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Midwest Guardrail System for Long-Span Culvert Application

Robert W. Bielenberg
University of Nebraska - Lincoln, rbielenberg2@unl.edu

Ronald K. Faller
University of Nebraska - Lincoln, rfaller1@unl.edu

John R. Rohde
University of Nebraska - Lincoln, jrohde1@unl.edu

Dean L. Sicking
University of Nebraska - Lincoln, dsicking1@unl.edu

James C. Holloway
University of Nebraska - Lincoln, jholloway1@unl.edu

See next page for additional authors

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Authors

Robert W. Bielenberg, Ronald K. Faller, John R. Rohde, Dean L. Sicking, James C. Holloway, Karla A. Polivka, John D. Reid, and Erin M. Allison

Midwest Guardrail System for Long-Span

Culvert Applications

Submitted by

Robert W. Bielenberg, M.S.M.E., E.I.T.
Research Associate Engineer

John R. Rohde, Ph.D., P.E.
Associate Professor

Dean L. Sicking, Ph.D., P.E.
Professor and MwRSF Director

Erin M. Allison
Undergraduate Research Assistant

Ronald K. Faller, Ph.D., P.E.
Research Assistant Professor

John D. Reid, Ph.D.
Professor

James C. Holloway, M.S.C.E., E.I.T.
Research Manager

Karla A. Polivka, M.S.M.E., E.I.T.
Research Associate Engineer

MIDWEST ROADSIDE SAFETY FACILITY
University of Nebraska-Lincoln
527 Nebraska Hall
Lincoln, Nebraska 68588-0529
(402) 472-0965

Submitted to

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16. Abstract (Limit: 200 words)

     Long-span guardrail systems have been recognized as an effective means of shielding low-fill culverts. These designs are popular due to their ability to safely shield the culvert while creating little additional construction effort and limiting the damage and repair of the culvert when compared to other systems that attach posts to the top of the culvert. However, previous long-span designs were limited by the need to use long sections of nested guardrail to prevent rail rupture and the need for large lateral offsets between the barrier and the culvert. The MGS long-span guardrail described herein eliminates those two shortcomings by applying the benefits of the Midwest Guardrail System (MGS) to a long-span design. The MGS long-span increased vehicle capture and stability through increased rail height, limited the potential for pocketing and wheel snag through the use of CRT posts adjacent to the unsupported span, and greatly increased the tensile capacity of the rail through the movement of splices away from the posts and the use of shallower post embedment. These features allowed the system to be developed without the use of nested guardrail and with a minimal barrier offset that places the back of the guardrail posts even with the front face of the culvert.

     Two full-scale crash tests were conducted on the MGS long-span according to the Update to NCHRP Report No. 350 requirements for TL-3 test designation no. 3-11. Both tests were conducted with the heavier 2270P vehicle in order to generate higher rail loads and dynamic deflections. The MGS long-span design met all of the safety requirements of the Update to NCHRP Report No. 350. The MGS long-span guardrail's ability to perform safely without nested rail and a minimal barrier offset make this new barrier a very functional and safe option for protection of low-fill culverts.

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Ron Seitz, P.E., Bureau Chief
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Montana Department of Transportation

Susan Sillick, Research Bureau Chief

Nebraska Department of Roads

Amy Starr, Research Engineer
Phil Tenhulzen, P.E., Design Standards Engineer
Jodi Gibson, Research Coordinator

New Jersey Department of Transportation

Kiran Patel, P.E., P.M.P., C.P.M., Deputy State Transportation Engineer

Ohio Department of Transportation

Dean Focke, P.E., Standards Engineer

South Dakota Department of Transportation

David Huft, Research Engineer
Bernie Clocksin, Lead Project Engineer

Wisconsin Department of Transportation

John Bridwell, Standards Development Engineer
Erik Emerson, Stadards Development Engineer

Wyoming Department of Transportation

William Wilson, P.E., Standards Engineer

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1 INTRODUCTION

1.1 Problem Statement

Proper drainage of water and runoff is an important consideration in the design of highways. Design features for drainage can include drainage channels, inlets, and other features. Often, it becomes necessary for designers to divert water from one side of the roadway to another through the use of cross-drainage structures. Cross-drainage structures range from small concrete and corrugated metal pipes to larger concrete box culverts and structural plate pipes. Because these types of structures are comprised of significant structural sections, it is generally recommended that cross-drainage structures be extended so that the inlets and outlets are placed outside of the clear zone whenever possible. However, space limitations and drainage considerations can make such placement unfeasible due to the need to purchase increased right-of-way or increased earthwork requirements.

If the culvert or cross-drainage structure is located on a traversable slope, a second available option is to adjust the length of the structure and bevel the inlet and outlet to match the existing slope. The inlet and outlet can then be covered with steel bars, grates, or pipes in order to prevent a vehicle and its wheel assembly from significantly penetrating the opening, potentially resulting in vehicle instability or increased decelerations. Previous research and culvert design guidelines have shown that for smaller culverts, a single round pipe 900 mm (35.5 in.) or less in diameter or multiple round pipes 750 mm (29.5 in.) or less in diameter, no additional treatment is required (1). Larger culvert structures, those wider than 1,000 mm (39.375 in.), can be made traversable by covering the inlet and outlet. Full-scale testing has shown that automobiles can safely traverse cross-grated culvert end sections located on slopes as

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steep as 3:1 and at speeds between 32.2 and 96.5 km/h (20.0 and 60.0 mph) using steel Schedule 40 pipes spaced 762 mm (30 in.) on center (2-3).

Large culvert structures can be difficult and costly to extend and making the structure traversable can be difficult. For these types of culvert installations, the best option is to shield the culvert with a crashworthy barrier system. In the past, systems designed to shield large culvert structures have included strong-post guardrails with steel posts bolted to the top of the culvert, guardrail with nested sections of rail and reduced post spacing, and long-span guardrail systems which shield the hazard with a length of unsupported guardrail over the culvert. However, many culvert installations provide very little soil fill above the culvert for guardrail post embedment, as shown in Figure 1. Crash testing has demonstrated that posts with very shallow embedment depths can easily be pulled out of the ground, thus resulting in vehicle snagging or vaulting and causing potentially disastrous results (4) and has also demonstrated that posts attached to the culvert are severely deformed and often pulled loose, causing significant damage to the culvert as well as expensive repair costs (4-5). Thus, long-span guardrail systems provide certain benefits over the other shielding designs in that they do not require additional construction effort and repairs due to attachment of posts to the culvert, nor do they not have to consider the very shallow post embedment depth hazard posed by low-fill culverts.

A design for shielding low-fill culverts with long-span guardrail was developed previously at the Texas Transportation Institute (TTI) (6-7). The long-span system tested was designed for culverts between 3.81-m and 5.72-m (12.5-ft and 18.78-ft) long. While this long-span design provided an improved and economical long-span guardrail system, several State Departments of Transportation encountered situations where unsupported lengths in excess of 5.72 m (18.77 ft) and up to 7.62 m (25.0 ft) were required. In addition, the previously described

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Figure 1. Low Fill Culverts

designs were crash tested according to the evaluation criteria provided by the National Cooperative Highway Research Program (NCHRP) Report No. 230, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances* (8). Consequently, these existing designs can no longer be used on Federal-aid highways unless shown to meet current impact safety standards, and any new designs with unsupported lengths in excess of 5.72 m (18.77 ft) must also be subjected to crash testing.

Researchers at the Midwest Roadside Safety Facility (MwRSF) developed the only NCHRP Report No. 350 (9) compliant long-span system to date that is capable of shielding culvert lengths up to 7.62-m (25.0-ft) long (10-12). This system was designed based on standard strong-post W-beam guardrail and used 30.48 m (100 ft) of nested W-beam guardrail combined with breakaway wood CRT posts adjacent to the unsupported guardrail section in order to shield the culvert. Design recommendations for the system stated that the back face of the guardrail be placed no less than 1.5 m (4.92 ft) from the front face of the culvert head wall.

Recent improvements in the design of W-beam guardrail led researchers to believe that the existing MwRSF long-span guardrail could be improved. The Midwest Guardrail System (MGS) has shown marked improvement over W-beam guardrail in a variety of crash tests (13-15). The MGS, as shown in Figure 2, has been modified and improved beyond standard strong-post W-beam guardrail by the following changes:

1. The guardrail splices have been moved to the mid-span and away from the posts to reduce stress concentrations, thus reducing the potential for increased rail strain and fracture.
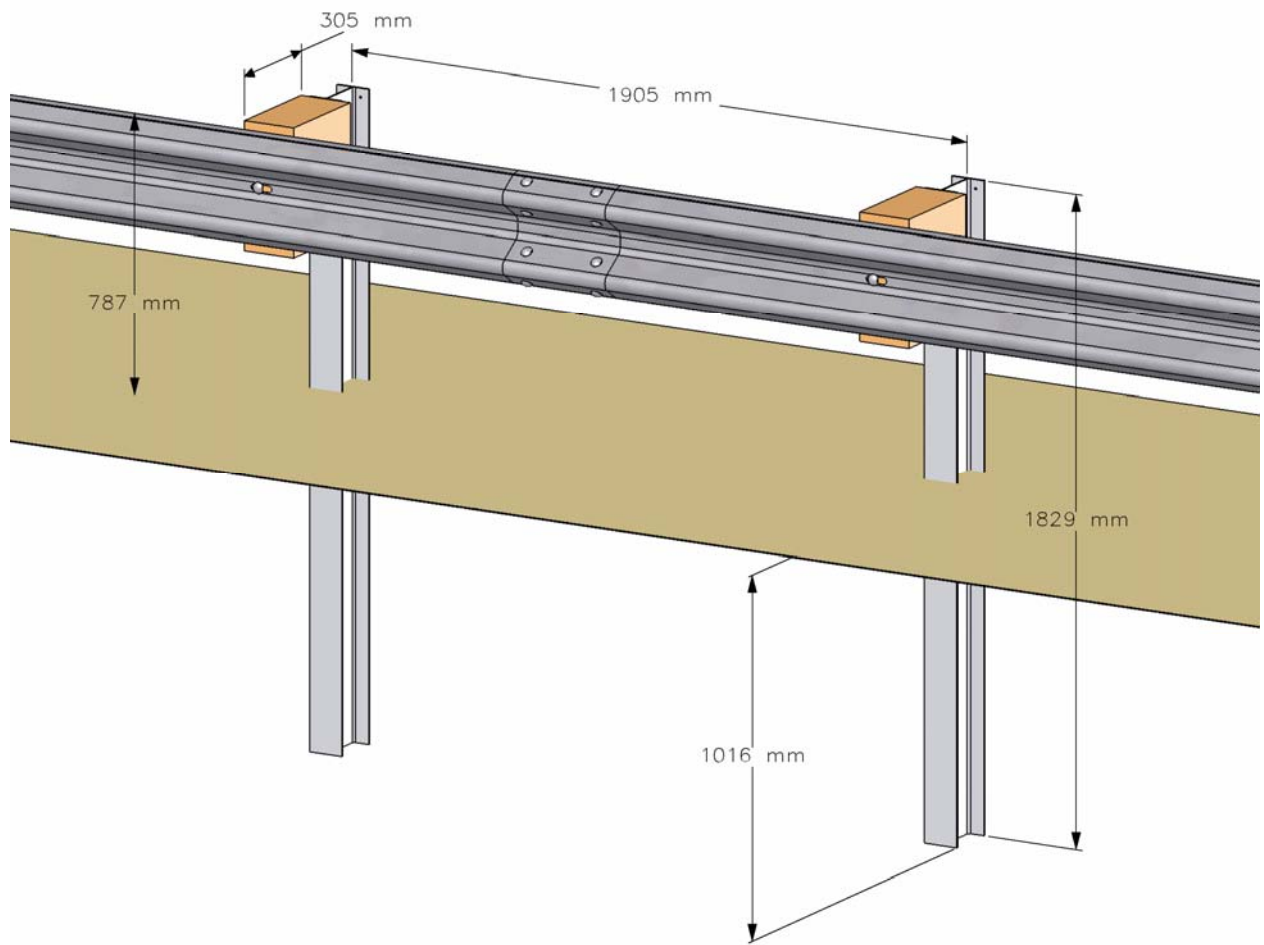
Figure 2. Midwest Guardrail System

2. The nominal top mounting height of the rail has been increased to 787 mm (31.0 in.) in order to more effectively capture and contain high center-of-gravity vehicles.

3. The spacer block or blockout depth has been increased to 305 mm (12 in.) in order to reduce the potential for wheel snag on the guardrail posts in the system and to better maintain rail height as the system deflects backward.

4. The standard post embedment depth has been reduced by 83 mm (3.25 in.) which effectively reduces the loading and strain in the W-beam guardrail, thus further reducing the potential for rail rupture.

The net effect of these changes produced a guardrail system with increased rail capacity as well as enhanced vehicle capture and stability that greatly improved upon standard W-beam guardrail's ability to safely capture and redirect errant vehicles.

The researchers believed that the improved performance of the MGS system could be applied to the design of the long-span guardrail system to make the design more efficient while improving the safety performance. In addition, it was hoped that a long-span design based on the MGS system could reduce or potentially eliminate the need for the nested guardrail as well as allow the guardrail to be placed much closer to the culvert headwall when compared to the previous design.

1.2 Research Objective

The objective of this research was to develop an MGS long-span guardrail system that was capable of traversing culverts with a span of 7.62 m (25.0 ft) in length by utilizing the benefits of the recently developed MGS guardrail. The MGS long-span system was designed to meet the Test Level 3 (TL-3) safety performance criteria set forth in the proposed Update to

NCHRP Report No. 350. This study was performed by the Midwest Roadside Safety Facility (MwRSF) in cooperation with the Midwest States' Regional Pooled Fund Program.

2 DESIGN OF THE MGS LONG-SPAN GUARDRAIL SYSTEM

2.1 Design Considerations

The development of the MGS long-span guardrail system considered four main factors that were critical to the design of a successful system; (1) vehicle capture, (2) pocketing and snagging, (3) lateral offset to the culvert, and (4) rail tensile capacity. These factors are discussed in more detail in the proceeding sections.

2.1.1 Vehicle Capture

The first of these design considerations was vehicle capture. For a long, unsupported length of guardrail extending across a culvert, vehicle capture becomes a significant consideration. With a long unsupported guardrail length, there exists a potential for the guardrail height to drop during deflection of the system and the vehicle to vault and override the guardrail. However, the researchers believed that the design enhancements of the MGS guardrail would alleviate the potential capture issues posed by a long-span design. The increased rail height and larger blockout depth combine to provide increased stability and capture over standard W-beam, and the performance of the MGS design during previous testing led the researchers to believe that the vehicle capture of the MGS long-span design would be sufficient.

2.1.2 Pocketing and Wheel Snag

Potential for pocketing of the system and wheel snag were major considerations in the design of the MGS long-span due to concerns that the large unsupported guardrail length adjacent to a stiffer guardrail could cause a pocket to form ahead of the impacting vehicle. A second concern was that it would allow sufficient deflection to cause wheel snag on the posts. Both of these could lead to vehicle instability. The existing MwRSF long-span guardrail design had addressed the pocketing and wheel snag issues by placing three wood breakaway CRT posts

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adjacent to each end of the unsupported guardrail length. The CRT posts functioned well during testing of the previous design to reduce wheel snag and pocketing, and it was decided to leave these breakaway posts in the MGS long-span design as well.

2.1.3 Lateral Offset

The third design consideration for the MGS long-span guardrail was minimizing the lateral offset between the guardrail and the culvert headwall. As mentioned previously, the existing MwRSF long-span design recommended a 1.5 m (4.92 ft) offset between the back face of the guardrail and the front face of the culvert headwall. The 1.5-m (4.92-ft) offset was deemed conservative based on the dynamic deflection and wheel trajectory of the previous long-span design. The offset was also conservative because the original MwRSF long-span was tested on level ground without an actual culvert installed behind it, and no conclusions about vehicle interaction with the culvert could be made. A large guardrail offset poses problems for many low fill culvert installations where space is limited. Thus, it was desired to minimize this offset as much as possible. However, the trade off with minimizing the guardrail offset was increased interaction between the vehicle and the culvert head wall during impacts with the unsupported length of guardrail. The researchers believed that the improved vehicle capture and stability provided by the MGS enhancements would allow placement of the back of the guardrail posts 305 mm (12.0 in.) or closer to the front face of the culvert headwall. In order to insure that interaction between the impacting vehicle and the culvert was represented, the testing of the MGS long-span included a culvert headwall installed behind the system.

2.1.4 Rail Tensile Capacity

The final and possibly most critical design consideration for the MGS long-span was rail tensile capacity. Previous long-span designs had recognized that high rail strains and potential

guardrail rupture were a problem for long-span designs. While the AASHTO M180 steel used in W-beam guardrails is a relatively ductile material and can sustain significant plastic strain without failure, full-scale crash tests indicated that guardrails tend to fail at relatively low plastic strains. This behavior can be directly related to several factors. Recall that the cross-section of a W-beam rail element is reduced by approximately 15 percent at the rail splice. This reduction in cross-section tends to localize strain in the splice region and leads to rail rupture near the point that the full cross-section begins to yield. In addition to the reduced section, placement of the splice at the posts creates bending strains as the rail and splice deform around the post as well as stress concentrations at the splice due to its edges and slots. This combination of minimal tensile area, stress concentrations, and high bending strains caused by deflections around a post creates an increased potential for rail rupture.

The design of the MGS long-span system alleviated many of the issues with rail tensile capacity due to the movement of the splice position and the reduced post embedment depth of the system. First, the MGS system moved the rail splices away from the post and to the mid-span. This change moves the minimum tensile area away from the area of highest bending strain and reduces stress concentrations and strains in the splice because it no longer bends around the post. The second major factor that effectively increased the rail tensile capacity in the MGS system was the reduced embedment depth and stiffness of the posts. Reduction of the embedment depth and post stiffness allows the deflection to be spread over a longer distance along the guardrail, creating a more effective load distribution and lowering the strains and forces in the rail sections.

This effect can be illustrated by a simple example shown in Figure 3. This figure displays one guardrail system with relatively stiff posts that has a deflected length L_1 and a dynamic

deflection D_1, and a second guardrail system with less stiff posts that has a deflected length L_2 and a dynamic deflection D_2. Based on calculations for the simple deflected geometry shown, the change in length of each section of deflected guardrail can easily be calculated along with the corresponding engineering strains ε_1 and ε_2. This simple model was applied to two previous tests of W-beam guardrail conducted as part of the NCHRP 22-14 project (16-17), test nos. 2214WB-2 and 2214MG-2. Test no. 2214WB-2 consisted of a 2,270-kg (5,000-lb) Dodge Ram Quad Cab pickup impacting a standard steel post W-beam guardrail at a speed of 100.3 km/h (62.3 mph) and at an angle of 24.3 degrees. Test no. 2214MG-2 consisted of a 2,270-kg (5,000-lb) Dodge Ram Quad Cab pickup impacting the MGS guardrail at a speed of 101.2 km/h (62.9 mph) and at an angle of 24.5 degrees. The impact severities for these two impacts were within 3.4 percent, but test no. 2214MG-2 had lower stiffness posts in the system due to a reduction in post embedment depth of 83 mm (3.25 in.). Applying the deflected length and dynamic deflection measurements from these two tests and calculating the engineering strain yielded a decrease in rail strain of 50.9 percent for the 2214MG-2 system with lower stiffness posts. While this simple model does not take into account all of the factors that affect rail strain during a vehicle impact with a guardrail system, it does suggest that reduced post embedment and stiffness can cause a significant reduction in rail strain and a corresponding increase in rail capacity.

Based on the benefits of the movement of the splice to the mid-span and the reduction in rail strain due to the decreased post embedment, the researchers believed that a MGS long-span design would be able to safely redirect an impacting vehicle without the use of any nested guardrail sections.
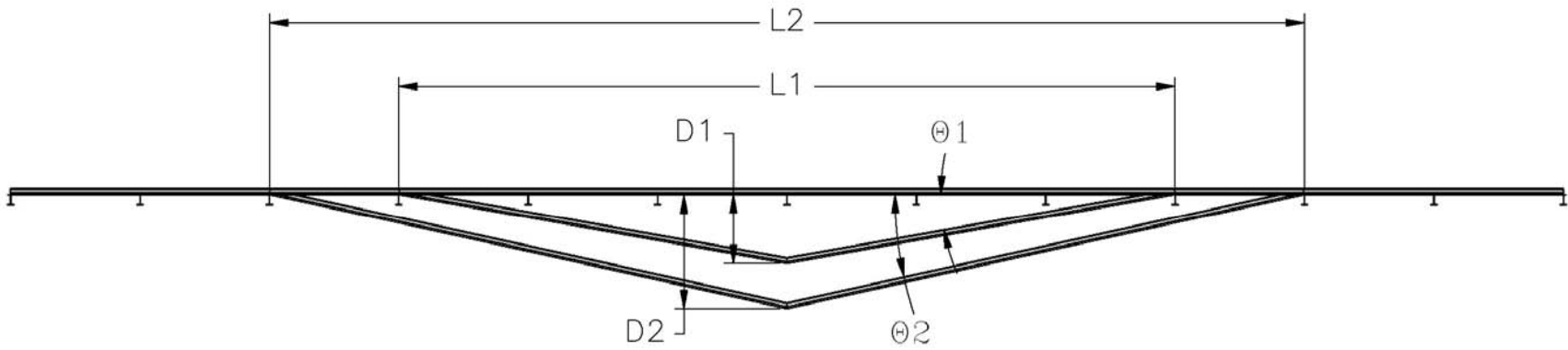
$$\theta_1 = \tan^{-1}\left(\frac{D_1}{L_1 / 2}\right)$$

$$\varepsilon_1 = \frac{\Delta L_1}{L_1}$$

$$\Delta L_1 = \frac{L_1}{\cos(\theta_1)} - L_1$$

$$\theta_2 = \tan^{-1}\left(\frac{D_2}{L_2 / 2}\right)$$

$$\varepsilon_2 = \frac{\Delta L_2}{L_2}$$

$$\Delta L_2 = \frac{L_2}{\cos(\theta_2)} - L_2$$

Figure 3. Rail Strain Comparison

3 MGS LONG-SPAN DESIGN DETAILS – TEST NO. LSC-1

Design details for the initial test of the MGS long-span guardrail system, test no. LSC-1, are shown in Figures 4 through 13. The MGS long-span design consisted of 55.25 m (181.25 ft) of standard 2.67-mm (12-gauge) thick W-beam guardrail supported by steel posts and six CRT posts. Anchorage systems similar to those used on tangent guardrail terminals were utilized on both the upstream and downstream ends of the guardrail system. Photographs of the test installation are shown in Figures 14 through 16.

The entire system was constructed with twenty-six guardrail posts. Post nos. 3 through 10 and 17 through 24 were galvanized ASTM A36 steel W152x13.4 (W6x9) sections measuring 1,829 mm (72.0 in.) long. Post nos. 1, 2, 26, and 27 were BCT timber posts measuring 140 mm wide x 190 mm deep x 1,080 mm long (5.5 in. wide x 7.5 in. deep x 42.5 in. long) and were placed in 1,829-mm (72.0-in.) long steel foundation tubes. The timber posts and foundation tubes were part of anchor systems designed to replicate the capacity of a tangent guardrail terminal. Post nos. 11 through 16 were 152-mm wide x 203-mm deep x 1,829-mm long (6.0-in. wide x 8.0-in. deep x 72.0-in. long) timber, breakaway CRT posts.

Post nos. 3 through 24 were spaced 1,905 mm (75.0 in.) on center with a soil embedment depth of 1,016 mm (40.0 in.), as shown in Figure 4. Three posts were omitted in the center section of the guardrail to create a 7.62-m (25.0-ft) long, unsupported guardrail length in the center of the system. The posts were placed in a compacted course, crushed limestone material that met Grading B of AASHTO M147-65 (1990) as found in NCHRP Report No. 350. For post nos. 3 through 24, 152-mm wide x 305-mm deep x 362-mm long (6.0-in. wide x 12.0-in. deep x 14.25-in long) wood spacer blockouts were used to block the rail away from the front face of the steel and CRT posts.

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Standard 2.67-mm (12-gauge) thick W-beam rails with additional post bolt slots at half post spacing intervals were placed between post nos. 1 and 29, as shown in Figure 4. The nominal top mounting height of the W-beam rail was 787 mm (31.0 in.) with a 632-mm (24.875-in.) center height. The rail splices have been moved to the center of the span location. All lap-splice connections between the rail sections were configured to reduce vehicle snag at the splice during the crash test. No nested guardrail sections were used in the MGS long-span design.

A simulated culvert headwall was constructed behind the MGS long-span guardrail in order to simulate any potential vehicle drop off of the edge of the culvert and to simulate the effect of the culvert headwall on the deflection of adjacent guardrail posts during an impact. The design of the headwall was based on a survey of common culvert designs from the sponsoring agencies. For test no. LSC-1, the simulated culvert headwall consisted of a 229-mm thick x 1,219-mm tall (9.0-in. thick x 48.0-in. tall) reinforced concrete wall installed 305 mm (12.0 in.) behind the back of the CRT posts in the system or 898 mm (35.35 in.) behind the face of the rail. The headwall ran parallel to the guardrail from 1,219 mm (48.0 in.) downstream of post no. 13 until 305 mm (12.0 in.) upstream of post no. 14. At 305 mm (12.0 in.) upstream of post no. 14, the headwall angled away from the guardrail at a 45 degree angle for 1,805 mm (71.0 in.) to form the downstream wingwall of the culvert. The top of the simulated concrete headwall was installed at the ground height for the guardrail system and a 1,219-mm (48.0 in.) deep pit was excavated behind the headwall to create the necessary drop-off. The soil around the culvert headwall and the top of the headwall itself remained level for this installation in order to simplify the installation. This simplification could be made because test no. LSC-1 was designed to evaluate the capacity of the system, and it was believed that the interaction of the vehicle with the culvert walls would be minimal.
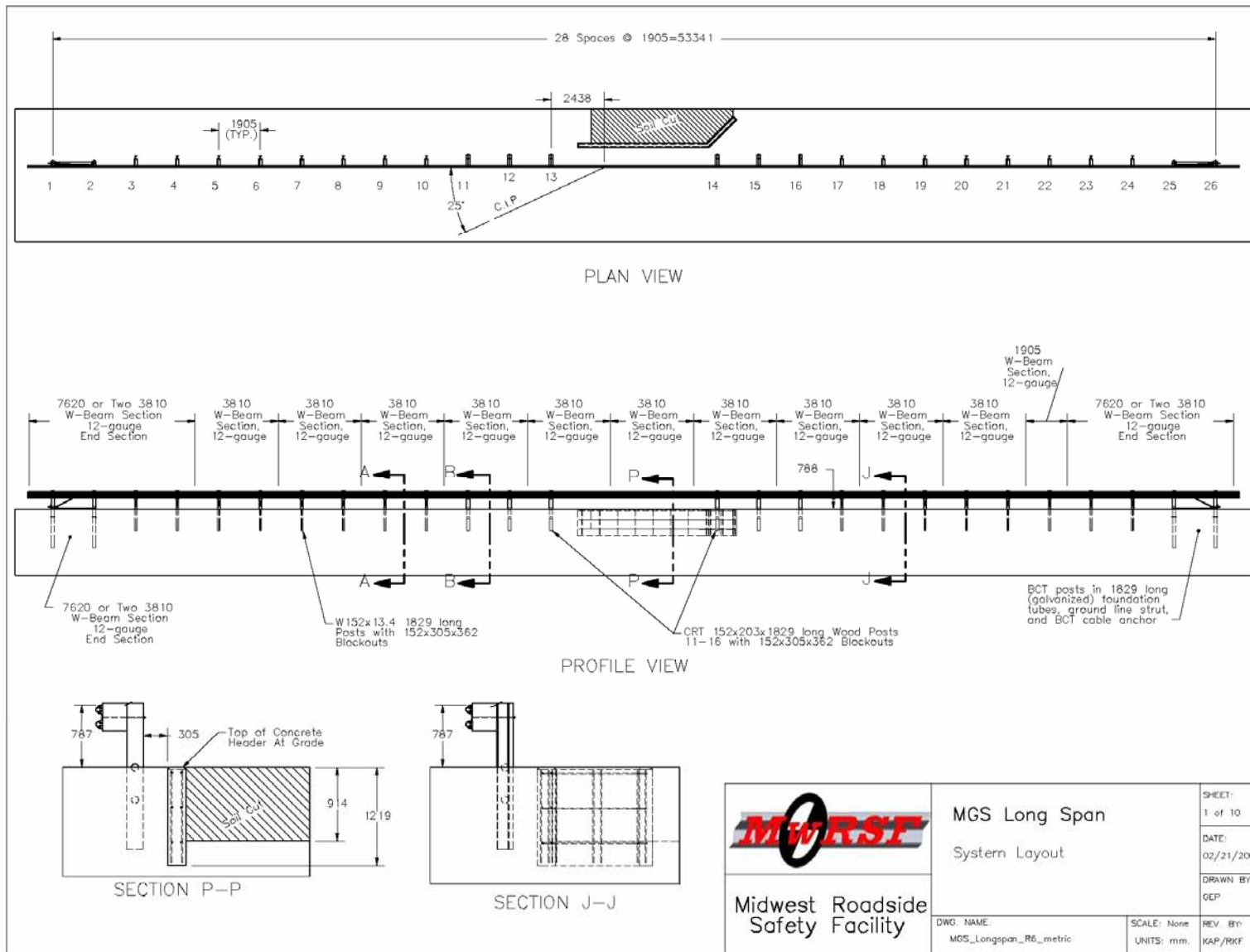
Figure 4. MGS Long Span Design Details, Test No. LSC-1

Figure 5. MGS Long Span Design Details, Test No. LSC-1

Figure 6. MGS Long Span Design Details, Test No. LSC-1

PLAN VIEW

152
76
181
Ø19

1829
813
400

PROFILE VIEW

203
Ø89

SIDE VIEW

CRT Wood Post
Part e1

Ø16x559 long
Guardrail Post
Bolt

a2

16D Double
Head Nail

787
813

1016

SECTION B-B

MwRSF

Midwest Roadside
Safety Facility

MGS Long Span

Post 11-16 Detail
CRT Wood Posts

DWG. NAME:
MGS_Longspan_R6_metric

SHEET:
4 of 10

DATE:
02/21/2006

DRAWN BY:
GEP

SCALE: None
UNITS: mm.

REV. BY:
KAP/RKF

Figure 7. MGS Long Span Design Details, Test No. LSC-1

Figure 8. MGS Long Span Design Details, Test No. LSC-1

Figure 9. MGS Long Span Design Details, Test No. LSC-1

Figure 10. MGS Long Span Design Details, Test No. LSC-1

2223

1905 W—Beam Section, 12 gauge

51
216
R13x32 Slot

DETAIL E
SCALE 1 : 15

4128
1905 (TYP)

F
F

3810 W—Beam Section, 12 gauge

SECTION F—F

102 (TYP.)
R13 x32 Slot

DETAIL G
SCALE 1 : 15

7938
2362
1111 (TYP)

7620 W—Beam Section, 12 gauge, End Section

Ø19x64 Slots

MwRSF
Midwest Roadside
Safety Facility

MGS Long Span
Rail Section Details

DWG. NAME.
MGS_Longspan_R6_metric

SCALE: None
UNITS: mm.

SHEET:
8 of 10
DATE:
02/21/2006
DRAWN BY:
GEP
REV. BY:
KAP/RKF
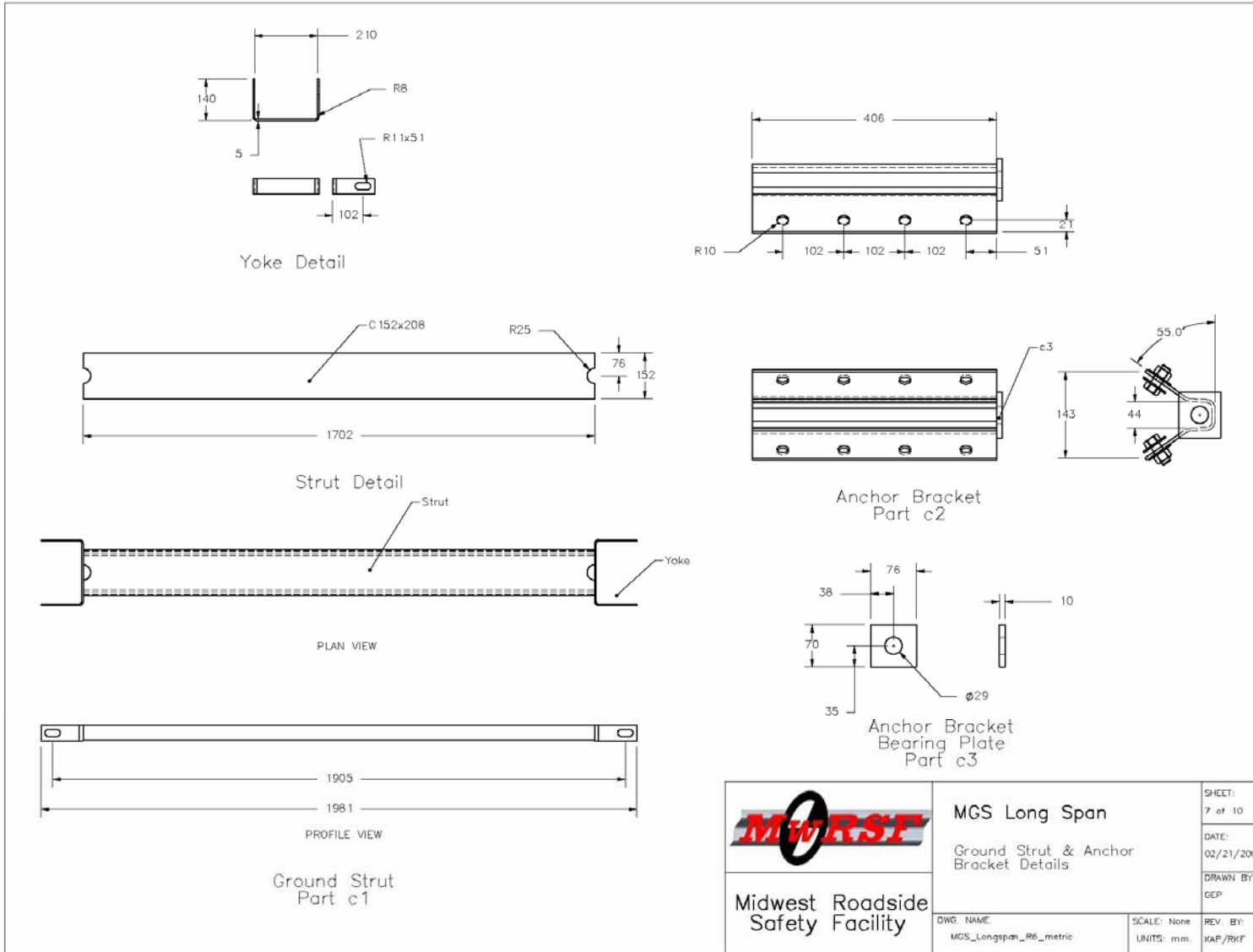
Figure 11. MGS Long Span Design Details, Test No. LSC-1
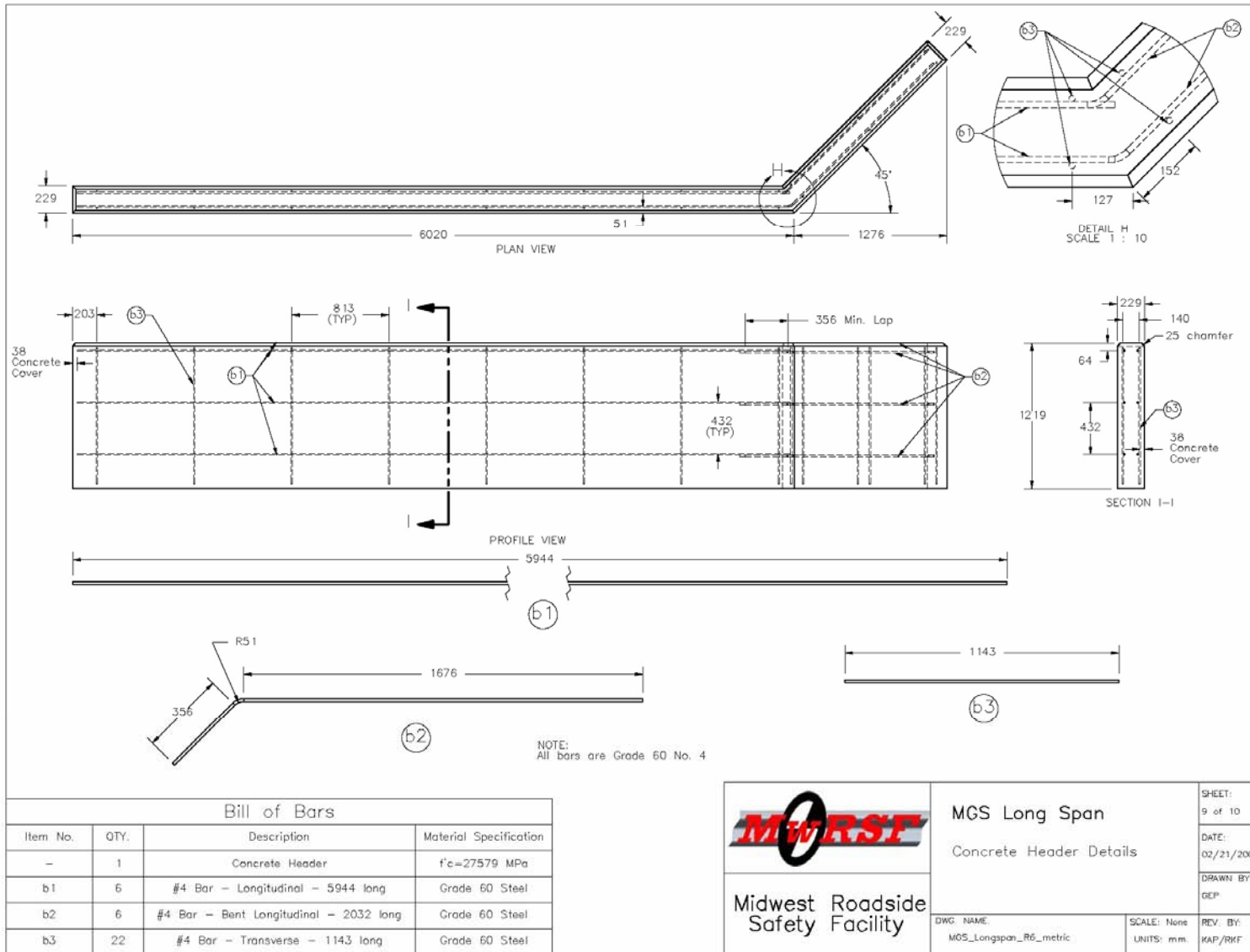
Figure 12. MGS Long Span Design Details, Test No. LSC-1
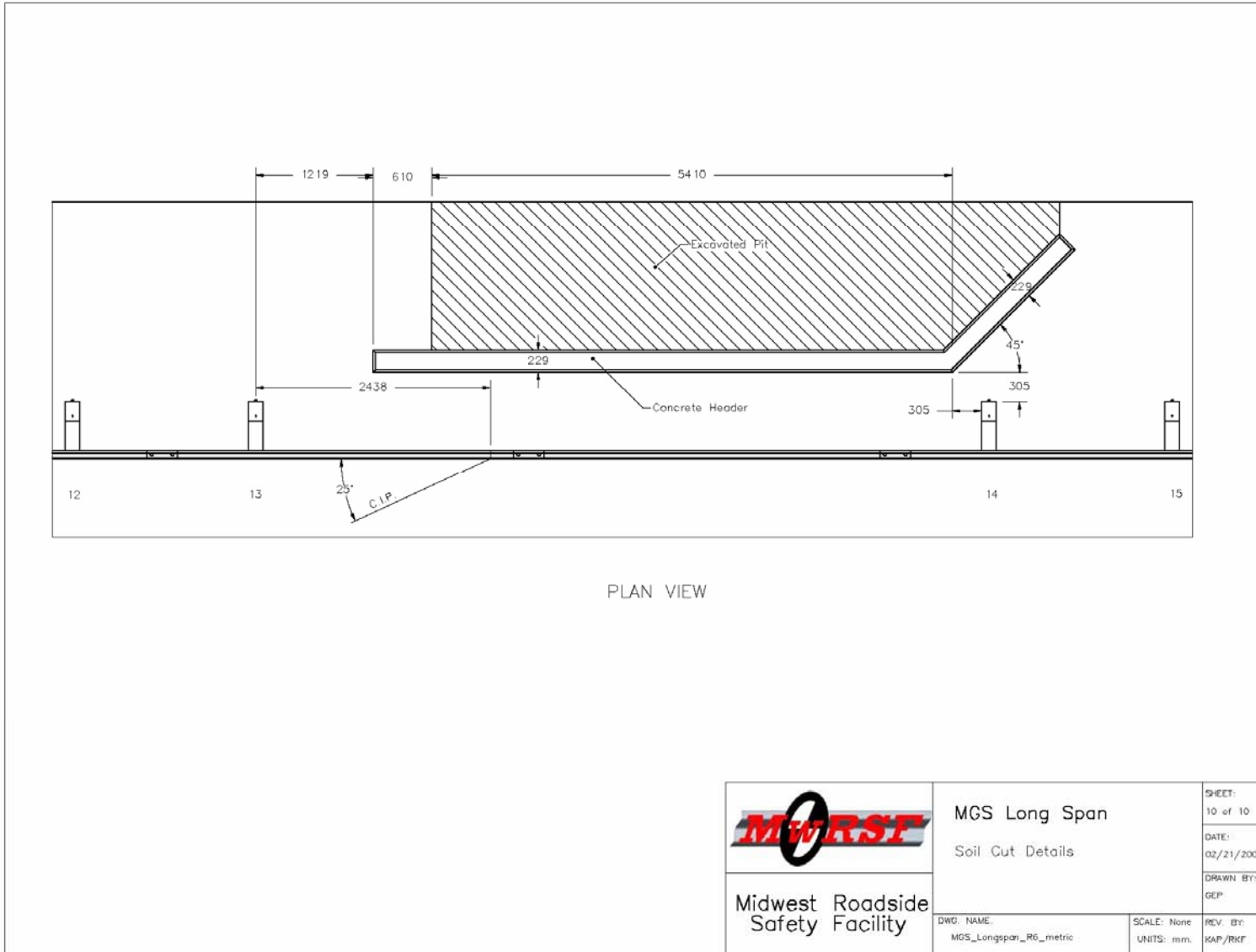
Figure 13. MGS Long Span Design Details, Test No. LSC-1

Figure 14. MGS Long Span Design Photographs, Test No. LSC-1

Figure 15. MGS Long Span Design Photographs, Test No. LSC-1

Figure 16. MGS Long Span Design Photographs, Post Detail, Test No. LSC-1

4 TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 Test Requirements

Historically, longitudinal barriers, such as W-beam guardrail systems, have been required to satisfy impact safety standards in order to be accepted by the Federal Highway Administration (FHWA) for use on National Highway System (NHS) construction projects or as a replacement for existing designs not meeting current safety standards. In recent years, these safety standards have consisted of the guidelines and procedures published in NCHRP Report No. 350 (9). However, NCHRP Project 22-14(2) generated revised testing procedures and guidelines for use in the evaluation of roadside safety appurtenances and were presented in the draft report entitled, *NCHRP Report 350 Update* (18). Therefore, according to Test Level 3 (TL-3) of the Update to NCHRP Report No. 350, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests. The two full-scale crash tests are as follows:

1. Test Designation 3-10, consisting of a 1,100-kg (2,425-lb) passenger car impacting at a nominal speed and angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively.

2. Test Designation 3-11, consisting of a 2,270-kg (5,004-lb) pickup truck impacting at a nominal speed and angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively.

The test conditions for TL-3 longitudinal barriers are summarized in Table 1. Test Designation 3-11 was conducted for the MGS system described herein.

However, W-beam barriers struck by small cars have been shown to meet safety performance standards, being essentially rigid (13-15,19-22), with no significant potential for occupant risk problems arising from vehicle pocketing or severe wheel snagging on the post at the downstream end of the long-span design. In addition, the pickup truck test was deemed more critical as the more massive truck would induce much higher rail loads and system deflections,

thus yielding the highest potential for structural failure of the system and/or vehicle instabilities. Therefore, the 1,100-kg (2,425-lb) small car crash test was deemed unnecessary for this project.

The researchers realized that testing of the MGS long-span design would need to incorporate two Critical Impact Points (CIPs). Previous testing of the MwRSF long-span design had selected a CIP based upon the impact condition which produced the greatest potential for wheel-assembly snagging or vehicle pocketing on the first post at the downstream end of the long-span section and the greatest potential for rail rupture. Thus, one test of the MGS long-span would need to be conducted at this original CIP in order to ensure that the system possessed sufficient capacity to redirect the pickup truck without rail failure. However, because the researchers wished to minimize the lateral offset of the MGS long-span from the culvert headwall, a second test was needed at a CIP that maximized the interaction of the impacting vehicle with the culvert wingwalls.

Thus, two full-scale crash tests were chosen to be conducted to evaluate the MGS long-span system, test nos. LSC-1 and LSC-2. Test no. LSC-1 consisted of an impact of a 2270P vehicle at a speed of 100 km/h (62.14 mph) and an angle of 25 degrees at a CIP located 2,438 mm (96.0 in.) downstream of post no. 13 in order to maximize the potential for pocketing, wheel snag, and rail rupture. This CIP was based on BARRIER VII ([23]) simulation of the previous MwRSF long-span design. Test no. LSC-2 consisted of an impact of a 2270P vehicle at a speed of 100 km/h (62.14 mph) and an angle of 25 degrees at a CIP chosen to maximize the interaction of the impacting vehicle with the walls of the culvert. This CIP was chosen based on the deflection and wheel trajectories from test no. LSC-1.

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 barrier to contain, redirect, or allow controlled vehicle penetration in a predictable manner. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is an indicator of the potential for the post-impact trajectory of the vehicle to cause subsequent multi-vehicle accidents. It is also an indicator for the potential safety hazard for the occupants of the other vehicles or the occupants of the impacting vehicle when subjected to secondary collisions with other fixed objects. These three evaluation criteria are summarized in Table 1 and described in greater detail in the Update to NCHRP Report No. 350 (18). Finally, the full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in the Update to NCHRP Report No. 350.

Table 1. Test Requirements

| Test Article | Test Level | Barrier Section | Test Designation | Impact Conditions | | | | Evaluation Criteria[*] |
| | | | | Test Vehicle | Speed | | Angle | |
					km/h	(mph)	degrees	
Longitudinal Barrier	3	Length of Need	3-10	1100C	100	(62.1)	25	A,D,F,H,I,M
			3-11	2270P	100	(62.1)	25	A,D,F,H,I,M

*Evaluation Criteria explained in Table 2.

Table 2. Evaluation Criteria

Structural Adequacy	A.	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.
Occupant Risk	D.	Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.
	F.	The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.
	H.	Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9 m/s (29.53 ft/s), or at least below the maximum allowable value of 12 m/s (39.37 ft/s).
	I.	Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15 Gs, or at least below the maximum allowable value of 20 Gs.
Vehicle Trajectory	M.	The exit angle from the test article preferably should be less than 60 percent of the test impact angle measured at the time of vehicle loss of contact with the test device.

5 TEST CONDITIONS

5.1 Test Facility

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

5.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch (24) was used to steer the test vehicle. A guide-flag, attached to the front-right wheel and the guide cable, was sheared off before impact with the barrier system. The 9.5-mm (0.375-in.) diameter guide cable was tensioned to approximately 15.6 kN (3,500 lbs), and supported laterally and vertically every 30.48 m (100 ft) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide-flag struck and knocked each stanchion to the ground. For test nos. LSC-1 and LSC-2, the vehicle guidance systems were 332 m (1090 ft) and 333 m (1092 ft) long, respectively.

5.3 Test Vehicles

For test no. LSC-1, a 2002 Dodge Ram Quad Cab pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,264 kg (4,992 lbs). The test vehicle is shown in Figure 17, and its dimensions are shown in Figure 18.

Figure 17. Test Vehicle, Test No. LSC-1

Date: 4/21/06   Test Number: LSC-1   Model: Ram 1500 Q.C.

Make: Dodge   Vehicle I.D.#: 3D7HA18N32G183419

Tire Size: P165/70 R17   Year: 2002   Odometer: 139375

*(All Measurements Refer to Impacting Side)
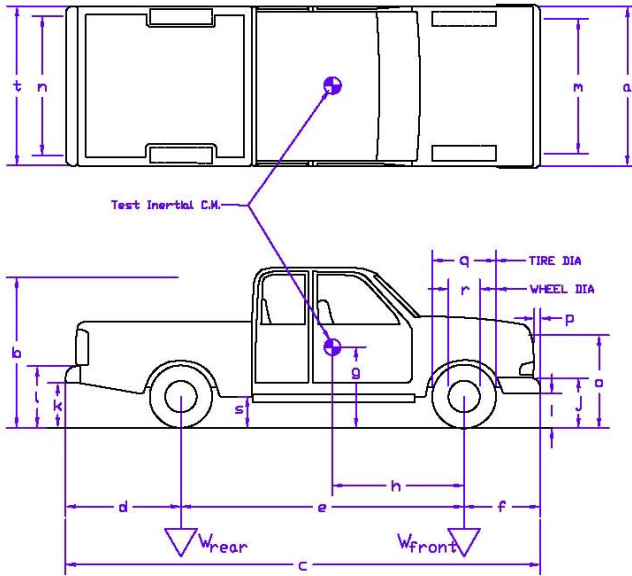
Vehicle Geometry — mm (in.)

a 2000 (78.75)   b 1905 (75.0)
c 5779 (227.5)   d 1251 (49.25)
e 3562 (140.25)   f 965 (38.0)
g 711 (28.0)   h 1597 (62.875)
i 406 (16.0)   j 768 (30.25)
k 521 (20.5)   l 749 (29.5)
m 1734 (68.25)   n 1708 (67.25)
o 1168 (46.0)   p 83 (3.25)
q 800 (31.5)   r 470 (18.5)
s 394 (15.5)   t 1921 (75.625)

Wheel Center Height Front 381 (15.0)
Wheel Center Height Rear   381 (15.0)
Wheel Well Clearance (FR) 905 (35.625)
Wheel Well Clearance (RR) 967 (37.875)
Frame Height (FR) 464 (18.25)
Frame Height (RR) 629 (24.75)

Engine Type 8 CYL. GAS
Engine Size 4.7 L
Transmission Type:
(Automatic) or Manual
FWD or (RWD) or 4WD

Weights kg (lbs)

	Curb	Test Inertial	Gross Static
W_front	1271 (2801)	1244 (2742)	1244 (2742)
W_rear	1007 (2220)	1021 (2250)	1021 (2250)
W_total	2277 (5021)	2264 (4992)	2264 (4992)

GVWR Ratings   FR 3650
                Rr 3900
                Tot 6650

Note any damage prior to test: None

Figure 18. Vehicle Dimensions, Test No. LSC-1

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For test no. LSC-2, a 2002 Dodge Ram Quad Cab pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,261 kg (4,984-lbs). The test vehicle is shown in Figure 19, and its dimensions are shown in Figure 20.

Black and white, checkered targets were placed on the vehicle, as shown in Figures 21 and 22, to aid in the analysis of the high-speed digital video. One target was placed directly above each of the wheels, and another was placed at the vehicle's center of gravity on both the driver and passenger sides. In addition, targets were placed on the top of the vehicle. One was placed at the vehicle's center of gravity, two were placed on the windshield, one was placed on the hood of the vehicle, two were placed in the pickup box, and four targets were placed on the side walls of the box, aligned with those placed in the box.

The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so the vehicle would track properly along the guide cable. A 5B flash bulb was mounted on the left quarter point of the vehicle's dash to pinpoint the time of impact with the test article on the high-speed video footage. The flash bulb was fired by a pressure tape switch mounted at the left-front corner of the front bumper. A remote-controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

5.4 Data Acquisition Systems

Three data acquisition systems, two accelerometers and one rate transducer, were used to measure the motion of the vehicle. The results of all three were analyzed and plotted using "DynaMax 1 (DM-1)" and "DADiSP" computer software programs.

5.4.1 Accelerometers

One triaxial piezoresistive accelerometer system with a range of ± 200 Gs was used to

Figure 19. Test Vehicle, Test No. LSC-2

Date: 6/07/06　　Test Number: LSC-2　　Model: 2270P

Make: Dodge　　Vehicle I.D.#: 3B7HA18N72E116381

Tire Size: LT 265/70 R17　　Year: 2002　　Odometer: 122,864

*(All Measurements Refer to Impacting Side)

Vehicle Geometry — mm (in.)
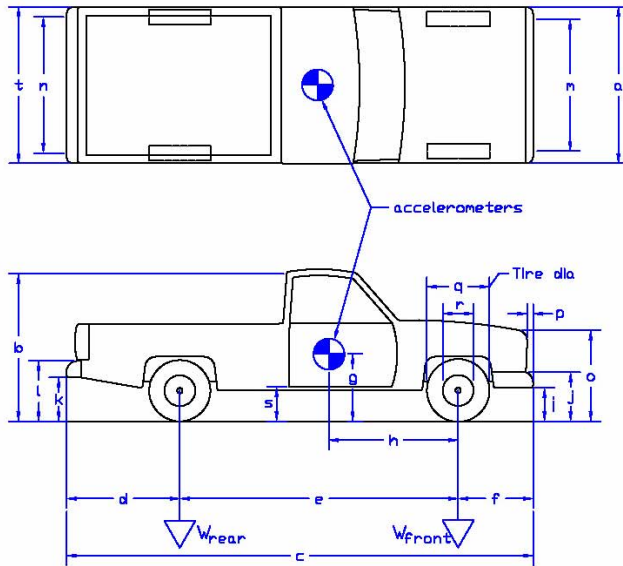
a 1981 (78)　　b 1895 (74.63)
c 5626 (221.5)　　d 1194 (47)
e 3559 (140.13)　　f 1026 (40.38)
g 716 (28.2)　　h 1586 (62.45)
i 400 (15.75)　　j 660 (26)
k 559 (22)　　l 752 (29.63)
m 1727 (68)　　n 1721 (67.75)
o 1111 (43.75)　　p 76 (3)
q 800 (31.5)　　r 470 (18.5)
s 416 (16.38)　　t 1911 (75.25)

Wheel Center Height Front　381 (15)
Wheel Center Height Rear　391 (15.375)
Wheel Well Clearance (FR)　908 (35.75)
Wheel Well Clearance (RR)　968 (38.13)
Frame Height (FR)　454 (17.88)
Frame Height (RR)　645 (25.38)
Engine Type　8 CYL. GAS
Engine Size　4.7 L
Transmission Type:
(Automatic) or Manual
FWD or (RWD) or 4WD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	1277 (2816)	1257 (2771)	1257 (2771)
W_{rear}	982 (2166)	1004 (2213)	1004 (2213)
W_{total}	2260 (4982)	2261 (4984)	2261 (4984)

GVWR Ratings
Front 1656 (3650)
Back 1769 (3900)
Total 3016 (6650)

Note any damage prior to test: None

Figure 20. Vehicle Dimensions, Test No. LSC-2

Figure 21. Vehicle Target Locations, Test No. LSC-1
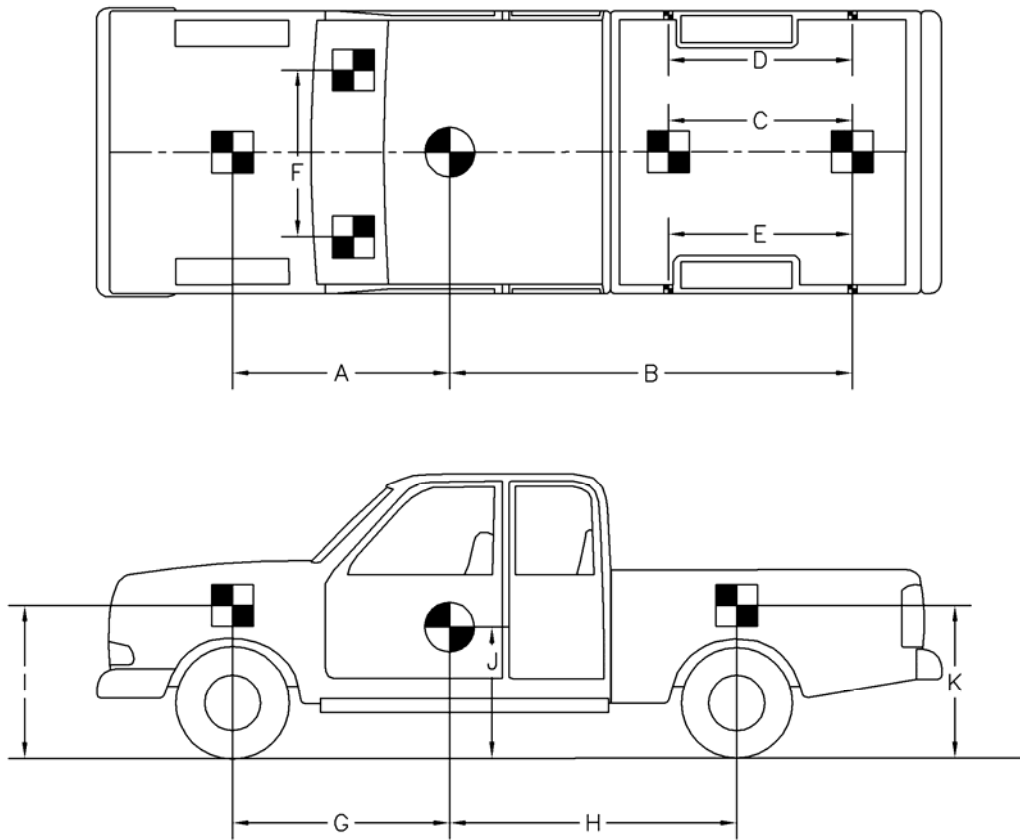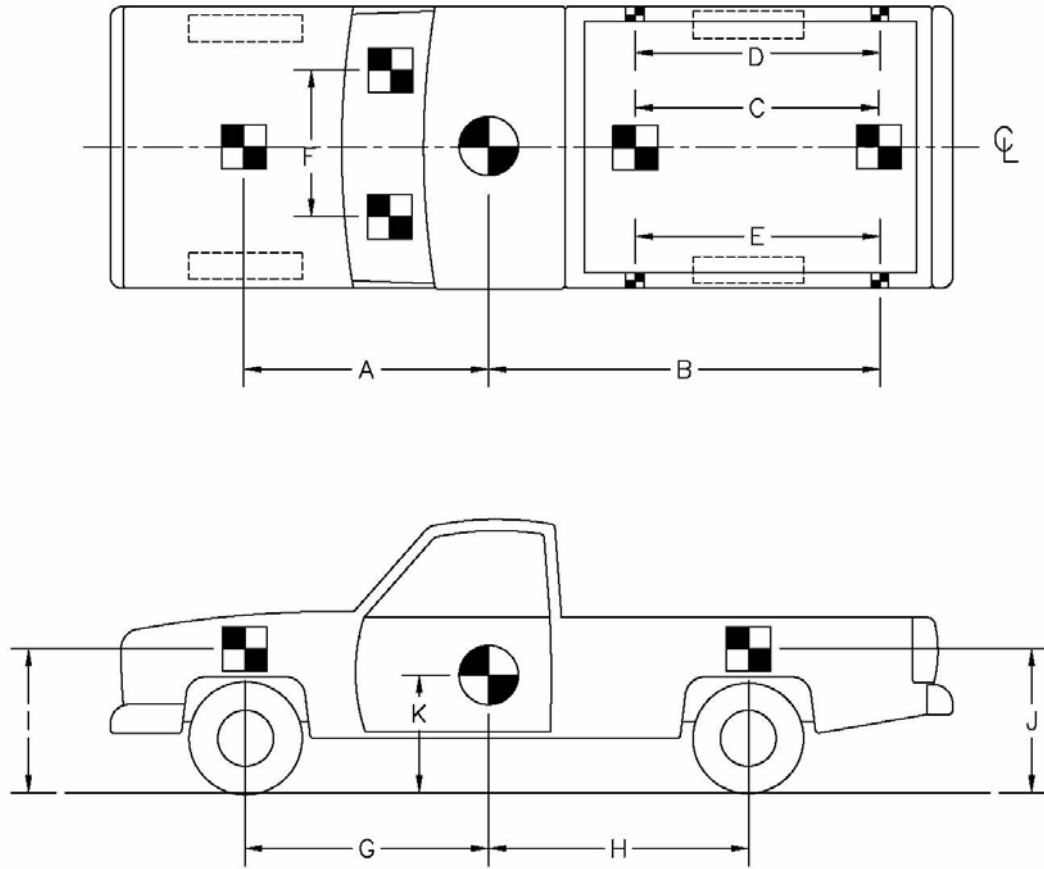
TEST #: LSC-2

TARGET GEOMETRY -- mm (in.)

A 1975 (77.75)   D 1622 (63.88)   G 1586 (62.45)   J 1080 (42.5)

B 2524 (99.38)   E 1619 (63.75)   H 1973 (77.68)   K 716 (28.2)

C 1080 (42.5)   F 895 (35.25)   I 1022 (40.25)

Figure 22. Vehicle Target Locations, Test No. LSC-2

measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 10,000 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-4M6, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan and includes three differential channels as well as three single-ended channels. The EDR-4 was configured with 6 MB of RAM memory and a 1,500 Hz lowpass filter.

Another triaxial piezoresistive accelerometer system with a range of ± 200 Gs was also used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 3,200 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-3, was developed by Instrumental Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM memory and a 1,120 Hz lowpass filter.

5.4.2 Rate Transducers

An Analog Systems 3-axis rate transducer with a range of 1,200 degrees/sec in each of the three directions (pitch, roll, and yaw) was used to measure the rates of motion of the test vehicle. The rate transducer was mounted inside the body of the EDR-4M6 and recorded data at 10,000 Hz to a second data acquisition board inside the EDR-4M6 housing. The raw data measurements were then downloaded, converted to the appropriate Euler angles for analysis, and plotted.

5.4.3 High-Speed Photography

For test no. LSC-1, four high-speed AOS VITcam digital video cameras and seven digital video cameras were used. Camera details, lens information, and camera operating speeds are shown along with a schematic of the camera locations in Figure 23.

For test no. LSC-2, four high-speed AOS VITcam digital video cameras and seven digital

video cameras were used. Camera details, lens information, and camera operating speeds are shown along with a schematic of the camera locations in Figure 24.

The AOS videos were analyzed using the ImageExpress MotionPlus software. Camera speed and camera divergence factors were considered in the analysis of the high-speed videos.

5.4.4 Pressure Tape Switches

For both tests, five pressure-activated tape switches, spaced at 2-m (6.56-ft) intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the left-front tire of the test vehicle passed over it. The test vehicle speed was then determined from the electronic timing mark data recorded using TestPoint software. 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.

LSC-1 Camera Summary

	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	1	Vitcam CTM	500	20 mm fixed	
	2	Vitcam CTM	500	Sigma 24-135	35
	3	Vitcam CTM	500	Sigma 70-200	
	4	Vitcam CTM	500	Sigma 24-70	26
Digital Video	2	Canon-ZR10	29.97		
	4	Canon-ZR30	29.97		
	6	Canon-ZR25	29.97		
	7	Canon-ZR90	29.97		
	8	Canon-ZR90	29.97		
	1	JVC - GZ-MC500 (Everio)	29.97		
	2	JVC - GZ-MC40u (Everio)	29.97		
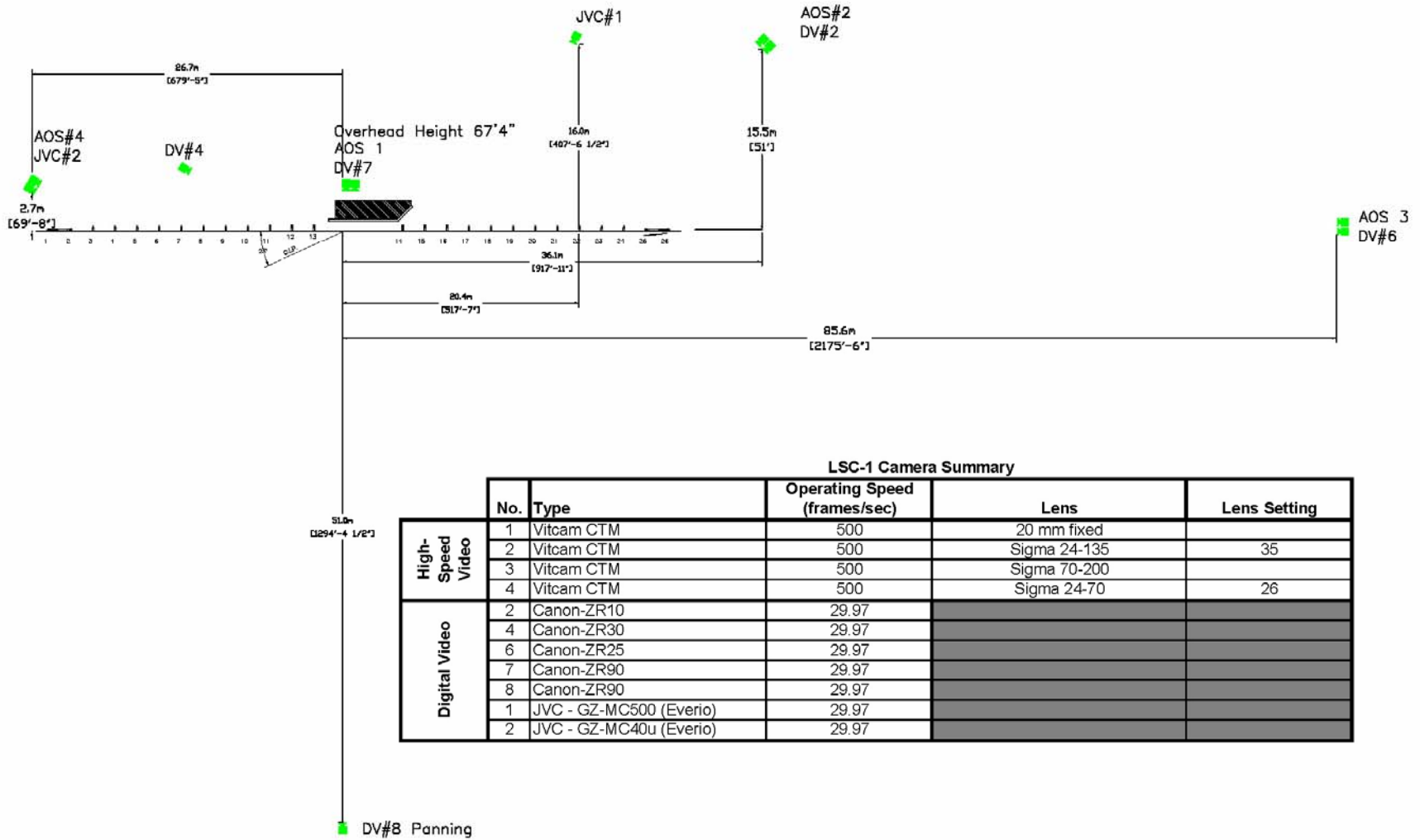
Figure 23. Location of High-Speed Cameras, Test No. LSC-1

Figure 24. Location of High-Speed Cameras, Test No. LSC-2

6 FULL-SCALE TEST NO. LSC-1

6.1 Test No. LSC-1

For test no. LSC-1, a 2,264-kg (4,992-lb) pickup truck impacted the MGS long-span guardrail system at a speed of 100.5 km/h (62.5 mph) and at an angle of 24.8 degrees. A summary of the test results and the sequential photographs are shown in Figure 25. The summary of the test results and sequential photographs in English units is shown in Appendix B. Additional sequential photographs are shown in Figure 26. Documentary photographs of the crash test are shown in Figures 27 and 28.

6.2 Test Description

Initial vehicle impact was to occur between post nos. 13 and 14, or 2.44 m (8 ft) downstream from post no. 13, as shown in Figure 29. Actual vehicle impact occurred 2.44 m (8.0 ft) downstream from the centerline of post no. 13. By 0.054 sec, the left-front corner of the pickup truck had reached the center of the unsupported rail section and deflected the guardrail backward. At 0.108 sec, the first CRT post downstream of the unsupported rail fractured before the truck reached it, thereby reducing snag. At 0.156 sec, the left-front tire had rolled off of the culvert headwall, and post no. 14 had fractured at its base as the pickup truck continued to redirect. At 0.212 sec, the left-front tire contacted the top of the culvert wingwall. At 0.364 sec after impact, the vehicle became parallel to the guardrail with a speed of 73.4 km/h (45.6 mph), and post nos. 15 and 16 had fractured at the base. The vehicle continued to redirect until it exited the system at 1.334 sec with a speed of 56.7 km/hr (35.2 mph) and at an angle of 1 degree. The pickup exited the guardrail in a stable manner and came to rest 31.14-m (102.17-ft) downstream

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from impact and 8.05-m (26.41-ft) laterally behind the traffic-side face of the rail, as shown in Figures 25 and 30.

6.3 System Damage

As shown in Figures 32 through 36, damage to the barrier was moderate, consisting mostly of deformed W-beam, contact marks on a guardrail section, and deformed and fractured guardrail posts. The W-beam damage consisted of contact marks and deformation and flattening of the impacted section between post nos. 13 and 20. No indications of rail rupture or tearing were visible on the W-beam. The W-beam rail was pulled off of post nos. 2 through 9. Three CRT posts, post nos. 14 through 16, were completely fractured, while CRT post nos. 12 and 13 were rotated backward. Steel post nos. 17 through 20 were bent and deformed backward and downstream. Neither significant post damage nor deformations occurred to the remaining posts in the system. The maximum lateral permanent set rail deflection was approximately 724 mm (28.5 in.), 1,905 mm (75 in.) upstream of post no. 14, as measured in the field. The maximum lateral dynamic post and rail deflections were 1,205 mm (47.4 in.) at post no. 16 and 2,343 mm (92.24 in) at the centerline of post no. 15, respectively, as determined from the high-speed video analysis. The working width of the system was 2,373 mm (93.43 in.), as determined from the high-speed film analysis.

6.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 37 and 38. The left-front quarter panel was crushed inward, and the left side of the front bumper was also bent back toward the engine compartment. The left-front wheel assembly was disengaged from the upper and lower control arms but remained attached to the steering linkage. The left-front tire was still

inflated. Some deformation and damage were noted on the left-front suspension components. Contact marks and minor deformation were found along most of the lower-left side of the pickup truck. The left-rear quarter panel and the left corner of the rear bumper were dented as well. The left-rear taillight was disengaged from its housing. Interior occupant compartment damage was minimal, as shown in Figure 39 with a maximum vertical deformation of 19 mm (0.75 in.) measured near the right side of the driver-side footwell on the floorpan.

6.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities (OIVs) were determined to be -2.92 m/s (-9.58 ft/s) and 3.23 m/s (10.59 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations (ORDs) in the longitudinal and lateral directions were -6.48 Gs and 5.91 Gs, respectively. It is noted that the occupant impact velocities and the occupant ridedown decelerations were within the suggested limits provided in the Update to NCHRP Report No. 350. The results of the occupant risk, determined from the accelerometer data, are summarized in Figure 25. Results are shown graphically in Appendix D. Roll, pitch, and yaw data were collected from the rate gyroscope and are shown graphically in Appendix D.

6.6 Discussion

The analysis of the test results for test no. LSC-1 showed that the MGS long-span guardrail adequately contained and redirected the vehicle with controlled lateral displacements of the guardrail. Detached elements and debris from the test article did not penetrate nor show potential for penetrating the occupant compartment. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The vehicle remained upright during and after collision. Vehicle roll, pitch, and yaw angular displacements were noted,

but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. It is noted that the occupant impact velocities (OIV) and occupant ridedown decelerations (ORD) were within the suggested limits provided in the Update to NCHRP Report No. 350. After collision, the vehicle's trajectory intruded slightly into adjacent traffic lanes but was determined to be acceptable. In addition, the vehicle exited the barrier with the exit box, as shown in Figure 31. Therefore, test no. LSC-1 conducted on the MGS long-span guardrail system was determined to be acceptable according to the Update to NCHRP Report No. 350 criteria. It should also be noted that this test successfully evaluated the strength capacity of the system through the choice of a CIP that maximized the potential for pocketing, wheel snag, and rail rupture and the use of the 2270P vehicle to maximize rail loading.

| 0.000 sec | 0.122 sec | 0.234 sec | 0.344 sec | 0.526 sec |
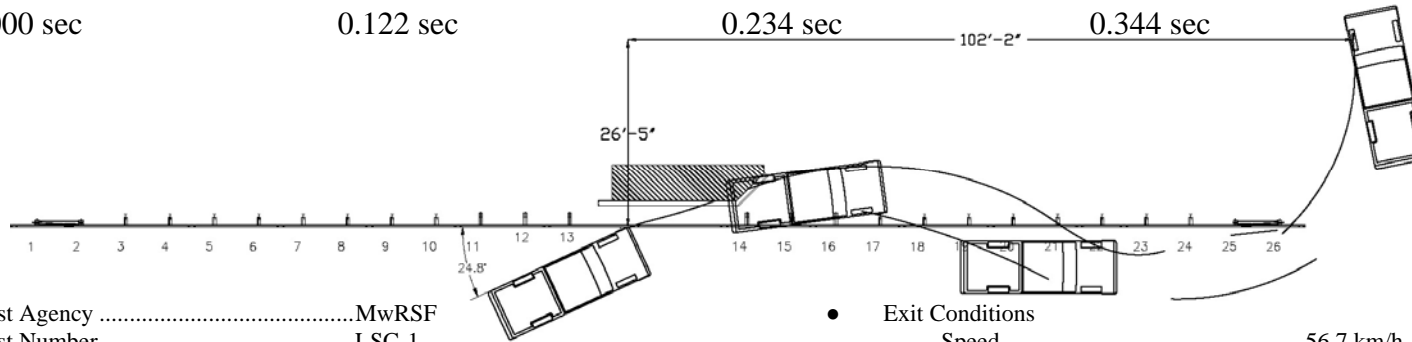
- Test Agency ....MwRSF
- Test Number..LSC-1
- Date...4/21/06
- NCHRP 350 Update Test Designation ..3-11
- Appurtenance ....MGS Longspan with Culvert
- Total Length..55.25 m
- Long Span Length ....7620 mm
- Distance Headwall to Back of Post ....305 mm
- Key Elements - Steel W-Beam
    - Thickness......................................2.66 mm
    - Top Mounting Height ....787 mm
- Key Elements - Steel Posts
    - Post Nos. 3-10, 17-24 ....W152 x 13.4 by 1,829 mm long
- Key Elements - Wood Posts
    - Post Nos. 11-16 (CRT) ....152 mm x 203 mm x 1,829 mm long
    - Post Nos. 1-2, 25-26 (BCT). ....140 mm x 190 mm x 1,168 mm long
- Key Elements - Steel Foundation Tube 1,829 mm long
- Key Elements - Wood Spacer Blocks
    - Post Nos. 3-24..............................152 mm x 305 mm by 362 mm long
- Type of Soil...Grading B - AASHTO M 147-65
- Test Vehicle
    - Type/Designation.........................2270P
    - Make and Model ....2002 Dodge 1500 Quad Cab
    - Curb ....2,277 kg
    - Test Inertial................................2,264 kg
    - Gross Static.................................2,264 kg
- Impact Conditions
    - Speed .... 100.5 km/h
    - Angle .... 24.8 degrees
    - Impact Location .... 2,438 mm downstream of Post 13

- Exit Conditions
    - Speed ....56.7 km/h
    - Angle ....1 degree
    - Exit Box Criterion............................Pass
- Post-Impact Trajectory
    - Vehicle Stability................................Satisfactory
    - Stopping Distance ....31.14 m downstream of impact, 8.05 m laterally behind impact
- Occupant Impact Velocity
    - Longitudinal......................................-2.92 m/s < 12 m/s
    - Lateral ....3.23 m/s < 12 m/s
- Occupant Ridedown Deceleration
    - Longitudinal......................................-6.48 Gs < 20 Gs
    - Lateral ....5.91 Gs < 20 Gs
- THIV (not required) ....NA
- PHD (not required)....................................NA
- Test Article Damage...................................Minimal
- Test Article Deflections
    - Permanent Set ....724 mm
    - Dynamic...2,343 mm
    - Working Width ....2,373 mm
- Vehicle Damage ....Moderate
    - VDS[25]..11-LFQ-3
    - SAE[26] 11LDES5
    - Maximum Deformation....................19 mm near the left and right side of the driver floorpan

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Figure 25. Summary of Test Results and Sequential Photographs, Test No. LSC-1

0.000 sec

0.000 sec

0.138 sec

0.166 sec

0.322 sec

0.286 sec

0.624 sec

0.396 sec

1.038 sec

0.552 sec

1.482 sec

0.718 sec

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

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

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Figure 28. Documentary Photographs, Test No. LSC-1
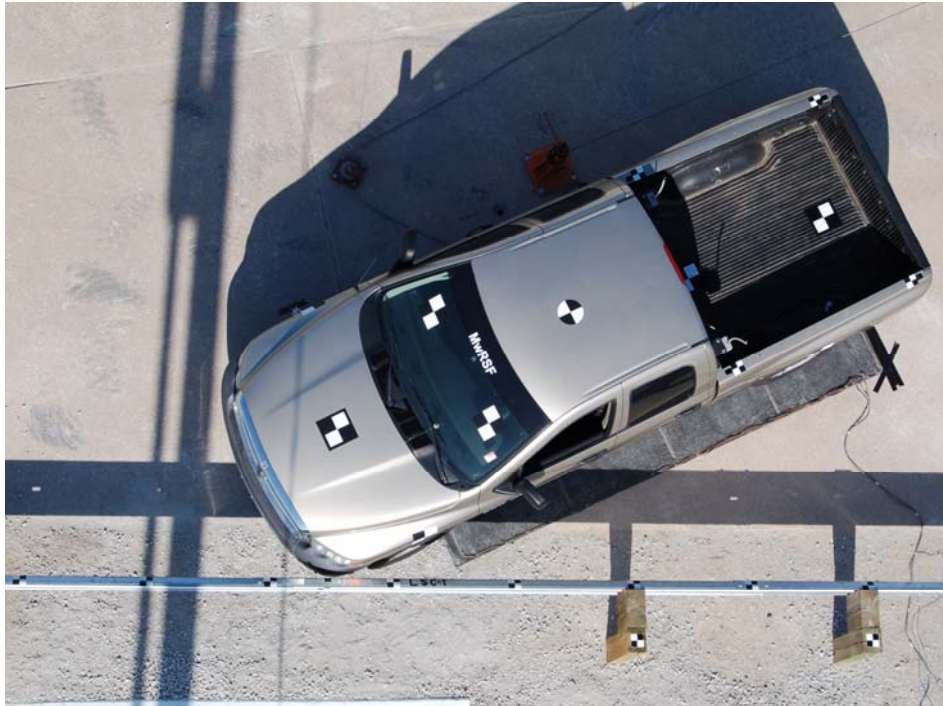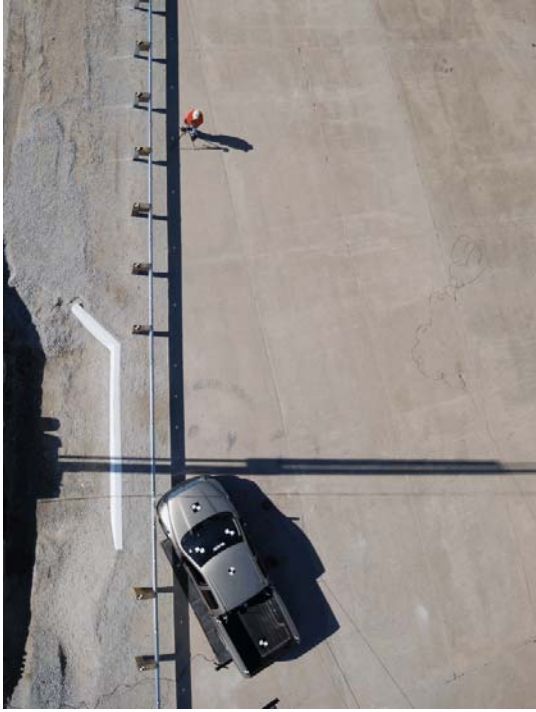
Figure 29. Impact Location, Test No. LSC-1

Figure 30. Trajectory and Final Position, Test No. LSC-1

53
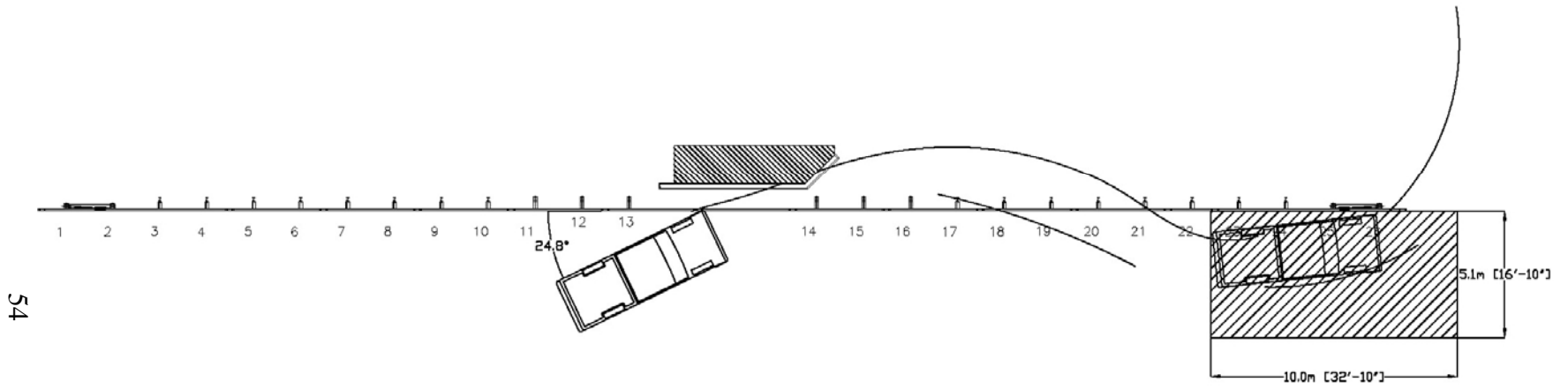
Figure 31. Exit Box, Test No. LSC-1

Figure 32. System Overall Damage, Test No. LSC-1

Figure 33. System Post Damage, Test No. LSC-1

Figure 34. System Post Damage, Test No. LSC-1

Figure 35. System Post Damage, Test No. LSC-1

Figure 36. System Anchor Damage, Test No. LSC-1

Figure 37. Vehicle Damage, Test No. LSC-1
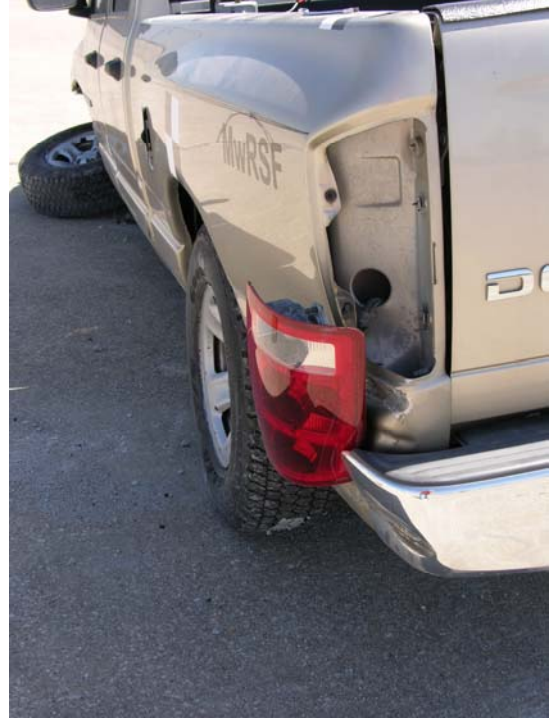
Figure 38. Vehicle Damage, Test No. LSC-1

Figure 39. Occupant Compartment Deformation, Test No. LSC-1

7 MGS LONG-SPAN DESIGN DETAILS – TEST NO. LSC-2

The design of the MGS long-span guardrail remained unchanged for test no. LSC-2, but modifications were made to the design of the culvert and the lateral offset between the guardrail and the culvert headwall. Recall that the purpose of test no. LSC-2 was to evaluate the hazard posed by an impact that maximized the interaction between the vehicle and the culvert wall. Thus, a more detailed, representative culvert headwall was developed for this test. Additionally, the dynamic deflection and vehicle trajectory of the previous test, test no. LSC-1, led the researchers to believe that the lateral offset between the barrier and the culvert headwall could be further reduced.

Details of the MGS long-span and the revised culvert detail are shown in Figures 40 through 49. The culvert design was modified to include both the upstream and downstream wingwalls as well as a typical slope profile based on representative culvert designs submitted by the sponsoring agencies. The culvert consisted of a 229-mm thick x 1,219-mm tall (9.0-in. thick x 48.0-in.) reinforced concrete wall installed flush with the back of the CRT posts in the system or 591 mm (23.25 in.) behind the face of the rail. The headwall ran parallel to the guardrail from 305 mm (12.0 in.) downstream of post no. 13 until 305 mm (12.0 in.) upstream of post no. 14. At 305 mm (12.0 in.) upstream of post no. 14 and 305 mm (12.0 in.) downstream of post no. 13, the headwall angled away from the guardrail at a 45 degree angle for 1,819 mm (71.61 in.) to form the wingwall of the culvert. The top of the simulated concrete headwall was installed at the ground height for the guardrail system. A 3:1 slope was started 610 mm (24.0 in.) behind the back face of the guardrail posts of the MGS long-span, and the wingwalls were modified to match the soil slope. The choice of the slope profile was based on choosing the flattest slope of the typical culvert installations submitted by the sponsoring states. The choice of the flattest

slope maximized the potential for vehicle interaction with the wingwalls of the culvert during the impact event. A 1,219 mm (48.0 in) deep pit was excavated behind the headwall to create the necessary drop-off. Photographs of the test installation are shown in Figures 50 and 51.

As mentioned previously, the CIP for test no. LSC-2 was selected to maximize the potential for vehicle interaction with the walls of the culvert. In order to determine the CIP, vehicle and wheel trajectory and vehicle dimension data taken from test no. LSC-1 were applied to the system layout for test no. LSC-2 to determine the snag potential for either the left or right front wheels on the walls of the culvert. This analysis took into account the shortened offset from the back of the post to the headwall used for test no. LSC-2. Results from this analysis found that the left-front wheel impact was more critical than the right-front wheel due to the increased vertical drop of the left-front wheel and its potential for interaction with the culvert wingwall. Based on this analysis, the CIP was chosen to be 12.57 m (41.24 ft) upstream of post no. 14 in order to maximize the impact of the left-front wheel on the upstream wingwall of the culvert.
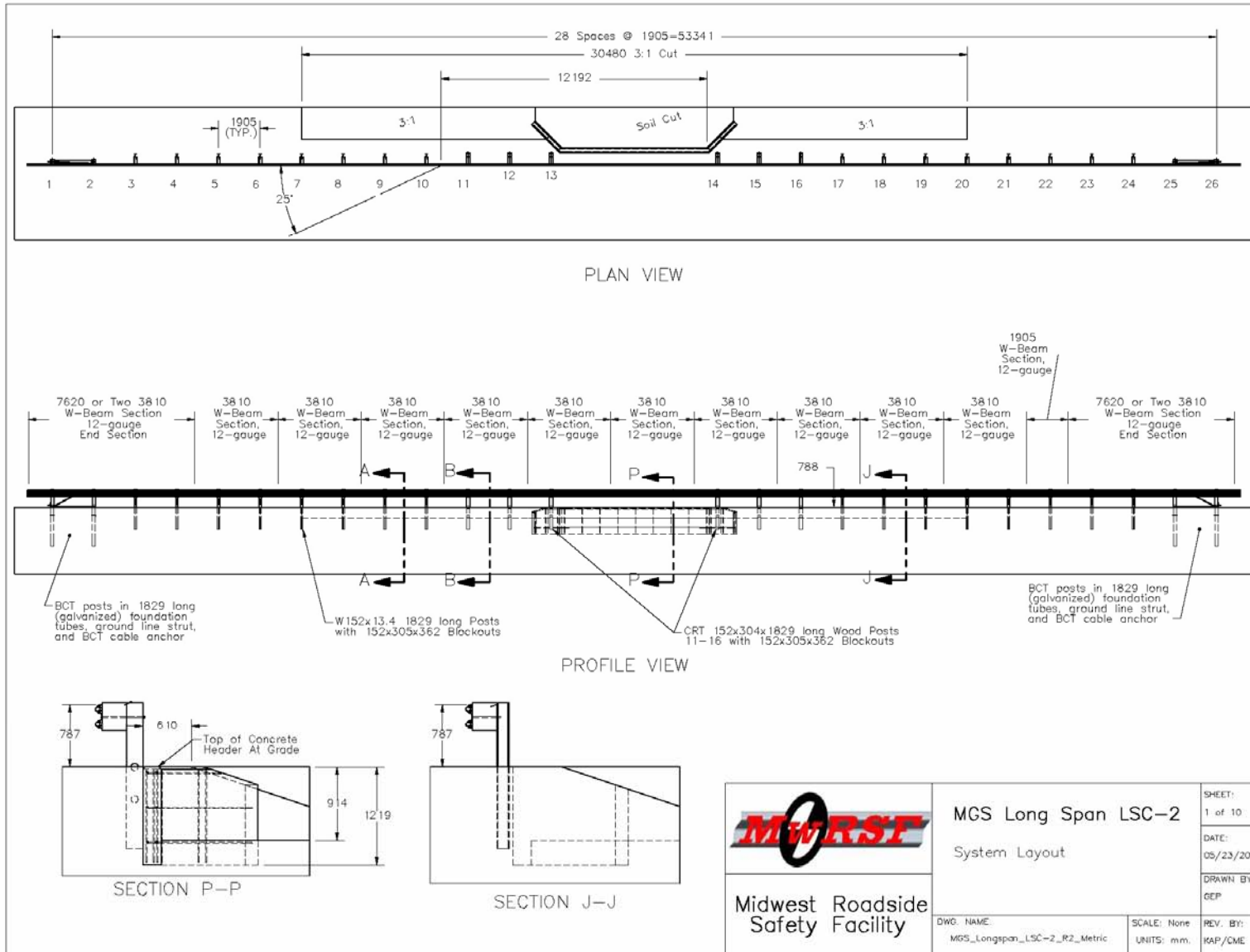
Figure 40. MGS Long Span Design Details, Test No. LSC-2
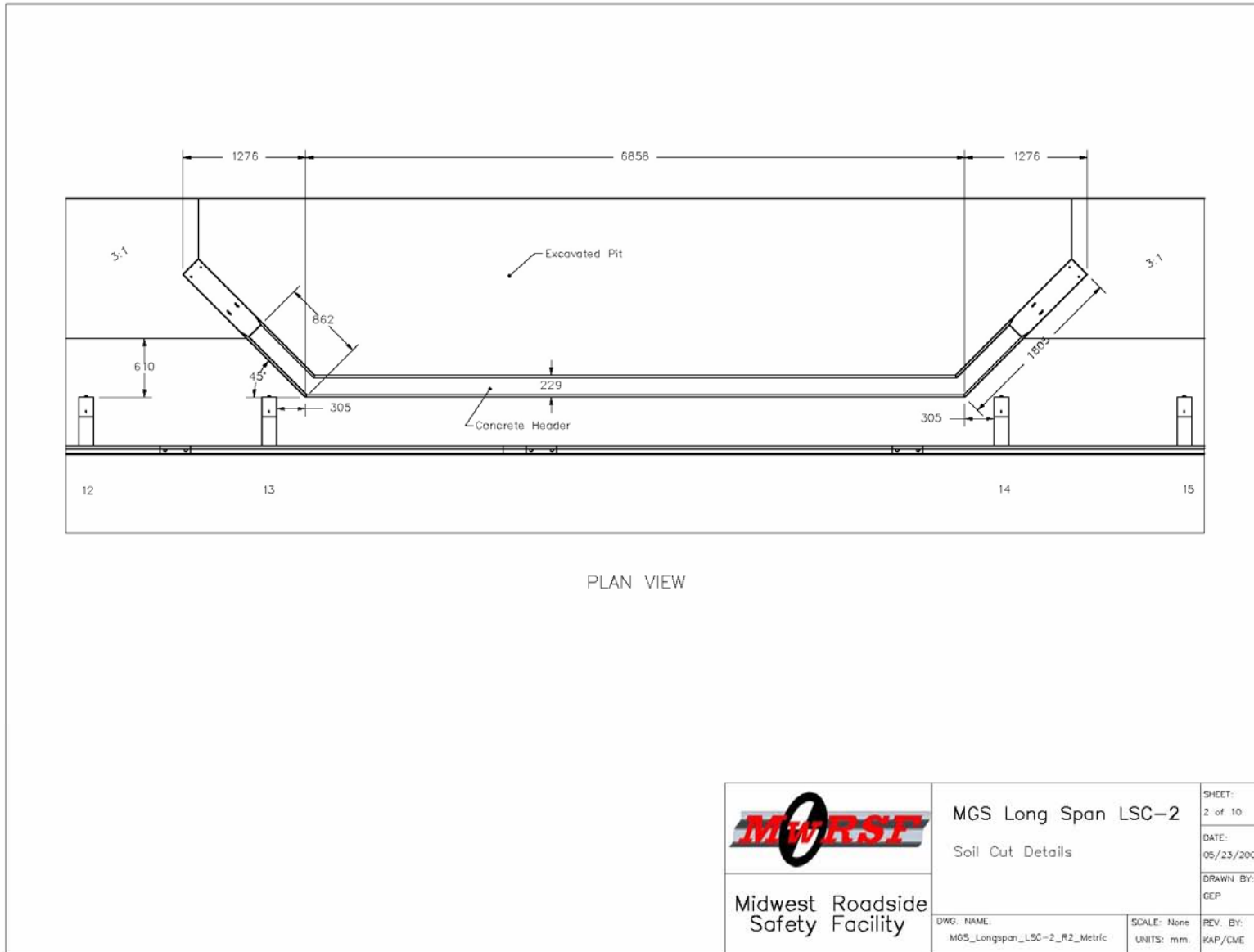
Figure 41. MGS Long Span Design Details, Test No. LSC-2
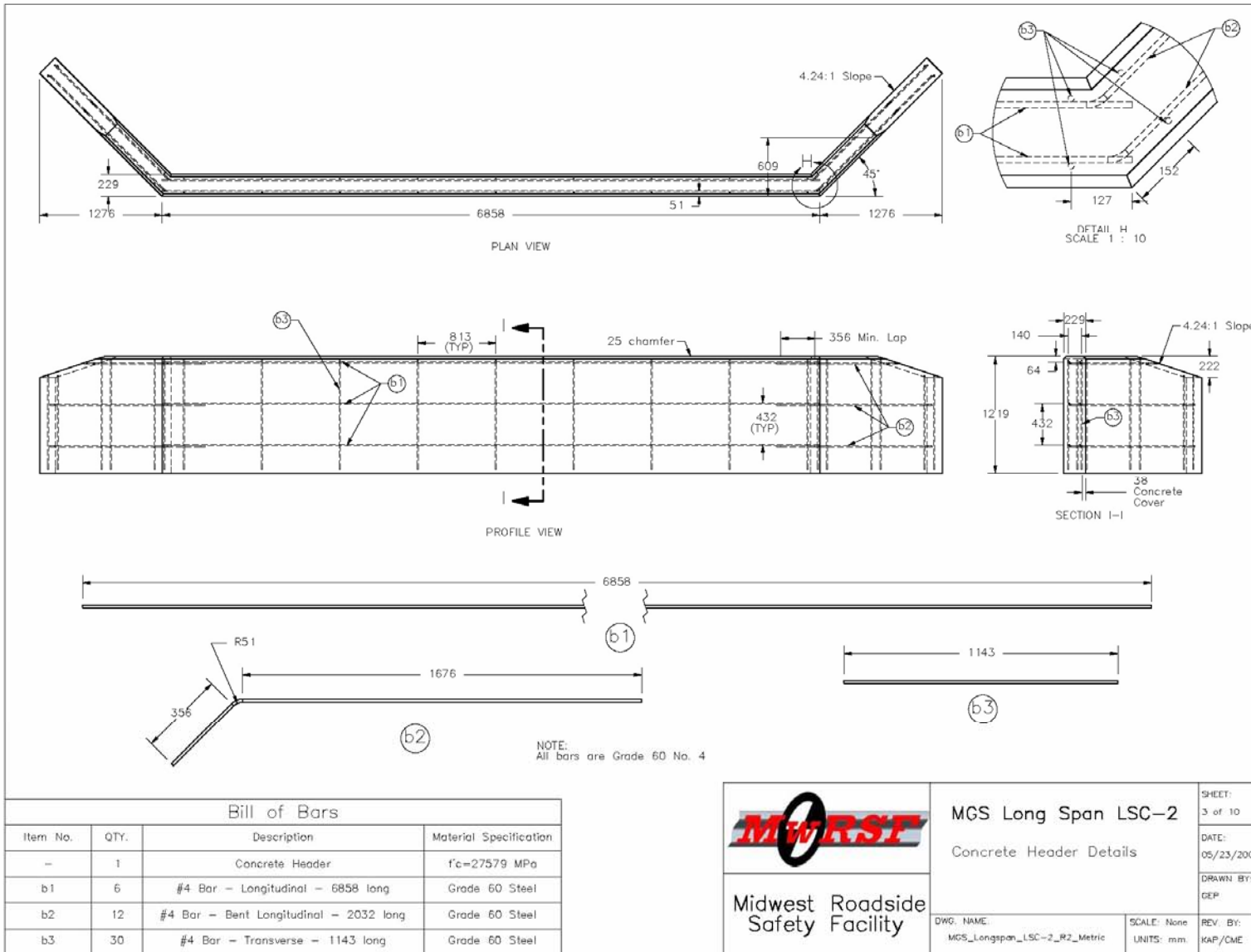
Figure 42. MGS Long Span Design Details, Test No. LSC-2

Ø16 Std. Guardrail
splice bolts

Ø16 x 533
Guardrail Post
Bolt

Ø19 x 64
Rail Slot

SPLICE DETAIL

DETAIL C
SCALE 1 : 15

2358

1226

Ø16 x 254
Guardrail
Post Bolt

Ø16 x 254
Hex Head Bolt
with washers

Ø22 x 191
Hex Head Bolt

Post 2

Post 1

END RAIL DETAIL

MGS Long Span LSC-2

End Rail Detail
Splice Detail

Midwest Roadside
Safety Facility

DWG. NAME:
MGS_Longspan_LSC-2_R2_Metric

SHEET:
4 of 10

DATE:
05/23/2006

DRAWN BY:
GEP

SCALE: None

UNITES: inches

REV. BY:
KAP/CME

Figure 43. MGS Long Span Design Details, Test No. LSC-2

PLAN VIEW

25
19
25
181
ø6

ø19

1829

305

152
44
181
362
ø19

W–Beam Blockout
Part a2

PROFILE VIEW   SIDE VIEW

W152x13.4–Beam Post
Part a1

Ø 16 x 356
long Guardrail
Post Bolt

16D Double
Head Nail

787   813

1016

SECTION A–A

MGS Long Span LSC-2

Post 3-10 &
17-24 Detail
W152x13.4 Posts

Midwest Roadside
Safety Facility

SHEET:
5 of 10

DATE:
05/23/2006

DRAWN BY:
GEP

DWG. NAME:
MGS_Longspan_LSC-2_R2_Metric

SCALE: None
UNITS: mm.

REV. BY:
KAP/CME

Figure 44. MGS Long Span Design Details, Test No. LSC-2

PLAN VIEW

152
76

181

Ø19

1829

813

400

Ø89

PROFILE VIEW

203

SIDE VIEW

CRT Wood Post
Part e1

Ø16 x 559 long
Guardrail Post
Bolt

16D Double
Head Nail

a2

787

813

1016

SECTION B-B

MGS Long Span LSC-2

Post 11-16 Detail
CRT Wood Posts

Midwest Roadside
Safety Facility

DWG. NAME:
MGS_Longspan_LSC-2_R2_Metric

SHEET:
6 of 10

DATE:
05/23/2006

DRAWN BY:
OEP

SCALE: None
UNITS: mm.

REV. BY:
KAP/CME

70
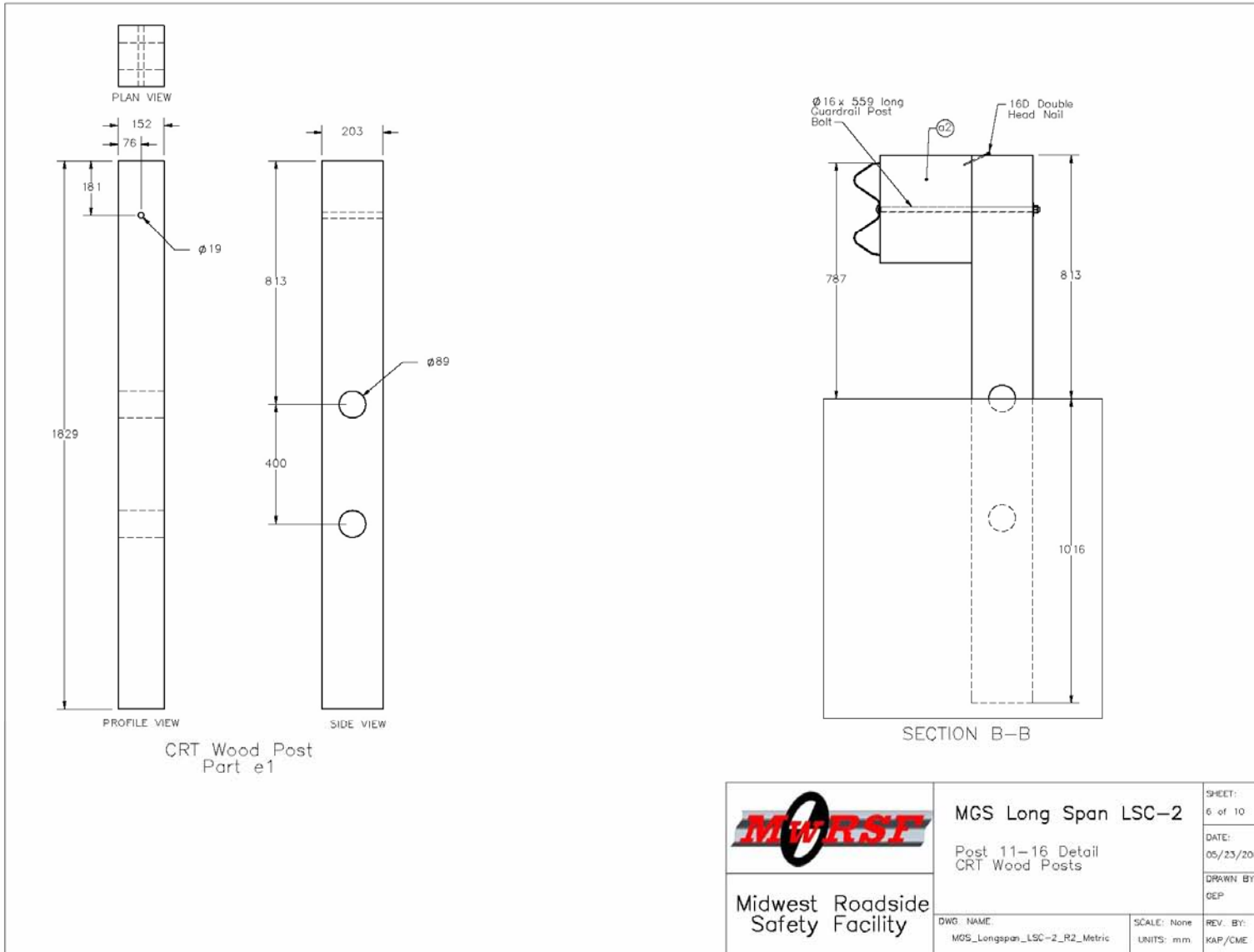
Figure 45. MGS Long Span Design Details, Test No. LSC-2
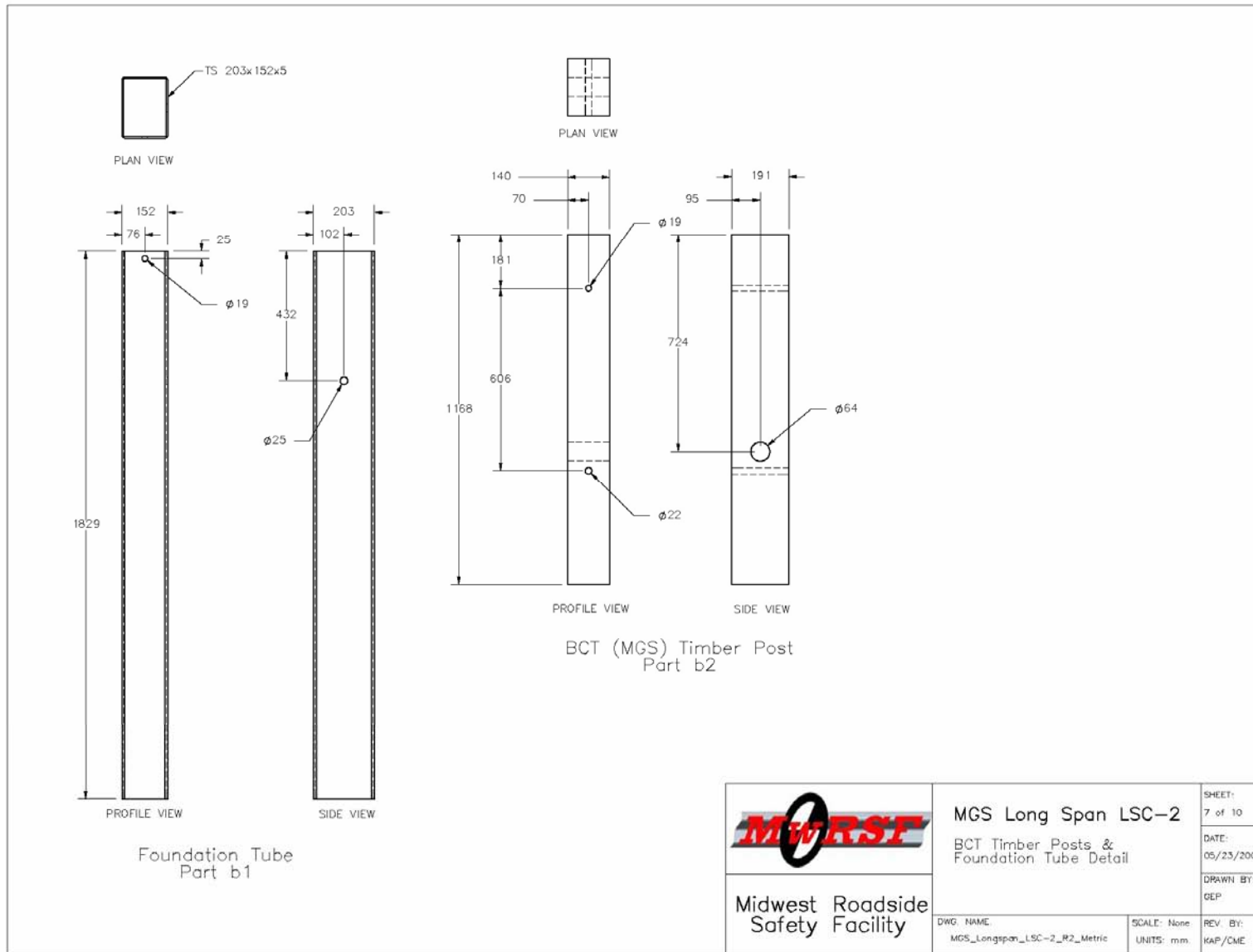
Figure 46. MGS Long Span Design Details, Test No. LSC-2

2032

1270

Cable End

Ø25 Washer A325

Ø25 Heavy Hex
Nut A325

BCT Anchor Cable
Part d1

D

381

178

127

25-8UNC Threaded
Entire Length

38

Ø32

DETAIL D
SCALE 1 : 5

203

102

127

203

Ø29

SIDE VIEW

16

PROFILE VIEW

Anchor Cable
Bearing Plate
Part d2

MGS Long Span LSC-2

BCT Anchor Cable Detail

SHEET:
8 of 10

DATE:
05/23/2006

DRAWN BY:
GEP

Midwest Roadside
Safety Facility

DWG. NAME
MGS_Longspan_LSC-2_R2_Metric

SCALE: None
UNITS: mm.

REV. BY:
KAP/CME

Figure 47. MGS Long Span Design Details, Test No. LSC-2
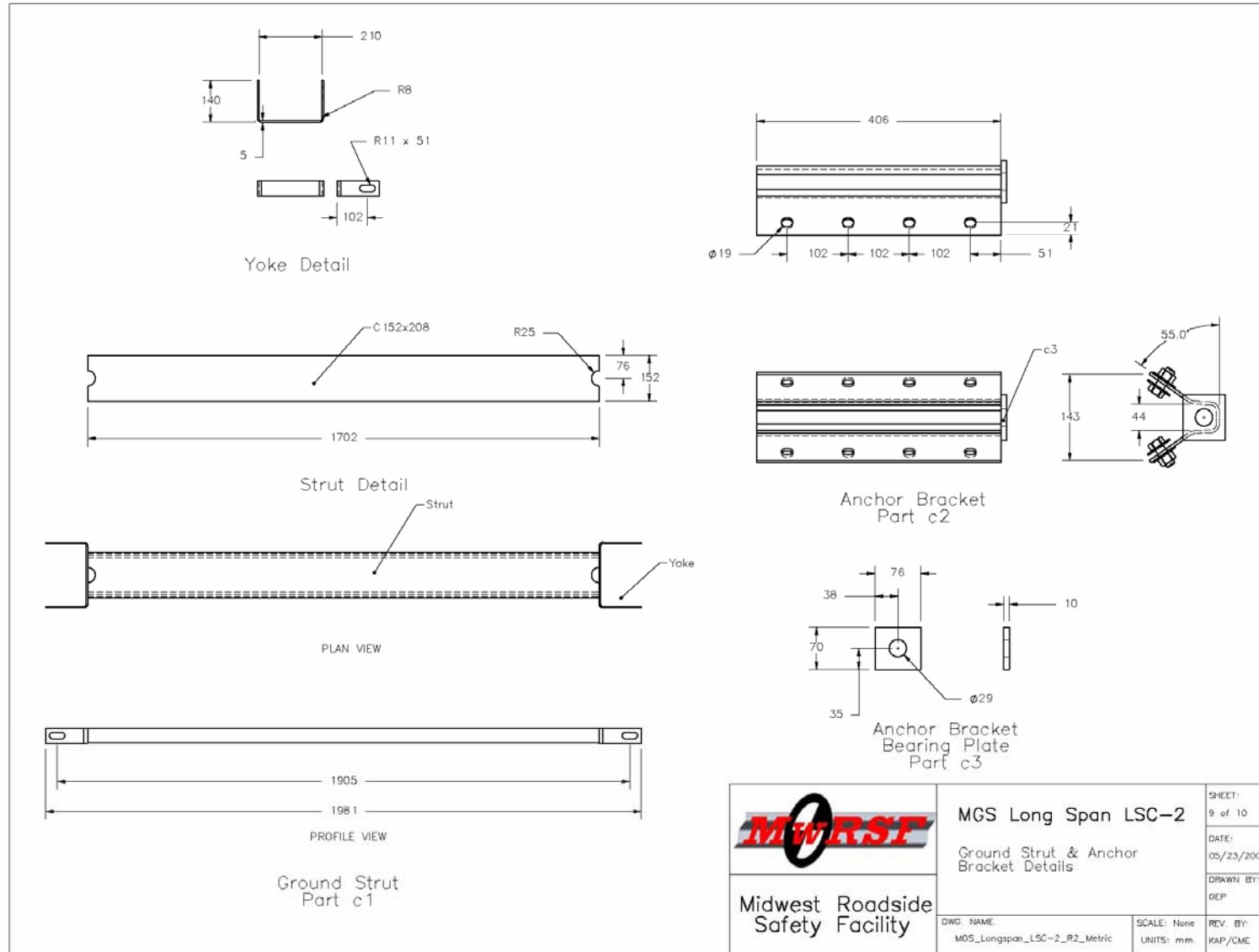
Figure 48. MGS Long Span Design Details, Test No. LSC-2
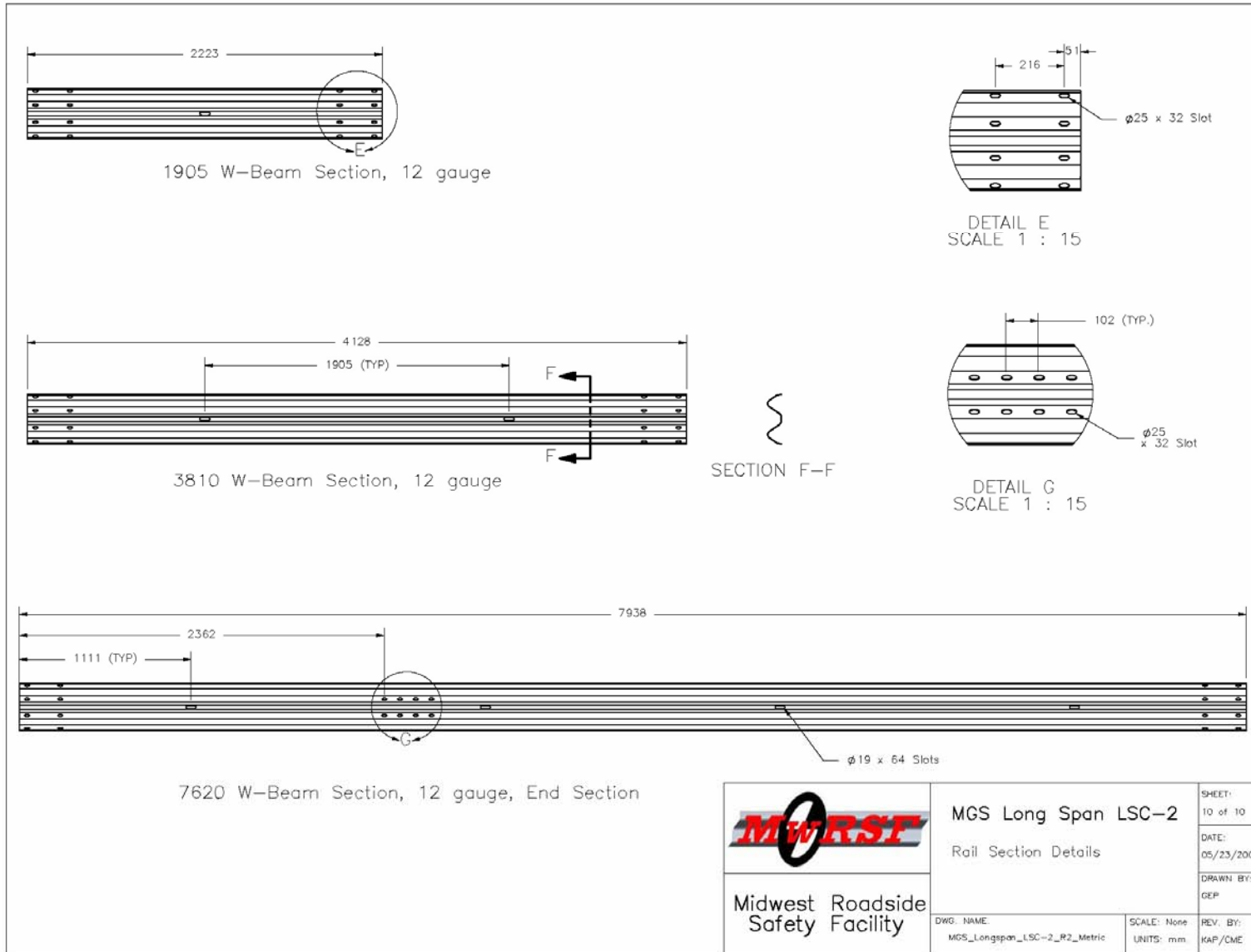
Figure 49. MGS Long Span Design Details, Test No. LSC-2

Figure 50. MGS Long Span Design Photographs, Test No. LSC-2

Figure 51. MGS Long Span Design Photographs, Test No. LSC-2

8 FULL-SCALE TEST NO. LSC-2

8.1 Test No. LSC-2

For test no. LSC-2, a 2,261-kg (4,984-lb) pickup truck impacted the MGS long-span guardrail system at a speed of 99.6 km/h (61.9 mph) and at an angle of 24.9 degrees. A summary of the test results and the sequential photographs are shown in Figure 52. The summary of the test results and sequential photographs in English units is shown in Appendix F. Additional sequential photographs are shown in Figure 53. Documentary photographs of the crash test are shown in Figures 54 and 55.

8.2 Test Description

Initial vehicle impact was to occur between post nos. 10 and 11, or 12.67 m (41.6 ft) upstream from the centerline of post no. 14, as shown in Figure 56. Actual vehicle impact occurred 12.57 m (41.24 ft) upstream from the centerline of post no. 14. By 0.170 sec, the pickup truck had moved downstream and began redirecting which caused post nos. 11 through 13 to deflect backward and post no. 13 to fracture at its base. At 0.252 sec, the left-front tire rolled off of the culvert wingwall, and the pickup truck continued to redirect. At 0.368 sec after impact, the vehicle became parallel to the guardrail with a speed of 77.6 km/h (48.2 mph), and the left-front quarter panel and left-front wheel of the vehicle continued to drop vertically into the area behind the culvert. The pickup continued to redirect with both the left-front and left-rear tires extended over the edge of the culvert. At 0.470 sec, the left-front tire contacted the side of the downstream culvert wingwall, causing the left-front wheel to completely disengage from the vehicle suspension and steering. The vehicle continued to redirect in a stable manner after the disengagement of the left-front wheel until it exited the system at 0.992 sec with a speed of 54.3

km/hr (33.7 mph) and at an angle of 18.8 degrees. The pickup exited the guardrail in a stable manner and came to rest 51.55-m (169.13-ft) downstream from impact and 5.69-m (18.67-ft) laterally away from the traffic-side face of the rail, as shown in Figures 52 and 57.

8.3 System Damage

As shown in Figures 59 through 63, damage to the barrier was moderate, consisting mostly of deformed W-beam, contact marks on a guardrail section, and deformed and fractured guardrail posts. The W-beam damage consisted of contact marks and deformation and flattening of the impacted section between post nos. 10 and 16. No indications of rail rupture or tearing were visible on the W-beam. The W-beam rail was pulled off of post nos. 1 through 14. Two CRT posts, post nos. 11 and 13, were completely fractured, while CRT post nos. 12, 14, and 15 were rotated backward in the soil. Steel post nos. 9 and 10 were bent and deformed back and downstream. No significant post damage or deformations occurred to the remaining posts in the system. Contact marks and concrete spalling were visible on the top of the culvert headwall as well as on the downstream wingwall, as shown in Figure 60. The maximum lateral permanent set rail deflection was approximately 1,372 mm (54.0 in.) at 3,810 mm (150 in.) downstream from the centerline of post no. 13, as measured in the field. The maximum lateral dynamic post and rail deflections were 1,186 mm (46.7 in.) at post no. 12 and 1,968 mm (77.5 in.) at 1,905 mm (75 in.) downstream of post no. 13, respectively, as determined from the high-speed video analysis. The working width of the system was 2,133 mm (84.0-in), as determined from the high-speed video analysis.

8.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 64 through 66. The left-front quarter panel was crushed inward, and the left side of the front bumper was also bent back toward the engine compartment. The left-front wheel assembly was completely disengaged from the axle, suspension, and steering systems. Some deformation and damage were noted on the left-front suspension components, including the upper and lower control arms, the stabilizer bar, and the joints connecting the suspension components. Contact marks and minor deformation were found along most of the lower-left side of the pickup truck. The left-rear quarter panel and the left corner of the rear bumper were dented as well. The left-rear tire was deflated, and the right-front tire de-beaded from the rim. Interior occupant compartment damage was minimal, as shown in Figure 67, with maximum lateral deformations of 19 mm (0.75 in.) measured near both the right and left sides of the driver-side footwell on the floorpan.

8.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities (OIV) were determined to be -4.90 m/s (-16.08 ft/s) and 4.09 m/s (13.42 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations (ORD) in the longitudinal and lateral directions were -7.34 Gs and 4.24 Gs, respectively. It is noted that the occupant impact velocities and the occupant ridedown decelerations were within the suggested limits provided in the Update to NCHRP Report No. 350. The results of the occupant risk, determined from the accelerometer data, are summarized in Figure 52. Results are shown graphically in Appendix H. Roll, pitch, and yaw data were collected from the rate gyroscope and are shown graphically in Appendix H.

8.6 Discussion

The analysis of the test results for test no. LSC-2 showed that the MGS long-span guardrail adequately contained and redirected the vehicle with controlled lateral displacements of the guardrail. Detached elements and debris from the test article did not penetrate nor show potential for penetrating the occupant compartment. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The vehicle remained upright during and after collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. It is noted that the occupant impact velocities (OIV) and occupant ridedown decelerations (ORD) were within the suggested limits provided in the Update to NCHRP Report No. 350. After collision, the vehicle's trajectory intruded slightly into adjacent traffic lanes but was determined to be acceptable. In addition, the vehicle did not exit the barrier within the exit box, as shown in Figure 58. Therefore, test no. LSC-2 conducted on the MGS long-span guardrail system was determined to be acceptable according to the Update to NCHRP Report No. 350 criteria. It should be noted that this test successfully evaluated the potential for vehicle instability through the choice of a CIP that maximized the impact of the left-front wheel on the upstream wingwall of the culvert. Additionally, the 0-mm (0-in.) offset from the back of the posts to the front face of the culvert headwall did not adversely affect the safety performance of the system and was believed to be a reasonable minimal offset distance for the MGS long-span based on this test. It is not believed that the reduced barrier offset in this test would have had any effect on the outcome of test no. LSC-1, which focused on the rail capacity of the system and not vehicle interaction with the culvert.
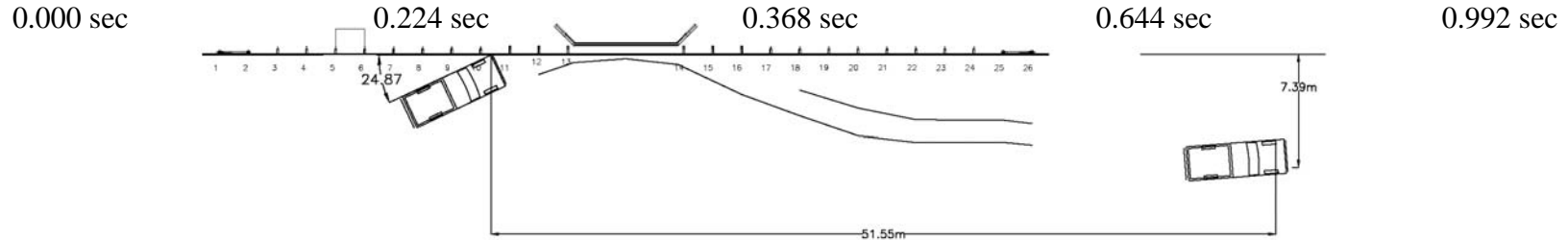
| 0.000 sec | 0.224 sec | 0.368 sec | 0.644 sec | 0.992 sec |

- Test Agency ....MwRSF
- Test Number...LSC-2
- Date 6/07/06
- NCHRP 350 Update Test Designation ..3-11
- Appurtenance ....MGS Longspan with Culvert
- Total Length...55.25 m
- Long Span Length ....7620 mm
- Distance Headwall to Back of Post ....0 mm
- Key Elements - Steel W-Beam..............
    - Thickness.....................................2.66 mm
    - Top Mounting Height ....787 mm
- Key Elements - Steel Posts
    - Post Nos. 3-10, 17-24   ....W152 x 13.4 by 1,829 mm long
- Key Elements - Wood Posts
    - Post Nos. 11-16 (CRT) ....152 mm x 203 mm x 1,829 mm long
    - Post Nos. 1-2, 25-26 (BCT). ....140 mm x 190 mm x 1,080 mm long
- Key Elements - Steel Foundation Tube 1,829 mm long
- Key Elements - Wood Spacer Blocks
    - Post Nos. 3-24............................152 mm x 305 mm by 356 mm long
- Type of Soil..Grading B - AASHTO M 147-65
- Test Vehicle
    - Type/Designation.........................2270P
    - Make and Model ....2002 Dodge 1500 Quad Cab
    - Curb ....2260 kg
    - Test Inertial.................................2261 kg
    - Gross Static.................................2261 kg

- Impact Conditions
    - Speed ....99.63 km/h
    - Angle ....24.87 degrees
    - Impact Location ....11 mm downstream of Post 10
- Exit Conditions
    - Speed ....54.3 km/h
    - Angle ....18.8 degrees
    - Exit Box Criterion.............................Fail
- Post-Impact Trajectory
    - Vehicle Stability...............................Satisfactory
    - Stopping Distance ....51.55 m downstream of impact,
      5.69 m laterally away
- Occupant Impact Velocity (350 Update)
    - Longitudinal.....................................-4.90 m/s < 12 m/s
    - Lateral ....4.09 m/s < 12 m/s
- Occupant Ridedown Deceleration (350 Update)
    - Longitudinal.....................................-7.34 Gs < 20 Gs
    - Lateral ....4.24 Gs < 20 Gs
- THIV (not required) ....6.08 m/s
- PHD (not required)....................................7.56 Gs
- Test Article Damage..................................Moderate
- Test Article Deflections
    - Permanent Set ....1,372 mm
    - Dynamic...1,968 mm
    - Working Width ....2,133 mm
- Vehicle Damage ....Moderate
    - VDS[25]..11-LFQ-3
    - SAE[26] 11LDES5
    - Maximum Deformation....................19 mm near the left and right side
      of the driver floorpan

Figure 52. Summary of Test Results and Sequential Photographs, Test No. LSC-2

81

0.000 sec	0.000 sec
0.094 sec	0.104 sec
0.182 sec	0.207 sec
0.422 sec	0.345 sec
0.710 sec	0.587 sec
0.966 sec	0.897 sec

Figure 53. Additional Sequential Photographs, Test No. LSC-2

Figure 54. Documentary Photographs, Test No. LSC-2

83

Figure 55. Documentary Photographs, Test No. LSC-2
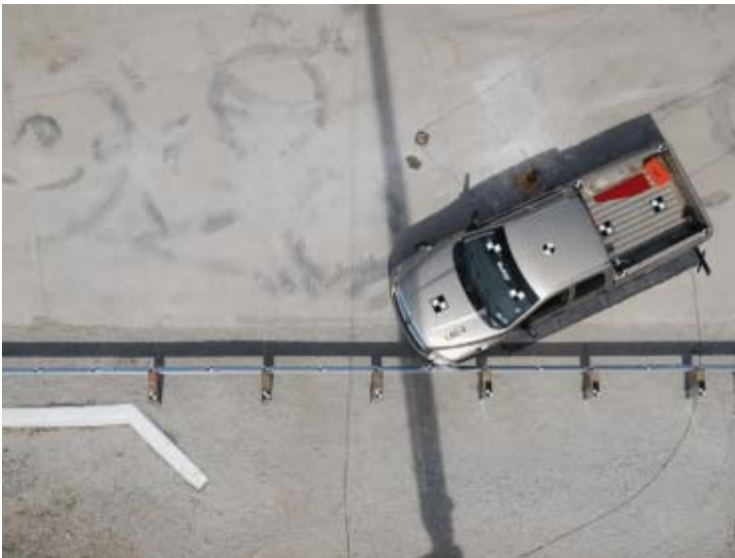
Figure 56. Impact Location, Test No. LSC-2

Figure 57. Trajectory and Final Position, Test No. LSC-2
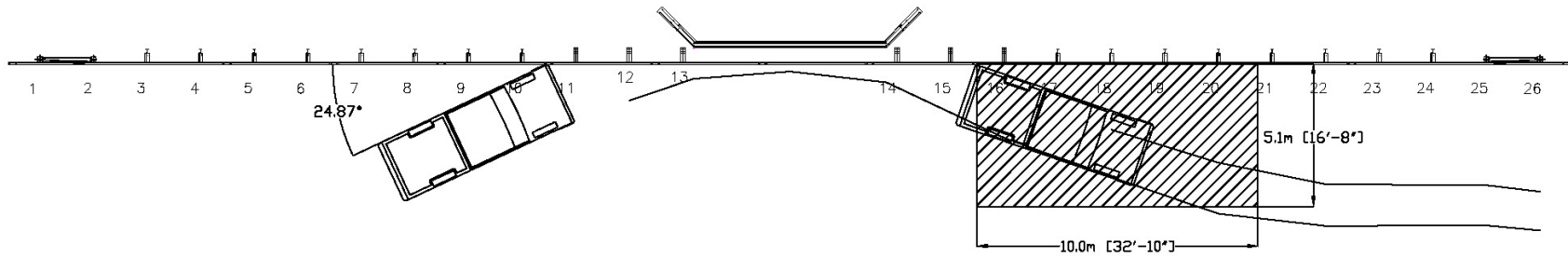
Figure 58. Exit Box, Test No. LSC-2

Figure 59. System Overall Damage, Test No. LSC-2

Figure 60. System Culvert Wall Damage, Test No. LSC-2

Figure 61. System Post Damage, Test No. LSC-2

Figure 62. System Rail Damage, Test No. LSC-2

Figure 63. System Anchor Damage, Test No. LSC-2

Figure 64. Vehicle Damage, Test No. LSC-2

Figure 65. Vehicle Damage, Test No. LSC-2

Figure 66. Vehicle Damage, Test No. LSC-2

Figure 67. Occupant Compartment Deformation, Test No. LSC-2

9 SUMMARY AND CONCLUSIONS

Long-span guardrail systems have been recognized as an effective means of shielding low-fill culverts. These designs are popular due to their ability to safely shield the culvert while creating little additional construction effort and limiting the damage and repair of the culvert when compared to other systems that attach posts to the top of the culvert. However, previous long-span designs were limited by the need to use long sections of nested guardrail to prevent rail rupture and the need for large lateral offsets between the barrier and the culvert. The MGS long-span guardrail described herein eliminates those two shortcomings by applying the benefits of the Midwest Guardrail System to a long-span design. The MGS long-span guardrail increased vehicle capture and stability through increased rail height, limited the potential for pocketing and wheel snag through the use of CRT posts adjacent to the unsupported span, and greatly increased the tensile capacity of the rail through the movement of splices away from the posts and the use of shallower post embedment. These features allowed the system to be developed without the use of nested guardrail and with a minimal barrier offset that places the back of the guardrail posts even with the front face of the culvert.

Two full-scale crash tests were conducted on the MGS long-span according to the proposed Update to the NCHRP Report No. 350 requirements for TL-3 test designation no. 3-11. These tests are summarized in Table 3. Both tests were conducted with the 2270P vehicle proposed by NCHRP 22-14, the Update to NCHRP Report No. 350, in order to generate higher rail loads and dynamic deflections. The first test, test no. LSC-1, was designed to evaluate the structural capacity of the system by selecting a CIP that maximized the potential for pocketing, wheel snag, and rail rupture. In test no. LSC-1, a 2,264-kg (4,491-lb) pickup truck impacted the MGS long-span system 2,438 mm (96.0 in.) downstream of post no. 13 at a speed of 100.5 km/h

(62.5 mph) and at an angle of 24.8 degrees, and the vehicle was safely redirected. A second test, test no. LSC-2, was conducted to evaluate the potential for vehicle instability by selecting a CIP that maximized the interaction of the left-front wheel of the pickup truck with the wingwall of the culvert. In test no. LSC-2, a 2,261-kg (4,985-lb) pickup truck impacted the MGS long-span system 12.57 m (41.24 ft) upstream of post no. 14 at a speed of 99.6 km/h (61.9 mph) and at an angle of 24.9 degrees, and the vehicle was safely redirected.

The MGS long-span design met all of the safety requirements of the proposed Update to the NCHRP Report No. 350. The MGS long-span guardrail's ability to perform safely without nested rail and a minimal barrier offset makes this new barrier a very functional and safe option for protection of low-fill culverts.

Table 3. Test Summary

Test No.	Test Designation and Description	Actual Impact Conditions		Occupant Risk				Comments	Assessment
		Speed (km/h)	Angle (Deg)	OIV (m/s)		ORD (Gs)			
				Long.	Lat.	Long.	Lat.		
LSC-1	Test 3-11 – 2270P Pickup truck redirection	100.5 (62.4 mph)	24.8	-2.92 (-9.6 ft/s)	3.23 (10.6 ft/s)	-6.48	5.91	The vehicle was safely and smoothly redirected.	**PASS**
LSC-2	Test 3-11 – 2270P Pickup truck redirection	99.6 (61.9 mph)	24.9	-4.90 (-16.1 ft/s)	4.09 (13.4 ft/s)	-7.34	4.24	The vehicle was safely and smoothly redirected.	**PASS**

10 RECOMMENDATIONS

The testing of the MGS long-span system described herein indicated that this long-span guardrail is a suitable design for use on high-speed, high-volume highways. However, as with any new hardware system, there are certain design and installation recommendations that should be stated with regards to the MGS long-span. While the tested design consisted of a 7.62-m (25.0-ft) long unsupported rail section, there are many culvert installations that could be shielded with shorter unsupported guardrail lengths, such as 3.81 m (12.5 ft) or 5.72 m (18.75 ft) lengths. The use of shorter unsupported sections is allowable with the MGS long-span due to the fact that rail deflections and vehicle instabilities should decrease as the unsupported rail length is shortened. However, it is recommended that the use of three CRT posts adjacent to the upstream and downstream ends of the unsupported section be maintained to reduce the potential for pocketing and wheel snag. The use of unsupported lengths longer than 7.62 m (25.0 ft) is not recommended at this time without further analysis and full-scale crash testing. If a low-fill culvert longer than 7.62 m (25.0 ft) must be shielded, a guardrail over culvert design with posts that bolt to the culvert is recommended (27-28).

The lateral barrier offset used in the testing of the MGS long-span placed the back face of the guardrail posts flush with the front face of the culvert headwall. This placement is the recommended minimum offset for the system at this time without further analysis and/or testing due to concerns that placing the guardrail closer to the culvert headwall would adversely affect the performance of the system. Installation of the system at offsets farther from the culvert headwall is allowed as long as adequate space is available.

The MGS long-span guardrail described herein was tested with a top rail height of 787 mm (31.0 in.). Previous reports on the standard MGS system have allowed installation at heights

as low as 705 mm (27.75 in.). However, as noted previously, the reduced post embedment of the MGS system was a major factor in the performance of the MGS long-span design. Thus, in order to retain the improved load distribution and reduced rail strains, the MGS long span should be installed with a top rail mounting height of 787 mm (31.0 in.). Reduction of the rail height below this value will likely reduce the performance of the barrier system.

Often, culvert headwalls may extend 152 mm (6.0 in.) or more above the groundline. Headwall extensions of this magnitude would represent a vertical curb underneath the barrier and could pose a stability hazard. Thus, it is recommended that headwall extends no higher than 51 mm (2.0 in.) above the groundline and that any extensions greater than 51 mm (2.0 in.) be ground down to match the ground profile.

There has been interest from long-span guardrail users as to whether the MGS long-span guardrail could be installed within a long run of conventional W-beam guardrail. The researchers believe that a gradual transition between the conventional W-beam and the MGS long-span could be designed to allow this type of installation, but further analysis of the transition design is required.

With any longitudinal barrier system, there exists a minimum length of guardrail that is required to ensure that the system adequately contains and redirects the impacting vehicles. The minimum effective length for W-beam guardrail systems, such as the MGS long-span, has not been quantitatively defined. Most of the strong-post, W-beam guardrail systems have been crash tested using a system length of approximately 53.34 m (175 ft). For these lengths, it has been demonstrated that the barrier system will meet impact safety standards and allow the designer/researcher to gain knowledge on dynamic barrier performance. Whether or not the system's performance or deflection is adversely affected by an installed length shorter than the

tested length is unknown. For an impact closer to the barrier system ends, dynamic barrier deflection may actually increase when impacted at the same 25-degree angle. Special systems such as the MGS long-span could actually further increase the loading of the barrier system and create higher anchor loads and affect the length of the system and the anchorage. Although it is likely that guardrail lengths shorter than 53.34 m (175 ft) can redirect 2270P vehicles impacting at the TL-3 conditions, there is no crash test data to support or recommend the use of shorter lengths at this time.

In addition, trailing-end guardrail treatments are typically used to anchor the downstream end of strong-post, W-beam guardrail systems when vehicular impacts are not expected on the system end. These trailing-end designs consist of varying configurations using blunt ends or spoons, turned-down terminals, tension rods with concrete anchors, etc. In addition, these downstream anchorage devices are often located longitudinally near to the hazard that is shielded by the roadside barrier system. To date, no trailing-end (downstream) terminals have been evaluated according to the NCHRP Report No. 350 guidelines. There are concerns that vehicle impacts slightly upstream of the trailing-end terminals may induce rollover or severe snagging on the anchor system. Further, if the downstream anchor proves to release too quickly, vehicles impacting a short distance upstream of the terminal may be allowed to penetrate through the guardrail and strike the shielded hazard. Therefore, a need exists to standardize the trailing-end, guardrail anchorage systems that are capable of meeting current impact safety standards.

Based on these noted concerns, it is recommended that the minimum installation length of the MGS long-span be set at 53.34 m (175 ft) for a long span length of 7.62 m (25 ft). However, if a shorter long span length is used, it is still recommended that the upstream and downstream lengths of the installation including the end anchorage be no less than 19.05 m (62.5

ft) beginning at the third CRT post. This length is based on the 53.34 m (175 ft) system length that was tested. There may be a potential to reduce the downstream distance, but this would require further analysis and verification with full-scale crash testing.

Finally, the guardrail system was configured with the entire length installed tangent to the roadway. However, in actual field installations, this guardrail system can be installed with either one or both ends flared away from the traveled way in order to minimize the length of the system. For locations where a guardrail flare will be used, the minimum recommended length of tangent section adjacent to the unsupported length is 19.05 m (62.5 ft).

11 REFERENCES

1. *Roadside Design Guide*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., January 1996.

2. Ross, H.E., Jr., Hirsch, T.J., Jackson, B., Jr., and Sicking, D.L., *Safety Treatment of Roadside Cross-Drainage Structures*, Research Report No. 280-l, Performed by the Texas Transportation Institute, Texas A&M University, March l98l.

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12 APPENDICES

APPENDIX A MGS Long-Span Design Details, Test No. LSC-1, English Units

Figure A-1. MGS Long-Span Design Details, Test No. LSC-1
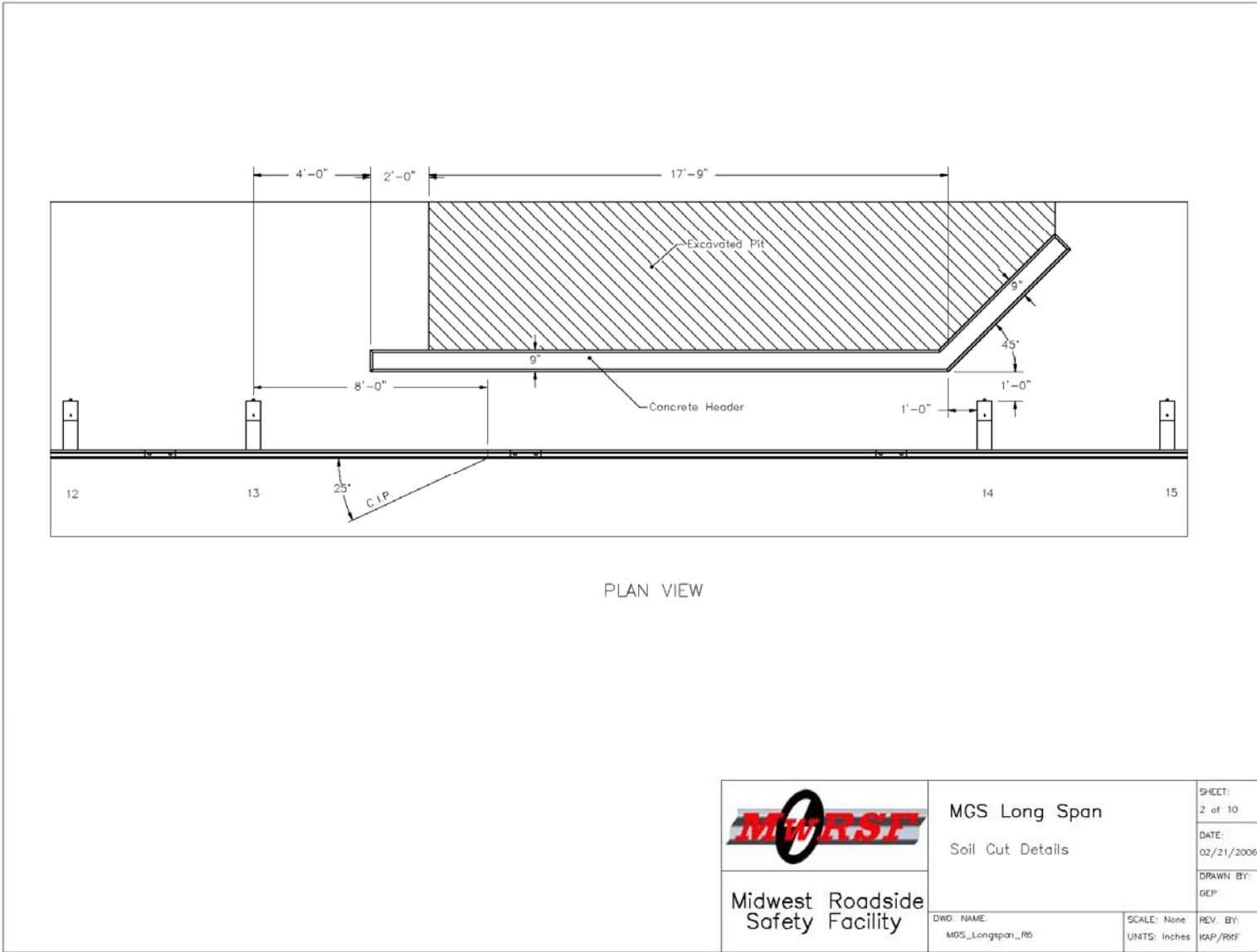
Figure A-2. MGS Long-Span Design Details, Test No. LSC-1
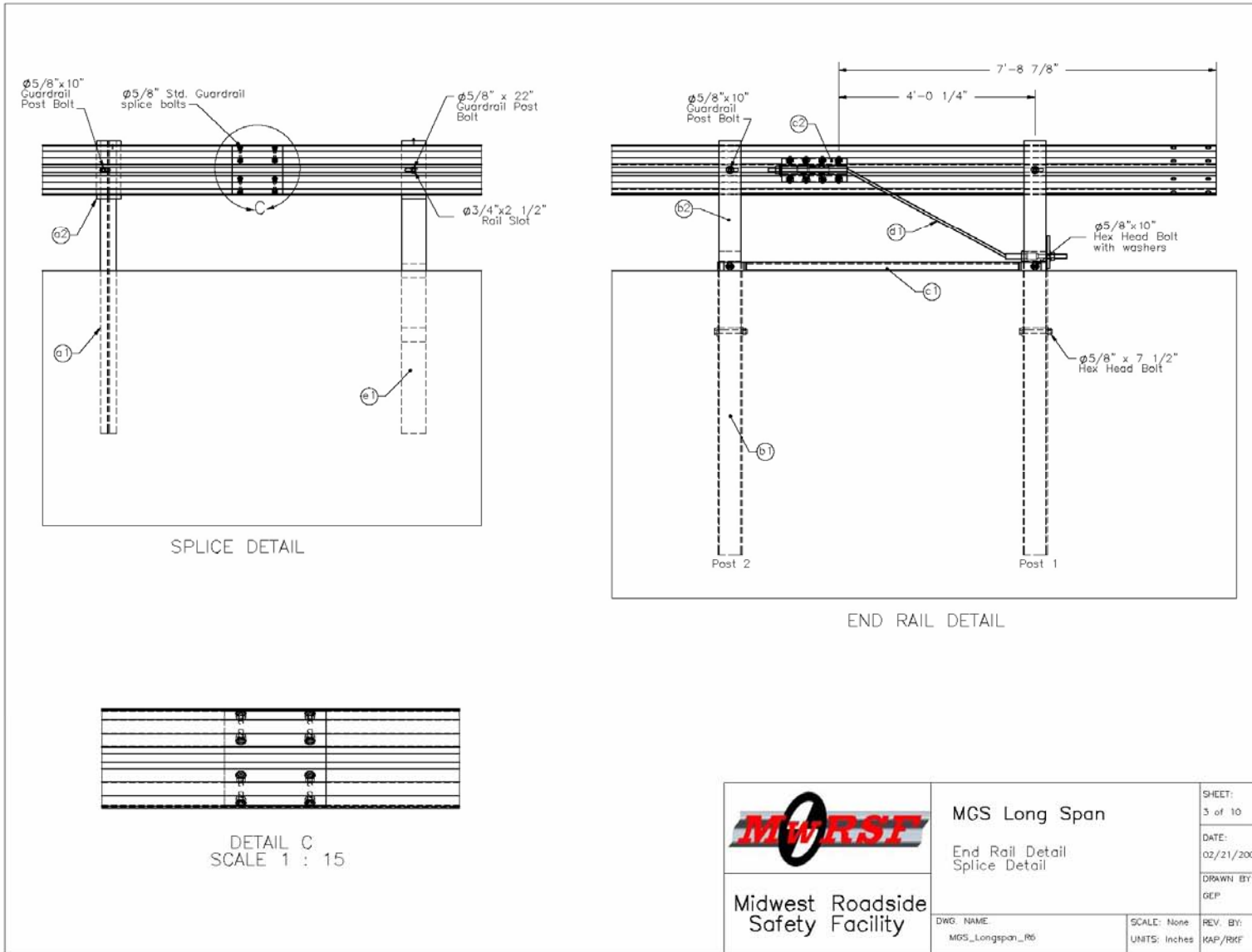
Figure A-3. MGS Long-Span Design Details, Test No. LSC-1
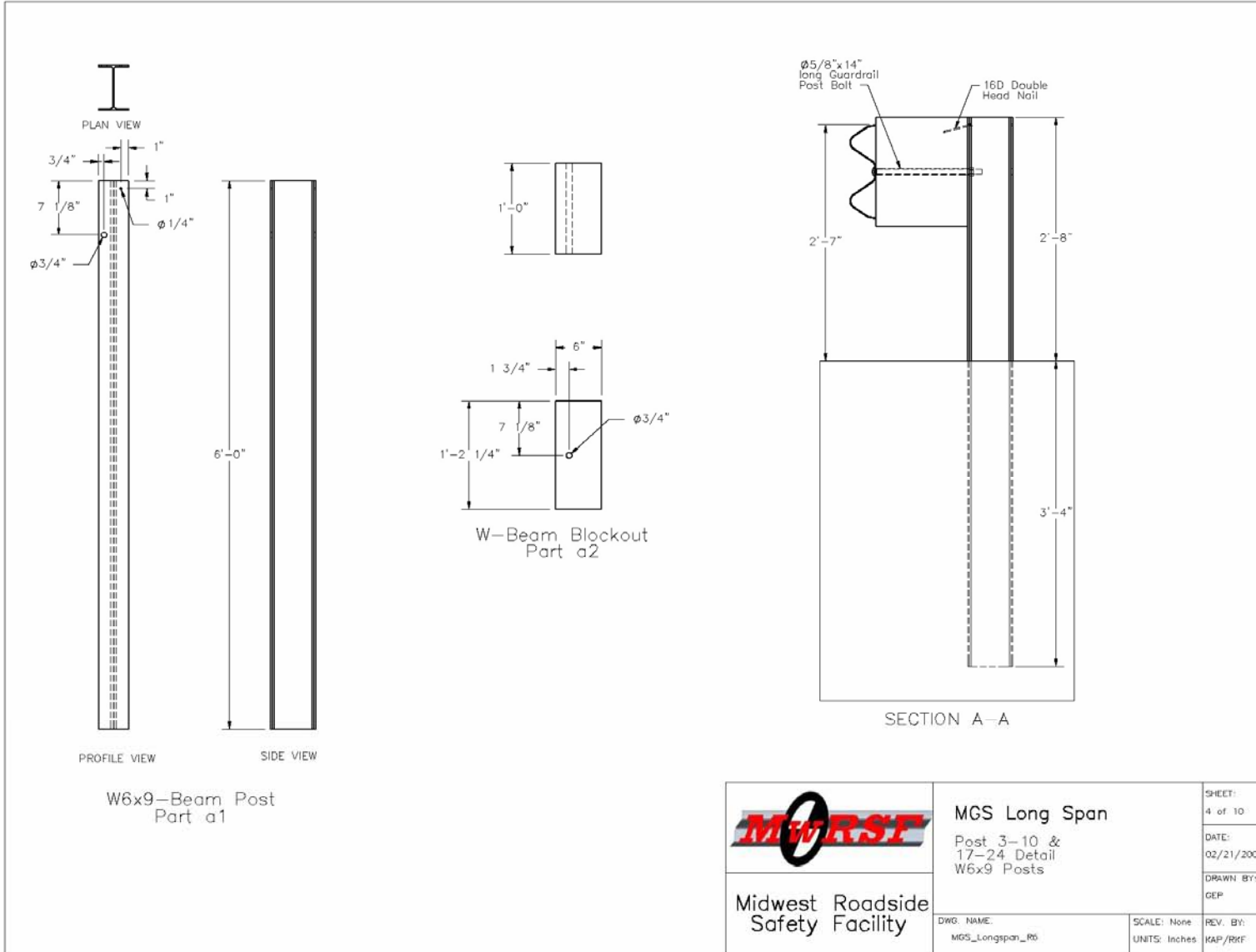
Figure A-4. MGS Long-Span Design Details, Test No. LSC-1
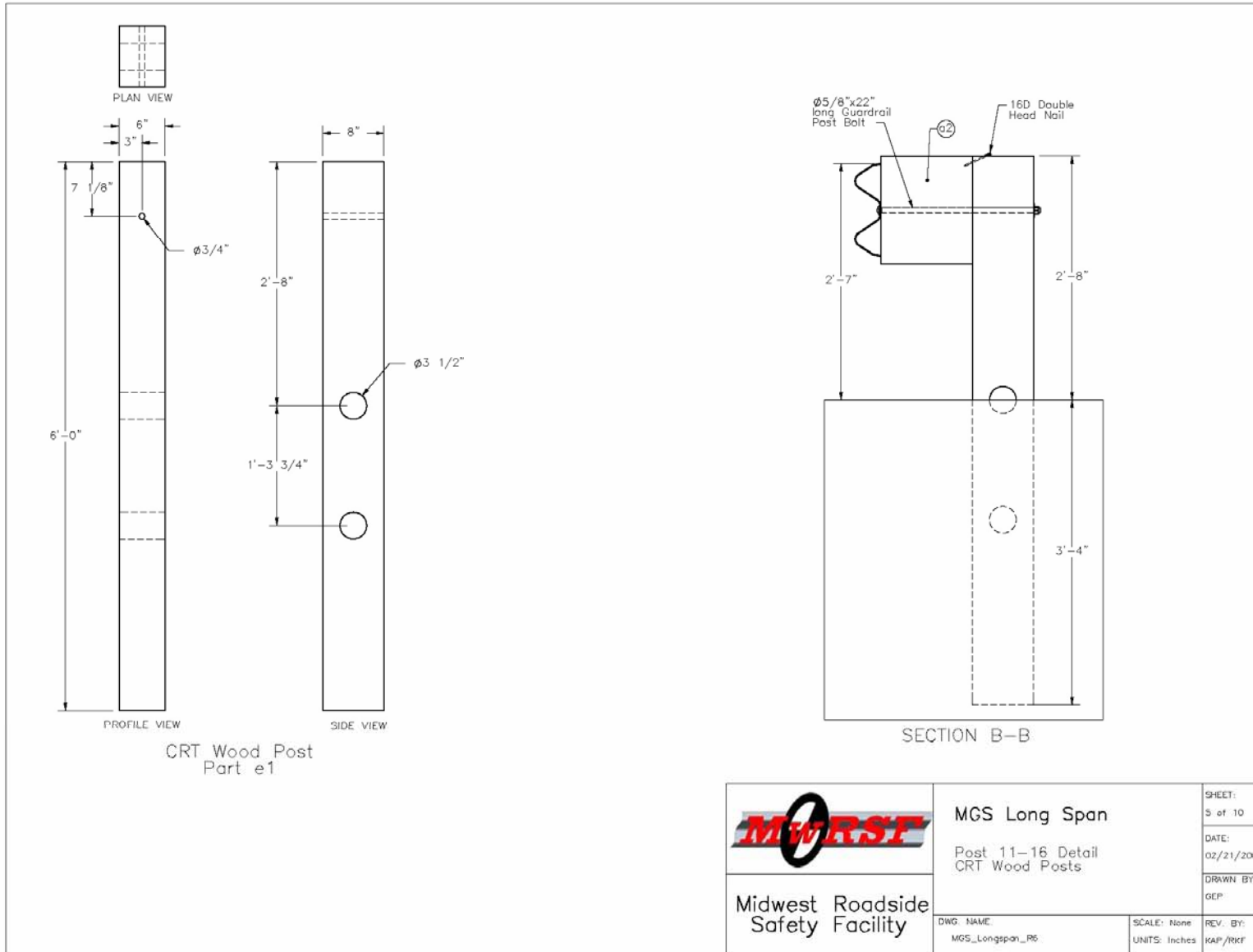
Figure A-5. MGS Long-Span Design Details, Test No. LSC-1
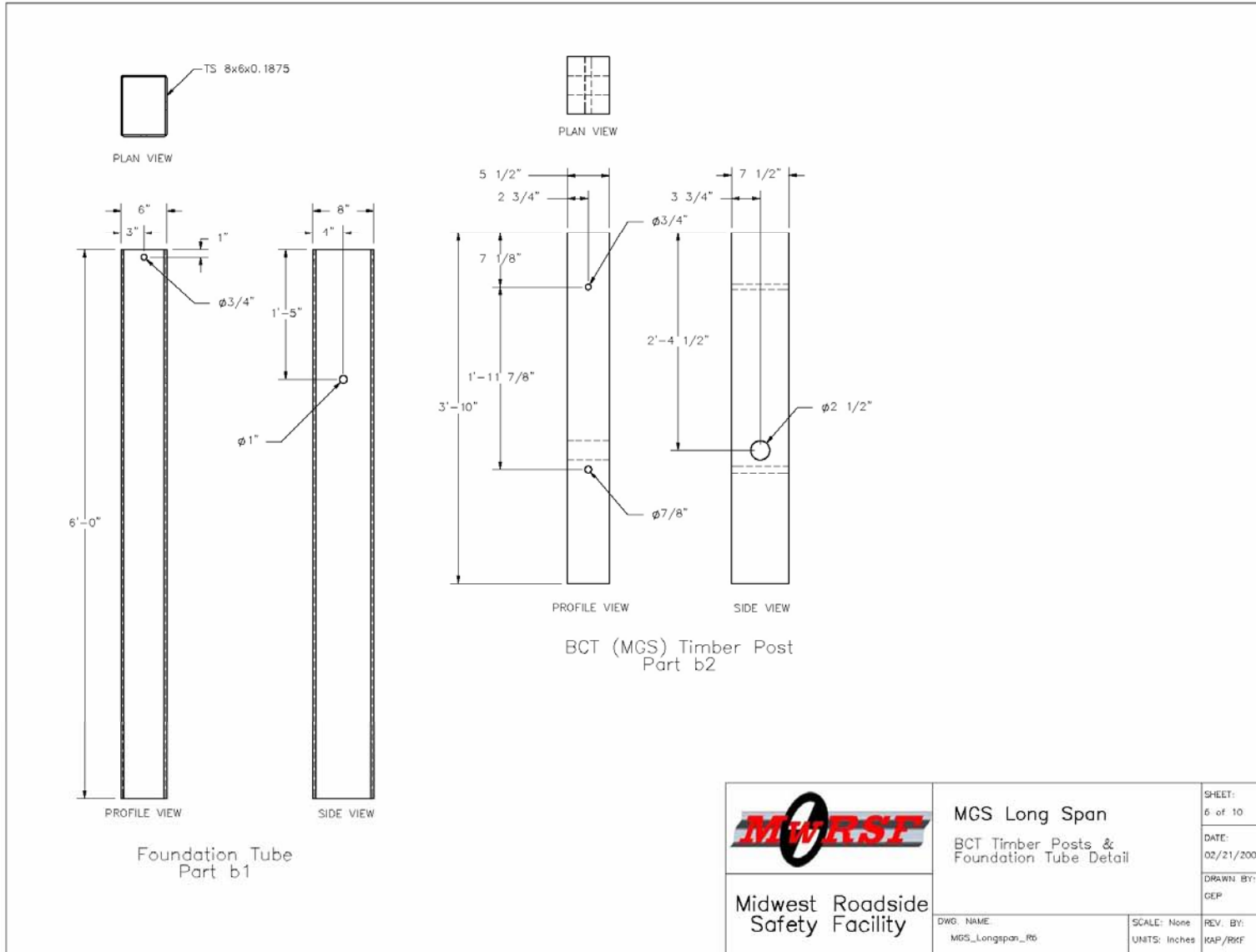
Figure A-6. MGS Long-Span Design Details, Test No. LSC-1

6'-8"

4'-2"

Cable End

Ø3/4" Washer A325

Ø1" Heavy Hex
Nut A325

BCT Anchor Cable
Part d1

D

1'-3"

7"

5"

1 1/2"

Ø1 1/4"

1"-8UNC Threaded
Entire Length

DETAIL D
SCALE 1 : 5

8"

4"

5"

8"

Ø1 1/8"

SIDE VIEW

5/8"

PROFILE VIEW

Anchor Cable
Bearing Plate
Part d2

MGS Long Span

BCT Anchor Cable Detail

Midwest Roadside
Safety Facility

SHEET:
7 of 10

DATE:
02/21/2006

DRAWN BY:
GEP

DWG. NAME:
MGS_Longspan_R6

SCALE: None

UNITS: Inches

REV. BY:
KAP/RKF
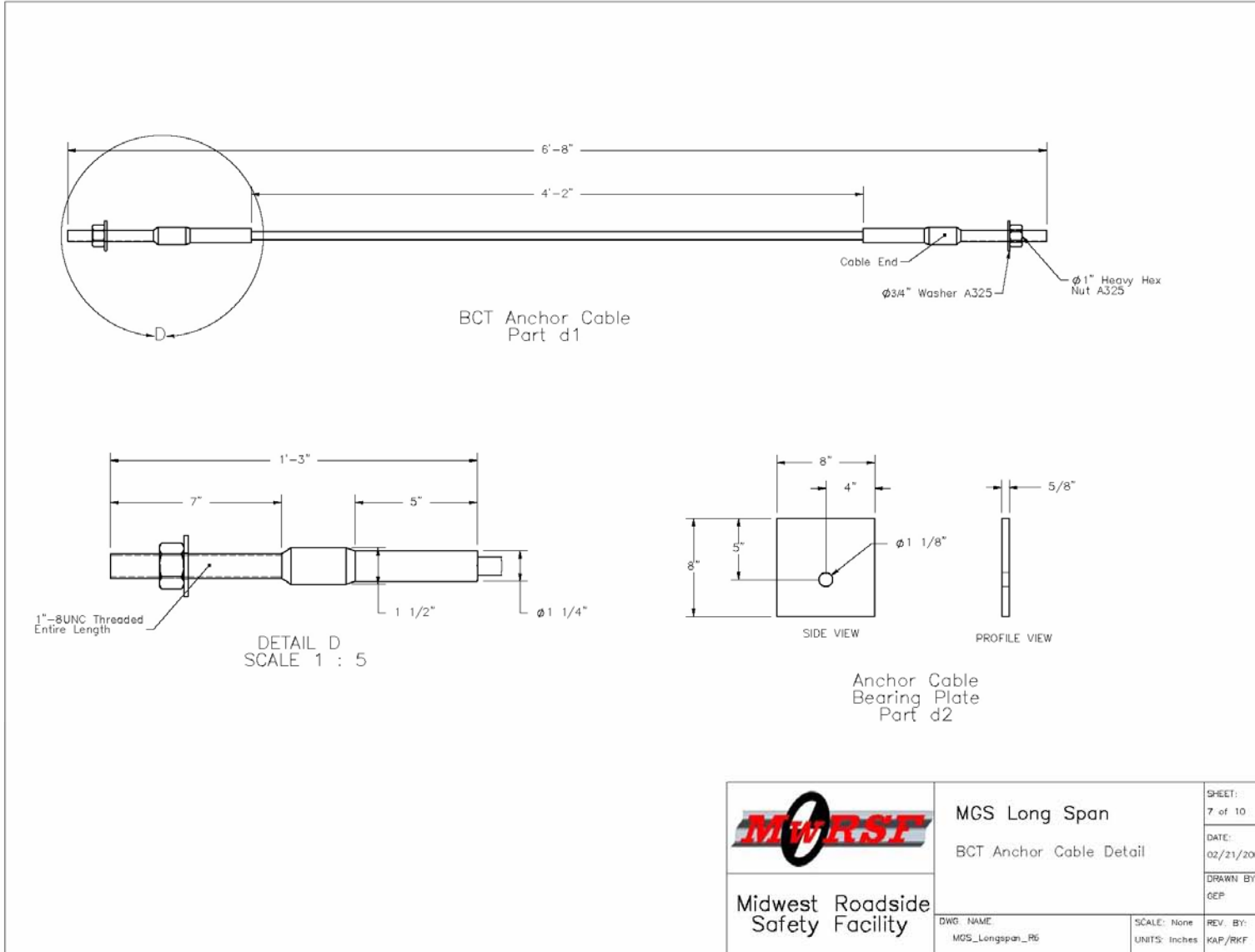
Figure A-7. MGS Long-Span Design Details, Test No. LSC-1
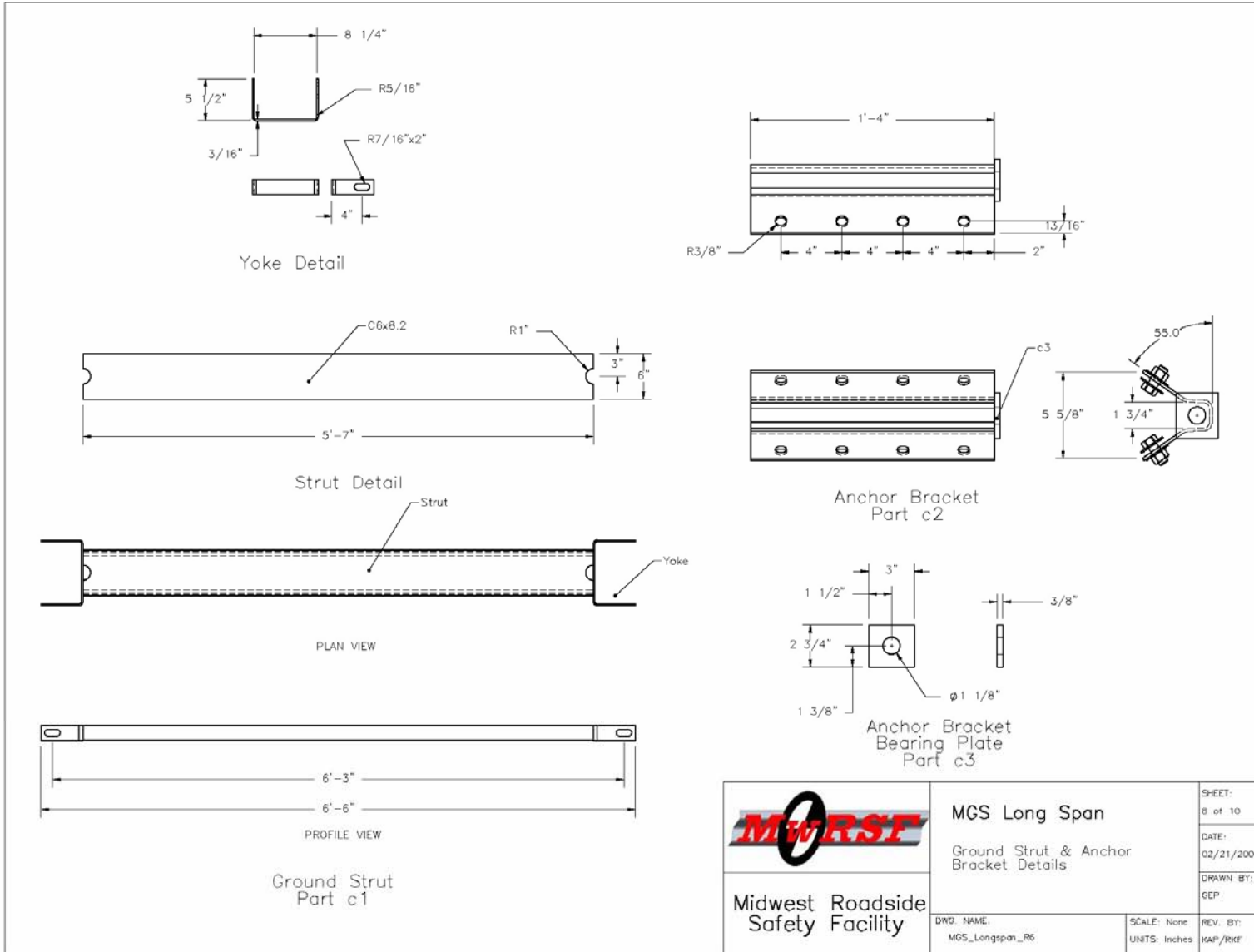
Figure A-8. MGS Long-Span Design Details, Test No. LSC-1

7'-3 1/2"

6'-3" W-Beam Section, 12 gauge

8 1/2"

2"

R1/2"x1 1/4" Slot

DETAIL E
SCALE 1 : 15

13'-6 1/2"

6'-3" (TYP)

F

F

12'-6" W-Beam Section, 12 gauge

SECTION F-F

4" (TYP.)

R1/2"
x1 1/4" Slot

DETAIL G
SCALE 1 : 15

26'-0 1/2"

7'-9"

3'-7 3/4" (TYP)

G

ø3/4"x2 1/2" Slots

25' W-Beam Section, 12 gauge, End Section

MGS Long Span

Rail Section Details

Midwest Roadside
Safety Facility

SHEET:
9 of 10

DATE:
02/21/2006

DRAWN BY:
GEP

DWG. NAME.
MGS_Longspan_R6

SCALE: None
UNITS: Inches

REV. BY:
KAP/RKF

Figure A-9. MGS Long-Span Design Details, Test No. LSC-1

Figure A-10. MGS Long-Span Design Details, Test No. LSC-1

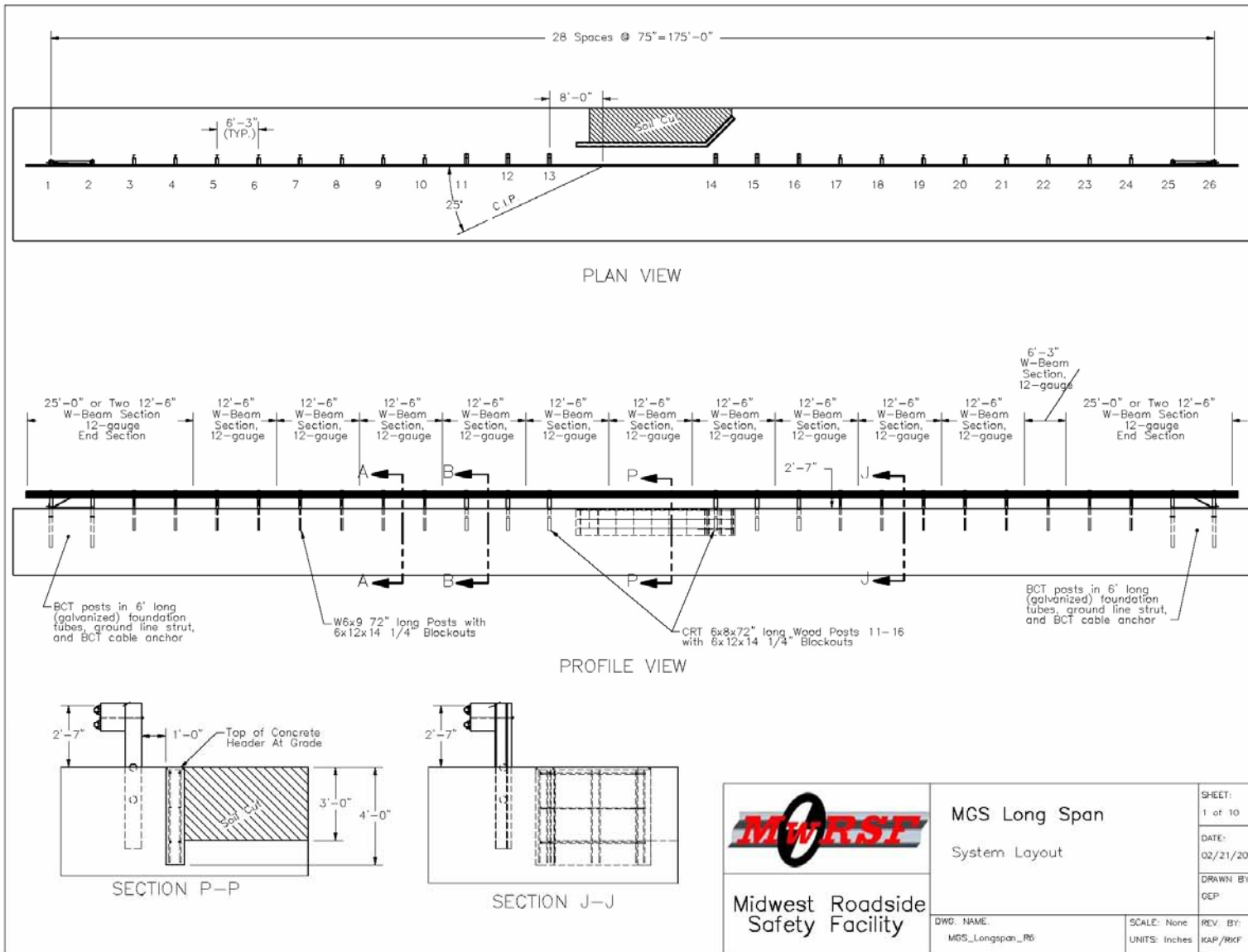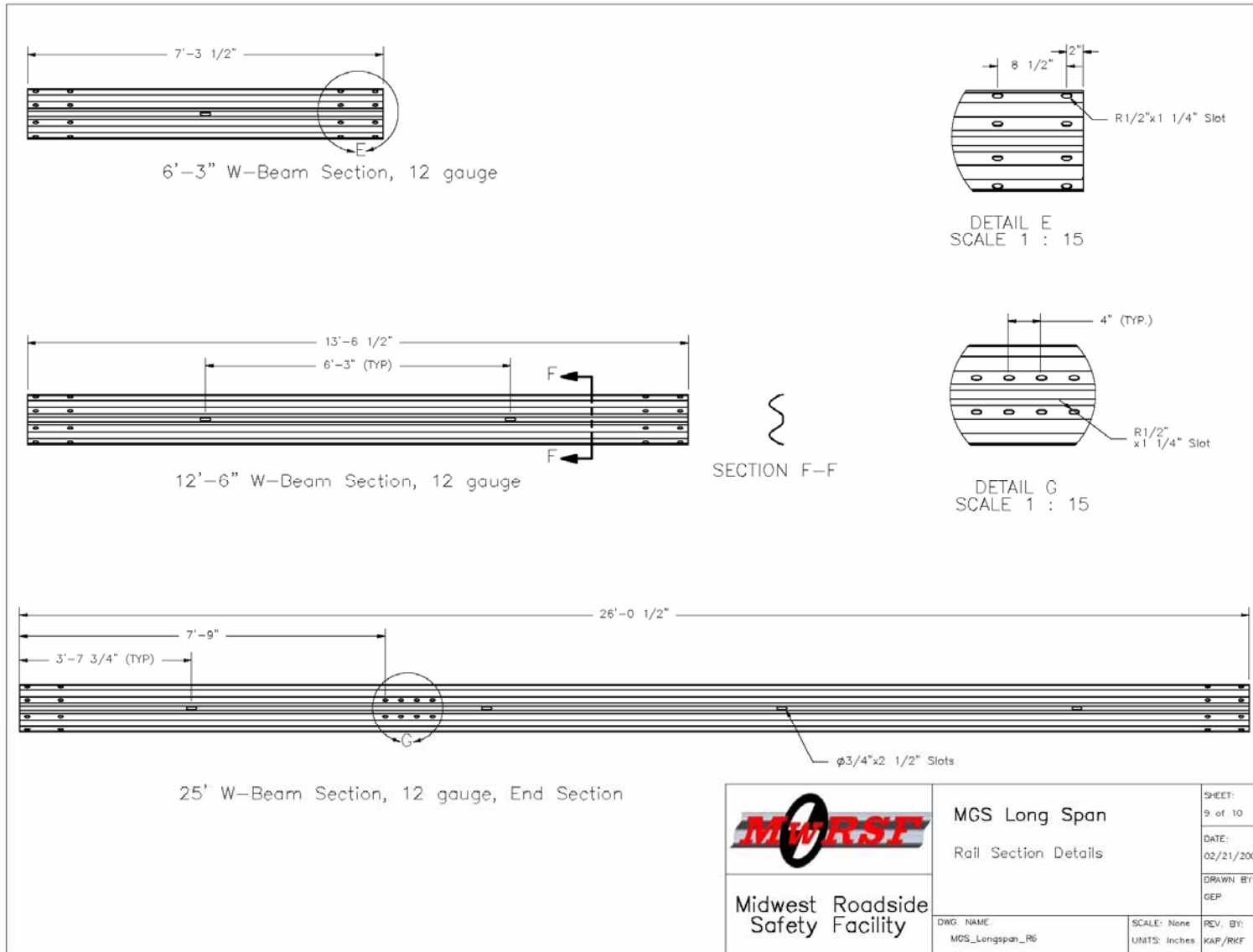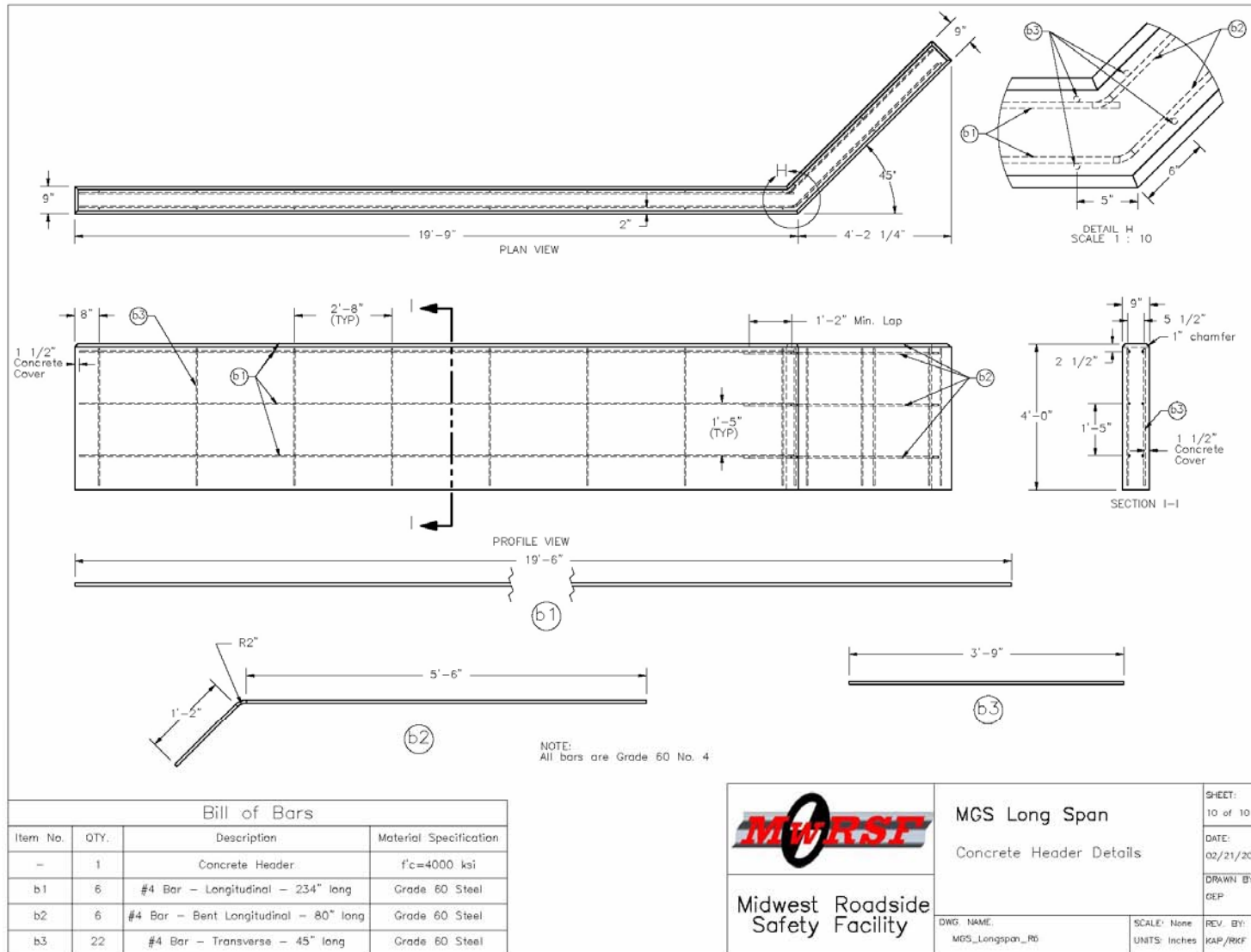**APPENDIX B Test Summary Sheet in English Units, Test No. LSC-1**

| 0.000 sec | 0.122 sec | 0.234 sec | 0.344 sec | 0.526 sec |
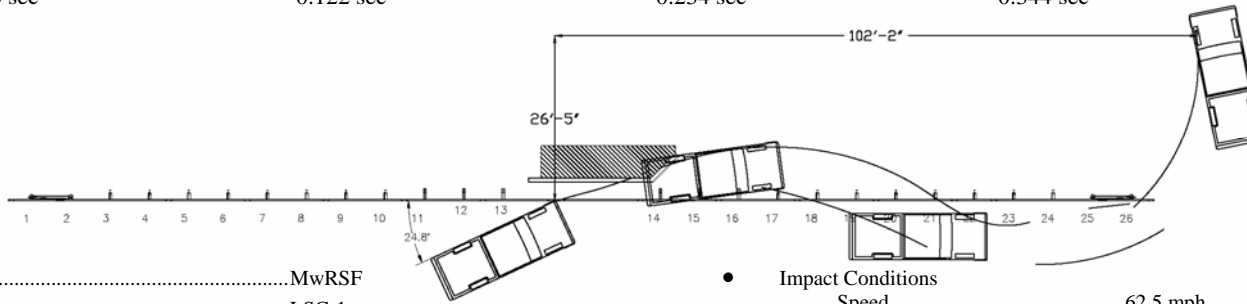
- Test Agency...MwRSF
- Test Number LSC-1
- Date...4/21/06
- NCHRP 350 UpdateTest Designation..................3-11
- Appurtenance...MGS Longspan with Culvert
- Total Length ....181.25 ft
- Long Span Length ....25 ft
- Distance Headwall to Back of Post......................12 in.
- Key Elements - Steel W-Beam
  - Thickness...12-gauge
  - Top Mounting Height................................31 in.
- Key Elements - Steel Posts
  - Post Nos. 3-10, 17-24................................W6x9 x 72 in. long
- Key Elements – Wood Posts
  - Post Nos. 11-16 (CRT)..............................6 x 8 x 72 in. long
  - Post Nos. 1-2, 25-26 (BCT) ....5.5 x 7.5 x 46 in. long
- Key Elements – Steel Foundation Tube...............72.0 in.
- Key Elements – Wood Spacer Blocks
  - Post Nos. 3-24 ....6 x 12 x 14.25 in. long
- Soil Type Grading B – AASHTO M 147-65
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model..2002 Dodge 1500 Quad Cab
  - Curb ....5,021 lbs
  - Test Inertial..4,992 lbs
  - Gross Static...4,992 lbs

- Impact Conditions
  - Speed..62.5 mph
  - Angle...24.8 deg
  - Impact Location ....96.0 in. downstream of Post 13
- Exit Conditions
  - Speed..35.2 mph
  - Angle...1 deg
  - Exit Box Criterion........................Pass
- Post-Impact Trajectory
  - Vehicle Stability ....Satisfactory
  - Stopping Distance........................102 ft 2 in. downstream of impact, 26 ft 5 in. laterally behind
- Occupant Ridedown Deceleration
  - Longitudinal.................................-6.48 Gs < 20 Gs
  - Lateral ....5.91 Gs < 20 Gs
- Occupant Impact Velocity
  - Longitudinal.................................-9.58 ft/s < 39.37 ft/s
  - Lateral ....10.60 ft/s < 39.37 ft/s
- THIV (not required)................................NA
- PHD (not required) ....NA
- Vehicle Damage ....Minimal
  - VDS[25]...11-LFQ-3
  - SAE[26] 11LDES5
  - Maximum Deformation ....0.75 in. near right side of driver floorpan
- Test Article Damage..............................Moderate
- Test Article Deflections
  - Permanent Set ....28.4 in.
  - Dynamic..92.2 in.
  - Working Width ....93.4 in.

Figure B-1. Summary of Test Results and Sequential Photographs, Test LSC-1

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APPENDIX C Occupant Compartment Deformation, Test No. LSC-1

TEST: LSC-1
VEHICLE: 2002 Dodge Ram 1500

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	29	-29	-1	29	-29	-1	0	0	0
2	30.5	-25.5	-2	30.5	-25	-2	0	0.5	0
3	31.75	-19.75	-3.75	31.5	-19.25	-3.5	-0.25	0.5	0.25
4	30.75	-14.25	-2.75	30.75	-13.75	-2.75	0	0.5	0
5	27.75	-8.75	-0.5	27.75	-8.5	-0.25	0	0.25	0.25
6	26.25	-29.75	-5.5	26.25	-29.75	-5.5	0	0	0
7	27.25	-23.75	-5.75	27	-23.5	-5.75	-0.25	0.25	0
8	26.5	-17	-5.75	26.5	-17	-5.5	0	0	0.25
9	26.25	-11.75	-5.5	26.25	-11.75	-5.75	0	0	-0.25
10	22	-8.5	-3.25	21.75	-8.5	-3	-0.25	0	0.25
11	21	-26.25	-8.5	21.25	-26	-8.5	0.25	0.25	0
12	21.25	-21.25	-8.25	21.5	-20.75	-8.5	0.25	0.5	-0.25
13	21.25	-14.25	-8.25	21.75	-14.25	-8	0.5	0	0.25
14	20.25	-9.25	-5.75	20.25	-9	-5.5	0	0.25	0.25
15	17.5	-29.5	-9.25	17.75	-29.75	-9.25	0.25	-0.25	0
16	17.5	-25	-9	17.75	-25	-9	0.25	0	0
17	17.75	-18.5	-9	17.75	-18.75	-8.75	0	-0.25	0.25
18	16.75	-12.75	-8.5	17	-12.75	-8.5	0.25	0	0
19	13.25	-29.25	-9	13.5	-29.25	-9	0.25	0	0
20	13.5	-23.5	-8.75	13.5	-23.25	-8.75	0	0.25	0
21	13	-16	-8.5	13.5	-16.25	-8.5	0.5	-0.25	0
22	13	-10	-7.75	13.5	-9.75	-7.5	0.5	0.25	0.25
23	9	-28.75	-8.75	9.25	-28.75	-8.75	0.25	0	0
24	9.25	-23.75	-8.5	9.25	-23.75	-8.5	0	0	0
25	9	-18	-8.25	9.25	-18	-8.25	0.25	0	0
26	8.5	-10.5	-8	9	-10.75	-7.75	0.5	-0.25	0.25
27	5	-23.5	-8	4.75	-23.5	-8	-0.25	0	0
28	4.75	-16.25	-7.75	4.75	-16.5	-7.75	0	-0.25	0
29									
30									
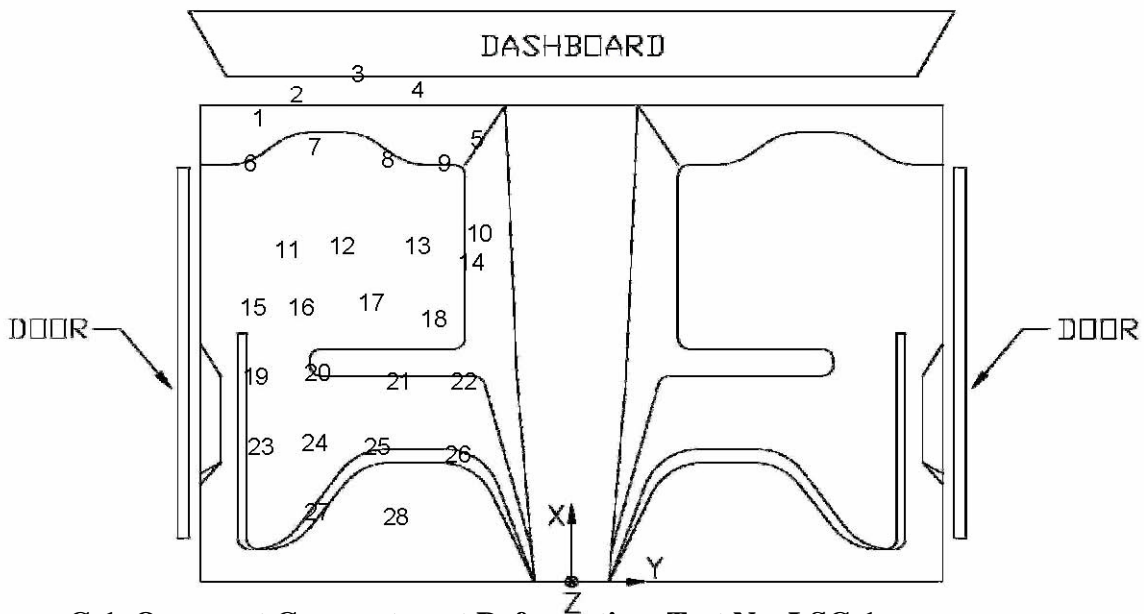
Figure C-1. Occupant Compartment Deformation, Test No. LSC-1

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TEST: LSC-1
VEHICLE: 2002 Dodge Ram 1500

| POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	51.75	-14.75	-1.75	51.75	-14.75	-2	0	0	-0.25
2	53.25	-11.25	-3.25	53.25	-10.75	-3.5	0	0.5	-0.25
3	54.5	-5.5	-5	54.25	-5	-5.5	-0.25	0.5	-0.5
4	53.5	0	-4.25	53.5	0.5	-4.75	0	0.5	-0.5
5	50.5	5.5	-2	50.5	5.75	-2.75	0	0.25	-0.75
6	49	-15.5	-6.25	49	-15.5	-6.75	0	0	-0.5
7	50	-9.5	-6.75	49.75	-9.25	-7.25	-0.25	0.25	-0.5
8	49.25	-2.75	-7	49.25	-2.75	-7.25	0	0	-0.25
9	49	2.5	-7.25	49	2.5	-8	0	0	-0.75
10	44.75	5.75	-4.75	44.5	5.75	-5.5	-0.25	0	-0.75
11	43.75	-12	-9.5	44	-11.75	-9.75	0.25	0.25	-0.25
12	44	-7	-9.5	44.25	-6.5	-10	0.25	0.5	-0.5
13	44	0	-9.75	44.5	0	-10.25	0.5	0	-0.5
14	43	5	-7.5	43	5.25	-8	0	0.25	-0.5
15	40.25	-15.25	-10	40.5	-15.5	-10.25	0.25	-0.25	-0.25
16	40.25	-10.75	-10	40.5	-10.75	-10.25	0.25	0	-0.25
17	40.5	-4.25	-10.25	40.5	-4.5	-10.5	0	-0.25	-0.25
18	39.5	1.5	-10	39.75	1.5	-10.5	0.25	0	-0.5
19	36	-15	-9.5	36.25	-15	-9.75	0.25	0	-0.25
20	36.25	-9.25	-9.25	36.25	-9	-10	0	0.25	-0.75
21	35.75	-1.75	-9.75	36.25	-2	-10.25	0.5	-0.25	-0.5
22	35.75	4.25	-9	36.25	4.5	-9.5	0.5	0.25	-0.5
23	31.75	-14.5	-9.25	32	-14.5	-9.5	0.25	0	-0.25
24	32	-9.5	-9.5	32	-9.5	-9.75	0	0	-0.25
25	31.75	-3.75	-9.5	32	-3.75	-9.75	0.25	0	-0.25
26	31.25	3.75	-9.25	31.75	3.5	-9.75	0.5	-0.25	-0.5
27	27.75	-9.25	-9	27.5	-9.25	-9.25	-0.25	0	-0.25
28	27.5	-2	-9	27.5	-2.25	-9.25	0	-0.25	-0.25
29									
30									
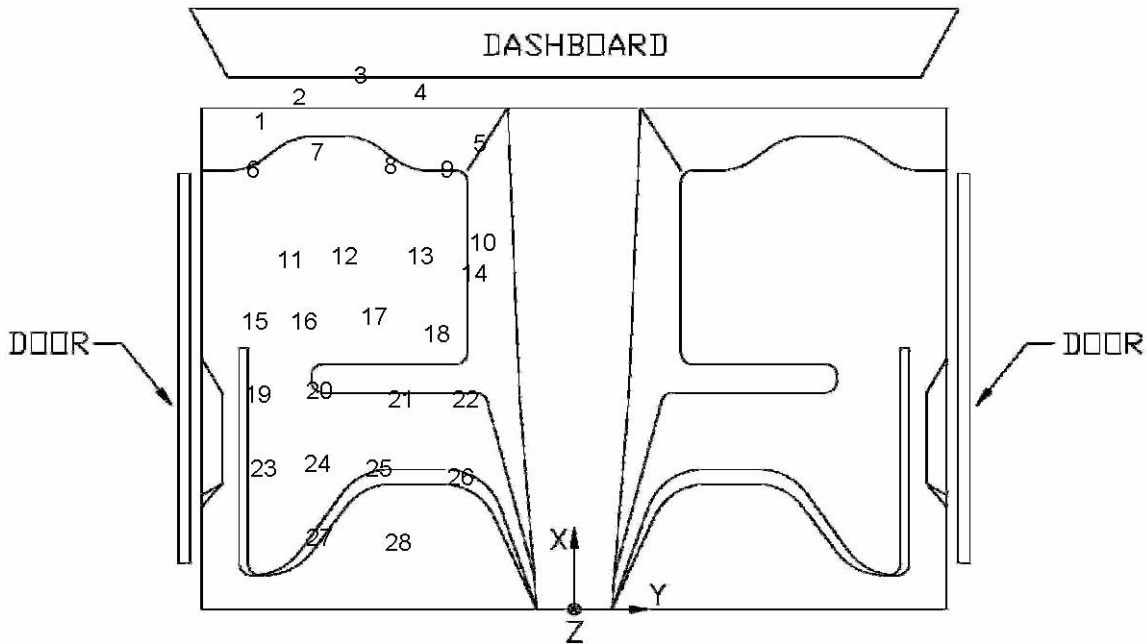
Figure C-2. Occupant Compartment Deformation, Test No. LSC-1

<u>Occupant Compartment Deformation Index (OCDI)</u>

Test No.   LSC-1
Vehicle Type: 2002 Dodge Ram 1500

OCDI = XXABCDEFGHI

XX = location of occupant compartment deformation

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

B = distance between the roof and the floor panel

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

D = distance between the lower dashboard and the floor panel

E = interior width

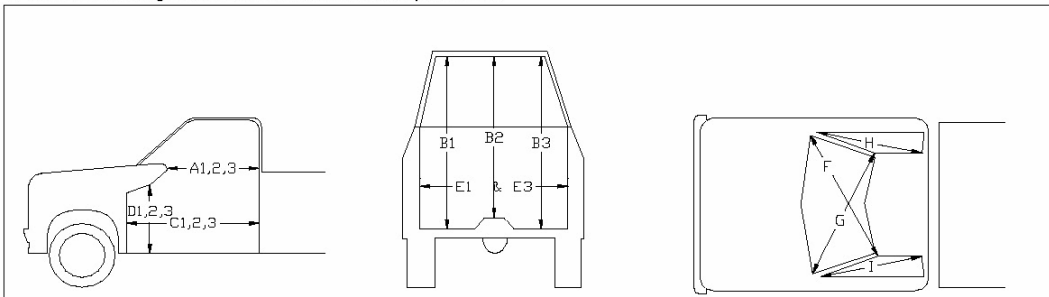F = distance between the lower edge of right window and the upper edge of left window

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

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

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

Severity Indices

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

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

Location:

Measurement	Pre-Test (in.)	Post-Test (in.)	Change (in.)	% Difference	Severity Index
A1	69.25	69.25	0.00	0.00	0
A2	70.25	70.00	-0.25	-0.36	0
A3	71.25	71.25	0.00	0.00	0
B1	46.50	46.25	-0.25	-0.54	0
B2	42.00	42.00	0.00	0.00	0
B3	46.50	46.50	0.00	0.00	0
C1	61.00	61.00	0.00	0.00	0
C2	46.25	46.25	0.00	0.00	0
C3	58.50	58.50	0.00	0.00	0
D1	15.75	15.75	0.00	0.00	0
D2	13.50	13.50	0.00	0.00	0
D3	17.00	17.00	0.00	0.00	0
E1	65.00	65.00	0.00	0.00	0
E3	64.75	64.75	0.00	0.00	0
F	59.75	59.75	0.00	0.00	0
G	59.25	59.25	0.00	0.00	0
H	40.75	40.75	0.00	0.00	0
I	41.00	41.00	0.00	0.00	0

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

```
                    XX A B C D E F G H I
Final OCDI:         LF 0 0 0 0 0 0 0 0 0
```

Figure C-3. Occupant Compartment Deformation Index (OCDI), Test No. LSC-1

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APPENDIX D Accelerometer and Rate Gyro Analysis, Test No. LSC-1
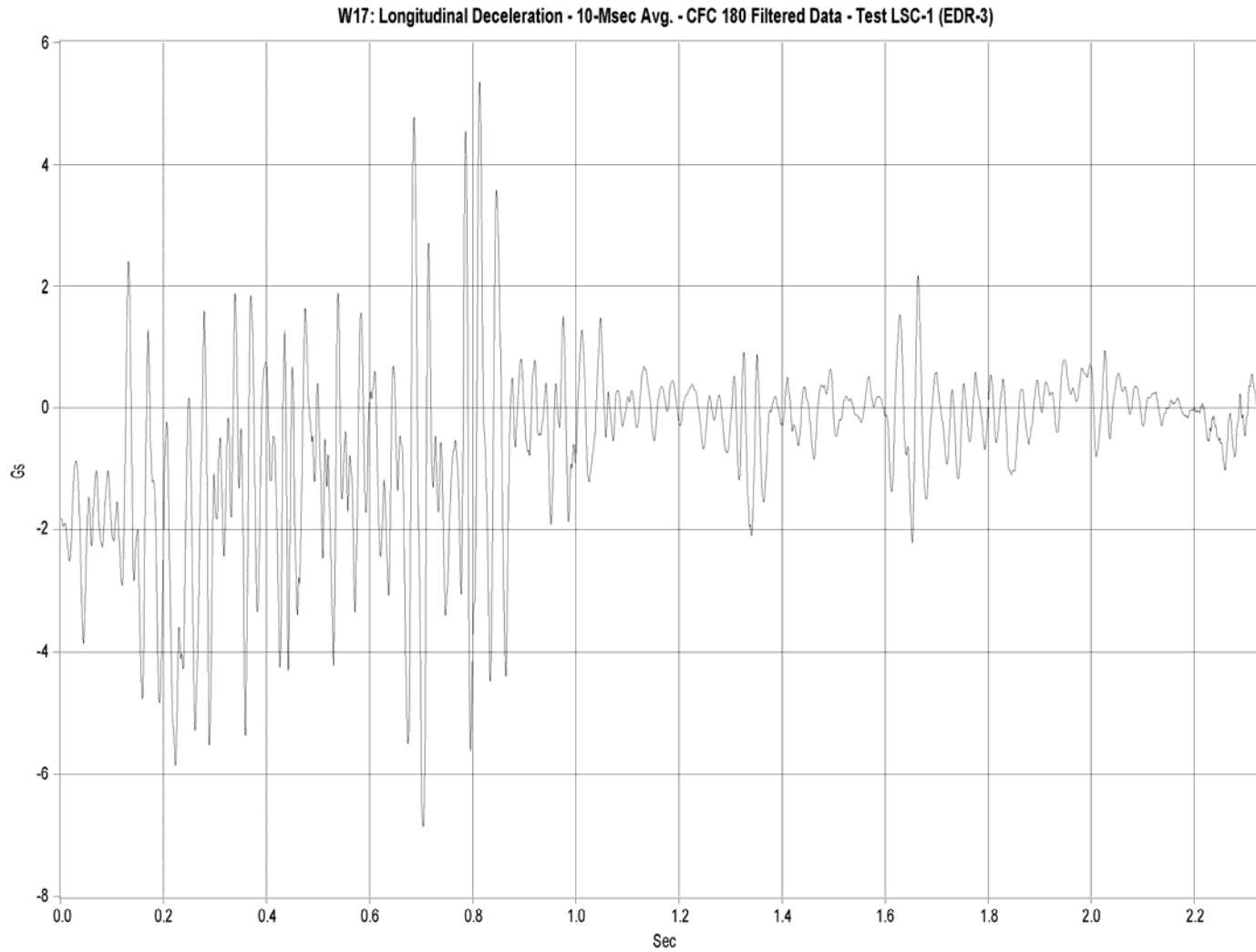
Figure D-1. Graph of Longitudinal Acceleration, Test No. LSC-1
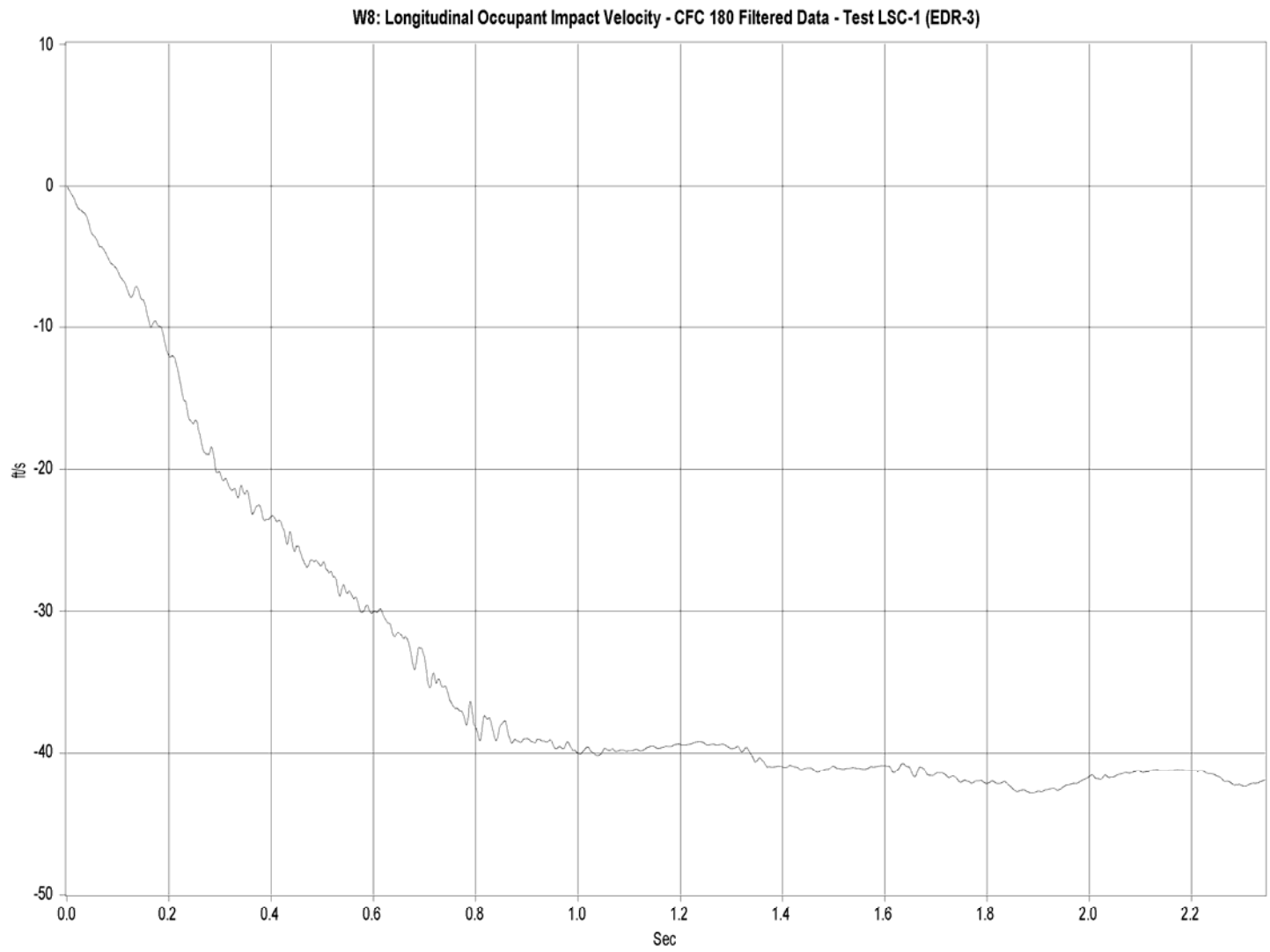
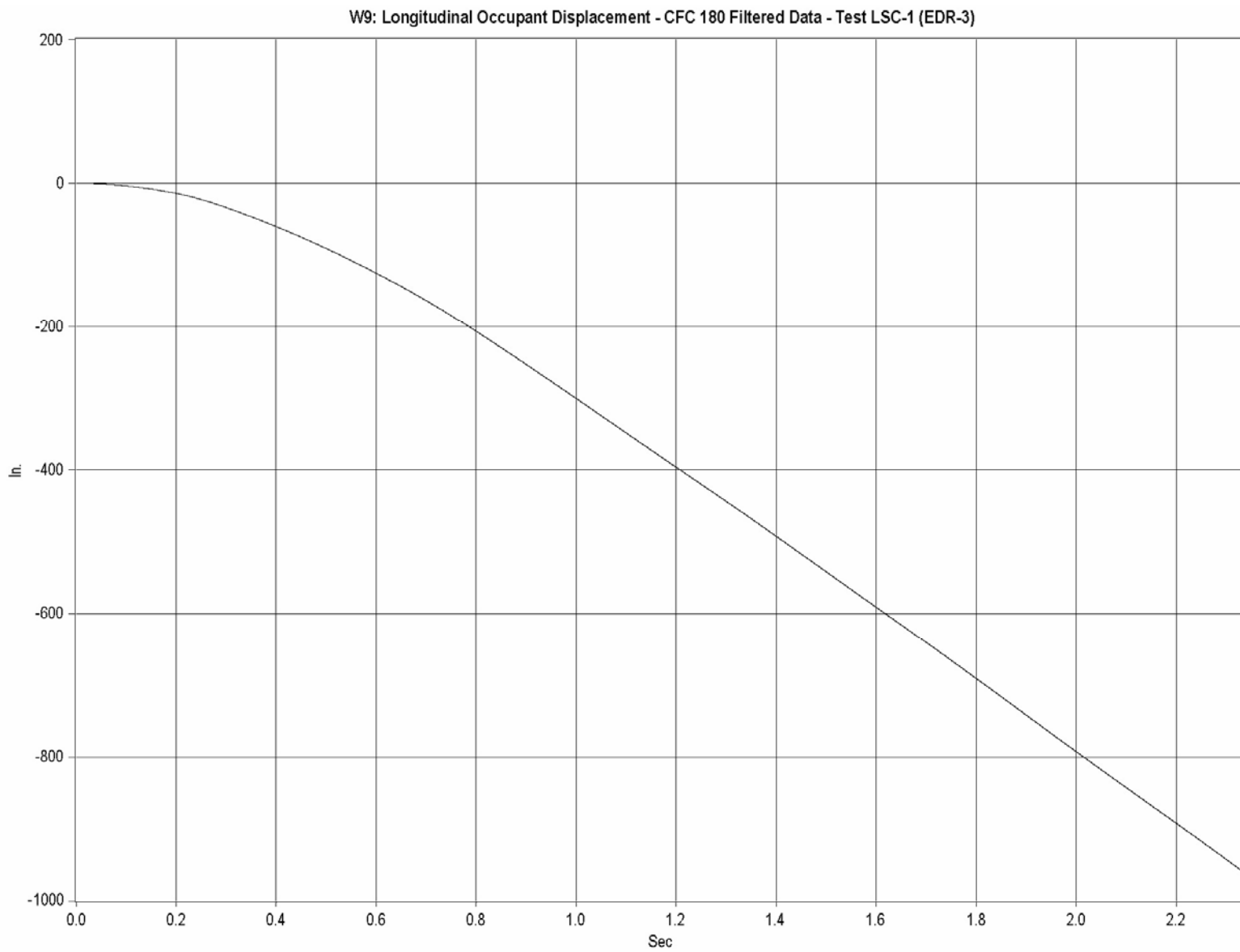**Figure D-2. Graph of Longitudinal Occupant Impact Velocity, Test No. LSC-1**

Figure D-3. Graph of Longitudinal Occupant Displacement, Test No. LSC-1

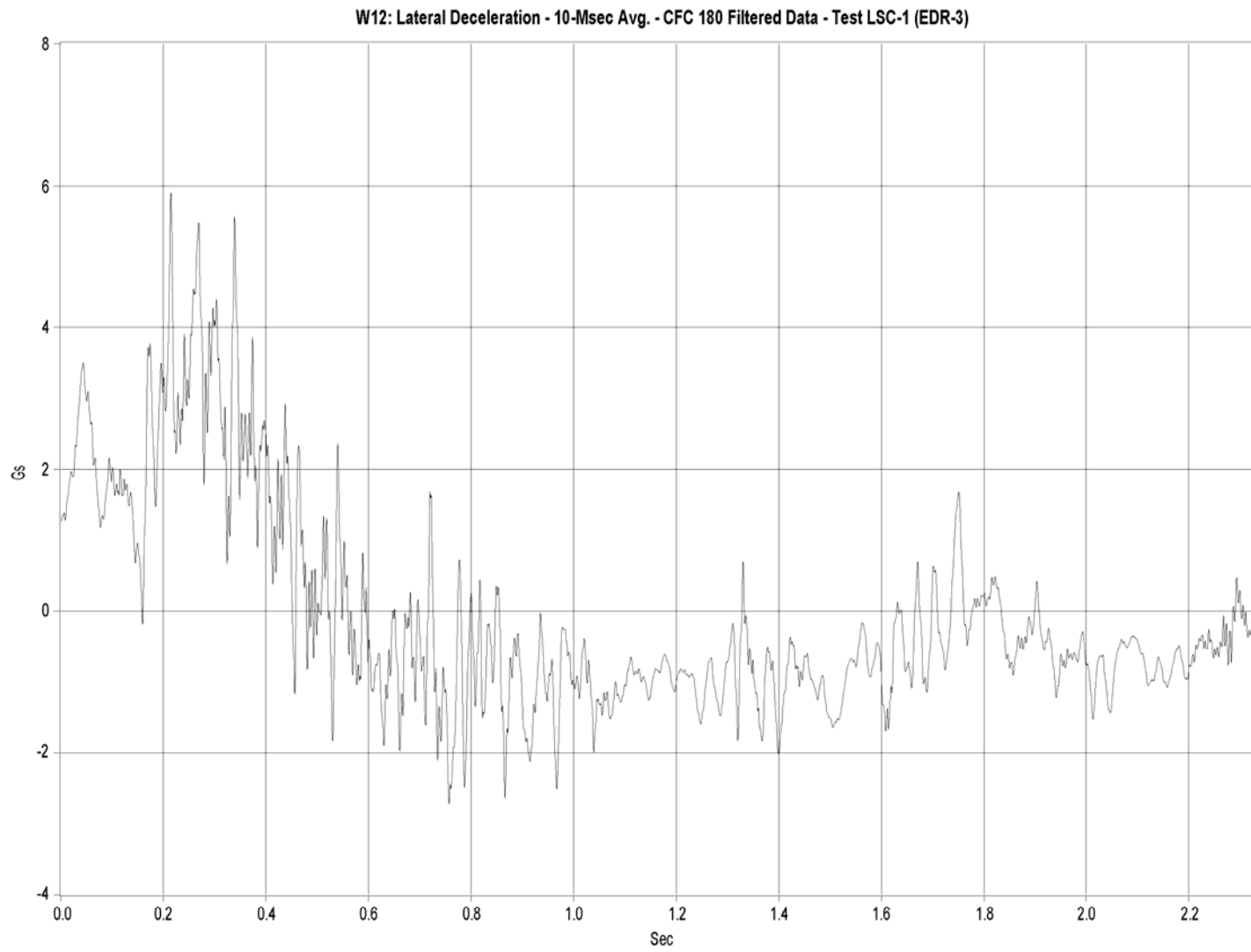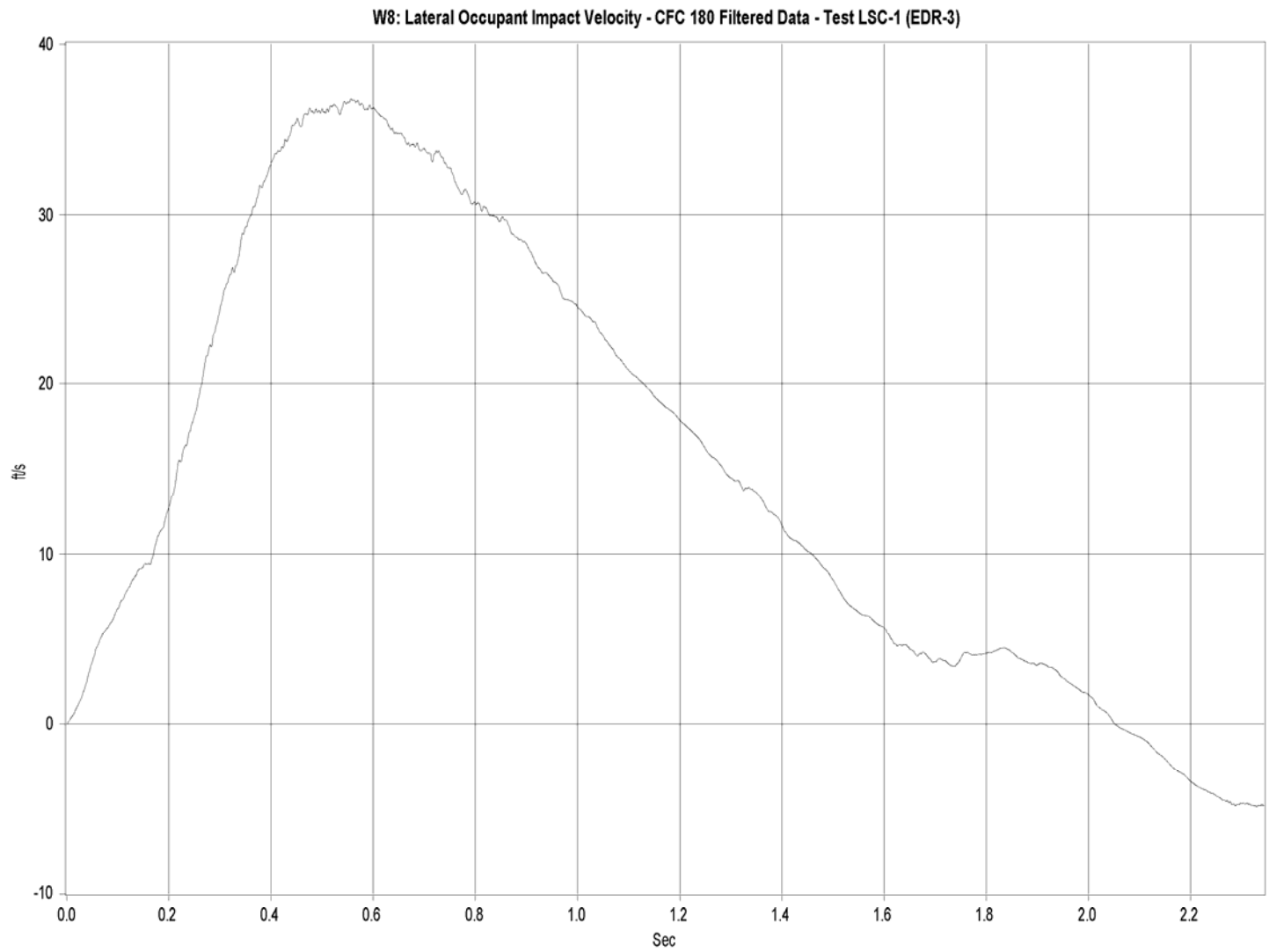**Figure D-4. Graph of Lateral Acceleration, Test No. LSC-1**

Figure D-5. Graph of Lateral Occupant Impact Velocity, Test No. LSC-1

130
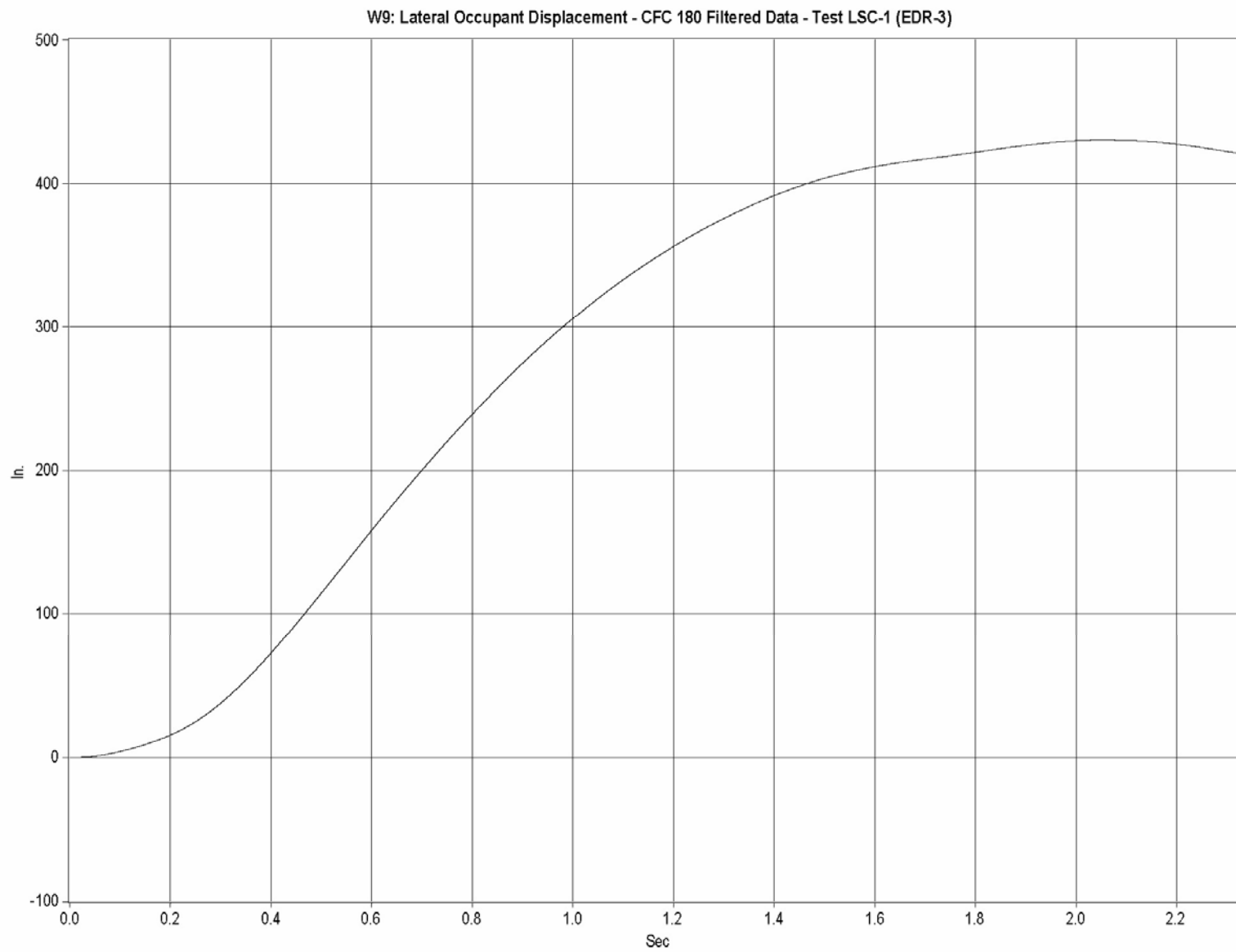
Figure D-6. Graph of Lateral Occupant Displacement, Test No. LSC-1

131
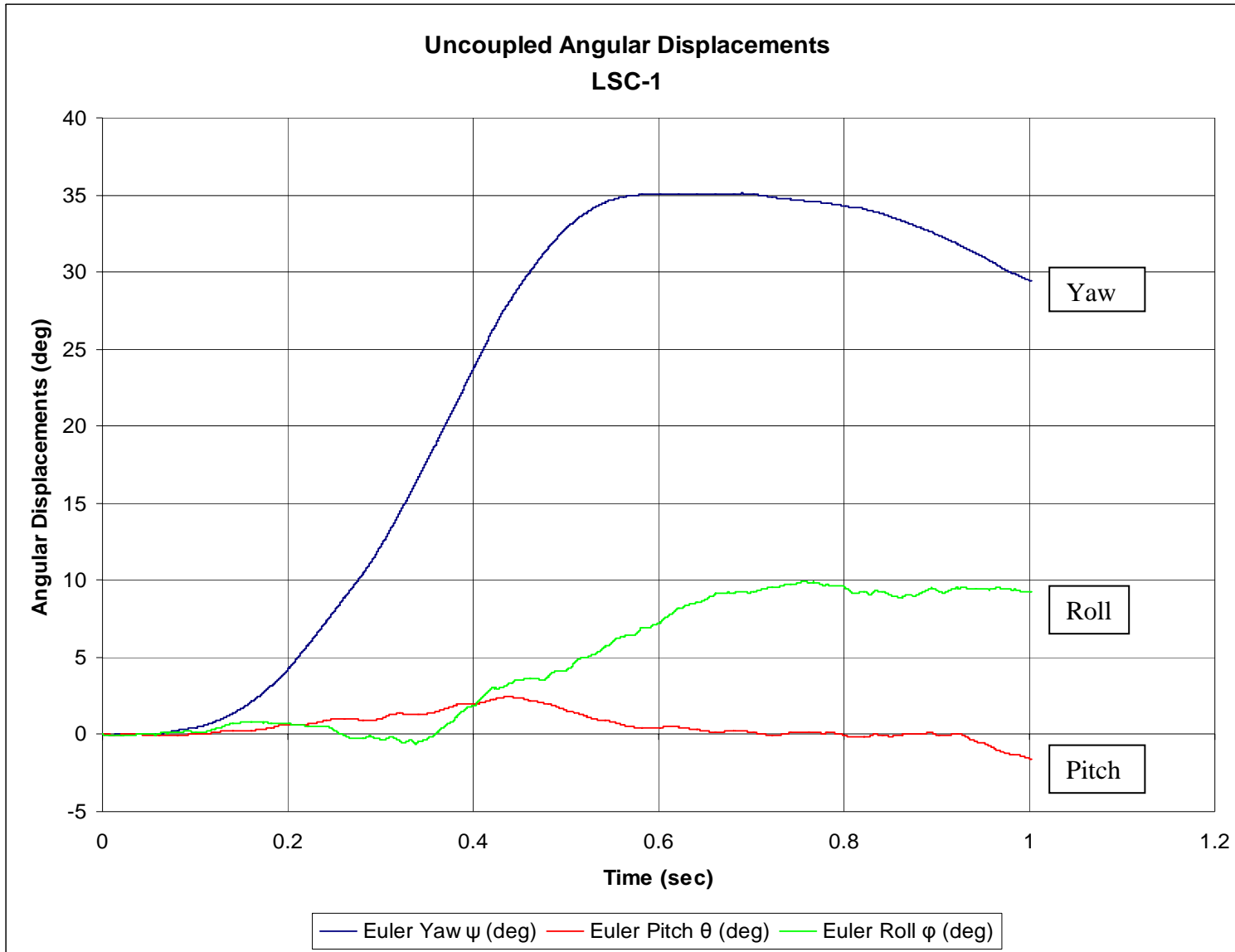
Figure D-7. Angular Displacements, Test No. LSC-1

APPENDIX E MGS Long-Span Design Details, Test No. LSC-2, English Units

Figure E-1. MGS Long-Span Design Details, Test No. LSC-2

PLAN VIEW

50 1/4"   270"   50 1/4"

Excavated Pit

34"

24"

45°   9"

12"   Concrete Header   12"

71 1/8"

12   13   14   15

MGS Long Span LSC-2

Soil Cut Details

SHEET:
2 of 10

DATE:
05/23/2006

DRAWN BY:
GEP

Midwest Roadside
Safety Facility

DWG. NAME:
MGS_Longspan_LSC-2_R2

SCALE: None
UNITS: Inches

REV. BY:
KAP/CME

Figure E-2. MGS Long-Span Design Details, Test No. LSC-2
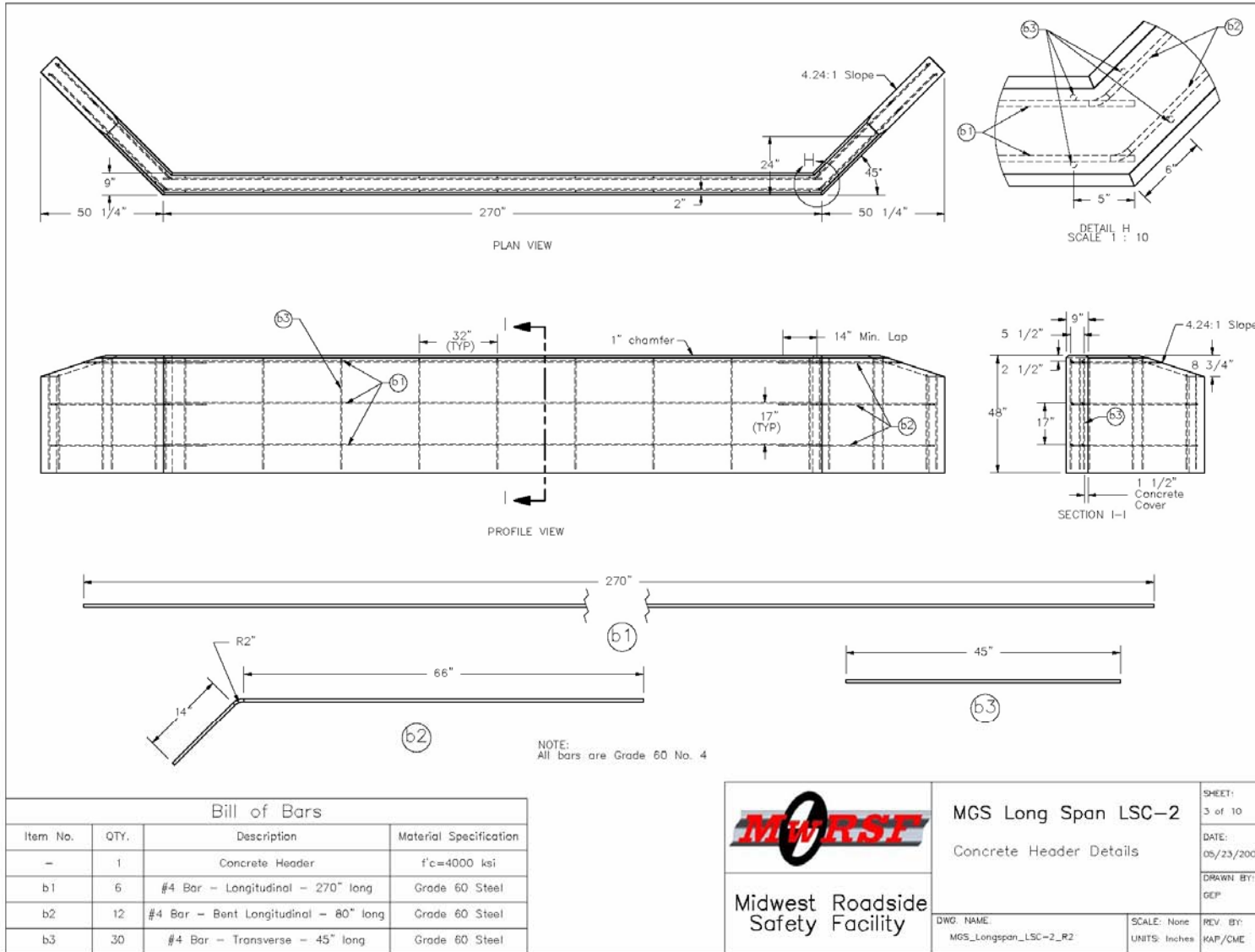
Figure E-3. MGS Long-Span Design Details, Test No. LSC-2
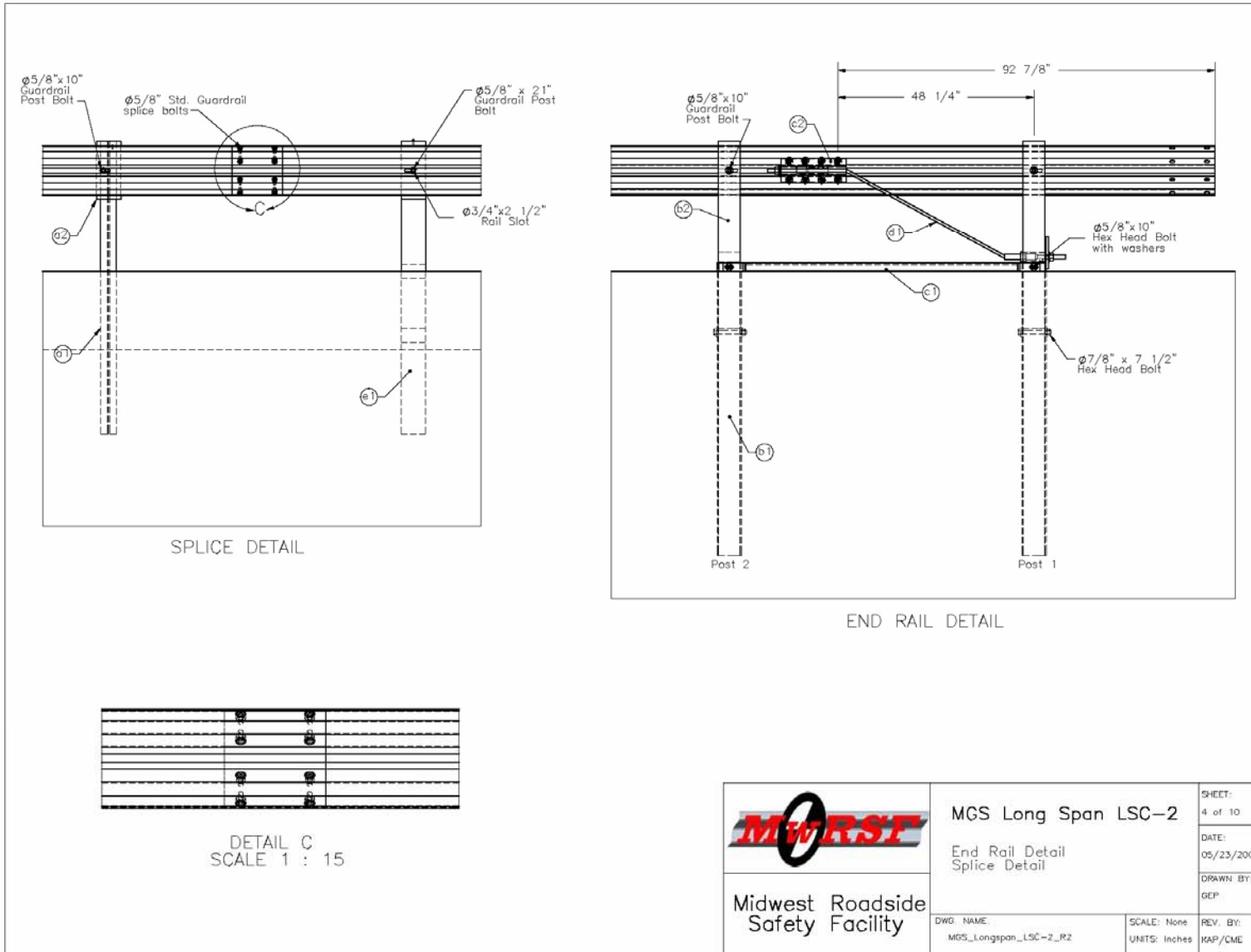
Figure E-4. MGS Long-Span Design Details, Test No. LSC-2

Figure E-5. MGS Long-Span Design Details, Test No. LSC-2

PLAN VIEW

6"

7 1/8"

ø3/4"

32"

72"

ø3 1/2"

15 3/4"

8"

PROFILE VIEW

SIDE VIEW

CRT Wood Post
Part e1

Ø5/8"x22"
long Guardrail
Post Bolt

a2

16D Double
Head Nail

31"

32"

40"

SECTION B-B

MGS Long Span LSC-2

SHEET:
6 of 10

DATE:
05/23/2006

Post 11-16 Detail
CRT Wood Posts

DRAWN BY:
GEP

Midwest Roadside
Safety Facility

DWG. NAME.
MGS_Longspan_LSC-2_R2

SCALE: None

UNITS: Inches

REV. BY:
KAP/CME

Figure E-6. MGS Long-Span Design Details, Test No. LSC-2

TS 8x6x0.1875

PLAN VIEW

PLAN VIEW

5 1/2"

2 3/4"

7 1/2"

3 3/4"

6"

3"

1"

8"

4"

ø3/4"

7 1/8"

ø3/4"

17"

28 1/2"

23 7/8"

46"

72"

ø2 1/2"

ø7/8"

PROFILE VIEW

SIDE VIEW

PROFILE VIEW

SIDE VIEW

BCT (MGS) Timber Post
Part b2
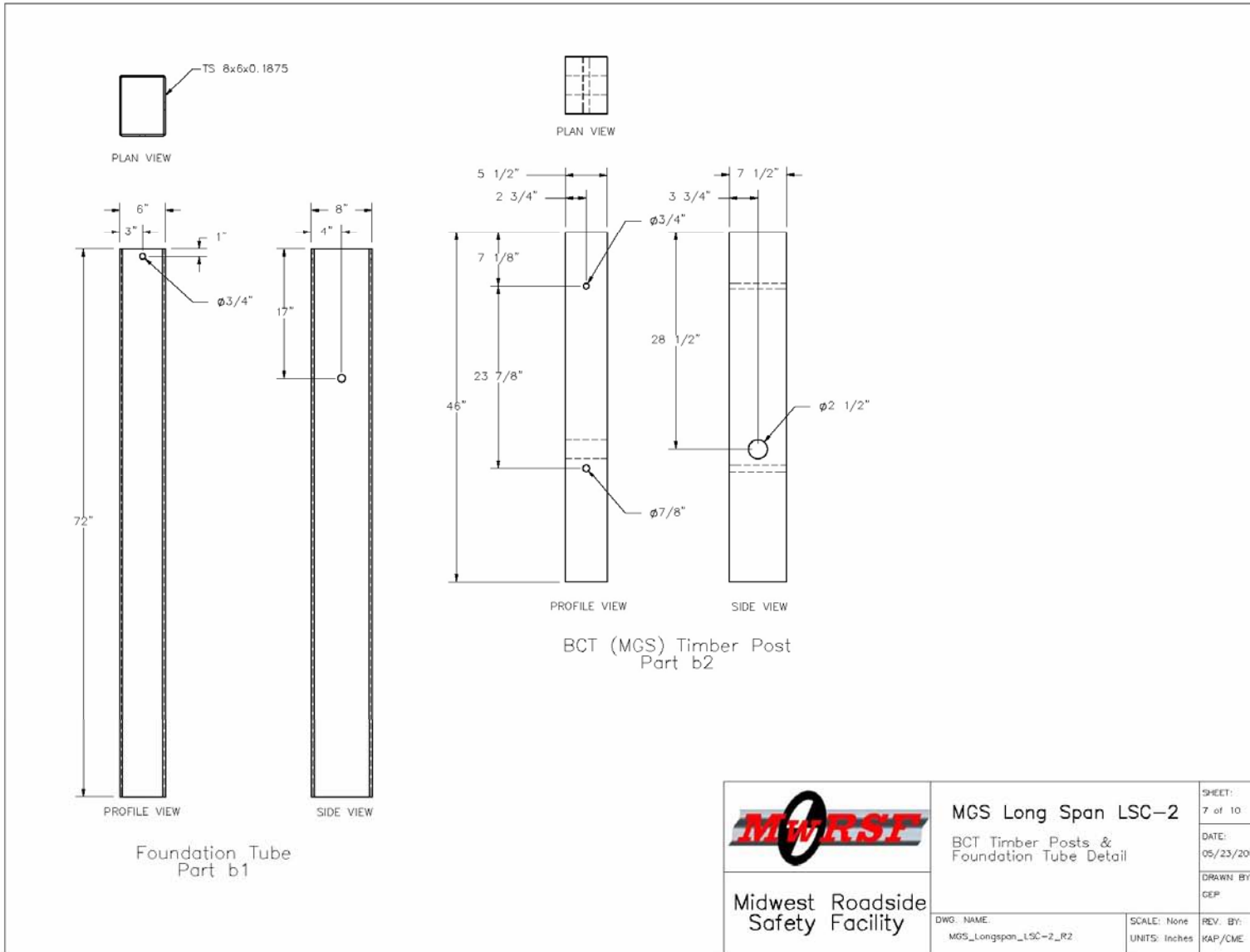
Foundation Tube
Part b1

MGS Long Span LSC-2

BCT Timber Posts &
Foundation Tube Detail

SHEET:
7 of 10

DATE:
05/23/2006

DRAWN BY:
GEP

Midwest Roadside
Safety Facility

DWG. NAME.
MGS_Longspan_LSC-2_R2

SCALE: None

UNITS: Inches

REV. BY:
KAP/CME

Figure E-7. MGS Long-Span Design Details, Test No. LSC-2

80"

50"

Cable End

Ø1" Washer A325

Ø1" Heavy Hex
Nut A325

BCT Anchor Cable
Part d1

D

15"

7"

5"

1"–8UNC Threaded
Entire Length

1 1/2"

Ø1 1/4"

DETAIL D
SCALE 1 : 5

8"

4"

5"

8"

Ø1 1/8"

SIDE VIEW

5/8"

PROFILE VIEW

Anchor Cable
Bearing Plate
Part d2

SHEET:
8 of 10

MGS Long Span LSC-2

DATE:
05/23/2006

BCT Anchor Cable Detail

DRAWN BY:
GEP

MwRSF

Midwest Roadside
Safety Facility

DWG NAME
MGS_Longspan_LSC-2_R2

SCALE: None
UNITS: Inches

REV. BY:
KAP/CME

Figure E-8. MGS Long-Span Design Details, Test No. LSC-2

Figure E-9. MGS Long-Span Design Details, Test No. LSC-2

Figure E-10. MGS Long-Span Design Details, Test No. LSC-2

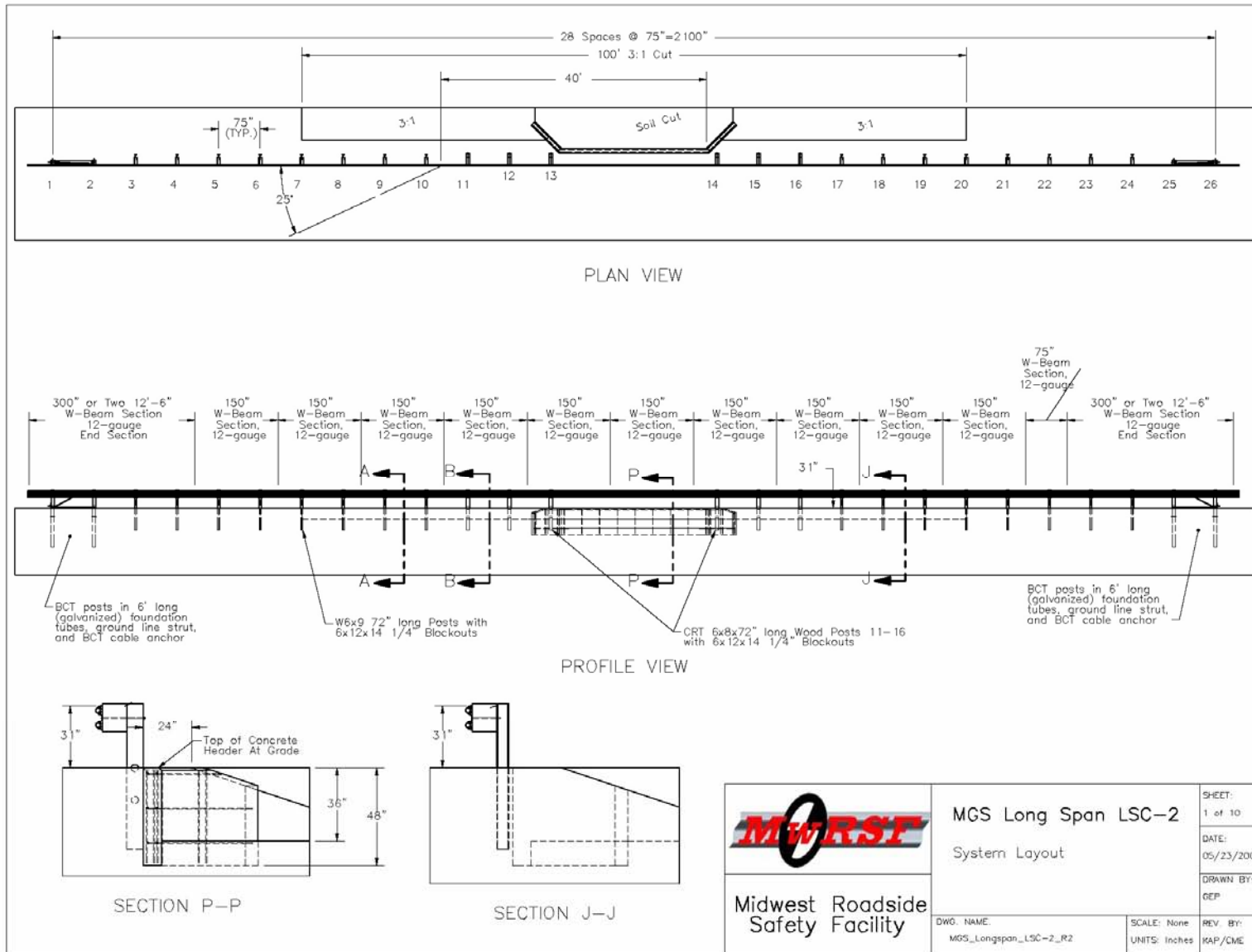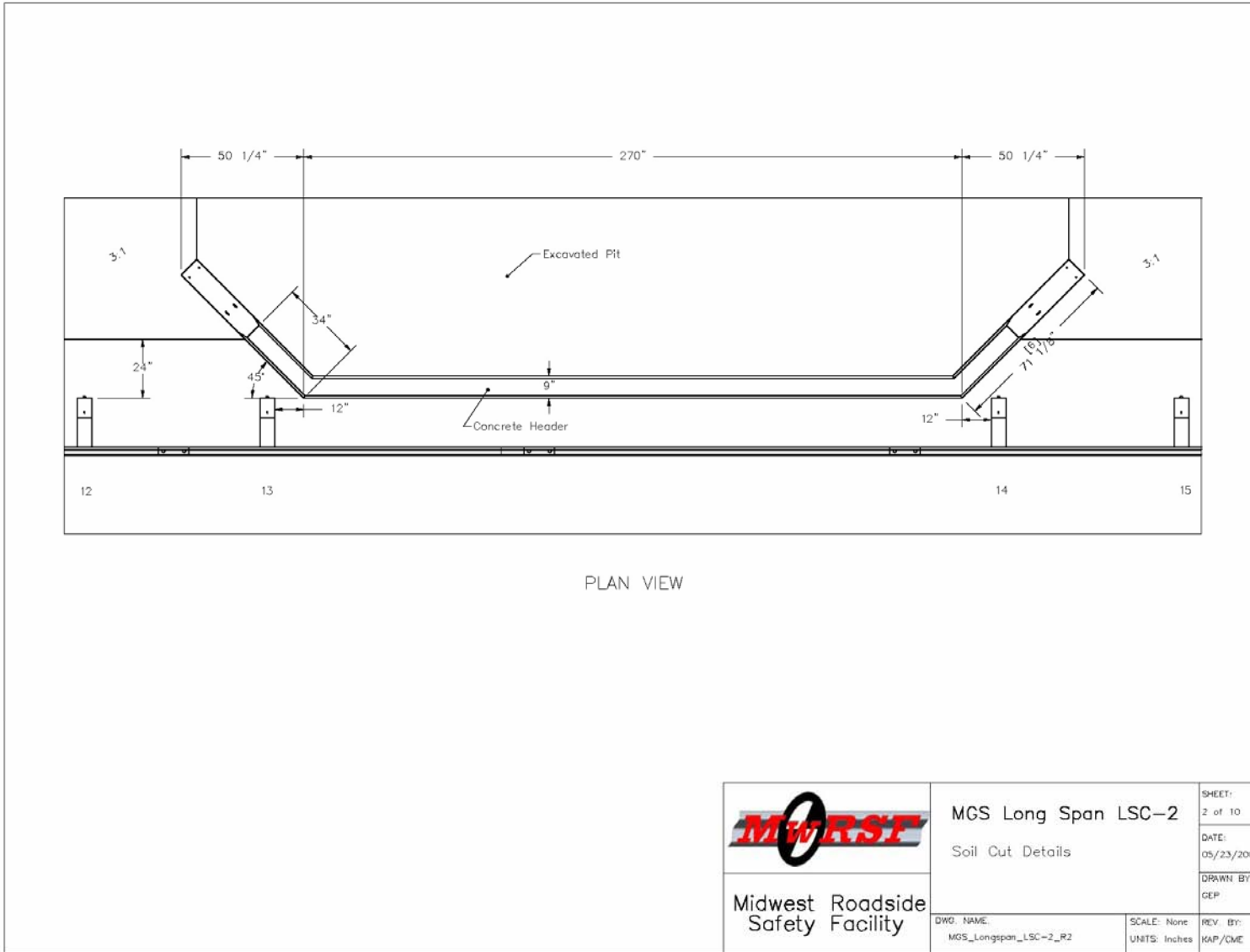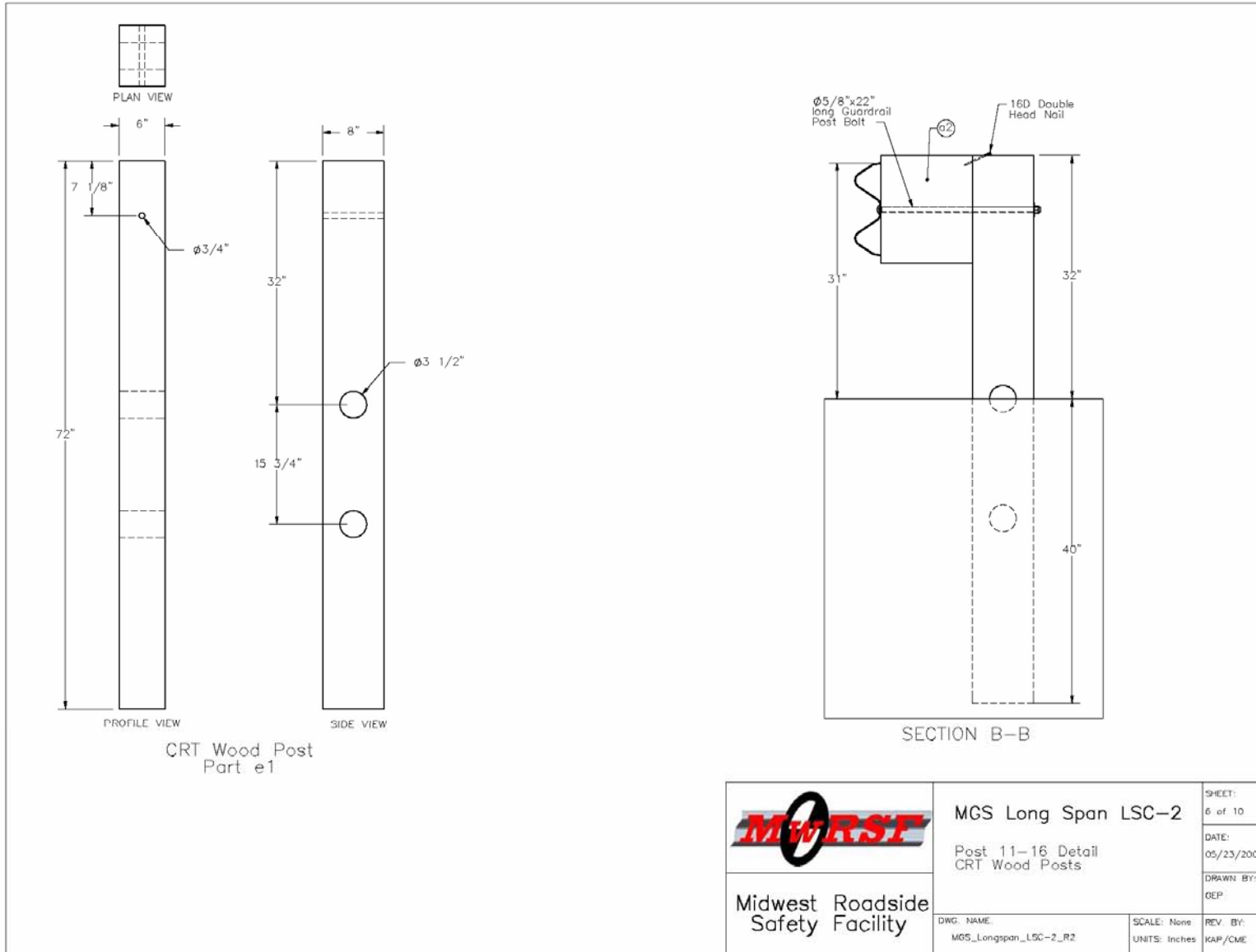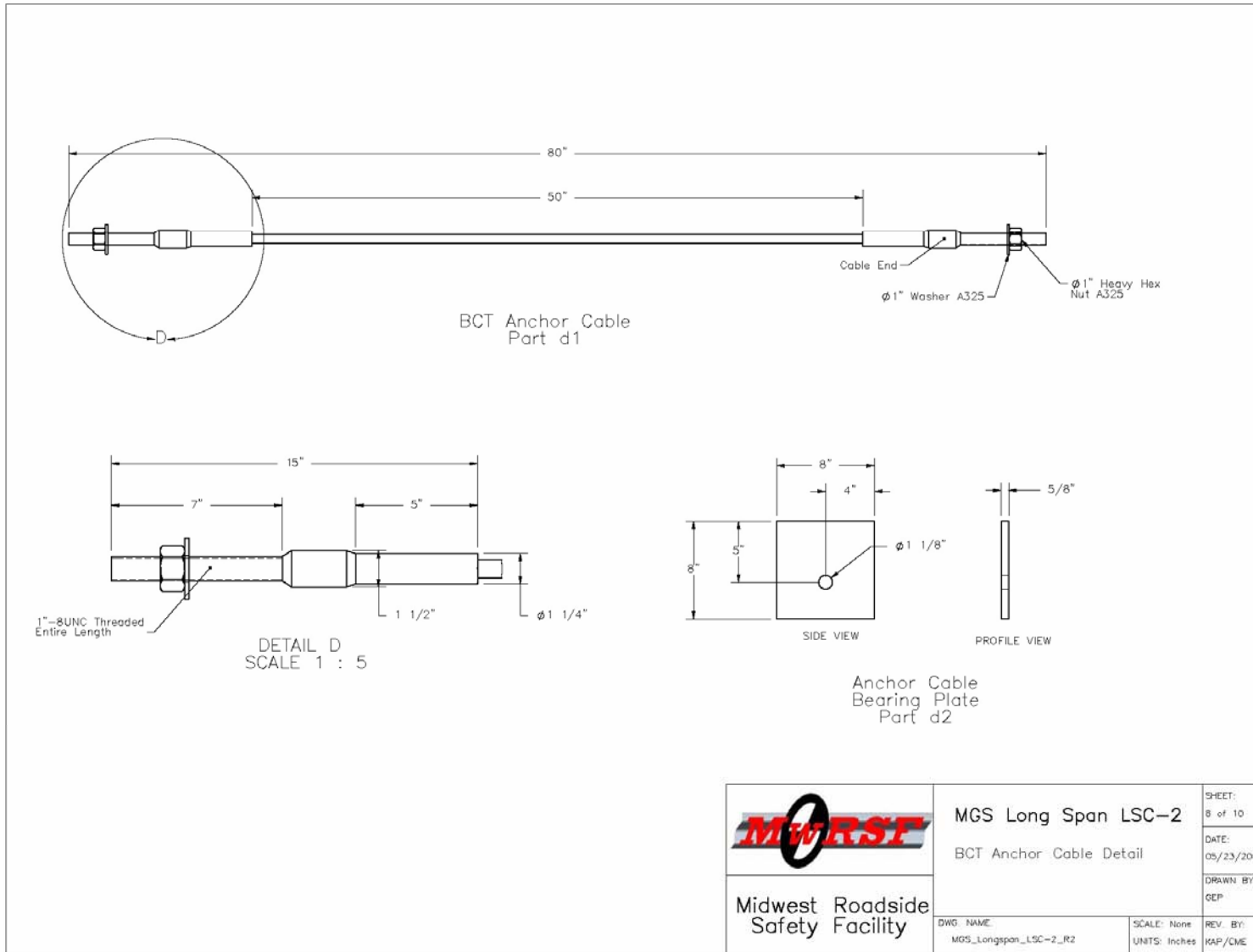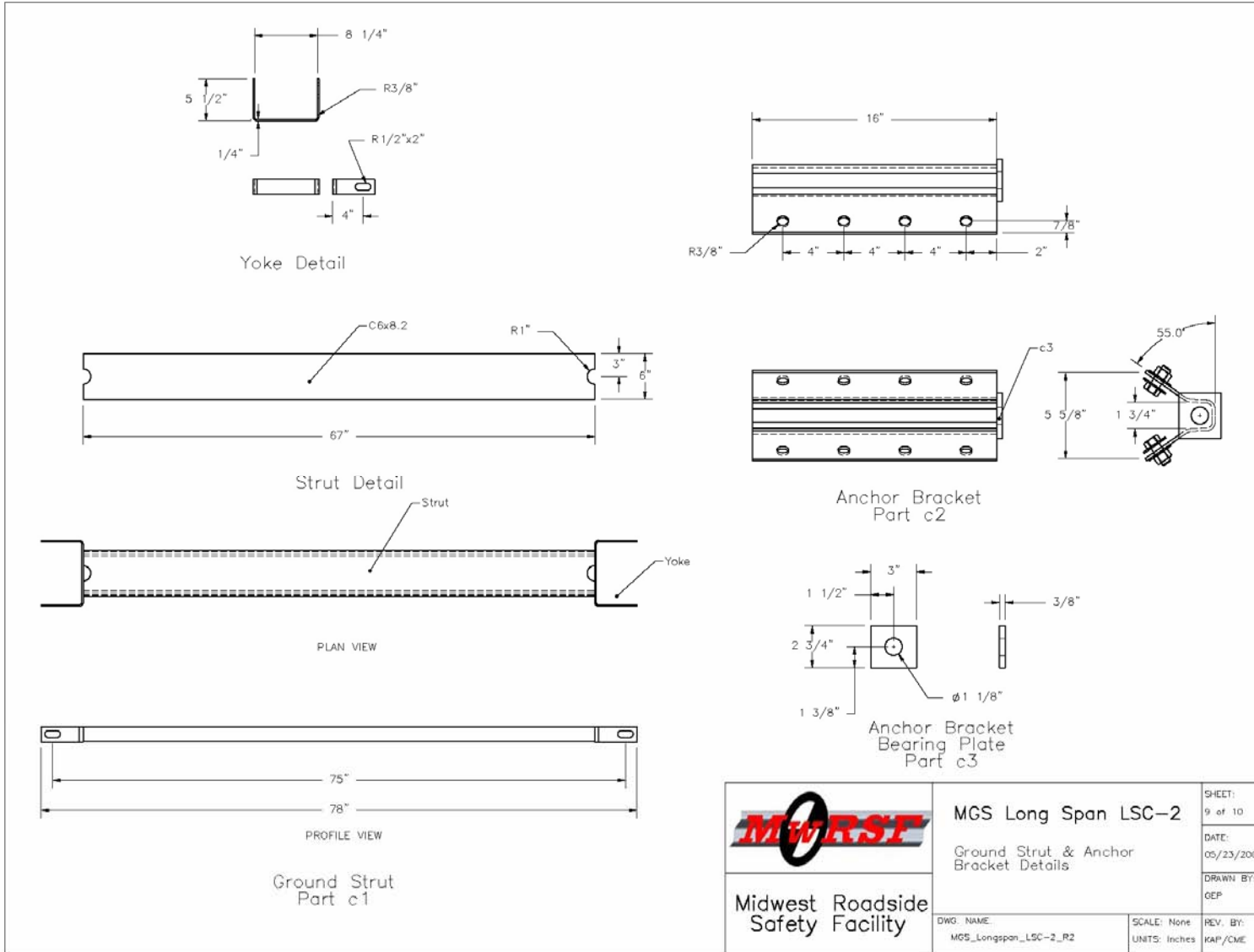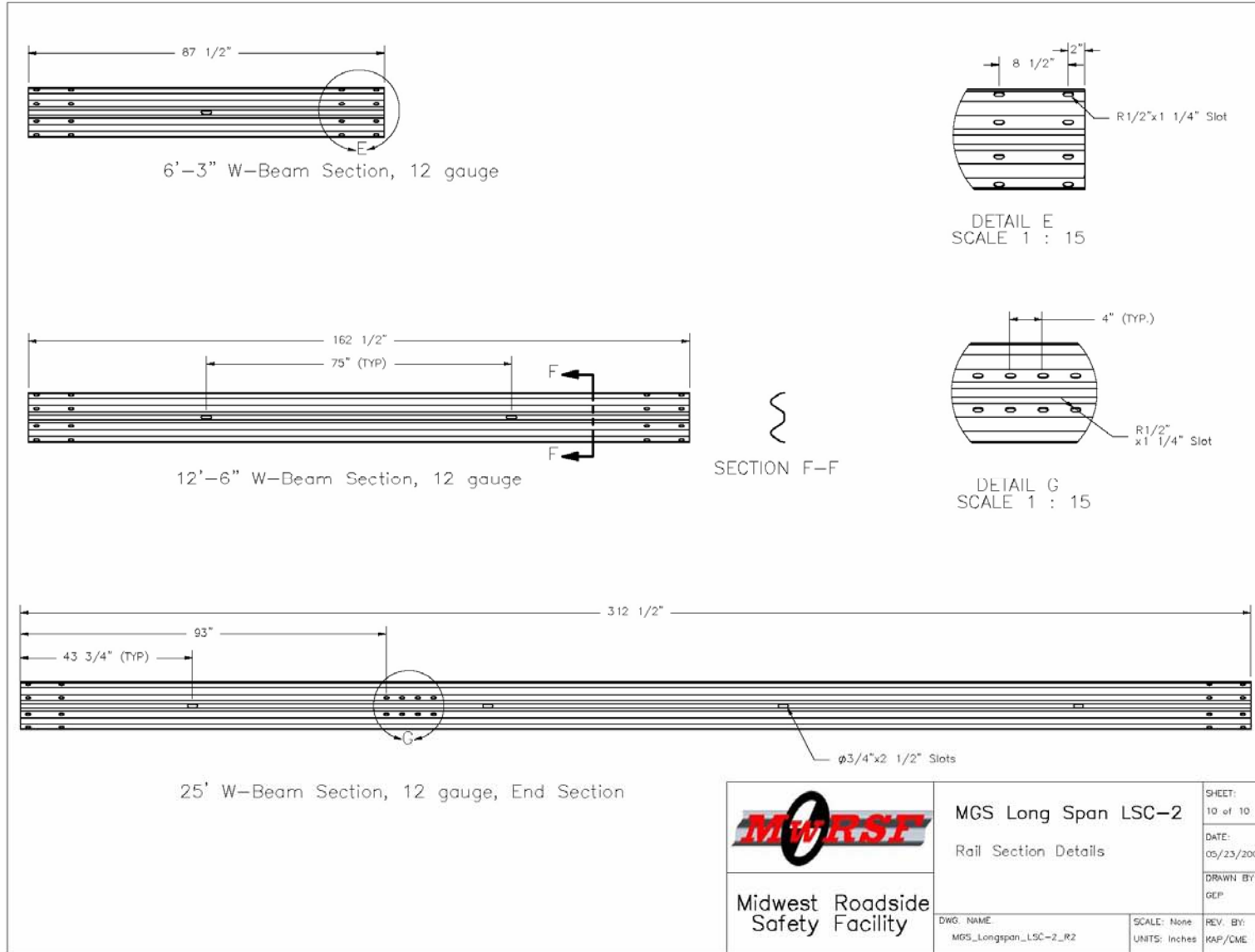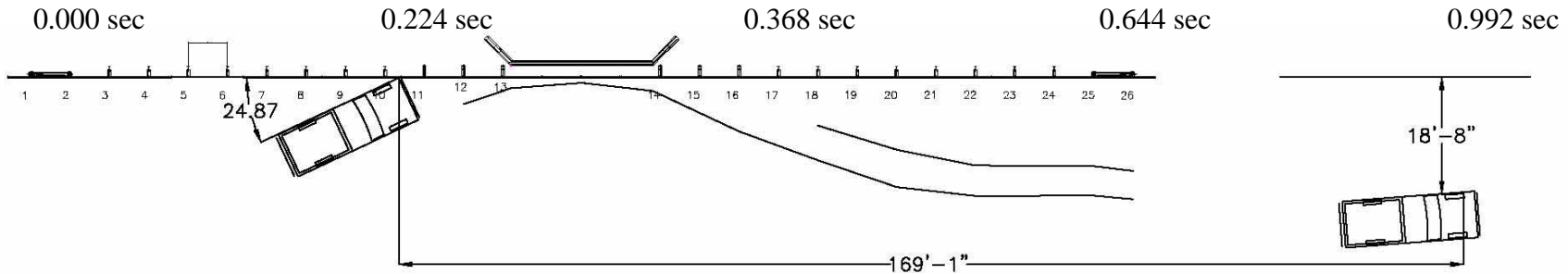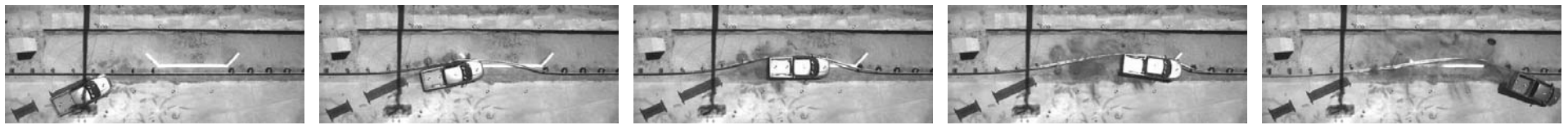**APPENDIX F Test Summary Sheet in English Units, Test No. LSC-2**

| 0.000 sec | 0.224 sec | 0.368 sec | 0.644 sec | 0.992 sec |

- Test Agency...MwRSF
- Test Number...LSC-2
- Date 6/07/06
- NCHRP 350 Update Test Designation 3-11
- Appurtenance ....MGS Longspan with Culvert
- Total Length ....181.25 ft
- Long Span Length ....25 ft
- Distance Headwall to Back of Post..................0 in.
- Key Elements - Steel Thrie-Beam
        Thickness...12-gauge
        Top Mounting Height..........................31 in.
- Key Elements-Steel Posts
        Post Nos. 3-10, 17-24 ....W6x9 x 72 in long
- Key Elements-Wood Posts
        Post Nos. 11-16 (CRT)........................6 in. x 8 in. x 72 in. long
        Post Nos. 1-2, 25-26 (BCT). . ...5.5 in. x 7.5 in. by 42.5 in. long
- Key Elements-Steel Foundation Tube ....72 in. long
- Key Elements-Wood Spacer Blocks
        Post Nos. 3-24 ....6 in. x 12 in. by 14.25 in. long
- Type of Soil..Grading B - AASHTO M 147-65
- Test Vehicle
        Type/Designation 2270P
        Make and Model................................2002 Dodge 1500 Quad Cab
        Curb ....4,982 lbs
        Test Inertial.......................................4,985 lbs
        Gross Static.......................................4,985 lbs

- Impact Conditions
        Speed... 61.91 mph
        Angle... 24.87 degrees
        Impact Location .... 28 in. downstream of Post 10
- Exit Conditions
        Speed... 33.7 mph
        Angle... 18.8 degrees
        Exit Box Criterion.............................. Fail
- Post-Impact Trajectory
        Vehicle Stability .... Satisfactory
        Stopping Distance.............................. 169 ft 1 in. downstream of impact, 18 ft 8 in. laterally away
- Occupant Impact Velocity (350 Update)
        Longitudinal....................................... -16.08 ft/s < 39.37 ft/s
        Lateral .... 13.42 ft/s < 39.37 ft/s
- Occupant Ridedown Deceleration (350 Update)
        Longitudinal....................................... -7.34 Gs < 20 Gs
        Lateral .... 4.24 Gs<20 Gs
- THIV (not required) .... 19.95 ft/s
- PHD (not required)... 7.56 Gs < 20 Gs
- Test Article Damage...................................... Moderate
- Test Article Deflections
        Permanent Set .... 54.0 in.
        Dynamic.. 77.5 in.
        Working Width .... 84.0 in.
- Vehicle Damage .... Moderate
        VDS[25] 11-LFQ-3
        SAE[26] 11LDES5
        Maximum Deformation........ 0.75 in near the left and right side of the driver floorpan

Figure F-1. Summary of Test Results and Sequential Photographs, Test No. LSC-2

APPENDIX G Occupant Compartment Deformation, Test No. LSC-2

TEST: LSC-2
VEHICLE: 2002 Dodge Ram 1500 QC

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

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	27.75	-30	-2.75	27.75	-29.75	NA	0	0.25	NA
2	31	-24.5	-2.5	31	-23.75	NA	0	0.75	NA
3	32.5	-19.25	-3.5	32.5	-19	NA	0	0.25	NA
4	31	-15	-3.25	31.25	-14.75	NA	0.25	0.25	NA
5	27.5	-9	-1.75	27.5	-8.25	NA	0	0.75	NA
6	24.25	-30.25	-7.25	24.25	-29.75	NA	0	0.5	NA
7	26	-24.75	-6.25	26.25	-24.25	NA	0.25	0.5	NA
8	26.5	-19	-6	26.25	-19	NA	-0.25	0	NA
9	25.75	-14	-6.5	25.75	-13.75	NA	0	0.25	NA
10	22.25	-8.5	-3.5	22.25	-8.25	NA	0	0.25	NA
11	19.5	-29.75	-9.25	19.75	-29	NA	0.25	0.75	NA
12	21	-24.5	-8.75	21	-24.25	NA	0	0.25	NA
13	21.5	-19.25	-8.5	21.5	-19	NA	0	0.25	NA
14	21.25	-12.75	-8.5	21.5	-12.5	NA	0.25	0.25	NA
15	17.5	-8.75	-5	17.5	-9	NA	0	-0.25	NA
16	15	-29.5	-9.25	15	-29.25	NA	0	0.25	NA
17	14.75	-23.75	-9	14.75	-23.25	NA	0	0.5	NA
18	14.75	-17.75	-8.75	14.75	-17.75	NA	0	0	NA
19	14.5	-12.5	-8.75	14.5	-12.25	NA	0	0.25	NA
20	12.25	-8.25	-3.5	12.25	-8.5	NA	0	-0.25	NA
21	10.75	-28.75	-8.5	10.75	-29	NA	0	-0.25	NA
22	9.75	-23	-8.5	9.75	-22.75	NA	0	0.25	NA
23	1.5	-18.25	-8.25	10.5	-18.25	NA	9	0	NA
24	10	-12.25	-8.5	9.25	-12.25	NA	-0.75	0	NA
25	7.25	-8.5	-3.75	7	-8.75	NA	-0.25	-0.25	NA
26	5.25	-27.25	-7.75	5.5	-27.25	NA	0.25	0	NA
27	6	-19.25	-7.75	6	-19.25	NA	0	0	NA
28	5.5	-13	-7.5	5.5	-13.25	NA	0	-0.25	NA
29									
30									

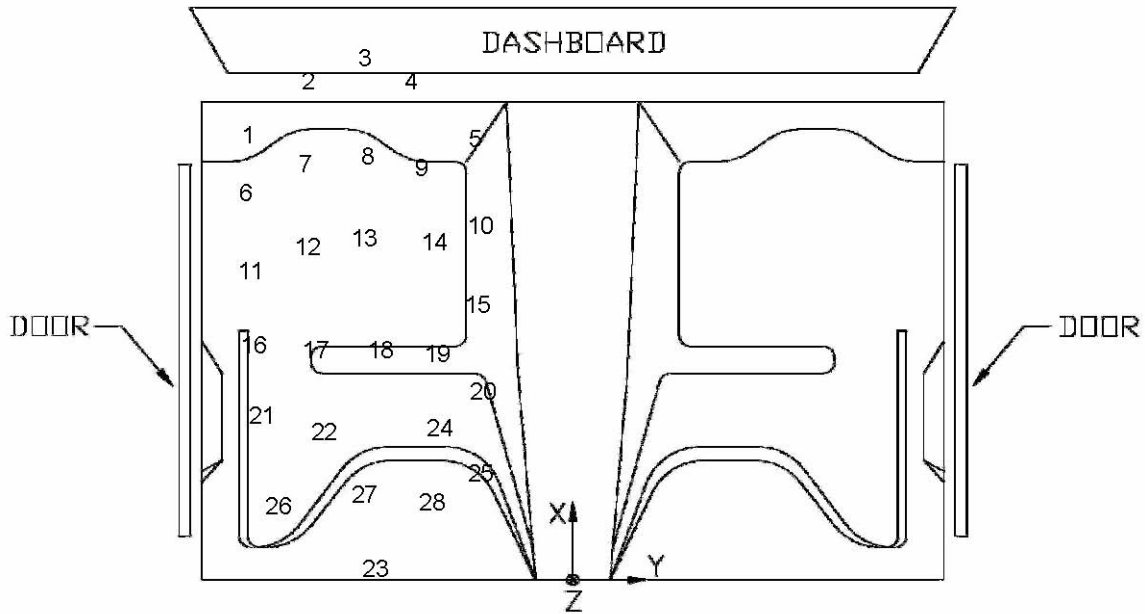**Figure G-1. Occupant Compartment Deformation, Test No. LSC-2**

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TEST: LSC-2
VEHICLE: 2002 Dodge Ram 1500 QC

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

| POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	50	-15.75	-4	50	-15.5	-3.5	0	0.25	0.5
2	53.25	-10.25	-4	53.25	-9.5	-3.5	0	0.75	0.5
3	54.75	-5	-5	54.75	-4.75	-4.75	0	0.25	0.25
4	53.25	-0.75	-5.25	53.5	-0.5	-5	0.25	0.25	0.25
5	49.75	5.25	-4	49.75	6	-3.75	0	0.75	0.25
6	46.5	-16	-8.25	46.5	-15.5	-8	0	0.5	0.25
7	48.25	-10.5	-7.5	48.5	-10	-7.25	0.25	0.5	0.25
8	48.75	-4.75	-7.5	48.5	-4.75	-7.5	-0.25	0	0
9	48	0.25	-8.25	48	0.5	-8.25	0	0.25	0
10	44.5	5.75	-5.25	44.5	6	-5.5	0	0.25	-0.25
11	41.75	-15.5	-10.25	42	-14.75	-10.25	0.25	0.75	0
12	43.25	-10.25	-10	43.25	-10	-10	0	0.25	0
13	43.75	-5	-10	43.75	-4.75	-10	0	0.25	0
14	43.5	1.5	-10.25	43.75	1.75	-10.25	0.25	0.25	0
15	39.75	5.5	-6.75	39.75	5.25	-7	0	-0.25	-0.25
16	37.25	-15.25	-9.75	37.25	-15	-10	0	0.25	-0.25
17	37	-9.5	-9.75	37	-9	-10	0	0.5	-0.25
18	37	-3.5	-10	37	-3.5	-10.25	0	0	-0.25
19	36.75	1.75	-10.25	36.75	2	-10.5	0	0.25	-0.25
20	34.5	6	-4.75	34.5	5.75	-5	0	-0.25	-0.25
21	33	-14.5	-9.25	33	-14.75	-9.5	0	-0.25	-0.25
22	32	-8.75	-9.25	32	-8.5	-9.5	0	0.25	-0.25
23	23.75	-4	-9.5	32.75	-4	-9.75	9	0	-0.25
24	32.25	2	-9.75	31.5	2	-10	-0.75	0	-0.25
25	29.5	5.75	-5	29.25	5.5	-5	-0.25	-0.25	0
26	27.5	-13	-8.25	27.75	-13	-8.25	0.25	0	0
27	28.25	-5	-8.5	28.25	-5	-8.5	0	0	0
28	27.75	1.25	-8.5	27.75	1	-8.5	0	-0.25	0
29									
30									
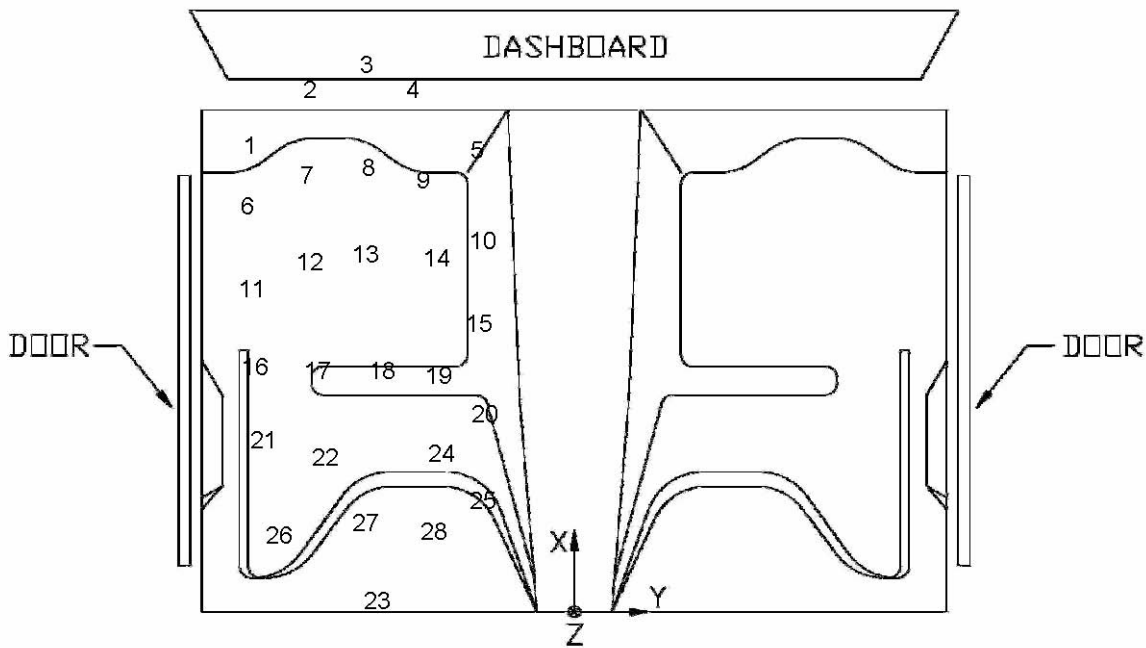
Figure G-2. Occupant Compartment Deformation, Test No. LSC-2

<u>Occupant Compartment Deformation Index (OCDI)</u>

Test No.   LSC-2
Vehicle Type: 2002 Dodge Ram 1500 QC

OCDI = XXABCDEFGHI

XX = location of occupant compartment deformation

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

B = distance between the roof and the floor panel

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

D = distance between the lower dashboard and the floor panel

E = interior width

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

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

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

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

Severity Indices

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

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

Location:

Measurement	Pre-Test (in.)	Post-Test (in.)	Change (in.)	% Difference	Severity Index
A1	69.50	69.25	-0.25	-0.36	0
A2	70.00	70.00	0.00	0.00	0
A3	71.25	71.00	-0.25	-0.35	0
B1	46.50	46.25	-0.25	-0.54	0
B2	42.50	42.50	0.00	0.00	0
B3	47.50	47.50	0.00	0.00	0
C1	65.25	65.00	-0.25	-0.38	0
C2	46.50	46.25	-0.25	-0.54	0
C3	63.50	63.50	0.00	0.00	0
D1	15.25	15.25	0.00	0.00	0
D2	20.25	20.25	0.00	0.00	0
D3	18.00	17.75	-0.25	-1.39	0
E1	65.00	65.50	0.50	0.77	0
E3	67.50	67.50	0.00	0.00	0
F	59.00	59.00	0.00	0.00	0
G	58.25	58.25	0.00	0.00	0
H	40.75	40.75	0.00	0.00	0
I	40.25	40.00	-0.25	-0.62	0

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

```
                              XX A B C D E F G H I
             Final OCDI:      LF 0 0 0 0 0 0 0 0 0
```

Figure G-3. Occupant Compartment Deformation Index (OCDI), Test No. LSC-2

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APPENDIX H Accelerometer and Rate Gyro Analysis, Test No. LSC-2
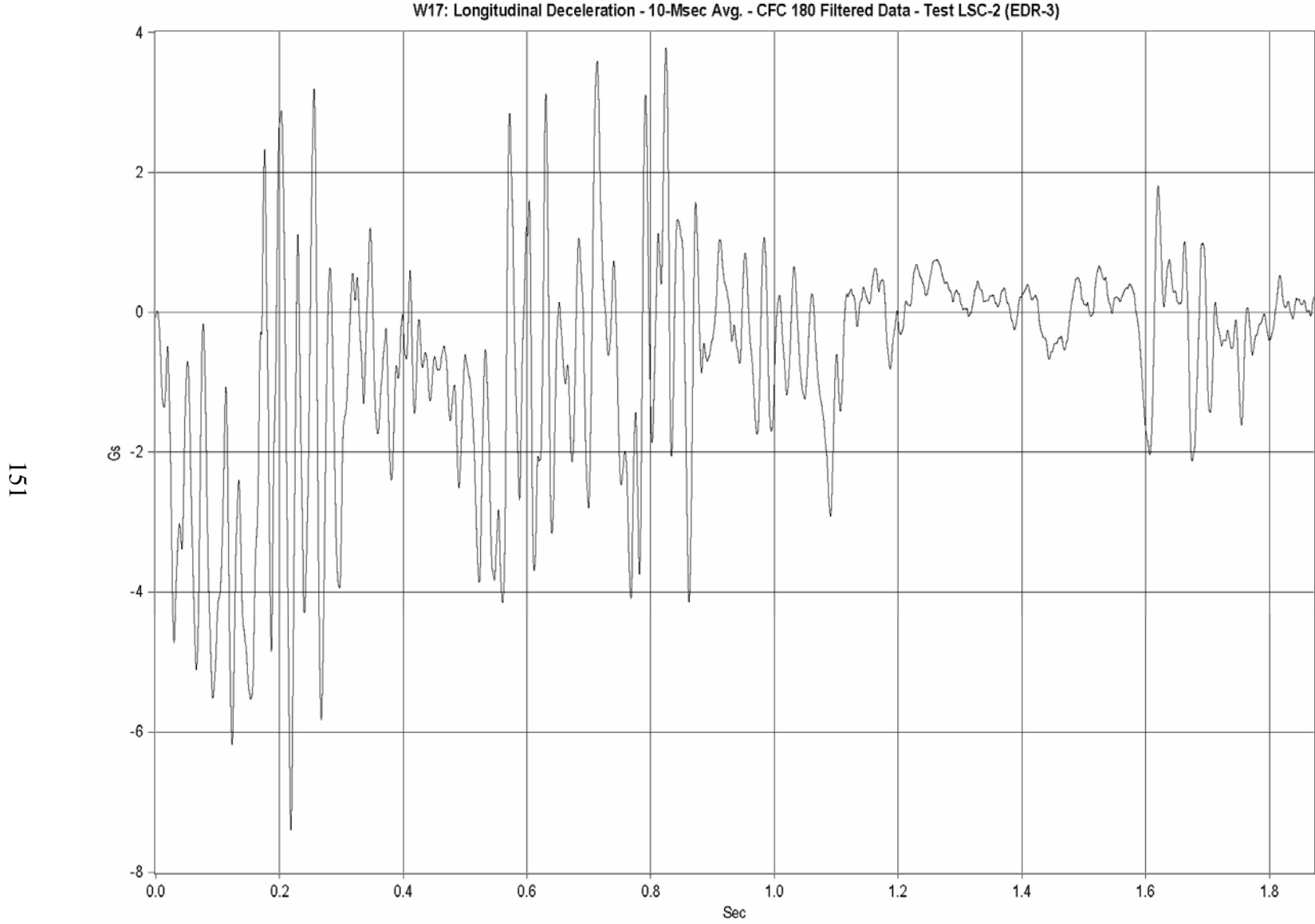
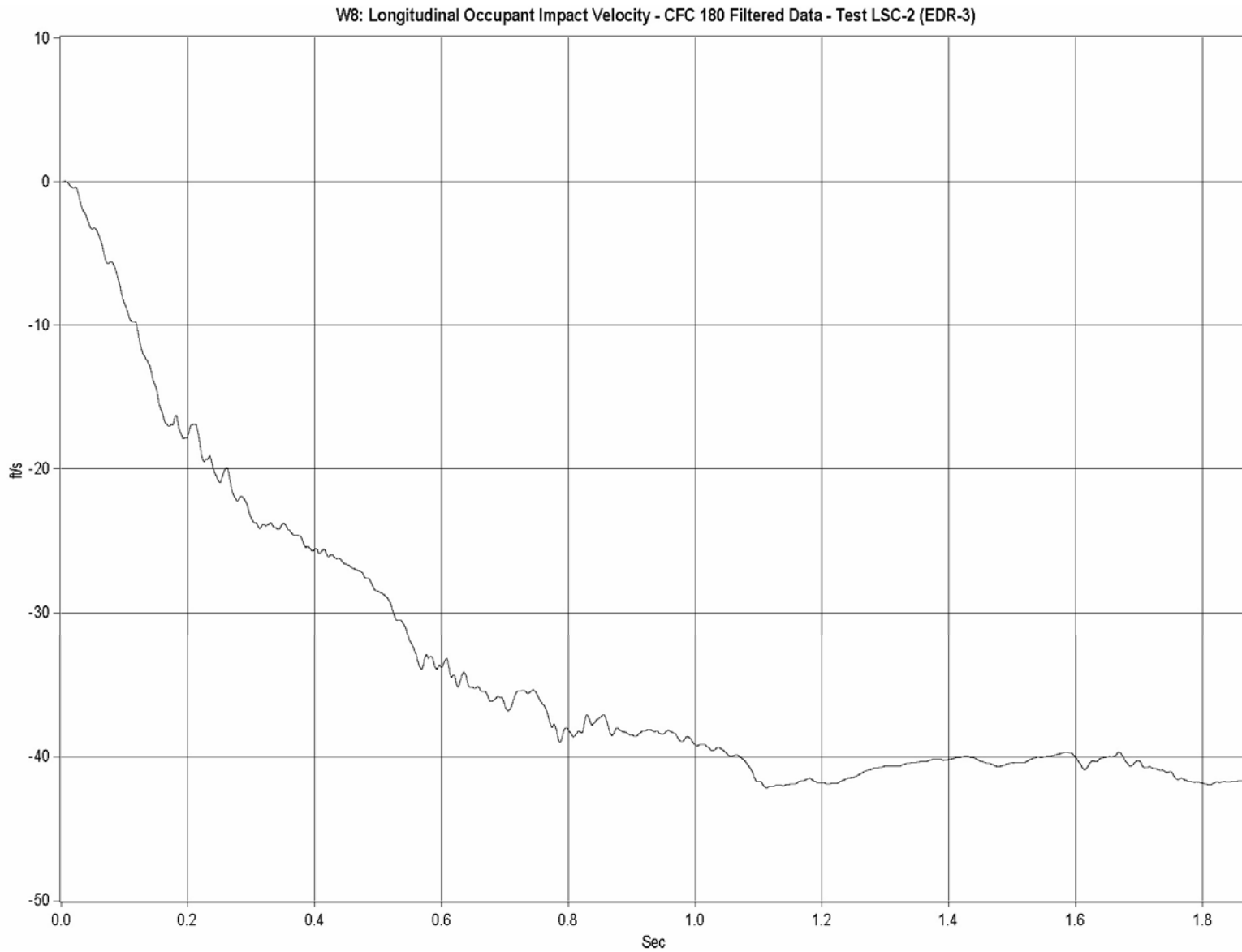**Figure H-1. Graph of Longitudinal Acceleration, Test No. LSC-2**

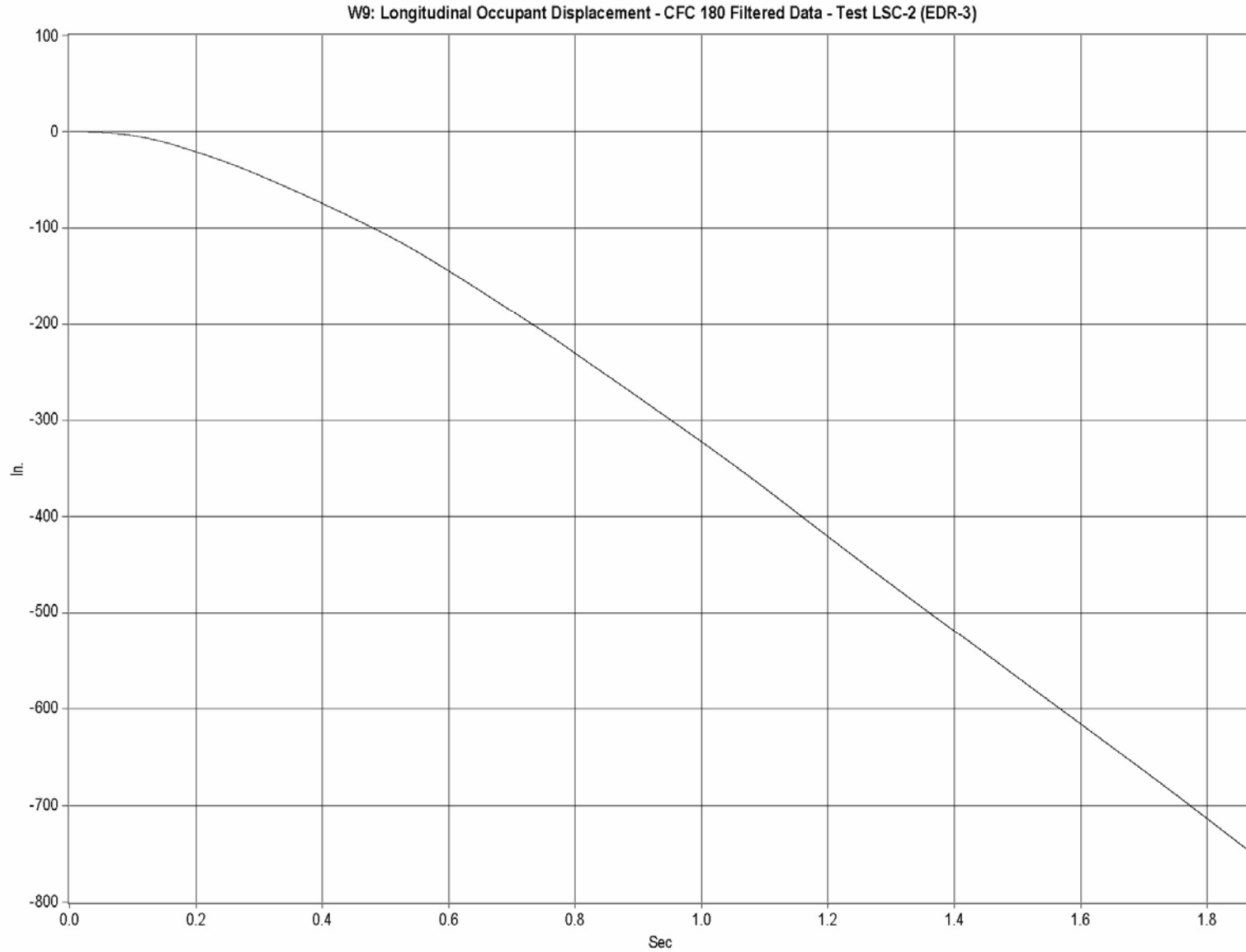**Figure H-2. Graph of Longitudinal Occupant Impact Velocity, Test No. LSC-2**

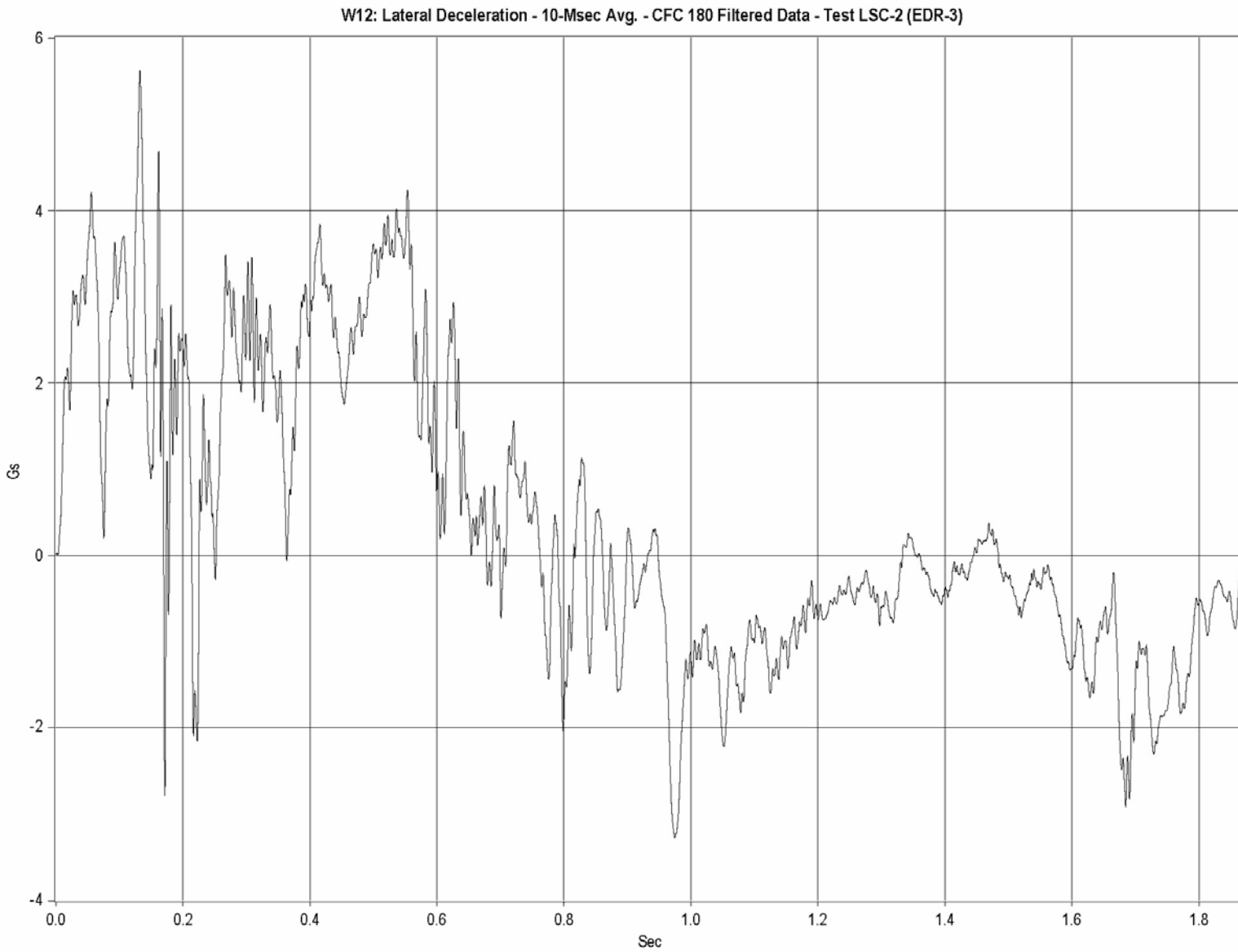**Figure H-3. Graph of Longitudinal Occupant Displacement, Test No. LSC-2**

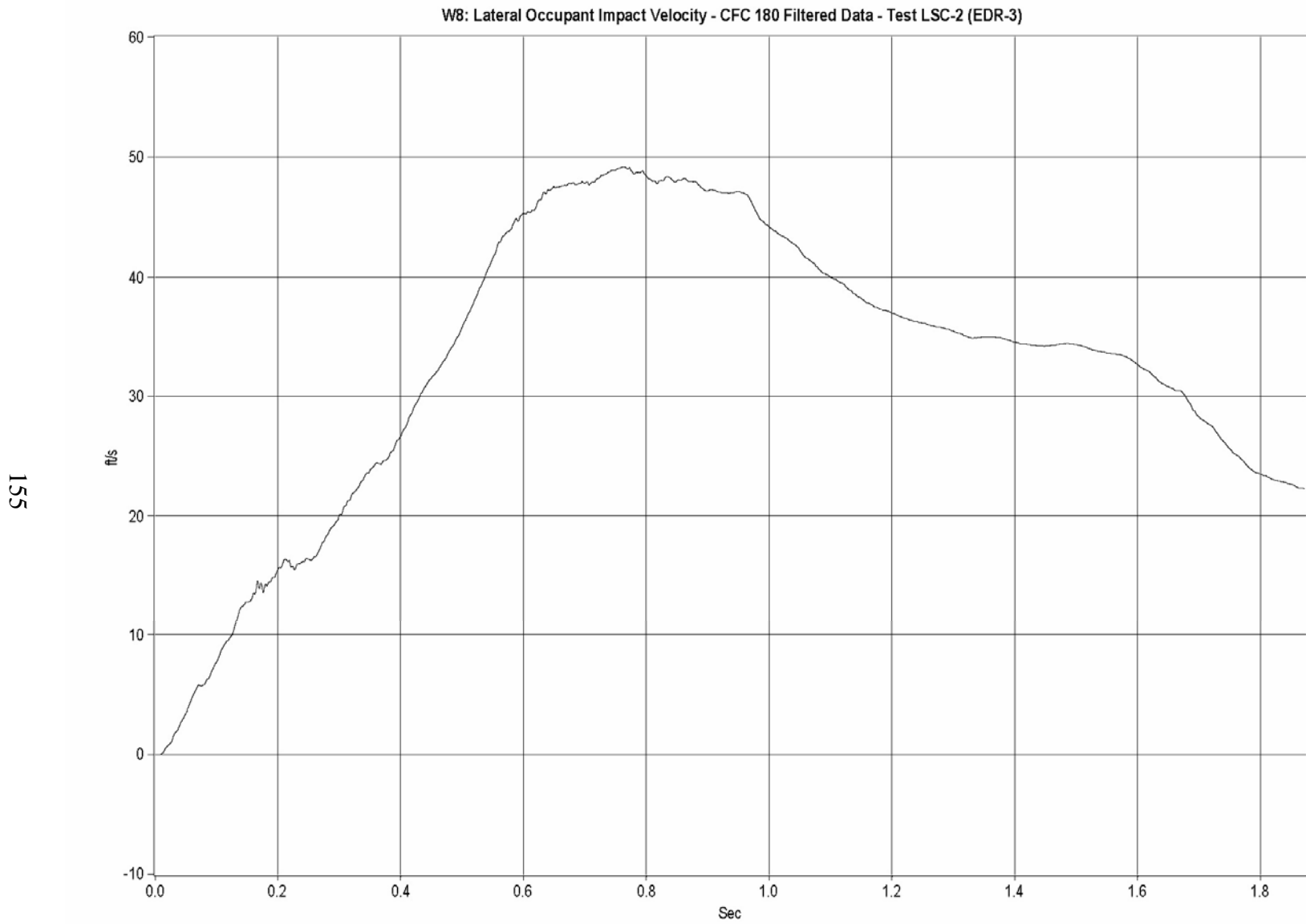**Figure H-4. Graph of Lateral Acceleration, Test No. LSC-2**

W8: Lateral Occupant Impact Velocity - CFC 180 Filtered Data - Test LSC-2 (EDR-3)

Figure H-5. Graph of Lateral Occupant Impact Velocity, Test No. LSC-2
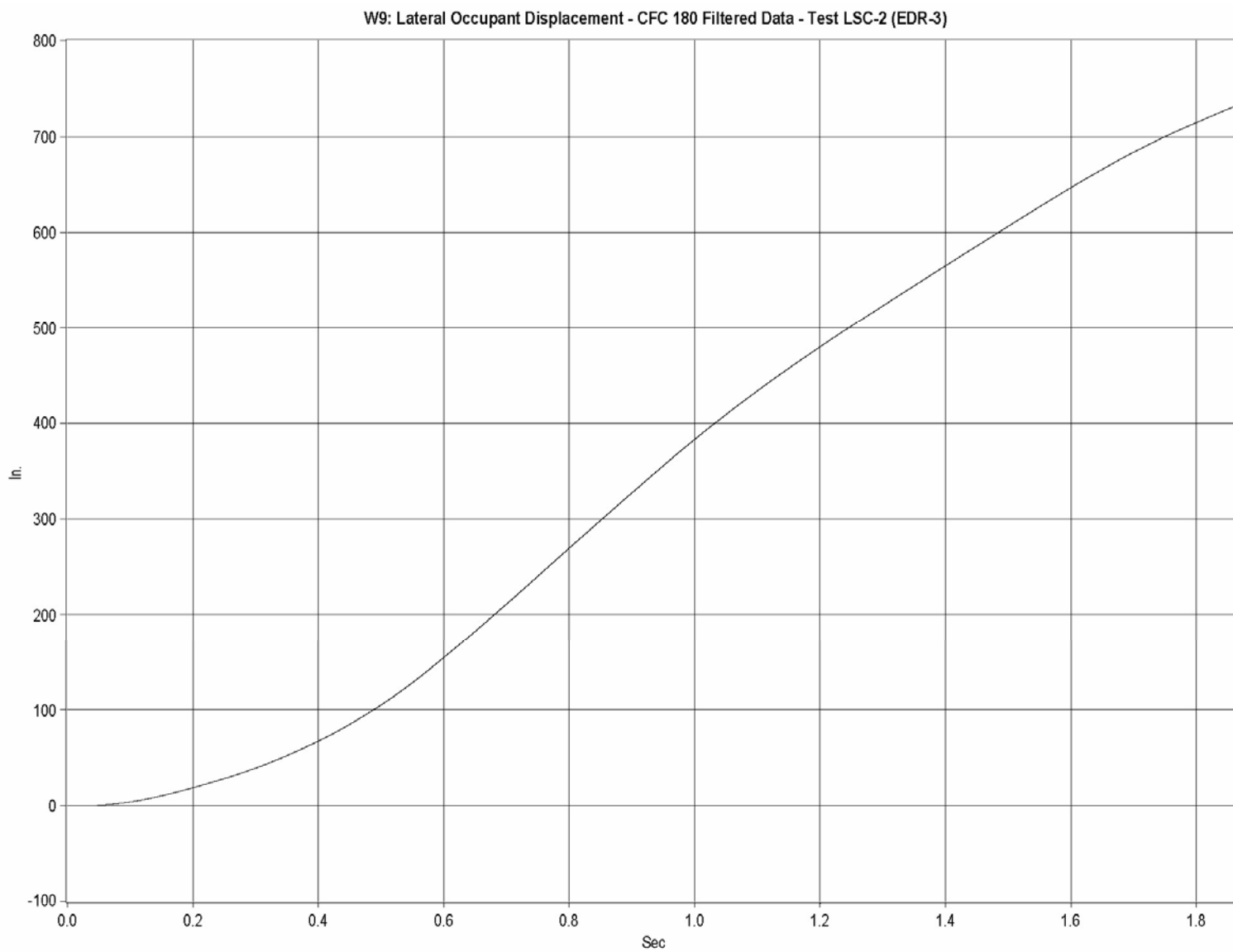
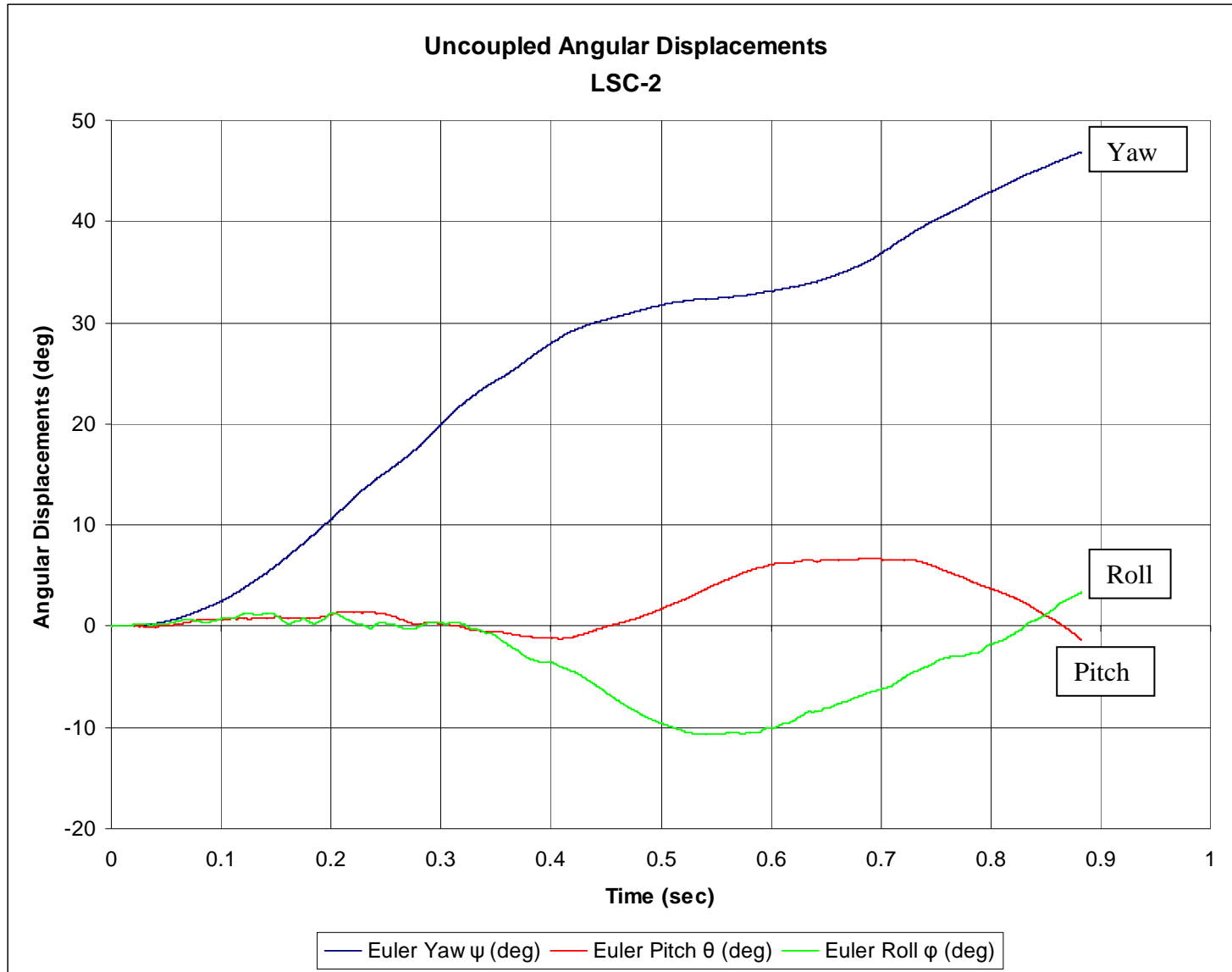**Figure H-6. Graph of Lateral Occupant Displacement, Test No. LSC-2**

Figure H-7. Angular Displacements, Test No. LSC-2