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DETERMINATION OF THE MAXIMUM MGS MOUNTING HEIGHT – PHASE I CRASH TESTING

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16. Abstract (Limit: 200 words)

Post-and-rail guardrail systems encounter environmental conditions, such as severe frost heave or erosion, which may drastically affect the post embedment depth and rail mounting height. In addition, guardrail systems may be designed to accommodate future roadway surface overlays. As these scenarios arise, it becomes evident that the rail mounting height tolerances for post-and-rail systems need to be evaluated. Over the years, the recommended minimum top rail mounting height for the MGS was established as 27¾ in. (705 mm) based on crash testing with pickup trucks at 25-degree angles and according to the NCHRP Report No. 350 and MASH safety standards. However, no maximum height has been set.

The primary objective of this study was to evaluate the potential for increasing the maximum rail mounting height of the MGS. The research study included two full-scale crash tests with Kia Rio passenger cars, each weighing approximately 2,425 lb (1,100 kg). The first system utilized a 34-in. (864-mm) top rail mounting height and a line post embedment depth of 37 in. (940 mm). The second system utilized a 36-in. (914-mm) top rail mounting height with a line post embedment depth of 35 in. (889 mm). Following the success of the full-scale crash test program, both system heights were found to satisfy MASH TL-3 evaluation criteria for test no. 3-10. Evaluation of these rail heights under pickup truck impacts (test no. 3-11) is necessary before these taller systems can be deemed crashworthy according to 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 safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

The Independent Approving Authority (IAA) for the data contained herein was Mario Mongiardini, Post-Doctoral Research Assistant.

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1 INTRODUCTION

1.1 Background

In post-and-rail systems, the rail height plays a crucial role in the way an errant vehicle interacts with the barrier. A low rail height may increase the chance of vehicle rollover, while an excessively tall rail may cause vehicle snagging, underride, and occupant compartment penetration. The rail mounting height and the post embedment depth may be altered by various installation or environmental occurrences, such as soil erosion, frost heave, human error, and future roadway surface overlays. Hence, the maximum and minimum heights of a barrier system are selected to mitigate concerns for mounting height variability while allowing for safe vehicle containment and redirection.

The Midwest Guardrail System (MGS) is a post-and-rail system which was originally developed according to the Test Level 3 (TL-3) standards set forth by the National Cooperative Highway Research Program (NCHRP) Report No. 350 [1] to provide a reliable W-beam guardrail system capable of capturing and redirecting larger vehicles, specifically the ¾-ton pickup truck, while minimizing the potential for barrier underride by the small car [2]. The MGS has also been successfully crash tested and evaluated according to the TL-3 procedures provided in the *Manual for Assessing Safety Hardware* (MASH) [3] for both the 1100C passenger car and the 2270P pickup truck [4-5]. For the NCHRP Report No. 350 and MASH testing programs, the top rail mounting height of the MGS was 32 in. (813 mm) for passenger cars and 31 in. (787 mm) for pickup trucks.

Although the MGS was crash tested with pickup trucks using a 31-in. (787-mm) top rail mounting height, the MGS would provide acceptable safety performance at lower mounting heights. For example, the modified G4(1S) W-beam guardrail system demonstrated acceptable safety performance according to the TL-3 criteria provided in MASH when installed with a 27¾-

in. (705-mm) top rail mounting height [6, 7]. Prior full-scale crash testing with pickup trucks at 25-degree angles has demonstrated that the MGS provides improved barrier performance over that observed with the modified G4(1S) barrier system. Therefore, the MGS should also meet the TL-3 requirements found in MASH when installed with a top rail height of 27¾ in. (705 mm). Based on prior crash testing of the modified G4(1S) and MGS barrier systems, researchers at the Midwest Roadside Safety Facility (MwRSF) reasoned that the standard MGS would provide acceptable safety performance when installed with top rail mounting heights ranging between 27¾ in. (705 mm) and 32 in. (813 mm). Therefore, the recommended minimum and maximum top rail mounting heights for the standard MGS were previously established as 27¾ in. (705 mm) and 32 in. (813 mm), respectively.

The MGS has also been successfully crash-tested and evaluated with 820C small passenger cars with flare rates as high as 5:1 [8]. The increased impact severity of this particular configuration did not accompany barrier underride and provided evidence that the upper height tolerance for the MGS may be increased significantly from the current maximum allowable value.

Raising the height of the rail can lead to the following five problems regarding system performance of the MGS: (1) vehicle underride (small car); (2) post snagging (small car); (3) occupant compartment penetration (small car); (4) excessive deflection due to reduced lateral resistance (pickup truck); and (5) overloaded anchors that were designed for shorter heights (pickup truck). Before the larger deflections are quantified or the anchorages are evaluated at new heights, the rail height limit for acceptable small car interaction has to be defined. Although many full-scale crash tests have utilized a small car impacting a guardrail system, there have been no recent underride issues which could provide useful insight into the upper limits for the MGS.

1.2 Objectives

The objective of this research project was to evaluate the safety performance of an increased-height MGS with respect to underride and post snagging for small cars. The guardrail systems were to be evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth by the American Association of State Highway and Transportation Officials (AASHTO) in MASH [3].

1.3 Scope

The research objectives were achieved through the completion of several tasks. First, a literature review was performed of recent W-beam tests to examine the interaction between small cars and guardrails. Second, engineering analysis, evaluation of 1100C vehicle and W-beam rail geometries, dynamic response for posts embedded in soil, and experience with crash testing various guardrail systems were all considered to determine the initial maximum top rail height for the MGS. Next, two full-scale crash tests were performed on the MGS with a top rail mounting height of 34 in. (864 mm) and 36 in. (914 mm), respectively, impacted by 1100C vehicles. Finally, conclusions and recommendations were made that pertain to the safety performance of the maximum-height MGS.

2 LITERATURE REVIEW

2.1 Introduction

Several differences exist between the NCHRP Report No. 350 and MASH testing criteria for longitudinal barriers [1, 3]. First, the small car vehicle utilized in NCHRP Report No. 350 weighed 1,808 lb (820 kg), while the small car vehicle utilized in MASH weighs 2,425 lb (1,100 kg). Second, the impact angle for the TL-3 small car full-scale crash test was 20.0 degrees for NCHRP Report No. 350, but was increased to 25.0 degrees for MASH. Both of these changes result in a significantly higher impact severity (IS) for the MASH testing. On the other hand, the 820C vehicle is expected to have higher occupant ridedown accelerations. Third, the height of the center of gravity (c.g.) for the pickup truck was set at 28 in. (711 mm) in MASH, whereas there was no required c.g. height in NCHRP Report No. 350. Finally, the weight of the pickup truck was increased from 4,409 lb (2,000 kg) to 5,000 lb (2,268 kg).

Most of the current strong-post, W-beam systems have been modified to improve performance for impacts with high-center-of-gravity light trucks introduced by MASH. One of the typical modifications includes raising the top rail mounting height from the previous standard of 27 or 27¾ in. (686 or 705 mm) to a nominal top mounting height of 31 in. (787 mm). Although this height increase improves system performance for pickup truck impacts, it also makes the system more susceptible to vehicle snag and/or underride when impacted by small cars.

The guardrail systems incorporating the increased mounting height have typically been tested to NCHRP Report No. 350 [1]. However, with the adoption of the new MASH standards [3], some systems have been tested with the new 2,425-lb (1,100-kg) 1100C small car. Systems that have been validated by either NCHRP Report No. 350 or MASH at higher top rail mounting heights will be discussed in detail in the following sections. A summary of passenger car tests on

Table 1. Recent Small-Car Testing Performed on W-Beam Guardrail Systems

Test No.	Proprietary (Y/N)	System	Top Rail Height in. (mm)	Barrier Features	Accepted to	Vehicle	Developer	Ref. No.
GMS-2	Y	GMS Guardrail	31 (787)	Gregory Mini-Spacer, no blockouts	350 / MASH	820C	Gregory Highway Products	9-11
057073101	Y	NU-GUARD	31 (787)	Rib-Bak U-Channel Posts, no blockouts	350 / MASH	820C	Nucor Steel Marion, Inc.	12
220570-1	Y	T-31	31 (787)	Modified W6x8.5 (W152x12.6) steel posts, no blockouts	350 / MASH	1100C	Trinity Highway Safety Products	14-15
220570-4	Y	T-31	31 (787)	Modified W6x8.5 (W152x12.6) steel posts, no blockouts	350 / MASH	820C	Trinity Highway Safety Products	14-15
400001-TGS2	Y	TGS	31 (787)	Standard W6x8.5 (W152x12.6) steel posts, no blockouts	350 / MASH	820C	Trinity Highway Safety Products	16
NPG-1	N	MGS	32 (813)	Standard W6x8.5 (W152x12.6) steel posts, 12-in. deep blockouts	350	820C	MwRSF	2, 17-19
2214MG-3	N	MGS	32 (813)	Standard W6x8.5 (W152x12.6) steel posts, 12-in. deep blockouts	MASH	1100C	MwRSF	5, 20-21
FR-3	N	MGS	31 (787)	Standard W6x8.5 (W152x12.6) steel posts, 12-in. deep blockouts, 7:1 flare	No acceptance granted currently	820C	MwRSF	8
FR-5	N	MGS	31 (787)	Standard W6x8.5 (W152x12.6) steel posts, 12-in. deep blockouts, 5:1 flare	No acceptance granted currently	820C	MwRSF	8

guardrail systems utilizing higher top rail mounting heights is shown in Table 1. A majority of sources from agencies outside the Midwest Roadside Safety Facility were in the form of Federal Highway Administration (FHWA) acceptance letters and Transportation Research Board (TRB) articles and papers. Therefore, testing information and specific system detail are limited for these agencies.

2.2 Proprietary Systems

2.2.1 Gregory Highway Products

In 2006, Gregory Highway Products developed a proprietary fastener called the Gregory Mini Spacer (GMS) to replace standard guardrail bolts. Southwest Research Institute (SwRI) conducted two tests using this fastener on a Modified G4(1S) W-beam system utilizing 820C and 2270P vehicles. The modified G4(1S) system has a nominal barrier height of 31 in. (787 mm) and no blockouts. Test no. GMS-2 with the 820C vehicle was successful, and FHWA gave acceptance for the fastener to be used in place of a standard guardrail bolt on any non-proprietary strong or weak post W-beam system that currently meets NCHRP Report No. 350 standards [8]. The guardrail system utilizing this new fastener is called the GMS Guardrail [10]. Although the system was tested with the pickup truck specified in MASH, it was not accepted to MASH standards at this time.

In 2008, Gregory Highway Products requested formal FHWA acceptance of the GMS Guardrail under the provisions of the new MASH standards. Two tests, in addition to the ones performed for the previous acceptance letter, were performed using 2270P vehicles. The system was tested with a top rail height of 27⅝ in. (702 mm). No new tests were performed using the small car, although acceptance was granted for use of the GMS Guardrail system under MASH standards [11].

2.2.2 Nucor Steel Marion, Inc.

In 2007, Nucor Steel Marion Inc. developed a new post for their NU-Guard 31-in. (787-mm) high and NU-Guard 27-in. (686-mm) high strong post W-beam systems. Nucor sought FHWA acceptance for both NCHRP Report No. 350 and MASH standards for the 31-in. (787-mm) system, but just NCHRP Report No. 350 acceptance for the 27-in. (686-mm) system. In order to reduce the number of tests required to meet both standards, and to avoid redundancy, three tests were conducted by Holmes Solutions of New Zealand. Test nos. 3-10 and 3-11 with 820C and 2270P vehicles, respectively, were conducted on the 31-in. (787-mm) system, while test no. 3-11 with a 2000P vehicle was performed on the 27-in. (686-mm) system. An 1100C vehicle was not used due to the lighter 820C vehicle having an increased propensity for excessive ridedown decelerations, snag, and underride.

MASH test no. 3-10 (test no. 057073101) was performed on a median barrier configuration of the 31-in.(787-mm) system. It was considered to produce the greatest risk to the occupant because it was stiffer than the roadside configuration. The 31-in. (787-mm) system did not utilize blockouts in either the median or roadside applications. The test was successful utilizing the 820C small car with a 31 in. (787 mm) top rail mounting height, and the system was accepted to both NCHRP Report No. 350 and MASH standards for blocked and non-blocked configurations [12-13].

2.2.3 Trinity Highway Safety Products

In 2005, a strong post W-beam guardrail system called the T-31 was designed by Trinity Highway Safety Products Division. The system was tested by Texas Transportation Institute (TTI) and uses standard 12-gauge W-beam and modified W6x8.5 (W152x12.6) steel posts with a top rail height of 31 in. (787 mm). Three tests were performed on this barrier: (1) NCHRP Report No. 350 test no. 3-10 utilizing an 820C vehicle (test no. 220570-4), (2) MASH test no. 3-

10 utilizing an 1100C vehicle (test no. 220570-1), and (3) MASH test no. 3-11 utilizing a 2270P vehicle (test no. 220570-2). At the time, these vehicles were tested in the anticipation of the MASH testing standards. All test results satisfied the safety criteria of NCHRP Report No. 350 and MASH. Therefore, the T-31 was accepted as a TL-3 barrier under both NCHRP Report No. 350 and MASH [14-15].

In 2007, TTI tested another proprietary guardrail system called the Trinity Guardrail System (TGS) for Trinity Highway Safety Products Division. The TGS used standard W6x8.5 (W150x12.6) steel line posts without blockouts and a 12-gauge W-beam mounted at a top rail height of 31 in. (787 mm). Two tests were performed on this barrier: (1) MASH test no. 3-11 (test no. 400001-TGS1) utilizing a 2270P vehicle, and (2) NCHRP Report No. 350 test no. 3-10 (test no. 400001-TGS2) utilizing an 820C vehicle. Results from both tests satisfied the safety performance criteria of their corresponding standard, NCHRP Report No. 350 or MASH. Therefore, the TGS was accepted as a TL-3 barrier under both NCHRP Report No. 350 and MASH [16].

2.3 Non-Proprietary Systems

2.3.1 Midwest Roadside Safety Facility (MwRSF)

In the early 2000s, researchers at the Midwest Roadside Safety Facility (MwRSF) developed a new guardrail system called the Midwest Guardrail System (MGS) in order to improve performance for high-center-of-gravity light trucks. The MGS incorporated a 31-in. (787-mm) nominal height to the top of the rail, splices located between posts, and an increased blockout depth of 12 in. (305 mm). One small car test was performed on the new system, NCHRP Report No. 350 test no. 3-10 with an 820C vehicle (test no. NPG-1). For this test, the top of the rail was placed at 32 in. (813 mm) to demonstrate the barrier performance at the maximum allowable rail height, and the MGS satisfied NCHRP Report 350 evaluation criteria

[2, 17-18]. Subsequently, FHWA acceptance was granted for the MGS to NCHRP Report No. 350 standards in 2005 [19].

While the MASH document was being written, NCHRP Project No. 22-14(2) was undertaken by researchers at MwRSF to evaluate current roadside safety devices. One of the selected barriers was the MGS barrier mounted at a top rail height of 32 in. (813 mm) when impacted by a 2,425-lb (1,100-kg) small car (test no. 2214MG-3). Test results showed the barrier satisfied the TL-3 evaluation criteria found in MASH [5,20]. The MGS has since been accepted according to MASH standards [21].

In 2008, MwRSF conducted a study that examined critical flare rates for the MGS. Two tests were performed with an 820C small car and a 31-in. (787-mm) nominal rail mounting height. The first test, test no. FR-3, was performed on the MGS with a flare rate of 7:1, while the second, test no. FR-5, had a flare rate of 5:1. Thus, the effective impact angles for these tests were 28.7 and 31.8 degrees, respectively. Both tests satisfied the safety performance criteria of NCHRP Report No. 350. Tests with vehicles in the light truck category were also successfully performed and reported [8], thus establishing the maximum recommended flare rate of 5:1.

2.4 Terminals

With the modification of several standard barriers to a new rail height, terminals for these barriers were affected. FHWA accepted several terminals to be used with the taller W-beam strong post systems. Terminals that were accepted for the MGS are: SKT (test no. SMG-1), SKT-LITE, FLEAT (test nos. FLEAT-5, FLEAT-6, and FLEAT-8), and the ET-Plus 31 (test no. 220601-2) [22-25]. Additionally, researchers at MwRSF tested an SKT-MGS Tangent End Terminal while working on NCHRP Project 22-14(2) (test no. 2214TT-1). The rail was mounted at a height of 32 in. (813 mm) and met the proposed standards of MASH [26]. SKT and FLEAT terminals were also accepted for use with the GMS-WB31 system through similarities to the

MGS [27]. The SRT-31 terminal has been accepted for use with the MGS, T-31, and GMS-WB31 systems through test no. 220541-2 [28].

2.5 Discussion

All of the systems discussed in this literature review were deemed acceptable according to the respective standards to which they were tested. Upon reviewing the test results, the potential for wheel snag and underride was evident.

Two concerns arise when wheel snag occurs: (1) the wheel is pushed rearward against the wheel well, which could deform the floorpan and (2) the longitudinal forces on the wheel increase the occupant risk values. Test no. FR-3 showed the propensity for wheel snag, as shown in Figure 1. Additionally, the small car utilized in test no. FR-5 encountered wheel snag on post no. 15, as shown in Figure 2. These flare rate tests, however, were more severe than a standard W-beam test, as the small car impacted at a higher effective angle of 31.8 degrees. As stated before, both of these tests passed the NCHRP Report No. 350 test criteria, and experienced acceptable floorpan deflections and occupant risk values. Thus, wheel snag may not pose a critical risk to the small car at higher rail heights. In test no. 2214MG-3, slight wheel snag occurred that did not abruptly stop the vehicle but caused it to yaw toward the barrier, as shown in Figures 3 and 4.

Barrier underride also poses a significant risk for two reasons: (1) the rail slides along the top of the hood and comes into contact with the base of the windshield, which could cause unacceptable deformations of the windshield and/or intrusion into the occupant compartment, and (2) the vehicle may traverse under the rail and impact a hazard behind the barrier. No recent W-beam guardrail tests have experienced significant barrier underride. Thus, recent tests were evaluated for the potential for barrier underride.

The potential for barrier underride was seen in several tests. In some tests, the rail contacted the front of the vehicle and began to slide upward, but snagged under the hood and the quarter panel, as shown in Figure 5. The hood snag did not pose a threat to the occupants of the vehicle, but the rail may not be caught under the hood at higher rail heights, which would allow underride to occur.

Figure 1. Test No. FR-3, Potential for Wheel Snag

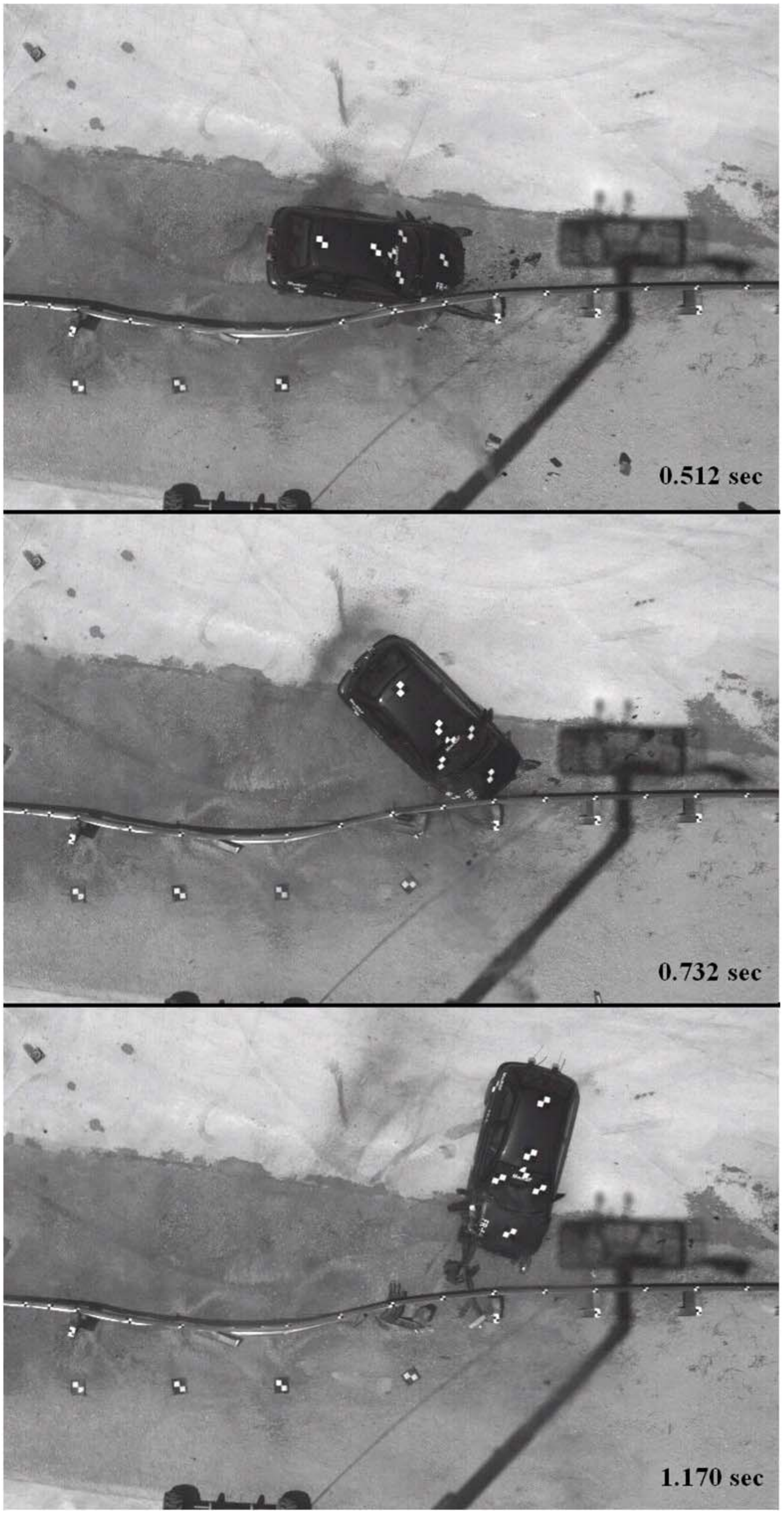


Figure 2. Test No. FR-5, Wheel Snag

Figure 3. Test No. 2214MG-3, Wheel Snag

Figure 4. Test No. 2214MG-3, Vehicle Yaws Toward the Barrier

Figure 5. Test No. 2214MG-3, Rail Snags Under the Hood

3 RAIL HEIGHT TESTING RECOMMENDATION

3.1 Introduction

The MGS has successfully redirected an 1100C small car with the top rail height at 32 in. (813 mm) and several 820C small cars at a top rail height of 31 in. (787 mm). Several factors need to be considered in order to make a recommendation for a maximum top rail height for the MGS. These factors include small car geometry, rail geometry, soil and post yielding forces, post length, and post embedment depth. The new height will affect the way the light truck interacts with the system, but that is beyond the scope of this project.

3.2 Vehicle and Rail Geometry

Front end geometry of the 1100C vehicle is a key factor in deciding how high the rail can be raised without the vehicle underriding the barrier. Averaged vehicle dimensions are shown in Figure 6, and dimensions for two specific 1100C vehicles are shown in Figure 7.

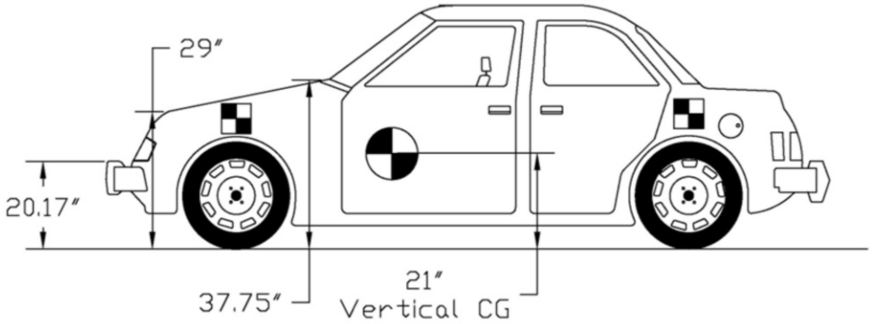
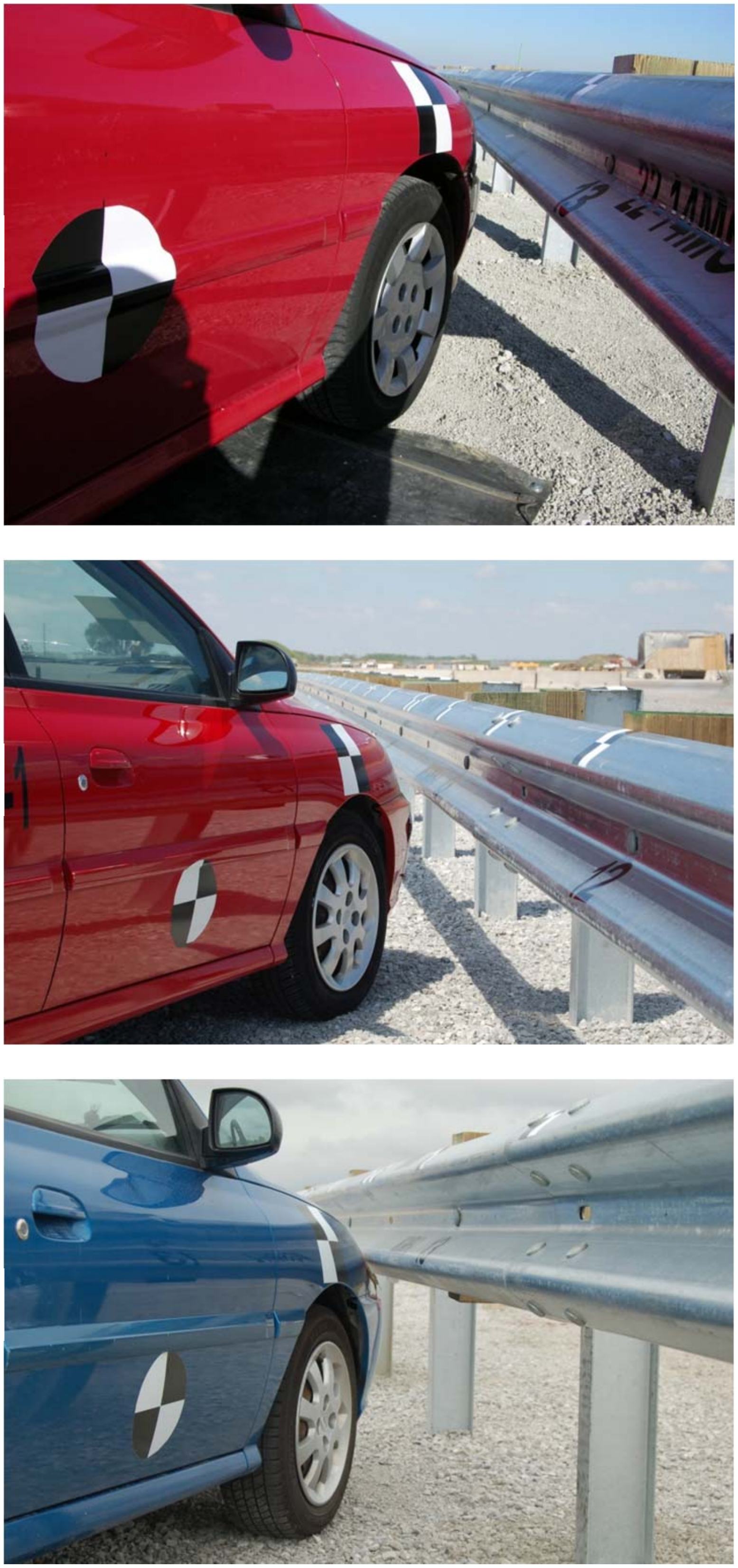


Figure 6. 1100C Vehicle Schematic, Average Measurements

Another key geometric factor is the vehicle to rail relationship, as shown in Figures 8 and 9. When the rail is mounted at a height of 32 in. (813 mm), the rail no longer contacts the bumper—its contact is primarily with the hood and side quarter panel of the vehicle. Because several tests have successfully passed with that type of contact, the height of the rail may be increased several inches and still successfully capture the vehicle. As shown in Figure 6, the distance between the top of the bumper and the upper edge of the side panel is approximately

17.5 in. (445 mm), providing a broad area for rail interaction without the rail contacting the A-pillar.

Figure 7. 1100C Front End Dimensions



32-in. (813-mm)
MGS

34-in. (864-mm)
MGS

36-in. (914-mm)
MGS

Figure 8. 1100C Next to 32-, 34-, and 36-in. (813-, 864-, and 914-mm) MGS – Rear View

32-in. (813-mm)
MGS

34-in. (864-mm)
MGS

36-in. (914-mm)
MGS

Figure 9. 1100C Next to 32-, 34-, and 36-in. (813-, 864-, and 914-mm) MGS – Front View

3.3 Post Length, Post Embedment Depth, and Rail Height

A different factor to be considered is post length and embedment depth. If the top rail height increases, so is the height of the post above the ground. Since it is desired to use the standard, 72-in. (1,829-mm) length, W6x8.5 or W6x9 (W152x12.6 or W152x13.4) steel post, as used in the original MGS, the embedment depth will decrease in direct proportion to the raising of the rail.

The post height above ground is 1 in. (25 mm) higher than the top of the rail height. Thus, for the nominal rail height of 31 in. (787 mm), the nominal post embedment depth is 40 in. (1,016 mm).

When the rail is raised, the dynamic yield force for the post-soil interaction is decreased due to the longer moment arm between the ground and the mounting height of the rail.

$$F_{new} h_{new} = F_{nominal} h_{nominal} \qquad \text{[Eq. 1]}$$

where

F = dynamic yield force

h = rail mounting height (or acting force height)

As the post embedment depth is decreased, the dynamic yield force also decreases. According to Appendix A of NCHRP Report No. 350 [1], this relationship is given as:

$$F_{new} = F_{nominal} \left(\frac{d_{new}}{d_{nominal}} \right)^2 \qquad \text{[Eq. 2]}$$

where

d = post embedment depth

Since both of these factors are occurring in raising the standard MGS, the accumulative effect on the dynamic yield force would be:

$$F_{new} = F_{nominal} \left(\frac{h_{nominal}}{h_{new}} \right) \left(\frac{d_{new}}{d_{nominal}} \right)^2 \qquad \text{[Eq. 3]}$$

Using Equation 3, the effect on the dynamic yield force can be investigated for various rail heights and corresponding post embedment depths.

However, the nominal dynamic yield force is not simply defined. Based on many previous post-in-soil bogie testing [2,3,29,30], the typical dynamic yield force falls within a range of 6-10 kips (27-44 kN). Thus, dynamic yield forces for top rail heights of 32-38 in. (813-965 mm) by 1-in. (25-mm) increments were calculated for nominal dynamic yield forces of 6, 8, and 10 kips (27, 36, and 44 kN). Results are shown in Table 2. Calculations were performed for Equations 1, 2, and 3 so that the individual, as well as the accumulative, effect of raising the rail could be distinguished.

Table 2. Post-Soil Dynamic Yield Forces

		nominal							
Top Rail Height [in.]		31	32	33	34	35	36	37	38
Acting Force Height [in.]		24.875	25.875	26.875	27.875	28.875	29.875	30.875	31.875
Embedment Depth [in.]		40	39	38	37	36	35	34	33
			calculated Dynamic Yield Forces based on decreased embedment depth						
			(impact height remains at 24.875 in.)						
Dynamic Yield Force [kips]		6	5.7	5.4	5.1	4.9	4.6	4.3	4.1
Dynamic Yield Force [kips]		8	7.6	7.2	6.8	6.5	6.1	5.8	5.4
Dynamic Yield Force [kips]		10	9.5	9.0	8.6	8.1	7.7	7.2	6.8
			calculated Dynamic Yield Forces based on increased rail height						
			(embedment depth stays at 40 in.)						
Dynamic Yield Force [kips]		6	5.8	5.6	5.4	5.2	5.0	4.8	4.7
Dynamic Yield Force [kips]		8	7.7	7.4	7.1	6.9	6.7	6.4	6.2
Dynamic Yield Force [kips]		10	9.6	9.3	8.9	8.6	8.3	8.1	7.8
			calculated Dynamic Yield Forces based on both						
			increased rail height and decreased embedment depth						
Dynamic Yield Force [kips]		6	5.5	5.0	4.6	4.2	3.8	3.5	3.2
Dynamic Yield Force [kips]		8	7.3	6.7	6.1	5.6	5.1	4.7	4.2
Dynamic Yield Force [kips]		10	9.1	8.4	7.6	7.0	6.4	5.8	5.3

3.4 Discussion and Recommendation

There is no “formula” that can be applied to determine the maximum rail height to test. The goal is to determine what might be considered a reasonable and practical maximum height to the experts in roadside safety. This includes a thoughtful use of the geometry and force information detailed in sections 3.2 and 3.3. The rail should be low enough such that a good portion of it remains alongside of the vehicle's side fender and door, and not rely on capture via the A-pillar and window area of the door. Other small vehicles, with a lower profile than the current 1100C, should be kept in mind. Calculated post-in-soil dynamic yield forces around 8 kips (36 kN) might be considered ideal, but less than 6 kips (27 kN) should be avoided if possible.

After several discussions and time for contemplation, it was recommended to test the MGS at a rail height of 34 in. (864 mm). If that test were to pass all MASH criteria, then a follow-up test at 36 in. (914 mm) would be recommended unless test results clearly indicated that a higher or lower height should be considered.

4 TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 Test Requirements

Longitudinal barriers, such as W-beam guardrails, must satisfy impact safety standards in order to be accepted by FHWA for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH [3]. 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 noted below:

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 5,000-lb (2,268-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 3.

Table 3. 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 4.

4.2 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 guardrail system to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/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 4 and defined in greater detail in MASH. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in MASH.

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), and the Acceleration Severity Index (ASI) were determined and reported on the test summary sheets. Additional discussion on PHD, THIV and ASI is provided in MASH.

4.3 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 the designated 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 from this static test become the baseline requirement for soil strength in future full-scale crash testing in which the designated soil is used. An additional post installed near the impact point is statically tested on the day of the full-scale crash test in the same manner as used in the baseline static test. The full-scale crash test can be conducted only if the static test results show a soil resistance equal to or greater than 90 percent of the baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Otherwise, the crash test must be postponed until the soil demonstrates adequate post-soil strength.

Table 4. MASH Evaluation Criteria for Longitudinal Barrier

<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="10">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</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</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>

5 TEST CONDITIONS

5.1 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.

5.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch [31] 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 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 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.

5.3 Test Vehicles

For test no. MGSMRH-1, a 2003 Kia Rio sedan was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,401 lb (1,089 kg), 2,429 lb (1,102 kg), and 2,599 lb (1,179 kg), respectively. The test vehicle is shown in Figure 10, and vehicle dimensions are shown in Figure 11.

For test no. MGSMRH-2, a 2004 Kia Rio sedan was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,449 lb (1,111 kg), 2,412 lb (1,094 kg), and

Figure 10. Test Vehicle, Test No. MGSMRH-1

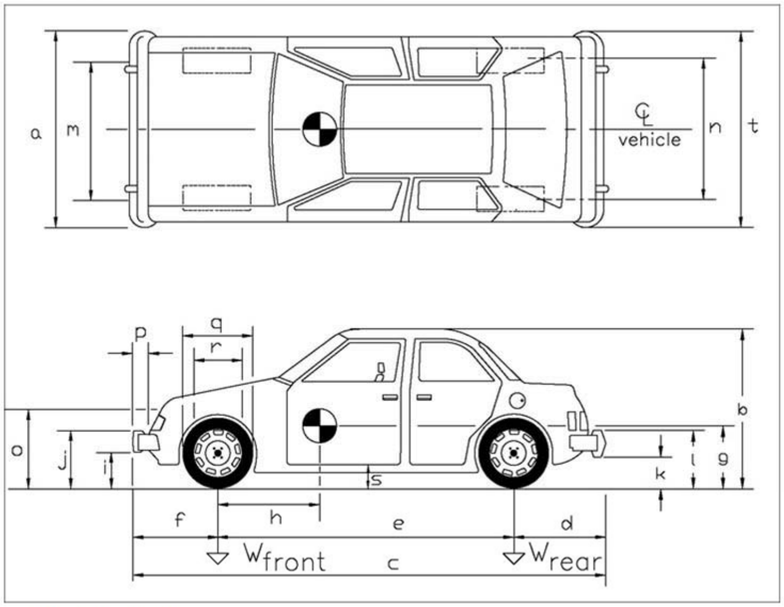
Date: 6/29/2010 **Test Number:** MGSMRH-1 **Model:** 1100C Rio Sedan

Make: Kia **Vehicle I.D.#:** KNADC125036275583

Tire Size: 175/65 R14 **Year:** 2003 **Odometer:** 63193

Tire Inflation Pressure: 30psi

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



Vehicle Geometry -- in. (mm)

a	64 1/4	(1632)	**b**	55	(1397)
c	166 1/4	(4223)	**d**	38	(965)
e	95	(2413)	**f**	33 1/4	(845)
g	18	(457)	**h**	36	(915)
i	8	(203)	**j**	21 1/2	(546)
k	11	(279)	**l**	22 1/4	(565)
m	56	(1422)	**n**	56 3/4	(1441)
o	26 1/2	(673)	**p**	3 1/4	(83)
q	23	(584)	**r**	15 1/2	(394)
s	12	(305)	**t**	64 1/4	(1632)

Wheel Center Height Front	10 1/4	(260)
Wheel Center Height Rear	10 3/4	(273)
Wheel Well Clearance (F)	24	(610)
Wheel Well Clearance (R)	24	(610)
Frame Height (F)	9 1/4	(235)
Frame Height (R)	16	(406)

Engine Type 4cyl. Gas

Engine Size 1.5L

Transmition Type:

[✓ Automatic] Manual

[✓ FWD] RWD 4WD

Mass Distribution

Gross Static	**LF**	793	**RF**	795
	LR	491	**RR**	520

Weights lbs (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	1517 (688)	1500 (680)	1588 (720)
W-rear	884 (401)	929 (421)	1011 (459)
W-total	2401 (1089)	2429 (1102)	2599 (1179)

GVWR Ratings

Front 1808

Rear 1742

Total 3379

Dummy Data

Type: Hybrid 1

Mass: 170 lbs.

Seat Position: Passenger

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

Figure 11. Vehicle Dimensions, Test No. MGSMRH-1

2,583 lb (1,172 kg), respectively. The test vehicle is shown in Figure 12, and vehicle dimensions are shown in Figure 13.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights [32]. The vertical component of the c.g. of each 1100C vehicle was estimated based on historical c.g. height measurements. The location of the final c.g. of each vehicle is shown in Figures 11 and 13 through 15. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black and white-checkered targets were placed on each vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 14 and 15. Round, checkered targets were placed at the center of gravity on the left-side door, the right-side door, and the roof of each vehicle.

The front wheels of each test vehicle were aligned to vehicle standards except the toe-in value was adjusted to zero so that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted on the right side of the vehicle’s dash and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed videos. A remote controlled brake system was installed in each test vehicle so the vehicle could be brought safely to a stop after the test.

5.4 Simulated Occupant

For both tests, a Hybrid II 50th Percentile Adult Male 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, 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.

Figure 12. Test Vehicle, Test No. MGSMRH-2

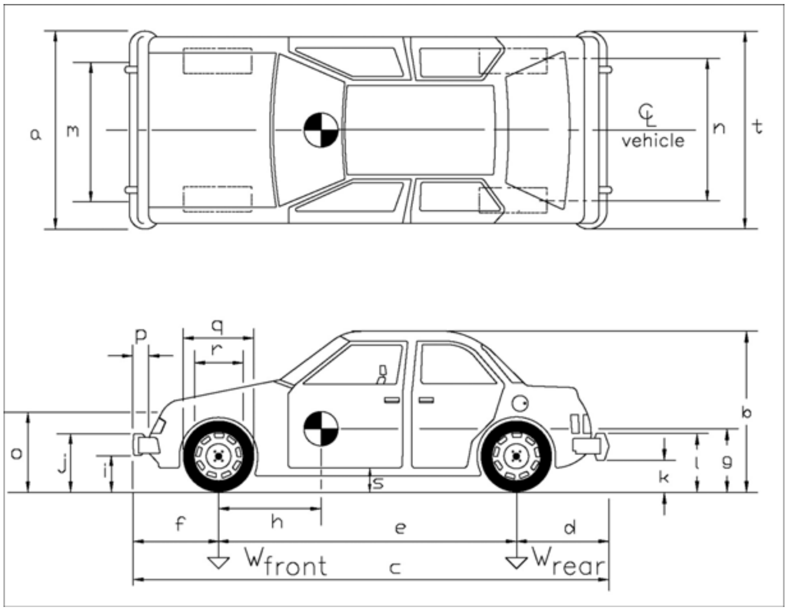
Date: 9/9/2010 **Test Number:** MGSMRH-2 **Model:** 1100C RIO

Make: Kia **Vehicle I.D.#:** KNADC125046337310

Tire Size: P175/65 R14 **Year:** 2004 **Odometer:** 93345

Tire Inflation Pressure: 30 psi.

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



Vehicle Geometry -- in. (mm)

a	64 3/4	(1645)	b	55 1/2	(1410)
c	166 3/4	(4235)	d	38	(965)
e	95	(2413)	f	33 3/4	(857)
g	17	(432)	h	36	(916)
i	9	(229)	j	21 3/8	(543)
k	11	(279)	l	22 3/8	(568)
m	57 1/4	(1454)	n	56 7/8	(1445)
o	27 3/8	(695)	p	3 1/4	(83)
q	22 5/8	(575)	r	15 1/2	(394)
s	12	(305)	t	64 1/4	(1632)

Wheel Center Height Front	10 3/4	(273)
Wheel Center Height Rear	10 7/8	(276)
Wheel Well Clearance (F)	24 3/8	(619)
Wheel Well Clearance (R)	214 1/2	(5448)
Frame Height (F)	6 7/8	(175)
Frame Height (R)	16 1/2	(419)

Engine Type 4cyl Gas

Engine Size 1.6L

Transmition Type:

[✓ Automatic] Manual

[✓ FWD] RWD 4WD

Mass Distribution

Gross Static	LF	775	RF	807
	LR	482	RR	518

Weights lbs (kg)	Curb	Test Inertial	Gross Static
W-front	1532 (695)	1495 (678)	1582 (718)
W-rear	917 (416)	917 (416)	1000 (454)
W-total	2449 (1111)	2412 (1094)	2583 (1172)

GVWR Ratings

Front 1808

Rear 1742

Total 3399

Dummy Data

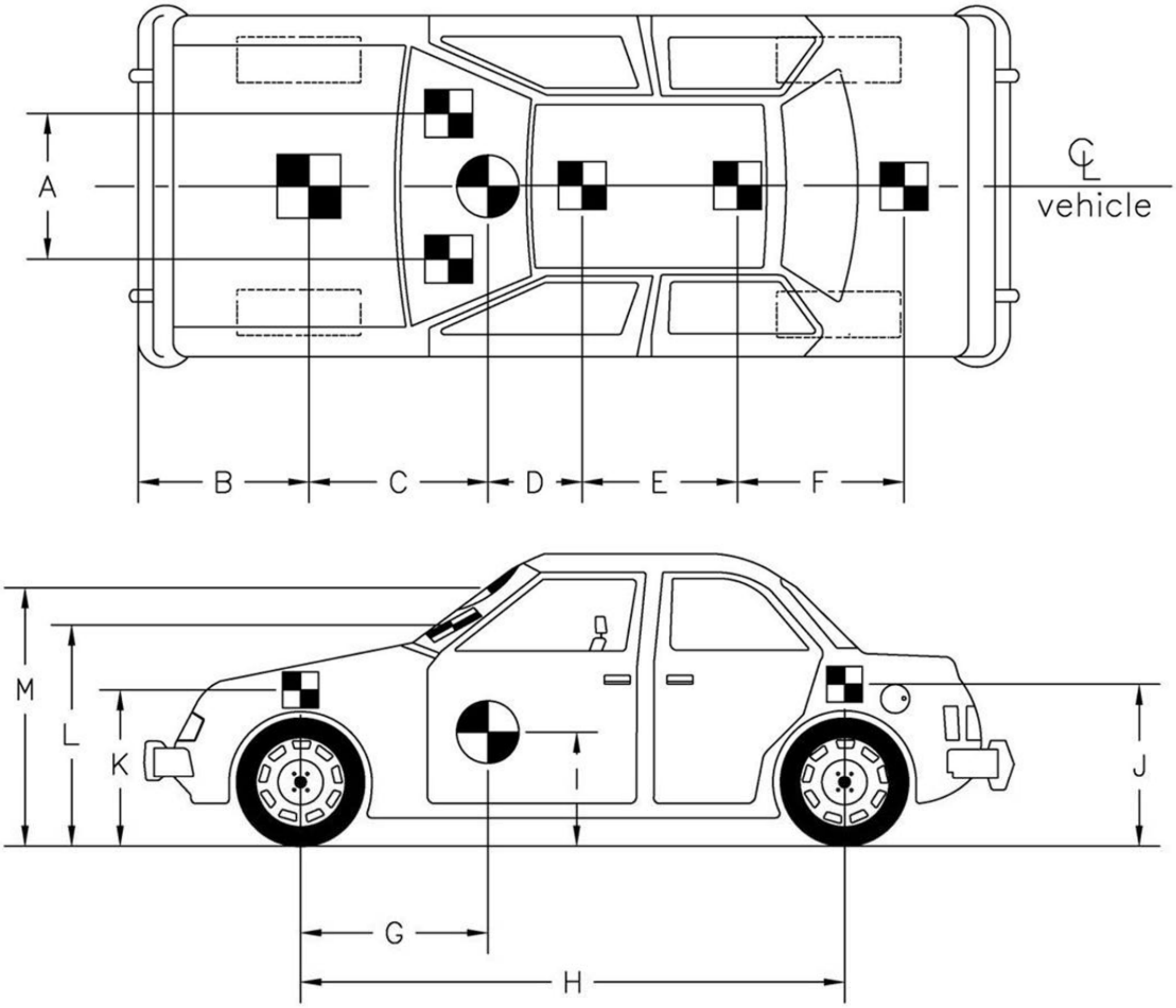
Type: Hybrid 1

Mass: 170 lbs.

Seat Position: Passenger

Note any damage prior to test: None

Figure 13. Vehicle Dimensions, Test No. MGSMRH-2

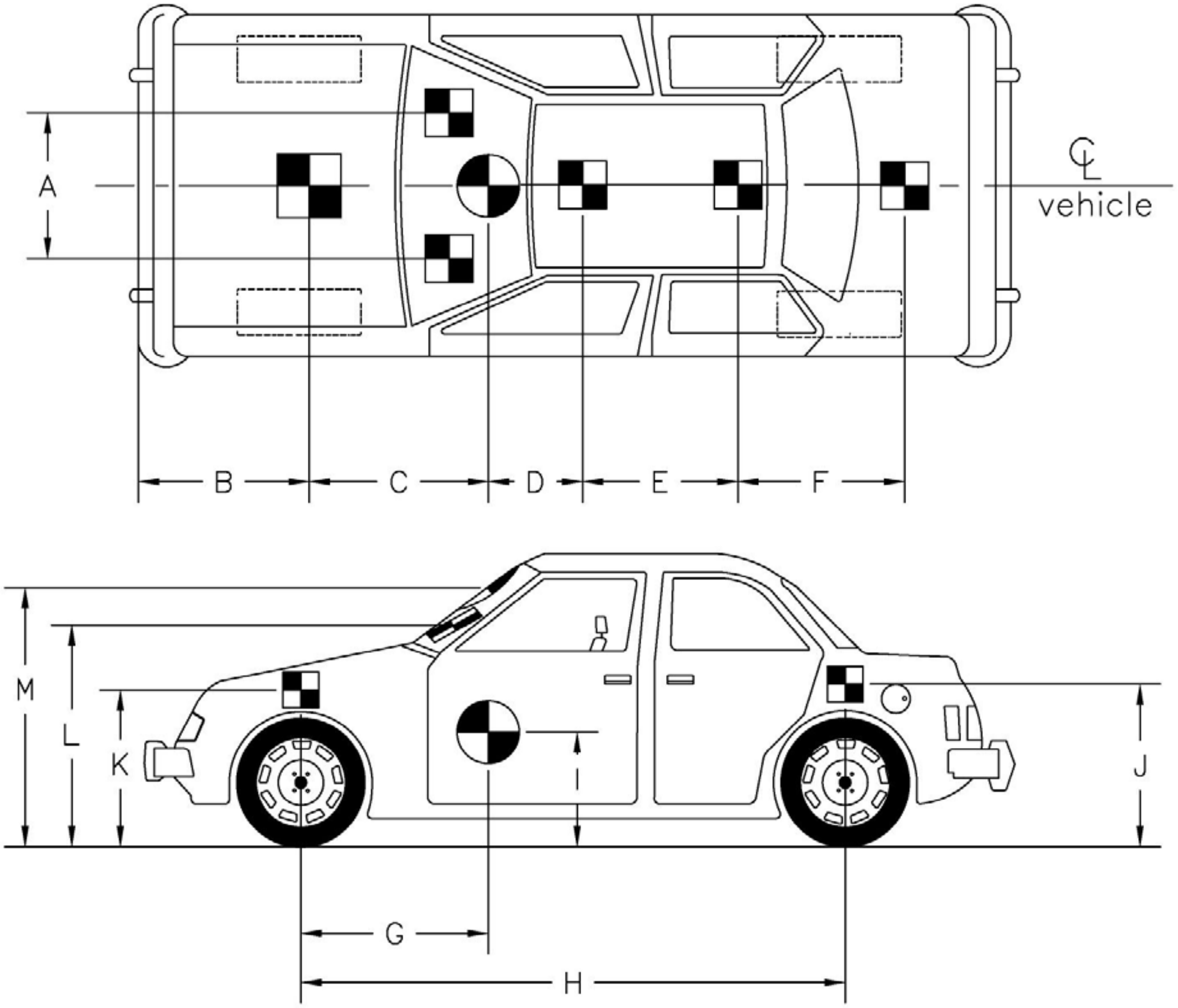


TEST #: MGSMRH-1

TARGET GEOMETRY-- in. (mm)

A	33	(838)	E	28	(711)	I	18	(457)
B	24 3/4	(629)	F	35 1/4	(895)	J	28 1/4	(718)
C	46	(1168)	G	36	(914)	K	28	(711)
D	22 1/2	(572)	H	95	(2413)	L	41 1/4	(1048)
						M	50 3/4	(1289)

Figure 14. Target Geometry, Test No. MGSMRH-1



TEST #: MGSMRH-2

TARGET GEOMETRY-- in. (mm)

A	**30 3/4**	**(781)**	**E**	**37**	**(940)**	**I**	**17**	**(432)**
B	**21 3/4**	**(552)**	**F**	**36 1/4**	**(921)**	**J**	**28 1/2**	**(724)**
C	**45 1/4**	**(1149)**	**G**	**36**	**(914)**	**K**	**28 1/4**	**(718)**
D	**15 1/4**	**(387)**	**H**	**96**	**(2438)**	**L**	**46**	**(1168)**
						M	**53 3/4**	**(1365)**

Figure 15. Target Geometry, Test No. MGSMRH-2

5.5 Data Acquisition Systems

5.5.1 Accelerometers

Two 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. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [33].

The first accelerometer system was a two-arm piezoresistive accelerometer system manufactured 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. The accelerometers were configured and controlled using a system developed and manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. More specifically, data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M. 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 second system, Model EDR-3, was a triaxial piezoresistive accelerometer system manufactured by 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 low-pass filter. The "DynaMax 1 (DM-1)" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

5.5.2 Rate Transducers

An 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 vehicles. 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.

For test no. MGSMRH-2, a second system, 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 vehicles. 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. The "EDR4COM" and "DynaMax Suite" computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate transducer data.

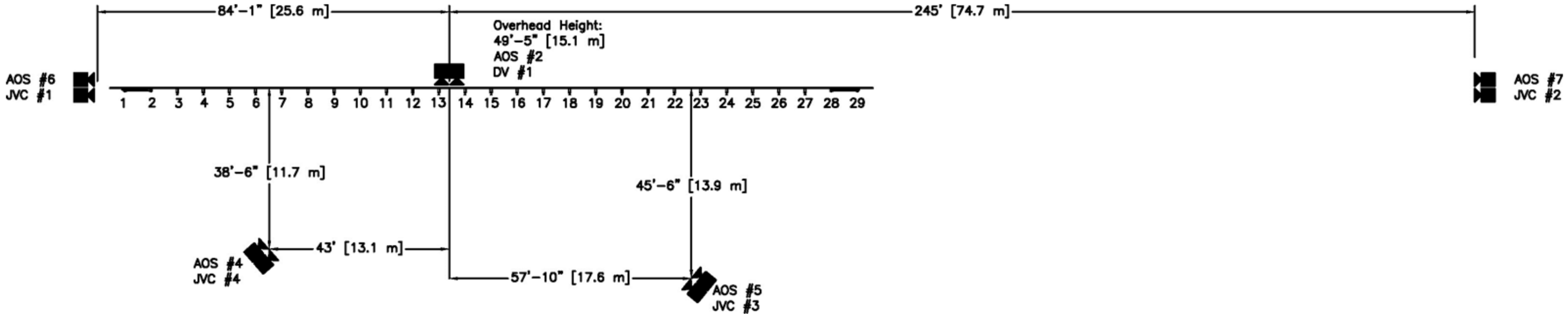
5.5.3 Pressure Tape Switches

For test nos. MGSMRH-1 and MGSMRH-2, five pressure-activated tape switches, spaced at approximately 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.

5.5.4 Digital Cameras

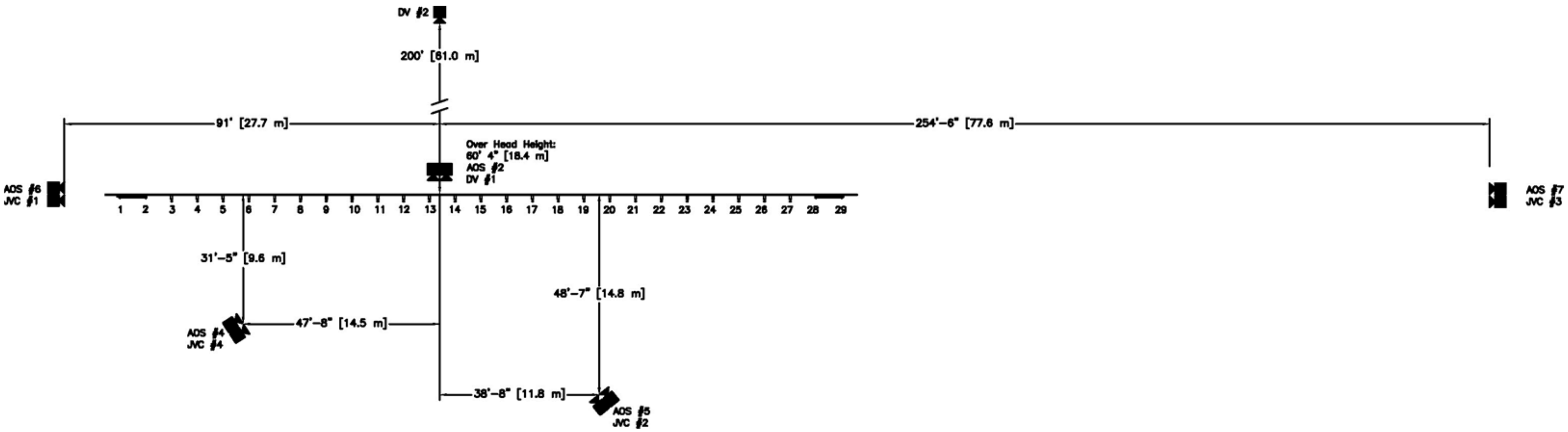
For test nos. MGSMRH-1 and MGSMRH-2, two AOS VITcam high-speed digital video cameras, three AOS X-PRI high-speed digital video cameras, and four JVC digital video cameras were utilized to film the full-scale crash test. In addition, one Canon digital video camera was utilized to film test no. MGSMRH-1 and two Canon digital video cameras were utilized to film test no. MGSMRH-2. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figures 16 and 17.

The high-speed videos were analyzed using ImageExpress MotionPlus and RedLake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A Nikon D50 digital still camera was also used to document pre- and post-test conditions for all tests.



	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	2	AOS Vitcam CTM	500	Cosmicar 12.5mm Fixed	NA
	4	AOS Vitcam CTM	500	Canon 17-102	75
	5	AOS X-PRI Gigabit	500	Sigma 50mm Fixed	NA
	6	AOS X-PRI Gigabit	500	Fujinon 50mm Fixed	NA
	7	AOS X-PRI Gigabit	500	Sigma 24-135	100
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		

Figure 16. Camera Locations, Speeds, and Lens Settings, Test No. MGSMRH-1



	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	2	AOS Vitcam CTM	500	Cosmicar 12.5mm Fixed	NA
	4	AOS Vitcam CTM	500	Sigma 24-70	70
	5	AOS X-PRI Gigabit	500	Fujinon 50mm Fixed	NA
	6	AOS X-PRI Gigabit	500	Sigma 50mm Fixed	NA
	7	AOS X-PRI Gigabit	500	Sigma 24-135	100
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 17. Camera Locations, Speeds, and Lens Settings, Test No. MGSMRH-2

6 DESIGN DETAILS – 34-IN. (864-mm) TOP RAIL MOUNTING HEIGHT

The test installation consisted of 175 ft (53.3 m) of MGS with a top rail mounting height of 34 in. (864 mm), as shown in Figures 18 through 27. Photographs of the test installation are shown in Figure 28. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The system was constructed with 29 guardrail posts. Post nos. 3 through 27 were galvanized, ASTM A36, W6x8.5 (W152x12.6) steel sections measuring 72 in. (1,829 mm) long. Post nos. 1, 2, 28, and 29 were 5½-in. wide x 7½-in. deep x 46-in. long (140-mm x 191-mm x 1,168-mm) BCT timber posts. The anchor posts were set 16 in. (406 mm) into a 6-in. wide x 8-in. deep x 72-in. long (152-mm x 203-mm x 1,829-mm), ASTM A500 Grade B, steel foundation tube, as shown in Figures 20 and 21. Post nos. 1, 2, 28, and 29 were placed such that the top of the BCT post was 32 in. (813 mm) from the groundline. The BCT posts and foundation tubes were part of the anchor system designed to replicate the capacity of a tangent guardrail terminal.

All posts were spaced 75 in. (1,905 mm) on center and placed in a compacted, coarse, crushed limestone material that met Grading B of AASHTO M147-65 (1990), as recommended by MASH [3]. Posts nos. 3 through 27 had an embedment depth of 37 in. (940 mm). A 6-in. wide x 12-in. deep x 14¼-in. long (152-mm x 305-mm x 362-mm) southern yellow pine wood spacer blockout was used to block the rail away from the front face of each steel post, as shown in Figure 22. A 16D double head nail was also driven through a hole in the front flange of the post into the top of the blockout assembly to prevent rotation of the blockout.

Standard 12-gauge (2.66-mm thick) W-beam rails with additional post bolt slots at half-post spacing intervals were mounted on post nos. 1 through 29, as shown in Figures 18, 19, and 26. The W-beam top rail height was 34 in. (864 mm) above ground surface with a 27⅞-in. (708-mm) center mounting height, such that the center of the rail was mounted 4⅛ in. (105 mm) from the top of the BCT timber posts. Rail splices were located at the midspan between posts, as shown in Figures 18 and 19. The lap splice connections between the rail sections were configured to reduce vehicle snag potential at the splice during the crash test.

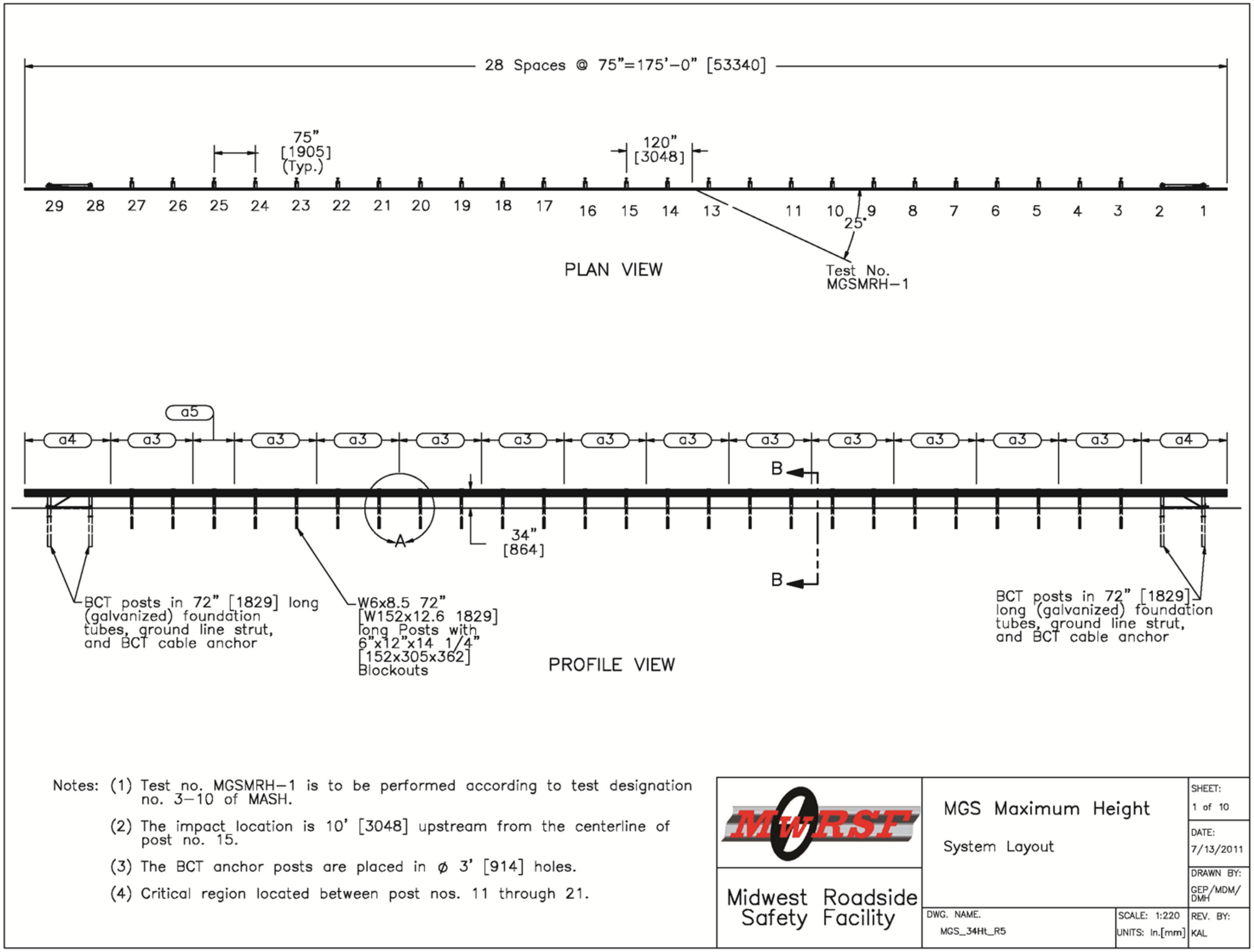


Figure 18. Test Installation Layout, Test No. MGSMRH-1

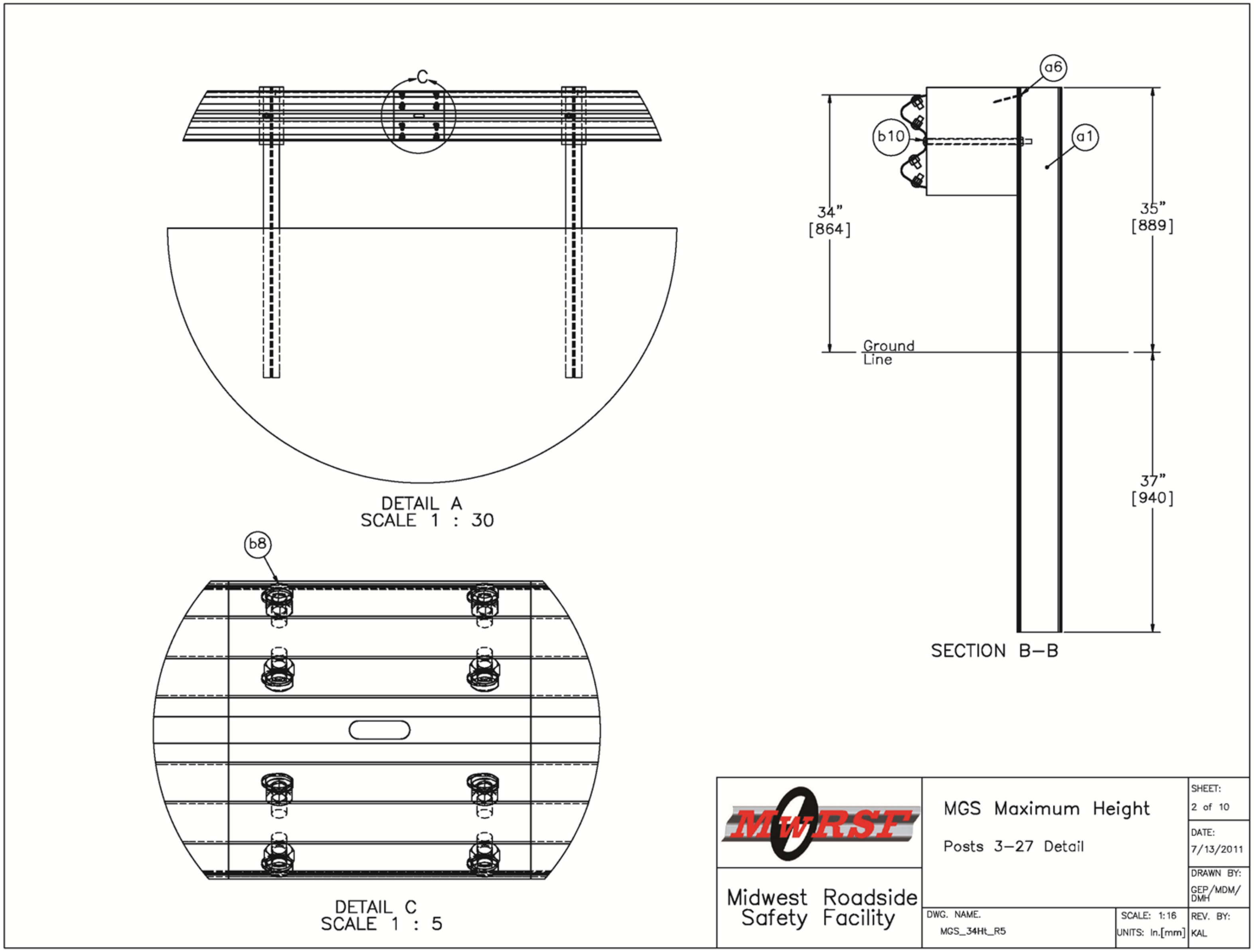


Figure 19. 34-in. (864-mm) Tall MGS Details, Test No. MGSMRH-1

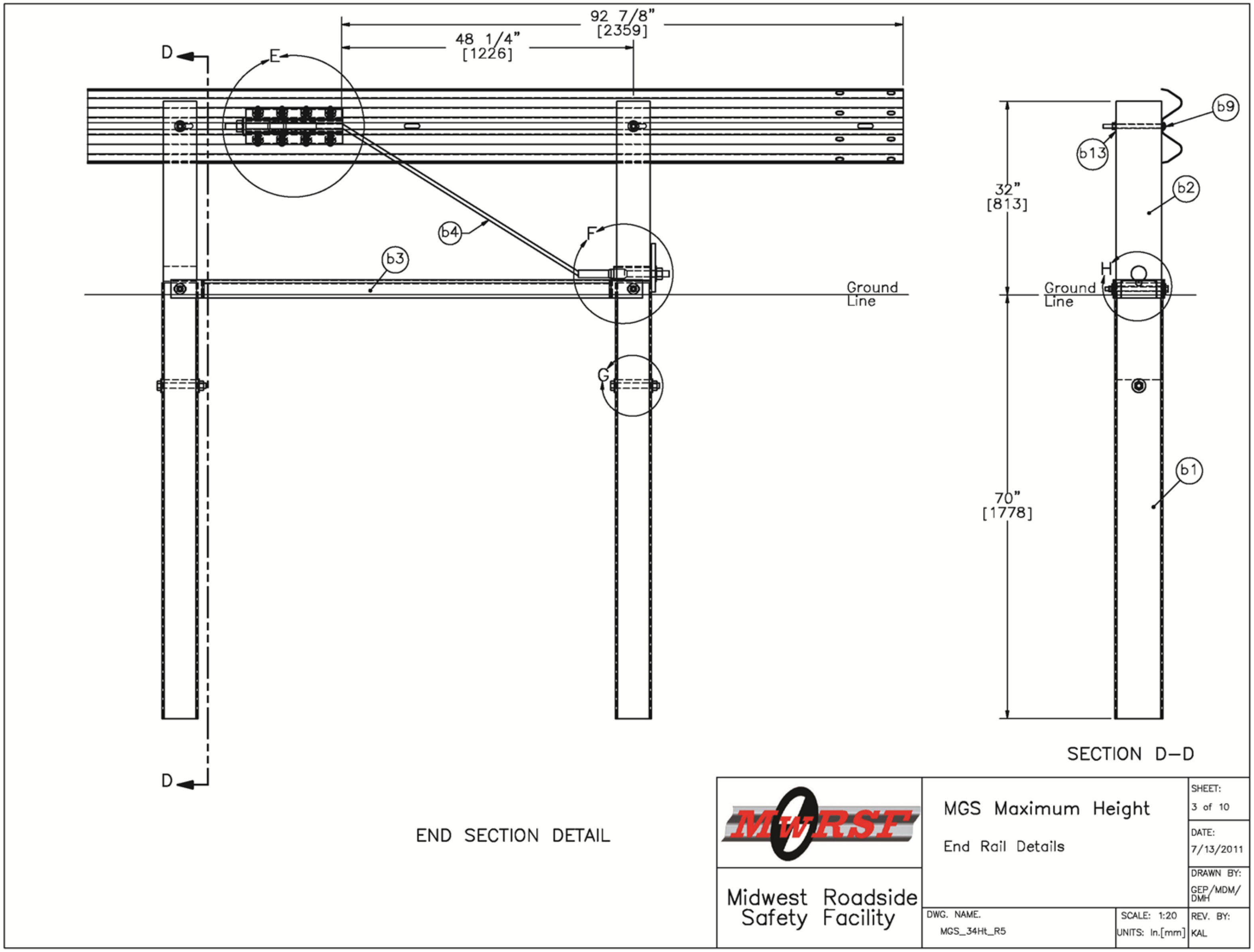


Figure 20. BCT End Anchor Details, Test No. MGSMRH-1

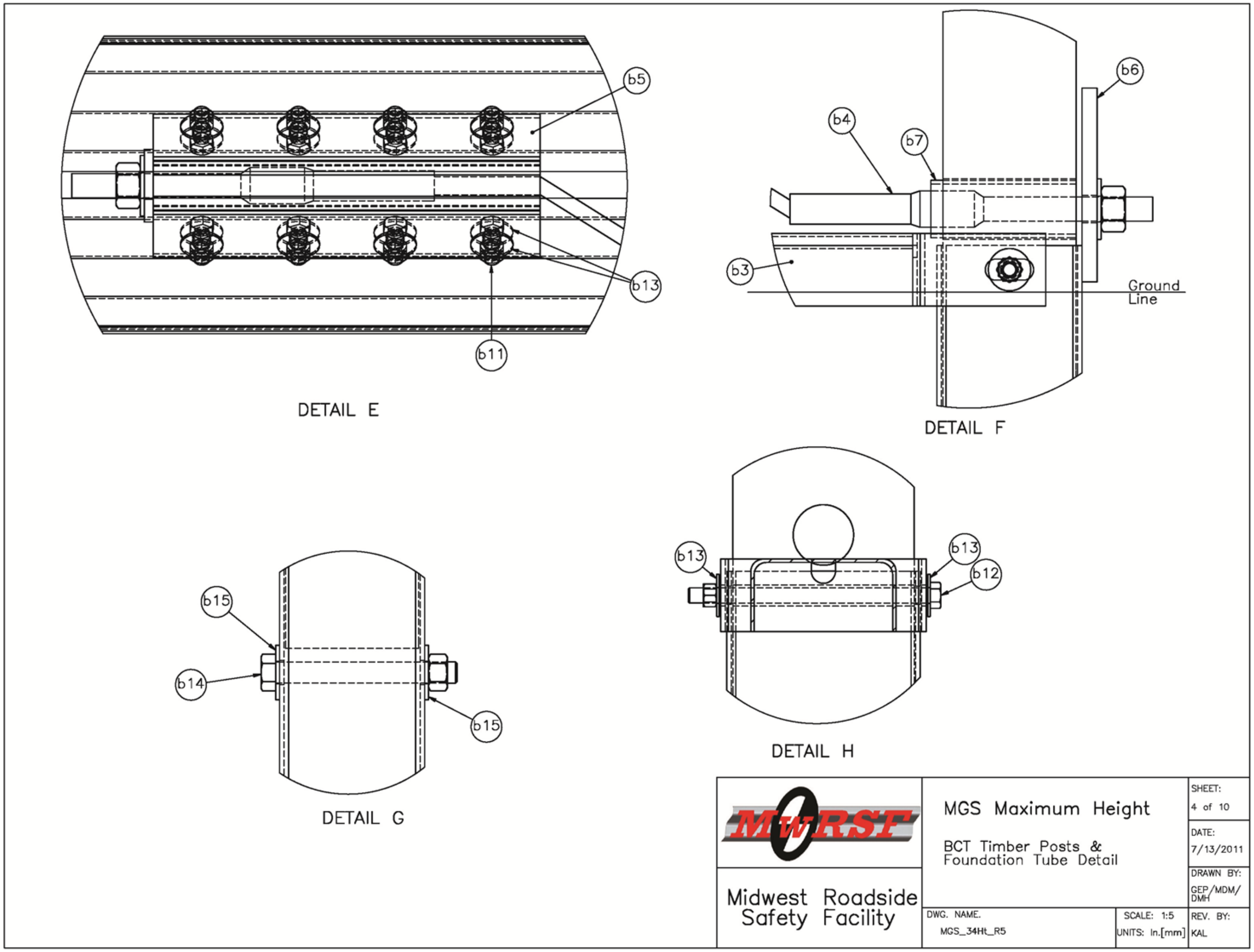


Figure 21. BCT End Anchor Details, Test No. MGSMRH-1

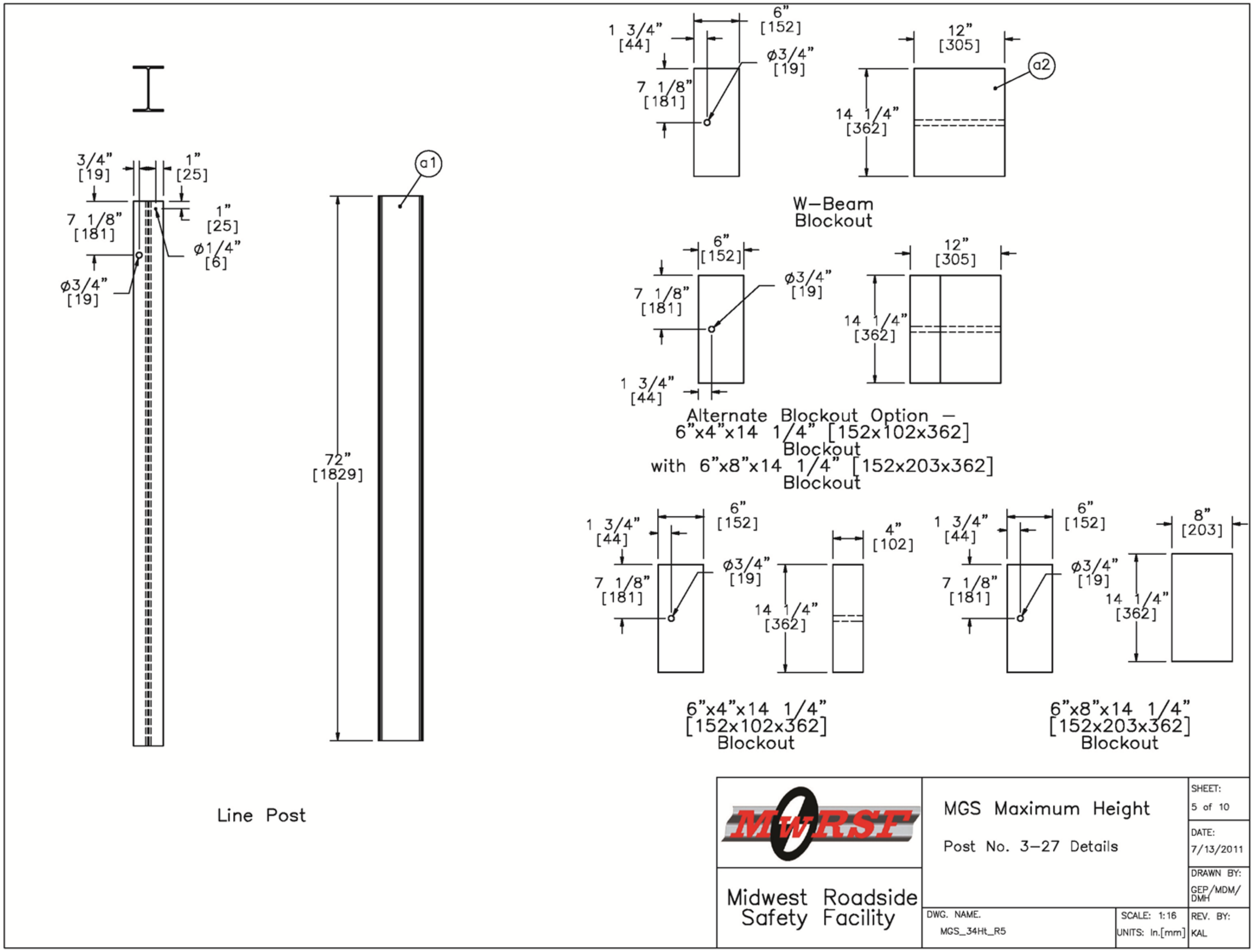


Figure 22. Line Post Details, Test No. MGSMRH-1

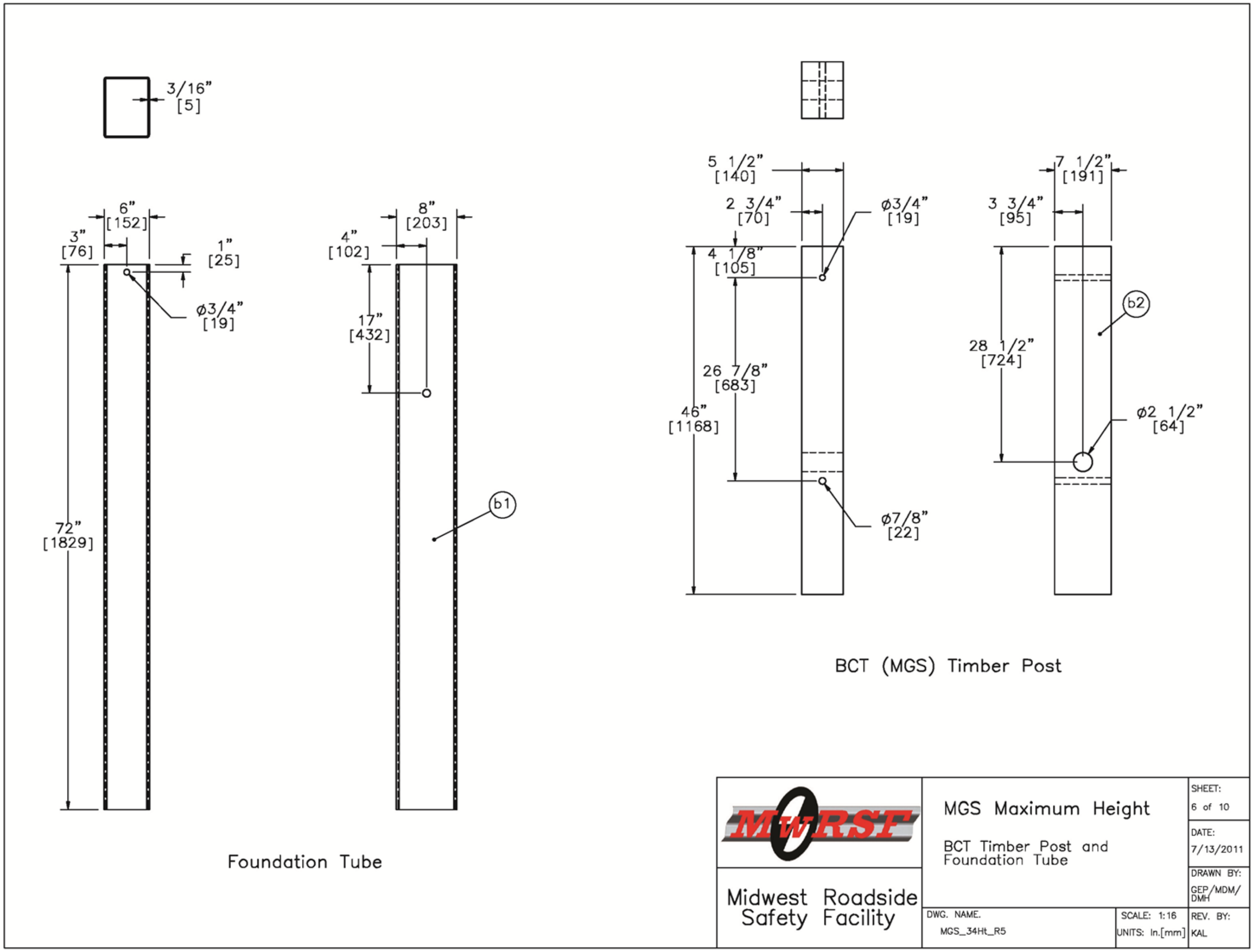


Figure 23. Anchor Post Details, Test No. MGSMRH-1

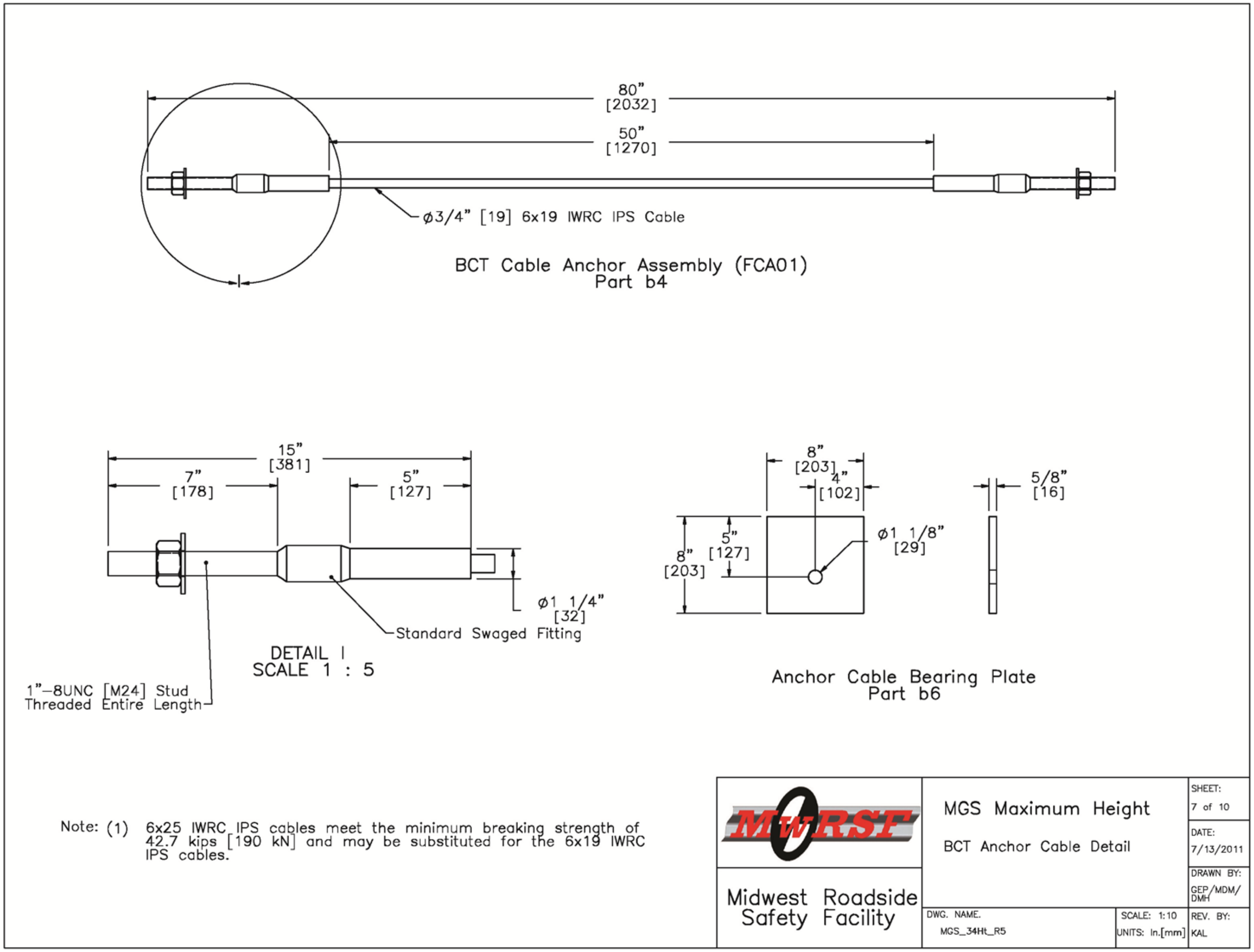


Figure 24. BCT Anchor Cable Details, Test No. MGSMRH-1

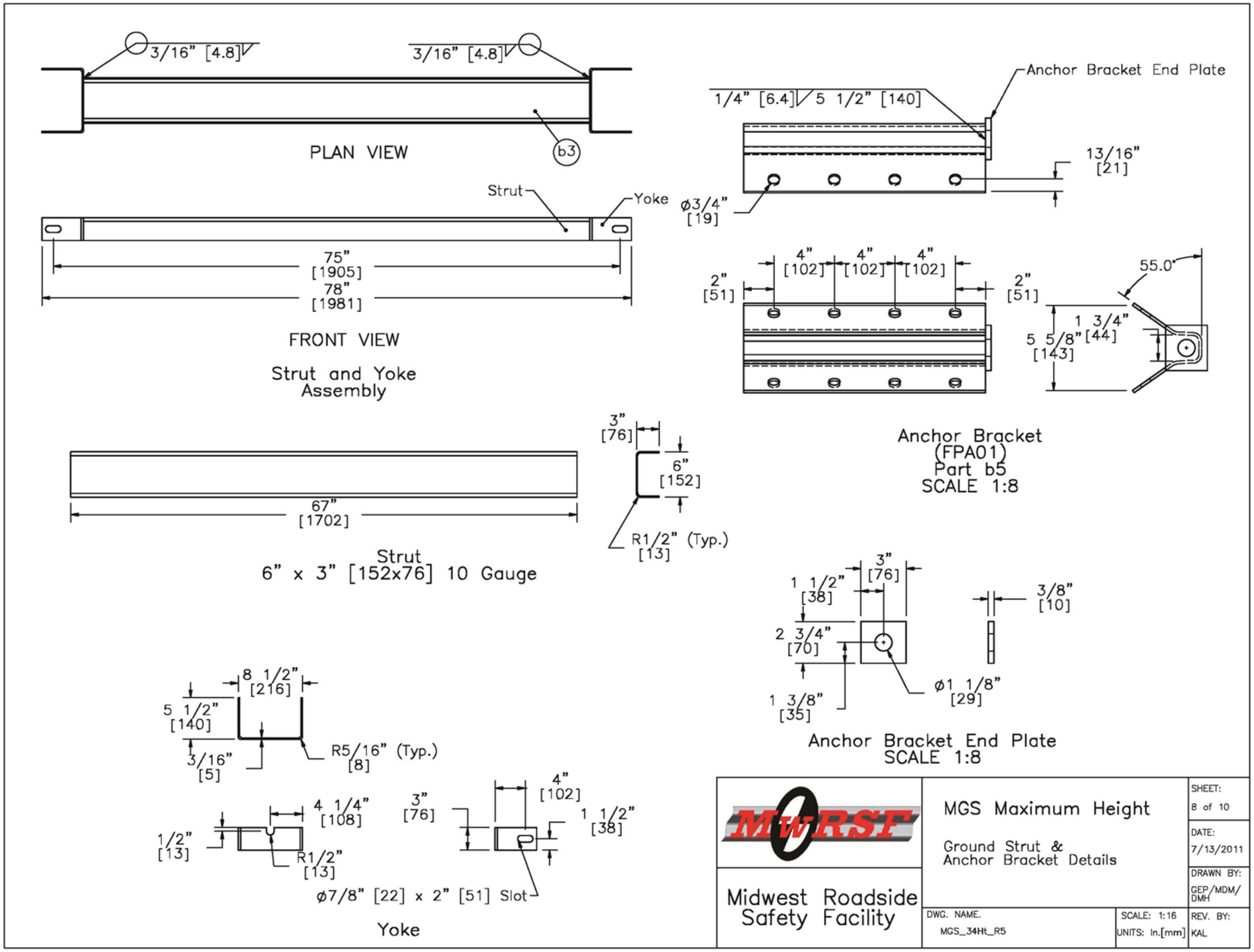


Figure 25. Ground Strut and Anchor Bracket Details, Test No. MGSMRH-1

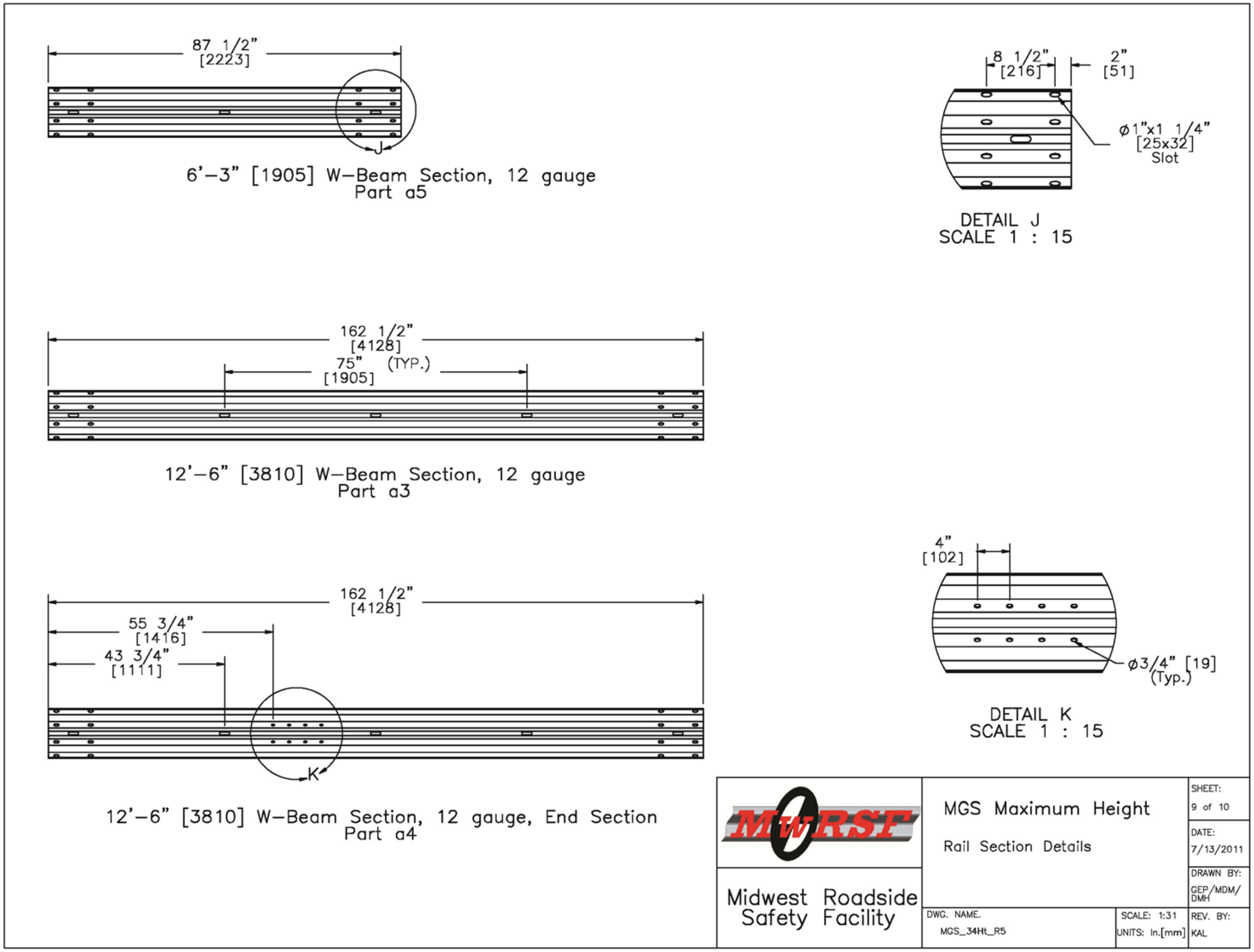


Figure 26. W-Beam Guardrail Details, Test No. MGSMRH-1

Midwest Guardrail System at 34" Rail Height				
Item No.	QTY.	Description	Material Specification	Hardware Guide
a1	25	W6x8.5 72in [W152x12.6 1829] long Steel Post	ASTM A36 Steel	PWE06
a2	25	6"x12"x14 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 [2.7] AASHTO M180	RWM14a
a5	1	6'-3" [1905] W-Beam MGS Section	12 gauge [2.7] AASHTO M180	RWM01a
a6	25	16D Double Head Nail	–	–
b1	4	72" [1829] Foundation Tube	ASTM A500 Grade B	PTE06
b2	4	BCT Timber Post -MGS Height	SYP Grade No. 1 or better (No knots, 18" [457] above or below ground tension face)	PDF01
b3	2	Strut and Yoke Assembly	ASTM A36 Steel Galvanized	–
b4	2	BCT Cable Anchor Assembly	ϕ3/4" [19] 6x19 IWRC IPS Galvanized Wire Rope	FCA01-02
b5	2	Anchor Bracket Assembly	ASTM A36 Steel	FPA01
b6	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel	FPB01
b7	2	2 3/8" [60] O.D.x 6" [152] long BCT Post Sleeve	ASTM A53 Grade B Schedule 40	FMM02
b8	112	5/8"Dia. x 1 1/2" [M16 x 38] Guardrail Bolt and Nut	ASTM A307	FBB01
b9	4	5/8"Dia. x 10" [M16 x 254] long Guardrail Bolt and Nut	ASTM A307	FBB03
b10	25	5/8"Dia. x 14" [M16 x 356] long Guardrail Bolt and Nut	ASTM A307	FBB06
b11	16	5/8"Dia. x 1 1/2" [M16 x 38] long Hex Head Bolt and Nut	ASTM A307	FBX16a
b12	4	5/8"Dia. x 9 1/2" [M16 x 241] long Hex Head Bolt and Nut	ASTM A307	FBX16a
b13	44	5/8"Dia. [16] Flat Washer	ASTM F436 Grade 1	FWC14a
b14	4	3/4"Dia. x 7 1/2" [M20 x 191] long Hex Head Bolt and Nut	ASTM A325	FBX22a
b15	8	3/4"Dia. [19] Flat Washer	ASTM F436 Grade 1	FWC22a

MwRSF
Midwest Roadside Safety Facility

MGS Maximum Height

Bill of Materials

SHEET: 10 of 10
DATE: 7/13/2011
DRAWN BY: GEP/MDM/DMH
DWG. NAME. MGS_34Ht_R5
SCALE: None
UNITS: In.[mm]
REV. BY: KAL

Figure 27. Bill of Materials, Test No. MGSMRH-1

Figure 28. Test Installation Photographs, Test No. MGSMRH-1

7 FULL-SCALE CRASH TEST NO. MGSMRH-1

7.1 Static Soil Test

Before full-scale crash test no. MGSMRH-1 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 C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

7.2 Test No. MGSMRH-1

The 2,599-lb (1,179-kg) passenger car impacted the 34-in. (864-mm) tall MGS at a speed of 63.6 mph (102.4 km/h) and at an angle of 25.0 degrees. A summary of the test results and sequential photographs are shown in Figure 29. Additional sequential photographs are shown in Figures 30 through 33.

7.3 Weather Conditions

Test no. MGSMRH-1 was conducted on June 29, 2010 at approximately 11:45 am. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 5.

Table 5. Weather Conditions, Test No. MGSMRH-1

Temperature	78° F
Humidity	49 %
Wind Speed	5 mph
Wind Direction	60° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.02 in.
Previous 7-Day Precipitation	1.32 in.

7.4 Test Description

Initial vehicle impact was to occur 10 ft (3.0 m) upstream of the centerline of post no. 15, as shown in Figure 34, which was selected using the critical impact point (CIP) plots found in Section 2.3 of MASH. The actual point of impact was 10 ft – 1 in. (3.1 m) upstream from the centerline of post no. 15. A sequential description of the impact events is contained in Table 6. The vehicle came to rest facing downstream, located 190 ft – 5 in. (58.0 m) downstream from impact and 5 ft – 11¼ in. (1.8 m) laterally behind the front face of the guardrail. The vehicle trajectory and final position are shown in Figures 29 and 35.

Table 6. Sequential Description of Impact Events, Test No. MGSMRH-1

TIME (sec)	EVENT
0.000	The right side of the front bumper impacted the bottom corrugation of the W-beam guardrail 1 in. (25 mm) upstream of the intended impact location.
0.008	Post no. 14 deflected laterally backward.
0.024	Post no. 13 deflected laterally backward.
0.028	The right side of the front bumper contacted the blockout on post no. 14.
0.032	Post no. 15 deflected laterally backward, the posts upstream of impact twisted downstream.
0.038	The vehicle redirected downstream, and the engine hood became ajar.
0.042	The right side of the front bumper contacted the front face of post no. 14.
0.052	Rail flattening occurred at post no. 14, and the vehicle rolled away from the barrier.
0.056	Post no. 16 deflected laterally backward.
0.062	Post nos. 17 through 19 twisted upstream
0.094	The rail separated from post no. 15, and the right side of the front bumper contacted the upstream side of post no. 15 and disengaged from the vehicle.
0.106	Post no. 17 deflected laterally backward, and the vehicle continued to redirect and roll away from the barrier.
0.112	Right-front tire became airborne.
0.162	The rail downstream of post no. 15 contacted the base of the A-pillar, the vehicle rolled toward the barrier, and the front-right corner of the windshield cracked.
0.174	The right-rear quarter panel contacted the face of the rail just downstream of post no. 14, the right side of the front bumper contacted the upstream side of post no. 16, the rail separated from post no. 16, and the 16D double headed nail preventing

	blockout rotation in post no. 16 bent which allowed the top of the blockout to rotate upstream.
0.180	The right side mirror disengaged from the vehicle.
0.188	Post no. 18 deflected laterally backward.
0.236	Post no. 17 twisted upstream, and the vehicle was parallel to the system with a velocity of 43.8 mph (70.5 km/h).
0.262	The right-rear tire became airborne.
0.268	The rail separated from post no. 17.
0.290	The right-front tire contacted the upstream edge of the front flange of post no. 17.
0.304	The right-front wheel rim contacted the upstream edge of the front flange of post no. 17 and bent inward, and the right-front tire deflated.
0.386	The right-front tire contacted the ground as the vehicle continued to redirect and roll toward the right.
0.438	The vehicle ceased to yaw.
0.518	The right-rear quarter panel lost contact with the rail between post nos. 17 and 18, and the vehicle exited the system with a velocity of 39.3 mph (63.2 km/h) and at an angle of 12.3 degrees.
0.528	Right-rear tire contacted the ground.
0.556	The vehicle ceased to roll to the right.

7.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 36 through 45. Barrier damage consisted of deformed guardrail posts, disengaged wooden blockouts, contact marks on posts and guardrail, and deformed W-beam rail. The length of vehicle contact along the barrier was approximately 25 ft – 10½ in. (7.9 m) which spanned from 10 ft – 1 in. (3.1 m) upstream of the centerline of post no. 15 to 35½ in. (902 mm) upstream of post no. 18.

Red paint transfer was found on the rail between the impact location and post no. 18. Minor kinks in the top and bottom corrugations of the rail were found between post nos. 12 and 19, as shown in Figure 38. Flattening and deformation of the rail occurred between post nos. 13 and 18. The bottom corrugation was flattened between post nos. 14 and 16. The bottom edge of the rail was folded upward at post no. 14.

The post bolt pulled through the slots in the rail at post nos. 15 through 17. There was a ¾-in. (19-mm) long tear in the bolt slot at post no. 15. There was a 2¼-in. (57-mm) long tear and a 1½-in. (38-mm) long tear on the upstream and downstream sides, respectively, of the bolt slot on post no. 16. There was a 1¼-in. (32-mm) long tear and a 1-in. (25-mm) long tear on the upstream and downstream sides, respectively, of the bolt slot on post no. 17. There was a ⅜-in. (10-mm) lateral separation between the W-beam sections in the splices between post nos. 12 and 13 and between post nos. 14 and 15. The splices between post nos. 14 and 15, 16 and 17, and 18 and 19 were extended ⅛ in. (3 mm) longitudinally. The splice damage is shown in Figures 41 and 42.

Contact marks were found on the front flange of post no. 14, on the upstream edge of the front flange and on the face of the back flange of post no. 15, on the front flange and the upstream side of the web of post no. 16 as well as on the corresponding blockout, and on both the upstream edge of the front flange on post no. 17 and the corresponding blockout.

Post nos. 3 through 12 twisted downstream. Post no. 14 rotated backward, and the top of the blockout rotated upstream. Post no. 15 was bent downstream and the blockout was disengaged. The front flange of post no. 15 twisted upstream, and the downstream edge of the front flange buckled at groundline. Post no. 16 was completely pulled out of the ground. The post bolt was bent, and the blockout split. The back flange of post no. 16 buckled 44 in. (1,118 mm) from the top of the post. Post no. 17 bent and twisted downstream, and the top of the blockout rotated upstream. The post bolt on post no. 17 bent, and the front flange was bent outward at two locations along the upstream edge.

A soil gap measuring 1½ in. (38 mm) was present on the upstream side of post no. 1, as shown in Figure 40. A soil gap measuring ⅜ in. (10-mm) was present on the downstream side of post no. 2. A $^{1}/_{16}$-in. (2-mm) soil gap was present on the front face of post nos. 12 and 18. A 1¼-

in. (32-mm) soil gap was present on the front face of post no. 13. Soil gaps measuring 2½ in. (64 mm) and 2 in. (51 mm) were present on the front and back faces of post no. 14, respectively. A 3-in. (76-mm) soil gap was present on the front side of post no. 15. A soil crater was present at the base of post no. 16. A $^1/_{16}$-in. (2-mm) soil gap was present on the back face of post no. 18.

The maximum permanent set rail and post deflections of the barrier system were 18¼ in. (464 mm) at the midspan between post nos. 15 and 16 and 17 in. (432 in.) at post no. 16, respectively, as measured in the field. The maximum lateral dynamic rail and post deflections were 29.0 in. (737 mm) at the midspan between post nos. 15 and 16 and 20.2 in. (513 mm) at post no. 16, respectively, as determined from high-speed video analysis. The working width of the system was found to be 49.4 in. (1,255 mm), also determined from high-speed digital video analysis.

7.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 46 through 49. The maximum occupant compartment deformations are listed in Table 7 alongside the deformation limits established in MASH for various areas of the occupant compartment. It should be noted that none of the MASH established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Contact marks spanned the length of the right side of the vehicle. Part of the plastic covering from the right tail light disengaged. Two dents were located along the right-rear quarter panel, and there was a 1¼-in. (32-mm) gap between the right-rear quarter panel and the right side of the rear bumper. Small dents were found in the right-rear and right-front doors. The right-front fender and wheel well cover crushed inward. A 5-in. (127-mm) long tear was located in the

Table 7. Maximum Occupant Compartment Deformations by Location, Test No. MGSMRH-1

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	¾ (19)	≤ 9 (229)
Floor Pan & Transmission Tunnel	½ (13)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	½ (13)	≤ 12 (305)
Side Door (Above Seat)	¼ (6)	≤ 9 (229)
Side Door (Below Seat)	¼ (6)	≤ 12 (305)
Roof	NA	≤ 4 (102)
Windshield	NA	≤ 3 (76)

right-front fender. The right side mirror disengaged, and the mirror mount fractured. The base of the right-side A-pillar crushed inward. The right-front tire deflated and the rim folded inward. The upper control arm connector on the right-front wheel bent at the thread location. The right-front hood corner crushed inward. The right-side bumper cover and foam disengaged. The right-side headlight disengaged and was fractured. The bumper cover was pulled down ½ in. (13 mm). The left side of the hood was ajar. The antenna disengaged. The windshield washer fluid container was dented, cracked, and leaking fluid. The drive linkage was leaking fluid at the transmission housing. Minor scraping was found near the bumper connection to the unibody. Minor spiderweb cracking was found at the right side of the windshield along the entire height of the windshield. All other window glass, the roof, the rear, and the left side of the vehicle were undamaged.

7.7 Occupant Risk

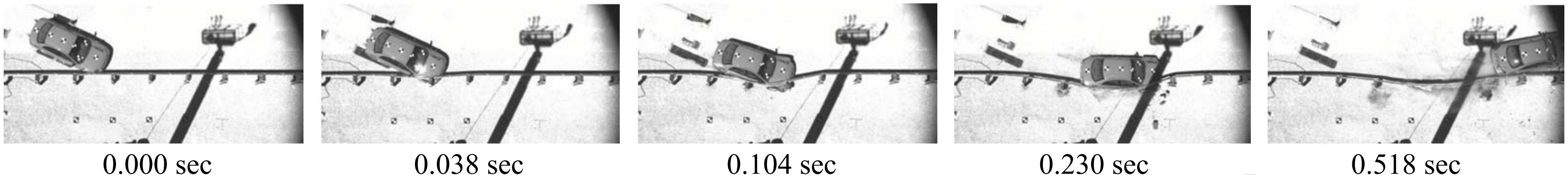
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 8. It is noted that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 8. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 29. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

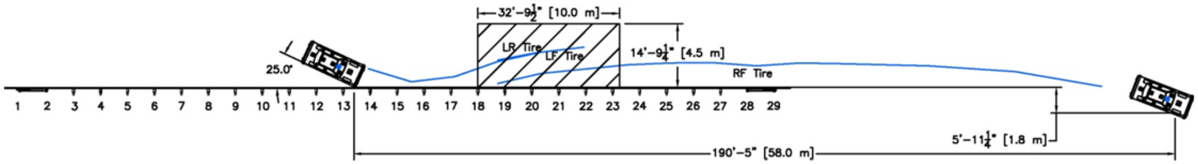
Table 8. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSMRH-1

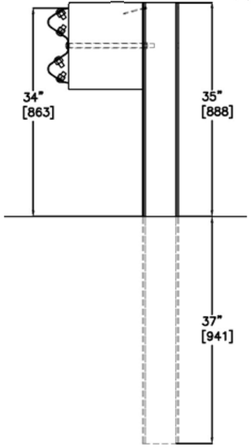
Evaluation Criteria		**Transducer**		**MASH Limits**
		EDR-3	**DTS**	
OIV ft/s (m/s)	Longitudinal	-15.56 (-4.74)	-15.84 (-4.83)	≤ 40 (12.2)
	Lateral	-17.65 (-5.38)	-19.03 (-5.80)	≤40 (12.2)
ORA g's	Longitudinal	-8.45	-8.41	≤ 20.49
	Lateral	-8.17	-9.19	≤ 20.49
THIV ft/s (m/s)		NA	22.94 (6.99)	not required
PHD g's		NA	11.29	not required
ASI		0.90	0.90	not required

7.8 Discussion

The analysis of the test results for test no. MGSMRH-1 showed that the 34-in. (864-mm) tall MGS adequately contained and redirected the 1100C vehicle with controlled lateral displacements of 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 not occur. The test vehicle did not penetrate nor underride the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 12.3 degrees and its trajectory did not violate the bounds of the exit box. Therefore, test no. MGSMRH-1 conducted on the 34-in. (864-mm) tall MGS was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-10.





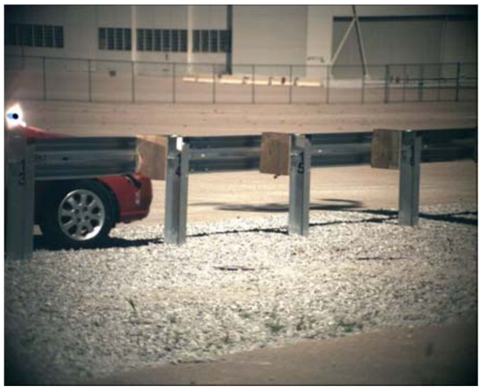


- Test Agency .... MwRSF
- Test Number MGSMRH-1
- Date 6/29/10
- MASH Test Designation 3-10
- Test Article .... 34-in. (864-mm) Tall MGS Guardrail
- Total Length .... 175 ft (53.3 m)
- Key Component – Steel MGS Rail
    - Thickness .... 12 gauge (2.66 mm)
    - Top Mounting Height .... 34 in. (864 mm)
- Key Component – Steel Posts
    - Post Spacing .... 75 in. (1,905 mm)
    - Post Dimensions .... W6x8.5 x 72 in. long (W152x12.6 x 1,829 mm)
    - Embedment Depth .... 37 in. (940 mm)
- Key Component – Wood Spacer Blocks
    - Dimensions .... 6 x 12 x 72 in. (152 x 305 x 1,829 mm)
- Soil Type .... Grade B, AASHTO M147-65 (1990)
- Vehicle Make /Model .... 2003 Kia Rio
    - Curb .... 2,401 lb (1,089 kg)
    - Test Inertial .... 2,429 lb (1,102 kg)
    - Gross Static .... 2,599 lb (1,179 kg)
- Impact Conditions
    - Speed .... 63.6 mph (102.4 km/h)
    - Angle .... 25.0 deg
    - Impact Location .... 10 ft – 1 in. (3.1 m) upstream of post no. 15
- Exit Conditions
    - Speed .... 39.3 mph (63.2 km/h)
    - Angle .... 12.3 deg
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 190 ft – 5 in. (58.0 m) downstream
  5 ft – 11¼ in. (1.8 m) laterally behind
- Vehicle Damage .... Moderate
    - VDS[34] 01-RFQ-5
    - CDC[35] 01-RYAW-5
    - Maximum Interior Deformation .... ¾ in. (19 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
    - Permanent Set .... 18¼ in. (464 mm)
    - Dynamic .... 29.0 in. (737 mm)
    - Working Width .... 49.4 in. (1,255 mm)
- Maximum Angular Displacements
    - Roll .... -10.6 ° < 75°
    - Pitch .... -5.1 ° < 75°
    - Yaw .... -36.8 °
- Impact Severity (IS) .... 58.7 kip-ft (79.5 kJ) > 51.4 kip-ft (69.7 kJ)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		EDR-3	DTS	
OIV ft/s (m/s)	Longitudinal	-15.56 (-4.74)	-15.84 (-4.83)	≤ 40 (12.2)
	Lateral	-17.65 (-5.38)	-19.03 (-5.80)	≤ 40 (12.2)
ORA g's	Longitudinal	-8.45	-8.41	≤ 20.49
	Lateral	-8.17	-9.19	≤ 20.49
THIV – ft/s (m/s)		NA	22.94 (6.99)	not required
PHD – g's		NA	11.29	not required
ASI		0.90	0.90	not required

Figure 29. Summary of Test Results and Sequential Photographs, Test No. MGSMRH-1


0.000 sec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0.064 sec


0.094 sec


0.108 sec


0.156 sec


0.206 sec


0.302 sec

Figure 30. Additional Sequential Photographs, Test No. MGSMRH-1

0.000 sec

0.096 sec

0.160 sec

0.244 sec

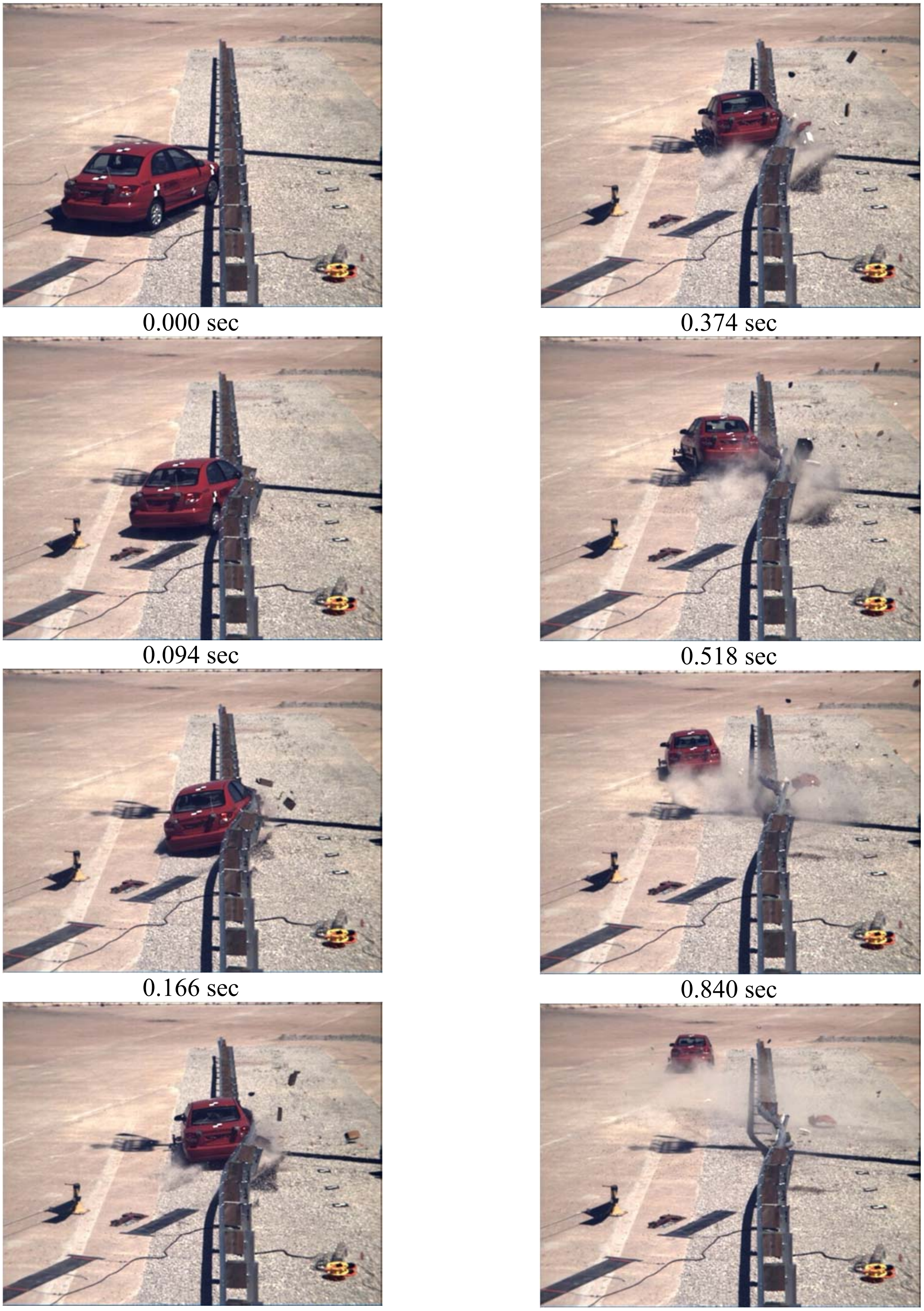
0.290 sec

0.344 sec

0.424 sec

0.488 sec

Figure 31. Additional Sequential Photographs, Test No. MGSMRH-1



0.000 sec

0.094 sec

0.166 sec

0.274 sec

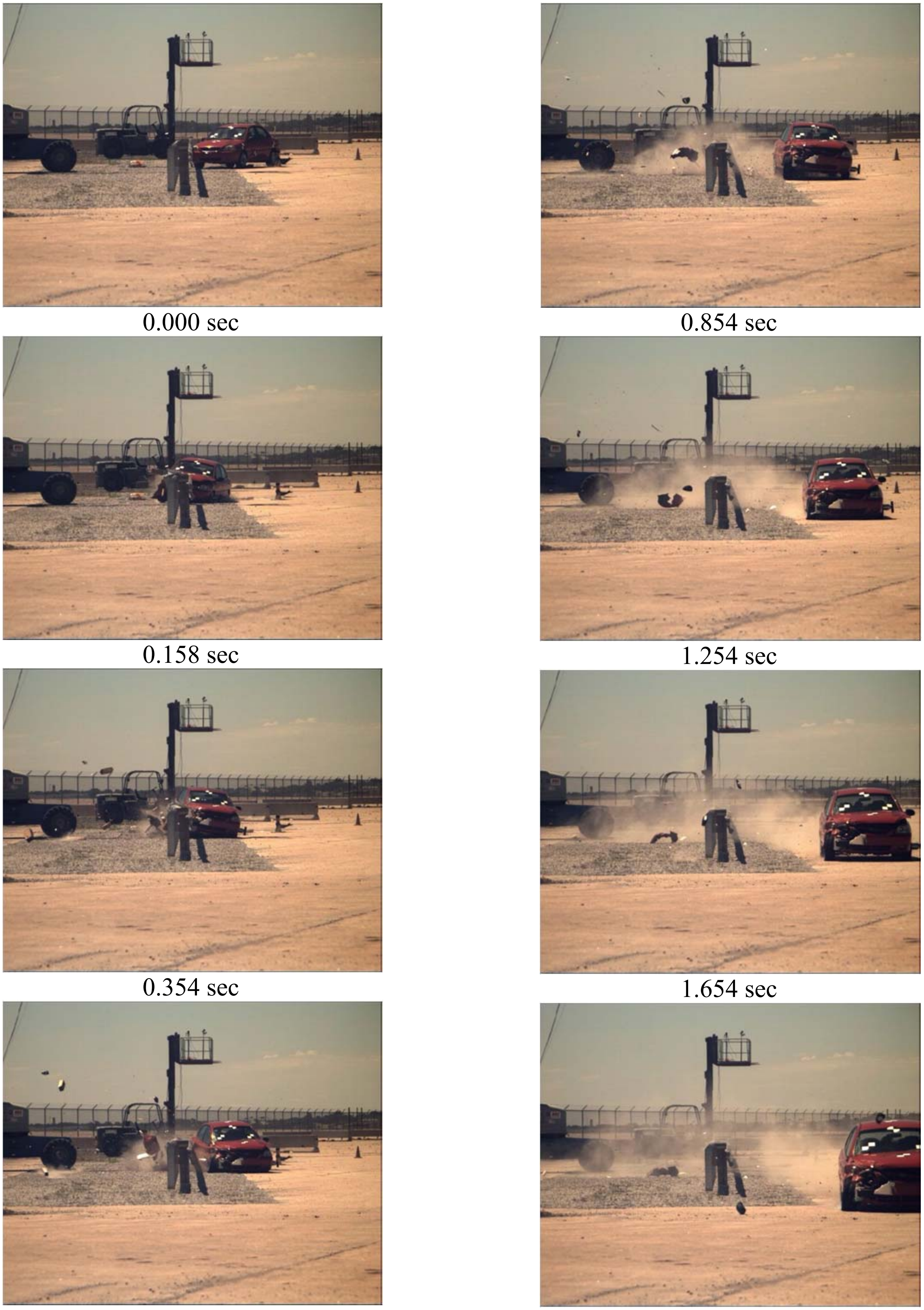
0.374 sec

0.518 sec

0.840 sec

1.594 sec

Figure 32. Additional Sequential Photographs, Test No. MGSMRH-1



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2.254 sec

Figure 33. Additional Sequential Photographs, Test No. MGSMRH-1

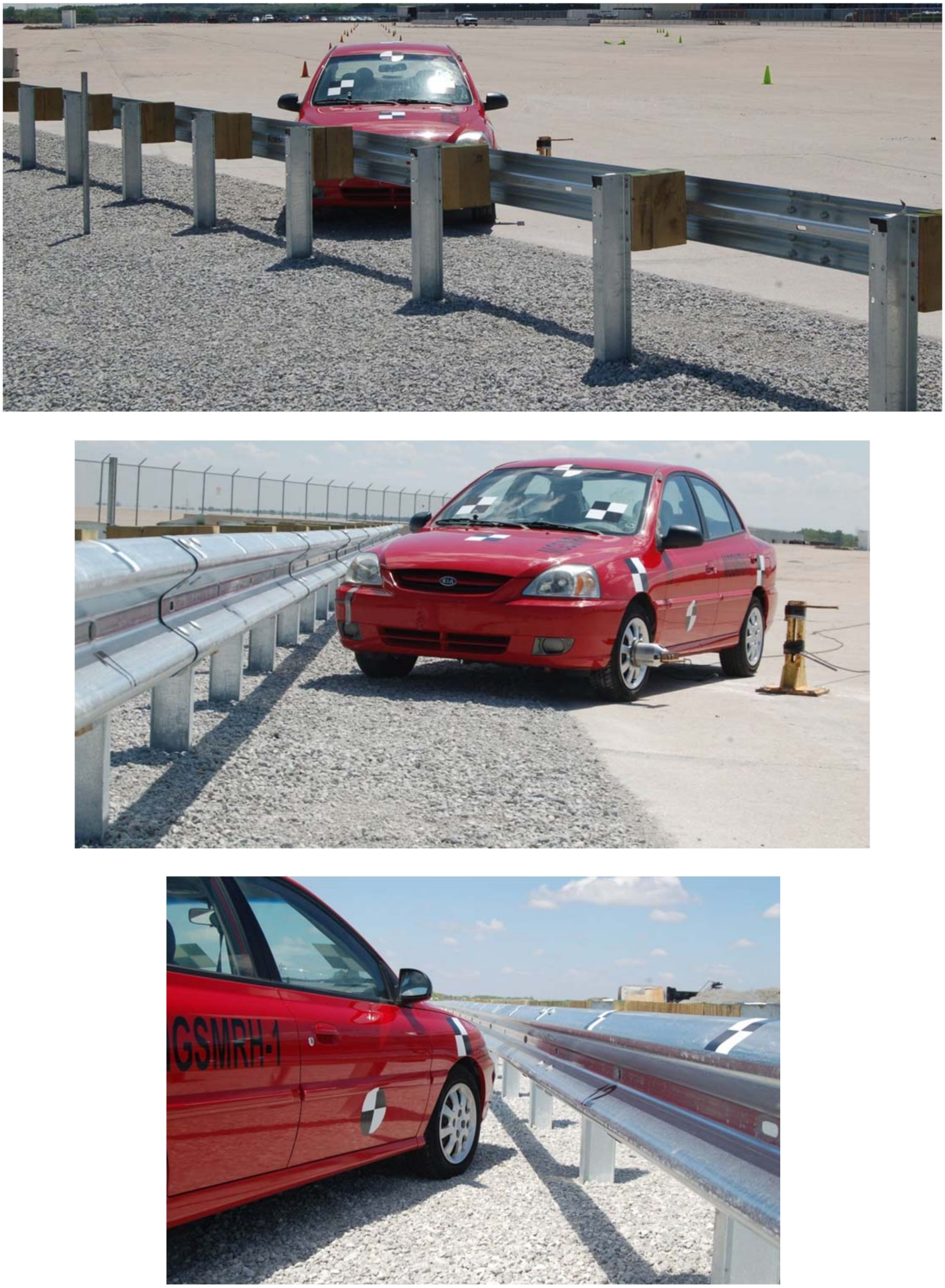


Figure 34. Impact Location, Test No. MGSMRH-1

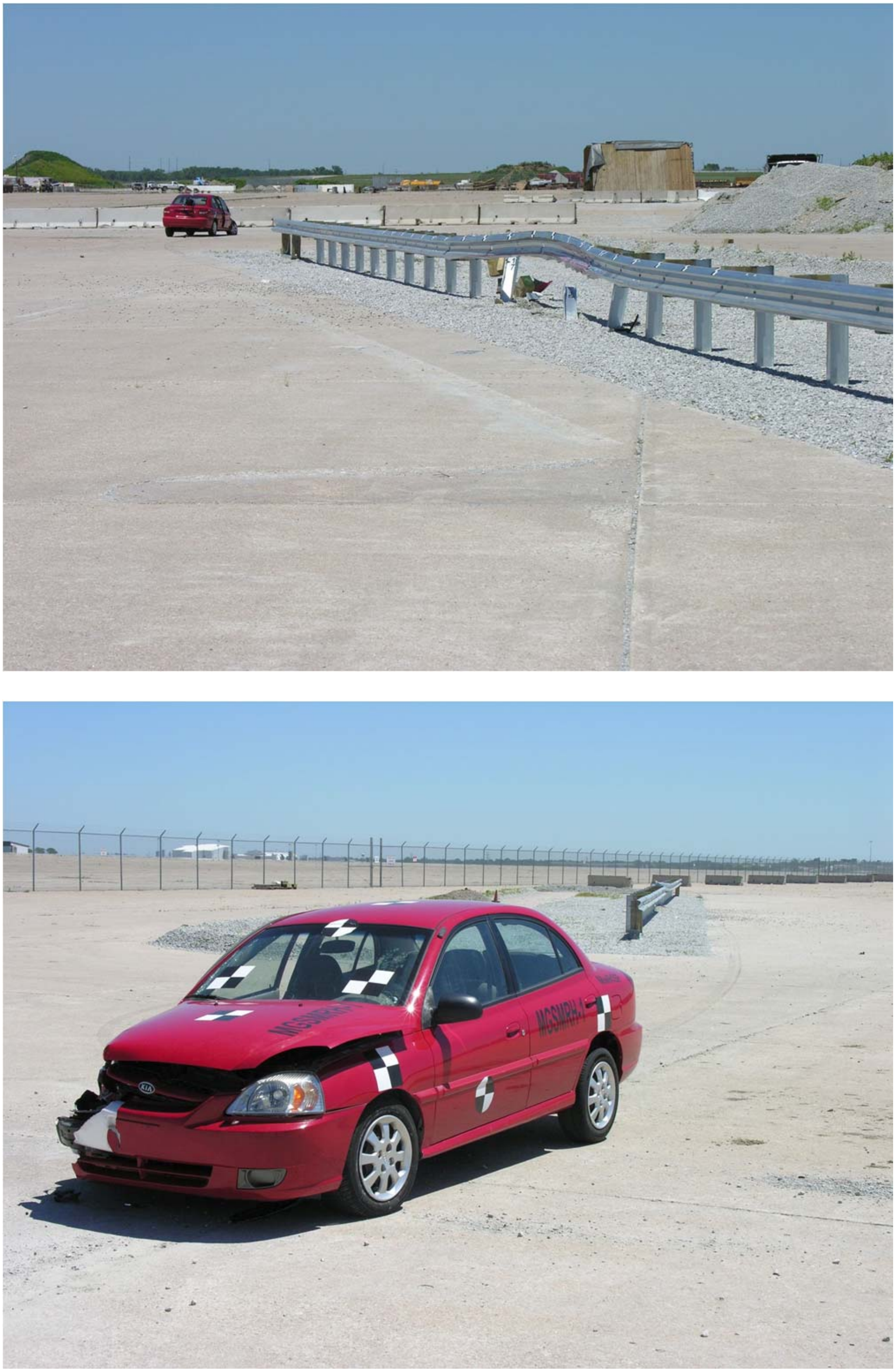


Figure 35. Vehicle Final Position and Trajectory Marks, Test No. MGSMRH-1

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

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

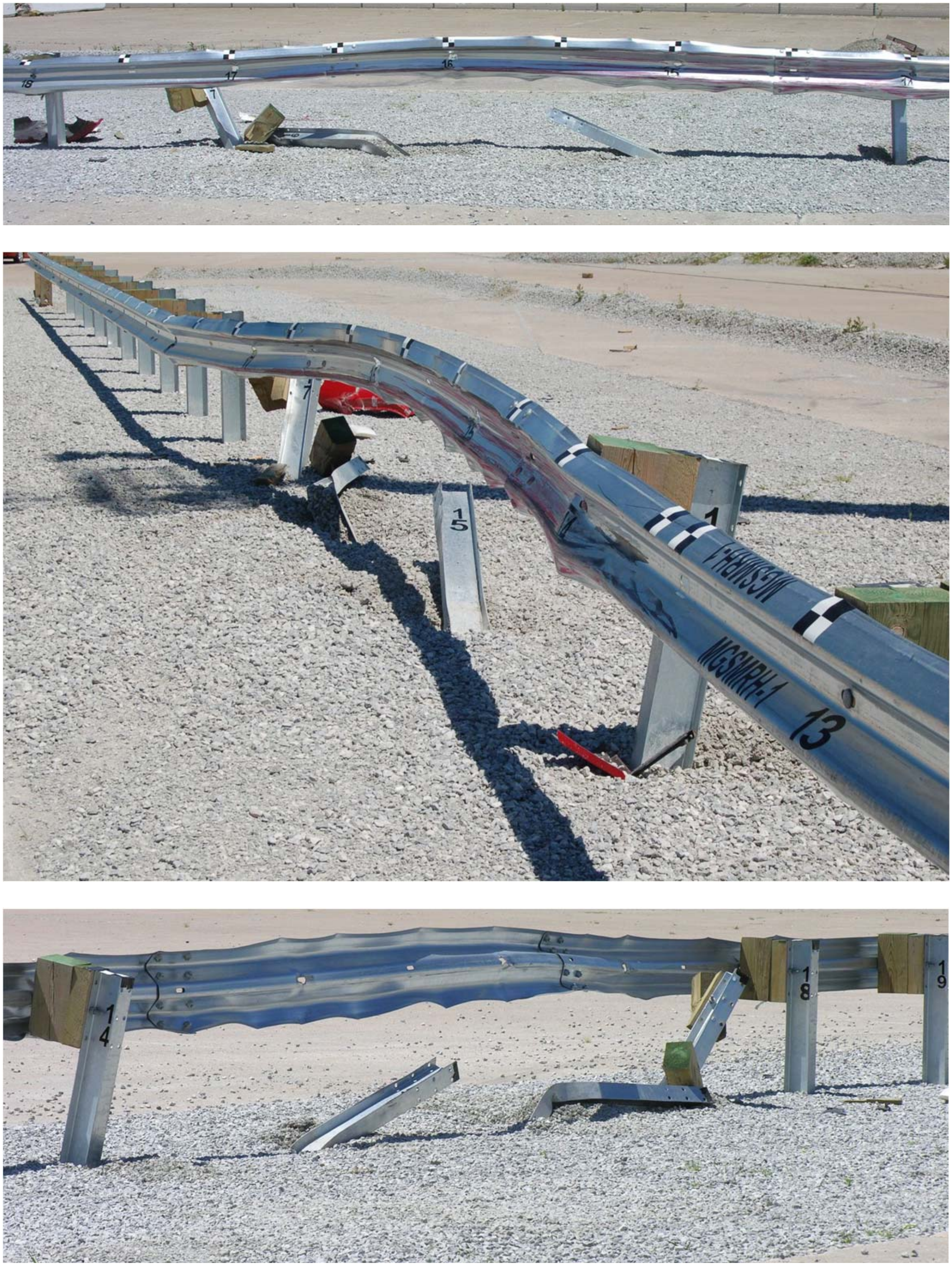
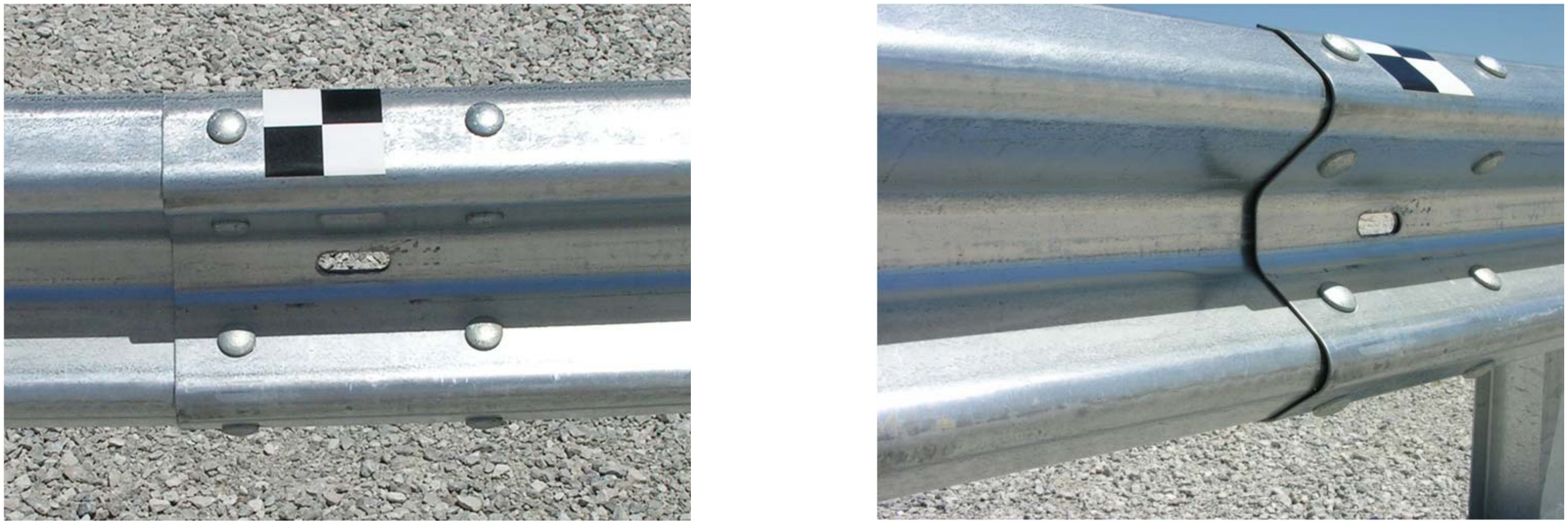


Figure 38. System Damage, Test No. MGSMRH-1

Figure 39. System Damage, Test No. MGSMRH-1

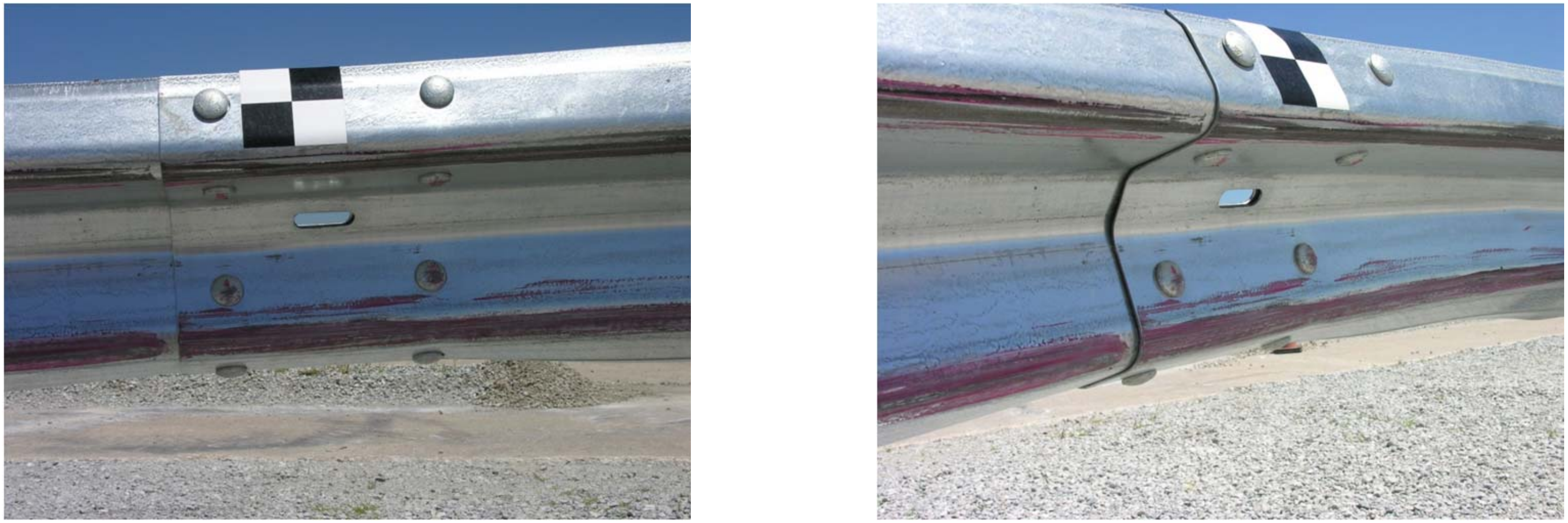
Figure 40. Soil Gap at Upstream End Anchor, Test No. MGSMRH-1



Splice Between Post Nos. 12 and 13

Splice Between Post Nos. 14 and 15

Figure 41. Splice Damage, Test No. MGSMRH-1



Splice Between Post Nos. 16 and 17

Splice Between Post Nos. 18 and 19

Figure 42. Splice Damage, Test No. MGSMRH-1

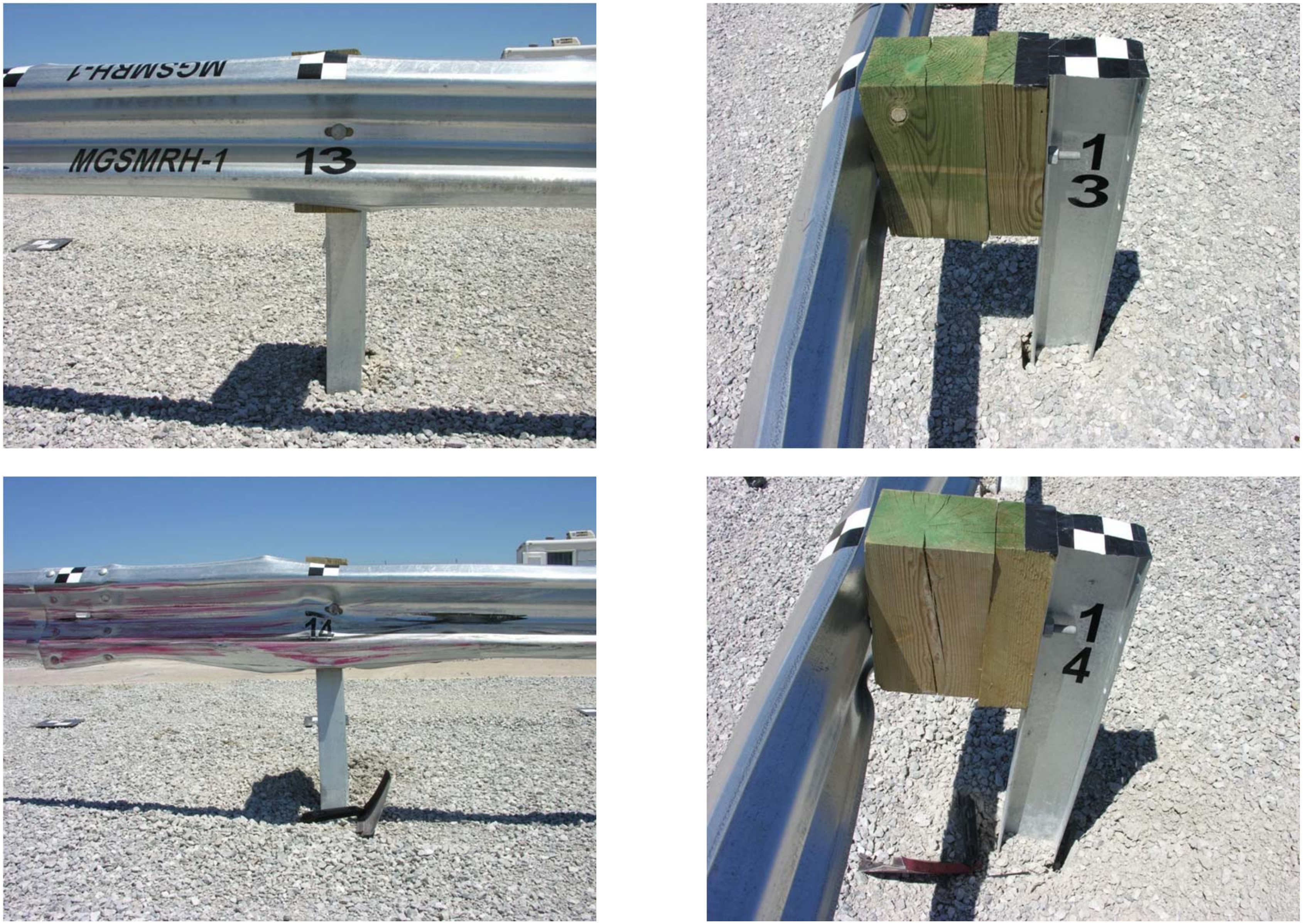


Figure 43. Post Nos. 13 and 14 Damage, Test No. MGSMRH-1

Figure 44. Post Nos. 15 and 16 Damage, Test No. MGSMRH-1

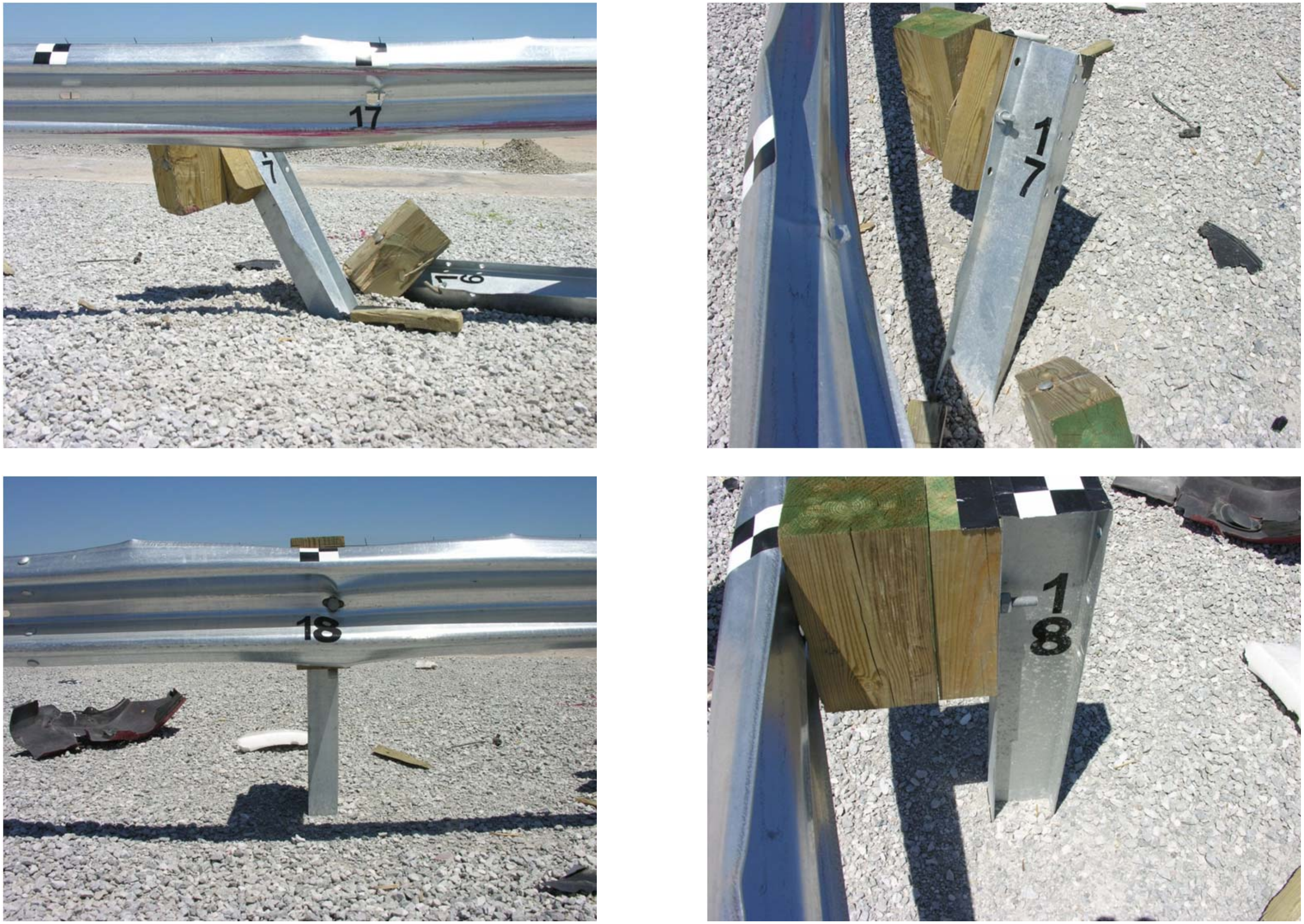


Figure 45. Post Nos. 17 and 18 Damage, Test No. MGSMRH-1

Figure 46. Vehicle Damage, Test No. MGSMRH-1

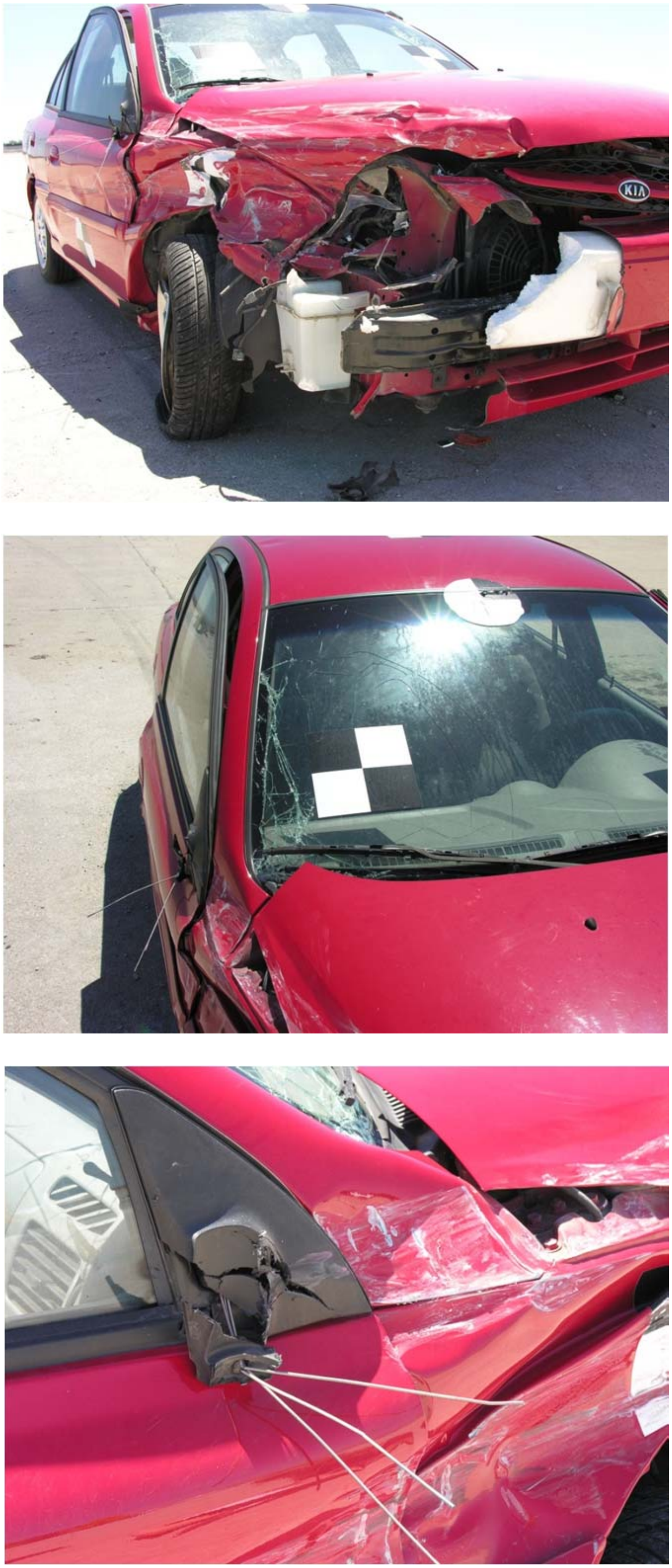


Figure 47. Vehicle Damage, Test No. MGSMRH-1

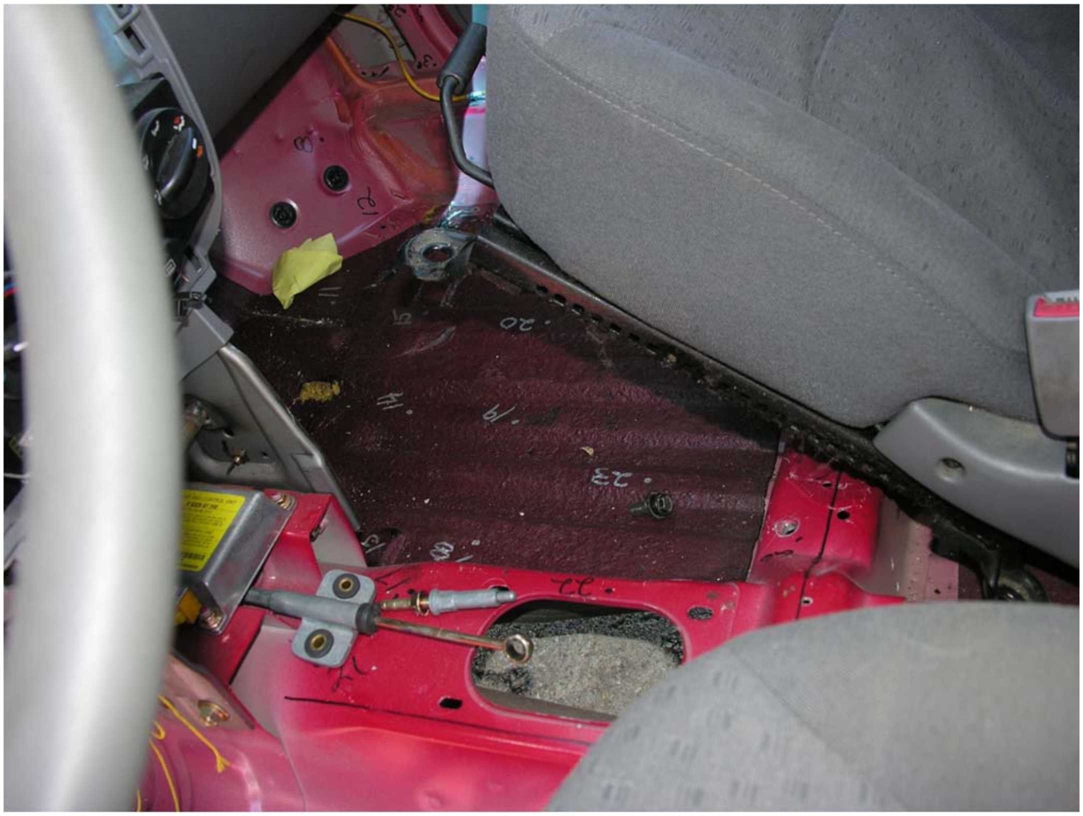


Figure 48. Occupant Compartment Damage, Test No. MGSMRH-1

Figure 49. Undercarriage Damage, Test No. MGSMRH-1

8 DESIGN DETAILS – 36-IN. (914-mm) TOP RAIL MOUNTING HEIGHT

The W-beam guardrail system tested in test no. MGSMRH-2 was identical to that of test no. MGSMRH-1, except that the top rail mounting height was increased from 34 in. (864 mm) to 36 in. (914 mm), as shown in Figures 50 through 52. The line posts, post no. 3 through 27, were embedded to a depth of 35 in. (889 mm), such that the top of the post was 37 in. (940 mm) from the ground. Similar to test no. MGSMRH-1, the top of the BCT anchor posts were 32 in. (813 mm) from the groundline. The center of the guardrail was mounted 2⅛ in. (54 mm) from the top of the BCT timber post. A full set of design details is shown in Appendix F. Photographs of the test installation are shown in Figure 53. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

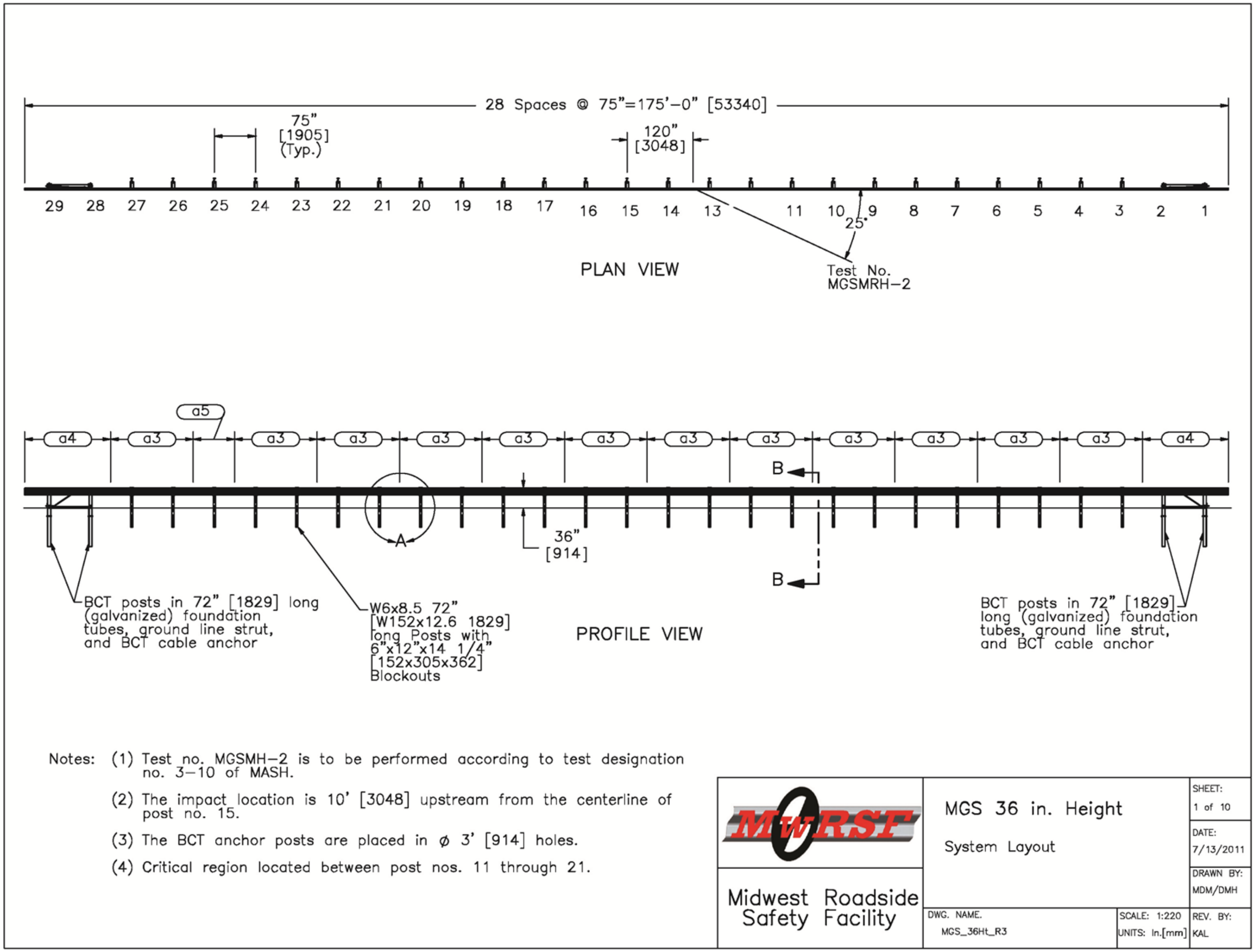


Figure 50. Test Installation Layout, Test No. MGSMRH-2

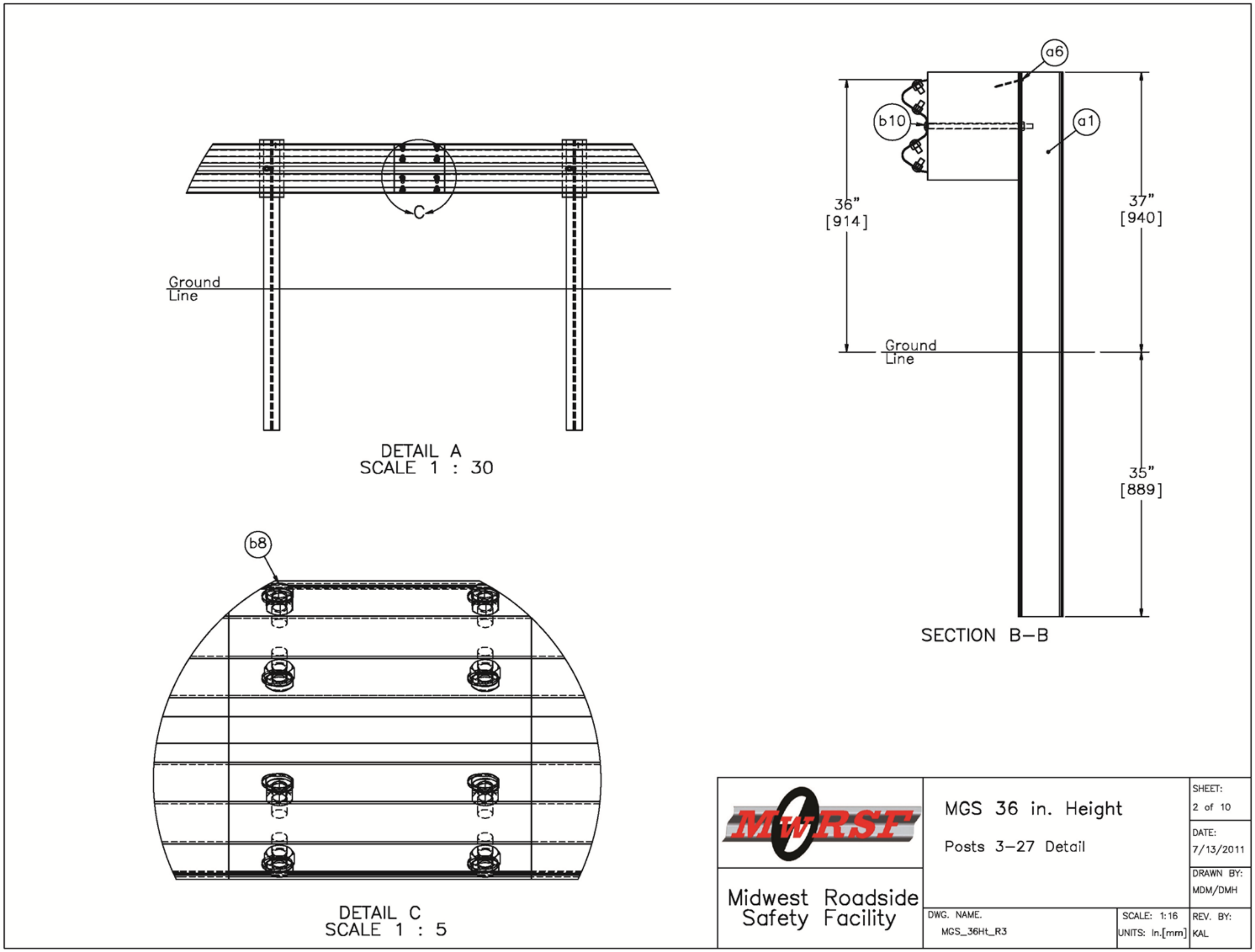


Figure 51. 36-in. (914-mm) Tall MGS Details, Test No. MGSMRH-2

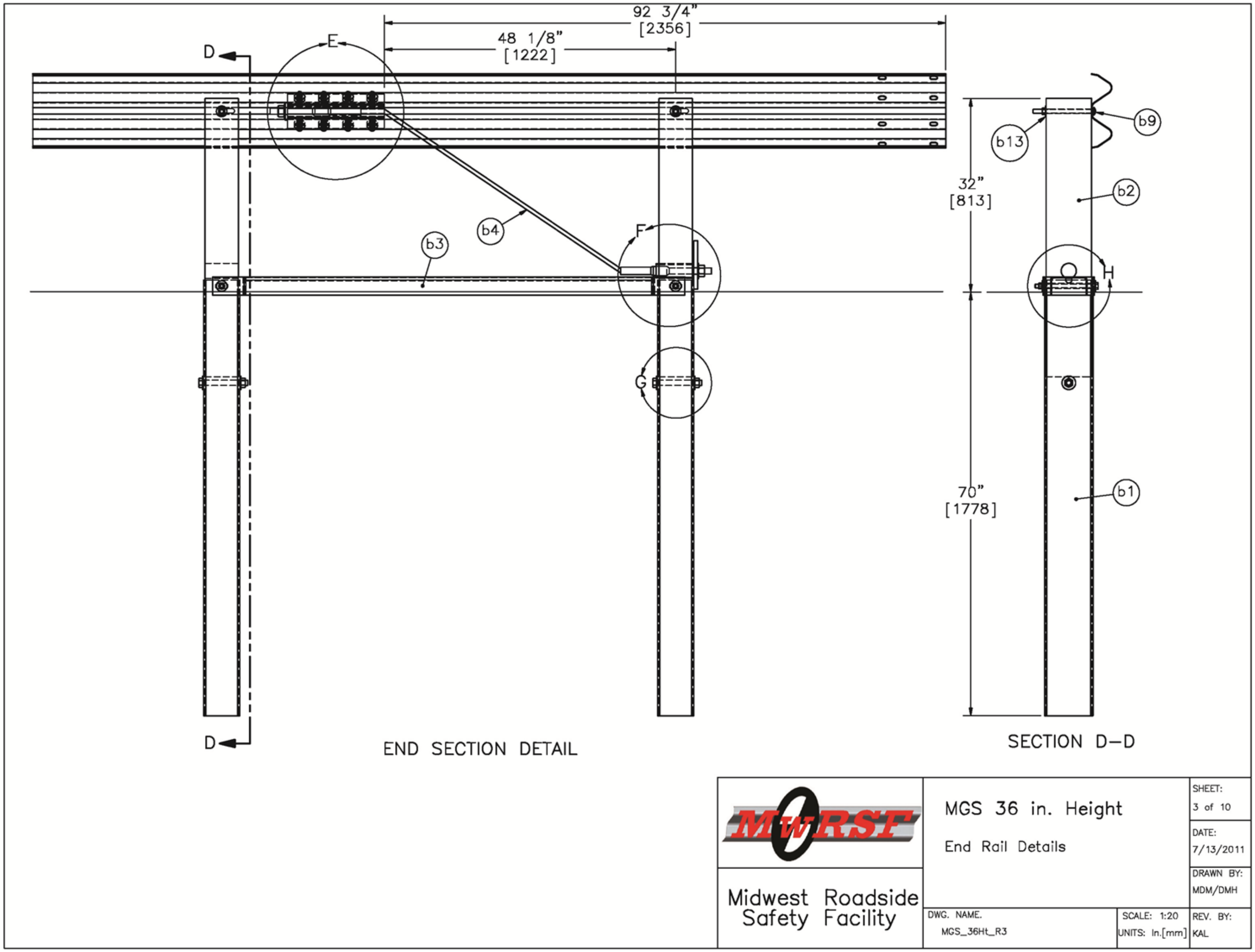


Figure 52. BCT End Anchor Details, Test No. MGSMRH-2

Figure 53. Test Installation Photographs, Test No. MGSMRH-2

9 FULL-SCALE CRASH TEST NO. MGSMRH-2

9.1 Static Soil Test

Before full-scale crash test no. MGSMRH-2 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 C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

9.2 Test No. MGSMRH-2

The 2,583-lb (1,172-kg) passenger car impacted the 36-in. (914-mm) MGS at a speed of 64.1 mph (103.2 km/h) and at an angle of 25.6 degrees. A summary of the test results and sequential photographs are shown in Figure 54. Additional sequential photographs are shown in Figures 55 through 57. Documentary photographs of the crash test are shown in Figure 58.

9.3 Weather Conditions

Test no. MGSMRH-2 was conducted on September 9, 2010 at approximately 2:45 pm. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 9.

Table 9. Weather Conditions, Test No. MGSMRH-2

Temperature	77° F
Humidity	71%
Wind Speed	15 mph
Wind Direction	130° from True North
Sky Conditions	Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.01 in.
Previous 7-Day Precipitation	0.01 in.

9.4 Test Description

Initial vehicle impact was to occur 10 ft (3.0 m) upstream of the centerline of post no. 15, as shown in Figure 59, which was selected using the CIP plots found in Section 2.3 of MASH. The actual point of impact was 9 ft – 8 in. (2.9 m) upstream of post no. 15. A sequential description of the impact events is contained in Table 10. The vehicle came to rest facing downstream at 129 ft – 9 in. (39.5 m) downstream of the initial impact point and 61 ft – 1 in. (18.6 m) laterally away from the front of the rail. The vehicle trajectory and final position are shown in Figures 54 and 60.

Table 10. Sequential Description of Impact Events, Test No. MGSMRH-2

TIME (sec)	EVENT
0.000	The right headlight contacted the bottom corrugation of the rail downstream of the intended impact location.
0.006	Post no. 14 deflected laterally backward, and the right side of the front bumper contacted the rail between post nos. 13 and 14.
0.018	Post no. 13 deflected laterally backward, and the engine hood became ajar.
0.024	The vehicle rolled toward the left.
0.030	Post no. 15 deflected laterally backward, and the posts upstream of impact twisted downstream.
0.040	A buckle point formed in the rail at post no. 15.
0.060	The vehicle began to redirect downstream.
0.078	The rail separated from post no. 15 as the right side of the front bumper contacted the blockout on post no. 15.
0.088	The front bumper contacted the upstream flange of post no. 15 as the right-front tire became airborne.
0.106	The surrogate occupant’s head contacted the right-front window causing the window to shatter, and post no. 17 deflected laterally backward.
0.132	The rail released from post no. 16.
0.162	The vehicle rolled toward the right, and post no. 18 deflected laterally backward.
0.170	The right-rear tire became airborne.
0.182	The right side of the front bumper contacted the upstream side of post no. 16.
0.208	Right-rear quarter panel contacted the rail.
0.232	The right-rear tire contacted the upstream side of post no. 15.

0.262	The vehicle was parallel to the system with a velocity of 41.1 mph (66.1 km/h).
0.276	The right-front tire contacted the upstream side of post no. 17.
0.532	Vehicle rolled toward the left.
0.562	The vehicle exited the system at a speed of 36.2 mph (58.3 km/h) and at an angle of 21.9 degrees as the right-rear quarter panel lost contact with the rail at post no. 18.

9.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 61 through 67. Barrier damage consisted of deformed W-beam rail, contact marks on the sections of guardrail and posts, and deformed steel posts. The length of vehicle contact along the barrier was approximately 28 ft – 3 in. (8.6 m) which spanned from 9 ft – 8 in. (2.9 m) upstream of the centerline of post no. 15 through 2 in. (51 mm) upstream of the centerline of post no. 18.

Deformation and flattening of the W-beam guardrail occurred between post nos. 14 and 16. A buckle point occurred in the W-beam at post no. 18. A kink occurred in the W-beam's top corrugation at 22½ in. (572 mm) downstream of post no. 18. The W-beam guardrail was detached from post nos. 15 through 17 as the bolt head was pulled through the rail. The slot in the rail at post no. 18 was deformed.

Post nos. 13 and 14 rotated backward. Post nos. 15 through 17 bent and deflected downstream. Post nos. 15 and 17 were also twisted downstream. The front flange of post no. 15 was slightly deformed, and a buckle on the downstream side of the front flange was located 40½ in. (1,029 mm) from the top of the post. Post no. 16 was twisted upstream. A buckle on the downstream side of the front flange of post no. 16 was located 44 in. (1,118 mm) from the top of the post. The wood blockouts detached from post nos. 15 through 17.

A ¾-in. (19-mm) soil gap was present at the upstream face of post no. 1, as shown in Figure 63. A ⅛-in. (3-mm) soil gap was present on the front face of post no. 12. A ¼-in. (6-mm) soil gap was present on the back face of post no. 13 and the front face of post no. 18. A 1-in. (25-

mm) soil gap was present on the front face of post no. 13. A 3½-in. (89-mm) soil gap was present at the front face of post no. 14, and a 1¼-in. (32-mm) soil gap was present at the back face. A 2½-in. (64-mm) soil gap was present at the front face of post nos. 15 and 16. A 3-in. (76-mm) soil gap was present at the upstream face of post no. 16. A 1¾-in. (44-mm) soil gap was present at the upstream face of post no. 17, and a 2-in. (51-mm) soil gap was present at the front face. A ⅜-in. (10-mm) soil gap was present at the back face of post no. 18. A 39-in. diameter by 2¾-in. tall (991- x 70-mm) soil heave was present at post no. 14. A 37-in. diameter by 2-in. tall (940- x 51-mm) soil heave was present at post no. 16.

The maximum permanent set rail and post deflections were 16¾ in. (425 mm) at the midspan between post nos. 15 and 16 and 15½ in. (394 mm) at post no. 15, respectively, as measured in the field. The maximum lateral dynamic set rail and post deflections were 23.5 in. (597 mm) at post no. 15 and 15.9 in. (404 mm) at post no. 15, respectively, as determined from high-speed digital video analysis. The working width of the system was 40.5 in. (1,029 mm), also determined from high-speed digital video analysis.

9.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 68 through 71. The maximum occupant compartment deformations are listed in Table 11 with the deformation limits established in MASH for various areas of the occupant compartment. It should be noted that none of the MASH established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

The majority of the damage was concentrated on the right-front corner and right side of the vehicle where the impact occurred. The right fender was crushed back and inward. A fold was present in the right fender above the wheel. The right-front wheel was scuffed. The right-

Table 11. Maximum Occupant Compartment Deformations by Location, Test No. MGSMRH-2

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	½ (13)	≤ 9 (229)
Floor Pan & Transmission Tunnel	¾ (19)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	¼ (6)	≤ 12 (305)
Side Door (Above Seat)	¼ (6)	≤ 9 (229)
Side Door (Below Seat)	½ (13)	≤ 12 (305)
Roof	NA	≤ 4 (102)
Windshield	NA	≤ 3 (76)

front door was ajar, and there was a 2½-in. (64-mm) gap between the right-front door and fender. The right-front window shattered. Scraping and denting occurred across the top of the right-side doors. There was a dent in the roof above the right-side doors. The right-rear door and right-rear quarter panel were scraped. A 16-in. (406-mm) long dent was present in the right-rear quarter panel. The right corner of the trunk and taillight were scuffed. A ¾-in. (19-mm) gap was present between the left fender and the left-front door. The right side of the hood was crushed inward, and a buckle was present in the left side of the hood. The right side of the bumper cover was disengaged, and the right side of the bumper was dented. The radiator was pushed inward and the vehicle frame around the radiator bent. The windshield washer fluid container was broken. Power steering fluid was present beneath the vehicle. The grill fractured. The left headlight was partially disengaged. The right headlight fractured. Cracking occurred on the right side of the windshield, and a fold in the glass was present 2¼-in. (57-mm) from the right side. The remaining window glass was undamaged.

9.7 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 12. It is noted that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 12. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 54. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix G.

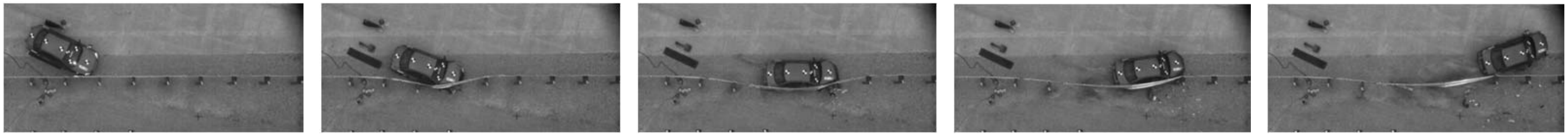
Table 12. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSMRH-2

Evaluation Criteria		**Transducer**			**MASH Limits**
		EDR-3	**EDR-4**	**DTS**	
OIV ft/s (m/s)	Longitudinal	-17.46 (-5.32)	-16.26 (-4.96)	-17.44 (-5.32)	≤ 40 (12.2)
	Lateral	-18.08 (-5.51)	-16.27 (-4.96)	-18.87 (-5.75)	≤40 (12.2)
ORA g's	Longitudinal	-9.16	-7.95	-9.27	≤ 20.49
	Lateral	-9.27	-7.85	-8.64	≤ 20.49
THIV ft/s (m/s)		NA	23.30 (7.10)	23.14 (7.05)	not required
PHD g's		NA	10.35	11.19	not required
ASI		0.87	0.80	0.90	not required

9.8 Discussion

The analysis of the test results for test no. MGSMRH-2 showed that the 36-in. (914-mm) tall MGS adequately contained and redirected the 1100C vehicle with controlled lateral displacements of 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 not occur. The test vehicle did not penetrate nor underride the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 21.9 degrees. The vehicle trajectory did violate the bounds of the exit box as the vehicle was smoothly redirected. However, the exit box criteria is preferable but not a test requirement. Therefore, test no. MGSMRH-2 conducted on the 36-in. (914-mm) tall MGS was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-10.



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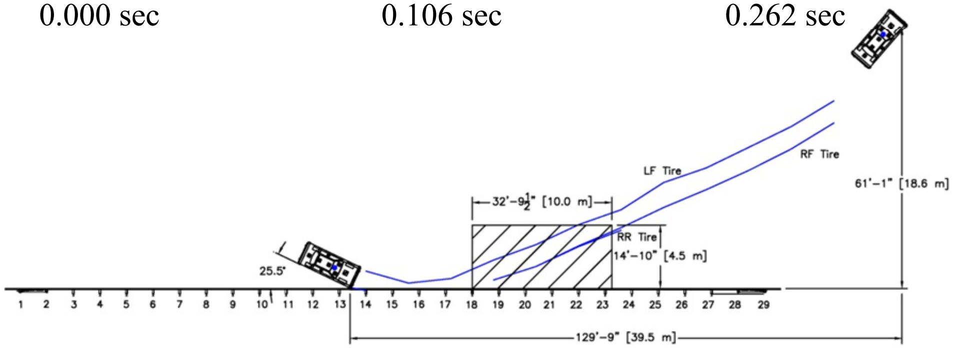

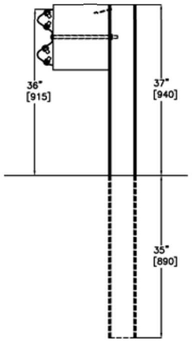

- Test Agency .... MwRSF
- Test Number MGSMRH-2
- Date 9-9-2010
- MASH Test Designation 3-10
- Test Article .... 36-in. (914-mm) Tall MGS
- Total Length .... 175 ft (53.3 m)
- Key Component – Steel MGS Rail
  - Thickness .... 12 gauge (2.66 mm)
  - Top Mounting Height .... 36 in. (914 mm)
- Key Component – Steel Posts
  - Post Spacing .... 75 in. (1,905 mm)
  - Post Dimensions .... W6x8.5 x 72 in. long (W152x12.6 x 1,829 mm)
  - Embedment Depth .... 35 in. (889 mm)
- Key Component – Wood Spacer Blocks
  - Dimensions .... 6 x 12 x 72 in. (152 x 305 x 1,829 mm)
- Soil Type .... Grade B, AASHTO M147-65 (1990)
- Vehicle Make /Model .... 2004 Kia Rio
  - Curb .... 2,449 lb (1,111 kg)
  - Test Inertial .... 2,412 lb (1,094 kg)
  - Gross Static .... 2,583 lb (1,172 kg)
- Impact Conditions
  - Speed .... 64.1 mph (103.2 km/h)
  - Angle .... 25.6 deg
  - Impact Location .... 9 ft - 8 in. (2.9 m) upstream of post no. 15
- Exit Conditions
  - Speed .... 36.2 mph (58.3 km/h)
  - Angle .... 21.9 deg
- Exit Box Criterion .... Fail
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 129 ft – 9 in. (39.5 m) downstream
  61 ft – 1 in. (18.6 m) laterally away
- Vehicle Damage .... Moderate
  - VDS[34] 01-RFQ-5
  - CDC[35] 01-RYAN-5
  - Maximum Interior Deformation .... ¾ in. (19 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 16¾ in. (425 mm)
  - Dynamic .... 23.5 in. (597 mm)
  - Working Width .... 40.5 in. (1,029 mm)
- Maximum Angular Displacements
  - Roll .... -10.8 ° < 75°
  - Pitch .... -2.4 ° < 75°
  - Yaw .... -45.3 °
- Impact Severity (IS) .... 61.9 kip-ft (83.9 kJ) > 51.4 kip-ft (69.7 kJ)
- Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		EDR-3	EDR-4	DTS	
OIV ft/s (m/s)	Longitudinal	-17.46 (-5.32)	-16.26 (-4.96)	-17.44 (-5.32)	≤ 40 (12.2)
	Lateral	-18.08 (-5.51)	-16.27 (-4.96)	-18.87 (-5.75)	≤ 40 (12.2)
ORA g's	Longitudinal	-9.16	-7.95	-9.27	≤ 20.49
	Lateral	-9.27	-7.85	-8.64	≤ 20.49
THIV – ft/s (m/s)		NA	23.30 (7.10)	23.14 (7.05)	not required
PHD – g's		NA	10.35	11.19	not required
ASI		0.87	0.80	0.90	not required

Figure 54. Summary of Test Results and Sequential Photographs, Test No. MGSMRH-2


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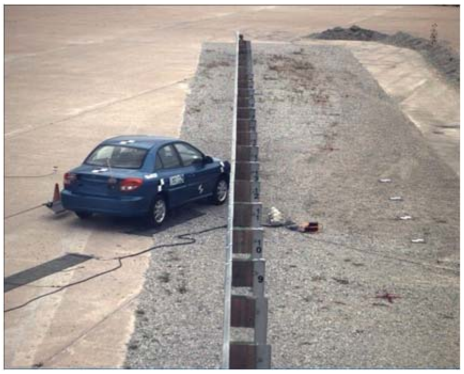
Figure 55. Additional Sequential Photographs, Test No. MGSMRH-2



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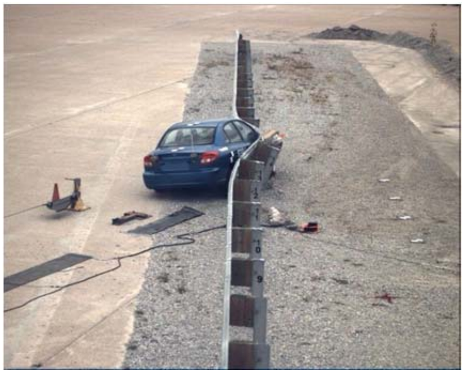

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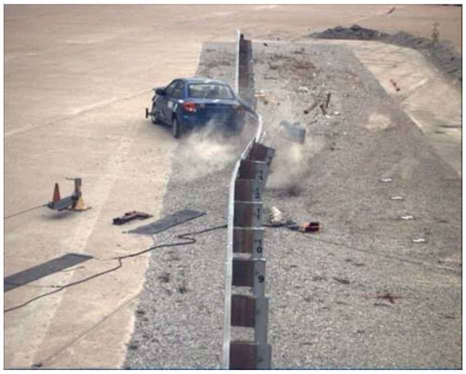

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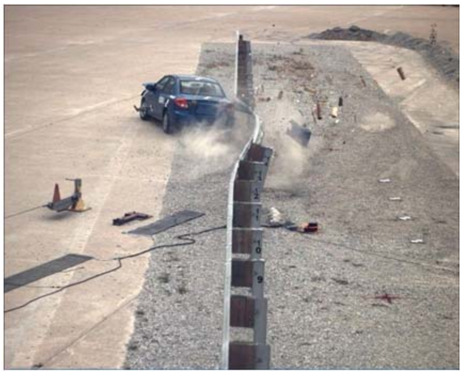

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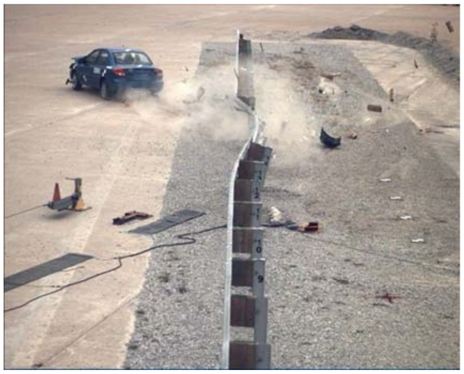

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Figure 56. Additional Sequential Photographs, Test No. MGSMRH-2

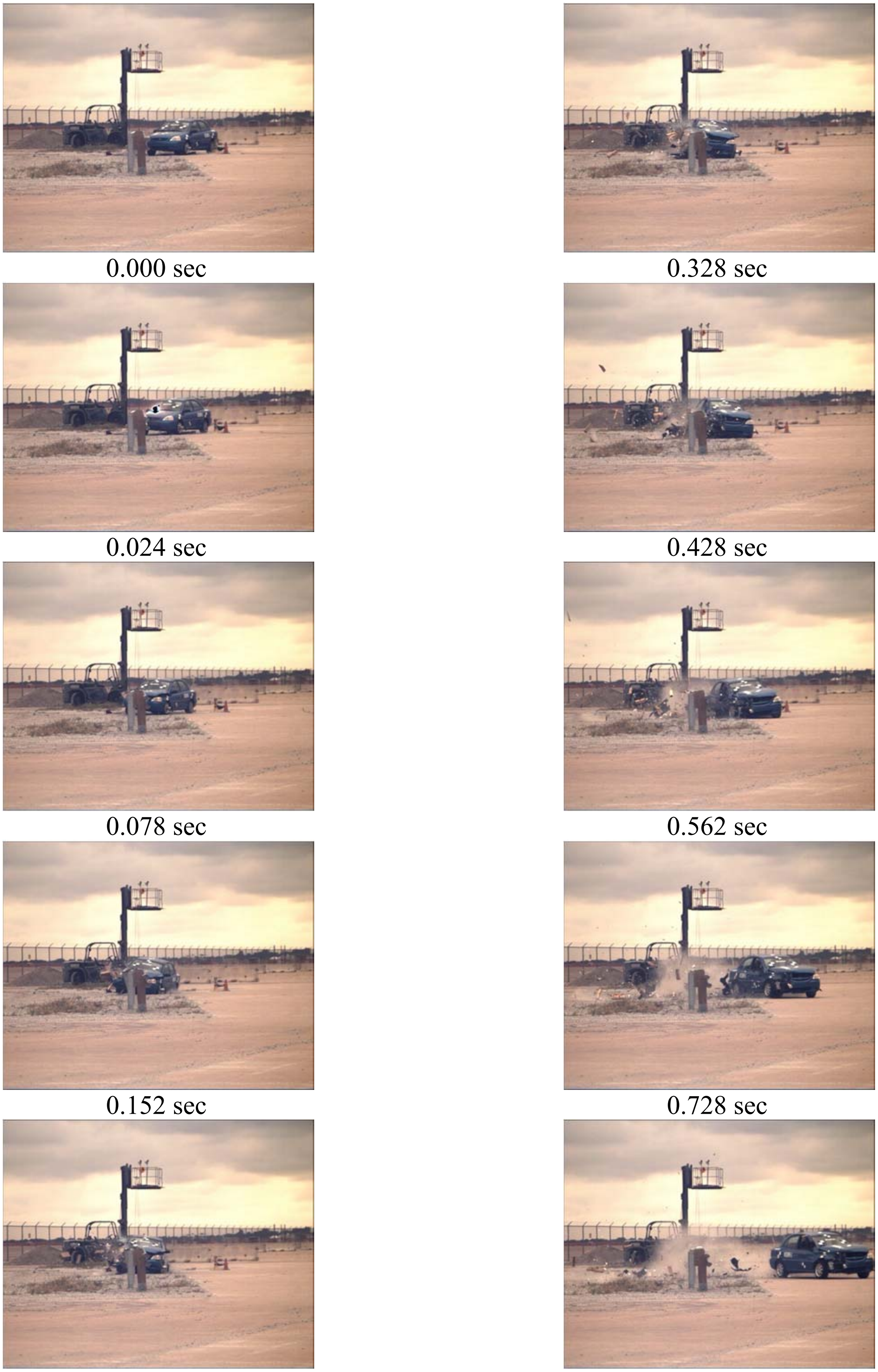

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Figure 57. Additional Sequential Photographs, Test No. MGSMRH-2

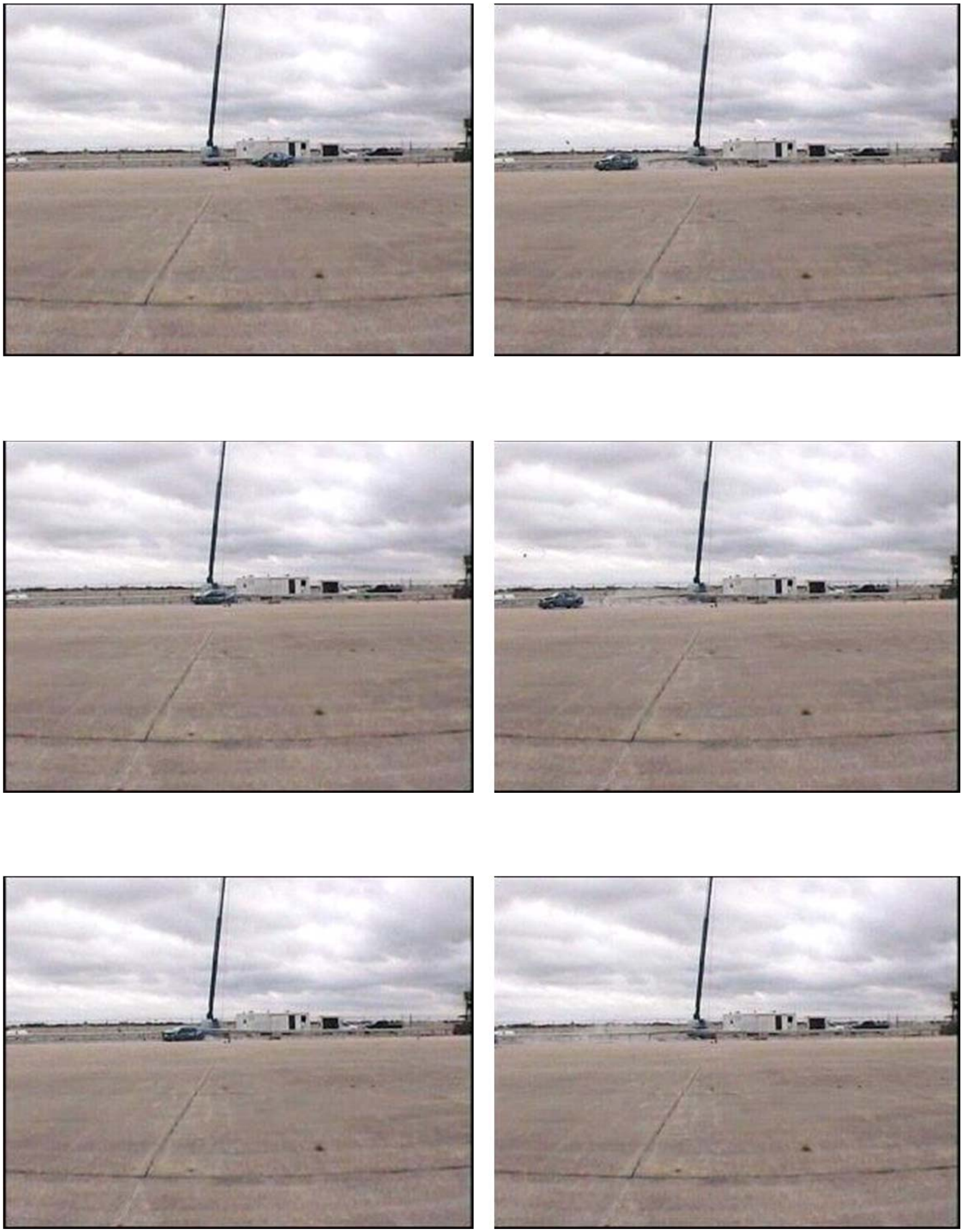

Figure 58. Documentary Photographs, Test No. MGSMRH-2

Figure 59. Impact Location, Test No. MGSMRH-2

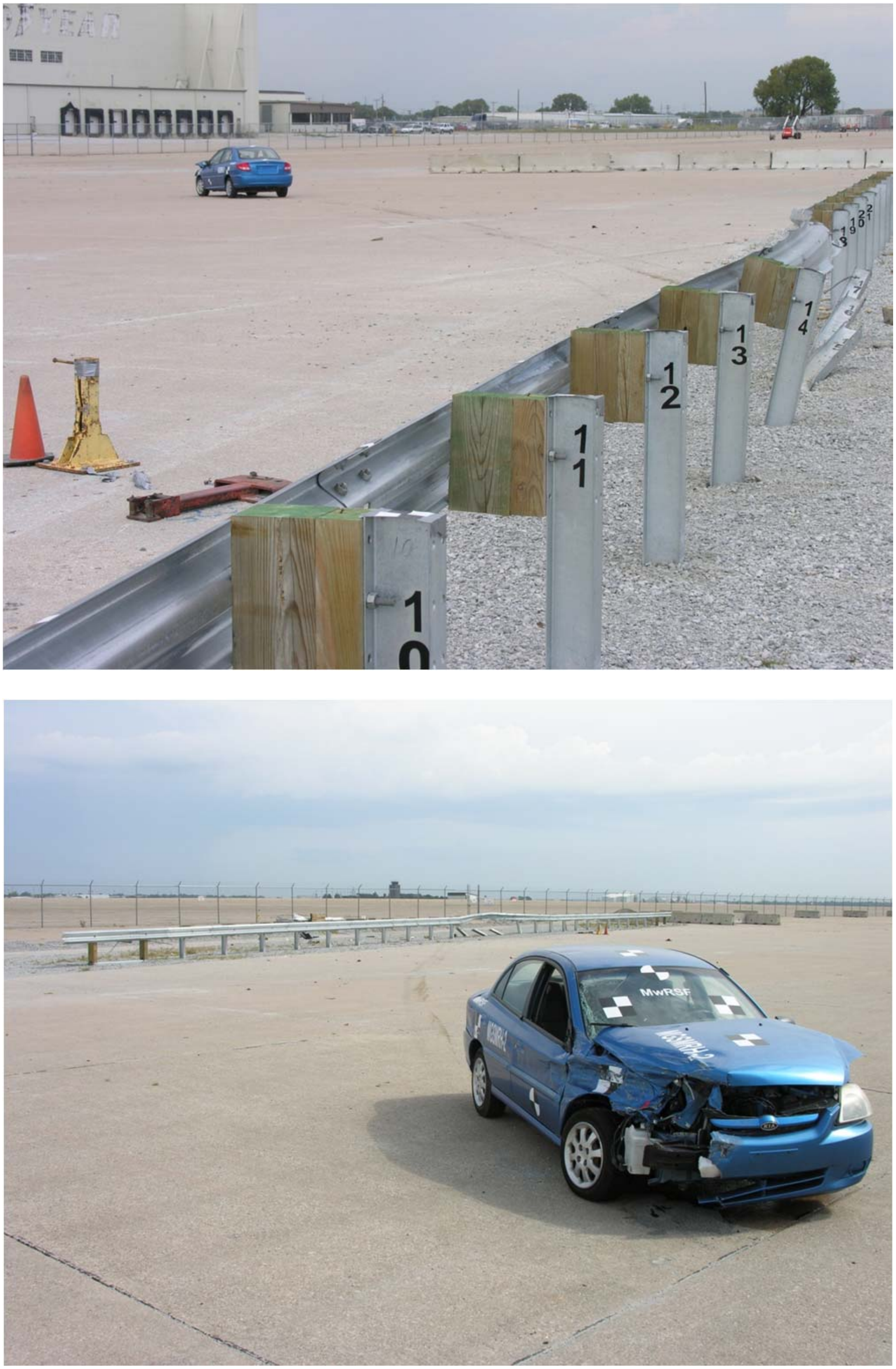

Figure 60. Vehicle Final Position and Trajectory Marks, Test No. MGSMRH-2

Figure 61. System Damage, Test No. MGSMRH-2

Figure 62. System Damage, Test No. MGSMRH-2

Figure 63. Soil Gap at Upstream End Anchor, Test No. MGSMRH-2

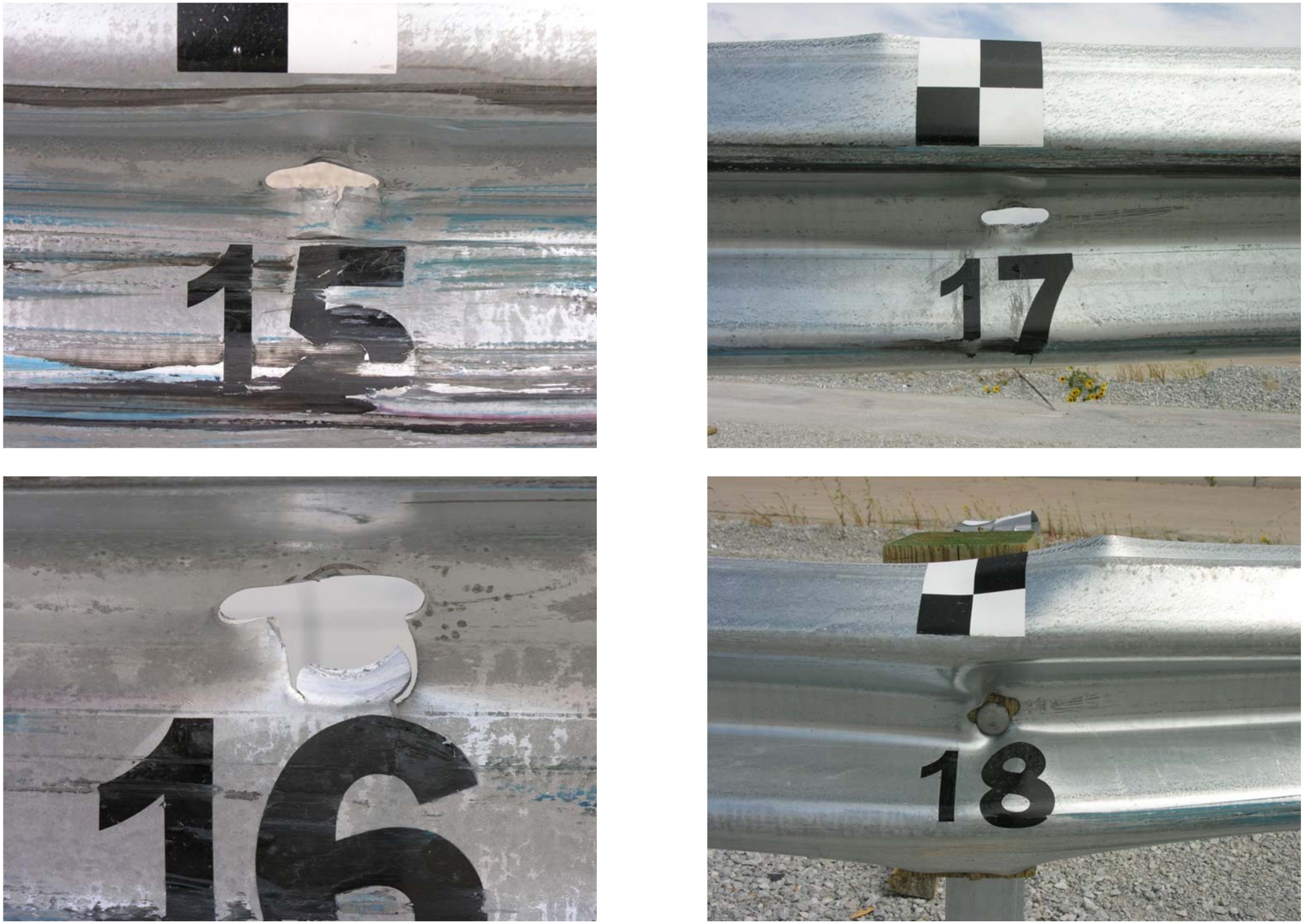

Figure 64. Post-To-Rail Bolt Hole Damage, Test No. MGSMRH-2

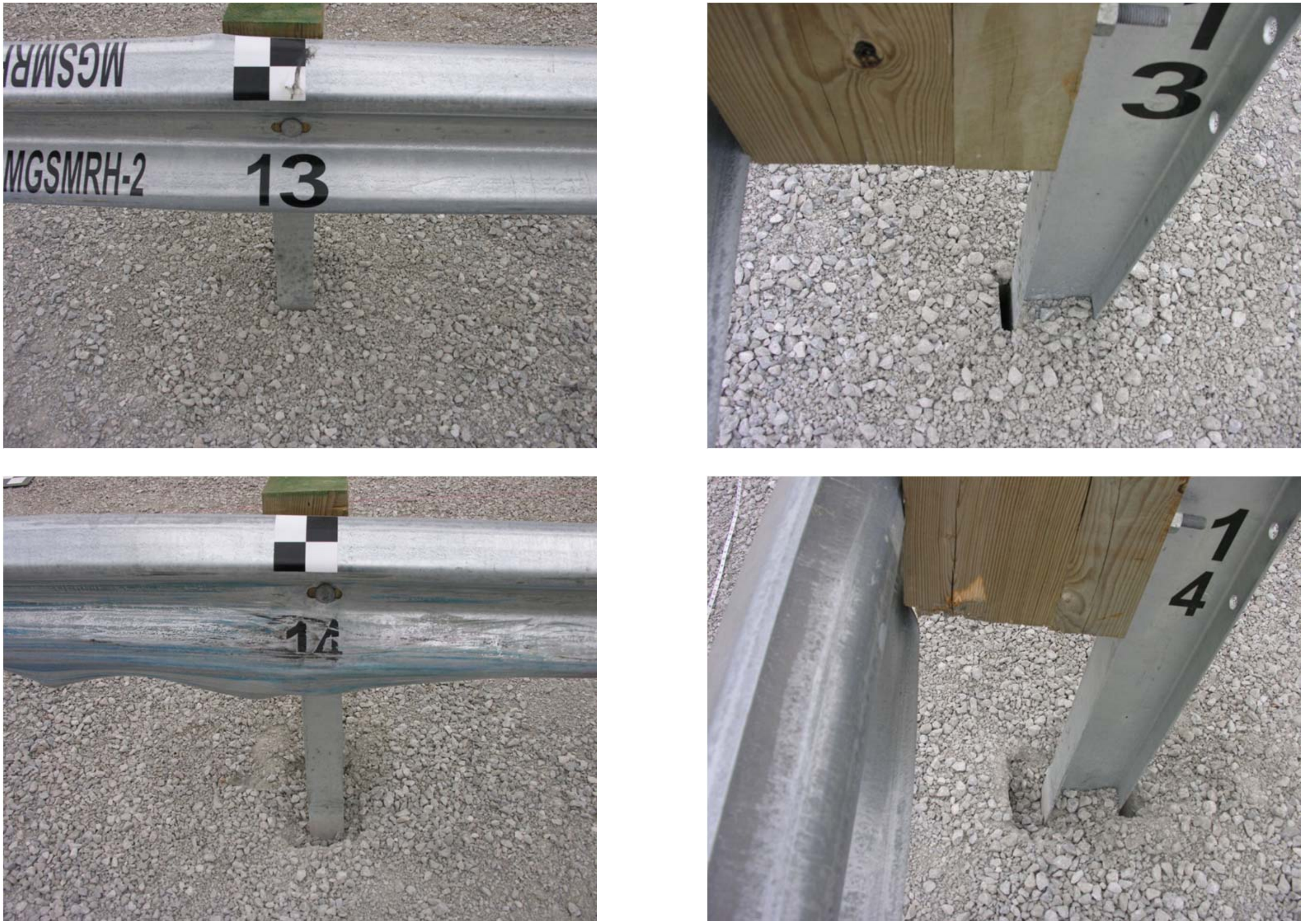

Figure 65. Post Damage, Test No. MGSMRH-2

Figure 66. Post Damage, Test No. MGSMRH-2

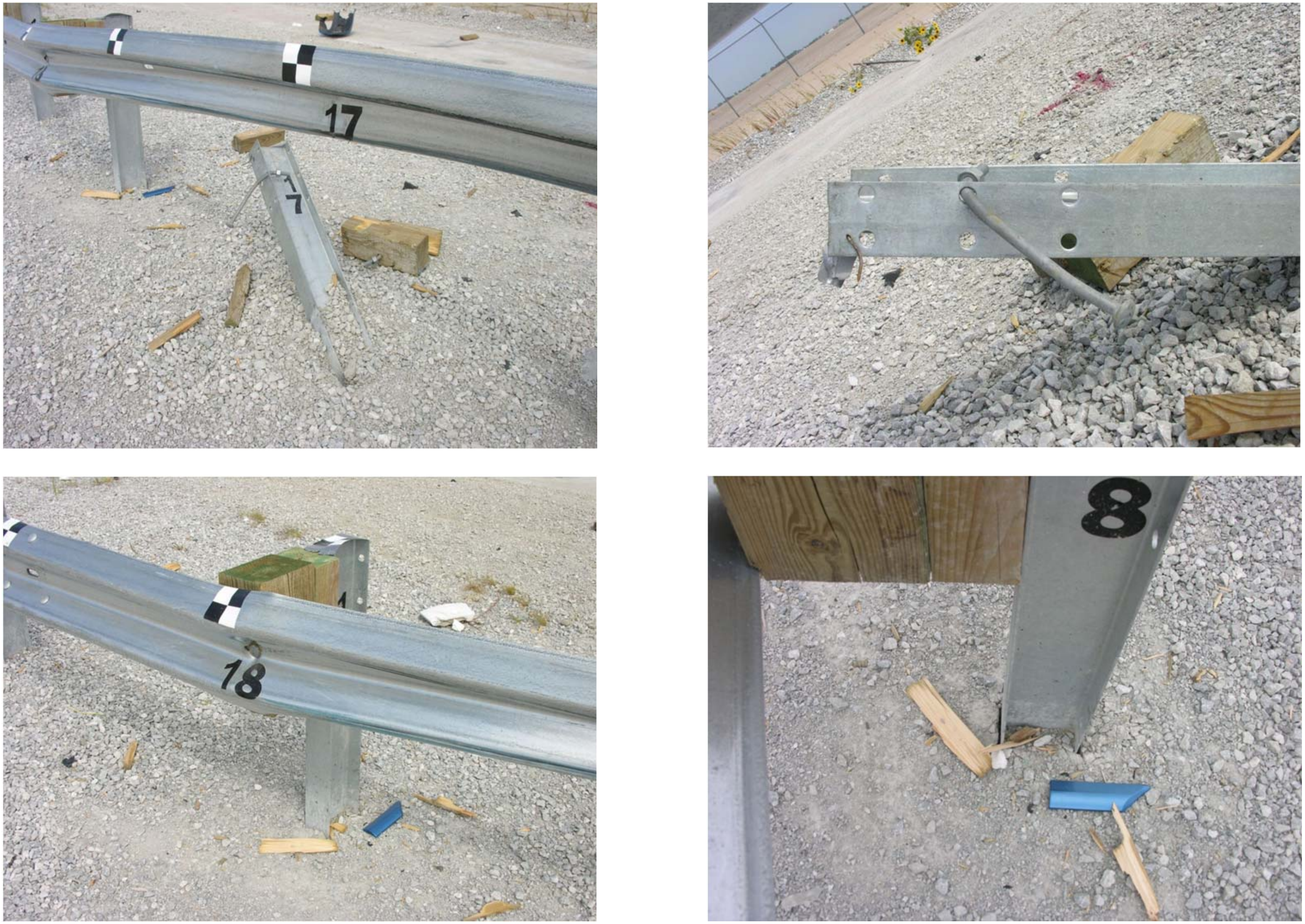

Figure 67. Post Damage, Test No. MGSMRH-2

Figure 68. Vehicle Damage, Test No. MGSMRH-2

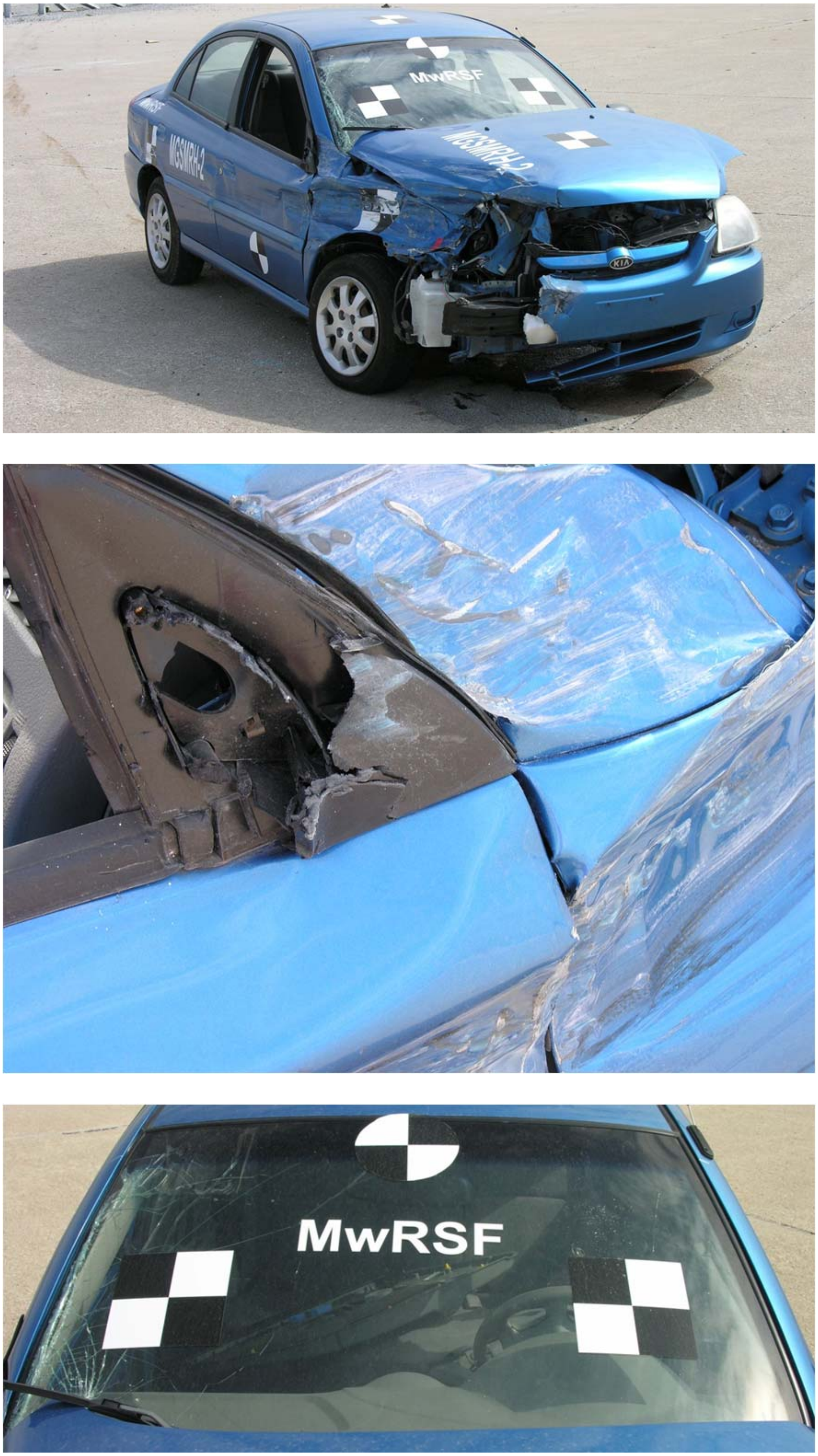

Figure 69. Vehicle Damage, Test No. MGSMRH-2

Figure 70. Occupant Compartment Damage, Test No. MGSMRH-2

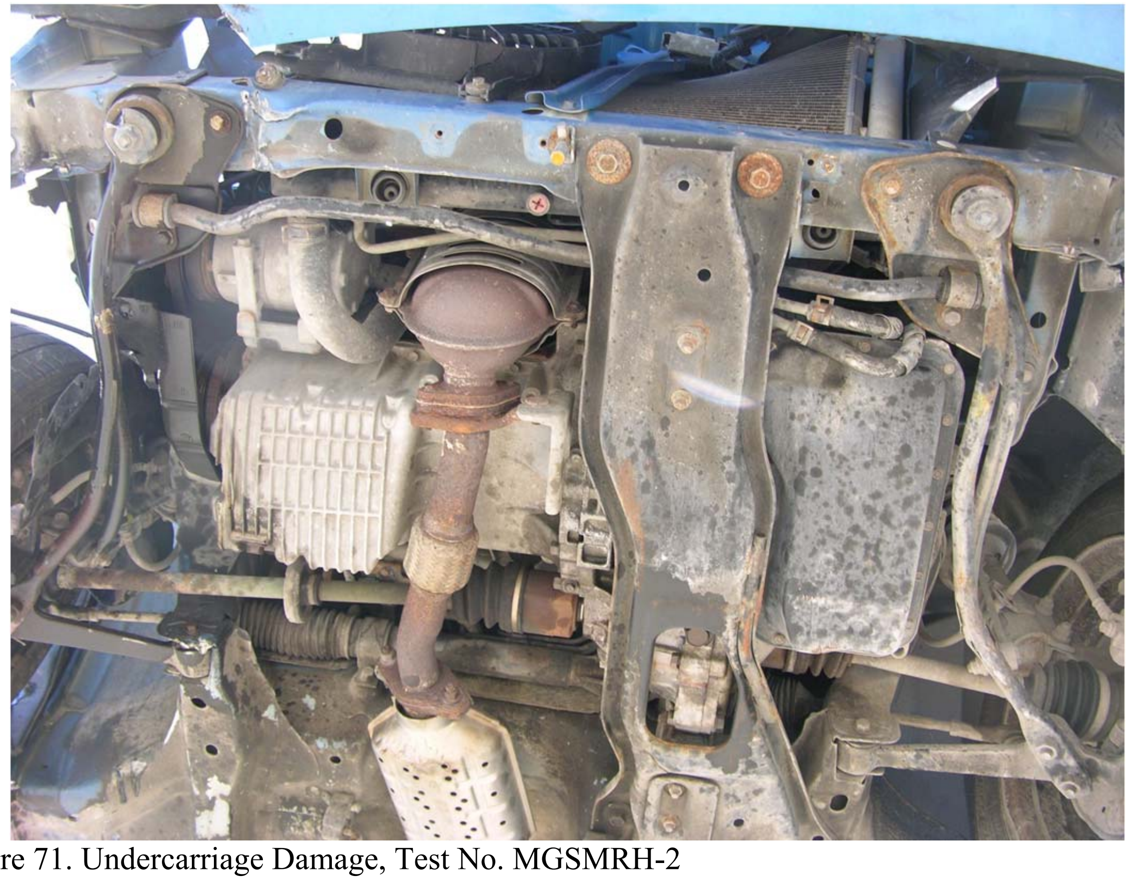

Figure 71. Undercarriage Damage, Test No. MGSMRH-2

10 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This study set out to evaluate the maximum allowable rail mounting height for the MGS when impacted by a small passenger vehicle. All safety performance evaluations were performed using the criteria found in MASH. Two full-scale crash tests were run on the steel-post MGS with different rail mounting heights. The barrier system test installations were 175 ft (53.3 m) long. A summary of the safety performance evaluation of the two full-scale crash tests is provided in Table 13.

The first full-scale crash test, test no. MGSMRH-1, was performed on the MGS with a top rail mounting height of 34 in. (864 mm). The system incorporated 72-in. (1,829-mm) long, W6x9 (W152x13.4) steel posts with an embedment depth of 37 in. (940 mm). The test consisted of a 2,599-lb (1,179-kg) passenger car impacting the barrier system at a speed of 63.6 mph (102.4 km/h) and at an angle of 25.0 degrees. During the test, the vehicle was smoothly redirected without any significant snagging or vehicle underride. The maximum permanent set and dynamic deflections were 18¼ in. (464 mm) and 29.0 in. (737 mm), respectively. The working width of the system was found to be 49.4 in. (1,255 mm). The test results were found to meet all of the MASH safety requirements for test designation 3-10.

The second full-scale crash test, test no. MGSMRH-2, was performed on the MGS with a top rail mounting height of 36 in. (914 mm). The system incorporated 72-in. (1,829-mm) long, W6x9 (W152x13.4) steel posts with an embedment depth of 35 in. (889 mm). The test consisted of a 2,583-lb (1,172-kg) passenger car impacting the barrier system at a speed of 64.1 mph (103.2 km/h) and at an angle of 25.6 degrees. During the test, the vehicle was smoothly redirected without any significant snagging or vehicle underride. The maximum permanent set and dynamic deflections were 16¾ in. (425 mm) and 23.5 in. (597 mm), respectively. The working width of the system was found to be 40.5 in. (1,029 mm). The test results were found to meet all of the MASH safety requirements for test designation 3-10.

10.1 Discussion

Wheel snag did not pose a significant threat to the vehicle in test nos. MGSMRH-1 or MGSMRH-2. In test no. MGSMRH-1, wheel snag occurred when the right-front tire contacted the upstream edge of the front flange of post no. 17. At that time, post no. 17 was not attached to the rail. After contact with the wheel, the post twisted and bent downstream. Wheel snag did not occur in test no. MGSMRH-2, and the vehicle was smoothly redirected.

Rail snag under the hood did not occur for either test. For the 32-in. (813-mm) tall MGS, the corner of the 1100C vehicle hood was located above the top corrugation of the rail. In test nos. MGSMRH-1 and MGSMRH-2, the corner of the hood was located between the corrugations of the rail, as shown in Figures 8 and 9. As a result, the corner of the hood slid into the valley of the W-beam and crumpled, jarring the hood open.

During redirection, the rail deflected upward as it released from the posts and slid up the side of the vehicle. The vehicle contacted the detached posts and overrode them, which caused the vehicle to pitch upward and roll away from the barrier, as shown in Figures 72 and 73. In both tests, the vehicle reached a maximum roll angle of about 11 degrees and pitched upward about 2 degrees. As the vehicle rolled away from the barrier, the right side of the vehicle that was in contact with the rail moved upward. As a consequence, the rail slid up the vehicle, contacted the base of the A-pillar, and did not slide any higher. At this same time, the rail was applying a downward force on the vehicle which counteracted the vehicle roll.

Table 13. Summary of Safety Performance Evaluation Results

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. MSGMRH-1</th><th>Test No. MGSMRH-2</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>S</td><td>S</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>S</td><td>S</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>S</td><td>S</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</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><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</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><td>S</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

34-in. (864-mm) tall rail

36-in. (914-mm) tall rail

Figure 72. Vehicle-to-Rail Interaction

34-in. (864-mm) tall rail

36-in. (914-mm) tall rail

Figure 73. Vehicle-to-Rail Interaction

The MGS performed very similarly with mounting heights at 32, 34, and 36 in. (813, 864, and 914 mm). A summary of the barrier performances are shown in Table 14.

Table 14. Comparison of Wheel Snag and Barrier Underride Factors

Parameter	Units	Test No.		
		2214MG-3	MGSMRH-1	MGSMRH-2
Barrier Height	in. (mm)	32 (813)	34 (864)	36 (914)
Maximum Floorpan Deflection near Wheel Well	in. (mm)	¼ (6)	¼ (6)	¼ (6)
Maximum Lateral Rail Dynamic Deflections	in. (mm)	35.9 (913)	29.0 (737)	23.5 (597)
Longitudinal OIV	ft/s (m/s)	-14.83 (-4.52)	-15.56 (-4.74)	-17.46 (-5.32)
Longitudinal ORA	g's	-16.14	-8.45	-9.16
Exit Speed	mph (km/h)	30.1 (48.4)	39.3 (63.2)	36.2 (58.3)
Exit Angle	deg.	14.1	12.3	21.9
Exit Orientation Angle	deg.	1.6 toward barrier	11.1 away from barrier	16.5 away from barrier
Maximum Roll Angle during Redirection	deg.	-12.8	-10.6	-10.8
Maximum Pitch Angle during Redirection	deg.	1.2	1.9	1.6

The 32-in. (813-mm) tall MGS showed greater wheel snag than the 34- or 36-in. (864- or 914-mm) tall MGS, as evidenced by the high ORA value, the damage to the wheel, and the disparity between the exit angle and the exit orientation angle. The wheel snag and barrier underride performances observed in tests MGSMRH-1 and MGSMRH-2 were nearly identical to one another. Both the 34- and 36-in. (864- and 914-mm) tall MGS had similar OIV and ORA values. The exit angle and exit orientation angle were both higher for the 36-in. (914-mm) tall

MGS than the 34-in. (864-mm) MGS, but the vehicle appeared to exit the system with all wheels tracking in those systems.

System damage differed between the 32-, 34-, and 36-in. (813-, 864-, and 914-mm) tall MGS, as shown in Figure 74. In test no. 2214MG-3, the 32-in. (813-mm) tall MGS rail did not fully flatten, although rail kinking occurred between post nos. 13 and 17 and the rail lifted approximately 1½ in. (38 mm). In test no. MGSMRH-1, the 34-in. (864-mm) MGS rail was not fully flattened, but the corrugations were compressed between post nos. 14 and 17, and the rail lifted approximately 2½ in. (64 mm). In test no. MGSMRH-2, the lower corrugation of the 36-in. (914-mm) tall MGS was flattened beginning at the splice between post nos. 14 and 15 and ending at the splice between post nos. 16 and 17. The rail was lifted approximately 3 in. (76 mm), and the degree of rail twist was greater than the twist in the 32- and 34-in. (813- and 864-mm) tall MGS.

The post-soil interaction also differed between the systems. Soil comparisons cannot be made between test no. 2214MG-3 and test nos. MGSMRH-1 and MGSMRH-2, as the soil compaction method was not the same. The lateral post deflections seen in test no. MGSMRH-1 were, on average, larger than the lateral post deflections seen in test no. MGSMRH-2. The static soil strength data for each system is shown in Figure 75. The 34-in. (864-mm) tall MGS had slightly stiffer soil at the time of the test, but the overall rail deflection was greater than the deflection of the 36-in. (914-mm) tall MGS. However, more posts were deformed during the test of the 36-in. (914-mm) tall MGS.

32-in.
(813-mm)
MGS

34-in.
(864-mm)
MGS

36-in.
(914-mm)
MGS

Figure 74. System Damage Comparison

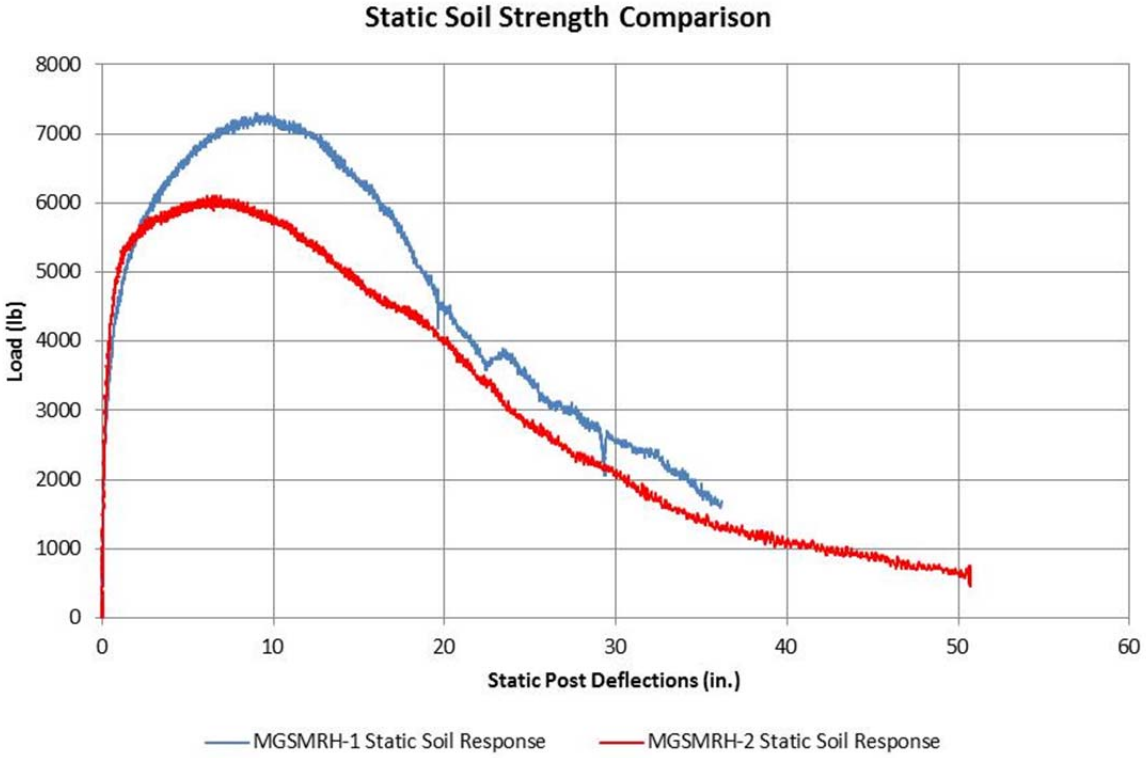

Figure 75. Static Soil Strength Comparison

10.2 Future Work

Current MASH FHWA approval for the MGS consists of a nominal 31-in. (787-mm) top rail mounting height. The crash tests reported herein indicate that there exists a considerable factor-of-safety applicable to barrier height. However, a taller MGS is not ready for MASH approval as more research must be performed on the system.

Phase II of this project will utilize LS-DYNA computer simulation to investigate several issues related to increased rail height (and corresponding decreased post embedment depth), including: (1) the 2270P behavior; (2) the effects on the end anchorages due to increased cable anchor angle; (3) the non-blocked MGS; and (4) end terminals and the possibility of a transition between the 31-in. (787-mm) rail to a higher rail height.

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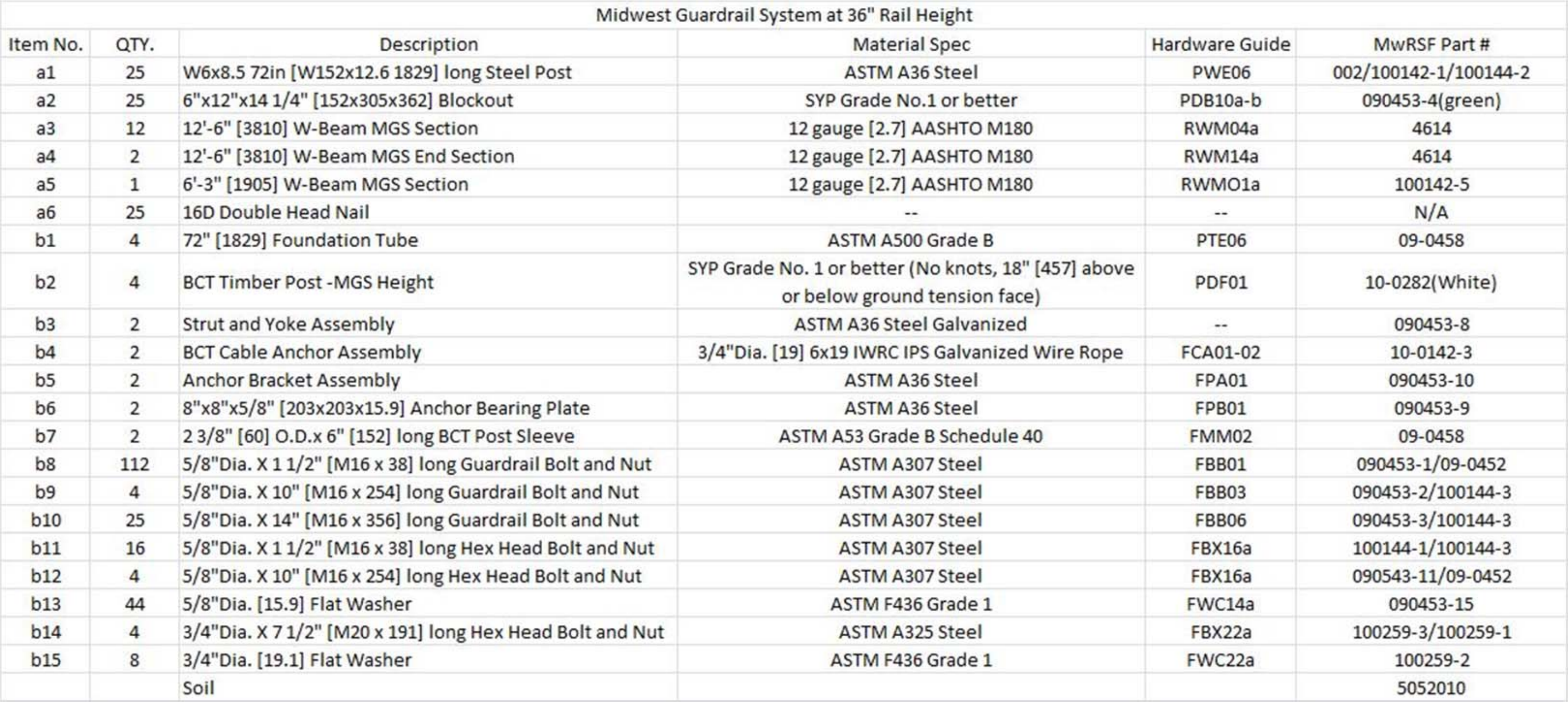
12 APPENDICES

Appendix A - Material Specifications

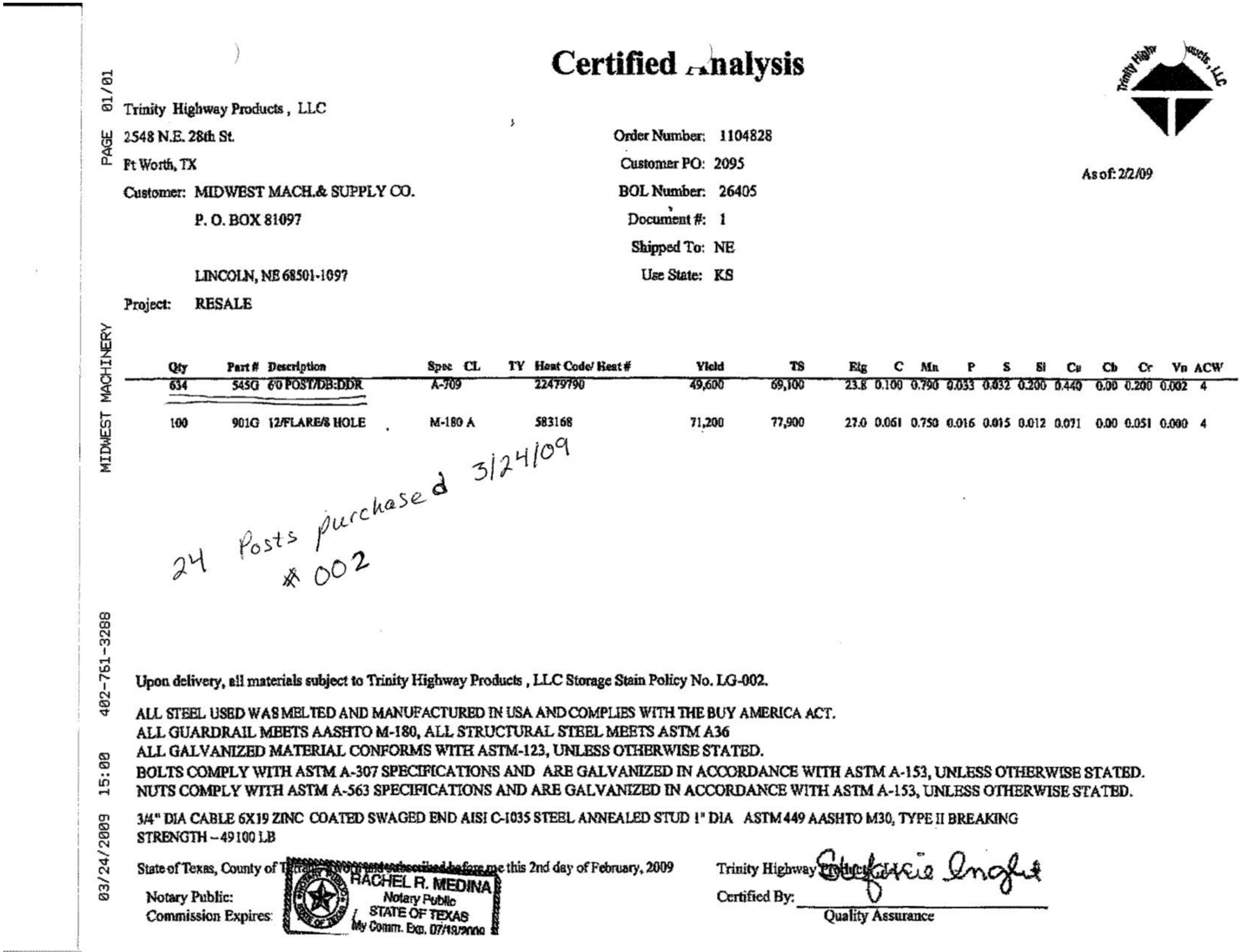
Table A-1. Material Certification Listing for Test No. MGSMRH-1

Midwest Guardrail System at 34" Rail Height					
Item No.	QTY.	Description	Material Spec	Hardware Guide	MwRSF Part #
a1	25	W6x8.5 72in [W152x12.6 1829] long Steel Post	ASTM A36 Steel	PWE06	002/100142-1
a2	25	6"x12"x14 1/4" [152x305x362] Blockout	SYP Grade No.1 or better	PDB10a-b	090453-4(green)
a3	12	12'-6" [3810] W-Beam MGS Section	12 gauge [2.7] AASHTO M180	RWM04a	4614
a4	2	12'-6" [3810] W-Beam MGS End Section	12 gauge [2.7] AASHTO M180	RWM14a	4614
a5	1	6'-3" [1905] W-Beam MGS Section	12 gauge [2.7] AASHTO M180	RWMO1a	100142-5
a6	25	16D Double Head Nail	--	--	N/A
b1	4	72" [1829] Foundation Tube	ASTM A500 Grade B	PTE06	09-0458
b2	4	BCT Timber Post -MGS Height	SYP Grade No. 1 or better (No knots, 18" [457] above or below ground tension face)	PDF01	10-0142(Red)
b3	2	Strut and Yoke Assembly	ASTM A36 Steel Galvanized	--	090453-8
b4	2	BCT Cable Anchor Assembly	3/4"Dia. [19] 6x19 IWRC IPS Galvanized Wire Rope	FCA01-02	10-0142-3
b5	2	Anchor Bracket Assembly	ASTM A36 Steel	FPA01	090453-10
b6	2	8"x8"x5/8" [203x203x15.9] Anchor Bearing Plate	ASTM A36 Steel	FPB01	090453-9
b7	2	2 3/8" [60] O.D.x 6" [152] long BCT Post Sleeve	ASTM A53 Grade B Schedule 40	FMM02	09-0458
b8	112	5/8"Dia. X 1 1/2" [M16 x 38] long Guardrail Bolt and Nut	ASTM A307 Steel	FBB01	090453-1/09-0452
b9	4	5/8"Dia. X 10" [M16 x 254] long Guardrail Bolt and Nut	ASTM A307 Steel	FBB03	090453-2/100144-3
b10	25	5/8"Dia. X 14" [M16 x 356] long Guardrail Bolt and Nut	ASTM A307 Steel	FBB06	090453-3/100144-3
b11	16	5/8"Dia. X 1 1/2" [M16 x 38] long Hex Head Bolt and Nut	ASTM A307 Steel	FBX16a	100144-1/100144-3
b12	4	5/8"Dia. X 10" [M16 x 254] long Hex Head Bolt and Nut	ASTM A307 Steel	FBX16a	090543-11/09-0452
b13	44	5/8"Dia. [15.9] Flat Washer	ASTM F436 Grade 1	FWC14a	090453-15
b14	4	3/4"Dia. X 7 1/2" [M20 x 191] long Hex Head Bolt and Nut	ASTM A325 Steel	FBX22a	100259-3/100259-1
b15	8	3/4"Dia. [19.1] Flat Washer	ASTM F436 Grade 1	FWC22a	100259-2

Table A-2. Material Certification Listing for Test No. MGSMRH-2



Midwest Guardrail System at 36" Rail Height					
Item No.	QTY.	Description	Material Spec	Hardware Guide	MwRSF Part #
a1	25	W6x8.5 72in [W152x12.6 1829] long Steel Post	ASTM A36 Steel	PWE06	002/100142-1/100144-2
a2	25	6"x12"x14 1/4" [152x305x362] Blockout	SYP Grade No.1 or better	PDB10a-b	090453-4(green)
a3	12	12'-6" [3810] W-Beam MGS Section	12 gauge [2.7] AASHTO M180	RWM04a	4614
a4	2	12'-6" [3810] W-Beam MGS End Section	12 gauge [2.7] AASHTO M180	RWM14a	4614
a5	1	6'-3" [1905] W-Beam MGS Section	12 gauge [2.7] AASHTO M180	RWMO1a	100142-5
a6	25	16D Double Head Nail	--	--	N/A
b1	4	72" [1829] Foundation Tube	ASTM A500 Grade B	PTE06	09-0458
b2	4	BCT Timber Post -MGS Height	SYP Grade No. 1 or better (No knots, 18" [457] above or below ground tension face)	PDF01	10-0282(White)
b3	2	Strut and Yoke Assembly	ASTM A36 Steel Galvanized	--	090453-8
b4	2	BCT Cable Anchor Assembly	3/4"Dia. [19] 6x19 IWRC IPS Galvanized Wire Rope	FCA01-02	10-0142-3
b5	2	Anchor Bracket Assembly	ASTM A36 Steel	FPA01	090453-10
b6	2	8"x8"x5/8" [203x203x15.9] Anchor Bearing Plate	ASTM A36 Steel	FPB01	090453-9
b7	2	2 3/8" [60] O.D.x 6" [152] long BCT Post Sleeve	ASTM A53 Grade B Schedule 40	FMM02	09-0458
b8	112	5/8"Dia. X 1 1/2" [M16 x 38] long Guardrail Bolt and Nut	ASTM A307 Steel	FBB01	090453-1/09-0452
b9	4	5/8"Dia. X 10" [M16 x 254] long Guardrail Bolt and Nut	ASTM A307 Steel	FBB03	090453-2/100144-3
b10	25	5/8"Dia. X 14" [M16 x 356] long Guardrail Bolt and Nut	ASTM A307 Steel	FBB06	090453-3/100144-3
b11	16	5/8"Dia. X 1 1/2" [M16 x 38] long Hex Head Bolt and Nut	ASTM A307 Steel	FBX16a	100144-1/100144-3
b12	4	5/8"Dia. X 10" [M16 x 254] long Hex Head Bolt and Nut	ASTM A307 Steel	FBX16a	090543-11/09-0452
b13	44	5/8"Dia. [15.9] Flat Washer	ASTM F436 Grade 1	FWC14a	090453-15
b14	4	3/4"Dia. X 7 1/2" [M20 x 191] long Hex Head Bolt and Nut	ASTM A325 Steel	FBX22a	100259-3/100259-1
b15	8	3/4"Dia. [19.1] Flat Washer	ASTM F436 Grade 1	FWC22a	100259-2
		Soil			5052010



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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.

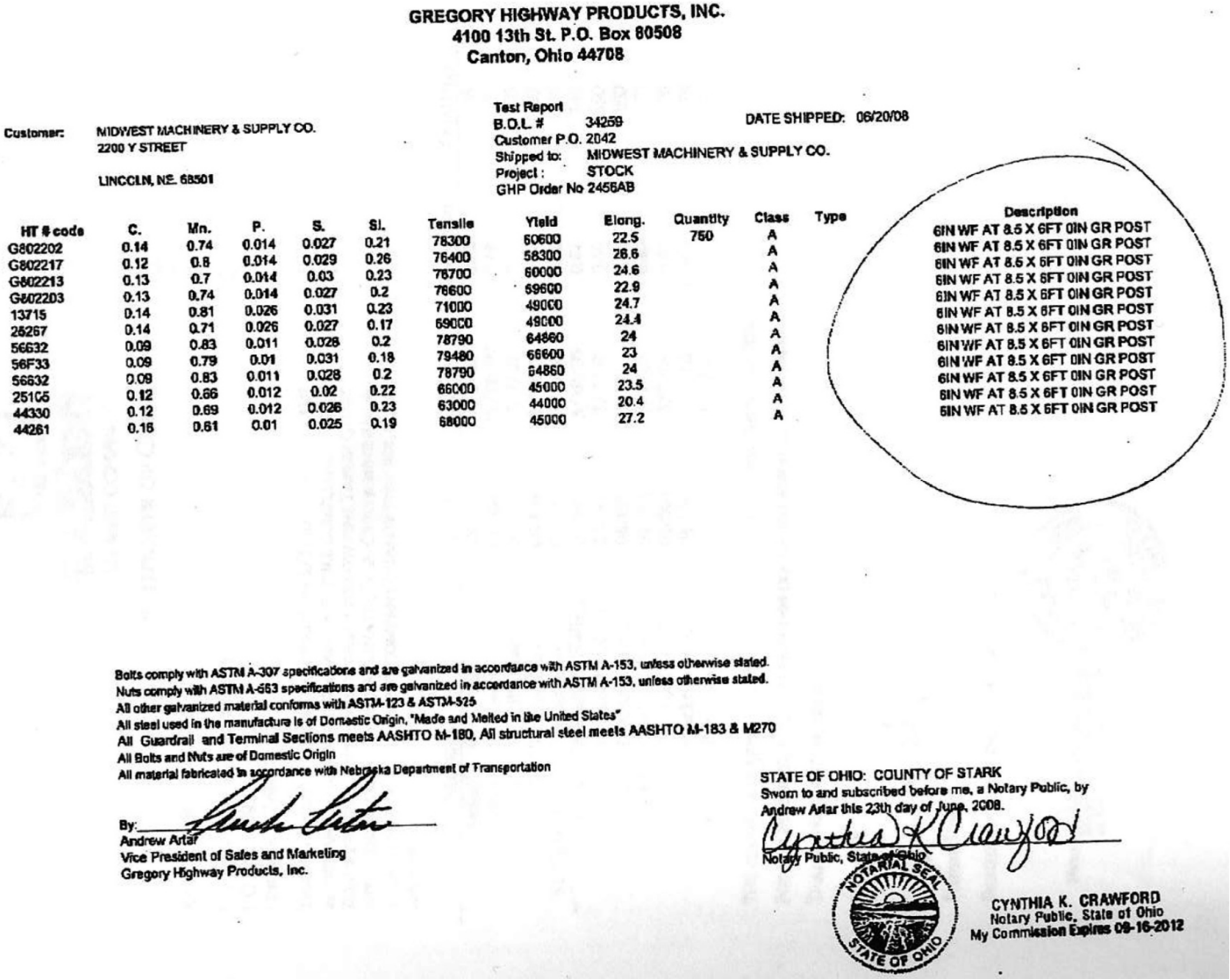
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of T[illegible] 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:
Quality Assurance

Figure A-1. W6x8.5 (W152x12.6) Steel Post Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



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

Customer: MIDWEST MACHINERY & SUPPLY CO.
2200 Y STREET

LINCCLN, NE. 68501

Test Report
B.O.L. # 34259
Customer P.O. 2042
Shipped to: MIDWEST MACHINERY & SUPPLY CO.
Project : STOCK
GHP Order No 2456AB

DATE SHIPPED: 06/20/08

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
G802202	0.14	0.74	0.014	0.027	0.21	78300	60600	22.5	750	A		6IN WF AT 8.5 X 6FT 0IN GR POST
G802217	0.12	0.8	0.014	0.029	0.26	76400	58300	28.6		A		6IN WF AT 8.5 X 6FT 0IN GR POST
G802213	0.13	0.7	0.014	0.03	0.23	78700	60000	24.6		A		6IN WF AT 8.5 X 6FT 0IN GR POST
G802203	0.13	0.74	0.014	0.027	0.2	78600	69600	22.9		A		6IN WF AT 8.5 X 6FT 0IN GR POST
13715	0.14	0.81	0.026	0.031	0.23	71000	49000	24.7		A		6IN WF AT 8.5 X 6FT 0IN GR POST
28267	0.14	0.71	0.026	0.027	0.17	69000	49000	24.4		A		6IN WF AT 8.5 X 6FT 0IN GR POST
56632	0.09	0.83	0.011	0.028	0.2	78790	64860	24		A		6IN WF AT 8.5 X 6FT 0IN GR POST
56F33	0.09	0.79	0.01	0.031	0.18	79480	66600	23		A		6IN WF AT 8.5 X 6FT 0IN GR POST
56632	0.09	0.83	0.011	0.028	0.2	78790	64860	24		A		6IN WF AT 8.5 X 6FT 0IN GR POST
25105	0.12	0.66	0.012	0.02	0.22	66000	45000	23.5		A		6IN WF AT 8.5 X 6FT 0IN GR POST
44330	0.12	0.69	0.012	0.026	0.23	63000	44000	20.4		A		6IN WF AT 8.5 X 6FT 0IN GR POST
44261	0.16	0.61	0.01	0.025	0.19	68000	45000	27.2		A		6IN WF AT 8.5 X 6FT 0IN GR POST

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
All material fabricated in accordance with Nebraska Department of Transportation

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

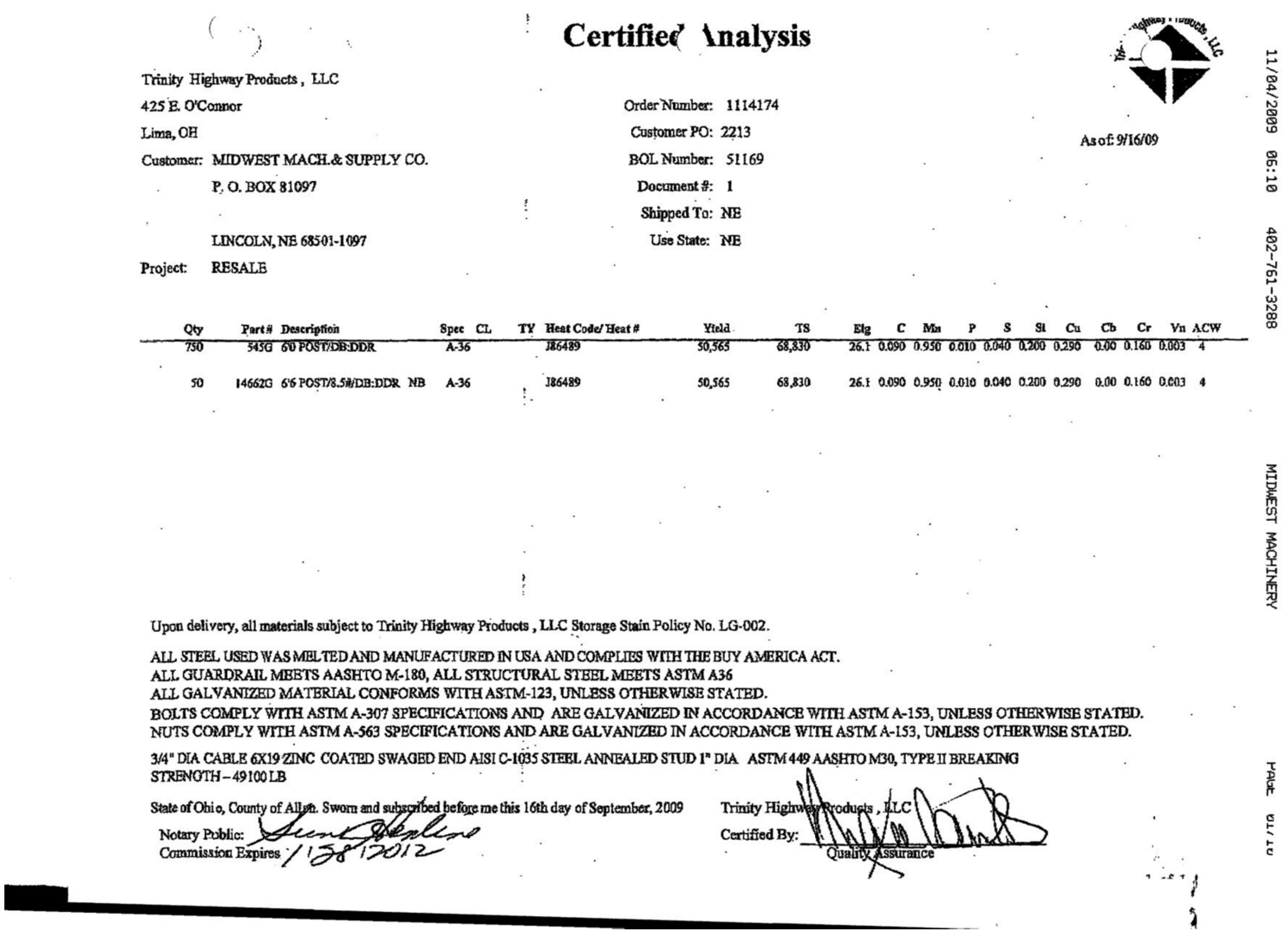
STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 23th day of June, 2008.

Cynthia K Crawford

Notary Public, State of Ohio

CYNTHIA K. CRAWFORD
Notary Public, State of Ohio
My Commission Expires 09-16-2012

Figure A-2. W6x8.5 (W152x12.6) Steel Post Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



11/04/2009 06:10 402-761-3288 MIDWEST MACHINERY PAGE 01/10

Certified Analysis

Trinity Highway Products, LLC
425 E. O'Connor
Lima, OH
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097
Project: RESALE

Order Number: 1114174
Customer PO: 2213
BOL Number: 51169
Document #: 1
Shipped To: NE
Use State: NE

As of: 9/16/09

Qty	Part#	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
750	545G	6'0 POST/DB:DDR	A-36			J86489	50,565	68,830	26.1	0.090	0.950	0.010	0.040	0.200	0.290	0.00	0.160	0.003	4
50	14662G	6'6 POST/8.5#/DB:DDR NB	A-36			J86489	50,565	68,830	26.1	0.090	0.950	0.010	0.040	0.200	0.290	0.00	0.160	0.003	4

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

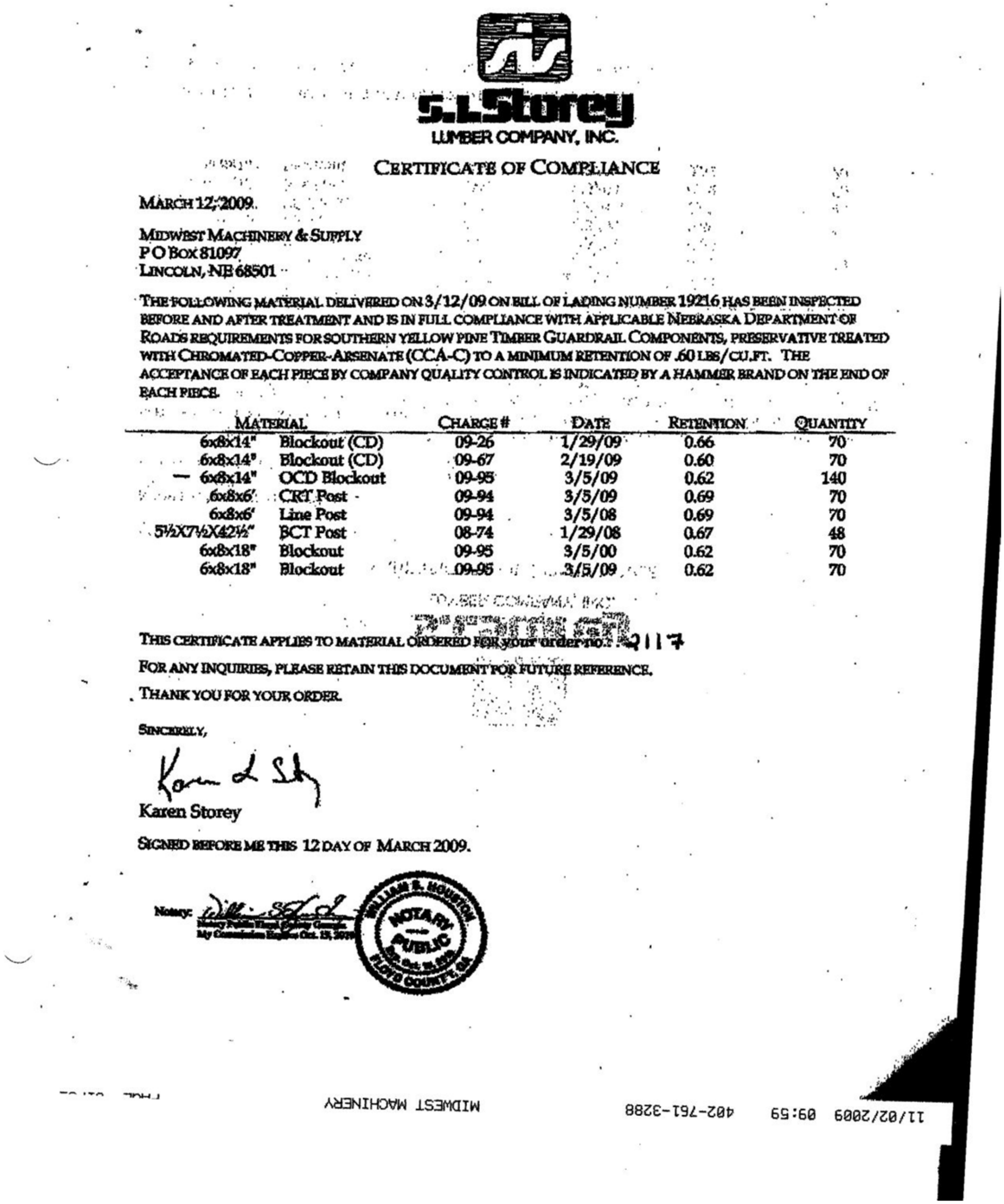
ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE 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 Ohio, County of Allen. Sworn and subscribed before me this 16th day of September, 2009
Notary Public:
Commission Expires 1/28/2012

Trinity Highway Products, LLC
Certified By:
Quality Assurance

Figure A-3. W6x8.5 (W152x12.6) Steel Post Material Specifications, Test No. MGSMRH-2



S.L.Storey
LUMBER COMPANY, INC.

CERTIFICATE OF COMPLIANCE

MARCH 12, 2009.

MIDWEST MACHINERY & SUPPLY
P O BOX 81097
LINCOLN, NE 68501

THE FOLLOWING MATERIAL DELIVERED ON 3/12/09 ON BILL OF LADING NUMBER 19216 HAS BEEN INSPECTED BEFORE AND AFTER TREATMENT AND IS IN FULL COMPLIANCE WITH APPLICABLE NEBRASKA DEPARTMENT OF ROADS REQUIREMENTS FOR SOUTHERN YELLOW PINE TIMBER GUARDRAIL COMPONENTS, PRESERVATIVE TREATED WITH CHROMATED-COPPER-ARSENATE (CCA-C) TO A MINIMUM RETENTION OF .60 LBS/CU.FT. THE ACCEPTANCE OF EACH PIECE BY COMPANY QUALITY CONTROL IS INDICATED BY A HAMMER BRAND ON THE END OF EACH PIECE.

MATERIAL		CHARGE #	DATE	RETENTION	QUANTITY
6x8x14"	Blockout (CD)	09-26	1/29/09	0.66	70
6x8x14"	Blockout (CD)	09-67	2/19/09	0.60	70
— 6x8x14"	OCD Blockout	09-95	3/5/09	0.62	140
6x8x6'	CRT Post	09-94	3/5/09	0.69	70
6x8x6'	Line Post	09-94	3/5/08	0.69	70
5½X7½X42½"	BCT Post	08-74	1/29/08	0.67	48
6x8x18"	Blockout	09-95	3/5/00	0.62	70
6x8x18"	Blockout	09-95	3/5/09	0.62	70

THIS CERTIFICATE APPLIES TO MATERIAL ORDERED FOR your order no.: 2117

FOR ANY INQUIRIES, PLEASE RETAIN THIS DOCUMENT FOR FUTURE REFERENCE.

THANK YOU FOR YOUR ORDER.

SINCERELY,

Karen L Storey

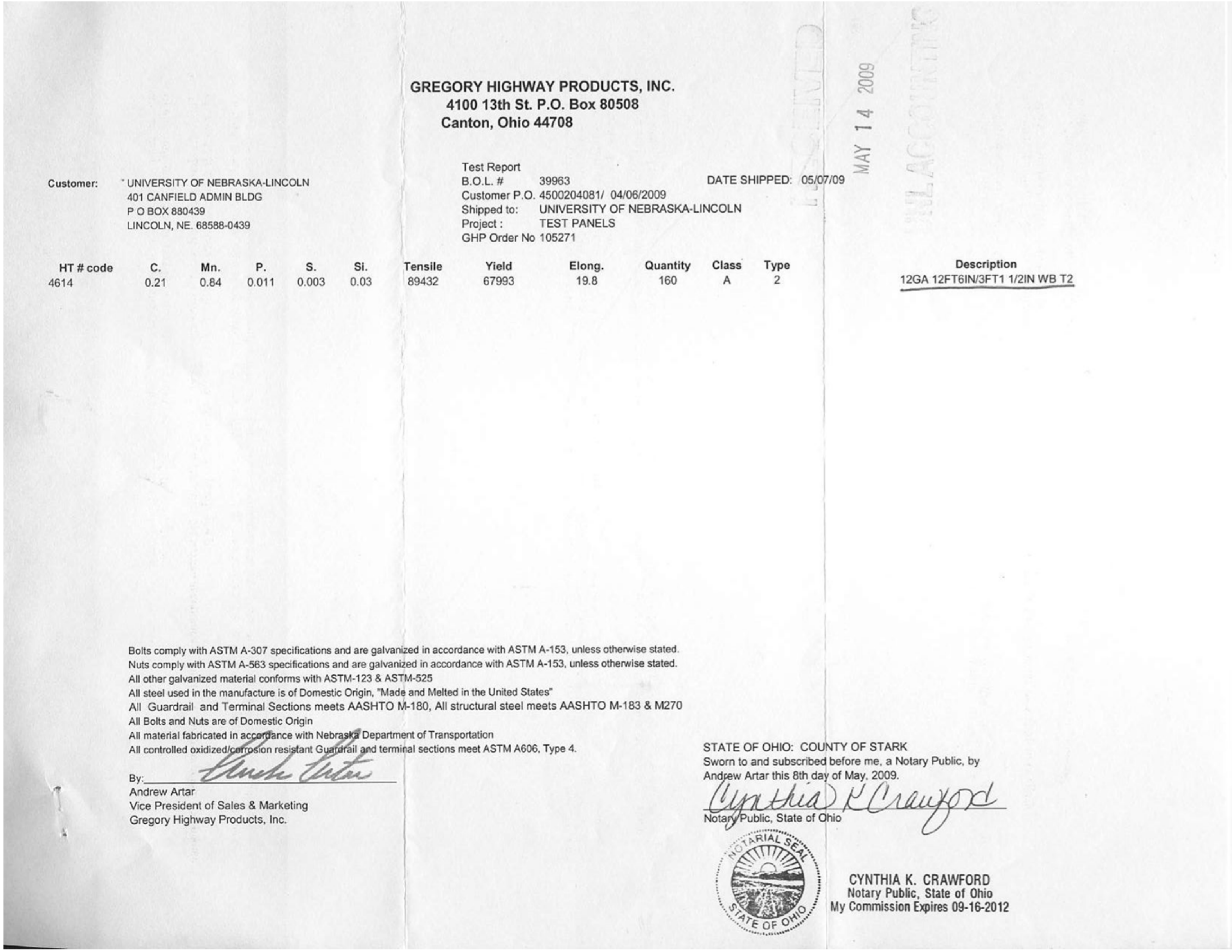
Karen Storey

SIGNED BEFORE ME THIS 12 DAY OF MARCH 2009.

Notary: William S. Houston

WILLIAM S. HOUSTON
NOTARY PUBLIC
FLOYD COUNTY, GA

Figure A-4. Wood Blockout Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



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

Test Report
B.O.L. # 39963 DATE SHIPPED: 05/07/09
Customer P.O. 4500204081/ 04/06/2009
Shipped to: UNIVERSITY OF NEBRASKA-LINCOLN
Project : TEST PANELS
GHP Order No 105271

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

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
4614	0.21	0.84	0.011	0.003	0.03	89432	67993	19.8	160	A	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
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

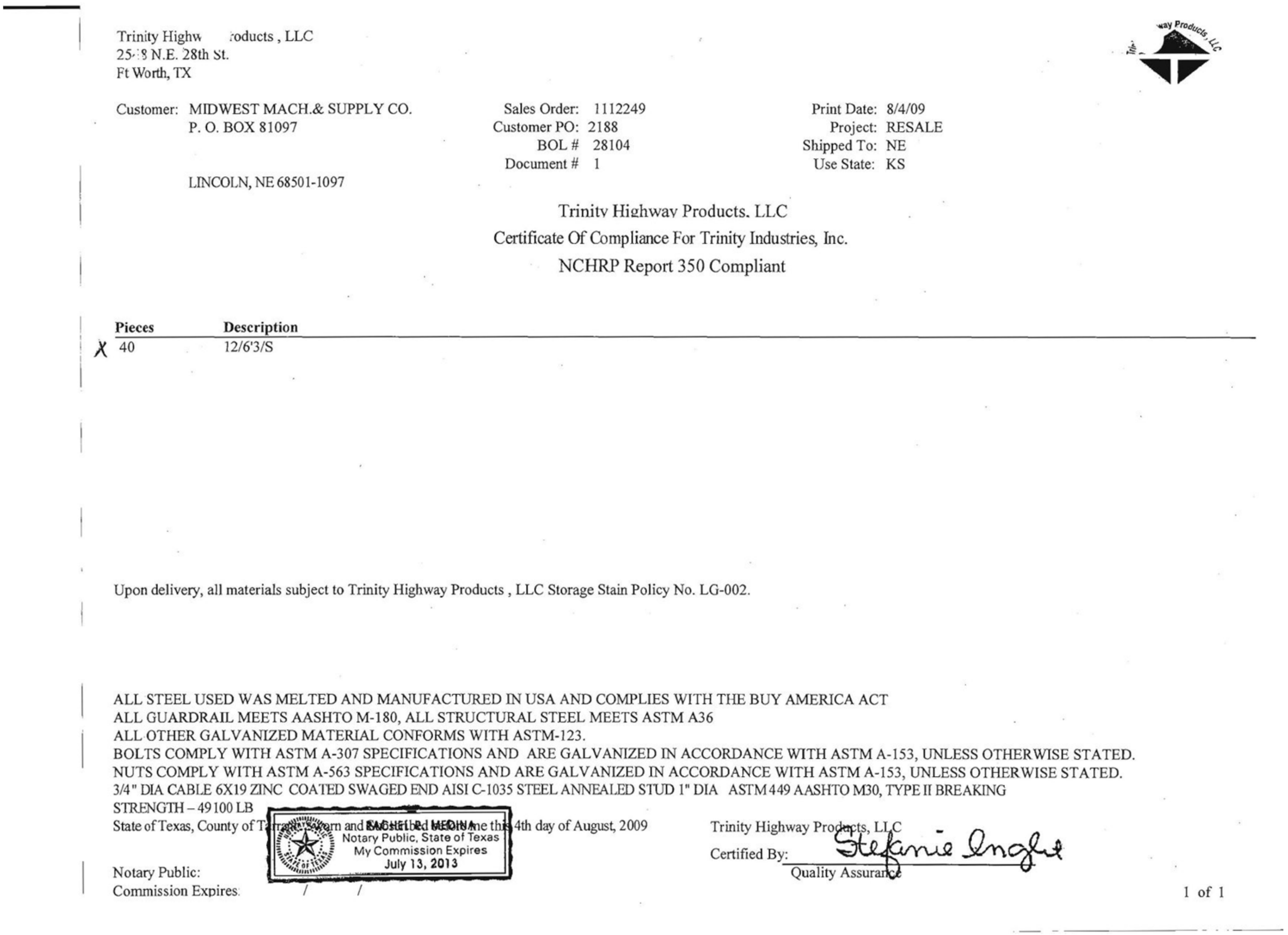
By: Andrew Artar
Andrew Artar
Vice President of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 8th day of May, 2009.

Cynthia K Crawford
Notary Public, State of Ohio

CYNTHIA K. CRAWFORD
Notary Public, State of Ohio
My Commission Expires 09-16-2012

Figure A-5. 12-ft 6-in. (3.8-m) Long W-Beam Section Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



Trinity Highw roducts , LLC
25 8 N.E. 28th St.
Ft Worth, TX

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

LINCOLN, NE 68501-1097

Sales Order: 1112249
Customer PO: 2188
BOL # 28104
Document # 1

Print Date: 8/4/09
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products, LLC
Certificate Of Compliance For Trinity Industries, Inc.
NCHRP Report 350 Compliant

	Pieces	**Description**
X	40	12/6'3/S

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 OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
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 4th day of August, 2009

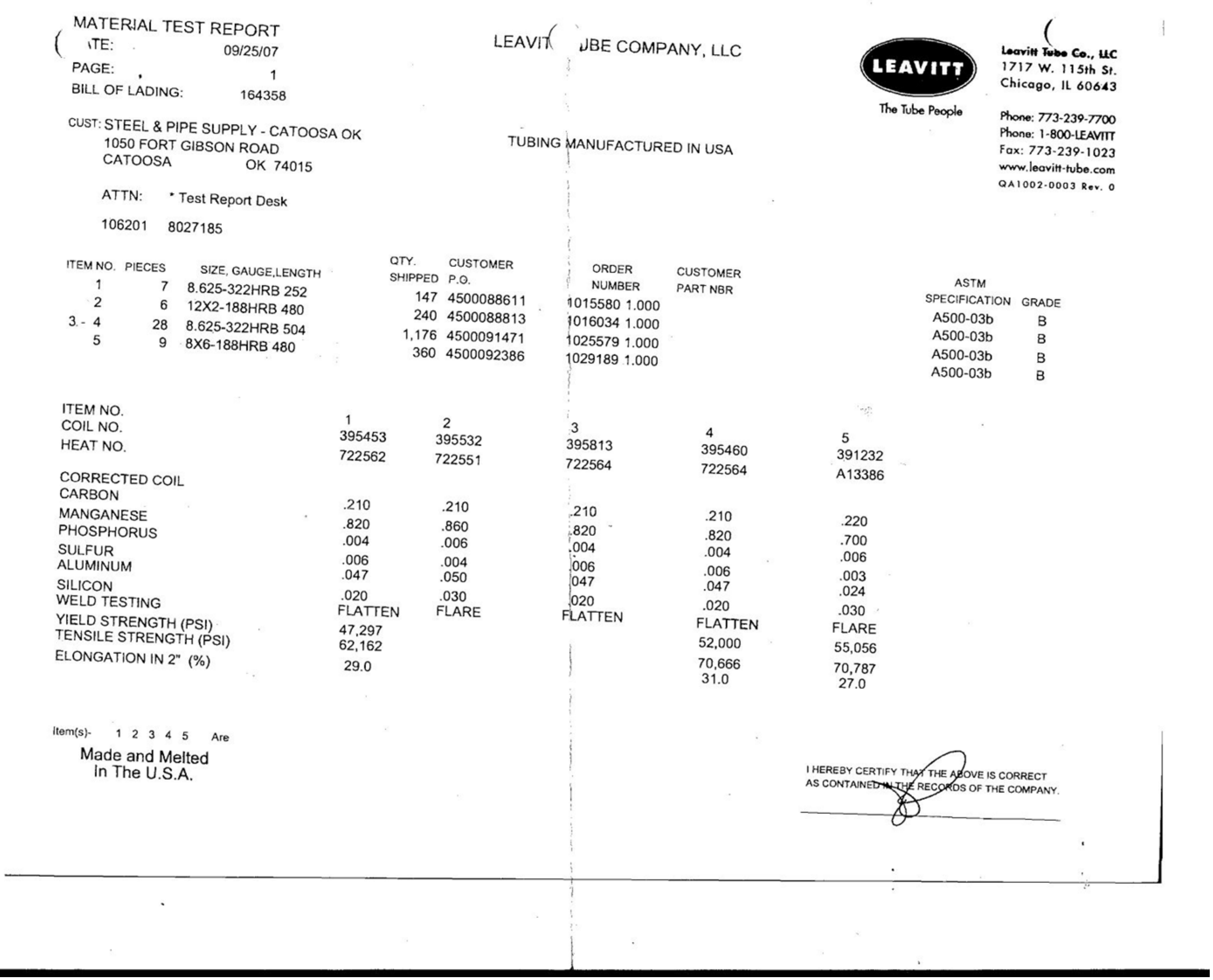
RACHEL P. MEDINA
Notary Public, State of Texas
My Commission Expires
July 13, 2013

Notary Public:
Commission Expires: / /

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

1 of 1

Figure A-6. 75-in. (1,905-mm) Long W-Beam Section Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



MATERIAL TEST REPORT
ATE: 09/25/07
PAGE: 1
BILL OF LADING: 164358

LEAVIT UBE COMPANY, LLC

LEAVITT
The Tube People

Leavitt Tube Co., LLC
1717 W. 115th St.
Chicago, IL 60643

Phone: 773-239-7700
Phone: 1-800-LEAVITT
Fax: 773-239-1023
www.leavitt-tube.com
QA1002-0003 Rev. 0

CUST: STEEL & PIPE SUPPLY - CATOOSA OK
1050 FORT GIBSON ROAD
CATOOSA OK 74015

TUBING MANUFACTURED IN USA

ATTN: * Test Report Desk

106201 8027185

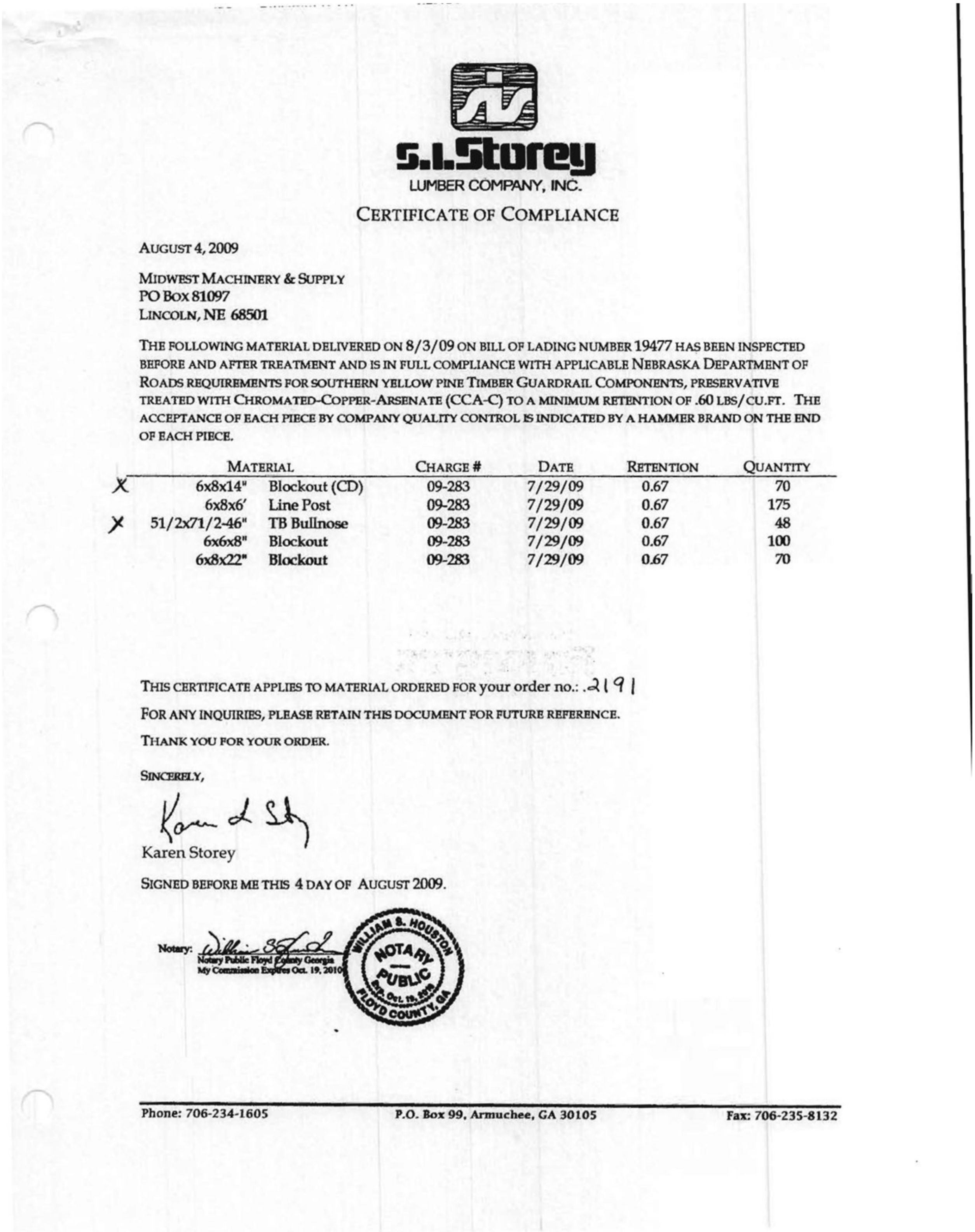
ITEM NO.	PIECES	SIZE, GAUGE,LENGTH	QTY. SHIPPED	CUSTOMER P.O.	ORDER NUMBER	CUSTOMER PART NBR	ASTM SPECIFICATION	GRADE
1	7	8.625-322HRB 252	147	4500088611	1015580 1.000		A500-03b	B
2	6	12X2-188HRB 480	240	4500088813	1016034 1.000		A500-03b	B
3.- 4	28	8.625-322HRB 504	1,176	4500091471	1025579 1.000		A500-03b	B
5	9	8X6-188HRB 480	360	4500092386	1029189 1.000		A500-03b	B

ITEM NO.	1	2	3	4	5
COIL NO.	395453	395532	395813	395460	391232
HEAT NO.	722562	722551	722564	722564	A13386
CORRECTED COIL					
CARBON	.210	.210	.210	.210	.220
MANGANESE	.820	.860	.820	.820	.700
PHOSPHORUS	.004	.006	.004	.004	.006
SULFUR	.006	.004	006	.006	.003
ALUMINUM	.047	.050	047	.047	.024
SILICON	.020	.030	020	.020	.030
WELD TESTING	FLATTEN	FLARE	FLATTEN	FLATTEN	FLARE
YIELD STRENGTH (PSI)	47,297			52,000	55,056
TENSILE STRENGTH (PSI)	62,162			70,666	70,787
ELONGATION IN 2" (%)	29.0			31.0	27.0

Item(s)- 1 2 3 4 5 Are
Made and Melted
In The U.S.A.

I HEREBY CERTIFY THAT THE ABOVE IS CORRECT
AS CONTAINED IN THE RECORDS OF THE COMPANY.

Figure A-7. BCT Anchor Foundation Tube Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



S.I. Storey
LUMBER COMPANY, INC.

CERTIFICATE OF COMPLIANCE

AUGUST 4, 2009

MIDWEST MACHINERY & SUPPLY
PO BOX 81097
LINCOLN, NE 68501

THE FOLLOWING MATERIAL DELIVERED ON 8/3/09 ON BILL OF LADING NUMBER 19477 HAS BEEN INSPECTED BEFORE AND AFTER TREATMENT AND IS IN FULL COMPLIANCE WITH APPLICABLE NEBRASKA DEPARTMENT OF ROADS REQUIREMENTS FOR SOUTHERN YELLOW PINE TIMBER GUARDRAIL COMPONENTS, PRESERVATIVE TREATED WITH CHROMATED-COPPER-ARSENATE (CCA-C) TO A MINIMUM RETENTION OF .60 LBS/CU.FT. THE ACCEPTANCE OF EACH PIECE BY COMPANY QUALITY CONTROL IS INDICATED BY A HAMMER BRAND ON THE END OF EACH PIECE.

	MATERIAL		CHARGE #	DATE	RETENTION	QUANTITY
X	6x8x14"	Blockout (CD)	09-283	7/29/09	0.67	70
	6x8x6'	Line Post	09-283	7/29/09	0.67	175
X	51/2x71/2-46"	TB Bullnose	09-283	7/29/09	0.67	48
	6x6x8"	Blockout	09-283	7/29/09	0.67	100
	6x8x22"	Blockout	09-283	7/29/09	0.67	70

THIS CERTIFICATE APPLIES TO MATERIAL ORDERED FOR your order no.: .2191

FOR ANY INQUIRIES, PLEASE RETAIN THIS DOCUMENT FOR FUTURE REFERENCE.

THANK YOU FOR YOUR ORDER.

SINCERELY,

Karen Storey

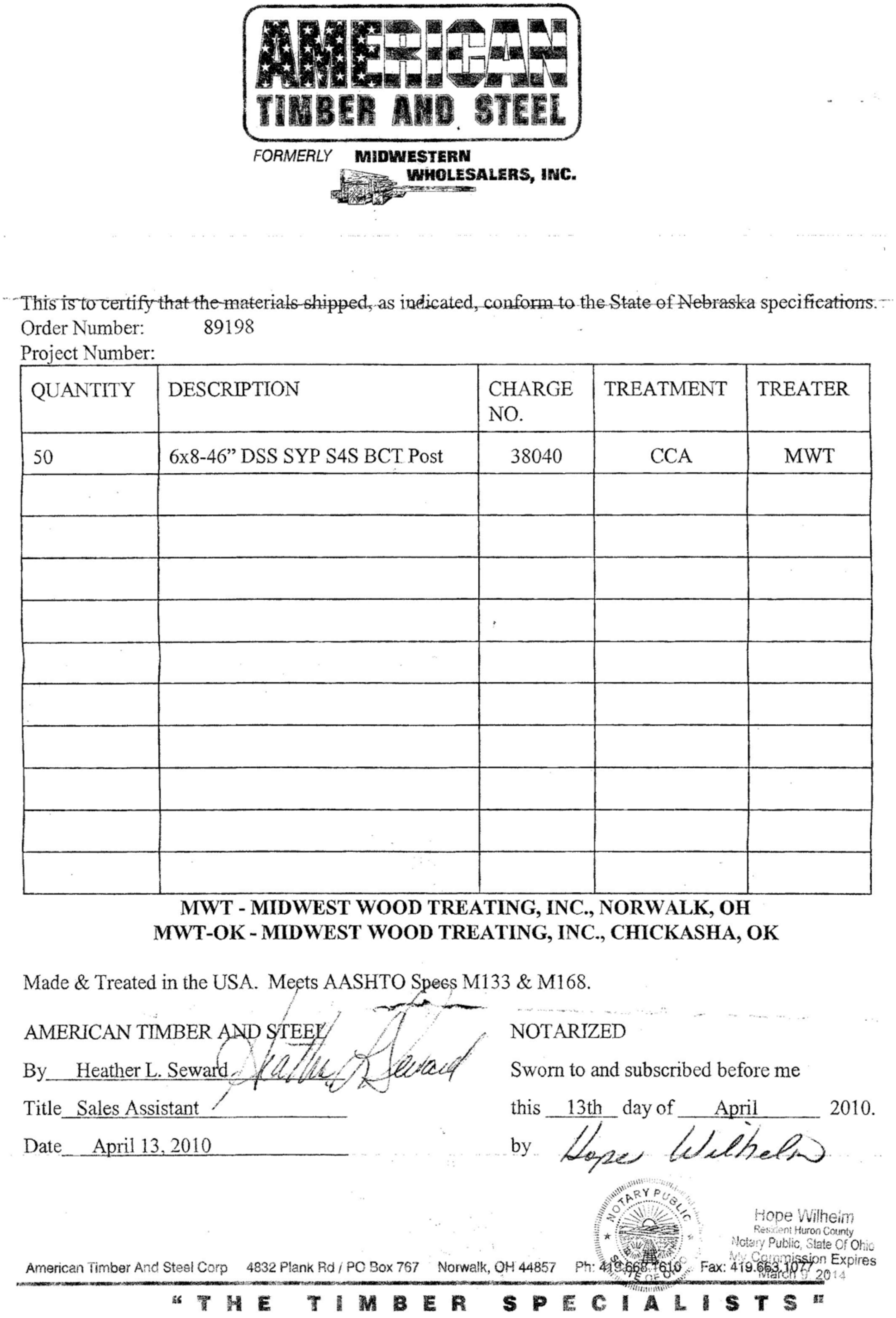
SIGNED BEFORE ME THIS 4 DAY OF AUGUST 2009.

Notary:
Notary Public Floyd County Georgia
My Commission Expires Oct. 19, 2010

William S. Houston
Exp. Oct. 19, 2010

Phone: 706-234-1605 P.O. Box 99, Armuchee, GA 30105 Fax: 706-235-8132

Figure A-8. BCT Anchor Timber Post Material Specifications, Test No. MGSMRH-1



AMERICAN TIMBER AND STEEL

FORMERLY **MIDWESTERN WHOLESALERS, INC.**

This is to certify that the materials shipped, as indicated, conform to the State of Nebraska specifications.

Order Number: 89198

Project Number:

QUANTITY	DESCRIPTION	CHARGE NO.	TREATMENT	TREATER
50	6x8-46" DSS SYP S4S BCT Post	38040	CCA	MWT

MWT - MIDWEST WOOD TREATING, INC., NORWALK, OH
MWT-OK - MIDWEST WOOD TREATING, INC., CHICKASHA, OK

Made & Treated in the USA. Meets AASHTO Specs M133 & M168.

AMERICAN TIMBER AND STEEL
By Heather L. Seward Heather L Seward
Title Sales Assistant
Date April 13, 2010

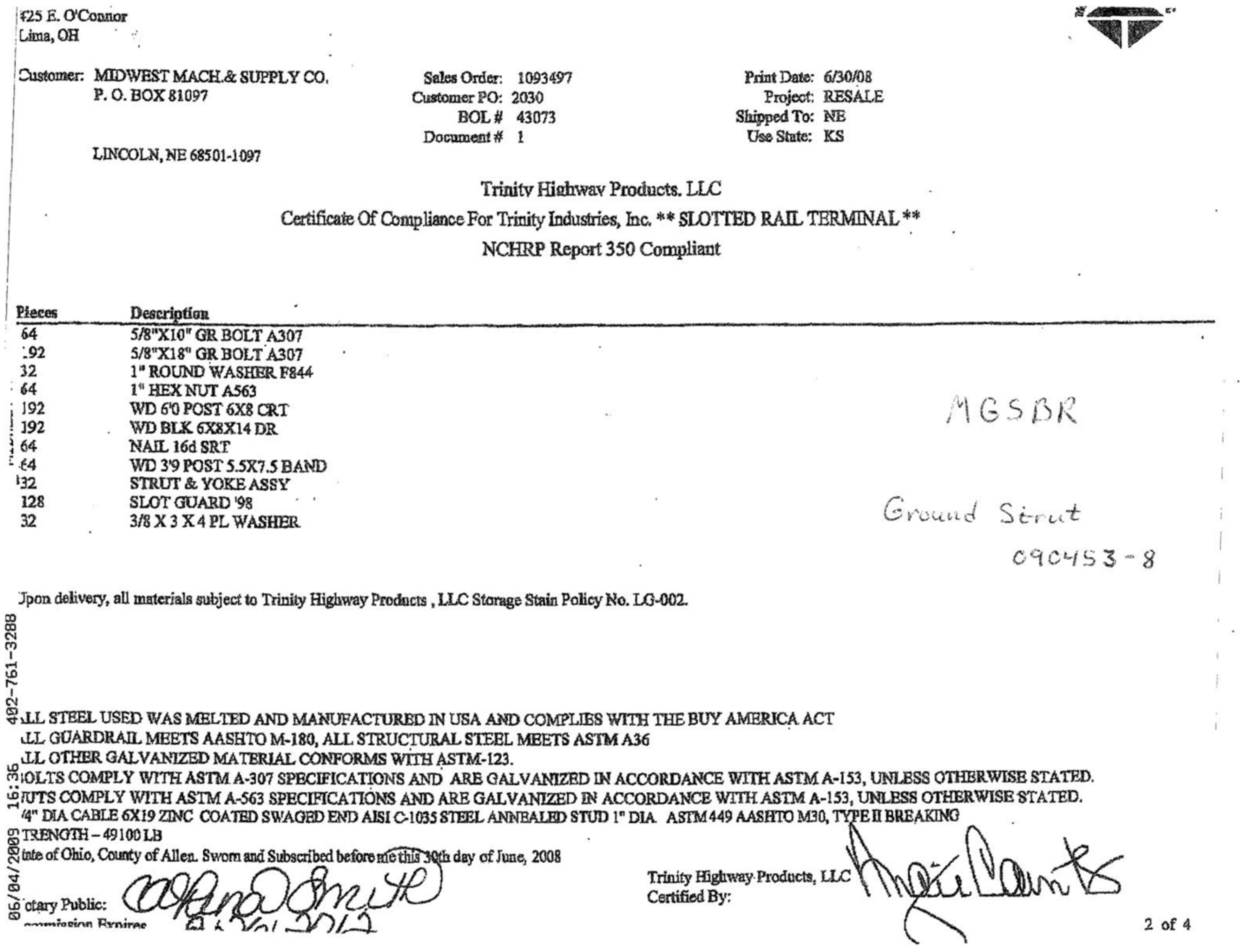
NOTARIZED
Sworn to and subscribed before me
this 13th day of April 2010.
by Hope Wilhelm

Hope Wilheim
Resident Huron County
Notary Public, State Of Ohio
My Commission Expires
March 9, 2014

American Timber And Steel Corp 4832 Plank Rd / PO Box 767 Norwalk, OH 44857 Ph: 419.668.7610 Fax: 419.663.1077

"THE TIMBER SPECIALISTS"

Figure A-9. BCT Anchor Timber Post Material Specifications, Test No. MGSMRH-2



425 E. O'Connor
Lima, OH

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

LINCOLN, NE 68501-1097

Sales Order: 1093497
Customer PO: 2030
BOL # 43073
Document # 1

Print Date: 6/30/08
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products. LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

Pieces	Description
64	5/8"X10" GR BOLT A307
192	5/8"X18" GR BOLT A307
32	1" ROUND WASHER F844
64	1" HEX NUT A563
192	WD 6'0 POST 6X8 CRT
192	WD BLK 6X8X14 DR
64	NAIL 16d SRT
64	WD 3'9 POST 5.5X7.5 BAND
32	STRUT & YOKE ASSY
128	SLOT GUARD '98
32	3/8 X 3 X 4 PL WASHER

MGSBR

Ground Strut
090453-8

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

05/04/2009 16:36 402-761-3288

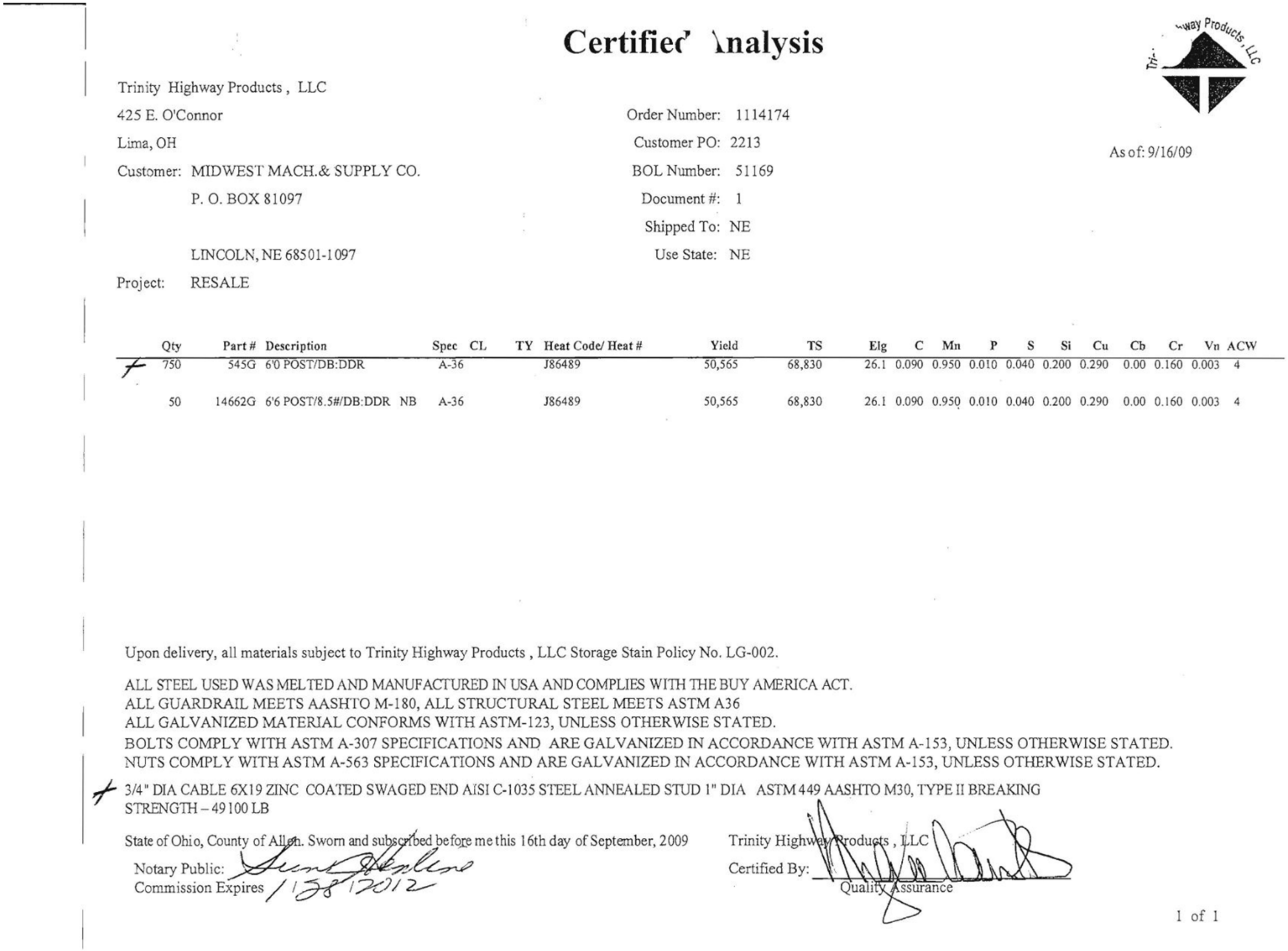
LL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
LL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
LL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
OLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
UTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING
TRENGTH – 49100 LB
tate of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

otary Public: Alana Smith
ommission Expires

Trinity Highway Products, LLC
Certified By:

2 of 4

Figure A-10. BCT Anchor Groundline Strut and Yoke Assembly Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



Certified Analysis

Trinity Highway Products , LLC
425 E. O'Connor
Lima, OH
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097
Project: RESALE

Order Number: 1114174
Customer PO: 2213
BOL Number: 51169
Document #: 1
Shipped To: NE
Use State: NE

As of: 9/16/09

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
750	545G	6'0 POST/DB:DDR	A-36			J86489	50,565	68,830	26.1	0.090	0.950	0.010	0.040	0.200	0.290	0.00	0.160	0.003	4
50	14662G	6'6 POST/8.5#/DB:DDR NB	A-36			J86489	50,565	68,830	26.1	0.090	0.950	0.010	0.040	0.200	0.290	0.00	0.160	0.003	4

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.

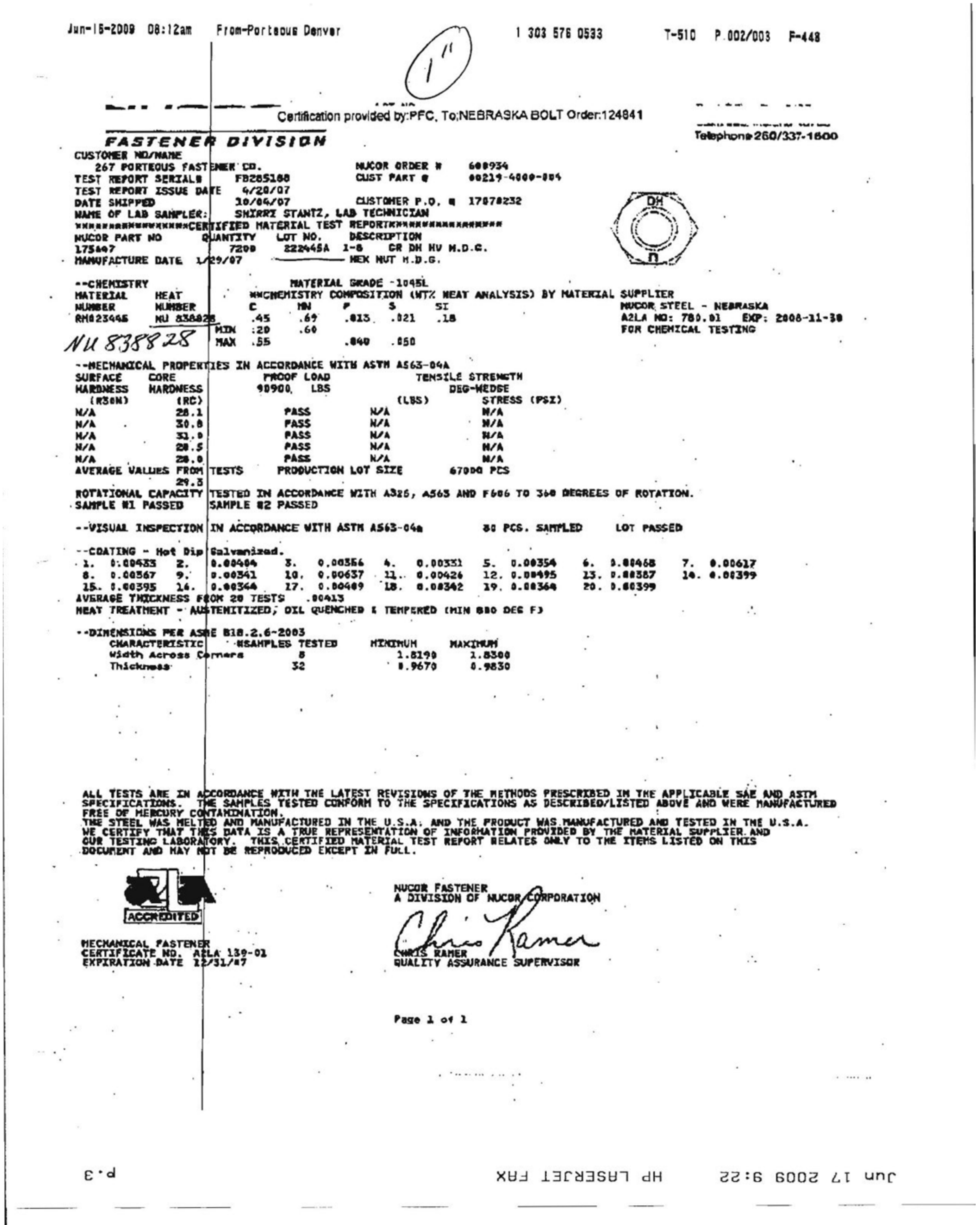
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Ohio, County of Allen. Sworn and subscribed before me this 16th day of September, 2009
Notary Public:
Commission Expires 1/28/2012

Trinity Highway Products , LLC
Certified By:
Quality Assurance

1 of 1

Figure A-11. BCT Cable Anchor Assembly Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



Jun-16-2009 08:12am From-Porteous Denver 1 303 576 0533 T-510 P.002/003 F-448

1"

Certification provided by:PFC, To;NEBRASKA BOLT Order:124841

Telephone 260/337-1600

FASTENER DIVISION

CUSTOMER NO/NAME
267 PORTEOUS FASTENER CO.
TEST REPORT SERIAL# FB285180
TEST REPORT ISSUE DATE 4/20/07
DATE SHIPPED 10/04/07
NAME OF LAB SAMPLER: SHIRRI STANTZ, LAB TECHNICIAN

NUCOR ORDER # 600934
CUST PART # 00219-4000-004
CUSTOMER P.O. # 17078232

******************CERTIFIED MATERIAL TEST REPORT******************

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175007	7200	222445A 1-8	CR DH HV H.D.G.

MANUFACTURE DATE 1/29/07 ——— HEX NUT H.D.G.

--CHEMISTRY

MATERIAL GRADE -1045L

**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER

MATERIAL NUMBER	HEAT NUMBER		C	MN	P	S	SI
RM023446	NU 838828		.45	.69	.013	.021	.18
		MIN	:20	.60			
		MAX	.55		.040	.050	

NU 838828

NUCOR STEEL - NEBRASKA
A2LA NO: 780.01 EXP: 2008-11-30
FOR CHEMICAL TESTING

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-04A

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 90900 LBS	TENSILE STRENGTH DEG-WEDGE (LBS)	STRESS (PSI)
N/A	28.1	PASS	N/A	N/A
N/A	30.0	PASS	N/A	N/A
N/A	31.0	PASS	N/A	N/A
N/A	28.5	PASS	N/A	N/A
N/A	28.0	PASS	N/A	N/A

AVERAGE VALUES FROM TESTS PRODUCTION LOT SIZE 67000 PCS
29.3

ROTATIONAL CAPACITY TESTED IN ACCORDANCE WITH A325, A563 AND F606 TO 360 DEGREES OF ROTATION.
SAMPLE #1 PASSED SAMPLE #2 PASSED

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-04a 80 PCS. SAMPLED LOT PASSED

--COATING - Hot Dip Galvanized.

1. 0.00433	2. 0.00404	3. 0.00366	4. 0.00331	5. 0.00354	6. 0.00468	7. 0.00617
8. 0.00367	9. 0.00341	10. 0.00637	11. 0.00426	12. 0.00495	13. 0.00387	14. 0.00399
15. 0.00395	16. 0.00344	17. 0.00409	18. 0.00342	19. 0.00364	20. 0.00399	

AVERAGE THICKNESS FROM 20 TESTS .00413
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2003

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.8190	1.8300
Thickness	32	0.9670	0.9830

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A.
WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

A2LA
ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 139-01
EXPIRATION DATE 12/31/07

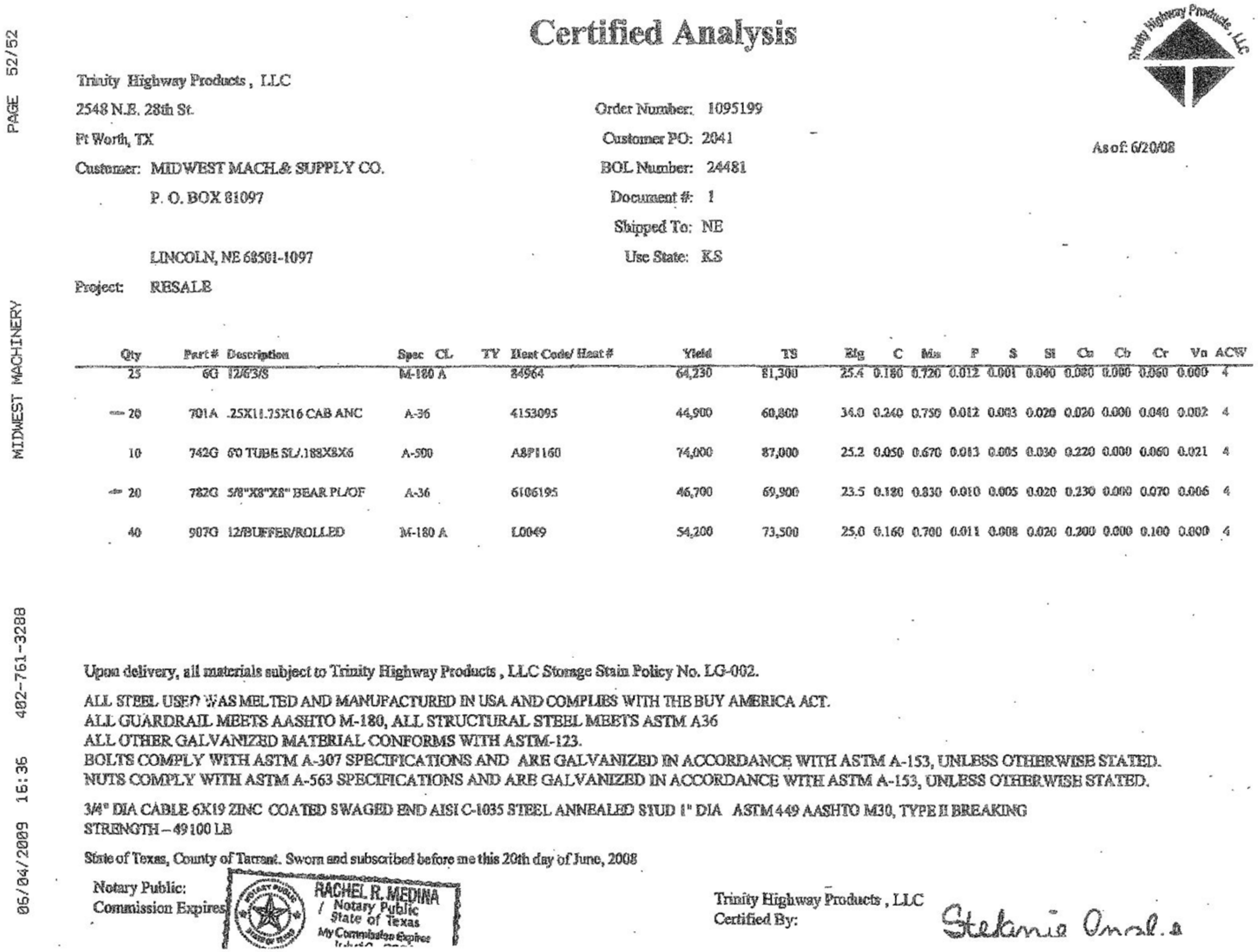
NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

Chris Ramer
CHRIS RAMER
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

Jun 17 2009 9:22 HP LASERJET FAX p.3

Figure A-12. BCT Cable Anchor Assembly Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



05/04/2009 16:36 402-761-3288 MIDWEST MACHINERY PAGE 52/52

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: 1095199
Customer PO: 2041
BOL Number: 24481
Document #: 1
Shipped To: NE
Use State: KS

As of: 6/20/08

Qty	Part#	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	6G	12/6'3/S	M-180	A		84964	64,230	81,300	25.4	0.180	0.720	0.012	0.001	0.040	0.080	0.000	0.060	0.000	4
20	701A	.25X11.75X16 CAB ANC	A-36			4153095	44,900	60,800	34.0	0.240	0.750	0.012	0.003	0.020	0.020	0.000	0.040	0.002	4
10	742G	6'0 TUBE SL/.188X8X6	A-500			A8P1160	74,000	87,000	25.2	0.050	0.670	0.013	0.005	0.030	0.220	0.000	0.060	0.021	4
20	782G	5/8"X8"X8" BEAR PL/OF	A-36			6106195	46,700	69,900	23.5	0.180	0.830	0.010	0.005	0.020	0.230	0.000	0.070	0.006	4
40	907G	12/BUFFER/ROLLED	M-180	A		L0049	54,200	73,500	25.0	0.160	0.700	0.011	0.008	0.020	0.200	0.000	0.100	0.000	4

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 OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
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 20th day of June, 2008

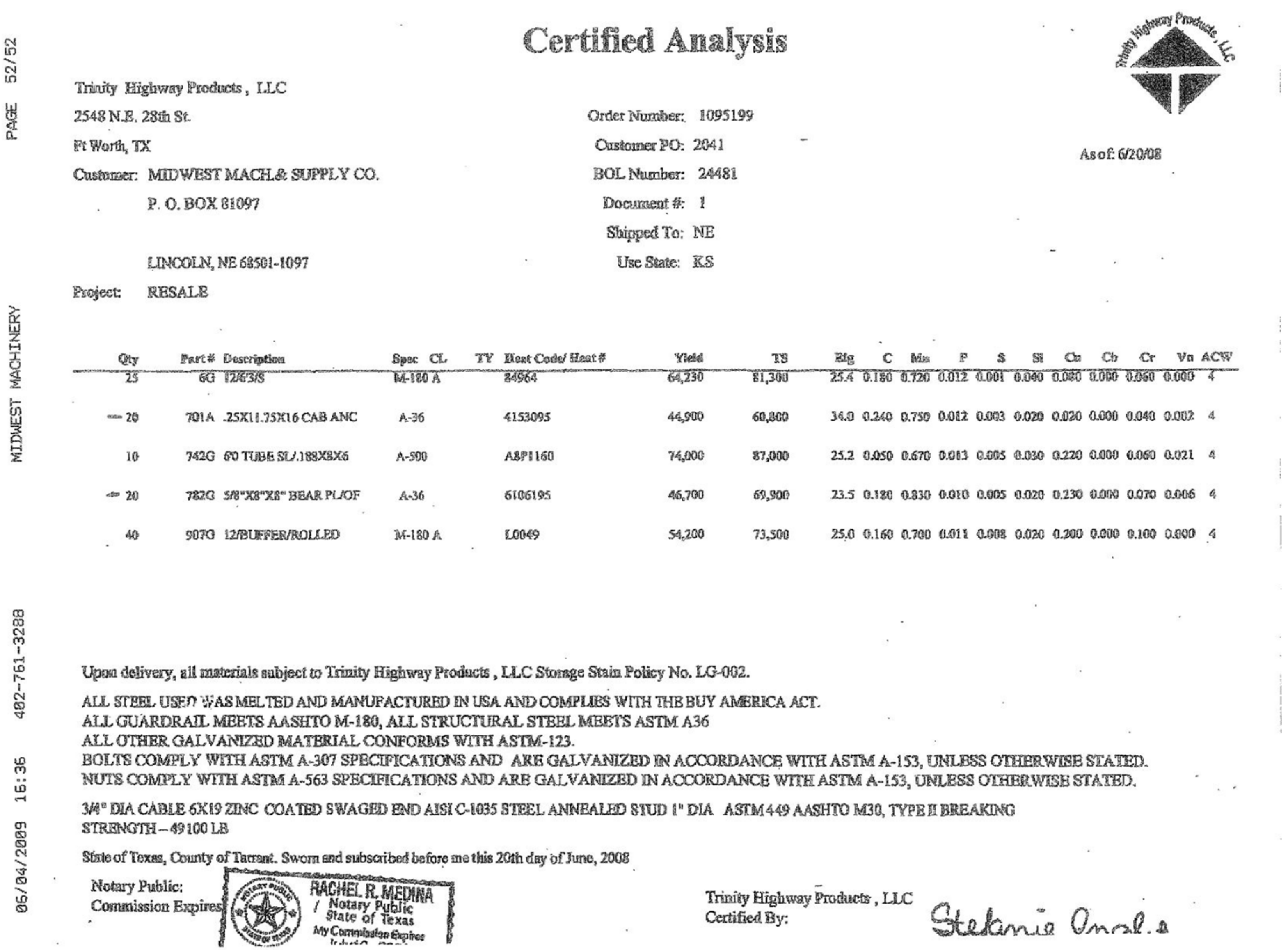
Notary Public:
Commission Expires

RACHEL R. MEDINA
Notary Public
State of Texas
My Commission Expires

Trinity Highway Products , LLC
Certified By:

Stefanie Onal.a

Figure A-13. BCT Anchor Bracket Assembly Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



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: 1095199
Customer PO: 2041
BOL Number: 24481
Document #: 1
Shipped To: NE
Use State: KS

As of: 6/20/08

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	6G	12/6'3/S	M-180	A		84964	64,230	81,300	25.4	0.180	0.720	0.012	0.001	0.040	0.080	0.000	0.060	0.000	4
20	701A	.25X11.75X16 CAB ANC	A-36			4153095	44,900	60,800	34.0	0.240	0.750	0.012	0.003	0.020	0.020	0.000	0.040	0.002	4
10	742G	6'0 TUBE SL/.188X8X6	A-500			A8P1160	74,000	87,000	25.2	0.050	0.670	0.013	0.005	0.030	0.220	0.000	0.060	0.021	4
20	782G	5/8"X8"X8" BEAR PL/OF	A-36			6106195	46,700	69,900	23.5	0.180	0.830	0.010	0.005	0.020	0.230	0.000	0.070	0.006	4
40	907G	12/BUFFER/ROLLED	M-180	A		L0049	54,200	73,500	25.0	0.160	0.700	0.011	0.008	0.020	0.200	0.000	0.100	0.000	4

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ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
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

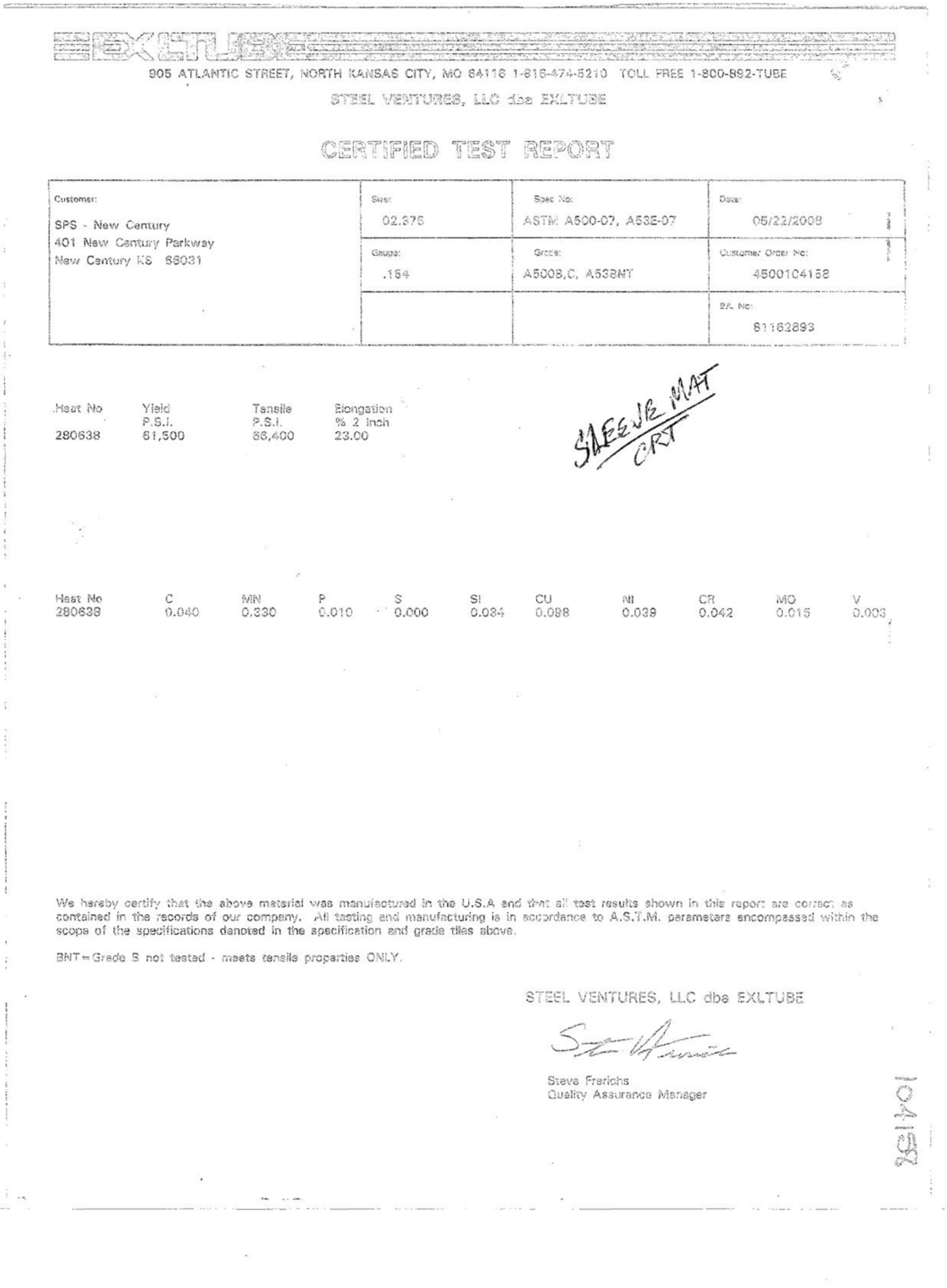
State of Texas, County of Tarrant. Sworn and subscribed before me this 20th day of June, 2008

Notary Public:
Commission Expires

RACHEL R. MEDINA
Notary Public
State of Texas
My Commission Expires

Trinity Highway Products , LLC
Certified By:

Figure A-14. BCT Anchor Bearing Plate Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



EXLTUBE

905 ATLANTIC STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

CERTIFIED TEST REPORT

Customer: SPS - New Century 401 New Century Parkway New Century KS 66031	Size: 02.375	Spec No: ASTM A500-07, A53E-07	Date: 05/22/2008
	Gauge: .154	Grade: A500B,C, A53BNT	Customer Order No: 4500104158
			B/L No: 81162893

Heat No	Yield P.S.I.	Tensile P.S.I.	Elongation % 2 inch
280638	61,500	66,400	23.00

SLEEVE MAT
CRT

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
280638	0.040	0.330	0.010	0.000	0.034	0.098	0.039	0.042	0.016	0.003

We hereby certify that the above material was manufactured in the U.S.A and that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade tiles above.

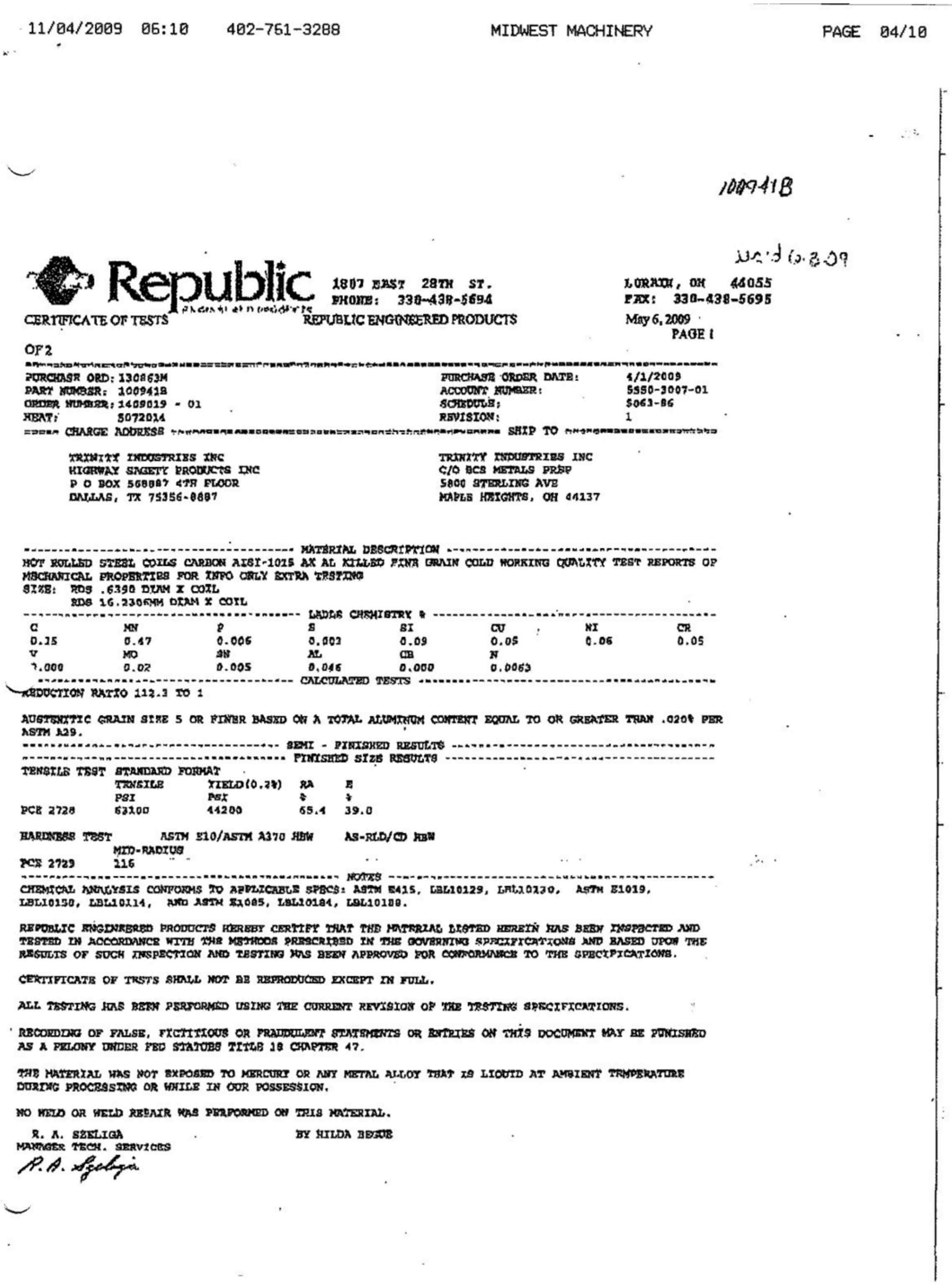
BNT=Grade B not tested - meets tensile properties ONLY.

STEEL VENTURES, LLC dba EXLTUBE

Steve Frerichs
Quality Assurance Manager

104158

Figure A-15. BCT Anchor Post Sleeve Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



11/04/2009 06:10 402-761-3288 MIDWEST MACHINERY PAGE 04/10

100941B

Rec'd 6.8.09

Republic
1807 EAST 28TH ST.
PHONE: 330-438-5694
LORAIN, OH 44055
FAX: 330-438-5695

CERTIFICATE OF TESTS
REPUBLIC ENGINEERED PRODUCTS
May 6, 2009
PAGE 1 OF 2

PURCHASE ORD: 130863M
PART NUMBER: 100941B
ORDER NUMBER: 1409019 - 01
HEAT: 5072014
PURCHASE ORDER DATE: 4/1/2009
ACCOUNT NUMBER: 5550-3007-01
SCHEDULE: S063-86
REVISION: 1

CHARGE ADDRESS

TRINITY INDUSTRIES INC
HIGHWAY SAFETY PRODUCTS INC
P O BOX 568887 4TH FLOOR
DALLAS, TX 75356-8887

SHIP TO

TRINITY INDUSTRIES INC
C/O BCS METALS PREP
5800 STERLING AVE
MAPLE HEIGHTS, OH 44137

MATERIAL DESCRIPTION

HOT ROLLED STEEL COILS CARBON AISI-1015 AK AL KILLED FINE GRAIN COLD WORKING QUALITY TEST REPORTS OF MECHANICAL PROPERTIES FOR INFO ONLY EXTRA TESTING
SIZE: RDS .6390 DIAM X COIL
RDS 16.2306MM DIAM X COIL

LADLE CHEMISTRY %

C	MN	P	S	SI	CU	NI	CR
0.15	0.47	0.006	0.003	0.09	0.05	0.06	0.05
V	MO	SN	AL	CB	N		
0.000	0.02	0.005	0.046	0.000	0.0063		

CALCULATED TESTS

REDUCTION RATIO 112.3 TO 1

AUSTENITIC GRAIN SIZE 5 OR FINER BASED ON A TOTAL ALUMINUM CONTENT EQUAL TO OR GREATER THAN .020% PER ASTM A29.

SEMI - FINISHED RESULTS

FINISHED SIZE RESULTS

TENSILE TEST STANDARD FORMAT

	TENSILE PSI	YIELD(0.2%) PSI	RA %	E %
PCE 2728	63100	44200	65.4	39.0

HARDNESS TEST ASTM E10/ASTM A370 HBW AS-RLD/CD HBW
MID-RADIUS
PCE 2729 116

NOTES

CHEMICAL ANALYSIS CONFORMS TO APPLICABLE SPECS: ASTM E415, LBL10129, LBL10130, ASTM E1019, LBL10150, LBL10114, AND ASTM E1085, LBL10184, LBL10188.

REPUBLIC ENGINEERED PRODUCTS HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

CERTIFICATE OF TESTS SHALL NOT BE REPRODUCED EXCEPT IN FULL.

ALL TESTING HAS BEEN PERFORMED USING THE CURRENT REVISION OF THE TESTING SPECIFICATIONS.

RECORDING OF FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELONY UNDER FED STATUES TITLE 18 CHAPTER 47.

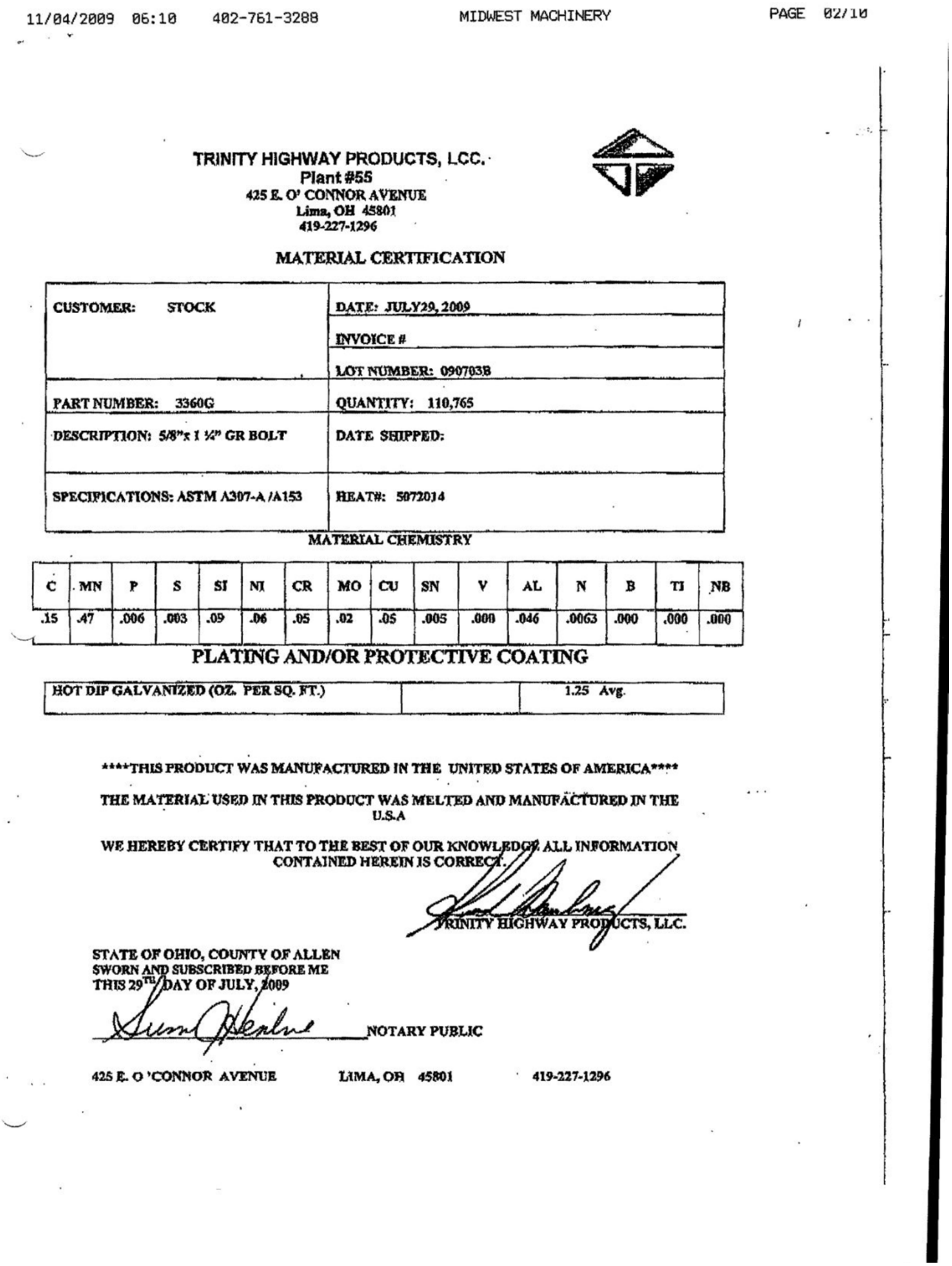
THE MATERIAL WAS NOT EXPOSED TO MERCURY OR ANY METAL ALLOY THAT IS LIQUID AT AMBIENT TEMPERATURE DURING PROCESSING OR WHILE IN OUR POSSESSION.

NO WELD OR WELD REPAIR WAS PERFORMED ON THIS MATERIAL.

R. A. SZELIGA
MANAGER TECH. SERVICES
R. A. Szeliga

BY HILDA BESUE

Figure A-16. Guardrail Splice Bolt Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



11/04/2009 06:10 402-761-3288 MIDWEST MACHINERY PAGE 02/10

TRINITY HIGHWAY PRODUCTS, LCC.
Plant #55
425 E. O' CONNOR AVENUE
Lima, OH 45801
419-227-1296

MATERIAL CERTIFICATION

CUSTOMER: STOCK	DATE: JULY29, 2009
	INVOICE #
	LOT NUMBER: 090703B
PART NUMBER: 3360G	QUANTITY: 110,765
DESCRIPTION: 5/8"x 1 ¼" GR BOLT	DATE SHIPPED:
SPECIFICATIONS: ASTM A307-A /A153	HEAT#: 5072014

MATERIAL CHEMISTRY

C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
.15	.47	.006	.003	.09	.06	.05	.02	.05	.005	.000	.046	.0063	.000	.000	.000

PLATING AND/OR PROTECTIVE COATING

HOT DIP GALVANIZED (OZ. PER SQ. FT.)		1.25 Avg.

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A

WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

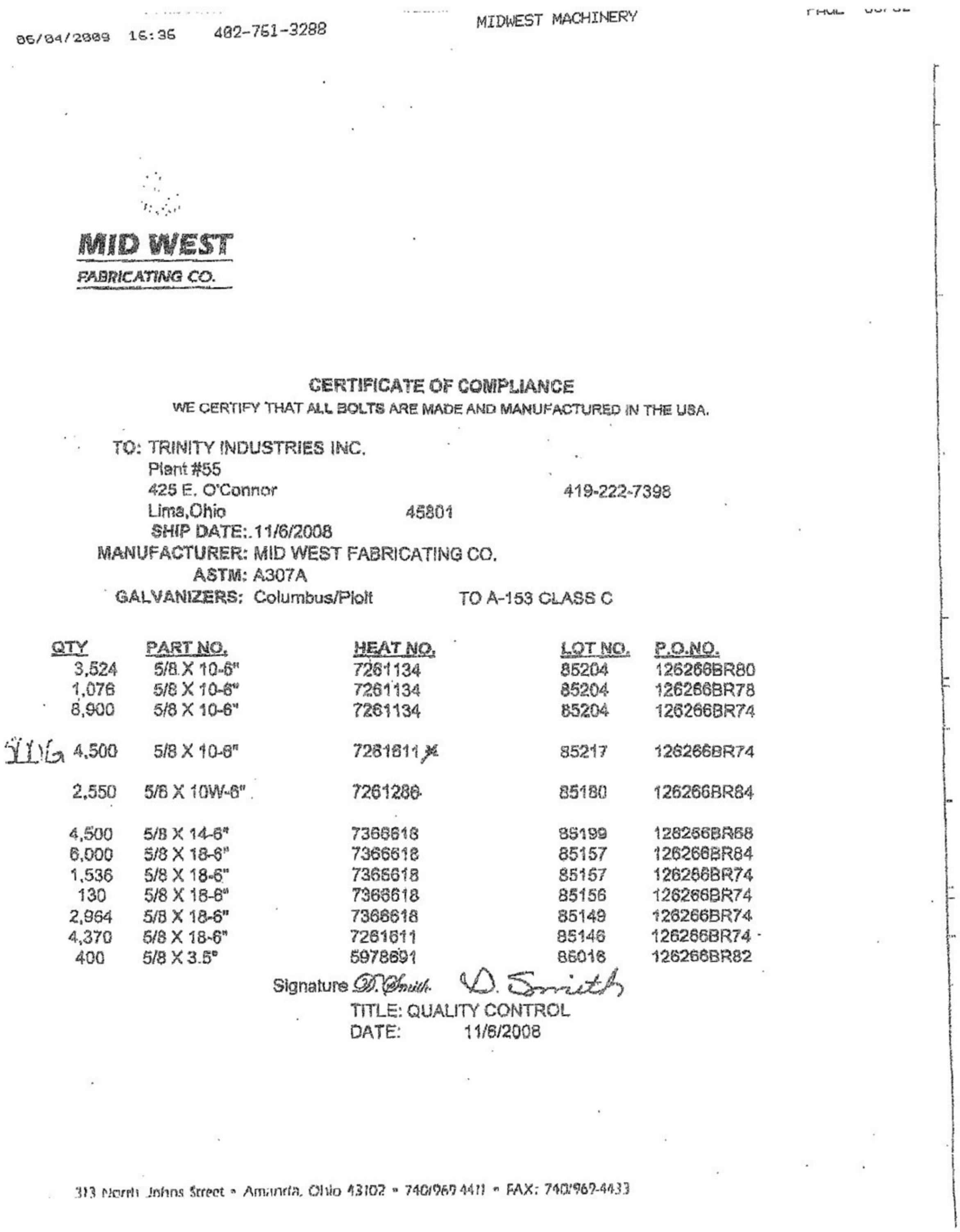
TRINITY HIGHWAY PRODUCTS, LLC.

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME
THIS 29TH DAY OF JULY, 2009

NOTARY PUBLIC

425 E. O 'CONNOR AVENUE LIMA, OH 45801 419-227-1296

Figure A-17. Guardrail Splice Bolt Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY

MID WEST
FABRICATING CO.

CERTIFICATE OF COMPLIANCE

WE CERTIFY THAT ALL BOLTS ARE MADE AND MANUFACTURED IN THE USA.

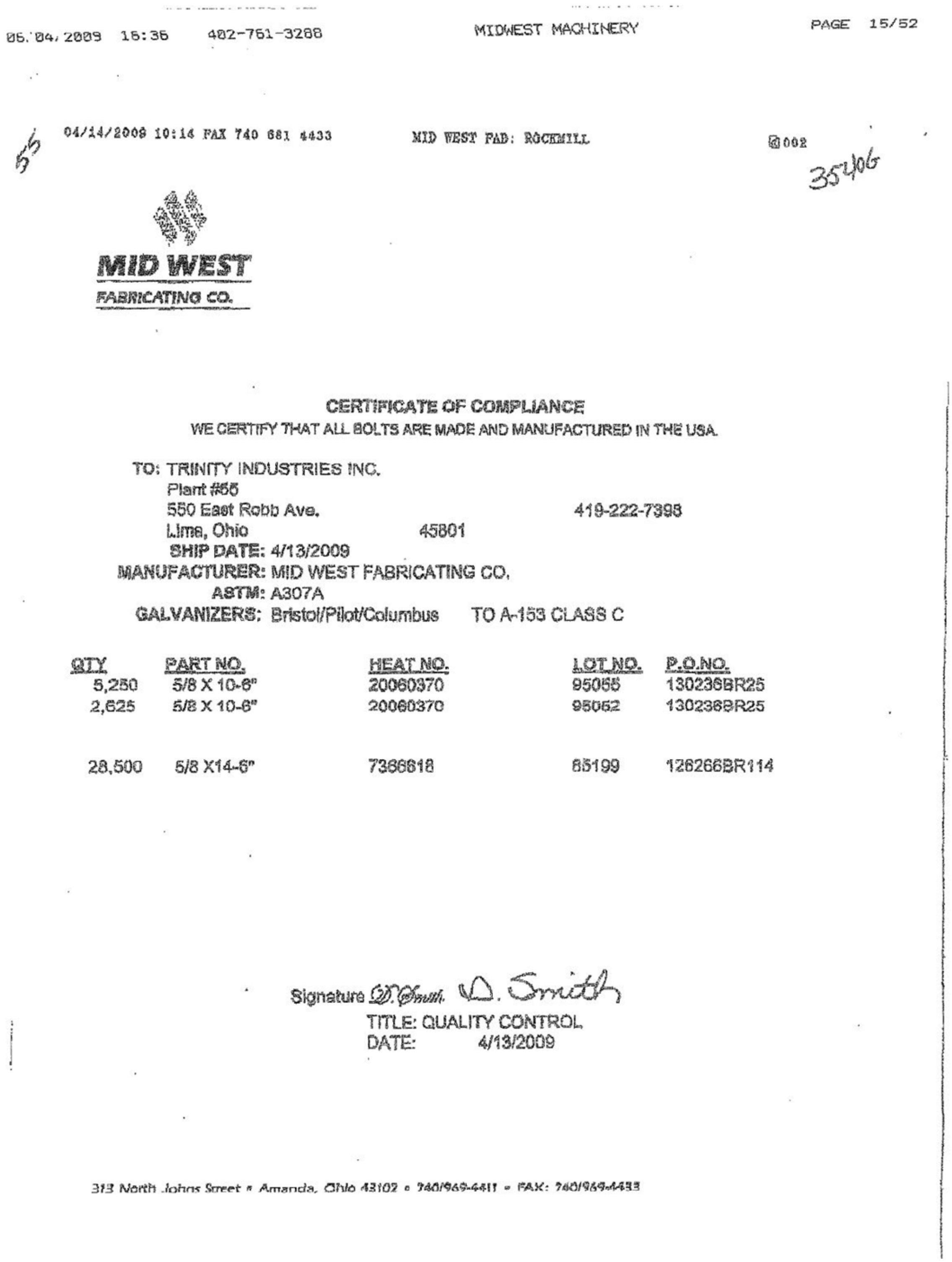
TO: TRINITY INDUSTRIES INC.
Plant #55
425 E. O'Connor 419-222-7398
Lima,Ohio 45801
SHIP DATE: 11/6/2008
MANUFACTURER: MID WEST FABRICATING CO.
ASTM: A307A
GALVANIZERS: Columbus/Piolt TO A-153 CLASS C

	QTY	PART NO.	HEAT NO.	LOT NO.	P.O.NO.
	3,524	5/8 X 10-6"	7261134	85204	126266BR80
	1,076	5/8 X 10-6"	7261134	85204	126266BR78
	8,900	5/8 X 10-6"	7261134	85204	126266BR74
[illegible]	4,500	5/8 X 10-6"	7261611 ✗	85217	126266BR74
	2,550	5/8 X 10W-6"	7261286	85180	126266BR84
	4,500	5/8 X 14-6"	7366618	85199	126266BR68
	6,000	5/8 X 18-6"	7366618	85157	126266BR84
	1,536	5/8 X 18-6"	7366618	85157	126266BR74
	130	5/8 X 18-6"	7366618	85156	126266BR74
	2,964	5/8 X 18-6"	7366618	85149	126266BR74
	4,370	5/8 X 18-6"	7261611	85146	126266BR74
	400	5/8 X 3.5"	5978691	86016	126266BR82

Signature D. Smith D. Smith
TITLE: QUALITY CONTROL
DATE: 11/6/2008

313 North Johns Street • Amanda, Ohio 43102 • 740/969-4411 • FAX: 740/969-4433

Figure A-18. 10-in. (254-mm) Guardrail Bolt Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



05.'04.2009 16:36 402-761-3288 MIDWEST MACHINERY PAGE 15/52

55

04/14/2009 10:14 FAX 740 681 4433 MID WEST FAB: ROCKMILL 002

35406

MID WEST
FABRICATING CO.

CERTIFICATE OF COMPLIANCE

WE CERTIFY THAT ALL BOLTS ARE MADE AND MANUFACTURED IN THE USA.

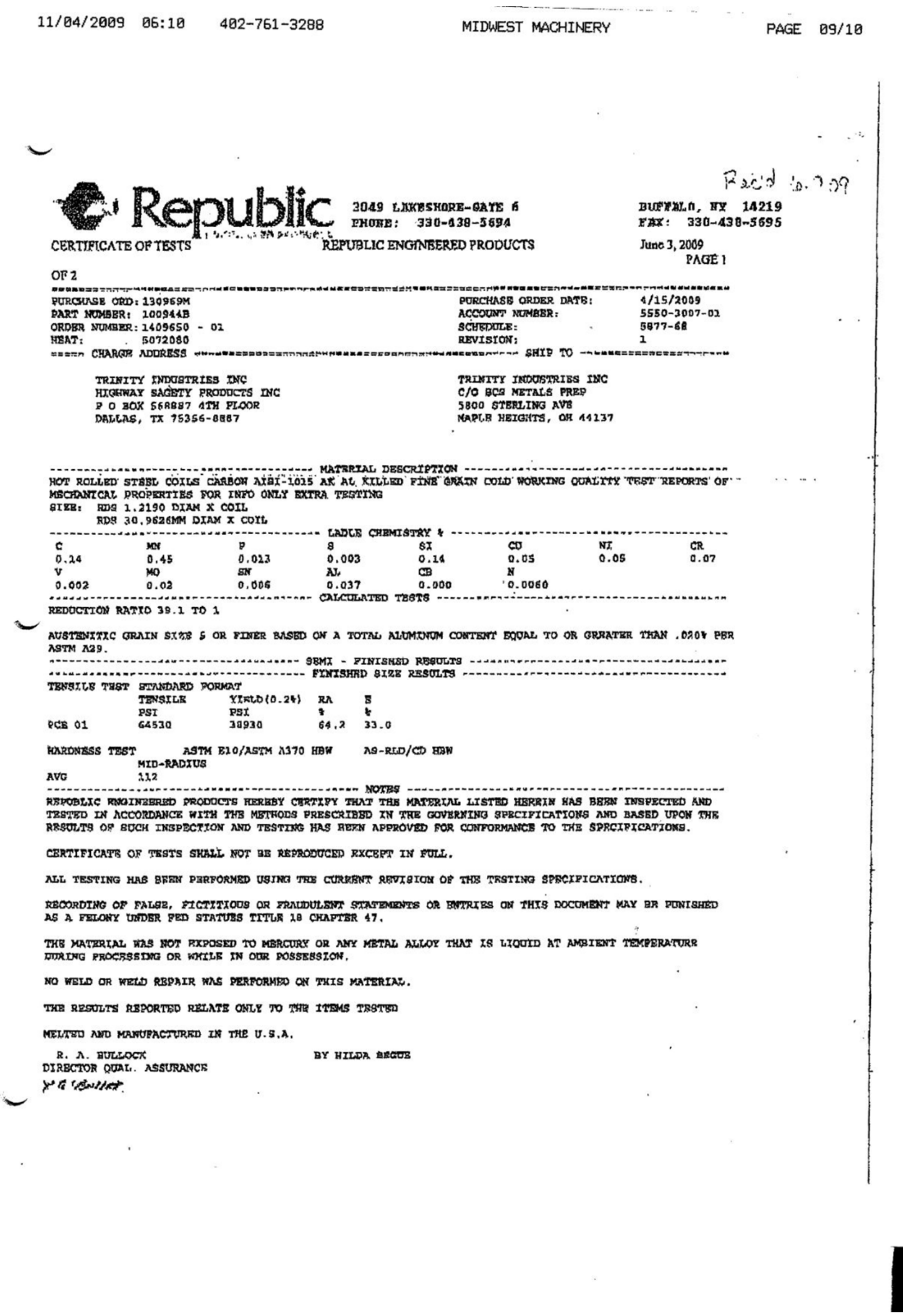
TO: TRINITY INDUSTRIES INC.
Plant #55
550 East Robb Ave. 419-222-7398
Lima, Ohio 45801
SHIP DATE: 4/13/2009
MANUFACTURER: MID WEST FABRICATING CO.
ASTM: A307A
GALVANIZERS: Bristol/Pilot/Columbus TO A-153 CLASS C

QTY	PART NO.	HEAT NO.	LOT NO.	P.O.NO.
5,250	5/8 X 10-6"	20060370	95055	130236BR25
2,625	5/8 X 10-6"	20060370	95052	130236BR25
28,500	5/8 X14-6"	7366618	85199	126266BR114

Signature D.Smith D. Smith
TITLE: QUALITY CONTROL
DATE: 4/13/2009

313 North Johns Street • Amanda, Ohio 43102 • 740/969-4411 • FAX: 740/969-4433

Figure A-19. 14-in. (356-mm) Guardrail Bolt Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



11/04/2009 06:10 402-761-3288 MIDWEST MACHINERY PAGE 09/10

Rec'd 10.7.09

Republic
3049 LAKESHORE-GATE 6 BUFFALO, NY 14219
PHONE: 330-438-5694 FAX: 330-438-5695

CERTIFICATE OF TESTS REPUBLIC ENGINEERED PRODUCTS June 3, 2009
PAGE 1
OF 2

PURCHASE ORD:	130969M	PURCHASE ORDER DATE:	4/15/2009
PART NUMBER:	100944B	ACCOUNT NUMBER:	5550-3007-01
ORDER NUMBER:	1409650 - 01	SCHEDULE:	5877-68
HEAT:	5072080	REVISION:	1

CHARGE ADDRESS ---- SHIP TO

TRINITY INDUSTRIES INC	TRINITY INDUSTRIES INC
HIGHWAY SAGETY PRODUCTS INC	C/O BCS METALS PREP
P O BOX 568887 4TH FLOOR	5800 STERLING AVE
DALLAS, TX 75356-8887	MAPLE HEIGHTS, OH 44137

MATERIAL DESCRIPTION

HOT ROLLED STEEL COILS CARBON AISI-1015 AK AL KILLED FINE GRAIN COLD WORKING QUALITY TEST REPORTS OF MECHANICAL PROPERTIES FOR INFO ONLY EXTRA TESTING

SIZE: RDS 1.2190 DIAM X COIL
RDS 30.9626MM DIAM X COIL

LADLE CHEMISTRY %

C	MN	P	S	SI	CU	NI	CR
0.14	0.45	0.013	0.003	0.14	0.05	0.05	0.07
V	MO	SN	AL	CB	N		
0.002	0.02	0.006	0.037	0.000	0.0060		

CALCULATED TESTS

REDUCTION RATIO 39.1 TO 1

AUSTENITIC GRAIN SIZE 5 OR FINER BASED ON A TOTAL ALUMINUM CONTENT EQUAL TO OR GREATER THAN .020% PER ASTM A29.

SBMI - FINISHED RESULTS

FINISHED SIZE RESULTS

TENSILE TEST STANDARD FORMAT

	TENSILE PSI	YIELD(0.2%) PSI	RA %	E %
PCE 01	64530	38930	64.2	33.0

HARDNESS TEST ASTM E10/ASTM A370 HBW A9-RLD/CD HBW

	MID-RADIUS
AVG	112

NOTES

REPUBLIC ENGINEERED PRODUCTS HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

CERTIFICATE OF TESTS SHALL NOT BE REPRODUCED EXCEPT IN FULL.

ALL TESTING HAS BEEN PERFORMED USING THE CURRENT REVISION OF THE TESTING SPECIFICATIONS.

RECORDING OF FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELONY UNDER FED STATUES TITLE 18 CHAPTER 47.

THE MATERIAL WAS NOT EXPOSED TO MERCURY OR ANY METAL ALLOY THAT IS LIQUID AT AMBIENT TEMPERATURE DURING PROCESSING OR WHILE IN OUR POSSESSION.

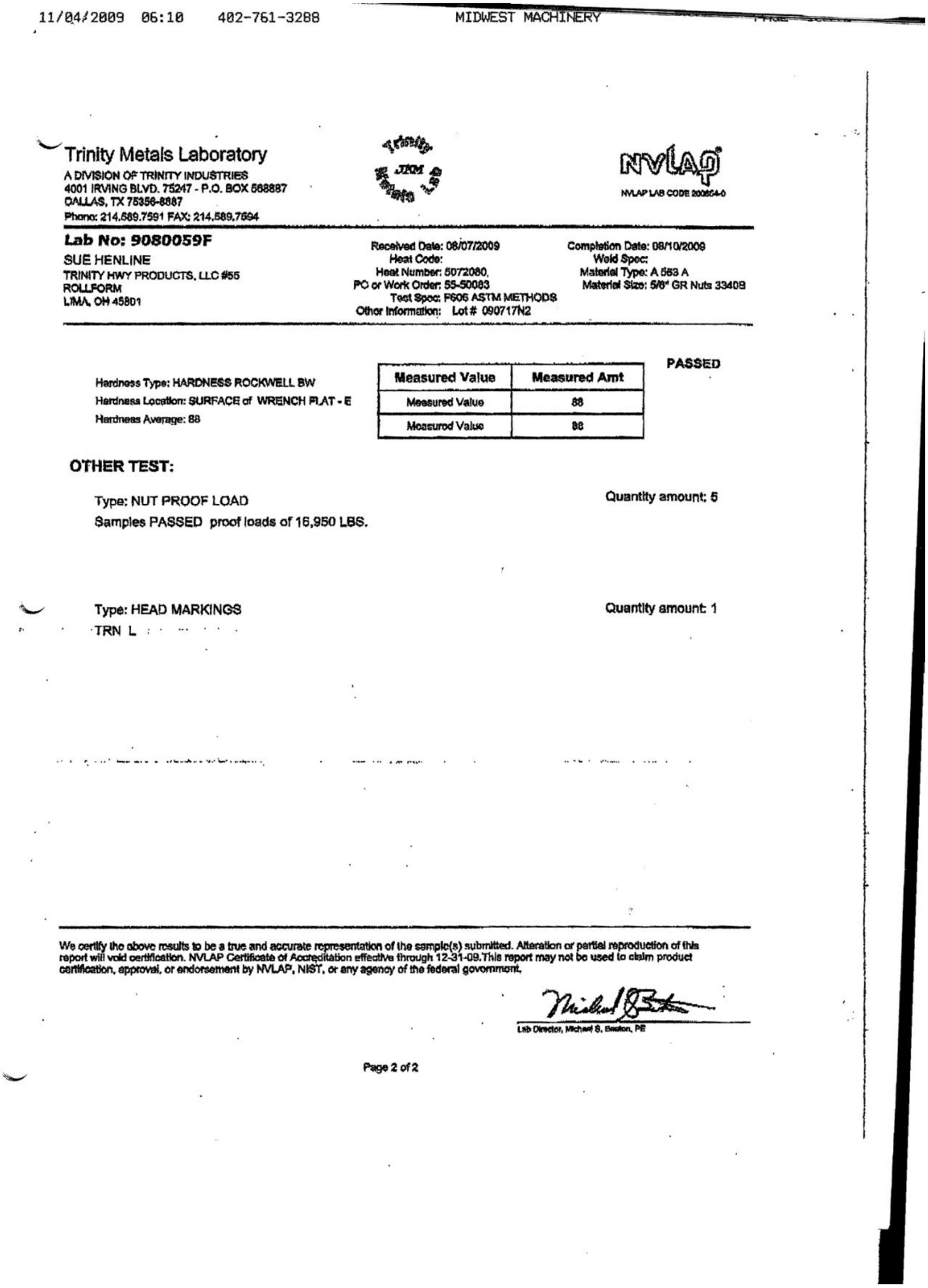
NO WELD OR WELD REPAIR WAS PERFORMED ON THIS MATERIAL.

THE RESULTS REPORTED RELATE ONLY TO THE ITEMS TESTED

MELTED AND MANUFACTURED IN THE U.S.A.

R. A. BULLOCK BY HILDA BEGUE
DIRECTOR QUAL. ASSURANCE
R A Bullock

Figure A-20. Guardrail Nut Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



11/04/2009 06:10 402-761-3288 MIDWEST MACHINERY

Trinity Metals Laboratory
A DIVISION OF TRINITY INDUSTRIES
4001 IRVING BLVD. 75247 - P.O. BOX 568887
DALLAS, TX 75356-8887
Phone: 214.589.7591 FAX: 214.589.7594

NVLAP LAB CODE 200664-0

Lab No: 9080059F
SUE HENLINE
TRINITY HWY PRODUCTS, LLC #55
ROLLFORM
LIMA, OH 45801

Received Date: 08/07/2009
Heat Code:
Heat Number: 5072080,
PO or Work Order: 55-50083
Test Spec: F606 ASTM METHODS
Other Information: Lot # 090717N2

Completion Date: 08/10/2009
Weld Spec:
Material Type: A 563 A
Material Size: 5/8" GR Nuts 3340B

PASSED

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: SURFACE of WRENCH FLAT - E
Hardness Average: 88

Measured Value	Measured Amt
Measured Value	88
Measured Value	88

OTHER TEST:

Type: NUT PROOF LOAD
Quantity amount: 5
Samples PASSED proof loads of 16,950 LBS.

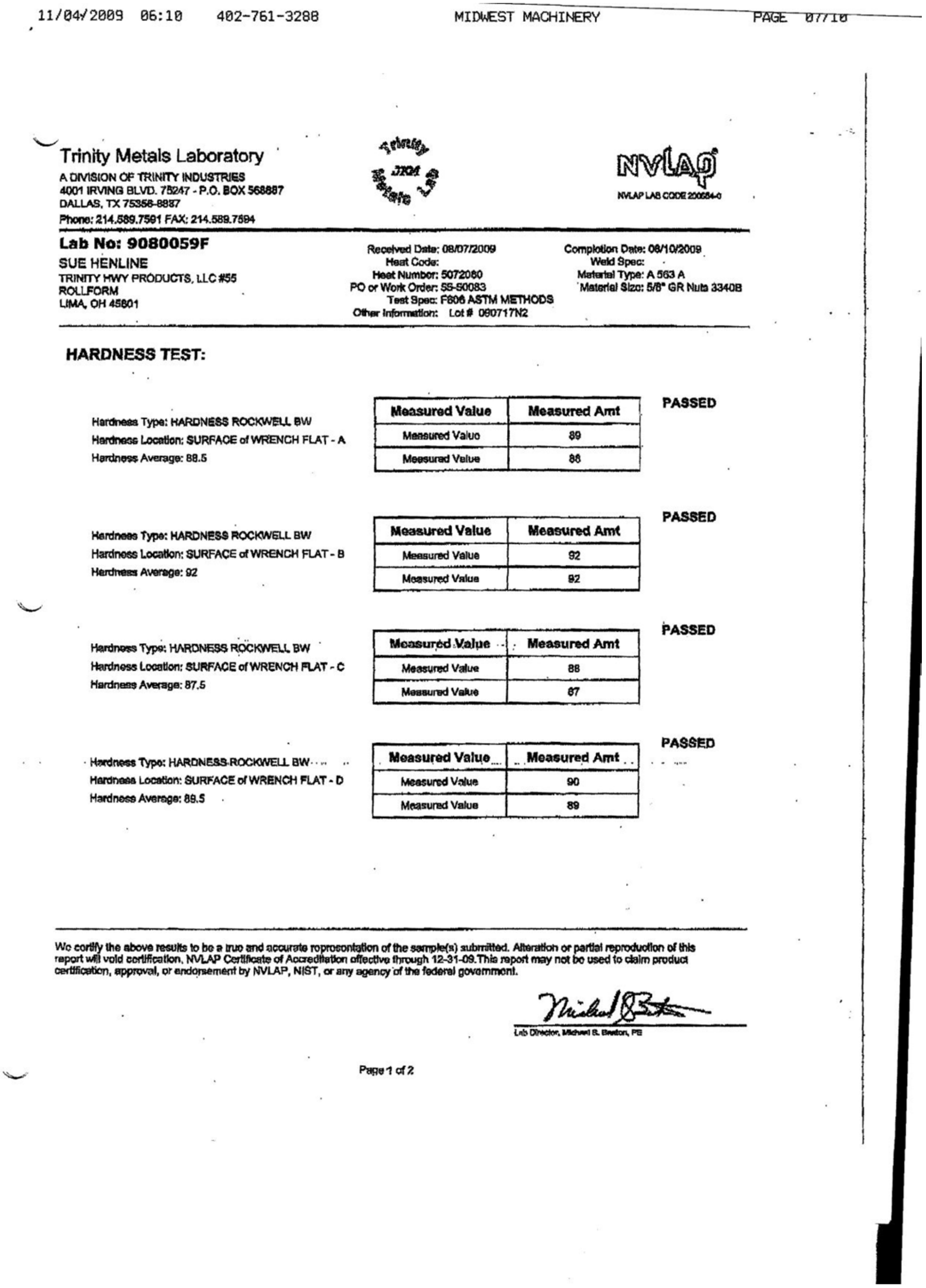
Type: HEAD MARKINGS
Quantity amount: 1
TRN L

We certify the above results to be a true and accurate representation of the sample(s) submitted. Alteration or partial reproduction of this report will void certification. NVLAP Certificate of Accreditation effective through 12-31-09.This report may not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

Michael S Baston
Lab Director, Michael S. Baston, PE

Page 2 of 2

Figure A-21. Guardrail Nut Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



11/04/2009 06:10 402-761-3288 MIDWEST MACHINERY PAGE 07/10

Trinity Metals Laboratory
A DIVISION OF TRINITY INDUSTRIES
4001 IRVING BLVD. 75247 - P.O. BOX 568887
DALLAS, TX 75356-8887
Phone: 214.589.7591 FAX: 214.589.7594

NVLAP LAB CODE 200664-0

Lab No: 9080059F
SUE HENLINE
TRINITY HWY PRODUCTS, LLC #55
ROLLFORM
LIMA, OH 45801

Received Date: 08/07/2009
Heat Code:
Heat Number: 5072060
PO or Work Order: 55-50083
Test Spec: F606 ASTM METHODS
Other Information: Lot # 090717N2

Completion Date: 08/10/2009
Weld Spec:
Material Type: A 563 A
Material Size: 5/8" GR Nuts 3340B

HARDNESS TEST:

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: SURFACE of WRENCH FLAT - A
Hardness Average: 88.5

Measured Value	Measured Amt
Measured Value	89
Measured Value	88

PASSED

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: SURFACE of WRENCH FLAT - B
Hardness Average: 92

Measured Value	Measured Amt
Measured Value	92
Measured Value	92

PASSED

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: SURFACE of WRENCH FLAT - C
Hardness Average: 87.5

Measured Value	Measured Amt
Measured Value	88
Measured Value	87

PASSED

Hardness Type: HARDNESS ROCKWELL BW
Hardness Location: SURFACE of WRENCH FLAT - D
Hardness Average: 89.5

Measured Value	Measured Amt
Measured Value	90
Measured Value	89

PASSED

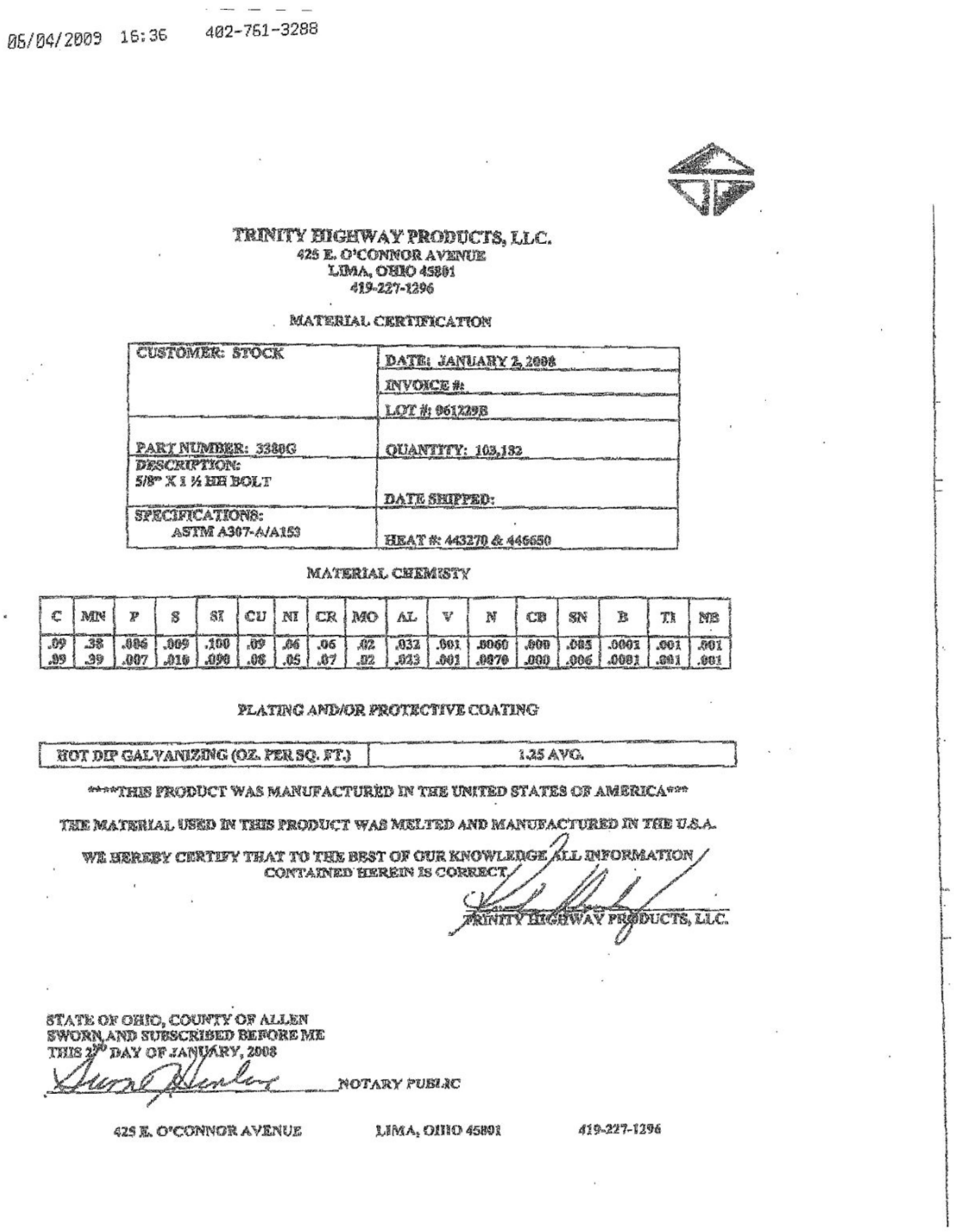
We certify the above results to be a true and accurate representation of the sample(s) submitted. Alteration or partial reproduction of this report will void certification. NVLAP Certificate of Accreditation effective through 12-31-09. This report may not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

Michael S. Benton

Lab Director, Michael S. Benton, PE

Page 1 of 2

Figure A-22. Guardrail Nut Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



05/04/2009 16:36 402-761-3288

TRINITY HIGHWAY PRODUCTS, LLC.
425 E. O'CONNOR AVENUE
LIMA, OHIO 45801
419-227-1296

MATERIAL CERTIFICATION

CUSTOMER: STOCK	DATE: JANUARY 2, 2008 INVOICE #: LOT #: 061229B
PART NUMBER: 3380G	QUANTITY: 103,182
DESCRIPTION: 5/8" X 1 ½ HH BOLT	DATE SHIPPED:
SPECIFICATIONS: ASTM A307-A/A153	HEAT #: 443270 & 446650

MATERIAL CHEMISTY

C	MN	P	S	SI	CU	NI	CR	MO	AL	V	N	CB	SN	B	TI	NB
.09	.38	.006	.009	.100	.09	.06	.06	.02	.032	.001	.0060	.000	.005	.0001	.001	.001
.09	.39	.007	.010	.090	.08	.05	.07	.02	.023	.001	.0070	.000	.006	.0001	.001	.001

PLATING AND/OR PROTECTIVE COATING

HOT DIP GALVANIZING (OZ. PER SQ. FT.)	1.25 AVG.

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA***

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A.

WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

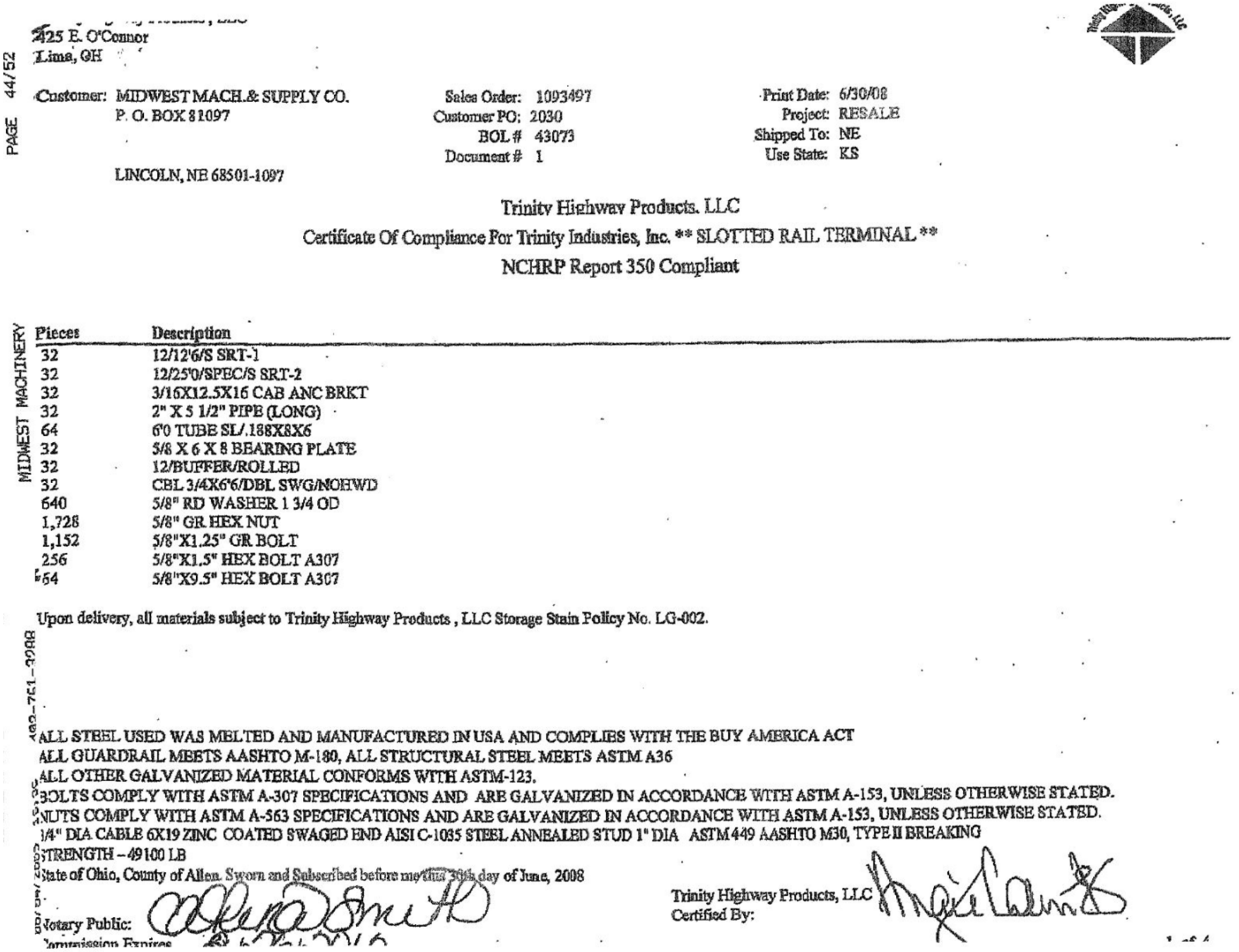
TRINITY HIGHWAY PRODUCTS, LLC.

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME
THIS 2ND DAY OF JANUARY, 2008

NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 45801 419-227-1296

Figure A-23. 1½-in. (38-mm) Hex Bolt Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



425 E. O'Connor
Lima, OH

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

LINCOLN, NE 68501-1097

Sales Order: 1093497
Customer PO: 2030
BOL # 43073
Document # 1

Print Date: 6/30/08
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products. LLC
Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **
NCHRP Report 350 Compliant

Pieces	Description
32	12/12'6/S SRT-1
32	12/25'0/SPEC/S SRT-2
32	3/16X12.5X16 CAB ANC BRKT
32	2" X 5 1/2" PIPE (LONG)
64	6'0 TUBE SL/.188X8X6
32	5/8 X 6 X 8 BEARING PLATE
32	12/BUFFER/ROLLED
32	CBL 3/4X6'6/DBL SWG/NOHWD
640	5/8" RD WASHER 1 3/4 OD
1,728	5/8" GR HEX NUT
1,152	5/8"X1.25" GR BOLT
256	5/8"X1.5" HEX BOLT A307
64	5/8"X9.5" HEX BOLT A307

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 OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
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 Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public: Alena Smith
Commission Expires

Trinity Highway Products, LLC
Certified By:

Figure A-24. 9½-in. (241-mm) Hex Bolt Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2

0 82893 62577 8

PFC LOT NO. (K) 15100302

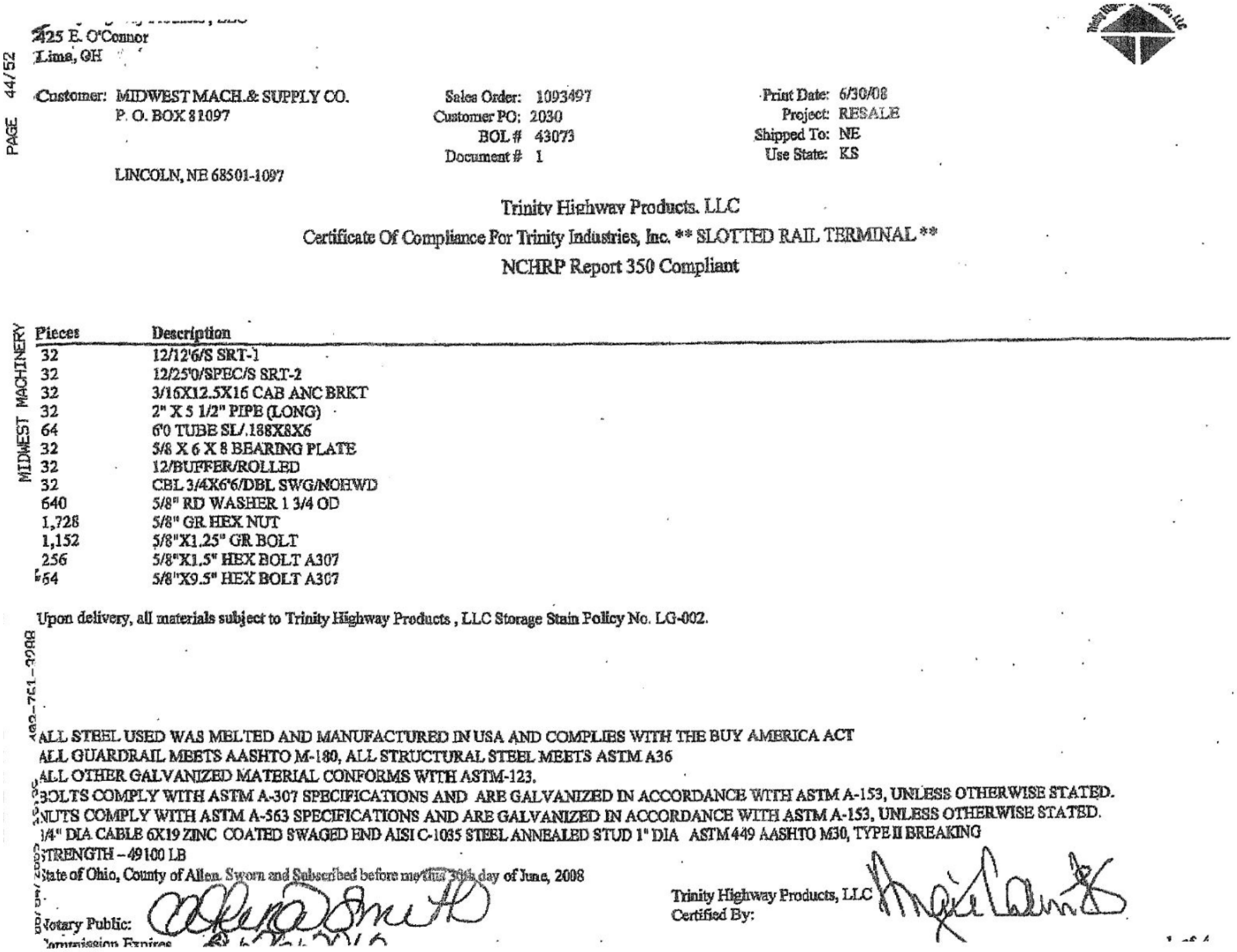
FK/FKJ MFG Lot No.: N580167GH CHINA

BOX SEALED TO SECURE INTEGRITY

5/8 – 11

FINISHED HEX NUTS COARSE

Figure A-25. ⅝-in. (16-mm) Diameter Hex Nut Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



PAGE 44/52

425 E. O'Connor
Lima, OH

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

LINCOLN, NE 68501-1097

Sales Order: 1093497
Customer PO: 2030
BOL # 43073
Document # 1

Print Date: 6/30/08
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

MIDWEST MACHINERY

Pieces	Description
32	12/12'6/S SRT-1
32	12/25'0/SPEC/S SRT-2
32	3/16X12.5X16 CAB ANC BRKT
32	2" X 5 1/2" PIPE (LONG)
64	6'0 TUBE SL/.188X8X6
32	5/8 X 6 X 8 BEARING PLATE
32	12/BUFFER/ROLLED
32	CBL 3/4X6'6/DBL SWG/NOHWD
640	5/8" RD WASHER 1 3/4 OD
1,728	5/8" GR HEX NUT
1,152	5/8"X1.25" GR BOLT
256	5/8"X1.5" HEX BOLT A307
64	5/8"X9.5" HEX BOLT A307

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

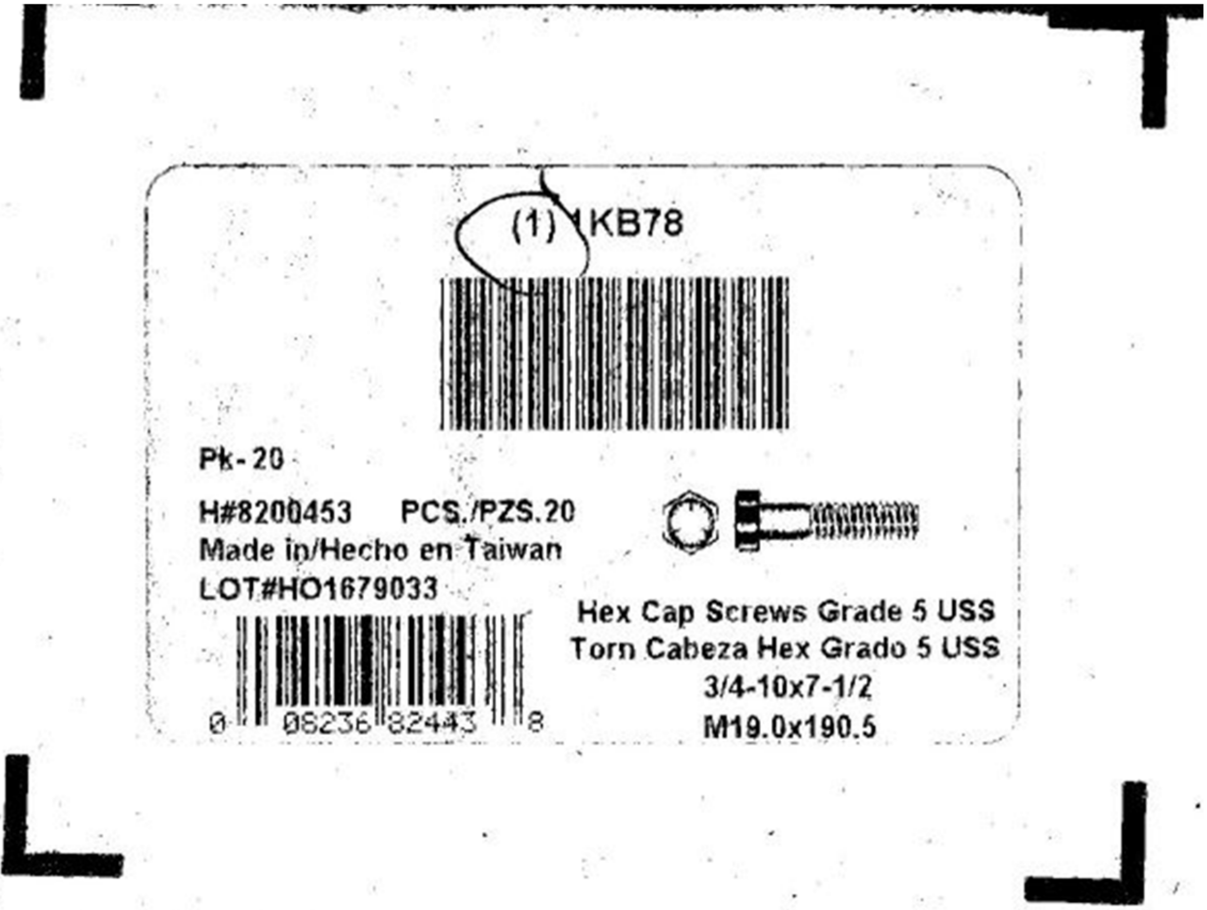
ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, 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 Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public:
Commission Expires

Trinity Highway Products, LLC
Certified By:

Figure A-26. ⅝-in. (16-mm) Diameter Flat Washer Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



(1) 1KB78

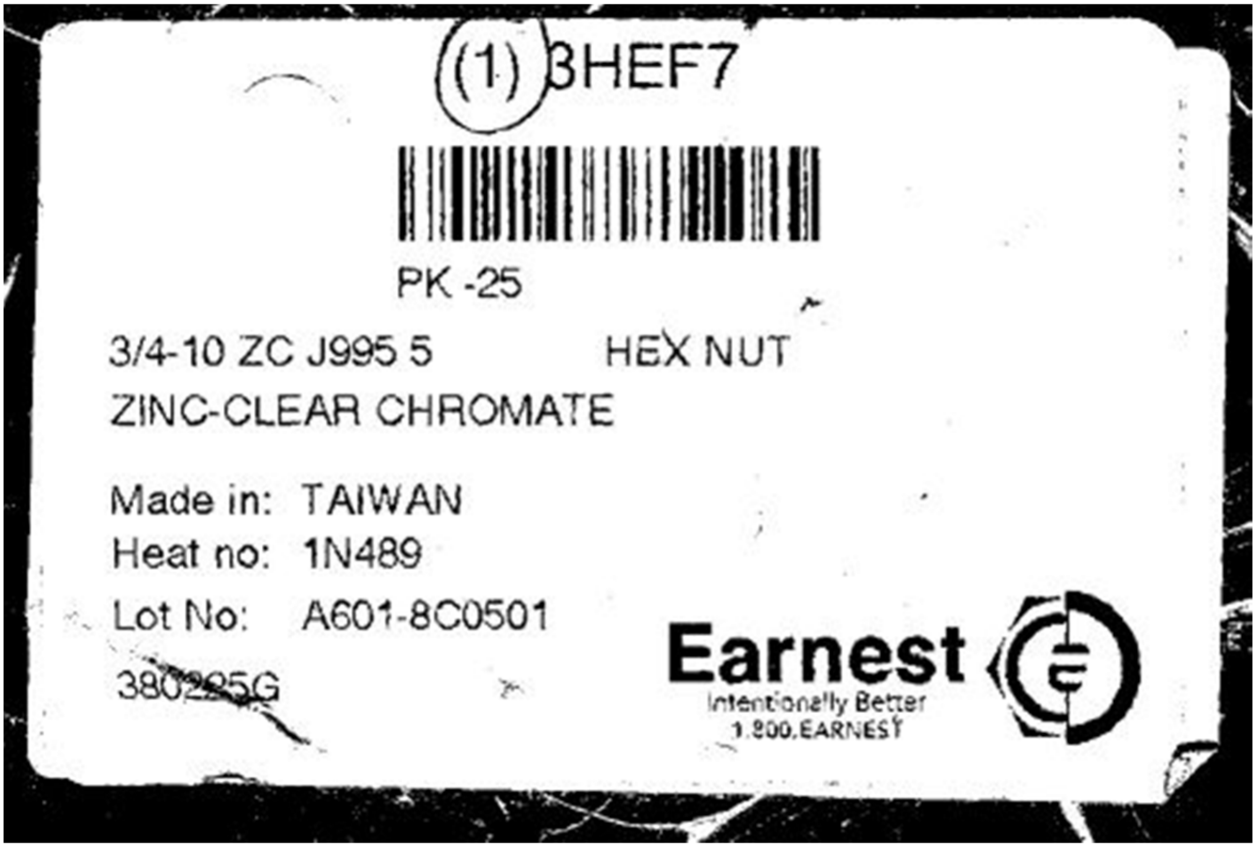
Pk- 20

H#8200453 PCS./PZS.20
Made in/Hecho en Taiwan
LOT#HO1679033

0 08236 82443 8

Hex Cap Screws Grade 5 USS
Torn Cabeza Hex Grado 5 USS
3/4-10x7-1/2
M19.0x190.5

Figure A-27. ¾-in. (19-mm) Diameter Hex Bolt Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



(1) 3HEF7

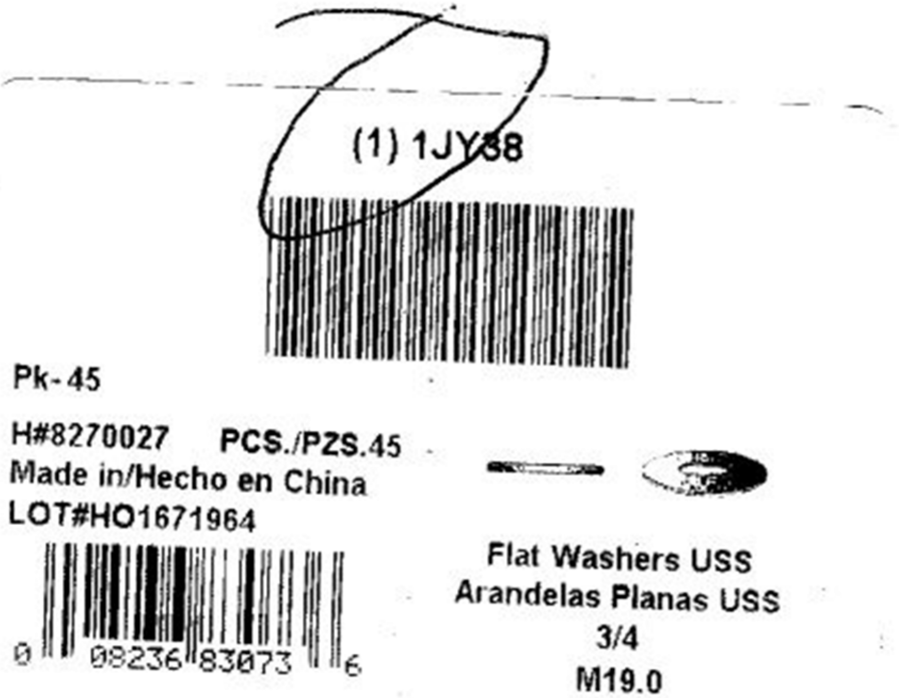
PK -25

3/4-10 ZC J995 5 HEX NUT
ZINC-CLEAR CHROMATE

Made in: TAIWAN
Heat no: 1N489
Lot No: A601-8C0501
380225G

Earnest
Intentionally Better
1.800.EARNEST

Figure A-28. ¾-in. (19-mm) Diameter Hex Nut Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2



(1) 1JY38

Pk-45

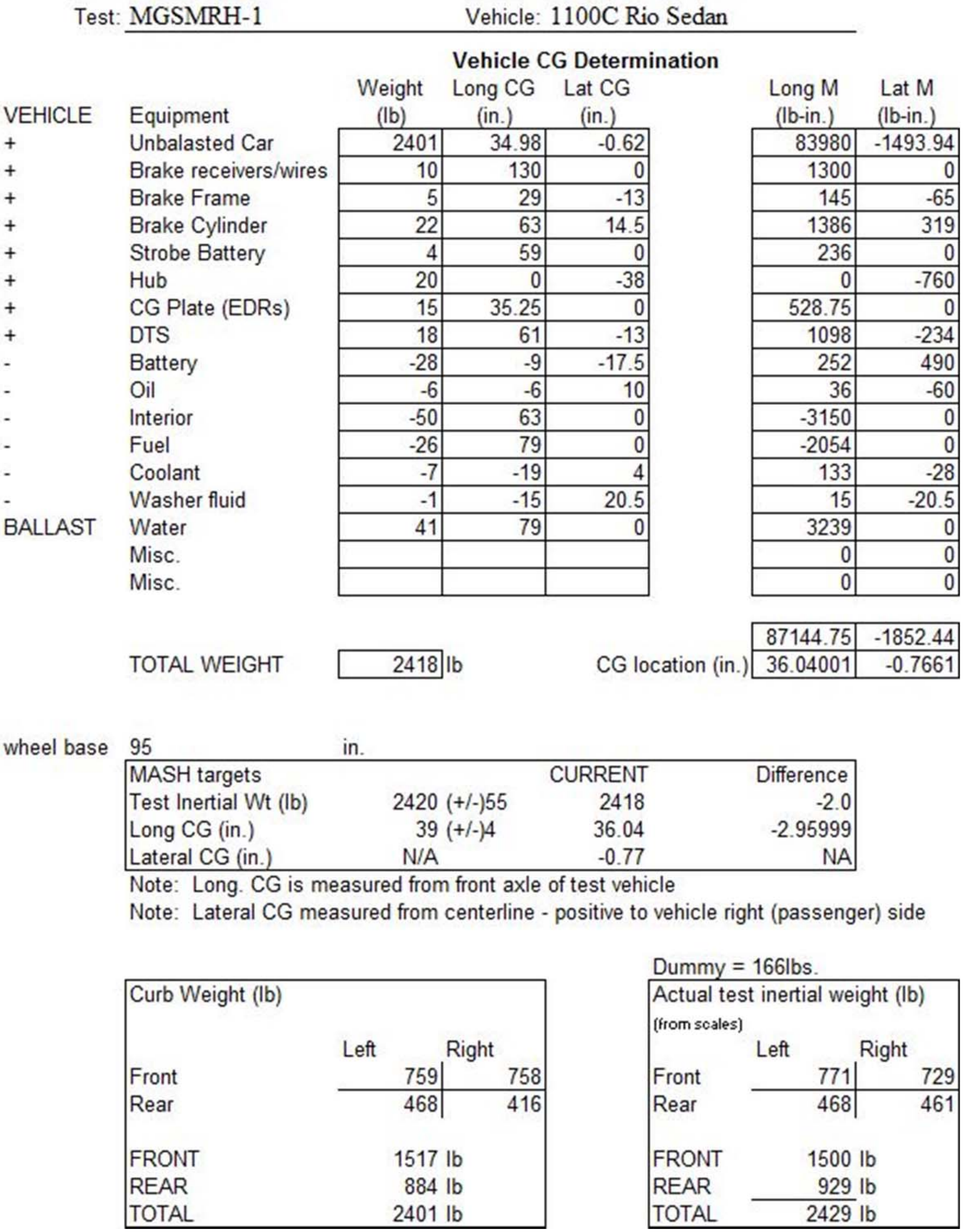
H#8270027 PCS./PZS.45
Made in/Hecho en China
LOT#HO1671964

0 08236 83073 6

Flat Washers USS
Arandelas Planas USS
3/4
M19.0

Figure A-29. ¾-in. (19-mm) Diameter Flat Washer Material Specifications, Test Nos. MGSMRH-1 and MGSMRH-2

Appendix B - Vehicle Center of Gravity Determination



Test: MGSMRH-1 Vehicle: 1100C Rio Sedan

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Long CG (in.)	Lat CG (in.)	Long M (lb-in.)	Lat M (lb-in.)
+	Unbalasted Car	2401	34.98	-0.62	83980	-1493.94
+	Brake receivers/wires	10	130	0	1300	0
+	Brake Frame	5	29	-13	145	-65
+	Brake Cylinder	22	63	14.5	1386	319
+	Strobe Battery	4	59	0	236	0
+	Hub	20	0	-38	0	-760
+	CG Plate (EDRs)	15	35.25	0	528.75	0
+	DTS	18	61	-13	1098	-234
-	Battery	-28	-9	-17.5	252	490
-	Oil	-6	-6	10	36	-60
-	Interior	-50	63	0	-3150	0
-	Fuel	-26	79	0	-2054	0
-	Coolant	-7	-19	4	133	-28
-	Washer fluid	-1	-15	20.5	15	-20.5
BALLAST	Water	41	79	0	3239	0
	Misc.				0	0
	Misc.				0	0
					87144.75	-1852.44
	TOTAL WEIGHT	2418 lb		CG location (in.)	36.04001	-0.7661

wheel base 95 in.

MASH targets		CURRENT	Difference
Test Inertial Wt (lb)	2420 (+/-)55	2418	-2.0
Long CG (in.)	39 (+/-)4	36.04	-2.95999
Lateral CG (in.)	N/A	-0.77	NA

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

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

Curb Weight (lb)

	Left	Right
Front	759	758
Rear	468	416

FRONT 1517 lb
REAR 884 lb
TOTAL 2401 lb

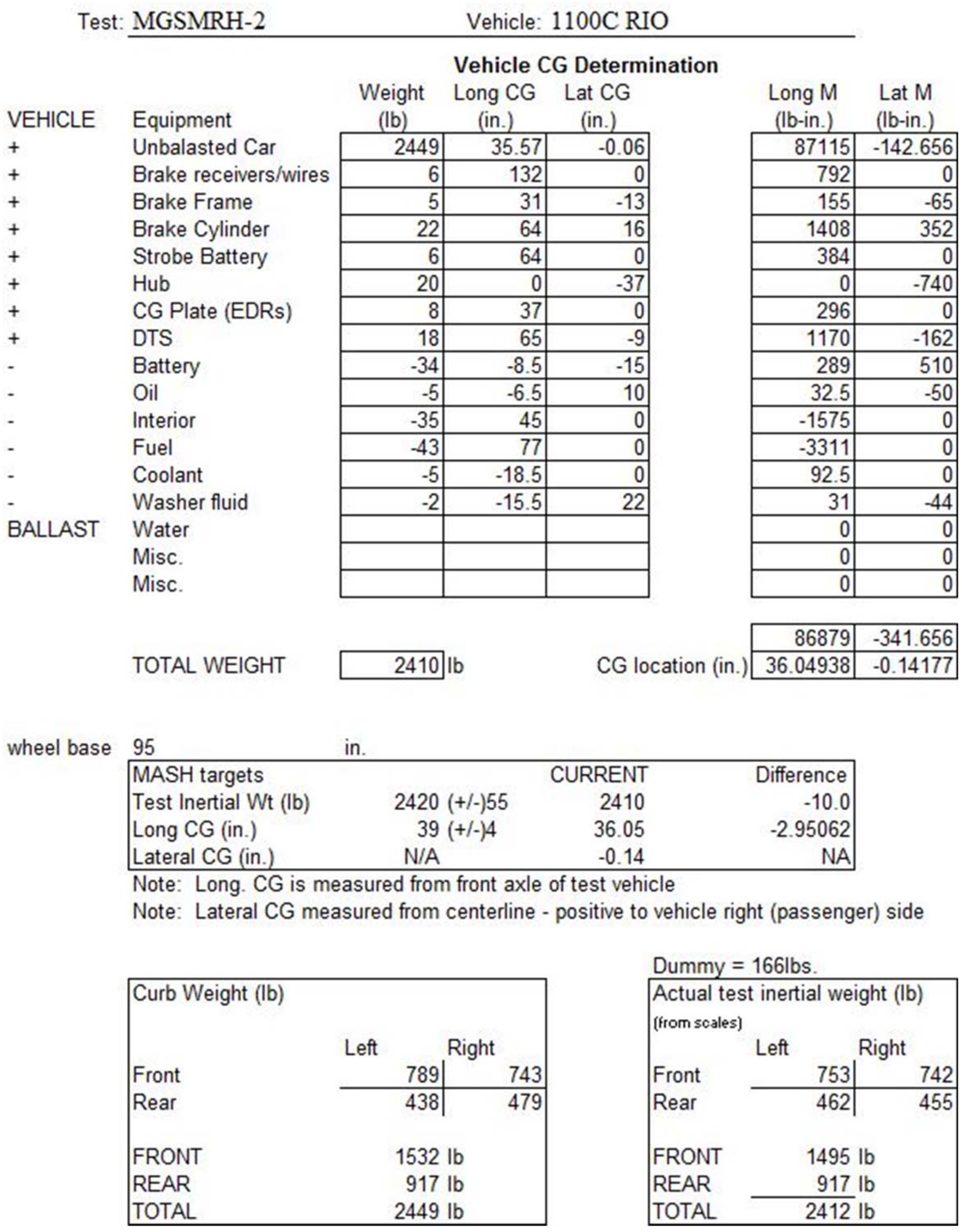
Dummy = 166lbs.

Actual test inertial weight (lb)
(from scales)

	Left	Right
Front	771	729
Rear	468	461

FRONT 1500 lb
REAR 929 lb
TOTAL 2429 lb

Figure B-1. Vehicle Mass Distribution, Test No. MGSMRH-1



Test: MGSMRH-2 Vehicle: 1100C RIO

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Long CG (in.)	Lat CG (in.)	Long M (lb-in.)	Lat M (lb-in.)
+	Unbalasted Car	2449	35.57	-0.06	87115	-142.656
+	Brake receivers/wires	6	132	0	792	0
+	Brake Frame	5	31	-13	155	-65
+	Brake Cylinder	22	64	16	1408	352
+	Strobe Battery	6	64	0	384	0
+	Hub	20	0	-37	0	-740
+	CG Plate (EDRs)	8	37	0	296	0
+	DTS	18	65	-9	1170	-162
-	Battery	-34	-8.5	-15	289	510
-	Oil	-5	-6.5	10	32.5	-50
-	Interior	-35	45	0	-1575	0
-	Fuel	-43	77	0	-3311	0
-	Coolant	-5	-18.5	0	92.5	0
-	Washer fluid	-2	-15.5	22	31	-44
BALLAST	Water				0	0
	Misc.				0	0
	Misc.				0	0
					86879	-341.656
	TOTAL WEIGHT	2410 lb		CG location (in.)	36.04938	-0.14177

wheel base 95 in.

MASH targets		CURRENT	Difference
Test Inertial Wt (lb)	2420 (+/-)55	2410	-10.0
Long CG (in.)	39 (+/-)4	36.05	-2.95062
Lateral CG (in.)	N/A	-0.14	NA

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

Curb Weight (lb)

	Left	Right
Front	789	743
Rear	438	479
FRONT	1532 lb	
REAR	917 lb	
TOTAL	2449 lb	

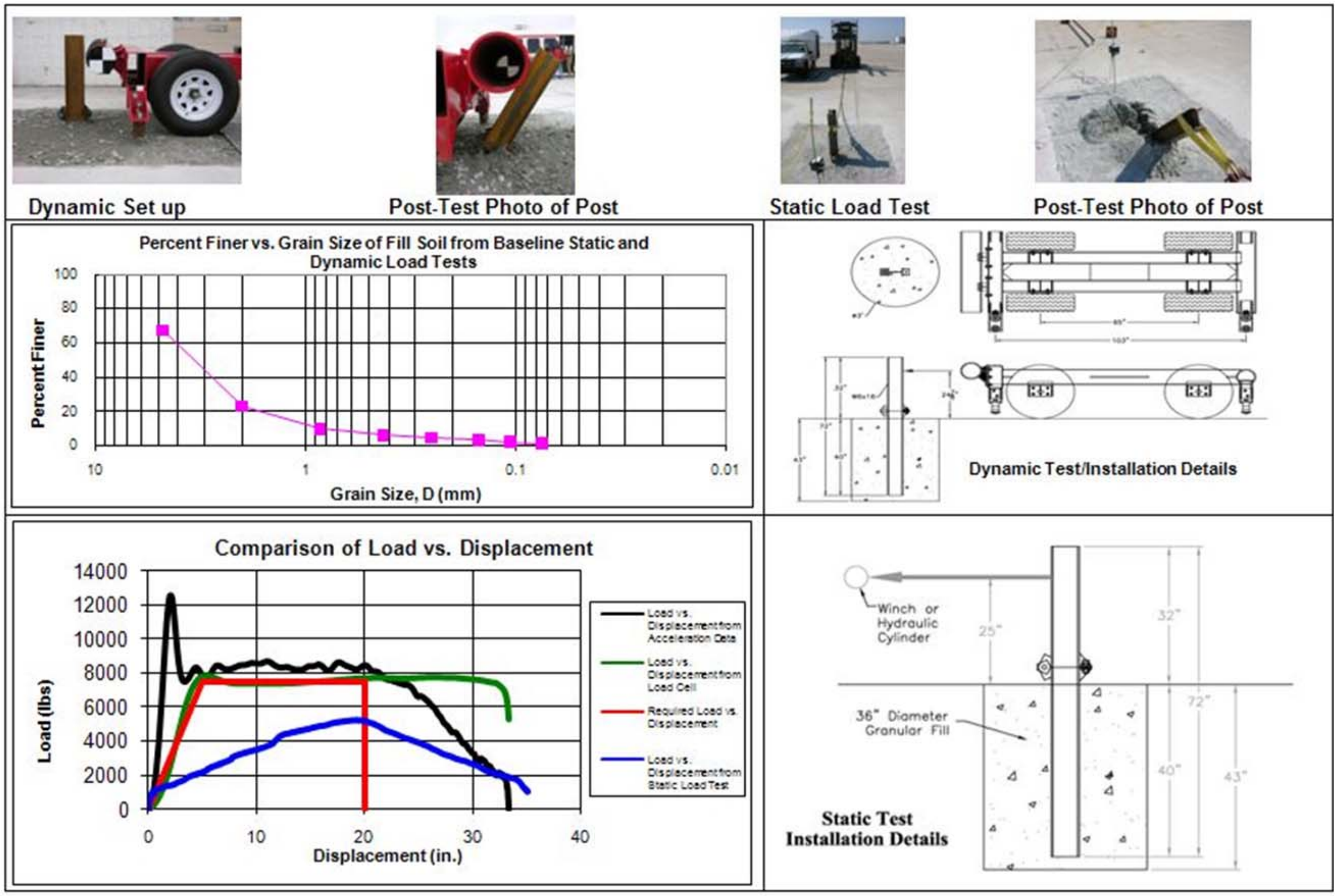
Dummy = 166lbs.

Actual test inertial weight (lb)
(from scales)

	Left	Right
Front	753	742
Rear	462	455
FRONT	1495 lb	
REAR	917 lb	
TOTAL	2412 lb	

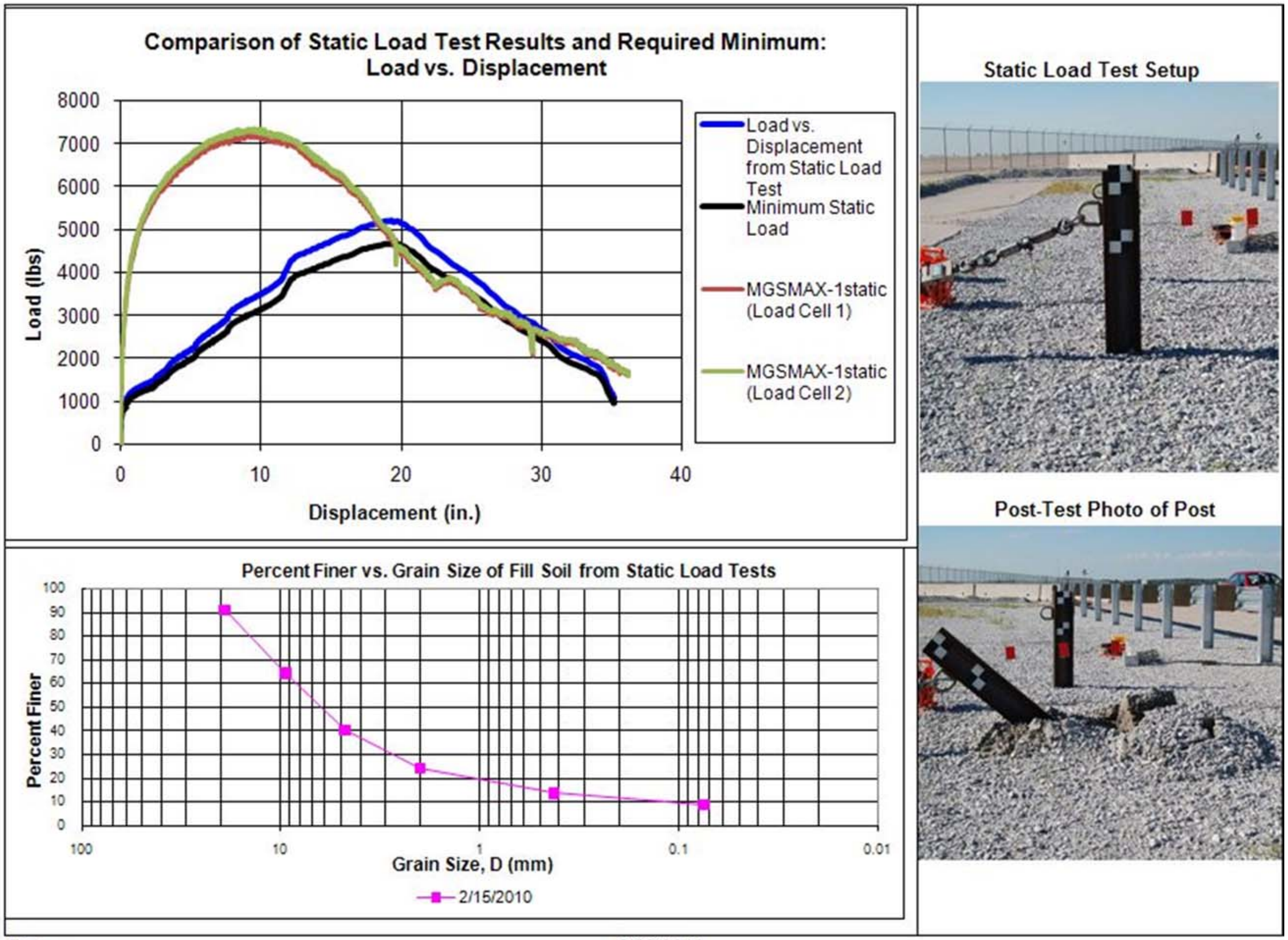
Figure B-2. Vehicle Mass Distribution, Test No. MGSMRH-2

Appendix C - Static Soil Tests



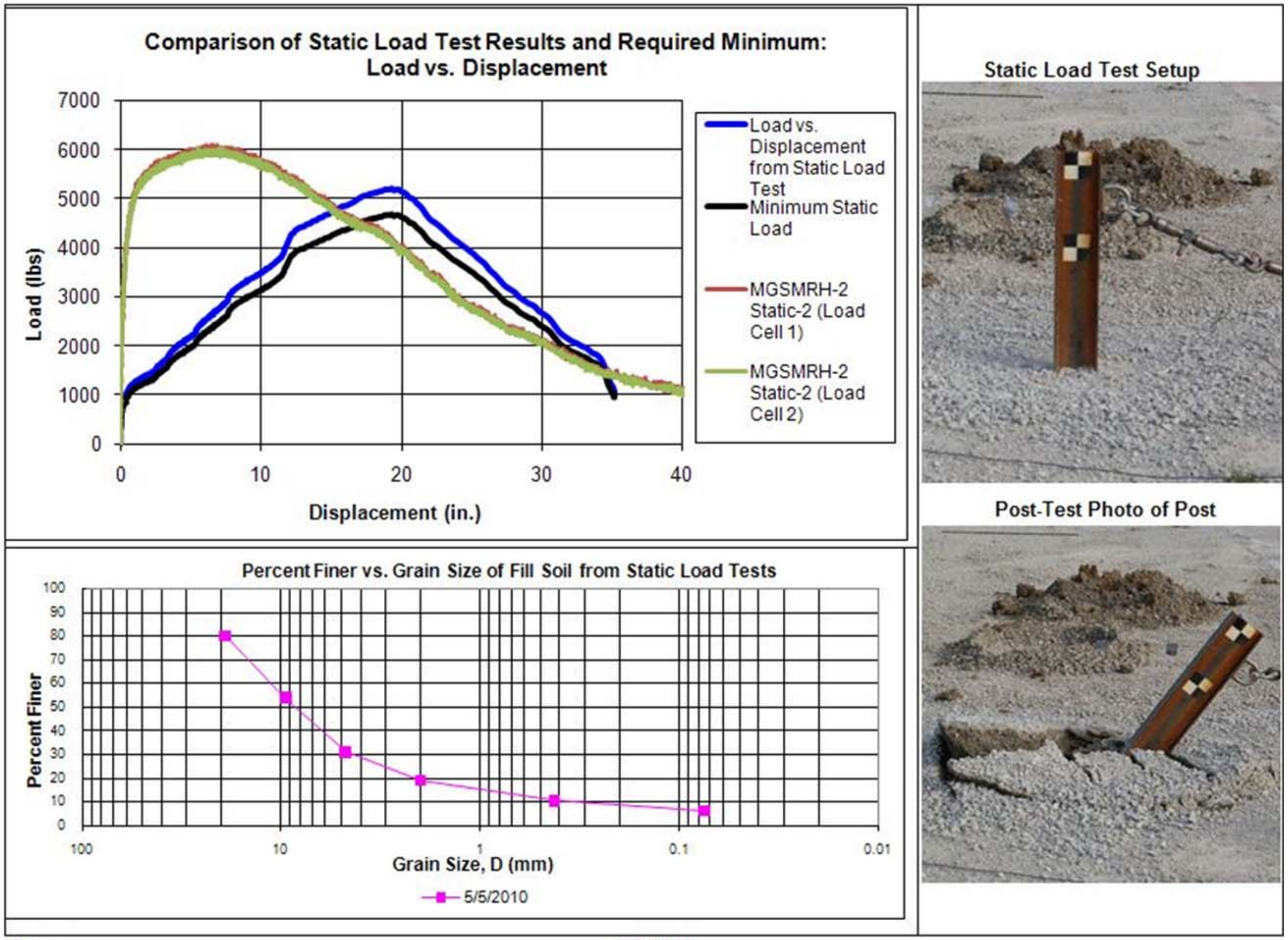
Date	7/7/2005
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well Graded Gravel (GW)
Fill material description (ASTM D2487) & sieve analysis	Well Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	6-inch lifts tamped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

Figure C-1. Soil Strength, Initial Baseline Tests



Date... 6/29/2010
Test Facility & Site Location.. Midwest Roadside 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 C-2. Static Soil Test, Test No. MGSMRH-1



Date	9/9/2010
Test Facility & Site Location	Midwest Roadside 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 C-3. Static Soil Test, Test No. MGSMRH-2

Appendix D - Vehicle Deformation Records

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MGSMRH-1
VEHICLE: 1100C Rio Sedan

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

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	28	8 1/4	-4 1/2	28 1/4	8 1/2	-4 3/4	1/4	1/4	- 1/4
2	29 3/4	12 3/4	-4 1/2	30	13	-4 1/2	1/4	1/4	0
3	30 1/4	18	-3 1/4	30	18 1/4	-3 1/2	- 1/4	1/4	- 1/4
4	26	24 3/4	-1 3/4	25 3/4	24 1/2	-1 3/4	- 1/4	- 1/4	0
5	23 3/4	7 1/2	-7 1/4	23 3/4	7 3/4	-7 1/2	0	1/4	- 1/4
6	25 3/4	12 3/4	-8 1/4	26	13	-8 1/4	1/4	1/4	0
7	26	17 1/4	-8	26 1/4	17 1/4	-7 1/4	1/4	0	3/4
8	24 1/4	25 3/4	-4 3/4	24 1/4	25 3/4	-4 3/4	0	0	0
9	20 1/4	7 1/2	-9 1/2	20 1/4	7 3/4	-9 1/2	0	1/4	0
10	21 1/4	13	-9 1/2	21 1/4	13 1/4	-9 3/4	0	1/4	- 1/4
11	22	19	-8 1/2	22	19 1/4	-8 3/4	0	1/4	- 1/4
12	22	24 1/2	-8 1/2	22 1/4	24 1/2	-8 1/2	1/4	0	0
13	16	8	-9	16	8 1/4	-9 1/4	0	1/4	- 1/4
14	16 1/2	13 1/4	-9	16 1/2	13 3/4	-9 1/4	0	1/2	- 1/4
15	17 3/4	18 1/4	-8 1/2	17 1/2	18 3/4	-8 3/4	- 1/4	1/2	- 1/4
16	18	25 1/2	-8 1/2	18	25	-8 1/2	0	- 1/2	0
17	9 3/4	3 1/4	-4 1/2	9 3/4	3 1/4	-4 3/4	0	0	- 1/4
18	11 1/4	8 1/4	-9	11 1/2	8 1/4	-9	1/4	0	0
19	11 3/4	13 1/2	-9	12	13 1/2	-9	1/4	0	0
20	12	18 1/4	-8 1/4	12	18 1/2	-8 1/2	0	1/4	- 1/4
21	14 1/2	24 1/4	-8 1/4	14 1/2	25	-8 1/4	0	3/4	0
22	4 3/4	4	-4 1/4	4 3/4	4	-4 1/4	0	0	0
23	6 1/2	11	-8 1/2	6 3/4	11 1/4	-8 3/4	1/4	1/4	- 1/4
24	7	19 1/2	-8	6 3/4	19 3/4	-8	- 1/4	1/4	0
25	6 3/4	25	-7 3/4	6 3/4	25 1/4	-7 3/4	0	1/4	0
26	3/4	6 1/2	-4 3/4	3/4	6 1/2	-4 3/4	0	0	0
27	1/2	13 1/4	-5 1/4	1/2	13 1/4	-5 1/4	0	0	0
28	1/2	23	-4 1/4	1/4	23 1/4	-4 1/4	- 1/4	1/4	0
29							0	0	0
30							0	0	0
31							0	0	0

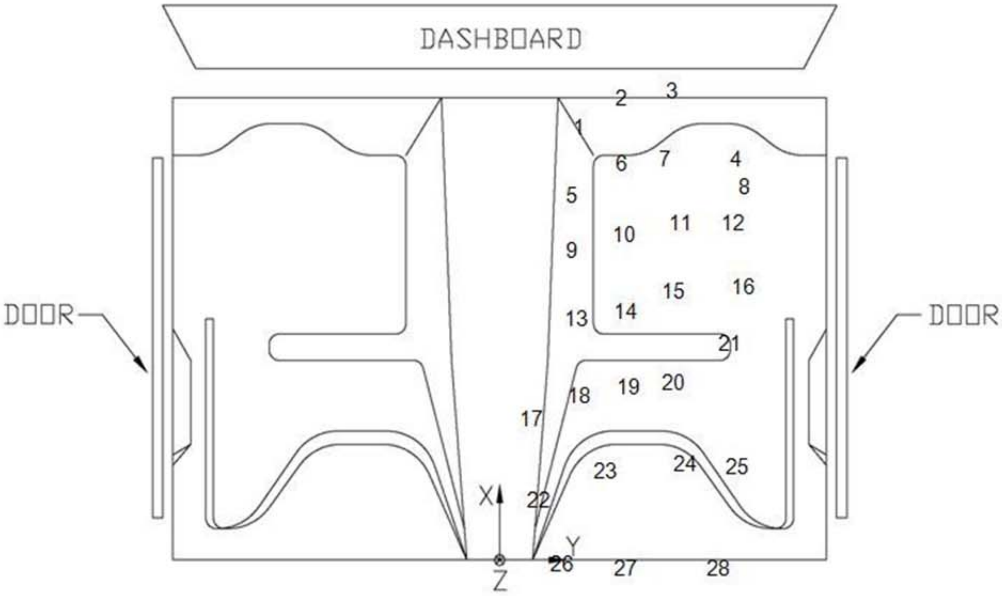


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. MGSMRH-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MGSMRH-1
VEHICLE: 1100C Rio Sedan

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

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	38	12	-4	38	12	-4 1/4	0	0	- 1/4
2	40	16 1/2	-4 1/2	39 3/4	16 1/2	-4 3/4	- 1/4	0	- 1/4
3	40 1/4	22	-4	39 3/4	22	-4	- 1/2	0	0
4	35 3/4	28 1/4	-3	35 1/2	28 1/4	-3 1/4	- 1/4	0	- 1/4
5	33 3/4	11 1/4	-7	33 3/4	11 1/2	-7	0	1/4	0
6	36	16 1/4	-8 1/2	36	16 1/4	-8 1/2	0	0	0
7	36 1/4	21	-7 3/4	36 1/4	20 3/4	-7 3/4	0	- 1/4	0
8	34 1/4	29 1/2	-6 1/4	34 1/4	29 1/2	-6 1/4	0	0	0
9	30 1/2	11 1/2	-9	30 1/2	11 1/2	-9 1/4	0	0	- 1/4
10	31 1/2	16 3/4	-9 1/2	31 1/2	16 3/4	-10	0	0	- 1/2
11	32 1/4	22 3/4	-9 1/4	32 1/4	22 3/4	-9 1/2	0	0	- 1/4
12	32 1/2	27 3/4	-9 3/4	32 1/4	28	-10	- 1/4	1/4	- 1/4
13	26	11 1/2	-8 1/2	26 1/4	11 1/2	-9	1/4	0	- 1/2
14	26 3/4	17 1/4	-9 1/4	27	17	-9 1/2	1/4	- 1/4	- 1/4
15	28	22 1/4	-9 1/4	28	22 1/2	-9 1/2	0	1/4	- 1/4
16	28 1/4	28 1/4	-9 3/4	28 1/4	28 3/4	-9 3/4	0	1/2	0
17	19 1/2	7 1/4	-3 3/4	19 1/2	7 1/4	-4	0	0	- 1/4
18	22	11 1/2	-8 3/4	22	11 1/2	-8 3/4	0	0	0
19	22 1/2	17	-9	22 1/2	16 3/4	-9 1/4	0	- 1/4	- 1/4
20	22 3/4	21 1/2	-9	22 3/4	21 1/2	-9	0	0	0
21	25	28 1/4	-9 1/2	24 3/4	28 1/4	-9 1/2	- 1/4	0	0
22	14 3/4	8	-3 1/2	14 1/2	8	-3 1/2	- 1/4	0	0
23	17	14 1/2	-8 1/2	17	14 1/2	-8 3/4	0	0	- 1/4
24	17	23	-8 3/4	17 1/4	23	-8 3/4	1/4	0	0
25	17	28 1/2	-9 1/4	17 1/4	28 1/2	-9 1/4	1/4	0	0
26	10 3/4	10 1/2	-4 1/4	10 3/4	10 1/4	-4 1/2	0	- 1/4	- 1/4
27	10 3/4	17 1/4	-5 1/2	10 3/4	17	-5 1/2	0	- 1/4	0
28	10 3/4	27	-5 1/2	10 3/4	26 3/4	-5 1/2	0	- 1/4	0
29							0	0	0
30							0	0	0
31							0	0	0

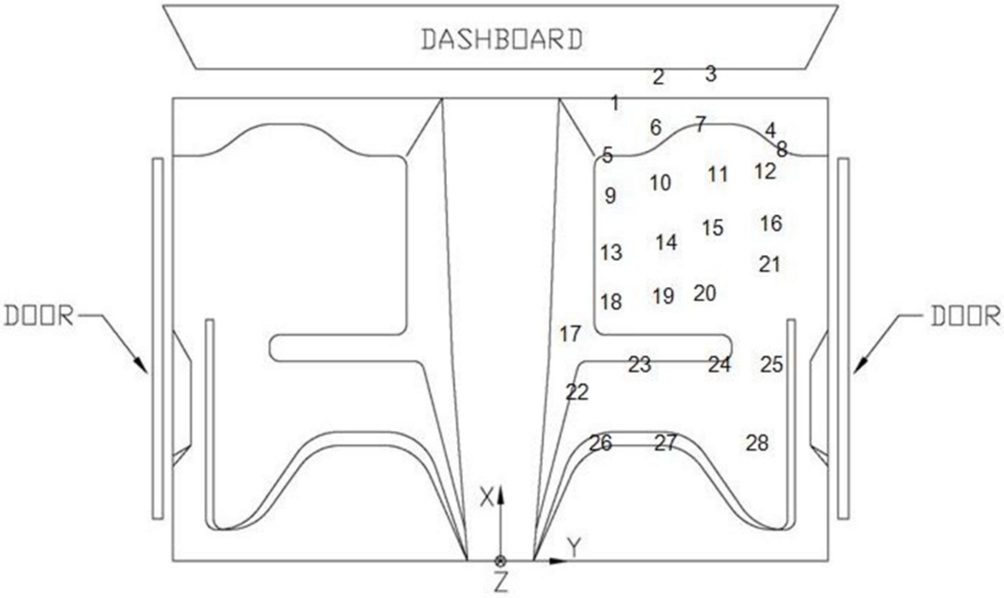


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. MGSMRH-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MGSMRH-1
VEHICLE: 1100C Rio Sedan

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

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	33 1/2	32	18 1/2	33 1/4	31 3/4	18 3/4	- 1/4	- 1/4	1/4
	A2	33 1/2	38 3/4	19	33 1/2	38 1/2	19	0	- 1/4	0
	A3	33 1/2	45 1/2	19 1/4	33 1/2	45 1/2	19 1/4	0	0	0
	A4	28 1/2	33 1/4	14	28 1/4	32 1/2	13 3/4	- 1/4	- 3/4	- 1/4
	A5	28 1/2	40	14 1/4	28 1/2	39 1/4	14 1/4	0	- 3/4	0
	A6	28 1/2	48 1/4	14 1/4	28 1/4	47 1/2	14 1/2	- 1/4	- 3/4	1/4
SIDE PANEL	B1	32 3/4	24 1/4	-3	32 3/4	24 3/4	-3 1/4	0	1/2	- 1/4
	B2	30	24 1/2	3/4	30	25	1/2	0	1/2	- 1/4
	B3	29	23 3/4	-2 1/2	29	24	-3	0	1/4	- 1/2
IMPACT SIDE DOOR	C1	26 3/4	36	16 3/4	26 3/4	36	16 1/2	0	0	- 1/4
	C2	17 1/2	36	17 3/4	17 1/2	36 1/4	17 3/4	0	1/4	0
	C3	8	36 3/4	18 3/4	8	37	18 3/4	0	1/4	0
	C4	21 3/4	29 3/4	- 1/4	21 3/4	29 3/4	- 1/2	0	0	- 1/4
	C5	13 3/4	29 1/2	-1 1/2	13 3/4	29 1/2	-1 1/2	0	0	0
	C6	3 3/4	30 1/2	5	3 3/4	30 3/4	5 1/4	0	1/4	1/4
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

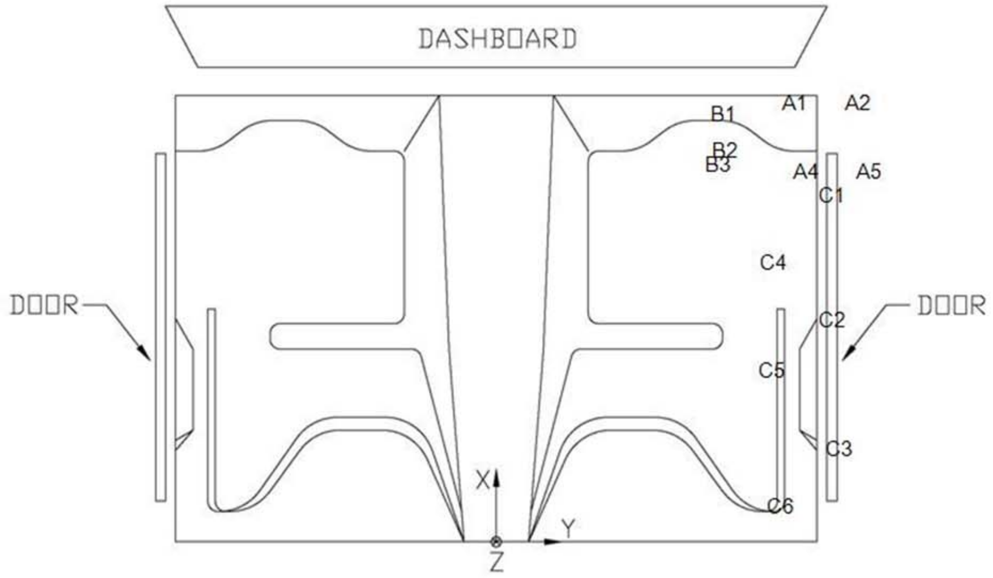


Figure D-3. Occupant Compartment Deformation Data – Set 1, Test No. MGSMRH-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MGSMRH-1
VEHICLE: 1100C Rio Sedan

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

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	49 3/4	34 1/2	19	50	34 1/4	19	1/4	- 1/4	0
	A2	50	41	18 1/2	50 1/4	41	18 1/2	1/4	0	0
	A3	50 1/4	48	17 3/4	50 1/4	48	17 3/4	0	0	0
	A4	45 1/2	34 1/4	14	45 3/4	34 1/4	14	1/4	0	0
	A5	45 3/4	41 1/4	13 1/2	45 3/4	41 1/4	13 1/2	0	0	0
	A6	45 1/2	49 1/2	12 3/4	45 1/2	49 1/4	13	0	- 1/4	1/4
SIDE PANEL	B1	52	28	-5	52	28	-4 3/4	0	0	1/4
	B2	49 1/4	27	-1	49 1/4	27	-1	0	0	0
	B3	48 1/4	26 1/4	-4 1/4	48 1/2	26 1/4	-4 1/4	1/4	0	0
IMPACT SIDE DOOR	C1	30 1/2	38	14 3/4	30 1/4	38	14 3/4	- 1/4	0	0
	C2	21	38 3/4	16	21	38 3/4	16	0	0	0
	C3	11 1/2	39 1/2	17	11 1/2	39 1/2	17	0	0	0
	C4	28 1/4	33 1/4	-2	28 1/4	33 1/4	-2	0	0	0
	C5	20 1/4	33 1/4	-3 1/4	20 1/4	33 1/4	-3	0	0	1/4
	C6	8 3/4	34	3 1/4	9	34 1/4	3 1/2	1/4	1/4	1/4
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

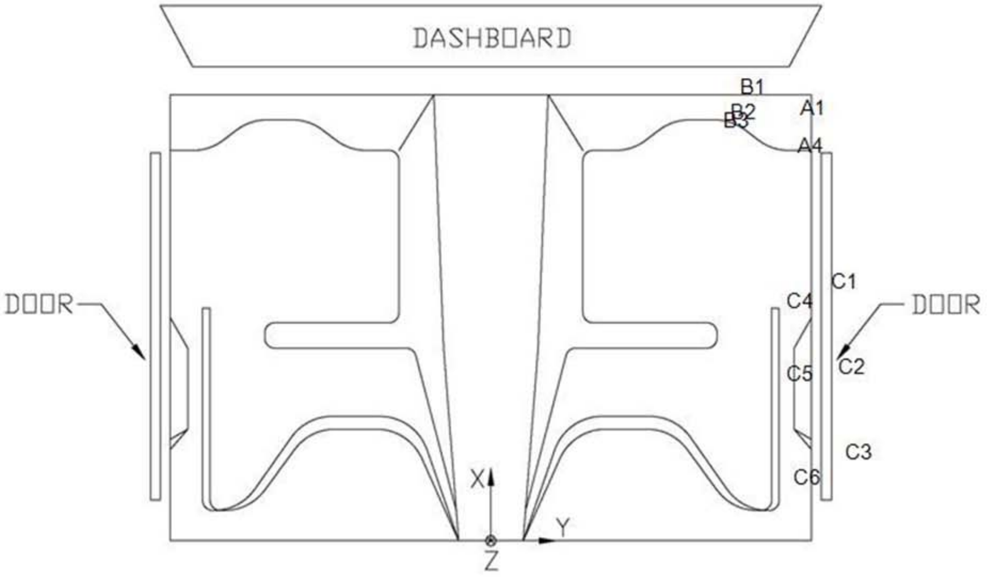
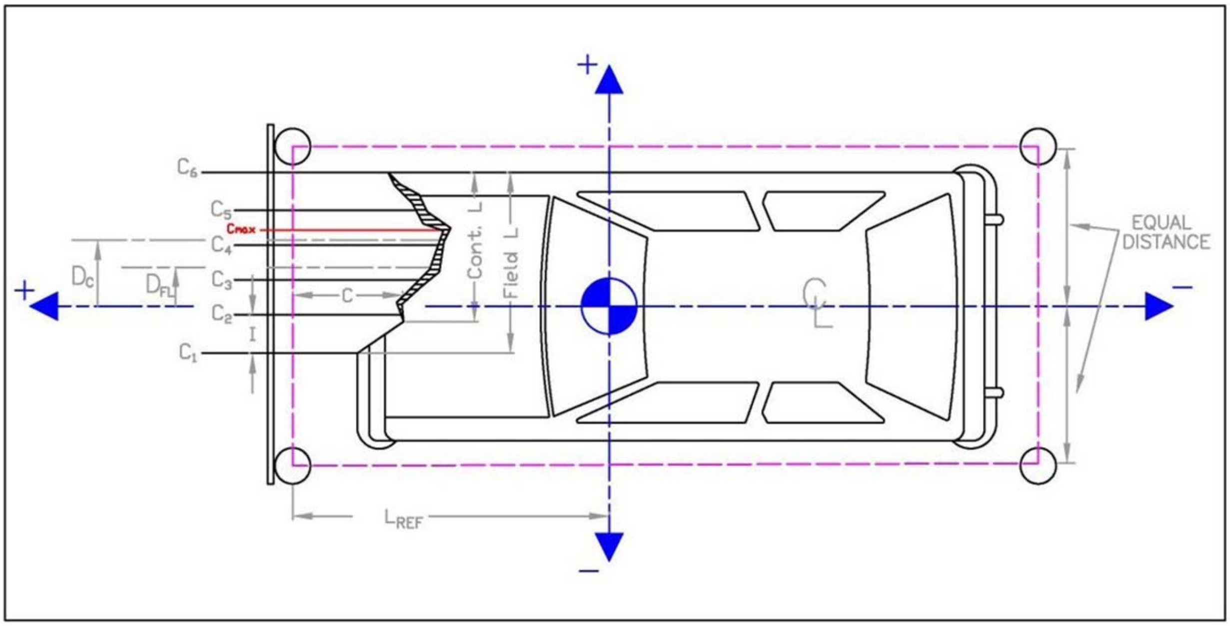


Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. MGSMRH-1

Date: 7/6/2010 **Test Number:** MGSMRH-1

Make: Kia **Model:** 1100C Rio Sedan **Year:** 2003



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	77	(1956)
Width of contact and induced crush - Field L:	32.125	(816)
Crush measurement spacing interval (L/5) - I:	6.425	(163)
Distance from center of vehicle to center of Field L - D_{FL}:	16.0625	(408)
Width of Contact Damage:	28.125	(714)
Distance from center of vehicle to center of contect damage - D_C:	18.0625	(459)

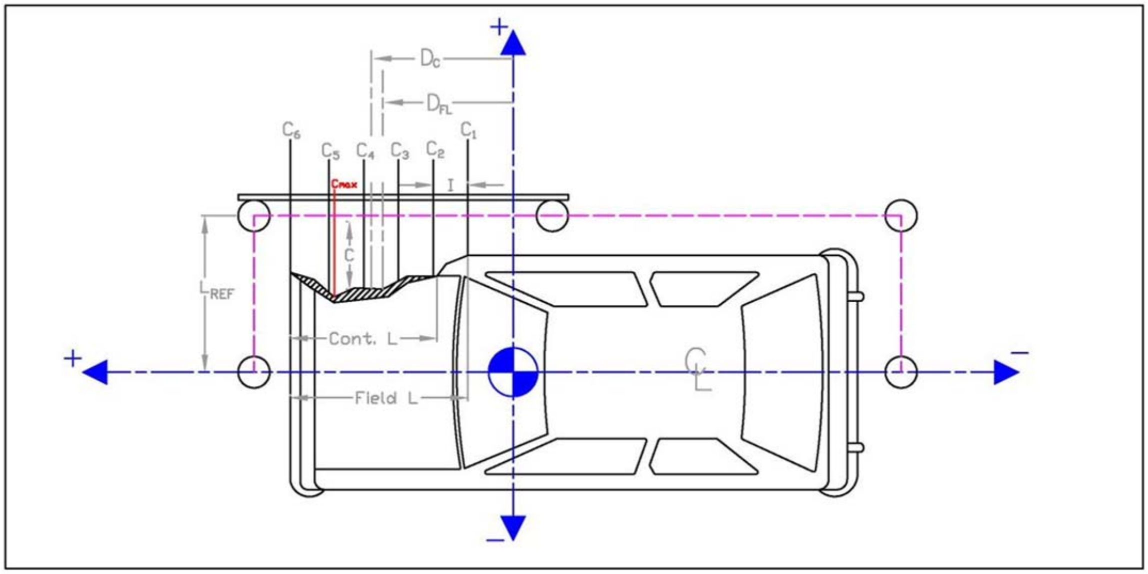
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	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	8	(203)	0	()	9.25	(235)	-1.54	-(39)	0.3	(7)
C_2	9	(229)	6.425	(163)	9.39	(239)			1.1	(29)
C_3	9.5	(241)	12.85	(326)	10.02	(254)			1.0	(26)
C_4	14	(356)	19.275	(490)	11.52	(292)			4.0	(102)
C_5	30	(762)	25.7	(653)	14.09	(358)			17.4	(443)
C_6	31	(787)	32.125	(816)	29.50	(749)			3.0	(77)
C_{MAX}	30	(762)	25.7	(653)	14.09	(358)			17.4	(443)

Figure D-5. Exterior Vehicle Crush (NASS) - Front, Test No. MGSMRH-1

Date: 7/6/2010 **Test Number:** MGSMRH-1

Make: Kia **Model:** 1100C Rio Sedan **Year:** 2003



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	39	(991)
Width of contact and induced crush - Field L:	166	(4216)
Crush measurement spacing interval (L/5) - I:	33.2	(843)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-14	-(356)
Width of Contact Damage:	58.75	(1492)
Distance from vehicle c.g. to center of contect damage - D_C:	39.875	(1013)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been remeoved)

	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	NA	NA	-97	-(2464)	22.75	(578)	3	(76)	NA	NA
C_2	7.5	(191)	-63.8	-(1621)	4.25	(108)			0.3	(6)
C_3	6.5	(165)	-30.6	-(777)	3.13	(79)			0.4	(10)
C_4	6.25	(159)	2.6	(66)	3.13	(79)			0.1	(3)
C_5	Na	NA	35.8	(909)	4.00	(102)			NA	NA
C_6	NA	NA	69	(1753)	23.50	(597)			NA	NA
C_{MAX}	14	(356)	47	(1194)	4.38	(111)			6.6	(168)

Figure D-6. Exterior Vehicle Crush (NASS) - Side, Test No. MGSMRH-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MGSMRH-2
VEHICLE: 1100C RIO

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

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	27 1/2	8	-4 3/4	27 1/2	8	-4 1/2	0	0	1/4
2	29 1/4	12 3/4	-4 3/4	29 1/4	12 3/4	-4 1/2	0	0	1/4
3	28 3/4	17	-4 1/2	28 3/4	17 1/2	-4	0	1/2	1/2
4	26 1/4	24	-1 3/4	26	24 1/2	-1 1/4	- 1/4	1/2	1/2
5	24 1/4	8	-6 1/4	24 1/4	8	-6	0	0	1/4
6	25 1/2	11 1/4	-8	25 1/2	11 1/4	-7 1/2	0	0	1/2
7	25 3/4	17	-7	26	17	-6 1/2	1/4	0	1/2
8	24 1/2	24 3/4	-4 3/4	24 1/4	25	-4 1/2	- 1/4	1/4	1/4
9	20 1/2	8	-8 3/4	20 1/2	8	-8 1/2	0	0	1/4
10	21 1/2	12 3/4	-9	21 1/2	12 3/4	-8 3/4	0	0	1/4
11	21 3/4	17	-8	22	17	-7 3/4	1/4	0	1/4
12	21 1/2	23 3/4	-8 1/4	21 1/2	23 3/4	-7 3/4	0	0	1/2
13	16 1/4	7 1/2	-8 1/4	16 1/4	7 1/2	-8 1/4	0	0	0
14	16 1/2	13 3/4	-8 1/2	16 3/4	13 1/2	-8 1/4	1/4	- 1/4	1/4
15	17	18 1/2	-8	17	18 1/2	-7 3/4	0	0	1/4
16	18	24 1/2	-8	18	24 3/4	-7 1/2	0	1/4	1/2
17	9 3/4	4	-3 1/2	9 3/4	4	-3 1/2	0	0	0
18	11 1/2	7 3/4	-8	11 1/2	7 3/4	-8	0	0	0
19	11 3/4	14	-8	11 3/4	13 3/4	-7 3/4	0	- 1/4	1/4
20	12	18 1/2	-7 1/2	12	18 3/4	-7 1/2	0	1/4	0
21	11 1/4	24 1/2	-7 1/2	11 1/4	24 1/2	-6 1/2	0	0	1
22	6 1/4	4	-3 1/4	6	4	-3 1/4	- 1/4	0	0
23	6 3/4	11 1/4	-7 3/4	6 3/4	11 1/4	-7 1/2	0	0	1/4
24	6 3/4	18 1/2	-7 1/4	6 3/4	18 3/4	-7	0	1/4	1/4
25	7 3/4	25 1/4	-7 1/4	7 1/2	25	-6 1/2	- 1/4	- 1/4	3/4
26	1 1/4	7 3/4	-4	1 1/4	7 3/4	-3 3/4	0	0	1/4
27	1	17 1/4	-4 1/2	1	17 1/4	-4 1/4	0	0	1/4
28	1 1/2	24 1/2	-3 3/4	1 1/2	24 1/4	-3 3/4	0	- 1/4	0
29							0	0	0
30							0	0	0
31							0	0	0

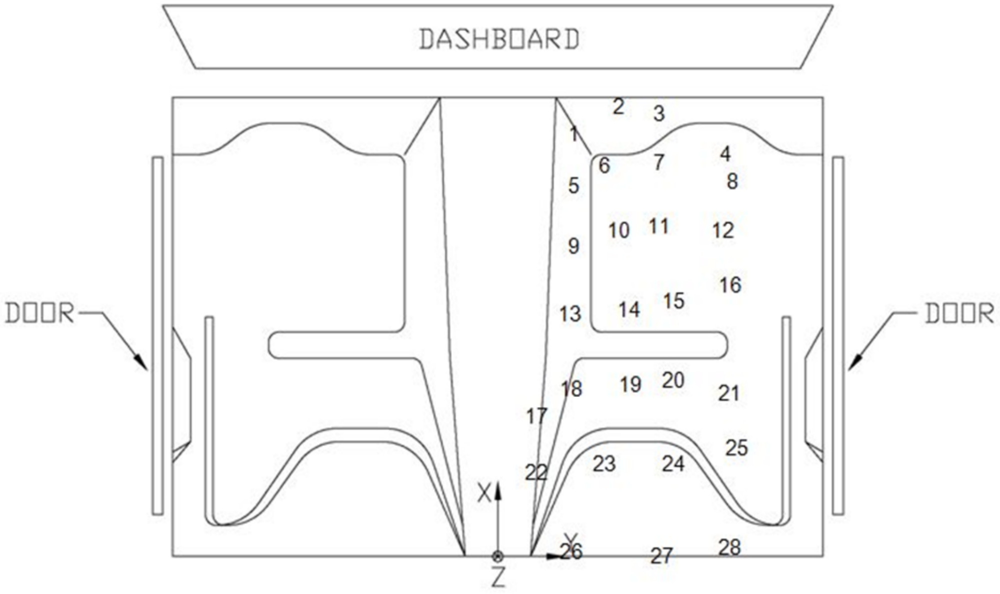


Figure D-7. Floor Pan Deformation Data – Set 1, Test No. MGSMRH-2

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MGSMRH-2
VEHICLE: 1100C RIO

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

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	33.5	11.25	-4.25	33.5	11.75	-4.25	0	1/2	0
2	35.25	16.5	-4	35.25	16.25	-4.25	0	- 1/4	- 1/4
3	34.75	21.25	-3.75	34.5	21.25	-4	- 1/4	0	- 1/4
4	32	28	-1.25	31.75	28.5	-1.25	- 1/4	1/2	0
5	30.25	11.25	-5.75	30.25	11	-5.75	0	- 1/4	0
6	31.75	14.25	-7.5	31.75	14.75	-7.25	0	1/2	1/4
7	32	20.25	-6.5	32	20.5	-6.5	0	1/4	0
8	30.25	29	-4.5	30.25	29.5	-4.5	0	1/2	0
9	26.5	11.5	-8.5	26.5	11.25	-8.5	0	- 1/4	0
10	27.5	16.25	-8.5	27.5	16.25	-8.75	0	0	- 1/4
11	28	20.25	-7.5	28	20.5	-7.75	0	1/4	- 1/4
12	27.5	27.5	-8	27.5	28	-8	0	1/2	0
13	22.25	11.5	-8	22.5	11.25	-8	1/4	- 1/4	0
14	22.75	17	-8.25	23	16.75	-8.5	1/4	- 1/4	- 1/4
15	23.25	21.75	-8	23.25	22	-8	0	1/4	0
16	24	28.25	-8	24	28.5	-7.5	0	1/4	1/2
17	15.75	8	-3.5	15.75	8	-3.5	0	0	0
18	17.5	11.75	-8	17.5	11.25	-8	0	- 1/2	0
19	18	17.75	-8	18	17.5	-8	0	- 1/4	0
20	18.25	22.25	-7.75	18.25	22.5	-7.75	0	1/4	0
21	17.5	28.25	-7.75	17.25	28.5	-6.75	- 1/4	1/4	1
22	12.25	8	-3.25	12	7.5	-3.25	- 1/4	- 1/2	0
23	12.75	15.25	-7.75	13	15.25	-8	1/4	0	- 1/4
24	13	22.25	-7.5	13	22.5	-7.5	0	1/4	0
25	14	29	-7.5	13.5	29.25	-7	- 1/2	1/4	1/2
26	7.25	11.5	-4.25	7.5	11.5	-4.25	1/4	0	0
27	7	21	-4.75	7.25	21	-4.75	1/4	0	0
28	7.25	28.25	-4.25	7.5	28	-4.25	1/4	- 1/4	0
29							0	0	0
30							0	0	0
31							0	0	0

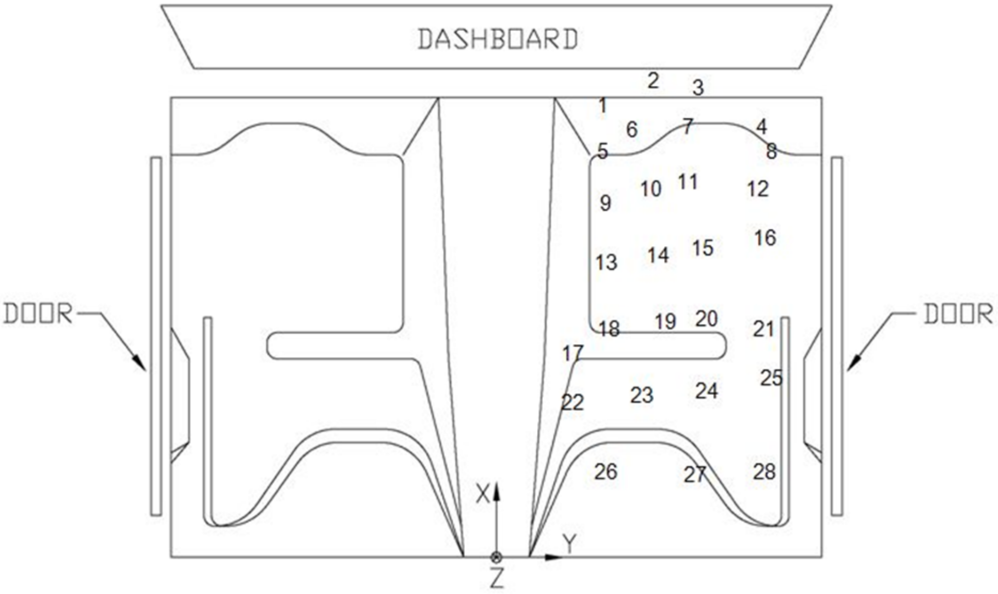


Figure D-8. Floor Pan Deformation Data – Set 2, Test No. MGSMRH-2

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MGSMRH-2
VEHICLE: 1100C RIO

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

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	49 3/4	31 3/4	19 3/4	49 3/4	31 1/2	20	0	- 1/4	1/4
	A2	50 1/4	39	19 3/4	50 1/4	39	20	0	0	1/4
	A3	50 1/4	45 1/2	19 1/2	50	45 1/2	19 3/4	- 1/4	0	1/4
	A4	45 1/4	33 1/4	14 1/2	45 1/4	33	14 3/4	0	- 1/4	1/4
	A5	45 1/2	39 3/4	14 3/4	45 1/2	39 1/2	14 3/4	0	- 1/4	0
	A6	45 1/2	47	14 3/4	45 1/2	47	15	0	0	1/4
SIDE PANEL	B1	21	23 1/4	1/2	21	23 1/4	1/2	0	0	0
	B2	22 1/4	23 1/2	-2 3/4	22 1/2	23 3/4	-2 1/2	1/4	1/4	1/4
	B3	19 3/4	23	-2 1/2	19 3/4	23 1/4	-2 1/4	0	1/4	1/4
IMPACT SIDE DOOR	C1	26	33	17	25 3/4	33	17 1/4	- 1/4	0	1/4
	C2	15	36 1/2	18 1/2	14 3/4	36 3/4	18 1/2	- 1/4	1/4	0
	C3	6 3/4	37 1/4	19 3/4	6 1/2	37 1/2	19 3/4	- 1/4	1/4	0
	C4	21 1/2	26	1	21 1/2	26	1	0	0	0
	C5	15	29 3/4	- 3/4	14 1/2	29 3/4	- 1/2	- 1/2	0	1/4
	C6	3 1/2	30 1/2	3	3 1/4	30 1/4	3 1/4	- 1/4	- 1/4	1/4
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5	Omitted due to improbability of damage						0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

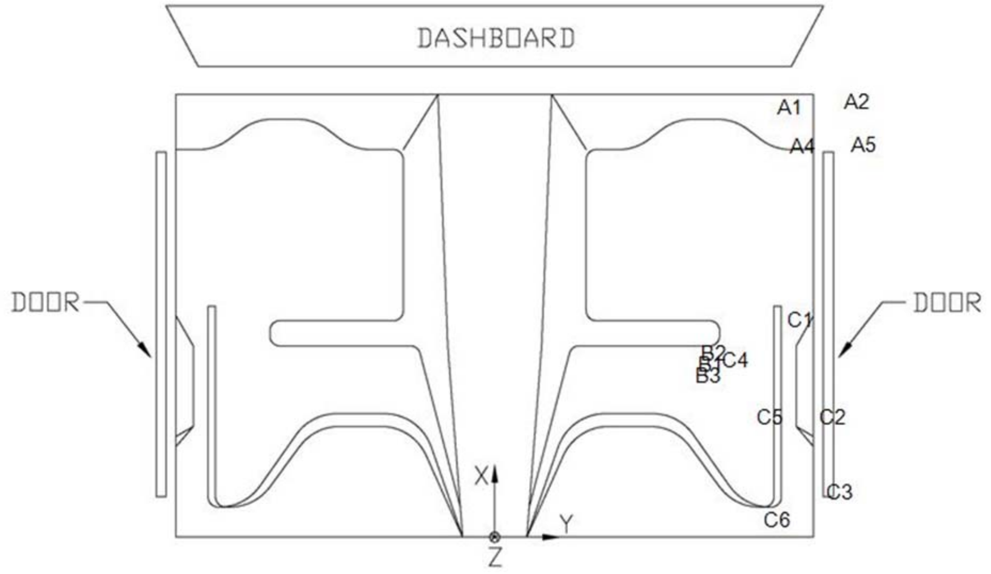


Figure D-9. Occupant Compartment Deformation Data – Set 1, Test No. MGSMRH-2

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MGSMRH-2
VEHICLE: 1100C RIO

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

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	32 3/4	32 3/4	19 3/4	32 3/4	32 1/2	19 1/2	0	- 1/4	- 1/4
	A2	33 1/4	39 1/4	19 3/4	33	39 3/4	20	- 1/4	1/2	1/4
	A3	33 1/4	45 3/4	19 1/2	33	46	19 3/4	- 1/4	1/4	1/4
	A4	29 3/4	33 3/4	14 3/4	29 1/2	33 3/4	14 3/4	- 1/4	0	0
	A5	29 3/4	40 1/4	15	29 3/4	40 1/4	14 3/4	0	0	- 1/4
	A6	30	47 1/4	15	29 3/4	47 1/2	14 3/4	- 1/4	1/4	- 1/4
SIDE PANEL	B1	26 1/2	24 1/2	3/4	26 1/2	24 1/2	1/2	0	0	- 1/4
	B2	28	24	-2 1/2	28 1/4	24 1/4	-2 1/2	1/4	1/4	0
	B3	25 1/2	23 3/4	-2 1/4	25 1/2	24	-2 1/4	0	1/4	0
IMPACT SIDE DOOR	C1	30	57 1/4	17	30	57	17	0	- 1/4	0
	C2	19 1/4	57 1/2	18	19	57 1/4	18	- 1/4	- 1/4	0
	C3	11	57 1/2	19	11	57 3/4	19	0	1/4	0
	C4	28 1/2	53 1/4	3/4	28 1/2	53 3/4	1/2	0	1/2	- 1/4
	C5	22 1/2	53 1/4	-1	22 1/4	53 1/4	-1	- 1/4	0	0
	C6	11 1/4	53 1/4	2 1/2	11	53 1/4	2 1/2	- 1/4	0	0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5	Omitted due to improbability of damage						0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

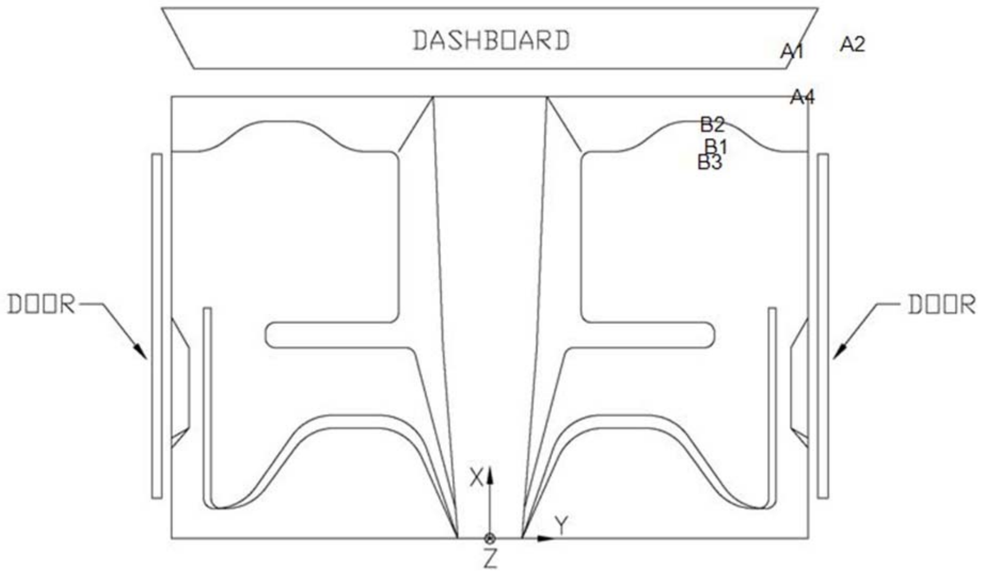
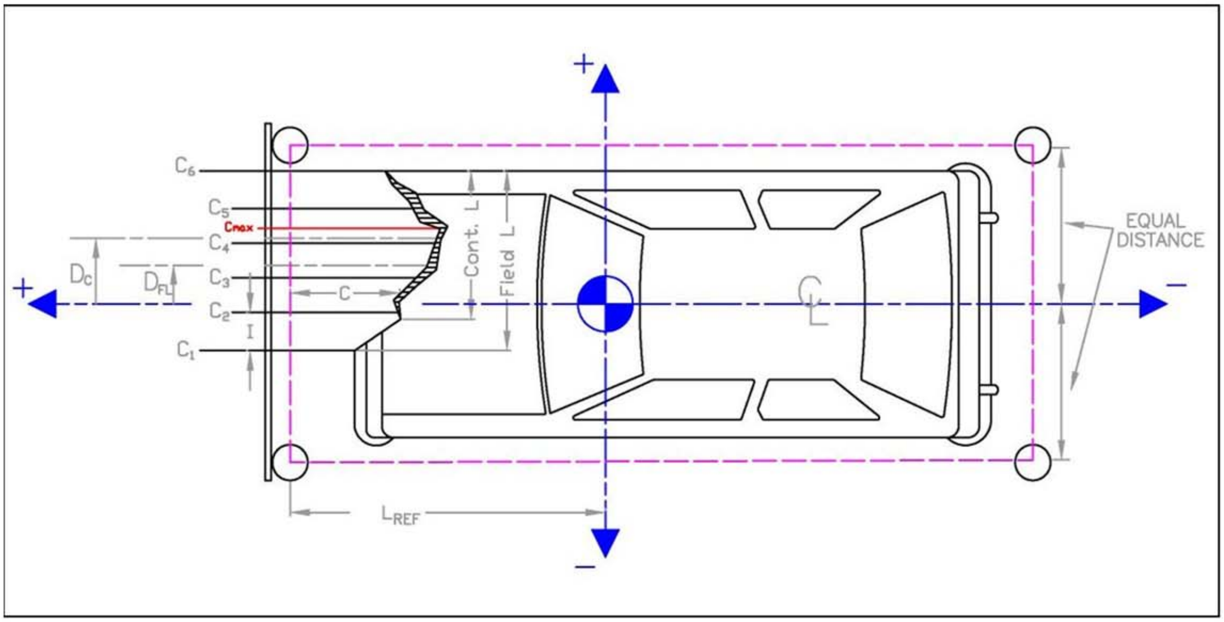


Figure D-10. Occupant Compartment Deformation Data – Set 2, Test No. MGSMRH-2

Date: 9/10/2010 **Test Number:** MGSMRH-2

Make: Kia **Model:** 1100C RIO **Year:** 2004



b

	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	71.75	(1822)
Width of contact and induced crush - Field L:	32.375	(822)
Crush measurement spacing interval (L/5) - I:	6.475	(164)
Distance from center of vehicle to center of Field L - D_{FL}:	16.1875	(411)
Width of Contact Damage:	25.375	(645)
Distance from center of vehicle to center of contect damage - D_C:	19.6875	(500)

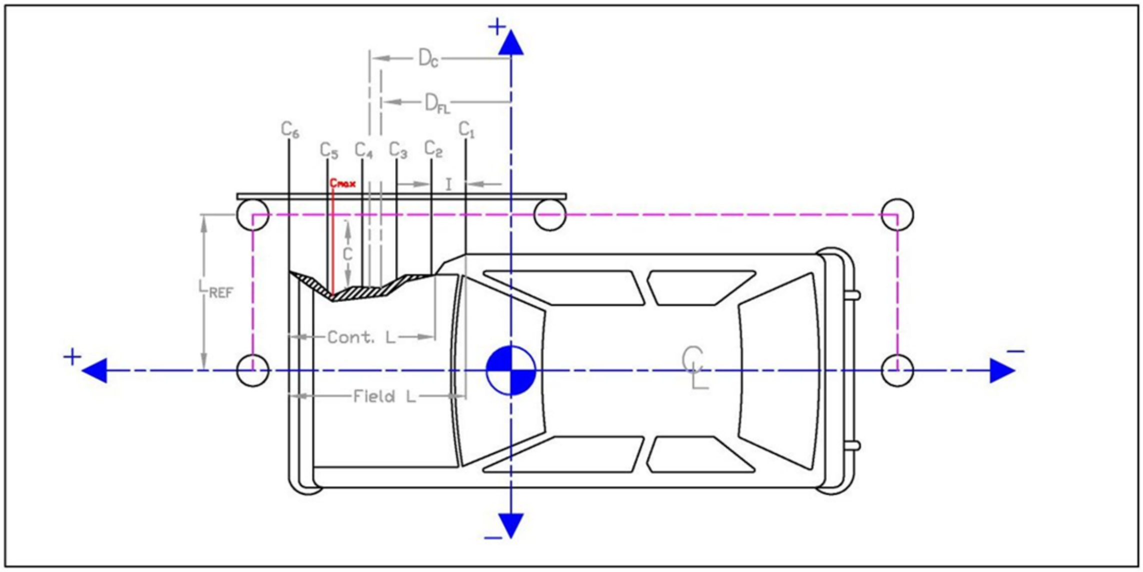
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	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	(76)	0	()	9.25	(235)	-6.80	-(173)	0.5	(14)
C_2	3.5	(89)	6.475	(164)	9.39	(239)			0.9	(23)
C_3	4.25	(108)	12.95	(329)	10.02	(254)			1.0	(26)
C_4	9.5	(241)	19.425	(493)	11.52	(292)			4.8	(122)
C_5	12.25	(311)	25.9	(658)	14.23	(362)			4.8	(122)
C_6	NA	NA	32.375	(822)	29.50	(749)			NA	NA
C_{MAX}	8.25	(210)	14	(356)	10.25	(260)			4.8	(122)

Figure D-11. Exterior Vehicle Crush (NASS) - Front, Test No. MGSMRH-2

Date: 9/10/2010 **Test Number:** MGSMRH-2

Make: Kia **Model:** 1100C RIO **Year:** 2004



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	39	(991)
Width of contact and induced crush - Field L:	90.75	(2305)
Crush measurement spacing interval (L/5) - I:	18.15	(461)
Distance from vehicle c.g. to center of Field L - D_{FL}:	24.375	(619)
Width of Contact Damage:	90.75	(2305)
Distance from vehicle c.g. to center of contect damage - D_C:	50.25	(1276)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been remeoved)

	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	7.25	(184)	-21	-(533)	3.13	(79)	3	(76)	1.1	(29)
C_2	7.25	(184)	-2.85	-(72)	3.13	(79)			1.1	(29)
C_3	7.75	(197)	15.3	(389)	3.13	(79)			1.6	(41)
C_4	7.75	(197)	33.45	(850)	4.00	(102)			0.8	(19)
C_5	12.25	(311)	51.6	(1311)	4.03	(102)			5.2	(133)
C_6	NA	NA	69.75	(1772)	23.50	(597)			NA	NA
C_{MAX}	18	(457)	57	(1448)	5.00	(127)			10.0	(254)

Figure D-12. Exterior Vehicle Crush (NASS) - Side, Test No. MGSMRH-2

Appendix E - Accelerometer and Rate Transducer Data Plots, Test No. MGSMRH-1

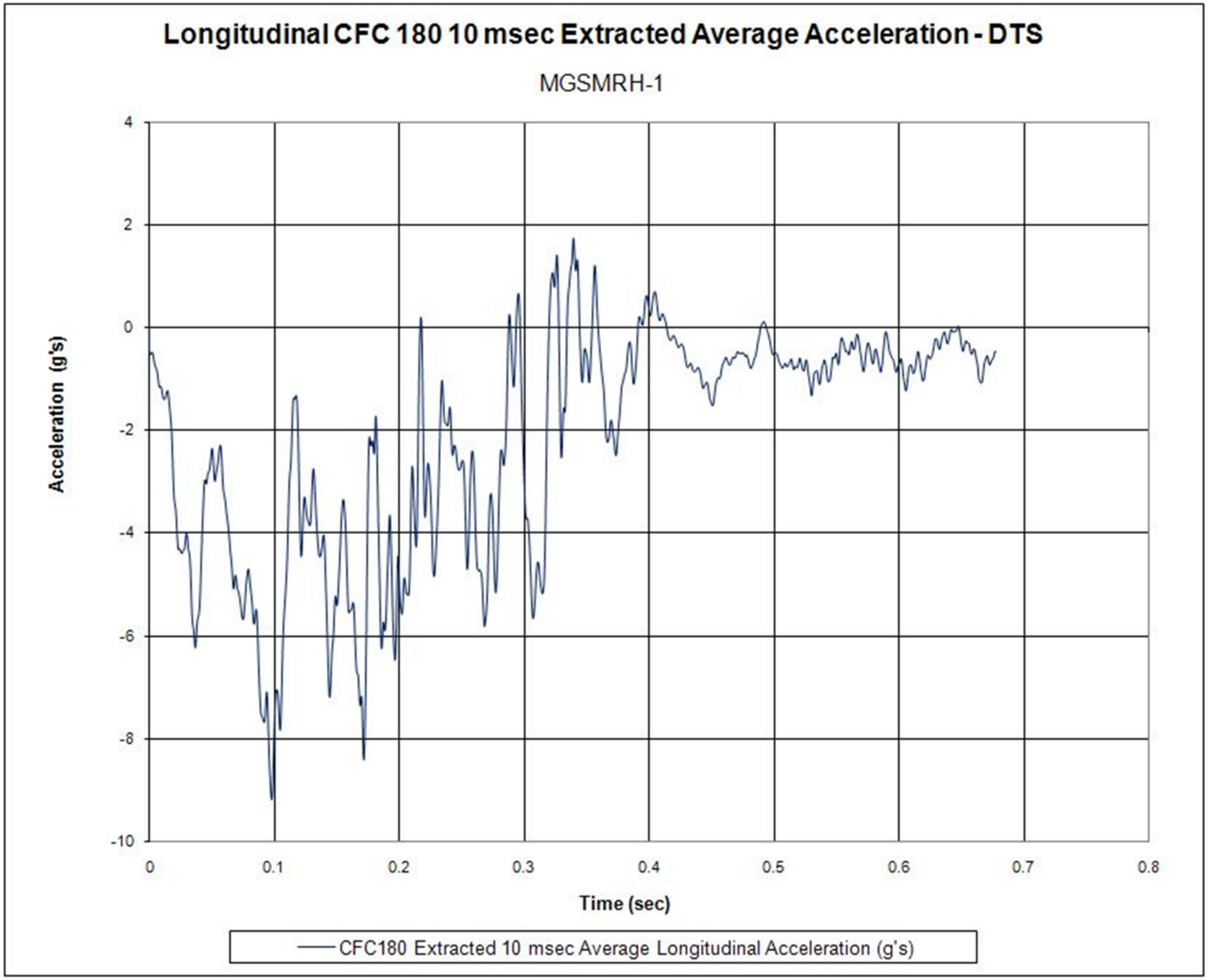


Figure E-1. 10-ms Average Longitudinal Deceleration (DTS), Test No. MGSMRH-1

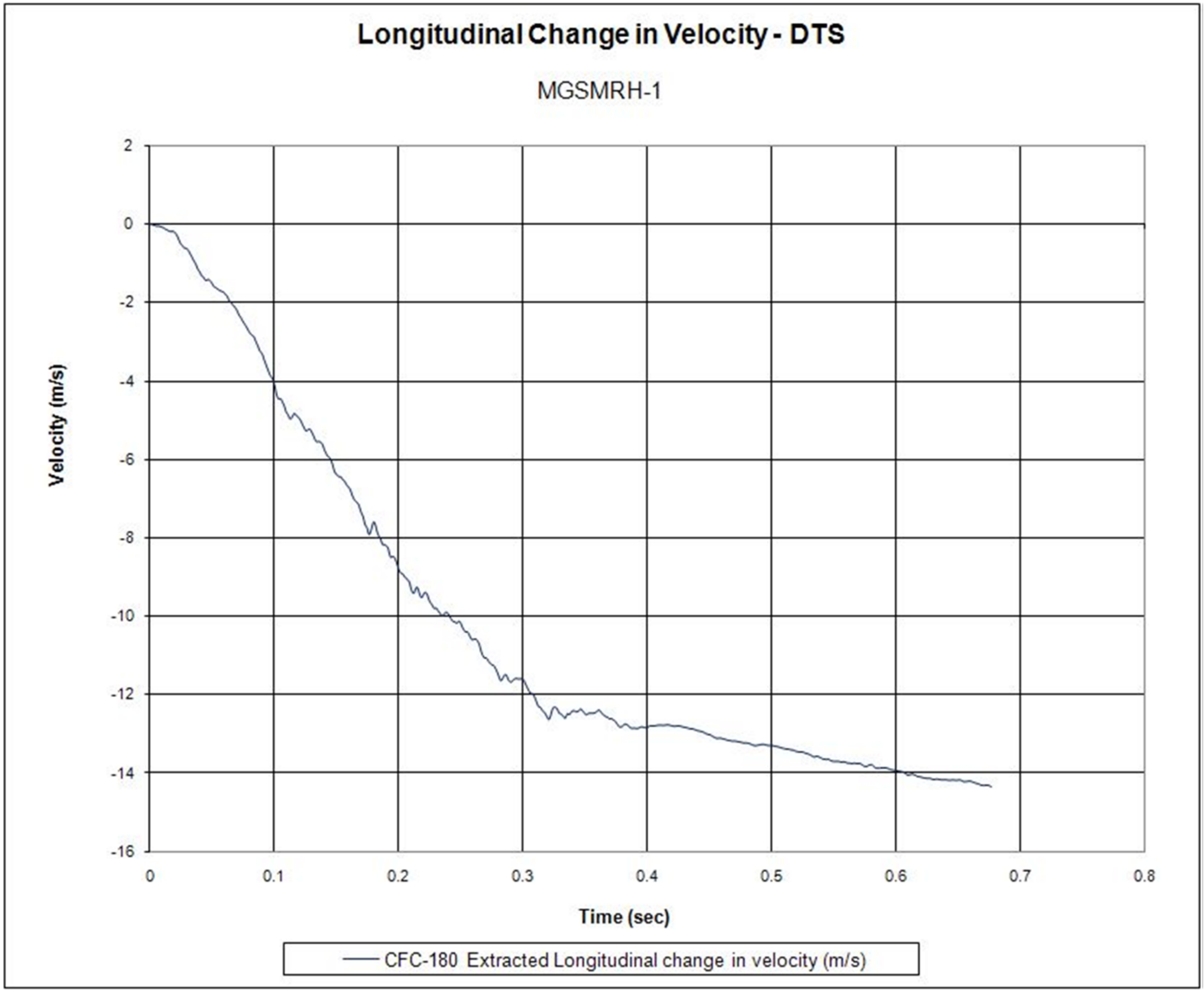


Figure E-2. Longitudinal Occupant Impact Velocity (DTS), Test No. MGSMRH-1

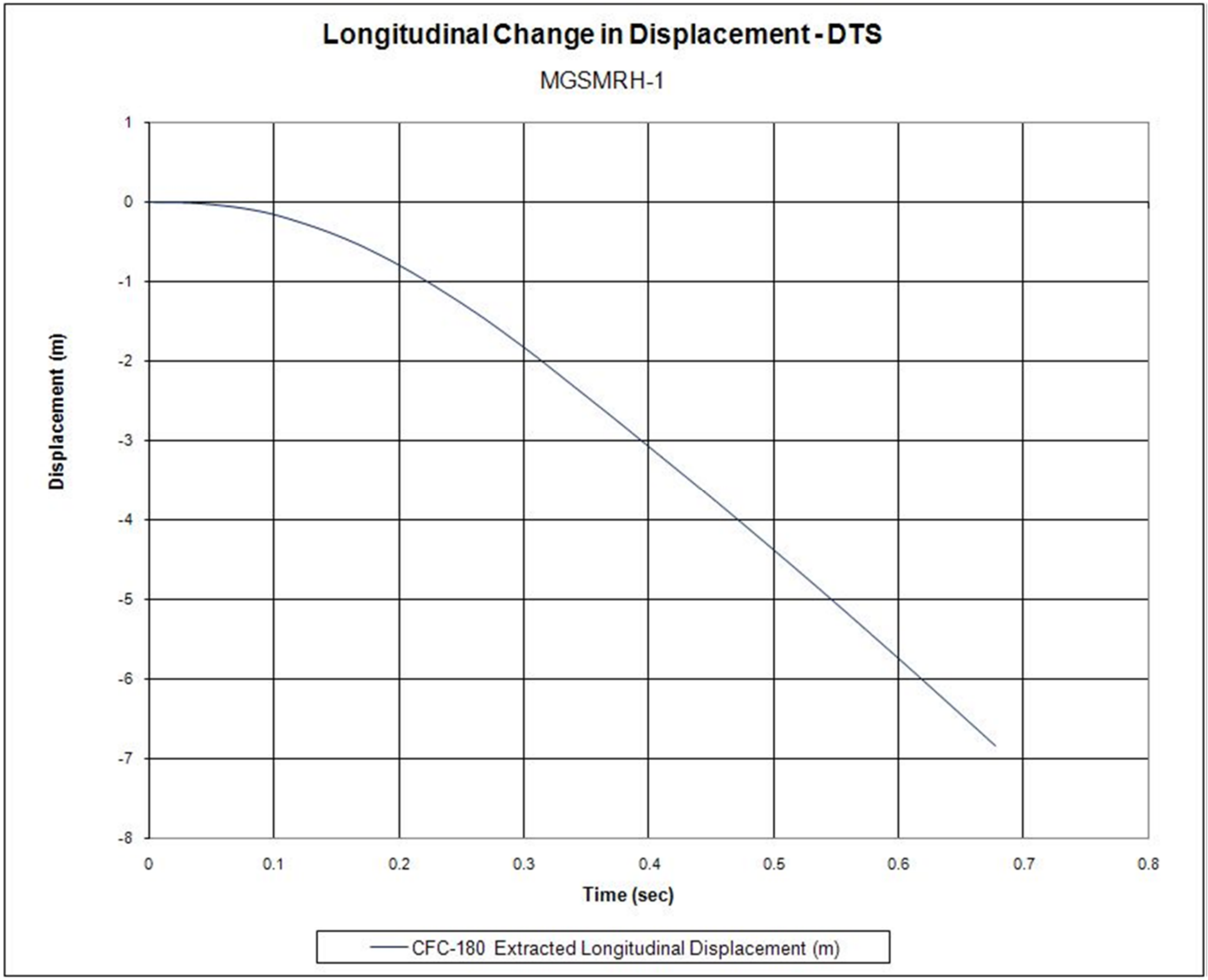


Figure E-3. Longitudinal Occupant Displacement (DTS), Test No. MGSMRH-1

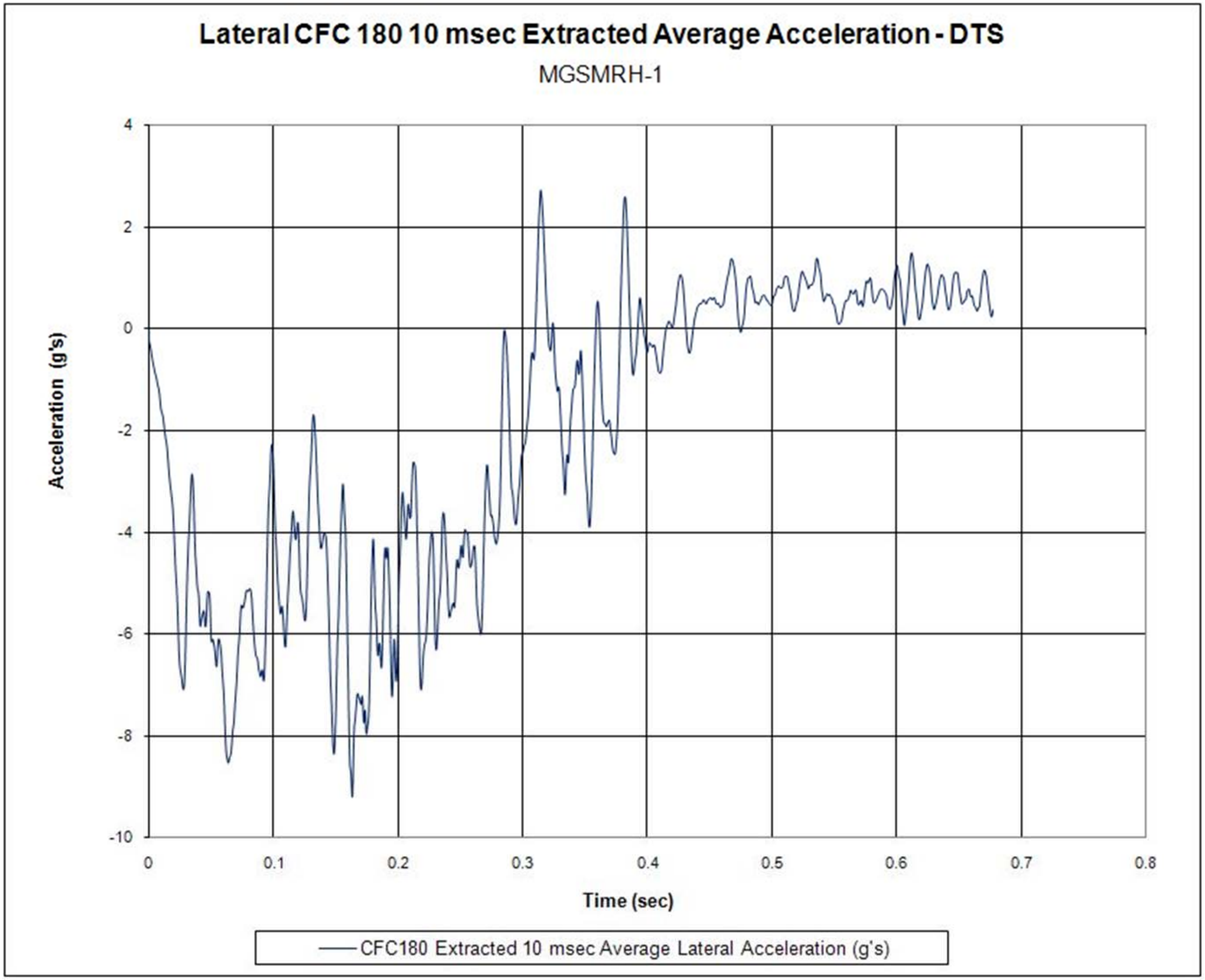


Figure E-4. 10-ms Average Lateral Deceleration (DTS), Test No. MGSMRH-1

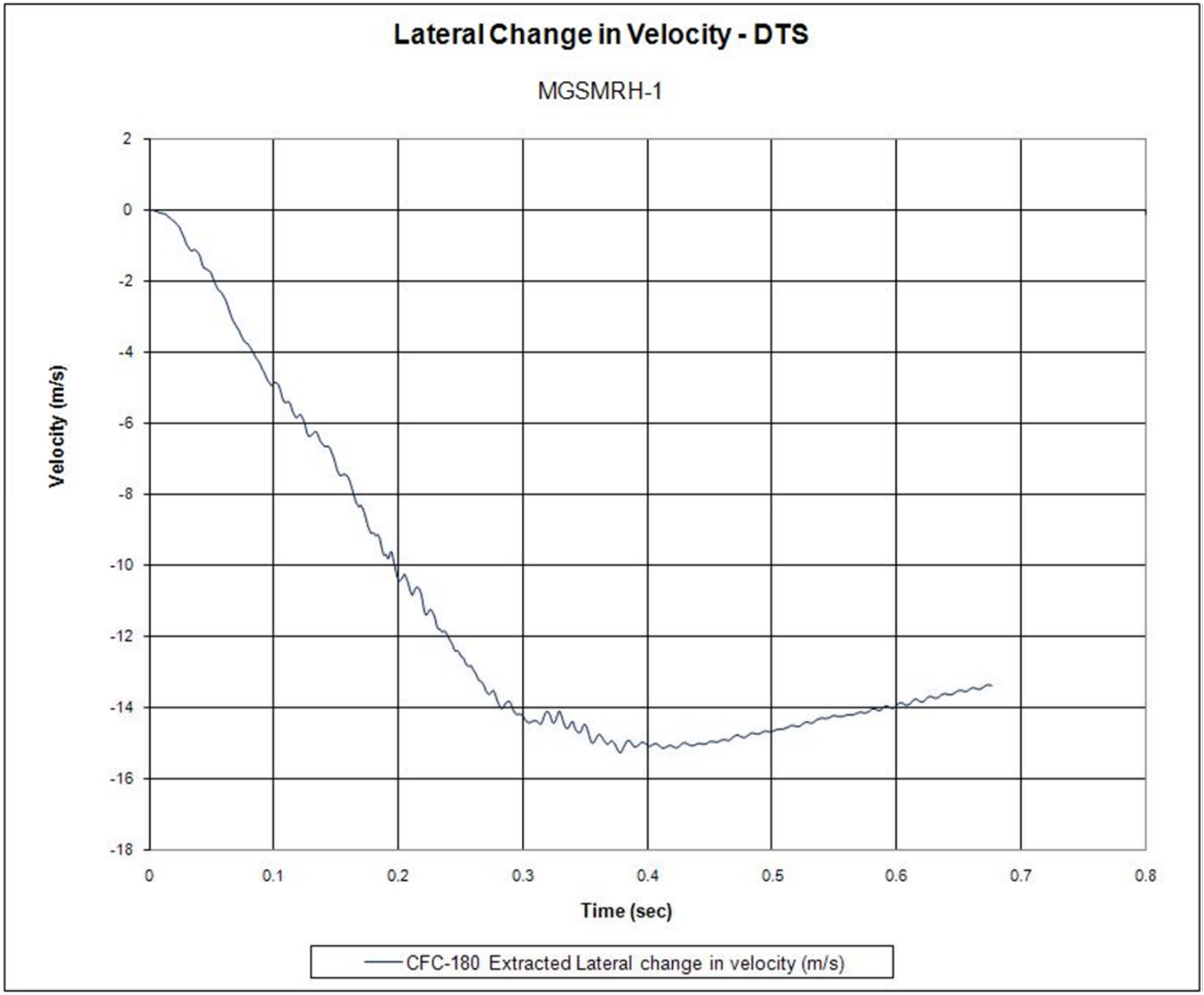


Figure E-5. Lateral Occupant Impact Velocity (DTS), Test No. MGSMRH-1

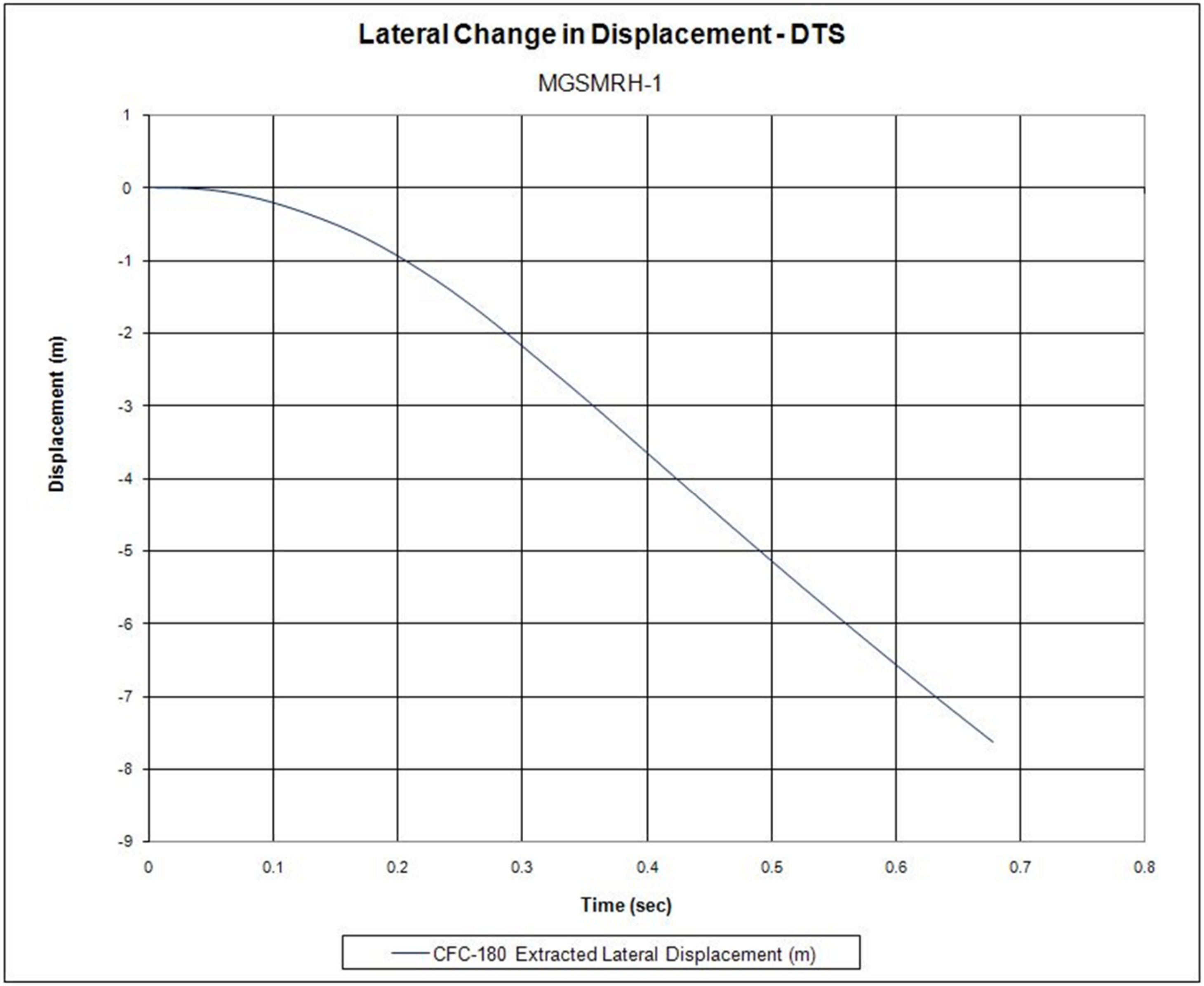


Figure E-6. Lateral Occupant Displacement (DTS), Test No. MGSMRH-1

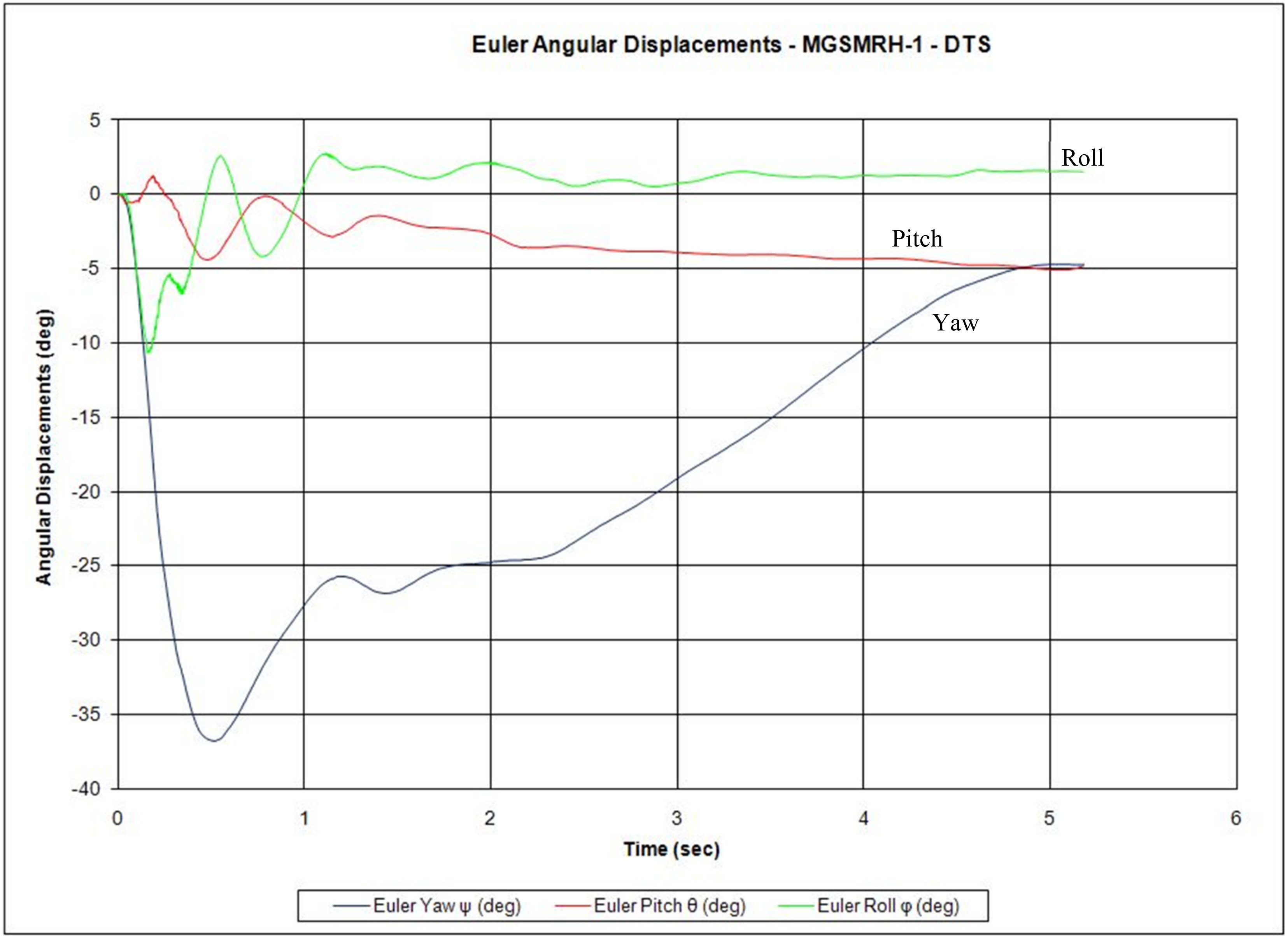


Figure E-7. Vehicle Angular Displacements (DTS), Test No. MGSMRH-1

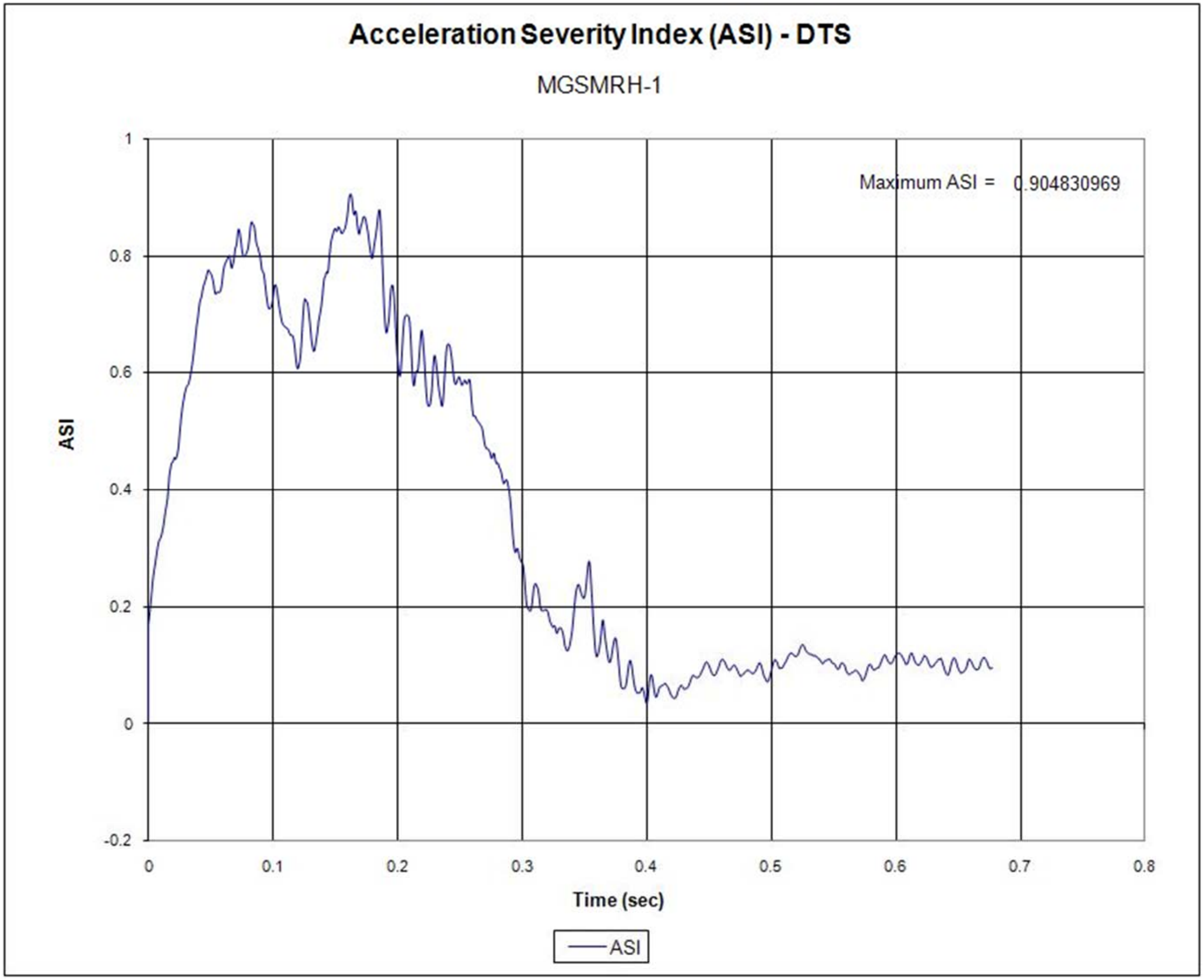


Figure E-8. Acceleration Severity Index (DTS), Test No. MGSMRH-1

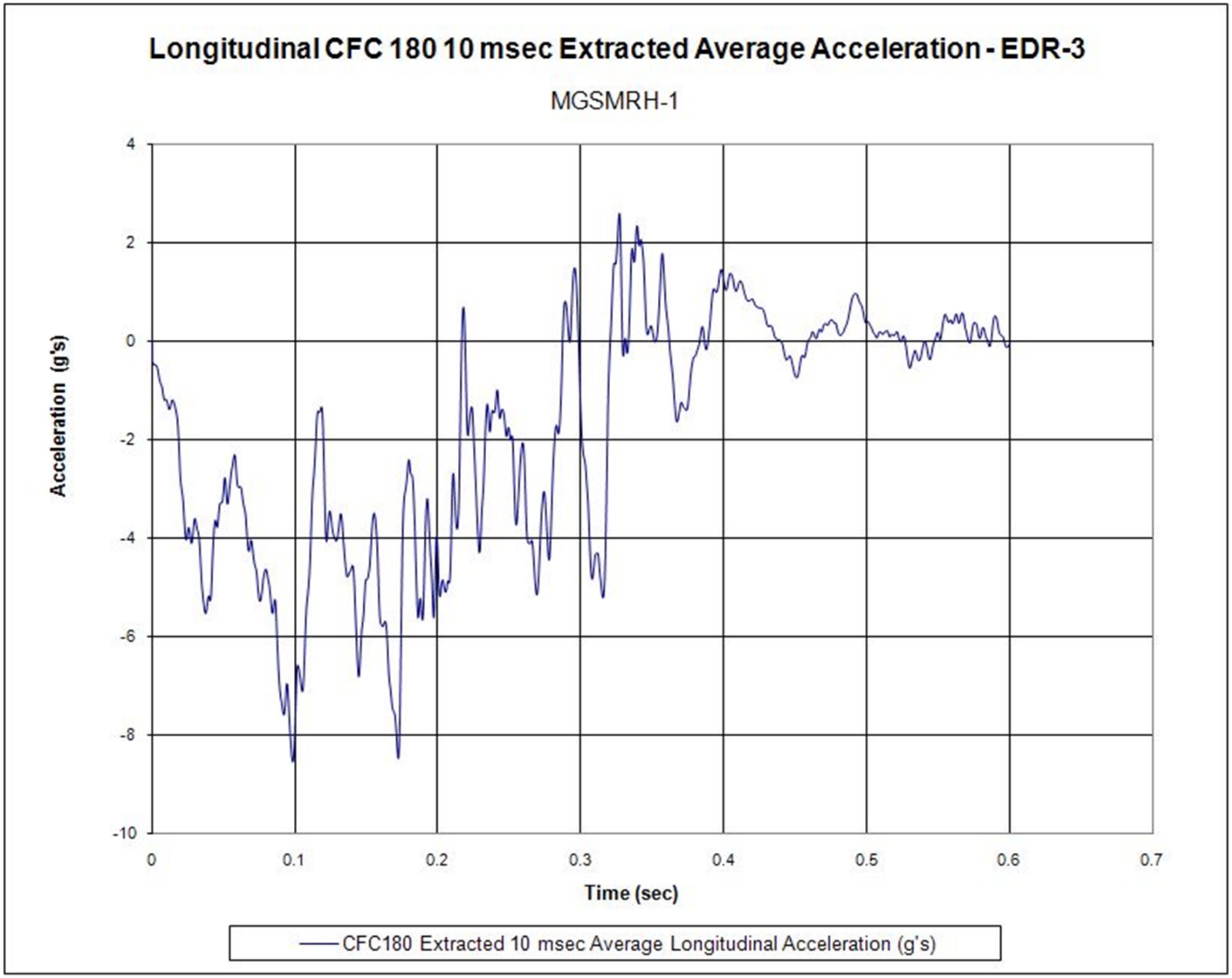


Figure E-9. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. MGSMRH-1

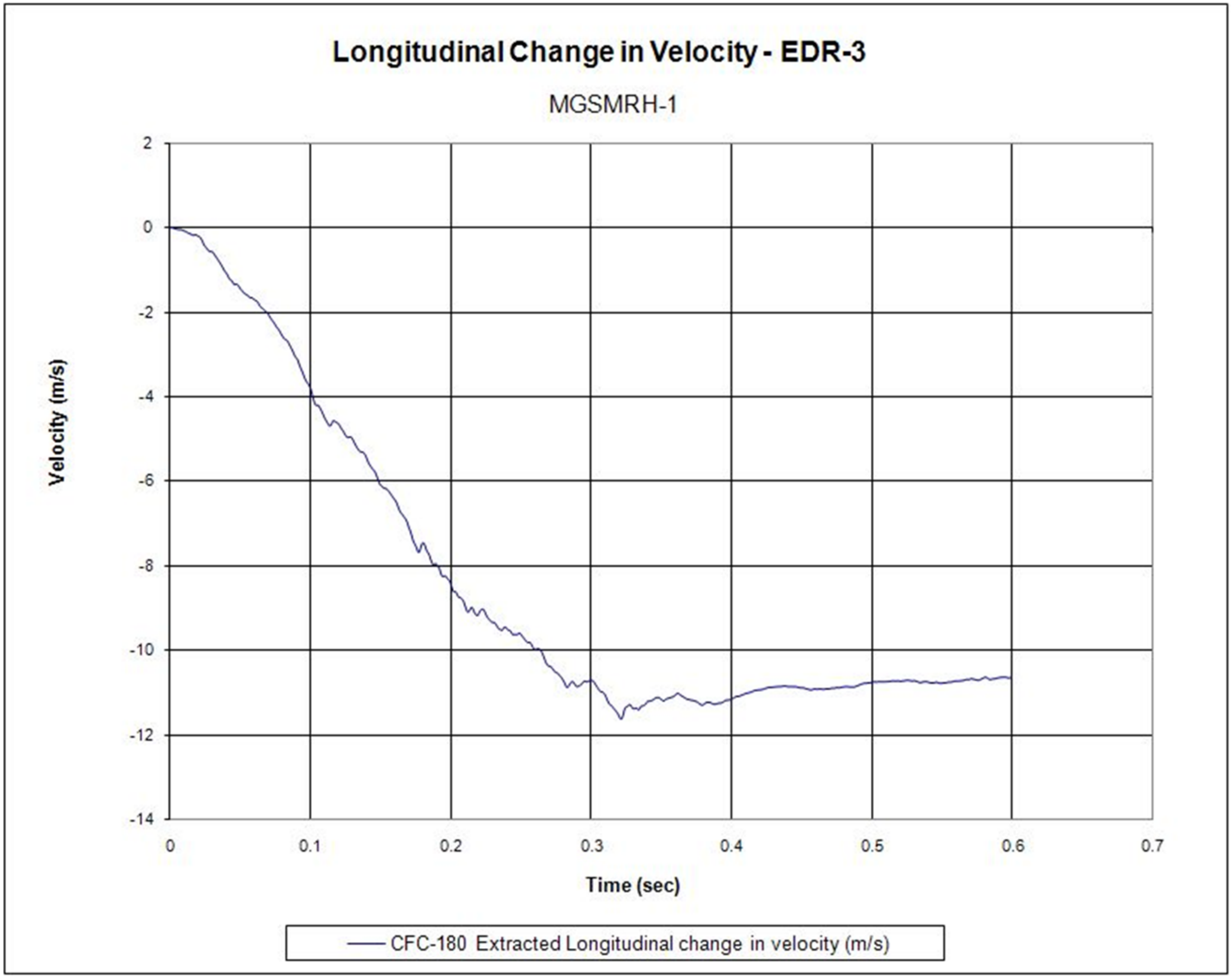


Figure E-10. Longitudinal Occupant Impact Velocity (EDR-3), Test No. MGSMRH-1

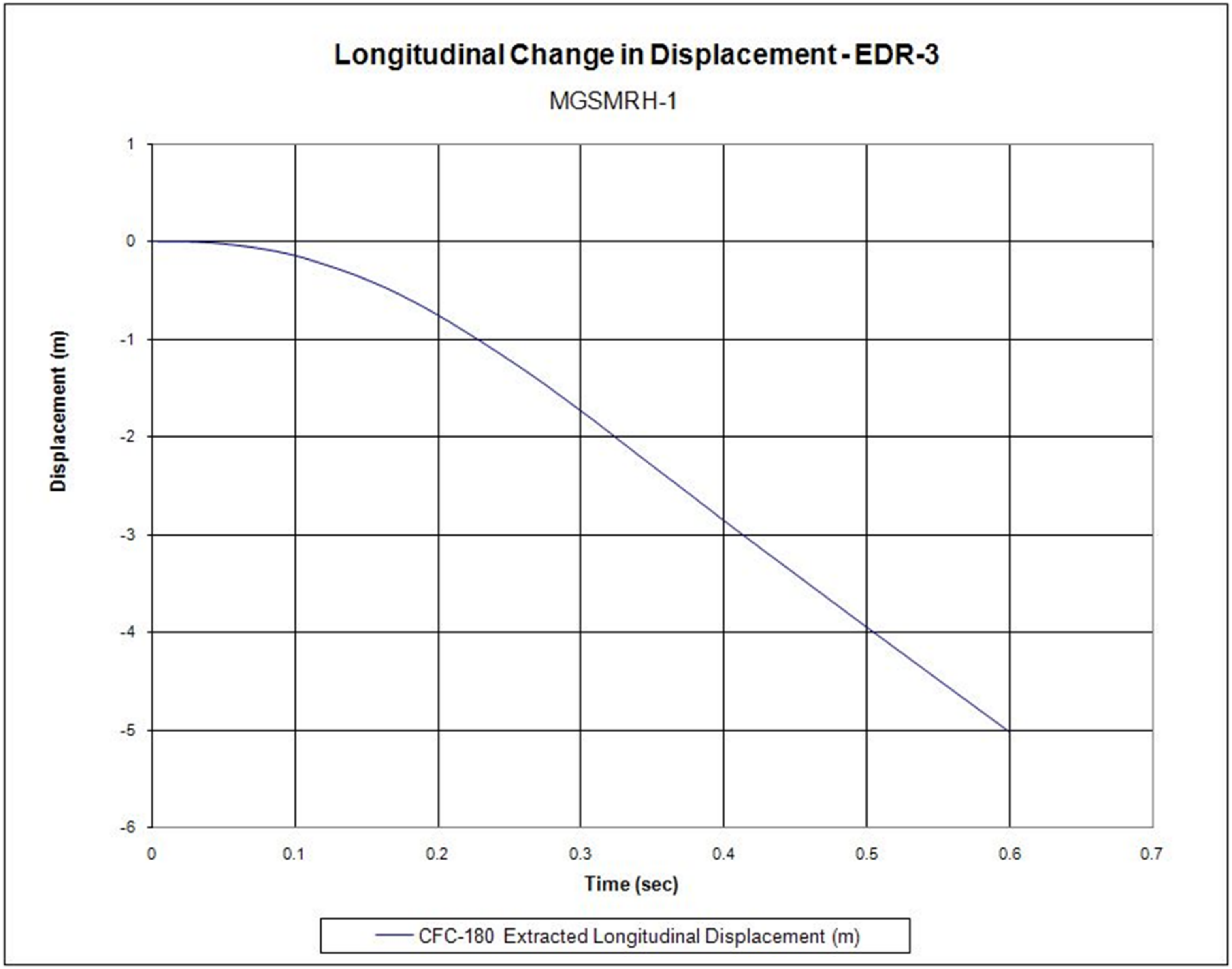


Figure E-11. Longitudinal Occupant Displacement (EDR-3), Test No. MGSMRH-1

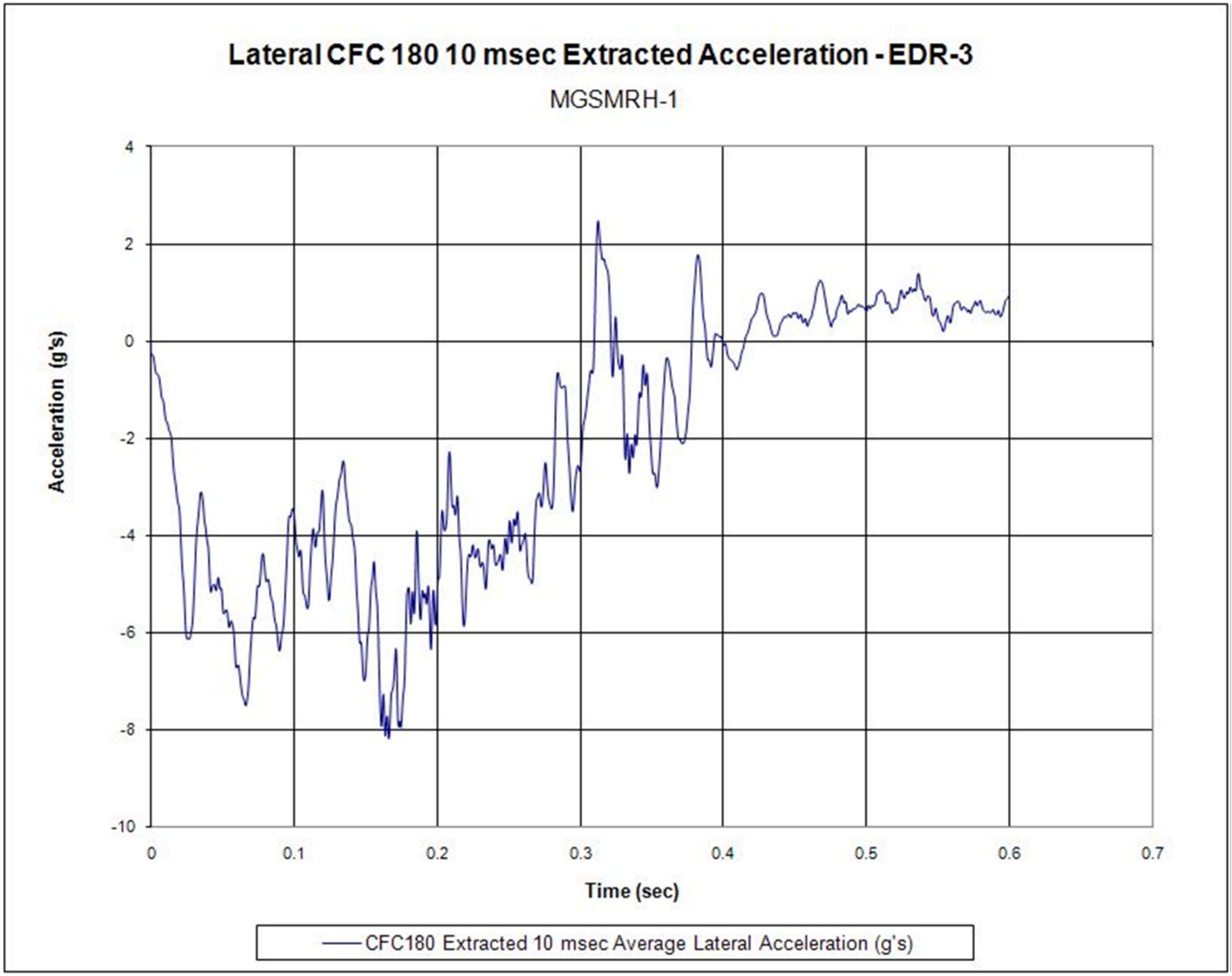


Figure E-12. 10-ms Average Lateral Deceleration (EDR-3), Test No. MGSMRH-1

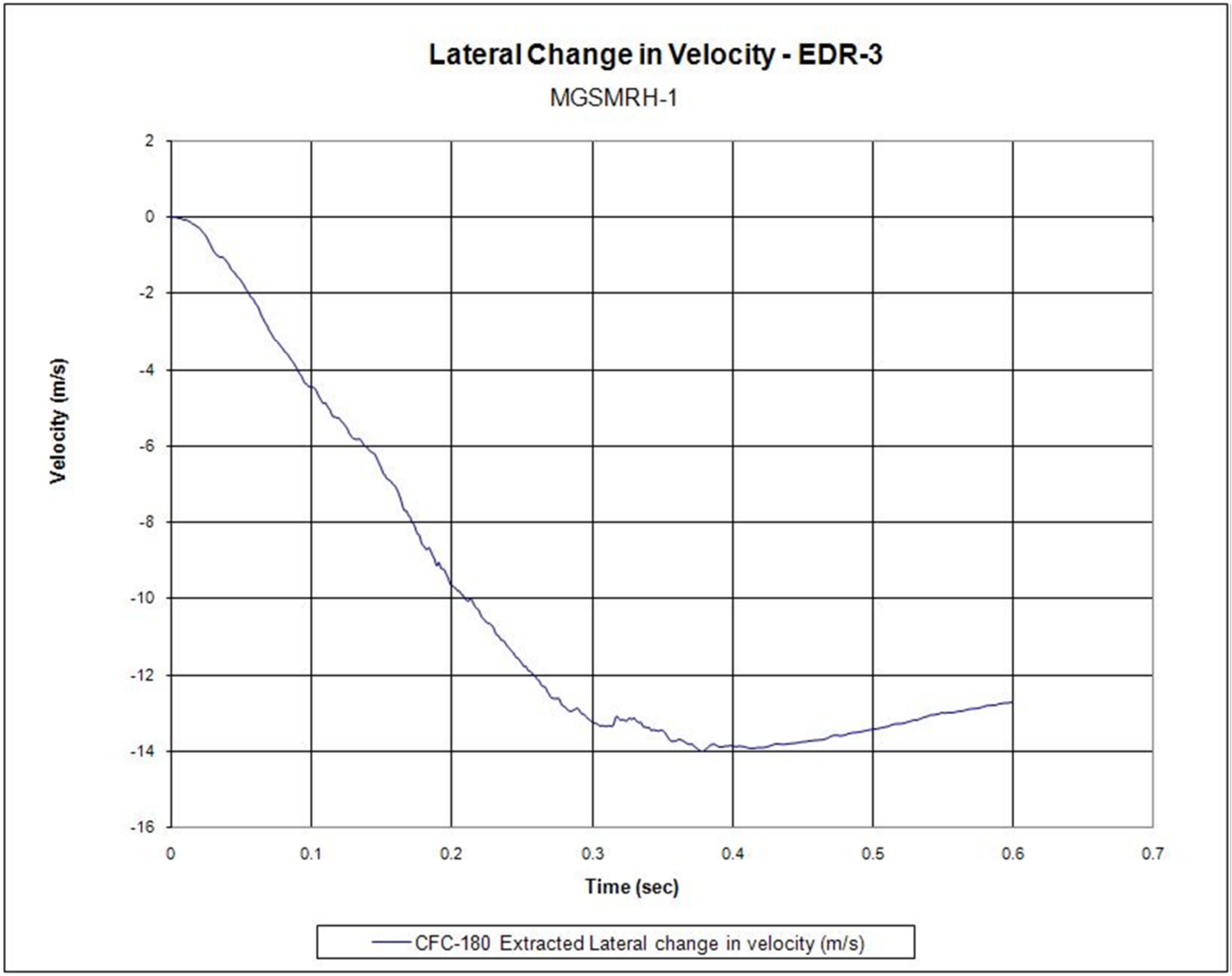


Figure E-13. Lateral Occupant Impact Velocity (EDR-3), Test No. MGSMRH-1

Figure E-14. Lateral Occupant Displacement (EDR-3), Test No. MGSMRH-1

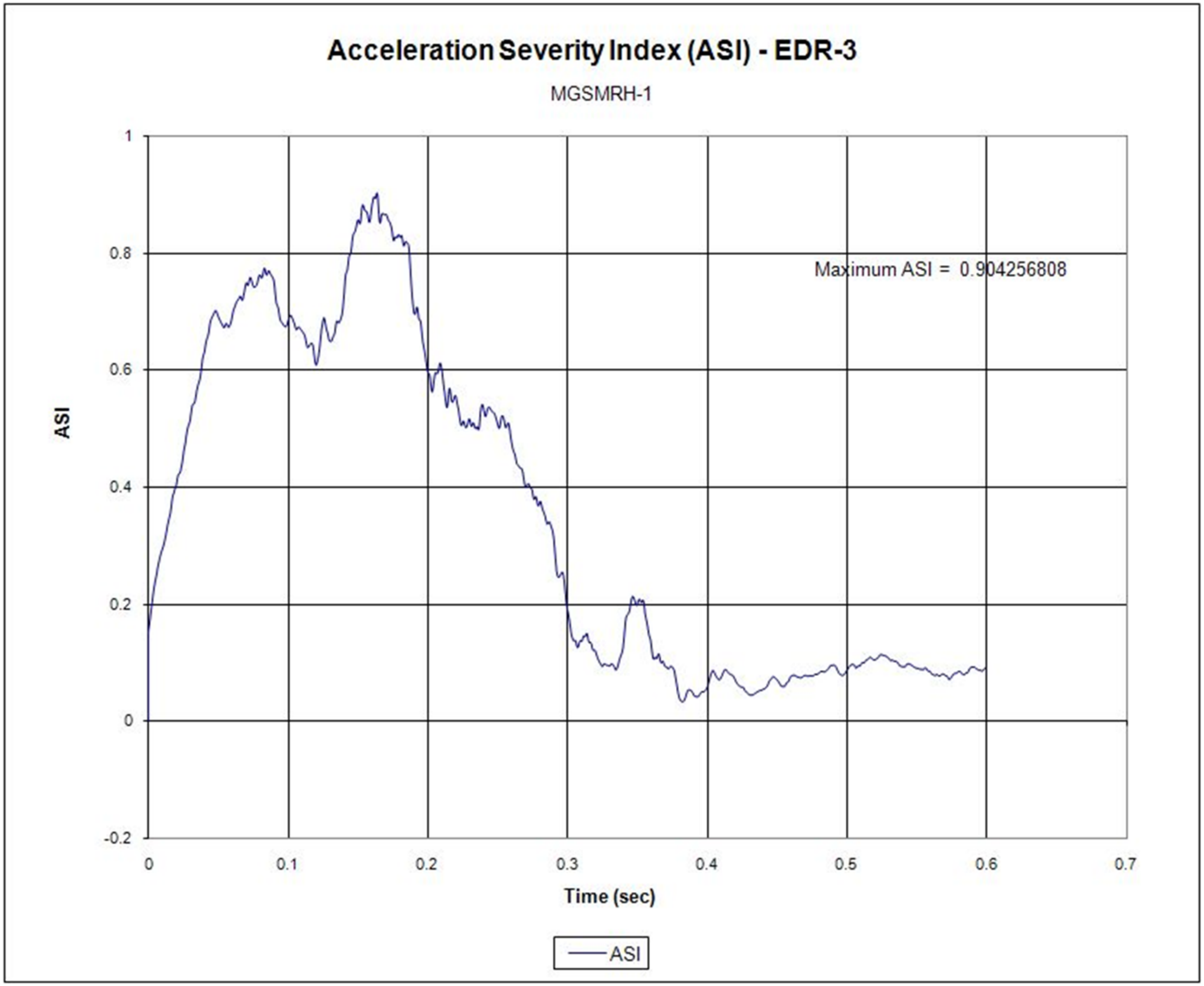
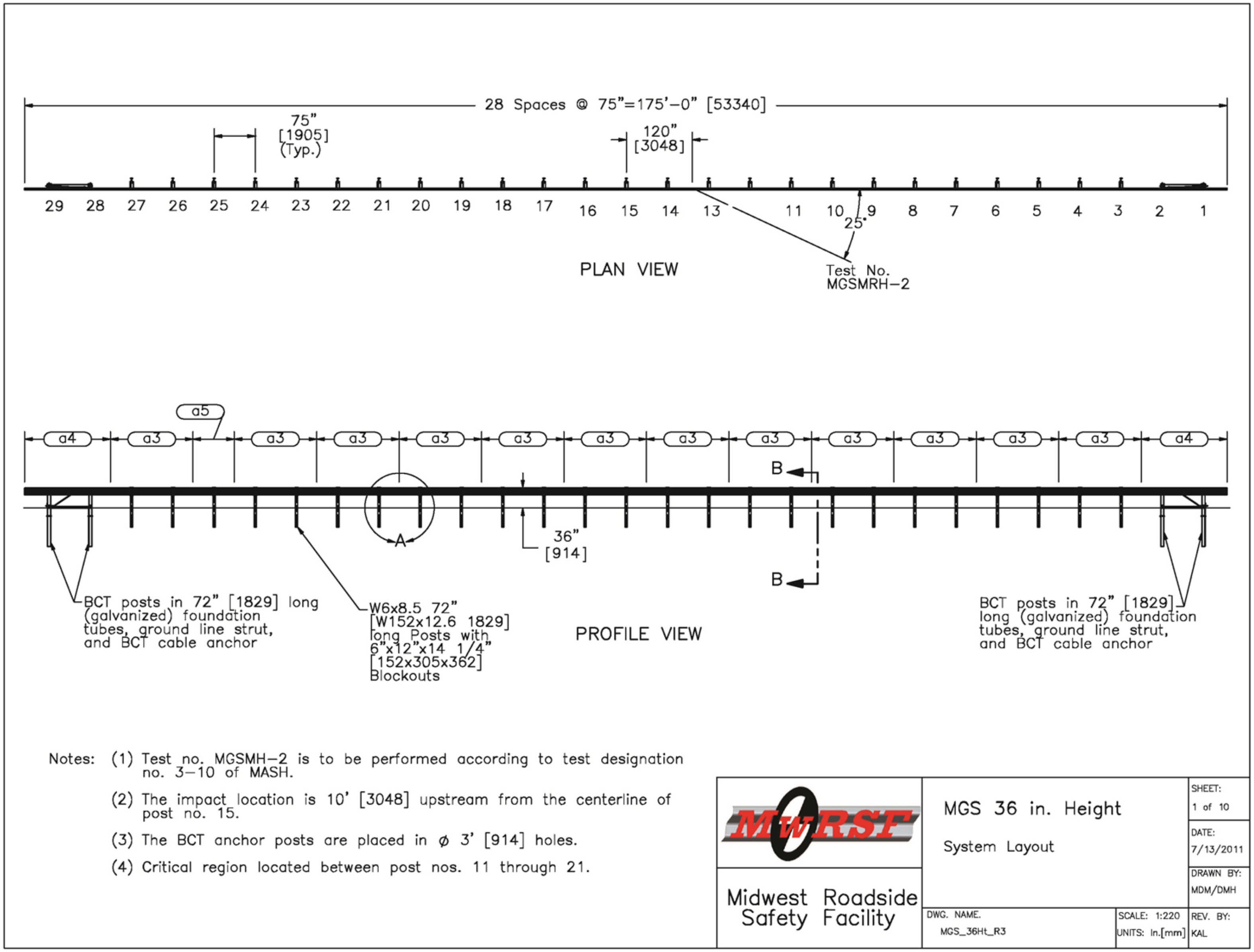


Figure E-15. Acceleration Severity Index (EDR-3), Test No. MGSMRH-1

Appendix F – System Details, Test No. MGSMRH-2



Notes: (1) Test no. MGSMH-2 is to be performed according to test designation no. 3-10 of MASH.

(2) The impact location is 10' [3048] upstream from the centerline of post no. 15.

(3) The BCT anchor posts are placed in ϕ 3' [914] holes.

(4) Critical region located between post nos. 11 through 21.

Figure F-1. Test Installation Layout, Test No. MGSMRH-2

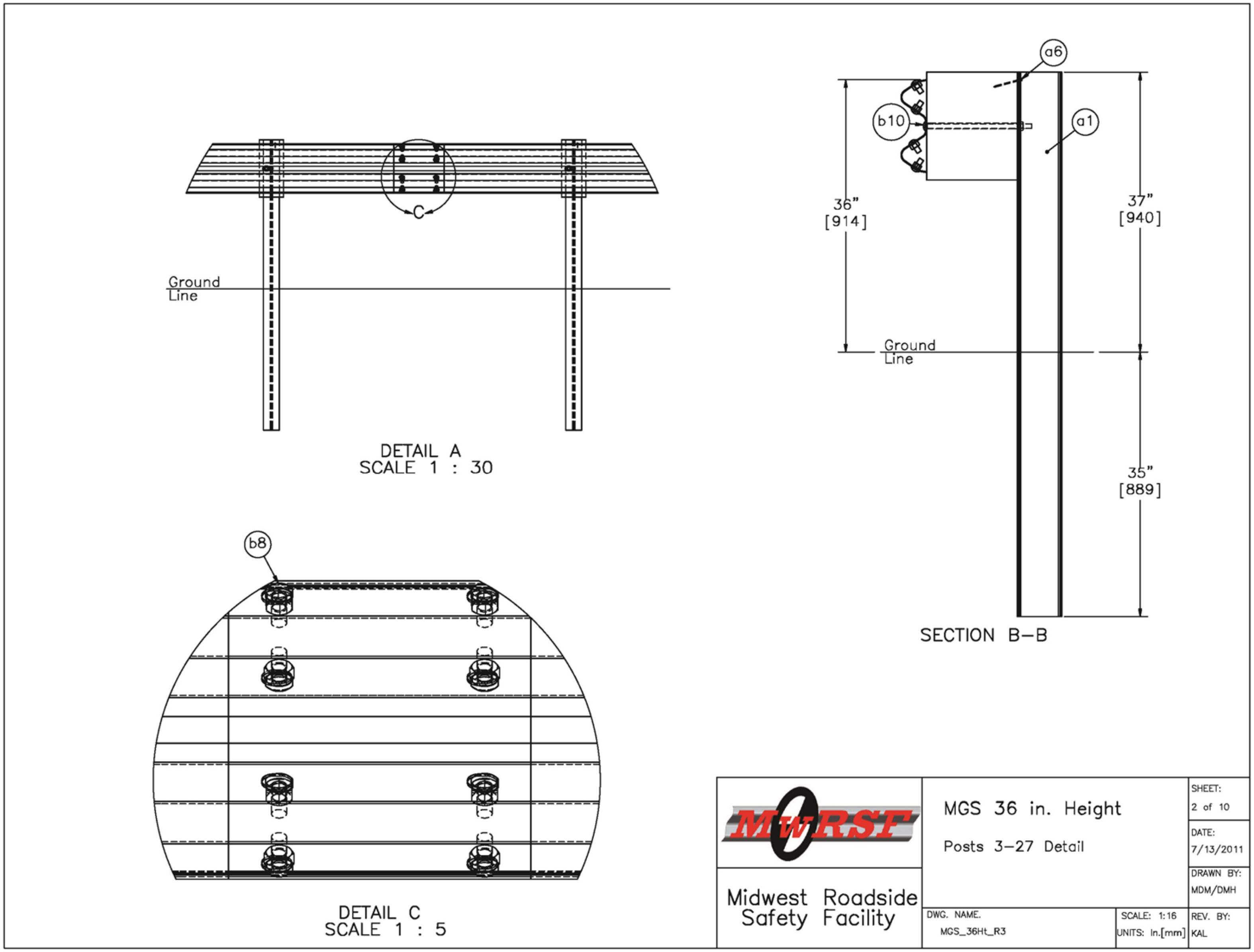


Figure F-2. 36-in. (914-mm) Tall MGS Details, Test No. MGSMRH-2

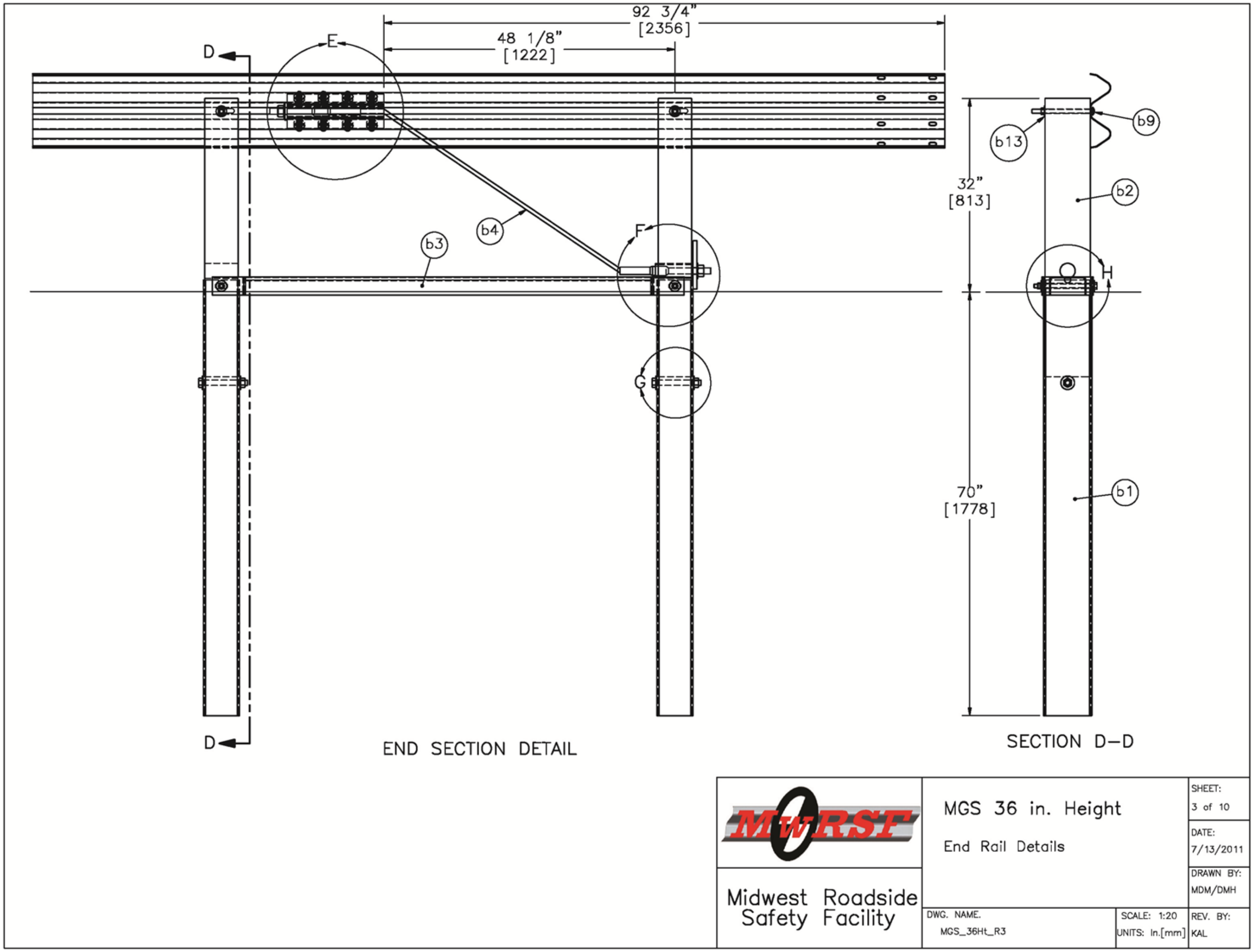


Figure F-3. BCT End Anchor Details, Test No. MGSMRH-2

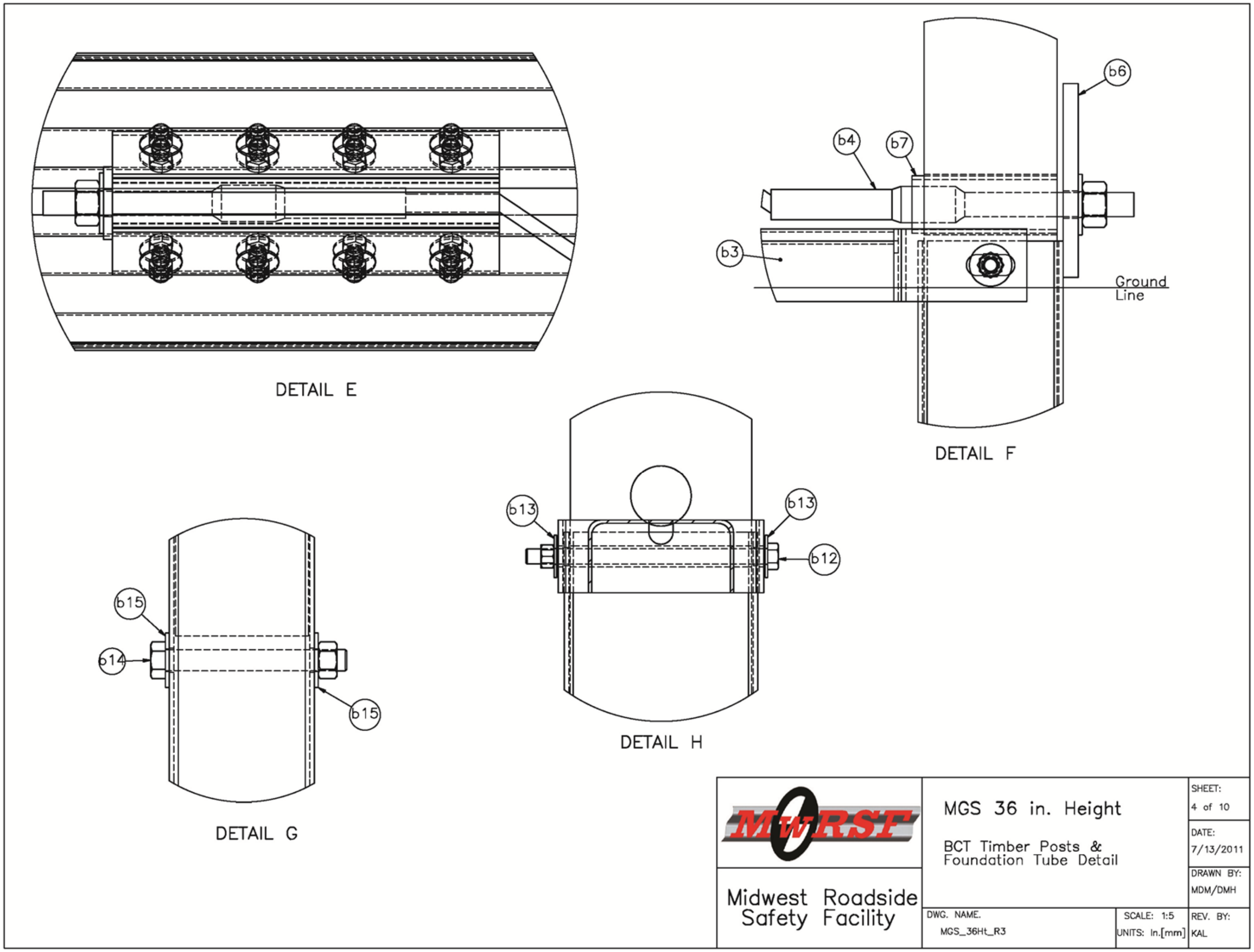


Figure F-4. BCT End Anchor Details, Test No. MGSMRH-2

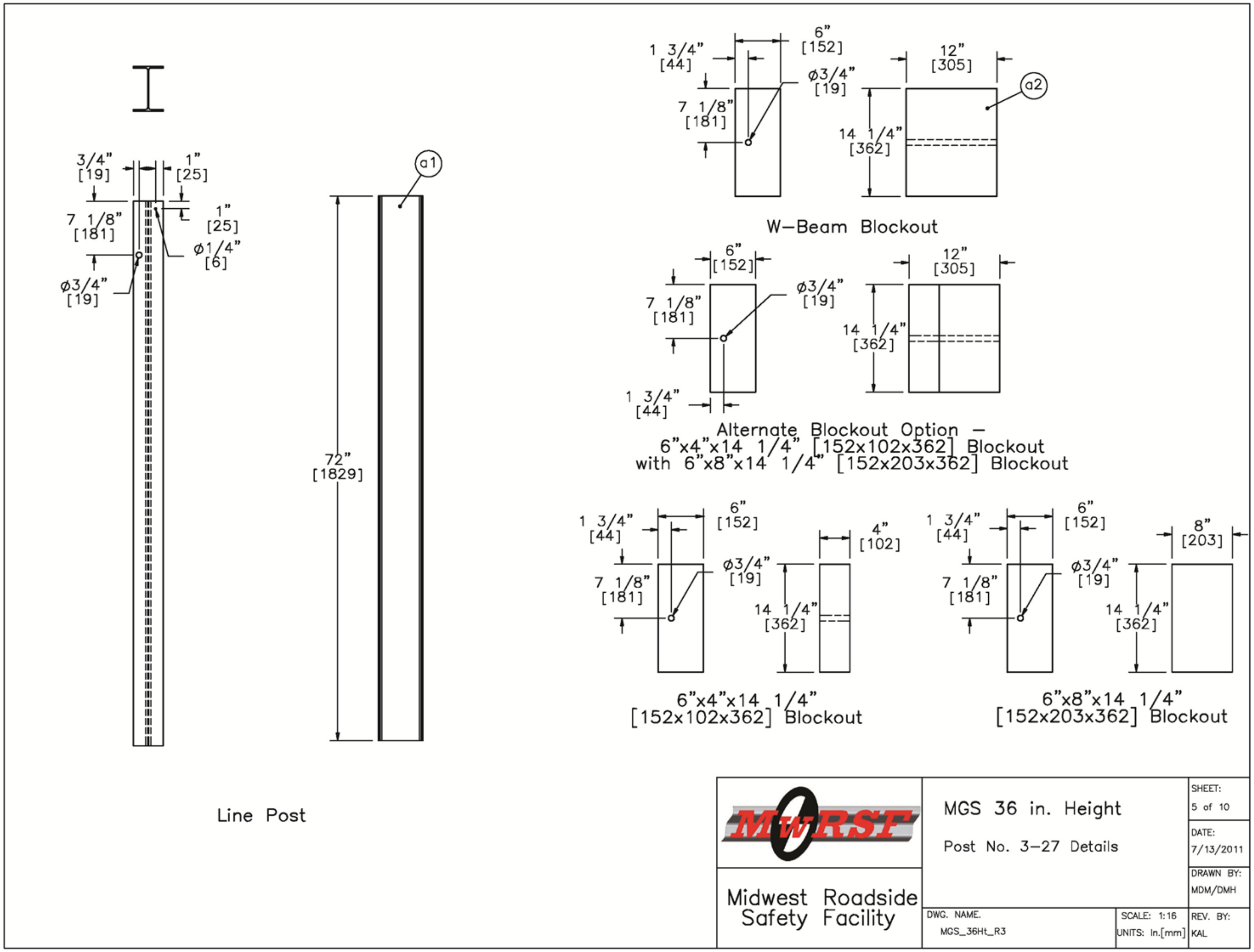


Figure F-5. Line Post Details, Test No. MGSMRH-2

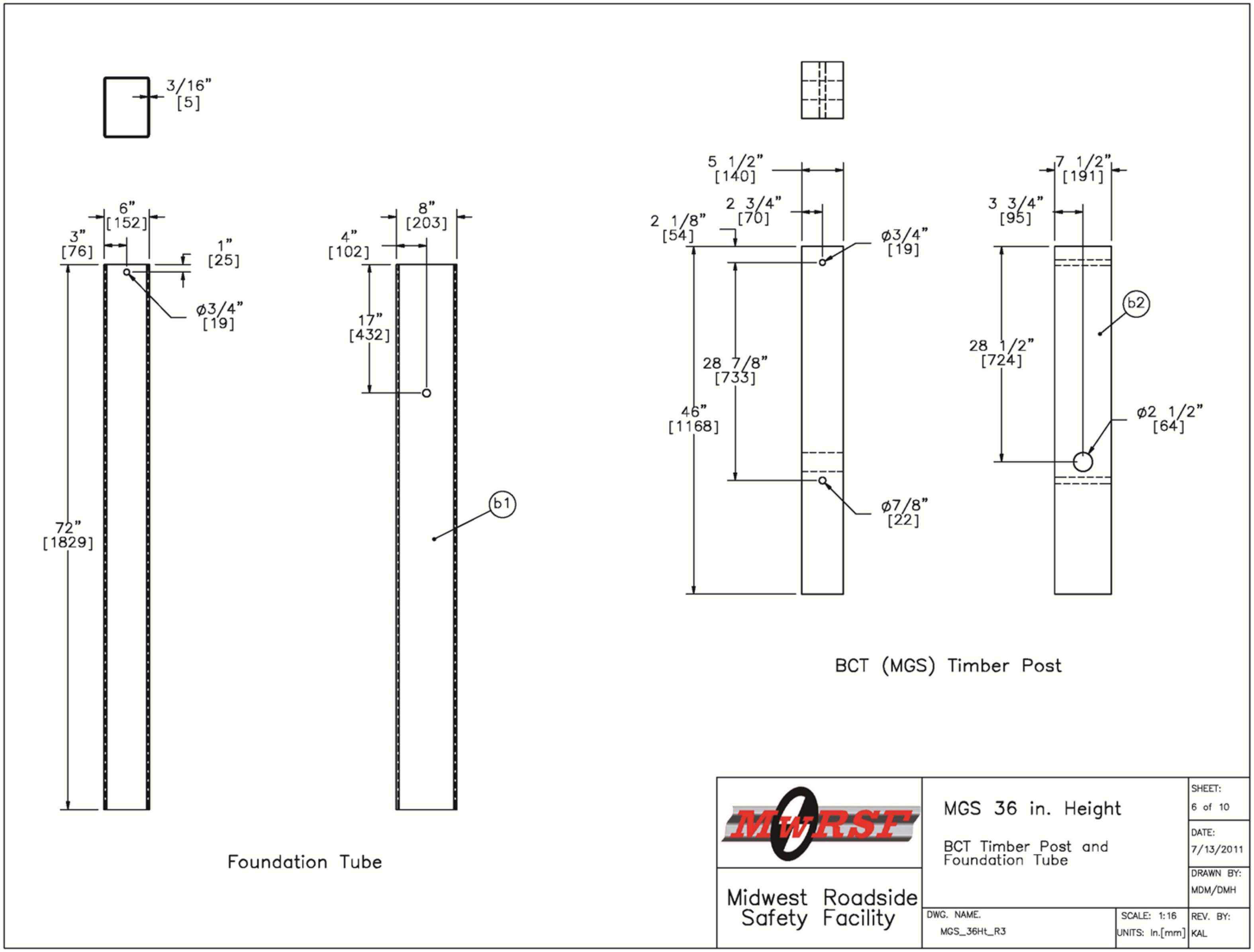


Figure F-6. Anchor Post Details, Test No. MGSMRH-2

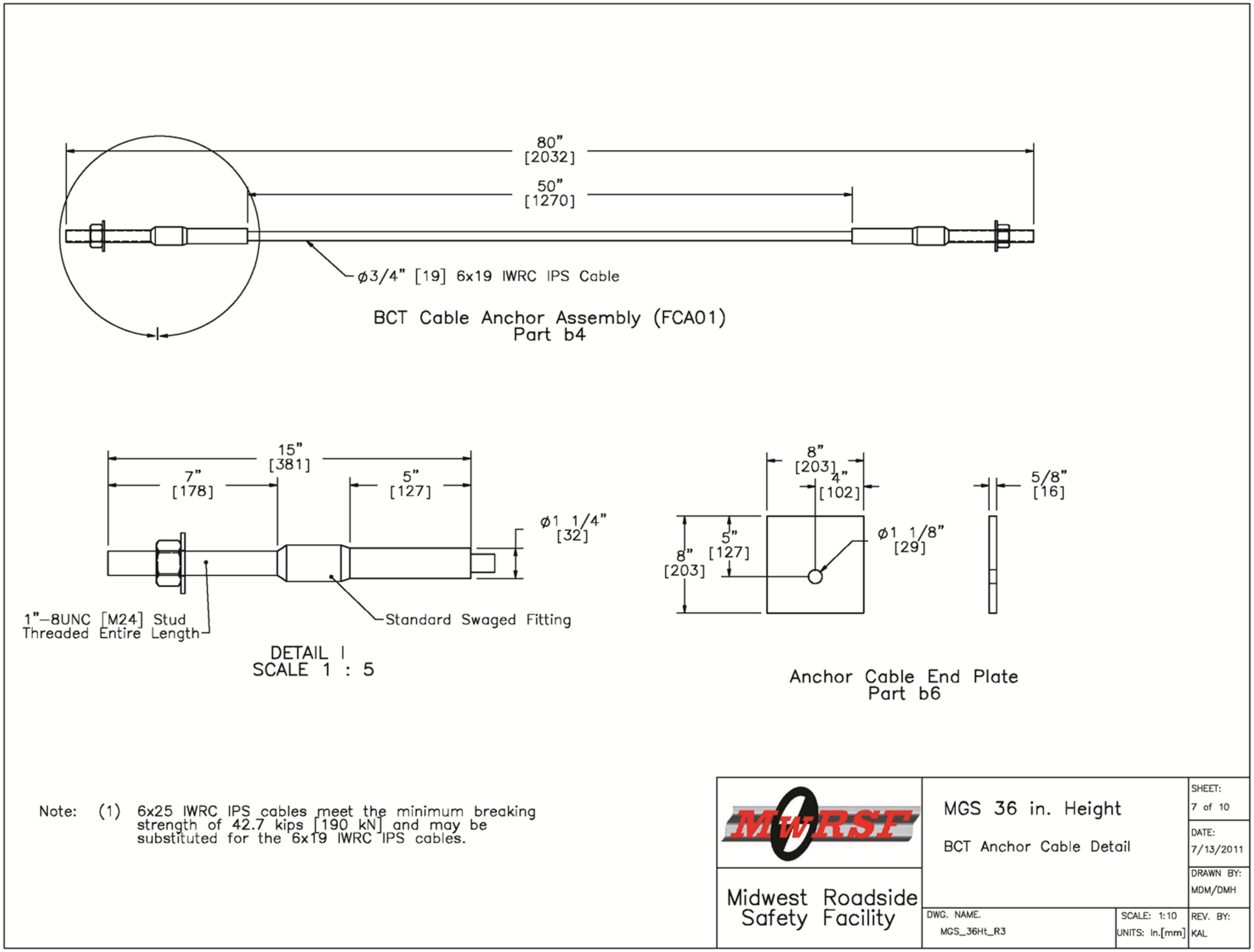


Figure F-7. BCT Anchor Cable Details, Test No. MGSMRH-2

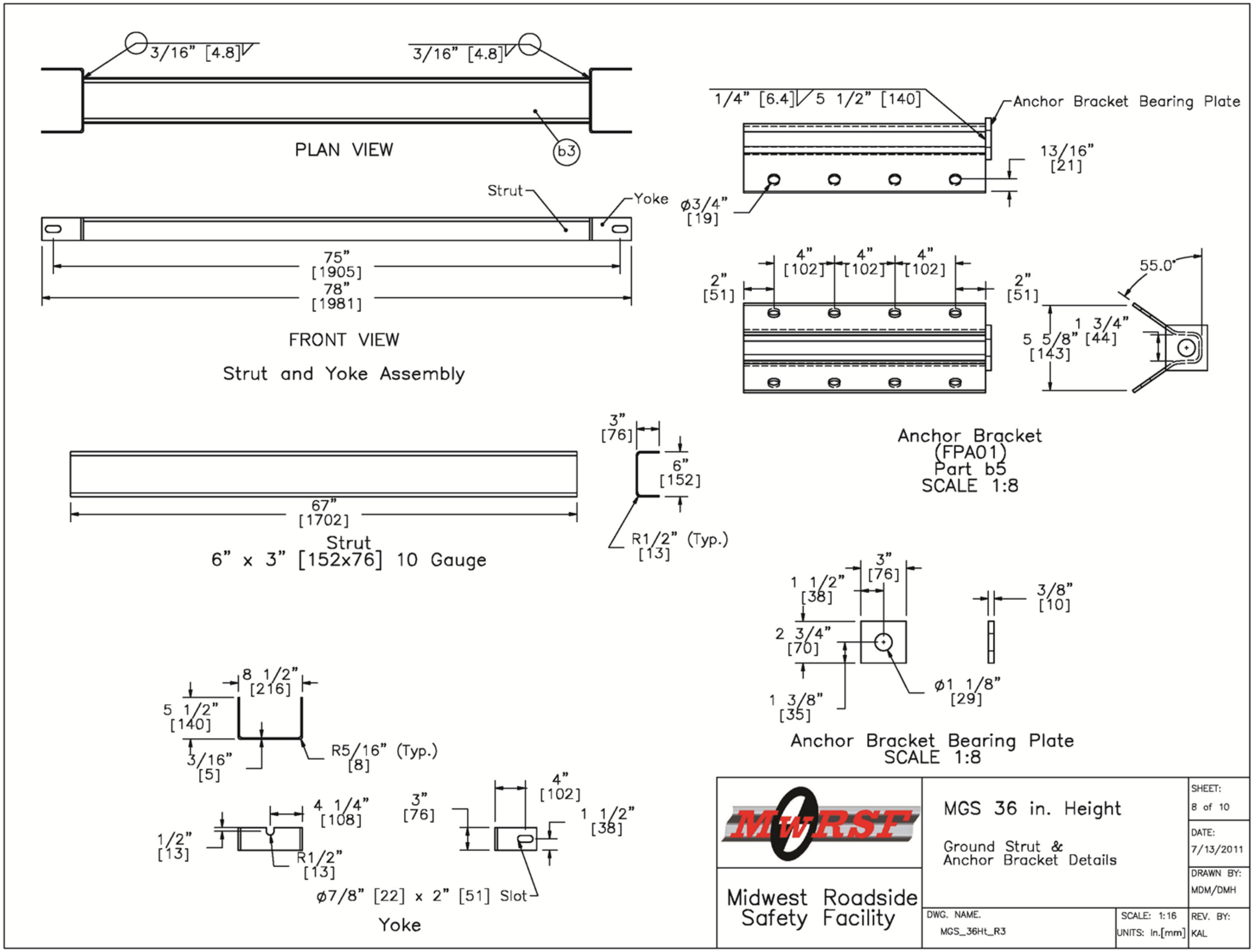


Figure F-8. Ground Strut and Anchor Bracket Details, Test No. MGSMRH-2

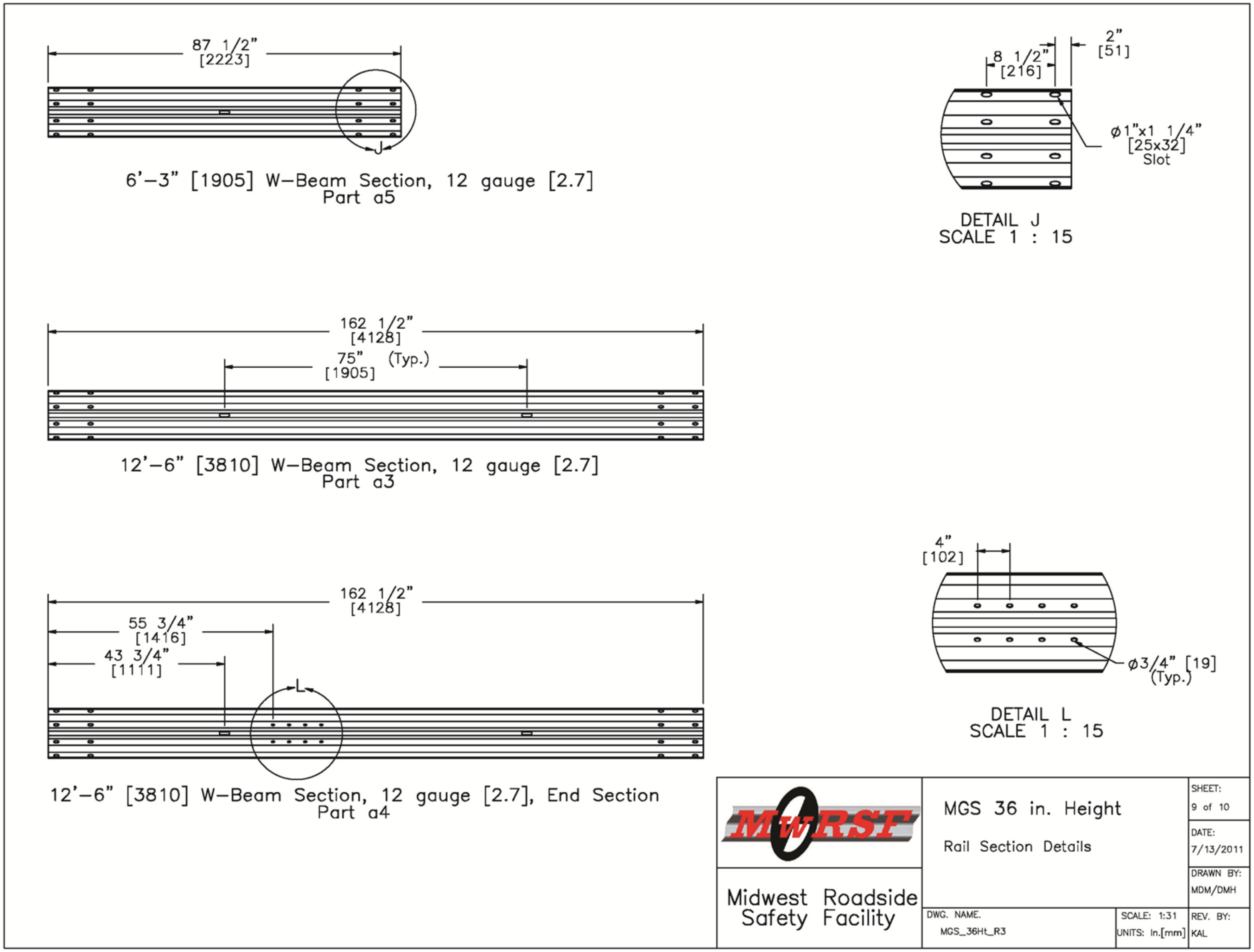


Figure F-9. W-Beam Guardrail Details, Test No. MGSMRH-2

Midwest Guardrail System at 36" Rail Height

Item No.	QTY.	Description	Material Specification	Hardware Guide
a1	25	W6x8.5 72in [W152x12.6 1829] long steel post	ASTM A36 Steel	PWE06
a2	25	6"x12"x14 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	1	12'-6" [3810] W-Beam MGS End Section	12 gauge [2.7] AASHTO M180	RWM14a
a5	1	6'-3" [1905] W-Beam MGS Section	12 gauge [2.7] AASHTO M180	RWM01a
a6	25	16D Double Head Nail	–	–
b1	4	72" [1829] Foundation Tube	ASTM A500 Grade B	PTE06
b2	4	BCT Timber Post -MGS Height	SYP Grade No. 1 or better (No knots, 18" [457] above or below ground tension face)	PDF01
b3	2	Strut and Yoke Assembly	ASTM A36 Steel Galvanized	–
b4	2	BCT Cable Anchor Assembly	ϕ3/4" [19] 6x19 IWRC IPS Galvanized Wire Rope	FCA01-02
b5	2	Anchor Bracket Assembly	ASTM A36 Steel	FPA01
b6	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel	FPB01
b7	2	2 3/8" [60] O.D.x 6" [152] long BCT Post Sleeve	ASTM A53 Grade B Schedule 40	FMM02
b8	112	5/8"Dia. x 1 1/2" [M16 x 38] Guardrail Bolt and Nut	ASTM A307 Steel	FBB01
b9	4	5/8"Dia. x 10" [M16 x 254] long Guardrail Bolt and Nut	ASTM A307 Steel	FBB03
b10	25	5/8"Dia. x 14" [M16 x 356] long Guardrail Bolt and Nut	ASTM A307 Steel	FBB06
b11	16	5/8"Dia. x 1 1/2" [M16 x 38] long Hex Head Bolt and Nut	ASTM A307 Steel	FBX16a
b12	4	5/8"Dia. x 10" [M16 x 254] long Hex Head Bolt and Nut	ASTM A307 Steel	FBX16a
b13	44	5/8"Dia. [16] Flat Washer	ASTM F436 Grade 1	FWC14a
b14	4	3/4"Dia. x 7 1/2" [M20 x 191] long Hex Head Bolt and Nut	ASTM A325 Steel	FBX22a
b15	8	3/4"Dia. [19] Flat Washer	ASTM F436 Grade 1	FWC22a

Midwest Roadside Safety Facility

MGS 36 in. Height

Bill of Materials

SHEET: 10 of 10
DATE: 7/13/2011
DRAWN BY: MDM/DMH
DWG. NAME. MGS_36Ht_R3
SCALE: None
UNITS: In.[mm]
REV. BY: KAL

Figure F-10. Bill of Materials, Test No. MGSMRH-2

Appendix G - Accelerometer and Rate Transducer Data Plots, Test No. MGSMRH-2

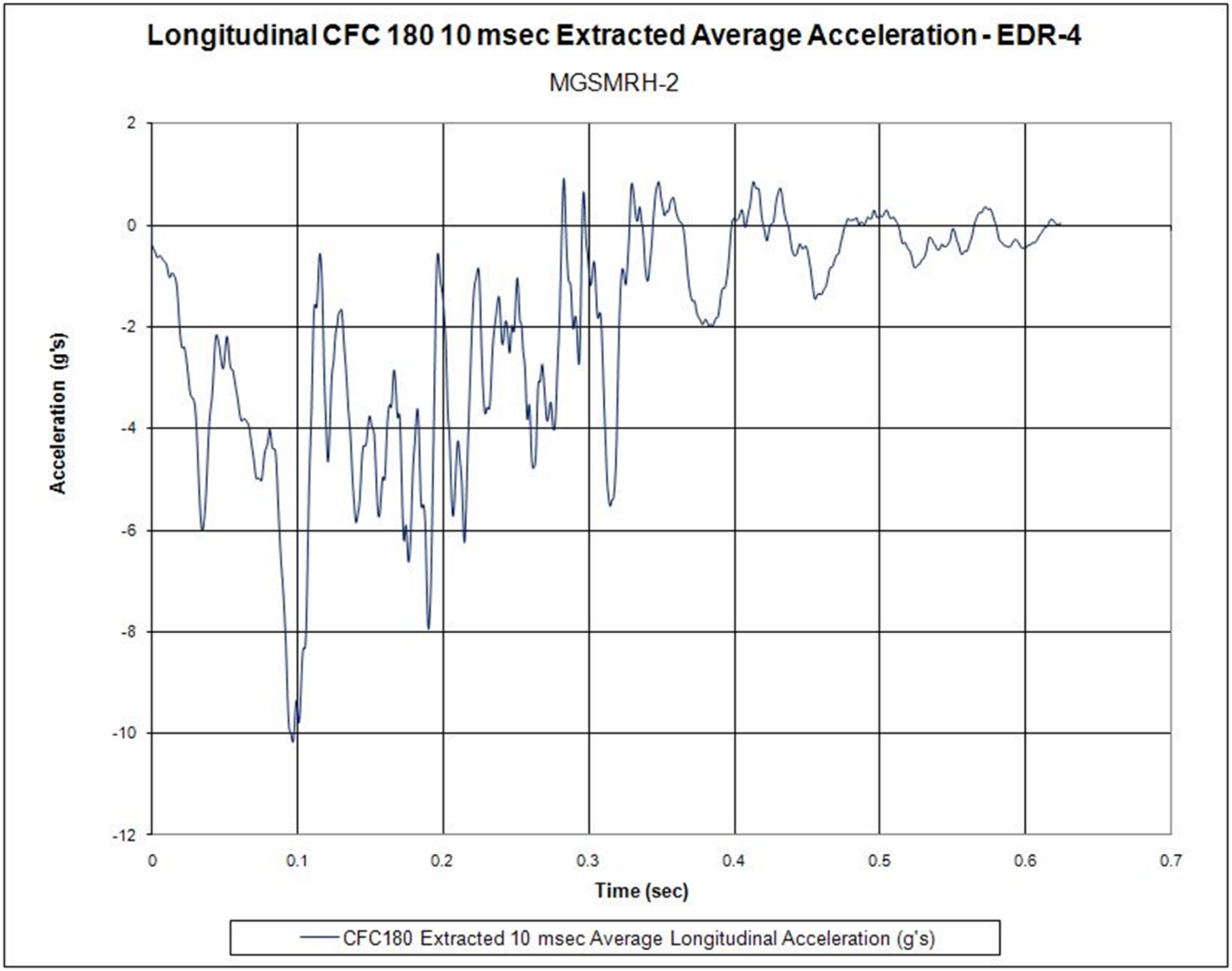


Figure G-1. 10-ms Average Longitudinal Deceleration (EDR-4), Test No. MGSMRH-2

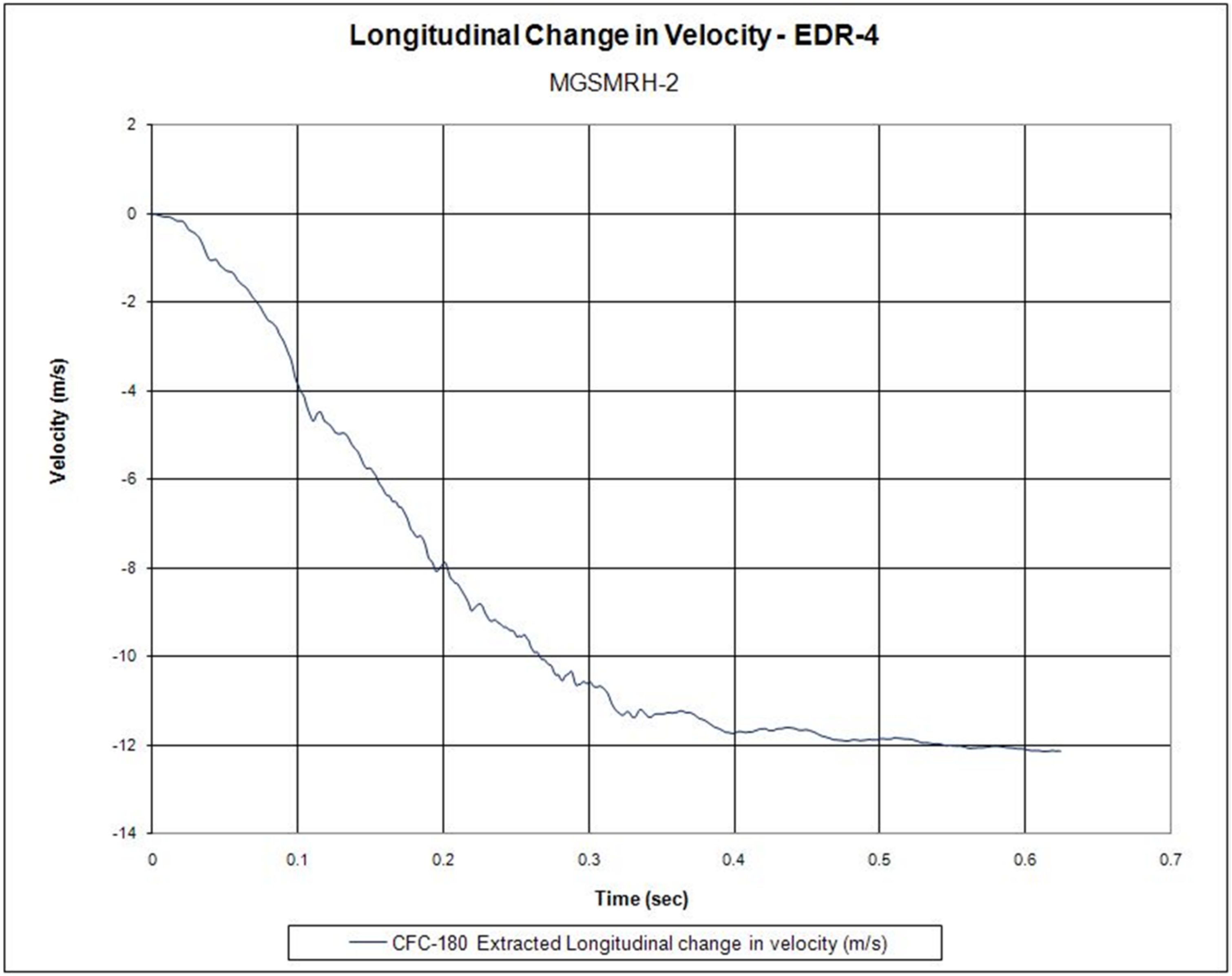


Figure G-2. Longitudinal Occupant Impact Velocity (EDR-4), Test No. MGSMRH-2

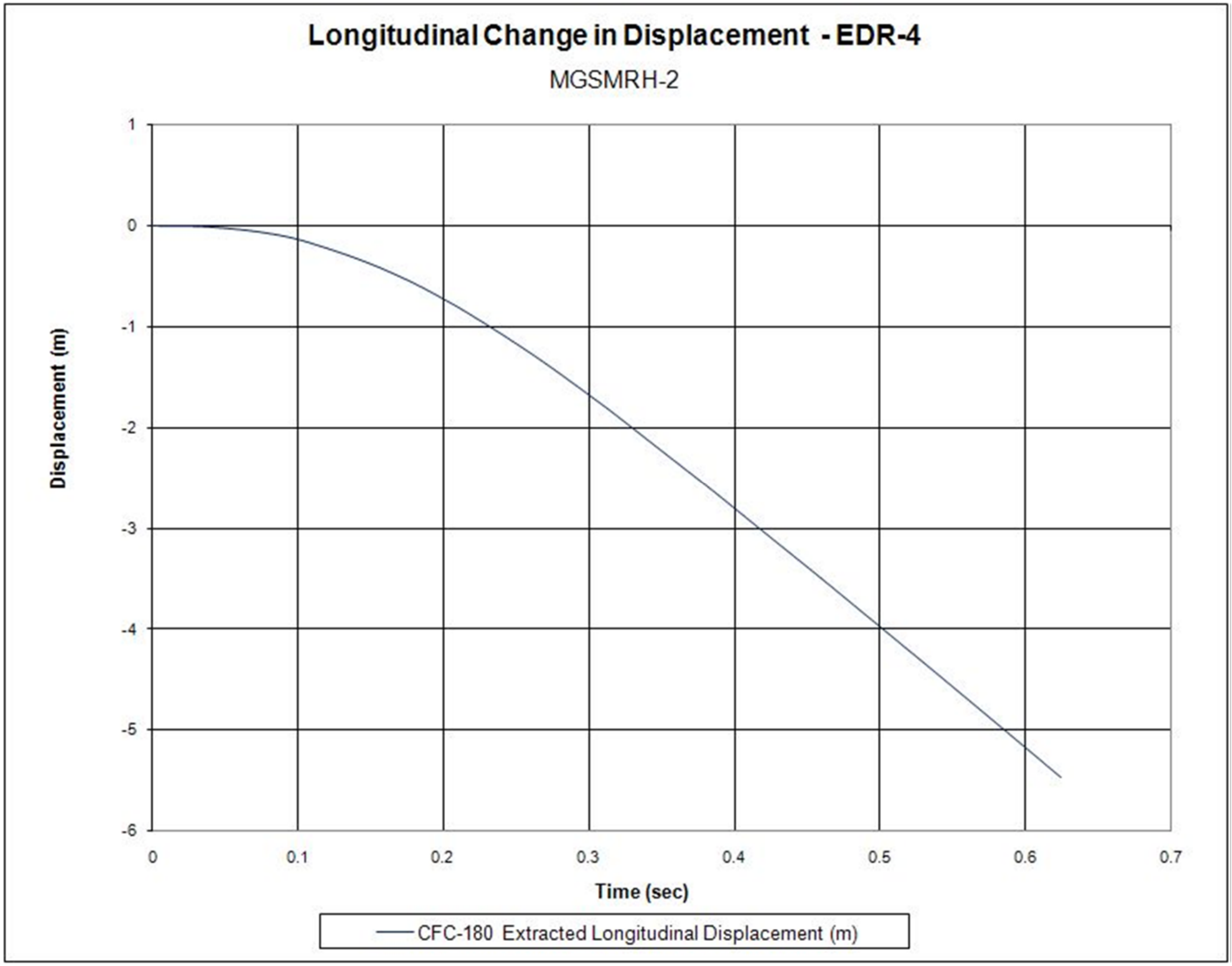


Figure G-3. Longitudinal Occupant Displacement (EDR-4), Test No. MGSMRH-2

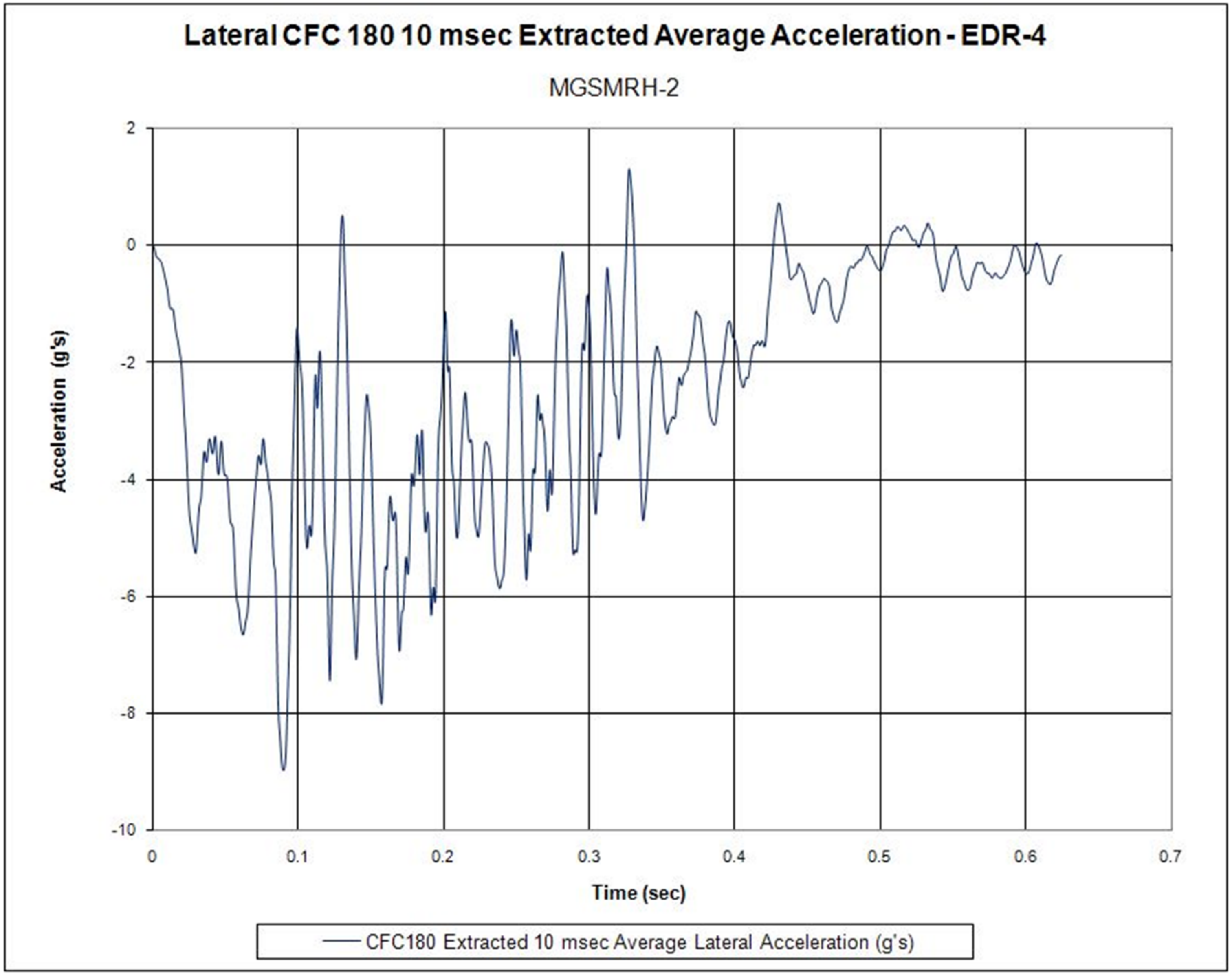


Figure G-4. 10-ms Average Lateral Deceleration (EDR-4), Test No. MGSMRH-2

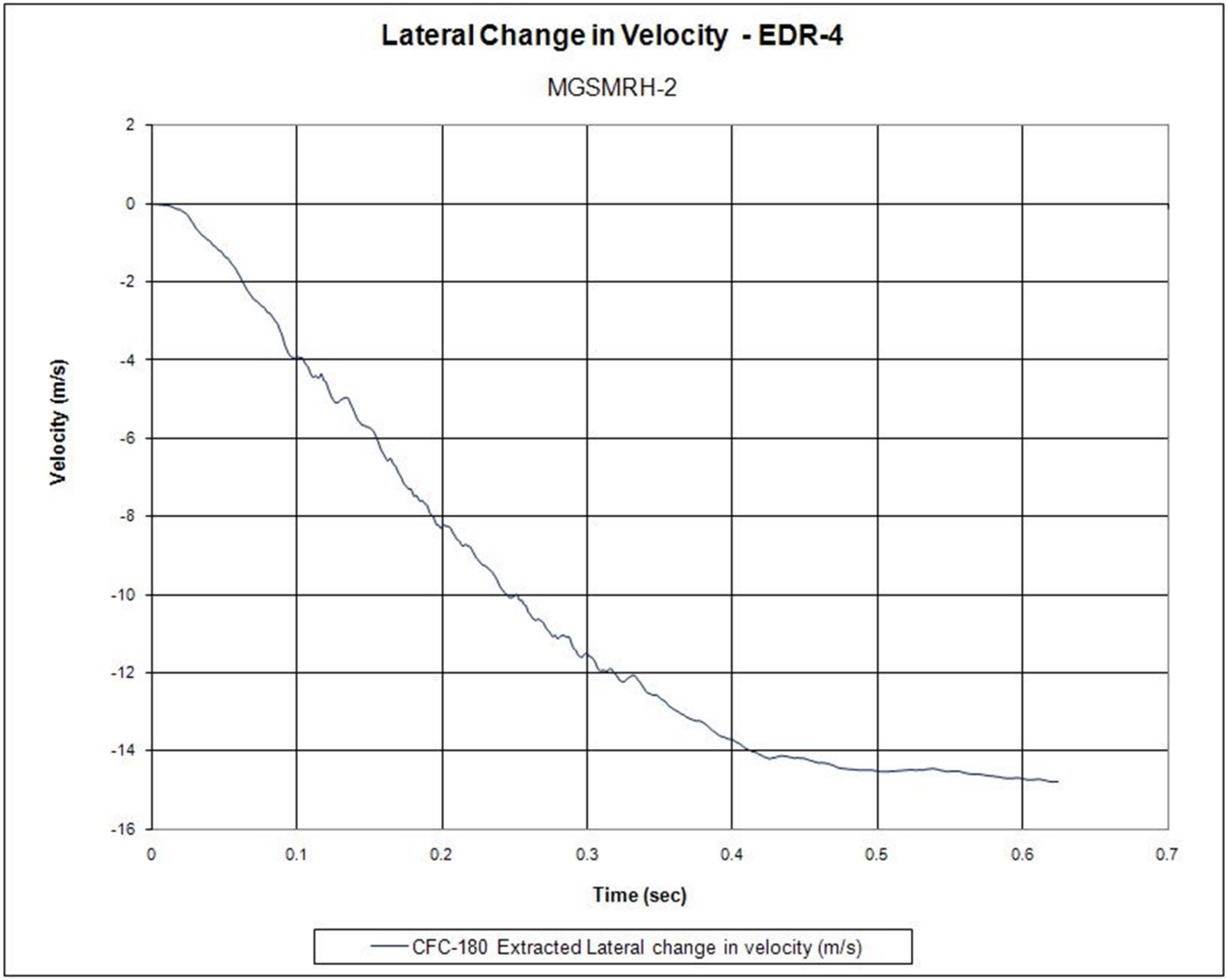


Figure G-5. Lateral Occupant Impact Velocity (EDR-4), Test No. MGSMRH-2

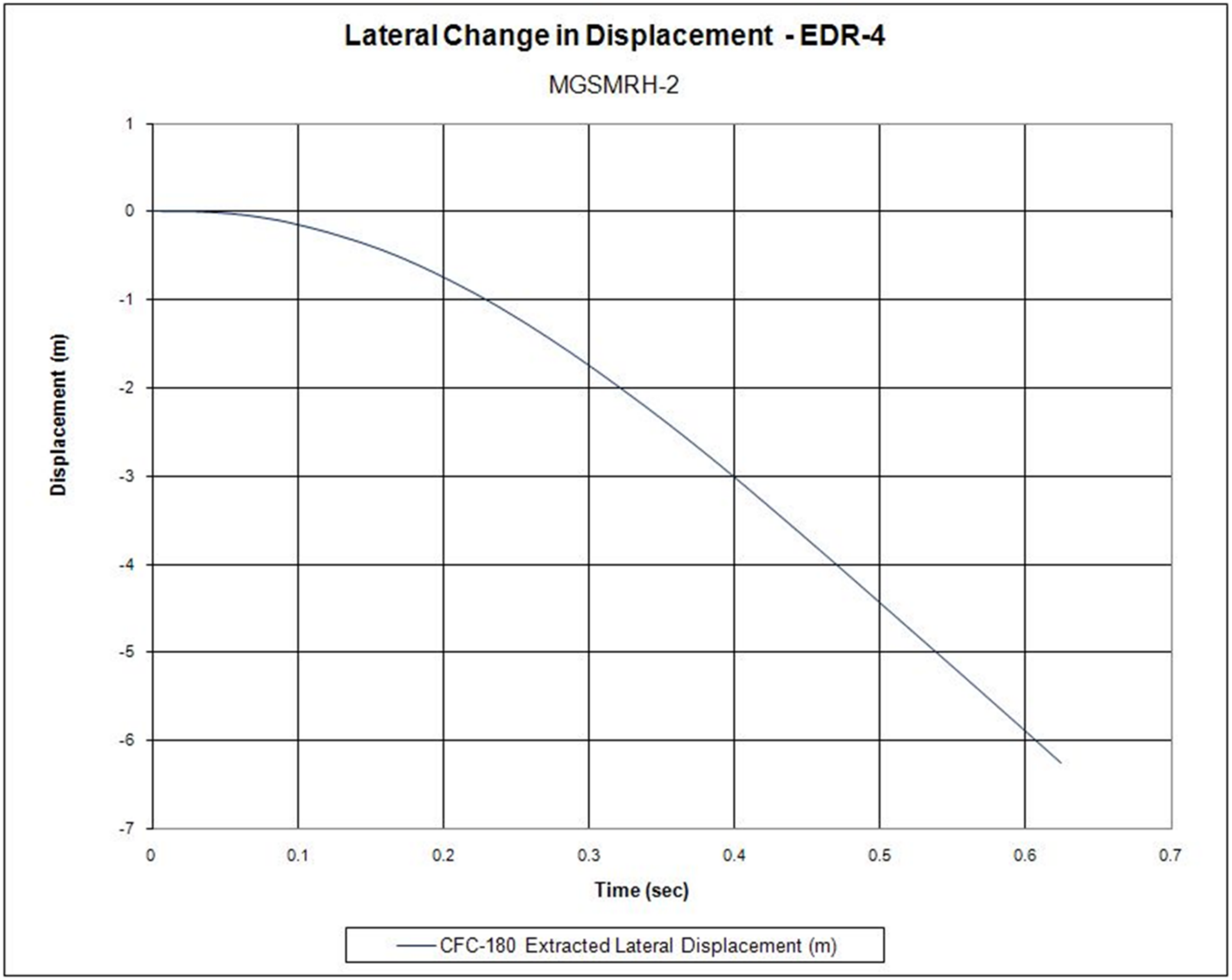


Figure G-6. Lateral Occupant Displacement (EDR-4), Test No. MGSMRH-2

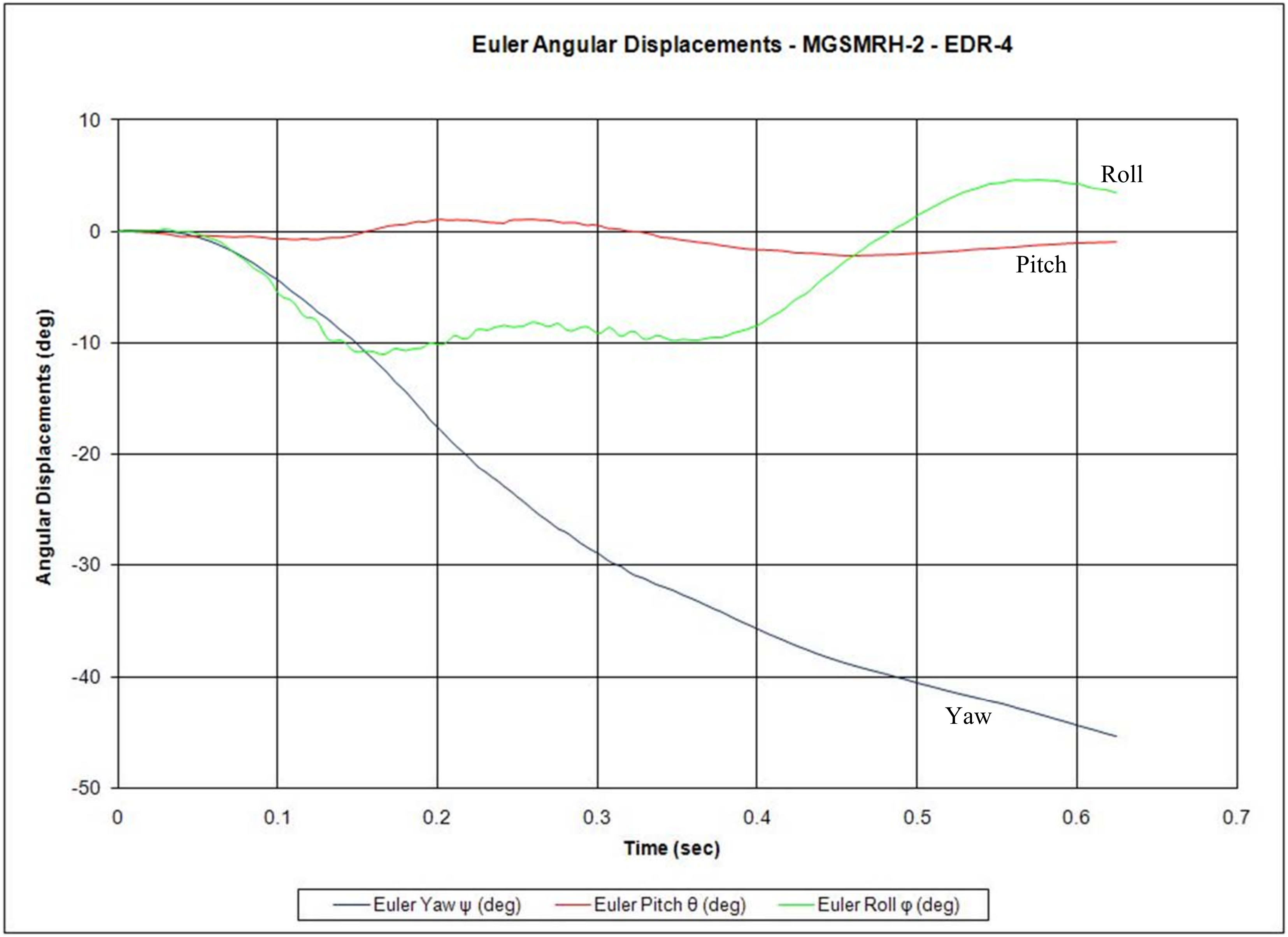


Figure G-7. Vehicle Angular Displacements (EDR-4), Test No. MGSMRH-2

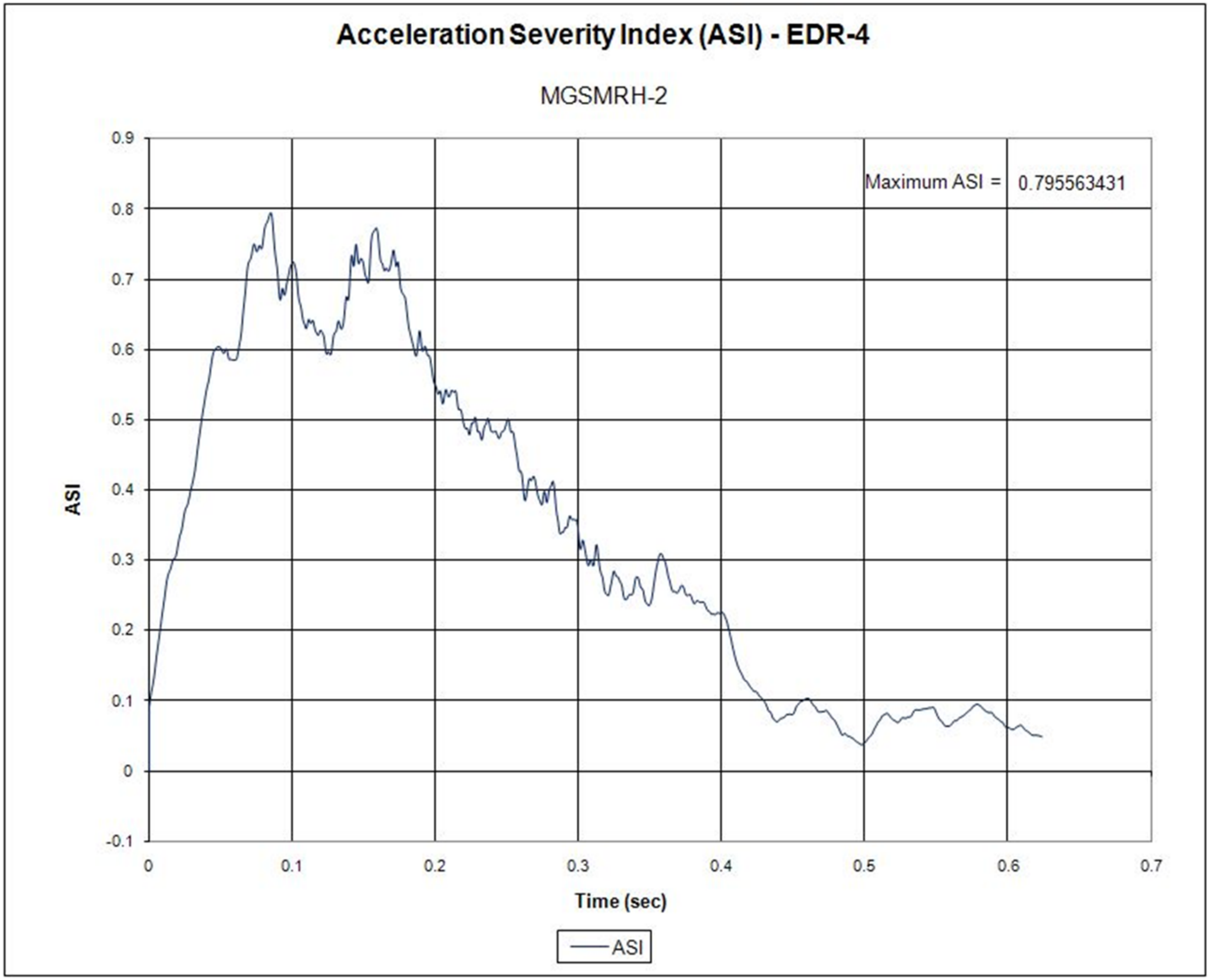


Figure G-8. Acceleration Severity Index (EDR-4), Test No. MGSMRH-2

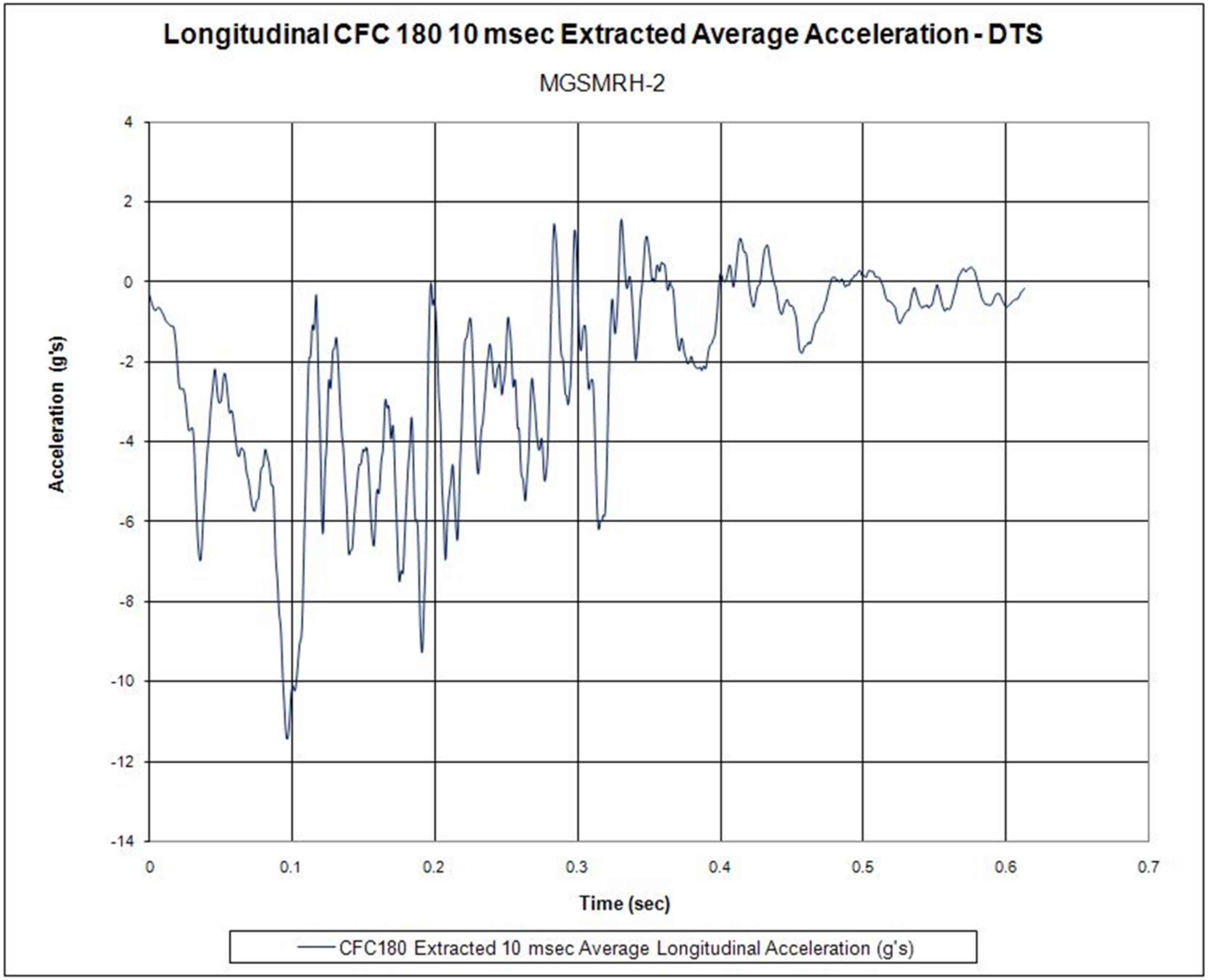


Figure G-9. 10-ms Average Longitudinal Deceleration (DTS), Test No. MGSMRH-2

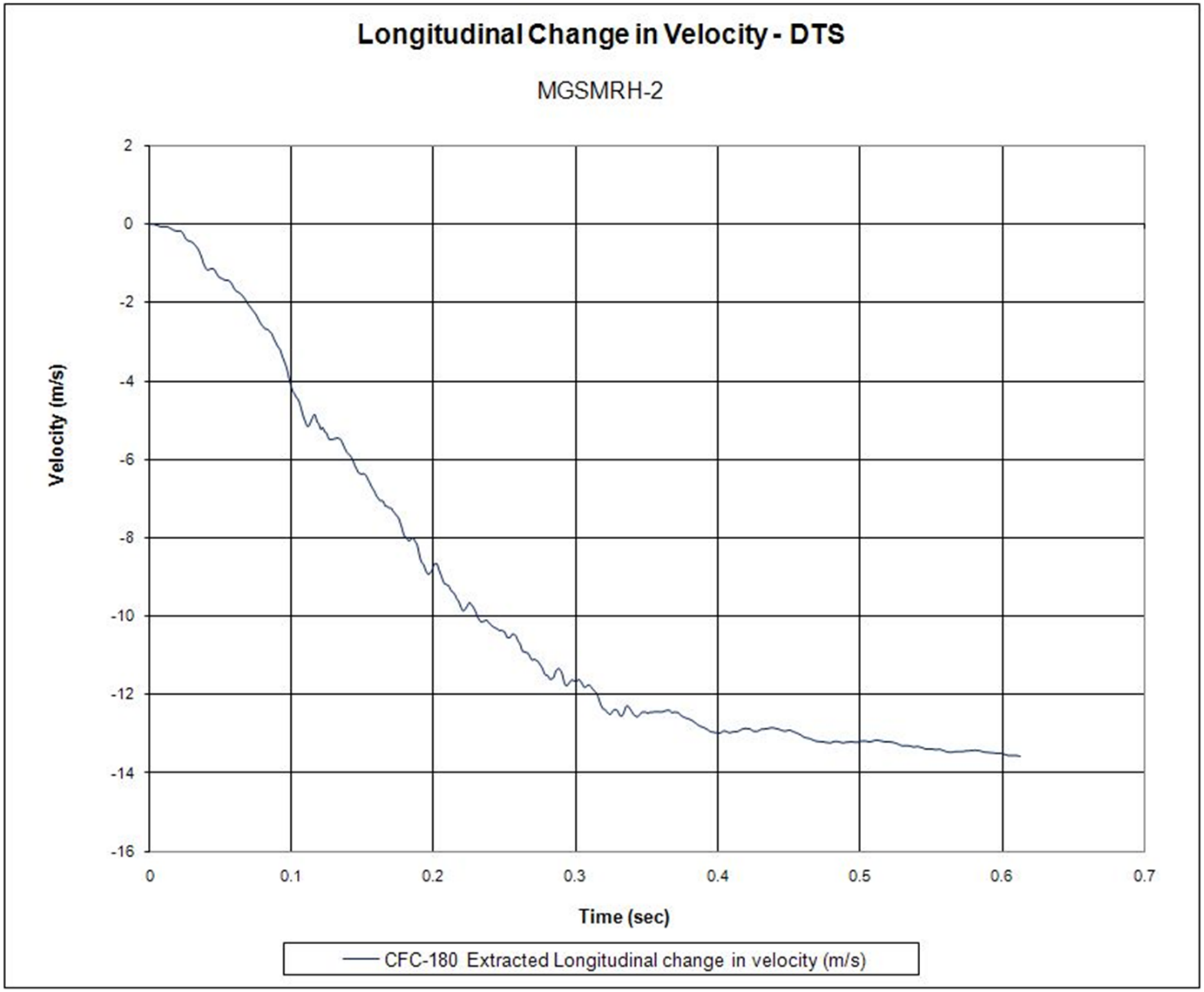


Figure G-10. Longitudinal Occupant Impact Velocity (DTS), Test No. MGSMRH-2

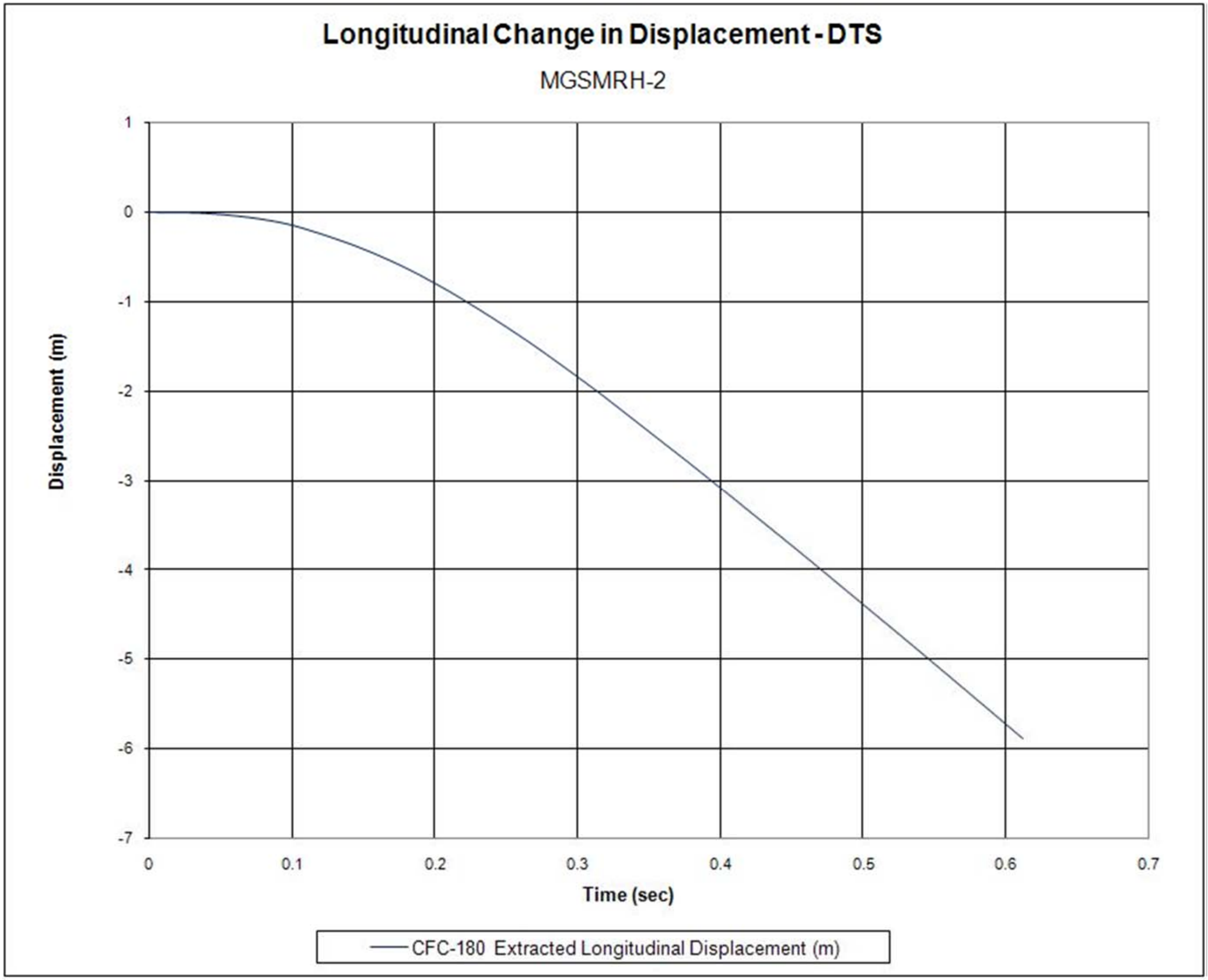


Figure G-11. Longitudinal Occupant Displacement (DTS), Test No. MGSMRH-2

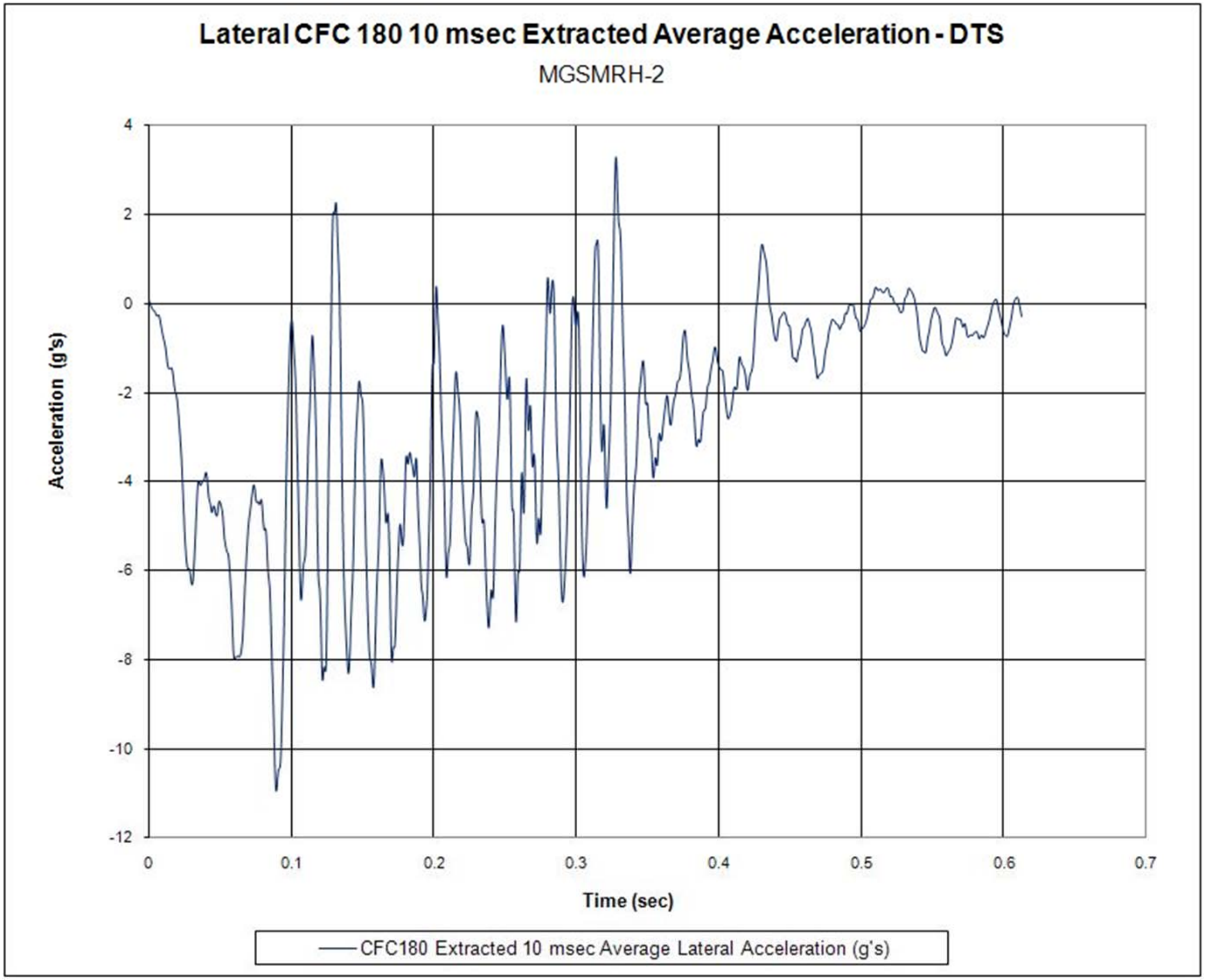


Figure G-12. 10-ms Average Lateral Deceleration (DTS), Test No. MGSMRH-2

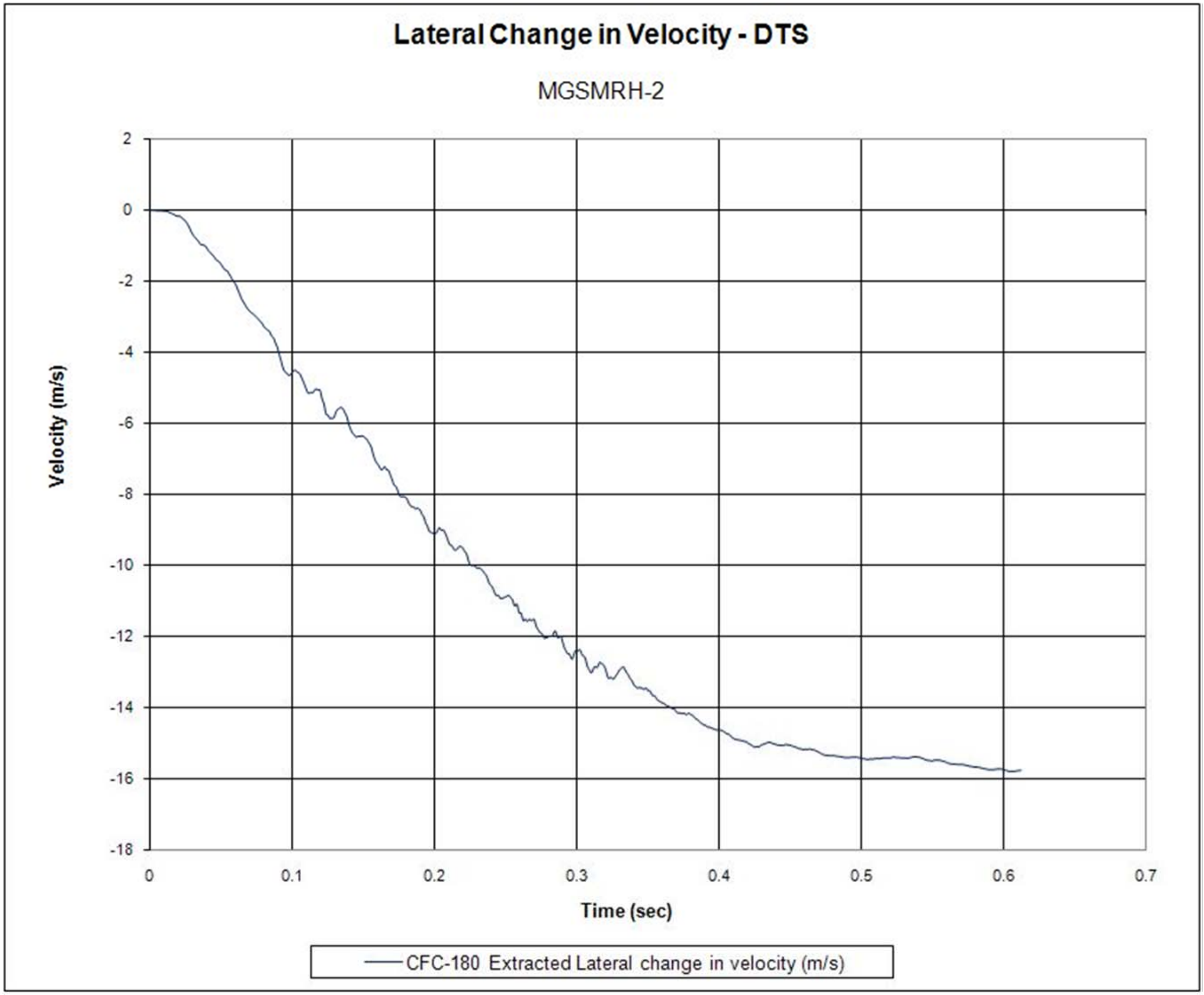


Figure G-13. Lateral Occupant Impact Velocity (DTS), Test No. MGSMRH-2

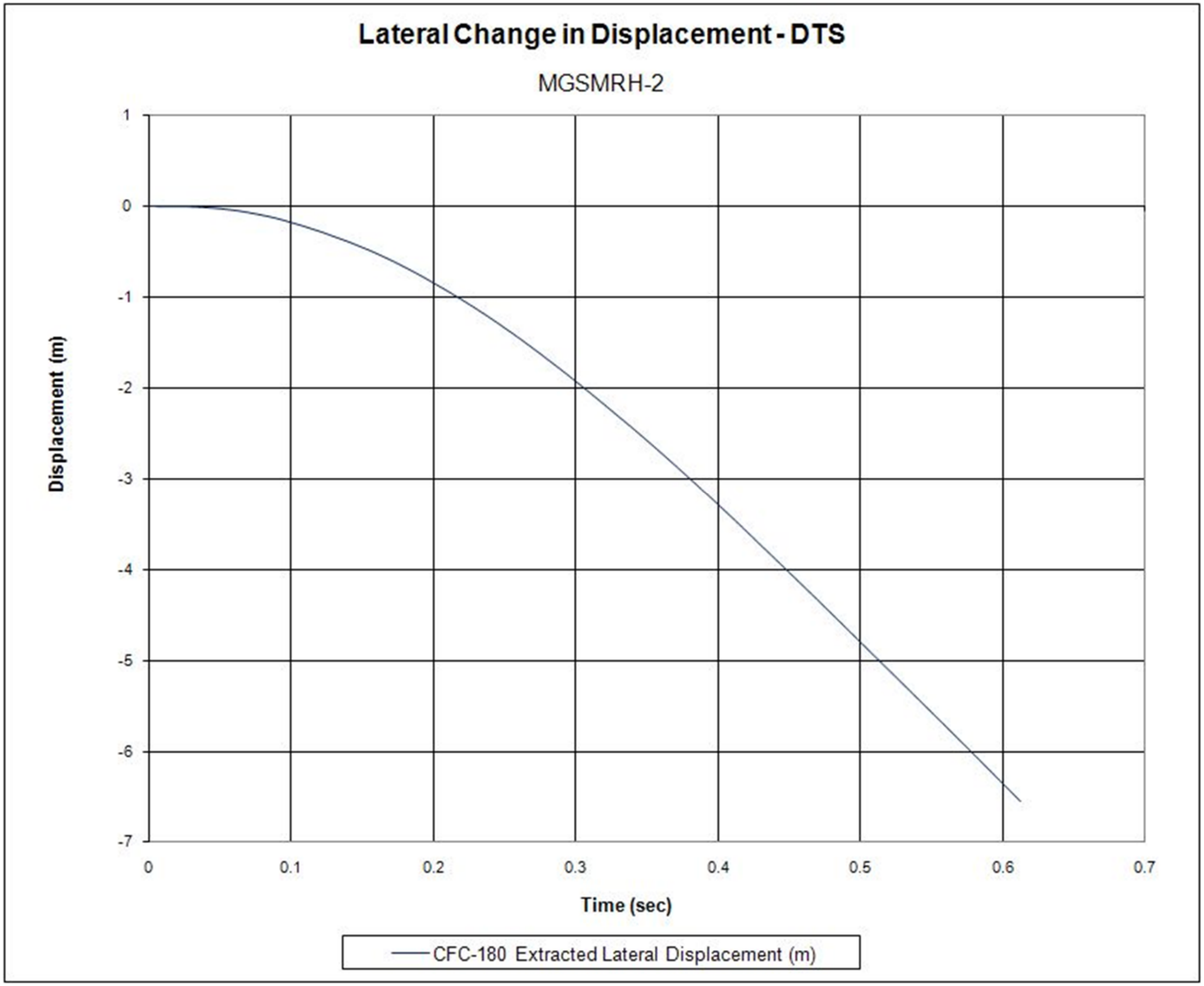


Figure G-14. Lateral Occupant Displacement (DTS), Test No. MGSMRH-2

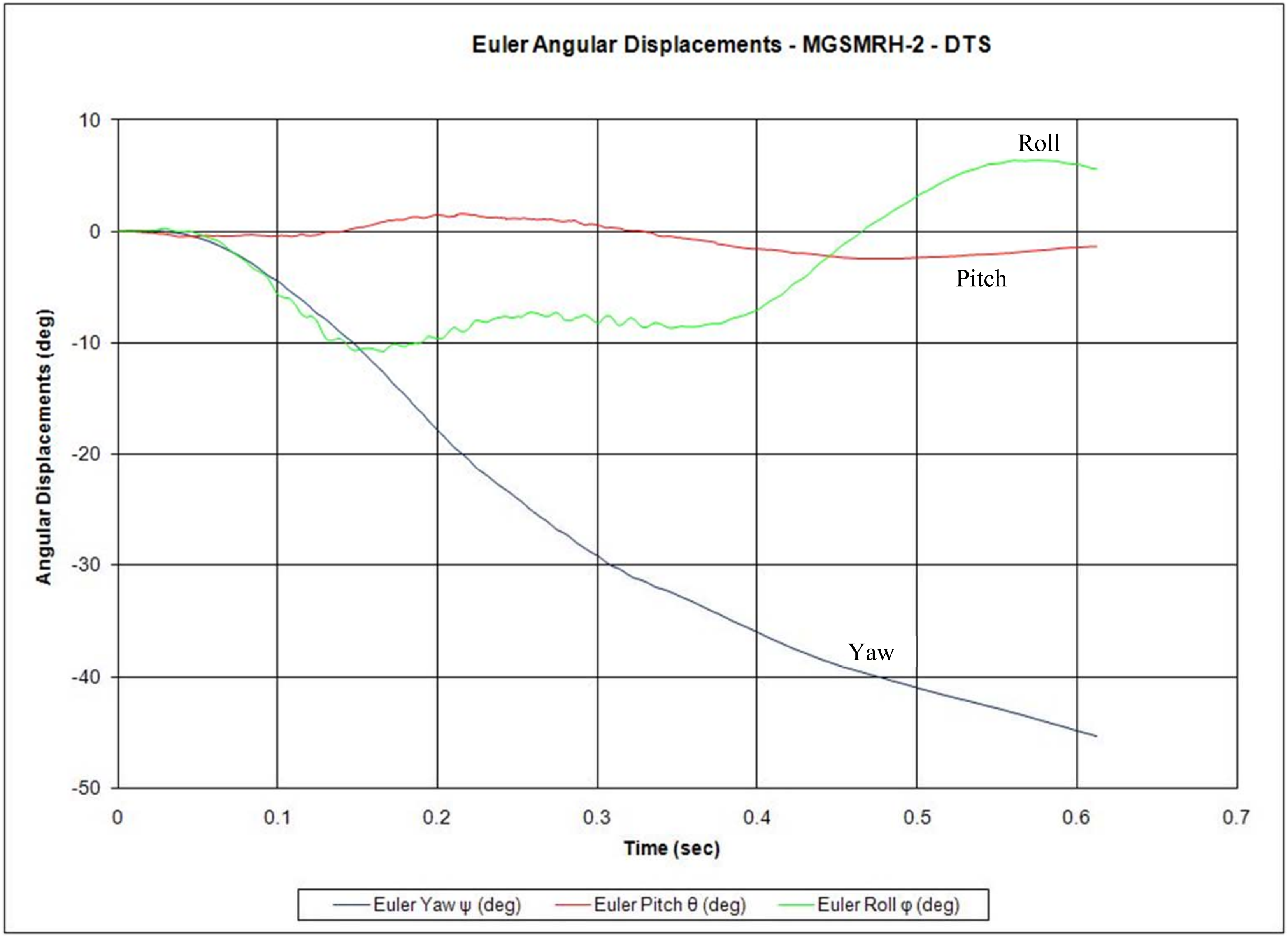


Figure G-15. Vehicle Angular Displacements (DTS), Test No. MGSMRH-2

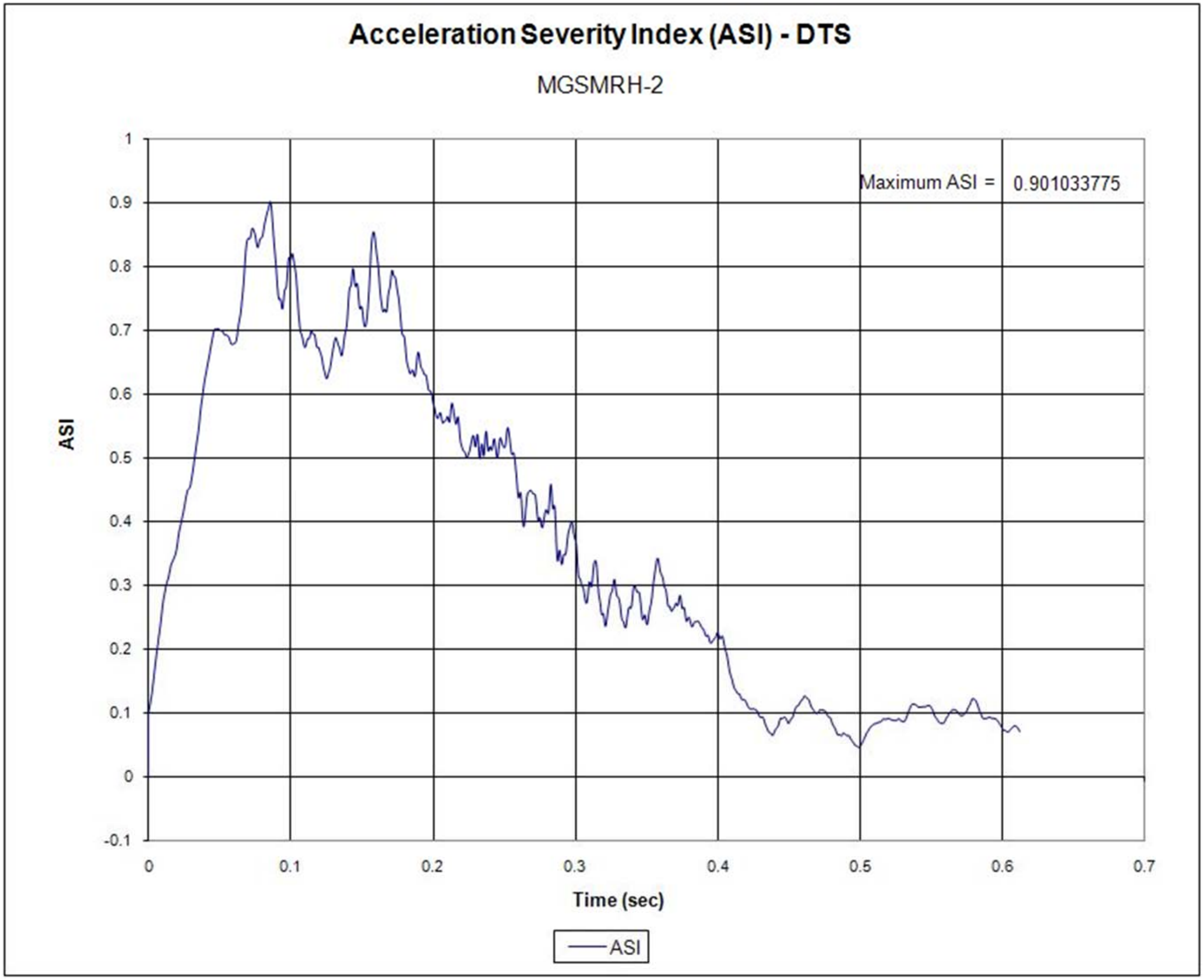


Figure G-16. Acceleration Severity Index (DTS), Test No. MGSMRH-2

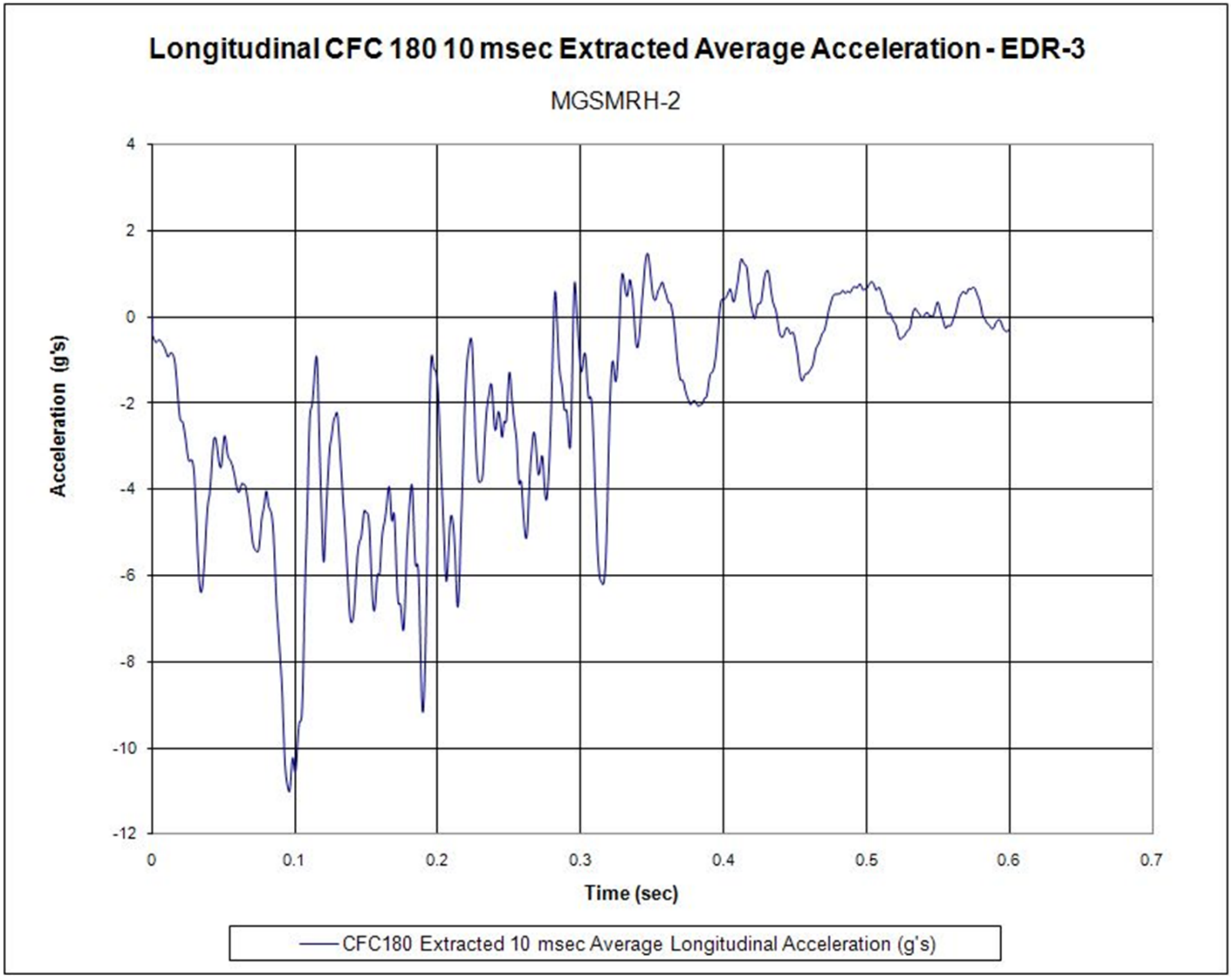


Figure G-17. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. MGSMRH-2

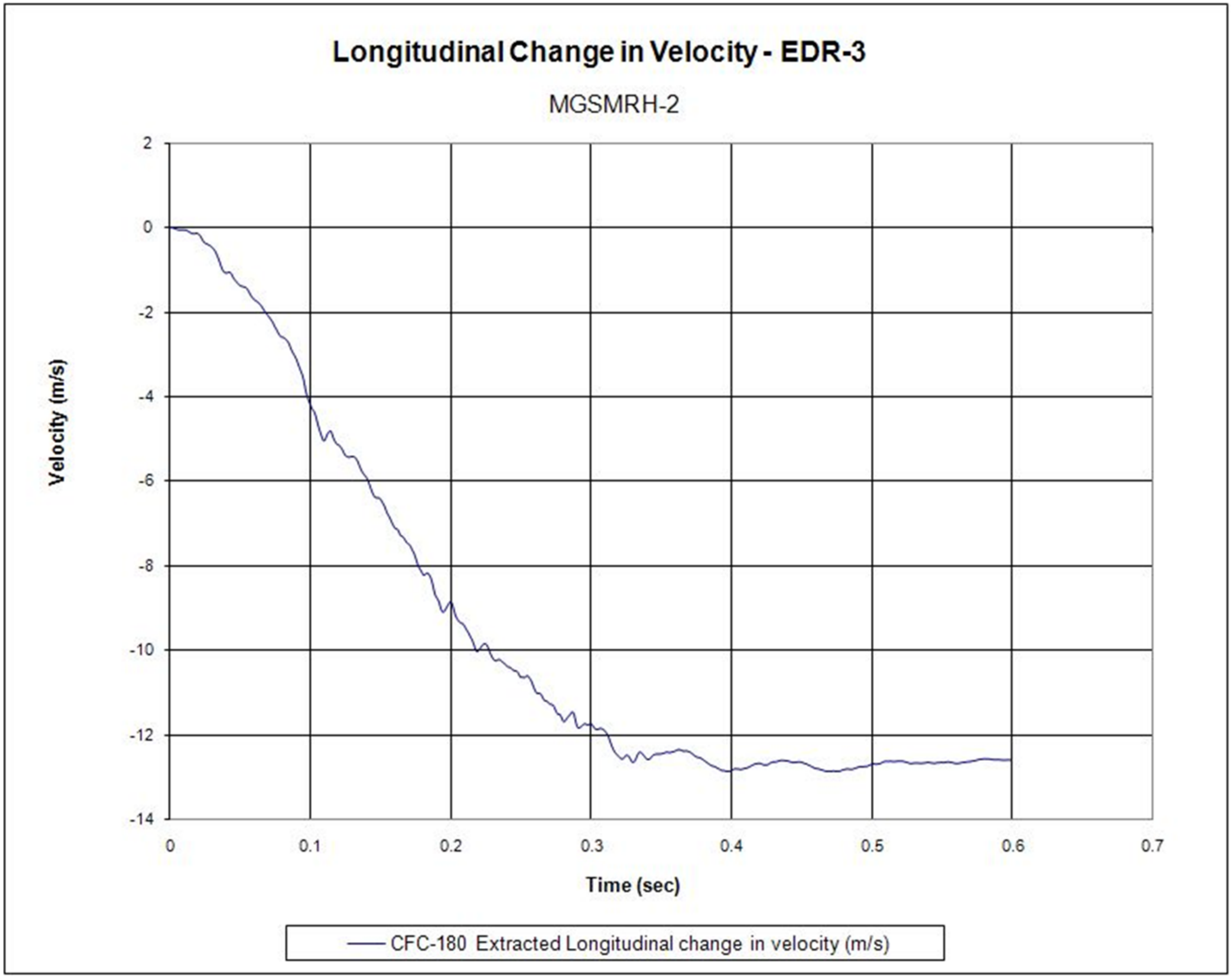


Figure G-18. Longitudinal Occupant Impact Velocity (EDR-3), Test No. MGSMRH-2

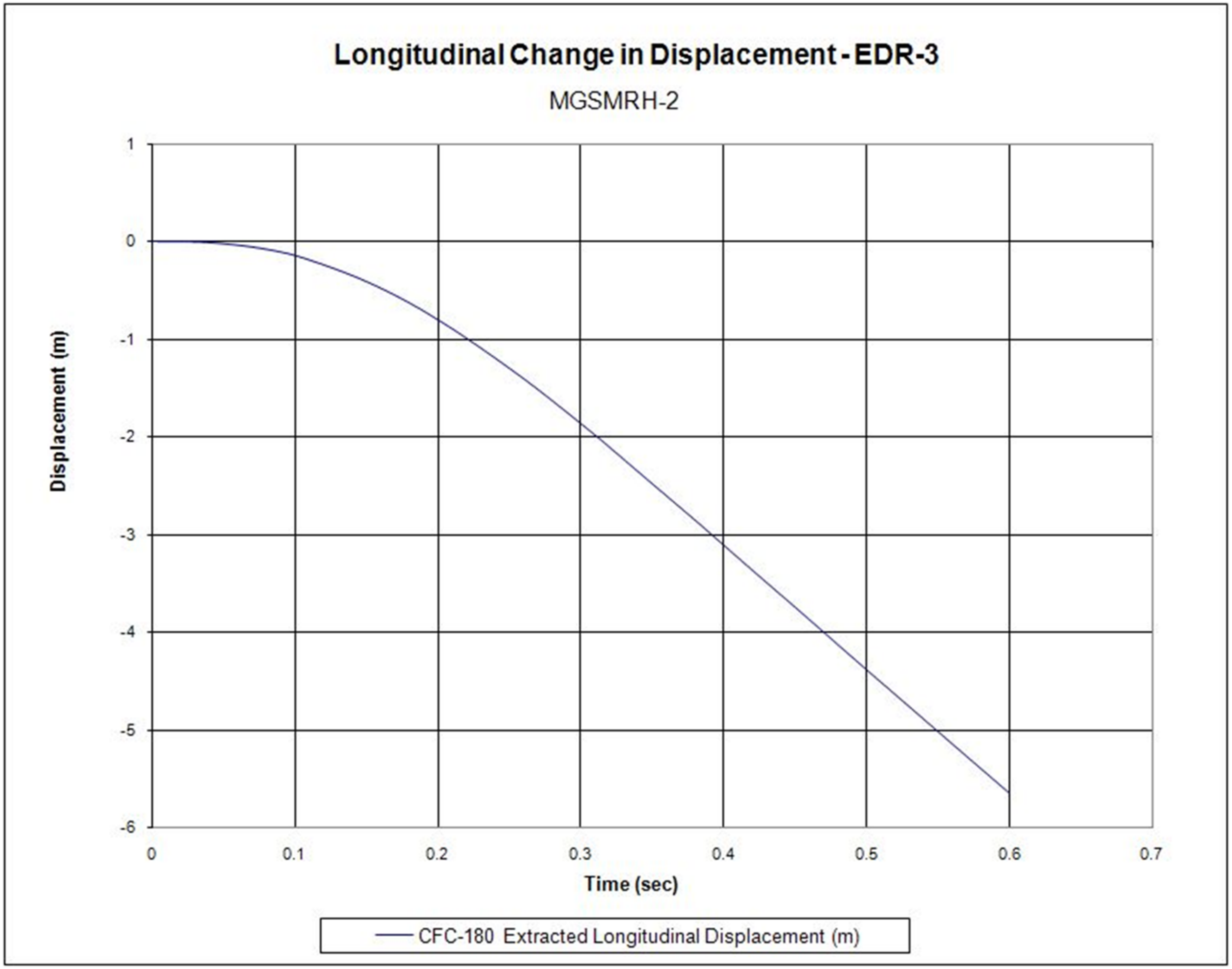


Figure G-19. Longitudinal Occupant Displacement (EDR-3), Test No. MGSMRH-2

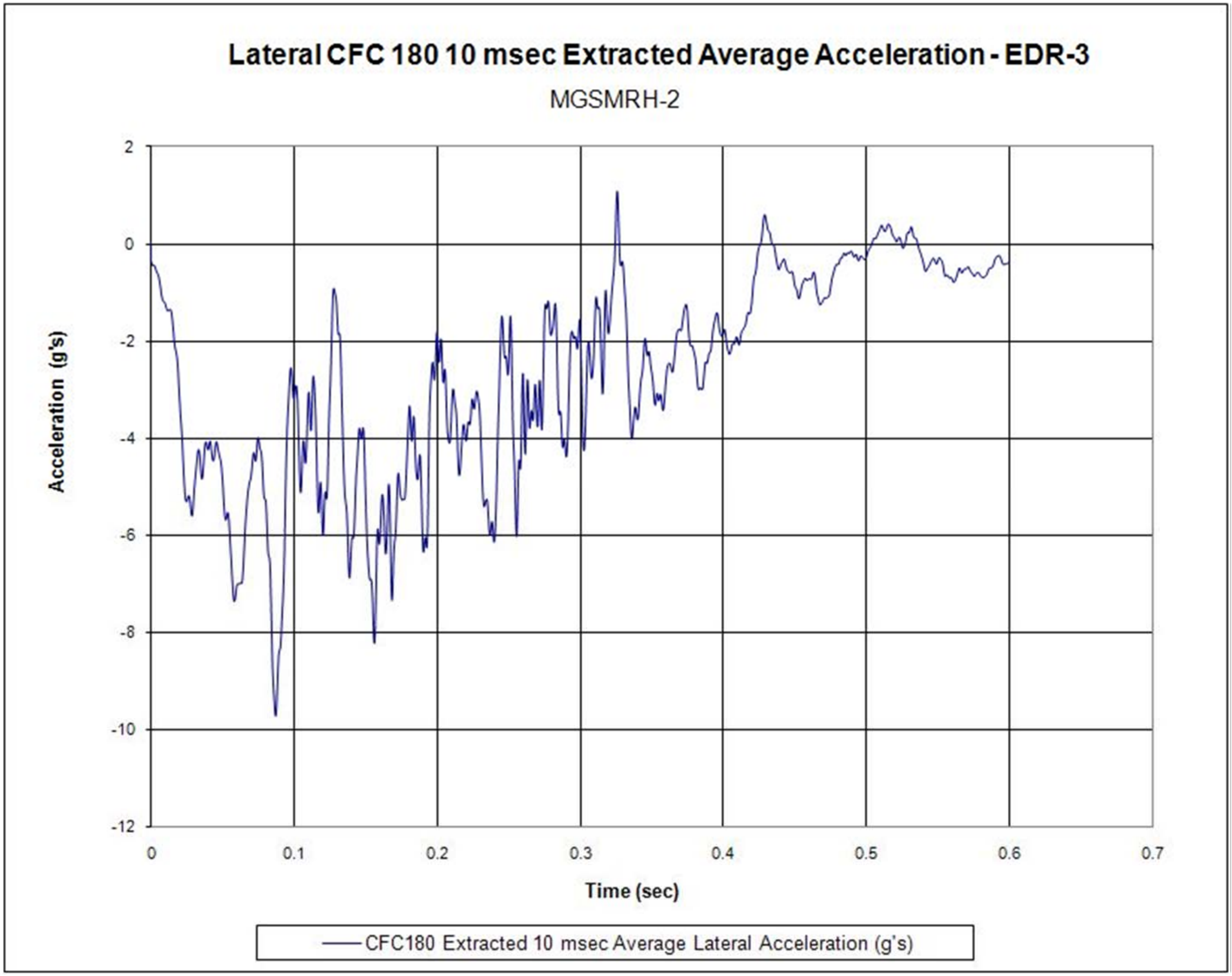


Figure G-20. 10-ms Average Lateral Deceleration (EDR-3), Test No. MGSMRH-2

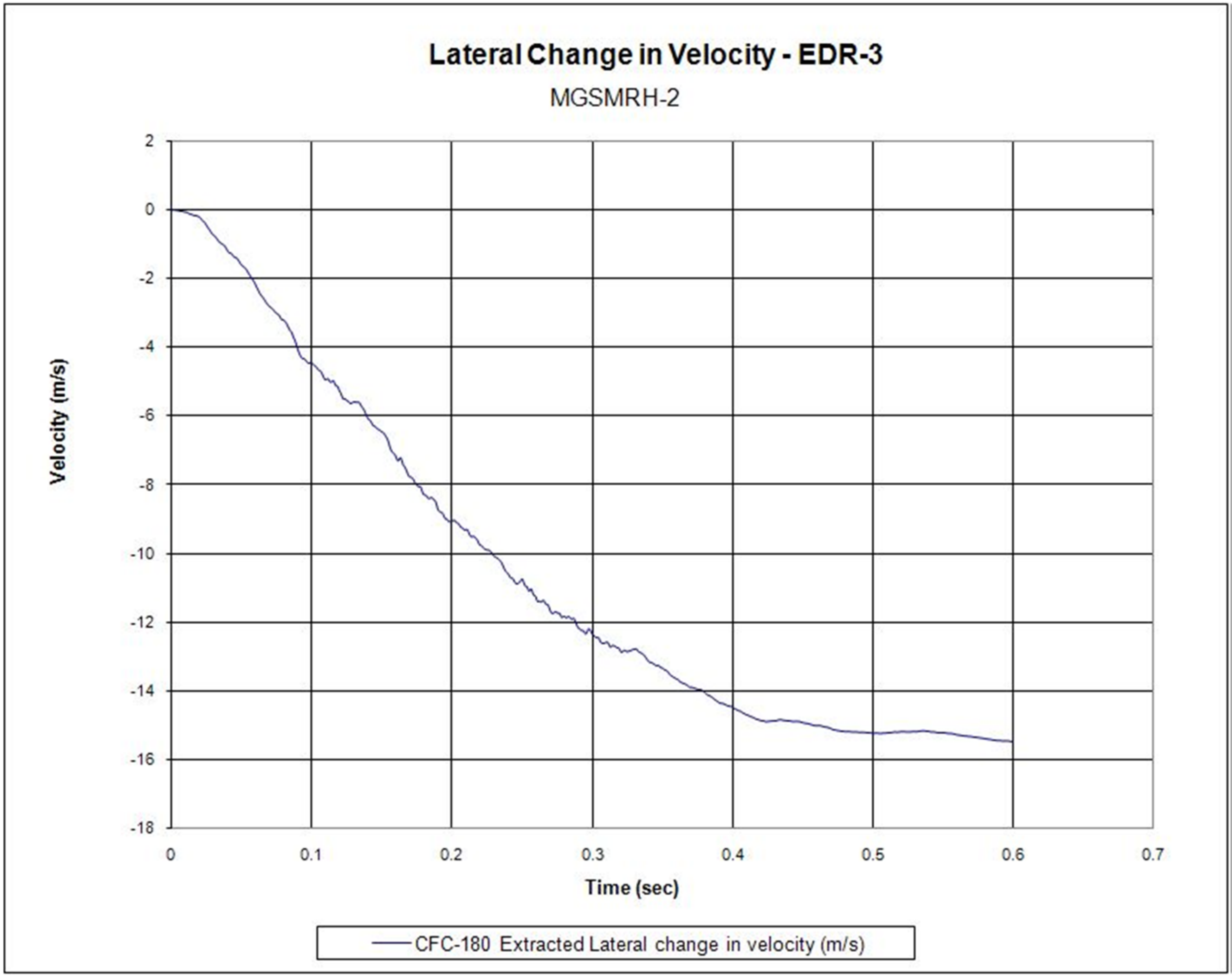


Figure G-21. Lateral Occupant Impact Velocity (EDR-3), Test No. MGSMRH-2

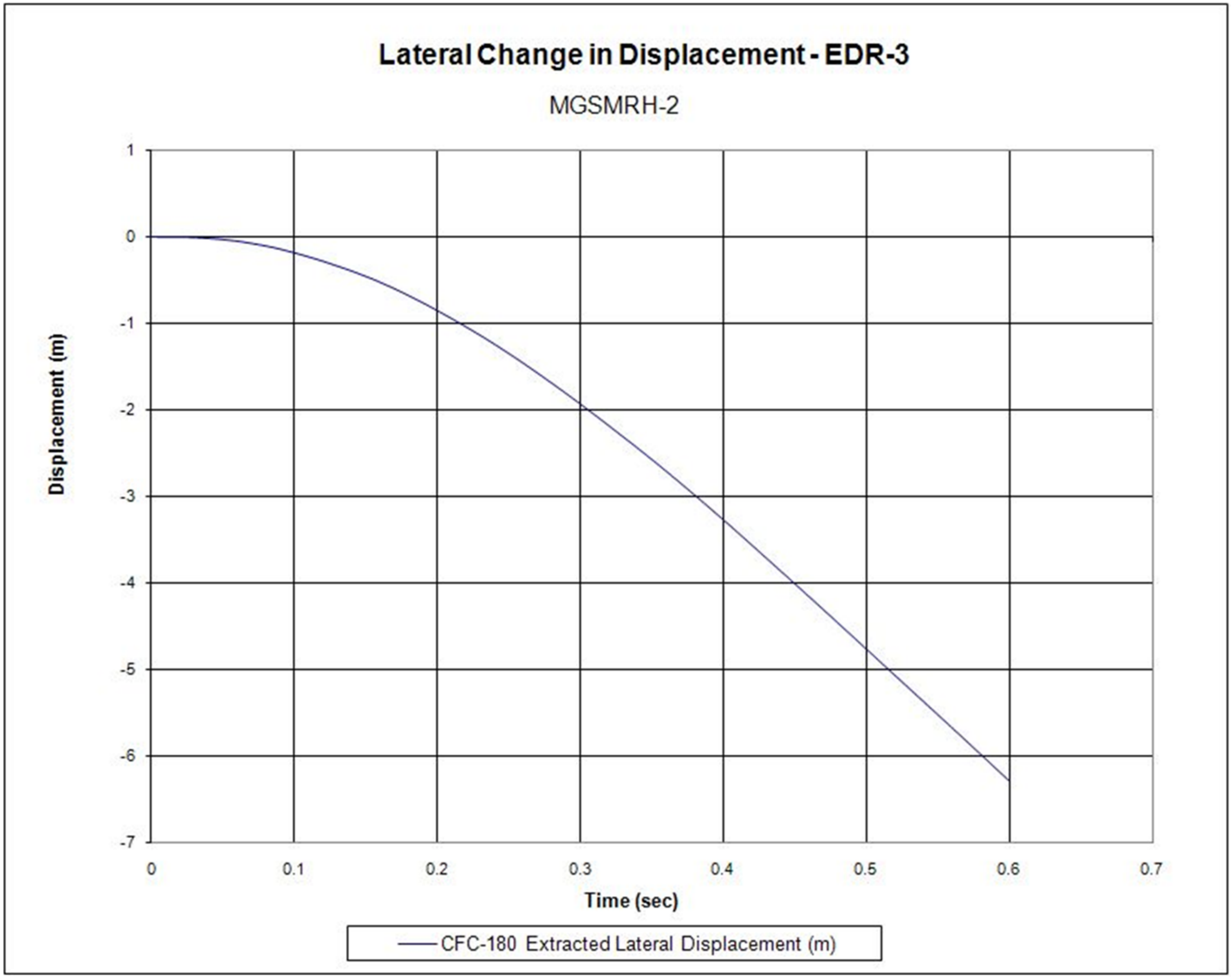


Figure G-22. Lateral Occupant Displacement (EDR-3), Test No. MGSMRH-2

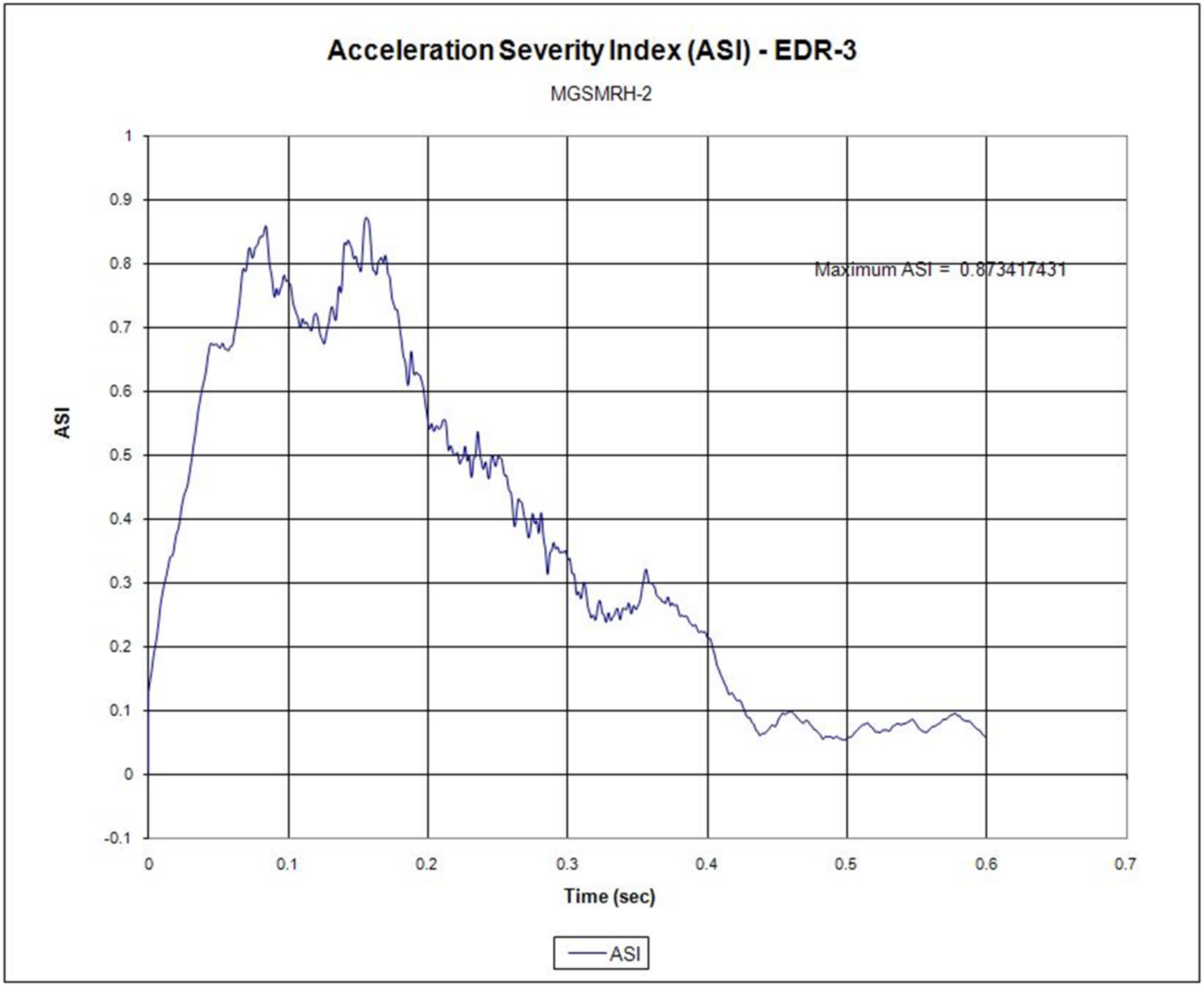


Figure G-23. Acceleration Severity Index (EDR-3), Test No. MGSMRH-2

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