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Performance Limits for 6-In. High Curbs Placed in Advance of the MGS Using Mash Vehicles Part:II Full-Scale Crash Testing

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PERFORMANCE LIMITS FOR 6-IN. (152-MM) HIGH CURBS PLACED IN ADVANCE OF THE MGS USING MASH VEHICLES PART II: FULL-SCALE CRASH TESTING

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16. Abstract (Limit: 200 words)

A full-scale crash test using Manual for Assessing Safety Hardware (MASH) Test Level 3 (TL-3) criteria was performed on the Midwest Guardrail System (MGS) offset 8 ft (2.44 m) behind a 6-in. (152-mm) high AASHTO Type B curb with a top mounting height of 31 in. (787 mm) relative to the ground [37 in. (940 mm) relative to the roadway]. In the test, the vehicle was contained by the guardrail, but became unstable and rolled over. Analysis of the test revealed that the right-front tire snagged on a post and detached. The right-rear tire of the pickup traversed over the detached tire, causing the rear of the vehicle to pitch upward. The vehicle subsequently became unstable and rolled over. Thus, the MGS offset 8 ft (2.44 mm) behind a 6-in. (152-mm) high curb with a top mounting height of 31 in. (787 mm) was deemed to be unacceptable according to TL-3 of MASH.

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UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

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1 INTRODUCTION

1.1 Problem Statement

Highway design policy typically discourages the use of 6 to 8-in. (152 to 203-mm) vertical curbs on high-speed roadways because of their potential to cause drivers to lose control in a crash (1). Curbs can also affect the interaction of errant vehicles with roadside barriers by causing vaulting or underride of the barrier. However, the use of curbs is often required because of restricted right-of-way, drainage considerations, access control, and other curb functions. Often, there is a desire to offset the guardrail from the curb to reduce the propensity for snow plows to gouge and/or damage the W-beam rail sections or to allow for placement of sidewalks or other roadside features.

When curbs are required, the offset of the barrier from the curb has been shown to be critical in the performance of the system through modeling and crash testing. Previous work with steel-post, nested W-beam guardrail has shown that a 4-in. (102-mm) high sloped curb with the toe of the curb placed at the front face of the guardrail is capable of meeting National Cooperative Highway Research Program (NCHRP) Report No. 350 safety requirements (2-4). Further research with standard wood-post W-beam guardrail has shown that a 4-in. (102-mm) high sloped curb with its toe set out 1 in. (25 mm) from the front face of the guardrail is also capable of meeting TL-3 requirements (5).

Investigation of curb-barrier combinations was reported in NCHRP Report 537, *Recommended Guidelines for Curbs and Curb-Barrier Combinations* (6). This study developed guidelines for the use of curbs and curb-barrier combinations on roadways with operating speeds greater than 37.3 mph (60 km/h). The study recommended that guardrail be installed flush with the face of the sloped curb or offset more than 8.2 ft (2.5 m) behind the curb for operating speeds

in excess of 37.3 mph (60 km/h). In addition, the study recommended that guardrail should not be offset behind sloped curbs for speeds of 62.1 mph (100 km/h) or more.

The recent development and testing of the Midwest Guardrail System (MGS) has demonstrated that this system can be used with a 6-in. (152-mm) tall, American Association of State Highway Transportation Officials (AASHTO) Type B curb positioned 6 in. (152 mm) in front of the face of the guardrail element (7-8). Although this guardrail-to-curb configuration provides increased hydraulic flow for roadway runoff as well as reduced guardrail maintenance arising from snow plowing operations, state departments of transportation (DOTs) often desire to locate roadside curbs farther away from the front face of the guardrail. Thus, a research effort was begun with the goal of determining placement guidelines for the MGS in relation to curbs.

1.2 Background

In 2008, testing was performed with the small car and pickup truck vehicles specified in the *Manual for Assessing Safety Hardware* (MASH) (9). The tests involved the vehicles impacting a 6-in. (152-mm) high AASTHO Type B curb under Test Level 3 (TL-3) conditions (62 mph or 100 km/h, 25 degrees) to determine vehicle behavior following impact (10-11). The vehicles' pitch angles and bumper trajectories were the data of interest.

With this, the critical override/underride offset for placing the MGS behind the curb was determined by comparing the critical bumper impact point trajectories against the MGS top/bottom corrugation heights. Results of this analysis created offset guidelines for placement of the MGS with a 6-in. (152-mm) high curb (10-11).

To further investigate the critical offset distance for MGS placement behind an AASHTO Type B curb, finite element analysis was performed. The MGS offset from a 6-in. (152-mm) high AASTHO Type B curb at various distances was impacted with the 2000P test vehicle.

Based on previous vehicle-curb simulation results and to ensure reliability of the model, the offset distance was only investigated for the range of 0.0 ft (0.0 m) to 7.35 ft (2.25 m) behind the curb. Results of the simulation indicated that the current pickup model (2000P) was fairly accurate in predicting the vehicle trajectory within 7.35 ft (2.24 m) behind the curb. Details of this research effort are documented in report references 10 and 11.

1.3 Objective

The objective of this research project was to conduct a full-scale crash test on the MGS offset 8 ft (2.44 m) behind a 6-in. (152-mm) tall AASHTO Type B curb and to evaluate the barrier's performance according to the TL-3 safety performance criteria set forth in MASH.

1.4 Scope

The research objective was achieved through the completion of several tasks. First, a full-scale vehicle crash test was performed on the MGS system offset 8 ft (2.44 m) behind a 6-in. (152-mm) high AASTHO Type B curb. The MGS was raised 6 in. (152 mm) resulting in a top mounting height of 31 in. (787 mm) relative to the ground. The crash test utilized a pickup truck, weighing approximately 5,004 lb (2,270 kg). Target impact conditions for the test were an impact speed of 62 mph (100 km/h) and an impact angle of 25 degrees. Next, the test results were analyzed, evaluated, and documented. Finally, conclusions and recommendations were made that pertain to the safety performance of the MGS and curb system relative to the test performed.

2 DESIGN DETAILS

The test installation consisted of 175 ft (53.3 m) of MGS guardrail supported by steel posts and positioned 8 ft (2.44 m) behind a 6-in. (152-mm) tall AASHTO Type B curb. 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 1 through 10. Photographs of the test installation are shown in Figures 11 through 15. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The MGS was constructed with twenty-nine guardrail posts. Post nos. 3 through 27 were galvanized ASTM A36 steel W6x8.5 (W152x12.6) sections measuring 72 in. (1,829 mm) long. Post nos. 1, 2, 28, and 29 were timber posts measuring 5 ½ in. wide x 7 ½ in. deep x 46 in. long (140 mm x 190 mm x 1,168 mm) and were placed in 72-in. (1,829-mm) long steel foundation tubes, as shown in Figures 3 and 6. 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 75 in. (1,905 mm) on center with a soil embedment depth of 40 in. (1,016 mm), as shown in Figures 1 and 2. The posts were placed in a compacted, coarse, crushed limestone material that met Grading B of AASHTO M147-65 (1990) as described in MASH. For post nos. 3 through 27, 6-in. wide x 12-in. deep x 14 ¼-in. long (152-mm x 305-mm x 362-mm) wood spacer blockouts were used to block the rail away from the front face of the steel posts, as shown in Figures 2 and 5.

Standard 12-gauge (2.67-mm 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 1, 3, and 9. The W-beam's top rail height was 31 in. (787 mm) above the ground surface with a 24 ⅞-in.

(632-mm) center mounting height, or 37 in. (940 mm) above the roadway surface. Rail splices were located at the center of the guardrail span locations, as shown in Figures 1 and 3. All lap splice connections between the rail sections were configured to reduce vehicle snag at the splice during the crash test.

A 6-in. (152-mm) tall AASHTO Type B curb was placed in front of the MGS. The concrete curb constructed in front of the MGS system was 73 ft-6 in. (22.4 m) long, beginning at the midspan between post nos. 8 and 9 to post no. 20, as shown in Figure 1. The toe of the curb was offset 8 ft (2.44 m) in front of the front face of the guardrail. The concrete consisted of a concrete mix with a minimum compressive strength of 4,000 psi (27.6 MPa). All steel reinforcement was specified as ASTM A615 Grade 40 or Grade 60 rebar. Reinforcement consisted of No. 4 longitudinal and vertical bars, as shown in Figure 2.

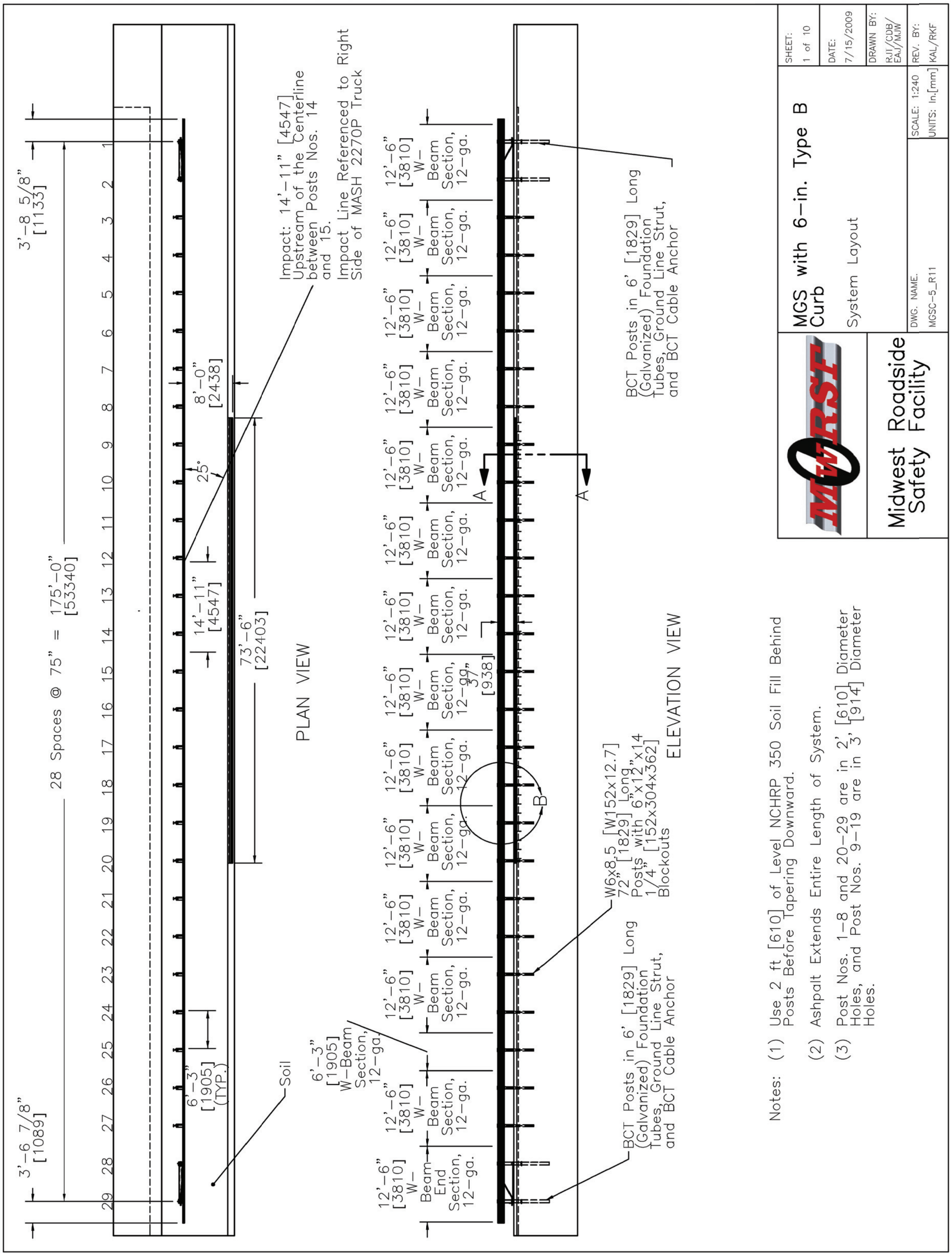


Figure 1. Test Installation Layout, Test No. MGSC-5

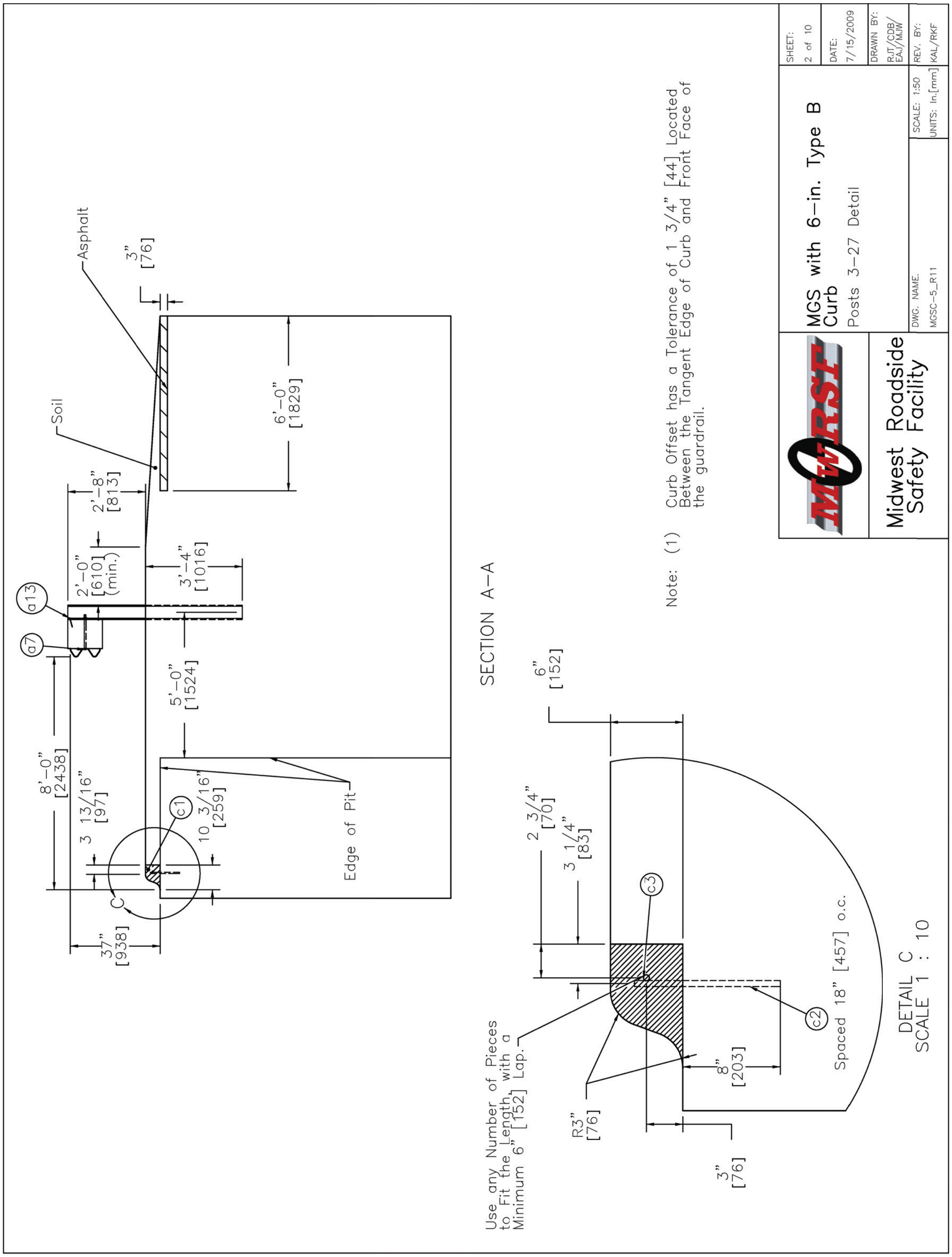


Figure 2. Post and Curb Details, Test No. MGSC-5

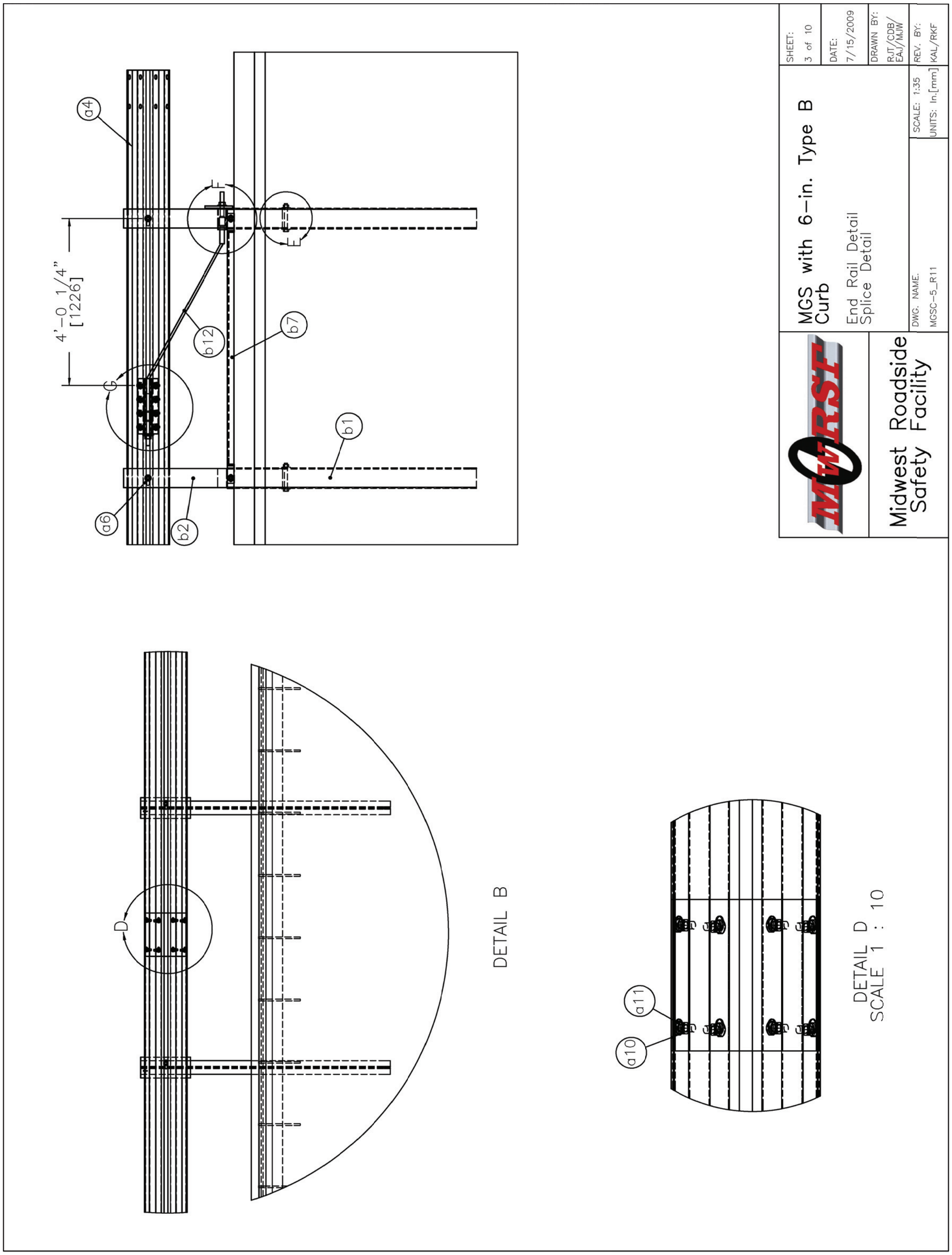


Figure 3. End Rail and Splice Details, Test No. MGSC-5

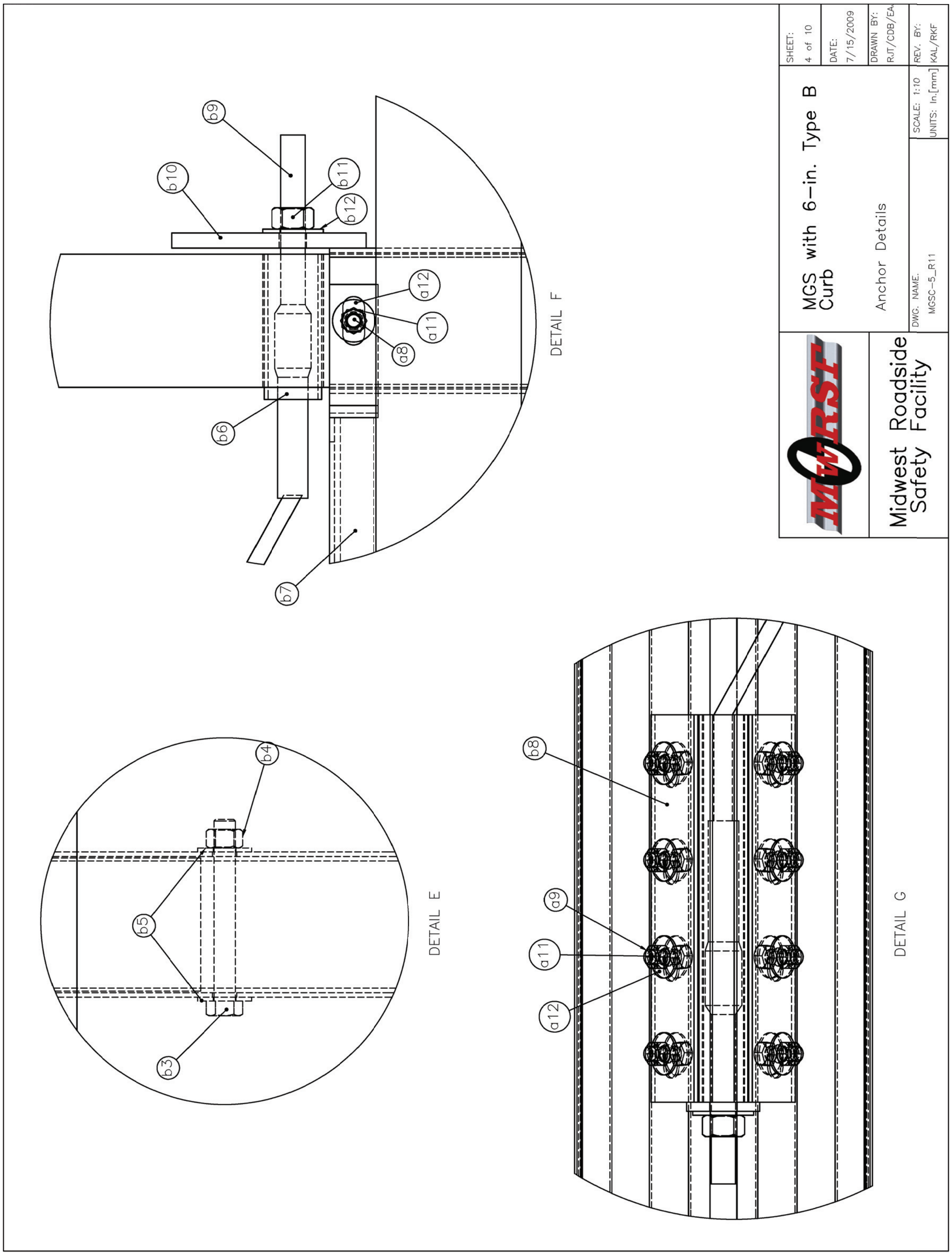


Figure 4. Anchor Details, Test No. MGSC-5

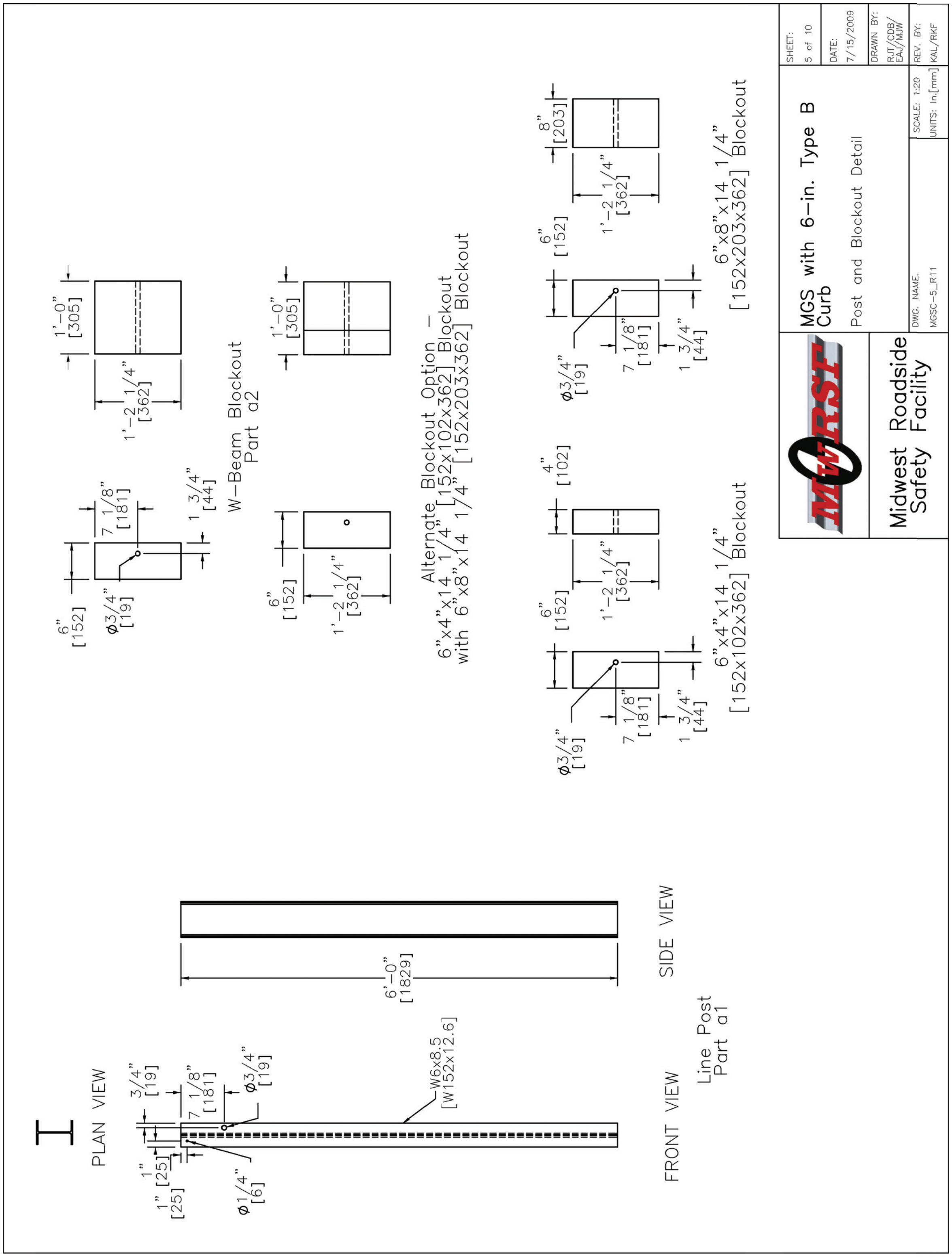


Figure 5. Post and Blockout Details, Test No. MGSC-5

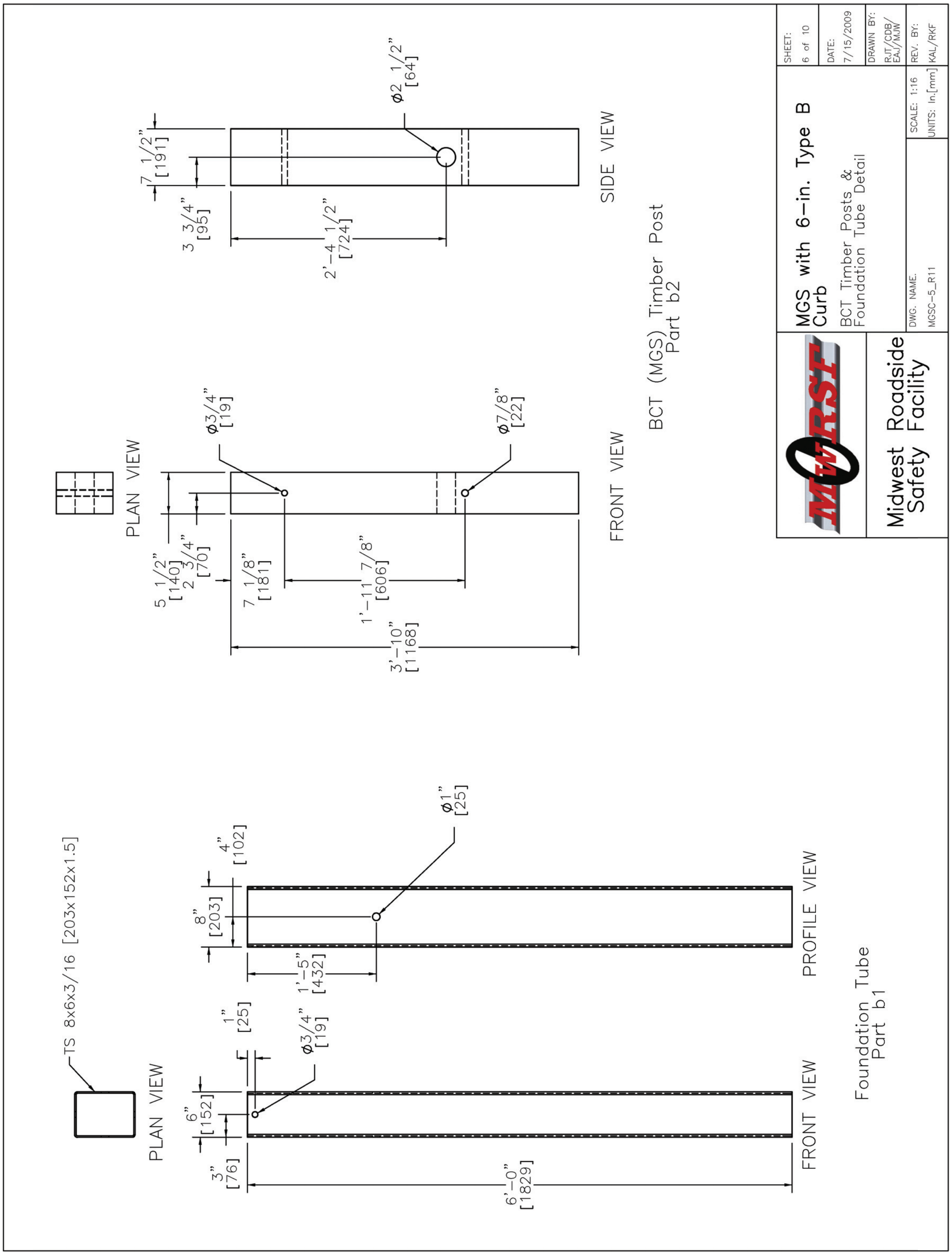


Figure 6. BCT Timber Post and Foundation Tube Details, Test No. MGSC-5

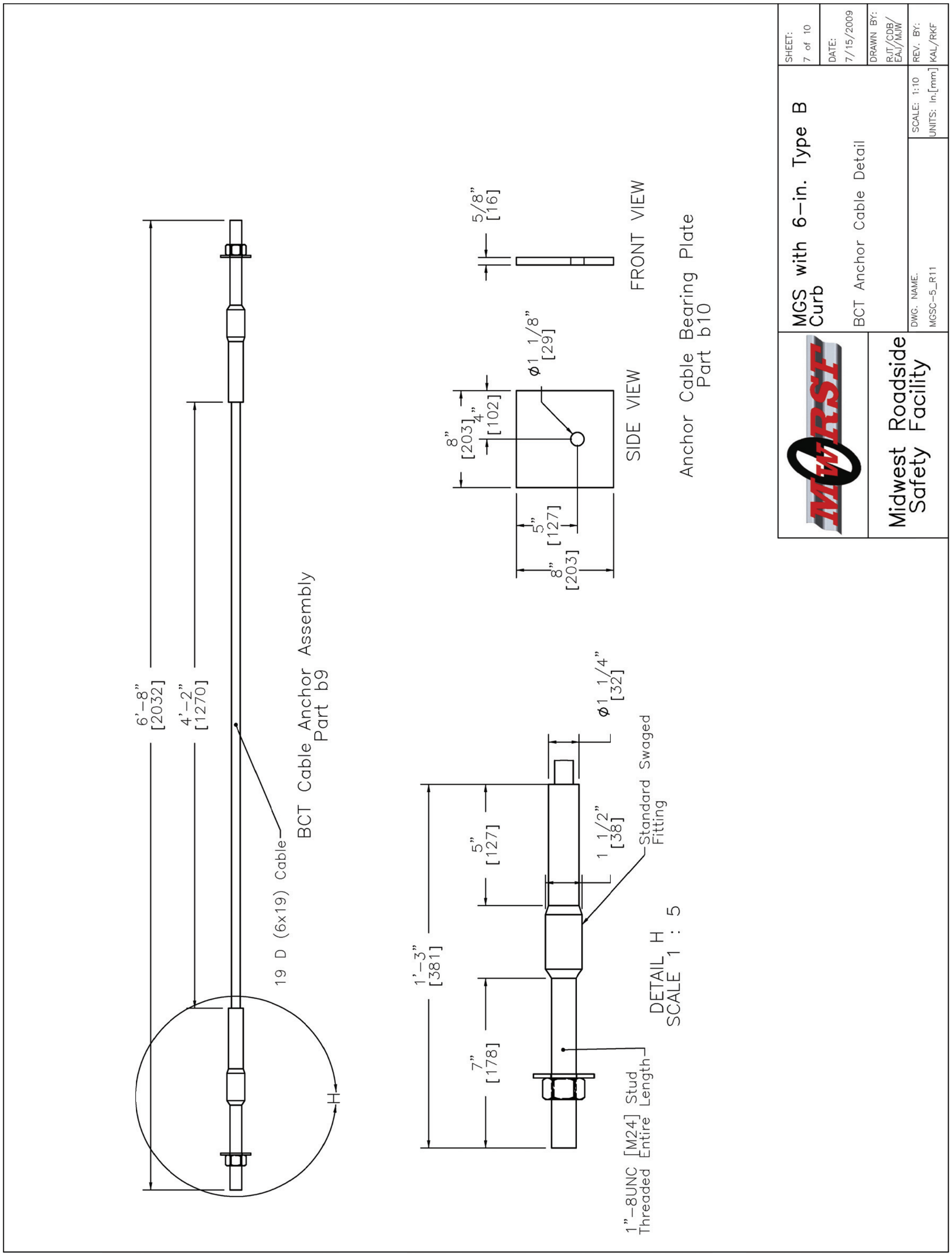


Figure 7. BCT Anchor Cable Details, Test No. MGSC-5

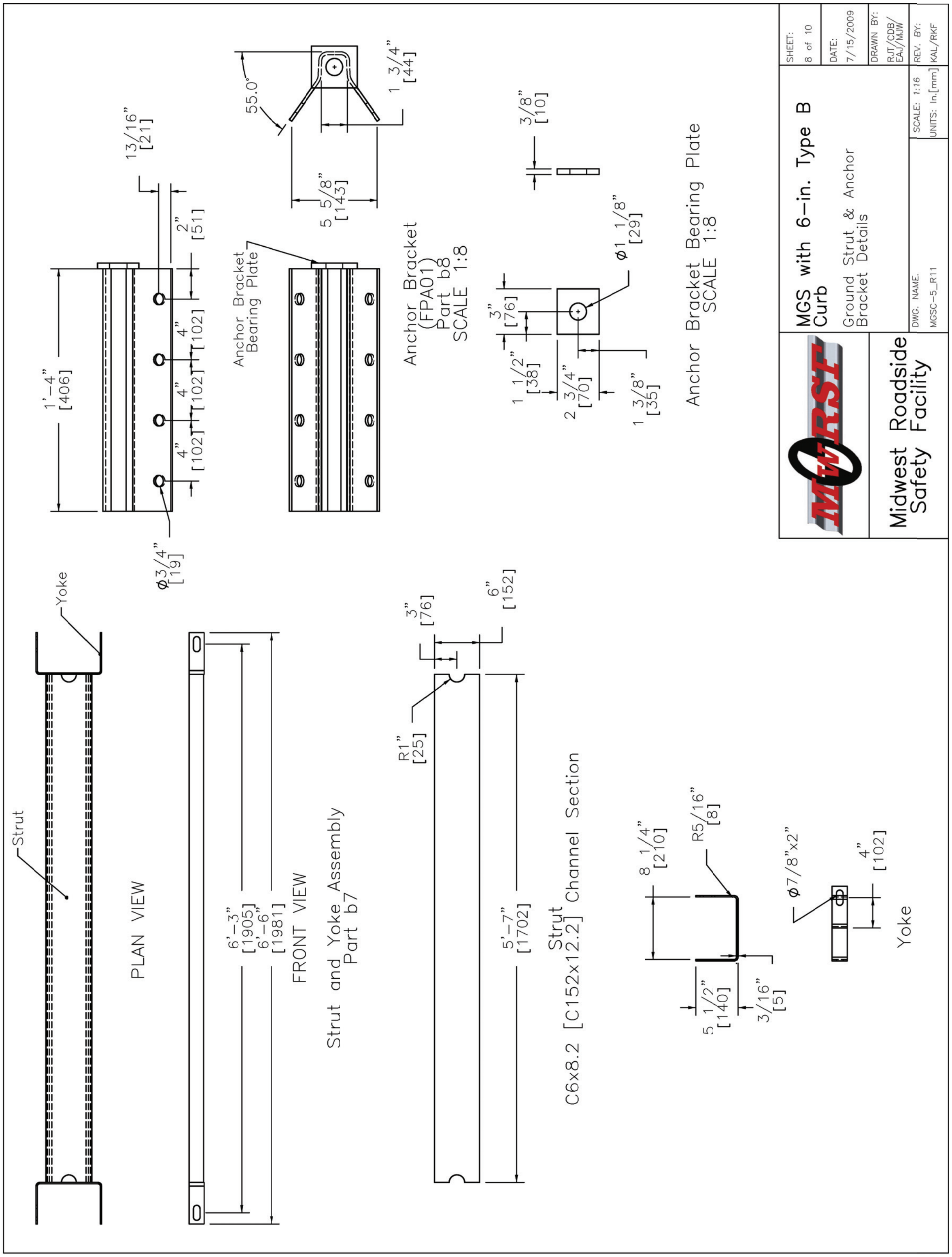


Figure 8. Ground Strut and Anchor Bracket Details, Test No. MGSC-5

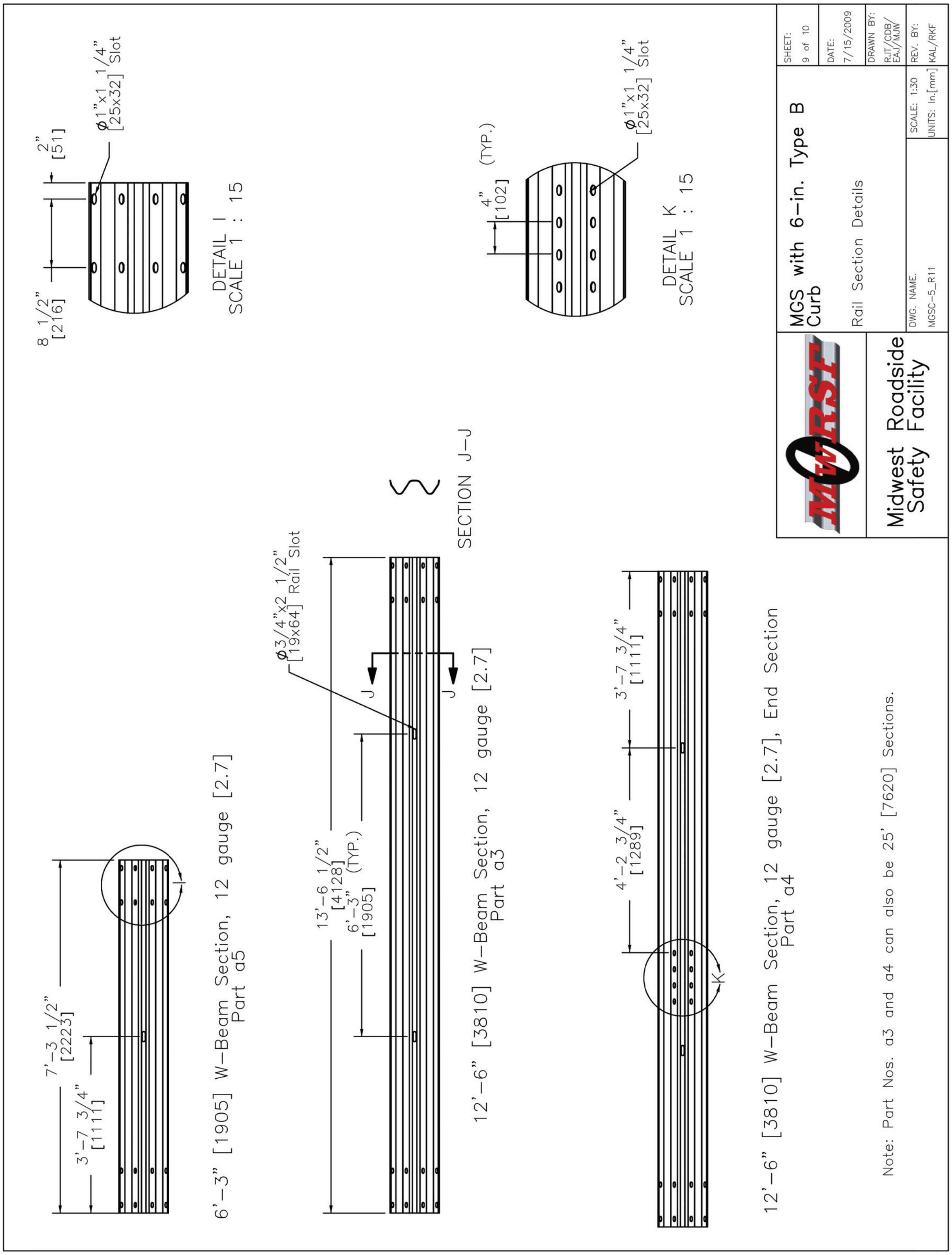


Figure 9. Rail Section Details, Test No. MGSC-5

Item No.	QTY.	Description	Material Spec	Hardware Guide
a1	25	W6x8.5 [W152x12.6] 72" [1829] long	A36 Steel	–
a2	25	6x12x14 1/4" [152x305x362] Blockout	SYP Grade No.1 or better	PDB10a–b
a3	12	12'–6" [3810] W–Beam MGS Section	12 gauge [2.7] AASHTO M180	RWM04a
a4	2	12'–6" [3810] W–Beam MGS End Section	12 gauge AASHTO M180	RWM04a
a5	1	6'–3" [1905] W–Beam MGS Section	12 gauge [2.7] AASHTO M180	RWM01a
a6	4	5/8" [16] Dia. x 10" [254] long Guardrail Bolt	A307	FBB03
a7	25	5/8" [16] Dia. x 14" [356] long Guardrail Bolt	A307	FBB06
a8	4	5/8" [16] Dia. x 10" [254] long Hex Head Bolt	A307	FBX16a
a9	16	5/8" [16] Dia. x 1 1/2" [38] long Hex Head Bolt	A307	FBX16a
a10	112	5/8" [16] Dia. x 1 1/2" [38] Guardrail Bolt	A307	FBB01
a11	161	5/8" [16] Dia. Hex Nut	A563DH	FBX16a
a12	44	5/8" [16] Dia. Flat Washer	F436 Gr. 1	FWC16b
a13	25	16D Double Head Nail	–	–
b1	4	72" [1829] Foundation Tube	A500 Gr. B	PTE05
b2	4	BCT Timber Post	SYP Grade No. 1 or better (No knots, 18" [457] above or below ground tension face)	PDF01
b3	4	7/8" [22] Dia. x 7 1/2" [191] long Hex Head Bolt	A325	FBX22a
b4	4	7/8" [22] Dia. Hex Nut	A563DH	FBX22a
b5	8	7/8" [22] Dia. Flat Washer	F436 Gr. 1	FWC22a
b6	2	2 3/8" [60] O.D.x 6" [152] long BCT Post Sleeve	ASTM A53 Grade B Schedule 40	FMM02
b7	2	Strut and Yoke Assembly	A36 Steel	PFP01
b8	2	Anchor Bracket	A36	FPA01
b9	2	BCT Cable Anchor Assembly	ϕ3/4" [19] 6x19 IWRC IPS Galvanized Wire Rope	FCA01–02
b10	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	A36 Steel	FPB01
b11	4	1" [25] Dia. Hex Nut	A563DH	FNX24a
b12	4	1" [25] Dia. Flat Washer	F436 Gr. 1	FWC24a
c1	1	Curb	Concrete (s/g mix) – Min. 4000 psi [27.6 MPa] Comp. Strength	–
c2	49	#4 Rebar 12" [305] Long	ASTM A615 Grade 40 or Grade 60	–
c3	1	#4 Rebar 73' [22.3 m] Long	ASTM A615 Grade 40 or Grade 60	–

MwRSF
Midwest Roadside Safety Facility

MGS with 6–in. Type B Curb
Bill of Materials

SHEET: 10 of 10
DATE: 2/17/2009
DRAWN BY: RJT/CDB/EAJ
DWG. NAME. MGSC–5_R10
SCALE: None
UNITS: In.[mm]
REV. BY: KAL/RKF

Figure 10. Bill of Materials, Test No. MGSC-5

Figure 11. Test Installation Photographs, Test No. MGSC-5

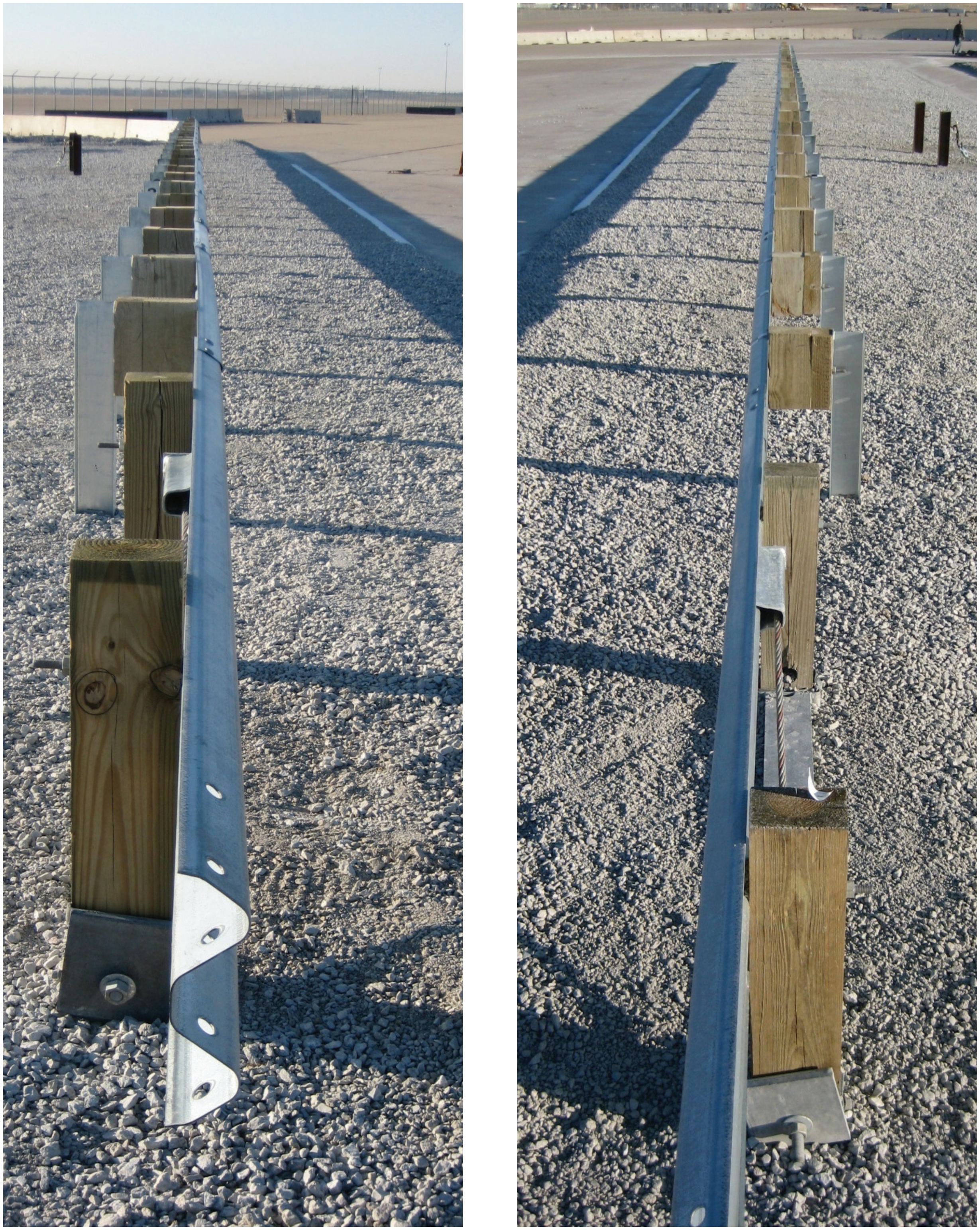


Figure 12. Test Installation Photographs, Test No. MGSC-5

Figure 13. Test Installation Photographs, Test No. MGSC-5

Figure 14. Test Installation Photographs, Test No. MGSC-5

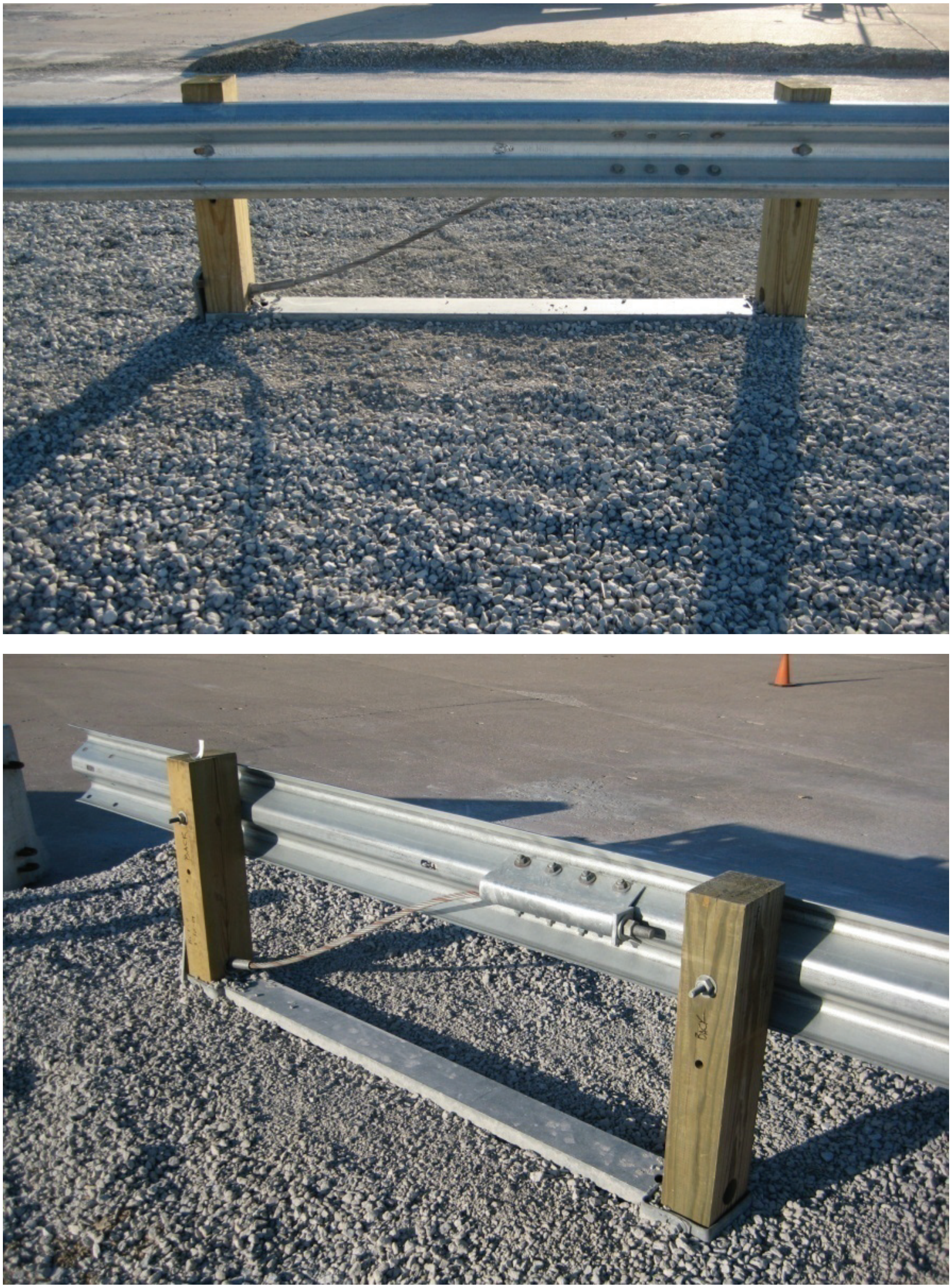


Figure 15. Test Installation Photographs, Test No. MGSC-5

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as W-beam guardrail systems with curbs, must satisfy impact safety standards provided in MASH (9) in order to be accepted by the Federal Highway Administration (FHWA) for use on National Highway System (NHS) new construction projects or as a replacement for existing designs not meeting current safety standards. According to TL-3 of MASH, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests. The two full-scale crash tests are as follows:

1. Test Designation 3-10 consisting of a 2,425-lb (1,100-kg) passenger car impacting the system at a nominal speed and angle of 62 mph (100 km/h) and 25 degrees, respectively.
2. Test Designation 3-11 consisting of a 5,004-lb (2,270-kg) pickup truck impacting the system at a nominal speed and angle of 62 mph (100 km/h) and 25 degrees, respectively.

The test conditions of TL-3 longitudinal barriers are summarized in Table 1.

Table 1. MASH TL-3 Crash Test Conditions

Test Article	Test Designation	Test Vehicle	Impact Conditions			Evaluation Criteria [1]
			Speed		Angle (deg.)	
			mph	km/h		
Longitudinal Barrier	3-10	1100C	62	100	25	A,D,F,H,I
	3-11	2270P	62	100	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

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 and redirect impacting vehicles. 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 become involved in secondary collisions with other vehicles or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 2 and defined in greater detail in MASH. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in MASH.

3.3 Soil Strength Requirements

In order to limit the variation of soil strength among testing agencies, foundation soil must satisfy the recommended performance characteristics set forth in Chapter 3 and Appendix B of MASH. Testing facilities must first subject their soil to a dynamic post test to demonstrate a minimum dynamic load of 7.5 kips (33.4 kN) at deflections between 5 and 20 in. (127 and 508 mm). If satisfactory results are observed, a static test is conducted using an identical test installation. The results of this static test become the baseline requirement for soil strength in future full-scale testing. On the full-scale test day, an additional post installed near the impact point is statically tested in the same manner as the baseline test. If the static test results show a resistance equal to 90 percent or greater of the baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm), the soil has adequate strength and the full-scale test can be conducted.

The static test results for the full-scale test along with the baseline static test are shown in Appendix B.

Table 2. MASH Evaluation Criteria for Longitudinal Barriers

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="9">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocities (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits, ft/s (m/s)</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits (g’s)</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

4 TEST CONDITIONS

4.1 Test Facility

The testing facility is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles (8.0 km) northwest 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 barrier system. A digital speedometer on the tow vehicle increased 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 barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lbf (15.6 kN) and supported both laterally and vertically every 100 ft (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 test no. MGSC-5, the vehicle guidance system was 1,101 ft (336 m) long.

4.3 Test Vehicles

For test no. MGSC-5, a 2003 Dodge Ram 1500 Quad Cab pickup truck was used as the test vehicle. The test inertial and gross static weights were 5,028 lb (2,281 kg) and 5,198 lb (2,358 kg), respectively. The test vehicle is shown in Figure 16, and vehicle dimensions are shown in Figure 17.

Figure 16. Test Vehicle, Test No. MGSC-5

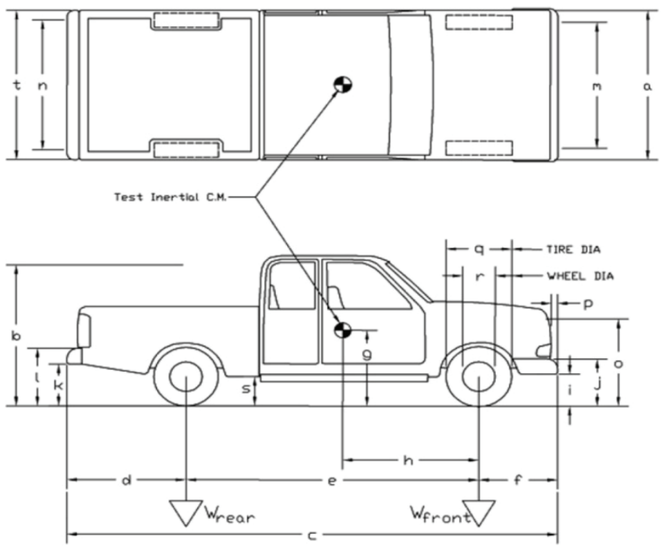
Date: 4/8/2009 **Test Number:** MGSC-5 **Model:** Ram 1500 Q.C.

Make: Dodge **Vehicle I.D.#:** 1D7HA18N83J526581

Tire Size: 265/70 R17 **Year:** 2003 **Odometer:** 139905

Tire Inflation Pressure: 32 p.s.i.

***(All Measurements Refer to Impacting Side)**



Vehicle Geometry -- in. (mm)

a	78.5 (1994)	b	75.25 (1911)
c	229.5 (5829)	d	45.25 (1149)
e	140.25 (3562)	f	44 (1118)
g	28.13 (714)	h	62.33 (1583)
i	15.5 (394)	j	27.5 (699)
k	21.5 (546)	l	28.5 (724)
m	68 (1727)	n	67.75 (1721)
o	46 (1168)	p	3.5 (89)
q	31.5 (800)	r	18.5 (470)
s	15.5 (394)	t	77.5 (1969)

Wheel Center Height Front	15.25 (387)
Wheel Center Height Rear	15.375 (391)
Wheel Well Clearance (F)	36 (914)
Wheel Well Clearance (R)	38 (965)
Frame Height (F)	18 (457)
Frame Height (R)	25 (635)
Engine Type	8 CYL. GAS
Engine Size	4.7

Transmition Type: Automatic (circled) Manual

FWD RWD (circled) 4WD

Mass Distribution

Gross Static				
	LF	1449	RF	1436
	LR	1117	RR	1196

Weights lbs (kg)	Curb	Test Inertial	Gross Static
W-front	2854 (1295)	2769 (1256)	2885 (1309)
W-rear	2297 (1042)	2259 (1025)	2313 (1049)
W-total	5151 (2336)	5028 (2281)	5198 (2358)

GVWR Ratings

Front	3650
Rear	3900
Total	6650

Dummy Data

Type:	Hybrid II
Mass:	170 lbs
Seat Position:	Passenger, Full Rearward

Note any damage prior to test: Repaired SR-8 test vehicle, some cosmetic damage

Figure 17. Vehicle Dimensions, Test No. MGSC-5

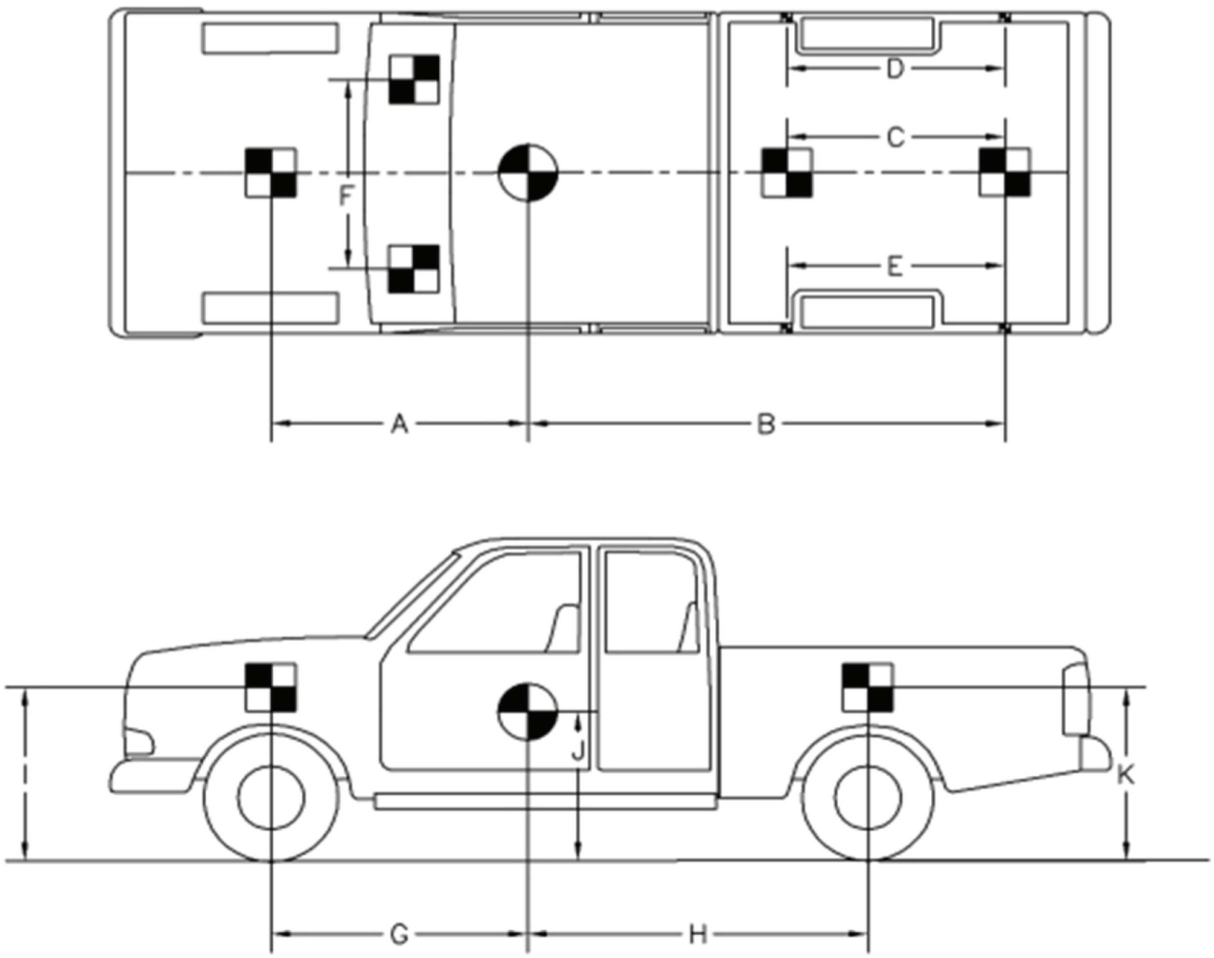
The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method (13) was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition, as is shown in Figures 17 and 18. Data used to calculate the location of the c.g. is shown in Appendix C.

Square, black and white, checkered targets were placed on the vehicle to aid in the analysis of the high-speed videos, as shown in Figure 18. Round, checkered targets were placed on the center of gravity on the left-side door, the right-side door, and the roof of the vehicle. The remaining targets were located for references so that they could be viewed from the high-speed cameras for video 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. A 5B flash bulb was mounted near the center of the vehicle's dash to pinpoint the time of impact with the barrier system on the high-speed videos. The flash bulb was fired by a pressure tape switch mounted at the impact corner 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 Simulated Occupant

A Hybrid II 50th Percentile Adult Male Test Dummy, equipped with clothing and footwear, was placed in the right-front seat of the test vehicle with the seat belt fastened. The dummy, which had a final weight of 170 lb (77 kg), was represented by model no. 572 and



TEST #: MGSC-5

TARGET GEOMETRY-- in. (mm)

A	**73.625**	**(1870)**	**E**	**64**	**(1626)**	**I**	**40.25**	**(1022)**
B	**107**	**(2718)**	**F**	**36.25**	**(921)**	**J**	**28.5**	**(724)**
C	**48**	**(1219)**	**G**	**62**	**(1575)**	**K**	**42.5**	**(1080)**
D	**64**	**(1626)**	**H**	**78.25**	**(1988)**			

Figure 18. Target Geometry, Test No. MGSC-5

serial no. 451 and was manufactured by Android Systems of Carson, California. As recommended by MASH, the dummy was not included in calculating the c.g. location.

4.5 Data Acquisition Systems

4.5.1 Accelerometers

Three environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. All of the accelerometers were mounted near the center of gravity of the test vehicles.

One triaxial piezoresistive accelerometer system, Model EDR-4 6DOF-500/1200, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan and included three differential channels as well as three single-ended channels. The EDR-4 was configured with 24 MB of RAM memory, a range of ±500 g's, a sample rate of 10,000 Hz and a 1,677 Hz anti-aliasing filter. "EDR4Com" and "DynaMax Suite" computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The second accelerometer system was a two-Arm piezoresistive accelerometer system developed by Endevco of San Juan Capistrano, California. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. Data was collected using a Sensor Input Module (SIM), Model TDAS3-SIM-16M, which was developed by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SIM was configured with 16 MB SRAM memory and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were

crashworthy. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The third system, Model EDR-3, was a triaxial piezoresistive accelerometer, also developed by Instrumented Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM memory, a range of ±200 g's, a sample rate of 3,200 Hz, and a 1,120 Hz lowpass filter. "DynaMax 1 (DM-1)" and "DADiSP" computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.5.2 Rate Transducers

An Analog Systems 3-axis rate transducer with a range of 1,200 degrees/sec in each of the three directions (roll, pitch, and yaw) was used to measure the rates of motion of the test vehicle. The rate transducer was mounted inside the body of the EDR-4 6DOF-500/1200 and recorded data at 10,000 Hz to a second data acquisition board inside the EDR-4 6DOF-500/1200 housing. The raw data measurements were then downloaded, converted to the appropriate Euler angles for analysis, and plotted. "EDR4Com" and "DynaMax Suite" computer software programs and a customized Microsoft Excel spreadsheet were used to analyze and plot the rate transducer data.

An additional angle rate sensor, the ARS-1500, with a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) was used to measure the rates of rotation of the test vehicle. The angular rate sensor was mounted on an aluminum block inside the test vehicle near the center of gravity and recorded data at 10,000 Hz to the SIM. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

4.5.3 Pressure Tape Switches

For test no. MGSC-5, five pressure-activated tape switches spaced at 6.56 ft (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 speeds were determined from electronic timing mark data recorded using TestPoint and LabVIEW computer software programs. Strobe lights and high-speed video analysis are used only as a backup in the event that vehicle speed cannot be determined from the electronic data.

4.5.4 Digital Photography

Two high-speed AOS VITcam digital video cameras, three high-speed AOS X-PRI digital video cameras, four JVC digital video cameras, and two Canon digital video cameras were utilized to film test no. MGSC-5. Camera details, camera operating speeds, lens information, and a schematic of the camera locations are shown in Figure 19. The high-speed videos were analyzed using ImageExpress MotionPlus software. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos.

	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	2	AOS Vitcam CTM	500	Fixed 12.5 mm	-
	3	AOS Vitcam CTM	500	Sigma 24 - 135 mm	50 mm
	5	AOS X-PRI	500	Sigma 70 - 200 mm	100 mm
	6	AOS X-PRI	500	Sigma 24 - 70 mm	24 mm
	7	AOS X-PRI	500	Sigma Fixed 50 mm	-
Digital Video	1	JVC - GZ-MC500 (Everio)	29.97		
	2	JVC - GZ-MG27u (Everio)	29.97		
	3	JVC - GZ-MG27u (Everio)	29.97		
	4	JVC - GZ-MG27u (Everio)	29.97		
	1	Canon-ZR90	29.97		
	2	Canon-ZR10	29.97		

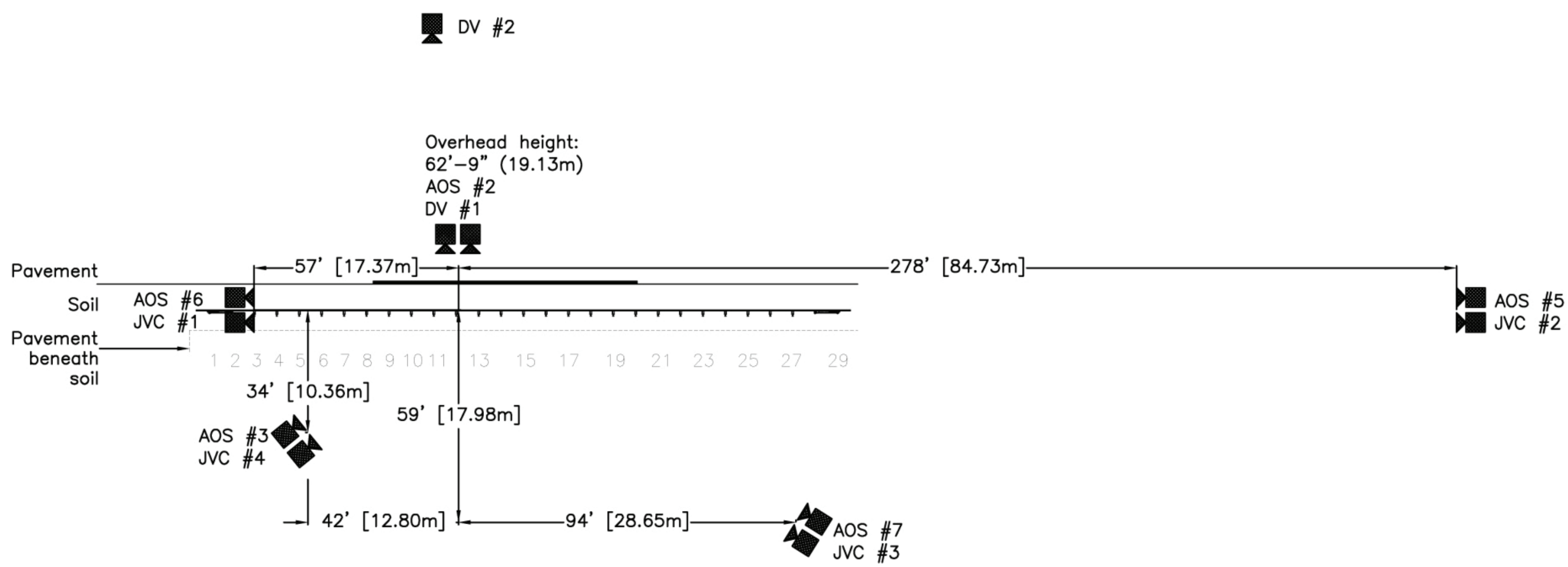


Figure 19. Camera Locations, Test No. MGSC-5

5 FULL-SCALE CRASH TEST NO. MGSC-5

5.1 Static Soil Test

Before full-scale test no. MGSC-5 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix B, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and the barrier system was approved for full-scale testing.

5.2 Test No. MGSC-5

The 5,198-lb (2,358-kg) pickup truck, with a dummy placed in the right-front seat, impacted the curb at a speed of 61.9 mph (99.5 km/h) and at an angle of 25.7 degrees. After mounting the curb, the vehicle impacted the guardrail at an angle of 24.4 degrees. A summary of the test results and sequential photographs are shown in Figure 20. Additional sequential photographs are shown in Figures 21 and 22. Documentary photographs of the crash test are shown in Figures 23 and 24.

5.3 Weather Conditions

Test no. MGSC-5 was performed April 8, 2009, at approximately 1:30 p.m. The weather conditions were reported as shown in Table 3.

Table 3. Weather Conditions, Test No. MGSC-5

Temperature	65°F
Humidity	22%
Wind Speed	11 mph
Wind Direction	0° deg from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.03 in.
Previous 7-Day Precipitation	0.03 in.

5.4 Test Description

Initial vehicle impact with the guardrail was to occur between post nos. 12 and 13, or 14 ft-11 in. (4.55 m) upstream of the splice between post nos. 14 and 15, as shown in Figure 25. The actual point of impact was 14 ft-7 ½ in. (4.46 m) upstream of the splice between post nos. 14 and 15. A sequential description of the impact events is contained in Table 4. The final position of the vehicle was determined to be 130 ft-8 ½ in. (39.84 m) downstream from impact and 22 ft-10 in. (6.96 m) laterally away from the traffic-side face of the barrier, as shown in Figures 20 and 26.

Table 4. Sequential Description of Impact Events

TIME (sec)	EVENT
-0.192	The right-front tire contacted face of mountable curb.
-0.156	The vehicle rolled toward the left.
-0.060	The right-rear tire contacted face of the mountable curb.
-0.048	The left-front tire contacted face of the mountable curb.
-0.016	The right-front tire became airborne.
-0.012	The vehicle rolled toward the right.
0.000	The right-front bumper corner contacted the rail.
0.002	The guardrail deformed at impact location.
0.004	Post nos. 12 and 13 deflected laterally backward.
0.008	Posts upstream of impact twisted such that their front flanges turned downstream as the rail was tensioned.
0.04	Post no. 13 twisted such that its front flange turned upstream.
0.042	Post nos. 11 and 14 deflected laterally backward.
0.046	The front end of the vehicle yawed away from the barrier.
0.062	The rail disengaged from post no. 13, and the right-front tire stopped rotating.
0.074	Post no. 15 deflected laterally backward and twisted such that its front flange turned upstream.
0.096	A buckle point formed in the rail at post no. 15, downstream of vehicle.

0.106	The left-rear tire contacted the front face of the mountable curb, and the rail disengaged from post no. 14.
0.124	The left-front tire became airborne.
0.128	Post no. 16 deflected laterally backward.
0.150	The vehicle rolled toward the right.
0.156	The left-rear tire became airborne.
0.160	A buckle point formed in the rail at post no. 12, upstream of vehicle.
0.170	The right-front tire contacted post no. 14 and disengaged from vehicle.
0.208	Post no. 17 deflected laterally backward.
0.216	The front of vehicle pitched upward.
0.220	The rail disengaged from post no. 15.
0.244	The right-rear bumper corner contacted the rail upstream of post no. 13.
0.258	The right side of vehicle contacted the rail along its entire length.
0.284	The rail disengaged from post no. 16, which twisted such that its front flange turned downstream.
0.296	The vehicle became parallel to the barrier with a resultant velocity of 52.5 mph (84.5 km/h).
0.304	Post no. 18 deflected laterally backward.
0.324	The right-rear bumper corner contacted the rail, and the right-front tire contacted the wood blockout at post no. 16.
0.370	The rear end of the vehicle pitched upward.
0.382	The right-rear tire climbed up the face of the rail.
0.384	The front end of the vehicle continued to yaw away from the barrier
0.450	The right-rear tire lost contact with the top of the rail at post no. 15, and the vehicle exited the system while completely airborne and continuing to roll.
0.508	The rail disengaged from post no. 17.
0.534	The vehicle reached its critical roll angle and rolled over the barrier.
0.556	The right-rear tire contacted the wood blockout at post no. 16, causing the blockout to fracture.
0.634	The vehicle continued to roll.
0.720	The right-front quarter panel contacted the top of the rail between post nos. 20 and 21.
0.982	The right-front bumper corner contacted the ground in front of post no. 23.
1.012	The vehicle rolled approximately 90 degrees.
1.440	The top-right of the truck bed contacted the top of the rail at post no. 26.
1.528	The vehicle rolled approximately 180 degrees.
1.840	The vehicle rolled approximately 270 degrees.

2.130	The vehicle rolled approximately 360 degrees
2.334	The vehicle rolled approximately 450 degrees.
2.652	The vehicle rolled approximately 540 degrees.

5.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 27 through 38. Barrier damage consisted of deformed guardrail posts, disengaged wooden blockouts, contact marks on several sections of guardrail and the curb, and deformed W-beam rail. Five areas of contact between the vehicle and guardrail occurred, with the most substantial damage occurring at the original impact point. Three regions of light scuff marks occurred downstream of the original impact as the vehicle rolled. The final contact area occurred when the vehicle landed upside-down on the guardrail. The length of the original vehicle contact along the system was approximately 30 ft-3 in. (9.22 m), which spanned from 12 in. (305 mm) downstream of post no. 12 through the centerline of post no. 17.

Deformation and flattening of the W-beam guardrail occurred between post nos. 12 and 17, the primary vehicle contact region. Contact marks were visible on the guardrail beginning 12 in. (305 mm) downstream from post nos. 12 and ending at post no. 17. Additional contact marks were found on the top of the rail and included a 37-in. (940-mm) long mark beginning 25 ¾ in. (654 mm) downstream of post no. 20, a 77-in. (1,956-mm) long mark beginning 6 ½ in. (165 mm) downstream of post no. 21, an 18-in. (457-mm) long mark beginning 3 in. (76 mm) upstream of post no. 23, and a 96-in. (2,438-mm) long mark beginning 20 in. (508 mm) downstream of post no. 25.

Slight buckling occurred in the guardrail at post no. 11, with significant buckling at post nos. 12, 16, and 17. The bottom portion of the W-beam was bent upward between post no. 15 and the centerline of the splice between post nos. 16 and 17. The top of the W-beam deformed downward at post nos. 26 and 27 and the splice between post nos. 27 and 28. The W-beam guardrail was detached from post nos. 13 through 17, 26, and 27 as the bolt head was pulled through the rail. Local yielding occurred around the post bolt slots at post nos. 12 through 17, 26, and 27. A rail gap of ⅜ in. (9.5 mm) occurred at the splice between post nos. 12 and 13.

Post nos. 11 through 18 and 26 through 27 sustained varying degrees of bending, rotation, and twisting. Post nos. 13 and 15 twisted and rotated backward and downstream. Post no. 14 also twisted, rotated backward, and deflected downstream to the ground. Post no. 16 rotated backward and downstream, but did not twist. Post nos. 26 and 27 bent downstream, with post no. 26 bending to a greater extent than post no. 27. Post nos. 26 and 27 also sustained deformations at their tops. A soil gap of ⅜ in. (10 mm) was present at the front face of post no. 11. Soil gaps of 1 ¼ in. (32 mm) and 1 ¾ in. (44 mm) were present at the front and back faces of post no. 12, respectively. Soil gaps of 8 in. (203 mm), 5 in. (127 mm), 4 ¼ in. (108 mm), and 3 ¼ in. (83 mm) were present at the front faces of post nos. 13, 14, 16, and 17, respectively. A minimal soil gap was present at the front face of post no. 18, and a ½-in. (13-mm) soil gap was present at its back face. A 6-in. (152-mm) soil gap was present on the upstream side of post no. 26. The upstream anchorage system moved slightly longitudinally, but the downstream anchorage system did not. All four wood BCT posts in both anchorage systems remained undamaged.

The blockout at post no. 13 sustained minor damage near its bottom edge due to contact with the rail. The 4-in. (102-mm) deep blockout at post no. 14 fractured and detached, while the

8-in. (203-mm) deep blockout remained attached after sustaining damage from rail contact. The blockouts at post no. 15 twisted away from the post, bending the bolt, and the 4-in. (102-mm) deep blockout sustained a small fracture at its back face. The 4-in. (102-mm) deep blockout at post no. 16 also fractured and detached, while the 8-in. (203-mm) deep blockout remained attached by the deformed guardrail bolt. The 8-in. (203-mm) deep blockout at post no. 17 twisted, but remained attached to the post. All other blockouts remained attached to the posts and undamaged.

The permanent set of the barrier system is shown in Figure 27. The maximum permanent set rail and post deflections were 24 in. (610 mm) at post no. 15 and 28 in. (711 mm) at post no. 14, respectively, as measured in the field. The maximum lateral dynamic rail and post deflections were 50.5 in. (1,283 mm) at post no. 14 and 28.5 in. (724 mm) at post no. 13, respectively, as determined from high-speed digital video analysis. The working width was not determined due to vehicle rollover.

5.6 Vehicle Damage

The damage to the vehicle was extensive, as shown in Figures 39 through 43. Occupant compartment deformations were judged to be significant to cause serious injury to vehicle occupants. Deformations to the vehicle floorboard were relatively minor, with maximum longitudinal, lateral, and vertical deflections of ¼ in. (6 mm) located throughout the right-side floorboard, ½ in. (13 mm) located along the right side of the right-side floorboard, and 2 in. (51 mm) located near the center of the vehicle's floorboard, respectively. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Exterior damage was located on all portions of the vehicle. Both right-side wheel assemblies were detached from the vehicle. The right-front wheel spindle and assembly detached from the suspension control arms. The rear axle fractured at the right-rear wheel. The right-front quarter panel and bumper were deformed inward toward the engine compartment. Scrapes and gouges were found along the right-side doors and right-rear quarter panel. The right-side headlight and both rear tail lights fractured. The left side of the truck box was significantly deformed and bent away from the cab. Minor deformations occurred along the left-side doors, left-front quarter panel, and rear bumper. Both the left- and right-side mirrors disengaged from the truck. The hood and grill were slightly deformed and displaced. The roof was crushed inward, especially on the left side. The windshield was severely shattered and partially displaced. The right-front door, rear, and both left-side door window glass was fractured and removed from the vehicle. The right-rear door window glass remained undamaged.

5.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 5. It is noted that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV and PHD values are also shown in Table 5. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 20. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

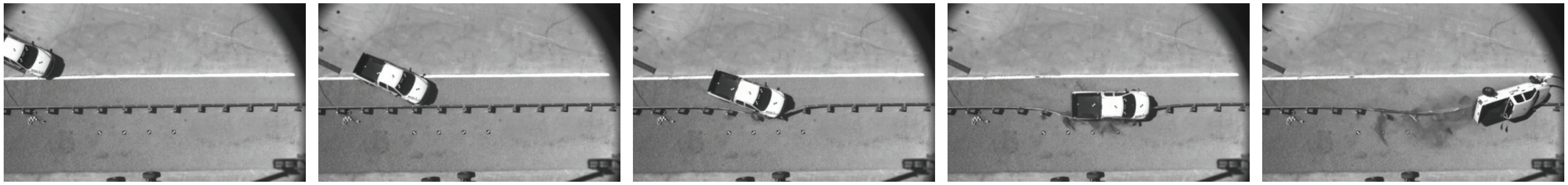
Table 5. Summary of OIV, ORA, THIV, and PHD Values, Test No. MGSC-5

		Transducer		
		EDR-4	**DTS**	**EDR-3**
OIV ft/s (m/s)	Longitudinal	-14.89 (-4.54)	-16.77 (-5.11)	-16.29 (-4.97)
	Lateral	-12.35 (-3.76)	-12.54 (-3.82)	-12.86 (-3.92)
ORA g's	Longitudinal	-13.49	-14.38	-14.12
	Lateral	-15.13	-16.33	-6.74
THIV ft/s (m/s)		18.21 (5.55)	20.06 (6.11)	--
PHD g's		14.37	15.40	--

5.8 Discussion

The analysis of the test results for test no. MGSC-5 showed that the MGS guardrail and curb configuration did not adequately contain nor redirect the 2270P vehicle, since 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 intrusions into the occupant compartment that could have caused serious injury did occur with the deformation of the vehicle's roof. Vehicle roll, pitch, and yaw angular displacements were noted, as shown in Appendix E, and were deemed unacceptable because they adversely influenced occupant risk safety criteria. Therefore, test no. MGSC-5 conducted on the MGS offset 8 ft (2.438 m) behind a 6-in. (152-mm) high curb was determined to be unacceptable according to test designation no. 3-11 of the TL-3 safety performance criteria found in MASH.

Following the unacceptable test results, the causes of vehicle rollover were determined from a series of events. As the vehicle impacted the guardrail, redirection was initiated; however, due to the upward lift of the truck following curb contact, the right-front wheel contacted the guardrail. As the system rotated, post no. 15 applied an upward force on the vehicle's front end, causing the front of the vehicle to pitch upward and the front bumper to rise above the guardrail. At this same time, the right-front wheel snagged on post no. 15, causing the pickup to roll toward the system. Subsequently, the right-front wheel detached from the vehicle due to the snag and was pulled underneath the pickup truck. As the vehicle continued along its path, the right-rear wheel then contacted the disengaged right-front wheel and overrode it. This caused the rear end of the vehicle to pitch upward, and shortly thereafter the vehicle became airborne. The pickup, which previously began to roll due to wheel snag, lost contact with the guardrail and continued to roll while airborne. This in turn caused the vehicle to roll over completely.



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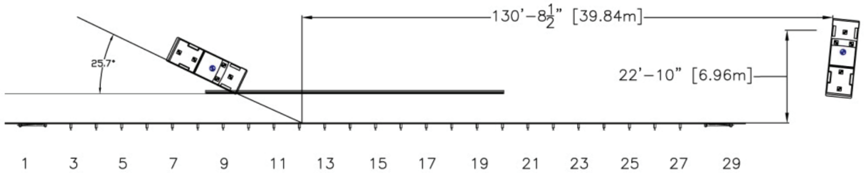
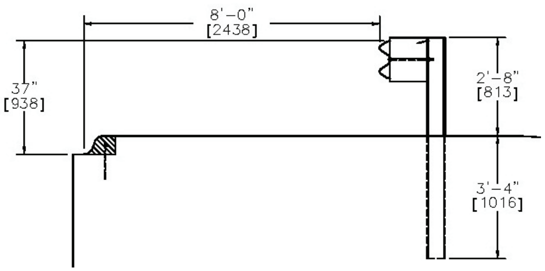




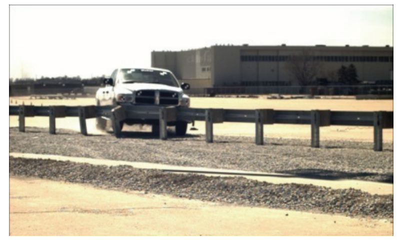
- Test Agency .... MwRSF
- Test Number MGSC-5
- Date .... April 8, 2009
- MASH Test Designation 3-11
- Test Article .... MGS offset 8 ft behind 6-in. high curb
- Total Length .... 175 ft (53.3 m)
- Key Component – Midwest Guardrail System
  - Length .... 175 ft (53.3 m)
  - Post Spacing .... 75 in. (1,905 mm)
- Key Component – AASHTO Type B Curb
  - Length .... 73 ft-6 in. (22.4 m)
  - Height .... 6 in. (152 mm)
- Soil Type .... Grade B, AASHTO M147-65 (1990)
- Vehicle Model .... 2003 Dodge Ram 1500 Quad Cab Pickup Truck
  - Curb .... 5,151 lb (2,336 kg)
  - Test Inertial .... 5,028 lb (2,281 kg)
  - Gross Static .... 5,198 lb (2,358 kg)
- Impact Conditions
  - Speed .... 61.9 mph (99.5 km/h)
  - Angle (Curb) .... 25.7 degrees
  - Angle (Guardrail) .... 24.4 degrees
  - Location .... 14 ft 7 ½ in. (4.6 m) US of splice between posts 14 and 15
- Exit Conditions
  - Speed .... N/A
  - Angle .... N/A
  - Exit Box .... N/A
- Vehicle Stability .... Unsatisfactory, rollover
- Vehicle Stopping Distance .... 130 ft-8 ½ in. (39.8 m) downstream
  22 ft-10 in. (7.0 m) traffic-side face
- THIV (EDR-4 – not required) .... 18.21 ft/s (5.55 m/s)
- PHD (EDR-4 – not required) .... 14.37 g's
- THIV (DTS – not required) .... 20.06 ft/s (6.11 m/s)
- PHD (DTS – not required) .... 15.40 g's
- Occupant Ridedown Acceleration (DTS)
  - Longitudinal .... -14.38 g's < 20.49 g's
  - Lateral .... -16.33 g's < 20.49 g's
- Occupant Impact Velocity (DTS)
  - Longitudinal .... -16.77 ft/s (-5.11 m/s) < 40 ft/s (12.2 m/s)
  - Lateral .... -12.54 ft/s (-3.82 m/s) < 40 ft/s (12.2 m/s)
- Occupant Ridedown Acceleration (EDR-4)
  - Longitudinal .... -13.49 g's < 20.49 g's
  - Lateral .... -15.13 g's < 20.49 g's
- Occupant Impact Velocity (EDR-4)
  - Longitudinal .... -14.89 ft/s (-4.54 m/s) < 40 ft/s (12.2 m/s)
  - Lateral .... -12.35 ft/s (-3.76 m/s) < 40 ft/s (12.2 m/s)
- Occupant Ridedown Acceleration (EDR-3)
  - Longitudinal .... -14.12 g's < 20.49 g's
  - Lateral .... -6.74 g's < 20.49 g's
- Occupant Impact Velocity (EDR-3)
  - Longitudinal .... -16.29 ft/s (-4.97 m/s) < 40 ft/s (12.2 m/s)
  - Lateral .... -12.86 ft/s (-3.92 m/s) < 40 ft/s (12.2 m/s)
- Vehicle Damage .... Extensive
  - VDS[14] .... 1-RFQ-4, 1-R&T-7
  - CDC[15] 01-RFAW3
  - Maximum Interior Deformation .... 2 in. (51 mm), center of floorboard
- Test Article Damage .... Moderate
- Test Article Deflections
  - Permanent Set .... 28 in. (711 mm)
  - Dynamic .... 50.5 in. (1,280 mm)
  - Working Width .... N/A
- Angular Displacements (EDR-4)
  - Roll .... 792 degrees
  - Pitch .... -25 degrees
  - Yaw .... -138 degrees

Figure 20. Summary of Test Results and Sequential Photographs, Test No. MGSC-5

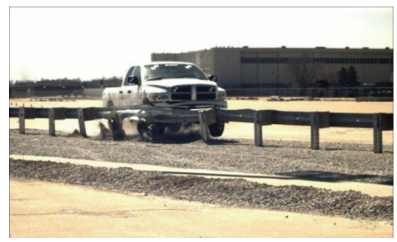

0.000 sec


-0.156 sec

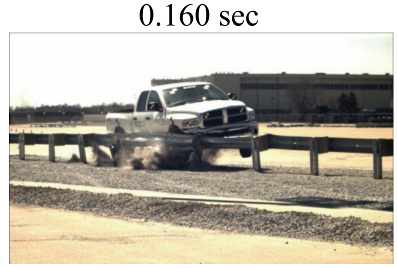
0.096 sec


0.062 sec

0.170 sec


0.160 sec


0.258 sec


0.220 sec


0.324 sec


0.324 sec


0.450 sec


0.556 sec

Figure 21. Additional Sequential Photographs, Test No. MGSC-5

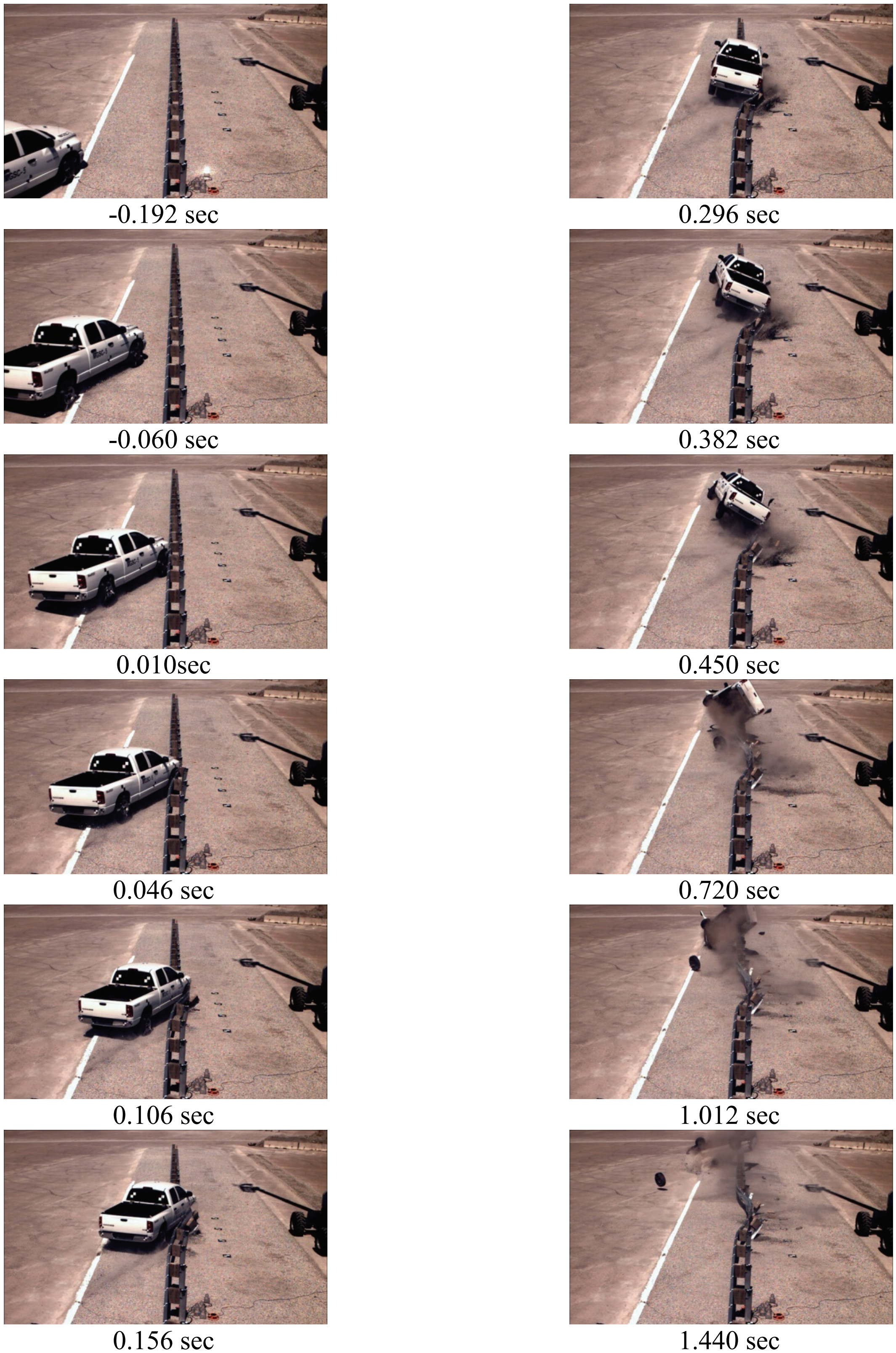


Figure 22. Additional Sequential Photographs, Test No. MGSC-5

Figure 23. Documentary Photographs, Test No. MGSC-5

Figure 24. Documentary Photographs, Test No. MGSC-5

Figure 25. Impact Location, Test No. MGSC-5

Figure 26. Vehicle Final Position and Trajectory Marks, Test No. MGSC-5

Figure 27. System Damage, Test No. MGSC-5

Figure 28. Curb Damage, Test No. MGSC-5

Figure 29. Rail Damage, Post Nos. 12 and 13, Test No. MGSC-5

Figure 30. Rail Damage, Post Nos. 14 and 15, Test No. MGSC-5

Figure 31. Rail Damage, Post Nos. 16 and 17, Test No. MGSC-5

Figure 32. Rail Damage, Post Nos. 21, 22, 26, and 27, Test No. MGSC-5

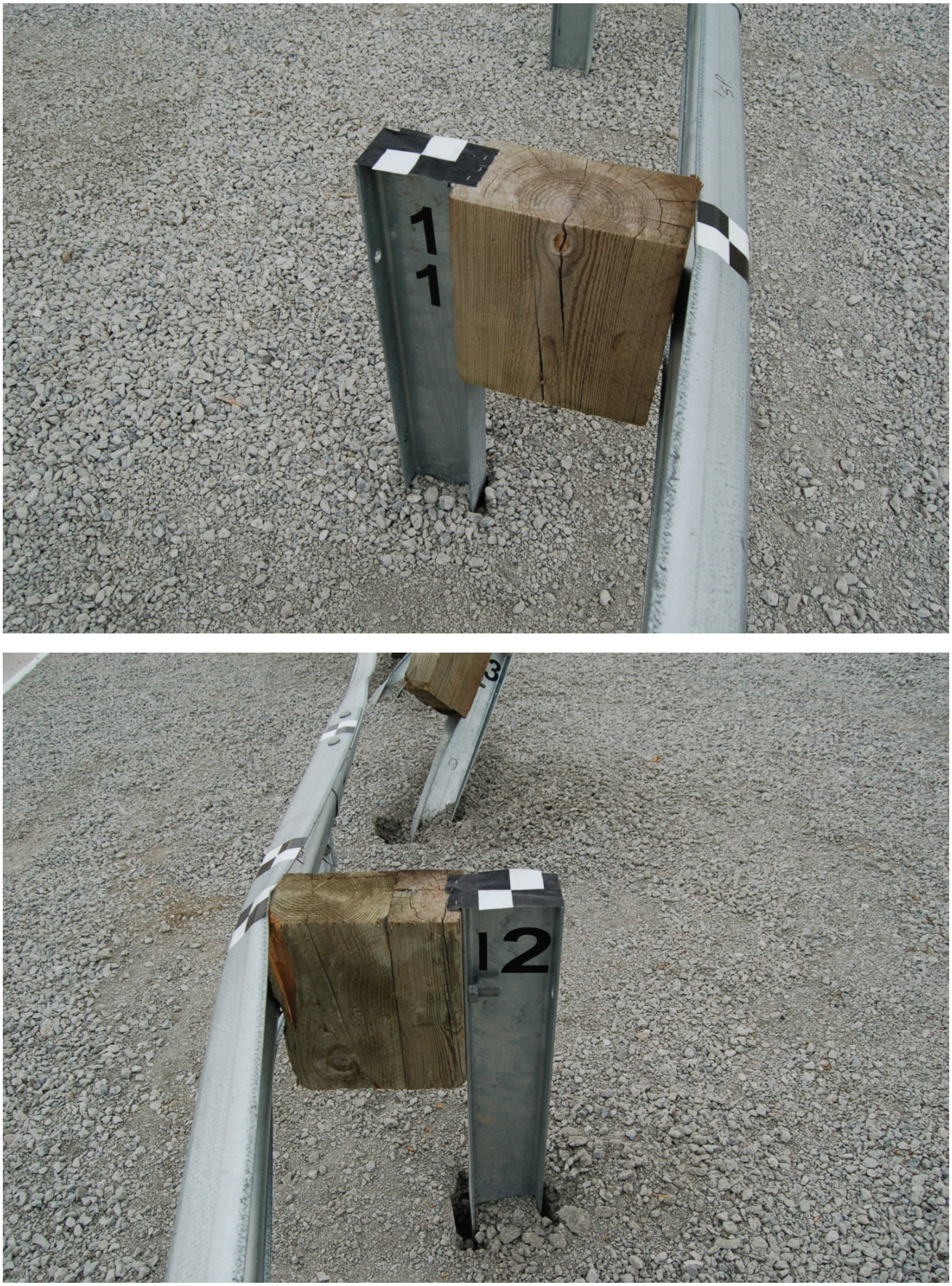


Figure 33. Post Nos. 11 and 12 Damage, Test No. MGSC-5

Figure 34. Post Nos. 13 and 14 Damage, Test No. MGSC-5

Figure 35. Post Nos. 15 and 16 Damage, Test No. MGSC-5

Figure 36. Post Nos. 17 and 18 Damage, Test No. MGSC-5

Figure 37. Post Nos. 26 and 27 Damage, Test No. MGSC-5

Figure 38. Upstream Anchorage Damage, Test No. MGSC-5

Figure 39. Vehicle Damage, Test No. MGSC-5

Figure 40. Vehicle Damage, Test No. MGSC-5

Figure 41. Vehicle Damage, Test No. MGSC-5

Figure 42. Undercarriage Damage, Test No. MGSC-5

Figure 43. Occupant Compartment Damage, Test No. MGSC-5

6 SUMMARY AND CONCLUSIONS

The MGS installed 8 ft (2.44 m) behind a 6-in. (152-mm) tall AASHTO Type B curb was constructed and full-scale crash tested. One full-scale vehicle crash test was performed according to test designation 3-11 as defined in MASH. The test consisted of a 5,198-lb (2,358-kg) pickup truck impacting the curb at a speed of 61.9 mph (99.5 km/h) and at an angle of 25.7 degrees. After mounting the curb, the vehicle impacted the guardrail at an angle of 24.4 degrees. The impact point for this test was 14 ft 7 ½ in. (4.6 m) upstream of the splice between posts 14 and 15. The vehicle began to redirect, but became unstable during the event and rolled multiple times. This rollover is believed to have been caused by the upward lift of the pickup truck following impact with the curb, snag and disengagement of the right-front tire, and subsequent override of the detached tire by the right-rear tire. Thus, this test was judged to be unacceptable according to the safety performance criteria presented in MASH. A summary of the safety performance evaluation is provided in Table 6.

Table 6. Summary of Safety Performance Evaluation Results

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. MGSC-5</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>U</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D.</td><td>Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td><td>U</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>U</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocities (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:
<table><tr><th colspan="3">Occupant Impact Velocity Limits, ft/s (m/s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr></table></td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:
<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits (g's)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15.0 g's</td><td>20.49 g's</td></tr></table></td><td>S</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Available

7 REFERENCES

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11. Zhu, L., Reid, J.D., Faller, R.K., Bielenberg, R.W., Sicking, D.L., Polivka, K.A., Rohde, J.R., *Installation Guidelines for MGS and 6-in. High, AASHTO Type B Curb Combination – Part I: Vehicle-Curb Testing and LS-DYNA Analysis*, Final Report to the Regional Pooled Fund Program, Transportation Research Report No. TRP-03-205-09, Project No. SPR-3 (017)-Year 17, Project Code RPFP-07-03, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, May 6, 2009.

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8 APPENDICES

Appendix A. Material Specifications

This Shipping Order must be filled in, in ink, in indelible Pencil, or in Carbon, and retained by the Agent

Carrier's Pro No.
Shipper's Bill of Lading No.
Consignee's Reference/PO No.
Carrier's Code (SCAC)

(Name of Carrier)

RECEIVED, subject to individually determined rates or contracts that have been agreed upon in writing between the carrier and shipper, if applicable, otherwise to the rates, classifications and rules that have been established by the carrier and are available to the shipper on request;

at March 24 20 09 From

the property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown), marked, consigned, and destined as indicated below, which said carrier (the word carrier being understood throughout this contract as meaning any person or corporation in possession of the property under the contract), agrees to carry to its usual place of delivery at said destination, if on its route, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any said property, that every service to be performed hereunder shall be subject to all the terms and conditions of the Uniform Domestic Straight Bill of Lading set forth (1) in Official, Southern, Western and Illinois Freight Classification in effect on the date hereof, if this is a rail or a rail-water shipment, or (2) in the applicable motor carrier classification or tariff if this is a motor carrier shipment.

Shipper hereby certifies that he is familiar with all the terms and conditions of the said bill of lading, including those on the back thereof, set forth in the classification or tariff which governs the transportation of this shipment, and the said terms and conditions are hereby agreed to by the shipper and accepted for himself and his assigns.

Consigned to Midwest Roadside Safety Facility

(Mail or street address of consignee – For purposes of notification only.)

Destination Air Park **State** NE. **Zip** **County** **Delivery Address ★**

★ To be filled in only when shipper desires and governing tariffs provide for delivery thereof.

Route Lincoln

Delivering Carrier **Car or Vehicle Initials** **No.**

No. Packages	Kind of Package, Description of Articles, Special Marks, and Exceptions	*WEIGHT (Subject to Correction)	Class or Rate	Check Column
24	W6 X 8.5 X 6-0 steel post			
	A. Tom McMaster			

Subject to Section 7 of Conditions of applicable bill of lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement.
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

(Signature of Consignor)

Freight charges are PREPAID unless marked collect. CHECK BOX IF COLLECT ☐

Received $ ____ to apply in prepayment of the charges on the property described hereon.

Agent or Cashier

Per ____ (The signature here acknowledges only the amount prepaid.)

Charges Advanced:

$ ____

†Shipper's imprint in lieu of stamp; not a part of Bill of Lading approved by the Interstate Commerce Commission.

* If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading state whether it is carrier's or shipper's weight.
NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.
The agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding ____ per ____

Liability Limitation for loss or damage on this shipment may be applicable. See 49 U.S.C. § 14706(c)(1)(A) and (B).

†The fibre boxes used for this shipment conform to the specifications set forth in the box maker's certificate thereon, and all other requirements of the Consolidated Freight Classification.

Midwest Machinery **Shipper, Per** Ray S.

Agent must detach and retain this Shipping Order and must sign the Original Bill of Lading.

Permanent post-office address of shipper

2

REDIFORM

Carbonless Speediset® Forms
Rediform, Inc. Made in Canada

44-301•Triplicate
44-302•Quadruplicate

Figure A-1. W6x8.5 Post Material Certification, Test No. MGSC-5

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Project: RESALE

Order Number: 1104828
Customer PO: 2095
BOL Number: 26405
Document #: 1
Shipped To: NE
Use State: KS

As of: 2/2/09

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
634	545G	6'0 POST/DB:DDR	A-709			22479790	49,600	69,100	23.8	0.100	0.790	0.033	0.032	0.200	0.440	0.00	0.200	0.002	4
100	901G	12/FLARE/8 HOLE	M-180	A		583168	71,200	77,900	27.0	0.061	0.750	0.016	0.015	0.012	0.071	0.00	0.051	0.000	4

24 Posts purchased 3/24/09
#002

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 2nd day of February, 2009

Notary Public:
Commission Expires:

RACHEL R. MEDINA
Notary Public
STATE OF TEXAS
My Comm. Exp. 07/19/2009

Trinity Highway Products, LLC
Certified By: Stefanie Inglet
Quality Assurance

Figure A-2. W6x8.5 Post Material Certification, Test No. MGSC-5

03/09/2009 14:21 4024722022 MWRSF PAGE 01

RECEIVED
OCT 05 2005
UNL FMP

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. P.O. Box 80508
Canton, Ohio 44708

Test Report

Customer: UNIVERSITY OF NEBRASKA-LINCOLN
401 CANFIELD ADMIN BLDG
P O BOX 880439
LINCOLN, NE. 68588-0439

B.O.L. #: 15808 DATE SHIPPED: 09/27/05
Customer P.O.: VERBAL JOHN ROHDE
Shipped to: UNIVERSITY OF NEBRASKA-LINCOLN
Project: STOCK
GHP Order No.: 44822

HEAT #	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
3390	0.21	0.8	0.013	0.007	0.01	81660	62520	20.76	160		2	12GA 12FT6IN/3FT1 1/2IN WB T2

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-525
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin

By: [signature]
Andrew Artar
Vice President of Sales and Marketing
Gregory Highway Products, Inc.

RECEIVED
OCT 3 2005
UNL ACCOUNTING

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 28th day of September, 2005
[signature]
Dawn R. Batton
Notary Public, State of Ohio
My Commission Expires February 24, 2008

Figure A-3. W-Beam Material Certification, Test No. MGSC-5

Certified Test Report

NORTH STAR BLUESCOPE STEEL LLC
6767 County Road 9
Delta, Ohio 43515
Telephone: (888) 822-2112

Customer:
Lawson Steel, Inc.
3238 E. 82nd St.
Cleveland, OH 44104
Customer P.O.: 021336
Cust. Ref/Part # n/a

Order Number	171137	**Ordered Width (mm/in)**	1454.150 / 57.250
Line Item Number	1	**Ordered Gauge (mm/in)**	2.438 / 0.096
Heat Number	111813	**Material Description**	ASTM A568, 1018 CQ Modified
Coil Number	842536	**Production Date/Time**	Mar 1 2008 5:41PM

Heat Chemical Analysis (wt%)

Type	C	Mn	P	S	Si	Al	Cu	Cr	Ni	Mo	Sn	N	B	V	Nb	Ti	Ca
Heat	0.19	0.73	0.012	0.003	0.03	0.02	0.09	0.04	0.03	0.01	0.00	0.005	0.0000	0.000	0.000	0.002	0.002

Mechanical Test Report

All mechanical tests are performed on a sample from the tail of a coil.

Yield Strength	Tensile Strength	% Elongation in 2 inches
64,860 psi	83,230 psi	23.5%

This material has been produced and tested in accordance with each of the following applicable standards: ASTM E 1806-96, ASTM E 415-99a, ASTM A 751-01, ASTM A 370-03a, JIS Z2201:1998, JIS Z 2241:1998. This report certifies that the above test results are representative of those contained in the records of North Star BlueScope Steel LLC for the material identified in this test report and is intended to comply with the requirements of the material description. North Star BlueScope Steel LLC is not responsible for the inability of this material to meet specific applications. Any modifications to this certification as provided negates the validity of this test report. All reproductions must have the written approval of North Star BlueScope Steel. This product was manufactured, melted, cast, and hot-rolled (min. 3:1 reduction ratio), entirely within the U.S.A at North Star BlueScope Steel LLC, Delta, Ohio. This material was not exposed to Mercury or any alloy which is liquid at ambient temperature during processing or while in North Star BlueScope Steel LLC possession. Test equipment calibration certificates are available upon request. NIST traceability is established through test equipment calibration certificates which are available upon request. Uncertainty calculations are calculated in accordance with NIST standards and are maintained at a 4:1 ratio in accordance with NIST standards. Uncertainty data is available upon request.

Tim Mitchell — **Manager Quality Assurance and Technology**

Date Issued: Mar 12, 2008 11:00:32
Revision#: 01

Figure A-4. W-Beam Material Certification, Test No. MGSC-5

Aug. 12. 2008 6:34PM TRINITY SHIPPING 419 227 0019 No. 8811 P. 1/12

COMMERCIAL GROUP LIFTING PRODUCTS
2427 East Judd Rd., Burton, MI 48529 • Phone (810) 744-4540 • Fax (810) 744-1588

3000G

JULY 28TH, 2008

6-6 cables

TRINITY INDUSTRIES
PLANT # 55
425 E. O'CONNOR
LIMA, OHIO 45801

ATTN: MR. KEITH HAMBURG

ENCLOSED ARE THE NECESSARY COMPLIANCE CERTIFICATES FOR YOUR PURCHASE ORDER # 126446 B RELEASE # 26. THESE CERTIFICATES ARE FOR YOUR PART # 003000G (1,000) PCS 3/4" X 6'6" DOUBLE SWAGE GUARD RAIL ASSEMBLIES. THEY SHOW THE DOMESTICITY OF ALL MATERIAL USED, MELTED AND MANUFACTURED IN THE USA.

VERY TRULY YOURS

Joe Carpenter
JOE CARPENTER
OFFICE / CUSTOMER SERVICE MGR

08/12/2008 15:59 402-761-3288 MIDWEST MACHINERY PAGE 01/19

Figure A-5. Anchor Cable Certificate of Compliance, Test No. MGSC-5

WireCo
WorldGroup

April 2, 2008

Order No. 1596192

CERTIFICATION OF COMPLIANCE

This is to certify that the diameter, strand construction, minimum breaking strength, and wire coating weights for RP122260 3/4 6x19W RR A741 CL-A SC-US produced on SJR2227 are in accordance with ASTM A741-98(2003) titled "Standard Specification for Zinc Coated Steel Wire Rope and Fittings for Highway Guard Rail".

All wire and rope manufacturing processes occurred in the United States.
All steel used was melted and manufactured in the United States.

ACTUAL TEST DATA

MEASURED ROPE DIAMETER:	.750		
STRAND CONSTRUCTION:	19 WARRINGTON 1-6-(6+6)		
BREAKING STRENGTH:	69,000 pounds	Req'd. 42,800 pounds	
ZINC COATING WEIGHTS (Class A):	Wire Dia.	Min. Oz/ft^2	Avg. Oz/ft^2
	.395"	N/A	.42
	.460"	.40	.43
	.540"	.40	.63
	.610"	.40	.45

WIRE ROPE CORPORATION OF AMERICA, INC.

Administrator Engineering Information

12200 NW Ambassador Drive, Kansas City, MO 64163-1244
T 816-270-4700 F 816-270-4707 www.WireCoWorldGroup.com

AUG.12.2008 6:34PM TRINITY SHIPPING 419 227 0019 NO.8811 P. 2/12
08/12/2008 15:59 402-761-3288 MIDWEST MACHINERY PAGE 08/13

Figure A-6. Anchor Cable Certificate of Compliance, Test No. MGSC-5

WireCo WorldGroup

4/2/08

Certificate of Compliance

Report of Chemical Analysis and Physical Tests

Customer: The Commercial Group
G-2427 E Judd
Road
Burton, MI 48529

Order No. 1596192 | Reel numbers SJR2227-01 | Rope Description 3/4 6x19W RR A741 CL-A SC-US

Item		Tensile Strength		Wt.	Torsion Test	Heat					
No.	Description	Lbs.	Lbs. per sq. in.	Coat	8"	No.	C	Mn	P	S	Si
001	.0395" Galvanized Wire										
	0.0395	334	273,000	.430	85	07R513018	.77	.57	012	011	.25
						07R514031	79	.59	014	.014	.22
		295	241,000	.410	84	07R513018	.77	.57	012	.011	25
002	.0460" Galvanized Wire										
	0.0460	443	267,000	.442	55	07R506543	78	.54	.008	.016	.23
		420	253,000	.400	67	07R514031	.79	.59	.014	014	.22
		421	253,000	.420	67	07R506543	.78	.54	.006	.016	.23
		458	276,000	.464	77	06R503889	.81	.54	015	.012	.20
		443	267,000	.400	67	07R506543	78	.54	.008	.016	.23
003	.0540" Galvanized Wire										
	0.0540	638	279,000	.630	54	07G46700	.77	.56	.004	.006	22
004	.0610" Galvanized Wire										
	0.0610	818	280,000	.440	49	07R509396	.77	.56	010	.009	.22
						00G33836	.80	.54	007	.016	.24
		760	260,000	.430	60	07G47297	.76	.54	.007	.007	.24
		800	274,000	.447	44	07R509397	.77	.56	.011	.007	.23
						00G33833	78	52	.003	010	.24
		767	262,000	.485	47	07R509397	.77	.56	.011	.007	.23
						07R506811	.79	.57	008	.013	.17

The material covered by this certification was manufactured and tested in accordance with specifications as listed above. We certify that representative samples of the material have been tested and the results conform to the requirements outlined in these specifications.

The chemical, physical, or mechanical tests reported above are correct as contained in the records of the corporation.

Signed: C. Kelli Smith

12200 NW Ambassador Drive, Kansas City, MO 64163-1244
T 816-270-4700 F 816-270-4707 www.WireCoWorldGroup.com

AUG. 12. 2008 6:35PM TRINITY SHIPPING 419 227 0019 NO. 881 P. 3/12

08/12/2008 15:59 402-761-3288 MIDWEST MACHINERY PAGE 09/19

Figure A-7. Anchor Cable Certificate of Compliance, Test No. MGSC-5

SJR 2227

Rocky Mountain Steel Mills
P.O. Box 316
Pueblo, CO 81002 USA

MATERIAL TEST REPORT

Date Printed: 29-JUN-06

Date Shipped: 29-JUN-06	Product: ROD 7/32"	Specification: AISI 1075	
Mts ASTM A-510	PWIF: 77186613	Customer: WIRE ROPE CORPORATION OF AMERICA, INC.	Cust. PO: FQ-00761

CHEMICAL ANALYSIS

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ca	Ti
503889	0.81	0.54	0.015	0.012	0.20	0.21	0.08	0.11	0.018	0.003	0.002	0.0002	0.000	0.010	0.0065	0.0001	0.001

MECHANICAL PROPERTIES

	Ultimate (Psi)	Red/Area (%)	Size	Ovality
Minimum	171280	26.8	.221	.008
Maximum	178100	34.4	.221	.008
Average	173653	30.7	.221	.008
Std. Dev	2088	2.6	.000	.000
Count	10	10	10	10

ALL MELTING AND MANUFACTURING PROCESSES OF THE MATERIAL SUBJECT TO THIS TEST CERTIFICATE OCCURRED IN THE UNITED STATES OF AMERICA.

THIS MATERIAL HAS BEEN PRODUCED AND TESTED IN ACCORDANCE WITH THE REQUIREMENTS OF THE APPLICABLE SPECIFICATIONS. WE HEREBY CERTIFY THAT THE ABOVE TEST RESULTS REPRESENT THOSE CONTAINED IN THE RECORDS OF THE COMPANY.

Mark f Luparell

Quality Assurance Department

Figure A-8. Anchor Cable Certificate of Compliance, Test No. MGSC-5

Rocky Mountain Steel Mills
P.O. Box 316
Pueblo, CO 81002 USA

SDR22257

MATERIAL TEST REPORT

Date Printed: 15-FEB-07

Date Shipped: 15-FEB-07	Product: ROD 7/32"	Specification: AISI 1075	
Mls ASTM A-510	PWIP: 77186613	Customer: WIRE ROPE CORPORATION OF AMERICA, INC.	Cust. PO: P000785

CHEMICAL ANALYSIS

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ca	Ti
506543	0.78	0.54	0.006	0.016	0.23	0.16	0.06	0.06	0.017	0.002	0.001	0.0002	0.000	0.008	0.0071	0.0003	0.001

MECHANICAL PROPERTIES

	Ultimate (Psi)	Red/Area (%)	Size	Quality
Minimum	161380	33.9	.219	.004
Maximum	167680	45.9	.220	.006
Average	164760	37.4	.219	.005
Std. Dev	2003	4.3	.000	.001
Count	10	10	10	10

ALL MELTING AND MANUFACTURING PROCESSES OF THE MATERIAL SUBJECT TO THIS TEST CERTIFICATE OCCURRED IN THE UNITED STATES OF AMERICA.

THIS MATERIAL HAS BEEN PRODUCED AND TESTED IN ACCORDANCE WITH THE REQUIREMENTS OF THE APPLICABLE SPECIFICATIONS. WE HEREBY CERTIFY THAT THE ABOVE TEST RESULTS REPRESENT THOSE CONTAINED IN THE RECORDS OF THE COMPANY.

Mark F. Lapanee
Quality Assurance Department

Figure A-9. Anchor Cable Certificate of Compliance, Test No. MGSC-5

Rocky Mountain Steel Mills
P.O. Box 316
Pueblo, CO 81002 USA

SJR 222

MATERIAL TEST REPORT

Date Printed: 14-FEB-07

Date Shipped: 14-FEB-07	Product: ROD 7/32"	Specification: AISI 1075
Mts ASTM A-510	FWIP: 77186613	Customer: WIRE ROPE CORPORATION OF AMERICA, INC. Cust. PO: P800785

CHEMICAL ANALYSIS

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ca	Ti
508811	0.79	0.57	0.008	0.013	0.17	0.14	0.05	0.06	0.009	0.002	0.001	0.0002	0.000	0.007	0.0064	0.0001	0.001

MECHANICAL PROPERTIES

	Ultimate (Psi)	Red/Area (%)	Size	Ovality
Minimum	161690	28.7	.218	.007
Maximum	166620	39.1	.218	.007
Average	163407	33.2	.218	.007
Std. Dev	1347	2.7	.000	.000
Count	10	10	10	10

ALL MELTING AND MANUFACTURING PROCESSES OF THE MATERIAL SUBJECT TO THIS TEST CERTIFICATE OCCURRED IN THE UNITED STATES OF AMERICA.

THIS MATERIAL HAS BEEN PRODUCED AND TESTED IN ACCORDANCE WITH THE REQUIREMENTS OF THE APPLICABLE SPECIFICATIONS. WE HEREBY CERTIFY THAT THE ABOVE TEST RESULTS REPRESENT THOSE CONTAINED IN THE RECORDS OF THE COMPANY.

Mark F. Lupamer

Quality Assurance Department

Figure A-10. Anchor Cable Certificate of Compliance, Test No. MGSC-5

08/12/2008 16:59 402-761-3288 MIDWEST MACHINERY

AUG.12. 2008 6:35PM TRINITY SHIPPING 419 227 0019 NO.8811 P. 7/12

Rocky Mountain Steel Mills
P.O. Box 316
Pueblo, CO 81002 USA

SJR 2227

MATERIAL TEST REPORT

Date Printed: 21-MAR-07

Date Shipped: 21-MAR-07	Product: ROD 7/32"	Specification: AISI 1075
Mts ASTM A-510	FWIP: 77186613	Customer: WIRE ROPE CORPORATION OF AMERICA, INC. Cust. PO: BB00297

CHEMICAL ANALYSIS

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ca	Ti
509397	0.77	0.56	0.011	0.007	0.23	0.12	0.05	0.09	0.010	0.002	0.001	0.0003	0.001	0.007	0.0050	0.0003	0.001

MECHANICAL PROPERTIES

	Ultimate (Psi)	Red/Area (%)	Size	Ovality
Minimum	165130	32.4	.218	.005
Maximum	169490	38.3	.218	.005
Average	167678	35.7	.218	.005
Std. Dev	1401	2.0	.000	.000
Count	10	10	10	10

ALL MELTING AND MANUFACTURING PROCESSES OF THE MATERIAL SUBJECT TO THIS TEST CERTIFICATE OCCURRED IN THE UNITED STATES OF AMERICA.

THIS MATERIAL HAS BEEN PRODUCED AND TESTED IN ACCORDANCE WITH THE REQUIREMENTS OF THE APPLICABLE SPECIFICATIONS. WE HEREBY CERTIFY THAT THE ABOVE TEST RESULTS REPRESENT THOSE CONTAINED IN THE RECORDS OF THE COMPANY.

Quality Assurance Department

Figure A-11. Anchor Cable Certificate of Compliance, Test No. MGSC-5

Rocky Mountain Steel Mills
P.O. Box 316
Pueblo, CO 81002 USA

SJR 2227

MATERIAL TEST REPORT

Date Printed: 12-SEP-07

Date Shipped: 12-SEP-07	Product: ROD 7/32"	Specification: ASTM-A-510 AISI 1075
Mts ASTM A-510	FWIP: 77186613	Customer: WIRE ROPE CORPORATION OF AMERICA, INC. Cust. PO: P000807

CHEMICAL ANALYSIS

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ca	Ti
513018	0.77	0.57	0.012	0.011	0.25	0.18	0.06	0.09	0.015	0.002	0.001	0.0002	0.000	0.009	0.0059	0.0004	0.001

MECHANICAL PROPERTIES

	Ultimate (Psi)	Red/Area (%)	Size	Ovality
Minimum	161510	35.4	.218	.005
Maximum	170970	40.0	.219	.005
Average	165983	36.7	.218	.005
Std. Dev	2805	1.2	.000	.000
Count	10	10	10	10

ALL MELTING AND MANUFACTURING PROCESSES OF THE MATERIAL SUBJECT TO THIS TEST CERTIFICATE OCCURRED IN THE UNITED STATES OF AMERICA.

THIS MATERIAL HAS BEEN PRODUCED AND TESTED IN ACCORDANCE WITH THE REQUIREMENTS OF THE APPLICABLE SPECIFICATIONS. WE HEREBY CERTIFY THAT THE ABOVE TEST RESULTS REPRESENT THOSE CONTAINED IN THE RECORDS OF THE COMPANY.

Quality Assurance Department

Figure A-12. Anchor Cable Certificate of Compliance, Test No. MGSC-5

08/12/2008 16:59 402-761-3288 MIDWEST MACHINERY PAGE 13/13

AUG.12. 2008 6:36PM TRINITY SHIPPING 419 227 0019 NO.8811 P. 9/12

Rocky Mountain Steel Mills
P.O. Box 316
Pueblo, CO 81002 USA

STR 22

MATERIAL TEST REPORT

Date Printed: 25-OCT-07

Date Shipped: 25-OCT-07	Product: ROD 7/32"	Specification: ASTM-A-510 AISI 1075
Mfs ASTM A-510	FWIP: 77186613	Customer: WIRE ROPE CORPORATION OF AMERICA, INC. Cust PO: P000811

CHEMICAL ANALYSIS

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ca	Ti
514831	0.79	0.59	0.014	0.014	0.22	0.18	0.06	0.11	0.018	0.002	0.007	0.0002	0.000	0.008	0.0054	0.0005	0.001

MECHANICAL PROPERTIES

	Ultimate (Psi)	Red/Area (%)	Size	Ovality
Minimum	169960	34.1	.218	.005
Maximum	173490	40.5	.219	.005
Average	171989	36.9	.218	.005
Std. Dev	963	1.9	.000	.000
Count	10	10	10	10

ALL MELTING AND MANUFACTURING PROCESSES OF THE MATERIAL SUBJECT TO THIS TEST CERTIFICATE OCCURRED IN THE UNITED STATES OF AMERICA.

THIS MATERIAL HAS BEEN PRODUCED AND TESTED IN ACCORDANCE WITH THE REQUIREMENTS OF THE APPLICABLE SPECIFICATIONS. WE HEREBY CERTIFY THAT THE ABOVE TEST RESULTS REPRESENT THOSE CONTAINED IN THE RECORDS OF THE COMPANY.

Mark Espamer

Quality Assurance Department

Figure A-13. Anchor Cable Certificate of Compliance, Test No. MGSC-5

SJK2221/

MITTAL

T/S 1 of 1
Page: 1 of 1
Date: 09-30-2007

Bill Of Lading & Certified Mill Test Report

Sold To	: 50023 WIRE ROPE CORP - CHILL	Ship To	: 29212 WIRE ROPE-CHILLI
Load #	: 105920	ICN/Line	: 071188/1
PO #	: P000806/RD219/75	Part#	: RD219-75
Size	: 7/32	Grade	: 75
Ship Mode	: RR	Frt Terms	: PD
Carrier	: CSX Transportatio(305)	Vehicle	: TTJX80111
Consigned	: N	Wgt Source	: Coil
Pieces	: 38	Weight	: 154,640 Lbs

Heat: 46700 Charge: 768 Pieces: 38 Weight: 154,640 LBS

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Sn	Al	B	N	Nb
0.77	0.56	0.004	0.006	0.22	0.06	0.03	0.03	0.006	0.00	0.00	0.002	0.000	0.006	0.00

Ti	Ca
0.001	0.000

Low Tensile	High Tensile	Average Tensile	Reduction Of Area
160,000	161,200	160,700	47%

COIL	146	147	149	151	156	157	158	159	160	161	163	164	165	166	167
LBS	4069	4065	4108	4071	4147	4048	4139	4144	4105	3945	3065	4111	4159	4112	4155
COIL	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182
LBS	4107	4077	4075	4164	4067	4101	4110	4165	4161	4055	4091	4062	4107	4145	3990
COIL	183	184	185	186	187	188	189	190							
LBS	4062	4060	4096	4100	4148	4103	4105	4056							

10/12/2007

This material was tested with the necessary specifications for the ordered product and was found to be in conformance. The report must not be reproduced except in full and relates only to the item(s) tested. Certified to be in accordance with relevant data on file at ISG Georgetown Inc., and in conformance with ordered specifications. Chemical analysis values are reported in % concentration and performed in accord with accredited test methods within the scope of accreditation on file. 100% Melted and Manufactured at ISG Georgetown Inc., Georgetown, South Carolina USA.

William J Jillas
Superintendent Quality Assurance

AUG.12. 2008 6:38PM TRINITY SHIPPING 419 227 0019 NO.8811 P. 10/12
08/12/2008 16:59 402-761-3288 MIDWEST MACHINERY PAGE 16/19

Figure A-14. Anchor Cable Certificate of Compliance, Test No. MGSC-5

SJ Kanai

MITTAL

...67 : T/S 2 of 2
...ge 1 of 1
...ate: 09-28-2007

Bill Of Lading & Certified Mill Test Report

Sold To	: 50023 WIRE ROPE CORP - CHILL	Ship To	: 29212 WIRE ROPE-CHILLI
Load #	: 105922	ICN/Line	: 071185/1
PO #	: P000806/RD219/10/165	Part#	: RD219-10-165
Size	: 7/32	Grade	: 165-10
Ship Mode	: RR	Frt Terms	: PD
Carrier	: CSX Transportatio(305)	Vehicle	: CSXT709114
Consigned	: N	Wgt Source	: Coil
Pieces	: 38	Weight	: 152,390 Lbs

OK for spec 15 GB 10/12/2008

Heat: 47297 Charge: 421 Pieces: 38 Weight: 152,390 LBS

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Sn	Al	B	N	Nb
0.76	0.54	0.007	0.007	0.24	0.04	0.02	0.02	0.003	0.00	0.00	0.002	0.000	0.005	0.00

Ti	Ca
0.001	0.001

Low Tensile	High Tensile	Average Tensile	Reduction Of Area
161,100	165,400	163,400	44%

COIL	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207
LBS	4038	4070	4057	4032	4080	4066	4042	4092	4066	4085	4040	4074	4082	4042	4070
COIL	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222
LBS	4084	4041	4083	4091	2103	4015	4080	4052	4035	4082	4040	4071	4080	4035	4074
COIL	223	224	225	226	227	230	231	232							
LBS	4081	4039	4070	4080	4052	4031	4064	4071							

C-8

This material was tested with the [illegible] and was found to be in conformance. The report must not be reproduced except in full and relates only to the item(s) tested. Certified to be in accordance with relevant data on file at ISG Georgetown Inc., and in conformance with ordered specifications. Chemical analysis values are reported in % [illegible] and performed in accord with accredited test methods within the scope of accreditation on file. 100% Melted and Manufactured at ISG Georgetown Inc., Georgetown, South Carolina USA.

W J Jarac
William J Jarac
Superintendent Quality Assurance

AUG. 12. 2008 6:36PM TRINITY SHIPPING 419 227 0019 NO. 8811 P. 11/12

08/12/2008 16:59 402-761-3288 MIDWEST MACHINERY PAGE 17/19

Figure A-15. Anchor Cable Certificate of Compliance, Test No. MGSC-5

Steel Dynamics, Inc.
Engineered Bar Products Division

8500 N. County Road 225 East
Pittsboro, IN 46167
Phone: (317) 892-7000
Fax: (317) 892-7265

Certified Material Test Report

Cert #: 47916	Mill Order: 0801504	Heat #: A080409	Issued: 2/21/2008 10:12:24
Work Order: 56762	Sales Order: 41777-1	Customer: New Dimension Metals Cor	PO #: 14168-1
Load #: 68070	Reference #:	Reference Desc:	End Use:
Size: 1-5/8"	Shape: Round	Grade: 1035	Length: 20'00"
Grain Practice: Al Fine Grain (5-8) per ASTM A29		Reduction Ratio: 67.9 to 1	Disposition: 1

Ladle Chemistry Analysis (ASTM A29)

C	Mn	P	S	Si	Al	Cu	Ni	Cr	Mo	Sn	N	V	Cb	B	Ca	W	Ti	DI
0.37	0.74	0.023	0.019	0.26	0.027	0.26	0.10	0.14	0.02	0.012	0.0085	0.003	0.001	0.0002	0.0000	0.000	0.019	1.28

Pb	Co	As	Sb	H	Ceq
0.000	0.007	0.007	0.006	1.2	0.51

Product Check Analysis (ASTM A29)

	C	Mn	P	S	Si	Al	Cu	Ni	Cr	Mo	Sn	N	V	Cb	Ti	B	Ca
Front																	
Back																	

Jominy (ASTM A255)

	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J12	J14	J16	J18	J20	J24	J28	J32
Calc'd																		
Front																		
Back																		

Microcleanliness (ASTM E45)

Method A								Method C		Method E		Austenitic Grainsize	Macrostructure ASTM E381		
AT	AH	BT	BH	CT	CH	DT	DH	S	O	SAM "B"	SAM "D"		S	R	C

Mechanical Properties (ASTM A370)

Tensile Properties				Hardness		Magnetic Particle Inspection	
Tensile Strength	0.2% Yield Strength	% Elong (2")	% ROA	(MR)	(Surf)	Frequency	Severity

Steel Dynamics - Engineered Bar Products has a quality system in place which has been certified ISO 9001:2000 compliant.

Comments/Specs:

ASTM A576-90b (latest rev.) — Electric Arc Furnace Melted - Vacuum Tank Degassed

Condition: As-Rolled, Hot-Rolled

I hereby certify that the content of this report is correct and accurate, and that all tests and operations performed on this material were in compliance with applicable material specifications and purchaser designated requirements.

Garrett Bouyea - Rolling Mill Metallurgist

Any alteration to this report voids Steel Dynamic's warranting of results. No weld repair has been performed on this material. This material is not radioactive and has not been exposed to radioactivity while under the control of Steel Dynamics. This material has not been exposed to mercury while under the control of Steel Dynamics. Unless otherwise noted, this material was melted, continually cast, and rolled in the USA; w/ all testing performed by Steel Dynamics.

AUG.12.2008 6:37PM TRINITY SHIPPING 419 227 0019 NO.881 P.12/12

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Figure A-16. Anchor Cable Certificate of Compliance, Test No. MGSC-5

CAUTION
FRESH CONCRETE

Body and or eye contact with fresh (moist) concrete should be avoided because it contains alkali and is caustic.

Ready Mixed Concrete Company

6200 Cornhusker Highway, P.O. Box 29288
Lincoln, Nebraska 68529
Telephone 402-434-1844

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
01	13013000	1.25	0135	056	N01		01:27PM	03/05/09	1117450

CUSTOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R.	LOADS
00003		COD---MIDWEST ROADSIDE				1

DELIVERY ADDRESS	SPECIAL INSTRUCTIONS	P.O. NUMBER
4800 NW 35TH	N/ OF THE NO. GOODYEAR HANGER INSIDE FENCE	450-6250

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UNIT PRICE	AMOUNT
1.25	1.25	1.25	13013000	SG 3000 2.00	86.50	108.13
				MINIMUM HAUL		57.50
				WINTER SERVICE		5.00

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 0 GAL.

RECEIVED BY

SUBTOTAL	170.63
TAX	11.94
TOTAL	182.57

Figure A-17. Concrete Material Certification, Test No. MGSC-5

CONCRETE INDUSTRIES, INC.
6300 Cornhusker Highway, Lincoln, NE 6)-0529
402-434-1800 Fax: 402-434-1899
www.ConcreteIndustries.com

Customer Receipt

Driver:
Truck #:
Ordered By: CALL

Bill To:
5 CASH SALES-CONCRETE INDUSTRIES

Ship To:
UNL MIDWEST ROADSIDE SAFETY
CURT MEYER

Ship From:
CONCRETE INDUSTRIES
6300 CORNHUSKER HWY
LINCOLN NE 68507

Delivery Directions:

09:28 Order Number: SP 1102642 0 Delivery Date: 02/10/09 Customer PO Number:

Line	Item Description	Picked	Ordered	Back Order	Units	Unit Price	Discount	Extension
1	#4 STOCK REBAR GRADE 60 20'-0" R46020		7.00		EA	6.0200		42.14
	Heat # M644041 Gerdau Ameristeel							

Received by__________ **Print Name/Company**__________

Returns: No returns w/o invoice. No returns on unusable material, seconds, architectural, decorative, all special order materials, and fractional units. All returnable materials subject to 50% restocking charge. No returns accepted after 30 days from date of purchase.

Terms: All invoices must be paid within 30 days of invoice. Past due accounts will be charged an interest rate of 1.33% per month which is 16% per year.

Tax Code:CINTE Nebraska Tax Exempt
Total Weight: 93.52
Total Cubic:

Sub Total:	42.14
Sales Tax:	
Total Amount:	42.14
Down Payment:	
Balance Due:	42.14

Document: 0 0 Print Date: 02/10/09 Print Time: 09:28 Page: 1 bobb

Figure A-18. Reinforcing Steel Material Certification, Test No. MGSC-5

Page 2 of 2

GERDAU AMERISTEEL

ST PAUL STEEL MILL
1678 RED ROCK ROAD
ST PAUL MN 55119 USA
(651) 731-5600

Chemical and Physical Test Report

MADE IN UNITED STATES

ATTN CURT

M-058717

PRODUCED IN: ST PAUL

SHIP TO	INVOICE TO	SHIP DATE
CONCRETE INDUSTRIES INC 6300 CORNHUSKER HWY LINCOLN, NE 68521	CONCRETE INDUSTRIES INC PO BOX 29529 LINCOLN, NE 68529-0529	05/21/08 CUST. ACCOUNT NO 60052172

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
X13MM REBAR (# 4)	280 (40)	A615/A615M-07 Grade 40/280 A6/A6M-07	8054869-01	70692-01

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	N	Sn	Al	Ti	Ca	Zn	Co
M644041	.15	.66	.010	.030	.18	.38	.14	.13	.027	.002	.001	.0104	.013	.002	.00100	.00080	.01100	.008

Mechanical Test: Yield 49000 PSI, 337.84 MPA Tensile: 67500 PSI, 465.4 MPA %El: 25.0/8in, 25.0/203.2mm Bend: OK Red R 155.69 Std Dev:0 Id Diam: .492

Customer Requirements SOURCE: GA-STP CASTING: STRAND CAST

Comment Steel not exposed to mercury, no weld repairment performed, Melt shop heat #81491M

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
X13MM REBAR (# 4)	280 (40)	A615/A615M-07 Grade 40/280 A6/A6M-07	8054869-01	70692-01

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	N	Sn	Al	Ti	Ca	Zn	Co
M644042	.16	.64	.012	.030	.19	.31	.13	.14	.027	.002	.003	.0183	.016	.002	.00200	.00020	.00700	.008

Mechanical Test: Yield 49500 PSI, 341.29 MPA Tensile: 68000 PSI, 468.84 MPA %El: 28.8/8in, 28.8/203.2mm Bend: OK Red R 155.59 Std Dev:0 Id Diam: .495

Customer Requirements SOURCE: GA-STP CASTING: STRAND CAST

Comment Steel not exposed to mercury, no weld repairment performed.
melt shop heat #81469M

This material, including the billets, was produced and manufactured in the United States of America

Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

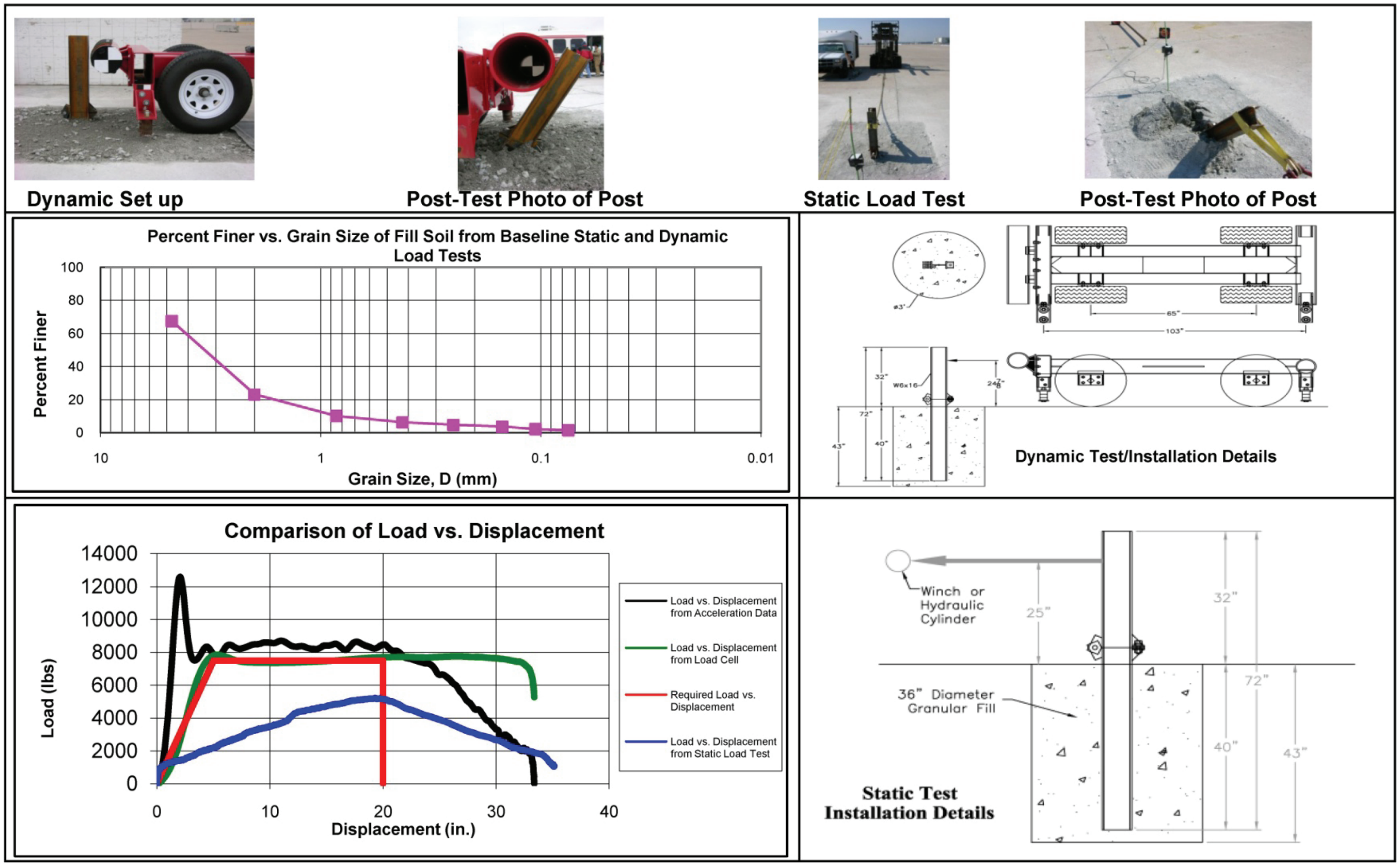
THE ABOVE FIGURES ARE CERTIFIED EXTRACTS FROM THE ORIGINAL CHEMICAL AND PHYSICAL TEST RECORDS AS CONTAINED IN THE PERMANENT RECORDS OF COMPANY.

Mgr. Metallurg. Svcs.
ST PAUL STEEL MILL

Seller warrants that all material furnished shall comply with specifications subject to standard published manufacturing variations. NO OTHER WARRANTIES, EXPRESSED OR IMPLIED, ARE MADE BY THE SELLER, AND SPECIFICALLY EXCLUDED ARE WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.
In no event shall seller be liable for indirect, consequential or punitive damages arising out of or related to the materials furnished by seller.
Any claim for damages for materials that do not conform to specifications must be made from buyer to seller immediately after delivery of same in order to allow the seller the opportunity to inspect the material in question.

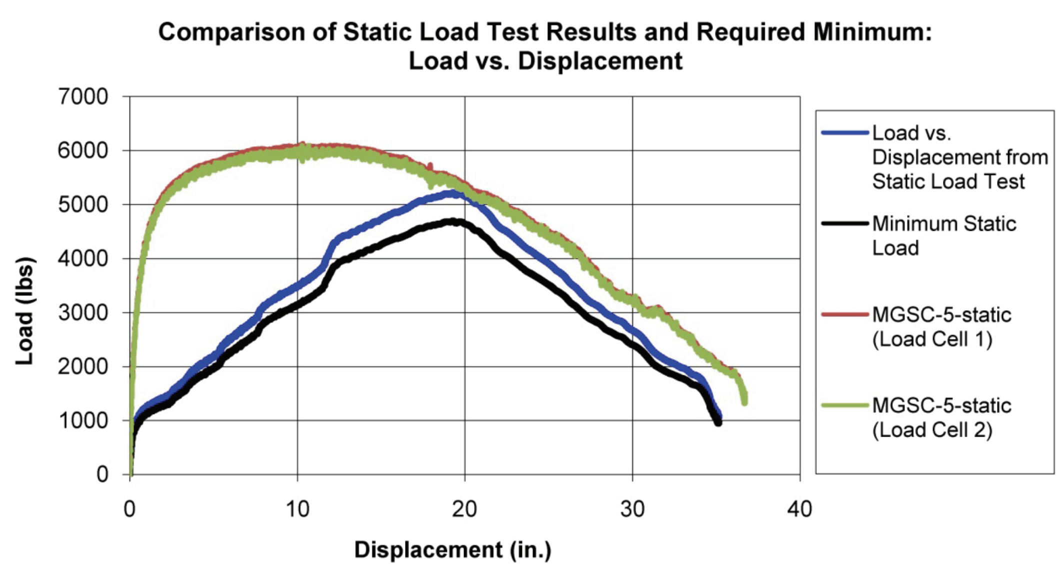
Figure A-19. Reinforcing Steel Material Certification, Test No. MGSC-5

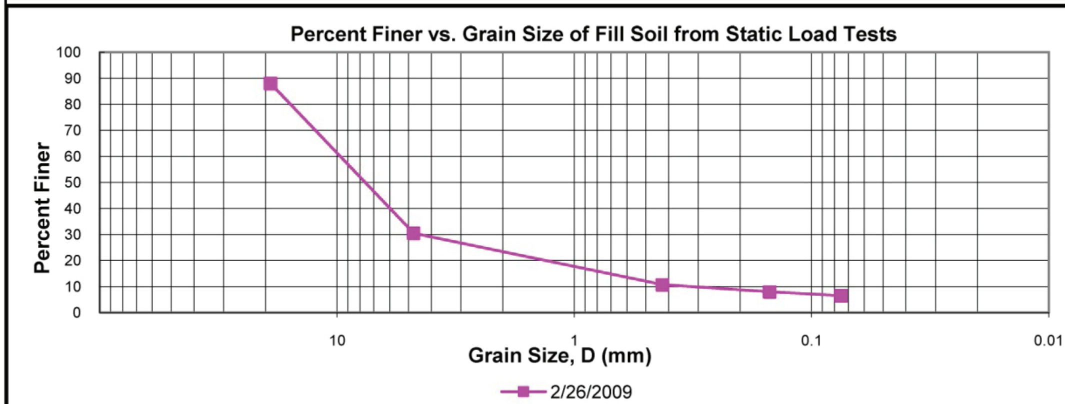
Appendix B. Static Soil Tests



Date	7/7/2005
Test Facility & Site Location	Midwest Road Side Safety Facility
In situ soil description (ASTM D2487)	Well Graded Gravel (GW)
Fill material description (ASTM D2487) & sieve analysis	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	6-inch lifts tamped with a pneumatic compactor
Bogie Weight	1605 lbs
Impact Velocity	19.08 mph

Figure B-1. Soil Strength, Initial Calibration Tests





Date……………………………………………………………………	4/8/2009
Test Facility & Site Location……………………………………………	Midwest Road Side Safety Facility
In situ soil description (ASTM D2487)………………………………	Well Graded Gravel (GW)
Fill material description (ASTM D2487) & sieve analysis…………	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure……………………………..	8-inch lifts tamped with a pneumatic compactor

Figure B-2. Static Soil Test, Test No. MGSC-5 Static

Appendix C. Vehicle Center of Gravity Determination

	MGSC-5		Vehicle:	Ram 1500 Q.C.		
			Vehicle CG Determination			
VEHICLE	Equipment	Weight	Long CG	Vert CG	HOR M	Vert M
+	Unbalasted Truck(Curb)	5151	62.53031	28.14133	322093.6	144956
+	Brake receivers/wires	5	106	52	530	260
+	Brake Frame	7	34	25	238	175
+	Brake Cylinder (Nitrogen)	22	74	27	1628	594
+	Strobe/Brake Battery	6	68	30	408	180
+	Hub	27	0	15	0	405
+	CG Plate (EDRs)	8	54	32	432	256
-	Battery	-38	-7	40	266	-1520
-	Oil	-10	8	19	-80	-190
-	Interior	-78	57	32	-4446	-2496
-	Fuel	-159	111	20	-17649	-3180
-	Coolant	-10	-18	35	180	-350
-	Washer fluid	-7	-16	25	112	-175
BALLAST	Water	62	111	20	6882	1240
	Misc. (DTS+Battery)	25	70	32	1750	800
	Misc.				0	0
					312344.6	140955
	TOTAL WEIGHT	5011			62.3318	28.12912

wheel base 140.25

Calculated Test Inertial Weight

MASH Targets	Targets	CURRENT	Difference
Test Inertial Weight	5000	5011	11.0
Long CG	62	62.33	0.33180
Vert CG	28	28.13	0.12912

Note, Long. CG is measured from front axle of test vehicle

Curb Weight

	Left	Right
Front	1422	1432
Rear	1181	1116
FRONT	2854	
REAR	2297	
TOTAL	5151	

Actual test inertial weight (from scales)

	Left	Right
Front	1434	1335
Rear	1102	1157
FRONT	2769	
REAR	2259	
TOTAL	5028	

Figure C-1. Vehicle Mass Distribution, Test No. MGSC-5

Appendix D. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH INFO

TEST: MGSC-5
VEHICLE: Ram 1500 Q.C.

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

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	28.75	29.25	-0.75	28.75	29.25	NA	0	0	#VALUE!
2	31.5	25.25	-0.75	31.5	25.5	NA	0	0.25	#VALUE!
3	31.5	19.25	-0.75	31.5	19	NA	0	-0.25	#VALUE!
4	27.25	10.75	-0.25	27	10.5	NA	-0.25	-0.25	#VALUE!
5	27.5	30	-2.75	27.5	29.5	NA	0	-0.5	#VALUE!
6	28.75	26.5	-3	29	26.25	NA	0.25	-0.25	#VALUE!
7	30.5	20.5	-4.25	30.5	20	NA	0	-0.5	#VALUE!
8	25.75	11	-0.5	25.5	11	NA	-0.25	0	#VALUE!
9	26	30.5	-5	26.25	30	NA	0.25	-0.5	#VALUE!
10	26.5	25.25	-5.5	26.5	25.5	NA	0	0.25	#VALUE!
11	26.5	20	-6	26.25	19.5	NA	-0.25	-0.5	#VALUE!
12	24.5	11.5	-1.25	24.5	12	NA	0	0.5	#VALUE!
13	22.5	8.75	-1.25	22.25	8.5	NA	-0.25	-0.25	#VALUE!
14	20.5	27.5	-8.75	20.5	27	NA	0	-0.5	#VALUE!
15	20.25	22.75	-9.25	20.25	22.25	NA	0	-0.5	#VALUE!
16	19.75	14.25	-5.75	19.5	14	NA	-0.25	-0.25	#VALUE!
17	17.5	7.5	-3	17.5	7.75	NA	0	0.25	#VALUE!
18	15.25	2.5	-3.5	15.25	2.5	NA	0	0	#VALUE!
19	13.25	27.75	-9	13.25	27.25	NA	0	-0.5	#VALUE!
20	12.5	21	-9.5	12.5	20.5	NA	0	-0.5	#VALUE!
21	12.5	15.5	-10	12.5	15.25	NA	0	-0.25	#VALUE!
22	9.5	6.75	-4	9.25	6.75	NA	-0.25	0	#VALUE!
23	9.25	1.75	-4.25	9	1.75	NA	-0.25	0	#VALUE!
24	0.5	28.25	-4.75	0.5	28.25	NA	0	0	#VALUE!
25	0.75	21.75	-5.25	0.75	21.5	NA	0	-0.25	#VALUE!
26	1	15	-6	0.75	14.75	NA	-0.25	-0.25	#VALUE!
27	1.25	7.75	-3.75	1.25	8	NA	0	0.25	#VALUE!
28	1.25	2	-4	1.25	2	NA	0	0	#VALUE!
29							0	0	0
30							0	0	0
31							0	0	0

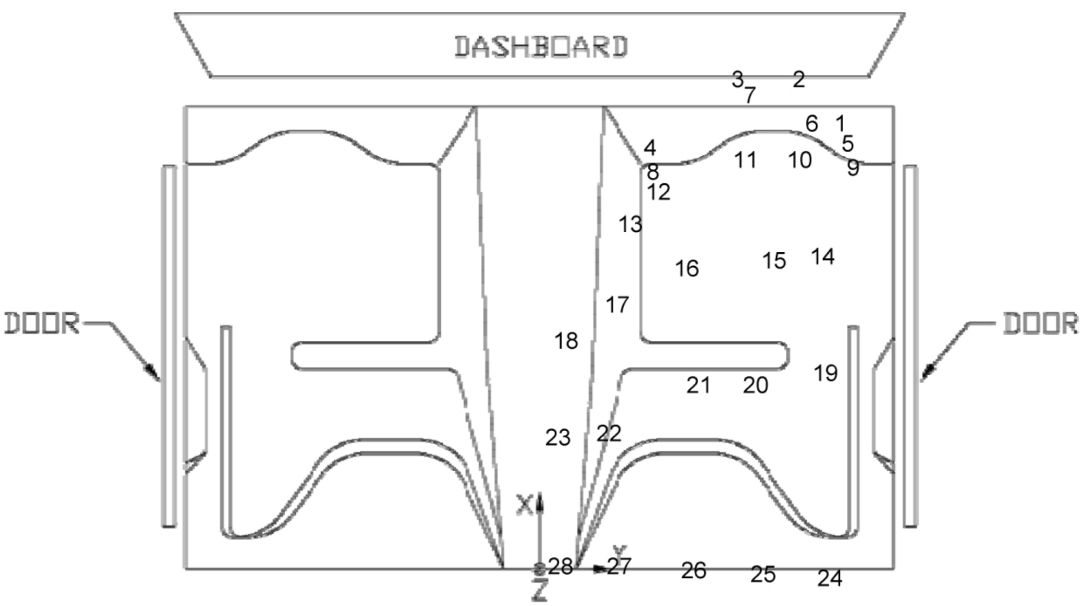


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. MGSC-5

VEHICLE PRE/POST CRUSH INFO

TEST: MGSC-5
VEHICLE: Ram 1500 Q.C.

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

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	54.5	27.75	-1.5	NA	NA	-0.75	#VALUE!	#VALUE!	0.75
2	54.5	21.75	-1.5	NA	NA	-0.5	#VALUE!	#VALUE!	1
3	50.25	13.25	-1	NA	NA	0.5	#VALUE!	#VALUE!	1.5
4	50.5	32.5	0.5	NA	NA	2	#VALUE!	#VALUE!	1.5
5	51.75	29	-3.25	NA	NA	-3	#VALUE!	#VALUE!	0.25
6	53.5	23	-3.5	NA	NA	-2.5	#VALUE!	#VALUE!	1
7	48.75	13.5	-4.5	NA	NA	-3.25	#VALUE!	#VALUE!	1.25
8	49	33	-0.5	NA	NA	1.25	#VALUE!	#VALUE!	1.75
9	49.5	27.75	-5.75	NA	NA	-5.25	#VALUE!	#VALUE!	0.5
10	49.5	22.5	-6	NA	NA	-5.25	#VALUE!	#VALUE!	0.75
11	47.5	14	-6.25	NA	NA	-5	#VALUE!	#VALUE!	1.25
12	45.5	11.25	-1.25	NA	NA	0.5	#VALUE!	#VALUE!	1.75
13	43.5	30	-1	NA	NA	1	#VALUE!	#VALUE!	2
14	43.25	25.25	-9	NA	NA	-8.5	#VALUE!	#VALUE!	0.5
15	42.75	16.75	-9.25	NA	NA	-8.25	#VALUE!	#VALUE!	1
16	40.5	10	-5.75	NA	NA	-4	#VALUE!	#VALUE!	1.75
17	38.25	5	-2.75	NA	NA	-1.25	#VALUE!	#VALUE!	1.5
18	36.25	30.25	-3	NA	NA	-1.75	#VALUE!	#VALUE!	1.25
19	35.5	23.5	-9	NA	NA	-8.5	#VALUE!	#VALUE!	0.5
20	35.5	18	-9.25	NA	NA	-8.5	#VALUE!	#VALUE!	0.75
21	32.5	9.25	-9.5	NA	NA	-8.25	#VALUE!	#VALUE!	1.25
22	32.25	4.25	-3.25	NA	NA	-1.5	#VALUE!	#VALUE!	1.75
23	23.5	30.75	-3.5	NA	NA	-2	#VALUE!	#VALUE!	1.5
24	23.75	24.25	-4.25	NA	NA	-4.5	#VALUE!	#VALUE!	-0.25
25	24	17.5	-4.5	NA	NA	-4	#VALUE!	#VALUE!	0.5
26	24.25	10.25	-5	NA	NA	-4.25	#VALUE!	#VALUE!	0.75
27	24.25	4.5	-2.75	NA	NA	-1.5	#VALUE!	#VALUE!	1.25
28	24.25	4.5	-3	NA	NA	-1.75	#VALUE!	#VALUE!	1.25
29							0	0	0
30							0	0	0
31							0	0	0

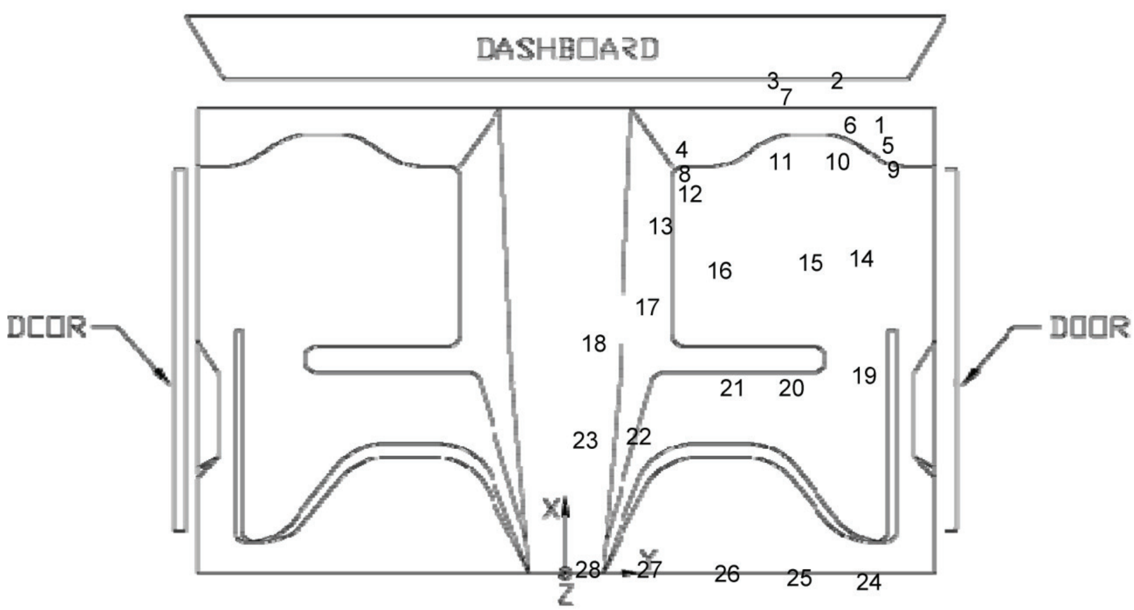


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. MGSC-5

Occupant Compartment Deformation Index (OCDI)

Test No. MGSC-5
Vehicle Type: Ram 1500 Q.C.

OCDI = XXABCDEFGHI

XX = location of occupant compartment deformation

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

B = distance between the roof and the floor panel

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

D = distance between the lower dashboard and the floor panel

E = interior width

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

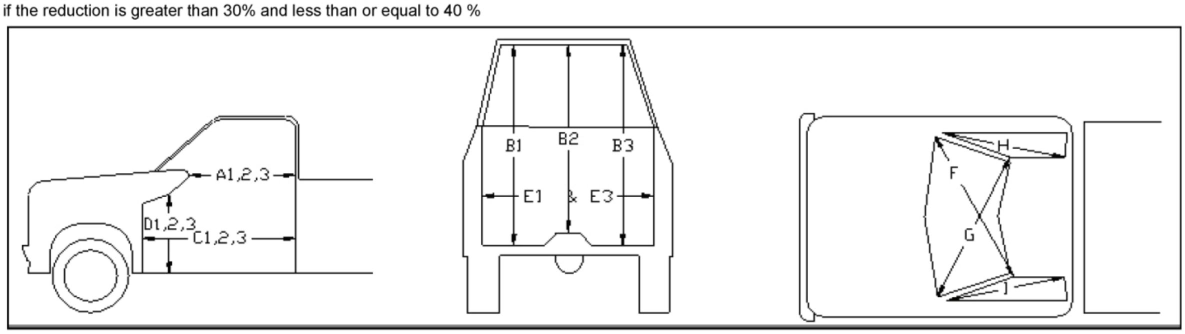
G = distance between the lower edge of left window and the upper edge of right window

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

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

Severity Indices

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



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

Location:

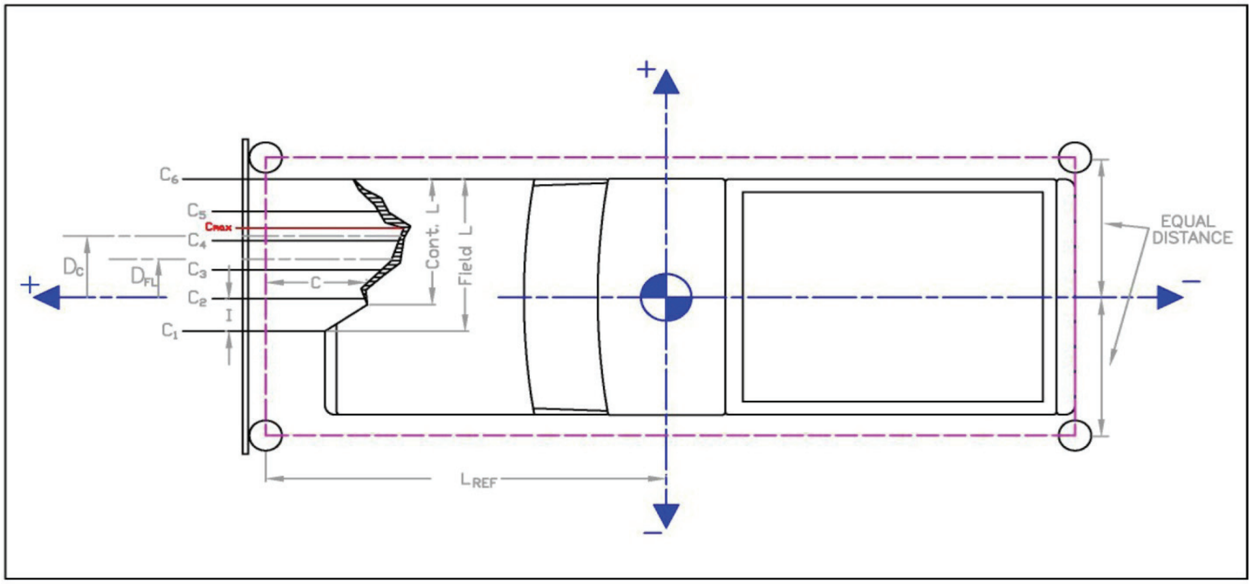
Measurement	Pre-Test (in.)	Post-Test (in.)	Change (in.)	% Difference	Severity Index
A1	54.75	53.75	-1.00	-1.83	0
A2	50.50	50.00	-0.50	-0.99	0
A3	56.50	57.00	0.50	0.88	0
B1	47.25	40.00	-7.25	-15.34	2
B2	42.25	30.00	-12.25	-28.99	3
B3	47.00	44.00	-3.00	-6.38	1
C1	69.50	69.50	0.00	0.00	0
C2	46.50	47.00	0.50	1.08	0
C3	66.50	66.25	-0.25	-0.38	0
D1	23.25	23.00	-0.25	-1.08	0
D2	13.25	13.25	0.00	0.00	0
D3	23.00	22.75	-0.25	-1.09	0
E1	66.00	66.00	0.00	0.00	0
E3	64.75	64.50	-0.25	-0.39	0
F	56.00	55.00	-1.00	-1.79	0
G	56.25	61.00	4.75	8.44	1
H	37.00	37.50	0.50	1.35	0
I	37.75	38.00	0.25	0.66	0

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

	XX	A	B	C	D	E	F	G	H	I
Final OCDI:	RF	0	3	0	0	0	0	1	0	0

Figure D-3. Occupant Compartment Deformation Index (OCDI), Test No. MGSC-5

Date:	**4/8/2009**	**Test Number:**	**MGSC-5**		
Make:	**Dodge**	**Model:**	**Ram 1500 Q.C.**	**Year:**	**2003**

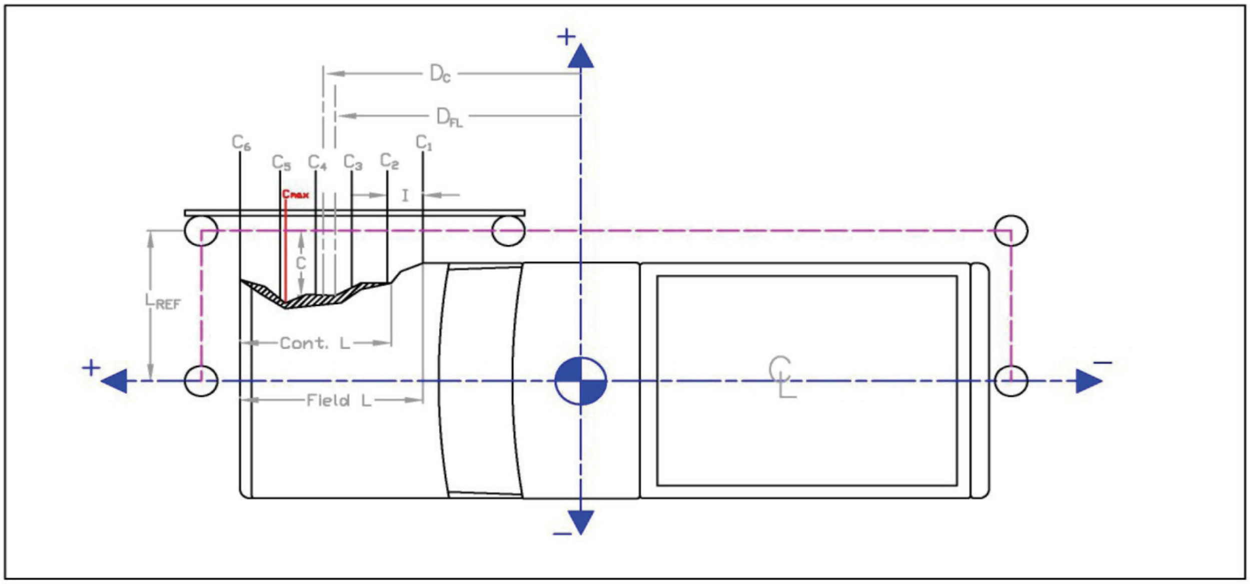


	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	105	(2667)
Width of contact and induced crush - Field L:	27.25	(692)
Crush measurement spacing interval (L/5) - I:	5.45	(138)
Distance from center of vehicle to center of Field L - D_{FL}:	25.625	(651)
Width of Contact Damage:	27.25	(692)
Distance from center of vehicle to center of contect damage - D_C:	25.75	(654)

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	3.75	(95)	12	(305)	11	(279)	-7.0818	-(180)	-0.1682	-(4)
C_2	6.25	(159)	17.45	(443)	11.9844	(304)			1.34742	(34)
C_3	12.5	(318)	22.9	(582)	13.2344	(336)			6.34742	(161)
C_4	na	#######	28.35	(720)	15.3594	(390)			#######	#######
C_5	na	#######	33.8	(859)	19.0313	(483)			#######	#######
C_6	na	#######	39.25	(997)	29	(737)			#######	#######
C_{MAX}	24.5	(622)	29	(737)	15.6875	(398)			15.8943	(404)

Figure D-4. Exterior Vehicle Crush (NASS) - Front, Test No. MGSC-5

Date:	4/8/2009	**Test Number:**	MGSC-5		
Make:	Dodge	**Model:**	Ram 1500 Q.C.	**Year:**	2003



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	45	(1143)
Width of contact and induced crush - Field L:	67.625	(1718)
Crush measurement spacing interval (L/5) - I:	13.525	(344)
Distance from vehicle c.g. to center of Field L - D_{FL}:	72.8125	(1849)
Width of Contact Damage:	67.625	(1718)
Distance from vehicle c.g. to center of contect damage - D_C:	171.375	(4353)

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	6.75	(171)	39	(991)	11.25	(286)	-5	-(127)	0.5	(13)
C_2	na	#######	52.525	(1334)	11	(279)			#######	#######
C_3	na	#######	66.05	(1678)	10.5	(267)			#######	#######
C_4	14.75	(375)	79.575	(2021)	0	()			19.75	(502)
C_5	22	(559)	93.1	(2365)	12.75	(324)			14.25	(362)
C_6	na	#######	106.625	(2708)	37	(940)			#######	#######
C_{MAX}	14.75	(375)	79.58	(2021)	0	()			19.75	(502)

Figure D-5. Exterior Vehicle Crush (NASS) - Side, Test No. MGSC-5

Appendix E. Accelerometer and Rate Transducer Data Plots

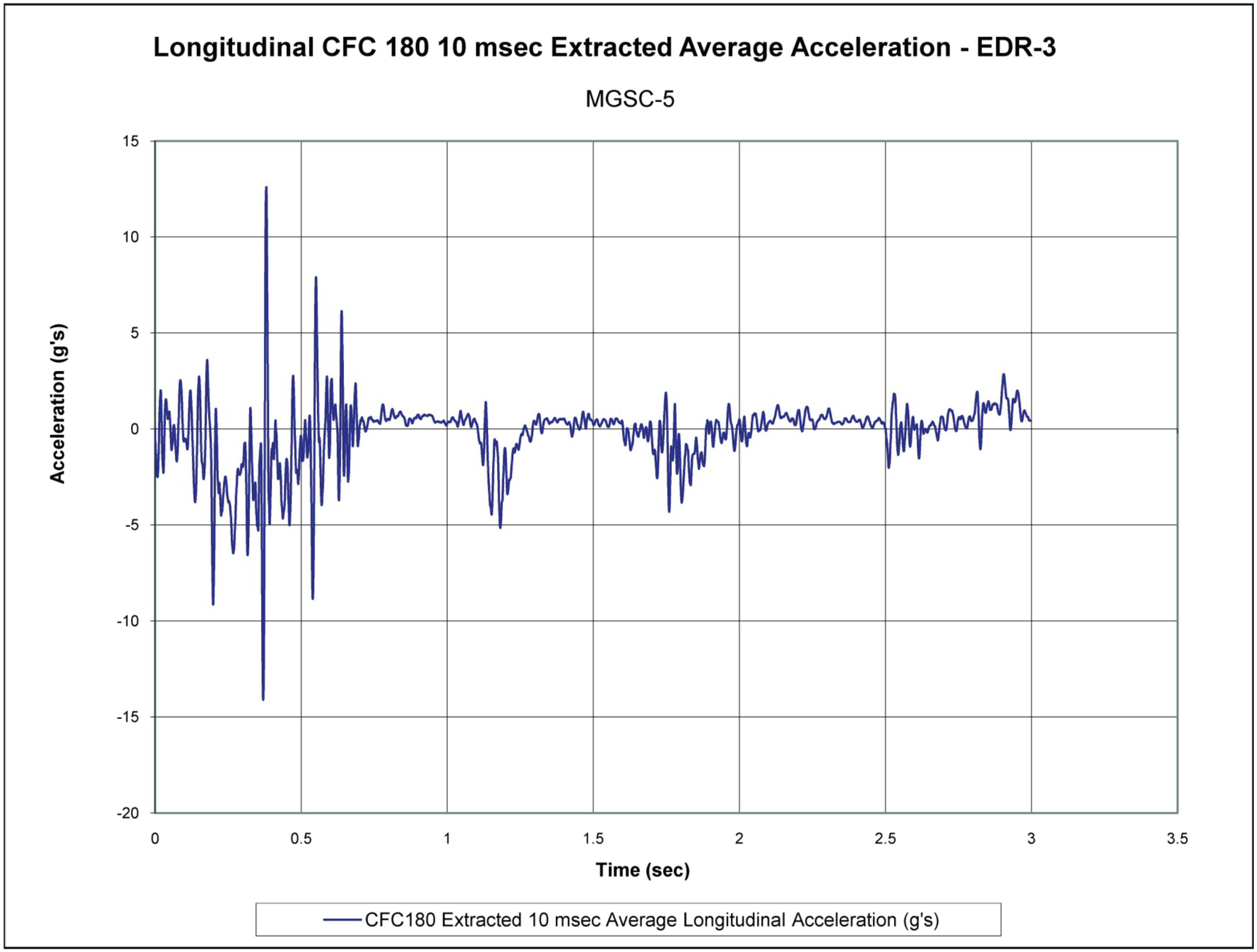


Figure E-1. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. MGSC-5

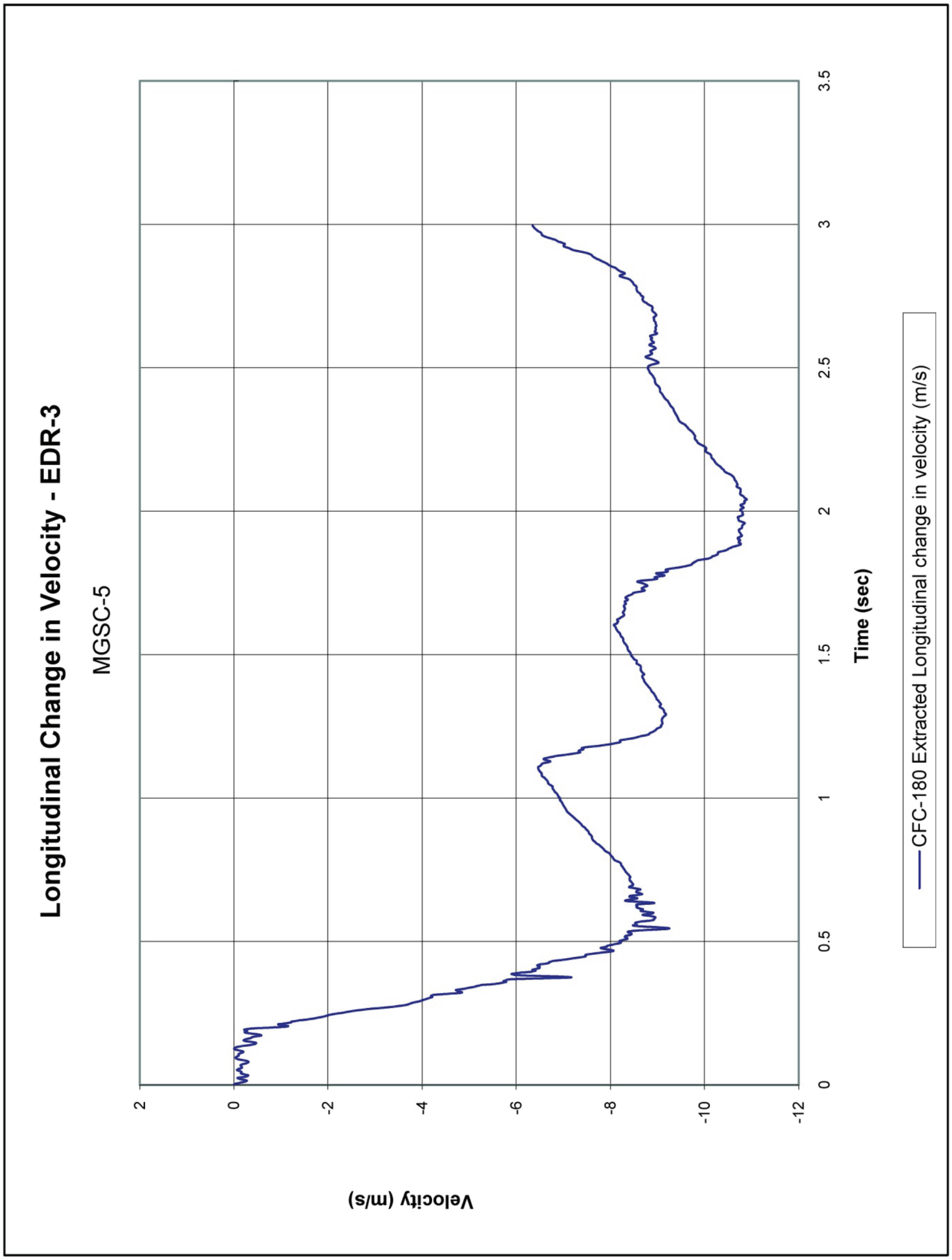


Figure E-2. Longitudinal Occupant Impact Velocity (EDR-3), Test No. MGSC-5

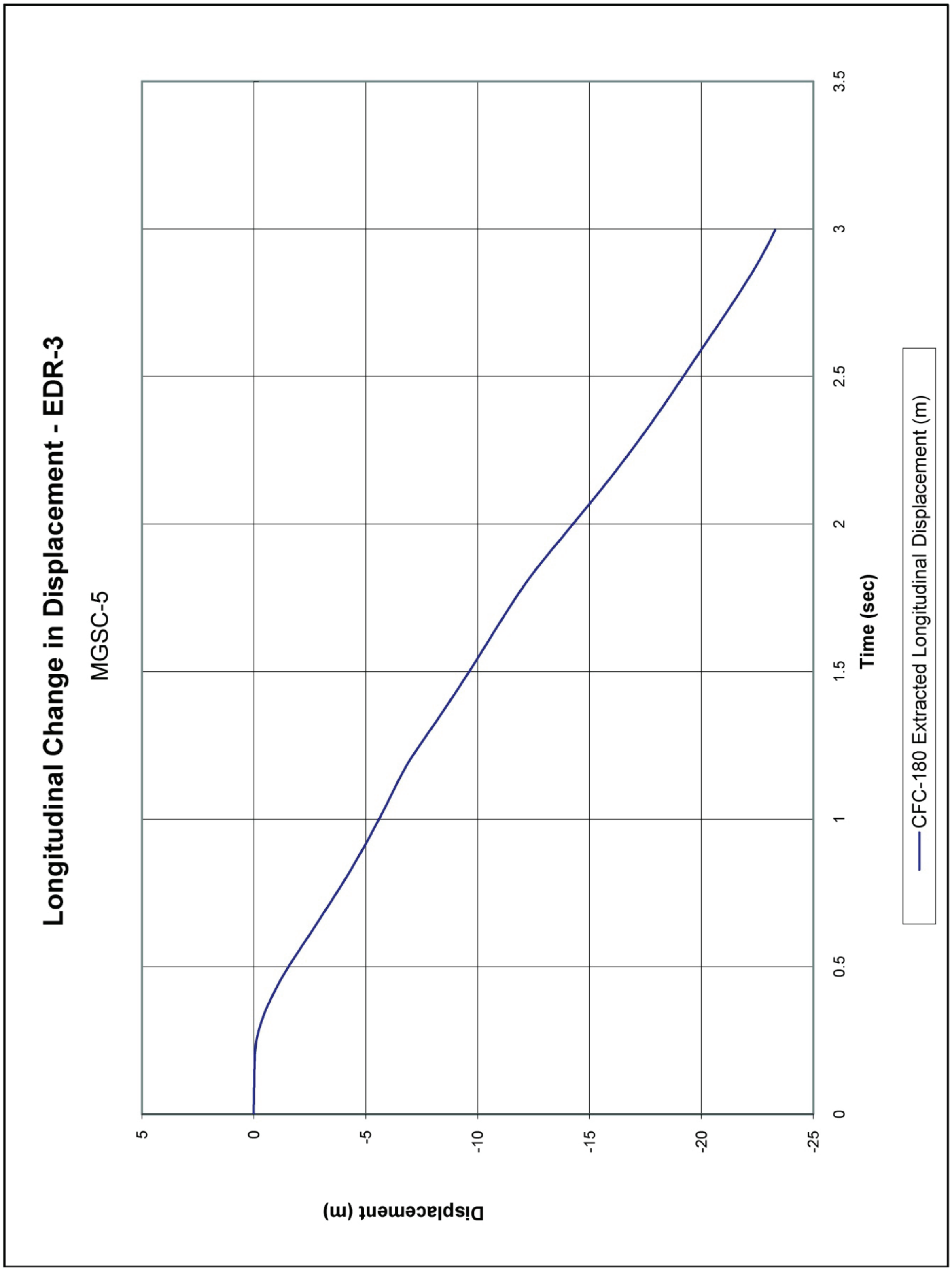


Figure E-3. Longitudinal Occupant Displacement (EDR-3), Test No. MGSC-5

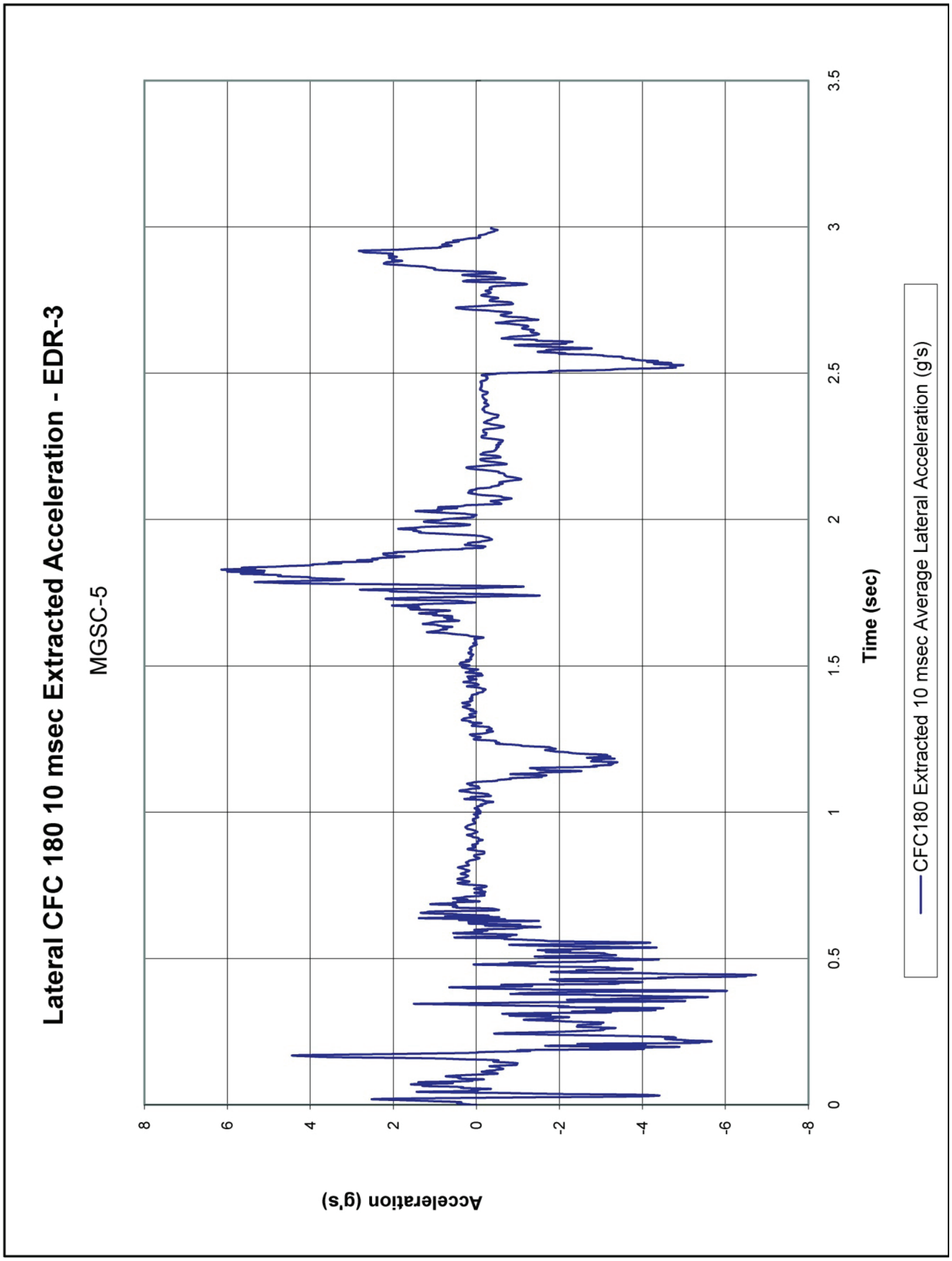


Figure E-4. 10-ms Average Lateral Deceleration (EDR-3), Test No. MGSC-5

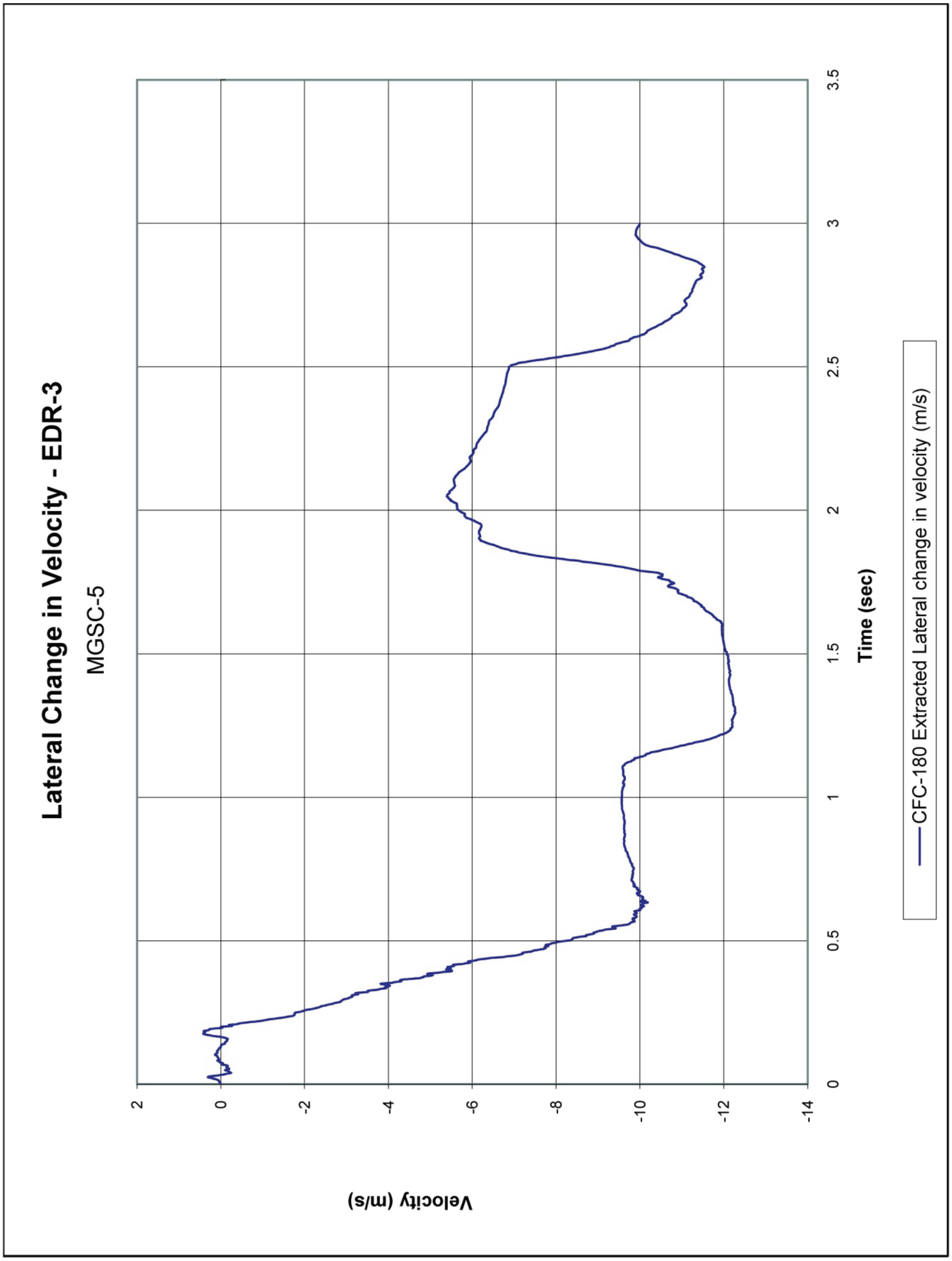


Figure E-5. Lateral Occupant Impact Velocity (EDR-3), Test No. MGSC-5

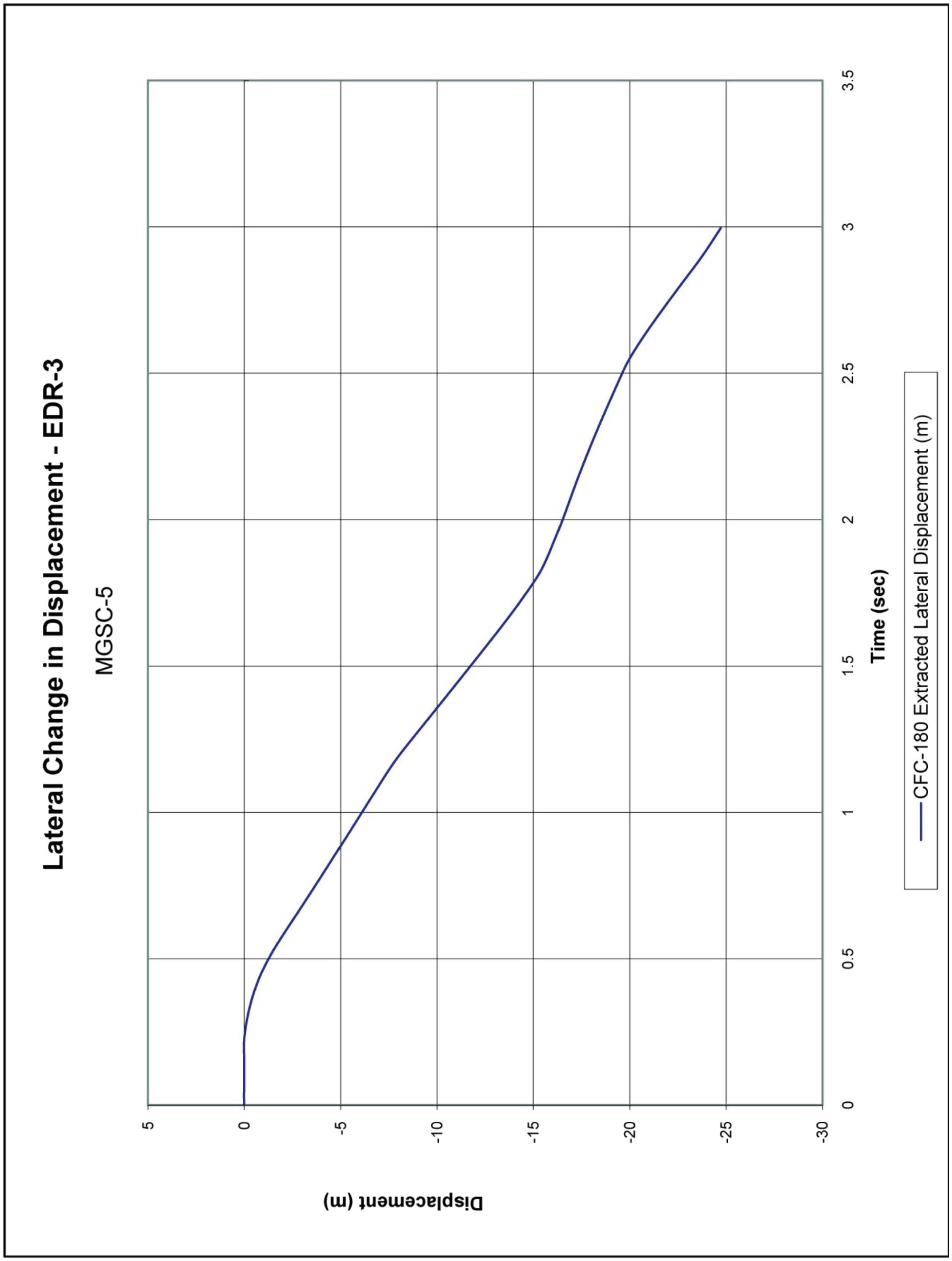


Figure E-6. Lateral Occupant Displacement (EDR-3), Test No. MGSC-5

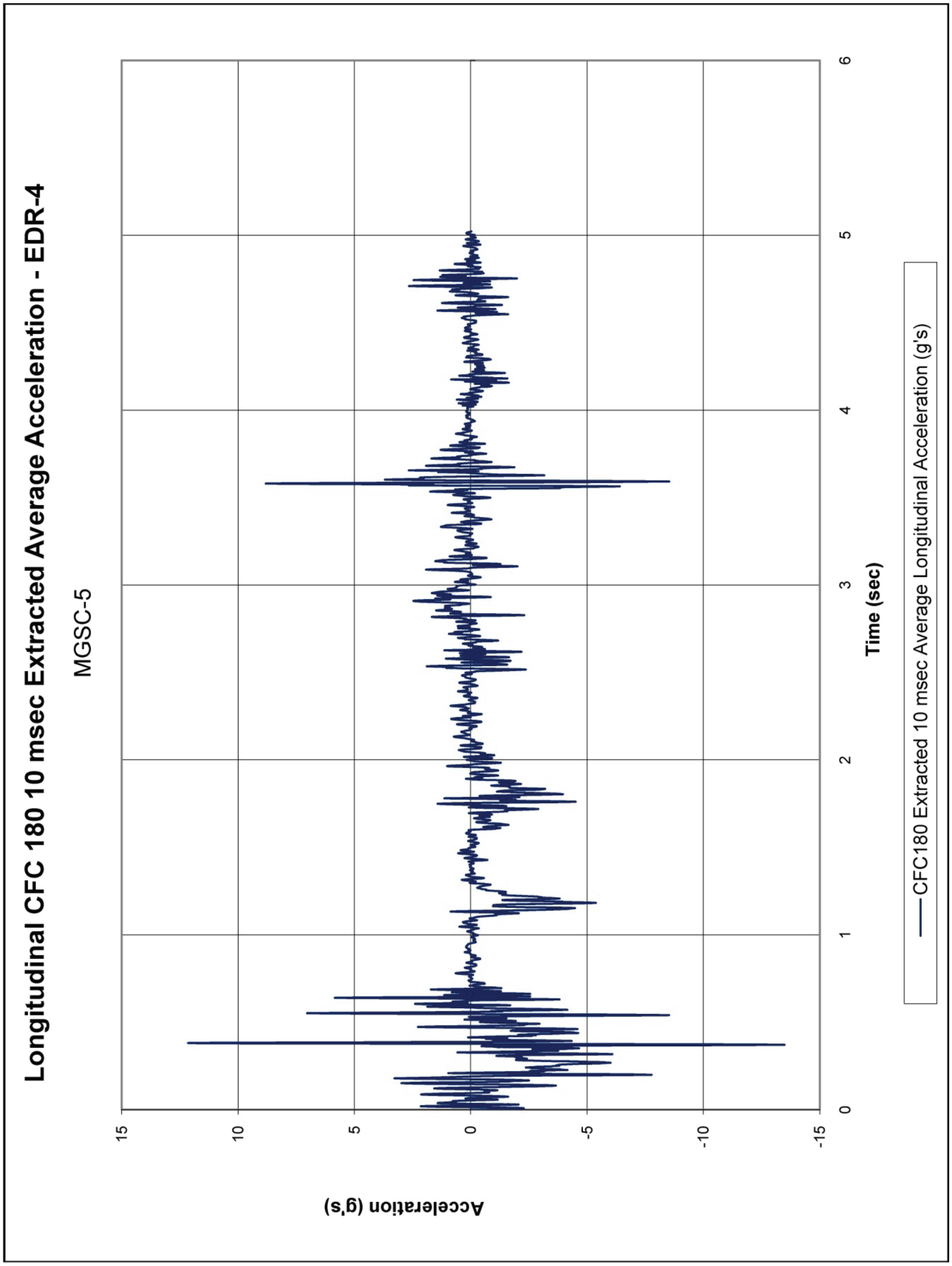


Figure E-7. 10-ms Average Longitudinal Deceleration (EDR-4), Test No. MGSC-5

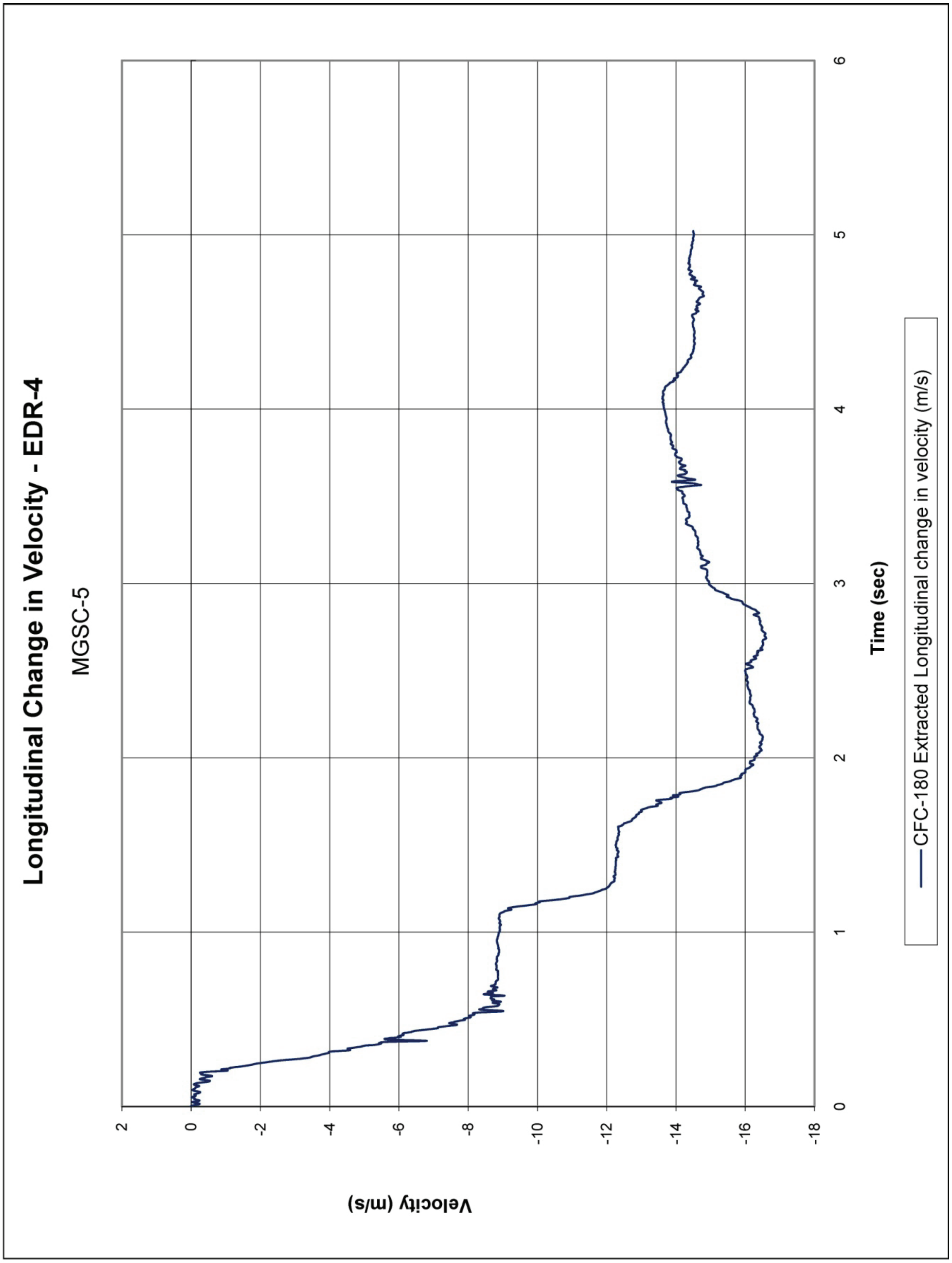


Figure E-8. Longitudinal Occupant Impact Velocity (EDR-4), Test No. MGSC-5

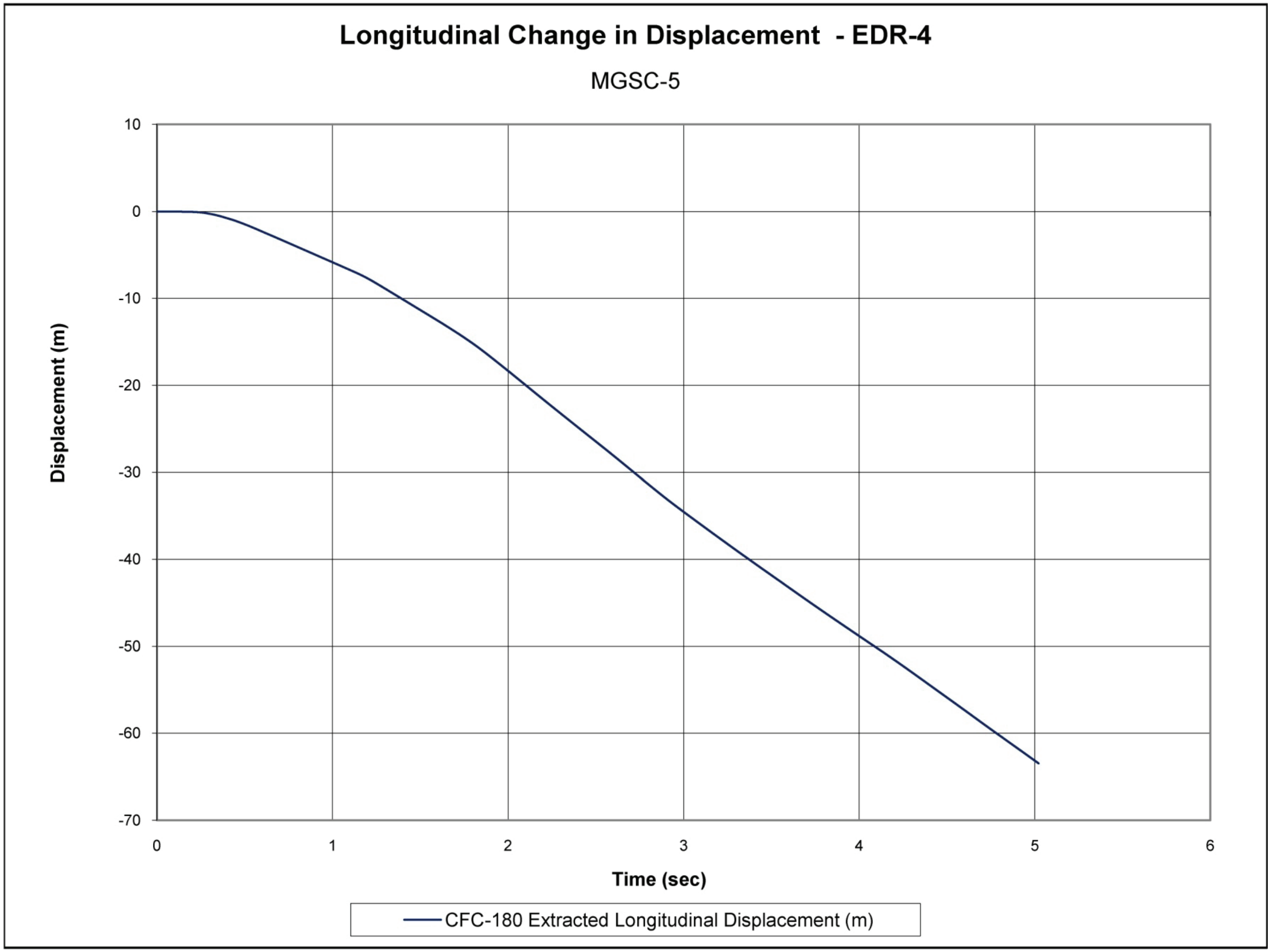


Figure E-9. Longitudinal Occupant Displacement (EDR-4), Test No. MGSC-5

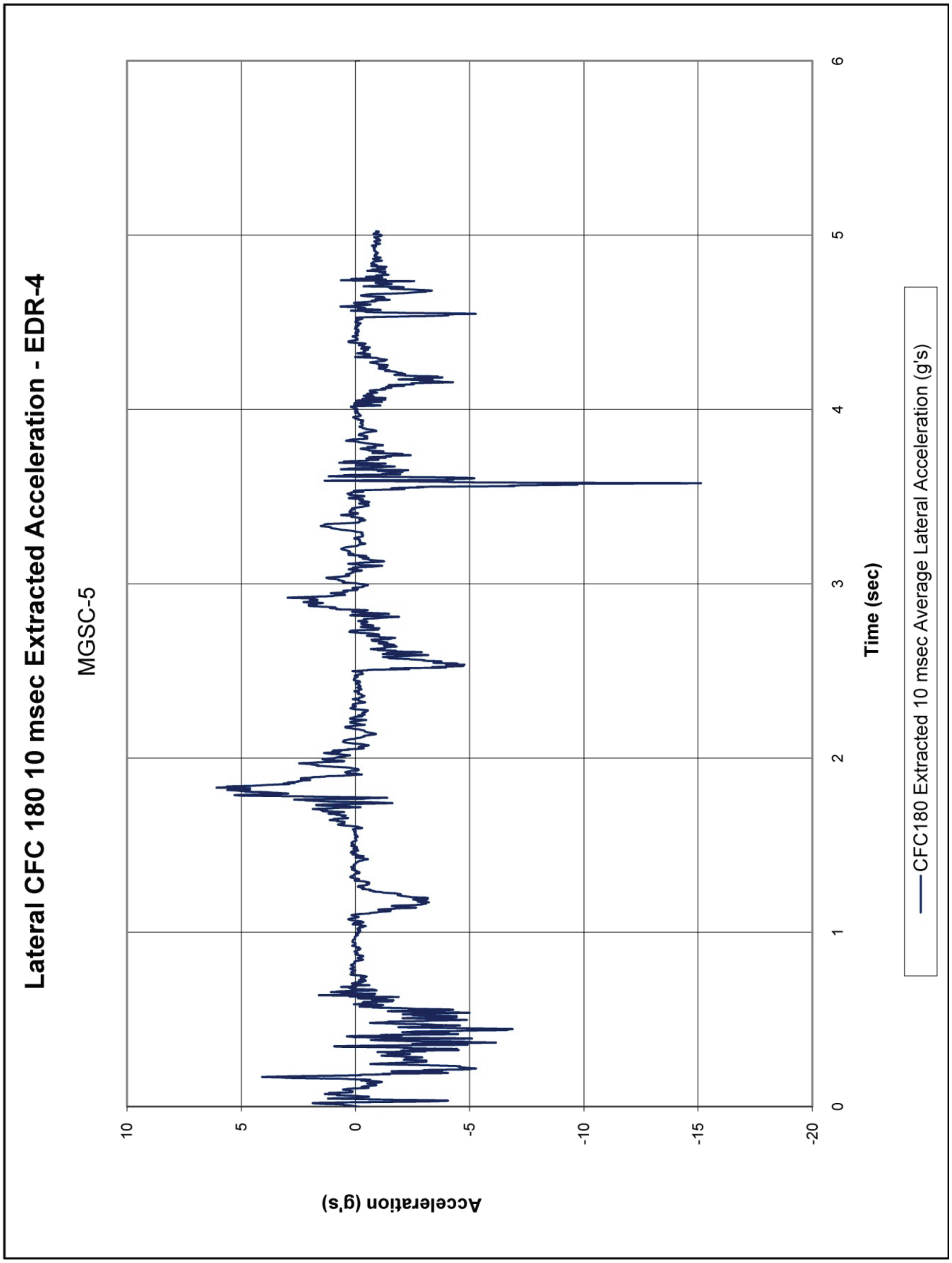


Figure E-10. 10-ms Average Lateral Deceleration (EDR-4), Test No. MGSC-5

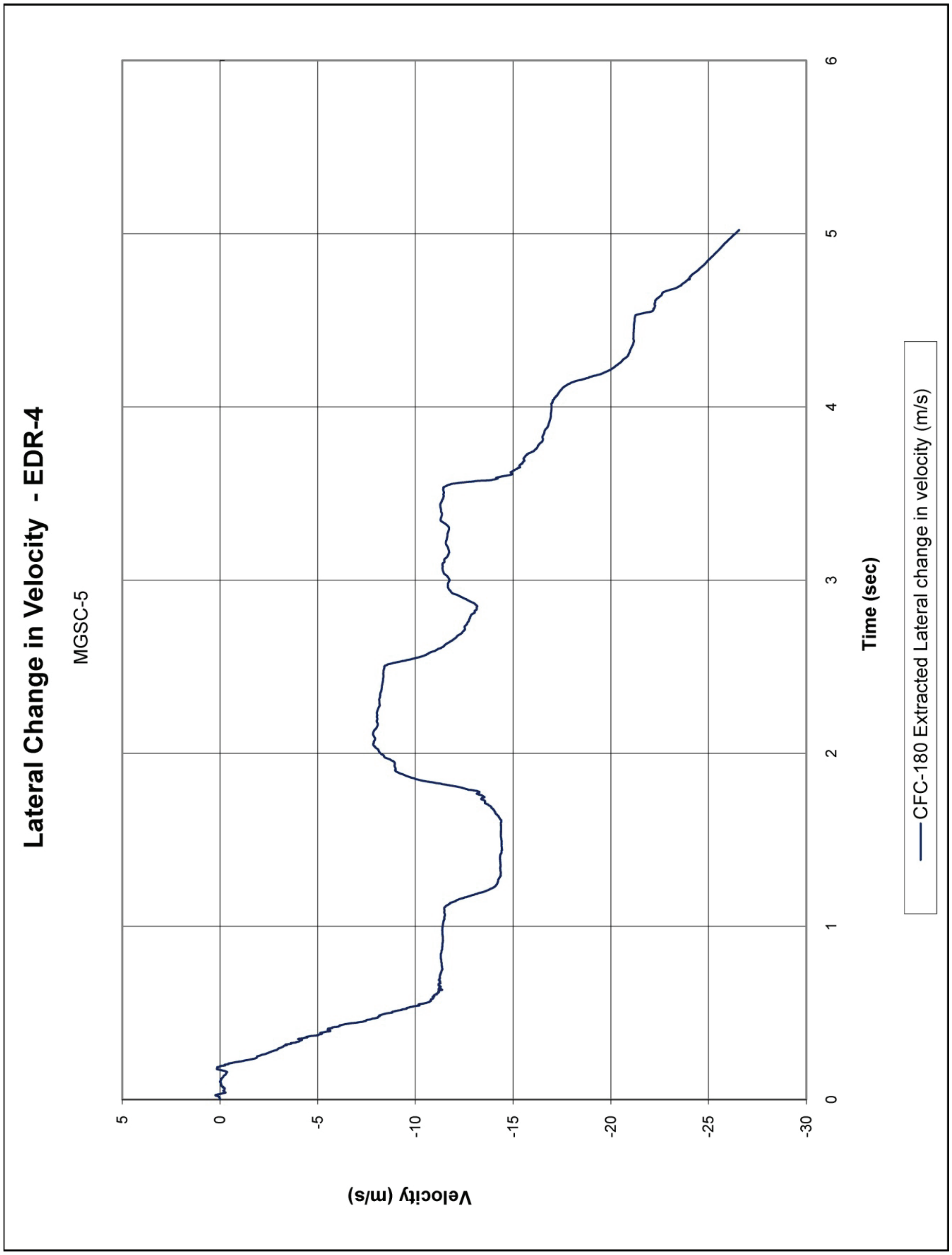


Figure E-11. Lateral Occupant Impact Velocity (EDR-4), Test No. MGSC-5

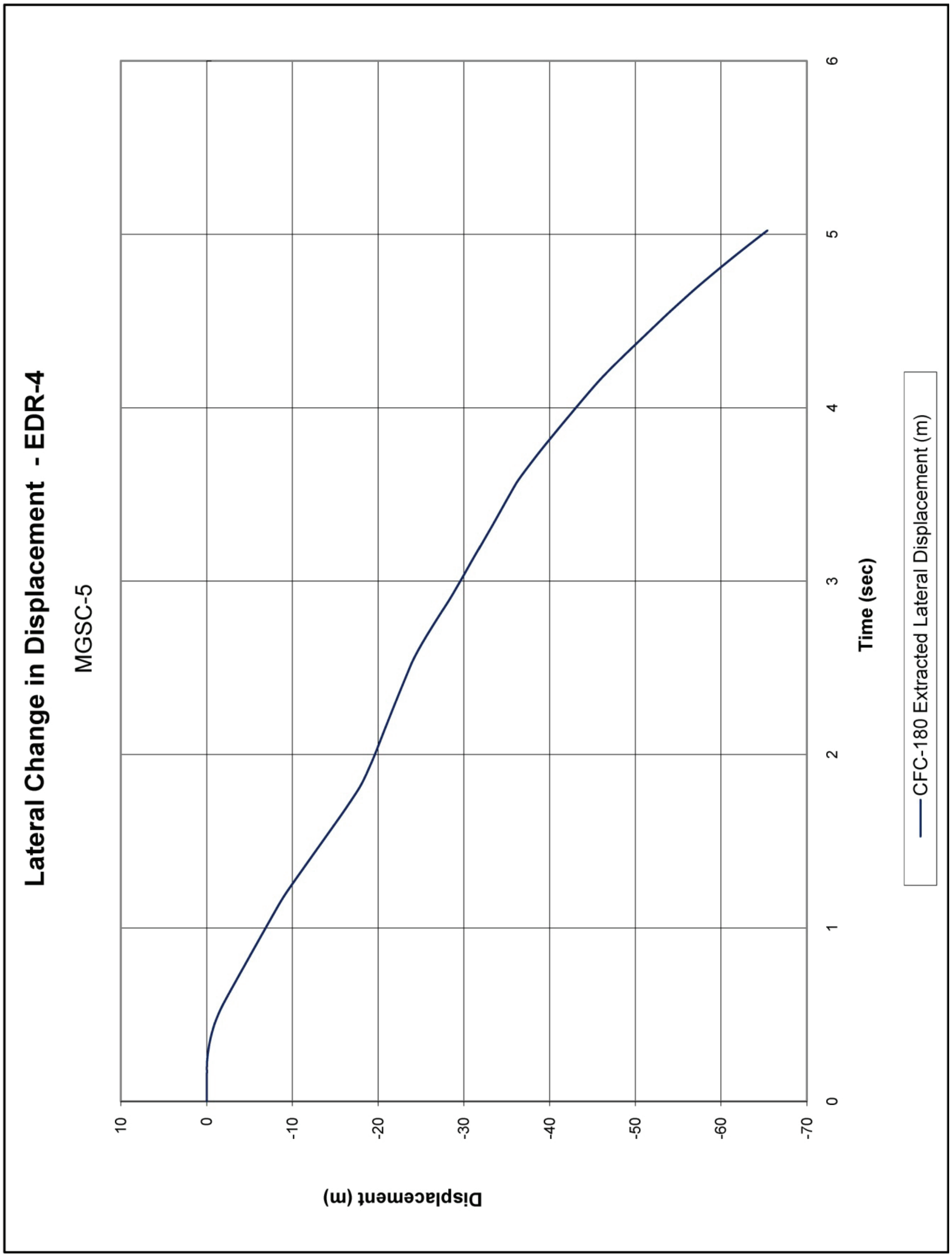


Figure E-12. Lateral Occupant Displacement (EDR-4), Test No. MGSC-5

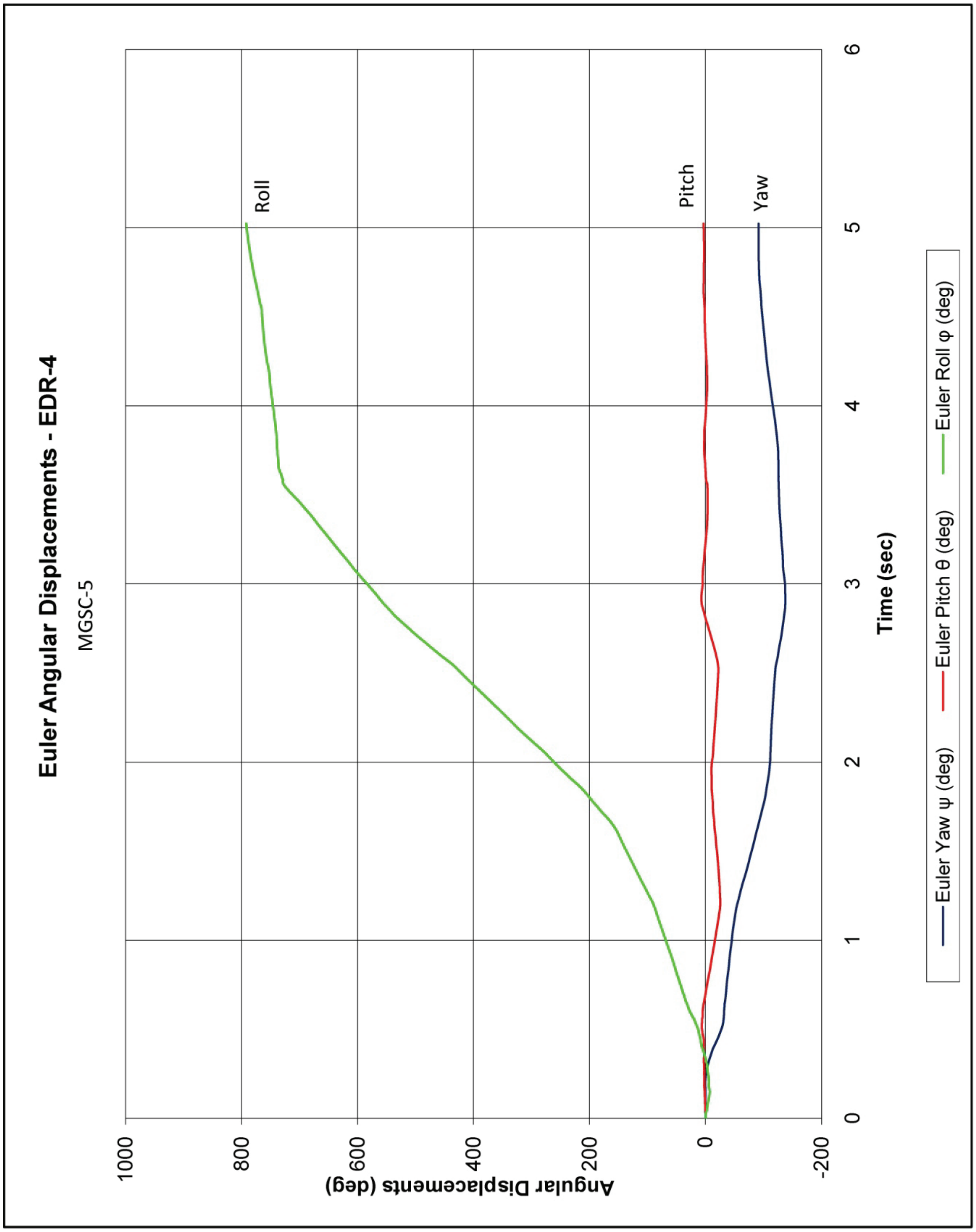


Figure E-13. Vehicle Angular Displacements (EDR-4), Test No. MGSC-5

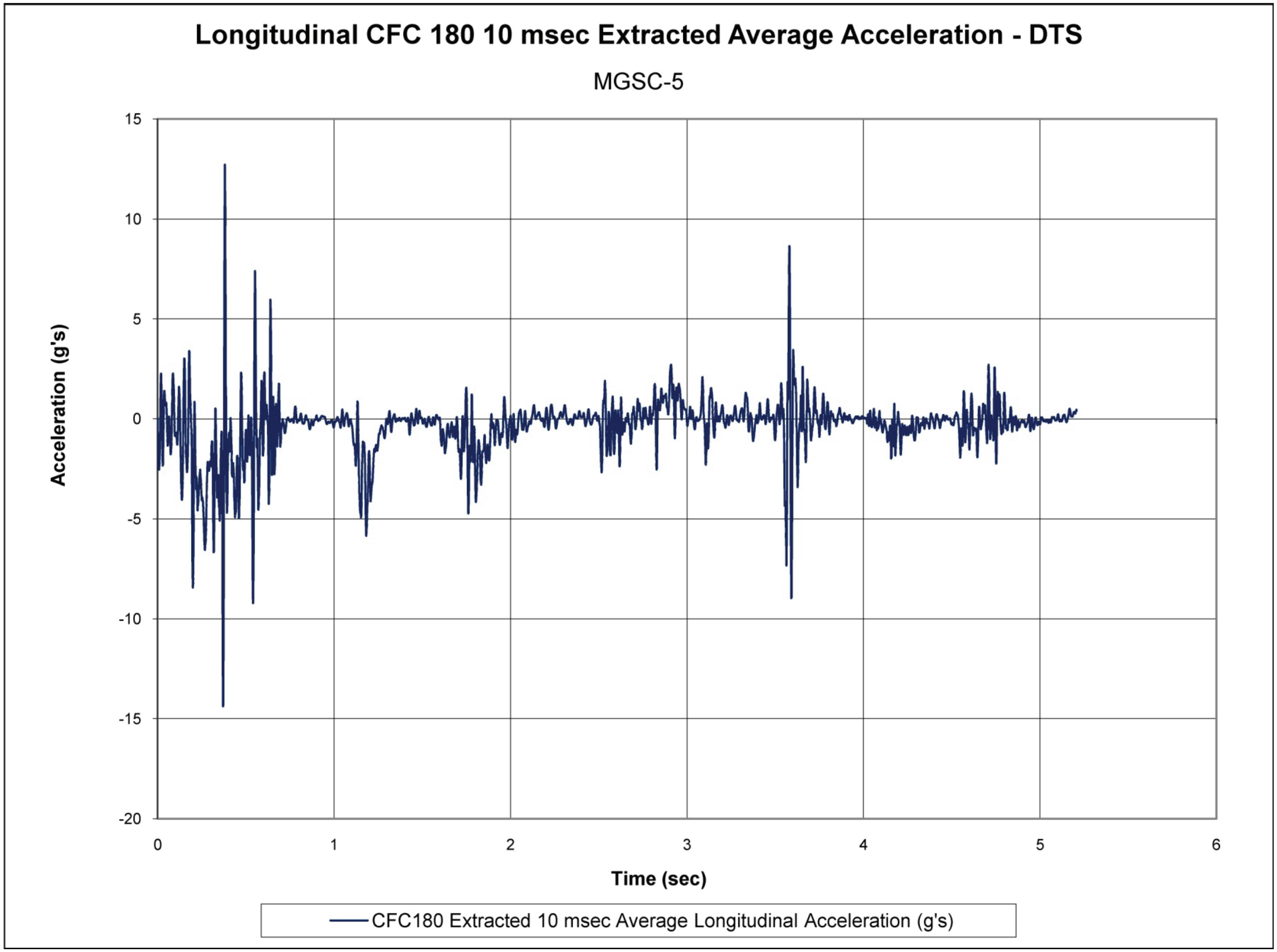


Figure E-14. 10-ms Average Longitudinal Deceleration (DTS), Test No. MGSC-5

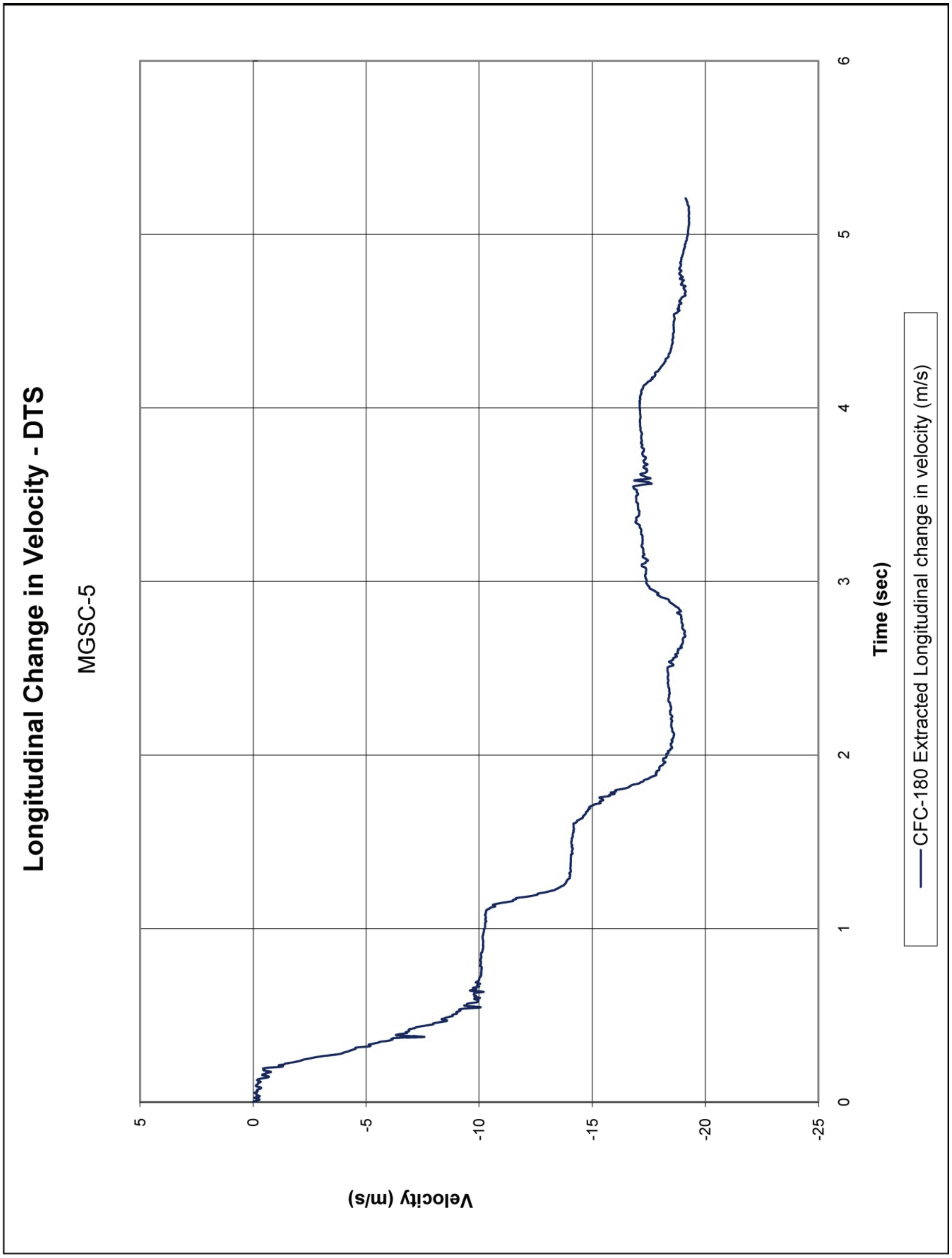


Figure E-15. Longitudinal Occupant Impact Velocity (DTS), Test No. MGSC-5

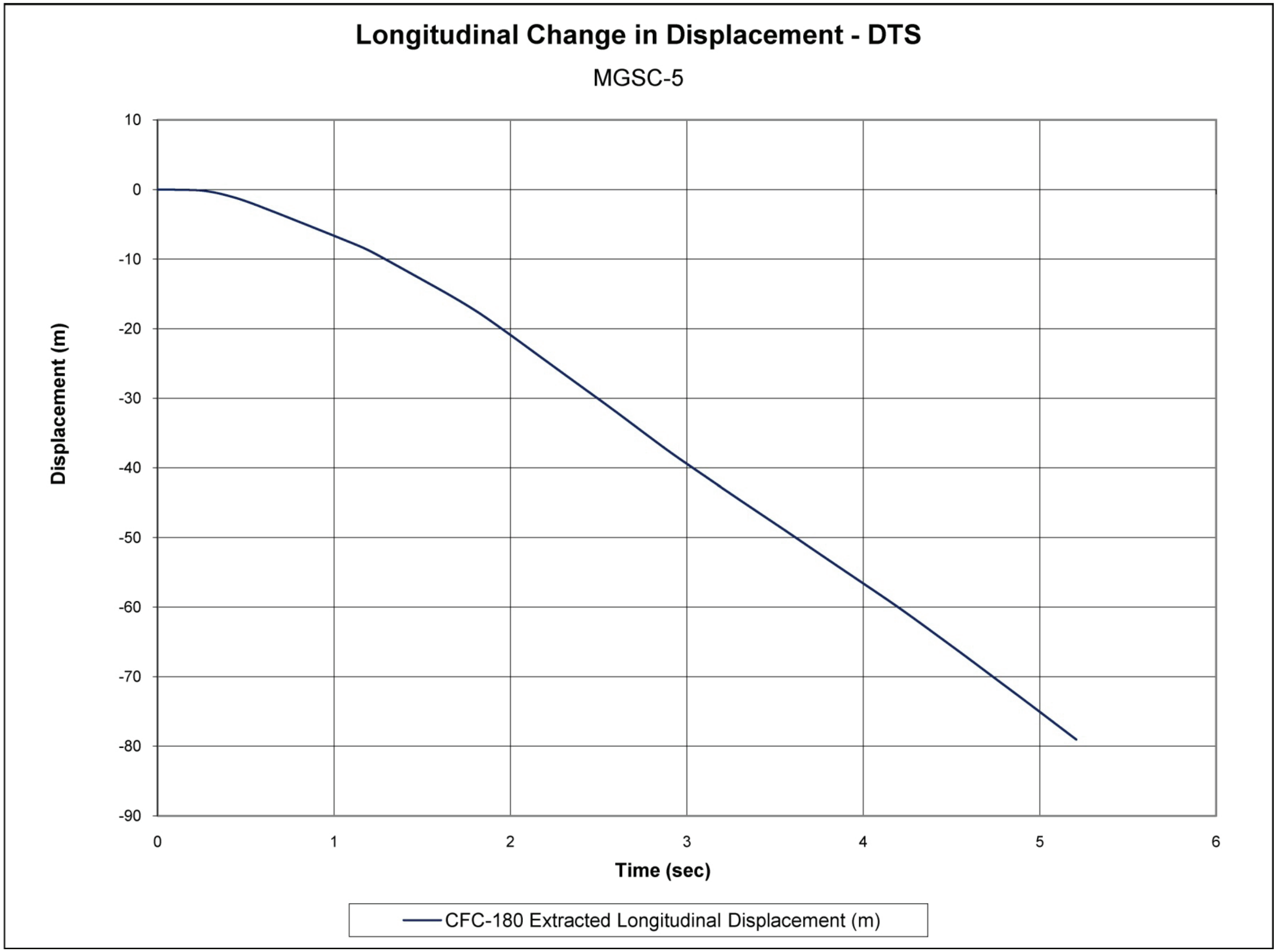


Figure E-16. Longitudinal Occupant Displacement (DTS), Test No. MGSC-5

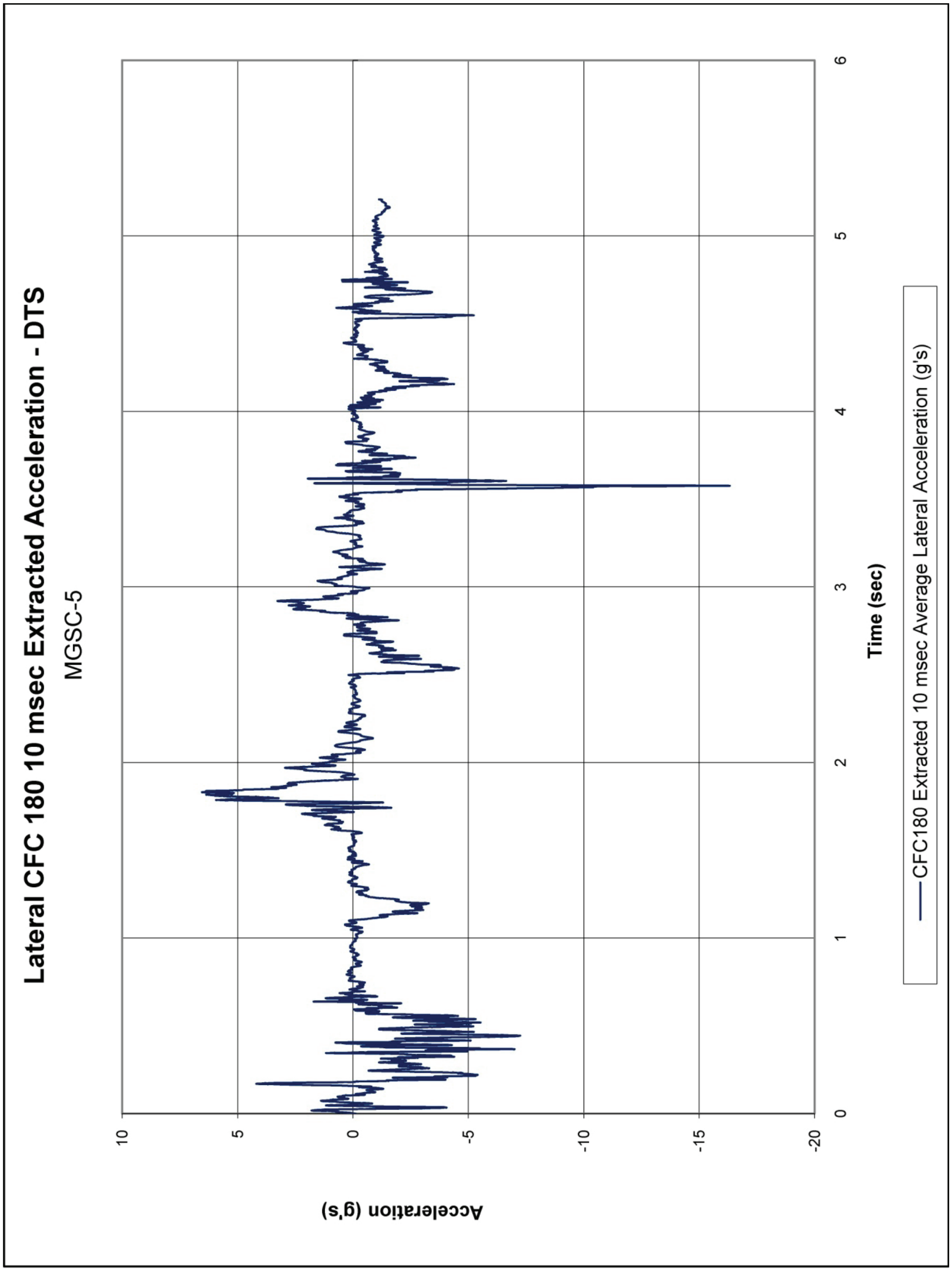


Figure E-17. 10-ms Average Lateral Deceleration (DTS), Test No. MGSC-5

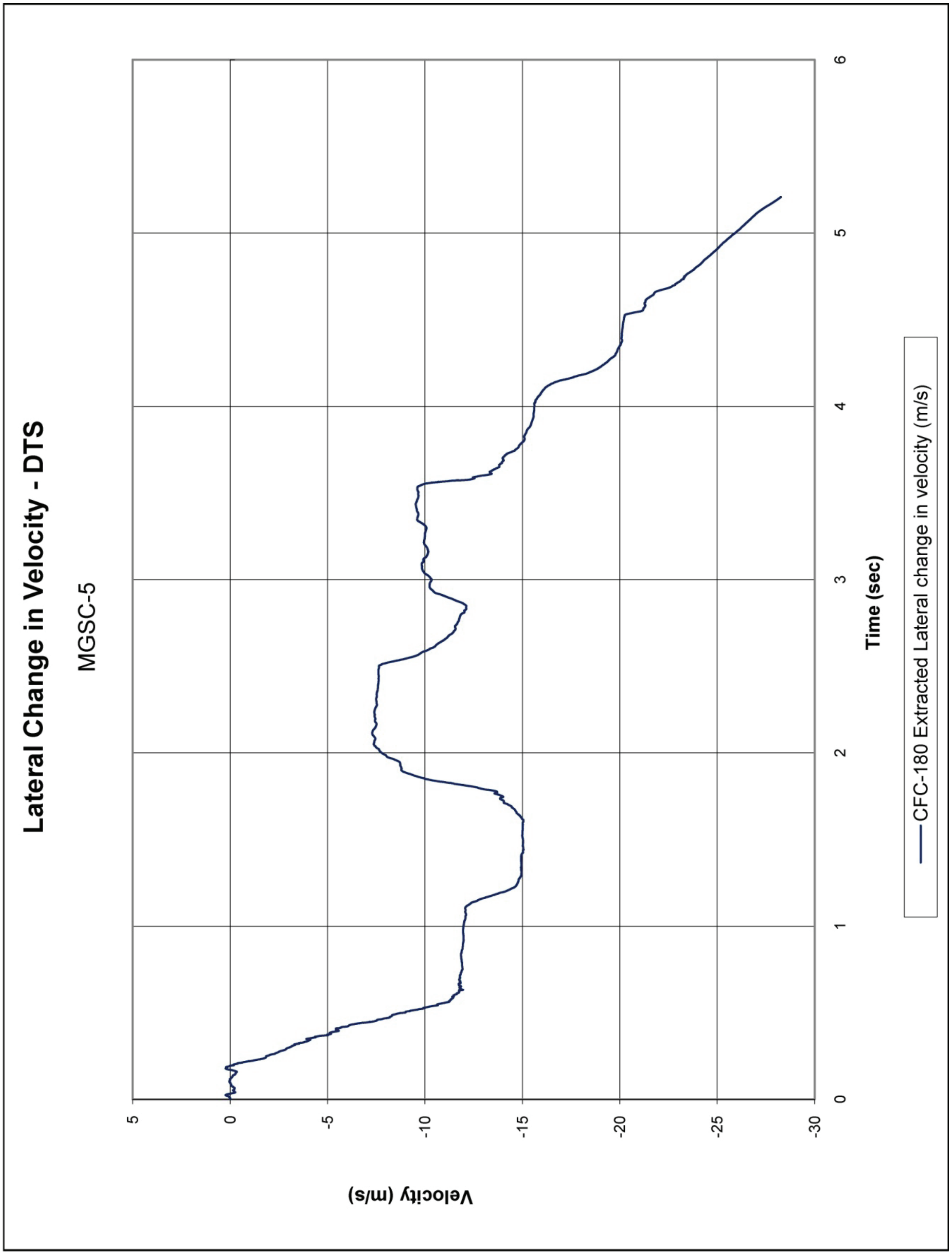


Figure E-18. Lateral Occupant Impact Velocity (DTS), Test No. MGSC-5

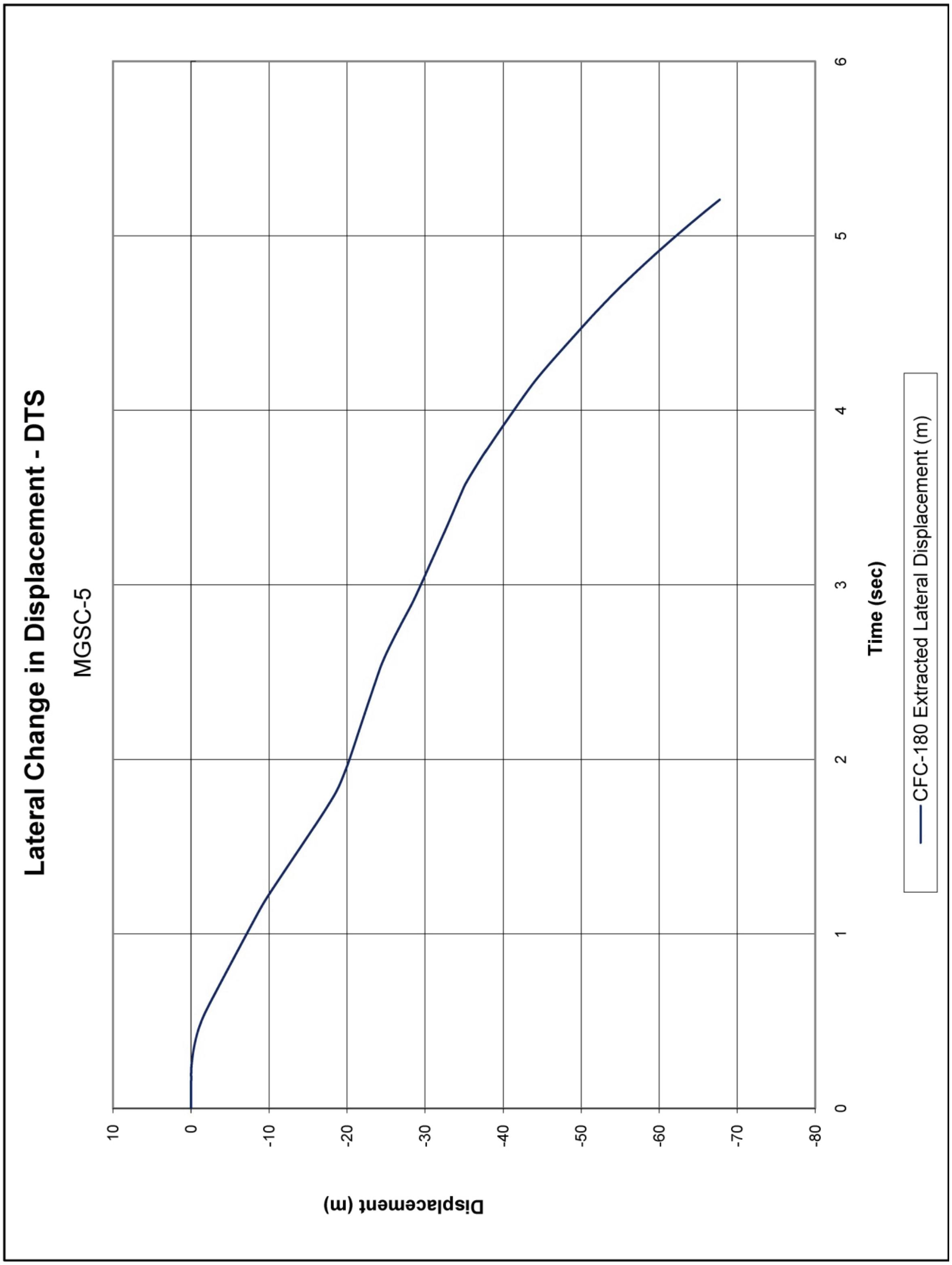


Figure E-19. Lateral Occupant Displacement (DTS), Test No. MGSC-5

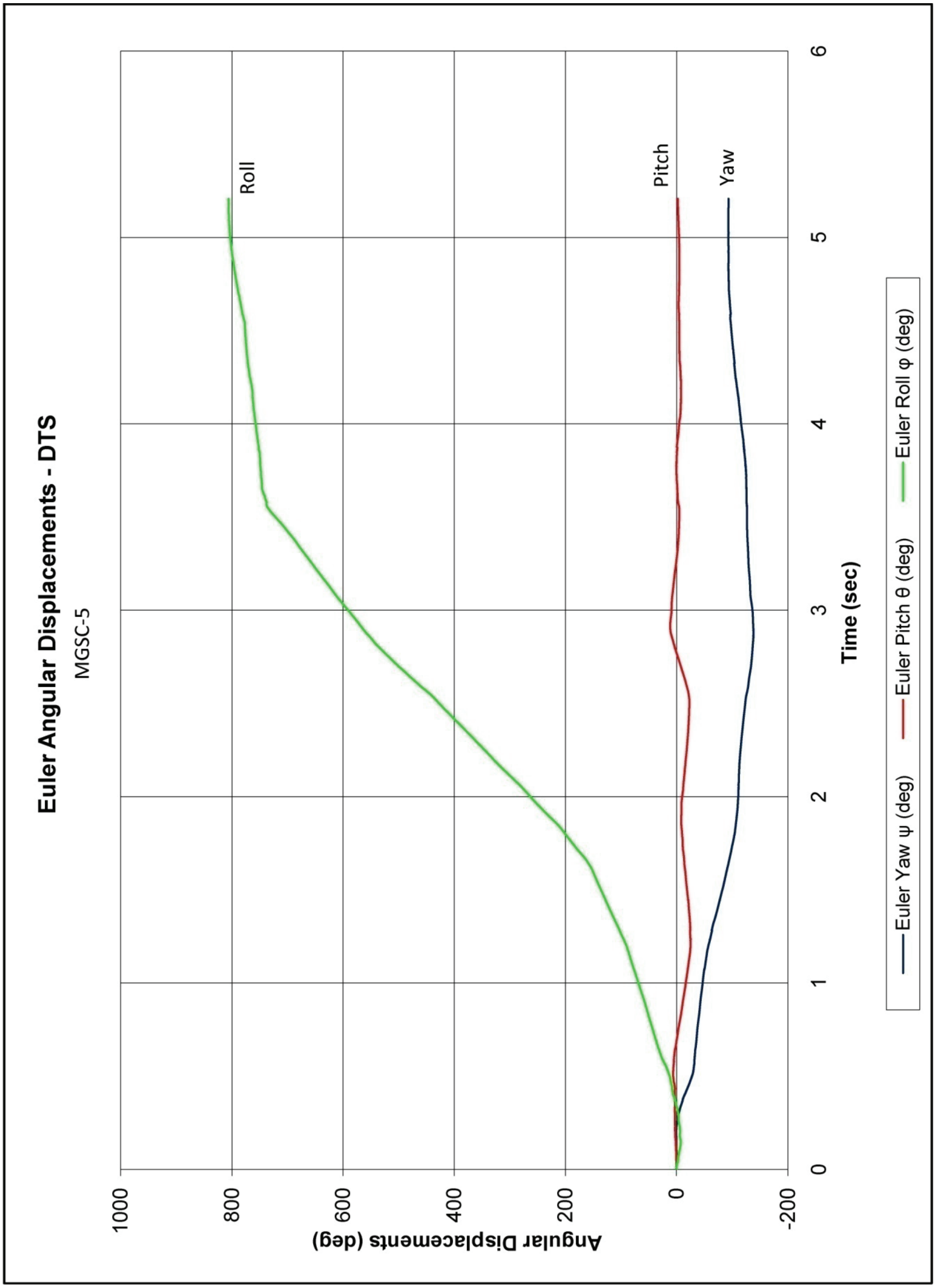


Figure E-20. Vehicle Angular Displacements (DTS), Test No. MGSC-5

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