reduced post spacing configuration.

Table 6. Final Validated BARRIER VII Input Parameters for NPG-6 Simulation

BARRIER VII Parameters		**NPG-6 Final Validation Run Input Values**
K_B - Post Stiffness Along B (strong axis)	kN/mm (kip/in.)	1.056 (6.03)
K_A - Post Stiffness Along A (weak axis)	kN/mm (kip/in.)	0.701 (4.00)
M_A - Moment About A (weak axis)	kN*mm (kip*in.)	16230 (143.65)
M_B - Moment About B (strong axis)	kN*mm (kip*in.)	10494 (92.88)
δ_F - Failure Displacement Along B	mm (in.)	381 (15)
μ_k - Kinetic Friction Coefficient	Vehicle to Barrier	0.475
Im_Z - 2000P Mass Moment of Inertia - Yaw	$N*m*s^2$ ($lb*ft*s^2$)	5356 (47400)

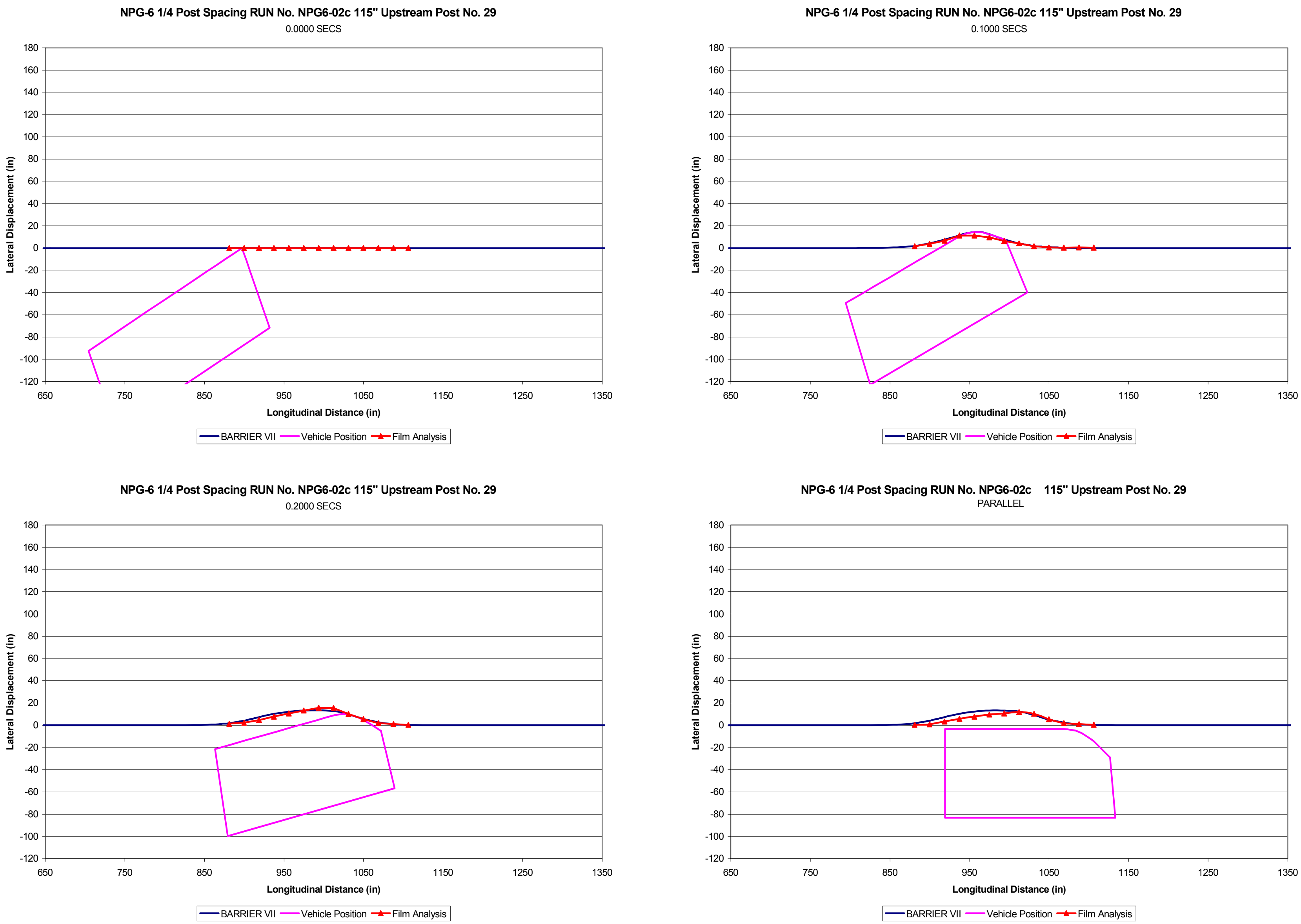


Figure 141. Sequential Figures from BARRIER VII Simulation of NPG-6

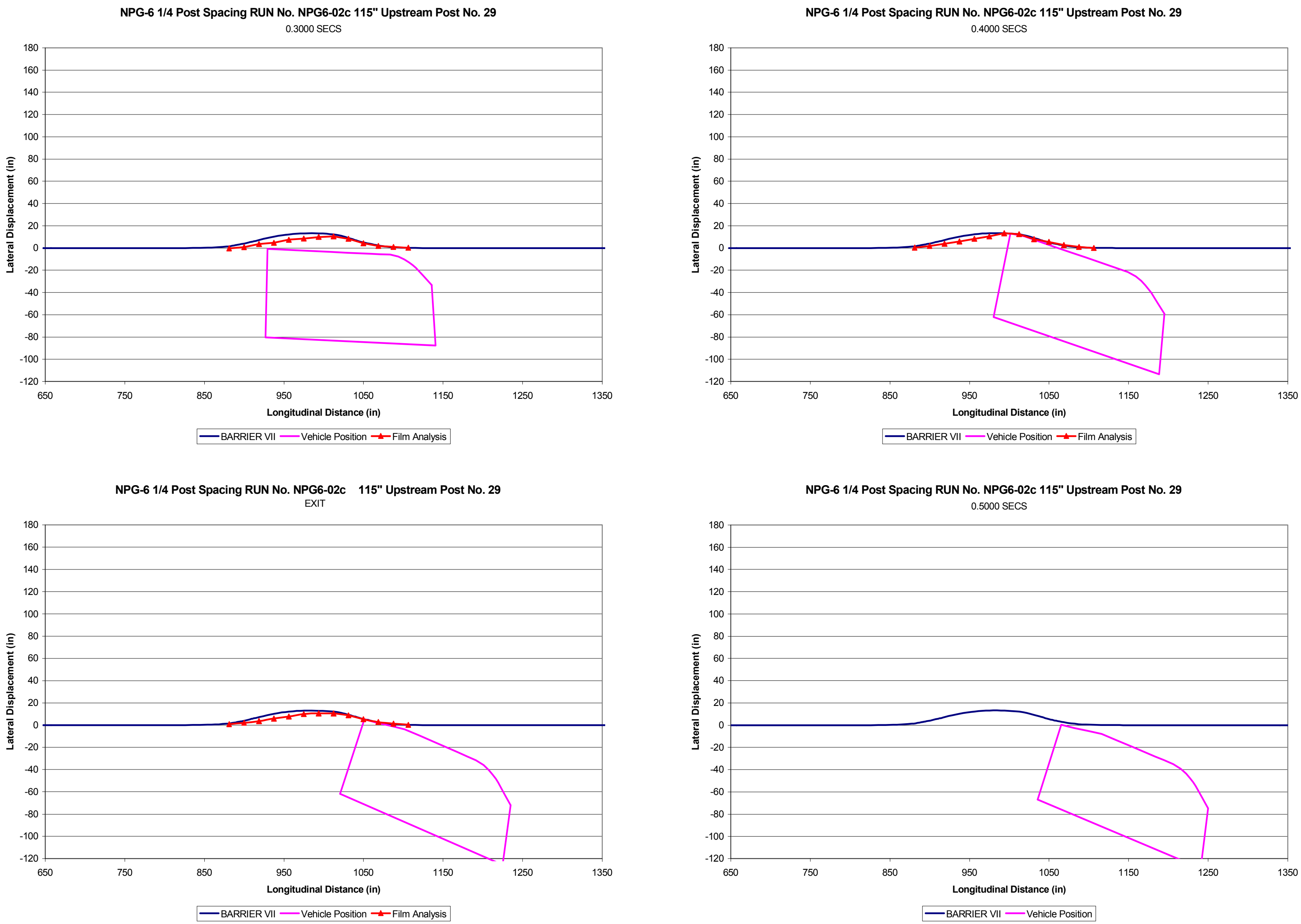
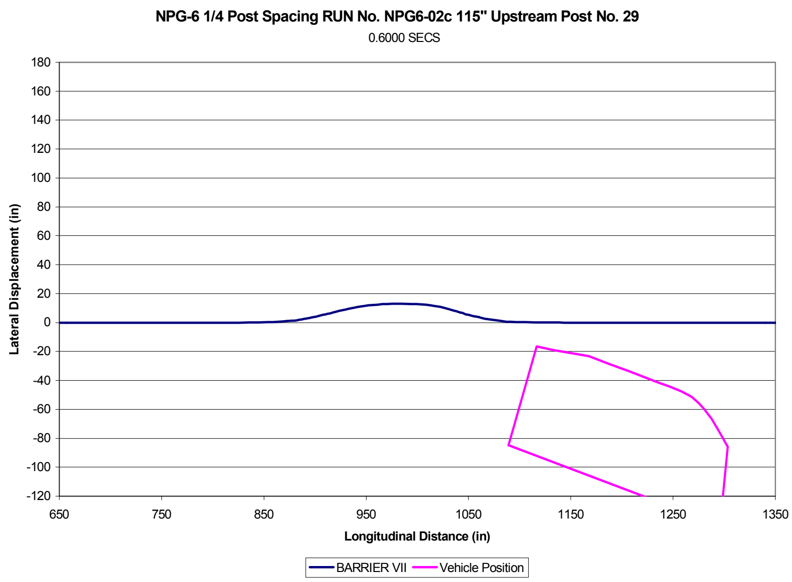


Figure 142. Sequential Figures from BARRIER VII Simulation of NPG-6 (continued)



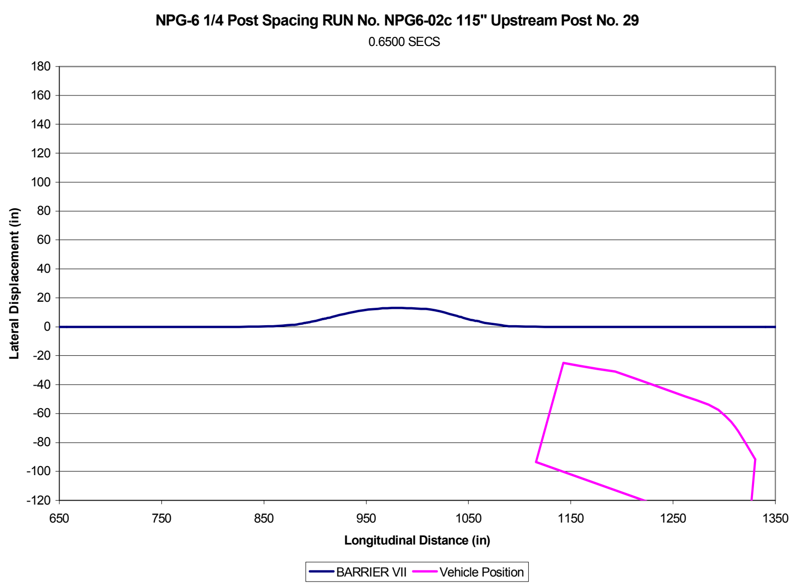


Figure 143. Sequential Figures from BARRIER VII Simulation of NPG-6 (continued)

Table 7. Working Width, Vehicle Behavior, and Barrier Displacements for NPG-6

Evaluation Parameters		Results Comparison 476.25-mm (18 ¾-in.) Post Spacing	
		Test No. NPG-6	Simulation
Parallel Time	ms	296.8	284.7
Dynamic Rail Deflection	mm (in.)	447 (17.5)	418 (16.5)
Working Width	mm (in.)	931 (37)	845 (33.3)
Working Width Indicator		Post	Post
Exit Time	ms	490.6	472.0
Exit Angle	degrees	17.5	17.1
Exit Velocity Vector	degrees	12.9	14.4
Resultant Velocity at Exit	km/h (mph)	59.5 (37.0)	50.44 (31.3)

It is noted that full-scale vehicle crash tests were successfully performed at the extreme limits for the *Midwest Guardrail System* (i.e., standard- and quarter-post spacing design variations). Early in the research and development effort, MwRSF researchers determined that if the guardrail system performed well at those limits, then crash testing would not be required for variations falling within those limits, such as for the half-post spacing design variation. Subsequently, BARRIER VII computer simulation modeling was successfully used to validate and predict barrier performance for both standard- and quarter-post spacing designs. As a result, it was believed that computer simulation modeling then could be used in lieu of full-scale vehicle crash testing in order to determine dynamic barrier performance for the half-post spacing design. Therefore, researchers determined that the final post properties used in the NPG-4 and NPG-6 validation efforts were appropriate for NPG-H (half-post spacing) simulation. However, the researchers reasoned that it was necessary to adjust the vehicle-to-rail coefficient of friction to 0.425 for reasons previously discussed. The BARRIER VII input parameters for simulation NPG-H are provided in Table 8. A graphical representation of the simulation for NPG-H is provided in Figures 144 through 146. The BARRIER VII input deck can be seen in Appendix L.

Table 8. BARRIER VII Input Parameters for NPG-H Simulation

BARRIER VII Parameters		**NPG-H Simulation Run Input Values**
K_B - Post Stiffness Along B (strong axis)	kN/mm (kip/in.)	1.056 (6.03)
K_A - Post Stiffness Along A (weak axis)	kN/mm (kip/in.)	0.701 (4.00)
M_A - Moment About A (weak axis)	kN*mm (kip*in.)	16230 (143.65)
M_B - Moment About B (strong axis)	kN*mm (kip*in.)	10494 (92.88)
δ_F - Failure Displacement Along B	mm (in.)	381 (15)
μ_k - Kinetic Friction Coefficient	Vehicle to Barrier	0.425
Im_Z - 2000P Mass Moment of Inertia - Yaw	$N*m*s^2$ ($lb*ft*s^2$)	5356 (47400)

In addition to the comparisons shown previously, researchers chose to compare the longitudinal and lateral accelerations as well as changes in the vehicle's velocity after the final NPG-4 and 6 validation runs were completed. Therefore, the same SAE filtering procedures outlined in NCHRP Report No. 350 were applied to the simulation data in order to obtain CFC 60 (100 Hz) vehicle accelerations and CFC 180 (300 Hz) changes in velocity and on data acquired with the same sample rate. The results of this comparison are shown in Figures 147 and 148. For the NPG-4 comparison, BARRIER VII generally predicted the acceleration trends but could not predict peaks. While peak accelerations could not be reproduced, changes in vehicle velocity were shown to be reasonably accurate through approximately 300 ms or close to the vehicle parallel condition. For

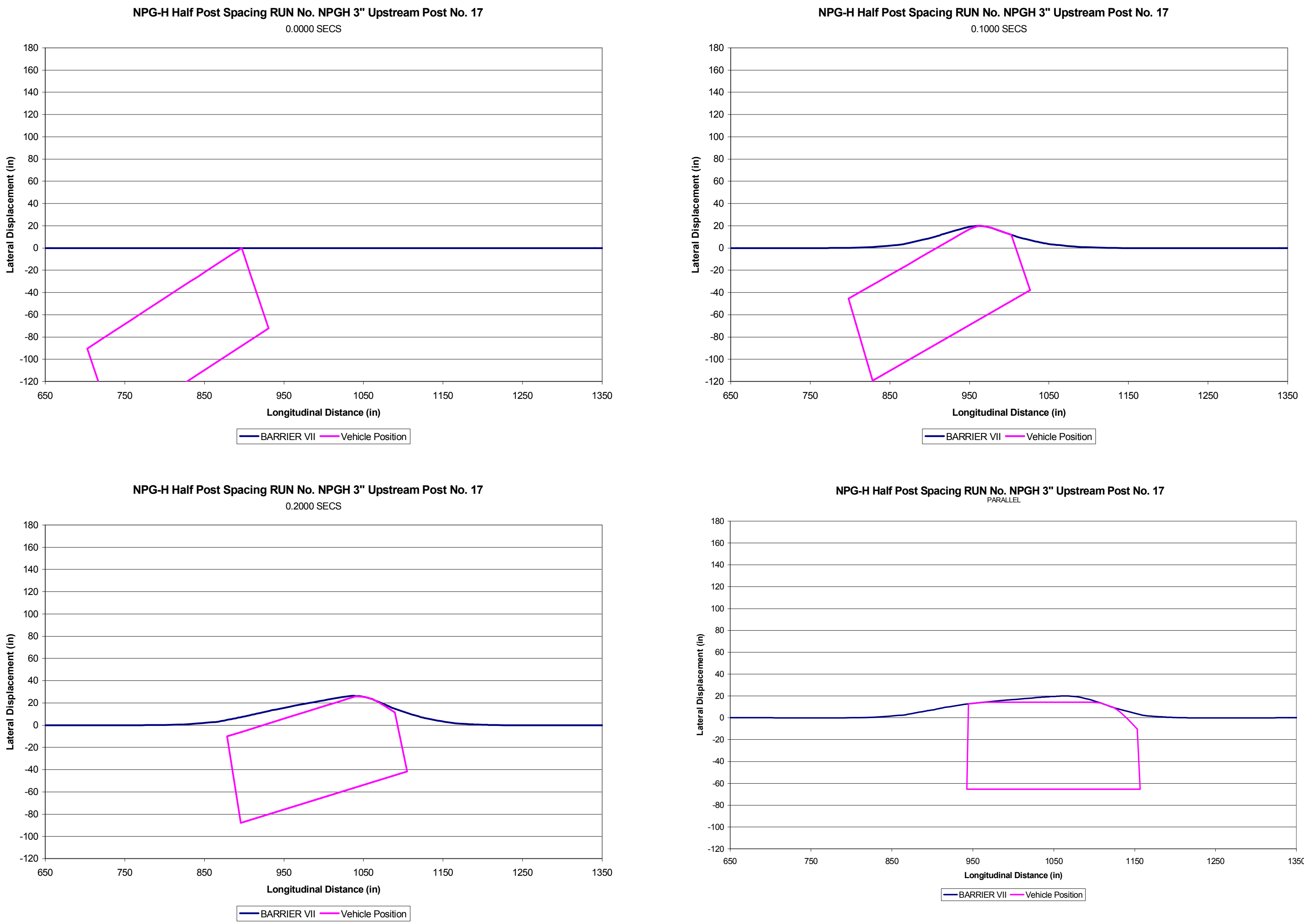


Figure 144. Sequential Figures from BARRIER VII Simulation of NPG-H

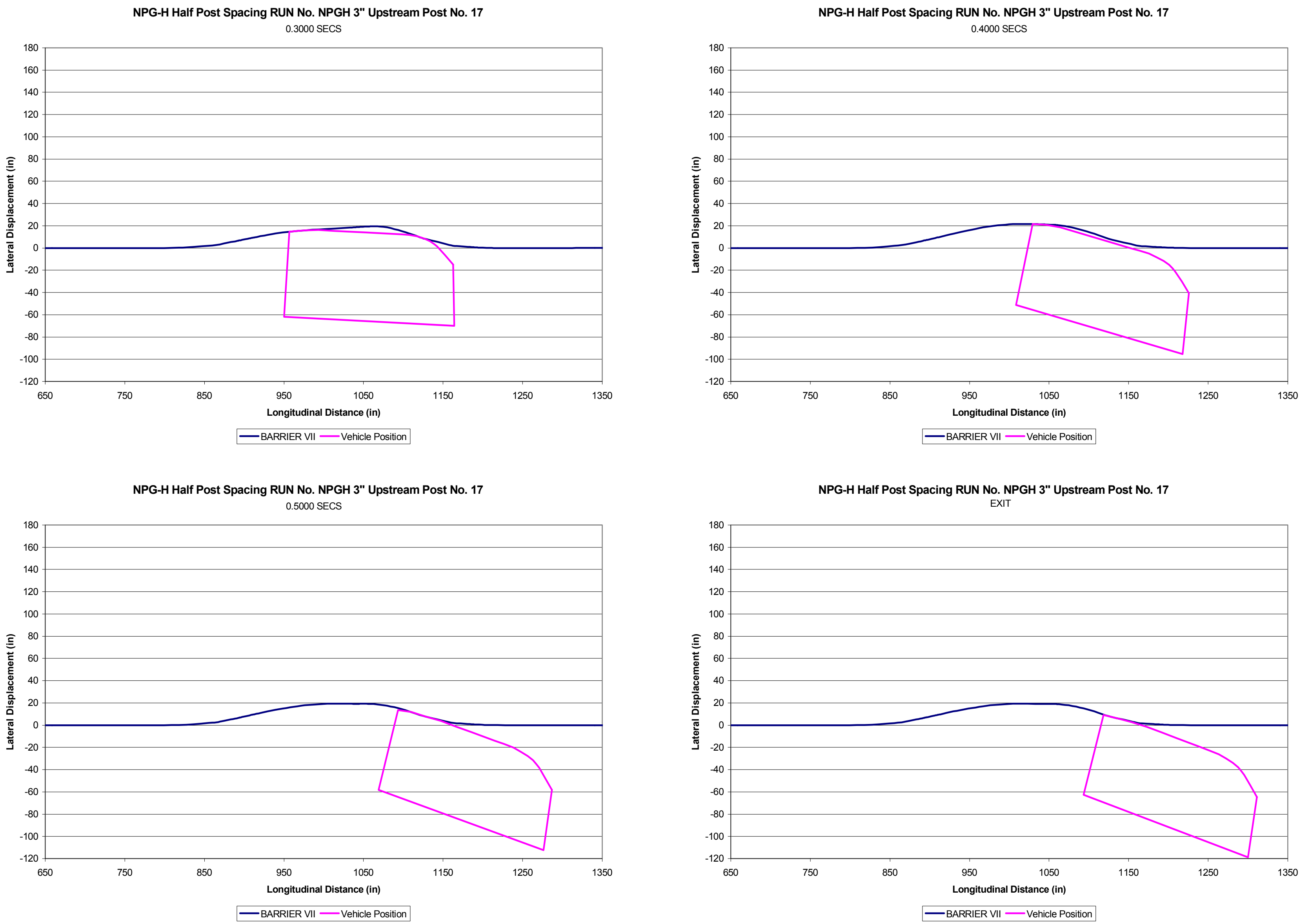
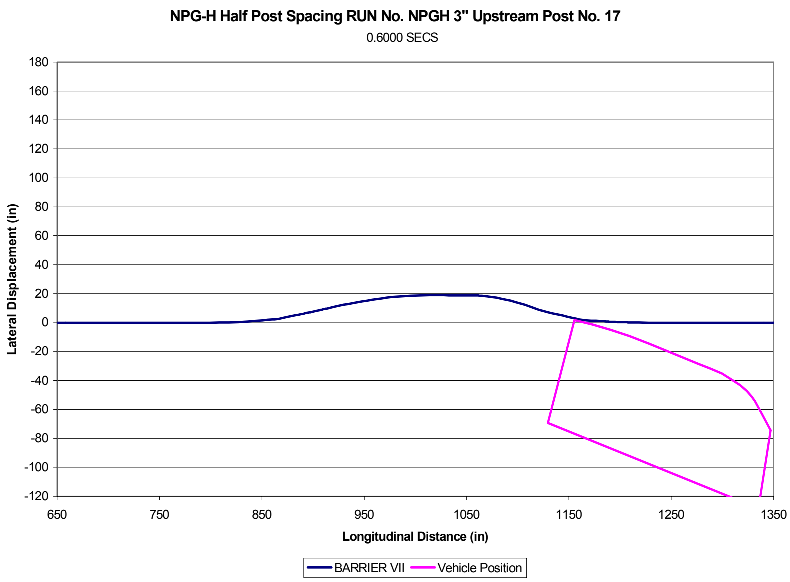


Figure 145. Sequential Figures from BARRIER VII Simulation of NPG-H (continued)



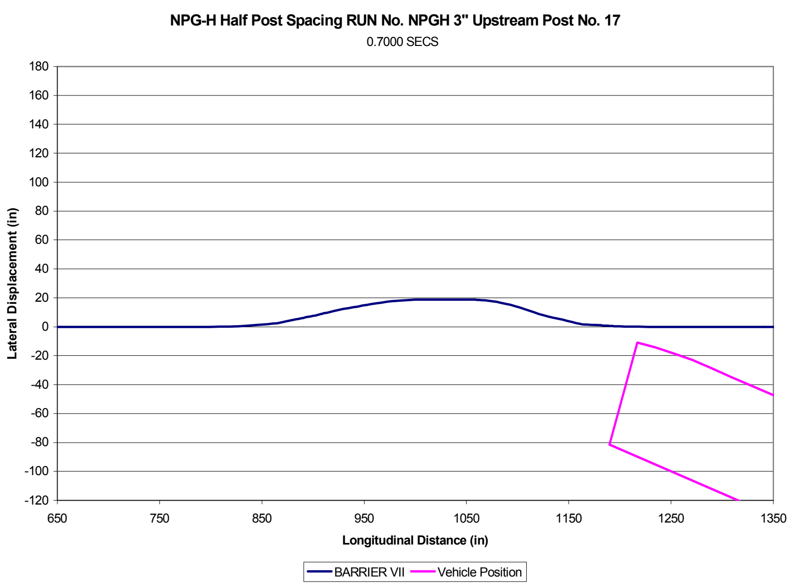


Figure 146. Sequential Figures from BARRIER VII Simulation of NPG-H (continued)

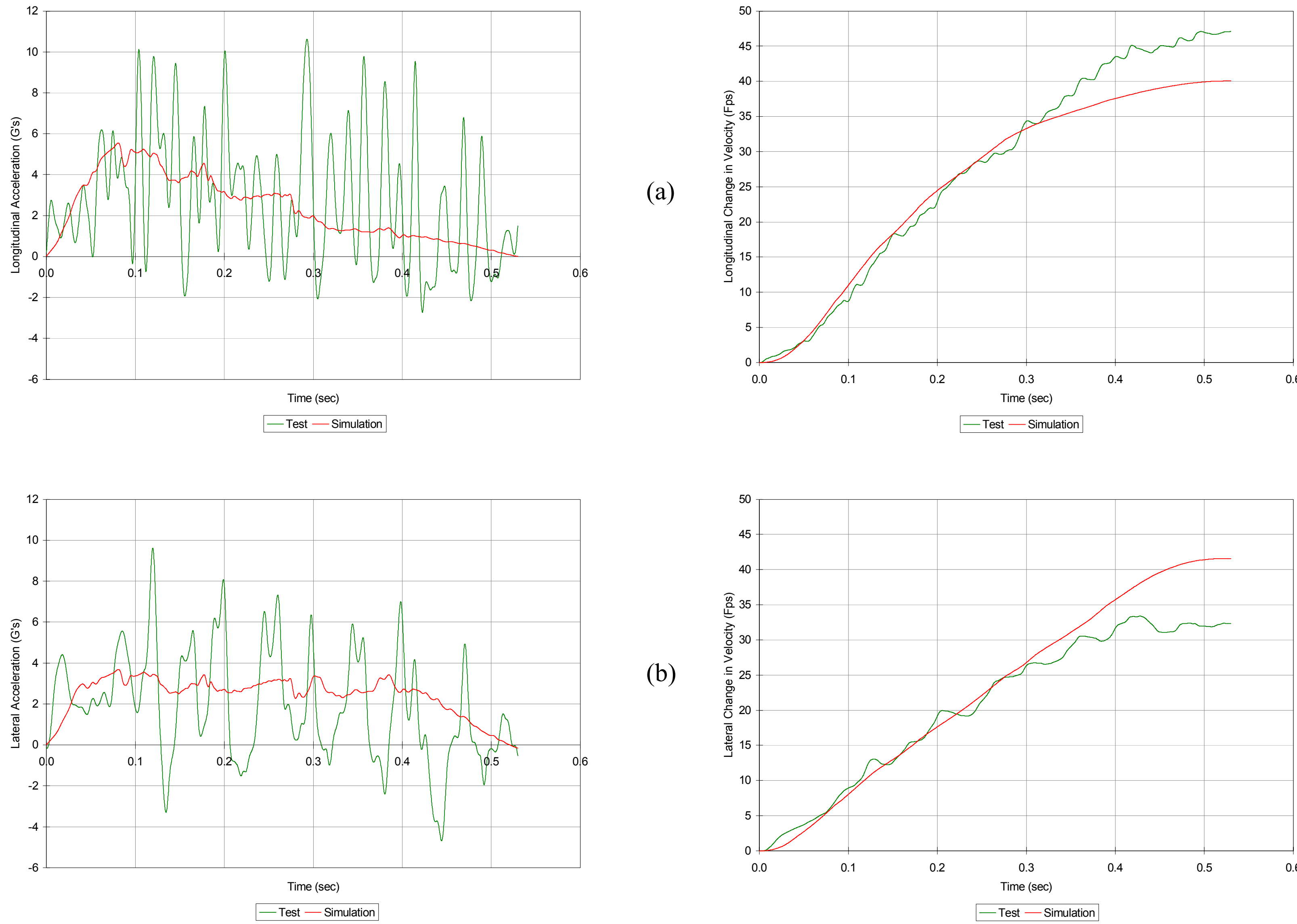


Figure 147. Comparison of Test and Simulation Results for Test NPG-4: (a) Longitudinal Direction and (b) Lateral Direction

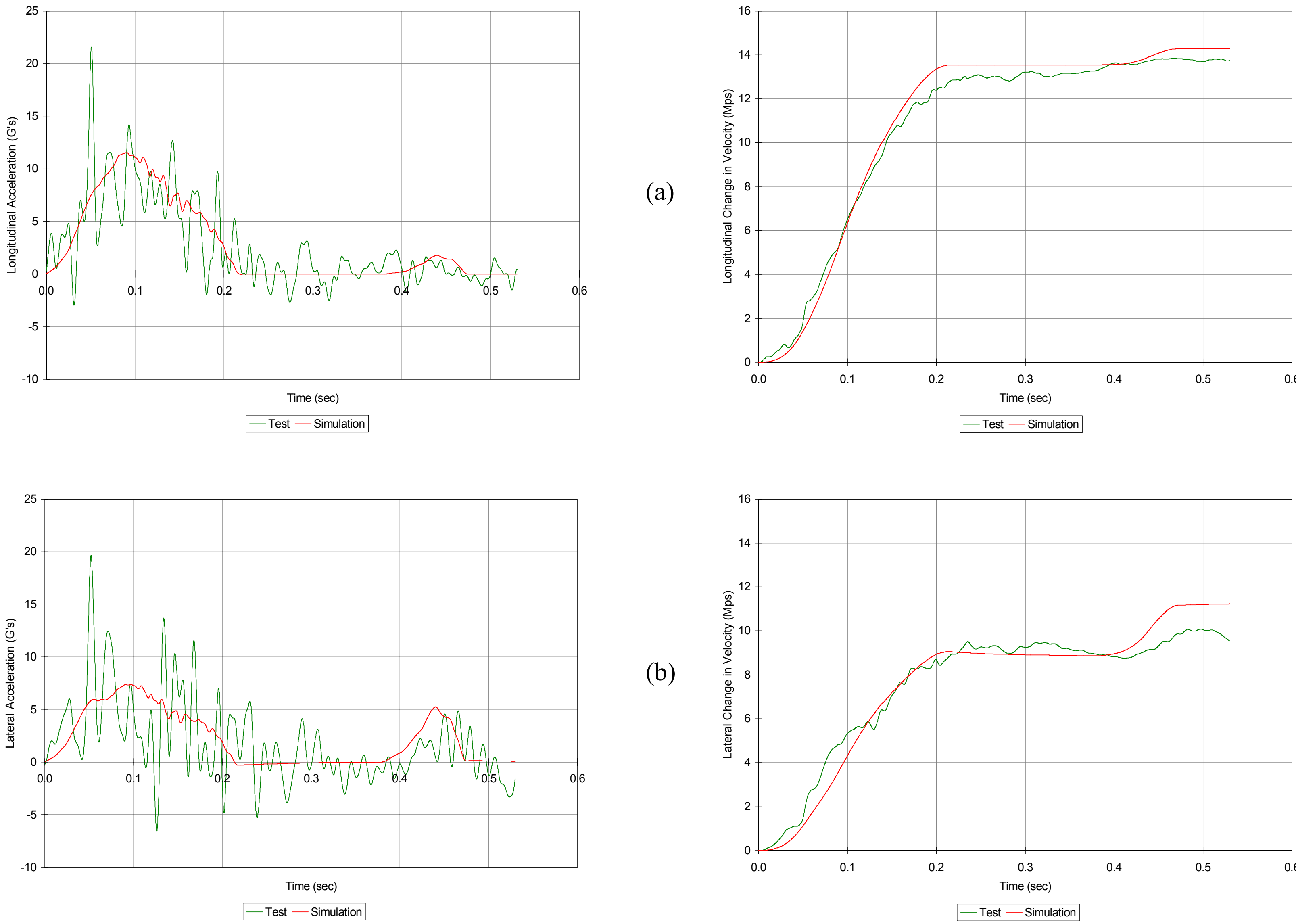


Figure 148. Comparison of Test and Simulation Results for Test NPG-6: (a) Longitudinal Direction and (b) Lateral Direction

the NPG-6 comparison, BARRIER VII more accurately predicted the acceleration trends than observed in the NPG-4 comparisons. However, it was once again incapable of predicting peak accelerations. More importantly though, BARRIER VII was very accurate in predicting vehicle changes in velocity for the stiffened barrier configuration.

For this study, BARRIER VII modeling was also used to predict overall guardrail performance and working width for the standard-, half-, and quarter-post designs at the TL-3 impact conditions of NCHRP Report No. 350. These results would later be used to provide guidance for determining appropriate guardrail placement practices. Each post configuration was evaluated using an analysis technique to determine the Critical Impact Point (CIP) for the three designs. In past studies, the CIP has been based upon the impact condition which maximized (1) wheel-assembly snagging on guardrail posts, (2) vehicle pocketing into the guardrail system, (3) predicted strains in the W-beam rail, or (4) combinations thereof. As such, simulations were performed on each design and at incremental distances along the rail in order to determine the predicted maximum dynamic rail deflection as well as an estimate for the maximum working width. The working width for a given barrier design should be used to determine the appropriate guardrail placement in front of and for shielding a rigid hazard. Results of the CIP simulations are listed in Table 9.

Based on a CIP analysis for the three systems, a maximum dynamic rail deflection of 1,059 mm (41.7 in.), 705 mm (27.8 in.), and 447 mm (17.6 in.), was observed for the standard-, half-, and quarter-post spacing designs, respectively. Similarly, each barrier's working width, based on engine hood extent over the rail, was found to be 1,230 mm (48.4 in.), 976 mm (38.4 in.), and 815 mm (32.1 in.), for the standard-, half-, and quarter-post spacing designs, respectively. In addition, each barrier's working width, based on the lateral position of the back of the post, was found to be 1,391

Table 9. Results of CIP Analysis for Standard-, Quarter-, and Half-Post Spacings

Run No.	Impact Node	Impact Conditions		Maximum Dynamic Rail Deflection	Maximum Rail Tension	Post Spacing	Exit Conditions		
		Speed	Angle				Time	Resultant Velocity	Velocity Trajectory
		km/h	degrees	mm	kN	mm	msec	km/h	degrees
4n60	60	100.0	25.0	994 @ Node 79	268 @ Elements 60 & 61	1905	508.5	37.09	11.8
4n61	61	100.0	25.0	1014 @ Node 81	272 @ Element 60	1905	499.0	36.79	12.9
4n62	62	100.0	25.0	1018 @ Node 82	278 @ Elements 63 & 64	1905	484.0	36.77	13.3
4n63	63	100.0	25.0	1028 @ Node 84	274 @ Element 60	1905	472.0	36.61	13.9
4n64	64	100.0	25.0	1047 @ Node 85	270 @ Elements 60 & 61	1905	460.0	36.5	13.9
4n65	65	100.0	25.0	1059 @ Node 85	270 @ Element 60	1905	531.0	36.88	11.6
4n66	66	100.0	25.0	1056 @ Node 86	266 @ Element 60	1905	518.0	36.93	11.6
4n67	67	100.0	25.0	1023 @ Node 86	268 @ Element 69	1905	522.5	36.97	12.4
4n68	68	100.0	25.0	971 @ Node 86	277 @ Element 69	1905	502.0	37.34	11.1
4n69	69	100.0	25.0	978 @ Node 87	279 @ Element 79	1905	518.0	37.47	10.9
6n60	60	100.0	25.0	447 @ Node 71	384 @ Element 64	476.25	475.0	31.84	15.2
6n61	61	100.0	25.0	444 @ Node 73	391 @ Element 66	476.25	475.5	31.76	15.6
6n62	62	100.0	25.0	436 @ Node 73	393 @ Element 69	476.25	466.0	32.39	14.8
6n63	63	100.0	25.0	430 @ Node 75	404 @ Element 70	476.25	463.0	32.47	15.2
6n64	64	100.0	25.0	428 @ Node 75	421 @ Element 72	476.25	455.5	32.8	14.7
6n65	65	100.0	25.0	435 @ Node 77	420 @ Element 72	476.25	461.5	32.52	15.2
6n66	66	100.0	25.0	433 @ Node 77	421 @ Element 74	476.25	456.0	32.79	14.7
6n67	67	100.0	25.0	433 @ Node 79	421 @ Element 72	476.25	456.5	32.83	14.8
6n68	68	100.0	25.0	427 @ Node 79	422 @ Element 76	476.25	451.5	32.95	14.8
6n69	69	100.0	25.0	428 @ Node 79	423 @ Element 76	476.25	453.0	32.98	14.7
Hn60	60	100.0	25.0	705 @ Node 75	322 @ Element 60	952.5	440.5	34.86	11.6
Hn61	61	100.0	25.0	691 @ Node 76	334 @ Element 64	952.5	442.0	35.21	11.8
Hn62	62	100.0	25.0	681 @ Node 77	334 @ Element 64	952.5	432.5	35.34	11.7
Hn63	63	100.0	25.0	683 @ Node 78	330 @ Elements 72 & 73	952.5	436.0	35.31	12.2
Hn64	64	100.0	25.0	689 @ Node 79	336 @ Element 64	952.5	437.5	35.24	11.9
Hn65	65	100.0	25.0	673 @ Node 80	342 @ Element 69	952.5	432.0	35.55	11.9
Hn66	66	100.0	25.0	672 @ Node 81	335 @ Element 71	952.5	423.5	35.63	11.5
Hn67	67	100.0	25.0	680 @ Node 82	342 @ Elements 69, 70 & 71	952.5	431.5	35.59	11.8
Hn68	68	100.0	25.0	683 @ Node 82	344 @ Element 69	952.5	435.0	35.51	11.8
Hn69	69	100.0	25.0	683 @ Node 83	343 @ Element 69	952.5	435.5	35.53	11.8

mm (54.8 in.), 1,094 mm (43.1 in.), and 871 mm (34.3 in.), for the standard-, half-, and quarter-post spacing designs, respectively. Although the working width was governed by post displacement for the standard post spacing design, it is unlikely that the post would remain attached to the rail for that displacement. Therefore, if the working width were governed by intrusion of the corner of the engine hood, the working width would be 1,230 mm (48.4 in.). A summary of the working width predictions are shown in Table 10.

Table 10. BARRIER VII CIP Analysis Working Width Predictions

BARRIER VII Critical Impact Point Analysis Results				
Evaluation Parameter	Units	Full-Post Spacing	Half-Post Spacing	Quarter-Post Spacing
Maximum Rail Displacement	mm (in.)	1058.9 (41.7)	705.1 (27.8)	447.0 (17.6)
Working Width Determined by 2000P Hood Corner	mm (in.)	1229.5 (48.4)	976.3 (38.4)	815.1 (32.1)
Working Width Determined by Guardrail Post	mm (in.)	1390.9 (54.8)*	1094.0 (43.1)	870.5 (34.3)
Maximum Rail Tension	kN (kips)	278.1 (62.5)	343.8 (77.2)	422.6 (95.0)

*Although the post was the working width indicator, it is unlikely it would remain attached at that displacement, and the predicted hood corner intrusion would be the deciding factor at 1229.5 mm (48.4 in.).

19 GUARDRAIL PLACEMENT GUIDELINES

One research objective was to determine guardrail placement guidelines for shielding rigid hazards using the standard *Midwest Guardrail System* (MGS) as well as the two stiffened variations. Based on an analysis of the test and simulation results, the minimum recommended distances that the *Midwest Guardrail System* (MGS) should be placed away from a rigid hazard are 1.25 m (49 in.), 1.12 m (44 in.), and 0.90 m (35 in.) for the standard-, half-, and quarter-post spacing designs, respectively, as measured from the front face of the W-beam rail to the front face of the hazard.

20 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The *Midwest Guardrail System* (MGS), as described in this report, was developed in order to provide increased safety for high center-of-mass vehicles, provide improved height tolerances, and reduce the potential for W-beam rupture. This new guardrail system was also successfully crash tested according to the criteria found in NCHRP Report No. 350. The test results indicate that this design is suitable for use on Federal-aid highways. However, any significant modifications made to the W–beam guardrail design would require additional analysis and can only be verified through the use of full-scale crash testing. A summary of the safety performance evaluation is provided in Table 11.

The barrier system has been shown to perform well for small car impacts when mounted as high as 813 mm (32 in.) and has performed very well during light truck impacts for the standard top mounting height of 787 mm (31 in.) for three different placement situations. The standard *Midwest Guardrail System* (MGS) design performed very well for the standard configuration with a 1905-mm (6-ft 3-in.) post spacing, for the midpoint of the standard configuration's front face placed 152 mm (6 in.) behind a 152-mm (6-in.) high concrete curb, and for the reduced post spacing configuration with a 476 mm (1-ft 6¾-in.) post spacing. It should be noted that the length of the steel foundation tube was increased to a total length of 1,829 mm (6 ft). In each test, the *Midwest Guardrail System* (MGS) safely redirected the ¾-ton pickup truck in a very stable manner. These test results clearly indicate that the new barrier will reduce the high rollover rates currently associated with light truck impacts on standard guardrail designs. Further, in every pickup truck test conducted thus far on the *Midwest Guardrail System* (MGS), the test vehicle was brought to a safe stop immediately adjacent to the barrier. Thus, the *Midwest Guardrail System* (MGS) will provide improved safety for light

Table 11. Summary of Safety Performance Evaluation Results

Evaluation Factors	Evaluation Criteria	Test NPG-1	Test NPG-2	Test NPG-3	Test NPG-4	Test NPG-5	Test NPG-6
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.	S	U	M	S	S	S
Occupant Risk	D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	S	S	S	S	S	S
	F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	S	U	S	S	S	S
	H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9 m/s (29.53 ft/s), or at least below the maximum allowable value of 12 m/s (39.37 ft/s).	S	NA	NA	NA	NA	NA
	I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15 g's, or at least below the maximum allowable value of 20 g's.	S	NA	NA	NA	NA	NA
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	S	S	S	S	S	S
	L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec (39.37 ft/sec), and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.	NA	S	S	S	S	S
	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	U	M	M	S	S

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

truck impacts, not only by reducing the propensity for rollover during high speed/high angle impacts but also by keeping the impacting vehicles close to the guardrail, thereby eliminating the potential for secondary impacts with other vehicles. It should be noted that the complete sets of metric- and English-unit drawings for each of the three *Midwest Guardrail System* (MGS) applications: (1) the standard MGS system, (2) the MGS system installed over a curb, and (3) the reduced post spacing MGS system are found in Appendices F, H, and J, respectively.

A combination of full-scale crash testing, dynamic component testing, and computer simulation was also used to identify maximum barrier deflections and working widths for the *Midwest Guardrail System* (MGS) when installed with standard-, half-, and quarter-post spacings. As previously provided, these guidelines should allow designers to utilize the new barrier with confidence, even when fixed hazards are located very near the face of the guardrail.

Unfortunately, two problems remain to be resolved before the *Midwest Guardrail System* (MGS) can be fully implemented. No guardrail system can be widely implemented without an acceptable method for terminating the barrier. Therefore, existing guardrail terminal designs must be adapted to the new mounting height before the *Midwest Guardrail System* (MGS) can be utilized. Higher guardrail mounting heights may allow small cars to penetrate under the impact heads and buffer nose sections utilized on the ends of W-beam guardrail. Further, both the increased height and the associated reduction in post embedment depth has been shown to increase the loading on guardrail terminal anchors. Therefore, the revised designs must be retested at the beginning of the length-of-need with a ¾-ton pickup truck. Finally, the raised height and reduced embedment depth and anchorage may also create problems for small cars impacting the barrier upstream of the beginning of length-of-need. Hence, it is strongly recommended that manufacturers conduct three full-scale crash tests (NCHRP Report No. 350 test designations 3-30, 3-34, and 3-35) on the currently approved guardrail terminal systems attached to the *Midwest Guardrail System* (MGS) before the design can be implemented widely.

One of the most common applications for W-beam guardrails is on the approach to bridge railings. Hence, another barrier to implementation of the *Midwest Guardrail System* (MGS) is the development of acceptable guardrail/bridge rail transitions. Most guardrail/bridge rail transition designs incorporate thrie beam rail elements with a top height of 787 mm (31 in.). These designs incorporate a thrie beam to W-beam transition element that allows the center of the W-beam and thrie beam rails to be mounted at the same height. In order to attach the *Midwest Guardrail System* (MGS) to these transition systems, a revised thrie beam that flares downward must be successfully tested. This effort is currently underway in a separate study, and it is hoped that the testing will completed before the beginning of the 2004 construction season.

In summary, the *Midwest Guardrail System* (MGS) development is nearing completion. All testing conducted to date indicates that by reducing the propensity for causing rollovers, the new barrier will offer greatly improved protection for occupants of light trucks. The new barrier was developed with funding from the Midwest States' Pooled Fund program and is entirely non-proprietary. Highway agencies are strongly encouraged to consider adopting the new barrier system as soon as FHWA acceptance letters are issued for the guardrail system as well as the modified terminals and transitions.

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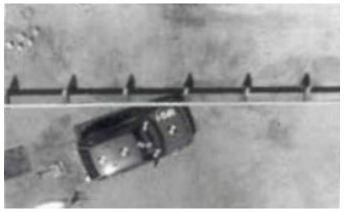
22 APPENDICES

APPENDIX A

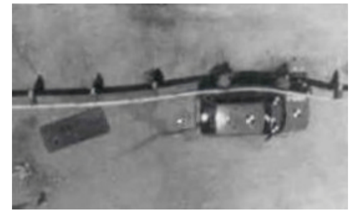
Test Summary Sheets in English Units



0.000 sec

0.088 sec

0.147 sec



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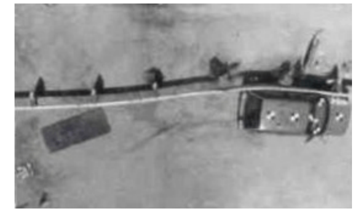

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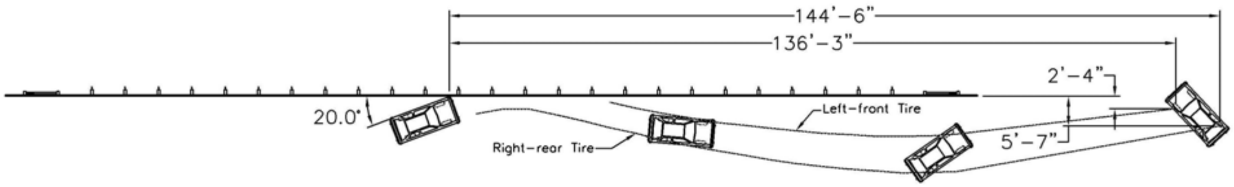
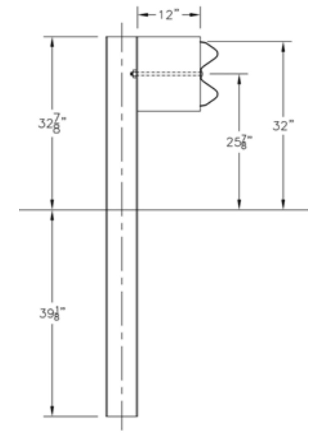
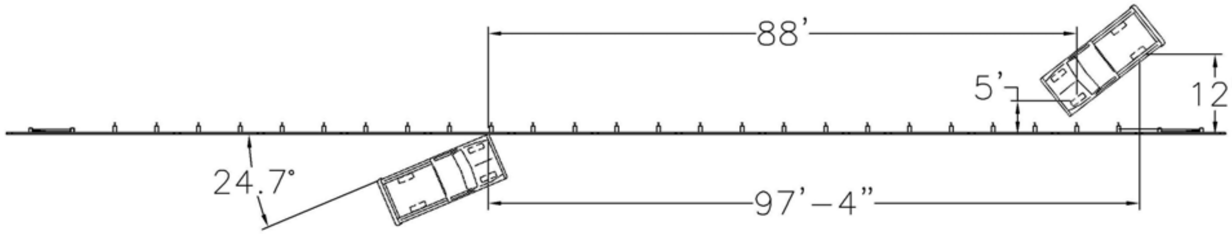


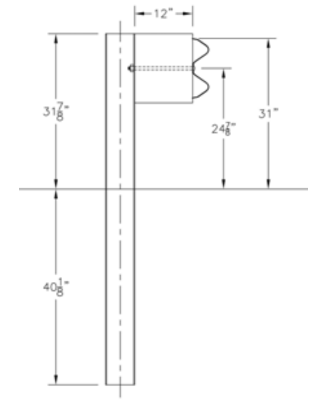


- Test Number NPG-1
- Date 6/29/01
- Appurtenance . . . . *Midwest Guardrail System*
  - Key Elements . . . . increased mounting height, blockout depth, and bolt slot length, mid-span splices
- Total Length . . . . 181 ft-3 in.
- Steel W-beam
  - Thickness . . . . 12 gauge
  - Top Mounting Height . . . . 32 in.
  - Bolt Slot Length . . . . 4 in.
- Steel Posts
  - Post Nos. 3 - 27 . . . . W6x9 by 6-ft long
  - Spacing . . . . 75 in.
- Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) . 5½ in. x 7½ in. by 42½-in. long
- Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 6 in. x 12 in. by 14-in. long
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1994 Geo Metro
  - Curb . . . . 1645 lbs
  - Test Inertial . . . . 1790 lbs
  - Gross Static . . . . 1956 lbs
- Vehicle Speed
  - Impact . . . . 63.9 mph
  - Exit (resultant) . . . . 57.4 mph
- Vehicle Angle
  - Impact (trajectory) . . . . 20.0 deg
  - Exit (trajectory) . . . . 9 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 6.13 g's < 20 g's
  - Lateral (not required) . . . . 7.97 g's
- Occupant Impact Velocity
  - Longitudinal . . . . 11.55 ft/s < 39.37 ft/s
  - Lateral (not required) . . . . 18.63 ft/s
- Vehicle Damage . . . . Moderate
  - TAD[31] 11-LFQ-3
  - SAE[32] 11LFEW3
- Vehicle Stopping Distance . . . . 136 ft-3 in. downstream, 2 ft-4 in. traffic-side face
- Barrier Damage . . . . Moderate
- Maximum Rail Deflections
  - Permanent Set . . . . 9 ⅜ in.
  - Dynamic . . . . 17 ⅜ in.
- Working Width . . . . 40 ¼ in.

Figure A-1. Summary of Test Results and Sequential Photographs (English), Test NPG-1

0.042 sec   0.102 sec   0.227 sec   0.303 sec   0.464 sec

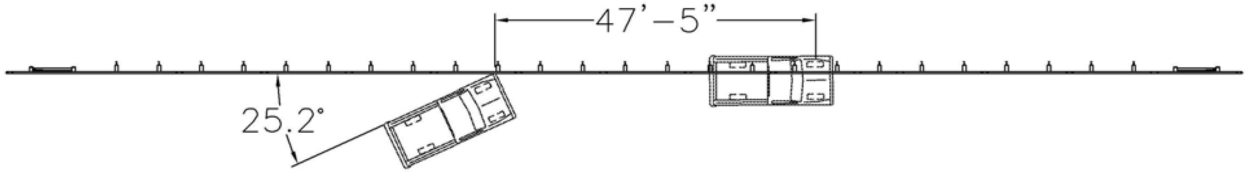


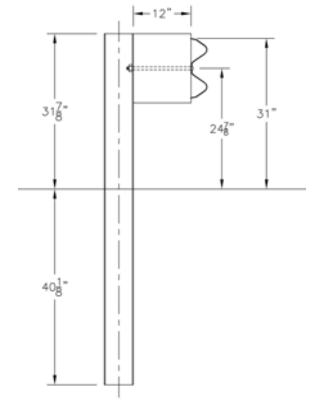


- Test Number NPG-2
- Date 8/9/01
- Appurtenance .... *Midwest Guardrail System*
  - Key Elements .... increased mounting height, blockout depth, and bolt slot length, mid-span splices
- Total Length .... 181 ft-3 in.
- Steel W-beam
  - Thickness .... 12 gauge
  - Top Mounting Height .... 31 in.
  - Bolt Slot Length .... 4 in.
- Steel Posts
  - Post Nos. 3 - 27 .... W6x9 by 6-ft long
  - Spacing .... 75 in.
- Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) . 5½ in. x 7½ in. by 42½-in. long
- Wood Spacer Blocks
  - Post Nos. 3 - 27 .... 6 in. x 12 in. by 14-in. long
- Soil Type .... Grading B - AASHTO M 147-65 (1990)
- Vehicle Model .... 1995 Chevrolet 2500 4x4 pickup
  - Curb .... 4750 lbs
  - Test Inertial .... 4941 lbs
  - Gross Static .... 4941 lbs
- Vehicle Speed
  - Impact .... 61.5 mph
  - Exit (resultant) .... NA
- Vehicle Angle
  - Impact (trajectory) .... 24.7 deg
  - Exit (trajectory) .... NA
- Vehicle Stability .... Unsatisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal .... 6.51 g's < 20 g's
  - Lateral (not required) .... 8.19 g's
- Occupant Impact Velocity
  - Longitudinal .... 16.33 ft/s < 39.37 ft/s
  - Lateral (not required) .... 10.32 ft/s
- Vehicle Damage .... Extensive
  - TAD[31] .... 11-FFQ-3, L&T-4
  - SAE[32] 11LFEW3, 00TDDO6
- Vehicle Stopping Distance .... 88 ft downstream
  5 ft laterally behind
- Barrier Damage .... Extensive
- Maximum Deflections
  - Permanent Set .... NA
  - Dynamic .... NA
- Working Width .... NA

Figure A-2. Summary of Test Results and Sequential Photographs (English), Test NPG-2

0.000 sec　0.052 sec　0.135 sec　0.167 sec　0.227 sec

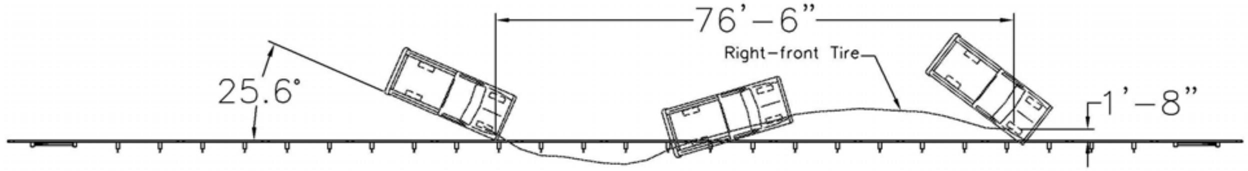


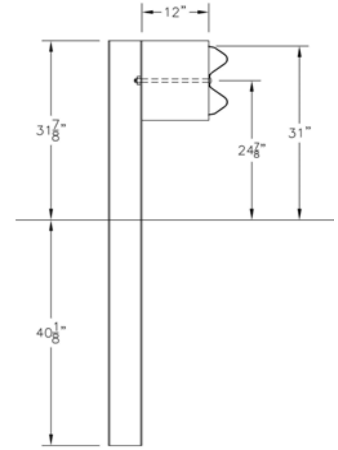


- Test Number NPG-3
- Date 8/20/01
- Appurtenance . . . . *Midwest Guardrail System*
  - Key Elements . . . . increased mounting height, blockout depth, and bolt slot length, mid-span splices
- Total Length . . . . 181 ft-3 in.
- Steel W-beam
  - Thickness . . . . 12 gauge
  - Top Mounting Height . . . . 31 in.
  - Bolt Slot Length . . . . 4 in.
- Steel Posts
  - Post Nos. 3 - 27 . . . . W6x9 by 6-ft long
  - Spacing . . . . 75 in.
- Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) . 5½ in. x 7½ in. by 42½-in. long
- Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 6 in. x 12 in. by 14-in. long
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1995 Chevrolet 2500 ¾-ton pickup
  - Curb . . . . 4290 lbs
  - Test Inertial . . . . 4491 lbs
  - Gross Static . . . . 4491 lbs
- Vehicle Speed
  - Impact . . . . 63.3 mph
  - Exit (resultant) . . . . NA
- Vehicle Angle
  - Impact (trajectory) . . . . 25.2 deg
  - Exit (trajectory) . . . . NA
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 6.49 g's < 20 g's
  - Lateral (not required) . . . . 8.31 g's
- Occupant Impact Velocity
  - Longitudinal . . . . 16.55 ft/s < 39.37 ft/s
  - Lateral (not required) . . . . 11.97 ft/s
- Vehicle Damage . . . . Minimal
  - TAD[31] 11-LFQ-4, 11-FL-3
  - SAE[32] 11LFEW4
- Vehicle Stopping Distance . . . . 47 ft-5 in. downstream, 0 m lateral
- Barrier Damage . . . . Moderate
- Maximum Deflections
  - Permanent Set . . . . NA
  - Dynamic . . . . NA
- Working Width . . . . NA

Figure A-3. Summary of Test Results and Sequential Photographs (English), Test NPG-3

0.000 sec 0.101 sec 0.190 sec 0.323 sec 0.446 sec





- Test Number NPG-4
- Date 6/14/02
- Appurtenance . . . . *Midwest Guardrail System*
  - Key Elements . . . . increased mounting height, blockout depth and foundation tube length, mid-span splices
- Total Length . . . . 181 ft-3 in.
- Steel W-beam
  - Thickness . . . . 12 gauge
  - Top Mounting Height . . . . 31 in.
  - Bolt Slot Length . . . . 2 ½ in.
- Steel Posts
  - Post Nos. 3 - 27 . . . . W6x9 by 6-ft long
  - Spacing . . . . 75 in.
- Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) . 5½ in. x 7½ in. by 42½-in. long
- Steel Foundation Tube Length . . . . . 6 ft
- Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 6 in. x 12 in. by 14-in. long
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1995 GMC 2500 ¾-ton pickup
  - Curb . . . . 4218 lbs
  - Test Inertial . . . . 4378 lbs
  - Gross Static . . . . 4378 lbs
- Vehicle Speed
  - Impact . . . . 61.0 mph
  - Exit (resultant) . . . . 34.2 mph
- Vehicle Angle
  - Impact (trajectory) . . . . 25.6 deg
  - Exit (trajectory) . . . . 19.3 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 9.50 g's < 20 g's
  - Lateral (not required) . . . . 6.94 g's
- Occupant Impact Velocity
  - Longitudinal . . . . 18.32 ft/s < 39.37 ft/s
  - Lateral (not required) . . . . 12.78 ft/s
- Vehicle Damage . . . . Minimal
  - TAD[31] 1-RFQ-4
  - SAE[32] 01RFEW5
- Vehicle Stopping Distance . . . . 76 ft-6 in. downstream
  1 ft-8 in. traffic-side face
- Barrier Damage . . . . Moderate
- Maximum Deflections
  - Permanent Set . . . . 26 in.
  - Dynamic . . . . 43 in.
- Working Width . . . . 49 ⅝ in.

Figure A-4. Summary of Test Results and Sequential Photographs (English), Test NPG-4

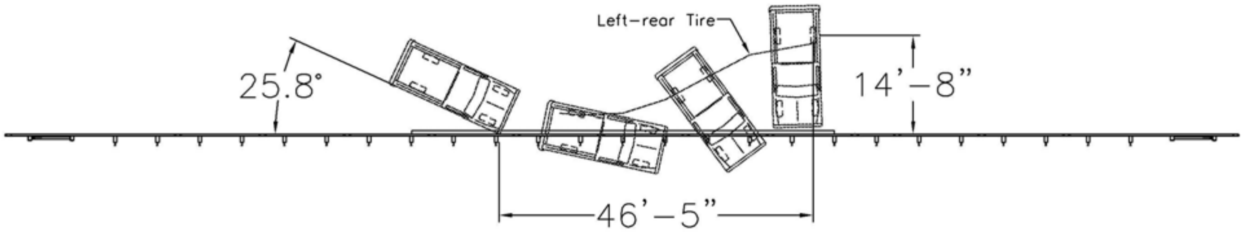
0.000 sec

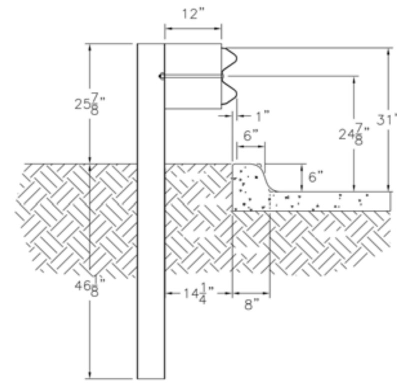
0.080 sec

0.151 sec

0.237 sec

0.504 sec



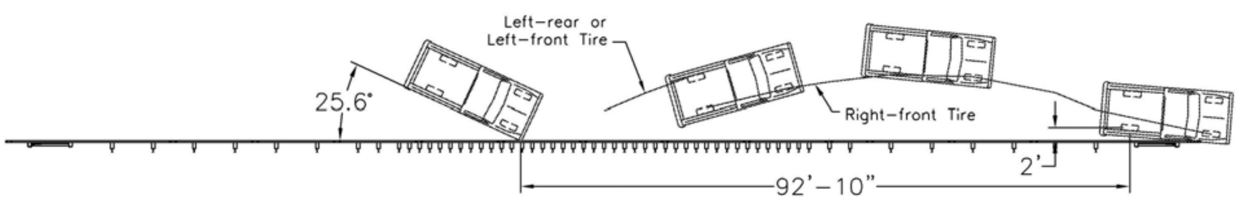


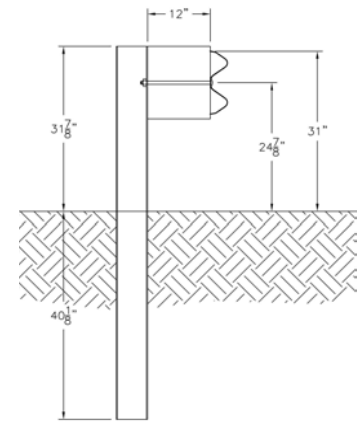
- Test Number NPG-5
- Date 9/4/02
- Appurtenance . . . . *Midwest Guardrail System* with Curb
  - Key Elements . . . . increased mounting height, blockout depth, and foundation tube length, mid-span splices, and curb
- Total Length . . . . 181 ft-3 in.
- Steel W-beam
  - Thickness . . . . 12 gauge
  - Top Mounting Height . . . . 31 in.
  - Bolt Slot Length . . . . 2 ½ in.
- Steel Posts
  - Post Nos. 3 - 27 . . . . W6x9 by 6-ft long
  - Spacing . . . . 75 in.
- Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) . 5½ in. x 7½ in. by 42½-in. long
- Steel Foundation Tube Length . . . . . 6 ft
- Wood Spacer Blocks
  - Post Nos. 3 - 27 . . . . 6 in. x 12 in. by 14-in. long
- Curb . . . . 6-in. Tall Type B mounted 6 in. in front of guardrail face
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1997 Chevrolet C2500 ¾-ton pickup
  - Curb . . . . 3997 lbs
  - Test Inertial . . . . 4389 lbs
  - Gross Static . . . . 4389 lbs

- Vehicle Speed
  - Impact . . . . 60.1 mph
  - Exit (resultant) . . . . 29.8 mph
- Vehicle Angle
  - Impact (trajectory) . . . . 25.8 deg
  - Exit (trajectory) . . . . 6.7 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 10.50 g's < 20 g's
  - Lateral (not required) . . . . 8.66 g's
- Occupant Impact Velocity
  - Longitudinal . . . . 17.16 ft/s < 39.37 ft/s
  - Lateral (not required) . . . . 12.91 ft/s
- Vehicle Damage . . . . Moderate
  - TAD[31] 1-RFQ-4
  - SAE[32] 01RFEW5
- Vehicle Stopping Distance . . . . 46 ft-5 in. downstream 14 ft-8 in. traffic-side face
- Barrier Damage . . . . Moderate
- Maximum Deflections
  - Permanent Set . . . . 24 in.
  - Dynamic . . . . 40 in.
- Working Width . . . . 57 in.

Figure A-5. Summary of Test Results and Sequential Photographs (English), Test NPG-5

0.000 sec 0.077 sec 0.164 sec 0.295 sec 0.625 sec





- Test Number NPG-6
- Date 10/18/02
- Appurtenance . . . . *Midwest Guardrail System* with reduced post spacing
  - Key Elements . . . . reduced post spacing, increased mounting height, blockout depth, and foundation tube length
- Total Length . . . . 181 ft-3 in.
- Steel W-beam
  - Thickness . . . . 12 gauge
  - Top Mounting Height . . . . 31 in.
  - Bolt Slot Length . . . . 2 ½ in.
- Steel Posts
  - Post Nos. 3 - 59 . . . . W6x9 by 6-ft long
- Steel Post Spacing
  - Post Nos. 3 -8, 54 -59 . . . . 75 in.
  - Post Nos. 9 - 10, 52 - 53 . . . . . . 37 ½ in.
  - Post Nos. 11 - 51 . . . . 18 ¾ in.
- Wood Posts
  - Post Nos. 1 -2, 60 -61 (BCT) . . 5½ in. x 7½ in. by 42½-in. long
- Steel Foundation Tube Length . . . . . 6 ft
- Wood Spacer Blocks
  - Post Nos. 3 - 59 . . . . 6 in. x 12 in. by 14-in. long
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1997 GMC C2500 ¾-ton pickup
  - Curb . . . . 4345 lbs
  - Test Inertial . . . . 4411 lbs
  - Gross Static . . . . 4411 lbs
- Vehicle Speed
  - Impact . . . . 60.2 mph
  - Exit (resultant) . . . . 37.0 mph
- Vehicle Angle
  - Impact (trajectory) . . . . 25.6 deg
  - Exit (trajectory) . . . . 12.9 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 10.67 g's < 20 g's
  - Lateral (not required) . . . . 8.97 g's
- Occupant Impact Velocity
  - Longitudinal . . . . 25.00 ft/s < 39.37 ft/s
  - Lateral (not required) . . . . 5.61 ft/s
- Vehicle Damage . . . . Moderate
  - TAD[31] 1-RFQ-5
  - SAE[32] 01RYEW7
- Vehicle Stopping Distance . . . . 92 ft-10 in. downstream, 2 ft laterally
- Barrier Damage . . . . Moderate
- Maximum Deflections
  - Permanent Set . . . . 12 in.
  - Dynamic . . . . 17 ½ in.
- Working Width . . . . 37 in.

Figure A-6. Summary of Test Results and Sequential Photographs (English), Test NPG-6

APPENDIX B

Accelerometer and Rate Transducer Data Analysis, Test NPG-1

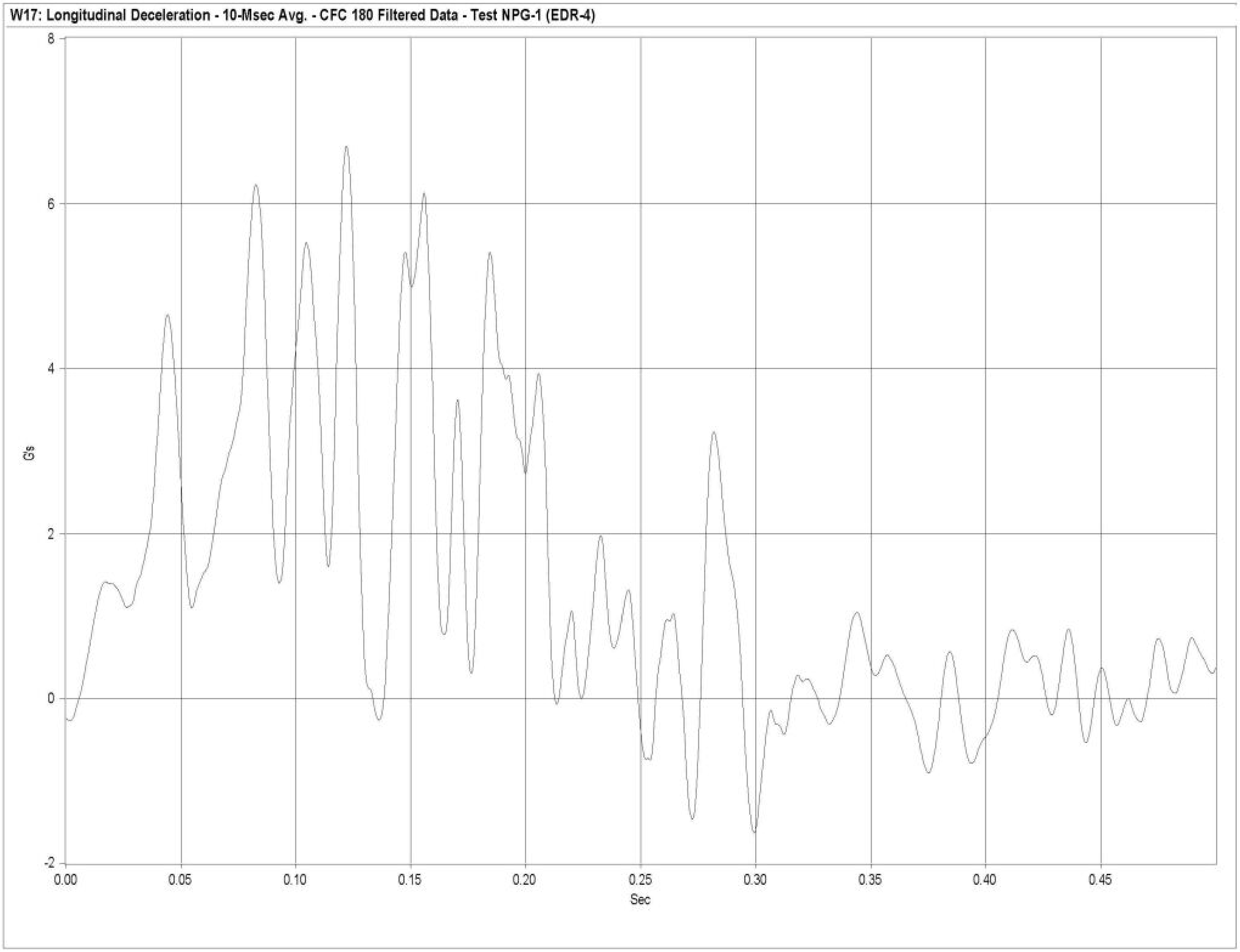


Figure B-1. Graph of Longitudinal Deceleration Test NPG-1

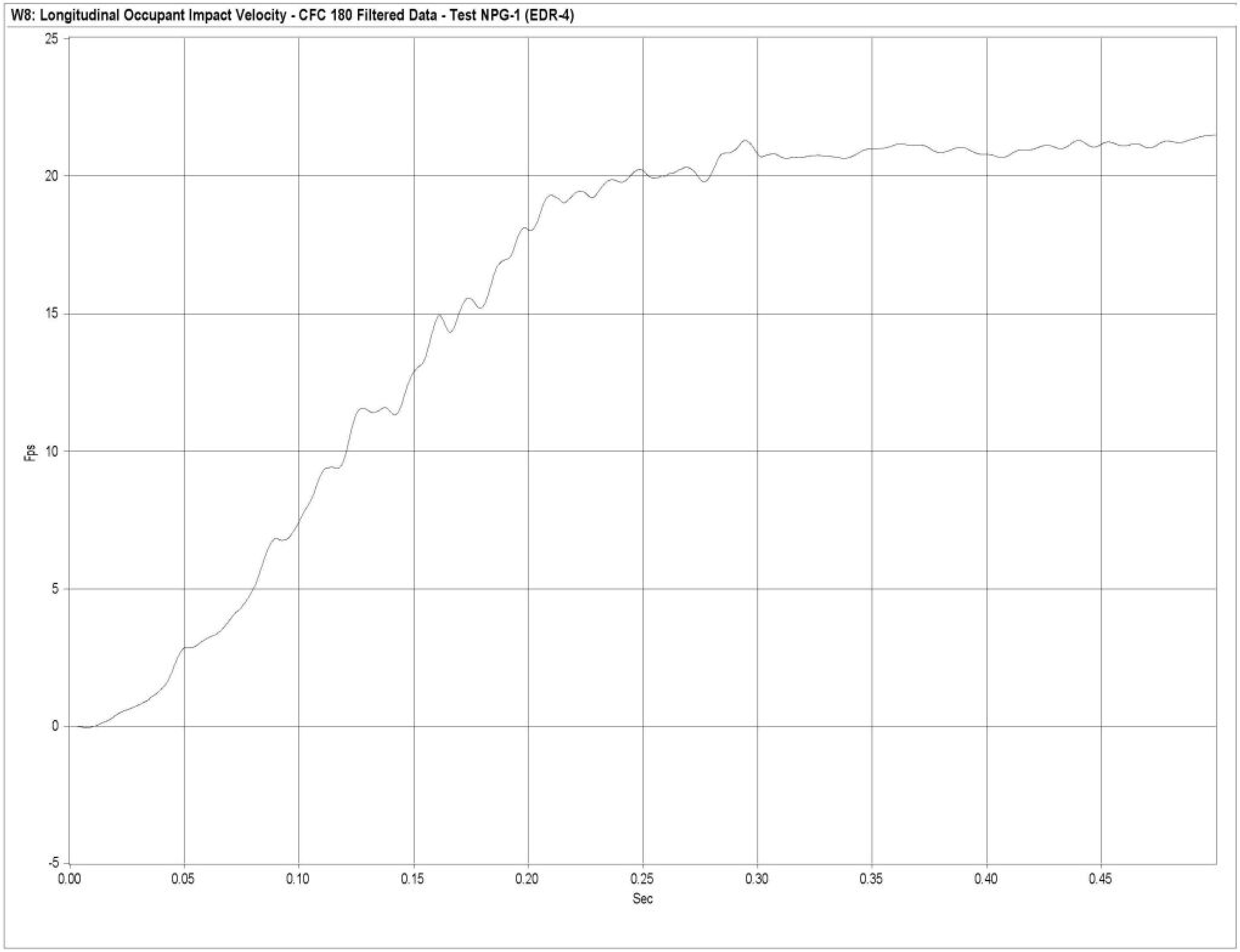


Figure B-2. Graph of Longitudinal Occupant Impact Velocity, Test NPG-1

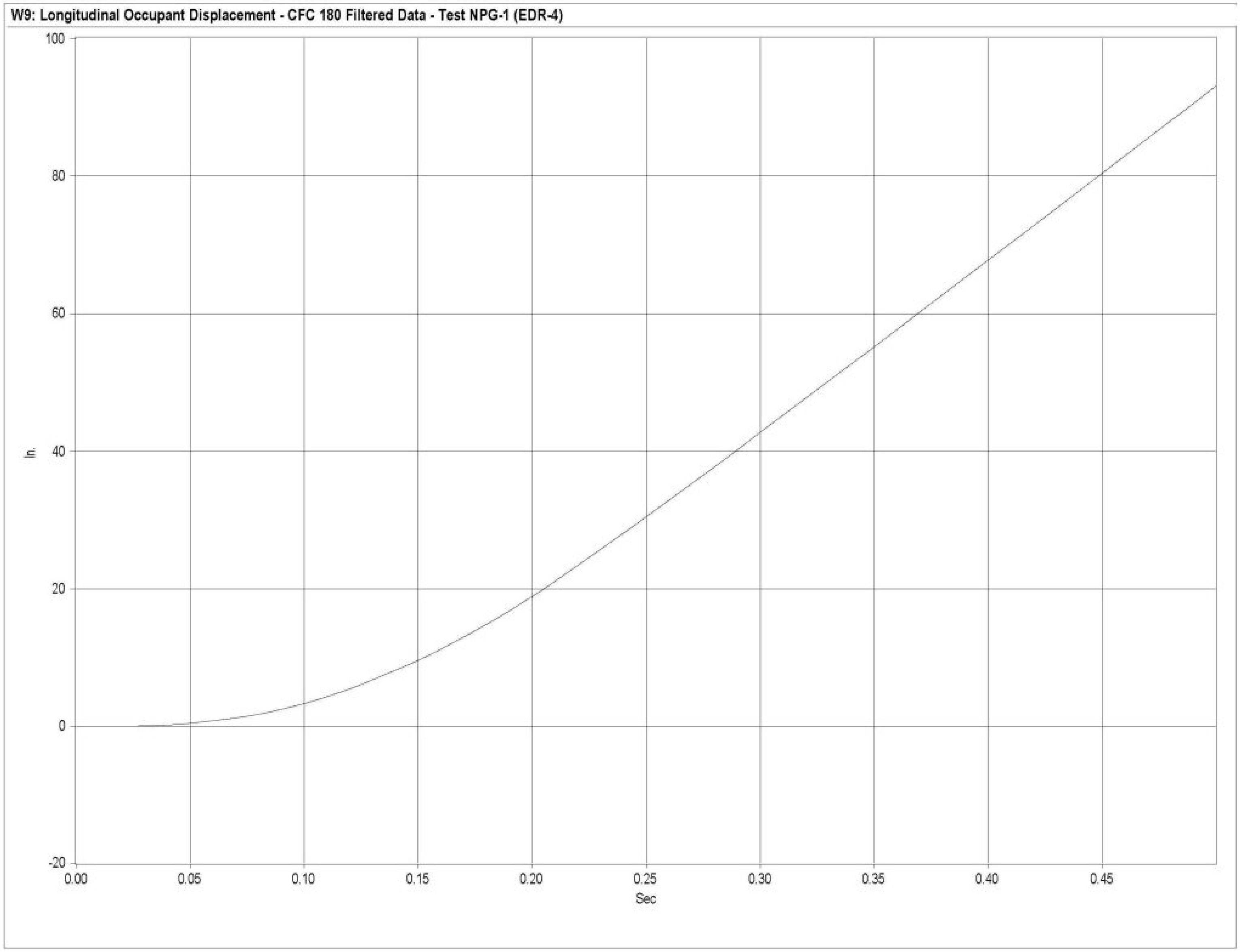


Figure B-3. Graph of Longitudinal Occupant Displacement, Test NPG-1

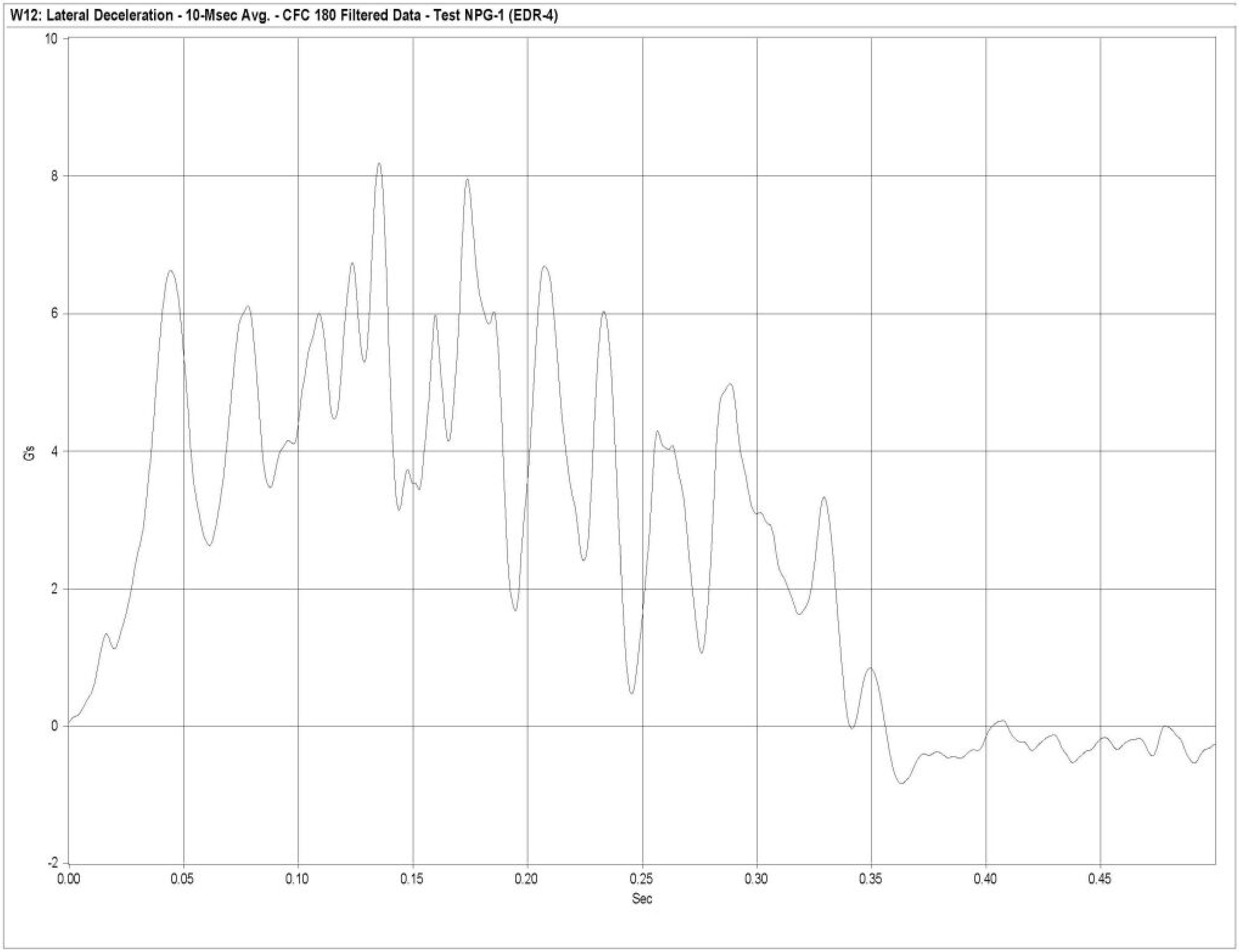


Figure B-4. Graph of Lateral Deceleration, Test NPG-1

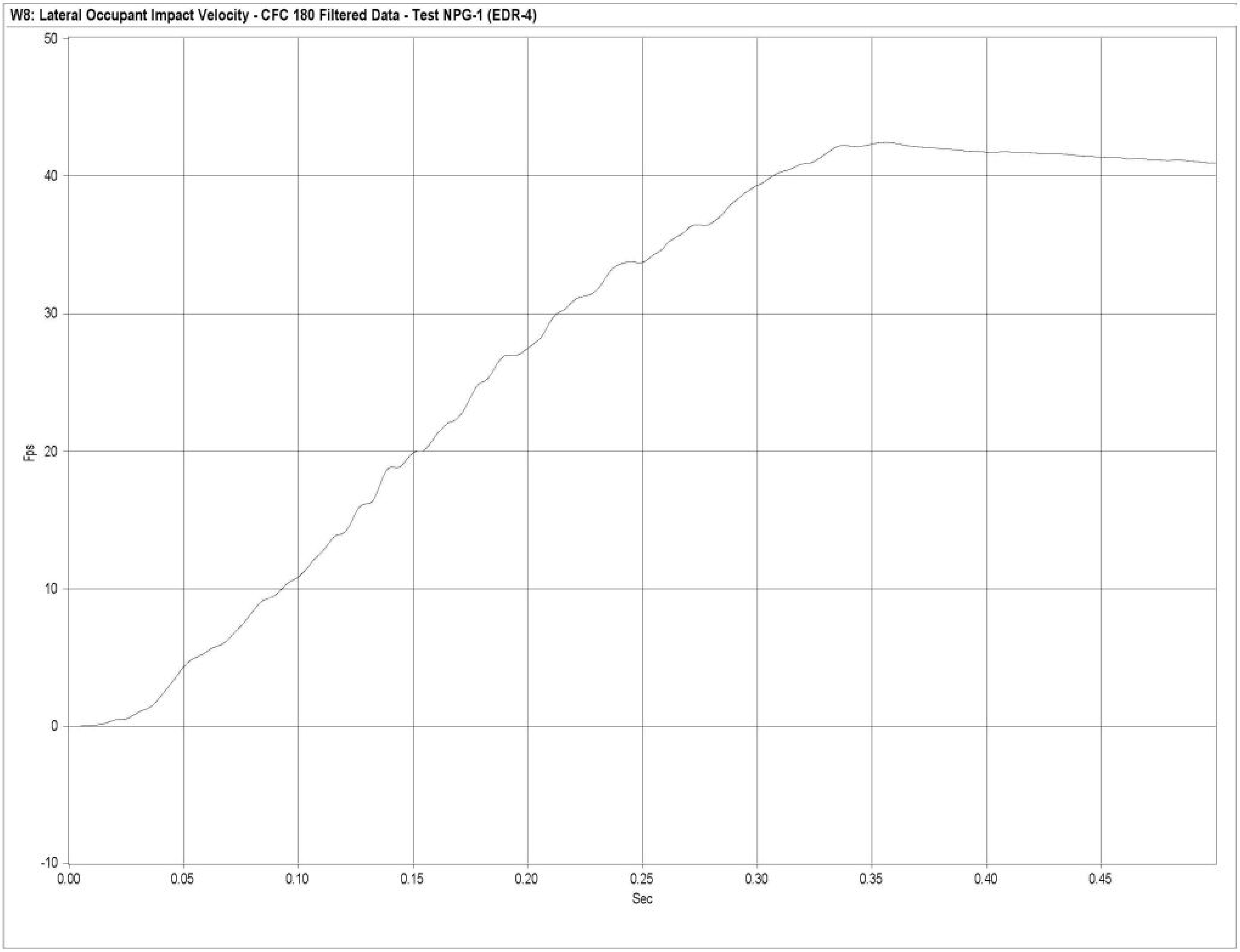


Figure B-5. Graph of Lateral Occupant Impact Velocity, Test NPG-1

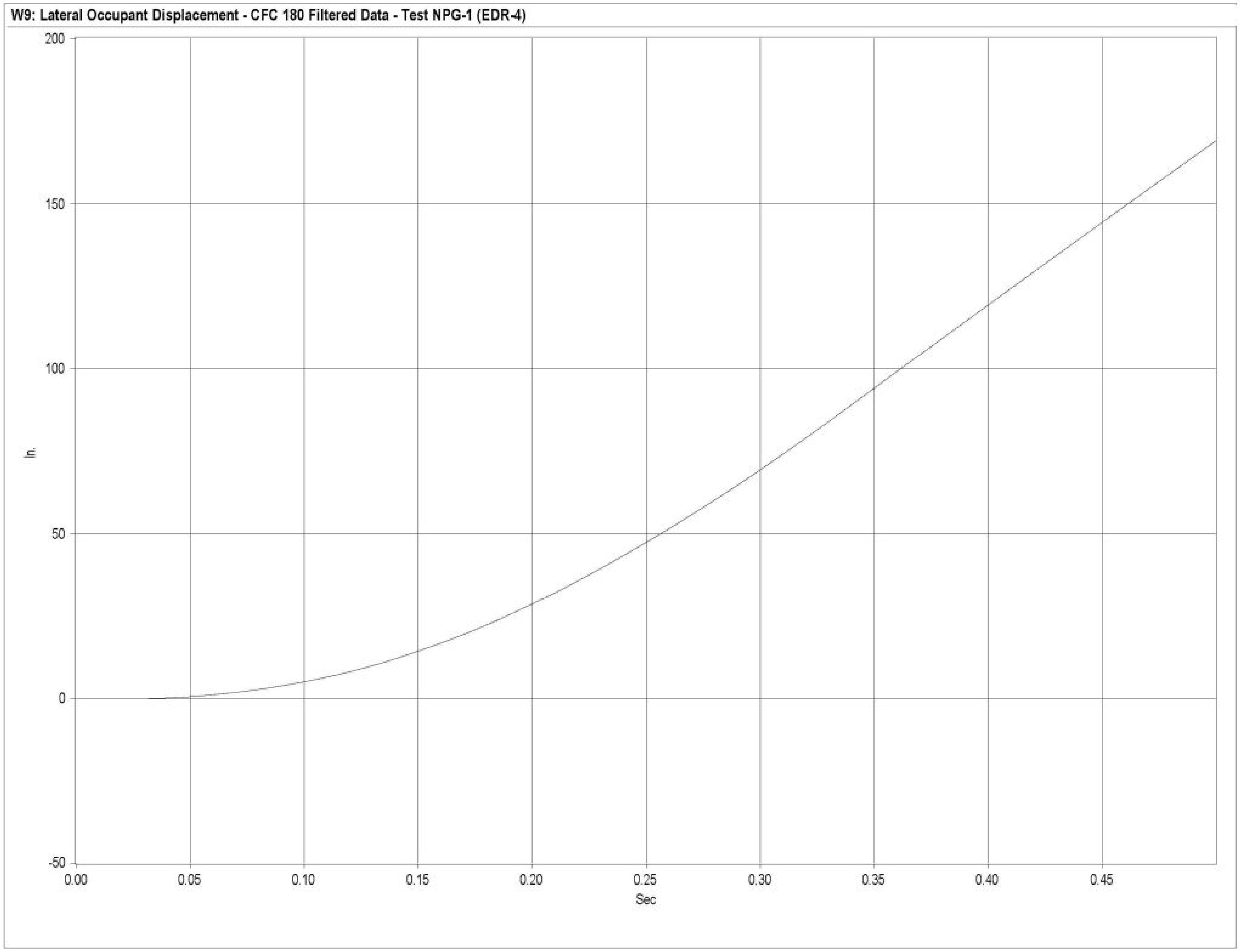


Figure B-6. Graph of Lateral Occupant Displacement, Test NPG-1

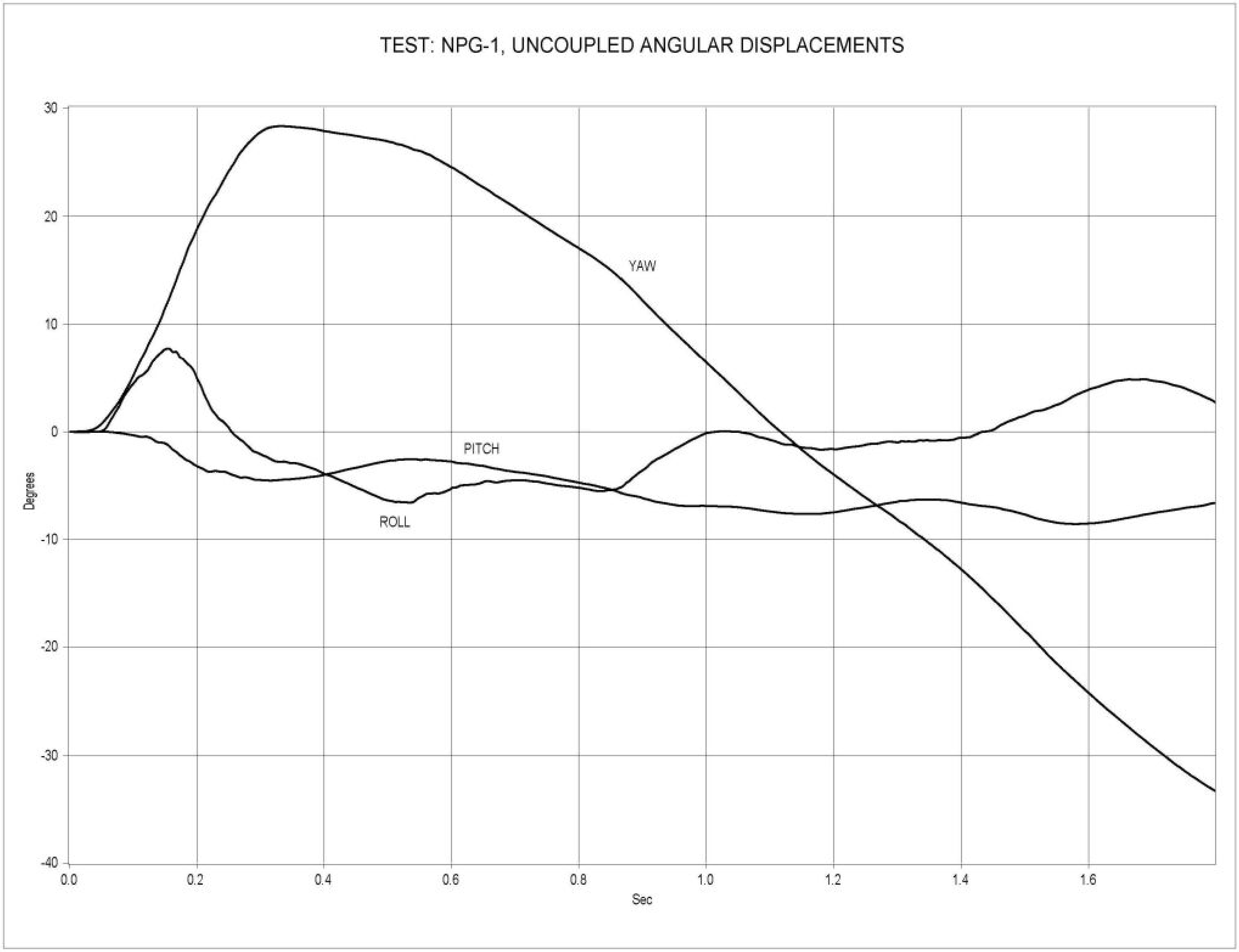


Figure B-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test NPG-1

APPENDIX C

Accelerometer and Rate Transducer Data Analysis, Test NPG-2

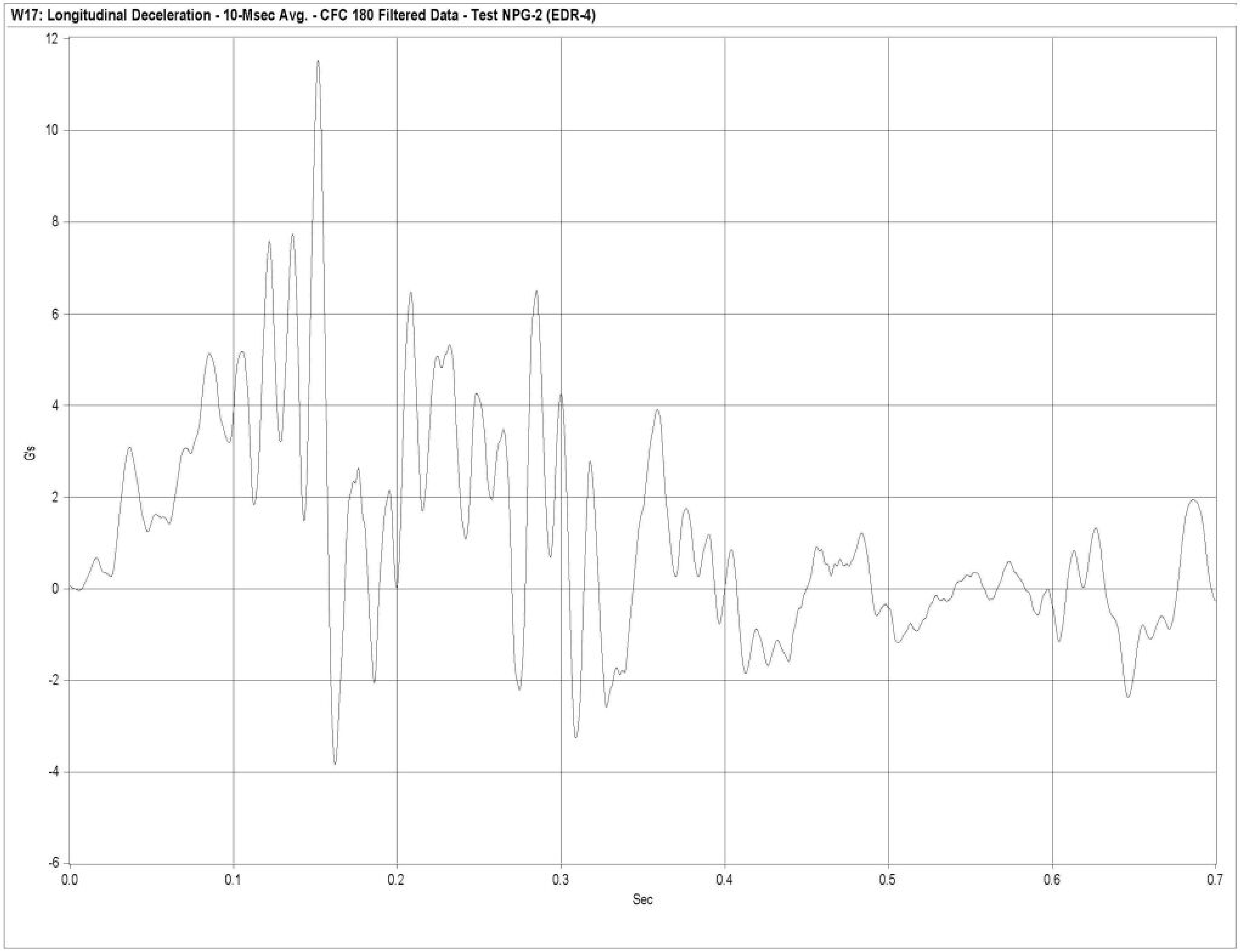


Figure C-1. Graph of Longitudinal Deceleration Test NPG-2

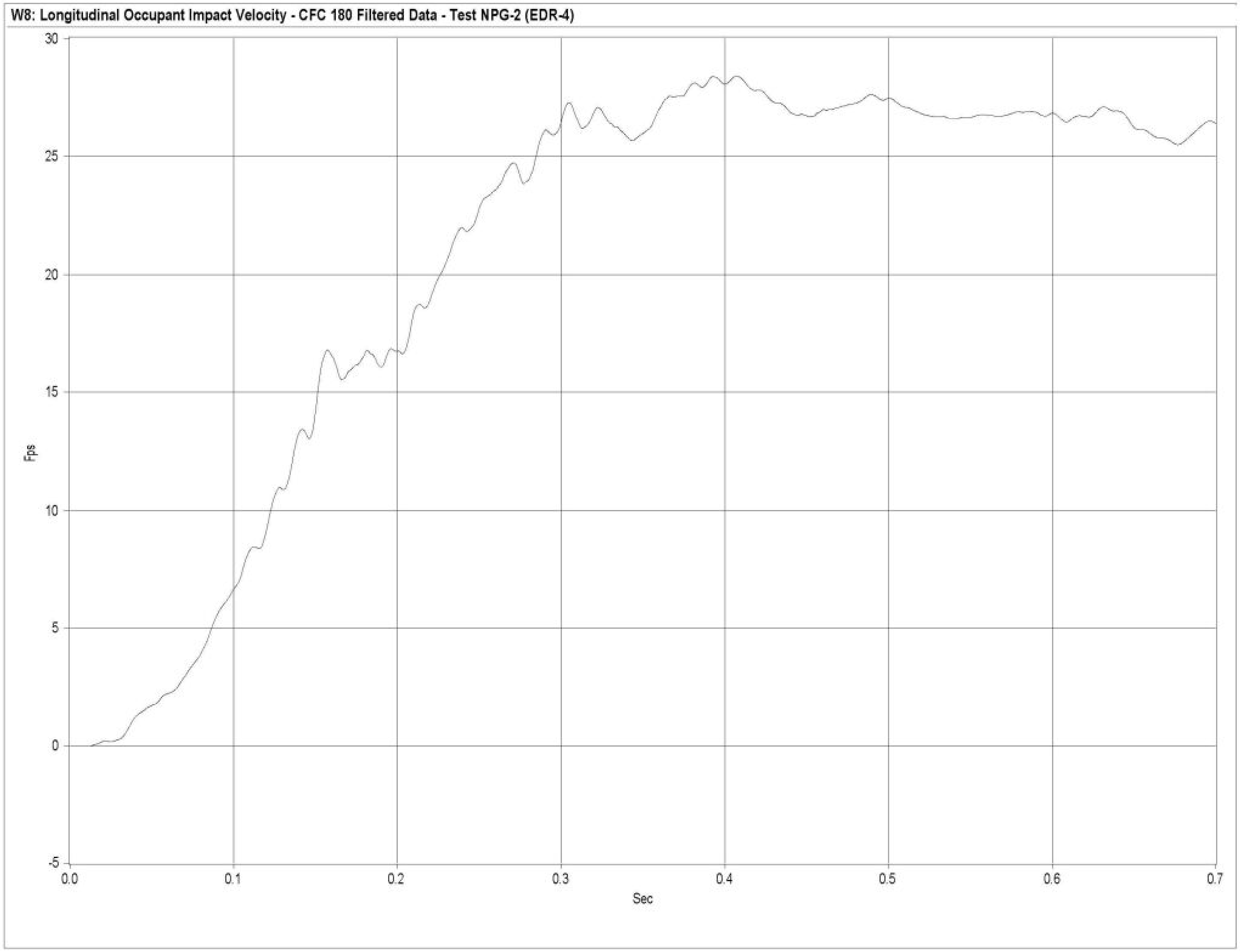


Figure C-2. Graph of Longitudinal Occupant Impact Velocity, Test NPG-2

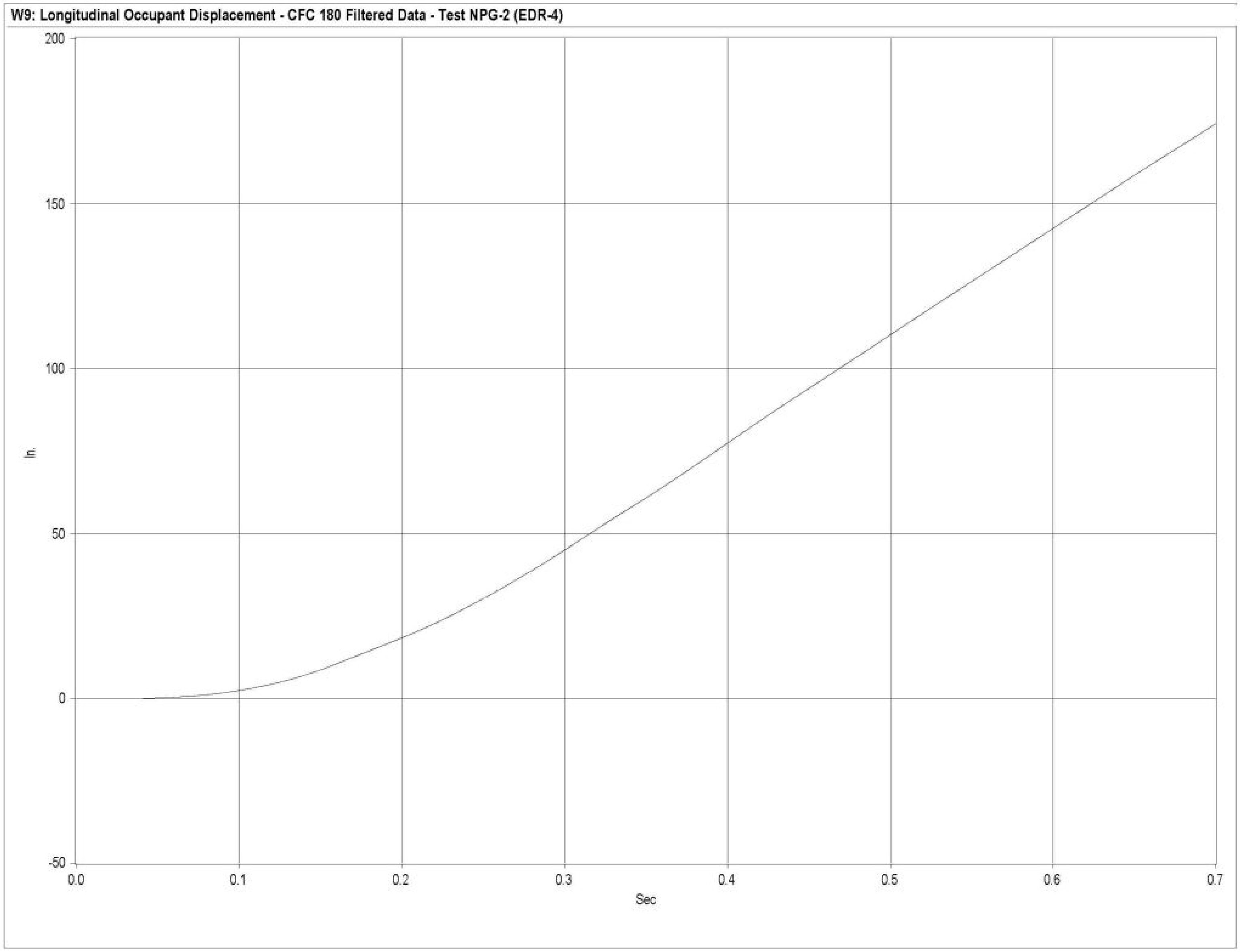


Figure C-3. Graph of Longitudinal Occupant Displacement, Test NPG-2

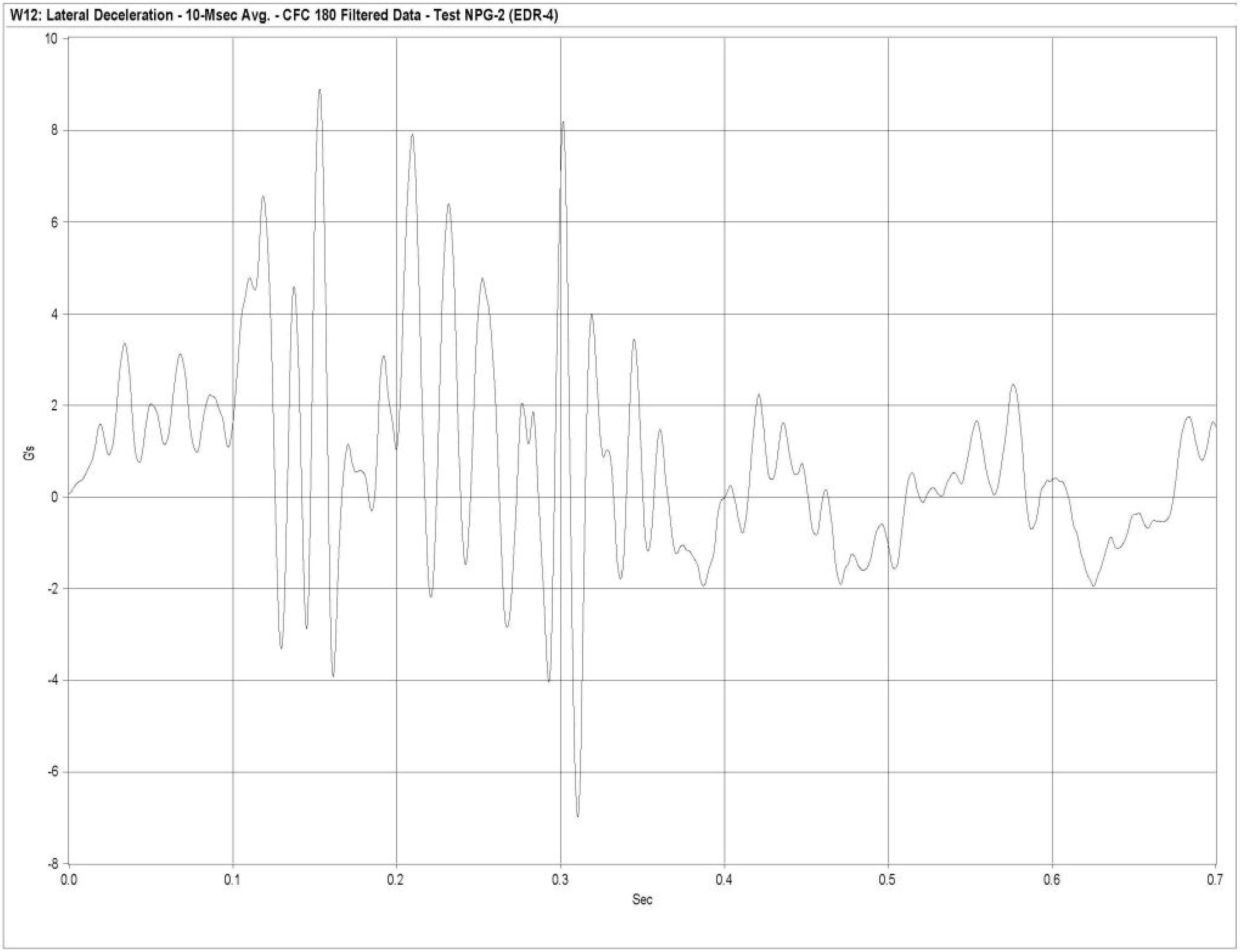


Figure C-4. Graph of Lateral Deceleration, Test NPG-2

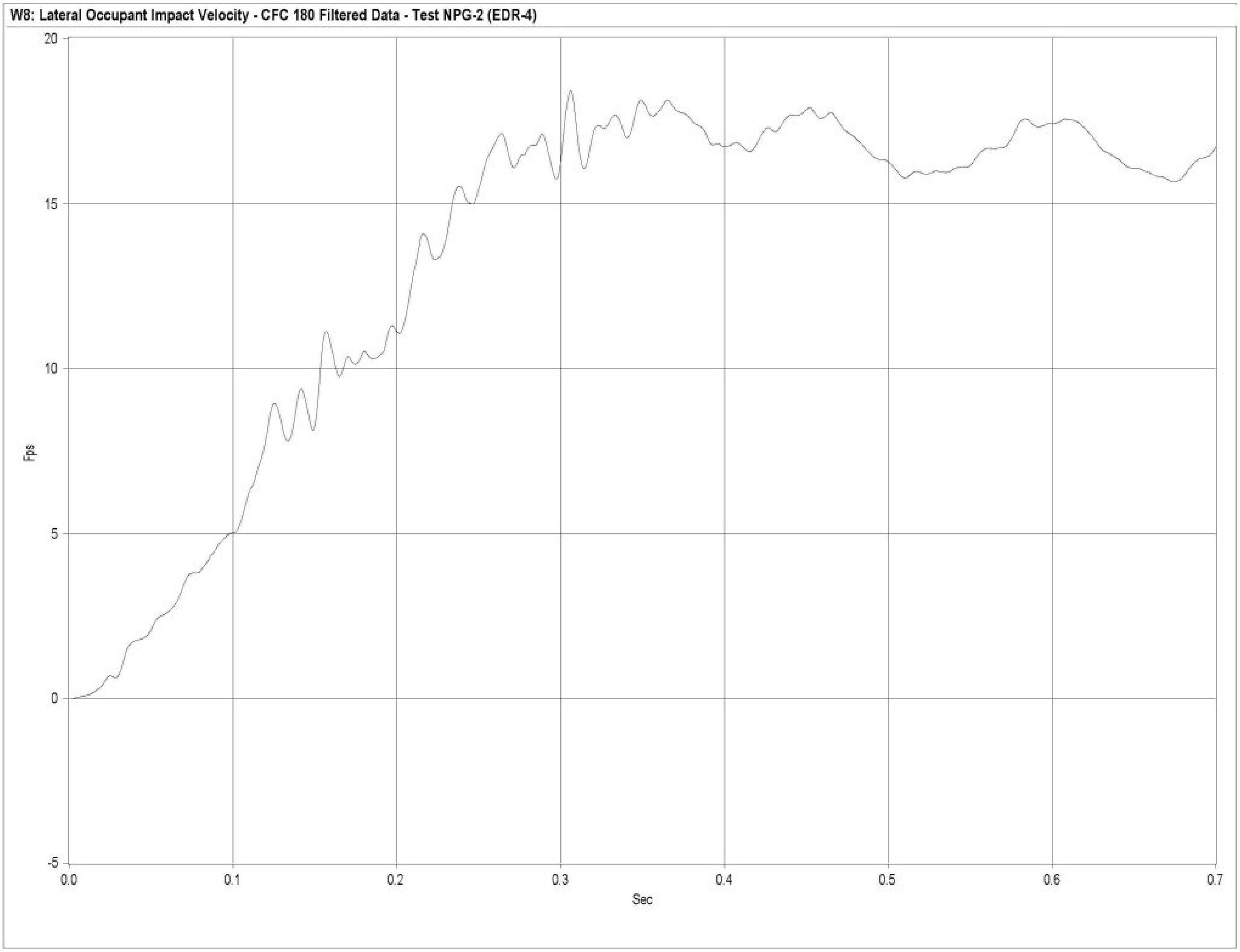


Figure C-5. Graph of Lateral Occupant Impact Velocity, Test NPG-2

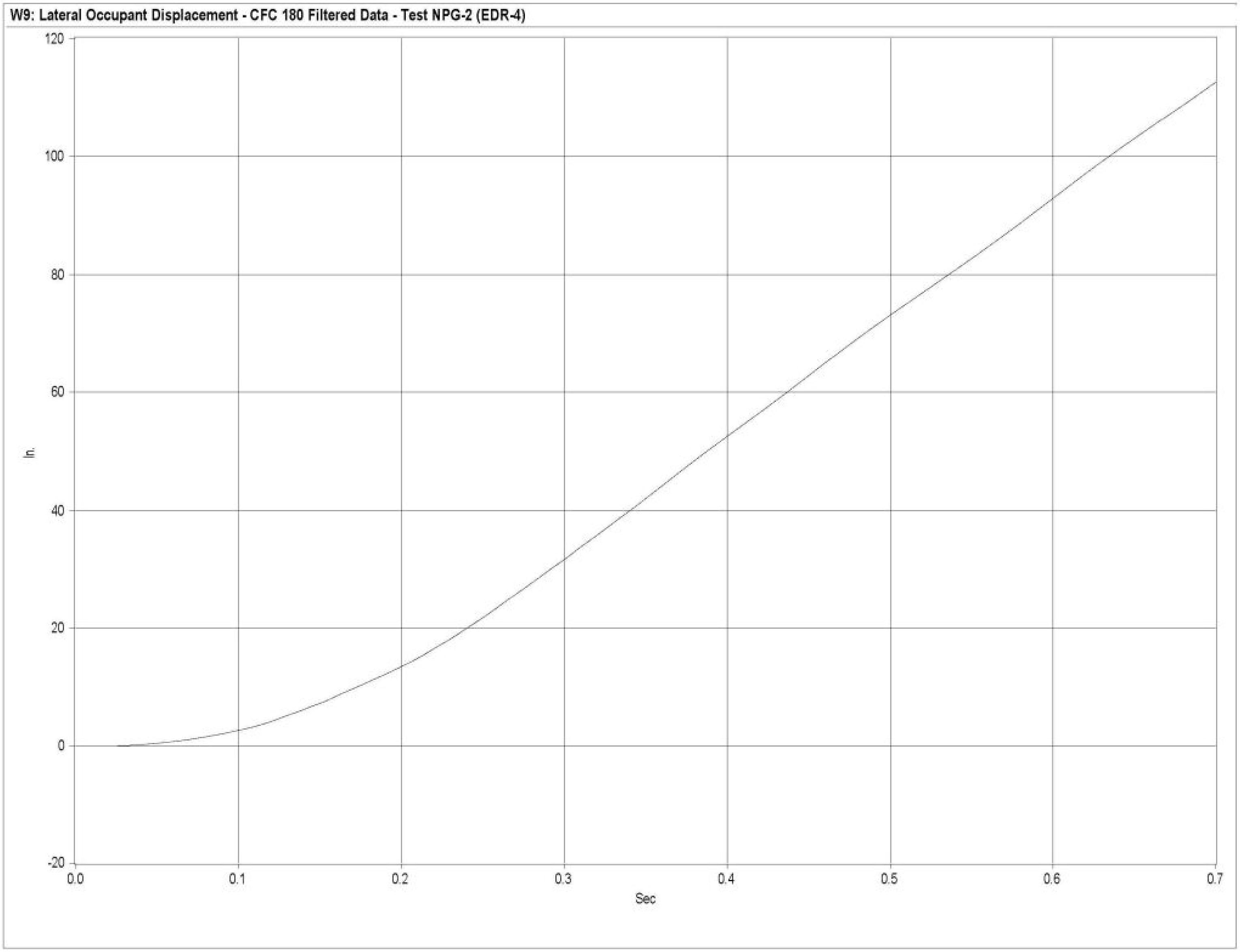


Figure C-6. Graph of Lateral Occupant Displacement, Test NPG-2

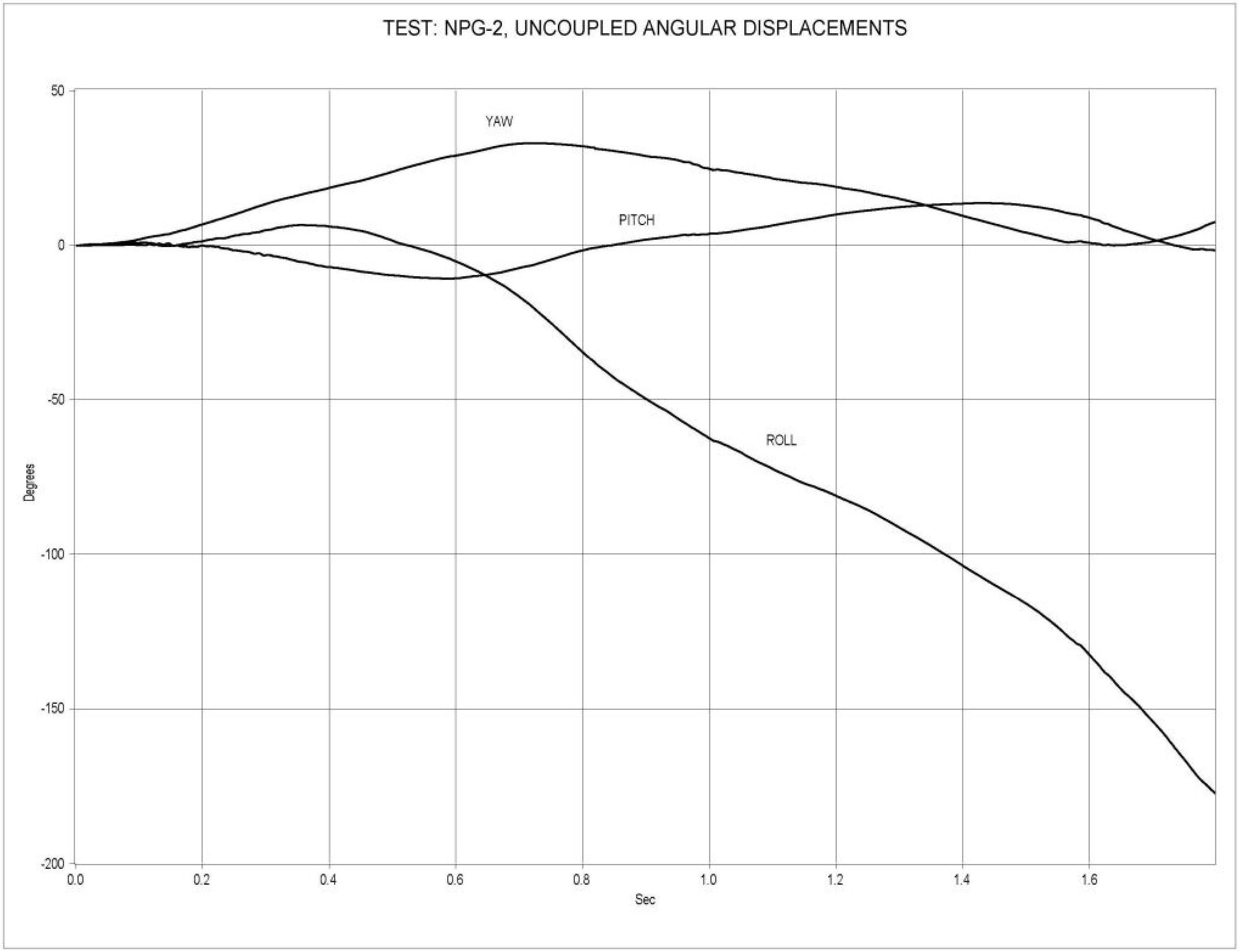


Figure C-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test NPG-2

APPENDIX D

Occupant Compartment Deformation Data

VEHICLE PRE/POST CRUSH INFO

TEST: NPG-3
VEHICLE: 1995/Chevy/2500/White

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	57.25	-28.25	-0.25	57.5	-28.25	-0.75	0.25	0	-0.5
2	57.5	-22	-2	57.5	-22	-2	0	0	0
3	57	-14.75	-2.75	57	-15	-2.75	0	-0.25	0
4	53.75	-6	-0.75	53.75	-6	-1.5	0	0	-0.75
5	53.25	-1	2	53.5	1	1.75	0.25	2	-0.25
6	51.25	-27.75	-5.25	51.5	-27.25	-5	0.25	0.5	0.25
7	50.75	-19.25	-6	51.5	-18.5	-5.75	0.75	0.75	0.25
8	50.75	-12	-5.5	51	-11.5	-5.25	0.25	0.5	0.25
9	48.75	-6.25	-2	48.75	-6	-2	0	0.25	0
10	48.5	-0.5	-0.75	48.5	-0.75	-0.5	0	-0.25	0.25
11	45	-27.75	-6	44.75	-26.75	-6	-0.25	1	0
12	44.75	-21	-6	45	-20.75	-6	0.25	0.25	0
13	45	-12.75	-6.5	45.5	-12.5	-6.25	0.5	0.25	0.25
14	44.5	-5.75	-1.75	44.5	-5.5	-1.75	0	0.25	0
15	44.5	-0.75	-1	44.5	-0.75	-0.75	0	0	0.25
16	40.25	-26.75	-6	40.5	-26.5	-5.75	0.25	0.25	0.25
17	40.75	-20.75	-6.25	41	-20.5	-6	0.25	0.25	0.25
18	40.5	-13.25	-6.75	40.5	-12.25	-6.5	0	1	0.25
19	39	-3.75	-1.5	39	-3.25	-1.25	0	0.5	0.25
20	35.75	-26.5	-6	35.75	-26	-5.75	0	0.5	0.25
21	34.75	-18.75	-6.25	34.75	-18.75	-6.25	0	0	0
22	35.25	-12.5	-6.5	35.25	-12.25	-6.5	0	0.25	0
23	33.25	-3.5	-1.25	33.5	-4	-1.75	0.25	-0.5	-0.5
24	29	-19.75	-6	29.75	-20.25	-6	0.75	-0.5	0
25	29.75	-14.5	-6.25	30	-14.5	-6.25	0.25	0	0
26	26.25	-17.5	-5.25	26.5	-17.5	-5.25	0.25	0	0
27	27	-4.75	-2	26.75	-4.75	-1.75	-0.25	0	0.25
28	28	-32.75	0	28	-32.25	0	0	0.5	0
29	43.25	-26.25	26.25	42.5	-26	25.5	-0.75	0.25	-0.75
30	43.5	-2.75	25.5	43.5	-2.75	25.5	0	0	0

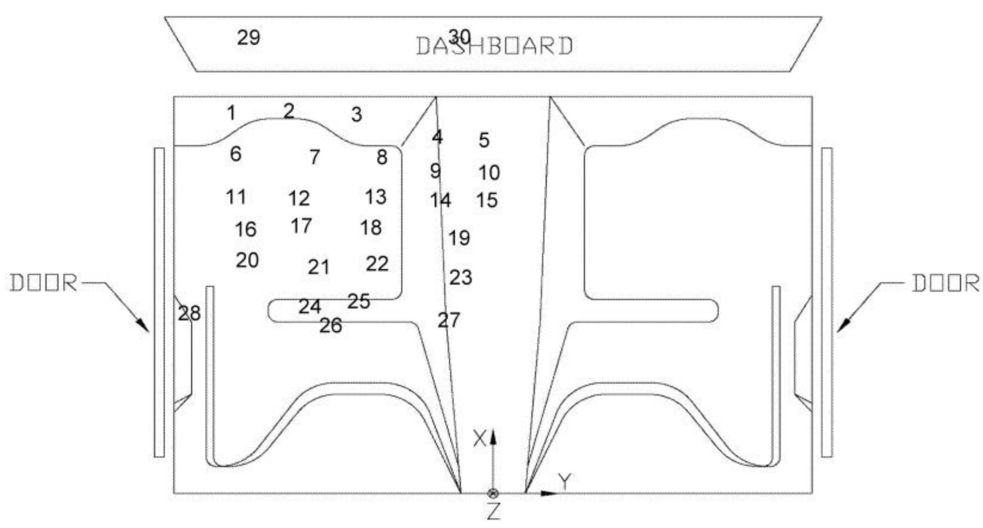


Figure D-1. Occupant Compartment Deformation Data, Test NPG-3

VEHICLE PRE/POST CRUSH INFO

TEST: NPG-4
VEHICLE: 1995/GMC

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	53	3.5	-1	52.75	3.5	-2.25	-0.25	0	-1.25
2	53.75	8.5	0.25	53.75	8.25	-1	0	-0.25	-1.25
3	54.5	10.5	3.25	55	9.75	2.25	0.5	-0.75	-1
4	58	18.75	2.25	57	18.5	1.25	-1	-0.25	-1
5	57.5	27.5	1.25	57	26.75	0.5	-0.5	-0.75	-0.75
6	48.5	2.5	0.75	48.25	2.5	-0.5	-0.25	0	-1.25
7	48.25	8.25	1	48.25	8	0	0	-0.25	-1
8	51.25	15.25	6.75	51	14.5	5.5	-0.25	-0.75	-1.25
9	51.25	21.25	6.75	50.75	20.5	5.5	-0.5	-0.75	-1.25
10	51.5	27	5.75	51.25	20.75	5.25	-0.25	-6.25	-0.5
11	42.25	3	1	42.25	3	0	0	0	-1
12	42.75	9.5	4.75	42.75	9.25	4	0	-0.25	-0.75
13	43.5	16.25	6.25	43.25	16	5.5	-0.25	-0.25	-0.75
14	42.75	24.75	6.25	43	24.75	6	0.25	0	-0.25
15	37	1.5	1.5	37	1.5	0.75	0	0	-0.75
16	37.75	10.25	6	37.75	9.75	5.25	0	-0.5	-0.75
17	37.75	19	6.25	37.75	18.75	5.75	0	-0.25	-0.5
18	37	25.75	6.5	37.5	25.75	6	0.5	0	-0.5
19	30.25	3	2	30	3	1.25	-0.25	0	-0.75
20	31.25	11.5	6.25	31.25	11.25	5.75	0	-0.25	-0.5
21	30.75	24.25	6	31	24.25	5.75	0.25	0	-0.25
22	31	30.5	7.75	31	30.5	7.75	0	0	0
23	17.5	5	2.25	17.5	5	2	0	0	-0.25
24	17.25	16.25	6.25	17.25	16.25	6	0	0	-0.25
25	26	32.25	0	26	32.25	0	0	0	0
26	43.5	0	-25.5	43.5	0	-25.5	0	0	0
27	51.25	14.5	-21.75	51.25	14.5	-21.75	0	0	0
28	48.5	26.75	-21.5	48.5	26.75	-21.5	0	0	0
29									
30									

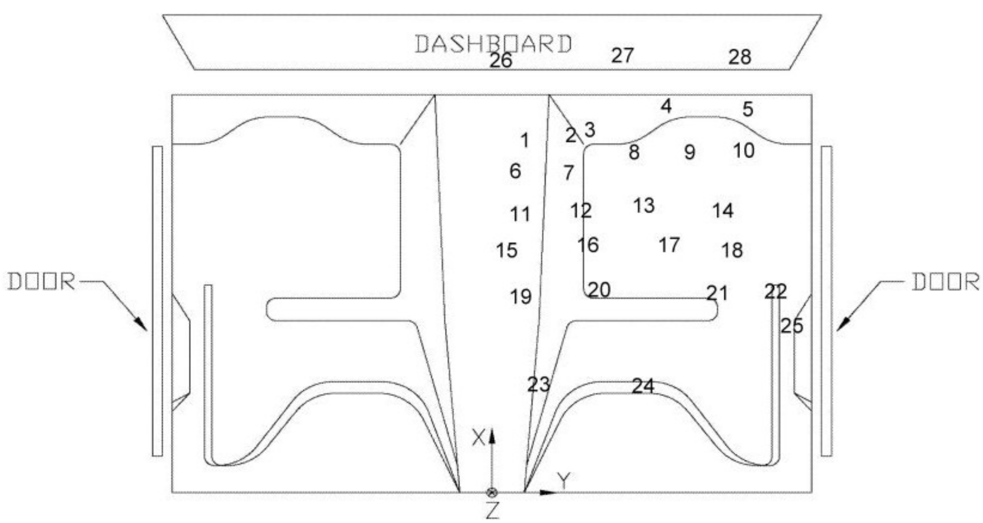


Figure D-2. Occupant Compartment Deformation Data, Test NPG-4

VEHICLE PRE/POST CRUSH INFO

TEST: NPG-5
VEHICLE: 1997/Chevy

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	52.5	5.25	-1	52.5	5.25	-1.25	0	0	-0.25
2	56.5	10.25	0	56.75	10	-0.75	0.25	-0.25	-0.75
3	59	17.25	1.25	59.25	17	1	0.25	-0.25	-0.25
4	58.5	24.25	1	58.5	23.75	0.5	0	-0.5	-0.5
5	48.5	4	0.5	48.5	4	0	0	0	-0.5
6	51.5	9.25	3.5	51.75	9	2.75	0.25	-0.25	-0.75
7	54	15.25	5	54	14.5	4.5	0	-0.75	-0.5
8	54	21.75	5.5	54	21.25	5	0	-0.5	-0.5
9	54.25	28	5	54.5	27.5	4.5	0.25	-0.5	-0.5
10	43.5	3.75	0.75	43.5	3.75	0.25	0	0	-0.5
11	45	11.75	6.5	45.25	11.5	6	0.25	-0.25	-0.5
12	47.25	18.75	7	47.5	18	6.5	0.25	-0.75	-0.5
13	47	27.75	7.25	47	27.5	6.75	0	-0.25	-0.5
14	36.5	5	1.5	36.5	5	1	0	0	-0.5
15	39.5	9.5	5.25	39.25	9.25	4.5	-0.25	-0.25	-0.75
16	41.25	16.25	6.5	41	15.5	6.25	-0.25	-0.75	-0.25
17	41.5	24	7	41.75	23.75	6.5	0.25	-0.25	-0.5
18	41.5	27.5	7.25	42	27.5	7	0.5	0	-0.25
19	31.25	4.75	1.75	31.25	4.75	1.25	0	0	-0.5
20	32	11.5	6	32.25	11.5	5.75	0.25	0	-0.25
21	34.5	20.5	6.25	34.5	20.75	6	0	0.25	-0.25
22	33.75	25.75	6.75	33.75	26	6.5	0	0.25	-0.25
23	26.75	12	5.5	26.5	12.25	5.5	-0.25	0.25	0
24	27.5	28.75	7	27.25	28.75	7	-0.25	0	0
25	21.5	17.25	6.25	21.5	17.5	6	0	0.25	-0.25
26	28.25	32.25	-10	28.25	32.75	-10	0	0.5	0
27	42.25	0	-24.5	42.5	0	-25.75	0.25	0	-1.25
28	40	24.75	-25.5	40	24.75	-25	0	0	0.5
29									
30									

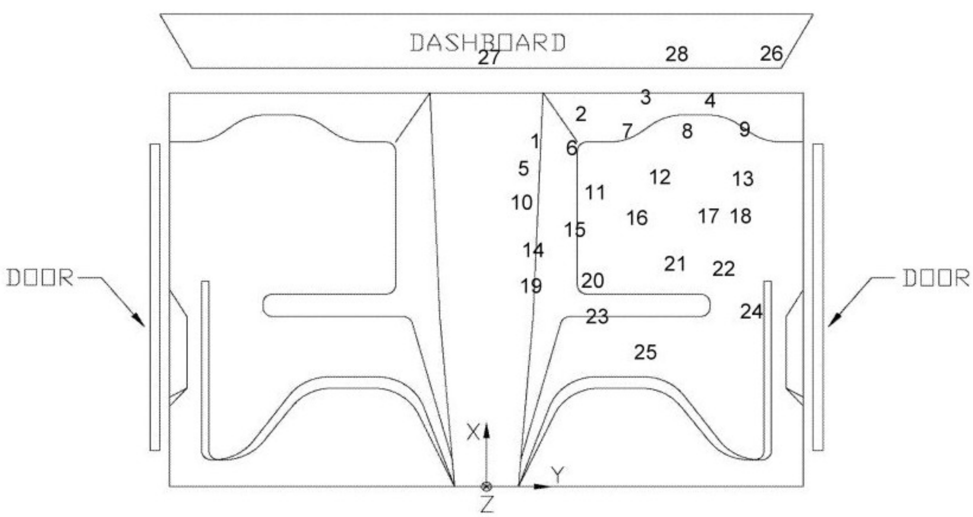


Figure D-3. Occupant Compartment Deformation Data, Test NPG-5

VEHICLE PRE/POST CRUSH INFO

TEST: NPG-6
VEHICLE: 1997 GMC

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	53	4.5	2	52.75	4.5	4	-0.25	0	2
2	56.5	10.25	1.5	56.75	9.25	2.5	0.25	-1	1
3	59.25	17	0.25	59.75	15.75	0.5	0.5	-1.25	0.25
4	58.5	23.75	0	58.75	22.5	0	0.25	-1.25	0
5	48.25	4.75	-0.25	48.25	4.5	-2	0	-0.25	-1.75
6	52.5	9.25	-1.5	52.5	8.5	-0.25	0	-0.75	1.25
7	54.5	14.25	-3	55	12.75	-2.5	0.5	-1.5	0.5
8	54.75	20.75	-3.25	55	19.5	-3.25	0.25	-1.25	0
9	55	29	-3	55	27.25	-3	0	-1.75	0
10	43	5.25	-0.5	43	5.25	-1.75	0	0	-1.25
11	46.75	9	-3	46.75	8.5	-1.5	0	-0.5	1.5
12	48.5	16.5	-5.75	48.5	15.5	-4.75	0	-1	1
13	48.25	25.5	-5.5	48	24.75	-5.75	-0.25	-0.75	-0.25
14	39.5	5	-0.75	39.5	5	-1.25	0	0	-0.5
15	43.25	10.75	-5.5	43	9.25	-4.5	-0.25	-1.5	1
16	44.5	16.5	-5.75	44.5	15.25	-4.5	0	-1.25	1.25
17	44.75	26.25	-5.75	44.5	25	-5.75	-0.25	-1.25	0
18	35.75	4.75	-1	35.75	4.5	-0.75	0	-0.25	0.25
19	37.75	17.25	-5.5	37.5	15.75	-4.5	-0.25	-1.5	1
20	39.25	26.25	-5.75	39.25	25.5	-5.5	0	-0.75	0.25
21	30.25	4.25	-1.5	30	4.25	-0.25	-0.25	0	1.25
22	30.75	15.5	-5.5	31	14.75	-4.75	0.25	-0.75	0.75
23	32.25	26	-5.52	32	25	-5.25	-0.25	-1	0.27
24	32.5	31	-7.25	32.5	30.5	-6.75	0	-0.5	0.5
25	20.75	15.75	-5.5	20.75	15.5	-4.75	0	-0.25	0.75
26	20.5	25	-4.75	20	24.5	-4.5	-0.5	-0.5	0.25
27	25.25	30.25	8.75	24.5	30.5	9.75	-0.75	0.25	1
28	2.25	42.75	25.75	2.5	42.25	28.25	0.25	-0.5	2.5
29	25.25	40.25	26	25.5	40.25	27.25	0.25	0	1.25
30									

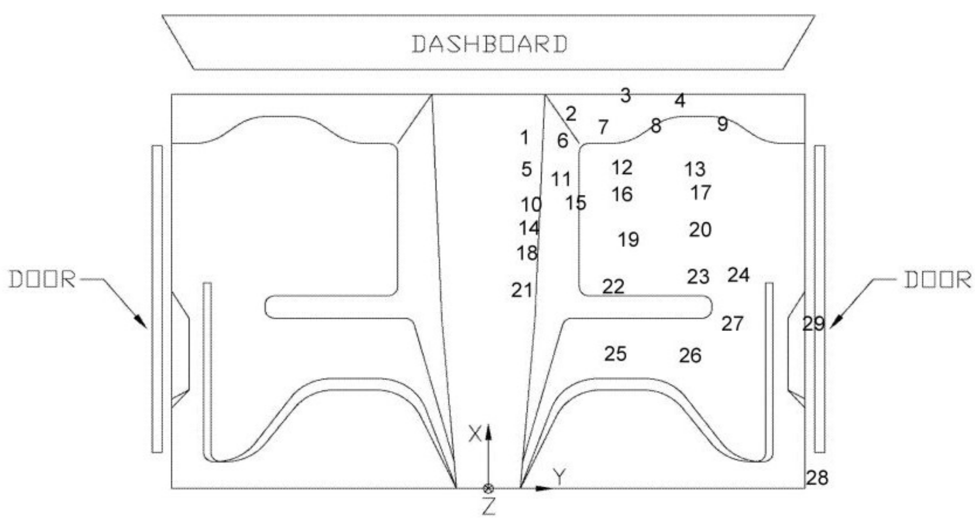


Figure D-4. Occupant Compartment Deformation Data, Test NPG-6

APPENDIX E

Accelerometer and Rate Transducer Data Analysis, Test NPG-3

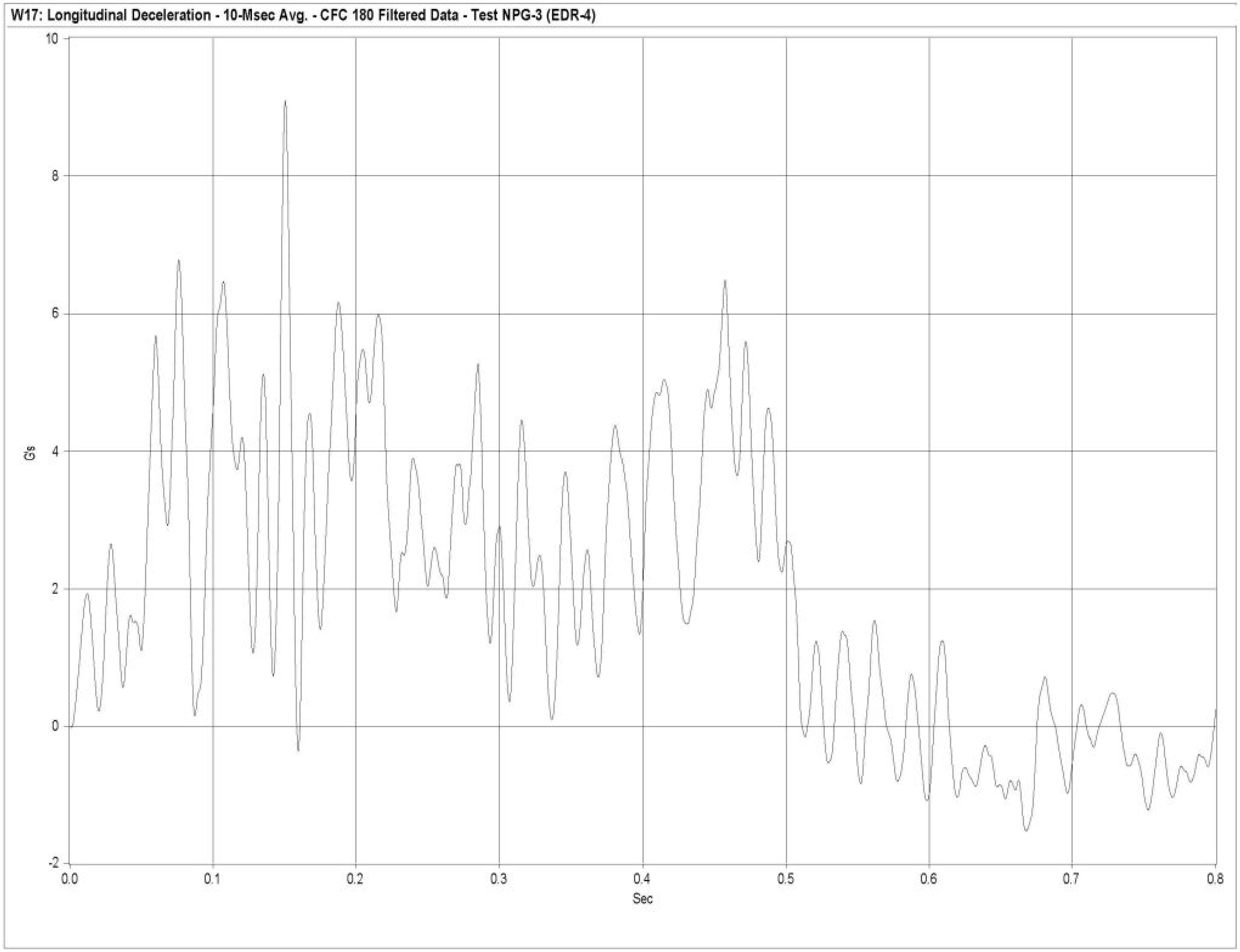


Figure E-1. Graph of Longitudinal Deceleration Test NPG-3

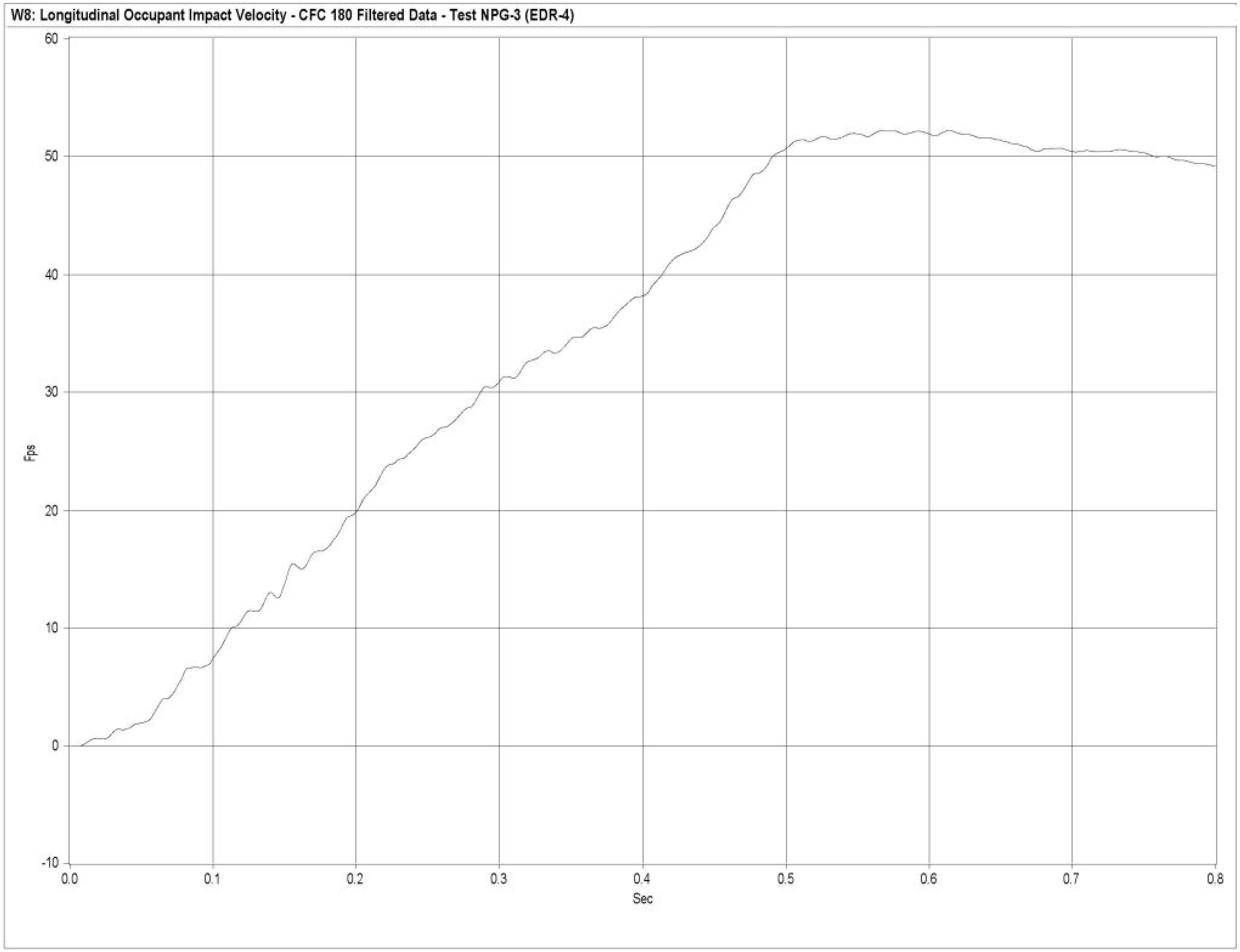


Figure E-2. Graph of Longitudinal Occupant Impact Velocity, Test NPG-3

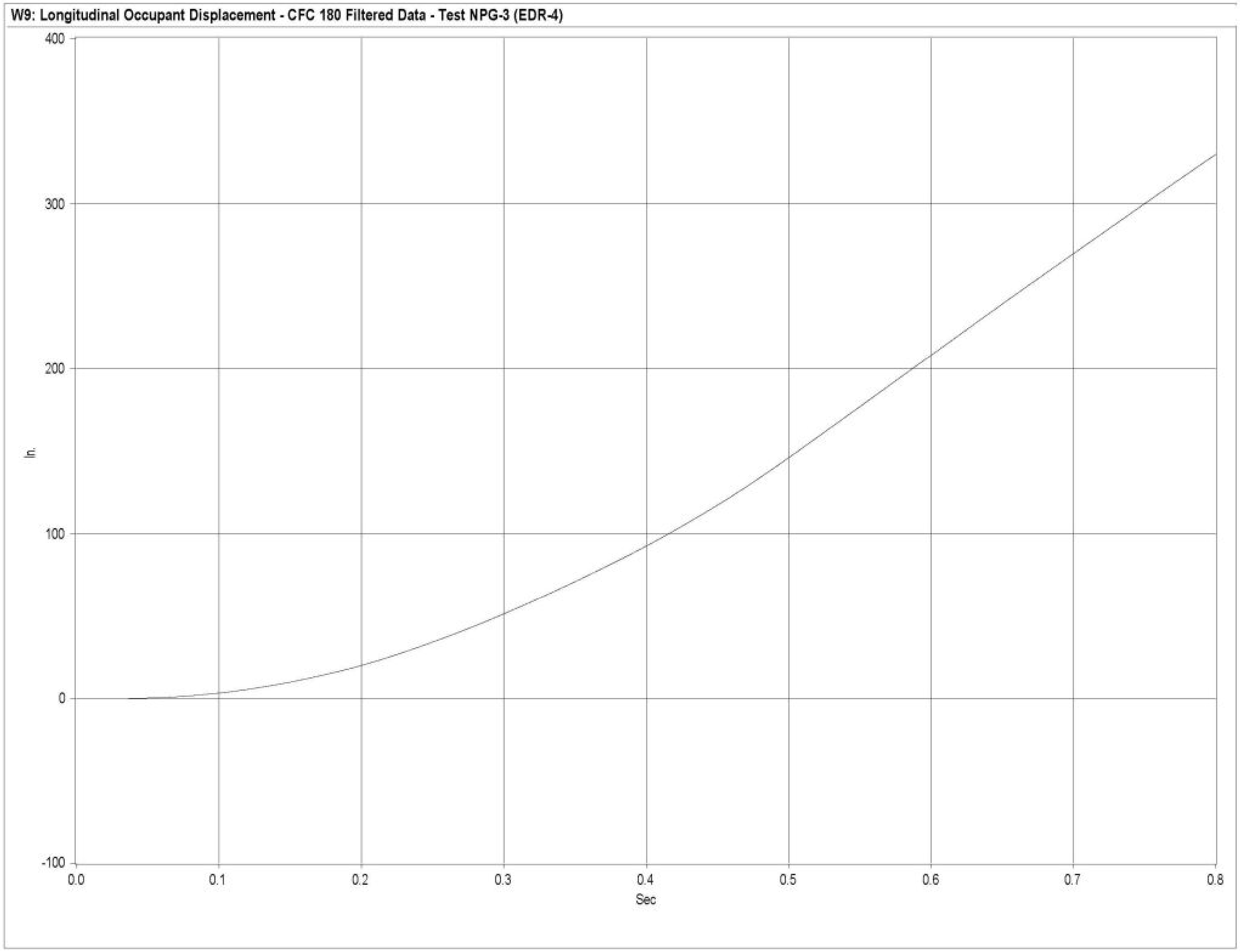


Figure E-3. Graph of Longitudinal Occupant Displacement, Test NPG-3

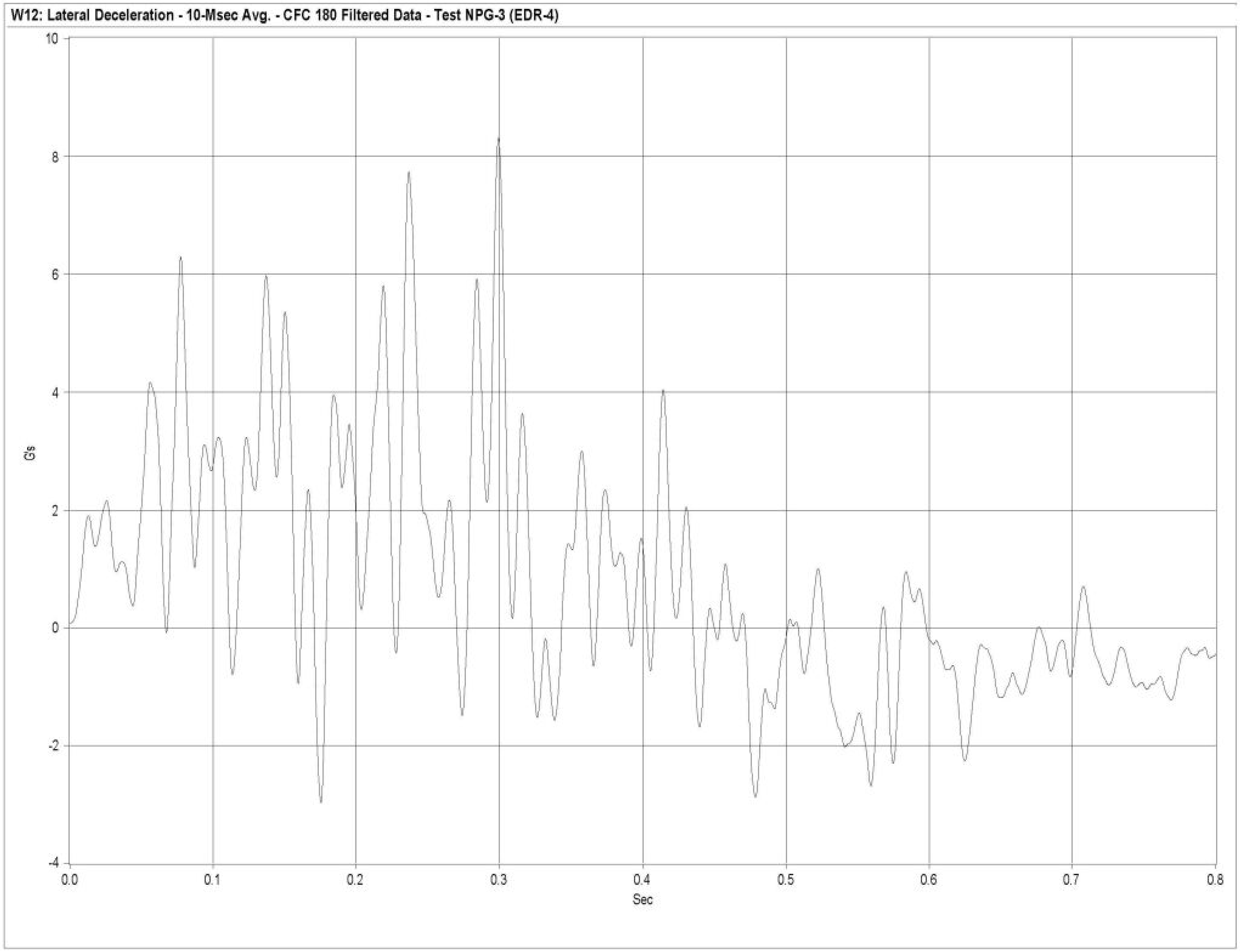


Figure E-4. Graph of Lateral Deceleration, Test NPG-3

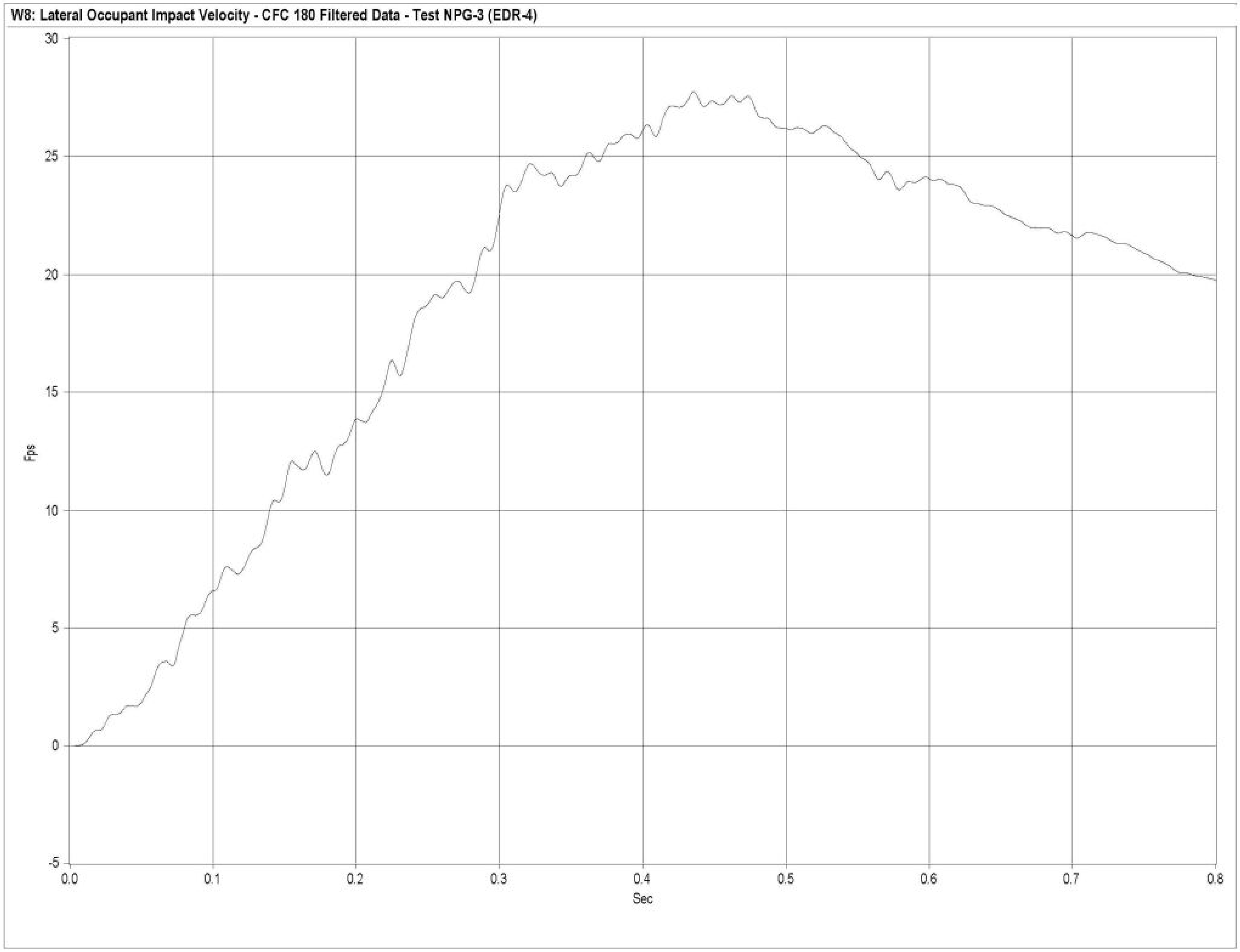


Figure E-5. Graph of Lateral Occupant Impact Velocity, Test NPG-3

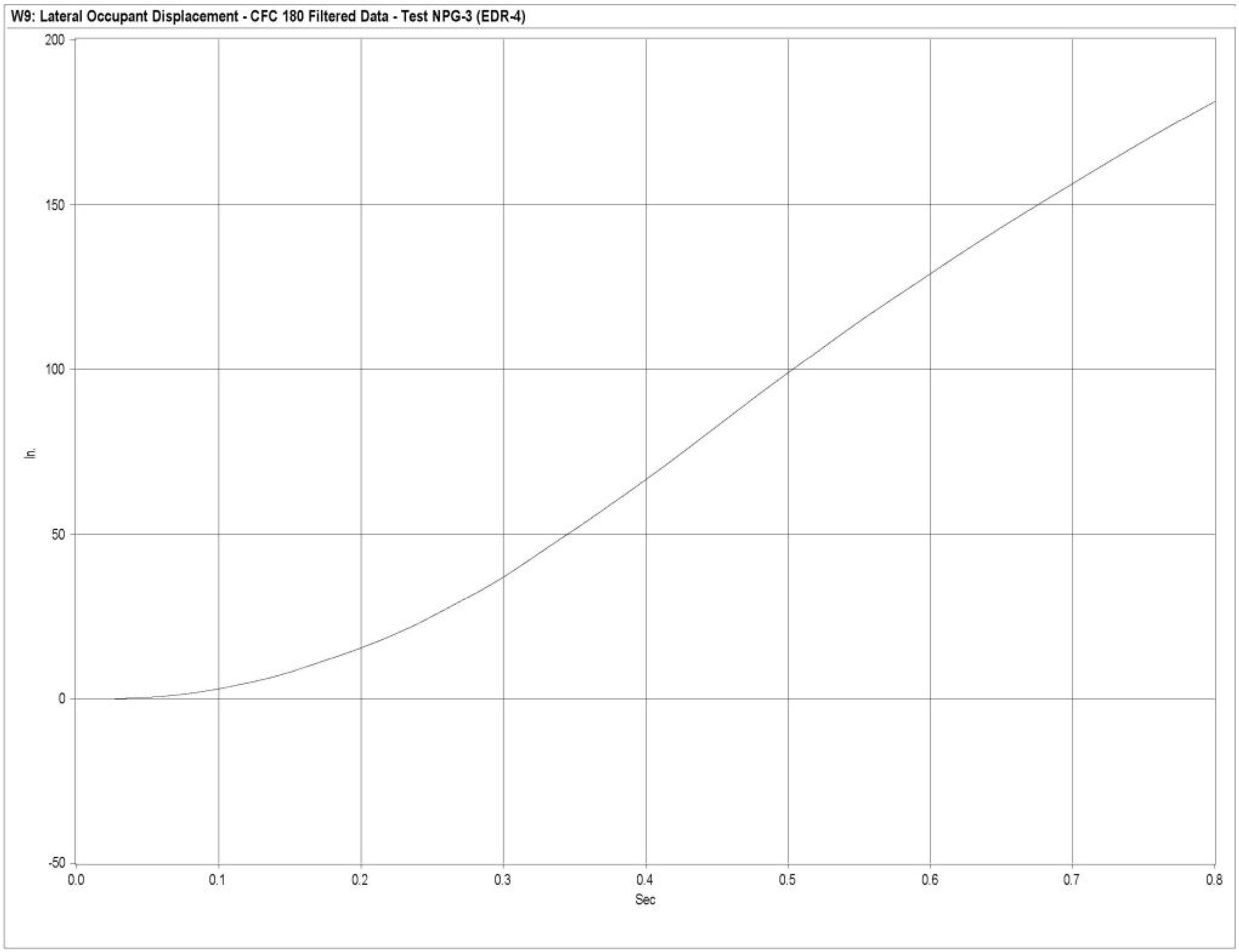


Figure E-6. Graph of Lateral Occupant Displacement, Test NPG-3

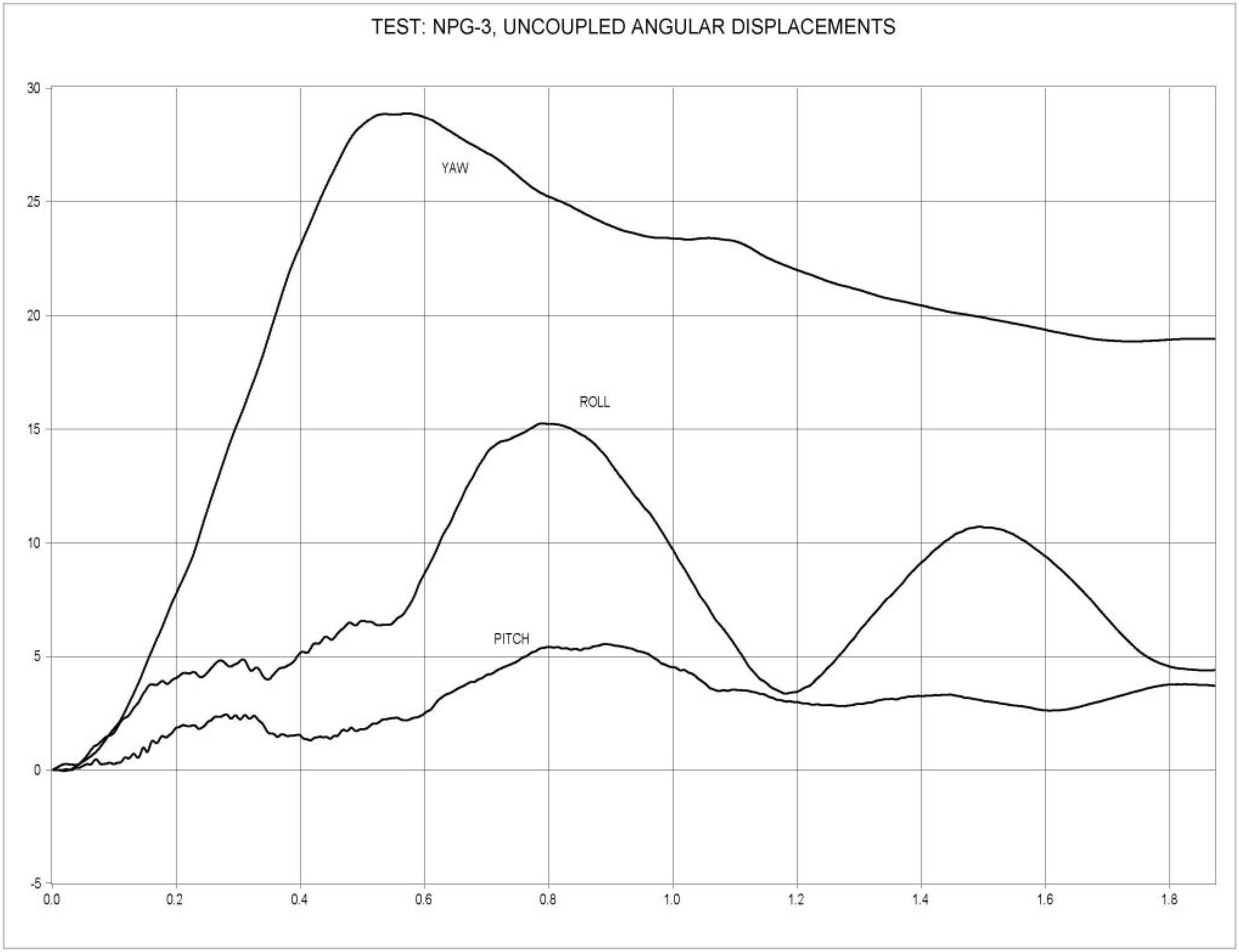


Figure E-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test NPG-3

APPENDIX F

Midwest Guardrail System Standard Post Spacing System Drawings

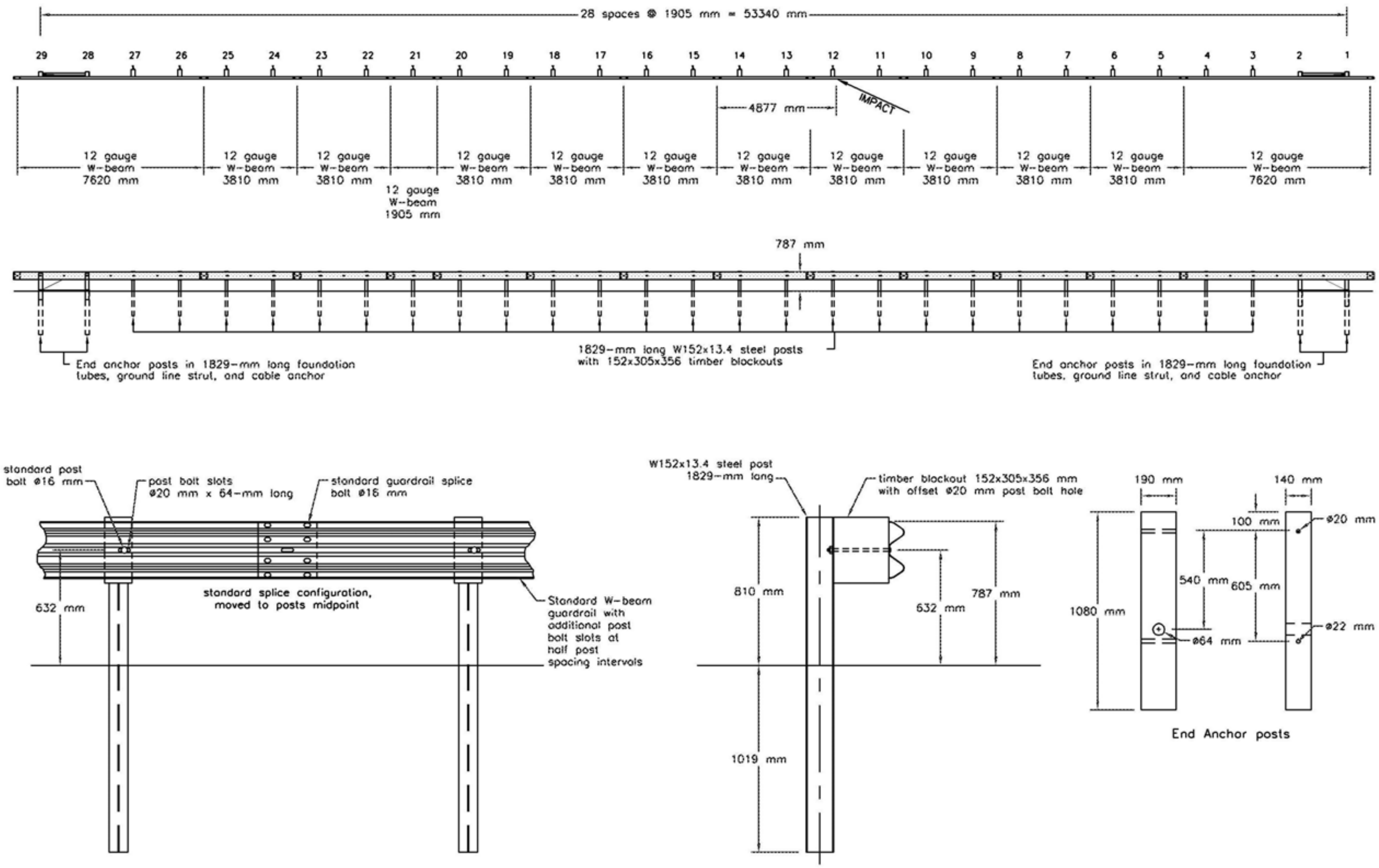


Figure F-1. *Midwest Guardrail System* Standard Post Spacing (Metric)

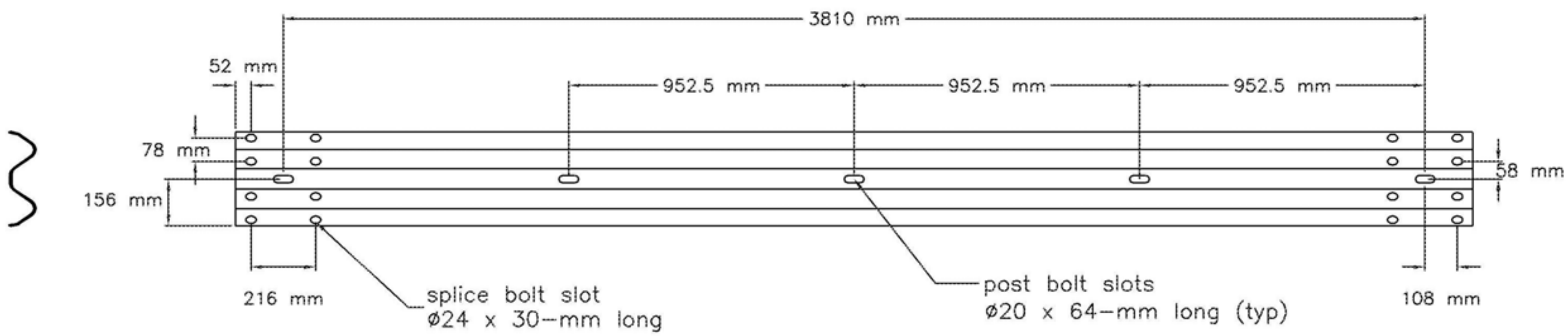


Figure F-2. *Midwest Guardrail System* Standard Post Spacing - Rail Design Details (Metric)

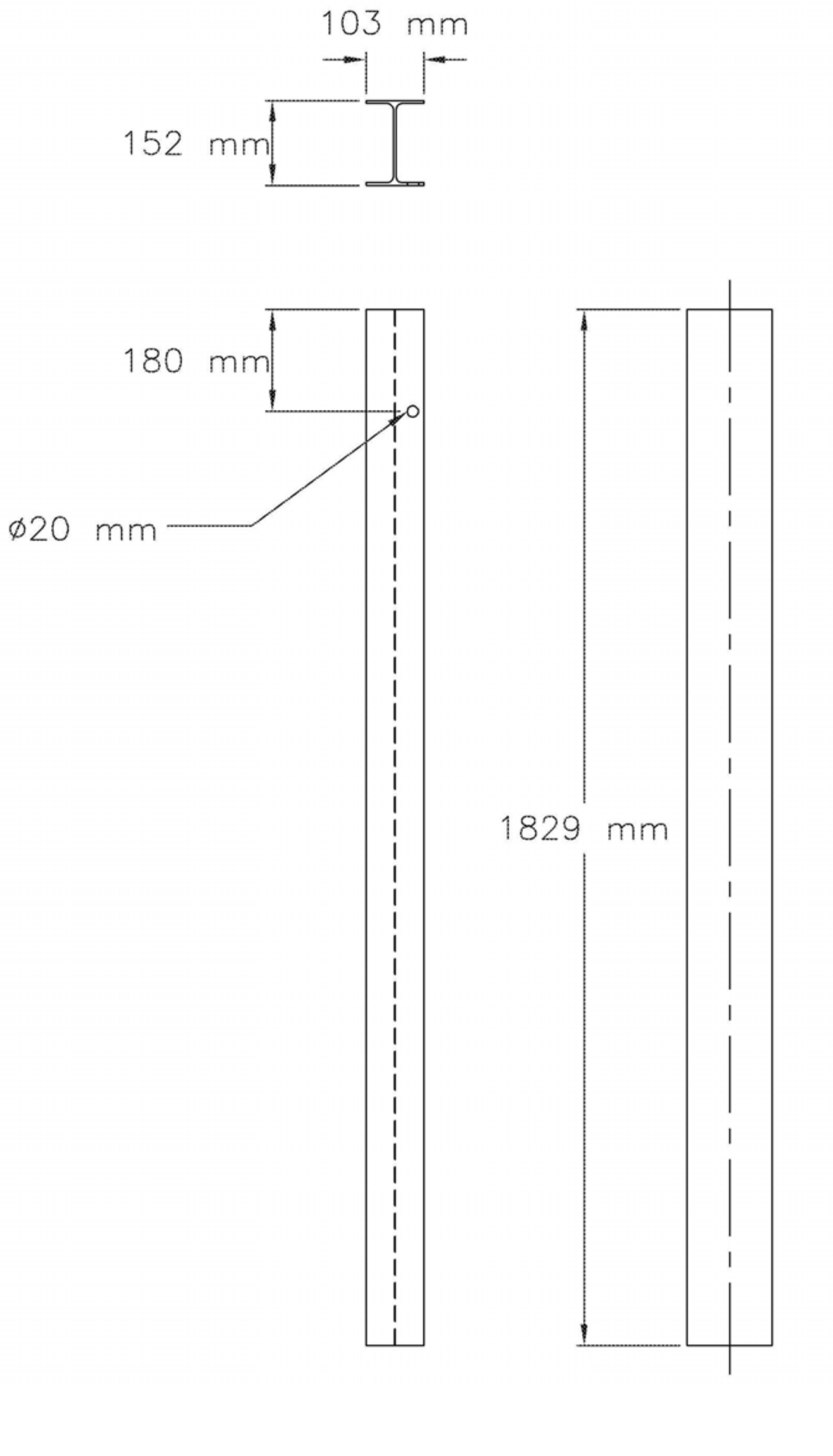


Figure F-3. *Midwest Guardrail System* Standard Post Spacing - Post Design Details (Metric)

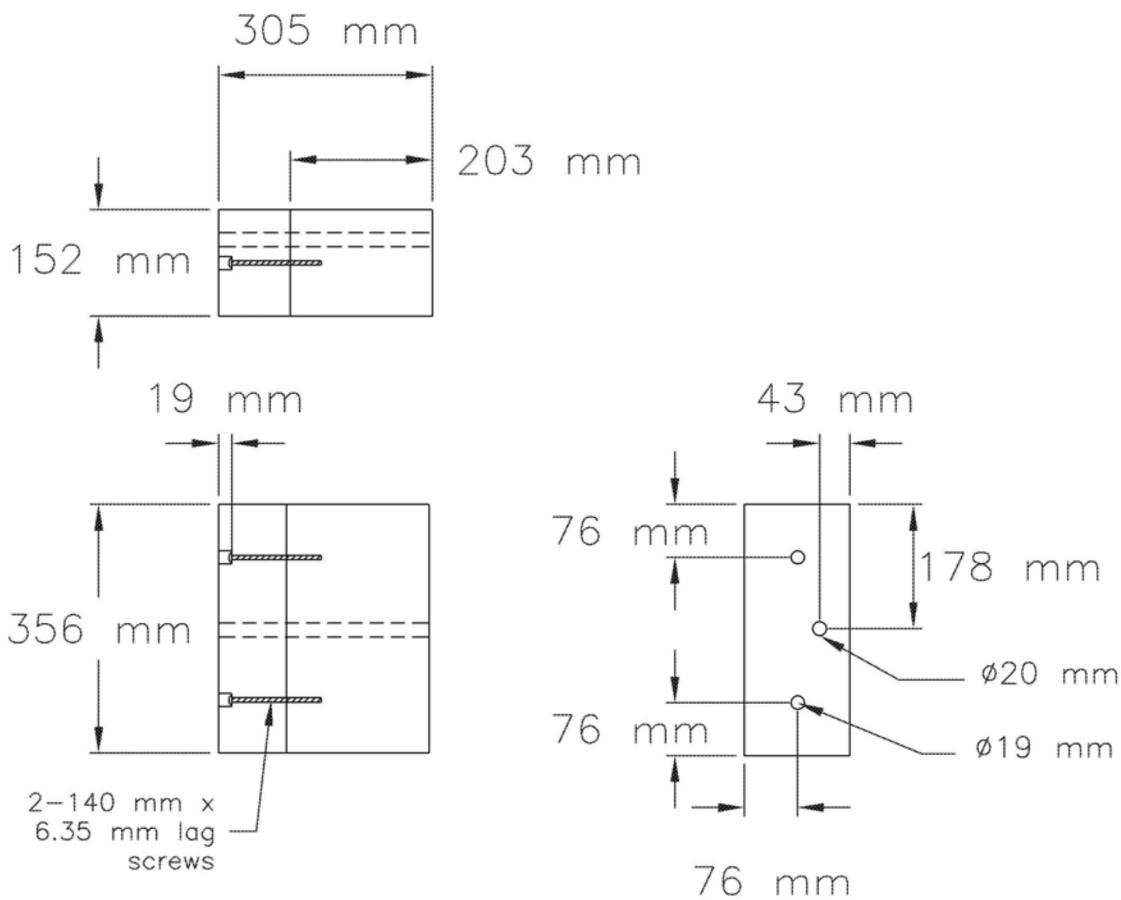


Figure F-4. *Midwest Guardrail System* Standard Post Spacing - Blockout Design Details (Metric)

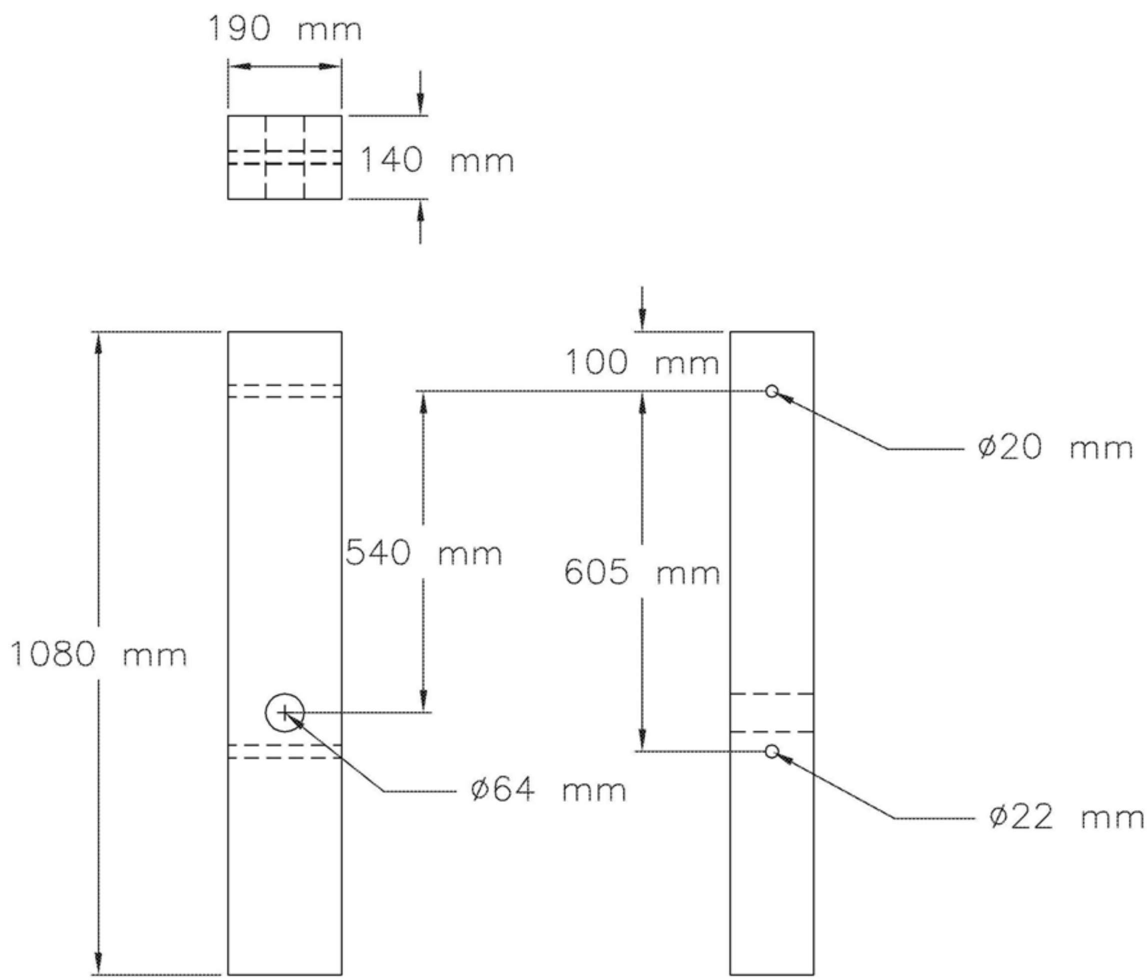


Figure F-5. *Midwest Guardrail System* Standard Post Spacing - Anchor Post Design Details (Metric)

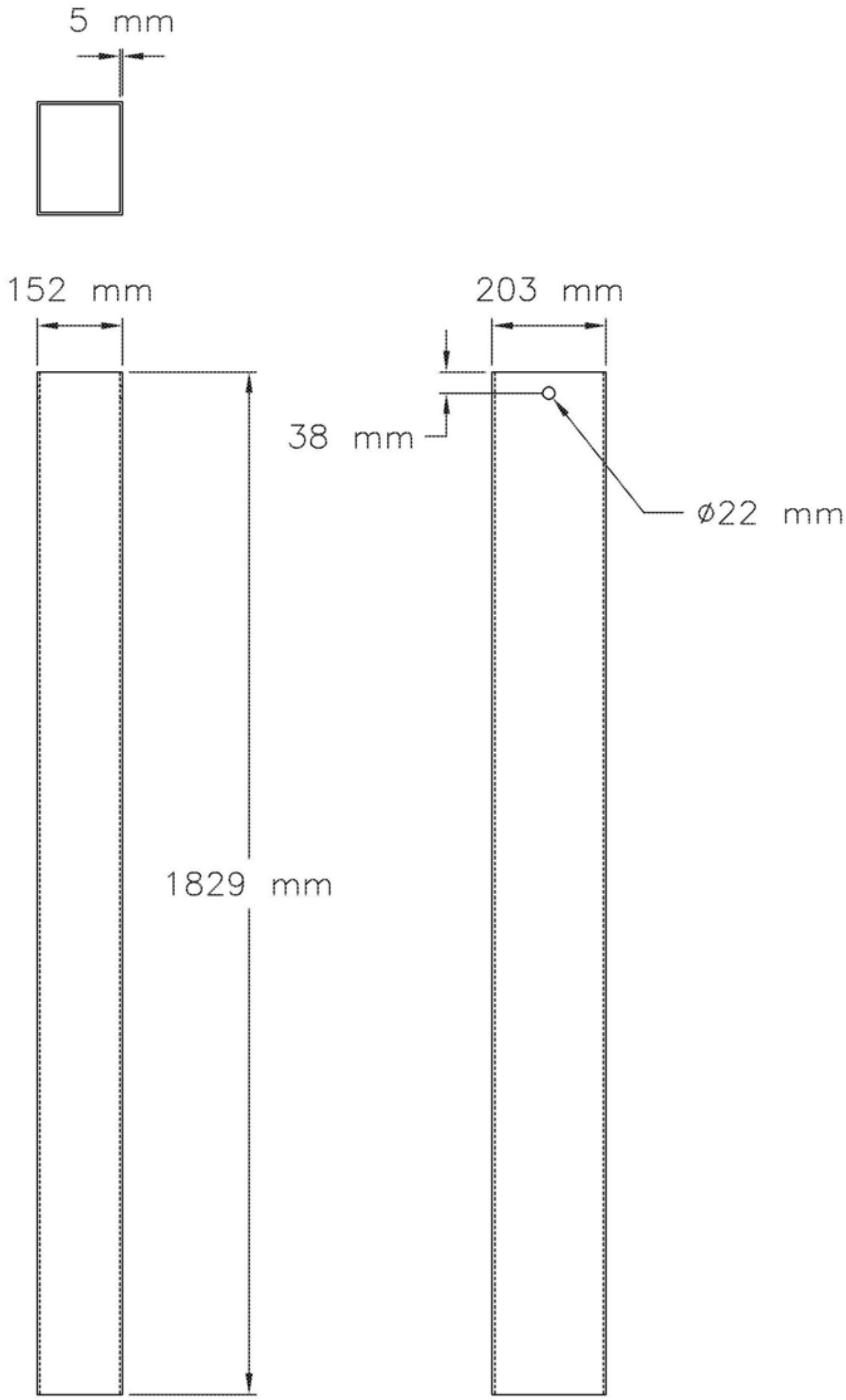


Figure F-6. *Midwest Guardrail System* Standard Post Spacing - Foundation Tube Design Details (Metric)

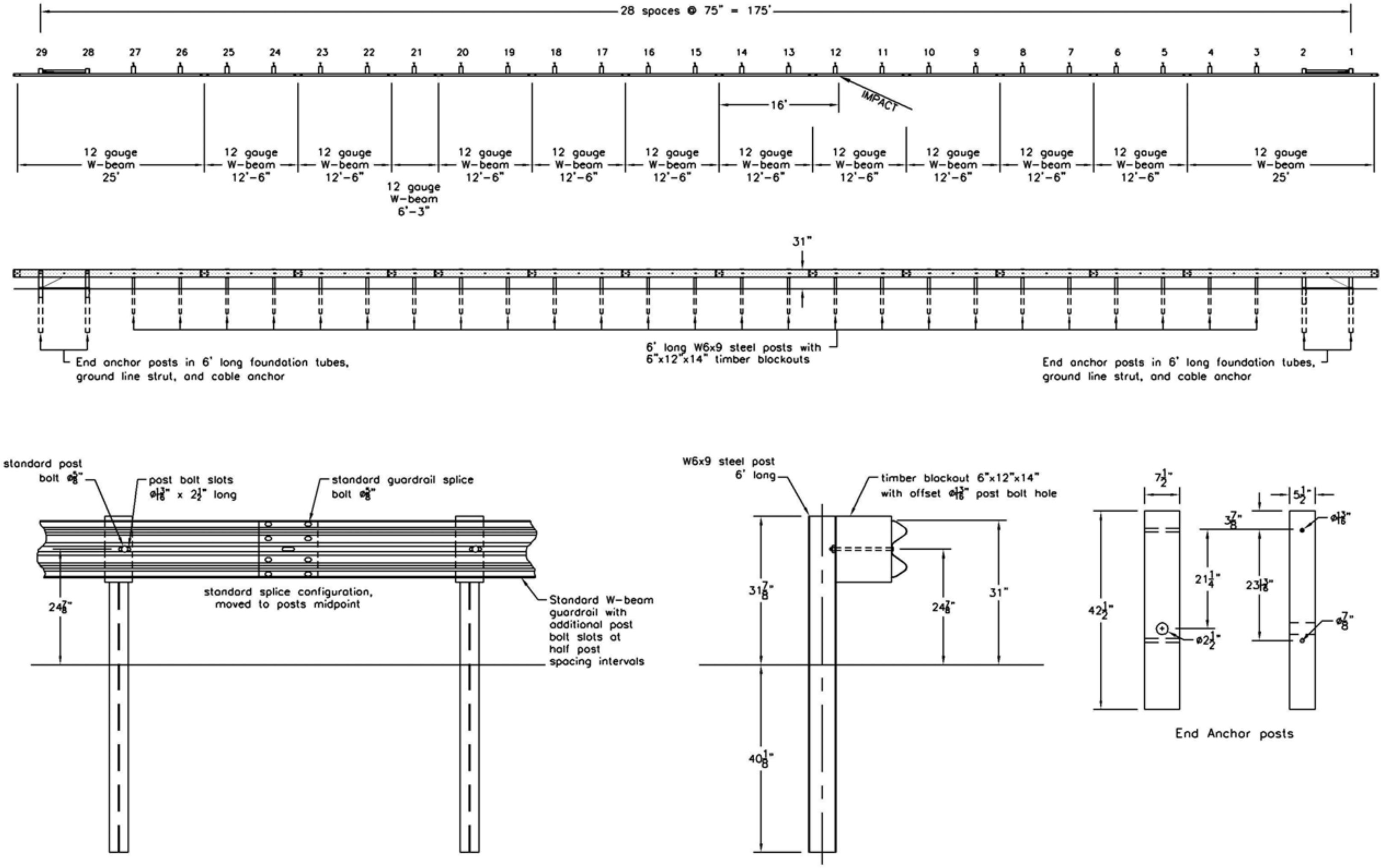


Figure F-7. *Midwest Guardrail System* Standard Post Spacing (English)

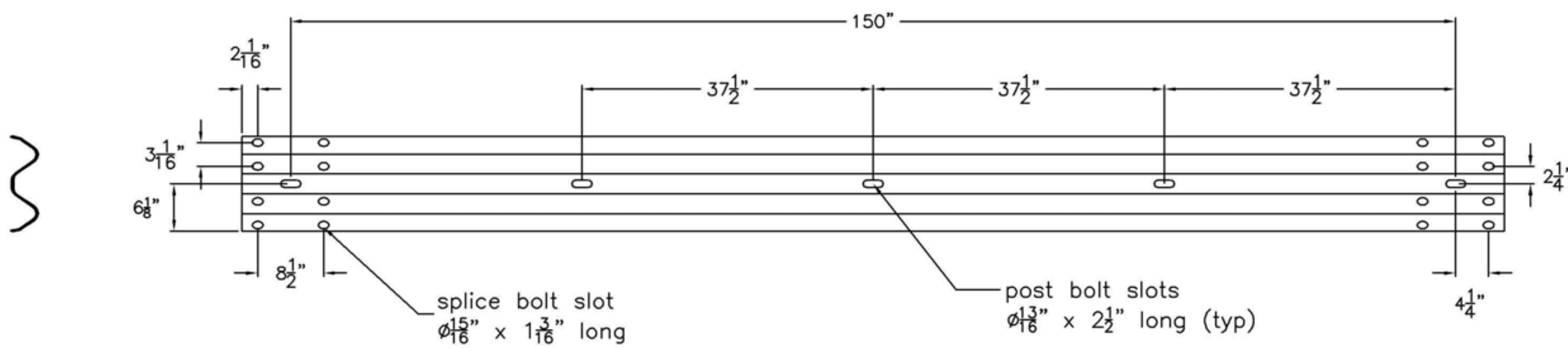


Figure F-8. *Midwest Guardrail System* Standard Post Spacing - Rail Design Details (English)

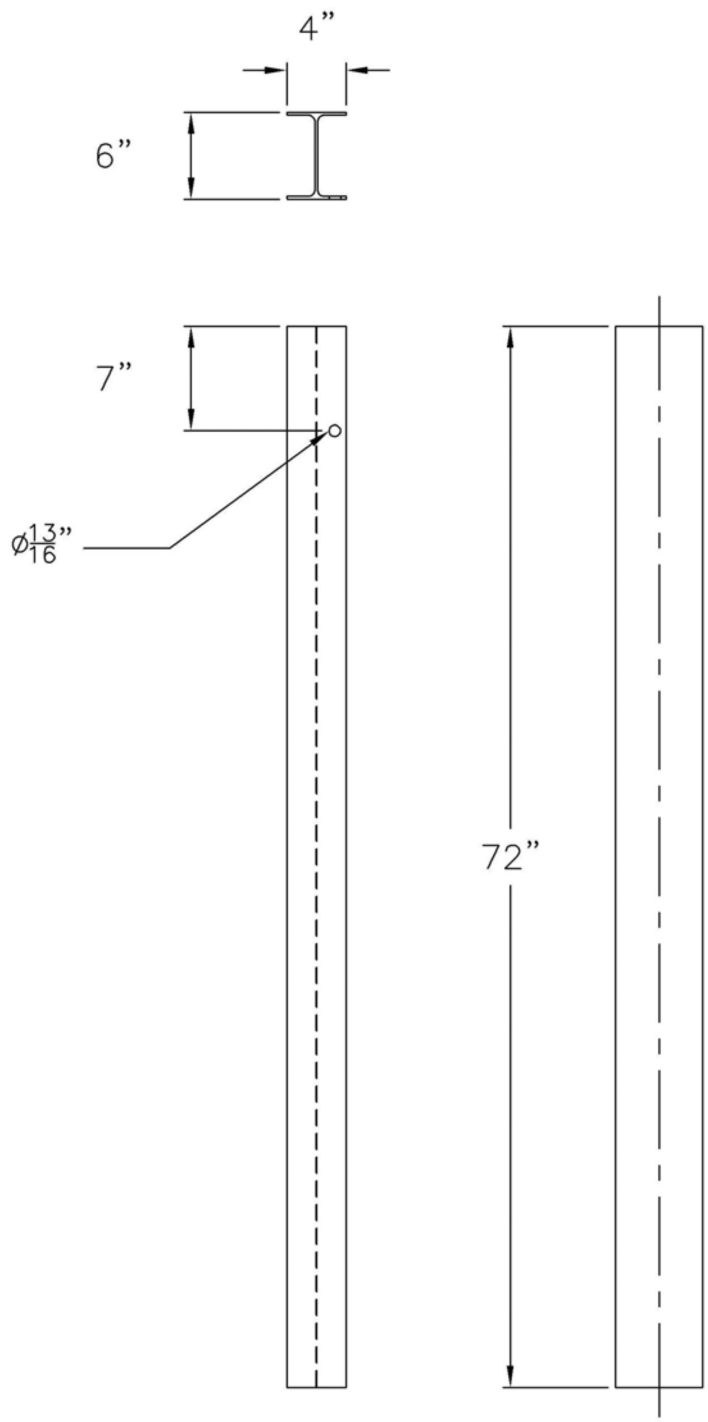


Figure F-9. *Midwest Guardrail System* Standard Post Spacing - Post Design Details (English)

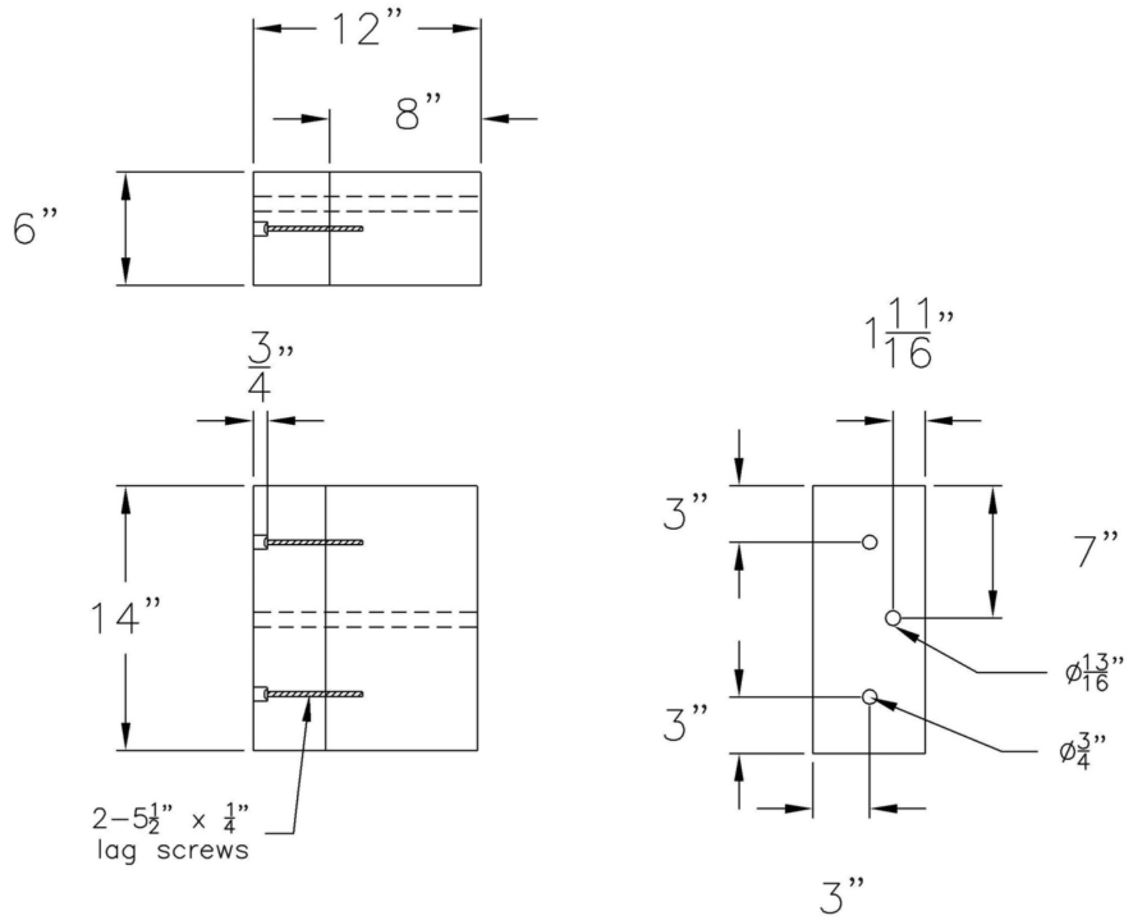


Figure F-10. *Midwest Guardrail System* Standard Post Spacing - Blockout Design Details (English)

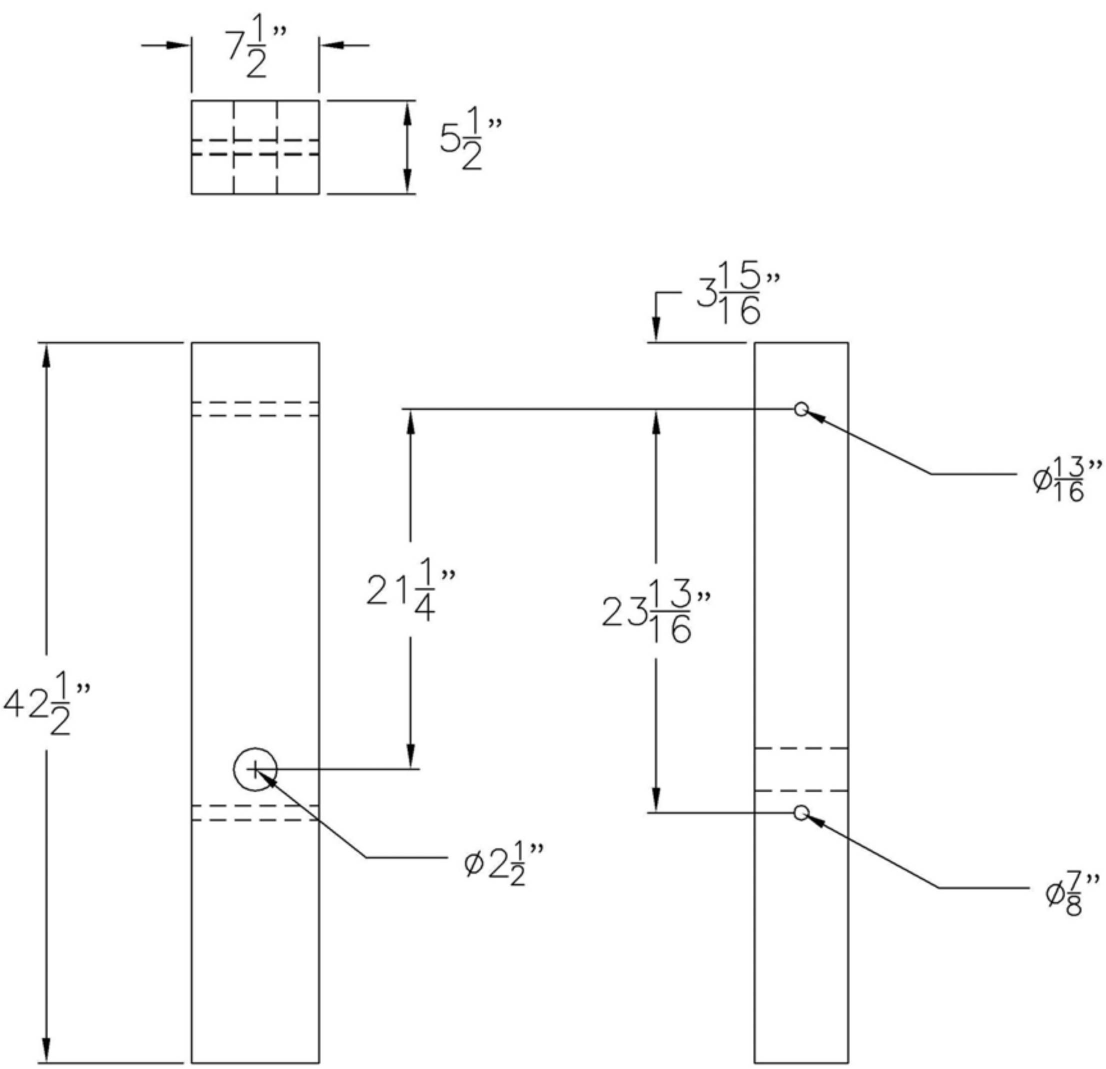


Figure F-11. *Midwest Guardrail System* Standard Post Spacing - Anchor Post Design Details (English)

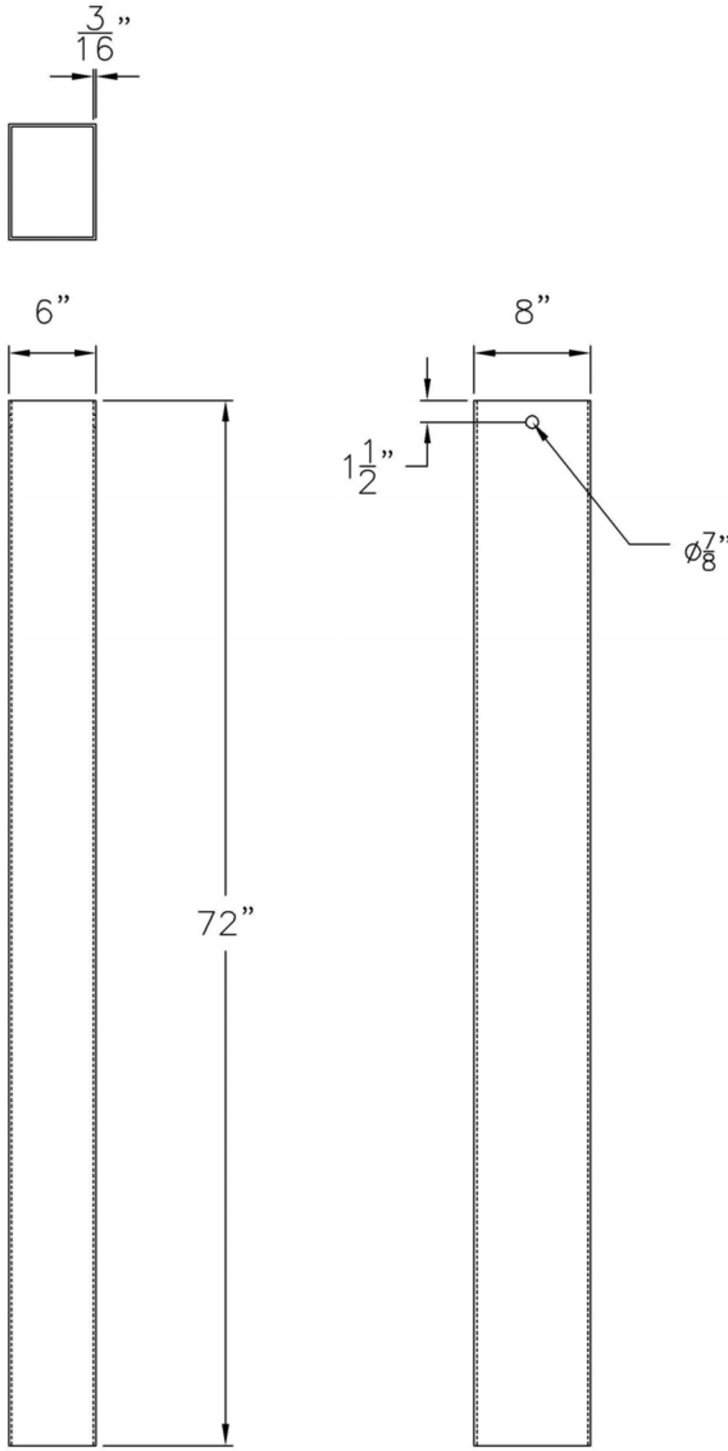


Figure F-12. *Midwest Guardrail System* Standard Post Spacing - Foundation Tube Design Details (English)

APPENDIX G

Accelerometer and Rate Transducer Data Analysis, Test NPG-4

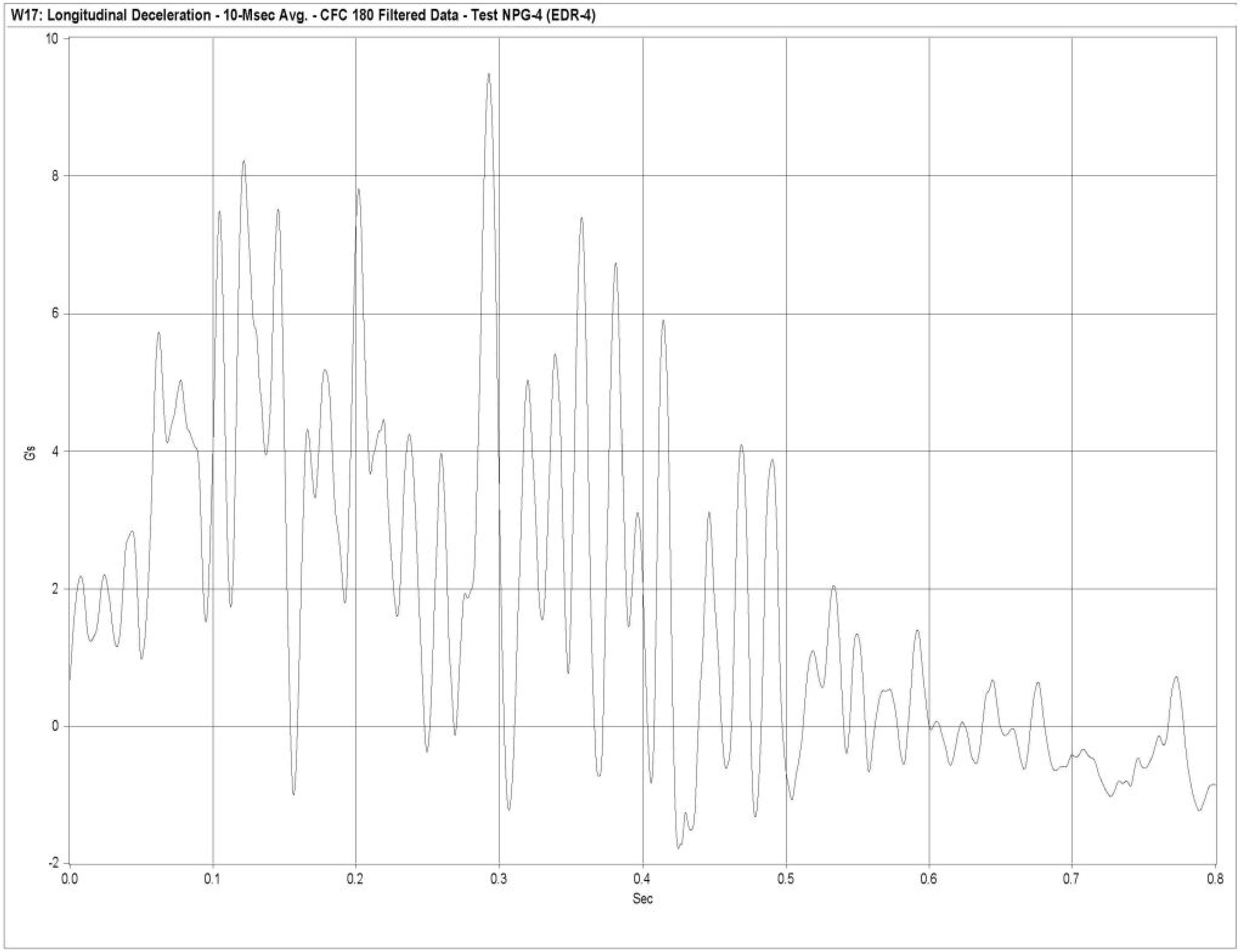


Figure G-1. Graph of Longitudinal Deceleration Test NPG-4

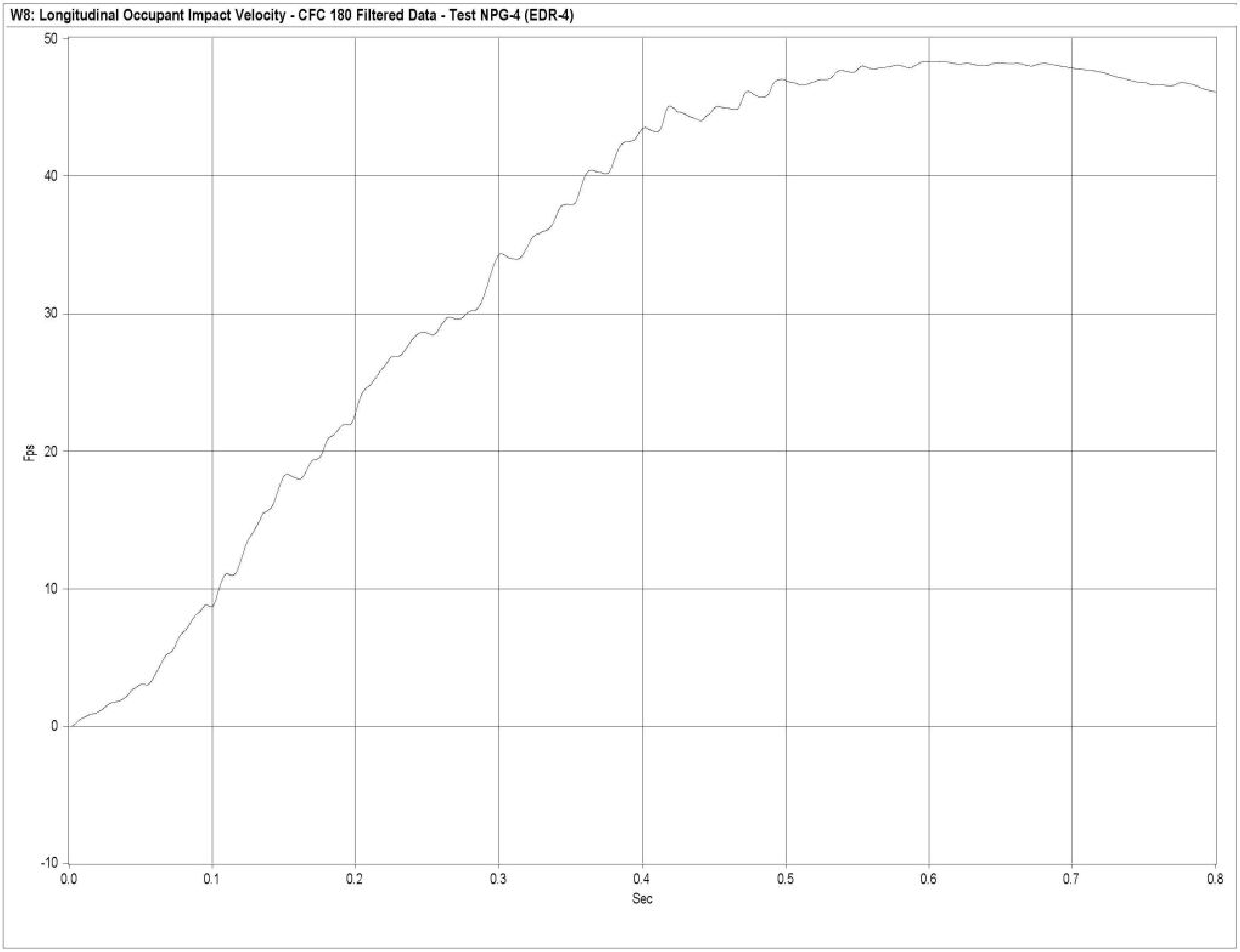


Figure G-2. Graph of Longitudinal Occupant Impact Velocity, Test NPG-4

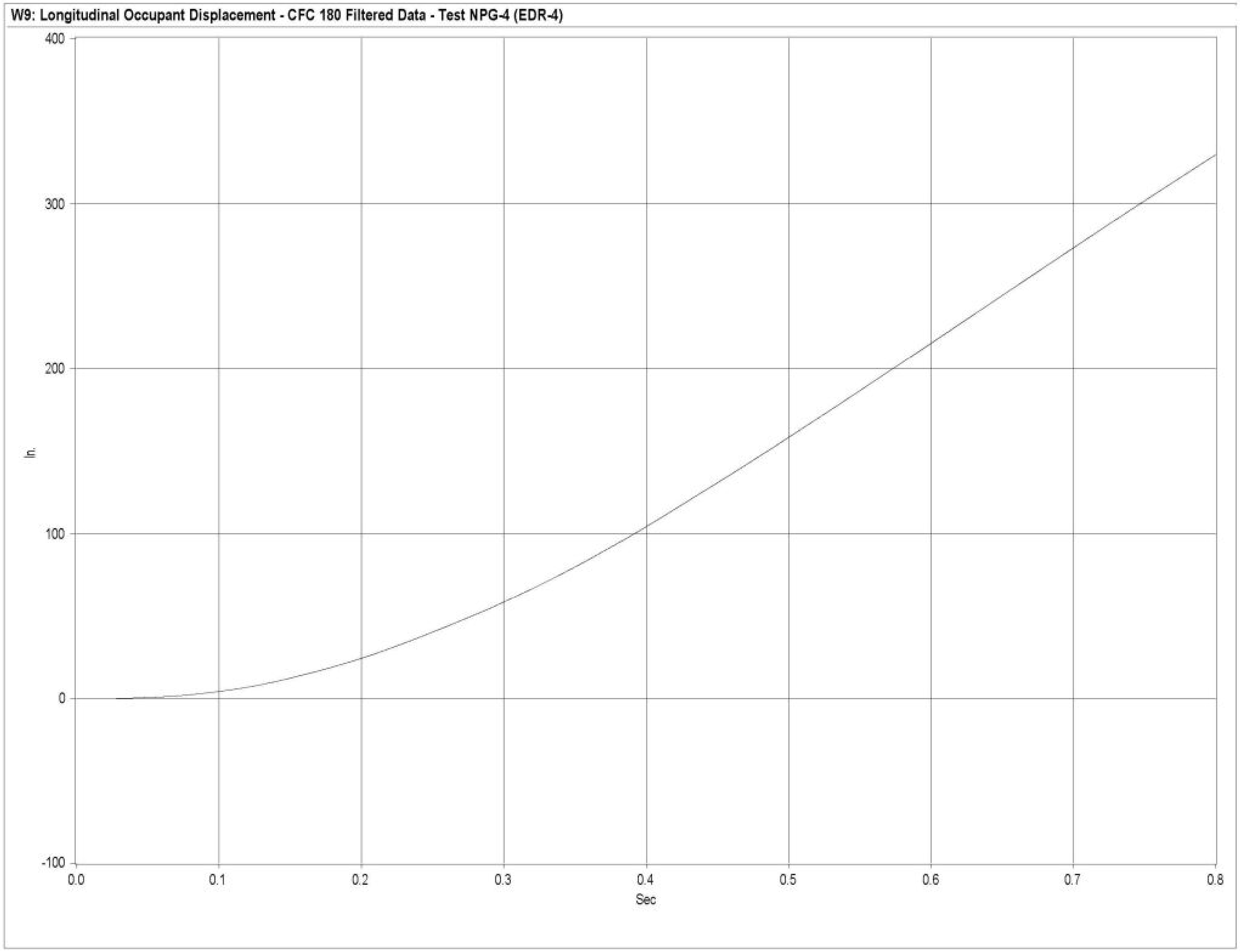


Figure G-3. Graph of Longitudinal Occupant Displacement, Test NPG-4

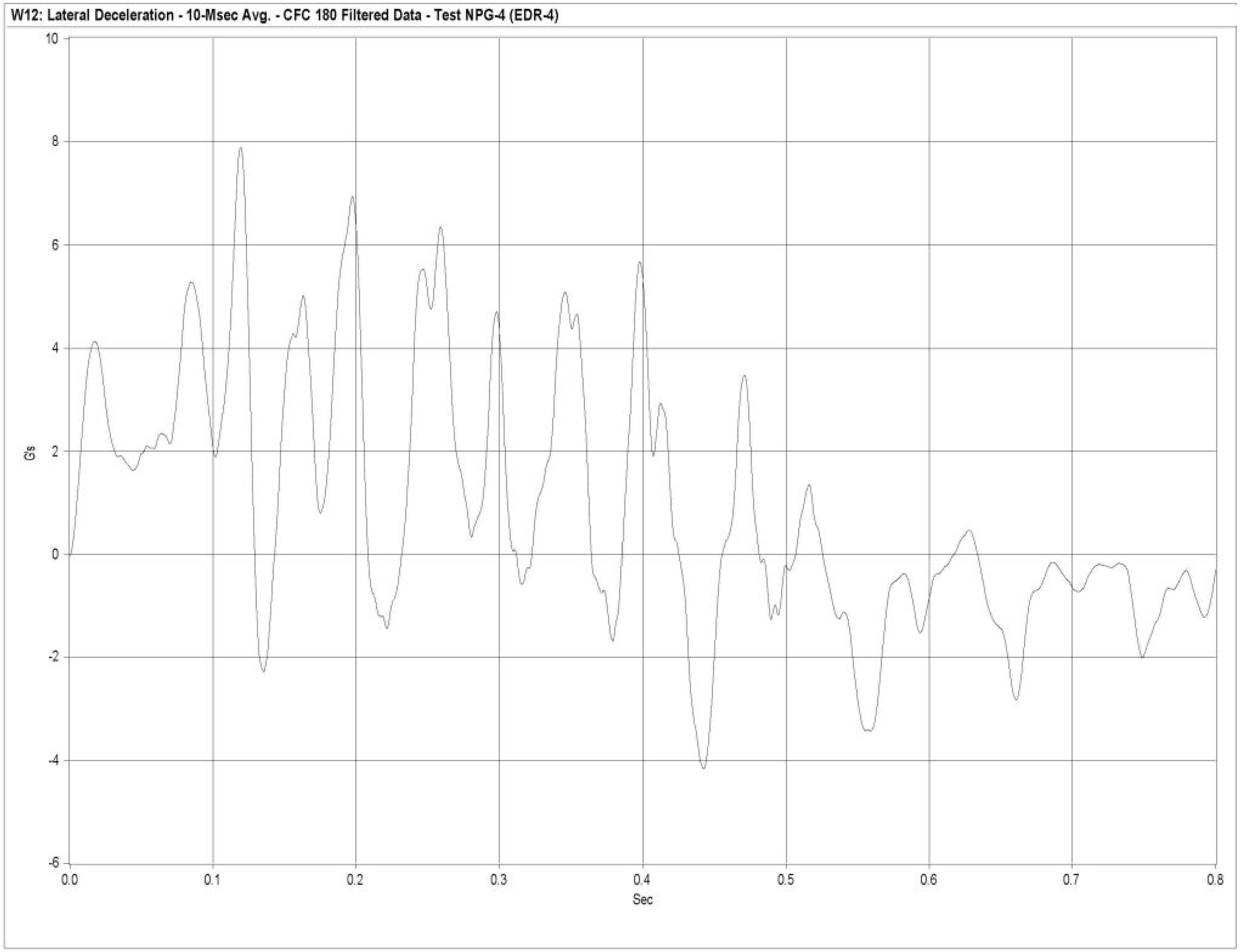


Figure G-4. Graph of Lateral Deceleration, Test NPG-4

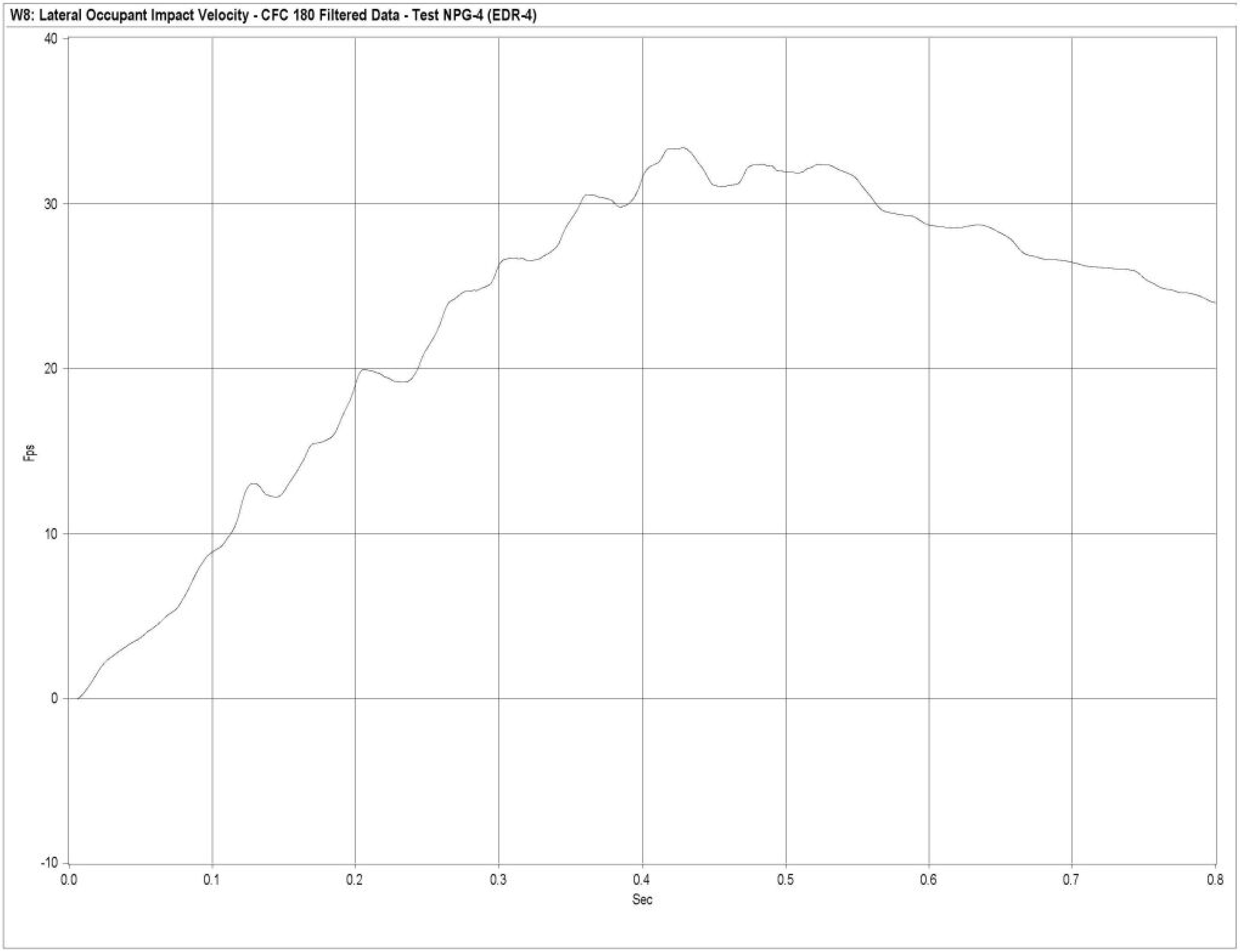


Figure G-5. Graph of Lateral Occupant Impact Velocity, Test NPG-4

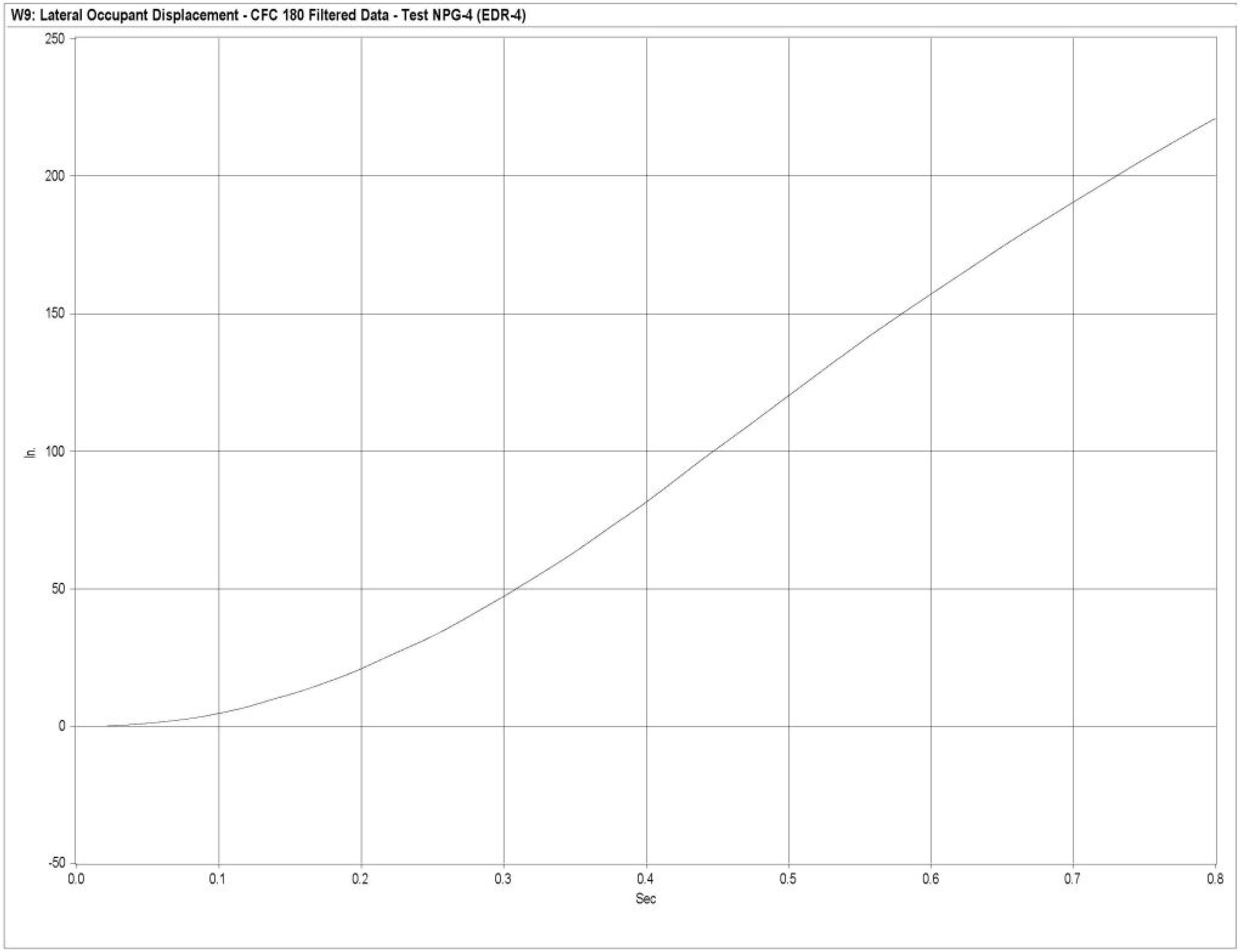


Figure G-6. Graph of Lateral Occupant Displacement, Test NPG-4

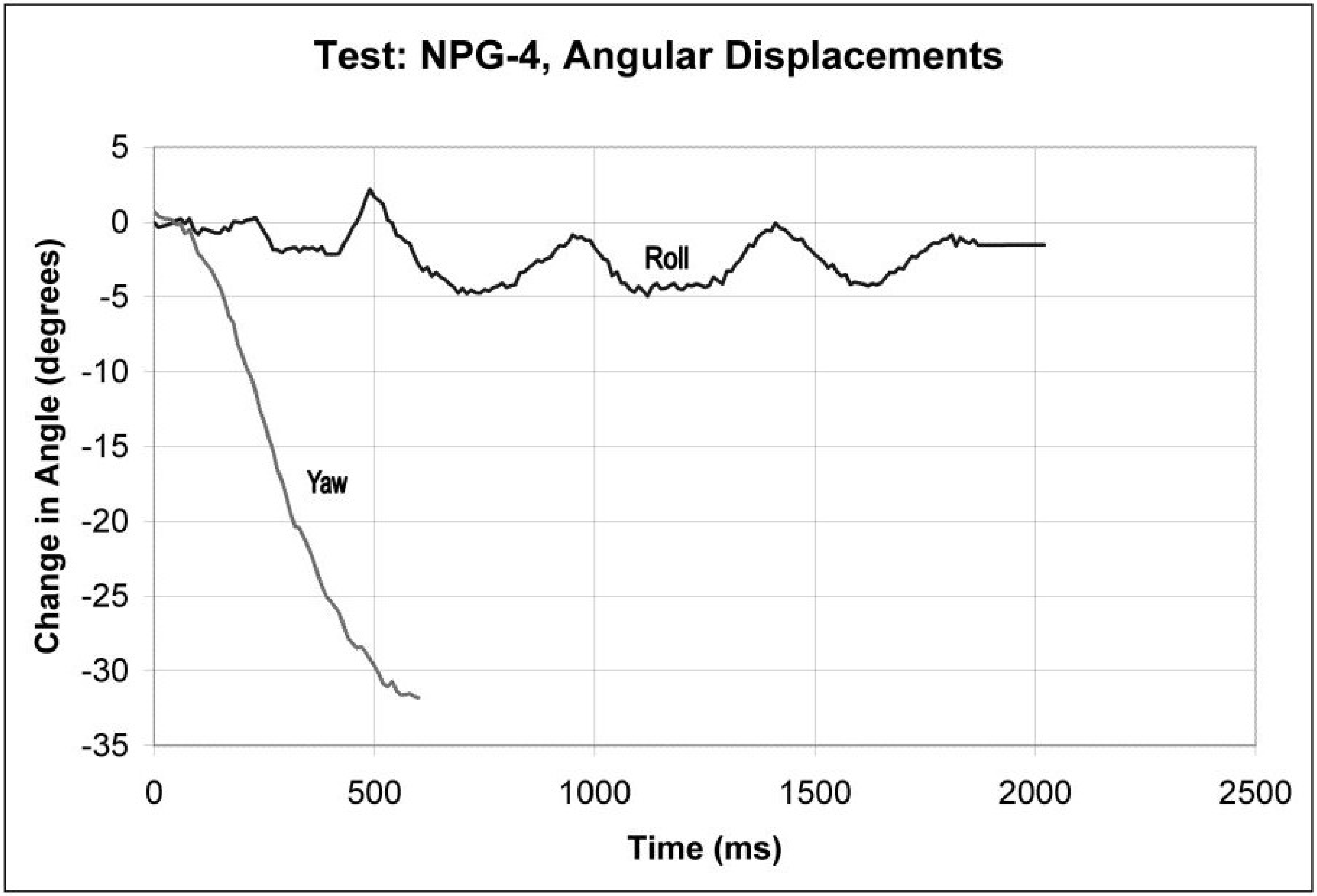


Figure G-7. Graph of Roll and Yaw Angular Displacements, Test NPG-4

APPENDIX H

Midwest Guardrail System Standard Post Spacing System with Curb Drawings

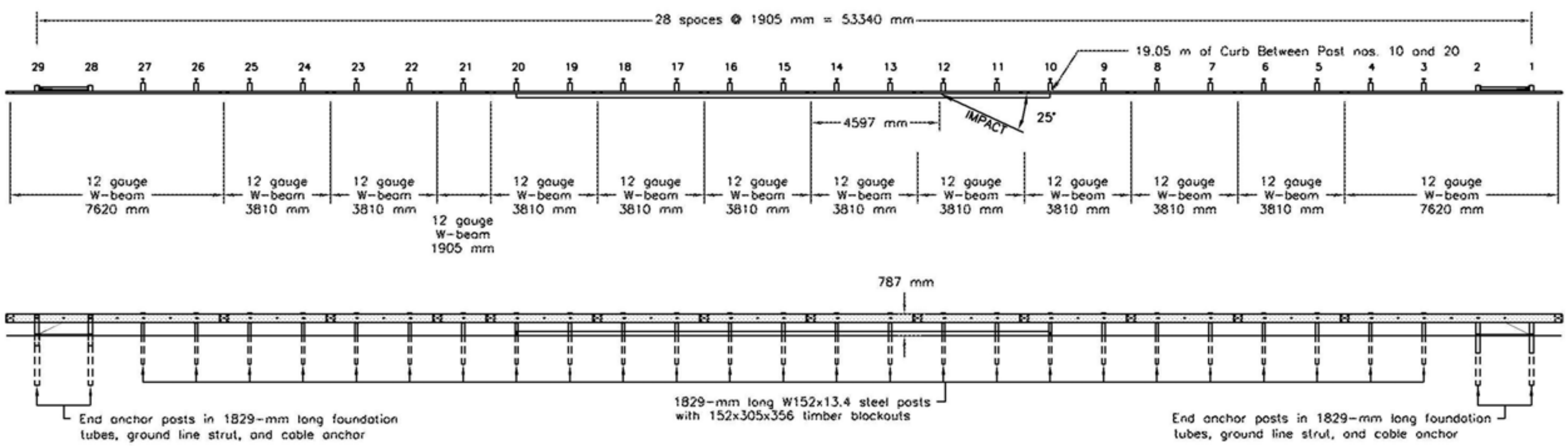


Figure H-1. *Midwest Guardrail System* Standard Post Spacing with Curb (Metric)

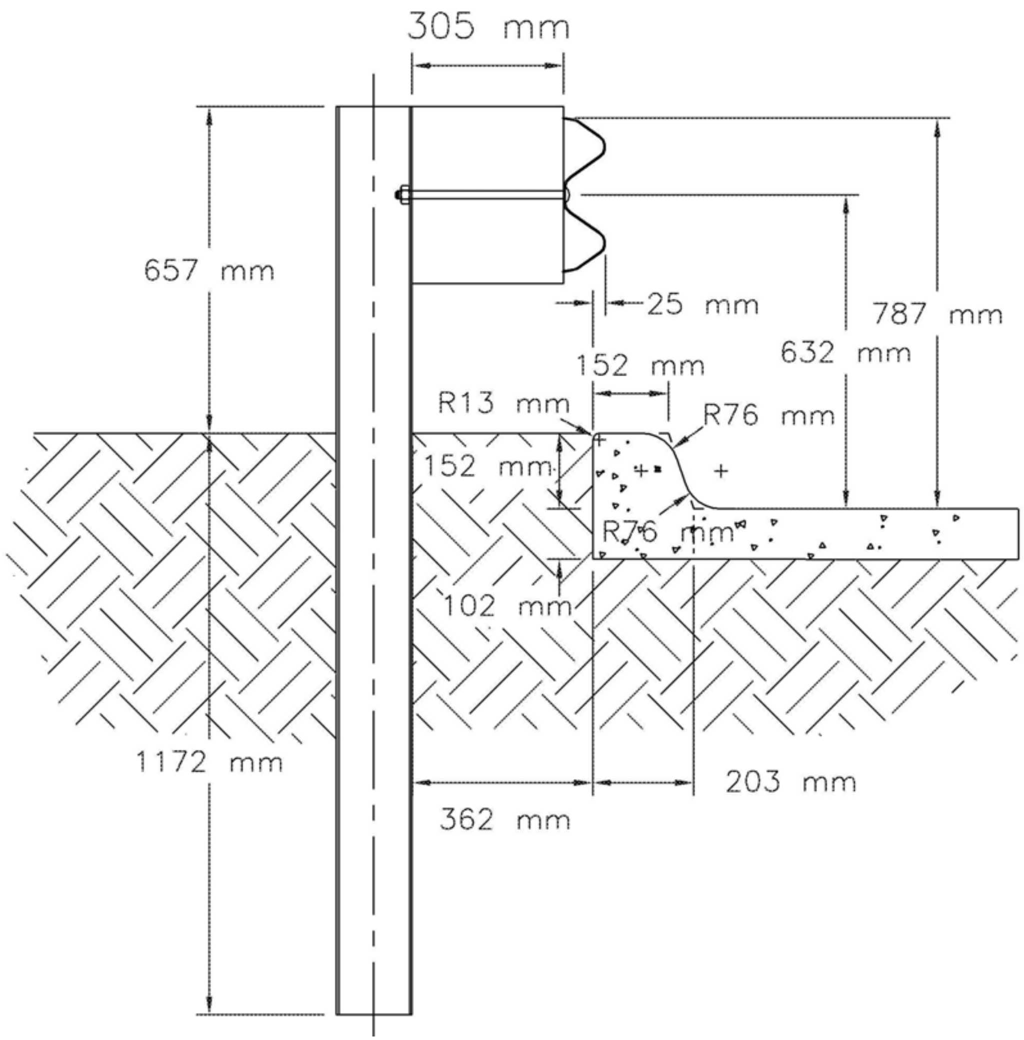


Figure H-2. *Midwest Guardrail System* Standard Post Spacing with Curb - System Profile (Metric)

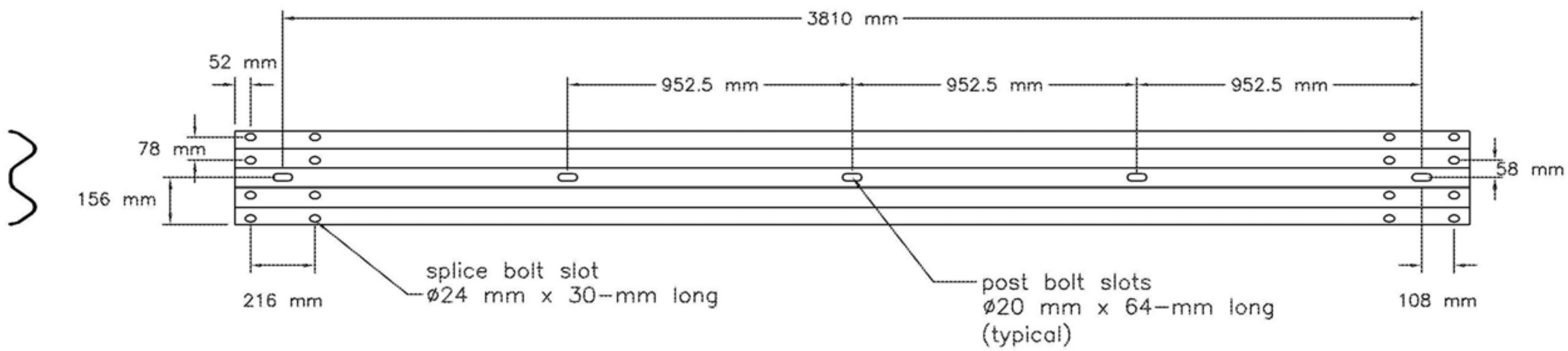


Figure H-3. *Midwest Guardrail System* Standard Post Spacing with Curb - Rail Design Details (Metric)

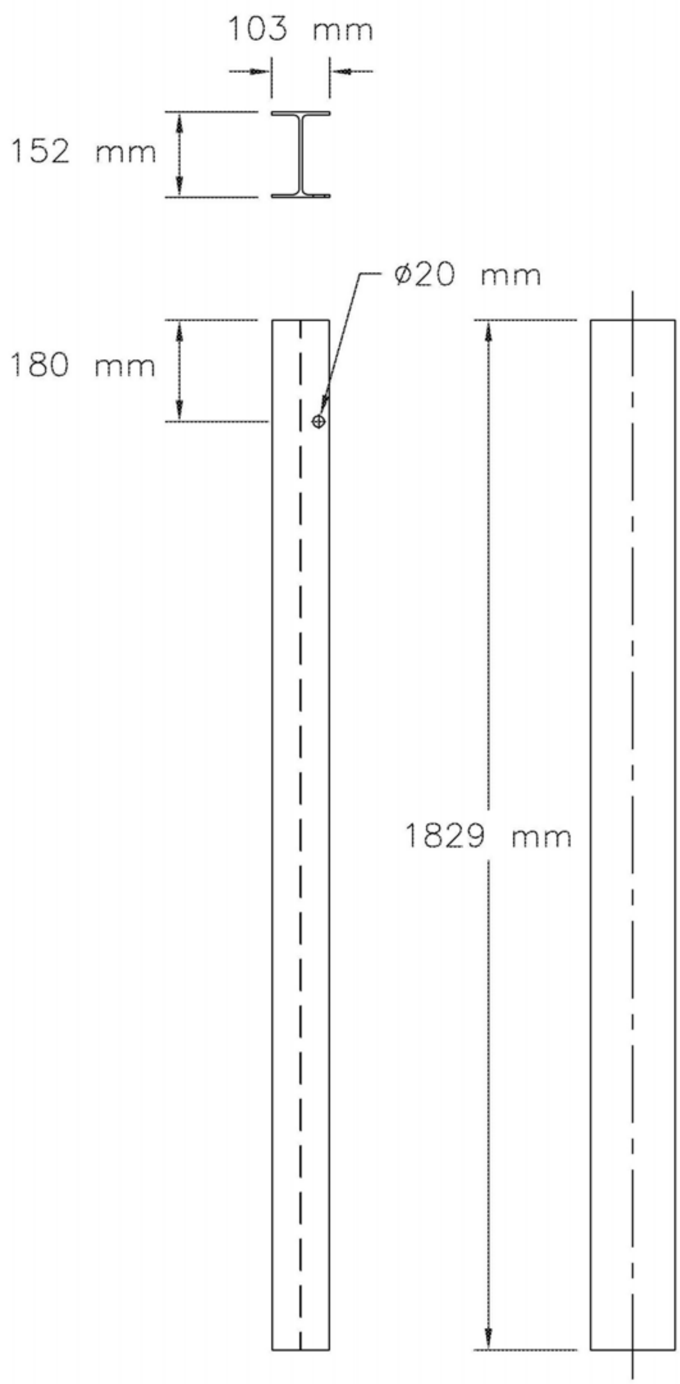


Figure H-4. *Midwest Guardrail System* Standard Post Spacing with Curb - Post Design Details (Metric)

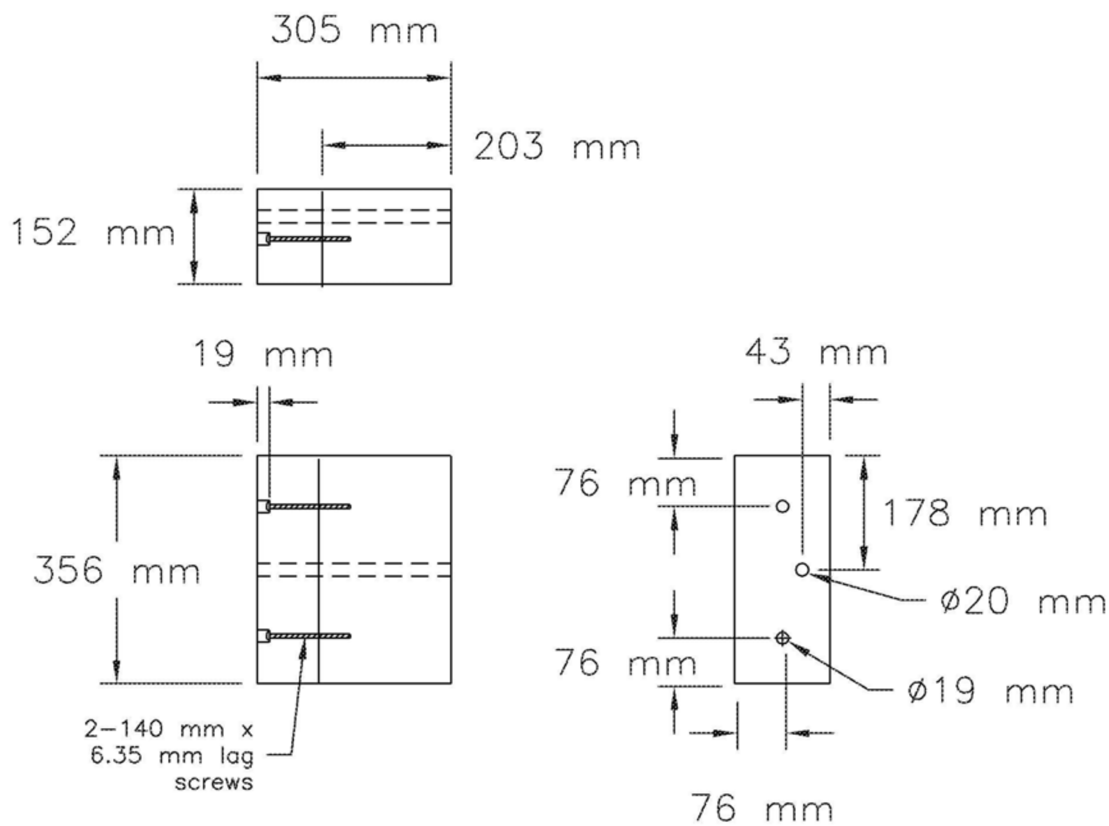


Figure H-5. *Midwest Guardrail System* Standard Post Spacing with Curb - Blockout Design Details (Metric)

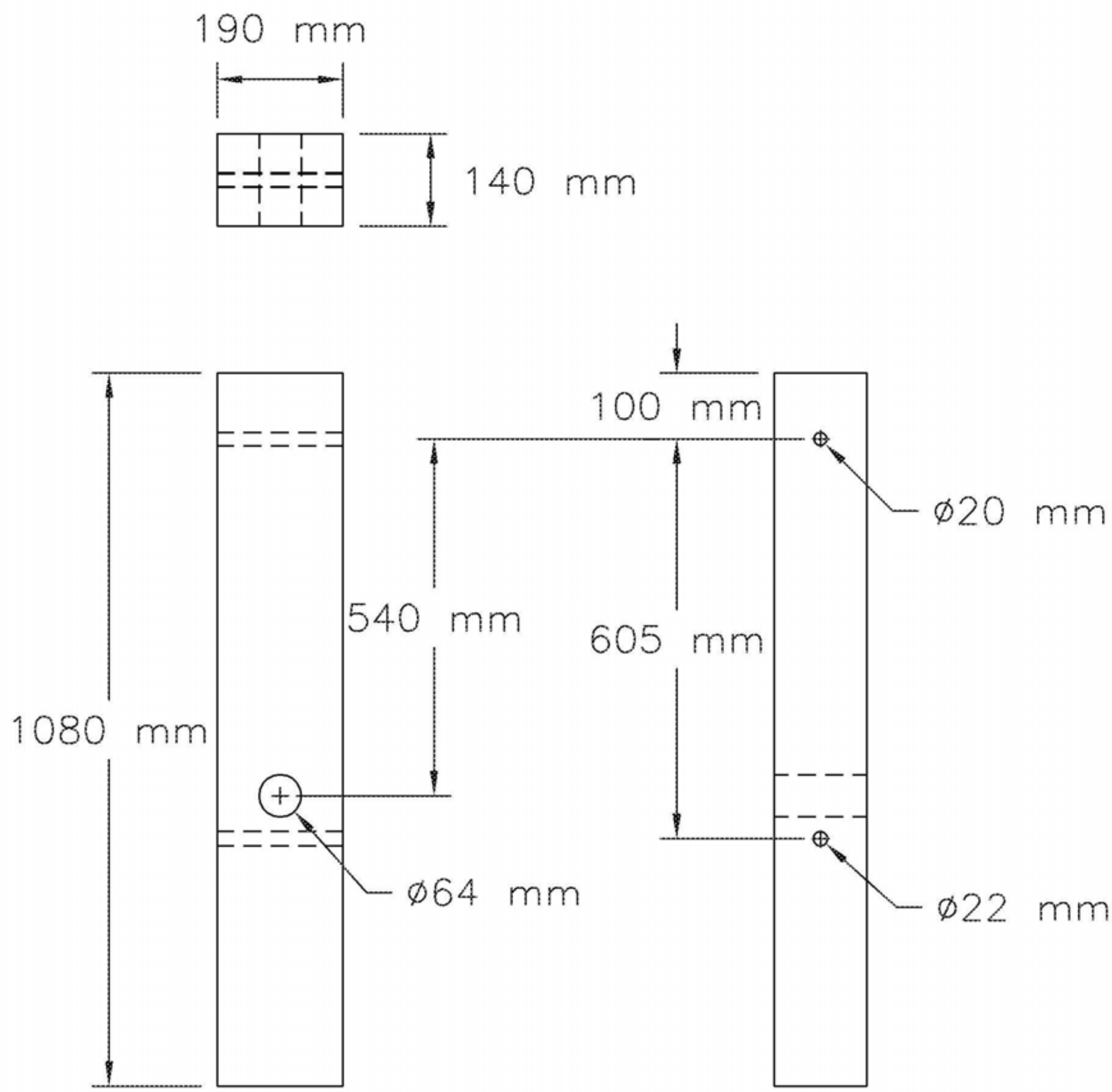


Figure H-6. *Midwest Guardrail System* Standard Post Spacing with Curb - Anchor Post Design Details (Metric)

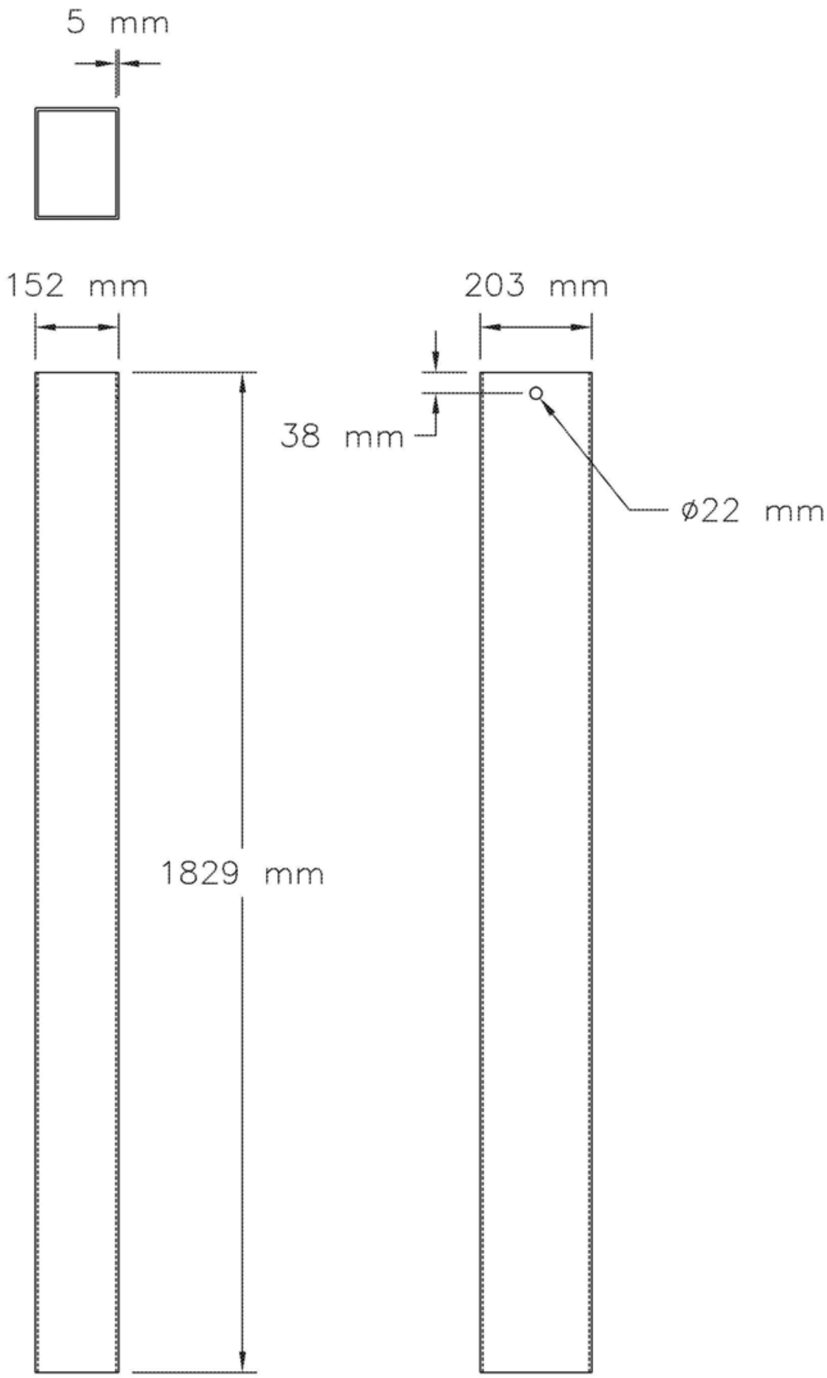


Figure H-7. *Midwest Guardrail System* Standard Post Spacing with Curb - Foundation Tube Design Details (Metric)

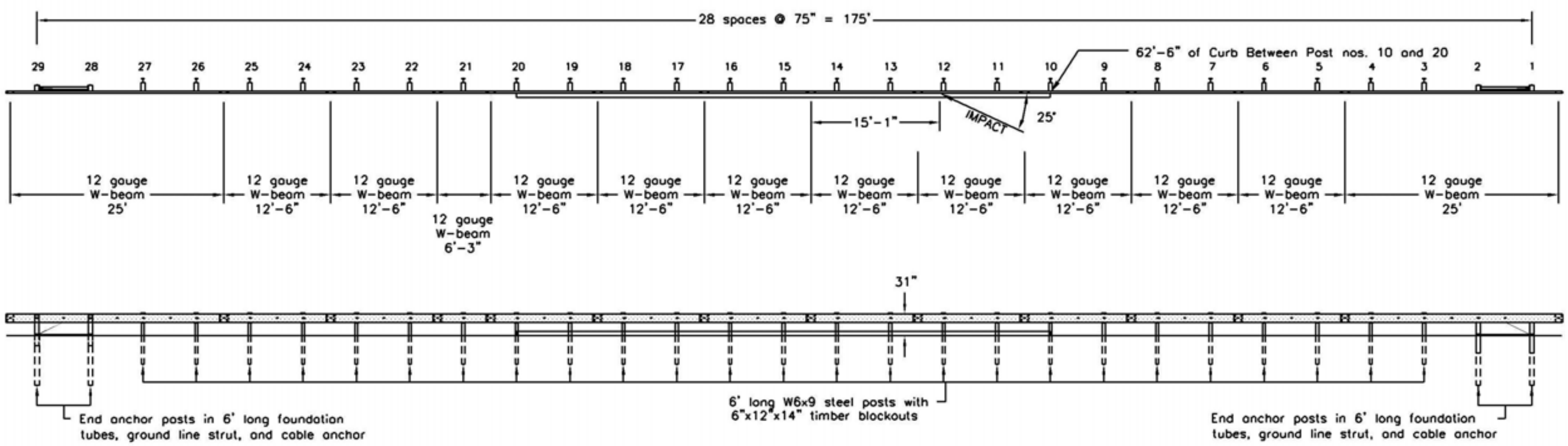


Figure H-8. *Midwest Guardrail System* Standard Post Spacing with Curb (English)

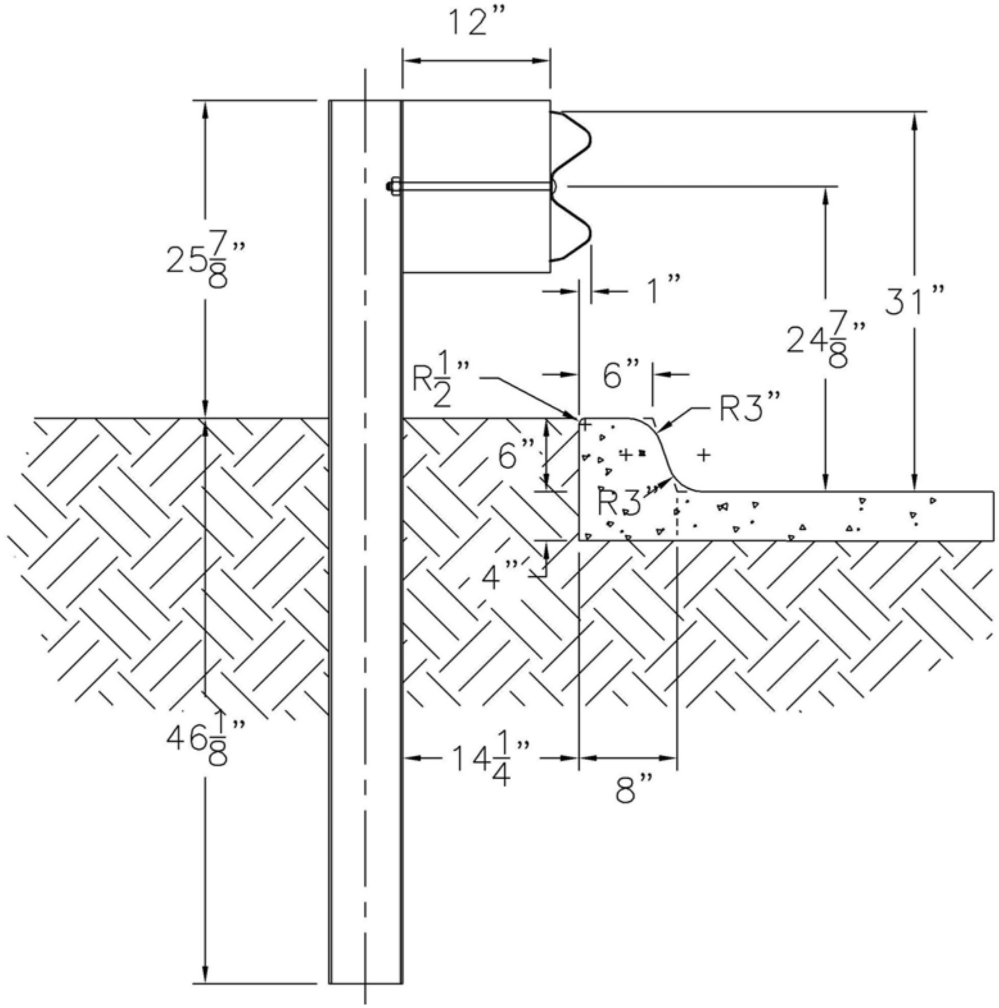


Figure H-9. *Midwest Guardrail System* Standard Post Spacing with Curb - System Profile (English)

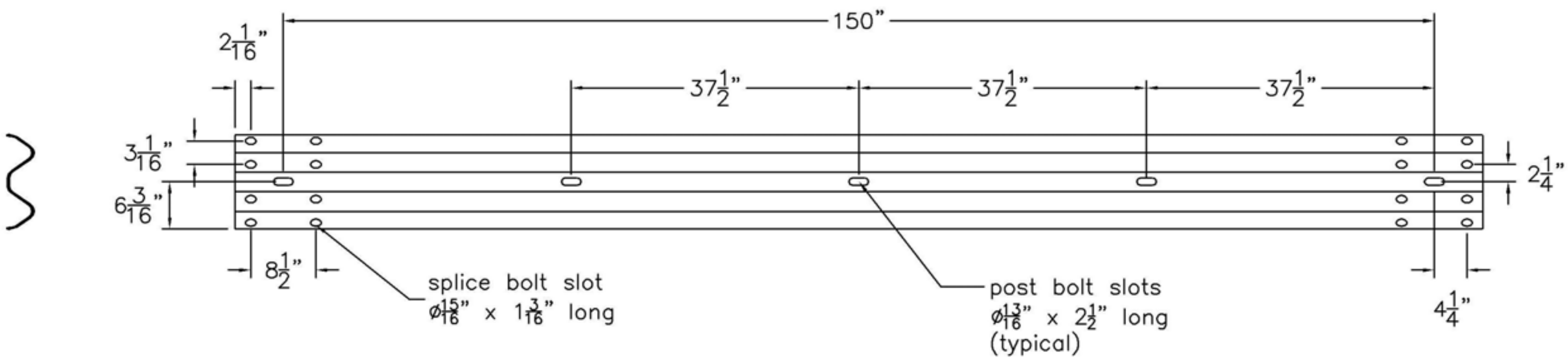


Figure H-10. *Midwest Guardrail System* Standard Post Spacing with Curb - Rail Design Details (English)

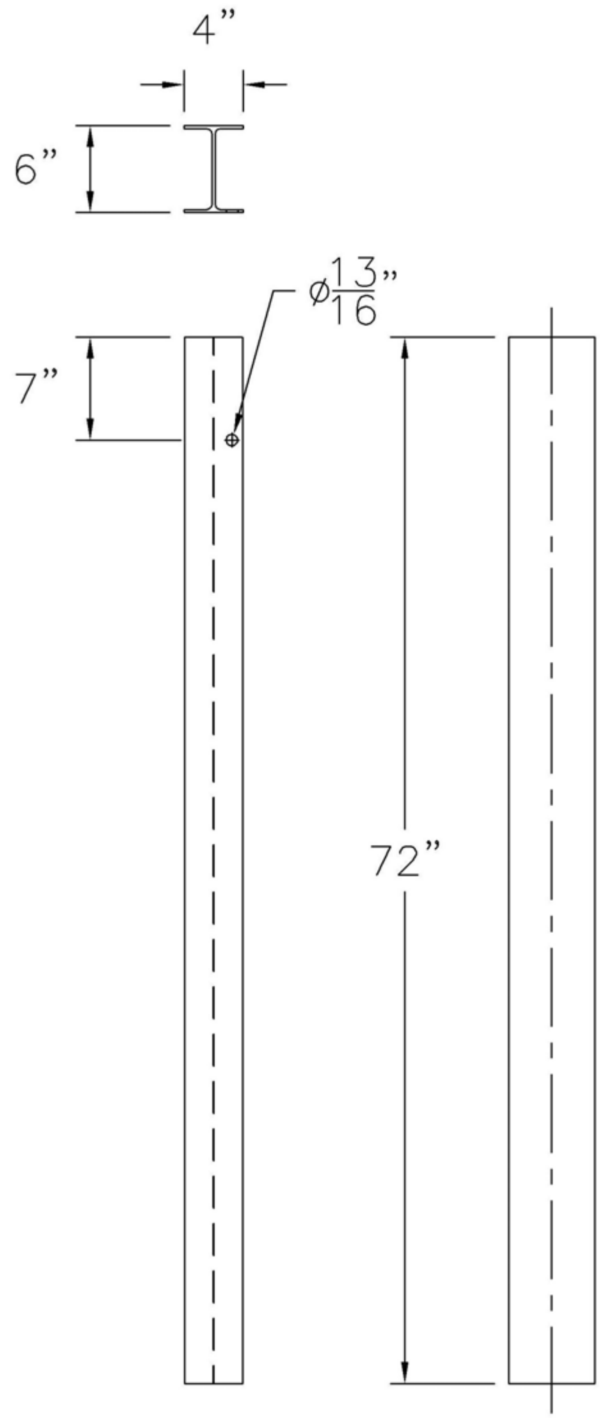


Figure H-11. *Midwest Guardrail System* Standard Post Spacing with Curb - Post Design Details (English)

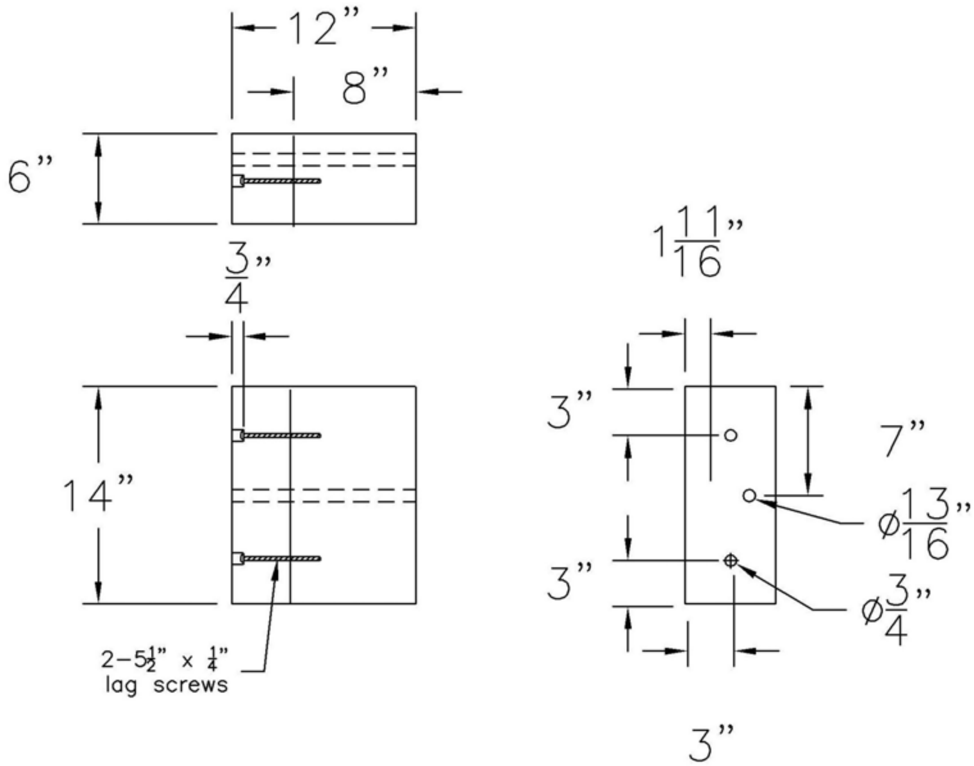


Figure H-12. *Midwest Guardrail System* Standard Post Spacing with Curb - Blockout Design Details (English)

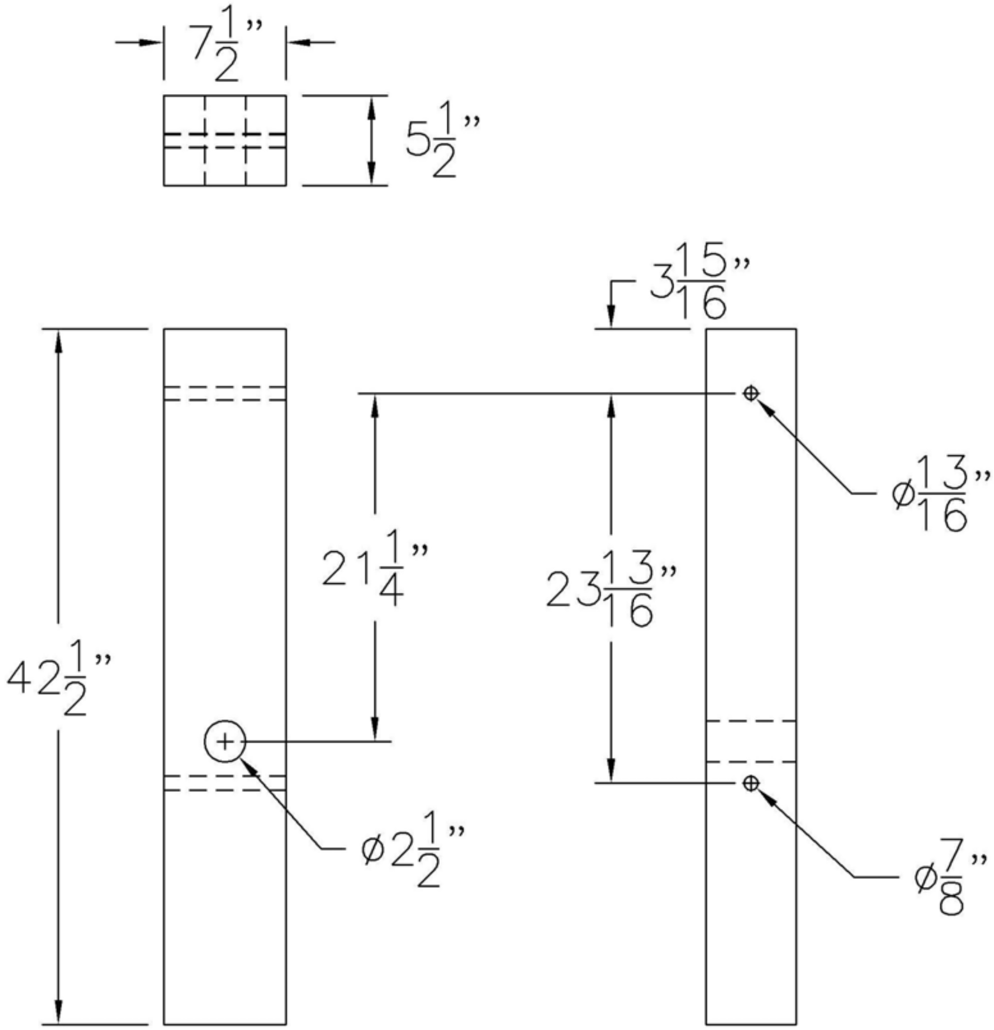


Figure H-13. *Midwest Guardrail System* Standard Post Spacing with Curb - Anchor Post Design Details (English)

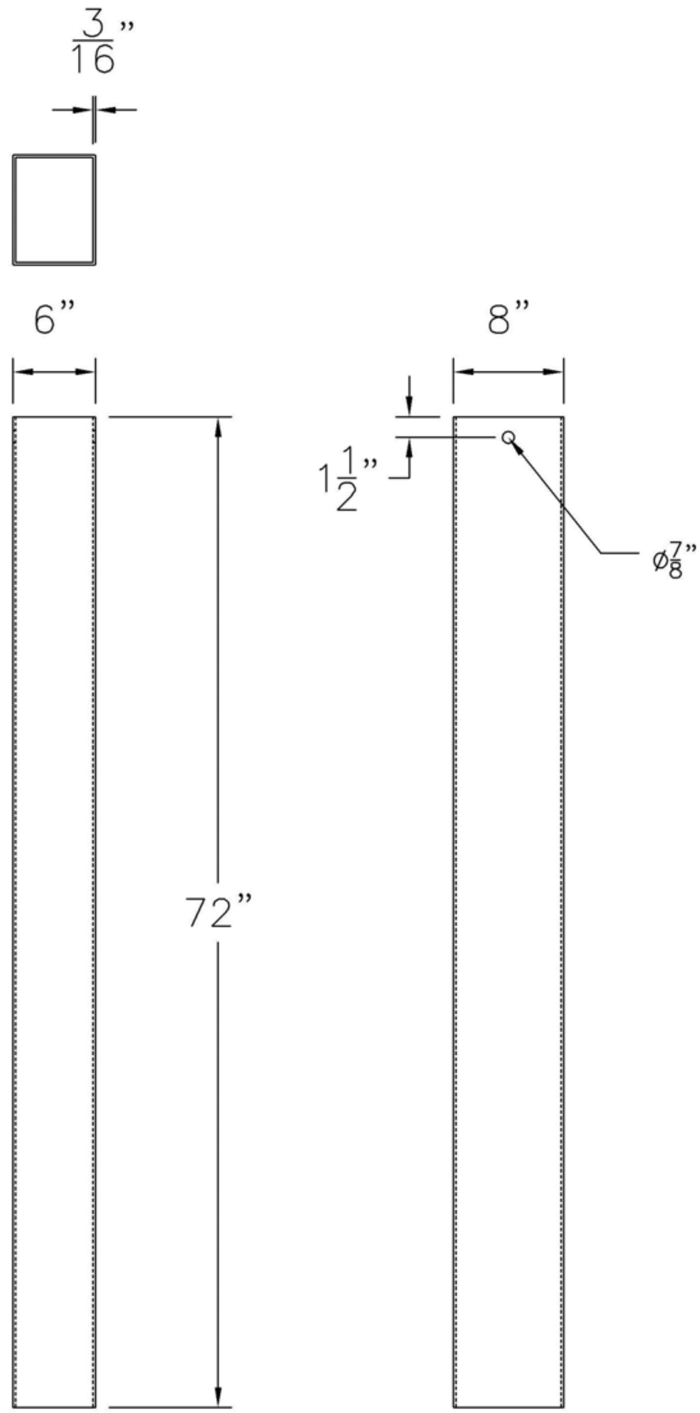


Figure H-14. *Midwest Guardrail System* Standard Post Spacing with Curb - Foundation Tube Design Details (English)

APPENDIX I

Accelerometer and Rate Transducer Data Analysis, Test NPG-5

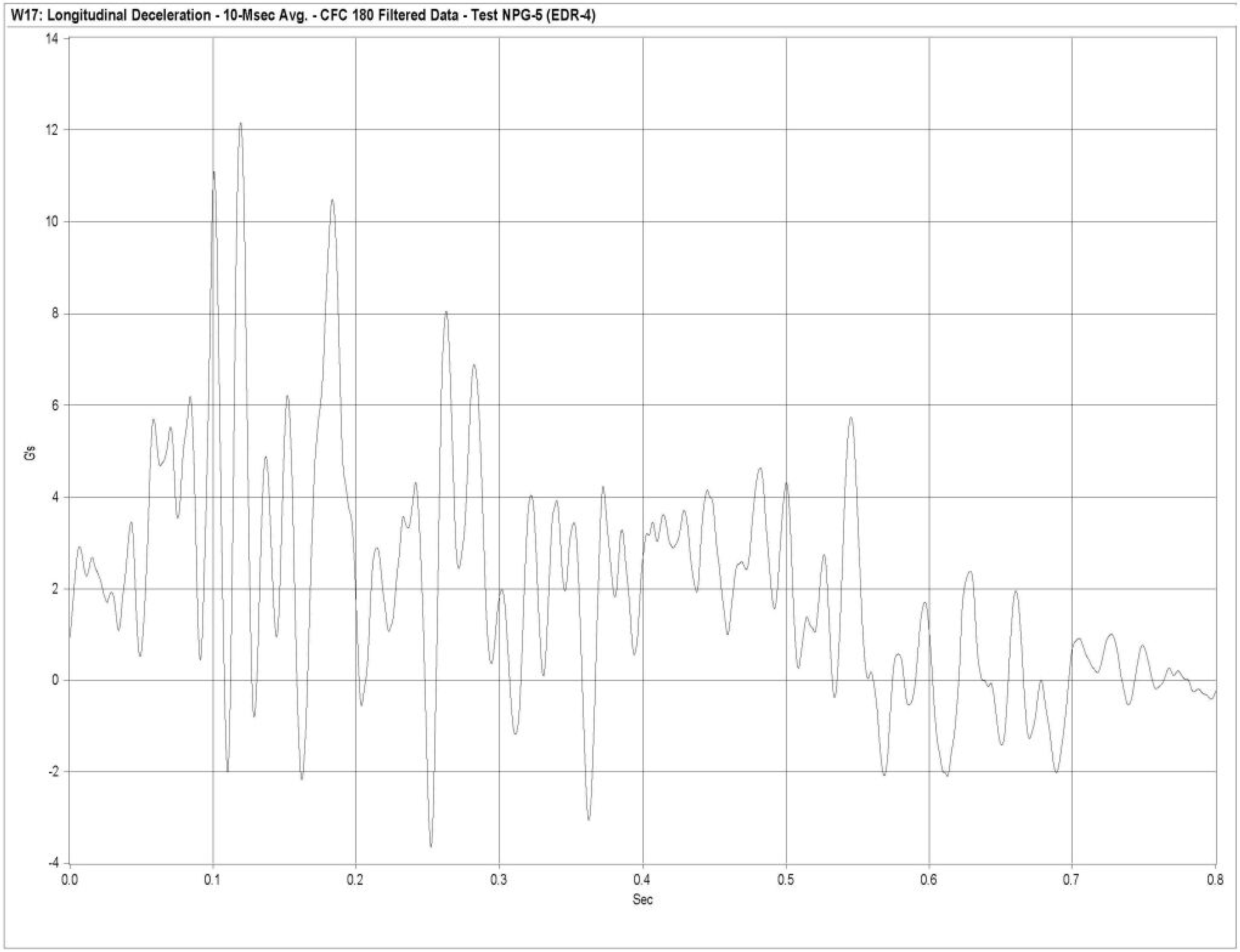


Figure I-1. Graph of Longitudinal Deceleration Test NPG-5

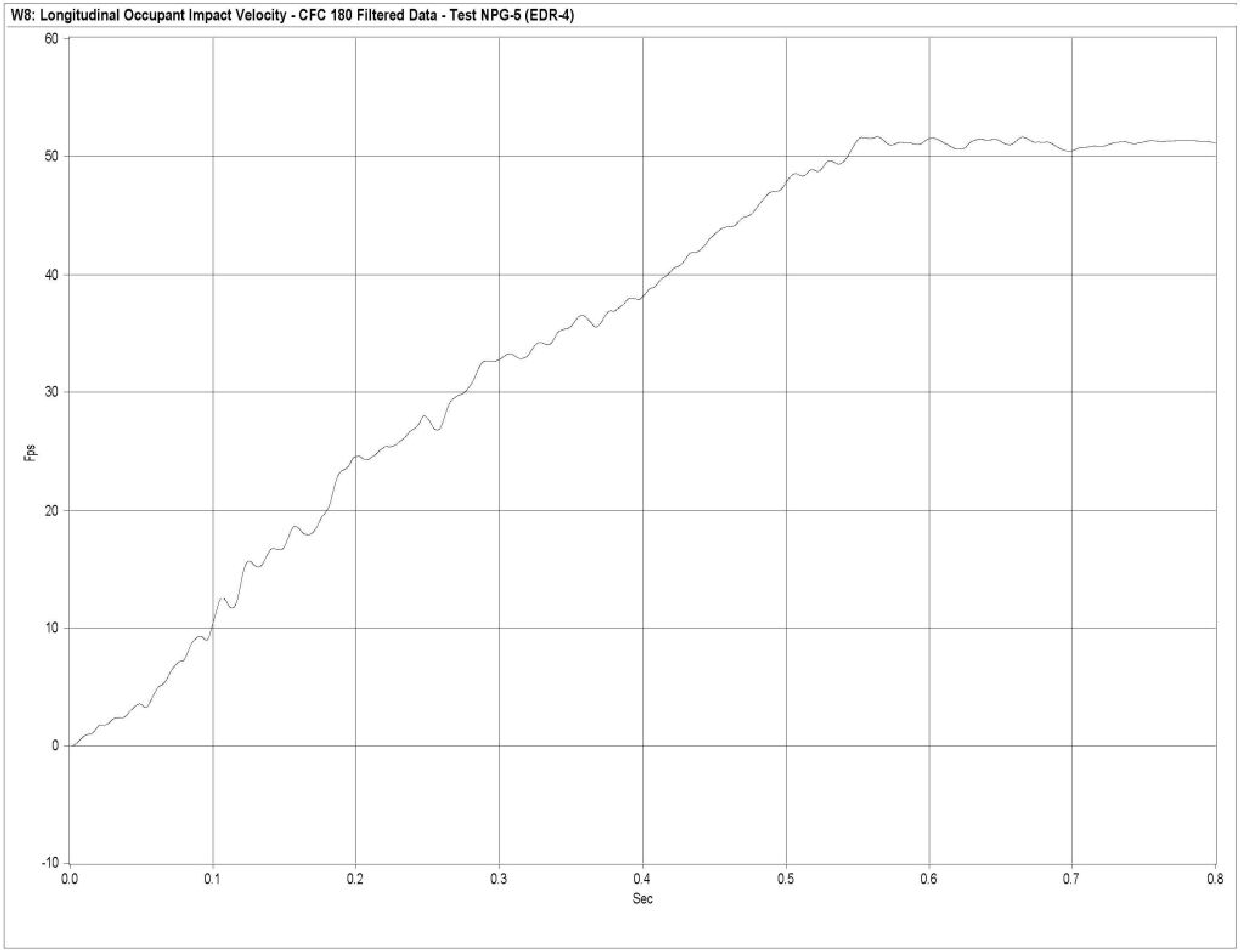


Figure I-2. Graph of Longitudinal Occupant Impact Velocity, Test NPG-5

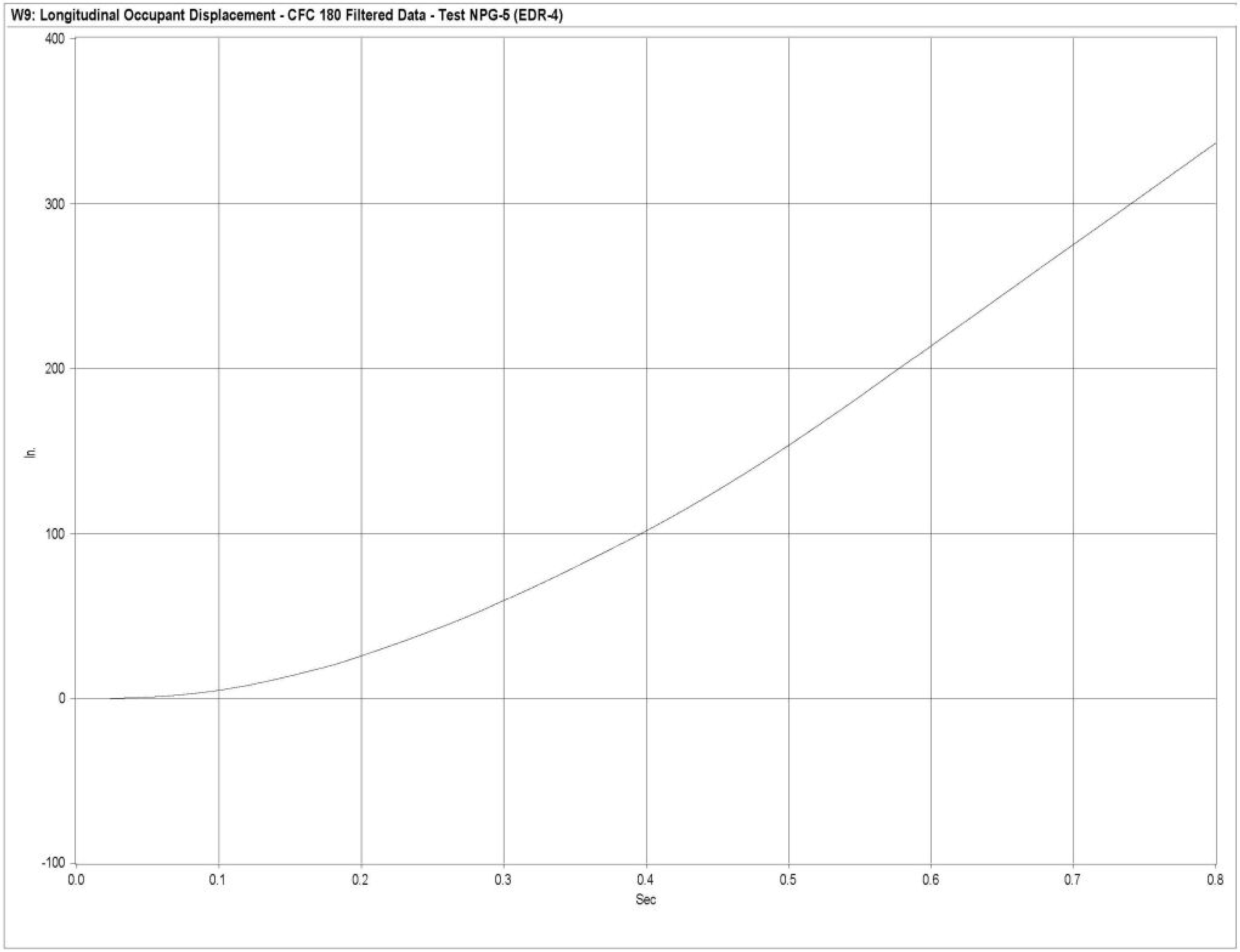


Figure I-3. Graph of Longitudinal Occupant Displacement, Test NPG-5

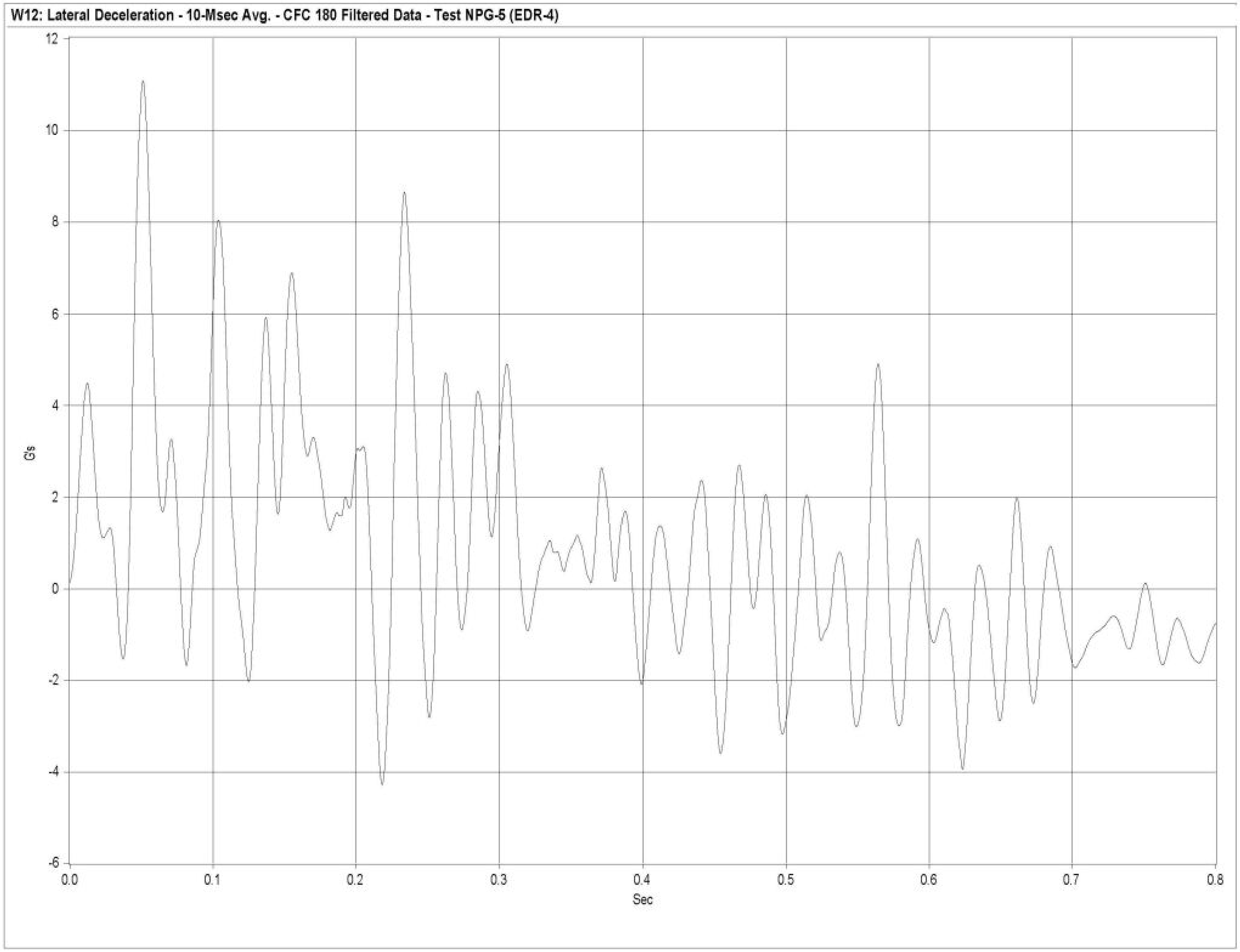


Figure I-4. Graph of Lateral Deceleration, Test NPG-5

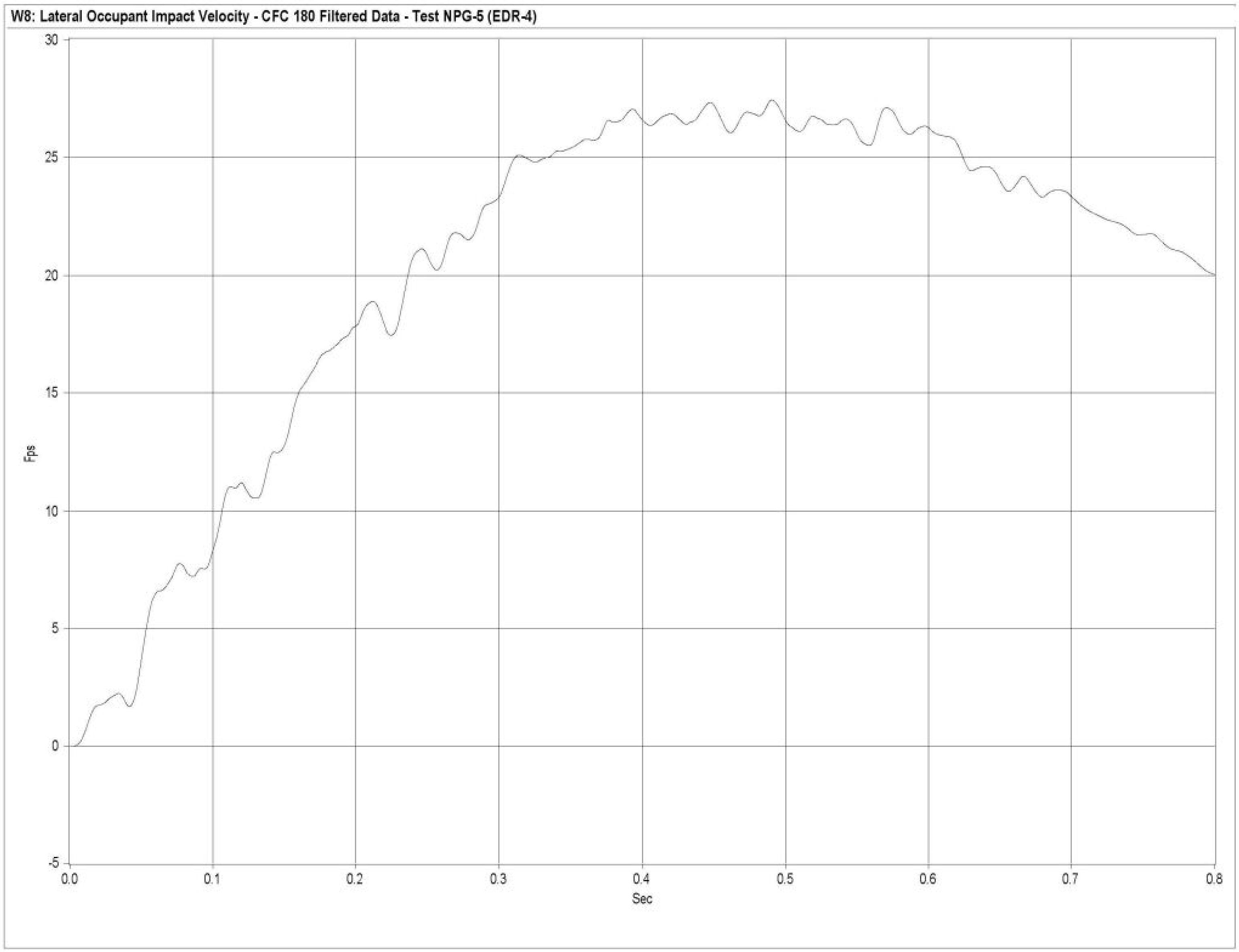


Figure I-5. Graph of Lateral Occupant Impact Velocity, Test NPG-5

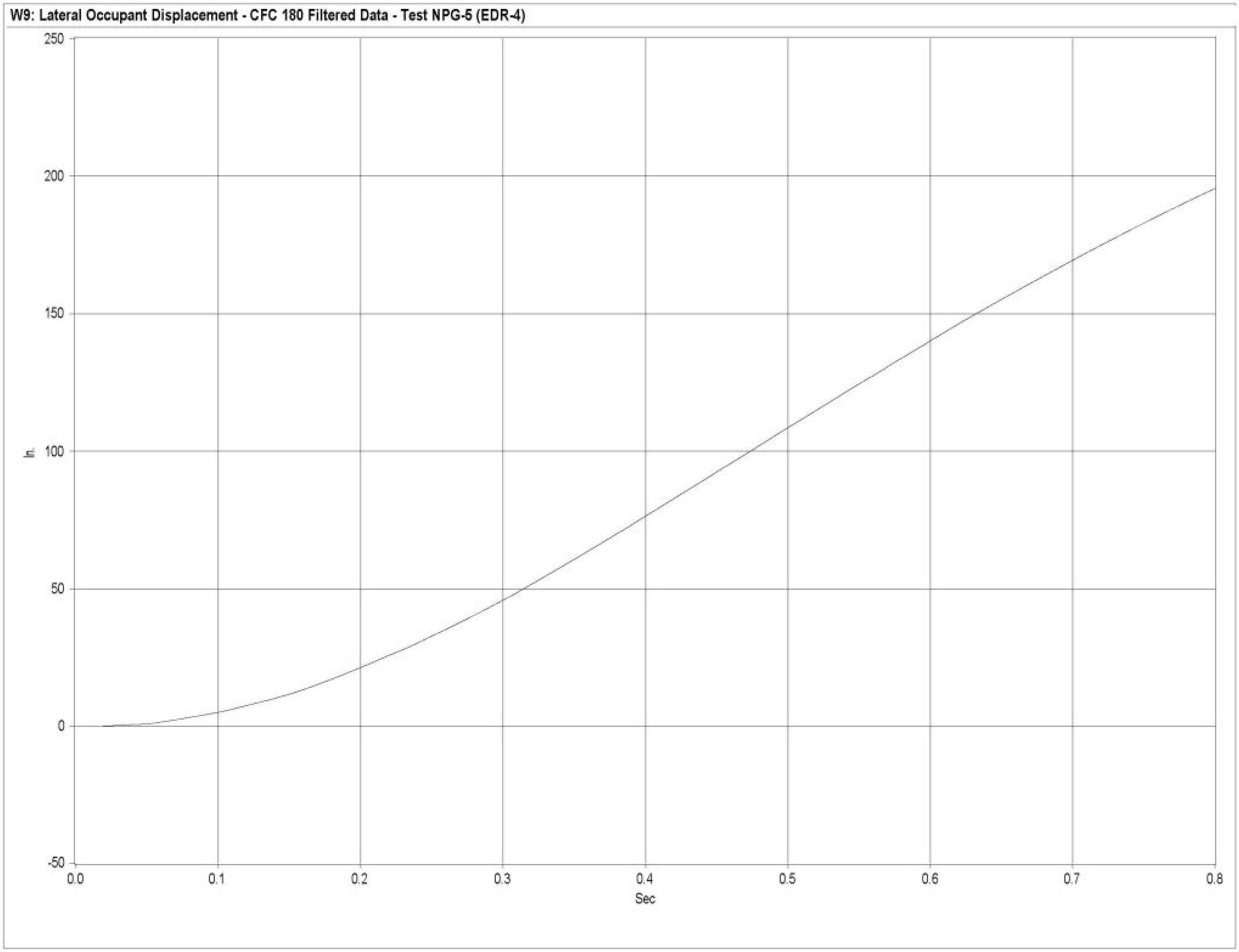


Figure I-6. Graph of Lateral Occupant Displacement, Test NPG-5

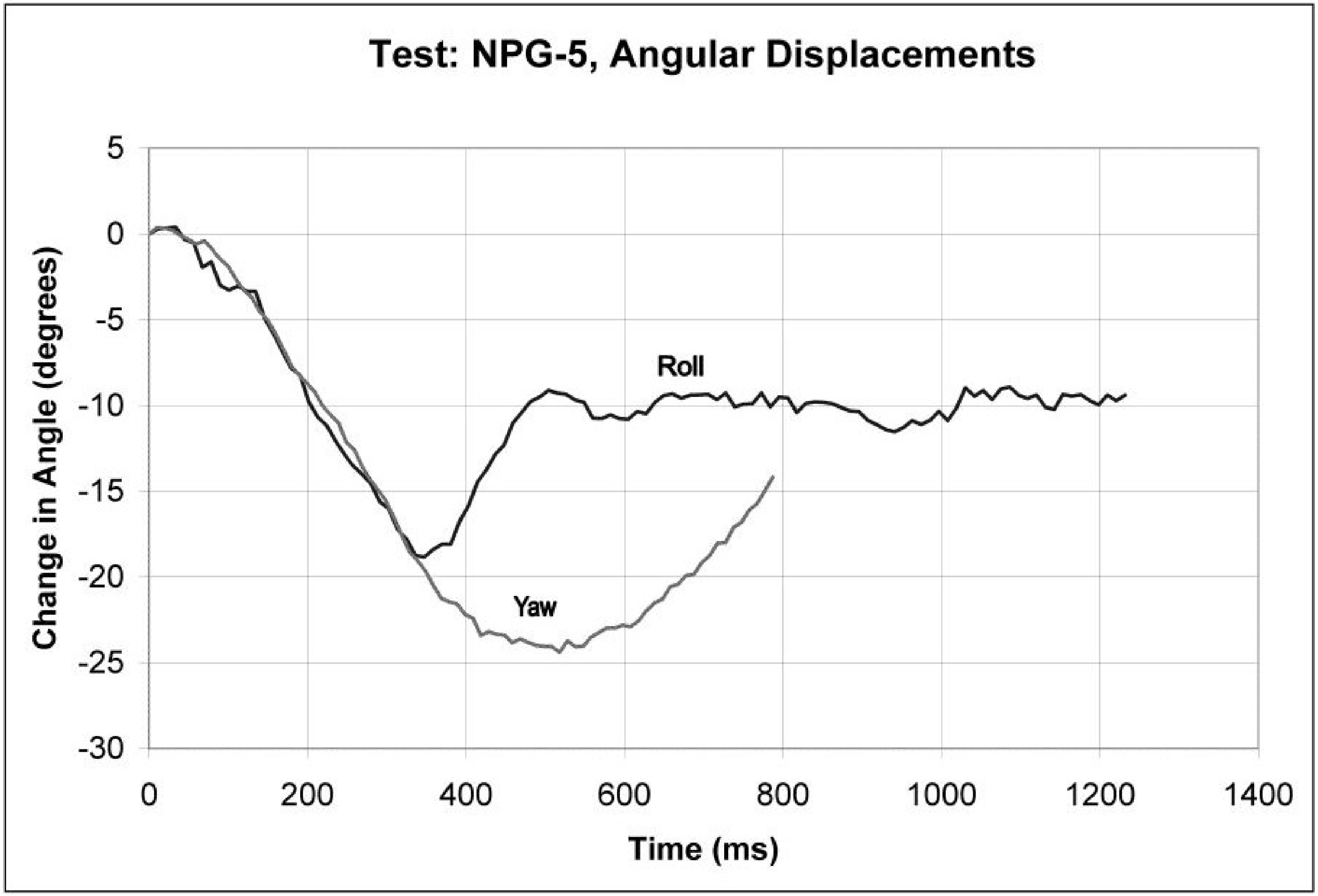


Figure I-7. Graph of Roll and Yaw Angular Displacements, Test NPG-5

APPENDIX J

Midwest Guardrail System Reduced Post Spacing System Drawings

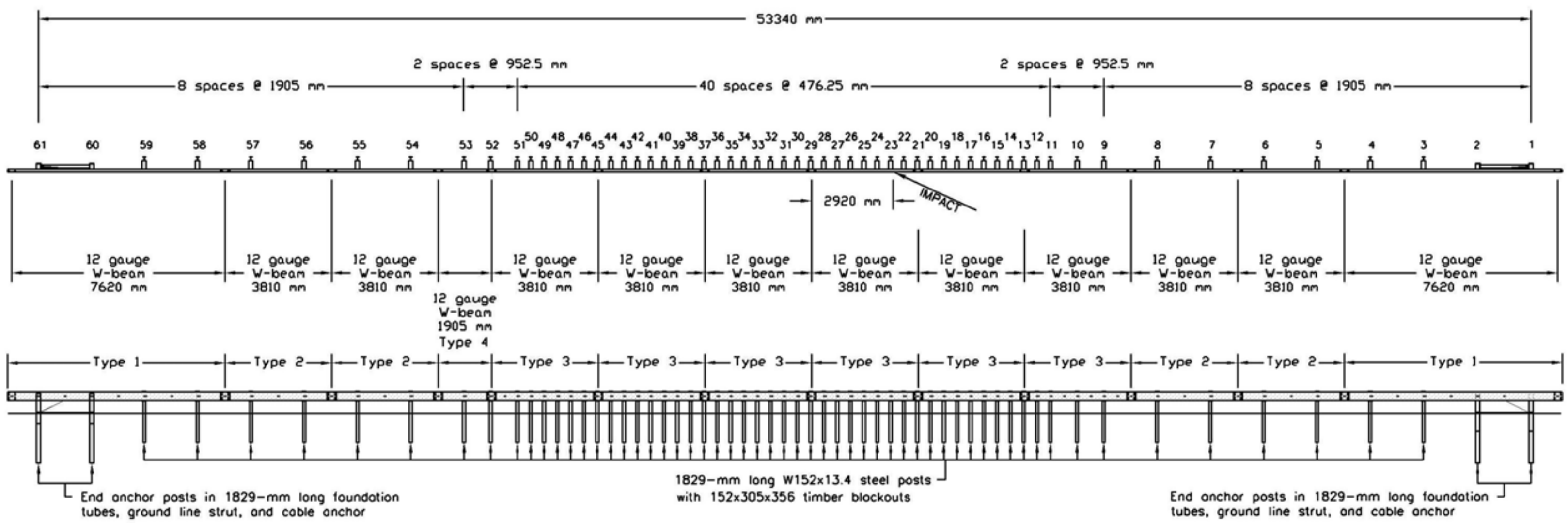


Figure J-1. *Midwest Guardrail System* Reduced Post Spacing (Metric)

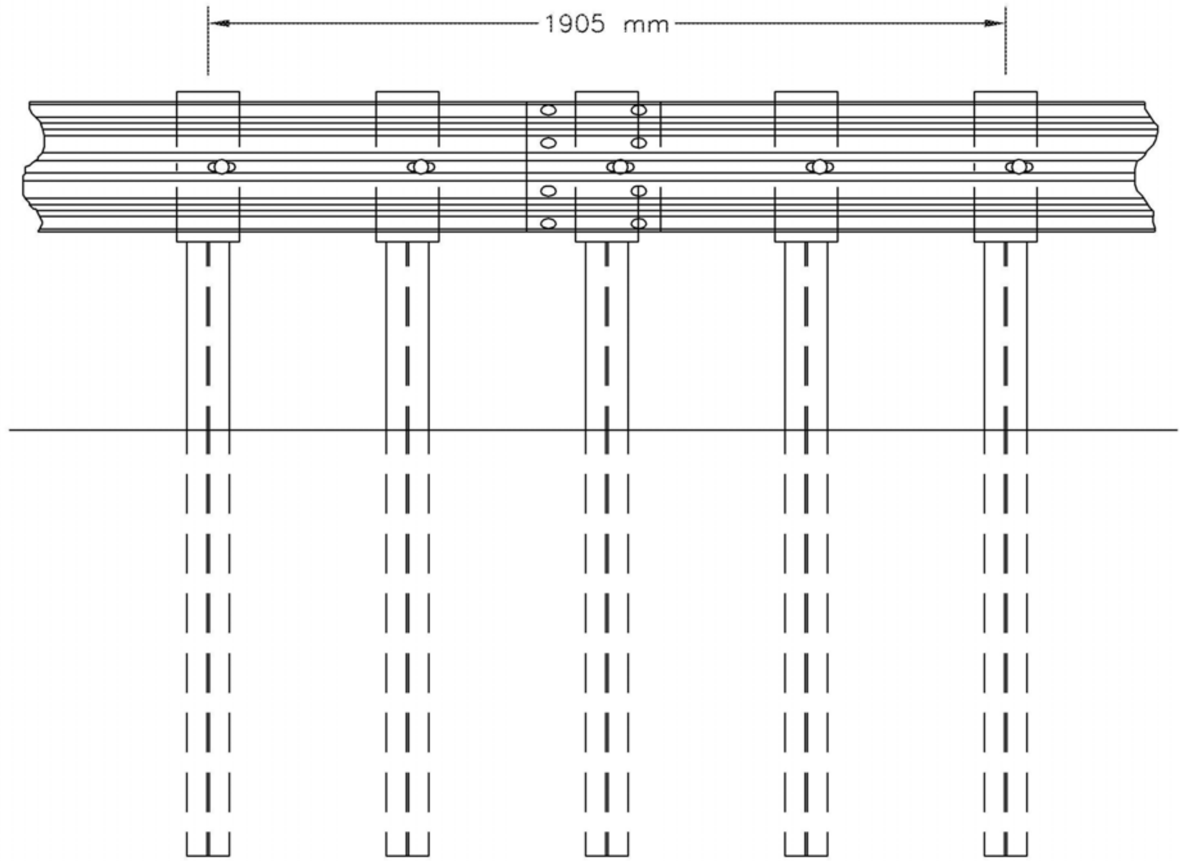


Figure J-2. *Midwest Guardrail System* Reduced Post Spacing Details (Metric)

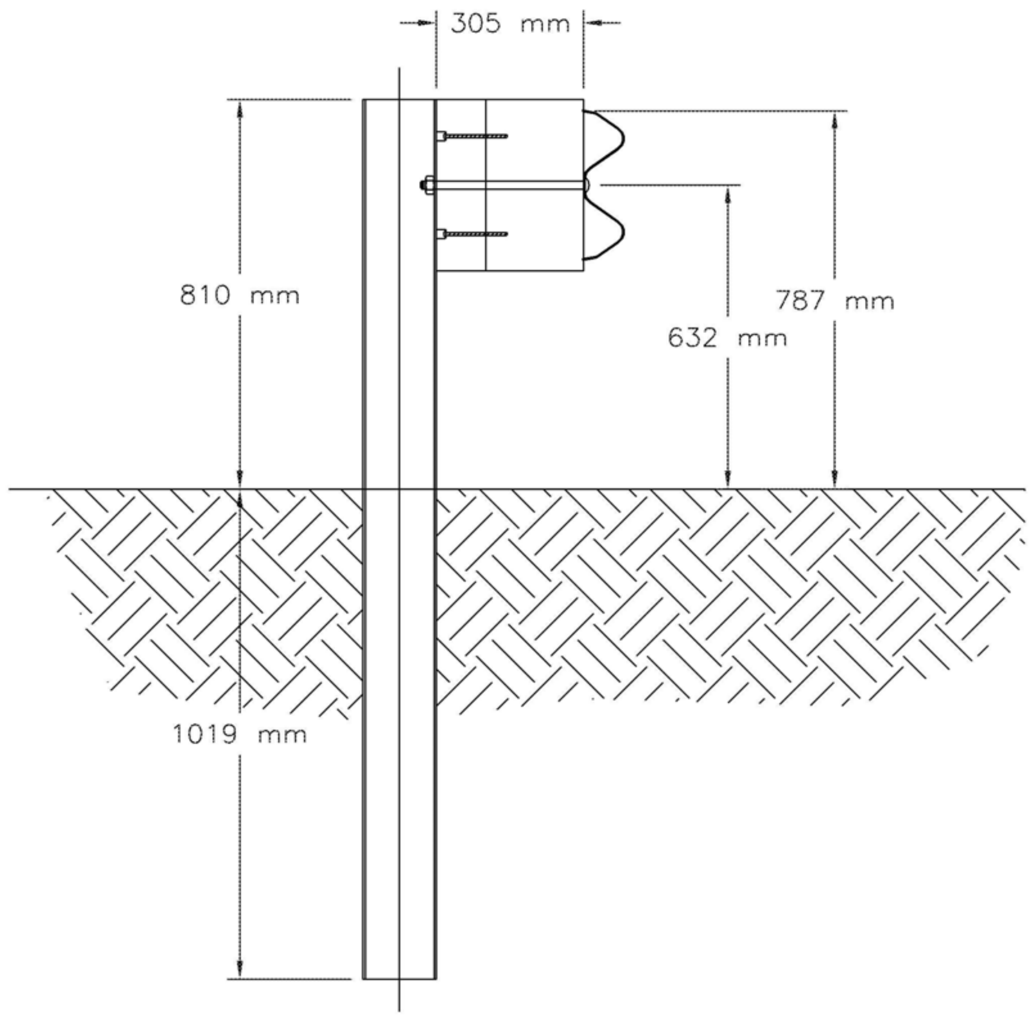


Figure J-3. *Midwest Guardrail System* Reduced Post Spacing - System Details (Metric)

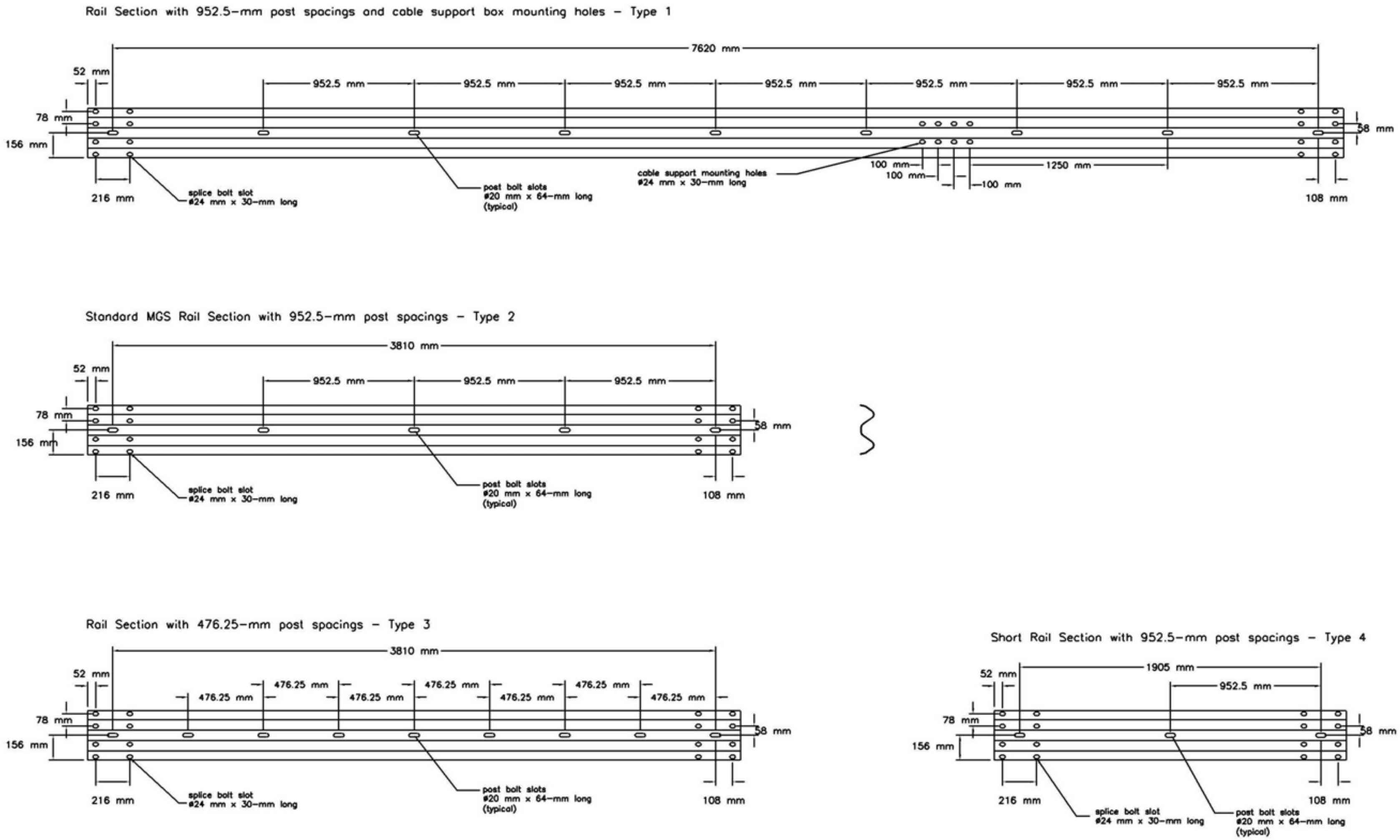


Figure J-4. *Midwest Guardrail System* Reduced Post Spacing - Type 1, 2, 3, and 4 Rail Section Design Details (Metric)

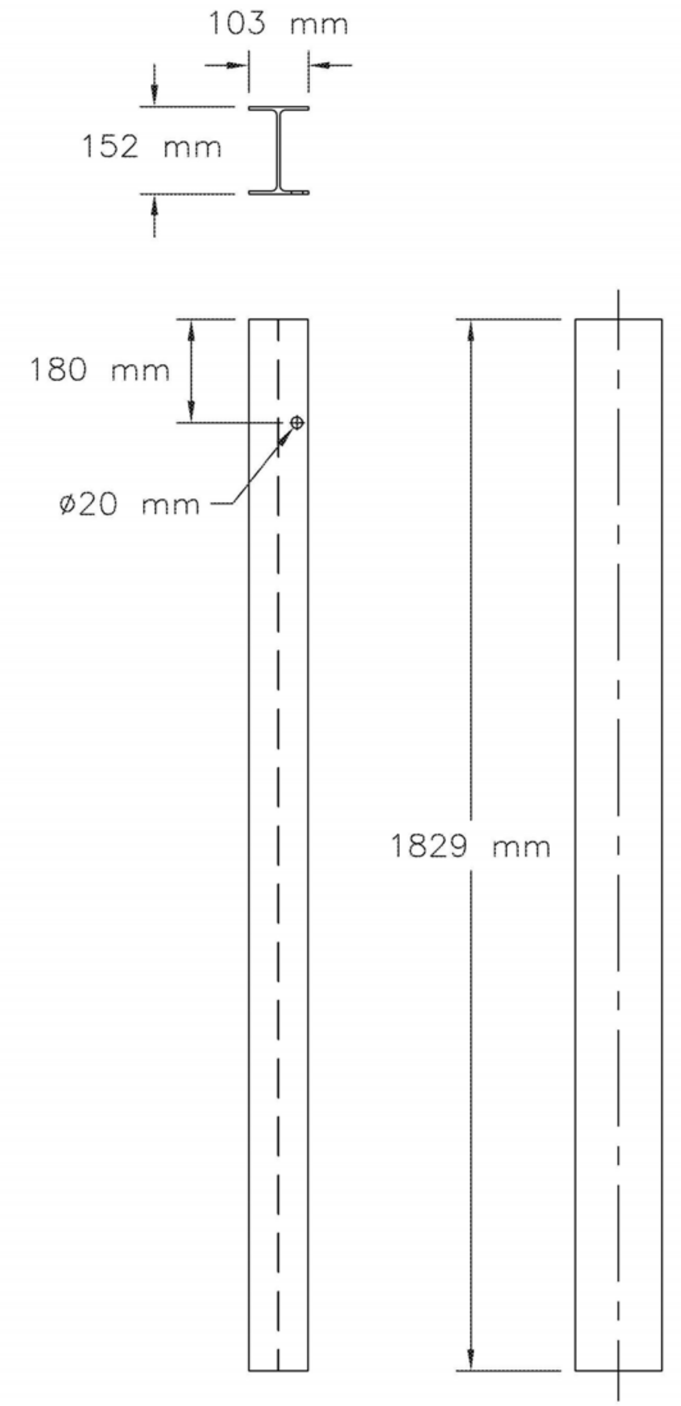


Figure J-5. *Midwest Guardrail System* Reduced Post Spacing - Post Design Details (Metric)

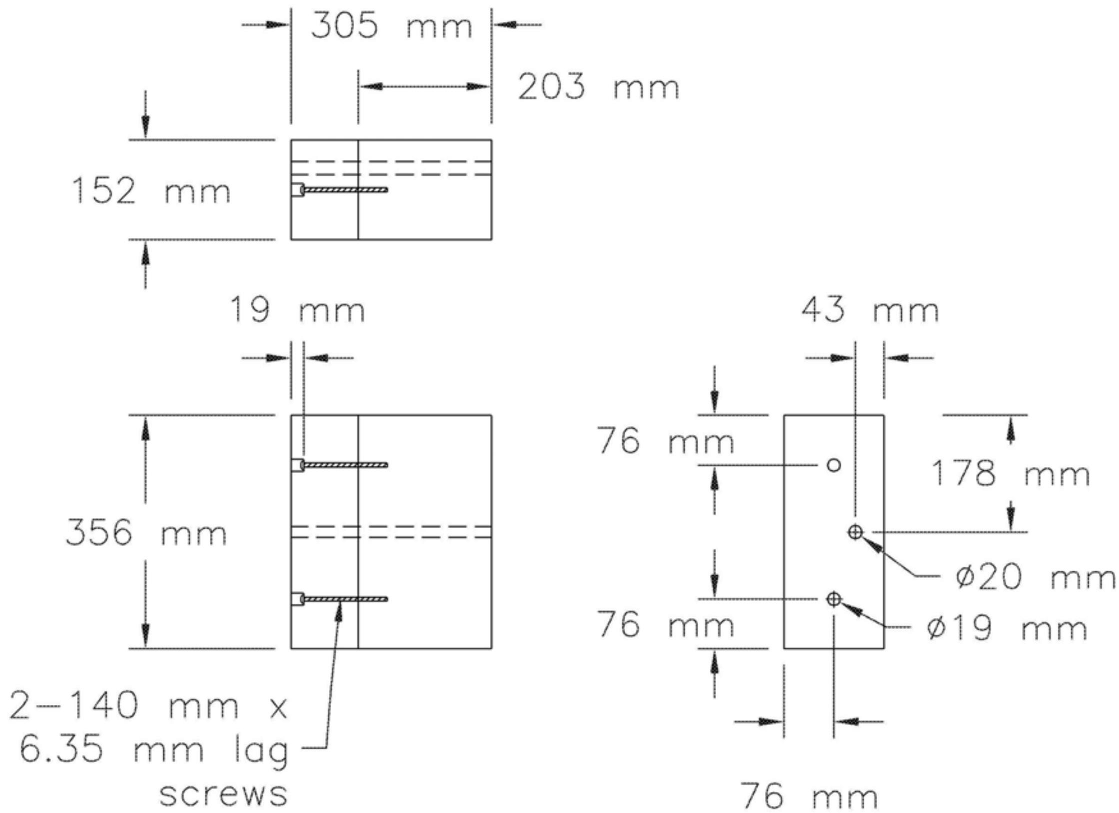


Figure J-6. *Midwest Guardrail System* Reduced Post Spacing - Blockout Design Details (Metric)

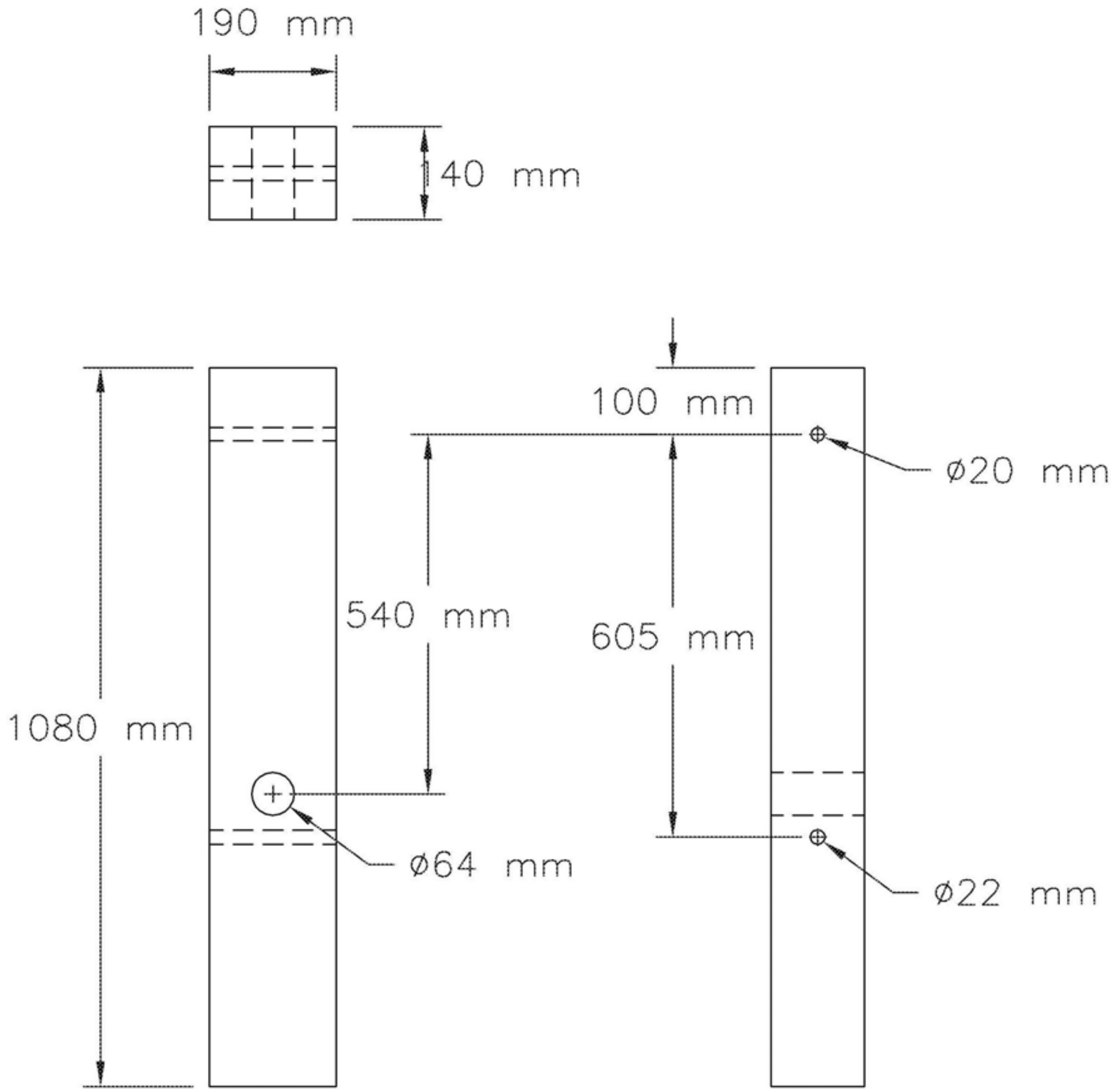


Figure J-7. *Midwest Guardrail System* Reduced Post Spacing - Anchor Post Design Details (Metric)

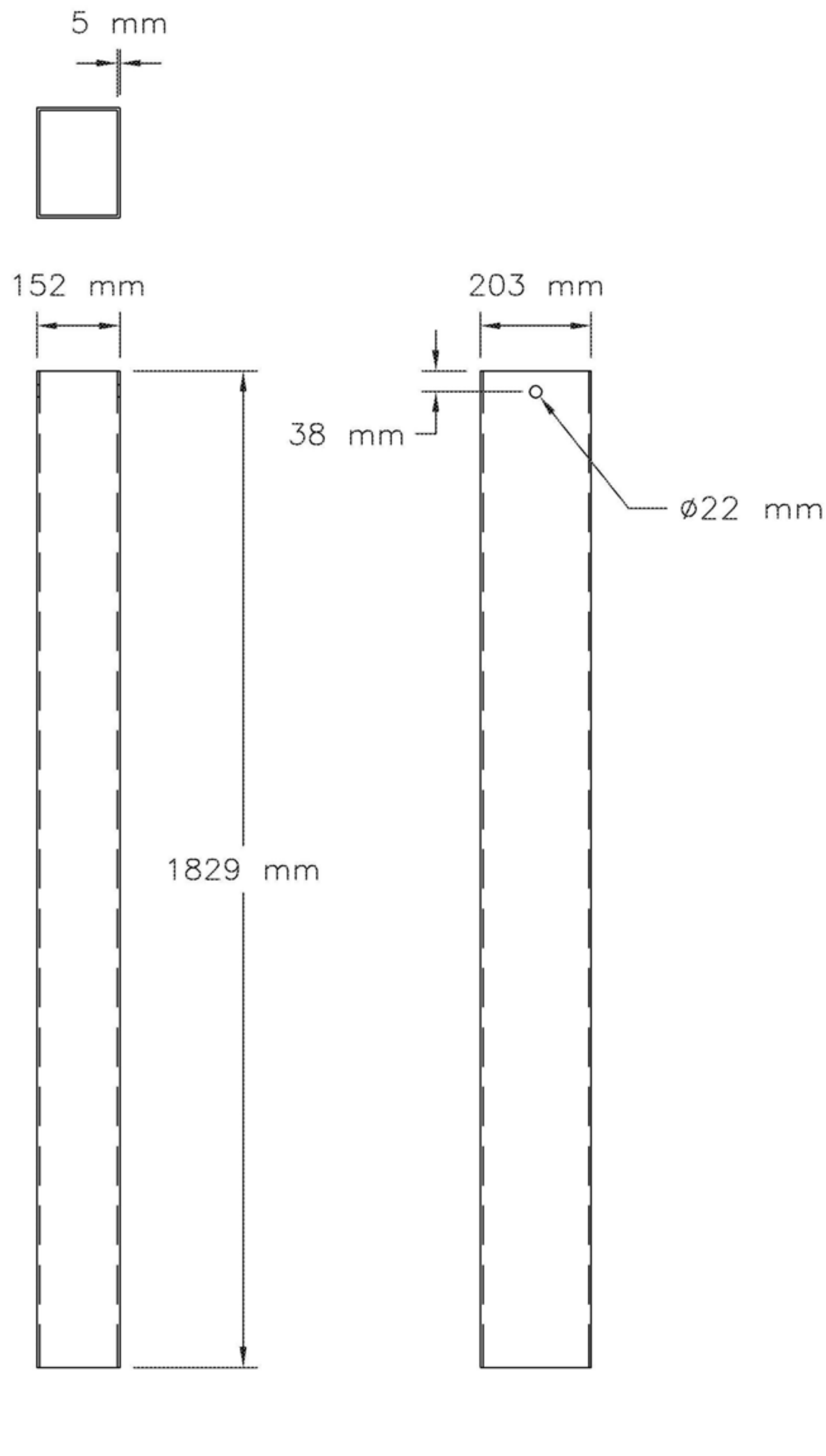


Figure J-8. *Midwest Guardrail System* Reduced Post Spacing - Foundation Tube Design Details (Metric)

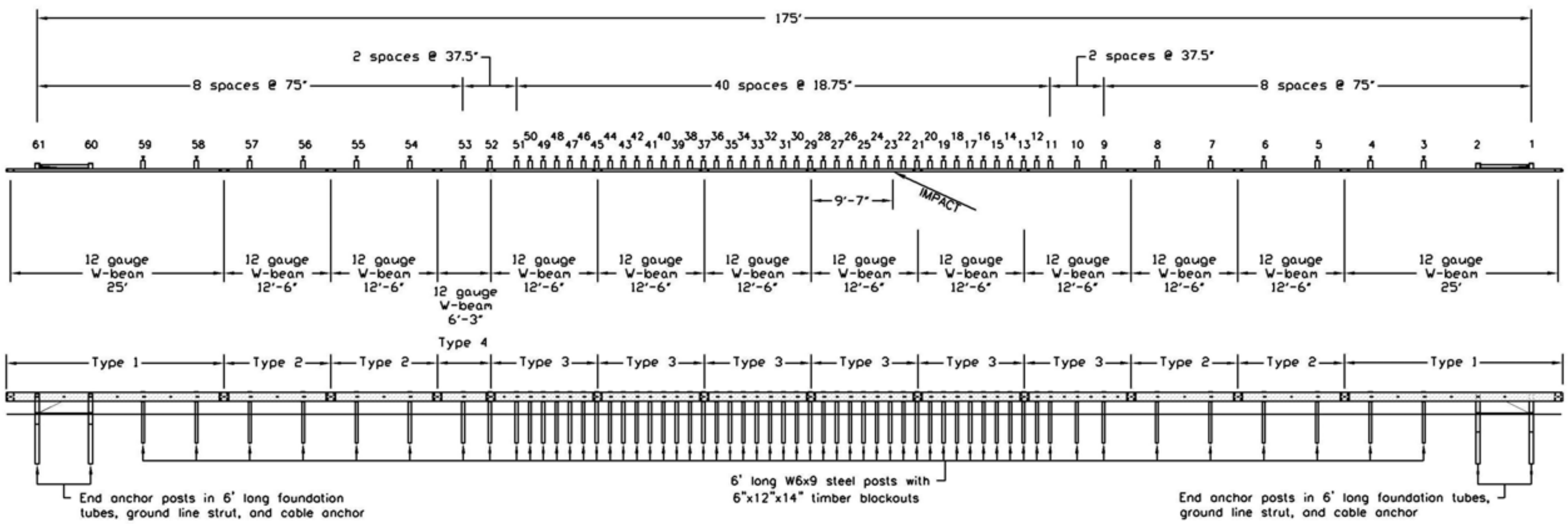


Figure J-9. *Midwest Guardrail System* Reduced Post Spacing (English)

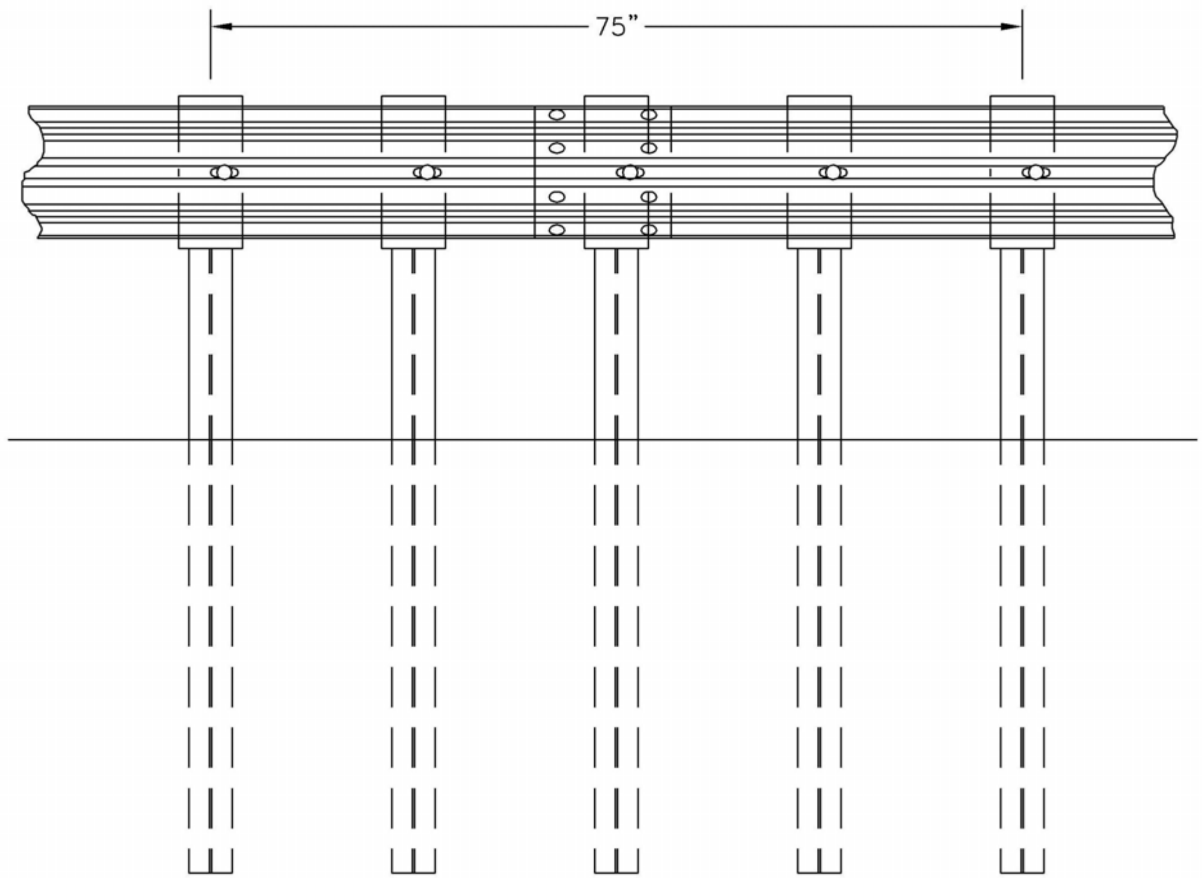


Figure J-10. *Midwest Guardrail System* Reduced Post Spacing Details (English)

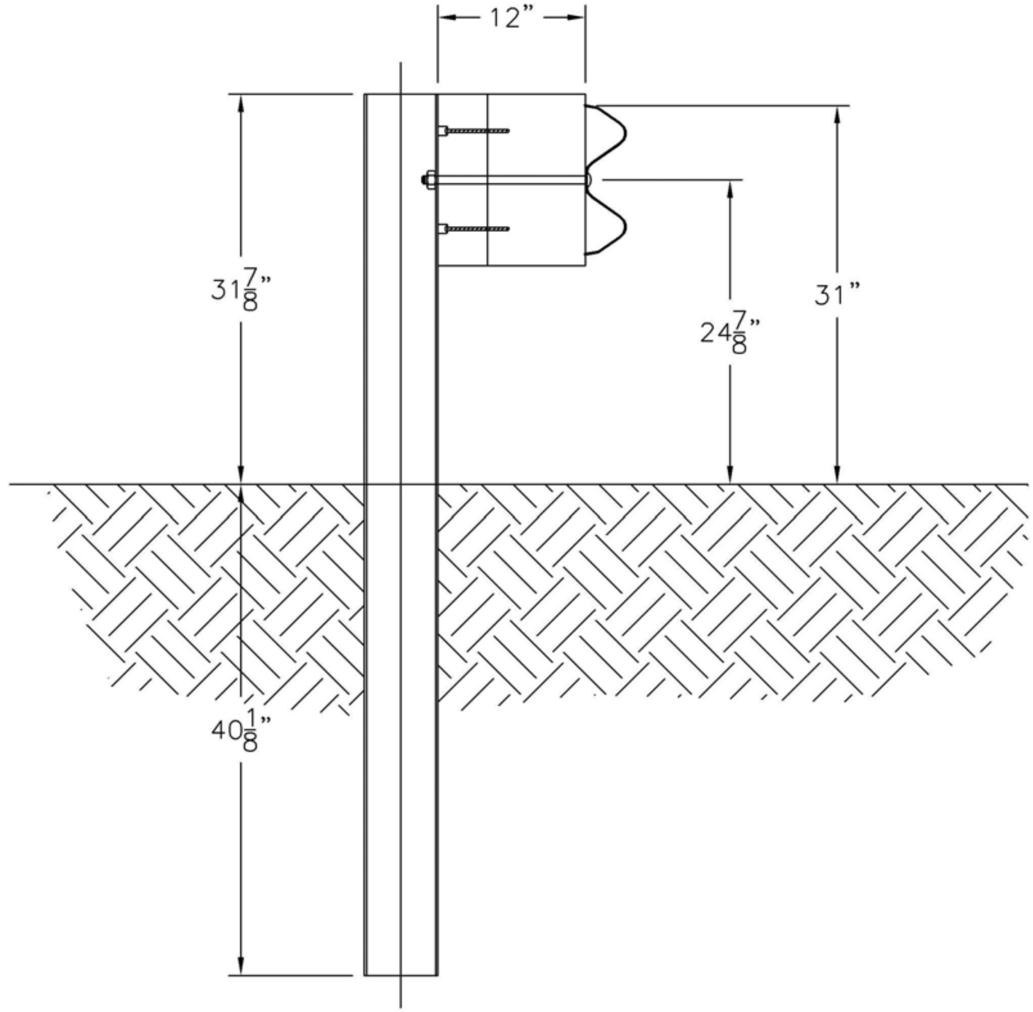


Figure J-11. *Midwest Guardrail System* Reduced Post Spacing - System Details (English)

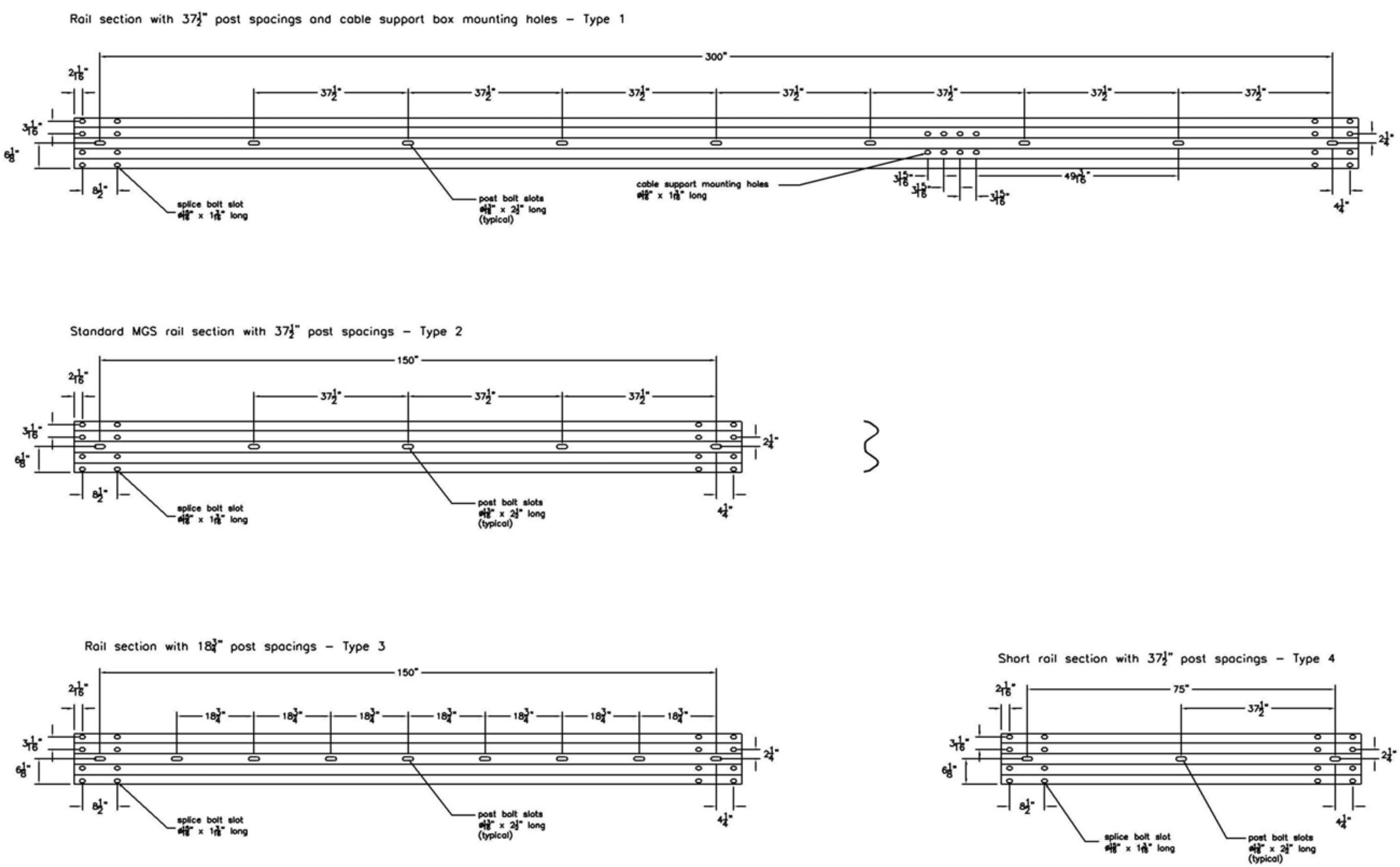


Figure J-12. *Midwest Guardrail System* Reduced Post Spacing - Type 1, 2, 3, and 4 Rail Section Design Details (English)

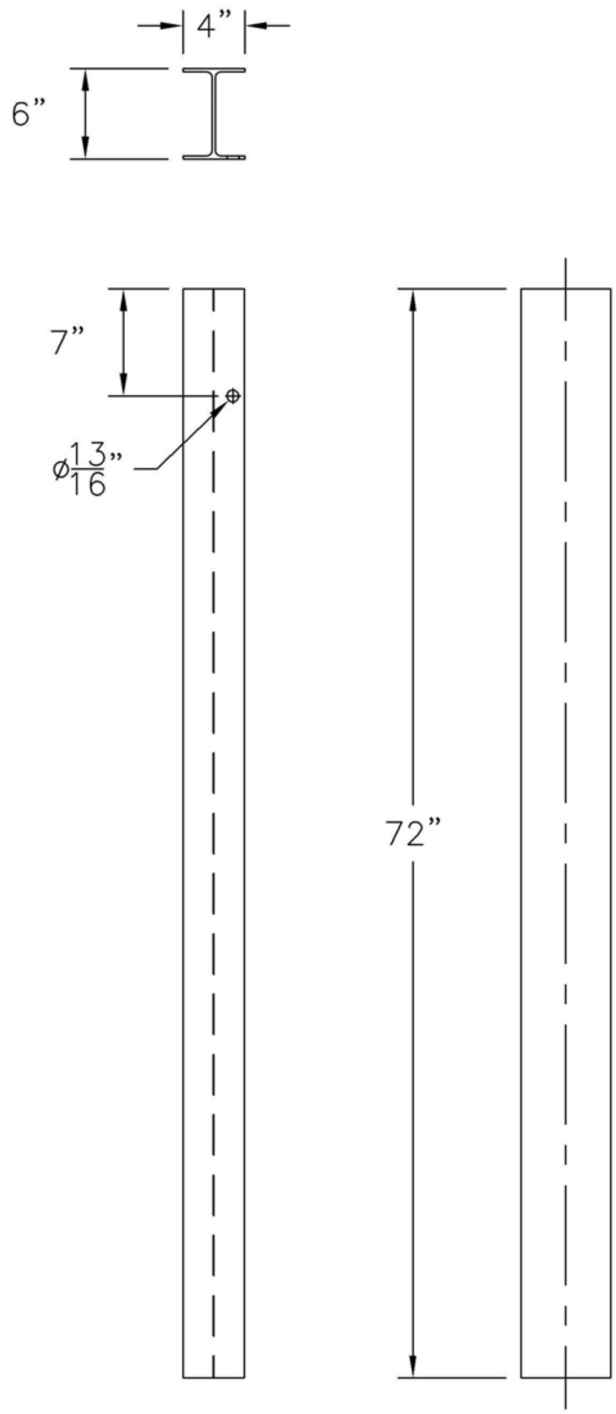


Figure J-13. *Midwest Guardrail System* Reduced Post Spacing - Post Design Details (English)

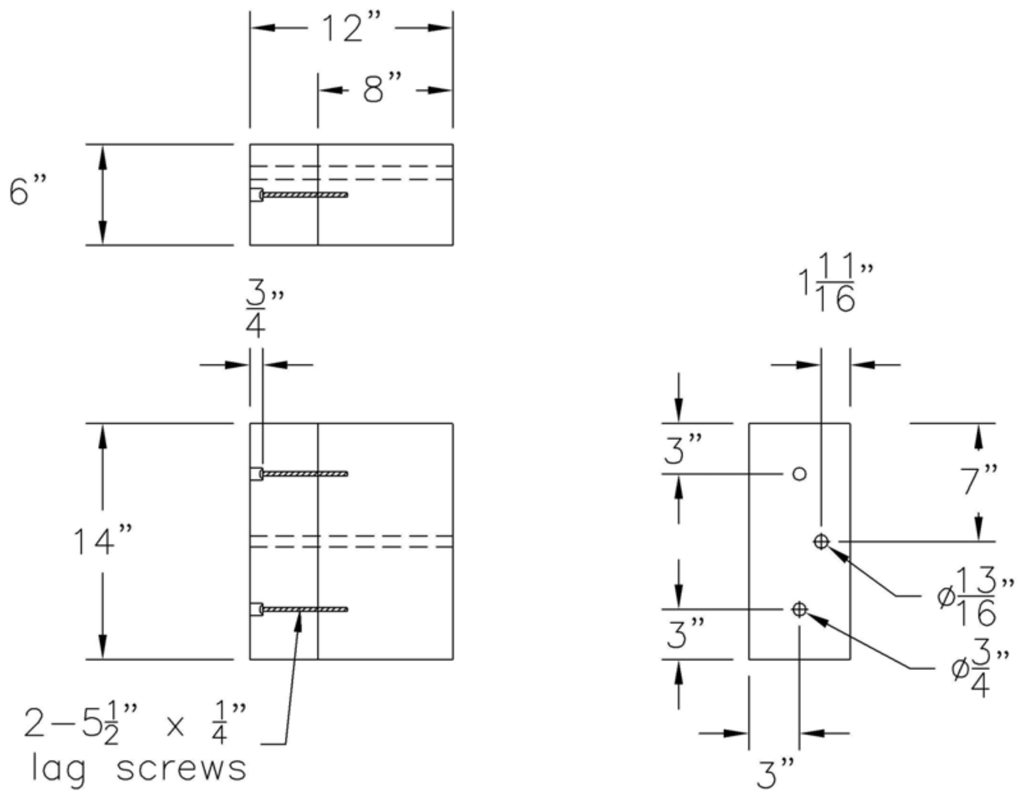


Figure J-14. *Midwest Guardrail System* Reduced Post Spacing - Blockout Design Details (English)

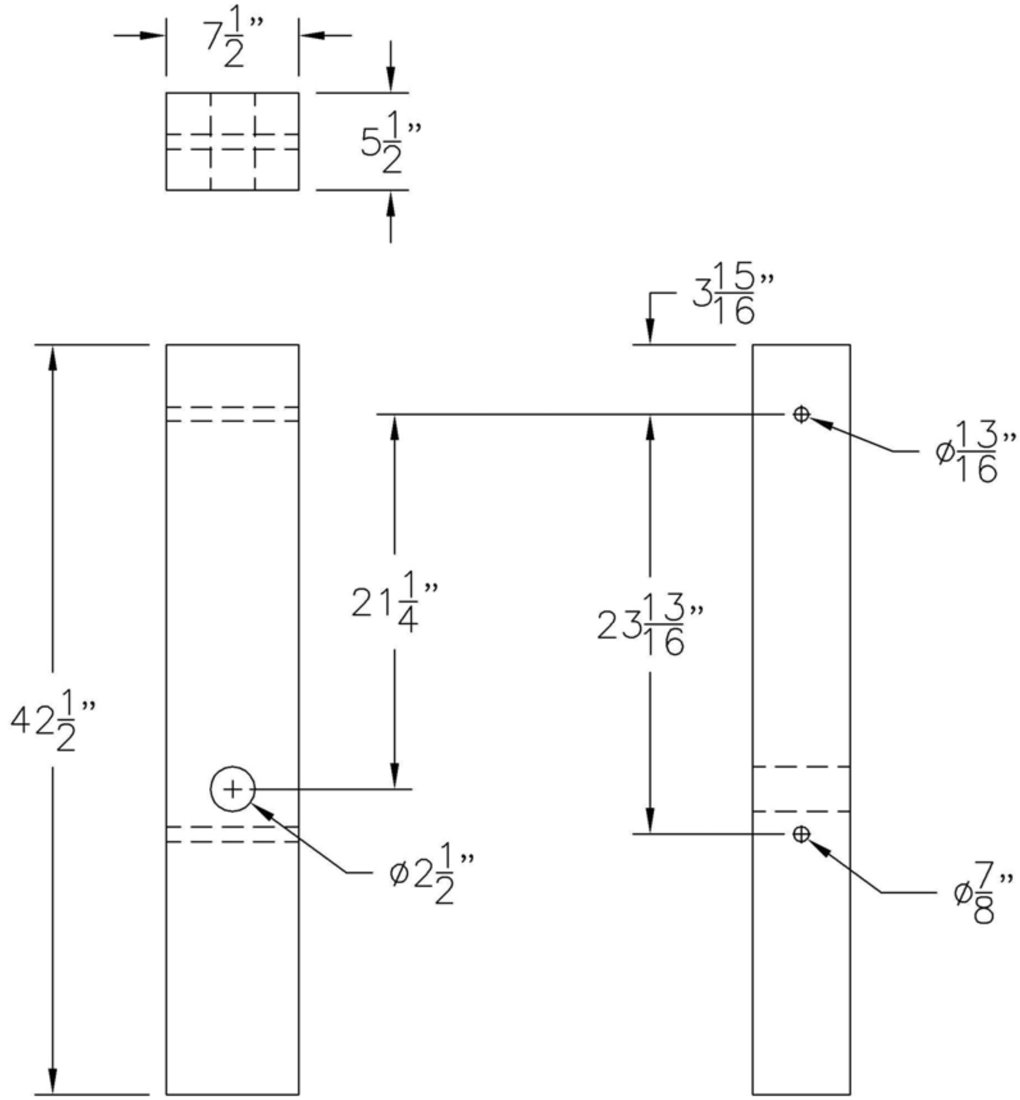


Figure J-15. *Midwest Guardrail System* Reduced Post Spacing - Anchor Post Design Details (English)

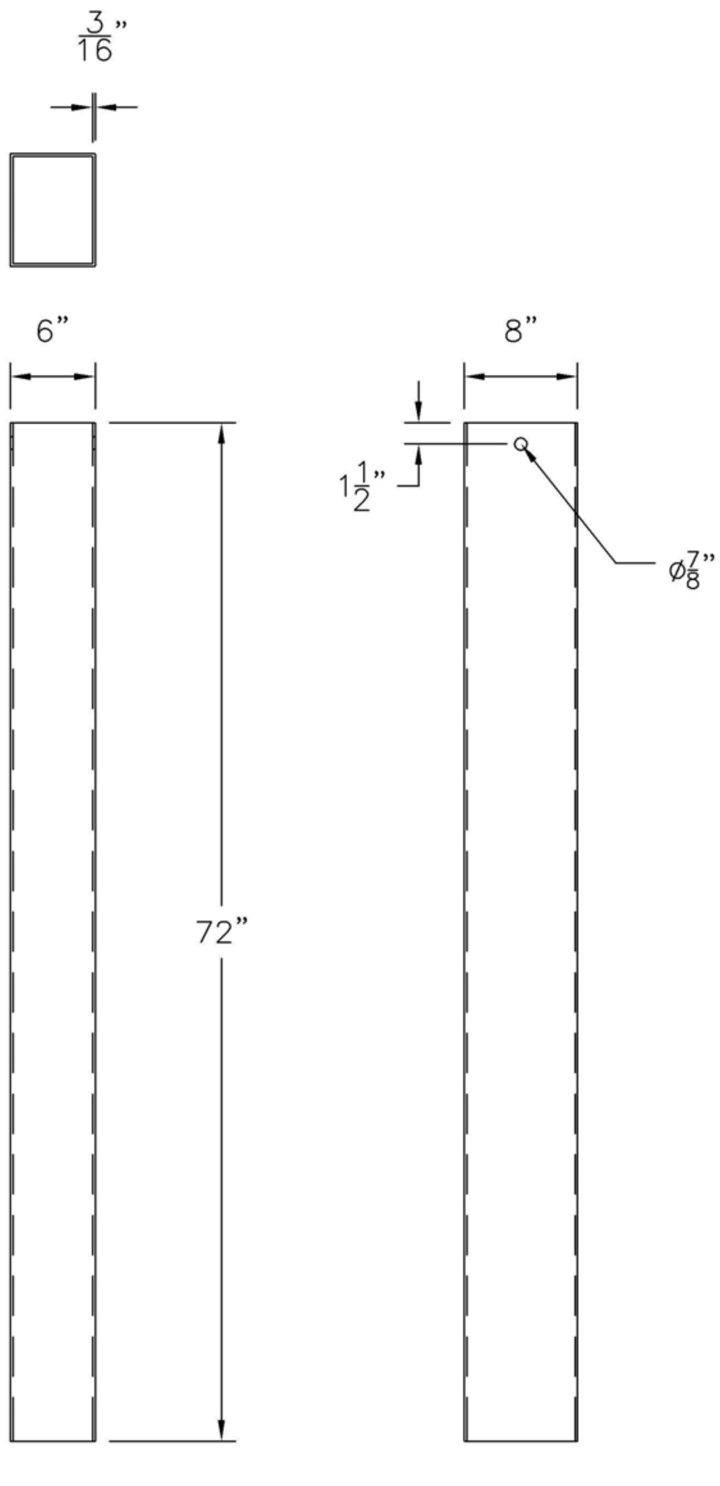


Figure J-16. *Midwest Guardrail System* Reduced Post Spacing - Foundation Tube Design Details (English)

APPENDIX K

Accelerometer and Rate Transducer Data Analysis, Test NPG-6

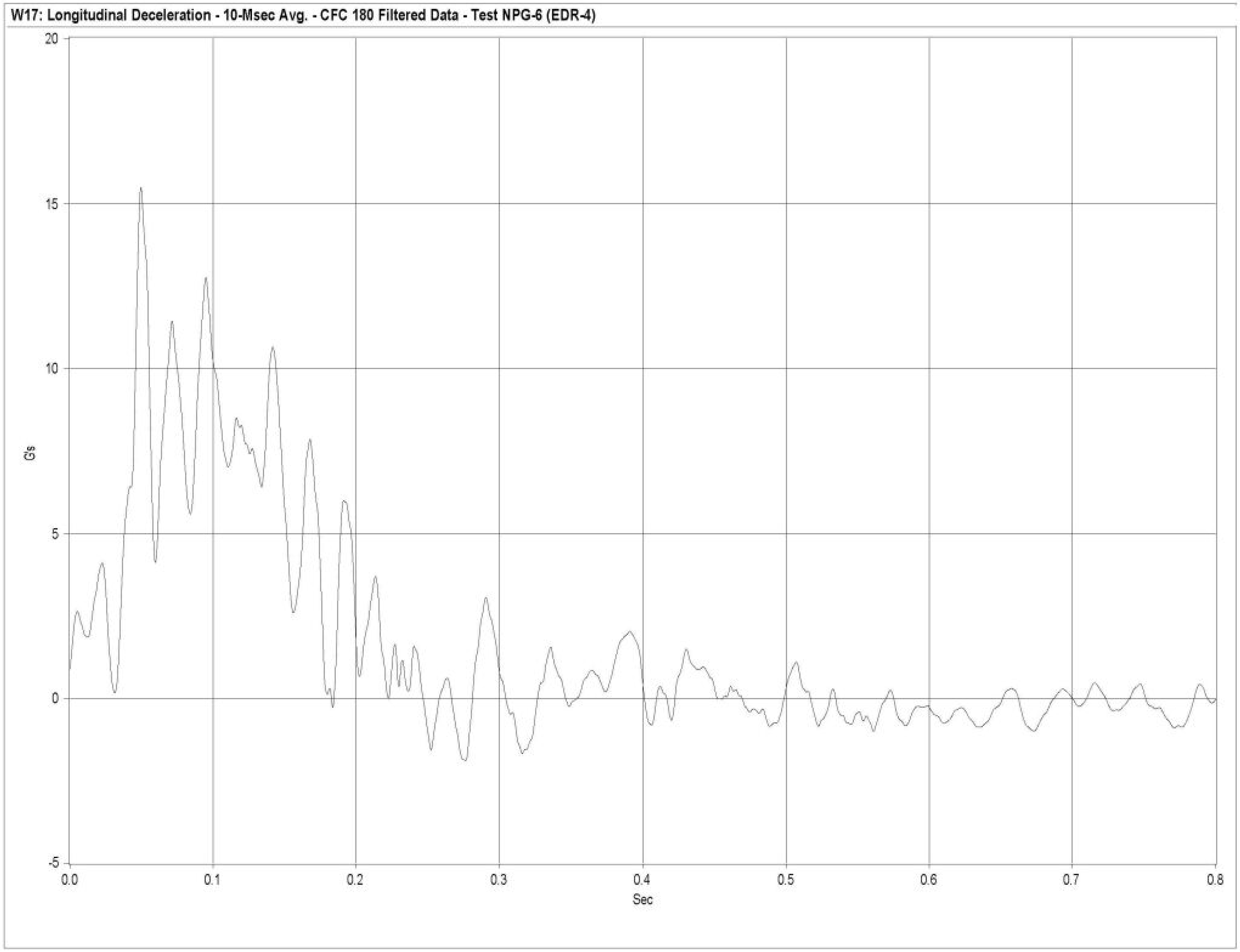


Figure K-1. Graph of Longitudinal Deceleration Test NPG-6

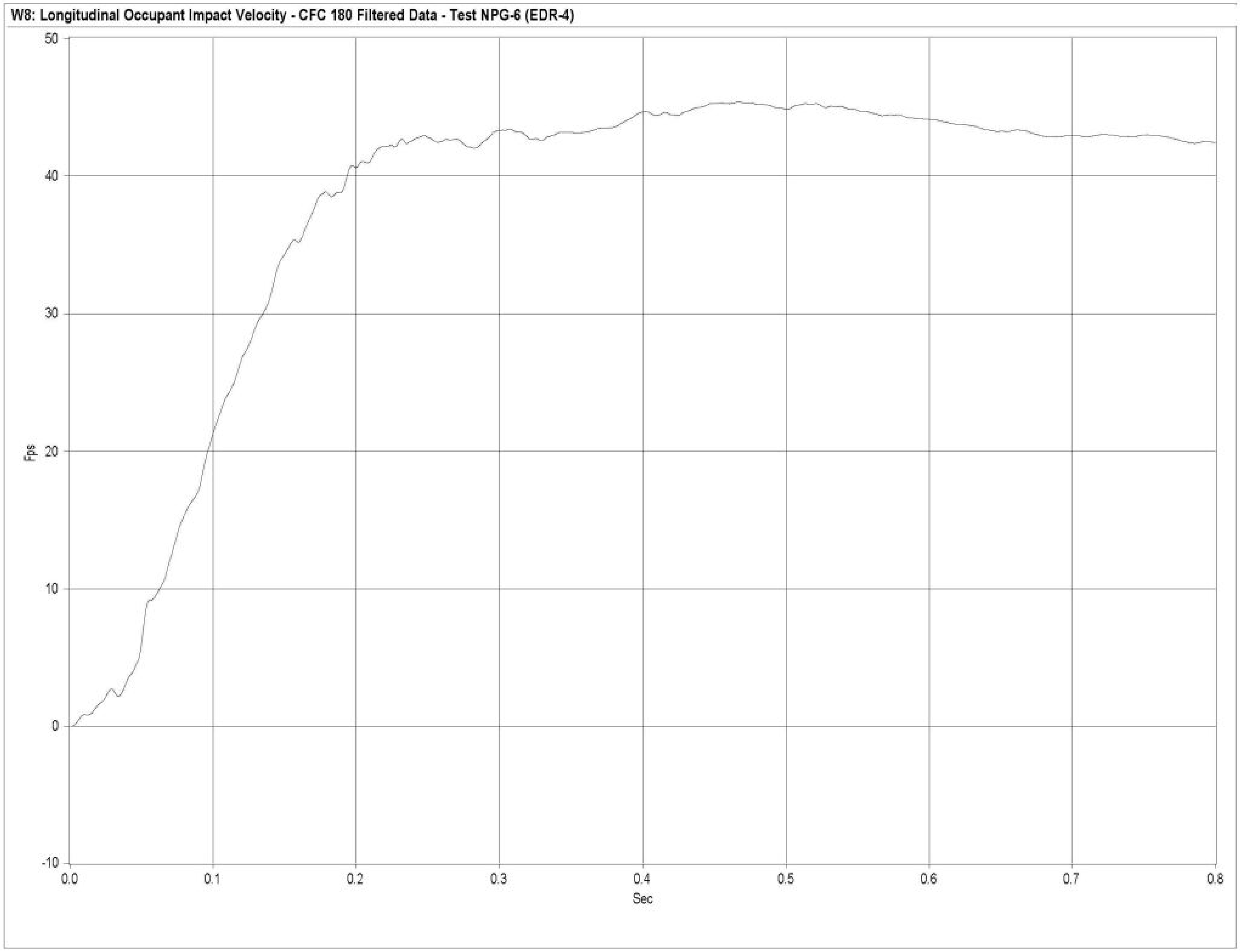


Figure K-2. Graph of Longitudinal Occupant Impact Velocity, Test NPG-6

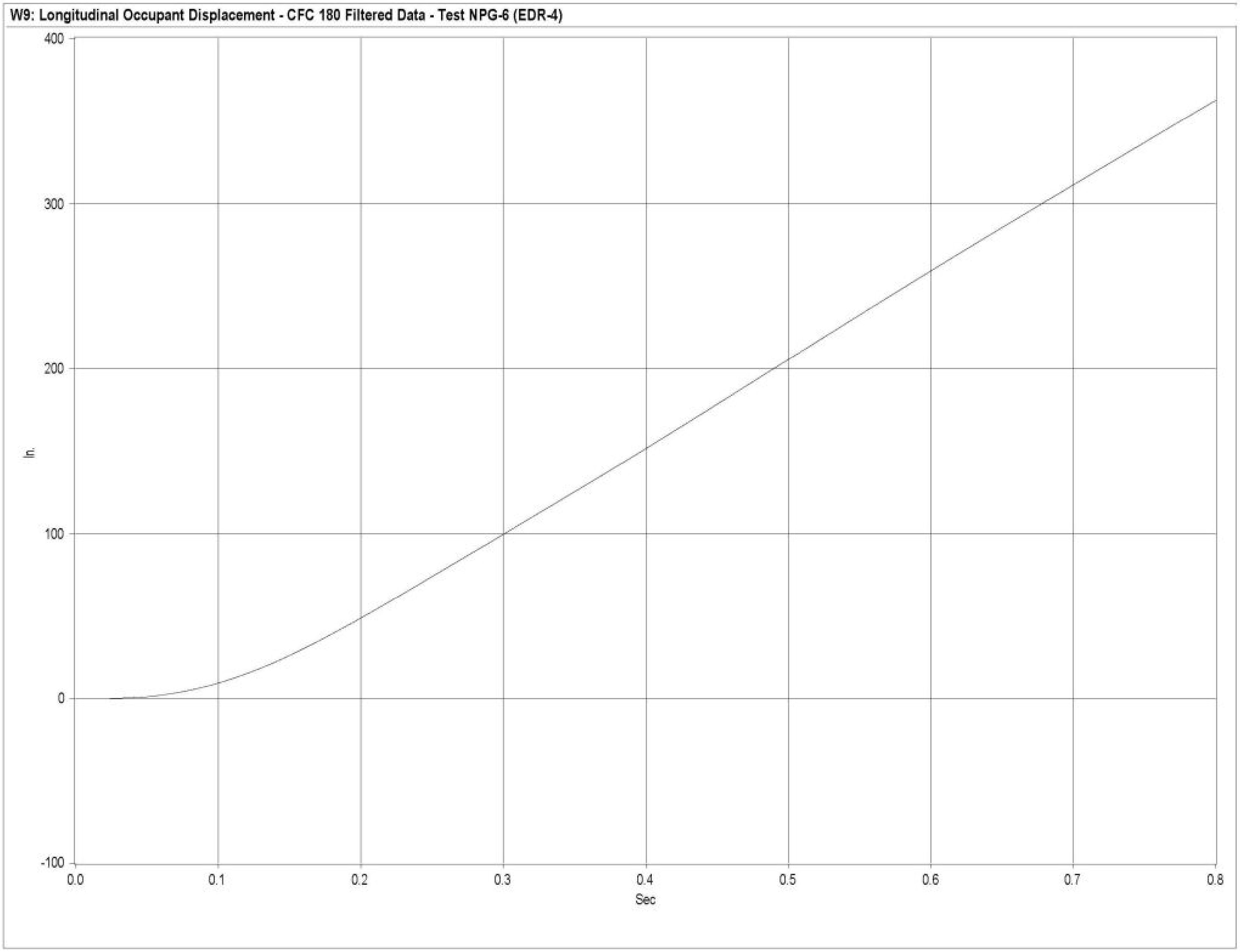


Figure K-3. Graph of Longitudinal Occupant Displacement, Test NPG-6

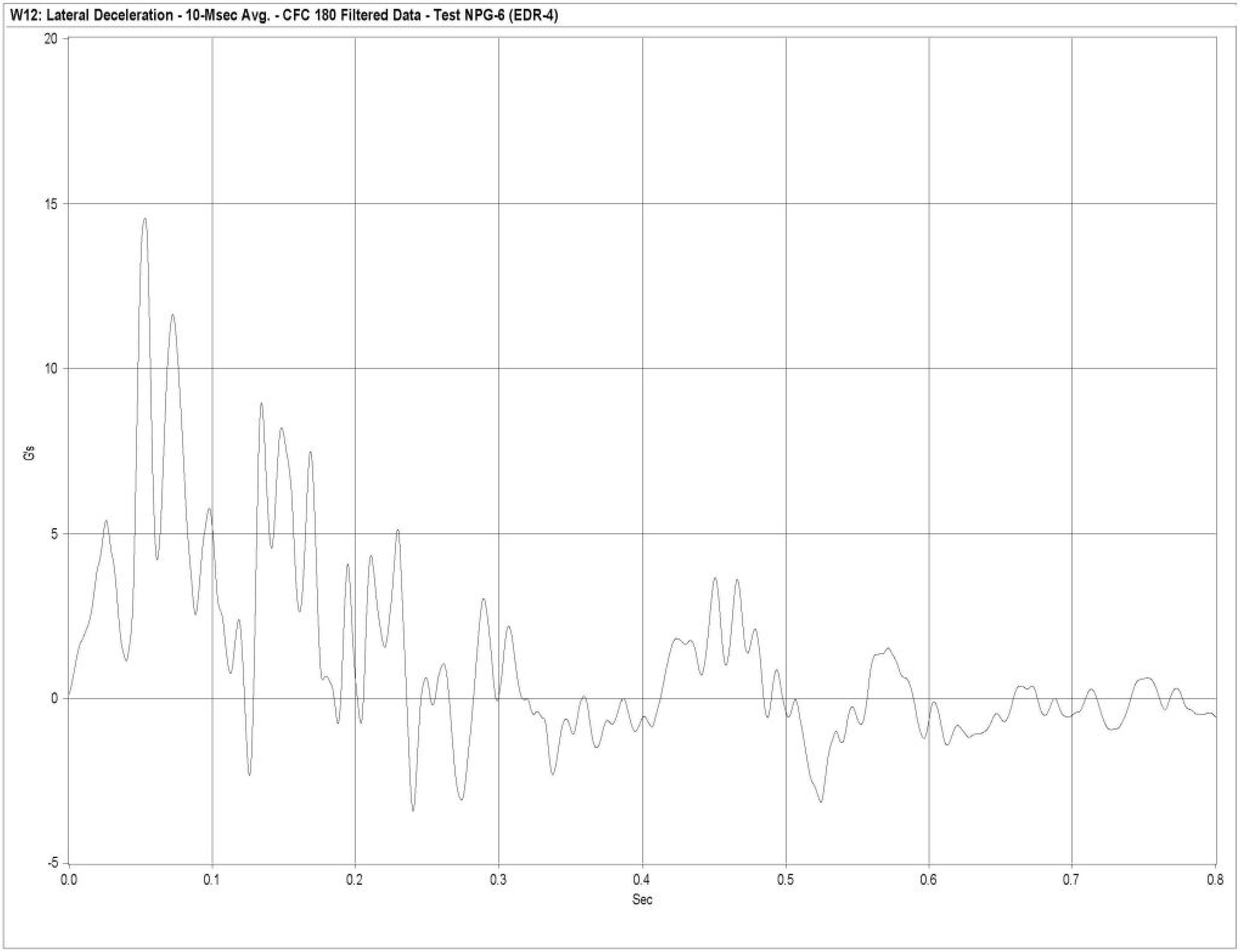


Figure K-4. Graph of Lateral Deceleration, Test NPG-6

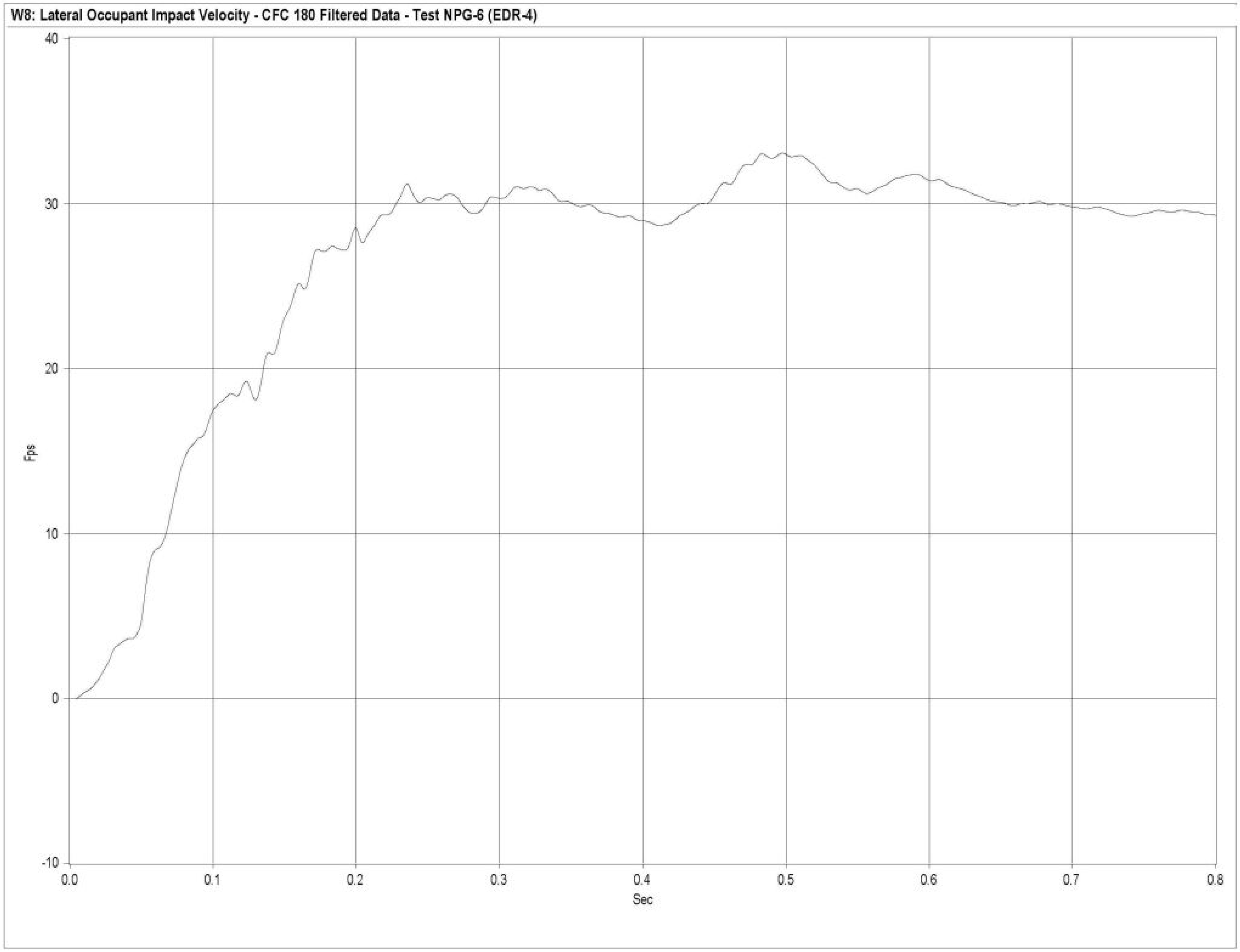


Figure K-5. Graph of Lateral Occupant Impact Velocity, Test NPG-6

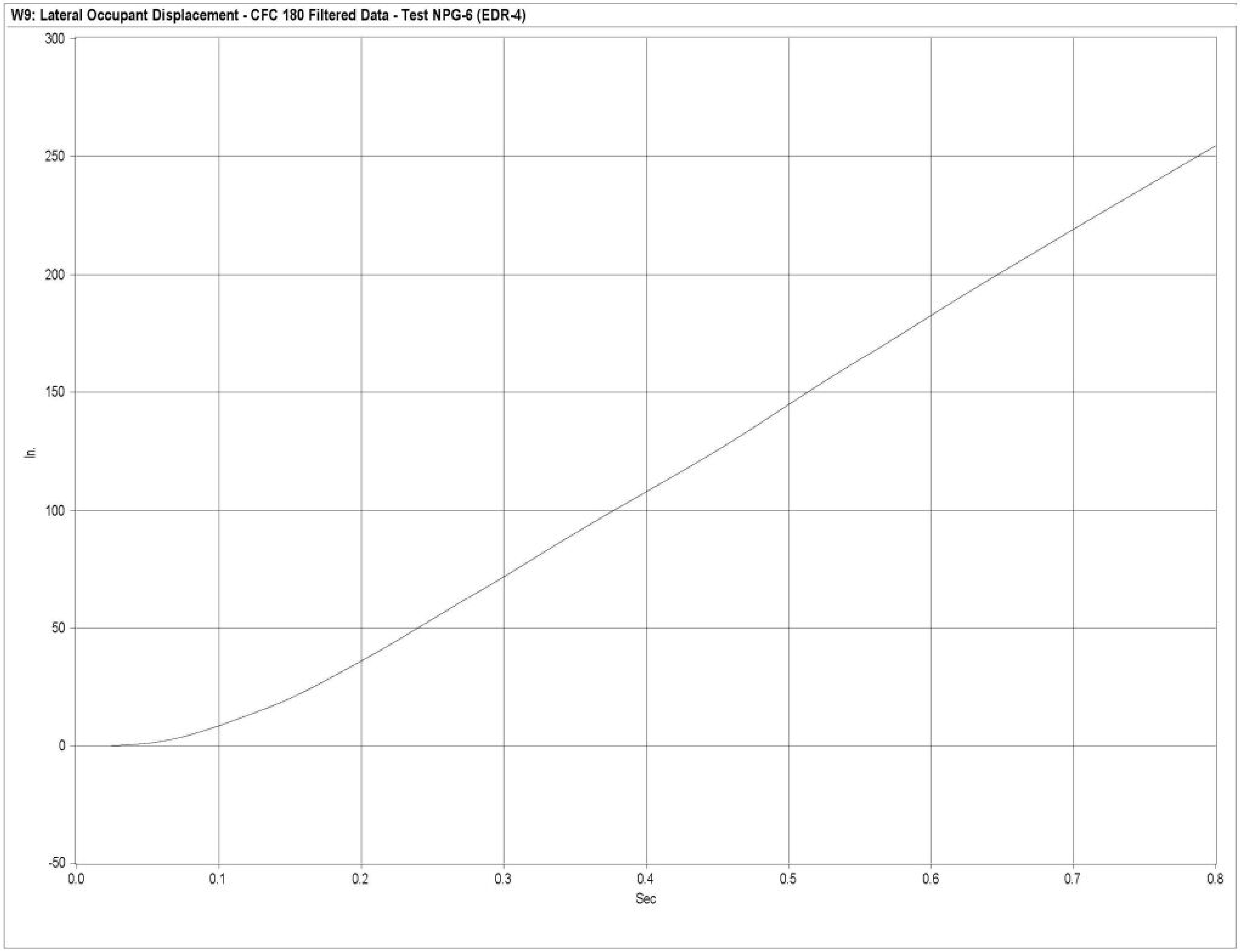


Figure K-6. Graph of Lateral Occupant Displacement, Test NPG-6

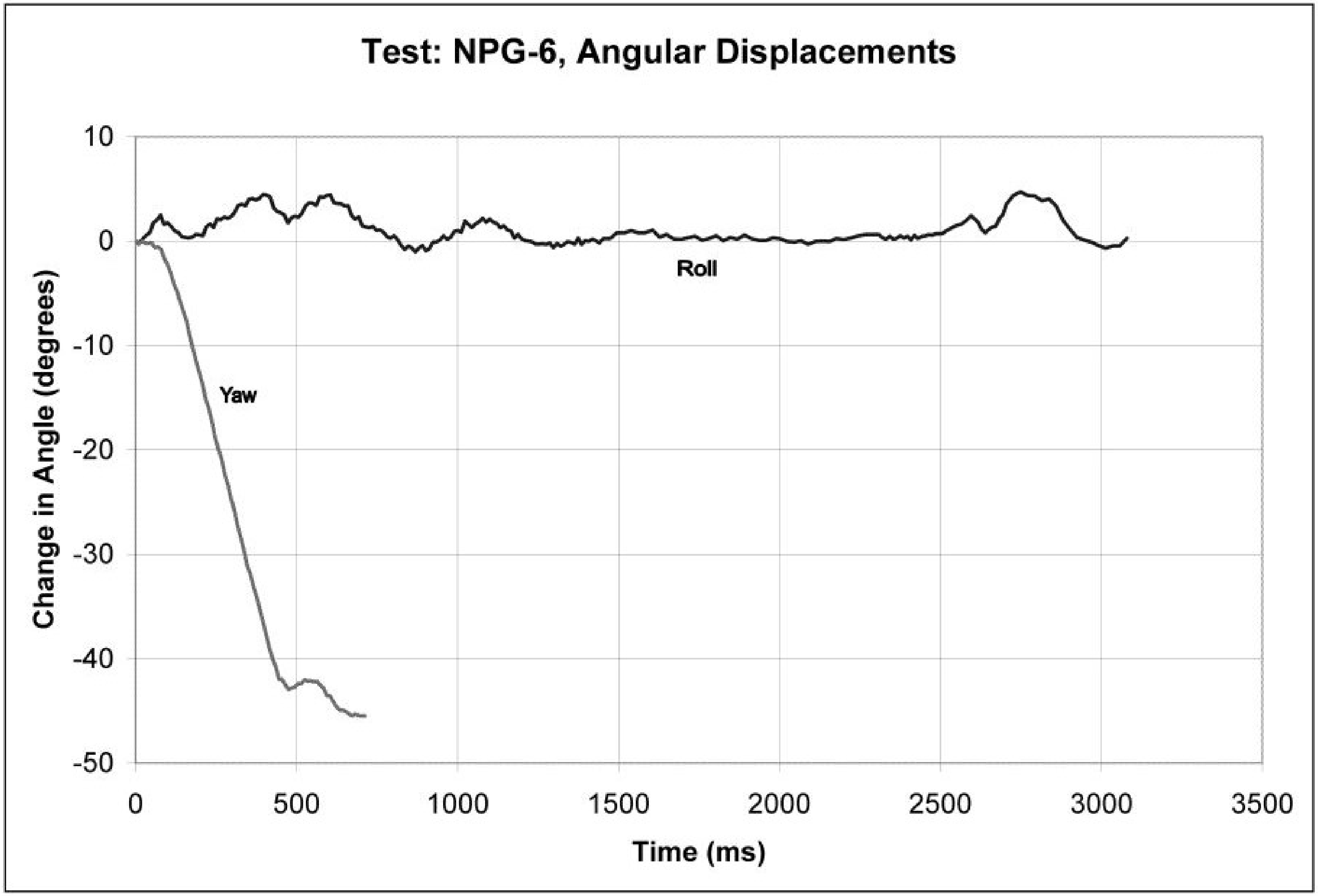


Figure K-7. Graph of Roll and Yaw Angular Displacements, Test NPG-6

APPENDIX L

BARRIER VII Input Files

Note that the example BARRIER VII input data files included in Appendix L correspond with examples of the standard-, quarter-, and half-post spacings (NPG-4, NPG-6, and NPG-H), respectively.

```
NPG-4  Full Post Spacing   RUN No. NPG4-51p    3" Upstream Post No. 12
  173   71   28    1  233  105    2    0
    0.0001    0.0001      0.8002000    0       1.0    1
    1    5    5    5    5    5    1
    1       0.0       0.0
    3     75.00       0.0
    5    150.00       0.0
    9    225.00       0.0
   12    281.25       0.0
   13   290.625       0.0
   14  295.3125       0.0
   15    300.00       0.0
   16  304.6875       0.0
   17   309.375       0.0
   18    318.75       0.0
   21    375.00       0.0
   25    450.00       0.0
   29    525.00       0.0
   32    581.25       0.0
   33   590.625       0.0
   34  595.3125       0.0
   35    600.00       0.0
   36  604.6875       0.0
   37   609.375       0.0
   38    618.75       0.0
   44    675.00       0.0
   52    750.00       0.0
   60    825.00       0.0
   66    881.25       0.0
   67   890.625       0.0
   68  895.3125       0.0
   69    900.00       0.0
   70  904.6875       0.0
   71   909.375       0.0
   72    918.75       0.0
   78    975.00       0.0
   84   1031.25       0.0
   85  1040.625       0.0
   86 1045.3125       0.0
   87   1050.00       0.0
   88 1054.6875       0.0
   89  1059.375       0.0
   90   1068.75       0.0
   96   1125.00       0.0
  102   1181.25       0.0
  103  1190.625       0.0
  104 1195.3125       0.0
  105   1200.00       0.0
  106 1204.6875       0.0
  107  1209.375       0.0
  108   1218.75       0.0
  114   1275.00       0.0
  122   1350.00       0.0
  130   1425.00       0.0
  136   1481.25       0.0
  137  1490.625       0.0
  138 1495.3125       0.0
  139   1500.00       0.0
  140 1504.6875       0.0
  141  1509.375       0.0
  142   1518.75       0.0
  145   1575.00       0.0
  149   1650.00       0.0
  153   1725.00       0.0
  156   1781.25       0.0
  157  1790.625       0.0
  158 1795.3125       0.0
  159   1800.00       0.0
  160 1804.6875       0.0
  161  1809.375       0.0
  162   1818.75       0.0
  165   1875.00       0.0
```

```
169   1950.00       0.0
171   2025.00       0.0
173   2100.00       0.0
  1     3    1    1       0.0
  3     5    1    1       0.0
  5     9    3    1       0.0
  9    12    2    1       0.0
 18    21    2    1       0.0
 21    25    3    1       0.0
 25    29    3    1       0.0
 29    32    2    1       0.0
 38    44    5    1       0.0
 44    52    7    1       0.0
 52    60    7    1       0.0
 60    66    5    1       0.0
 72    78    5    1       0.0
 78    84    5    1       0.0
 90    96    5    1       0.0
 96   102    5    1       0.0
108   114    5    1       0.0
114   122    7    1       0.0
122   130    7    1       0.0
130   136    5    1       0.0
142   145    2    1       0.0
145   149    3    1       0.0
149   153    3    1       0.0
153   156    2    1       0.0
162   165    2    1       0.0
165   169    3    1       0.0
169   171    1    1       0.0
171   173    1    1       0.0
  1   173       0.40
173   172  171  170  169  168  167  166  165  164
163   162  161  160  159  158  157  156  155  154
153   152  151  150  149  148  147  146  145  144
143   142  141  140  139  138  137  136  135  134
133   132  131  130  129  128  127  126  125  124
123   122  121  120  119  118  117  116  115  114
113   112  111  110  109  108  107  106  105  104
103   102  101  100   99   98   97   96   95   94
 93    92   91   90   89   88   87   86   85   84
 83    82   81   80   79   78   77   76   75   74
 73    72   71   70   69   68   67   66   65   64
 63    62   61   60   59   58   57   56   55   54
 53    52   51   50   49   48   47   46   45   44
 43    42   41   40   39   38   37   36   35   34
 33    32   31   30   29   28   27   26   25   24
 23    22   21   20   19   18   17   16   15   14
 13    12   11   10    9    8    7    6    5    4
  3     2    1
100    24
  1      2.29      1.99     37.50   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  2      2.29      1.99     18.75   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  3      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  4      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  5      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  6      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  7      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  8      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  9      2.29      1.99     18.75   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 10      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 11      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 12      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 13      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 14      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 15      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 16      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 17      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 18      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 19      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 20      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 21      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
```

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   22      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
   23      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
   24      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  300   16
    1    24.875      0.00       6.0       6.0     100.0     450.0     450.0 0.05 Simulated Strong
Anchor Post
     100.0     100.0      10.0      10.0
    2    24.875      0.00       3.0       3.0     100.0     100.0    150.00 0.05 Second BCT Post
      50.0      50.0       7.0       7.0
    3    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    4    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    5    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    6    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    7    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    8    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    9    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   10    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   11    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   12    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   13    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   14    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   15    24.875       0.0      0.01      0.01      0.01      0.01      0.01 0.05 W6x9 Posts 1/2-Post
Spacing (Removed)
      0.01      0.01      0.01      0.01
   16    24.875       0.0      0.01      0.01      0.01      0.01      0.01 0.05 W6x9 Posts 1/4-Post
Spacing (Removed)
      0.01      0.01      0.01      0.01
    1    1    2    4    1  101       0.0       0.0       0.0
    5    5    6   11    1  102       0.0       0.0       0.0
   12   12   13            103       0.0       0.0       0.0
   13   13   14            104       0.0       0.0       0.0
   14   14   15            105       0.0       0.0       0.0
   15   15   16            106       0.0       0.0       0.0
   16   16   17            107       0.0       0.0       0.0
   17   17   18            108       0.0       0.0       0.0
   18   18   19   31    1  109       0.0       0.0       0.0
   32   32   33            110       0.0       0.0       0.0
   33   33   34            111       0.0       0.0       0.0
   34   34   35            112       0.0       0.0       0.0
   35   35   36            113       0.0       0.0       0.0
   36   36   37            114       0.0       0.0       0.0
   37   37   38   66    1  115       0.0       0.0       0.0
   67   67   68            116       0.0       0.0       0.0
   68   68   69            117       0.0       0.0       0.0
   69   69   70            118       0.0       0.0       0.0
   70   70   71            119       0.0       0.0       0.0
   71   71   72   84    1  120       0.0       0.0       0.0
   85   85   86            121       0.0       0.0       0.0
   86   86   87            122       0.0       0.0       0.0
   87   87   88            123       0.0       0.0       0.0
   88   88   89            124       0.0       0.0       0.0
   89   89   90  102    1  120       0.0       0.0       0.0
  103  103  104            119       0.0       0.0       0.0
  104  104  105            118       0.0       0.0       0.0
  105  105  106            117       0.0       0.0       0.0
  106  106  107            116       0.0       0.0       0.0
  107  107  108  136    1  115       0.0       0.0       0.0
  137  137  138            114       0.0       0.0       0.0
  138  138  139            113       0.0       0.0       0.0
  139  139  140            112       0.0       0.0       0.0
```

140	140	141			111	0.0	0.0	0.0		
141	141	142			110	0.0	0.0	0.0		
142	142	143	155	1	109	0.0	0.0	0.0		
156	156	157			108	0.0	0.0	0.0		
157	157	158			107	0.0	0.0	0.0		
158	158	159			106	0.0	0.0	0.0		
159	159	160			105	0.0	0.0	0.0		
160	160	161			104	0.0	0.0	0.0		
161	161	162			103	0.0	0.0	0.0		
162	162	163	168	1	102	0.0	0.0	0.0		
169	169	170	172	1	101	0.0	0.0	0.0		
173	1				301	0.0	0.0	0.0	0.0	0.0
174	3				302	0.0	0.0	0.0	0.0	0.0
175	5				303	0.0	0.0	0.0	0.0	0.0
176	9				303	0.0	0.0	0.0	0.0	0.0
177	15				303	0.0	0.0	0.0	0.0	0.0
178	21				303	0.0	0.0	0.0	0.0	0.0
179	25				303	0.0	0.0	0.0	0.0	0.0
180	29				303	0.0	0.0	0.0	0.0	0.0
181	35				303	0.0	0.0	0.0	0.0	0.0
182	44				304	0.0	0.0	0.0	0.0	0.0
183	52				305	0.0	0.0	0.0	0.0	0.0
184	60				306	0.0	0.0	0.0	0.0	0.0
185	69				307	0.0	0.0	0.0	0.0	0.0
186	78				308	0.0	0.0	0.0	0.0	0.0
187	87				309	0.0	0.0	0.0	0.0	0.0
188	96				310	0.0	0.0	0.0	0.0	0.0
189	105				311	0.0	0.0	0.0	0.0	0.0
190	114				312	0.0	0.0	0.0	0.0	0.0
191	122				313	0.0	0.0	0.0	0.0	0.0
192	130				314	0.0	0.0	0.0	0.0	0.0
193	139				303	0.0	0.0	0.0	0.0	0.0
194	145				303	0.0	0.0	0.0	0.0	0.0
195	149				303	0.0	0.0	0.0	0.0	0.0
196	153				303	0.0	0.0	0.0	0.0	0.0
197	159				303	0.0	0.0	0.0	0.0	0.0
198	165				303	0.0	0.0	0.0	0.0	0.0
199	169				303	0.0	0.0	0.0	0.0	0.0
200	171				302	0.0	0.0	0.0	0.0	0.0
201	173				301	0.0	0.0	0.0	0.0	0.0
202	40				315	0.0	0.0	0.0	0.0	0.0
203	48				315	0.0	0.0	0.0	0.0	0.0
204	56				315	0.0	0.0	0.0	0.0	0.0
205	64				315	0.0	0.0	0.0	0.0	0.0
206	74				315	0.0	0.0	0.0	0.0	0.0
207	82				315	0.0	0.0	0.0	0.0	0.0
208	92				315	0.0	0.0	0.0	0.0	0.0
209	100				315	0.0	0.0	0.0	0.0	0.0
210	110				315	0.0	0.0	0.0	0.0	0.0
211	118				315	0.0	0.0	0.0	0.0	0.0
212	126				315	0.0	0.0	0.0	0.0	0.0
213	134				315	0.0	0.0	0.0	0.0	0.0
214	46				316	0.0	0.0	0.0	0.0	0.0
215	50				316	0.0	0.0	0.0	0.0	0.0
216	54				316	0.0	0.0	0.0	0.0	0.0
217	58				316	0.0	0.0	0.0	0.0	0.0
218	62				316	0.0	0.0	0.0	0.0	0.0
219	66				316	0.0	0.0	0.0	0.0	0.0
220	72				316	0.0	0.0	0.0	0.0	0.0
221	76				316	0.0	0.0	0.0	0.0	0.0
222	80				316	0.0	0.0	0.0	0.0	0.0
223	84				316	0.0	0.0	0.0	0.0	0.0
224	90				316	0.0	0.0	0.0	0.0	0.0
225	94				316	0.0	0.0	0.0	0.0	0.0
226	98				316	0.0	0.0	0.0	0.0	0.0
227	102				316	0.0	0.0	0.0	0.0	0.0
228	108				316	0.0	0.0	0.0	0.0	0.0
229	112				316	0.0	0.0	0.0	0.0	0.0
230	116				316	0.0	0.0	0.0	0.0	0.0
231	120				316	0.0	0.0	0.0	0.0	0.0
232	124				316	0.0	0.0	0.0	0.0	0.0
233	128				316	0.0	0.0	0.0	0.0	0.0

```
 4400.0   47400.0   20    6    4    0    1
  1      0.055      0.12      6.00      17.0
  2      0.057      0.15      7.00      18.0
  3      0.062      0.18     10.00      12.0
  4      0.110      0.35     12.00       6.0
  5       0.35      0.45      6.00       5.0
  6       1.45      1.50     15.00       1.0
  1     100.75    15.875    1      12.0    1    1    0    0
  2     100.75    27.875    1      12.0    1    1    0    0
  3     100.75    39.875    2      12.0    1    1    0    0
  4      88.75    39.875    2      12.0    1    1    0    0
  5      76.75    39.875    2      12.0    1    1    0    0
  6      64.75    39.875    2      12.0    1    1    0    0
  7      52.75    39.875    2      12.0    1    1    0    0
  8      40.75    39.875    2      12.0    1    1    0    0
  9      28.75    39.875    2      12.0    1    1    0    0
 10      16.75    39.875    2      12.0    1    1    0    0
 11     -13.25    39.875    3      12.0    1    1    0    0
 12     -33.25    39.875    3      12.0    1    1    0    0
 13     -53.25    39.875    3      12.0    1    1    0    0
 14     -73.25    39.875    3      12.0    1    1    0    0
 15     -93.25    39.875    3      12.0    1    1    0    0
 16    -113.25    39.875    4      12.0    1    1    0    0
 17    -113.25   -39.875    4      12.0    0    0    0    0
 18     100.75   -39.875    1      12.0    0    0    0    0
 19      69.25     37.75    5       1.0    1    1    0    0
 20     -62.75     37.75    6       1.0    1    1    0    0
  1      69.25     32.75       0.0      608.
  2      69.25    -32.75       0.0      608.
  3     -62.75     32.75       0.0      492.
  4     -62.75    -32.75       0.0      492.
  1        0.0       0.0
  3     822.00       0.0      25.6     60.98       0.0       0.0       1.0
```

```
NPG-6  1/4 Post Spacing   RUN No. NPG6-02c    115" Upstream Post No. 29
  173   71   28    1  233  105    2    0
    0.0001    0.0001      0.8002000    0       1.0    1
    1    5    5    5    5    5    1
    1       0.0       0.0
    3     75.00       0.0
    5    150.00       0.0
    9    225.00       0.0
   12    281.25       0.0
   13   290.625       0.0
   14  295.3125       0.0
   15    300.00       0.0
   16  304.6875       0.0
   17   309.375       0.0
   18    318.75       0.0
   21    375.00       0.0
   25    450.00       0.0
   29    525.00       0.0
   32    581.25       0.0
   33   590.625       0.0
   34  595.3125       0.0
   35    600.00       0.0
   36  604.6875       0.0
   37   609.375       0.0
   38    618.75       0.0
   44    675.00       0.0
   52    750.00       0.0
   60    825.00       0.0
   66    881.25       0.0
   67   890.625       0.0
   68  895.3125       0.0
   69    900.00       0.0
   70  904.6875       0.0
   71   909.375       0.0
   72    918.75       0.0
   78    975.00       0.0
   84   1031.25       0.0
   85  1040.625       0.0
   86 1045.3125       0.0
   87   1050.00       0.0
   88 1054.6875       0.0
   89  1059.375       0.0
   90   1068.75       0.0
   96   1125.00       0.0
  102   1181.25       0.0
  103  1190.625       0.0
  104 1195.3125       0.0
  105   1200.00       0.0
  106 1204.6875       0.0
  107  1209.375       0.0
  108   1218.75       0.0
  114   1275.00       0.0
  122   1350.00       0.0
  130   1425.00       0.0
  136   1481.25       0.0
  137  1490.625       0.0
  138 1495.3125       0.0
  139   1500.00       0.0
  140 1504.6875       0.0
  141  1509.375       0.0
  142   1518.75       0.0
  145   1575.00       0.0
  149   1650.00       0.0
  153   1725.00       0.0
  156   1781.25       0.0
  157  1790.625       0.0
  158 1795.3125       0.0
  159   1800.00       0.0
  160 1804.6875       0.0
  161  1809.375       0.0
  162   1818.75       0.0
  165   1875.00       0.0
```

```
169   1950.00       0.0
171   2025.00       0.0
173   2100.00       0.0
  1    3    1    1       0.0
  3    5    1    1       0.0
  5    9    3    1       0.0
  9   12    2    1       0.0
 18   21    2    1       0.0
 21   25    3    1       0.0
 25   29    3    1       0.0
 29   32    2    1       0.0
 38   44    5    1       0.0
 44   52    7    1       0.0
 52   60    7    1       0.0
 60   66    5    1       0.0
 72   78    5    1       0.0
 78   84    5    1       0.0
 90   96    5    1       0.0
 96  102    5    1       0.0
108  114    5    1       0.0
114  122    7    1       0.0
122  130    7    1       0.0
130  136    5    1       0.0
142  145    2    1       0.0
145  149    3    1       0.0
149  153    3    1       0.0
153  156    2    1       0.0
162  165    2    1       0.0
165  169    3    1       0.0
169  171    1    1       0.0
171  173    1    1       0.0
  1  173     0.475
173  172  171  170  169  168  167  166  165  164
163  162  161  160  159  158  157  156  155  154
153  152  151  150  149  148  147  146  145  144
143  142  141  140  139  138  137  136  135  134
133  132  131  130  129  128  127  126  125  124
123  122  121  120  119  118  117  116  115  114
113  112  111  110  109  108  107  106  105  104
103  102  101  100   99   98   97   96   95   94
 93   92   91   90   89   88   87   86   85   84
 83   82   81   80   79   78   77   76   75   74
 73   72   71   70   69   68   67   66   65   64
 63   62   61   60   59   58   57   56   55   54
 53   52   51   50   49   48   47   46   45   44
 43   42   41   40   39   38   37   36   35   34
 33   32   31   30   29   28   27   26   25   24
 23   22   21   20   19   18   17   16   15   14
 13   12   11   10    9    8    7    6    5    4
  3    2    1
100   24
  1      2.29      1.99     37.50   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  2      2.29      1.99     18.75   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  3      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  4      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  5      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  6      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  7      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  8      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  9      2.29      1.99     18.75   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 10      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 11      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 12      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 13      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 14      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 15      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 16      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 17      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 18      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 19      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 20      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 21      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
```

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   22      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
   23      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
   24      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  300   16
    1    24.875      0.00       6.0       6.0     100.0     450.0     450.0 0.05 Simulated Strong
Anchor Post
     100.0     100.0      10.0      10.0
    2    24.875      0.00       3.0       3.0     100.0     100.0    150.00 0.05 Second BCT Post
      50.0      50.0       7.0       7.0
    3    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    4    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    5    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    6    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    7    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    8    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    9    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   10    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   11    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   12    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   13    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   14    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   15    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 Posts 1/2-Post
Spacing (Active)
       6.0      15.0      15.0      15.0
   16    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 Posts 1/4-Post
Spacing (Active)
       6.0      15.0      15.0      15.0
    1    1    2    4    1  101       0.0       0.0       0.0
    5    5    6   11    1  102       0.0       0.0       0.0
   12   12   13            103       0.0       0.0       0.0
   13   13   14            104       0.0       0.0       0.0
   14   14   15            105       0.0       0.0       0.0
   15   15   16            106       0.0       0.0       0.0
   16   16   17            107       0.0       0.0       0.0
   17   17   18            108       0.0       0.0       0.0
   18   18   19   31    1  109       0.0       0.0       0.0
   32   32   33            110       0.0       0.0       0.0
   33   33   34            111       0.0       0.0       0.0
   34   34   35            112       0.0       0.0       0.0
   35   35   36            113       0.0       0.0       0.0
   36   36   37            114       0.0       0.0       0.0
   37   37   38   66    1  115       0.0       0.0       0.0
   67   67   68            116       0.0       0.0       0.0
   68   68   69            117       0.0       0.0       0.0
   69   69   70            118       0.0       0.0       0.0
   70   70   71            119       0.0       0.0       0.0
   71   71   72   84    1  120       0.0       0.0       0.0
   85   85   86            121       0.0       0.0       0.0
   86   86   87            122       0.0       0.0       0.0
   87   87   88            123       0.0       0.0       0.0
   88   88   89            124       0.0       0.0       0.0
   89   89   90  102    1  120       0.0       0.0       0.0
  103  103  104            119       0.0       0.0       0.0
  104  104  105            118       0.0       0.0       0.0
  105  105  106            117       0.0       0.0       0.0
  106  106  107            116       0.0       0.0       0.0
  107  107  108  136    1  115       0.0       0.0       0.0
  137  137  138            114       0.0       0.0       0.0
  138  138  139            113       0.0       0.0       0.0
  139  139  140            112       0.0       0.0       0.0
```

140	140	141			111	0.0	0.0	0.0		
141	141	142			110	0.0	0.0	0.0		
142	142	143	155	1	109	0.0	0.0	0.0		
156	156	157			108	0.0	0.0	0.0		
157	157	158			107	0.0	0.0	0.0		
158	158	159			106	0.0	0.0	0.0		
159	159	160			105	0.0	0.0	0.0		
160	160	161			104	0.0	0.0	0.0		
161	161	162			103	0.0	0.0	0.0		
162	162	163	168	1	102	0.0	0.0	0.0		
169	169	170	172	1	101	0.0	0.0	0.0		
173	1				301	0.0	0.0	0.0	0.0	0.0
174	3				302	0.0	0.0	0.0	0.0	0.0
175	5				303	0.0	0.0	0.0	0.0	0.0
176	9				303	0.0	0.0	0.0	0.0	0.0
177	15				303	0.0	0.0	0.0	0.0	0.0
178	21				303	0.0	0.0	0.0	0.0	0.0
179	25				303	0.0	0.0	0.0	0.0	0.0
180	29				303	0.0	0.0	0.0	0.0	0.0
181	35				303	0.0	0.0	0.0	0.0	0.0
182	44				304	0.0	0.0	0.0	0.0	0.0
183	52				305	0.0	0.0	0.0	0.0	0.0
184	60				306	0.0	0.0	0.0	0.0	0.0
185	69				307	0.0	0.0	0.0	0.0	0.0
186	78				308	0.0	0.0	0.0	0.0	0.0
187	87				309	0.0	0.0	0.0	0.0	0.0
188	96				310	0.0	0.0	0.0	0.0	0.0
189	105				311	0.0	0.0	0.0	0.0	0.0
190	114				312	0.0	0.0	0.0	0.0	0.0
191	122				313	0.0	0.0	0.0	0.0	0.0
192	130				314	0.0	0.0	0.0	0.0	0.0
193	139				303	0.0	0.0	0.0	0.0	0.0
194	145				303	0.0	0.0	0.0	0.0	0.0
195	149				303	0.0	0.0	0.0	0.0	0.0
196	153				303	0.0	0.0	0.0	0.0	0.0
197	159				303	0.0	0.0	0.0	0.0	0.0
198	165				303	0.0	0.0	0.0	0.0	0.0
199	169				303	0.0	0.0	0.0	0.0	0.0
200	171				302	0.0	0.0	0.0	0.0	0.0
201	173				301	0.0	0.0	0.0	0.0	0.0
202	40				315	0.0	0.0	0.0	0.0	0.0
203	48				315	0.0	0.0	0.0	0.0	0.0
204	56				315	0.0	0.0	0.0	0.0	0.0
205	64				315	0.0	0.0	0.0	0.0	0.0
206	74				315	0.0	0.0	0.0	0.0	0.0
207	82				315	0.0	0.0	0.0	0.0	0.0
208	92				315	0.0	0.0	0.0	0.0	0.0
209	100				315	0.0	0.0	0.0	0.0	0.0
210	110				315	0.0	0.0	0.0	0.0	0.0
211	118				315	0.0	0.0	0.0	0.0	0.0
212	126				315	0.0	0.0	0.0	0.0	0.0
213	134				315	0.0	0.0	0.0	0.0	0.0
214	46				316	0.0	0.0	0.0	0.0	0.0
215	50				316	0.0	0.0	0.0	0.0	0.0
216	54				316	0.0	0.0	0.0	0.0	0.0
217	58				316	0.0	0.0	0.0	0.0	0.0
218	62				316	0.0	0.0	0.0	0.0	0.0
219	66				316	0.0	0.0	0.0	0.0	0.0
220	72				316	0.0	0.0	0.0	0.0	0.0
221	76				316	0.0	0.0	0.0	0.0	0.0
222	80				316	0.0	0.0	0.0	0.0	0.0
223	84				316	0.0	0.0	0.0	0.0	0.0
224	90				316	0.0	0.0	0.0	0.0	0.0
225	94				316	0.0	0.0	0.0	0.0	0.0
226	98				316	0.0	0.0	0.0	0.0	0.0
227	102				316	0.0	0.0	0.0	0.0	0.0
228	108				316	0.0	0.0	0.0	0.0	0.0
229	112				316	0.0	0.0	0.0	0.0	0.0
230	116				316	0.0	0.0	0.0	0.0	0.0
231	120				316	0.0	0.0	0.0	0.0	0.0
232	124				316	0.0	0.0	0.0	0.0	0.0
233	128				316	0.0	0.0	0.0	0.0	0.0

```
 4400.0   47400.0   20    6    4    0    1
 1     0.055      0.12      6.00      17.0
 2     0.057      0.15      7.00      18.0
 3     0.062      0.18     10.00      12.0
 4     0.110      0.35     12.00       6.0
 5      0.35      0.45      6.00       5.0
 6      1.45      1.50     15.00       1.0
 1    100.75    15.875   1      12.0    1    1    0    0
 2    100.75    27.875   1      12.0    1    1    0    0
 3    100.75    39.875   2      12.0    1    1    0    0
 4     88.75    39.875   2      12.0    1    1    0    0
 5     76.75    39.875   2      12.0    1    1    0    0
 6     64.75    39.875   2      12.0    1    1    0    0
 7     52.75    39.875   2      12.0    1    1    0    0
 8     40.75    39.875   2      12.0    1    1    0    0
 9     28.75    39.875   2      12.0    1    1    0    0
10     16.75    39.875   2      12.0    1    1    0    0
11    -13.25    39.875   3      12.0    1    1    0    0
12    -33.25    39.875   3      12.0    1    1    0    0
13    -53.25    39.875   3      12.0    1    1    0    0
14    -73.25    39.875   3      12.0    1    1    0    0
15    -93.25    39.875   3      12.0    1    1    0    0
16   -113.25    39.875   4      12.0    1    1    0    0
17   -113.25   -39.875   4      12.0    0    0    0    0
18    100.75   -39.875   1      12.0    0    0    0    0
19     69.25     37.75   5       1.0    1    1    0    0
20    -62.75     37.75   6       1.0    1    1    0    0
 1     69.25     32.75      0.0      608.
 2     69.25    -32.75      0.0      608.
 3    -62.75     32.75      0.0      492.
 4    -62.75    -32.75      0.0      492.
 1       0.0       0.0
 3    897.50       0.0     25.6     60.16       0.0       0.0       1.0
```

```
NPG-H  Half Post Spacing   RUN No. NPGH        3" Upstream Post No. 17
  173   71   28    1  233  105    2    0
    0.0001    0.0001      0.8002000    0       1.0    1
    1    5    5    5    5    5    1
    1       0.0       0.0
    3     75.00       0.0
    5    150.00       0.0
    9    225.00       0.0
   12    281.25       0.0
   13   290.625       0.0
   14  295.3125       0.0
   15    300.00       0.0
   16  304.6875       0.0
   17   309.375       0.0
   18    318.75       0.0
   21    375.00       0.0
   25    450.00       0.0
   29    525.00       0.0
   32    581.25       0.0
   33   590.625       0.0
   34  595.3125       0.0
   35    600.00       0.0
   36  604.6875       0.0
   37   609.375       0.0
   38    618.75       0.0
   44    675.00       0.0
   52    750.00       0.0
   60    825.00       0.0
   66    881.25       0.0
   67   890.625       0.0
   68  895.3125       0.0
   69    900.00       0.0
   70  904.6875       0.0
   71   909.375       0.0
   72    918.75       0.0
   78    975.00       0.0
   84   1031.25       0.0
   85  1040.625       0.0
   86 1045.3125       0.0
   87   1050.00       0.0
   88 1054.6875       0.0
   89  1059.375       0.0
   90   1068.75       0.0
   96   1125.00       0.0
  102   1181.25       0.0
  103  1190.625       0.0
  104 1195.3125       0.0
  105   1200.00       0.0
  106 1204.6875       0.0
  107  1209.375       0.0
  108   1218.75       0.0
  114   1275.00       0.0
  122   1350.00       0.0
  130   1425.00       0.0
  136   1481.25       0.0
  137  1490.625       0.0
  138 1495.3125       0.0
  139   1500.00       0.0
  140 1504.6875       0.0
  141  1509.375       0.0
  142   1518.75       0.0
  145   1575.00       0.0
  149   1650.00       0.0
  153   1725.00       0.0
  156   1781.25       0.0
  157  1790.625       0.0
  158 1795.3125       0.0
  159   1800.00       0.0
  160 1804.6875       0.0
  161  1809.375       0.0
  162   1818.75       0.0
  165   1875.00       0.0
```

```
169   1950.00       0.0
171   2025.00       0.0
173   2100.00       0.0
  1    3    1    1       0.0
  3    5    1    1       0.0
  5    9    3    1       0.0
  9   12    2    1       0.0
 18   21    2    1       0.0
 21   25    3    1       0.0
 25   29    3    1       0.0
 29   32    2    1       0.0
 38   44    5    1       0.0
 44   52    7    1       0.0
 52   60    7    1       0.0
 60   66    5    1       0.0
 72   78    5    1       0.0
 78   84    5    1       0.0
 90   96    5    1       0.0
 96  102    5    1       0.0
108  114    5    1       0.0
114  122    7    1       0.0
122  130    7    1       0.0
130  136    5    1       0.0
142  145    2    1       0.0
145  149    3    1       0.0
149  153    3    1       0.0
153  156    2    1       0.0
162  165    2    1       0.0
165  169    3    1       0.0
169  171    1    1       0.0
171  173    1    1       0.0
  1  173     0.425
173  172  171  170  169  168  167  166  165  164
163  162  161  160  159  158  157  156  155  154
153  152  151  150  149  148  147  146  145  144
143  142  141  140  139  138  137  136  135  134
133  132  131  130  129  128  127  126  125  124
123  122  121  120  119  118  117  116  115  114
113  112  111  110  109  108  107  106  105  104
103  102  101  100   99   98   97   96   95   94
 93   92   91   90   89   88   87   86   85   84
 83   82   81   80   79   78   77   76   75   74
 73   72   71   70   69   68   67   66   65   64
 63   62   61   60   59   58   57   56   55   54
 53   52   51   50   49   48   47   46   45   44
 43   42   41   40   39   38   37   36   35   34
 33   32   31   30   29   28   27   26   25   24
 23   22   21   20   19   18   17   16   15   14
 13   12   11   10    9    8    7    6    5    4
  3    2    1
100   24
  1      2.29      1.99     37.50   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  2      2.29      1.99     18.75   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  3      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  4      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  5      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  6      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  7      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  8      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  9      2.29      1.99     18.75   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 10      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 11      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 12      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 13      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 14      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 15      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 16      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 17      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 18      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 19      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 20      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
 21      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
```

```
   22      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
   23      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
   24      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05 12-Gauge W-Beam
  300   16
    1    24.875      0.00       6.0       6.0     100.0     450.0     450.0 0.05 Simulated Strong
Anchor Post
     100.0     100.0      10.0      10.0
    2    24.875      0.00       3.0       3.0     100.0     100.0    150.00 0.05 Second BCT Post
      50.0      50.0       7.0       7.0
    3    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    4    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    5    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    6    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    7    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    8    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
    9    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   10    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   11    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   12    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   13    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   14    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 by 6' Long
       6.0      15.0      15.0      15.0
   15    24.875       0.0      4.00      6.03      54.0     92.88    143.65 0.05 W6x9 Posts 1/2-Post
Spacing (Active)
       6.0      15.0      15.0      15.0
   16    24.875       0.0      0.01      0.01      0.01      0.01      0.01 0.05 W6x9 Posts 1/4-Post
Spacing (Removed)
      0.01      0.01      0.01      0.01
    1    1    2    4    1  101       0.0       0.0       0.0
    5    5    6   11    1  102       0.0       0.0       0.0
   12   12   13            103       0.0       0.0       0.0
   13   13   14            104       0.0       0.0       0.0
   14   14   15            105       0.0       0.0       0.0
   15   15   16            106       0.0       0.0       0.0
   16   16   17            107       0.0       0.0       0.0
   17   17   18            108       0.0       0.0       0.0
   18   18   19   31    1  109       0.0       0.0       0.0
   32   32   33            110       0.0       0.0       0.0
   33   33   34            111       0.0       0.0       0.0
   34   34   35            112       0.0       0.0       0.0
   35   35   36            113       0.0       0.0       0.0
   36   36   37            114       0.0       0.0       0.0
   37   37   38   66    1  115       0.0       0.0       0.0
   67   67   68            116       0.0       0.0       0.0
   68   68   69            117       0.0       0.0       0.0
   69   69   70            118       0.0       0.0       0.0
   70   70   71            119       0.0       0.0       0.0
   71   71   72   84    1  120       0.0       0.0       0.0
   85   85   86            121       0.0       0.0       0.0
   86   86   87            122       0.0       0.0       0.0
   87   87   88            123       0.0       0.0       0.0
   88   88   89            124       0.0       0.0       0.0
   89   89   90  102    1  120       0.0       0.0       0.0
  103  103  104            119       0.0       0.0       0.0
  104  104  105            118       0.0       0.0       0.0
  105  105  106            117       0.0       0.0       0.0
  106  106  107            116       0.0       0.0       0.0
  107  107  108  136    1  115       0.0       0.0       0.0
  137  137  138            114       0.0       0.0       0.0
  138  138  139            113       0.0       0.0       0.0
  139  139  140            112       0.0       0.0       0.0
```

140	140	141			111	0.0	0.0	0.0		
141	141	142			110	0.0	0.0	0.0		
142	142	143	155	1	109	0.0	0.0	0.0		
156	156	157			108	0.0	0.0	0.0		
157	157	158			107	0.0	0.0	0.0		
158	158	159			106	0.0	0.0	0.0		
159	159	160			105	0.0	0.0	0.0		
160	160	161			104	0.0	0.0	0.0		
161	161	162			103	0.0	0.0	0.0		
162	162	163	168	1	102	0.0	0.0	0.0		
169	169	170	172	1	101	0.0	0.0	0.0		
173	1				301	0.0	0.0	0.0	0.0	0.0
174	3				302	0.0	0.0	0.0	0.0	0.0
175	5				303	0.0	0.0	0.0	0.0	0.0
176	9				303	0.0	0.0	0.0	0.0	0.0
177	15				303	0.0	0.0	0.0	0.0	0.0
178	21				303	0.0	0.0	0.0	0.0	0.0
179	25				303	0.0	0.0	0.0	0.0	0.0
180	29				303	0.0	0.0	0.0	0.0	0.0
181	35				303	0.0	0.0	0.0	0.0	0.0
182	44				304	0.0	0.0	0.0	0.0	0.0
183	52				305	0.0	0.0	0.0	0.0	0.0
184	60				306	0.0	0.0	0.0	0.0	0.0
185	69				307	0.0	0.0	0.0	0.0	0.0
186	78				308	0.0	0.0	0.0	0.0	0.0
187	87				309	0.0	0.0	0.0	0.0	0.0
188	96				310	0.0	0.0	0.0	0.0	0.0
189	105				311	0.0	0.0	0.0	0.0	0.0
190	114				312	0.0	0.0	0.0	0.0	0.0
191	122				313	0.0	0.0	0.0	0.0	0.0
192	130				314	0.0	0.0	0.0	0.0	0.0
193	139				303	0.0	0.0	0.0	0.0	0.0
194	145				303	0.0	0.0	0.0	0.0	0.0
195	149				303	0.0	0.0	0.0	0.0	0.0
196	153				303	0.0	0.0	0.0	0.0	0.0
197	159				303	0.0	0.0	0.0	0.0	0.0
198	165				303	0.0	0.0	0.0	0.0	0.0
199	169				303	0.0	0.0	0.0	0.0	0.0
200	171				302	0.0	0.0	0.0	0.0	0.0
201	173				301	0.0	0.0	0.0	0.0	0.0
202	40				315	0.0	0.0	0.0	0.0	0.0
203	48				315	0.0	0.0	0.0	0.0	0.0
204	56				315	0.0	0.0	0.0	0.0	0.0
205	64				315	0.0	0.0	0.0	0.0	0.0
206	74				315	0.0	0.0	0.0	0.0	0.0
207	82				315	0.0	0.0	0.0	0.0	0.0
208	92				315	0.0	0.0	0.0	0.0	0.0
209	100				315	0.0	0.0	0.0	0.0	0.0
210	110				315	0.0	0.0	0.0	0.0	0.0
211	118				315	0.0	0.0	0.0	0.0	0.0
212	126				315	0.0	0.0	0.0	0.0	0.0
213	134				315	0.0	0.0	0.0	0.0	0.0
214	46				316	0.0	0.0	0.0	0.0	0.0
215	50				316	0.0	0.0	0.0	0.0	0.0
216	54				316	0.0	0.0	0.0	0.0	0.0
217	58				316	0.0	0.0	0.0	0.0	0.0
218	62				316	0.0	0.0	0.0	0.0	0.0
219	66				316	0.0	0.0	0.0	0.0	0.0
220	72				316	0.0	0.0	0.0	0.0	0.0
221	76				316	0.0	0.0	0.0	0.0	0.0
222	80				316	0.0	0.0	0.0	0.0	0.0
223	84				316	0.0	0.0	0.0	0.0	0.0
224	90				316	0.0	0.0	0.0	0.0	0.0
225	94				316	0.0	0.0	0.0	0.0	0.0
226	98				316	0.0	0.0	0.0	0.0	0.0
227	102				316	0.0	0.0	0.0	0.0	0.0
228	108				316	0.0	0.0	0.0	0.0	0.0
229	112				316	0.0	0.0	0.0	0.0	0.0
230	116				316	0.0	0.0	0.0	0.0	0.0
231	120				316	0.0	0.0	0.0	0.0	0.0
232	124				316	0.0	0.0	0.0	0.0	0.0
233	128				316	0.0	0.0	0.0	0.0	0.0

```
 4400.0   47400.0   20    6    4    0    1
  1     0.055      0.12      6.00      17.0
  2     0.057      0.15      7.00      18.0
  3     0.062      0.18     10.00      12.0
  4     0.110      0.35     12.00       6.0
  5      0.35      0.45      6.00       5.0
  6      1.45      1.50     15.00       1.0
  1    100.75    15.875    1      12.0    1    1    0    0
  2    100.75    27.875    1      12.0    1    1    0    0
  3    100.75    39.875    2      12.0    1    1    0    0
  4     88.75    39.875    2      12.0    1    1    0    0
  5     76.75    39.875    2      12.0    1    1    0    0
  6     64.75    39.875    2      12.0    1    1    0    0
  7     52.75    39.875    2      12.0    1    1    0    0
  8     40.75    39.875    2      12.0    1    1    0    0
  9     28.75    39.875    2      12.0    1    1    0    0
 10     16.75    39.875    2      12.0    1    1    0    0
 11    -13.25    39.875    3      12.0    1    1    0    0
 12    -33.25    39.875    3      12.0    1    1    0    0
 13    -53.25    39.875    3      12.0    1    1    0    0
 14    -73.25    39.875    3      12.0    1    1    0    0
 15    -93.25    39.875    3      12.0    1    1    0    0
 16   -113.25    39.875    4      12.0    1    1    0    0
 17   -113.25   -39.875    4      12.0    0    0    0    0
 18    100.75   -39.875    1      12.0    0    0    0    0
 19     69.25     37.75    5       1.0    1    1    0    0
 20    -62.75     37.75    6       1.0    1    1    0    0
  1     69.25     32.75       0.0      608.
  2     69.25    -32.75       0.0      608.
  3    -62.75     32.75       0.0      492.
  4    -62.75    -32.75       0.0      492.
  1       0.0       0.0
  3    897.00       0.0      25.0     62.14       0.0       0.0       1.0
```