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Phase I Development of a Non-Proprietary, Four-Cable, High Tension Median Barrier

Mitchell J. Wiebelhaus
University of Nebraska-Lincoln, mitchw1@huskers.unl.edu

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

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

Karla A. Lechtenberg
University of Nebraska - Lincoln, kpolivka2@unl.edu

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

See next page for additional authors

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Authors

Mitchell J. Wiebelhaus, Dean L. Sicking, Ronald K. Faller, Karla A. Lechtenberg, John R. Rohde, Robert W. Bielenberg, Scott Rosenbaugh, Erin A. Johnson, and John D. Reid

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PHASE I DEVELOPMENT OF A NON-PROPRIETARY, FOUR-CABLE, HIGH TENSION MEDIAN BARRIER

Submitted by

Mitch J. Wiebelhaus
Graduate Research Assistant

Erin A. Johnson, B.S.M.E., E.I.T.
Former Graduate Research Assistant

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

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

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

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

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

John D. Reid, Ph.D.
Professor

Scott K. Rosenbaugh, M.S.C.E., E.I.T.
Research Associate Engineer

MIDWEST ROADSIDE SAFETY FACILITY
Nebraska Transportation Center
University of Nebraska-Lincoln
130 Whittier Research Center
2200 Vine Street
Lincoln, Nebraska 68583-0853
(402) 472-6864

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Midwest Roadside Safety Facility (MwRSF)
Nebraska Transportation Center
University of Nebraska-Lincoln
130 Whittier Research Center
2200 Vine Street
Lincoln, Nebraska 68583-0853

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16. Abstract (Limit: 200 words)

During the last decade, the use of cable median barriers has risen dramatically. Cable barriers are often utilized in depressed medians with widths ranging from 30 to 50 ft (9.1 to 15.2 m) and with fill slopes as steep as 4H:1V. Although cable barriers have been shown to contain and redirect many heavy trucks, a careful review of accident records has indicated that passenger vehicles do occasionally penetrate through the standard 3-cable median barrier and enter opposing traffic lanes. As a result, the Midwest States Pooled Fund Program sponsored a research and development project to improve the safety performance of existing, non-proprietary, cable median barriers. These safety improvements included increased cable spacing, increased cable height, the use of four cables, increased cable tension, and optimized cable attachment to posts.

Three Test Level 3 crash tests were performed on a four-cable, high-tension median barrier placed in a 46-ft (14.0-m) wide, 4H:1V V-ditch. All tests were conducted according to the safety performance guidelines provided in the Manual for Assessing Safety Hardware (MASH). The first test utilized a 2270P pickup truck impacting the barrier placed on a downslope and 12 ft (3.7 m) laterally away from the front slope break point. The vehicle was contained and redirected by the barrier and deemed acceptable according to the MASH guidelines. The second test utilized a 1100C small car impacting the barrier placed 27 ft (8.2 m) laterally away from the front slope breakpoint or 4 ft (1.2 m) up the back slope of the V-ditch. During the second test, the small car impacted the ditch bottom with a soft-soil condition and began to plow into the soil, thus causing moderate decelerations and velocity change before contacting the barrier and a marginal impact performance. The third test utilized a 1100C small car impacting the barrier in the same position as used in the second test. During the third test, the small car impacted the ditch bottom with a hard-soil condition and was contained by the barrier. However, excessive roof crush resulted when one of the cables slide up the vehicle and later snagged on the cable-to-post attachment hardware, thus resulting in a failed test. Design modifications are anticipated in a Phase II R&D effort.

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UNCERTAINTY OF MEASUREMENT STATEMENT

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

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

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C.L. Meyer, B.S.M.E., E.I.T., Research Associate Engineer
A.T. Russell, B.S.B.A., Shop Manager
K.L. Krenk, B.S.M.A., Maintenance Mechanic
Undergraduate and Graduate Assistants

Illinois Department of Transportation

David Piper, P.E., Safety Implementation Engineer

Iowa Department of Transportation

David Little, P.E., Assistant District Engineer
Deanna Maifield, P.E., Methods Engineer
Chris Poole, P.E., Roadside Safety Engineer

Kansas Department of Transportation

James Brewer, P.E., Engineering Manager - State Road Office
Ron Seitz, P.E., Bureau Chief
Rod Lacy, P.E., Metro Engineer
Scott W. King, P.E., Road Design Leader

Minnesota Department of Transportation

Michael Elle, P.E., Design Standards Engineer

Missouri Department of Transportation

Joseph G. Jones, P.E., Engineering Policy Administrator

Nebraska Department of Roads

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Phil TenHulzen, P.E., Design Standards Engineer
Jodi Gibson, Research Coordinator

Ohio Department of Transportation

Dean Focke, P.E., Road Safety Engineer (Retired)
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Bernie Clocksin, Lead Project Engineer

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John Bridwell, P.E., Standards Development Engineer
Erik Emerson, P.E., Standards Development Engineer
Jerry Zogg, P.E., Chief Roadway Standards Engineer

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Danny Briggs, Nebraska Division Office
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James Dunlap, President and Owner

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1 INTRODUCTION

1.1 Background and Problem Statement

The use of cable median barriers has risen dramatically during the last several years. These barriers are most frequently utilized in the medians of suburban or rural freeways that have experienced large increases in traffic volumes. Cable barriers are often placed in depressed medians with widths ranging from 30 to 50 ft (9.1 to 15.2 m) and with fill slopes as steep as 4H:1V. Although cable barriers have been shown to contain and redirect many heavy trucks, a careful review of accident records has indicated that passenger vehicles do occasionally penetrate through the standard 3-cable median barrier and enter opposing traffic lanes. A detailed evaluation of accidents involving the low-tension, non-proprietary, cable median barrier seems to indicate that the barrier is most vulnerable when struck from the one cable side. Further, crash testing has demonstrated that cables mounted on the back side of the posts are often ineffective for containing and redirecting an impacting vehicle.

Therefore, the Midwest States Pooled Fund Program sponsored a research study at the Midwest Roadside Safety Facility (MwRSF) to improve the safety performance of existing, low-tension, cable median barriers in an effort to reduce cross-over median crashes as well as to reduce dynamic barrier deflections. For this initial effort, MwRSF reviewed existing low-tension, cable median barriers, identified key design features, and developed several prototype four-cable, low-tension median barrier systems [1]. For this study, three full-scale vehicle crash tests were performed using pickup truck and small sedan test vehicles. For the testing program, each cable barrier system was installed on level terrain with the understanding that the final barrier system later would be tested and evaluated in a depressed median. Although the preliminary testing program resulted in both unsuccessful and satisfactory outcomes, members of the Midwest States Pooled Fund Program chose to discontinue the R&D effort to develop an improved low-tension, cable median barrier system. Instead, the Pooled Fund members refocused their resources to develop a new, non-proprietary, high-tension, cable barrier system for use on both generally level terrain and in depressed medians.

During the initial R&D effort, MwRSF completed several tasks contributing to the development of new system components. These tasks included: the design and testing of an improved cable-to-post attachment mechanism to satisfy predetermined loading requirements; the identification, modification, and testing of cable end-fittings and splices for use in the new barrier system; and design and component testing of new barrier post to provide similar energy absorption as previous cable system posts [2-3]. Following the completion of these initial component studies, additional research funding was provided to configure, test, and evaluate the prototype high-tension, cable median barrier system when installed in a depressed median.

1.2 Research Objectives

The primary research objective was to develop an improved, non-proprietary, high-tension, cable median barrier system that would provide acceptable safety performance when installed on generally flat terrain as well as when placed at any location within a depressed median with fill slopes equal to or flatter than 4H:1V. The new barrier system should limit dynamic barrier deflections using cable-to-post attachment hardware that maximized the energy dissipated by the support posts as well as to select the appropriate range for cable tension. In addition, the new barrier system should mitigate vehicle underride and/or override by selecting the appropriate number of cables, the upper and lower cable heights, as well as a reasonable cable spacing. LS-DYNA simulations were to be performed to determine the critical ditch width, cable barrier placement within the depressed median, and the top cable height for use in the full-scale crash testing program. Finally, the cable median barrier system was to be tested and evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth in the *Manual for Assessing Safety Hardware* (MASH) [4].

1.3 Research Scope

The high-tension, cable median barrier system was initially configured using information obtained from MwRSF's prior research studies pertaining to the development of an improved cable median barrier. Next, LS-DYNA simulations were performed to: (1) determine the critical ditch width for use in the crash testing program; (2) determine cable barrier placement that provided the worst-practical condition for the crash testing program using test designation nos. 3-10 and 3-11; and (3) modify the top and bottom cable heights and the resulting cable spacing in order to prevent both vehicle override and underride of the barrier system. Design details were prepared for the prototype, high-tension, four-cable, median barrier system. The cable median barrier was constructed in a 4H:1V V-ditch for use in the testing and evaluation program. Three full-scale vehicle crash tests were conducted. The first test utilized a ½-ton Quad Cab pickup truck, weighing approximately 5,000 lb (2,268 kg), impacting at a speed and angle of 62.1 mph (100.0 km/h) and 25.0 degrees, respectively. The second and third tests utilized a small car, weighing approximately 2,425 lb (1,100 kg), impacting at a speed and angle of 62.1 mph (100.0 km/h) and 25.0 degrees, respectively. Finally, the test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made that pertain to the safety performance of the cable barrier system.

2 BARRIER DESIGN

2.1 Barrier Components

From the onset of this study, multiple R&D tasks were undertaken to develop various barrier components. One such R&D task involved the design and testing of new cable-to-post attachment hardware. This effort involved the evaluation of various brackets, clips, U-bolts, J-bolts, keyway arrangements, and slots. Each of these options were designed in an attempt to provide significant lateral resistance while at the same time releasing vertically under low loads (e.g., under 1,000 lb). The component test results concluded that an 1/8-in. (3-mm) thick steel bracket attached to the post with shoulder bolts provided the best results [2]. Thus, these brackets were recommended for use in the new high-tension, cable median barrier.

Another R&D study was conducted to optimize the barrier system posts. Previous cable barriers were comprised of steel posts with soil plates welded to the front face to provide additional resistance to rotation through the soil. MwRSF researchers sought to eliminate the need for these plates by extending the embedment depth of the post. Dynamic component tests revealed that an S3x5.7 (S76x85) steel post embedded 43 in. (1,092 mm) into the soil provided similar resistance to the previous post designs [3]. Therefore, the 90-in. (2,286-mm) long, S3x5.7 (S76x85) posts were utilized in the new barrier design.

An analysis was also conducted to select the pretension in the cables. Thermal expansion and contraction due to temperature changes can have a huge impact on the magnitude of pretension in a cable barrier system. Calculations showed that a long run of cable exposed to a temperature swing of 100 deg Fahrenheit (38 deg Celsius) can vary the load by 4,000 lb (17.8 kN). BARRIER VII computer simulations were conducted to evaluate the effect of varying the cable pretensions [5].

Results showed that the cable tension had only a minimal effect on the maximum deflection of the system. Thus, increasing the tension in the cables would not negatively affect the performance of the barrier [6]. However, taking tension out of the system and allowing the cables to sag could not only reduce the barrier's ability to capture errant vehicles through cable-sheet metal interlock but also require additional maintenance after minor impacts. Therefore, a pretension corresponding to 4,000 lb (17.8 kN) at 110 deg Fahrenheit (43 deg Celsius) was prescribed for the new barrier system.

2.2 Barrier Configuration and Critical Locations

One goal for this research study was to develop a new, high-tension, four-cable median barrier system that could be located anywhere in a 4H:1V sloped V-ditch. The difficulty in developing a barrier that can be placed anywhere in a ditch is that the vertical position of an errant vehicle in relation to the ground is no longer constant as it is for vehicles traversing level terrain. Instead, the vertical position of the vehicle can vary between being airborne when traveling off the slope break point and into the V-ditch to being at ground level when landing in the ditch and compressing the vehicle suspension. In order to determine the appropriate cable heights and ensure the capture of errant vehicles, it became necessary to identify both critical barrier locations within the V-ditch as well as a critical ditch width.

The research team believed that the upper and lower limits for cable heights would be controlled by two conditions, vehicle override and underride, respectively. The greatest chance of vehicle override would occur when a pickup truck entering the ditch was airborne and at its maximum height above the sloped ground directly below it. This maximum height would be directly related to a specific lateral offset, or a critical barrier location. Thus, the critical barrier location for override and the height to the upper cable (maximum height of the vehicle) would be determined from the trajectory of the pickup off the slope break point and into the 4H:1V sloped V-ditch.

Using NCHRP Report No. 350 or MASH TL-3 impact conditions and LS-DYNA computer simulations, the pickup truck's trajectory was tracked. From this analysis, the truck's bumper would reach a maximum height of 43 in. (1,092 mm) above the sloped ditch at an offset distance of 12 ft (3.7 m) laterally from the slope break point, as shown in Figure 1. Thus, the upper cable was prescribed a minimum height of 43 in. (1,092 mm) and the critical barrier offset distance was established as 12 ft (3.7m) for the full-scale test evaluating pickup containment and override potential.

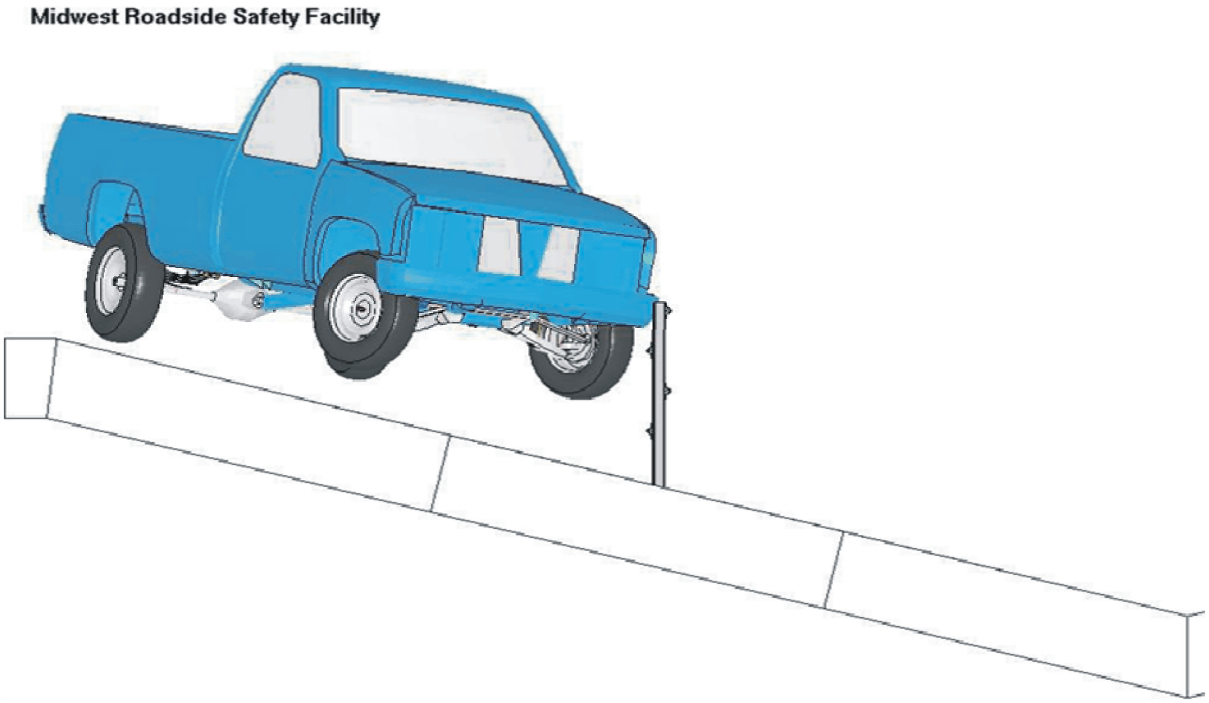


Figure 1. Critical Cable Height and Barrier Offset for 2000P Pickup Truck

The lower cable height would be designed to prevent vehicle underride, and the greatest potential for underride occurs when a small car lands in the V-ditch causing the front wheel suspension to be maximally compressed prior to engaging the lower cable with the vehicle's front bumper. However, vehicle traversals through different ditch widths result in varying levels of compression for the front suspension. As a result, a combination of critical ditch width and critical barrier offset was required to identify the necessary height for the lowest cable.

In evaluating underride potential, two V-ditch widths were evaluated: (1) a relatively common 32 ft (9.8 m) wide section and (2) an extended 46 ft (14.0 m) wide section.NCHRP Report No. 350 or MASH TL-3 impact conditions and LS-DYNA were again utilized during the underride analysis as well as an actual field survey of small car front bumper heights and front-end designs. The 46-ft (14.0-m) wide V-ditch was determined to be more critical as it allowed the vehicle to maximize its airborne flight, thus falling further vertically before impacting the back slope near the ditch bottom. Once striking the ground surface, the vehicle's front suspension began to compress as the vehicle traversed up the back slope. When the maximum suspension compression was observed, the vehicle's leading corner was approximately 4 ft (1.2 m) up the back slope, and the front bumper had bottomed out. Thus, the second critical barrier location (for the small car underride condition) was established as 4 ft (1.2 m) up the back slope of a 46-ft (14.0-m) wide V-ditch. Selected simulation results for the Geo Metro and Dodge Neon at a time just prior to barrier impact are shown in Figures 2 and 3, respectively.

Based on the selected lower and upper limits for cable heights of 13 in. (330 mm) and 43 in. (1,092 mm), respectively, and the desire to utilize four cables within the system, a 10-in. (254-mm) cable spacing was chosen. Thus, the heights of the four cables were selected as 13 in. (330 mm), 23 in. (584 mm), 33 in. (838 mm), and 43 in. (1,092 mm), as measured between the centerline of each cable and ground level.

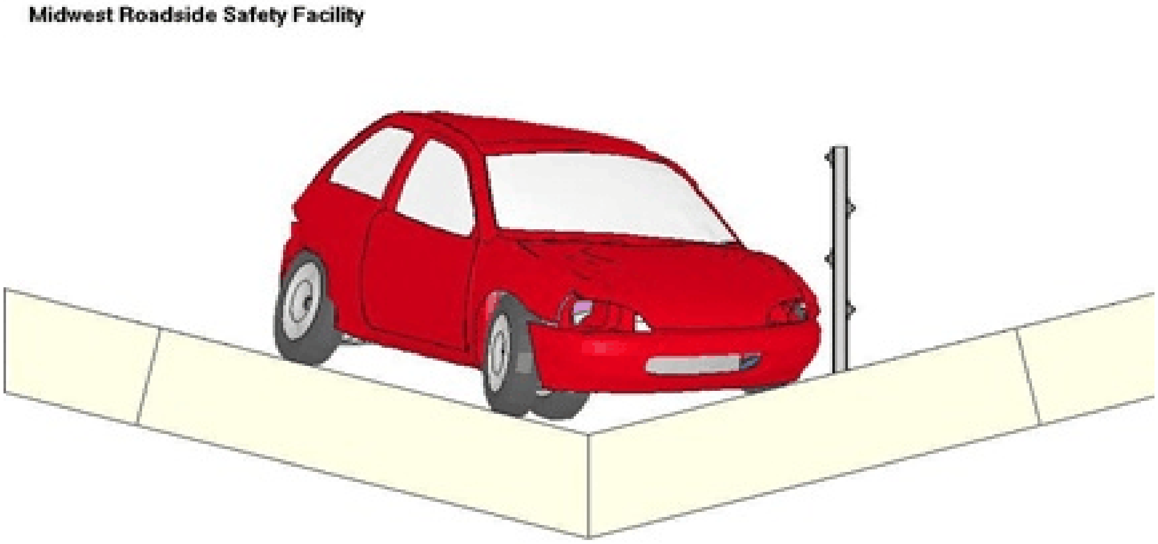


Figure 2. Geo Metro Prior to Impact - 46-ft (14.0-m) Wide V-Ditch

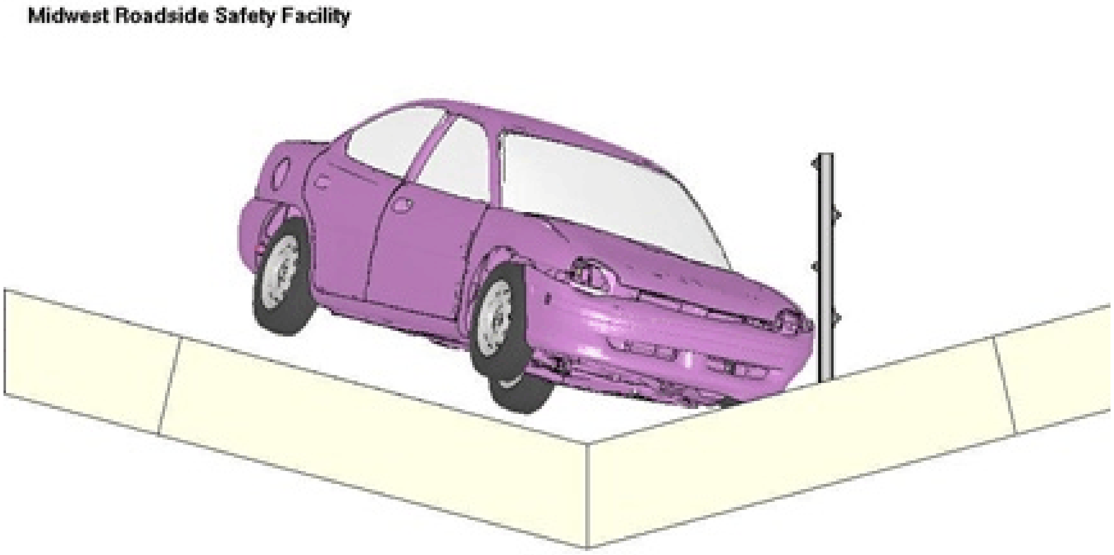


Figure 3. Dodge Neon Prior to Impact - 46-ft (14.0-m) Wide V-Ditch

However, several uncertainties existed within the LS-DYNA computer simulations, including: (1) unavailability of accurate models for MASH test vehicles to perform the simulations; (2) actual upper and lower slope break points will vary from the idealized configurations; (3) variability with vehicle and tire behavior while traversing slope break points; and (4) the state of tire and suspension compression possibly aiding the launching of the vehicles when departing the slope break point. Due to these uncertainties in the simulations and to be conservative against vehicle override, each cable height was increased by 2 in. (51 mm) while maintaining the 10-in. (254-mm) cable spacing. As such, the cable heights were revised prior to testing and positioned at 15 in. (381 mm), 25 in. (635 mm), 35 in. (889 mm), and 45 in. (1,143 mm) above grade. However, the 46-ft (14.0-m) wide V-ditch was retained. The critical lateral barrier offset of 12 ft (3.7 m) from the front slope break point was utilized to evaluate the maximum override propensity for pickup trucks. In addition, a critical lateral barrier offset of 4 ft (1.2 m) from the ditch bottom was used to evaluate the maximum underride propensity for small cars.

3 CABLE MEDIAN BARRIER DESIGN DETAILS FOR TEST NO. 4CMB-1

The cable barrier system was constructed using a total length of 608 ft (185.3 m) with the majority of the barrier system placed within a simulated depressed median. The test installation consisted of several distinct components, systems, and features: (1) a depressed V-ditch; (2) wire ropes or cables; (3) steel support posts; (4) cable-to-post attachment brackets; (5) cable splice hardware; (6) breakaway end terminal hardware; (7) reinforced concrete foundations; (8) cable end fittings; (9) turnbuckle assemblies; and (10) load cell end assemblies. Design details were prepared for the cable median barrier system installed in a simulated depressed median, as shown in Figures 4 through 19. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

A 360-ft (109.7-m) long simulated depressed median V-ditch was constructed using an overall width of 46 ft (14.0 m) in combination with 4H:1V side slopes. As a result, the vertical depth at the center of the ditch was approximately 5 ft - 9 in. (1.75 m). The full ditch cross section was constructed for a length of 280 ft (85.3 m). A 40-ft (12.2 m) long sloped transition region was located at the upstream and downstream ends of the V-ditch, thus allowing for the ditch to be raised to the roadway elevation.

Four ¾-in. (19-mm) diameter, Class A galvanized 3x7 (pre-stretched) wire ropes were utilized for the cable rail elements. The cables were either supported or anchored at 40 different locations, as shown in Figure 4. Post nos. 1 and 40 were configured to serve as the upstream and downstream end anchors, respectively, and these locations incorporated breakaway end terminal hardware supported by 2-ft (610-mm) diameter by 10-ft (3,048-mm) long reinforced concrete foundations. Post nos. 2 and 39 consisted of breakaway steel support posts anchored to 1-ft (305-

mm) diameter by 4-ft (1,219-mm) long reinforced concrete foundations. Post nos. 3 through 38 consisted of S3x5.7 (S76x8.5) standard steel line posts measuring 7 ft - 3 in. (2,210 mm) in length. The standard line posts were embedded 39 in. (991 mm) into the compacted soil foundation. The spacing between post nos. 1 and 2 as well as 39 and 40 was 8 ft (2.44 m), while the post spacing between post nos. 2 through 39 was 16 ft (4.88 m). For the standard line posts, the four cables were attached to the posts and placed at 15 in. (381 mm), 25 in. (635 mm), 35 in. (889 mm), and 45 in. (1,143 mm) above the ground surface, as shown in Figures 4 and 6.

Each cable was attached to the line posts using an ⅛-in. (3.2-mm) thick ASTM A36 steel keyway bracket, two 5/16-in. (7.9-mm) diameter ASTM A307 hex head shoulder bolts, and the appropriate nuts and washers. Details for the cable-to-post attachment bracket, mounting hardware, and locations can be found in Figures 18 and 19.

It should be noted that the initial barrier configuration had planned to utilize a 42-in. (1,067-mm) post embedment depth along with cable locations of 13 in. (330 mm), 23 (584 mm), 33 (838 mm), and 43 in. (1,093 mm). After the steel posts had been fabricated, further analysis led the research team to raise the top cable height from 43 in. to 45 in. as well as to incorporate a similar incremental upward shift for the lower three cables. It was also realized that an insufficient top end distance of approximately 1 in. (25 mm) was available for attaching the upper cable-to-post bracket to the top of each post. As such, each line post was raised 3 in. (76 mm) to accommodate the two late design modifications, thus resulting in a 39-in. (991-mm) post embedment depth with cable heights of 15 in. (381 mm), 25 in. (625) mm), 35 in. (879 mm), and 45 in. (1,143 mm). However, it was the research team’s opinion that these changes would not negatively effect the safety performance of the barrier system, and new longer posts were not fabricated.

Each of the four wire ropes were spliced together using special cable splice hardware located between post nos. 18 through 21, as shown in Figure 5. At the ends of the cable barrier system, each cable was sloped down to the ground and anchored to a simulated breakaway end terminal system, as shown in Figure 7 and 10 through 13. As noted previously, post nos. 1 and 40 served as the end cable anchors and consisted of a cable anchor bracket, cable release lever, brass keeper rod, special end fittings, and a reinforced concrete foundation. Details for the concrete foundation are provided in Figure 10. The cable anchor bracket was fabricated using six different ASTM A36 steel plates that were welded together, as shown in Figures 11 and 12. The cable release lever was manufactured from three 1¼-in. (32-mm) square steel tubes, a steel plate, and two triangular steel gusset plates, as shown in Figure 13.

As noted previously, posts nos. 2 and 39 served as breakaway steel support posts with attached hanger hardware, as shown in Figure 14. The S3x5.7 (S76x8.5) posts incorporated a steel bracket plate near the top of the post as well as a slipbase connection near the groundline, as shown in Figures 15 and 16. Each post was inserted into steel foundation tube assembly measuring 4 in. x 3 in. x 1/4 in. (102 mm x 76 mm x 6.3 mm) and conforming to ASTM A500 Grade B. A 3/4-in. (19.1 mm) diameter by 6-in. (152-mm) long, ASTM A307 hex head bolt, nut, and two washers were used to support the post and ensure proper embedment, as shown in Figure 17. Each steel tube assembly was embedded within a reinforced concrete foundation.

Near the upstream end of the barrier system, one 50,000-lb (222.4-kN) capacity tension load cell was spliced into each of the cable lines between post nos. 3 and 4, as shown in Figures 6 and 8. Details for the load cells, threaded rods, turnbuckles, end fittings, and rod couplers are provided in Figures 8 and 9.

As discussed in the previous chapter, the pretension in the cables was selected to be 4,000 lb (17.8 kN) at 110 deg Fahrenheit (43 deg Celsius). A cable tensioning chart was developed as a function of the ambient air temperature and for use when installing the barrier system, as provided in Table 1. MASH specifies that all cable systems be tested/evaluated under tensions corresponding to a temperature of 100 deg Fahrenheit (38 deg Celsius). As a result, the cables were pretensioned to a target load of 4,213 lb (18.7 kN).

Table 1. Pre-Stretched Cable Tension Chart

Ambient Air Temperature (Degrees Fahrenheit)	Cable Tension (lb)
110	4,000
100	4,213
90	4,427
80	4,640
70	4,853
60	5,067
50	5,280
40	5,493
30	5,706
20	5,920
10	6,133
0	6,346
-10	6,560
-20	6,773
-30	6,986
-40	7,200

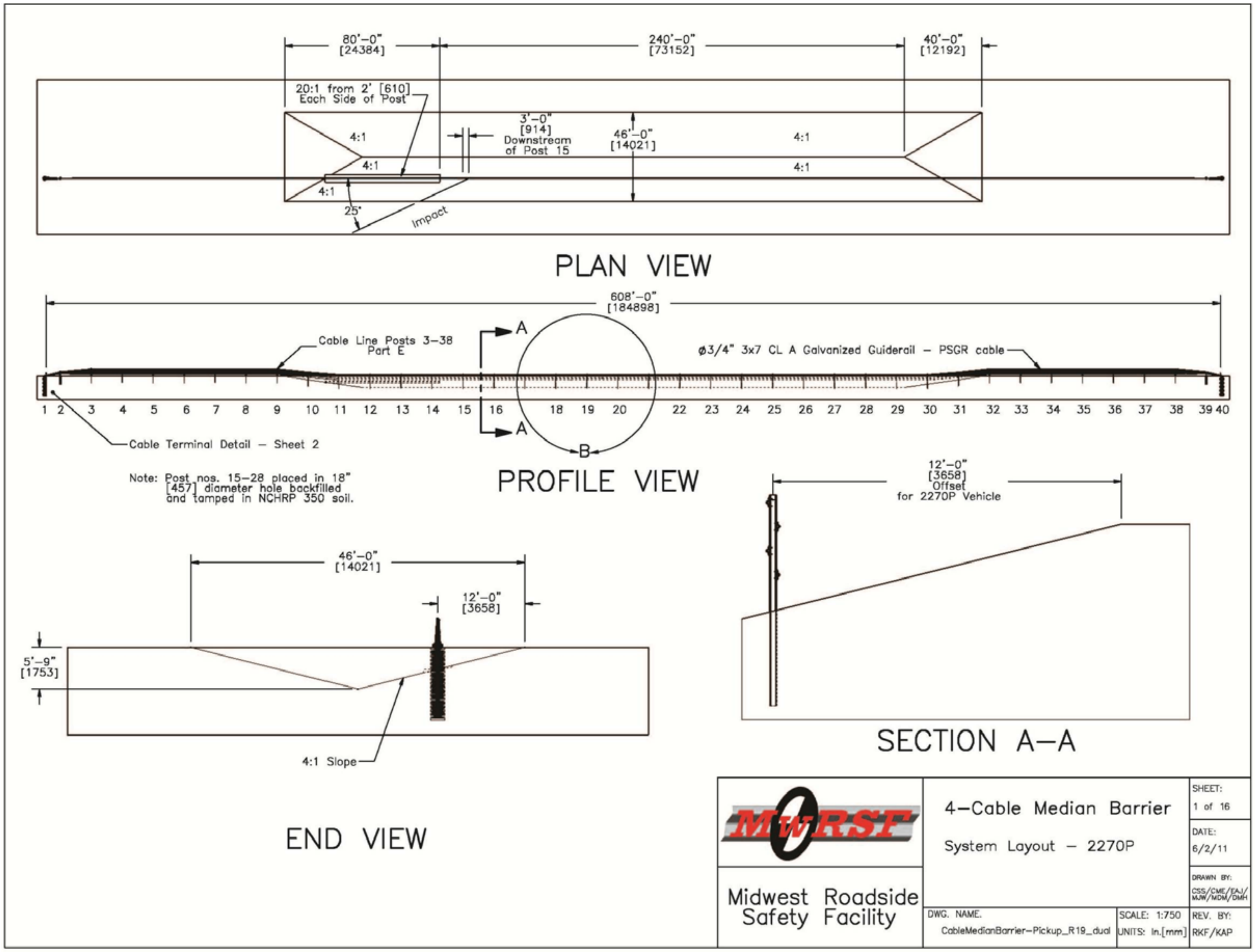
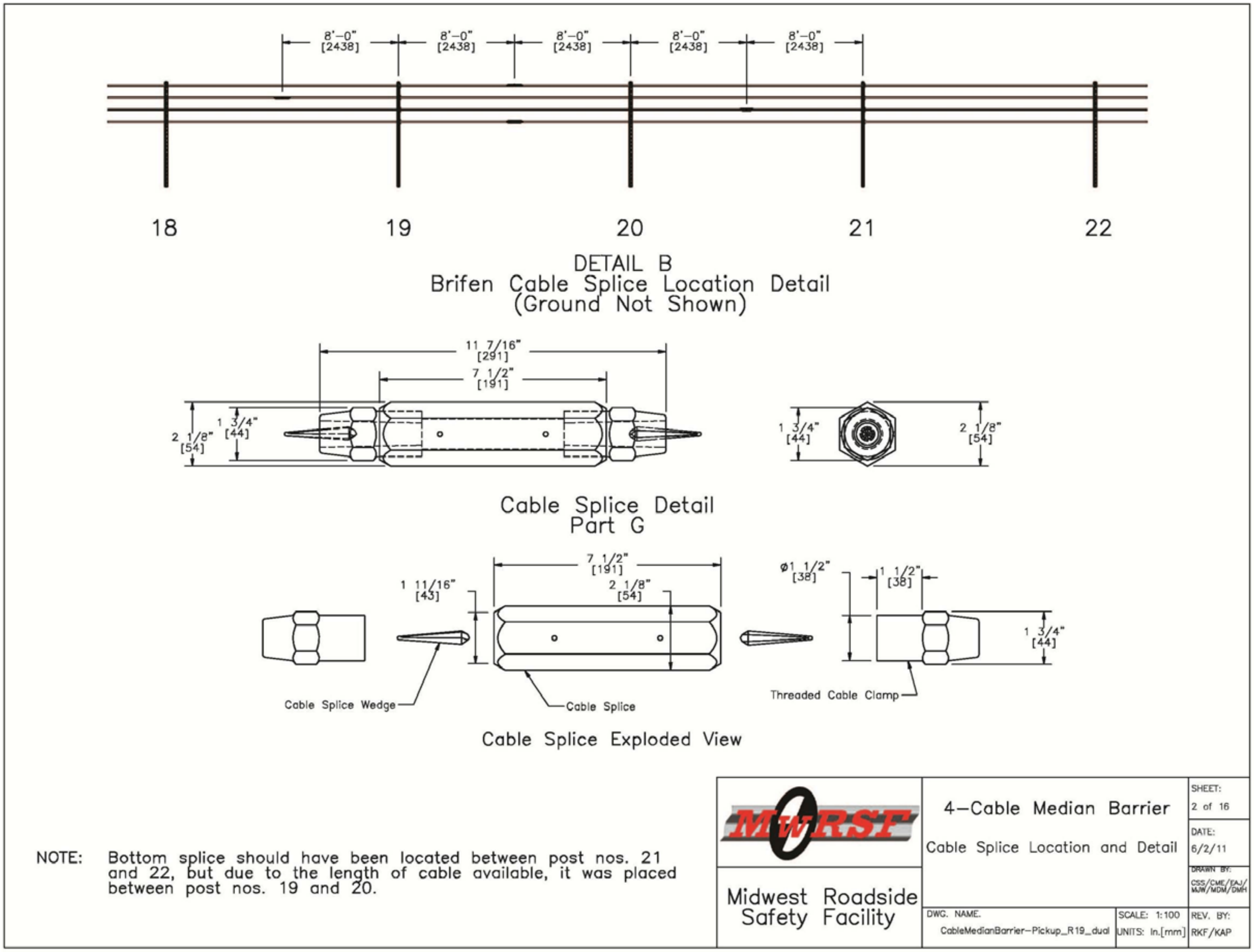


Figure 4. System Layout, Test No. 4CMB-1



NOTE: Bottom splice should have been located between post nos. 21 and 22, but due to the length of cable available, it was placed between post nos. 19 and 20.

Figure 5. Cable Splice Location and Detail, Test No. 4CMB-1

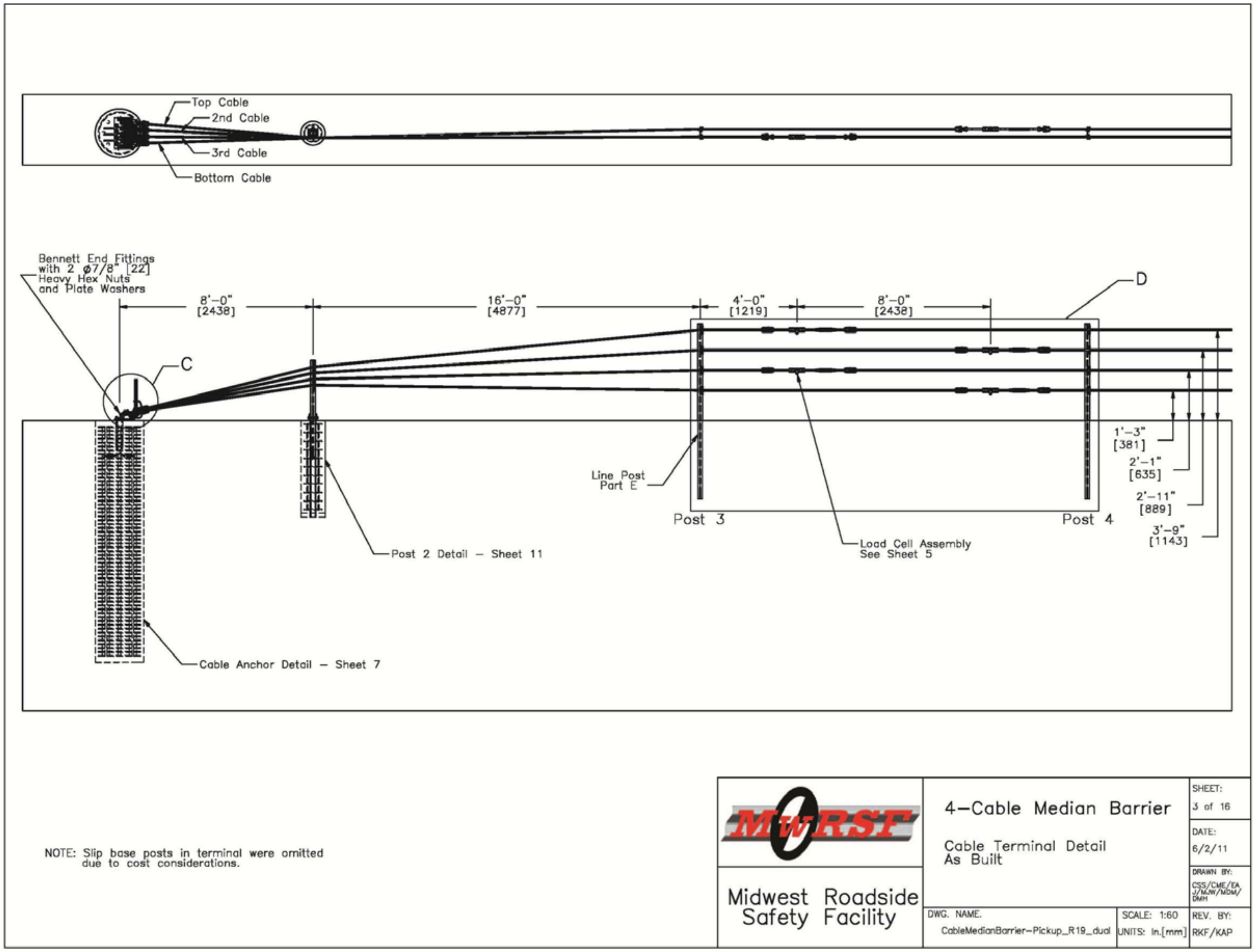


Figure 6. Cable Terminal Detail, Test No. 4CMB-1

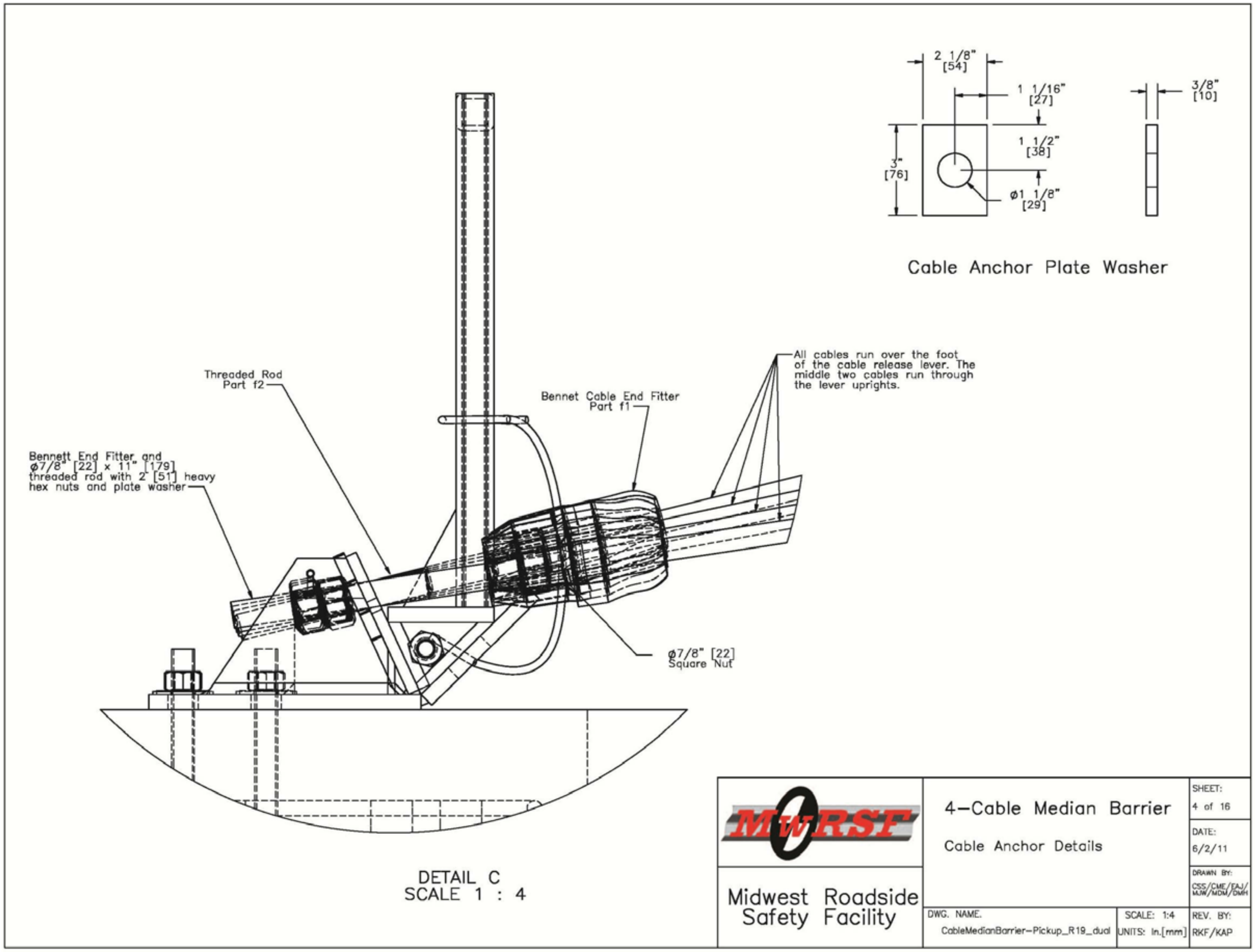


Figure 7. Cable Anchor Details, Test No. 4CMB-1

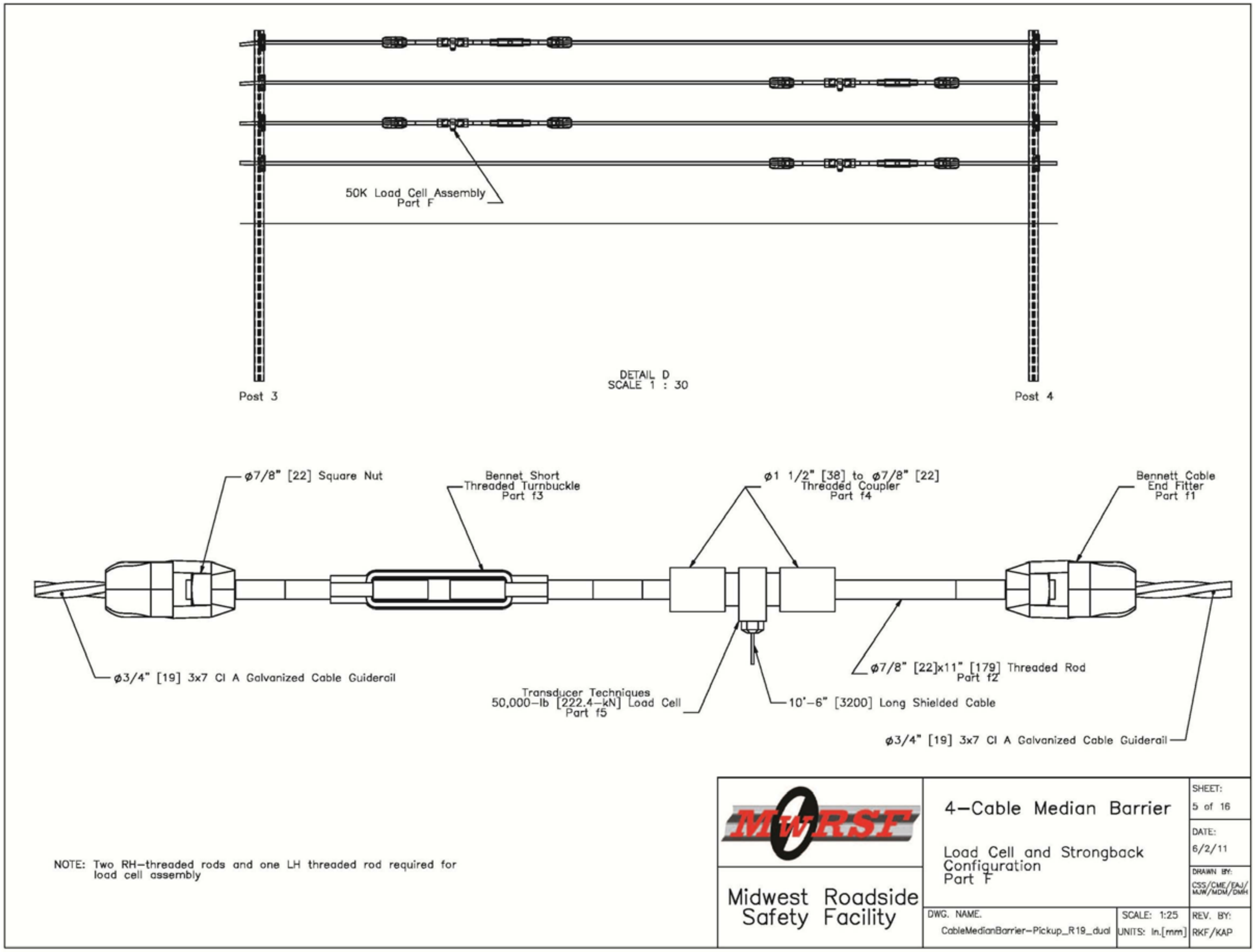


Figure 8. Load Cell and Strongback Configuration, Test No. 4CMB -1

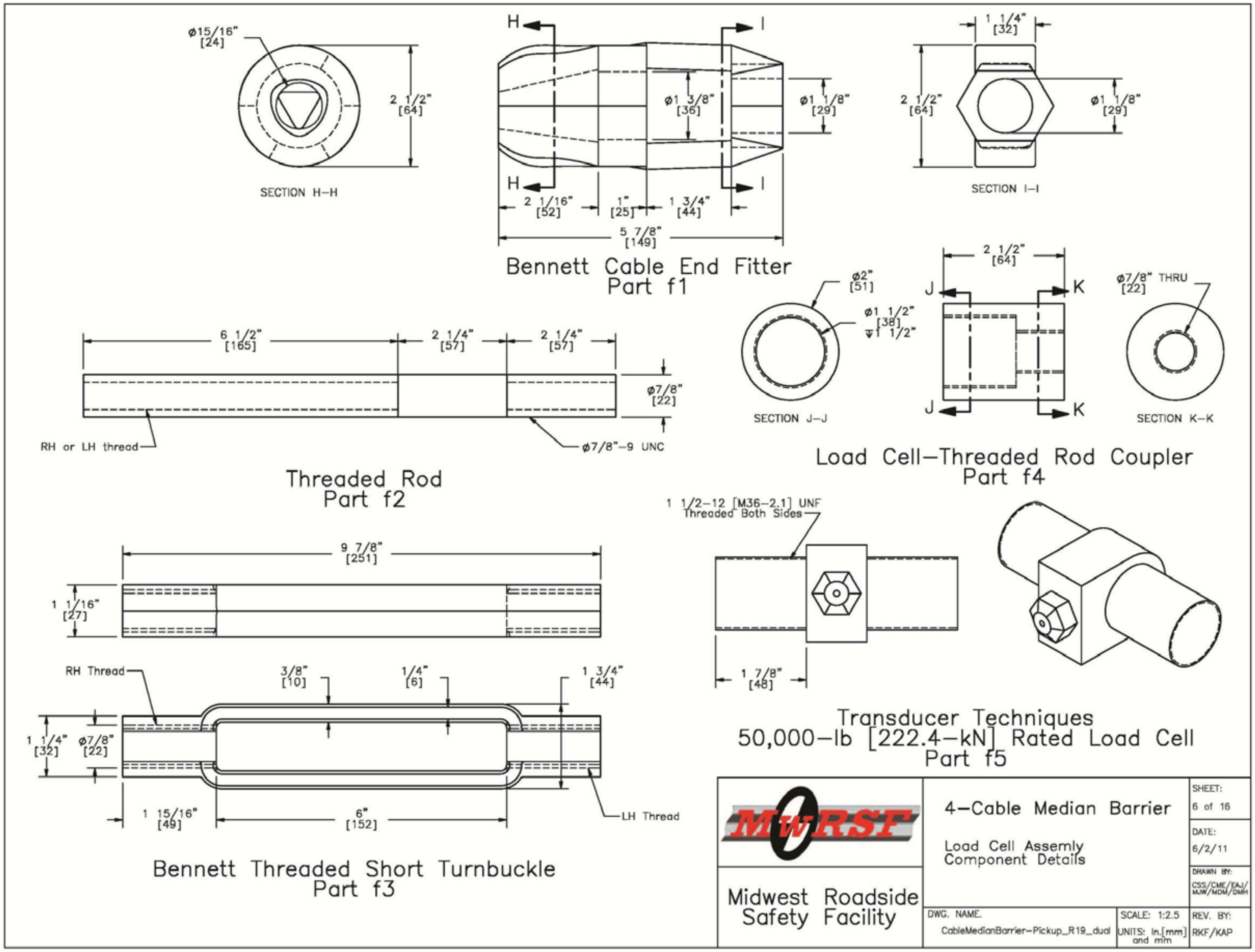
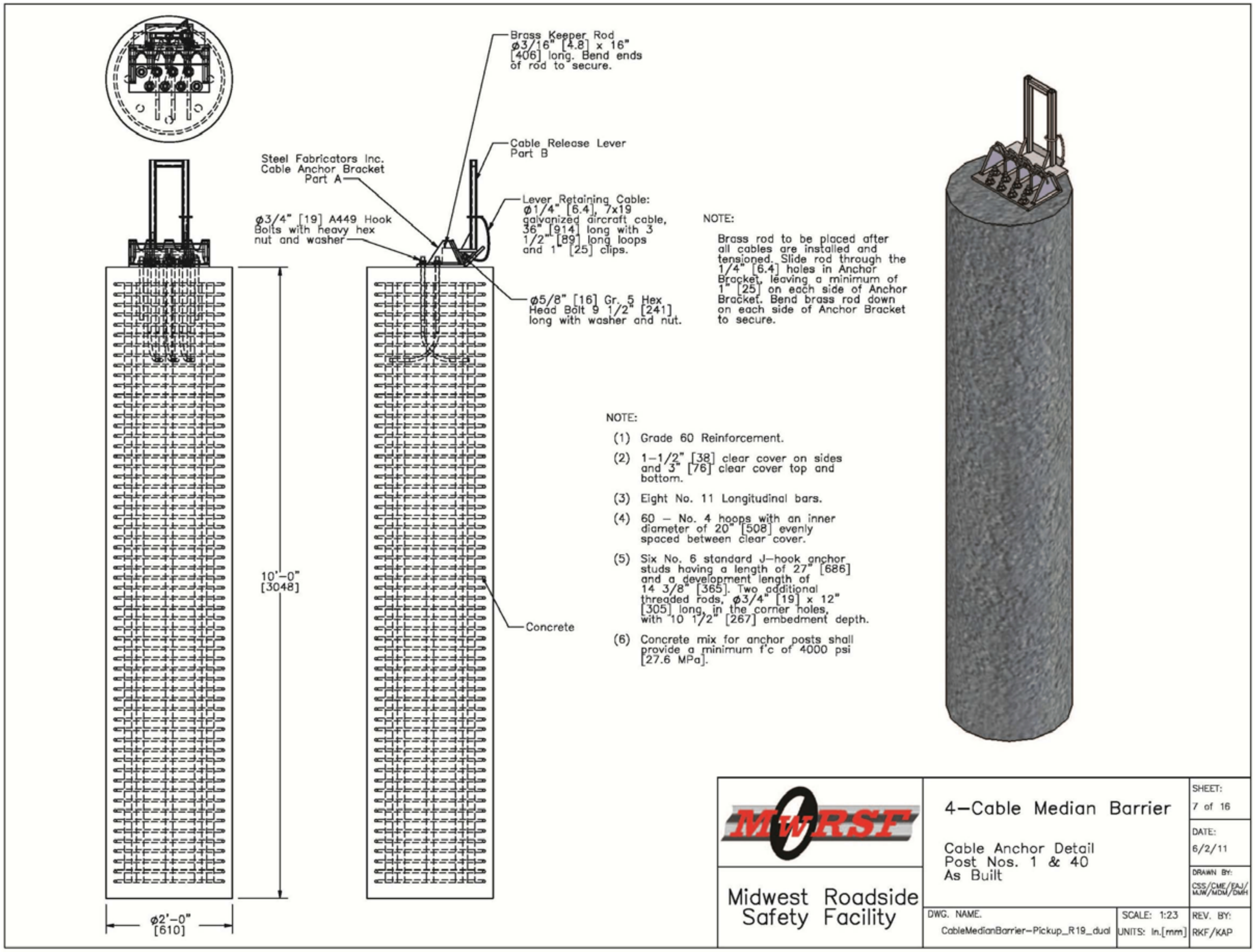


Figure 9. Load Cell Assembly Component Details, Test No. 4CMB-1



NOTE:

Brass rod to be placed after all cables are installed and tensioned. Slide rod through the 1/4" [6.4] holes in Anchor Bracket, leaving a minimum of 1" [25] on each side of Anchor Bracket. Bend brass rod down on each side of Anchor Bracket to secure.

NOTE:

(1) Grade 60 Reinforcement.

(2) 1-1/2" [38] clear cover on sides and 3" [76] clear cover top and bottom.

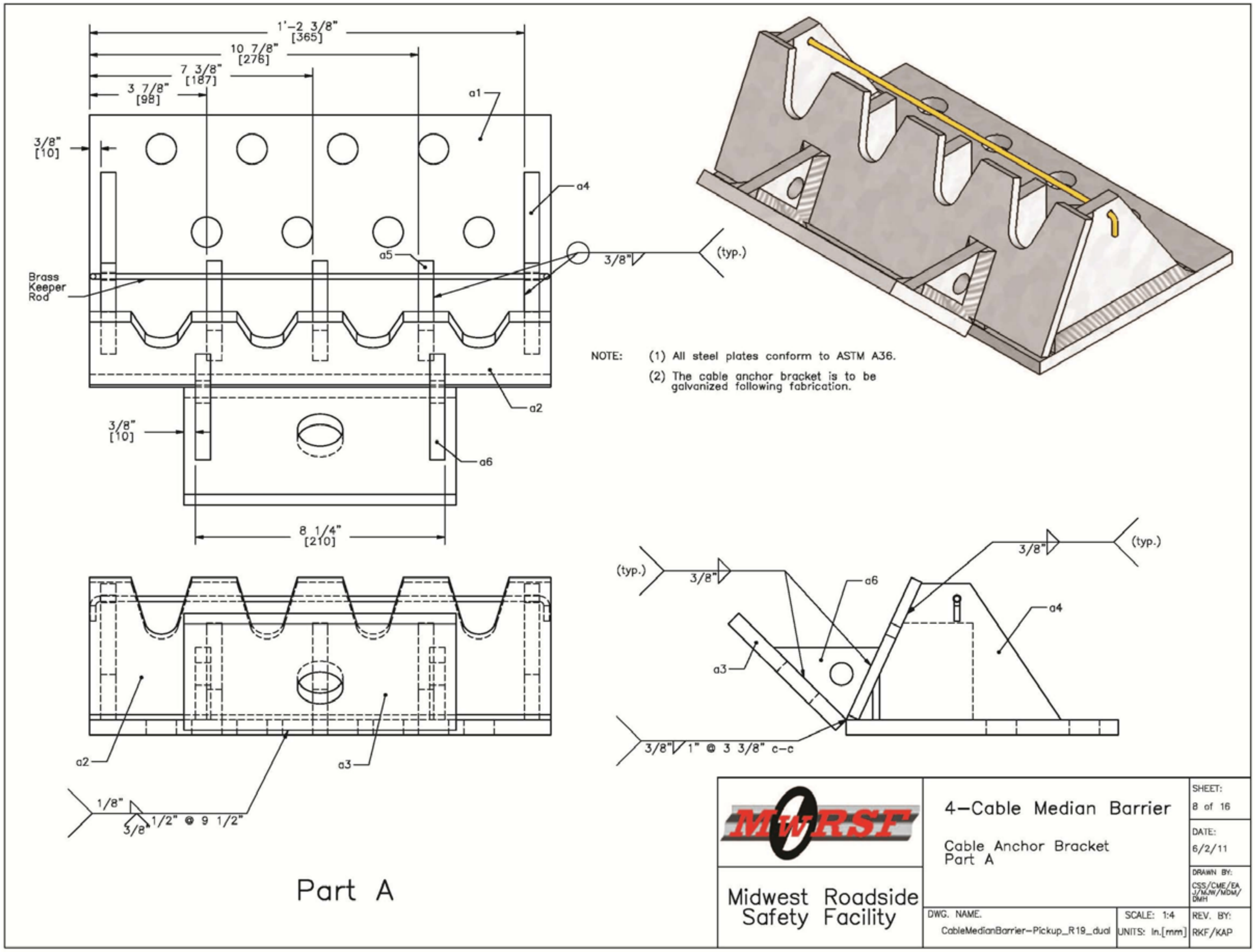
(3) Eight No. 11 Longitudinal bars.

(4) 60 – No. 4 hoops with an inner diameter of 20" [508] evenly spaced between clear cover.

(5) Six No. 6 standard J-hook anchor studs having a length of 27" [686] and a development length of 14 3/8" [365]. Two additional threaded rods, ø3/4" [19] x 12" [305] long, in the corner holes, with 10 1/2" [267] embedment depth.

(6) Concrete mix for anchor posts shall provide a minimum f'c of 4000 psi [27.6 MPa].

Figure 10. Cable Anchor Detail, Post Nos. 1 & 40, Test No. 4CMB-1



NOTE: (1) All steel plates conform to ASTM A36.

(2) The cable anchor bracket is to be galvanized following fabrication.

Figure 11. Cable Anchor Bracket, Part A, Test No. 4CMB-1

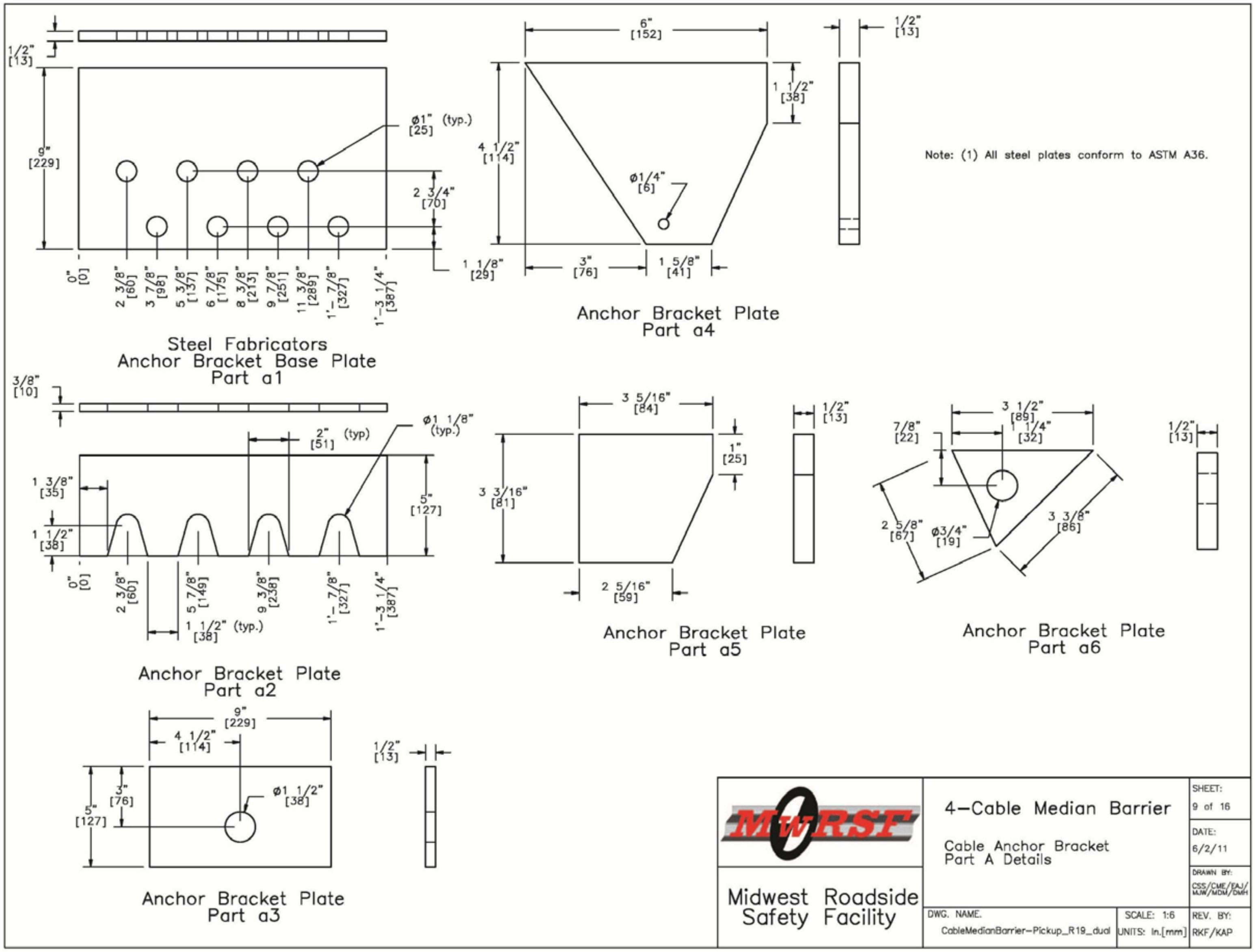
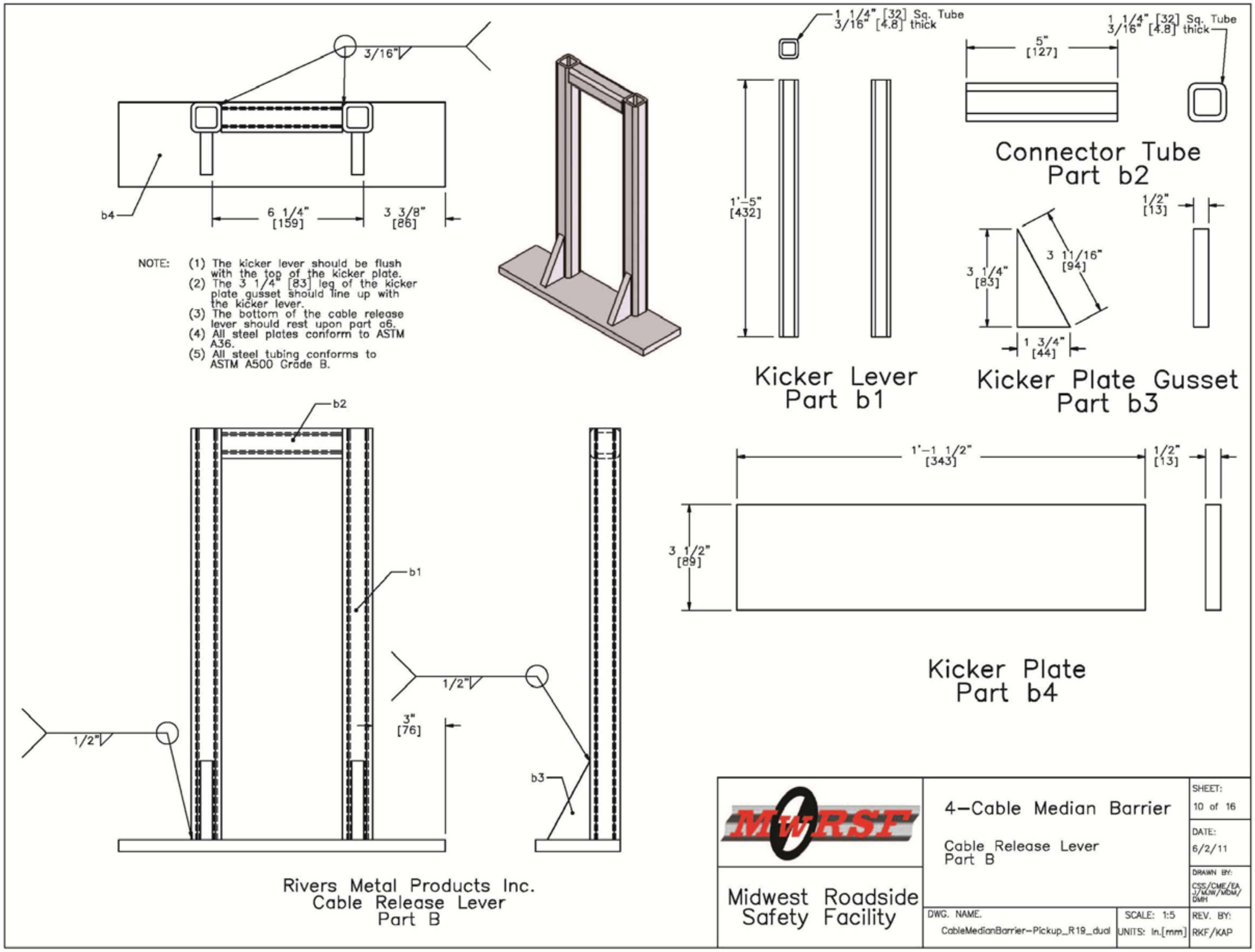


Figure 12. Cable Anchor Bracket Details, Test No. 4CMB-1



NOTE:
(1) The kicker lever should be flush with the top of the kicker plate.
(2) The 3 1/4" [83] leg of the kicker plate gusset should line up with the kicker lever.
(3) The bottom of the cable release lever should rest upon part a6.
(4) All steel plates conform to ASTM A36.
(5) All steel tubing conforms to ASTM A500 Grade B.

Figure 13. Cable Release Lever, Test No. 4CMB-1

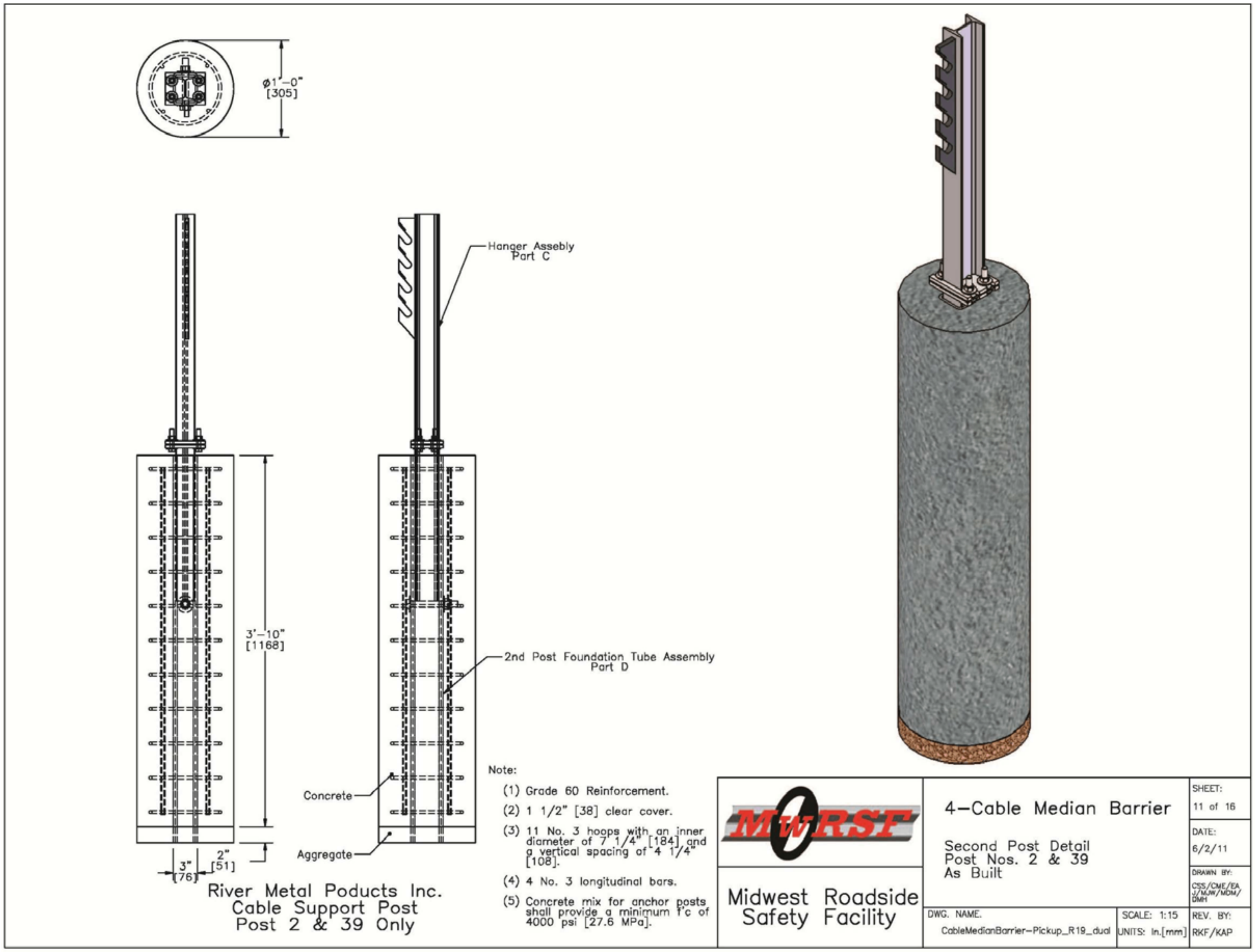


Figure 14. Post Nos. 2 & 39 Details, Test No. 4CMB-1

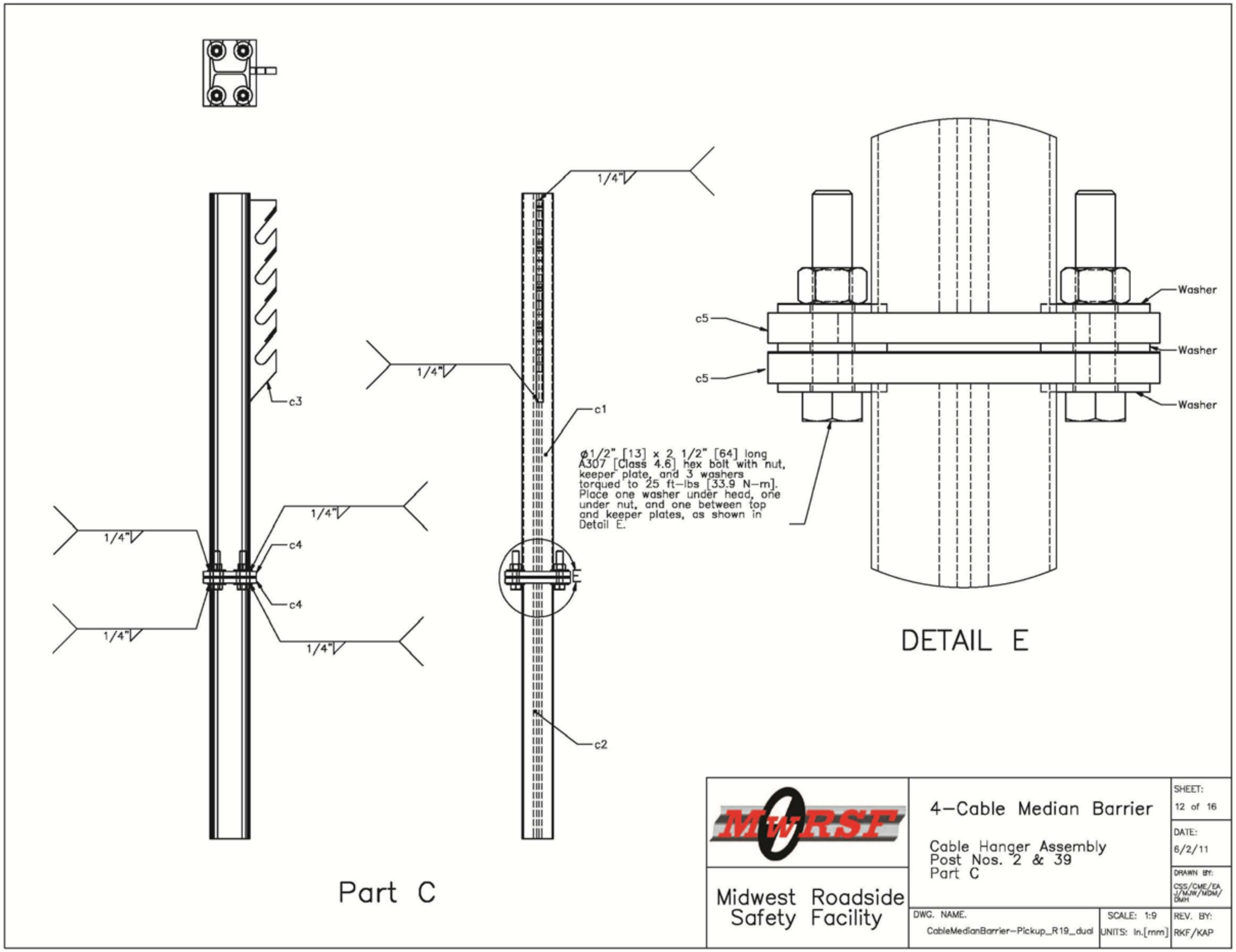


Figure 15. Cable Hanger Assembly, Post Nos. 2 & 39, Test No. 4CMB-1

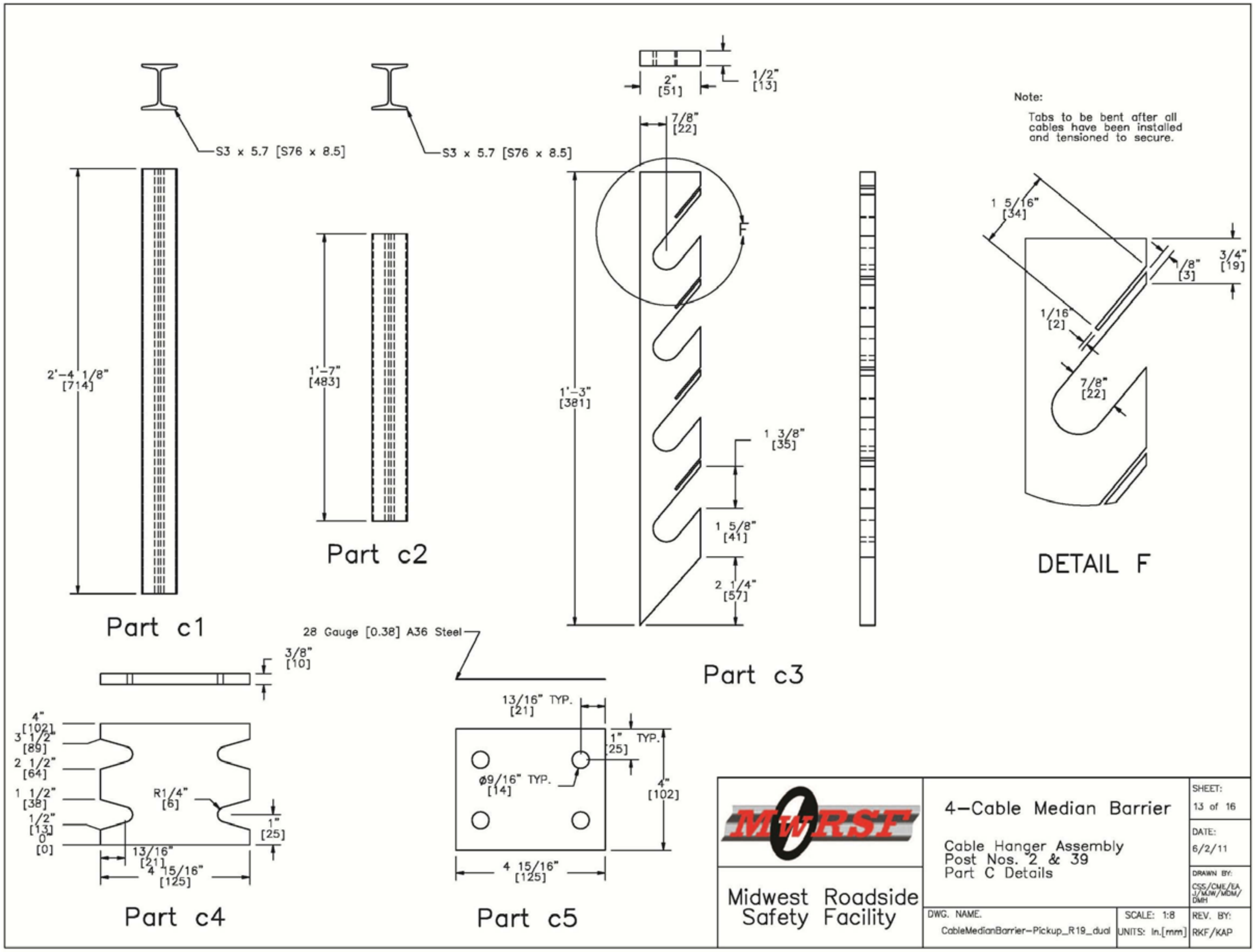


Figure 16. Cable Hanger Assembly, Post Nos. 2 & 39, Test No. 4CMB-1

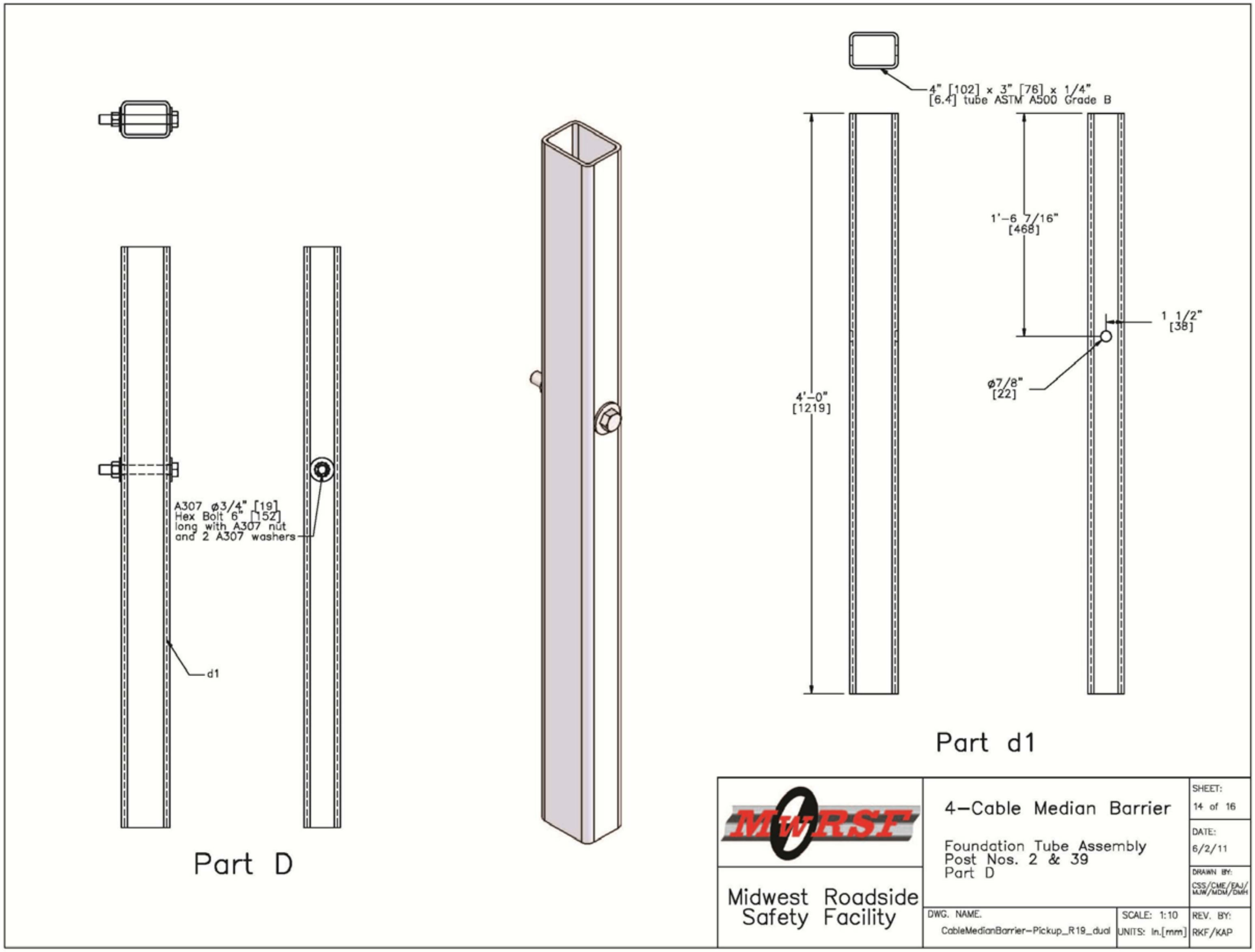


Figure 17. Foundation Tube Assembly, Post Nos. 2 & 39, Test No. 4CMB-1

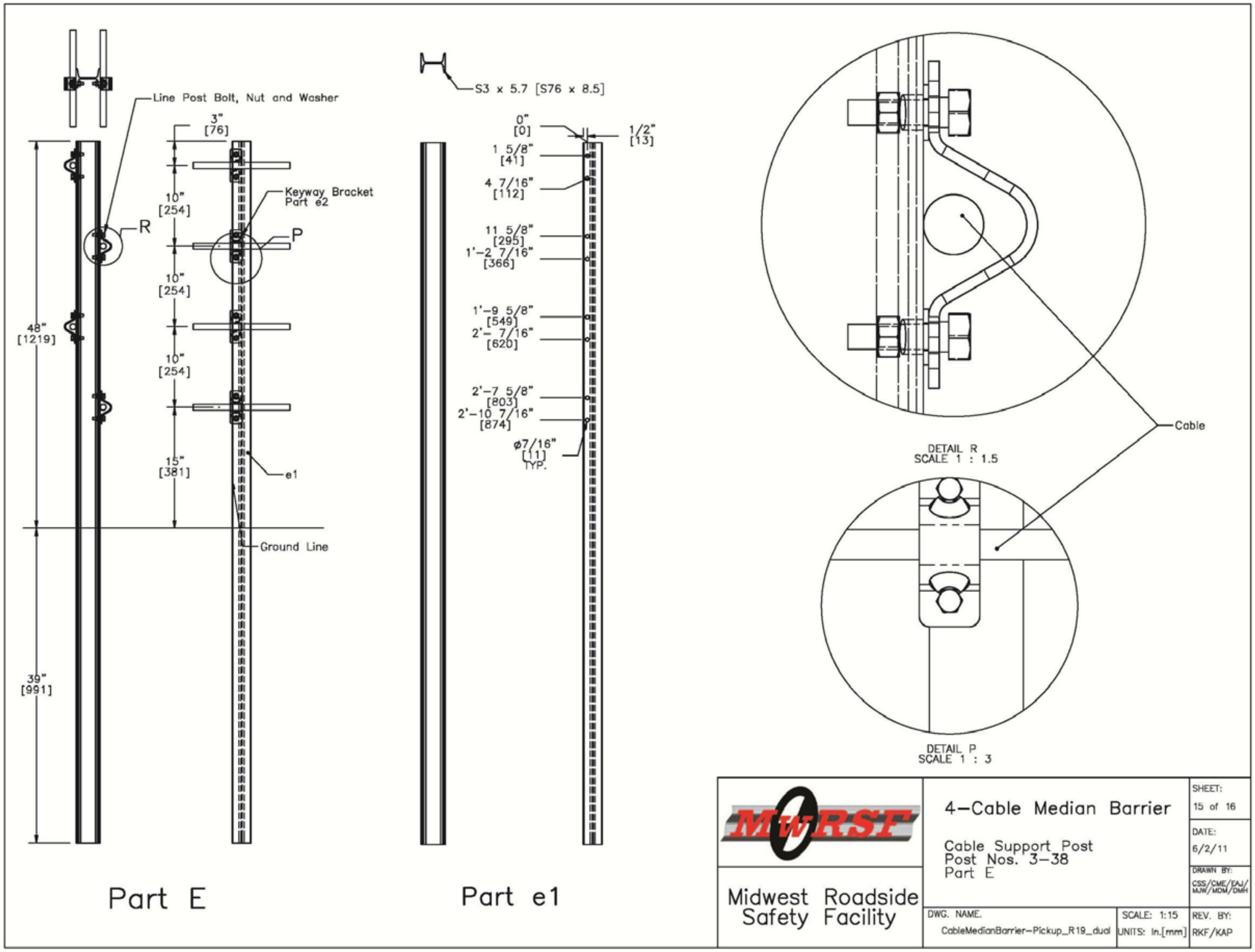


Figure 18. Cable Support Post, Post Nos. 3-38, Test No. 4CMB-1

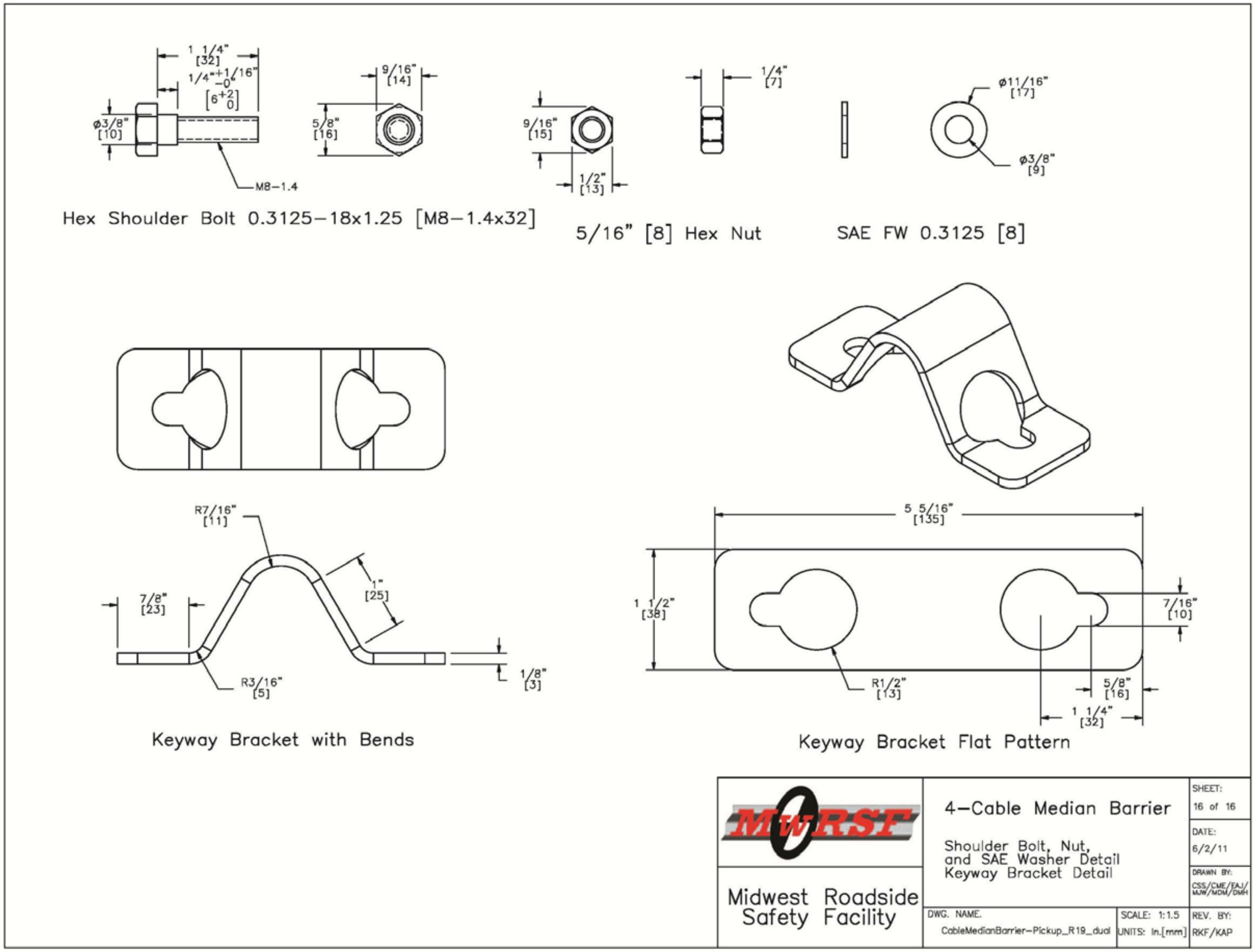


Figure 19. Shoulder Bolt, Nut, Washer, and Keyway Bracket Detail, Test No. 4CMB-1

4 TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 Test Requirements

Longitudinal barriers, such as cable median barriers, must satisfy the requirements provided in MASH to be accepted for use on National Highway System (NHS) construction projects or as a replacement for existing systems not meeting current safety standards [4]. According to Test Level 3 (TL-3) of MASH, the barrier system must be subjected to two full-scale vehicle crash tests. The two crash tests are as follows:

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

2. Test Designation 3-11 consists of a 5,000-lb (2,268-kg) pickup truck impacting the cable median barrier at a nominal speed and angle of 62.1 mph (100.0 km/h) and 25 degrees, respectively.

The test conditions for TL-3 longitudinal barriers are summarized in Table 2.

Table 2. MASH Test Level 3 Crash Test Conditions

Test Article	Test Designation	Test Vehicle	Impact Conditions			Evaluation Criteria[1]
			Speed		Angle (degrees)	
			(km/h)	(mph)		
Longitudinal Barriers	3-10	1100C	100.0	62.1	25	A,D,F,H,I
	3-11	2270P	100.0	62.1	25	A,D,F,H,I

[1] - Evaluation criteria explained in Table 3.

4.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on two appraisal areas: (1) structural adequacy and (2) occupant risk. Criteria for structural adequacy are intended to evaluate the ability of the cable terminal 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. These two evaluation criteria are defined in Table 3. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in MASH.

4.3 Soil Strength Requirements

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

It should be noted that test nos. 4CMB-1 and 4CMB-2 were conducted prior to the official release of MASH, and although the test conditions reflected the anticipated test criteria, static soil tests were not performed.

Table 3. MASH Evaluation Criteria for Crash Tests

<table>
<tr><th>Evaluation Factors</th><th colspan="3">Evaluation Criteria</th></tr>
<tr><td>Structural Adequacy</td><td colspan="3">A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable</td></tr>
<tr><td rowspan="11">Occupant Risk</td><td colspan="3">D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td></tr>
<tr><td colspan="3">F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td colspan="3">H. Occupant Impact Velocities (OIV) (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits, ft/s (m/s)</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
<tr><td>Longitudinal</td><td>10 ft/s (3.0 m/s)</td><td>16.4 ft/s (5.0 m/s)</td></tr>
<tr><td colspan="3">I. The Occupant Ride Down Acceleration (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits (g’s)</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

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 5 mi. (8 km) NW of the University of Nebraska-Lincoln.

5.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch [7] 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 ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and was supported laterally and vertically every 100 ft (30.48 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable. As the test vehicle was towed down the line, the guide-flag struck and knocked each stanchion to the ground. For tests 4CMB-1, 4CMB-2, and 4CMB-3, the vehicle guidance systems were 961 ft (293 m), 920 ft (280 m), and 798 ft (243 m) long, respectively.

5.3 Test Vehicles

For test no. 4CMB-1, a 2002 Dodge Ram 1500 Quad-Cab pickup truck was used as the test vehicle. The test inertial and gross static weight was 4,988 lb (2,263 kg). The test vehicle is shown in Figure 20, and vehicle dimensions are shown in Figure 21.

For test no. 4CMB-2, a 2002 Kia Rio sedan was used as the test vehicle. The test inertial and gross static weights were 2,393 lb (1,085 kg) and 2,557 lb (1,160 kg), respectively. The test vehicle is shown in Figure 22, and vehicle dimensions are shown in Figure 23.

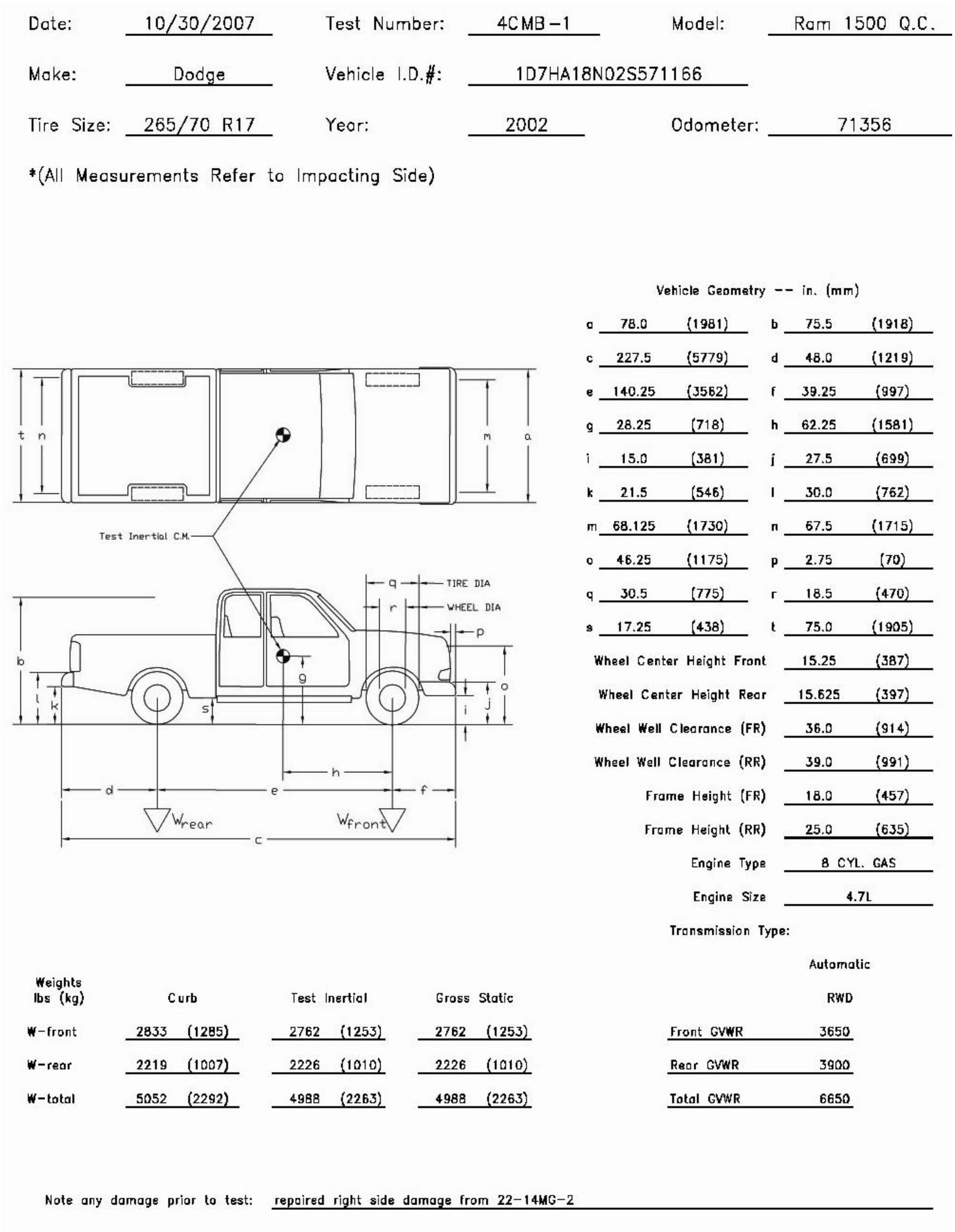
For test no. 4CMB-3, a 2002 Kia Rio sedan was used as the test vehicle. The test inertial and gross static weights were 2,411 lb (1,094 kg) and 2,586 lb (1,173 kg). The test vehicle is shown in Figure 24, and vehicle dimensions are shown in Figure 25.

The vertical and longitudinal components of the center of gravity was determined using the measured axle weights. The location of the final centers of gravity are shown in Figures 26 through 28.

Square, black- and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film analysis, as shown in Figures 26 through 28. Round, checkered targets were placed on the center of gravity on the driver's side door, on the passenger's side door, and on the roof of the vehicle. The remaining targets were located for reference so that they could be viewed from the high-speed cameras for film analysis.

The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable. One 5B flash bulb was mounted on both the hood and roof of the vehicle to pinpoint the time of impact with the barrier on the high-speed film and video. The flash bulb was fired by a pressure tape switch mounted on the front face of the bumper. A remote-controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

Figure 20. Test Vehicle, Test No. 4CMB-1



Date: 10/30/2007 Test Number: 4CMB-1 Model: Ram 1500 Q.C.

Make: Dodge Vehicle I.D.#: 1D7HA18N02S571166

Tire Size: 265/70 R17 Year: 2002 Odometer: 71356

*(All Measurements Refer to Impacting Side)

Vehicle Geometry -- in. (mm)

a	78.0	(1981)	b	75.5	(1918)
c	227.5	(5779)	d	48.0	(1219)
e	140.25	(3562)	f	39.25	(997)
g	28.25	(718)	h	62.25	(1581)
i	15.0	(381)	j	27.5	(699)
k	21.5	(546)	l	30.0	(762)
m	68.125	(1730)	n	67.5	(1715)
o	46.25	(1175)	p	2.75	(70)
q	30.5	(775)	r	18.5	(470)
s	17.25	(438)	t	75.0	(1905)

Wheel Center Height Front 15.25 (387)

Wheel Center Height Rear 15.625 (397)

Wheel Well Clearance (FR) 36.0 (914)

Wheel Well Clearance (RR) 39.0 (991)

Frame Height (FR) 18.0 (457)

Frame Height (RR) 25.0 (635)

Engine Type 8 CYL. GAS

Engine Size 4.7L

Transmission Type:

Automatic

RWD

Weights lbs (kg)	Curb	Test Inertial	Gross Static
W-front	2833 (1285)	2762 (1253)	2762 (1253)
W-rear	2219 (1007)	2226 (1010)	2226 (1010)
W-total	5052 (2292)	4988 (2263)	4988 (2263)

Front GVWR 3650

Rear GVWR 3900

Total GVWR 6650

Note any damage prior to test: repaired right side damage from 22-14MG-2

Figure 21. Vehicle Dimensions, Test No. 4CMB-1

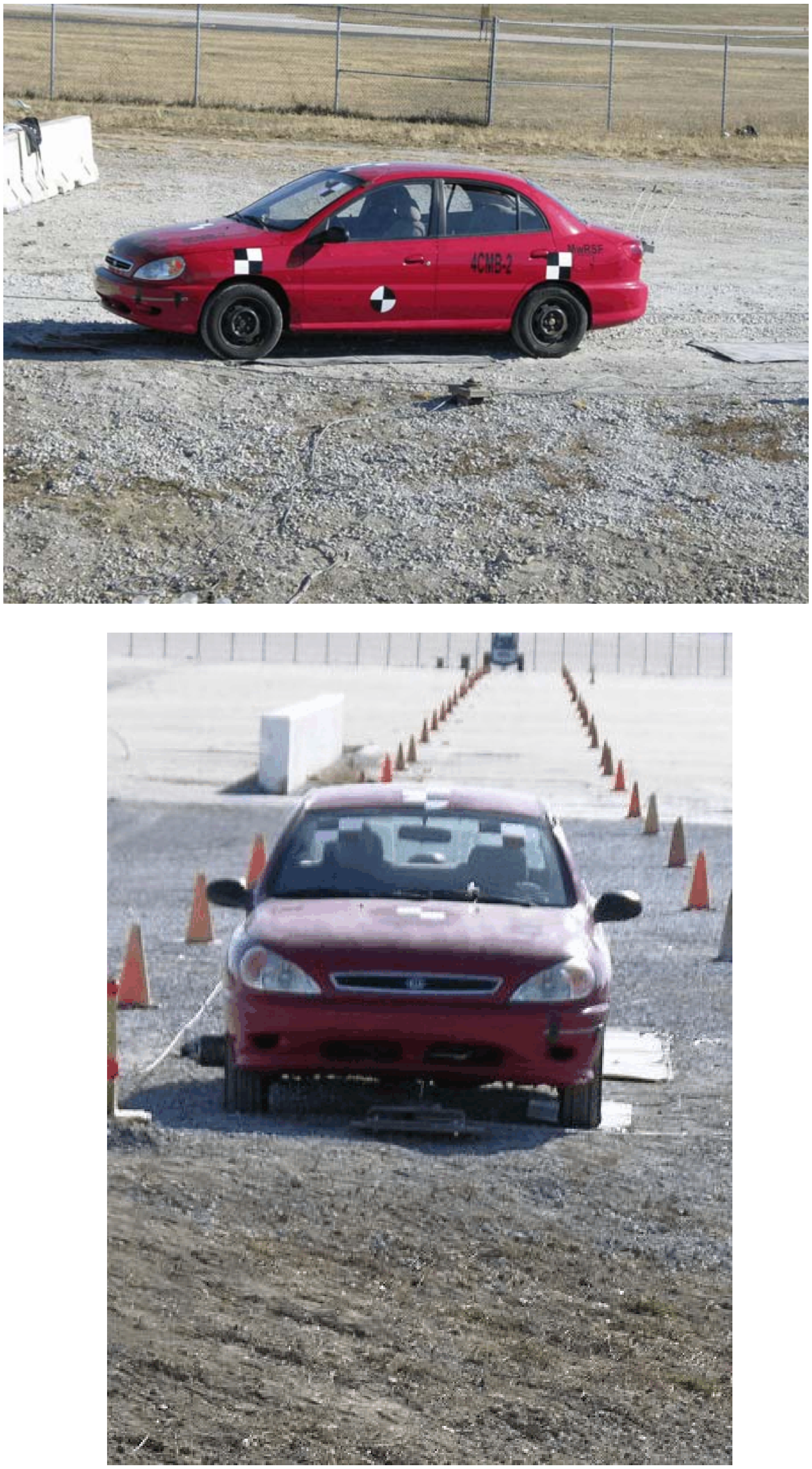


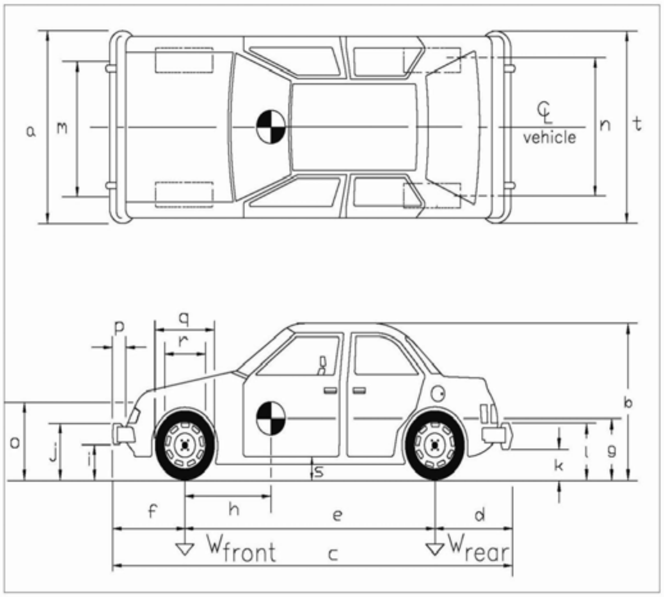
Figure 22. Test Vehicle, Test No. 4CMB-2

Date: 11/16/2007 Test Number: 4CMB-2 Model: Rio Sedan

Make: Kia Vehicle I.D.#: KNADC123X26149132

Tire Size: P175/65R14 Year: 2002 Odometer: 78103

Tire Inflation Pressure: 29
*(All Measurements Refer to Impacting Side)



Vehicle Geometry -- in. (mm)

a	64.0	(1626)	b	56.0	(1422)
c	166.0	(4216)	d	38.25	(972)
e	95.25	(2419)	f	34.5	(876)
g	18.0	(457)	h	40.5	(1029)
i	9.0	(229)	j	21.0	(533)
k	10.5	(267)	l	21.0	(533)
m	55.25	(1403)	n	56.875	(1445)
o	22.0	(559)	p	3.25	(83)
q	22.625	(575)	r	15.375	(391)
s	11.75	(298)	t	64.75	(1645)

Wheel Center Height Front	10.625	(270)
Wheel Center Height Rear	11.0	(279)
Wheel Well Clearance (FR)	25.375	(645)
Wheel Well Clearance (RR)	23.75	(603)
Frame Height (FR)	NA	NA
Frame Height (RR)	NA	NA

Engine Type 4cyl Gas

Engine Size 1.5L

Transmission Type:

Automatic [✓ Manual]

[✓ FWD] RWD 4WD

Weights lbs (kg)	Curb		Test Inertial		Gross Static	
W-front	1366	(620)	1024	(464)	1451	(658)
W-rear	883	(401)	1369	(621)	1106	(502)
W-total	2249	(1020)	2393	(1085)	2557	(1160)

GVWR Ratings

Front 1808

Rear 1742

Total (3315)

Dummy Data

Type: Hybrid 2

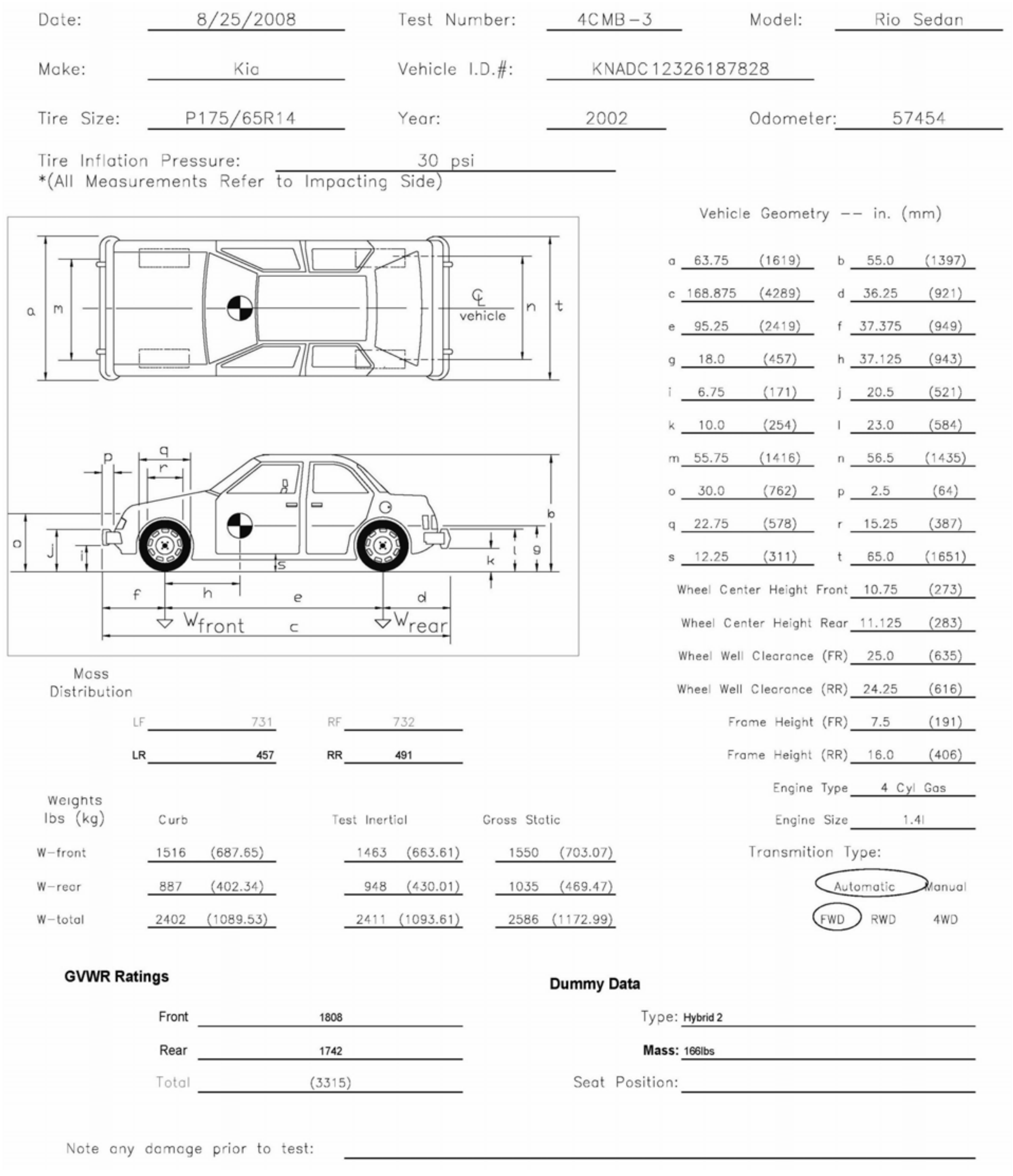
Mass: 166lbs

Seat Position: Driver's side

Note any damage prior to test: none

Figure 23. Vehicle Dimensions, Test No. 4CMB-2

24. Test Vehicle, Test No. 4CMB-3



Date: 8/25/2008 Test Number: 4CMB-3 Model: Rio Sedan

Make: Kia Vehicle I.D.#: KNADC12326187828

Tire Size: P175/65R14 Year: 2002 Odometer: 57454

Tire Inflation Pressure: 30 psi
*(All Measurements Refer to Impacting Side)

Vehicle Geometry -- in. (mm)

a	63.75	(1619)	b	55.0	(1397)
c	168.875	(4289)	d	36.25	(921)
e	95.25	(2419)	f	37.375	(949)
g	18.0	(457)	h	37.125	(943)
i	6.75	(171)	j	20.5	(521)
k	10.0	(254)	l	23.0	(584)
m	55.75	(1416)	n	56.5	(1435)
o	30.0	(762)	p	2.5	(64)
q	22.75	(578)	r	15.25	(387)
s	12.25	(311)	t	65.0	(1651)

Wheel Center Height Front 10.75 (273)
Wheel Center Height Rear 11.125 (283)
Wheel Well Clearance (FR) 25.0 (635)
Wheel Well Clearance (RR) 24.25 (616)
Frame Height (FR) 7.5 (191)
Frame Height (RR) 16.0 (406)
Engine Type 4 Cyl Gas
Engine Size 1.4l

Transmition Type:
[✓ Automatic] Manual
[✓ FWD] RWD 4WD

Mass Distribution

LF 731 RF 732
LR 457 RR 491

Weights lbs (kg)	Curb	Test Inertial	Gross Static
W-front	1516 (687.65)	1463 (663.61)	1550 (703.07)
W-rear	887 (402.34)	948 (430.01)	1035 (469.47)
W-total	2402 (1089.53)	2411 (1093.61)	2586 (1172.99)

GVWR Ratings

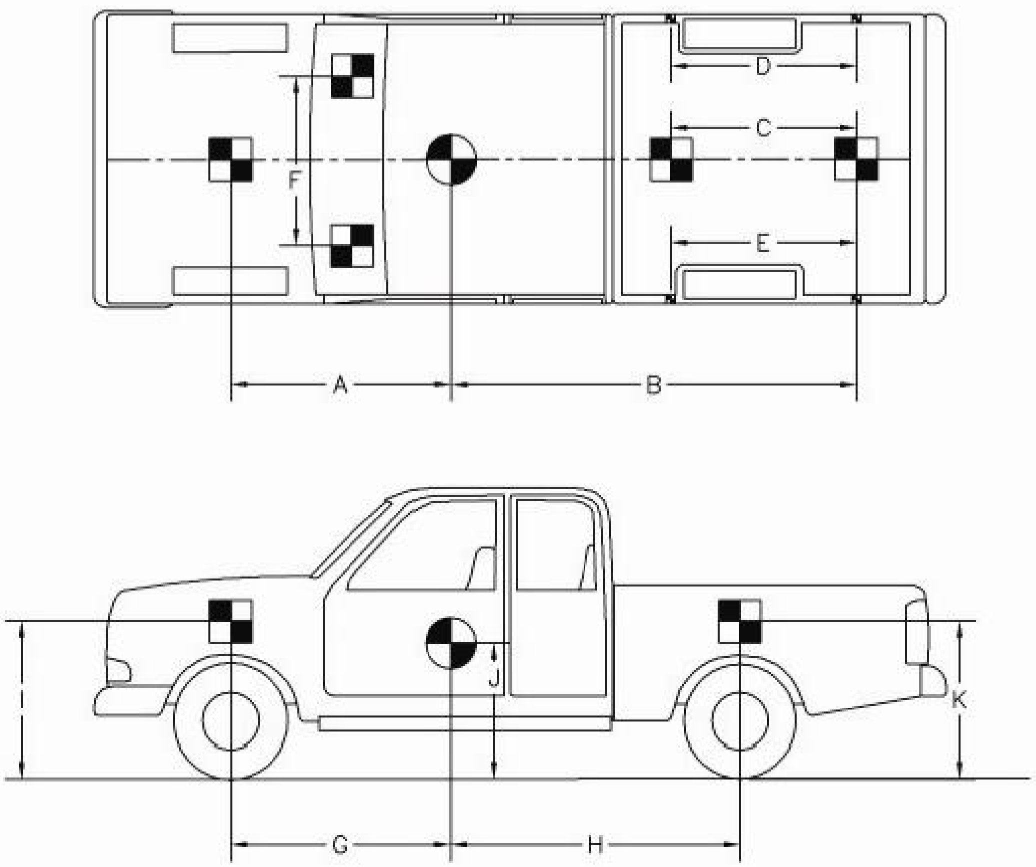
Front 1808
Rear 1742
Total (3315)

Dummy Data

Type: Hybrid 2
Mass: 166lbs
Seat Position:

Note any damage prior to test:

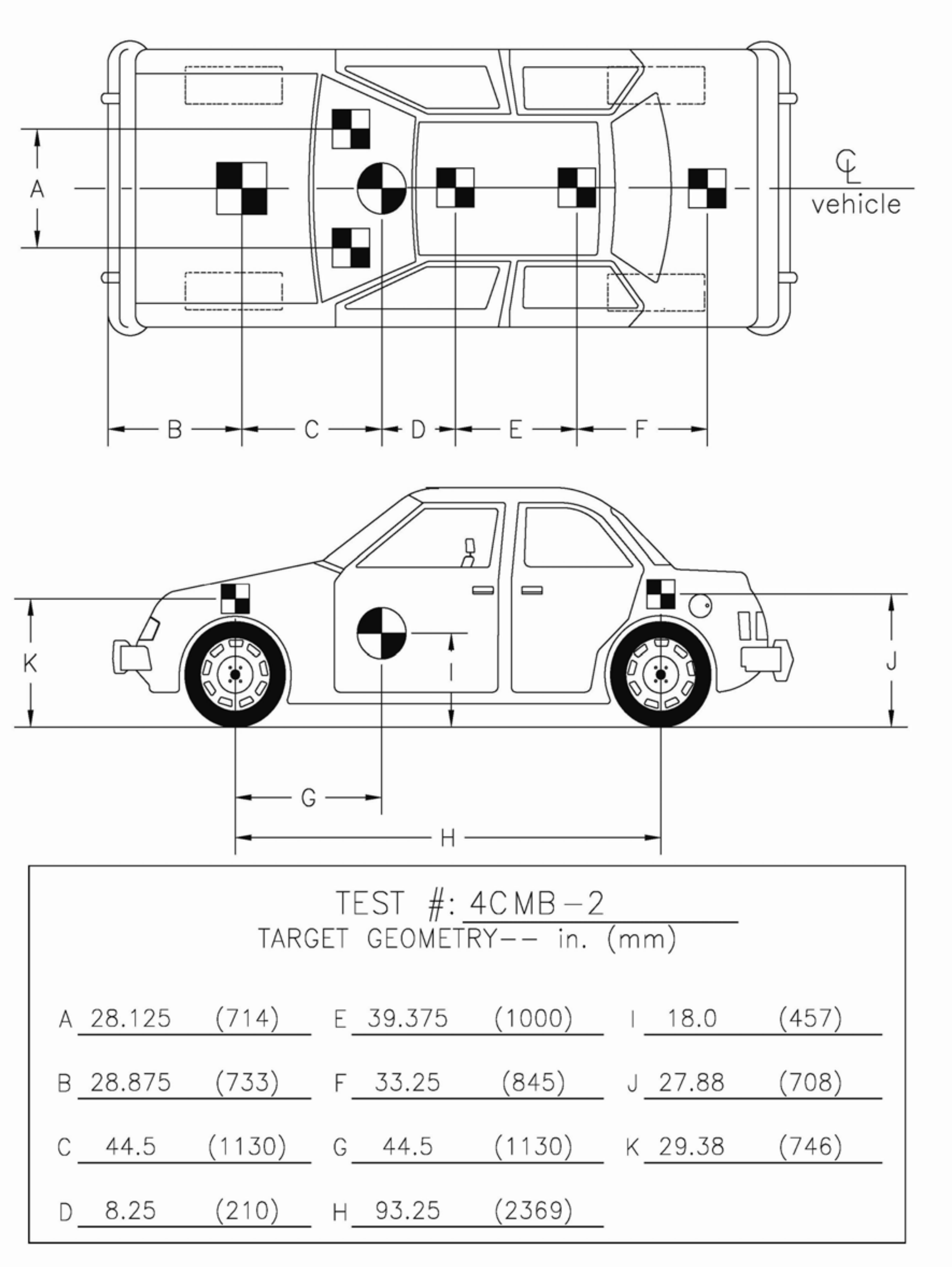
Figure 25. Vehicle Dimensions, Test No. 4CMB-3



TEST #: 4CMB-1
TARGET GEOMETRY-- in. (mm)

A	70.5	(1791)	E	63.75	(1619)	I	40.5	(1029)
B	104.0	(2642)	F	45.75	(1162)	J	28.25	(718)
C	48.0	(1219)	G	62.5	(1588)	K	43.25	(1099)
D	63.5	(1613)	H	78.0	(1981)			

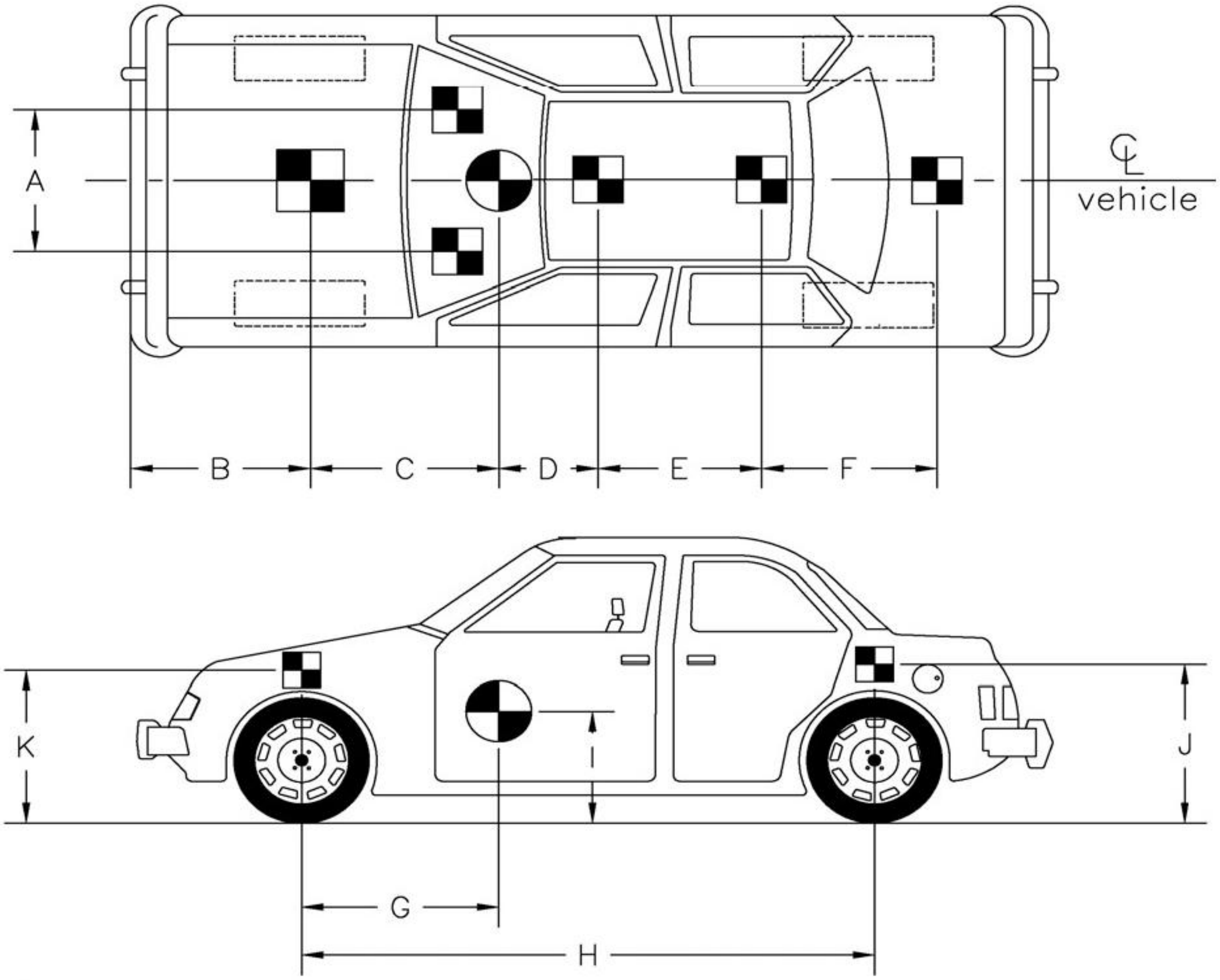
Figure 26. Vehicle Target Locations, Test No. 4CMB-1



TEST #: 4CMB-2
TARGET GEOMETRY-- in. (mm)

A	28.125 (714)	E	39.375 (1000)	I	18.0 (457)
B	28.875 (733)	F	33.25 (845)	J	27.88 (708)
C	44.5 (1130)	G	44.5 (1130)	K	29.38 (746)
D	8.25 (210)	H	93.25 (2369)		

Figure 27. Vehicle Target Locations, Test No. 4CMB-2



TEST #: 4CMB-3
TARGET GEOMETRY-- in. (mm)

A	26.25	667	E	36.0	914	I	18.0	457
B	29.0	737	F	37.25	946	J	28.5	724
C	39.5	1003	G	37.125	943	K	28.75	730
D	12.0	305	H	95.25	2419			

Figure 28. Vehicle Target Locations, Test No. 4CMB-3

5.4 Data Acquisition Systems

5.4.1 Accelerometers

One triaxial piezoresistive accelerometer system with a range of ±200 Gs was 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. “DynaMax 1 (DM-1)” and “DADiSP” were used to analyze and plot the accelerometer data.

A second system consisted of a two-Arm piezoresistive accelerometer that was developed by Endevco of San Juan Capistrano, California. The accelerometer system was used to measure the longitudinal, lateral, and vertical accelerations at a sample rate of 10,000 Hz. Data was collected using a Sensor Input Module (SIM), Model TDAS3-SIM-16M, which was developed by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SIM was configured with 16 MB SRAM memory and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 Communication, and an internal back-up battery. Both the SIM and module rack are crash worthy. Computer software programs “DTS TDAS Control”, “DADiSP”, and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data from the DTS unit. All of the accelerometers were mounted near the center of gravity of the test vehicle.

For test no. 4CMB-1, 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 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. “DynaMax 1 (DM-1)”, “DADiSP”, and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data. Due to technical difficulties with the EDR-4 accelerometer, its data was not used for analysis.

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. “DynaMax 1”, “DADiSP,” and a customized Microsoft Excel worksheet were used to analyze and plot the rate transducer data.

5.4.3 High-Speed Photography

For test no. 4CMB-1, four high-speed AOS VITcam digital video cameras, all operating at 500 frames/sec, were used to film the crash test. Four JVC digital video cameras and two Canon digital video cameras, all with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all ten camera locations for test no. 4CMB-1 are shown in Figure 29.

For test 4CMB-2, five high-speed AOS VITcam digital video cameras, all operating at 500 frames/sec, were used to film the crash test. Four JVC digital video cameras and two Canon digital video cameras, all with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all eleven camera locations for test no. 4CMB-2 is shown in Figure 30.

For test 4CMB-3, four high-speed AOS VITcam digital video cameras, all operating at 500 frames/sec, were used to film the crash test. Five JVC digital video cameras and two Canon digital video cameras, all with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all eleven camera locations for test no. 4CMB-3 is shown in Figure 31.

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

5.4.4 Pressure Tape Switches

For tests 4CMB-1, 4CMB-2, and 4CMB-3, five pressure-activated tape switches, spaced at 6.56-ft (2-m) intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the left-front tire of the test vehicle passed over it. Test vehicle speed was determined from electronic timing mark data recorded using the Test Point software. Strobe lights and high-speed film analysis are used only as a backup in the event that vehicle speed cannot be determined from the electronic data.

5.4.5 Cable Instrumentation

Electronic sensors were placed near the end terminal anchors used in the four-cable, high tension, median barrier system. Load cell and string potentiometers were used and are described below.

5.4.5.1 Load Cells

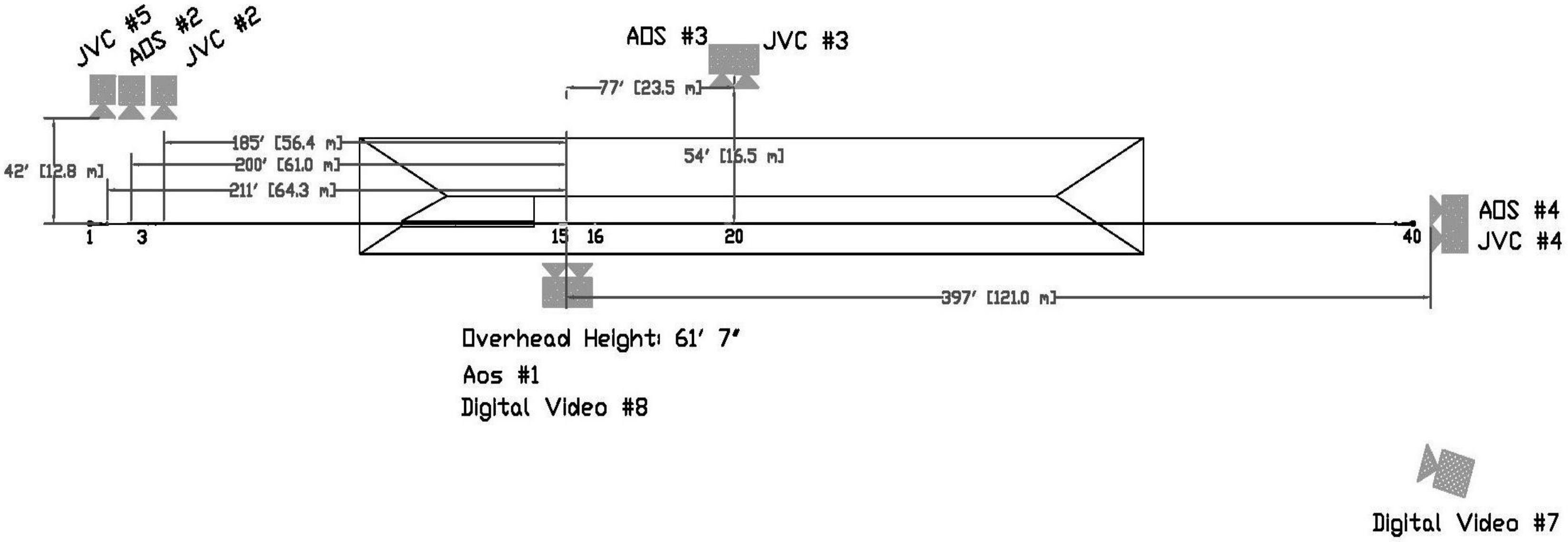
Four load cells were installed along the four-cable barrier system. Each load cell was positioned in line with each cable on the upstream end. The load cells were placed between post nos. 3 and 4, as shown in Figure 32.

The load cells were manufactured by Transducer Techniques and conformed to model no. TLL-50K with a load range up to 50,000 lb (222.4 kN). During testing, output voltage signals were sent from the load cells to a Keithly Metrabyte DAS-1802HC data acquisition board, acquired with Test Point software, and stored permanently on a personal computer. The data collection rate for the load cells was 10,000 samples per second (10,000 Hz).

5.4.5.2 String Potentiometers

A string potentiometer (linear variable displacement transducer) was installed on the upstream end terminal anchorage system and used to monitor longitudinal anchor displacement, as shown in Figure 33.

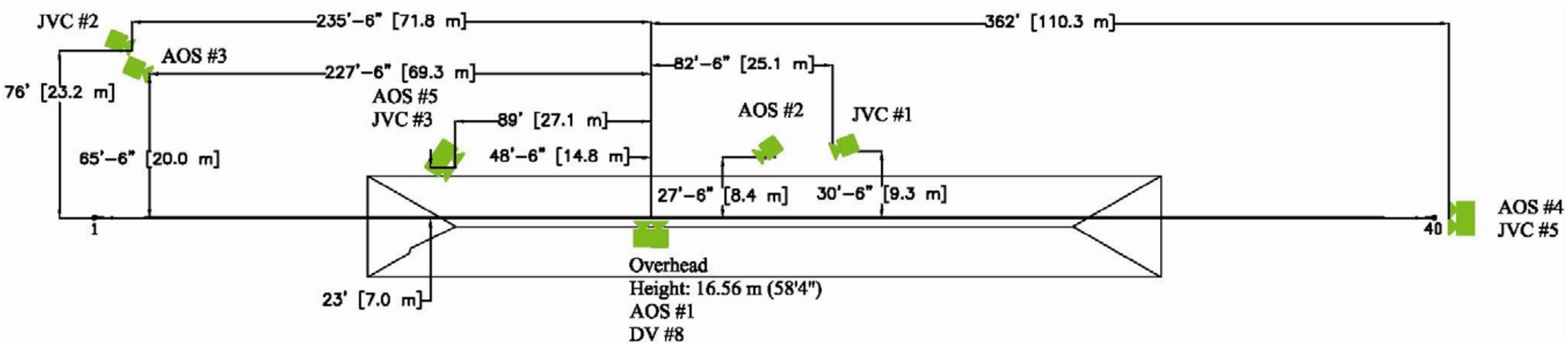
A UniMeasure PA-50 string potentiometer, with a range of 50 in. (1.27 m), was used. A Measurements Group Vishay Model 2310 signal conditioning amplifier was used to condition and amplify the low-level signals to high-level outputs for multichannel, simultaneous dynamic recording on the Test Point software. After each signal was amplified, it was sent to a Keithly Metrabyte DAS-1802HC data acquisition board and then stored permanently on a personal computer. The data collection rate for of the string potentiometers was 10,000 samples per second (10,000 Hz).



4CMB-1 Camera Summary

	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	1	AOS Vitcam CTM	500	8.5 mm fixed	
	2	AOS Vitcam CTM	500	12.5 mm fixed	
	3	AOS Vitcam CTM	500	COMPUTAR 12.5 mm fixed	
	4	AOS Vitcam CTM	500	Sigma 70-200	70
Digital Video	2	JVC - GZ-MC500 (Everio)	29.97		
	3	JVC - GZ-MC500 (Everio)	29.97		
	4	JVC - GZ-MC500 (Everio)	29.97		
	5	JVC - GZ-MC500 (Everio)	29.97		
	7	Canon-ZR90	29.97		
	8	Canon-ZR90	29.97		

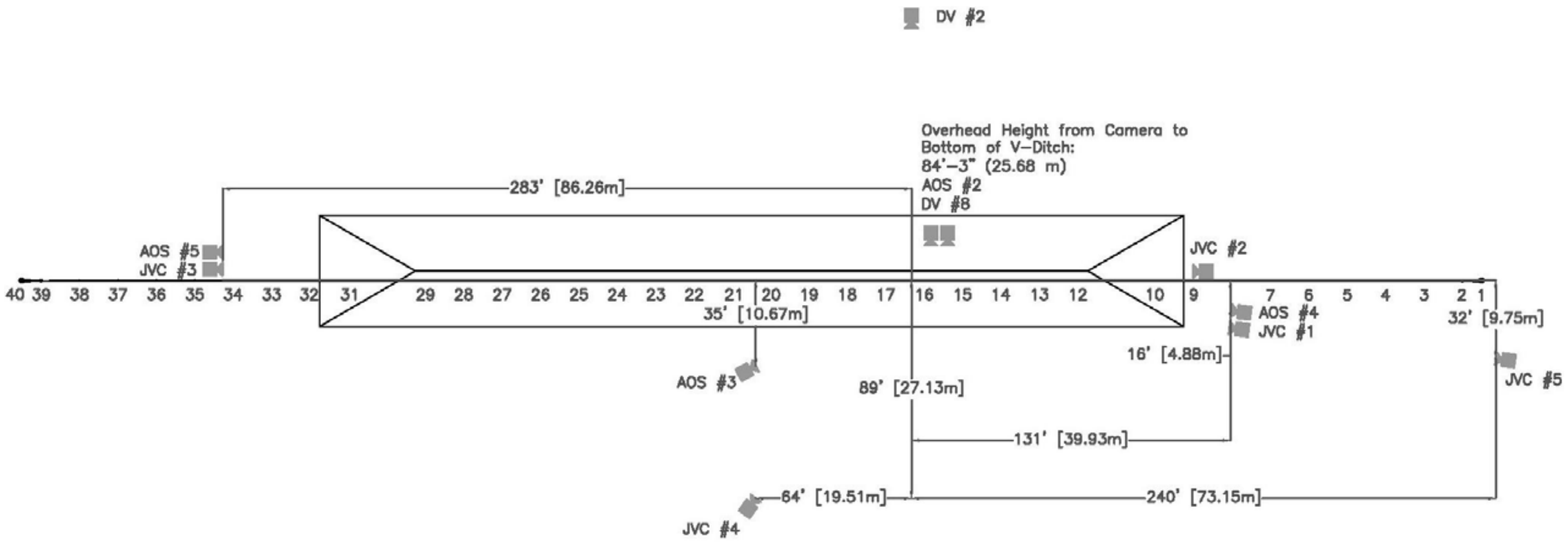
Figure 29. Camera Locations, Test No. 4CMB-1



4CMB-2 Camera Summary

	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	1	AOS Vitcam CTM	500	8.5 mm fixed	
	2	AOS Vitcam CTM	500	12.5 mm fixed	
	3	AOS Vitcam CTM	500	COMPUTAR 12.5 mm fixed	
	4	AOS Vitcam CTM	500	Sigma 70-200	200
	5	AOS Vitcam CTM	500	Sigma 24-70	28
Digital Video	1	JVC - GZ-MC500 (Everio)	29.97		
	2	JVC - GZ-MC500 (Everio)	29.97		
	3	JVC - GZ-MC500 (Everio)	29.97		
	5	JVC - GZ-MC500 (Everio)	29.97		
	7	Canon-ZR90	29.97		
	8	Canon-ZR90	29.97		

Figure 30. Camera Locations, Test No. 4CMB-2



4CMB-3 Camera Summary

	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	2	AOS Vitcam CTM	500	8 mm fixed	
	3	AOS Vitcam CTM	500	6.5 mm fixed	
	4	AOS Vitcam CTM	500	Sigma 24-70	24
	5	AOS Vitcam CTM	500	Sigma 70-200	100
Digital Video	1	JVC - GZ-MC500 (Everio)	29.97		
	2	JVC - GZ-MC500 (Everio)	29.97		
	3	JVC - GZ-MC500 (Everio)	29.97		
	4	JVC - GZ-MC500 (Everio)	29.97		
	5	JVC - GZ-MC500 (Everio)	29.97		
	2	Canon-ZR10	29.97		
	8	Canon-ZR90	29.97		

Figure 31. Camera Locations, Test No. 4CMB-3

Figure 32. Typical Load Cell Locations

Figure 33. Typical String Potentiometer Positioning

6 FULL-SCALE CRASH TEST NO. 4CMB-1

6.1 Test No. 4CMB-1

The 4,988-lb (2,263-kg) pickup truck impacted the cable median barrier at a speed of 61.8 mph (99.4 km/h) and at an angle of 27.9 degrees. A summary of the test results and sequential photographs are shown in Figure 34. Additional sequential photographs are shown in Figures 35 and 36. Documentary photographs are shown in Figure 37.

6.2 Weather Conditions

Test no. 4CMB-1 was conducted on October 30, 2007 at approximately 3:30 pm. The weather conditions were documented, as shown in Table 4.

Table 4. Weather Conditions, Test No. 4CMB-1

Temperature	72° F
Humidity	40 %
Wind Speed	21 mph
Wind Direction	180° from True North
Sky Conditions	Overcast
Visibility	14.2 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

6.3 Test Description

Initial vehicle impact was to occur between post nos. 15 and 16, or 36 in. (914 mm) downstream from post no. 15, as shown in Figure 38. Table 5 contains a sequential description of the impact events. The final position of the vehicle was determined to be 143 ft (43.6 m) downstream of impact and 4 ft - 6 in. (1.4 m) laterally behind the barrier as shown in Figure 39.

Table 5. Sequential Description of Impact Events, Test No. 4CMB-1

Time (sec)	Event
-0.258	Left-front tire encroached upon the ditch, and the vehicle rolled to the left and pitched downward.
0.000	Vehicle impacted the top cable of the barrier system.
0.012	Post no. 15 began to deflect laterally backward and rotated counterclockwise.
0.028	Vehicle became airborne.
0.040	Post nos. 14 and 16 deflected laterally backward.
0.062	Left-front tire overrode the bottom three cables while the top cable was wrapped around the left-front quarter panel.
0.102	Front of the vehicle contacted post no. 16.
0.116	Post no. 17 deflected laterally backward.
0.120	Vehicle began to redirect downstream.
0.148	Top cable detached from post no. 16, and the right-front side of the grill contacted post no. 15.
0.168	Post no. 18 deflected laterally backward.
0.194	Post no. 19 deflected laterally backward.
0.206	Upper-middle cable disengaged from post no. 15.
0.216	Top cable disengaged from post no. 17.
0.270	Post no. 20 deflected laterally backward.
0.276	Right-front tire overrode the bottom three cables.
0.292	Left-front tire contacted the ground.
0.352	Left-rear tire contacted the ground.
0.392	Top cable disengaged from post no. 18.
0.406	Post no. 21 deflected laterally backward.
0.414	Top cable disengaged from post no. 15.
0.466	Top cable disengaged from post no. 19.
0.478	Post no. 22 deflected laterally backward.
0.508	Post no. 23 deflected laterally backward.
0.514	Right-front tire contacted the ground.
0.620	Truck began to roll to the right.

0.634	Left-front tire became airborne.
0.640	Vehicle yawed to the left and continued to roll to the right.
0.726	Top cable disengaged from post no. 20.
0.876	Vehicle yawed to the right as it exited the barrier.
1.164	Vehicle was parallel to the barrier.
1.622	Top cable disengaged from post no. 21.
1.674	Left-front tire contacted the ground, and the vehicle ceased to roll.

6.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 40 through 43. Barrier damage consisted of bent and rotated guardrail posts and detached cables. During the test, the vehicle was in contact with the cable median barrier for 143 ft (43.6 m), which spanned from the point of impact to post no. 24. After the test, the vehicle remained in contact with the system.

The top cable bracket on post no. 3 was removed. The cable and brackets were still attached for post nos. 4 through 14. The top two cable brackets on post no. 15 were removed, and the bottom two cable brackets were slightly bent. The top two cable brackets on post no. 16 were also removed, and the bottom two brackets were deformed. The top two cable brackets on post no. 17 were removed, and the bottom two brackets were slightly bent. The top two cable brackets on post no. 18 were removed, the third bracket from the top was slightly bent, and the bottom bracket showed no visible damage. The top two cable brackets on post no. 19 were also removed, and the bottom two brackets were bent. The top three cable brackets on post no. 20 were removed, the lower bolt for the third bracket was also missing, and the bottom bracket was deformed. All cable brackets for post nos. 21 through 24 were removed, with the exception of the top bracket on post no. 22. The top bracket on post no. 38 was also removed.

Post nos. 8 through 11 had a maximum groundline deflection of ¼ in. (6 mm) with post no.

8 moving in the downstream direction and post nos. 10 and 11 deflecting backward. Post no. 12 was pushed backward approximately 1⅞ in. (48 mm) with a 2-ft (610-mm) soil crack along the front flange of the post with soil movement forming a 1-ft (305-mm) radius, half-circle crack behind the post. Post no. 13 was deflected backward 3⅝ in. (92 mm) at the groundline. Post no. 14 was deflected backward 1⅝ in. (41 mm) at the groundline and was twisted approximately 45 degrees in a counterclockwise direction. A 2-ft (610-mm) long soil crack was observed along the front flange of the post no. 14, thus creating a 1-ft (305-mm) radius soil crack behind the post. Post no. 15 deflected backward 1¾ in. (44 mm) at the groundline and was twisted approximately 45 degrees in the counterclockwise direction. Post no. 16 deflected backward 3 in. (76 mm) and downstream 5 in. (127 mm) at the groundline. Post no. 16 also encountered minor twisting in the counterclockwise direction. Post no. 17 deflected backward 5½ in. (140 mm) and downstream 2 in. (51 mm) at the groundline. Post no. 18 deflected backward 5 in. (127 mm) and downstream 3 in. (76 mm) at the groundline. Post no. 19 deflected backward 6½ in. (165 mm) and downstream 5 in. (127 mm) at the groundline. Post no. 20 was deflected both backward and downstream approximately 9½ in. (241 mm) at the groundline with the top of the post positioned 18 in. (457 mm) above the ground. At the groundline, post no. 21 was pushed backward 8¼ in. (210 mm) and downstream 7 in. (178 mm) with the top of the post positioned 9 in. (229 mm) above the ground. Post no. 22 deflected backward 3½ in. (89 mm) and downstream 5¾ in. (146 mm) at the groundline with the top of the post positioned 15 in. (381 mm) above the ground. Post no. 23 was deflected backward 1⅛ in. (29 mm) and downstream 4½ in. (114 mm) at the groundline with the top of the post positioned 14½ in. (368 mm) above the ground. Post no. 24 deflected backward 2½ in. (64 mm) and downstream 2 in. (51 mm) at the groundline with the top of the post positioned 12 in. (305 mm) above the ground and held

down by the truck. Post no. 25 was pushed backward ⅛ in. (3 mm) at the groundline, while post nos. 27 and 30 were shifted forward ⅛ in. (3 mm) at the groundline.

The permanent set of the posts is shown in Figures 41 through 43. The maximum lateral permanent set post deflections were not calculated for this test. The maximum lateral dynamic post deflection was 54 in. (1,372 mm) at post no. 18, as determined from the high-speed video analysis. The maximum lateral cable deflection occurred in the top cable and was determined to be 170.1 in. (4,321 mm) and the working width was determined to be 173.1 in. (4,397 mm), as determined from high speed video analysis.

6.5 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 44 through 46 and Figure 48. Occupant compartment deformation was minimal and did not exceed ½ in. (13 mm) of deformation, as shown in Figure 47.

Driver’s side damage consisted of a creased fender near the front door joint; a broken headlight lens cover; major cable scrapes and marks 12 in. (305 mm) up from the bottom of the door; gouging through the sheet metal, fender, and door approximately 6 in. (152 mm) long; and more cable scrapes and marks along the entire length of vehicle at approximately the c.g. height. The passenger side damage consisted of the rear tail light cover removed; scrapes along the entire length of the box, continuing up to the front door handle; smaller scrapes and deformations along the bottom of the door; 3-in. (76-mm) long tears near both door handles; right-front tire disengagement from the rim; and a 1-in. (25 mm) long tear along the tire sidewall. The front of the vehicle received major deformation on the bumper, primarily on the left side. The plastic bumper cover was also removed. The undercarriage showed slight scraping on the right lower control arm, the lower tie rod was pulled out on the right-front side, the right-rear shock was deformed near the lower connection, and there was slight scraping on the drive shaft and other components.

6.6 Occupant Risk Values

The calculated occupant impact velocities (OIVs) and 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 6. It is noted that the OIV's and ORA's were within the suggested limits provided in MASH. The calculated THIV and PHD values are also shown in Table 6. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 34. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix B. The EDR-4 data was collected during the test, but researchers believed that the data inaccurately represented the impact event as the data was inconsistent with the other accelerometers. The DTS was mounted in a different location than the EDR-3, resulting in a large difference between the longitudinal OIV values.

Table 6. Summary of OIV, ORA, THIV, and PHD Values, Test No. 4CMB-1

Evaluation Criteria		Transducers	
		EDR-3	DTS
OIV [ft/s (m/s)]	Longitudinal	-5.93 (-1.81)	-8.53 (-2.60)
	Lateral	9.06 (2.76)	8.97 (2.73)
ORA [g's]	Longitudinal	-5.19	-5.33
	Lateral	3.97	4.61
THIV [ft/s (m/s)]		N/A	10.00 (3.05)
PHD [g's]		N/A	5.54

6.7 Load Cell Results

As previously discussed, tension load cells were installed inline with the cables at the upstream end of the barrier system in order to monitor the total load transferred to the anchor with respect to time. The load cell results are summarized in Table 7. As noted previously, the target cable tension was 4,213 lb (18.7 kN) at 100 deg Fahrenheit (23.6 deg Celsius). Prior to the testing, the actual cable tension in the top, upper middle, lower middle, and bottom cables was 4,160 lb (18.5 kN), 4,140 lb (18.4 kN), 4,020 lb (17.9 kN), and 4,060 lb (18.1 kN), respectively. These readings were measured using a cable tension meter or cable tensiometer.

The individual cable loads, along with the total combined cable load imparted to the upstream end anchor, were determined and are shown graphically in Figure 49. The total axial force imparted to the upstream anchor was 46.82 kips (208.3 kN) and occurring at 0.459 sec after vehicle impact with the barrier system. The maximum cable force was 23.28 kips (103.6 kN) and occurred in the top cable. The upper middle and lower middle cables experienced a maximum load of 13.67 kips (60.81 kN) and 10.86 kips (48.31 kN), respectively. The bottom cable experienced a maximum load of 7.08 kips (31.49 kN).

Table 7. Load Cell Results, Test No. 4CMB-1

Cable Location	Sensor Location	Maximum Cable Load		Time[1] (sec)
		kips	kN	
Combined Cables	Upstream End	46.82	208.3	0.459
Top Cable	Upstream End	23.28	103.6	0.392
Upper Middle Cable	Upstream End	13.67	60.80	0.569
Lower Middle Cable	Upstream End	10.86	48.30	1.484
Bottom Cable	Upstream End	7.08	31.49	0.204

[1] - Time determined from initial vehicle impact with the barrier system.

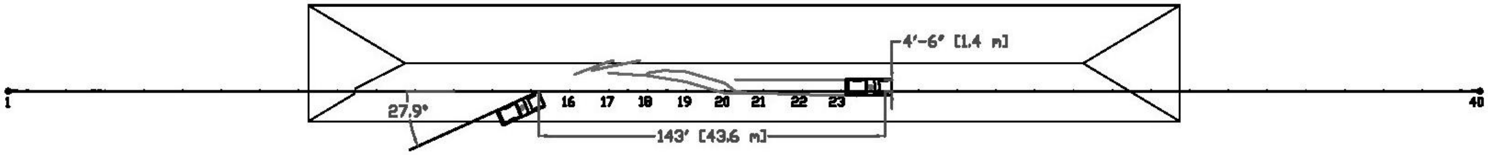
After the crash test, the tension in each cable was again measured using the cable tensiometer. With the pickup truck engaged with the cable barrier system, the cable tension at the upstream end and in the top, upper middle, lower middle, and bottom cables was 1,580 lb (7.0 kN), 3,120 lb (13.9 kN), 3,320 lb (14.8 kN), and 3,480 lb (15.5 kN), respectively. On the contrary and with the pickup truck engaged with the barrier, the cable tension at the downstream end and in the top, upper middle, lower middle, and bottom cables was 1,540 lb (6.9 kN), 3,120 lb (13.9 kN), 3,360 lb (14.9 kN), and 3,640 lb (16.2 kN), respectively.

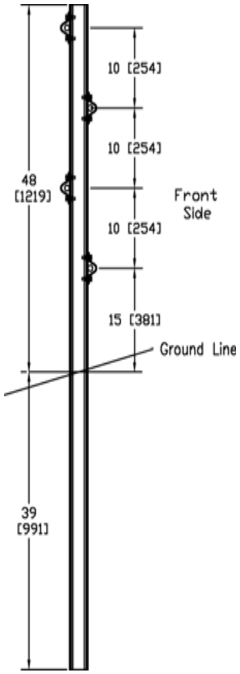
With the pickup truck disengaged from the cable barrier system, the cable tension at the upstream end and in the top, upper middle, lower middle, and bottom cables was 880 lb (3.9 kN), 2,460 lb (10.9 kN), 3,140 lb (14.0 kN), and 3,580 lb (15.9 kN), respectively. On the contrary and with the pickup truck disengaged from the barrier, the cable tension at the downstream end and in the top, upper middle, lower middle, and bottom cables was 800 lb (3.6 kN), 2,240 lb (10.0 kN), 3,140 lb (14.0 kN), and 3,640 lb (16.2 kN), respectively.

6.8 Discussion

The analysis of the test results for test no. 4CMB-1 (test designation no. 3-11) showed that the high-tension, four-cable median barrier system adequately contained and redirected the 2270P vehicle when the barrier was placed in a V-ditch with 4H:1V side slopes and 12 ft laterally away from the slope break point. The vehicle remained upright after collision with the barrier system. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. After collision, the vehicle’s trajectory did not intrude into adjacent traffic lanes as it remained within the ditch section. Therefore, test no. 4CMB-1 was determined to be acceptable according to the TL-3 safety performance criteria found in MASH.


0.000 sec 0.120 sec 0.276 sec 0.376 sec 0.618 sec





Test Agency	MwRSF
Test Number	4CMB-1
Date	10/30/07
NCHRP 350 Update Test Designation	3-11
Appurtenance	Four-Cable High-Tension Median Barrier Installed on 4:1 Slope
Median Width	46 ft (14.0 m)
Total Length	608 ft (1.85 m)
Placement	12 ft (3.7 m) down from slope break point
Key Elements - Wire Rope	
Diameter	¾ in. (19 mm)
Size	3x7
Top Cable Height	45 in. (1,143 mm)
Bottom Cable Height	15 in. (381 mm)
Incremental Spacing	10 in. (254 mm)
Key Elements - End Anchor Posts	
Post Nos. 1 and 40	24 in. (610 mm) diameter by 120 in. (3,048 mm) long concrete footer
Post Nos. 2 and 39	S3x5.7 (S76x8.5) by 28⅛ in. (714 mm) long with S3x5.7 (S76x8.5) by 19 in. (483 mm) 12 in. (305 mm) diameter by 46 in. (1,168 mm) long concrete footer
Key Elements - Line Posts	
Post Nos. 3-38	S3x5.7 (S76x8.5) by 87 in. (2,210 mm) long
Spacing	16 ft (4.9 m)
Type of Soil	Grading B - AASHTO M 147-65 (1990)
Test Vehicle	
Type/Designation	2270P
Make and Model	2002 Dodge Ram 1500 Quad Cab
Curb	5,052 lb (2,291 kg)
Test Inertial	4,988 lb (2,263 kg)
Gross Static	4,988 lb (2,263 kg)
Impact Conditions	
Speed	61.8 mph (99.4 km/h)
Angle	27.9 degrees
Impact Location	3 ft (914 mm) downstream of post 15
Exit Conditions	
Speed	N/A
Angle	N/A
Exit Box Criterion	N/A

Post-Impact Trajectory	
Vehicle Stability	Satisfactory
Stopping Distance	143 ft (43.6 m) downstream 4½ ft (1.4 m) laterally behind
Occupant Impact Velocity (EDR-3)	
Longitudinal	-5.93 ft/s (1.81 m/s) < 40 ft/s (12.2 m/s)
Lateral	9.06 ft/s (2.76 m/s) < 40 ft/s (12.2 m/s)
Occupant Ridedown Acceleration (EDR-3)	
Longitudinal	-5.19 g's < 20.49 g's
Lateral	3.97 g's < 20.49 g's
Occupant Impact Velocity (EDR-4)	
Longitudinal	-6.09 ft/s (1.86 m/s) < 40 ft/s (12.2 m/s)
Lateral	6.43 ft/s (1.96 m/s) < 40 ft/s (12.2 m/s)
Occupant Ridedown Acceleration (EDR-4)	
Longitudinal	-3.58 g's < 20.49 g's
Lateral	2.74 g's < 20.49 g's
Occupant Impact Velocity (DTS)	
Longitudinal	-8.53 ft/s (-2.60) < 40 ft/s (12.2 m/s)
Lateral	8.97 ft/s < (2.73 m/s) 40 ft/s (12.2 m/s)
Occupant Ridedown Acceleration (DTS)	
Longitudinal	-5.33 g's < 20.49 g's
Lateral	4.61 g's < 20.49 g's
THIV (not required)	10.00 ft/s (30.48 m/s)
PHD (not required)	5.54 g's
Test Article Damage	Minimal
Test Article Deflections	
Permanent Set	N/A
Dynamic (Post)	54 in. (1,372 mm)
Dynamic (Cable)	170.1 in. (4,321 mm)
Working Width	173.1 in. (4,397 mm)
Vehicle Damage	Minimal
VDS[8]	11-LFQ-2
CDC[9]	11-LYEN5
Maximum Deformation	½ in. (13 mm)
Angular Displacements	
Roll	-29.8 deg
Pitch	-7.6 deg
Yaw	26.5 deg

Figure 34. Summary of Test Results and Sequential Photographs, Test No. 4CMB-1

0.642 sec

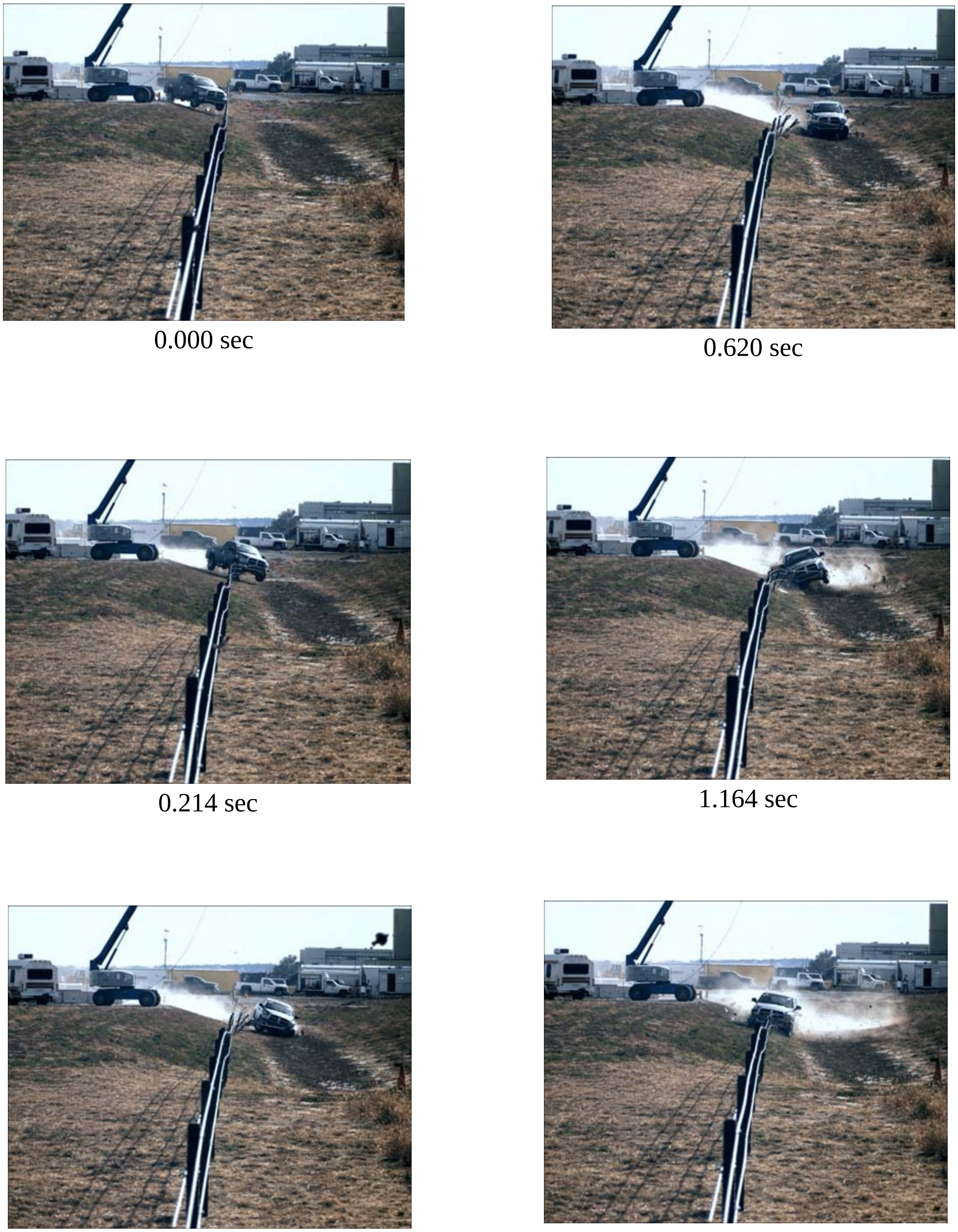
1.022 sec

1.288 sec

1.560 sec

1.676 sec

Figure 35. Additional Sequential Photographs, Test No. 4CMB-1



0.000 sec

0.214 sec

0.466 sec

0.620 sec

1.164 sec

1.674 sec

Figure 36. Additional Sequential Photographs, Test No. 4CMB-1

Figure 37. Documentary Photographs, Test No. 4CMB-1

Figure 38. Impact Location, Test No. 4CMB-1

Figure 39. Vehicle Final Position and Trajectory Marks, Test No. 4CMB-1

Figure 40. System Damage, Test No. 4CMB-1

Figure 41. Posts Nos. 14-16 Damage, Test No. 4CMB-1

Figure 42. Posts Nos. 17-19 Damage, Test No. 4CMB-1

Figure 43. Post Nos. 20-22 Damage, Test No. 4CMB-1

Figure 44. Vehicle Damage, Test No. 4CMB-1

Figure 45. Vehicle Damage, Test No. 4CMB-1

Figure 46. Vehicle Damage, Test No. 4CMB-1

Figure 47. Occupant Compartment Damage, Test No. 4CMB-1

Figure 48. Vehicle Undercarriage Damage, Test No. 4CMB-1

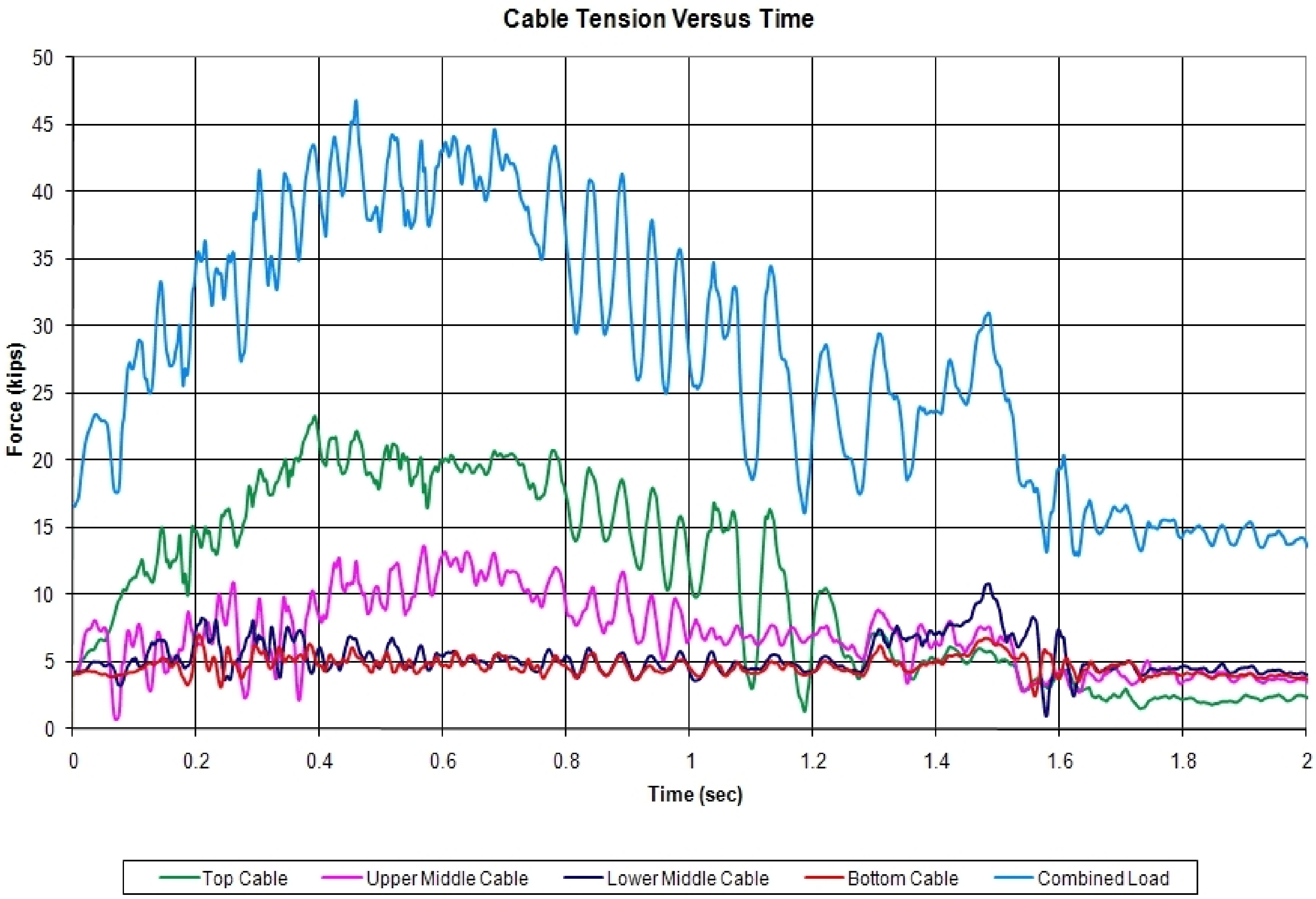


Figure 49. Cable Tension Versus Time, Test No. 4CMB-1

7 DESIGN DETAILS AND MODIFICATIONS FOR TEST NO. 4CMB-2

For test no. 4CMB-2, the actual barrier system was nearly identical to the system that was constructed and evaluated in test no. 4CMB-1. However, some minor changes were incorporated into the overall configuration. First, the barrier system was repositioned to a new location on the back slope where the centerline of the steel posts were installed 4 ft (1.2 m) laterally from the bottom of the V-ditch in order to maximize the potential for the small car to underride the bottom cable.

The cable heights, post spacings, and post embedment depths were identical to those used in test no. 4CMB-1. The only difference was that the cable placement relative to the post was reversed. For test no. 4CMB-2, the bottom cable (cable no. 4) and the second cable (cable no. 2) were attached to the back side of the posts, while the third cable (cable no. 3) and the top cable (cable no. 1) were placed on the impacted side of the posts.

The end anchors were installed with a 3-ft (0.9-m) lateral offset away from the ditch bottom and in the direction of the back slope. Therefore, the end anchors were positioned with a 1-ft (0.3 m) lateral offset toward the traffic-side face of the barrier system. This 1-ft (0.3 m) lateral offset was removed by installing post nos. 1 through 9 and 32 through 40 on a taper or through the use of a flared end section. The updated system drawings for test no 4CMB-2 are shown in Figures 102 and 117.

For test no. 4CMB-2, the bottom of the 4H:1V V-ditch was appropriated graded surrounding the cable median barrier system. However, the bottom surface region of the V-ditch was not compacted as firmly as utilized for the soil material which supported the actual steel posts. Instead, the V-ditch bottom surface was constructed in a manner that was believed to allow or accentuate some tire rutting and an increased propensity for underride. However, researchers also understood that there may be a potential for increased loss of vehicle speed prior to striking the barrier system. As such, the ground surface was believed to provide somewhat of a soft-soil condition when the airborne small car would contact the ditch bottom, undergo compression of the front suspension, and have the leading corner of the front bumper gouge the sloped terrain.

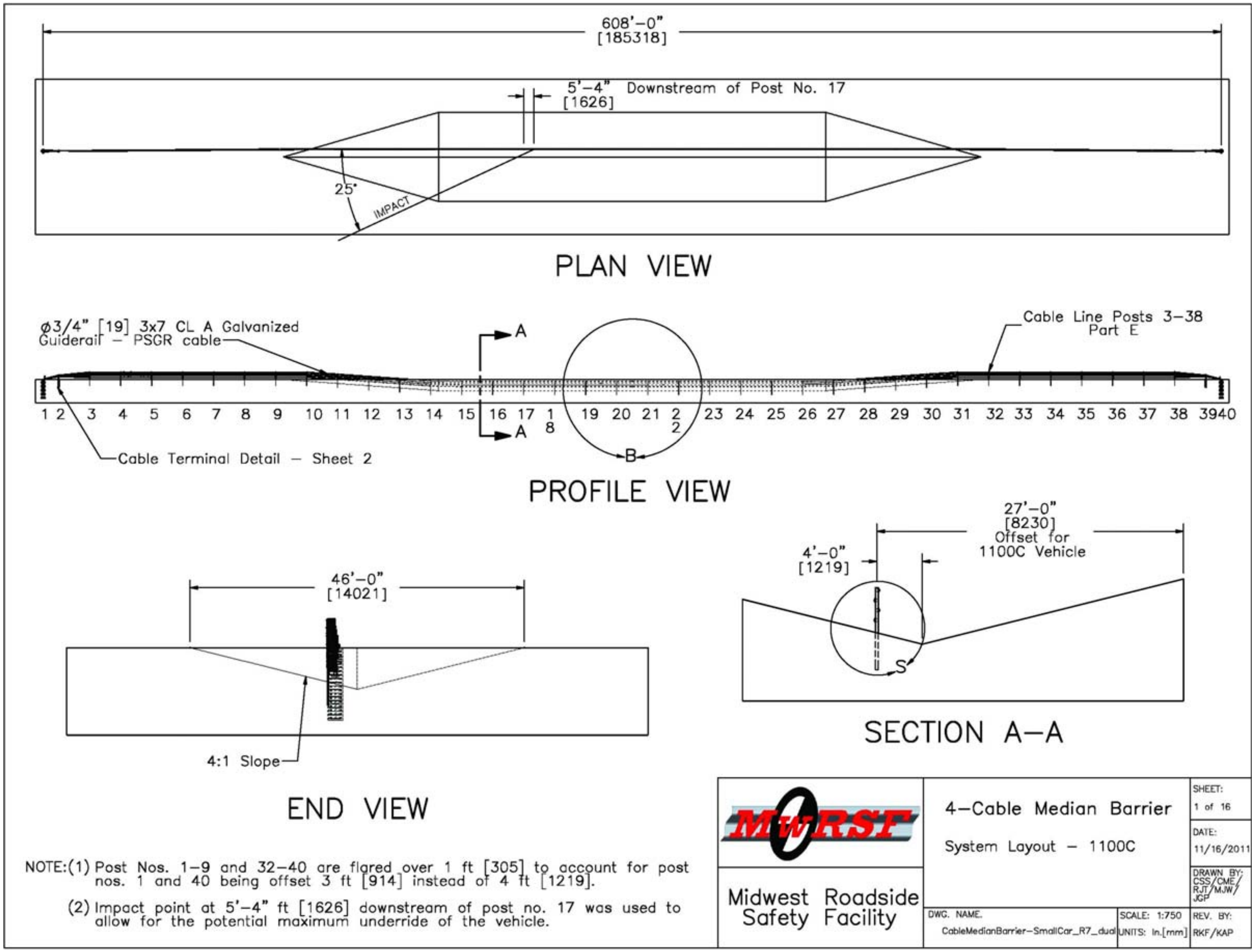


Figure 50. System Layout, Test No. 4CMB-2

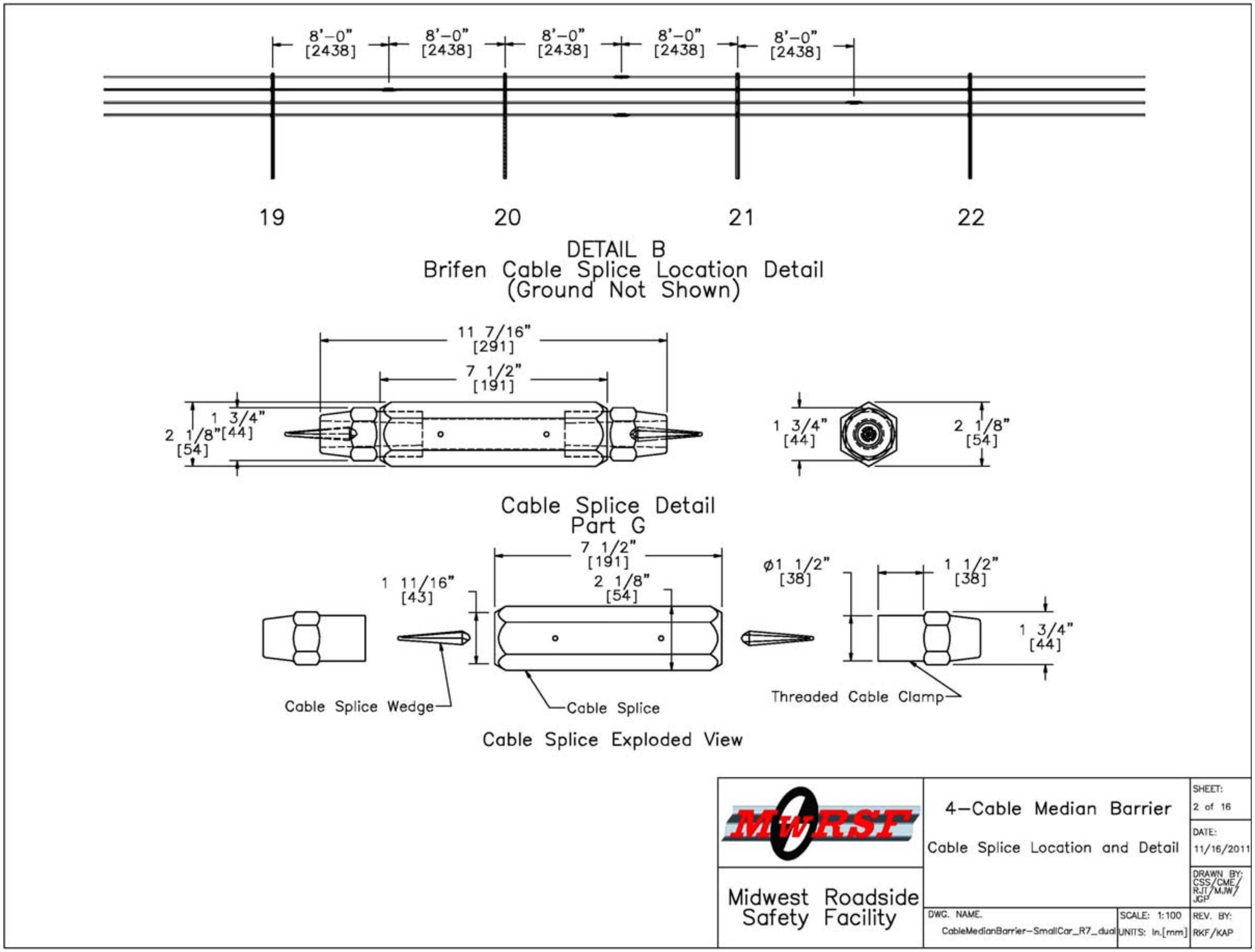


Figure 51. Cable Splice Location and Detail, Test No. 4CMB-2

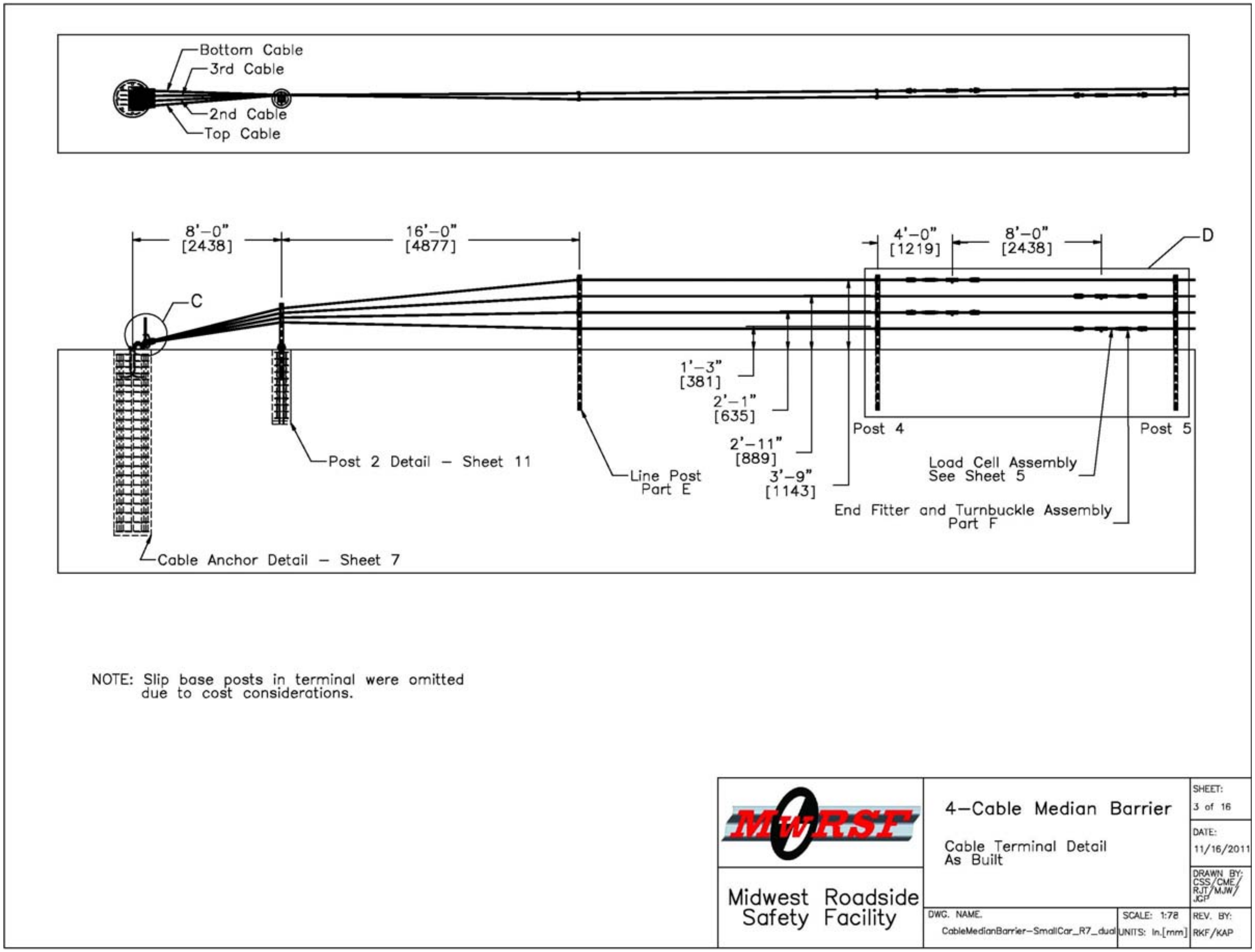


Figure 52. Cable Terminal Detail, Test No. 4CMB-2

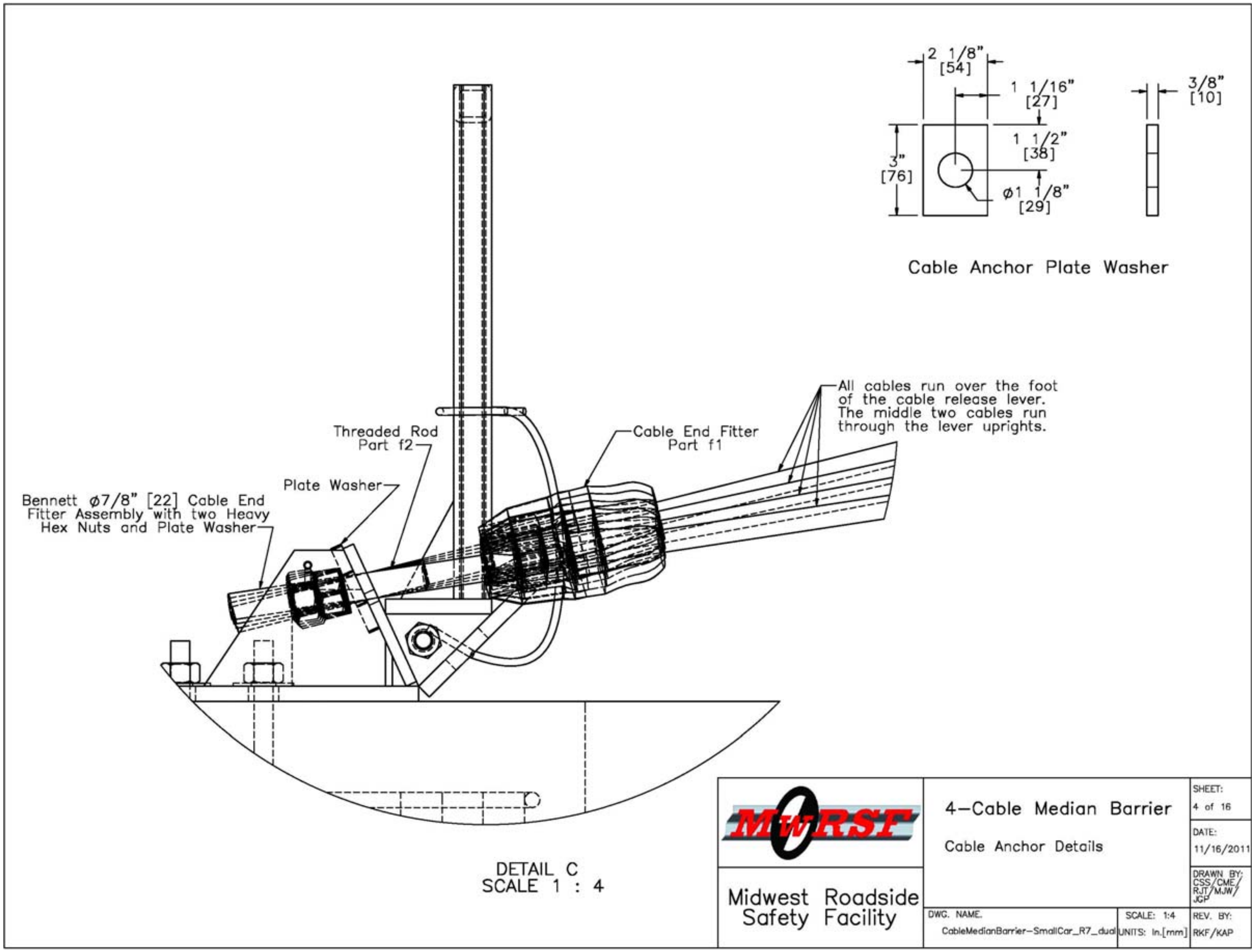


Figure 53. Cable Anchor Details, Test No. 4CMB-2

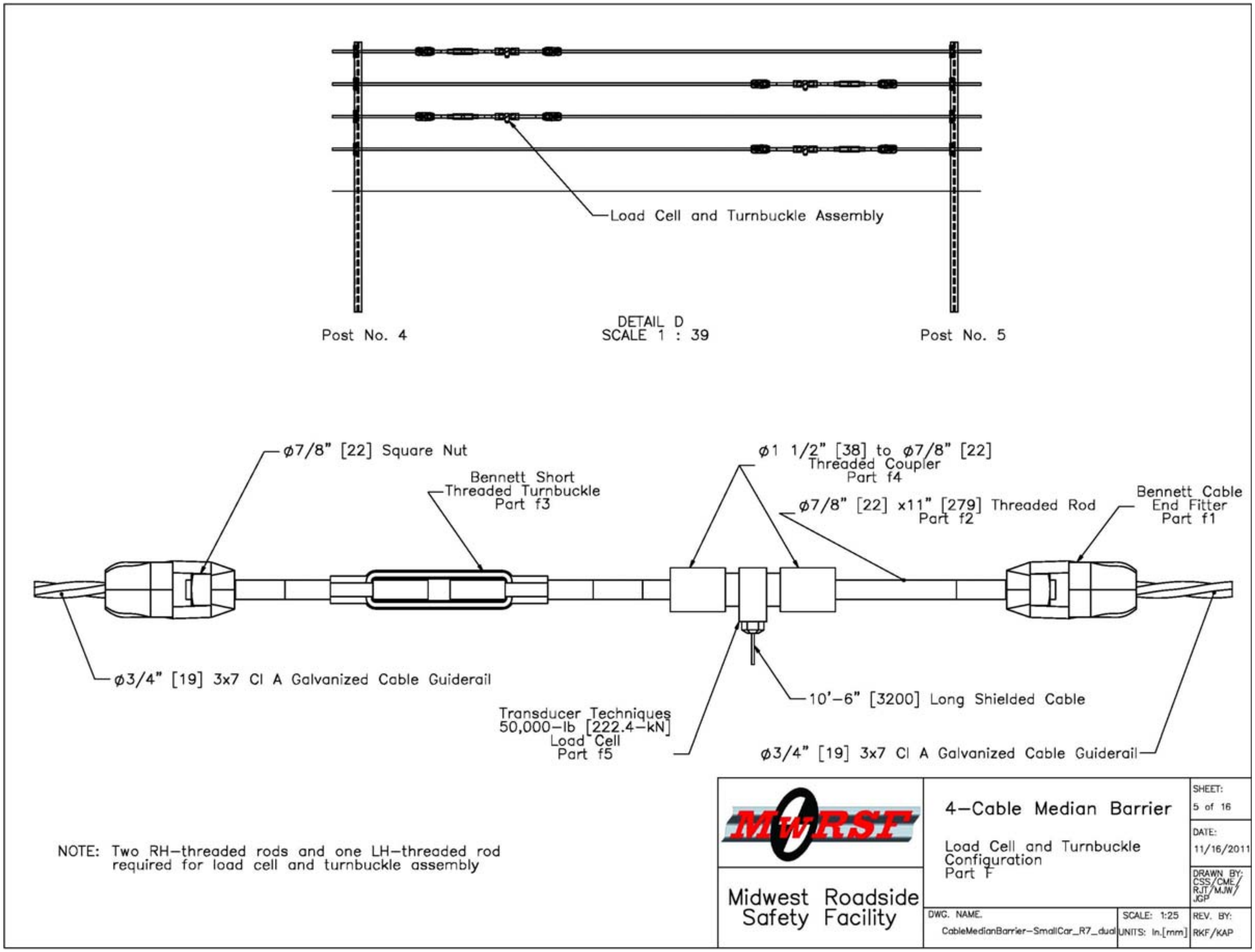


Figure 54. Load Cell and Strongback Configuration, Test No. 4CMB-2

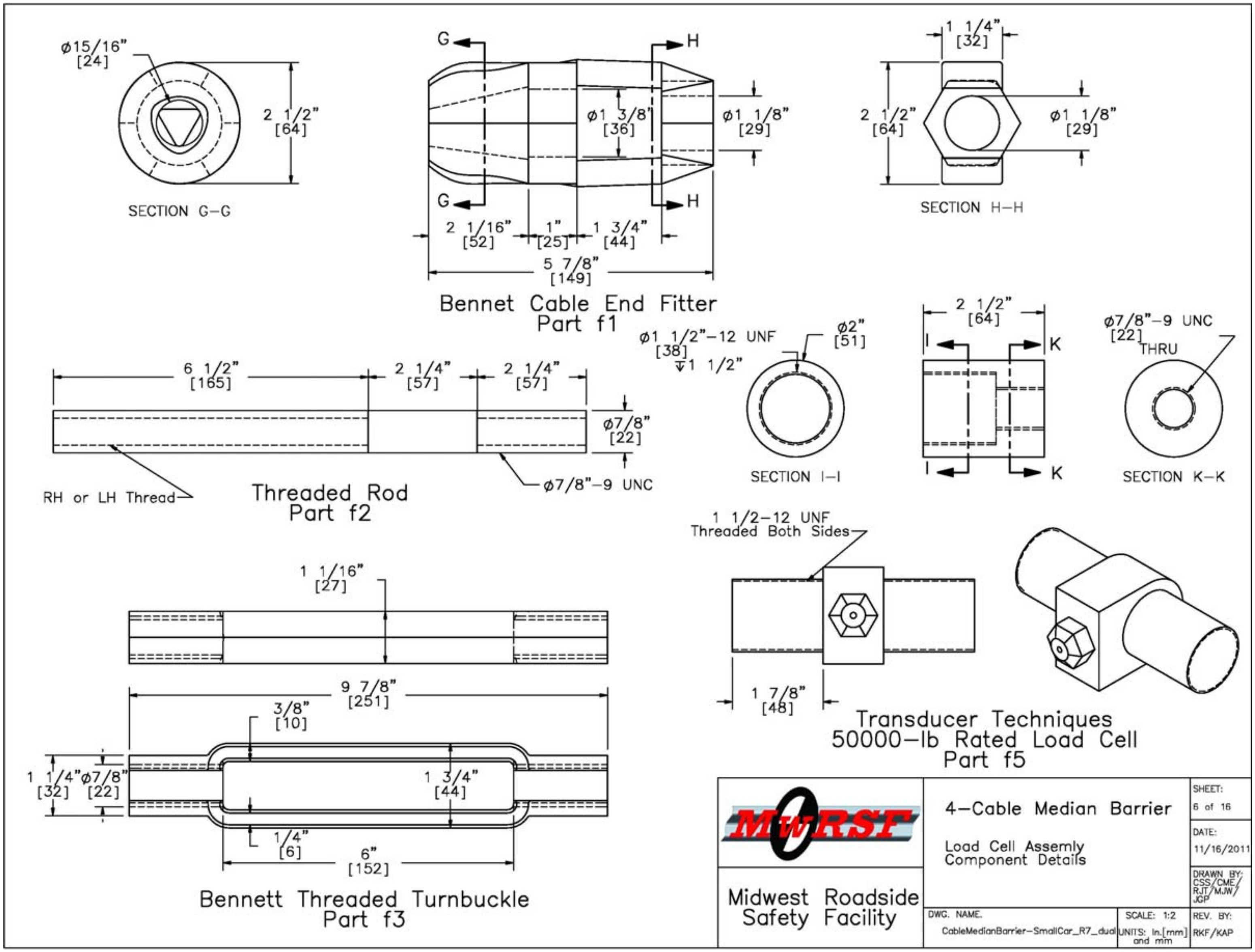
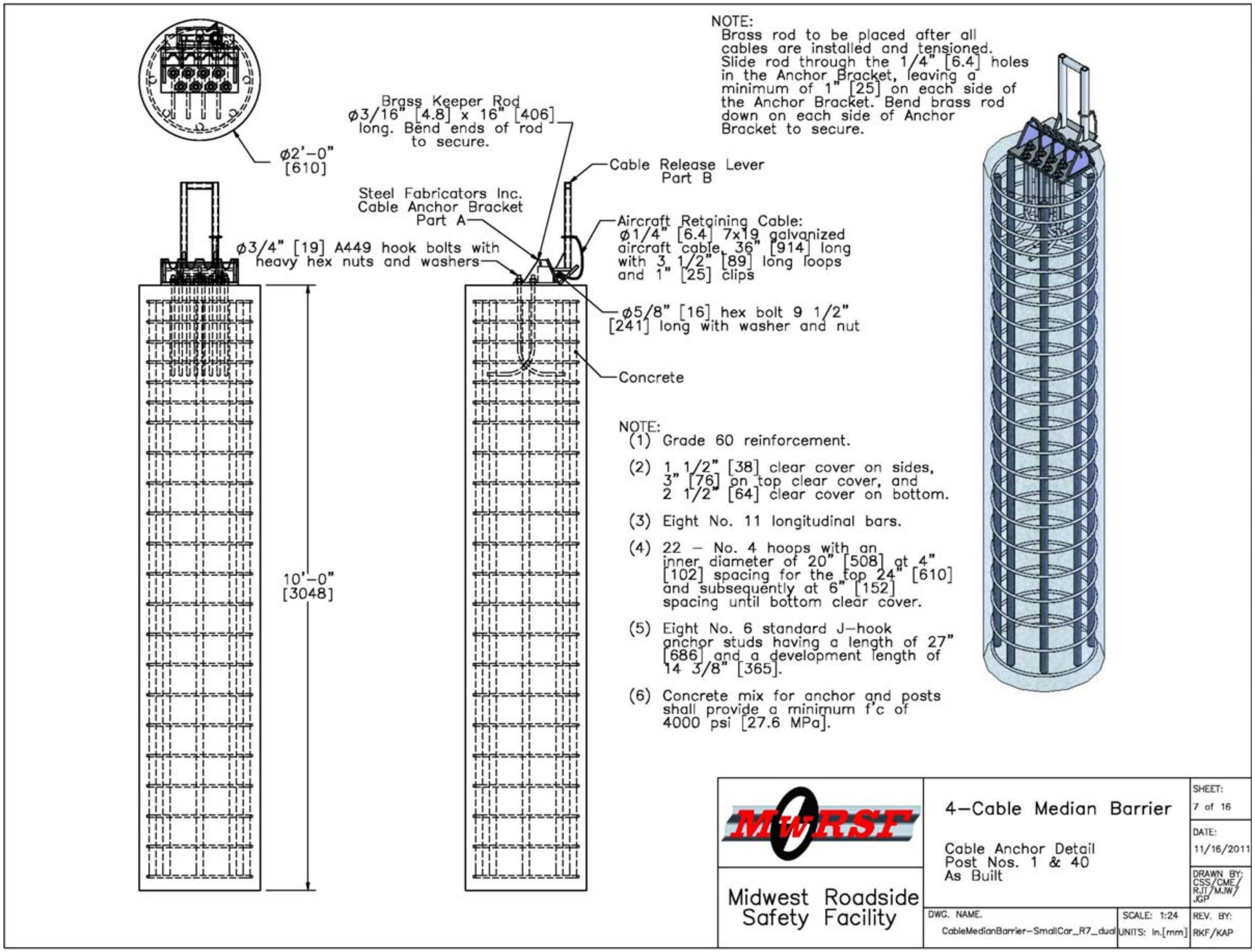


Figure 55. Load Cell Assembly Component Details, Test No. 4CMB-2



NOTE:
Brass rod to be placed after all cables are installed and tensioned. Slide rod through the 1/4" [6.4] holes in the Anchor Bracket, leaving a minimum of 1" [25] on each side of the Anchor Bracket. Bend brass rod down on each side of Anchor Bracket to secure.

NOTE:
(1) Grade 60 reinforcement.
(2) 1 1/2" [38] clear cover on sides, 3" [76] on top clear cover, and 2 1/2" [64] clear cover on bottom.
(3) Eight No. 11 longitudinal bars.
(4) 22 – No. 4 hoops with an inner diameter of 20" [508] at 4" [102] spacing for the top 24" [610] and subsequently at 6" [152] spacing until bottom clear cover.
(5) Eight No. 6 standard J-hook anchor studs having a length of 27" [686] and a development length of 14 3/8" [365].
(6) Concrete mix for anchor and posts shall provide a minimum f'c of 4000 psi [27.6 MPa].

Figure 56. Cable Anchor Details, Post Nos. 1 & 40, Test No. 4CMB-2

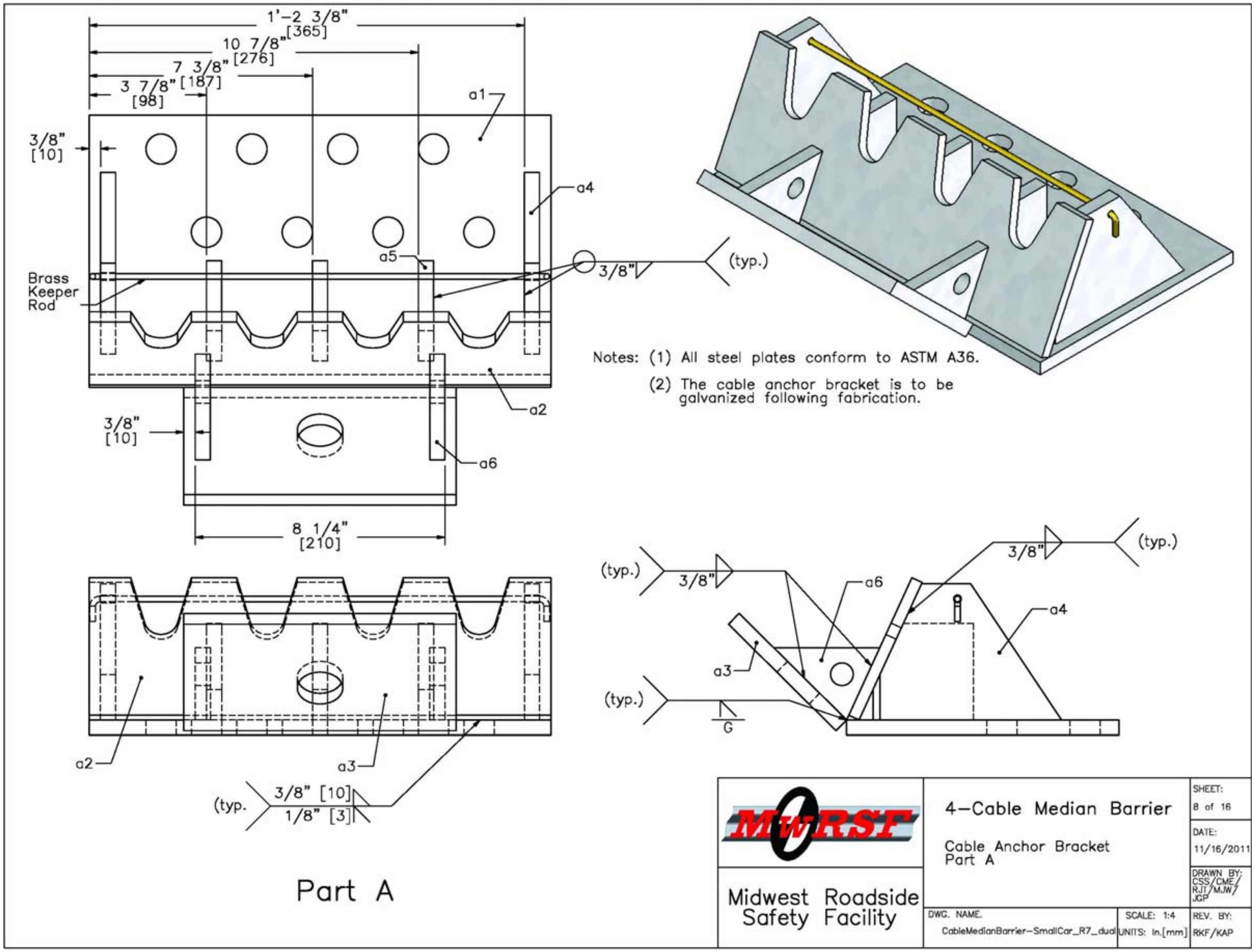


Figure 57. Cable Anchor Bracket, Part A, Test No. 4CMB-2

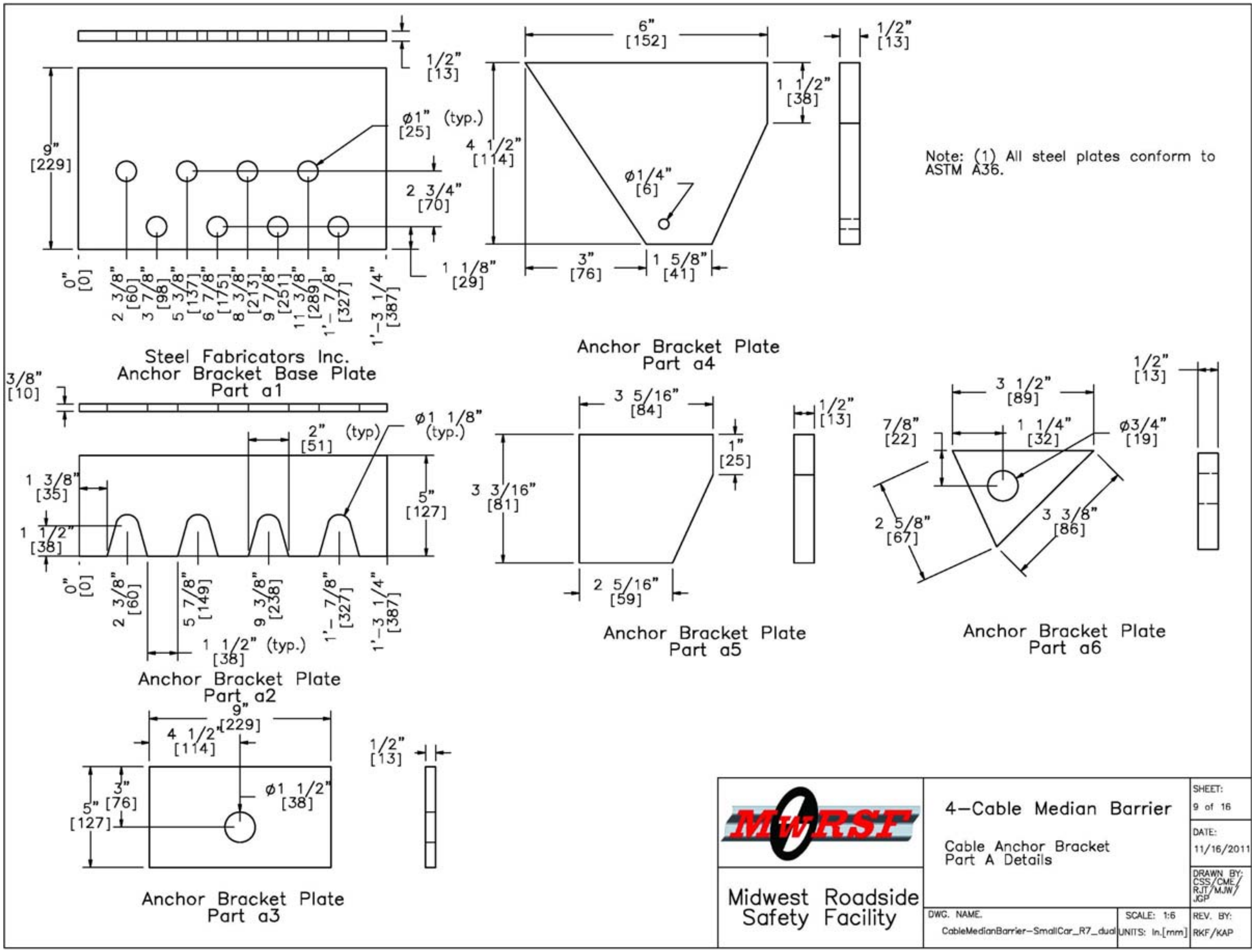
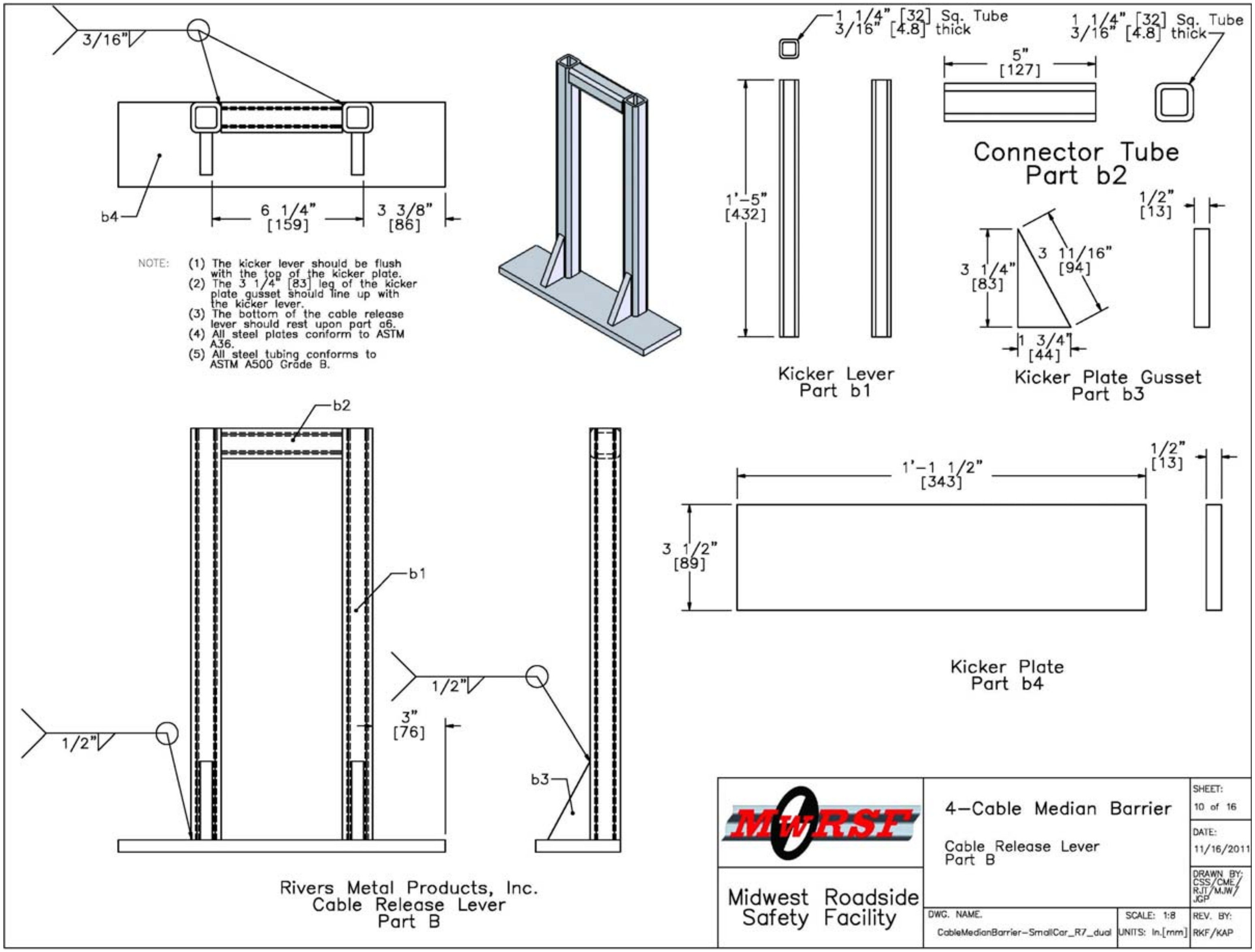


Figure 58. Cable Anchor Bracket Details, Test No. 4CMB-2



NOTE:
(1) The kicker lever should be flush with the top of the kicker plate.
(2) The 3 1/4" [83] leg of the kicker plate gusset should line up with the kicker lever.
(3) The bottom of the cable release lever should rest upon part a6.
(4) All steel plates conform to ASTM A36.
(5) All steel tubing conforms to ASTM A500 Grade B.

4-Cable Median Barrier
Cable Release Lever
Part B
SHEET: 10 of 16
DATE: 11/16/2011
DRAWN BY: CSS/CME/RJT/MJW/JGP
DWG. NAME. CableMedianBarrier-SmallCar_R7_dual
SCALE: 1:8
UNITS: In.[mm]
REV. BY: RKF/KAP

Figure 59. Cable Release Lever, Test No. 4CMB-2

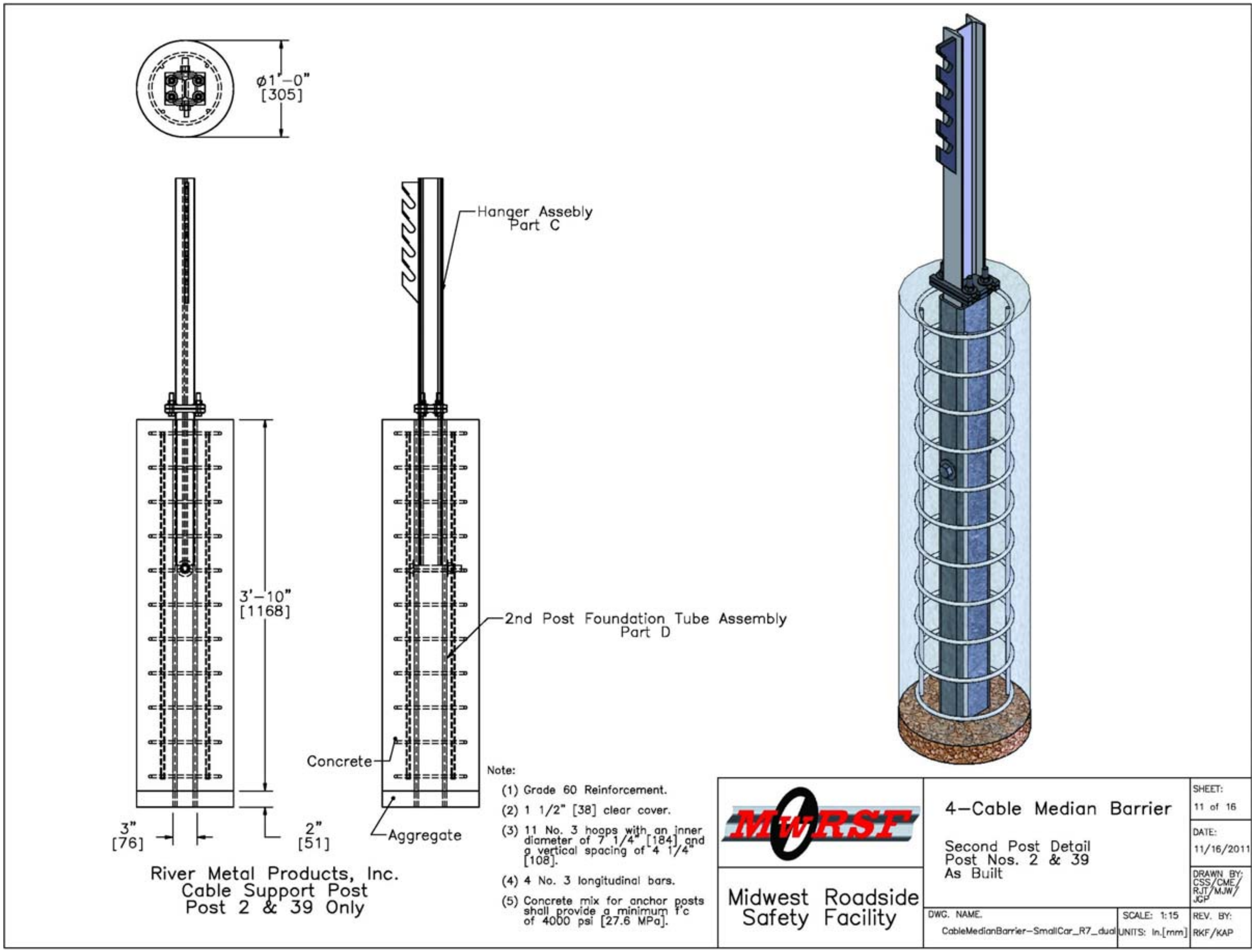


Figure 60. Post Nos. 2 & 39 Details, Test No. 4CMB-2

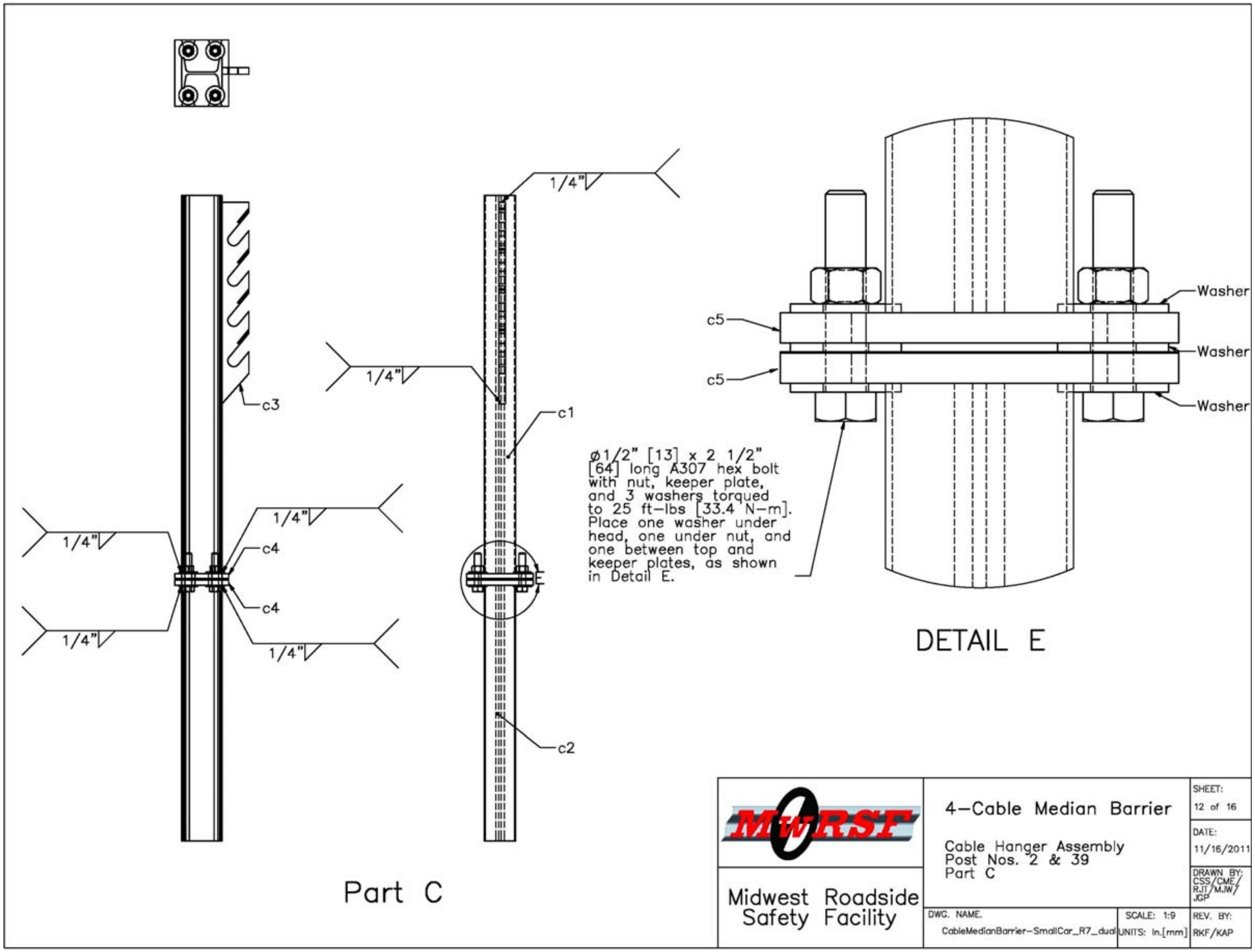


Figure 61. Cable Hanger Assembly, Post Nos. 2 & 39, Test No. 4CMB-2

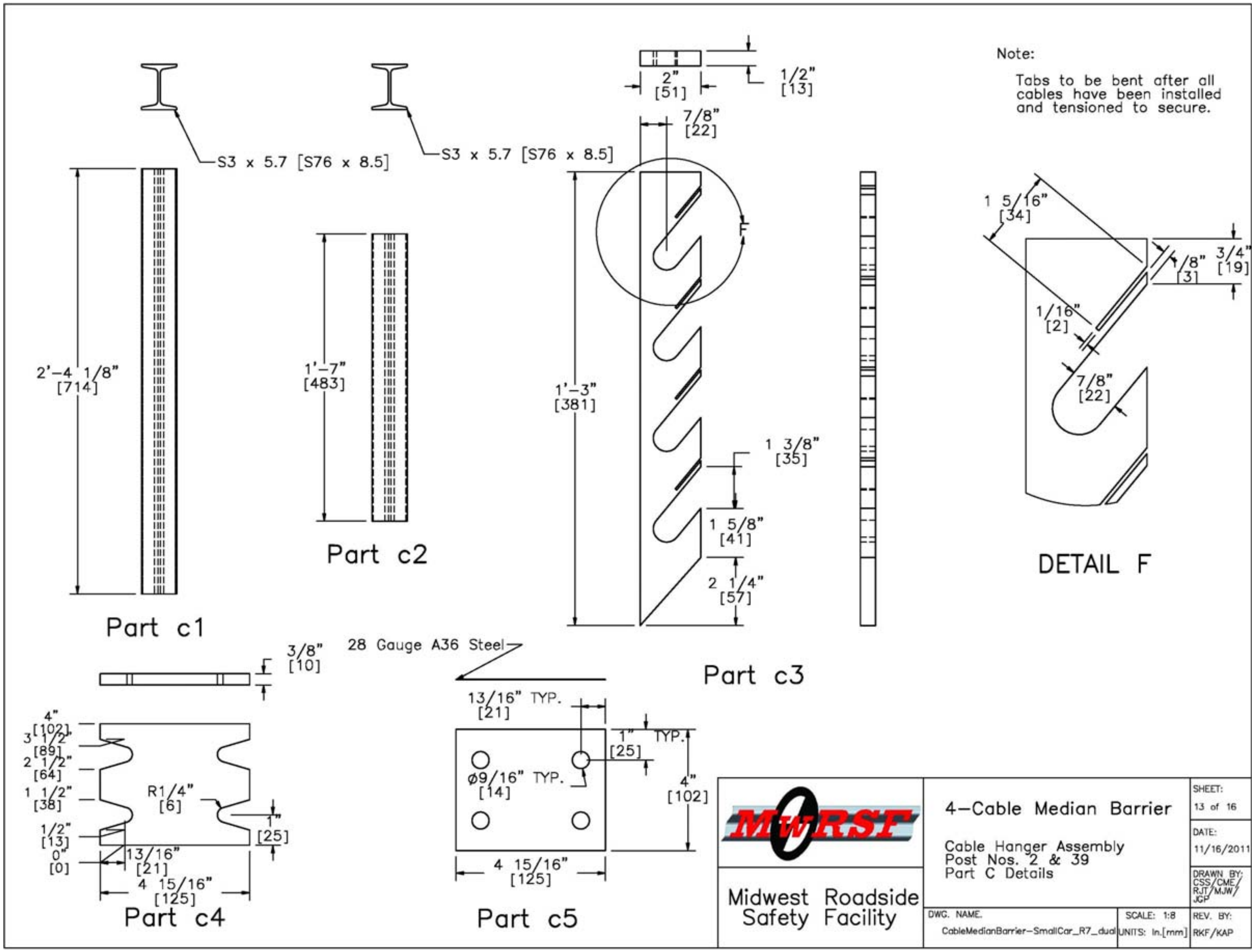


Figure 62. Cable Hanger Assembly, Post Nos. 2 & 39, Test No. 4CMB-2

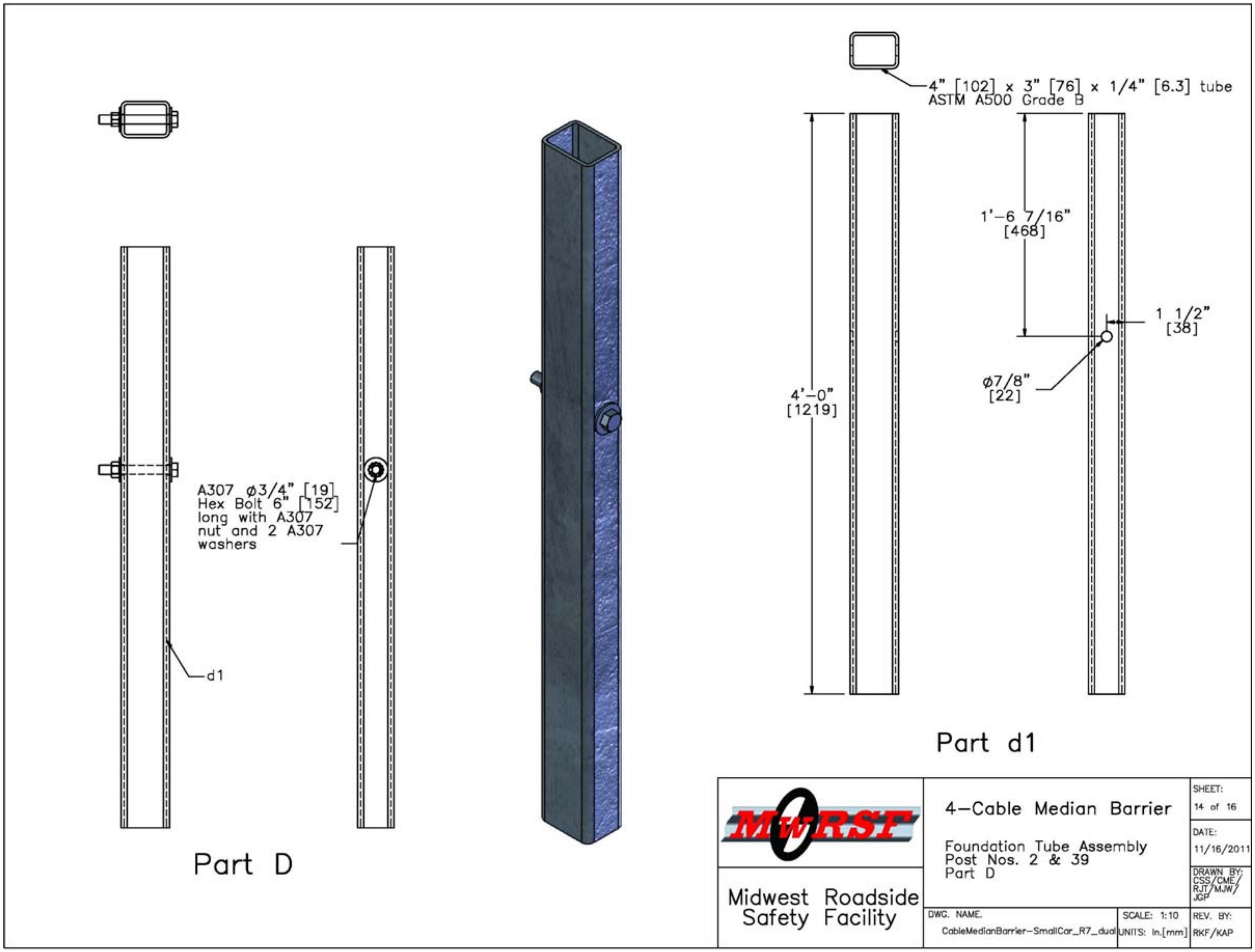


Figure 63. Foundation Tube Assembly, Post Nos. 2 & 39, Test No. 4CMB-2

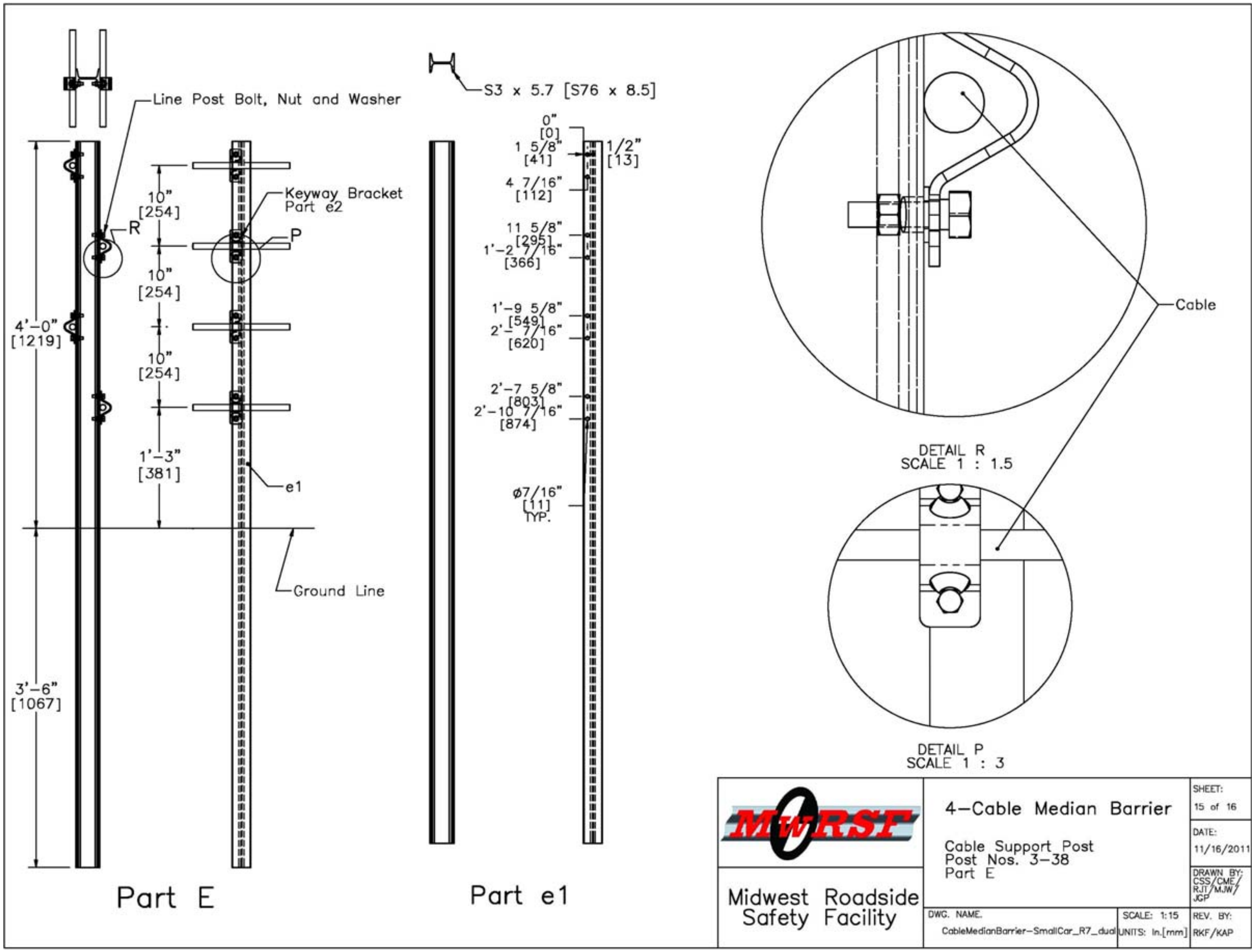


Figure 64. Cable Support Post, Post Nos. 3-38, Test No. 4CMB-2

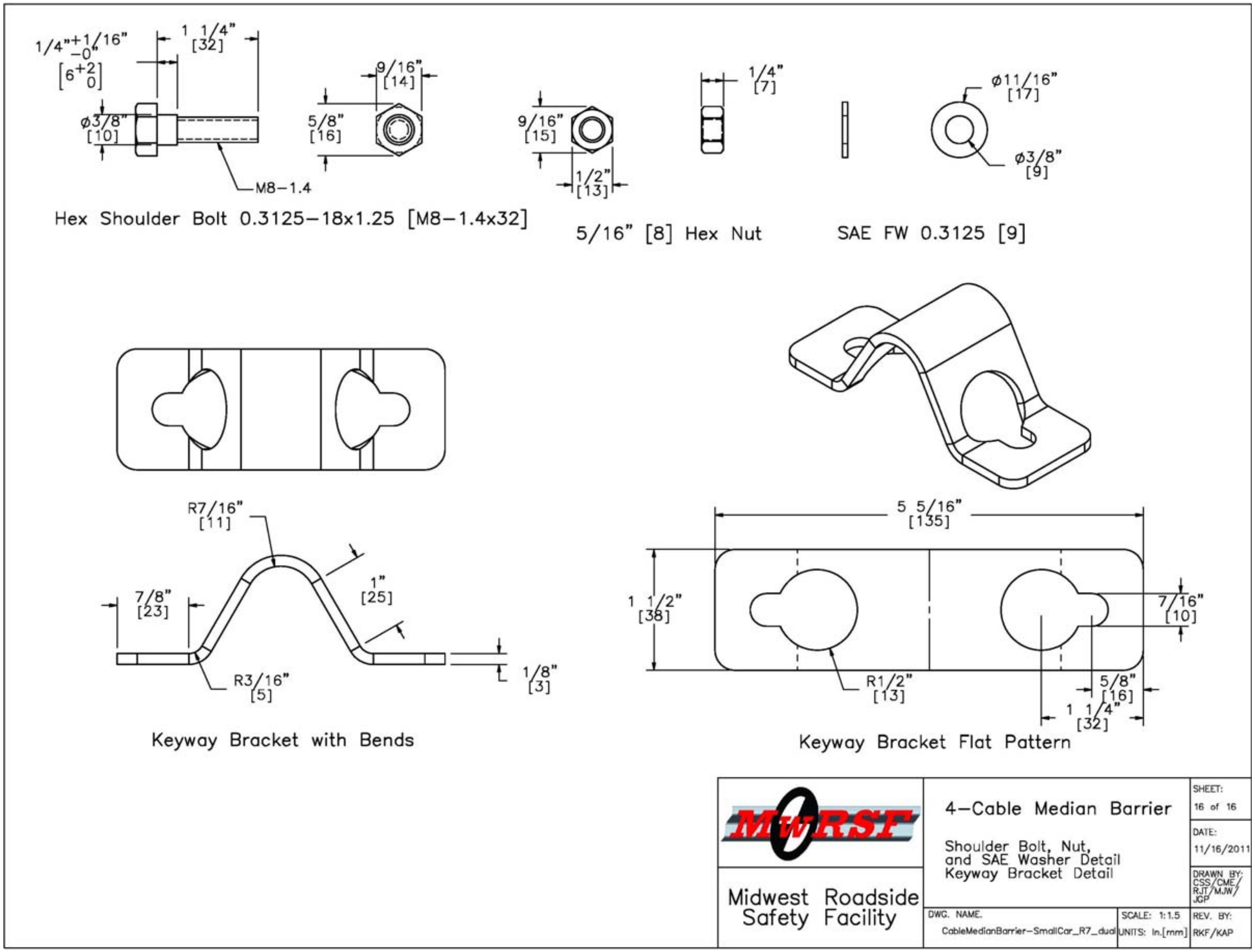


Figure 65. Shoulder Bolt, Nut, Washer, and Keyway Bracket Detail, Test No. 4CMB-2

8 FULL-SCALE CRASH TEST NO. 4CMB-2

8.1 Test No. 4CMB-2

The 2,557-lb (1,160-kg) small car impacted the cable median barrier at a speed of 62.7 mph (100.9 km/h) and at an angle of 26.8 degrees. A summary of the test results and sequential photographs are shown in Figure 66. Additional sequential photographs are shown in Figure 67. Documentary photographs are shown in Figures 68 and 69.

8.2 Weather Conditions

Test no. 4CMB-2 was conducted on November 16, 2007 at approximately 3:00 pm. The weather conditions were documented as shown in Table 8.

Table 8. Weather Conditions, Test No. 4CMB-2

Temperature	60° F
Humidity	24 %
Wind Speed	0 mph
Wind Direction	N/A
Sky Conditions	Clear
Visibility	10.0 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.01 in.

8.3 Test Description

Initial vehicle impact was to occur between post nos. 17 and 18, or 64 in. (1,626 mm) downstream of post no. 17, as shown in Figure 70. Table 9 contains a sequential description of the impact events. The final vehicle position was determined to be 24 ft (7.3 m) downstream and 0.0 ft (0.0 m) laterally from vehicle impact, as shown in Figure 71.

Table 9. Sequential Description of Impact Events, Test No. 4CMB-2

Time (sec)	EVENT
-0.702	Left-front tire encroached upon the ditch, and the vehicle rolled to the left and pitched downward.
-0.022	Left side of the front bumper contacted the ground
0.000	Left side of engine hood contacted the bottom cable.
0.004	Post no. 17 deflected laterally backward.
0.056	Post no. 18 deflected laterally backward.
0.076	Upper- and lower-middle cables were in contact with the windshield, pushing it inward.
0.160	Right-front bumper cover contacted post no. 18.
0.188	Top cable contacted the left A-pillar, and all four cables were in contact with the vehicle.
0.232	Post no. 19 deflected laterally backward, and the top, upper-middle, and lower-middle cables were located at the front left corner of the windshield.
0.282	Vehicle overrode post no. 18.
0.348	Top, upper-middle, and lower-middle cables continued to wrap around the front of the windshield, causing it to crack.
0.372	Post no. 20 deflected laterally backward.
0.470	Post no. 18 lost contact with the bottom of the vehicle.
0.808	Vehicle ceased to travel downstream.

8.4 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 72 through 74. Barrier damage consisted of bent and twisted guardrail posts and detached cables. The length of vehicle contact along the cable median barrier system was about 24 ft (7.3 m) which spanned from post nos. 17 to 19.

Post nos. 11 through 15 raised 4 in. (102 mm), 1 in. (25 mm), ¼ in. (6.4 mm), 7 in. (178 mm), and 6 in. (152 mm) from their original positions, respectively. Post no. 16 raised 5¾ in. (146 mm) from its original position, and rotated 2 in. (51 mm) at the ground line, laterally away from traffic side of the system. Post no. 17 raised 11 in. (279 mm) from its original position, and rotated 1½ in. (38 mm) at the ground line, laterally away from the traffic side of the system. Post no. 18 was completely removed from the soil and its final placement was 12 in. (305 mm) upstream of post no. 19. Post no. 19 rotated 1⅜ in. (35 mm) at the ground line, laterally away from the traffic side of the system. Post no. 20 raised 3 in. (76 mm) from its original position, and rotated ¾ in. (19 mm) at the ground line, laterally away from the traffic side of the system. Post no. 21 rotated ½ in. (12.7 mm) at the ground line, laterally away from the traffic side of the system.

Several cable brackets were detached from posts. The cable brackets are numbered from top to bottom with no. 1 corresponding to the top cable and no. 4 corresponding to the bottom cable. For post no. 18, the 2nd, 3rd, and 4th cable brackets were detached, but the 1st bracket was still attached. The 2nd bracket was found 8 ft - 10 in. (2.7 m) downstream of post no. 19 and 6 in. (152 mm) in front of the system. The 3rd bracket was found 7 ft - 6 in. (2.3 m) upstream of post no. 19 and 3½ ft (1.1 m) behind the system. The 4th bracket was found 2 ft (0.6 m) downstream of post no. 20 and 9 ft - 4 in. (2.8 m) behind the system. For post no. 19, the 2nd and 4th cable brackets were detached. The 2nd bracket was found 19 in. (483 mm) downstream of post no. 19 and 15 in. (381 mm) behind the system. The 4th bracket was found 20 in. (508 mm) downstream of post no. 19 and 2 in. (51 mm) in front of the system. For post no. 20, the 4th cable bracket was missing, and it was found 4 in. (102 mm) downstream of post no. 20 and on the longitudinal centerline of the system.

The permanent set of the posts is shown in Figures 73 and 74. The maximum lateral permanent set post deflection was not calculated for this test. The maximum lateral dynamic post deflection was 21.2 in. (537 mm) at post no. 18, as determined from the high-speed film analysis. The maximum cable deflection occurred in the bottom cable and was determined to be 33.5 in. (851 mm), and the working width was determined to be 47.6 in. (1,208 mm), as determined from the high-speed film analysis.

8.5 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 75 through 77. Minimal damage was observed in the interior occupant compartment of the vehicle, as shown in Figure 78.

The left-front fender was severely damaged and heavily creased toward the front of the car. It was also torn near the door joint. There was heavy cable contact and loading damage at the bottom of the A-pillar, and scrapes from the cables continued along the entire length of the pillar to the roof line. The left-front steel rim had an 8 in. (203 mm) long by 3 in. (76 mm) deep indent, and the tire was completely disengaged from the rim. The right-rear bumper cover attachment was pulled off, and there was heavy damage to the right-front fender. The right-front window was also broken out. The right-front steel rim was slightly dented, and the tire was deflated and disengaged. There were minor contact marks on the right-front quarter panel, and the entire wheel assembly was pushed in toward the engine.

The face of the front bumper was heavily damaged from cable contact. The radiator support brackets were buckled, crushing other components in the engine compartment. The hood was also deformed on the front end and buckled toward the center. There was major damage along the bottom-left side of the windshield and along the A-pillar where it had disengaged from the frame. Interior damage included a buckled and broken dash. On the left-front suspension, the vertical stabilizer was disengaged at the lower ball joint, the lower A-frame component was bent, and the front wheel drive line component was bent backward. There was also left-front occupant compartment damage on the firewall and floor pan. The maximum deformation of the occupant compartment was 3 in. (76 mm), located at the right-front corner of the left toe pan.

The windshield was severely crushed and deformed inward. Three points were measured using a steel straight edge and an undamaged vehicle for reference. The windshield glass was detached from its adhesive along the A-pillar about 12 in. (305 mm). The maximum intrusion into the occupant compartment was 1½ in. (38 mm) and was located at two points. The coordinates for these points are 47 in. (1,194 mm) from the right side of the windshield and 20¼ in. (514 mm) from the top, and 48½ in. (1,232 mm) from the right side of the windshield and 24¾ in. (629 mm) from the top.

8.6 Occupant Risk Values

The calculated occupant impact velocities (OIVs) and 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 10. It is noted that the OIVs were not within the suggested limits provided in MASH. The calculated THIV and PHD values are also shown in Table 10. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 66. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix C.

Table 10. Summary of OIV, ORA, THIV, and PHD Values, Test No. 4CMB-2

Evaluation Criteria		Transducers	
		EDR-3	DTS
OIV [ft/s (m/s)]	Longitudinal	-41.32 (-12.6)	-40.45 (-12.33)
	Lateral	-4.48 (-1.37)	-7.27 (-2.21)
ORA [g's]	Longitudinal	-7.94	-7.34
	Lateral	-6.25	-6.60
THIV [ft/s (m/s)]		N/A	41.74 (12.72)
PHD [g's]		N/A	7.96

8.7 Load Cell Results

As previously discussed, tension load cells were installed in line with the cables at the upstream end of the barrier system in order to monitor the total load transferred to the anchor with respect to time. The load cell results are summarized in Table 11. As noted previously, the target cable tension was 4,213 lb (18.7 kN) at 100 degrees Fahrenheit (23.6 degrees Celsius). Prior to testing, the actual cable tension located in the upstream end of the barrier system and in the top, upper-middle, lower-middle, and bottom cables was 4,220 lb (18.8 kN), 4,200 lb (18.7 kN), 4,260 lb (18.9 kN), and 3,820 lb (17.0 kN), respectively. These readings were measured using a cable tension meter or cable tensiometer.

The individual cable loads, along with the total combined cable load imparted to the upstream anchor, were determined and are shown graphically in Figure 79. The total axial force imparted to the upstream anchor was 28.97 kips (128.9 kN) and occurring at 0.363 sec after vehicle impact with the barrier system. The maximum force was 8.41 kips (37.4 kN) and occurred in the bottom cable. The upper middle and lower middle cables experienced a maximum load of 7.15 kips

(31.8 kN) and 8.25 kips (36.7 kN), respectively. The top cable experienced a maximum load of 6.23 kips (27.7 kN).

Table 11. Load Cell Results, Test No. 4CMB-2

Cable Location	Sensor Location	Maximum Cable Load		Time[1] (sec)
		kips	kN	
Combined Cables	Upstream End	28.97	128.9	0.363
Top Cable	Upstream End	6.23	27.7	0.315
Upper Middle Cable	Upstream End	7.15	31.8	0.163
Lower Middle Cable	Upstream End	8.25	36.7	0.333
Bottom Cable	Upstream End	8.41	37.4	0.405

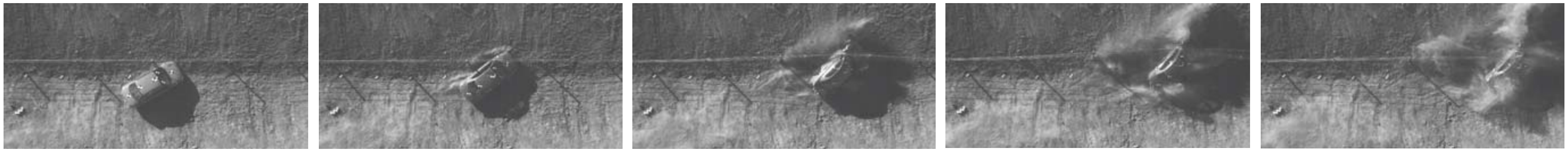
[1] - Time determined from initial vehicle impact with the barrier system.

After the crash test, the tension in each cable was again measured. With the small car engaged in the system, the cable tension at the upstream end and in the top, upper-middle, lower-middle, and bottom cables was 3,100 lb (13.8 kN), 2,980 lb (13.3 kN), 3,500 lb (15.6 kN), and 3,380 lb (15.0 kN), respectively. On the contrary and with the small car engaged with the barrier, the cable tension at the downstream end and in the top, upper-middle, lower-middle, and bottom cables was 2,940 lb (13.1 kN), 3,300 lb (14.7 kN), 3,620 lb (16.1 kN), and 3,600 lb (16.0 kN), respectively.

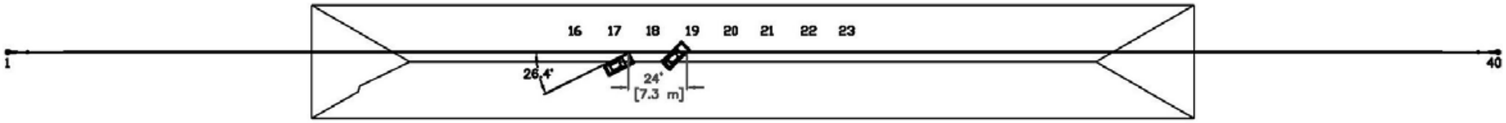
With the small car disengaged from the cable barrier system, the cable tension at the upstream end and in the top, upper-middle, lower-middle, and bottom cables was 3,060 lb (13.6 kN), 2,940 lb (13.1 kN), 2,920 lb (13.0 kN), and 2,720 lb (12.1 kN), respectively. On the contrary and with the small car disengaged from the barrier, the cable tension at the downstream end and in the top, upper-middle, lower-middle, and bottom cables was 3,160 lb (14.1 kN), 3,160 lb (14.1 kN), 3,120 lb (13.9 kN), and 2,720 lb (12.1 kN), respectively.

8.8 Discussion

The analysis of the test results for test no. 4CMB-2 (test designation no. 3-10) showed that the high-tension, four-cable median barrier adequately contained the 1100C vehicle with controlled lateral displacements of the barrier system when placed in a V-ditch with 4H:1V side slopes and 4 ft (1.2 m) laterally away from the ditch bottom and up the back slope. Note that a softer soil condition was intentionally used for the ditch bottom surface. The vehicle remained upright after collision with the barrier system. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle and front bumper marginally underrode the barrier system although the four cables did contain the vehicle on the engine hood and front windshield. Vehicle roll, pitch, and yaw angular displacements were noted and were deemed acceptable because they did not adversely influence occupant risk safety criteria, nor result in vehicle rollover. After collision, the vehicle’s trajectory did not intrude into adjacent traffic lanes as it remained within the ditch section. It should be noted that the longitudinal OIV exceeded the limit provided in MASH of 40 ft/s (12.2 m/s) when considering the loss in vehicle speed during tire rutting and soil plowing just prior to vehicle contact with the barrier. Therefore, test no. 4CMB-2 was determined to be marginally acceptable according to the TL-3 safety performance criteria found in MASH when the barrier was placed near the ditch bottom configured with a soft soil condition.



0.000 sec 0.072 sec 0.2248 sec 0.436 sec 0.716 sec



Test Agency	MwRSF
Test Number	4CMB-2
Date	11/16/07
NCHRP 350 Update Test Designation	3-10
Appurtenance	Four-Cable High-Tension Median Barrier Installed on 4:1 Slope
Median Width	46 ft (14.0 m)
Total Length	608 ft (185.3 m)
Placement	4 ft (1.2 m) up back slope from ditch bottom
Key Elements - Wire Rope	
Diameter	¾ in. (19 mm)
Size	3x7
Top Cable Height	45 in. (1,143 mm)
Bottom Cable Height	15 in. (381 mm)
Incremental Spacing	10 in. (254 mm)
Key Elements - End Anchor Posts	
Post Nos. 1 and 40	24 in. (610 mm) diameter by 120 in. (3,048 mm) long concrete footer
Post Nos. 2 and 39	S3x5.7 (S76x8.5) by 28⅛ in. (714 mm) long with S3x5.7 (S76x8.5) by 19 in. (483 mm) long in a 12 in. (305 mm) diameter by 46 in. (1,168 mm) long concrete footer
Key Elements - Line Posts	
Post Nos. 3-38	S3x5.7 (S76x8.5) by 87 in. (2,210 mm) long
Spacing	16 ft (4,877 mm)
Type of Soil	Grading B - AASHTO M 147-65 (1990) (Soft Soil Conditions)
Test Vehicle	
Type/Designation	1100C
Make and Model	2002 Kia Rio Sedan
Curb	2,249 lb (1,020 kg)
Test Inertial	2,393 lb (1,085 kg)
Gross Static	2,557 lb (1,160 kg)
Impact Conditions	
Speed	62.7 mph (100.9 km/h)
Angle	26.8 degrees
Impact Location	64 in. (1,626 mm) downstream of post 17

Exit Conditions	
Speed	N/A
Angle	N/A
Exit Box Criterion	N/A
Post-Impact Trajectory	
Vehicle Stability	Satisfactory
Stopping Distance	24 ft (7.3 m) downstream contacting barrier
Occupant Impact Velocity (EDR-3)	
Longitudinal	-41.32 ft/s (-12.60 m/s) > 40 ft/s (12.2 m/s)
Lateral	-4.48 ft/s (-1.37 m/s) < 40 ft/s (12.2 m/s)
Occupant Ridedown Deceleration (EDR-3)	
Longitudinal	-7.94 g's < 20.49 g's
Lateral	-6.25 g's < 20.49 g's
Occupant Impact Velocity (DTS)	
Longitudinal	-40.45 ft/s (-12.33 m/s) > 40 ft/s (12.2 m/s)
Lateral	-7.27 ft/s (-2.21 m/s) < 40 ft/s (12.2 m/s)
Occupant Ridedown Deceleration (DTS)	
Longitudinal	-7.34 g's < 20.49 g's
Lateral	6.60 g's < 20.49 g's
THIV (not required)	41.74 ft/s (12.72 m/s)
PHD (not required)	7.96 g's
Test Article Damage	Minimal
Test Article Deflections	
Permanent Set	N/A
Dynamic (Post)	21.2 in. (537 mm)
Dynamic (Cable)	33.5 in. (851 mm)
Working Width	47.6 in. (1,208 mm)
Vehicle Damage	Moderate
VDS[8]	11-LFQ-5
CDC[9]	11-LYAN6
Maximum Deformation	3.0 in. (76 mm)
Angular Displacements	
Roll	55.0 deg
Pitch	5.0 deg
Yaw	31.0 deg

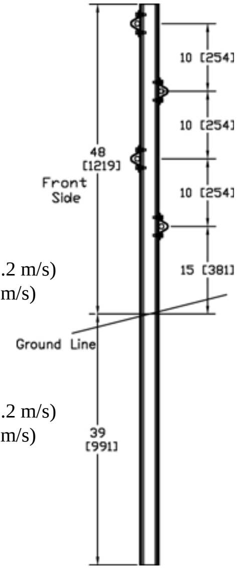


Figure 66. Summary of Test Results and Sequential Photographs, Test No. 4CMB-2

-0.278 sec

-0.046 sec

0.000 sec

0.050 sec

0.162 sec

0.222 sec

0.344 sec

1.064 sec

Figure 67. Additional Sequential Photographs, Test No. 4CMB-2

Figure 68. Documentary Photographs, Test No. 4CMB-2

Figure 69. Documentary Photographs, Test No. 4CMB-2

Figure 70. Impact Location, Test No. 4CMB-2

Figure 71. Vehicle Final Position and Trajectory Marks, Test No. 4CMB-2

Figure 72. System Damage, Test No. 4CMB-2

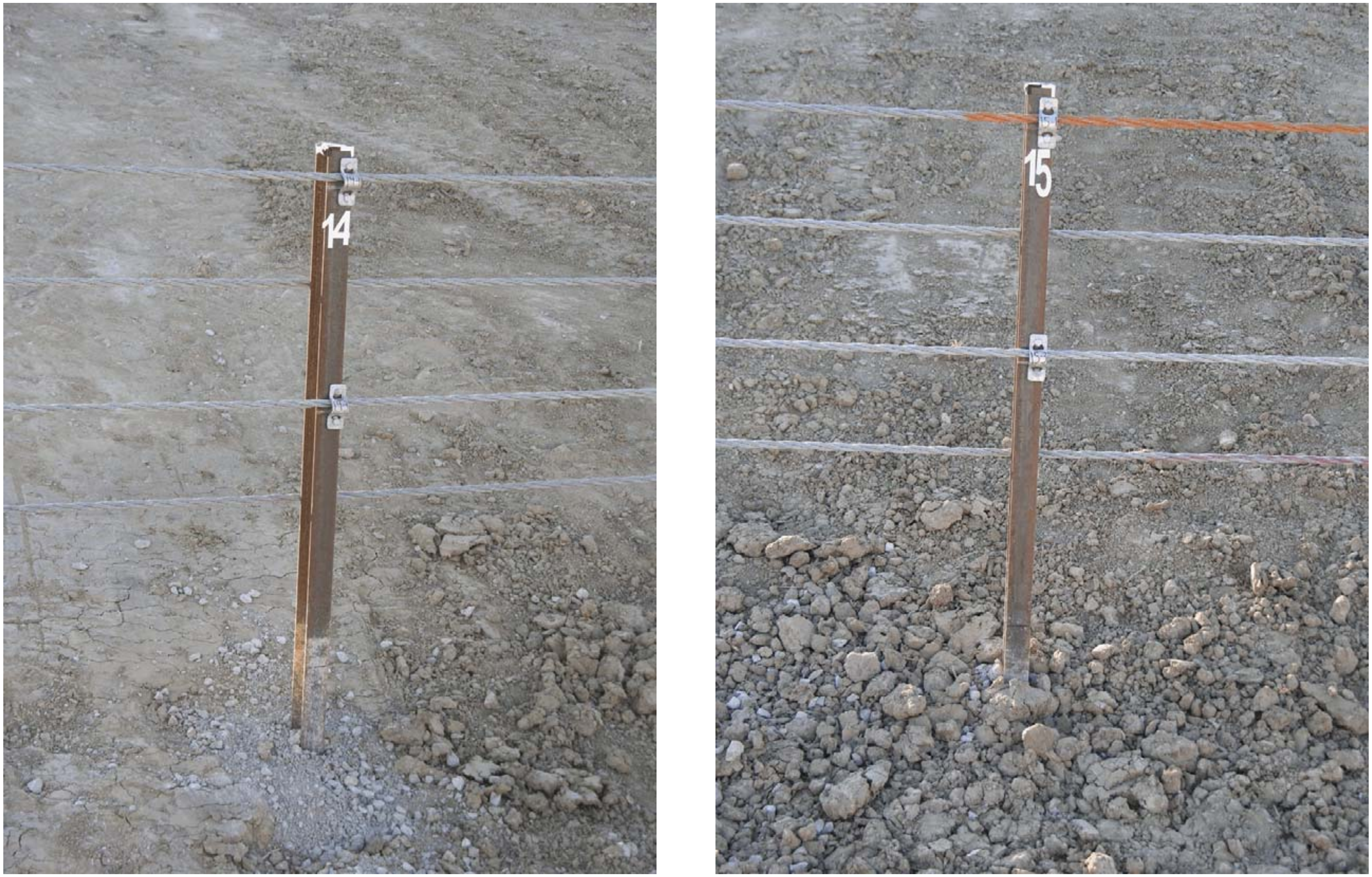


Figure 73. Post Nos. 14 and 15 Damage, Test No. 4CMB-3

Figure 74. Post No. 17 Damage, Test No. 4CMB-2

Figure 75. Vehicle Damage, Test No. 4CMB-2

Figure 76. Windshield Damage, Test No. 4CMB-2

Figure 77. Vehicle Damage, Test No. 4CMB-2

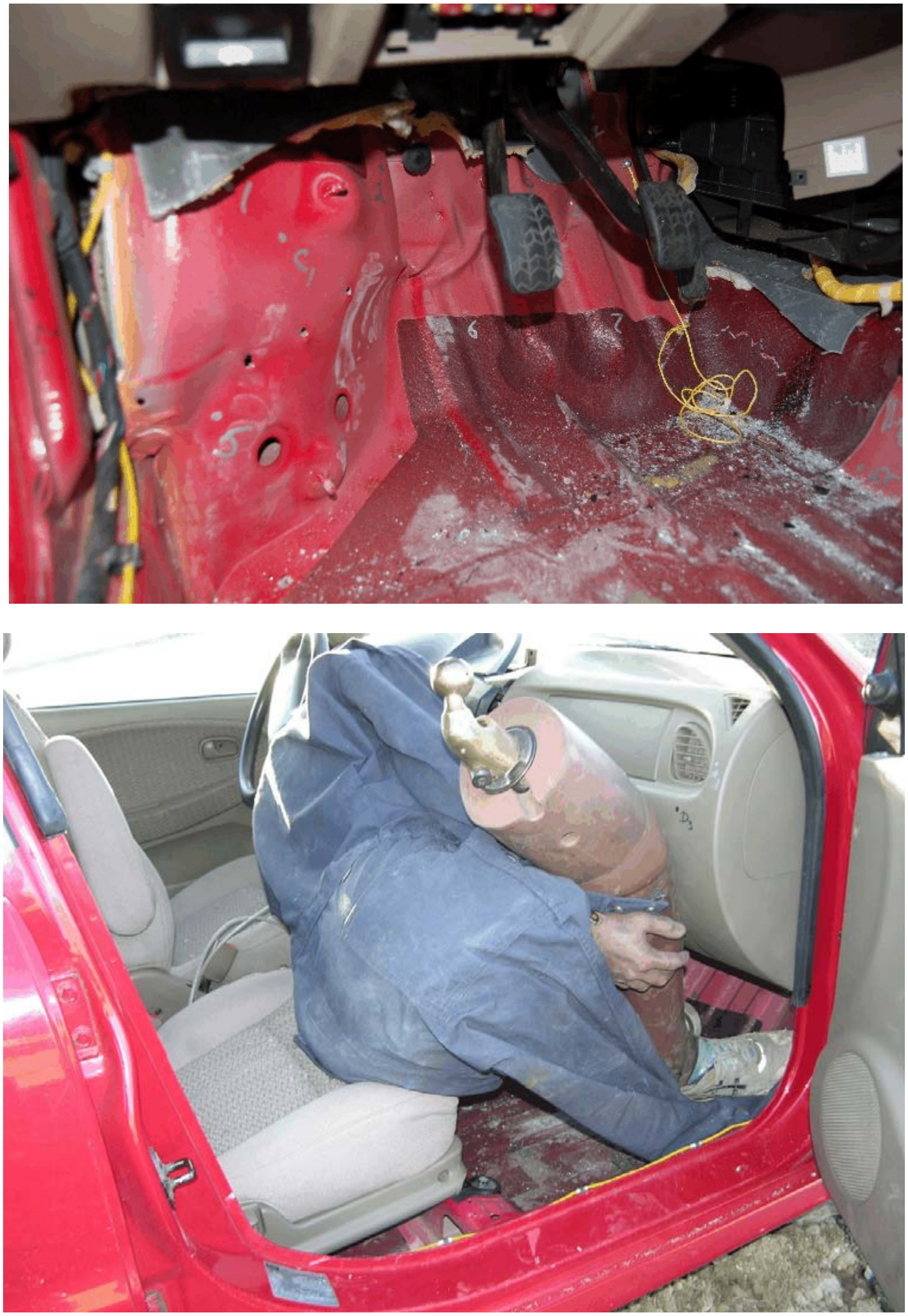


Figure 78. Occupant Compartment Damage, Test No. 4CMB-2

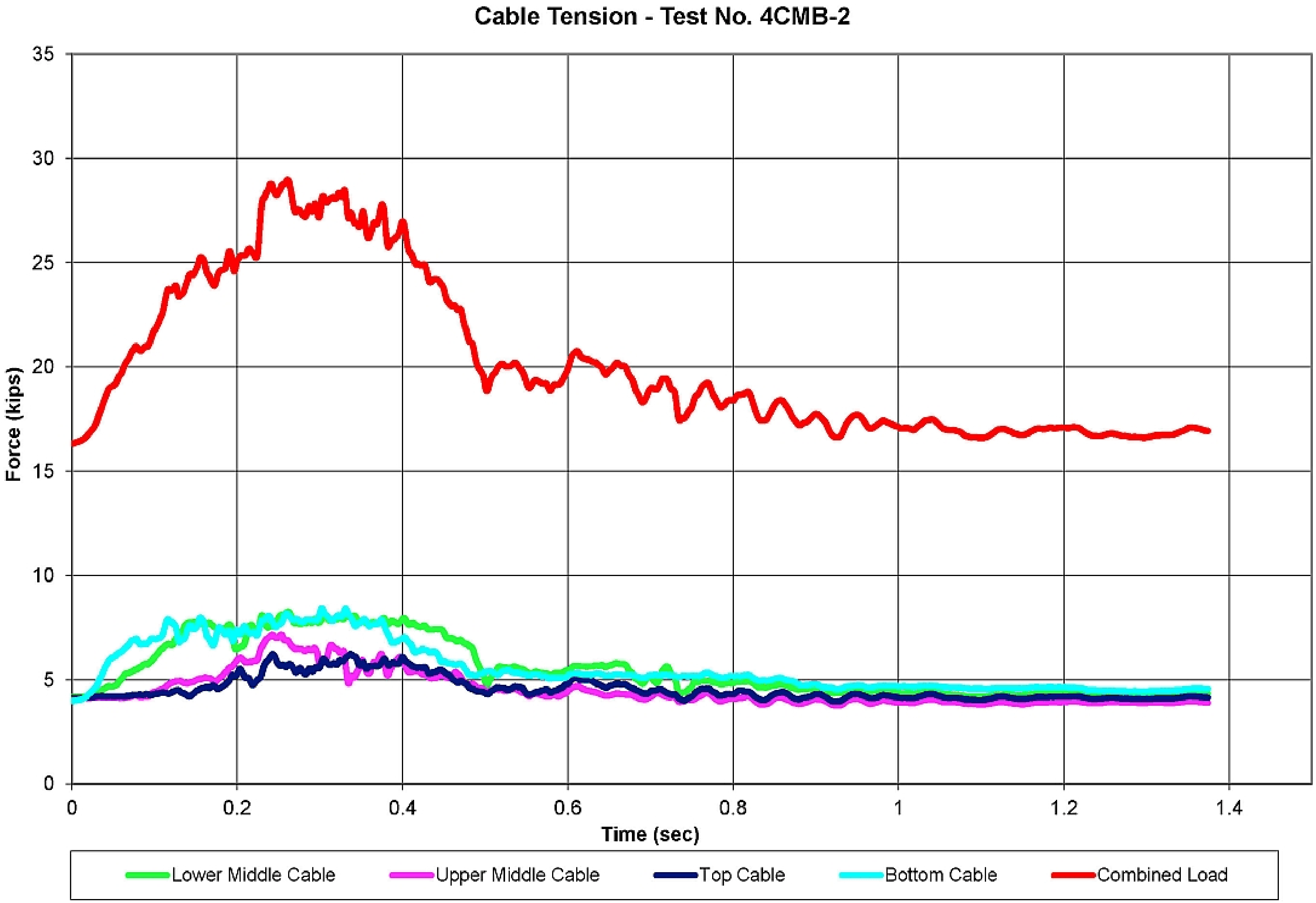


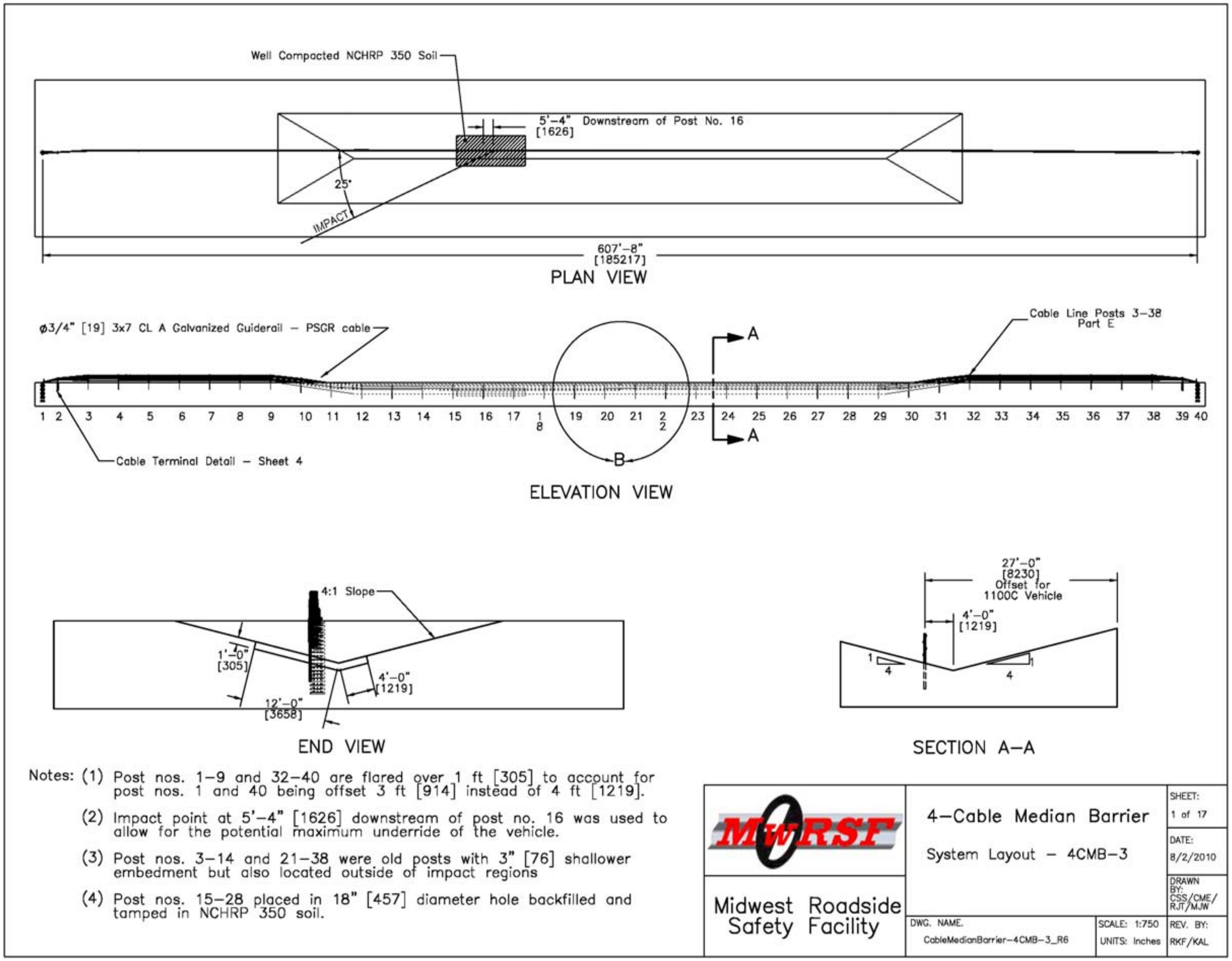
Figure 79. Cable Tensions, Test No. 4CMB-2

9 DESIGN DETAILS AND MODIFICATIONS FOR TEST NO. 4CMB-3

For test no. 4CMB-3, the cable barrier system was nearly identical to the system that was constructed and evaluated in test no. 4CMB-2. The position of the barrier system within the ditch was the same as used for test no. 4CMB-2, or 4 ft (1.2 m) laterally away from the bottom of the V-ditch. However, some moderate changes were incorporated into the overall configuration.

Once again, the bottom of the 4H:1V V-ditch was graded surrounding the cable median barrier system. However, the bottom of the sloped V-ditch near the region of impact was configured with a compacted, strong-soil condition similar to the compacted soil material used to support the steel posts. The soil material conformed to grading B specified in NCHRP Report No. 350. The compacted soil region started 19 ft - 4 in. (5.9 m) upstream from the impact location with the barrier, continued for a length of 36 ft (11 m), and extended 7.7 ft (2.3 m) laterally on either side of the posts. The soil was compacted for a depth of 1 ft (305 mm) using 6 in. (152 mm) lifts. It was believed that the compacted soil pad would reduce the propensity for tire rutting within the ditch bottom, decrease vehicle plowing through the soft soil, and reduce the potential for abrupt changes in velocity, as observed in test no. 4CMB-2.

For this test, the heights of the four cables were modified. The lowest cable (cable no. 4) was positioned 13½ in. (343 mm) above grade, while the 3rd, 2nd, and 1st cables were positioned at 24 in. (610 mm), 34½ in. (876 mm), and 45 in. (1,143 mm), respectively. Note, the height to the top cable remained unchanged. The revised cable spacing was 10½ in. (267 mm). In addition, the embedment depth for post nos. 3 through 38 was increased from 39 in.(991 mm) to 42 in. (1,067 mm). As a result, the post length was increased to 90 in. (2,286 mm). Updated CAD details for the modified barrier system are provided in Figures 80 through 96.



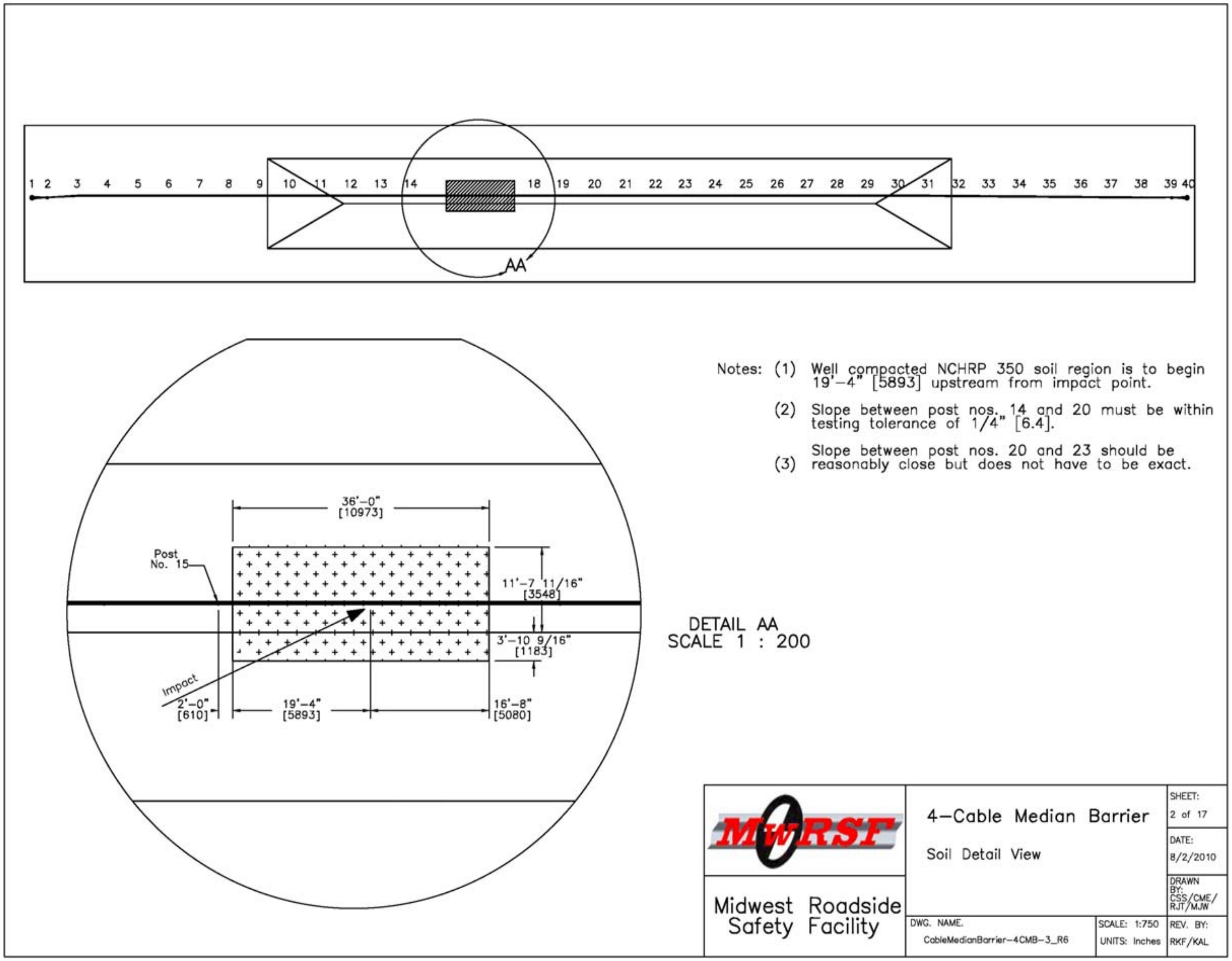
Notes: (1) Post nos. 1–9 and 32–40 are flared over 1 ft [305] to account for post nos. 1 and 40 being offset 3 ft [914] instead of 4 ft [1219].

(2) Impact point at 5'-4" [1626] downstream of post no. 16 was used to allow for the potential maximum underride of the vehicle.

(3) Post nos. 3–14 and 21–38 were old posts with 3" [76] shallower embedment but also located outside of impact regions

(4) Post nos. 15–28 placed in 18" [457] diameter hole backfilled and tamped in NCHRP 350 soil.

Figure 80. System Layout, Test No. 4CMB-3



Notes: (1) Well compacted NCHRP 350 soil region is to begin 19'–4" [5893] upstream from impact point.

(2) Slope between post nos. 14 and 20 must be within testing tolerance of 1/4" [6.4].

(3) Slope between post nos. 20 and 23 should be reasonably close but does not have to be exact.

Figure 81. Soil Detail View, Test No. 4CMB-3

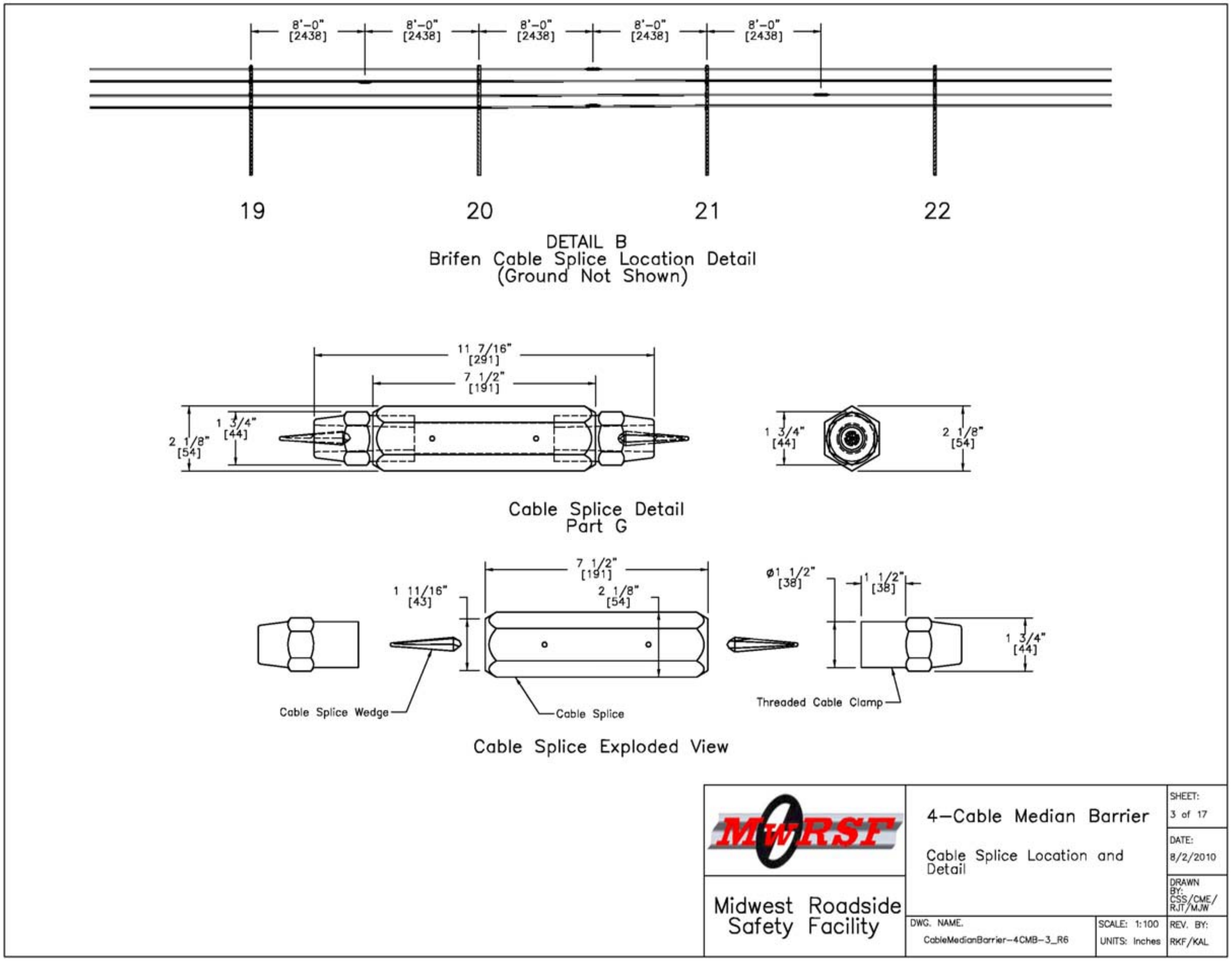


Figure 82. Cable Splice Location and Detail, Test No. 4CMB-3

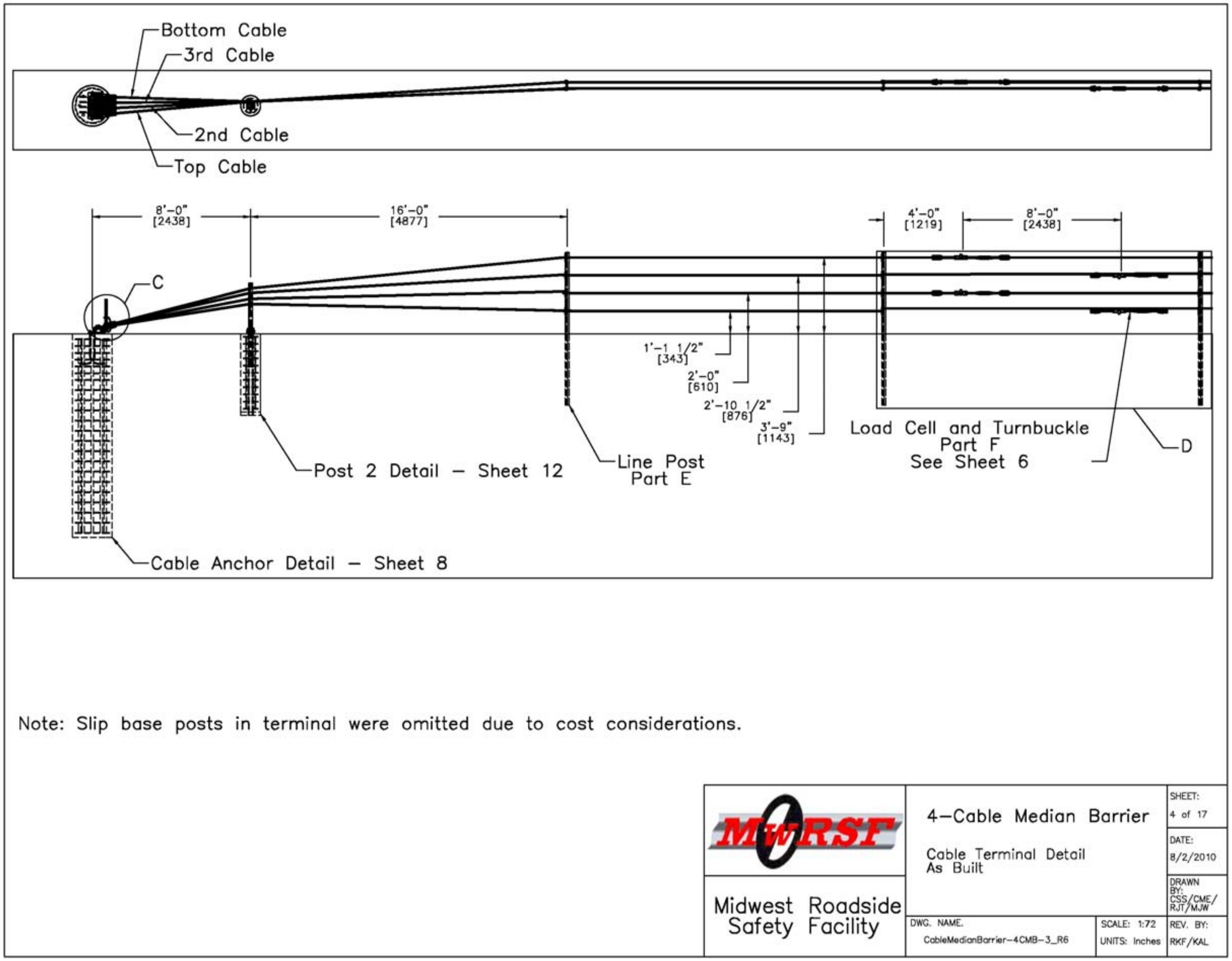


Figure 83. Cable Terminal Detail, Test No. 4CMB-3

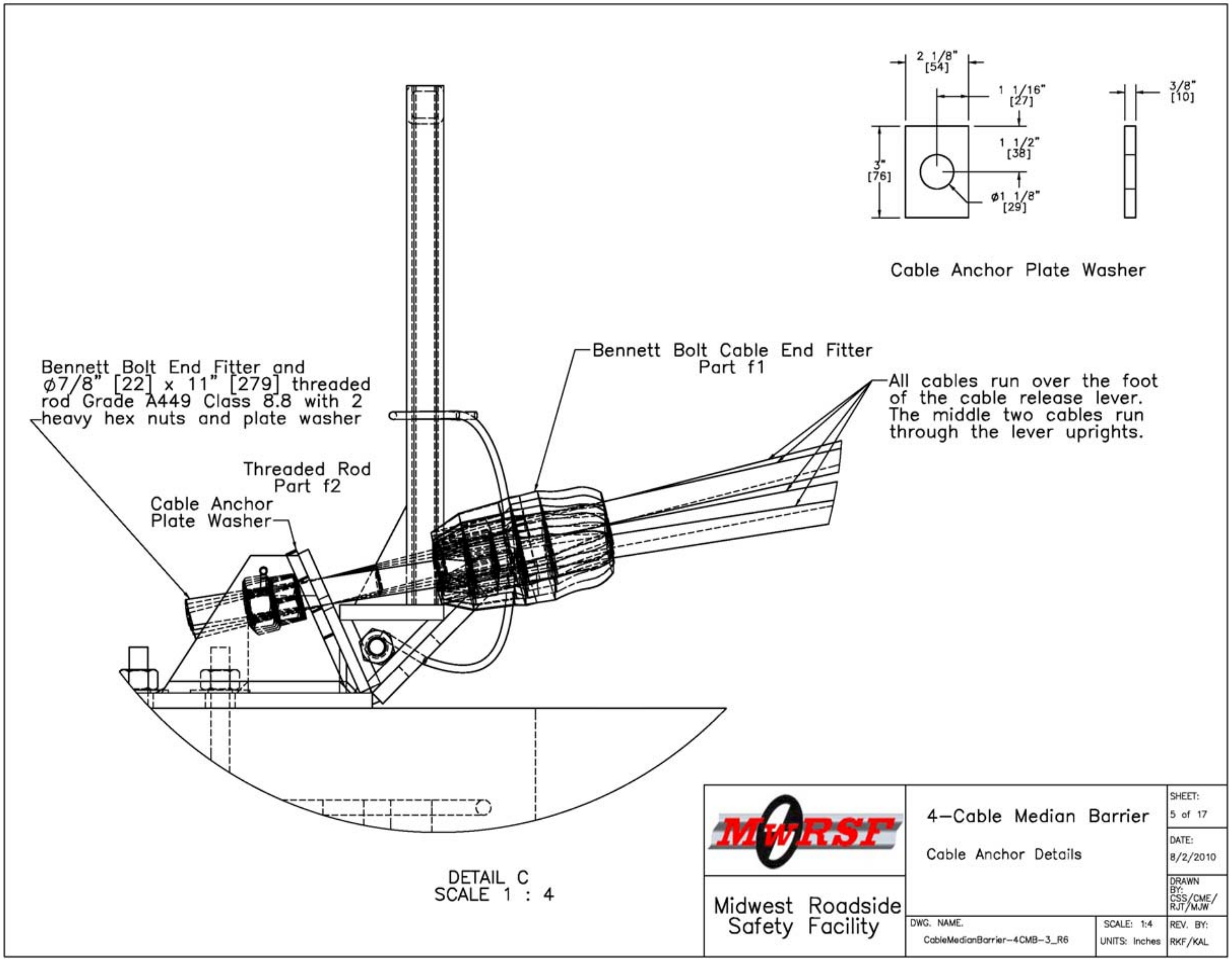


Figure 84. Cable Anchor Details, Test No. 4CMB-3

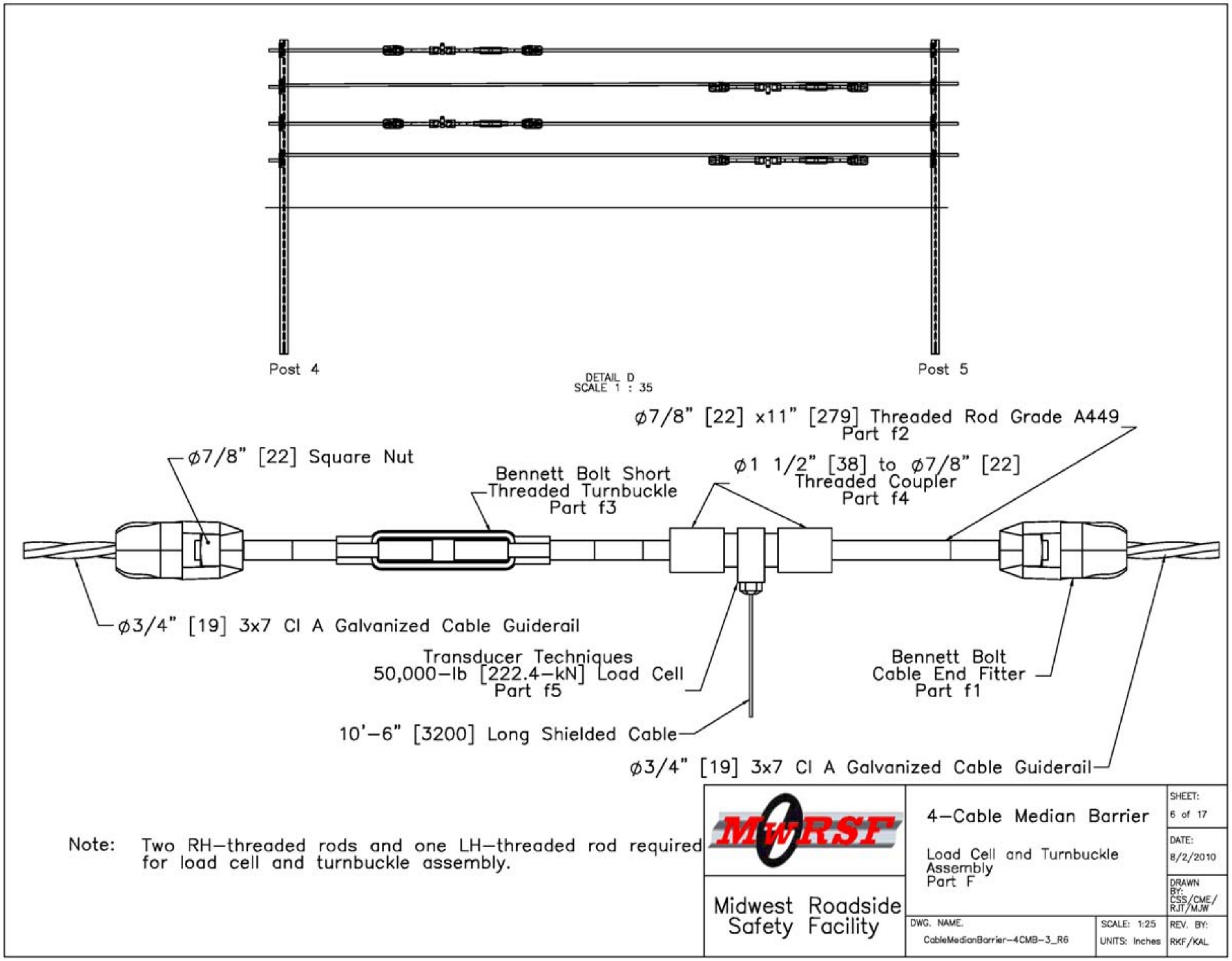


Figure 85. Load Cell and Turnbuckle Assembly, Test No. 4CMB-3

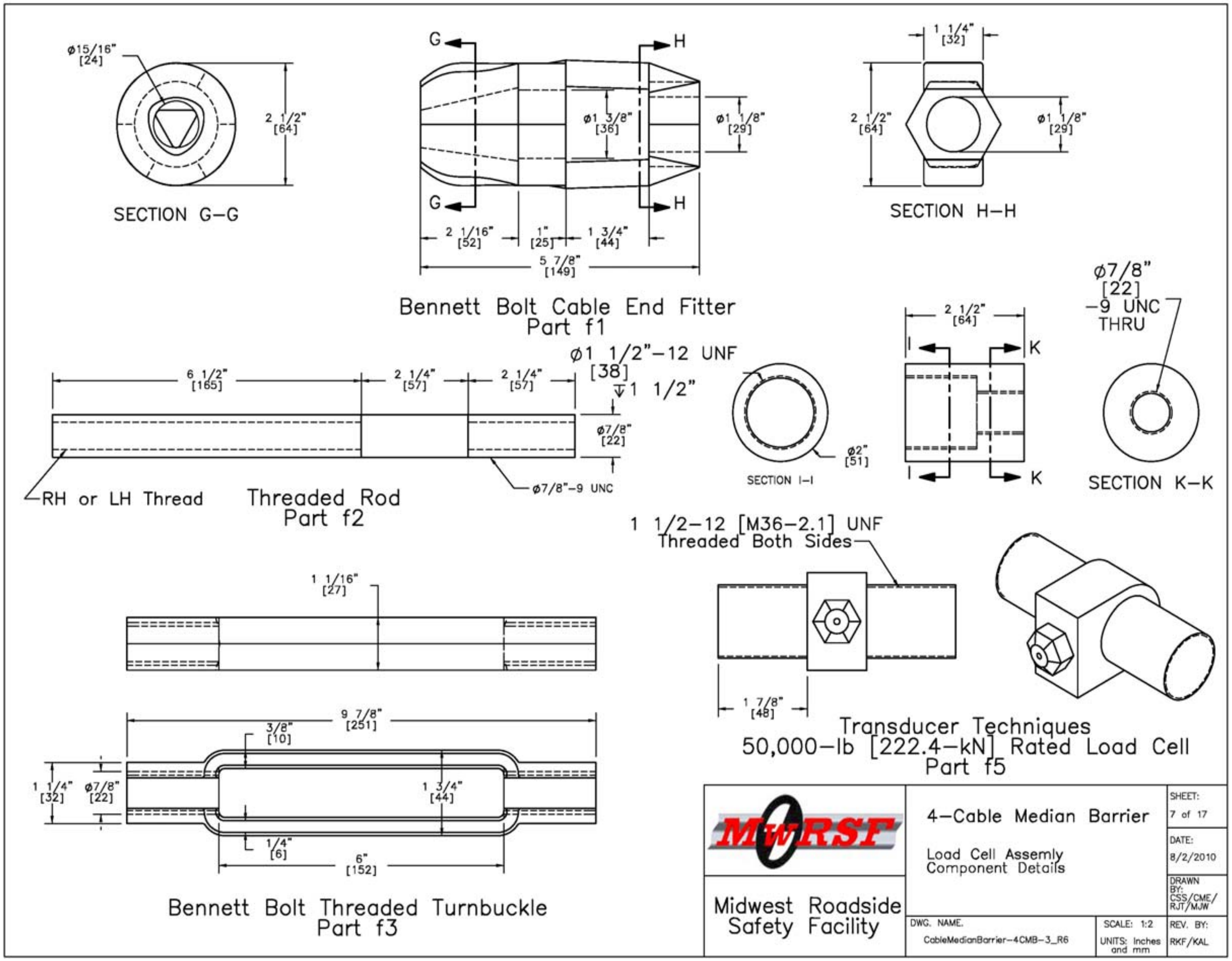
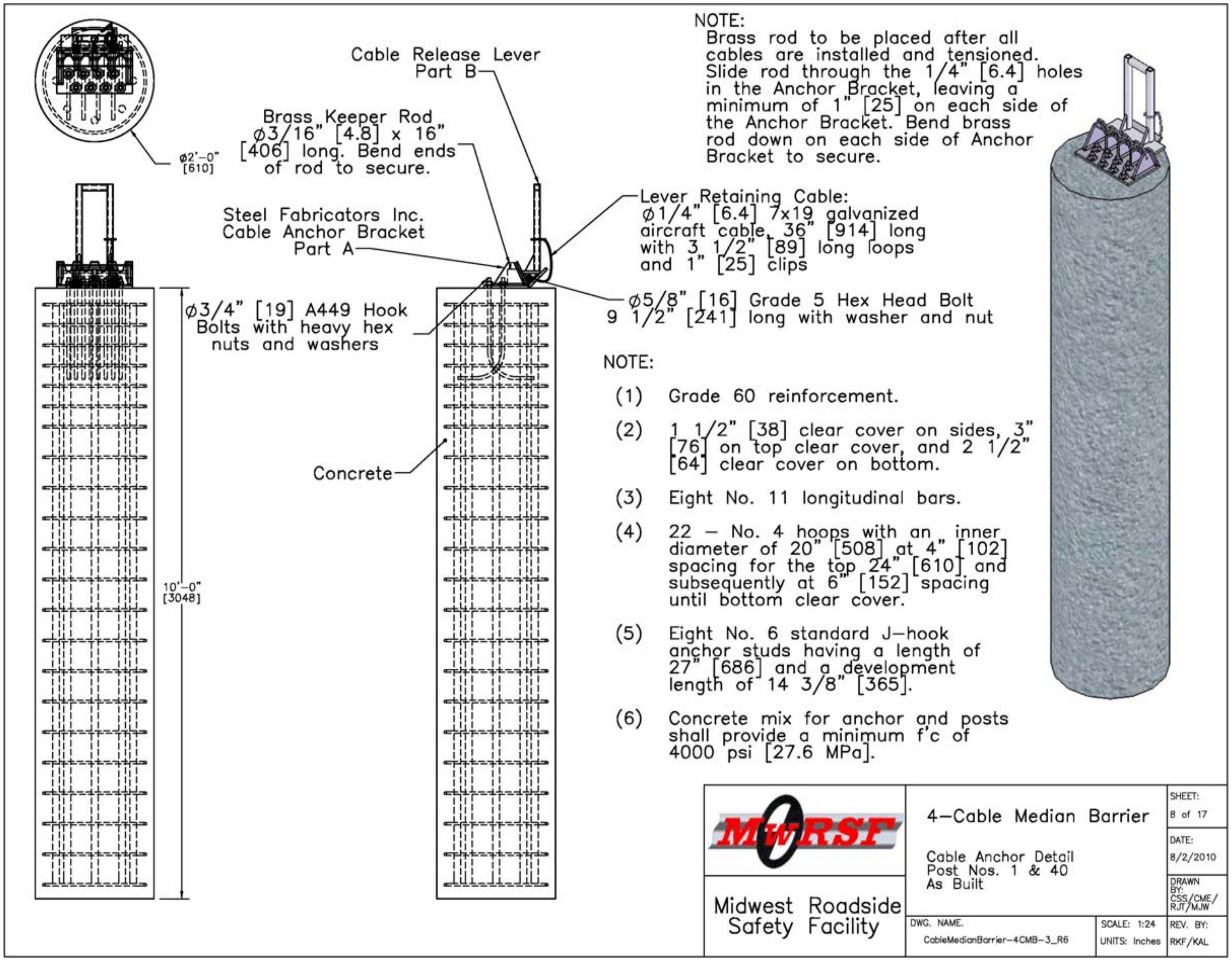


Figure 86. Load Cell Assembly, Component Details, Test No. 4CMB-3



NOTE:
Brass rod to be placed after all cables are installed and tensioned. Slide rod through the 1/4" [6.4] holes in the Anchor Bracket, leaving a minimum of 1" [25] on each side of the Anchor Bracket. Bend brass rod down on each side of Anchor Bracket to secure.

NOTE:

(1) Grade 60 reinforcement.

(2) 1 1/2" [38] clear cover on sides, 3" [76] on top clear cover, and 2 1/2" [64] clear cover on bottom.

(3) Eight No. 11 longitudinal bars.

(4) 22 – No. 4 hoops with an inner diameter of 20" [508] at 4" [102] spacing for the top 24" [610] and subsequently at 6" [152] spacing until bottom clear cover.

(5) Eight No. 6 standard J-hook anchor studs having a length of 27" [686] and a development length of 14 3/8" [365].

(6) Concrete mix for anchor and posts shall provide a minimum f'c of 4000 psi [27.6 MPa].

Figure 87. Cable Anchor Detail, Post Nos. 1 & 40, Test No. 4CMB-3

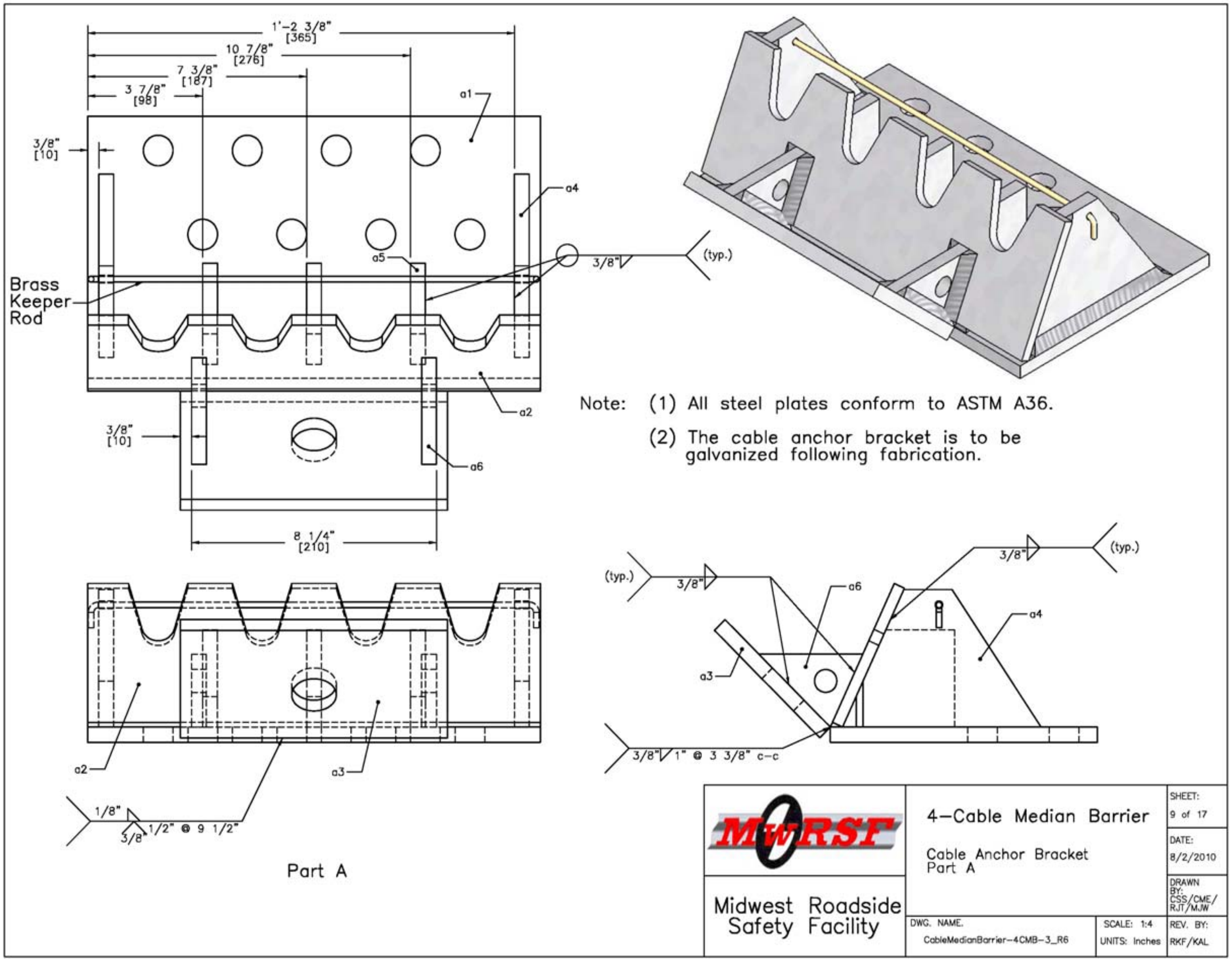


Figure 88. Cable Anchor Bracket, Test No. 4CMB-3

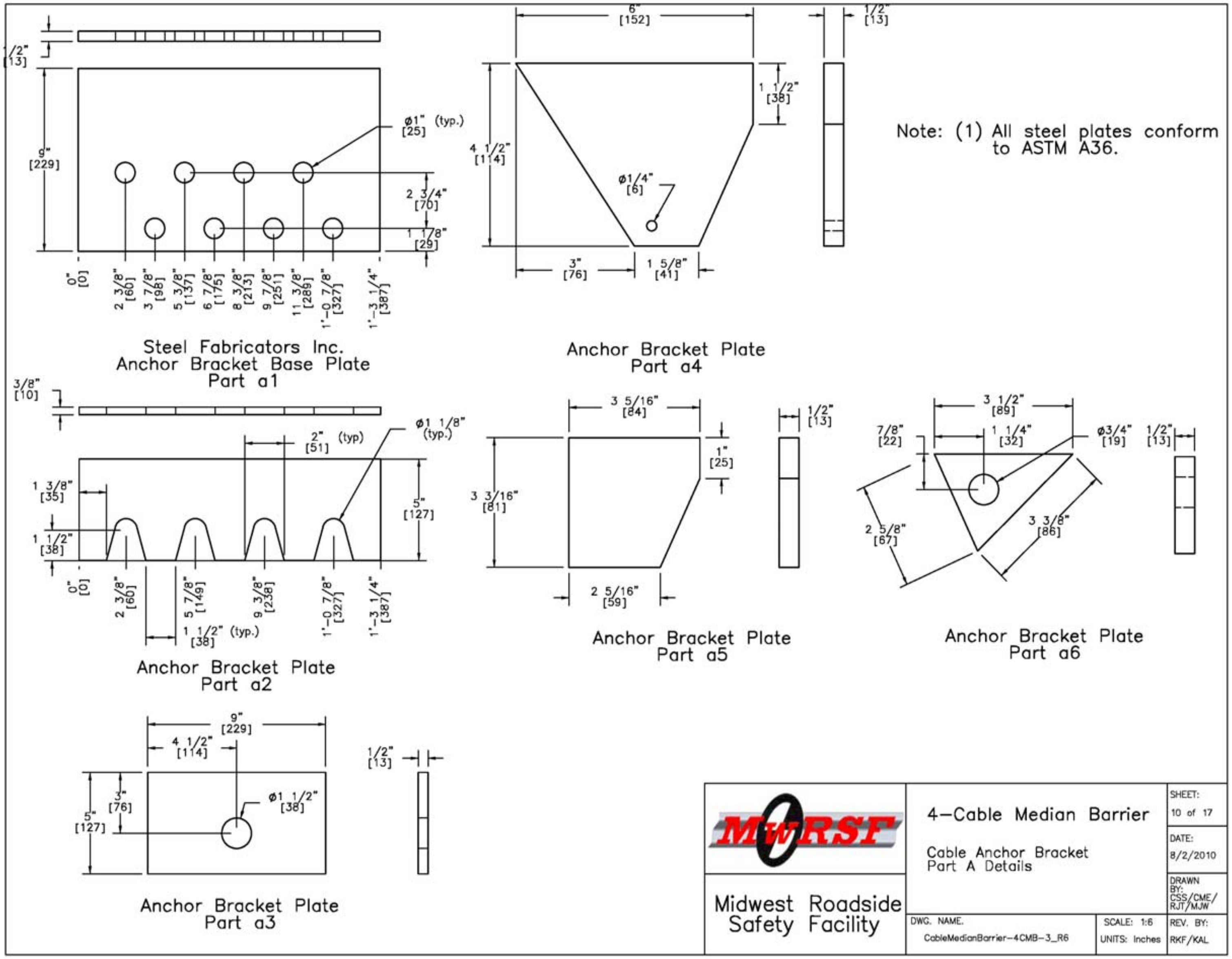


Figure 89. Cable Anchor Bracket Details, Test No. 4CMB-3

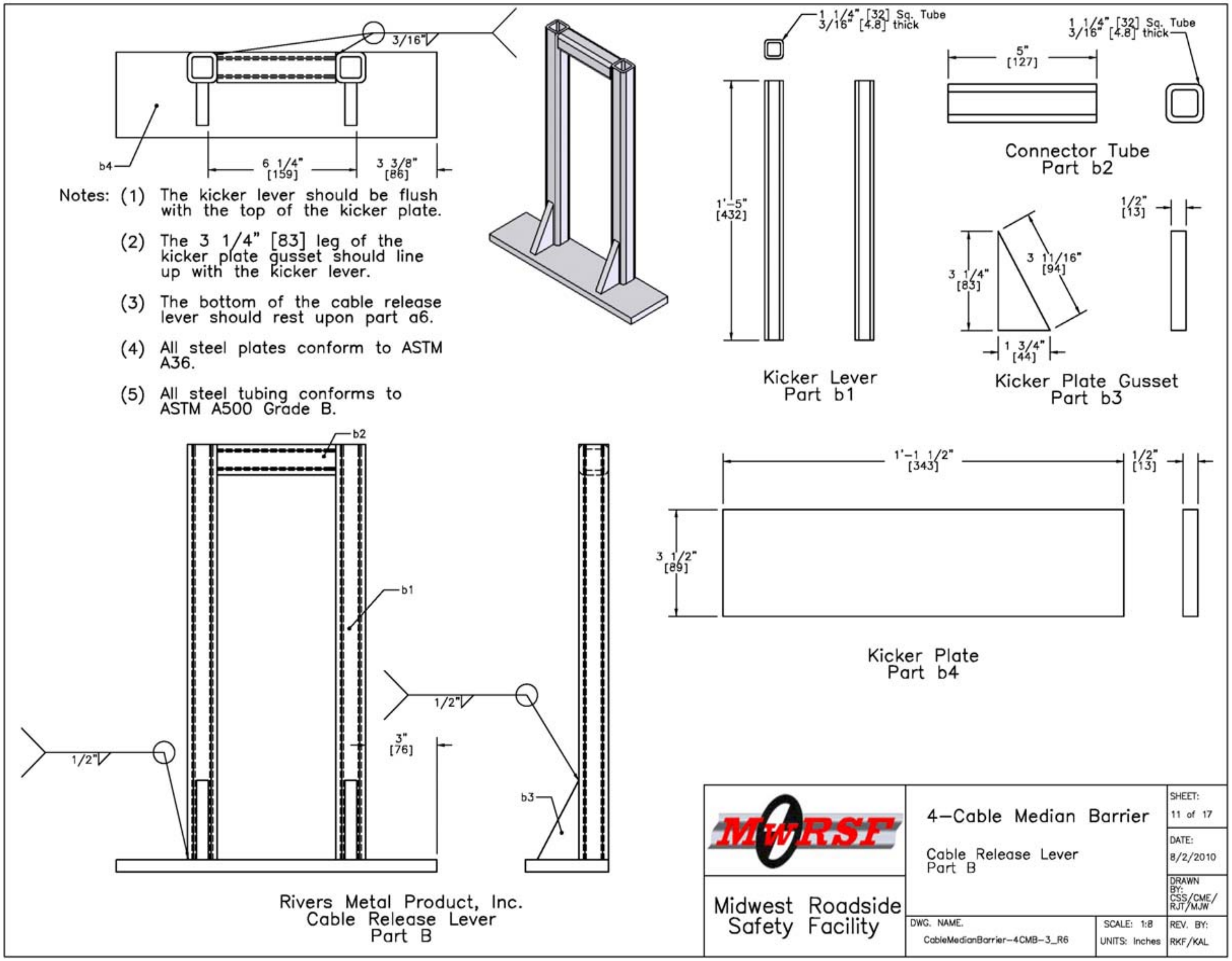
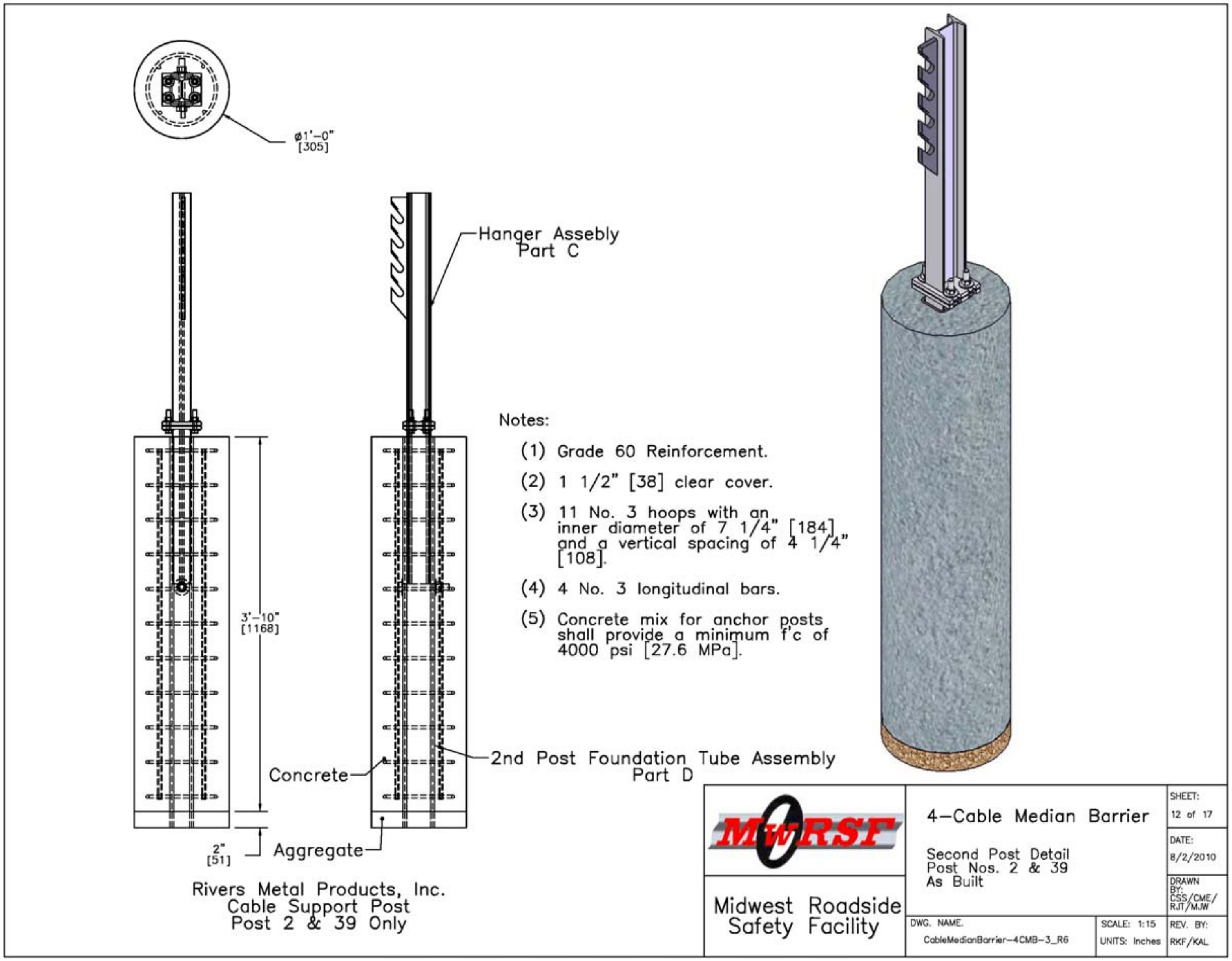


Figure 90. Cable Release Lever, Test No. 4CMB-3



Notes:

(1) Grade 60 Reinforcement.

(2) 1 1/2" [38] clear cover.

(3) 11 No. 3 hoops with an inner diameter of 7 1/4" [184] and a vertical spacing of 4 1/4" [108].

(4) 4 No. 3 longitudinal bars.

(5) Concrete mix for anchor posts shall provide a minimum f'c of 4000 psi [27.6 MPa].

Figure 91. Second Post Detail, Post Nos. 2 & 39, Test No. 4CMB-3

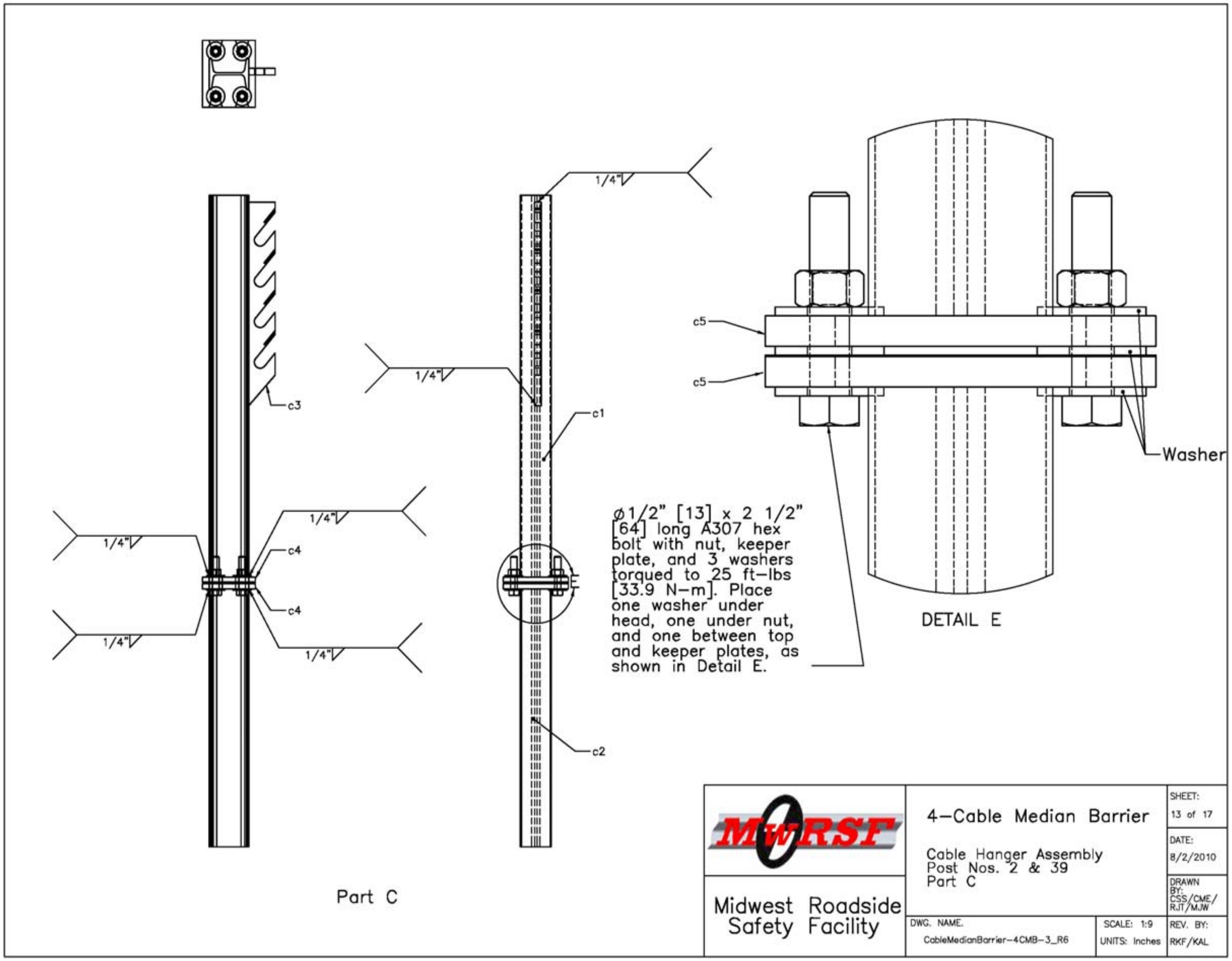


Figure 92. Cable Hanger Assembly, Post Nos. 2 & 39, Test No. 4CMB-3

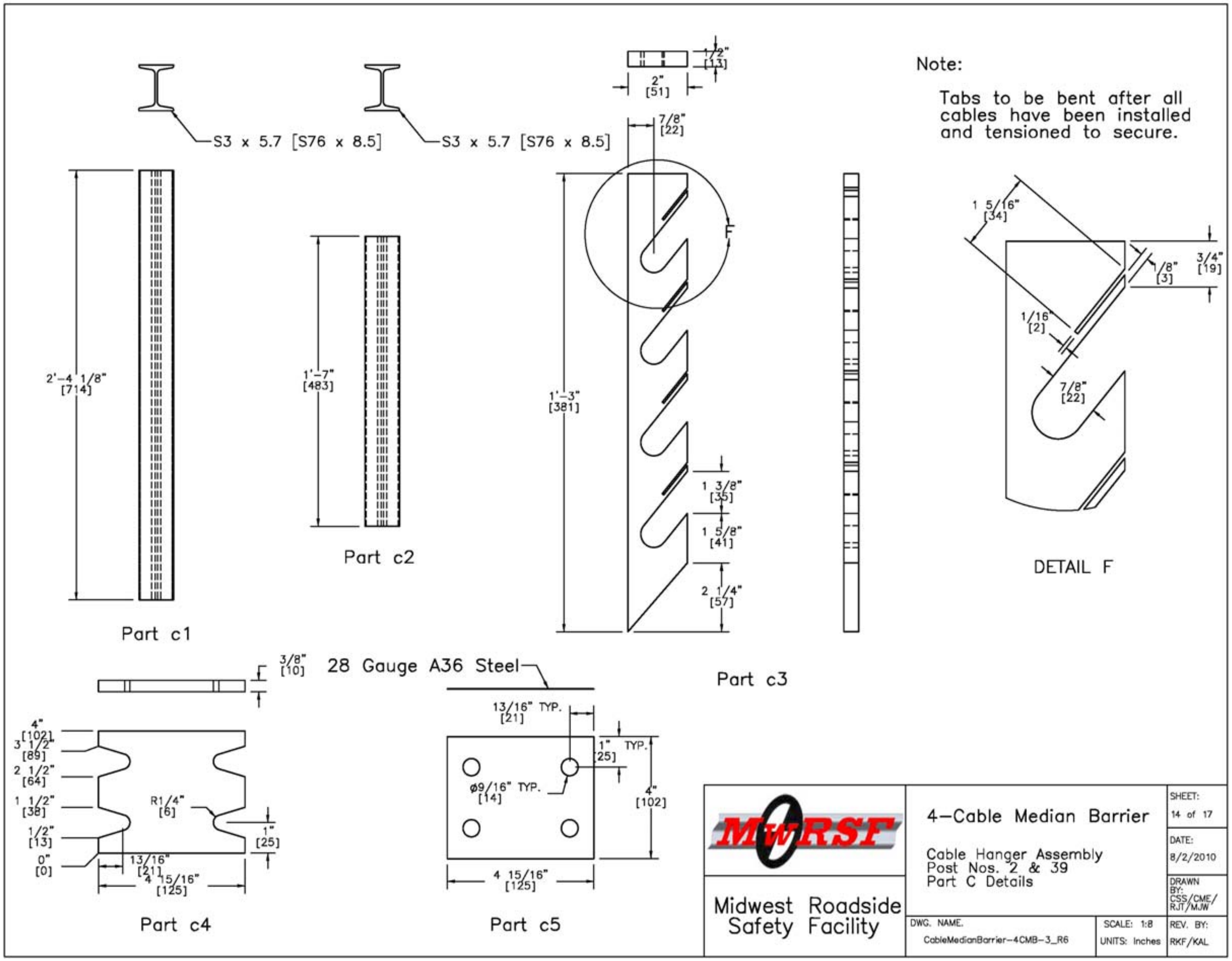


Figure 93. Cable Hanger Assembly Details, Post Nos. 2 & 39, Test No. 4CMB-3

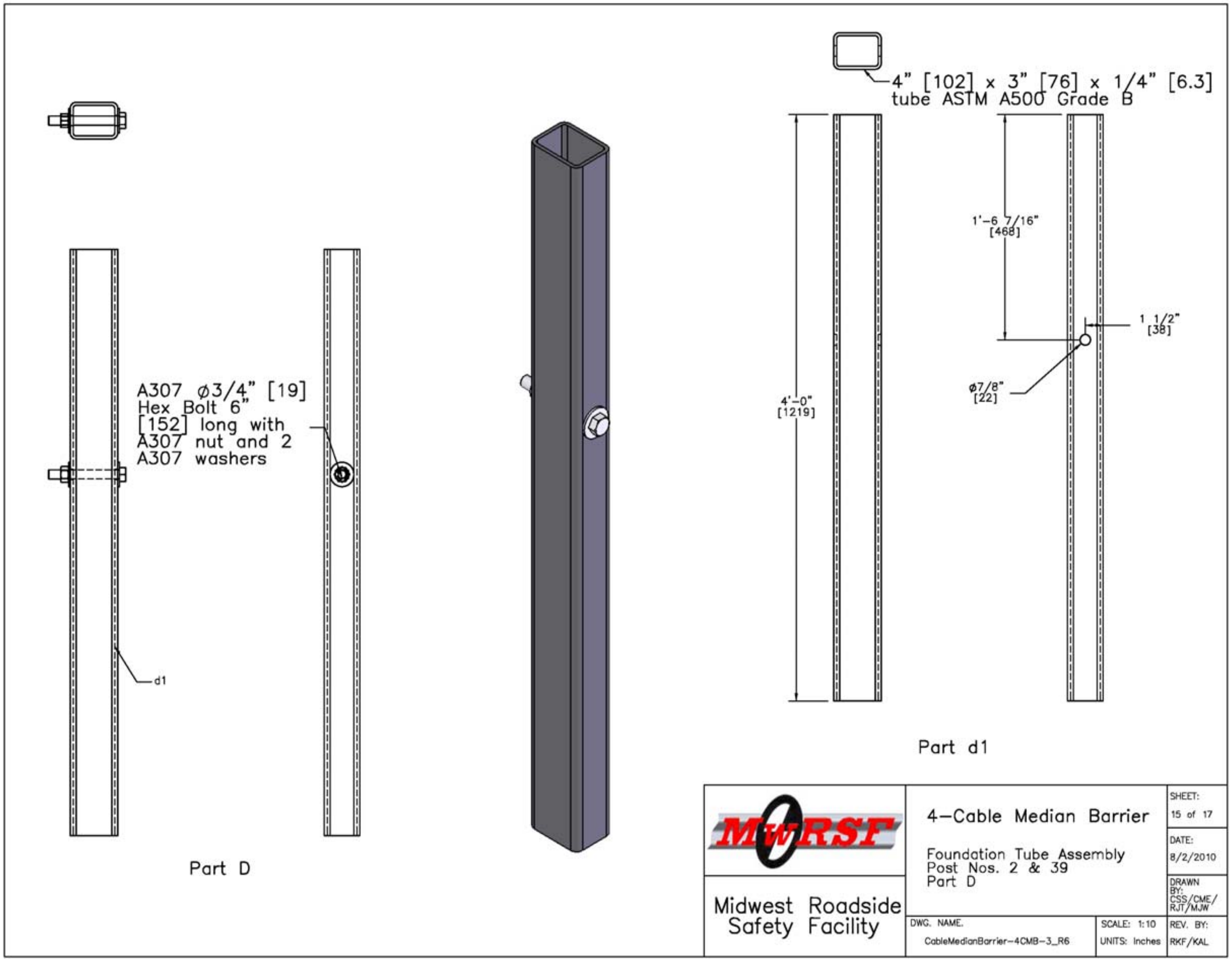


Figure 94. Foundation Tube Assembly, Post Nos. 2 & 39, Test No. 4CMB-3

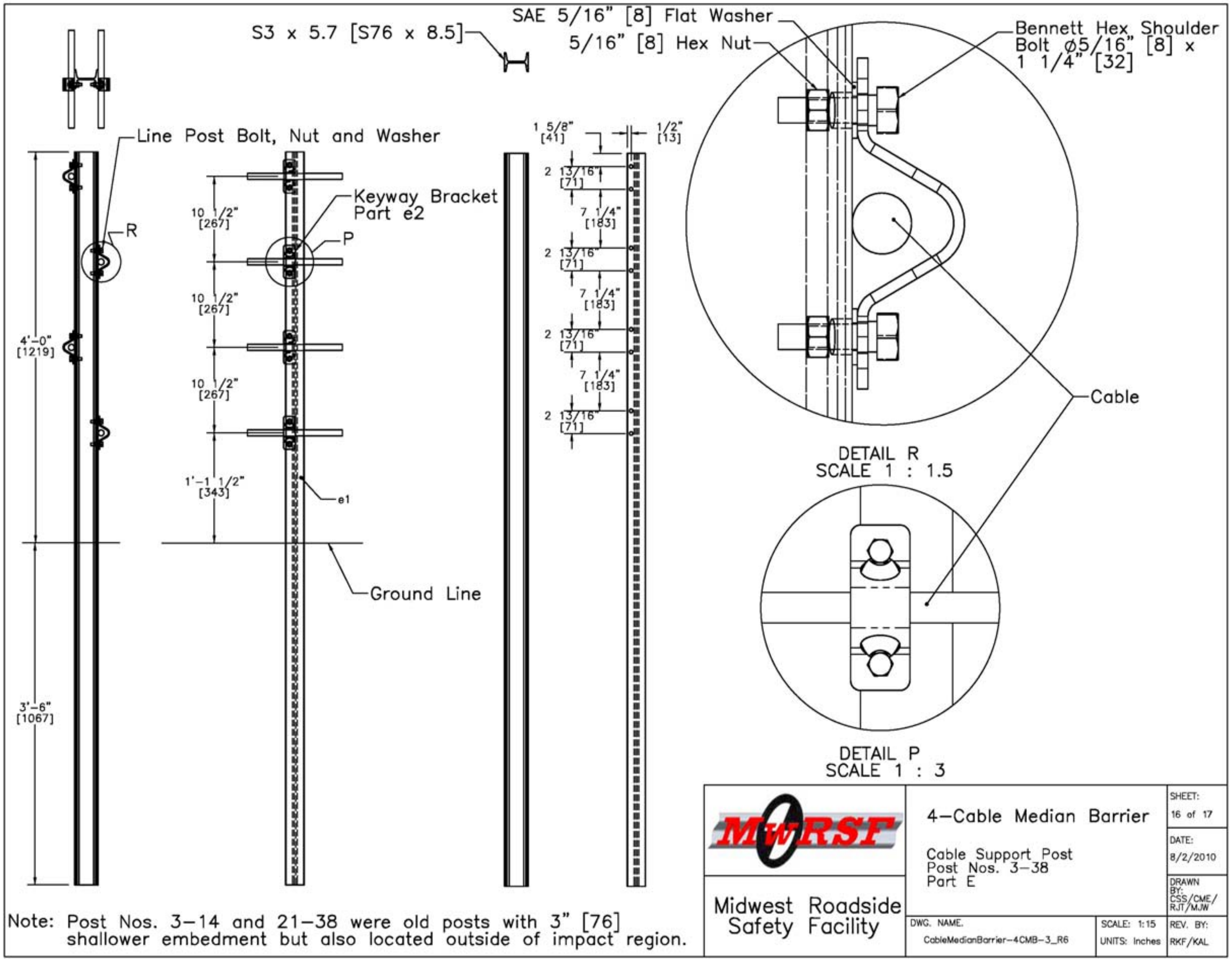


Figure 95. Cable Support Post, Post Nos. 3-38, Test No. 4CMB-3

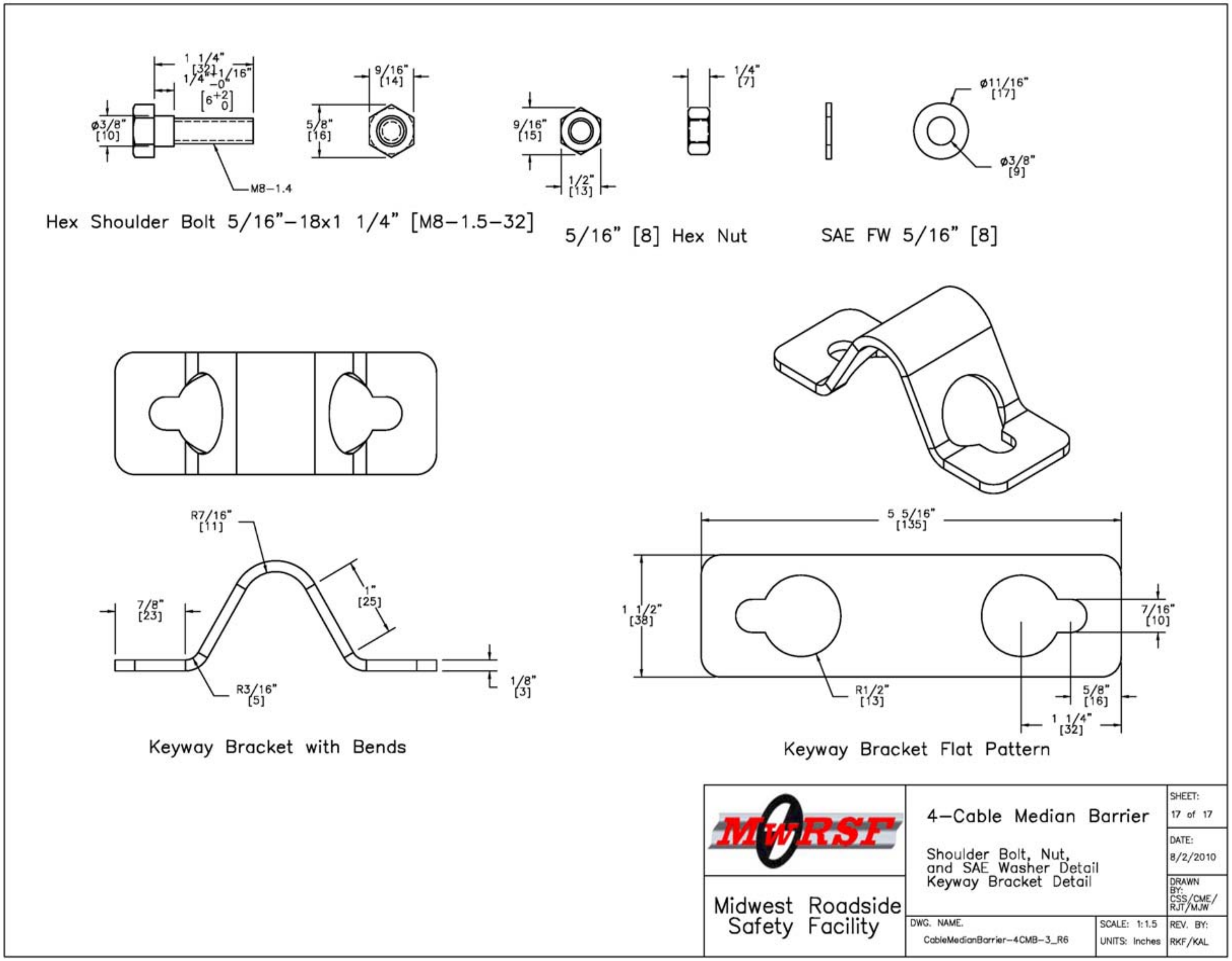


Figure 96. Shoulder Bolt, Nut, Washer, and Keyway Bracket Detail, Test No. 4CMB-3

10 FULL-SCALE CRASH TEST NO. 4CMB-3

10.1 Static Soil Test

Before full-scale test No. 4CMB-3 was conducted, the strength of the foundation soil was evaluated with a static test, as recommended by MASH. The static test results, as shown in Appendix D, demonstrated that adequate post-soil resistance was provided above the baseline soil strength limit. Thus, the barrier system was approved for use in the evaluation full-scale crash testing program.

10.2 Test No. 4CMB-3

The 2,568-lb (1,173-kg) small car impacted the cable median barrier at a speed of 62.0 mph (99.8 km/h) and at an angle of 27.2 degrees. A summary of the test results and sequential photographs are shown in Figure 97. Additional sequential photographs are shown in Figures 98 through 100. Documentary photographs are shown in Figures 101 and 102.

10.3 Weather Conditions

Test no. 4CMB-3 was conducted on August 25, 2008 at approximately 4:15 pm. The weather conditions were documented, as shown in Table 12.

10.4 Test Description

Initial vehicle impact was to occur between post nos. 16 and 17, or 5 ft - 4 in. (1,626 mm) downstream from the centerline of post no. 16, as shown in Figure 103. Table 13 contains a sequential description of the impact events. The final vehicle position was determined to be 28 ft - 5 in. (8.7 m) downstream of impact and 36 in. (914 mm) laterally behind the barrier, as shown in Figure 104.

Table 12. Weather Conditions, Test No. 4CMB-3

Temperature	82° F
Humidity	38 %
Wind Speed	7 mph
Wind Direction	120° from True North
Sky Conditions	Clear
Visibility	10.0 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.46 in.
Previous 7-Day Precipitation	0.46 in.

Table 13. Sequential Description of Impact Events, Test No. 4CMB-3

Time (sec)	Event
-0.714	Left-front tire encroached upon the ditch, and the vehicle rolled to the left and pitched downward.
-0.110	Left-front tire contacted the back slope of the ditch, and the vehicle pitched upward and rolled to the right.
-0.054	Left side of the front bumper contacted the ground.
0.000	Left side of the front bumper impacted the bottom cable.
0.030	Left-front corner of the engine hood contacted the lower-middle cable.
0.046	Lower-middle cable crumpled the top-left corner of the engine hood, and post no. 17 deflected laterally backward.
0.064	Post no. 16 deflected laterally backward.
0.072	Center of the engine hood contacted the upper-middle cable.
0.096	Bottom cable disengaged from post no. 17.
0.110	Left side of the front bumper disengaged from the vehicle.
0.116	Right-front bumper cover impacted post no. 17.

0.122	Bottom cable disengaged from post no. 18 as the post deflected laterally backward.
0.132	Upper- and lower-middle cables contacted the left-side mirror, left A-pillar deflected inward, and upper-middle cable disengaged from post no. 17.
0.148	Top cable disengaged from post no. 17.
0.166	Upper- and lower-middle cables disengaged from post no. 18.
0.192	Lower-middle cable disengaged from post no. 19.
0.224	Vehicle ceased to pitch.
0.250	Upper- and lower-middle cables traveled up the left A-pillar, and the windshield fractured along the left edge.
0.264	Top cable overrode the vehicle.
0.332	Vehicle yawed away from the barrier.
0.278	Upper-middle cable disengaged from post no. 19.
0.316	Lower-middle cable disengaged from post no. 20.
0.366	Top of the left A-pillar deformed inward, allowing upper- and lower-middle cables to penetrate the occupant compartment.
0.386	Left-front window shattered.
0.478	Right side of front bumper contacted post no. 18.
0.496	Top cable disengaged from post no. 18.
0.638	the front of the vehicle impacted the ground, the rear end of the vehicle pitches upward, causing the vehicle to decelerate rapidly
0.702	Vehicle yawed away from the barrier.
1.154	Vehicle came to a rest in contact with the system.

10.5 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 105 through 108. Barrier damage consisted of deformed guardrail posts, disengaged cables, and deformed retaining bolts. The length of the vehicle contact along the cable median barrier was about 28 ft - 5 in. (8.66 m), which spanned from the midspan between post nos.16 and 17 through post no. 19.

Post no. 16 rotated in the soil, and there was a ¾-in. (19-mm) soil gap at the base of the post. Post no. 17 was bent downstream about the weak axis of bending. A portion of post no. 18 was covered by the vehicle, and the post was primarily bent downstream. Post nos. 19 and 20 rotated slightly toward the non-impact side, and there was a ⅛-in. (3-mm) soil gap at the base of the post. All other posts remained undamaged.

The lower-middle cable bracket at post no. 16 released vertically upward. At post no. 17, all four cable brackets released vertically upward. At the lower-middle cable bracket, the upper bolt fractured, while all other bolts were bent. At post no. 18, all four cable brackets released, and the lower-middle cable was held down by the upper bolt of the upper cable bracket. All bolts were bent, with the exception of the upper bolt on the lower-middle cable bracket, which was fractured. At the vehicle’s final resting place, the lower-middle cable was pulled above the upper-middle cable. At post no. 19, the lower and lower-middle cables released from the brackets. The upper bolt on the lower-middle cable bracket was fractured, and the lower and lower-middle cable brackets were bent. At post no. 20, the lower-middle cable released, and the lower-middle cable bracket was bent. The lower cable bracket was slightly deformed as the cable pulled away from the post.

The permanent set of the posts is shown in Figures 103 through 105. The maximum lateral and longitudinal dynamic post deflections were 13½ in. (343 mm) and 23.3 in. (591 mm), respectively, at post no. 17. The maximum lateral cable deflection occurred in the bottom cable and was determined to be 50.3 in. (1,278 mm), and the working width was determined to be 64½ in. (1,638 mm), as determined from the high-speed film analysis.

10.6 Vehicle Damage

Exterior vehicle damage was severe, as shown in Figures 105 through 108. Damage was concentrated on the left-front corner of the vehicle. The lower cable was lodged between the tire and the left-front quarter panel. The left-front tire was deflated, the rim was severely bent, and it was turned almost 90 degrees toward the driver’s side. The left-side mirror was broken off. The windshield was severely damaged on the left side, and the A-pillar was bent into the occupant compartment. It should be noted that these deformation to the windshield and A-pillar exceeded the occupant compartment deformation limitations described n MASH. The left door was pulled outward at the bottom and inward toward the top. There were orange cable marks and deformation on the roof, caused by the top cable which was painted orange. The left-front window was shattered and there was some vehicle damage from the cables on the B-pillar.

The right-front door was bent slightly out of its frame, and the right-front quarter panel was deformed upward and outward. Post no. 18 was lodged in the right-front bumper and quarter panel. The right-front region of the engine hood was damaged in several places. Blue marks were present, thus indicating that the lower-middle cable caused the damage. The front bumper and both headlights were separated from the vehicle. The lower cable was pulled into the left headlight assembly area. Plastic panels from the undercarriage were broken off of the vehicle.

10.7 Occupant Risk Values

The calculated occupant impact velocities (OIVs) and 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 14. It is noted that the OIV’s and ORA’s were within the suggested limits provided in MASH. The calculated THIV and PHD values were not recorded. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 97. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

Table 14. Summary of OIV and ORA Values, Test No. 4CMB-3

Evaluation Criteria		Transducers	
		EDR-3	DTS
OIV [ft/s (m/s)]	Longitudinal	-31.17 (-9.50)	-27.30 (-8.32)
	Lateral	-2.85 (-0.87)	-4.37 (-1.33)
ORA [g's]	Longitudinal	-6.51	-6.19
	Lateral	-6.86	-7.53
THIV [ft/s (m/s)]		NA	NA
PHD [g's]		NA	NA

10.8 Load Cell Results

As previously discussed, tension load cells were installed inline with the cables and at both ends of the barrier system to monitor the total load transferred to the anchor with respect to time. The load cell results are summarized in Table 15. As noted previously, the target cable tension was 4,213 lb (18.7 kN) at 100 degrees Fahrenheit (23.6 degrees Celsius). Prior to testing, the actual cable tension in the top, upper-middle, lower-middle, and bottom cables located on the upstream end was 4,080 lb (18.1 kN), 4,200 lb (18.7 kN), 4,420 lb (19.7 kN), and 4,380 lb (19.5 kN), respectively. These readings were measured using a cable tension meter or cable tensiometer.

The individual cable loads, along with the total combined cable load imparted to the upstream anchor, were determined and are shown in Figure 112. The total axial force imparted to the upstream anchor was 35.04 kips (155.9 kN) and occurring at 0.121 seconds after vehicle impact with the barrier system. The top cable experienced a maximum load of 5.91 kips (26.3 kN). The upper-middle and lower-middle cables experience maximum loads of 7.51 kips (33.4 kN) and 10.98 kips (48.8 kN), respectively. The bottom cable experienced the highest maximum load of 13.73 kips (61.1 kN).

Table 15. Load Cell Results, Test No. 4CMB-3

Cable Location	Sensor Location	Maximum Cable Load		Time[1] (sec)
		kips	kN	
Combined Cables	Upstream End	35.04	155.9	0.121
Top Cable	Upstream End	5.91	26.2	0.139
Upper Middle Cable	Upstream End	7.51	33.4	0.198
Lower Middle Cable	Upstream End	10.98	48.8	0.123
Bottom Cable	Upstream End	13.73	61.1	0.121

[1] - Time determined from initial vehicle impact with the barrier system.

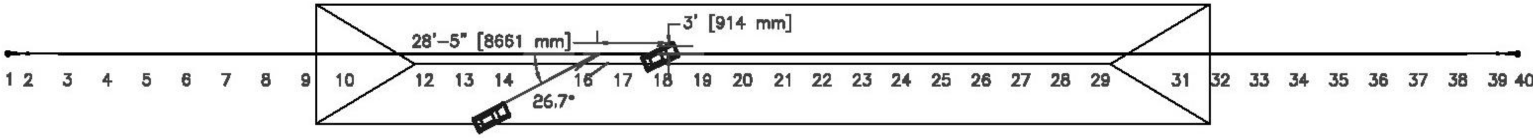
After the crash test, the tension in each cable was again measured. With the small car engaged with the system, the cable tension at the upstream end and in the top, upper-middle, lower-middle, and bottom cables was 4,060 lb (18.1 kN), 4,380 lb (19.5 kN), 5,640 lb (25.1 kN), and 5,000 lb (22.2 kN), respectively. On the contrary and with the small car engaged with the barrier, the cable tension at the downstream end and in the top, upper-middle, lower-middle, and bottom cables was 4,040 lb (18.0 kN), 4,420 lb (19.7 kN), 6,260 lb (27.8 kN), and 5,040 lb (22.4 kN), respectively.

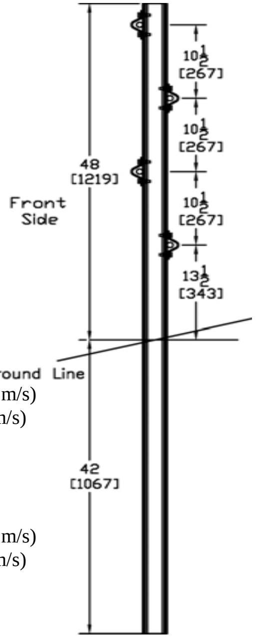
With the small car disengaged from the cable barrier system, the cable tension at the upstream end and in the top, upper-middle, lower-middle, and bottom cables was 4,720 lb (21.0 kN), 4,960 lb (22.1 kN), 4,280 lb (19.0 kN), and 3,460 lb (15.4 kN), respectively. On the contrary and with the small car disengaged from the barrier, the cable tension at the downstream end and in the top, upper-middle, lower-middle, and bottom cables was 4,620 lb (20.6 kN), 5,000 lb (22.2 kN), 2,560 lb (20.3 kN), and 3,600 lb (16.0 kN), respectively.

10.9 Discussion

The analysis of the test results for test no. 4CMB-3 (test designation no. 3-10) showed that the high-tension, four-cable median barrier adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier system when placed in a V-ditch with 4H:1V side slopes and 4 ft (1.2 m) laterally up the back slope from the ditch bottom. Note that a strong/stiff soil condition was used for the ditch bottom. The test vehicle did not penetrate nor ride over the barrier system and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted and were deemed acceptable because they did not adversely influence occupant risk safety criteria nor result in vehicle rollover. After collision, the vehicle's trajectory did not intrude into adjacent traffic lanes as it remained within the ditch bottom. However, there were barrier elements which showed potential for penetrating the occupant compartment. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did occur. The driver's side front window was shattered, and the left A-pillar deformed with cables penetrating the occupant compartment. Therefore, test no. 4CMB-3 was determined to be unacceptable according to the TL-3 safety performance criteria found in MASH when the barrier was placed in a strong/stiff soil condition near the ditch bottom.

0.000 sec 0.118 sec 0.368 sec 0.536 sec 1.056 sec





- Test Agency .... MwRSF
- Test Number 4CMB-3
- Date 8/25/08
- MASH Test Designation 3-10
- Appurtenance .... Four-Cable High-Tension Median Barrier Installed on on 4:1 Slope
- Median Width .... 46 ft (14.0 m)
- Total Length .... 608 ft (185.3 m)
- Placement .... 4 ft (1.2 m) up back slope from ditch bottom
- Key Elements - Wire Rope
    - Diameter .... ¾ in. (19 mm)
    - Size 3x7
    - Top Cable Height .... 45 in. (1,143 mm)
    - Bottom Cable Height ...... 13½ in. (343 mm)
    - Incremental Spacing ...... 10½ in. (267 mm)
- Key Elements - End Anchor Posts
    - Post Nos. 1 and 40 .... 24 in. (610 mm) diameter by 120 in. (3,048 mm) long concrete footer
    - Post Nos. 2 and 39 .... S3x5.7 (S76x8.5) by 28⅛ in. (714 mm) long with S3x5.7 (S76x8.5) by 19 in. (483 mm) long in a 12 in. (305 mm) diameter by 46 in. (1,164 mm) long concrete footer
- Key Elements - Line Posts
    - Post Nos. 3-38 .... S3x5.7 (S76x8.5) by 90 in. (2,286 mm) long
    - Spacing .... 16 ft (4.88 m)
- Type of Soil .... Grading B - AASHTO M 147-65 (1990) (Strong/stiff soil condition)
- Test Vehicle
    - Type/Designation 1100C
    - Make and Model .... 2002 Kia Rio Sedan
    - Curb .... 2,402 lb (1,090 kg)
    - Test Inertial .... 2,411 lb (1,094 kg)
    - Gross Static .... 2,586 lb (1,173 kg)
- Impact Conditions
    - Speed .... 62.0 mph (99.8 km/h)
    - Angle .... 27.2 degrees
    - Impact Location .... 64 in. (1,626 mm) downstream of post 16
- Exit Conditions
    - Speed .... NA
    - Angle .... NA
    - Exit Box Criterion .... NA
- Post-Impact Trajectory
    - Vehicle Stability .... Satisfactory
    - Stopping Distance .... 28 ft - 5 in. (8.66 m) downstream 3 ft (914 mm) laterally behind
- Occupant Impact Velocity (EDR-3)
    - Longitudinal .... -31.17 ft/s (-9.50 m/s) < 40 ft/s (12.2 m/s)
    - Lateral .... -2.85 ft/s (-0.87 m/s) < 40 ft/s (12.2 m/s)
- Occupant Ridedown Deceleration (EDR-3)
    - Longitudinal .... -6.51 g's < 20.49 g's
    - Lateral .... -6.86 g's < 20.49 g's
- Occupant Impact Velocity (DTS)
    - Longitudinal .... -27.30 ft/s (-8.32 m/s) < 40 ft/s (12.2 m/s)
    - Lateral .... -4.37 ft/s (-1.33 m/s) < 40 ft/s (12.2 m/s)
- Occupant Ridedown Deceleration (DTS)
    - Longitudinal .... -6.19 g's < 20.49 g's
    - Lateral .... -7.53 g's < 20.49 g's
- THIV (not required) .... NA
- PHD (not required) .... NA
- Test Article Damage .... Moderate
- Test Article Deflections
    - Permanent Set .... N/A
    - Dynamic (Post) .... 13.5 in. (343 mm)
    - Dynamic (Cable) .... 50.3 in. (1,278 mm)
    - Working Width .... 64.5 in. (1,638 mm)
- Vehicle Damage .... Severe
    - VDS[8] 11-LFQ-6
    - CDC[9] 11-LYAW8
    - Maximum Deformation .... 10½ in. (267 mm)
- Angular Displacements
    - Roll .... -20.63 deg
    - Pitch .... 14.38 deg
    - Yaw .... 22.02 deg

Figure 97. Summary of Test Results and Sequential Photographs, Test No. 4CMB-3

-0.056 sec

0.084 sec

0.156 sec

0.220 sec

0.360 sec

0.532 sec

0.756 sec

1.158 sec

Figure 98. Additional Sequential Photographs, Test No. 4CMB-3

-0.428 sec

0.010 sec

0.084 sec

0.136 sec

0.318 sec

0.400 sec

0.690 sec

0.984 sec

Figure 99. Additional Sequential Photographs, Test No. 4CMB-3

-0.056 sec

0.054 sec

0.100 sec

0.202 sec

0.304 sec

0.420 sec

0.592 sec

1.208 sec

Figure 100. Additional Sequential Photographs, Test No. 4CMB-3

Figure 101. Documentary Photographs, Test No. 4CMB-3

Figure 102. Documentary Photographs, Test No. 4CMB-3

Figure 103. Vehicle Impact Location, Test No. 4CMB-3

Figure 104. Vehicle Final Position and Trajectory Marks, Test No. 4CMB-3

Figure 105. System Damage, Test No. 4CMB-3

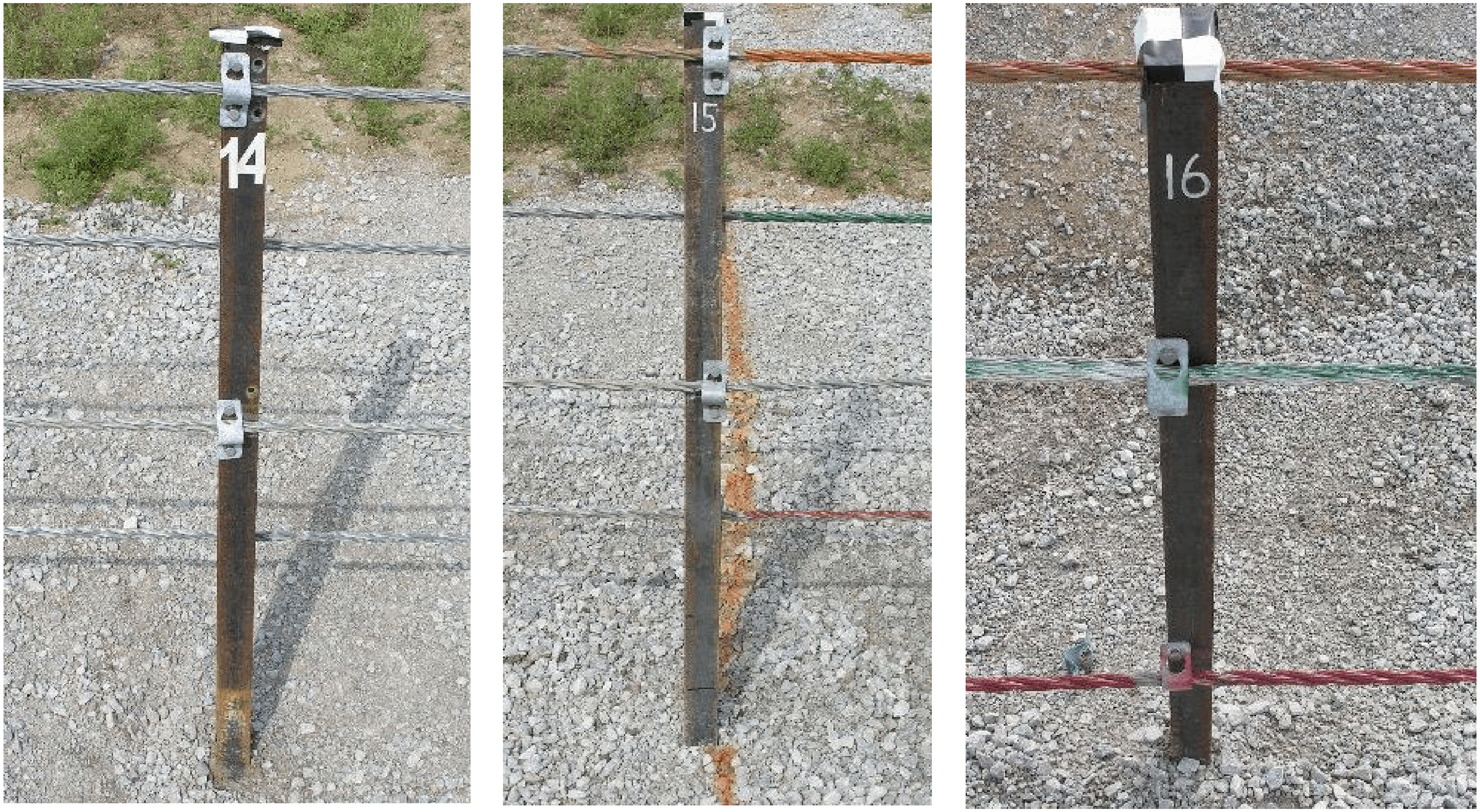


Figure 106. Post Nos. 14 through 16 Damage, Test No. 4CMB-3

Figure 107. Post No. 17 Damage, Test No. 4CMB-3

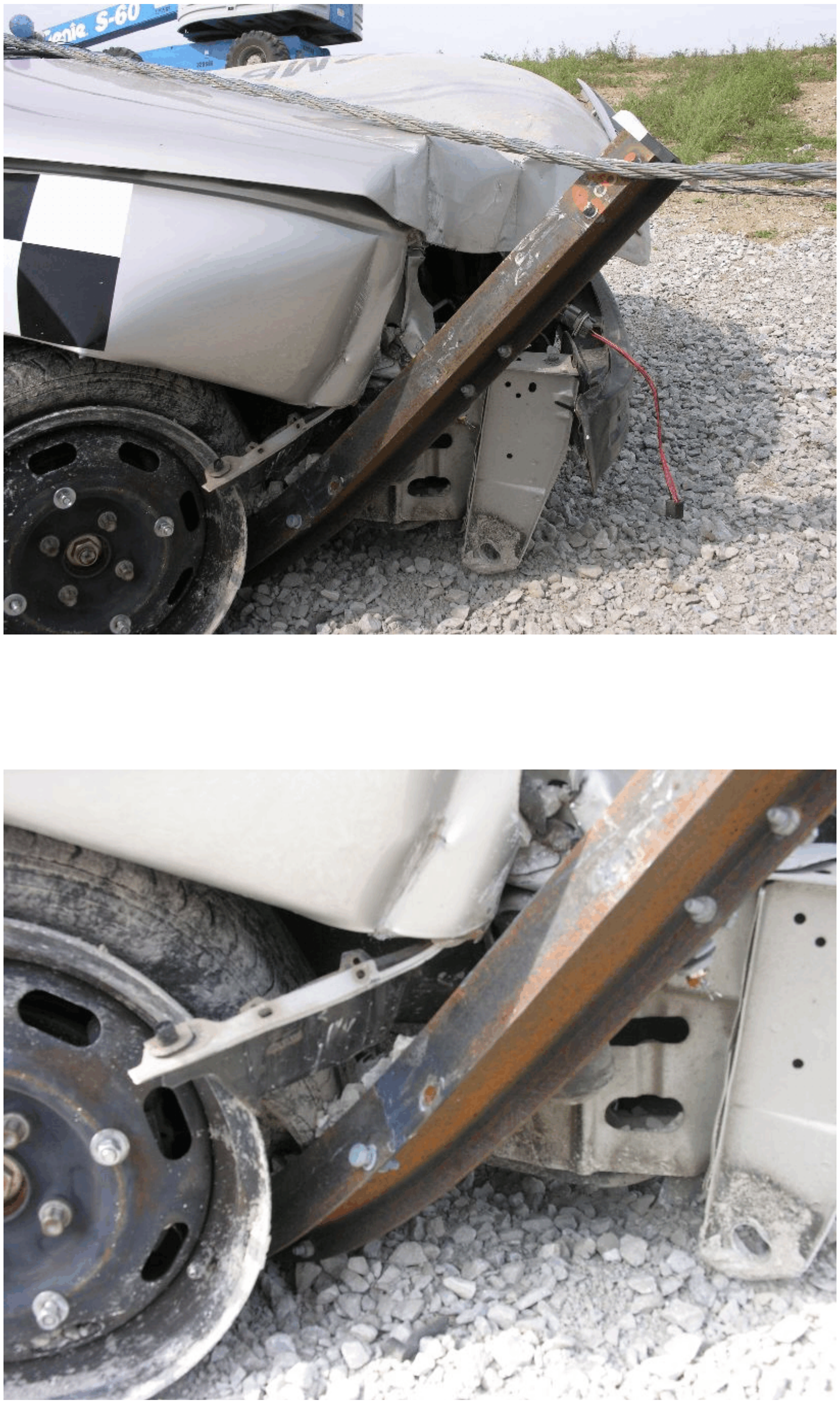


Figure 108. Post No. 18 Damage, Test No. 4CMB-3

Figure 109. Vehicle Damage, Test No. 4CMB-3

Figure 110. Vehicle Damage, Test No. 4CMB-3

Figure 111. Windshield Damage, Test No. 4CMB-3

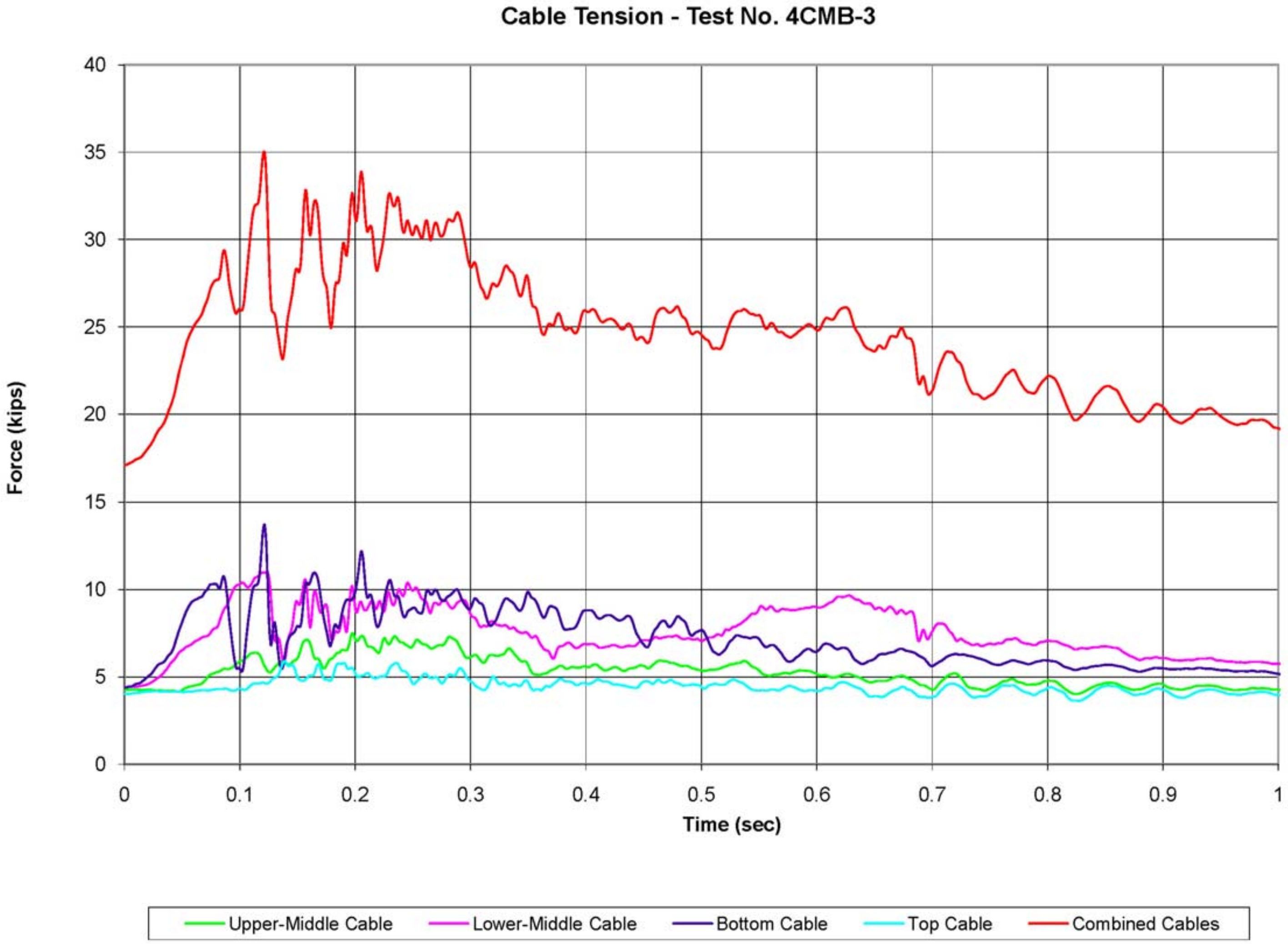


Figure 112. Load Cell Results, Test No. 4CMB-3

11 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Under the guidance of the Midwest States Pooled Fund program, MwRSF researchers were asked to develop, test, and evaluate a new high-tension, four-cable barrier system for use in sloped medians as steep as 4H:1V and using a V-ditch configuration. In addition, the new cable barrier system was to accommodate placement anywhere within the sloped median ditch.

Based on this main directive, a new barrier system was developed while considering several other goals. First, the barrier system was designed to be capable withstanding and redirecting errant vehicles on either side of the barrier under the Test Level 3 (TL-3) impact safety standards provided in MASH. The barrier system was configured to limit dynamic barrier deflections as compared to other cable systems using improved cable-to-post attachment hardware to maximize the energy dissipated by the support posts as well as to select an appropriate cable tension. The barrier system was also configured to mitigate concerns for vehicle override and underride with the selection of four cables, an upper cable height of 45 in. (1,143 mm), a lower cable height of 13½ in. (343 mm) and a cable spacing of 10½ in. (267 mm). LS-DYNA computer simulations, in conjunction with field measurements of bumper heights and front-end geometries for small car vehicles, were utilized to determine the critical V-ditch width of 46 ft (14.02 m), a critical lateral barrier offset of 12 ft (3.66 m) for evaluating pickup truck override, and a critical lateral barrier offset of 4 ft (1.22 m) for evaluating small car underride. In addition, the barrier system was intended to maintain an open aesthetic appeal, but it was configured for easy maintenance and repair following impact events.

A full-scale vehicle crash testing program was conducted according to the TL-3 safety performance guidelines found in MASH. Three full-scale crash tests were performed on different cable barrier systems installed at various locations within the 46-ft (14.02 m) wide ditch with 4H:1V side slopes. A summary of each safety performance evaluation is shown in Table 16.

The first full-scale crash test, test no. 4CMB-1 (override test), consisted of a 4,988-lb (2,263-kg) pickup truck impacting the cable median barrier at a speed of 61.8 mph (99.5 km/h) and at an angle of 27.9 degrees. The system was located 12 ft (3.66 m) laterally away from the front slope break point and down the fore-slope of the ditch. The impact point for this test was 3 ft (914 mm) downstream from the centerline of post no. 15. During the test, the cable barrier system adequately contained and redirected the vehicle. Therefore, the system passed all of the evaluation criteria for test designation no. 3-11 of the MASH impact safety standards.

Test nos. 4CMB-2 and 4CMB-3 (underride tests) were performed on a barrier system positioned on the back slope and 4 ft (1.22 m) laterally from the ditch bottom. The second full-scale test, test no. 4CMB-2, consisted of a 2,557-lb (1,160-kg) small car impacting the cable median barrier at a speed of 62.7 mph (100.9 km/h) and at an angle of 26.8 degrees. A soft soil condition was utilized for the ditch bottom. The impact point for this test was 61 in. (787 mm) downstream from the centerline of post no. 17. During the test, the vehicle made contact with the back slope prior to impacting the barrier system. The vehicle undercarriage and wheels penetrated, gouged, and/or rutted the soft soil, thus causing additional vehicle loss of speed prior to impacting with the cable median barrier. As a result of these occurrences, the vehicle’s front end penetrated slightly under the bottom cable. However, the barrier system still contained the vehicle. It should also be noted that the longitudinal OIV exceeded the MASH limit of 40 ft/s (12.2 m/s) when considering the loss in vehicle speed during tire rutting and soil plowing prior to vehicle contact with the barrier. Therefore, test no. 4CMB-2 was determined to be only marginally acceptable according to the TL-3 safety performance criteria found in MASH under test designation no. 3-10 when the barrier was placed near the ditch bottom configured with a soft soil condition.

For test no. 4CMB-3, the soft soil condition was replaced with a heavily compacted soil to the region surrounding the posts near the vehicle impact location. Test no. 4CMB-3 consisted of a 2,586-lb (1,173-kg) small car impacting the cable median barrier at a speed of 62.0 mph (99.8 km/h) and at an angle of 27.2 degrees. The impact point for this test was 64 in. (1,626 mm)downstream from the centerline of post no. 16. During the test, the vehicle was contained by the cable barrier system. However, some cables were observed to snag on the bolt heads corresponding with the keyway bracket, thus resulting in significant deformations to the A-pillar on the driver's side of the vehicle as well as windshield penetration. Therefore, the cable barrier system did not meet the TL-3 impact standards set forth in MASH for test designation no. 3-10 when the barrier was placed near the ditch bottom configured with a strong/stiff soil condition.

As a result of the unacceptable small car performance observed in test no. 4CMB-3, MwRSF researchers deemed it necessary to redesign the keyway bracket to mitigate concerns for cable snag on the bolt heads. In addition, members of the Midwest States Pooled Fund program expressed some concern with the number of small components and associated complexity of each keyway bracket. Thus, the keyway bracket was recommended for replacement to improve the safety performance of the high-tension cable barrier system as well as provide a simplified cable-to-post attachment mechanism.

Table 16. Summary of Safety Performance Evaluations Under MASH Guidelines

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. 4CMB-1</th><th>Test No. 4CMB-2</th><th>Test No. 4CMB-3</th></tr>
<tr><td>Structural Adequacy</td><td colspan="4">A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td><td>S</td><td>S</td></tr>
<tr><td rowspan="12">Occupant Risk</td><td colspan="4">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 should not exceed limits set forth in Section 5.3 and Appendix E of MASH 08.</td><td>S</td><td>S</td><td>U</td></tr>
<tr><td colspan="4">F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>S</td><td>S</td></tr>
<tr><td colspan="4">H. Occupant Impact Velocities (OIV) (see Appendix A, Section A5.3 of MASH 08 for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">U/S*</td><td rowspan="4">S</td></tr>
<tr><td rowspan="3"></td><td colspan="3">Occupant Impact Velocity Limits, ft/s (m/s)</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Lateral and Longitudinal</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
<tr><td colspan="4">I. The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH 08 for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">S</td><td rowspan="4">S</td></tr>
<tr><td rowspan="3"></td><td colspan="3">Occupant Ridedown Acceleration Limits (g’s)</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

S - Satisfactory U - Unsatisfactory

* - Results were unsuccessful when contact with ditch back slope prior to barrier contact is considered. Results were successful when beginning of impact is defined as first contact with barrier.

12 REFERENCES

1. Molacek, K.J., Lechtenberg, K.A., Faller, R.K., Rohde, J.R., Sicking, D.L., Bielenberg, R.W., Reid, J.D., Stolle, C.J., Johnson, E.A., Stolle, C.S., *Design and Evaluation of a Low-Tension Cable Median Barrier System*, Final Report Submitted to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-195-08, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, December 8, 2008.

2. Thiele, J.C., Bielenberg, R.W., Faller, R.K., Sicking, D. L., Rohde, J.R., Reid, J.D., Polivka, K.A., and Holloway, J.C., *Design and Evaluation of High-Tension Cable Median Barrier Hardware*, Final Report Submitted to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-200-08, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, February 25, 2008.

3. Stolle, C.S., Faller, R.K., and Polivka, K.A., *Dynamic Impact Testing of S76x8.5 (S3x5.7) Steel Posts for use in Cable Guardrail Systems*, Final Report Submitted to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-186-07, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, December 19, 2007.

4. *Manual for Assessing Safety Hardware (MASH)*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2009.

5. Powell, G.H., *Barrier VII: A Computer Program for Evaluation of Automobile Barrier Systems*, Report No. FHWA-RD-73-51, Department of Civil Engineering, University of California, Berkeley, California, April 1973.

6. Zhu, L., Rhode, J.R., Terpsma, R.J., *Foundation Design for High Tension Cable Guardrails*, Final Report Submitted to the Mid-America Transportation Center, Transportation Research Report No. TRP-03-236-10, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, June, 2010.

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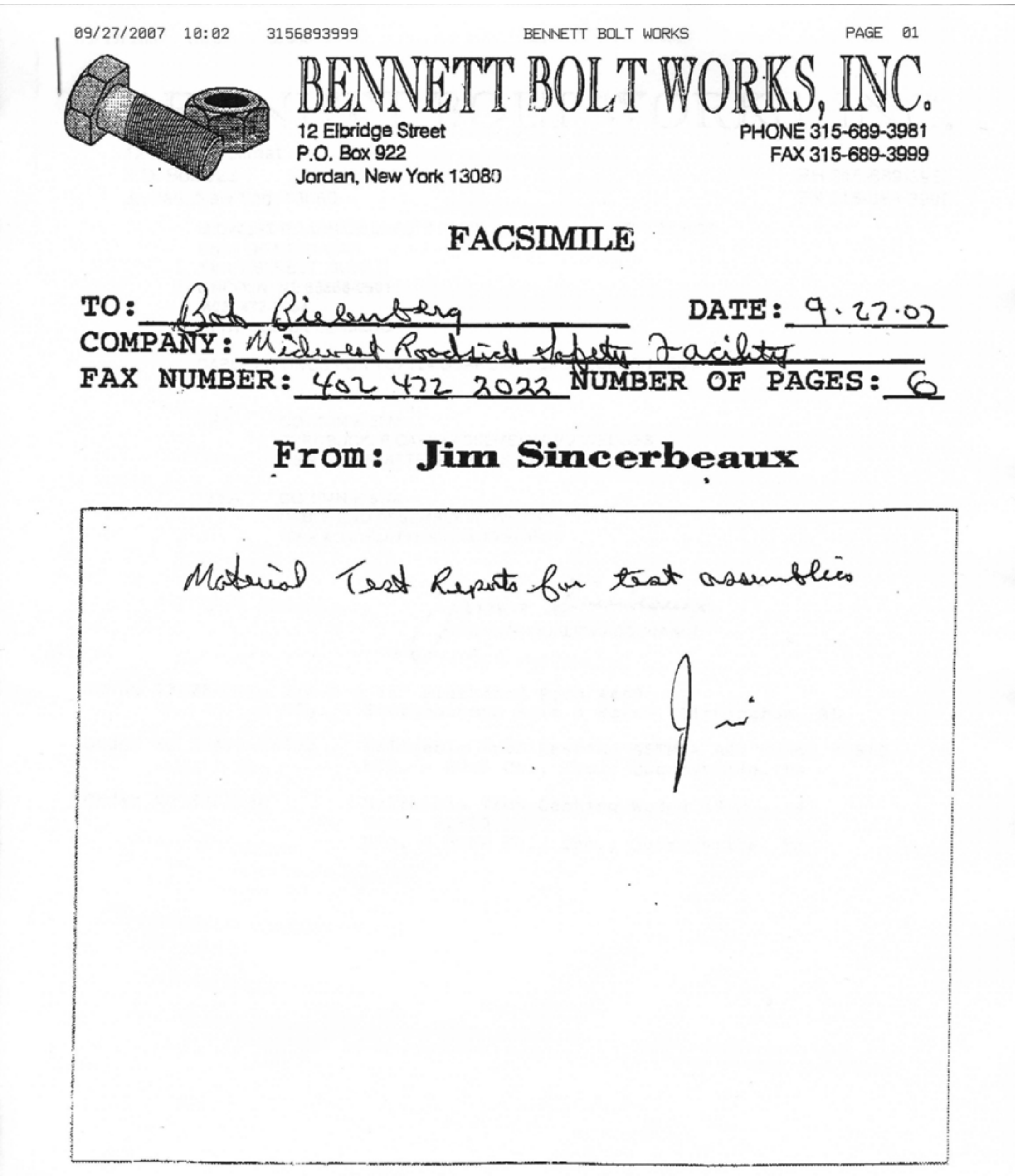
8. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.

9. *Collision Deformation Classification - Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

13 APPENDICES

APPENDIX A

Material Specifications



09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 01

BENNETT BOLT WORKS, INC.

12 Elbridge Street
P.O. Box 922
Jordan, New York 13080

PHONE 315-689-3981
FAX 315-689-3999

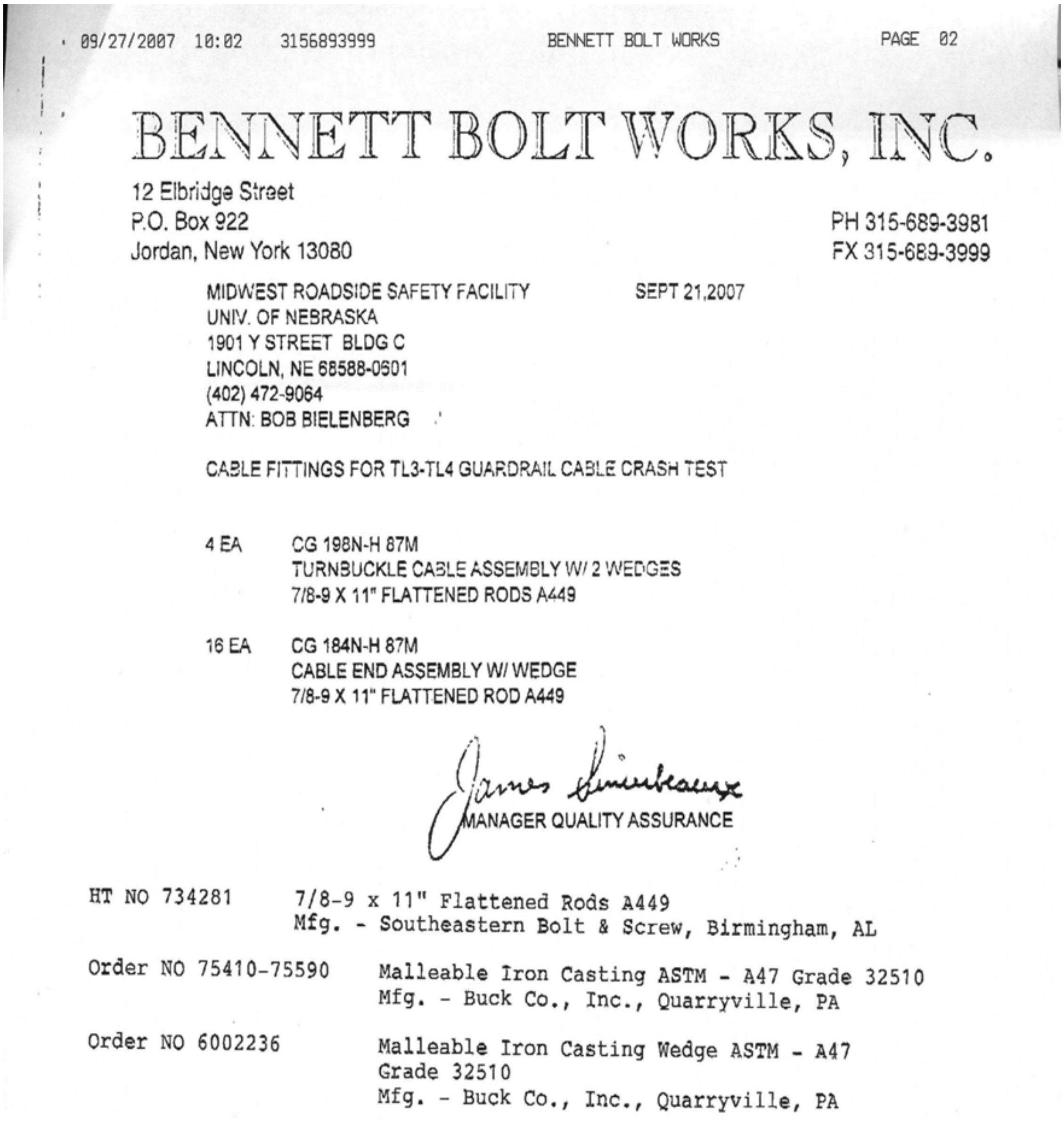
FACSIMILE

TO: Bob Bielenberg
DATE: 9.27.07
COMPANY: Midwest Roadside Safety Facility
FAX NUMBER: 402 472 2022
NUMBER OF PAGES: 6

From: Jim Sincerbeaux

Material Test Reports for test assemblies

Figure A-1. Bennett Bolt End-Fitting Material Specifications



09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 02

BENNETT BOLT WORKS, INC.

12 Elbridge Street
P.O. Box 922
Jordan, New York 13080

PH 315-689-3981
FX 315-689-3999

MIDWEST ROADSIDE SAFETY FACILITY
UNIV. OF NEBRASKA
1901 Y STREET BLDG C
LINCOLN, NE 68588-0601
(402) 472-9064
ATTN: BOB BIELENBERG

SEPT 21,2007

CABLE FITTINGS FOR TL3-TL4 GUARDRAIL CABLE CRASH TEST

4 EA CG 198N-H 87M
TURNBUCKLE CABLE ASSEMBLY W/ 2 WEDGES
7/8-9 X 11" FLATTENED RODS A449

16 EA CG 184N-H 87M
CABLE END ASSEMBLY W/ WEDGE
7/8-9 X 11" FLATTENED ROD A449

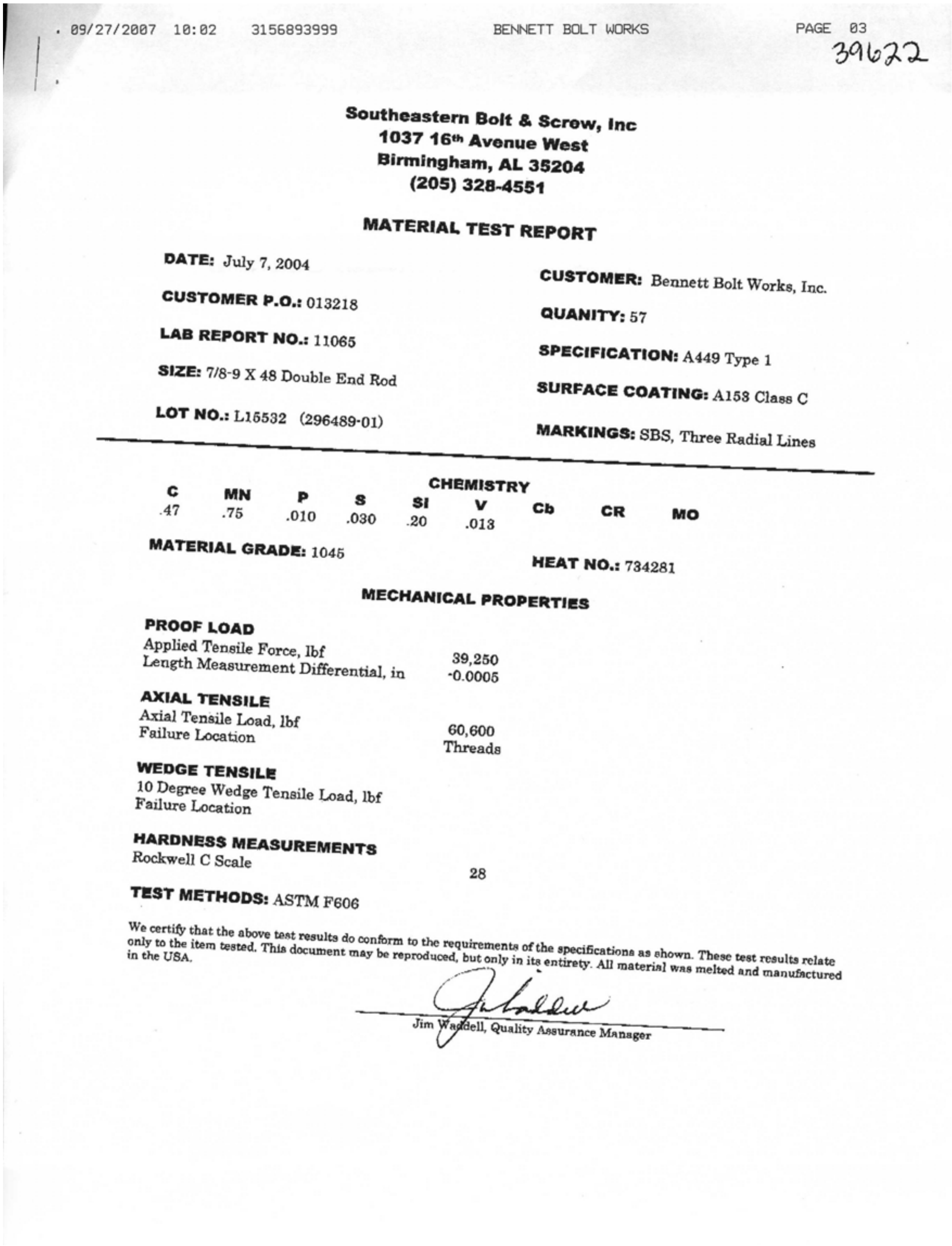
James
MANAGER QUALITY ASSURANCE

HT NO 734281 7/8-9 x 11" Flattened Rods A449
Mfg. - Southeastern Bolt & Screw, Birmingham, AL

Order NO 75410-75590 Malleable Iron Casting ASTM - A47 Grade 32510
Mfg. - Buck Co., Inc., Quarryville, PA

Order NO 6002236 Malleable Iron Casting Wedge ASTM - A47
Grade 32510
Mfg. - Buck Co., Inc., Quarryville, PA

Figure A-2. Bennett Bolt End-Fitting Material Specifications



09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 03

39622

Southeastern Bolt & Screw, Inc
1037 16th Avenue West
Birmingham, AL 35204
(205) 328-4551

MATERIAL TEST REPORT

DATE: July 7, 2004

CUSTOMER P.O.: 013218

LAB REPORT NO.: 11065

SIZE: 7/8-9 X 48 Double End Rod

LOT NO.: L15532 (296489-01)

CUSTOMER: Bennett Bolt Works, Inc.

QUANITY: 57

SPECIFICATION: A449 Type 1

SURFACE COATING: A153 Class C

MARKINGS: SBS, Three Radial Lines

CHEMISTRY

C	MN	P	S	SI	V	Cb	CR	MO
.47	.75	.010	.030	.20	.013			

MATERIAL GRADE: 1045

HEAT NO.: 734281

MECHANICAL PROPERTIES

PROOF LOAD

Applied Tensile Force, lbf	39,250
Length Measurement Differential, in	-0.0005

AXIAL TENSILE

Axial Tensile Load, lbf	60,600
Failure Location	Threads

WEDGE TENSILE

10 Degree Wedge Tensile Load, lbf	
Failure Location	

HARDNESS MEASUREMENTS

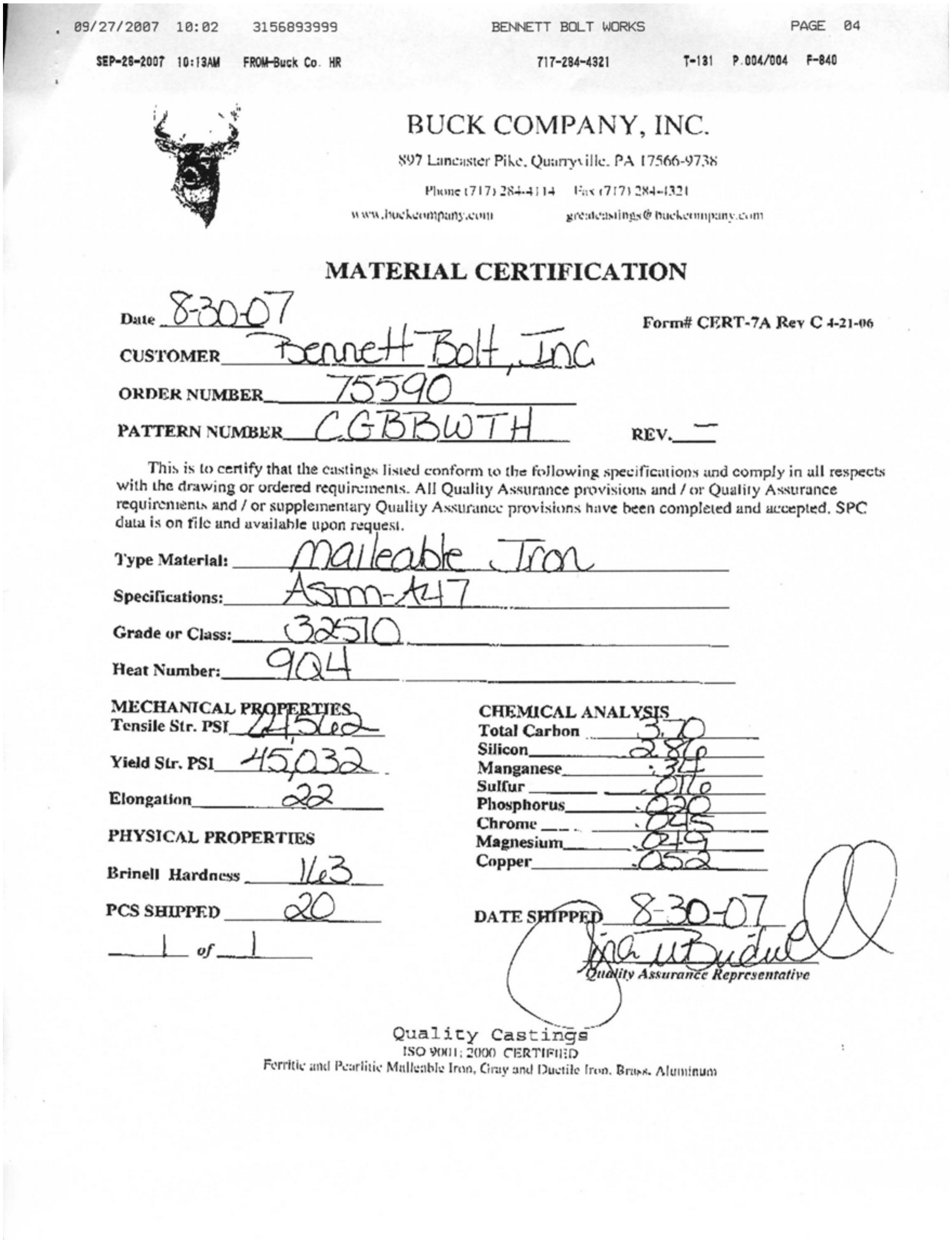
Rockwell C Scale	28

TEST METHODS: ASTM F606

We certify that the above test results do conform to the requirements of the specifications as shown. These test results relate only to the item tested. This document may be reproduced, but only in its entirety. All material was melted and manufactured in the USA.

Jim Waddell, Quality Assurance Manager

Figure A-3. Bennett Threaded Rod Material Certification



09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 04

SEP-26-2007 10:13AM FROM-Buck Co. HR 717-284-4321 T-131 P.004/004 F-840

BUCK COMPANY, INC.

897 Lancaster Pike, Quarryville, PA 17566-9738
Phone (717) 284-4114 Fax (717) 284-4321
www.buckcompany.com greatcastings@buckcompany.com

MATERIAL CERTIFICATION

Date 8-30-07

Form# CERT-7A Rev C 4-21-06

CUSTOMER Bennett Bolt, Inc

ORDER NUMBER 75590

PATTERN NUMBER CGBBWTH **REV.** –

This is to certify that the castings listed conform to the following specifications and comply in all respects with the drawing or ordered requirements. All Quality Assurance provisions and / or Quality Assurance requirements and / or supplementary Quality Assurance provisions have been completed and accepted. SPC data is on file and available upon request.

Type Material: Malleable Iron

Specifications: ASTM-A47

Grade or Class: 32510

Heat Number: 904

MECHANICAL PROPERTIES

Tensile Str. PSI 24,562

Yield Str. PSI 45,032

Elongation 22

PHYSICAL PROPERTIES

Brinell Hardness 163

PCS SHIPPED 20

1 *of* 1

CHEMICAL ANALYSIS

Total Carbon 3.70

Silicon 2.86

Manganese .34

Sulfur .016

Phosphorus .020

Chrome .045

Magnesium .049

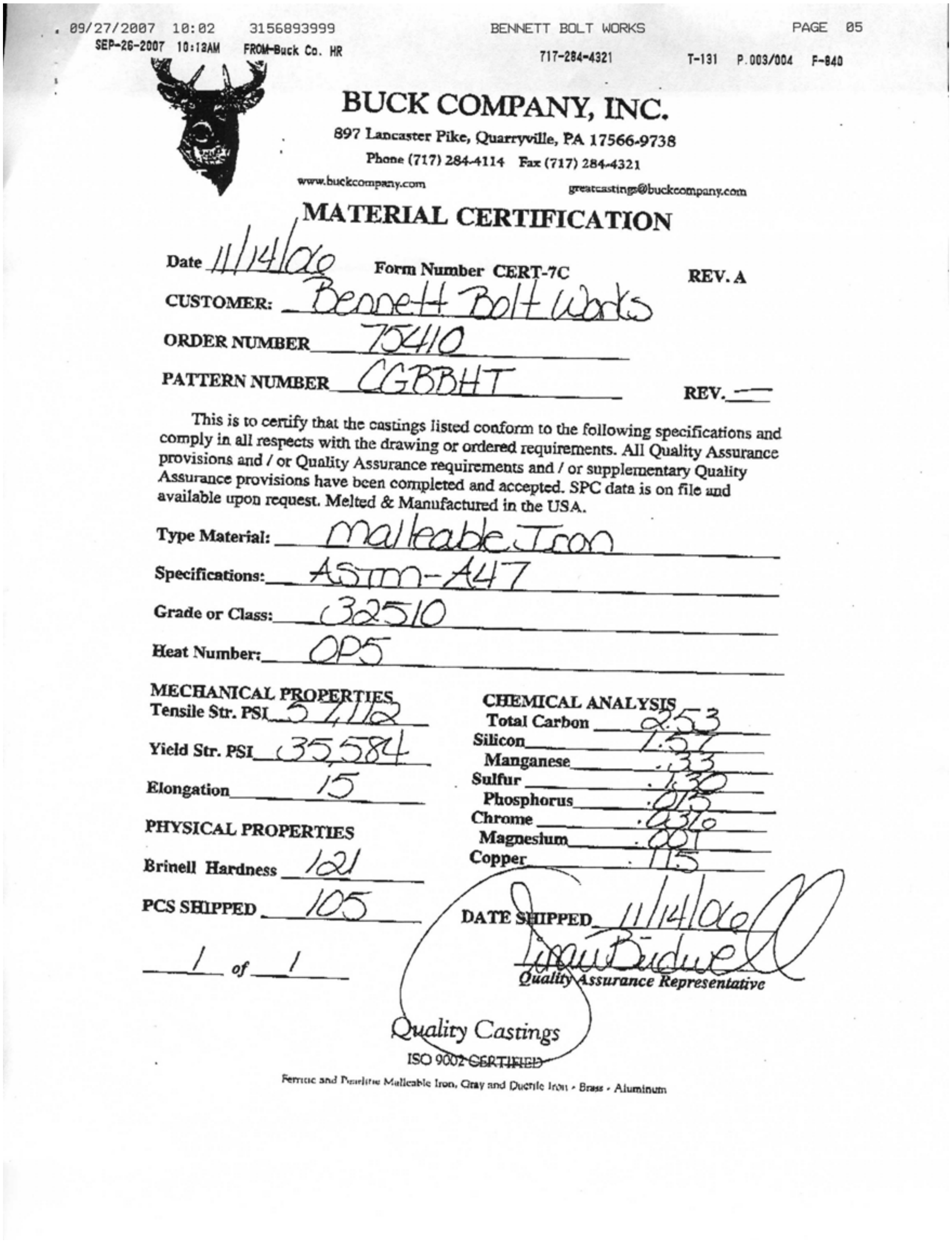
Copper .052

DATE SHIPPED 8-30-07

Quality Assurance Representative

Quality Castings
ISO 9001: 2000 CERTIFIED
Ferritic and Pearlitic Malleable Iron, Gray and Ductile Iron, Brass, Aluminum

Figure A-4. Bennet Bolt End-Fitting Material Specifications



. 09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 05
SEP-26-2007 10:12AM FROM-Buck Co. HR 717-284-4321 T-131 P.003/004 F-840

BUCK COMPANY, INC.
897 Lancaster Pike, Quarryville, PA 17566-9738
Phone (717) 284-4114 Fax (717) 284-4321
www.buckcompany.com greatcastings@buckcompany.com

MATERIAL CERTIFICATION

Date 11/14/06 **Form Number CERT-7C** **REV. A**

CUSTOMER: Bennett Bolt Works

ORDER NUMBER 75410

PATTERN NUMBER CGBBHT **REV.** —

This is to certify that the castings listed conform to the following specifications and comply in all respects with the drawing or ordered requirements. All Quality Assurance provisions and / or Quality Assurance requirements and / or supplementary Quality Assurance provisions have been completed and accepted. SPC data is on file and available upon request. Melted & Manufactured in the USA.

Type Material: Malleable Iron

Specifications: ASTM-A47

Grade or Class: 32510

Heat Number: OP5

MECHANICAL PROPERTIES
Tensile Str. PSI 57,112
Yield Str. PSI 35,584
Elongation 15

PHYSICAL PROPERTIES
Brinell Hardness 121
PCS SHIPPED 105

CHEMICAL ANALYSIS
Total Carbon 2.53
Silicon 1.57
Manganese .33
Sulfur .130
Phosphorus .015
Chrome .036
Magnesium .001
Copper .115

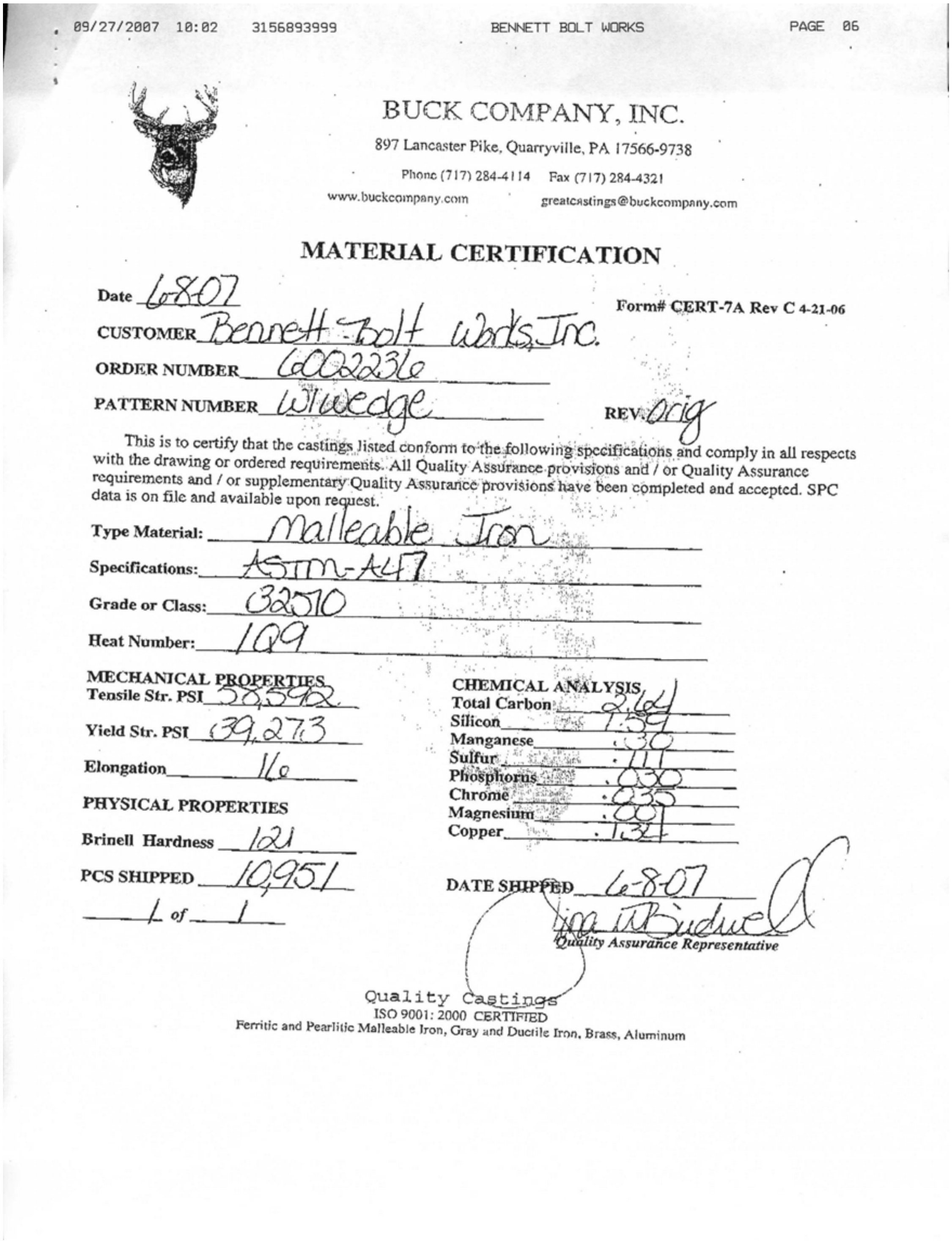
DATE SHIPPED 11/14/06

Quality Assurance Representative

1 *of* 1

Quality Castings
ISO 9002 CERTIFIED
Ferritic and Pearlitic Malleable Iron, Gray and Ductile Iron • Brass • Aluminum

Figure A-5. Bennett Bolt End-Fitting Material Specifications



09/27/2007 10:02 3156893999 BENNETT BOLT WORKS PAGE 06

BUCK COMPANY, INC.
897 Lancaster Pike, Quarryville, PA 17566-9738
Phone (717) 284-4114 Fax (717) 284-4321
www.buckcompany.com greatcastings@buckcompany.com

MATERIAL CERTIFICATION

Date 6-8-07

Form# CERT-7A Rev C 4-21-06

CUSTOMER Bennett Bolt Works, Inc.

ORDER NUMBER 60022316

PATTERN NUMBER W1 wedge

REV. Orig

This is to certify that the castings listed conform to the following specifications and comply in all respects with the drawing or ordered requirements. All Quality Assurance provisions and / or Quality Assurance requirements and / or supplementary Quality Assurance provisions have been completed and accepted. SPC data is on file and available upon request.

Type Material: Malleable Iron

Specifications: ASTM-A47

Grade or Class: 32510

Heat Number: 1Q9

MECHANICAL PROPERTIES

Tensile Str. PSI 58,592

Yield Str. PSI 39,273

Elongation 16

PHYSICAL PROPERTIES

Brinell Hardness 121

PCS SHIPPED 10,951

1 of 1

CHEMICAL ANALYSIS

Total Carbon 2.64

Silicon 1.59

Manganese .30

Sulfur .11

Phosphorus .050

Chrome .035

Magnesium .001

Copper .134

DATE SHIPPED 6-8-07

Lisa M Bidwell
Quality Assurance Representative

Quality Castings
ISO 9001: 2000 CERTIFIED
Ferritic and Pearlitic Malleable Iron, Gray and Ductile Iron, Brass, Aluminum

Figure A-6. Bennett Bolt End-Fitting Material Specifications

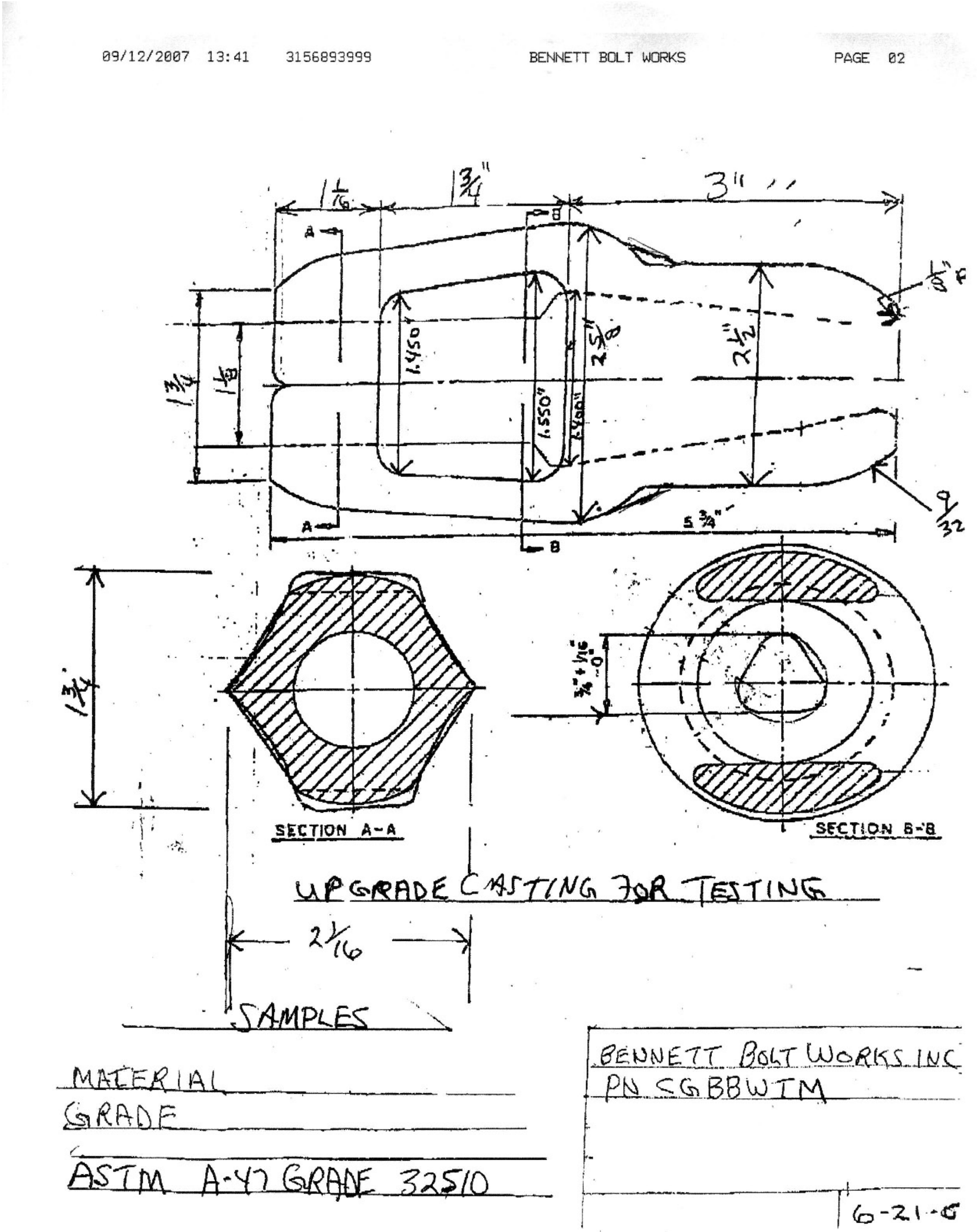
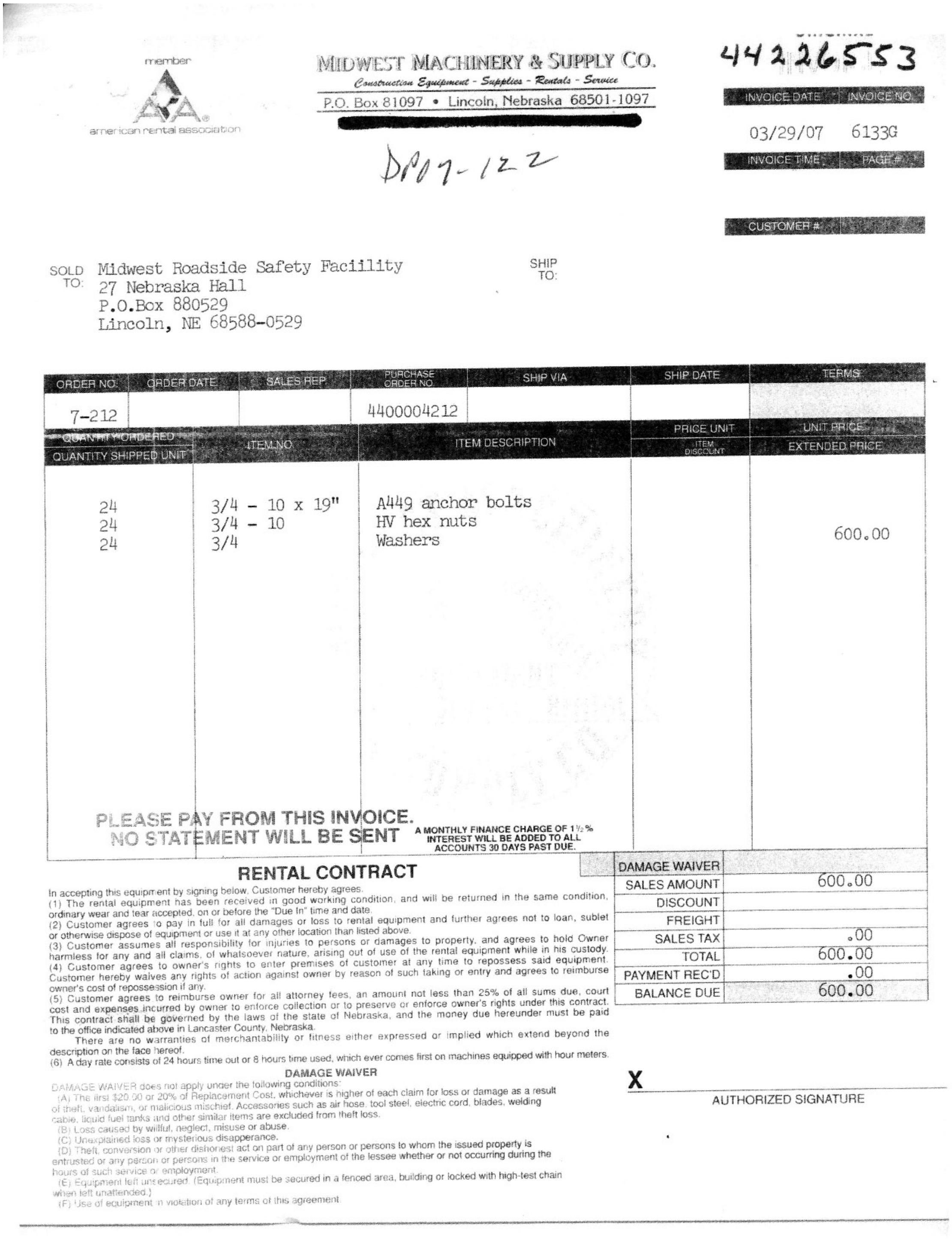


Figure A-7. Bennett Bolt End-Fitting Material Specifications



44226553

member
ARA
american rental association

MIDWEST MACHINERY & SUPPLY CO.
Construction Equipment - Supplies - Rentals - Service
P.O. Box 81097 • Lincoln, Nebraska 68501-1097
[redacted]

DP07-122

INVOICE DATE	INVOICE NO.
03/29/07	6133G
INVOICE TIME	PAGE #
CUSTOMER #	

SOLD TO:
Midwest Roadside Safety Faciility
27 Nebraska Hall
P.O.Box 880529
Lincoln, NE 68588-0529

SHIP TO:

ORDER NO.	ORDER DATE	SALES REP	PURCHASE ORDER NO.	SHIP VIA	SHIP DATE	TERMS
7-212			4400004212			

QUANTITY ORDERED QUANTITY SHIPPED UNIT	ITEM NO.	ITEM DESCRIPTION	PRICE UNIT ITEM DISCOUNT	UNIT PRICE EXTENDED PRICE
24	3/4 - 10 x 19"	A449 anchor bolts		
24	3/4 - 10	HV hex nuts		600.00
24	3/4	Washers		

PLEASE PAY FROM THIS INVOICE.
NO STATEMENT WILL BE SENT

A MONTHLY FINANCE CHARGE OF 1½ % INTEREST WILL BE ADDED TO ALL ACCOUNTS 30 DAYS PAST DUE.

DAMAGE WAIVER	
SALES AMOUNT	600.00
DISCOUNT	
FREIGHT	
SALES TAX	.00
TOTAL	600.00
PAYMENT REC'D	.00
BALANCE DUE	600.00

RENTAL CONTRACT

In accepting this equipment by signing below, Customer hereby agrees.
(1) The rental equipment has been received in good working condition, and will be returned in the same condition, ordinary wear and tear accepted, on or before the "Due In" time and date.
(2) Customer agrees to pay in full for all damages or loss to rental equipment and further agrees not to loan, sublet or otherwise dispose of equipment or use it at any other location than listed above.
(3) Customer assumes all responsibility for injuries to persons or damages to property, and agrees to hold Owner harmless for any and all claims, of whatsoever nature, arising out of use of the rental equipment while in his custody.
(4) Customer agrees to owner's rights to enter premises of customer at any time to repossess said equipment. Customer hereby waives any rights of action against owner by reason of such taking or entry and agrees to reimburse owner's cost of repossession if any.
(5) Customer agrees to reimburse owner for all attorney fees, an amount not less than 25% of all sums due, court cost and expenses incurred by owner to enforce collection or to preserve or enforce owner's rights under this contract. This contract shall be governed by the laws of the state of Nebraska, and the money due hereunder must be paid to the office indicated above in Lancaster County, Nebraska.

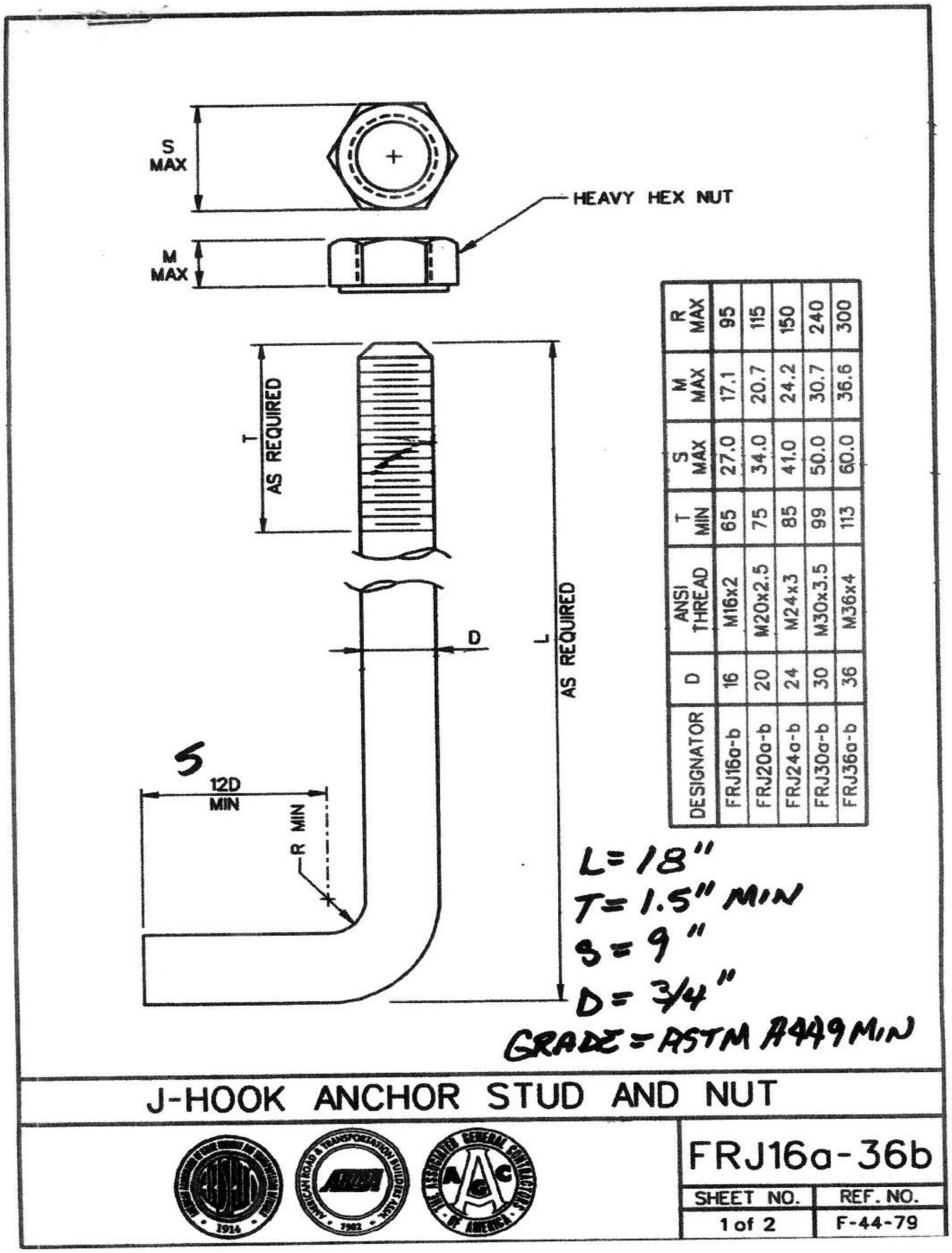
There are no warranties of merchantability or fitness either expressed or implied which extend beyond the description on the face hereof.
(6) A day rate consists of 24 hours time out or 8 hours time used, which ever comes first on machines equipped with hour meters.

DAMAGE WAIVER

DAMAGE WAIVER does not apply under the following conditions:
(A) The first $20.00 or 20% of Replacement Cost, whichever is higher of each claim for loss or damage as a result of theft, vandalism, or malicious mischief. Accessories such as air hose, tool steel, electric cord, blades, welding cable, liquid fuel tanks and other similar items are excluded from theft loss.
(B) Loss caused by willful, neglect, misuse or abuse.
(C) Unexplained loss or mysterious disapperance.
(D) Theft, conversion or other dishonest act on part of any person or persons to whom the issued property is entrusted or any person or persons in the service or employment of the lessee whether or not occurring during the hours of such service or employment.
(E) Equipment left unsecured. (Equipment must be secured in a fenced area, building or locked with high-test chain when left unattended.)
(F) Use of equipment in violation of any terms of this agreement.

X
AUTHORIZED SIGNATURE

Figure A-8. J-Hook Anchor Stud Material Specifications



DESIGNATOR	D	ANSI THREAD	T MIN	S MAX	M MAX	R MAX
FRJ16a-b	16	M16x2	65	27.0	17.1	95
FRJ20a-b	20	M20x2.5	75	34.0	20.7	115
FRJ24a-b	24	M24x3	85	41.0	24.2	150
FRJ30a-b	30	M30x3.5	99	50.0	30.7	240
FRJ36a-b	36	M36x4	113	60.0	36.6	300

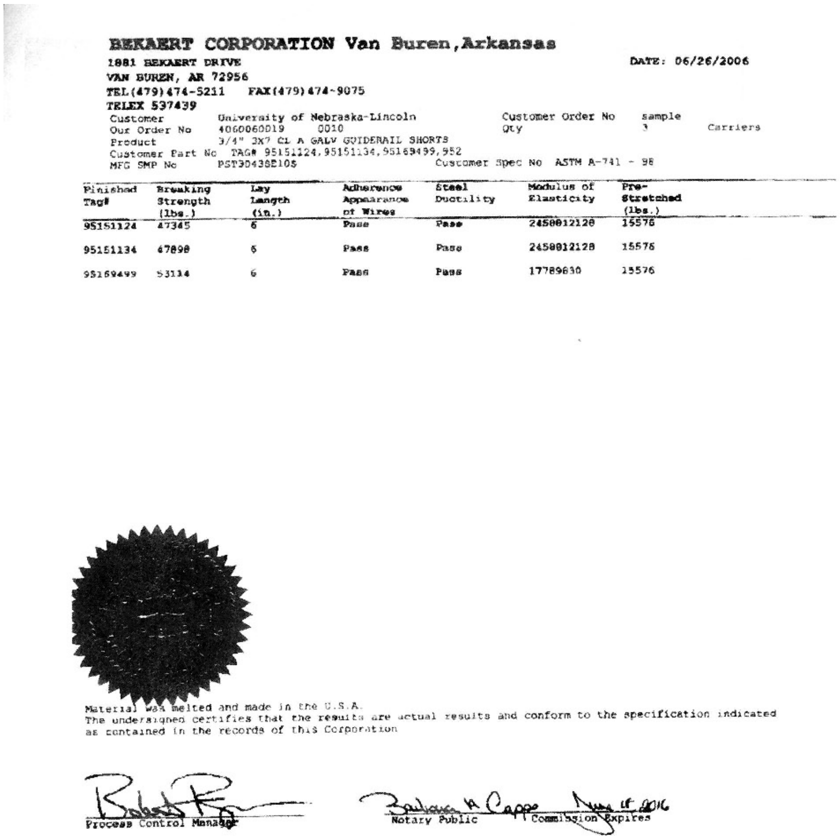
L= 18"
T= 1.5" MIN
S= 9"
D= 3/4"
GRADE= ASTM A449 MIN

J-HOOK ANCHOR STUD AND NUT

FRJ16a-36b

SHEET NO.	REF. NO.
1 of 2	F-44-79

Figure A-9. J-Hook Anchor Stud Material Specifications



BEKAERT CORPORATION Van Buren,Arkansas

1881 BEKAERT DRIVE
VAN BUREN, AR 72956
TEL(479)474-5211 FAX(479)474-9075
TELEX 537439

DATE: 06/26/2006

Customer University of Nebraska-Lincoln
Our Order No 4060060019 0010
Product 3/4" 3X7 CL A GALV GUIDERAIL SHORTS
Customer Part No TAG# 95151124,95151134,95169499,952
MFG SMP No PST30438E105
Customer Order No sample
Qty 3 Carriers
Customer Spec No ASTM A-741 - 98

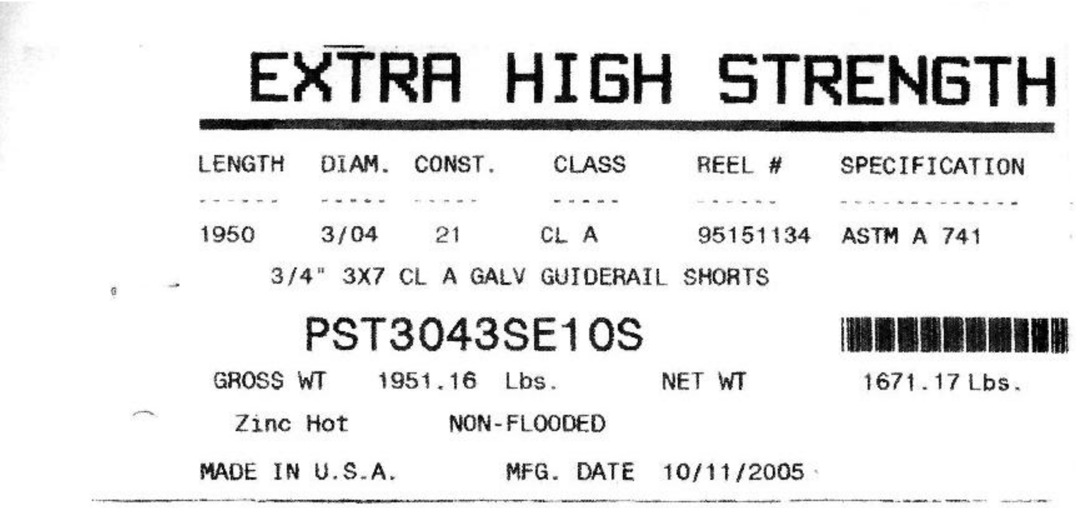
Finished Tag#	Breaking Strength (lbs.)	Lay Length (in.)	Adherence Appearance of Wires	Steel Ductility	Modulus of Elasticity	Pre-Stretched (lbs.)
95151124	47345	6	Pass	Pass	2458012128	15576
95151134	47898	6	Pass	Pass	2458012128	15576
95169499	53134	6	Pass	Pass	17789830	15576

Material was melted and made in the U.S.A.
The undersigned certifies that the results are actual results and conform to the specification indicated as contained in the records of this Corporation

Process Control Manager

Notary Public June 18, 2016
Commission Expires

Figure A-10. Cable Material Certification



EXTRA HIGH STRENGTH

LENGTH	DIAM.	CONST.	CLASS	REEL #	SPECIFICATION
------	-----	-----	-----	------	-------------
1950	3/04	21	CL A	95151134	ASTM A 741

3/4" 3X7 CL A GALV GUIDERAIL SHORTS

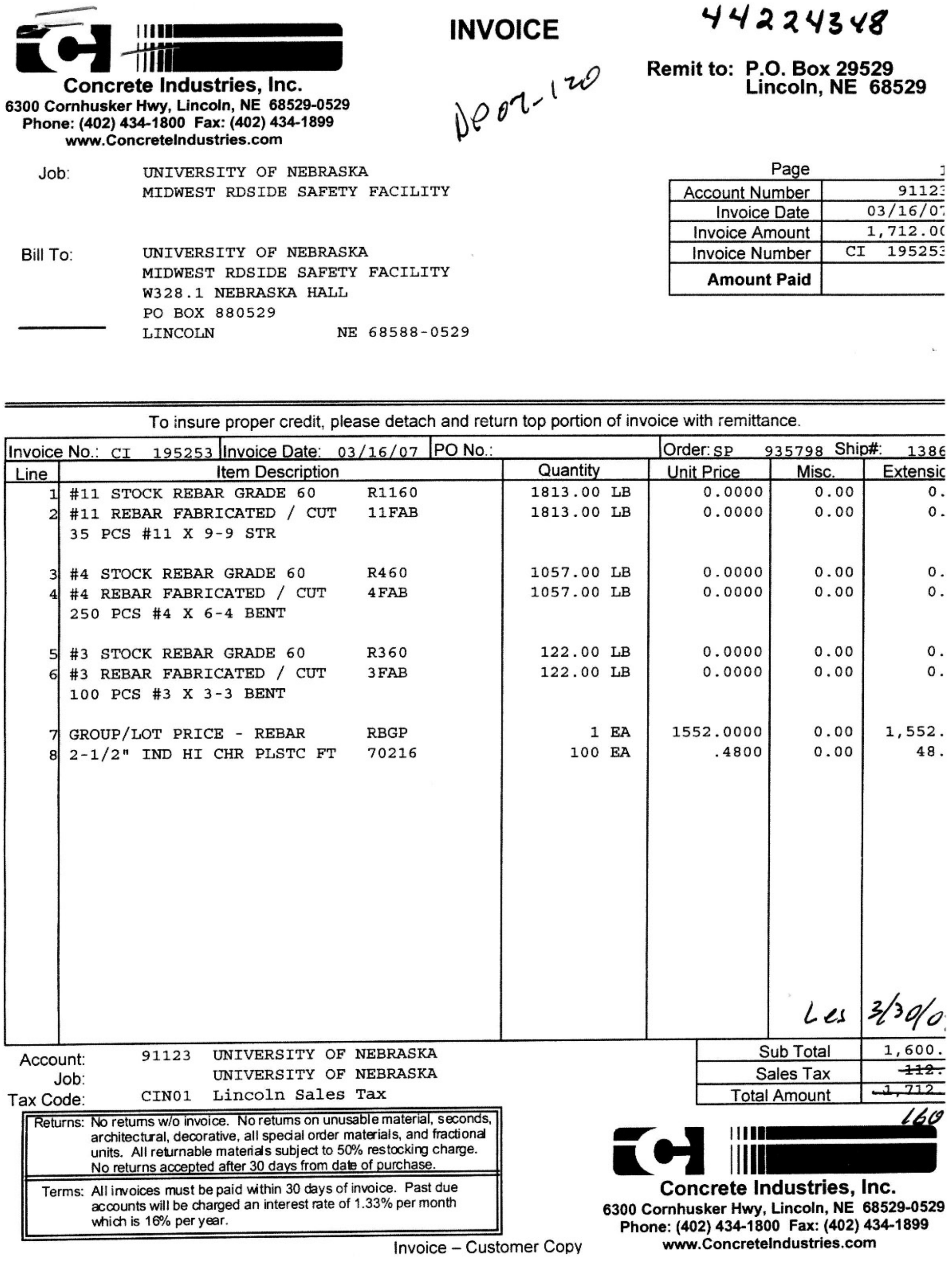
PST3043SE10S

GROSS WT 1951.16 Lbs. NET WT 1671.17 Lbs.

Zinc Hot NON-FLOODED

MADE IN U.S.A. MFG. DATE 10/11/2005

Figure A-11. Cable Material Specifications



Concrete Industries, Inc.
6300 Cornhusker Hwy, Lincoln, NE 68529-0529
Phone: (402) 434-1800 Fax: (402) 434-1899
www.ConcreteIndustries.com

INVOICE

44224348

DE07-120

Remit to: P.O. Box 29529
Lincoln, NE 68529

Job: UNIVERSITY OF NEBRASKA
MIDWEST RDSIDE SAFETY FACILITY

Bill To: UNIVERSITY OF NEBRASKA
MIDWEST RDSIDE SAFETY FACILITY
W328.1 NEBRASKA HALL
PO BOX 880529
LINCOLN NE 68588-0529

Page 1

Account Number	91123
Invoice Date	03/16/07
Invoice Amount	1,712.00
Invoice Number	CI 195253
Amount Paid	

To insure proper credit, please detach and return top portion of invoice with remittance.

Invoice No.: CI 195253 Invoice Date: 03/16/07 PO No.: Order: SP 935798 Ship#: 1386

Line	Item Description		Quantity	Unit Price	Misc.	Extensi
1	#11 STOCK REBAR GRADE 60	R1160	1813.00 LB	0.0000	0.00	0.
2	#11 REBAR FABRICATED / CUT 35 PCS #11 X 9-9 STR	11FAB	1813.00 LB	0.0000	0.00	0.
3	#4 STOCK REBAR GRADE 60	R460	1057.00 LB	0.0000	0.00	0.
4	#4 REBAR FABRICATED / CUT 250 PCS #4 X 6-4 BENT	4FAB	1057.00 LB	0.0000	0.00	0.
5	#3 STOCK REBAR GRADE 60	R360	122.00 LB	0.0000	0.00	0.
6	#3 REBAR FABRICATED / CUT 100 PCS #3 X 3-3 BENT	3FAB	122.00 LB	0.0000	0.00	0.
7	GROUP/LOT PRICE - REBAR	RBGP	1 EA	1552.0000	0.00	1,552.
8	2-1/2" IND HI CHR PLSTC FT	70216	100 EA	.4800	0.00	48.

Les 3/30/0

Account: 91123 UNIVERSITY OF NEBRASKA
Job: UNIVERSITY OF NEBRASKA
Tax Code: CIN01 Lincoln Sales Tax

Sub Total	1,600.
Sales Tax	~~112.~~
Total Amount	~~1,712.~~

160

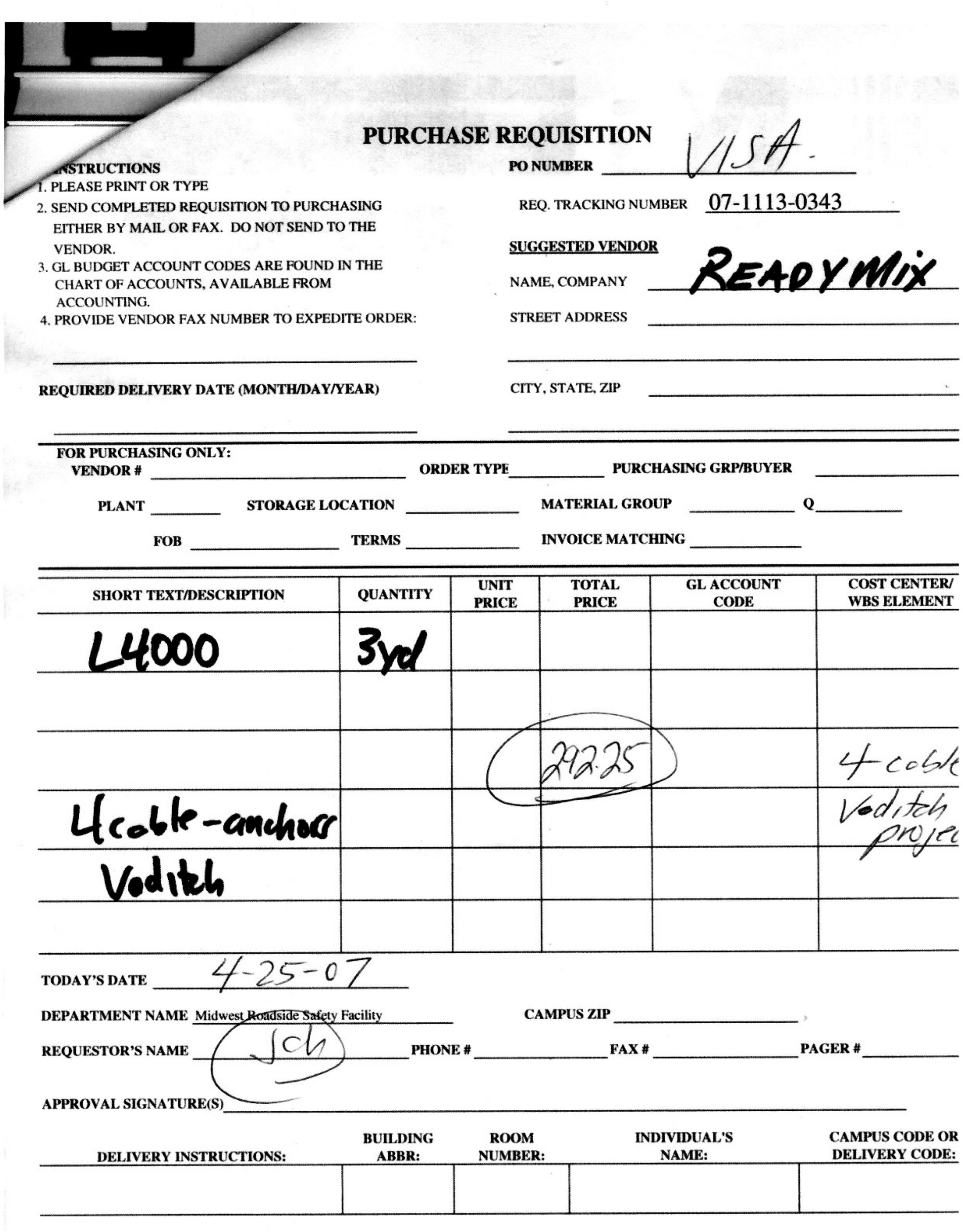
Returns: No returns w/o invoice. No returns on unusable material, seconds, architectural, decorative, all special order materials, and fractional units. All returnable materials subject to 50% restocking charge. No returns accepted after 30 days from date of purchase.

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

Invoice – Customer Copy

Concrete Industries, Inc.
6300 Cornhusker Hwy, Lincoln, NE 68529-0529
Phone: (402) 434-1800 Fax: (402) 434-1899
www.ConcreteIndustries.com

Figure A-12. Anchor Rebar Material Specifications



PURCHASE REQUISITION

NSTRUCTIONS
1. PLEASE PRINT OR TYPE
2. SEND COMPLETED REQUISITION TO PURCHASING EITHER BY MAIL OR FAX. DO NOT SEND TO THE VENDOR.
3. GL BUDGET ACCOUNT CODES ARE FOUND IN THE CHART OF ACCOUNTS, AVAILABLE FROM ACCOUNTING.
4. PROVIDE VENDOR FAX NUMBER TO EXPEDITE ORDER:

REQUIRED DELIVERY DATE (MONTH/DAY/YEAR)

PO NUMBER VISA.
REQ. TRACKING NUMBER 07-1113-0343

SUGGESTED VENDOR
NAME, COMPANY READYMIX
STREET ADDRESS
CITY, STATE, ZIP

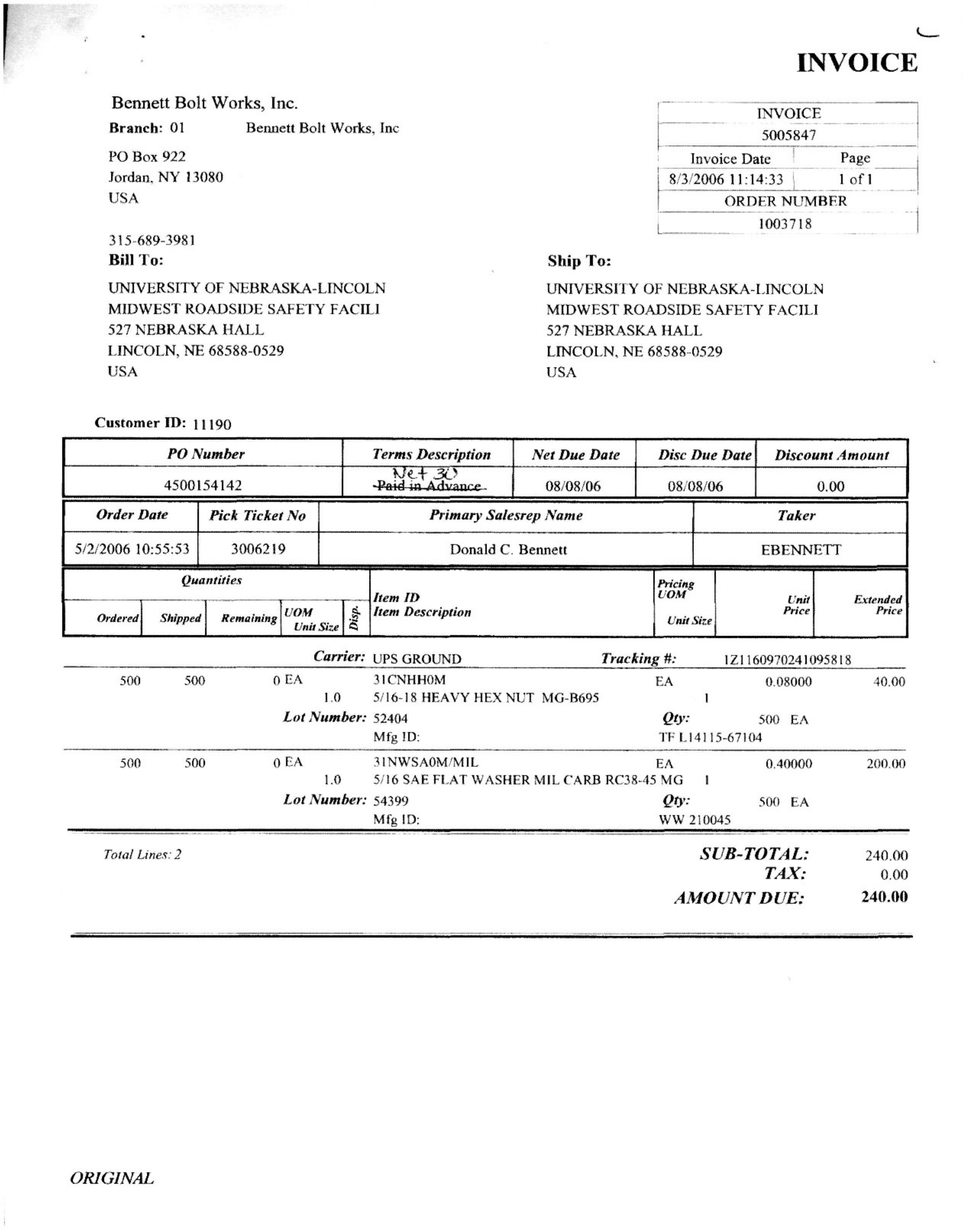
FOR PURCHASING ONLY:
VENDOR # **ORDER TYPE** **PURCHASING GRP/BUYER**
PLANT **STORAGE LOCATION** **MATERIAL GROUP** **Q**
FOB **TERMS** **INVOICE MATCHING**

SHORT TEXT/DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL PRICE	GL ACCOUNT CODE	COST CENTER/ WBS ELEMENT
L4000	3yd				
			292.25		4 cabl
4cable-anchor					Voditch projec
Voditch					

TODAY'S DATE 4-25-07
DEPARTMENT NAME Midwest Roadside Safety Facility **CAMPUS ZIP**
REQUESTOR'S NAME Jch **PHONE #** **FAX #** **PAGER #**
APPROVAL SIGNATURE(S)

DELIVERY INSTRUCTIONS:	BUILDING ABBR:	ROOM NUMBER:	INDIVIDUAL'S NAME:	CAMPUS CODE OR DELIVERY CODE:

Figure A-13. Concrete Anchor Material Specifications



INVOICE

Bennett Bolt Works, Inc.
Branch: 01 Bennett Bolt Works, Inc

PO Box 922
Jordan, NY 13080
USA

315-689-3981

INVOICE	
5005847	
Invoice Date	Page
8/3/2006 11:14:33	1 of 1
ORDER NUMBER	
1003718	

Bill To:

UNIVERSITY OF NEBRASKA-LINCOLN
MIDWEST ROADSIDE SAFETY FACILI
527 NEBRASKA HALL
LINCOLN, NE 68588-0529
USA

Ship To:

UNIVERSITY OF NEBRASKA-LINCOLN
MIDWEST ROADSIDE SAFETY FACILI
527 NEBRASKA HALL
LINCOLN, NE 68588-0529
USA

Customer ID: 11190

PO Number	*Terms Description*	*Net Due Date*	*Disc Due Date*	*Discount Amount*
4500154142	Net 30 ~~Paid in Advance~~	08/08/06	08/08/06	0.00

Order Date	*Pick Ticket No*	*Primary Salesrep Name*	*Taker*
5/2/2006 10:55:53	3006219	Donald C. Bennett	EBENNETT

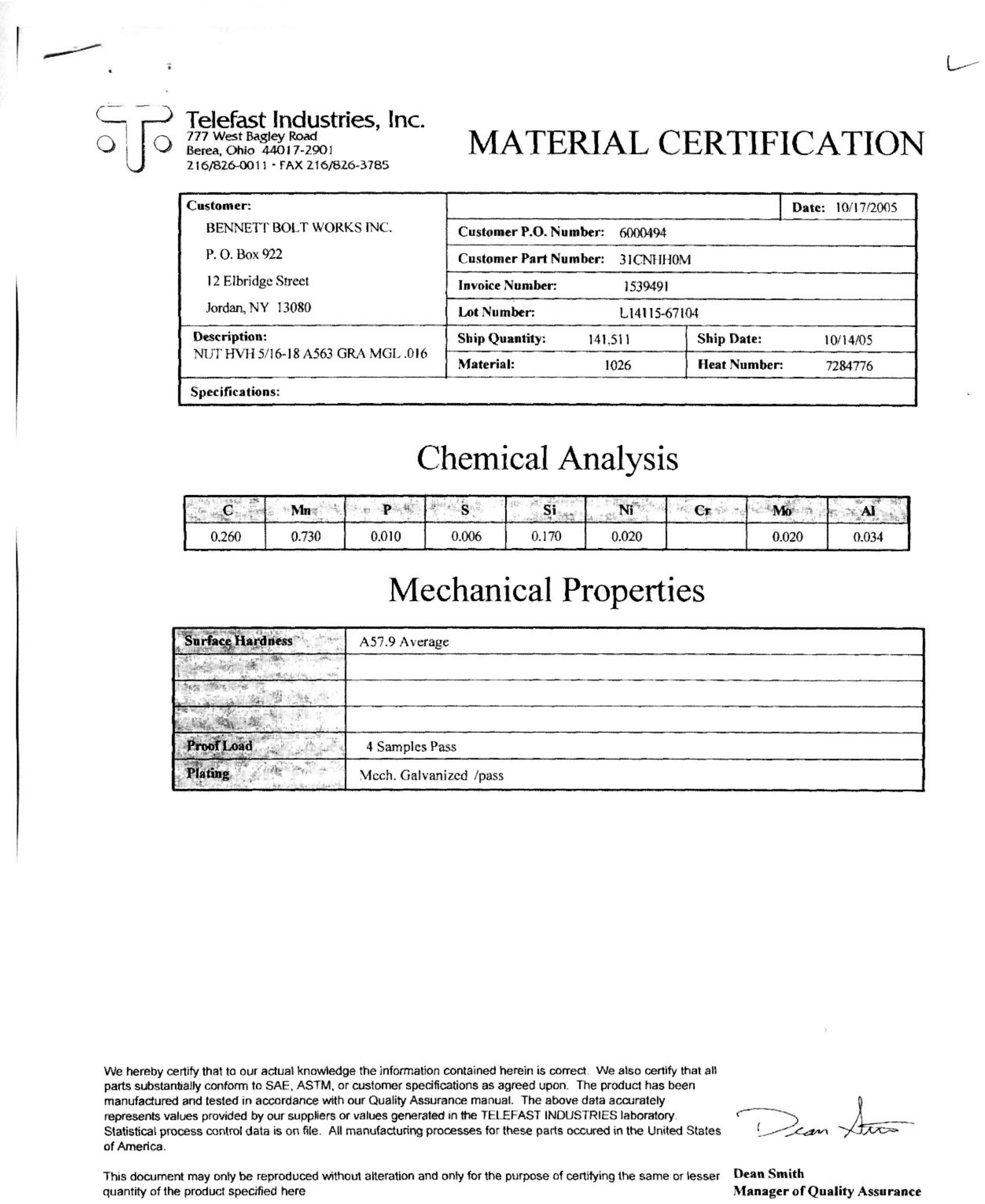
Quantities					*Item ID* *Item Description*	*Pricing UOM* *Unit Size*	*Unit Price*	*Extended Price*
Ordered	*Shipped*	*Remaining*	*UOM* *Unit Size*	*Disp.*				
				Carrier:	UPS GROUND	***Tracking #:***	1Z1160970241095818	
500	500	0	EA 1.0		31CNHH0M 5/16-18 HEAVY HEX NUT MG-B695	EA 1	0.08000	40.00
				Lot Number:	52404 Mfg ID:	***Qty:*** TF L14115-67104	500 EA	
500	500	0	EA 1.0		31NWSA0M/MIL 5/16 SAE FLAT WASHER MIL CARB RC38-45 MG	EA 1	0.40000	200.00
				Lot Number:	54399 Mfg ID:	***Qty:*** WW 210045	500 EA	

Total Lines: 2

SUB-TOTAL:	240.00
TAX:	0.00
AMOUNT DUE:	**240.00**

ORIGINAL

Figure A-14. Shoulder Nut and Washer Material Specifications



Telefast Industries, Inc.
777 West Bagley Road
Berea, Ohio 44017-2901
216/826-0011 · FAX 216/826-3785

MATERIAL CERTIFICATION

Customer: BENNETT BOLT WORKS INC. P. O. Box 922 12 Elbridge Street Jordan, NY 13080			**Date:**	10/17/2005
	Customer P.O. Number:	6000494		
	Customer Part Number:	31CNHH0M		
	Invoice Number:	1539491		
	Lot Number:	L14115-67104		
Description: NUT HVH 5/16-18 A563 GRA MGL .016	**Ship Quantity:**	141,511	**Ship Date:**	10/14/05
	Material:	1026	**Heat Number:**	7284776
Specifications:				

Chemical Analysis

C	Mn	P	S	Si	Ni	Cr	Mo	Al
0.260	0.730	0.010	0.006	0.170	0.020		0.020	0.034

Mechanical Properties

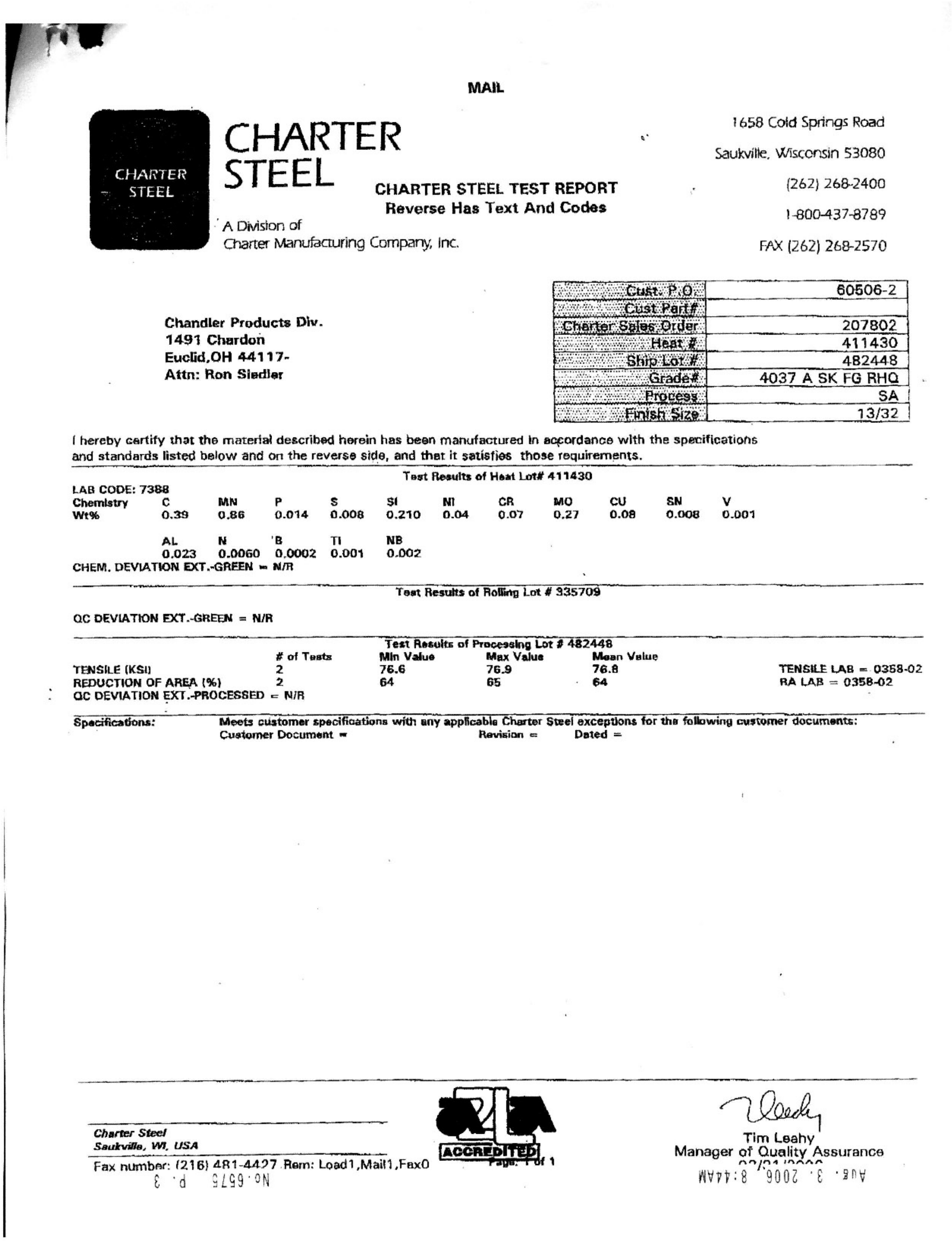
Surface Hardness	A57.9 Average
Proof Load	4 Samples Pass
Plating	Mech. Galvanized /pass

We hereby certify that to our actual knowledge the information contained herein is correct. We also certify that all parts substantially conform to SAE, ASTM, or customer specifications as agreed upon. The product has been manufactured and tested in accordance with our Quality Assurance manual. The above data accurately represents values provided by our suppliers or values generated in the TELEFAST INDUSTRIES laboratory. Statistical process control data is on file. All manufacturing processes for these parts occured in the United States of America.

This document may only be reproduced without alteration and only for the purpose of certifying the same or lesser quantity of the product specified here

Dean Smith
Manager of Quality Assurance

Figure A-15. Shoulder Nut Material Specifications



MAIL

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Chandler Products Div.
1491 Chardon
Euclid,OH 44117-
Attn: Ron Siedler

Cust. P.O.	60506-2
Cust Part#	
Charter Sales Order	207802
Heat #	411430
Ship Lot #	482448
Grade#	4037 A SK FG RHQ
Process	SA
Finish Size	13/32

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side, and that it satisfies those requirements.

Test Results of Heat Lot# 411430

LAB CODE: 7388

Chemistry	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
Wt%	0.39	0.86	0.014	0.008	0.210	0.04	0.07	0.27	0.08	0.008	0.001
	AL	N	B	TI	NB						
	0.023	0.0060	0.0002	0.001	0.002						

CHEM. DEVIATION EXT.-GREEN = N/R

Test Results of Rolling Lot # 335709

QC DEVIATION EXT.-GREEN = N/R

Test Results of Processing Lot # 482448

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE (KSI)	2	76.6	76.9	76.8	TENSILE LAB = 0358-02
REDUCTION OF AREA (%)	2	64	65	64	RA LAB = 0358-02

QC DEVIATION EXT.-PROCESSED = N/R

Specifications: Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = Revision = Dated =

Charter Steel
Saukville, WI, USA

Fax number: (216) 481-4427 Rem: Load1,Mail1,Fax0

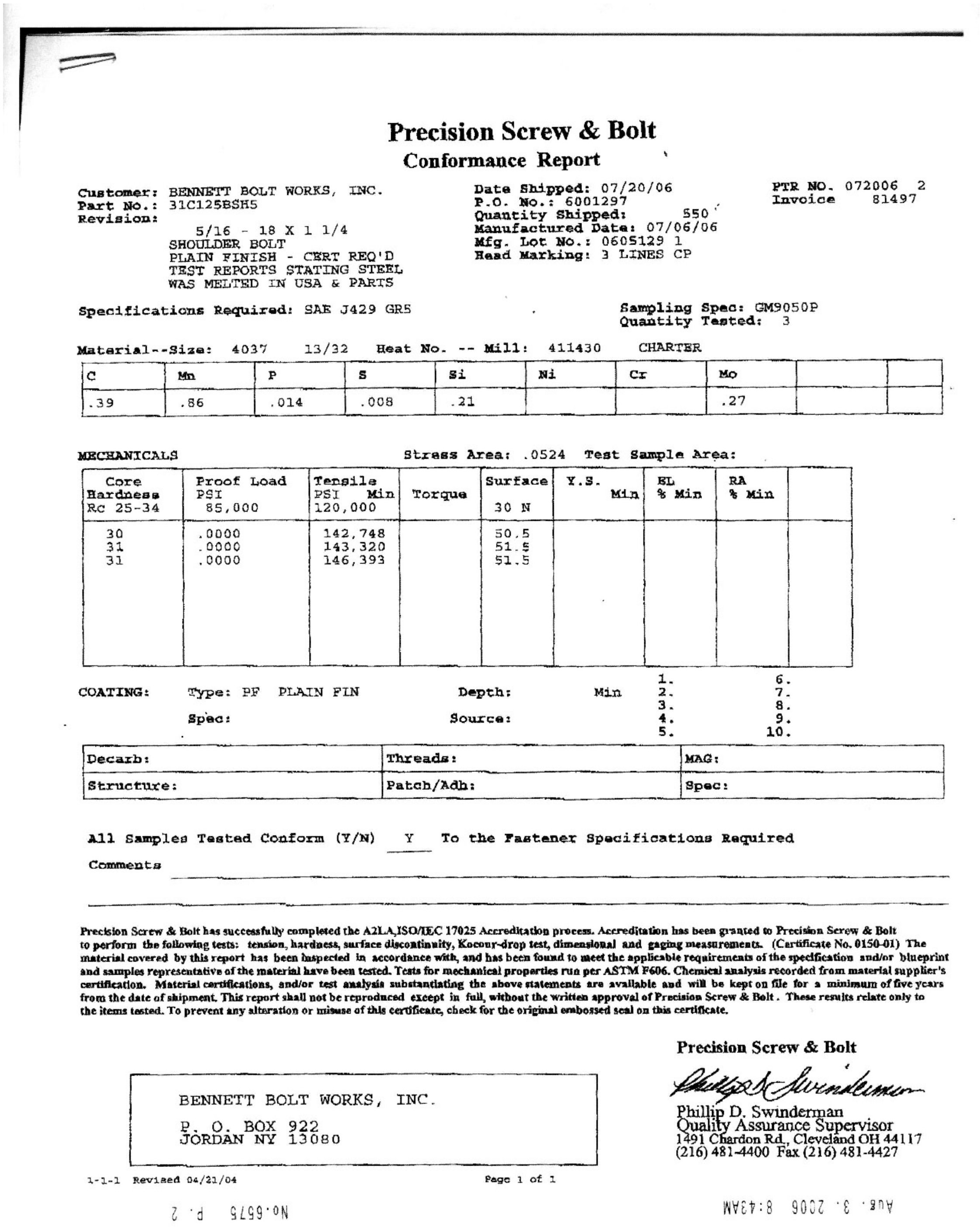
ACCREDITED
Page: 1 of 1

TLeahy
Tim Leahy
Manager of Quality Assurance

No.6575 P. 3

Aug. 3. 2006 8:44AM

Figure A-16. Post Bracket Material Specifications



Precision Screw & Bolt
Conformance Report

Customer: BENNETT BOLT WORKS, INC.
Part No.: 31C125BSH5
Revision:
5/16 - 18 X 1 1/4
SHOULDER BOLT
PLAIN FINISH - CERT REQ'D
TEST REPORTS STATING STEEL
WAS MELTED IN USA & PARTS

Date Shipped: 07/20/06
P.O. No.: 6001297
Quantity Shipped: 550
Manufactured Date: 07/06/06
Mfg. Lot No.: 0605129 1
Head Marking: 3 LINES CP

PTR NO. 072006 2
Invoice 81497

Specifications Required: SAE J429 GR5

Sampling Spec: GM9050P
Quantity Tested: 3

Material--Size: 4037 13/32 **Heat No. -- Mill:** 411430 CHARTER

C	Mn	P	S	Si	Ni	Cr	Mo		
.39	.86	.014	.008	.21			.27		

MECHANICALS **Stress Area:** .0524 **Test Sample Area:**

Core Hardness Rc 25-34	Proof Load PSI 85,000	Tensile PSI Min 120,000	Torque	Surface 30 N	Y.S. Min	EL % Min	RA % Min	
30	.0000	142,748		50.5				
31	.0000	143,320		51.5				
31	.0000	146,393		51.5				

COATING: Type: PF PLAIN FIN **Depth:** Min
Spec: **Source:**

1. 6.
2. 7.
3. 8.
4. 9.
5. 10.

Decarb:	**Threads:**	**MAG:**
Structure:	**Patch/Adh:**	**Spec:**

All Samples Tested Conform (Y/N) Y **To the Fastener Specifications Required**

Comments

Precision Screw & Bolt has successfully completed the A2LA,ISO/IEC 17025 Accreditation process. Accreditation has been granted to Precision Screw & Bolt to perform the following tests: tension, hardness, surface discontinuity, Kocour-drop test, dimensional and gaging measurements. (Certificate No. 0150-01) The material covered by this report has been inspected in accordance with, and has been found to meet the applicable requirements of the specification and/or blueprint and samples representative of the material have been tested. Tests for mechanical properties run per ASTM F606. Chemical analysis recorded from material supplier's certification. Material certifications, and/or test analysis substantiating the above statements are available and will be kept on file for a minimum of five years from the date of shipment. This report shall not be reproduced except in full, without the written approval of Precision Screw & Bolt. These results relate only to the items tested. To prevent any alteration or misuse of this certificate, check for the original embossed seal on this certificate.

BENNETT BOLT WORKS, INC.
P. O. BOX 922
JORDAN NY 13080

Precision Screw & Bolt
Phillip D. Swinderman
Phillip D. Swinderman
Quality Assurance Supervisor
1491 Chardon Rd., Cleveland OH 44117
(216) 481-4400 Fax (216) 481-4427

1-1-1 Revised 04/21/04

Page 1 of 1

Figure A-17. Post Bolt Material Specifications

APPENDIX B

Accelerometer and Rate Transducer Data Plots, Test No. 4CMB-1

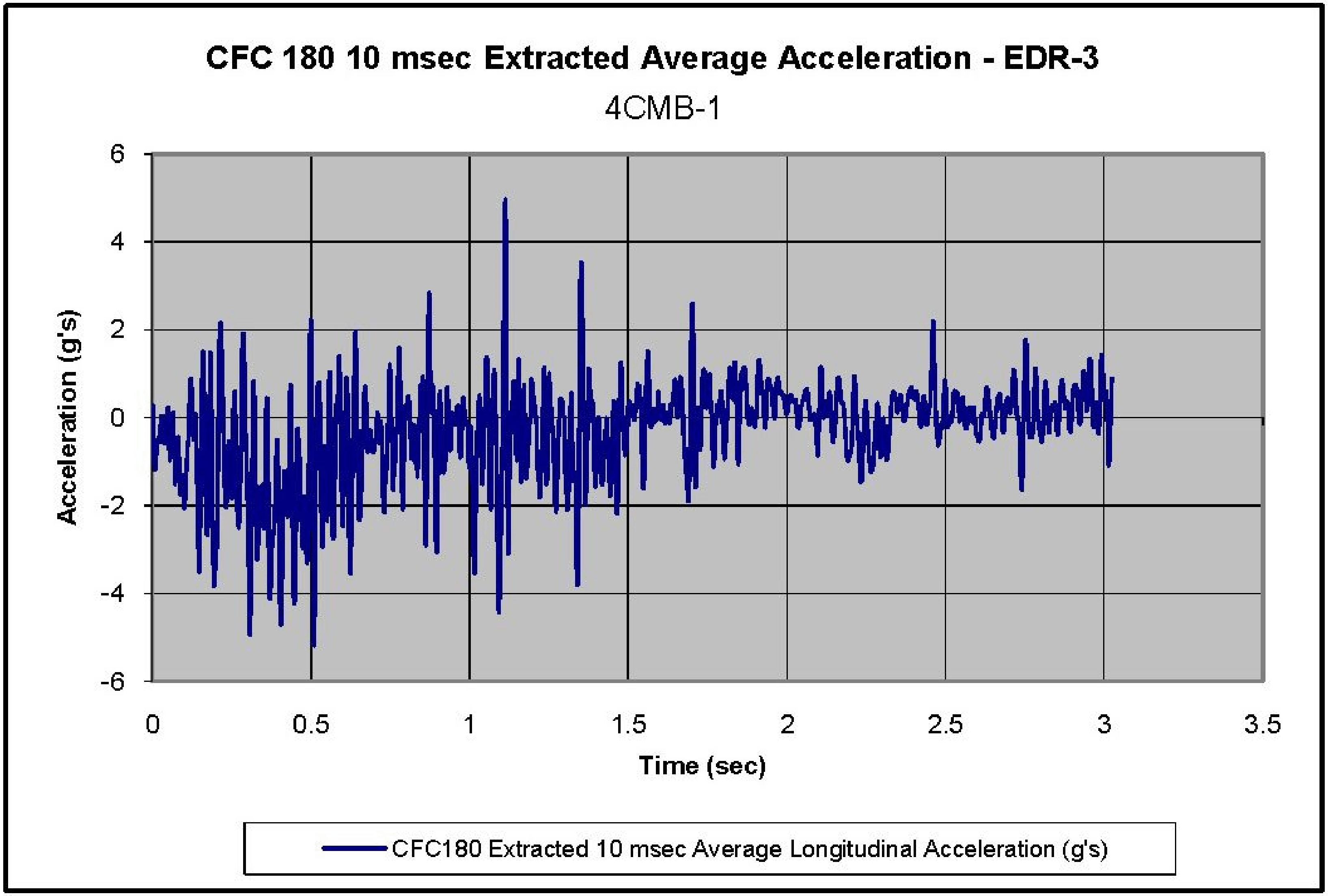


Figure B-1. Longitudinal Deceleration, Test No. 4CMB-1

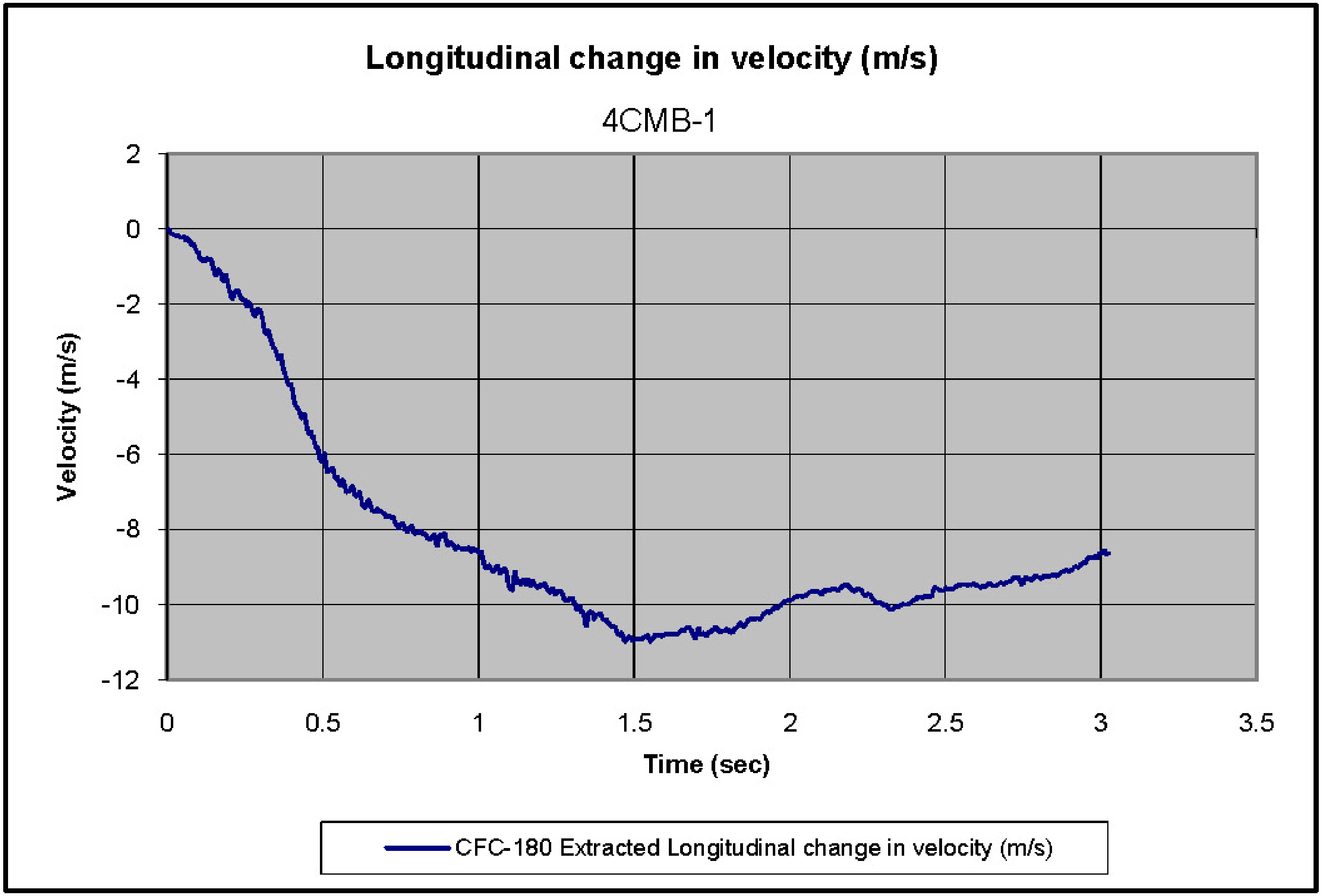


Figure B-2. Lateral Occupant Impact Velocity, Test No. 4CMB-1

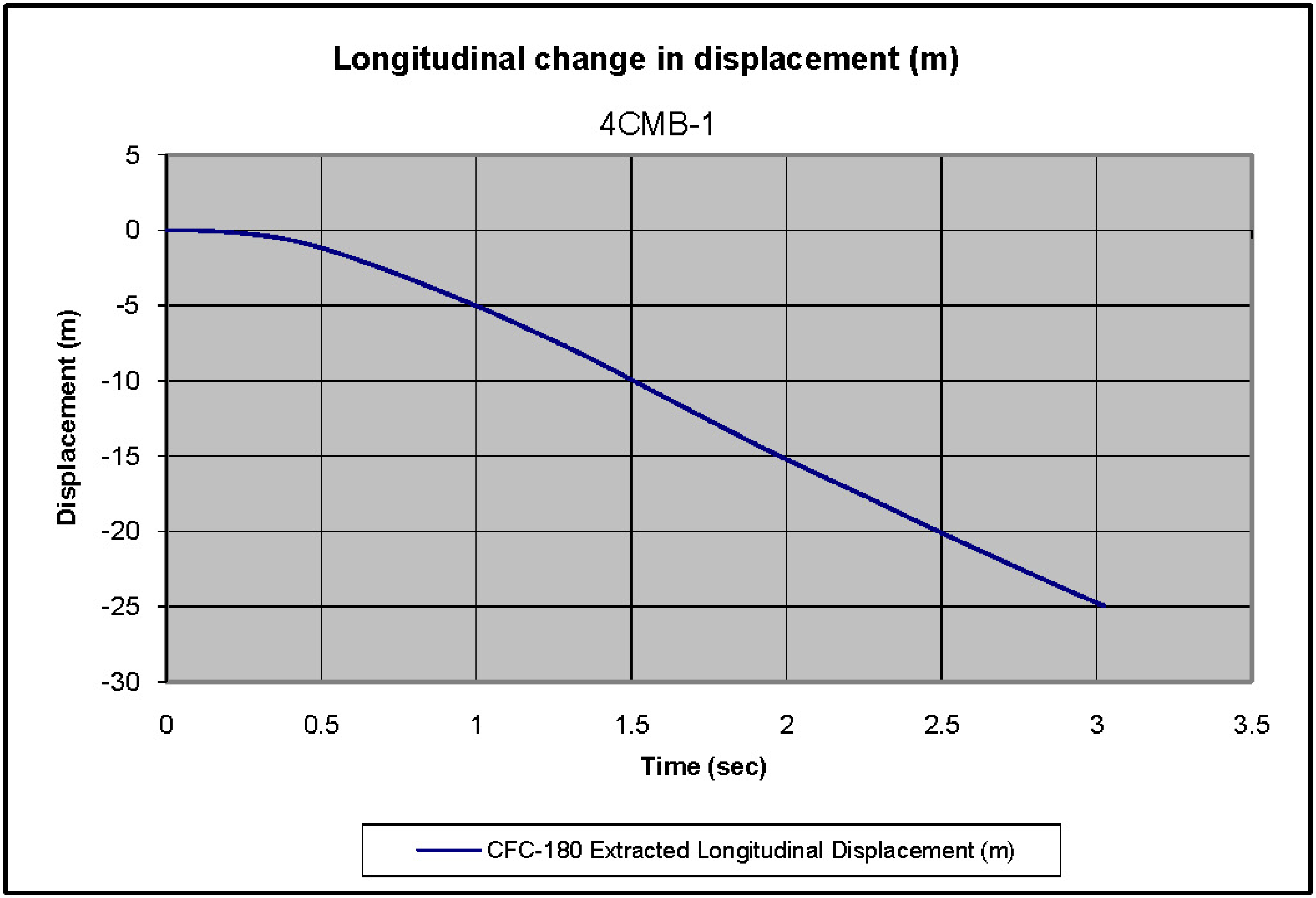


Figure B-3. Longitudinal Occupant Displacement, Test No. 4CMB-1

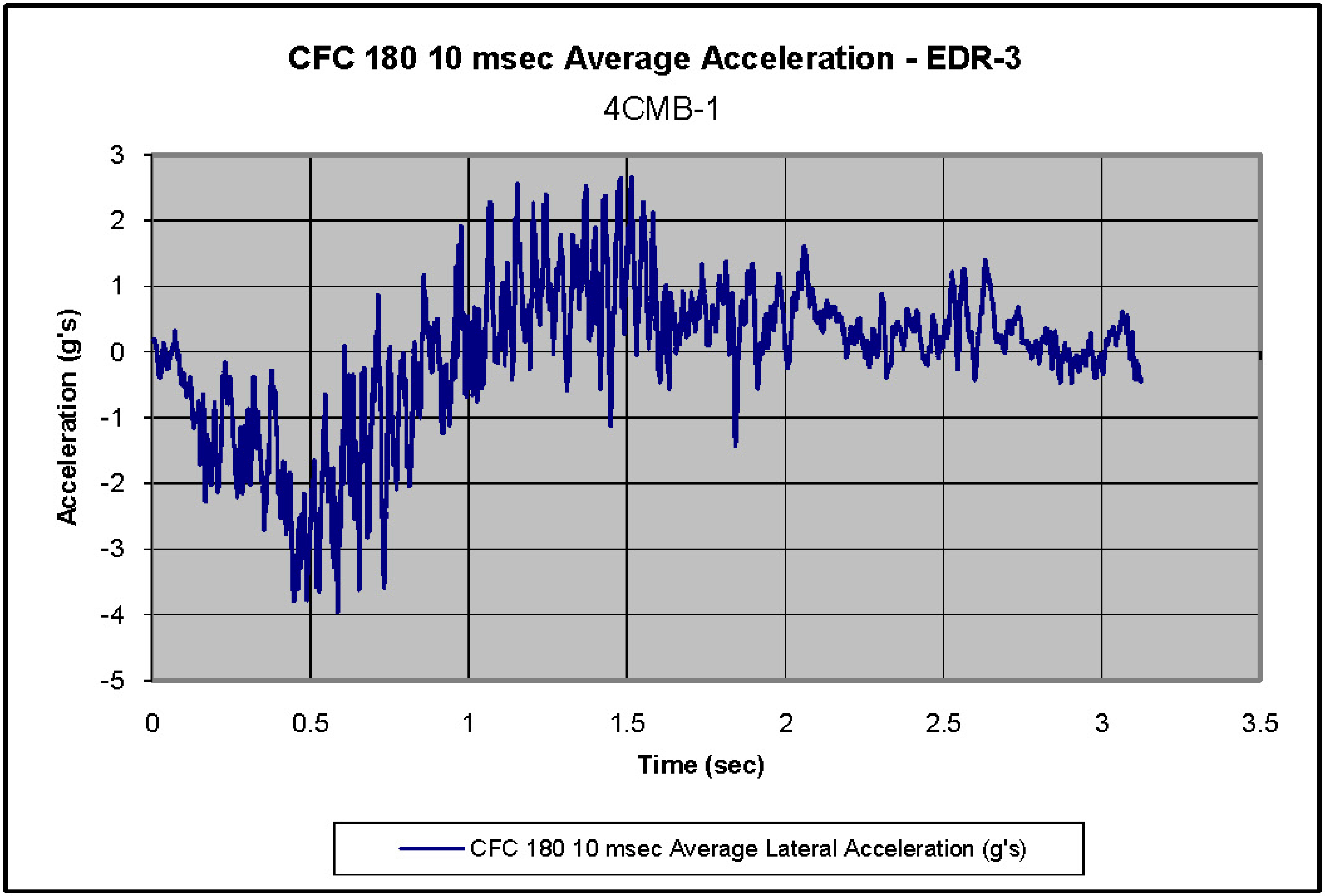


Figure B-4. Lateral Deceleration, Test No. 4CMB-1

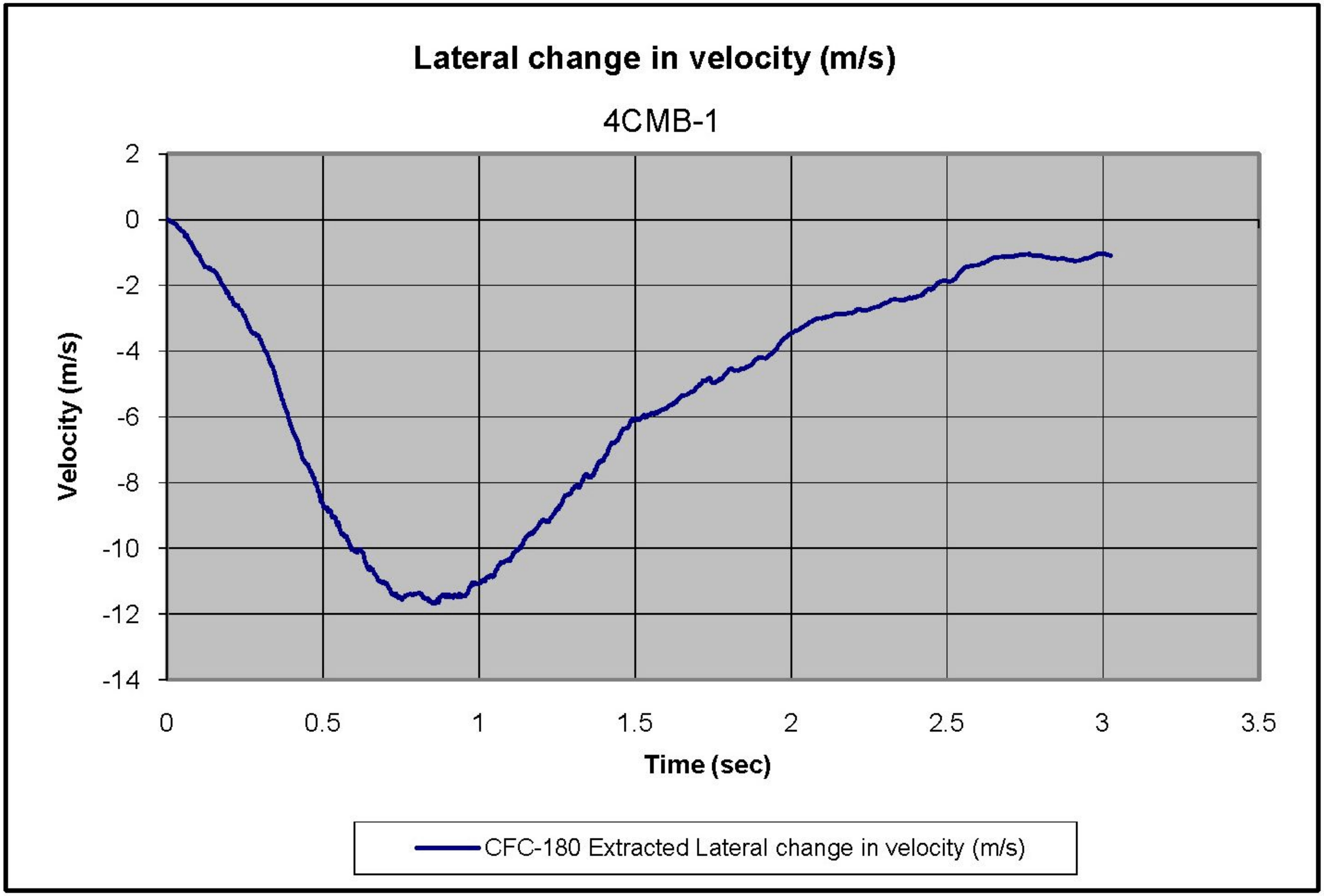


Figure B-5. Lateral Occupant Impact Velocity, Test No. 4CMB-1

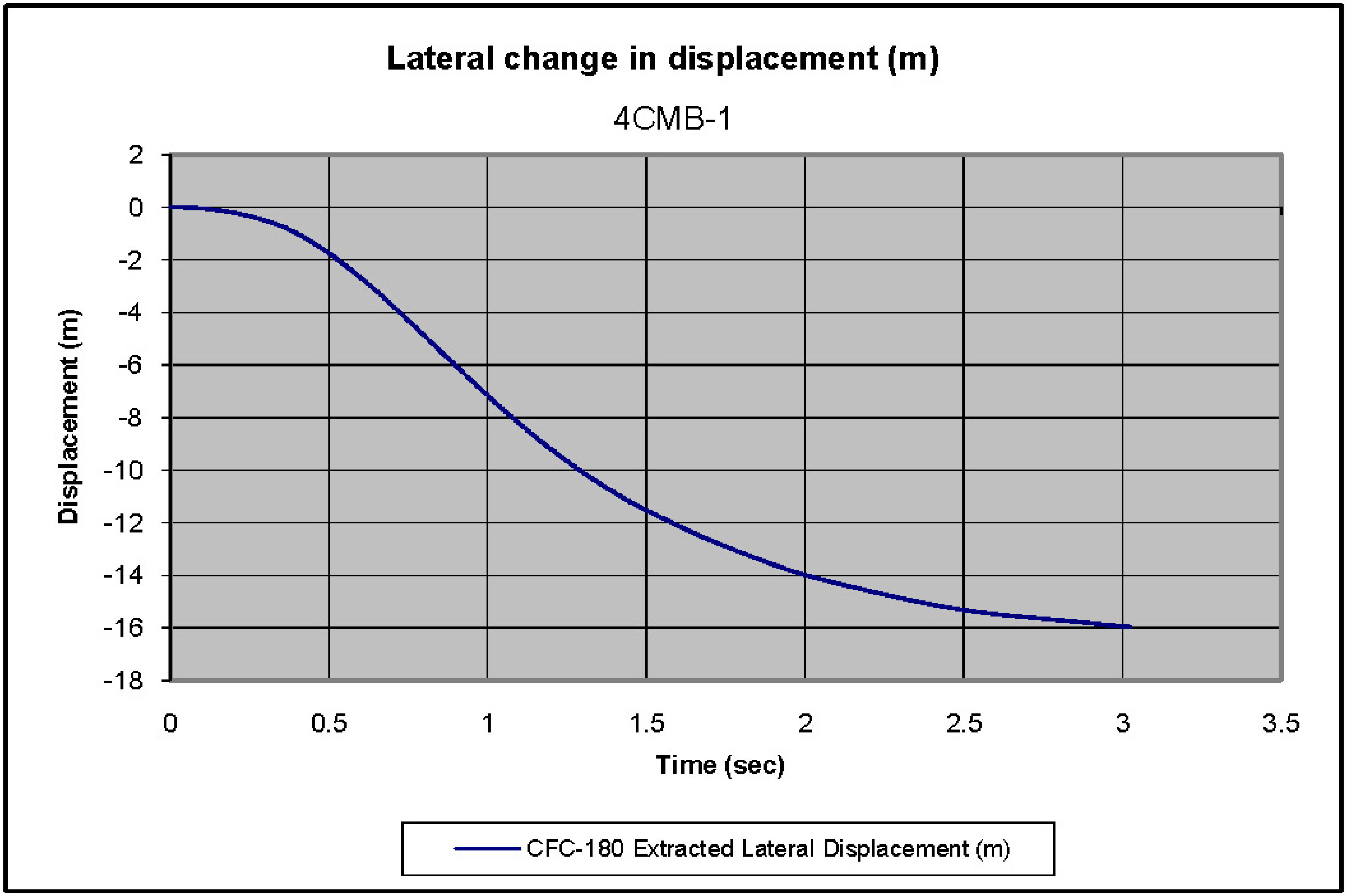


Figure B-6. Lateral Occupant Displacement, Test No. 4CMB-1

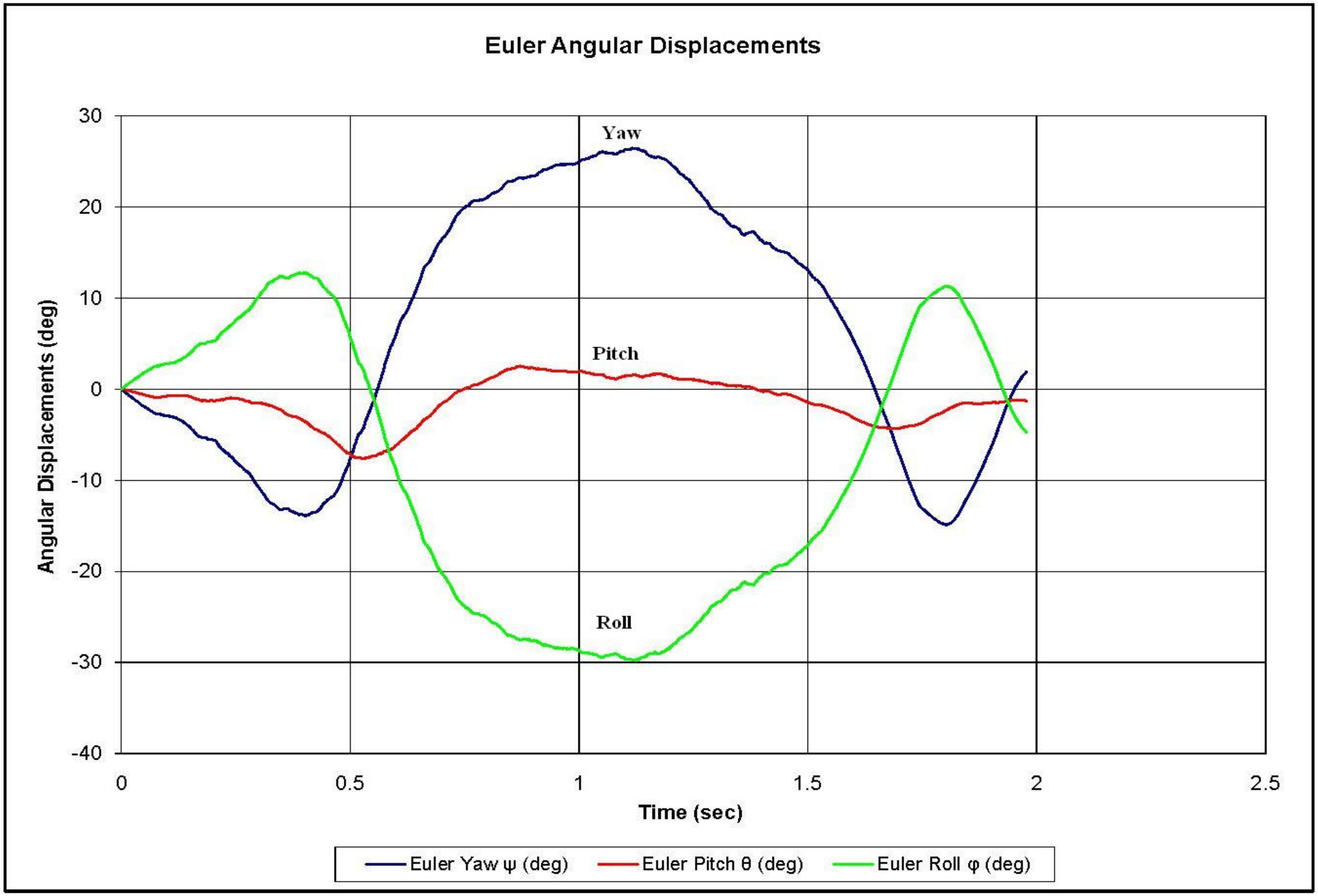


Figure B-7. Euler Angular Displacements, Test No. 4CMB-1

APPENDIX C

Accelerometer and Rate Transducer Data Plots, Test No. 4CMB-2

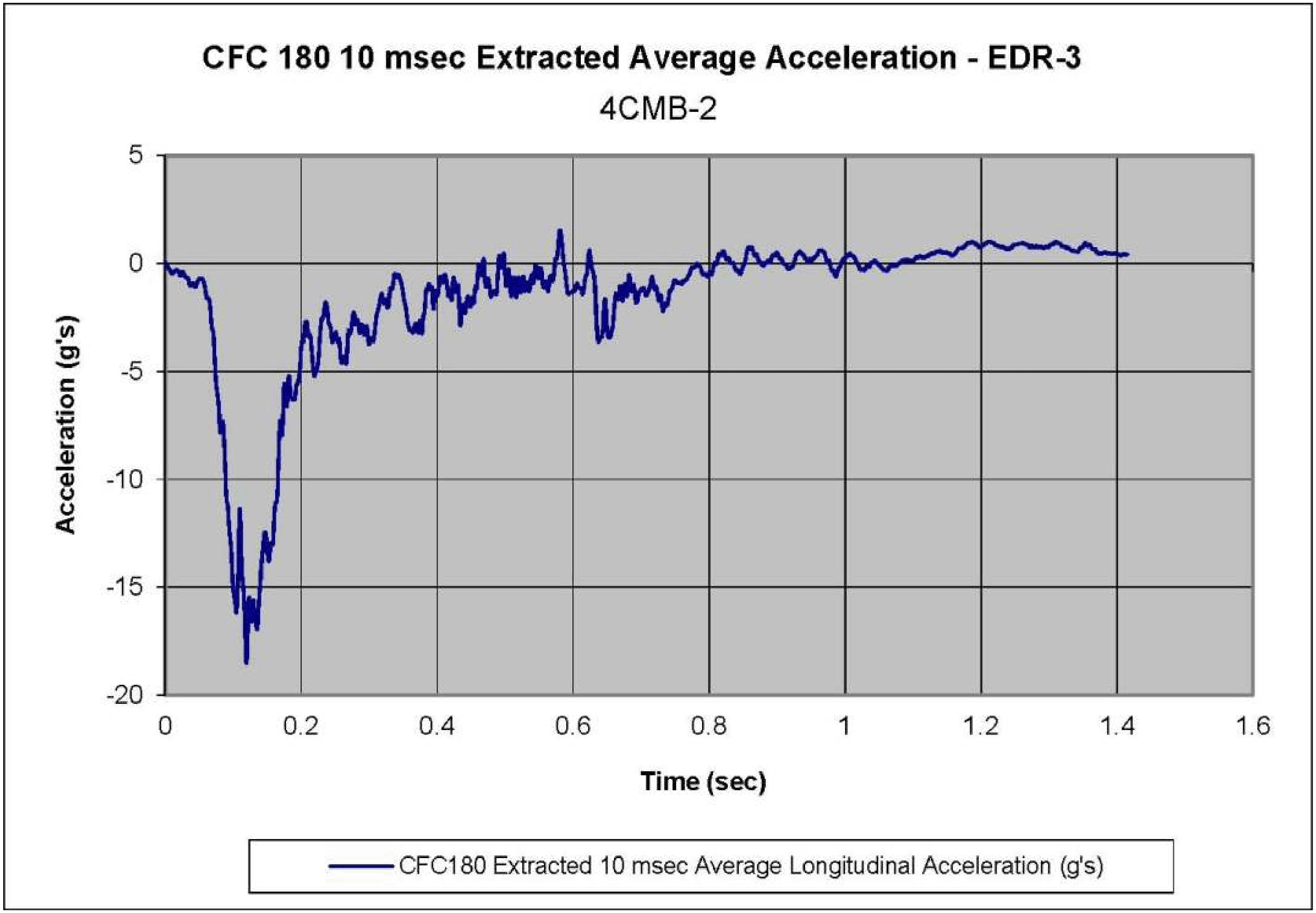


Figure C-1. Longitudinal Deceleration, Test No. 4CMB-2

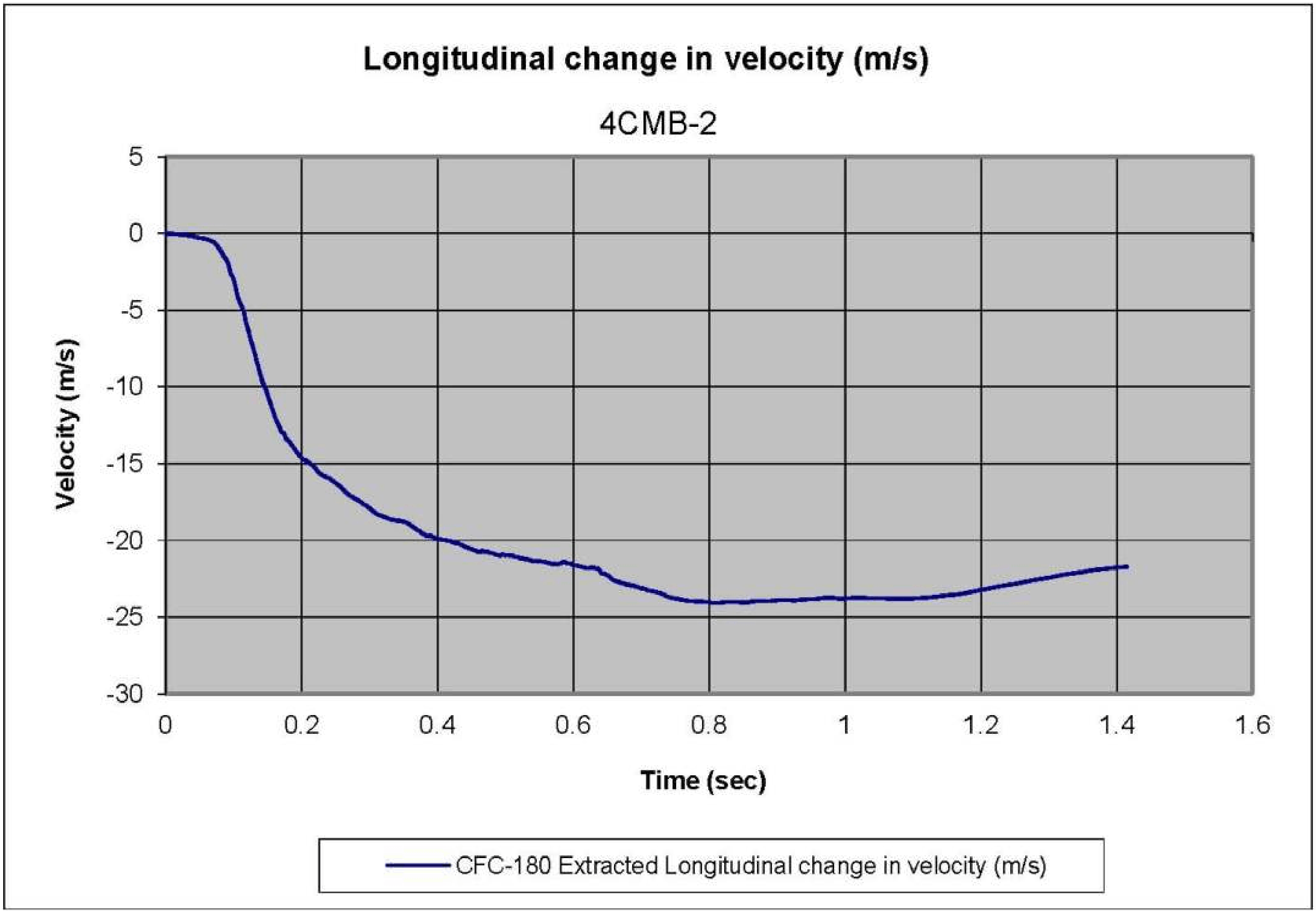


Figure C-2. Longitudinal Occupant Impact Velocity, Test No. 4CMB-2

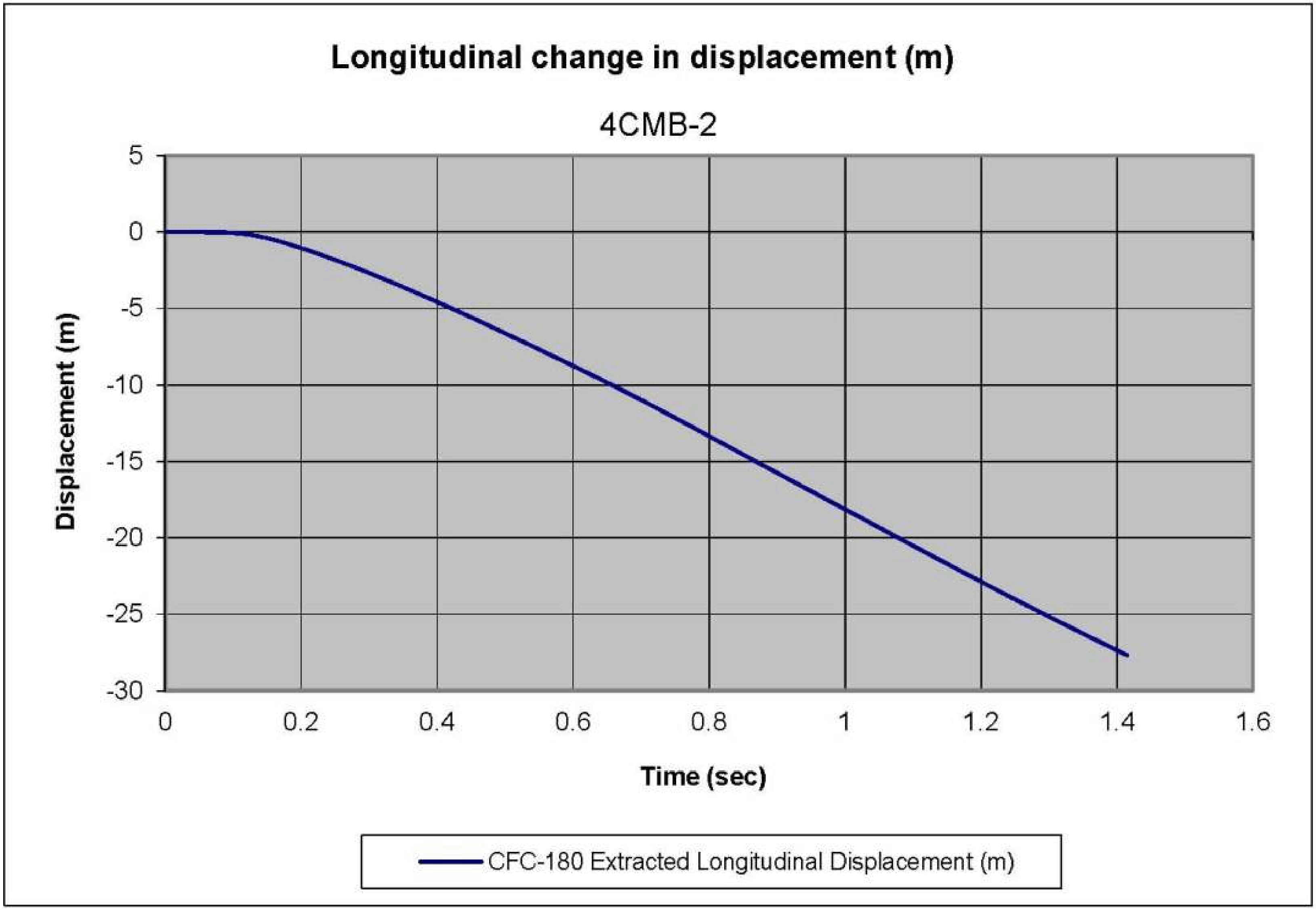


Figure C-3. Longitudinal Occupant Displacement, Test No. 4CMB-2

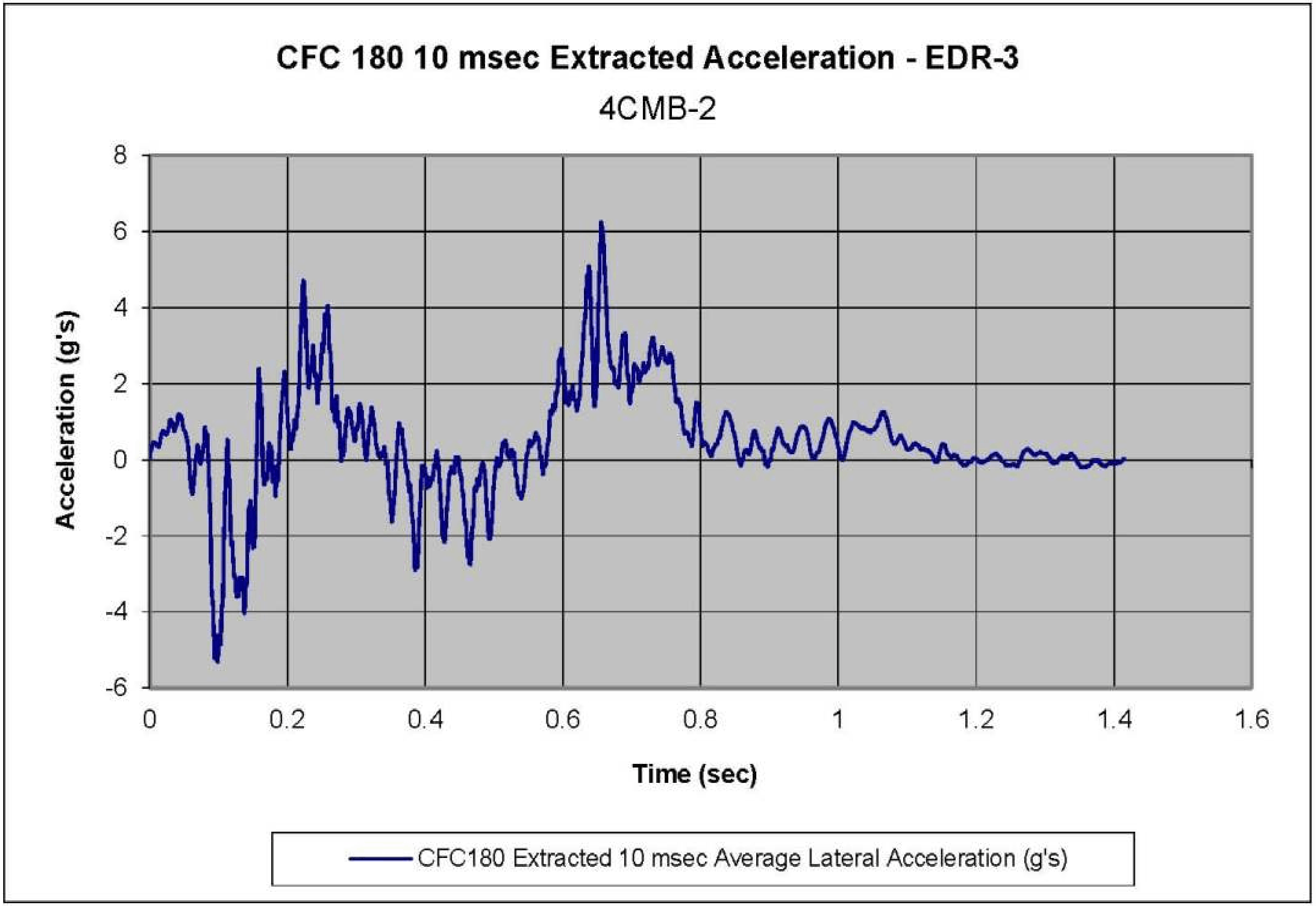


Figure C-4. Lateral Deceleration, Test No. 4CMB-2

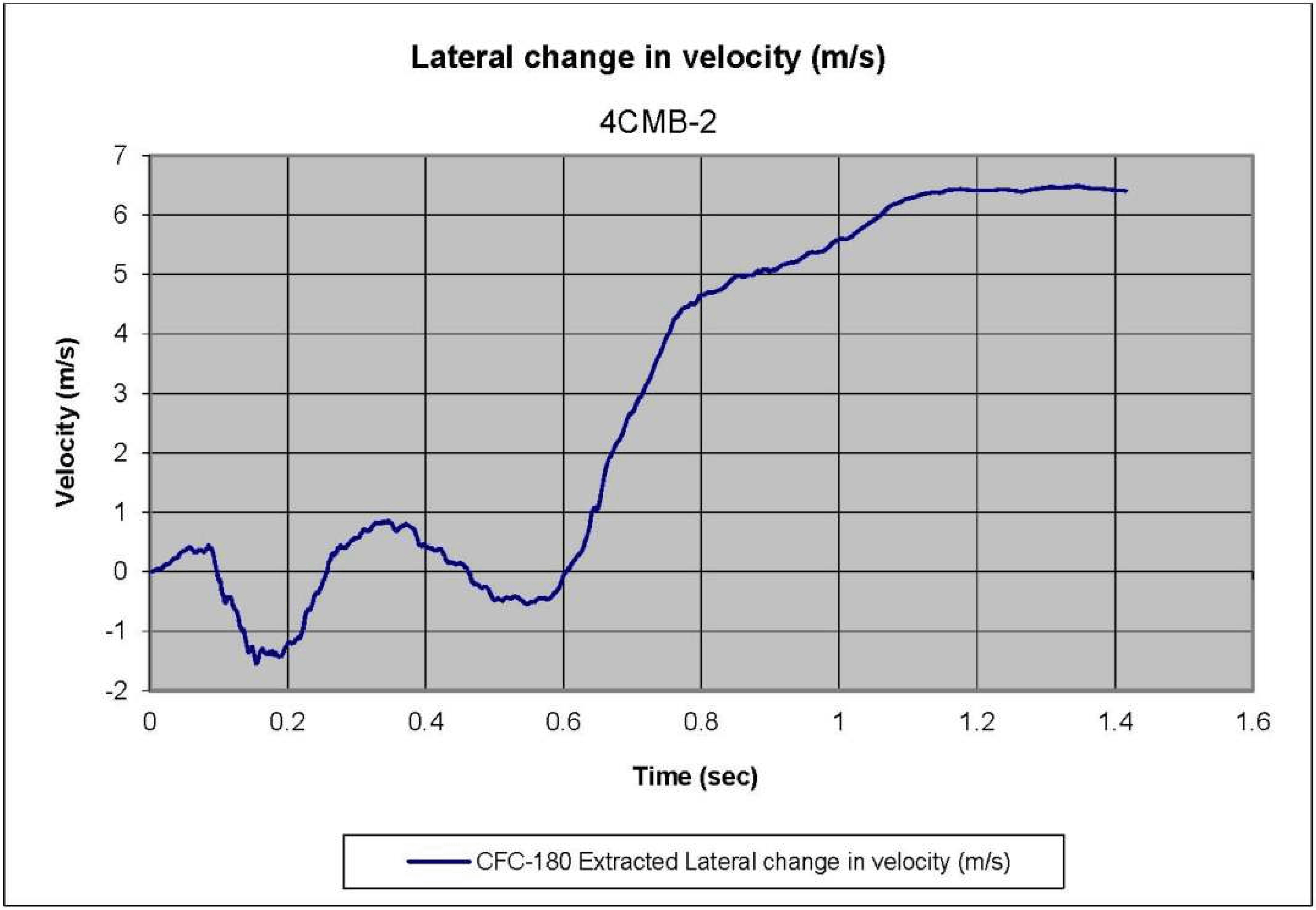


Figure C-5. Lateral Occupant Impact Velocity, Test No. 4CMB-2

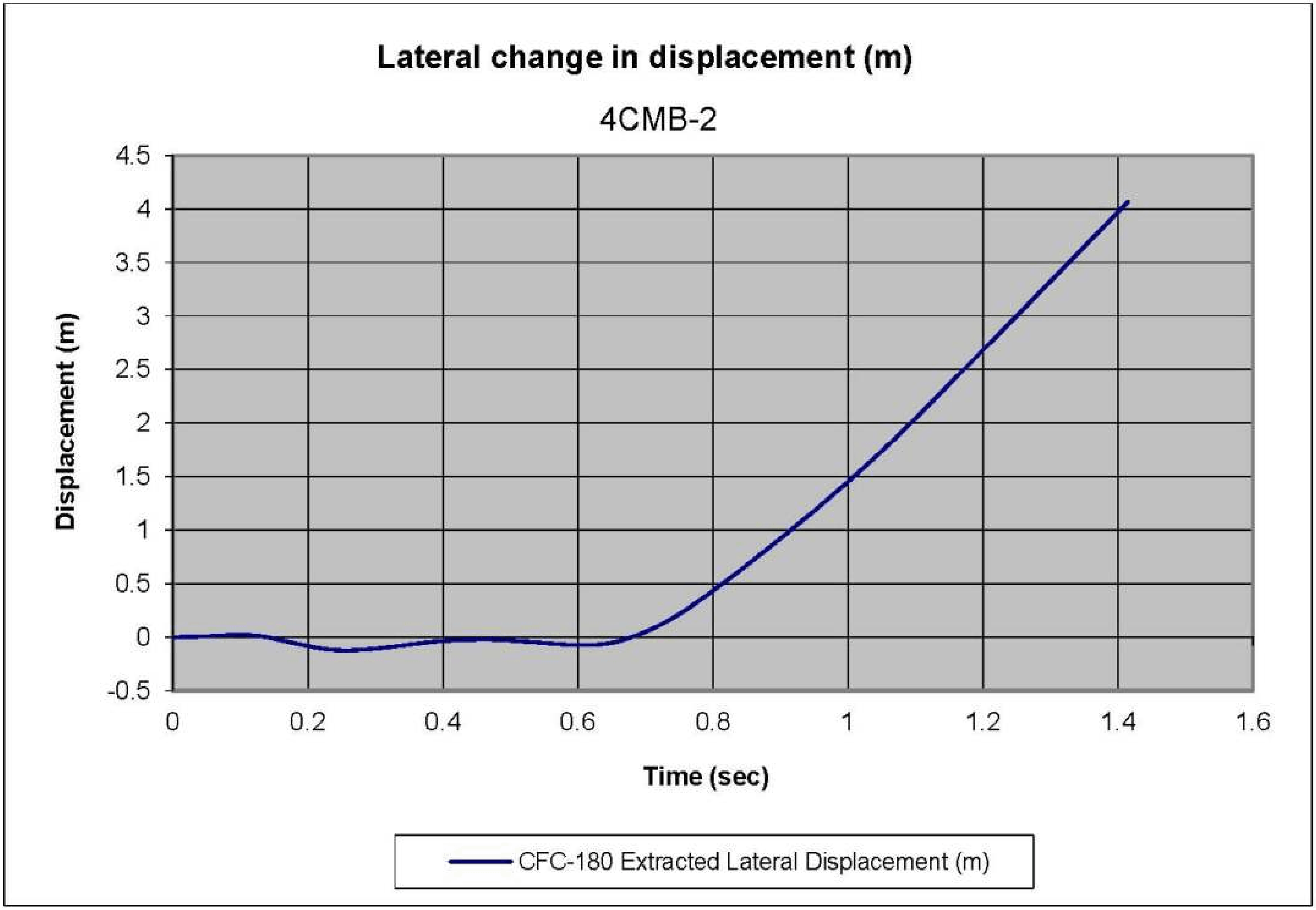
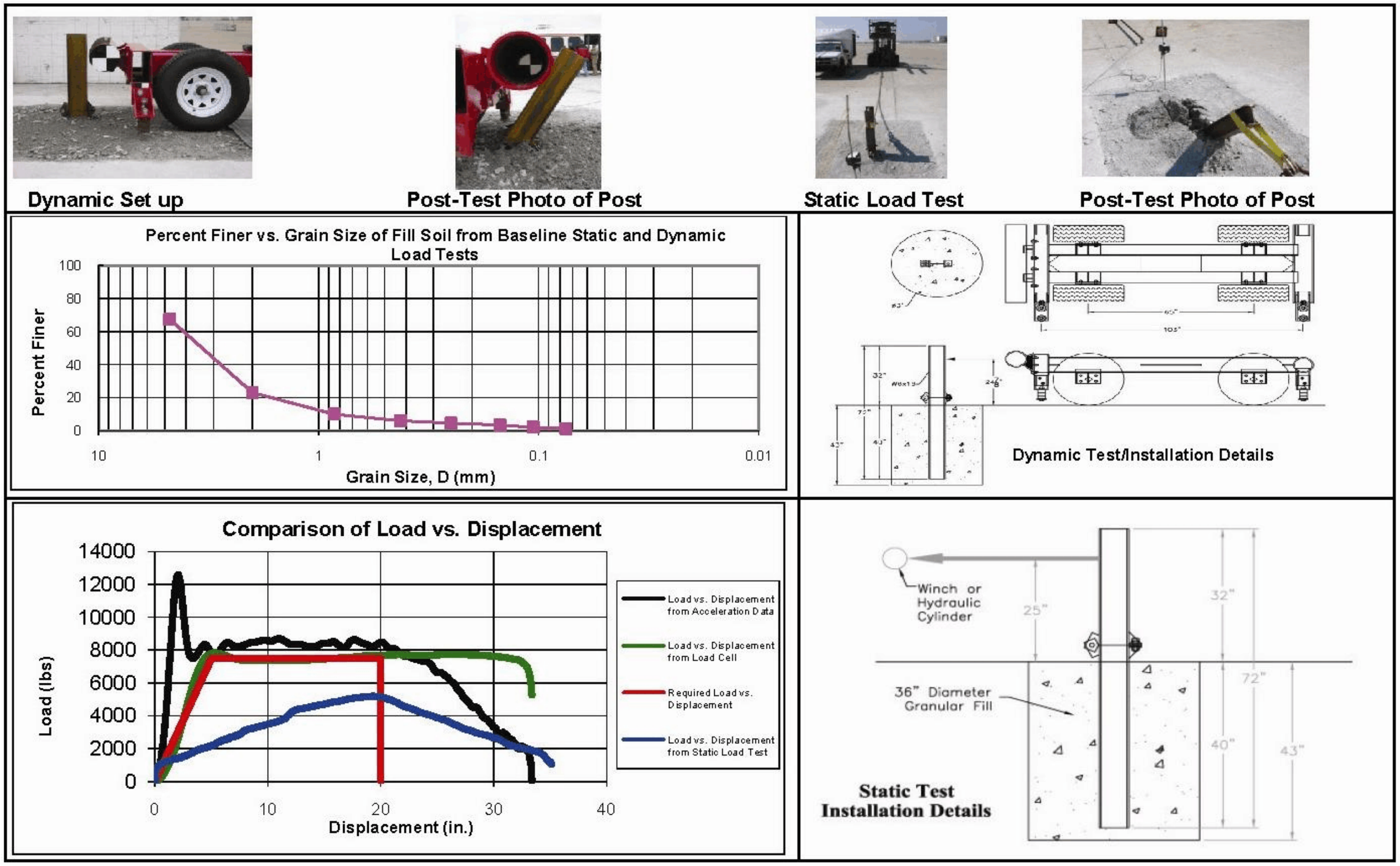


Figure C-6. Lateral Occupant Displacement, Test No. 4CMB-2

Figure C-7. Euler Angular Displacements, Test No. 4CMB-2

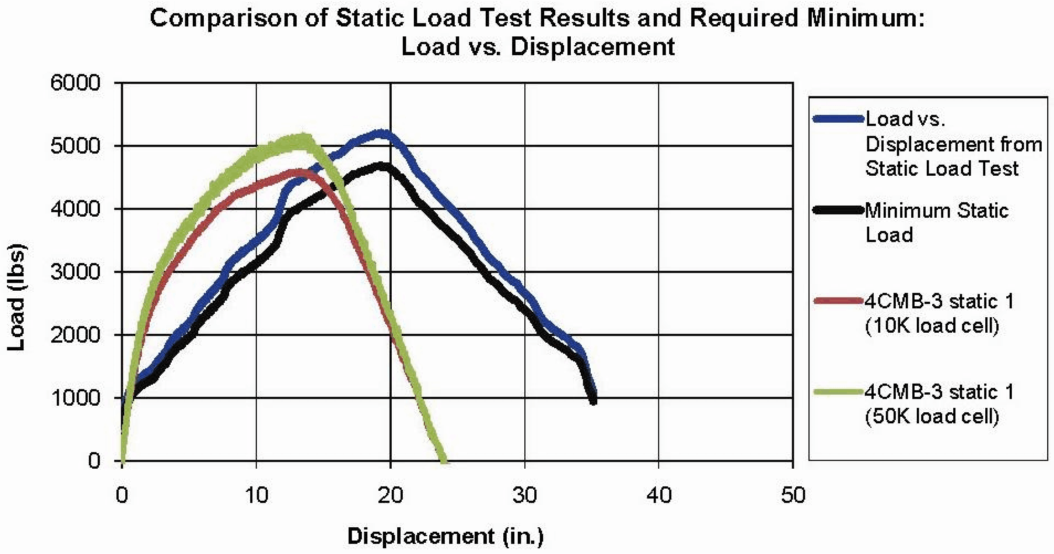
APPENDIX D

Soil Static Tests



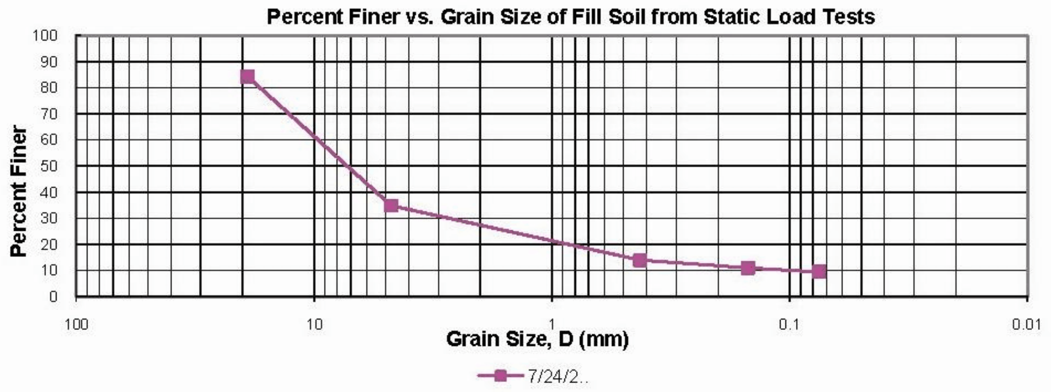
Date……………………………………………………………………………	7/7/2005
Test Facility & Site Location………………………………………………	Midwest Road Side Safety Facility
In situ soil description (ASTM D2487)…………………………………	Well Graded Gravel (GW)
Fill material description (ASTM D2487) & sieve analysis…………	Well Graded Gravel (GW) (see sieve analyses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

Figure D-1. Soil Strength, Initial Calibration Tests



Static Load Set up

Post-Test Photo of Post



Date.. 8/25/2008

Test Facility & Site Location... Midwest Road Side Safety Facility

In situ soil description (ASTM D2487)....................................... Well Graded Gravel (GW)

Fill material description (ASTM D2487) & sieve analysis............ Well Graded Gravel (GW) (see sieve analyses above)

Description of fill placement procedure.................................... 6-inch lifts tamped with a pneumatic compactor

Figure D-2. Static Soil Test, Test No. 4CMB-3

APPENDIX E

Accelerometer and Rate Transducer Data Plots, Test No. 4CMB-3

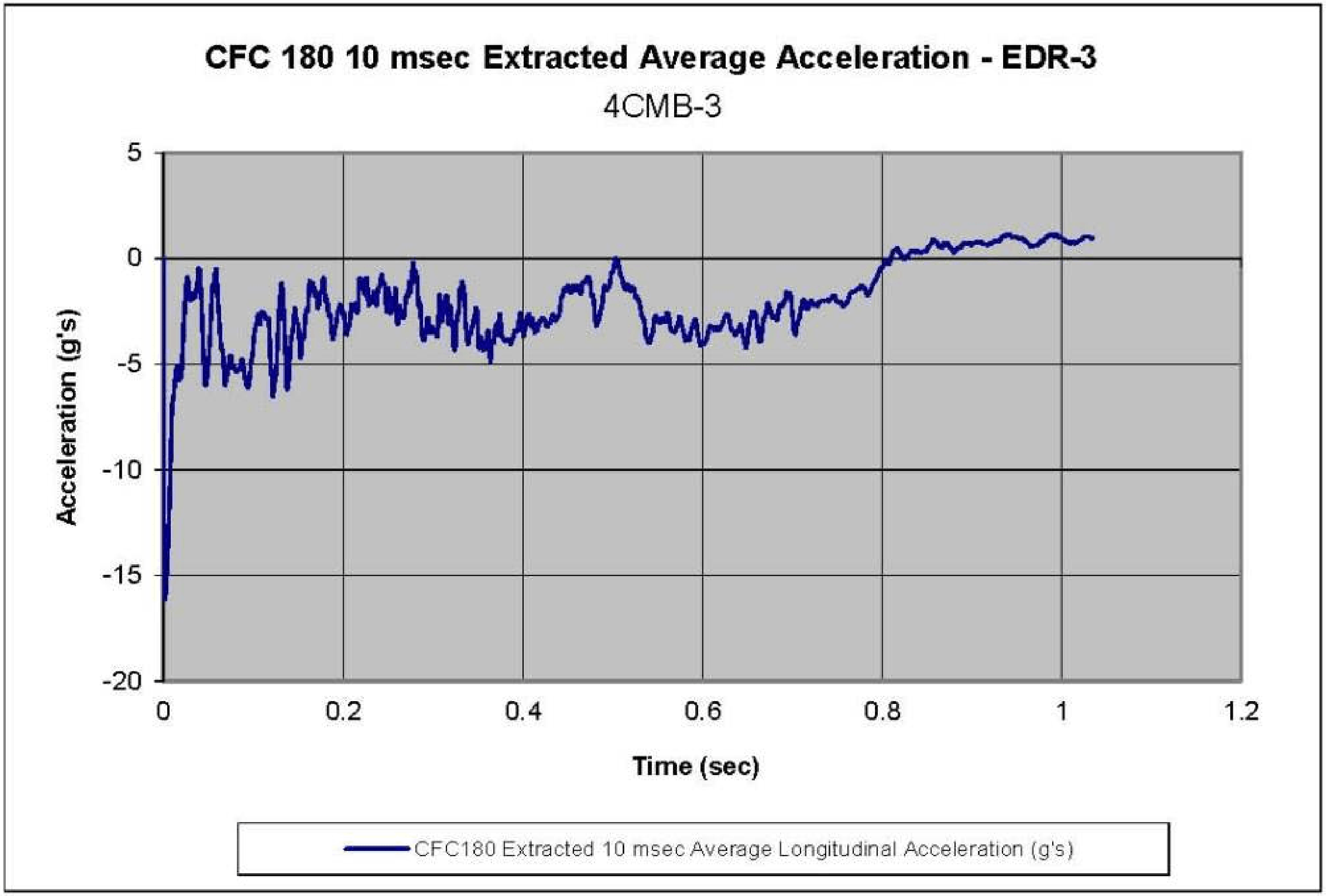


Figure E-1. Longitudinal Deceleration, Test No. 4CMB-3

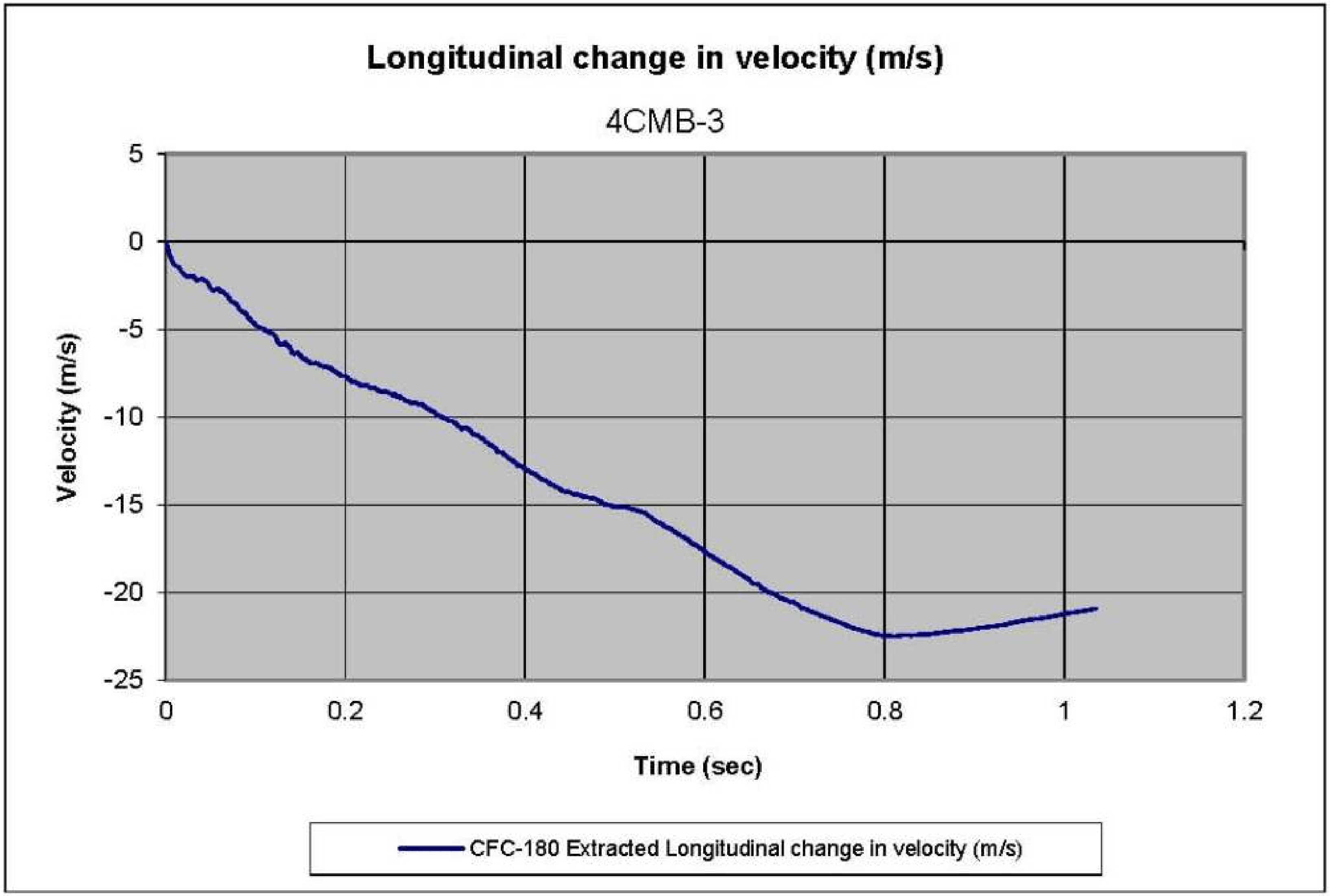


Figure E-2. Longitudinal Occupant Impact Velocity, Test No. 4CMB-3

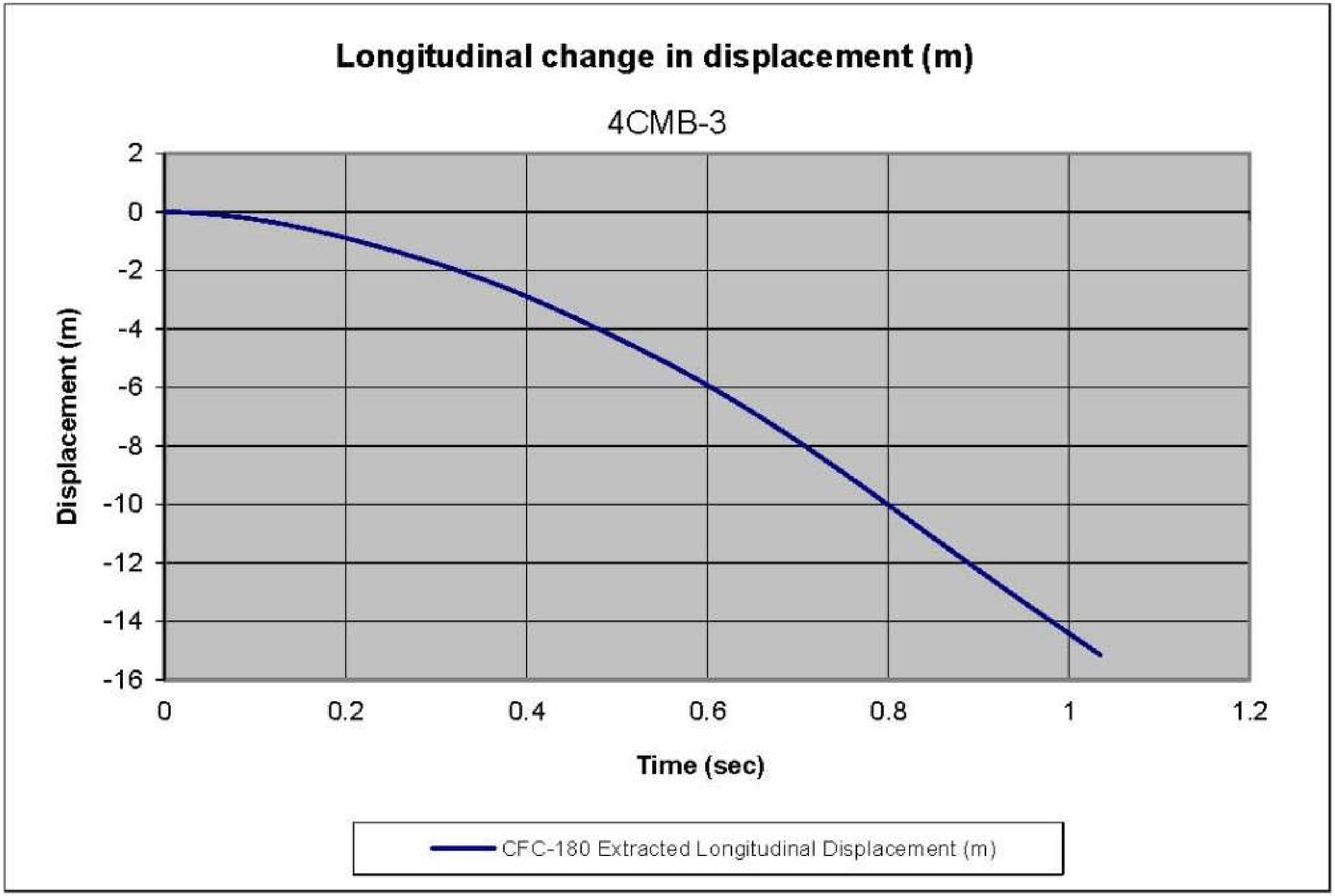


Figure E-3. Longitudinal Occupant Displacement, Test No. 4CMB-3

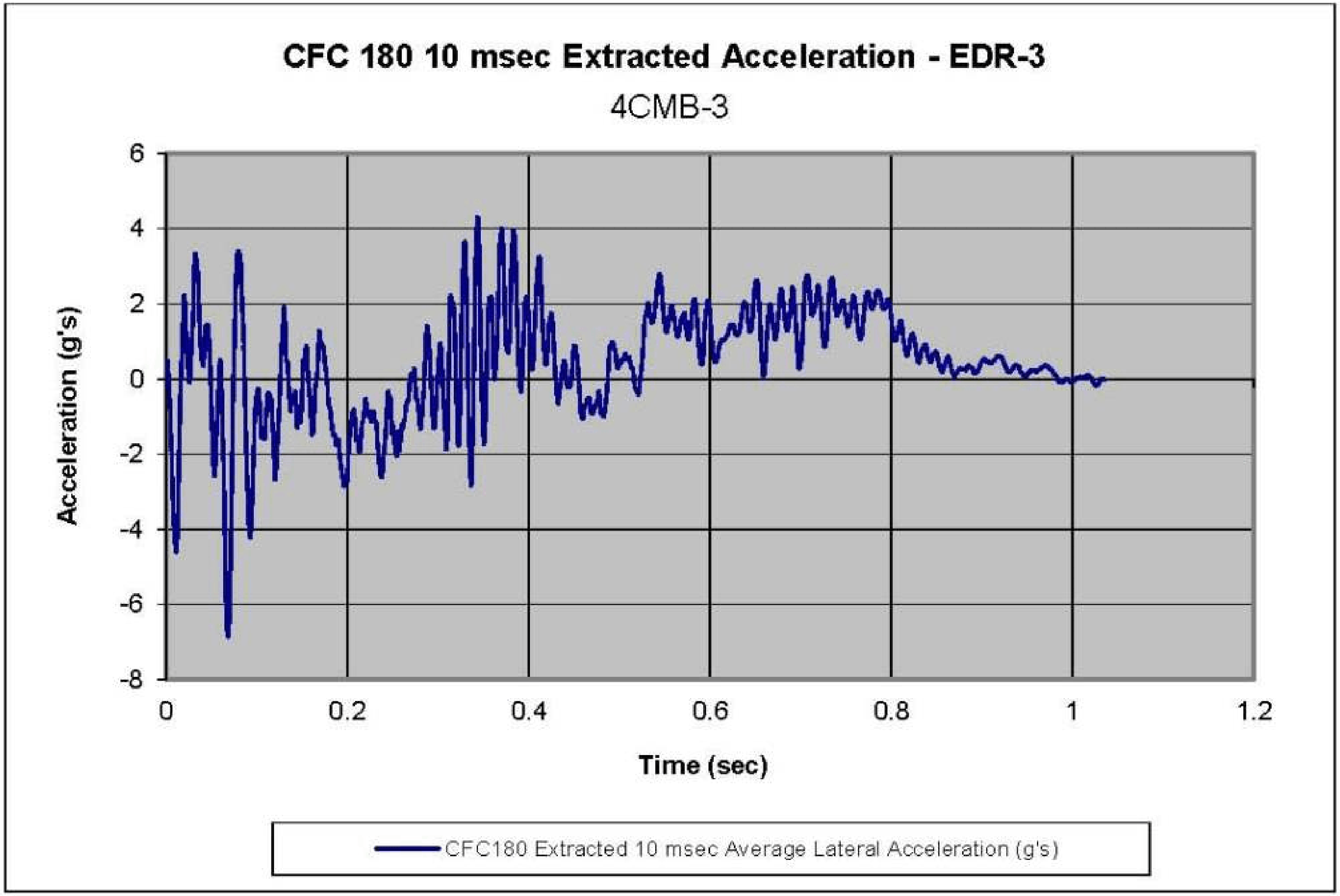


Figure E-4. Lateral Deceleration, Test No. 4CMB-3

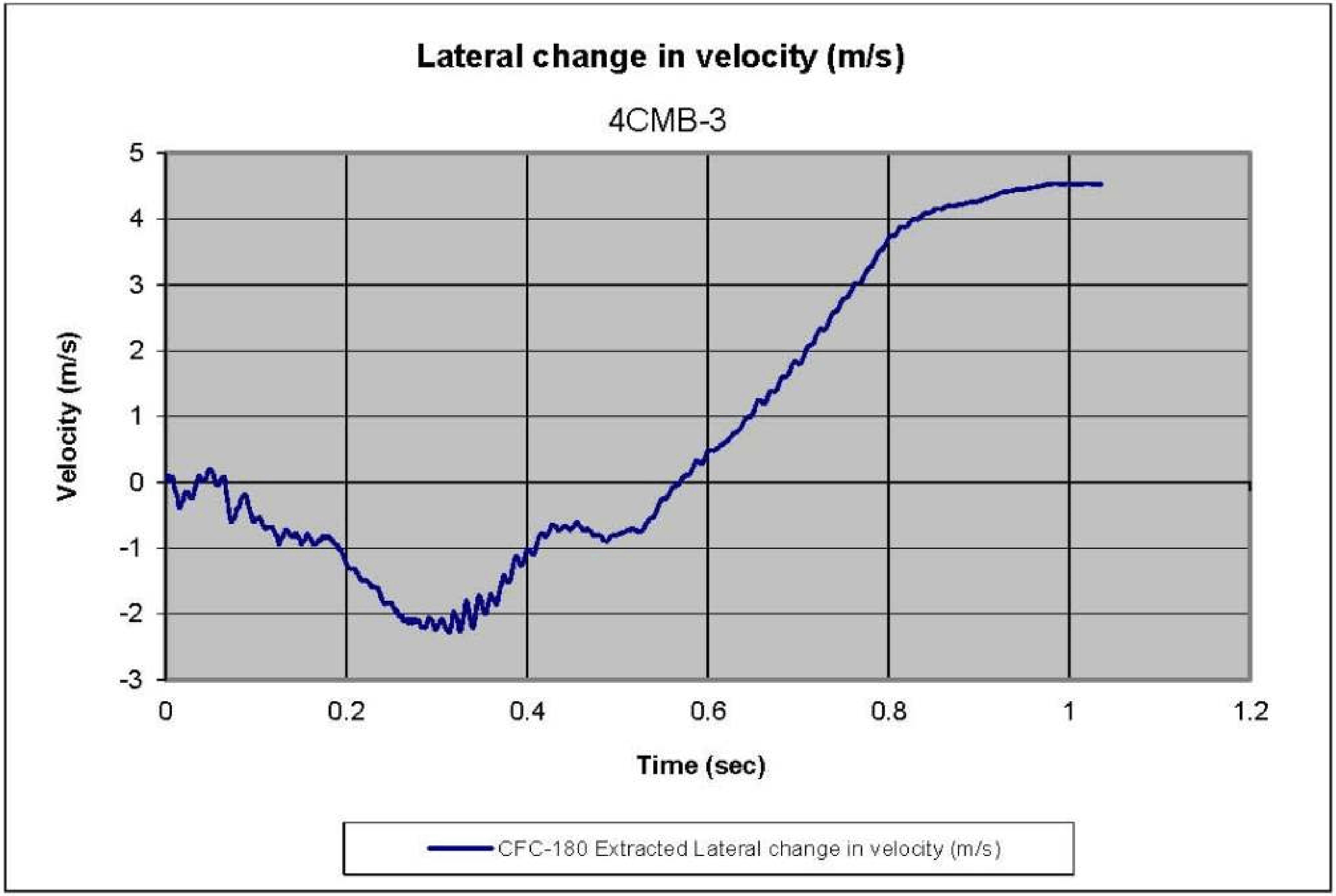


Figure E-5. Lateral Occupant Impact Velocity, Test No. 4CMB-3

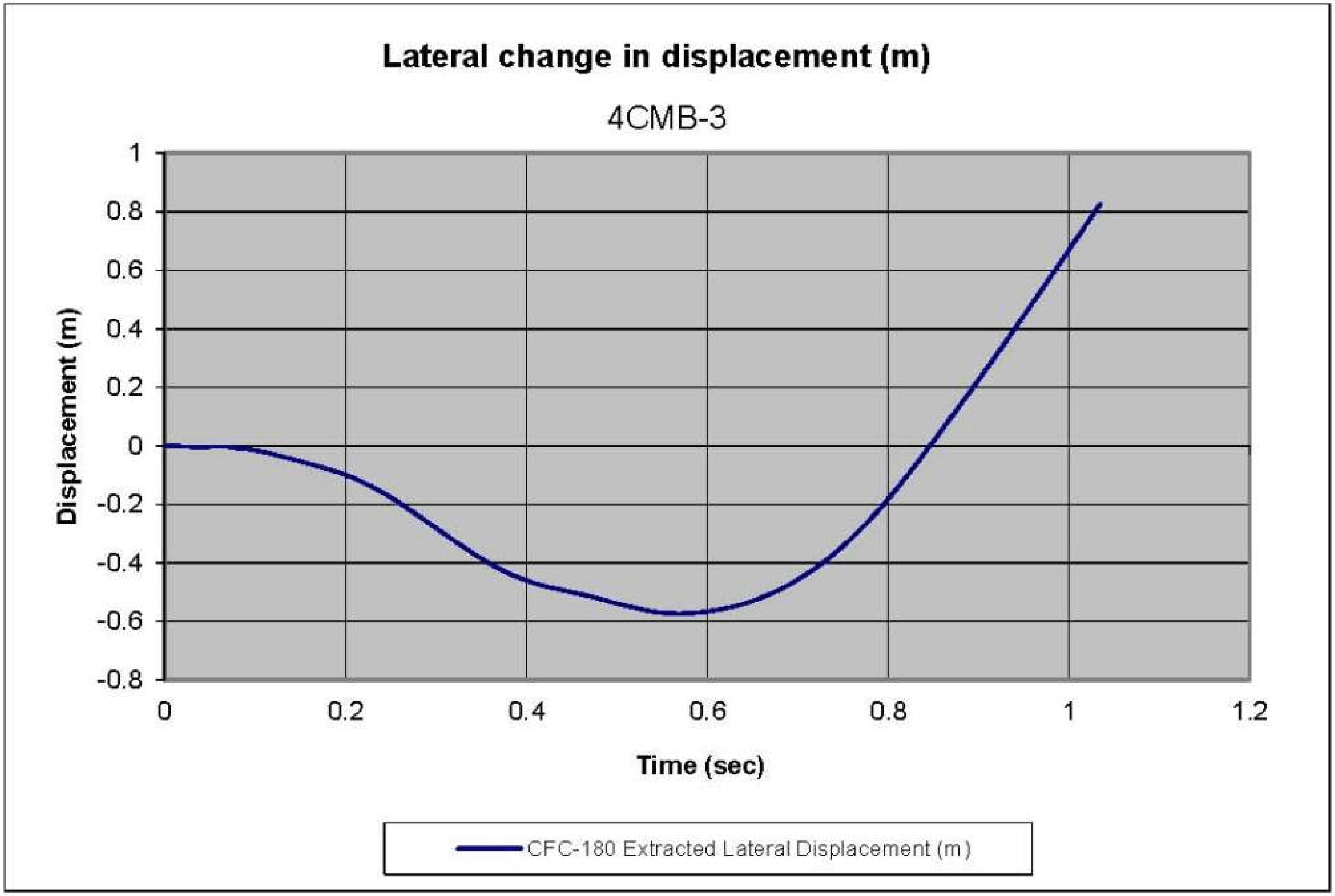


Figure E-6. Lateral Occupant Displacement, Test No. 4CMB-3

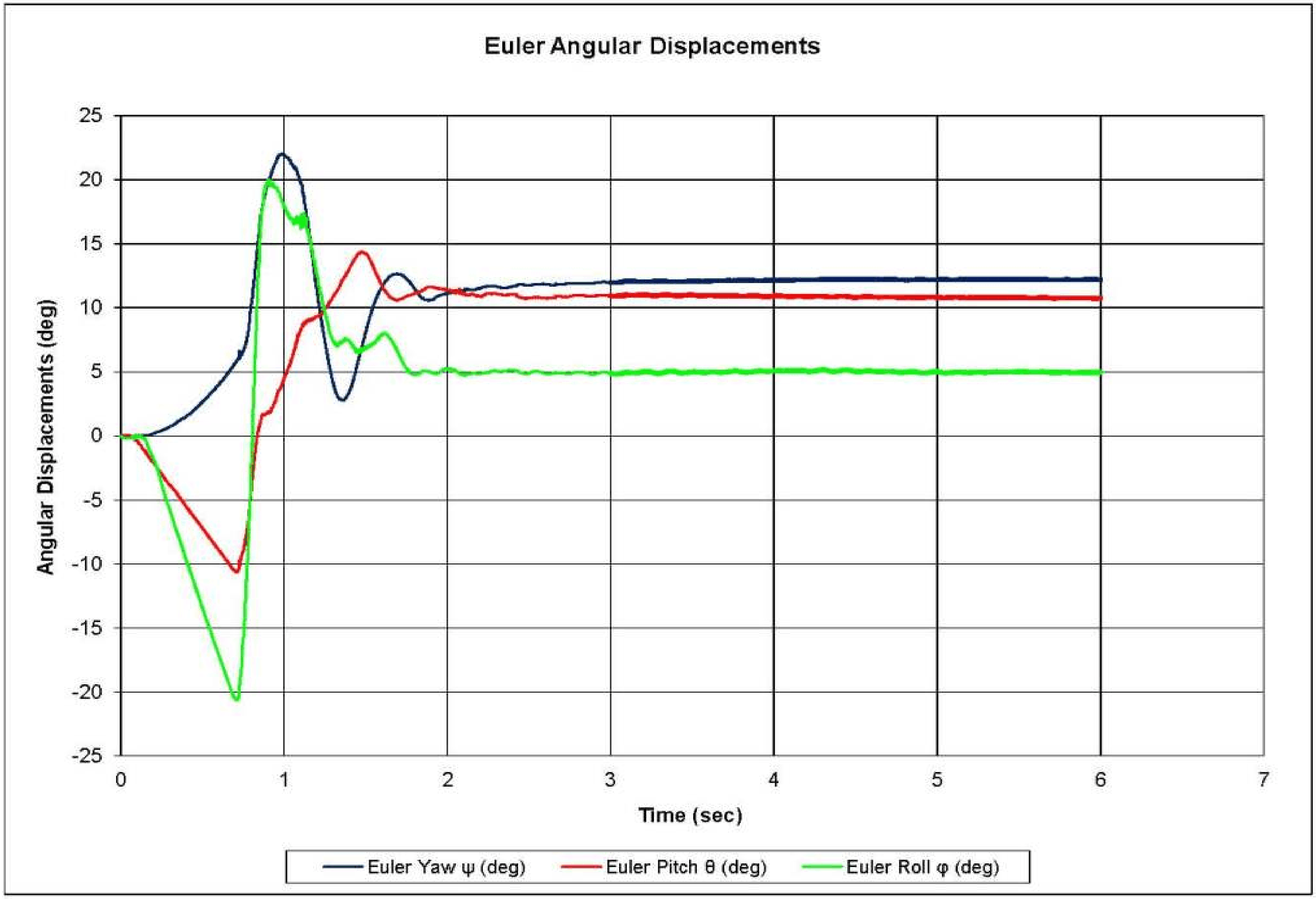


Figure E-7. Euler Angular Displacements, Test No. 4CMB-3

APPENDIX F

Occupant Compartment Deformation Data

VEHICLE PRE/POST CRUSH INFO
Set-1

TEST: 4CMB-1
VEHICLE: 2002 Ram 1500 Q.C. 4x2

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	30.75	-27.75	-0.5	30.75	-27.5	-1	0	0.25	-0.5
2	34	-23.75	-1	34	-24	-1.25	0	-0.25	-0.25
3	34.25	-16.75	-1.75	34	-16.25	-1.75	-0.25	0.5	0
4	30	-10.5	0	29.75	-11	0	-0.25	-0.5	0
5	27.5	-28.75	-4.75	27.25	-29.25	-5.25	-0.25	-0.5	-0.5
6	28.5	-22.25	-6	28.5	-22.5	-6.25	0	-0.25	-0.25
7	28.5	-15.5	-6.25	28.5	-15.75	-6.5	0	-0.25	-0.25
8	27.5	-9.75	-5.5	27.75	-10.25	-5.75	0.25	-0.5	-0.25
9	20	-29.5	-9.5	19.75	-29.5	-10	-0.25	0	-0.5
10	19.75	-23	-9.5	20	-23.5	-10	0.25	-0.5	-0.5
11	19.75	-17	-10	19.75	-17.25	-10	0	-0.25	0
12	19.25	-11	-10	19.5	-11	-10.25	0.25	0	-0.25
13	15.25	-3.25	-3	15.25	-3.25	-3.25	0	0	-0.25
14	14	-29.75	-9.5	14.25	-29.75	-9.5	0.25	0	0
15	14.25	-23	-9.25	14.25	-23	-9.5	0	0	-0.25
16	14.25	-17.5	-9.5	14.25	-17.75	-9.75	0	-0.25	-0.25
17	13.75	-11	-9.75	13.75	-11	-10	0	0	-0.25
18	11.25	-3.5	-3	11.25	-3.5	-3.25	0	0	-0.25
19	9	-29.25	-8.5	9	-29.5	-8.75	0	-0.25	-0.25
20	9	-23.25	-8.75	9	-23.5	-9	0	-0.25	-0.25
21	9	-16.5	-9.25	9	-16.5	-9.25	0	0	0
22	9	-11	-9.5	9	-11.5	-9.5	0	-0.5	0
23	7.25	-1.5	-3.5	7.25	-1.5	-3.5	0	0	0
24	1.25	-28.5	-4.5	1.25	-28.5	-4.75	0	0	-0.25
25	1	-23.25	-4.25	1	-23.25	-4.5	0	0	-0.25
26	1.25	-17	-4.75	1.25	-17	-4.75	0	0	0
27	1	-11.5	-5	1	-11.5	-5	0	0	0
28	1.75	-2	-3	1.75	-2	-3	0	0	0
29									
30									

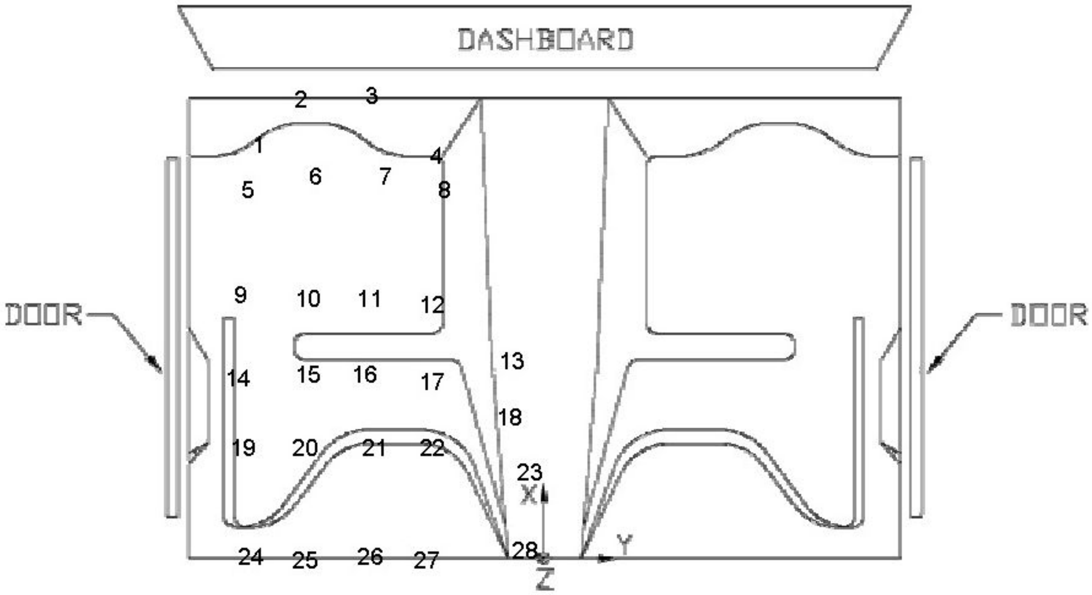


Figure F-1. Vehicle Crush Info Set 1, Test No. 4CMB-1

VEHICLE PRE/POST CRUSH INFO
Set-2

TEST: 4CMB-1
VEHICLE: 2002 Ram 1500 Q.C, 4x2

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

	22.5	1.5							
POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	53.25	-26.25	-1.5	53.25	-26	-1.25	0	0.25	0.25
2	56.5	-22.25	-1.5	56.5	-22.5	-1.5	0	-0.25	0
3	56.75	-15.25	-1.75	56.5	-14.75	-1.75	-0.25	0.5	0
4	52.5	-9	0	52.25	-9.5	0	-0.25	-0.5	0
5	50	-27.25	-5.5	49.75	-27.75	-5.5	-0.25	-0.5	0
6	51	-20.75	-6.5	51	-21	-6.75	0	-0.25	-0.25
7	51	-14	-6.5	51	-14.25	-6.5	0	-0.25	0
8	50	-8.25	-5.75	50.25	-8.75	-5.75	0.25	-0.5	0
9	42.5	-28	-10.5	42.25	-28	-10.5	-0.25	0	0
10	42.25	-21.5	-10.25	42.5	-22	-10.25	0.25	-0.5	0
11	42.25	-15.5	-10.25	42.25	-15.75	-10.25	0	-0.25	0
12	41.75	-9.5	-10.25	42	-9.5	-10.25	0.25	0	0
13	37.75	-1.75	-3	37.75	-1.75	-3	0	0	0
14	36.5	-28.25	-10.5	36.75	-28.25	-10.25	0.25	0	0.25
15	36.75	-21.5	-10	36.75	-21.5	-9.75	0	0	0.25
16	36.75	-16	-10	36.75	-16.25	-10	0	-0.25	0
17	36.25	-9.5	-10	36.25	-9.5	-10	0	0	0
18	33.75	-2	-3	33.75	-2	-3	0	0	0
19	31.5	-27.75	-9.5	31.5	-28	-9.5	0	-0.25	0
20	31.5	-21.75	-9.5	31.5	-22	-9.5	0	-0.25	0
21	31.5	-15	-9.5	31.5	-15	-9.75	0	0	-0.25
22	31.5	-9.5	-9.75	31.5	-10	-9.75	0	-0.5	0
23	29.75	0	-3.5	29.75	0	-3.25	0	0	0.25
24	23.75	-27	-5.5	23.75	-27	-5.5	0	0	0
25	23.5	-21.75	-5	23.5	-21.75	-5	0	0	0
26	23.75	-15.5	-5.25	23.75	-15.5	-5.25	0	0	0
27	23.5	-10	-5.5	23.5	-10	-5.5	0	0	0
28	24.25	-0.5	-2.75	24.25	-0.5	-3	0	0	-0.25
29									
30									

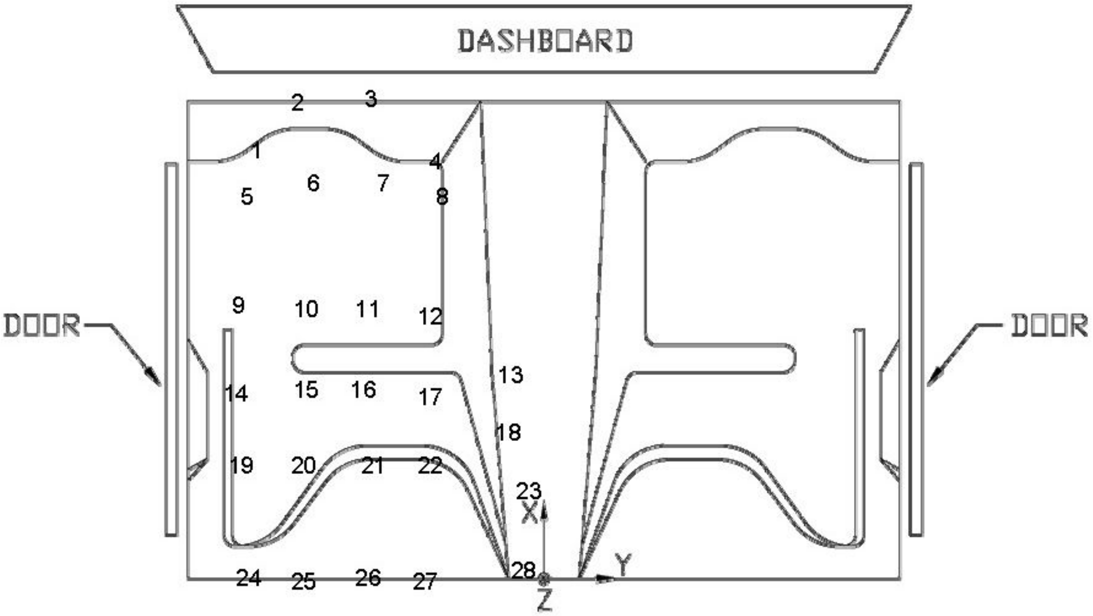


Figure F-2. Vehicle Crush Info Set 2, Test No. 4CMB-1

Occupant Compartment Deformation Index (OCDI)

Test No. 4CMB-1
Vehicle Type: 2002 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

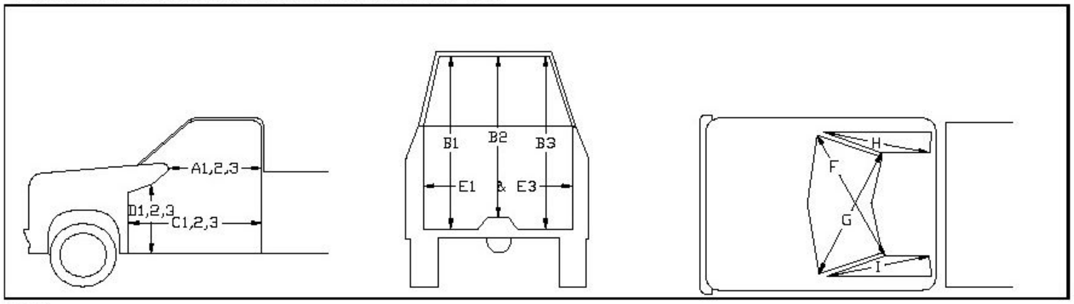
G = distance between the lower edge of left window and the upper edge of right window

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	54.75	54.75	0.00	0.00	0
A2	50.25	50.00	-0.25	-0.50	0
A3	56.25	56.25	0.00	0.00	0
B1	47.25	47.25	0.00	0.00	0
B2	42.25	42.50	0.25	0.59	0
B3	48.00	48.00	0.00	0.00	0
C1	66.25	66.50	0.25	0.38	0
C2	46.50	46.50	0.00	0.00	0
C3	63.00	63.00	0.00	0.00	0
D1	23.00	23.00	0.00	0.00	0
D2	13.25	13.25	0.00	0.00	0
D3	23.00	23.00	0.00	0.00	0
E1	66.00	66.00	0.00	0.00	0
E3	65.00	64.75	-0.25	-0.38	0
F	56.25	56.50	0.25	0.44	0
G	56.00	56.00	0.00	0.00	0
H	37.00	37.25	0.25	0.68	0
I	37.50	37.25	-0.25	-0.67	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 F-3. Occupant Compartment Deformation Index, Test No. 4CMB-1

VEHICLE PRE/POST CRUSH INFO

TEST: 4CMB-2
VEHICLE: 2002 Kia Rio Sedan

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	26	-20	-0.25	23	-18.75	-0.75	-3	1.25	-0.5
2	29	-15	-1	26.5	-13.25	0	-2.5	1.75	1
3	31	-6.75	-1.5	30.25	-6.5	-1.25	-0.75	0.25	0.25
4	31.25	-2	0	31.5	-2	0	0.25	0	0
5	23.75	-20	-5.5	22	-19	-4.75	-1.75	1	0.75
6	27.5	-9.75	-6.5	27.75	-8.75	-6.25	0.25	1	0.25
7	27.5	-3.25	-7	27.5	-2.75	-6.75	0	0.5	0.25
8	28	-0.25	-6.5	28	-0.5	-6.5	0	-0.25	0
9	19.75	-19.5	-9	19.25	-18.75	-9.25	-0.5	0.75	-0.25
10	20.75	-7.25	-9.5	20.75	-7.25	-9.25	0	0	0.25
11	20.5	-1.75	-10	20.5	-1	-10	0	0.75	0
12	18	0.25	-9.75	17.75	1	-9.75	-0.25	0.75	0
13	14.25	-20.25	-8.5	14.5	-19.5	-8.75	0.25	0.75	-0.25
14	14.5	-10.25	-9	14.5	-9.75	-9	0	0.5	0
15	14.25	-1.5	-9.5	14.25	-1.5	-9.5	0	0	0
16	11.75	0	-9.25	11.75	0.5	-9.5	0	0.5	-0.25
17	11.5	4	-5	11.5	4	-5.25	0	0	-0.25
18	9.25	-20.5	-8.25	9.25	-20.25	-8.25	0	0.25	0
19	9.5	-9.75	-8.5	9.25	-9.25	-8.75	-0.25	0.5	-0.25
20	10	-1.75	-9.25	10	-1.5	-9.5	0	0.25	-0.25
21	8.25	6	-5	8.5	6.25	-5	0.25	0.25	0
22	5	-25	-3.5	5	-25	-3.75	0	0	-0.25
23	1.5	-20.25	-4.75	1.5	-20.25	-5	0	0	-0.25
24	1.25	-13	-5.75	1.25	-13	-6	0	0	-0.25
25	1.25	-6	-6	1.25	-6	-6.25	0	0	-0.25
26	1.25	0.75	-5.25	1.25	1	-5.25	0	0.25	0
27	1.25	6.75	-4.5	1.25	7	-4.5	0	0.25	0
28							0	0	0
29									
30									

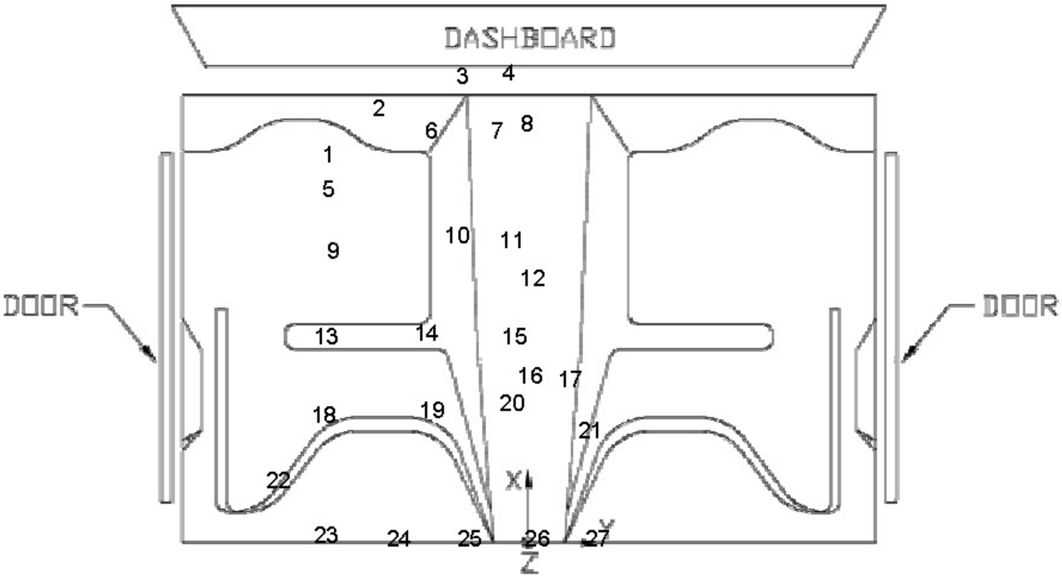


Figure F-4. Vehicle Crush Info, Test No. 4CMB-2

Occupant Compartment Deformation Index (OCDI)

Test No. 4CMB-2
Vehicle Type: 2002 Kia Rio Sedan

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

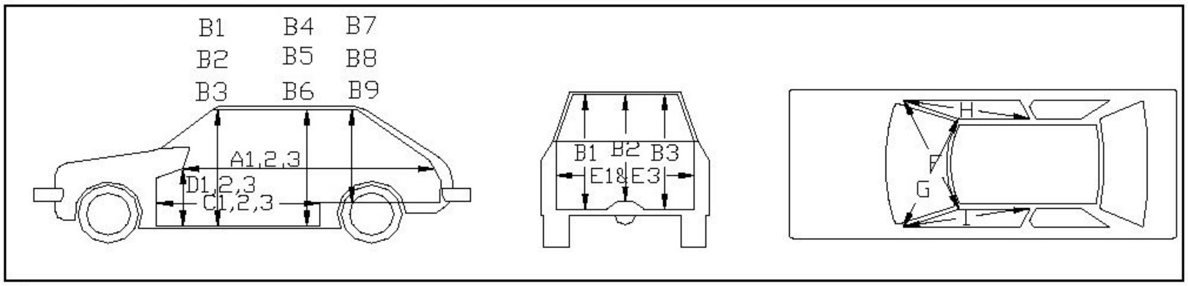
G = distance between the lower edge of left window and the upper edge of right window

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	48.75	47.50	-1.25	-2.56	0
A2	45.25	44.75	-0.50	-1.10	0
A3	47.25	47.75	0.50	1.06	0
B1	41.00	41.50	0.50	1.22	0
B2	37.50	37.50	0.00	0.00	0
B3	40.75	41.00	0.25	0.61	0
C1	55.00	52.00	-3.00	-5.45	1
C2	60.25	60.25	0.00	0.00	0
C3	55.25	55.00	-0.25	-0.45	0
D1	20.00	20.00	0.00	0.00	0
D2	18.75	17.50	-1.25	-6.67	1
D3	22.50	22.50	0.00	0.00	0
E1	52.75	52.50	-0.25	-0.47	0
E3	53.50	53.50	0.00	0.00	0
F	44.00	44.00	0.00	0.00	0
G	44.00	42.75	-1.25	-2.84	0
H	38.50	38.50	0.00	0.00	0
I	38.00	38.00	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	1	1	0	0	0	0	0

Figure F-5. Occupant Compartment Deformation Index, Test No. 4CMB-2

VEHICLE PRE/POST CRUSH INFO

TEST: 4CMB-3
VEHICLE: 2002 Kia Rio Sedan

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	26.25	-25	0	22	-22.5	1.75	-4.25	2.5	1.75
2	29	-19.5	-2	27.75	-18.5	-1	-1.25	1	1
3	31.5	-14	-2.75	30.25	-13.5	-2	-1.25	0.5	0.75
4	31	-4.75	-4.5	31	-4.5	-4.25	0	0.25	0.25
5	24.25	-25	-4	21.75	-23	-2.75	-2.5	2	1.25
6	27	-19.25	-6	25.75	-18.25	-5	-1.25	1	1
7	29	-13.5	-7.25	28.75	-13	-6.25	-0.25	0.5	1
8	28.25	-4.75	-8.5	28.75	-5	-8	0.5	-0.25	0.5
9	17	-25.5	-5.5	16.75	-25.5	-5.75	-0.25	0	-0.25
10	17.75	-18.5	-10.25	17.75	-18.25	-10	0	0.25	0.25
11	17.5	-13.75	-10.5	17.25	-13.5	-10	-0.25	0.25	0.5
12	17.5	-9.5	-11.25	17.25	-9.25	-10.75	-0.25	0.25	0.5
13	16	-5	-11	16	-4.75	-11	0	0.25	0
14	12	-0.75	-7	12	-1	-7	0	-0.25	0
15	13	-25.5	-5.25	12.75	-25.5	-5.5	-0.25	0	-0.25
16	12.75	-19.5	-9.75	12.75	-19.25	-10	0	0.25	-0.25
17	13	-13.25	-10.25	12.75	-13	-10	-0.25	0.25	0.25
18	13.25	-7.25	-11	13	-7	-10.75	-0.25	0.25	0.25
19	9.75	-1	-6.75	9.5	-1	-6.75	-0.25	0	0
20	9.25	-25.5	-4.75	9.25	-25.25	-5	0	0.25	-0.25
21	10.25	-21.5	-9.5	10.5	-21.25	-9.5	0.25	0.25	0
22	10	-17	-9.5	10	-16.75	-9.5	0	0.25	0
23	10.25	-9.5	-10.75	10.25	-9.25	-10.5	0	0.25	0.25
24	7.75	-1.75	-6.75	7.75	-2	-6.5	0	-0.25	0.25
25	1	-24.25	-5	1	-24	-5.25	0	0.25	-0.25
26	1	-19	-6.25	1	-19	-6.5	0	0	-0.25
27	1	-13	-7	1	-13	-7	0	0	0
28	0.75	-4.5	-6.75	0.75	-4.5	-6.75	0	0	0
29									
30									

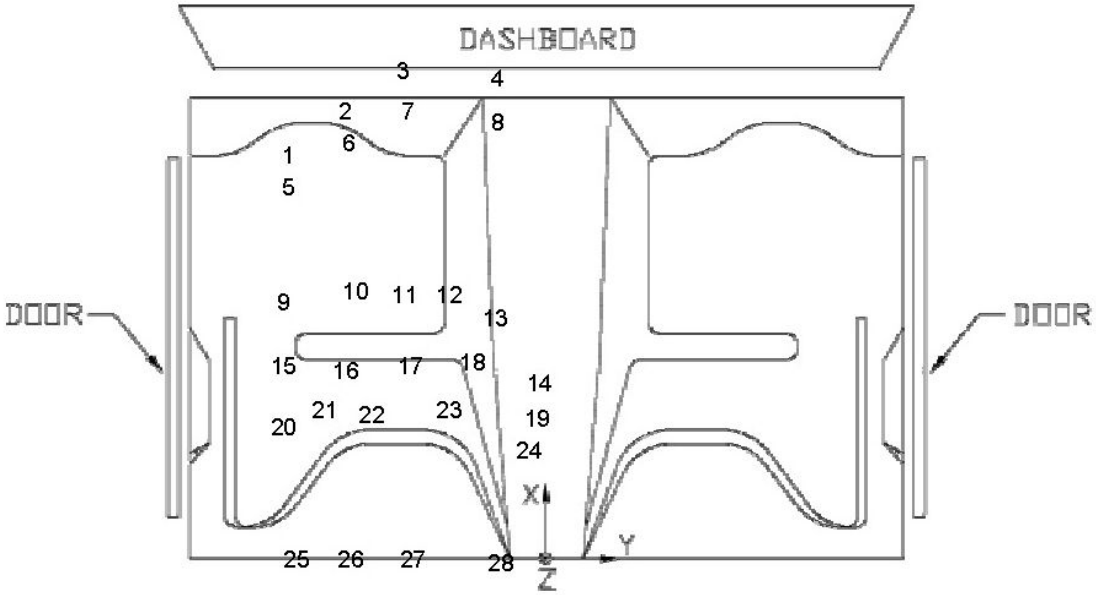


Figure F-6. Vehicle Crush Info, Test No. 4CMB-3

Occupant Compartment Deformation Index (OCDI)

Test No. 4CMB-3
Vehicle Type: 2002 Kia Rio Sedan

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

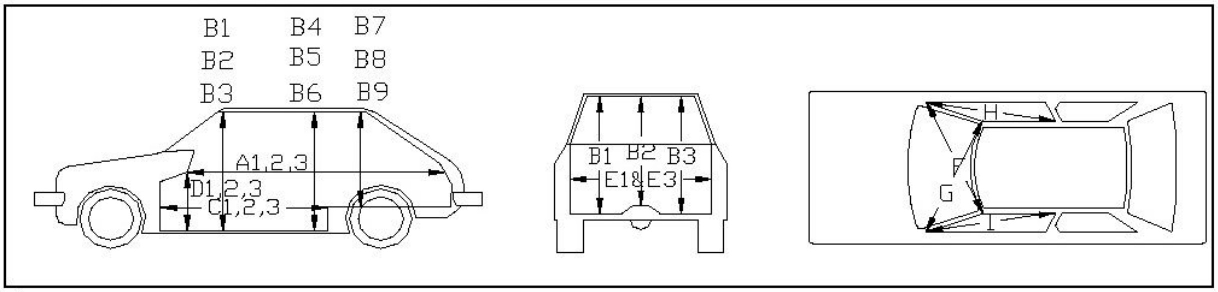
G = distance between the lower edge of left window and the upper edge of right window

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	49.50	49.00	-0.50	-1.01	0
A2	49.00	48.50	-0.50	-1.02	0
A3	50.25	50.25	0.00	0.00	0
B1	42.00	36.50	-5.50	-13.10	2
B2	37.50	36.00	-1.50	-4.00	1
B3	41.75	41.75	0.00	0.00	0
C1	60.75	59.00	-1.75	-2.88	0
C2	43.50	43.25	-0.25	-0.57	0
C3	60.50	50.00	-10.50	-17.36	2
D1	21.00	20.75	-0.25	-1.19	0
D2	19.50	19.75	0.25	1.28	0
D3	22.25	22.25	0.00	0.00	0
E1	52.75	52.50	-0.25	-0.47	0
E3	53.75	54.00	0.25	0.47	0
F	47.00	41.25	-5.75	-12.23	2
G	47.75	48.25	0.50	1.05	0
H	39.50	39.50	0.00	0.00	0
I	39.75	39.00	-0.75	-1.89	0

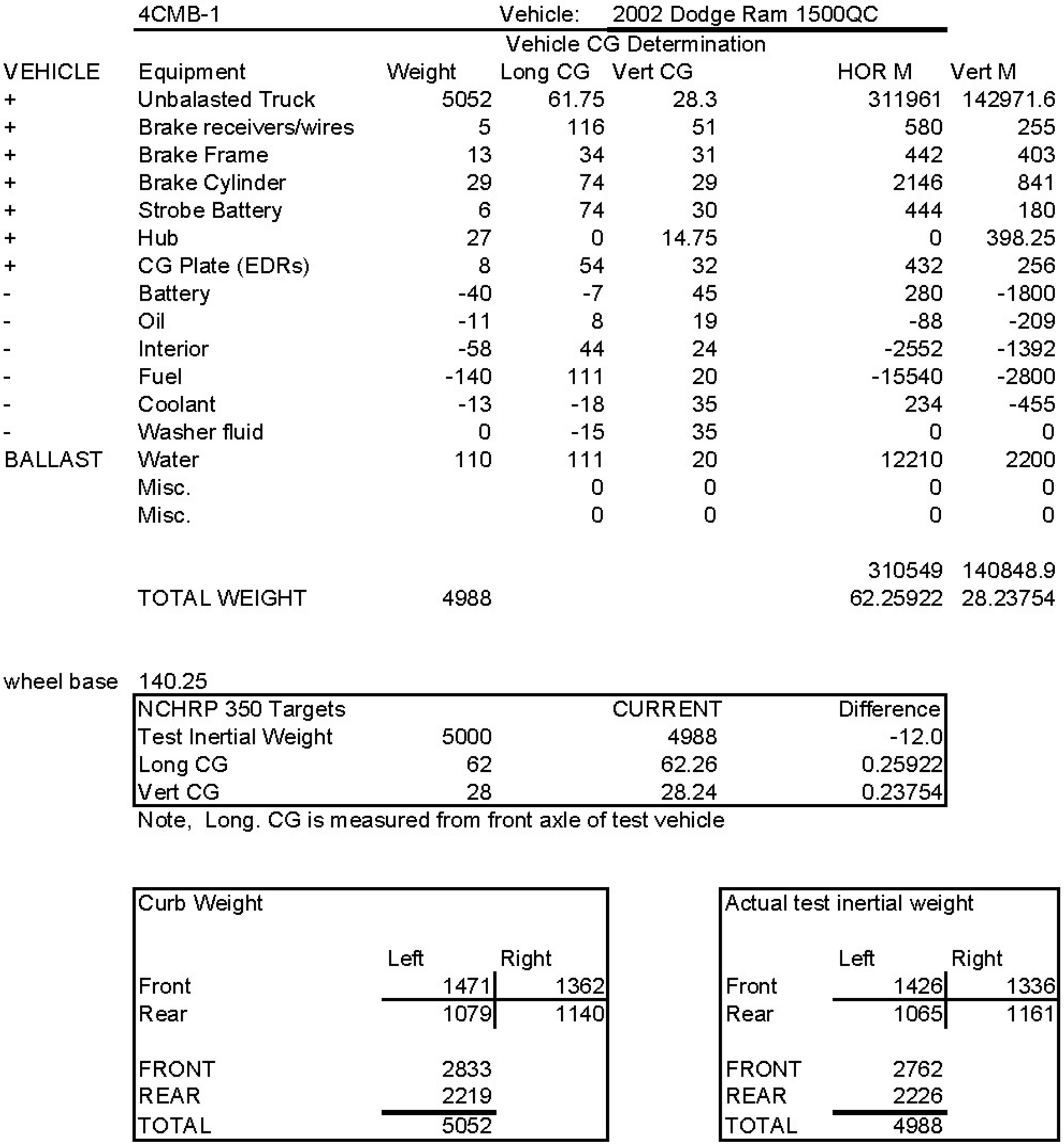
Note: Maximum sevrity index for each variable (A-I) is used for determination of final OCDI value

	XX	A	B	C	D	E	F	G	H	I
Final OCDI:	LF	0	2	2	0	0	2	0	0	0

Figure F-7. Occupant Compartment Deformation Index, Test No. 4CMB-3

APPENDIX G

Vehicle Center of Gravity Determination



4CMB-1 Vehicle: 2002 Dodge Ram 1500QC

Vehicle CG Determination

VEHICLE	Equipment	Weight	Long CG	Vert CG	HOR M	Vert M
+	Unbalasted Truck	5052	61.75	28.3	311961	142971.6
+	Brake receivers/wires	5	116	51	580	255
+	Brake Frame	13	34	31	442	403
+	Brake Cylinder	29	74	29	2146	841
+	Strobe Battery	6	74	30	444	180
+	Hub	27	0	14.75	0	398.25
+	CG Plate (EDRs)	8	54	32	432	256
-	Battery	-40	-7	45	280	-1800
-	Oil	-11	8	19	-88	-209
-	Interior	-58	44	24	-2552	-1392
-	Fuel	-140	111	20	-15540	-2800
-	Coolant	-13	-18	35	234	-455
-	Washer fluid	0	-15	35	0	0
BALLAST	Water	110	111	20	12210	2200
	Misc.		0	0	0	0
	Misc.		0	0	0	0
					310549	140848.9
	TOTAL WEIGHT	4988			62.25922	28.23754

wheel base 140.25

NCHRP 350 Targets		CURRENT	Difference
Test Inertial Weight	5000	4988	-12.0
Long CG	62	62.26	0.25922
Vert CG	28	28.24	0.23754

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

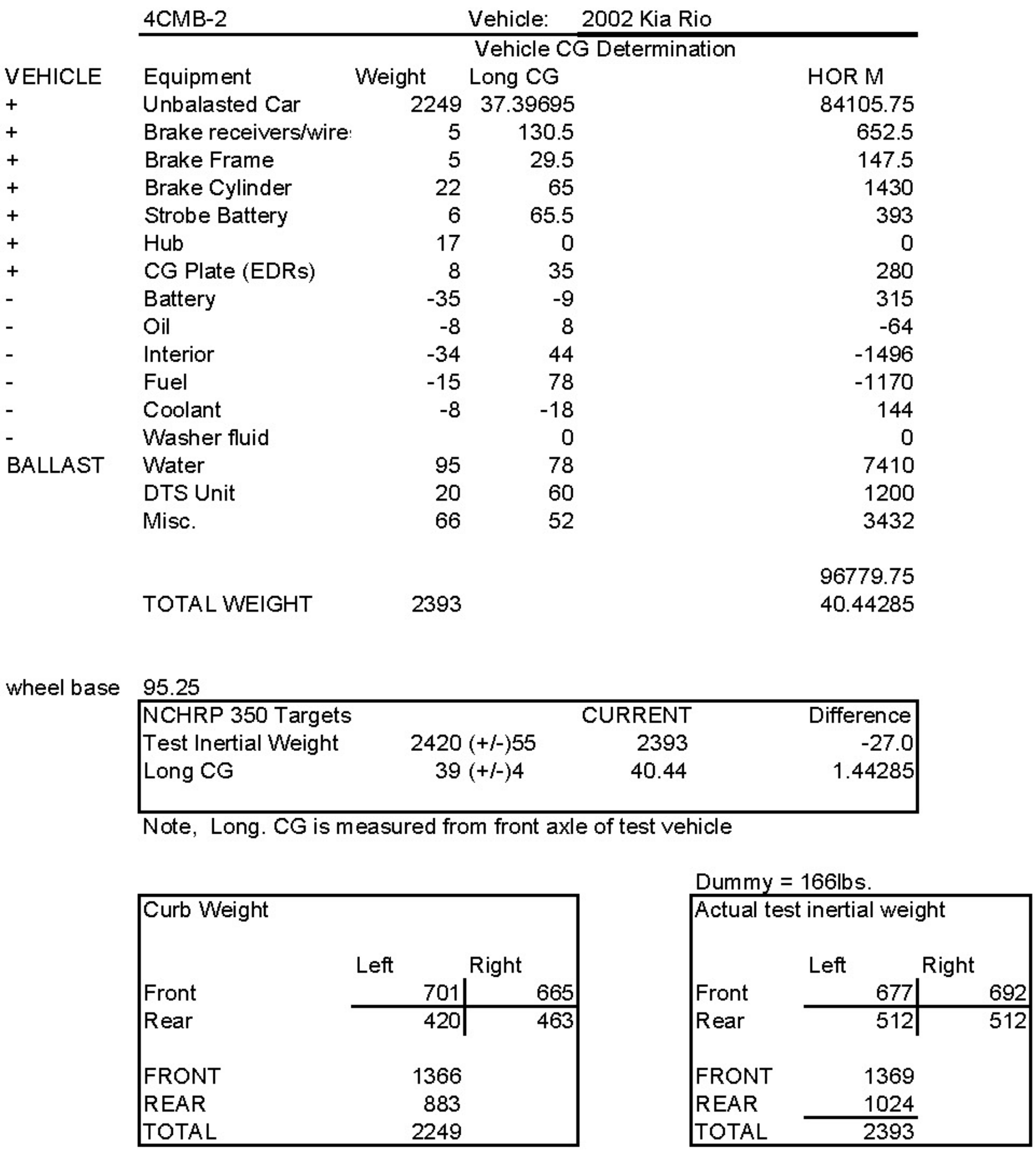
Curb Weight

	Left	Right
Front	1471	1362
Rear	1079	1140
FRONT	2833	
REAR	2219	
TOTAL	5052	

Actual test inertial weight

	Left	Right
Front	1426	1336
Rear	1065	1161
FRONT	2762	
REAR	2226	
TOTAL	4988	

Figure G-1. Vehicle Mass Distribution, Test No. 4CMB-1



4CMB-2 Vehicle: 2002 Kia Rio

Vehicle CG Determination

VEHICLE	Equipment	Weight	Long CG	HOR M
+	Unbalasted Car	2249	37.39695	84105.75
+	Brake receivers/wire	5	130.5	652.5
+	Brake Frame	5	29.5	147.5
+	Brake Cylinder	22	65	1430
+	Strobe Battery	6	65.5	393
+	Hub	17	0	0
+	CG Plate (EDRs)	8	35	280
-	Battery	-35	-9	315
-	Oil	-8	8	-64
-	Interior	-34	44	-1496
-	Fuel	-15	78	-1170
-	Coolant	-8	-18	144
-	Washer fluid		0	0
BALLAST	Water	95	78	7410
	DTS Unit	20	60	1200
	Misc.	66	52	3432
				96779.75
	TOTAL WEIGHT	2393		40.44285

wheel base 95.25

NCHRP 350 Targets		CURRENT	Difference
Test Inertial Weight	2420 (+/-)55	2393	-27.0
Long CG	39 (+/-)4	40.44	1.44285

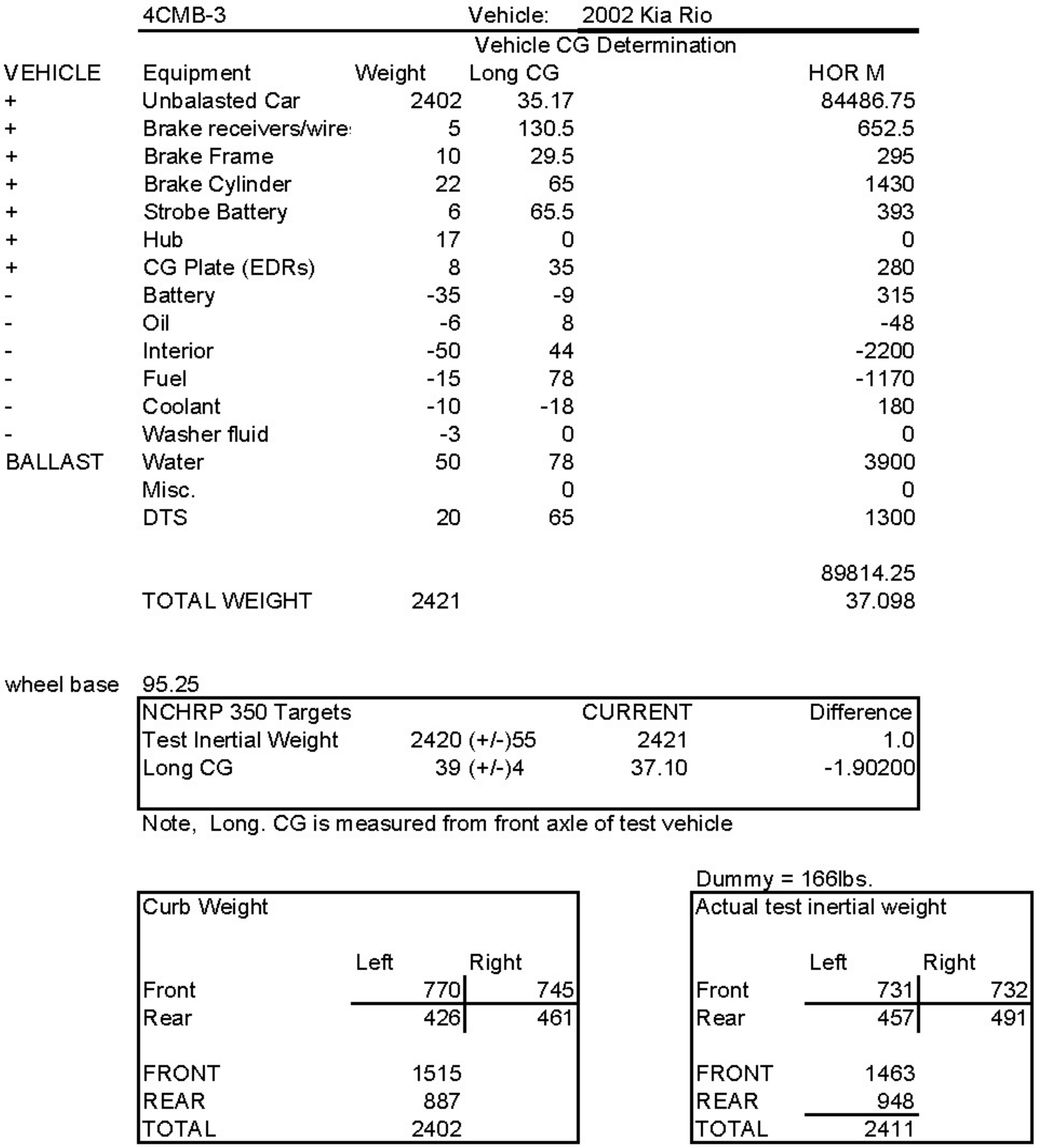
Note, Long. CG is measured from front axle of test vehicle

Curb Weight		
	Left	Right
Front	701	665
Rear	420	463
FRONT	1366	
REAR	883	
TOTAL	2249	

Dummy = 166lbs.

Actual test inertial weight		
	Left	Right
Front	677	692
Rear	512	512
FRONT	1369	
REAR	1024	
TOTAL	2393	

Figure G-2. Vehicle Mass Distribution, Test No. 4CMB-2



4CMB-3 Vehicle: 2002 Kia Rio

Vehicle CG Determination

VEHICLE	Equipment	Weight	Long CG	HOR M
+	Unbalasted Car	2402	35.17	84486.75
+	Brake receivers/wire	5	130.5	652.5
+	Brake Frame	10	29.5	295
+	Brake Cylinder	22	65	1430
+	Strobe Battery	6	65.5	393
+	Hub	17	0	0
+	CG Plate (EDRs)	8	35	280
-	Battery	-35	-9	315
-	Oil	-6	8	-48
-	Interior	-50	44	-2200
-	Fuel	-15	78	-1170
-	Coolant	-10	-18	180
-	Washer fluid	-3	0	0
BALLAST	Water	50	78	3900
	Misc.		0	0
	DTS	20	65	1300
				89814.25
	TOTAL WEIGHT	2421		37.098

wheel base 95.25

NCHRP 350 Targets		CURRENT	Difference
Test Inertial Weight	2420 (+/-)55	2421	1.0
Long CG	39 (+/-)4	37.10	-1.90200

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

Dummy = 166lbs.

Curb Weight		
	Left	Right
Front	770	745
Rear	426	461
FRONT	1515	
REAR	887	
TOTAL	2402	

Actual test inertial weight		
	Left	Right
Front	731	732
Rear	457	491
FRONT	1463	
REAR	948	
TOTAL	2411	

Figure G-3. Vehicle Mass Distribution, Test No. 4CMB-3

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