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DEVELOPMENT OF A STEEL H-SECTION TEMPORARY BARRIER FOR USE IN LIMITED DEFLECTION APPLICATIONS

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16. Abstract (Limit: 200 words)

A tie-down system was developed for use with Iowa's steel H-section temporary barrier. For this system, the original barrier connection detail was modified in order to simplify barrier attachment to one another as well as to more easily accommodate deviations in horizontal and vertical alignment. At each barrier joint, two steel shear plates were positioned within an opening on the adjacent barrier section and held in place with two steel drop pins. Four steel angle brackets were welded to the barrier's base at every joint in order to allow for the barriers to be rigidly attached to the concrete bridge deck using drop-in anchors.

Two full-scale vehicle crash tests, using ¾-ton pickup trucks, were performed on the steel H-section barrier system. Due to vehicle snag and subsequent vehicle rollover, the first test was unsuccessful. Following minor design modifications, the barrier system was retested. The second test was successfully conducted on the tied-down steel H-barrier system which safely redirected the pickup truck. The tests were conducted and reported in accordance with the requirements specified in the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. The safety performance of the tie-down system for use with Iowa's steel H-section temporary barrier was determined to be acceptable according to the Test Level 3 (TL-3) evaluation criteria specified in NCHRP Report No. 350.

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1 INTRODUCTION

1.1 Problem Statement

Roadway construction or work zones are found along almost all Federal, State, and local highways in the United States. In most cases, these roadways often require the redirection of vehicular traffic around or through the construction zone. Typically, some form of temporary barrier is used to separate the flow of traffic within the construction area. In general, temporary barriers are segmented units which are attached end-to-end by a load-bearing connection. The segmentation of the barriers allows them to be easily installed, repositioned, and removed from the work-zone region. The barrier system is designed to protect equipment and workers in the work zone, to prevent errant vehicles from leaving the traveled way, and to safely redirect those vehicles impacting the barrier.

Often, temporary barriers are used in applications where it is desired that their deflection during vehicular impact be limited. One such application is the installation of temporary barriers placed adjacent to the edge of a bridge deck in order to provide adequate lane width. However, freestanding barrier installations placed close to the deck edge pose a major safety hazard to errant vehicles as there is a significant risk for the barrier segments to be propelled off of the bridge. Thus, large dynamic deflections, in conjunction with a narrow gap located behind the barriers, may prove sufficient to push the barriers off of the deck along with the impacting vehicle.

Developed by the Iowa Department of Transportation (IaDOT) and utilized by the State of Iowa for many years, the steel H-section temporary barrier rail provides a positive barrier system where space is limited. The current system has previously been tested successfully according to the Performance Level 2 (PL-2) pickup truck evaluation criteria set forth in the American Association of State Highways and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings*

(1). Although there are many advantages to this barrier, the current connection system has very little spacing tolerance (2). This means that slight variations in the pavement surface and curves makes the H-section barriers difficult to assemble. In addition, the Midwest Pooled Fund States' DOT's have the desire to use these barriers in limited deflection applications. Therefore, a need exists to develop a tie-down system for the steel H-section temporary barrier to reduce barrier deflections and restrain the barriers from falling off of a bridge and that which will meet the safety performance criteria found in National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (3).

1.2 Objective

The objective of the research project was to design a connection system which would (1) allow the steel H-section temporary barrier to be assembled and disassembled easily, even in cases where there is vertical and/or horizontal curvature in the roadway, and (2) limit barrier deflections. The steel H-section temporary barrier rail and connection system were to be evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth in NCHRP Report No. 350.

1.3 Scope

The research objective was achieved by performing several tasks. First, a literature review was performed on previously crash tested steel temporary barriers and tie-down systems. Secondly, a design phase was conducted to develop a tie-down system for the H-section barriers which also creates a more efficient way of assembling and disassembling the barriers. After the final design and fabrication of the systems, full-scale vehicle crash tests were performed using ¾-ton pickup trucks, weighing approximately 2,000 kg, with target impact speeds and angles of 100 km/hr 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 steel H-section temporary barrier system.

2 LITERATURE REVIEW

2.1 Steel Temporary Barriers

The original steel H-section temporary barrier was developed and is used primarily by the IaDOT. The barrier is comprised of two ASTM A36 steel, HP 356 mm x 109 mm by 6.1-m long beams stacked above one another with the flange ends placed back to back. The two beams are inter-connected using welded 89 mm x 381 mm x 9.5-mm thick steel straps placed vertically across the longitudinal seams and spaced 1,394 mm on center. In order to provide additional weight and stiffness, the box section formed by the stacked HP shapes is filled with concrete. Adjacent barrier sections are attached end-to-end using either welded or bolted, 12.7-mm thick steel splice plates and angle brackets, forming a very stiff temporary barrier system.

In 1989, Midwest Roadside Safety Facility (MwRSF) conducted a crash test on a freestanding, 61.0-m long H-section temporary barrier installation. This test, test no. I5-1, involved a 2,495-kg pickup impacting at a speed of 97.5 km/hr and at an angle of 22.5 degrees (2). The barrier encountered maximum permanent set deflections of 446 mm as it redirected the pickup in a stable manner. Therefore, this test was successfully performed according to the AASHTO PL-2 evaluation criteria. Furthermore, since the actual impact conditions of this test were higher than the target conditions, the resulting impact severity of 99.3 kip-ft is only 3 percent less than that provided by the TL-3 impact conditions of NCHRP Report No. 350.

2.2 Tie-Down Systems

In 1993, the Texas Transportation Institute (TTI) developed and tested a tie-down system for portable concrete barriers that was compliant with the NCHRP Report No. 350 safety criteria for longitudinal barriers (4). The TTI system consisted of 9.1-m long barrier segments that were constrained by a set of four 31.8-mm diameter by 521-mm long steel pins that passed through 35-mm diameter holes drilled into the front of the barrier and into the concrete slab to a depth of 127 mm. The holes were drilled at an angle of 40.1 degrees in order to maximize the constraint on the barrier while keeping the depth of the pins to a minimum. The maximum permanent set and dynamic deflections measured during the test of the system were found to be 200 mm and 400 mm, respectively.

In 1999, the California Department of Transportation (CALTRANS) successfully developed and tested a K-rail system according to the NCHRP Report No. 350 evaluation criteria (5). The K-rail system consisted of 6.1-m long segments of New Jersey safety shape barrier connected by a pin and loop connection. Each barrier was constrained by a set of four 25-mm diameter by 610-mm long steel stakes that were driven into the asphalt road surface to a depth of 420 mm through cast holes near the corners of the barrier. The system limited the permanent set and dynamic deflections to 70 mm and 254 mm, respectively.

In 2001, MwRSF developed a double tie-down system for use with temporary barriers and successfully tested the system according to the NCHRP Report No. 350 evaluation criteria (6-7). The tie-down system consisted of 3.81-m long segments of Iowa F-shape barriers connected by a pin and loop connection and double steel straps to constrain the motion of the barrier joints. The steel strap consisted of a 76-mm wide x 6.4-mm thick x 914-mm long piece of ASTM A36 steel that was bent at four points along the strap to form a trapezoidal shape. A 22-mm diameter hole, punched 51 mm from each end of the plate, was used to accommodate the two Red Head 19-mm diameter drop-in anchors and the 19-mm diameter x 57-mm long ISO Class 8.8 bolts which constrained the strap. In addition, 76-mm wide x 6.4-mm thick x 83-mm long steel plates with identically sized holes were welded to the strap at the hole locations in order to reinforce the strap. A third 35-mm diameter hole was also punched in the center of the strap to accommodate the vertical pin used to connect the barrier segments. The center hole in the plate was reinforced by a 76-mm wide x 12.7-mm thick x 83-mm long ASTM A36 steel plate. The maximum permanent set and dynamic deflections measured during the test of the double tie-down system were found to be 850 mm and 960 mm, respectively.

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as temporary steel barriers, 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 temporary barrier system 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 small car impacting the temporary barrier system at a nominal speed and angle of 100.0 km/hr and 20 degrees, respectively.

2. Test Designation 3-11. A 2,000-kg pickup truck impacting the temporary barrier system at a nominal speed and angle of 100.0 km/hr and 25 degrees, respectively.

However, rigid New Jersey safety shape barriers struck by small cars have been shown to meet safety performance standards (8-9). In the same manner, a rigid, F-shape bridge rail impacted by a small car was successfully tested to current safety performance standards (10). Similarly, when impacted by small cars, temporary New Jersey safety shape concrete median barriers have encountered only slight barrier deflections (11). Thus, since impacts with safety shapes are more severe than those with vertical barriers, the 820-kg small car test was deemed unnecessary for this project. 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 tests were 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 (km/hr)	Angle (degrees)	
Longitudinal Barrier	3-10	820C	100	20	A,D,F,H,I,K,M
	3-11	2000P	100	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 (3)

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, or at least below the maximum allowable value of 12 m/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, 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 H-SECTION TEMPORARY BARRIER TIE-DOWN DESIGN (DESIGN NO. 1)

4.1 Desired Design Features

Although the Iowa DOT has used the H-section temporary barrier system for many years, contractors routinely encounter difficulties when installing the barrier system on uneven roadway surfaces or at locations where changes in horizontal alignment are required. For barrier removal, the process was also often made difficult due to the large number of tightly-fit splice bolts or the presence of welded splice plates placed between barrier sections. As a result, MwRSF researchers were approached to redesign and simplify the connection detail used between barrier sections in order to improve its constructability and better accommodate changes in both vertical and horizontal alignment.

The original barrier connection consisted of a set of 12.7-mm thick steel splice plates that were used to bolt the barrier sections together. First, redesigning this connection was desired in order to simplify it and make the assembly and disassembly easier. Furthermore, it was desired to redesign the connection to limit barrier horizontal and vertical rotations to 4.0 and 2.4 degrees, respectively, in order to simplify placement of the barriers during installation. In addition, the steel temporary barriers were to be retrofitted with a tie-down system that would reduce barrier displacements from those observed in the freestanding barrier test as well as to prevent the deflected barriers from falling off of the bridge deck edge. Finally, the new tie-down barrier system was required to provide a symmetric barrier face such that either vertical surface could be safely impacted.

4.2 Design Details

The main structure of the H-section temporary barrier system remained unchanged from its original configuration. The 61.25-m long test installation consisted of ten H-section temporary barrier rails installed 610 mm from the edge of the simulated bridge deck edge, as shown in Figures 1 through 5. Photographs of the constructed system are shown in Figures 5 through 8.

However, each barrier connection was redesigned to use two drop pins and two steel shear plates, as shown in Figures 1 through 3, 6, and 7. A pair of 330-mm wide x 314-mm long x 12.7-mm thick steel shear plates, each with two 51-mm diameter holes, were welded to the two webs from the HP sections which formed the box section on one end of the barrier rail. The ends of shear plates were tapered to a width of 295 mm and extended 168 mm into the adjacent barrier rail. Each shear plate was positioned 13 mm away from the adjacent web surface. The opposite end of the barrier had two matching 51-mm diameter holes cut into the webs of the HP shapes. When the barrier ends were pushed together, two 38-mm diameter by 308-mm long ASTM A36 steel pins dropped through the holes to complete the moment connection. The combination of the tapered shear plates, their welded vertical location, and the 13-mm diameter difference between the connecting pins and the holes allowed the barrier to meet the design rotation requirements of 4.0 and 2.4 degrees about the transverse and vertical axes, respectively.

The H-section barrier rails were also retrofitted with a series of steel angle brackets that were used as tie-downs to constrain the barrier motion, as shown in Figures 1, 3, and 8. Four 102 mm x 152 mm x 12.7-mm thick by 152-mm long ASTM A36 steel angle brackets were welded to the base of each side of the steel barrier and placed at 381 mm and 762 mm from each end. The base of each angle bracket was drilled with a 32-mm diameter hole. The brackets were fastened to the concrete bridge deck using 19-mm Red Head drop-in anchors with 19-mm diameter by 57-mm long ASTM A325 bolts and using 64-mm wide x 64-mm long x 4.8-mm thick steel plate washers.

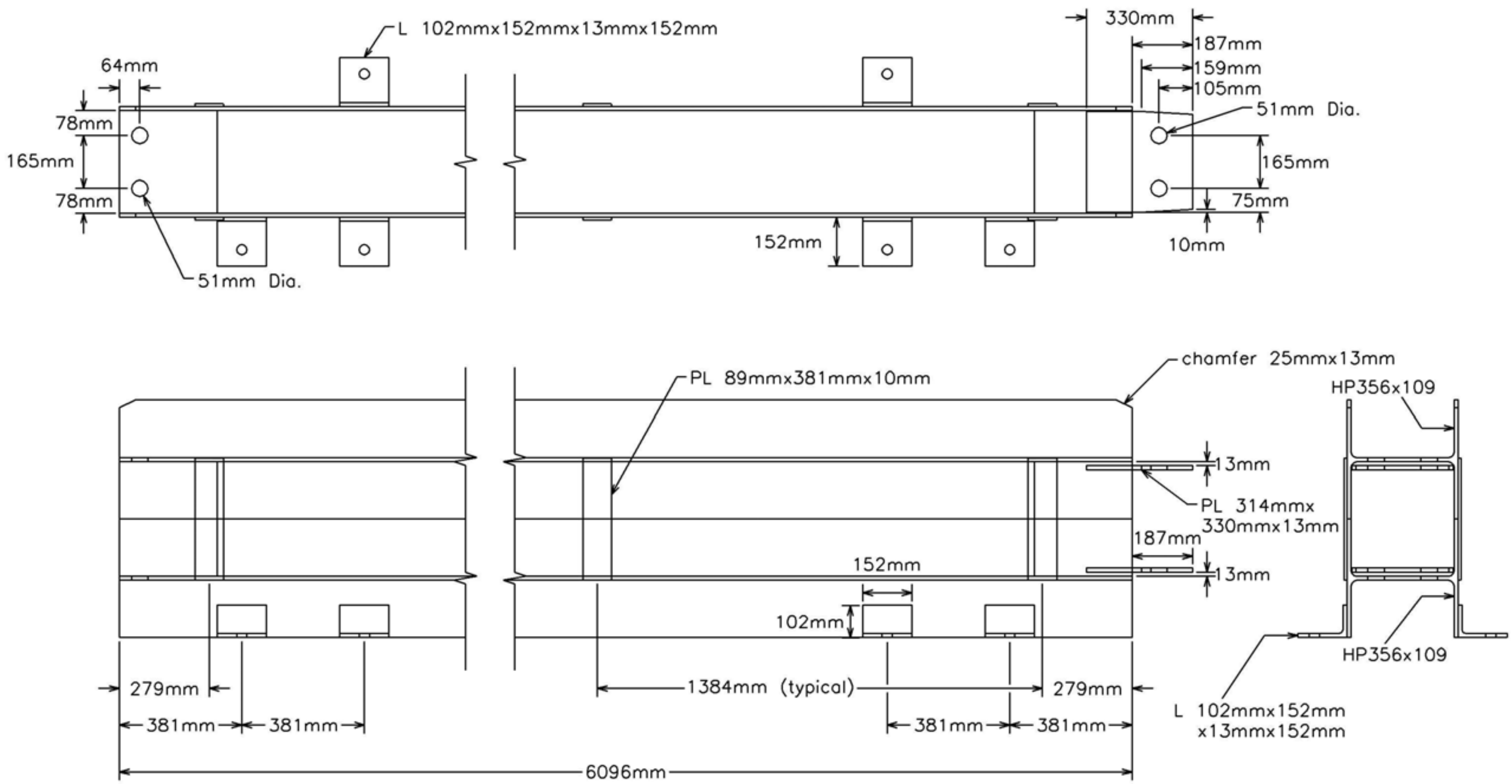


Figure 1. Steel H-section Temporary Barrier Design Details

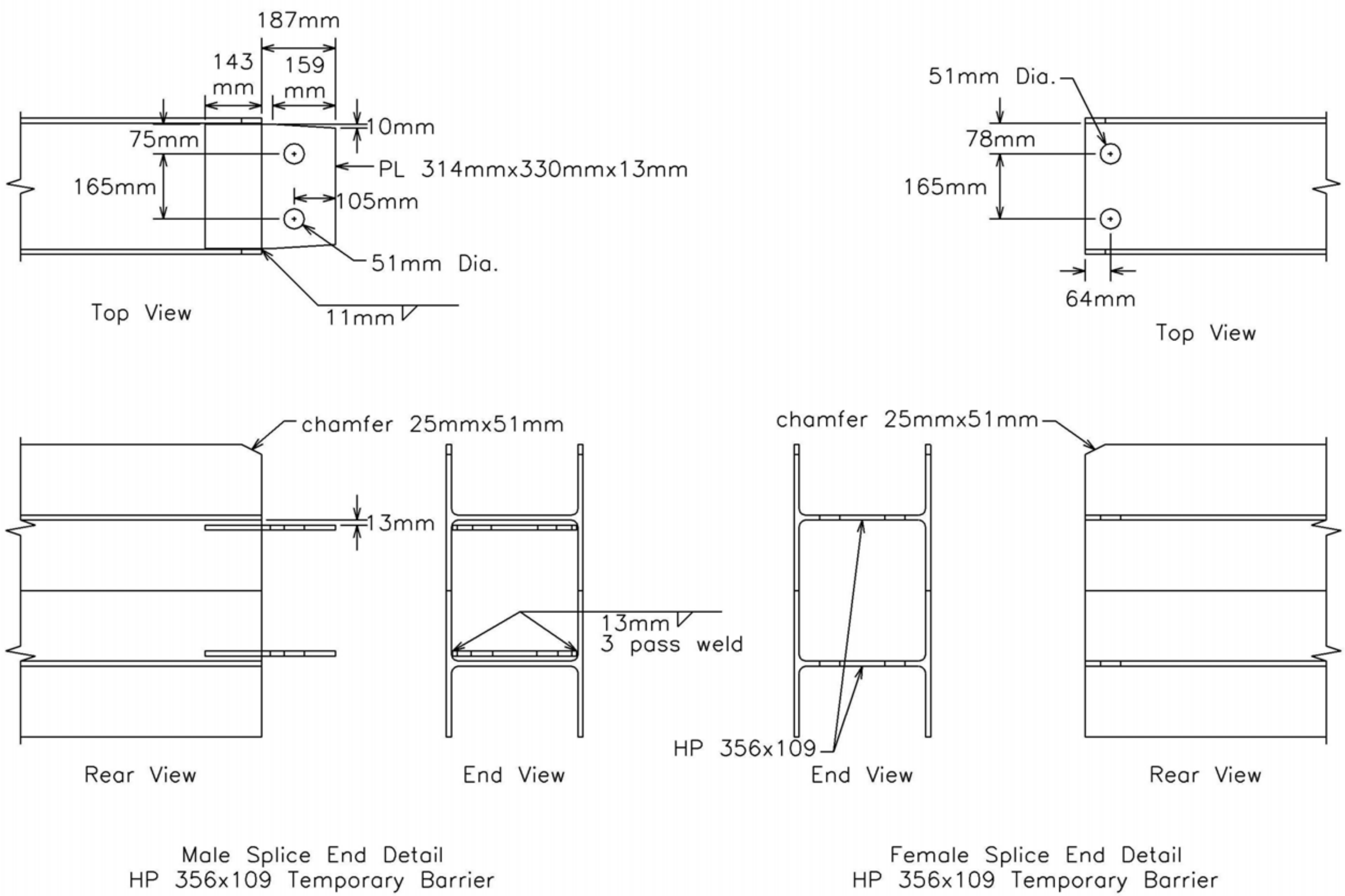


Figure 2. Steel H-section Temporary Barrier End Details

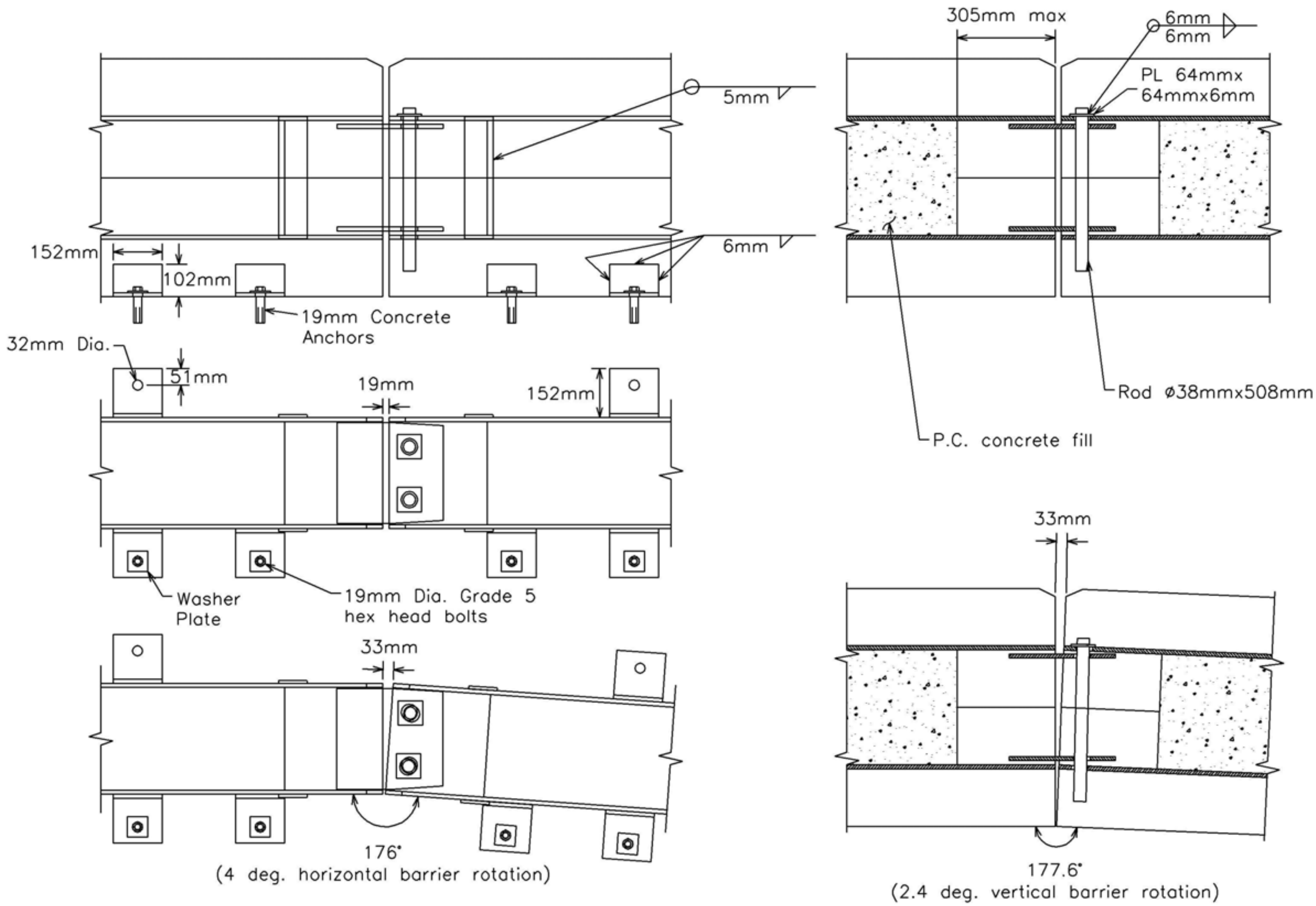
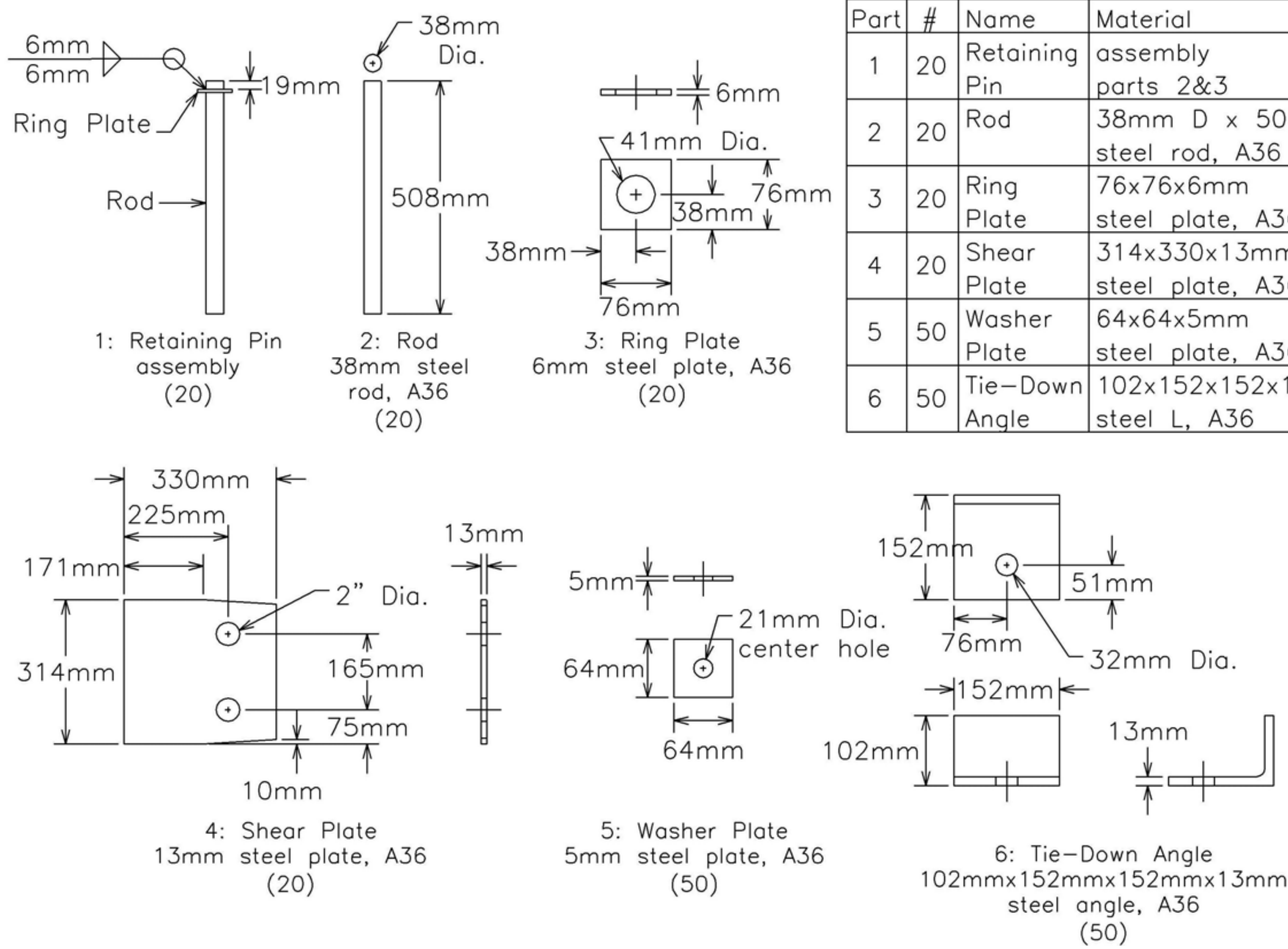


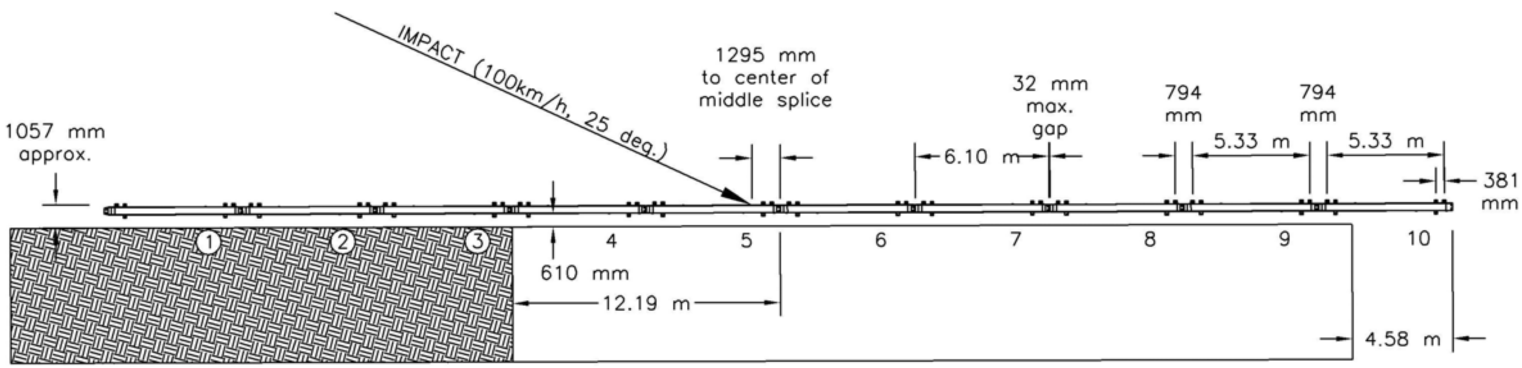
Figure 3. Steel H-section Temporary Barrier Splice Details



Bill of Parts			
Part	#	Name	Material
1	20	Retaining Pin	assembly parts 2&3
2	20	Rod	38mm D x 508mm steel rod, A36
3	20	Ring Plate	76x76x6mm steel plate, A36
4	20	Shear Plate	314x330x13mm steel plate, A36
5	50	Washer Plate	64x64x5mm steel plate, A36
6	50	Tie−Down Angle	102x152x152x13mm steel L, A36

Figure 4. Steel H-section Temporary Barrier Details

Temporary H-Barrier Test
HTB-1
NCHRP 350 Test: 3-11
2000P Pickup Truck
100 km/h
25 degrees



Notes:
Use 19-mm Grade 5 bolts in 19-mm dia. concrete anchors to secure barrier to deck. (40 each for entire installation.)
4 anchor bolts per barrier, traffic side only.
Maximize barrier gaps when installing for test.

Figure 5. Steel H-section Temporary Barrier Test Layout

Figure 5. Steel H-section Temporary Barrier Test Installation

Figure 6. Splice Details for Steel H-section Temporary Barrier

Figure 7. End Details for Steel H-section Temporary Barrier

Figure 8. Tie-Down Anchors for Steel H-section Temporary Barrier

5 TEST CONDITIONS

5.1 Test Facility

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

5.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the barrier system. A digital speedometer was located on the tow vehicle to increase the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch (12) was used to steer the test vehicle. A guide-flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the guardrail system. The 9.5-mm diameter guide cable was tensioned to approximately 13.3 kN, and supported laterally and vertically every 30.48 m 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 HTB-1 and HTB-2, the vehicle guidance systems were approximately 290-m and 204-m long, respectively.

5.3 Test Vehicles

For test HTB-1, a 1995 Chevrolet 2500 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,031 kg. The test vehicle is shown in Figure 9, and vehicle dimensions are shown in Figure 10.

For test HTB-2, a 1995 GMC 2500 ¾-ton pickup truck was used as the test vehicle. The test

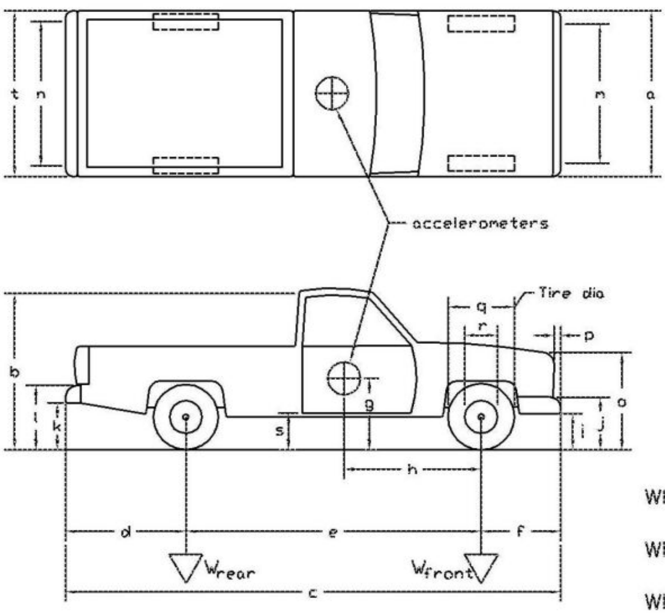
Figure 9. Test Vehicle, Test HTB-1

Date: 8/14/01 Test Number: HTB-1 Model: 2500

Make: Chevrolet Vehicle I.D.#: 1GCGC24K2SE170072

Tire Size: 245/75 R16 Year: 1995 Odometer: 182796

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm

a	1902	b	1842
c	5550	d	1327
e	3327	f	895
g	667	h	1393
i	464	j	679
k	606	l	791
m	1588	n	1622
o	1016	p	89
q	759	r	441
s	495	t	1870

Wheel Center Height Front 362

Wheel Center Height Rear 368

Wheel Well Clearance (FR) 905

Wheel Well Clearance (RR) 965

Engine Type 8 CYL. GAS

Engine Size 5.7 L 350 CID

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

Weights – kg	Curb	Test Inertial	Gross Static
W_{front}	1134	1181	1181
W_{rear}	882	850	850
W_{total}	2016	2031	2031

Note any damage prior to test: ______

Figure 10. Vehicle Dimensions, Test HTB-1

inertial and gross static weights were 1,988 kg. 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 9 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 and 14. Round, checkered targets were placed on the center of gravity on the driver's side door, the passenger's side door, and on the roof of the vehicle. The remaining targets were located for reference so that they could be viewed from the high-speed cameras for film analysis.

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

5.4 Data Acquisition Systems

5.4.1 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

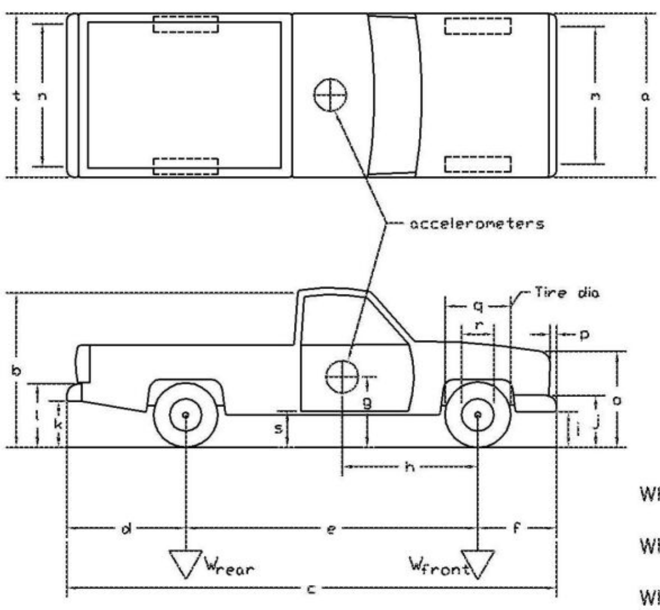
Figure 11. Test Vehicle, Test HTB-2

Date: 5/10/02 Test Number: HTB-2 Model: 2500

Make: GMC Vehicle I.D.#: 1GDGC24K0SE502263

Tire Size: 245/75 R16 Year: 1995 Odometer: 250778

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm

a 1886 b 1829

c 5537 d 1327

e 3327 f 883

g 667 h 1384

i 467 j 683

k 603 l 806

m 1588 n 1626

o 1029 p 89

q 743 r 445

s 483 t 1848

Wheel Center Height Front 371

Wheel Center Height Rear 375

Wheel Well Clearance (FR) 908

Wheel Well Clearance (RR) 965

Engine Type 8 CYL. GAS

Engine Size 5.7 L 350 CID

Transmission Type:

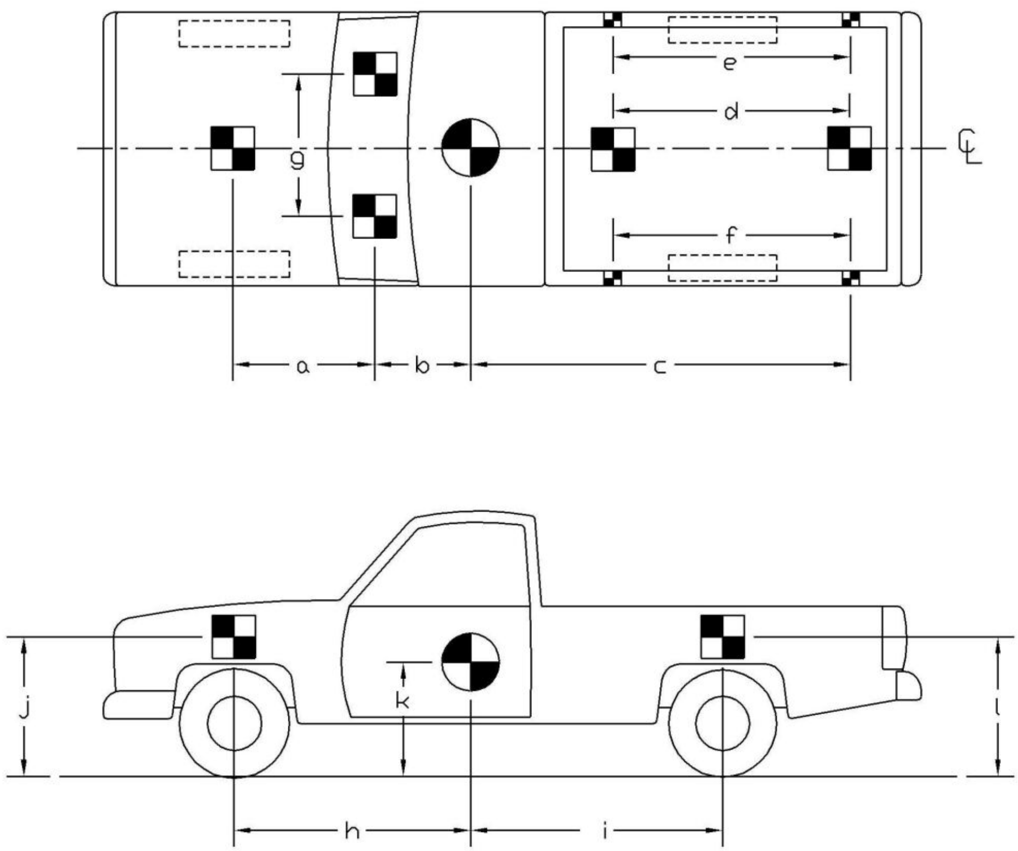
(Automatic) or Manual

FWD or (RWD) or 4WD

Weights – kg	Curb	Test Inertial	Gross Static
W_{front}	1116	1161	1161
W_{rear}	827	827	827
W_{total}	1943	1988	1988

Note any damage prior to test: Small dents in hood, left fender, and box

Figure 12. Vehicle Dimensions, Test HTB-2

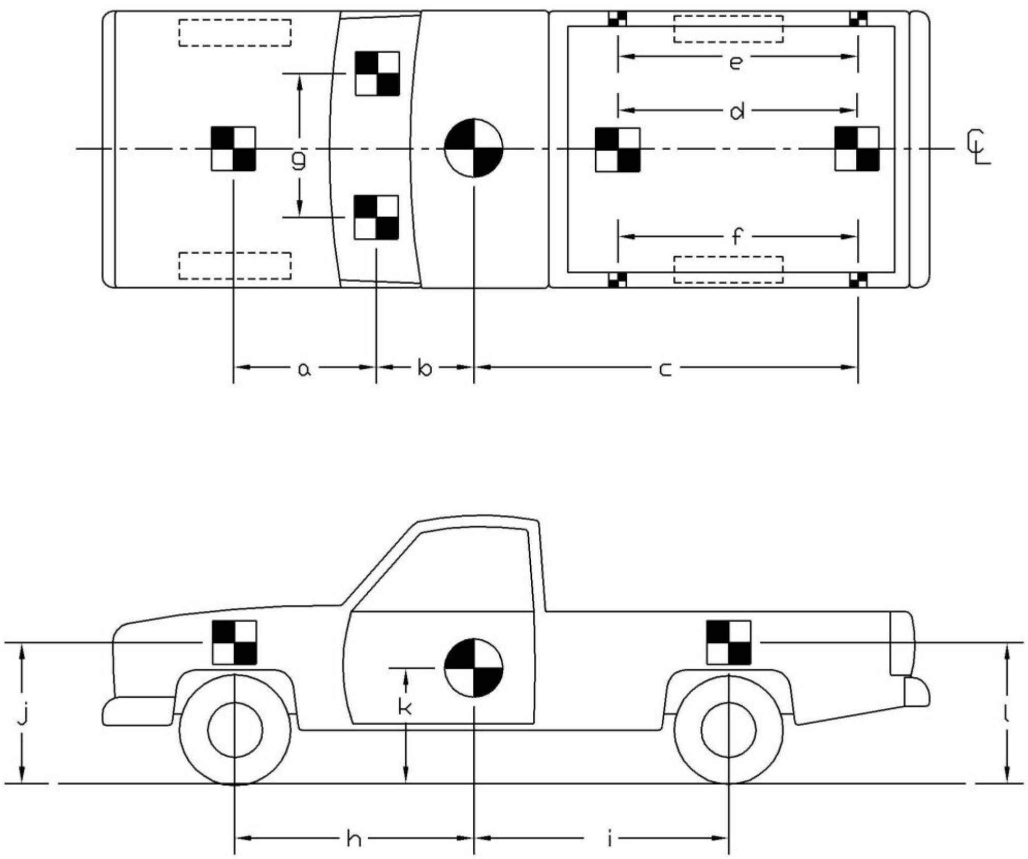


TEST #: HTB-1

TARGET GEOMETRY (mm)

a	895	d	1838	g	1146	j	1006
b	689	e	2153	h	1393	k	667
c	2731	f	2153	i	1807	l	1092

Figure 13. Vehicle Target Locations, Test HTB-1



TEST #: HTB-2

TARGET GEOMETRY (mm)

a	870	d	1803	g	1156	j	1060
b	692	e	2153	h	1384	k	667
c	3010	f	2153	i	1943	l	1016

Figure 14. Vehicle Target Locations, Test HTB-2

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.

5.4.2 Rate Transducers

For test HTB-1, 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.

5.4.3 High-Speed Photography

For test HTB-1, two high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. 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 Canon digital video camera, and a Nikon 995 digital 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. Two high-speed E/cam video cameras 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 twelve camera locations for test HTB-1 is shown in Figure 15.

For test HTB-2, two high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. One Photron high-speed video camera and four high-speed Red Lake E/cam video cameras, all 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, a high-speed Photron video camera, and a high-speed E/cam video camera 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 upstream 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 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 twelve camera locations for test HTB-2 is shown in Figure 16. 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.

5.4.4 Pressure Tape Switches

For tests HTB-1 and HTB-2, five pressure-activated tape switches, spaced at 2-m intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the right-front tire of the test vehicle passed over it. Test vehicle speed was determined from electronic timing mark data recorded using 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.

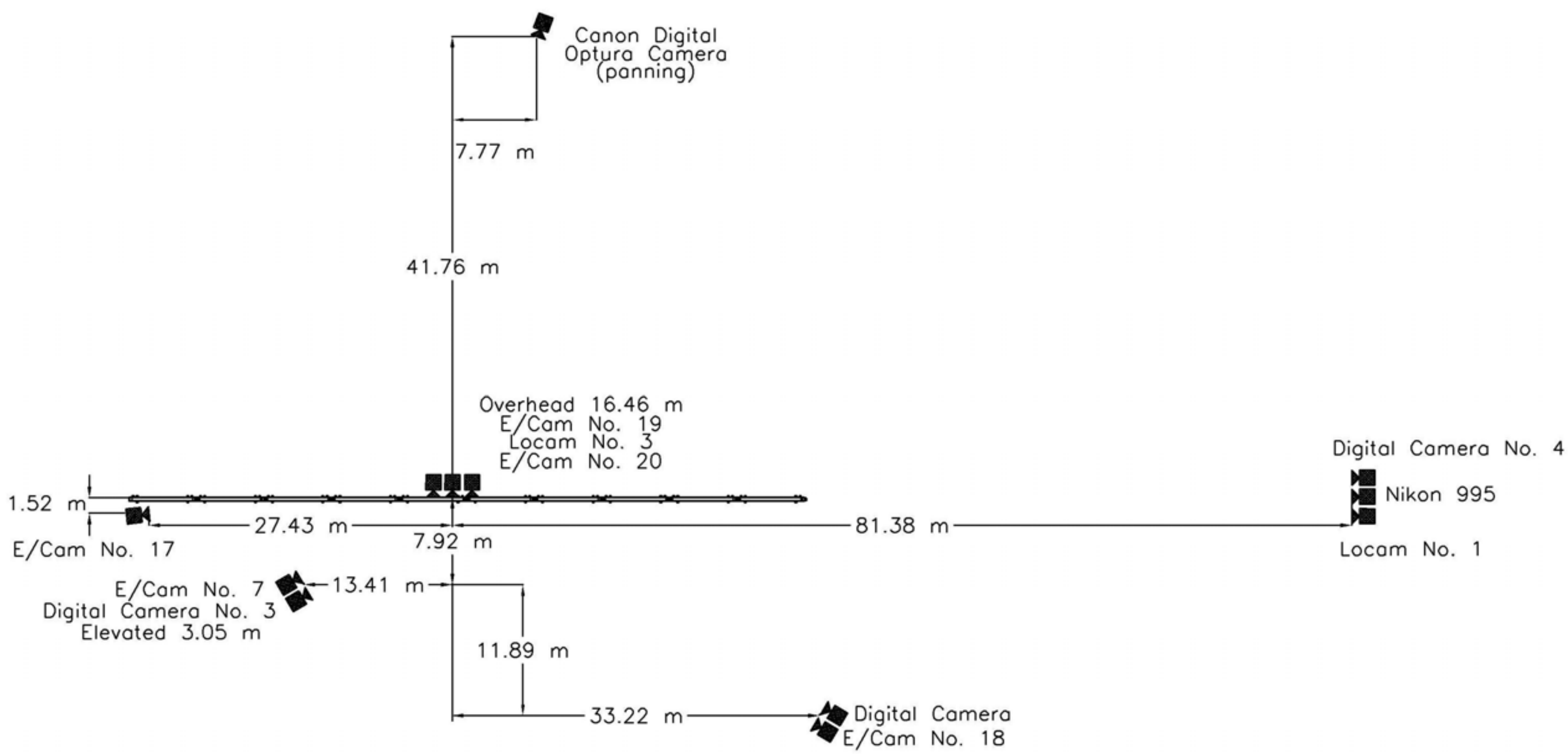


Figure 15. Location of High-Speed Cameras, Test HTB-1

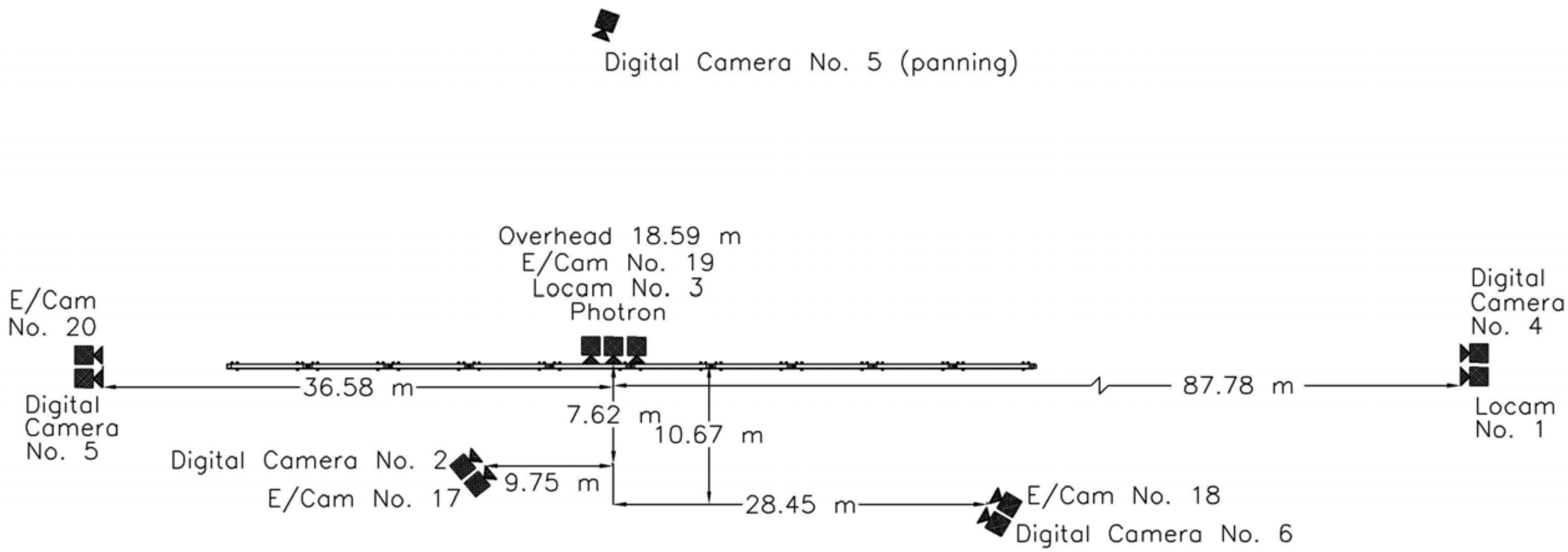


Figure 16. Location of High-Speed Cameras, Test HTB-2

6 CRASH TEST NO. 1 (DESIGN NO. 1)

6.1 Test HTB-1

The 2,031-kg pickup truck impacted the temporary barrier system at a speed of 100.4 km/hr and at an angle of 26.6 degrees. A summary of the test results and the sequential photographs are shown in Figure 17. Additional sequential photographs are shown in Figures 18 and 19. Documentary photographs of the crash test are shown in Figures 20 and 21.

6.2 Test Description

Initial impact was to occur 1,295-mm upstream from the splice between barrier nos. 5 and 6, as shown in Figure 22. Actual vehicle impact occurred 1,549-mm upstream from the splice between barrier nos. 5 and 6. At 0.036 sec after impact, the grill deformed inward as the front bumper twisted downward. At 0.048 sec, the right-front corner of the vehicle began to deform inward. At 0.094 sec, the right-front corner of the vehicle reached its maximum intrusion of 581 mm over the barrier as the vehicle began to redirect. At this same time, the top of the right-side door jarred open as the middle of it deformed inward. At 0.108 sec, the front of the vehicle was lifted by the contact with the barrier. At 0.123 sec, the left-front tire became airborne. At 0.150 sec, the right-front corner of the vehicle's box contacted the barrier. At 0.171 sec, the left-rear tire became airborne as the vehicle's cab rolled approximately 25 degrees clockwise (CW) toward the barrier and the box rolled slightly counterclockwise (CCW) away from the barrier. At 0.212 sec, the vehicle became parallel to the barrier with a resultant velocity of 73.1 km/hr. At this same time, the grill disengaged from the front. At 0.222 sec, the bottom of the vehicle's rear bumper contacted the top of the barrier causing the vehicle to continue to roll CW toward the barrier and pitch the rear of the vehicle upward. At 0.238 sec, the vehicle's right-front corner lost contact with the barrier as the cab rolled significantly CW toward the barrier. At 0.280 sec, the vehicle's box began to roll significantly CW toward the barrier. At 0.330 sec, the right-front tire became airborne as the vehicle continued to roll CW. At 0.358 sec, the vehicle's cab lost contact with the barrier. At 0.401 sec, both right-side tires contacted the ground with the right-rear corner of the vehicle in contact with the top of the barrier. At 0.428 sec after impact, the vehicle exited the barrier at a resultant velocity of 74.1 km/hr as it continued to roll toward its right side. At 0.745 sec, the right-front corner of the vehicle contacted the ground as the vehicle rolled onto its right side. At 1.060 sec, the vehicle was positioned on its right side and was sliding away from the barrier. The vehicle's post-impact trajectory is shown in Figures 17 and 23. The vehicle came to rest on its right side 52.04-m downstream from impact and 9.14-m laterally away from the traffic-side face of the barrier, as shown in Figures 17 and 23.

6.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 24 through 27. Barrier damage consisted mostly of minor damage to the tie-down angle brackets, cracking of the concrete near a few of the drop-in anchors, and scraping and tire marks on the barrier. Contact marks were found on barrier nos. 5 and 6 from impact to approximately 2,540-mm downstream of initial contact. Slight concrete failure occurred around the drop-in anchors at the joint between barrier nos. 5 and 6. Minor deformations to the tie-down angle brackets were found at the downstream end of barrier no. 5 and upstream end of barrier no. 6.

The permanent set of the barrier system is shown in Figures 23 through 25. The maximum lateral permanent set barrier deflection was 32 mm at the downstream end of barrier no. 5 and at the upstream end of barrier no. 6, as measured in the field. The maximum lateral dynamic barrier deflection was 63 mm at the upstream end of barrier no. 6, as determined from the high-speed film analysis.

6.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 28 through 32. Moderate occupant compartment deformations occurred with deformations to the firewall, the right-side floor pan, and the dashboard, as shown in Figure 32. Occupant compartment deformations and the corresponding locations are provided in Appendix A.

Damage was concentrated on the right-front corner and right side of the vehicle. The entire right-front corner of the vehicle was crushed inward and back including the fender, bumper, and frame rail. The right-front wheel was pushed up and back into the firewall, deflating the tire, and deforming the steel rim. The steel rim on the right-rear wheel was deformed, and the tire was torn and deflated. The right-side door was flattened and pulled away from the upper portion of the occupant compartment. Contact marks were found along the entire right side of the vehicle. The left-front fender was deformed slightly. The grill broke around the right-side headlight and remained attached by the wiring harness. The windshield sustained minor cracks. The roof, the hood, the left-side, and the rear of the vehicle remained undamaged. The left-side, right-side, and rear window glass also remained undamaged.

6.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be 6.57 m/sec and 7.20 m/sec, respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 5.81 g's and 6.39 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 17. Results are shown graphically in Appendix B. The results from the rate transducer are shown graphically in Appendix C.

6.6 Discussion

The analysis of the test results for test HTB-1 showed that the tie-down system for the steel H-section temporary barrier adequately contained the vehicle but inadequately redirected the vehicle as the vehicle did not remain upright after collision with the barrier. 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. After collision, the vehicle's trajectory revealed minimum intrusion into adjacent traffic lanes, but rollover of the vehicle was unacceptable. In addition, the vehicle's exit angle was less than 60 percent of the impact angle. Therefore, test HTB-1 conducted on the tie-down system for the steel H-section temporary barrier was determined to be unacceptable according to the TL-3 safety performance criteria found in NCHRP Report No. 350.

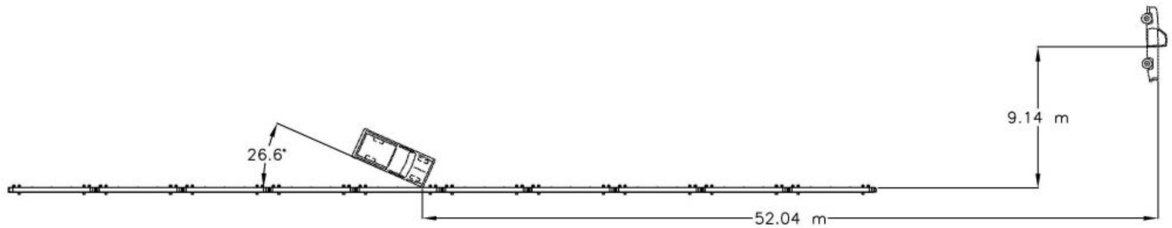
0.000 sec

0.094 sec

0.150 sec

0.238 sec

0.358 sec



- Test Number HTB-1
- Date 8/14/01
- Appurtenance . . . . Tie-Down Steel H-Section Temporary Barrier
- Total Length . . . . 61.25 m
- Placement from Bridge Deck Edge . 610 mm to back of rail
- Steel H-section Temporary Barriers
  - Material . . . . ASTM A36 steel
  - Configuration . . . . Two HP 356x109 mm by 6.1-m long beams stacked and connected by welded 89x381x9.5-mm vertical straps
  - Splice Connections . . . . Two 330x314x12.7-mm steel shear plates welded to HP webs with two 38-mm steel pins
- Barrier Tie-Downs
  - Material . . . . ASTM A36 steel
  - Angle Brackets . . . . Four 102x152x152x12.7-mm welded to the base of each side of the barrier
  - Drop-in Anchors . . . . Four 19-mm Red Head drop-in anchors with ASTM A325 bolts and plate washers
- Soil Type . . . . On dry pavement
- Vehicle Model . . . . 1995 Chevrolet 2500 ¾-ton pickup
  - Curb . . . . 2,016 kg
  - Test Inertial . . . . 2,031 kg
  - Gross Static . . . . 2,031 kg
- Vehicle Speed
  - Impact . . . . 100.4 km/hr
  - Exit (resultant) . . . . 74.1 km/hr
- Vehicle Angle
  - Impact . . . . 26.6 deg
  - Exit (trajectory) . . . . Approximately 10 deg
- Vehicle Snagging . . . . Wheel snag on vertical steel straps
- Vehicle Pocketing . . . . None
- Vehicle Stability . . . . Unsatisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 5.81 < 20 G's
  - Lateral (not required) 6.39
- Occupant Impact Velocity
  - Longitudinal . . . . 6.57 < 12 m/s
  - Lateral (not required) 7.20
- Vehicle Damage . . . . Moderate
  - TAD[13] 1-RFQ-5
  - SAE[14] 1-RFAO3
- Vehicle Stopping Distance . . . . 52.04 m downstream 9.14 m traffic-side face
- Barrier Damage . . . . Minimal
- Maximum Deflections
  - Permanent Set . . . . 32 mm
  - Dynamic . . . . 63 mm
- Working Width . . . . 581 mm

Figure 17. Summary of Test Results and Sequential Photographs, Test HTB-1

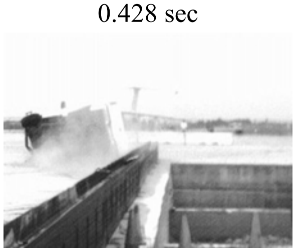
0.000 sec

0.108 sec

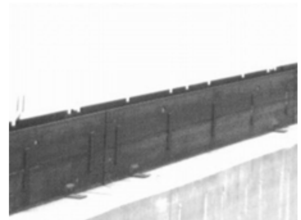
0.178 sec

0.272 sec

0.428 sec



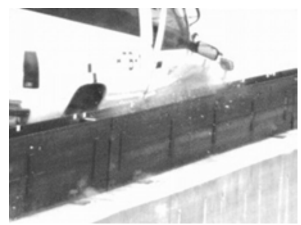
1.060 sec



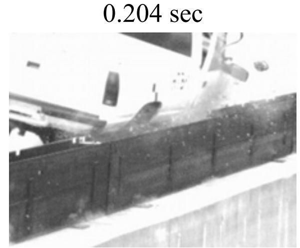
0.000 sec

0.086 sec

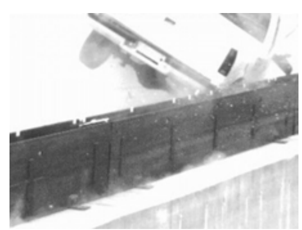
0.118 sec



0.204 sec



0.272 sec



0.440 sec

Figure 18. Additional Sequential Photographs, Test HTB-1

Figure 19. Additional Sequential Photographs, Test HTB-1

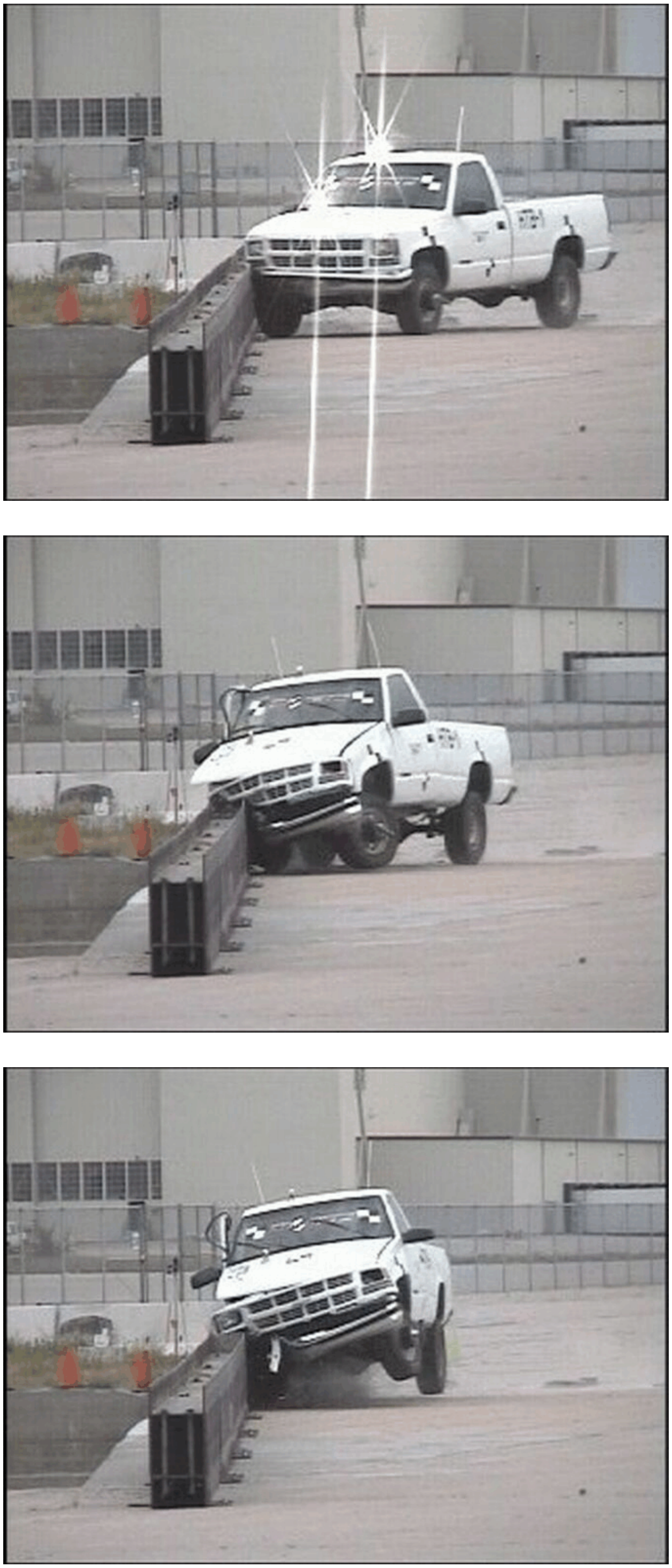


Figure 20. Documentary Photographs, Test HTB-1

Figure 21. Documentary Photographs, Test HTB-1

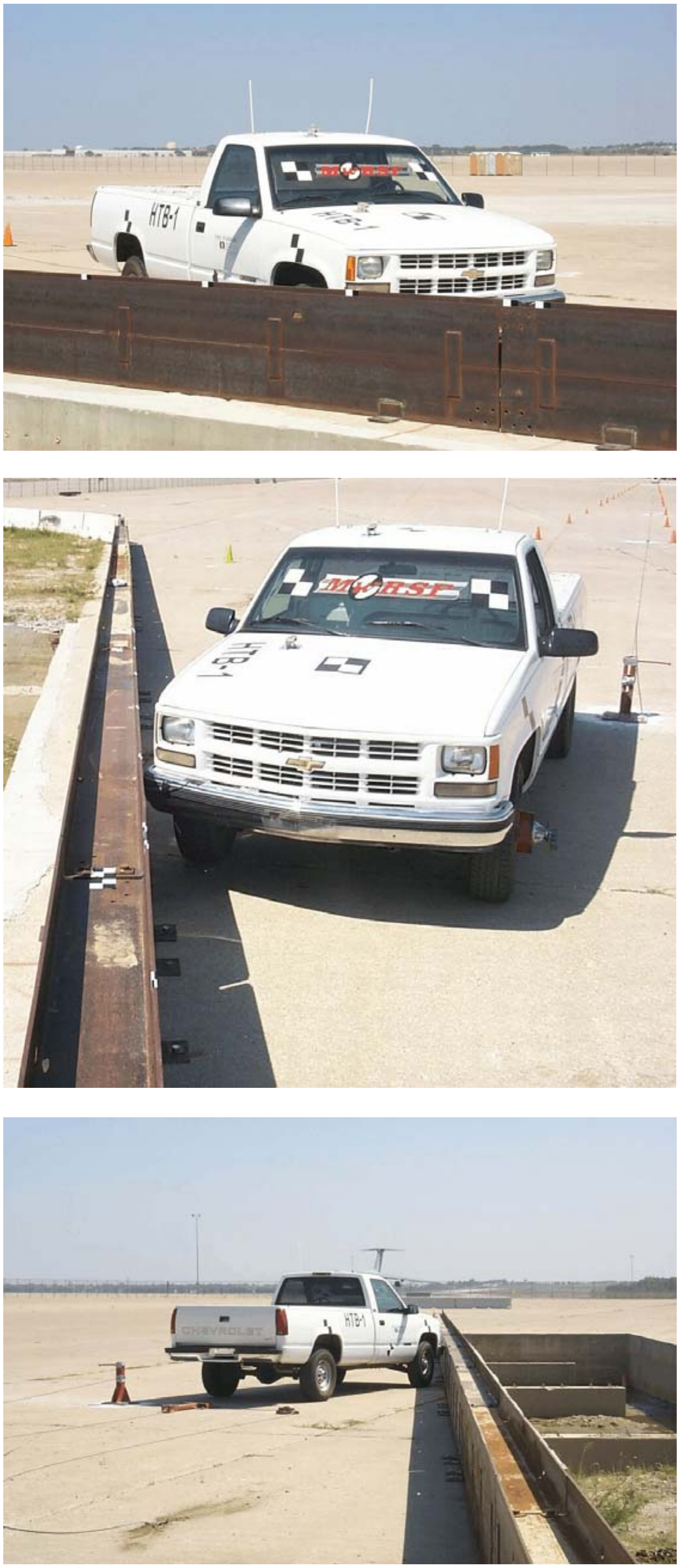


Figure 22. Impact Location, Test HTB-1

Figure 23. Vehicle Final Position and Trajectory Marks, Test HTB-1

Figure 24. Steel H-section Barrier System Damage, Test HTB-1

Figure 25. Steel H-section Barrier System Damage, Test HTB-1

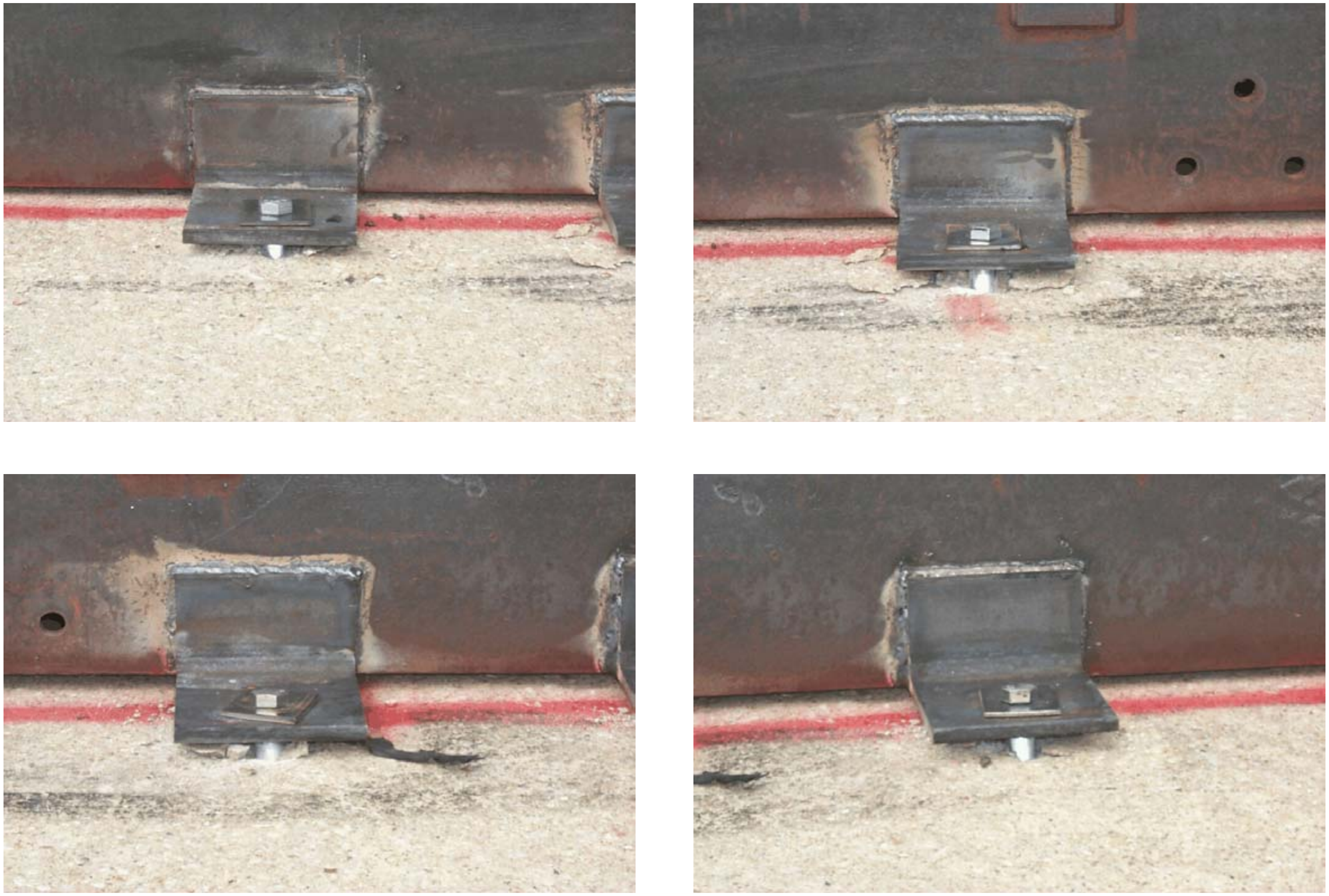


Figure 26. Tie-Down Anchor Damage, Test HTB-1

Figure 27. Tie-Down Anchor Bolt Damage, Test HTB-1

Figure 28. Vehicle Damage, Test HTB-1

Figure 29. Vehicle Damage, Test HTB-1

Right-Front

Right-Rear

Figure 30. Rim and Tire Damage, Test HTB-1

Figure 31. Undercarriage Vehicle Damage, Test HTB-1

Figure 32. Occupant Compartment Deformations, Test HTB-1

7 DISCUSSIONS AND MODIFICATIONS (DESIGN NO. 2)

Following test HTB-1, a safety performance evaluation was conducted, and Design No. 1 was determined to be unacceptable according to the NCHRP Report No. 350 criteria. Due to the unsuccessful crash test of Design No. 1, it was necessary to determine the cause of the poor barrier performance so that design modifications could be made to the barrier system in order to improve its overall safety performance.

From an analysis of the test results, MwRSF researchers believe that the rollover was caused by snagging of the pickup truck on the barrier. More specifically, the steel rims and sheet metal snagged on the 12.7-mm thick vertical straps holding the barriers together, the separation between the barrier joints, and the top of the barrier section. This conclusion was based on the damage to the vehicle's right-side sheet metal and steel wheel rims as well as the right-front fender being pulled down during the test as observed on the high-speed film.

Following this investigation, MwRSF researchers determined that the safety performance of the H-section temporary barrier tie-down system (Design No. 1) could be significantly improved by reducing the potential for snag. In order to eliminate the snag potential, two modifications were made to the barrier tie-down system. First, the vertical steel straps positioned on the traffic-side face of the barrier were removed and replaced with a longitudinal seam weld. Second, the anchor bolts used in conjunction with the drop-in anchors were changed from ASTM A325 to ASTM A307 grade bolts. The bolt grade reduction was made in order to reduce the load capacity of the tie-down attachments and allow for a slight increase in the deflection of the system. It was believed that allowing slightly higher deflections would potentially reduce any additional vehicle snag on the top of the barrier section and at the joints. These modifications, included in Design No. 2, are shown in Figures 33 through 36.

The main structure of the H-section temporary barrier system remained unchanged from its original configuration, and the 61.25-m long test installation consisted of ten H-section temporary barrier rails installed 330 mm from the edge of the simulated bridge deck edge, as shown in Figures 33 through 37. Photographs of the constructed system are shown in Figure 38 through 41.

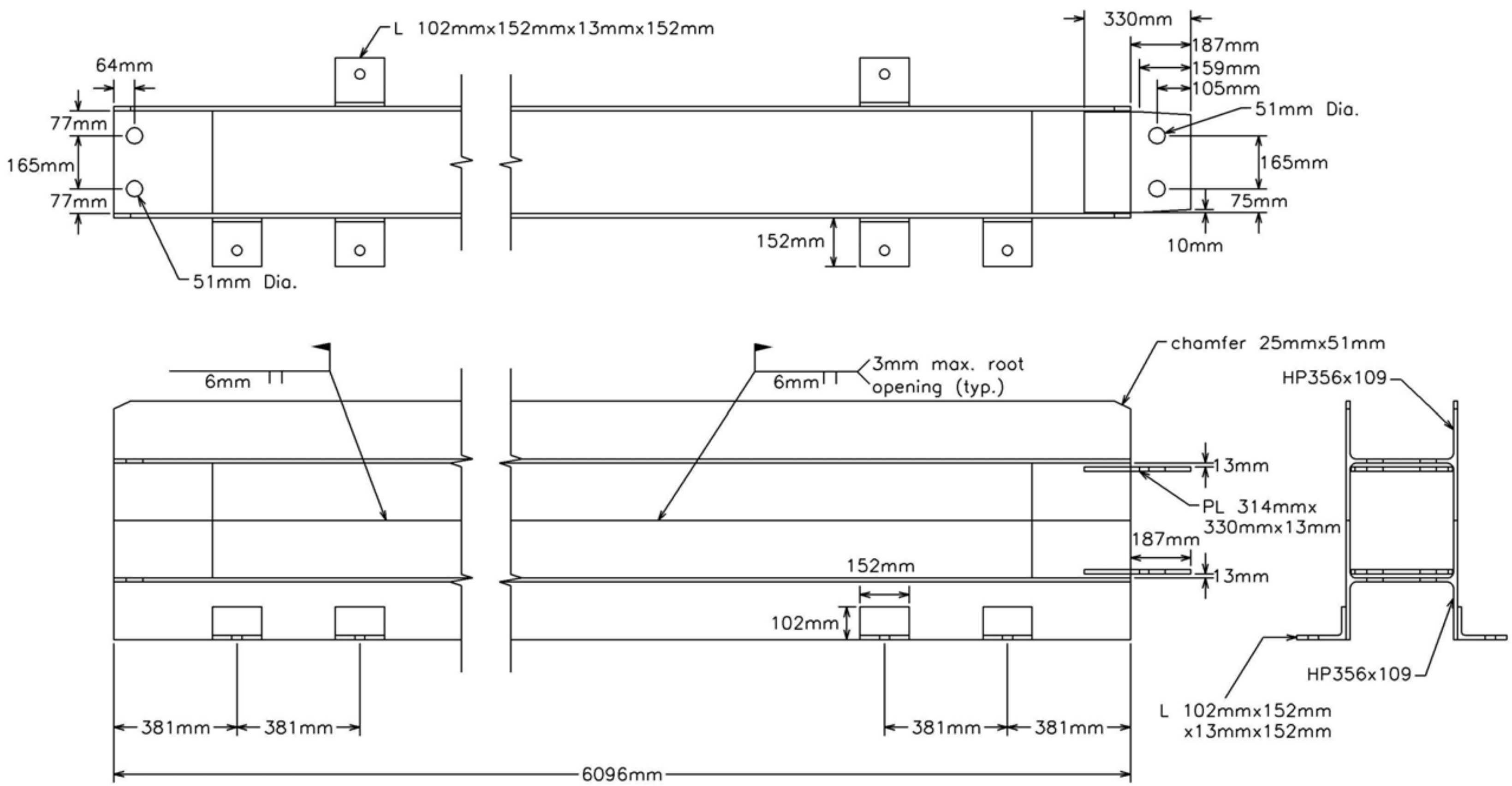


Figure 33. Steel H-section Temporary Barrier Design Details (Design No. 2)

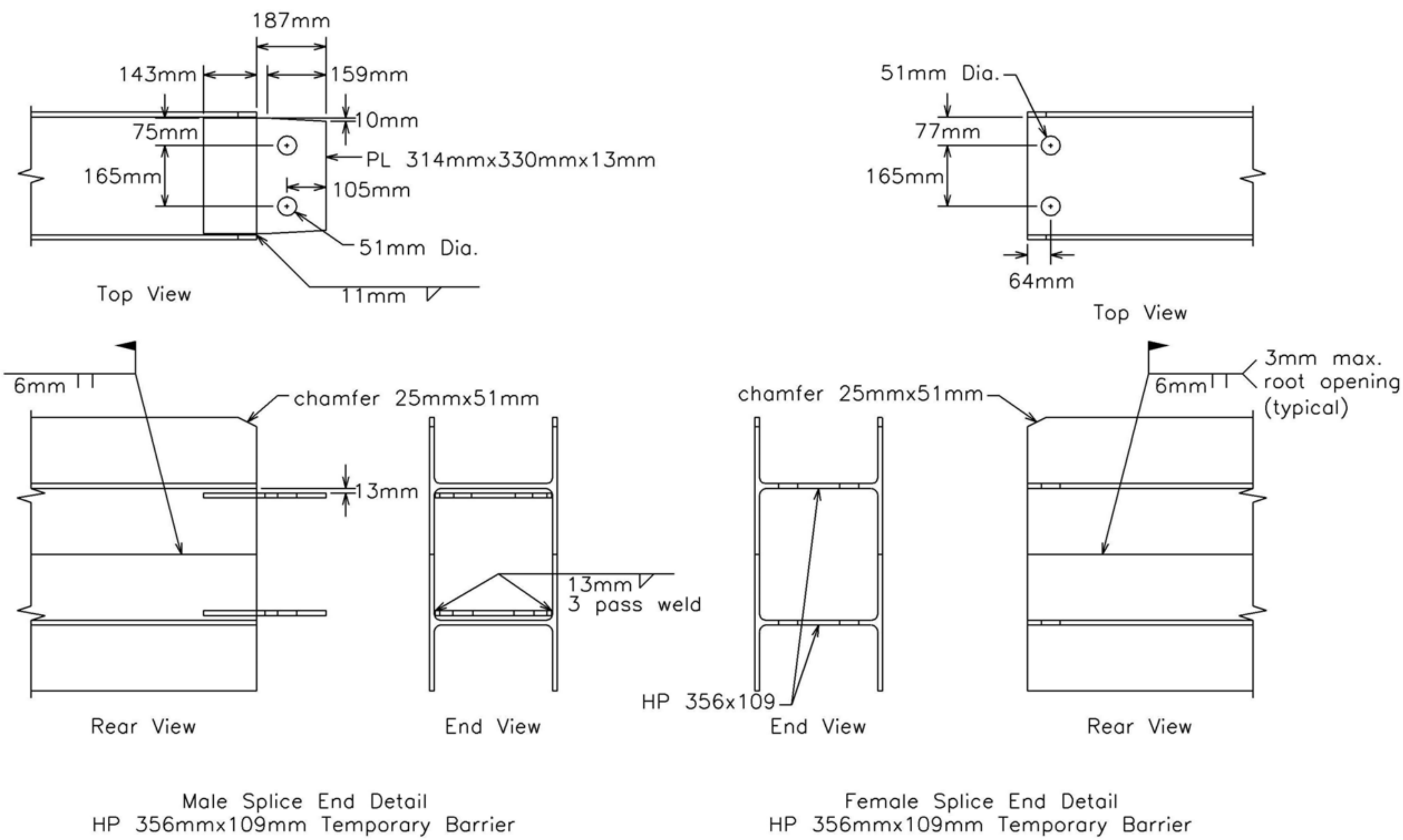


Figure 34. Steel H-section Temporary Barrier End Details (Design No. 2)

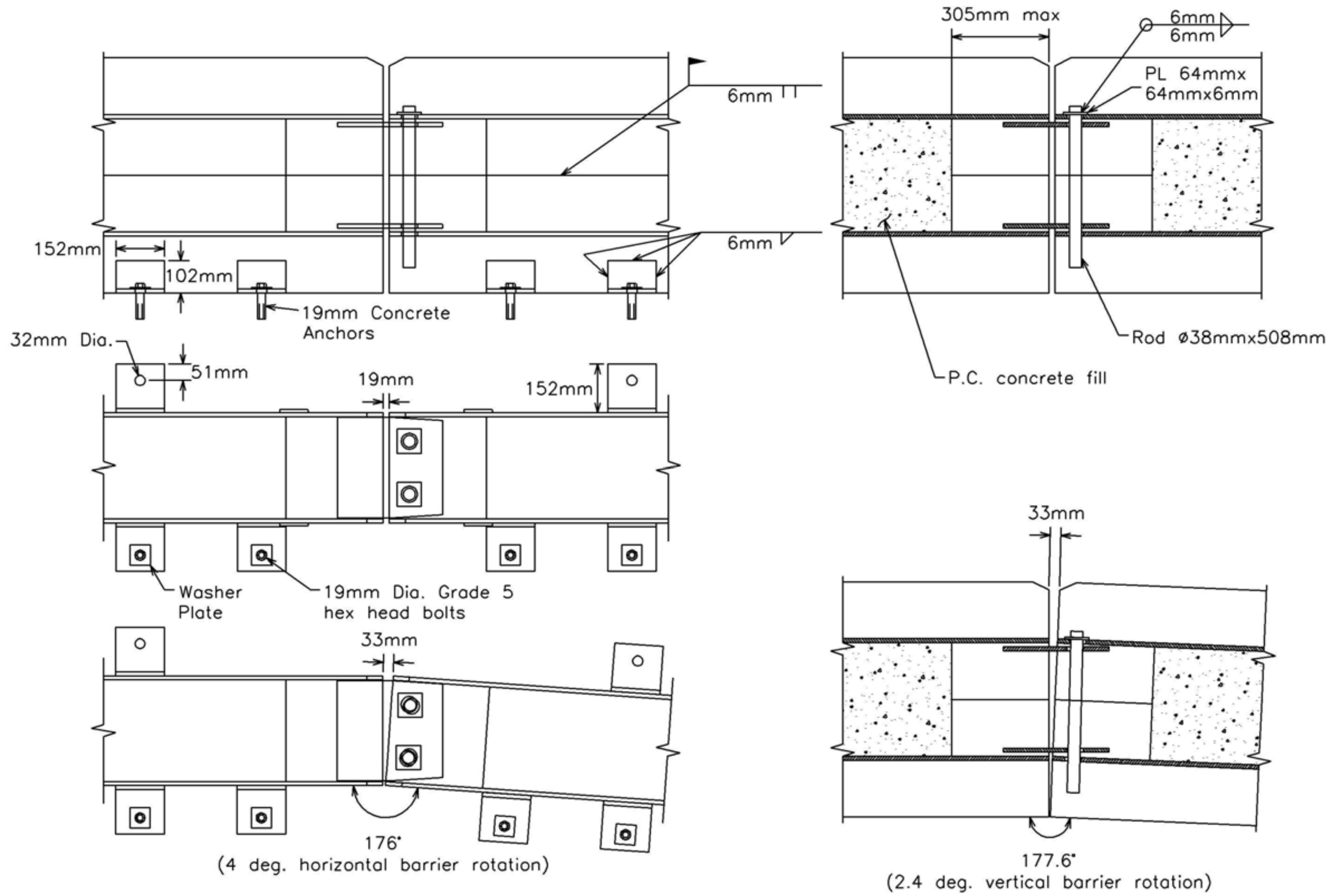
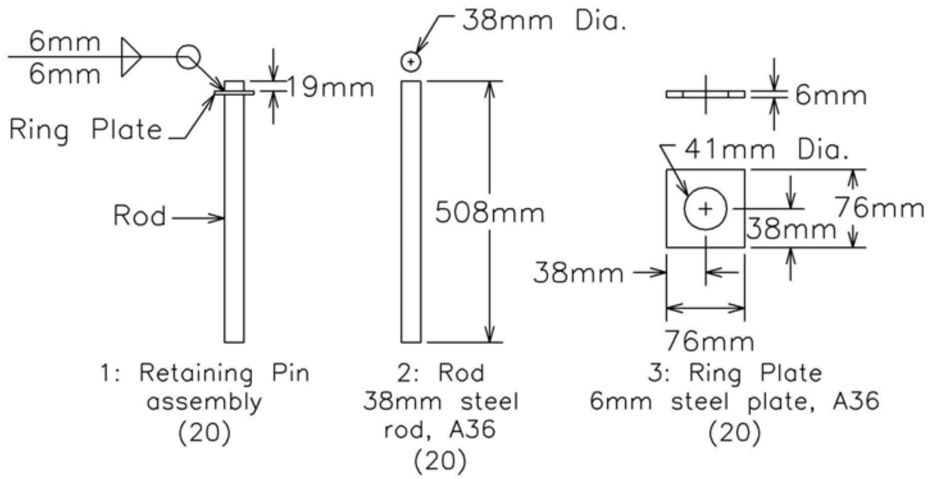


Figure 35. Steel H-section Temporary Barrier Splice Details (Design No. 2)



Bill of Parts			
Part	#	Name	Material
1	20	Retaining Pin	assembly parts 2&3
2	20	Rod	38mm D x 508mm steel rod, A36
3	20	Ring Plate	152x152x6mm steel plate, A36
4	20	Shear Plate	314x330x13mm steel plate, A36
5	50	Washer Plate	64x64x5mm steel plate, A36
6	50	Tie-Down Angle	102x152x152x13mm steel L, A36

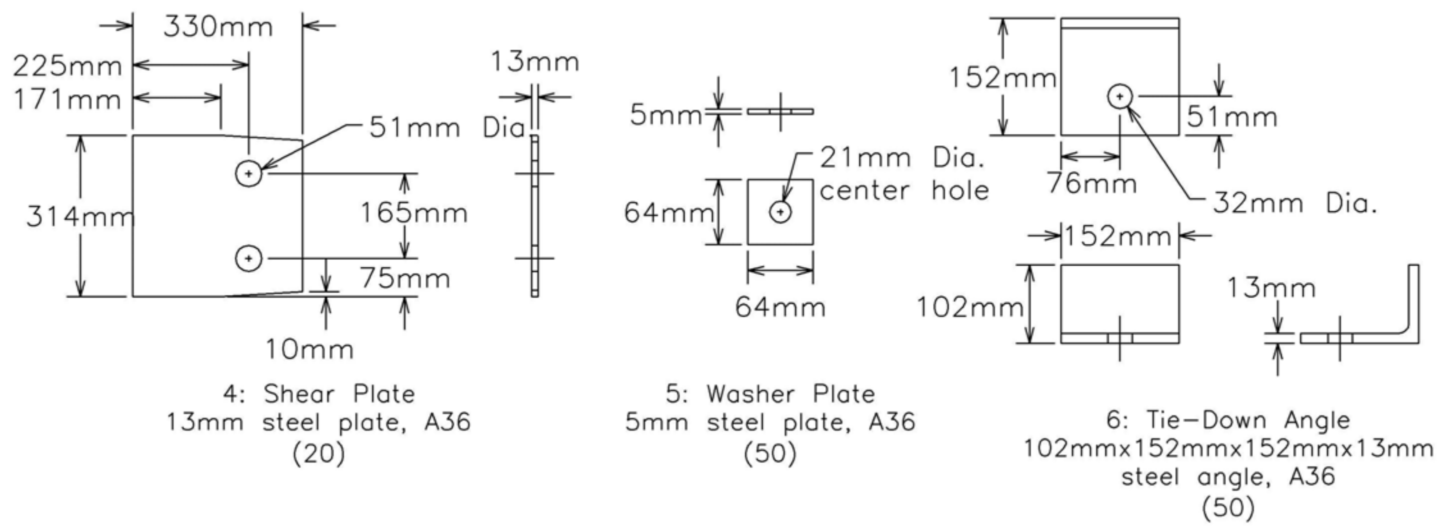


Figure 36. Steel H-section Temporary Barrier Details (Design No. 2)

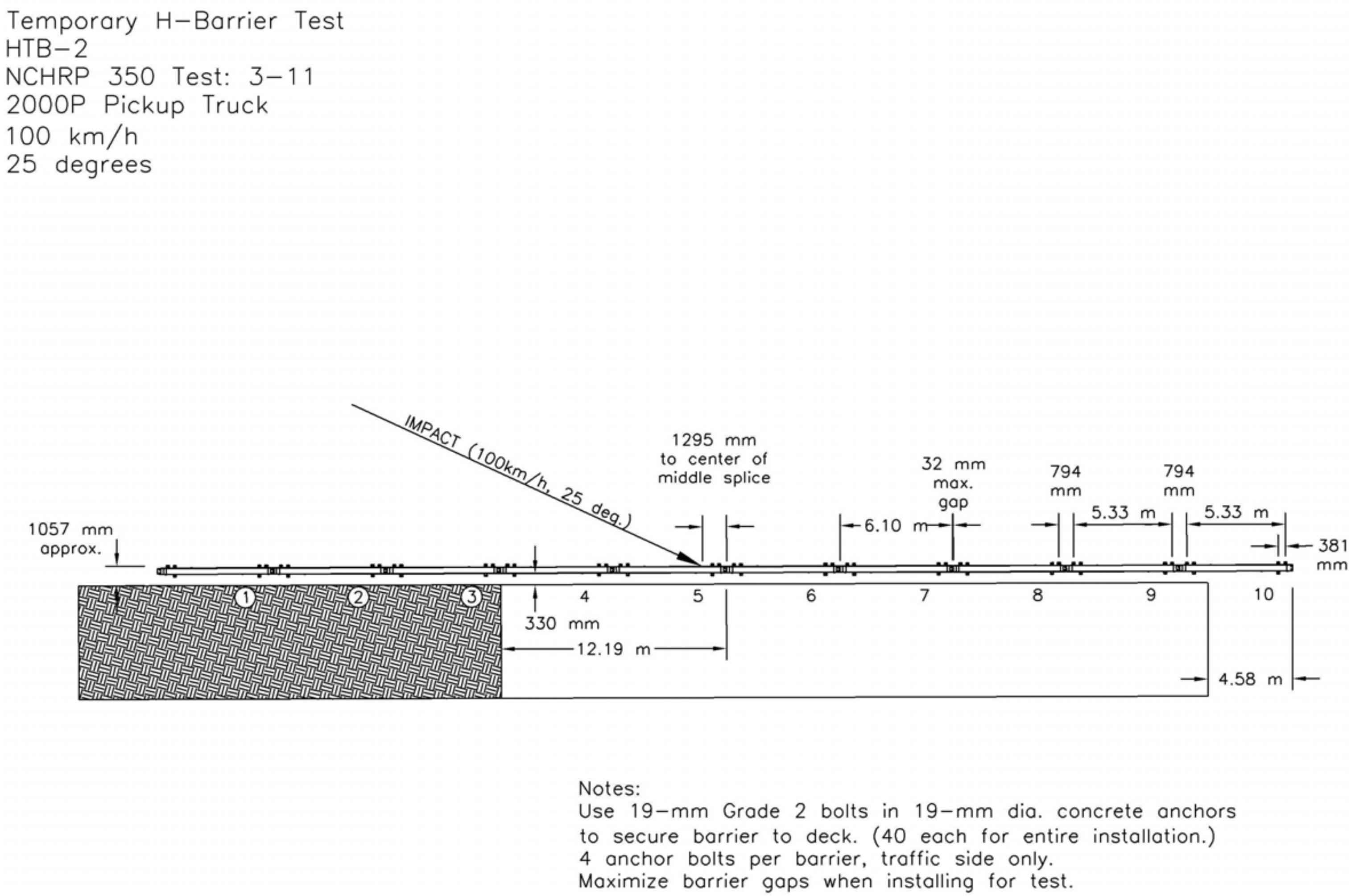


Figure 37. Steel H-section Temporary Barrier Test Layout (Design No. 2)

Figure 38. Steel H-section Temporary Barrier Test Installation (Design No. 2)

Figure 39. End Details for Steel H-section Temporary Barrier (Design No. 2)

Figure 40. Splice and Seam Weld Details for Steel H-section Temporary Barrier (Design No. 2)

Figure 41. Tie-Down Anchors for Steel H-section Temporary Barrier (Design No. 2)

8 CRASH TEST NO. 2 (DESIGN NO. 2)

8.1 Test HTB-2

The 1,988-kg pickup truck impacted the temporary barrier system at a speed of 100.7 km/hr and at an angle of 26.0 degrees. A summary of the test results and the sequential photographs are shown in Figure 42. Additional sequential photographs are shown in Figures 43 and 44. Documentary photographs of the crash test are shown in Figures 45 through 47.

8.2 Test Description

Initial impact was to occur 1,295-mm upstream from the splice between barrier nos. 5 and 6, as shown in Figure 48. Actual vehicle impact occurred 1,448-mm upstream from the splice between barrier nos. 5 and 6. At 0.037 sec, the right-front wheel assembly was deformed parallel to and in contact with the barrier. At this same time, the vehicle's right-front corner penetrated over the barrier. At 0.047 sec, the vehicle's right-front corner was positioned at the splice between barrier nos. 5 and 6. At 0.072 sec, the vehicle's front end pitched downward. At 0.079 sec, the right-front corner of the vehicle reached its maximum intrusion of 619 mm over the barrier. At 0.085 sec, the vehicle began to redirect as it rolled CW toward the barrier. At 0.142 sec, the right-front corner of the truck box was positioned at the splice between barrier nos. 5 and 6 as the left-rear tire became airborne. At this same time, the rear of the truck began to rise into the air. At 0.193 sec, the right-rear corner of the truck box impacted the barrier. At 0.205 sec, the vehicle became parallel to the barrier with a resultant velocity of 81.7 km/hr. At this same time, the right-side of the truck box deformed away from the tailgate. At 0.256 sec, the truck box reached its maximum intrusion of 688 mm over the barrier. At 0.303 sec, the barrier began to rebound back toward the traffic as the right-front corner of the vehicle lost contact with the barrier. At this same time, the right-rear corner of the truck box protruded over the barrier with the right-rear tire airborne. At 0.430 sec, the right-front tire dug into the ground. At 0.441 sec, the rolling motion of the truck ceased with both left-side tires airborne. At this same time, the right-rear corner of the vehicle remained in contact with the barrier. At 0.557 sec, the vehicle began to roll CCW away from the barrier. At 0.587 sec, the vehicle exited the barrier at a trajectory angle of 10.9 degrees and at a resultant velocity of 76.3 km/hr. At 0.797 sec, the left-front tire contacted the ground. At 0.983 sec, the right-rear tire contacted the ground. At 1.048 sec, the vehicle once again began to roll CW toward the barrier. At 1.134 sec, the rear of the vehicle pitched upward. At 1.512 sec, the front end of the vehicle began to pitch upward. At 2.014 sec, the vehicle's front end continued to pitch upward as the vehicle yawed back toward the barrier. The vehicle's post-impact trajectory is shown in Figures 42 and 49. The vehicle came to rest 63.16-m downstream from impact and 5.13-m laterally behind a line projected parallel to the traffic-side face of the barrier, as shown in Figures 42 and 49.

8.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 50 through 54. Barrier damage consisted mostly of scraping and tire marks on the barrier as well as release of several of the tie-down attachments. Contact marks were found on barrier nos. 5 and 6 from impact to approximately 3,048-mm downstream of initial contact. Contact marks were also found on the four tie-down angle brackets at the joint between barrier nos. 5 and 6. Tie-down failure occurred at the two angle brackets at the downstream end of barrier no. 5, the two angle brackets at the upstream end of barrier no. 6, and the upstream angle bracket at the downstream end of barrier no. 6. Four of the failures occurred due to fracture of the anchor bolts and the fifth was due to pullout of the drop-in anchor. In addition, the fifth failed angle bracket displayed partial fracture of the weld used to attach the bracket to the steel barrier and minor deformation. Slight concrete failure occurred around the drop-in anchors at the joints between barrier nos. 4, 5, 6, and 7.

The permanent set of the barrier system is shown in Figures 49 through 51. The maximum lateral permanent set barrier deflection was 241 mm at the downstream end of barrier no. 5, as measured in the field. The maximum lateral dynamic barrier deflection was 314 mm at the downstream end of barrier no. 5, as determined from the high-speed film analysis.

8.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 55 through 59. Moderate occupant compartment deformations occurred with deformations to the right-side floor pan and dash, as shown in Figure 59. Occupant compartment deformations and the corresponding locations are provided in Appendix D.

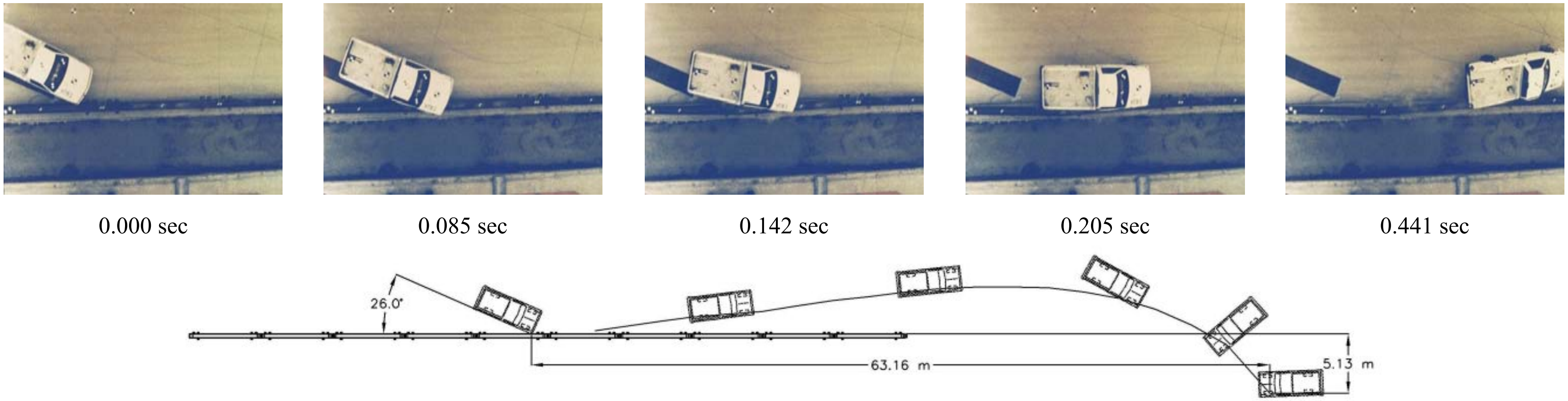
Damage was concentrated on the right-front corner and right side of the vehicle. The right-front corner of the vehicle was crushed inward and back including the fender, bumper, and frame rail. A buckling point was found at the center of the front bumper. Deformation of the right-side door and the right side of the truck bed were also observed. Both of the tires on the right side of the vehicle were torn and deflated. The right-front wheel was pushed backwards, but was not disengaged from the suspension. In addition, the right-front steel rim encountered major damage. Contact marks were found along the entire right side of the vehicle. The top of the right-side door was jarred open. The rear tailgate disengaged from the truck box. The right rear of the truck box was deformed at the top and near the box bed connections. The right side of the rear bumper was also deformed. The grill was broken and deformed around the right-side headlight. The roof, the hood, the left side of the vehicle, and all the window glass remained undamaged.

8.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be 5.60 m/sec and 7.04 m/sec, respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 5.26 g's and 12.36 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 42. Results are shown graphically in Appendix E. Roll and yaw data were collected from film analysis and are shown graphically in Appendix F.

8.6 Discussion

The analysis of the test results for test HTB-2 showed that the tie-down system for the steel H-section temporary barrier adequately contained and redirected the vehicle with controlled lateral displacements of the barrier system. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate or ride over the steel barrier 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 HTB-2 conducted on the tie-down system for the steel H-section temporary barrier was determined to be acceptable according to the TL-3 safety performance criteria found in NCHRP Report No. 350.



- Test Number HTB-2
- Date 5/10/02
- Appurtenance . . . . Tie-Down Steel H-Section Temporary Barrier
- Total Length . . . . 61.25 m
- Placement from Bridge Deck Edge . 330 mm to back of rail
- Steel H-section Temporary Barriers
  - Material . . . . ASTM A36 steel
  - Configuration . . . . Two HP 356x109 mm by 6.1-m long beams stacked and connected by longitudinal welds
  - Splice Connections . . . . Two 330x314x12.7 mm steel shear plates welded to HP webs with two 38-mm steel pins
- Barrier Tie-Downs
  - Material . . . . ASTM A36 steel
  - Angle Brackets . . . . Four 102x152x152x12.7-mm welded to the base of each side of the barrier
  - Drop-in Anchors . . . . Four 19-mm Red Head drop-in anchors with ASTM A307 bolts and plate washers
- Soil Type . . . . On dry pavement
- Vehicle Model . . . . 1995 GMC 2500 ¾-ton pickup
  - Curb . . . . 1,943 kg
  - Test Inertial . . . . 1,988 kg
  - Gross Static . . . . 1,988 kg
- Vehicle Speed
  - Impact . . . . 100.7 km/hr
  - Exit (resultant) . . . . 76.3 km/hr
- Vehicle Angle
  - Impact . . . . 26.0 deg
  - Exit (trajectory) . . . . 10.9 deg
- Vehicle Snagging . . . . None
- Vehicle Pocketing . . . . None
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 5.26 < 20 G's
  - Lateral (not required) 12.36
- Occupant Impact Velocity
  - Longitudinal . . . . 5.60 < 12 m/s
  - Lateral (not required) 7.04
- Vehicle Damage . . . . Moderate
  - TAD[13] 1-RFQ-3
  - SAE[14] 1-RFAW3
- Vehicle Stopping Distance . . . . 63.16 m downstream 5.13 m laterally behind
- Barrier Damage . . . . Minimal
- Maximum Deflections
  - Permanent Set . . . . 241 mm
  - Dynamic . . . . 314 mm
- Working Width . . . . 725 mm

Figure 42. Summary of Test Results and Sequential Photographs, Test HTB-2

0.000 sec

0.200 sec

0.370 sec

0.420 sec

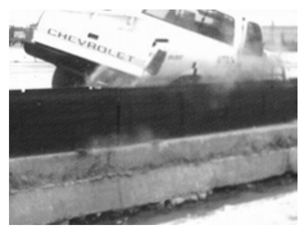
0.470 sec

0.610 sec

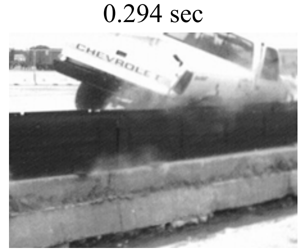
0.000 sec

0.072 sec

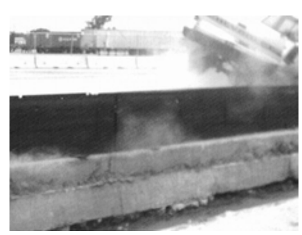
0.220 sec



0.294 sec



0.326 sec



0.506 sec

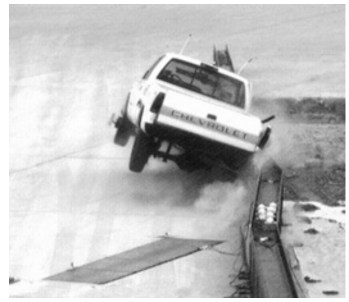
Figure 43. Additional Sequential Photographs, Test HTB-2

0.000 sec

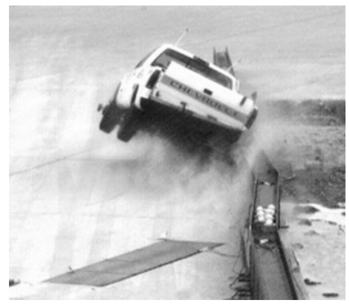
0.068 sec

0.144 sec

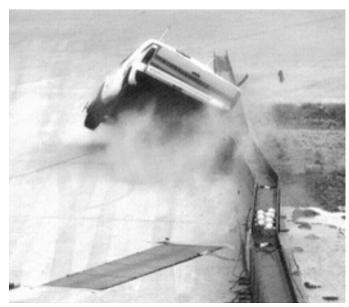
0.224 sec



0.310 sec



0.416 sec



0.584 sec

0.808 sec

Figure 44. Additional Sequential Photographs, Test HTB-2

Figure 45. Documentary Photographs, Test HTB-2

Figure 46. Documentary Photographs, Test HTB-2

Figure 47. Documentary Photographs, Test HTB-2

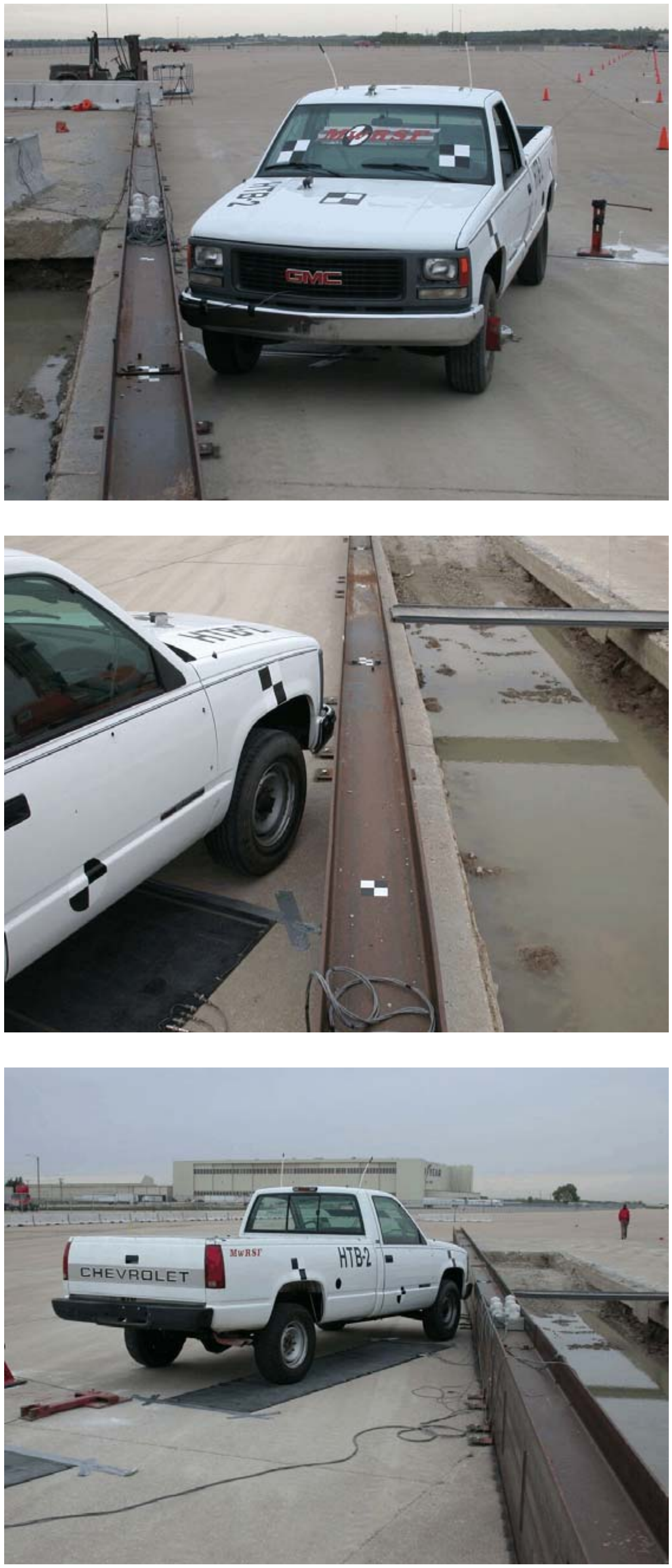


Figure 48. Impact Location, Test HTB-2

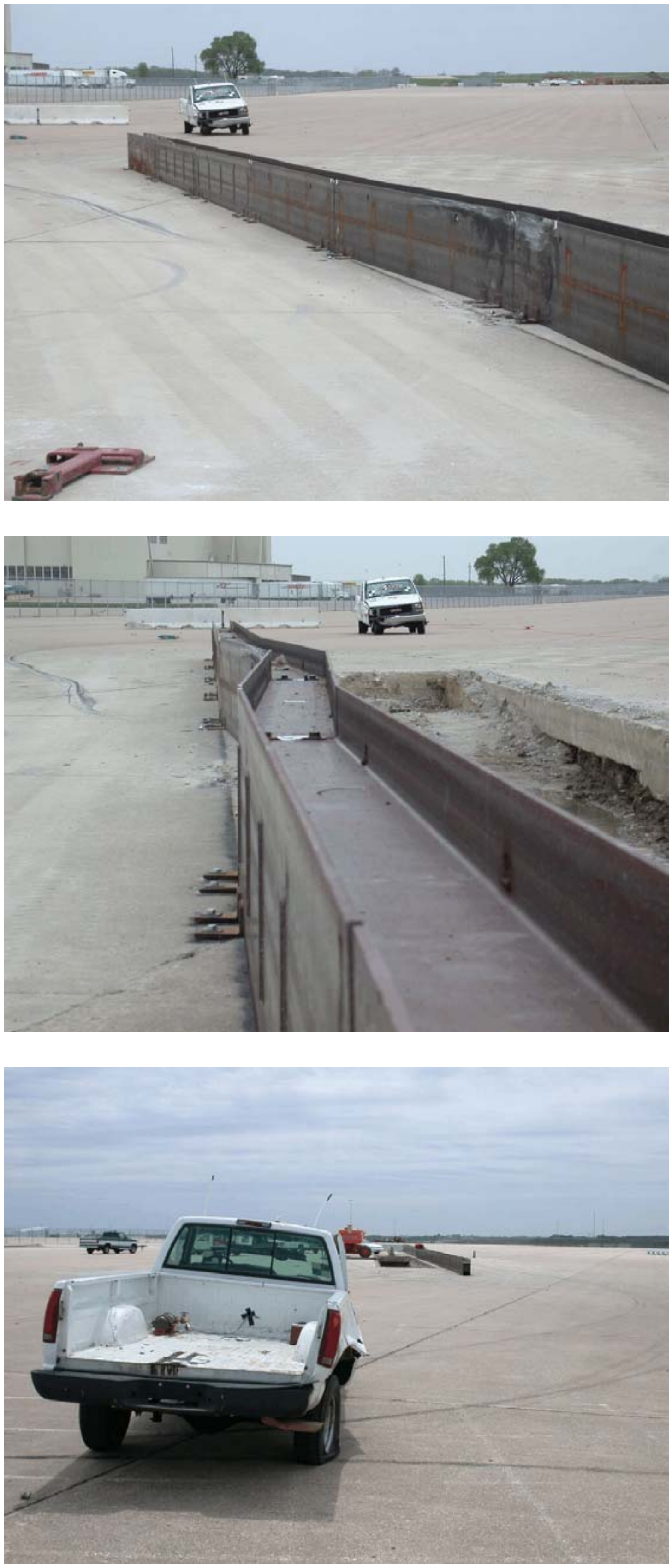


Figure 49. Vehicle Final Position and Trajectory Marks, Test HTB-2

Figure 50. Steel H-section Barrier System Damage, Test HTB-2

Figure 51. Steel H-section Barrier System Damage, Test HTB-2

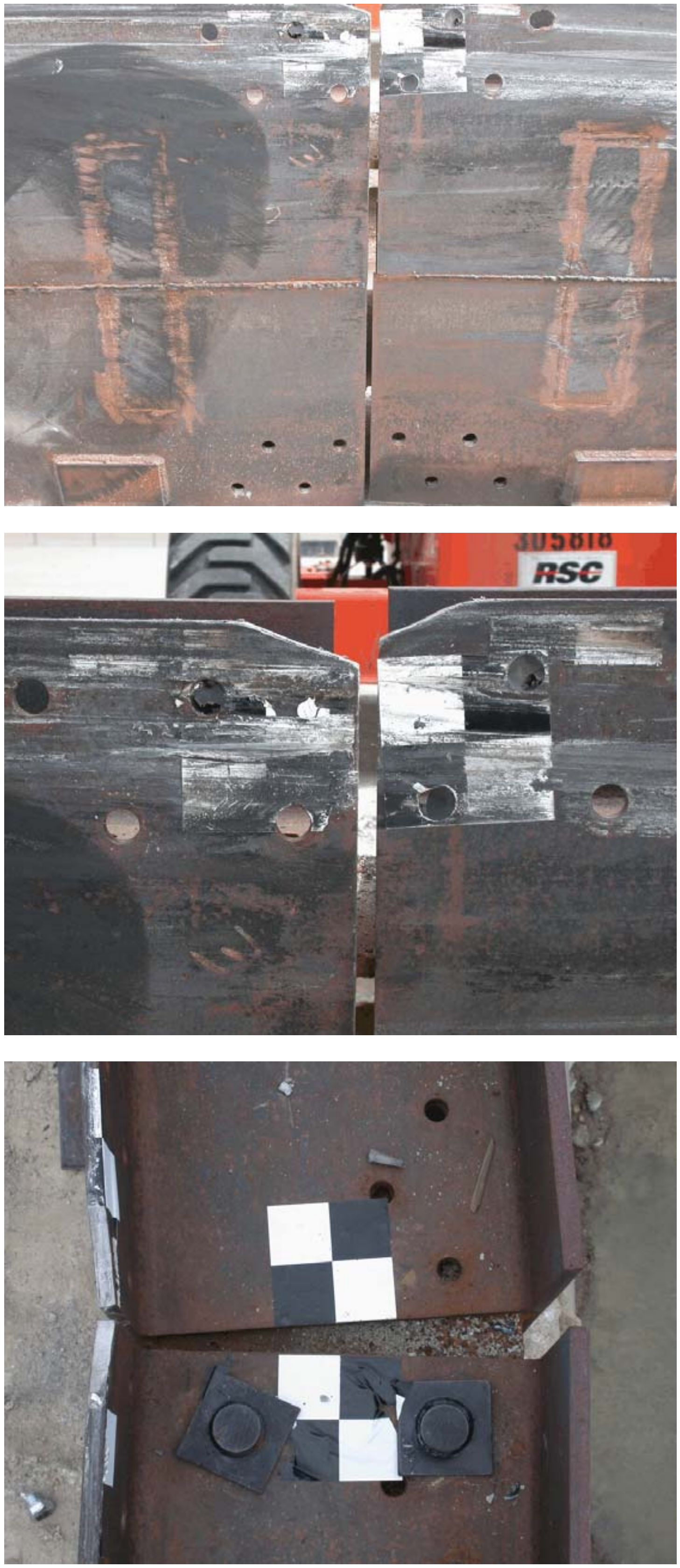


Figure 52. Splice Rotation and Damage, Test HTB-2

Figure 53. Tie-Down Anchor Damage, Test HTB-2

Figure 54. Tie-Down Anchor Damage, Test HTB-2

Figure 55. Vehicle Damage, Test HTB-2

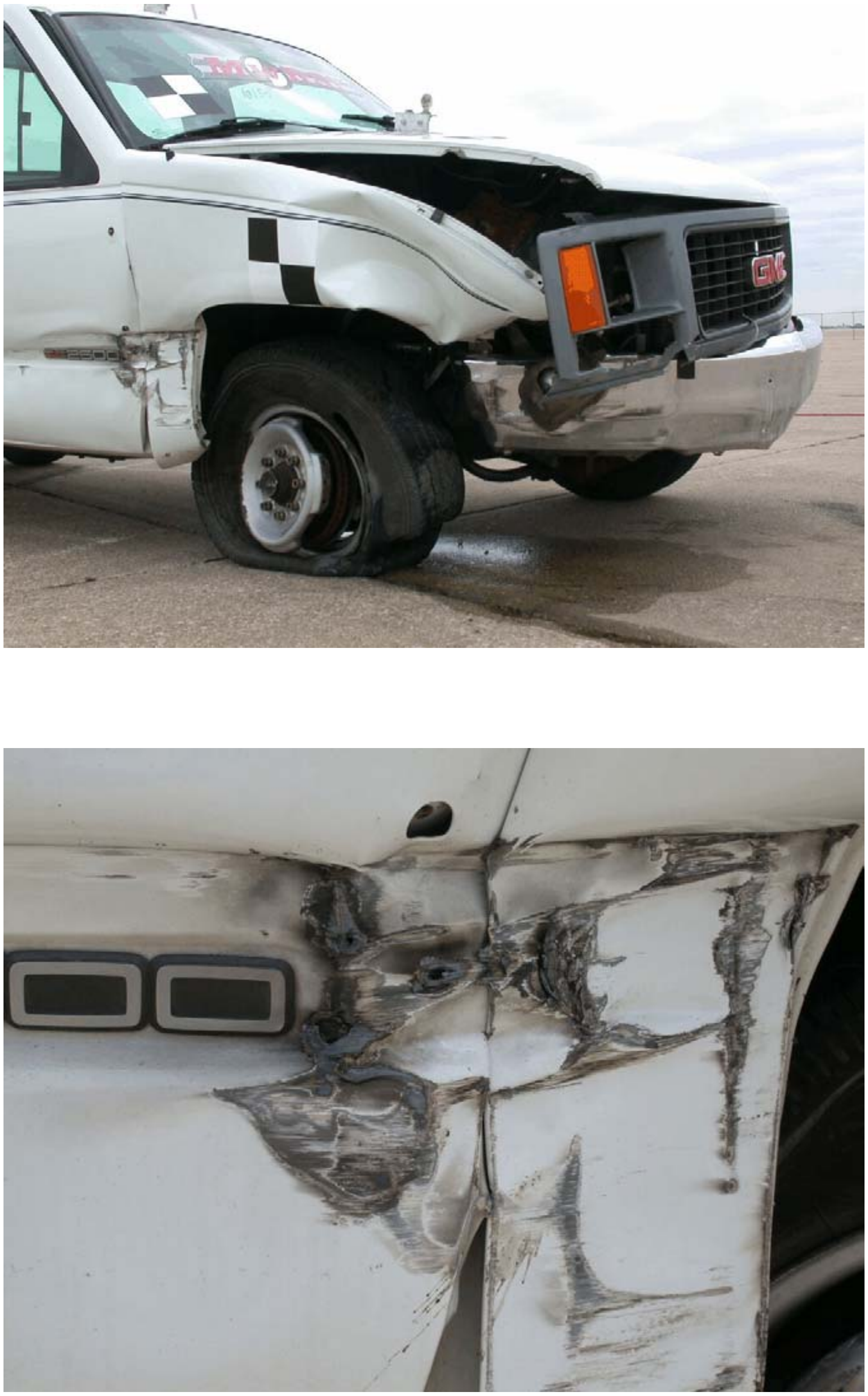


Figure 56. Vehicle Damage, Test HTB-2

Right-Front

Right-Rear

Figure 57. Rim and Tire Damage, Test HTB-2

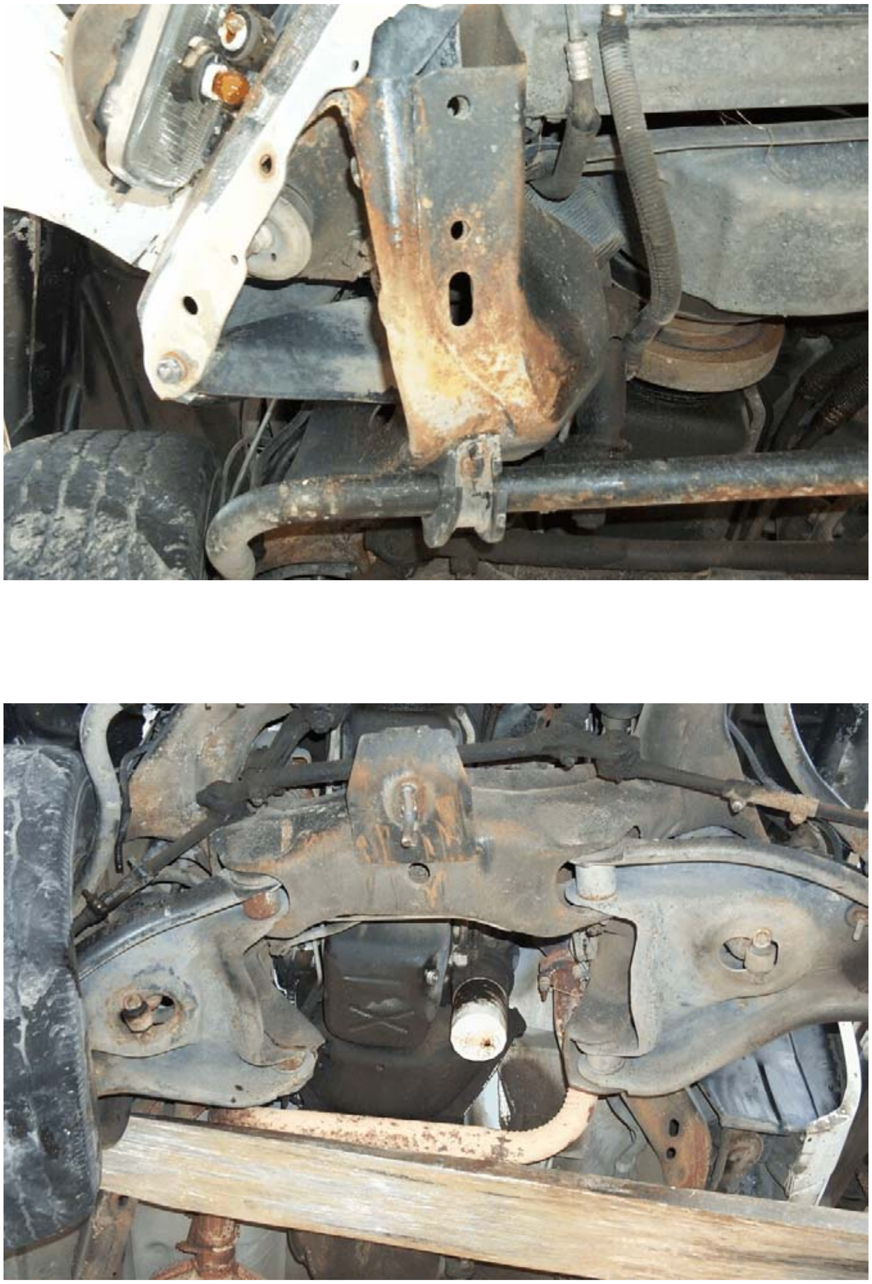


Figure 58. Undercarriage Vehicle Damage, Test HTB-2

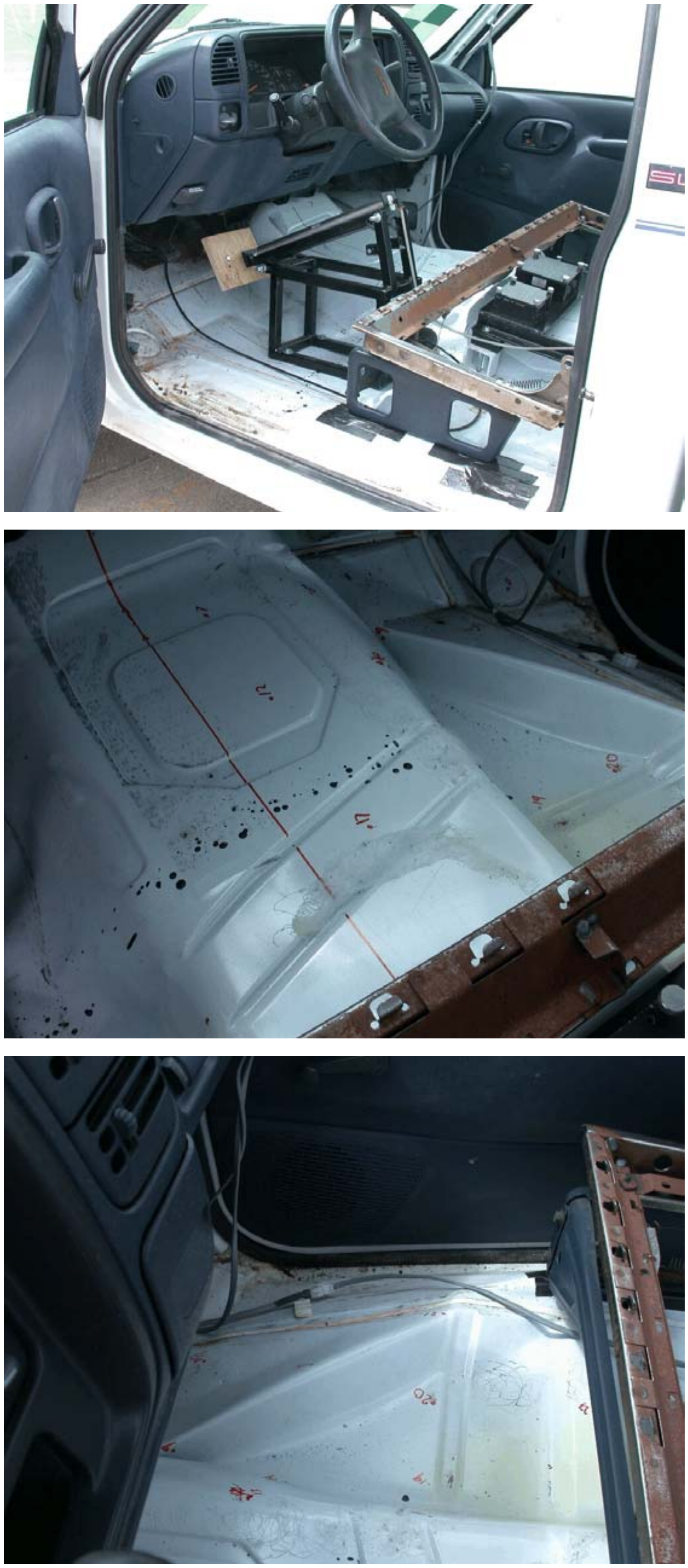


Figure 59. Occupant Compartment Deformations, Test HTB-2

9 SUMMARY AND CONCLUSIONS

A tie-down system for use with the steel H-section temporary barriers was developed and full-scale vehicle crash tested. The full-scale vehicle crash tests were performed according to the TL-3 criteria found in NCHRP Report No. 350. The tie-down system was designed to reduce barrier deflections from those observed during testing of comparable freestanding systems and to safely constrain deflected barriers installed in limited deflection applications on concrete bridge decks.

The new system provided a redesigned barrier connection detail that is simpler to construct and one which allowed for greater accommodation of its use along horizontal and vertical discontinuities. In addition, a simple tie-down detail was provided with the use of steel angle brackets welded to the barrier's base that formed a rigid attachment to the concrete using drop-in anchors. The initial test of the redesigned barrier, test no. HTB-1, was performed with a ¾-ton pickup truck. During vehicle redirection, the pickup truck rolled over, and the test was determined to be unacceptable according to the TL-3 safety performance criteria presented in NCHRP Report No. 350. The vehicle's instability was attributed to vehicle snag on the barriers.

Based on knowledge gained from test HTB-1 and to reduce vehicle snag, the system was modified. First, the grade of the bolts used with the drop-in anchors was changed in order to allow slightly higher deflections. Second, the 12.7-mm thick vertical steel straps were replaced with a longitudinal seam weld. A second test, test no. HTB-2, was performed on the modified system with a ¾-ton pickup truck and was determined to be acceptable according to the TL-3 safety performance criteria presented in NCHRP Report No. 350. The barrier safely redirected the pickup truck with minimal barrier deflections. A summary of the safety performance evaluation is provided in Table 3.

Table 3. Summary of Safety Performance Evaluation Results

Evaluation Factors	Evaluation Criteria	Test HTB-1	Test HTB-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.	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
	F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	U	S
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	S	S
	L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec, and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G'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	S

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

10 RECOMMENDATIONS

A tie-down system for rigidly attaching steel H-section temporary barriers to a concrete bridge deck was developed and successfully crash tested according to the criteria found in NCHRP Report No. 350 and is believed to be a suitable design for use on Federal-aid highways. The barrier system consisted of steel H-section temporary barriers with steel angle brackets welded to the barrier's base that formed a rigid attachment to the concrete using drop-in anchors with ASTM A307 grade bolts.

The tie-down system for steel H-section temporary barriers was tested with a clear gap of 330 mm between the backside of the barriers and the bridge deck edge. As observed in test no. HTB-2, no portion of the barrier segments were deflected off of the bridge deck. It should be noted that the maximum barrier deflections occurred at the downstream end of barrier no. 5 and the upstream end of barrier no. 6. However, it should be noted that the upstream end of barrier no. 5 and the downstream end of barrier no. 6 remained attached to the bridge deck. Along with this, the centers of barrier nos. 5 and 6 deflected a maximum of 149 mm and 135 mm, respectively. As such, it is believed that the 330-mm gap located behind the barrier could be slightly reduced and still allow for the safe redirection of impacting vehicles while constraining the deflected barriers to the bridge. Analysis of the test results, combined with additional engineering calculation,s suggest that the gap between the backside of the barriers and the bridge deck edge may be reduced to 150 mm and still provide acceptable performance. Therefore, it is recommended that the tie-down system for use with steel H-section temporary barriers can be safely installed with a 150-mm gap between the bridge deck edge and the backside of the barriers.

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12 APPENDICES

APPENDIX A

Occupant Compartment Deformation Data, Test HTB-1

Figure A-1. Occupant Compartment Deformation Data, Test HTB-1

VEHICLE PRE/POST CRUSH INFO

TEST: HTB-1
VEHICLE: 1995/CHEVY/2500/WHITE

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	53	1	-0.75	52	1	-5.25	-1	0	-4.5
2	53.5	5.75	-1	52.25	5.5	-7	-1.25	-0.25	-6
3	56.5	11.25	1	55.75	8.25	-2.25	-0.75	-3	-3.25
4	58.25	18	2.25	57.5	13.75	-0.5	-0.75	-4.25	-2.75
5	58.75	23	1.25	57.5	18.75	-0.5	-1.25	-4.25	-1.75
6	57.25	27.75	1.5	55.25	23.5	1	-2	-4.25	-0.5
7	46.25	2.5	1.5	44.5	2.25	-2.25	-1.75	-0.25	-3.75
8	46.5	6.75	1.75	45	6.75	-3	-1.5	0	-4.75
9	49.75	9.5	4.5	48.25	8.5	-0.75	-1.5	-1	-5.25
10	53.5	15	6	51.5	11.25	3.25	-2	-3.75	-2.75
11	53.5	19.75	6	51.5	15.25	4.25	-2	-4.5	-1.75
12	53.5	25	5.75	51	20.5	4.5	-2.5	-4.5	-1.25
13	42.5	2.25	1.75	41	2	-2	-1.5	-0.25	-3.75
14	43.25	8.5	3.25	41.75	8.75	-1.75	-1.5	0.25	-5
15	46.25	12.25	7.25	44.5	11	1.5	-1.75	-1.25	-5.75
16	47	23.25	7.5	45.75	18	5.25	-1.25	-5.25	-2.25
17	45.5	27	7.5	46	23.25	8	0.5	-3.75	0.5
18	38.5	3.75	2.25	36.75	4	-1.5	-1.75	0.25	-3.75
19	39	9	4.75	37.75	9	0	-1.25	0	-4.75
20	40.5	15.75	7.25	39.25	15.25	0.5	-1.25	-0.5	-6.75
21	40.75	26	7.5	40.5	23.5	6.5	-0.25	-2.5	-1
22	35.25	3.5	2.25	33.75	3.25	-0.5	-1.5	-0.25	-2.75
23	35.25	9	4.5	33.5	8.5	0.75	-1.75	-0.5	-3.75
24	35.75	20.25	6.75	35	20.25	1.75	-0.75	0	-5
25	31	15	6.75	30.5	14.75	2.75	-0.5	-0.25	-4
26	29	32.5	0.5	27.25	31.5	4	-1.75	-1	3.5
27	42.75	4.5	-25	44.75	4.25	-26	2	-0.25	-1
28	50.25	12.25	-22.25	51.5	12.25	-22.25	1.25	0	0
29	47.25	27.75	-20.75	47	28.5	-21.5	-0.25	0.75	-0.75
30									

ORIENTATION AND REFERENCE INFO

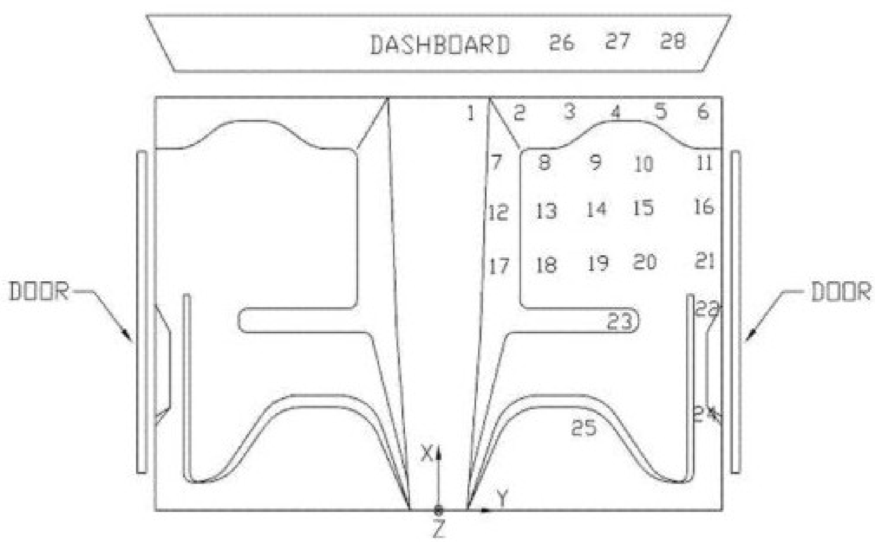

Figure A-1. Occupant Compartment Deformation Data, Test HTB-1

APPENDIX B

Accelerometer Data Analysis, Test HTB-1

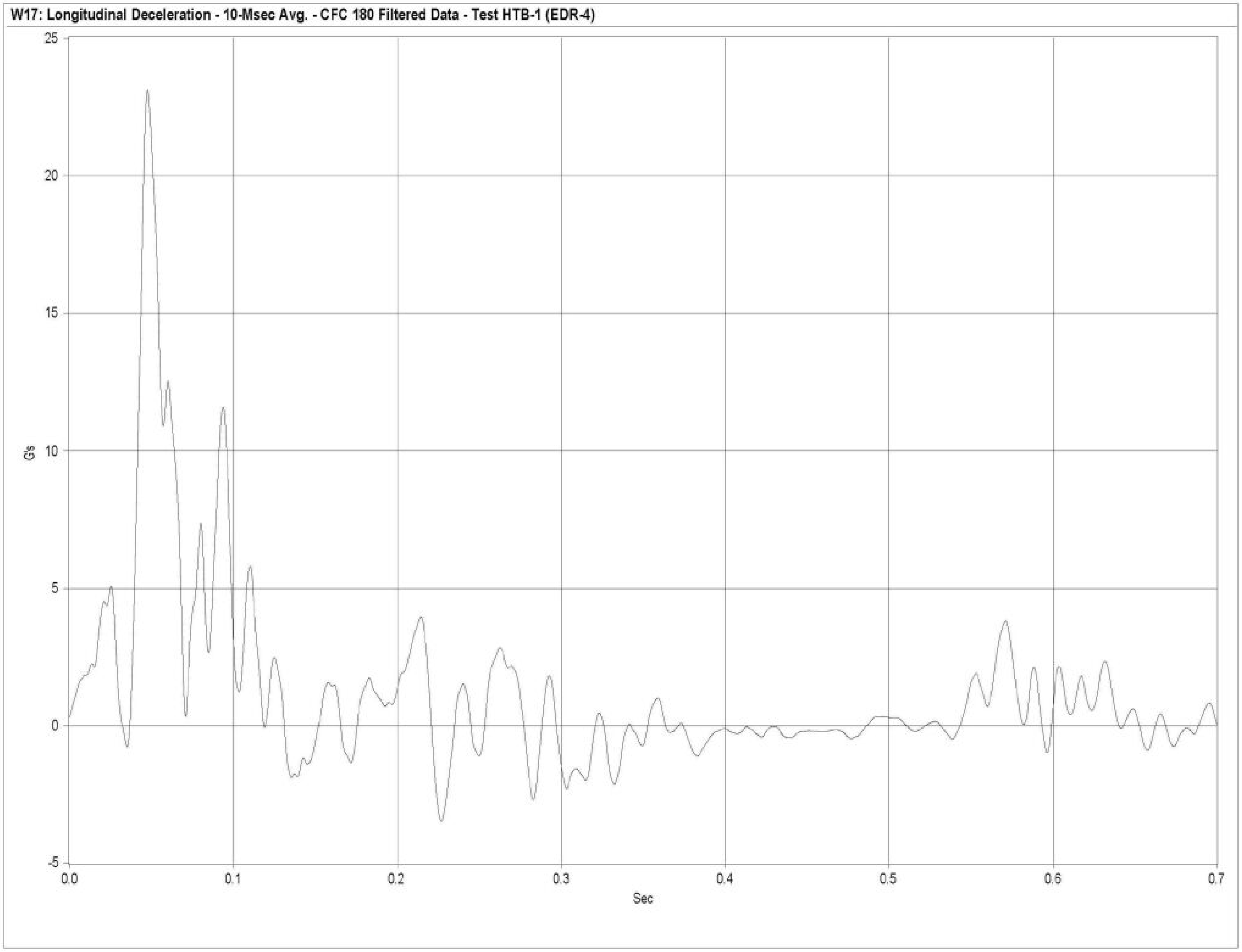

Figure B-1. Graph of Longitudinal Deceleration Test HTB-1

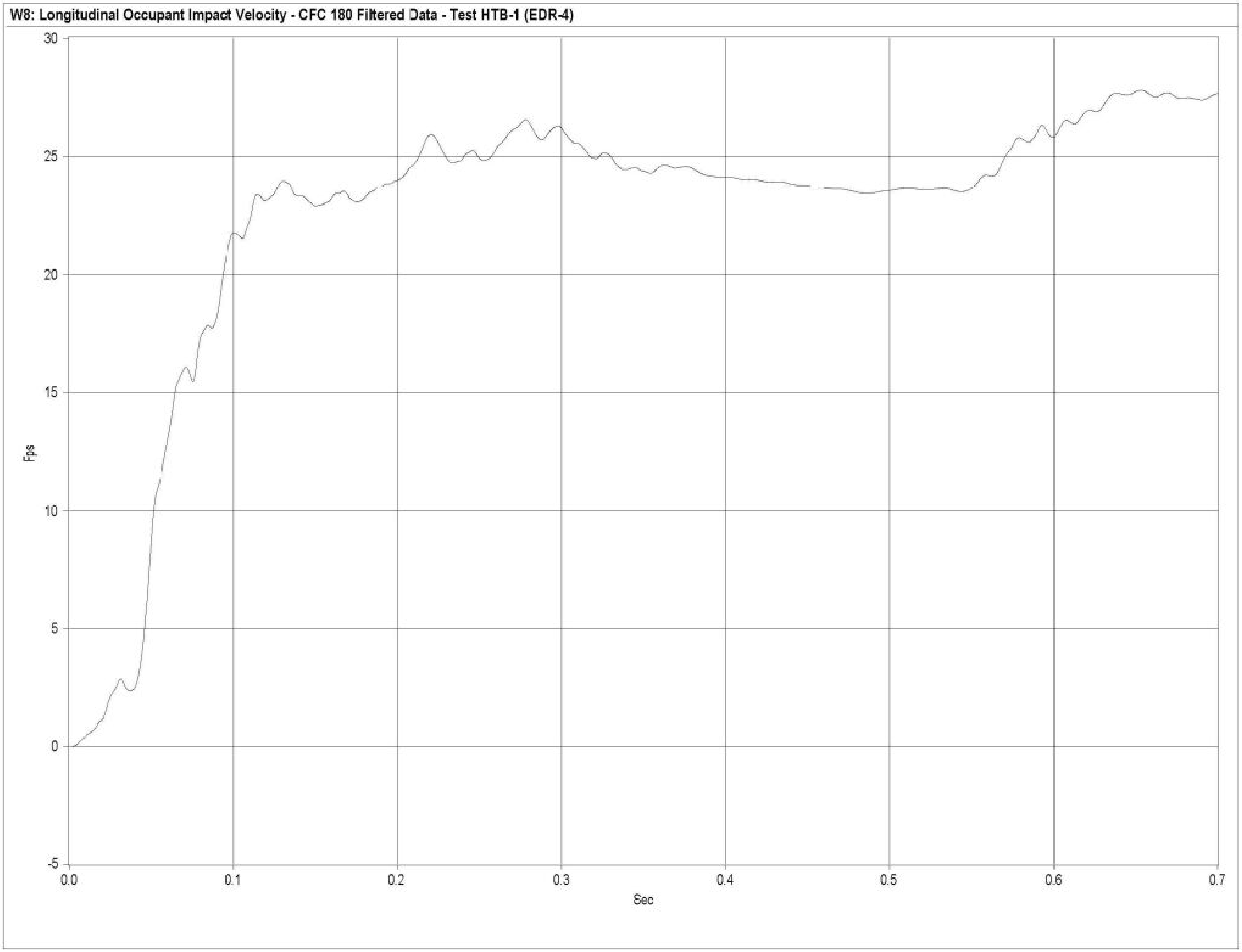

Figure B-2. Graph of Longitudinal Occupant Impact Velocity, Test HTB-1

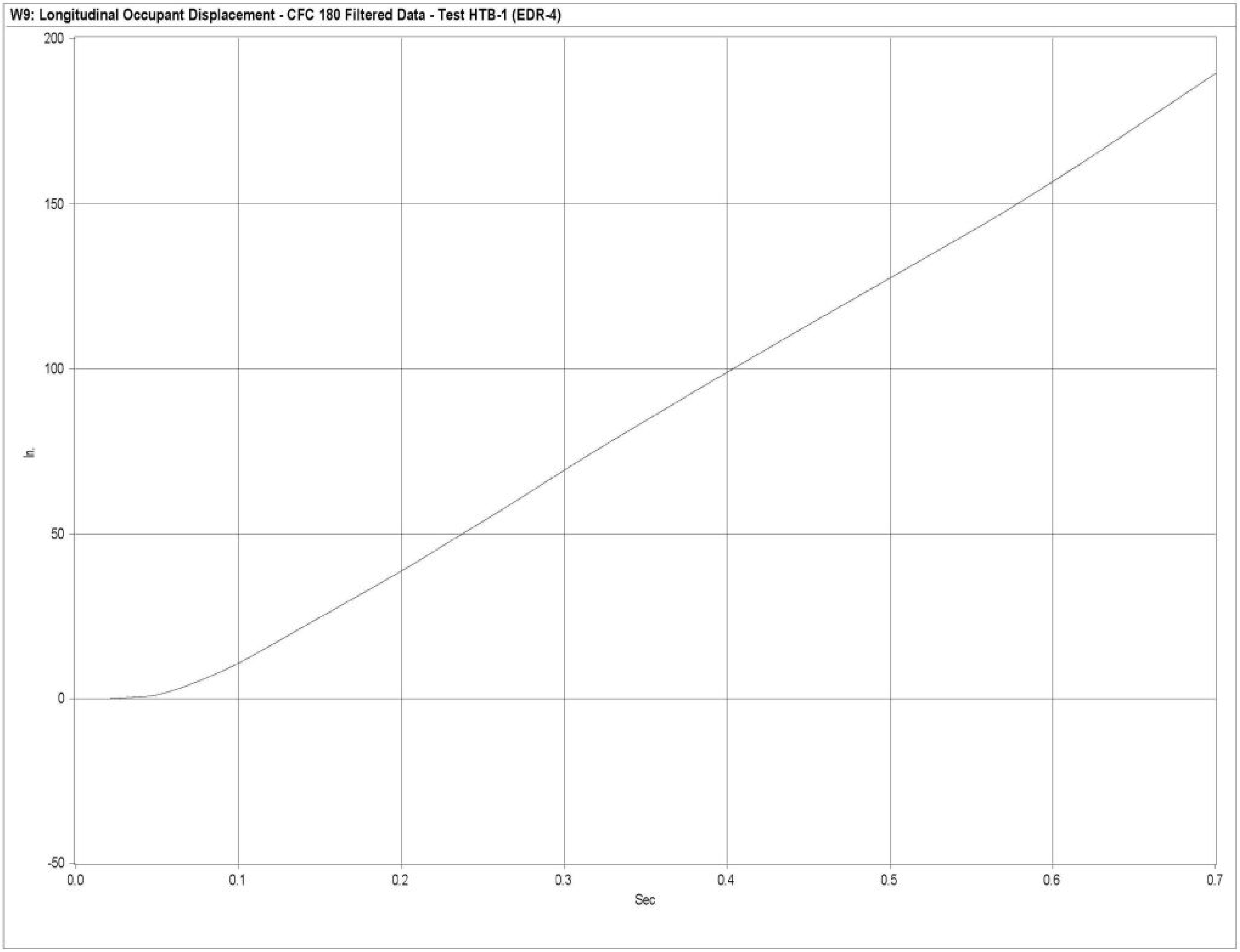

Figure B-3. Graph of Longitudinal Occupant Displacement, Test HTB-1

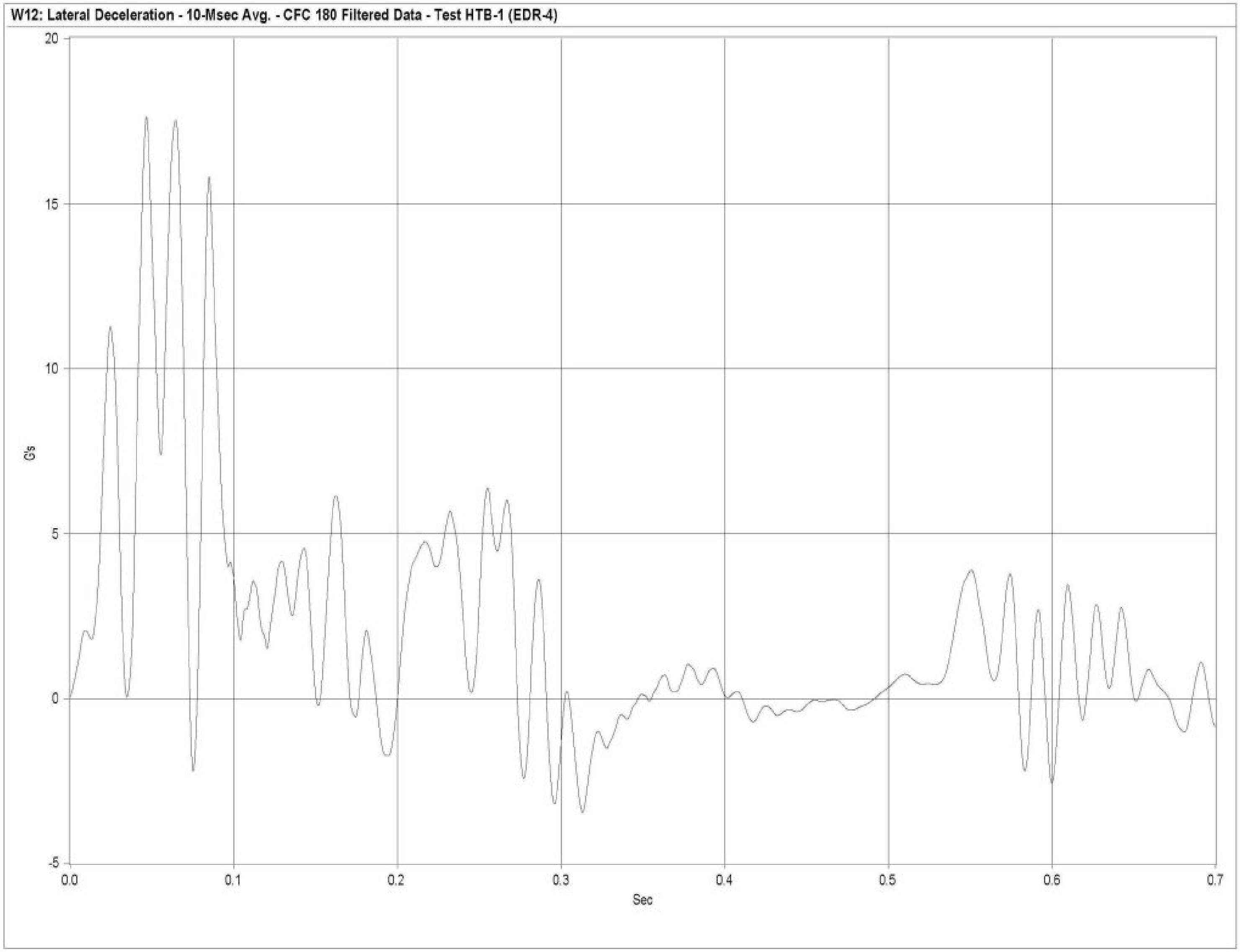

Figure B-4. Graph of Lateral Deceleration, Test HTB-1

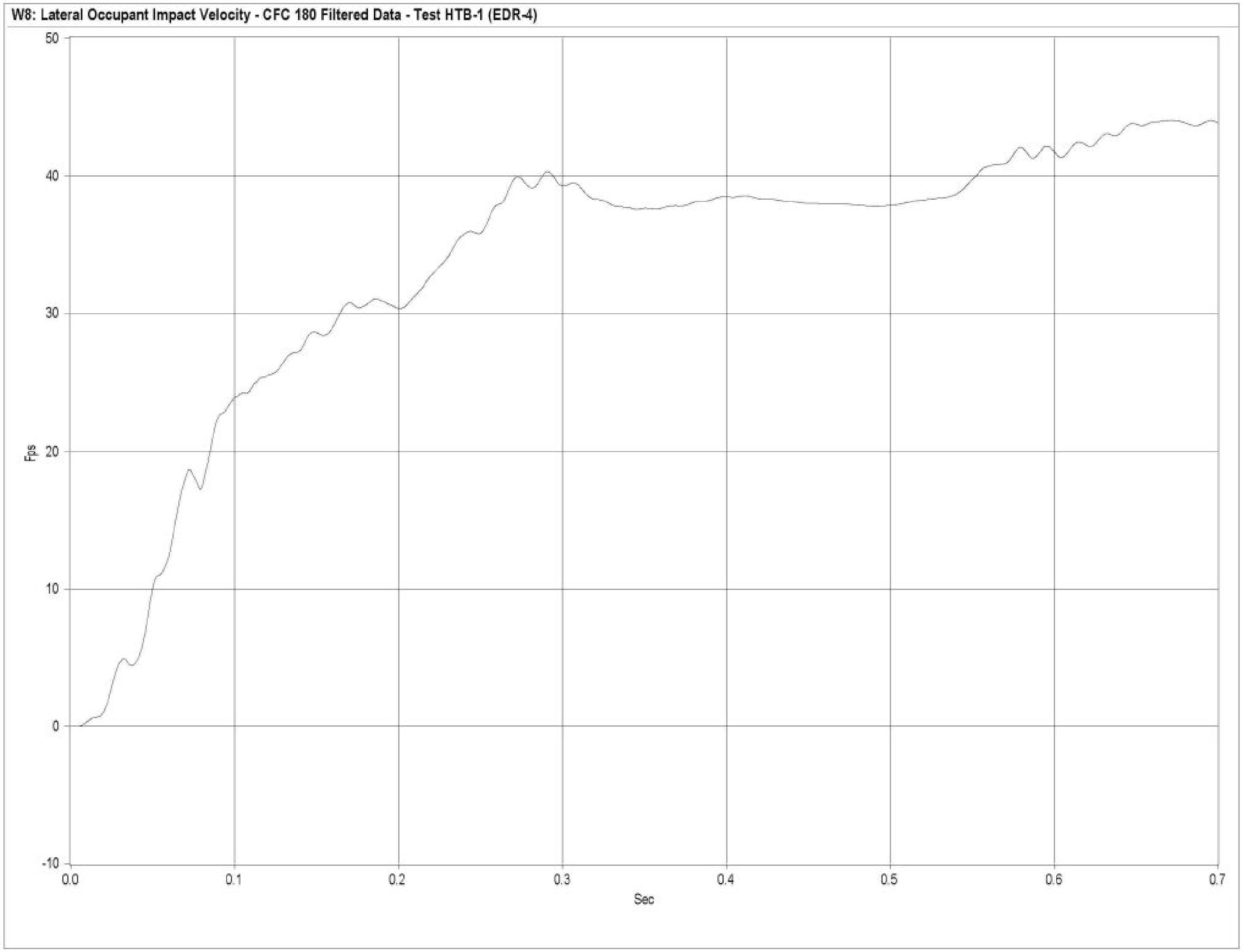

Figure B-5. Graph of Lateral Occupant Impact Velocity, Test HTB-1

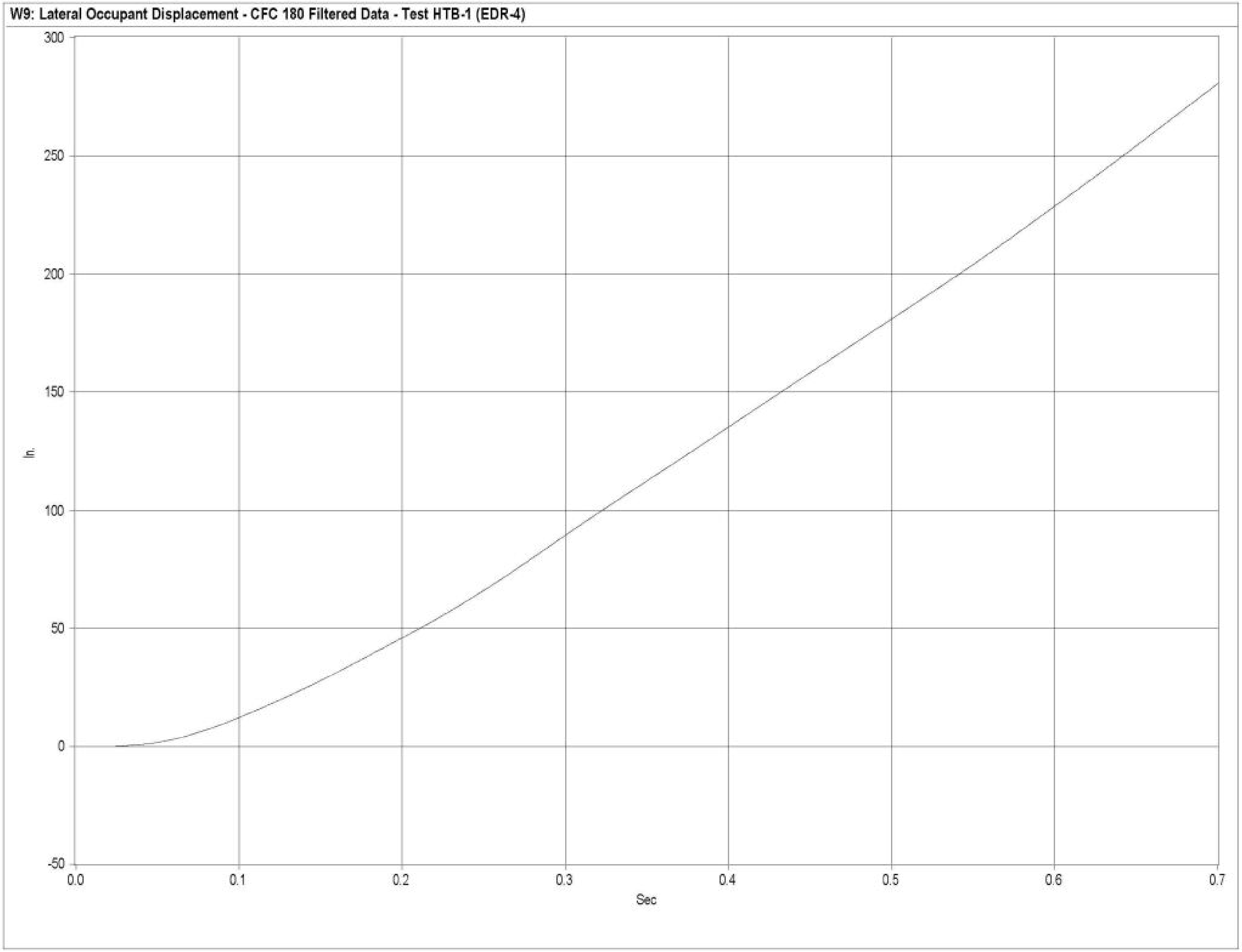

Figure B-6. Graph of Lateral Occupant Displacement, Test HTB-1

APPENDIX C

Rate Transducer Data Analysis, Test HTB-1

Figure C-1. Graph of Roll, Pitch, and Yaw Angular Displacements, Test HTB-1

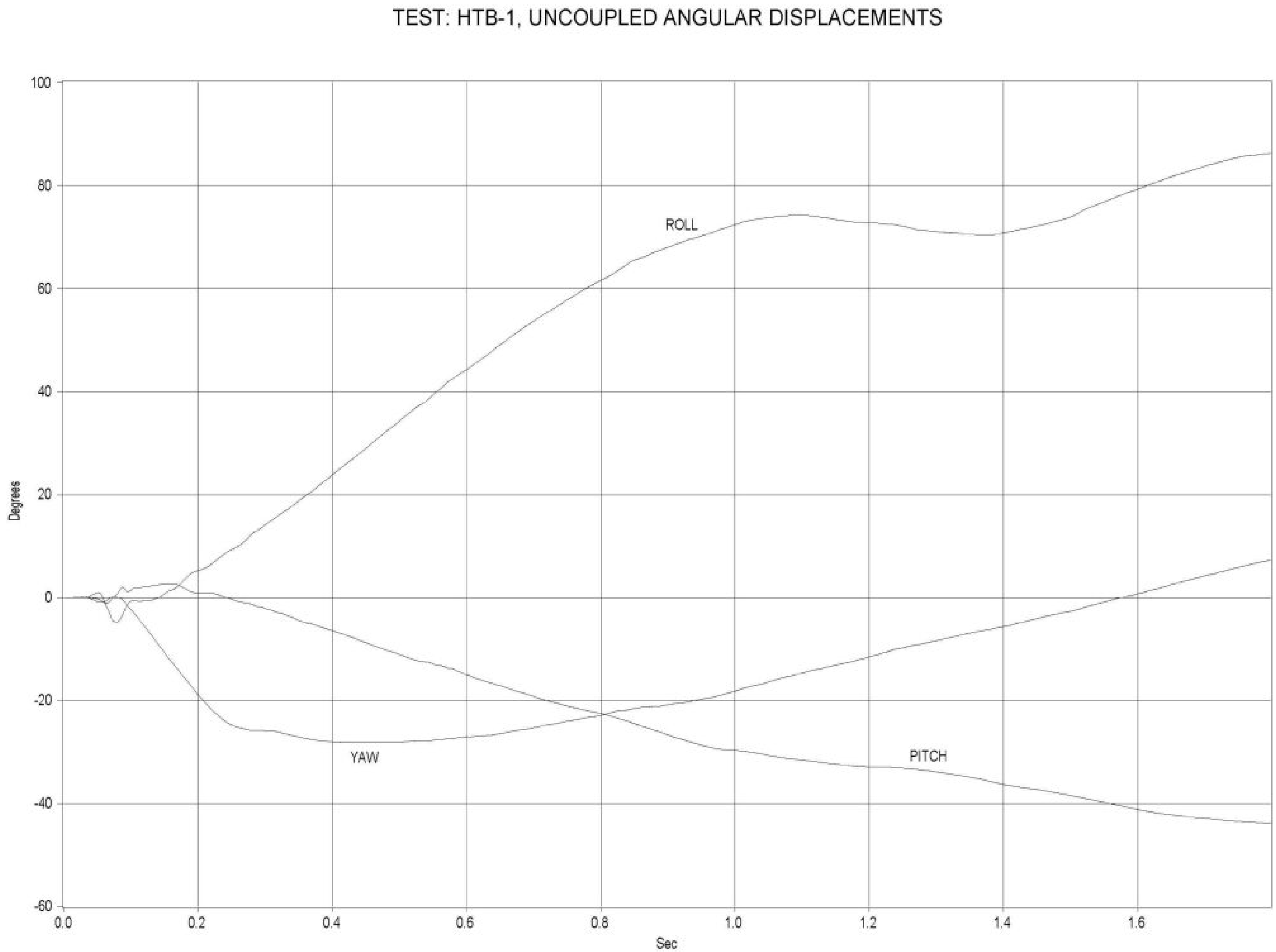

Figure C-1. Graph of Roll, Pitch, and Yaw Angular Displacements, Test HTB-1

APPENDIX D

Occupant Compartment Deformation Data, Test HTB-2

Figure D-1. Occupant Compartment Deformation Data, Test HTB-2

VEHICLE PRE/POST CRUSH INFO

TEST: HTB-2
VEHICLE: 1995/GMC/2500/WHITE

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	53.25	3.125	-2.25	52.75	3.125	-5.25	-0.5	0	-3
2	53.25	7.75	-1.25	52.75	7.875	-5	-0.5	0.125	-3.75
3	56.5	12.5	0.375	57	11.25	-2.25	0.5	-1.25	-2.625
4	56.75	19.25	2.5	56.75	16.75	0	0	-2.5	-2.5
5	58.5	26.75	-8	57.75	24.25	-3.25	-0.75	-2.5	4.75
6	57.5	30	0	57.5	28	-2	0	-2	-2
7	48.5	3	0.5	48	3	-3.25	-0.5	0	-3.75
8	47.75	8	1.125	47.5	7.875	-3	-0.25	-0.125	-4.125
9	47.5	12.75	6.375	46.5	11.5	1	-1	-1.25	-5.375
10	47.75	20.25	6.375	47	18.75	2.75	-0.75	-1.5	-3.625
11	51	26.75	6	51.75	25	4	0.75	-1.75	-2
12	42.25	2.75	0.75	41.75	2.75	-2.5	-0.5	0	-3.25
13	42.25	7.75	1.5	42	8	-2.25	-0.25	0.25	-3.75
14	41.5	10.75	5.75	41.5	11.125	2.25	0	0.375	-3.5
15	41.25	17.5	6.5	40.75	17	0.75	-0.5	-0.5	-5.75
16	40.625	27	6.75	40.25	25.125	4.75	-0.375	-1.875	-2
17	34.875	2.5	1.5	34.375	2.5	-1.75	-0.5	0	-3.25
18	34.5	8.25	2.375	34.5	8	-1	0	-0.25	-3.375
19	35	11.25	6	34.5	11.5	2.875	-0.5	0.25	-3.125
20	35	16	6	34.5	16.375	3.125	-0.5	0.375	-2.875
21	34.75	21.25	6	34	21	1.5	-0.75	-0.25	-4.5
22	27	3	1.75	27.75	3	-0.75	0.75	0	-2.5
23	26.5	15.75	5.5	26.375	16.125	3	-0.125	0.375	-2.5
24	20	30.25	7.75	19.5	29.5	7.25	-0.5	-0.75	-0.5
25	10.125	16.25	2	10.125	16.25	1.25	0	0	-0.75
26	43.25	-3.5	-25.625	43.25	-3.25	-27.75	0	0.25	-2.125
27	49.5	9.25	-21.375	49.75	9.25	-23.5	0.25	0	-2.125
28	49.75	23	-22	49.75	23	-23.5	0	0	-1.5
29									
30									

ORIENTATION AND REFERENCE INFO

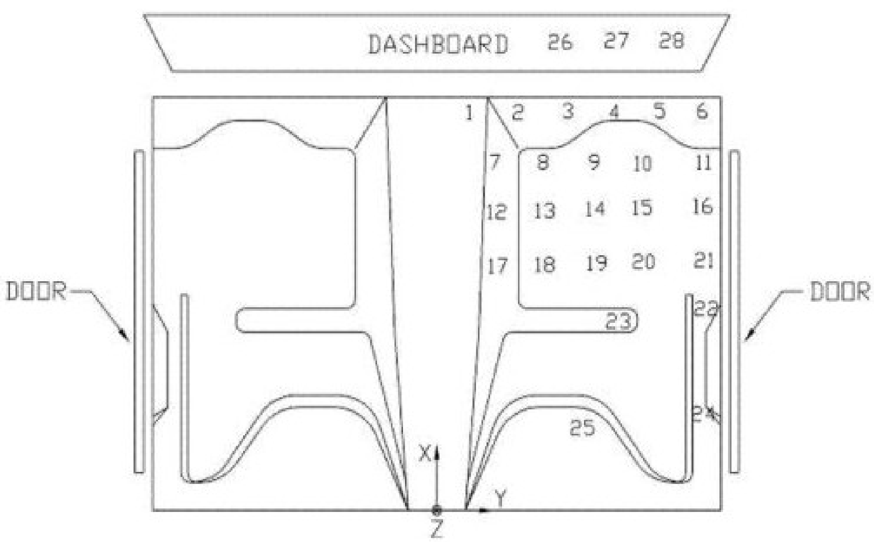

Figure D-1. Occupant Compartment Deformation Data, Test HTB-2

APPENDIX E

Accelerometer Data Analysis, Test HTB-2

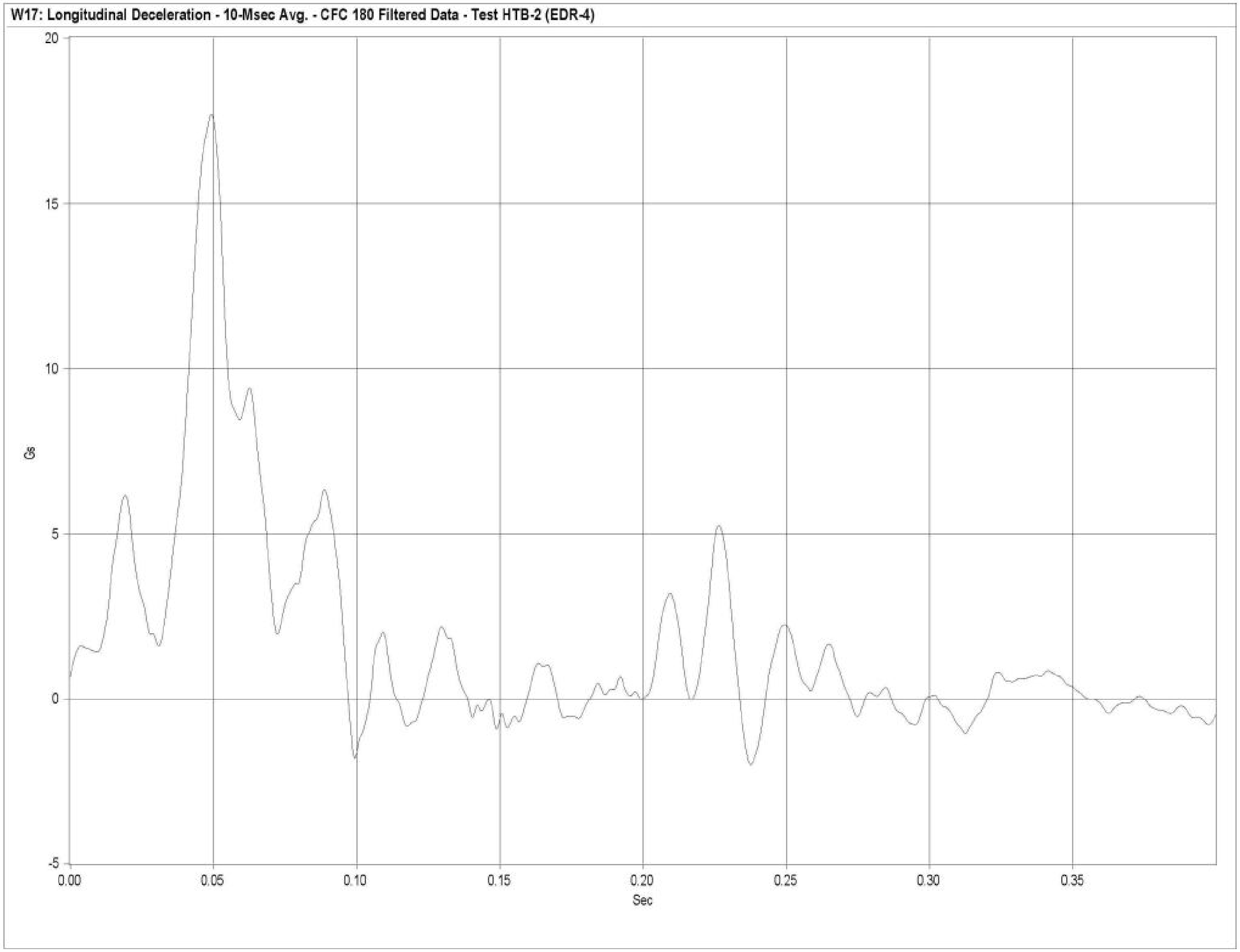

Figure E-1. Graph of Longitudinal Deceleration, Test HTB-2

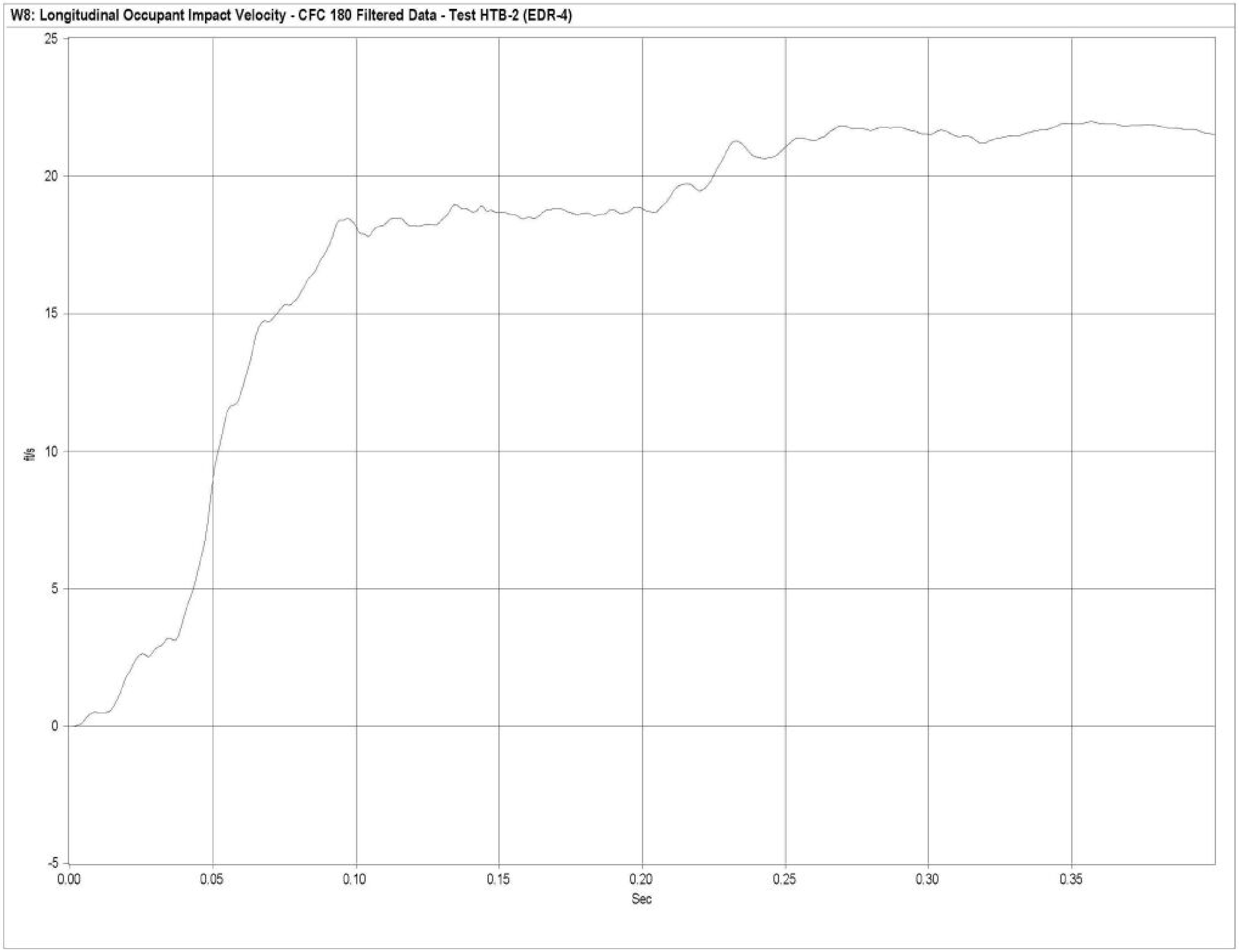

Figure E-2. Graph of Longitudinal Occupant Impact Velocity, Test HTB-2

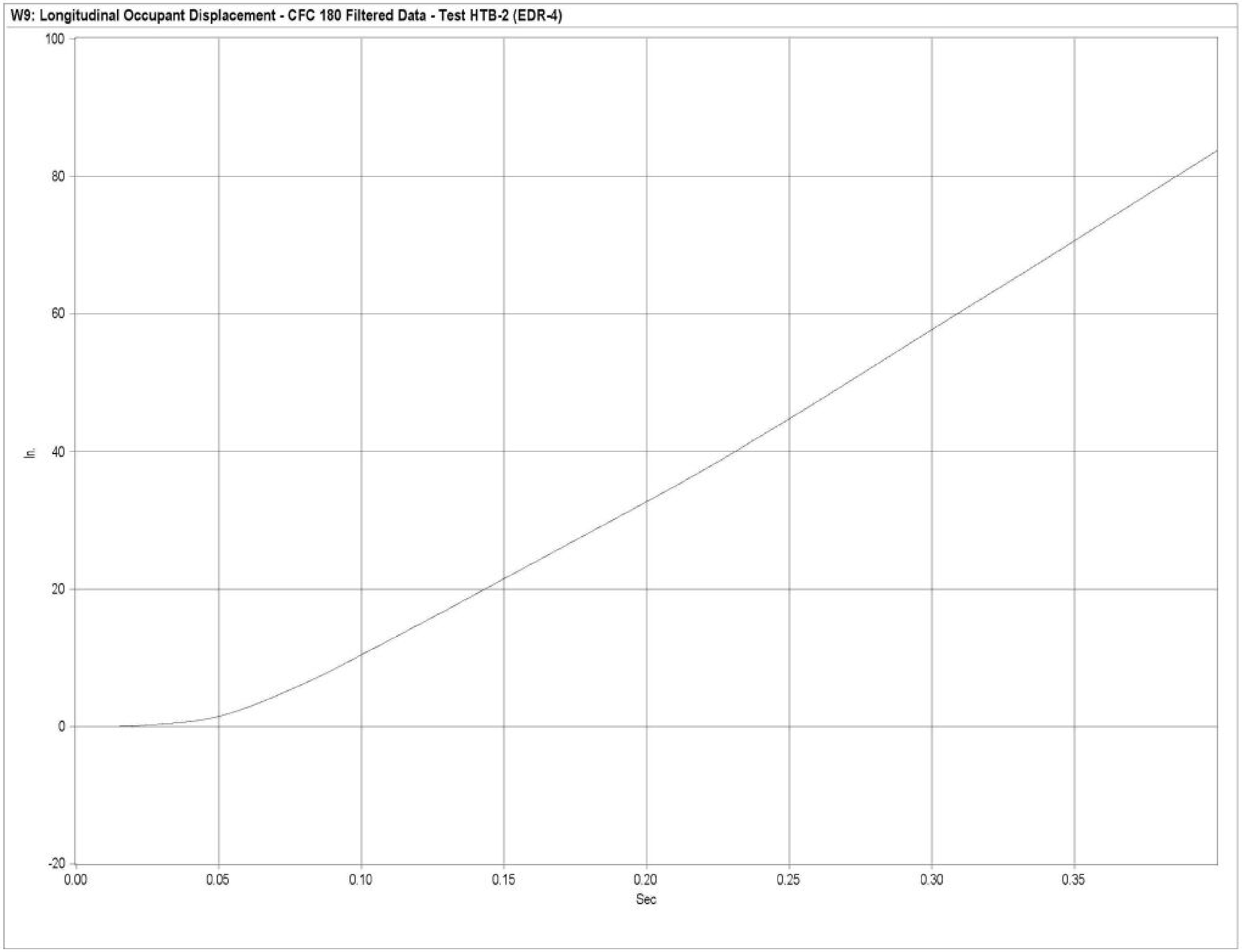

Figure E-3. Graph of Longitudinal Occupant Displacement, Test HTB-2

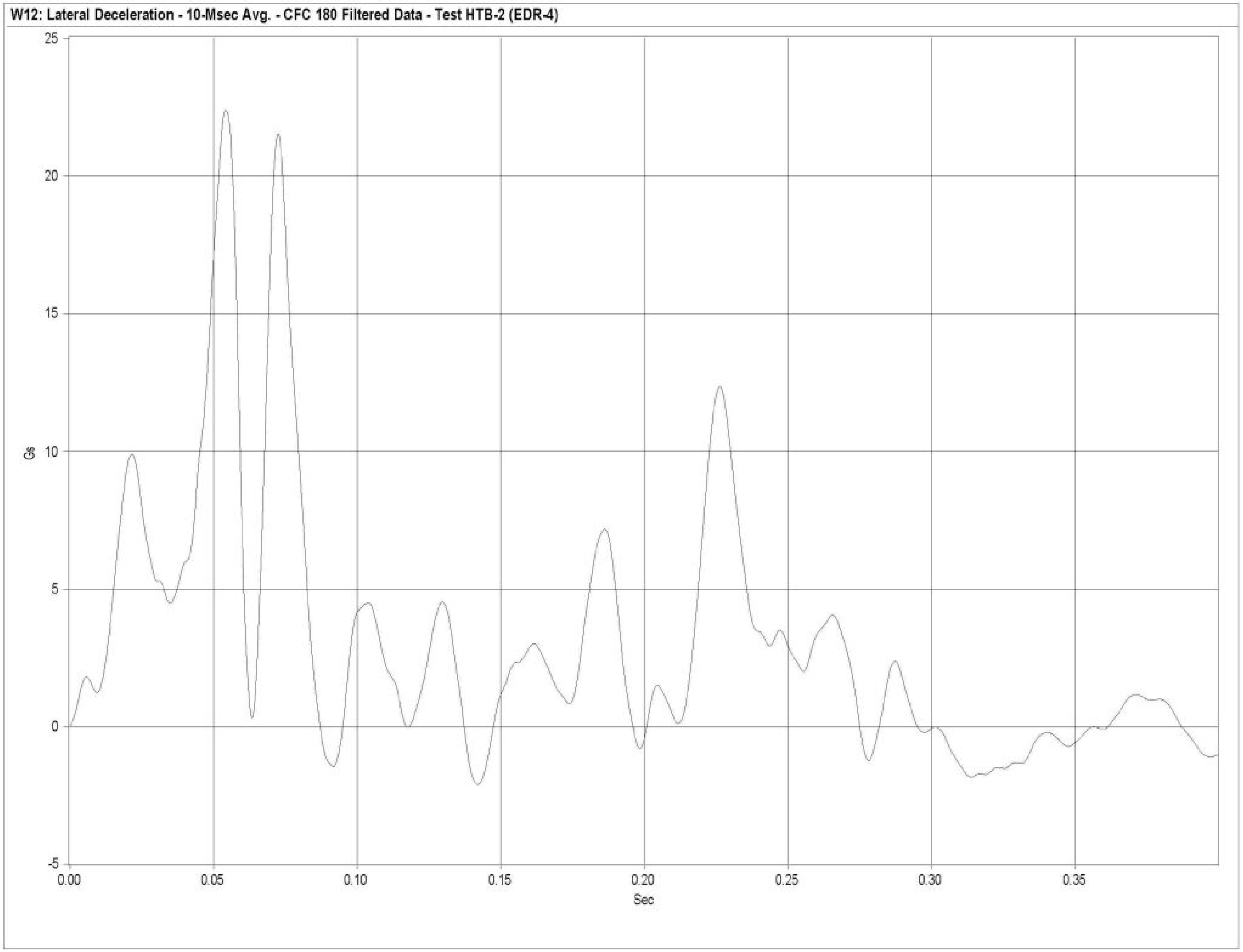

Figure E-4. Graph of Lateral Deceleration, Test HTB-2

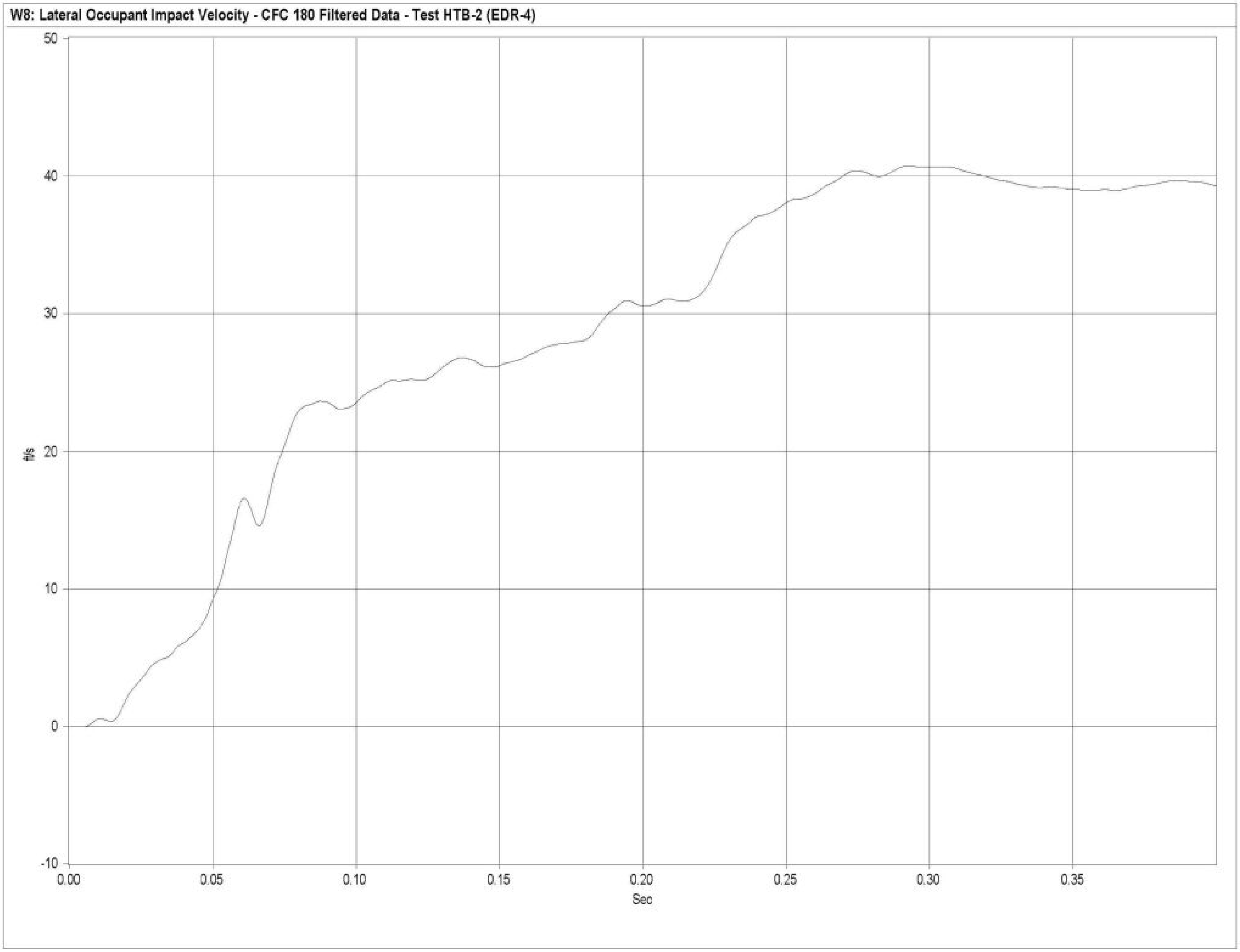

Figure E-5. Graph of Lateral Occupant Impact Velocity, Test HTB-2

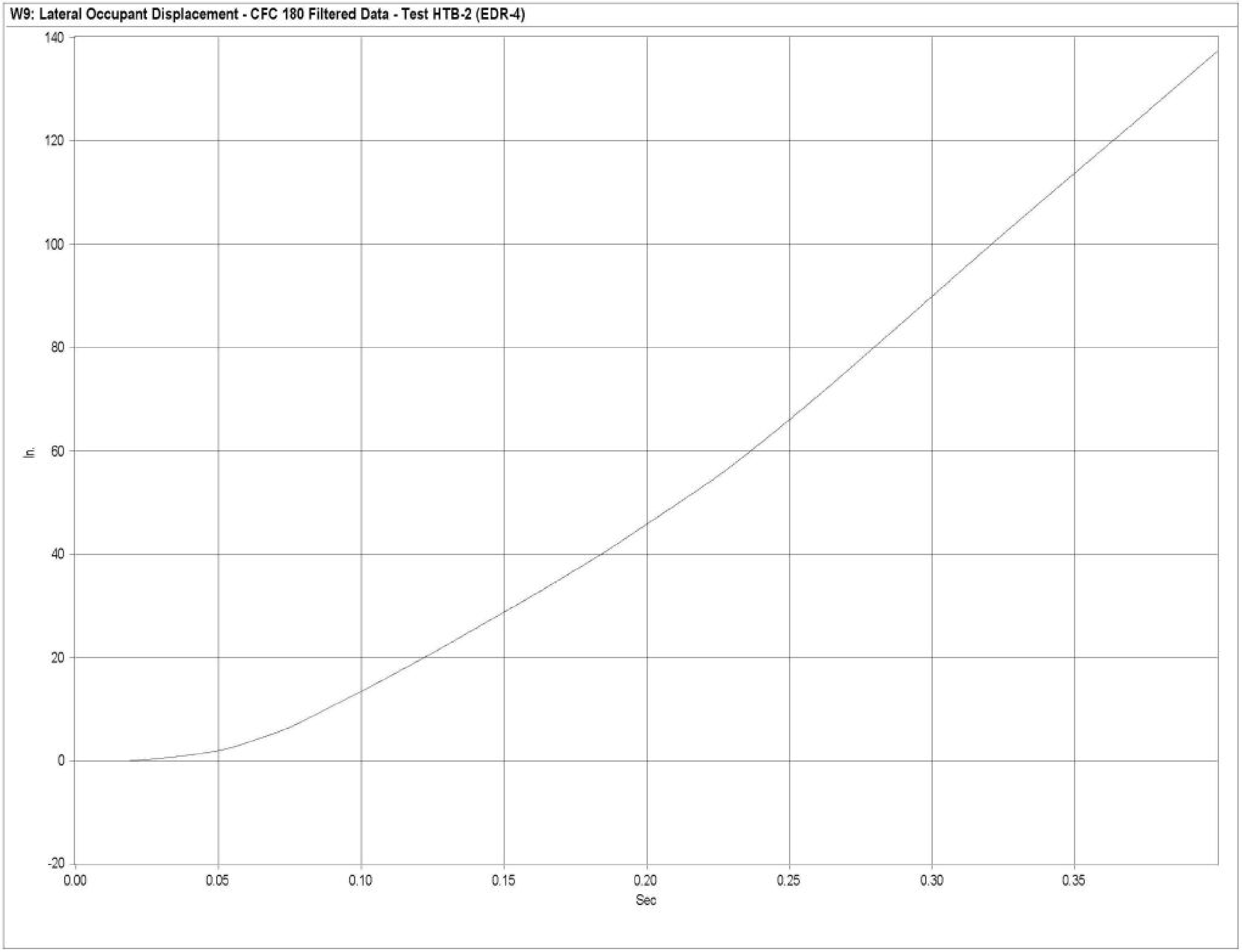

Figure E-6. Graph of Lateral Occupant Displacement, Test HTB-2

APPENDIX F

Roll and Yaw Data Analysis, Test HTB-2

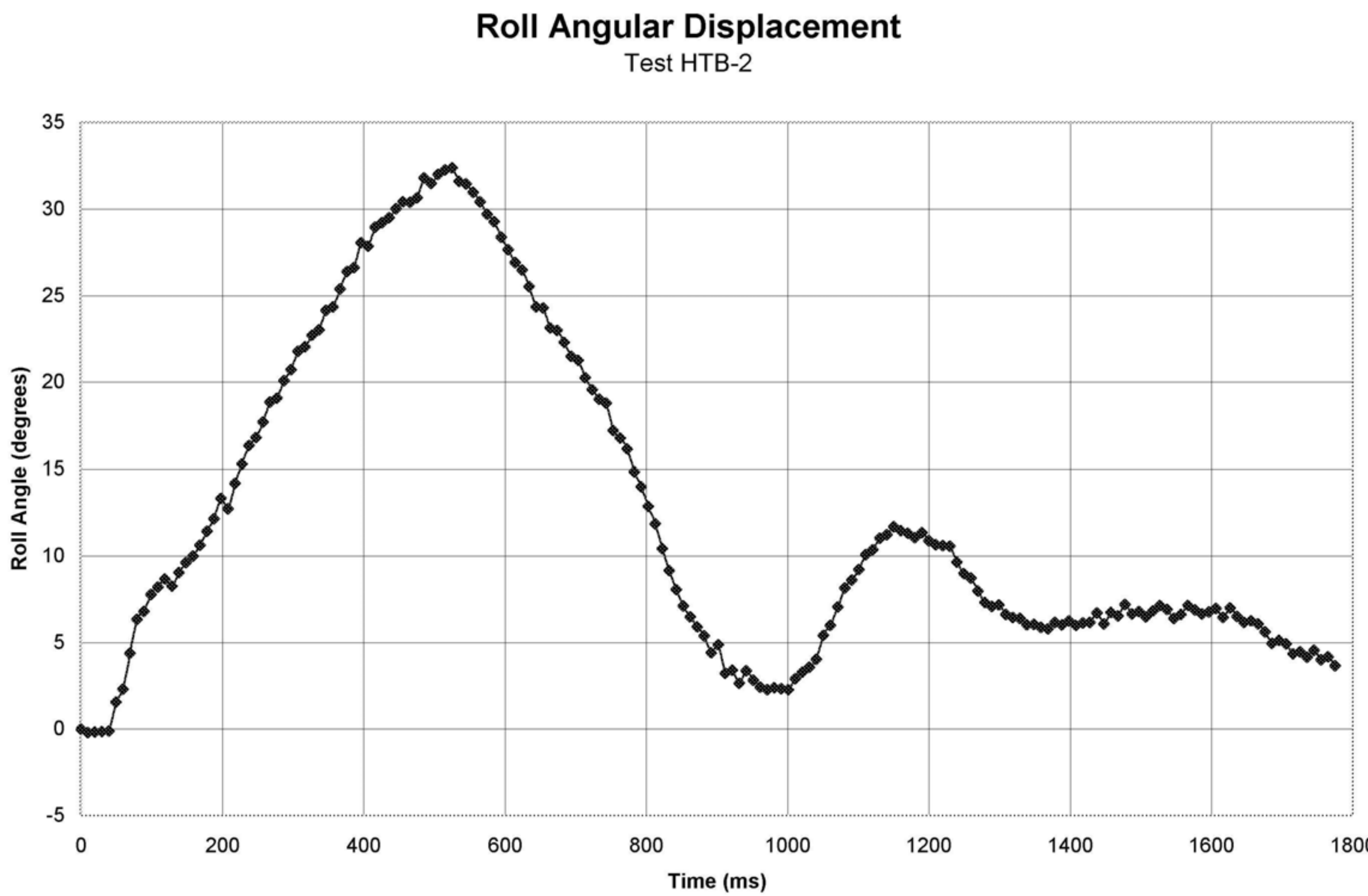

Figure F-1. Graph of Roll Angular Displacements, Test HTB-2

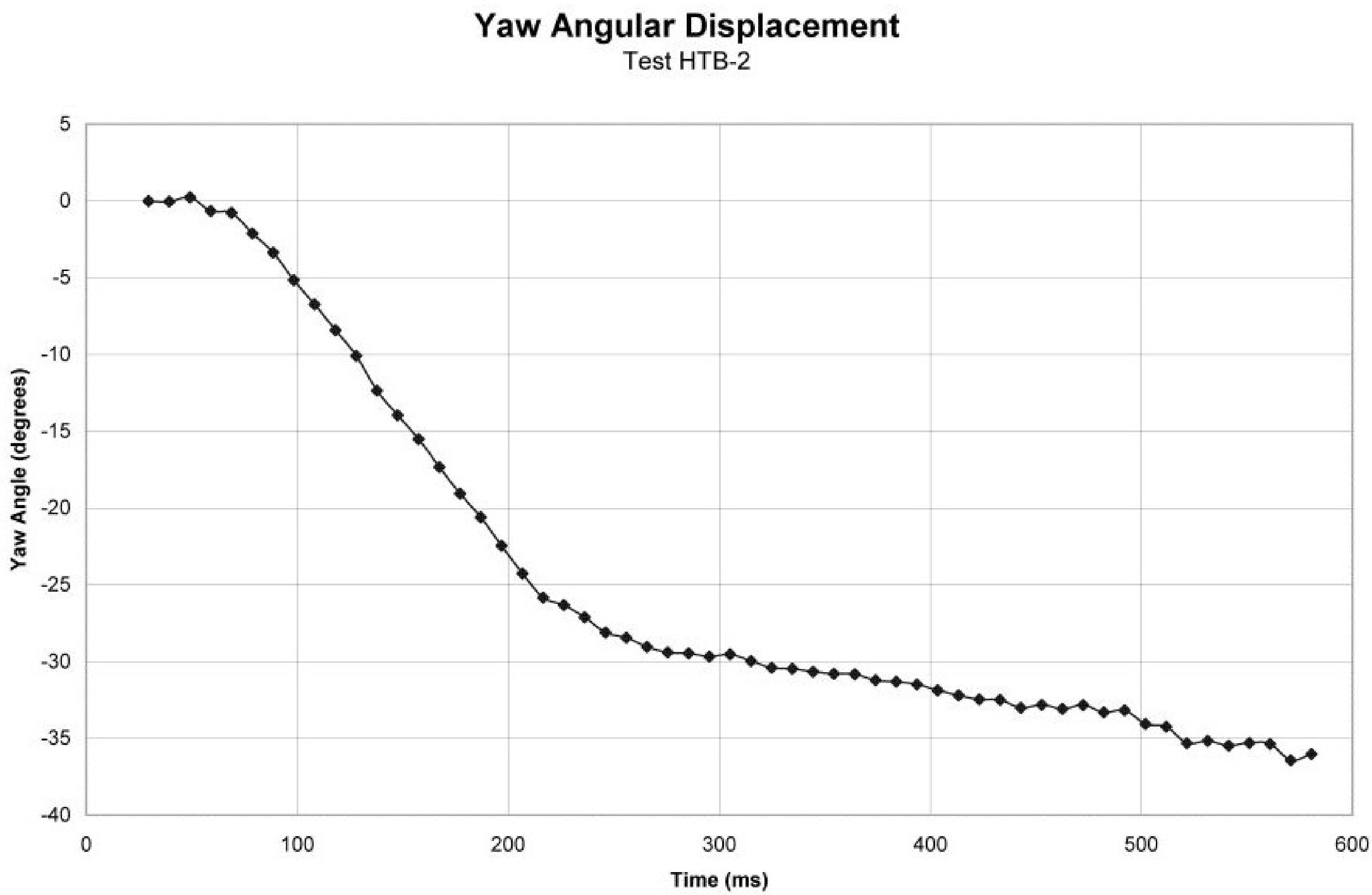

Figure F-2. Graph of Yaw Angular Displacements, Test HTB-2