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PLACEMENT OF BREAKAWAY LIGHT POLES LOCATED DIRECTLY BEHIND MIDWEST GUARDRAIL SYSTEM (MGS)

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16. Abstract

Light poles are commonly installed along highways to provide proper illumination in critical areas. When placing utility poles in close proximity to guardrail, the poles may affect the guardrail's ability to safely contain and redirect vehicles by creating unwanted stiffening or hinging of the barrier system around the pole. The pole may also present a snag obstacle to impacting vehicles and induce vehicle instabilities. In this study, the lateral offset between the face of the light pole and the back of the post was evaluated. The minimum safe lateral offset was determined to be 20 in. (508 mm) through crash testing and computer simulation with non-linear finite element analysis. Two crash tests were conducted according to the American Association of State Highway Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (MASH) Test Level 3 (TL-3) impact safety criteria. In test no. ILT-1, a 5,000-lb (2,268-kg) pickup truck impacted the combination Midwest Guardrail System (MGS) laterally offset 20 in. (508 mm) in front of a luminaire pole at a speed of 62.6 mph (100.7 km/h) and an angle of 25.2 degrees. In test no. ILT-1, the pickup truck was captured and safely redirected while impacting the luminaire pole and disengaging it at base. In test no. ILT-2, a 2,420-lb (1,098-kg) small car impacted the MGS laterally offset 20 in. (508 mm) in front of a luminaire pole at a speed of 62.7 mph (100.9 km/h) and an angle 24.8 degrees. In test no. ILT-2, the car was safely contained and redirected while minimally contacting the luminaire pole. The MGS provided acceptable safety performance under MASH TL-3 when critically impacted by a pickup truck and a small car. Thus, a minimum lateral offset of 20 in. (508 mm) between the back of the post and front face of the breakaway pole was sufficient to assure a safe performance of the MGS during vehicle impacts without undesired interaction with the pole. Accordingly, guidance was provided for safe pole placement behind the MGS.

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This report was completed with funding from the Illinois Tollway. The contents of this report reflect the views and opinions of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Tollway, the Illinois Department of Transportation, or the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

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

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Mr. Scott Rosenbaugh, Research Engineer.

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1 INTRODUCTION

1.1 Problem Statement

Obstacles, including light poles, typically should not be placed within the working width of a guardrail system. There are many instances where it is desirable to install light poles directly behind W-beam guardrail in order to provide adequate illumination along roadways. However, there are several concerns with placing light poles in close proximity to guardrail that may affect its ability to safely contain and redirect vehicles. First, interaction between a deflected guardrail system and a pole may create stiffening or hinging of the barrier system about the pole, which may cause pocketing and increased loading to the guardrail system. Second, impacting vehicles may snag on the pole, which could increase vehicle decelerations and instabilities. While the use of breakaway light poles may mitigate these concerns to some degree, the interaction between a guardrail system and a closely-positioned light pole requires further investigation.

The Illinois Tollway and the Illinois Department of Transportation have been using the Midwest Guardrail System (MGS) as their standard W-beam guardrail system for 10 years. The MGS has a 31-in. (787-mm) top rail mounting height, 75-in. (1,905-mm) post spacing, W6x9 steel posts, 12-in. (305-mm) blockout depth, and midspan rail splices. The MGS has been successfully full-scale crash tested with a 2,425-lb (1,100-kg) small car (designated 1100C) and a 5,000-lb (2,268-kg) pickup truck (designated 2270P) according to the *Manual for Assessing Safety Hardware* (MASH) Test Level 3 (TL-3) criteria [1-3].

The current Illinois Tollway standard denotes pole placement no closer to the guardrail post than 28 in. (711 mm) for the standard 6-ft 3-in. (1,905-mm) post spacing MGS, 23 in. (584 mm) for the half-post spacing MGS, and 14 in. (356 mm) for the quarter-post spacing MGS. The barrier clearance distance is defined as the perpendicular distance from a line connecting the back of guardrail posts to the near face of an obstacle, as shown in Figure 1.

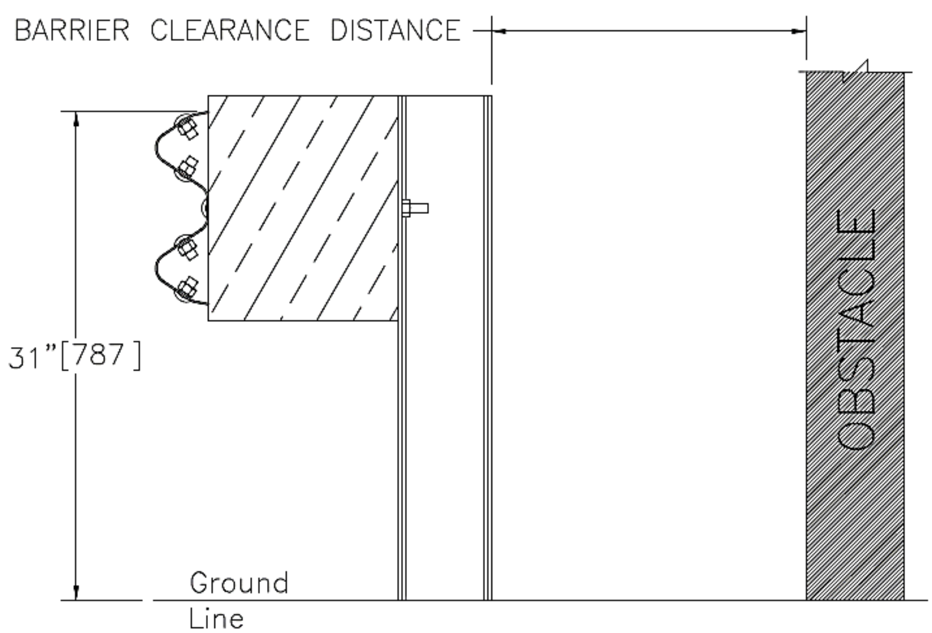


Figure 1. Barrier Clearance Distance

In order to accommodate poles positioned closer than the current minimum barrier clearance distance, an investigation should be conducted to determine safe placement of the light pole with respect to the guardrail system.

1.2 Research Objective

The objectives of this research project were to determine the minimum lateral offset of the light pole with respect to the standard guardrail system with 6 ft – 3 in. (1.9 m) post spacing and develop guidance for the safe placement of the Illinois Tollway standard light pole behind the MGS. The guardrail offset away from the light pole was to be tested and evaluated according to the Test Level 3 (TL-3) safety performance criteria in the *Manual for Assessing Safety Hardware* (MASH) [3].

1.3 Scope

The research objectives were achieved through the completion of several tasks in two phases. In phase I, a literature review was performed on previous testing of W-beam guardrail systems (including MGS) with and without poles to evaluate dynamic deflections, working widths, deflected barrier lengths, as well as vehicle pocketing and snagging risks. In addition, a review was performed on relevant breakaway light pole systems specified by the Illinois Tollway.

Second, a combination of LS-DYNA computer simulation [4], engineering analysis, and experience with MGS crash testing was utilized to select a minimum lateral pole offset for the MGS system with the standard post spacing as well as determine the critical impact points (CIPs) for full-scale crash testing with 2270P and 1100C vehicles.

In phase II, two full-scale crash tests were performed on the MGS with nearby light poles, as recommended in phase I. The first crash test utilized a 5,000-lb (2,268-kg) pickup truck impacting the MGS with pole at a speed of 62.1 mph (100 km/h) and an angle of 25 degrees. In the second crash test, a 2,425-lb (1,100-kg) small car impacted the MGS with pole at a speed of 62.1 mph (100 km/h) and an angle of 25 degrees.

Following the full-scale crash testing, the safety performance of the MGS with a minimum lateral offset away from a pole was evaluated. Implementation guidance was provided regarding the safety performance of the MGS with a nearby Illinois Tollway light pole. A summary report of the research project with respect to the as-tested light pole and the barrier combination was provided.

2 LITERATURE REVIEW

2.1 MGS Crash Testing and Computer Simulation

2.1.1 Dynamic Deflection and Working Width

A study was conducted by Midwest Roadside Safety Facility (MwRSF) to compile past testing of Midwest Guardrail System (MGS) at Test Level 3 (TL-3). The study also involved numerous simulations on the MGS at TL-1, TL-2, or TL-3 [5]. Working widths and dynamic deflections were found for each test level regarding the standard MGS and MGS with curb. Only simulations involving standard MGS at TL-3 were considered for the purpose of this project.

Maximum dynamic deflection of the system is a measure of the maximum distance any individual component deflected backward when compared to its undeflected position. Working width is defined as the farthest distance the barrier or vehicle extended laterally during impact, as measured from the original, undeformed front face of the guardrail. Working widths are always greater than or equal to dynamic deflections.

For TL-3, a minimum working width of 60.3 in. (1,532 mm) was determined based on the largest MGS working width observed in full-scale crash testing [5, 6]. If lateral offsets between guardrail systems and obstacles are reduced, the impacting vehicle may engage or interact with the shielded obstacle. States must determine if the benefits associated with decreased guardrail-to-obstacle offset and increased guardrail placement away from road outweigh the potential consequences of a vehicle engaging an obstacle while being redirected by the rail [5]. Currently, the Illinois Tollway uses a minimum barrier clearance distance of 28 in. (711 mm) for guardrail with standard post spacing. The current Illinois Tollway practice for minimum clearance distance of poles behind MGS with different post spacing is shown in Table 1. The Illinois Tollway bases these lateral offsets on the guardrail placement recommendations for shielding rigid obstacles found in the research report by Polivka et al. [7]. According to this study, the minimum recommended distances the MGS should be placed away from a rigid obstacle are 49 in. (1.25 m), 44 in. (1.12 m), and 35 in. (0.9 m) for the standard-, half-, and quarter-post spacing designs, respectively, as measured from the front face of the W-beam rail to the front face of the obstacle. Thus, the recommended distances from the back of the post to the front face of post would be 28 in. (711 mm), 23 in. (584 mm), and 14 in. (356 mm) for the standard-, half-, and quarter-post spacing designs, respectively.

Table 1. Illinois Tollway Barrier Clearance Distance

Guardrail System MGS with 31-in. (787-mm) Top Rail Height and 12-in. (305-mm) Deep Blockouts	**Post Spacing**	**Minimum Clearance Distance in. (mm)**
Type A - Standard	6 ft – 3 in. (1.9 m)	28 (711)
Type B - ½ Post Spacing	3 ft – 1½ in. (0.95 m)	23 (584)
Type C - ¼ Post Spacing	1 ft – 6¾ in. (0.48 m)	14 (356)

2.1.2 Guardrail Deflection Analysis

A report compiling guardrail tests from various organizations was completed at the Texas Transportation Institute (TTI) [8]. Various guardrail configurations were included and those with 31-in. (787-mm) top mounting height and 75 in. (1,905 mm) post spacing are summarized in Table 2 for test no. 3-11 and Table 3 for test no. 3-10. Many variations of the MGS have been tested, but only those with standard MGS configurations were referenced for this project. The MGS tested with douglas fir, ponderosa pine, southern yellow pine, and white pine posts were also included. In addition, guardrail configurations using alternate blockouts or no blockouts were included. In addition, TTI performed a full scale crash test on a W-beam system similar to the MGS [9]. The single difference between the standard MGS and this test was the blockout depth was reduced from 12 in. (305 mm) to 8 in. (203 mm). One crash test, test no. 420020-5, was performed at test designation no. 3-10 and the guardrail performed adequately. This test is also included in Table 3.

For test designation no. 3-11, the maximum, average, and minimum dynamic deflections were 60.2 in. (1,529 mm), 44.5 in. (1,131 mm), and 34.1 in. (866 mm), respectively. The maximum, average, and minimum working widths were 60.3 in. (1,532 mm), 51.3 in. (1,302 mm), and 43.2 in. (1,097 mm), respectively. For test designation no. 3-10 the maximum, average, and minimum dynamic deflections were 35.9 in. (912 mm), 26.6 in. (677 mm), and 17.4 in. (442 mm), respectively. The maximum, average, and minimum working widths were 48.3 in. (1,227 mm), 38.3 in. (973 mm), and 28.6 in. (726 mm), respectively.

Table 2. Guardrail Testing under Test Designation No. 3-11

Testing Agency	Test Number	Testing Criteria	Dynamic Deflection in. (mm)	Working Width in. (mm)
MwRSF	NPG-4	350	43.1 (1,094)	49.6 (1,260)
MwRSF	2214MG-1	MASH	57.0 (1,447)	58.6 (1,489)
MwRSF	2214MG-2	MASH	43.9 (1,114)	48.6 (1,234)
MwRSF	MGSMIN-1	MASH	42.2 (1,072)	48.8 (1,240)
MwRSF	MGSDF-1*	NCHRP 350 [10]	60.2 (1,529)	60.3 (1,530)
MwRSF	MGSPP-1*	NCHRP 350	37.6 (956)	48.6 (1,234)
MwRSF	MGSWP-1*	MASH	46.3 (1,176)	58.4 (1,483)
MwRSF	MGSSYP-1*	MASH	40.0 (1,016)	53.8 (1,367)
MwRSF	MGSNB-1**	MASH	34.1 (867)	43.2 (1,097)
TTI	220570-2**	MASH	40.9 (1,040)	44.0 (1,119)

*Guardrail with alternate posts and/or blockouts.
**Guardrail with no blockouts.

Table 3. Guardrail Testing under Test Designation No. 3-10

Testing Agency	Test Number	Testing Criteria	Dynamic Deflection in. (mm)	Working Width in. (mm)
MwRSF	NPG-1	NCHRP 350	17.4 (441)	40.3 (1,022)
MwRSF	2214MG-3	MASH	35.9 (913)	48.3 (1,227)
MwRSF	MGSSYP-2*	MASH	22.2 (564)	39.7 (1,008)
MwRSF	MGSRF-3*	MASH	NA	38.4 (975)
MwRSF	MGSNB-2**	MASH	29.1 (740)	34.5 (877)
TTI	420020-5	MASH	28.6 (725)	28.6 (725)

*Guardrail with alternate posts and/or blockouts.
**Guardrail with no blockouts.

2.2 Light Pole Testing Details

The light pole used by the Illinois Tollway is a standard 50 ft (15.2 m) tall pole with a 15-ft (4.6-m) mast arm, as manufactured by Hapco and Valmont. The pole has a 10-in. (254-mm) base diameter and a 6-in. (152-mm) top diameter. The pole is designed to meet the 2009 American Association of State Highway Transportation Officials (AASHTO) *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* [11].

The light pole is mounted on a CS370 transformer base, also manufactured by Valmont. The 9-in. (229-mm) tall breakaway transformer base was evaluated by Southwest Research Institute (SwRI) in 1990 according to AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* [11]. In June 1990, the light pole bases were impacted at 20 mph (32.2 km/h) with a 1,800-lb (816-kg) pendulum. The pendulum was fitted with a 10-stage crushable nose, which simulated the stiffness and energy dissipation of a 1979 Volkswagen Rabbit. The results of the tests are shown in Table 4. Test-13 and Test-14 had calculated changes in velocity greater than the FHWA requirement of 16 feet per second, but they were accepted due to the tendency to overestimate the calculated 60 mph values.

Both base designs received Federal Highway Administration (FHWA) aid reimbursement eligibility letters [12-14]. A similar base, the CS300, was also tested and received eligibility. All tested bases were manufactured by Akron, but three letters were required for the three distribution firms – Feralux, Akron Foundry, and Pole Lite. The two base designs are shown in Figures 2 and 3. The CS300 design is identical to the TB-AF-6-9 and the Pole Lite F-1300 designs, with the only difference being the distribution firm. The same is true for the CS370 design regarding the TB-AF-5-9 and Pole Lite F-1302 designs.

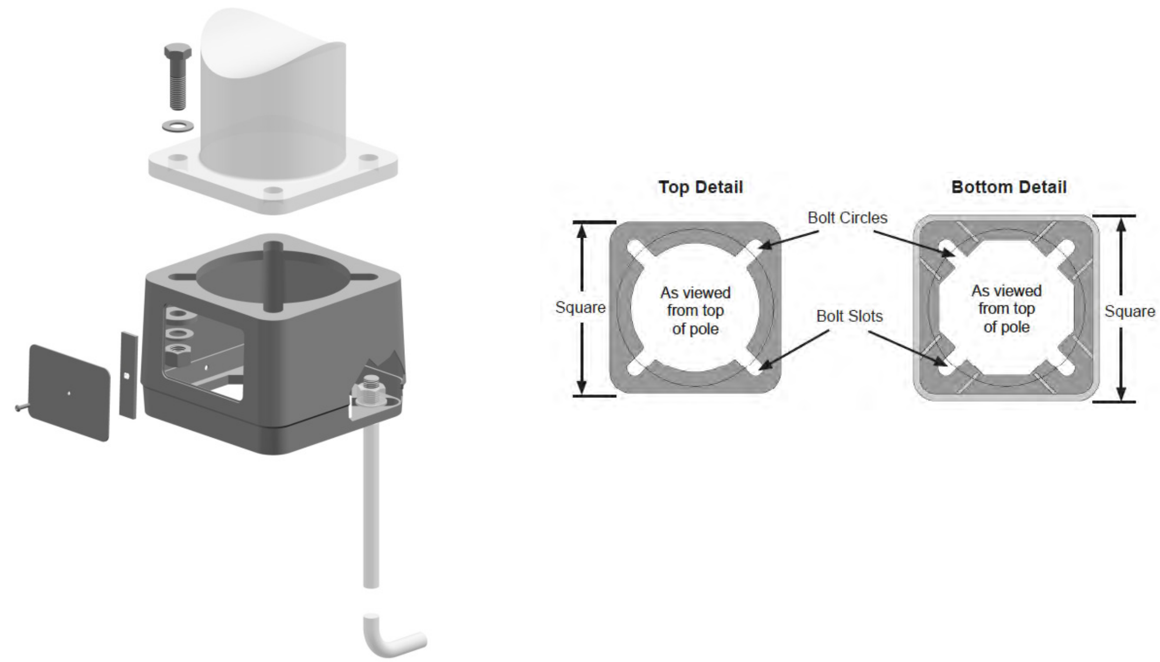


Figure 2. Feralux CS300 Light Pole Base

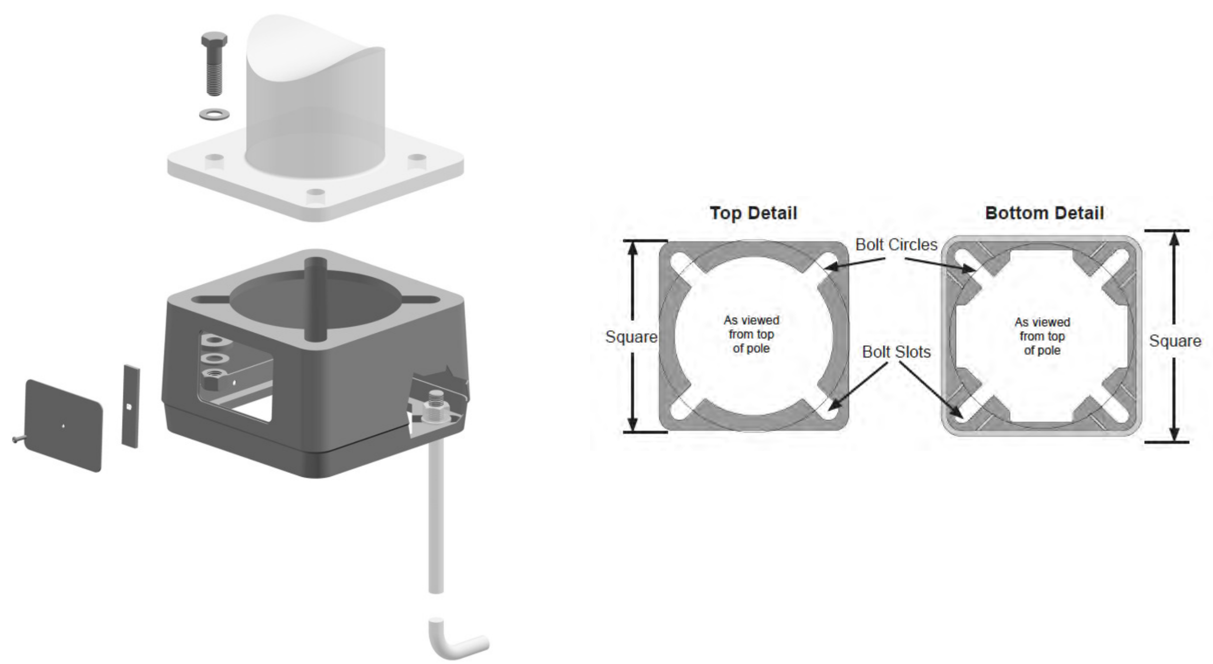


Figure 3. Feralux CS370 Light Pole Base

Table 4. Feralux Light Pole Base Testing

Test No.	Base	Pole Type	Pole Weight lb (kg)	Test Delta V at 20 mph fps (m/s)	Calculated Delta V at 60 mph fps (m/s)
Test-AF-1	Feralux CS-300	Aluminum	413 (187)	3.4 (1.0)	6.4 (2.0)
Test-1	Pole Lite F-1300 or TB-AF-6-9	Aluminum	413 (187)	4.7 (1.4)	6.8 (2.1)
Test-2	Feralux CS-300	Steel	777 (352)	5.3 (1.6)	11.1 (3.4)
Test-10	Pole Lite F-1300 or TB-AF-6-9	Steel	777 (352)	5.0 (1.5)	11.0 (3.4)
Test-11	Pole Lite F-1300 or TB-AF-6-9	Aluminum	442 (191)	4.9 (1.5)	7.0 (2.1)
Test-12	TB3-AF-1517-17 I.W.	Steel	955 (433)	7.9 (2.4)	17.1 (5.2)
Test-13	Feralux CS-370	Steel	955 (433)	6.6 (2.0)	16.5 (5.0)
Test-14	Pole Lite F-1302 or TB-AF-5-9	Steel	955 (433)	7.6 (2.3)	16.8 (5.1)
Test-15	Feralux CS-370	Aluminum	591 (268)	6.9 (2.1)	10.5 (3.2)
Test-16	Pole Lite F-1302 or TB-AF-5-9	Aluminum	591 (268)	5.8 (1.8)	10.1 (3.1)
Test-17	Feralux CS-300	Aluminum	442 (191)	4.5 (1.4)	6.9 (2.1)

2.3 Related Research

2.3.1 Light Pole and Guardrail

Breakaway poles are required on high-speed highways by the FHWA. In certain situations, guardrail systems will be placed in front of light poles. In 1994, guardrail and light pole systems were crash tested in Ohio using the standard Type 5 guardrail and either the Type AT-A or Type AT-X light pole base [15]. The Ohio Type 5 guardrail consisted of 7-in. (178-mm) diameter, 6-ft (1.83-m) long pine wood posts and 6-in. (152-mm) x 8-in. (203-mm) x 14-in. (356-mm) oak wood blockouts. The blockouts were contoured to fit the round posts. Posts were spaced 6 ft – 3 in. (1,905 mm) on center and embedded 42 in. (1,067 mm) into the soil. The guardrail had a top mounting height of 27 in. (686 mm). A 28-ft (8.54-m) tall steel light pole was selected and evaluated for this project. The GE Model M-400R2 luminaire was mounted on a 15-ft (4.57-m) arm with a 3-ft (914-mm) upsweep, as shown in Figure 4.

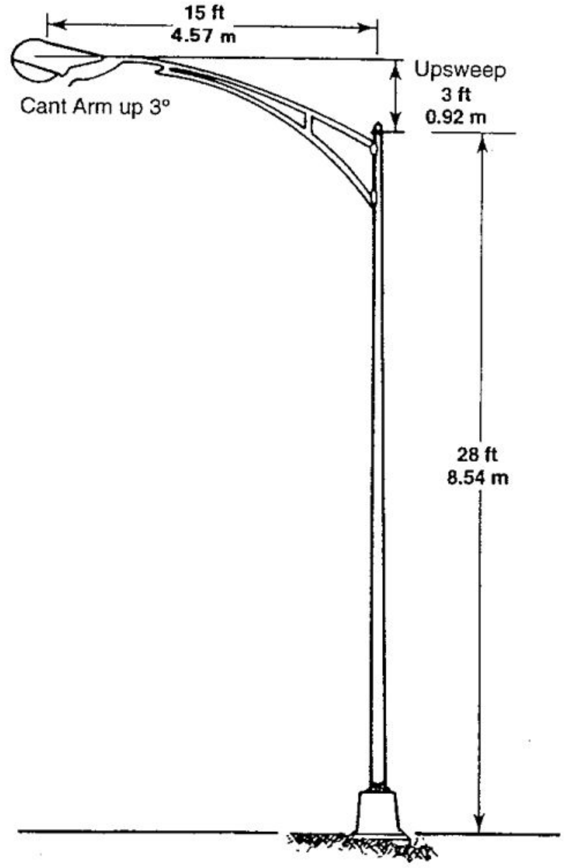
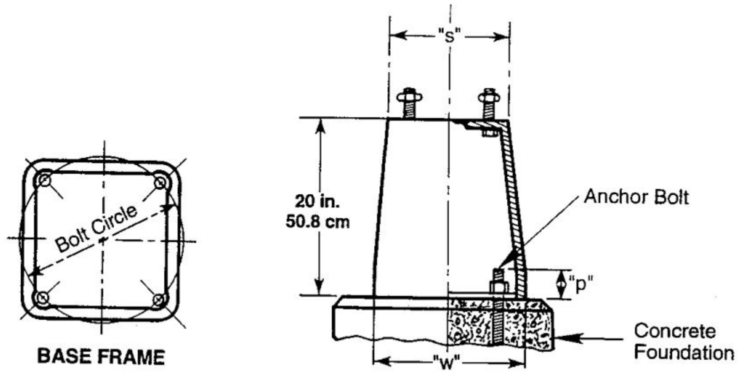


Figure 4. Ohio Study - GE Model M-400R2 Light Pole

Two aluminum base designs were utilized, and the dimensions of each differed. Type AT-A had a base width of $16^3/_8$ in. (416 mm) and tapered to 13 in. (330 mm) at the top, and Type AT-X had a 14-in. (356-mm) wide base and tapered to 13 in. (330 mm) at the top, as shown in Figure 5. The sizes of the bases resulted in the Type AT-A being placed 18 in. (457 mm) behind the back of the guardrail, and the Type AT-X placed 6 in. (152 mm) behind the back of the guardrail. A total of six tests were completed, four of which included light poles. The placement of the light poles along the guardrail was chosen based on either location of maximum guardrail deflection or highest kinetic energy of the impactor. The results of the six tests are shown in Table 5.



ALUMINUM TRANSFORMER BASES				
Type	"P"	"S"	"W"	Bolt Circle
AT-A	11.43 cm (4-1/2 inches)	33.02 cm (13 inches)	41.59 cm (16-3/8 inches)	38.10 cm (15 inches)
AT-C	11.43 cm (4-1/2 inches)	37.15 cm (14-5/8 inches)	43.82 cm (17-1/4 inches)	43.82 cm (17-1/4 inches)
AT-X	11.43 cm (4-1/2 inches)	33.02 cm (13 inches)	35.56 cm (14 inches)	31.75 cm (12-1/2 inches)

Figure 5. Ohio Study - Light Pole Bases

Table 5. Ohio Guardrail and Light Pole System Results

Test No.	Test Designation	Light Pole Base	Light Pole Distance from Impact ft (m)	Dynamic Deflection in. (mm)	Occupant Risk Collected	Pole Impacted by Vehicle (Snagging)
1	3-11	None	-	59.8 (1,518)	Yes	-
2	3-11	Type X	18¾ (5.72)	40.2 (1,021)	No	Yes
3	3-11	Type X	6 (1.83)	47.3 (1,201)	No	No
4	3-11	Type A	6¼ (1.91)	53.9 (1,369)	Yes	No
5	3-10	None	-	12.6 (320)	Yes	-
6	3-10	Type X	6¼ (1.91)	11.0 (280)	Yes	Yes

Test no. 1 was performed without a light pole to determine a baseline for the Type 5 guardrail under test designation no. 3-11. The guardrail was impacted at 60 mph (96.6 km/h) at 25.0 degrees. The exit angle was 10 degrees, and the occupant risk parameters were below the NCHRP Report No. 350 limit values.

Test no. 2 incorporated the type "X" base design, which placed the light pole 6 in. (152 mm) behind the guardrail. The base was located 18¾ ft (5.72 m) downstream from the intended impact point, because test no. 1 indicated this location would have the highest guardrail deflection. The guardrail system was impacted at 59.0 mph (95 km/h) at 24.6 degrees. Contact marks from the vehicle were found on the light pole. The pole did not break away, but it constrained the guardrail deflections, which resulted in an exit angle of 17.9 degrees and exceeded the evaluation criteria limit. Occupant risk values were not acquired due to an on-board computer malfunction.

Test no. 3 also used the type "X" base design, and the pole was positioned 6 in. (152 mm) behind the guardrail and 6 ft (1.83 m) downstream from the impact location, which was selected due to the high kinetic energy of the impactor at this point. The guardrail system was impacted at 60 mph (96.5 km/h) at 27.3 degrees. The light pole broke away, and the transformer base fractured. The guardrail deflections were less than when no light pole was present, and the exit angle was 25.4 degrees, which was greater than the allowable limit. Furthermore, vehicle damage was greater in test no. 3 than test no. 2, indicating that break away of the light pole did not correlate with reduced vehicle damage. The on-board computer malfunctioned and occupant risk values were not acquired.

Test no. 4 evaluated the "A" base design, which placed the light pole 18 in. (457 mm) behind the guardrail. The base was located 6ft – 3 in. (1,905 mm) downstream from the intended impact point. The guardrail system was impacted at 58.0 mph (93.3 km/h) at 26.7 degrees. The pole broke away, and the guardrail deflections were similar to when no light pole was present. The exit angle was 17.2 degrees, which was greater than the allowable limit. The light pole base performed as designed and fractured near the attachment lugs. Damage to the vehicle in test no. 4 was greater than the damage from test no. 3, even though the light pole was placed farther behind the guardrail. Occupant risk values for this test were below the allowable values in NCHRP Report No. 350.

Test no. 5 was performed without a light pole to determine a baseline for the Type 5 guardrail under test designation no. 3-10. The guardrail was impacted at 57.5 mph (92.5 km/h) at 20.7 degrees. The exit angle of 7.9 degrees and the occupant risk values were within the NCHRP Report No. 350 limits.

Test no. 6 used the "X" base design, and the pole was positioned 6 in. (152 mm) behind the guardrail and 6 ft – 3 in. (1.9 m) downstream from the intended impact location. The guardrail system was impacted at 64.9 mph (104.5 km/h) at 21.4 degrees. The light pole did not break away, and the base had an indentation on the impact side, likely caused by the left-front wheel. Again, the guardrail deflections in this test were less than when no light pole was present. The exit angle of 9.5 degrees and the occupant risk values were within the limits in NCHRP Report No. 350.

The primary objective was to determine if vehicle snag occurred on the poles during impact with the guardrail. The research report noted that the presence of light poles did not cause snagging of the test vehicle, and no change in the placement of light poles behind the guardrail was recommended. However, snagging was only noted if the vehicle contacted the pole and rapidly decelerated. Other contact between the test vehicles and the pole was observed, but it was not classified as snagging.

Furthermore, the effect of the light pole on guardrail performance was also evaluated. Unfortunately, it was difficult to make definitive conclusions based on the collected data. Impact speeds varied from 57.5 mph (92.5 km/h) to 65 mph (104.5 km/h), occupant risk factors could not be obtained from all tests, and the light pole was not critically impacted in all tests because the maximum rail deflection did not occur at the pole location. Finally, three of the four guardrail and light pole tests had exit angles greater than the 15 degrees requirement given in the NCHRP Report No. 350 [10]. These results suggest the light pole may have affected the guardrail's performance.

2.3.2 Sign Support and Guardrail

A project evaluating the safety performance of a sign support and guardrail system was completed by the Civil and Environmental Engineering Department at the University of Florence in Firenze, Italy in 2014 [16]. A variable message sign (VMS) with a non-breakaway sign support structure and an H3 steel barrier, as shown in Figure 6, were evaluated using finite element method (FEM) simulations and no crash testing. The objectives of the study were to evaluate heavy vehicle and sign support interaction as well as determine minimum lateral offset between sign support and barrier.

Figure 6. Sign Support and Guardrail

Initially, three separate models were created: a barrier; a heavy vehicle; and a sign support structure. The barrier model was evaluated and validated by a full scale crash test. The sign support structure model for this test included a VMS spanning a three lane motorway with an emergency lane and traditional sign supports made of high-strength steel (S355JO). Only the parts bearing the highest stress during the crash of the sign support were included in the model due to the complexity of the design. A 35,274-lb (16,000-kg) infinitely rigid cube with a 9.84-ft x 9.84-ft (3-m x 3-m) cross section was used to simulate a heavy goods vehicle (HGV) with an impact velocity of 49.7 mph (80 km/h). The sign support model was evaluated independently of the guardrail, and no risk of sign support failure was found.

The final stage of the project was to determine the minimum distance between the sign support and the guardrail where both would perform according to criteria defined in EN 1317-2:2010 [17]. After evaluating many simulations with varying placement along and behind the barrier, the minimum distance between the barrier and sign support was 51.2 in. (1,300 mm) away from the front of the barrier.

2.3.3 Zone of Intrusion

Stiff barriers, such as concrete barriers, have negligible deflections. However, zone of intrusion (ZOI), or vehicle intrusion over the top of the barrier, is a concern for attachments mounted on or near these barriers [18]. Subsequently, ZOI is considered for rigid bridge rails and parapets, not guardrail. In many of the reviewed tests, the vehicle's impacting corner intruded the farthest over the concrete barriers, and the greatest intrusion occurred early in the impact event.

TL-3 barriers were divided into three subgroups depending on their ZOI [18]. Group one consisted of slope-faced concrete barriers and steel tubular rails on 6-in. (152-mm) curbs or greater. The ZOI for group one was 18 in. (457 mm) away from the front face of the barrier. The ZOI for group two was 24 in. (610 mm) and included combination concrete and steel rails, vertical-faced concrete barriers, and timber rails. The ZOI for group three was 30 in. (762 mm) and included steel tubular rails not on curbs or on curbs less than 6 in. (152 mm) high.

Following this study, MwRSF performed three full-scale crash tests on a single-slope concrete barrier with adjacent light poles in 2008 [19]. The first two tests involved a light pole placed on top of the concrete barrier using a rearward pedestal, and the third test involved a ground-mounted light pole placed 10.5 in. (267 mm) behind the barrier. The first full-scale crash test, test no. ZOI-1, was performed according to test designation no. 4-12 of NCHRP Report No. 350. The test consisted of a 17,605-lb (7,985-kg) single-unit truck impacting the barrier at a speed of 50.4 mph (81.0 km/h) and an angle of 15.6 degrees. This test passed the NCHRP Report No. 350 safety requirements as the single-unit truck was safely brought to a controlled stop. The second full-scale crash test, test no. ZOI-2, was performed according to test designation no. 4-11 of NCHRP Report No. 350. The test consisted of a 4,430-lb (2,009-kg) pickup truck impacting the barrier at a speed of 61.7 mph (99.3 km/h) and an angle of 23.4 degrees. This test passed the NCHRP Report No. 350 safety requirements as the pickup truck was safely brought to a controlled stop. The third full-scale crash test, test no. ZOI-3, was performed according to test designation no. 4-12 of NCHRP Report No. 350. The test consisted of a 17,637-lb (8,000-kg) single-unit truck impacting the barrier at a speed of 50.2 mph (80.8 km/h) and an angle of 16.4 degrees. This test passed the NCHRP Report no. 350 safety requirements as the single-unit truck was safely brought to a controlled stop.

The impact location for the third test was selected such that the maximum vehicle intrusion over the barrier would occur at the light pole location. This placement would ensure a worst-case scenario impact. Test no. ZOI-3 was deemed acceptable according to the TL-4 criteria found in NCHRP Report No. 350 [10]. Unfortunately, the maximum intrusion occurred before the pole was impacted, and definitive recommendations could not be made for use of a ground-mounted luminaire pole placed behind a concrete barrier.

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Since it is not recommended to place obstacles within the working width of guardrail systems, closer pole placement behind the MGS would require crash testing and evaluation under TL-3 of MASH [3]. This study was conducted in compliance with MASH 2016. Note that there is no difference between MASH 2009 [20] and MASH 2016 for longitudinal barriers such as the system tested in this project. According to TL-3 of MASH, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 6.

Table 6. MASH TL-3 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed, mph (km/h)	Angle, deg.	
Longitudinal Barrier	3-10	1100C	2,425 (1,100)	62 (100)	25	A,D,F,H,I
	3-11	2270P	5,000 (2,268)	62 (100)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 7.

The critical impact points for both crash tests were determined using computer simulation to maximize vehicle and pole interaction, as discussed in the following chapter.

3.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the MGS with an offset light pole to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 7 and defined in greater detail in MASH. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in MASH.

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

3.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, additional W6x16 (W152 x 23.8) posts are to be installed near the impact region utilizing the same installation procedures as the system itself. Prior to full-scale testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips (33.4 kN) at post deflections between 5 and 20 in. (127 and 508 mm) and measured at a height of 25 in. (635 mm). If dynamic testing near the system is not desired, MASH permits a static test to be conducted instead and compared against the results of a previously established baseline test. In this situation, the soil must provide a resistance of at least 90% of the static baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Further details can be found in Appendix B of MASH.

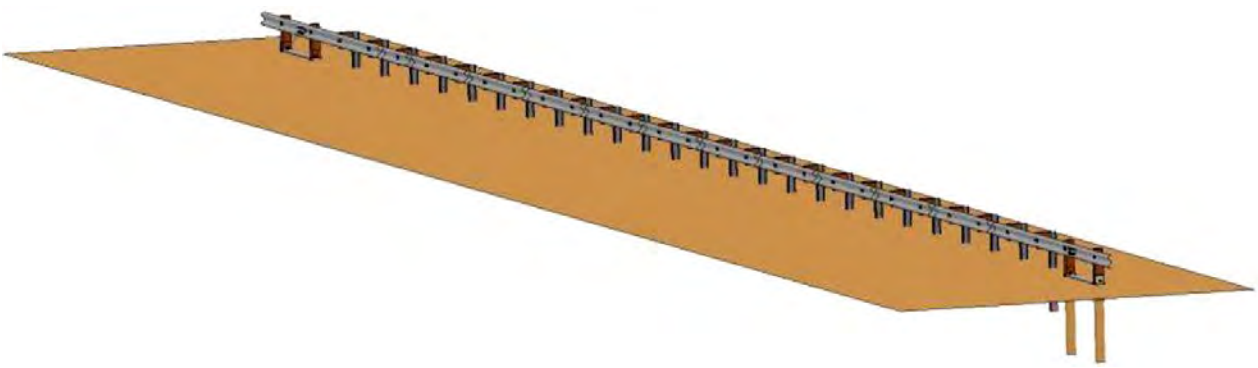
Table 7. MASH Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g's</td><td>20.49 g's</td></tr>
</table>

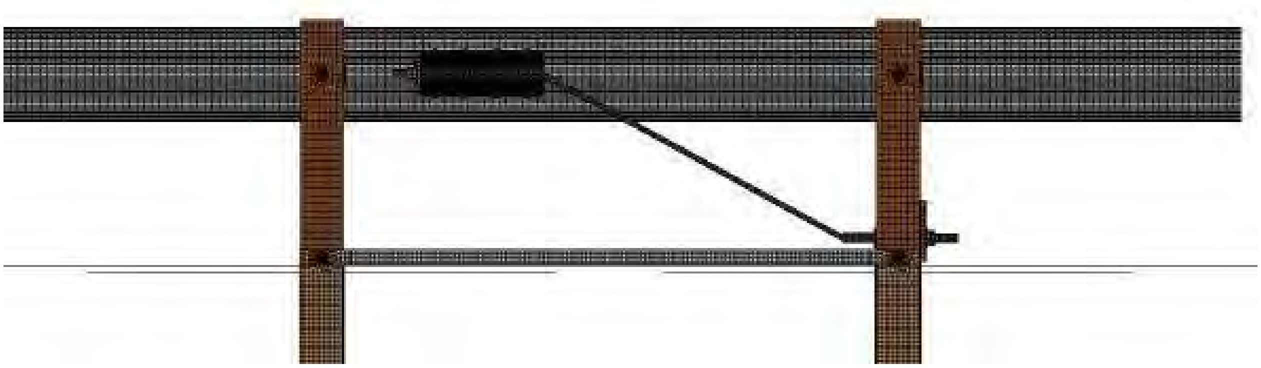
4 SELECTION OF POLE PLACEMENT THROUGH LS-DYNA SIMULATION

Computer simulation was utilized to select critical impact points and critical pole location for the full-scale crash tests. A baseline model of a 29-post, 175-ft (53.35-m) long Midwest Guardrail System (MGS) was validated with test nos. 2214MG-2 and 2214MG-3 using NCHRP Report No. W179 procedures for verification and validation of computer simulations used for roadside safety applications [1-2, 21].

The MGS model incorporated 72-in. (1,830-mm) long, W6x9 steel posts with 12-in. (305-mm) deep blockouts, as shown in Figure 7. The upstream and downstream ends of the system were anchored with the MGS trailing-end anchorage with two BCT posts on each end [22]. The post-soil resistance was simulated with lateral and longitudinal springs for the steel posts and downstream anchor posts considering the computational efficiency, and with a Drucker-Prager soil element material for the upstream anchor posts to represent soil resistance more accurately.



(a)



(b)

Figure 7. Finite Element Model of MGS: (a) System Layout and (b) End Anchorage

Table 8. Summary of MGS Model Parts and LS-DYNA Parameters [23]

Part Name	Element Type	Element Formulation	Material Type	Material Formulation
Anchor Cable	Beam	Belytschko-Schwer, Resultant Beam	6x19 ¾" Wire Rope	Moment, Curvature Beam
Anchor Post Bolt	Solid	Constant Stress Solid Element	ASTM A307	Rigid
Anchor Post Bolt Heads	Shell	Belytschko-Tsay	ASTM A307	Rigid
Anchor Post Washers	Solid	Constant Stress Solid Element	ASTM F844	Rigid
BCT Anchor Post	Solid	Fully Integrated, S/R	Wood	Plastic Kinematic
Bearing Plate	Solid	Constant Stress Solid Element	ASTM A36	Rigid
Blockout	Solid	Fully Integrated, S/R	Wood	Elastic
Blockout Bolts	Shell	Belytschko-Tsay	ASTM A307	Rigid
Bolt Springs	Discrete	DRO=Translational Spring/Damper	ASTM A307	Spring, Non-Linear Elastic
Ground-Line Strut	Shell	Belytschko-Tsay	ASTM A36	Piecewise, Linear Plastic
Post Soil Tubes	Shell	Belytschko-Tsay	Equivalent Soil	Rigid
Line Post Soil Springs	Discrete	DRO=Translational Spring/Damper	Equivalent Soil	Spring, General Non-Linear
W-Beam Guardrail Section	Shell	Fully Integrated, Shell Element	AASHTO M180, 12-Ga. Galvanized Steel	Piecewise, Linear Plastic
W6x9 Post	Shell	Fully Integrated, Shell Element	ASTM A992 Gr. 50	Piecewise, Linear Plastic
Anchorage Soil	Solid	Constant Stress Solid Element	Crushed Limestone	Drucker Prager

A series of computer simulations were conducted with the MGS with nearby poles to determine the minimum safe lateral pole offset based on risks of rail pocketing, rail rupture, vehicle instability, and other hazards. The analyses primarily focused on MASH TL-3 impacts with 2270P vehicles due to increased dynamic deflections, but several simulations with 1100C vehicle impacts were also performed to ensure that the lateral pole offset was safe for small cars.

4.1 Evaluation Criteria

The presence of a pole behind a guardrail may cause vehicle snag on the pole, posts impacting the pole, and interaction between the deflected rail and the pole, all of which may affect the guardrail's ability to safely contain and redirect vehicles. Vehicle snag on the pole can increase vehicle decelerations and instabilities. Interaction between a deflected guardrail system and a pole can cause pocketing and increased loading to the guardrail. Thus, several criteria, such as vehicle stability, occupant risk measures, rail pocketing, vehicle snag on pole, rail deflection, and rail load, were evaluated in each simulation.

Euler angles, including roll, pitch, and yaw angles, were used to evaluate vehicle stability. Roll and pitch angles should not exceed 75 degrees according to MASH [3]. Occupant risk measures, which evaluate the degree of hazard to the occupants in the impacting vehicle, included the longitudinal and lateral occupant impact velocities (OIVs) as well as longitudinal and lateral occupant ridedown accelerations (ORAs). According to MASH, longitudinal and lateral occupant impact velocities should fall below the maximum allowable value of 40.0 ft/s (12.2 m/s). MASH also states that longitudinal and lateral ORAs should fall below the maximum allowable value of 20.49 g's [3]. In addition, all post deflections in the impact region were examined to evaluate the pole-post interaction as well as its effects on snag, deceleration, and prevention of pole release.

Maximum pocketing angle is also a concern, as excessive pocketing angles can affect a system's capability to safely contain and redirect a vehicle. The pocketing angle is defined as the angle between the deflected rail during the impact event and initial guardrail orientation. In some situations, the rail can form a pocket between two adjacent posts due to large lateral rail displacement, which may impede the vehicle's redirection out of the system. The maximum pocketing angle for each simulation was calculated by tracking adjacent nodes on the rail to determine barrier deflections. The pocketing angle in the baseline simulation with no pole was 39.2 degrees.

The maximum rail load was also examined. The MGS W-beam rail consisted of AASHTO M180 steel [24], with a minimum ultimate strength of 70 ksi (482 MPa), which correlates to a rail tensile strength of 112 kips (498 kN) at the splice and 141 kips (627 kN) in the full-section. In another study, the maximum rail tensile strength of the MGS W-beam was estimated in a range of 92 to 98 kips (409 to 436 kN) at a splice [25].

4.2 LS-DYNA Baseline Simulations

An existing baseline model of the MGS impacted by a 2270P pickup truck was validated with the results from the test no. 2214MG-2 [1]. In test no. 2214MG-2, a 5,000-lb (2,268-kg) pickup truck impacted the steel-post MGS, which had a 31-in. (787-mm) top rail mounting height, was installed in standard soil, and with standard post spacing, at an impact speed of 62.9 mph (101.2 km/h) and an angle of 25.5 degrees.

The reduced-element, 2270P Chevrolet Silverado pickup truck model, originally developed by the National Crash Analysis Center (NCAC) and modified by MwRSF, was utilized to simulate test no. 2214MG-2 [26]. The 5,004-lb (2,270-kg) pickup truck model impacted the steel-post MGS installed in standard soil and with standard post spacing at an impact speed of 62.1 mph (100 km/h) and an angle of 25.4 degrees. A summary of the results from numerical simulation and test no. 2214MG-2 is shown in Table 9. The simulation and full-scale crash test were compared using NCHRP Report No. W179 procedures for verification and validation of computer simulations used for roadside safety applications [21]. The full V&V (Validation and Verification) comparison is shown in Appendix A. A comparison between the actual and finite element simulation of test no. 2214MG-2 is shown in Figure 8. In the test, dynamic deflection was 1.2 in. (30 mm) lower as compared to the simulation. Simulated maximum roll angle, longitudinal and lateral ORAs were higher than in the actual test. However, the simulation met the V&V procedure requirements. Therefore, the model was utilized for further numerical studies. In this study, the differences between the test and simulation results were considered when evaluating the results.

Table 9. Summary of Crash Test No. 2214MG-2 and Simulation Results

Evaluation Parameters	Max. Dynamic Deflection ft (m)	Length Contact ft (m)	Max. Roll Angle (degrees)	Max. Pitch Angle (degrees)	Max. Yaw Angle (degrees)	Long. ORA (g's)	Lateral ORA (g's)	Long. OIV ft/s (m/s)	Lateral OIV ft/s (m/s)
Physical Test	3.64 (1.11)	33.8 (10.3)	4.81°	1.84°	45.74°	8.23	6.93	15.32 (4.67)	15.61 (4.76)
Simulation	3.74 (1.14)	29.5 (9)	11.67°	3.17°	46.21°	11.16	9.05	14.53 (4.43)	16.37 (4.99)

Figure 8. 2270 Vehicle Crash: Test No. 2214MG-2 (left) and Simulation (right)

A Toyota Yaris model, developed by NCAC and modified by MwRSF, was used to simulate test no. 2214MG-3 [26]. The 2,775-lb (1,258-kg) passenger car model impacted the MGS installed in standard soil and using a standard post spacing at an impact speed of 62.1 mph (100 km/h) and an angle of 25 degrees. A summary of the results from numerical simulation and test no. 2214MG-3 is shown in Table 10. A comparison between the test and simulation results are shown in Figure 9.

Table 10. Summary of Crash Test No. 2214MG-3 and Simulation Results

Evaluation Parameters	Max. Dynamic Deflection ft (m)	Length Contact ft (m)	Max. Roll Angle (degrees)	Max. Pitch Angle (degrees)	Max. Yaw Angle (degrees)	Long. ORA (g's)	Lateral ORA (g's)	Long. OIV ft/s (m/s)	Lateral OIV ft/s (m/s)
Physical Test	3 (0.9)	27.3 (8.3)	12.8°	5.7°	28.6°	16.1	8.4	14.8 (4.5)	17.1 (5.2)
Simulation	2.3 (0.7)	25.6 (7.8)	3.5°	2.4°	41.0°	13.3	10.1	18.5 (5.6)	22 (6.7)

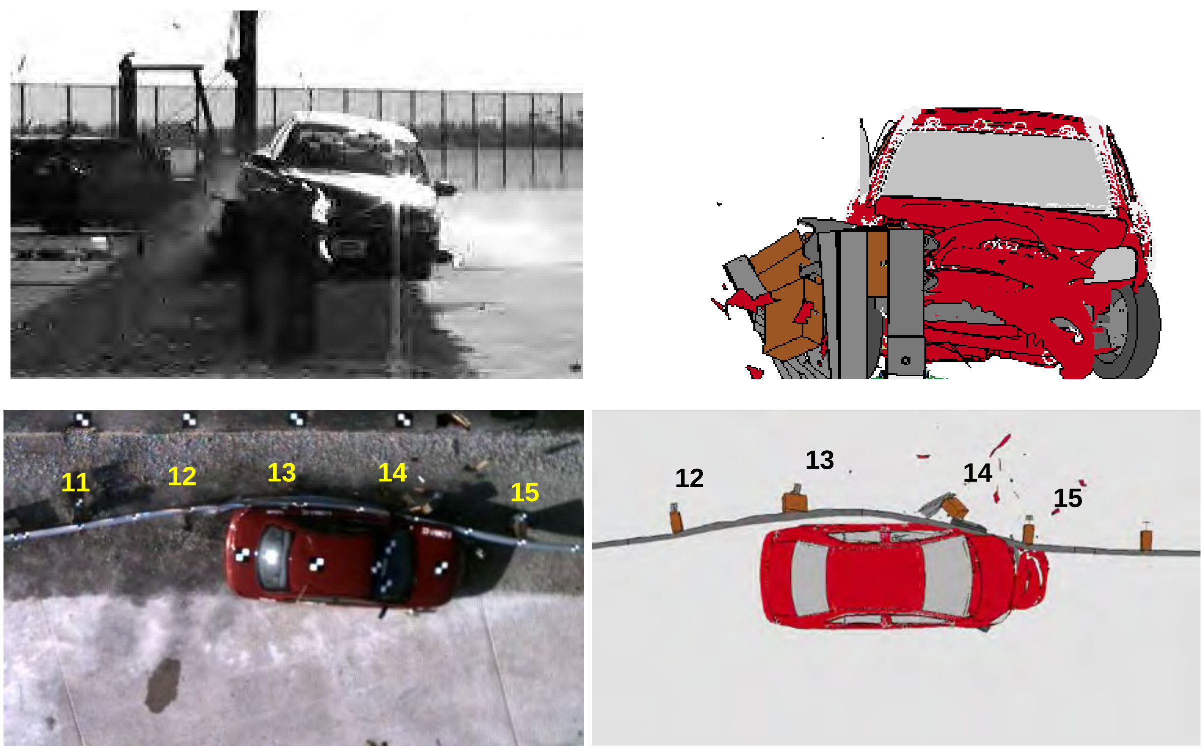


Figure 9. 1100C Vehicle Crash: Test No. 2214MG-3 (left) and Simulation (right)

The full V&V comparison is shown in Appendix B. The simulation did not meet the V&V procedure requirements primarily due to differences in maximum barrier deflection and maximum vehicle roll and yaw. The simulated dynamic deflection was 12 percent lower than observed in the crash test, and the roll angle was 8 degrees lower in the simulation than observed in the crash test. In the test, four posts deflected. While in the simulation, only three posts deflected during car impact. The 1100C Toyota Yaris model was geometrically different than the

1100C Kia Rio used in the crash test. Thus, the results were expected to differ. These differences were considered when determining the critical impact point and pole placement for MASH test no. 3-10.

4.3 Determination of Critical Impact Points

Prior to simulation of the MGS with an offset pole, it was desired to determine the critical impact point (CIP) along the MGS that would be most detrimental for interaction of the MGS and vehicle. According to MASH, the impact point should be selected to represent the critical location along a barrier system that will maximize the risk of test failure. For longitudinal barriers, including the MGS, CIPs are selected to maximize loading at rail splices and maximize the potential for wheel snag and vehicle pocketing. Based on the general MASH recommendation, testing agencies are encouraged to utilize a more detailed analysis, such as computer simulation, to estimate the CIP location for each full-scale crash test. Thus, several impact points along the MGS were evaluated through numerical simulations without a pole to determine the impact location that could maximize the risk of test failure in terms of increased occupant risk values, deflection, and potential for snagging and pocketing if a pole was present. These simulations were conducted to provide an insight into critical locations of impact on the MGS without pole, more refined simulations were performed to determine the critical pole location, as detailed in the following chapters. The critical impact point for the 2270P pickup test was determined to be 4 in. (100 mm) downstream from post no. 11, as shown in Figure 10a. This impact point maximized the MGS deflection, the longitudinal ORA, and the potential for snagging. A summary of the results simulated at various impact points on the MGS is shown in Table 11. The lateral and longitudinal OIVs were similar for all impact points with averages of 16 ft/s (4.9 m/s) and 15 ft/s (4.6 m/s), respectively.

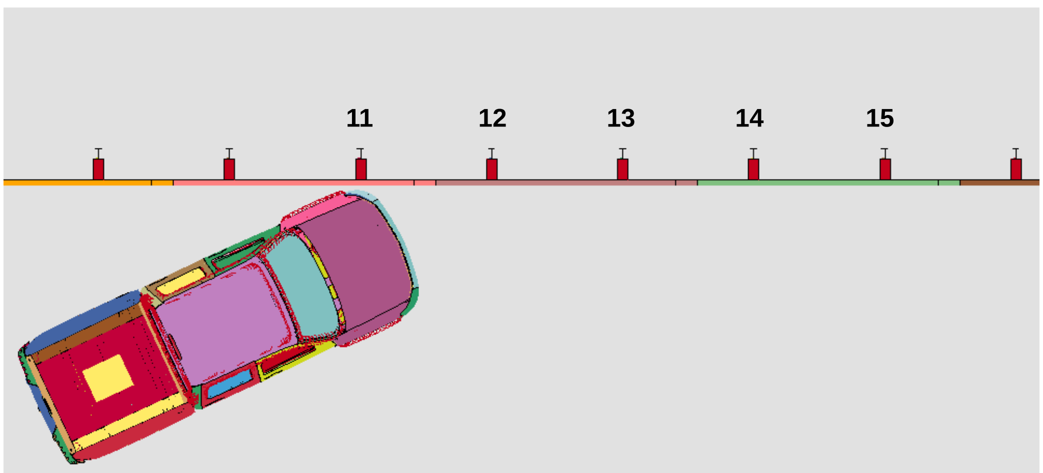
Table 11. Summary of Simulated Results with Varied Impact Points – Test Designation No. 3-11

Impact Point	Lateral ORA (g's)	Longitudinal ORA (g's)	Maximum Dynamic Deflection in. (mm)	Pocketing Angle (deg)
4 in. (100 mm) Downstream from Post No. 11	6.09	13.69	47 (1,199)	39.2
¼ Span Downstream from Post No. 11	6.22	7.55	45 (1,142)	32.8
Mid Span Downstream from Post No. 11	7.34	11.04	43 (1,080)	38.0
¾ Span Downstream from Post No. 11	9.06	11.17	45 (1,140)	33.4

Moreover, a series of simulations was conducted using a passenger car impacting the MGS at various impact points. For the passenger car case, the critical impact point on the MGS that led to maximum rail deflection (29.8 in. (757 mm)), maximum vehicle roll angle (14.3 degrees), and high occupant risk values (lateral ORA of 12.7 g's and longitudinal ORA of 14 g's) was at the mid-span between post nos. 11 and 12, as shown in Figure 10b. A summary of the results is shown in Table 12. The lateral and longitudinal OIVs were similar, with averages of 18.4 ft/s (5.6 m/s) and 21.6 ft/s (6.6 m/s), respectively.

Table 12. Summary of Simulated Results with Varied Impact Points – Test Designation No. 3-10

Impact Point	Lateral ORA (g's)	Longitudinal ORA (g's)	Maximum Dynamic Deflection in. (mm)	Pocketing Angle (deg)	Maximum Vehicle Roll Angle (deg)
4 in. (100 mm) Downstream from Post No. 11	10.3	13.3	26.9 (684)	18	3.5
¼ Span Downstream from Post No. 11	10.5	15	28.2 (717)	18	4.5
Mid Span Downstream from Post No. 11	12.7	14	29.8 (757)	18	14.3
¾ Span Downstream from Post No. 11	10.6	12.7	26.9 (683)	17.5	2



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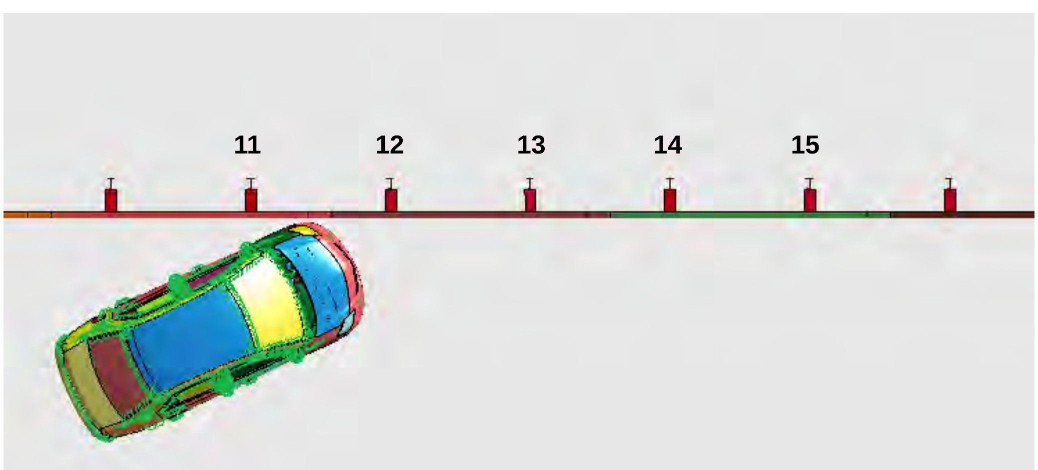


(b)

Figure 10. Critical Impact Points: (a) Test Designation No. 3-11 and (b) Test Designation No. 3-10

4.4 Pole Model

Computer models of a 50-ft (15.25-m) tall pole with a 9-in. (228-mm) tall base were generated using a fine mesh, as shown in Figure 11. An automatic, single-surface contact was provided for the pole, vehicle, and MGS contact. In the LS-DYNA simulations, the pole and base were modeled as rigid parts that were constrained in all directions using MAT_RIGID. Thus, the pole could not break away. Accurate modeling of the breakaway mechanism of the pole was out of the scope of this project. As such, this modification would lead to a more severe simulated impact as compared to the actual test and thus a more conservative pole placement. Also, the use of the rigid pole would still provide insight into the potential for barrier and vehicle interaction with the pole. The pole has a 10-in. (254-mm) diameter at the base and a 6-in. (152-mm) diameter at the top. Two aluminum material models were utilized to represent the pole and base. Material parameters are summarized in Table 13.

Figure 11. Computer Model of Pole and Base

Table 13. Summary of Material Parameters for Pole-Base Model

Material	Young's Modulus (GPa)	Density (kg/mm^3)	Poison's Ratio
MAT_20 (Transformer Base, A356-T6)	72.4	$2.67(10^{-6})$	0.33
MAT_20 (Pole, Al6063-T6)	68.9	$2.6(10^{-6})$	0.33

4.5 Determination of Critical Pole Offset

4.5.1 Determination of Critical Pole Offset for Test Designation No. 3-11

The baseline simulation was modified to simulate a 5,004-lb (2,270-kg) pickup truck impacting the MGS with a laterally offset pole and investigate the interaction between the vehicle, pole, and MGS. In order to identify worst-case scenarios, pickup truck impacts into the MGS model were simulated when the pole was placed behind the guardrail with the front face of pole laterally 12 in. to 28 in. (305 mm to 711 mm) behind the back of posts. The centerline of the pole was also shifted longitudinally away from the centerline of the posts along the barrier to maximize vehicle interaction with the barrier and pole, as shown in Figure 12.

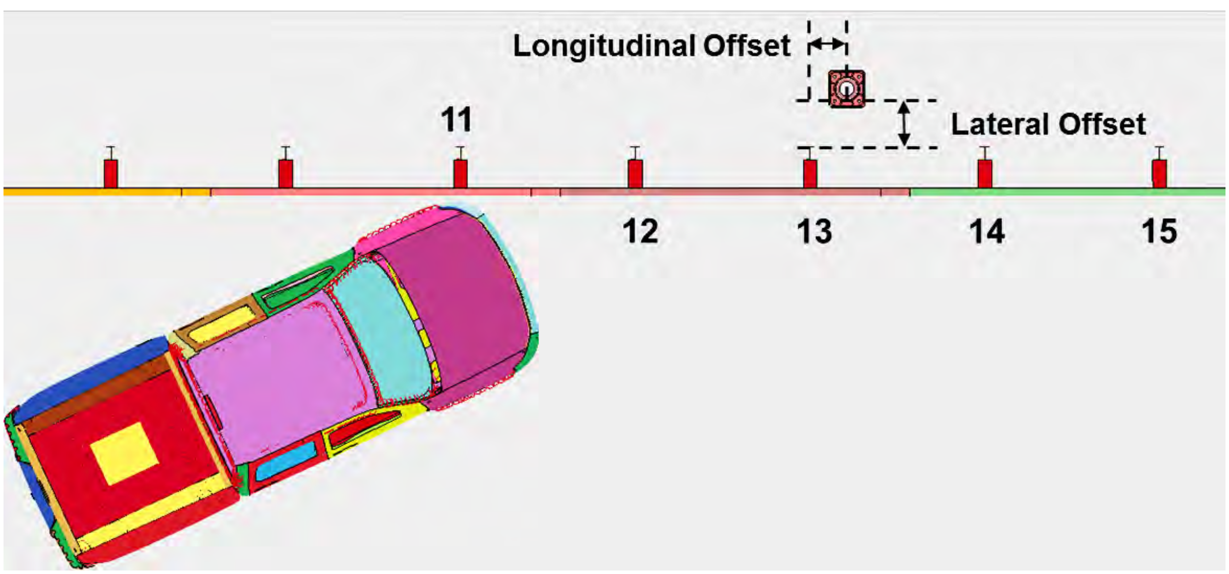


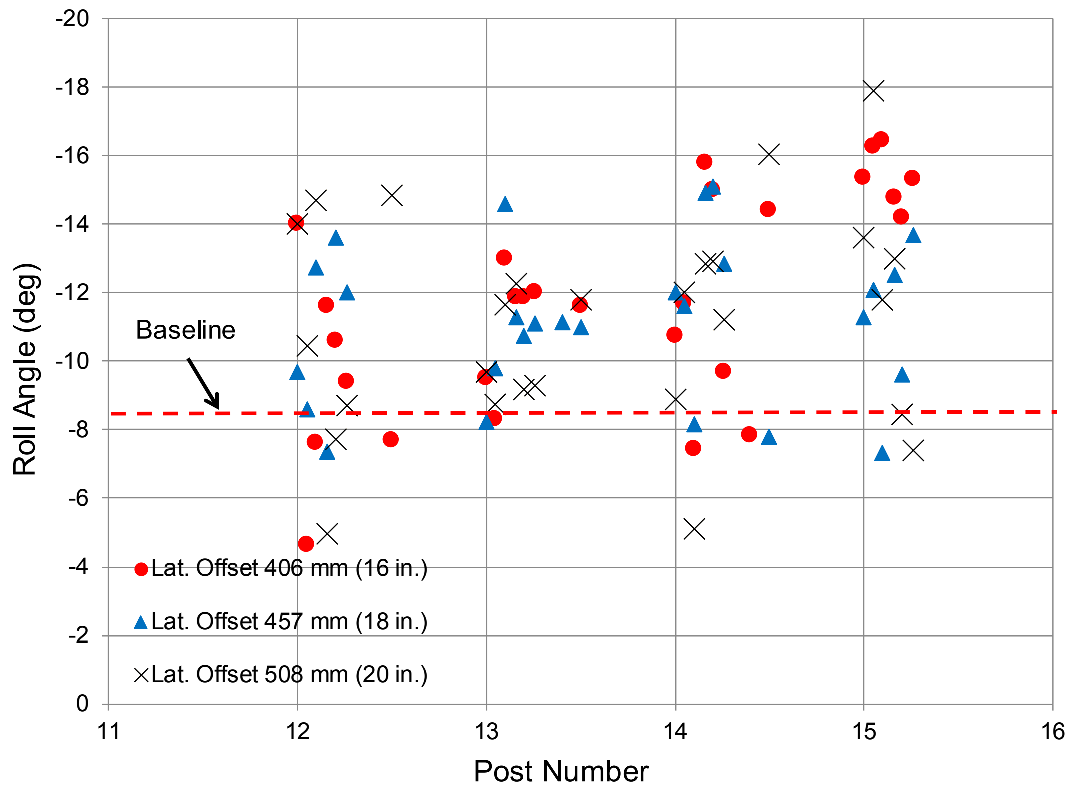
Figure 12. Longitudinal and Lateral Offset of Pole with Respect to MGS

In the baseline model, four posts (post nos. 12 to 15) deflected when impacted by the truck model. Thus, longitudinal pole offsets from the four posts were considered. The longitudinal offsets studied included: 0 in. (i.e., pole placed directly behind the post); 4; 8; 12; 16; 20; and mid-span 37.5 in. (102; 203; 305; 406; 508; and 953 mm).

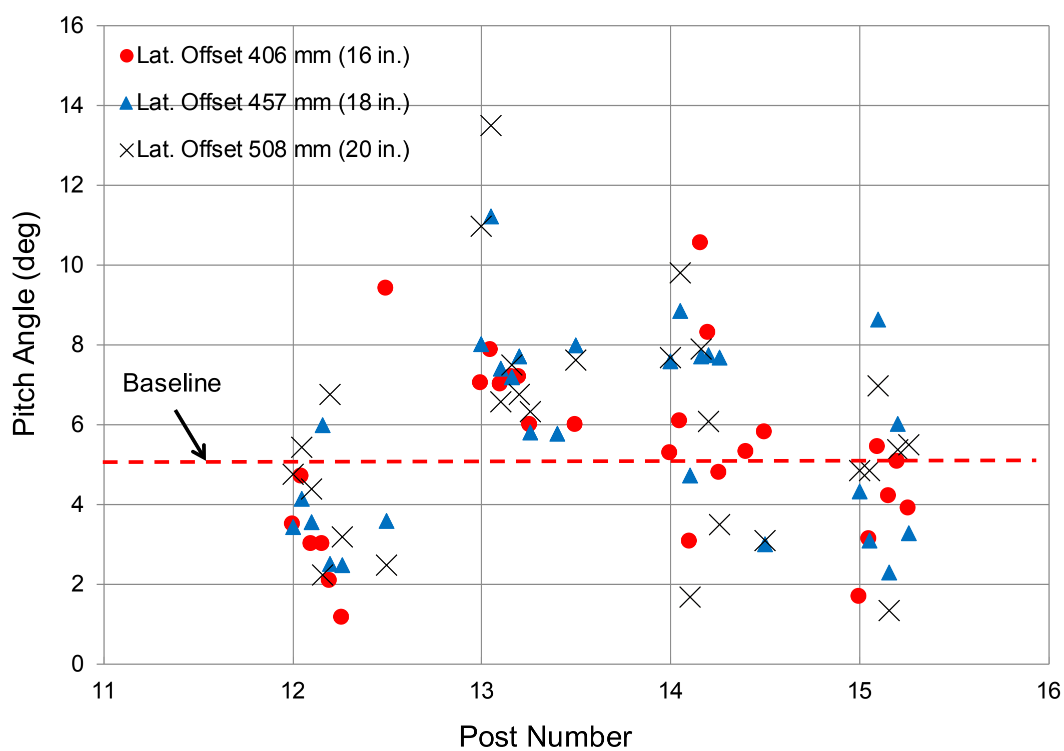
The 2270P model impacted the MGS at the CIP, or 4 in. (100 mm) downstream from post no. 11. Preliminary analyses indicated that lateral pole placement closer than 16 in. (406 mm) behind the post caused aggressive impacts with the rigid pole, and reliable results could not be obtained. One case with a 12-in. (305-mm) lateral offset was studied, but the simulation did not complete due to unresolvable errors. Pole offsets of 24 and 28 in. (610 and 711 mm) behind the MGS did not appear to be critical to the barrier performance, as the vehicle had minimal interaction with the pole. Thus, lateral offsets of 16, 18, and 20 in. (406, 457, and 508 mm) were selected for further analysis.

4.5.1.1 Vehicle Behavior

Vehicle behavior was examined to evaluate the potential for safe vehicle redirection without instability. In all simulations, the vehicle was smoothly redirected without any significant override or underride. However, all three lateral offsets resulted in increased vehicle-pole interaction with increased vehicle's roll and pitch angles, as shown in Figure 13. In this figure, the x-axis represents the post number in the MGS. The offset of the data points from the post number in the x-axis represents the relative longitudinal offset of the pole from the associated post in the MGS (except the baseline data point). For example, the data points with the x-coordinate of 12.5 represent the cases where pole was placed at mid-span between posts nos. 12 and 13. All angular displacement angles were within MASH limits.



(a)



(b)

Figure 13. Vehicle Behavior: (a) Maximum Roll Angle and (b) Maximum Pitch Angle

4.5.1.2 Occupant Risk

Occupant risk values were calculated for each simulation utilizing the local accelerometer node at the vehicle's center of gravity and processed the same way as MASH full-scale crash tests. The maximum occupant ridedown acceleration obtained from the LS-DYNA simulations at a 16-in. (406-mm) offset is shown in Figure 14. The x-axis represents the post number in the MGS, and y-axis indicates the longitudinal ORAs values. Data labels represent the longitudinal offset of the pole from the post no. associated with the x-axis.

As shown in Figure 14, cases with the pole offset away from post no. 13 had increased lateral and longitudinal ORAs, which indicates the potential for more aggressive contact between the pole, barrier, and vehicle. A similar trend was also observed for 18-in. (457-mm) and 20-in. (508-mm) lateral pole offsets, as shown in Figure 15.

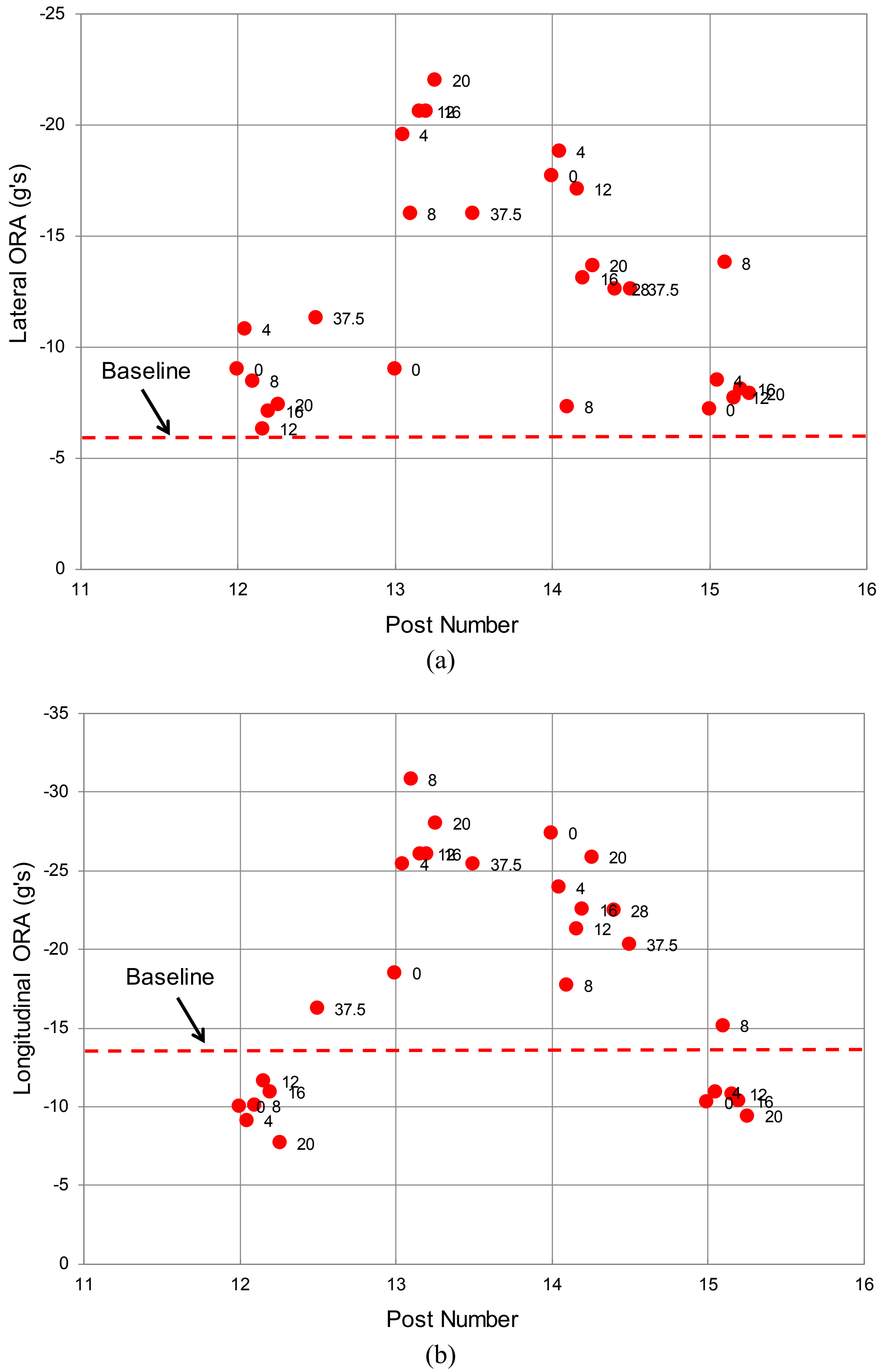
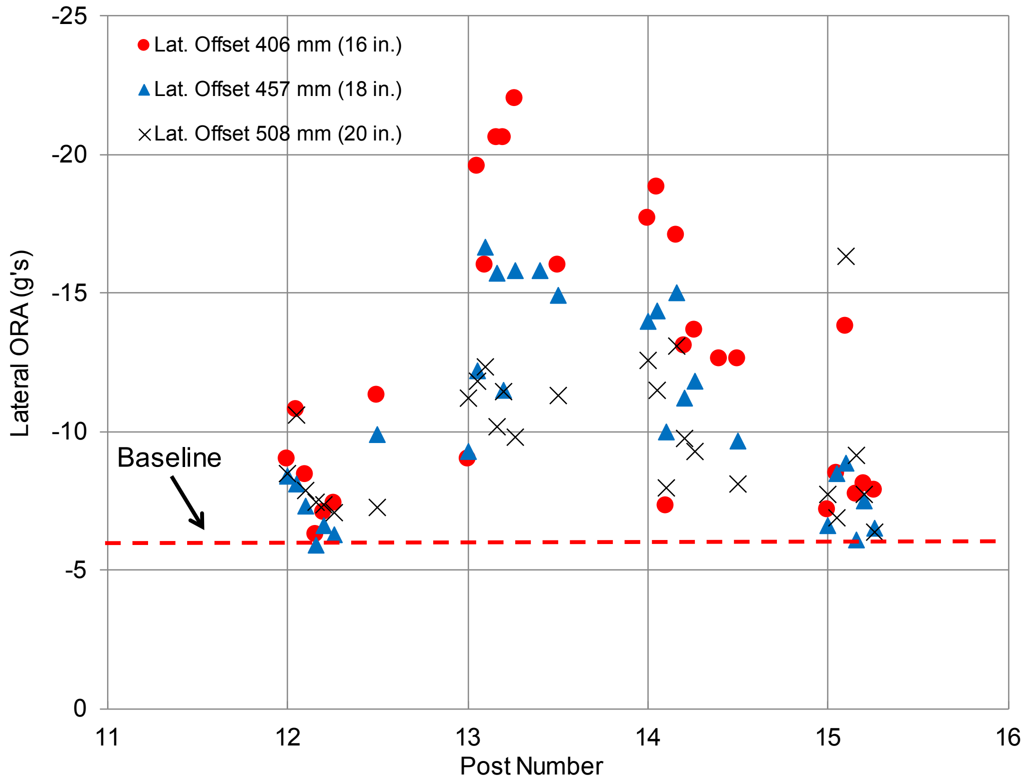
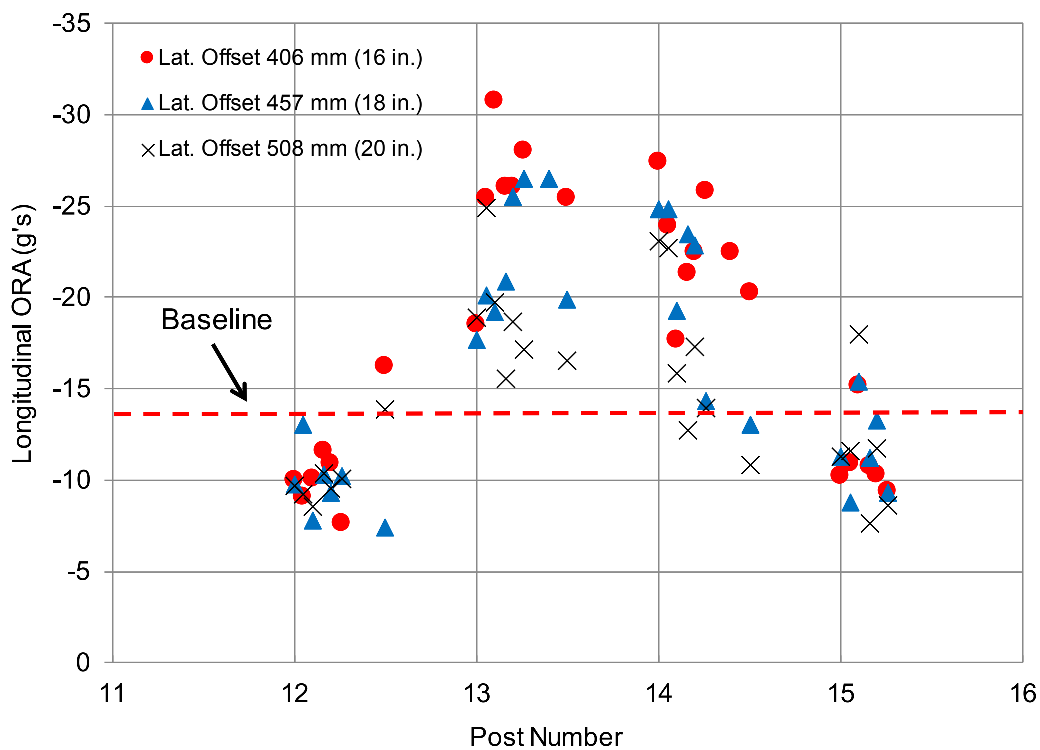


Figure 14. Occupant Ridedown Acceleration for 16-in. (406-mm) Lateral Offset: (a) Lateral and (b) Longitudinal



(a)



(b)

Figure 15. Occupant Ridedown Acceleration for 16, 18, and 20-in. (406, 457, and 508-mm) Lateral Offset: (a) Lateral and (b) Longitudinal

For all lateral pole offsets from 16 to 20 in. (406 to 508 mm), the longitudinal ORAs exceeded the acceptable MASH value with some longitudinal pole offsets. These cases mostly involved the pole at any longitudinal offset away from post no. 13 where maximum pole, barrier, and vehicle interaction occurred. As shown in Figure 14, the maximum longitudinal ORA occurred when the pole was located at a 16-in. (406-mm) lateral offset and an 8-in. (203-mm) longitudinal offset away from post no. 13. In this simulation, the vehicle's wheel snagged on post no. 13 and the base of the pole, as shown in Figure 16. The magnitude of these large lateral and longitudinal ORAs values were not expected in full-scale crash testing as the actual pole may break away during testing and induce less resistance than the simulations predicted. In addition, LS-DYNA tends to predict slightly larger lateral and longitudinal ORAs as compared to the crash testing results, which also occurred in the baseline simulation comparison due to lack of failure in wheel, tire, and suspension model assembly. Therefore, the large simulated lateral and longitudinal ORAs were deemed unlikely to occur in the physical testing and would be further evaluated with crash testing.

However, these decelerations did indicate increased vehicle and barrier interaction with an offset pole and raised the potential for degradation in barrier performance. For the cases with the pole located at 4-, 8-, 12-, and 16-in. (102-, 203-, 305-, and 406-mm) longitudinal offsets, more aggressive behavior occurred as compared to the cases when the pole was placed directly behind the post or at mid-span. This may be attributed to the wheel snagging on the base of the pole. As shown in Figure 17, the simulated lateral and longitudinal peak decelerations confirmed that a pole offset downstream from post no. 13 maximized pole, barrier, and vehicle interaction.

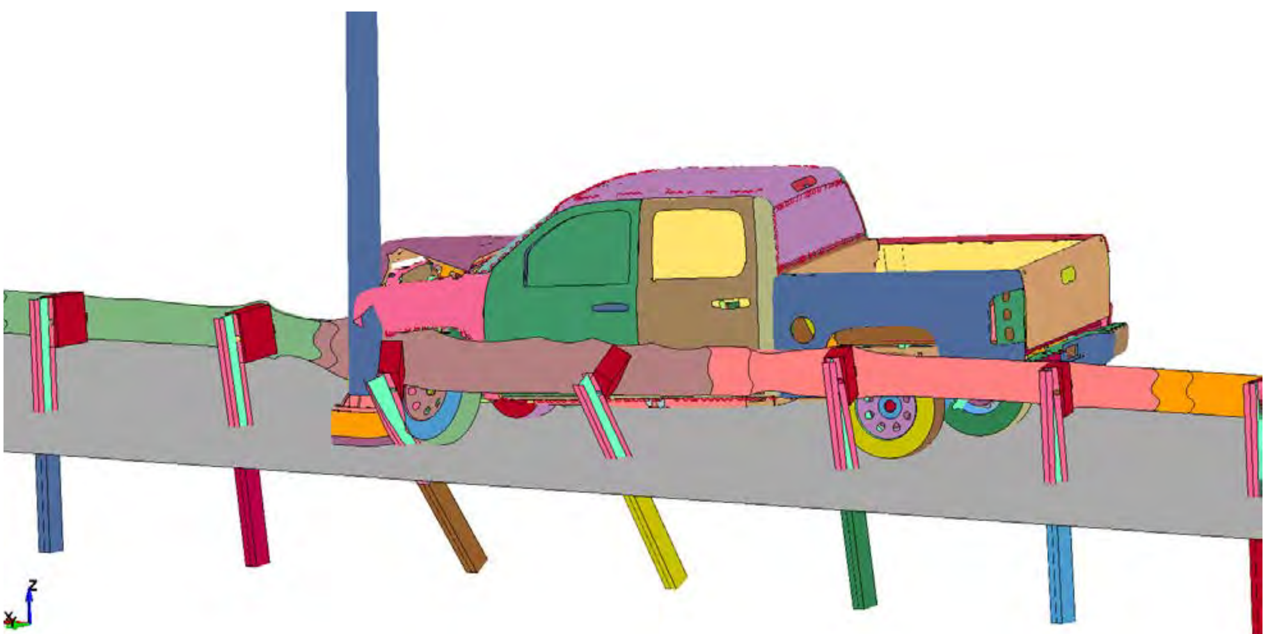
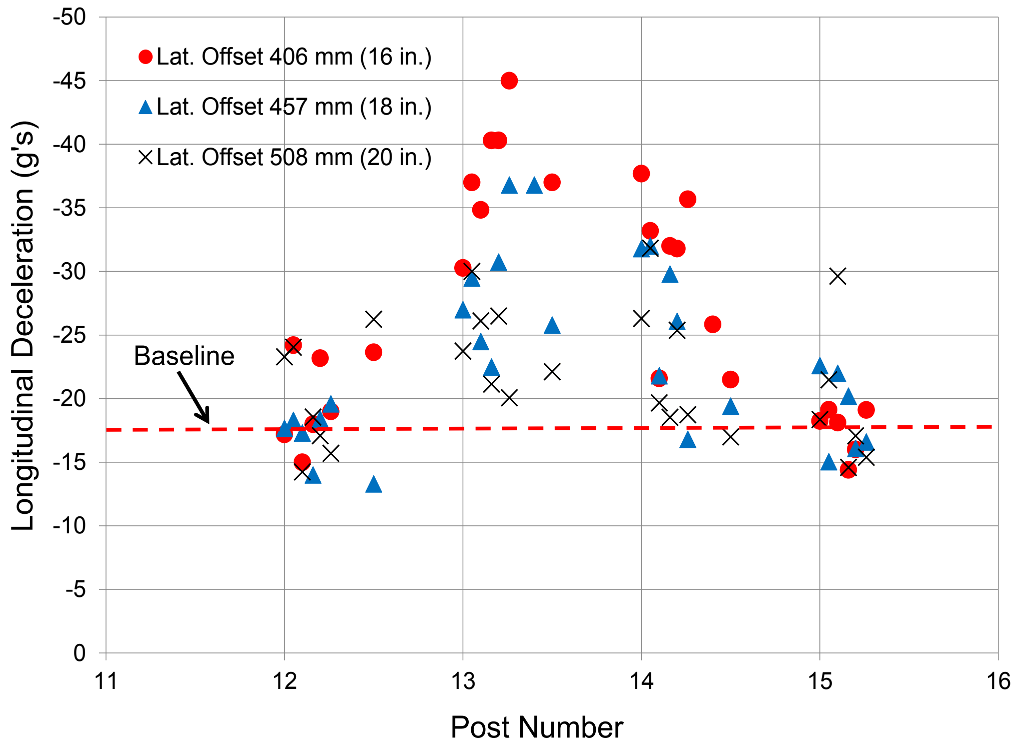
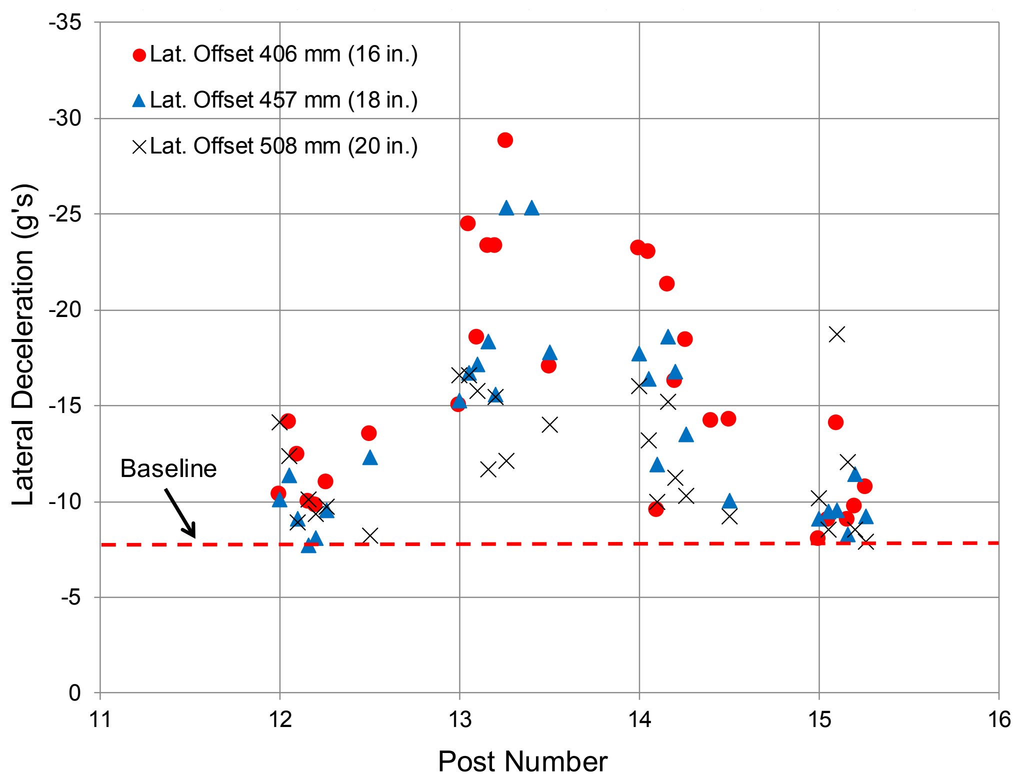


Figure 16. Maximum Vehicle, Barrier, and Pole Interaction – 16-in. (406-mm) Lateral Offset and 8-in. (203-mm) Longitudinal Offset Away from Post No. 13



(a)



(b)

Figure 17. Peak Deceleration: (a) Longitudinal and (b) Lateral

4.5.1.3 Rail Pocketing

Excessive pocketing angles can affect a system's capability to safely contain and redirect a vehicle. The simulated pocketing angles are shown in Figure 18. The pocketing angle in the baseline simulation was 39.2 degrees. The pole did not significantly increase the pocketing angle over the baseline simulation. A maximum simulated pocketing angle of 46 degrees was observed for a pole placed at a lateral offset of 18 in. (457 mm) and did not appear to be critical as the pickup truck was redirected.

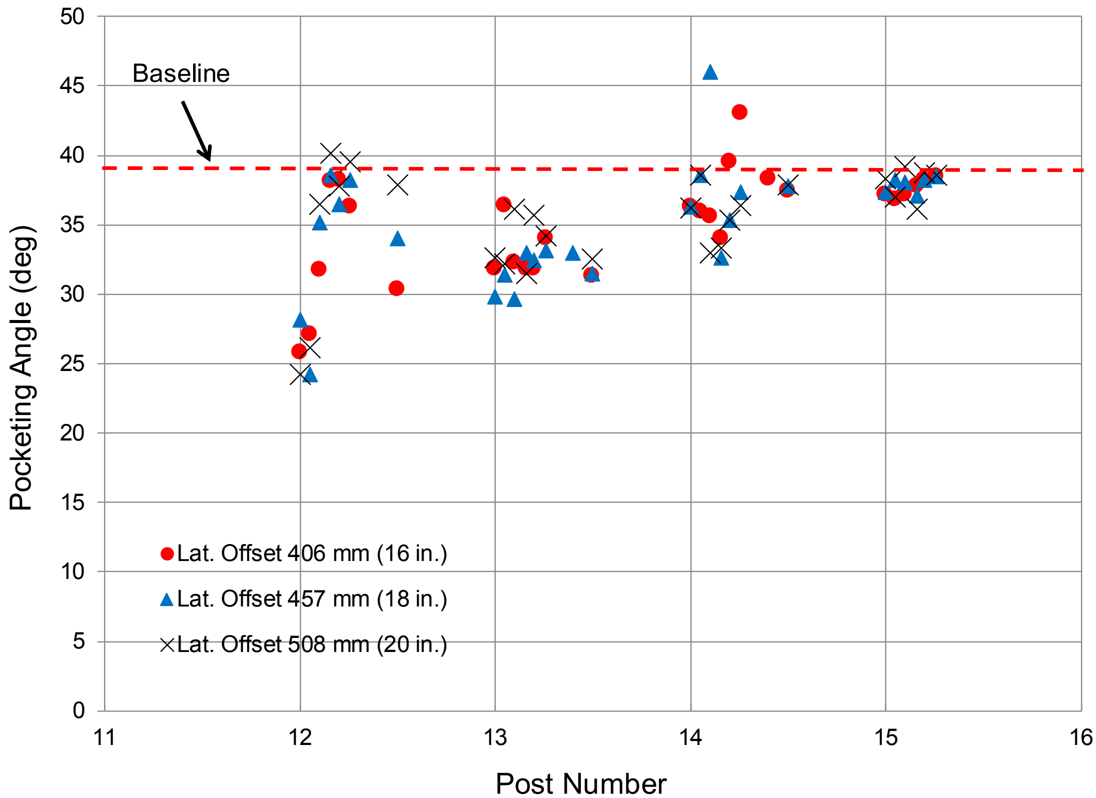
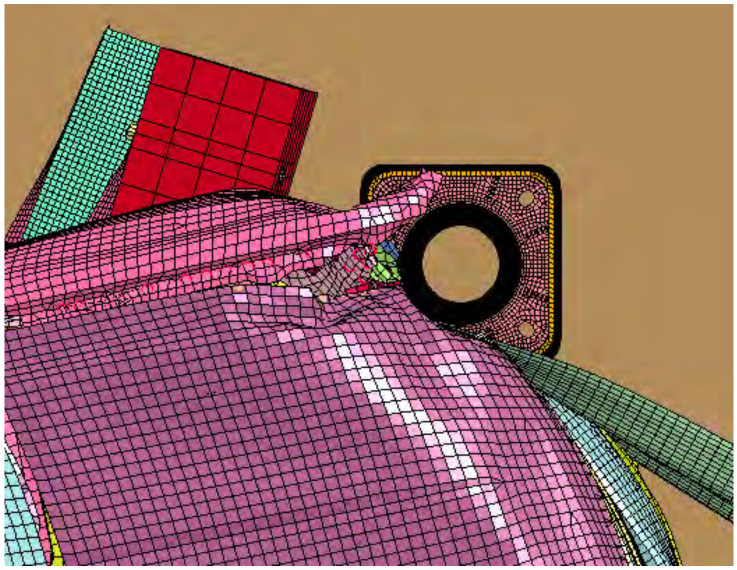


Figure 18. Rail Pocketing Angle – 2270P Vehicle

4.5.1.4 Vehicle Snag

In simulations, two mechanisms for vehicle snag on the pole were identified: fender snagging (shown in Figure 19a), and wheel snagging (shown in Figure 19b). The wheel snag on the pole appeared to be responsible for increased vehicle instability and occupant risk values. In the simulations, the maximum lateral snag distance was greater for the fender snag as compared to the wheel. A maximum fender snag of 14 in. (356 mm) occurred, as shown in Figure 20. However, fender snag was likely overrepresented in the simulation due to the lack of pole fracture.


(a)

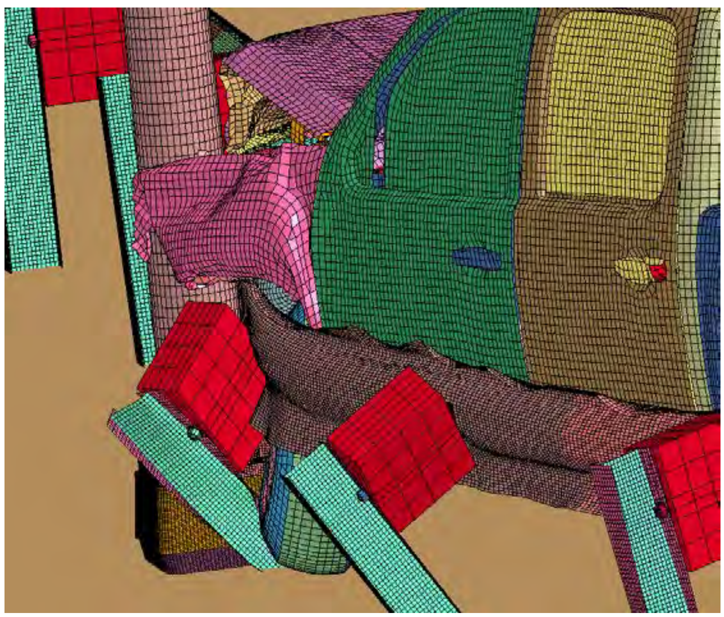

(b)

Figure 19. 2270P Vehicle Snag: (a) Fender Snag and (b) Wheel Snag

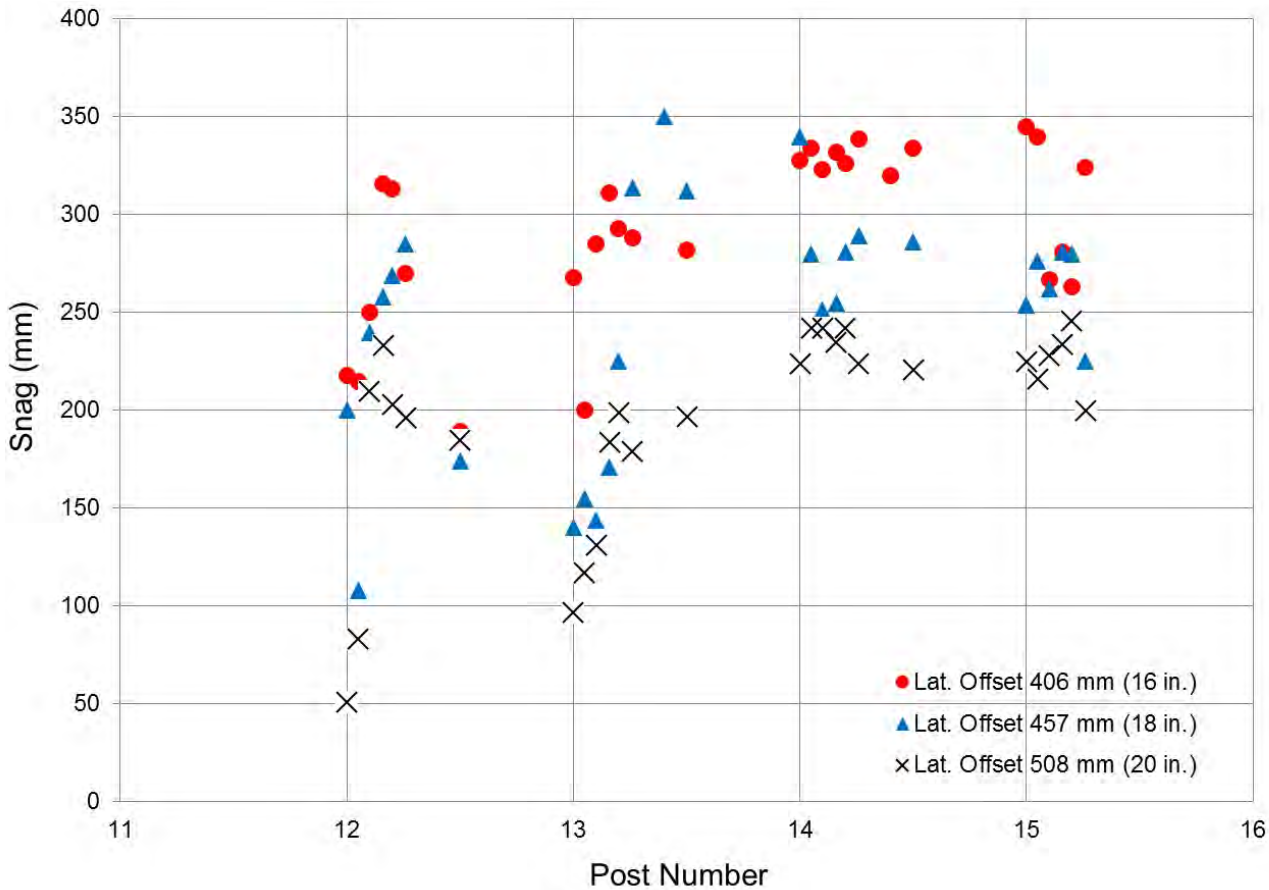


Figure 20. Maximum 2270P Vehicle Snag

4.5.1.5 Rail Deflection

The maximum simulated dynamic rail deflections at 16-, 18-, and 20-in. (406-, 457-, and 508-mm) lateral pole offsets is shown in Figure 21. In most cases, the pole restricted rail deflections by up to 30 percent as compared to the baseline case without a pole. However, these reduced barrier deflections were not believed to be detrimental to the barrier performance since the truck was still smoothly redirected.

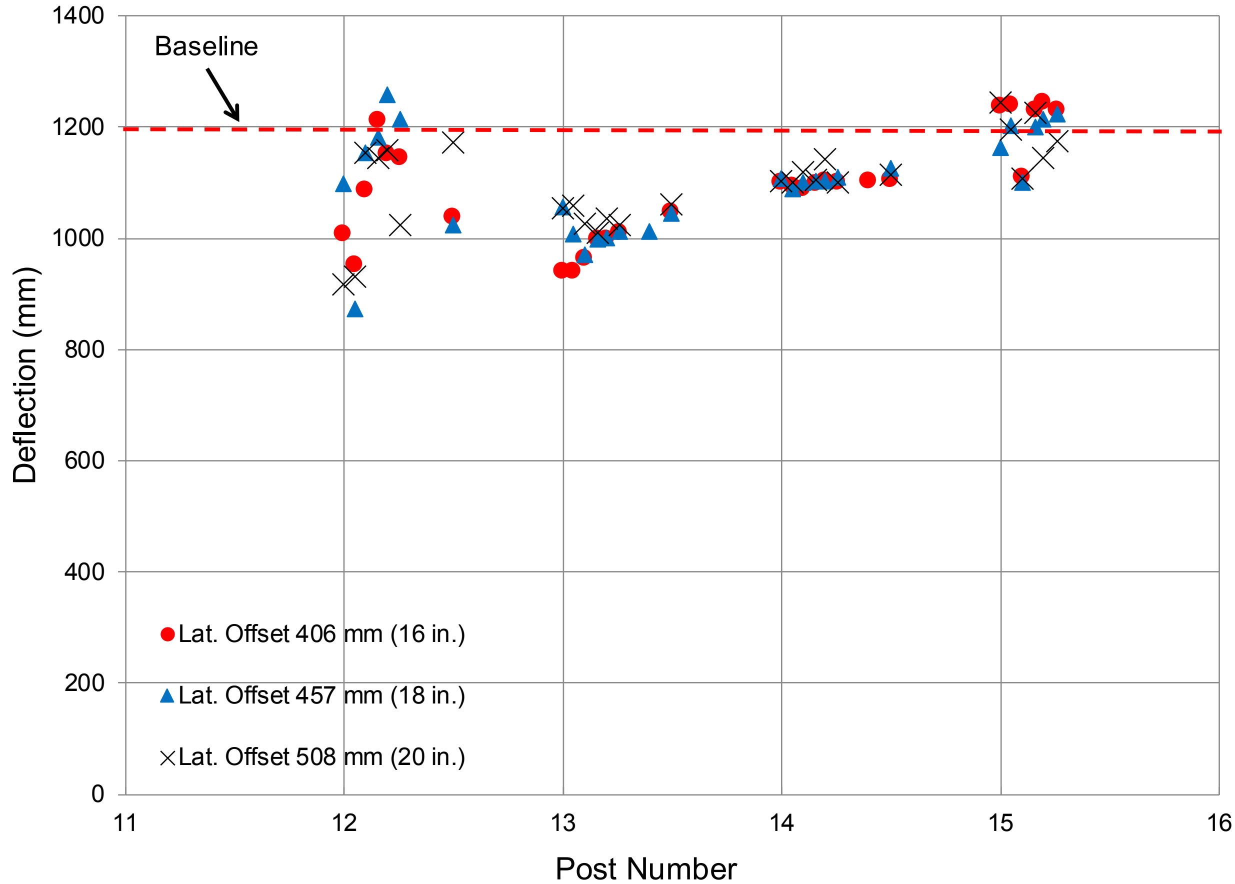


Figure 21. Maximum Rail Deflection – 2270P Vehicle

4.5.1.6 Tensile Rail Load

The maximum simulated tensile rail load at 16-, 18-, and 20-in. (406-, 457-, and 508-mm) lateral pole offsets is shown in Figure 22. The maximum tensile load on the rail was 66 kips (293.5 kN) when the pole was located at a 16-in. (406-mm) lateral offset and a 4-in. (102-mm) longitudinal offset away from post no. 12. Rail rupture was not a concern as the loads were well below the tensile capacity of the rail.

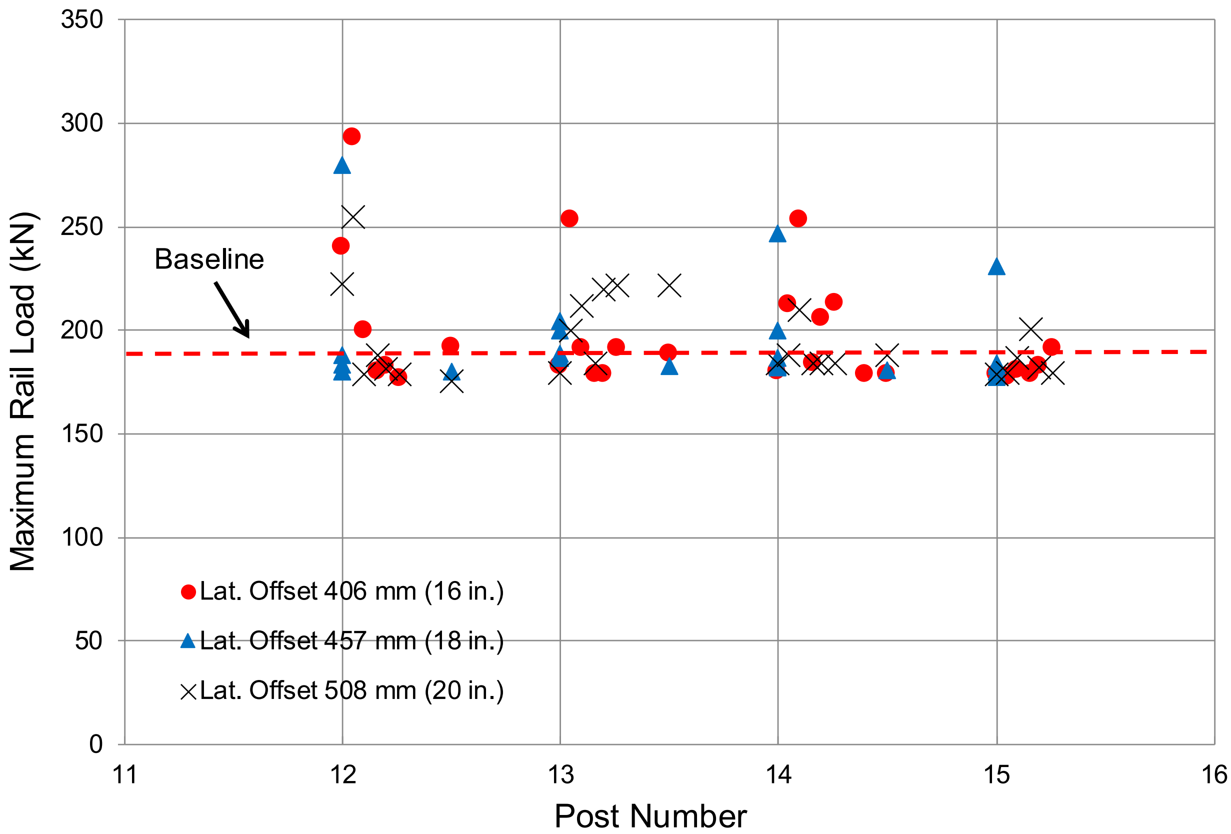


Figure 22. Maximum Rail Load – 2270P Vehicle

4.5.1.7 Critical Pole Placement

In all simulations, the vehicle was captured and redirected at lateral pole offsets of 16 in. to 20 in. (406 mm to 508 mm). Among all evaluation criteria (including vehicle stability, occupant risk, rail pocketing, vehicle snag, rail deflection, and rail load) large longitudinal ORAs and vehicle wheel snag on the pole's base were found to be the most critical. Longitudinal pole offsets downstream from post no. 13 increased longitudinal ORA and wheel snag. Based on the simulations results, a 16-in. (406-mm) lateral pole offset away from the back of the MGS posts was considered the minimum lateral offset that could reliably be evaluated with LS-DYNA without modeling the breakaway mechanism. The 16-in. (406-mm) lateral offset had a reasonable chance of passing MASH safety criteria as the large ORAs would not be likely to occur in a crash test if the pole broke away or if the impacting tire disengaged. Sequential photographs for the simulation with the most critical pole offset (i.e., pole located with a 16-in. (406-mm) lateral offset and an 8-in. (203-mm) longitudinal offset away from post no. 13) are shown in Figure 23.

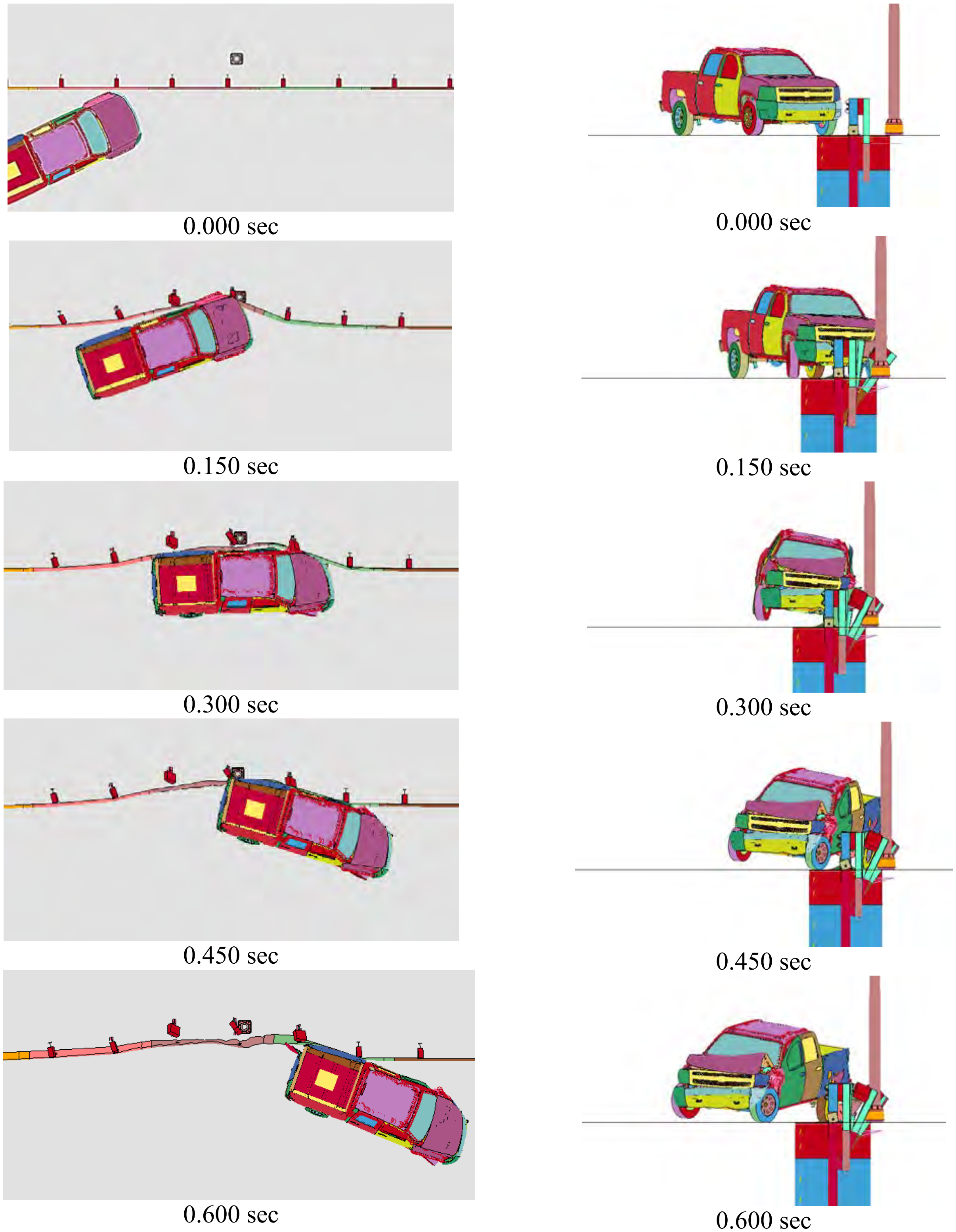


Figure 23. Sequential Photographs: 16 in. (406 mm) Lateral Offset and 8 in. (203 mm) Longitudinal Offset from Post No. 13

The project sponsor recommended using a 20-in. (508-mm) lateral pole offset between the MGS and the pole to allow sufficient clearance between a 30-in. (762-mm) diameter concrete foundation and line posts. The Illinois Tollway's leave-out requirement behind the guardrail post was 15 in. (381 mm), and the 20-in. (508-mm) lateral pole offset allows a 10-in. (254-mm) clearance from the back of steel post to the side of the concrete foundation. Other studies indicated that a 7-in. (178-mm) clear distance in the leave-out will not negatively affect post rotation and deflection [27]. In addition, constructability of the pole foundation and posts would be easier with the larger lateral offset. It was also believed that the 20-in. (508-mm) lateral pole offset would improve the performance of the combination MGS and the pole system as compared to the 16-in. (406-mm) lateral offset. Based on the simulations, the 20-in. (508-mm) lateral pole offset provided fewer concerns in terms of occupant risk, vehicle stability, roll and pitch angles, pocketing angle, rail load, and vehicle snagging as compared to the cases with 16-in. (406-mm) lateral pole offset. Thus, a 20-in. (508-mm) lateral pole offset was selected for evaluation using MASH test designation no. 3-11 crash test.

Given a 20-in. (508-mm) lateral pole offset, it was necessary to determine the critical longitudinal pole offset. It was observed that the posts do not deform in the same manner in the crash tests and simulations. Therefore, previous testing of a MGS to portable concrete barrier (PCB) transition (test no. MGSPCB-1) was analyzed to determine more precise post deflection trajectories and interaction with obstacles [28]. In test no. MGSPCB-1, a 5,079-lb (2,304-kg) pickup truck impacted the PCB to MGS transition, as shown in Figure 24, at a speed of 63.2 mph (101.7 km/h) and at an angle of 25.3 degrees. In this test, one of the posts (post no. 16) twisted, bent downstream, and hit the end of the portable concrete barrier, as shown in Figure 25. Similar post interaction was expected to occur with the presence of a pole. The trajectory of post no. 16 in test no. MGSPCB-1 (that represents post no. 13 in the present evaluation study) was closely examined with respect to the candidate longitudinal pole offsets of 8, 12, 16, 20, and 24 in. (203, 305, 406, and 610 mm), as shown in Figure 26. The longitudinal pole offset away from post no. 13 was selected to ensure that the post would have the maximum engagement with the pole upon vehicle impact. Accordingly, a 20-in. (508-mm) lateral and 24-in. (610-mm) longitudinal pole offset away from post no. 13 was recommended for evaluation under MASH test designation no. 3-11, as shown in Figure 27. Sequential photographs of the simulation with recommended pole placement for test no. 3-11 are shown in Figure 28.

Figure 24. MGS to PCB Transition, Test No. MGSPCB-1

(a)

(b)

Figure 25. Test No. MGSPCB-1: (a) Post Contact with PCB and (b) Barrier Damage

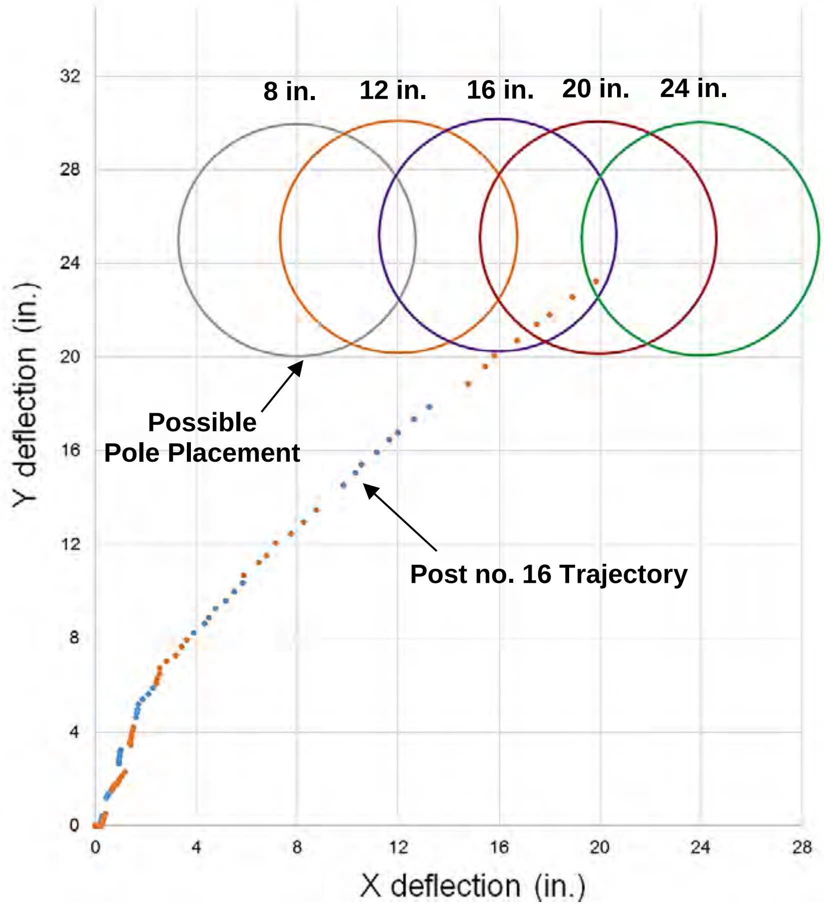


Figure 26. Estimated Possible Post and Pole Interaction

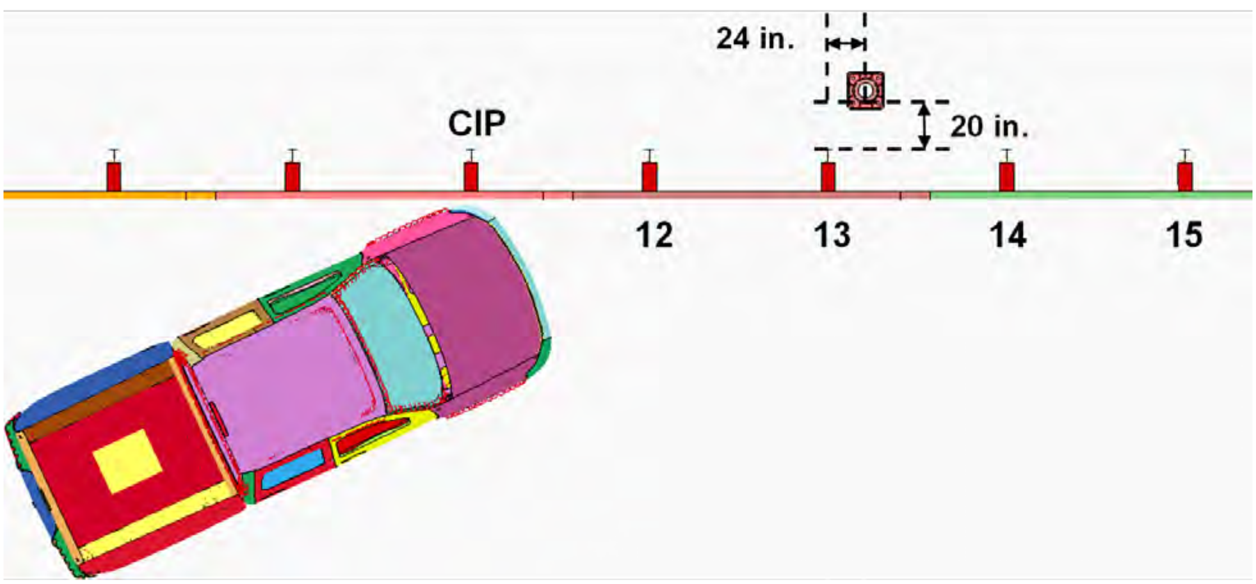


Figure 27. Recommended Pole Placement for MASH Test No. 3-11

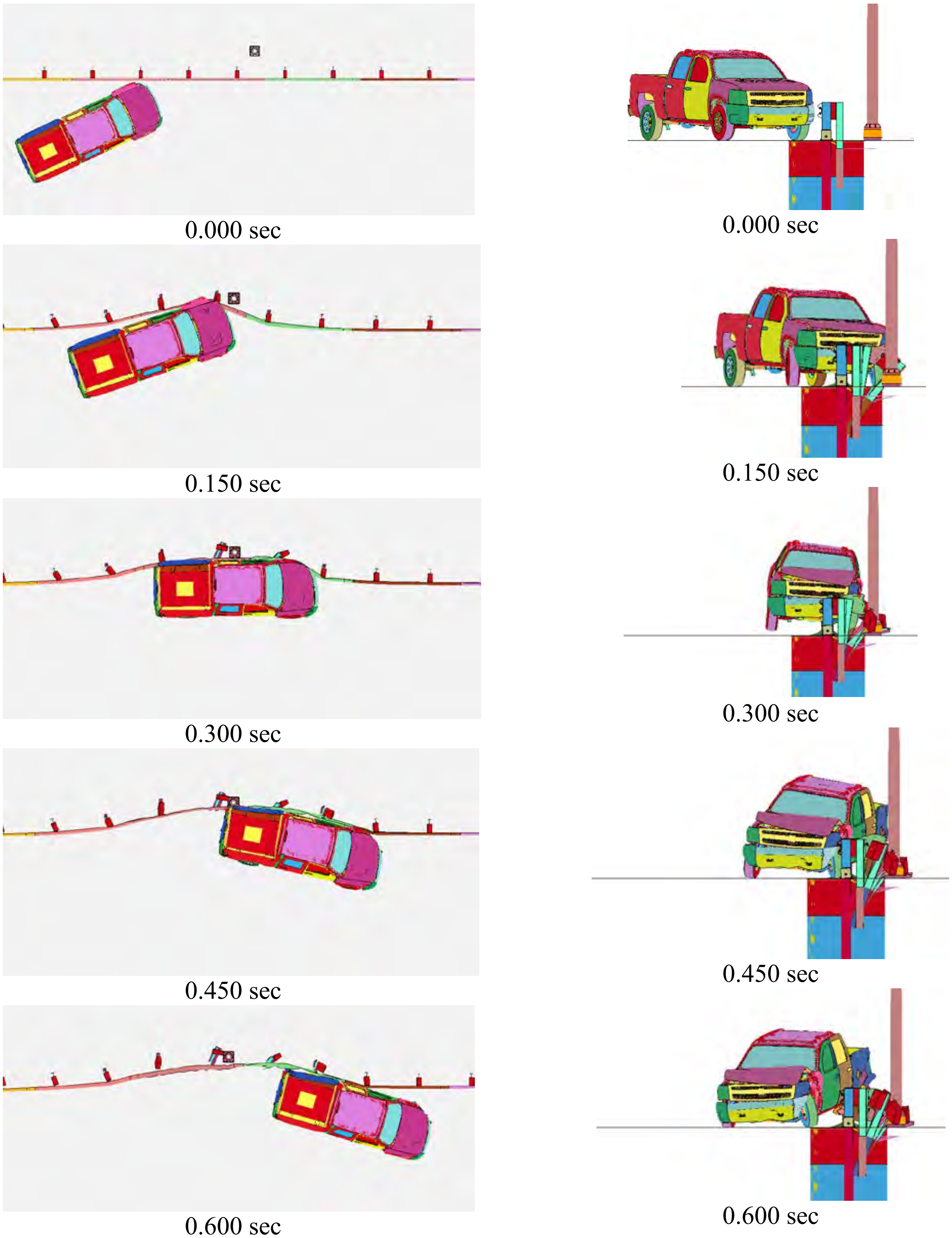


Figure 28. Sequential Photographs, Recommended Pole Placement for Test No. 3-11

4.5.2 Determination of Critical Pole Offset for Test Designation No. 3-10

The numerical analysis primarily focused on the 2270P vehicle. However, 1100C vehicle impacts were also evaluated using 16-in. and 20-in. (406-mm and 508-mm) lateral pole offsets. In test no. 2214MG-3, the maximum rail deflection was 914 mm (36 in.) [2]. The total width of the MGS is 21¼ in. (540 mm). With a 20-in. (508-mm) lateral pole offset away from the back of the post, interaction between the deflected rail and pole was not expected to occur. However, the maximum dynamic post deflection in test no. 2214MG-3 was 27 in. (686 mm). Therefore, the posts could potentially interact with the pole with a 20-in. (508-mm) lateral pole offset away from the back of the posts. Similar to the case of the 2270P pickup impacting the MGS offset away from the pole, the vehicle wheel could extend under the rail and interact with the posts and pole.

Several cases were simulated with the pole located 16 in. and 20 in. (406 mm and 508 mm) behind the back of post and longitudinal offsets varying from 4 in. to 16 in. (102 mm to 406 mm) downstream from the posts where the maximum deflection occurred (post nos. 13 and 14). The critical impact point was previously found at the midspan of post nos. 11 and 12. Similar to the pickup truck case, several simulation results were evaluated, including vehicle behavior, occupant risk, rail pocketing, vehicle snag, rail deflection, and rail load. A comparison of longitudinal ORAs, shown in Figure 29, indicated that pole placement longitudinally offset away from post no. 13 led to larger ORAs as compared to the cases where the pole was placed longitudinally offset away from post no. 14. Note, a 20-in. (508-mm) lateral pole offset was selected for the 1100C crash test, but the trend was expected to be similar.

Similar to pickup truck case, the large lateral and longitudinal ORAs, which represented increased vehicle-pole interaction, appeared to be the most important parameter, as shown in Figure 30. A summary of evaluation criteria with longitudinal offsets from post no. 13 and a 20-in. (508-mm) lateral offset is shown in Table 14. Based on the simulation, the critical pole location for small car testing was a 20 in. (508 mm) laterally offset and 8 in. (203 mm) longitudinally from post no. 13 due to high longitudinal ORAs. Sequential photographs for this simulation are shown in Figure 31.

However, a result comparison between test no. 2214MG-3 and the baseline simulation, as shown in Figure 9, indicated different post deformation and trajectories. As shown in Figure 32, the trajectory of post no. 16 in test no. 2214MG-3 was traced and overlaid with longitudinal pole offsets of 8, 12, and 16 in. (203, 305, and 406 mm). A 20-in. (508-mm) lateral and 16-in. (406-mm) longitudinal pole offset away from post no. 13 was recommended for full-scale crash testing, as shown in Figure 33. A 16-in. longitudinal offset was believed more conservative to guarantee the vehicle would impact pole. Simulated sequential images from the test designation no. 3-10 simulation with a 20-in. (508-mm) lateral pole offset and a 16-in. (406-mm) longitudinal pole offset are shown in Figure 34.

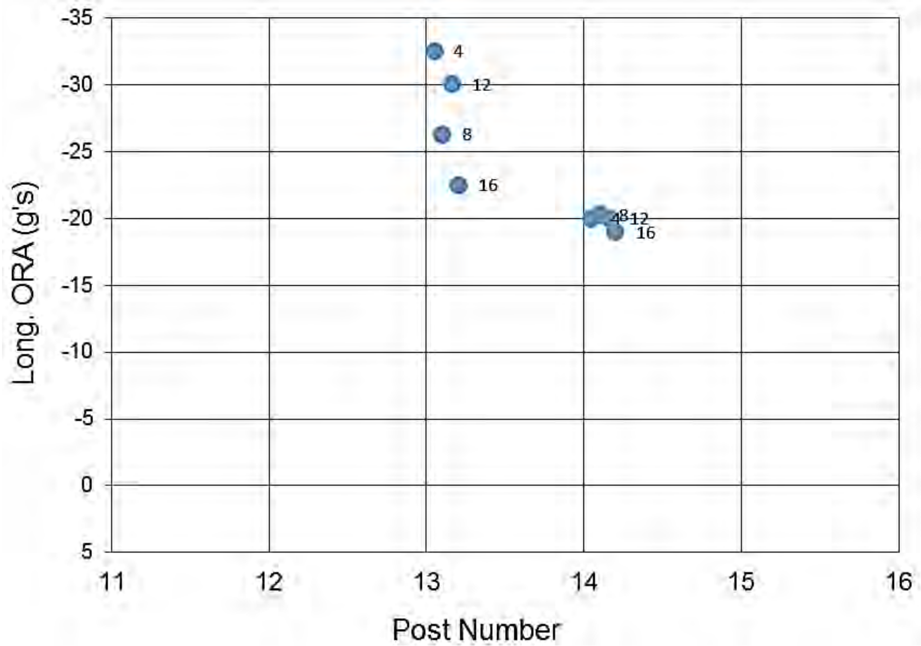


Figure 29. Simulated Longitudinal Occupant Ridedown Acceleration – 16-in. (406-mm) Lateral Offset – Test No. 3-10

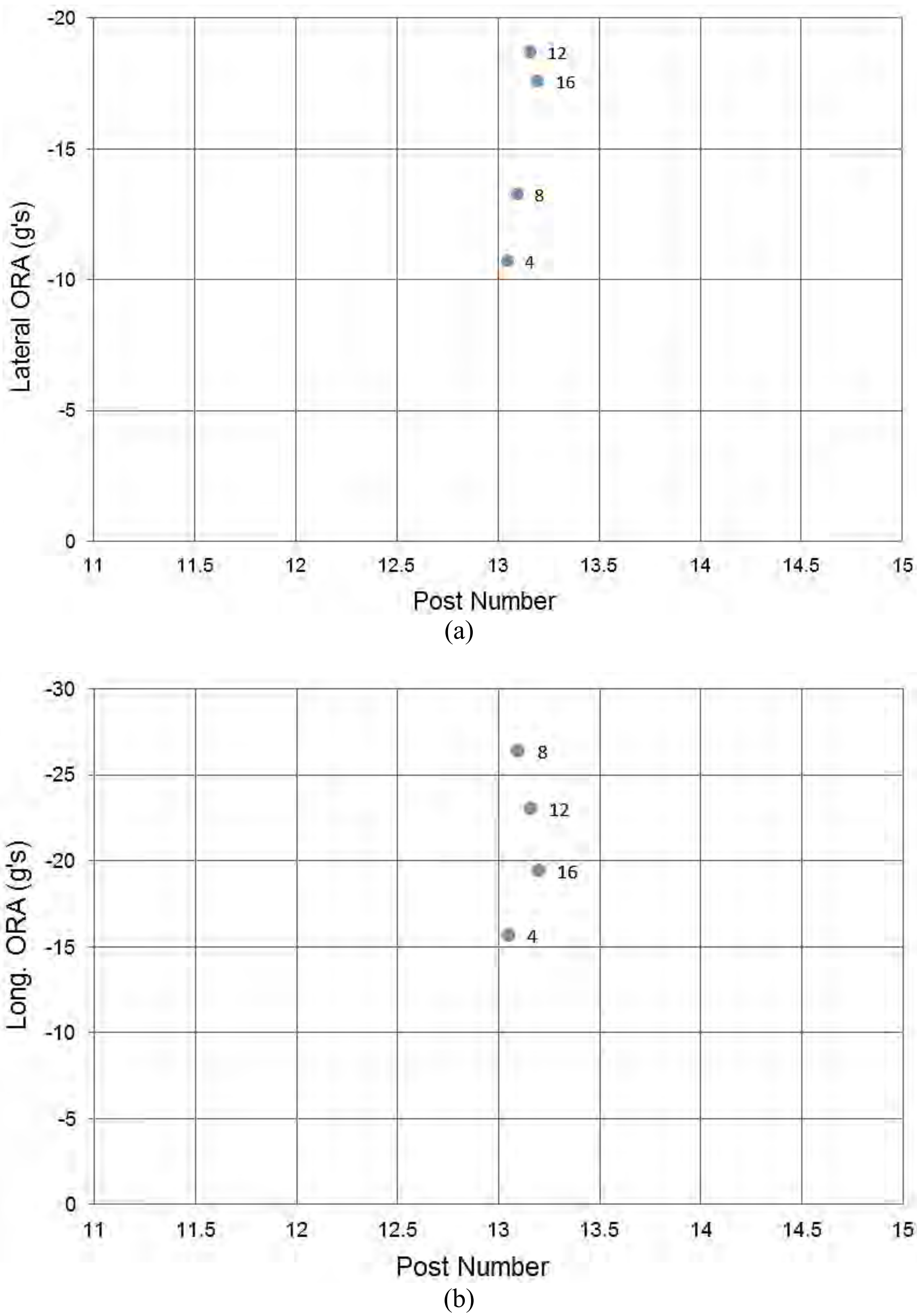


Figure 30. Simulated Occupant Ridedown Acceleration – 20-in. (508-mm) Lateral Offset from MGS – Test No. 3-10: (a) Lateral and (b) Longitudinal

Table 14. Summary of Simulation Results for Test No. 3-10 – Pole at 20-in. (508 mm) Lateral and Longitudinal Offset from Post No. 13

Case	Baseline	4 in. (102 mm) long. offset	8 in. (203 mm) long. offset	12 in. (305 mm) long. offset	16 in. (406 mm) long. offset
Lateral ORA (g's)	10.5	10.7	13.3	18.7	17.6
Longitudinal ORA (g's)	15.4	15.7	26.4	23	19.5
Lateral OIV m/s (ft/s)	18.4 (5.6)	16 (4.9)	18 (5.5)	18 (5.5)	18 (5.5)
Longitudinal OIV m/s (ft/s)	23.6 (7.2)	31 (9.4)	26 (8)	25.5 (7.8)	25.2 (7.7)
Roll (deg)	4.6	6.1	15	11.7	9.8
Pitch (deg)	1.7	3.4	9	6.5	5.1
Rail Deflection mm (in.)	28 (717)	30 (755)	26 (667)	27 (680)	27 (685)
Rail Load kN (kips)	36 (160)	36 (160)	35 (155)	32.5 (144.5)	30.6 (136)

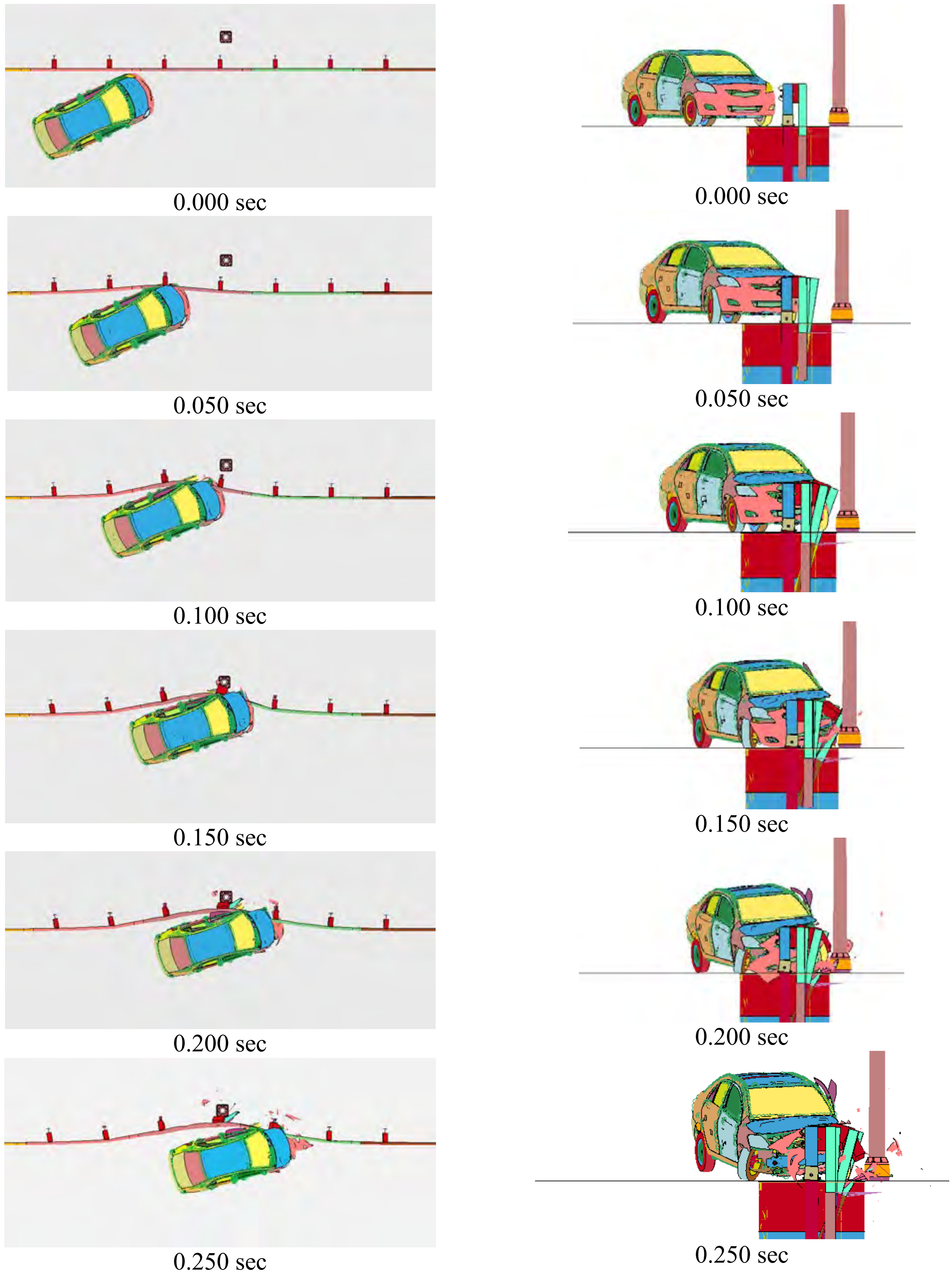


Figure 31. Simulated Sequential Photographs – 20-in. (508-mm) Lateral Offset and 8-in. (203-mm) Longitudinal Offset from Post No. 13, MASH Test No. 3-10

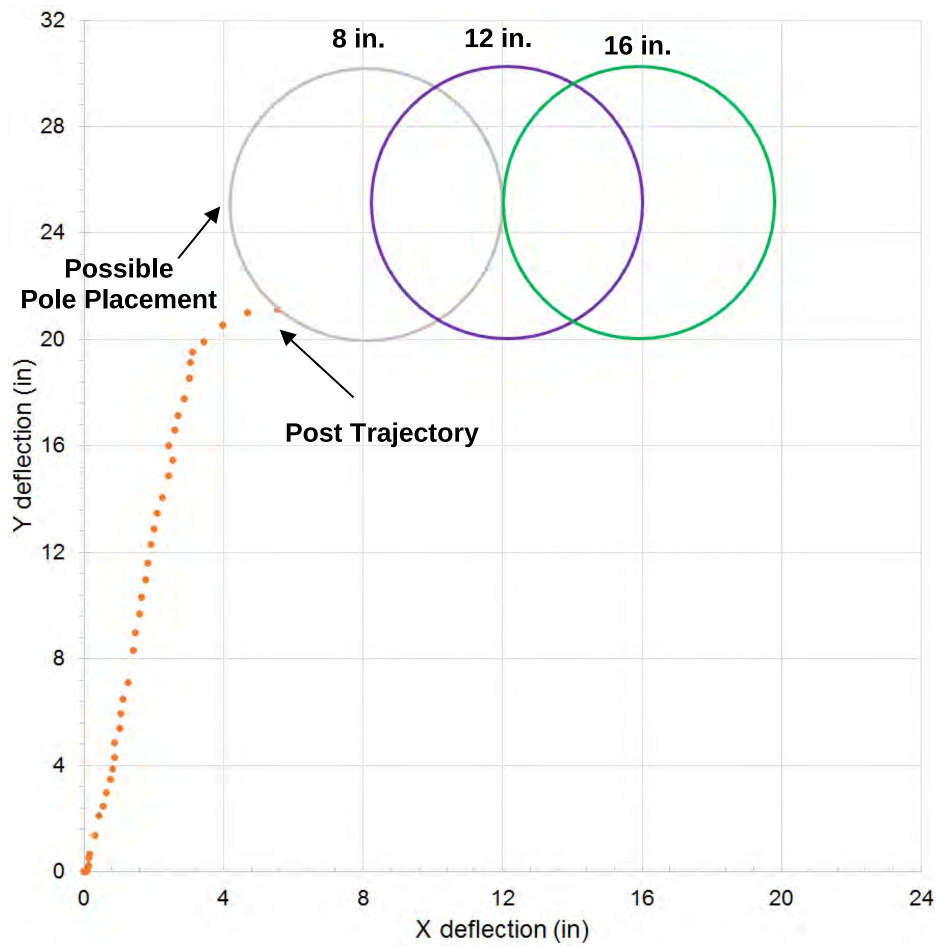


Figure 32. Estimated Possible Post and Pole Interaction – 1100C Vehicle

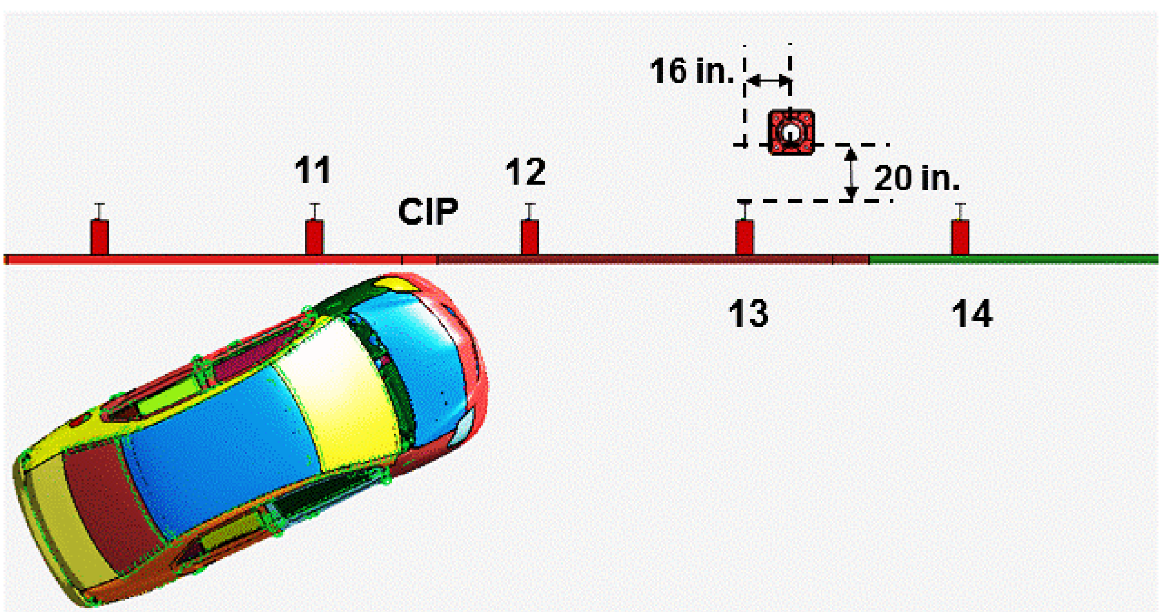


Figure 33. Recommended Pole Placement for MASH Test No. 3-10

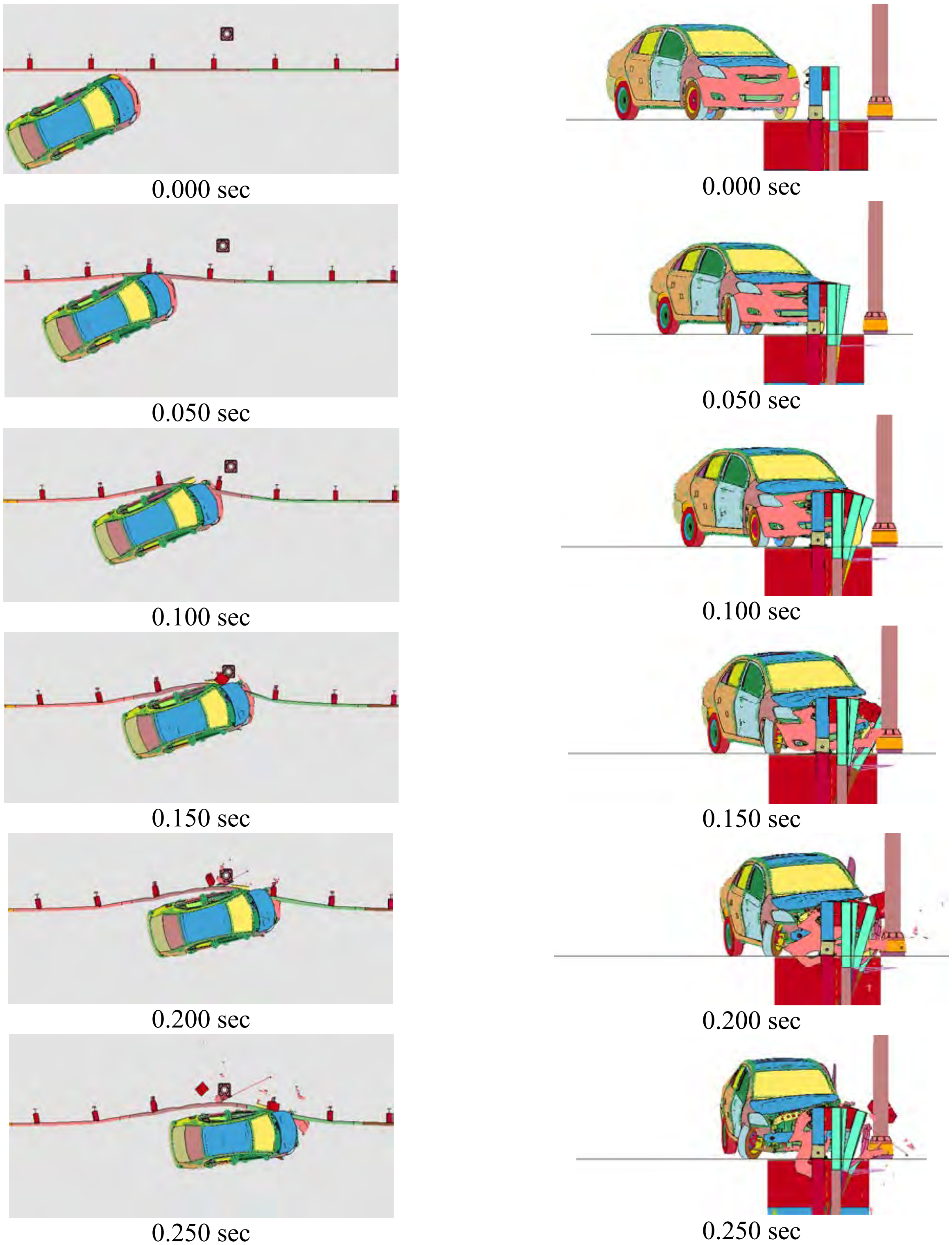


Figure 34. Simulated Sequential Photographs – 20-in. (508-mm) Lateral Offset, 16-in. (406-mm) Longitudinal Offset from Post No. 13, MASH Test No. 3-10

5 TEST INSTALLATION – DESIGN DETAILS

5.1 Test No. ILT-1

The W-beam guardrail system was comprised of 175 ft (53.25 m) of standard, 12-gauge (2.66-mm) thick W-beam rail segments supported by steel posts with a light pole placed 20 in. (508 mm) laterally behind the posts, as shown in Figure 35. End anchorage systems were used on both the upstream and downstream ends of the guardrail system. Design details are shown in Figures 35 through 62. Photographs of the test installation in a mirrored orientation are shown in Figures 63 through 66. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix E.

The MGS was constructed with 29 guardrail posts. Post nos. 3 through 27 w ere galvanized ASTM A992/A709-36 steel W6x8.5 sections measuring 6 ft (1,829 mm) long. Post nos. 1, 2, 28, and 29 were timber posts measuring 5.5 in. x 7.5 in. x 42.5 in. (140 mm wide x 190 mm deep x 1,080 mm long) and were placed in 6-ft (1,829-mm) long steel foundation tubes, as shown in Figures 39 and 40. The timber BCT posts and foundation tubes were part of the end anchor systems that were designed to replicate the capacity of a tangent guardrail terminal.

Post nos. 1 through 29 were spaced 75 in. (1,905 mm) on center with a soil embedment depth of 40 in. (1,016 mm), as shown in Figure 37. The posts were placed in a compacted coarse, crushed limestone material with a strength that satisfied MASH criteria. For post nos. 3 through 27, 6-in. x 12-in. x 14.25-in. (152-mm wide x 30 5-mm deep x 362 -mm long) wood spacer blockouts were used to block the rail away from the front face of the steel posts.

Standard 12-gauge (2.66-mm) thick W-beam rails were placed between post nos. 1 and 29, as shown in Figures 35 and 38. The top rail height was 31 in. (787 mm) with rail splices at the midspan locations. All lap-splice connections between the rail sections were configured to reduce vehicle snag at the splice during the crash test.

The Illinois Tollway standard light pole measures 50 ft (15.25 m) tall with a 15-ft (4.6-m) long mast arm and 0.31-in. (8-mm) wall thickness, as shown in Figure 36. The pole is supported on a breakaway transformer base manufactured by Hapco. The pole has a 10-in. (254-mm) base diameter and a 6-in. (152-mm) top diameter. The 9-in. (229-mm) tall breakaway transformer base was fabricated from 356-T6 aluminum, as shown in Figures 52 and 53. The weights of the pole shaft and arm mast were 484 lb (219.5 kg) and 52 lb (23.6 kg), respectively. Approximately 55 lb (25 kg) of steel plate was added to the end of the luminaire arm to simulate the luminaire weight. The total weight of the pole assembly was 591 lb (268.1 kg). The front face of the pole was offset 20 in. (508 mm) laterally behind the back of the posts, and the centerline of the pole was offset 24 in. (610 mm) longitudinally from the centerline of post no. 13.

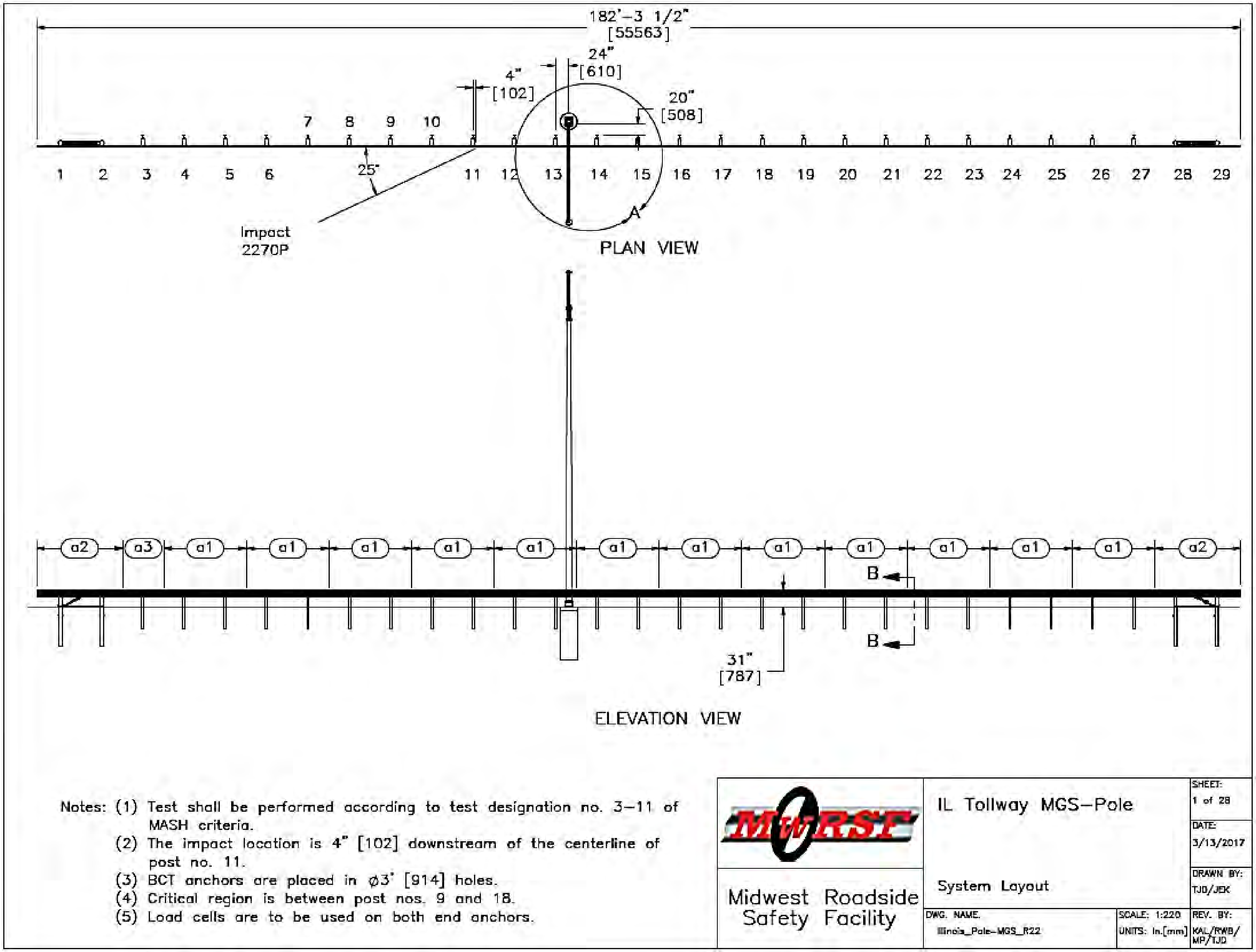


Figure 35. System Layout, Test No. ILT-1

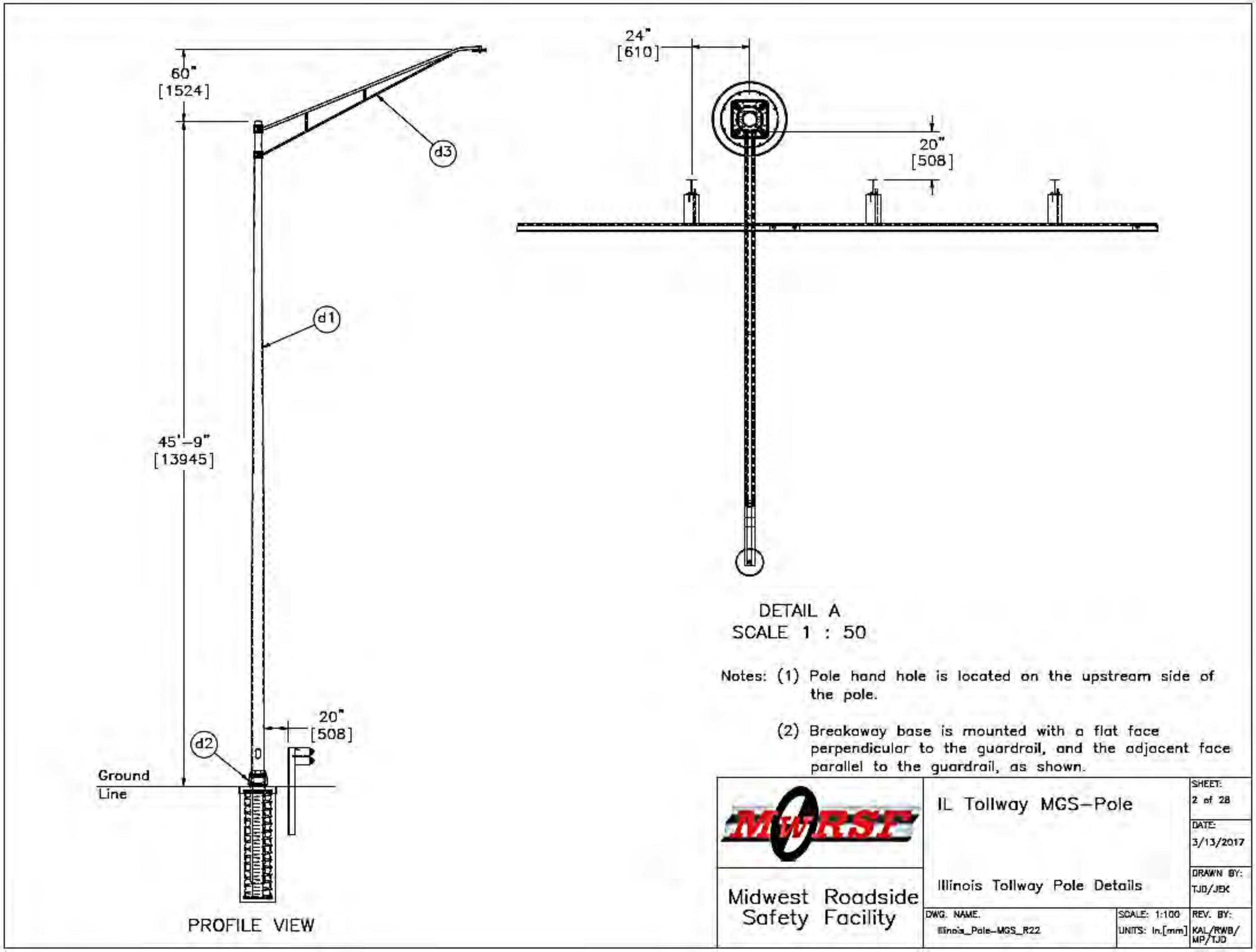


Figure 36. Illinois Tollway Pole Details, Test No. ILT-1

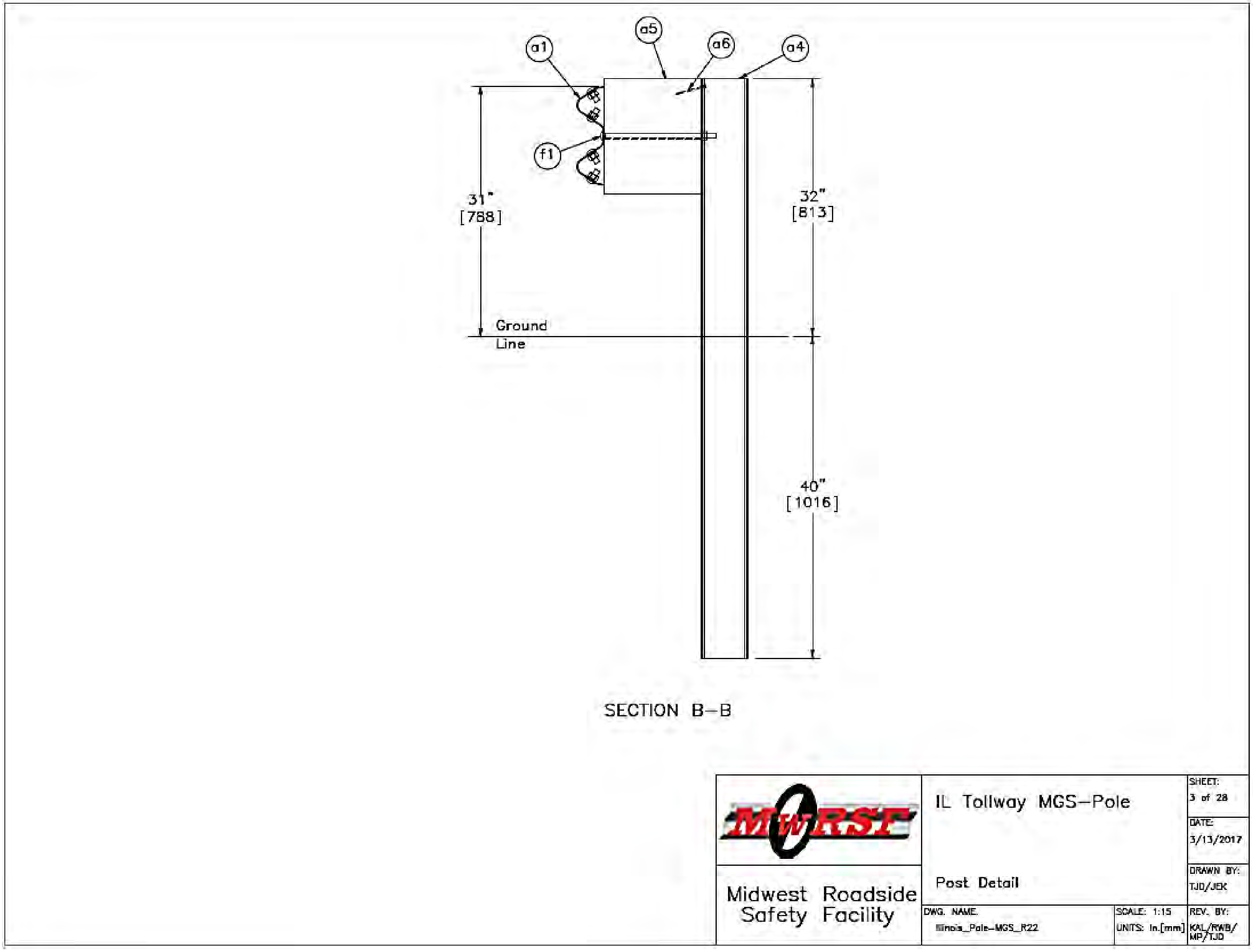


Figure 37. Post Detail, Test No. ILT-1

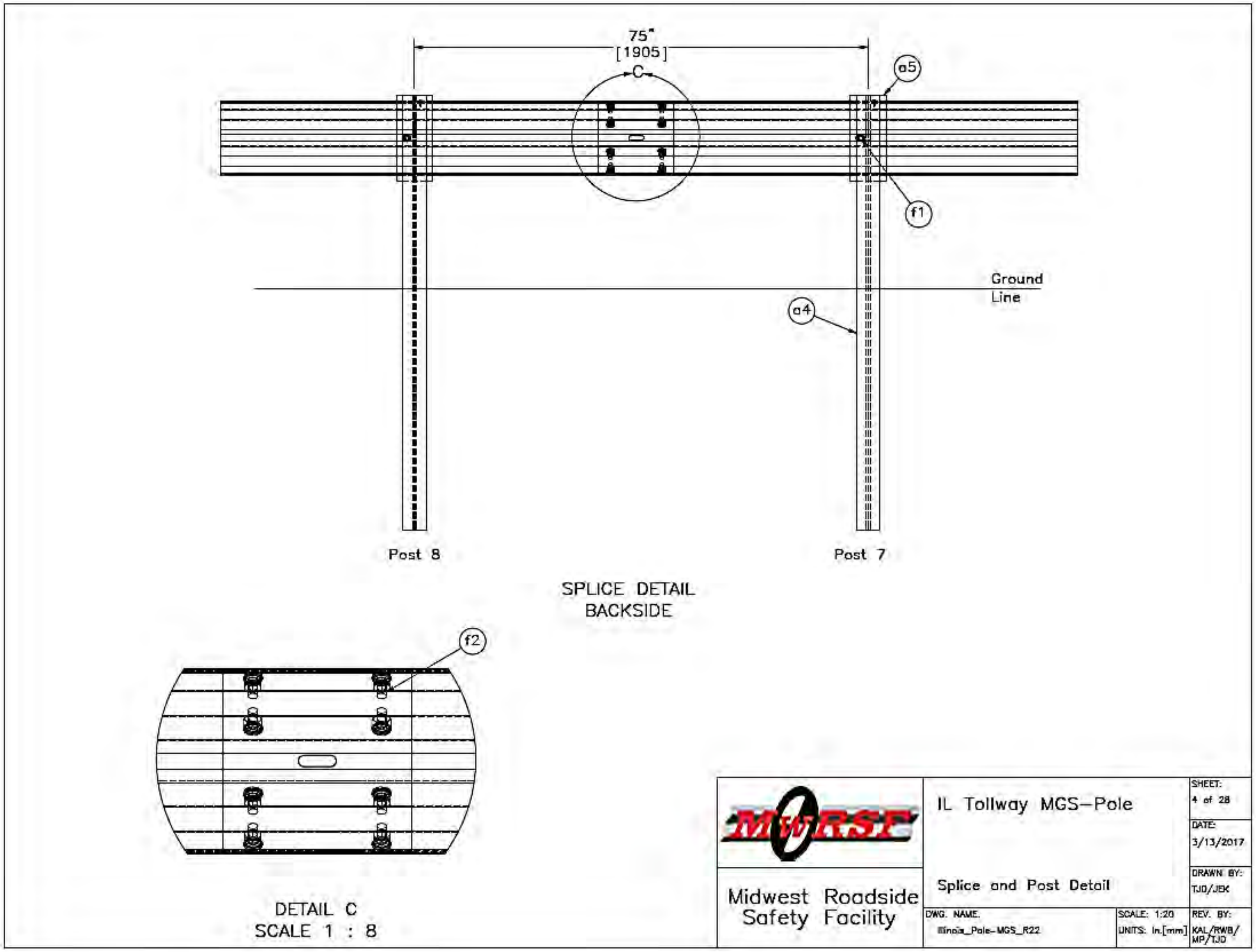


Figure 38. Splice and Post Detail, Test No. ILT-1

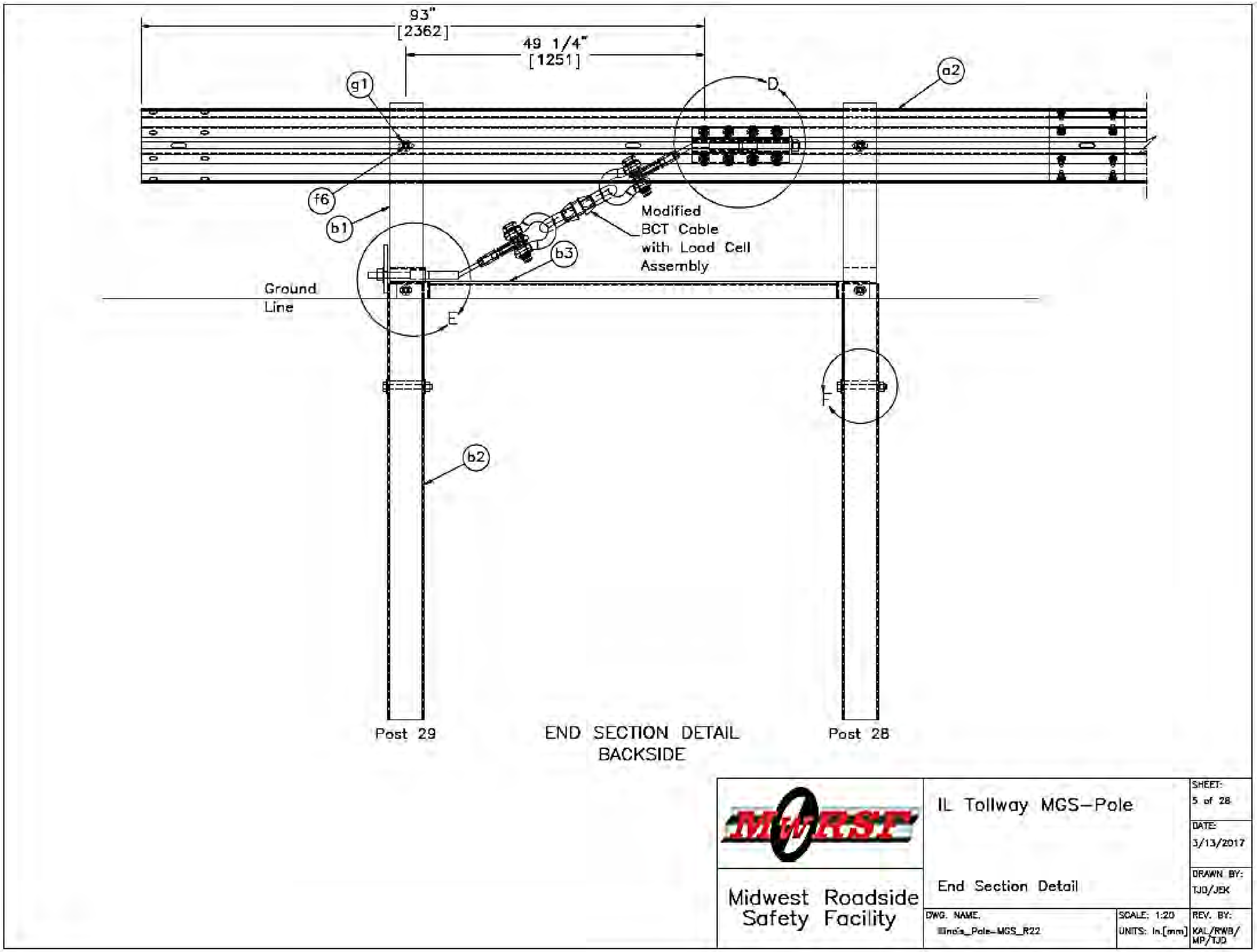


Figure 39. End Section Detail, Test No. ILT-1

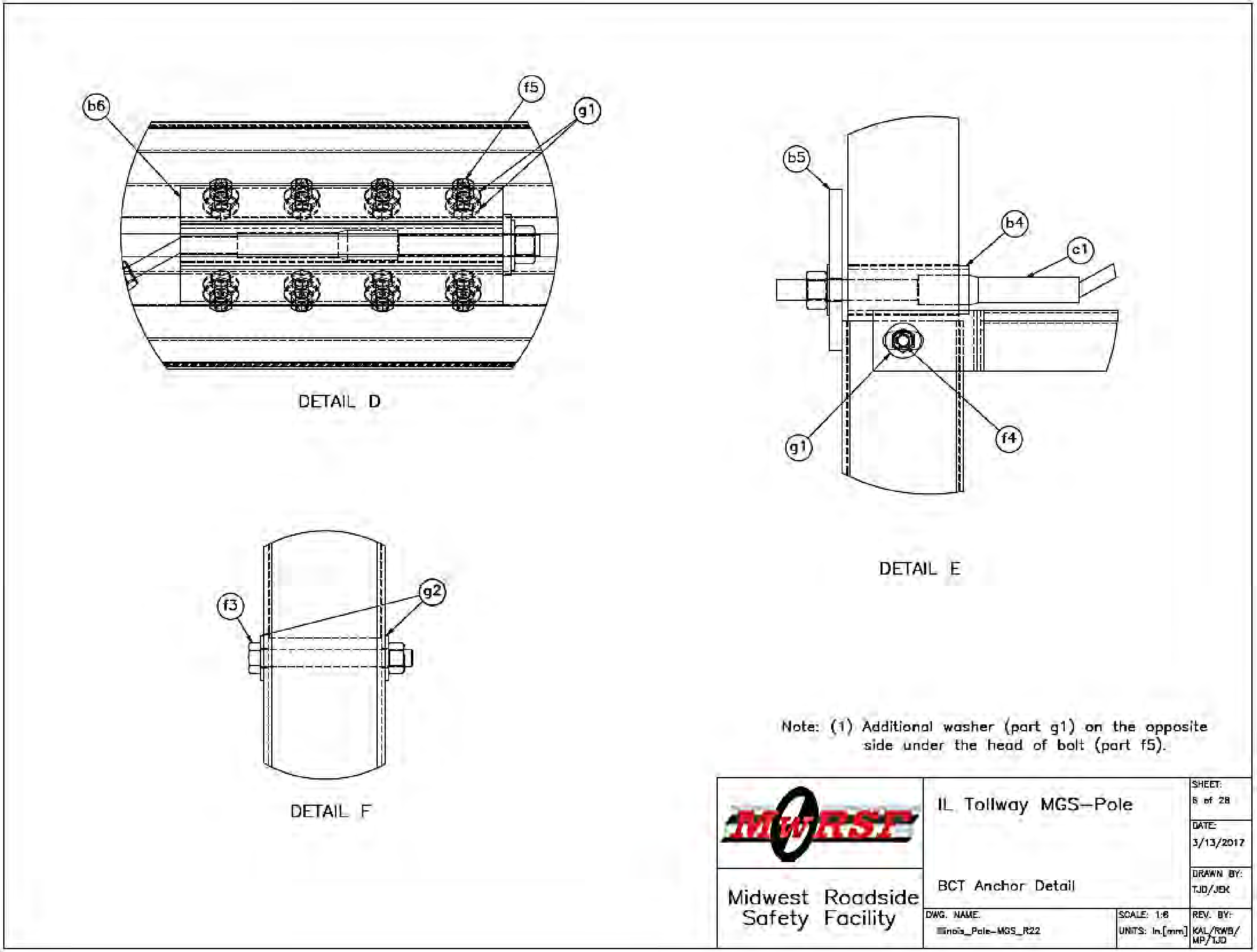


Figure 40. BCT Anchor Detail, Test No. ILT-1

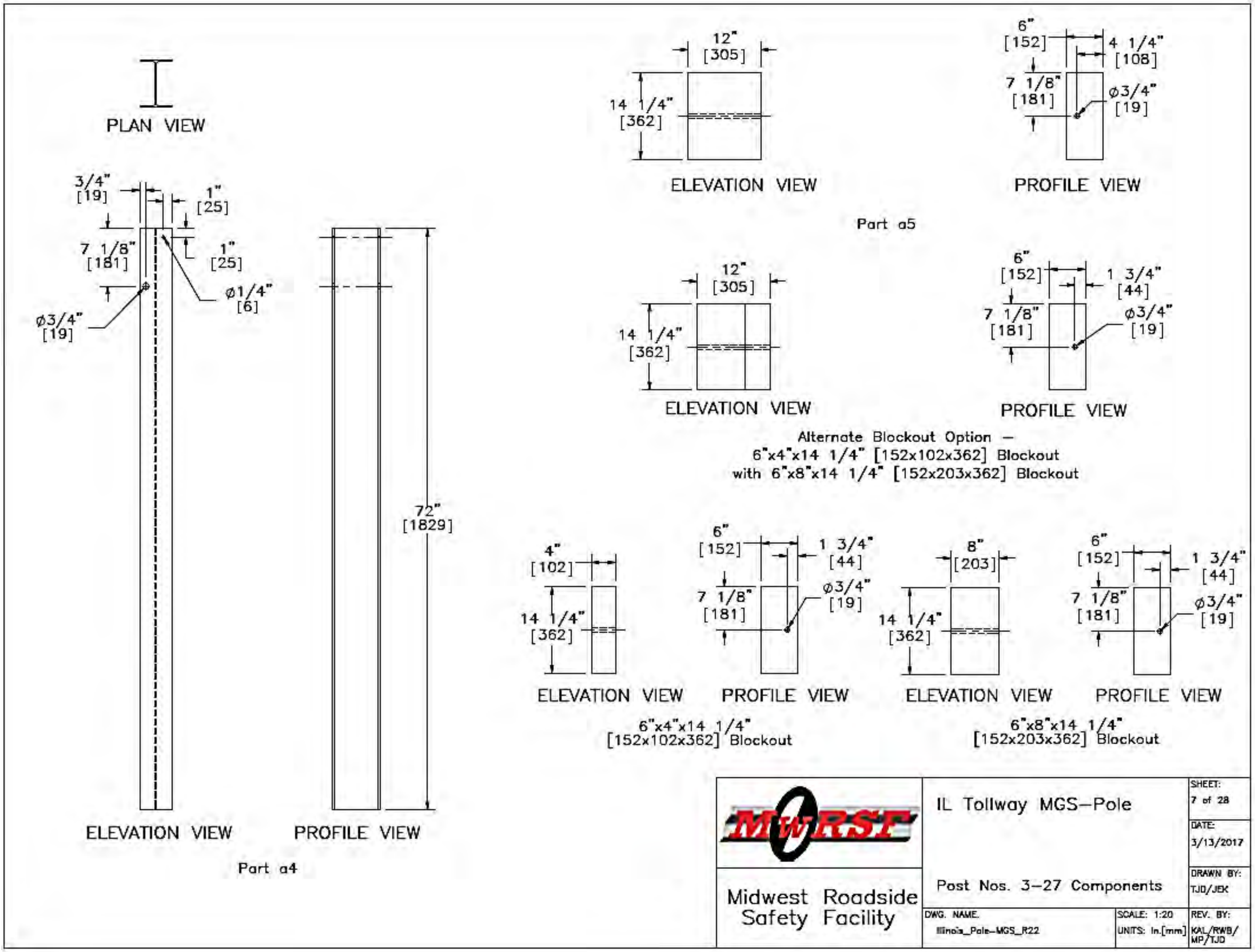


Figure 41. Post Nos. 3-27 Components, Test No. ILT-1

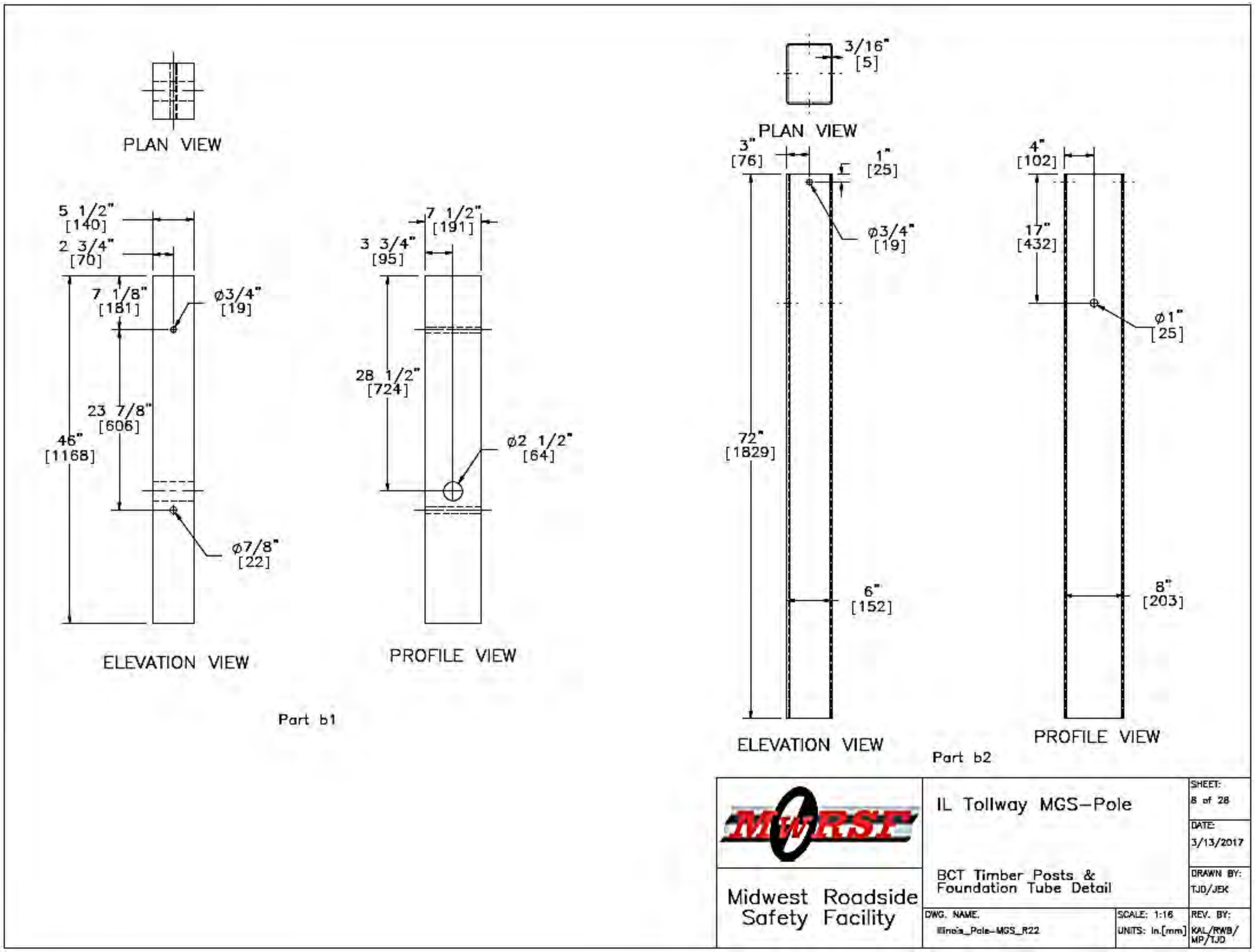


Figure 42. BCT Timber Posts and Foundation Tube Detail, Test No. ILT-1

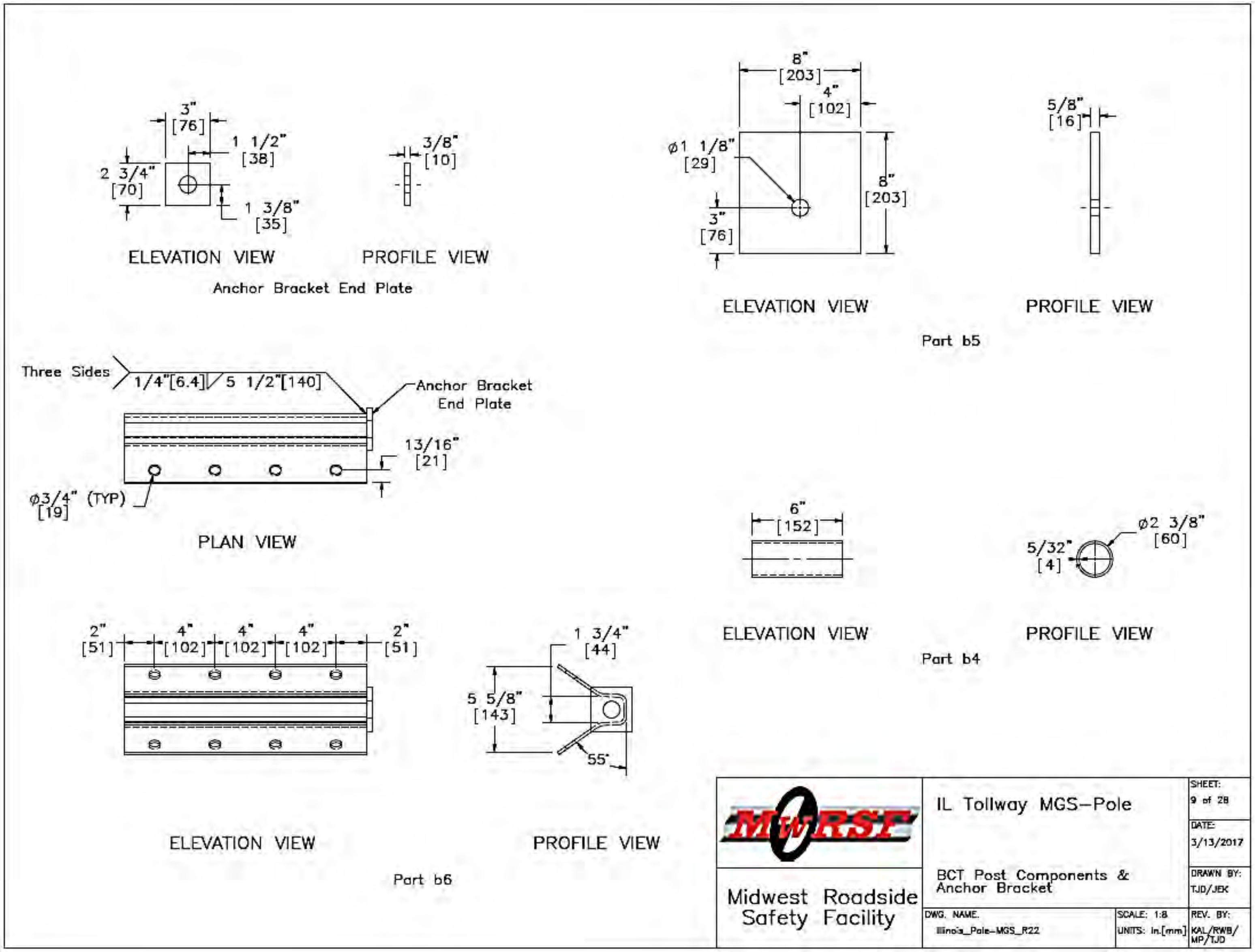


Figure 43. BCT Post Components and Anchor Bracket, Test No. ILT-1

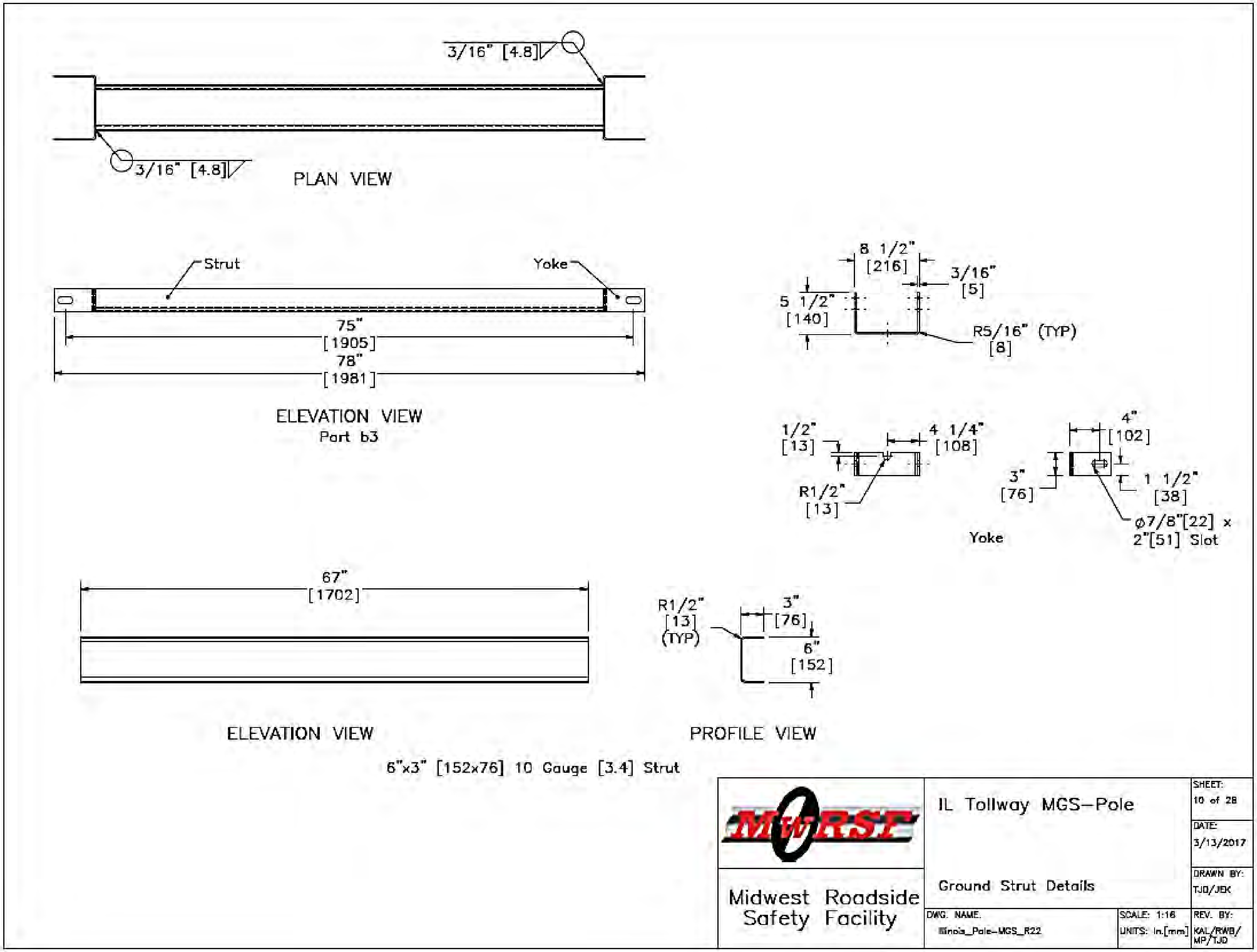


Figure 44. Ground Strut Details, Test No. ILT-1

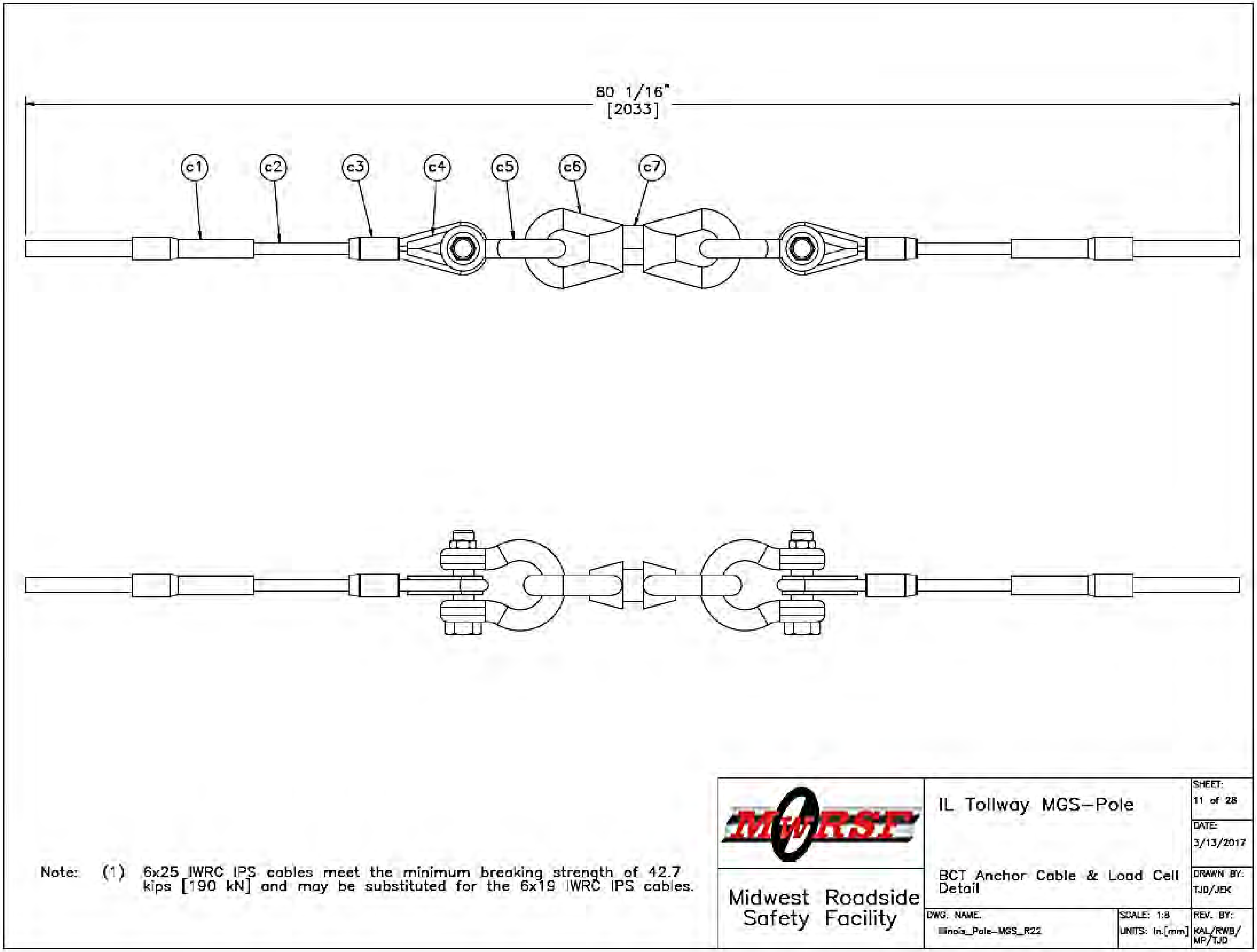


Figure 45. BCT Anchor Cable and Load Cell Detail, Test No. ILT-1

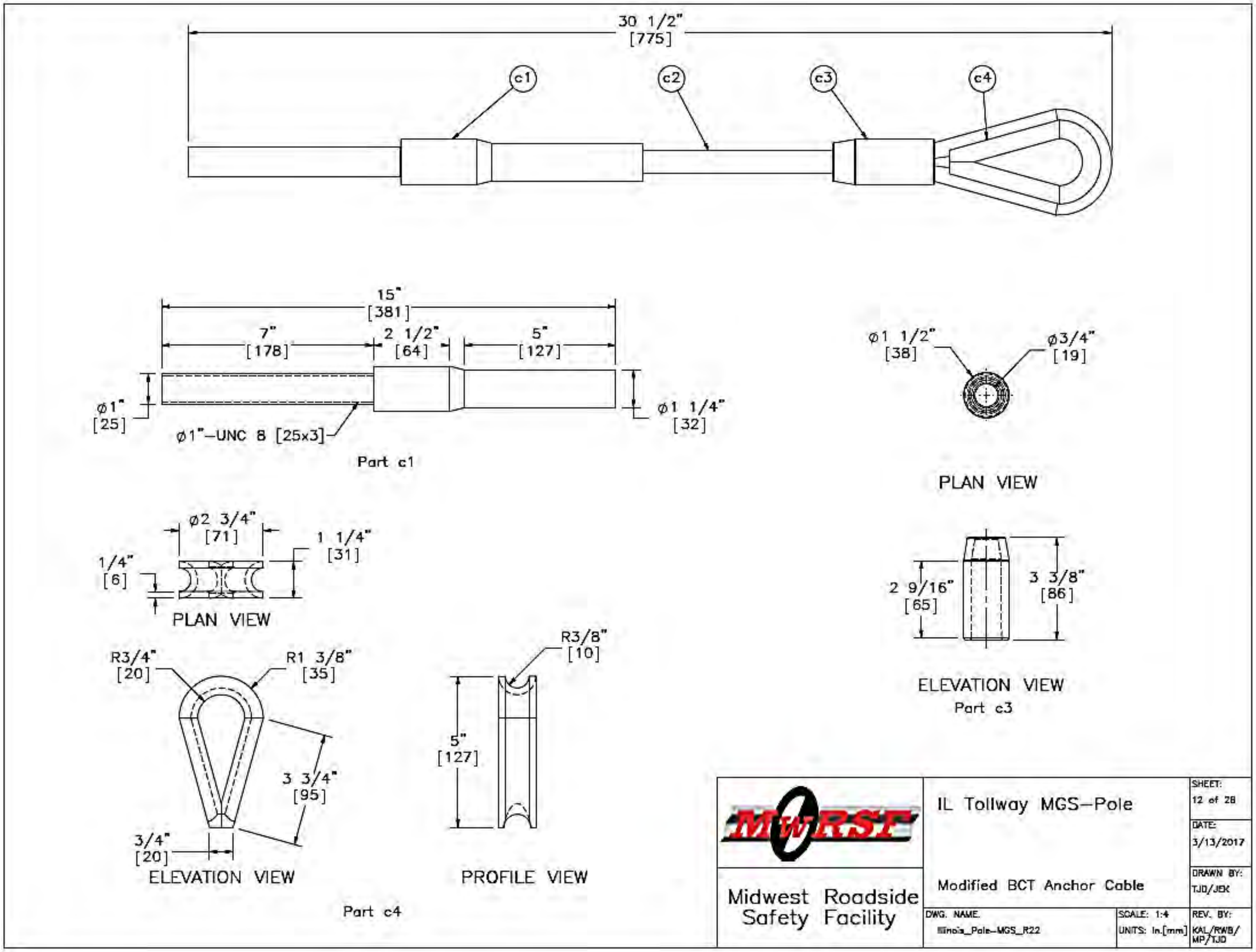


Figure 46. Modified BCT Anchor Cable, Test No. ILT-1

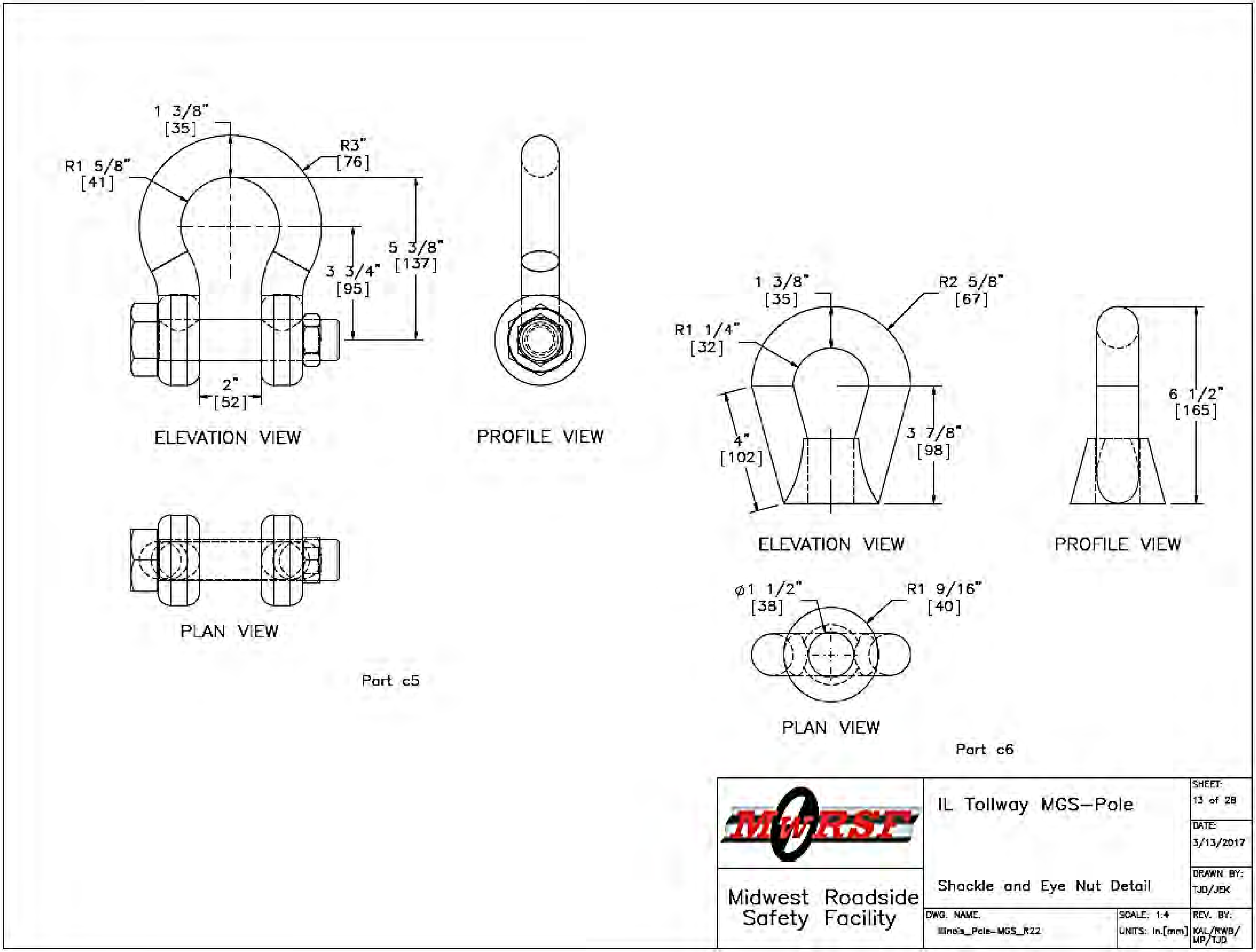


Figure 47. Shackle and Eye Nut Detail, Test No. ILT-1

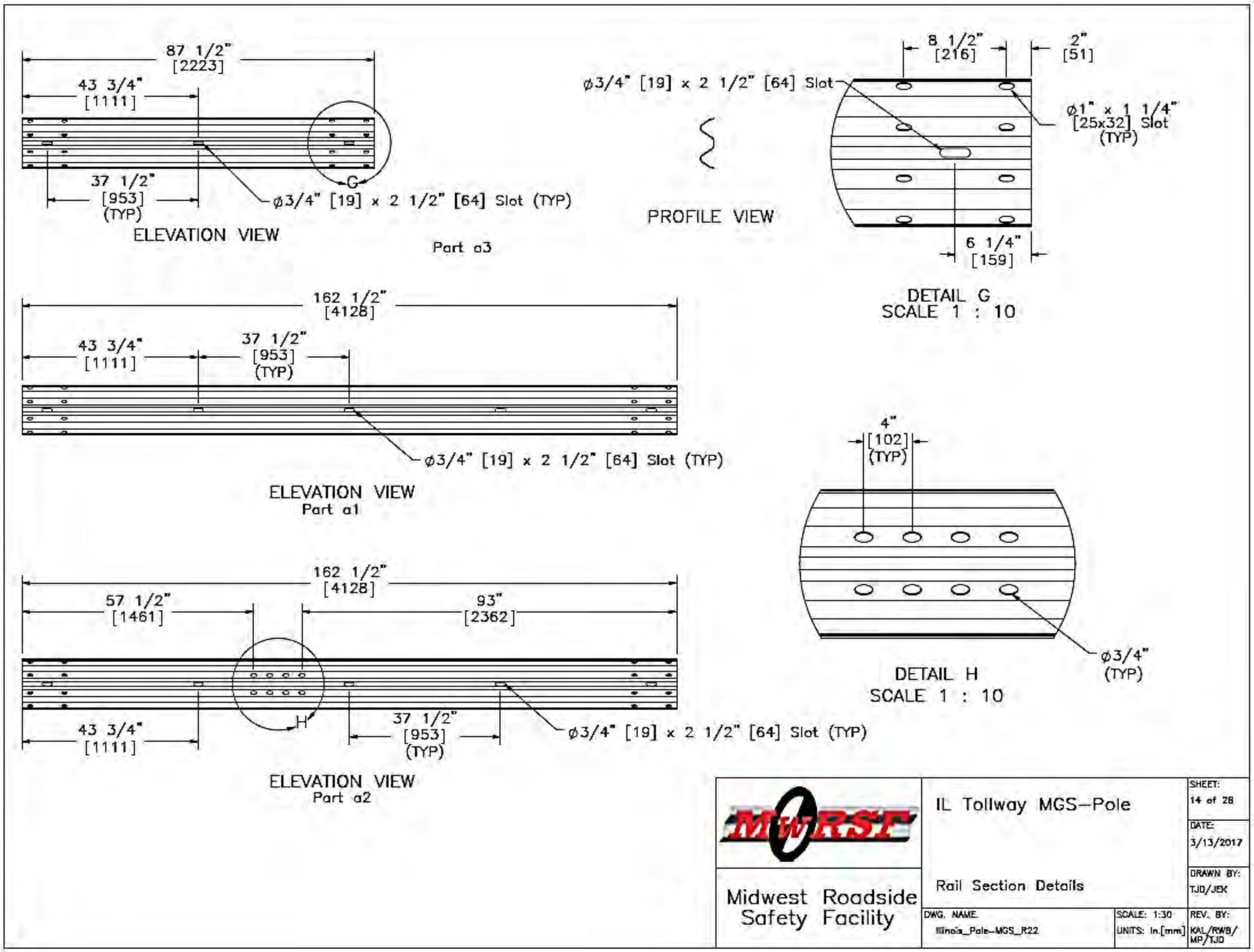


Figure 48. Rail Section Details, Test No. ILT-1

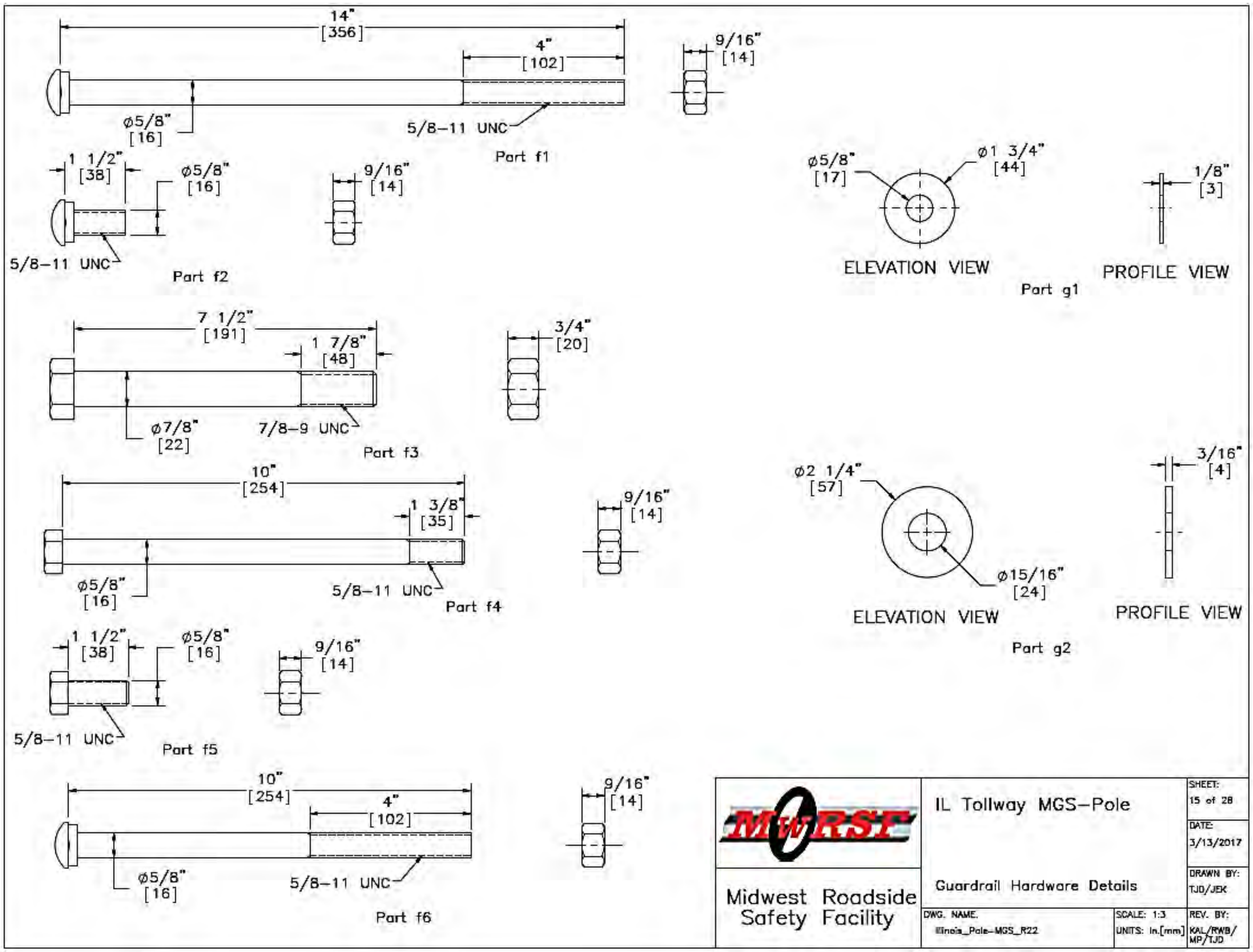


Figure 49. Guardrail Hardware Details, Test No. ILT-1

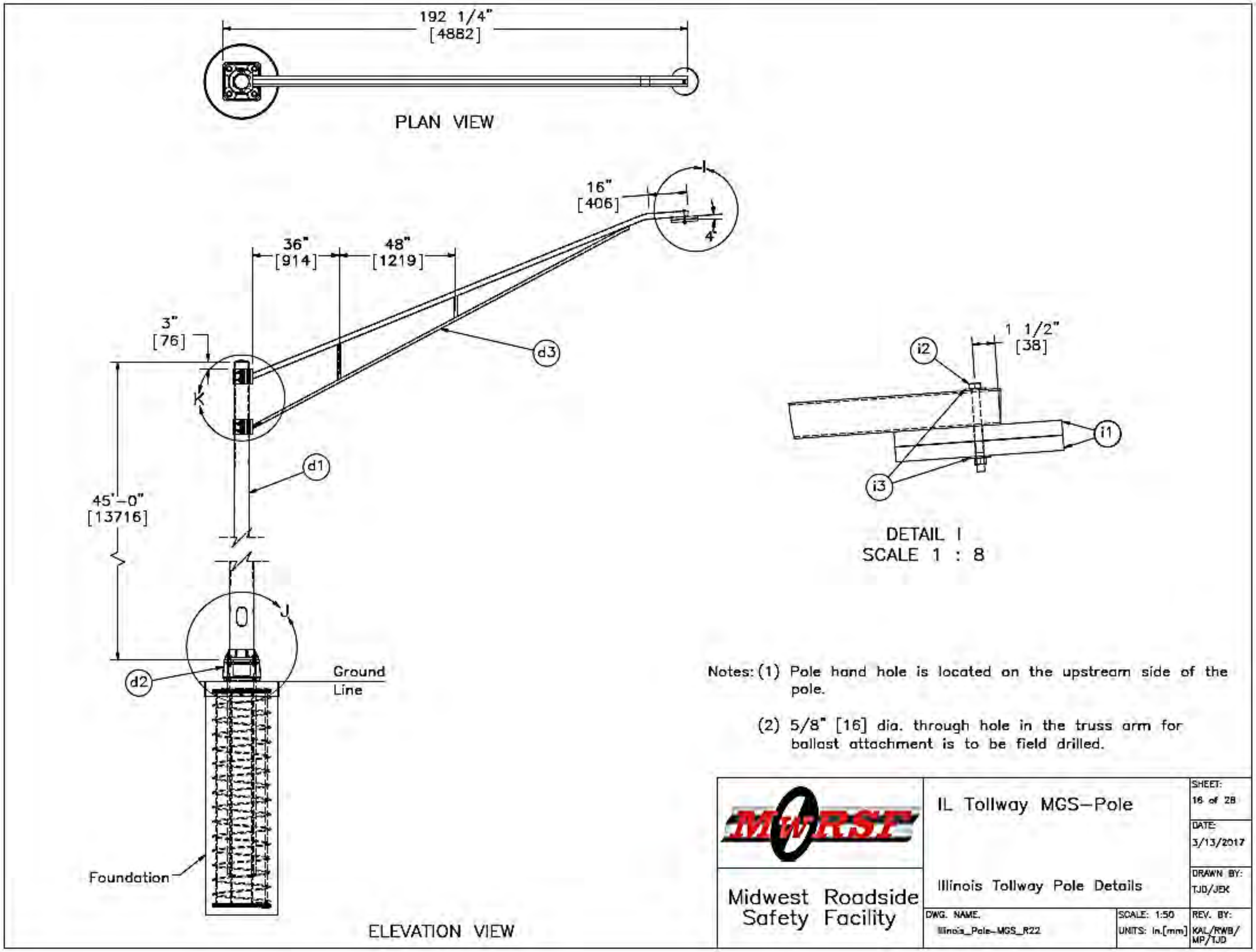


Figure 50. Illinois Tollway Pole Details, Test No. ILT-1

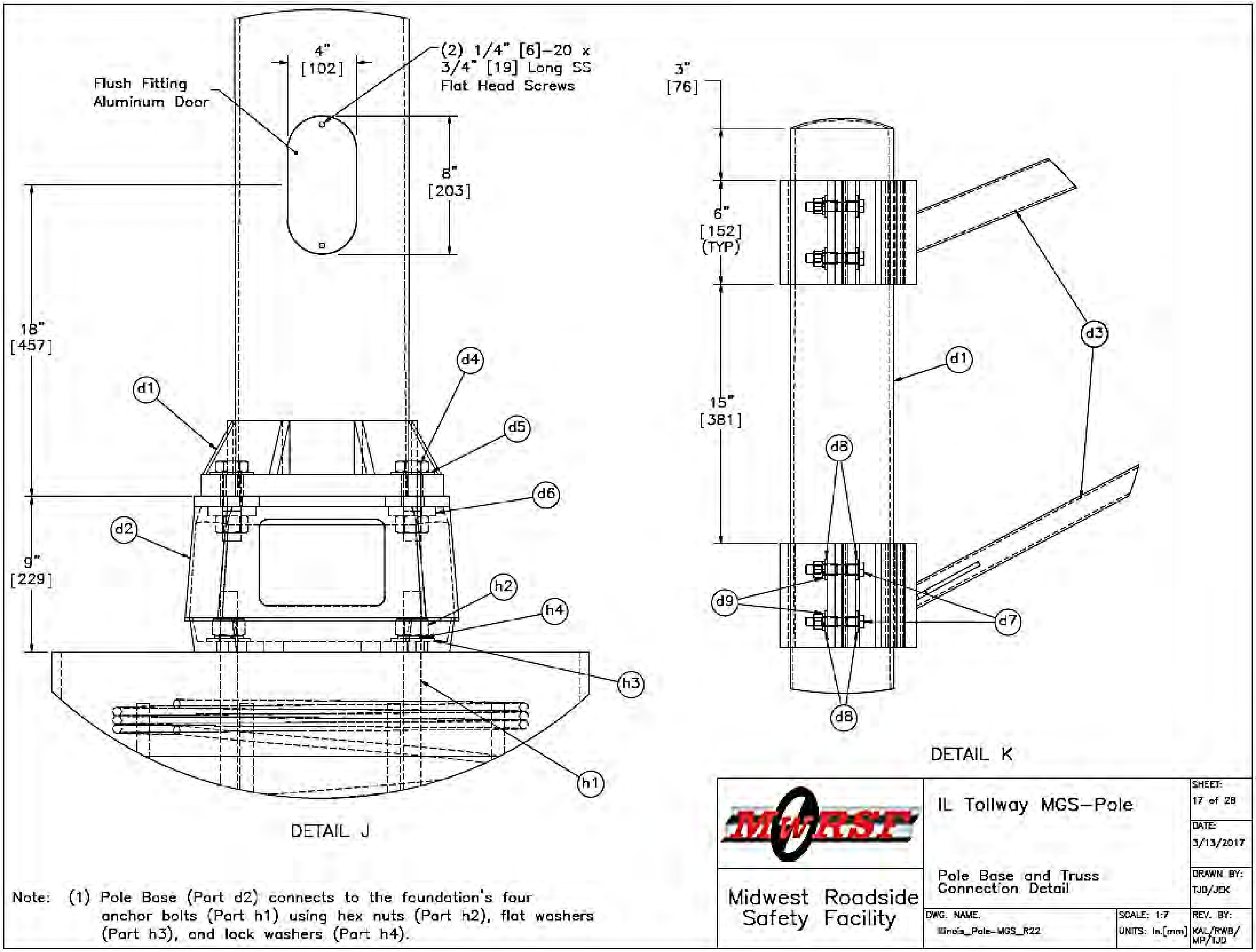


Figure 51. Pole Base and Truss Connection Detail, Test No. ILT-1

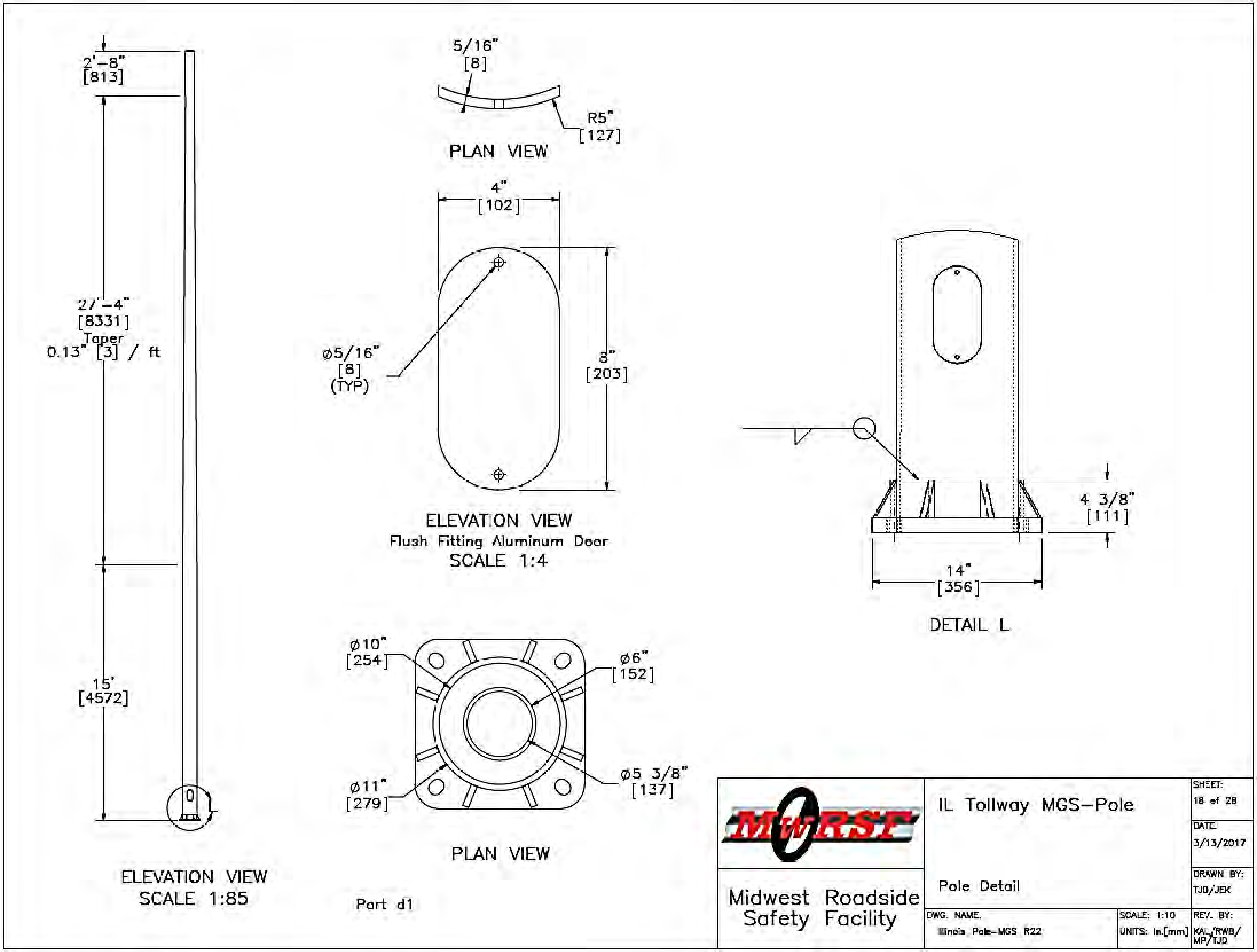


Figure 52. Pole Detail, Test No. ILT-1

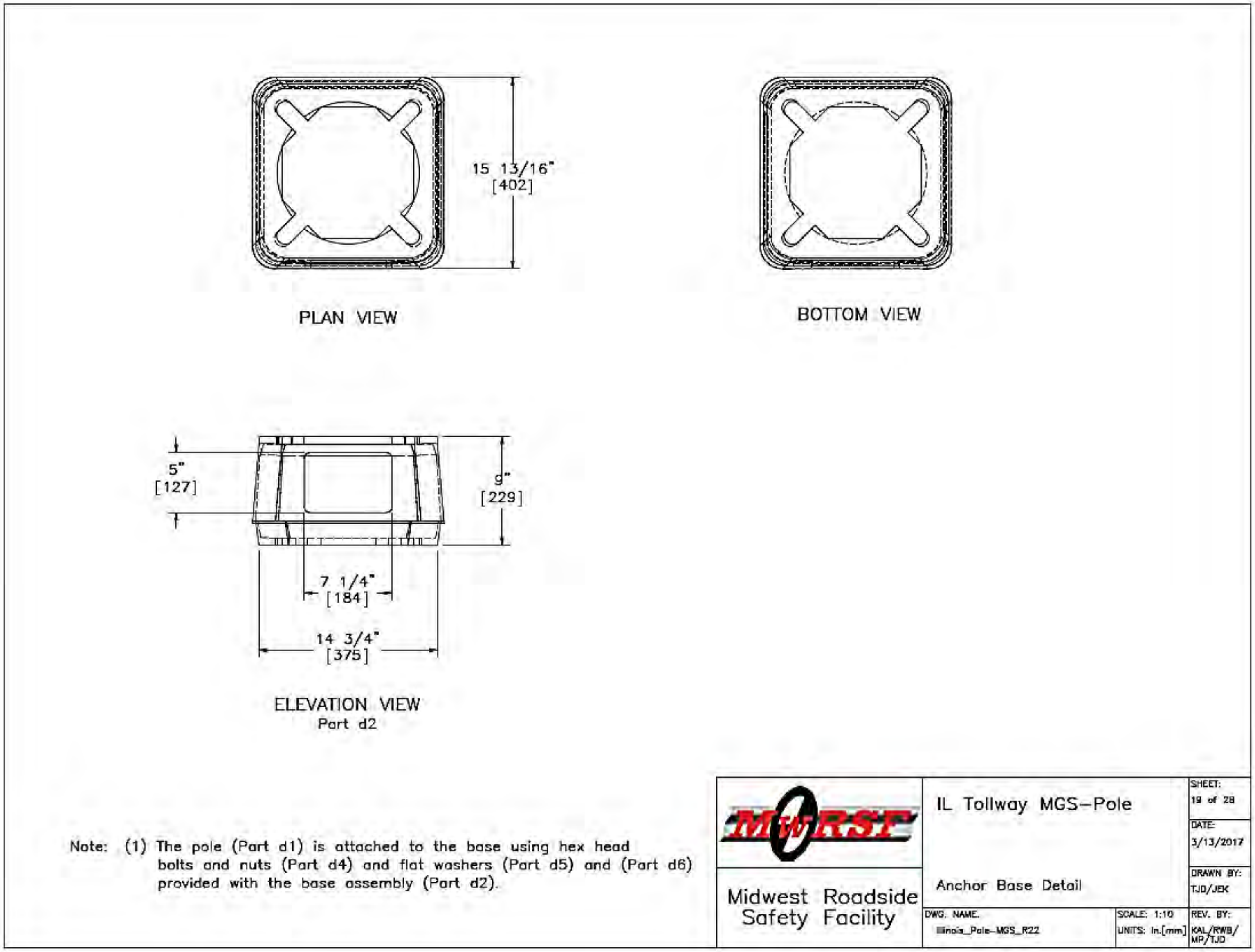


Figure 53. Anchor Base Detail, Test No. ILT-1

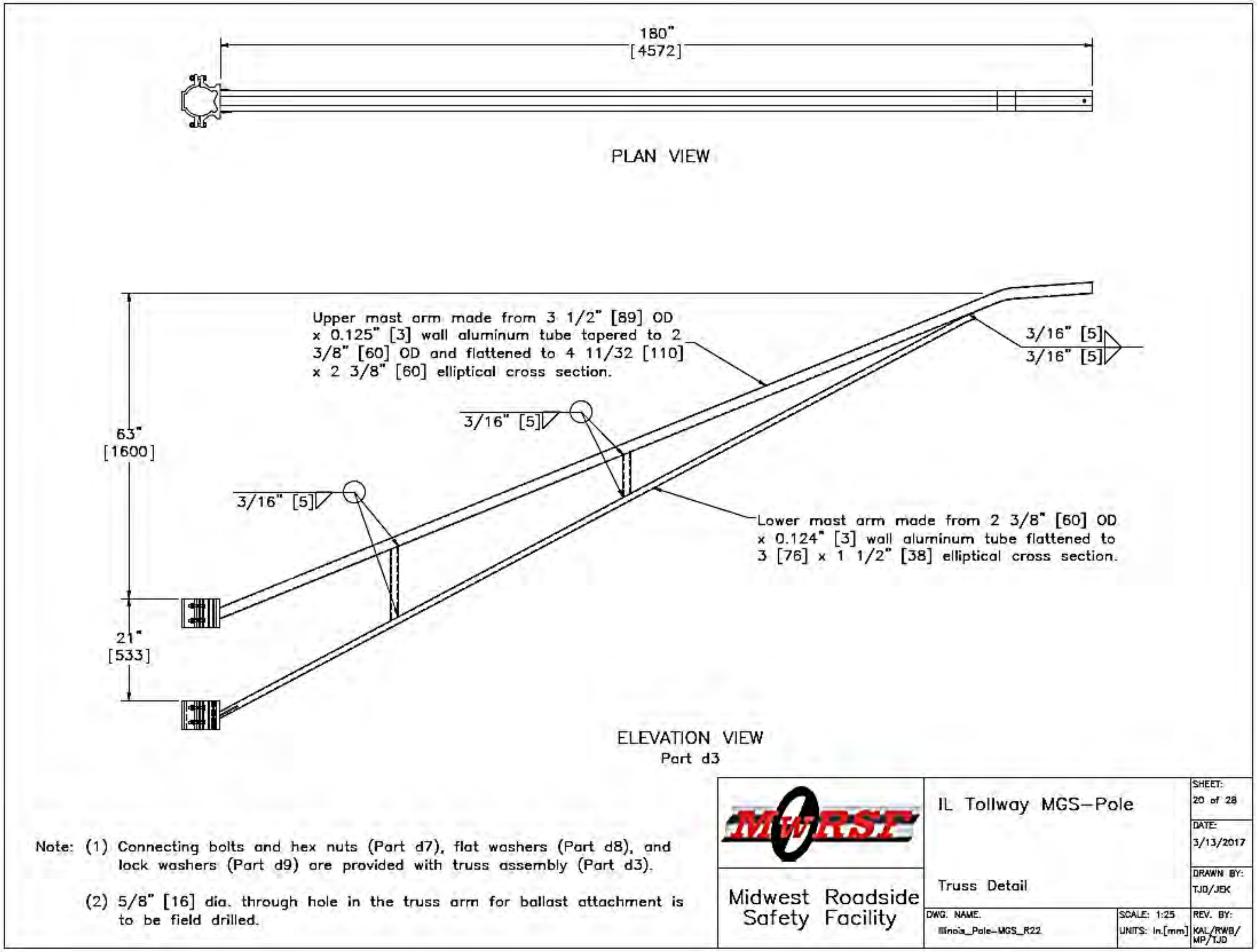


Figure 54. Truss Detail, Test No. ILT-1

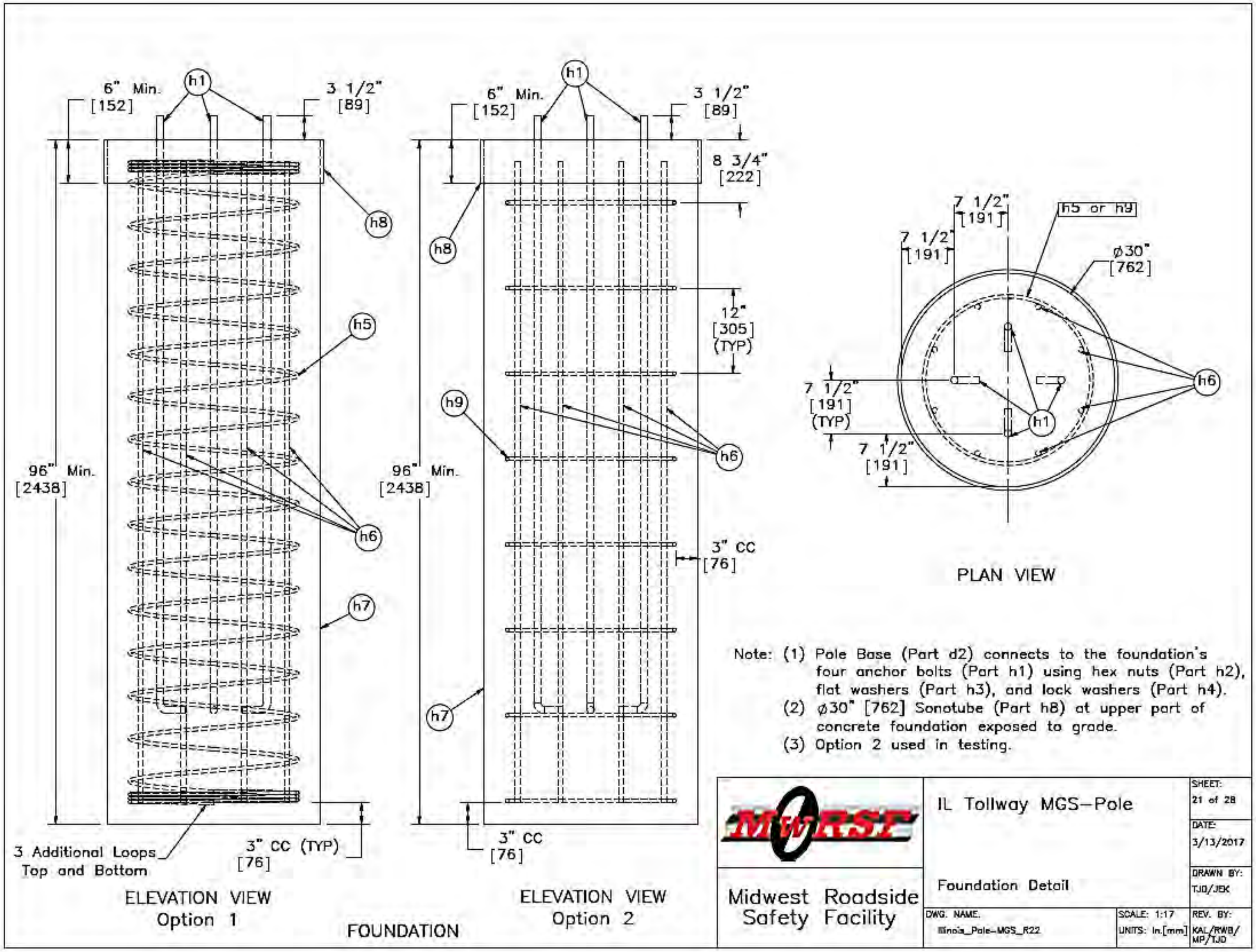


Figure 55. Foundation Detail, Test No. ILT-1

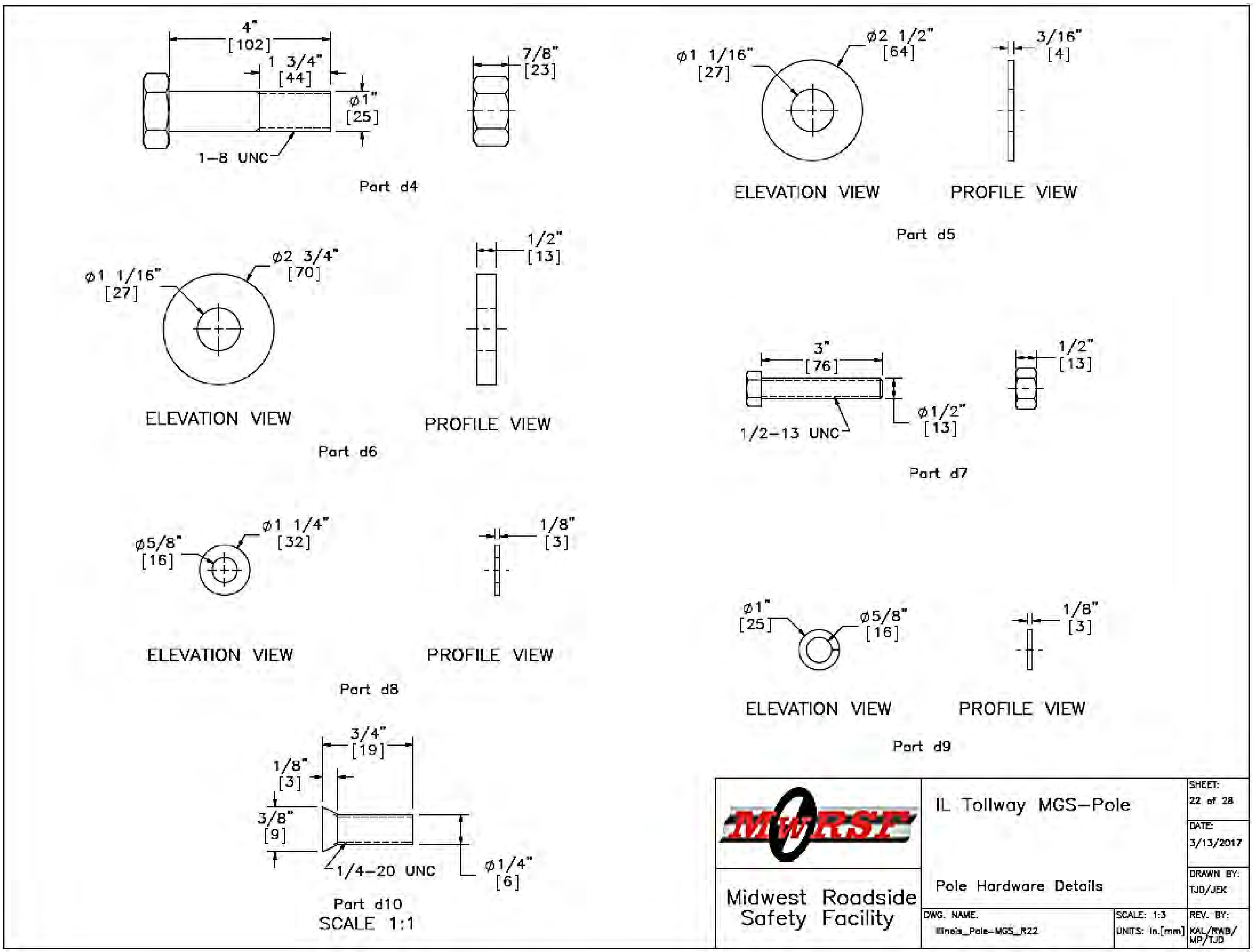


Figure 56. Pole Hardware Details, Test No. ILT-1

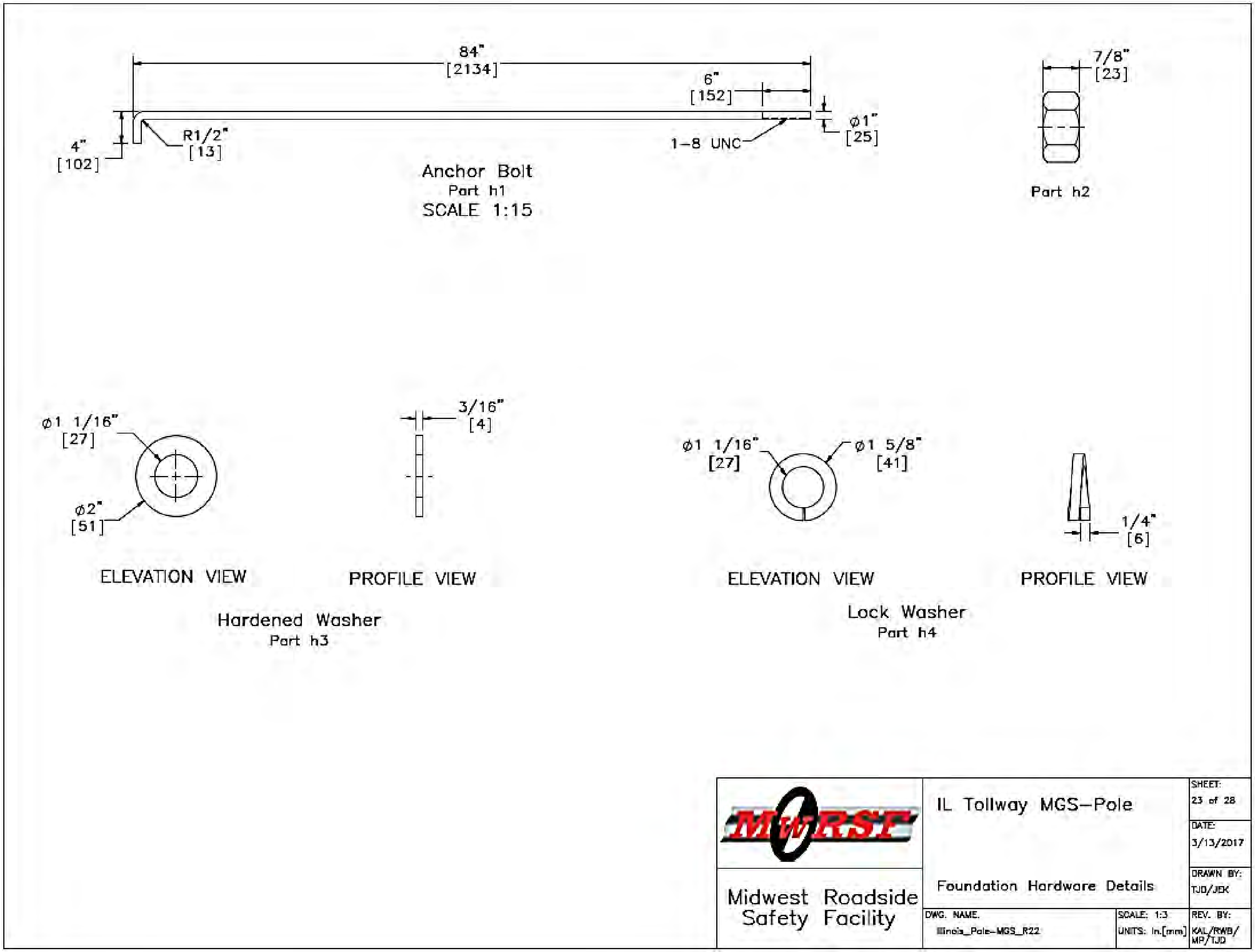


Figure 57. Foundation Hardware Details, Test No. ILT-1

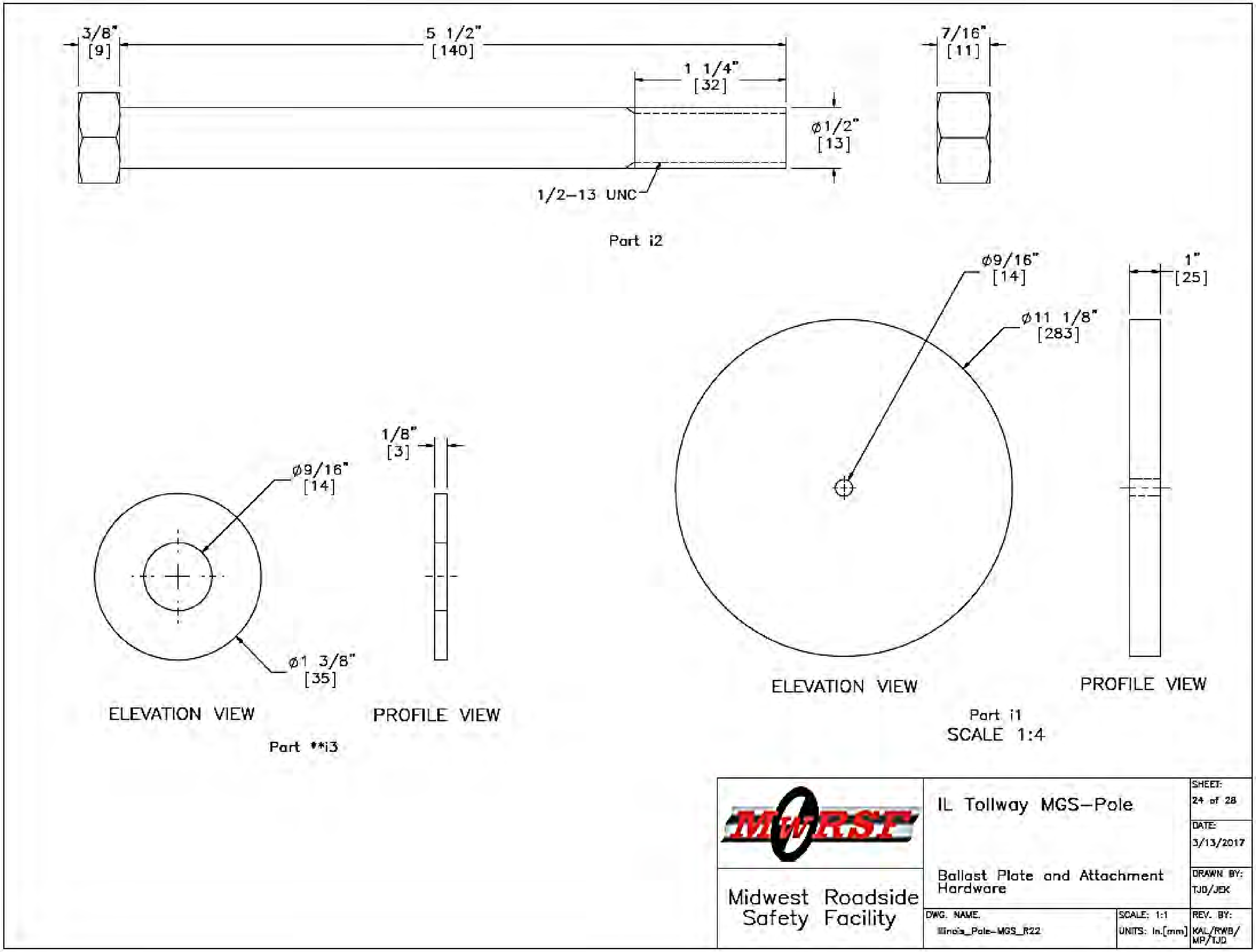
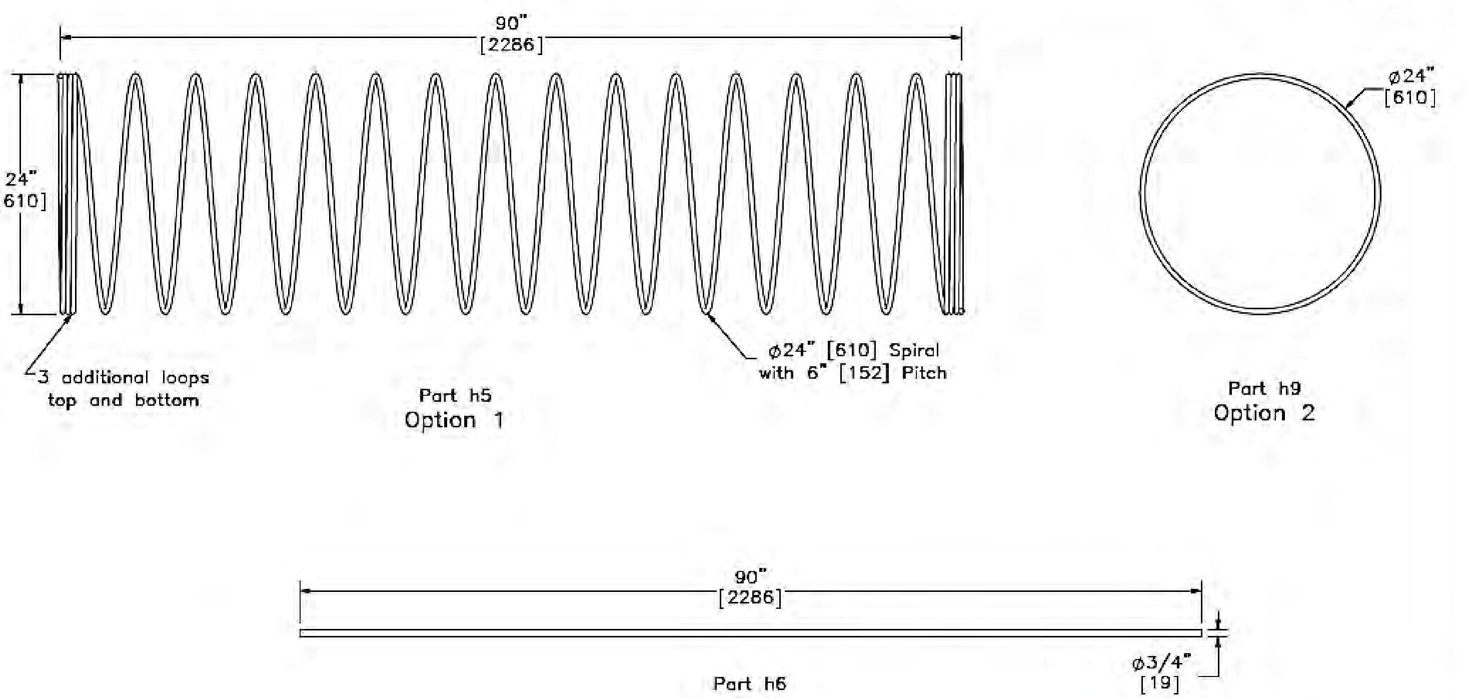


Figure 58. Ballast Plate and Attachment Hardware, Test No. ILT-1

BILL OF BARS				
ITEM NO.	QTY.	BAR SIZE	UNBENT LENGTH	MATERIAL SPEC.
h5 Option 1	1	#4 [13]	1517" [38532]	Epoxy-Coated ASTM A615 Gr. 60
h9 Option 2	8	#4 [13]	74" [1880]	Epoxy-Coated ASTM A615 Gr. 60
h6	8	#6 [19]	90" [2286]	Epoxy-Coated ASTM A615 Gr. 60



Midwest Roadside Safety Facility

IL Tollway MGS-Pole		SHEET: 25 of 28
		DATE: 5/18/2017
Bill of Bars		DRAWN BY: TJD/JEK/DTM
DWG. NAME. Illinois_Pole-MGS_R23	SCALE: 1:15 UNITS: in.[mm]	REV. BY: KAL/RWB/MP/TJD

Figure 59. Bill of Bars, Test No. ILT-1

Item No.	QTY.	Description	Material Specification	As-Tested Modification	Hardware Guide
a1	12	12'-6" [3810] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv. (ASTM A653)	–	RWM04a
a2	2	12'-6" [3810] W-Beam MGS End Section	12 gauge [2.7] AASHTO M180 Galv. (ASTM A653)	–	RWM14a
a3	1	6'-3" [1905] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv. (ASTM A653)	–	RWM04a
a4	25	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1829] Steel Post	ASTM A992 or ASTM A36 Min. 50 ksi [345 MPa] Steel Galv. Per AASHTO M111 (ASTM A123)	–	PWE06
a5	25	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–	PDB10a
a6	25	16D Double Head Nail	–	–	–
b1	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face)	–	PDF01
b2	4	72" [1829] Long Foundation Tube	ASTM A500 Grade B Galv. Per AASHTO M11 (ASTM A123)	–	PTE06
b3	2	Ground Strut Assembly	ASTM A36 Steel Galv. Per AASHTO M111 (ASTM A123)	A-1011-SS, Yield Strength 48,380 psi, Tensile Strength 64,020 psi	PFP02
b4	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40 Galv. Per AASHTO M111 (ASTM A123)	–	FMM02
b5	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel Galv. Per AASHTO M111 (ASTM A123)	–	FPB01
b6	2	Anchor Bracket Assembly	ASTM A36 Steel Galv. Per AASHTO M111 (ASTM A123)	–	FPA01
c1	4	BCT Anchor Cable End Swaged Fitting	Grade 5 – Galv. Fitting Per AASHTO M232 (ASTM A153), Stud Per AASHTO M232 or M298 (ASTM A153 or B695)	–	–
c2	2	3/4" [190] Dia. 6x19, 24 1/2" [622] Long IWRC IPS Wire Rope	IPS Galv. Per AASHTO M30 (ASTM A741) Type II Class A	–	–
c3	4	115-HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–	–
c4	4	Crosby Heavy Duty HT – 3/4" [19] Dia. Cable Thimble	Stock No. 1037773 – Galv. – As Supplied	–	–
c5	4	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 – As Supplied	–	–
c6	4	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNC 6 [M36x4]	Stock No. 107 – As Supplied	–	–
c7	2	TLL-50K-PTB Load Cell	–	–	–
d1	1	45' [13716] Long Aluminum Pole, Pay Item No. 903A10, JS830003	6063-T4 Aluminum Alloy	–	–
d2	1	CS-370 Anchor Base, Model No. 10R145153B9T	6063 Aluminum Alloy	–	–
d3	1	Truss, Model No. 1TA1566C60ZA	6063-T6 Aluminum Alloy	–	–

Midwest Roadside Safety Facility

IL Tollway MGS-Pole

Bill of Materials

SHEET: 26 of 28
DATE: 3/13/2017
DRAWN BY: TJD/JEK
DWG. NAME. Illinois_Pole-MGS_R22
SCALE: None
UNITS: In.[mm]
REV. BY: KAL/RWB/MP/TJD

Figure 60. Bill of Materials, Test No. ILT-1

Item No.	QTY.	Description	Material Specification	As-Tested Modification	Hardware Guide
d4	4	1" [25] Dia. UNC, 4" [102] Long Hex Head Bolt	Bolt – ASTM A449 or SAE J429 Grade 5 Galv. Per ASTM A153, Nut – ASTM A563DH Galv. Per ASTM A153	–	–
d5	8	1" [25] Dia. Hardened Flat Washer	ASTM A153 Galv. Low Carbon Steel	–	–
d6	4	1" [25] Dia. 1/2" [13] Thick Flat Washer	Q235 Steel, Galv. Per ASTM A123, Coating Grade 50	–	–
d7	8	1/2" [13] Dia. UNC x 3" [76] Long Hex Head Bolt and Nut	Bolt – 304 Stainless Steel or ASTM F593, Nut – ASTM F594 Stainless Steel	–	–
d8	16	1/2" [13] Dia. Flat Washer	18-8 Stainless Steel	–	–
d9	8	1/2" [13] Dia. Split Lock Washer	18-8 Stainless Steel	–	–
d10	2	1/4" [6] Dia. x 3/4" [19] Flat Head Screw	18-8 Stainless Steel	–	–
f1	25	5/8" [16] Dia. UNC x 14" [356] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FBB06
f2	114	5/8"[16] Dia. UNC x 1 1/2" [38] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FBB01
f3	4	7/8" Dia. [22] UNC x 7 1/2" [191] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FBX22a
f4	4	5/8" [16] Dia. UNC x 10" [254] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FBX16a
f5	16	5/8" [16] Dia. x 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FBX16a
f6	4	5/8" [16] Dia. UNC x 10" [254] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FBB03
g1	44	5/8" [16] Dia. Plain Round Washer	ASTM F844 Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FWC16a
g2	8	7/8" [22] Dia. Plain Round Washer	ASTM F844 Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FWC22a
h1	4	1" [25] Dia., 84" [2134] Long Anchor Bolt	ASTM F1554 Grade 105 or A449 Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	–
h2	4	1" [25] Dia. UNC Hex Nut	ASTM A563DH or A194 Gr. 2H Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FNX24b

Midwest Roadside Safety Facility

IL Tollway MGS-Pole

Bill of Materials

SHEET: 27 of 28
DATE: 3/13/2017
DRAWN BY: TJD/JEK
DWG. NAME. Illinois_Pole-MGS_R22
SCALE: None
UNITS: in.[mm]
REV. BY: KAL/RWB/MP/TJD

Figure 61. Bill of Materials, Test No. ILT-1

Item No.	QTY.	Description	Material Specification	As-Tested Modification	Hardware Guide
h3	4	1" [25] Dia. Hardened Round Washer	ASTM F436 Galv. Per ASTM B695	–	FWC24b
h4	4	1" [25] Dia. Split Lock Washer	Steel Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	–
*h5	1	1/2" [13] Dia. Bent Rebar, unbent 1517" [38532] Long	Epoxy-Coated ASTM A615 Gr. 60	–	–
h6	8	3/4" [19] Dia., 90" [2286] Long Rebar	Epoxy-Coated ASTM A615 Gr. 60	–	–
h7	1	Light Pole Concrete Foundation	Min. f'c = 3,500 psi [24.1 MPa]	–	–
h8	1	30" [762] Dia. x 6" [152] Sonotube	Sonotube	–	–
*h9	8	1/2" [13] Dia., Bent Rebar, unbent 74" [1880] Long	Epoxy-Coated ASMT A615 Gr. 60	–	–
i1	2	11 1/8" [283] Dia. x 1" [25] Thick Ballast Plate	ASTM A36	–	–
i2	1	1/2" [13] Dia. UNC, 5 1/2" [140] Long Hex Head Bolt	Bolt – ASTM A325 Type 1, Nut – ASTM A563C	–	FBX12b
**i3	2	1/2" [13] Dia. Plain Round Washer	ASTM F844	–	FWC12a

* Either Part h5 or Part h9 is used.

** Per researcher recommendation, use ASTM F844 washer instead of ASTM F436 to attach ballast.

MwRSF Midwest Roadside Safety Facility	IL Tollway MGS-Pole Bill of Materials	SHEET: 28 of 28 DATE: 3/13/2017 DRAWN BY: TJD/JEK
	DWG. NAME. Illinois_Pole-MGS_R22 / SCALE: None UNITS: in.[mm]	REV. BY: KAL/RWB/MP/TJD

Figure 62. Bill of Materials, Test No. ILT-1

Figure 63. Test Installation, Test No. ILT-1

Figure 64. Test Installation, Test No. ILT-1

Figure 65. Test Installation, Test No. ILT-1

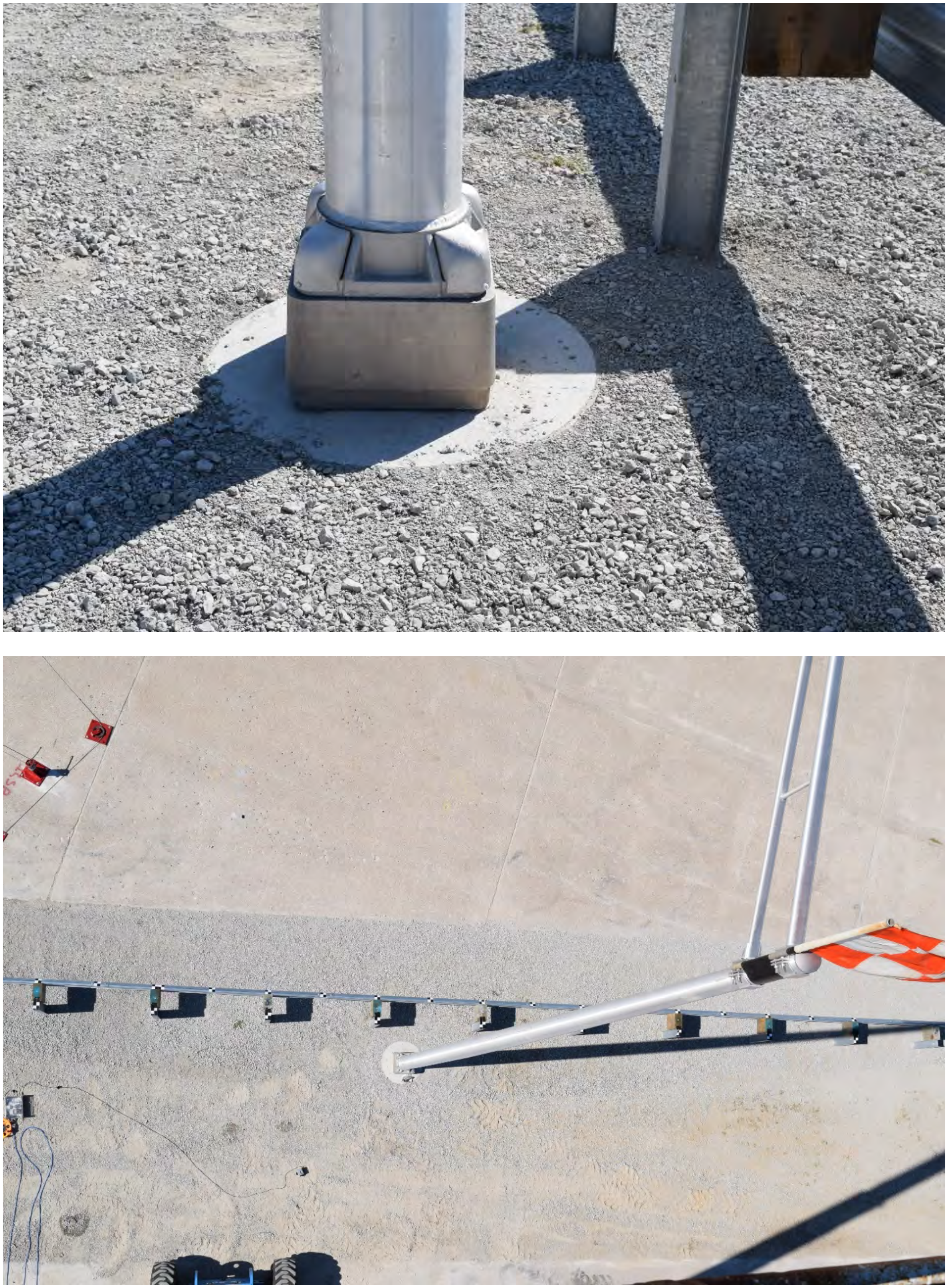


Figure 66. Test Installation, Test No. ILT-1

5.2 Test No. ILT-2

Similar to test no. ILT-1, test no. ILT-2 utilizes a 175-ft (53.3-m) MGS with a 50-ft (15.25-m) tall with a 15-ft (4.6-m) long mast arm light pole with 0.31-in. (8-mm) wall thickness as detailed in Figures 67 through 94. The weights of the pole shaft and arm mast were 474 lb (215 kg) and 55 lb (25 kg), respectively. Approximately 55 lb (25 kg) of steel plate was added to the end of the luminaire arm to simulate the luminaire weight. The total weight of the pole assembly was 584 lb (265 kg). The front face of the pole was offset 20 in. (508 mm) laterally behind the posts, and the centerline of the pole was offset 16 in. (406 mm) longitudinally downstream from post no. 13. Test no. ILT-2 was conducted on a barrier with a rail height of 32 in. (813 mm) to maximize potential vehicle underride and interaction with pole. Additional design details are shown in Figures 67 through 69. Photographs of the test installation are shown in Figures 95 through 98.

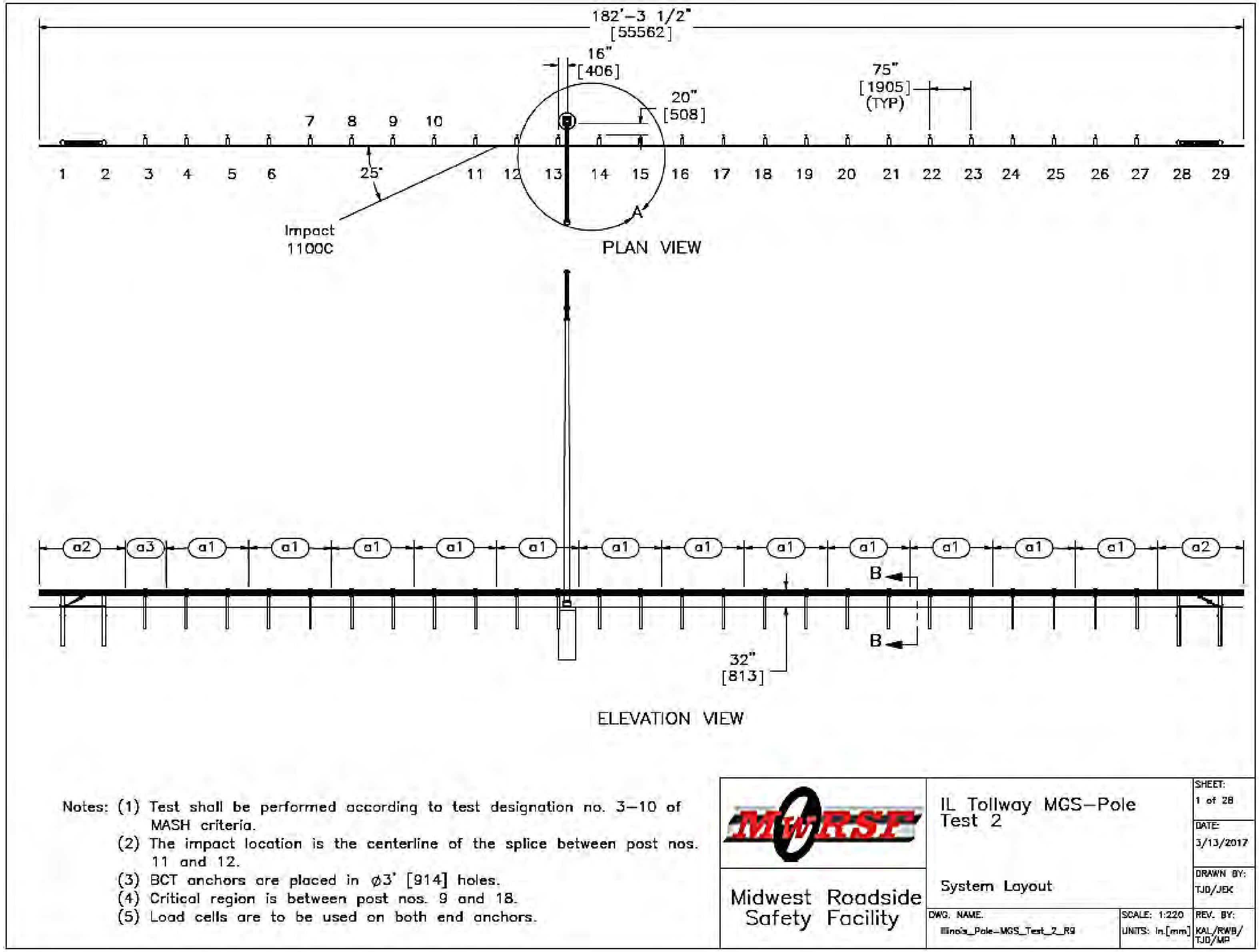


Figure 67. System Layout, Test No. ILT-2

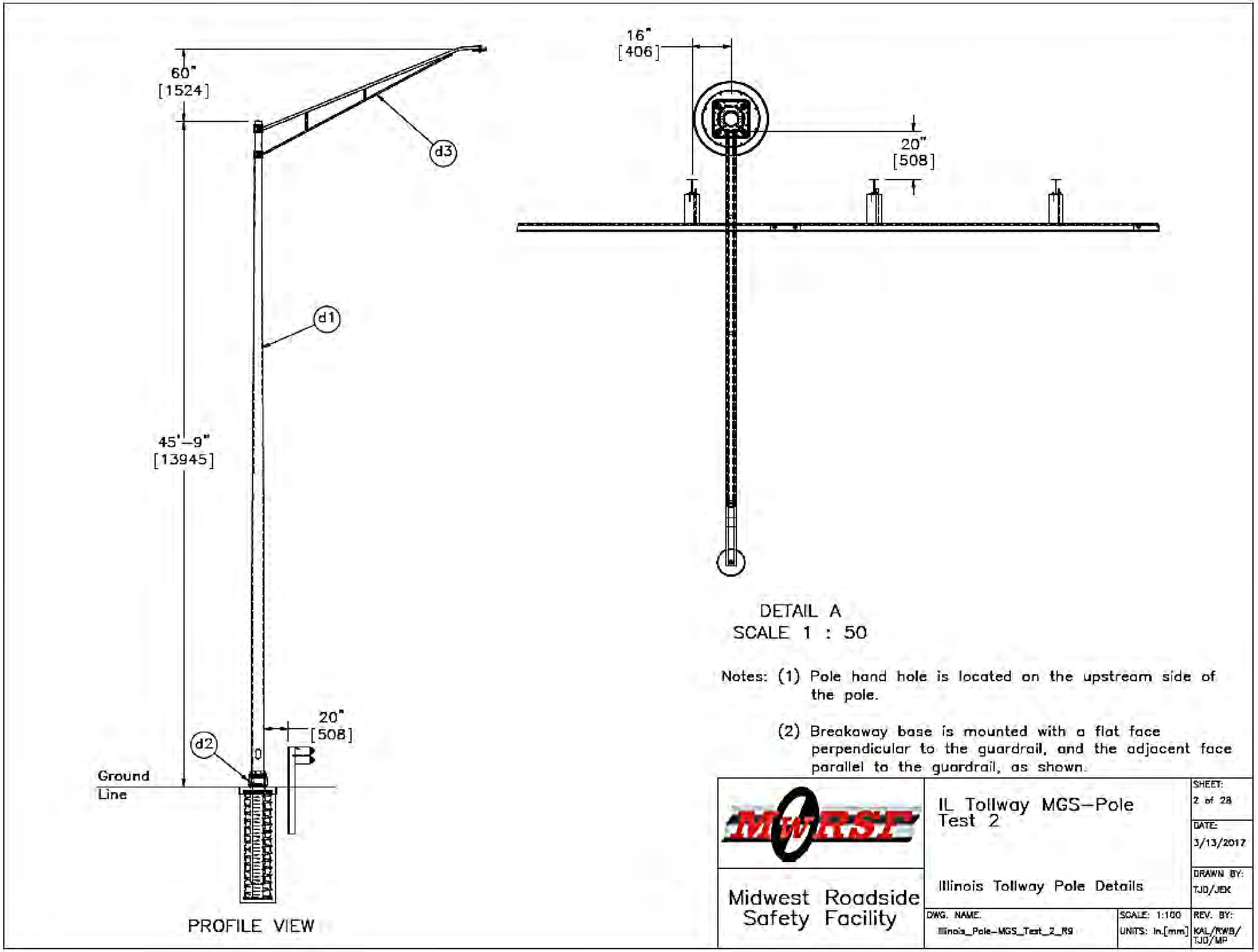


Figure 68. Illinois Tollway Pole Details, Test No. ILT-2

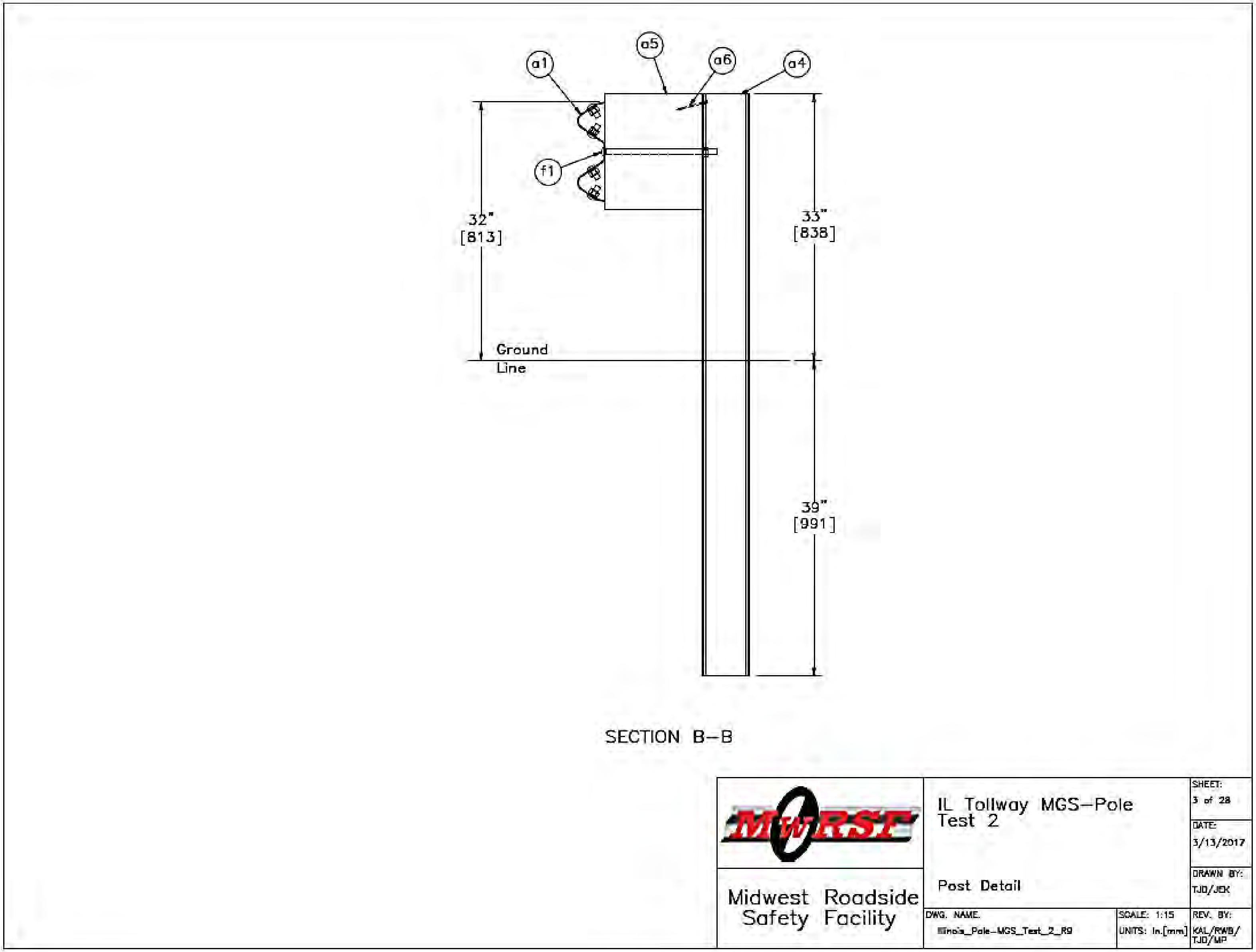


Figure 69. Post Detail, Test No. ILT-2

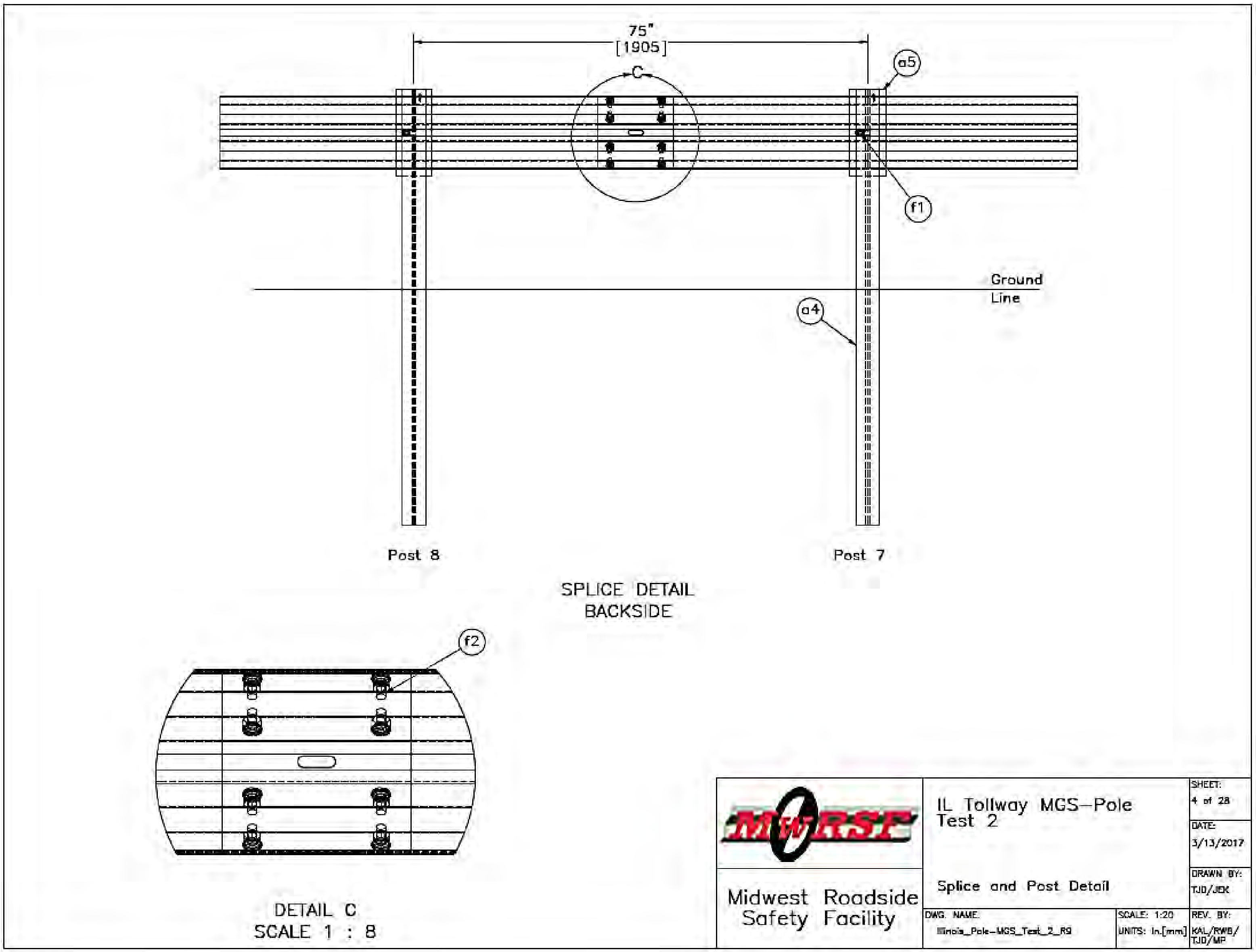


Figure 70. Splice and Post Detail, Test No. ILT-2

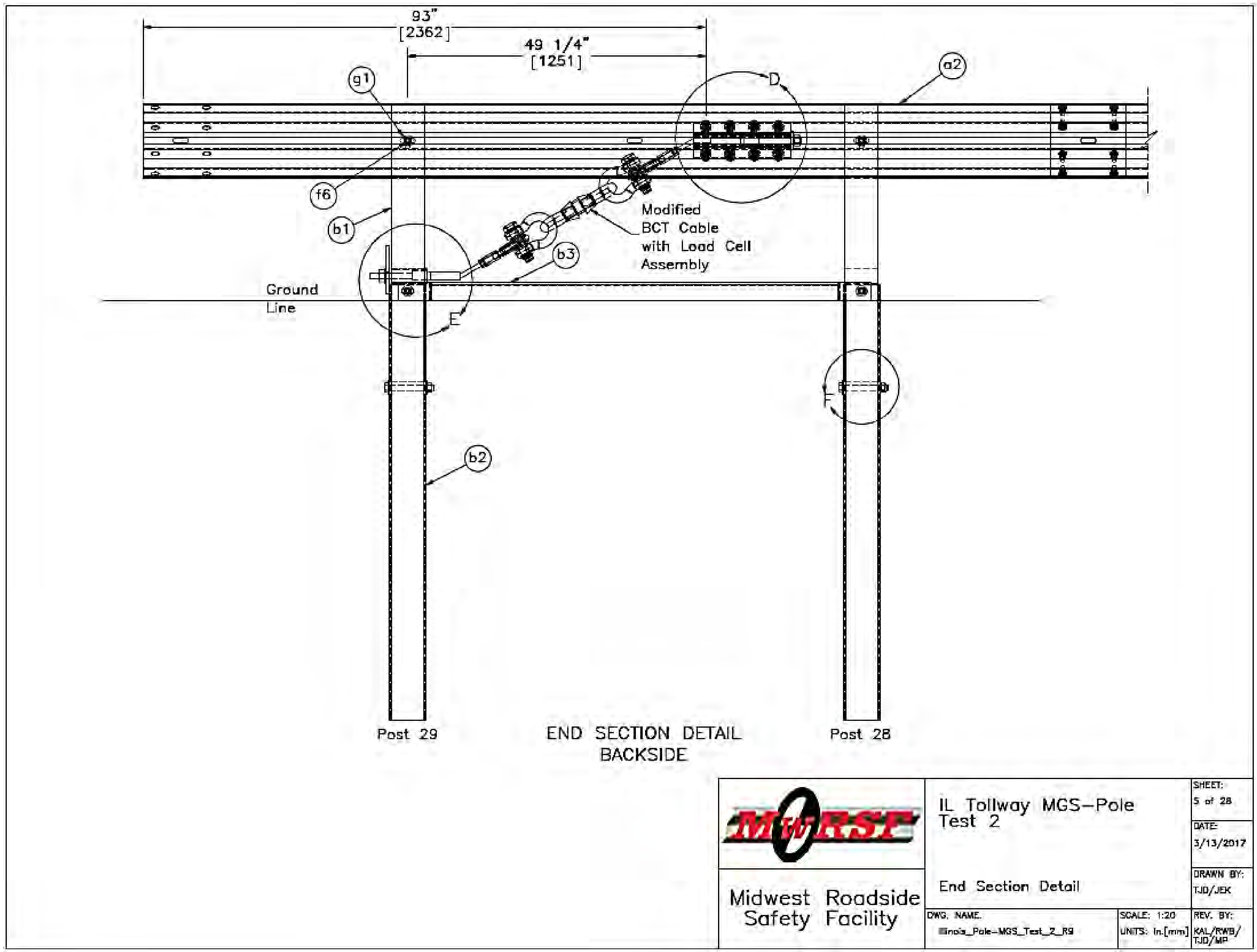


Figure 71. End Section Detail, Test No. ILT-2

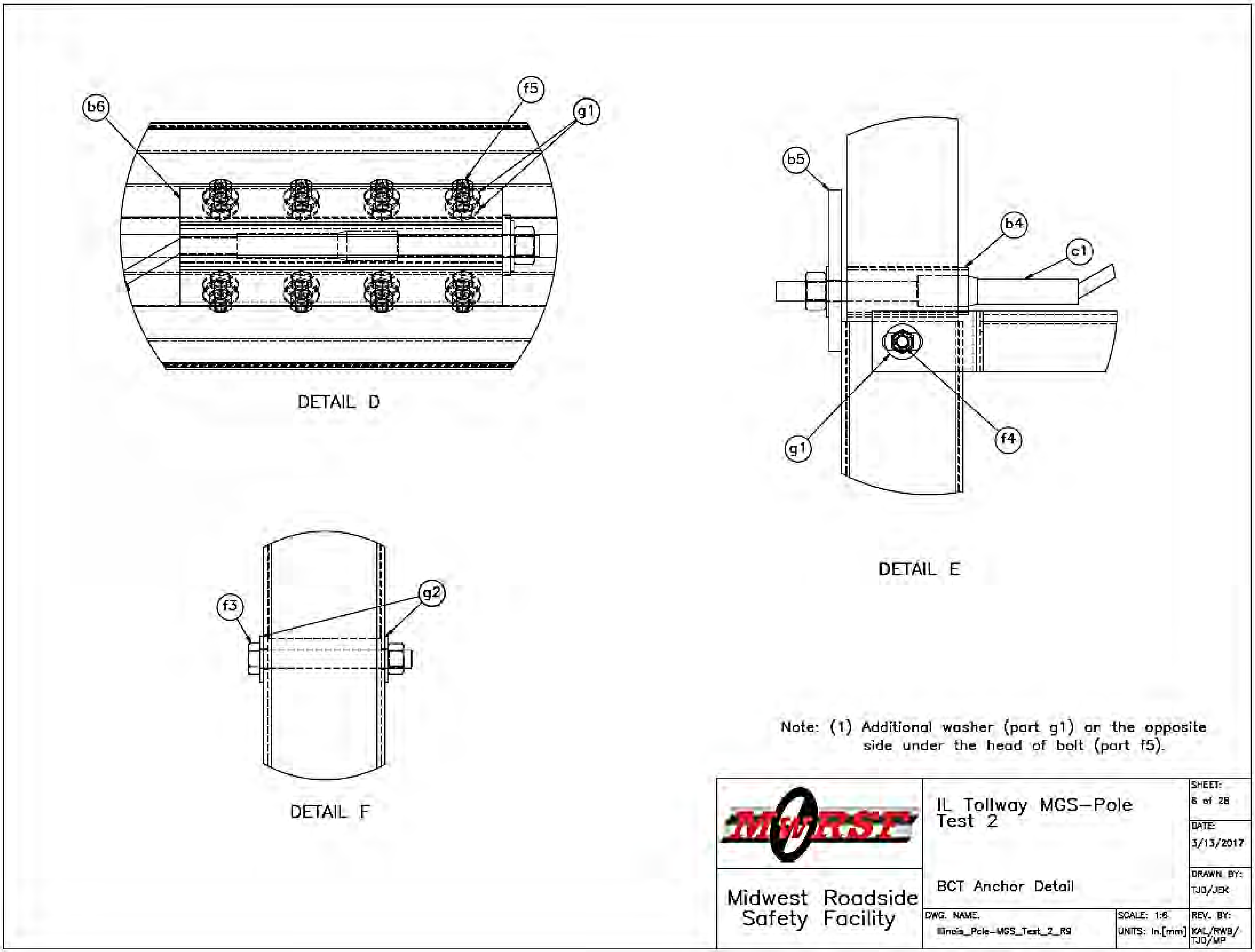


Figure 72. BCT Anchor Detail, Test No. ILT-2

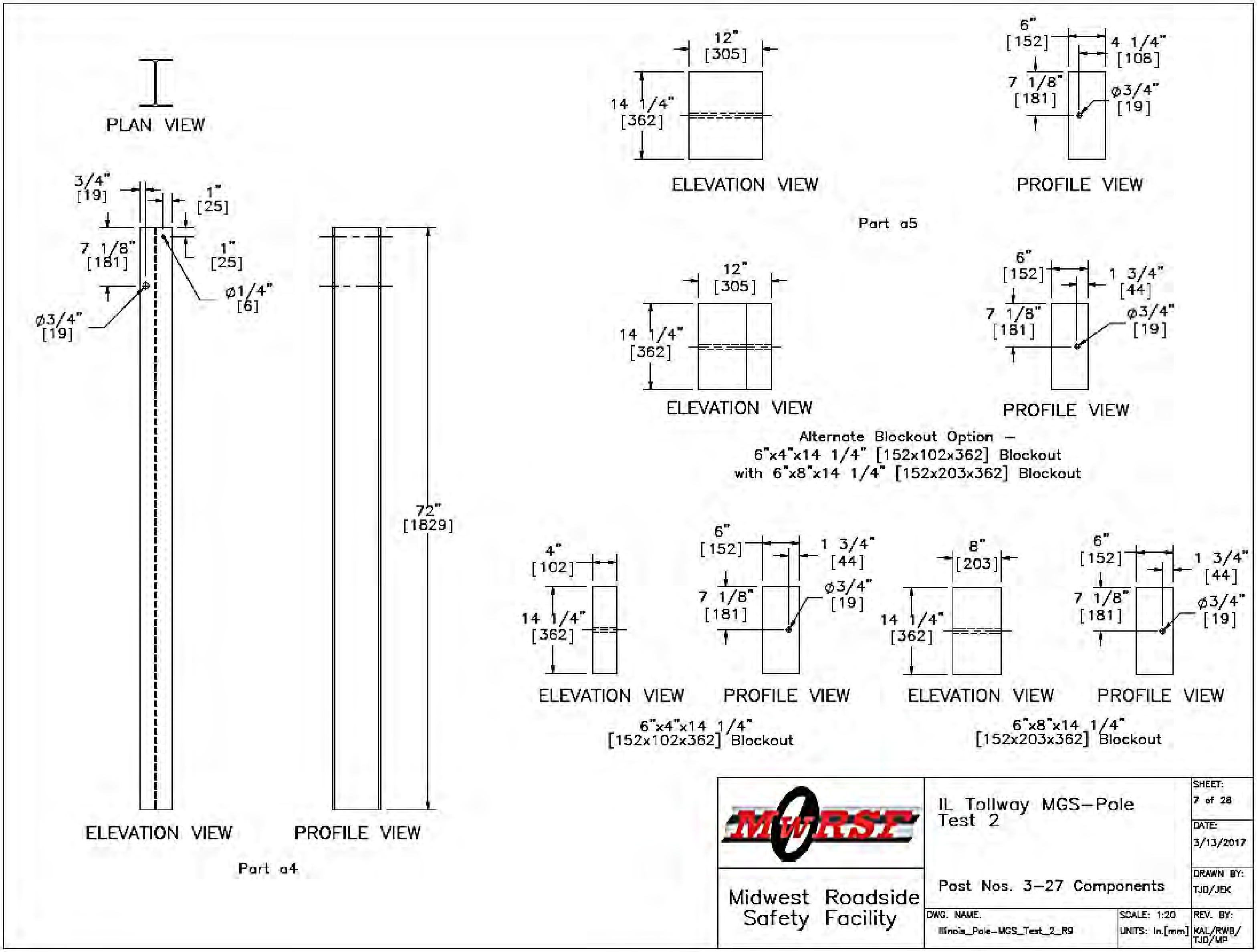


Figure 73. Post Nos. 3-27 Components, Test No. ILT-2

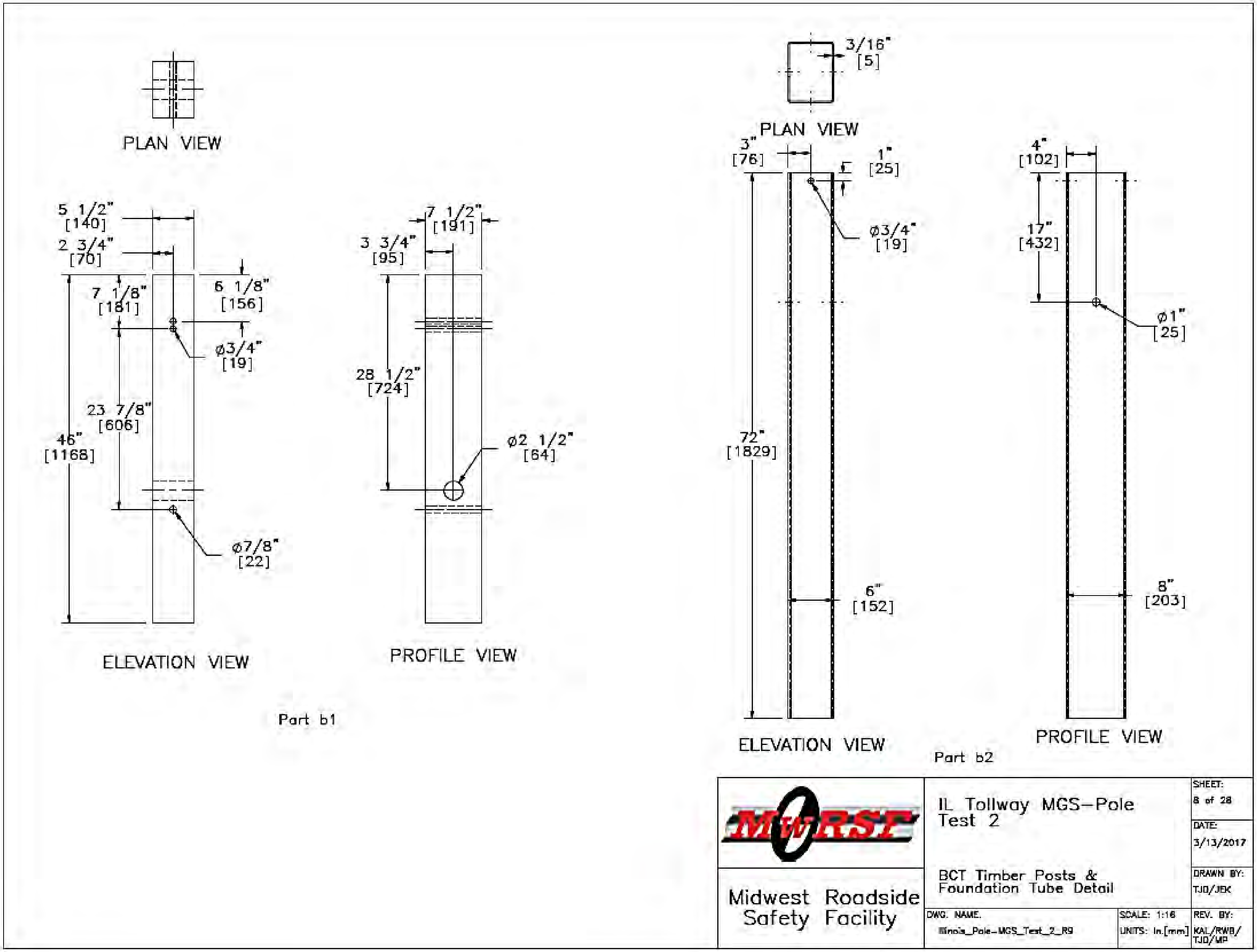


Figure 74. BCT Timber Posts and Foundation Tube Detail, Test No. ILT-2

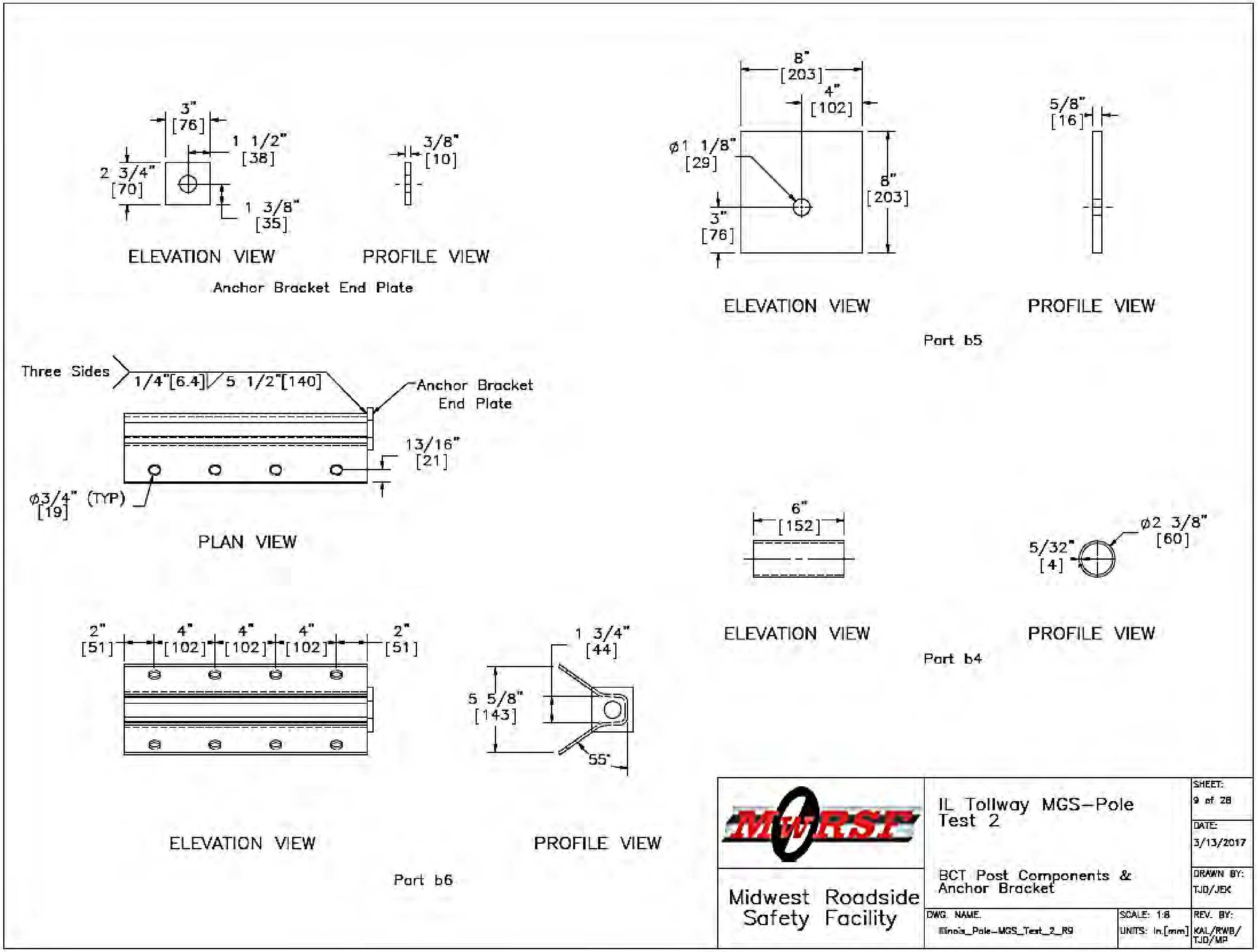


Figure 75. BCT Post Components and Anchor Bracket, Test No. ILT-2

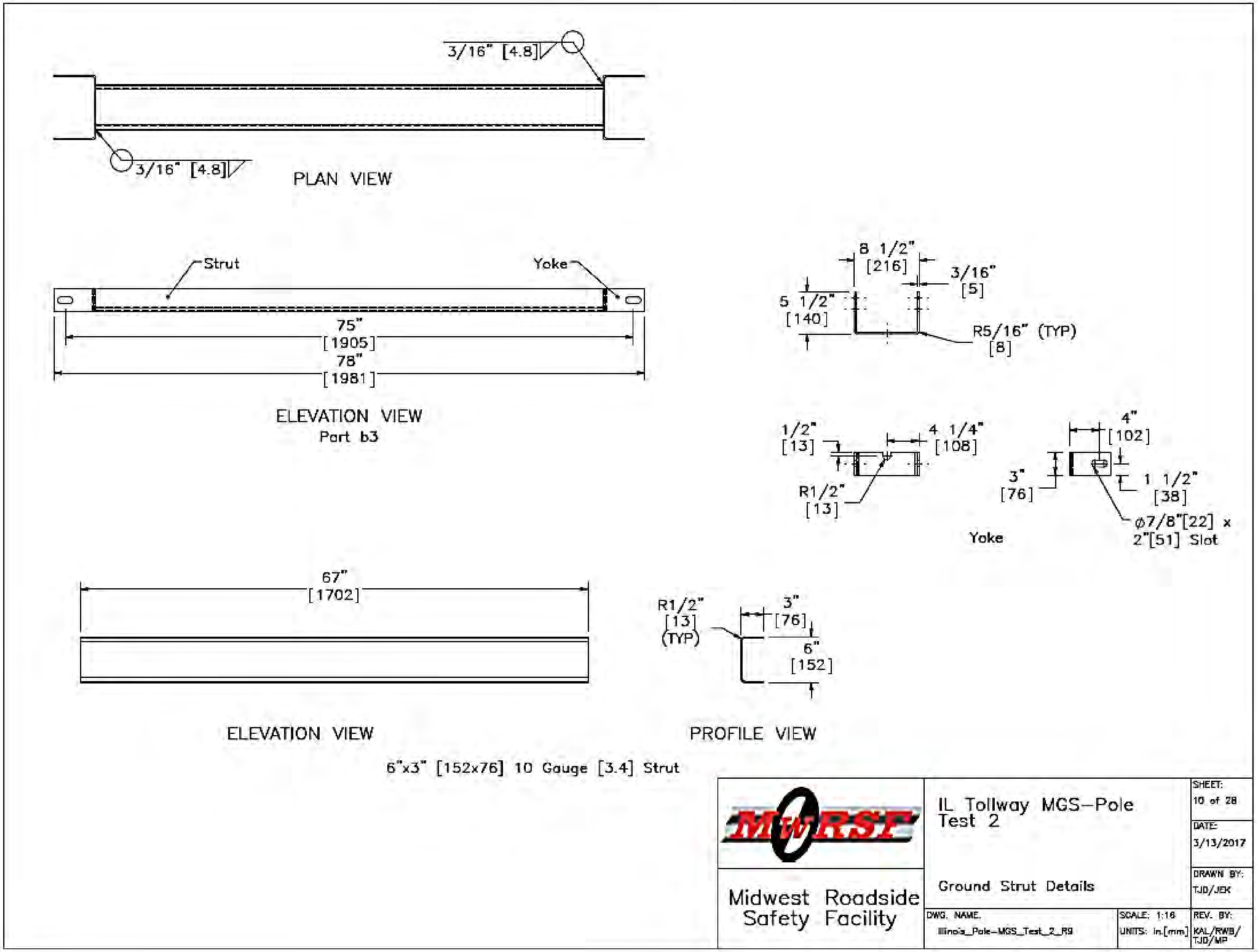


Figure 76. Ground Strut Details, Test No. ILT-2

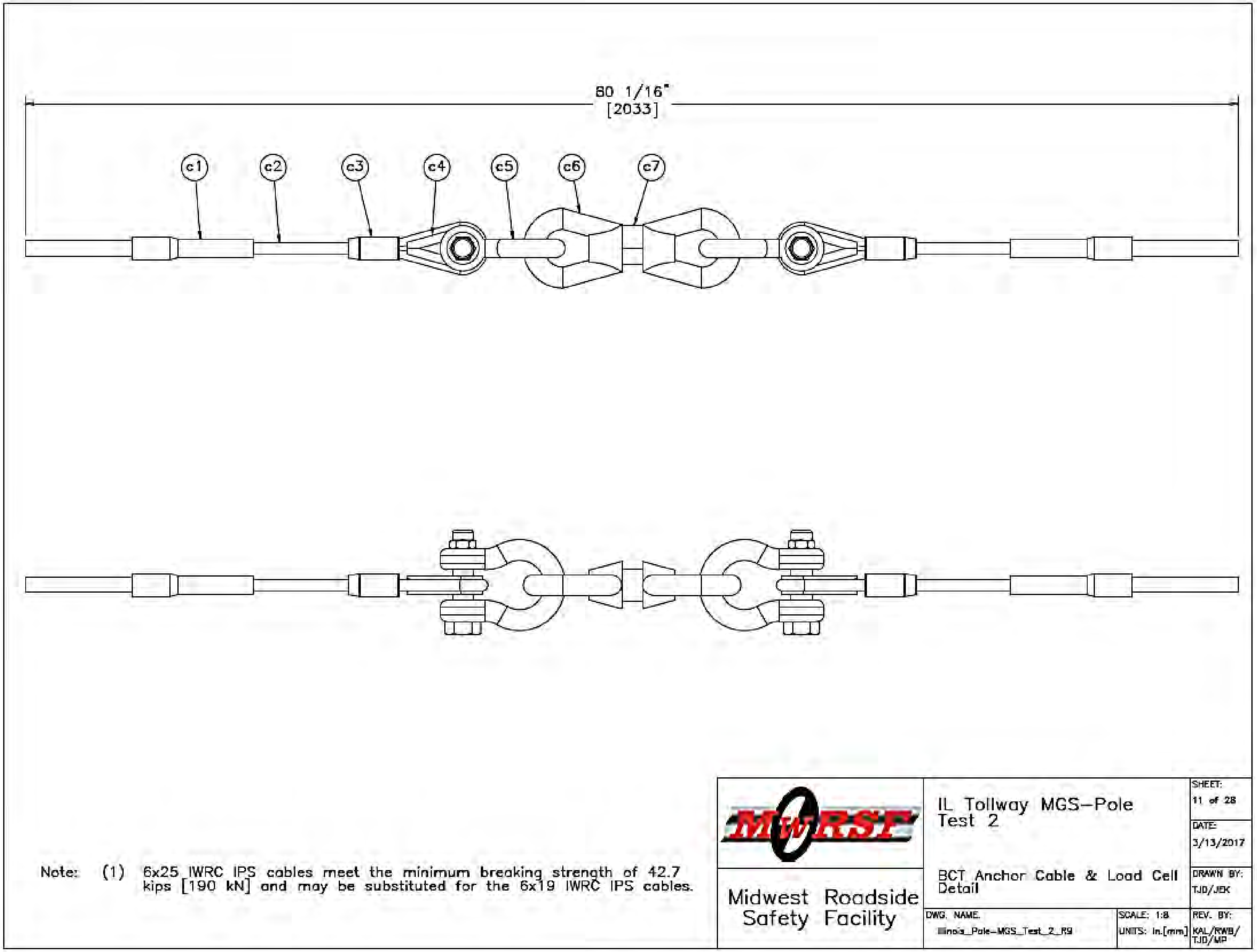


Figure 77. BCT Anchor Cable and Load Cell Detail, Test No. ILT-2

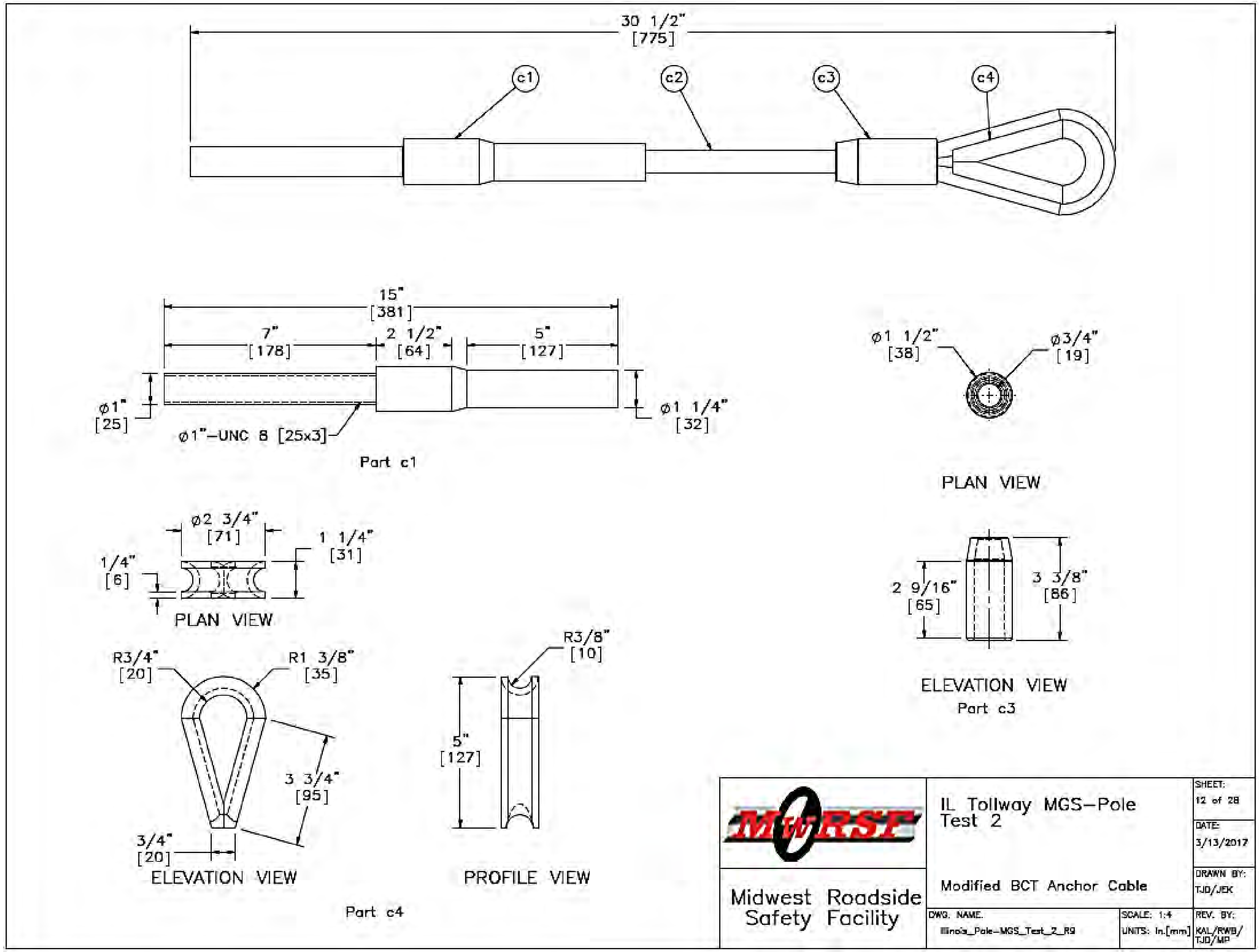


Figure 78. Modified BCT Anchor Cable, Test No. ILT-2

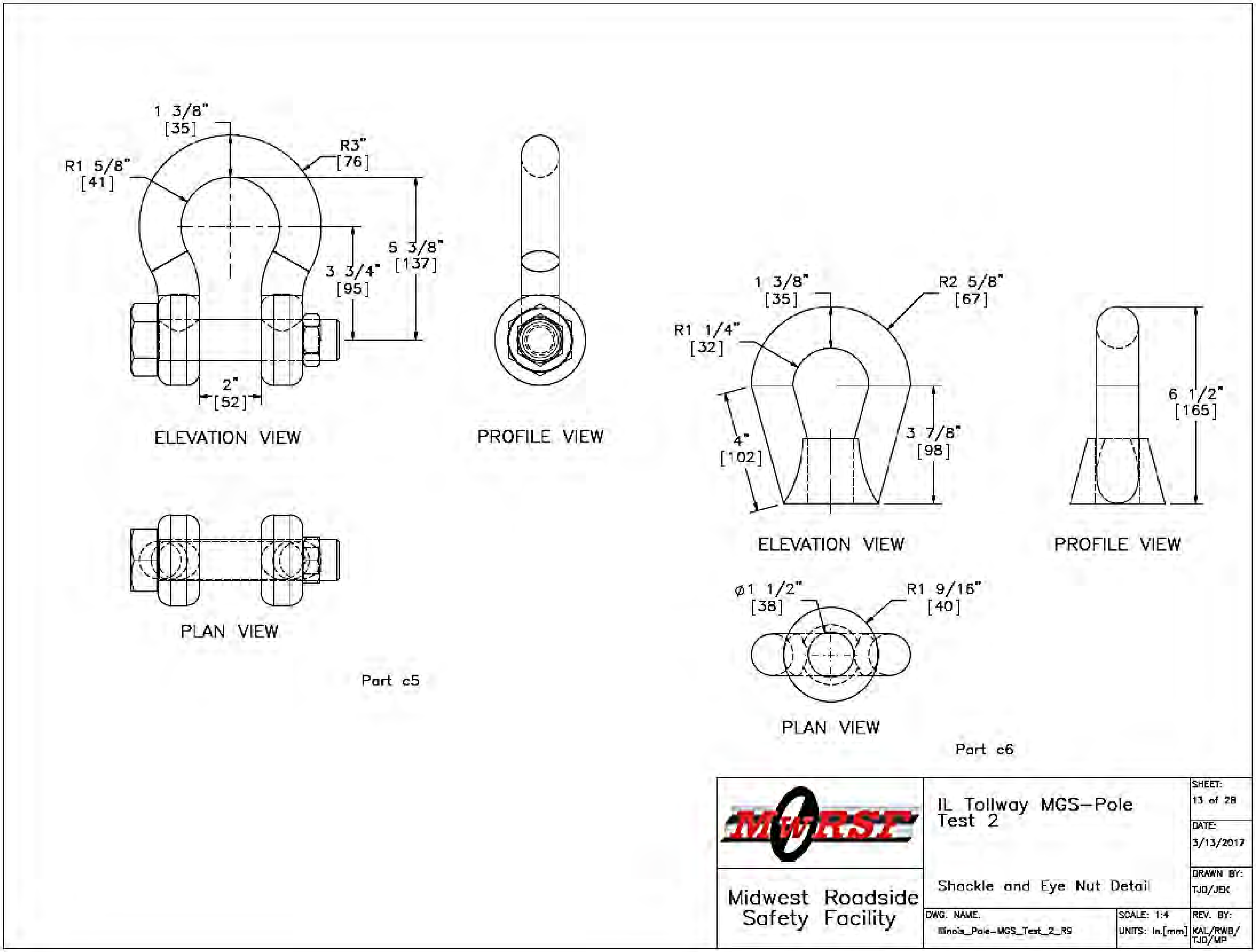


Figure 79. Shackle and Eye Nut Detail, Test No. ILT-2

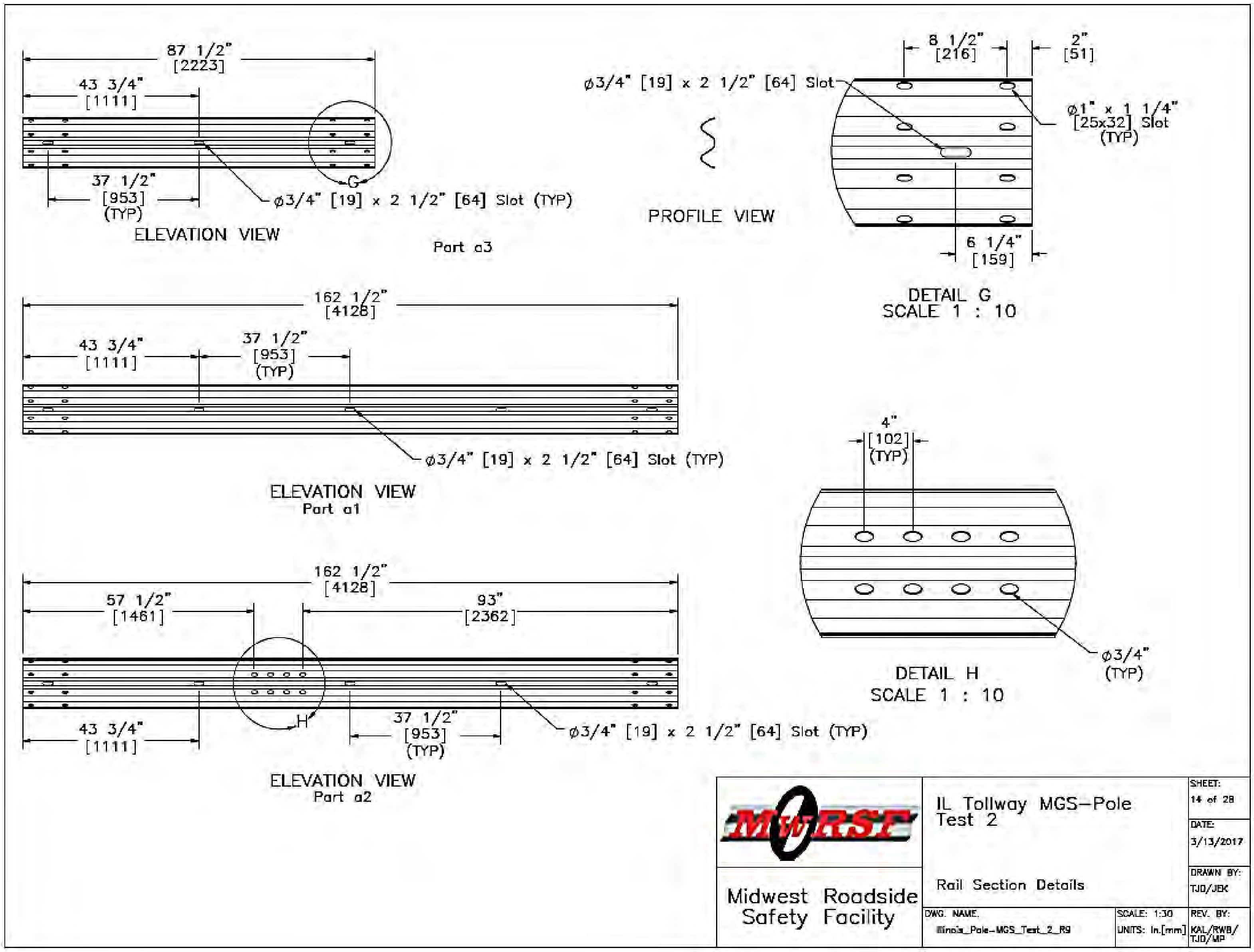


Figure 80. Rail Section Details, Test No. ILT-2

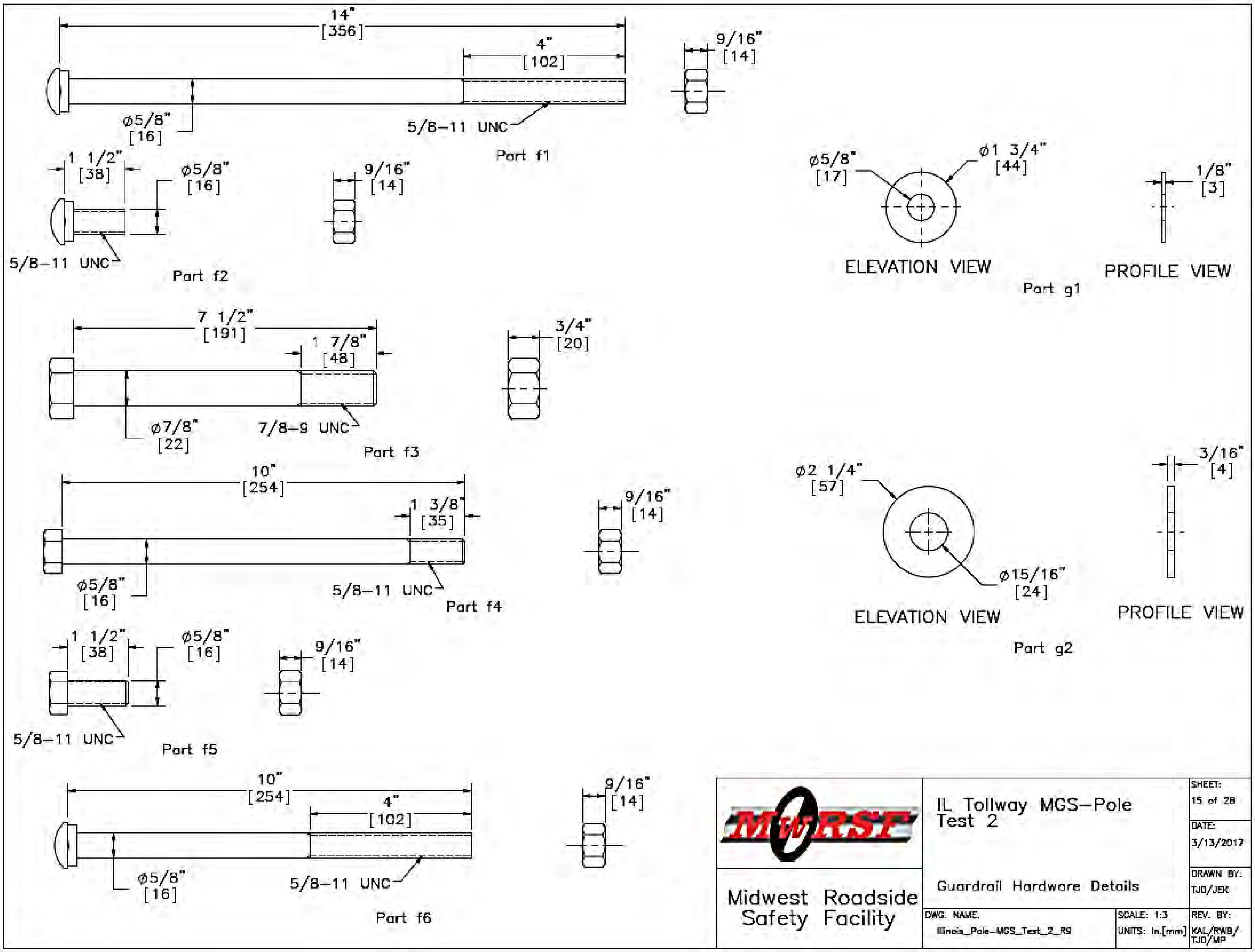


Figure 81. Guardrail Hardware Details, Test No. ILT-2

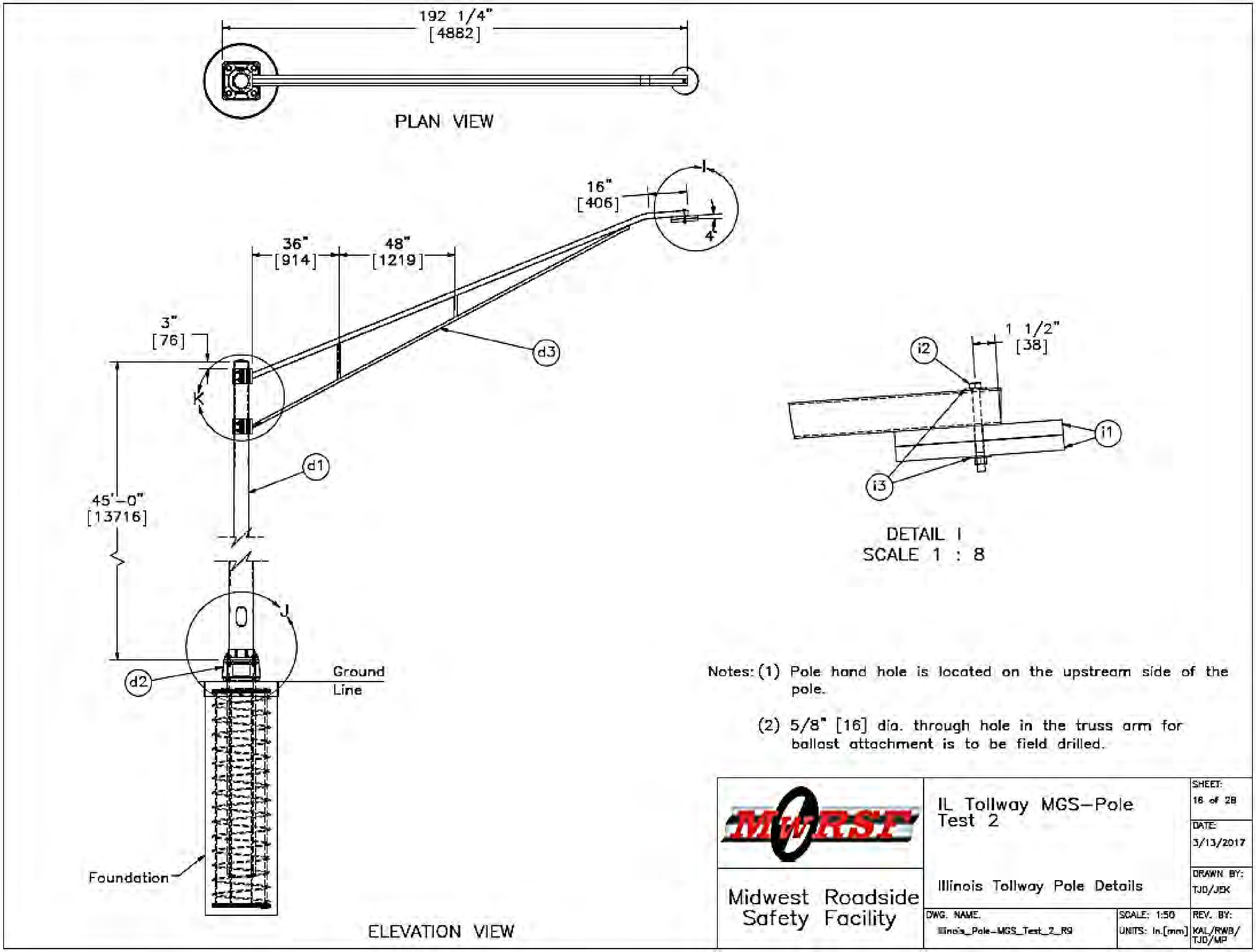


Figure 82. Illinois Tollway Pole Details, Test No. ILT-2

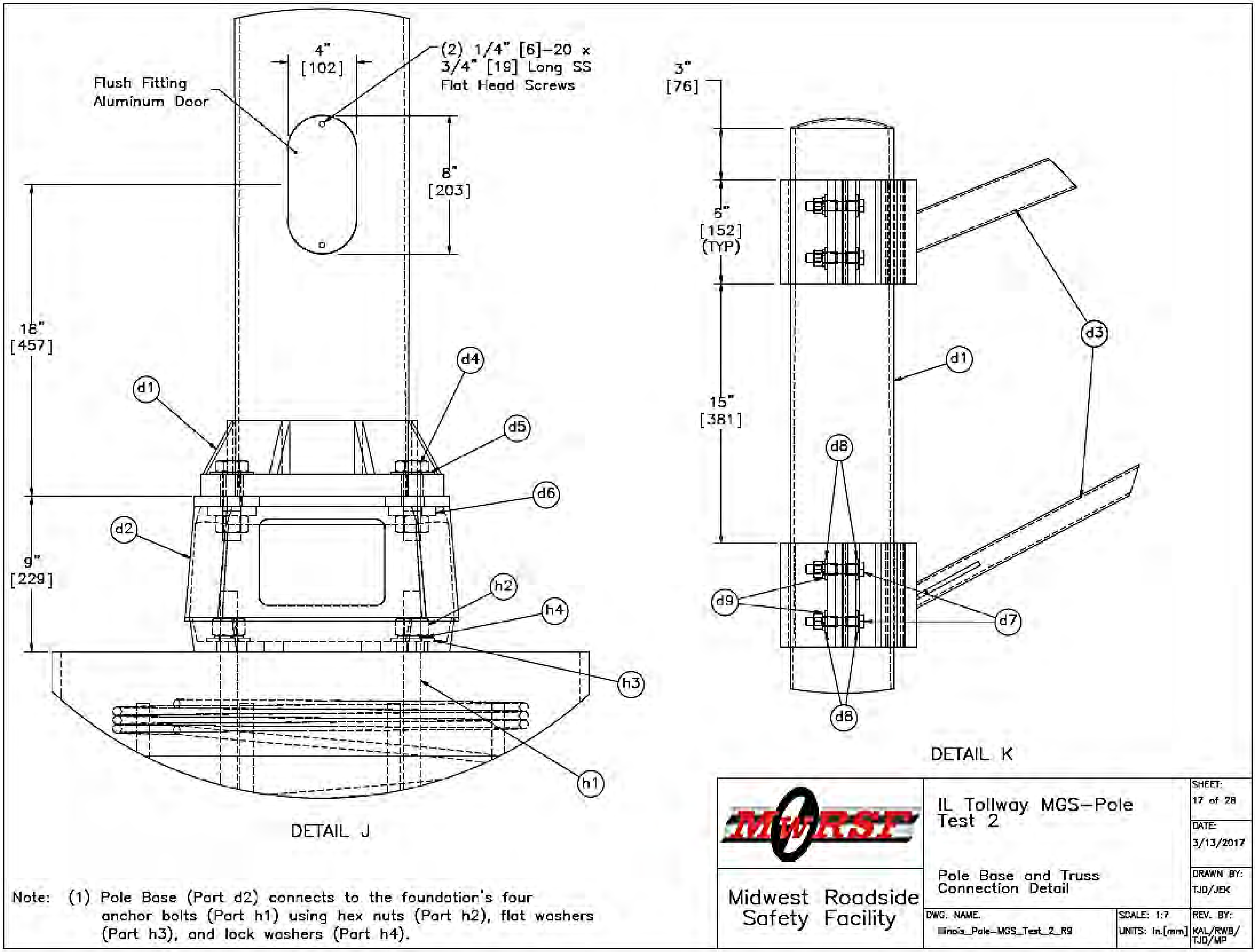


Figure 83. Pole Base and Truss Connection Detail, Test No. ILT-2

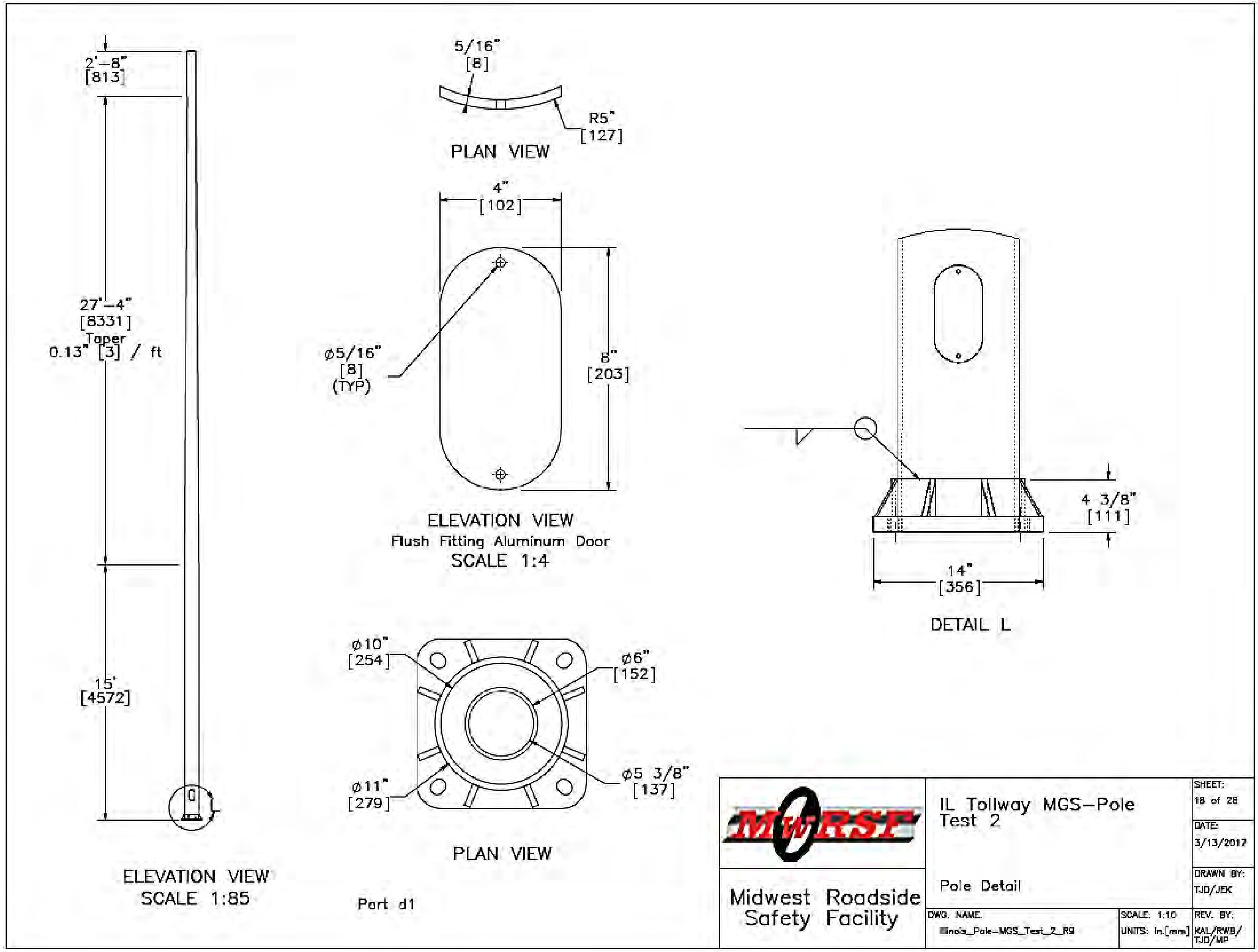


Figure 84. Pole Detail, Test No. ILT-2

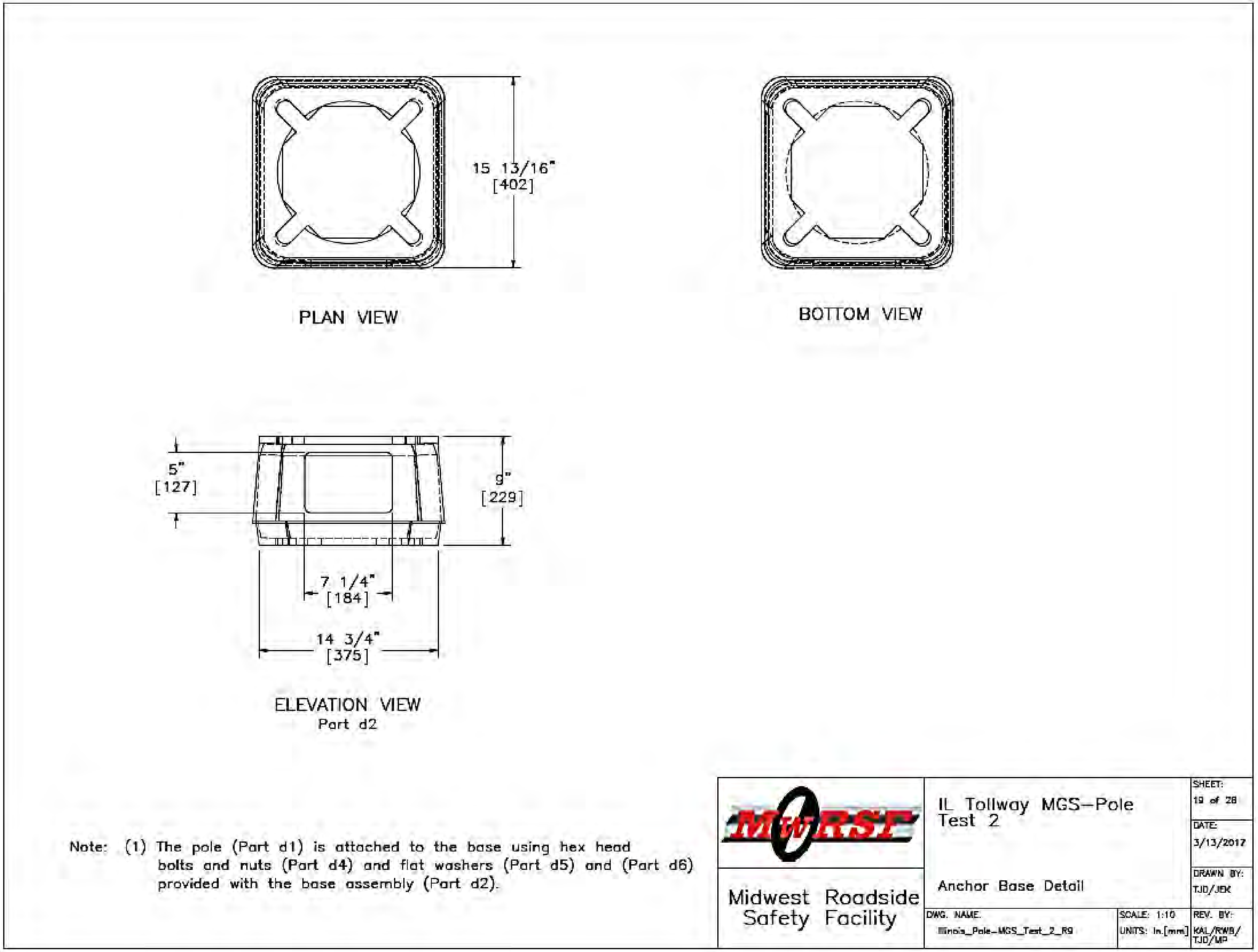


Figure 85. Anchor Base Detail, Test No. ILT-2

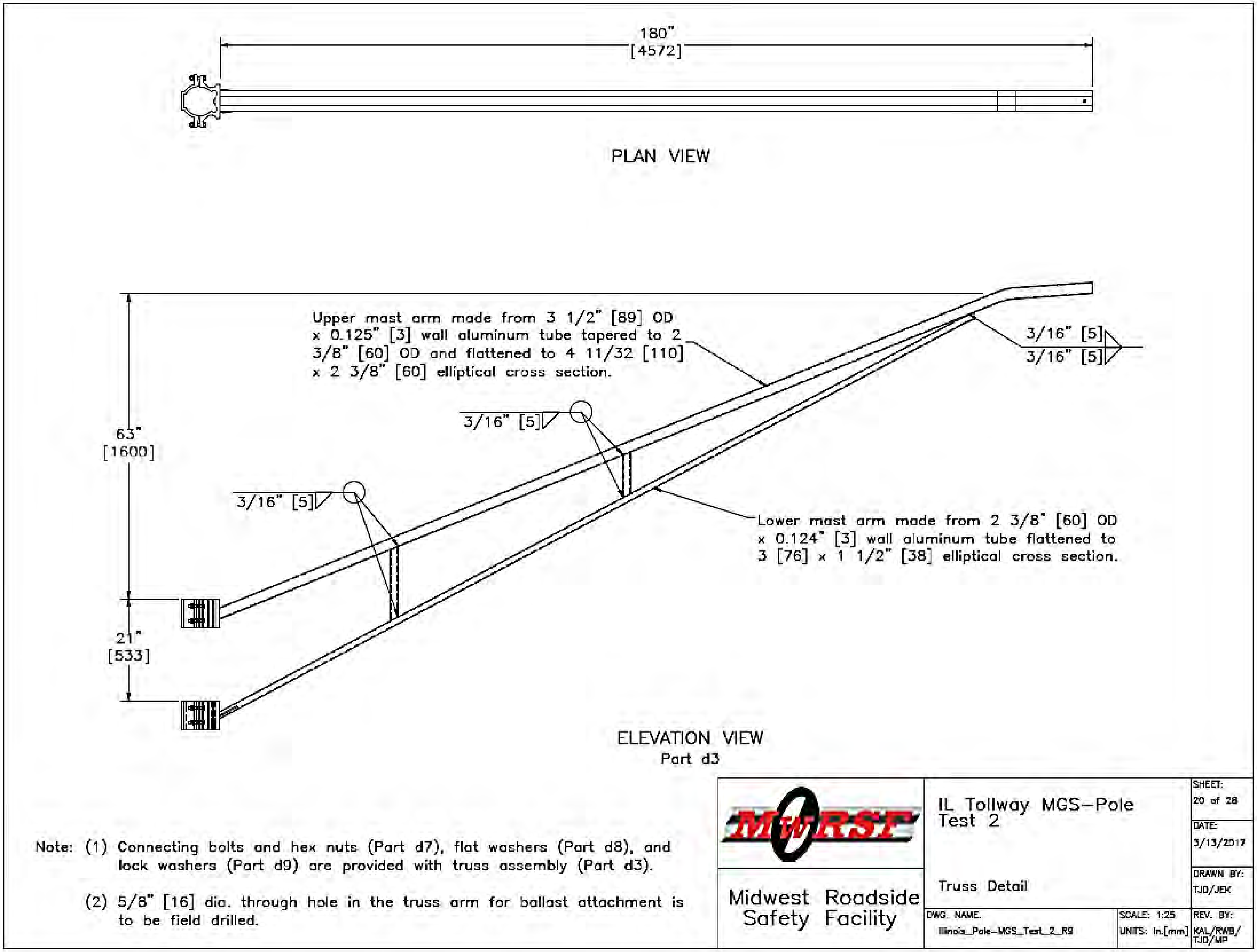


Figure 86. Truss Detail, Test No. ILT-2

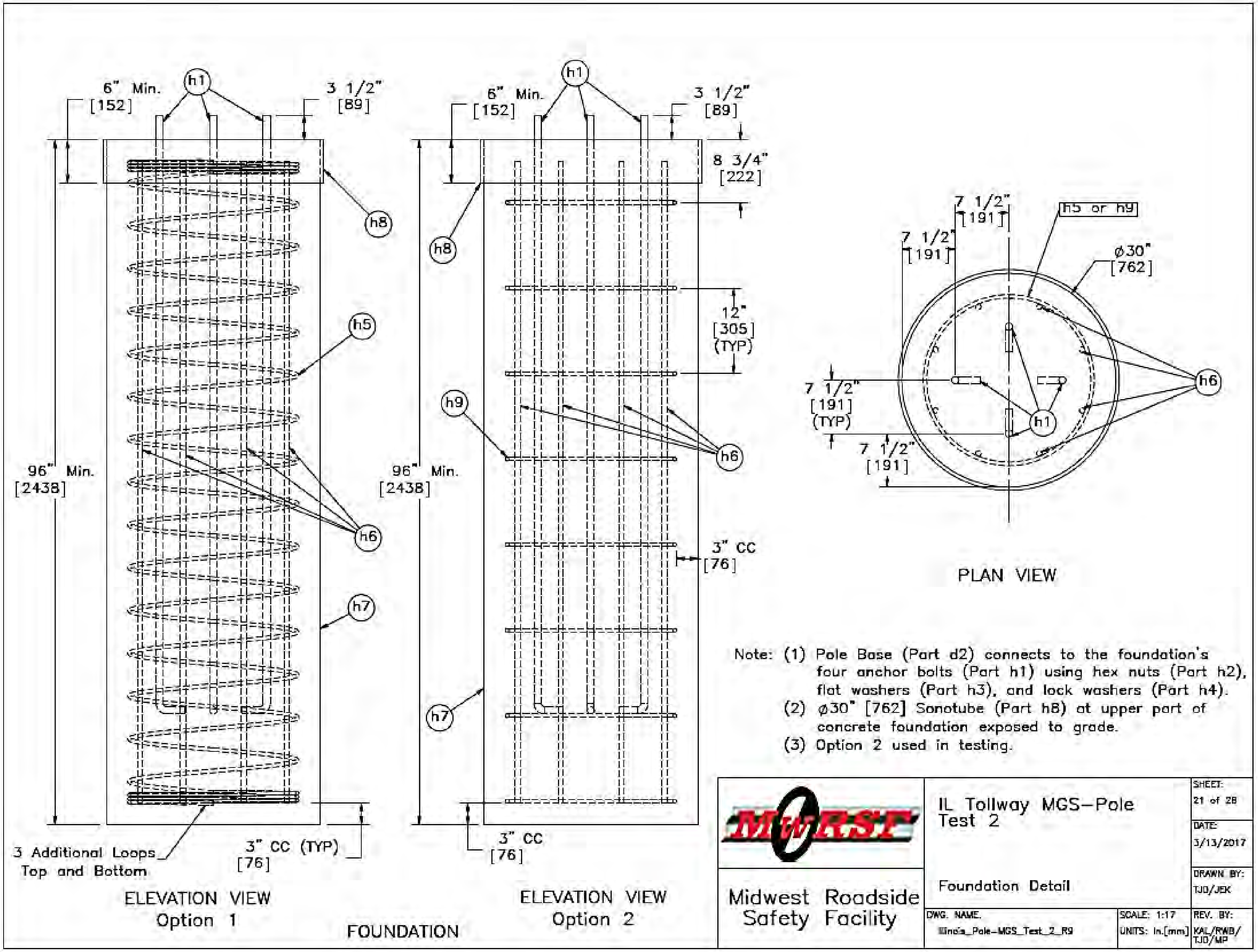


Figure 87. Foundation Detail, Test No. ILT-2

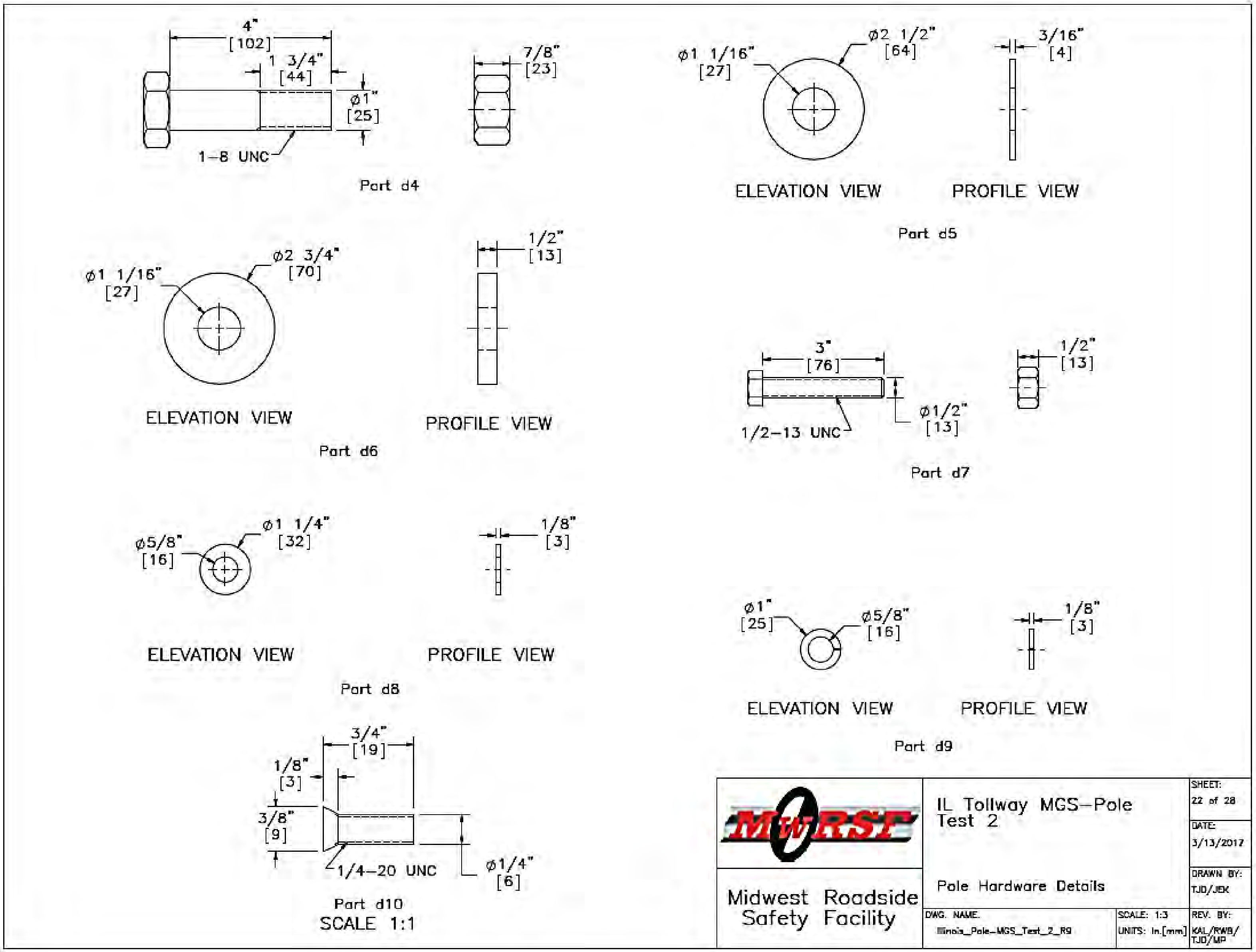


Figure 88. Pole Hardware Details, Test No. ILT-2

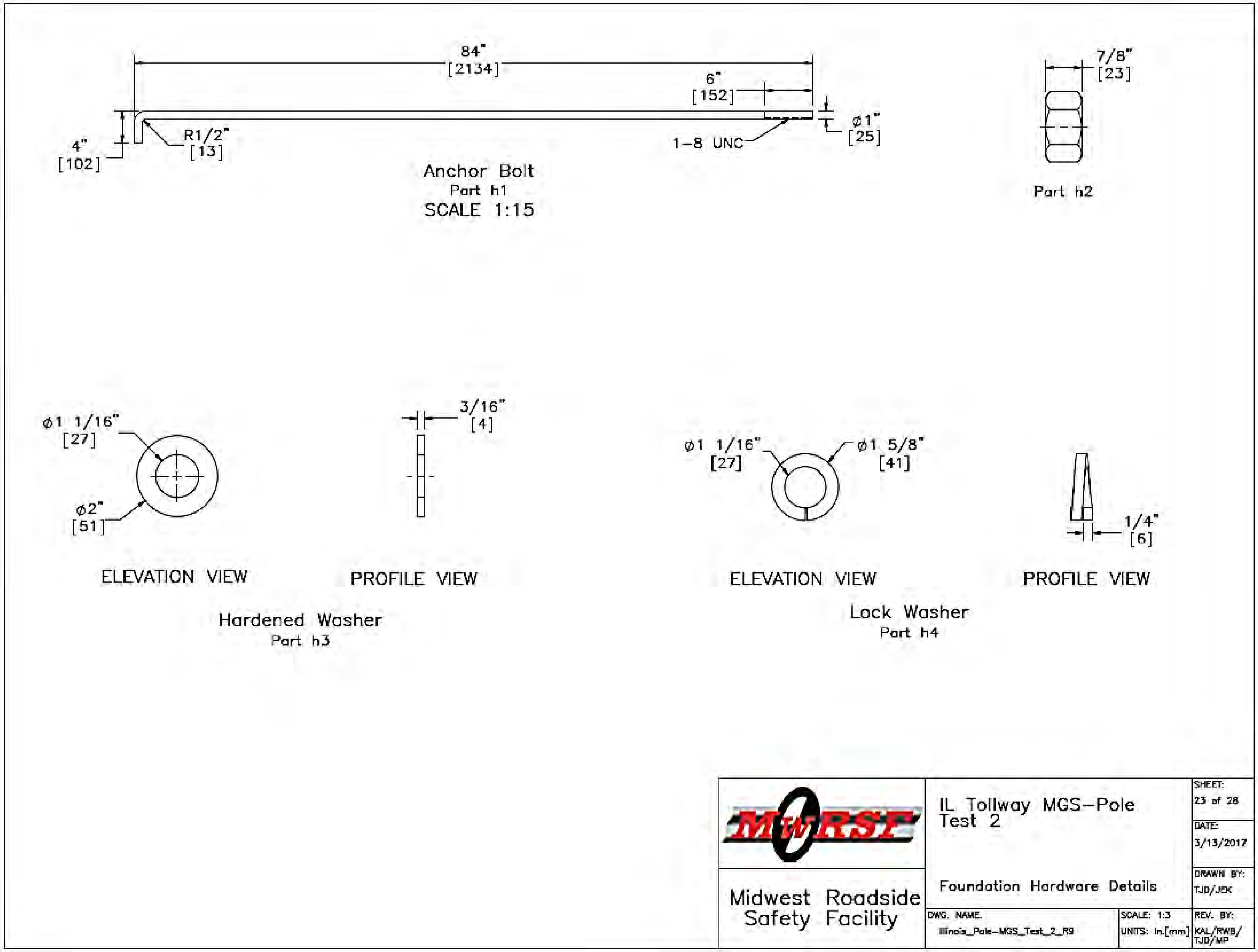


Figure 89. Foundation Hardware Details, Test No. ILT-2

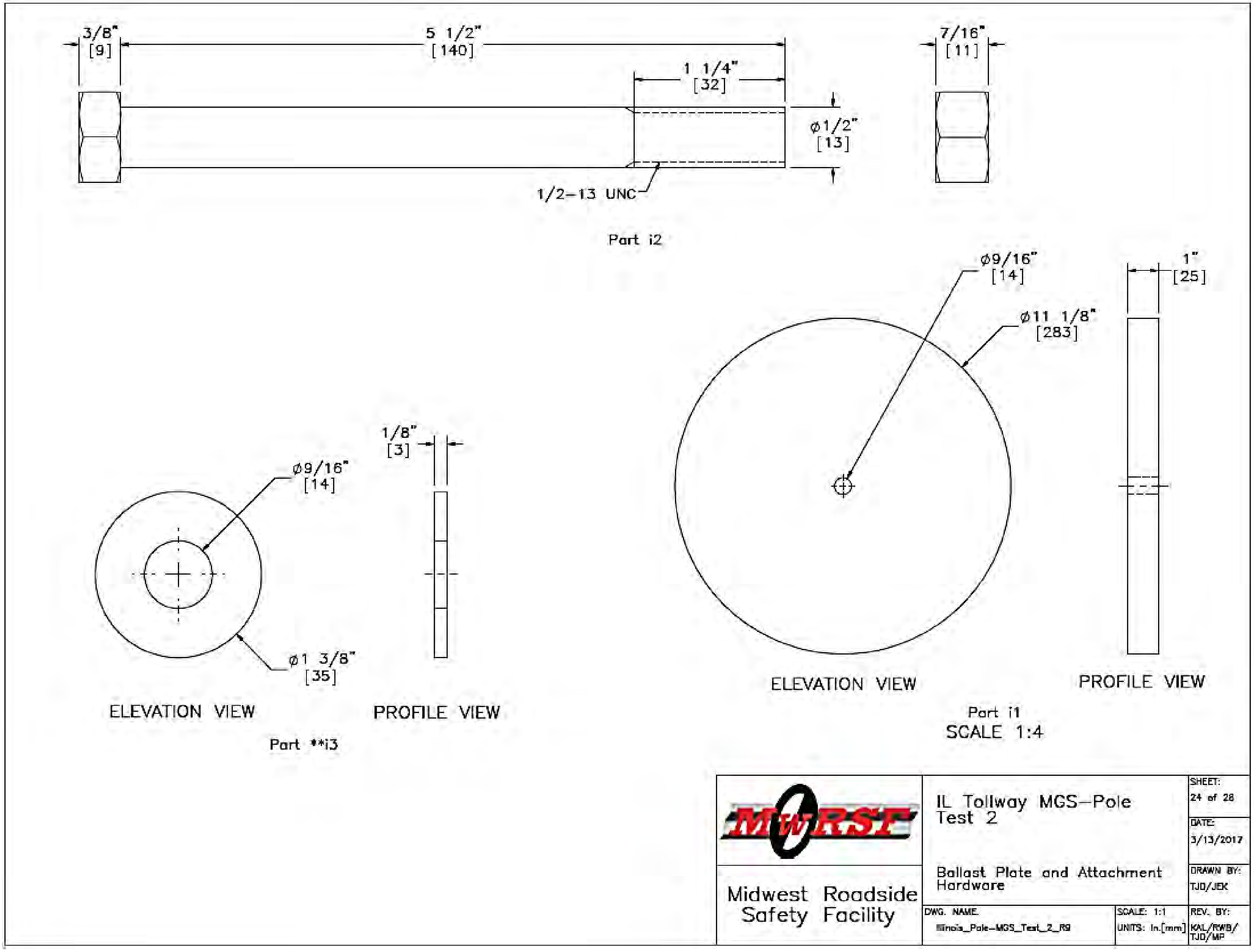
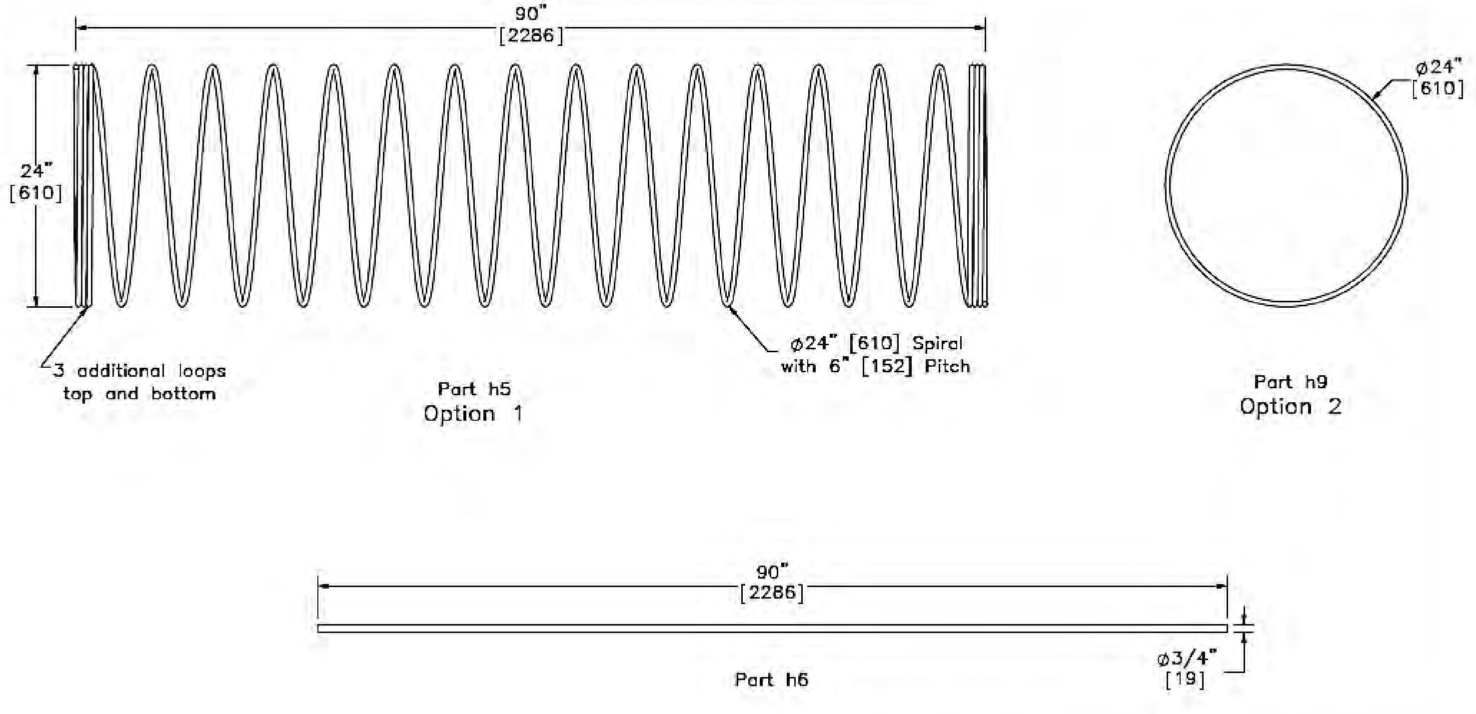


Figure 90. Ballast Plate and Attachment Hardware, Test No. ILT-2

BILL OF BARS				
ITEM NO.	QTY.	BAR SIZE	UNBENT LENGTH	MATERIAL SPEC.
h5 Option 1	1	#4 [13]	1517" [38532]	Epoxy-Coated ASTM A615 Gr. 60
h9 Option 2	8	#4 [13]	74" [1880]	Epoxy-Coated ASTM A615 Gr. 60
h6	8	#6 [19]	90" [2286]	Epoxy-Coated ASTM A615 Gr. 60



Midwest Roadside Safety Facility

IL Tollway MGS-Pole Test 2

Bill of Bars

SHEET: 25 of 28

DATE: 5/18/2017

DRAWN BY: TJD/JEK/DTM

DWG. NAME. Illinois_Pole-MGS_Test_2_R10

SCALE: 1:15

UNITS: In.[mm]

REV. BY: KAL/RWB/TJD/MP

Figure 91. Bill of Bars, Test No. ILT-2

Item No.	QTY.	Description	MaterialSpec	As–Tested Modification	Hardware Guide
a1	12	12'–6" [3810] W–Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv. (ASTM A653)	–	RWM04a
a2	2	12'–6" [3810] W–Beam MGS End Section	12 gauge [2.7] AASHTO M180 Galv. (ASTM A653)	–	RWM14a
a3	1	6'–3" [1905] W–Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv. (ASTM A653)	–	RWM04a
a4	25	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1829] Steel Post	ASTM A992 or ASTM A36 Min. 50 ksi [345 MPa] Steel Galv. Per AASHTO M111 (ASTM A123)	–	PWE06
a5	25	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better		PDB10a
a6	25	16D Double Head Nail	–	–	–
b1	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face)	–	PDF01
b2	4	72" [1829] Long Foundation Tube	ASTM A500 Grade B Galv. Per AASHTO M11 (ASTM A123)	–	PTE06
b3	2	Ground Strut Assembly	ASTM A36 Steel Galv. Per AASHTO M111 (ASTM A123)	A–1011–SS, Yield Strength 48,380 psi, Tensile Strength 64,020 psi	PFP02
b4	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40 Galv. Per AASHTO M111 (ASTM A123)	–	FMM02
b5	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel Galv. Per AASHTO M111 (ASTM A123)	–	FPB01
b6	2	Anchor Bracket Assembly	ASTM A36 Steel Galv. Per AASHTO M111 (ASTM A123)	–	FPA01
c1	4	BCT Anchor Cable End Swaged Fitting	Grade 5 – Galv. Fitting Per AASHTO M232 (ASTM A153), Stud Per AASHTO M232 or M298 (ASTM A153 or B695)	–	–
c2	2	3/4" [190] Dia. 6x19, 24 1/2" [622] Long IWRC IPS Wire Rope	IPS Galv. Per AASHTO M30 (ASTM A741) Type II Class A	–	–
c3	4	115–HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–	–
c4	4	Crosby Heavy Duty HT – 3/4" [19] Dia. Cable Thimble	Stock No. 1037773 – Galv. – As Supplied	–	–
c5	4	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 – As Supplied	–	–
c6	4	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNC 6 [M36x4]	Stock No. 107 – As Supplied	–	–
c7	2	TLL–50K–PTB Load Cell	–	–	–
d1	1	45' [13716] Long Aluminum Pole, Pay Item No. 903A10, JS830003	6063–T4 Aluminum Alloy		–
d2	1	CS–370 Anchor Base, Model No. 10R145153B9T	6063 Aluminum Alloy		–
d3	1	Truss, Model No. 1TA1566C60ZA	6063–T6 Aluminum Alloy		–

Midwest Roadside Safety Facility

IL Tollway MGS–Pole Test 2

Bill of Materials

SHEET: 28 of 28

DATE: 3/13/2017

DRAWN BY: TJD/JEK

DWG. NAME. Illinois_Pole–MGS_Test_2_R9

SCALE: None

UNITS: in.[mm]

REV. BY: KAL/RWB/TJD/MP

Figure 92. Bill of Materials, Test No. ILT-2

Item No.	QTY.	Description	Material Specification	As–Tested Modification	Hardware Guide
d4	4	1" [25] Dia. UNC, 4" [102] Long Hex Head Bolt	Bolt – ASTM A449 or SAE J429 Grade 5 Galv. Per ASTM A153, Nut – ASTM A563DH Galv. Per ASTM A153	–	–
d5	8	1" [25] Dia. Hardened Flat Washer	ASTM A153 Galv. Low Carbon Steel	–	–
d6	4	1" [25] Dia. 1/2" [13] Thick Flat Washer	Q235 Steel, Galv. Per ASTM A123, Coating Grade 50	–	–
d7	8	1/2" [13] Dia. UNC x 3" [76] Long Hex Head Bolt and Nut	Bolt – 304 Stainless Steel or ASTM F593, Nut – ASTM F594 Stainless Steel	–	–
d8	16	1/2" [13] Dia. Flat Washer	18–8 Stainless Steel	–	–
d9	8	1/2" [13] Dia. Split Lock Washer	18–8 Stainless Steel	–	–
d10	2	1/4" [6] Dia. x 3/4" [19] Flat Head Screw	18–8 Stainless Steel	–	–
f1	25	5/8" [16] Dia. UNC x 14" [356] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FBB06
f2	114	5/8"[16] Dia. UNC x 1 1/2" [38] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FBB01
f3	4	7/8" Dia. [22] UNC x 7 1/2" [191] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FBX22a
f4	4	5/8" [16] Dia. UNC x 10" [254] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FBX16a
f5	16	5/8" [16] Dia. x 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FBX16a
f6	4	5/8" [16] Dia. UNC x 10" [254] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FBB03
g1	44	5/8" [16] Dia. Plain Round Washer	ASTM F844 Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FWC16a
g2	8	7/8" [22] Dia. Plain Round Washer	ASTM F844 Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FWC22a
h1	4	1" [25] Dia., 84" [2134] Long Anchor Bolt	ASTM F1554 Grade 105 or A449 Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	–
h2	4	1" [25] Dia. UNC Hex Nut	ASTM A563DH or A194 Gr. 2H Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	FNX24b

Midwest Roadside Safety Facility

IL Tollway MGS–Pole Test 2

Bill of Materials

SHEET: 27 of 28
DATE: 3/13/2017
DRAWN BY: TJD/JEK
REV. BY: KAL/RWB/TJD/MP
SCALE: None
UNITS: in.[mm]
DWG. NAME. Illinois_Pole–MGS_Test_2_R9

Figure 93. Bill of Materials, Test No. ILT-2

Item No.	QTY.	Description	Material Specification	As–Tested Modification	Hardware Guide
h3	4	1" [25] Dia. Hardened Round Washer	ASTM F436 Galv. Per ASTM B695	–	FWC24b
h4	4	1" [25] Dia. Split Lock Washer	Steel Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	–	–
*h5	1	1/2" [13] Dia. Bent Rebar, unbent 1517" [38532] Long	Epoxy–Coated ASTM A615 Gr. 60	–	–
h6	8	3/4" [19] Dia., 90" [2286] Long Rebar	Epoxy–Coated ASTM A615 Gr. 60	–	–
h7	1	Light Pole Concrete Foundation	Min. f'c = 3,500 psi [24.1 MPa]	–	–
h8	1	30" [762] Dia. x 6" [152] Sonotube	Sonotube	–	–
*h9	8	1/2" [13] Dia., Bent Rebar, unbent 74" [1880] Long	Epoxy–Coated ASMT A615 Gr. 60	–	–
i1	2	11 1/8" [283] Dia. x 1" [25] Thick Ballast Plate	ASTM A36	–	–
i2	1	1/2" [13] Dia. UNC, 5 1/2" [140] Long Hex Head Bolt	Bolt – ASTM A325 Type 1, Nut – ASTM A563C	–	FBX12b
**i3	2	1/2" [13] Dia. Plain Round Washer	ASTM F844	–	FWC12a

* Either Part h5 or Part h9 is used.

** Per researcher recommendation, use ASTM F844 washer instead of ASTM F436 to attach ballast.

Midwest Roadside Safety Facility

IL Tollway MGS–Pole Test 2

Bill of Materials

SHEET: 28 of 28

DATE: 3/13/2017

DRAWN BY: TJO/JEK

DWG. NAME. Illinois_Pole–MGS_Test_2_R9

SCALE: None

UNITS: in.[mm]

REV. BY: KAL/RWB/TJO/MP

Figure 94. Bill of Materials, Test No. ILT-2

Figure 95. Test Installation, Test No. ILT-2

Figure 96. Test Installation, Test No. ILT-2

Figure 97. Test Installation, Test No. ILT-2

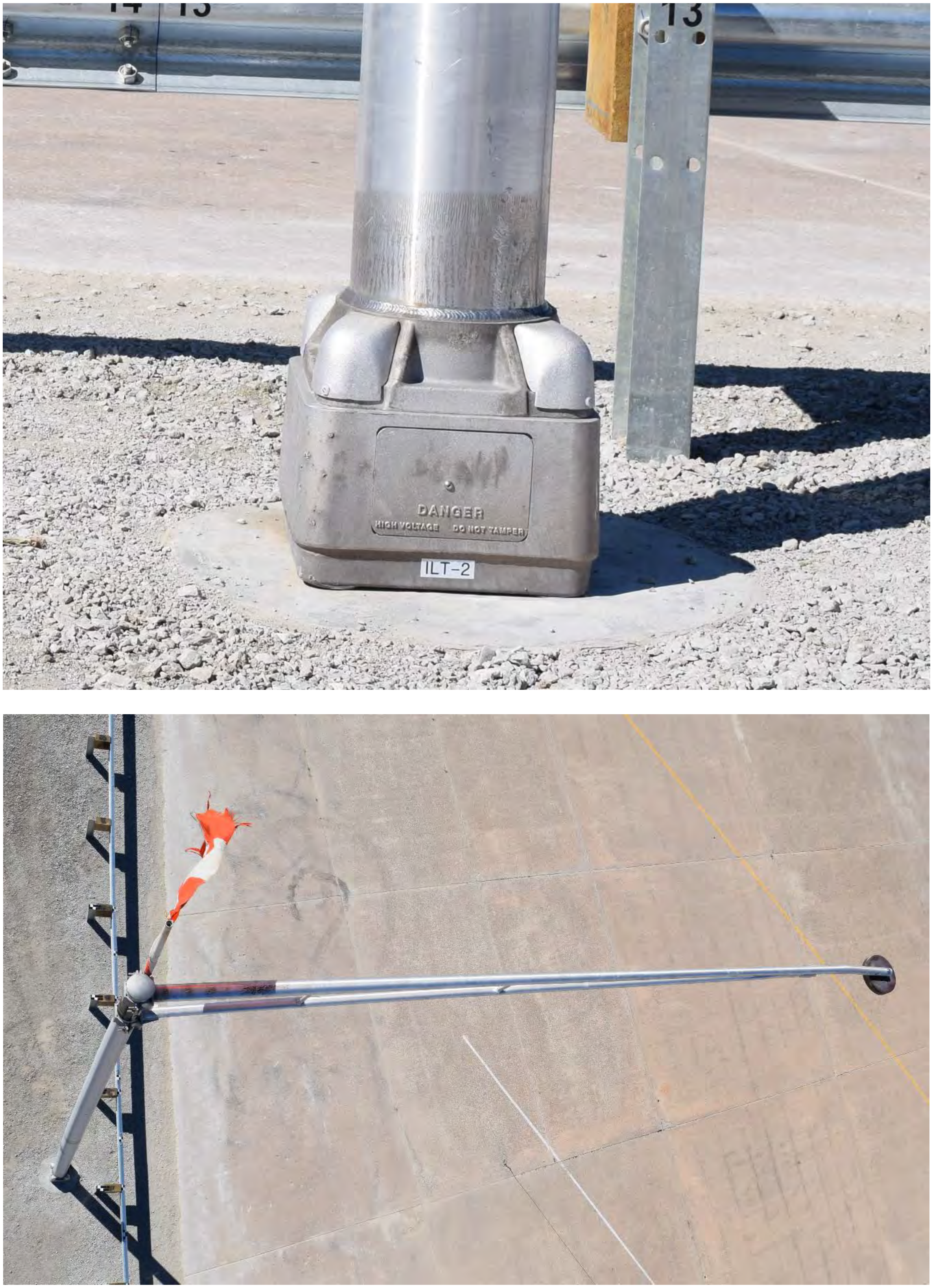


Figure 98. Test Installation, Test No. ILT-2

6 TEST CONDITIONS

6.1 Test Facility

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

6.2 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 used on the tow vehicle to increase the accuracy of the test vehicle's impact speed.

A vehicle guidance system that was developed by Hinch [29] was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable. As the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

6.3 Test Vehicle

For test no. ILT-1, a 2009 Dodge Ram 1500 Quadcab was used as the test vehicle. This vehicle meets the requirements for a MASH 2270P pickup truck. The curb, test inertial, and gross static vehicle weights were 4,961 lb (2,250 kg), 5000 lb (2,268 kg), and 5,165 lb (2,343 kg), respectively. The test vehicle is shown in Figure 99, and vehicle dimensions are shown in Figure 100.

For test no. ILT-2, a 2009 Hyundai Accent was used as the test vehicle. This vehicle meets the requirements for a MASH 1100C passenger car. The curb, test inertial, and gross static vehicle weights were 2,434 lb (1,104 kg), 2,420 lb (1,098 kg), and 2,586 lb (1,173 kg), respectively. The test vehicle is shown in Figure 101, and vehicle dimensions are shown in Figure 102.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [30] was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE [31]. The location of the c.g. for test nos. ILT-1 and ILT-2 are shown in Figures 100 and 102, respectively. Data used to calculate the location of the c.g. are shown in Appendix F.

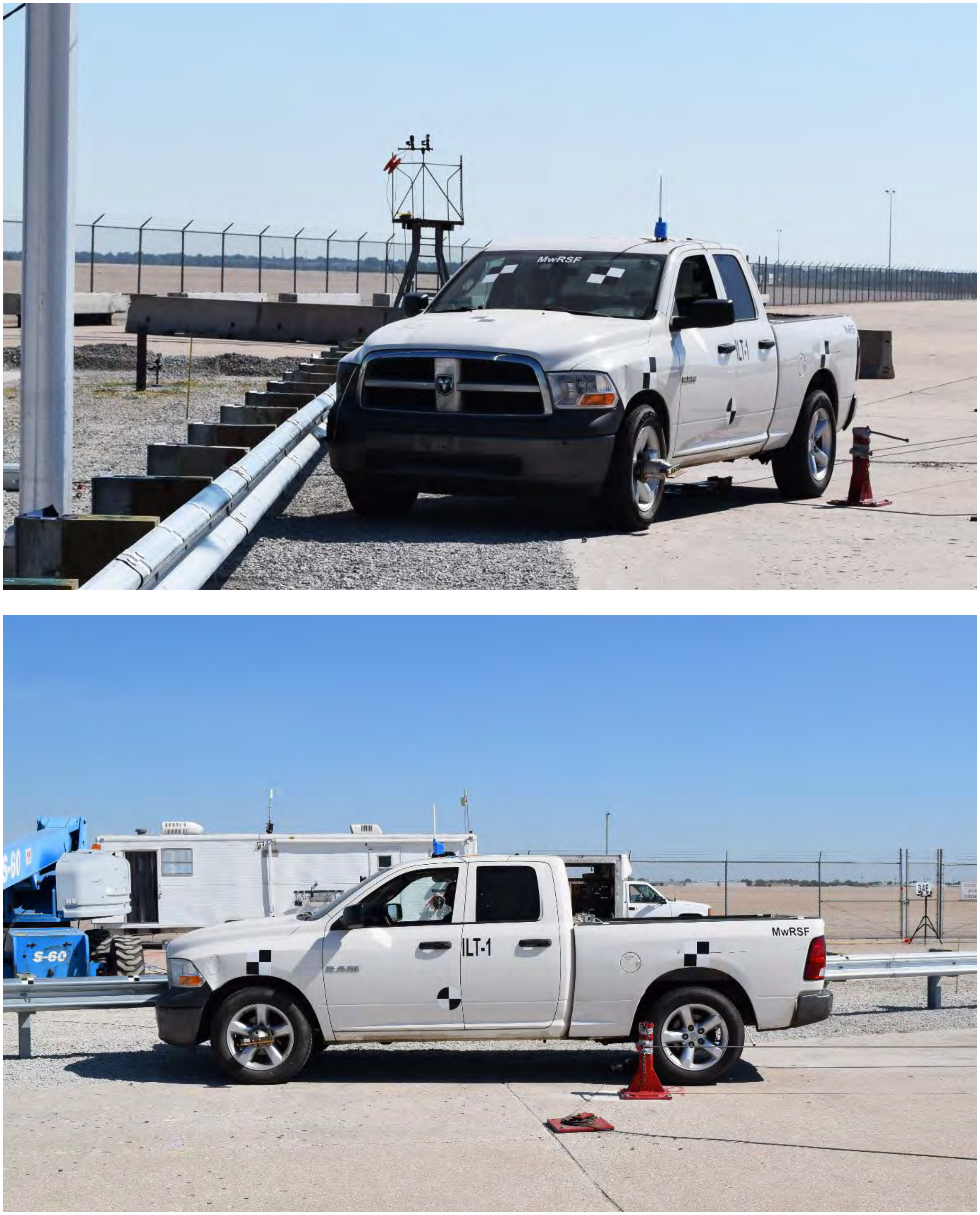


Figure 99. Test Vehicle, Test No. ILT-1

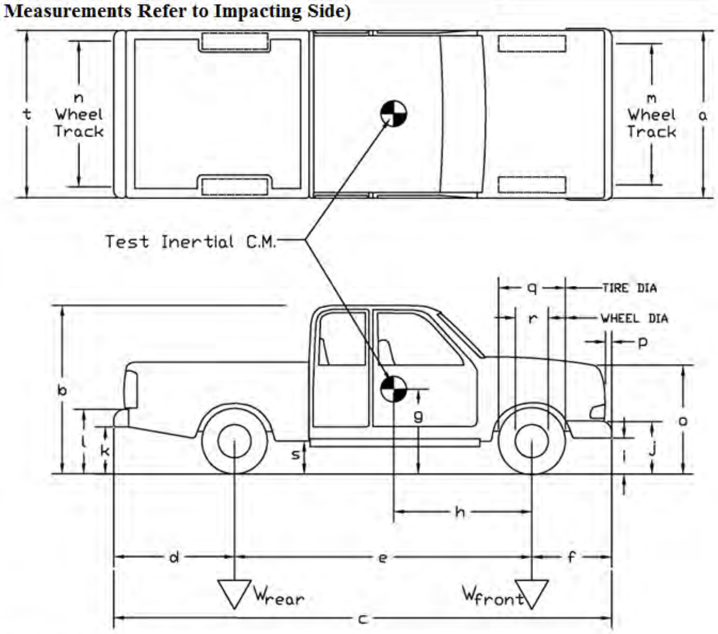
Date: 9/23/2016 **Test Number:** ILT-1 **Model:** Ram 1500 quadcab

Make: Dodge **Vehicle I.D.#:** 1D3HB18P49S746514

Tire Size: P275/60R20 **Year:** 2009 **Odometer:** 180118

Tire Inflation Pressure: 35

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



Vehicle Geometry -- in. (mm)

a	76 1/2	(1943)	b	74 5/8	(1895)
c	229 1/4	(5823)	d	48 7/8	(1241)
e	139 7/8	(3553)	f	39 3/8	(1000)
g	28 1/3	(720)	h	61	(1550)
i	9 1/8	(232)	j	28	(711)
k	20	(508)	l	30 1/4	(768)
m	69 1/8	(1756)	n	68 1/4	(1734)
o	46 3/4	(1187)	p	4 1/2	(114)
q	33	(838)	r	21 5/8	(549)
s	14 3/8	(365)	t	77 1/4	(1962)

Wheel Center Height Front	15 1/2	(394)
Wheel Center Height Rear	15 3/4	(400)
Wheel Well Clearance (F)	35 3/4	(908)
Wheel Well Clearance (R)	38 3/8	(975)
Frame Height (F)	14 3/8	(365)
Frame Height (R)	21 3/8	(543)
Engine Type	Gasoline	
Engine Size	4.7 L V8	
Transmission Type:	Automatic	
Drive Type:	RWD	

Mass Distribution lb (kg)

Gross Static	LF	1442 (654)	RF	1476 (670)
	LR	1141 (518)	RR	1106 (502)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2829 (1283)	2819 (1279)	2918 (1324)
W-rear	2132 (967)	2181 (989)	2247 (1019)
W-total	4961 (2250)	5000 (2268)	5165 (2343)

GVWR Ratings

Front	3700
Rear	3900
Total	6700

Dummy Data

Type: Hybrid II
Mass: 165 lb
Seat Position: Passenger

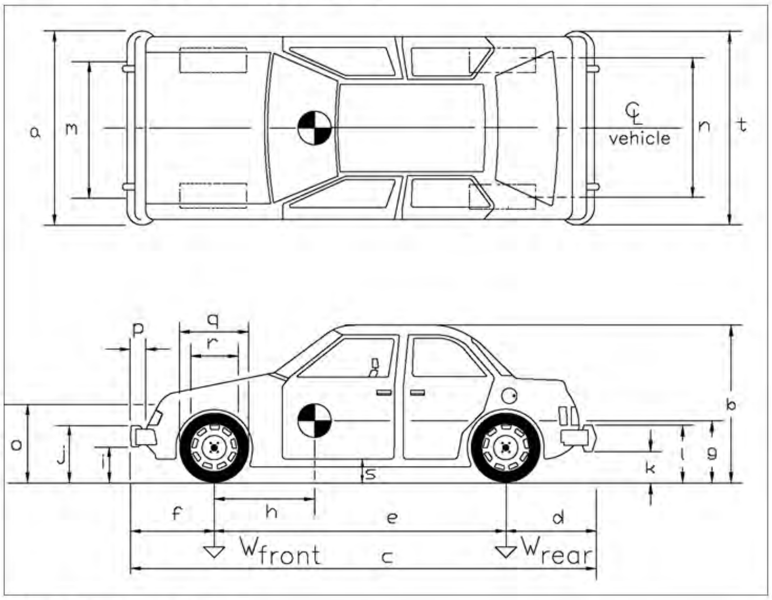
Figure 100. Vehicle Dimensions, Test No. ILT-1

Figure 101. Test Vehicle, Test No. ILT-2

Date:	9/28/2016	**Test Number:**	ILT-2	**Model:**	Accent
Make:	Hyundai	**Vehicle I.D.#:**	KMHCN46C39U286497		
Tire Size:	P185/65R14 85T	**Year:**	2009	**Odometer:**	59972

Tire Inflation Pressure: 32

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



Vehicle Geometry -- in. (mm)

a	66	(1676)	b	57 7/8	(1470)
c	168 1/4	(4274)	d	36 3/8	(924)
e	98 3/4	(2508)	f	32 7/8	(835)
g	22 5/7	(577)	h	37 4/5	(960)
i	8 5/8	(219)	j	20 7/8	(530)
k	11 1/4	(286)	l	24 3/4	(629)
m	57 3/4	(1467)	n	57 3/8	(1457)
o	28 1/2	(724)	p	2 1/8	(54)
q	23 1/8	(587)	r	15 3/8	(391)
s	8	(203)	t	64 7/8	(1648)

Wheel Center Height Front	10 3/4	(273)
Wheel Center Height Rear	11 1/8	(283)
Wheel Well Clearance (F)	25 5/8	(651)
Wheel Well Clearance (R)	25 3/8	(645)
Frame Height (F)	8 1/4	(210)
Frame Height (R)	16 1/4	(413)
Engine Type	Gasoline	
Engine Size	1.6 L	
Transmission Type:	Manual	
Drive Axle:	FWD	

Mass Distribution lb (kg)

Gross Static	LF	804 (365)	RF	777 (352)
	LR	516 (234)	RR	489 (222)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	1525 (692)	1494 (678)	1581 (717)
W-rear	909 (412)	926 (420)	1005 (456)
W-total	2434 (1104)	2420 (1098)	2586 (1173)

GVWR Ratings

Front	1918
Rear	1874
Total	3638

Dummy Data

Type:	Hybrid II
Mass:	166 lb
Seat Position:	Driver

Figure 102. Vehicle Dimensions, Test No. ILT-2

Square, black- and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 103 and 104. Round, checkered targets were placed on the center of gravity on the left-side door, the right-side door, and the roof of the vehicle. The front wheels of the test vehicle were aligned to vehicle standards except the toe-in value was adjusted to zero so that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted on the left side of the vehicle's dash and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed videos. A remote controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

6.4 Simulated Occupant

For test nos. ILT-1 and ILT-2, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the right-front and left-front seat of the test vehicles, respectively, with the seat belt fastened. The dummy, which had a final weight of approximately 170 lb (77 kg), was represented by model no. 572, serial no. 451, and was manufactured by Android Systems of Carson, California. As recommended by MASH, the dummy was not included in calculating the c.g. location.

6.5 Data Acquisition Systems

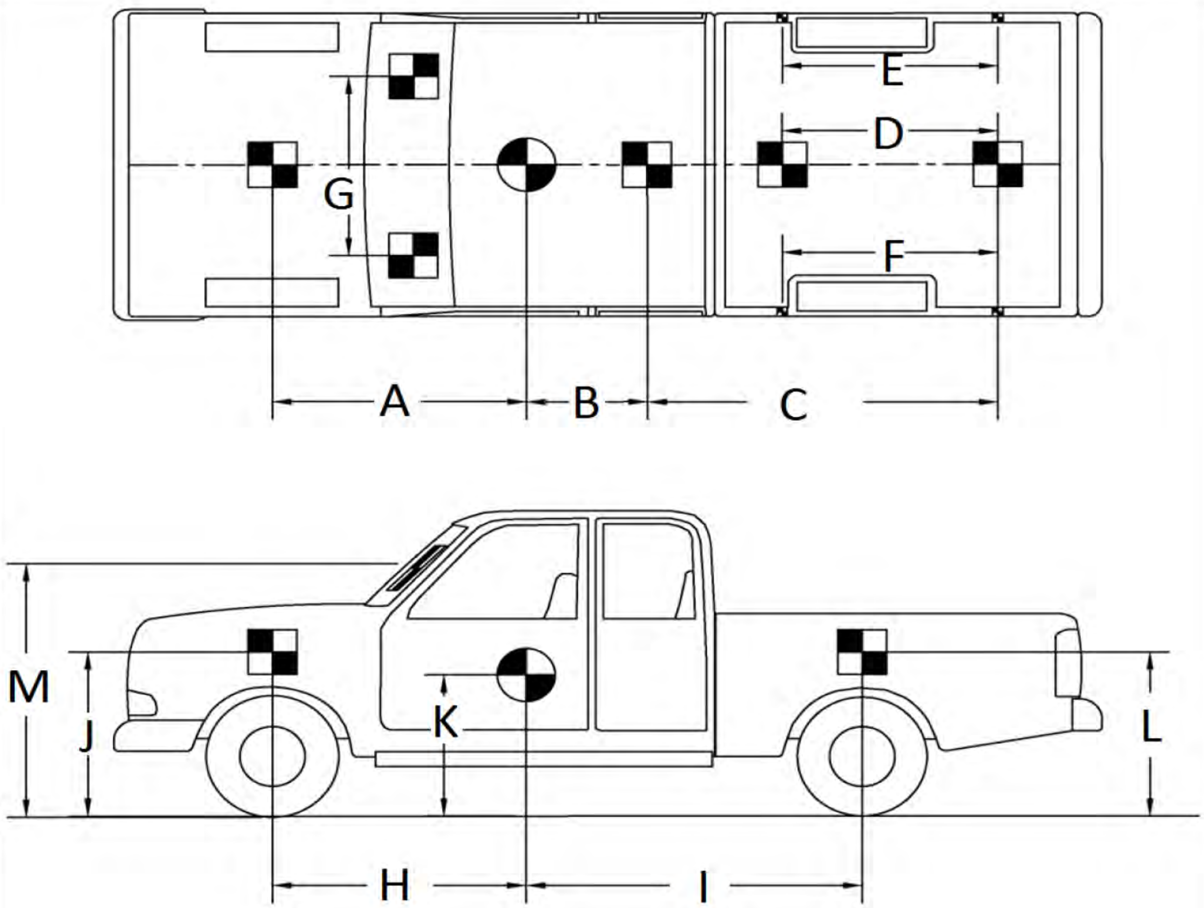
6.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometers were mounted near the center of gravity of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [32].

The SLICE-1 and SLICE-2 units were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The acceleration sensors were mounted inside the bodies of custom built SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

6.5.2 Rate Transducers

Two angular rate sensor systems mounted inside the bodies of the SLICE-1 and SLICE-2 event data recorders were used to measure the rates of rotation of the test vehicle. Each SLICE MICRO Triax ARS had a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the onboard microprocessors. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

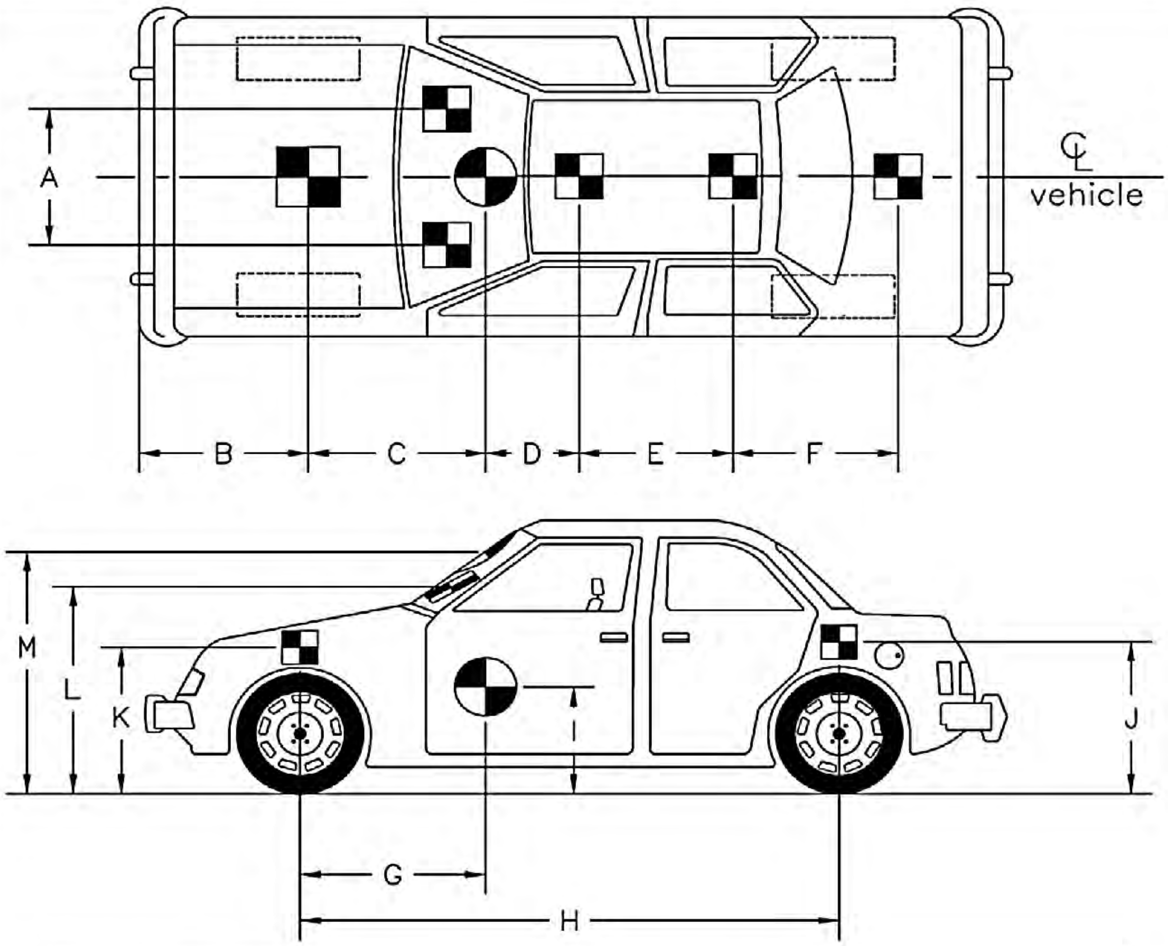


TEST #: ILT-1

TARGET GEOMETRY-- in. (mm)

A	77	(1956)	E	63 1/4	(1607)	J	40	(1016)
B	27 1/8	(689)	F	63 1/8	(1603)	K	28 3/8	(721)
C	73 1/4	(1861)	G	30 3/4	(781)	L	42 1/8	(1070)
D	48	(1219)	H	61	(1549)	M	64	(1626)
			I	79 1/2	(2019)			

Figure 103. Target Geometry, Test No. ILT-1



TEST #: ILT-2 Vehicle: Hyundai Accent

TARGET GEOMETRY-- in. (mm)

A	**29 1/8**	**(740)**	**E**	**24 1/8**	**(613)**	**I**	**22 3/4**	**(578)**
B	**21 1/4**	**(540)**	**F**	**43 7/8**	**(1114)**	**J**	**29 1/2**	**(749)**
C	**49 1/4**	**(1251)**	**G**	**37 3/4**	**(959)**	**K**	**30 1/8**	**(765)**
D	**16 3/4**	**(425)**	**H**	**98 5/8**	**(2505)**	**L**	**50**	**(1270)**
						M	**54 1/8**	**(1375)**

Figure 104. Target Geometry, Test No. ILT-2

6.5.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the vehicle before impact. Three retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the vehicle. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box activating the LED flashes. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

6.5.4 Load Cells

Load cells were installed at the downstream and upstream anchorage systems for test nos. ILT-1 and ILT-2. The load cells were Transducer Techniques model no. TLL-50K with a load range up t o 50 ki ps (222 kN). During testing, output voltage signals were sent from the transducers to a National Instruments PCI-6071E data acquisition board, acquired with LabView software, and stored on a personal computer at a sample rate of 10,000 Hz. The positioning and set up of the transducers are shown in Figure 105.

(a)

(b)

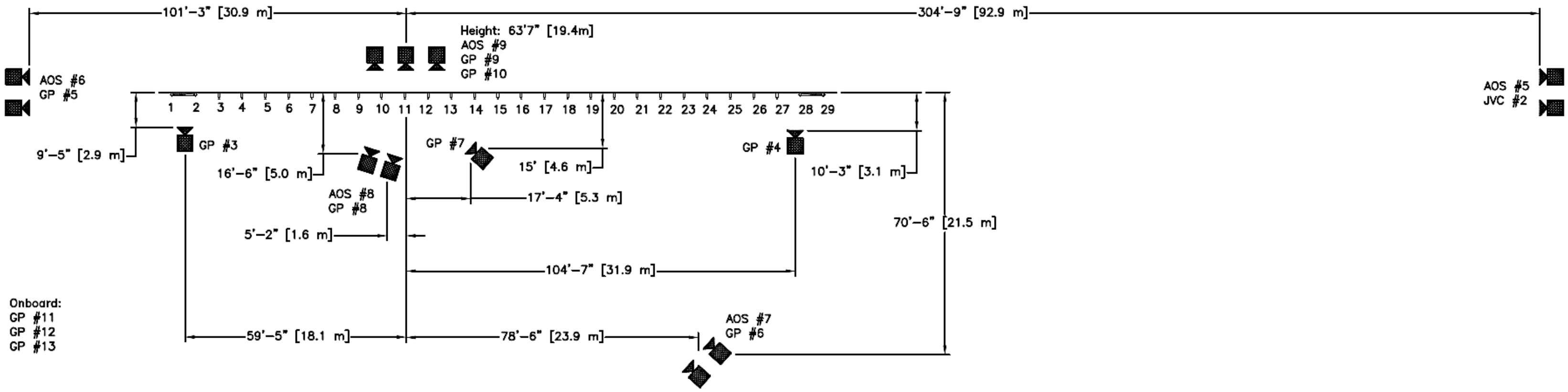
Figure 105. Location of Load Cells: (a) Upstream and (b) Downstream Anchorage Systems

6.5.1 Digital Photography

Three AOS X-PRI high-speed digital video cameras, one AOS S-VIT 1531 high-speed video camera, one AOS TRI–VIT 2236 high-speed video camera, four GoPro Hero 3+ digital video cameras, seven GoPro Hero 4 digital video cameras, and one JVC digital video camera were utilized to film test no. ILT-1. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 106.

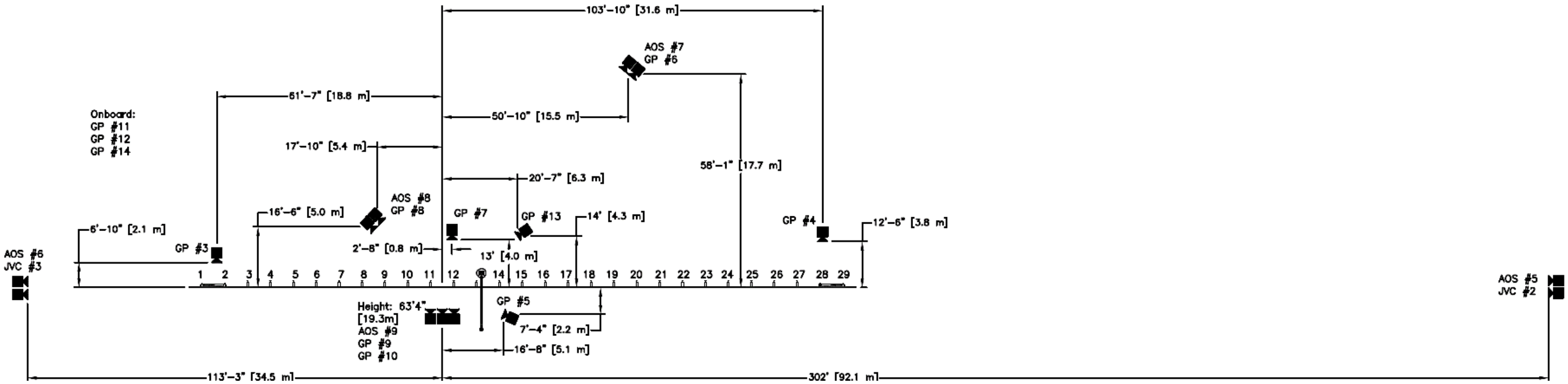
Three AOS X-PRI high-speed digital video cameras, one AOS S-VIT 1531 high-speed video camera, one AOS TRI–VIT 2236 high-speed video camera, four GoPro Hero 3+ digital video cameras, eight GoPro Hero 4 digital video cameras, and one JVC digital video camera were utilized to film test no. ILT-2. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 107.

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



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI Gigabit	500	Telespar 135mm Fixed	
AOS-6	AOS X-PRI Gigabit	500	Sigma 28-70 DG	
AOS-7	AOS X-PRI Gigabit	500	Sigma 28-70	35
AOS-8	AOS S-VIT 1531	500	Kowa 16 mm Fixed	35
AOS-9	AOS TRI-VIT 2236	1000	Kowa 12 mm Fixed	
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	240		
GP-10	GoPro Hero 4	120		
GP-11	GoPro Hero 4	120		
GP-12	GoPro Hero 4	120		
GP-13	GoPro Hero 4	120		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		

Figure 106. Camera Locations, Camera Speeds, and Lens Settings, Test No. ILT-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI Gigabit	500	Telespar 135mm Fixed	
AOS-6	AOS X-PRI Gigabit	500	Sigma 28-70 DG	
AOS-7	AOS X-PRI Gigabit	500	Sigma 28-70	35
AOS-8	AOS S-VIT 1531	500	Kowa 16 mm Fixed	35
AOS-9	AOS TRI-VIT 2236	1000	Kowa 12 mm Fixed	
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	240		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	240		
GP-11	GoPro Hero 4	120		
GP-12	GoPro Hero 4	120		
GP-13	GoPro Hero 4	240		
GP-14	GoPro Hero 4	120		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		

Figure 107. Camera Locations, Camera Speeds, and Lens Settings, Test No. ILT-2

7 FULL-SCALE CRASH TEST NO. ILT-1

7.1 Static Soil Test

Before full-scale crash test no. ILT-1 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix G, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

7.2 Weather Conditions

Test no. ILT-1 was conducted on September 23, 2016 at approximately 3:00 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 15.

Table 15. Weather Conditions, Test No. ILT-1

Temperature	91° F
Humidity	33%
Wind Speed	30 mph
Wind Direction	180° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in. (0 mm)
Previous 7-Day Precipitation	0 in. (0 mm)

7.3 Test Description

The 5,000-lb (2,268-kg) Dodge Ram pickup truck impacted the combination MGS with luminaire pole at a speed of 62.6 mph (100.7 km/h) and at an angle of 25.2 degrees. Initial vehicle impact was to occur 4 in. (102 mm) downstream from post no. 11, as shown in Figure 108. As detailed in Chapter 4, the impact point was selected through LS-DYNA analysis to maximize the MGS deflection, the longitudinal ORA, and the potential for vehicle snag. The actual impact point was 3 in. (76 mm) downstream from post no. 11. A sequential description of the impact events is contained in Table 16. A summary of the test results and sequential photographs are shown in Figure 109. Additional sequential photographs are shown in Figures 110 through 111.

Upon impact, the right-front bumper contacted the rail at post no. 11. At 0.160 seconds, the right-front fender struck the pole and began to crush inward. At 0.170, the right-front tire snagged on post no. 13, while the pickup truck was at an angle of 17.3 degrees relative to the MGS. Then, the light pole base fractured, disengaged, and began to fall toward the ground. At 0.320 seconds, the vehicle became parallel to the system, and at 0.860 seconds, the vehicle exited the system. At 1.414 seconds, the pole came to rest on top of the guardrail between post nos. 14 and 15. The vehicle came to rest 83 ft – 6 in. (25.5 m) downstream from impact and 6 ft – 6 in.

(2.0 m) laterally in front of the traffic side of the guardrail system. The vehicle trajectory and final position are shown in Figure 112.

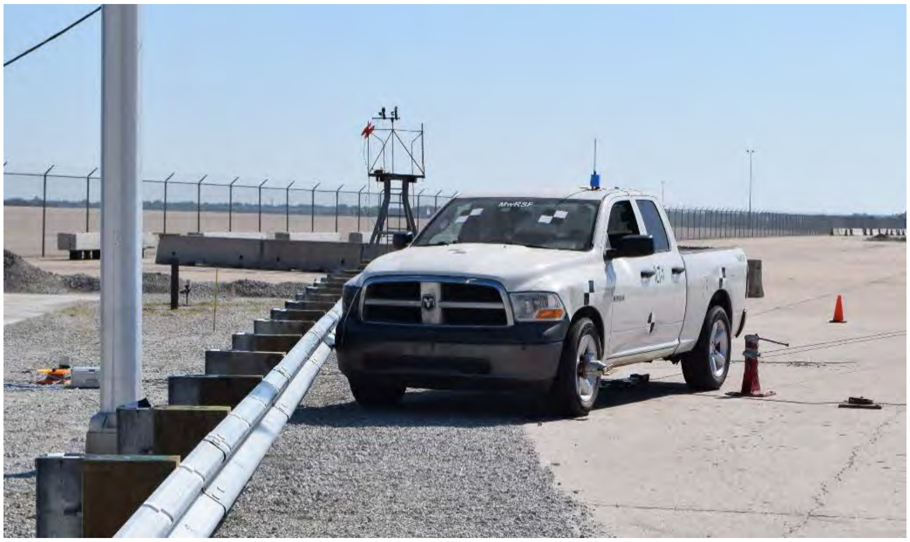


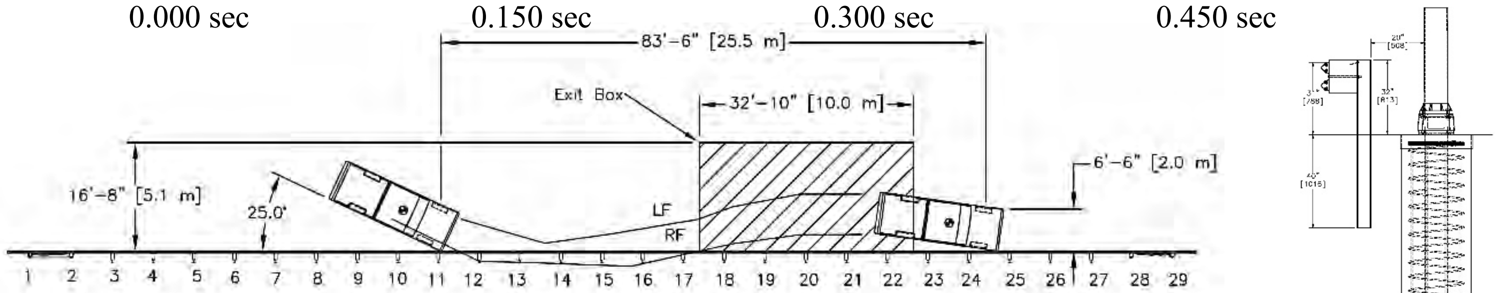
Figure 108. Impact Location, Test No. ILT-1

Table 16. Sequential Description of Impact Events, Test No. ILT-1

TIME (sec)	EVENT
0.0	Vehicle's right-front bumper contacted rail 3 in. (76 mm) downstream from post no. 11, and vehicle's front bumper deformed.
0.002	Post no. 11 deflected backward.
0.010	Post no. 12 deflected backward. Vehicle right fender contacted rail and deformed.
0.012	Post no. 10 deflected backward.
0.014	Vehicle's right headlight deformed.
0.023	Post no. 11 twisted clockwise.
0.026	Post no. 12 twisted counterclockwise.
0.028	Post no. 15 twisted counterclockwise; Post nos. 16, 17, and 18 twisted counterclockwise; and engine hood deformed.
0.030	Vehicle rolled toward barrier.
0.034	Post no. 14 twisted counterclockwise. Post nos. 7, 8, 9, and 10 twisted clockwise.
0.036	Post no. 13 twisted counterclockwise and deflected backward.
0.042	Post no. 12 bent backward and downstream.
0.054	Vehicle yawed away from barrier.
0.056	Post no. 13 bent downstream.
0.060	Post no. 14 deflected backward.
0.064	Post no. 12 disengaged away from rail.
0.114	Post no. 13 disengaged away from rail.
0.120	Post no. 14 bent downstream.
0.128	Post no. 15 deflected backward.
0.140	Blockout no. 13 contacted light pole.
0.160	Vehicle's right-front fender contacted light pole.
0.162	Post no. 14 disengaged away from rail.
0.164	Light pole fell toward ground.
0.170	Vehicle's right-front wheel contacted light pole base. Light pole base disengaged away from ground.
0.176	Vehicle's right-front door contacted rail and deformed.
0.182	Post no. 15 bent downstream.
0.188	Vehicle rolled away from barrier.
0.192	Post no. 16 deflected backward.
0.194	Vehicle's right-rear door deformed.

TIME (sec)	EVENT
0.210	Vehicle’s right quarter panel contacted rail and deformed.
0.226	Vehicle’s right-rear door contacted rail.
0.250	Blockout no. 15 disengaged away from rail at post no. 15.
0.272	Vehicle pitched downward.
0.314	Vehicle rolled toward barrier.
0.320	Vehicle became parallel to barrier at a speed of 37.5 mph (60.4 km/h)
0.780	Vehicle pitched upward.
0.860	Vehicle exited system at a speed of 21.6 mph (34.8 km/h) and at an angle of 12.95 degrees.
1.414	Light pole contacted rail between post no. 14 and post no. 15.
1.510	Top of light pole top contacted ground.
1.690	Top of light pole lost contact with rail.
1.946	Mast arm of light pole contacted post no. 11.
1.954	Mast arm of light pole top truss member contacted rail.
2.016	Vehicle’s right-front bumper contacted rail.
2.098	Light pole contacted ground.
2.242	Light pole regained contact with rail.

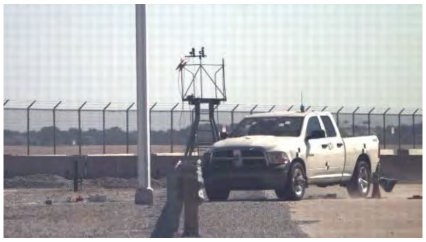
0.000 sec | 0.150 sec | 0.300 sec | 0.450 sec | 0.600 sec



- Test Agency .... MwRSF
- Test Number ILT-1
- Date 9/23/16
- MASH Test Designation No. 3-11
- Test Article .... MGS Offset from Illinois Tollway's Breakaway Light Pole
- Total Length .... 175 ft (53.3 m)
- Key Component – MGS Rail
  - Thickness .... 12 gauge (2.66 mm)
  - Top Mounting Height .... 31 in. (787 mm)
- Key Component – Steel Posts
  - Post Type .... W6x8.5 by 6' (1,829 mm)
  - Post Spacing .... 75 in. (1,905 mm)
- Key Component – Illinois Tollway Pole with CS370 Transformer Base
  - Pole Height .... 50 ft (15.2 m)
  - Pole Arm Mast Length .... 15 ft (4.570 m)
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make /Model .... 2009 Dodge Ram
  - Curb .... 4,961 lb (2,250 kg)
  - Test Inertial .... 5,000 lb (2,268 kg)
  - Gross Static .... 5,165 lb (2,343 kg)
- Impact Conditions
  - Speed .... 62.6 mph (100.7 km/h)
  - Angle .... 25.2 deg
  - Impact Location .... 3 in. (76 mm) Downstream from Post No. 11
- Impact Severity (IS) .... 117.0 kip-ft (158.6 kJ) > 106 kip-ft (144 kJ) limit from MASH
- Exit Conditions
  - Speed .... 21.6 mph (34.8 km/h)
  - Angle .... 12.95 deg
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 83 ft – 6 in. (25.5 m)
- Vehicle Damage .... Moderate
  - Vehicle Damage Scale [33] 1-FR-5
  - Collision Deformation Classification [34] 1-FREW-5
- Maximum Interior Deformation .... 0.55 in. (14 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 22.5 in. (572 mm)
  - Dynamic .... 44.1 in. (1,120 mm)
  - Working Width .... 47.3 in. (1,201 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		SLICE-1	SLICE-2 (Primary)	
OIV ft/s (m/s)	Longitudinal	-19.4 (-5.9)	-15.3 (-4.7)	± 40 (12.2)
	Lateral	-14.8 (-4.5)	-14.1 (-4.3)	± 40 (12.2)
ORA g's	Longitudinal	-6.2	-14.7	± 20.49
	Lateral	-7.1	-7.8	± 20.49
MAX ANGULAR DISP. deg.	Roll	5.2	-3.0	± 75
	Pitch	-4.9	-5.4	± 75
	Yaw	-33.5	-33.6	Not required
THIV – ft/s (m/s)		19.9 (6.0)	20 (6.1)	Not required
PHD – g's		16.0	16.4	Not required
ASI		0.675	0.714	Not required

Figure 109. Summary of Test Results and Sequential Photographs, Test No. ILT-1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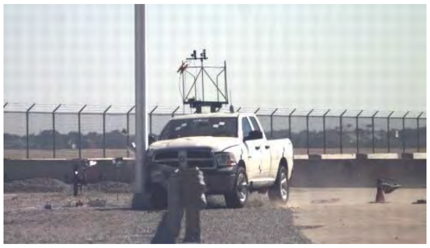
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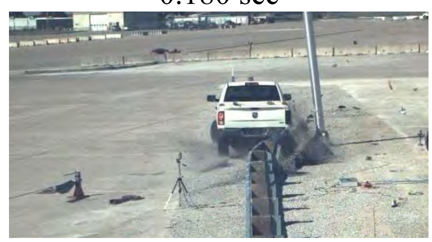
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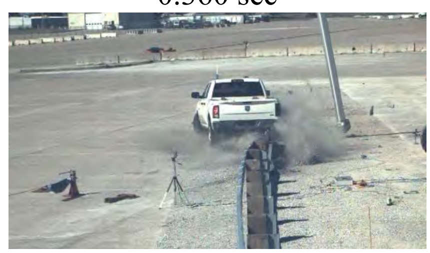
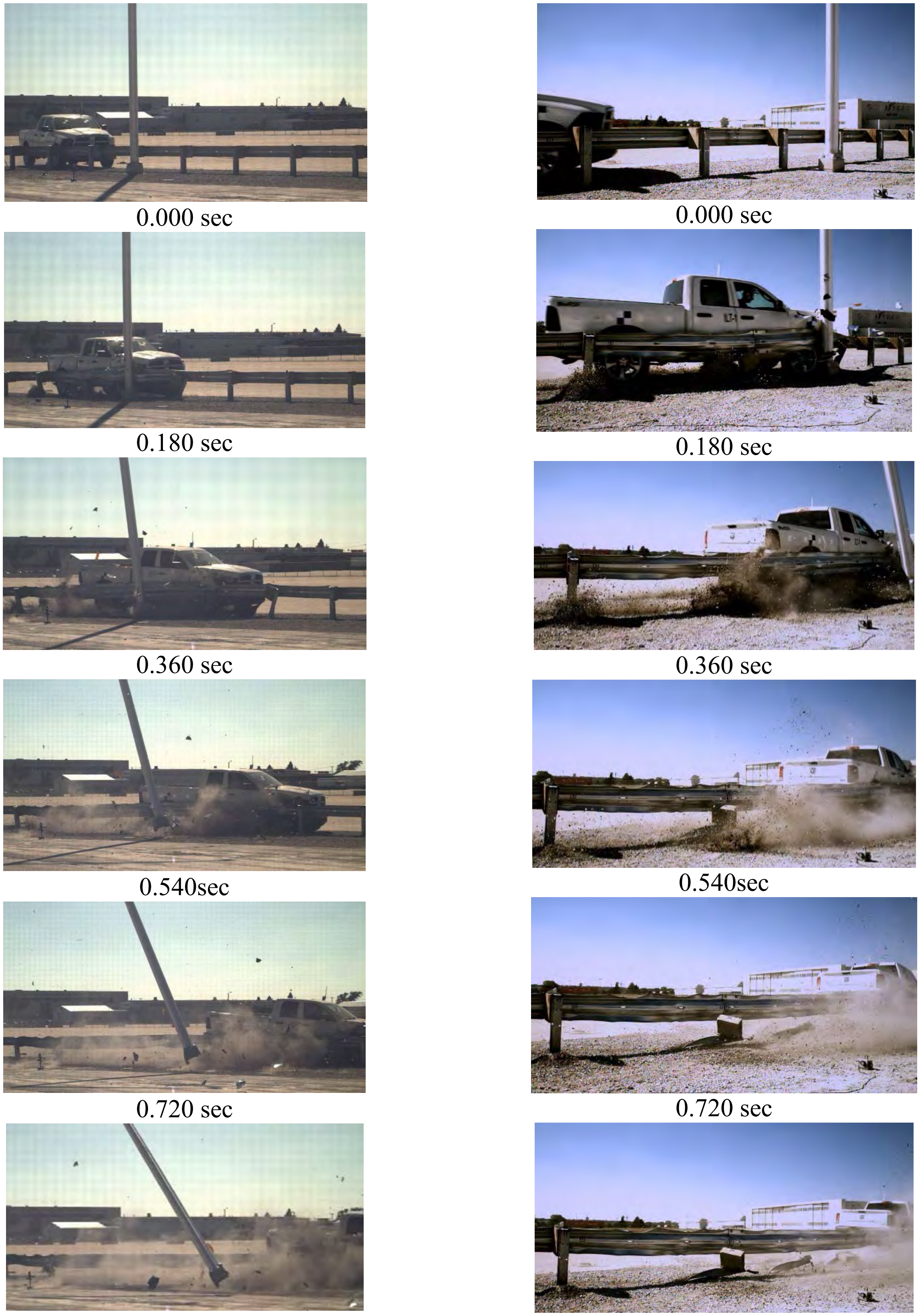

0.540sec


0.720 sec


0.900 sec

Figure 110. Additional Sequential Photographs, Test No. ILT-1



0.000 sec | 0.000 sec
0.180 sec | 0.180 sec
0.360 sec | 0.360 sec
0.540sec | 0.540sec
0.720 sec | 0.720 sec
0.900 sec | 0.900 sec

Figure 111. Additional Sequential Photographs, Test No. ILT-1

Figure 112. Vehicle Final Position and Trajectory Marks, Test No. ILT-1

7.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 113 through 118. Barrier damage consisted of deformed guardrail posts, disengaged wooden blockouts, contact marks on a guardrail section and posts, and deformed W-beam rail. The length of vehicle contact along the MGS was approximately 39 ft – 11 in. (12.2 m), which spanned 3 in. (76 mm) downstream from post no. 11 to 32 in. (813 mm) downstream from post no. 17. The second contact between the vehicle and the rail spanned from 32 in. (813 mm) upstream from post no. 24 to 15½ in. (394 mm) upstream from post no. 25.

Moderate deformation and flattening of the W-beam rail occurred between post nos. 11 and 14. Flattening occurred on the bottom corrugation of the rail from 47½ in. (1.2 m) downstream from post no. 11 to 23 in. (584 mm) upstream of the midspan between post nos. 14 and 15. Kinks were found in the rail at the top corrugation 36 in. (914 mm) downstream from post no. 11 and at the bottom corrugation 4½ in. (114 mm) upstream from post no. 12. The W-beam rail released from post nos. 13 through 16 during the impact and disengaged from post nos. 3 through 11 due to the secondary strike from the pole. All splice locations were measured before and after the test. A maximum splice movement of ¾ in. (19 mm) was recorded at one location in the contact region, which was located between post nos. 12 and 13.

Although the post bolts pulled through the rail at the upstream anchor, the cable anchor remained intact between the rail and the bottom of post no. 1, as shown in Figure 118. Blockout no. 13 disengaged away from post no. 13 after the post-to-rail bolt fractured. Post nos. 12 through 16 bent backward and downstream at the ground line. Soil heaves began to form behind the non-traffic side flange of post nos. 12 and 15. The downstream anchorage was undamaged.

The maximum lateral permanent set rail deflection was 22.5 in. (572 mm) at midspan between post nos. 14 and 15, as measured in the field. The maximum lateral dynamic rail and post deflections were 44.1 in. (1,120 mm)at the midspan between post nos. 14 and 15, and 16 in. (406 mm) at post no. 13, respectively, as determined from high-speed digital video analysis. The working width of the system was 47.3 in. (1,201 mm), as measured at the midspan between post nos. 14 and 15. The light pole landed 25.9 ft (7.9 m) behind and 27 1/8 in. (689 mm) in front of the rail face.

Figure 113. Midwest Guardrail System Damage, Test No. ILT-1

Figure 114. Rail Damage, Test No. ILT-1

Figure 115. System Damage, Post Nos. 8 through 14, Test No. ILT-1

Figure 116. System Damage, Post Nos. 15 through 17 Damage, Test No. ILT-1

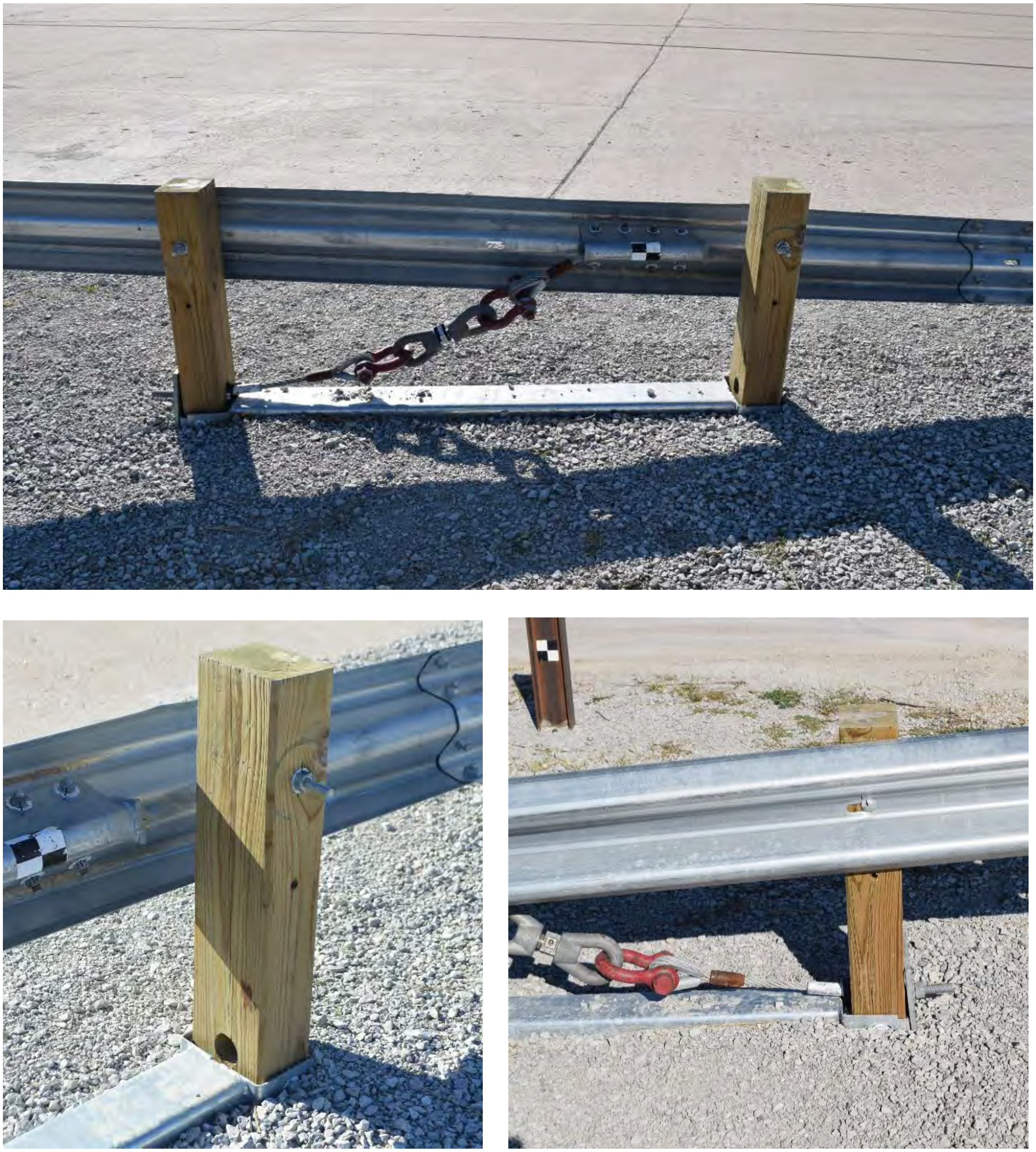


Figure 117. Upstream Anchor Damage, Test No. ILT-1

Figure 118. Downstream Anchor Damage, Test No. ILT-1

7.5 Light Pole Damage

In test no. ILT-1, the light pole base fractured, disengaged, thus causing the pole to fall on the guardrail, and then impacted the ground. Pole damage consisted of the base tearing out, detachment of bolt covers, fracture of mast arm braces, and contact marks on the pole and base. A 6-in. tall x 12-in. wide (152-mm tall x 305-mm wide) section on the upstream edge of the transformer base and a 6-in. tall x 4.5-in. wide (152-mm tall x 114-mm wide) section on the front side of the transformer base fractured, as shown in Figure 119. The foundation bolts were exposed, but not damaged. Contact marks were visible at 6 in. (152 mm) and 24 in. (610 mm) above the base along the front side of the pole, while scrapes were found on the back side of the pole at 31 in. above the base. The pole's mast arm braces fractured while hitting the guardrail. The vertical braces of mast arm fractured from the bottom member.

Figure 119. Pole Damage, Test No. ILT-1

7.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 120 and 121. The maximum occupant compartment deformations are listed in Table 17 along with the deformation limits established in MASH for various areas of the occupant compartment. None of the established MASH deformation limits were exceeded. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix H.

Table 17. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	0.5 (13)	≤ 9 (229)
Floor Pan & Transmission Tunnel	0.25 (6)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	0.29 (7)	≤ 12 (305)
Side Door (Above Seat)	0.55 (14)	≤ 9 (229)
Side Door (Below Seat)	0.5 (13)	≤ 12 (305)
Roof	0.20 (5)	≤ 4 (102)
Windshield	0.22 (6)	≤ 3 (76)

The majority of vehicle damage was concentrated on the right-front corner and right side of the vehicle where impact occurred. A 9/16-in. (14-mm) gap formed between the hood and right fender. The right-front corner of the bumper was crushed inward approximately 8 in. (203 mm). The right fender was crushed backward to the door panel and was dented and torn behind the right-front wheel. The right-front door had a 5-in. x 2-in. x ¼-in. (127-mm x 51-mm x 6-mm) dent approximately 8 in. (203 mm) above the bottom. The right headlight fractured and crushed backward. The left taillight cracked. The right-front wheel assembly deformed and crushed inward toward the engine compartment. The right-front tire was deflated, and it had a 1½-in. (38-mm) tear in its sidewall. The right-front rim was fractured, and a 9-in. x 7-in. (229-mm x 178-mm) section disengaged. Gouges and dents were found on the right-front door and the right-front corner of the hood. A 3-in. wide x 1-in. deep x 10-in. long (76-mm x 25-mm x 254-mm) gouge was found on the right-rear bumper. The airbags did not deployed during the impact. The overall undercarriage damage included some scraping on the driver-side front knuckle assembly, a tear above the lower control arm on the frame, and scraping on the transmission cross member end on the passenger side.

Figure 120. Vehicle Damage, Test No. ILT-1

Figure 121. Vehicle Damage, Test No. ILT-1

7.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 18. The OIVs and ORAs were within suggested limits, as provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 18. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Table 18. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix I. The SLICE-2 unit was designated as the primary accelerometer unit during this test, as it was mounted closer to the c.g. of the vehicle.

Table 18. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. ILT-1

Evaluation Criteria		Transducer		MASH Limits
		SLICE-1	SLICE-2 (Primary)	
OIV ft/s (m/s)	Longitudinal	-19.4 (-5.9)	-15.3 (-4.7)	± 40 (12.2)
	Lateral	-14.8 (-4.5)	-14.1 (-4.3)	± 40 (12.2)
ORA g's	Longitudinal	-6.2	-14.7	± 20.49
	Lateral	-7.1	-7.8	± 20.49
MAX. ANGULAR DISPL. deg.	Roll	5.2	-3.0	± 75
	Pitch	-4.9	-5.4	± 75
	Yaw	-33.5	-33.6	Not required
THIV ft/s (m/s)		19.9 (6.0)	20 (6.1)	Not required
PHD g's		16.0	16.4	Not required
ASI		0.675	0.714	Not required

7.8 Load Cells

The pertinent data from the load cells was extracted from the bulk signal and analyzed using the transducer's calibration factor. The recorded data and analyzed results are shown in Figure 122 and detailed in Appendix K. The exact moment of impact could not be determined from the transducer data as impact may have occurred a few milliseconds prior to a measurable signal increase in the data. Thus, the extracted data curves should not be taken as precise time after impact, but rather a general time line between events within the data curve itself.

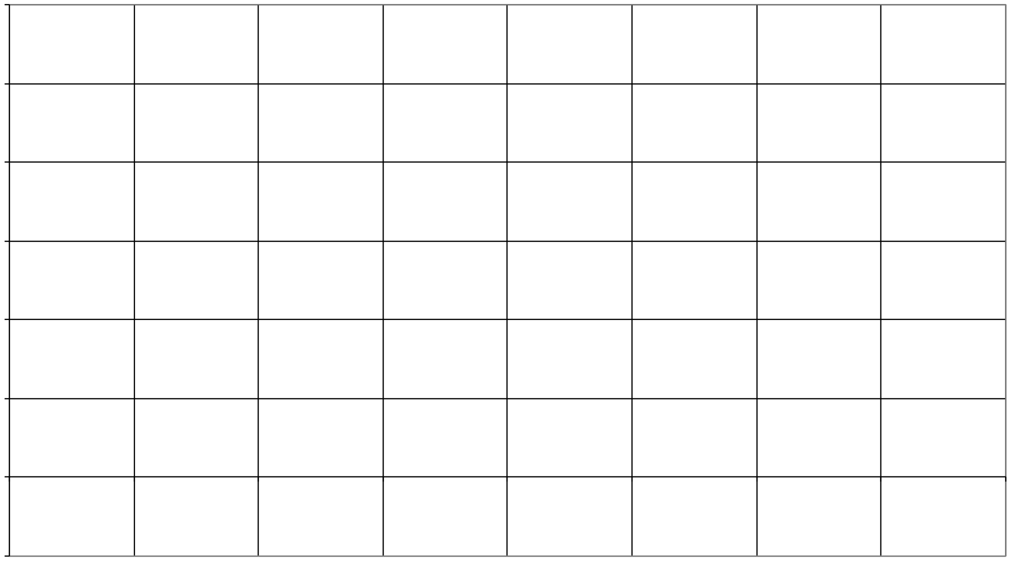


Figure 122. Cable Anchor Loads, Test No. ILT-1

7.9 Discussion

The analysis of the test results for test no. ILT-1 showed that the MGS with a light pole installed at a lateral pole offset of 20 in. (508 mm) behind the back of the steel post and a longitudinal offset of 24-in. (610-mm) away from post no. 13 adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. There were no detached elements nor fragments that showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix I, were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 11.7 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. ILT-1 conducted on the MGS with a 20-in. lateral offset away from a breakaway pole was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-11.

Regarding the comparison of the test and simulation results (presented in Chapter 4), it should be noted that due to the lack of pole fracture in the simulations, there were some discrepancies between the test observations and numerical results, including lower occupant risk values and less aggressive fender snag and crushing in the actual test. The lateral and longitudinal ORAs in test no. ILT-1 were 7.8 and 14.7 g's, while simulated lateral and longitudinal ORAs were 9.8 and 17.8 g's. In the actual test, the right fender was crushed backward to the door panel. Similar fender snag on the pole was observed in the simulation. In general, the simulation with the assumption of the rigid pole could conservatively replicate the impact well.

8 FULL-SCALE CRASH TEST NO. ILT-2

8.1 Static Soil Test

Before full-scale crash test no. ILT-2 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix G, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

8.2 Weather Conditions

Test no. ILT-2 was conducted on September 28, 2016 at approximately 2:00 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 19.

Table 19. Weather Conditions, Test No. ILT-2

Temperature	67° F (19° C)
Humidity	47%
Wind Speed	11 mph
Wind Direction	10° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in. (0 mm)
Previous 7-Day Precipitation	0 in. (0 mm)

8.3 Test Description

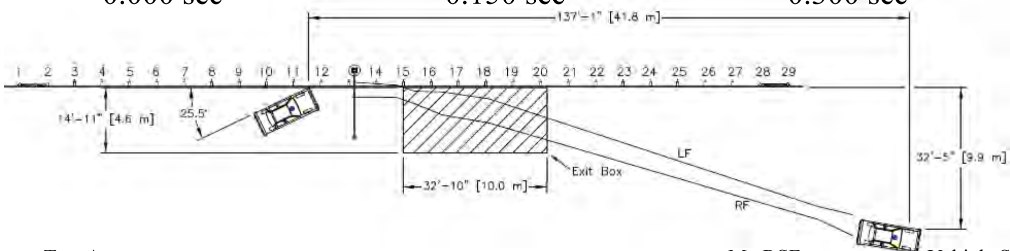
The 2,420-lb (1,098-kg) Hyundai Accent car impacted the combination MGS with luminaire pole at a speed of 62.7 mph (100.9 km/h) and at an angle of 24.8 degrees. Initial vehicle impact was to occur at midspan between post nos. 11 and 12, as shown in Figure 123, which was selected based on LS-DYNA analysis and previous crash testing. The actual impact point was 1 in. (25 mm) upstream from the targeted impact point (midspan between post nos. 11 an 12). A sequential description of the impact events is contained in Table 20. A summary of the test results and sequential photographs are shown in Figure 124. Additional sequential photographs are shown in Figures 125 and 126.

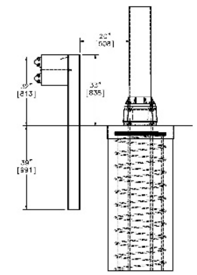
Upon impact, the vehicle's front bumper contacted the rail at 5¼ in. (133 mm) downstream from midspan between post nos. 11 and 12. At 0.090 seconds, vehicle bumper contacted post no. 13, and the left-front tire underrode the rail and snagged on post no. 13. Post no. 13 deflected backward but did not contact the pole nor the base. The left-front wheel barely grazed the base of the pole. Thus, the pole did not fracture. The vehicle was safely captured and redirected. At 0.320 seconds, the vehicle was parallel to the system. At 0.600 seconds, the vehicle exited the system. The vehicle came to rest 137 ft – 1 in. (41.8 m) downstream from impact and 32 ft – 5 in. (9.9 m) laterally in front of the traffic side of the guardrail system. The vehicle trajectory and final position are shown in Figure 127.

Figure 123. Impact Location, Test No. ILT-2

Table 20. Sequential Description of Impact Events, Test No. ILT-2

TIME (sec)	EVENT
0.0	Vehicle’s right-front bumper contacted rail 5¼ in. (133 mm) downstream from midspan between post nos. 11 and 12.
0.004	Vehicle’s front bumper deformed.
0.008	Post no. 12 deflected backward. Vehicle’s hood deformed.
0.010	Vehicle’s left-front headlight and left-front fender deformed.
0.016	Post no. 11 deflected backward.
0.018	Post no. 13 deflected backward.
0.031	Post no. 11 twisted counterclockwise.
0.036	Vehicle yawed away from barrier and post no. 10 twisted counterclockwise.
0.039	Post no. 9 twisted counterclockwise.
0.040	Post nos. 7 and 8 twisted counterclockwise.
0.041	Post no. 6 twisted counterclockwise and post no. 14 twisted clockwise.
0.044	Post nos. 15 and 16 twisted clockwise.
0.052	Post nos. 1 and 2 twisted counterclockwise.
0.056	Post no. 10 deflected backward. Vehicle rolled away from barrier.
0.060	Vehicle pitched downward.
0.062	Post no. 29 deflected upstream.
0.076	Vehicle left-front door deformed.
0.077	Post no. 13 twisted clockwise.
0.081	Post no. 13 deflected downstream and fracture at ground line.
0.089	Vehicle’s front bumper contacted post no. 13.
0.093	Post no. 13 disengaged away from rail.
0.097	Post nos. 14 and 15 deflected backward.
0.125	Vehicle detached front bumper contacted traffic side of light pole.
0.150	Vehicle pitched upward.
0.160	Post no. 14 deflected downstream.
0.166	Vehicle front bumper contacted post no. 14.
0.168	Post no. 14 disengaged away from rail and fractured at ground line
0.258	Post no. 15 deflected downstream. Vehicle’s front bumper contacted post no. 15.
0.276	Post no. 15 disengaged away from rail and fractured at ground line.
0.320	Vehicle became parallel to barrier at a speed of 29.4 mph (47.3 km/h)
0.450	Post no. 16 deflected downstream.
0.650	Vehicle exited system at a speed of 26.7 mph (42.9 km/h) and at an angle of 8.2 degrees.





- Test Agency .... MwRSF
- Test Number ILT-2
- Date 9/28/16
- MASH Test Designation No. 3-10
- Test Article .... MGS Offset from Illinois Tollway's Breakaway Light Pole
- Total Length .... 175 ft (53.3 m)
- Key Component – MGS Rail
  - Thickness .... 12 gauge (2.66 mm)
  - Top Mounting Height .... 32 in. (813 mm)
- Key Component – Steel Posts
  - Post Type .... W6x8.5 by 6' (1,829 mm)
  - Post Spacing .... 75 in. (1,905 mm)
- Key Component – Illinois Tollway Pole with CS370 Transformer Base
  - Pole Height .... 50 ft (15.2 m)
  - Pole Arm Mast Length .... 15 ft (4.570 m)
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make /Model .... 2009 Hyundai Accent
  - Curb .... 2,434 lb (1,104 kg)
  - Test Inertial .... 2,420 lb (1,098 kg)
  - Gross Static .... 2,586 lb (1,173 kg)
- Impact Conditions
  - Speed .... 62.7 mph (100.9 km/h)
  - Angle .... 24.8 deg
  - Impact Location .. 5¼ in. (133 mm) Downstream from Midspan between Post Nos. 11 and 12
- Impact Severity (IS) .... 59.4 kip-ft (80.5 kJ) > 51 kip-ft (69.7 kJ) limit from MASH
- Exit Conditions
  - Speed .... 26.7 mph (42.9 km/h)
  - Angle .... 12.7 deg
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 137 ft – 1 in. (41.8 m)
- Vehicle Damage .... Moderate
  - Vehicle Damage Scale [33] 1-FR-3
  - Collision Deformation Classification [34] 1-FREW-5
- Maximum Interior Deformation .... 0.4 in. (10 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 22.5 in. (572 mm)
  - Dynamic .... 29.4 in. (747 mm)
  - Working Width .... 35.8 in. (909 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		SLICE-1 (Primary)	SLICE-2	
OIV ft/s (m/s)	Longitudinal	-20.0 (-6.1)	-21.0 (-6.4)	± 40 (12.2)
	Lateral	15.4 (4.7)	15.4 (4.7)	± 40 (12.2)
ORA g's	Longitudinal	-10.5	-10.2	± 20.49
	Lateral	10.6	11.0	± 20.49
MAX ANGULAR DISP. deg.	Roll	6.6	7.5	± 75
	Pitch	-3.0	-2.8	± 75
	Yaw	40.6	39.7	Not required
THIV – ft/s (m/s)		24.3 (7.4)	23.9 (7.3)	Not required
PHD – g's		14.3	14.7	Not required
ASI		0.985	0.945	Not required

Figure 124. Summary of Test Results and Sequential Photographs, Test No. ILT-2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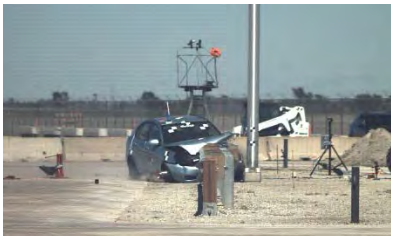
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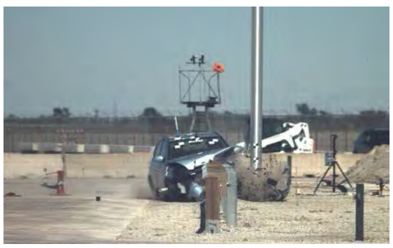
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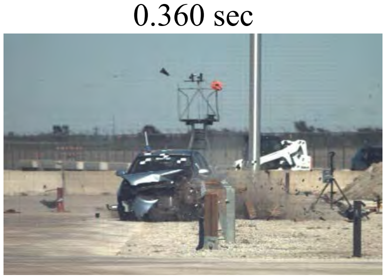
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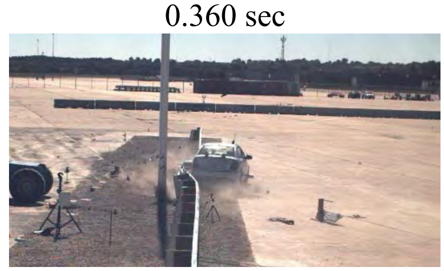
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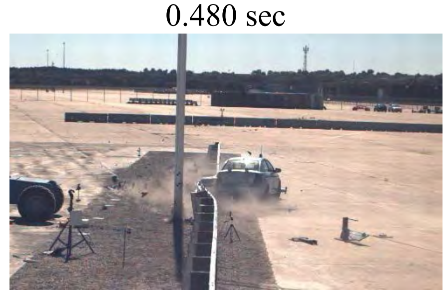
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Figure 125. Additional Sequential Photographs, Test No. ILT-2

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Figure 126. Additional Sequential Photographs, Test No. ILT-2

Figure 127. Vehicle Final Position and Trajectory Marks, Test No. ILT-2

8.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 128 through 131. Barrier damage consisted of deformed guardrail posts, disengaged wooden blockouts, contact marks on a guardrail section and posts, and deformed W-beam rail. The length of vehicle contact along the MGS was approximately 27 ft – 11 in. (8.5 m), which spanned from 1 in. (25 mm) upstream from the midspan between post nos. 11 and 12 to 4 in. (102 mm) upstream of post no. 16.

Moderate flattening of the W-beam rail occurred between post nos. 12 and 15. Several kinks were found at the top and bottom corrugations of the rail between post nos. 12 and 16. Tire marks were found at the top and bottom corrugation of the rail beginning from the impact point (1 in. (25 mm) upstream from the midspan between post nos. 11 and 12) up to post no. 16. All splice locations were measured before and after the test. A maximum splice movement of ¾ in. (19 mm) was recorded at one location in the contact region, which was located between post nos. 13 and 14.

Post nos. 13 and 14 bent longitudinally downstream at the ground-line. The 20-in. (508-mm) long part of the front flange of post no. 13 twisted. The front upstream flange of post nos. 14 and 15 bent inward toward the web. Post no. 15 partially rotated backward and downstream. Post nos. 13, 14, and 15 disengaged away from the rail. The blockout bolt hole at post no. 16 deformed, but it did not tear. Vertical cracks were found in the blockouts of post nos. 1 through 8, 17 and 18. A 4¼-in. (108-mm) and a 1¼-in. (32 mm) soil gap was found on the front and back sides of post no. 12, respectively. The upstream and downstream anchors were undamaged.

The maximum lateral permanent set rail deflection was 22.5 in. (572 mm) at the midspan between post nos. 13 and 14, as measured in the field. The maximum lateral dynamic rail and post deflections were 29.4 in. (747 mm) at the midspan between post nos. 13 and 14 and 15.1 in. (384 mm) at post no. 14, respectively, as determined from high-speed digital video analysis. The working width of the system was 35.8 in. (909 mm), as measured at the midspan between post nos. 13 and 14.

Figure 128. Midwest Guardrail System Damage, Test No. ILT-2

Figure 129. System Damage, Post Nos. 10 through 12, Test No. ILT-2

Figure 130. System Damage, Post Nos. 13 through 15, Test No. ILT-2

Figure 131. Post Nos. 12 through 15 Damage, Test No. ILT-2

8.5 Light Pole Damage

In test no. ILT-2, the left-front wheel barely grazed the base of the pole. Thus, the pole did not fracture. Contact marks were visible at the front side of the base, as shown in Figure 132.

Figure 132. Pole Contact Marks, Test No. ILT-2

8.6 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 133 through 135. The maximum occupant compartment deformations are listed in Table 21 along with the deformation limits established in MASH for various areas of the occupant compartment. None of the established MASH deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix H.

Table 21. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	0.25 (6)	≤ 9 (229)
Floor Pan & Transmission Tunnel	0.2 (5)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	0.4 (10)	≤ 12 (305)
Side Door (Above Seat)	0.4 (10)	≤ 9 (229)
Side Door (Below Seat)	0.2 (5)	≤ 12 (305)
Roof	0 (0)	≤ 4 (102)
Windshield	0.2 (5)	≤ 3 (76)

The vehicle damage was mostly concentrated on the left-front corner, where impact occurred. The left side of the hood buc kled upward and crushed backward. The left fender crushed inward approximately 14 in. (356 mm) toward the engine compartment. Scrapes were found along the left fender 18 in. and 26 in. (457 mm and 660 mm) from the bottom of the fender. A 5-in. (127-mm) gap formed between the hood and right fender. The front bumper and bumper cover detached. The left headlight fractured, crushed, and remained attached. A 5-in. wide x ½-in. deep x 8-in. long (127-mm wide x 13-mm deep x 203-mm long) dent and scratches occurred in the left-front door. The radiator bent and dented. The front wheel assembly remained undamaged. The lower left section of the windshield had a crack 11 in. (279 mm) inward and 26 in. (660 mm) upward, as shown in Figure 135. The left fender and the left-front door overlapped ½ in. (13 mm).

The overall undercarriage damage of the vehicle included a scrape behind the engine cross member and a 3 in. (76 mm) of crush on the driver-side frame horn. The radiator cross member bent upward on the driver side for 2 in. (51 mm).

Figure 133. Vehicle Damage, Test No. ILT-2

Figure 134. Vehicle Damage, Test No. ILT-2

Figure 135. Vehicle Windshield Crack, Test No. ILT-2

8.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 22. Note that the OIVs and ORAs were within suggested limits, as provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 22. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Table 22. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix J. The SLICE-1 unit was designated as the primary accelerometer unit during this test, as it was mounted closer to the c.g. of the vehicle.

Table 22. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. ILT-2

Evaluation Criteria		Transducer		MASH Limits
		SLICE-1 (Primary)	SLICE-2	
OIV ft/s (m/s)	Longitudinal	-20.0 (-6.1)	-21.0 (-6.4)	± 40 (12.2)
	Lateral	15.4 (4.7)	15.4 (4.7)	± 40 (12.2)
ORA g's	Longitudinal	-10.5	-10.2	± 20.49
	Lateral	10.6	11.0	± 20.49
MAX. ANGULAR DISPL. deg.	Roll	6.6	7.5	± 75
	Pitch	-3.0	-2.8	± 75
	Yaw	40.6	39.7	not required
THIV ft/s (m/s)		24.3 (7.4)	23.9 (7.3)	not required
PHD g's		14.3	14.7	not required
ASI		0.985	0.945	not required

8.8 Load Cells

The pertinent data from the load cells was extracted from the bulk signal and analyzed in Figure 136 and detailed in Appendix K. The exact moment of impact could not be determined from the transducer data as impact may have occurred a few milliseconds prior to a measurable signal increase in the data. Thus, the extracted data curves should not be taken as precise time after impact, but rather a general time line between events within the data curve itself.

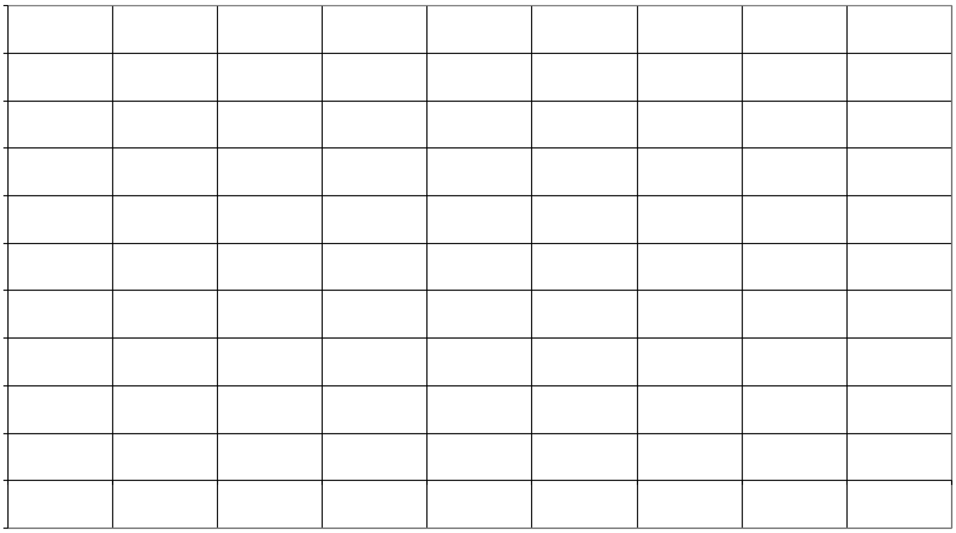


Figure 136. Cable Anchor Loads, Test No. ILT-2

8.9 Discussion

Analysis of the test results for test no. ILT-2 showed that the MGS with a light pole installed with a lateral offset of 20 in. (508 mm) from the back side of the steel-post MGS and a longitudinal offset of 16 in. (406 mm) from post no. 13 adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. There were no detached elements nor fragments that showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix J, were deemed acceptable, because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 12.7 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. ILT-2 was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-10.

The working width of the system was 35.8 in. (909 mm), as measured at the midspan between post nos. 13 and 14, which was 13.5 in. (343 mm) downstream from the pole. However, the maximum dynamic deflection of the rail was 29.4 in. (747 mm) at the midspan between post nos. 13 and 14, and the maximum dynamic deflections of the rail at the adjacent posts (i.e., post nos. 13 and 14) were 27.1 and 26.8 in. (688 and 681 mm), respectively. Since the difference in rail deflection for the entire 75-in. (1,905-mm) long span where the pole was located was less than one inch, it was believed that the pole placed at any location in the span would not interact with the guardrail. Moreover, even if the pole was located at the midspan between post nos. 13 and 14 where the maximum working width of 35.8 in. (909 mm) occurred, the vehicle would not have contacted the pole as it was offset 41 in. (1,041 mm) away from the front face of the rail.

9 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The safe placement of a light pole with respect to the Midwest Guardrail System was determined through computer simulation and full-scale crash testing. Computer simulation was utilized to select critical impact points and critical pole locations for the full-scale crash tests. A series of computer simulations were conducted on the MGS with varying lateral pole offsets varying from 12 in. to 28 in. (305 mm to 711 mm) and longitudinal pole offsets varying from 0 in. to 37.5 in. (0 mm to 953 mm) from the centerline of the post. In order to determine the minimum safe lateral pole offset, several criteria, such as vehicle stability, occupant risk measures, rail pocketing, vehicle snag on pole, rail deflection, and rail load were evaluated in each simulation. The analyses primarily focused on MASH TL-3 impacts with a 2270P vehicle due to increased dynamic deflections, but several simulations with 1100C vehicle impacts were also performed to ensure that the pole offset was safe for the small car. Based on the results of LS-DYNA simulations, a 406-mm (16-in.) lateral offset away from the back of the MGS posts to front face of pole was initially considered the minimum lateral offset. However, the project sponsor recommended a 20-in. (508-mm) lateral pole offset behind the MGS posts to allow a 10-in. (254-mm) clearance between the concrete pole foundation and line posts. Thus, a 20-in. (508-mm) lateral pole offset was selected.

Based on the simulation and previous crash testing, the most critical pole offset for pickup truck testing was a 20-in. (508-mm) lateral offset away from the back of posts to the front face of the pole and a 24-in. (610-mm) longitudinal offset away from post no. 13 to the centerline of the pole due to high longitudinal ORAs. For small car testing, an 8-in. (203-mm) longitudinal offset away from post no. 13 was found to be the most critical pole placement at a 20-in. (508-mm) lateral pole offset based on the simulation and previous MGS crash testing.

Two full-scale crash tests were performed on the combination MGS with nearby light pole according to the TL-3 safety performance criteria defined in MASH, test designation nos. 3-11 and 3-10. The 50-ft (15.25-m) tall light pole mounted on a 9-in. (229-mm) tall breakaway transformer base was utilized for the crash tests.

In test no. ILT-1, a 5,000-lb (2,268-kg) pickup truck impacted the 31-in. (787-mm) tall MGS offset away from the light pole at a speed of 62.6 mph (100.7 km/h) and at an angle of 25.2 degrees resulting in an impact severity of 117.0 kip-ft (158.6 kJ). The MGS adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. The pole broke away due to the contact with the pickup truck and fell safely on the ground. All occupant risk criteria were within the recommended MASH safety limits. Thus, test no. ILT-1 passed the safety criteria of MASH test designation no. 3-11. A summary of the safety performance evaluation is provided in Table 23.

In test no. ILT-2, a 2,420-lb (1,098-kg) Hyundai Accent car impacted the 32-in. (813-mm) tall MGS offset away from the light pole at a speed of 62.7 mph (100.9 km/h) and at an angle of 24.8 degrees resulting in an impact severity of 59.4 kip-ft (80.5 kJ). In test no. ILT-2, the left-front tire barely contacted the transformer base. The pole did not fracture, and the car was safely contained and redirected. All occupant risk criteria were within the recommended MASH safety limits, so test no. ILT-2 passed the safety criteria of MASH test designation no. 3-10. A summary of the safety performance evaluation is provided in Table 23.

Based on the results of the crash tests and numerical simulations, it was concluded that a lateral offset of 20 in. (508 mm) between the back of the post and front face of the Illinois Tollway's breakaway light pole (or 41-in. (1,041-mm) between the front face of the MGS rail with 12-in. (305-mm) deep blockouts and the front face of the pole) resulted in a safe performance of the MGS. This lateral offset may be applicable for poles and supports with a similar breakaway mechanism, height, mass, and material. However, different breakaway poles or supports require further evaluation and should not be used within the working width of the MGS.

Since the critical longitudinal offsets of the pole with respect to the MGS posts were evaluated, the breakaway light pole could be placed anywhere behind the MGS exclusive of the restrictions in special applications of the MGS. Further implementation guidance was developed for placement of breakaway poles in special applications, including in guardrail end terminals, MGS trailing-end anchorages, MGS stiffness transitions, approach slopes, long-span MGS, and wood post and non-blockout MGS. This information is provided in the following Chapter 10.

Table 23. Summary of Safety Performance Evaluation Results

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. ILT-1</th><th>Test No. ILT-2</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D.</td><td>Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</td><td>S</td><td>S</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH for calculation procedure) should satisfy the following limits:<table><tr><th colspan="3">Occupant Impact Velocity Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr></table></td><td>S</td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH for calculation procedure) should satisfy the following limits:<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr></table></td><td>S</td><td>S</td></tr>
<tr><td colspan="3">MASH Test Designation</td><td>3-11</td><td>3-10</td></tr>
<tr><td colspan="3">Pass/Fail</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

10 IMPLEMENTATION GUIDANCE

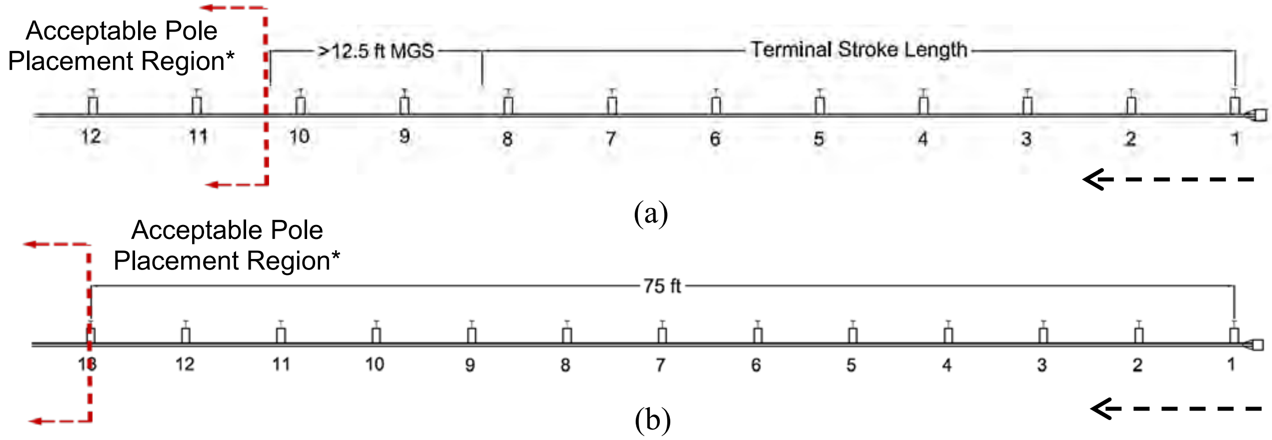
10.1 Background

As previously noted, the research detailed herein demonstrated that the MGS with a 20-in. (508-mm) lateral offset between the back of the MGS posts to the front face of the 50-ft (15.2-m) tall luminaire pole used by the Illinois Tollway mounted on the CS370 breakaway transformer base performed in an acceptable manner according to the TL-3 safety standards of MASH. For the MGS with steel posts spaced at 6 ft – 3 in. (1,905 mm) with 12-in. (305-mm) deep wood blockouts, the front face of the breakaway pole can be located 41 in. (1,041 mm) behind the front face of the W-beam rail, or 20 in. (508 mm) behind the back of the steel posts, with restrictions regarding terminals, anchorages, transitions, and special applications. Multiple variations of the MGS system have been developed for special applications that may be more sensitive to the placement of utility poles in close proximity to guardrail. These special applications include terminals and anchorages, MGS stiffness transition to thrie beam approach guardrail transitions, MGS long-span system, MGS adjacent to fill slopes, MGS on 8:1 approach slopes, MGS in combination with curbs, wood post MGS, MGS with 8-in. (203-mm) blockouts, and MGS without blockouts. Since multiple MGS variations are available, recommendations regarding the placement of the breakaway luminaire pole behind the MGS will likely vary depending on the nature and behavior of the special applications listed above.

The following sections provide implementation guidance and/or recommendations regarding pole placement within MGS special applications. This implementation guidance is only applicable to the breakaway light pole that was tested in this study. These recommendations are intended to ensure comparable safety performance of the guardrail systems laterally offset away from the breakaway luminaire pole, which are based on the full-scale testing and any associated research available at the conclusion of this project. Although some installation sites will require systems outside the bounds of these recommendations, the reasoning behind these recommendations should be considered along with other roadside treatments when selecting the specific final site design.

10.2 Guardrail Terminals and Anchorages

Multiple W-beam guardrail end terminals have been developed for use with the MGS. Guardrail terminals are sensitive systems that have been carefully designed to satisfy safety performance standards. Pole placement within a terminal region could significantly degrade a terminal's crashworthiness. For tangent, energy-absorbing approach terminals, it is recommended to have a minimum of 12.5 ft (3.8 m) of standard MGS beyond the inner end of a guardrail terminal (i.e., stroke length) to avoid heavy vehicle contact with pole while engaged with the terminal head, as shown in Figure 137a. Second, based on both FHWA Guidelines and 2011 AASHTO Roadside Design Guidelines [35], a pole should not be longitudinally placed within a distance of 75 ft (22.8 m) from the end terminal to prevent vehicle from contacting the pole, as shown in Figure 137b. Thus, a pole should not be longitudinally placed within a distance of 12.5 ft (3.8 m) plus the stroke length of an end terminal or 75 ft (22.8 m) from the end terminal, whichever is greater. While FHWA Guidelines enforces a minimum clearance distance of 75 ft (22.8 m), Illinois Tollway considers a clear distance of 90 ft (27.4 m) from the end terminal.



* Pole should not be longitudinally placed within a distance of 12.5 ft (3.8 m) plus the stroke length of an end terminal or 75 ft (22.8 m) from the end terminal, whichever is greater.

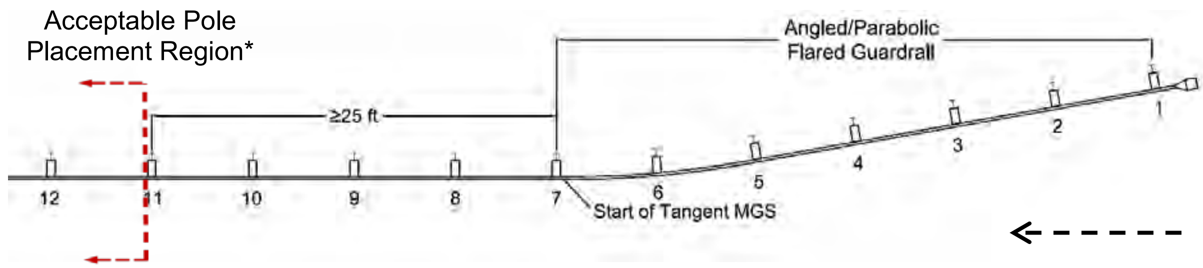
Figure 137. Recommended Distance Between Luminaire Pole Offset MGS and Tangent Energy-Absorbing Terminals

For energy-absorbing terminals that flare away from the roadway, the geometric layout results in increased effective impact angles, which increases system deflections for impacts on or near the flared terminal. Due to the increase in system deflections associated with guardrail flares, it is recommended to have at least 25 ft (7.6 m) of tangent MGS to separate a flared guardrail terminal and a pole, as shown in Figure 138a. Considering the FHWA Guidelines and 2011 AASHTO Roadside Design Guidelines in conjunction with flared approach terminals, a pole should not be longitudinally placed within a distance of 25 ft (7.6 m) of tangent MGS or 75 ft (22.8 m) from the end terminal, as shown in Figure 138b, whichever is greater. While FHWA Guidelines enforces a minimum clearance distance of 75 ft (22.8 m), Illinois Tollway considers a clear distance of 90 ft (27.4 m) from the end terminal.

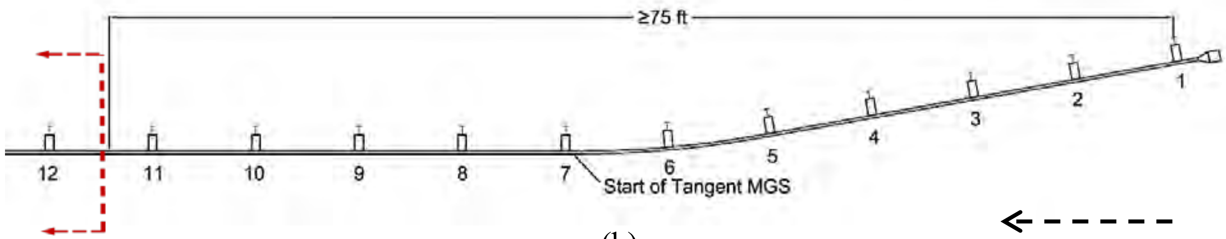
For non-energy absorbing end terminals, the minimum required obstacle-free longitudinal distance is more difficult to address due to different vehicle trajectories behind and beyond terminals. While AASHTO Roadside Design Guidelines recommends a minimum recovery area of 75 ft (22.8 m) long and 20 ft (6 m) wide behind a terminal, it denotes that a larger obstacle-free area for a non-energy absorbing terminal would be desirable. For non-energy absorbing terminals, it is recommended to refer to an end terminal's runout longitudinal distance, as provided by the manufacturers, when determining acceptable pole placement from the end of device.

Moreover, pole placement near trailing-end guardrail anchorages may affect system performance. In the previous study of a reduced-length MGS, a 2270P pickup truck impacted the MGS at 10th post from the downstream end of the guardrail. The maximum dynamic lateral deflection was 42.2 in. (1,072 mm) at 8th post from the downstream end of the guardrail. The working width of the system was found to be 48.8 in. (1,240 mm) [36].

From the noted study, it is believed that pole placement behind the 8th post [i.e., 43.75 ft (13.3 m) away from the downstream end of the guardrail system] and upstream from the 8th post would result in acceptable vehicle-to-barrier and vehicle-to-pole interaction, which would be similar to the current study findings. Therefore, it is recommended that no pole be placed closer than 43.75 ft (13.3 m) away from the downstream end of the guardrail system, as shown in Figure 139.



(a)



(b)

* Pole should not be longitudinally placed within a distance of 25 ft (7.6 m) of tangent MGS or 75 ft (22.8 m) from the end terminal, whichever is greater

Figure 138. Recommended Distance Between Luminaire Pole Offset MGS and Flared Energy-Absorbing Terminals

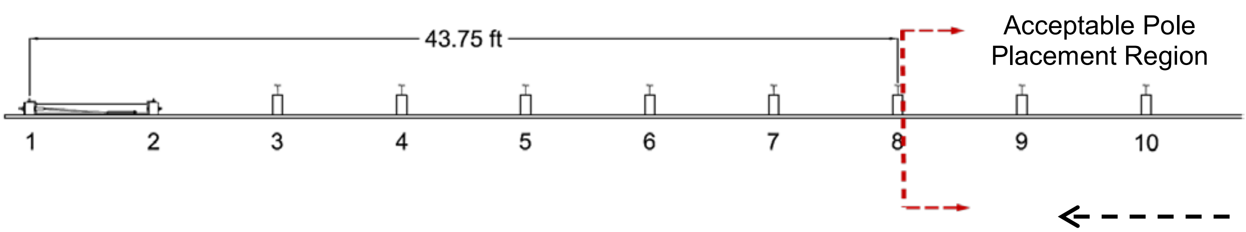


Figure 139. Recommended Distance Between Luminaire Pole Offset MGS and Trailing-End Guardrail Anchorages

10.3 MGS Stiffness Transition

The MGS stiffness transition was previously developed to connect standard MGS to various thrie beam approach guardrail transitions. Both steel post and wood post versions of the MGS stiffness transition have been developed, as well as a configuration for use adjacent to roadside curbs [37-39]. Within these previous studies, the maximum dynamic deflections and working widths of the MGS stiffness transition are listed in Table 24. In the current study, the maximum dynamic deflection and working width for test no. ILT-1 were 44.1 in. (1,120 mm) and 47.3 in. (1,201 mm), respectively. In test no. ILT-2, the maximum dynamic deflection and working width were 29.4 in. (747 mm) and 35.8 in. (909 mm), respectively. Therefore, it is believed that it would be acceptable to place a pole at 20 in. (508 mm) or farther between the back of the posts and pole face upstream from a MGS stiffness transition, assuming that a 41-in. (1,041 mm) lateral clearance between the face of the rail and the front face of the pole is provided.

Note that the thrie beam transition and W-beam-to-thrie-beam region deflect less than observed in the MGS due to its higher stiffness and strength. Therefore, a pole can be placed behind a MGS stiffness transition when using a 20-in. (508-mm) lateral offset between the back of post and pole face.

Table 24. Summary of MGS Stiffness Transition Crash Test Results

Test No.	Test Article	Vehicle	Weight/Mass lb (kg)	Speed mph (km/h)	Dynamic Deflection in. (mm)	Working Width in. (mm)
MWTSP-2	MGS Stiffness Transition	2270P	4,993 (2,265)	61.2 (98.5)	32.8 (833)	51.6 (1,310)
MWTSP-3	MGS Stiffness Transition	1100C	2,394 (1,086)	61.0 (98.2)	18.5 (470)	39.8 (1,011)
MWTC-2	MGS Stiffness Transition with Curb	1100C	2,410 (1,168)	61.3 (98.7)	16.4 (417)	32.5 (826)
MWTC-3	MGS Stiffness Transition with Curb	2270P	4,969 (2,254)	61.0 (98.2)	23.9 (607)	40.8 (1,036)
ILT-1	MGS Offset Pole	2270P	5,000 (2,268)	62.6 (100.7)	44.1 (1,120)	47.3 (1,201)
ILT-2	MGS Offset Pole	1100C	2,420 (1,098)	62.7 (100.9)	29.4 (747)	35.8 (909)

10.4 MGS Long-Span System

The MGS long-span guardrail system was successfully full-scale crash tested using an unsupported span length of 25 ft (7.6 m) with three Controlled Release Terminal (CRT) posts adjacent to each end of the unsupported span [40]. These CRT posts were incorporated into the system in order to mitigate concerns for wheel snag on posts adjacent to the unsupported span when traversing from the unsupported span to the downstream standard guardrail. The combination of the 25-ft (7.6-m) long unsupported span and breakaway CRT posts led to system deflections and working widths much higher than the standard MGS adjacent to both sides of the long-span system. Since safe pole placement and acceptable MGS performance is affected by system deflections, the pole should be located farther away from the long-span system to ensure that one system does not negatively affect the performance of the other system. Therefore, it is recommended that at least 25 ft (7.6 m) of standard MGS be utilized between the outer CRT post of a long-span system and the pole, applicable to each side of the long span, as shown in Figure 140.

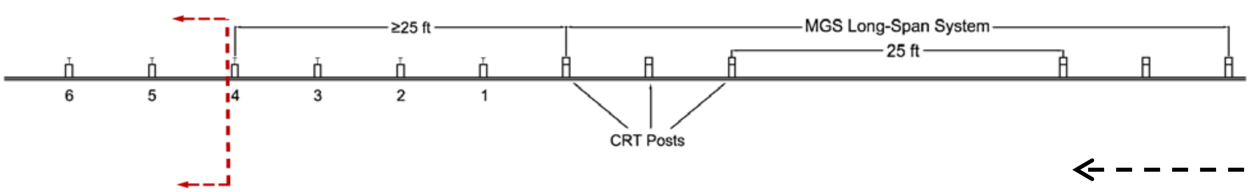


Figure 140. Recommended Distance between Pole Placement and MGS Long-Span System

10.5 MGS Adjacent to Slopes

Full-scale crash testing has been successfully conducted on three different MGS configurations placed on or adjacent to 1:2 fill slopes [41-43]. These configurations varied the post length and post placement relative to the slope break point. However, the lack of soil backfill behind the guardrail posts resulted in increased system deflections and working widths for all three MGS configurations. The working widths of the MGS with 6-ft (1.8-m) and 9-ft (2.7-m) long posts located at the slope break point of a 1:2 fill slope were 77.4 in. (1,966 mm) and 64.2 in. (1,631 mm), respectively. For now, it is not recommended to place a pole within these working widths for MGS systems installed at the slope break point of 1:2 to 1:3 fill slopes due to concerns for excessive deflections and an increased risk of post and vehicle interaction with the pole.

10.6 MGS on 1:8 Approach Slopes

Previously, full-scale crash testing was successfully performed on the MGS installed on a 1:8 approach slope with the W-beam positioned 5 ft (1.5 m) laterally behind the slope break point [44], as shown in Figure 141.

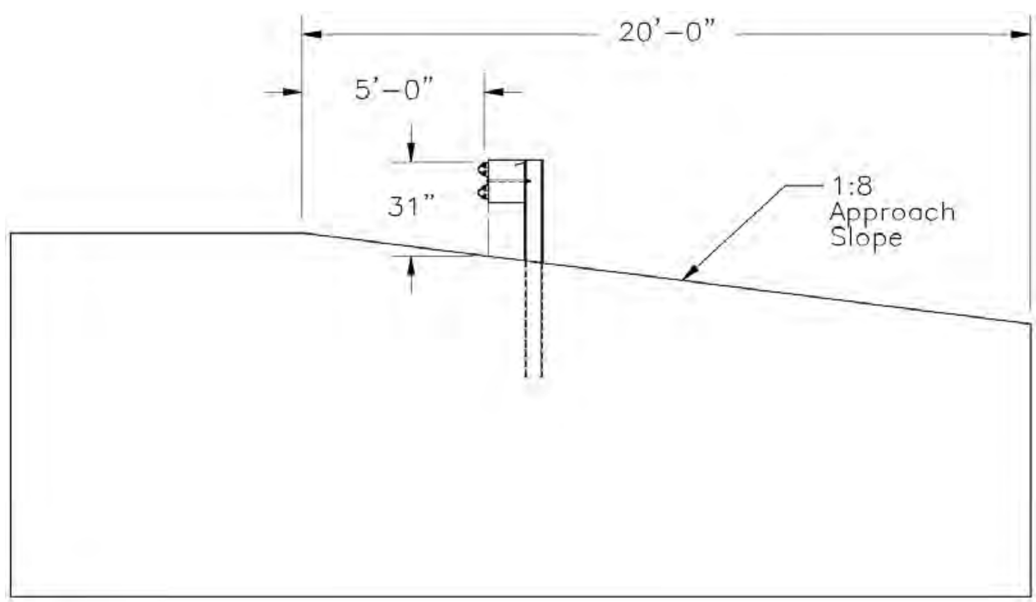


Figure 141. MGS on 1:8 Approach Slope

This testing program was conducted according to the NCHRP Report No. 350 impact safety standards using both an 820C small car and a 2000P pickup truck. From the crash testing program, the mounting height of the blocked MGS relative to the airborne trajectory of the front bumper and impact-side wheels was deemed critical for satisfactorily containing the 2000P pickup truck. Both the bumper and c.g. height of the MASH 2270P pickup are higher than the 2000P pickup. Thus, there are concerns that the same system may be unable to successfully capture the pickup truck according to the current MASH safety standards. The placement of a pole near the system may increase safety risks, such as excessive occupant risk, vehicle snag, and/or vehicle override. Since the system was not evaluated under MASH standards, pole placement behind an MGS installed on a 1:8 approach slope is not recommended until further evaluation is conducted. Note that it is likely acceptable to install a pole behind an MGS installed on a 1:10 approach slope or flatter.

10.7 MGS in Combination with Curbs

During the original MGS development effort, the MGS was crash tested under NCHRP Report No. 350 and MASH with nearly identical dynamic deflection and working width. The system was also evaluated in combination with a 6-in. (152-mm) tall, AASHTO Type B curb with its midpoint of front face placed 6 in. (152 mm) in front of the guardrail face [45]. Full-scale crash testing of this configuration was conducted with the 2000P vehicle under NCHRP Report No. 350 with dynamic deflection of 40.3 in. (1,033 mm) and working width of 57.2 in. (1,453 mm). This testing of MGS with curb under NCHRP Report No. 350 indicated lower dynamic deflection and higher working width as compared to the standard MGS [7]. Lower dynamic deflection may reduce potential for vehicle interaction with pole, and increased working width may increase barrier interaction with pole. At this time, the MGS in combination with curbs was not evaluated with small cars, nor has it been evaluated under MASH safety performance criteria. Recent MASH small car testing of an MGS stiffness transition with a 4-in. (102 mm) tall curb resulted in W-beam rail rupture due to partial vehicle underride as well as a combined lateral and vertical load being imparted to the lower rail [39]. The potential for similar splice loading exists with other curbs mounted beneath the MGS. Therefore, further evaluation of MGS adjacent to curbs under MASH TL-3 impact conditions with the 1100C and 2270P vehicles is needed to evaluate barrier dynamic deflection and working width as well as splice loading by the small car.

Illinois Tollway commonly uses a 5¼-in. (133-mm) sloped curb (gutter type G-3, as shown in Figure 142) with less height as compared to the 6-in. (152-mm) tall curb which was successfully tested under NCHRP Report No. 350. Based on the available data, there might be potential for using pole offsets reported in this study from the back of MGS post in combination with the Type G-3 curb gutter. However, further research and testing is recommended.

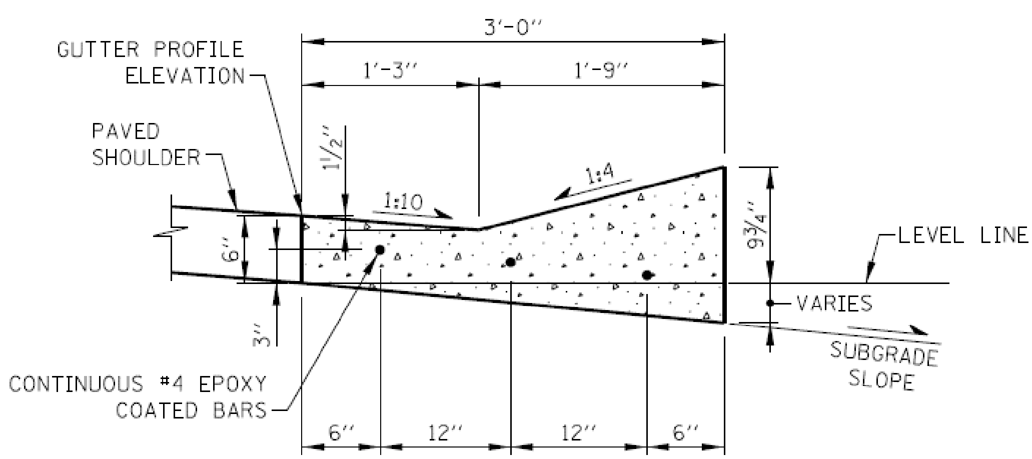


Figure 142. Gutter Type G-3 Used by Illinois Tollway

10.8 Wood Post MGS

An MGS utilizing 6-in. x 8-in. (152-mm x 203-mm) timber posts, fabricated from both Southern Yellow Pine and White Pine material were previously successfully tested and evaluated in accordance with MASH safety performance standards [46-47]. Full-scale testing illustrated that the MGS performed similarly when utilizing either W6x8.5 steel posts or 6-in. x 8-in. (152-mm x 203-mm) wood posts. System deflections, working widths, and vehicle decelerations were similar between these MGS configurations, as shown previously in Tables 2 and 3. As such, the placement of pole near a wood-post system with either Southern Yellow Pine or White Pine material should result in similar system behavior and performance. However, the wood posts are 2 in. (51 mm) deeper than the steel posts. Thus, the front face of the pole should be placed 20 in. (508 mm) behind the back face of the wood posts, or 43 in. (1,092 mm) behind the front face of the W-beam rail.

10.9 MGS without Blockouts

Previously, full-scale crash testing was successfully performed on the MGS without blockouts. The installation utilized standard steel guardrail posts and 12-in. (305-mm) long steel backup plates to prevent contact between the rail and post flanges to reduce the probability of rail tearing. The non-blocked MGS was successfully crash tested to MASH safety standards using both the 2270P and 1100C vehicles with smaller dynamic deflections and working widths as compared to the standard MGS [48]. The current study demonstrated a need to provide a 41-in. (1,041 mm) clearance between the face of the MGS rail and the front face of the pole to ensure safety performance. Thus, the same clearance should be provided between the face of the rail in the non-blocked MGS and the front face of the pole.

10.10 MGS with 8-in. (203-mm) Blockouts

The points noted in the previous section regarding non-blocked MGS may apply to other configurations utilizing a blockout depth less than 12 in. (305 mm). The safety performance of 8-in. (203-mm) and 12-in. (305-mm) deep blockouts with MGS has been shown to be acceptable [49]. Thus, it is believed that the effect of pole placement within an MGS installation of either blockout type should be similar as long as a lateral offset of 41 in. (1,041 mm) is provided between the rail face and front face of pole. The same implementation guidelines and restrictions from the front face of the rail should be used with the MGS configured with 8-in. (203-mm) deep blockouts, 41-in. (1,041-mm) for steel post MGS and 43-in. (1,092 mm) clearance for wood post MGS.

10.11 MGS with Reduced Post Spacing

A quarter-post spacing MGS was successfully full-scale crash tested according to NCHRP Report No. 350 [50]. A 26 percent reduction in working width from 49.6 in. (1,260 mm) (test no. NPG-4) for a standard MGS to 36.7 in. (932 mm) (test no. NPG-6) for a quarter-post spacing MGS was observed. For a half post spacing MGS, dynamic deflections and working widths were recommended based on Barrier VII numerical analysis. Reduced post spacing MGS has not been crash tested under MASH. Reduction of post spacing would potentially reduce the dynamic deflection and working width similar to the reductions observed in the NCHRP Report No. 350 testing and numerical analysis. Thus, the recommended 20-in. (508-mm) offset between the pole and back of the MGS with ¼- and ½-post spacing would be sufficient for safe vehicle redirection. However, potential reduction in pole offset from the back of the MGS with ¼- and ½- post spacing cannot be determined without further research with respect to reduced post spacing with the MGS under MASH TL-3 impact conditions.

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12 APPENDICES

Appendix A. Verification and Validation of Computer Simulations Test No. 2214MG-2

A ____________MASH 2270P Pickup Truck______________________________________
(Report 350 or MASH08 or EN1317 Vehicle Type)

Striking a ______31-in. tall Midwest Guardrail System______________________________
(roadside hardware type and name)

Report Date: ___1/26/2016____

Type of Report (check one)

☐ Verification (known numerical solution compared to new numerical solution) or
☒ Validation (full-scale crash test compared to a numerical solution).

General Information	Known Solution	Analysis Solution
Performing Organization:	MwRSF	MwRSF/Mojdeh Pajouh
Test/Run Number:	2214MG-2	2214MG-2_SIM_2014
Vehicle:	2002 Dodge Ram	MwRSF modified Silverado (NCAC/ V3e_C – reduced)
Reference:		
Impact Conditions		
Vehicle Mass:	2268 kg	2270 kg
Speed:	101.1 km/h	100 km/h
Angle:	25.5 degrees	25 degrees
Impact Point:	Between post nos. 11 and 12	Between post nos. 11 and 12

Composite Validation/Verification Score

	List the Report 350/MASH08 or EN1317 Test Number:
Part I	Did all solution verification criteria in Table E-1 pass?
Part II	Do all the time history evaluation scores from Table E-2 result in a satisfactory comparison (i.e., the comparison passes the criterion)? If all the values in Table E-2 did not pass, did the weighted procedure shown in Table E-3 result in an acceptable comparison. If all the criteria in Table E-2 pass, enter "yes." If all the criteria in Table E-2 did not pass but Table E-3 resulted in a passing score, enter "yes."
Part III	All the criteria in Table E-4 (Test-PIRT) passed?
	Are the results of Steps I through III all affirmative (i.e., YES)? If all three steps result in a "YES" answer, the comparison can be considered validated or verified. If one of the steps results in a negative response, the result cannot be considered validated or verified.

The analysis solution (check one) ☒ is ☐ is NOT verified/validated against the known solution.

PART I: BASIC INFORMATION

These forms may be used for validation or verification of roadside hardware crash tests. If the known solution is a full-scale crash test (i.e., physical experiment) which is being compared to a numerical solution (e.g., LSDYNA analysis) then the procedure is a validation exercise. If the known solution is a numerical solution (e.g., a prior finite element model using a different program or earlier version of the software) then the procedure is a verification exercise. This form can also be used to verify the repeatability of crash tests by comparing two full-scale crash test experiments. Provide the following basic information for the validation/verification comparison:

1. What type of roadside hardware is being evaluated (check one)?
   - ☒ Longitudinal barrier or transition
   - ☐ Terminal or crash cushion
   - ☐ Breakaway support or work zone traffic control device
   - ☐ Truck-mounted attenuator
   - ☐ Other hardware: ______________________________

2. What test guidelines were used to perform the full-scale crash test (check one)?
   - ☐ NCHRP Report 350
   - ☒ MASH08
   - ☐ EN1317
   - ☐ Other: ______________________________

3. Indicate the test level and number being evaluated (fill in the blank). __TL3-11_

4. Indicate the vehicle type appropriate for the test level and number indicated in item 3 according to the testing guidelines indicated in item 2.

NCHRP Report 350/MASH08

☐ 700C ☐ 820C ☐ 1100C

☐ 2000P ☒ 2270P ☐ Other:______________________________

☐ 8000S ☐ 10000S

☐ 36000V

☐ 36000T

EN1317

☐ Car (900 kg) ☐ Car (1300 kg) ☐ Car (1500 kg)

☐ Rigid HGV (10 ton) ☐ Rigid HGV (16 ton) ☐ Rigid HGV (30 ton)

☐ Bus (13 ton) ☐ Articulated HGV (38 ton) ☐ Other:________________________

PART II: ANALYSIS SOLUTION VERIFICATION

Using the results of the analysis solution, fill in the values for Table E-1. These values are indications of whether the analysis solution produced a numerically stable result and do not necessarily mean that the result is a good comparison to the known solution. The purpose of this table is to ensure that the numerical solution produces results that are numerically stable and conform to the conservation laws (e.g., energy, mass and momentum).

Table E-1. Analysis Solution Verification Table.

Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	0.4%	**Yes**
Hourglass Energy of the analysis solution at the end of the run is less than *five percent* of the total *initial energy* at the *beginning* of the run.	0.07%	**Yes**
Hourglass Energy of the analysis solution at the end of the run is less than *ten percent* of the total *internal energy* at the *end* of the run.	0.07%	**Yes**
The part/material with the highest amount of hourglass energy at the end of the run is less than ten percent of the total internal energy of the part/material at the end of the run. (Part id=2000683, hg=15175 N-m, internal energy max=1825 and at the end of run=260)	831%*	**No**
Mass added to the total model is less than five percent of the total model mass at the beginning of the run.	0.023%	**Yes**
The part/material with the most mass added had less than 10 percent of its initial mass added.	9.05	**Yes**
The moving parts/materials in the model have less than five percent of mass added to the initial moving mass of the model.	0.017	**Yes**
There are no shooting nodes in the solution?	No	**Yes**
There are no solid elements with negative volumes?	No	**Yes**

* Only one part, the left front tire of the vehicle has uncontrolled and unresolvable hourglass. It is reasonable to accept that.

If all the analysis solution verification criteria are scored as passing, the analysis solution can be verified or validated against the known solution. If any criterion in Table E-1 does not pass one of the verification criterion listed in Table E-1, the analysis solution cannot be used to verify or validate the known solution. If there are exceptions that the analyst things are relevant these should be footnoted in the table and explained below the table.

The Analysis Solution (check one) ☒ passes ☐ does NOT pass <u>all</u> the criteria in Table E1-1

☒with ☐without exceptions as noted.

PART III: TIME HISTORY EVALUATION TABLE

Using the RSVVP computer program ('Single channel' option), compute the Sprague-Geers MPC metrics and ANOVA metrics using time-history data from the known and analysis solutions for a time period starting at the beginning of the contact and ending at the loss of contact. Both the Sprague-Geers and ANOVA metrics must be calculated based on the original units the data was collected in (e.g., if accelerations were measured in the experiment with accelerometers then the comparison should be between accelerations. If rate gyros were used in the experiment, the comparison should be between rotation rates). If all six data channels are not available for both the known and analysis solutions, enter "N/A" in the column corresponding to the missing data. Enter the values obtained from the RSVVP program in Table E-2 and indicate if the comparison was acceptable or not by entering a "yes" or "no" in the "Agree?" column. Attach a graph of each channel for which the metrics have been compared at the end of the report.

Enter the filter, synchronization method and shift/drift options used in RSVVP to perform the comparison so that it is clear to the reviewer what options were used. Normally, SAE J211 filter class 180 is used to compare vehicle kinematics in full-scale crash tests. Either synchronization option in RSVVP is acceptable or both should result in a similar start point. The shift and drift options should generally only be used for the experimental curve since shift and drift are characteristics of sensors. For example, the zero point for an accelerometer sometimes "drifts" as the accelerometer sits out in the open environment of the crash test pad whereas there is no sensor to "drift" or "shift" in a numerical solution.

In order for the analysis solution to be considered in agreement with the known solution (i.e., verified or validated), <u>all</u> the criteria scored in Table E-2 must pass. If all the channels in Table E-2 do not pass, fill out Table E-3, the multi-channel weighted procedure.

If one or more channels do not satisfy the criteria in Table E-2, the multi-channel weighting option may be used. Using the RSVVP computer program ('Multiple channel' option), compute the Sprague-Geers MPC metrics and ANOVA metrics using all the time histories data from the known and analysis solutions for a time period starting at the beginning of the contact and ending at the loss of contact. If all six data channels are not available for both the known and analysis solutions, enter "N/A" in the column corresponding to the missing data.

For some types of roadside hardware impacts, some of the channels are not as important as others. An example might be a breakaway sign support test where the lateral (i.e., Y) and vertical (i.e., Z) accelerations are insignificant to the dynamics of the crash event. The weighting procedure provides a way to weight the most important channels more highly than less important channels. The procedure used is based on the area under the curve, therefore, the weighing scheme will weight channels with large areas more highly than those with smaller areas. In general, using the "Area (II)" method is acceptable although if the complete inertial properties of the vehicle are available the "inertial" method may be used. Enter the values obtained from the RSVVP program in Table E-3 and indicate if the comparison was acceptable or not by entering a "yes" or "no" in the "Agree?" column. In order for the analysis solution to be considered in agreement with the known solution (i.e., verified or validated), <u>all</u> the criteria scored in Table E-3 must pass.

Table E-2. Roadside Safety Validation Metrics Rating Table – Time History Comparisons (single channel option- CFC60)

	Evaluation Criteria	Time interval
O	***Sprague-Geers Metrics*** List all the data channels being compared. Calculate the M and P metrics using RSVVP and enter the results. Values less than or equal to 40 are acceptable.	**Time interval** [0 sec; 0.57 sec]

	RSVVP Curve Preprocessing Options								
	Filter Option	**Sync. Option**	**Shift True Curve**	**Shift Test Curve**	**Drift True Curve**	**Drift Test Curve**	**M**	**P**	**Pass?**
X acceleration	CFC 60	N	N	N	N	N	43.5	45	**No**
Y acceleration	CFC 60	N	N	N	N	N	0.7	28.5	**Yes**
Z acceleration	CFC 60	N	N	N	N	N	33	52.2	**No**
Roll rate	CFC 60	N	N	N	N	N	6.9	47.1	**No**
Pitch rate	CFC 60	N	N	N	N	N	449	51.6	**No**
Yaw rate	CFC 60	N	N	N	N	N	4.1	8.7	**Yes**

P ***ANOVA Metrics***

List all the data channels being compared. Calculate the ANOVA metrics using RSVVP and enter the results. Both of the following criteria must be met:

- The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \leq 0.05 \cdot a_{Peak}$) and
- The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \leq 0.35 \cdot a_{Peak}$)

	Mean Residual	**Standard Deviation of Residuals**	**Pass?**
X acceleration/Peak	1.4	44.2	**No**
Y acceleration/Peak	1.3	26.2	**Yes**
Z acceleration/Peak	3	45.6	**No**
Roll rate	21.5	46.2	**No**
Pitch rate	32.4	1184.8	**No**
Yaw rate	3.4	14.9	**Yes**

The Analysis Solution (check one) ☐ passes ☒ does NOT pass all the criteria in Table E-2 (single-channel time history comparison). If the Analysis Solution does NOT pass, perform the analysis in Table E-3 (multi-channel time history comparison).

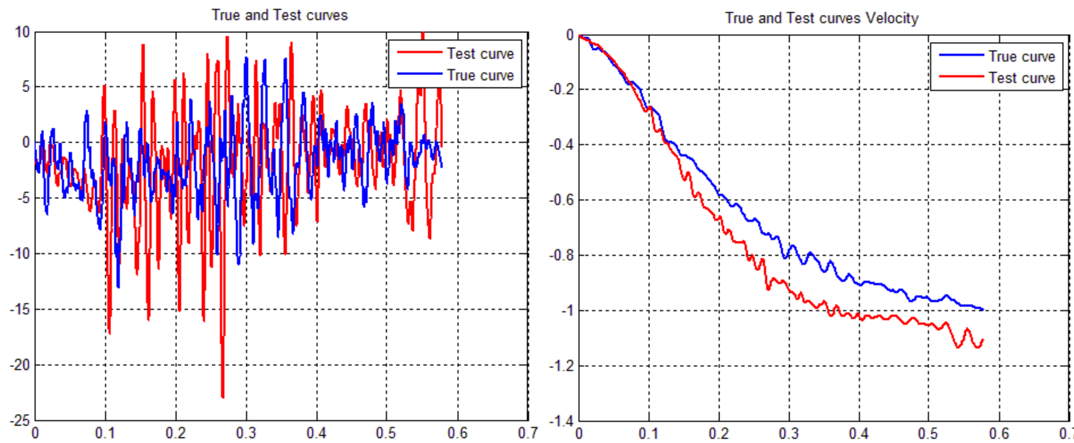


Figure 1. X-Channel (a) acceleration-time history data used to compute metrics, and (b) Integration of acceleration-time history data

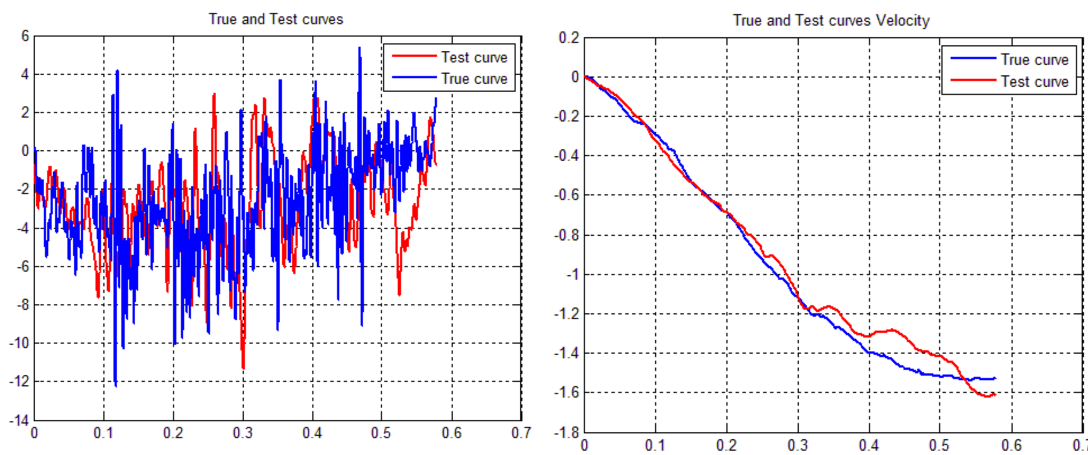


Figure 2. Y-Channel (a) acceleration-time history data used to compute metrics, and (b) Integration of acceleration-time history data

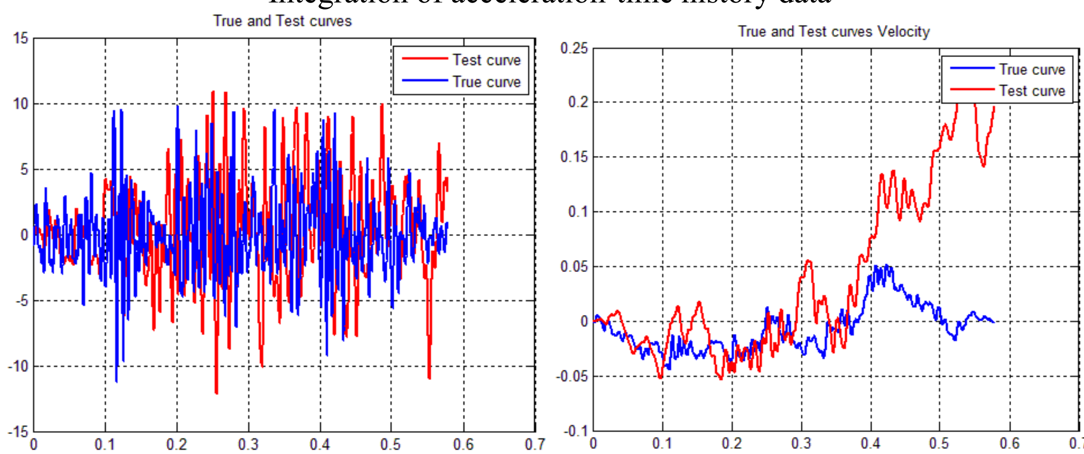


Figure 3. Z-Channel (a) acceleration-time history data used to compute metrics, and (b) Integration of acceleration-time history data

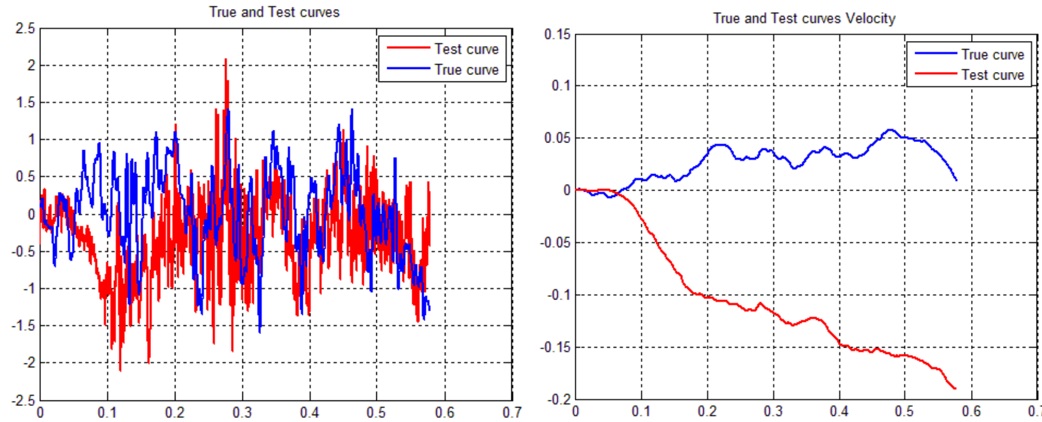


Figure 4. Roll Channel (a) angular rate-time history data used to compute metrics, and (b) Integration of angular rate-time history data

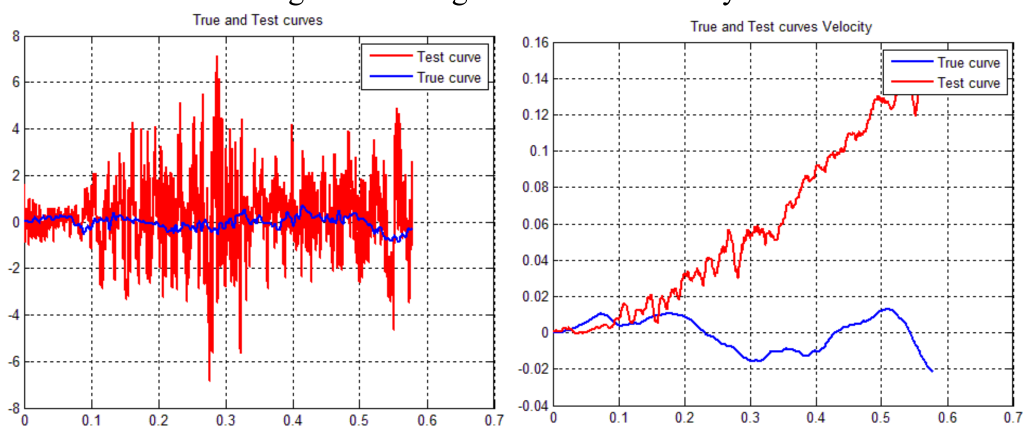


Figure 5. Pitch Channel (a) angular rate-time history data used to compute metrics, and (b) Integration of angular rate-time history data

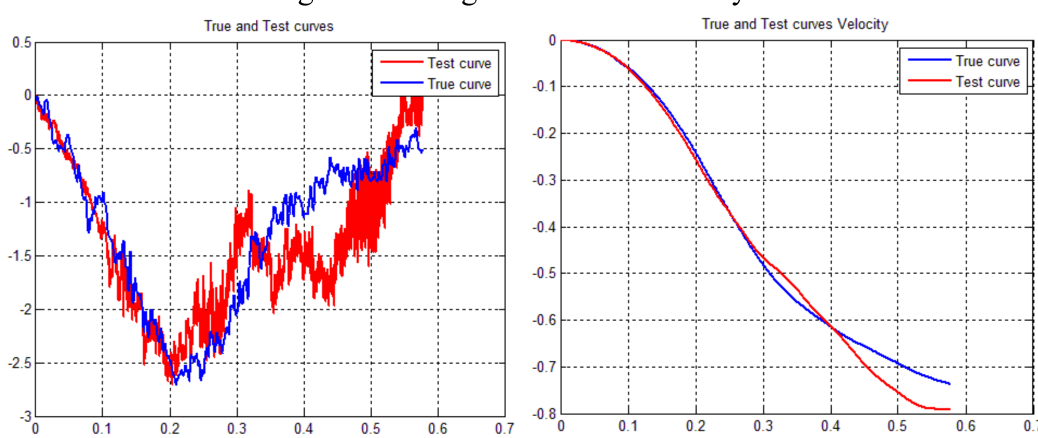
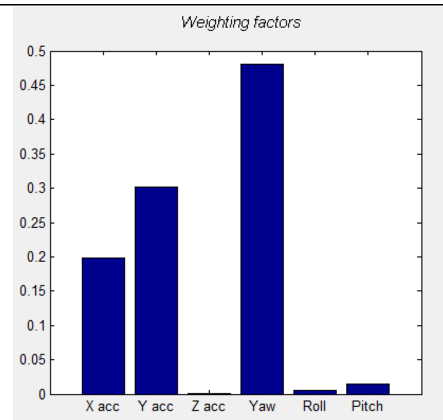


Figure 6. Yaw Channel (a) angular rate-time history data used to compute metrics, and (b) Integration of angular rate-time history data

Table E-3. Roadside Safety Validation Metrics Rating Table – Time History Comparisons (multi-channel option-CFC 60)

<table>
<tr><td colspan="3">Evaluation Criteria (time interval [0 sec; 0.57 sec])</td></tr>
<tr><td colspan="3">Channels (Select which were used)</td></tr>
<tr><td>☒ X Acceleration</td><td>☒ Y Acceleration</td><td>☒ Z Acceleration</td></tr>
<tr><td>☒ Roll rate</td><td>☒ Pitch rate</td><td>☒ Yaw rate</td></tr>
<tr><td>Multi-Channel Weights
☒ Area II method
☐ Inertial method</td><td>X Channel:
Y Channel:
Z Channel:
Yaw Channel:
Roll Channel: ___

Pitch Channel:</td><td>
</td></tr>
</table>

<table>
<tr><td rowspan="2">O</td><td rowspan="2">Sprague-Geer Metrics
Values less or equal to 40 are acceptable.</td><td>M</td><td>P</td><td>Pass?</td></tr>
<tr><td>17.1</td><td>22.7</td><td>Yes</td></tr>
<tr><td rowspan="2">P</td><td rowspan="2">ANOVA Metrics
Both of the following criteria must be met:
• The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \leq 0.05 \cdot a_{Peak}$)
• The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \leq 0.35 \cdot a_{Peak}$)</td><td>Mean Residual</td><td>Standard Deviation of Residuals</td><td>Pass?</td></tr>
<tr><td>2</td><td>26.7</td><td>Yes</td></tr>
</table>

The Analysis Solution (check one) ☒ passes ☐ does NOT pass all the criteria in Table E-3.

Table E-2. Roadside Safety Validation Metrics Rating Table – Time History Comparisons (single channel option- CFC180)

	Evaluation Criteria							Time interval [0 sec; 0.57 sec]		
O	***Sprague-Geers Metrics*** List all the data channels being compared. Calculate the M and P metrics using RSVVP and enter the results. Values less than or equal to 40 are acceptable.									
		RSVVP Curve Preprocessing Options						**M**	**P**	**Pass?**
		Filter Option	**Sync. Option**	**Shift**		**Drift**				
				True Curve	**Test Curve**	**True Curve**	**Test Curve**			
	X acceleration	CFC 180	N	N	N	N	N	110.5	46.5	**No**
	Y acceleration	CFC 180	N	N	N	N	N	15.7	32.6	**Yes**
	Z acceleration	CFC 180	N	N	N	N	N	118.5	52.3	**No**
	Roll rate	CFC 180	N	N	N	N	N	6.9	47.1	**No**
	Pitch rate	CFC 180	N	N	N	N	N	449	51.6	**No**
	Yaw rate	CFC 180	N	N	N	N	N	4.1	8.7	**Yes**
P	***ANOVA Metrics*** List all the data channels being compared. Calculate the ANOVA metrics using RSVVP and enter the results. Both of the following criteria must be met: • The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \leq 0.05 \cdot a_{Peak}$) and • The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \leq 0.35 \cdot a_{Peak}$)							**Mean Residual**	**Standard Deviation of Residuals**	**Pass?**
	X acceleration/Peak							1.3	61	**No**
	Y acceleration/Peak							1.3	32.5	**Yes**
	Z acceleration/Peak							3	65.7	**No**
	Roll rate							21.5	46.2	**No**
	Pitch rate							32.4	1184.8	**No**
	Yaw rate							3.4	14.9	**Yes**

The Analysis Solution (check one) ☐ passes ☒ does NOT pass all the criteria in Table E-2 (single-channel time history comparison). If the Analysis Solution does NOT pass, perform the analysis in Table E-3 (multi-channel time history comparison).

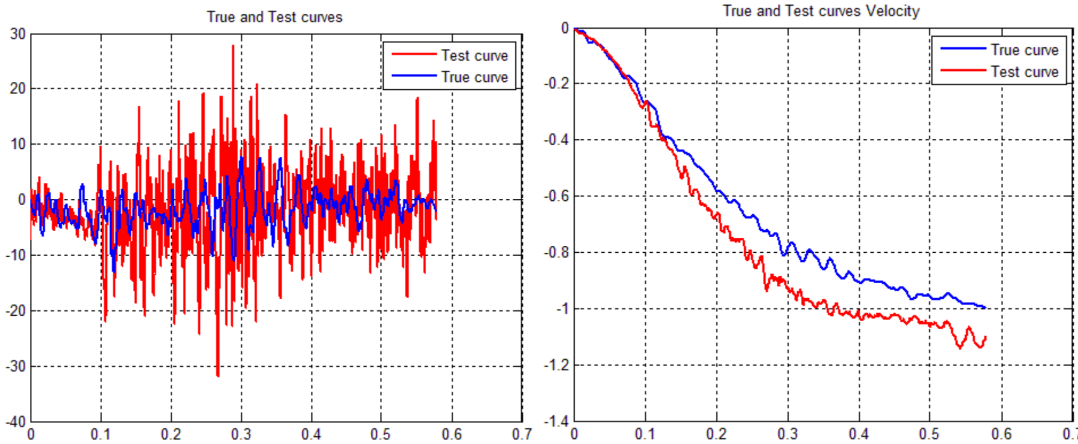


Figure 7. X-Channel (a) acceleration-time history data used to compute metrics, and (b) Integration of acceleration-time history data

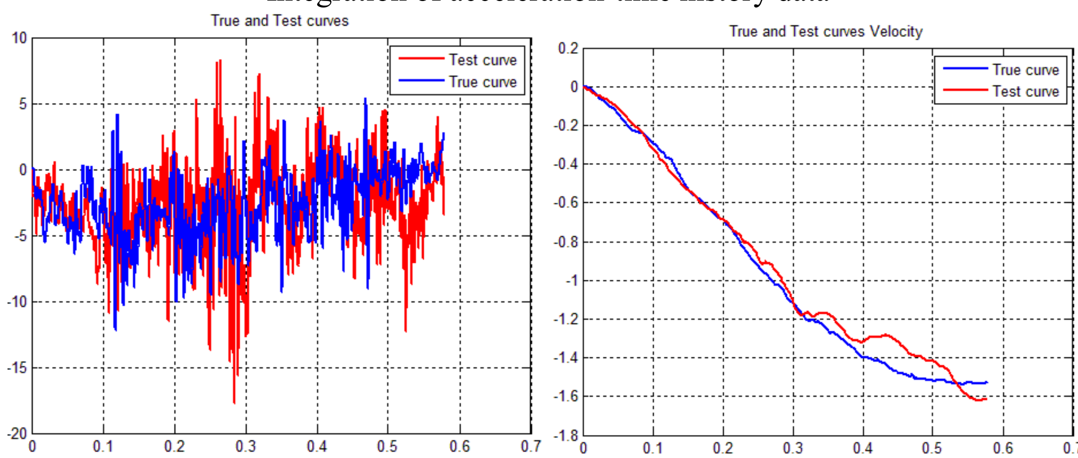


Figure 8. X-Channel (a) acceleration-time history data used to compute metrics, and (b) Integration of acceleration-time history data

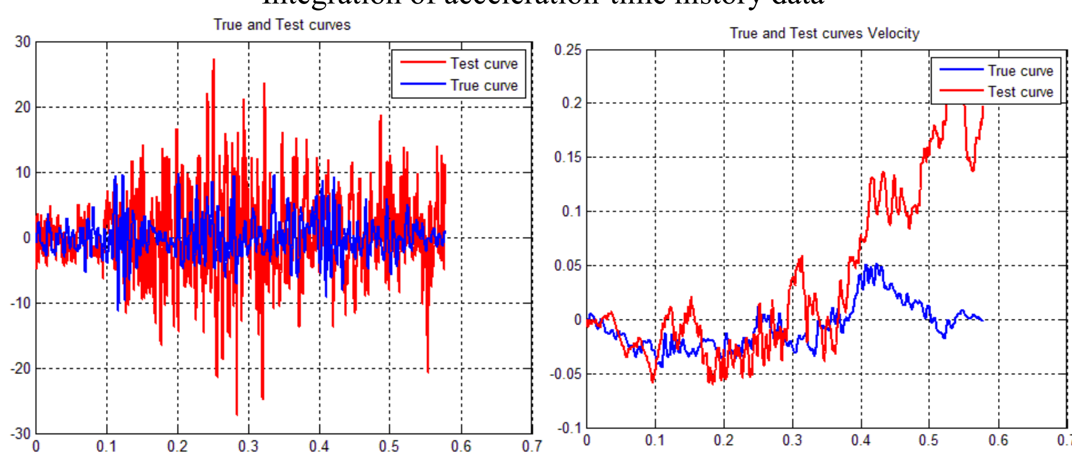
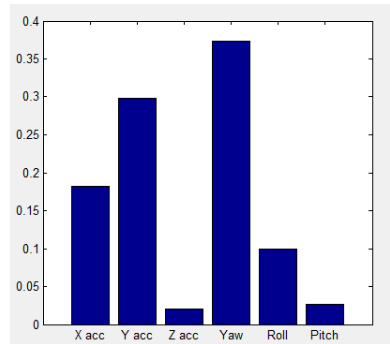


Figure 9. X-Channel (a) acceleration-time history data used to compute metrics, and (b) Integration of acceleration-time history data

Table E-3. Roadside Safety Validation Metrics Rating Table – Time History Comparisons (multi-channel option- CFC 180)

<table>
<tr><th colspan="6">Evaluation Criteria (time interval [0 sec; 0.57 sec])</th></tr>
<tr><td colspan="6">Channels (Select which were used)</td></tr>
<tr><td colspan="2">☒ X Acceleration</td><td colspan="2">☒ Y Acceleration</td><td colspan="2">☒ Z Acceleration</td></tr>
<tr><td colspan="2">☒ Roll rate</td><td colspan="2">☒ Pitch rate</td><td colspan="2">☒ Yaw rate</td></tr>
<tr><td colspan="2">Multi-Channel Weights
☒ Area II method
☐ Inertial method</td><td colspan="2">X Channel:
Y Channel:
Z Channel:
Yaw Channel:
Roll Channel: ___
Pitch Channel:</td><td colspan="2">
</td></tr>
<tr><td rowspan="2">O</td><td rowspan="2">Sprague-Geer Metrics
Values less or equal to 40 are acceptable.</td><td>M</td><td>P</td><td colspan="2">Pass?</td></tr>
<tr><td>34.9</td><td>24.2</td><td colspan="2">Yes</td></tr>
<tr><td rowspan="2">P</td><td rowspan="2">ANOVA Metrics
Both of the following criteria must be met:
• The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \leq 0.05 \cdot a_{Peak}$)
• The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \leq 0.35 \cdot a_{Peak}$)</td><td>Mean Residual</td><td>Standard Deviation of Residuals</td><td colspan="2">Pass?</td></tr>
<tr><td>2</td><td>31.9</td><td colspan="2">Yes</td></tr>
</table>

The Analysis Solution (check one) ☒ passes ☐ does NOT pass all the criteria in Table E-3.

PART IV: PHENOMENA IMPORTANCE RANKING TABLE

Table E-4 is similar to the evaluation tables in Report 350 and MASH. For the Report 350 or MASH test number identified in Part I (e.g., test 3-10, 5-12, etc.), circle all the evaluation criteria applicable to that test in Table E-4. The tests that apply to each criterion are listed in the far right column without the test level designator. For example, if a Report 350 test 3-11 is being compared (i.e., a pickup truck striking a barrier at 25 degrees and 100 km/hr), circle all the criteria in the second column where the number "11" appears in the far right column. Some of the Report 350 evaluation criteria have been removed (i.e., J and K) since they are not generally useful in assessing the comparison between the known and analysis solutions.

Table E-4. Evaluation Criteria Test Applicability Table

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Applicable Tests</th></tr>
<tr><td rowspan="2">uctural Adequacy</td><td>A</td><td>Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>10, 11, 12, 20, 21, 22, 35, 36, 37, 38</td></tr>
<tr><td>B</td><td>The test article should readily activate in a predictable manner by breaking away, fracturing or yielding.</td><td>60, 61, 70, 71, 80, 81</td></tr>
<tr><td></td><td>C</td><td>Acceptable test article performance may be by redirection, controlled penetration or controlled stopping of the vehicle.</td><td>30, 31,, 32, 33, 34, 39, 40, 41, 42, 43, 44, 50, 51, 52, 53</td></tr>
<tr><td rowspan="6">Occupant Risk</td><td>D</td><td>Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone.</td><td>All</td></tr>
<tr><td>E</td><td>Detached elements, fragments or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle. (Answer Yes or No)</td><td>70, 71</td></tr>
<tr><td>F</td><td>The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.</td><td>All except those listed in criterion G</td></tr>
<tr><td>G</td><td>It is preferable, although not essential, that the vehicle remain upright during and after collision.</td><td>12, 22 (for test level 1 – 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44)</td></tr>
<tr><td>H</td><td>Occupant impact velocities should satisfy the following:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>9</td><td>12</td></tr>
<tr><td>Longitudinal</td><td>3</td><td>5</td></tr>
</table></td><td>10, 20, 30,31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 80, 81 (Longitudinal and Lateral)
60, 61, 70, 71 (Longitudinal)</td></tr>
<tr><td>I</td><td>Occupant ridedown accelerations should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (g's)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>15</td><td>20</td></tr>
</table></td><td>10, 20, 30,31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 60, 61, 70, 71, 80, 81</td></tr>
<tr><td rowspan="3">Vehicle Trajectory</td><td>L</td><td>The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G's.</td><td>11,21, 35, 37, 38, 39</td></tr>
<tr><td>M</td><td>The exit angle from the test article preferable should be less than 60 percent of test impact angle, measured at the time of vehicle loss of contact with test device.</td><td>10, 11, 12, 20, 21, 22, 35, 36, 37, 38, 39</td></tr>
<tr><td>N</td><td>Vehicle trajectory behind the test article is acceptable.</td><td>30, 31, 32, 33, 34, 39, 42, 43, 44, 60, 61, 70, 71, 80, 81</td></tr>
</table>

Note: The circles around the letters indicate the criteria that are applicable to this case.

Complete Table E-5 according to the results of the known solution (e.g., crash test) and the numerical solution (e.g., simulation). Consistent with Report 350 and MASH, Task E-5 has three parts: the structural adequacy phenomena listed in Table E-5a, the occupant risk phenomena listed in Table E-5b and the vehicle trajectory criteria listed in Table E-5c. If the result of the analysis solution agrees with the known solution, mark the "agree" column "yes." For example, if the vehicle in both the known and analysis solutions rolls over and, therefore, fails criterion F1, the known and the analysis columns for criterion F1 would be evaluated as "no." Even though both failed the criteria, they agree with each other so the "agree" column is marked as "yes." Any criterion that is not applicable to the test being evaluated (i.e., not circled in Table E-4) should be indicated by entering "NA" in the "agree?" column for that row.

Many of the Report 350 evaluation criteria have been subdivided into more specific phenomenon. For example, criterion A is divided into eight sub-criteria, A1 through A8, that provide more specific and quantifiable phenomena for evaluation. Some of the values are simple yes or no questions while other request numerical values. For the numerical phenomena, the analyst should enter the value for the known and analysis result and then calculate the relative difference. Relative difference is always the absolute value of the difference of the known and analysis solutions divided by the known solution. Enter the value in the "relative difference" column. If the relative difference is less than 20 percent, enter "yes" in the "agree?" column.

Sometimes, when the values are very small, the relative difference might be large while the absolute difference is very small. For example, the longitudinal occupant ride down acceleration (i.e., criterion L2) in a test might be 3 g's and in the corresponding analysis might be 4 g's. The relative difference is 33 percent but the absolute difference is only 1 g and the result for both is well below the 20 g limit. Clearly, the analysis solution in this case is a good match to the experiment and the relative difference is large only because the values are small. The absolute difference, therefore, should also be entered into the "Difference" column in Table E-5.

The experimental and analysis result can be considered to agree as long as either the relative difference or the absolute difference is less than the acceptance limit listed in the criterion. Generally, relative differences of less than 20 percent are acceptable and the absolute difference limits were generally chosen to represent 20 percent of the acceptance limit in Report 350 or MASH. For example, Report 350 limits occupant ride-down accelerations to those less than 20 g's so 20 percent of 20 g's is 4 g's. As shown for criterion L2 in Table E-5, the relative acceptance limit is 20 percent and the absolute acceptance limit is 4 g's.

If a numerical model was not created to represent the phenomenon, a value of "NM" (i.e., not modeled) should be entered in the appropriate column of Table E-5. If the known solution for that phenomenon number is "no" then a "NM" value in the "test result" column can be considered to agree. For example, if the material model for the rail element did not include the possibility of failure, "NM" should be entered for phenomenon number T in Table E-5. If the known solution does not indicate rail rupture or failure (i.e., phenomenon T = "no"), then the known and analysis solutions agree and a "yes" can be entered in the "agree?" column. On the other hand, if the known solution shows that a rail rupture did occur resulting in a phenomenon T entry of "yes" for the known solution, the known and analysis solutions do not agree and "no" should be entered in the "agree?" column. Analysts should seriously consider refining their model to incorporate any phenomena that appears in the known solution and is shown in Table E-5.

All the criteria identified in Table E-4 are expected to agree but if one does not and, in the opinion of the analyst, is not considered important to the overall evaluation for this particular comparison, then a footnote should be provided with a justification for why this particular criteria can be ignored for this particular comparison.

Table E-5(a). Roadside Safety Phenomena Importance Ranking Table (Structural Adequacy)

Evaluation Criteria				Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Structural Adequacy	A	A1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable. (Answer Yes or No)	Yes	Yes		Yes
		A2	Maximum dynamic deflection: - Relative difference is less than 20 percent or - Absolute difference is less than 0.15 m	1.11 m	1.14 m	2.7 % 0.13 m	Yes
		A3	Length of vehicle-barrier contact: - Relative difference is less than 20 percent or - Absolute difference is less than 2 m	10.3 m	9 m	12.6 % 1.3 m	Yes
		A4	Number of broken or significantly bent posts is less than 20 percent. (reported: post nos 13,14,15 bent and web of the post 16 also bent)	4	4		Yes
		A5	Did the rail element rupture or tear (Answer Yes or No)	No	No		Yes
		A6	Were there failures of connector elements (Answer Yes or No)	No	No		Yes
		A7	Was there significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	No	No		Yes
		A8	Was there significant snagging between vehicle body components and barrier elements (Answer Yes or No).	No	No		Yes

Table E-5(b). Roadside Safety Phenomena Importance Ranking Table (Occupant Risk)

			Evaluation Criteria	Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Occupant Risk	D		Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone. (Answer Yes or No)	Pass	Pass		Yes
	F	F1	The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable. (Answer Yes or No)	Pass	Pass		Yes
		F2	Maximum roll of the vehicle: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	4.81°	11.67°*	142% 6.86°	No
		F3	Maximum pitch of the vehicle is: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	1.84°	3.17°	72% 1.33°	Yes
		F4	Maximum yaw of the vehicle is: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	45.74°	46.21°	1.02% 0.47°	Yes
	L	L1	Occupant impact velocities: - Relative difference is less than 20 percent or - Absolute difference is less than 2 m/s.				
			• Longitudinal OIV (m/s)	4.67	4.43	5.1% 0.24 m/s	Yes
			• Lateral OIV (m/s)	4.76	4.99	4.83% 0.23 m/s	Yes
			• THIV (m/s)	6.91	NA**		
		L2	Occupant accelerations: - Relative difference is less than 20 percent or - Absolute difference is less than 4 g's.				
			• Longitudinal ORA	8.23	11.16	35.6% 2.93 g	Yes
			• Lateral ORA	6.93	9.05	30.59% 2.12 g	Yes
			• PHD	10.76	NA		
			• ASI	NA	NA		

* The roll, pitch, and yaw Euler angles were calculated for the simulation using the same procedure for full-scale crash tests.
** Not required

Table E-5(c). Roadside Safety Phenomena Importance Ranking Table (Vehicle Trajectory)

Evaluation Criteria				Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Vehicle Trajectory	M	M1	The exit angle from the test article preferable should be less than 60 percent of test impact angle, measured at the time of vehicle loss of contact with test device.	13.5°	20.39		**Yes**
		M2	Exit angle at loss of contact: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	13.5°	20.39	51.03% 6.9 °*	**Yes**
		M3	Exit velocity at loss of contact: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	63.7 km/h	59.76 km/h	6.18 % 3.94 km/h	**Yes**
		M4	One or more vehicle tires failed or de-beaded during the collision event (Answer Yes or No).	Yes	NM		

* In the simulation, vehicle was still in contact with the barrier at time 500 msec. Moreover, a difference of 6.9° is relatively small.

The Analysis Solution (check one) ☐ passes ☒ does NOT pass all the criteria in Tables E-5a through E-5c ☐with exceptions as noted ☐ without exceptions.

Appendix B. Verification and Validation of Computer Simulations Test No. 2214MG-3

A ___________ MASH 1100C Small Car____
(Report 350 or MASH08 or EN1317 Vehicle Type)

Striking a ______32-in. tall Midwest Guardrail System _______________________________
(roadside hardware type and name)

Report Date: __1/26/2016____

Type of Report (check one)

☐ Verification (known numerical solution compared to new numerical solution) or
☒ Validation (full-scale crash test compared to a numerical solution).

General Information	Known Solution	Analysis Solution
Performing Organization:	MwRSF	MwRSF/ Mojdeh Pajouh
Test/Run Number:	2214MG-3	2214MG-3_SIM_2015
Vehicle:	2009 Hyundai Accent	MwRSF modified Yaris (NCAC/2012)
Reference:		
Impact Conditions		
Vehicle Mass:	1,174 kg	1,259 kg (Includes 2 dummies)
Speed:	97.8 km/h	100 km/h
Angle:	25.4 degrees	25 degrees
Impact Point:	Between nos. 13 and 14	Between nos. 13 and 14

Composite Validation/Verification Score

	List the Report 350/MASH08 or EN1317 Test Number:
Part I	Did all solution verification criteria in Table E-1 pass?
Part II	Do all the time history evaluation scores from Table E-2 result in a satisfactory comparison (i.e., the comparison passes the criterion)? If all the values in Table E-2 did not pass, did the weighted procedure shown in Table E-3 result in an acceptable comparison. If all the criteria in Table E-2 pass, enter "yes." If all the criteria in Table E-2 did not pass but Table E-3 resulted in a passing score, enter "yes."
Part III	All the criteria in Table E-4 (Test-PIRT) passed?
	Are the results of Steps I through III all affirmative (i.e., YES)? If all three steps result in a "YES" answer, the comparison can be considered validated or verified. If one of the steps results in a negative response, the result cannot be considered validated or verified.

The analysis solution (check one) ☒ is ☐ is NOT verified/validated against the known solution.

PART I: BASIC INFORMATION

These forms may be used for validation or verification of roadside hardware crash tests. If the known solution is a full-scale crash test (i.e., physical experiment) which is being compared to a numerical solution (e.g., LSDYNA analysis) then the procedure is a validation exercise. If the known solution is a numerical solution (e.g., a prior finite element model using a different program or earlier version of the software) then the procedure is a verification exercise. This form can also be used to verify the repeatability of crash tests by comparing two full-scale crash test experiments. Provide the following basic information for the validation/verification comparison:

5. What type of roadside hardware is being evaluated (check one)?
   - [x] Longitudinal barrier or transition
   - [ ] Terminal or crash cushion
   - [ ] Breakaway support or work zone traffic control device
   - [ ] Truck-mounted attenuator
   - [ ] Other hardware: ____________________

6. What test guidelines were used to perform the full-scale crash test (check one)?
   - [ ] NCHRP Report 350
   - [x] MASH08
   - [ ] EN1317
   - [ ] Other: ____________________

7. Indicate the test level and number being evaluated (fill in the blank). ____TL 3-10___

8. Indicate the vehicle type appropriate for the test level and number indicated in item 3 according to the testing guidelines indicated in item 2.

NCHRP Report 350/MASH08

☐ 700C	☐ 820C	☒ 1100C
☐ 2000P	☐ 2270P	☐ Other:____________________
☐ 8000S	☐ 10000S	
☐ 36000V		
☐ 36000T		

EN1317

☐ Car (900 kg)	☐ Car (1300 kg)	☐ Car (1500 kg)
☐ Rigid HGV (10 ton)	☐ Rigid HGV (16 ton)	☐ Rigid HGV (30 ton)
☐ Bus (13 ton)	☐ Articulated HGV (38 ton)	☐

Other:____________________

PART II: ANALYSIS SOLUTION VERIFICATION

Using the results of the analysis solution, fill in the values for Table E-1. These values are indications of whether the analysis solution produced a numerically stable result and do not necessarily mean that the result is a good comparison to the known solution. The purpose of this table is to ensure that the numerical solution produces results that are numerically stable and conform to the conservation laws (e.g., energy, mass and momentum).

Table E-1. Analysis Solution Verification Table.

Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	3.78%	**Yes**
Hourglass Energy of the analysis solution at the end of the run is less than *five percent* of the total *initial energy* at the *beginning* of the run.	3.88%	**Yes**
Hourglass Energy of the analysis solution at the end of the run is less than *ten percent* of the total *internal energy* at the *end* of the run.	9.66%	**Yes**
The part/material with the highest amount of hourglass energy at the end of the run is less than ten percent of the total internal energy of the part/material at the end of the run. (Part id=2000191, hg=3836 N-m, internal energy max=12215)	31.4%	**No**
Mass added to the total model is less than five percent of the total model mass at the beginning of the run.	0.11%	**Yes**
The part/material with the most mass added had less than 10 percent of its initial mass added.	6.79%	**Yes**
The moving parts/materials in the model have less than five percent of mass added to the initial moving mass of the model.	2.18%	**Yes**
There are no shooting nodes in the solution?	No	**Yes**
There are no solid elements with negative volumes?	No	**Yes**

* Only one part, the fender in vehicle has uncontrolled and unresolvable hourglass. It is reasonable to accept that.

If all the analysis solution verification criteria are scored as passing, the analysis solution can be verified or validated against the known solution. If any criterion in Table E-1 does not pass one of the verification criterion listed in Table E-1, the analysis solution cannot be used to verify or validate the known solution. If there are exceptions that the analyst things are relevant these should be footnoted in the table and explained below the table.
The Analysis Solution (check one) ☒ passes ☐ does NOT pass <u>all</u> the criteria in Table E1-1

☒with ☐without exceptions as noted.

PART III: TIME HISTORY EVALUATION TABLE

Using the RSVVP computer program ('Single channel' option), compute the Sprague-Geers MPC metrics and ANOVA metrics using time-history data from the known and analysis solutions for a time period starting at the beginning of the contact and ending at the loss of contact. Both the Sprague-Geers and ANOVA metrics must be calculated based on the original units the data was collected in (e.g., if accelerations were measured in the experiment with accelerometers then the comparison should be between accelerations. If rate gyros were used in the experiment, the comparison should be between rotation rates). If all six data channels are not available for both the known and analysis solutions, enter "N/A" in the column corresponding to the missing data. Enter the values obtained from the RSVVP program in Table E-2 and indicate if the comparison was acceptable or not by entering a "yes" or "no" in the "Agree?" column. Attach a graph of each channel for which the metrics have been compared at the end of the report.

Enter the filter, synchronization method and shift/drift options used in RSVVP to perform the comparison so that it is clear to the reviewer what options were used. Normally, SAE J211 filter class 180 is used to compare vehicle kinematics in full-scale crash tests. Either synchronization option in RSVVP is acceptable or both should result in a similar start point. The shift and drift options should generally only be used for the experimental curve since shift and drift are characteristics of sensors. For example, the zero point for an accelerometer sometimes "drifts" as the accelerometer sits out in the open environment of the crash test pad whereas there is no sensor to "drift" or "shift" in a numerical solution.

In order for the analysis solution to be considered in agreement with the known solution (i.e., verified or validated), all the criteria scored in Table E-2 must pass. If all the channels in Table E-2 do not pass, fill out Table E-3, the multi-channel weighted procedure.

If one or more channels do not satisfy the criteria in Table E-2, the multi-channel weighting option may be used. Using the RSVVP computer program ('Multiple channel' option), compute the Sprague-Geers MPC metrics and ANOVA metrics using all the time histories data from the known and analysis solutions for a time period starting at the beginning of the contact and ending at the loss of contact. If all six data channels are not available for both the known and analysis solutions, enter "N/A" in the column corresponding to the missing data.

For some types of roadside hardware impacts, some of the channels are not as important as others. An example might be a breakaway sign support test where the lateral (i.e., Y) and vertical (i.e., Z) accelerations are insignificant to the dynamics of the crash event. The weighting procedure provides a way to weight the most important channels more highly than less important channels. The procedure used is based on the area under the curve, therefore, the weighing scheme will weight channels with large areas more highly than those with smaller areas. In general, using the "Area (II)" method is acceptable although if the complete inertial properties of the vehicle are available the "inertial" method may be used. Enter the values obtained from the RSVVP program in Table E-3 and indicate if the comparison was acceptable or not by entering a "yes" or "no" in the "Agree?" column. In order for the analysis solution to be considered in agreement with the known solution (i.e., verified or validated), all the criteria scored in Table E-3 must pass.

Table E-2. Roadside Safety Validation Metrics Rating Table – Time History Comparisons (single channel option- CFC60)

Evaluation Criteria									**Time interval [0 sec; 0.48 sec]**		
O	***Sprague-Geers Metrics*** List all the data channels being compared. Calculate the M and P metrics using RSVVP and enter the results. Values less than or equal to 40 are acceptable.										
		RSVVP Curve Preprocessing Options							**M**	**P**	**Pass?**
		Filter Option	**Sync. Option**	**Shift**		**Drift**					
				True Curve	**Test Curve**	**True Curve**	**Test Curve**				
	X acceleration	CFC 60	N	N	N	N	N		14	30.7	Yes
	Y acceleration	CFC 60	N	N	N	N	N		18.7	29.5	Yes
	Z acceleration	CFC 60	N	N	N	N	N		47	48.1	No
	Roll rate	CFC 60	N	N	N	N	N		20.9	53.8	No
	Pitch rate	CFC 60	N	N	N	N	N		242.8	48.3	No
	Yaw rate	CFC 60	N	N	N	N	N		13.3	16.8	Yes
P	***ANOVA Metrics*** List all the data channels being compared. Calculate the ANOVA metrics using RSVVP and enter the results. Both of the following criteria must be met: • The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \leq 0.05 \cdot a_{Peak}$) and • The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \leq 0.35 \cdot a_{Peak}$)								**Mean Residual**	**Standard Deviation of Residuals**	**Pass?**
	X acceleration/Peak								3.1	21.2	Yes
	Y acceleration/Peak								0.8	25.5	Yes
	Z acceleration/Peak								4.7	50	No
	Roll rate								4.5	67.9	No
	Pitch rate								2.4	99.6	No
	Yaw rate								16.2	18.7	No

The Analysis Solution (check one) ☐ passes ☒ does NOT pass all the criteria in Table E-2 (single-channel time history comparison). If the Analysis Solution does NOT pass, perform the analysis in Table E-3 (multi-channel time history comparison).

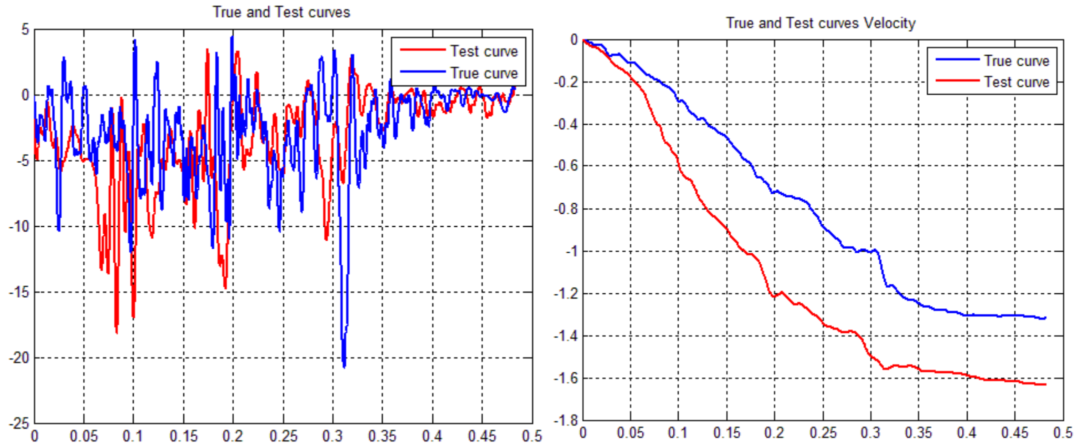


Figure 1. X-Channel (a) acceleration-time history data used to compute metrics, and (b) Integration of acceleration-time history data

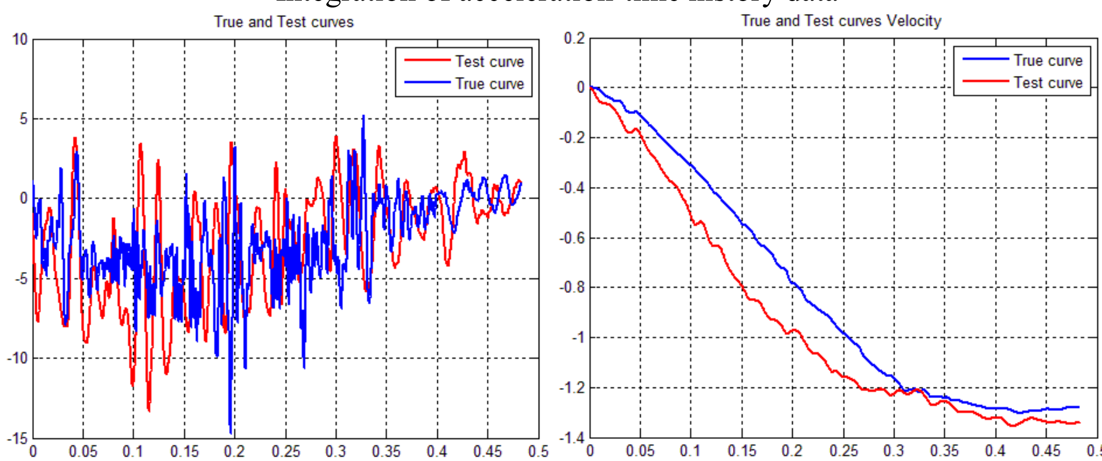


Figure 2. Y-Channel (a) acceleration-time history data used to compute metrics, and (b) Integration of acceleration-time history data

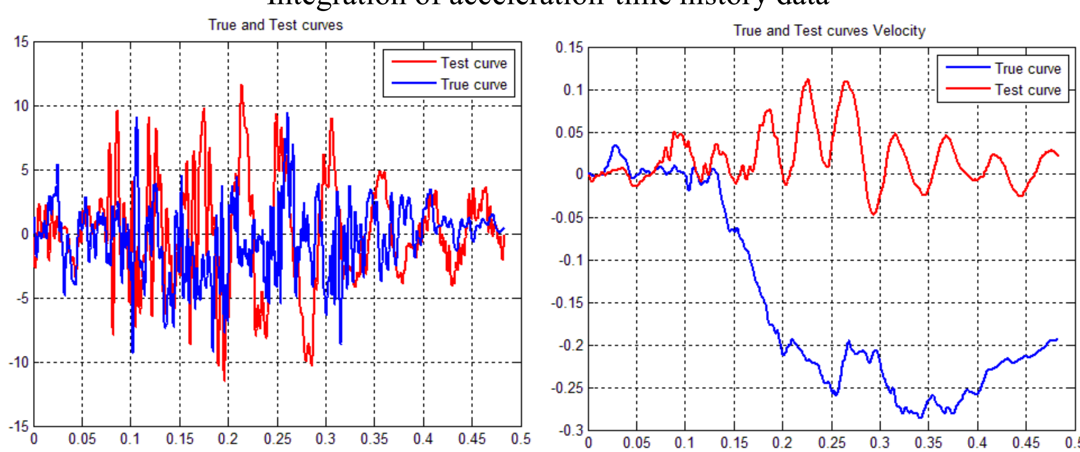


Figure 3. Z-Channel (a) acceleration-time history data used to compute metrics, and (b) Integration of acceleration-time history data

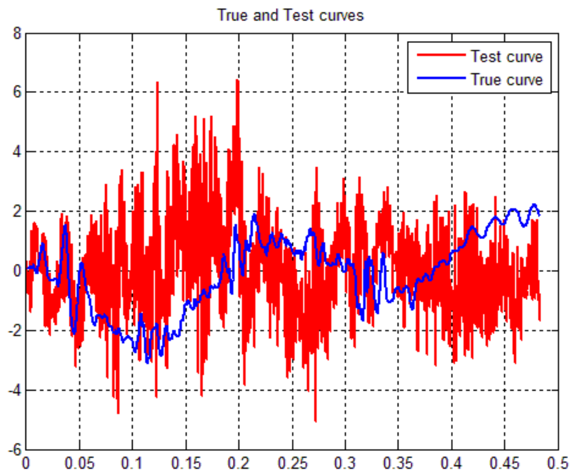


Figure 4. Roll Channel (a) angular rate-time history data used to compute metrics, and (b) Integration of angular rate-time history data

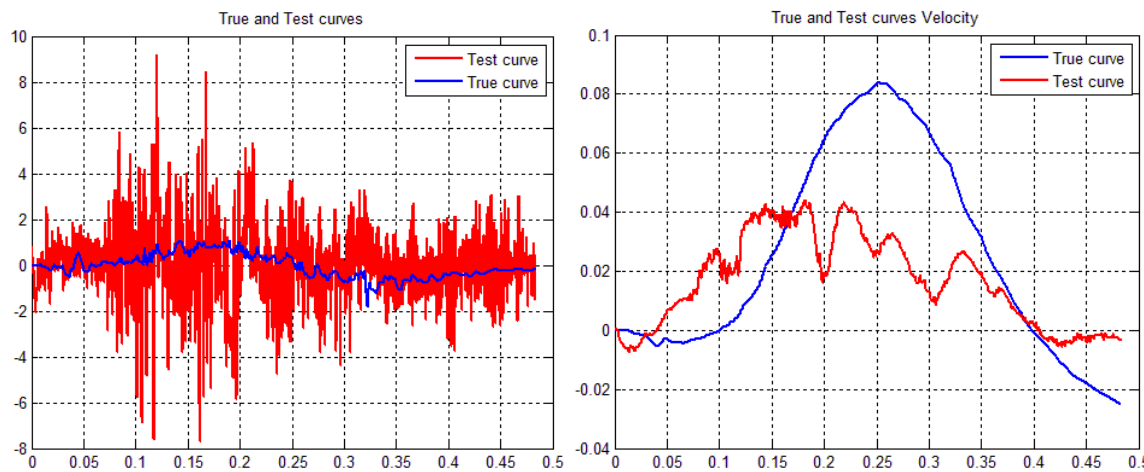


Figure 5. Pitch Channel (a) angular rate-time history data used to compute metrics, and (b) Integration of angular rate-time history data

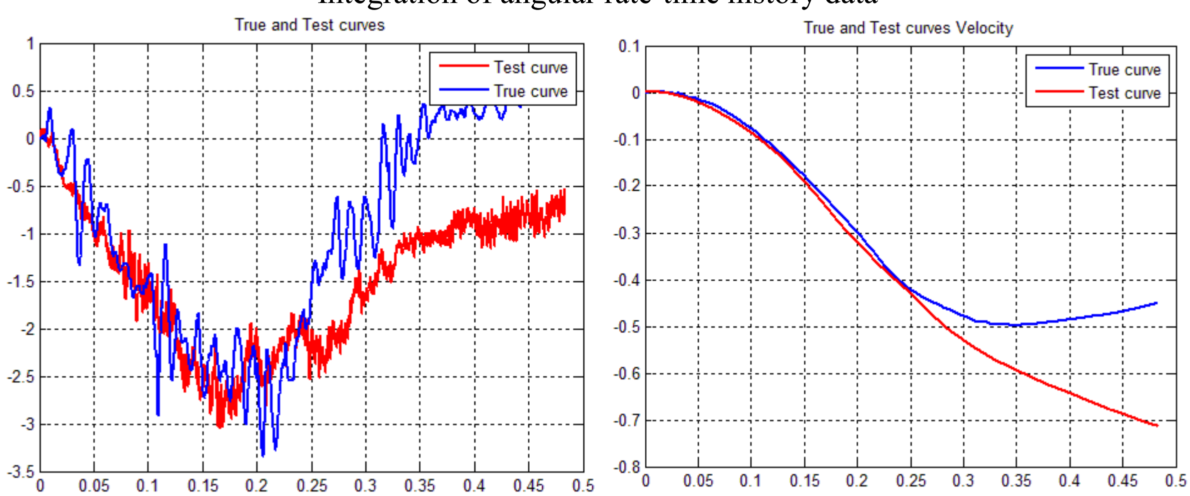
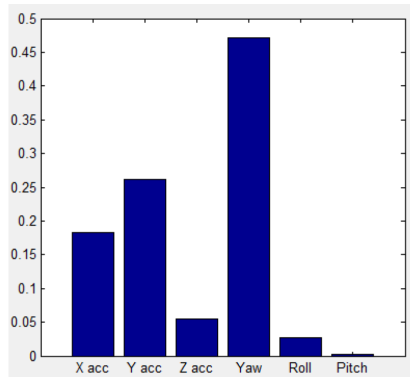


Figure 6. Yaw Channel (a) angular rate-time history data used to compute metrics, and (b) Integration of angular rate-time history data

Table E-3. Roadside Safety Validation Metrics Rating Table – Time History Comparisons (multi-channel option- CFC60)

<table>
<tr><th colspan="6">Evaluation Criteria (time interval [0 sec; 0.48 sec])</th></tr>
<tr><td colspan="6">Channels (Select which were used)</td></tr>
<tr><td colspan="2">☒ **X Acceleration**</td><td colspan="2">☒ **Y Acceleration**</td><td colspan="2">☒ **Z Acceleration**</td></tr>
<tr><td colspan="2">☒ **Roll rate**</td><td colspan="2">☒ **Pitch rate**</td><td colspan="2">☒ **Yaw rate**</td></tr>
<tr><td colspan="2">**Multi-Channel Weights**

☒ **Area II method**
☐ **Inertial method**</td><td colspan="2">**X Channel:**
Y Channel:
Z Channel:
Yaw Channel:
Roll Channel: ___

Pitch Channel:</td><td colspan="2">
</td></tr>
<tr><td rowspan="2">O</td><td rowspan="2">***Sprague-Geer Metrics***
Values less or equal to 40 are acceptable.</td><td>**M**</td><td>**P**</td><td colspan="2">**Pass?**</td></tr>
<tr><td>21.7</td><td>26.7</td><td colspan="2">**Yes**</td></tr>
<tr><td rowspan="2">P</td><td rowspan="2">***ANOVA Metrics***
Both of the following criteria must be met:
• The mean residual error must be less than five percent of the peak acceleration ($\overline{e} \leq 0.05 \cdot a_{Peak}$)
• The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \leq 0.35 \cdot a_{Peak}$)</td><td>**Mean Residual**</td><td>**Standard Deviation of Residuals**</td><td colspan="2">**Pass?**</td></tr>
<tr><td>7.4</td><td>26.3</td><td colspan="2">**Yes***</td></tr>
</table>

* The mean residual error is 7.4% which is close to 5%. Thus, it is acceptable.

The Analysis Solution (check one) ☒ passes ☐ does NOT pass <u>all</u> the criteria in Table E-3.

Table E-2. Roadside Safety Validation Metrics Rating Table – Time History Comparisons (single channel option- CFC 180)

Evaluation Criteria								Time interval [0 sec; 0.48 sec]		
O	***Sprague-Geers Metrics*** List all the data channels being compared. Calculate the M and P metrics using RSVVP and enter the results. Values less than or equal to 40 are acceptable.									
		RSVVP Curve Preprocessing Options						**M**	**P**	**Pass?**
		Filter Option	**Sync. Option**	**Shift**		**Drift**				
				True Curve	**Test Curve**	**True Curve**	**Test Curve**			
	X acceleration	CFC 180	N	N	N	N	N	29	33.1	Yes
	Y acceleration	CFC 180	N	N	N	N	N	35.4	32.5	Yes
	Z acceleration	CFC 180	N	N	N	N	N	274.2	48.4	No
	Roll rate	CFC 180	N	N	N	N	N	20.9	53.8	No
	Pitch rate	CFC 180	N	N	N	N	N	242.8	48.3	No
	Yaw rate	CFC 180	N	N	N	N	N	13.3	16.8	Yes
P	***ANOVA Metrics*** List all the data channels being compared. Calculate the ANOVA metrics using RSVVP and enter the results. Both of the following criteria must be met: • The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \leq 0.05 \cdot a_{Peak}$) and • The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \leq 0.35 \cdot a_{Peak}$)							**Mean Residual**	**Standard Deviation of Residuals**	**Pass?**
	X acceleration/Peak							3.1	24.8	Yes
	Y acceleration/Peak							0.8	30.6	Yes
	Z acceleration/Peak							4.7	11.2	No
	Roll rate							4.5	67.9	No
	Pitch rate							2.4	99.6	No
	Yaw rate							16.2	18.7	No

The Analysis Solution (check one) ☐ passes ☒ does NOT pass all the criteria in Table E-2 (single-channel time history comparison). If the Analysis Solution does NOT pass, perform the analysis in Table E-3 (multi-channel time history comparison).

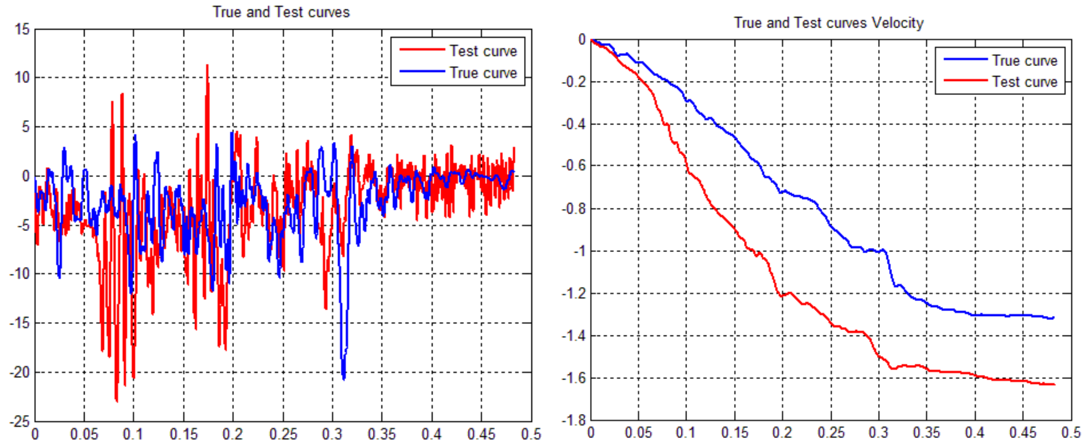


Figure 4. X-Channel (a) acceleration-time history data used to compute metrics, and (b) Integration of acceleration-time history data

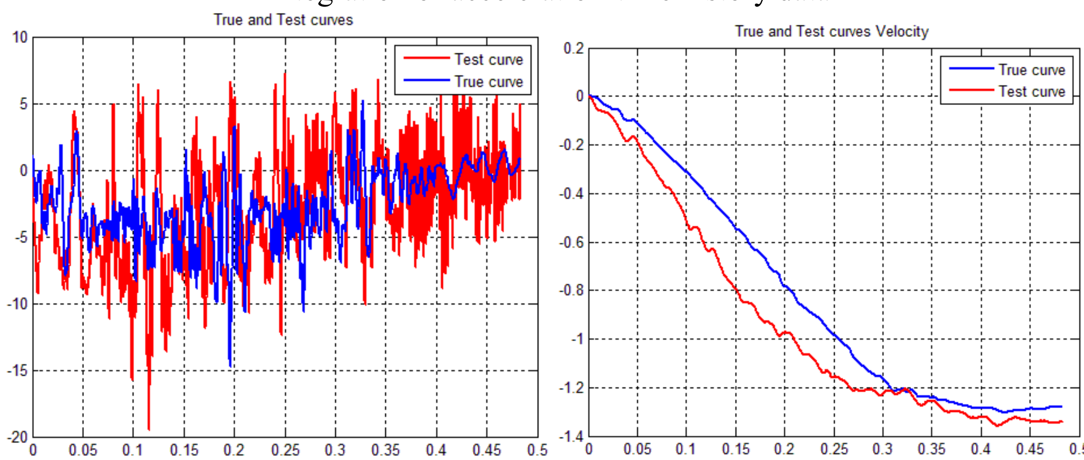


Figure 5. Y-Channel (a) acceleration-time history data used to compute metrics, and (b) Integration of acceleration-time history data

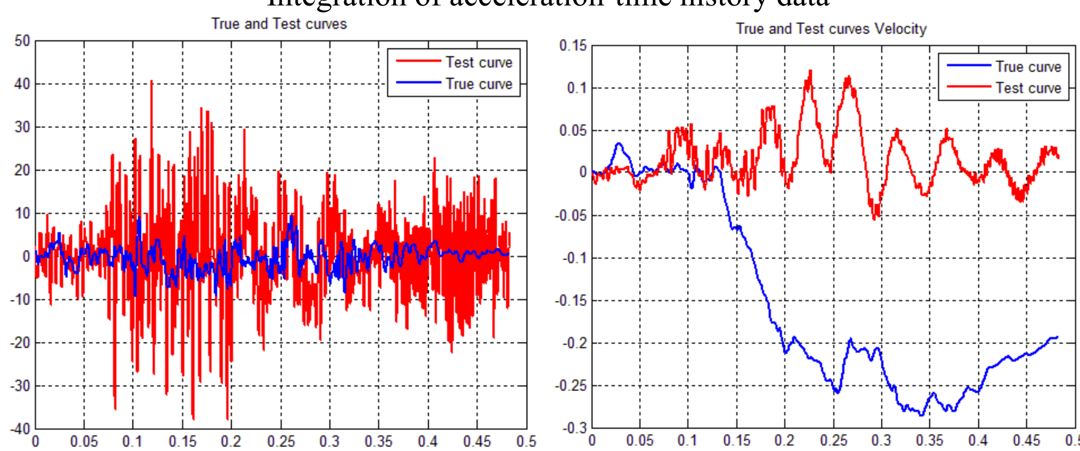
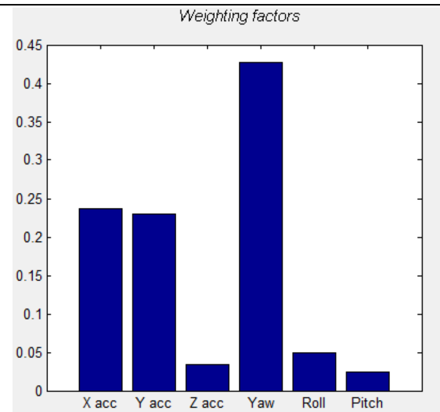


Figure 6. Z-Channel (a) acceleration-time history data used to compute metrics, and (b) Integration of acceleration-time history data

Table E-3. Roadside Safety Validation Metrics Rating Table – Time History Comparisons (multi-channel option- CFC 180)

Evaluation Criteria (time interval [0 sec; 0.48 sec])		
Channels (Select which were used)		
☒ **X Acceleration**	☒ **Y Acceleration**	☒ **Z Acceleration**
☒ **Roll rate**	☒ **Pitch rate**	☒ **Yaw rate**
Multi-Channel Weights ☒ **Area II method** ☐ **Inertial method**	**X Channel:** **Y Channel:** **Z Channel:** **Yaw Channel:** **Roll Channel:** ___ **Pitch Channel:**	

		M	**P**	**Pass?**
O	***Sprague-Geer Metrics*** Values less or equal to 40 are acceptable.	36.9	27.9	**Yes**

		Mean Residual	**Standard Deviation of Residuals**	**Pass?**
P	***ANOVA Metrics*** Both of the following criteria must be met: • The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \leq 0.05 \cdot a_{Peak}$) • The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \leq 0.35 \cdot a_{Peak}$)	7.4	30.4	**Yes***

* The mean residual error is 7.4% which is close to 5%. Thus, it is acceptable.

The Analysis Solution (check one) ☒ passes ☐ does NOT pass all the criteria in Table E-3.

PART IV: PHENOMENA IMPORTANCE RANKING TABLE

Table E-4 is similar to the evaluation tables in Report 350 and MASH. For the Report 350 or MASH test number identified in Part I (e.g., test 3-10, 5-12, etc.), circle all the evaluation criteria applicable to that test in Table E-4. The tests that apply to each criterion are listed in the far right column without the test level designator. For example, if a Report 350 test 3-11 is being compared (i.e., a pickup truck striking a barrier at 25 degrees and 100 km/hr), circle all the criteria in the second column where the number "11" appears in the far right column. Some of the Report 350 evaluation criteria have been removed (i.e., J and K) since they are not generally useful in assessing the comparison between the known and analysis solutions.

Table E-4. Evaluation Criteria Test Applicability Table.

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Applicable Tests</th></tr>
<tr><td rowspan="2">uctural Adequacy</td><td>A</td><td>Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>10, 11, 12, 20, 21, 22, 35, 36, 37, 38</td></tr>
<tr><td>B</td><td>The test article should readily activate in a predictable manner by breaking away, fracturing or yielding.</td><td>60, 61, 70, 71, 80, 81</td></tr>
<tr><td></td><td>C</td><td>Acceptable test article performance may be by redirection, controlled penetration or controlled stopping of the vehicle.</td><td>30, 31,, 32, 33, 34, 39, 40, 41, 42, 43, 44, 50, 51, 52, 53</td></tr>
<tr><td rowspan="7">Occupant Risk</td><td>D</td><td>Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone.</td><td>All</td></tr>
<tr><td>E</td><td>Detached elements, fragments or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle. (Answer Yes or No)</td><td>70, 71</td></tr>
<tr><td>F</td><td>The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.</td><td>All except those listed in criterion G</td></tr>
<tr><td>G</td><td>It is preferable, although not essential, that the vehicle remain upright during and after collision.</td><td>12, 22 (for test level 1 – 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44)</td></tr>
<tr><td rowspan="2">H</td><td>Occupant impact velocities should satisfy the following:
Occupant Impact Velocity Limits (m/s)
Component / Preferred / Maximum
Longitudinal and Lateral / 9 / 12</td><td>10, 20, 30,31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 80, 81</td></tr>
<tr><td>Longitudinal / 3 / 5</td><td>60, 61, 70, 71</td></tr>
<tr><td>I</td><td>Occupant ridedown accelerations should satisfy the following:
Occupant Ridedown Acceleration Limits (g's)
Component / Preferred / Maximum
Longitudinal and Lateral / 15 / 20</td><td>10, 20, 30,31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 60, 61, 70, 71, 80, 81</td></tr>
<tr><td rowspan="3">Vehicle Trajectory</td><td>L</td><td>The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G's.</td><td>11,21, 35, 37, 38, 39</td></tr>
<tr><td>M</td><td>The exit angle from the test article preferable should be less than 60 percent of test impact angle, measured at the time of vehicle loss of contact with test device.</td><td>10, 11, 12, 20, 21, 22, 35, 36, 37, 38, 39</td></tr>
<tr><td>N</td><td>Vehicle trajectory behind the test article is acceptable.</td><td>30, 31, 32, 33, 34, 39, 42, 43, 44, 60, 61, 70, 71, 80, 81</td></tr>
</table>

Note: The circles around the letters indicate the criteria that are applicable to this case.

Complete Table E-5 according to the results of the known solution (e.g., crash test) and the numerical solution (e.g., simulation). Consistent with Report 350 and MASH, Task E-5 has three parts: the structural adequacy phenomena listed in Table E-5a, the occupant risk phenomena listed in Table E-5b and the vehicle trajectory criteria listed in Table E-5c. If the result of the analysis solution agrees with the known solution, mark the "agree" column "yes." For example, if the vehicle in both the known and analysis solutions rolls over and, therefore, fails criterion F1, the known and the analysis columns for criterion F1 would be evaluated as "no." Even though both failed the criteria, they agree with each other so the "agree" column is marked as "yes." Any criterion that is not applicable to the test being evaluated (i.e., not circled in Table E-4) should be indicated by entering "NA" in the "agree?" column for that row.

Many of the Report 350 evaluation criteria have been subdivided into more specific phenomenon. For example, criterion A is divided into eight sub-criteria, A1 through A8, that provide more specific and quantifiable phenomena for evaluation. Some of the values are simple yes or no questions while other request numerical values. For the numerical phenomena, the analyst should enter the value for the known and analysis result and then calculate the relative difference. Relative difference is always the absolute value of the difference of the known and analysis solutions divided by the known solution. Enter the value in the "relative difference" column. If the relative difference is less than 20 percent, enter "yes" in the "agree?" column.

Sometimes, when the values are very small, the relative difference might be large while the absolute difference is very small. For example, the longitudinal occupant ride down acceleration (i.e., criterion L2) in a test might be 3 g's and in the corresponding analysis might be 4 g's. The relative difference is 33 percent but the absolute difference is only 1 g and the result for both is well below the 20 g limit. Clearly, the analysis solution in this case is a good match to the experiment and the relative difference is large only because the values are small. The absolute difference, therefore, should also be entered into the "Difference" column in Table E-5.

The experimental and analysis result can be considered to agree as long as either the relative difference or the absolute difference is less than the acceptance limit listed in the criterion. Generally, relative differences of less than 20 percent are acceptable and the absolute difference limits were generally chosen to represent 20 percent of the acceptance limit in Report 350 or MASH. For example, Report 350 limits occupant ride-down accelerations to those less than 20 g's so 20 percent of 20 g's is 4 g's. As shown for criterion L2 in Table E-5, the relative acceptance limit is 20 percent and the absolute acceptance limit is 4 g's.

If a numerical model was not created to represent the phenomenon, a value of "NM" (i.e., not modeled) should be entered in the appropriate column of Table E-5. If the known solution for that phenomenon number is "no" then a "NM" value in the "test result" column can be considered to agree. For example, if the material model for the rail element did not include the possibility of failure, "NM" should be entered for phenomenon number T in Table E-5. If the known solution does not indicate rail rupture or failure (i.e., phenomenon T = "no"), then the known and analysis solutions agree and a "yes" can be entered in the "agree?" column. On the other hand, if the known solution shows that a rail rupture did occur resulting in a phenomenon T entry of "yes" for the known solution, the known and analysis solutions do not agree and "no" should be entered in the "agree?" column. Analysts should seriously consider refining their model to incorporate any phenomena that appears in the known solution and is shown in Table E-5.

All the criteria identified in Table E-4 are expected to agree but if one does not and, in the opinion of the analyst, is not considered important to the overall evaluation for this particular comparison, then a footnote should be provided with a justification for why this particular criteria can be ignored for this particular comparison.

Table E-5(a). Roadside Safety Phenomena Importance Ranking Table (Structural Adequacy).

Evaluation Criteria				Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Structural Adequacy	A	A1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable. (Answer Yes or No)	Yes	Yes		**Yes**
		A2	Maximum dynamic deflection: - Relative difference is less than 20 percent or - Absolute difference is less than 0.15 m	0.913 m	0.7 m	23.3% 0.21 m	**No**
		A3	Length of vehicle-barrier contact: - Relative difference is less than 20 percent or - Absolute difference is less than 2 m	8.3 m	7.8 m	6.02% 0.5 m	**Yes**
		A4	Number of broken or significantly bent posts is less than 20 percent. (Post nos 13 through 18, totally 6 but 2 of them bent slightly as reported in the test description)	4	4		**Yes**
		A5	Did the rail element rupture or tear (Answer Yes or No)	No	No		**Yes**
		A6	Were there failures of connector elements (Answer Yes or No).	No	No		**Yes**
		A7	Was there significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	No	No		**Yes**
		A8	Was there significant snagging between vehicle body components and barrier elements (Answer Yes or No).	No	No		**Yes**

Table E-5(b). Roadside Safety Phenomena Importance Ranking Table (Occupant Risk).

			Evaluation Criteria	Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Occupant Risk	D		Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone. (Answer Yes or No)	Pass	Pass		Yes
	F	F1	The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable. (Answer Yes or No)	Pass	Pass		Yes
		F2	Maximum roll of the vehicle: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	12.8°	3.5°*	72% 9.3°	No
		F3	Maximum pitch of the vehicle is: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	5.76°	2.4°	58% 3.36°	Yes
		F4	Maximum yaw of the vehicle is: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	28.6°	41.06°*	44.5% 12.46°	No
	L	L1	Occupant impact velocities: - Relative difference is less than 20 percent or - Absolute difference is less than 2 m/s.				
			• Longitudinal OIV (m/s)	4.52	5.63		
			• Lateral OIV (m/s)	5.22	6.73		
			• THIV (m/s)	7.26	NA**		
		L2	Occupant accelerations: - Relative difference is less than 20 percent or - Absolute difference is less than 4 g's.				
			• Longitudinal ORA	16.14	13.33	17.4 % 2.81 g	Yes
			• Lateral ORA	8.37	10.15	21.2 % 1.78 g	Yes
			• PHD	16.2 g	NA		
			• ASI	NA	NA		

* The roll, pitch and yaw Euler angles were calculated for the simulation using the same procedure for full-scale crash tests.
** Not required

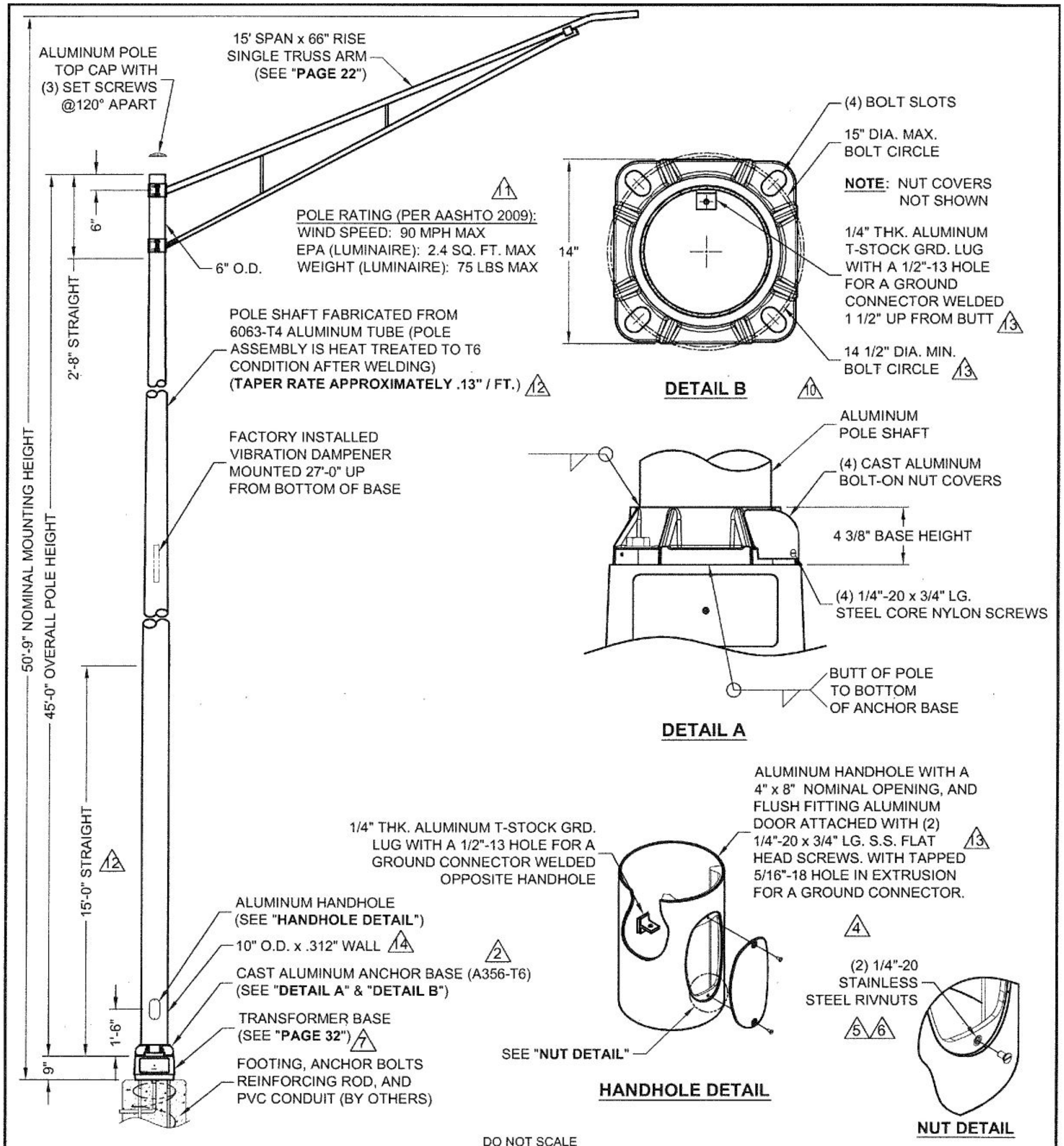
Table E-5(c). Roadside Safety Phenomena Importance Ranking Table (Vehicle Trajectory).

Evaluation Criteria				Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Vehicle Trajectory	M	M1	The exit angle from the test article preferable should be less than 60 percent of test impact angle, measured at the time of vehicle loss of contact with test device.	14.1°	8°		**Yes**
		M2	Exit angle at loss of contact: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	14.1°	8°	42.8% 6.1°*	**Yes**
		M3	Exit velocity at loss of contact: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	48.4 km/h	48.49 km/h	0.18% 0.09 km/h	**Yes**
		M4	One or more vehicle tires failed or de-beaded during the collision event (Answer Yes or No).	Yes	NM		

* In the simulation, vehicle was still in contact with the barrier at time 500 msec. Moreover, a difference of 6.1° is relatively small.

The Analysis Solution (check one) ☐ passes ☒ does NOT pass all the criteria in Tables E-5a through E-5c ☐ with exceptions as noted ☐ without exceptions.

Appendix C. Valmont and Hapco Light Pole and Base Drawings



valmont

Valmont Industries, Inc. Structures Division
20805 Eaton Ave Farmington, Minnesota 55024-7932
Phone: (651) 463-8990 (800) 899-7577
Fax: (651) 463-3349

TITLE: S PAY ITEM NUMBER: 903A10, JS830003
MODEL NO.:
MATERIAL: ALUMINUM ALLOY
FINISH: 100 GRIT SATIN FINISH
PROJECT: TOLLWAY
SOLD TO:
SHIP TO:
P.O. NO:
REP: LIGHTING SOLUTIONS

QTY: 1 | DWN BY: MWJ | CHK'D BY: | APPR BY: CEW | DATE: 2/8/05 | DWG NO: DR8014 | PAGE: 6 /32

REV	DATE	REVISION DESCRIPTION	BY
14	05-15-15	WALL THICKNESS	MPS
13	04-14-14	CHG'D SCREW/NOTES/BOLT CIRCLE, ADDED T-STOCK	PTP
12	01-17-14	REVISED TAPER LENGTH	PVB

Figure C-1. Valmont Light Pole

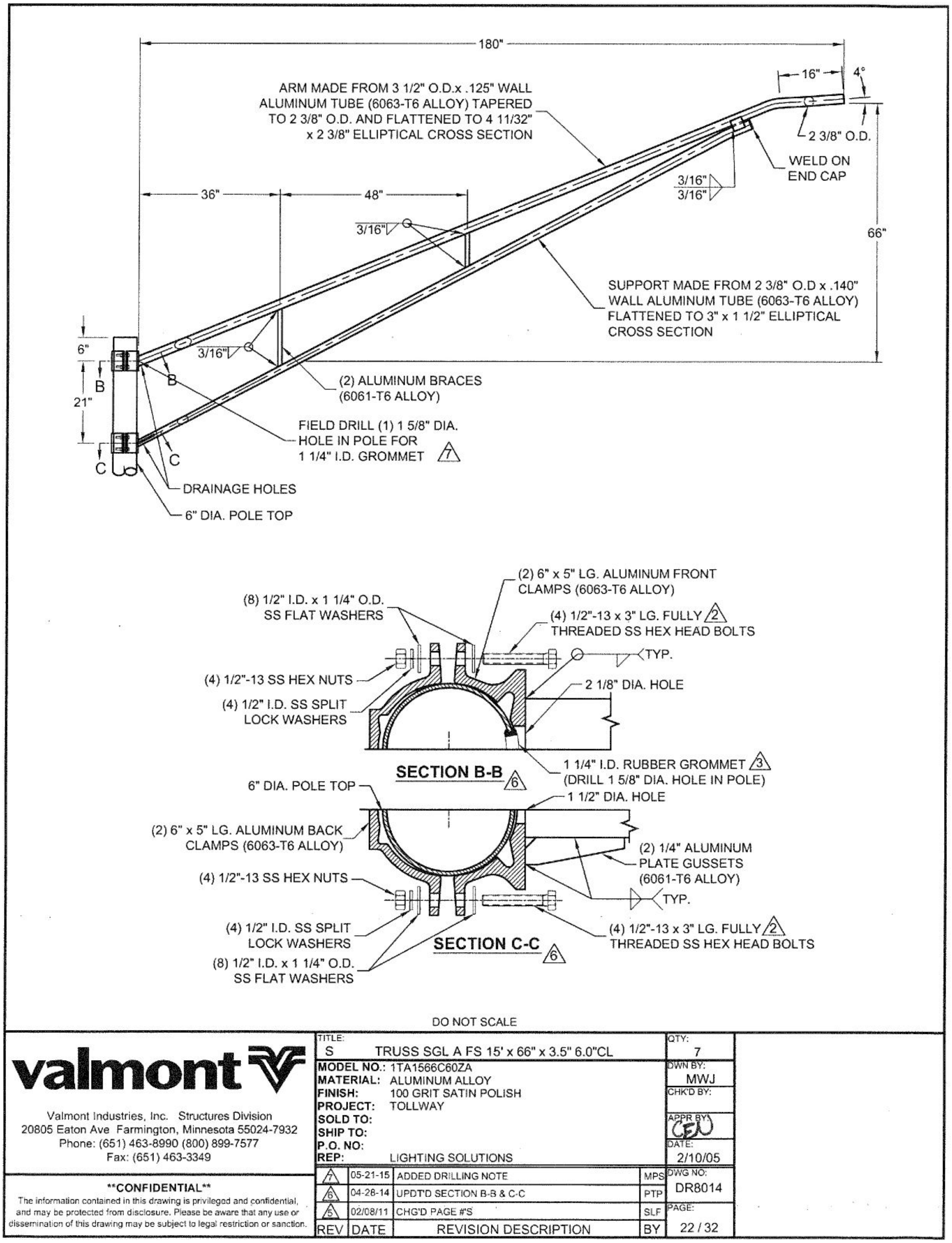


Figure C-2. Valmont Arm

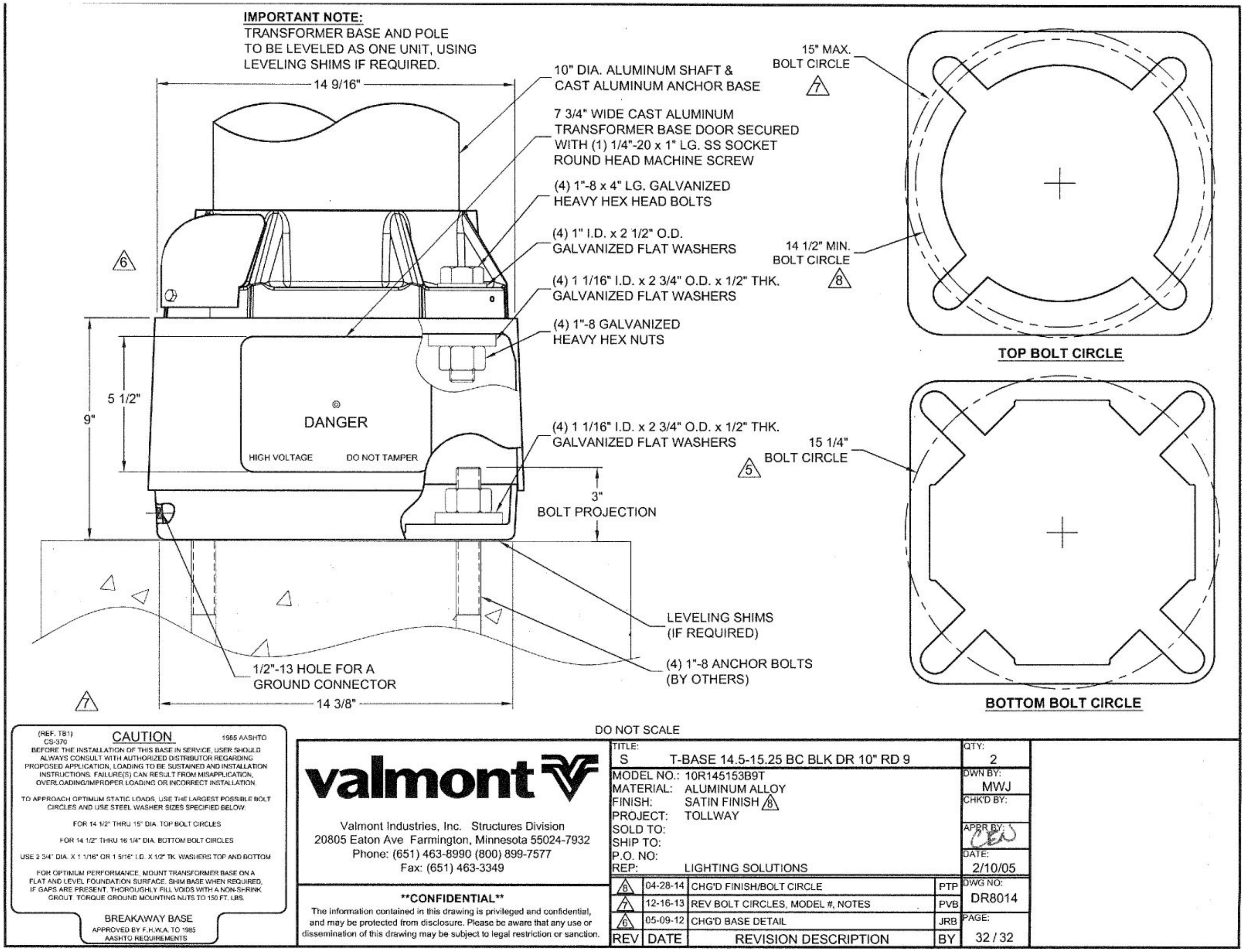


Figure C-3. Valmont Base

valmont STRUCTURES

TRANSFORMER BASE CS300
Aluminum

Transformer Base-Aluminum | CS300

Job Name:	Client Name:
Job Location - City: State:	Created By: Date:
Product: ---- Quote:	Customer Approval: Date:

SPECIFICATIONS

Transformer Base - The aluminum transformer base is accepted by the Federal Highway Administration (FHWA) as satisfying up to the LTS-6 edition of the American Association of State Highway and Transportation Officials' (AASHTO) breakaway requirements within the range of conditions tested. This base has specific loading restriction based on full scale testing performed by Valmont per the criteria set forth in the 2009 Fifth Edition of the AASHTO Standard Specification for the Supports for Highway Signs, Luminaries and Traffic Signals. Contact Valmont for loading restrictions.

Access Door - An aluminum access door and grounding provision is provided. The door opening is 5.00" tall, 7.25" wide. A plastic door is available upon request.

Hardware - Connecting bolts, flat washers, bearing washers and hex nuts are provided per base assembly. All structural fasteners are galvanized high strength carbon steel. All non-structural fasteners are galvanized or zinc-plated carbon steel or stainless steel.

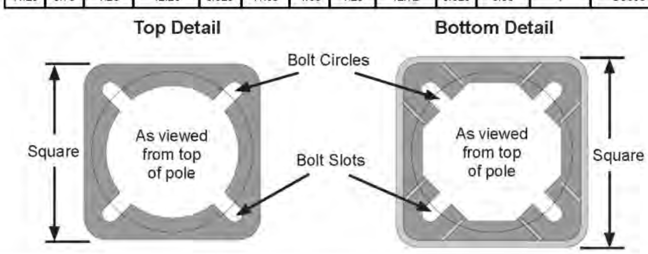
Finish - The satin finish is provided when ordering with an aluminum structure. A mill finish is provided when ordering with a steel structure. Additional finishes available upon request.

DETAILS

TOP PLATE					BOTTOM PLATE							
BOLT CIRCLE					BOLT CIRCLE							
DIA (IN)	± (IN)	MAX BOLT DIA (IN)	SQUARE (IN)	THK (IN)	DIA (IN)	± (IN)	MAX BOLT DIA (IN)	SQUARE (IN)	THK (IN)	HEIGHT (IN)	QTY OF ACCESS DOORS	MODEL NUMBER
11.25	0.75	1.25	12.25	0.625	11.38	1.38	1.25	12.72	0.625	9.00	1	CS300

INSTALLATION INSTRUCTIONS

1. Level transformer base with shims only. DO NOT USE LEVELING NUTS.
2. To approach optimum static loads, use the largest possible bolt circles and hardware supplied with the transformer base.



PRODUCT ORDERING CODES

MODEL NUMBER	FINISH	COLOR	OPTIONS
CS300			
	-- = Satin / Mill FP = Finish Paint	-- = Satin / Mill WH = White BK = Black SM = Silver Metallic SL = Silver LG = Light Gray MB = Medium Bronze CB = Bronze DB = Dark Bronze SC = Special Color (Contact Factory)	

SPC7532 09/15 valmontstructures.com carries the most current spec information and supersedes these guidelines.

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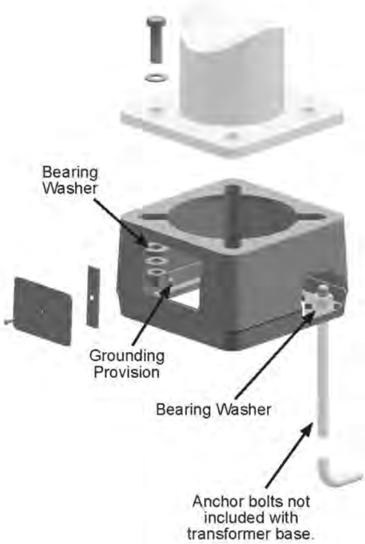
Figure C-4. Valmont CS300 Base

valmont STRUCTURES

TRANSFORMER BASE CS370 Aluminum

Transformer Base-Aluminum | CS370

Job Name:		Client Name:	
Job Location - City:	State:	Created By:	Date:
Product: ----	Quote:	Customer Approval:	Date:



SPECIFICATIONS

Transformer Base - The aluminum transformer base is accepted by the Federal Highway Administration (FHWA) as satisfying up to the LTS-6 edition of the American Association of State Highway and Transportation Officials' (AASHTO) breakaway requirements within the range of conditions tested. This base has specific loading restriction based on full scale testing performed by Valmont per the criteria set forth in the 2009 Fifth Edition of the AASHTO Standard Specification for the Supports for Highway Signs, Luminaries and Traffic Signals. Contact Valmont for loading restrictions.

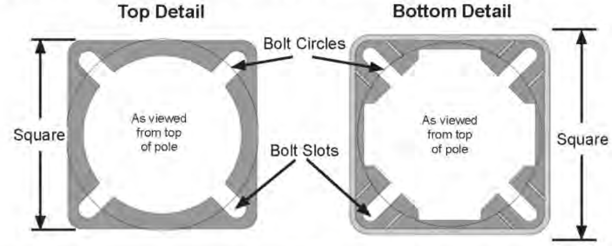
Access Door - An aluminum access door and grounding provision is provided. The door opening is 5.00" tall, 7.25" wide. A plastic door is available upon request.

Hardware - Connecting bolts, flat washers, bearing washers and hex nuts are provided per base assembly. All structural fasteners are galvanized high strength carbon steel. All non-structural fasteners are galvanized or zinc-plated carbon steel or stainless steel.

Finish - The satin finish is provided when ordering with an aluminum structure. A mill finish is provided when ordering with a steel structure. Additional finishes available upon request.

DETAILS

TOP PLATE					BOTTOM PLATE							
BOLT CIRCLE					BOLT CIRCLE							
DIA (IN)	± (IN)	MAX BOLT DIA (IN)	SQUARE (IN)	THK (IN)	DIA (IN)	± (IN)	MAX BOLT DIA (IN)	SQUARE (IN)	THK (IN)	HEIGHT (IN)	QTY OF ACCESS DOORS	MODEL NUMBER
14.75	0.25	1.25	14.75	0.625	15.38	0.88	1.25	15.31	0.625	9.00	1	CS370



INSTALLATION INSTRUCTIONS

1. Level transformer base with shims only. DO NOT USE LEVELING NUTS.
2. To approach optimum static loads, use the largest possible bolt circles and hardware supplied with the transformer base.

PRODUCT ORDERING CODES

MODEL NUMBER	FINISH	COLOR	OPTIONS
CS370			
	-- = Satin / Mill FP = Finish Paint	-- = Satin / Mill WH = White BK = Black SM = Silver Metallic SL = Silver LG = Light Gray MB = Medium Bronze CB = Bronze DB = Dark Bronze SC = Special Color (Contact Factory)	

SPC7533 09/15 valmontstructures.com carries the most current spec information and supersedes these guidelines.

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Figure C-5. Valmont CS370 Base

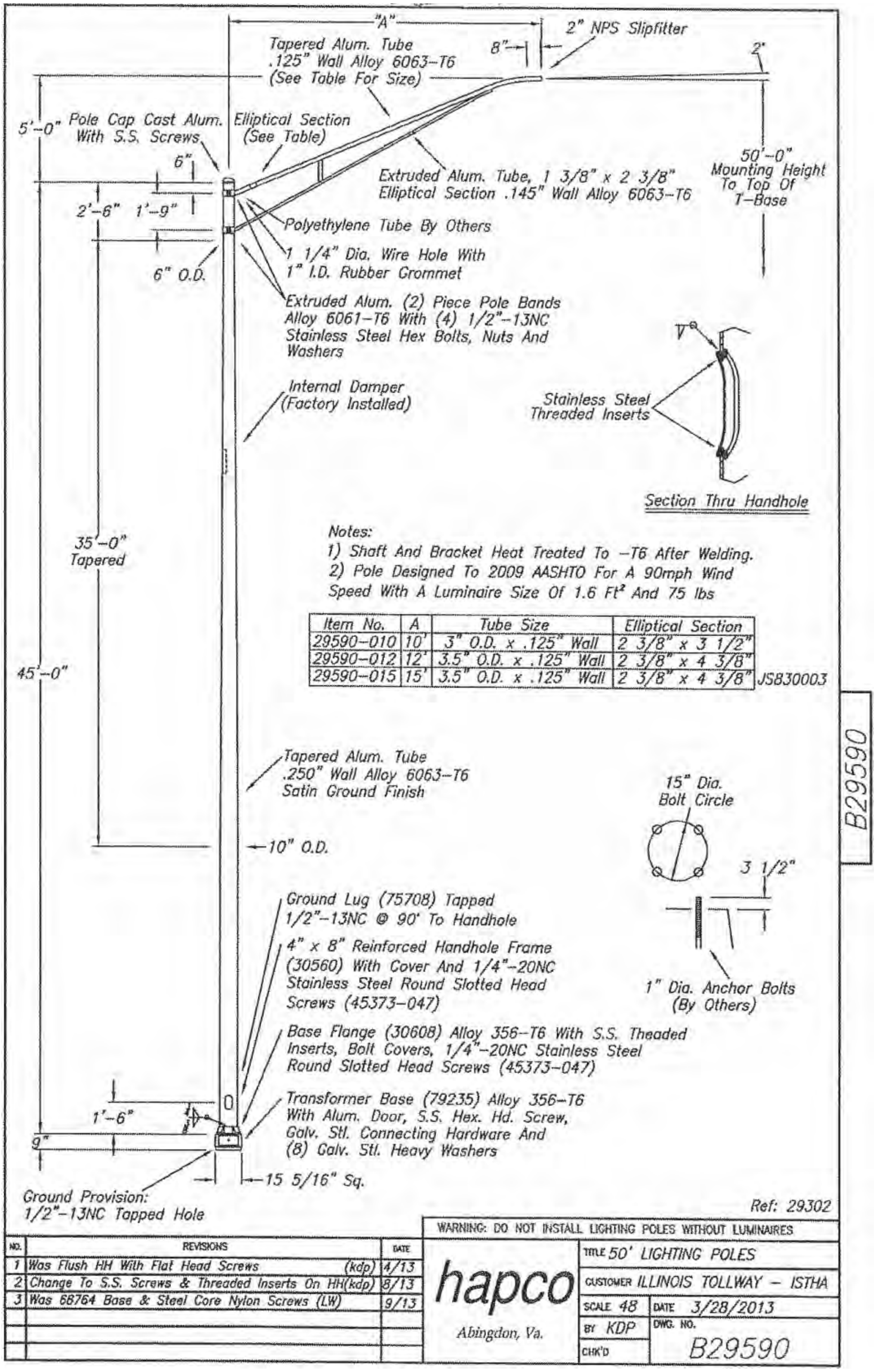

Figure C-6. Hapco Light Pole

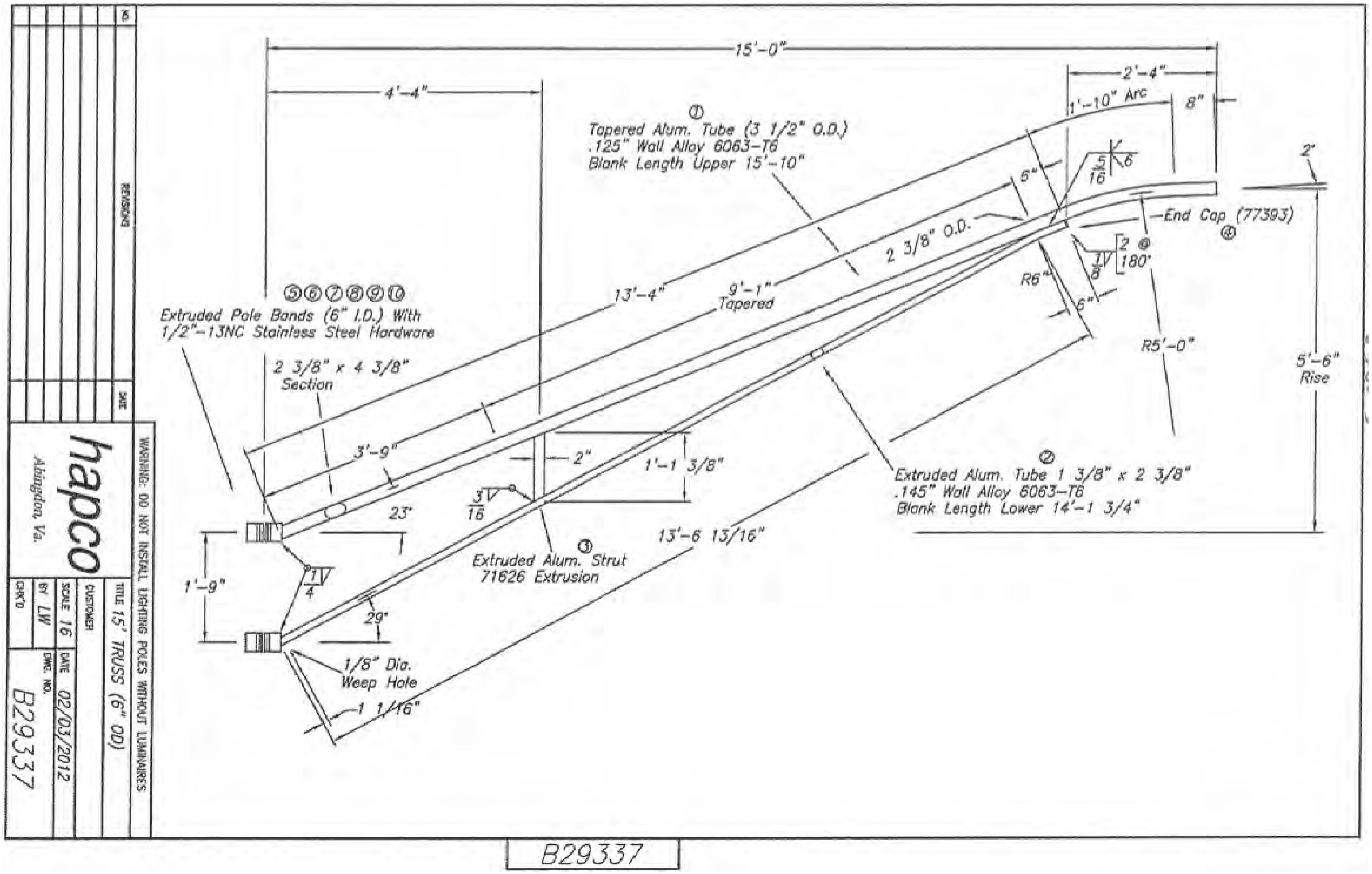

Figure C-7. Hapco Arm

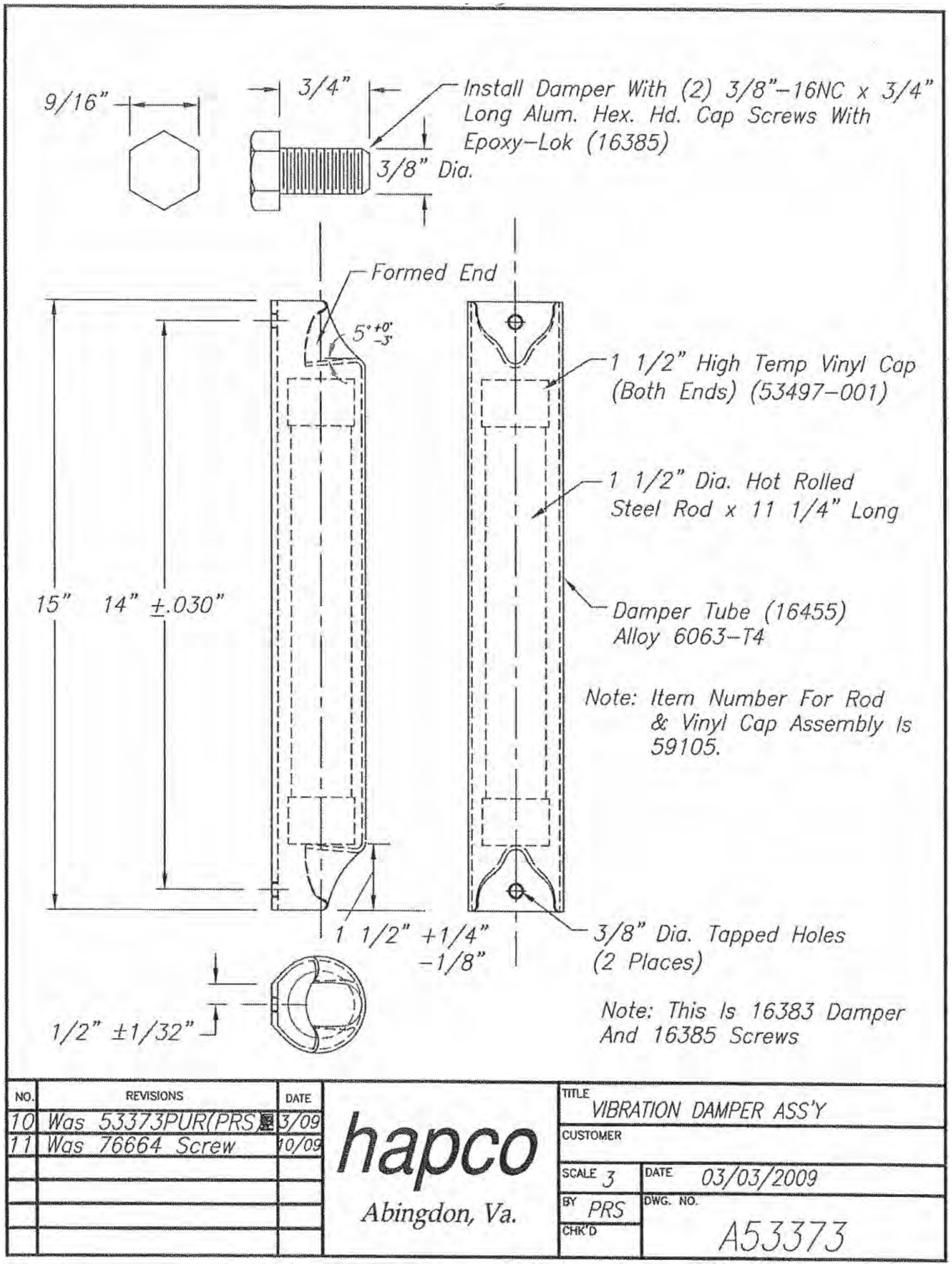

Figure C-8. Hapco Vibration Damper Assembly

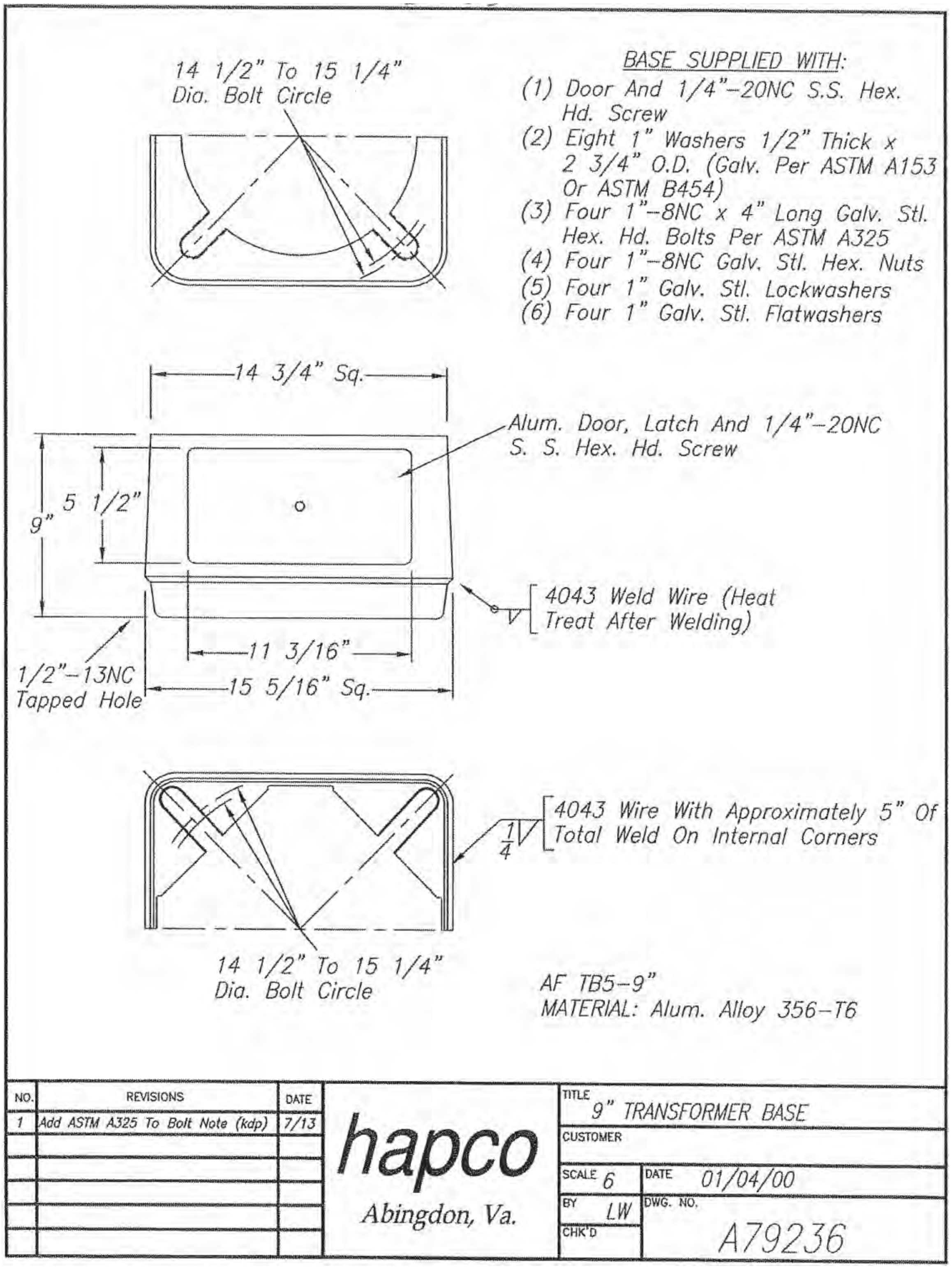

Figure C-9. Hapco Base

Appendix D. Federal Highway Administration Acceptance Letters

U.S. Department of Transportation
Federal Highway Administration

400 Seventh St., S.W.
Washington, D.C. 20590

6 '90

Refer to: HNG-14

Mr. Robert A. Sik
Vice President, Akron Foundry Company
2728 Wingate Avenue
P.O. Box 27028
Akron, Ohio 44319-0009

Dear Mr. Sik:

This is in response to your July 13 letter to Mr. Artimovich requesting acceptance by the Federal Highway Administration (FHWA) of Feralux CS-300 and CS-370 cast aluminum transformer bases for use on Federal-aid highway projects. Tests were conducted to assess compliance of the bases with FHWA breakaway requirements, which cite Section 7 of the 1985 American Association of State Highway and Transportation Officials' (AASHTO) Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals. The Southwest Research Institute forwarded copies of the five crash test reports (Project No. 06-3116-516), dated June 1990, containing results of the pendulum tests on various aluminum and steel poles with these bases. Fully dimensioned drawings and material test reports on the aluminum castings had been received from you on May 31.

The tests used an instrumented 1,800-pound pendulum fitted with a 10 stage crushable nose which simulates the left quarter point of a 1979 Volkswagen Rabbit. Impact speed was 20 mph. A summary of the tested hardware is presented below:

Test Number	Feralux Part Number	Height of Base	Tested Pole Type
Test-AF-1	Feralux CS-300	9 inches	8 inches Aluminum
Test-2	Feralux CS-300	9 inches	9 inches Steel
Test-17	Feralux CS-300	9 inches	8 inches Aluminum
Test-13	Feralux CS-370	9 inches	10 inches Steel
Test-15	Feralux CS-370	9 inches	10 inches Steel

Details of the tested hardware are shown in Enclosure I. Test parameters and measured and extrapolated test results and are shown on Enclosure II as part of Test Series IV. This information shows that the tested pole-base combinations will meet the change in velocity and stub-height requirements adopted by the FHWA.

The 16.5 fps calculated change in velocity of Test 13 exceeds FHWA requirements. However, as the calculated changes in velocities nearly always over estimate the 60 mph results, we will consider the results of Test 13 as meeting the new FHWA requirements.

Figure D-1. LS-17

2

Thus, the transformer bases manufactured for Feralux, as shown on the enclosed drawings, are acceptable for use on Federal-aid highway projects within the range of conditions tested, if proposed by a State. This acceptance is limited to breakaway characteristics of the bases and does not cover their structural features. Presumably, Feralux will supply potential users with sufficient information on structural design limitations and on installation requirements to ensure proper performance. We anticipate that the States will require certification from Feralux that the bases furnished have essentially the same chemistry, mechanical properties, and geometry as those used in the tests, and that supports with those bases will meet the FHWA breakaway requirements.

Since these breakaway support designs are proprietary items, to be used in a Federal-aid highway project they; (a) must be supplied through competitive bidding with equally suitable unpatented items; (b) the State highway agency must certify that they are essential for synchronization with existing highway facilities, or that no equally suitable alternate exists; or (c) they must be used for research or for a distinctive type of construction on relatively short sections of road for experimental purposes. Our regulations concerning proprietary products are contained in Title 23, Code of Federal Regulations, Section 635.411, a copy of which was provided with previous correspondence.

Sincerely yours,

L. A. Staron

L. A. Staron
Chief, Federal-Aid and Design Division

Enclosures

Geometric and Roadside Design Acceptance Letter LS-17

Figure D-2. LS-17

Endorsement to FHWA field offices: All of the transformer bases covered by this letter and Geometric and Roadside Design Acceptance Letters LS-18 and LS-19 were manufactured by Akron Foundry Company. For marketing purposes Akron Foundry has requested these three acceptance letters to cover what is essentially two 9-inch high transformer base models that will be manufactured by Akron Foundry and sold by three firms: Feralux, Pole Lite, and Akron Foundry. One model has top and bottom bolt circle ranges of 11.5 inches to 12.5 inches. It will carry a marking of CS-300 for Feralux, F-1300 for Pole Lite, and TB-AF6-9" for Akron. The other has top and bottom bolt circle ranges of 14.5 inches to 15.25 inches. It will carry a marking of CS-370 for Feralux, F-1302 for Pole Lite, and 9" for Akron. A separate series of tests was run to cover the Feralux model designations, while another series was run to cover the combined Pole Lite and Akron designations. It is our understanding that in production the Feralux bases will only be marked with Feralux's base numbers. On the other hand, bases to be marketed by either Pole Lite or Akron will be manufactured showing both suppliers' model numbers and before being shipped, one model number will be removed so that only the nominal supplier's model number will remain.

Figure D-3. LS-17

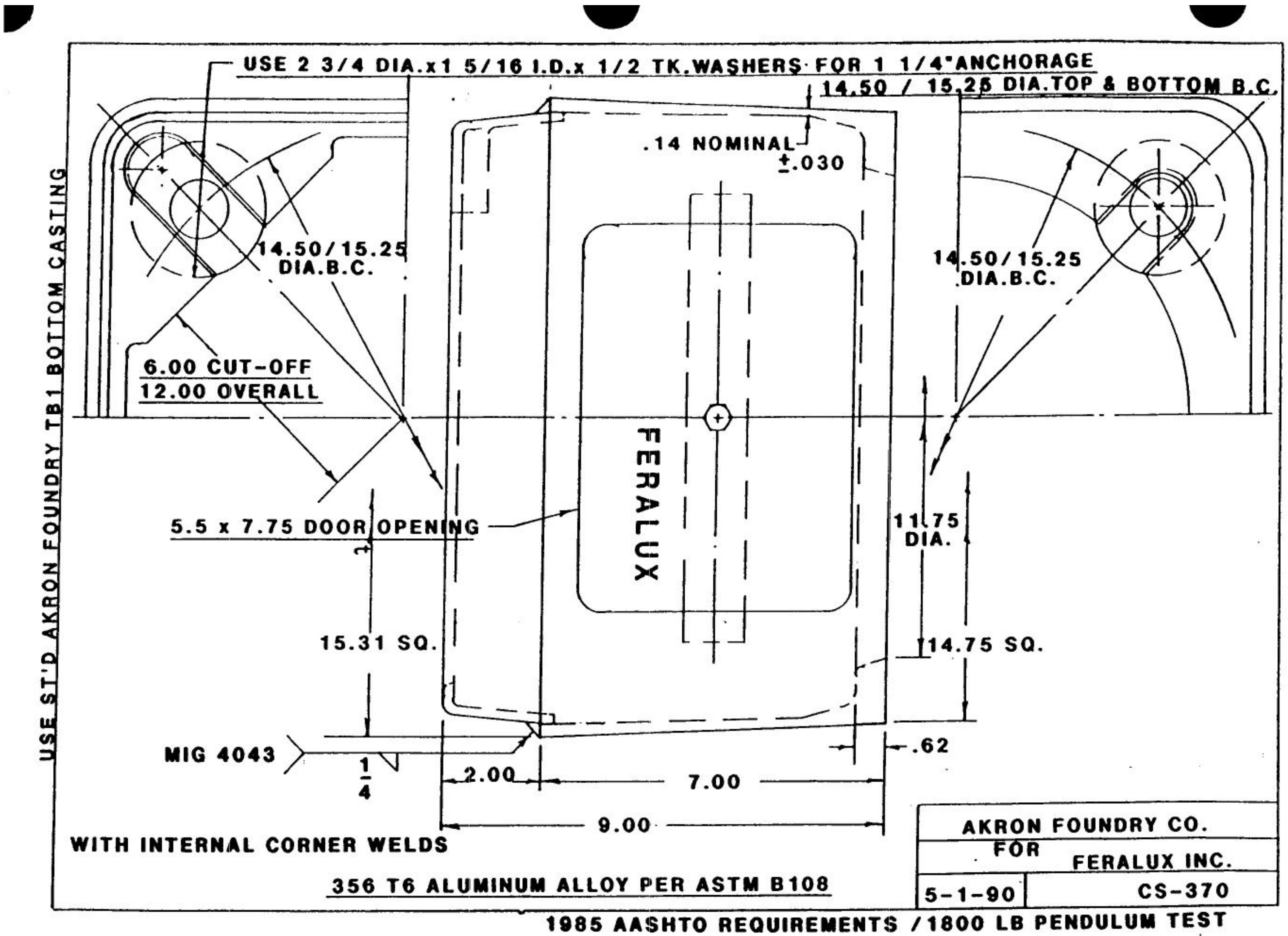

Figure D-4. LS-17

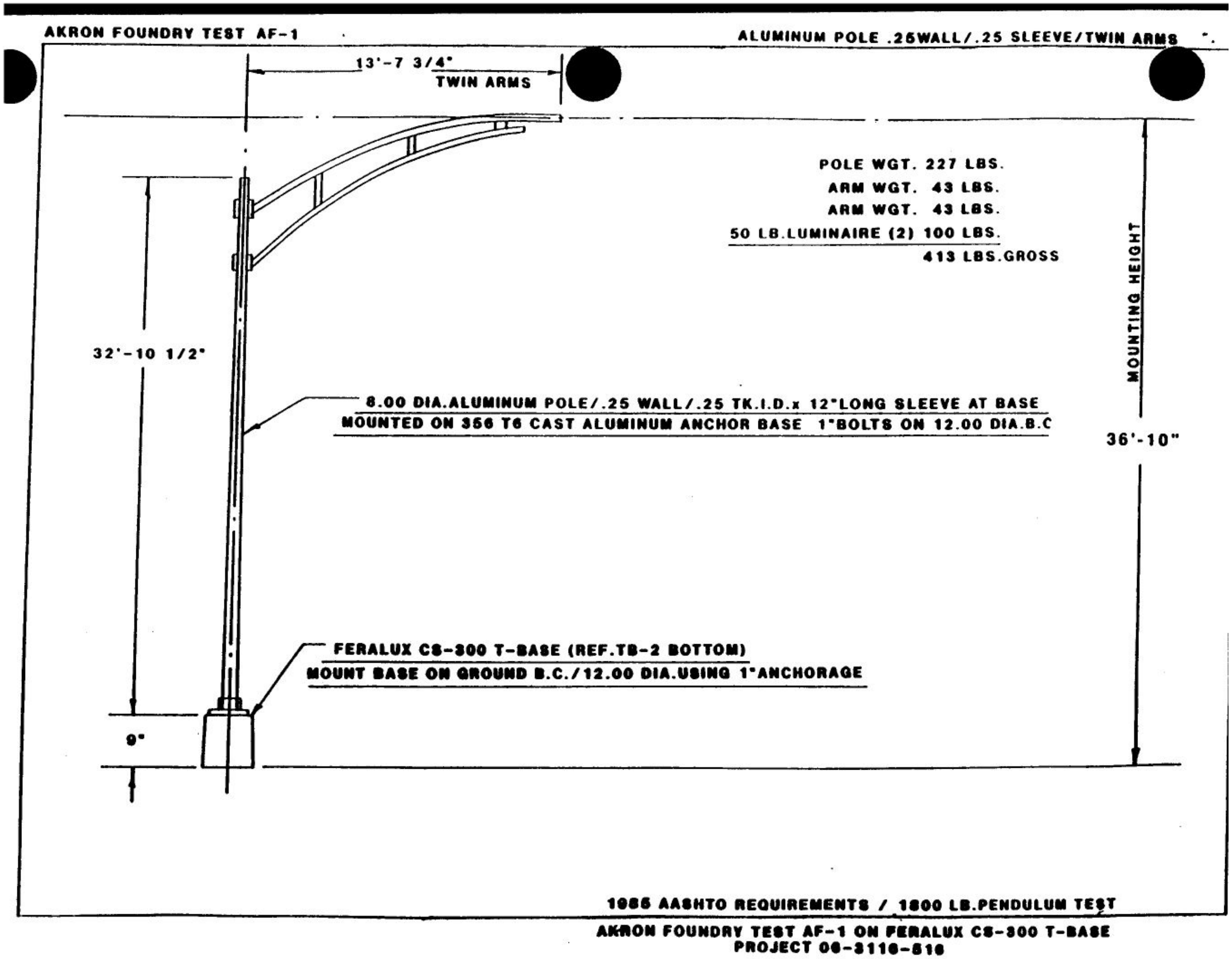

Figure 3. Assembly Drawing, Test AF-1

Figure D-5. LS-17

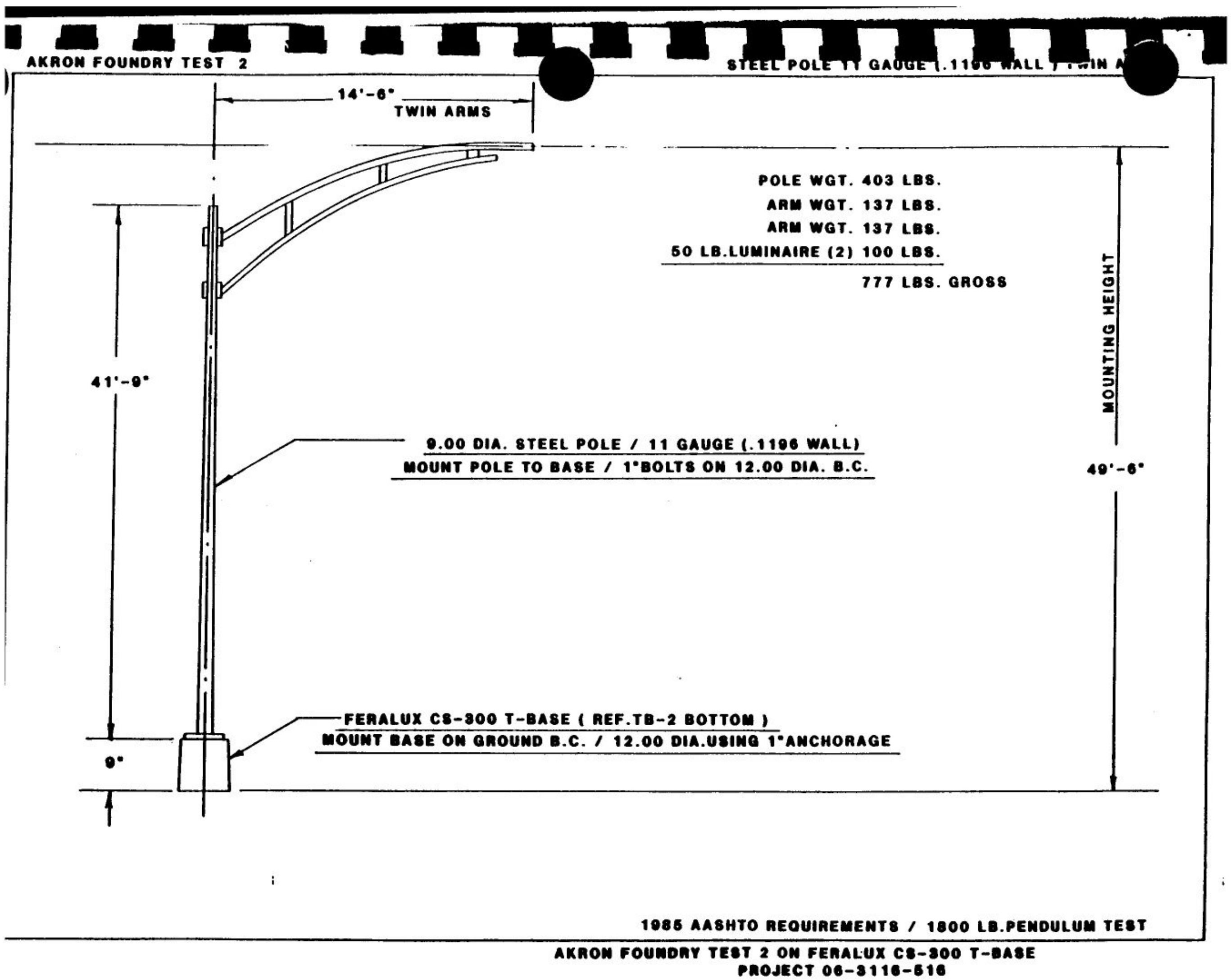

Figure 3. Assembly Drawing, Akron Foundry Test 2

Figure D-6. LS-17

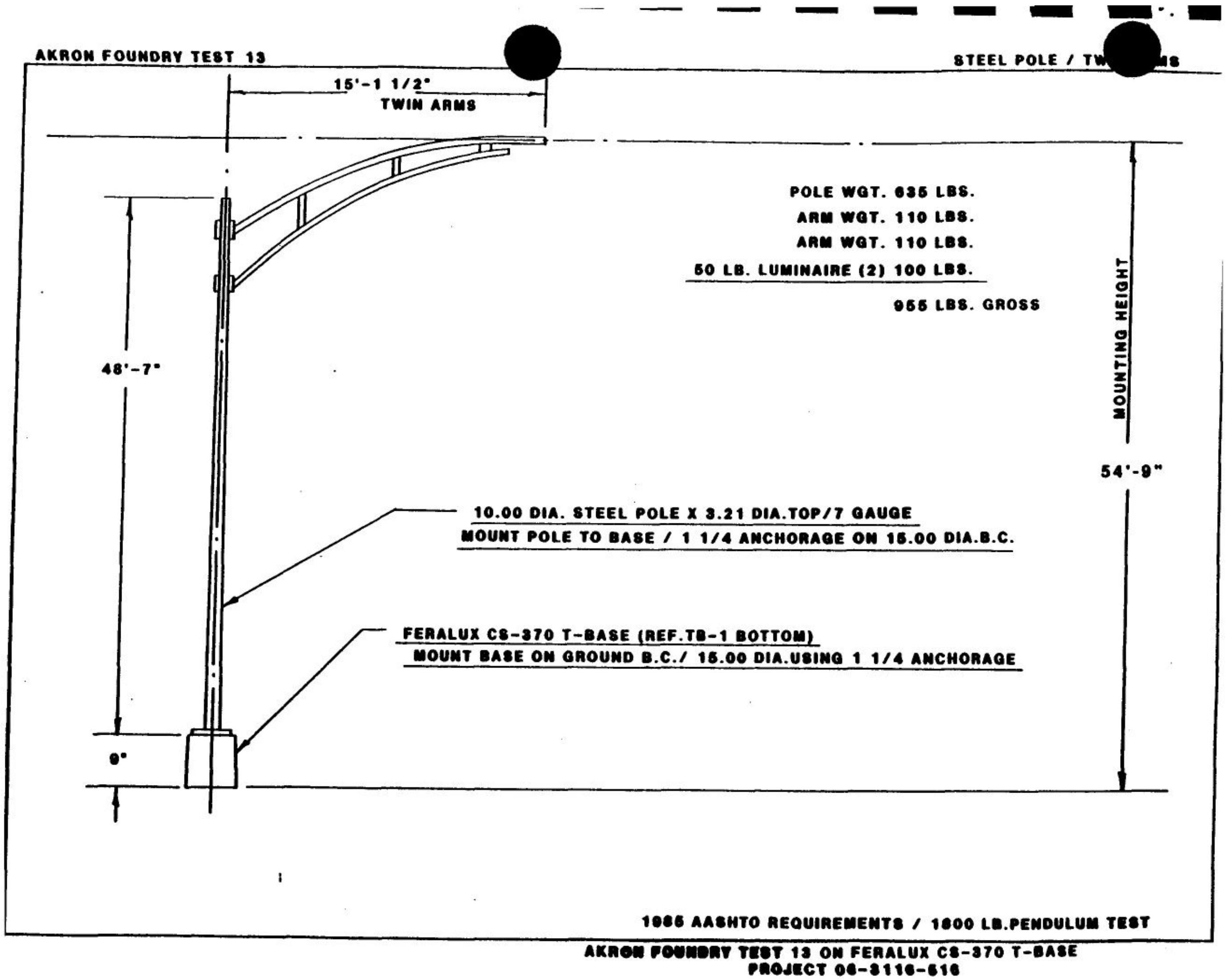

Figure 3. Assembly Drawing, Akron Foundry Test 13

Figure D-7. LS-17

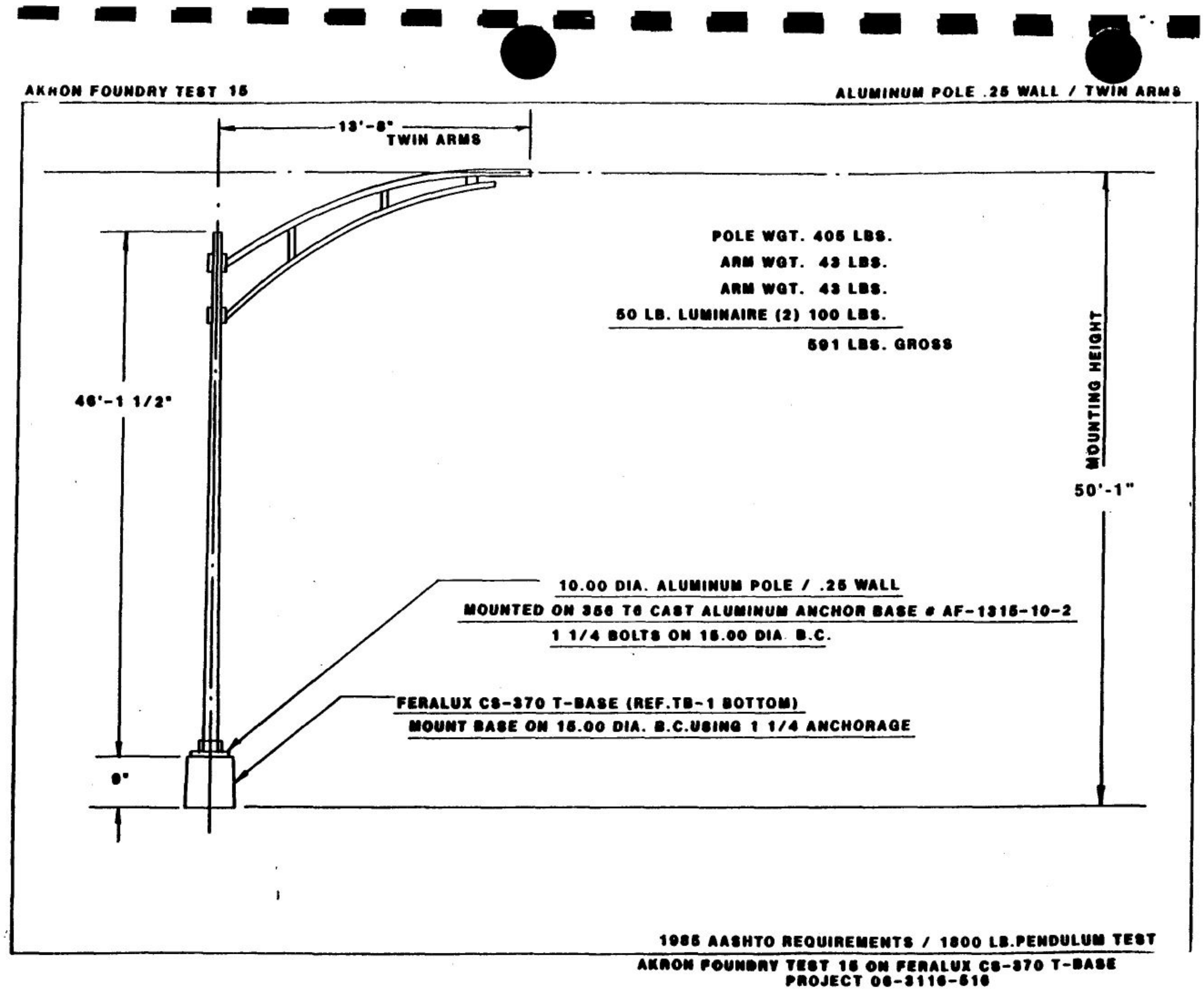

Figure 3. Assembly Drawing, Akron Foundry Test 15

Figure D-8. LS-17

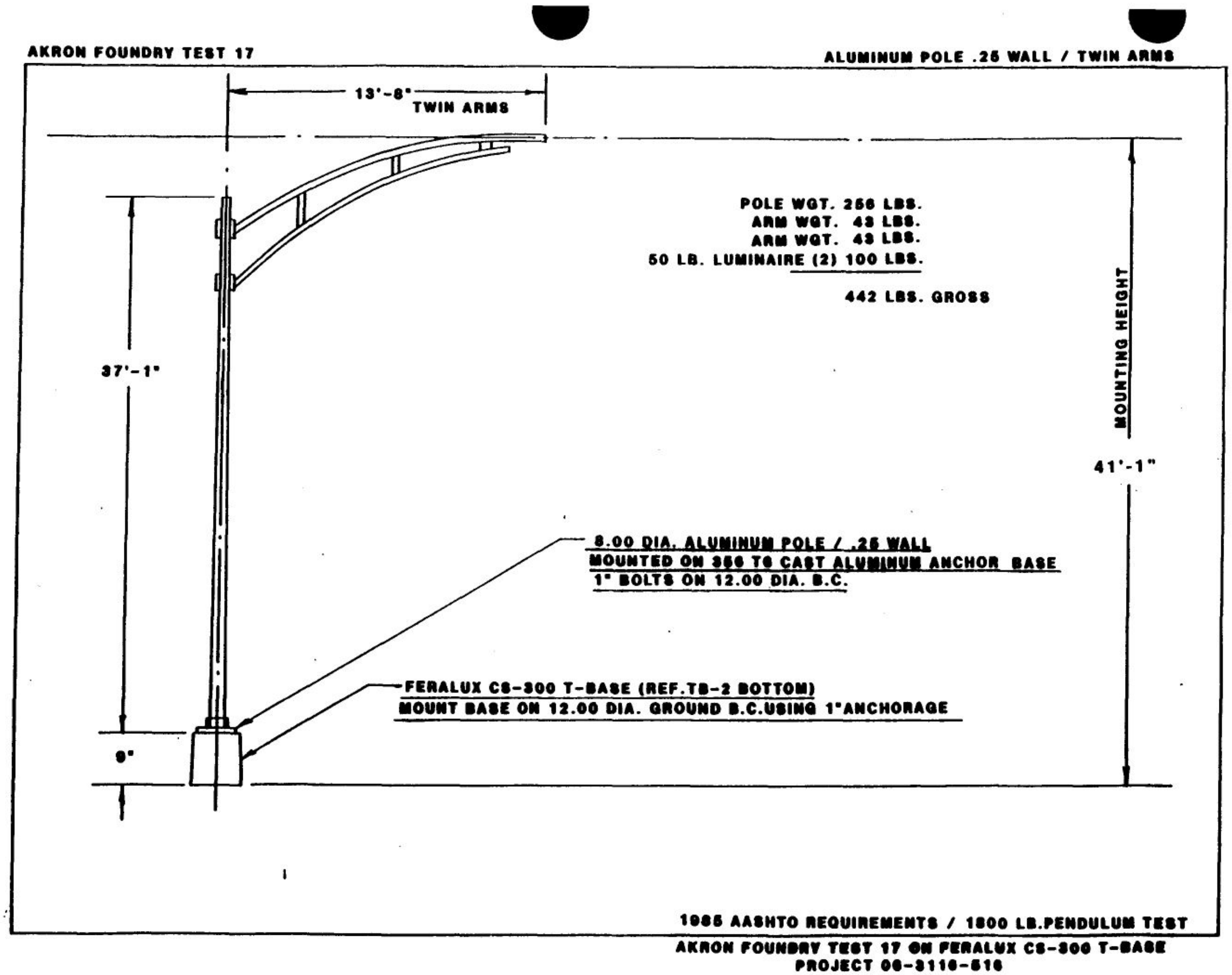

Figure 3. Assembly Drawing, Akron Foundry Test 17

Figure D-9. LS-17

Test Series	Test Number	Base Number	Test Delta V @ 20mph (fps)	Calc'd Delta V @ 60mph (fps)	Stub Height (in.)	Pole Weight W/arm & Dummy (pounds)	Pole Type	Nominal Luminaire Mounting Height (feet)	Mast Arm Length (ft) ++	Base Bottom Bolt Circle Diameter (in.)	Bottom Bolt Diameter (in.) *	Bottom Washer Outside Diameter (in.)	Bottom Washer Thick-ness (in.)	Base Top Bolt Circle Diameter (in.)	Top Bolt Diameter (in.)	Top Washer Outside Diameter (in.)	Top Washer Thick-ness (in.)
IV	AF-1	FERALUX CS-300	3.4	6.4	2.0	413	ALUMINUM	36.83	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-1	TB-AF-6-9 POLE LITE F-1300	4.7	6.8	2.0	413	ALUMINUM	36.83	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-2	FERALUX-CS-300	5.3	11.1	2.0	777	STEEL	49.50	14.50	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-10	TB-AF-6-9 POLE LITE F-1300	5.0	11.0	2.0	777	STEEL	49.50	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-11	TB-AF-6-9 POLE LITE F-1300	4.9	7.0	2.0	442	ALUMINUM	41.00	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-12	TB3-AF-1517-17 I.W.+	7.9	17.1	2.0	955	STEEL	55.42	15.13	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-13	FERALUX CS-370	6.6	16.5	2.0	955	STEEL	54.75	15.13	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-14	TB-AF-5-9 POLE LITE F-1302	7.6	16.8	2.0	955	STEEL	54.75	15.13	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-15	FERALUX CS-370	6.9	10.5	2.0	591	ALUMINUM	50.08	13.65	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-16	TB-AF-5-9 POLE LITE F-1302	5.8	10.1	2.0	591	ALUMINUM	50.08	13.65	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-17	FERALUX CS-300	4.5	6.9	2.0**	442	ALUMINUM	41.08	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2

\+ I.W. signifies Internal Weld

++ All tests run with twin mast arms.

* Anchor bolt nuts should not be torqued over 150 foot - pounds.

** A small shard of aluminum remained between 2 and 3 inches above the base plate.

Figure D-10. LS-17

U.S. Department of Transportation
Federal Highway Administration

AUG 6 1990

400 Seventh St., S.W.
Washington, D.C. 20590

Refer to: HNG-14

Mr. Robert A. Sik
Vice President, Akron Foundry Company
2728 Wingate Avenue
P.O. Box 27028
Akron, Ohio 44319-0009

Dear Mr. Sik:

This is in response to your July 13 letter to Mr. Artimovich requesting acceptance by the Federal Highway Administration (FHWA) of Pole Lite Model F-1300 and F-1302 cast aluminum transformer bases for use on Federal-aid highway projects. Tests were conducted to assess compliance of the bases with FHWA breakaway requirements, which cite Section 7 of the 1985 American Association of State Highway and Transportation Officials' (AASHTO) Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals. The Southwest Research Institute forwarded copies of the five crash test reports (Project No. 06-3116-516), dated June 1990, containing results of the pendulum tests on various aluminum and steel poles with these bases. Fully dimensioned drawings and material test reports on the aluminum castings had been received from you on May 31.

The tests used an instrumented 1,800-pound pendulum fitted with a 10 stage crushable nose which simulates the left quarter point of a 1979 Volkswagen Rabbit. Impact speed was 20 mph. A summary of the tested hardware is presented below:

Test Number	Pole Lite Number	Height of Base	Pole Type
Test-1	Pole Lite Model F-1300	9 inches	8 inches Aluminum
Test-10	Pole Lite Model F-1300	9 inches	9 inches Steel
Test-11	Pole Lite Model F-1300	9 inches	8 inches Aluminum
Test-14	Pole Lite Model F-1302	9 inches	10 inches Aluminum
Test-16	Pole Lite Model F-1302	9 inches	10 inches Steel

Details of the tested hardware are shown in Enclosure I. Test parameters and measured and extrapolated test results and are shown on Enclosure II as part of Test Series IV. This information shows that the tested pole-base combinations will meet the change in velocity and stub-height requirements adopted by the FHWA.

The 16.8 fps calculated change in velocity of Test 14 exceeds FHWA requirements. However, as the calculated changes in velocities nearly always over estimate the 60-mph results, we will consider the results of Test 14 as meeting the new FHWA requirements.

Figure D-11. LS-18

Thus, the transformer bases manufactured for Pole Lite, as shown on the enclosed drawings, are acceptable for use on Federal-aid highway projects within the range of conditions tested, if proposed by a State. This acceptance is limited to breakaway characteristics of the bases and does not cover their structural features. Presumably you or Pole Lite will supply potential users with sufficient information on structural design limitations and on installation requirements to ensure proper performance. We anticipate that the States will require certification from Pole Lite that the bases furnished have essentially the same chemistry, mechanical properties, and geometry as those used in the tests, and that supports with those bases will meet the FHWA breakaway requirements.

Since these breakaway support designs are proprietary items, to be used in a Federal-aid highway project they; (a) must be supplied through competitive bidding with equally suitable unpatented items; (b) the State highway agency must certify that they are essential for synchronization with existing highway facilities, or that no equally suitable alternate exists; or (c) they must be used for research or for a distinctive type of construction on relatively short sections of road for experimental purposes. Our regulations concerning proprietary products are contained in Title 23, Code of Federal Regulations, Section 635.411, a copy of which was provided with prior correspondence.

Sincerely yours,

L. A. Staron

L. A. Staron
Chief, Federal-Aid and Design Division

Enclosures

Geometric and Roadside Design Acceptance Letter LS-18

Figure D-12. LS-18

Endorsement to FHWA field offices: All of the transformer bases covered by this letter and Geometric and Roadside Design Acceptance Letters LS-17 and LS-19 were manufactured by Akron Foundry Company. For marketing purposes Akron Foundry has requested these three acceptance letters to cover what is essentially two 9-inch high transformer base models that will be manufactured by Akron Foundry and sold by three firms: Feralux, Pole Lite, and Akron Foundry. One model has top and bottom bolt circle ranges of 11.5 inches to 12.5 inches. It will carry a marking of CS-300 for Feralux, F-1300 for Pole Lite, and TB-AF6-9" for Akron. The other has top and bottom bolt circle ranges of 14.5 inches to 15.25 inches. It will carry a marking of CS-370 for Feralux, F-1302 for Pole Lite, and TB-AF5-9" for Akron. A separate series of tests was run to cover the Feralux model designations, while another series was run to cover the combined Pole Lite and Akron designations. It is our understanding that in production the Feralux bases will only be marked with Feralux's base numbers. On the other hand, bases to be marketed by either Pole Lite or Akron will be manufactured showing both suppliers' model numbers and before being shipped, one model number will be removed so that only the nominal supplier's model number will remain.

Figure D-13. LS-18

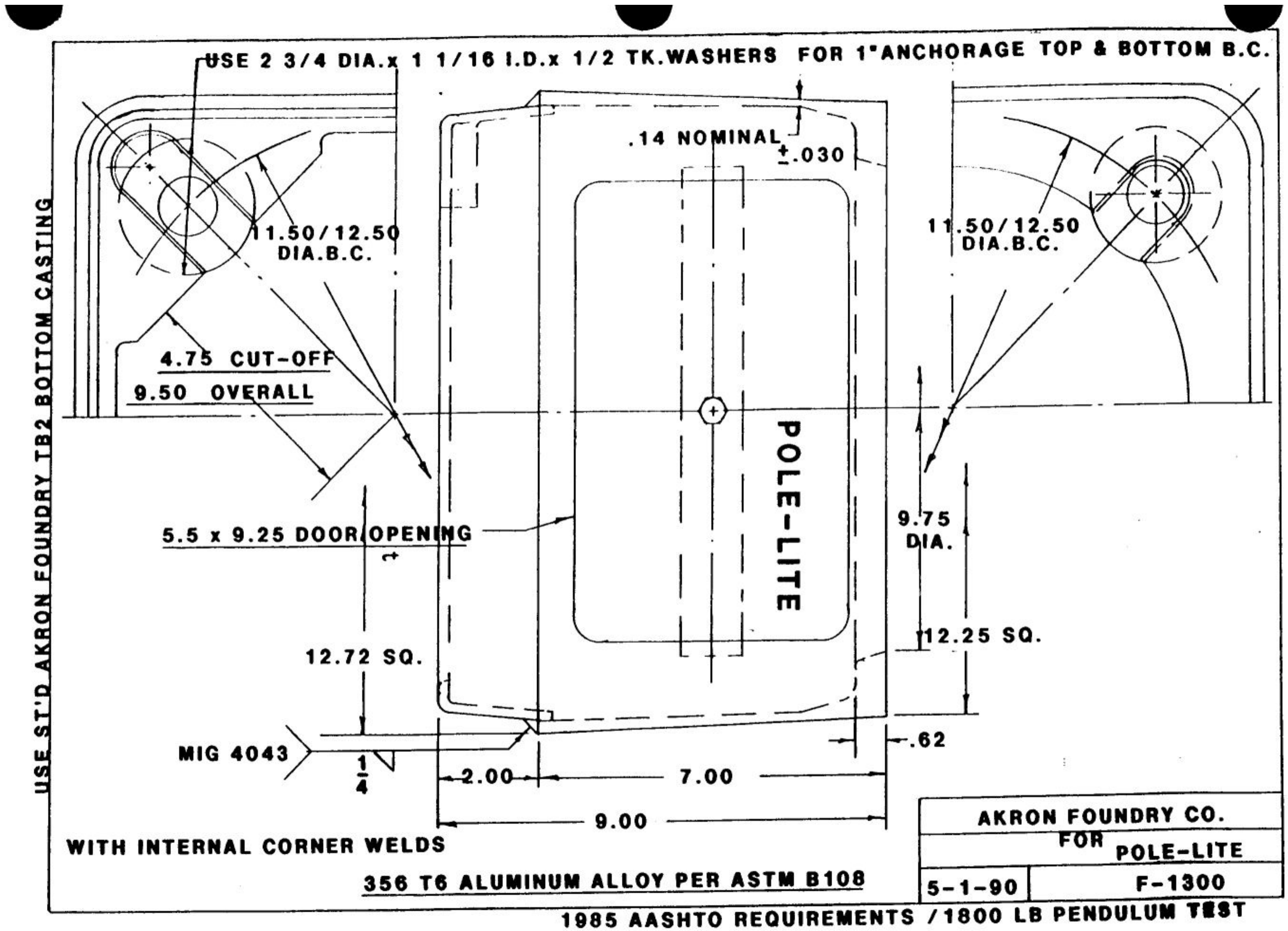

Figure D-14. LS-18

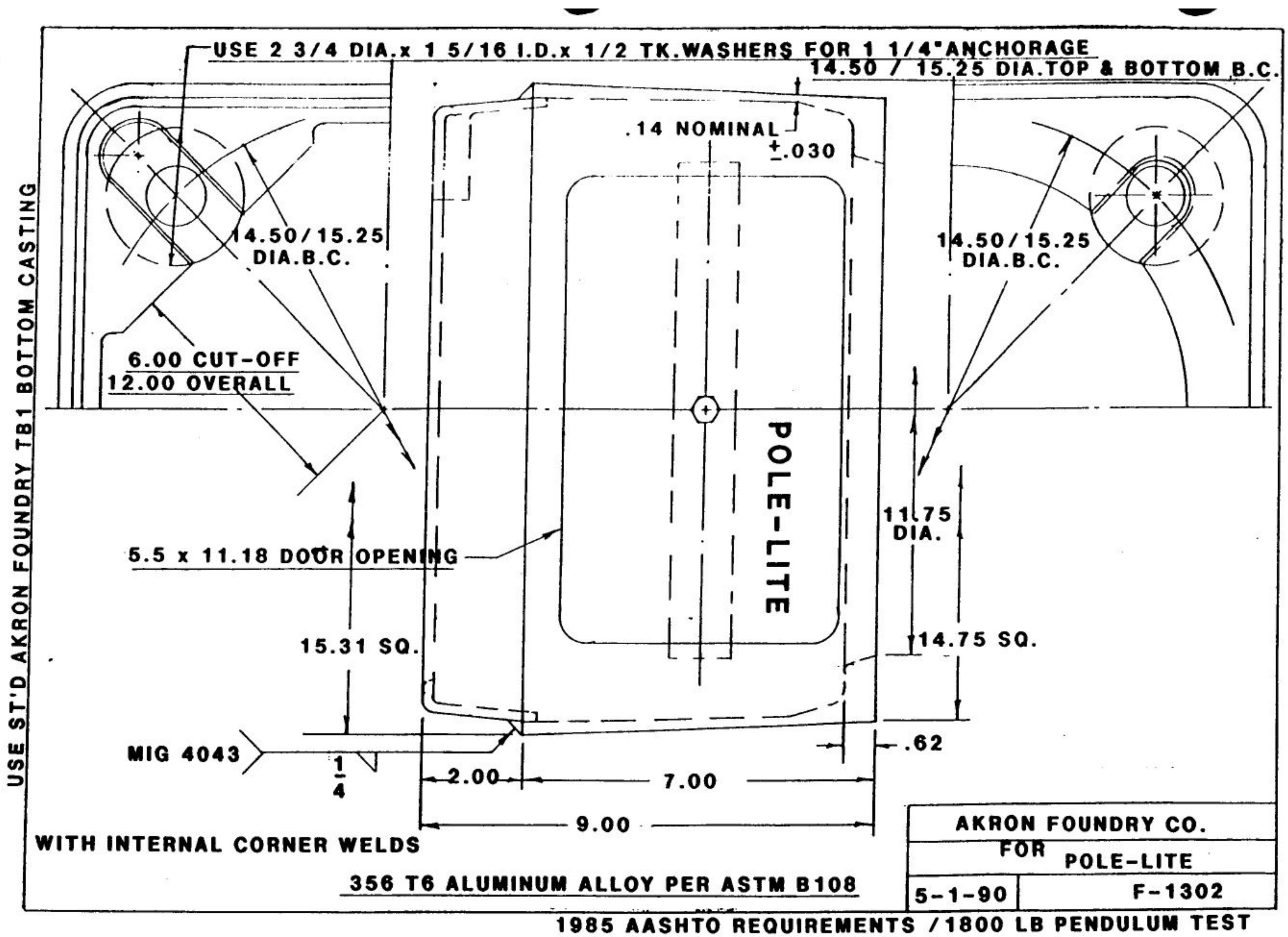

Figure D-15. LS-18

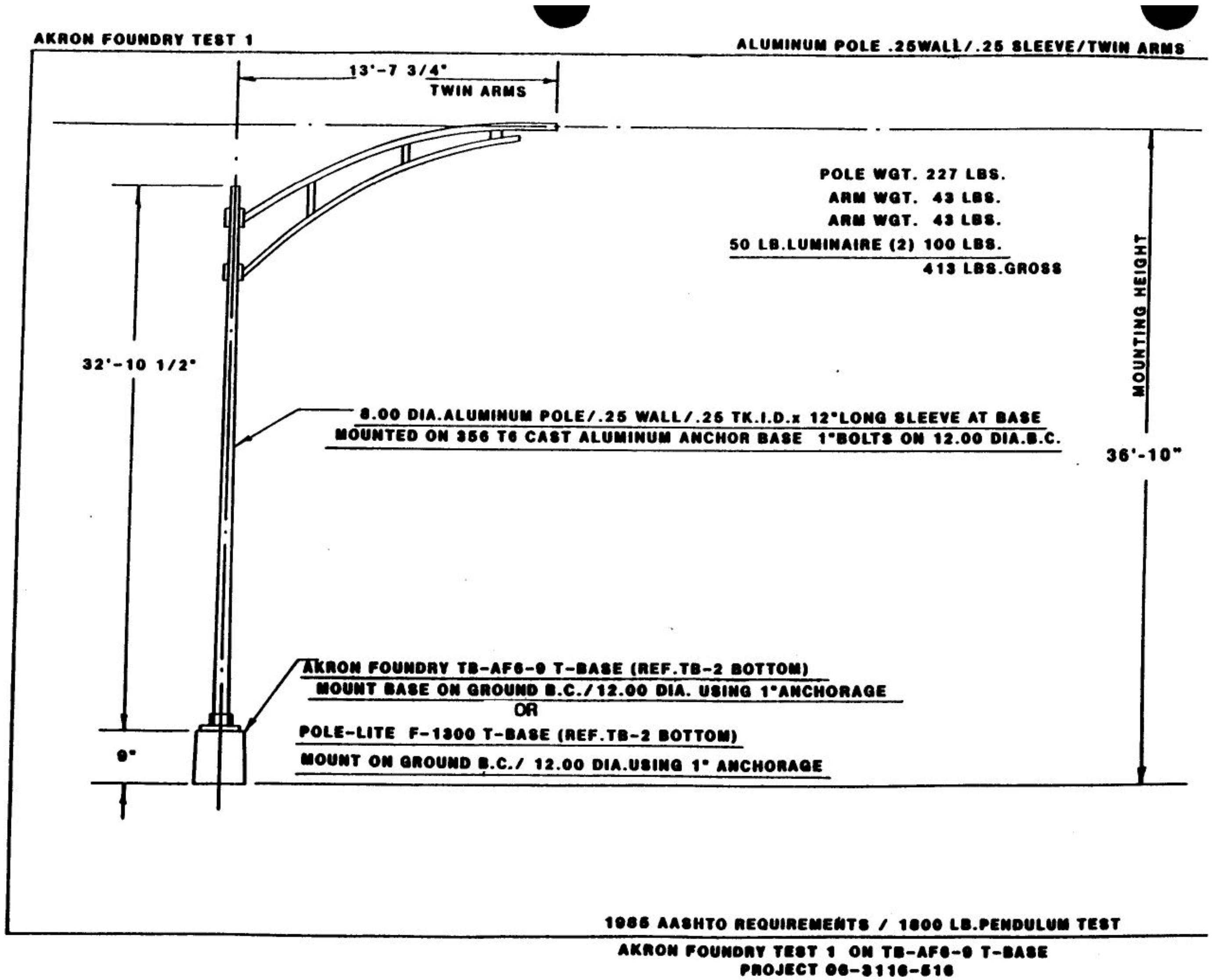

Figure 3. Assembly Drawing, Akron Foundry Test 1

Figure D-16. LS-18

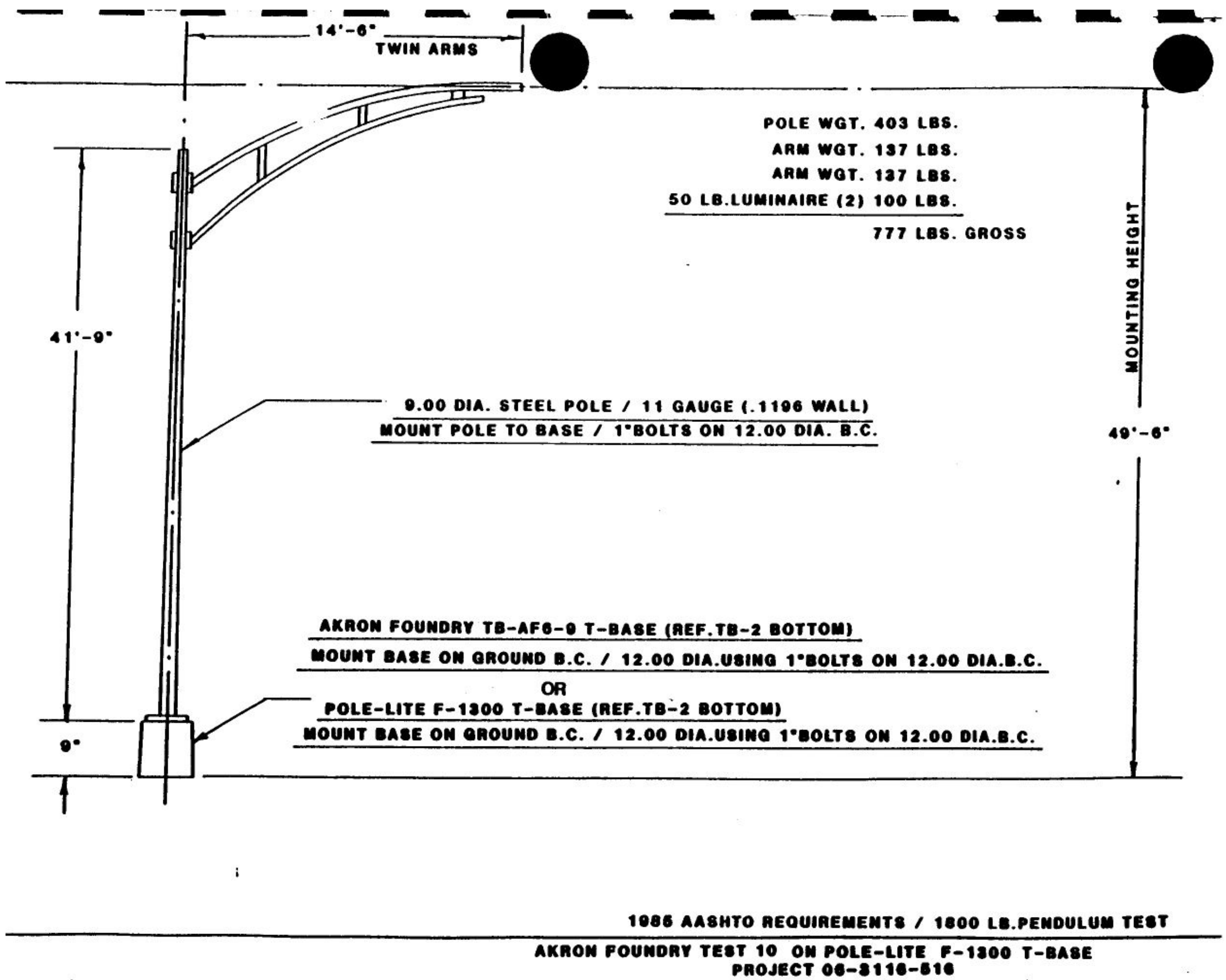

Figure 3. Assembly Drawing, Akron Foundry Test 10

Figure D-17. LS-18

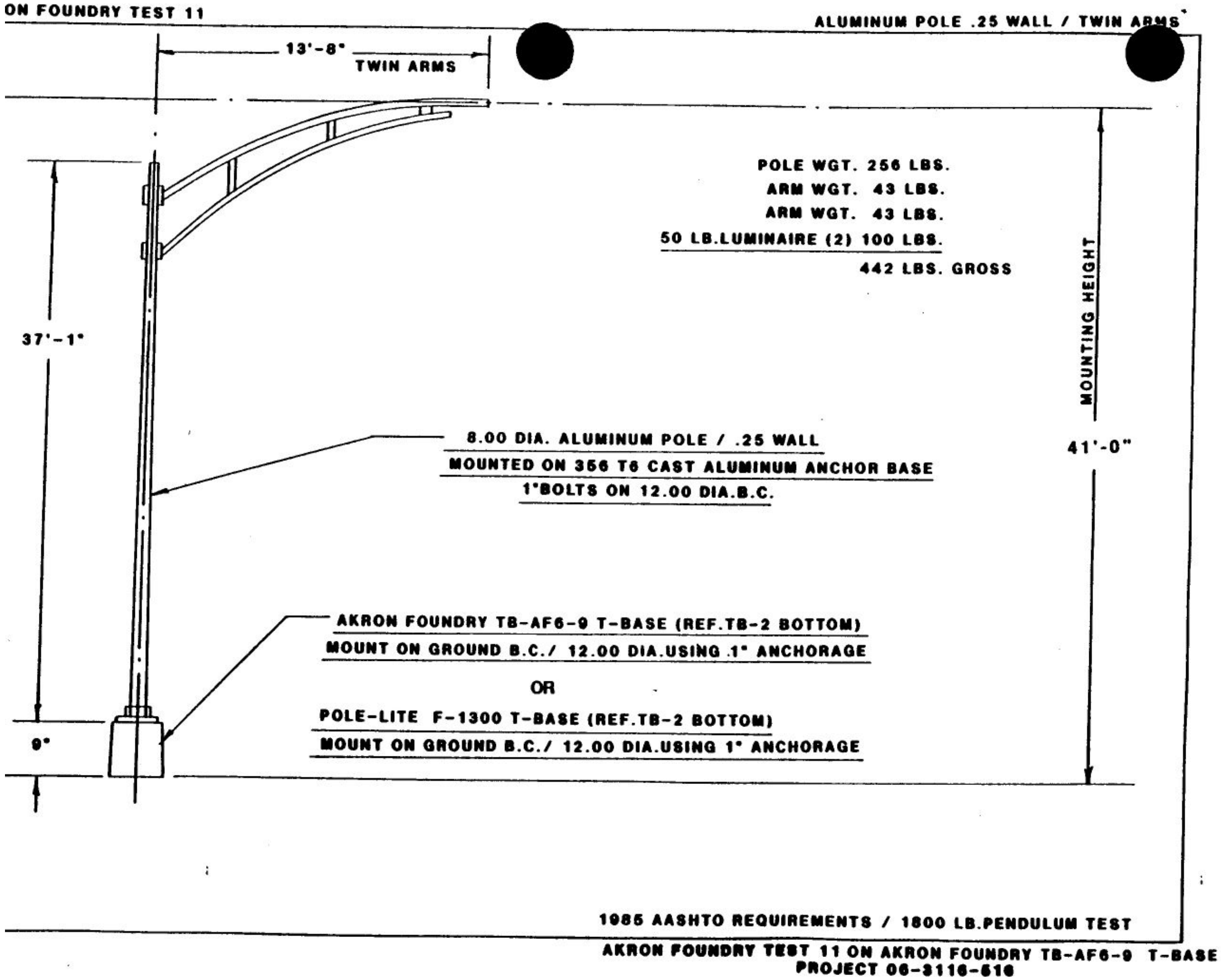

Figure 3. Assembly Drawing, Akron Foundry Test 11

Figure D-18. LS-18

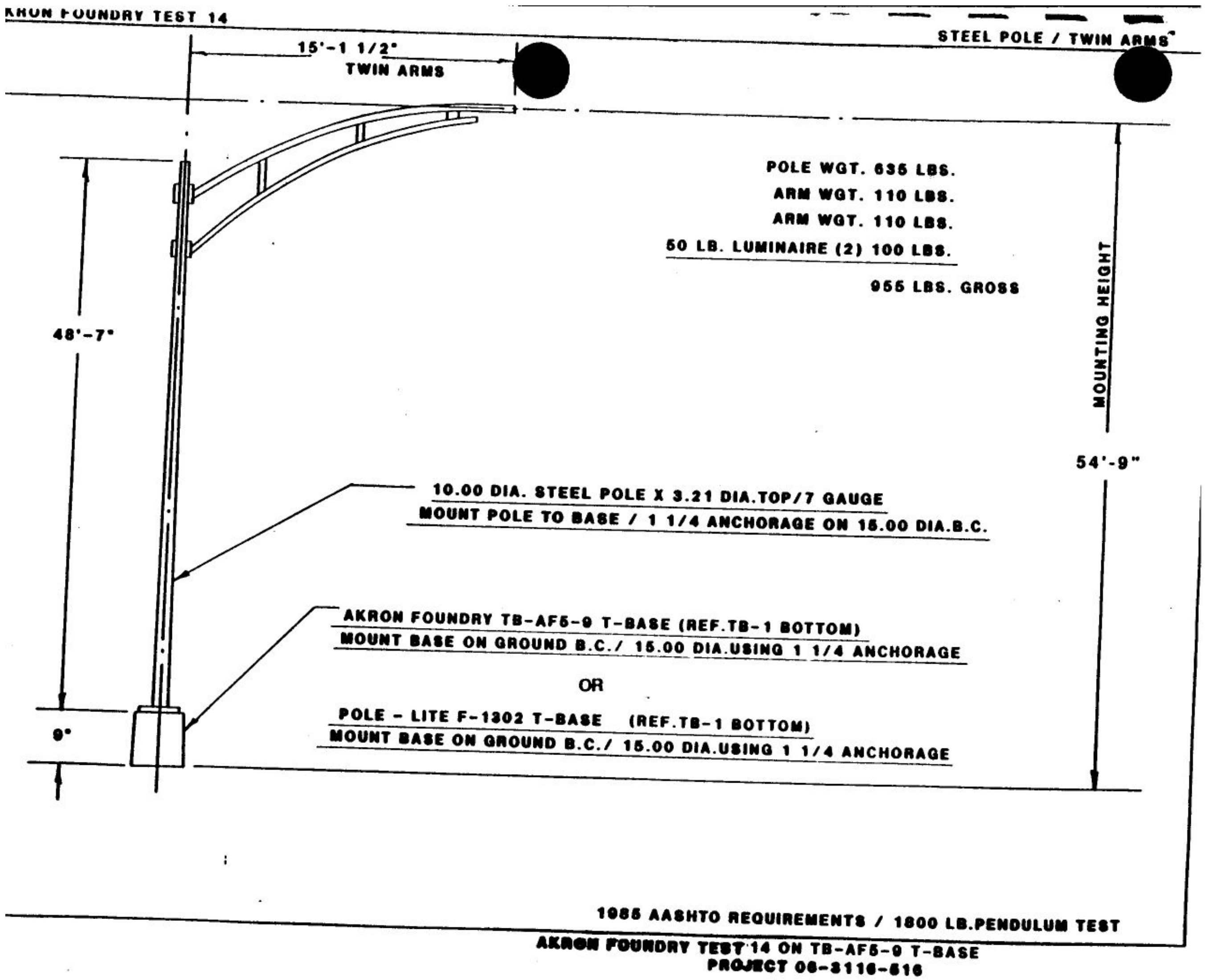

Figure 3. Assembly Drawing, Akron Foundry Test 14

Figure D-19. LS-18

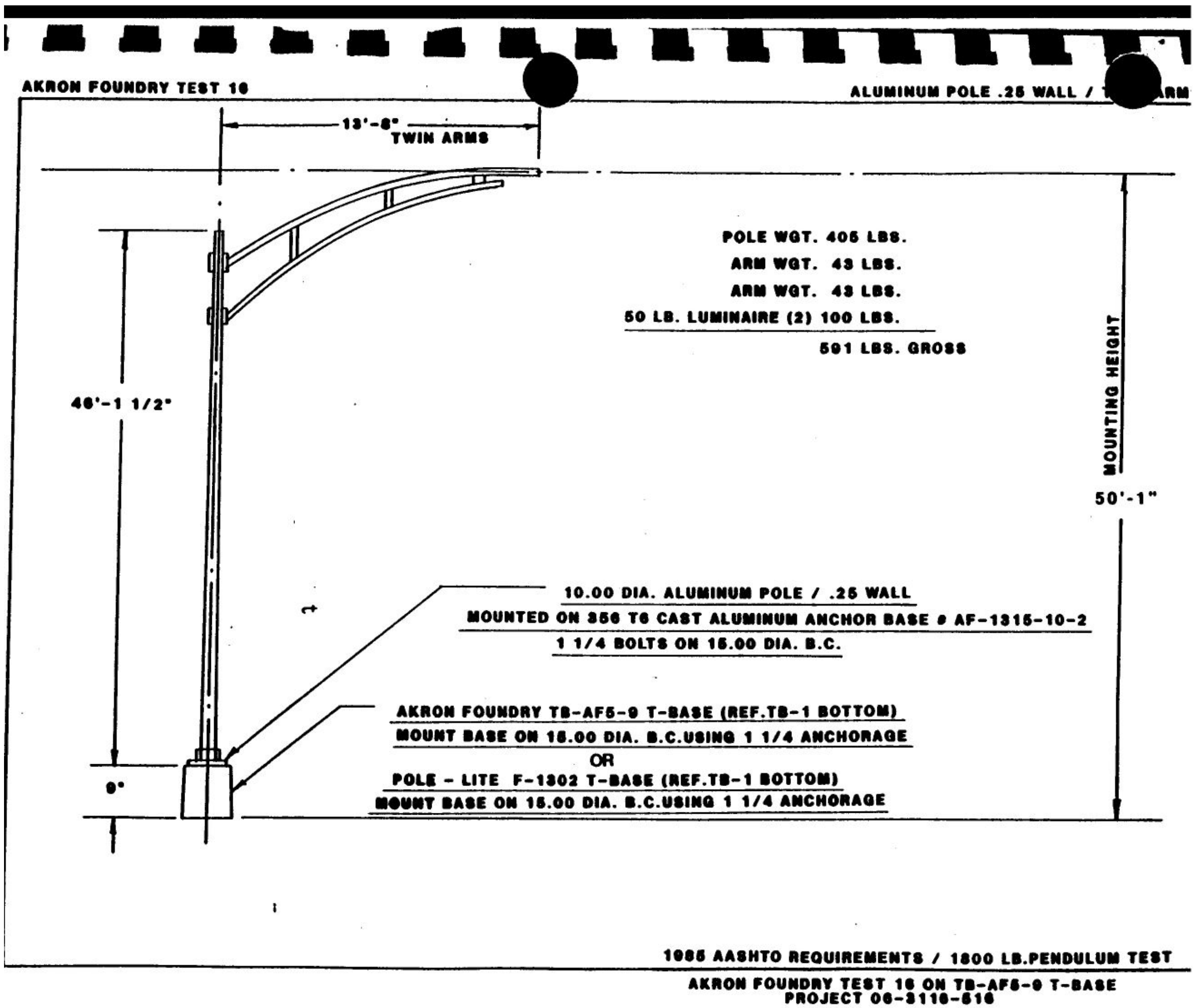

Figure 3. Assembly Drawing, Akron Foundry Test 16

Figure D-20. LS-18

Test Series	Test Number	Base Number	Test Delta V ● 20mph (fps)	Calc'd Delta V ● 60mph (fps)	Stub Height (in.)	Pole Weight W/arm & Dummy (pounds)	Pole Type	Nominal Luminaire Mounting Height (feet)	Mast Arm Length (ft) ++	Base Bottom Bolt Circle Diameter (in.)	Bottom Bolt Diameter (in.) *	Bottom Washer Outside Diameter (in.)	Bottom Washer Thick-ness (in.)	Base Top Bolt Circle Diameter (in.)	Top Bolt Diameter (in.)	Top Washer Outside Diameter (in.)	Top Washer Thick-ness (in.)
IV	AF-1	FERALUX CS-300	3.4	6.4	2.0	413	ALUMINUM	36.83	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-1	TB-AF-6-9 POLE LITE F-1300	4.7	6.8	2.0	413	ALUMINUM	36.83	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-2	FERALUX-CS-300	5.3	11.1	2.0	777	STEEL	49.50	14.50	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-10	TB-AF-6-9 POLE LITE F-1300	5.0	11.0	2.0	777	STEEL	49.50	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-11	TB-AF-6-9 POLE LITE F-1300	4.9	7.0	2.0	442	ALUMINUM	41.00	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-12	TB3-AF-1517-17 I.W.+	7.9	17.1	2.0	955	STEEL	55.42	15.13	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-13	FERALUX CS-370	6.6	16.5	2.0	955	STEEL	54.75	15.13	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-14	TB-AF-5-9 POLE LITE F-1302	7.6	16.8	2.0	955	STEEL	54.75	15.13	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-15	FERALUX CS-370	6.9	10.5	2.0	591	ALUMINUM	50.08	13.65	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-16	TB-AF-5-9 POLE LITE F-1302	5.8	10.1	2.0	591	ALUMINUM	50.08	13.65	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-17	FERALUX CS-300	4.5	6.9	2.0**	442	ALUMINUM	41.08	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2

+ I.W. signifies Internal Weld

++ All tests run with twin mast arms.

* Anchor bolt nuts should not be torqued over 150 foot - pounds.

** A small shard of aluminum remained between 2 and 3 inches above the base plate.

Figure D-21. LS-18

LS-19

U.S.Department
of Transportation
Federal Highway
Administmtion

400 Seventh St., S.W.
Washington, D.C. 20590

AUG 6 199

Refer to: HNG-14

Mr. Robert A. Sik
Vice President, Akron Foundry Company
2728 Wingate Avenue
P.O. Box 27028
Akron, Ohio 44319-0009

Dear Mr. Sik:

This is in response to your July 13 letter to Mr. Artimovich requesting acceptance by the Federal Highway Administration (FHWA) of your company's cast aluminum transformer bases for use on Federal-aid highway projects. Tests were conducted to assess compliance of the bases with FHWA breakaway requirements, which cite Section 7 of the 1985 American Association of State Highway and Transportation Officials' (AASHTO) Standard Specifications for Structural Suooorts for Hishwav Sians. Luminaires and Traffic Siqnals. The Southwest Research Institute forwarded copies of the five crash test reports (Project No. 06-3116-516), dated June 1990, containing results of the pendulum tests on various aluminum and steel poles with these bases. Fully dimensioned drawings and material test reports on the aluminum castings had been received from you on May 31.

The tests used an instrumented 1,800-pound pendulum fitted with a 10 stage crushable nose which simulates the left quarter point of a 1979 Volkswagen Rabbit. Impact speed was 20 mph. A summary of the tested hardware is presented below:

Test Number	Akron Foundrv Number	Height of Base	Pole Tvoe
Test-1	TB-AF-6-9	9 inches	8 inches Aluminum
Test-10	TB-AF-6-9	9 inches	9 inches Steel
Test-11	TB-AF-6-9	9 inches	8 inches Aluminum
Test-12	TB3-AF-1517-17 I.W.	17 inches	10 inches Steel
Test-14	TB-AF-5-9	9 inches	10 inches Steel
Test-16	TB-AF-5-9	9 inches	10 inches Steel

Details of the tested hardware are shown in Enclosure I. Test parameters and measured and extrapolated test results and are shown on Enclosure II as part of Test Series IV. This information shows that the tested pole-base combinations will meet the change in velocity and stub-height requirements adopted by the FHWA.

The 17.1 fps and 16.8 fps calculated changes in velocity of Tests 12 and 14, respectively, exceed FHWA requirements. However, as the calculated changes in velocities nearly always over estimate the 60-mph results, we will consider

Figure D-22. LS-19

the Test 14 results as meeting the new FHWA requirements. However, in the absence of other test evidence, we believe the calculated 60-mph change in velocity for Test 12 is beyond the limit we should accept without qualification.

Thus, the transformer bases manufactured by your company and distributed under the product numbers shown above, as shown on the enclosed drawings, are acceptable for use on Federal-aid highway projects within the range of conditions tested, if proposed by a State, except that for base TB3-AF-1517-17 I.W. for which our acceptance is limited to use were the combined supported weight of the pole, mast arm, and luminaire does not exceed 900 pounds. This acceptance is limited to breakaway characteristics of the bases and does not cover their structural features. Presumably, you will supply potential users with sufficient information on structural design limitations and on installation requirements to ensure proper performance. We anticipate that States will require certification from Akron Foundry that bases furnished have essentially the same chemistry, mechanical properties, and geometry as those used in the tests, and that supports with those bases will meet the FHWA breakaway requirements.

Since your company's breakaway support designs are proprietary items, to be used in a Federal-aid highway project they; (a) must be supplied through competitive bidding with equally suitable unpatented items; (b) the State highway agency must certify that they are essential for synchronization with existing highway facilities, or that no equally suitable alternate exists; or (c) they must be used for research or for a distinctive type of construction on relatively short sections of road for experimental purposes. Our regulations concerning proprietary products are contained in Title 23, Code of Federal Regulations, Section 635.411, a copy of which was provided with prior correspondence.

Your letter also requested acceptance for TB-1 and TB-2 bases tested with heavier pole hardware. Enclosure III is a copy of our letter of acceptance dated May 30, 1990, sent in response to an earlier request.

Sincerely yours,

L. A. Staron

L. A. Staron
Chief, Federal-Aid and Design Division

Enclosures

Geometric and Roadside Design Acceptance Letter LS-19

Figure D-23. LS-19

Endorsement to FHWA field offices: All of the transformer bases covered by this letter and Geometric and Roadside Design Acceptance Letters LS-17 and LS-18 were manufactured by Akron Foundry Company. For marketing purposes Akron Foundry has requested these three acceptance letters to cover what is essentially two 9-inch high transformer base models that will be manufactured by Akron Foundry and sold by three firms: Feralux, Pole Lite, and Akron Foundry. One model has top and bottom bolt circle ranges of 11.5 inches to 12.5 inches. It will carry a marking of CS-300 for Feralux, F-1300 for Pole Lite, and TB-AF6-9" for Akron. The other has top and bottom bolt circle ranges of 14.5 inches to 15.25 inches. It will carry a marking of CS-370 for Feralux, F-1302 for Pole Lite, and TB-AF5-9" for Akron. A separate series of tests was run to cover the Feralux model designations, while another series was run to cover the combined Pole Lite and Akron designations. It is our understanding that in production the Feralux bases will only be marked with Feralux's base numbers. On the other hand, bases to be marketed by either Pole Lite or Akron will be manufactured showing both suppliers' model numbers and before being shipped, one model number will be removed so that only the nominal supplier's model number will remain.

Figure D-24. LS-19

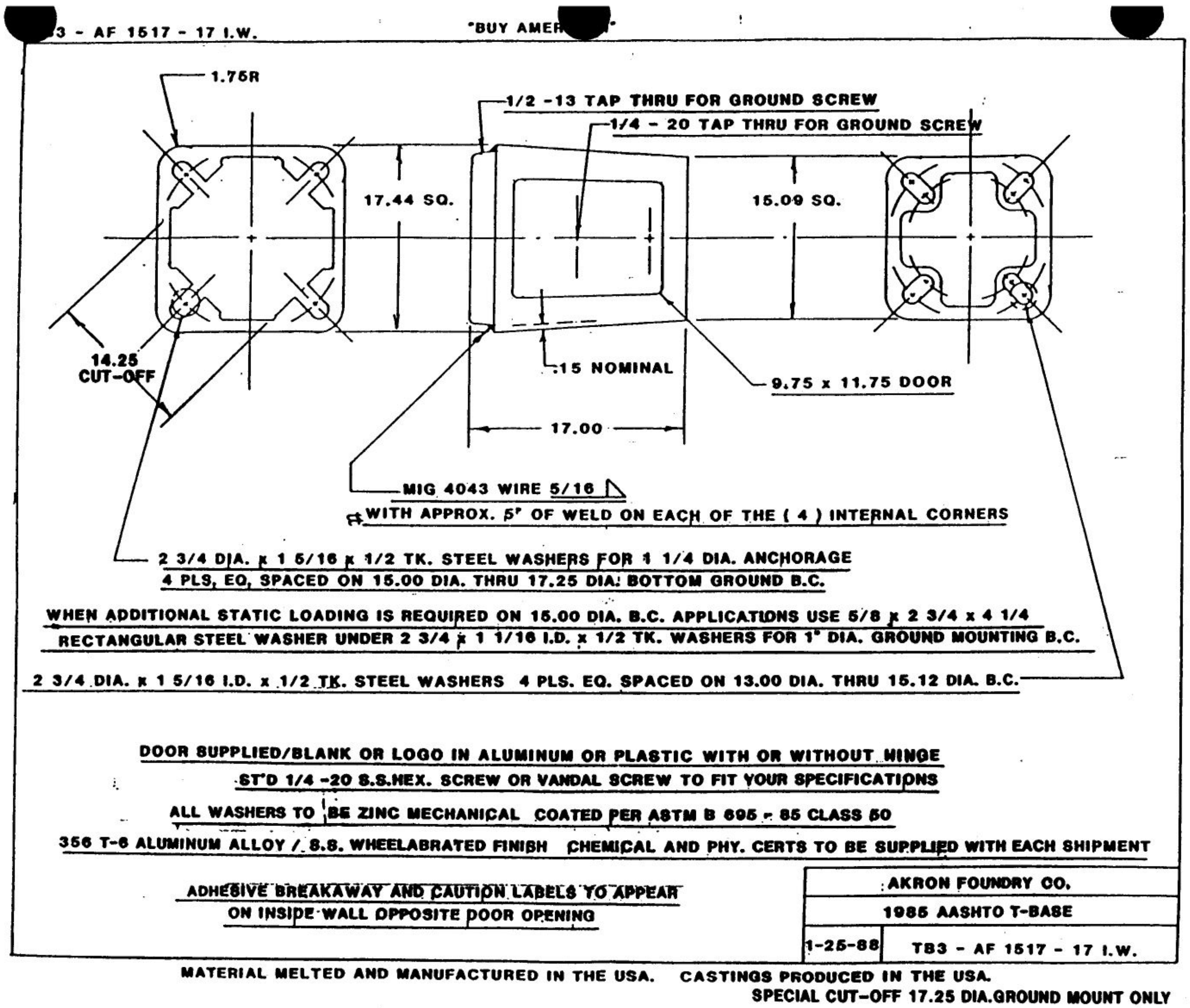

Figure D-25. LS-19

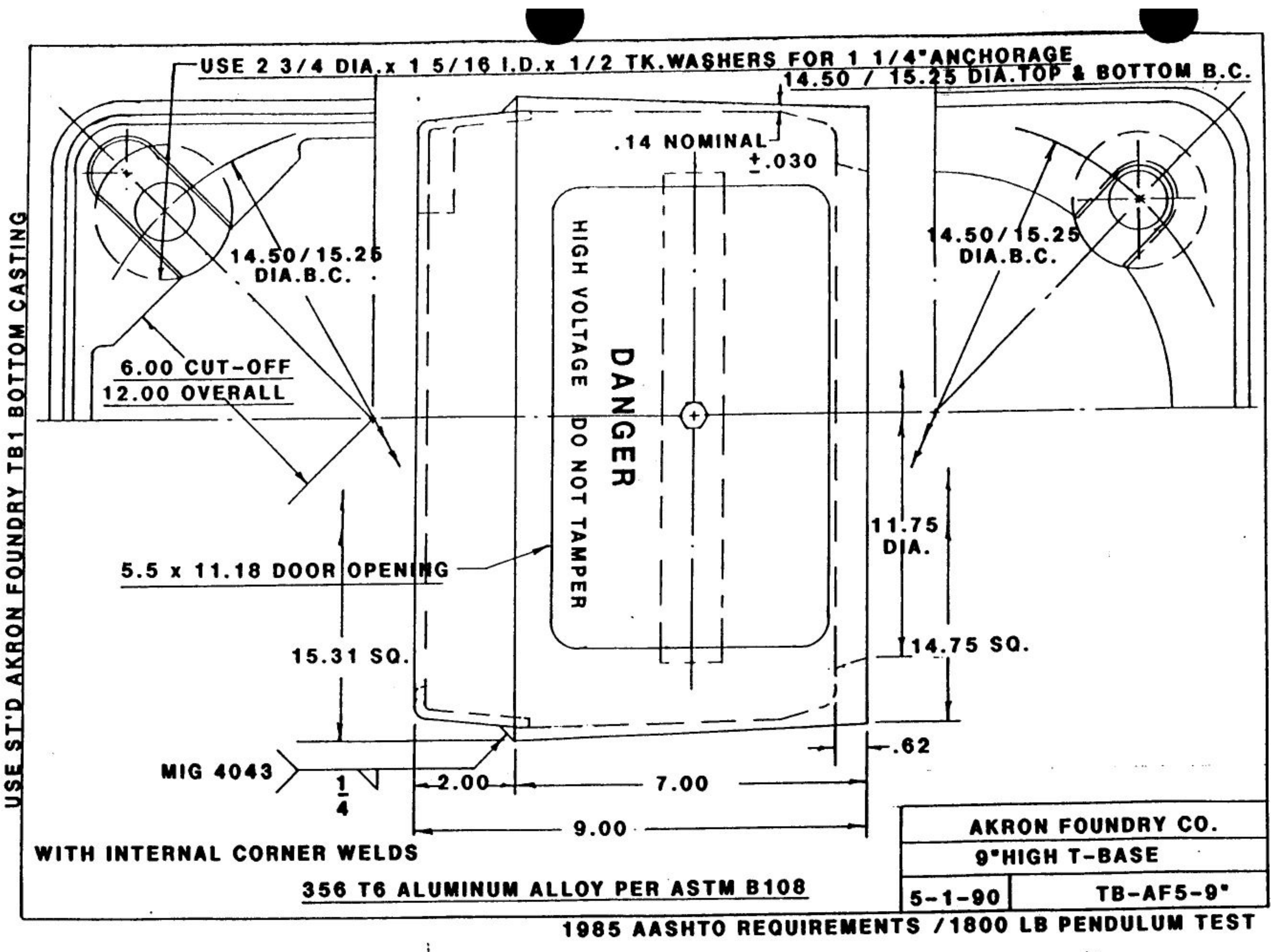

Figure D-26. LS-19

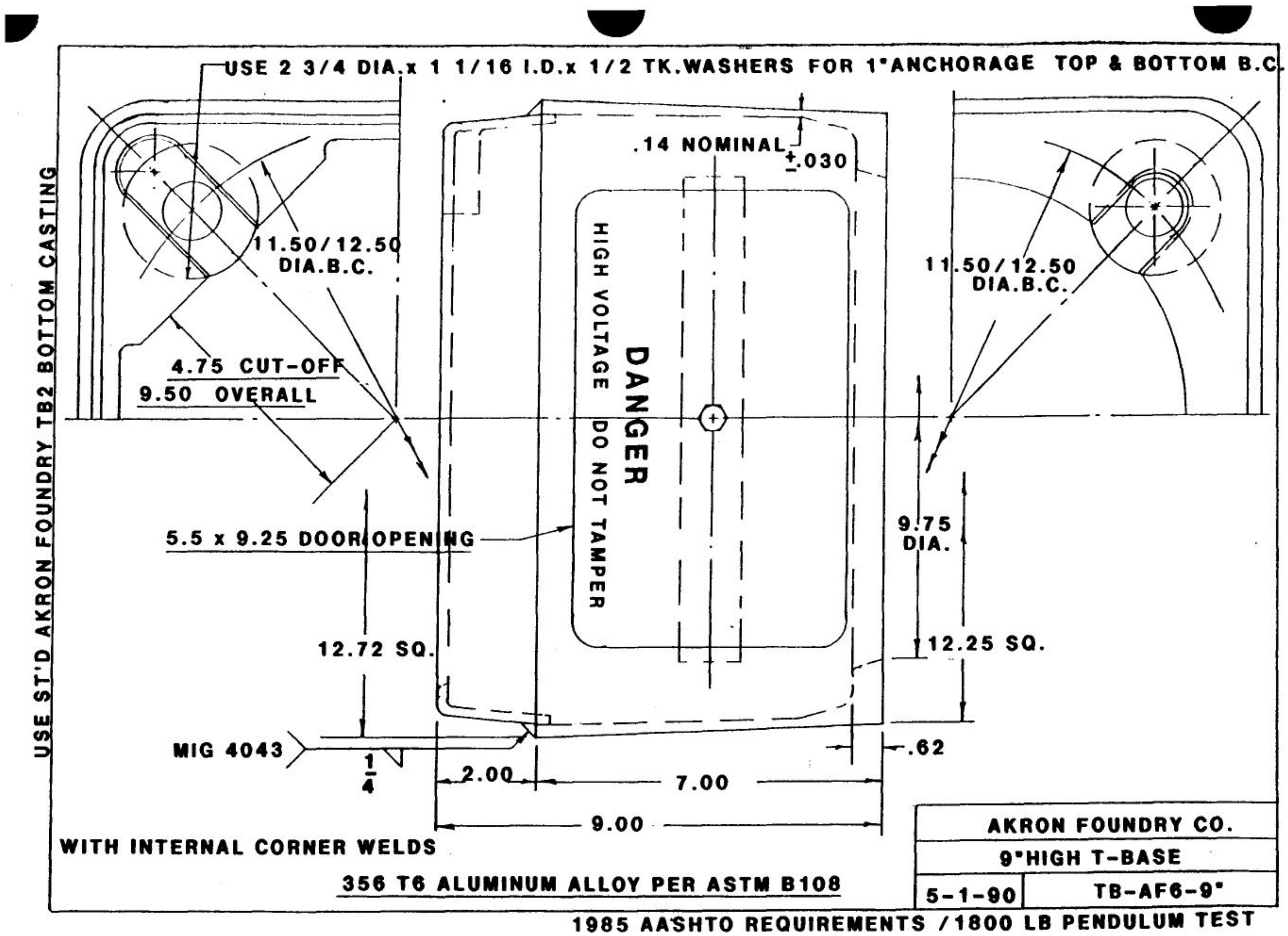

Figure D-27. LS-19

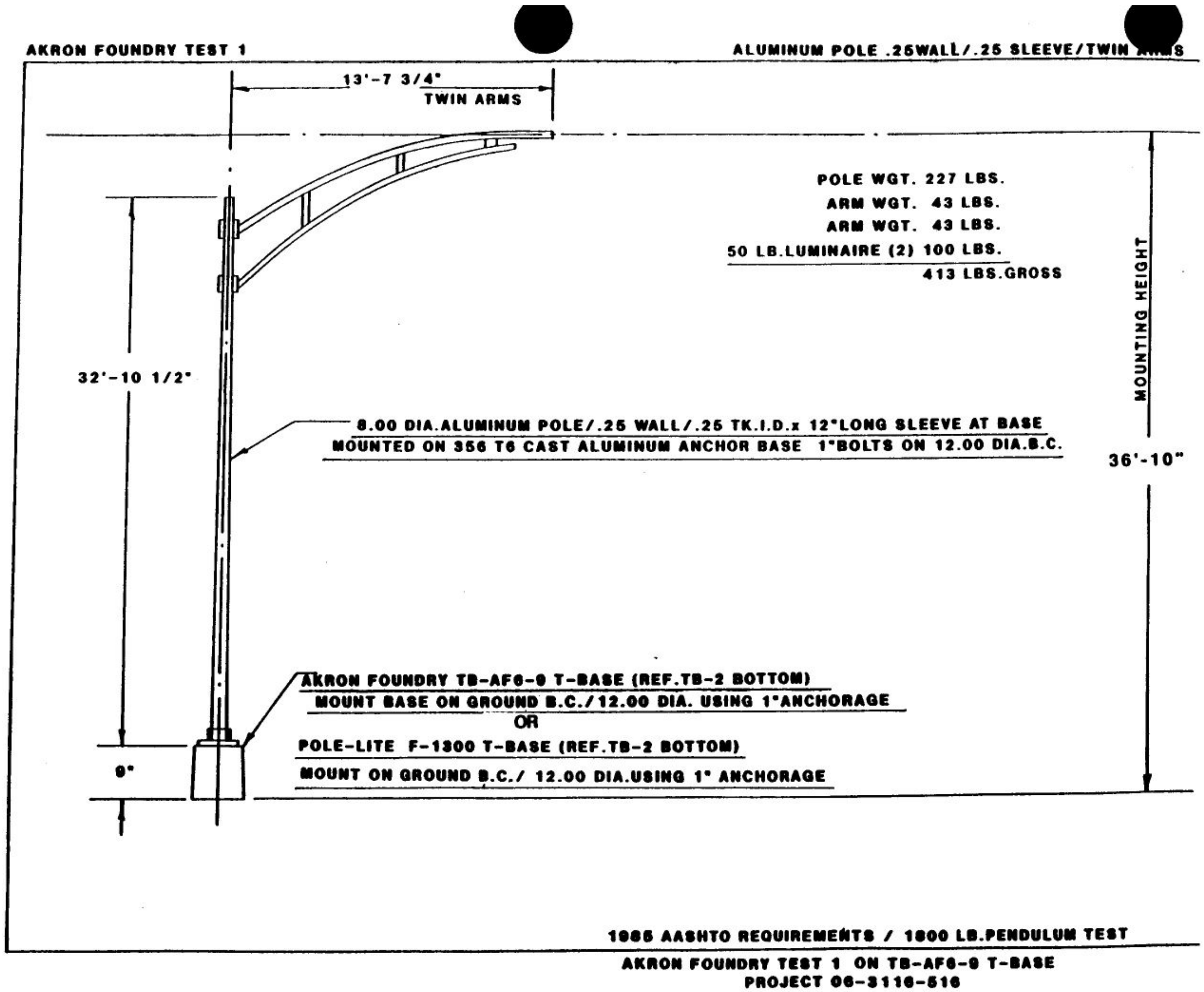

Figure 3. Assembly Drawing, Akron Foundry Test 1

Figure D-28. LS-19

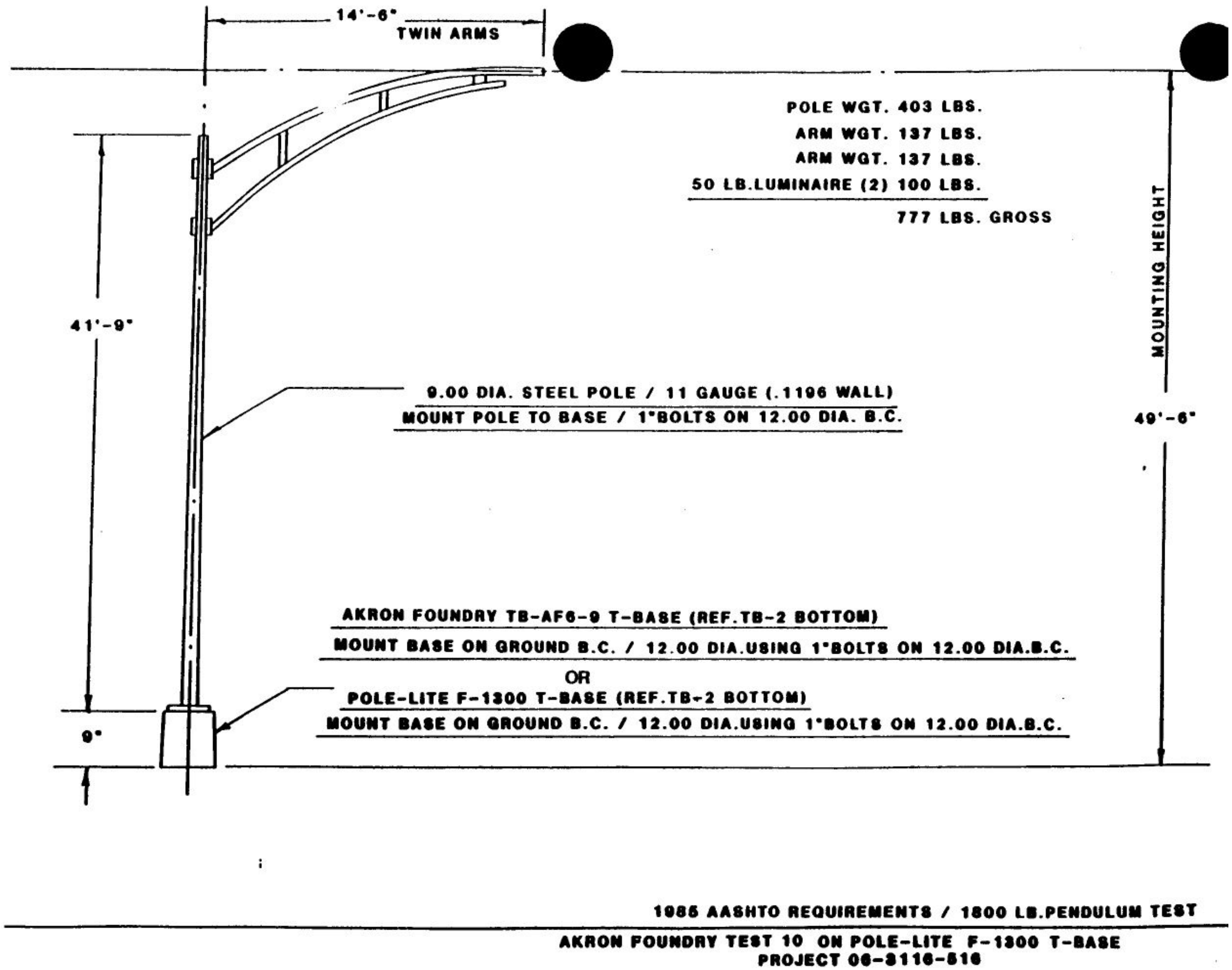

Figure 3. Assembly Drawing, Akron Foundry Test 10

Figure D-29. LS-19

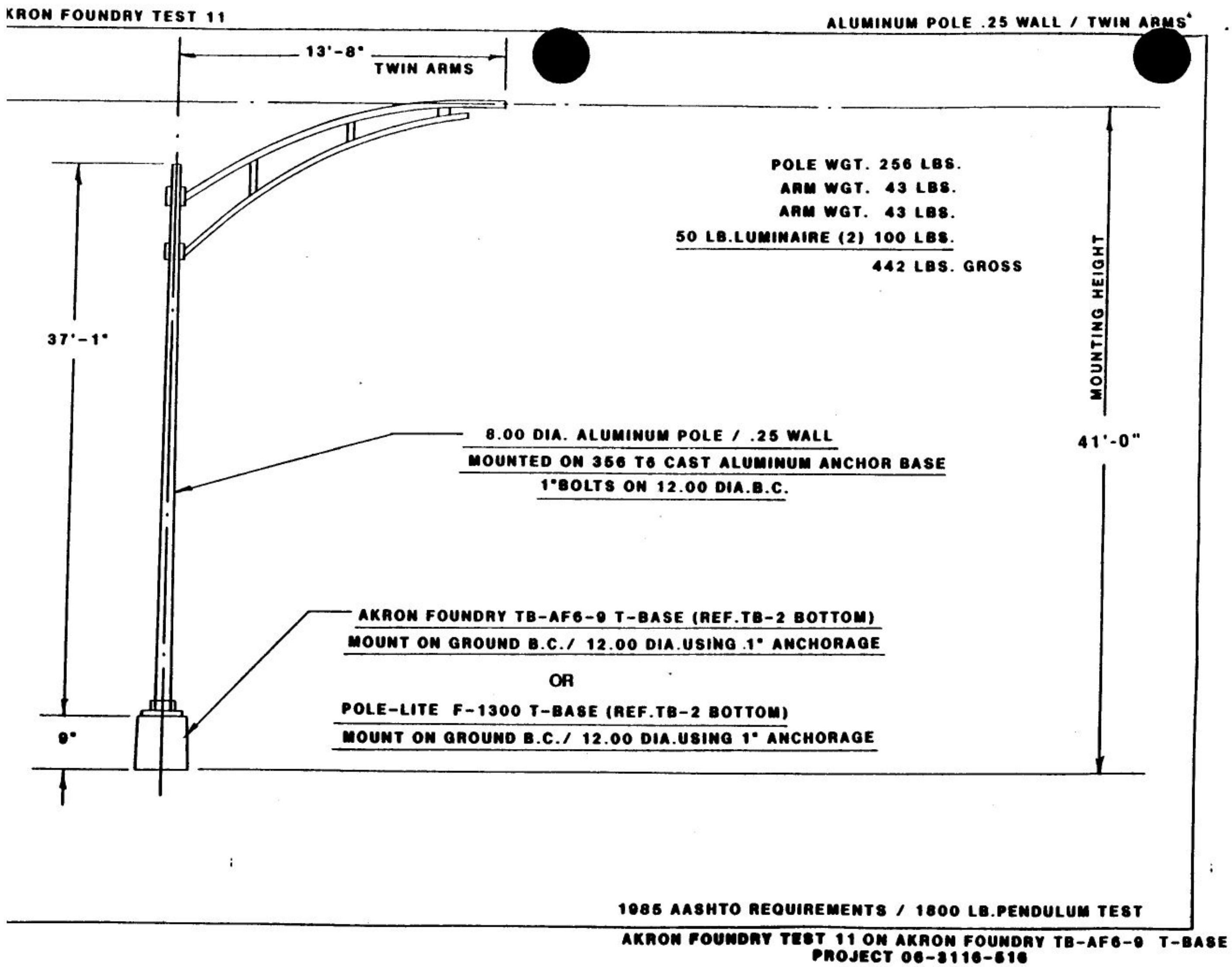

Figure 3. Assembly Drawing, Akron Foundry Test 11

Figure D-30. LS-19

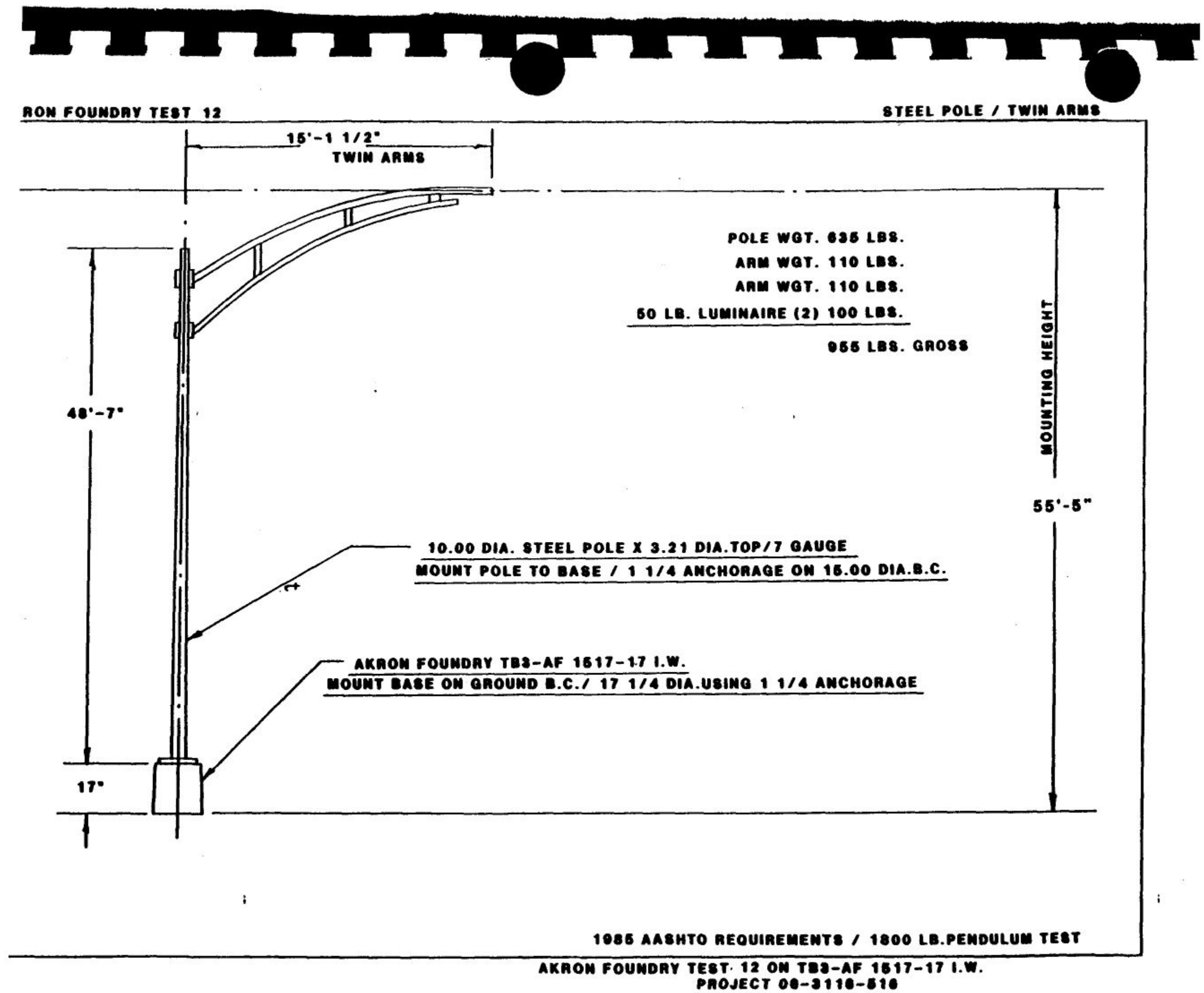

Figure 3. Assembly Drawing, Akron Foundry Test 12

Figure D-31. LS-19

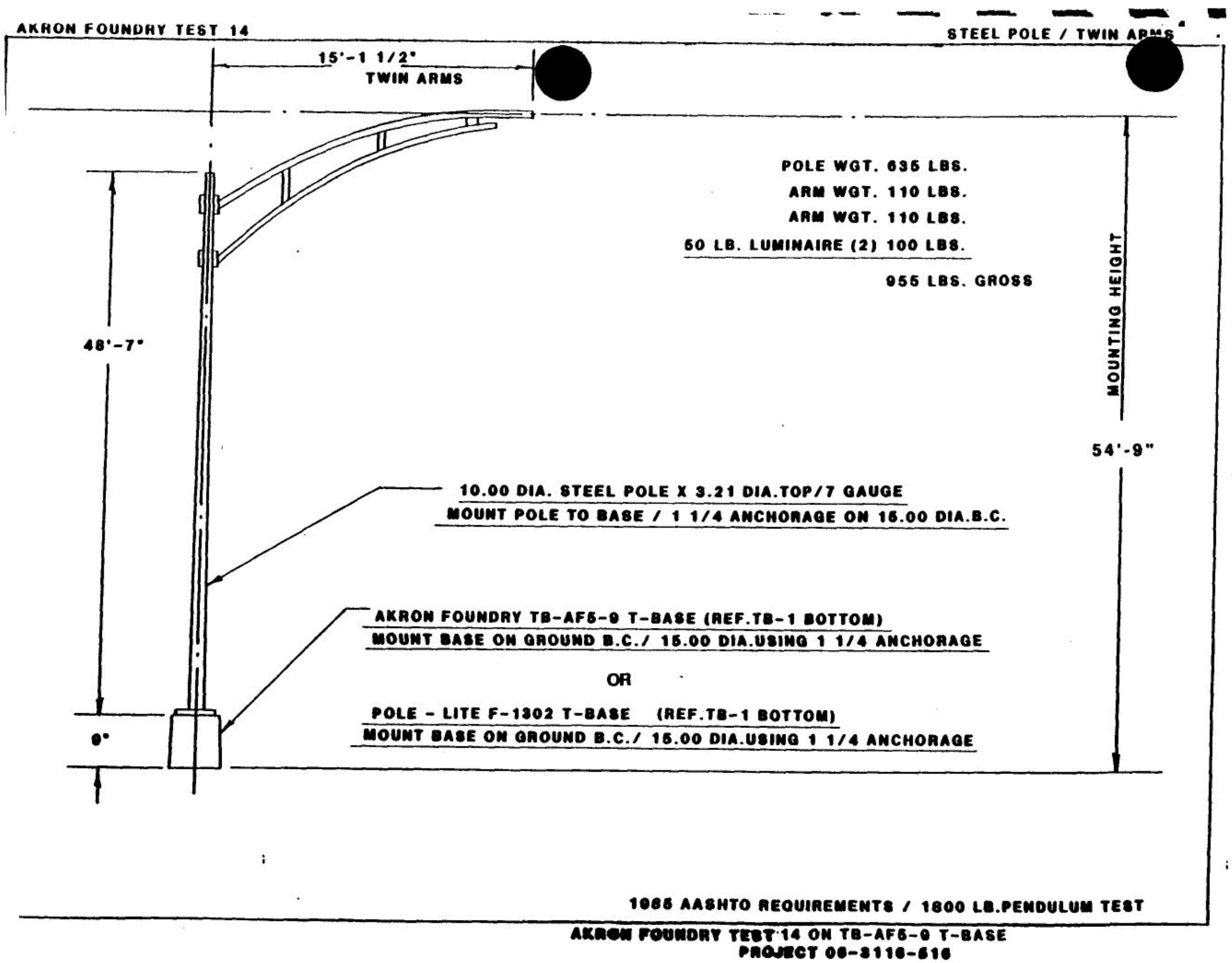

Figure 3. Assembly Drawing, Akron Foundry Test 14

Figure D-32. LS-19

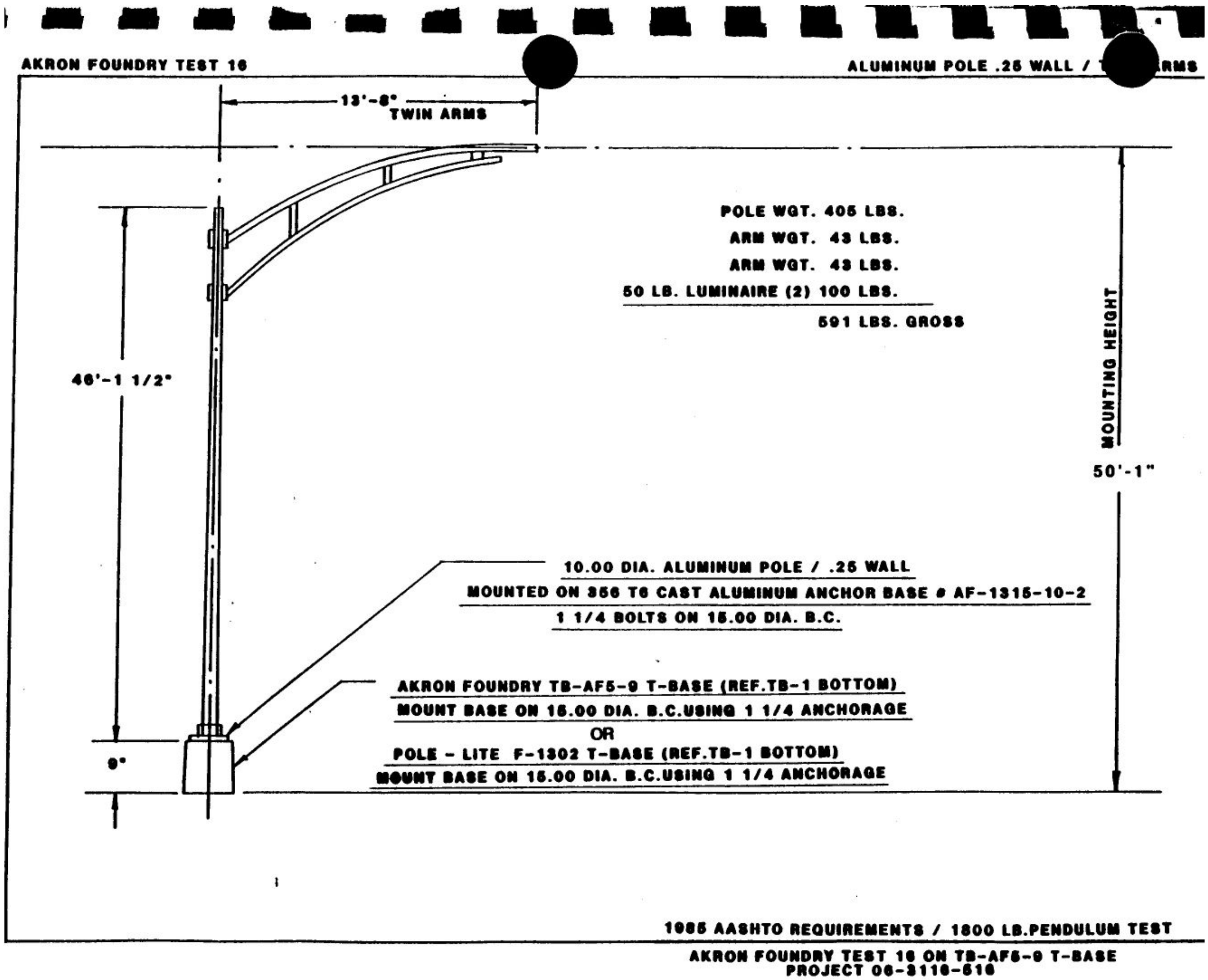

Figure 3. Assembly Drawing, Akron Foundry Test 16

Figure D-33. LS-19

Test Series	Test Number	Base Number	Test Delta V ● 20mph (fps)	Calc'd Delta V ● 60mph (fps)	Stub Height (in.)	Pole Weight W/arm & Dummy (pounds)	Pole Type	Nominal Luminaire Mounting Height (feet)	Mast Arm Length (ft) ++	Base Bottom Bolt Circle Diameter (in.)	Bottom Bolt Diameter (in.) *	Bottom Washer Outside Diameter (in.)	Bottom Washer Thickness (in.)	Base Top Bolt Circle Diameter (in.)	Top Bolt Diameter (in.)	Top Washer Outside Diameter (in.)	Top Washer Thickness (in.)
IV	AF-1	FERALUX CS-300	3.4	6.4	2.0	413	ALUMINUM	36.83	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-1	TB-AF-6-9 POLE LITE F-1300	4.7	6.8	2.0	413	ALUMINUM	36.83	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-2	FERALUX-CS-300	5.3	11.1	2.0	777	STEEL	49.50	14.50	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-10	TB-AF-6-9 POLE LITE F-1300	5.0	11.0	2.0	777	STEEL	49.50	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-11	TB-AF-6-9 POLE LITE F-1300	4.9	7.0	2.0	442	ALUMINUM	41.00	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2
IV	TEST-12	TB3-AF-1517-17 I.W.+	7.9	17.1	2.0	955	STEEL	55.42	15.13	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-13	FERALUX CS-370	6.6	16.5	2.0	955	STEEL	54.75	15.13	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-14	TB-AF-5-9 POLE LITE F-1302	7.6	16.8	2.0	955	STEEL	54.75	15.13	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-15	FERALUX CS-370	6.9	10.5	2.0	591	ALUMINUM	50.08	13.65	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-16	TB-AF-5-9 POLE LITE F-1302	5.8	10.1	2.0	591	ALUMINUM	50.08	13.65	15	1.25	2 3/4	1/2	15	1.25	2 3/4	1/2
IV	TEST-17	FERALUX CS-300	4.5	6.9	2.0**	442	ALUMINUM	41.08	13.65	12	1	2 3/4	1/2	12	1	2 3/4	1/2

\+ I.W. signifies Internal Weld

++ All tests run with twin mast arms.

* Anchor bolt nuts should not be torqued over 150 foot - pounds.

** A small shard of aluminum remained between 2 and 3 inches above the base plate.

Figure D-34. LS-19

Appendix E. Material Specifications

Table E-1. Bill of Materials, Test No. ILT-1

Item No.	Description	Material Specification	Material Cert Reference
a1	12'-6" [3810] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv. (ASTM A653)	R#16-0005 H#9411949
a2	12'-6" [3810] W-Beam MGS End Section	12 gauge [2.7] AASHTO M180 Galv. (ASTM A653)	B8479 R#15-0602 H#9511340
a3	6'-3" [1905] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv. (ASTM A653), CERT says AASHTO M180 does not say A653	R#12-0368 H#515691
a4	W6x8.5 [W152x12.6] 72" Long [1829] Steel Post	ASTM A992 or ASTM A36 Min. 50 ksi [345 MPa] Steel Galv. Per AASHTO M111 (ASTM A123)	H#55044251 R#16-635
a5	6x12x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	n/a
a6	16D Double Head Nail	-	n/a
b1	BCT Timber Post - MGS Height	SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face)	R#16-635 Charge#21638
b2	72" [1829] Long Foundation Tube	ASTM A500 Grade B Galv. Per AASHTO M11 (ASTM A123), A-500 w/o Grade B was used	H#0173175 R#15-0157
b3	Ground Strut Assembly	ASTM A36 Steel Galv. Per AASHTO M111 (ASTM A123) - South Strut: A-1011-SS, Yield Strength 48,380 psi, Tensile Strength 64,020 psi	North Strut: R#090453-8 South Strut: R#15-0157 H#163375
b4	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40 Galv. Per AASHTO M111 (ASTM A123), ASTM A500 Grade B, not Galvanized was used	R#15-0626 H#E86298
b5	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel Galv. Per AASHTO M111 (ASTM A123)	North: A3 Black Paint H#V911470 South: R#09-0453 H#6106196
b6	Anchor Bracket Assembly	ASTM A36 Steel Galv. Per AASHTO M111 (ASTM A123)	
Not listed	BCT Anchor Cable End Threaded Rods		R#15-0601 White Paint H#10348290 AND H#10350220

Table E-2. Bill of Materials, Test No. ILT-1 (Cont'd)

Item No.	Description	Material Specification	Material Cert Reference
c1	BCT Anchor Cable End Swaged Fitting	Grade 5 - Galv. Fitting Per AASHTO M232 (ASTM A153), Stud Per AASHTO M232 or M298 (ASTM A153 or B695), CERT gives a variety of different ASTM numenclatures not listed here	R#15-0601 H#498219 AND H#498221
c2	3/4" [190] Dia. 6x19, 24 1/2" [622] Long IWRC IPS Wire Rope	IPS Galv. Per AASHTO M30 (ASTM A741) Type II Class A	R#15-0601 H#53131485, H#53127002, 10342780, 10207730, 25807
c3	115-HT Mechanical Splice - 3/4" [19] Dia.	As Supplied	n/a
c4	Crosby Heavy Duty HT - 3/4" [19] Dia. Cable Thimble	Stock No. 1037773 - Galv. - As Supplied	n/a
c5	Crosby G2130 or S2130 Bolt Type Shackle - 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 - As Supplied	n/a
c6	Chicago Hardware Drop Forged Heavy Duty Eye Nut - Drilled and Tapped 1/2" [38] Dia. - UNC 6 [M36x4]	Stock No. 107 - As Supplied	n/a
c7	TLL-50K-PTB Load Cell	-	n/a
d1	45' [13716] Long Aluminum Pole, Pay Item No. 903A10, JS830003	6063-T4 Aluminum Alloy	Cast#416067
d2	CS-370 Anchor Base, Model No. 10R145153B9T	ASTM B108/B108M-12 VO#228196	H#096-16
d3	Truss, Model No. 1TA1566C60ZA	6063-T6 Aluminum Alloy, Valmont Order#327087-1-1	Cast#915028
d4	1" [25] Dia. UNC, 4" [102] Long Hex Head Bolt	Bolt - ASTM A449 or SAE J429 Grade 5 Galv. Per ASTM A153, Nut - ASTM A563DH Galv. Per ASTM A153	as supplied
d5	1" [25] Dia. Hardened Flat Washer	ASTM A153 Galv. Low Carbon Steel	as supplied

Table E-3. Bill of Materials, Test No. ILT-1 (Cont'd)

Item No.	Description	Material Specification	Material Cert Reference
d6	1" [25] Dia. 1/2" [13] Thick Flat Washer	Q235 Steel, Galv. Per ASTM A123, Coating Grade 50	as supplied
d7	1/2" [13] Dia. UNC x 3" [76] Long Hex Head Bolt and Nut	Bolt - 304 Stainless Steel or ASTM F593, Nut - ASTM F594 Stainless Steel	as supplied
d8	1/2" [13] Dia. Flat washer	18-8 Stainless Steel	as supplied
d9	1/2" [13] Dia. Split Lock Washer	18-8 Stainless Steel	as supplied
d10	1/4" [6] Dia. x 3/4" [19] Flat Head Screw	18-8 Stainless Steel	as supplied
f1	5/8" [16] Dia. UNC x 14" [356] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	R#15-0515 H#26859
f2	5/8"[16] Dia. UNC x 1 1/2" [38] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	Bolt: R#15-0602 H#20337380 Nut: R#15-0602 H#10351040
f3	7/8" Dia. [22] UNC x 7 1/2" [191] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	Bolts: R#15-0600 L#69685 H#2038622 Nuts: 15-0600 L#WA651 H#12101054
f4	5/8" [16] Dia. UNC x 10" [254] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	Bolts: R#16-0226 L#206239 H#DL15102793 Nuts: R#16-0217 P#36713 C#210101523

Table E-4. Bill of Materials, Test No. ILT-1 (Cont'd)

Item No.	Description	Material Specification	Material Cert Reference
f5	5/8" [16] Dia. x 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt ASTM A307Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	Bolts:R#16-0009 L#25203 H#10207560 Nuts: R#16-0217 P#36713 C#210101523
f6	5/8" [16] Dia. UNC x 10" [254] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM 563A Galv. Per AASHTO 232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	R#15-0627 L#1740530 LH#2029797
g1	5/8" [16] Dia. Plain Round Washer	ASTM F844 Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	n/a
g2	7/8" [22] Dia. Plain Round Washer	ASTM F844 Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	R#12-0037 L#HO1788740 H#8280072 COC
h1	1" [25] Dia., 84" [2134] Long Anchor Bolt	ASTM F1554 Grade 105 or A449 Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	R#17-75 L#36429 H#5802372003
h2	1" [25] Dia. UNC Hex Nut	ASTM A563DH or A194 Gr. 2H Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	R#17-78 Part#38210 Control#210110788 L#366055B H#DL15103032
h3	1" [25] Dia. Hardened Round Washer	ASTM F436 Galv. Per ASTM B695	R#17-78 Part#33176 L#322CAFN91 H#2MV88
h4	1" [25] Dia. Split Lock Washer	Steel Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	R#17-78 Part#33788 Control#120216445 H#DL15103032

Table E-5. Bill of Materials, Test No. ILT-1 (Cont'd)

Item No.	Description	Material Specification	Material Cert Reference
h5	"1/2" [13] Dia. Bent Rebar, unbent 1517" [38532]		
h6	3/4" [19] Dia., 90" [2286] Long Rebar	Epoxy-Coated ASTM A615 Gr. 60	R#16-658 H#KN15101296
h7	Light Pole Concrete Foundation	Min. f'c = 3,500 psi [24.1 MPa]	R#17-76
h8	30" [762] Dia. x 6" [152] Sonotube	Sonotube	n/a
h9	"1/2" [13] Dia., Bent Rebar, unbent 74" [1880]		
i1	11 1/8" [283] Dia. x 1" [25] Thick Ballast Plate	ASTM A36	n/a
i2	"1/2" [13] Dia. UNC, 5 1/2" [140] Long Hex		
i3	1/2" [13] Dia. Plain Round Washer	ASTM F844	n/a

Table E-6. Bill of Materials, Test No. ILT-2

Item No.	Description	Material Specification	Material Cert Reference
a1	12'-6" [3810] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv. (ASTM A653)	R#16-0005 H#9411949
a2	12'-6" [3810] W-Beam MGS End Section	12 gauge [2.7] AASHTO M180 Galv. (ASTM A653)	B8479 R#15-0602 H#9511340
a3	6'-3" [1905] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv. (ASTM A653), CERT says AASHTO M180 does not say A653	R#12-0368 H#515691
a4	W6x8.5 [W152x12.6] 72" Long [1829] Steel Post	ASTM A992 or ASTM A36 Min. 50 ksi [345 MPa] Steel Galv. Per AASHTO M111 (ASTM A123)	H#55044251 R#16-635
a5	6x12x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	n/a
a6	16D Double Head Nail	-	n/a
b1	BCT Timber Post - MGS Height	SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face)	R#16-635 Charge#21638
b2	72" [1829] Long Foundation Tube	ASTM A500 Grade B Galv. Per AASHTO M11 (ASTM A123), A-500 w/o Grade B was used	H#0173175 R#15-0157
b3	Ground Strut Assembly	ASTM A36 Steel Galv. Per AASHTO M111 (ASTM A123) - South Strut: A-1011-SS, Yield Strength 48,380 psi, Tensile Strength 64,020 psi	North Strut: R#090453-8 South Strut: R#15-0157 H#163375
b4	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40 Galv. Per AASHTO M111 (ASTM A123), ASTM A500 Grade B, not Galvanized was used	R#15-0626 H#E86298
b5	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel Galv. Per AASHTO M111 (ASTM A123)	North: A3 Black Paint H#V911470 South: R#09-0453 H#6106196
b6	Anchor Bracket Assembly	ASTM A36 Steel Galv. Per AASHTO M111 (ASTM A123)	
Not listed	BCT Anchor Cable End Threaded Rods		R#15-0601 White Paint H#10348290 AND H#10350220

Table E-7. Bill of Materials, Test No. ILT-2 (Cont'd)

Item No.	Description	Material Specification	Material Cert Reference
c1	BCT Anchor Cable End Swaged Fitting	Grade 5 - Galv. Fitting Per AASHTO M232 (ASTM A153), Stud Per AASHTO M232 or M298 (ASTM A153 or B695), CERT gives a variety of different ASTM numenclatures not listed here	R#15-0601 H#498219 AND H#498221
c2	3/4" [190] Dia. 6x19, 24 1/2" [622] Long IWRC IPS Wire Rope	IPS Galv. Per AASHTO M30 (ASTM A741) Type II Class A	R#15-0601 H#53131485, H#53127002, 10342780, 10207730, 25807
c3	115-HT Mechanical Splice - 3/4" [19] Dia.	As Supplied	n/a
c4	Crosby Heavy Duty HT - 3/4" [19] Dia. Cable Thimble	Stock No. 1037773 - Galv. - As Supplied	n/a
c5	Crosby G2130 or S2130 Bolt Type Shackle - 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 - As Supplied	n/a
c6	Chicago Hardware Drop Forged Heavy Duty Eye Nut - Drilled and Tapped 1/2" [38] Dia. - UNC 6 [M36x4]	Stock No. 107 - As Supplied	n/a
c7	TLL-50K-PTB Load Cell	-	n/a
d1	45' [13716] Long Aluminum Pole, Pay Item No. 903A10, JS830003	6063-T4 Aluminum Alloy	Cast#516133
d2	CS-370 Anchor Base, Model No. 10R145153B9T	ASTM B108/B108M-12 VO#228196	H#096-16
d3	Truss, Model No. 1TA1566C60ZA	6063-T6 Aluminum Alloy, Valmont Order#327087-1-1	Cast#54405
d4	1" [25] Dia. UNC, 4" [102] Long Hex Head Bolt	Bolt - ASTM A449 or SAE J429 Grade 5 Galv. Per ASTM A153, Nut - ASTM A563DH Galv. Per ASTM A153	as supplied
d5	1" [25] Dia. Hardened Flat Washer	ASTM A153 Galv. Low Carbon Steel	as supplied

Table E-8. Bill of Materials, Test No. ILT-2 (Cont'd)

Item No.	Description	Material Specification	Material Cert Reference
d6	1" [25] Dia. 1/2" [13] Thick Flat Washer	Q235 Steel, Galv. Per ASTM A123, Coating Grade 50	as supplied
d7	1/2" [13] Dia. UNC x 3" [76] Long Hex Head Bolt and Nut	Bolt - 304 Stainless Steel or ASTM F593, Nut - ASTM F594 Stainless Steel	as supplied
d8	1/2" [13] Dia. Flat washer	18-8 Stainless Steel	as supplied
d9	1/2" [13] Dia. Split Lock Washer	18-8 Stainless Steel	as supplied
d10	1/4" [6] Dia. x 3/4" [19] Flat Head Screw	18-8 Stainless Steel	as supplied
f1	5/8" [16] Dia. UNC x 14" [356] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	R#15-0515 H#26859
f2	5/8"[16] Dia. UNC x 1 1/2" [38] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	Bolt: R#15-0602 H#20337380 Nut: R#15-0602 H#103510040
f3	7/8" Dia. [22] UNC x 7 1/2" [191] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	Bolts: R#15-0600 L#69685 H#2038622 Nuts: 15-0600 L#WA651 H#12101054
f4	5/8" [16] Dia. UNC x 10" [254] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	Bolts: R#16-0226 L#206239 H#DL15102793 Nuts: R#16-0217 P#36713 C#210101523

Table E-9. Bill of Materials, Test No. ILT-2 (Cont'd)

Item No.	Description	Material Specification	Material Cert Reference
f5	5/8" [16] Dia. x 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt ASTM A307Galv., Nut ASTM A563A Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	Bolts:R#16-0009 L#25203 H#10207560 Nuts: R#16-0217 P#36713 C#210101523
f6	5/8" [16] Dia. UNC x 10" [254] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM 563A Galv. Per AASHTO 232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	R#15-0627 L#1740530 LH#2029797
g1	5/8" [16] Dia. Plain Round Washer	ASTM F844 Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	n/a
g2	7/8" [22] Dia. Plain Round Washer	ASTM F844 Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	R#12-0037 L#HO1788740 H#82800072 COC
h1	1" [25] Dia., 84" [2134] Long Anchor Bolt	ASTM F1554 Grade 105 or A449 Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	R#17-75 L#36429 H#5802372003
h2	1" [25] Dia. UNC Hex Nut	ASTM A563DH or A194 Gr. 2H Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	R#17-78 Part#38210 Control#210110788 L#366055B H#DL15103032
h3	1" [25] Dia. Hardened Round Washer	ASTM F436 Galv. Per ASTM B695	R#17-78 Part#33176 L#322CAFN91 H#2MV88
h4	1" [25] Dia. Split Lock Washer	Steel Galv. Per AASHTO M232 (ASTM A153) for Class C or Per AASHTO M298 (ASTM B695) for Class 50	R#17-78 Part#33788 Control#120216445 H#

Table E-10. Bill of Materials, Test No. ILT-2 (Cont'd)

Item No.	Description	Material Specification	Material Cert Reference
h5	"1/2" [13] Dia. Bent Rebar, unbent 1517" [38532]		
h6	3/4" [19] Dia., 90" [2286] Long Rebar	Epoxy-Coated ASTM A615 Gr. 60	R#16-658 H#KN15101296
h7	Light Pole Concrete Foundation	Min. f'c = 3,500 psi [24.1 MPa]	R#17-76
h8	30" [762] Dia. x 6" [152] Sonotube	Sonotube	n/a
h9	"1/2" [13] Dia., Bent Rebar, unbent 74" [1880]		
i1	11 1/8" [283] Dia. x 1" [25] Thick Ballast Plate	ASTM A36	n/a
i2	"1/2" [13] Dia. UNC, 5 1/2" [140] Long Hex		
i3	1/2" [13] Dia. Plain Round Washer	ASTM F844	n/a

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HEAT MASTER LISTING

Heat No.	Mill#	Name	YR	Primary Grade	Secondary Grade	CODE	Original Heat Number
9411949	ARC03	ARCELOR MITTAL USA, LLC	15	1021		8534	

******* Chemistry *******

Cr	Si	P	C	Mn	S	Cu	Ni	Mo	Sn	Al	V	Cb	N	Ti
0.0400	0.0100	0.0100	0.2100	0.7500	0.0060	0.0200	0.0100	0.0100	0.0020	0.0580	0.0020	0.0020	0.0042	0.0020

Ca
0.0003

******* Mechanical Test *******

YIELD	TENSILE	ELONGATION	ROCKWELL
56527	75774	27.15	78

Guardrail W-Beam
20ct/25'
100ct/12'
10ct/25ft w/MGS Anchor Panel
July 2015 SMT

Figure E-1. 12-ft 6-in. (3.8-m) Long W-Beam MGS Section, Test Nos. ILT-1 and ILT-2

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

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

Test Report
Ship Date: 7/9/2015
Customer P.O.: 4500274709/ 07/07/2015
Shipped to: UNIVERSITY OF NEBRASKA-LINCOLN
Project: TESTING COIL
GHP Order No.: 183306

HT # code	Heat #	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
8534	9411949	0.21	0.75	0.01	0.006	0.01	75774	56527	27.15	10	A	2	12GA 25FT WB T2 MGS ANCHOR PANEL
8534	9411949	0.21	0.75	0.01	0.006	0.01	75774	56527	27.15	100	A	2	12GA 12FT6IN/3FT1 1/2IN WB T2
8534	9411949	0.21	0.75	0.01	0.006	0.01	75774	56527	27.15	20	A	2	12GA 25FT0IN 3FT1 1/2IN WB T2

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: ______________________
Andrew Artar, VP of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 17 day of July, 2015

Notary Public, State of Ohio

NOTARIAL SEAL
STATE OF OHIO

DAWN R. BATTON
NOTARY PUBLIC
STATE OF OHIO
Comm. Expires
March 03, 2018
Recorded in
Portage County

Figure E-2. 12-ft 6-in. (3.8-m) Long W-Beam MGS Section, Test Nos. ILT-1 and ILT-2

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Customer:	MIDWEST MACHINERY & SUPPLY CO. P. O. BOX 703 MILFORD,NE,68405	Test Report Ship Date: Customer P.O.: Shipped to: Project: GHP Order No.:	 6/2/2015 3078 MIDWEST MACHINERY & SUPPLY CO. STOCK 181769

HT # code	Heat #	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
8424	4135788	0.2	0.72	0.01	0.008	0.01	77194	55406	25.48	10	A	1	12GA 15FT 7.5IN WB T1 HS 2@6FT3IN 1@3FT1.6IN
8331	4134527	0.24	0.77	0.011	0.005	0.01	82673	63255	27.87	40	A	1	12GA 12FT6IN/3FT1 1/2IN WB T1
8479	9511340	0.21	0.74	0.009	0.005	0.01	77105	59917	21	40	A	1	12GA 12FT6IN/3FT1 1/2IN WB T1
8244	31504980	0.2	0.85	0.01	0.002	0.03	84559	62542	13.3	40	A	1	12GA 12FT6IN/3FT1 1/2IN WB T1
8418	31512700	0.22	0.84	0.008	0.03	0.03	77442	54762	24.66	16	A	1	12GA 12FT6IN/3FT1 1/2IN WB T1
8420	C74349	0.2	0.49	0.008	0.002	0.03	79319	56709	23.4	10	A	1	12 GA 12FT6IN WB T1 FLEAT-SKT COMBO PAN
8367	4168272	0.21	0.78	0.01	0.007	0.01	78865	55889	21.81	6	A	1	12 GA 12FT6IN WB T1 FLEAT-SKT COMBO PAN
8479	9511340	0.21	0.74	0.009	0.005	0.01	77105	59917	21	100	A	1	12GA 25FT0IN 3FT1 1/2IN WB T1
8466	4135789	0.21	0.76	0.009	0.008		79006	61740	23.78	6	A	1	12GA 9FT4 1/2IN 3FT1 1/2IN WB T1

R#15-0602 H#8479

MGS 12'6" Guardrail W-Beam QTY 40

June 2015 SMT

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: ____________________
Andrew Artar, VP of Sales & Marketing
Gregory Highway Products, Inc.

NOTARIAL SEAL
STATE OF OHIO

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2019

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 3 day of June, 2015

Notary Public, State of Ohio

Figure E-3. 12-ft 6-in. (3.8-m) Long W-Beam MGS Section, Test Nos. ILT-1 and ILT-2

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1164746
Customer PO: 2563
BOL Number: 69500
Document #: 1
Shipped To: NE
Use State: KS

As of: 5/16/12

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
			M-180	A	2	515664	64,600	74,600	25.0	0.067	0.740	0.009	0.008	0.010	0.019	0.000	0.022	0.000	4
			M-180	A	2	515665	64,300	73,800	27.0	0.063	0.750	0.012	0.008	0.007	0.018	0.000	0.027	0.000	4
			M-180	A	2	515666	64,700	74,200	27.0	0.067	0.740	0.009	0.008	0.010	0.031	0.000	0.023	0.000	4
			M-180	A	2	515669	64,500	74,100	26.0	0.063	0.790	0.014	0.007	0.009	0.017	0.000	0.028	0.000	4
			M-180	A	2	515690	63,000	71,800	27.0	0.059	0.720	0.010	0.008	0.013	0.024	0.000	0.042	0.000	4
			M-180	A	2	515691	64,000	72,300	27.0	0.060	0.740	0.009	0.008	0.010	0.021	0.000	0.032	0.000	4
			M-180	A	2	515696	62,900	72,500	28.0	0.058	0.740	0.013	0.008	0.011	0.029	0.000	0.046	0.000	4
			M-180	A	2	515696	63,900	73,400	29.0	0.058	0.740	0.013	0.008	0.011	0.029	0.000	0.046	0.000	4
			M-180	A	2	515700	67,800	77,700	28.0	0.065	0.800	0.013	0.009	0.012	0.036	0.000	0.035	0.000	4
			M-180	A	2	515701	64,300	74,200	28.0	0.064	0.800	0.013	0.010	0.010	0.030	0.000	0.029	0.000	4
			M-180	A	2	515701	65,200	73,700	28.0	0.064	0.800	0.013	0.010	0.010	0.030	0.000	0.029	0.000	4
			M-180	A	2	521448	65,400	75,600	28.0	0.074	0.078	0.014	0.012	0.010	0.060	0.000	0.058	0.000	4
			M-180	A	2	616037	67,800	78,000	26.0	0.065	0.830	0.014	0.007	0.016	0.023	0.000	0.026	0.000	4
			M-180	A	2	616038	65,500	73,700	24.0	0.070	0.740	0.009	0.006	0.015	0.014	0.000	0.018	0.000	4
			M-180	A	2	616041	63,700	74,300	28.0	0.065	0.760	0.013	0.008	0.009	0.028	0.000	0.029	0.000	4
			M-180	A	2	616043	62,700	71,800	27.0	0.067	0.740	0.013	0.008	0.010	0.034	0.000	0.031	0.000	4
			M-180	A	2	616043	64,900	77,000	25.0	0.067	0.740	0.013	0.008	0.010	0.034	0.000	0.031	0.000	4
			M-180	A	2	616067	63,200	73,300	28.0	0.063	0.750	0.013	0.010	0.012	0.035	0.000	0.032	0.000	4
			M-180	A	2	616069	62,600	73,100	26.0	0.064	0.750	0.008	0.007	0.011	0.026	0.000	0.022	0.000	4
			M-180	A	2	616070	62,800	73,000	29.0	0.060	0.730	0.014	0.008	0.017	0.021	0.000	0.032	0.000	4
			M-180	A	2	616071	64,000	74,000	28.0	0.061	0.760	0.016	0.007	0.011	0.021	0.000	0.028	0.000	4
			M-180	A	2	616072	63,800	74,200	29.0	0.066	0.750	0.014	0.009	0.010	0.026	0.000	0.039	0.000	4
			M-180	A	2	616073	63,900	73,300	27.0	0.064	0.760	0.016	0.009	0.012	0.024	0.000	0.041	0.000	4
			M-180	A	2	616073	65,000	74,500	28.0	0.064	0.760	0.016	0.009	0.012	0.024	0.000	0.041	0.000	4
			M-180	A	2	621267	65,000	74,800	29.0	0.066	0.780	0.015	0.013	0.009	0.068	0.000	0.055	0.000	4
22	12365G	T12/12'6/8@1'6.75/S	M-180	A	2	151877	58,680	77,470	26.0	0.190	0.720	0.013	0.004	0.010	0.120	0.00	0.050	0.002	4

Figure E-4. 6-ft 3-in. (1,905-mm) Long W-Beam MGS Section, Test Nos. ILT-1 and ILT-2

HIGHWAY SAFETY CORP

P.O. BOX 358
GLASTONBURY, CT 06033

CERTIFICATE OF COMPLIANCE/ANALYSIS REPORT

SOLD TO:
MIDWEST MACHINERY & SUPPLY
974-238th Road

Milford, NE, USA

SHIP TO:
MIDWEST MACHINERY & SUPPLY
974 238TH ROAD
MILFORD,

INVOICE / S.O.: 0191502 / 0136701
CUSTOMER P.O.: 3262

REFERENCE: STOCK
DATE SHIPPED: 6/3/2016

QTY:	HEAT/LOT NO:	ITEM NUMBER:	YIELD:	CC:	TENSILE:	%ELONG:	DESCRIPTION:	C:	Mn:	P:	S:	Si:	Cl:	Type	ACW
850		T-POG060080600		IB-B0600800			THRIE POST W06 x 008.5# x 06'00 GALV								
(450)	55044251														
(400)	55044248														

ALL STEEL USED IN MANUFACTURING IS MADE AND MELTED IN THE USA, INCLUDING HARDWARE FASTENERS, AND COMPLIES WITH THE BUY AMERICA ACT. ALL COATINGS PROCESSES ARE PERFORMED IN THE USA AND COMPLY WITH THE BUY AMERICA ACT. BOLTS COMPLY WITH ASTMA-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153, UNLESS OTHERWISE STATED. NUTS COMPLY WITH ASTMA-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 AND/OR F-844 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153, UNLESS OTHERWISE STATED. ALL GUARDRAIL MEETS AASHTO M-180 AND ALL STRUCTURAL STEEL MEETS AASHTO M-270. ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTMA-123. ALL OTHER ITEMS COMPLY WITH AASHTO M-111, M-165, M-133, M-265, ASTM A36, ASTMA-709, ASTMA-123, ASTM A505, AND ASTMA588 SPECIFICATIONS IF APPLICABLE. COMPLIANCE WITH ALL SPECIFICATIONS OF DEPARTMENT OF PUBLIC WORKS, DEPARTMENT OF HIGHWAYS AND TRANSPORTATION, DIVISION OF ROADS AND BRIDGES AND STATE HIGHWAY ADMINISTRATION IS MET IN ALL RESPECTS.

GERDAU

CERTIFIED MATERIAL TEST REPORT

Page 1/1

US-ML-CARTERSVILLE
384 OLD GRASSDALE ROAD NE
CARTERSVILLE, GA 30121
USA

CUSTOMER SHIP TO
HIGHWAY SAFETY CORP
473 W FAIRGROUND ST
MARION,OH 43302-1701
USA

CUSTOMER BILL TO
HIGHWAY SAFETY CORP

GLASTONBURY,CT 06033-0358
USA

GRADE: A992/A709-36

SHAPE / SIZE: Wide Flange Beam / 6 X 8.5# / 150 X 13.0

DOCUMENT ID: 0000006197

LENGTH: 42'00"

WEIGHT: 44,982 LB

HEAT / BATCH: 55044251/02

SALES ORDER: 3399484/000010

CUSTOMER MATERIAL Nº: IB-B0600800

SPECIFICATION / DATE or REVISION
ASTM A6-14
ASTM A709-13A
ASTM A992-11
CSA G40.21-13 345WM

CUSTOMER PURCHASE ORDER NUMBER: 000167 PO#1677003

BILL OF LADING: 1323-0000066391

DATE: 03/16/2016

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %
0.14	0.90	0.014	0.019	0.19	0.28	0.08	0.09	0.023	0.012	0.017	0.000

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	G/L Inch	Elong. %
56700	77700	391	536	8.000	21.30
54800	75700	378	522	8.000	22.60

COMMENTS / NOTES

Figure E-5. Steel Posts, Test Nos. ILT-1 and ILT-2

CENTRAL NEBRASKA WOOD PRESERVERS, INC.
P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

R#16-635 BCT Posts
bought for MGS-IL Light Pole

Date: 1/27/16

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 10053289

Customer PO# 3196 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
GR6806PST	6x8-6' Post	70	21637	.657
GR6806PST	6x8-6' Post	35	21677	.736
GS6846PST	5.5x7.5-46" BCT PST	42	21638	.642
GR6806.5PST	6x8-6.5' PST	35	21637	.657
T004075	6x8-14" BLK	126	21201	.647
GR6814"	6x8-14" OCD BLK	126	21638	.642
GR6806.5CRT	6x8-6.5' CRT PST	70	21637	.657

I certify the above referenced material has been produced, treated and tested in accordance with AWPA standards and conforms to AASHTO M133 & M168.

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards, Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

Nick Sowl, General Counsel

1/27/16
Date

Figure E-6. BCT Timber Posts, Test Nos. ILT-1 and ILT-2

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: STOCK

Order Number: 1215324 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2884
BOL Number: 80821 Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 4/14/14

Foundation Tubes Green Paint
R#15-0157 September 2014 SMT

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	701A	.25X11.75X16 CAB ANC	A-36			A3V3361	48,600	69,000	29.1	0.180	0.410	0.010	0.005	0.040	0.270	0.000	0.070	0.001	4
	701A		A-36			JJ4744	50,500	71,900	30.0	0.150	1.060	0.010	0.035	0.240	0.270	0.002	0.090	0.021	4
12	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
15	736G	5'/TUBE SL/.188"X6"X8"FLA	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
12	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
5	783A	5/8X8X8 BEAR PL 3/16 STP	A-36			10903960	56,000	79,500	28.0	0.180	0.810	0.009	0.005	0.020	0.100	0.012	0.030	0.000	4
	783A		A-36			DL13106973	57,000	72,000	22.0	0.160	0.720	0.012	0.022	0.190	0.360	0.002	0.120	0.050	4
20	3000G	CBL 3/4X6'6/DBL	HW			99692													
25	4063B	WD 6'0 POST 6X8 CRT	HW			43360													
15	4147B	WD 3'9 POST 5.5"X7.5"	HW			2401													
20	15000G	6'0 SYT PST/8.5/31" GR HT	A-36			34940	46,000	66,000	25.3	0.130	0.640	0.012	0.043	0.220	0.310	0.001	0.100	0.002	4
10	19948G	.135(10Ga)X1.75X1.75	HW			P34744													
2	33795G	SYT-3"AN STRT 3-HL 6'6	A-36			JJ6421	53,600	73,400	31.3	0.140	1.050	0.009	0.028	0.210	0.280	0.000	0.100	0.022	4
4	34053A	SRT-31 TRM UP PST 2'6.625	A-36			JJ5463	56,300	77,700	31.3	0.170	1.070	0.009	0.016	0.240	0.220	0.002	0.080	0.020	4

Figure E-7. Foundation Tubes, Test Nos. ILT-1 and ILT-2

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: STOCK

Order Number: 1214903 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2878
BOL Number: 80278 Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 3/7/14

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
36	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
20	3000G	CBL 3/4X6'6/DBL	HW			98790													
22	9852A	STRUT & YOKE ASSY	A-1011-SS			163375	48,380	64,020	32.9	0.190	0.520	0.011	0.003	0.030	0.110	0.000	0.050	0.000	4
	9852A		A-36			11237730	45,500	70,000	30.0	0.170	0.500	0.010	0.008	0.020	0.080	0.000	0.070	0.001	4

Ground Strut Green Paint
R#15-0157 September 2014 SMT

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

Figure E-8. Ground Strut Assembly (South Strut), Test Nos. ILT-1 and ILT-2

425 E. O'Connor
Lima, OH

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

LINCOLN, NE 68501-1097

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

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

Trinity Highway Products, LLC

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

NCHRP Report 350 Compliant

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

MGSBR

Ground Strut

090453-8

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public:
Commission Expires

Trinity Highway Products, LLC
Certified By:

2

Figure E-9. Ground Strut Assembly (North Strut), Test Nos. ILT-1 and ILT-2

09Mar15 13:22 TEST CERTIFICATE No: MAR 268339

INDEPENDENCE TUBE CORPORATION
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 4500240795
Rel
S/O No MAR 280576-001
B/L No MAR 163860-003 Shp 09Mar15
Inv No Inv

Sold To: (5016)
STEEL & PIPE SUPPLY
1003 FORT GIBSON ROAD
CATOOSA, OK 74015

Ship To: (1)
STEEL & PIPE SUPPLY
1003 FORT GIBSON ROAD
CATOOSA, OK 74015

Tel: 918-266-6325 Fax: 918 266-4652

CERTIFICATE of ANALYSIS and TESTS Cert. No: MAR 268339
05Mar15

Part No 0010
ROUND A500 GRADE B(C)
2.375"OD (2"NPS) X SCH40 X 21'

		Pcs	Wgt
		111	8,508

Heat Number	Tag No	Pcs	Wgt
E86298	927111	37	2,836
	YLD=69600/TEN=79070/ELG=24.2		
E86298	927113	37	2,836
E86298	927114	37	2,836

Heat Number *** Chemical Analysis ***
E86298 C=0.1700 Mn=0.5100 P=0.0100 S=0.0110 Si=0.0190 Al=0.0450
Cu=0.0300 Cr=0.0300 Mo=0.0030 V=0.0010 Ni=0.0100 Cb=0.0010
MELTED AND MANUFACTURED IN THE USA

R#15-0626 H#E86298
BCT Pipe Sleeves
June 2015 SMT

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.

CURRENT STANDARDS:
.................................A500/A500M-13
.................................A513-12
.................................A252-10
.................................A847/A847M-12

MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH
ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

Figure E-10. 6-in. (152-mm) Long BCT Post Sleeve, Test Nos. ILT-1 and ILT-2

Certified Analysis

Trinity Highway Products, LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1145215
Customer PO: 2441
BOL Number: 61905
Document #: 1
Shipped To: NE
Use State: KS

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	[illegible]
10	206G	T12/6'3/S	M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	[illegible]	[illegible]	[illegible]	[illegible]
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	[illegible]	[illegible]	[illegible]
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	[illegible]	[illegible]	[illegible]
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	[illegible]	[illegible]	[illegible]	[illegible]
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	[illegible]	[illegible]	[illegible]	[illegible]
55	260G	T12/25/6'3/S	M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	[illegible]	[illegible]	[illegible]
			M-180	A	2	139206	61,730	78,580	26.0	0.180	0.710	0.012	0.004	0.020	0.140	[illegible]	[illegible]	[illegible]
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	[illegible]	[illegible]	[illegible]
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	[illegible]	[illegible]	[illegible]	[illegible]
			M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	[illegible]	[illegible]	[illegible]
	260G		M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	[illegible]	[illegible]	[illegible]
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	[illegible]	[illegible]	[illegible]
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	[illegible]	[illegible]	[illegible]
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	[illegible]	[illegible]	[illegible]
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	[illegible]	[illegible]	[illegible]	[illegible]
38	701A	.25X11.75X16 CAB ANC	A-36			V911470	51,460	71,280	27.5	0.120	0.800	0.015	0.030	0.190	0.300	[illegible]	[illegible]	[illegible]
	701A		A-36			N3540A	46,200	65,000	31.0	0.120	0.380	0.010	0.019	0.010	0.180	[illegible]	[illegible]	[illegible]
24	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.180	[illegible]	[illegible]	[illegible]
24	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.180	[illegible]	[illegible]	[illegible]
22	782G	5/8"X8"X8" BEAR PL/OF	A-36			18486	49,000	78,000	25.1	0.210	0.860	0.021	0.036	0.250	0.260	[illegible]	[illegible]	[illegible]
25	974G	T12/TRANS RAIL/6'3"/3'1.5	M-180	A	2	140735	61,390	80,240	27.1	0.200	0.740	0.014	0.003	0.010	[illegible]	[illegible]	[illegible]	[illegible]

Figure E-11. Anchor Bearing Plate, Test Nos. ILT-1 and ILT-2

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097
Project: RESALE

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

As of: 6/20/08

Qty	Part#	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	6G	12/63/S	M-180	A		84964	64,230	81,300	25.4	0.180	0.720	0.012	0.001	0.040	0.080	0.000	0.060	0.000	4
20	701A	.25X11.75X16 CAB ANC	A-36			4153095	44,900	60,800	34.0	0.240	0.750	0.012	0.003	0.020	0.020	0.000	0.040	0.002	4
10	742G	6'0 TUBE SL/.188X8X6	A-500			A8P1160	74,000	87,000	25.2	0.050	0.670	0.013	0.005	0.030	0.220	0.000	0.060	0.021	4
20	782G	5/8"X8"X8" BEAR PL/OF	A-36			6106195	46,700	69,900	23.5	0.180	0.830	0.010	0.005	0.020	0.230	0.000	0.070	0.006	4
40	907G	12/BUFFER/ROLLED	M-180	A		L0049	54,200	73,500	25.0	0.160	0.700	0.011	0.008	0.020	0.200	0.000	0.100	0.000	4

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

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

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

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

Notary Public:
Commission Expires

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

Trinity Highway Products , LLC
Certified By: Stefanie Ornelas

Figure E-12. Anchor Bearing Plate, Test Nos. ILT-1 and ILT-2

KEYSTONE THREADED PRODUCTS — **MATERIAL CERTIFICATION** — 7600 HUB PARKWAY, VALLEY VIEW, OHIO 44125

Sold To:	ASSEMBLY SPECIALTY PRODUCTS INC.	Order Date	8/21/14
	14700 BROOKPARK ROAD	Order No.	35651
	CLEVELAND, OHIO 44135	Shipped Date	1/05/15
		Invoice No.	70158-01

FULL THREAD STUDS - PLAIN FINISH

4867 Pcs. 1"-8 X 8-3/4"

PART NO. C-1681

MATERIAL DESCRIPTION

Weight	Size	Length	Shape	Grade	Type
7,980 LBS.	0.9090 / 0.9090	168.00	RND	1045	CD

Heat No.	Order No.	Rec. Date	Code
10348290	0024549	12/10/14	TSW

SPECIFICATIONS

ASTM A108-13 SAE J403

CHEMICALS

ELEMENTS:	C	MN	P	S	SI	NI	CR
AMOUNTS	0.4800	0.8400	0.0110	0.0250	0.2600	0.0500	0.1000
ELEMENTS:	MO	CU	SN	V	AL	N	B
AMOUNTS	0.0200	0.1500	0.0070	0.0030	0.0230	0.0060	0.0001
ELEMENTS:	TI	NB					
AMOUNTS	0.0010	0.0010					

STEEL MELTED AND MANUFACTURED IN THE U.S.A.

KIMBERLY STRAWBRIDGE-FOERSTER, NOTARY PUBLIC, STATE OF OHIO, COMM. EXP. MAR 12, 2016

RECEIVED JAN 05 2015

State of Ohio
County of Cuyahoga

Sworn to and subscribed before me
This 29 Day of DEC 20 14

We certify the foregoing a true and accurate report as represented by our suppliers.

Figure E-13. BCT Anchor Cable, Test Nos. ILT-1 and ILT-2

TAUBENSEE STEEL & WIRE COMPANY PAGE 3
600 DIENS DRIVE WHEELING, IL 60090
(847) 459-5100

MATERIAL ANALYSIS CERTIFICATION

SOLD TO: KEYSTONE THREADED PROD. (B)
P.O. BOX 31059
INDEPENDENCE OH 441310059

CUST P.O. #: SEE BELOW
TSW ORDER #: 3416130
TSW INVOICE #:

THE FOLLOWING TEST CONFORMS TO THE REQUIREMENTS OF THE GRADE SPECIFICATION ORDERED AND LISTED BELOW:

MATERIAL DESCRIPTION:

1000 SERIES(CARBON .29-.55%) COLD DRAW ROUND BARS TO ASTM A108-13 & SAE J403
"STEEL MELTED & MANUFACTURED IN USA"

PART NUMBER # 104509100-002
P.O.# 0024549

HEAT	SIZE	GRADE	LENGTH	WEIGHT	AVG TENSILE
10348290	.91	1045	168	7980	
10350220	.91	1045	168	8224	

HEAT:	CHEMICAL ANALYSIS:				
10348290	C 0.480	Mn 0.840	P 0.011	S 0.025	Si 0.260
	Ni 0.050	Cr 0.100	Mo 0.020	Al 0.023	B 0.0001
	Sn 0.007	V 0.003	N 0.006	Nb 0.001	Ti 0.001
	Cu 0.150	Pb .000/.000			
10350220	C 0.480	Mn 0.860	P 0.014	S 0.027	Si 0.280
	Ni 0.060	Cr 0.120	Mo 0.020	Al 0.025	B 0.0002
	Sn 0.007	V 0.002	N 0.005	Nb 0.001	Ti 0.002
	Cu 0.120	Pb .000/.000			

MECHANICAL PROPERTIES:
THE FOLLOWING MECHANICAL PROPERTIES SHOULD REPORT TYPICAL TO ASTM A108-95:
TENSILE, YIELD, ELONGATION, REDUCTION OF AREA, HARDNESS & HARDENABILITY

WE CERTIFY THAT THE INFORMATION SHOWN ABOVE IS TRUE AND EXACT AS CONTAINED IN THE PERMANENT ELECTRONIC RECORDS OF TAUBENSEE STEEL & WIRE CO.

STATE OF ILLINOIS
COUNTY OF COOK

Authorized Electronic Signature
Chuck Hrycko

Quality Technician

Figure E-14. BCT Anchor Cable, Test Nos. ILT-1 and ILT-2

TEST REPORT

REQ., JOB, CONTRACT NO.	PURCHASE ORDER NO.
	127234

VENDOR
ArcelorMittal USA Inc.
INDIANA HARBOR LONG CARBON
3300 DICKEY ROAD
EAST CHICAGO, INDIANA 46312-1644

SHIPPER'S NO.	MILL ORDER NO.
	294381
REPORT PRINT DATE: 09/26/2014	

TEST REPORT TO:
HERCULES DRAWN STEEL CORP
10221 CAPITAL AVE
OAK PARK MI 48237

SHIP TO:
HERCULES DRAWN STEEL
38901 AMRHEIN RD
LIVONIA MI, 48151

CMS (REG TM) SQ HOT ROLLED ROUNDS SAE 1035 /ESMS-1035 09/25/96 / FINE GRAIN/
/ASTM A576-90b (Reapproved 2012)/RESTRICTED MAX INCIDENTAL ELEMENTS/MRR FOR SPEC
SURF, SND & CLEAN/ASTM A29/

RND 1.6875 IN X 23 FT 7 IN TO 35 FT

HEAT: 498221					
	C : 0.35	Mn: 0.69	P : .013	S : .025	Si: 0.24
	Cu: .24	Ni: 0.11	Cr: 0.12	Mo: .03	Al: .027
	Cb: <.008	V : .003	N : .010	Ti: .001	

R.RATIO: 21.9:1 DI VALUE: 1.13

PART NUMBER: 1005437

MATERIAL IS FREE FROM SURFACE MERCURY CONTAMINATION AS OF THE TIME OF
SHIPMENT BASED ON PRESENT METHODS & EQUIPMENT FOR DETECTION OF THIS
KIND OF CONTAMINATION.
THIS MATERIAL HAS RECEIVED NO WELD REPAIR.
MATERIAL MEETS AUSTENITIC GRAIN SIZE REQUIREMENT OF 5 OR FINER
THIS STEEL IS WARRANTED TO MEET OR EXCEED MACRO/RATING OF " S4 R4 C4"
THIS STEEL IS WARRANTED TO MEET OR EXCEED MICROCLEANLINESS/ RATING OF "S5-O5"
PRODUCT WAS ROLLED AT ARCELORMITTAL EAST CHICAGO, INDIANA, USA
FROM CONTINUOUSLY BILLET CAST, ELECTRIC ARC FURNACE STEEL
MELTED AT ARCELORMITTAL EAST CHICAGO, INDIANA, USA.

Assembly Specialty Products, Inc.
14700 Brookpark Rd.
Cleveland, OH 44135

RECEIVED
DEC 30 2014

Unless otherwise stated, the steel described herein was manufactured, inspected and tested in accordance with the requirements of the contract or purchase order and conform to those requirements. This steel is compliant with European Union Directive 2002/95/EC. No mercury, radium or alpha source materials were used in the production of this steel. This steel has not been welded nor repair welded. Heat analyses are reported in weight percent. Heat analyses and test results marked with an asterisk (*) were reported by a ArcelorMittal USA Inc., Indiana Harbor Long Carbon approved third party. The "+" sign at the beginning of any line indicates an amendment to that line from a previously issued report for the same heat/order. All tests were performed by ArcelorMittal USA Inc., Indiana Harbor Long Carbon, in accordance with the following, unless otherwise specified: Chemistry per ASTM E415 & E1019; Hardenability per ASTM A255 and SAE J406; Macrostructure per ASTM E381 & E1180; Mechanical Properties per ASTM A370, E8 & E23; Hardness per ASTM E10-Type A, E18 & SAE J417; Cleanliness per SAE J421; Microstructure/Microcleanliness per ASTM E3, E45, E112, E1077, J419, J422 & JIS G0555; Rounding per ASTM E29. Tested per most recent standard, unless otherwise noted. Measurement uncertainty was determined and is available upon request. We hereby certify that the heat and/or test results in this report are applicable only to the items described herein, and are correct as contained in the records of the Company. This document shall not be reproduced except in full.

The management system governing the manufacturing processes of this product, at ArcelorMittal USA Inc., Indiana Harbor Long Carbon, is ISO/TS 16949:2009 certified, Certificate No. 44576; ISO 14001:2004 certified, Certificate No. 36274 and A2LA accredited in the fields of: Chemical, Mechanical and Environmental Testing-Certificate Nos. 111.01, 111.02 and 111.03

Dennis Harpole
Manager - Quality & Technical Services

Rev. 9/11/13

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Figure E-15. BCT Anchor Cable, Test Nos. ILT-1 and ILT-2

TEST REPORT

REQ., JOB, CONTRACT NO.	PURCHASE ORDER NO. 127234
SHIPPER'S NO.	BILL ORDER NO. 294381
REPORT PRINT DATE 09/26/2014	

VENDOR
ArcelorMittal USA Inc.
INDIANA HARBOR LONG CARBON
3300 DICKEY ROAD
EAST CHICAGO, INDIANA 46312-1644

TEST REPORT TO:	SHIP TO:
HERCULES DRAWN STEEL CORP	HERCULES DRAWN STEEL
10221 CAPITAL AVE	38901 AMRHEIN RD
OAK PARK MI 48237	LIVONIA MI, 48151

CMS (REG TM) SQ HOT ROLLED ROUNDS SAE 1035 /ESMS-1035 09/25/96 / FINE GRAIN/
/ASTM A576-90b (Reapproved 2012)/RESTRICTED MAX INCIDENTAL ELEMENTS/MRR FOR SPEC
SURF, SND & CLEAN/ASTM A29/

RND 1.6875 IN X 23 FT 7 IN TO 35 FT

HEAT:					
498219	C : 0.35	Mn: 0.66	P : .017	S : .022	Si: 0.22
	Cu: .22	Ni: 0.12	Cr: 0.16	Mo: .03	Al: .026
	Cb: <.008	V : .002	N : .008	Ti: .001	

R.RATIO: 21.9:1 DI VALUE: 1.15

PART NUMBER: 1005437

MATERIAL IS FREE FROM SURFACE MERCURY CONTAMINATION AS OF THE TIME OF
SHIPMENT BASED ON PRESENT METHODS & EQUIPMENT FOR DETECTION OF THIS
KIND OF CONTAMINATION.
THIS MATERIAL HAS RECEIVED NO WELD REPAIR.
MATERIAL MEETS AUSTENITIC GRAIN SIZE REQUIREMENT OF 5 OR FINER
THIS STEEL IS WARRANTED TO MEET OR EXCEED MACRO/RATING OF " S4 R4 C4"
THIS STEEL IS WARRANTED TO MEET OR EXCEED MICROCLEANLINESS/ RATING OF "S5-O5"
PRODUCT WAS ROLLED AT ARCELORMITTAL EAST CHICAGO, INDIANA, USA
FROM CONTINUOUSLY BILLET CAST, ELECTRIC ARC FURNACE STEEL
MELTED AT ARCELORMITTAL EAST CHICAGO, INDIANA, USA.

Assembly Specialty Products, Inc.
14700 Brookpark Rd.
Cleveland, OH 44135

RECEIVED
DEC 30 2014

Unless otherwise stated, the steel described herein was manufactured, inspected and tested in accordance with the requirements of the contract or purchase order and conform to those requirements. This steel is compliant with European Union Directive 2002/95/EC. No mercury, radium or alpha source materials were used in the production of this steel. This steel has not been welded nor repair welded. Heat analyses are reported in weight percent. Heat analyses and test results marked with an asterisk (*) were reported by a ArcelorMittal USA Inc., Indiana Harbor Long Carbon approved third party. The "+" sign at the beginning of any line indicates an amendment to that line from a previously issued report for the same heat/order. All tests were performed by ArcelorMittal USA Inc., Indiana Harbor Long Carbon, in accordance with the following, unless otherwise specified: Chemistry per ASTM E415 & E1019; Hardenability per ASTM A255 and SAE J406; Macrostructure per ASTM E381 & E1180; Mechanical Properties per ASTM A370, E8 & E23; Hardness per ASTM E10-Type A, E18 & SAE J417; Cleanliness per SAE J421; Microstructure/Microcleanliness per ASTM E3, E45, E112, E1077, J419, J422 & JIS G0555; Rounding per ASTM E29. Tested per most recent standard, unless otherwise noted. Measurement uncertainty was determined and is available upon request. We hereby certify that the heat and/or test results in this report are applicable only to the items described herein, and are correct as contained in the records of the Company. This document shall not be reproduced except in full.

The management system governing the manufacturing processes of this product, at ArcelorMittal USA Inc., Indiana Harbor Long Carbon, is ISO/TS 16949:2009 certified, Certificate No. 44576; ISO 14001:2004 certified, Certificate No. 36374 and A2LA accredited in the fields of: Chemical, Mechanical and Environmental Testing-Certificate Nos. 111.01, 111.02 and 111.03

Dennis Harpole
Manager - Quality & Technical Services

Rev. 9/11/13

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Figure E-16. BCT Anchor Cable, Test Nos. ILT-1 and ILT-2

GERDAU

US-ML-BEAUMONT
100 OLD HIGHWAY 90 WEST
VIDOR, TX 77662
USA

CERTIFIED MATERIAL TEST REPORT

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CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
WIREROPE WORKS INC 100 MAYNARD ST WILLIAMSPORT,PA 17701-5809 USA	WIREROPE WORKS INC 100 MAYNARD ST WILLIAMSPORT,PA 17701-5809 USA	1055M2	Wire Rod / 7/32"

LENGTH	WEIGHT	HEAT / BATCH
	12,721 LB	53131485/03

SALES ORDER	CUSTOMER MATERIAL Nº
931485/000010	600210

SPECIFICATION / DATE or REVISION

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
093846-R	4753-0000002940	08/22/2014

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	N %
0.5297	0.66	0.011	0.009	0.22	0.10	0.06	0.06	0.018	0.005	0.0074

MECHANICAL PROPERTIES

Std.Dev. PSI	R/A Avg %	UTS PSI	UTS MPa
898	62.4	129997	896

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

LEONARDO RADICCHI
QUALITY ASSURANCE MGR.

Figure E-17. ¾-in. Diameter Wire Rope, Test Nos. ILT-1 and ILT-2

GERDAU

US-ML-BEAUMONT
100 OLD HIGHWAY 90 WEST
VIDOR, TX 77662
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
WIREROPE WORKS INC 100 MAYNARD ST WILLIAMSPORT,PA 17701-5809 USA	WIREROPE WORKS INC 100 MAYNARD ST WILLIAMSPORT,PA 17701-5809 USA	1055M2	Wire Rod / 7/32"

LENGTH	WEIGHT	HEAT / BATCH
	38,762 LB	53127002/04

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
310880/000010	600210	

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
091073-C	4753-0000000807	08/02/2013

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	N %
0.5347	0.65	0.006	0.010	0.21	0.11	0.05	0.04	0.014	0.005	0.0069

MECHANICAL PROPERTIES

Std.Dev. PSI	R/A Avg %	UTS PSI	UTS MPa
1286	58.4	127626	880

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

THAD BOUDREAUX
QUALITY ASSURANCE MGR.

Figure E-18. ¾-in. Diameter Wire Rope, Test Nos. ILT-1 and ILT-2

CHARTER STEEL
A Division of Charter Manufacturing Company, Inc.

EMAIL

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

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Cust P.O.	94737-1
Customer Part #	600210
Charter Sales Order	70058684
Heat #	10342780
Ship Lot #	1141737
Grade	1055 R SK CG HRQ 7/32
Process	HR
Finish Size	7/32
Ship date	07-NOV-14

Wirerope Works, Inc.
100 Maynard St.
Williamsport,PA-17701
Kind Attn :Roger Gilliland

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and that it satisfies these requirements. The recording of false, fictitious and fraudulent statements or entries on this document may be punishable as a felony under federal statute.

Test results of Heat Lot # 10342780

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.52	.66	.008	.008	.260	.04	.06	.01	.06	.006	.002
	AL	N	B	TI	NB						
	.003	.0060	.0001	.002	.001						

Test results of Rolling Lot # 1141737

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE (KSI)	2	123.2	123.8	123.5	TENSILE LAB = 0358-02
REDUCTION OF AREA (%)	2	61	64	63	RA LAB = 0358-02
ROD SIZE (inch)	9	.215	.221	.218	
ROD OUT OF ROUND (inch)	2	.004	.005	.005	

REDUCTION RATIO=803:1

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 9/12/12
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = 6000 Revision = 8 Dated = 12-AUG-04

Additional Comments: Melted and Manufactured in the United States of America

Figure E-19. ¾-in. Diameter Wire Rope, Test Nos. ILT-1 and ILT-2

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

EMAIL

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

Wirerope Works, Inc.
100 Maynard St.
Roger Gilliland
Williamsport,PA-17701
Kind Attn :Roger Gilliland

Cust P.O.	089592-04
Customer Part #	600276
Charter Sales Order	70034920
Heat #	10207730
Ship Lot #	1078510
Grade	1069 M SK CG HRQ 7/32
Process	HR
Finish Size	7/32

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 these requirements.

Test Results of Heat Lot# 10207730

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.70	.65	.008	.008	.23	.03	.05	.01	.06	.004	.002

AL	N	TI	NB
.003	.0050	.001	.000

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 1078510

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE	2	150.9	155.1	153.0	TENSILE LAB = 0358-02
REDUCTION OF AREA	2	52	55	54	RA LAB = 0358-02
ROD SIZE	10	.217	.221	.219	
ROD OUT OF ROUND	3	.003	.004	.004	
REDUCTION RATIO = 803:1					

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = 6000 Revision = 8 Dated = 12-AUG-04

Additional Comments: Melted and Manufactured in the United States of America

Figure E-20. ¾-in. Diameter Wire Rope, Test Nos. ILT-1 and ILT-2

#197588 : T/S 3 of 5
Page 1 of 1
Date: 05-27-2014

Bill Of Lading &
Certified Mill Test Report

ArcelorMittal

Sold To	: 50002 WIREROPE WORKS, INC.	Ship To	: 28995 WIREROPE WORKS
Load #	: 161425	ICN/Line	: 140578/1
PO #	: 093636	Product	: WIRE COIL
Part#	: 600325		
Size	: 7/32	Grade	: 1075M
Ship Mode	: RR	Frt Terms	: PD
Carrier	: CSX Transportatio(305)	Vehicle	: TTJX82214
Consigned	: N	Wgt Source	: Coil
Pieces	: 8	Weight	: 32,421 Lbs

Heat: 25807 **Charge:** 692 **Pieces:** 8 **Weight:** 32,421 LBS

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Sn	Al	B	N	Nb
0.76	0.71	0.005	0.007	0.23	0.08	0.03	0.04	0.01	0.00	0.00	0.003	0.000	0.007	0.00

Ti	Ca
0.002	0.000

Low Tensile	High Tensile	Average Tensile	Reduction Of Area	Surface Index
158,200	160,900	159,400	45%	0

COIL	801	802	803	804	805	806	807	808
LBS	4050	4042	4088	4062	4085	4024	4050	4020

Figure E-21. ¾-in. Diameter Wire Rope, Test Nos. ILT-1 and ILT-2

valmont

Extrusion Department
58027 Charlotte Ave
Elkhart, IN 46517
Ph: (574) 295 6942

Certificate

Date: *April 21, 2016* Elkhart Internal Order No. *327087*

Customer: *FARMINGTON* Customer Order No. *94842*

Customer Part No. *43011010R*

No. of lengths. *12*

Alloy/Temper: *6063 - T4* Cast No. *416067*

Part Desc. *Extruded Tube 42 ft 6 ins long x 10 ins dia x 0.312 ins wall. (Elkhart Part # ALY1047)*

We hereby certify that the material shipped and covered by this document, has been inspected in accordance with the extruded tube dimensional requirements of "Aluminum standards and data 2000", as published by the Aluminum Association, and with other applicable requirements as stated on the customer order, and has been found to comply. The material meets the compositional limits for the alloy as indicated, and has been processed to comply with T4 temper requirements for the alloy.

Lynne Shafer

Pole length before tapering: 42 ft – 6 in.
Pole length after tapering: 45 ft

Chemical Composition (Wt %):

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other Elements	
Min	0.20				0.45				Each Max	Total Max
Max	0.6	0.35	0.10	0.10	0.9	0.10	0.10	0.10	0.05	0.15

* Aluminum = Remainder

Actual cast analysis provided by billet vendor is retained on file.

Melted and Manufactured in USA

Figure E-22. Aluminum Pole, Test No. ILT-1

"Material Melted and Manufactured in the United States"

Certified Report of Chemical Analysis & Mechanical Properties

Customer : Valmont/Structures	**Date:** 5/4/16	**Part #:**CS-370 Valmont#:228196
	P.O. #: 95079	**Assembly #:**
	Description: ASTM B108 / B108M-12	**Alloy:** 356
		Heat Treat Condition: HT T6 QTY:75
Job #:	**Work Order #:**73593	

		Mechanical Properties			Chemical Analysis in Percent												
PCS	Heat / Serial Number	Tensile PSI	Yield PSI	Elong % in 2"	BHN	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Sr	Sn	Pb
75	096-16	39,500	33,500	3	---	6.88	.12	.028	.006	.37	.002	.002	.010	.10	---	---	---

CAUTION: OSHA REQUIRED HAZARD COMMUNICATION LABEL
The Aluminum in this casting may contain elements in amounts considered hazardous under section 1910.1200 of the CFR 29.

HAZARD WARNING: Inhalation of dust generated in machining and grinding may be hazardous to your health. Inhalation of fumes generated while welding the casting may be hazardous to your health. This product should not generate any health risk in its unmodified or past-modified form. Refer to the Material Safety Data Sheet for additional information.

We hereby certify to the chemical and mechanical properties herein and to the fact that they were determined in conformance with the specifications listed above.

Akron Foundry Company
2728 Wingate Ave.
Akron, Oh 44314
USA
330-745-3101 fax: 330-745-7999

Sworn to and subscribed before me this 4th day of May. 2016

Larry A. Yergin — VP Permanent Mold

Robin Karl — Notary Public

Castings Produced in the United States of America
"Buy American"

Figure E-23. CS-370 Anchor Base, Test Nos. ILT-1 and ILT-2

CRYSTAL
NISHING SYSTEMS, INC.

Certificate# 653171-1
Date: 23-Dec-2015
PO: 93596

Certificate Of Conformance

Address:
2610 Ross Avenue
Schofield WI 54476
Phone: (715)-355-5351
Fax (715)-355-8812

Ship To:
Valmont Structures
20805 Eaton Avenue

Farmington MN 55024

Part Number	Die Nbr	Description	Ship Qty	Date Shipped
17003504R	1615	VALMONT 204^ [17'-0^}X3.5X.125 RD TUBE 204^ (161. 6063-T1	44.00	23-Dec-2015

Extrusion Info:

Cast	Alloy	Date Extruded
915028	6063	Wednesday, December 23, 2015
915028	6063	Wednesday, December 23, 2015
915028	6063	Wednesday, December 23, 2015

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Total	Al
6063	0.20 - 0.60	.35	0.10	0.10	0.45 - 0.90	0.10	0.10	0.10	0.05	0.15	Rest

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Total	Al
6105	0.60 - 1.00	.35	0.10	0.15	0.45 - 0.80	0.10	0.10	0.10	0.05	0.15	Rest

We hereby certify that the material shipped and covered by this document. Has been inspected in accordance with the extruded tube dimensional requirements of (Aluminum Standards and Data 2013), as published by the Aluminum Association and other applicable requirements as stated on the customer order, and has been found to comply. The material meets the compositional limits for the alloy as indicated, and has been processed to comply with the temper requirements for the alloy.

We Hereby certify to the best of our knowledge and beleif the foregoing data

Eric Zebro

Authorized Signature

Figure E-24. Truss, Test No. ILT-1

Certified Analysis

Trinity Highway Products, LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE **TARP LOAD** **TARP LOAD** **TARP LOAD**

Order Number: 1236801 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3028
BOL Number: 86849 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 3/13/15

5/8x14" Guardrail Bolts R#15-0515 H#26859
Light Blue April 2015 SMT

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	3000G	CBL 3/4X6'6/DBL	HW			192900													
4,000	3340G	5/8" GR HEX NUT	HW			DECKER1411N2													
3,000	3360G	5/8"X1.25" GR BOLT	HW			150220B													
225	3500G	5/8"X10" GR BOLT A307	HW			141121L													
875	3540G	5/8"X14" GR BOLT A307	HW			26859													
250	4235G	3/16"X1.75"X3" WSHR	HW			C6086													
20	9852A	STRUT & YOKE ASSY	A-36			4119013	49,500	66,000	33.0	0.180	0.380	0.006	0.008	0.010	0.040	0.001	0.030	0.000	4
	9852A		A-36			163373	47,260	65,650	33.6	0.190	0.530	0.012	0.004	0.020	0.120	0.000	0.050	0.000	4
	9852A		A-36			0171684	45,900	69,340	32.7	0.190	0.760	0.015	0.006	0.007	0.040	0.001	0.030	0.002	4
	9852A		HW			0806489398													
6	10967G	12/9'4.5/3'1.5/S			2	L13313													
			M-180	A	2	168413	54,570	71,150	31.7	0.190	0.720	0.012	0.004	0.020	0.130	0.000	0.070	0.001	4
			M-180	A	2	168415	55,740	72,640	31.3	0.190	0.730	0.012	0.004	0.020	0.140	0.000	0.060	0.001	4
			M-180	A	2	168416	53,470	71,880	30.8	0.190	0.730	0.011	0.002	0.020	0.120	0.000	0.060	0.001	4
			M-180	A	2	168417	57,590	73,620	30.1	0.190	0.740	0.012	0.003	0.020	0.130	0.000	0.060	0.001	4
			M-180	A	2	168748	56,810	73,060	30.5	0.190	0.730	0.011	0.005	0.020	0.130	0.000	0.060	0.001	4
			M-180	A	2	168749	57,900	73,710	28.4	0.200	0.730	0.012	0.004	0.020	0.120	0.001	0.060	0.000	4
			M-180	A	2	168750	55,480	72,750	29.5	0.190	0.730	0.010	0.003	0.020	0.130	0.000	0.060	0.001	4

Figure E-25. ⅝-in. (16-mm) Dia. UNC, 14-in. (356-mm) Long Guardrail Bolt and Nut, Test Nos. ILT-1 and ILT-2

CHARTER STEEL
A Division of Charter Manufacturing Company, Inc

LOAD

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

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Telefast Industries Inc.
777 West Bagley Road
Berea,OH-44017
Kind Attn :Jeff Leisinger

Cust P.O.	85523
Customer Part #	10005
Charter Sales Order	70058737
Heat #	10351040
Ship Lot #	4310508
Grade	1018 R AK FG RHQ 1-5/32
Process	HRCC
Finish Size	1-5/32
Ship date	21-NOV-14

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and that it satisfies these requirements. The recording of false, fictitious and fraudulent statements or entries on this document may be punishable as a felony under federal statute.

Test results of Heat Lot # 10351040

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.16	.64	.007	.007	.090	.05	.08	.01	.08	.007	.001
	AL	N	B	TI	NB						
	.023	.0060	.0001	.001	.001						

MACRO ETCH SAMPLE TYPE=R
MACRO ETCH SURFACE=1 MACRO ETCH RANDOM=1 MACRO ETCH CENTER=1

Figure E-26. ⅝-in. (16-mm) Dia. UNC, 1.25-in. (32-mm) Long Guardrail Bolt and Nut, Test Nos. ILT-1 and ILT-2

SILO FASTENERS
1415 S BENHAM ROAD
VERSAILLES IN 47042

Silo Fasteners

Date 11/07/2014

Part Number:	62C125BSP3
Description:	5/8-11 x 1-1/4 GUARD RAIL BOLT A307 HDG-A153 CLASS C
Job Number:	0090480-KD
Heat Number:	20337380
Wedge Angle:	6° Modified
Stress Area:	0.226
Specification:	ASTM A307 Grade A, ASTM F606

Performance Test Results

Specimen	Hardness Cross Section	Fracture Location	Load - lbf	Tensile - psi
	69 - 100HRB	Body/Thread	≥ 13,560	≥60,000
1	88			
2	93			
3	93			
4	92			
5	94			
6		Thread	18,100	80,002
7		Thread	18,050	79,781
8		Thread	17,995	79,538
9		Thread	18,030	79,693
10		Thread	17,950	79,339

QUALITY MANAGER
TERRY ELKINS

Figure E-27. ⅝-in. (16-mm) Dia. UNC, 1.25-in. (32-mm) Long Guardrail Bolt and Nut, Test Nos. ILT-1 and ILT-2

Certificate of Compliance

Birmingham Fastener Manufacturing
PO Box 10323
Birmingham, AL 35202
(205) 595-3512

25ct BCT 10" Hex Bolts
R#16-0226 L#206239
H#DL15102793 WHITE
December 2015

Customer Midwest Machinery & Supply **Date Shipped** ______

Customer Order Number 3180 **BFM Order Number** 1294219

Item Description

Description 5/8"-11 x 10" HEX BOLT **Qty** 153

Lot # 206239 **Specification** ASTM A307-14 Gr A **Finish** HDG

Raw Material Analysis

Heat# DL15102793

Chemical Composition (wt% Heat Analysis) By Material Supplier

C	Mn	P	S	Si	Cu	Ni	Cr	Mo
0.21	.82	0.015	0.019	.24	0.41	0.08	0.13	0.010

Mechanical Properties

Sample #	Hardness	Tensile Strength (lbs)	Tensile Strength (psi)
1	89 HRBW	19,980	88,000
2			
3			
4			
5			

This information represents the most recent analysis of the product supplied on the stated customer order. The samples tested conform to the ASTM standard listed above.
All steel melted and manufactured in the U.S.A.

Authorized Signature: [signature] **Date:** 12/4/2015

Cody Calvert
Quality Assurance

Figure E-28. ⅝-in. (16-mm) Dia. UNC, 10-in. (254-mm) Long Hex Head Bolt and Nut, Test Nos. ILT-1 and ILT-2

R#16-0217
BCT Hex Nuts
December 2015 SMT
Fastenal part#36713
Control# 210101523

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

- Sales Order #: 129980
- Part No: AFH2G0625C
- Cust Part No: 36713
- Quantity (PCS): 1200
- Description: 5/8-11 Fin Hx Nut Gr2 HDG/TOS 0.020
- Specification: SAE J995(99) - GRADE 2 / ANSI B18.2.2
- Stelfast I.D. NO: 595689-O201087
- Customer PO: 210101523
- Warehouse: DAL

The data in this report is a true representation of the information provided by the material supplier certifying that the product meets the mechanical and material requirements of the listed specification. This certificate applies to the product shown on this document, as supplied by STELFAST INC. Alterations to the product by our customer or a third party shall render this certificate void.

This document may only be reproduced unaltered and only for certifying the same or lesser quantity of the product specified herein. Reproduction or alteration of this document for any other purpose is prohibited.

Stelfast certifies parts to the above description. The customer part number is only for reference purposes.

David Biss
Quality Manager

Figure E-29. ⅝-in. (16-mm) Dia. UNC, 1½-in. (38-mm) Long Hex Head Bolt and Nut, Test Nos. ILT-1 and ILT-2

338

LOAD PO # 71267

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

Beta Steel
44225 Utica Rd.
Laurie Dailey
Utica,MI-48318

Cust P.O.	284371-01
Customer Part#	625010150000SF(SW1015-C)
Charter Sales Order	30048422
Heat #	10207560
Ship Lot #	1074155
Grade	1015 A SK FG IQ 5/8
Process	HR
Finish Size	5/8

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 these requirements.

Test Results of Heat Lot# 10207560

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.14	.41	.007	.011	.13	.05	.07	.02	.10	.009	.001

AL	N	B	TI	CA	NB
.022	.0050	.0002	.000	.0001	.004

JOMINY(HRC) J0M01
41

JOMINY SAMPLE TYPE ENGLISH = C
CHEM, DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 1074155

43,445

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE	3	59.7	60.1	59.9	TENSILE LAB = 0358-02
REDUCTION OF AREA	3	49	56	53	RA LAB = 0358-02

NUM DECARB = 1 AVE DECARB = .003
REDUCTION RATIO = 99:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = PS-1 Revision = Dated = 11-MAR-08

Additional Comments:

Figure E-30. ⅝-in. (16-mm) Dia. UNC, 1½-in. (38-mm) Long Hex Head Bolt and Nut, Test Nos. ILT-1 and ILT-2

INSPECTION CERTIFICATE

Customer	Specification	Size	Lot No.	Date
	ASTM A-563 GRADE DH HEAVY HEX NUT	7/8- 9 UNC	WA651	Jun. 29, '12

UNYTITE, INC.
One Unytite Drive
Peru, Illinois 61354
815-224-2221 — FAX# 815-224-3434

Mechanical properties tested in accordance to ASTM F606/F606M, ASTM A370, ASTM E18

Chemical Composition (%)

Mill Maker.	Material Size	Heat No. \ Spec.	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	
NUCOR	CARBON		0.20 0.55	-	MIN. 0.60	MAX. 0.040	MAX. 0.050	-	-	-	-	-
STEEL	STEEL	12101054	0.43	0.24	0.87	0.015	0.020	0.09	0.04	0.08	-	-

Shape & Dimension Inspection	ANSI B18.2.2 GOOD
Thread Precision Inspection	ANSI B1.1 CLASS 2B GOOD
Appearance Inspection	GOOD

Mechanical Property Inspection

Item	Proof Load	Cone stripping	Hardness	After Heat Treatment Hardness	Absorbed Energy	Heat Treatment
Spec.	80,850 lbf	- kN·kgf·lbf	24-38 HrC	HrB·HB	J·kgfm·ftlbf	T:MIN.800 F
Results	n 5	n -	29.4 28.9 29.7 29.7 29.5 29.4	5 Piece Average After Heat Treament		Q:FORGING Q (W.Q.) T:1058 F/45M. (W.C.)
	Results GOOD	Results -		Hardness Treatment After 24 Hr.X °F(°C)	at °F(°C)	Q: Quenching T: Tempering ST: Solution Treatment

Remarks:
"DH U"
Production Quantity 22,391 pcs.
BCT Foundation Tube Keeper Bolt Nuts
R#15-0600 June 2015 SMT

OFFICIAL SEAL
JEAN MARGHERIO
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/18/13
07-10-12

Material used for the nut was melted and manufactured in the USA. The nut was manufactured in the USA to the above specification.

We hereby certify that the material described has been manufactured and inspected satisfactorily with the requirement of the above specification.

Chief of Quality Assurance Section

Figure E-31. 7/8-in. (22-mm) Dia. UNC, 7½-in. (191-mm) Long Hex Head Bolt and Nut, Test Nos. ILT-1 and ILT-2

Heat Number 2038622
Shipper No 680907
Invoice No 701917
Customer PO# 5-7-2015 MIKE
Customer Name GAFFNEY BOLT CO.

CMC STEEL SOUTH CAROLINA
310 New State Road
Cayce SC 29033-3704

CERTIFIED MILL TEST REPORT
For additional copies call
800-637-3227

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

Richard S. Ray - CMC Steel SC
Quality Assurance Manager

CMC

1SERIES-BPS®

HEAT NO.:2038622 SECTION: ROUND 7/8 x 40'0" A36/52950 GRADE: ASTM A36-12/A529-05 Gr 50 ROLL DATE: 09/09/2014 MELT DATE: 09/08/2014	SOLD TO: Infra-Metals - Mars 1601 Broadway St Marseilles IL US 61341-9326 8009875283	SHIP TO: Infra-Metals - Mars 1601 Broadway St Marseilles IL US 61341-9326 8009875283	Delivery#: 81471569 BOL#: 70533247 CUST PO#: CE-485729 CUST P/N: DLVRY LBS / HEAT: 9075.000 LB DLVRY PCS / HEAT: 111 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.16%	Elongation Gage Lgth test 1	8IN		
Mn	0.73%	Reduction of Area test 1	58%		
P	0.013%	Yield to tensile ratio test1	0.75		
S	0.021%	Yield Strength test 2	56.9ksi		
Si	0.22%	Tensile Strength test 2	76.5ksi		
Cu	0.32%	Elongation test 2	25%		
Cr	0.13%	Elongation Gage Lgth test 2	8IN		
Ni	0.10%	Reduction of Area test 2	57%		
Mo	0.027%	Yield to tensile ratio test2	0.74		
V	0.000%	C+(Mn/6)	0.28%		
Cb	0.026%				
Sn	0.010%				
Al	0.000%				
Ti	0.001%				
N	0.0084%				
Carbon Eq A529	0.38%				
Yield Strength test 1	57.1ksi				
Tensile Strength test 1	76.3ksi				
Elongation test 1	23%				

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

ALSO MEETS ASTM GRADE A36 REV-03A, A529 GR.50, A572-2013A GR.50, A709 GR.36, A709 GR.50, A992, AASHTO GRADE M270 GR.36, M270 GR.50, CSA G40.21-04 GRADE 44W, 50WASME SA-36 2008A ADDEND A.

03/18/2015 14:05:35
Page 1 OF 1

Figure E-32. 7/8-in. (22-mm) Dia. UNC, 7½-in. (191-mm) Long Hex Head Bolt and Nut, Test Nos. ILT-1 and ILT-2

R#15-0627 H#20297970 L#140530L
5/8x10" Guardrail Bolt
June 2015 SMT White Paint

35006

TRINITY HIGHWAY PRODUCTS, LLC
425 East O'Connor Ave.
Lima, Ohio 45801
419-227-1296

MATERIAL CERTIFICATION

7/31/14

Customer: Stock

Date: June 25,2014

Invoice Number:

Lot Number: 140530L

Part Number: 3500G

Quantity: 17,173 Pcs.

Description: 5/8" x 10" G.R. Bolt

Heat Numbers: 20297970 17,173

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
20297970	.09	.33	.006	.001	.06	.03	.04	.01	.08	.002	.001	.026	.006	.0001	.001	.002

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.54 (2.0 Mils Minimum)

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

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

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

TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 11th day of July 2014

Sherri Braun NOTARY PUBLIC

NOTARIAL SEAL STATE OF OHIO

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

SHERRI BRAUN
Notary Public, State of Ohio
My Commission Expires
April 20, 2019

JUL 11 2014
Trinity Highway Products, LLC
Dallas, Texas Plant 99

Figure E-33. ⅝-in. (16-mm) Dia. UNC, 10-in. (254-mm) Long Hex Head Bolt and Nut, Test Nos. ILT-1 and ILT-2

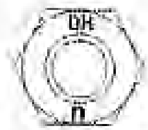
Figure E-34. ⅞-in. (22-mm) Dia. Plain Round Washer, Test Nos. ILT-1 and ILT-2

NUCOR
FASTENER DIVISION

LOT NO.
3660558

Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
8001 FASTENAL COMPANY-KS — NUCOR ORDER # 969123
TEST REPORT SERIAL# FB682520 — CUST PART # 36210
TEST REPORT ISSUE DATE 1/08/16
DATE SHIPPED 5/09/16 — CUSTOMER P.O. # 210110788
NAME OF LAB SAMPLER: JOSEPH BYERLY, LAB TECHNICIAN



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

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175447	400	3660558	1-8 GR DH HV H.D.G. HEX NUT H.D.G./GREEN LUBE

MANUFACTURE DATE 10/01/15

--CHEMISTRY MATERIAL GRADE -1045L

*%CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER NUCOR STEEL - SOUTH CAROL

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI
RM030068	DL15103032	.45	.67	.093	.019	.29

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-07a

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 99900 LBS	TENSILE STRENGTH DEG-WEDGE (LBS)	STRESS (PSI)
N/A	30.8	PASS	N/A	N/A
N/A	28.6	PASS	N/A	N/A
N/A	26.6	PASS	N/A	N/A
N/A	26.2	PASS	N/A	N/A
N/A	26.5	PASS	N/A	N/A

AVERAGE VALUES FROM TESTS
27.5
PRODUCTION LOT SIZE 42800 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-07a — 80 PCS. SAMPLED — LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-13 - GALVANIZING PERFORMED IN THE U.S.A.

1. 0.00278 2. 0.00692 3. 0.00426 4. 0.00237 5. 0.00321 6. 0.00226 7. 0.00603
8. 0.00676 9. 0.00315 10. 0.00321 11. 0.00371 12. 0.00264 13. 0.00252 14. 0.00348
15. 0.00287

AVERAGE THICKNESS FROM 15 TESTS .00388
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2010

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.825	1.833
Thickness	32	0.978	0.996

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO INTENTIONAL ADDITIONS OF BISMUTH, SELENIUM, TELLURIUM, OR LEAD WERE USED IN THE STEEL USED TO PRODUCE THIS PRODUCT.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A. PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

A2LA ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA #139.03
EXPIRATION DATE 01/31/16

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Figure E-35. 1-in. (254-mm) Dia. Lock Washer, Test Nos. ILT-1 and ILT-2

R#17-75 IL MGS Tollway F1554 Gr. 105 Anchor Bolts
H#5802372003 L#36429

LoT 22101

DOC ID 7.5.3.1F Rev B 4/6/12
Date created 8/8/16

MATERIAL TEST REPORT

PO# 38495 SO# 209683

Item: 1 - 8 X 84 L ANCHOR BOLT

Material Specification: ASTM A193(15) B7
F1554(07a) Gr 105

LOT#: 36429

Heat Number: 5802372003

Tensile Strength KSI:	145	Yield Strength KSI:	133
Elongation:	19	Reduction of Area:	56
Hardness:	32 HRC	Wedge Tensile:	NA
Macro Etch:	S1/R1/C1	Tempering Temp.:	1335 F

Quenched and Tempered - Stress Free

Carbon (C):	0.430	Chromium (CR):	0.820
Manganese (MN):	0.780	Molybdenum (MO):	0.180
Phosphorus (P):	0.010	Copper (CU):	NA
Sulfur (S):	0.014	Nitrogen (N):	NA
Silicon (SI):	0.260	Nickel (NI):	NA
Cobalt (CO):	NA	Aluminum (AL):	NA
Vanadium (V):	NA	Tin (SN):	NA
Tungsten (W):	NA	Titanium (TI):	NA
Columbium/Niobium (NB/CB):	NA	Boron (B):	NA
Calcium (CA):	NA		

We hereby certify that the material was manufactured, sampled, tested and inspected per the most recent revision of the product or material specification. The foregoing data was furnished to us by our supplier or resulting from a test performed in a recognized laboratory and is on file in the records of the corporation.
Name: Lori Walker

Figure E-36. 1-in. (25-mm) Dia. Anchor Bolt, Test Nos. ILT-1 and ILT-2

NUCOR
FASTENER DIVISION

LOT NO.
366055B

Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
8001 FASTENAL COMPANY-KS — NUCOR ORDER # 969123
TEST REPORT SERIAL# FB482520 — CUST PART # 38210
TEST REPORT ISSUE DATE 1/08/16
DATE SHIPPED 5/09/16 — CUSTOMER P.O. # 210110788
NAME OF LAB SAMPLER: JOSEPH BYERLY, LAB TECHNICIAN

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

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175647	400	366055B	1-8 GR DH HV H.D.G. HEX NUT H.D.G./GREEN LUBE

MANUFACTURE DATE 10/01/15

--CHEMISTRY — MATERIAL GRADE -1045L

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

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI	
RM030068	DL15103032	.45	.67	.003	.019	.20	NUCOR STEEL - SOUTH CAROL

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-07a

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 90900 LBS	TENSILE STRENGTH DEG-WEDGE (LBS)	STRESS (PSI)
N/A	30.8	PASS	N/A	N/A
N/A	28.6	PASS	N/A	N/A
N/A	26.4	PASS	N/A	N/A
N/A	26.2	PASS	N/A	N/A
N/A	24.5	PASS	N/A	N/A
AVERAGE VALUES FROM TESTS	27.3			

PRODUCTION LOT SIZE 42800 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-07a — 80 PCS. SAMPLED — LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-13 - GALVANIZING PERFORMED IN THE U.S.A.

1. 0.00278 2. 0.00892 3. 0.00428 4. 0.00237 5. 0.00321 6. 0.00228 7. 0.00603
8. 0.00676 9. 0.00315 10. 0.00321 11. 0.00371 12. 0.00264 13. 0.00252 14. 0.00348
15. 0.00287

AVERAGE THICKNESS FROM 15 TESTS .00388
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2012

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.823	1.833
Thickness	32	0.978	0.996

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO INTENTIONAL ADDITIONS OF BISMUTH, SELENIUM, TELLURIUM, OR LEAD WERE USED IN THE STEEL USED TO PRODUCE THIS PRODUCT.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A. PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 01/31/16

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Figure E-37. 1-in. (25-mm) Dia. UNC Hex Head Nut, Test Nos. ILT-1 and ILT-2

INSPECTION CERTIFICATE

MARKING

CUSTOMER	**FASTENAL COMPANY**		
PART NAME	ASTM F436 - 11 TYPE 1 WASHERS		
SIZE	1 "	DATE	February 19, 2014
PART NO. - Mfr.	W2A6CA001S6JZ	REPORT NO.	1030219-11
PART NO. - Cust.	33176	SHIPPING NO.	
MATERIAL / DIA.	10B20 / 30 mm	ORDER NO.	120187242
HEAT(COIL) NO.	2MV88	DOCUMENT NO.	10208021
LOT QTY	54,000 PCS	LOT NO.	322CAFN91

STANDARD OF SAMPLING SCHEME: ANSI / ASME B18.18.2 M-1993

HARDNESS TEST METHOD: ASTM F606-2010

COATING TEST METHOD: ASTM B499-2009

DIMENSIONS IN inch

INSPECTION ITEM		SPECIFICATION	TEST QTY	INSPECTION RESULTS		REMARKS
				MIN.	MAX.	
1	OUTSIDE DIAMETER	1.9370 - 2.0630	8	1.9803	2.0091	
2	INSIDE DIAMETER	1.0630 - 1.1260	8	1.1067	1.1126	
3	THICKNESS	0.1360 - 0.1770	8	0.1469	0.1531	
4	HARDNESS	HRC 38 - 45	5	40.4	42.1	
5	COATING	MECH. GALV. 53 μm	5	55.9	78.1	
6	APPEARANCE	VISUAL	100	OK		

INSPECTED BY *Yu Tain Lin* CERTIFIED BY *Jing Yeh Tsao*

Figure E-38. 1-in. (25-mm) Dia. Plain Round Washer, Test Nos. ILT-1 and ILT-2

Concrete Industries
6300 Cornhusker Highway
P.O. Box 29529
Lincoln, NE 68529-
Phone: (402)434-1800 FAX: (402)434-1899

JOB NUMBER	RELEASE NUMBER	REQ. DELIVERY DATE	PAGE
8000MISC.	CORY-708		1 of 1

JOB NAME: JOB COMPLETE — CC: STIG
CUSTOMER: MIDWEST ROADSIDE SAFETY — BY: CLR

MATERIAL TYPE	REFERENCE	DRAWING ID	DESCRIPTION
Rebar, Grade 60, Epoxy	(2) sets EPOXY rebar		IL Tollway MGS -Pole Foundation

Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
1	16	6	7-06	H6		180												0
	16.					180.												
2	16	4	7-09	H9	T3	83			6-032				1-06				2-00	1
	16.					83.												

Total Weight: 263 Lbs

Longest Length: 7-09

INSPECTOR

WEIGHT SUMMARY

SIZE	TOTAL ITEMS	TOTAL PIECES	TOTAL LBS	STRAIGHT ITEMS	STRAIGHT PIECES	STRAIGHT LBS	LIGHT BENDING ITEMS	LIGHT BENDING PIECES	LIGHT BENDING LBS	HEAVY BENDING ITEMS	HEAVY BENDING PIECES	HEAVY BENDING LBS
Rebar, Grade 60, Epoxy												
4	1	16	83	0	0	0	1	16	83	0	0	0
6	1	16	180	1	16	180	0	0	0	0	0	0
	2	32	263	1	16	180	1	16	83	0	0	0

Total Weight: 263 Lbs

Longest Length: 7-09

epoxy #4 GERDAU 57148356
epoxy #6 NUCOR KN15101296

Figure E-39. ¾-in. (19-mm) Dia. Epoxy-Coated Rebar, Item h6, Test Nos. ILT-1 and ILT-2

Page: 1

SOLD TO: SIMCOTE INC
1645 RED ROCK RD
ST PAUL, MN 55119-0000

NUCOR
NUCOR STEEL KANKAKEE, INC.

CERTIFIED MILL TEST REPORT

Ship from:
MTR #: 0000060929
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

Date: 24-Mar-2015
B.L. Number: 497801
Load Number: 259091

SHIP TO: SIMCOTE, INC
1645 RED ROCK ROAD
ST PAUL, MN 55119-0000

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	3612												
KN1510129602	Nucor Steel - Kankakee Inc	66,032	99,845	15.5%	OK	-3.1%	.36	1.10	.013	.051	.19	.37	
KN15101296	19/#6 Rebar	455MPa	688MPa			.049	.22	.11	.068	.009 0	.00	.034	
	40' A615M GR420 (Gr60)												
	ASTM A615/A615M-14 GR 60[420]												
	AASHTO M31-07												
	Melted 03/12/15 Rolled 03/20/15												

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form have not been used in the production of this material.

QUALITY ASSURANCE: Matt Luymes

Figure E-40. ¾-in. (19-mm) Dia. Epoxy-Coated Rebar, Item h6, Test Nos. ILT-1 and ILT-2

Simcote, Inc.
Daily Quality Report
Epoxy Coated Reinforcing Steel

Date: 4/10/15

1645 Red Rock Road
St. Paul, MN 55119

Phone: (651) 735-9660
Fax: (651) 735-9664

Heat #: KN15101296 M57147739
KN15101274
KN15101276
M57147738

Powder Lot # 5296018382

Type: VALSPAR

Inspector: TF
*Bend: 180 DEG.
Temp: 450 Fahrenheit
Cure Time: 40 Seconds

Bar Size	Heat #	Hldy.	1	2	3	4	5	6	7	8	9	10	Avg.
6.00	KN15101296	8	9.0	10.4	11.7	10.0	10.6	10.0	7.9	9.7	9.3	9.0	9.8
		6	8.8	9.5	8.0	10.0	11.8	8.6	8.8	9.5	8.1	10.9	9.4
		3	9.0	8.3	8.6	9.8	8.6	9.0	8.4	9.1	9.2	10.6	9.0
		9	10.2	11.5	9.9	10.4	10.9	8.6	9.2	8.0	11.6	9.3	9.9
		6	9.3	9.5	10.3	9.8	10.1	10.0	10.4	10.6	10.3	10.8	10.1
		5	9.9	9.4	9.7	10.3	9.2	9.5	9.5	9.8	9.6	10.1	9.7
		8	11.2	8.3	7.9	10.6	10.2	10.5	8.5	9.8	9.5	11.7	9.8
		6	9.3	8.2	8.3	9.0	8.9	9.8	8.2	8.9	9.7	9.0	8.9
6.00	KN15101274	9	8.9	8.4	9.3	8.3	8.1	9.2	9.1	9.2	9.8	9.5	9.0
		5	9.5	8.8	8.9	9.2	9.3	9.5	9.0	9.3	8.5	9.4	9.1
		6	9.1	9.8	9.1	9.1	9.4	8.9	7.4	9.1	8.1	9.2	8.9
		9	9.9	10.4	9.3	8.1	9.8	9.9	10.7	9.4	8.2	10.1	9.6
		4	8.9	9.0	9.0	9.5	7.9	9.5	10.3	9.6	8.1	9.0	9.1
		5	9.7	9.6	10.3	8.4	9.3	8.7	9.1	8.3	10.0	9.0	9.2
		6	11.4	8.3	9.3	9.7	9.8	9.7	8.9	9.9	10.0	11.1	9.8
		8	9.9	8.5	8.4	8.2	7.9	9.1	8.0	8.9	8.6	9.8	8.7
6.00	KN15101276	7	9.5	9.1	8.9	9.0	10.2	9.9	10.6	9.3	8.2	9.5	9.4
		9	9.0	9.4	8.8	8.9	11.5	9.2	9.9	9.2	9.7	11.7	9.7
		6	8.4	8.2	9.6	9.6	10.0	11.9	9.5	10.2	11.1	10.1	9.9
		5	8.1	9.8	9.5	9.3	8.5	9.0	10.0	8.4	11.0	8.6	9.2
		10	9.9	9.1	9.1	8.3	8.9	9.1	8.5	10.0	9.8	9.3	9.2
		6	10.4	10.8	9.3	9.3	9.6	9.2	8.5	11.7	11.2	9.1	9.9
		5	9.2	9.4	8.9	8.1	8.6	10.0	7.9	8.7	10.5	8.4	9.0
		9	9.2	10.5	11.8	9.2	8.2	9.3	8.0	8.8	11.9	11.2	9.8
6.00	KN15101274	6	9.7	9.4	10.4	10.2	8.6	9.4	8.0	8.6	8.1	9.2	9.2
		5	10.0	10.5	11.8	8.6	9.0	8.2	8.7	9.0	10.3	8.8	9.5
		6	10.7	11.4	11.7	11.2	9.4	9.9	9.2	10.0	10.7	9.4	10.4
		5	9.7	10.6	10.6	9.4	10.3	11.3	9.7	9.6	10.2	8.2	10.0
		9	10.3	9.7	10.1	11.4	11.1	9.2	8.5	10.1	9.9	10.1	10.1
		6	10.3	10.0	8.2	10.1	10.1	9.7	11.2	9.5	11.5	8.7	9.9
		5	8.5	8.1	10.2	9.4	9.1	10.3	11.5	12.3	9.8	11.2	10.0
		6	10.5	12.0	10.0	10.5	9.5	10.5	10.0	12.3	9.3	10.3	10.5
6.00	KN15101276	5	10.1	9.8	11.4	10.6	10.3	10.0	10.0	10.7	9.9	9.9	10.3
		5	10.7	10.9	9.8	10.1	12.1	11.7	11.6	11.9	11.2	9.8	11.0
		9	10.4	9.7	11.9	9.6	9.9	10.3	8.5	9.4	8.2	9.2	9.7
		6	9.4	9.5	8.3	9.4	10.8	7.9	9.4	10.9	9.3	9.8	9.5
		10	9.8	8.1	8.6	8.6	10.3	9.7	9.9	9.2	9.0	11.4	9.5
		5	10.7	9.0	9.3	10.0	8.6	8.4	10.4	10.5	11.2	10.1	9.8
		8	10.5	9.9	9.6	10.6	10.3	9.8	11.0	10.6	9.5	10.1	10.2
		9	11.3	10.6	9.4	9.8	9.0	8.6	9.3	12.1	12.2	10.3	10.2
6.00	KN15101296	6	11.6	11.7	10.3	8.5	8.4	12.4	10.6	11.2	11.3	8.6	10.5
		6	8.8	10.5	9.9	9.9	9.4	10.5	10.6	10.2	9.8	10.2	10.0
		9	11.1	9.9	9.3	8.8	10.0	9.9	9.5	9.8	8.9	9.8	9.7
		7	9.1	10.2	9.8	9.5	9.0	10.3	9.9	10.6	11.3	11.0	10.1
		11	11.2	10.1	9.4	10.0	9.1	9.8	10.6	12.5	9.7	8.4	10.1
		5	9.1	10.0	8.8	10.0	10.4	8.6	7.8	7.8	9.8	9.7	9.2
		8	9.0	9.6	9.0	10.7	9.0	8.8	10.4	9.9	8.9	9.5	9.5
		9	8.2	11.6	9.7	10.6	9.6	10.5	9.4	9.9	10.0	8.7	9.8
6.00	KN15101296	5	10.1	9.8	10.0	9.1	10.1	8.7	10.5	11.6	10.9	10.8	10.2
		6	12.0	11.3	10.5	10.3	10.5	9.1	8.9	9.7	9.8	9.4	10.1
		9	9.7	7.9	9.9	10.9	10.5	9.9	10.1	10.7	8.8	9.8	9.8
		5	9.8	9.1	10.9	9.2	9.1	8.9	11.4	11.8	9.5	9.9	10.0
		6	9.3	9.2	9.3	9.2	8.8	8.7	7.9	9.0	8.9	11.2	9.1
		8	9.0	8.8	8.6	7.9	10.3	9.0	10.4	10.8	8.5	11.7	9.5
		5	10.5	11.2	9.9	10.0	8.5	11.0	8.5	8.1	9.7	9.8	9.7
		3	9.6	10.2	10.8	9.4	8.9	9.2	9.8	10.1	10.7	10.3	9.9
6.00	KN15101296	7	10.0	10.4	8.5	11.0	11.6	11.0	10.6	10.8	10.7	11.9	10.7
		4	9.3	9.7	9.2	10.0	10.1	10.2	10.2	10.5	9.7	10.0	9.9

Bar Size	Heat #	Hldy.	1	2	3	4	5	6	7	8	9	10	Avg
		8	10.8	11.2	9.7	9.0	10.6	9.1	9.4	10.4	9.2	10.8	10.0
		5	9.4	11.4	9.5	9.0	9.4	9.7	9.8	9.8	9.2	11.2	9.9
		9	10.3	8.8	8.5	9.4	8.6	8.7	9.0	9.8	9.2	9.4	9.2
		6	11.6	9.1	8.2	9.9	10.4	9.4	8.8	9.1	9.8	9.2	9.5
		10	9.2	10.5	8.6	10.9	8.8	8.4	9.5	9.6	10.7	8.2	9.4
		5	11.2	8.4	8.5	10.1	8.3	8.7	11.2	10.0	11.1	11.0	9.8
6.00	KN15101296	10	10.5	9.1	9.8	9.9	9.2	9.2	8.9	8.7	10.0	8.9	9.4
		9	10.6	9.5	10.1	11.6	10.0	8.5	8.2	8.9	9.2	9.7	9.6
		10	8.6	9.2	9.6	11.1	9.7	9.7	9.5	8.8	10.6	10.1	9.7
		11	9.0	10.7	10.7	10.9	9.1	10.6	11.0	10.3	10.3	10.2	10.3
		14	10.6	8.6	9.0	8.6	9.4	9.0	9.7	10.1	9.2	8.6	9.3
		7	8.8	9.6	9.5	9.6	11.1	10.5	8.5	8.8	9.7	9.2	9.5
		8	9.0	9.3	9.6	9.8	9.4	10.4	12.0	9.8	8.4	9.0	9.7
		6	8.4	8.9	9.0	10.3	10.4	10.3	10.2	10.6	9.0	9.4	9.6
6.00	KN15101296	8	9.0	9.2	9.2	8.8	8.4	9.9	10.3	10.0	10.2	10.5	9.6
		6	9.0	9.0	8.1	10.1	10.2	10.7	9.9	11.4	11.2	10.5	10.0
		9	10.3	10.3	11.6	11.2	10.3	10.0	11.7	10.1	9.5	8.5	10.3
		10	11.0	10.7	9.4	9.9	10.0	8.8	8.7	10.1	10.9	8.7	9.8
		6	11.0	8.6	11.3	9.4	9.5	9.7	8.9	9.9	11.9	8.1	9.8
		8	8.7	8.0	8.5	8.3	9.8	8.0	8.6	9.5	8.5	8.3	8.6
		5	10.3	12.0	10.3	8.8	8.3	9.2	9.5	8.9	8.9	7.9	9.4
		9	7.9	8.5	8.2	10.6	10.1	9.8	9.6	9.5	10.2	10.3	9.5
6.00	KN15101296	6	9.5	9.0	10.0	8.7	8.6	10.0	9.5	8.9	8.9	8.8	9.2
		9	11.6	9.6	9.7	8.9	8.6	9.4	9.0	8.7	9.6	8.3	9.3
		8	9.5	10.1	9.7	9.0	9.2	10.7	10.1	9.4	9.8	9.7	9.7
		6	9.8	8.9	8.1	8.4	7.8	9.5	9.3	8.3	10.1	9.6	9.0
		9	9.5	9.1	11.0	10.0	9.7	9.1	9.3	10.3	10.8	9.0	9.8
		12	9.6	9.8	10.5	8.5	10.0	10.3	9.5	8.0	9.8	10.6	9.7
		10	8.9	9.6	10.0	9.5	12.1	9.3	10.1	8.4	9.9	9.1	9.7
		6	9.0	9.5	9.1	11.0	9.3	9.0	9.3	9.7	10.1	8.4	9.5
6.00	M57147738	5	8.1	9.7	12.1	9.7	11.7	9.6	9.0	9.3	9.2	9.7	9.8
		9	10.7	10.2	7.8	11.3	10.3	8.8	10.4	9.0	8.9	8.5	9.6
		10	10.1	11.8	10.2	9.5	10.0	8.4	9.8	8.8	9.9	9.4	9.8
		6	10.0	8.1	9.8	9.8	9.4	8.3	11.3	8.5	9.7	9.2	9.4
		8	9.2	9.1	8.7	9.0	10.1	11.6	9.8	8.7	10.7	10.6	9.7
		9	10.2	12.1	10.2	9.4	10.4	10.8	10.2	9.8	9.4	10.3	10.3
		6	9.7	11.0	9.4	10.0	9.6	9.8	9.6	10.1	11.2	10.8	10.1
		5	9.7	8.9	9.8	9.4	8.7	9.4	10.3	9.4	10.4	9.8	9.6
6.00	M57147738	8	10.0	10.2	10.5	8.0	8.2	8.5	9.6	9.7	8.6	11.9	9.5
		6	9.7	10.6	10.2	8.8	10.2	9.5	8.9	9.7	8.8	8.6	9.5
		6	9.1	10.1	10.7	10.0	10.0	10.6	9.7	10.0	10.0	11.1	10.1
		6	11.3	9.1	9.8	10.4	9.4	10.9	9.9	10.5	10.2	10.4	10.2
		9	10.6	8.6	8.4	10.4	11.4	8.9	10.5	10.4	8.8	9.8	9.8
		12	9.2	10.6	12.2	9.1	8.6	9.4	10.7	9.8	9.2	9.5	9.8
		10	10.9	10.8	9.5	8.7	10.0	9.9	9.4	10.2	10.3	9.0	9.9
		5	10.4	9.4	10.1	8.8	10.2	8.6	8.9	9.7	9.7	8.2	9.4
6.00	M57147739	8	9.2	9.5	10.6	10.7	12.0	11.4	11.2	8.4	8.5	9.8	10.1
		6	8.6	9.4	8.9	9.1	10.8	11.4	11.3	9.7	11.0	10.0	10.0
		9	11.2	9.1	10.8	9.2	9.9	8.6	8.4	7.9	7.9	8.3	9.1
		5	8.3	11.3	10.1	9.5	8.9	9.5	8.0	9.1	9.6	10.7	9.5
		8	11.1	10.9	11.6	9.6	8.0	10.4	9.7	8.1	9.5	8.0	9.7
		6	9.8	10.2	9.8	9.4	8.8	10.3	9.2	8.6	10.3	9.4	9.6
		9	7.9	8.4	9.1	11.1	9.3	9.5	9.4	10.3	10.7	8.3	9.4
		4	8.7	9.6	10.9	9.4	8.2	8.3	9.0	9.8	12.0	10.4	9.6
6.00	M57147738	6	12.3	11.3	9.8	8.6	9.2	10.5	10.3	8.6	9.1	8.2	9.8
		8	8.6	10.4	9.7	10.5	11.9	9.5	9.8	9.9	10.0	9.7	10.0
		9	10.7	10.2	10.0	10.2	10.9	9.2	10.0	10.5	11.7	9.2	10.3
		12	8.4	9.7	8.9	8.9	9.7	9.2	9.7	9.8	9.1	9.0	9.2

* - Indicates Bend Test on this Bar

Figure E-41. ¾-in. (19-mm) Dia. Epoxy-Coated Rebar, Item h6, Test Nos. ILT-1 and ILT-2

GERDAU

CERTIFIED MATERIAL TEST REPORT

Page 1/1

US-ML-KNOXVILLE
1919 TENNESSEE AVENUE N. W.
KNOXVILLE, TN 37921
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	
SIMCOTE INC 1645 RED ROCK SAINT PAUL,MN 55119 USA	SIMCOTE INC 1645 RED ROCK ROAD SAINT PAUL,MN 55119-6014 USA	60 (420) TMX	Rebar / #6 (19MM)	
		LENGTH: 40'00"	WEIGHT: 47,586 LB	HEAT / BATCH: 57147738/03

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1932465/000030		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
3610	1326-0000031957	03/17/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.32	0.55	0.010	0.045	0.19	0.33	0.11	0.12	0.041	0.012	0.002	0.44

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
81330	561	99410	685	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
12.50	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
3.90	0.050	0.107	0.472

COMMENTS / NOTES

This grade meets the requirements for the following grades:

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

LISA CHURNETSKI
QUALITY ASSURANCE MGR.

Figure E-42. ¾-in. (19-mm) Dia. Epoxy-Coated Rebar, Item h6, Test Nos. ILT-1 and ILT-2

CAUTION FRESH CONCRETE

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

Ready Mixed Concrete Company

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

R#17-76 IL MGS Tollway Concrete Anchors
August 2016 SMT

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
01	23533000	4.00	0223	9753			11:57	08/17/16	1204554

CUSTOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R.	LOADS
00003	3	CIA---MWRSS				41

DELIVERY ADDRESS	SPECIAL INSTRUCTIONS	P.O. NUMBER
4630 NW 36TH ST	AIRPARK NORTH OF NORTH GOODYEARHANGERS	JIM 4506250

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UNIT PRICE	AMOUNT
4.00	4.00	4.00	23533000	L-3500 TYPE 3	$118.05	$472.20
				SLUMP: 4.00		
				MINIMUM HAUL		30.00

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 6 GAL.

RECEIVED BY [signature]

SUBTOTAL $502.20
TAX
TOTAL $502.20
$502.20

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
0223	9753	user	1204554	19265	11:57	8/17/16

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
4.00 CYDS	23533000				W	41

Material	Description	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
G47B	47B GRAVEL	2130 lb	8648 lb	8640 lb	-0.09%	1.50% M	15 gl
L47B	47B ROCK	913 lb	3703 lb	3680 lb	-0.62%	1.40% M	6 gl
CEM3	CEMENT TYPE3	564 lb	2256 lb	2235 lb	- -0.93%		
WATER	WATER	32.0 GL	110.6 GL	110.2 GL	-0.28%		110.2 gl
AIR	MICRO AIR 200	4.50 oz	18.00 oz	17.00 oz	-5.56%		

Actual Num Batches: 1 Manual 11:57:36
Load Total: 15476 lb Design 0.474 Water/Cement 0.492 A Design 128.0 gl Actual 131.6 gl To Add: 0.0 gl
Slump: 4.00 in # Water in Truck: 0.0 GL Adjust Water: 0.0 GL / Load Trim Water: 0.0 GL/ CYD

Figure E-43. Pole Concrete Foundation, Test Nos. ILT-1 and ILT-2

valmont

Extrusion Department
58027 Charlotte Ave
Elkhart, IN 46517
Ph: (574) 295 6942

Certificate

Date: *June 16, 2016* Elkhart Internal Order No. *333874*

Customer: *FARMINGTON* Customer Order No. *95116*

Customer Part No. *43011010R*

No. of lengths. *1*

Alloy/Temper: *6063 - T4* Cast No. *516133*

Part Desc. *Extruded Tube 43 ft 1 ins long x 10 ins dia x 0.312 ins wall. (Elkhart Part # ALY1047)*

We hereby certify that the material shipped and covered by this document, has been inspected in accordance with the extruded tube dimensional requirements of "Aluminum standards and data 2000", as published by the Aluminum Association, and with other applicable requirements as stated on the customer order, and has been found to comply. The material meets the compositional limits for the alloy as indicated, and has been processed to comply with T4 temper requirements for the alloy.

Lynne Shafer

Pole length before tapering: 43 ft – 1 in.
Pole length after tapering: 45 ft

Chemical Composition (Wt %):

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other Elements	
									Each Max	Total Max
Min	0.20				0.45					
Max	0.6	0.35	0.10	0.10	0.9	0.10	0.10	0.10	0.05	0.15

* Aluminum = Remainder

Actual cast analysis provided by billet vendor is retained on file.

Melted and Manufactured in USA

Figure E-44. Aluminum Pole, Test No. ILT-2

PONum

CRYSTAL
FINISHING SYSTEMS, INC.

Certificate# 693004-1
Date: 15-Jul-2016
PO: P95432

Certificate Of Conformance

Address:
2610 Ross Avenue
Schofield WI 54476
Phone: (715)-355-5351
Fax (715)-355-8812

Ship To:
Valmont Structures
20805 Eaton Avenue

Farmington MN 55024

Part Number	Die Nbr	Description	Ship Qty	Date Shipped
17003504R	1615	VALMONT 204^ [17'-0^}X3.5X.125 RD TUBE 204^ (1615) 6063-T1	61.00	15-Jul-2016

Extrusion Info:

Cast	Alloy	Date Extruded
54405	6063	Wednesday, July 13, 2016

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Total	Al
6063	0.20 - 0.60	.35	0.10	0.10	0.45 - 0.90	0.10	0.10	0.10	0.05	0.15	Rest

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Total	Al
6105	0.60 - 1.00	.35	0.10	0.15	0.45 - 0.80	0.10	0.10	0.10	0.05	0.15	Rest

We hereby certify that the material shipped and covered by this document. Has been inspected in accordance with the extruded tube dimensional requirements of (Aluminum Standards and Data 2013), as published by the Aluminum Association and other applicable requirements as stated on the customer order, and has been found to comply. The material meets the compositional limits for the alloy as indicated, and has been processed to comply with the temper requirements for the alloy.

We Hereby certify to the best of our knowledge and beleif the foregoing data

Eric Zebro
Authorized Signature

Figure E-45. Truss, Test No. ILT-2

Appendix F. Vehicle Center of Gravity Determination

Test: ILT-1 Vehicle: Dodge Ram 1500 quadcab

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb.)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unbalasted Truck (Curb)	4961	28.21781	139988.56
+	Hub	19	15.65625	297.46875
+	Brake activation cylinder & frame	7	27.25	190.75
+	Pneumatic tank (Nitrogen)	27	27.5	742.5
+	Strobe/Brake Battery	5	27	135
+	Brake Reciever/Wires	5	52.5	262.5
+	CG Plate including DAS	42	30.25	1270.5
-	Battery	-47	40	-1880
-	Oil	-5	20	-100
-	Interior	-78	34	-2652
-	Fuel	-164	18.5	-3034
-	Coolant	-10	37	-370
-	Washer fluid	-2	32	-64
+	Water Ballast	132	18.5	2442
+	Onboard Battery	14	25.75	360.5
	Backseat	76	48	3648
Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle				141237.78

Estimated Total Weight (lb.)	4982
Vertical CG Location (in.)	28.34961

Wheel Base (in.) 139.875

Center of Gravity	2270P MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb.)	5000 ± 110	5000	0.0
Longitudinal CG (in.)	63 ± 4	61.01	-1.98653
Lateral CG (in.)	NA	-0.70061	NA
Vertical CG (in.)	28 or greater	28.35	0.34961

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

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

CURB WEIGHT (lb.)

	Left	Right
Front	1439	1390
Rear	1094	1038

FRONT	2829 lb.
REAR	2132 lb.
TOTAL	4961 lb.

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	1429	1390
Rear	1122	1059

FRONT	2819 lb.
REAR	2181 lb.
TOTAL	5000 lb.

Figure F-1. Vehicle Mass Distribution, Test No. ILT-1

Test: ILT-2 Vehicle: Hyundai Accent

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb.)
+	Non-ballasted Car (curb)	2434
+	Brake receivers/wires	5
+	Brake Actuator and Frame	7
+	Nitrogen Cylinder	22
+	Strobe/Brake Battery	5
+	Hub	19
+	Data Acquisition Tray	13
+	DTS Rack	0
-	Battery	-25
-	Oil	-6
-	Interior	-54
-	Fuel	-19
-	Coolant	-8
-	Washer fluid	-11
	Water Ballast	23
	Onboard Battery	12
	Misc.	0

Estimated Total Weight (lb.) 2417

Roof Height (in.) 57 7/8
Wheel base (in.) 98 3/4

Center of Gravity	1100C MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb.)	2420 (+/-)55	2420	0.0
Longitudinal CG (in.)	39 (+/-)4	37.79	-1.21384
Lateral CG (in.)	NA	0	NA
Vertical CG (in.)	NA	22.73	NA

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side
Note: Cells Highlighted in Red do not meet target requirements

CURB WEIGHT (lb.)

	Left	Right
Front	775	750
Rear	453	456

FRONT 1525 lb.
REAR 909 lb.
TOTAL 2434 lb.

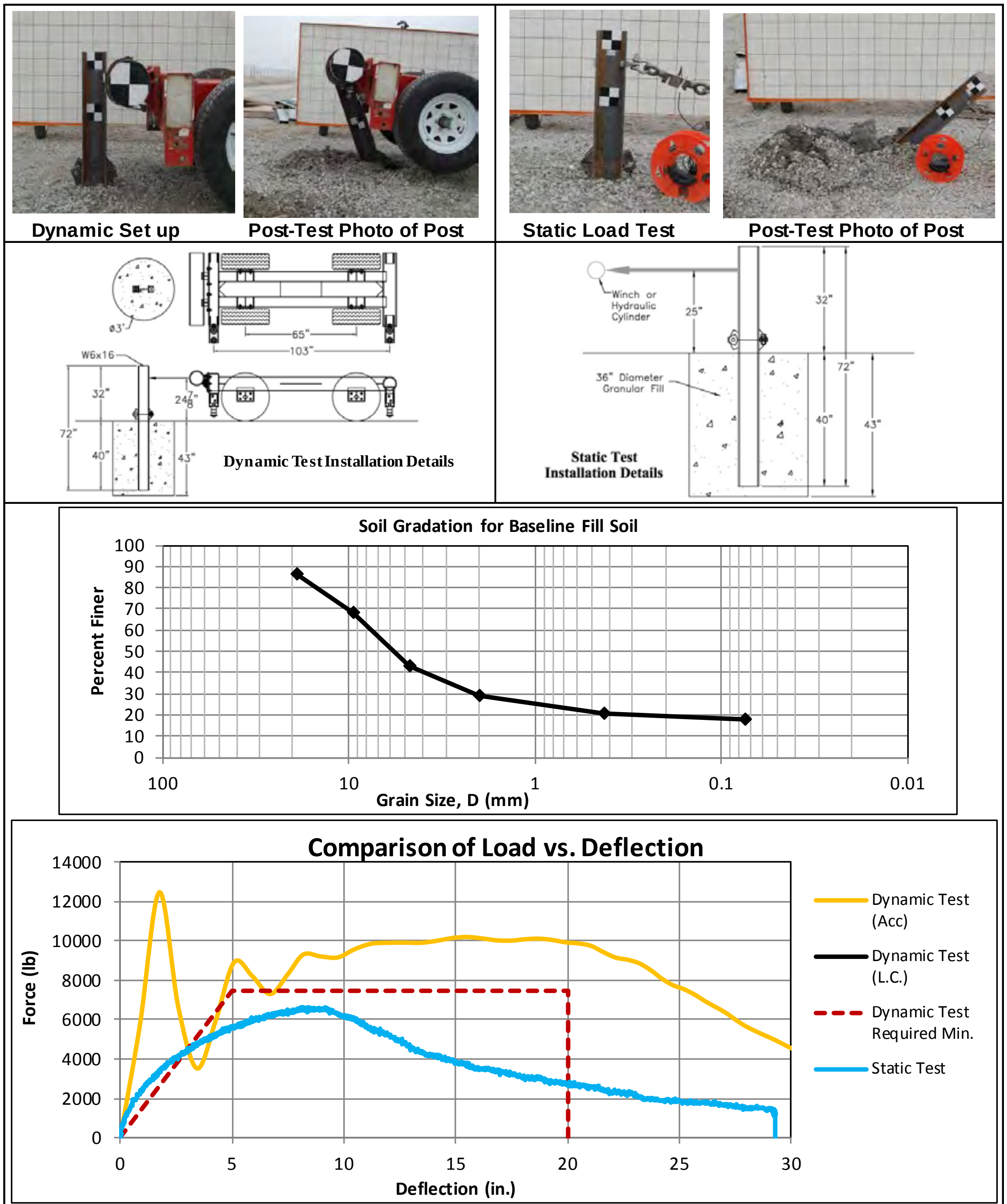
TEST INERTIAL WEIGHT (lb.)
(from scales)

	Left	Right
Front	745	749
Rear	462	464

FRONT 1494 lb.
REAR 926 lb.
TOTAL 2420 lb.

Figure F-2. Vehicle Mass Distribution, Test No. ILT-2

Appendix G. Static Soil Tests

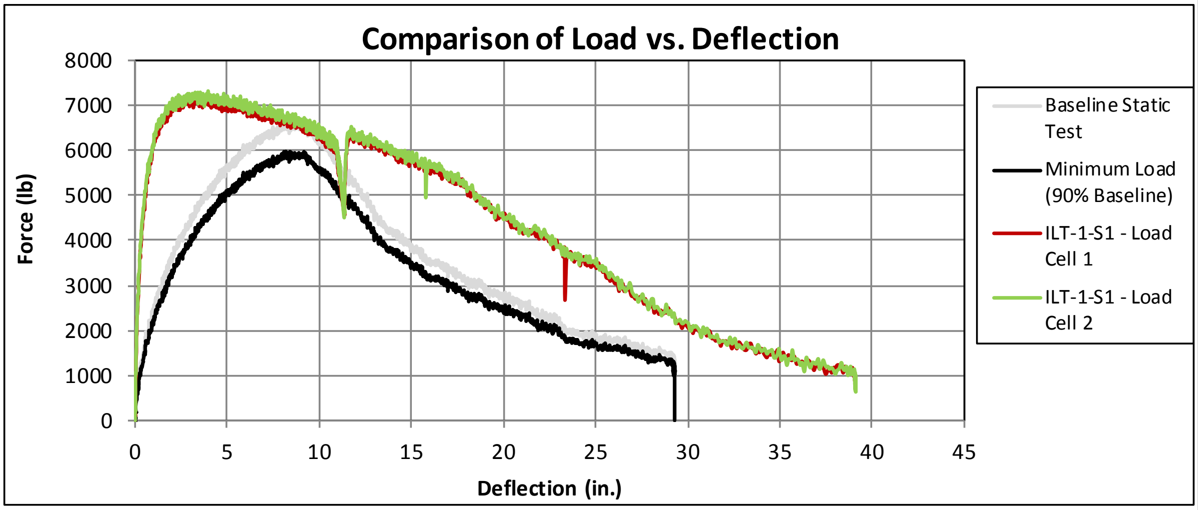


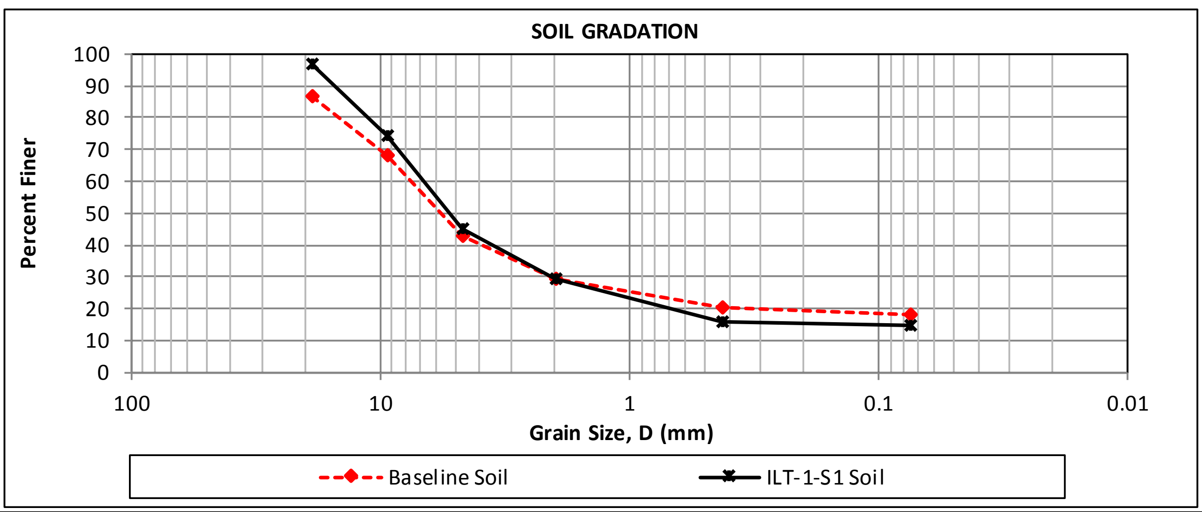
Date	4/4/2012	
Test Facility & Site Location	Midwest Roadside Safety Facility	
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)	
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)	
Description of fill placement procedure	3 Pass, 8" Lift	
Bogie Weight	1844 lb	836 kg
Impact Velocity	20.1 mph	32.3 km/h

Figure G-1. Soil Strength, Initial Calibration Tests

Static Load Test Setup

Post-Test Photo of Post



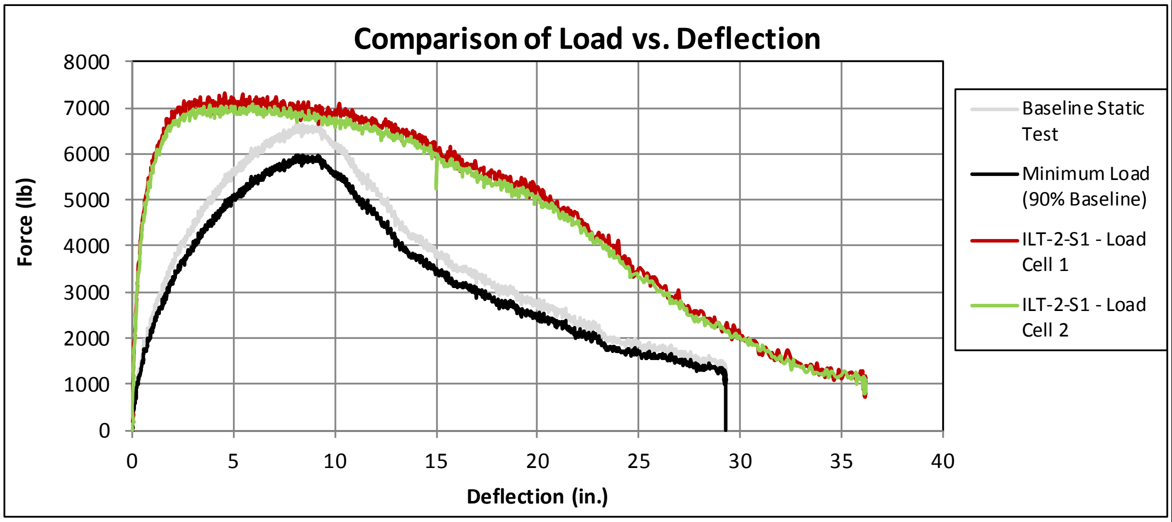


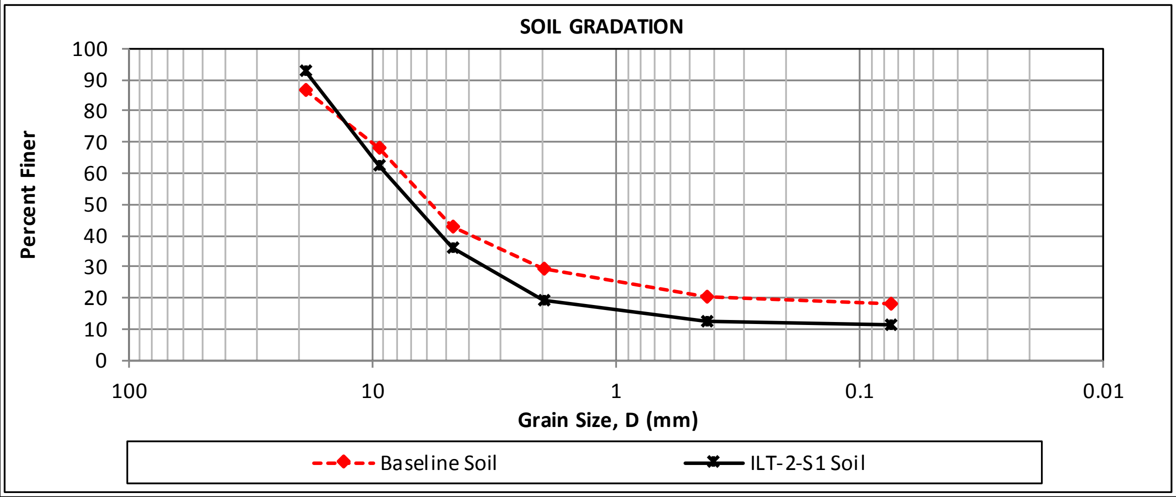
Date	9/22/2016
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	8-inch lifts tamped with a pneumatic compactor

Figure G-2. Static Soil Test, Test No. ILT-1

Static Load Test Setup

Post-Test Photo of Post





Date..	9/27/2016
Test Facility & Site Location.....................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)..........	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)......	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure.....	8-inch lifts tamped with a pneumatic compactor

Figure G-3. Static Soil Test, Test No. ILT-2

Appendix H. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: ILT-1
VEHICLE: Dodge Ram 1500 quadcab

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	26.470	11.377	2.614	26.437	11.447	2.628	-0.032	0.070	0.014
2	28.586	14.969	0.090	28.660	15.063	0.080	0.075	0.095	-0.010
3	30.042	20.336	0.900	30.022	20.381	0.982	-0.020	0.045	0.082
4	29.224	23.442	3.235	29.141	23.469	3.245	-0.083	0.027	0.009
5	22.181	11.126	0.398	22.128	11.153	0.360	-0.053	0.028	-0.038
6	23.319	15.241	-2.710	23.345	15.271	-2.738	0.026	0.031	-0.028
7	23.703	20.806	-2.390	23.683	20.789	-2.368	-0.020	-0.017	0.022
8	23.777	24.295	-1.957	23.638	24.248	-1.997	-0.140	-0.046	-0.039
9	19.051	11.190	-1.837	18.975	11.218	-1.923	-0.076	0.028	-0.085
10	20.234	15.211	-4.541	20.191	15.169	-4.541	-0.043	-0.041	0.000
11	20.458	21.078	-4.106	20.351	21.119	-4.112	-0.106	0.041	-0.006
12	20.419	24.590	-3.534	20.378	24.603	-3.518	-0.041	0.014	0.016
13	16.223	10.920	-4.833	16.221	10.840	-4.809	-0.003	-0.081	0.024
14	17.046	15.341	-5.201	16.930	15.271	-5.200	-0.116	-0.070	0.002
15	17.230	21.303	-4.469	17.034	21.137	-4.461	-0.195	-0.166	0.008
16	17.058	24.809	-4.132	17.060	24.777	-4.110	0.003	-0.032	0.022
17	12.100	11.308	-5.559	12.033	11.194	-5.555	-0.067	-0.114	0.004
18	12.742	15.637	-4.902	12.704	15.668	-4.867	-0.038	0.031	0.035
19	13.008	21.373	-4.344	13.011	21.339	-4.324	0.004	-0.034	0.020
20	13.128	25.057	-3.993	13.116	24.969	-3.987	-0.012	-0.088	0.006
21	6.685	11.366	-5.464	6.706	11.433	-5.450	0.021	0.066	0.014
22	7.148	15.842	-4.928	7.148	15.830	-4.920	0.000	-0.011	0.008
23	7.473	21.315	-4.264	7.508	21.294	-4.258	0.035	-0.020	0.006
24	7.580	24.561	-3.887	7.567	24.547	-3.895	-0.013	-0.014	-0.007
25	-0.104	10.801	-1.281	-0.154	10.823	-1.292	-0.050	0.023	-0.011
26	-0.240	15.305	-0.742	-0.259	15.343	-0.750	-0.020	0.038	-0.008
27	-0.135	20.735	-0.088	-0.117	20.743	-0.095	0.017	0.008	-0.008
28	-0.145	24.059	0.280	-0.161	24.109	0.272	-0.016	0.050	-0.009

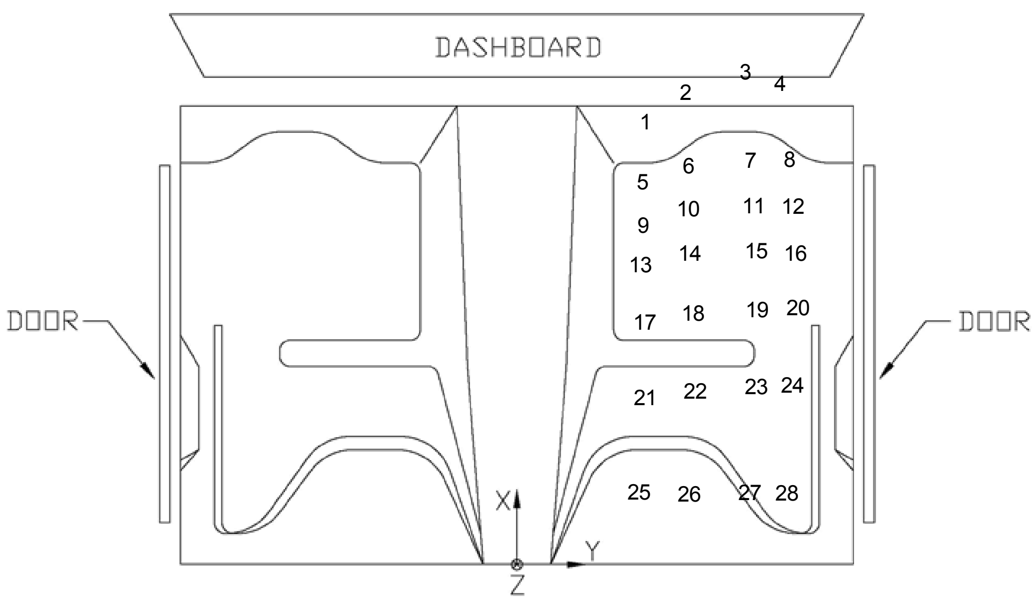


Figure H-1. Floorpan Deformation Data – Set 1, Test No. ILT-1

TEST: ILT-1
VEHICLE: Dodge Ram 1500 quadcab

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	49.314	15.549	1.212	49.032	15.664	1.020	-0.281	0.116	-0.192
2	51.498	18.808	-1.785	51.201	18.869	-2.001	-0.297	0.061	-0.216
3	52.976	24.207	-1.535	52.630	24.279	-1.897	-0.346	0.073	-0.361
4	52.169	27.411	0.201	51.859	27.575	-0.005	-0.310	0.164	-0.205
5	45.022	15.044	-0.864	44.706	15.097	-1.063	-0.316	0.053	-0.199
6	46.085	18.758	-4.395	45.886	18.810	-4.718	-0.200	0.052	-0.323
7	46.588	24.222	-4.829	46.203	24.385	-5.084	-0.385	0.163	-0.255
8	46.569	27.766	-4.864	46.276	27.801	-5.135	-0.293	0.035	-0.270
9	41.799	14.880	-3.084	41.511	14.896	-3.258	-0.288	0.016	-0.173
10	42.927	18.444	-6.201	42.629	18.579	-6.467	-0.298	0.136	-0.266
11	43.233	24.488	-6.541	42.952	24.434	-6.746	-0.281	-0.054	-0.205
12	43.237	27.940	-6.411	42.955	27.929	-6.632	-0.282	-0.011	-0.221
13	38.940	14.121	-5.830	38.675	14.261	-6.083	-0.265	0.140	-0.253
14	39.736	18.494	-6.774	39.390	18.612	-7.015	-0.346	0.118	-0.241
15	39.966	24.576	-6.849	39.616	24.496	-7.048	-0.350	-0.080	-0.199
16	39.888	28.012	-6.946	39.632	28.076	-7.167	-0.256	0.064	-0.222
17	34.791	14.547	-6.591	34.452	14.532	-6.733	-0.339	-0.015	-0.142
18	35.463	18.961	-6.493	35.128	18.897	-6.639	-0.336	-0.064	-0.146
19	35.884	24.611	-6.639	35.558	24.667	-6.846	-0.326	0.056	-0.208
20	35.993	28.303	-6.769	35.639	28.321	-6.977	-0.353	0.019	-0.208
21	29.497	14.738	-6.415	29.191	14.776	-6.549	-0.306	0.038	-0.133
22	29.907	19.193	-6.445	29.660	19.289	-6.600	-0.247	0.096	-0.155
23	30.355	24.711	-6.470	30.032	24.676	-6.656	-0.323	-0.035	-0.186
24	30.398	27.976	-6.514	30.161	27.997	-6.716	-0.237	0.021	-0.203
25	22.678	14.744	-2.085	22.412	14.786	-2.188	-0.265	0.042	-0.102
26	22.587	19.300	-2.115	22.365	19.312	-2.230	-0.222	0.012	-0.115
27	22.855	24.827	-2.134	22.494	24.827	-2.283	-0.361	0.000	-0.149
28	22.881	28.226	-2.196	22.533	28.205	-2.360	-0.348	-0.020	-0.164

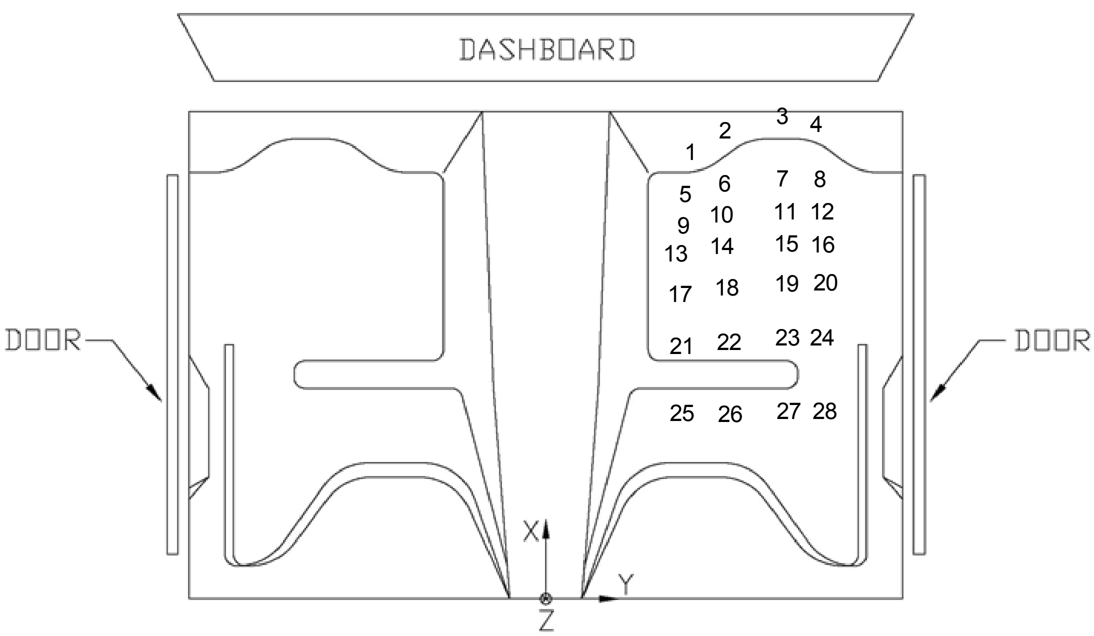


Figure H-2. Floorpan Deformation Data – Set 2, Test No. ILT-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: ILT-1
VEHICLE: Dodge Ram 1500 quadcab

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	11.868	-6.138	24.408	11.900	-6.159	24.481	0.032	-0.021	0.073
	2	14.437	9.639	24.874	14.416	9.518	24.935	-0.020	-0.121	0.061
	3	14.953	22.481	26.684	14.938	22.446	26.800	-0.015	-0.036	0.116
	4	8.755	-4.707	13.175	8.756	-4.692	13.203	0.001	0.015	0.028
	5	10.917	11.194	15.405	10.917	11.161	15.469	0.001	-0.033	0.064
	6	11.767	23.832	16.822	11.728	23.807	16.912	-0.039	-0.026	0.090
SIDE PANEL	7	25.091	28.706	5.563	24.987	28.605	5.787	-0.104	-0.101	0.224
	8	24.522	29.179	1.356	24.433	29.121	1.476	-0.089	-0.058	0.120
	9	20.477	28.502	7.968	20.472	28.220	8.011	-0.005	-0.282	0.043
IMPACT SIDE DOOR	10	11.868	28.825	22.276	11.686	28.734	22.109	-0.182	-0.091	-0.167
	11	0.500	28.798	21.846	0.286	28.923	21.791	-0.214	0.125	-0.055
	12	-12.321	29.171	22.444	-12.528	29.573	22.434	-0.206	0.402	-0.010
	13	7.390	31.986	6.568	7.171	31.832	6.485	-0.219	-0.154	-0.083
	14	-0.628	31.968	6.707	-0.891	32.008	6.766	-0.264	0.040	0.059
	15	-13.403	30.921	7.181	-13.599	31.295	7.312	-0.196	0.373	0.131
ROOF	1	8.509	-8.050	40.435	8.368	-8.084	40.391	-0.141	-0.034	-0.044
	2	8.224	-1.380	41.284	8.095	-1.466	41.249	-0.129	-0.086	-0.035
	3	7.511	4.755	41.959	7.374	4.723	41.949	-0.138	-0.032	-0.009
	4	6.291	10.870	42.527	6.096	10.779	42.558	-0.195	-0.092	0.030
	5	4.569	15.834	42.860	4.377	15.852	42.882	-0.192	0.018	0.022
	6	-3.610	-8.638	44.545	-3.805	-8.761	44.440	-0.195	-0.124	-0.105
	7	-4.405	-2.890	45.289	-4.537	-3.066	45.192	-0.131	-0.176	-0.097
	8	-4.542	2.253	45.778	-4.790	2.114	45.716	-0.248	-0.140	-0.062
	9	-5.650	7.283	46.276	-5.836	7.162	46.219	-0.186	-0.122	-0.057
	10	-6.425	12.359	46.611	-6.532	12.219	46.554	-0.107	-0.140	-0.057
	11	-11.047	-9.042	45.271	-11.209	-9.203	45.127	-0.162	-0.161	-0.143
	12	-12.285	-4.970	45.845	-12.521	-5.190	45.736	-0.236	-0.220	-0.109
	13	-13.706	0.726	46.517	-13.836	0.566	46.412	-0.129	-0.160	-0.105
	14	-14.010	5.849	46.940	-14.076	5.696	46.842	-0.066	-0.153	-0.098
	15	-14.562	11.127	47.305	-14.745	11.046	47.235	-0.183	-0.081	-0.070

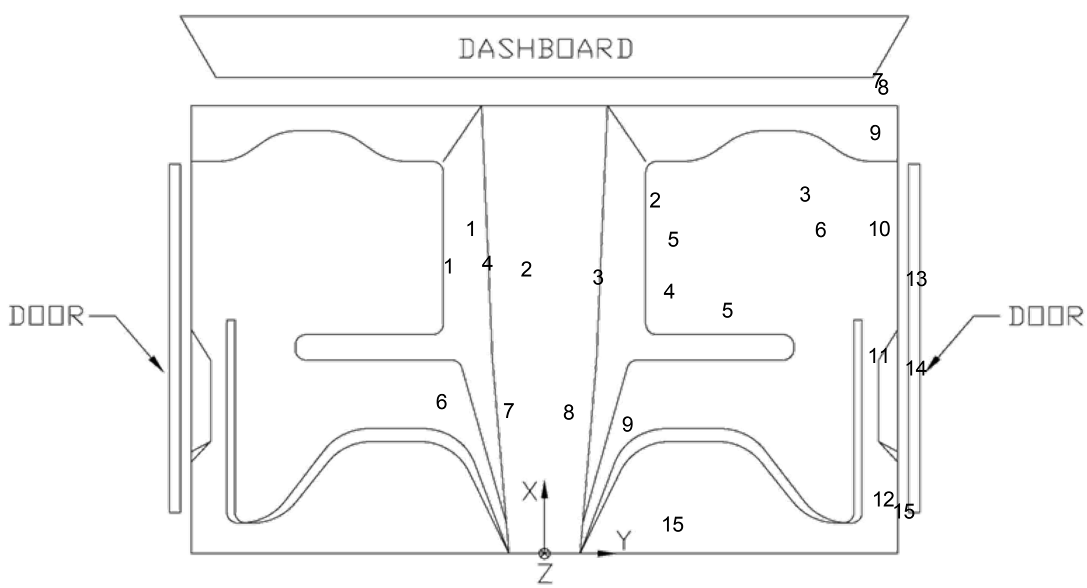


Figure H-3. Occupant Compartment Deformation Data – Set 1, Test No. ILT-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: ILT-1
VEHICLE: Dodge Ram 1500 quadcab

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	35.012	0.978	25.309	34.885	1.133	25.231	-0.127	0.155	-0.077
	2	37.642	16.572	23.712	37.537	16.727	23.637	-0.104	0.156	-0.075
	3	38.316	29.478	23.989	38.205	29.789	23.817	-0.112	0.312	-0.172
	4	31.701	1.035	14.050	31.558	1.192	13.944	-0.142	0.157	-0.105
	5	34.015	17.016	14.247	33.859	17.217	14.162	-0.156	0.200	-0.085
	6	34.999	29.735	14.077	34.776	29.969	13.963	-0.223	0.234	-0.115
SIDE PANEL	7	48.040	33.142	2.218	47.780	33.134	2.024	-0.260	-0.009	-0.194
	8	47.514	33.062	-2.149	47.146	33.090	-2.384	-0.369	0.028	-0.235
	9	43.598	33.254	4.609	43.336	33.074	4.377	-0.261	-0.180	-0.232
IMPACT SIDE DOOR	10	35.295	35.432	18.634	34.752	35.488	18.540	-0.543	0.056	-0.094
	11	23.961	35.460	18.626	23.461	35.732	18.346	-0.500	0.272	-0.281
	12	11.119	36.023	19.286	10.645	36.584	19.152	-0.475	0.561	-0.135
	13	30.509	36.651	2.847	30.061	36.578	2.652	-0.448	-0.074	-0.194
	14	22.526	36.749	3.295	22.007	36.856	3.007	-0.519	0.108	-0.288
	15	9.678	35.878	4.195	9.189	36.353	3.954	-0.489	0.475	-0.241
ROOF	1	31.834	1.181	41.548	31.752	1.376	41.409	-0.082	0.195	-0.139
	2	31.636	7.865	41.552	31.660	8.038	41.342	0.024	0.173	-0.209
	3	31.031	14.142	41.436	30.911	14.334	41.289	-0.120	0.191	-0.147
	4	29.725	20.127	41.353	29.680	20.363	41.147	-0.045	0.236	-0.206
	5	28.190	25.249	40.992	27.986	25.417	40.859	-0.204	0.168	-0.133
	6	19.867	1.128	45.851	19.773	1.355	45.765	-0.094	0.227	-0.086
	7	19.190	6.883	45.881	19.060	6.976	45.799	-0.130	0.093	-0.081
	8	19.074	12.013	45.733	18.823	12.205	45.657	-0.252	0.192	-0.076
	9	17.784	17.179	45.651	17.801	17.406	45.525	0.017	0.228	-0.126
	10	17.231	22.306	45.336	17.157	22.427	45.209	-0.074	0.121	-0.127
	11	12.328	0.939	46.758	12.099	1.031	46.695	-0.229	0.091	-0.063
	12	11.215	5.007	46.834	10.958	5.189	46.792	-0.257	0.182	-0.042
	13	9.823	10.791	46.816	9.687	10.861	46.759	-0.136	0.070	-0.057
	14	9.714	16.020	46.585	9.490	16.056	46.530	-0.224	0.036	-0.055
	15	9.040	21.266	46.322	8.827	21.359	46.251	-0.213	0.093	-0.071

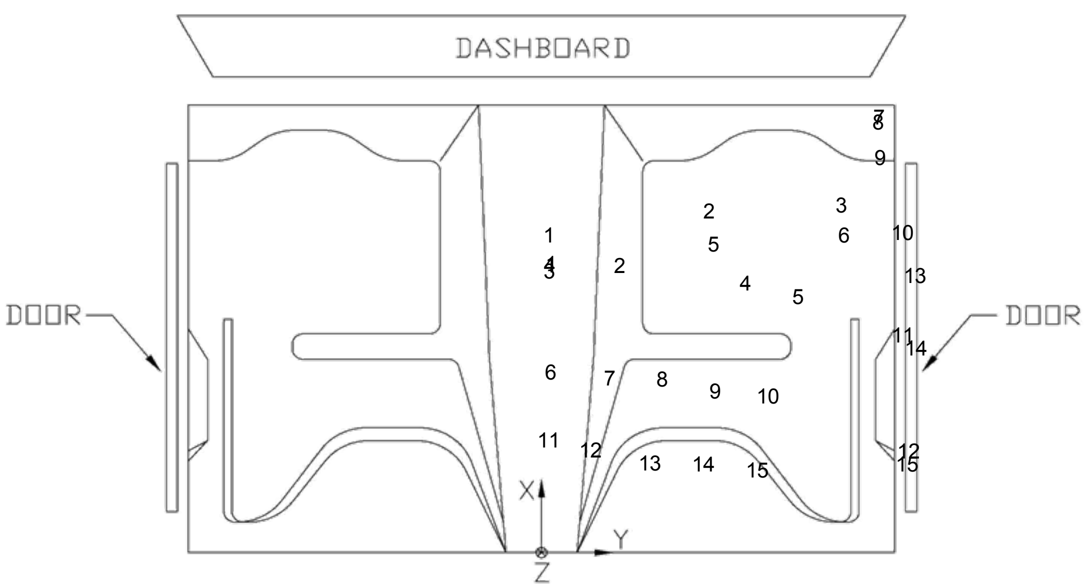
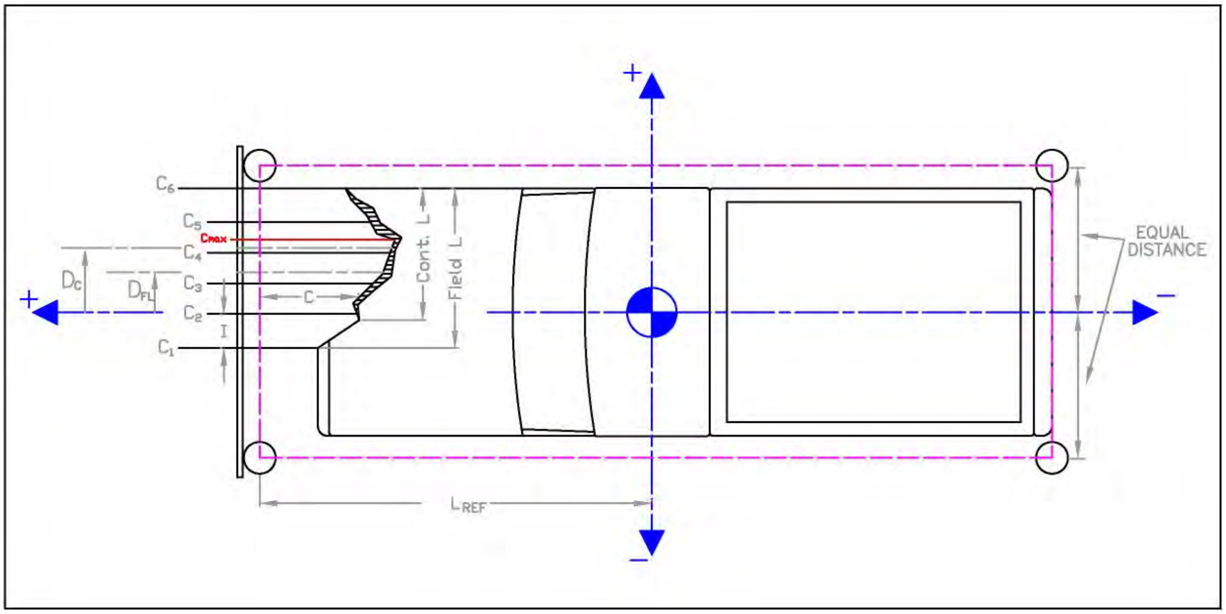


Figure H-4. Occupant Compartment Deformation Data – Set 2, Test No. ILT-1

Date: 9/23/2016 **Test Number:** ILT-1

Make: Dodge **Model:** Ram 1500 quadcab **Year:** 2009



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	105	(2667)
Total Vehicle Width:	76.5	(1943)
Width of contact and induced crush - Field L:	36	(914)
Crush measurement spacing interval (L/5) - I:	7.2	(183)
Distance from center of vehicle to center of Field L - D_{FL}:	20 1/4	(514)
Width of Contact Damage:	14 1/2	(368)
Distance from center of vehicle to center of contact damage - D_C:	31	(787)

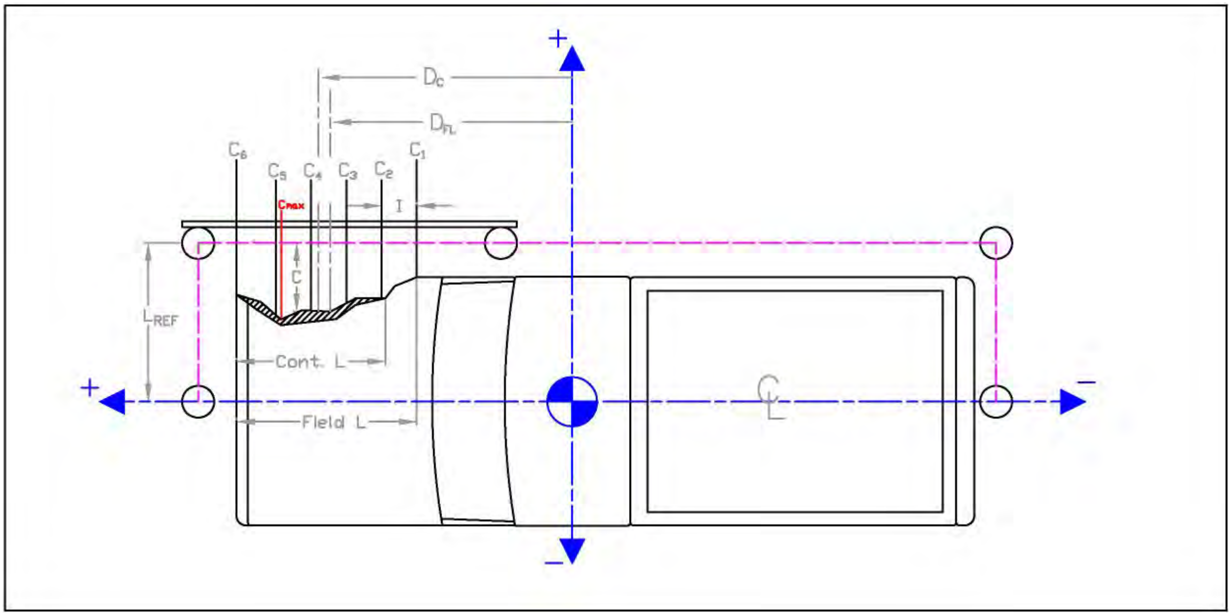
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	3 1/4	(83)	2 1/4	(57)	4	(102)	- 2/3	-(16)	- 1/9	-(3)
C_2	3 1/2	(89)	9 4/9	(240)	4 1/3	(110)			- 1/5	-(5)
C_3	5 3/4	(146)	16 2/3	(423)	5	(129)			1 1/3	(34)
C_4	12 3/8	(314)	23 6/7	(606)	6 1/3	(160)			6 5/7	(170)
C_5	NA	NA	31	(789)	10	(256)			NA	NA
C_6	NA	NA	38 1/4	(972)	20 1/2	(521)			NA	NA
C_{MAX}	17 1/2	(445)	29	(737)	8 5/8	(219)			9 1/2	(242)

Figure H-5. Exterior Vehicle Crush (NASS) - Front, Test No. ILT-1

Date: 9/23/2016 **Test Number:** ILT-1

Make: Dodge **Model:** Ram 1500 quadcab **Year:** 2009



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	48	(1219)
Total Vehicle Length:	229.25	(5823)
Width of contact and induced crush - Field L:	229 1/2	(5829)
Crush measurement spacing interval (L/5) - I:	45.9	(1166)
Distance from vehicle c.g. to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	229 1/2	(5829)
Distance from vehicle c.g. to center of contact damage - D_C:	0	()

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	11	(279)	######	-(2915)	5 4/7	(141)	4	(102)	1 3/7	(36)
C_2	NA	NA	-68 6/7	-(1749)	5 7/8	(149)			NA	NA
C_3	8	(203)	-23	-(583)	5	(129)			-1	-(28)
C_4	8 3/8	(213)	23	(583)	5 1/8	(130)			- 3/4	-(19)
C_5	20	(508)	68 6/7	(1749)	5	(127)			11	(279)
C_6	NA	NA	114 3/4	(2915)	33 1/2	(851)			NA	NA
C_{MAX}	20 1/2	(521)	71	(1803)	5 1/8	(130)			11 3/8	(289)

Figure H-6. Exterior Vehicle Crush (NASS) - Side, Test No. ILT-1

TEST: ILT-2
VEHICLE: Hyundai Accent

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	26.172	-21.973	1.094	25.942	-21.736	0.984	-0.230	0.237	-0.109
2	28.678	-18.612	-0.822	28.520	-18.417	-0.891	-0.157	0.195	-0.068
3	28.874	-12.235	-1.500	28.715	-12.061	-1.529	-0.160	0.174	-0.029
4	28.596	-6.670	-1.647	28.452	-6.539	-1.663	-0.144	0.132	-0.016
5	24.691	-22.750	-1.541	24.561	-22.605	-1.568	-0.130	0.145	-0.027
6	25.634	-19.204	-3.009	25.503	-19.091	-3.034	-0.131	0.113	-0.025
7	25.160	-12.309	-3.231	24.947	-12.179	-3.288	-0.213	0.130	-0.057
8	25.362	-6.804	-3.222	25.173	-6.576	-3.252	-0.190	0.227	-0.030
9	18.593	-22.562	-4.828	18.566	-22.454	-4.903	-0.027	0.107	-0.075
10	18.645	-19.222	-4.965	18.599	-19.027	-5.030	-0.046	0.195	-0.065
11	19.569	-12.040	-5.023	19.394	-12.010	-5.050	-0.175	0.030	-0.026
12	19.715	-6.851	-5.032	19.530	-6.680	-5.049	-0.185	0.171	-0.017
13	14.588	-22.833	-5.134	14.408	-22.757	-5.193	-0.180	0.075	-0.059
14	14.361	-18.914	-4.668	14.360	-18.856	-4.750	-0.001	0.058	-0.082
15	14.497	-11.483	-4.688	14.309	-11.397	-4.588	-0.188	0.086	0.100
16	14.742	-6.902	-5.117	14.585	-6.783	-5.117	-0.157	0.119	-0.001
17	10.647	-23.164	-4.971	10.625	-23.035	-5.049	-0.022	0.129	-0.078
18	10.153	-19.070	-4.444	10.085	-19.106	-4.562	-0.069	-0.037	-0.118
19	9.857	-11.330	-4.278	9.636	-11.176	-4.310	-0.221	0.153	-0.032
20	10.241	-6.878	-5.000	10.012	-6.810	-5.019	-0.229	0.068	-0.019
21	6.426	-23.253	-4.473	6.404	-23.129	-4.524	-0.022	0.123	-0.051
22	6.268	-19.032	-4.151	6.203	-19.058	-4.236	-0.064	-0.026	-0.085
23	6.284	-11.307	-4.084	6.025	-11.248	-4.096	-0.259	0.060	-0.012
24	6.927	-6.359	-4.499	6.767	-6.302	-4.538	-0.160	0.057	-0.039
25	-0.723	-22.904	0.193	-0.784	-22.846	0.191	-0.062	0.058	-0.002
26	-0.981	-18.978	0.099	-1.070	-18.947	0.095	-0.089	0.031	-0.003
27	-0.775	-10.773	0.050	-0.919	-10.718	0.040	-0.145	0.054	-0.010
28	-0.802	-6.564	0.019	-0.898	-6.532	0.009	-0.095	0.032	-0.011

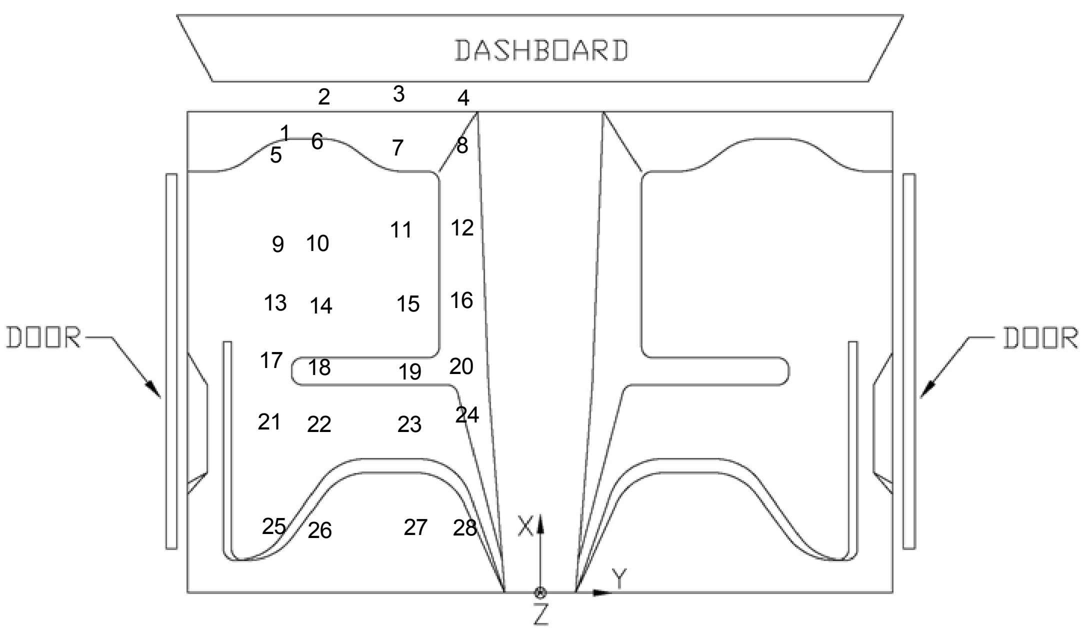


Figure H-7. Floorpan Deformation Data – Set 1, Test No. ILT-2

TEST: ILT-2
VEHICLE: Hyundai Accent

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	41.952	-24.349	4.427	41.829	-23.980	4.415	-0.123	0.369	-0.012
2	44.532	-20.976	2.741	44.470	-20.713	2.898	-0.063	0.263	0.156
3	44.755	-14.686	2.168	44.739	-14.287	2.302	-0.016	0.399	0.134
4	44.465	-9.024	2.088	44.465	-8.773	2.191	0.000	0.252	0.103
5	40.718	-25.158	1.582	40.703	-24.898	1.693	-0.015	0.260	0.111
6	41.765	-21.524	0.246	41.779	-21.268	0.376	0.014	0.256	0.130
7	41.176	-14.735	0.034	41.165	-14.338	0.126	-0.010	0.397	0.092
8	41.374	-9.217	0.172	41.380	-8.772	0.272	0.006	0.445	0.100
9	35.048	-25.023	-2.285	35.129	-24.664	-2.272	0.081	0.358	0.013
10	35.112	-21.758	-2.382	35.207	-21.347	-2.342	0.095	0.411	0.040
11	35.808	-14.487	-2.282	35.836	-14.194	-2.206	0.028	0.293	0.076
12	35.852	-9.243	-2.235	35.919	-8.885	-2.108	0.066	0.358	0.127
13	31.037	-25.374	-2.990	31.088	-25.007	-2.981	0.051	0.367	0.009
14	30.788	-21.528	-2.532	30.844	-21.128	-2.497	0.056	0.401	0.034
15	30.730	-13.925	-2.462	30.782	-13.649	-2.269	0.052	0.276	0.193
16	30.928	-9.337	-2.812	30.995	-9.065	-2.716	0.067	0.272	0.095
17	27.172	-25.621	-3.259	27.229	-25.358	-3.250	0.057	0.262	0.009
18	26.453	-21.717	-2.761	26.501	-21.353	-2.732	0.048	0.363	0.028
19	26.217	-14.045	-2.463	26.066	-13.570	-2.454	-0.151	0.475	0.009
20	26.375	-9.440	-3.161	26.499	-9.175	-3.099	0.124	0.265	0.062
21	22.875	-25.824	-3.175	22.960	-25.528	-3.167	0.085	0.296	0.008
22	22.644	-21.681	-2.832	22.700	-21.406	-2.842	0.056	0.276	-0.010
23	22.449	-13.928	-2.682	22.407	-13.621	-2.658	-0.042	0.308	0.024
24	23.005	-8.992	-2.985	23.099	-8.722	-2.960	0.094	0.270	0.025
25	15.251	-25.667	0.776	15.205	-25.368	0.789	-0.046	0.299	0.013
26	15.010	-21.640	0.691	14.999	-21.366	0.693	-0.011	0.274	0.003
27	15.128	-13.526	0.739	15.129	-13.209	0.743	0.002	0.317	0.004
28	14.956	-9.330	0.743	14.950	-9.065	0.750	-0.007	0.264	0.007

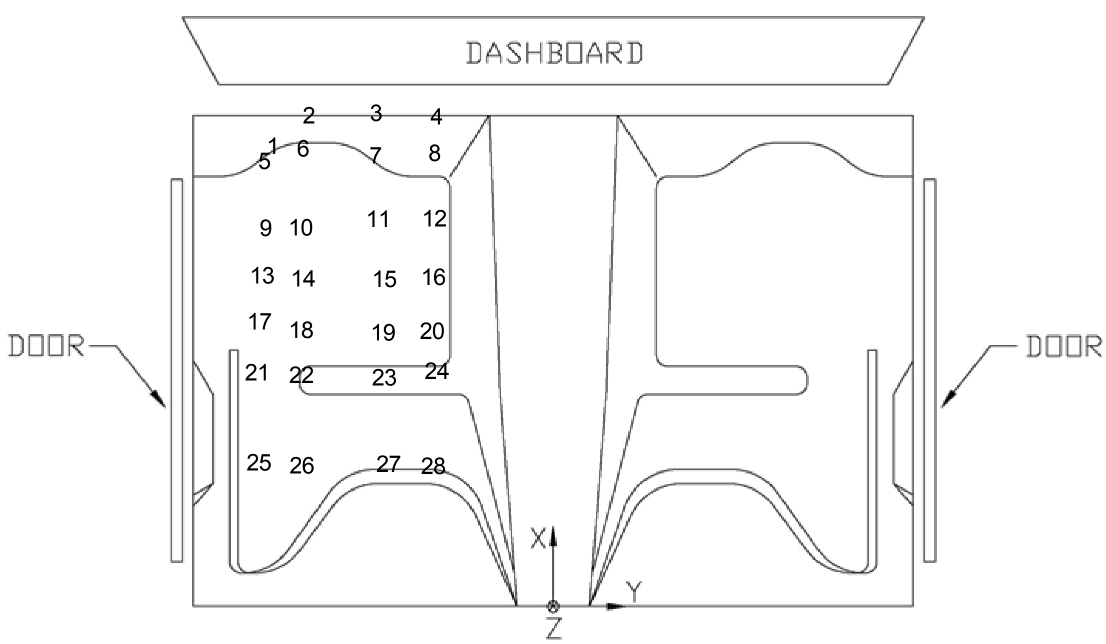


Figure H-8. Floorpan Deformation Data – Set 2, Test No. ILT-2

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: ILT-2
VEHICLE: Hyundai Accent

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	15.112	-22.508	22.941	15.007	-22.222	22.741	-0.105	0.287	-0.200
	2	11.815	-13.267	26.595	11.728	-12.989	26.548	-0.087	0.278	-0.047
	3	13.284	1.157	23.621	13.096	1.423	23.616	-0.188	0.266	-0.005
	4	13.195	-22.365	12.717	13.139	-22.133	12.736	-0.055	0.232	0.019
	5	12.328	-12.971	12.566	12.203	-12.699	12.532	-0.125	0.272	-0.034
	6	8.934	0.226	12.779	8.721	0.469	12.789	-0.212	0.244	0.011
SIDE PANEL	7	21.643	-26.701	5.671	21.624	-26.434	5.563	-0.019	0.267	-0.108
	8	18.045	-26.725	3.034	18.069	-26.512	2.992	0.024	0.213	-0.042
	9	21.212	-26.728	0.587	21.283	-26.536	0.461	0.071	0.192	-0.126
IMPACT SIDE DOOR	10	-13.724	-27.513	25.568	-13.570	-27.832	25.629	0.153	-0.320	0.061
	11	0.810	-27.382	23.464	0.837	-27.445	23.420	0.027	-0.064	-0.044
	12	11.521	-27.449	21.912	11.442	-27.219	21.871	-0.079	0.230	-0.041
	13	-11.248	-27.821	6.326	-11.115	-28.027	6.456	0.132	-0.206	0.130
	14	-0.324	-28.251	2.537	-0.359	-28.441	2.657	-0.034	-0.190	0.120
	15	9.050	-27.872	1.915	8.982	-28.044	1.869	-0.068	-0.172	-0.046
ROOF	1	2.457	-17.628	39.865	2.410	-17.436	39.936	-0.047	0.192	0.071
	2	3.094	-13.104	40.022	3.155	-12.904	40.018	0.061	0.200	-0.004
	3	3.440	-9.421	40.133	3.520	-9.286	40.095	0.079	0.135	-0.039
	4	3.892	-4.209	40.122	3.794	-4.005	40.148	-0.098	0.204	0.025
	5	3.967	0.314	40.105	3.863	0.389	40.116	-0.104	0.075	0.011
	6	-4.374	-17.091	42.882	-4.155	-16.980	42.884	0.219	0.111	0.002
	7	-3.516	-13.173	43.005	-3.398	-13.168	43.007	0.118	0.006	0.001
	8	-3.047	-8.878	43.144	-3.029	-8.809	43.163	0.018	0.068	0.020
	9	-2.826	-3.946	43.242	-2.869	-3.847	43.268	-0.043	0.099	0.027
	10	-2.611	-0.311	43.204	-2.729	-0.167	43.247	-0.118	0.144	0.043
	11	-10.764	-16.529	44.338	-10.548	-16.591	44.370	0.216	-0.061	0.032
	12	-10.514	-13.217	44.580	-10.434	-13.137	44.647	0.080	0.080	0.068
	13	-10.456	-9.382	44.809	-10.329	-9.401	44.853	0.127	-0.019	0.044
	14	-10.137	-4.241	44.934	-10.080	-4.097	44.980	0.057	0.144	0.046
	15	-10.459	-0.731	45.027	-10.414	-0.623	45.070	0.045	0.108	0.042

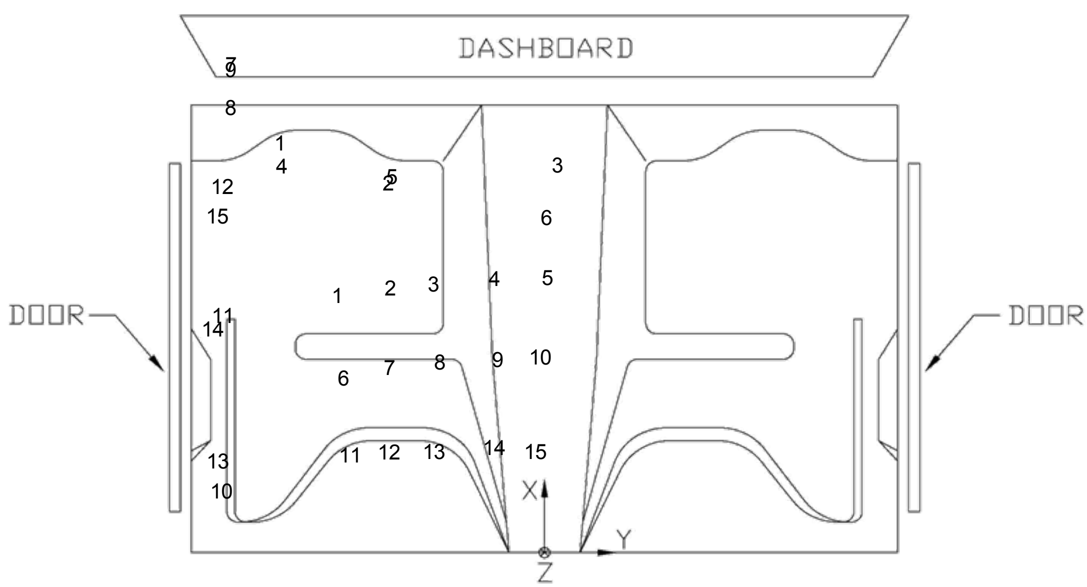


Figure H-9. Occupant Compartment Deformation Data – Set 1, Test No. ILT-2

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: ILT-2
VEHICLE: Hyundai Accent

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	28.720	-25.270	24.940	28.717	-24.865	24.927	-0.003	0.404	-0.014
	2	25.032	-16.114	28.465	24.841	-15.683	28.288	-0.191	0.432	-0.177
	3	26.548	-1.700	25.880	26.445	-1.312	25.858	-0.103	0.388	-0.022
	4	27.816	-25.080	14.727	27.818	-24.719	14.727	0.001	0.361	0.000
	5	26.876	-15.686	14.494	26.823	-15.278	14.547	-0.053	0.409	0.053
	6	23.251	-2.557	14.569	23.207	-2.123	14.584	-0.044	0.434	0.015
SIDE PANEL	7	37.098	-29.197	8.392	37.067	-28.817	8.413	-0.031	0.380	0.021
	8	33.774	-29.247	5.506	33.714	-28.895	5.528	-0.061	0.352	0.022
	9	37.186	-29.100	3.461	37.163	-28.767	3.429	-0.023	0.333	-0.032
IMPACT SIDE DOOR	10	-0.040	-30.739	24.690	0.012	-30.762	24.725	0.052	-0.023	0.035
	11	14.526	-30.385	24.000	14.466	-30.217	24.034	-0.060	0.168	0.034
	12	25.274	-30.277	23.441	25.324	-29.890	23.475	0.050	0.387	0.034
	13	4.339	-30.816	5.745	4.453	-30.700	5.838	0.114	0.116	0.092
	14	15.589	-31.043	3.087	15.558	-30.977	3.154	-0.031	0.066	0.067
	15	24.922	-30.528	3.396	24.909	-30.502	3.358	-0.012	0.026	-0.038
ROOF	1	14.242	-20.789	40.655	14.319	-20.513	40.657	0.077	0.275	0.003
	2	14.996	-16.231	40.852	14.972	-15.941	40.879	-0.024	0.291	0.027
	3	15.190	-12.512	41.064	15.314	-12.185	41.036	0.124	0.327	-0.028
	4	15.482	-7.453	41.169	15.546	-7.026	41.166	0.064	0.426	-0.003
	5	15.478	-2.885	41.211	15.546	-2.540	41.195	0.068	0.345	-0.016
	6	7.400	-20.359	42.924	7.309	-20.042	42.962	-0.090	0.317	0.038
	7	8.094	-16.498	43.179	8.078	-16.190	43.200	-0.016	0.308	0.021
	8	8.477	-12.128	43.405	8.446	-11.895	43.428	-0.031	0.233	0.023
	9	8.573	-7.247	43.571	8.530	-6.889	43.608	-0.043	0.359	0.037
	10	8.688	-3.589	43.599	8.657	-3.174	43.639	-0.031	0.415	0.040
	11	0.809	-19.970	43.760	0.924	-19.644	43.748	0.116	0.327	-0.012
	12	0.933	-16.552	44.064	0.937	-16.262	44.061	0.004	0.290	-0.003
	13	0.974	-12.857	44.317	0.969	-12.520	44.324	-0.005	0.336	0.007
	14	1.191	-7.562	44.519	1.137	-7.308	44.537	-0.054	0.253	0.018
	15	0.831	-4.112	44.608	0.757	-3.758	44.631	-0.074	0.354	0.023

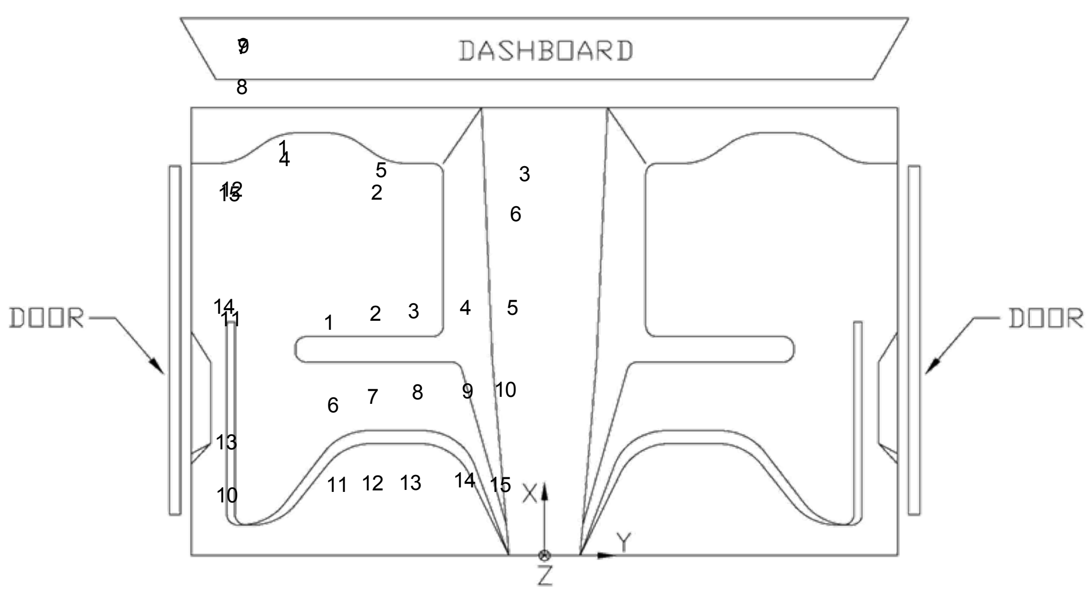
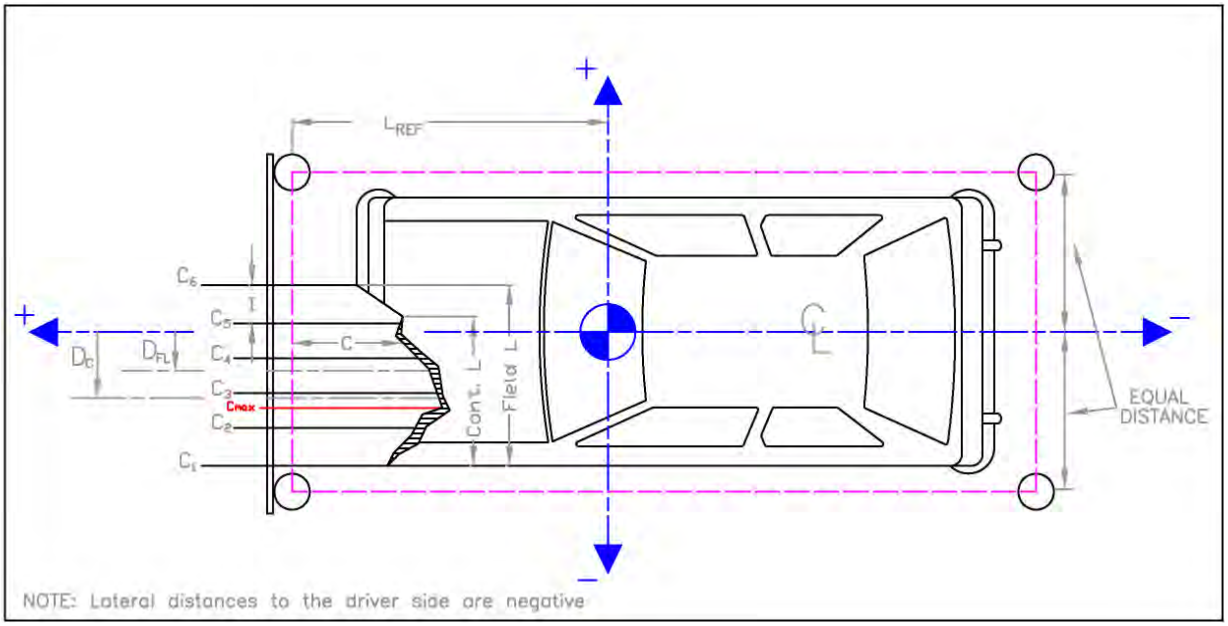


Figure H-10. Occupant Compartment Deformation Data – Set 2, Test No. ILT-2

Date: 9/28/2016 **Test Number:** ILT-2

Make: Hyundai **Model:** Accent **Year:** 2009



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	68 1/2	(1740)
Total Width of Vehicle:	66	(1676)
Width of contact and induced crush - Field L:	66	(1676)
Crush measurement spacing interval (L/5) - I:	13 1/5	(335)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	33	(838)
Distance from center of vehicle to center of contact damage - D_C:	16 1/2	(419)

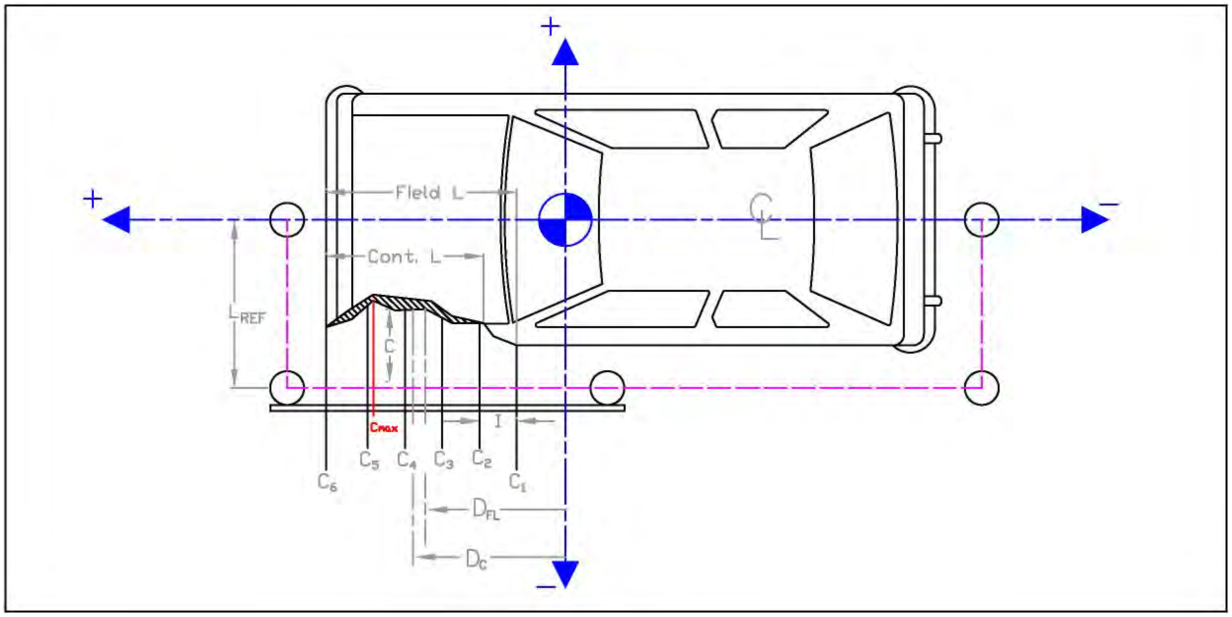
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	NA	NA	-33	-(838)	20 1/4	(514)	-4 2/7	-(109)	NA	NA
C_2	8 1/2	(216)	-19 4/5	-(503)	4 7/8	(124)			8	(201)
C_3	5 1/4	(133)	-6 3/5	-(168)	2 3/7	(62)			7 1/9	(181)
C_4	5 1/4	(133)	6 3/5	(168)	2 1/3	(59)			7 2/9	(183)
C_5	5 1/8	(130)	19 4/5	(503)	4 4/5	(122)			4 3/5	(117)
C_6	NA	NA	33	(838)	19 7/8	(505)			NA	NA
C_{MAX}	9 7/8	(251)	-15	-(381)	3 4/7	(90)			10 3/5	(269)

Figure H-11. Exterior Vehicle Crush (NASS) - Front, Test No. ILT-2

Date: 42641 **Test Number:** ILT-2

Make: Hyundai **Model:** Accent **Year:** 2009



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	37 3/4	(959)
Total Vehicle Length:	168.25	(4274)
Width of contact and induced crush - Field L:	90.5	(2299)
Crush measurement spacing interval (L/5) - I:	18.1	(460)
Distance from vehicle c.g. to center of Field L - D_{FL}:	25.3	(643)
Width of Contact Damage:	59 5/8	(1514)
Distance from vehicle c.g. to center of contact damage - D_C:	40.5	(1029)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	6 1/8	(156)	-19.95	-(507)	3.25	(83)	1.75	(44)	1.1	(29)
C_2	6	(152)	-1.85	-(47)	3.25	(83)			1.0	(25)
C_3	6.5	(165)	16.25	(413)	3.25	(83)			1.5	(38)
C_4	NA	NA	34.35	(872)	3.47	(88)			NA	NA
C_5	16.25	(413)	52.45	(1332)	3.84	(98)			10.7	(271)
C_6	NA	NA	70.55	(1792)	31.88	(810)			NA	NA
C_{MAX}	17	(432)	49	(1245)	4.00	(102)			11.3	(286)

Figure H-12. Exterior Vehicle Crush (NASS) - Side, Test No. ILT-2

Appendix I. Accelerometer and Rate Transducer Data Analysis Test No. ILT-1

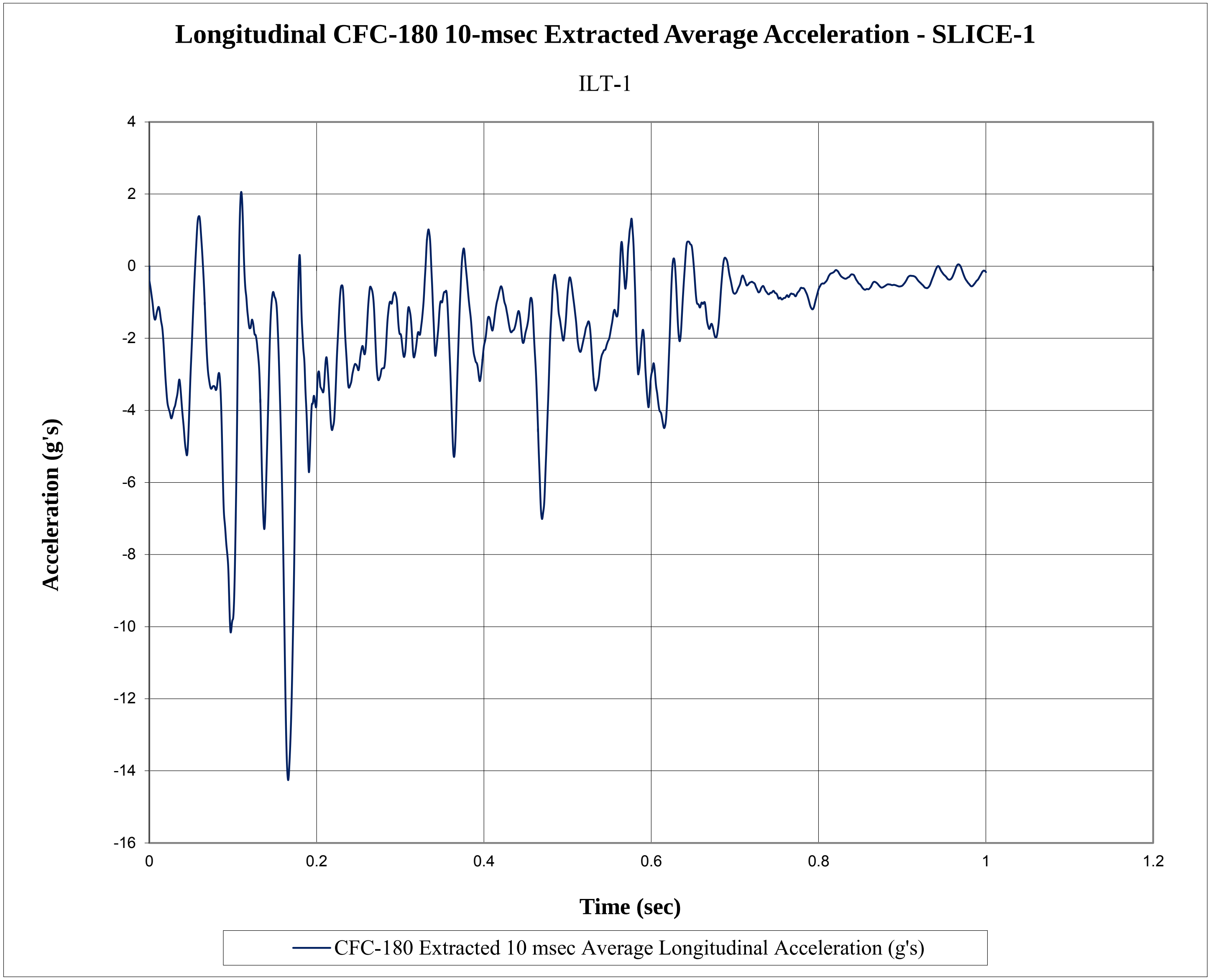


Figure I-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. ILT-1

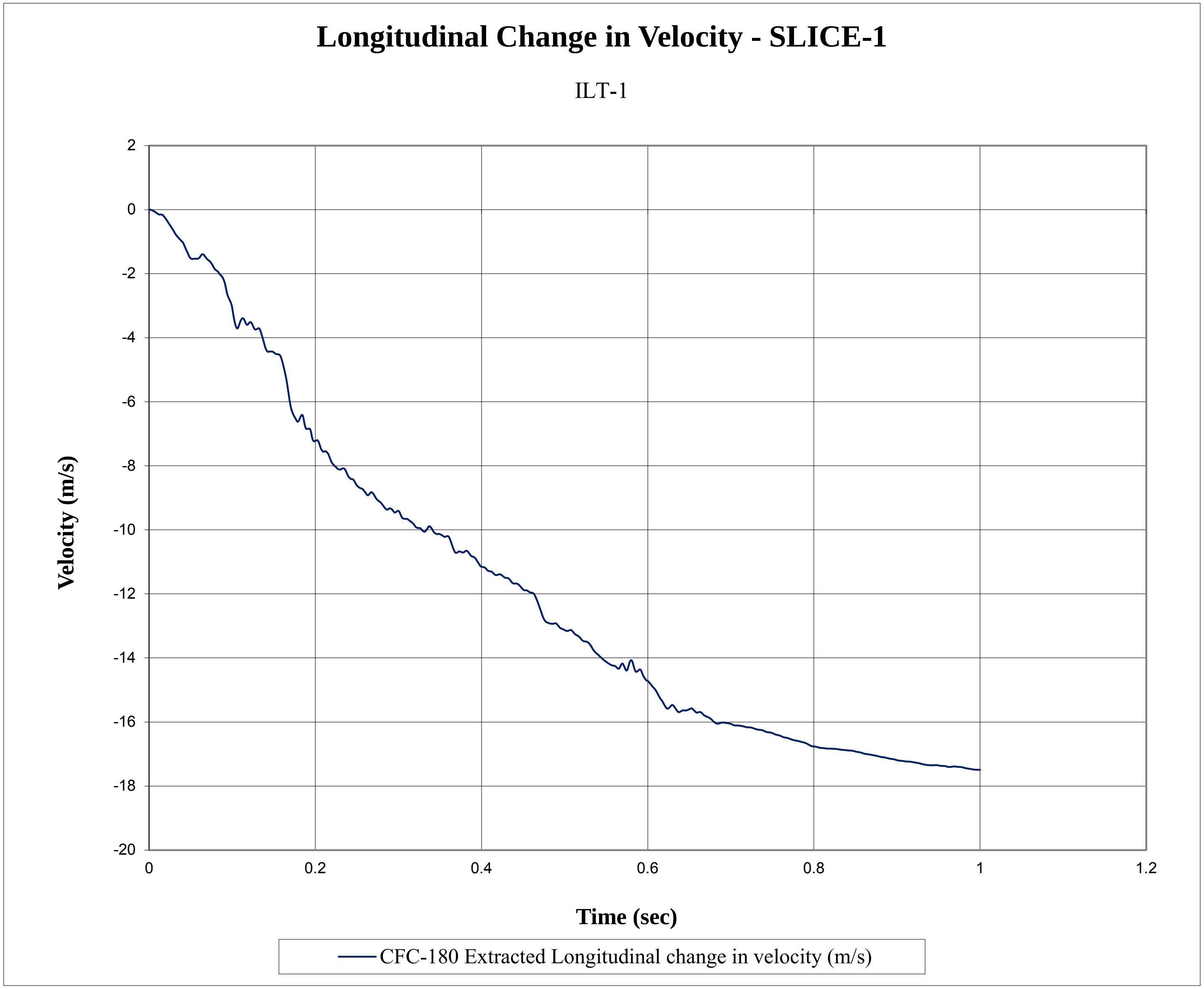


Figure I-2. Longitudinal Change in Velocity (SLICE-1), Test No. ILT-1

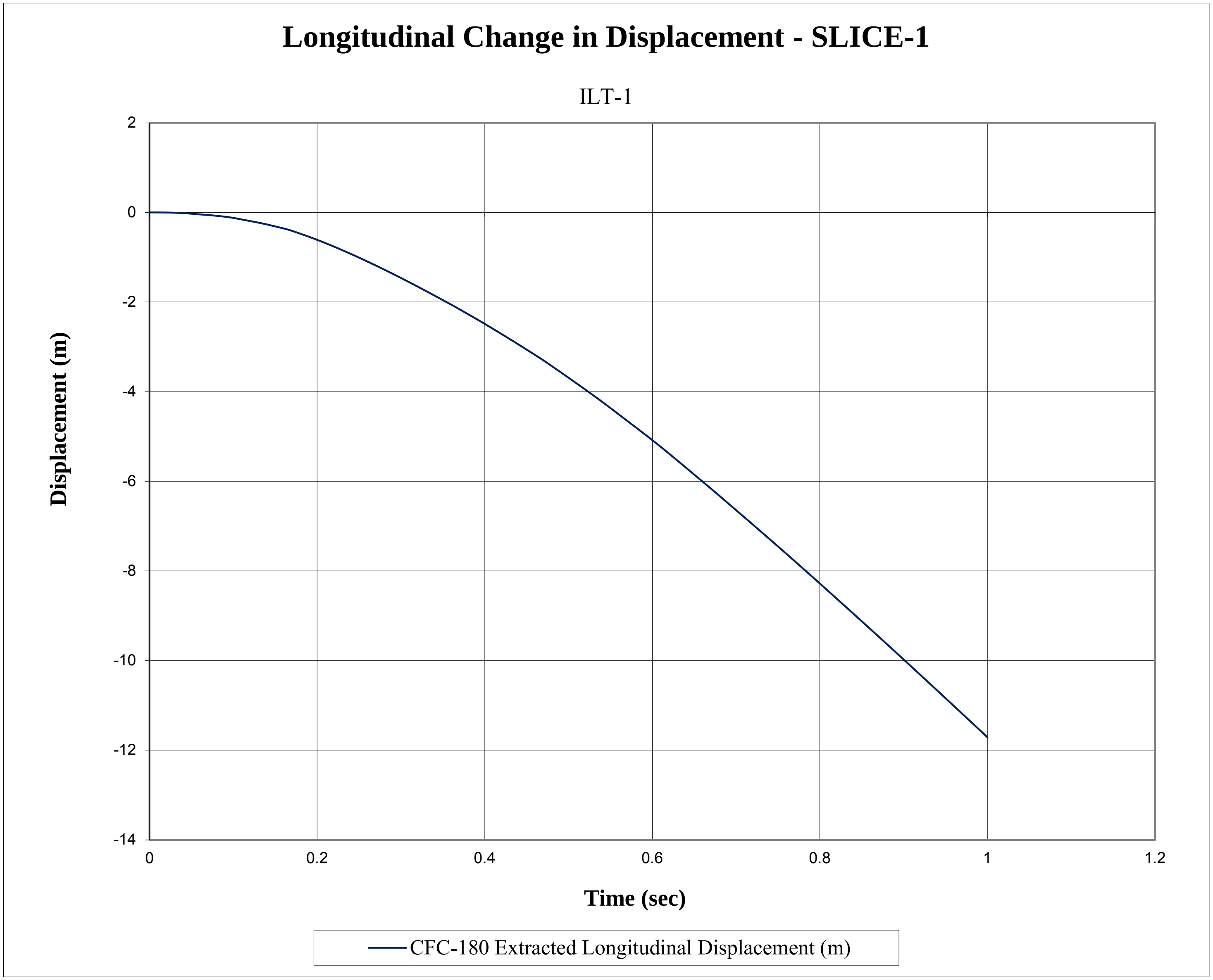


Figure I-3. Longitudinal Change in Displacement (SLICE-1), Test No. ILT-1

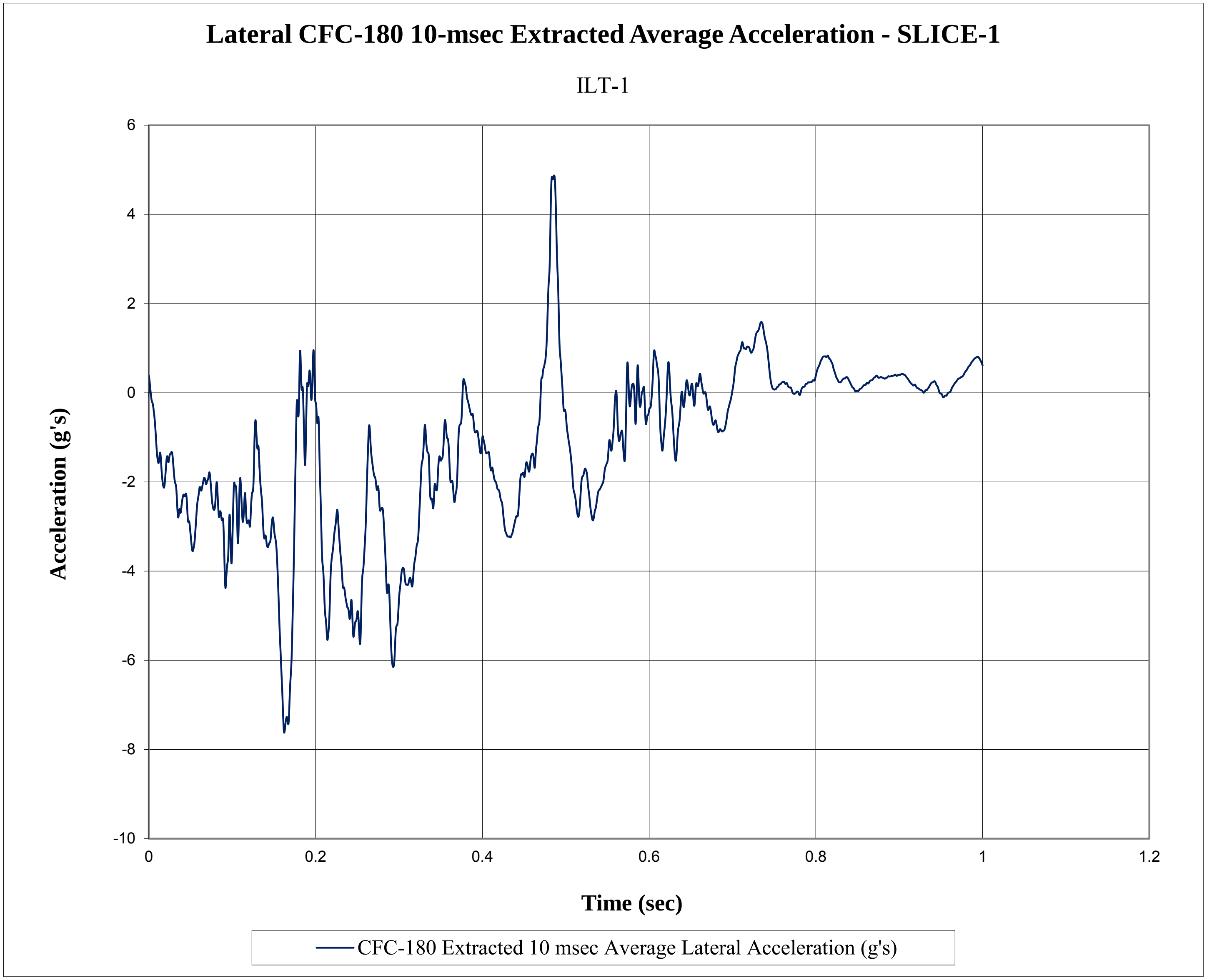


Figure I-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. ILT-1

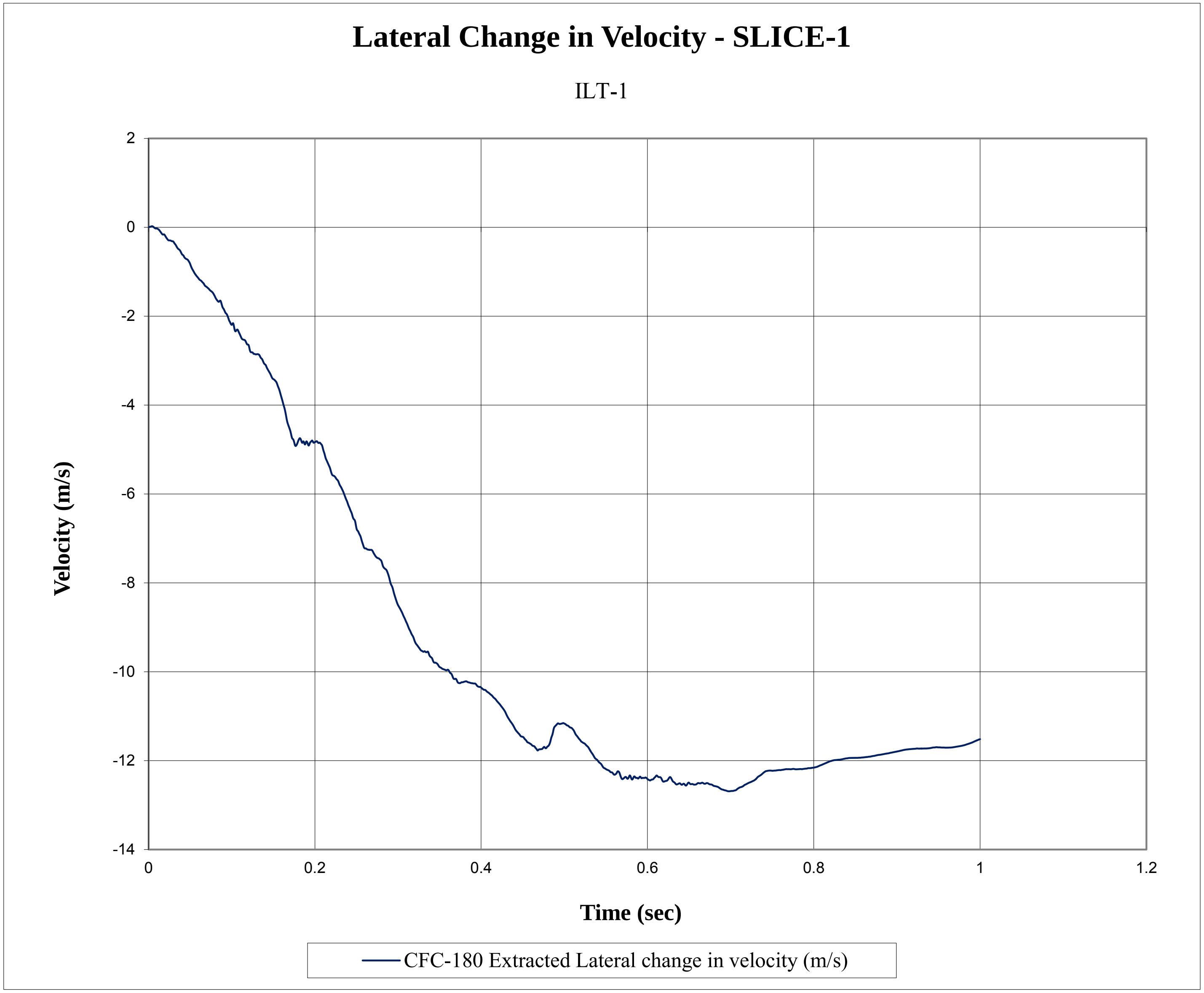


Figure I-5. Lateral Change in Velocity (SLICE-1), Test No. ILT-1

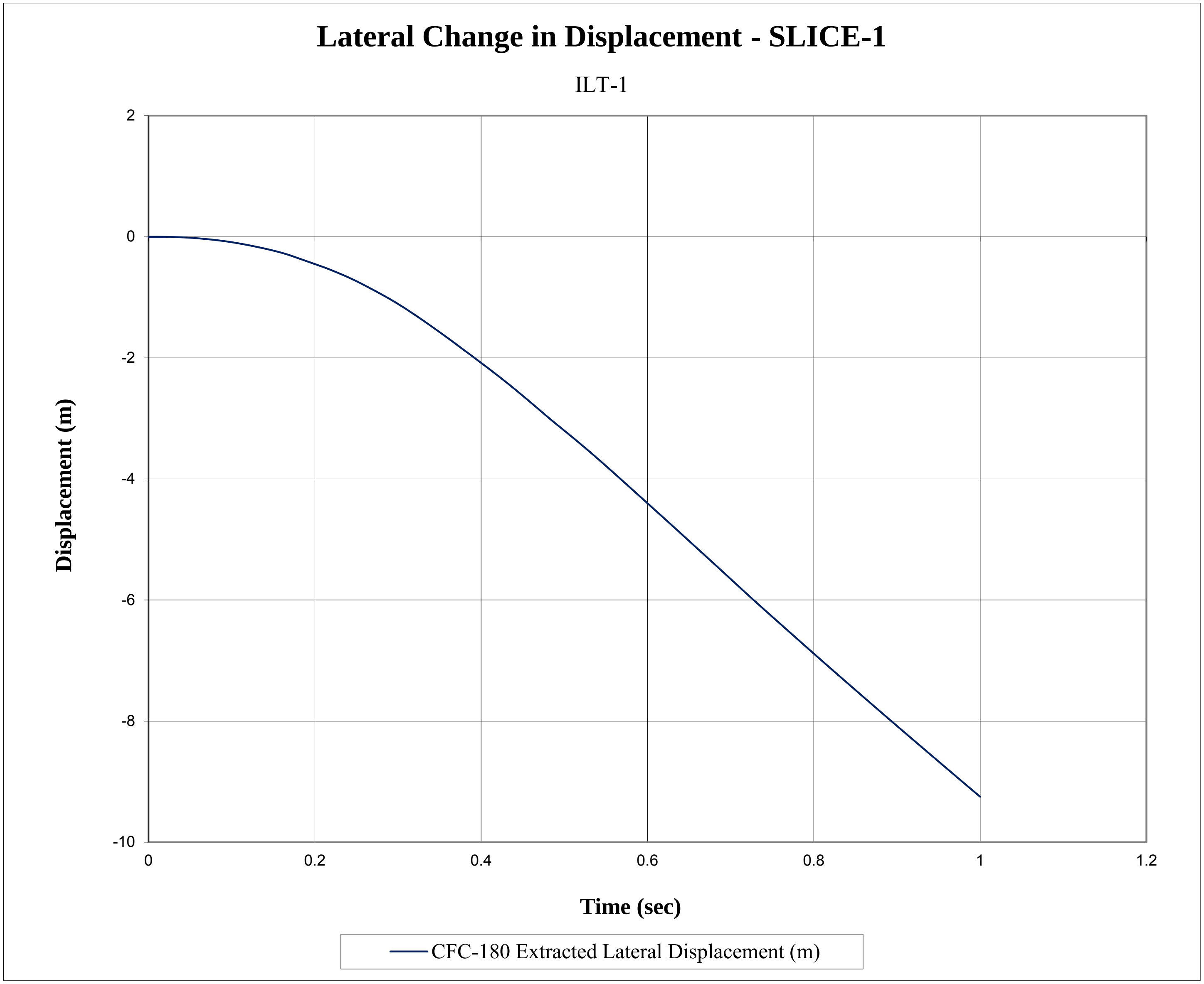


Figure I-6. Lateral Change in Displacement (SLICE-1), Test No. ILT-1

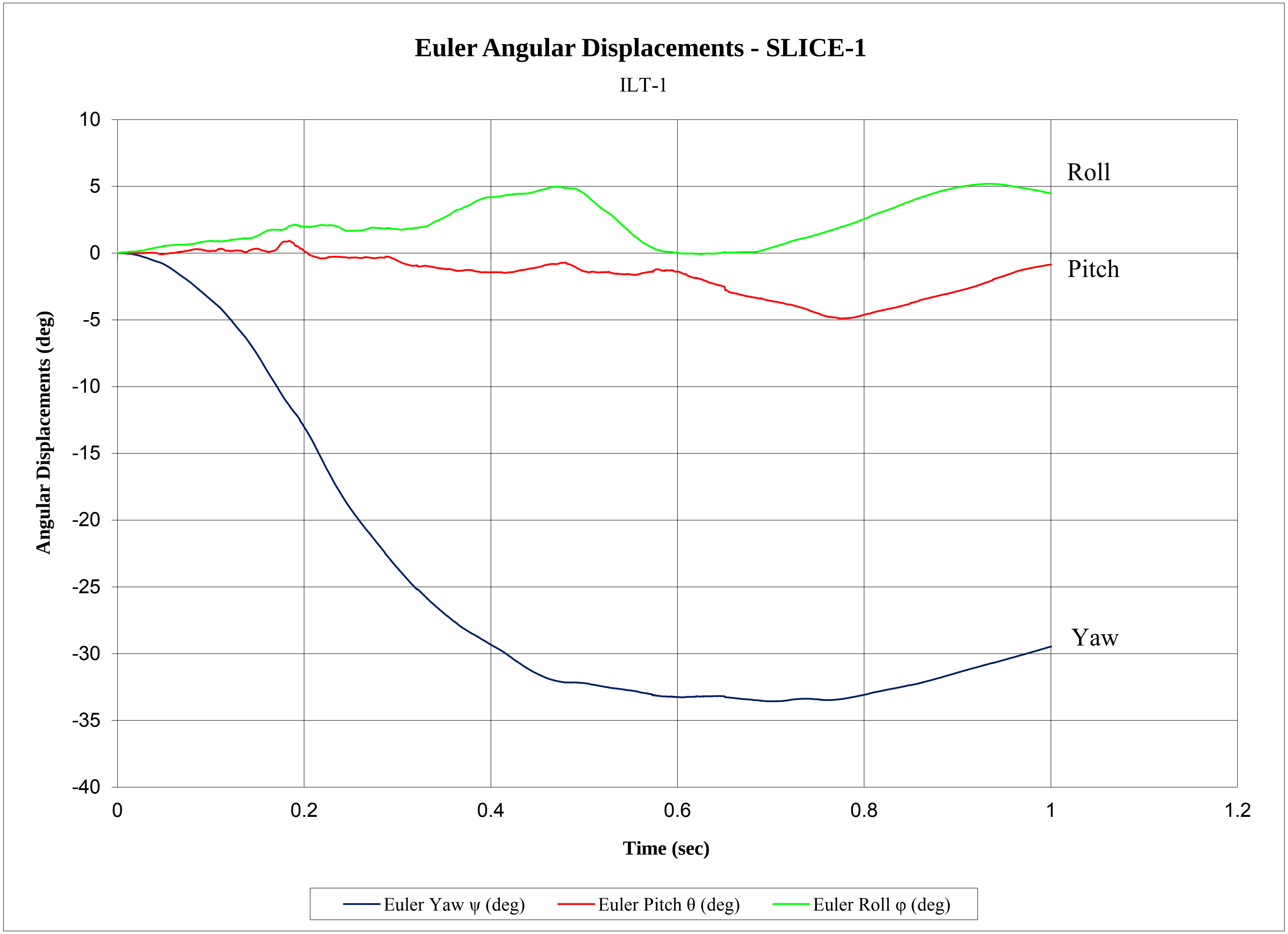


Figure I-7. Vehicle Angular Displacements (SLICE-1), Test No. ILT-1

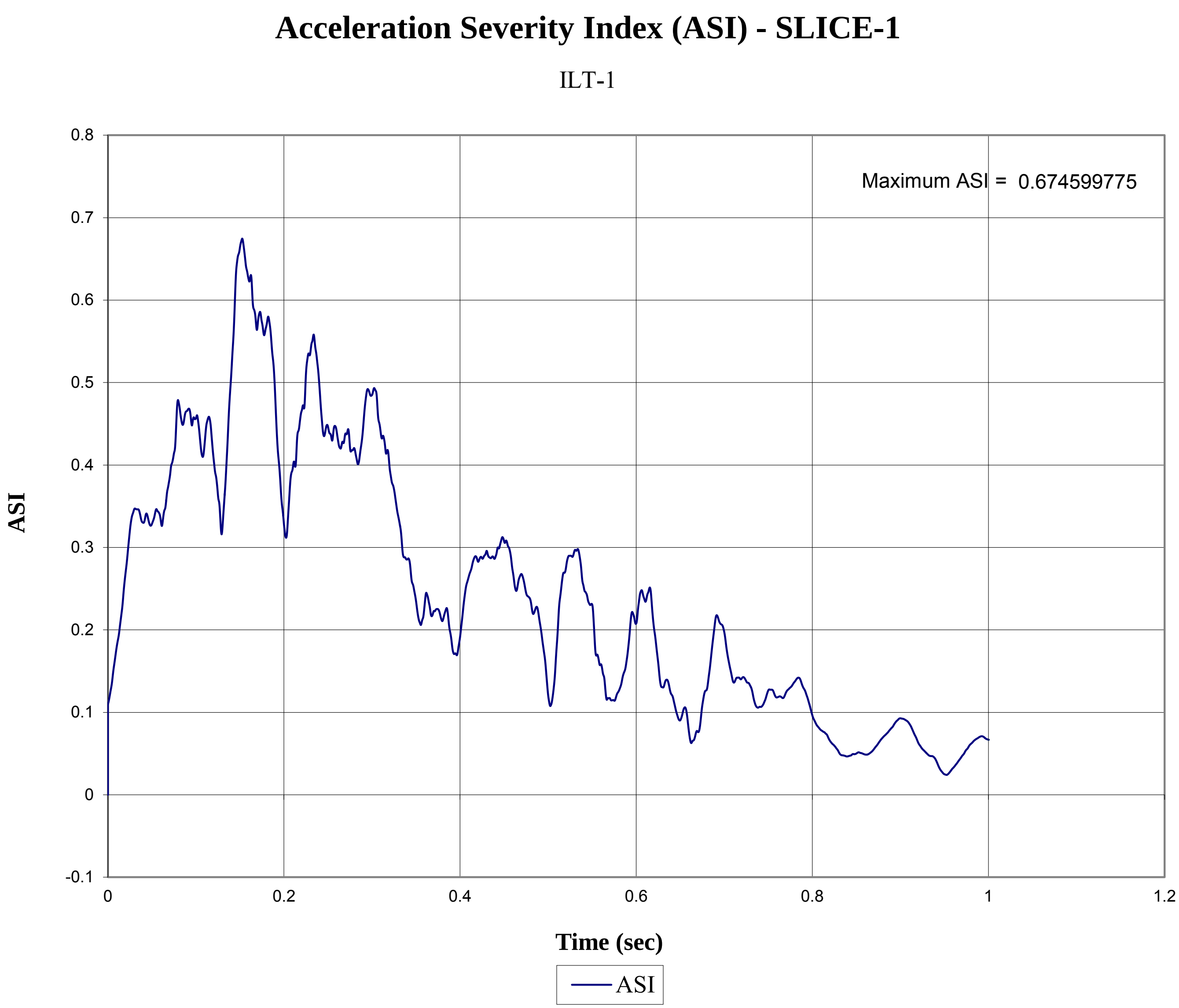


Figure I-8. Acceleration Severity Index (SLICE-1), Test No. ILT-1

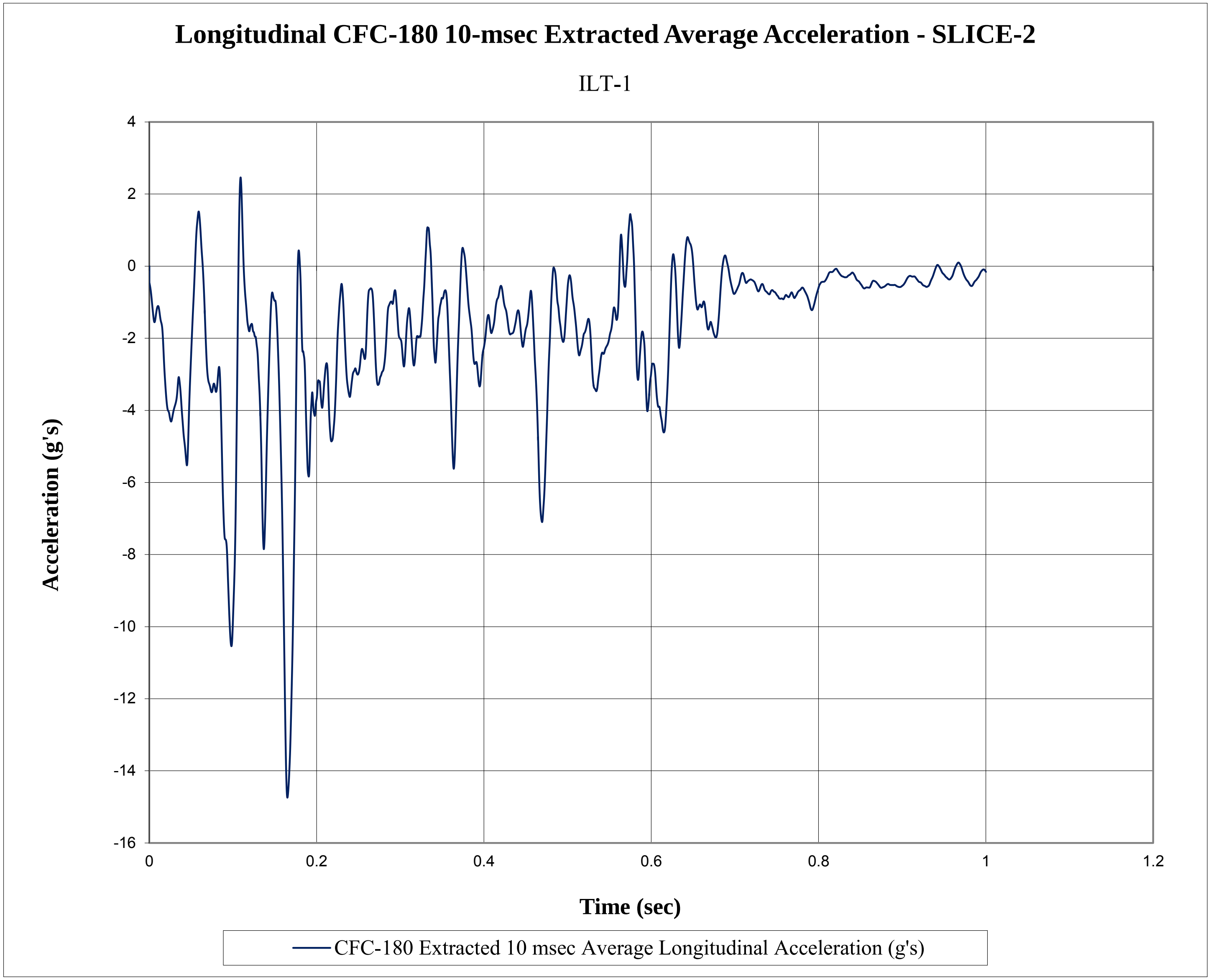


Figure I-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. ILT-1

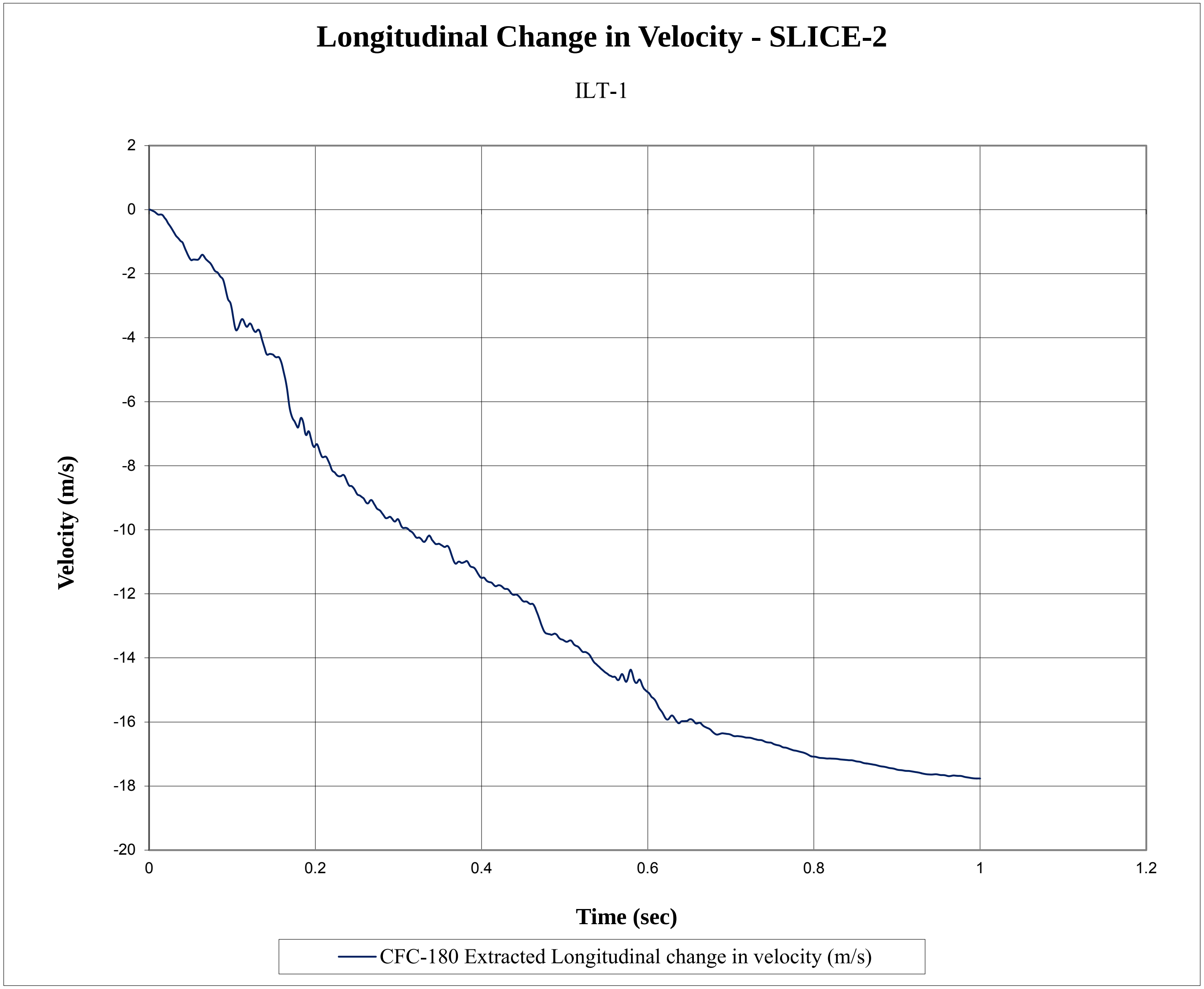


Figure I-10. Longitudinal Change in Velocity (SLICE-2), Test No. ILT-1

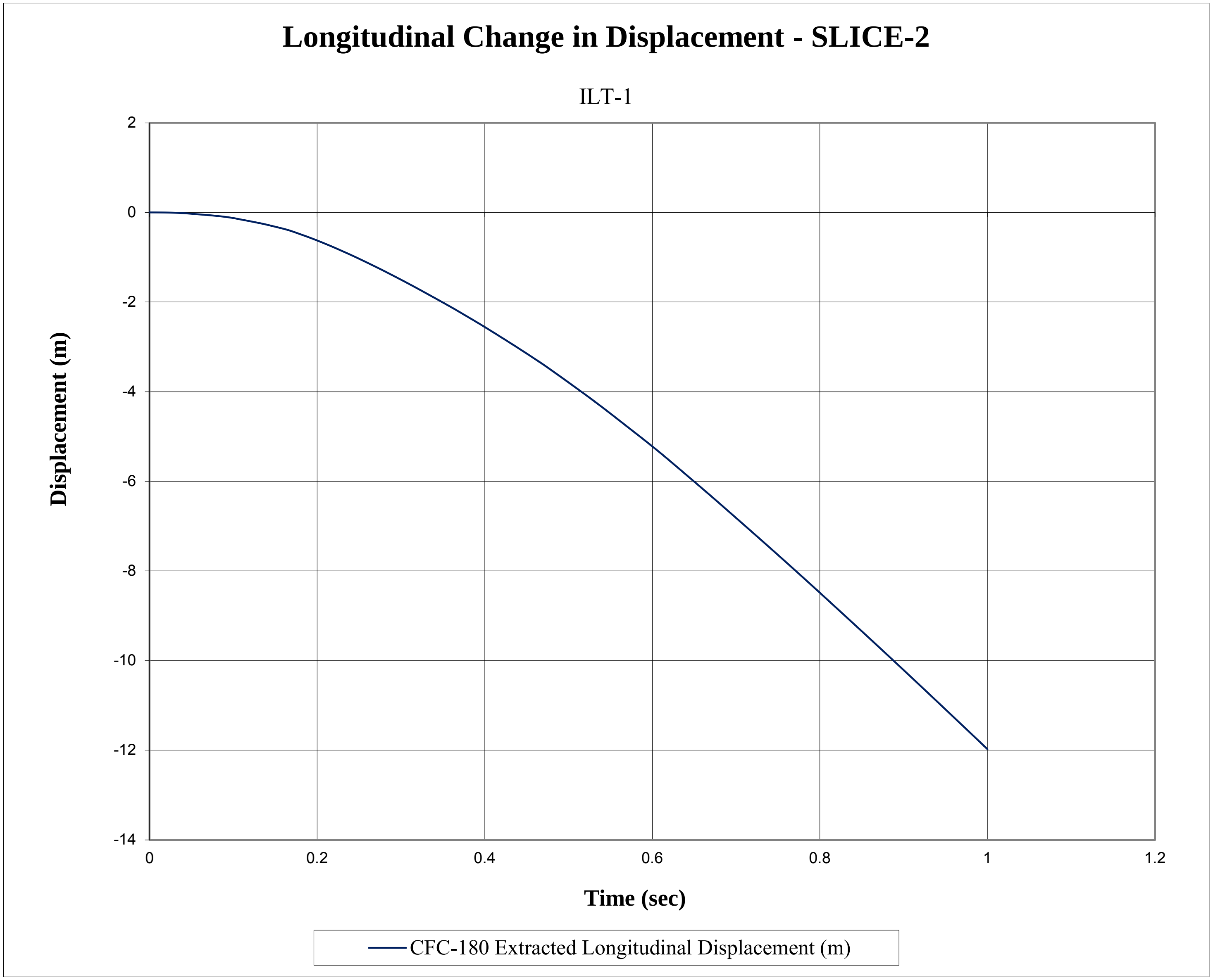


Figure I-11. Longitudinal Change in Displacement (SLICE-2), Test No. ILT-1

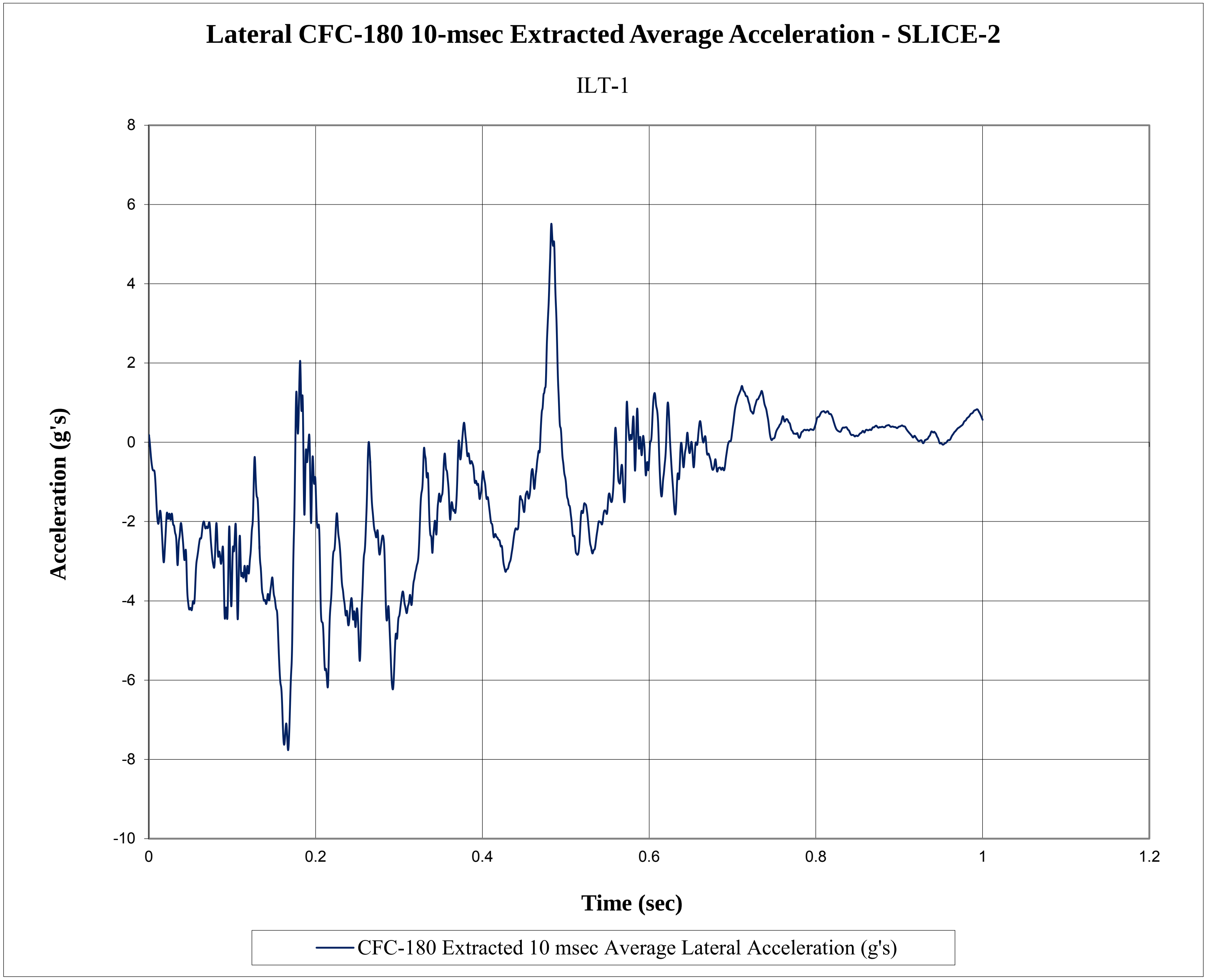


Figure I-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. ILT-1

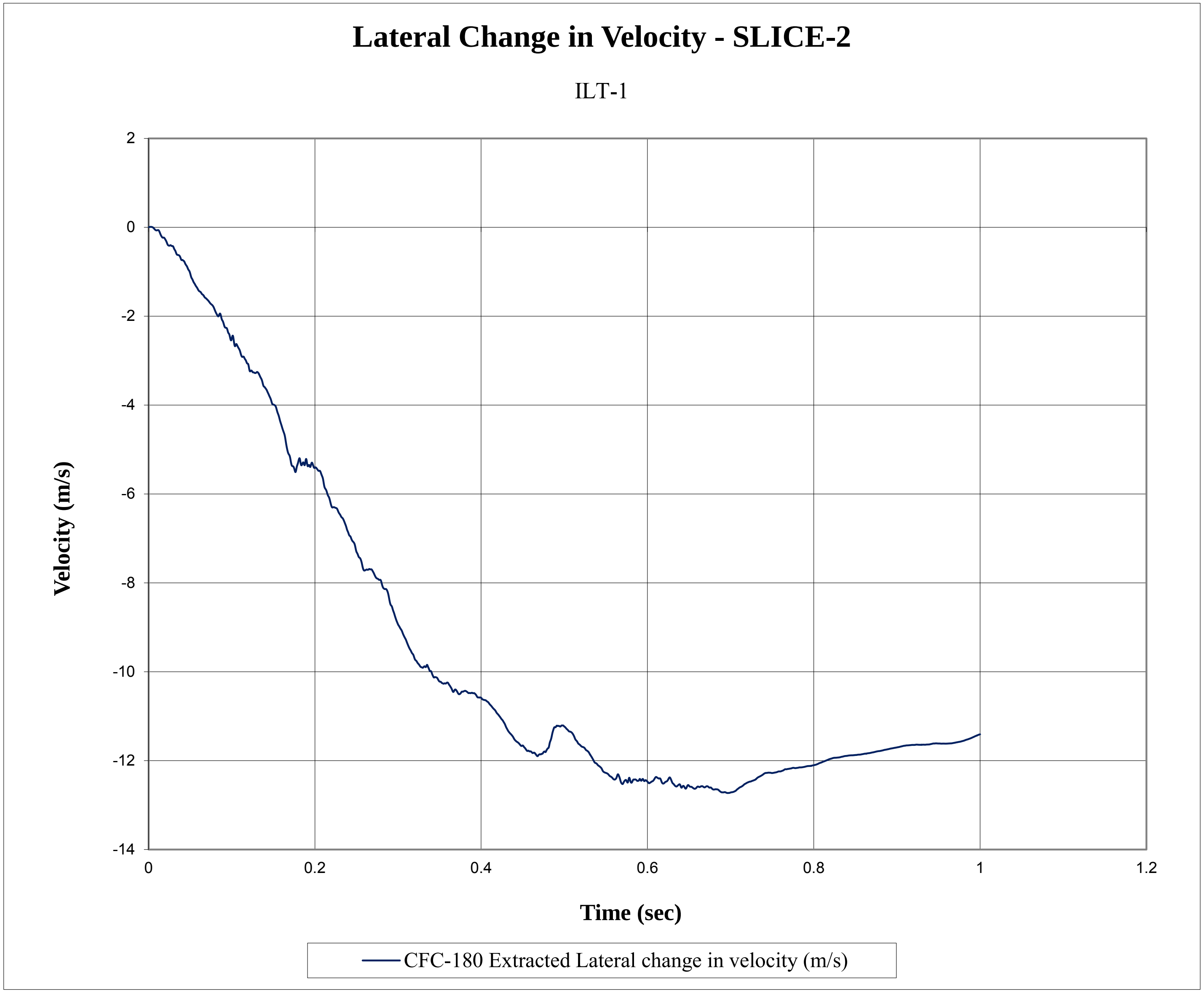


Figure I-13. Lateral Change in Velocity (SLICE-2), Test No. ILT-1

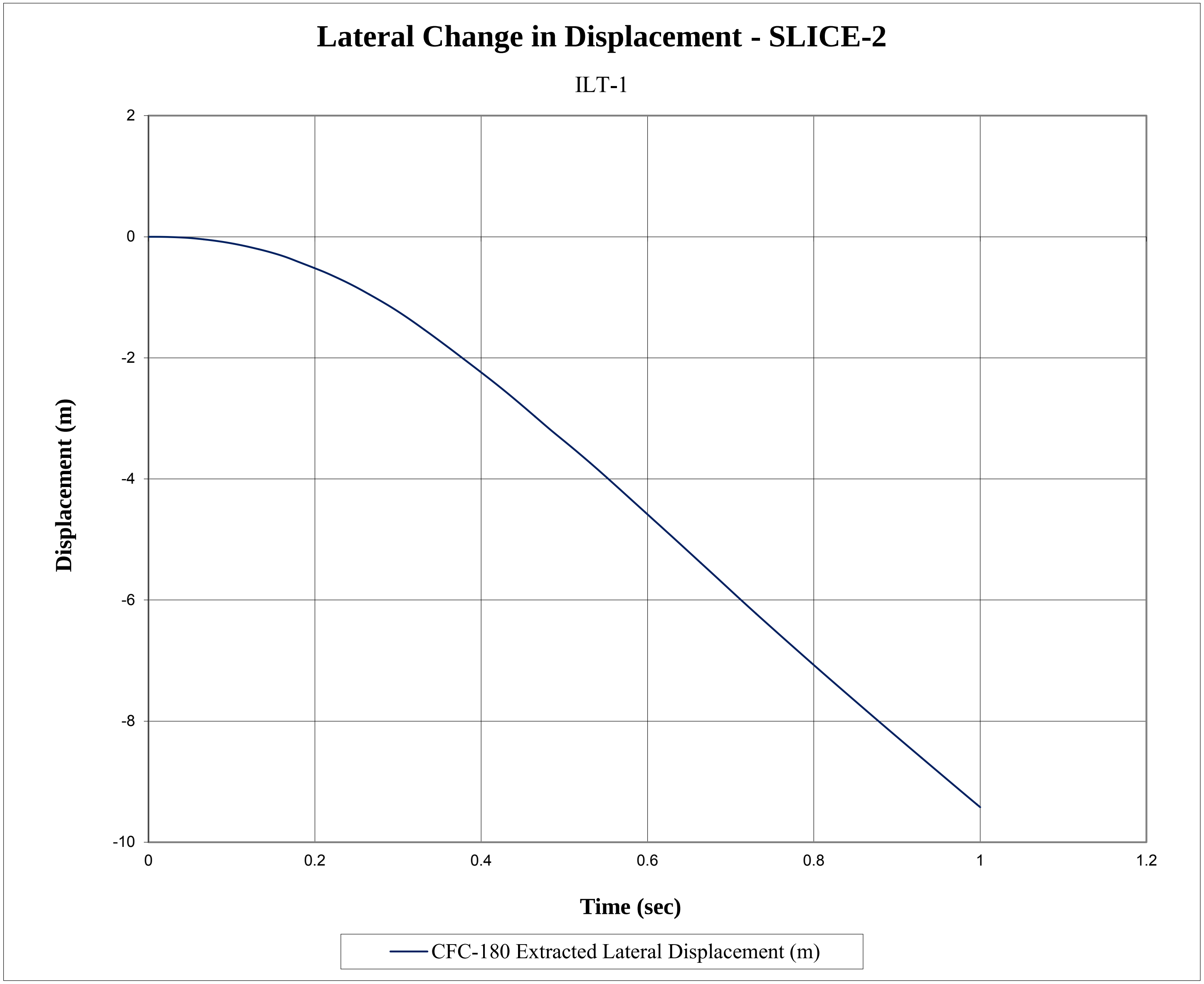


Figure I-14. Lateral Change in Displacement (SLICE-2), Test No. ILT-1

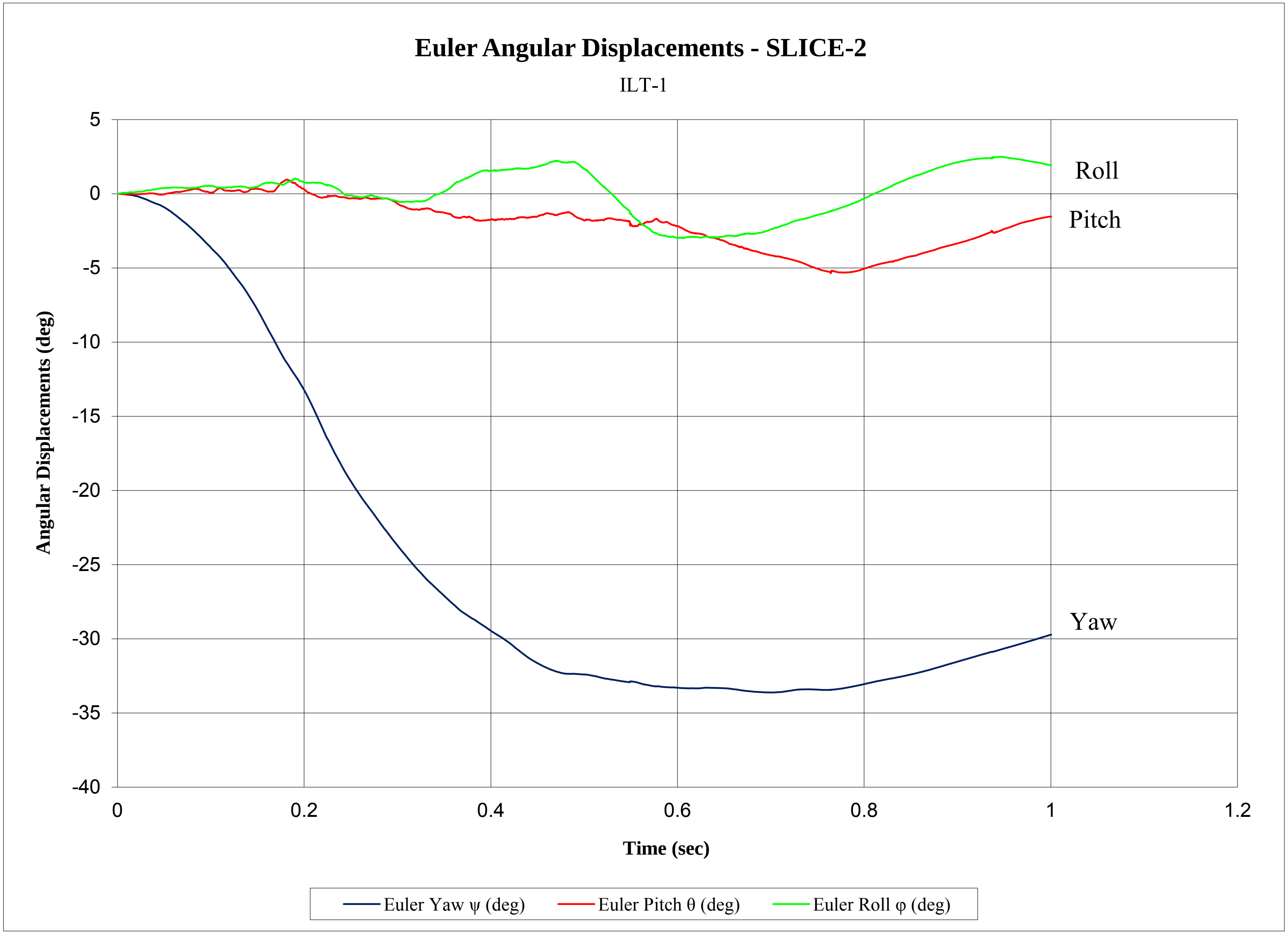


Figure I-15. Vehicle Angular Displacements (SLICE-2), Test No. ILT-1

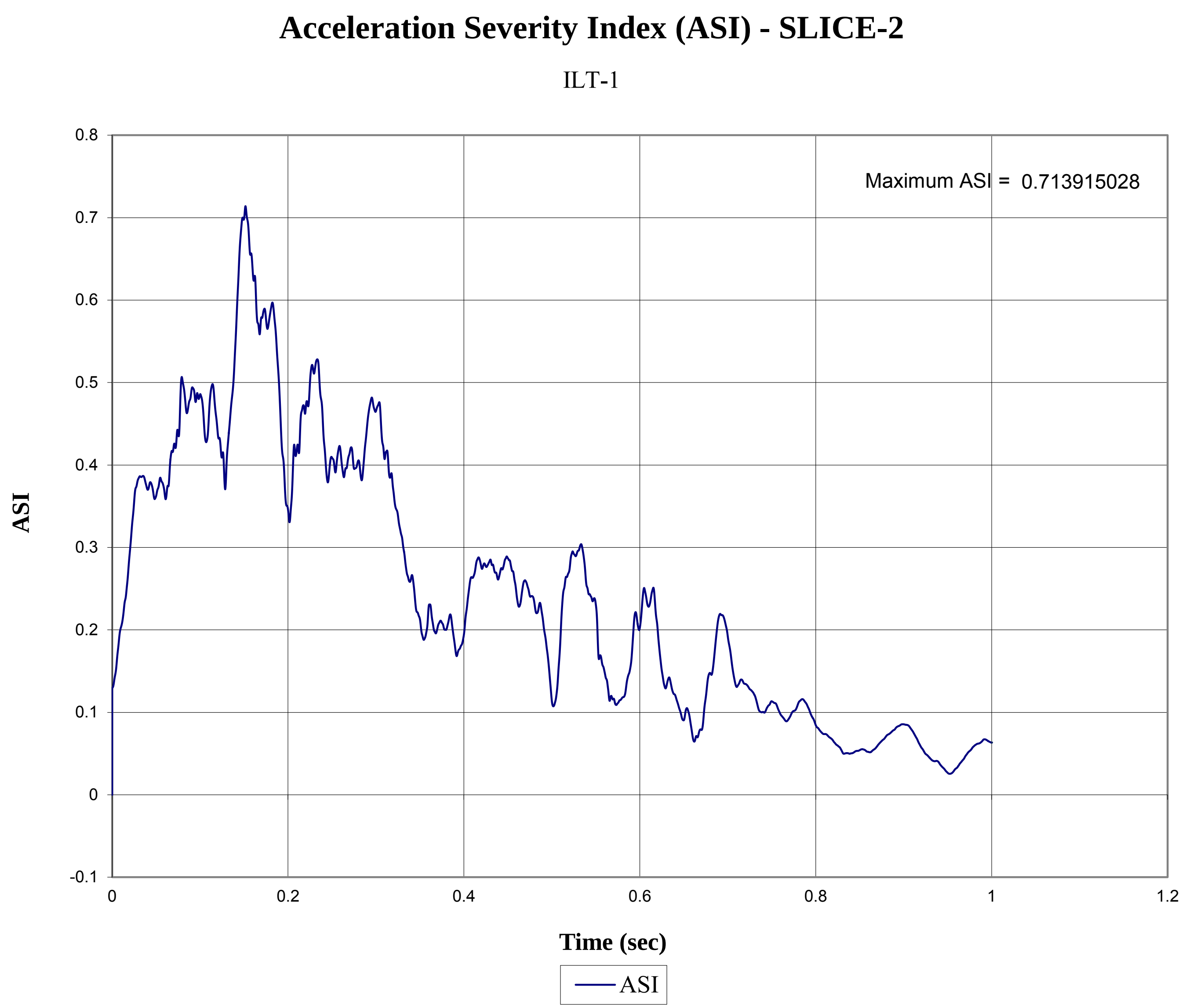


Figure I-16. Acceleration Severity Index (SLICE-2), Test No. ILT-1

Appendix J. Accelerometer and Rate Transducer Data Analysis Test No. ILT-2

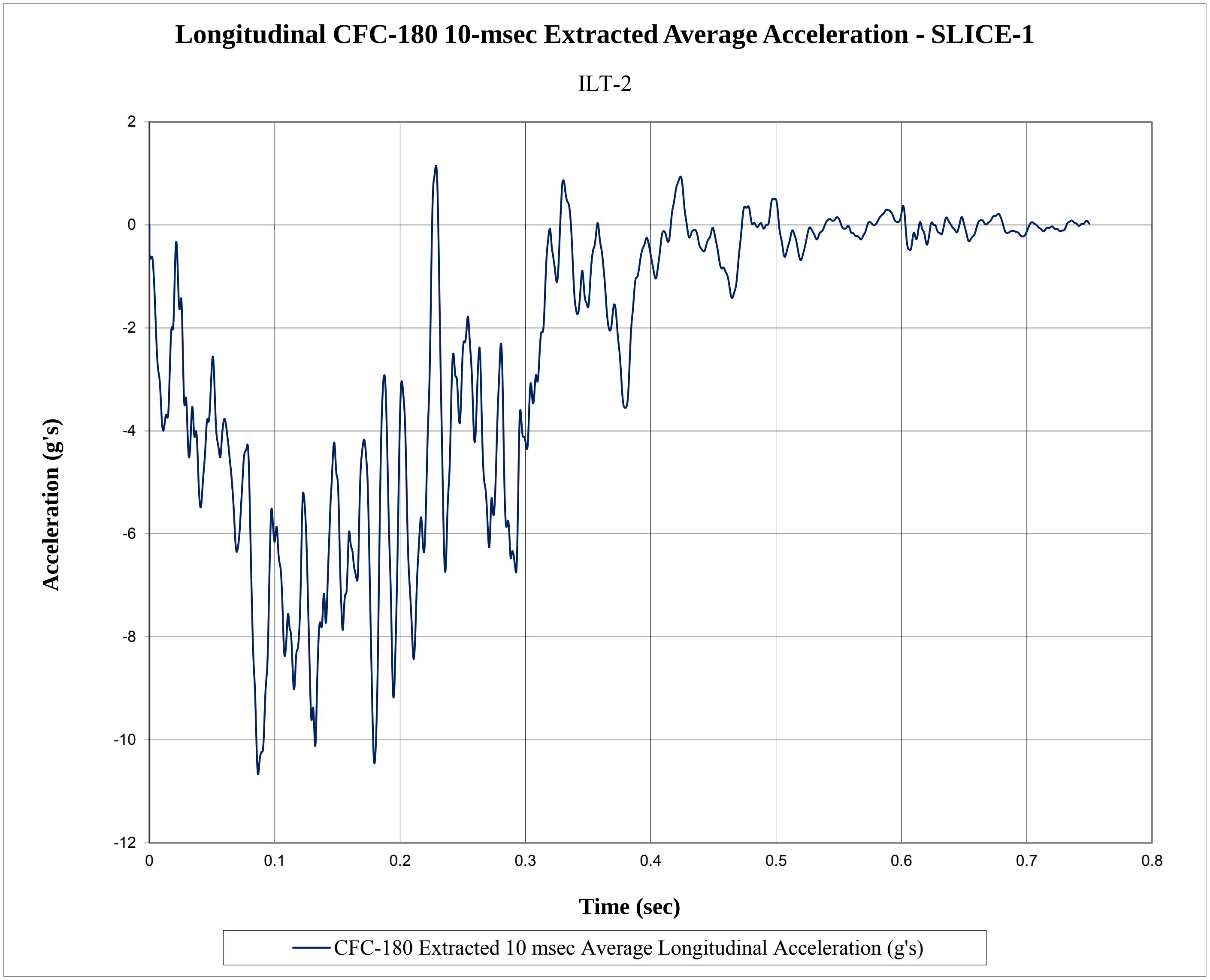


Figure J-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. ILT-2

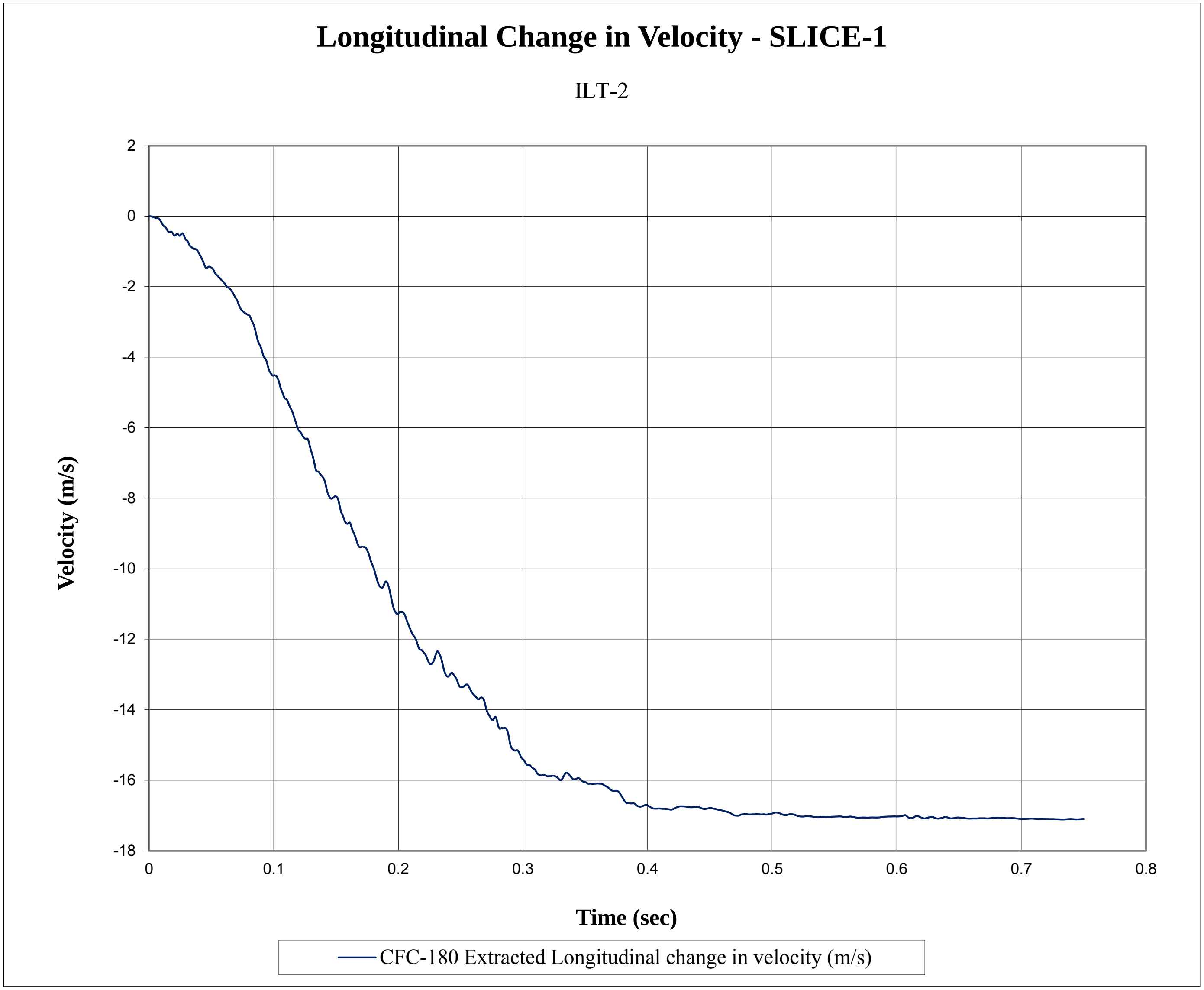


Figure J-2. Longitudinal Change in Velocity (SLICE-1), Test No. ILT-2

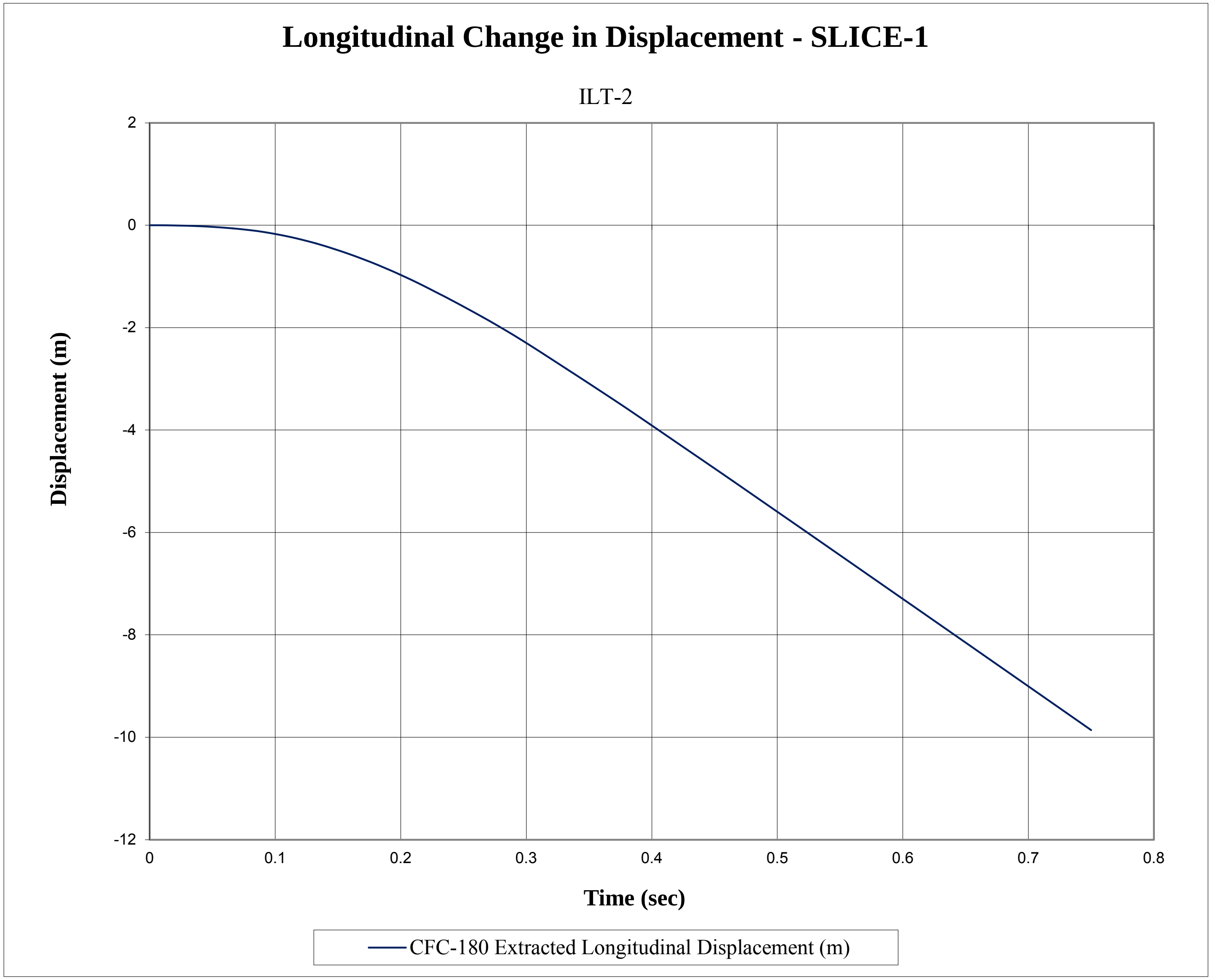


Figure J-3. Longitudinal Occupant Displacement (SLICE-1), Test No. ILT-2

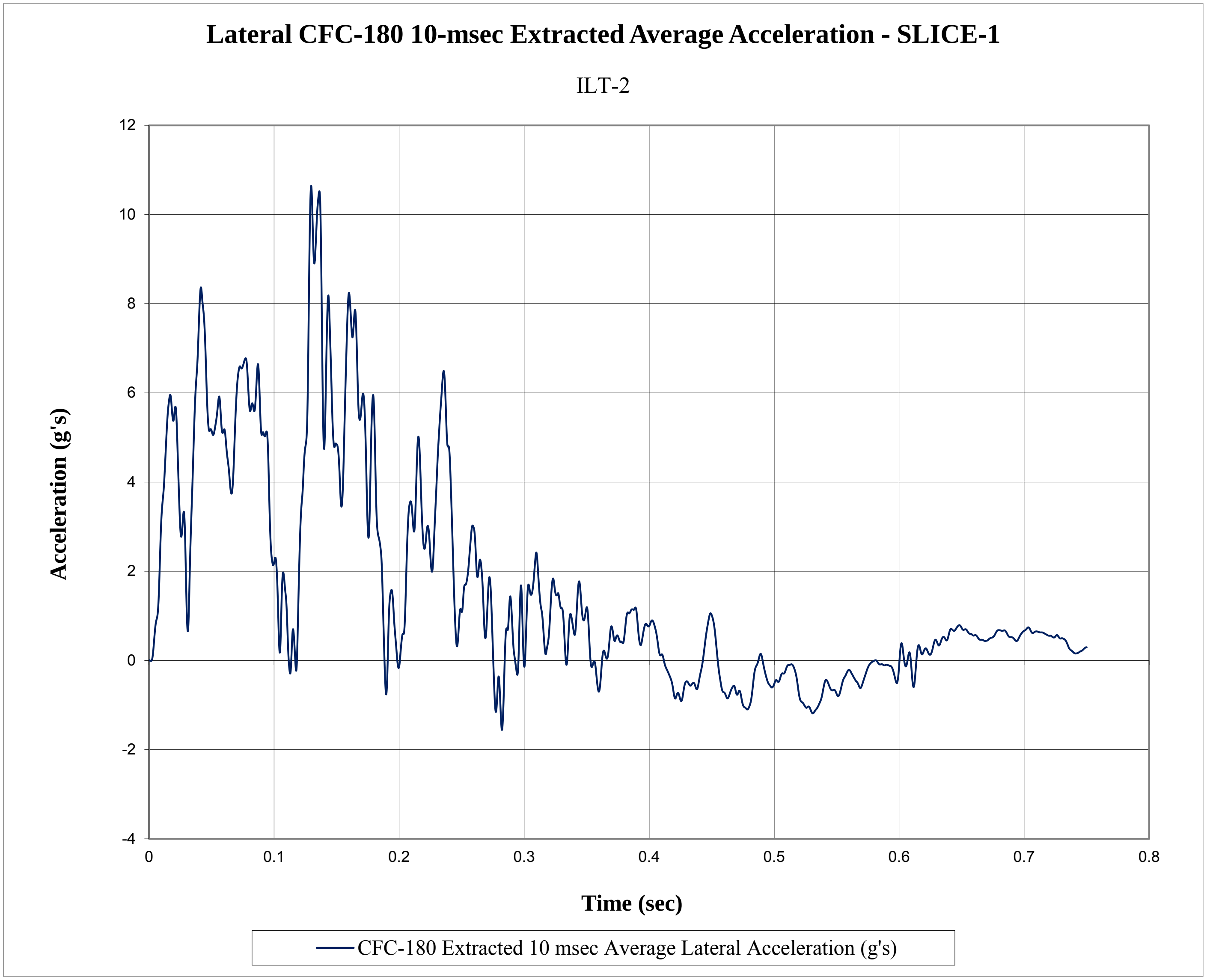


Figure J-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. ILT-2

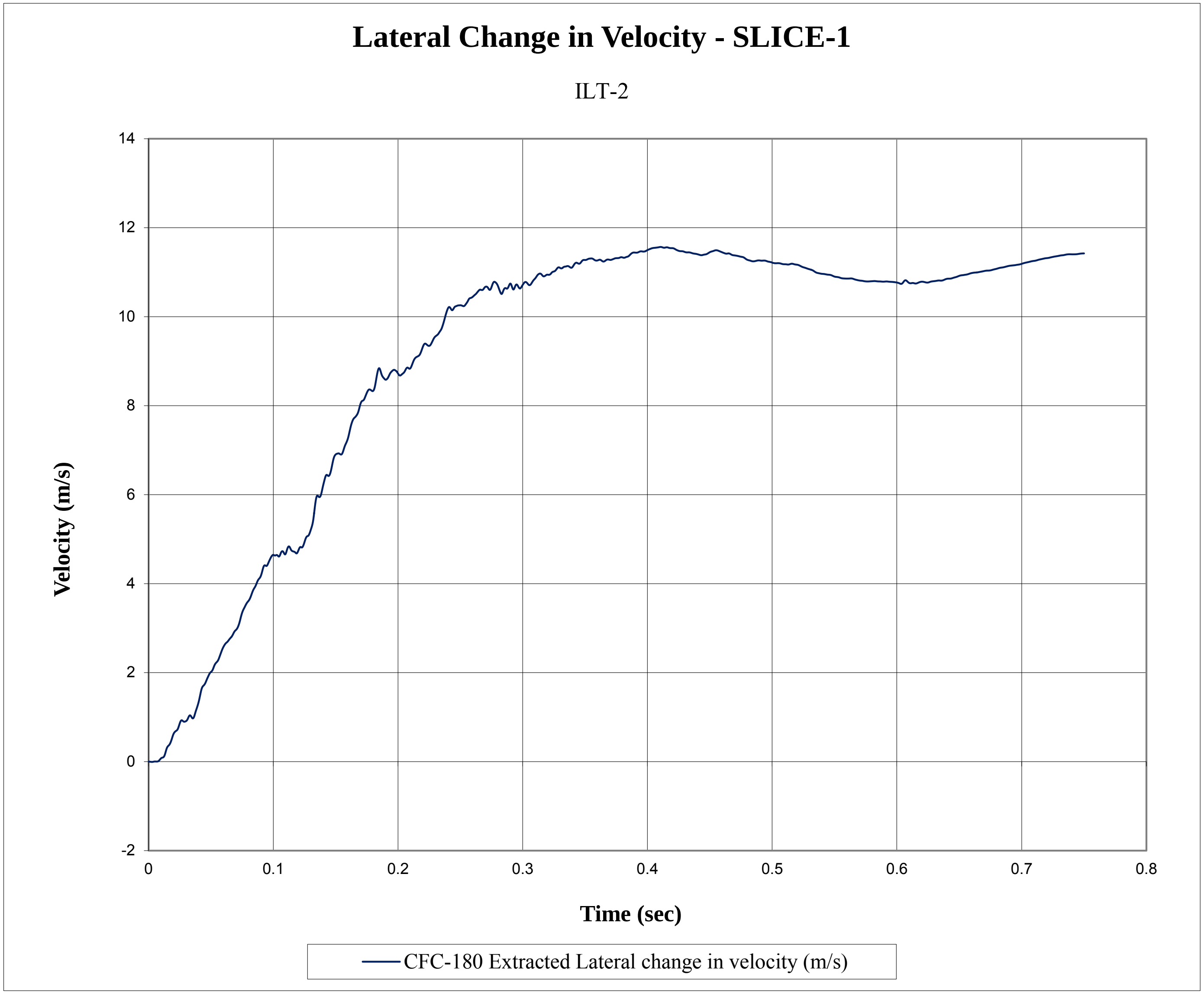


Figure J-5. Lateral Change in Velocity (SLICE-1), Test No. ILT-2

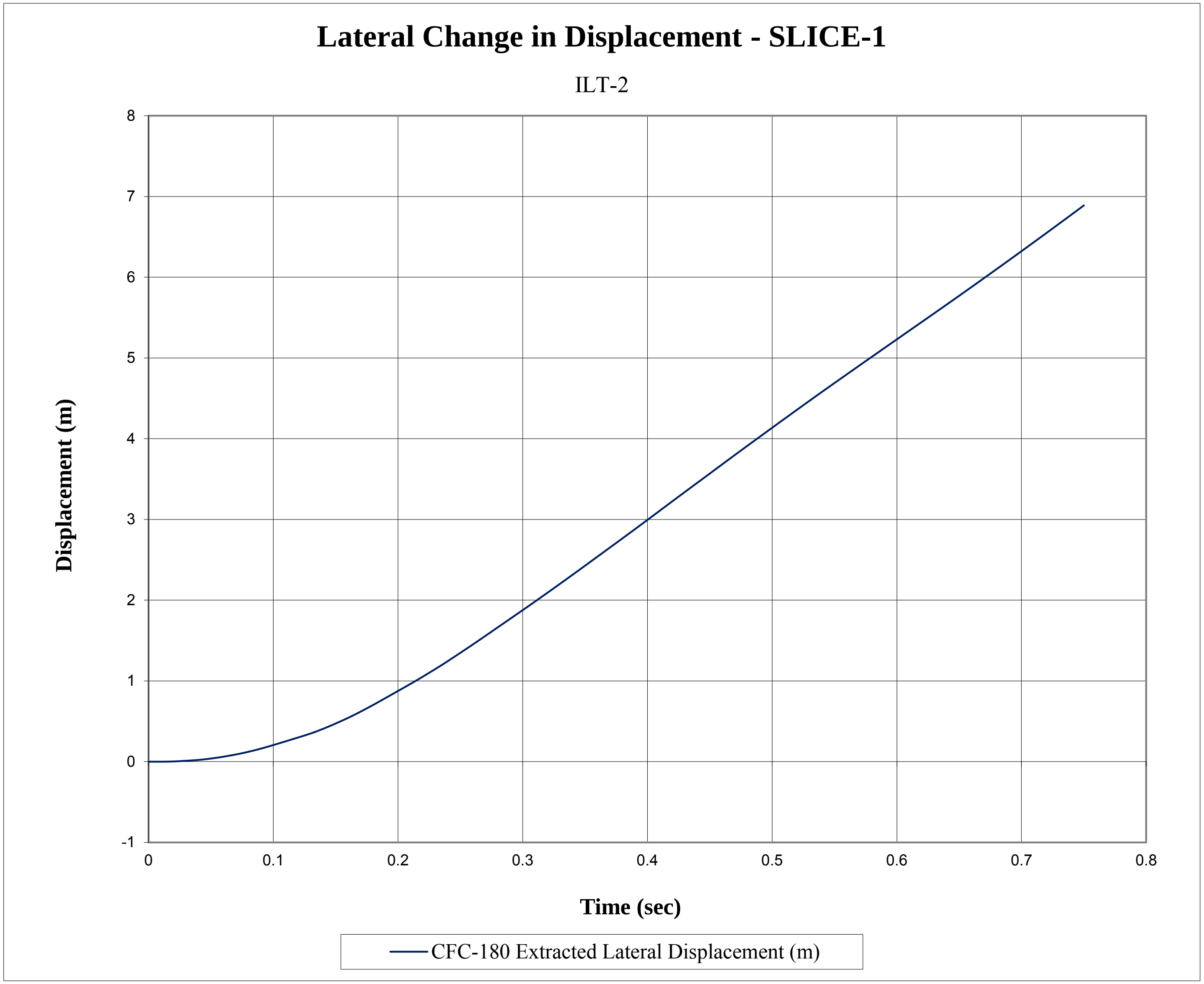


Figure J-6. Lateral Change in Displacement (SLICE-1), Test No. ILT-2

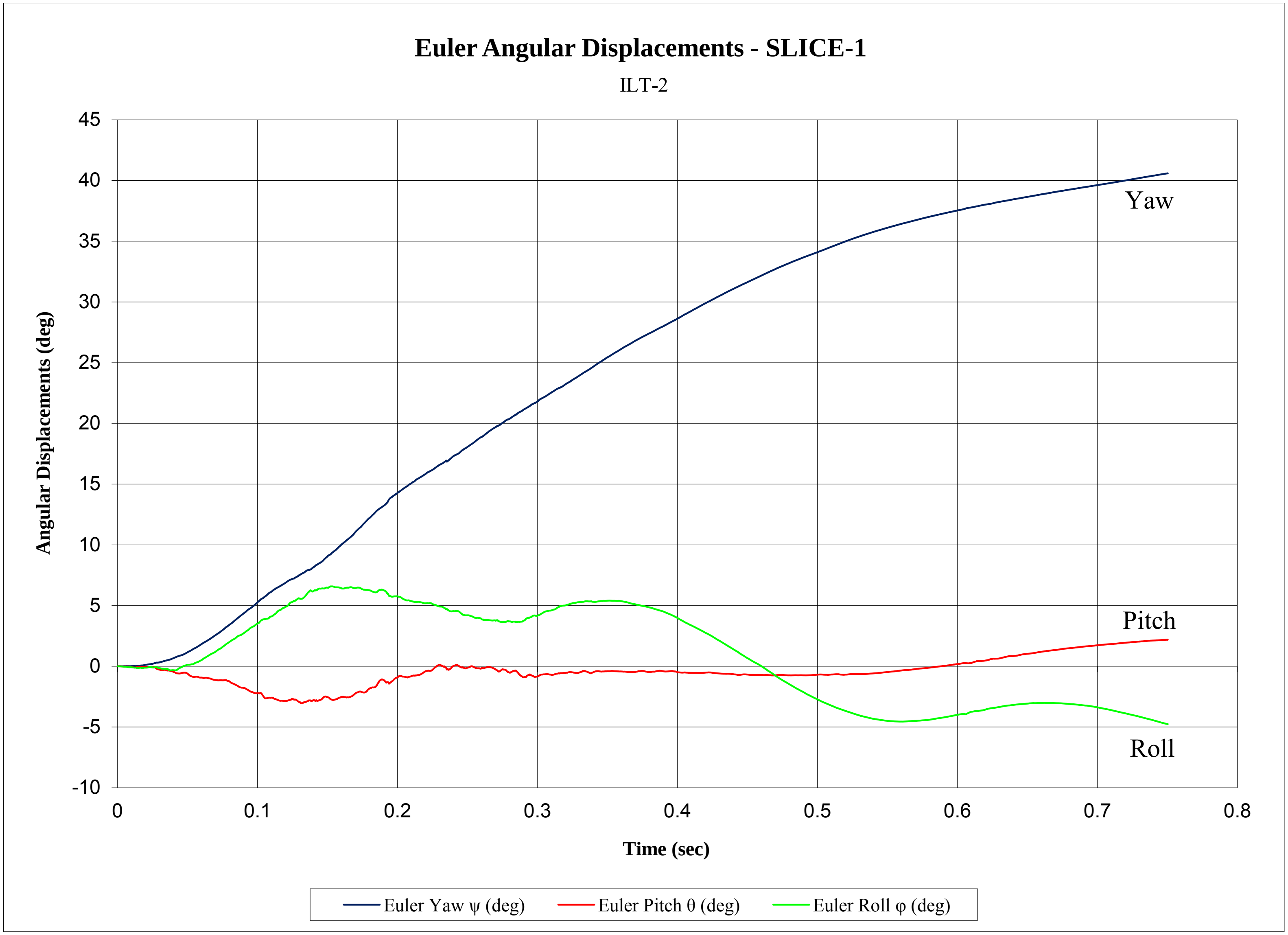


Figure J-7. Vehicle Angular Displacements (SLICE-1), Test No. ILT-2

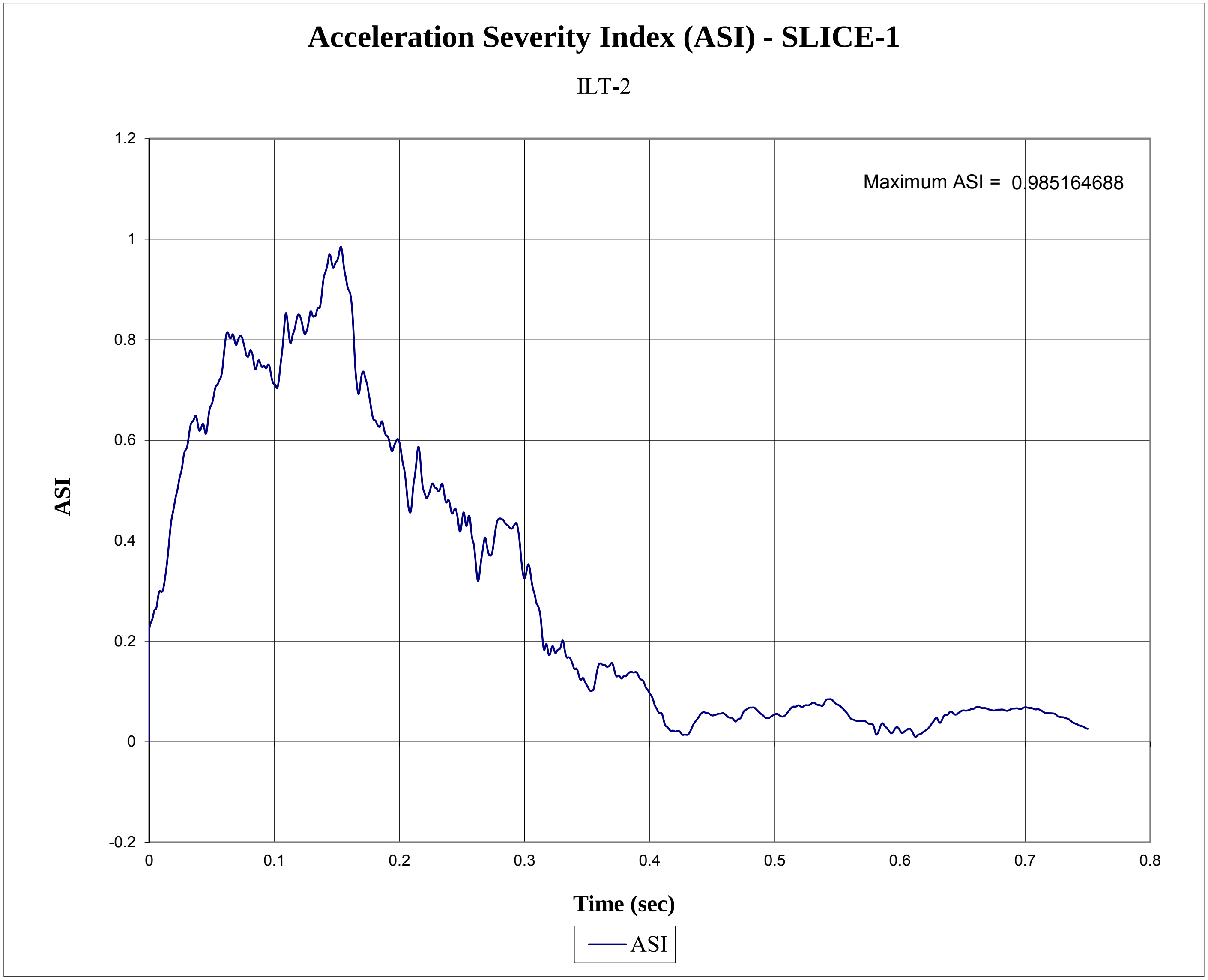


Figure J-8. Acceleration Severity Index (SLICE-1), Test No. ILT-2

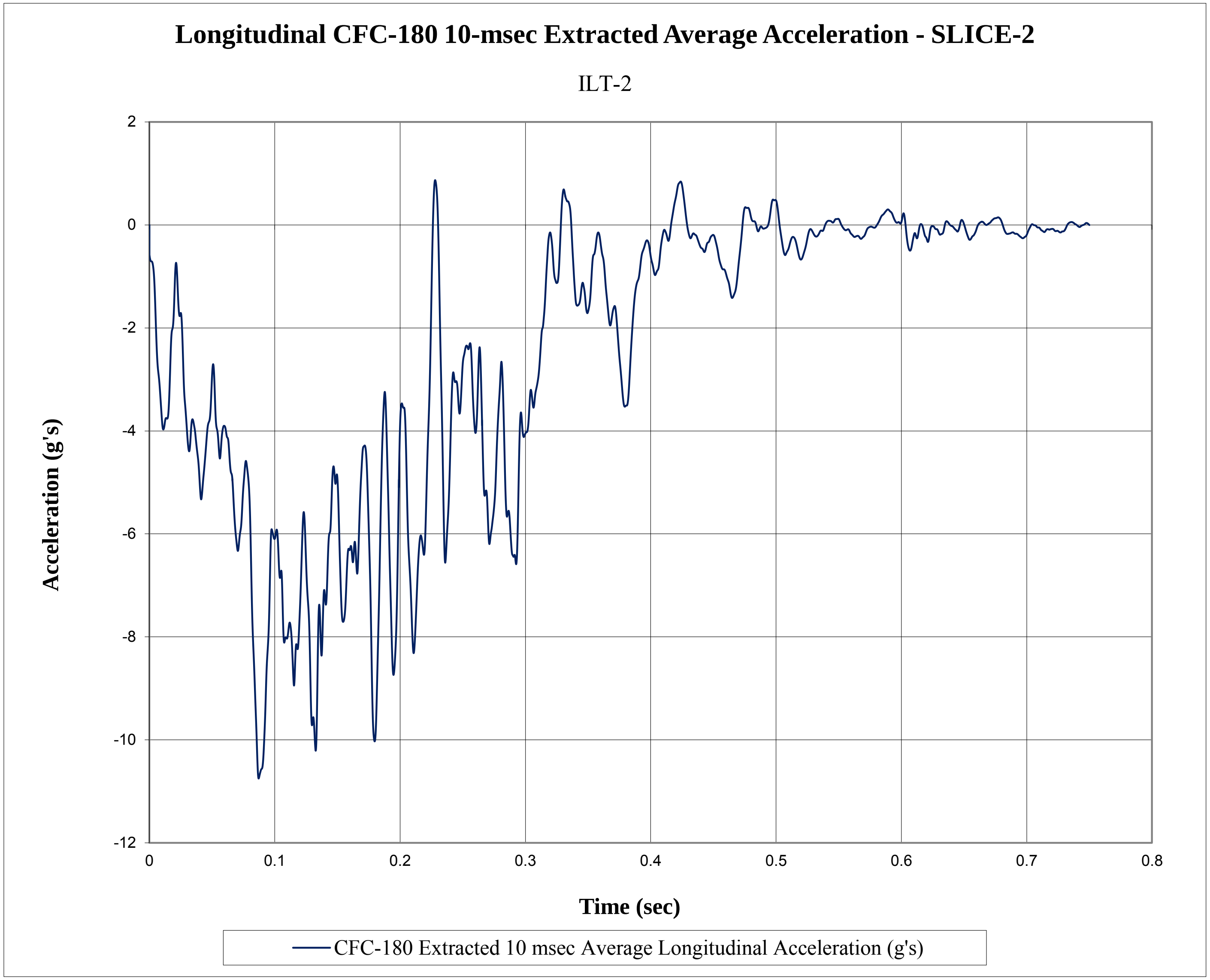


Figure J-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. ILT-2

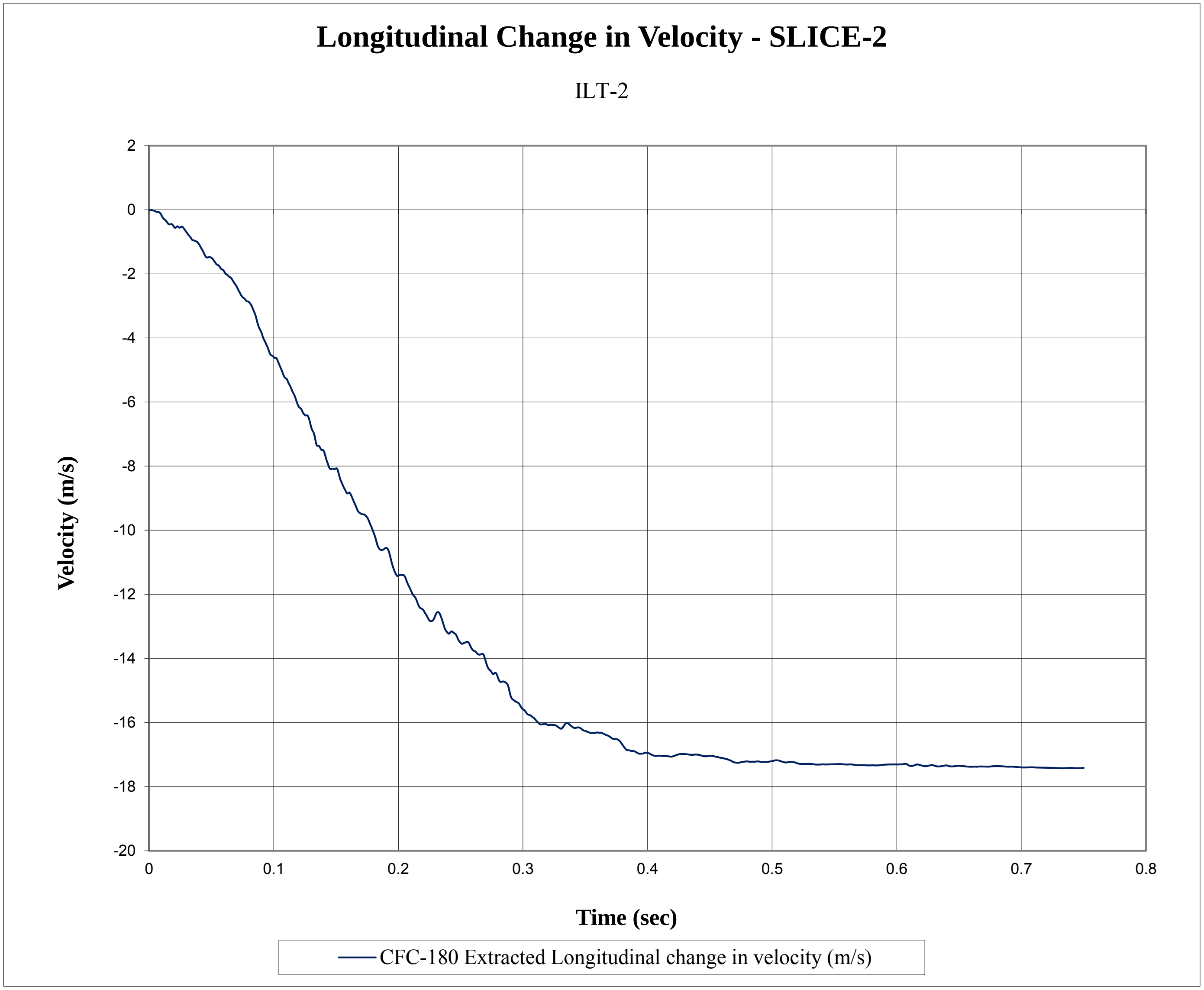


Figure J-10. Longitudinal Change in Velocity (SLICE-2), Test No. ILT-2

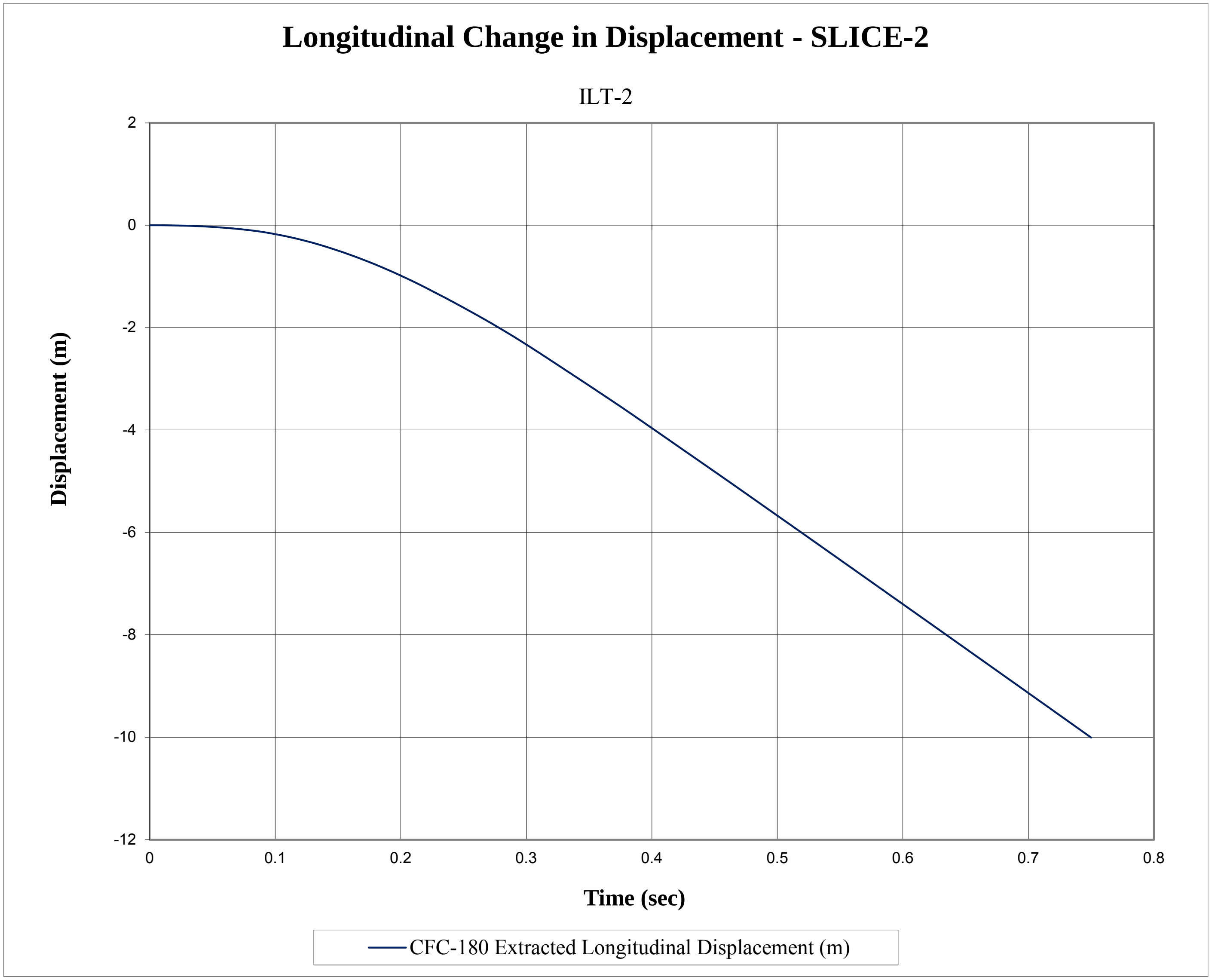


Figure J-11. Longitudinal Change in Displacement (SLICE-2), Test No. ILT-2

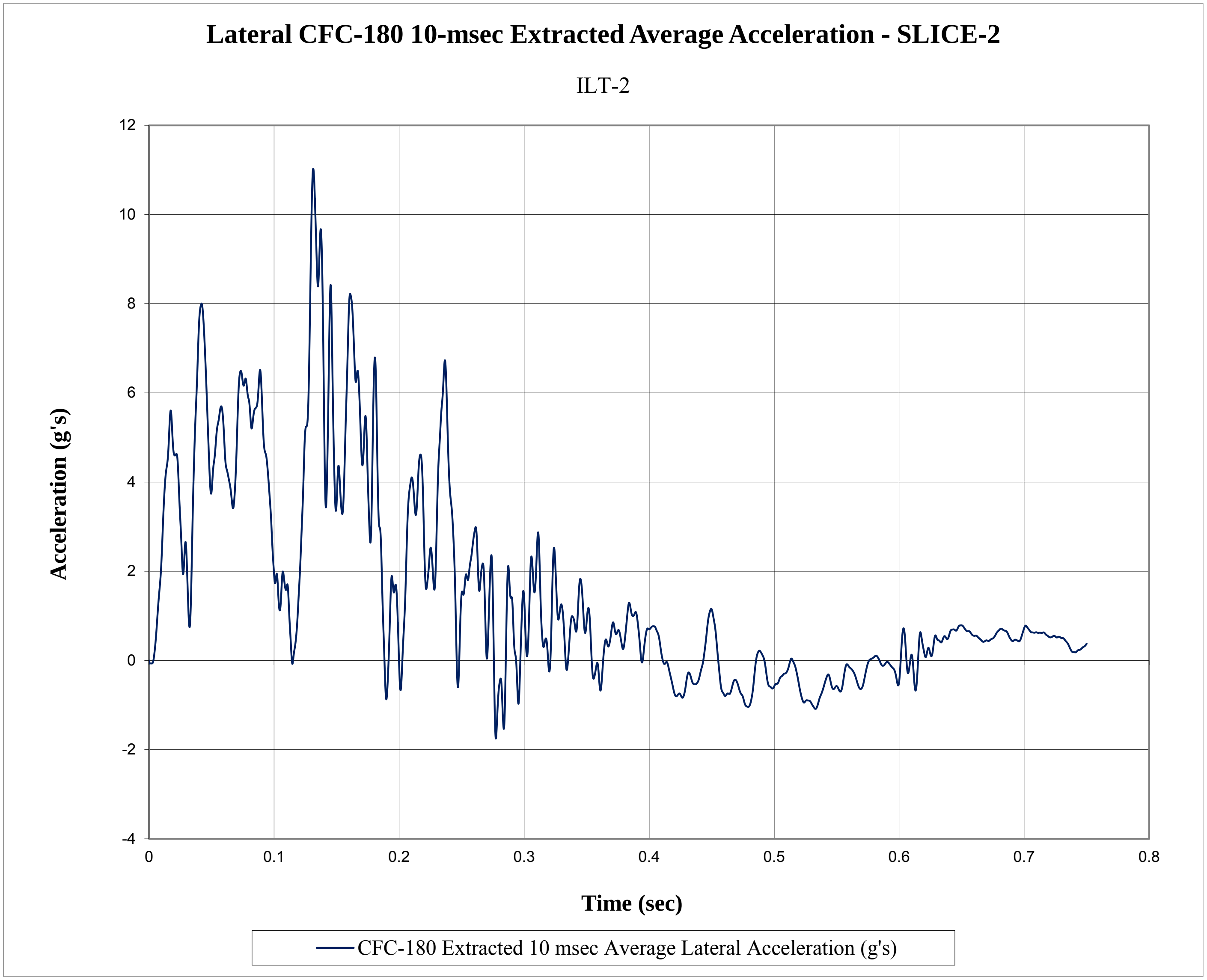


Figure J-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. ILT-2

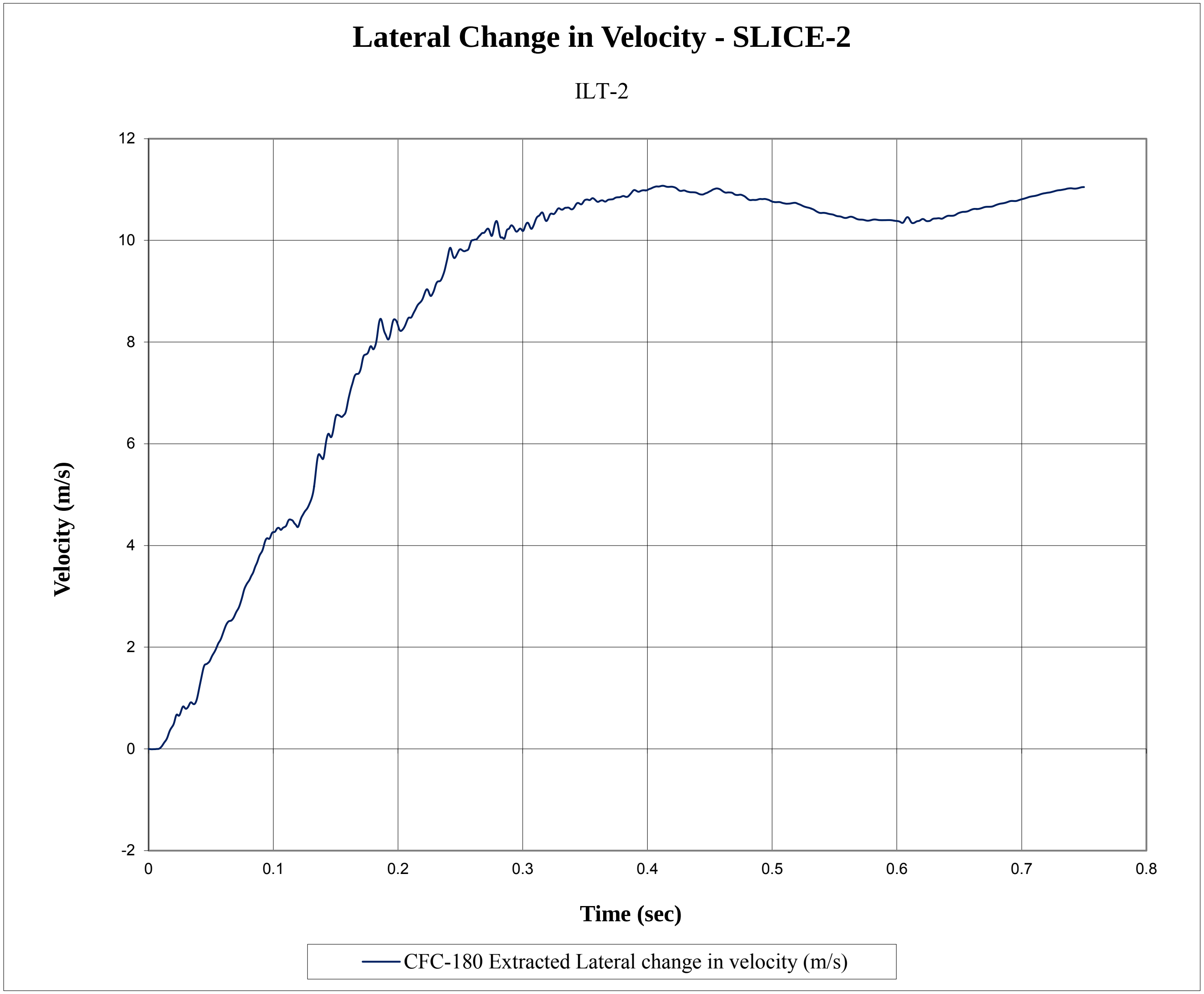


Figure J-13. Lateral Change in Velocity (SLICE-2), Test No. ILT-2

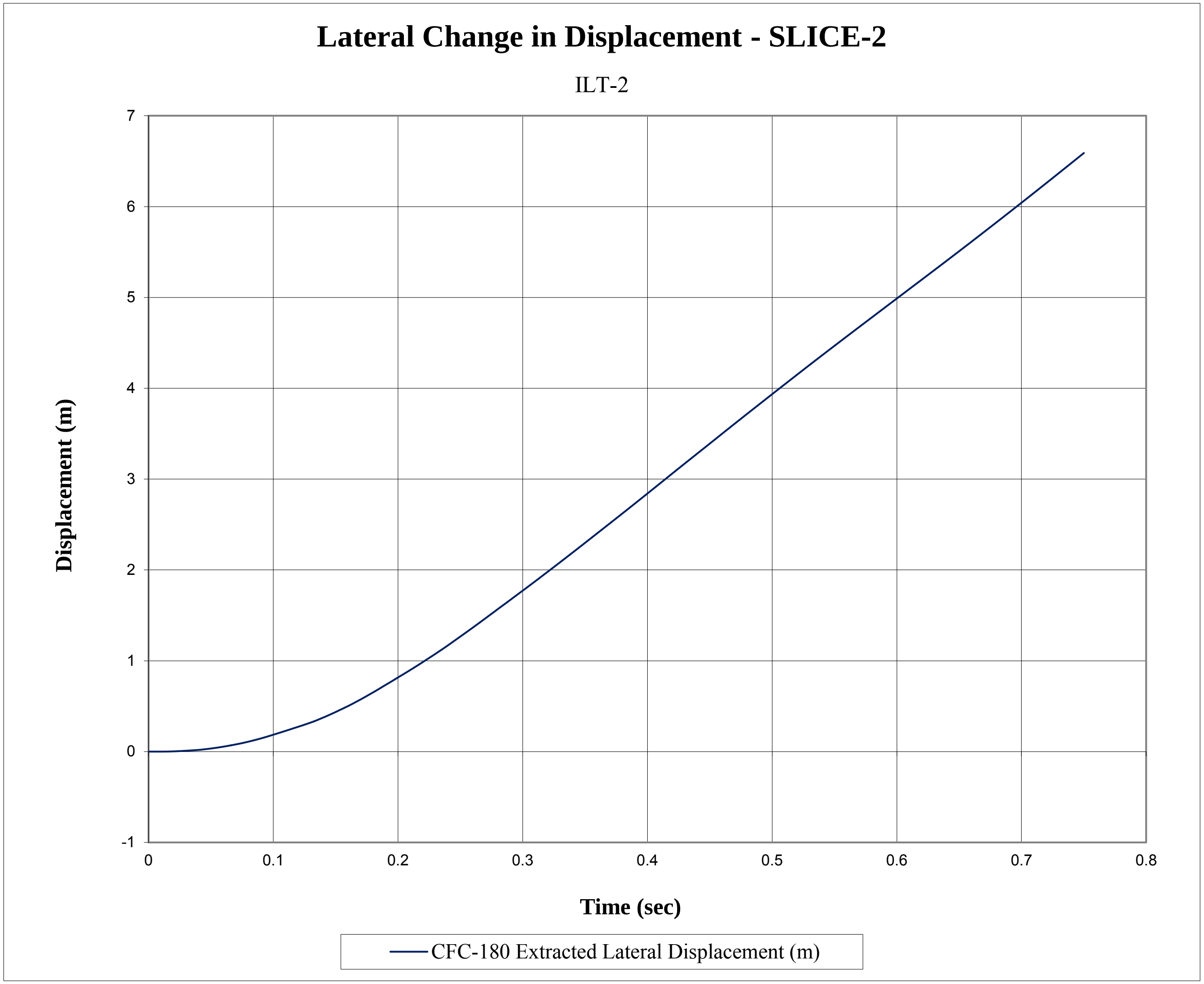


Figure J-14. Lateral Occupant Displacement (SLICE-2), Test No. ILT-2

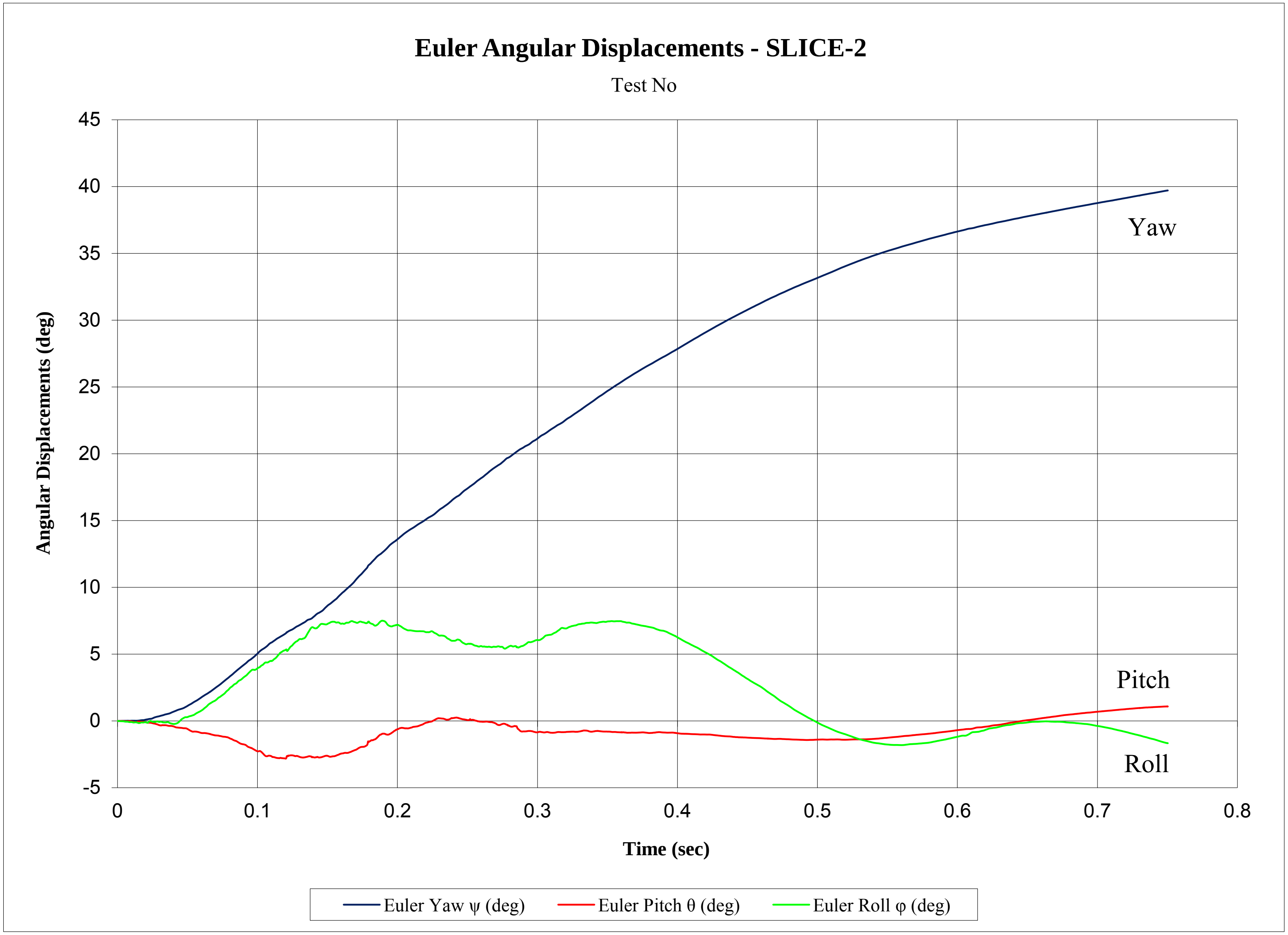


Figure J-15. Vehicle Angular Displacements (SLICE-2), Test No. ILT-2

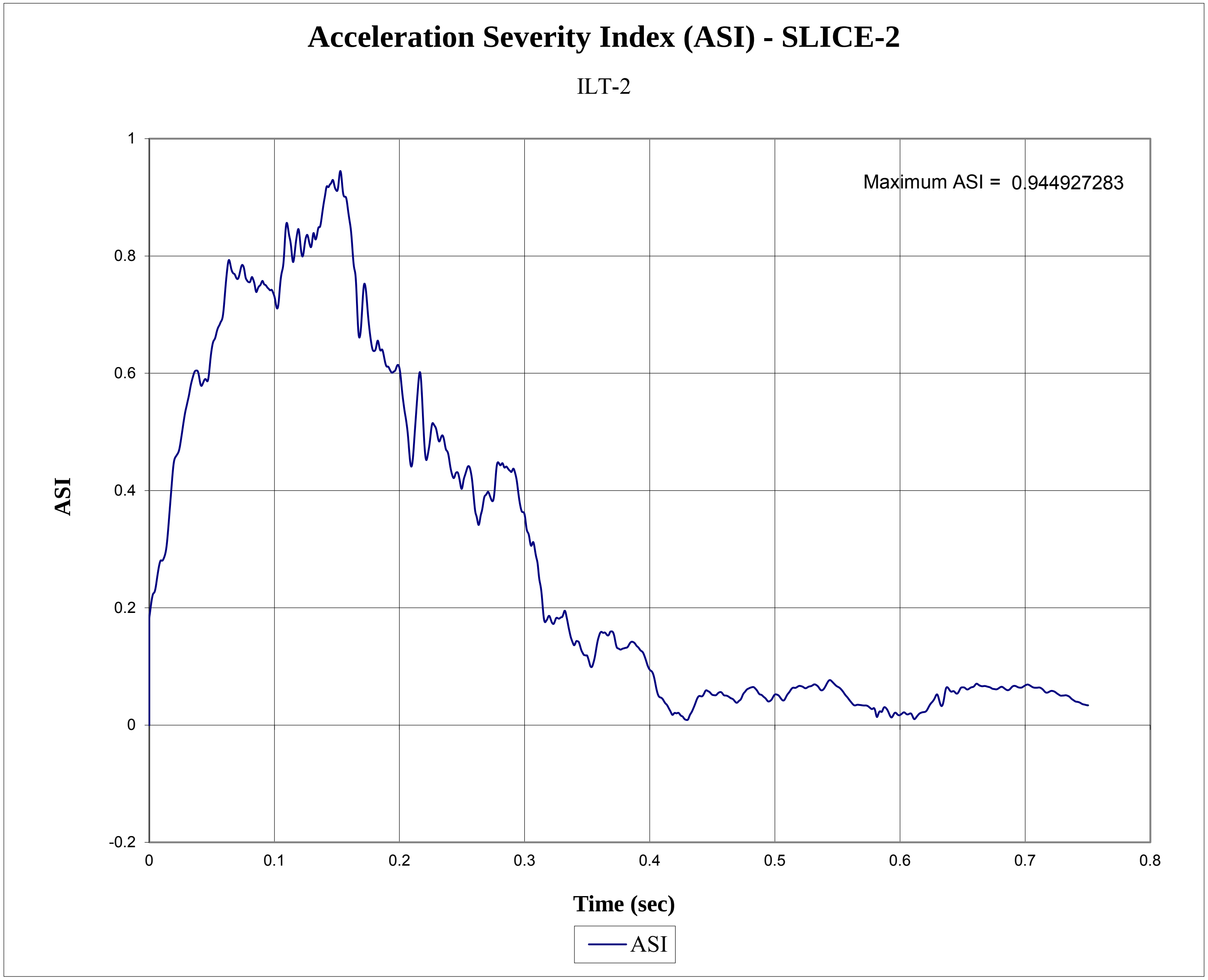


Figure J-16. Acceleration Severity Index (SLICE-2), Test No. ILT-2

Appendix K. Load Cell Data

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

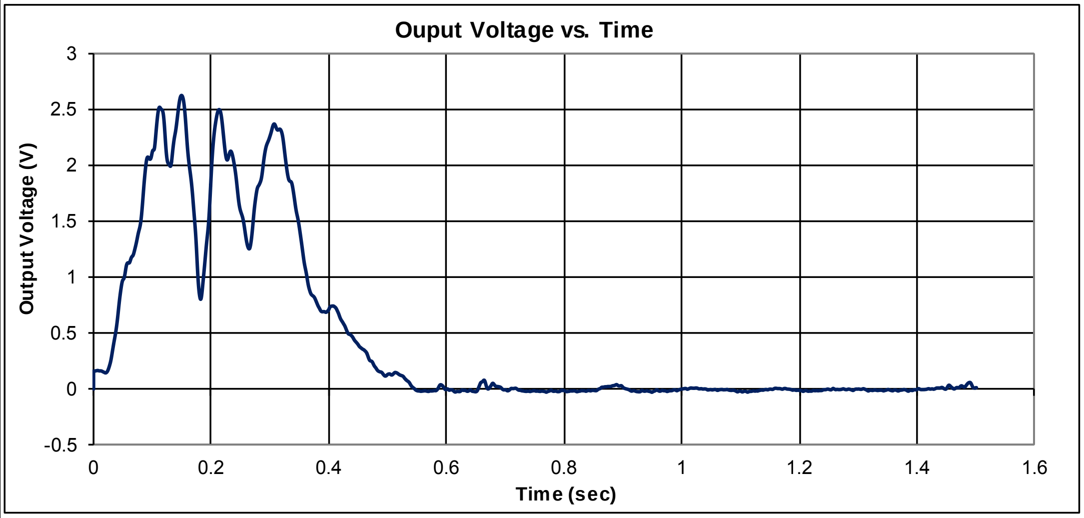
Test No:	ILT-1
Date:	9/23/2016
System / Test Article:	Luminaire Behind MGS
LC Location / Component:	Downstream/North End
Additional Notes:	

Load Cell Information:

Load Cell No.:	143432
Calibration Factor:	2.1597 mv/V
Input Voltage (excitation):	10 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	15.20 kips
Time of Max. Load:	0.1495 sec
Event Duration:	1.5 sec
Final Load:	0.08 kips



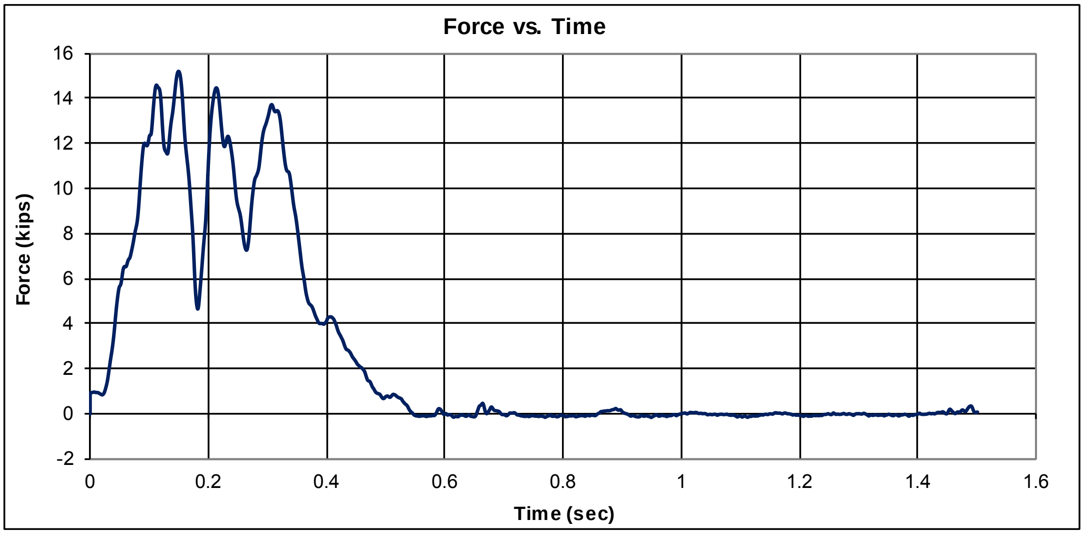


Figure K-1. Load Cell Data, Downstream Anchorage System, Test No. ILT-1

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

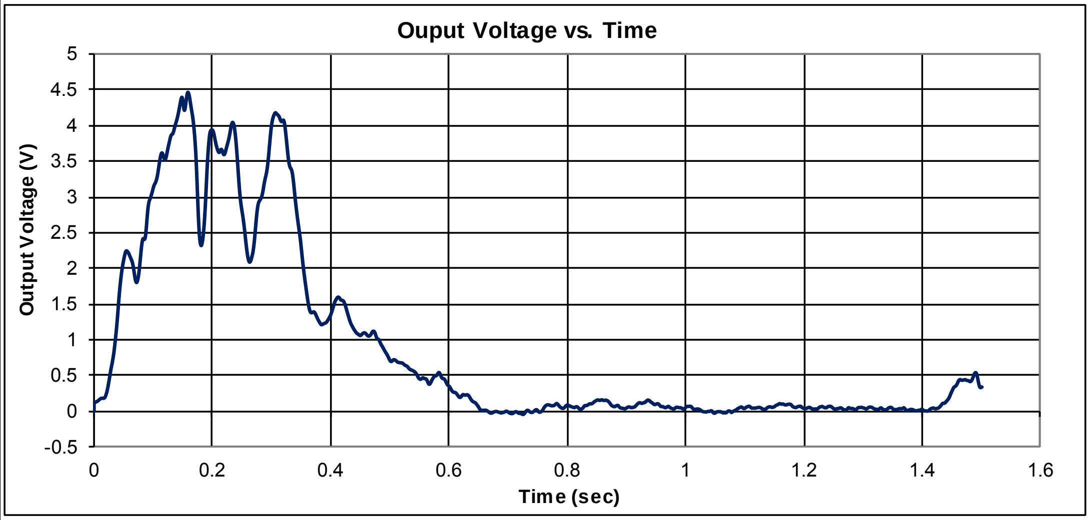
Test No:	ILT-1
Date:	9/23/2016
System / Test Article:	Luminaire Behind MGS
LC Location / Component:	Upstream/South Anchor
Additional Notes:	

Load Cell Information:

Load Cell No.:	143433
Calibration Factor:	2.1646 mv/V
Input Voltage (excitation):	9.99 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	25.80 kips
Time of Max. Load:	0.1587 sec
Event Duration:	1.5 sec
Final Load:	1.97 kips



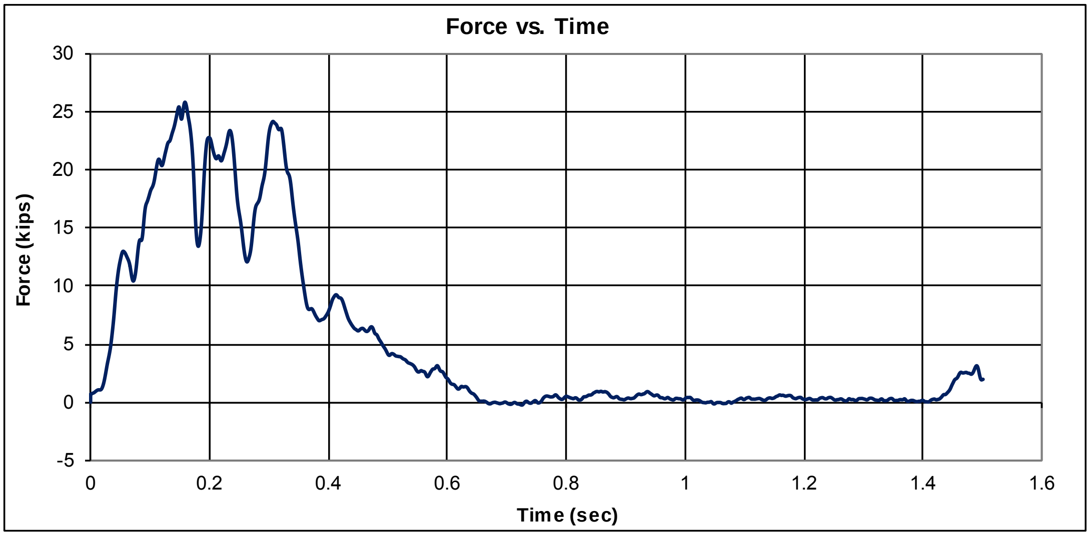


Figure K-2. Load Cell Data, Upstream Anchorage System, Test No. ILT-1

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

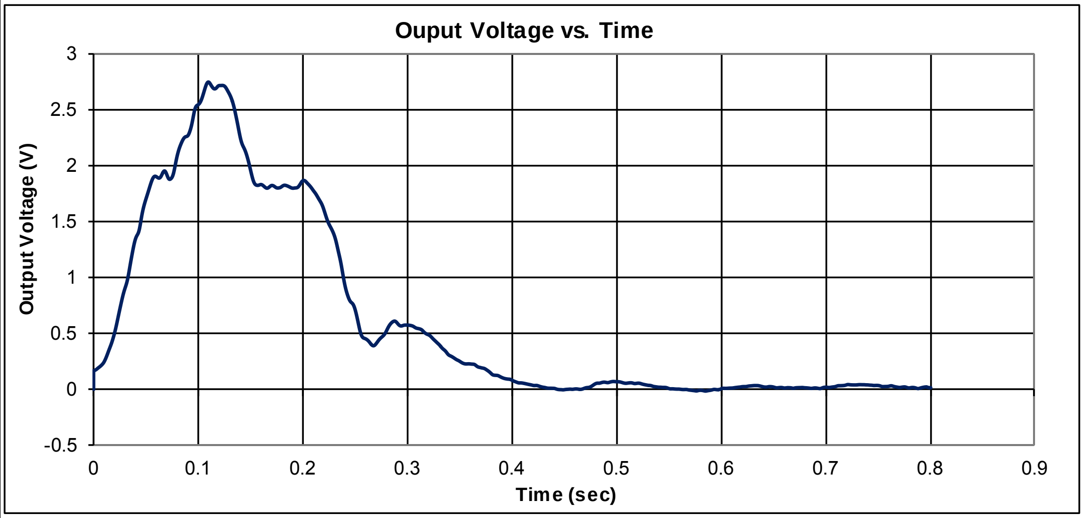
Test No:	ILT-2
Date:	9/28/2016
System / Test Article:	Luminaire Behind MGS
LC Location / Component:	Downstream/South End
Additional Notes:	

Load Cell Information:

Load Cell No.:	143433
Calibration Factor:	2.1646 mv/V
Input Voltage (excitation):	9.97 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	15.92 kips
Time of Max. Load:	0.1097 sec
Event Duration:	0.8 sec
Final Load:	0.09 kips



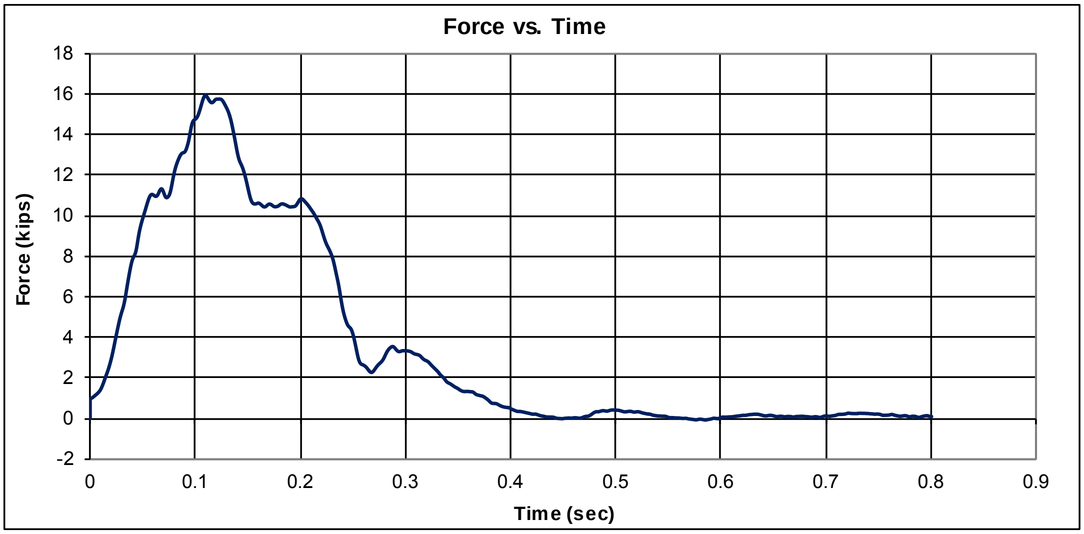


Figure K-3. Load Cell Data, Downstream Anchorage System, Test No. ILT-2

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:

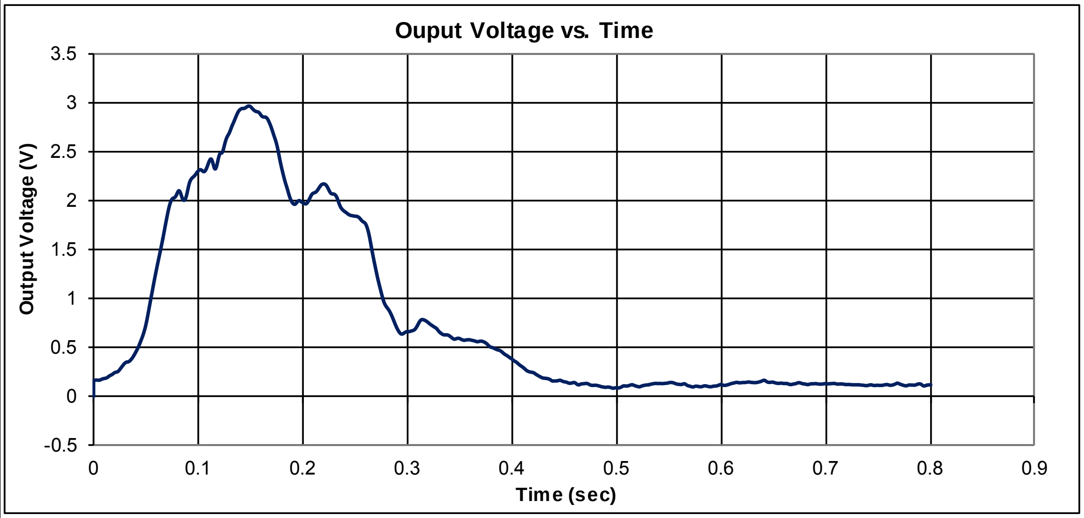
Test No:	ILT-2
Date:	9/28/2016
System / Test Article:	Luminaire Behind MGS
LC Location / Component:	Upstream/North Anchor
Additional Notes:	

Load Cell Information:

Load Cell No.:	143432
Calibration Factor:	2.1597 mv/V
Input Voltage (excitation):	10.01 Volts
Gain:	400
Full Scale Load:	50 kips
Sample Rate:	10000 Hz
Cutoff Frequency:	100 Hz

Results:

Preload:	0 kips
Max. Load:	17.15 kips
Time of Max. Load:	0.1485 sec
Event Duration:	0.8 sec
Final Load:	0.69 kips



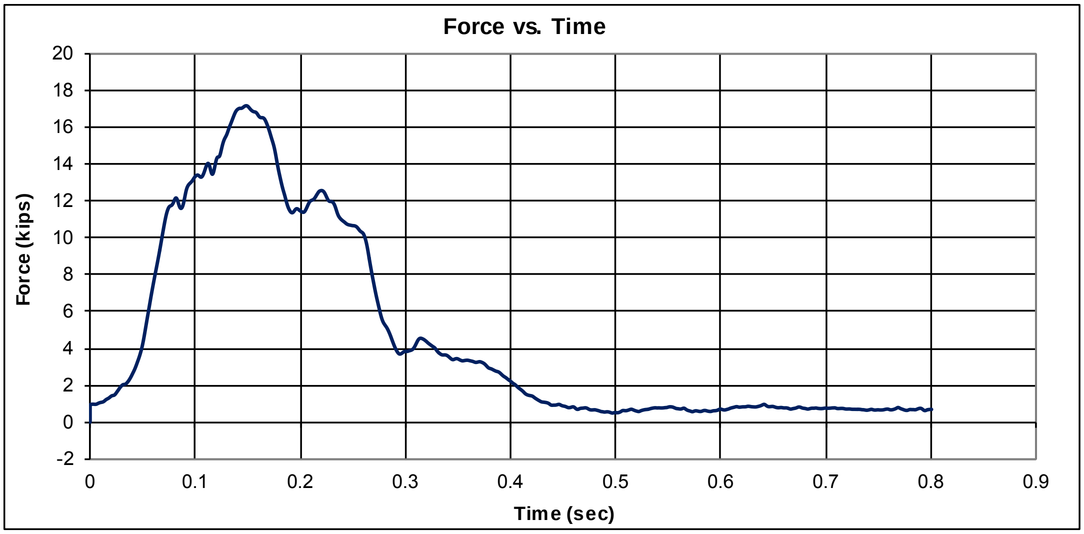


Figure K-4. Load Cell Data, Upstream Anchorage System, Test No. ILT-2

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