TESTING CERT # 2937.01

DYNAMIC EVALUATION OF NEW YORK STATE'S ALUMINUM PEDESTRIAN SIGNAL POLE SYSTEM

Submitted by

Scott Rosenbaugh, M.S.C.E., E.I.T. Research Associate Engineer	Ronald K. Faller, Ph.D., P.E. Research Assistant Professor
Karla A. Lechtenberg, M.S.M.E., E.I.T. Research Associate Engineer	Robert W. Bielenberg, M.S.M.E., E.I.T. Research Associate Engineer
Dean L. Sicking, Ph.D., P.E. Professor and MwRSF Director	John D. Reid, Ph.D. Professor

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

Submitted to

NEW YORK STATE DEPARTMENT OF TRANSPORTATION
Transportation Research and Development Bureau
50 Wolf Road
POD 34
Albany, New York 12232

MwRSF Research Report No. TRP-03-223-09

December 22, 2009

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.
TRP-03-223-09

2.

3. Recipient's Accession No.

4. Title and Subtitle
Dynamic Evaluation of New York State's Aluminum Pedestrian Signal Pole System

5. Report Date
December 22, 2009

6.

7. Author(s)
Rosenbaugh, S.K., Faller, R.K., Lechtenberg, K.A., Bielenberg, R.W., Sicking, D.L., and Reid, J.D.

8. Performing Organization Report No.
TRP-03-223-09

9. Performing Organization Name and Address
Midwest Roadside Safety Facility (MwRSF)
University of Nebraska-Lincoln
527 Nebraska Hall
Lincoln, Nebraska 68588-0529

10. Project/Task/Work Unit No.

11. Contract © or Grant (G) No.
TPF-5(193) Supplement No. 10

12. Sponsoring Organization Name and Address
New York State Department of Transportation
Transportation Research and Development Bureau
50 Wolf Road
POD 34
Albany, New York 12232

13. Type of Report and Period Covered
Final Report: 2009

14. Sponsoring Agency Code
TPF-5(193) Supplement No. 10

15. Supplementary Notes
Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration.

16. Abstract (Limit: 200 words)

The New York State Department of Transportation (NYSDOT) mounts pedestrian "hand/man" signals to aluminum poles and uses frangible transformer bases to allow the system to break away. However, engineers at NYSDOT believed that the material properties of the aluminum poles themselves would allow the pedestrian signal poles to break away without the use of transformer bases. Elimination of the frangible transformer base would result in significant savings.

An aluminum pedestrian signal pole system was erected at the Valmont testing facility and tested with the Valmont-MwRSF/UNL pendulum with crushable nose in accordance with NCHRP Report No. 350 test designation no. 3-60. Upon impact the pole broke away from the base plate assembly, and the surrogate vehicle change in velocity was measured to be 13.9 ft/s (4.2 m/s), satisfying the limit of 16.4 ft/s (5.0 m/s). However, the remaining stub height measured 4.5 in. (114 mm), and violated the 4 in. (100 mm). Thus, the test was deemed unsuccessful. The results from the impact test were used in a numerical analysis to predict the change in velocity for the high-speed impact test, test designation no. 3-61. This analysis showed that the aluminum pedestrian signal pole would also satisfy the occupant risk criteria during a high-speed test.

Since the pole cleanly broke away in the test and the high-speed impact analysis showed a satisfactory change in velocity, the excessive stub height was the only result that prevented this installation from becoming crashworthy. As such, three separate design modifications were presented for aiding the system to satisfy the stub maximum height limit.

17. Document Analysis/Descriptors
Highway Safety, Pendulum Test, Roadside Appurtenances, NCHRP Report No. 350, Signal Pole, Breakaway Pole, Crash Test, Compliance Test

18. Availability Statement
No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	78	

DISCLAIMER STATEMENT

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 New York State Department of Transportation nor 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 this project was Ms. Karla Lechtenberg, Reseach Associate Engineer, of the Midwest Roadside Safety Facility, University of Nebraska Lincoln.

ACKNOWLEDGEMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the New York State Department of Transportation for sponsoring the project and (2) Valmont Industries, Inc. for assisting MwRSF personnel with the pendulum testing program.

Acknowledgement is also given to the following individuals who made a contribution to the completion of this research project.

Midwest Roadside Safety Facility

C.L. Meyer, B.S.M.E., E.I.T., Research Associate Engineer

New York State Department of Transportation

Loretta Montgomery, Civil Engineer
Lyman L. Hale III, P.E., Senior Engineer

Valmont Industries, Inc.

Carl Macchietto, P.E., Director of Engineering
Travis Kraemer, Product Development Supervisor
Zach Thiemann, Associate Product Development Engineer
Anil Ayalasomayajula, Research & Development Engineer
Matthew Cone, Project Administrator
Tyler Pearce, Fabrication Technician

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Problem Statement

Historically, pedestrian “hand/man” signals have been commonly used at roadway crossings in areas with heavy foot traffic. Prior to 2009, the New York State Department of Transportation (NYSDOT) mounted these pedestrian signals on aluminum poles with frangible transformer bases which allowed the system to break away upon impact with an errant vehicle. However, engineers at NYSDOT believed that the material properties of the aluminum poles themselves would allow the pedestrian signal poles to break away without the use of the frangible transformer bases. By eliminating the need for the frangible transformer base, both time and money could be saved when installing these pedestrian signal poles. Therefore, the NYSDOT desired to evaluate the breakaway ability of their standard “hand/man” pedestrian signal mounted to an aluminum pole.

Modern safety performance standards for breakaway support structure systems are contained in two documents: (1) the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* [1] and (2) the *American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals, Fifth Edition* [2]. These two documents detail a crash testing matrix that includes two full-scale tests with a small passenger vehicle. However, the Federal Highway Administration (FHWA) has approved the use of the Valmont-MwRSF/UNL pendulum as a surrogate vehicle for analyzing breakaway devices [3]. Therefore, the NYSDOT desired to use the Valmont-MwRSF/UNL pendulum to evaluate safety performance of aluminum pedestrian signal poles.

1.2 Research Objective

The objective of this research study was to evaluate the safety performance of the NYSDOT aluminum pedestrian “hand/man” signal pole without the use of a frangible transformer base. The signal pole system was tested with the Valmont-MwRSF/UNL pendulum and evaluated according to the Test Level 3 (TL-3) criteria established in NCHRP Report No. 350 as well as to the *AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals, Fifth Edition*.

1.3 Scope

The project began with the selection of an aluminum pole that represented the common pedestrian signal pole used throughout the state of New York. Next, one low-speed, pendulum impact test was conducted in accordance with NCHRP Report No. 350 test designation no. 3-60. The low-speed test results were then used to estimate the results for the high-speed impact test, test designation no. 3-61, using an analytical method recognized by FHWA. Finally, conclusions were prepared for both the pendulum test as well as the high-speed extrapolation and data analysis and were documented and summarized herein.

2 CRUSHABLE NOSE PENDULUM DETAILS

2.1 Pendulum System Details

The Valmont-MwRSF/UNL pendulum that was utilized for this study consisted of three main components: (1) the support structure; (2) the pendulum assembly; and (3) the crushable nose. Each of these components is discussed briefly in the following sections. Detailed drawings and photographs of the pendulum system are shown in Figures 1 through 19.

2.1.1 Support Structure

The support structure consisted of two 60-ft (18.3-m) tall steel poles spaced 40 ft (12.2 m) apart laterally, as shown in Figure 1. The two support poles were connected at the top by a catwalk assembly and cross bracing, as shown in Figures 6 through 8. Four cables were attached to the support structure at a height of 42 ft – 11 in. (13.1 m) which supported the pendulum mass.

The rear lift structure was comprised of two additional steel poles. These poles had a height of 52 ft – 9 in. (16.1 m) and were spaced 6 ft (1.8 m) apart laterally. A winch was located at the base of these poles, and the winch cable extended up to a pulley attached to the top of the rear lift structure and continued to the back of the pendulum. This winch and pulley system was used to raise the pendulum mass to the desired elevation. The cable was released remotely to conduct the impact testing.

2.1.2 Pendulum Assembly

The pendulum body consisted of a welded, steel plate box frame, as shown in Figures 10 and 11. Two longitudinal steel tubes were mounted through the box frame to act as guides for the crushable nose. A second set of four steel tubes were installed laterally through the pendulum box frame for installing through-bolts for use in attaching ballast plates to the pendulum body. The inside of the box frame was filled with concrete in order to strengthen the frame and add the necessary mass.

The pendulum body was supported by four ½-in. (13-mm) diameter, 6x25 XIP IWRC wire ropes. These wire ropes were attached to the support structure at a height of 42 ft – 11 in. (13.1 m) and adjusted to set the impact height of the pendulum at 17½ in. (445 mm) above the groundline. The wire ropes were configured to support the pendulum and keep the body level during the pendulum swing.

It should be noted that the pendulum detailed herein was not configured with a sweeper plate, as shown on other pendulums used at the Federal Outdoor Impact Laboratory (FOIL) and the Texas Transportation Institute (TTI) [4-6]. The purpose of the sweeper plate, as stated in previous reports, was to act as a sacrificial element that grossly replicated the undercarriage of an automobile. It was not believed that the sweeper plate was necessary for the testing detailed in this report.

2.1.3 Crushable Nose

The crushable nose was mounted on the front of the pendulum mass. It was based on the crushable nose developed and tested on the FOIL pendulum [4-5]. The aluminum nose tubes were attached to the aluminum impact head and slide into the guide tubes on the body of the pendulum. The crushable nose contained ten energy-absorbing aluminum honeycomb elements with various geometries and stiffness separated by a series of sliding, fiberglass plates. The aluminum honeycomb configuration was configured to represent the front-end crush stiffness and crush of a 1979 Volkswagen Rabbit two-door sedan with a manual transmission. The aluminum honeycomb was pre-crushed in order to produce consistent force levels. Details of the crushable nose assembly and the aluminum honeycomb configuration are shown in Figures 13 through 18. Details for each of the ten aluminum honeycomb elements are shown in Table 1.

Table 1. Aluminum Honeycomb Details

Cartridge No.	Manufacturer (Part No.)	Density (pcf)	Dimensions (in.) (l x d)	Original Depth (in.)	Pre-Crush Depth (in.)	Crush Strength (psi)	Wall Thickness (in.)	Cell Size (in.)
1	Plascore (PAMG-XR1-3.1 3/16 .001N 5052)	3.1	2.75 x 16	3.25	3	130	0.001	0.1875
2	Plascore (PCGA-XR1-1.4 1/0 N 3003)	1.4	4 x 5	2	2	25	-	0.375
3	Plascore (PAMG-XR1-3.1 3/16 .001N 5052)	3.1	8 x 8	3.25	3	130	0.001	0.1875
4	Plascore (PAMG-XR1-4.3 1/4 .002N 5052)	4.3	8 x 8	3.25	3	230	0.002	0.25
5	Plascore (PAMG-XR1-4.3 1/4 .002N 5052)	4.3	8 x 8	3.25	3	230	0.002	0.25
6	Plascore (PAMG-XR1-4.3 1/4 .002N 5052)	4.3	8 x 8	3.25	3	230	0.002	0.25
7	Plascore (PAMG_XR1-5.7 3/16 .002N 5052)	5.7	8 x 8	3.25	3	400	0.002	0.1875
8	Plascore (PAMG_XR1-5.7 3/16 .002N 5052)	5.7	8 x 8	3.25	3	400	0.002	0.1875
9	Plascore (PAMG_XR1-5.7 3/16 .002N 5052)	5.7	8 x 8	3.25	3	400	0.002	0.1875
10	Plascore (PAMG_XR1-5.7 3/16 .002N 5052)	5.7	8 x 10	3.25	3	400	0.002	0.1875

2.2 Pendulum Weight

The Valmont-MwRSF/UNL crushable nose pendulum and all of its components were weighed and recorded prior to testing. The total weight of the pendulum, including the crushable nose and aluminum honeycomb, was 1,898 lb (861 kg).

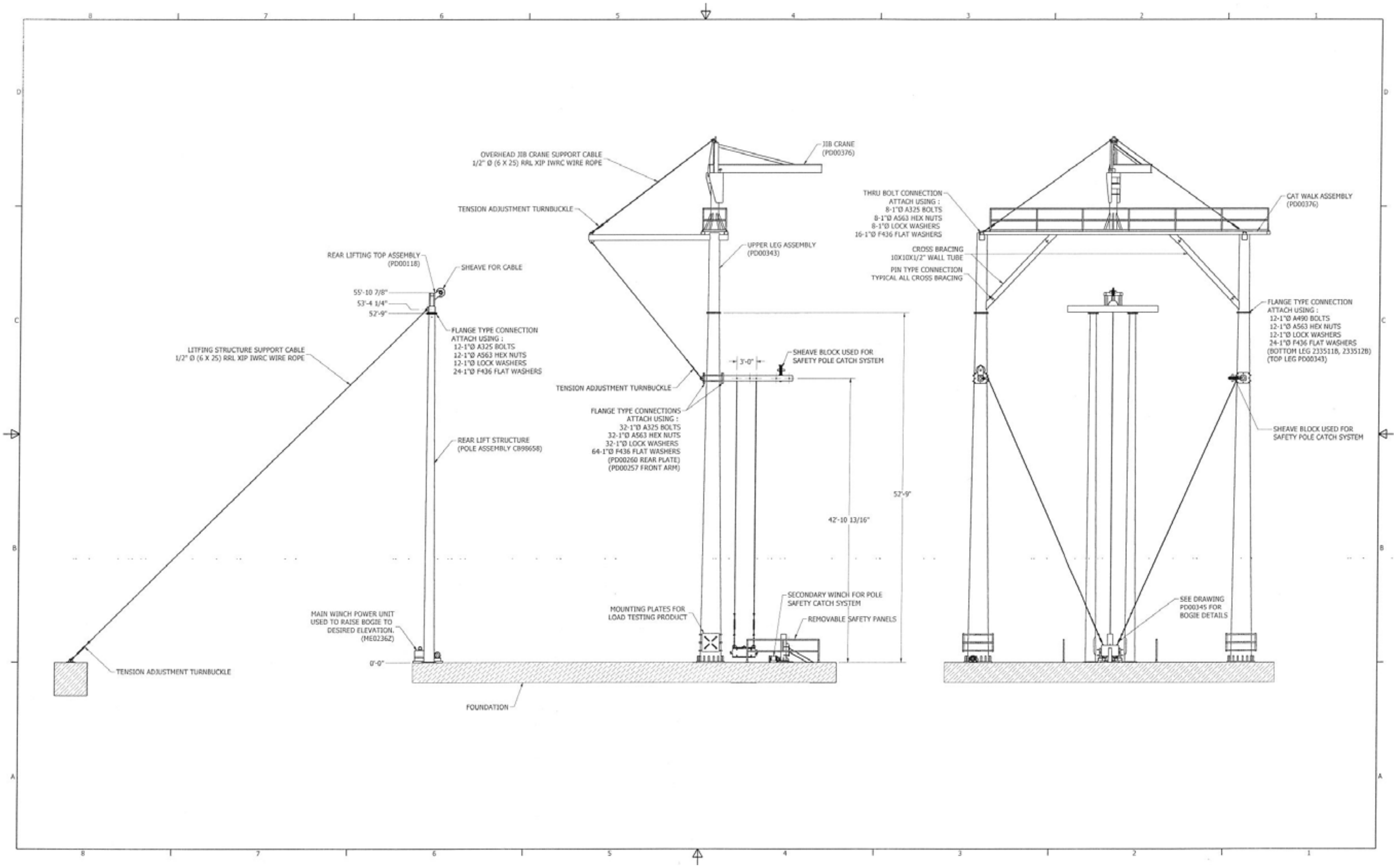


Figure 1. Pendulum Support Structure

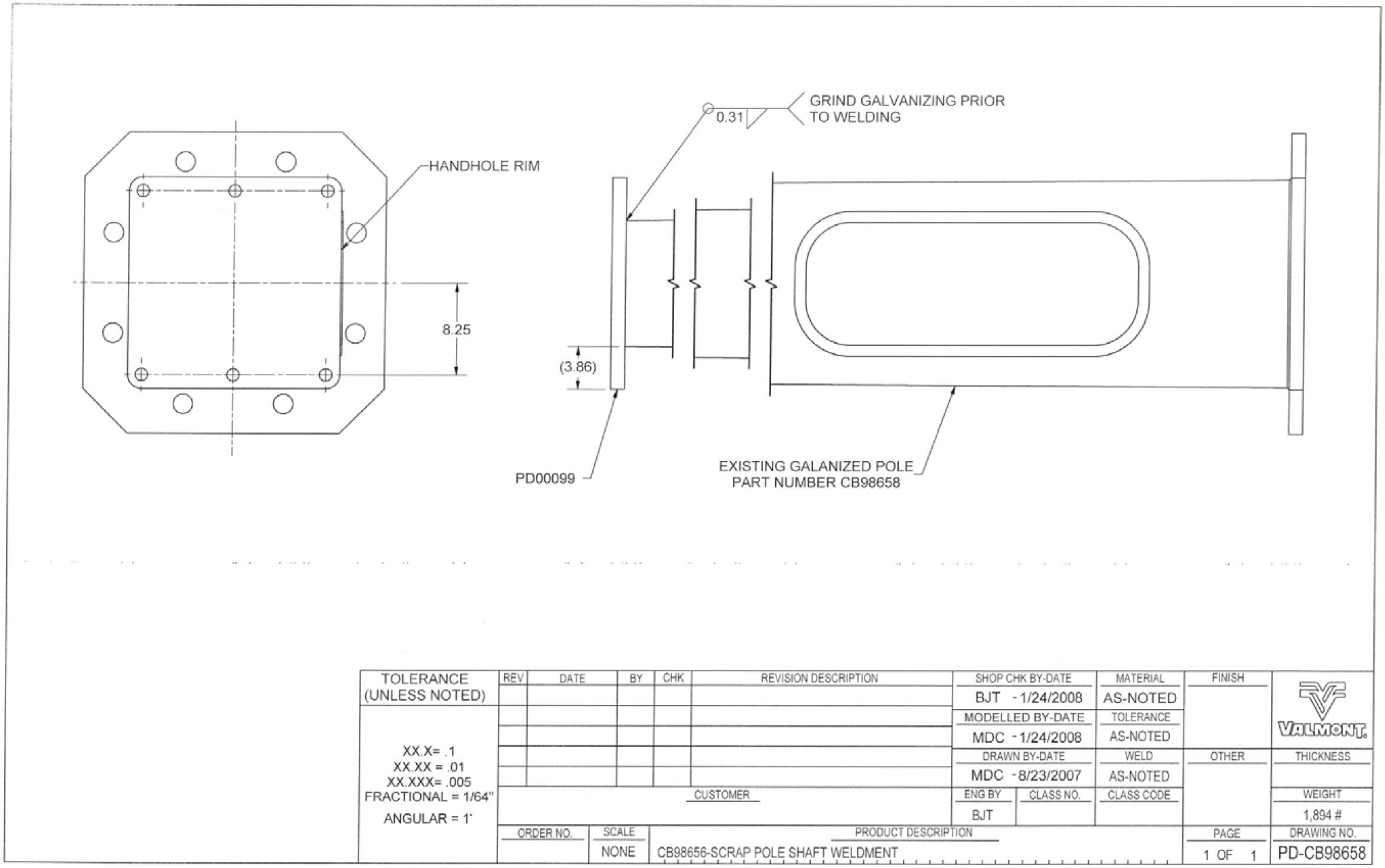


Figure 2. Pendulum Support Structure Details

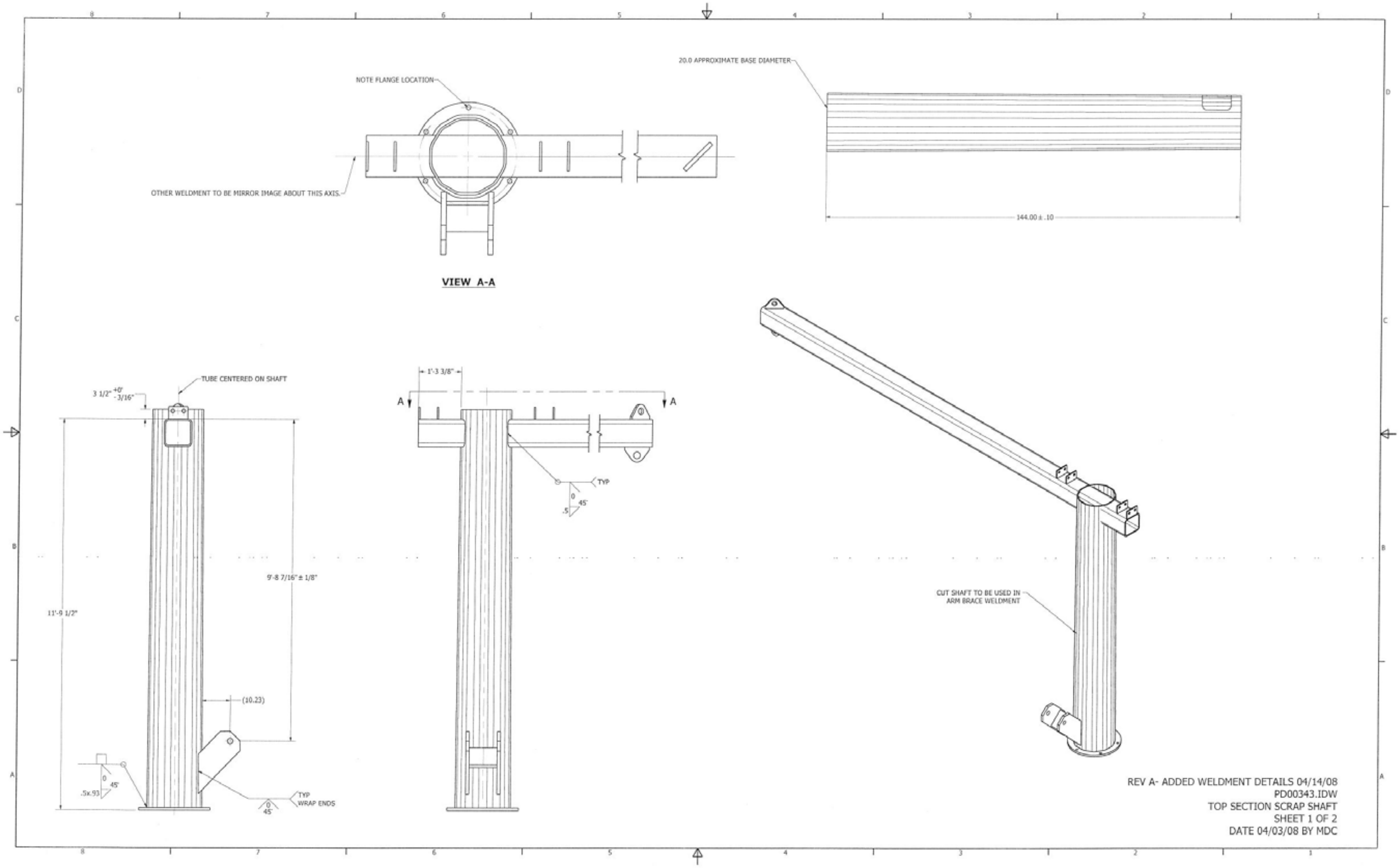


Figure 3. Pendulum Support Structure Details

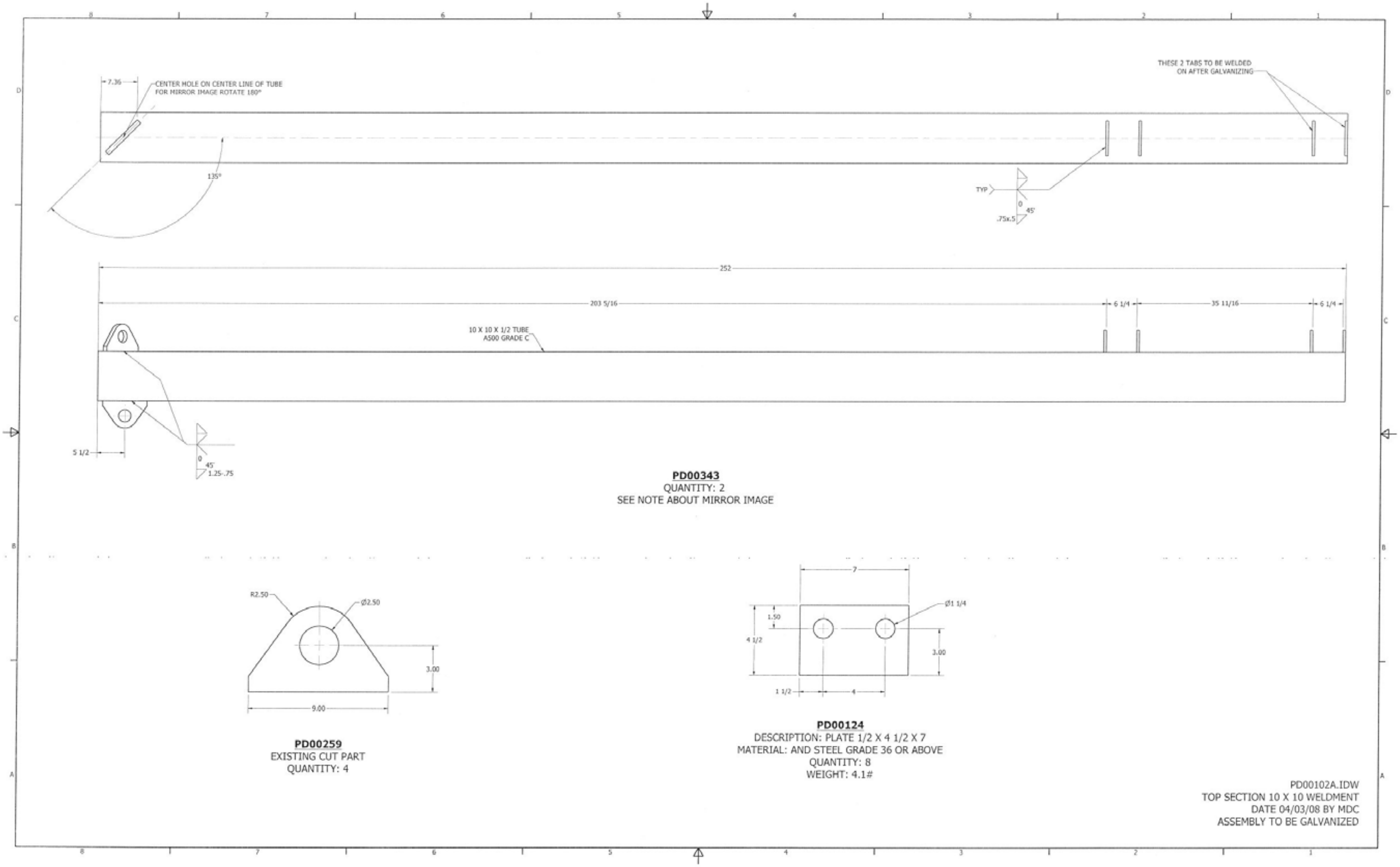


Figure 4. Pendulum Support Structure Details

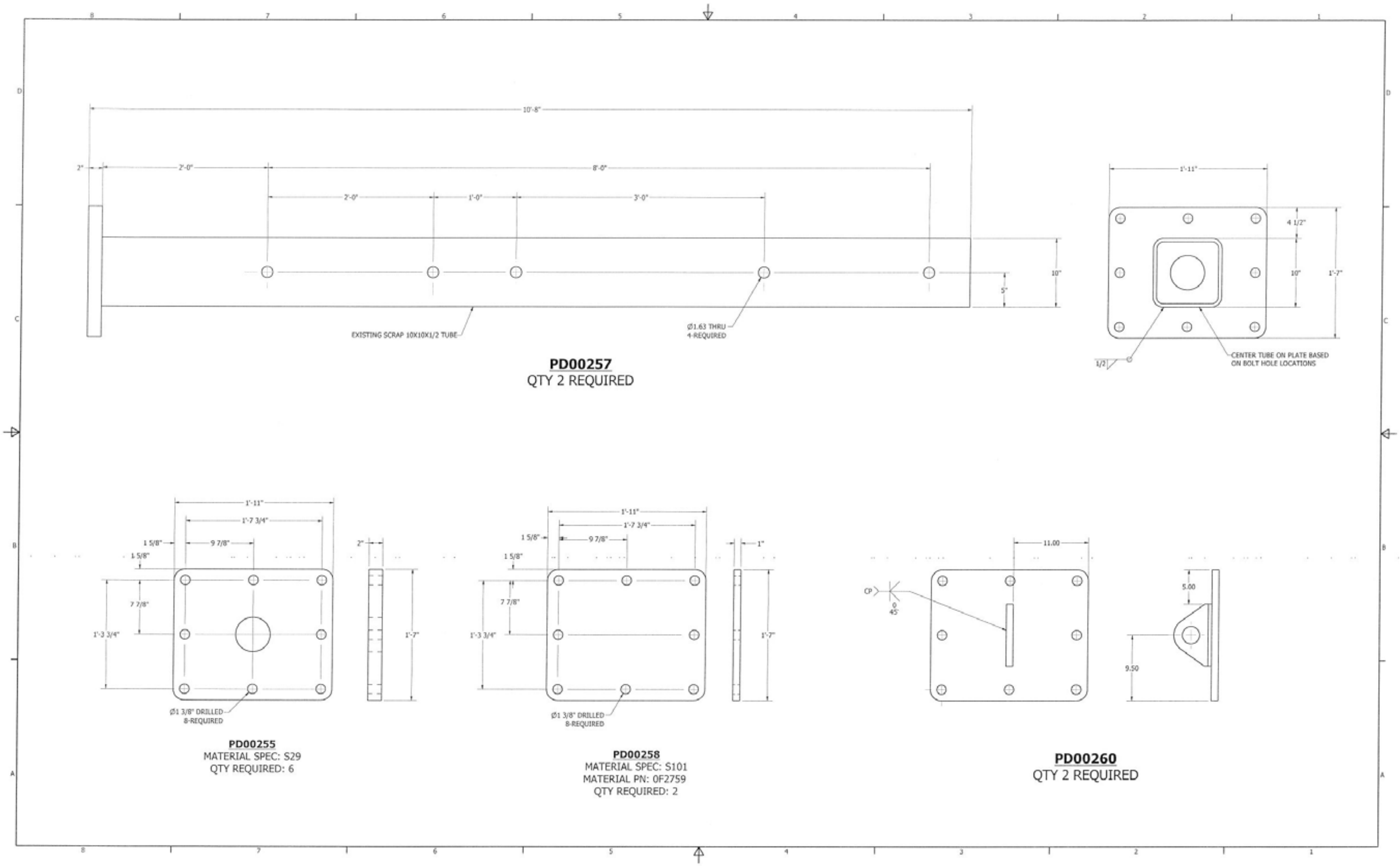


Figure 5. Pendulum Support Structure Details

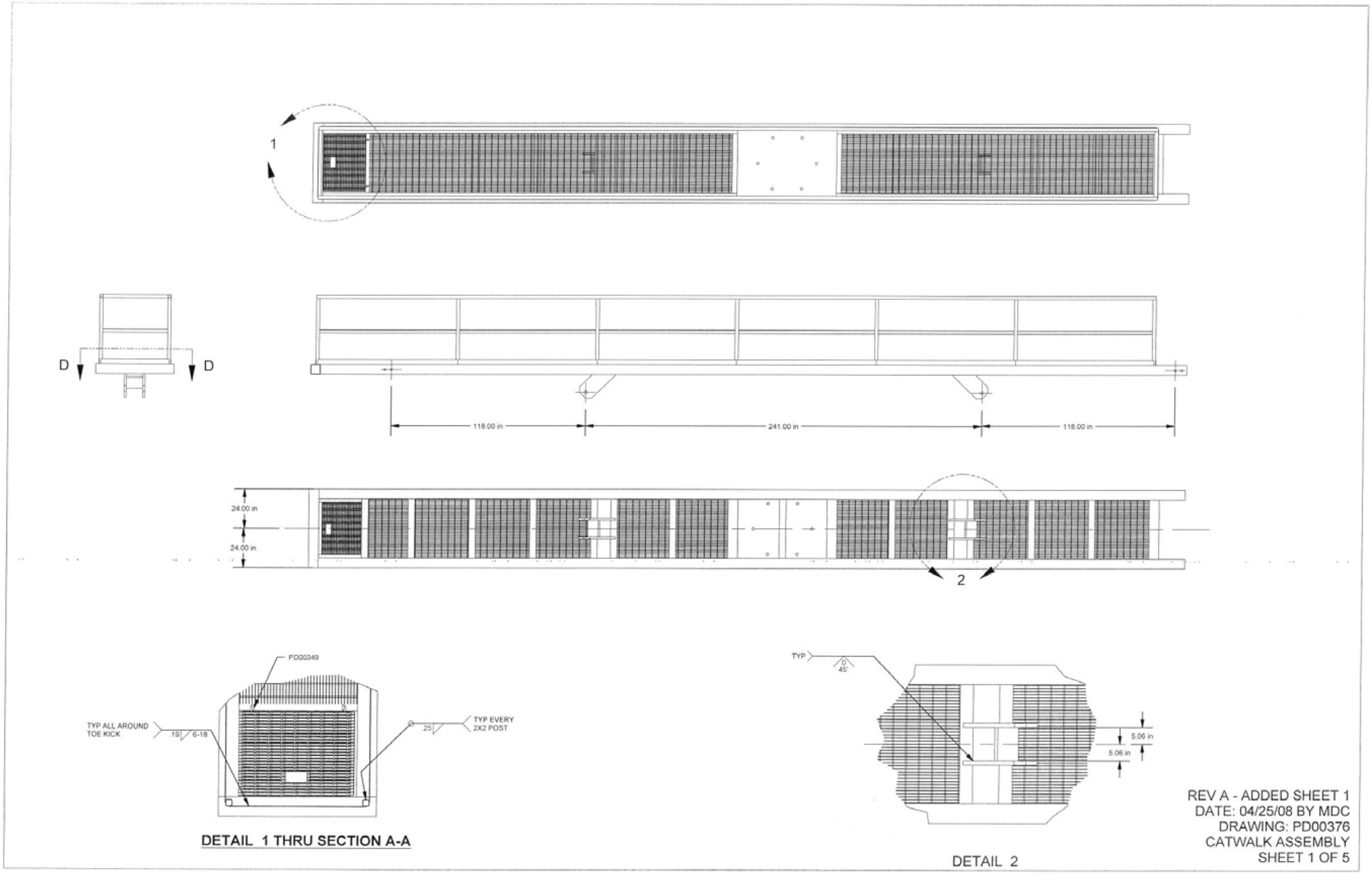


Figure 6. Pendulum Support Structure, Catwalk

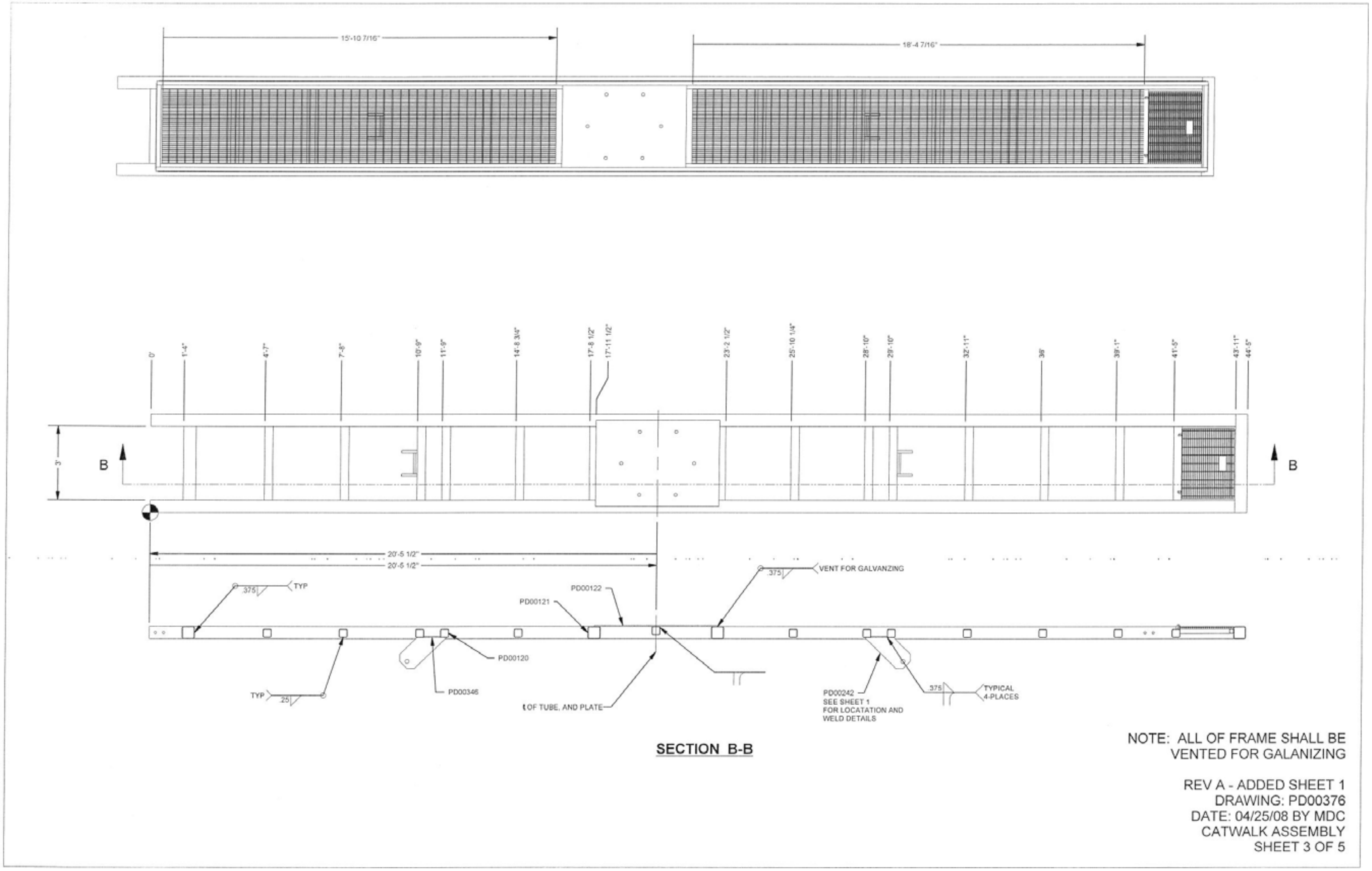


Figure 7. Pendulum Support Structure, Catwalk

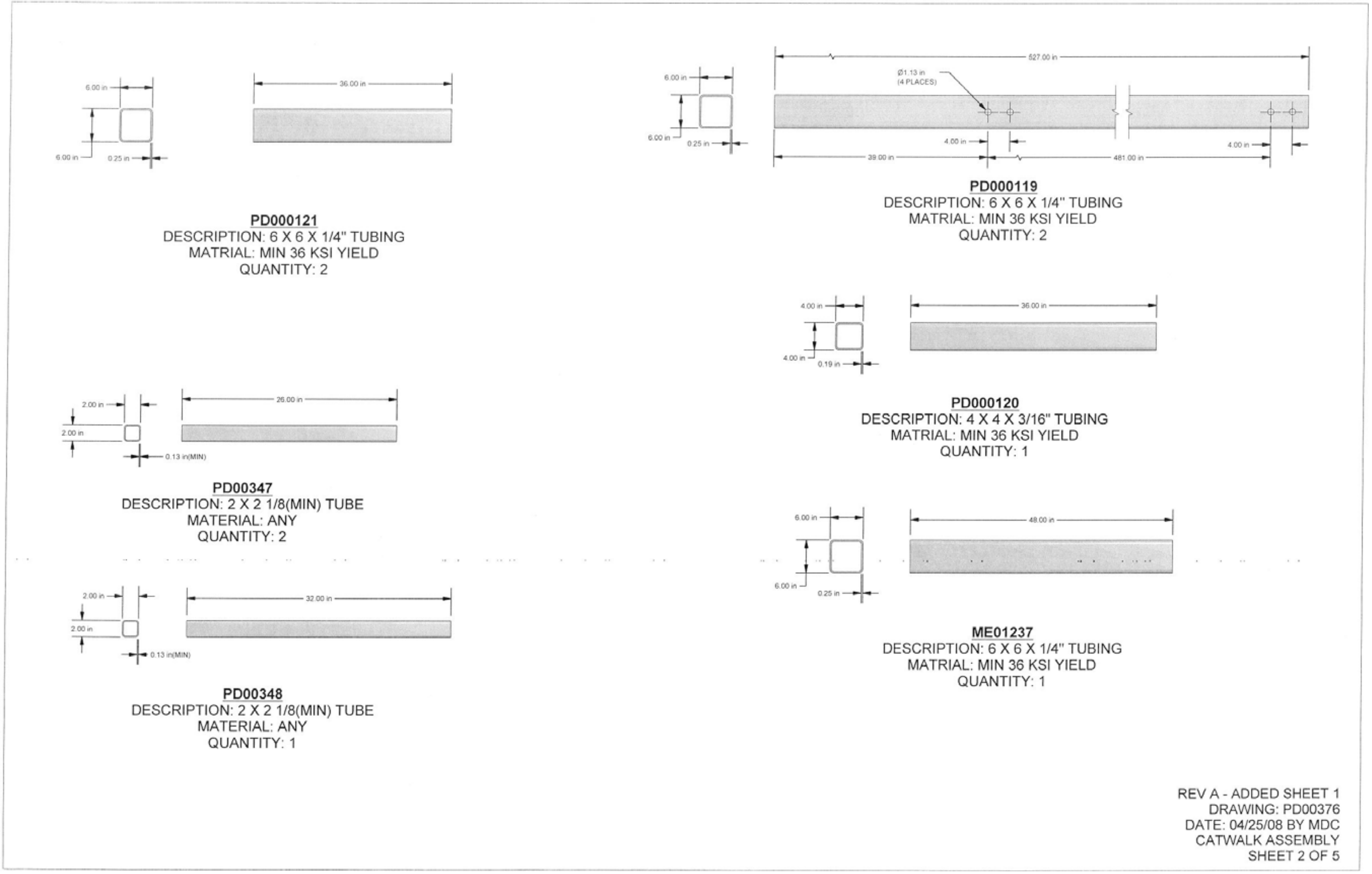


Figure 8. Pendulum Support Structure, Catwalk Details

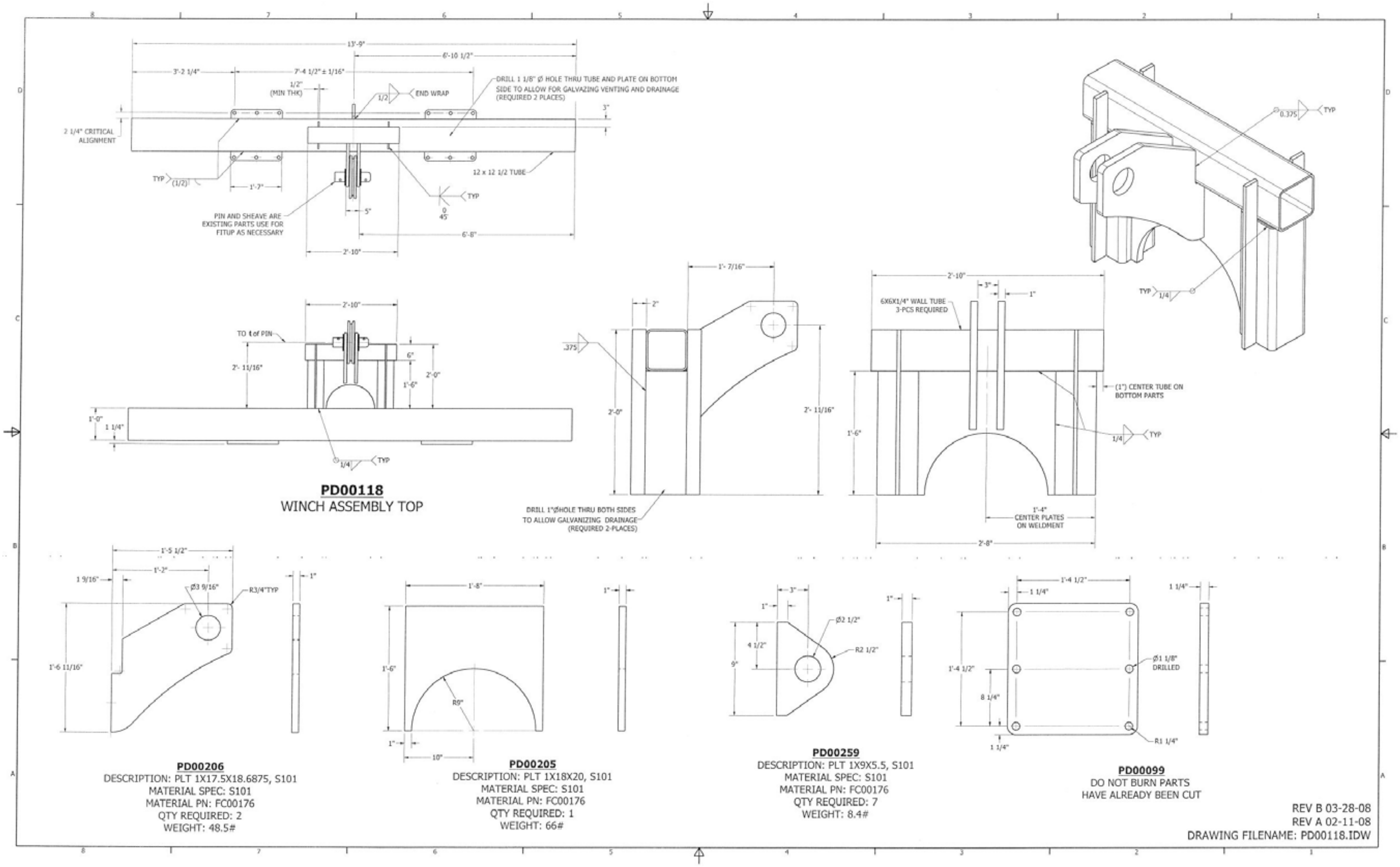


Figure 9. Pendulum Rear Lift Structure Details

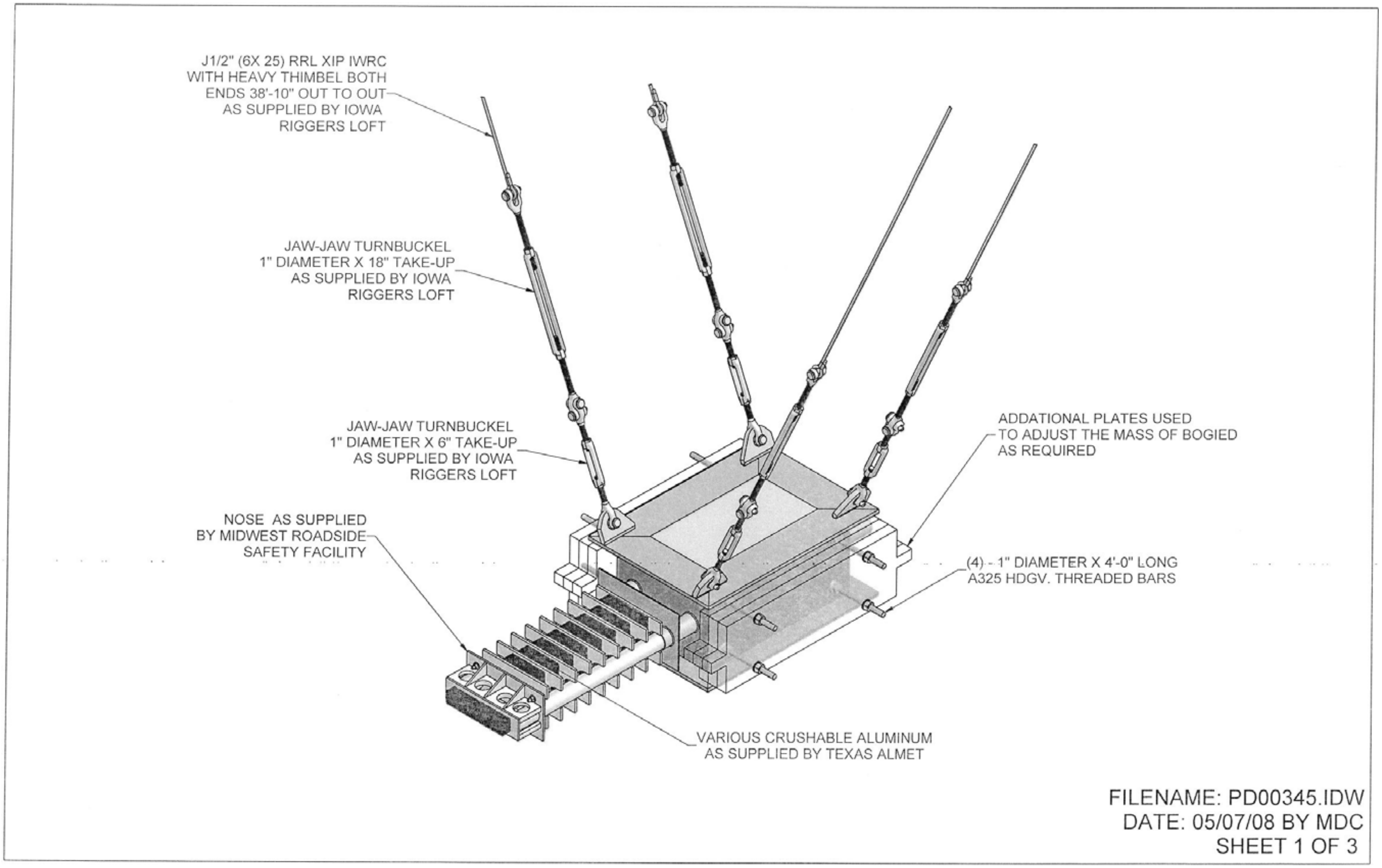


Figure 10. Pendulum and Crushable Nose Assembly

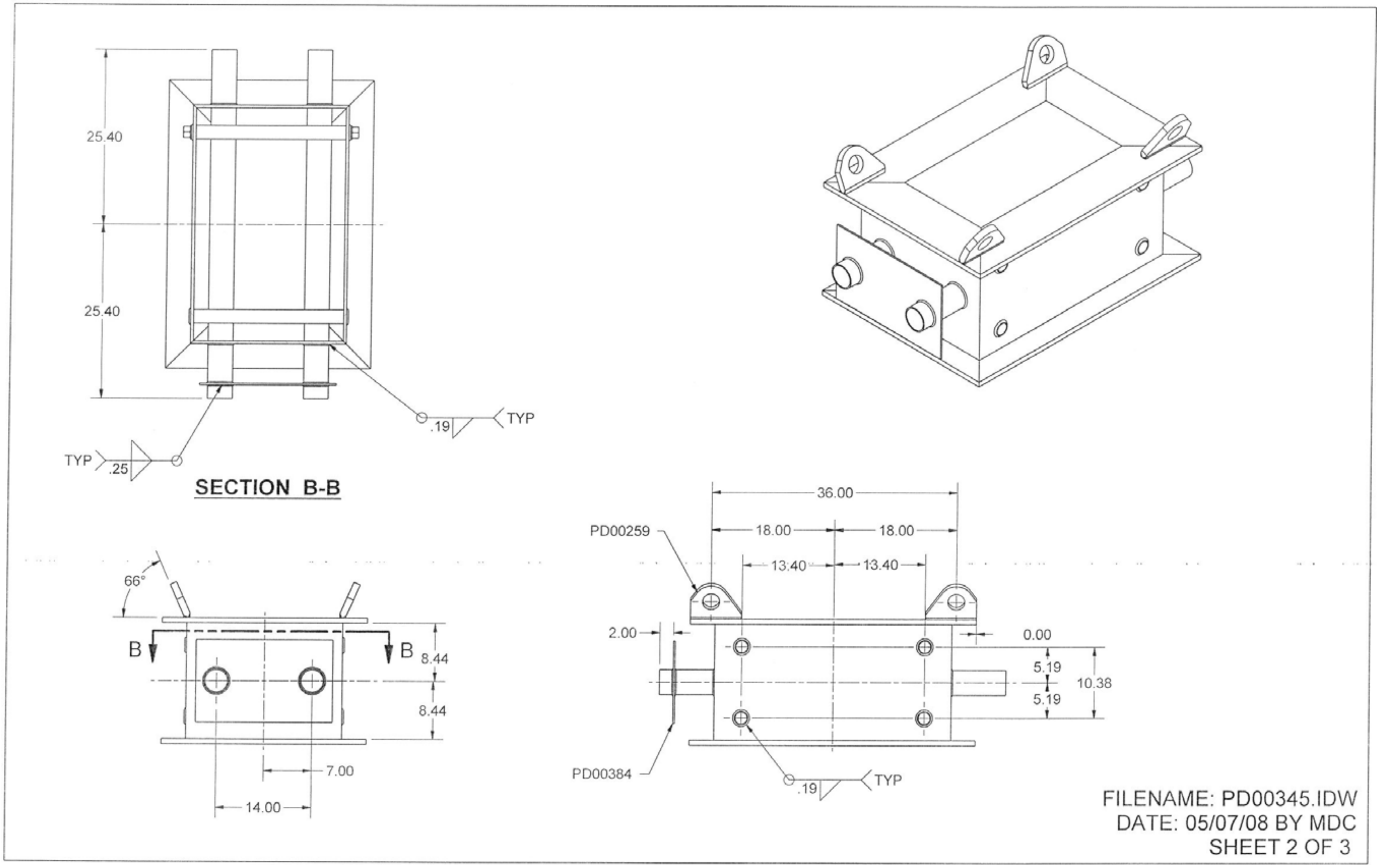


Figure 11. Pendulum Details

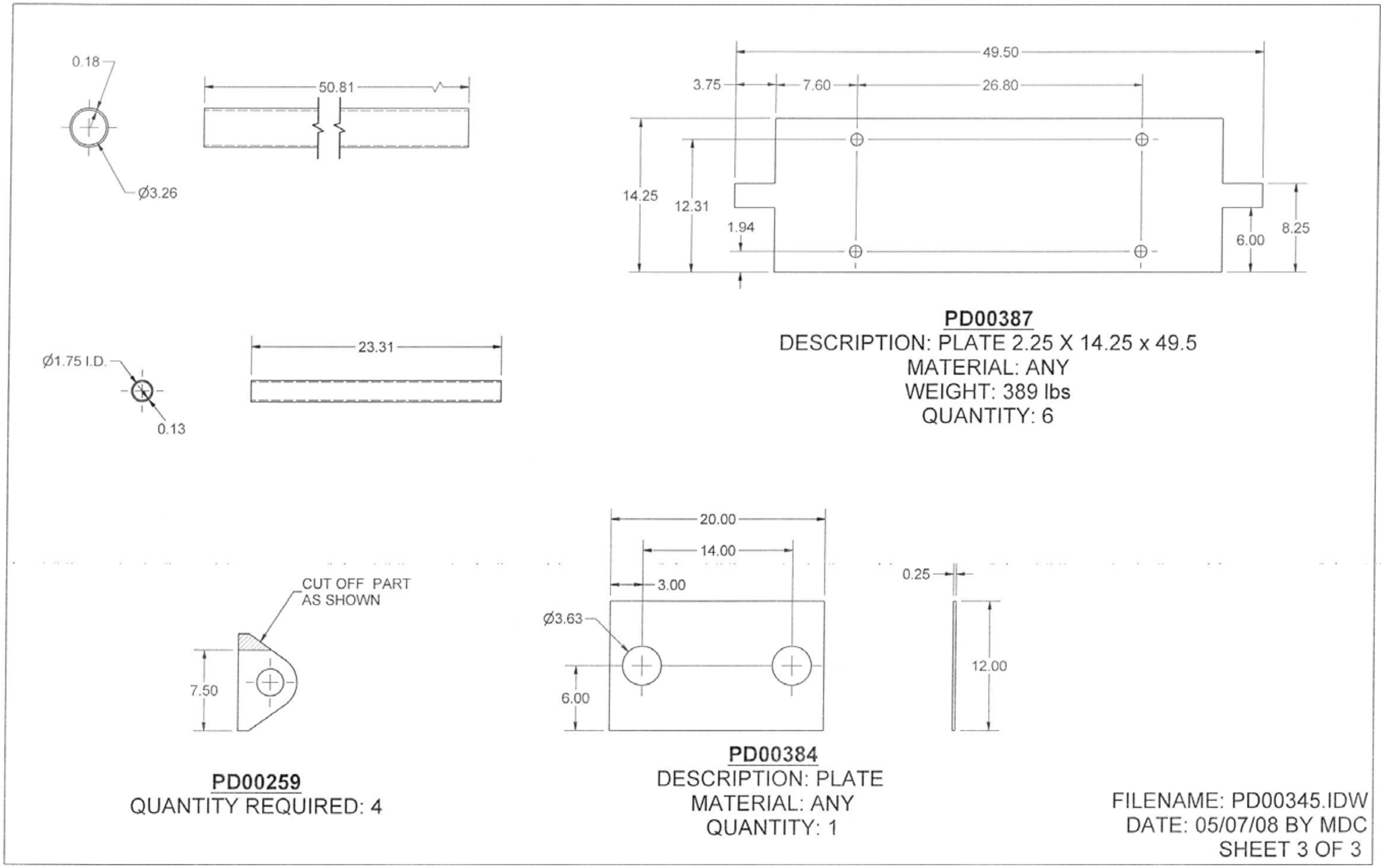


Figure 12. Pendulum Details

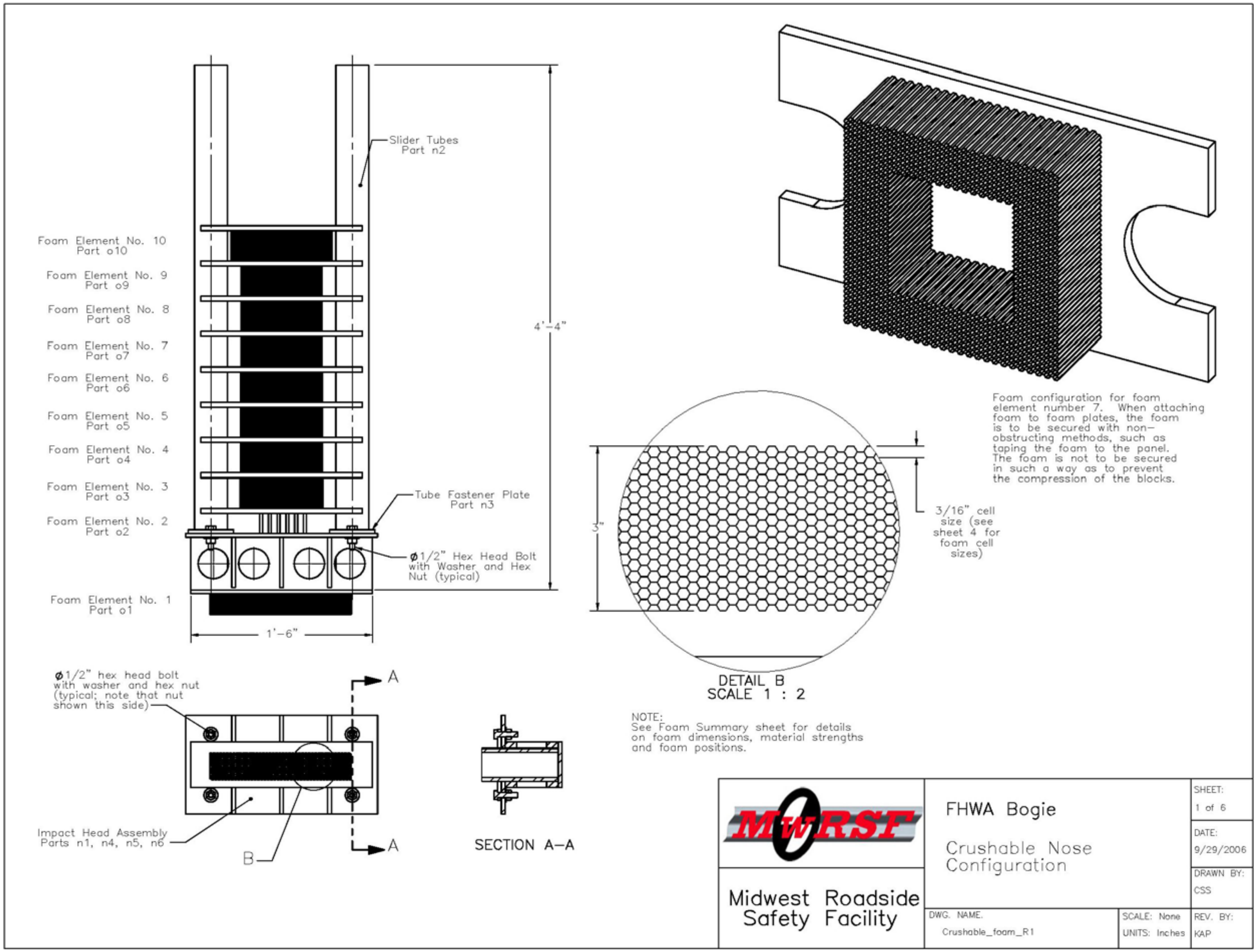


Figure 13. Crushable Nose Assembly

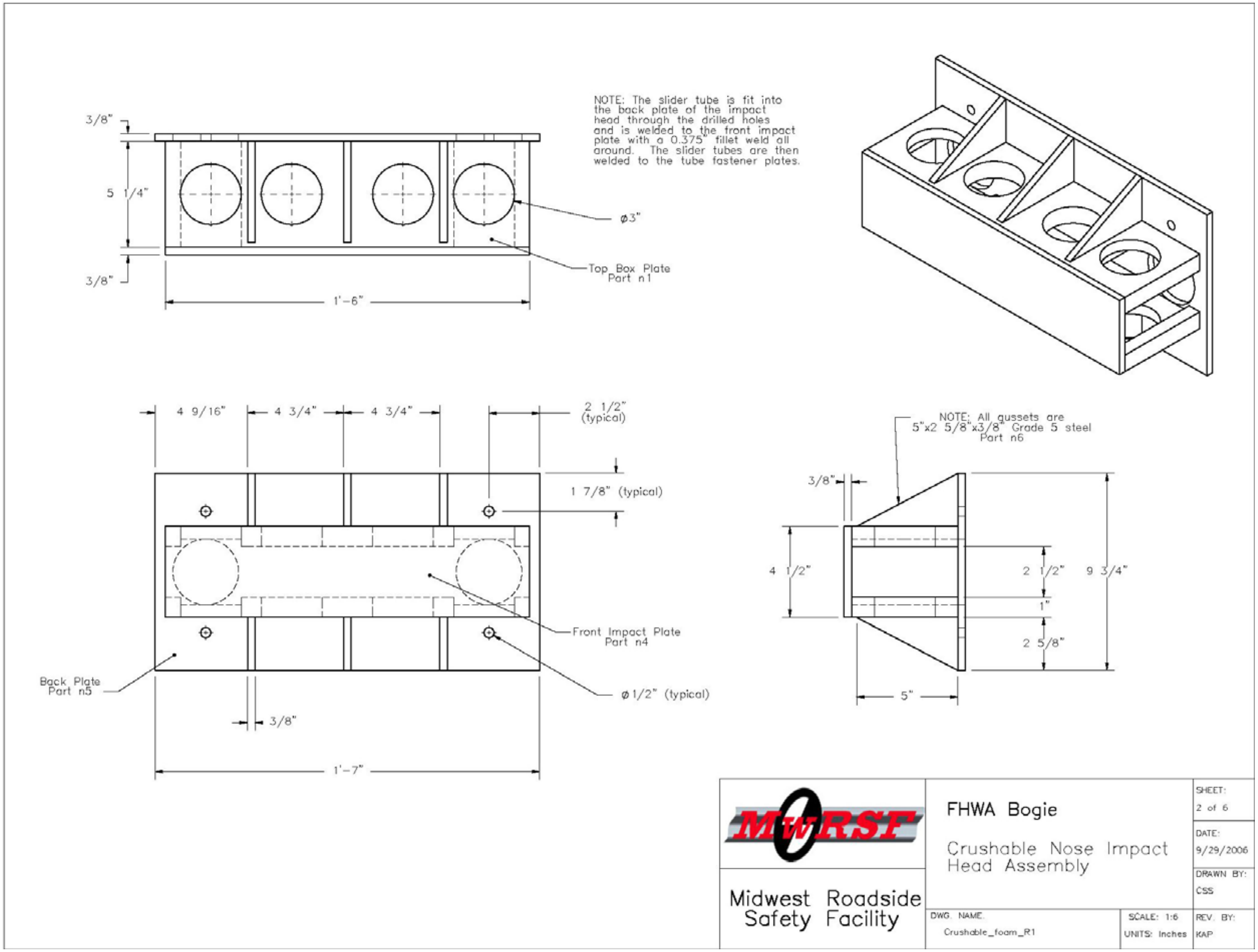


Figure 14. Crushable Nose Details

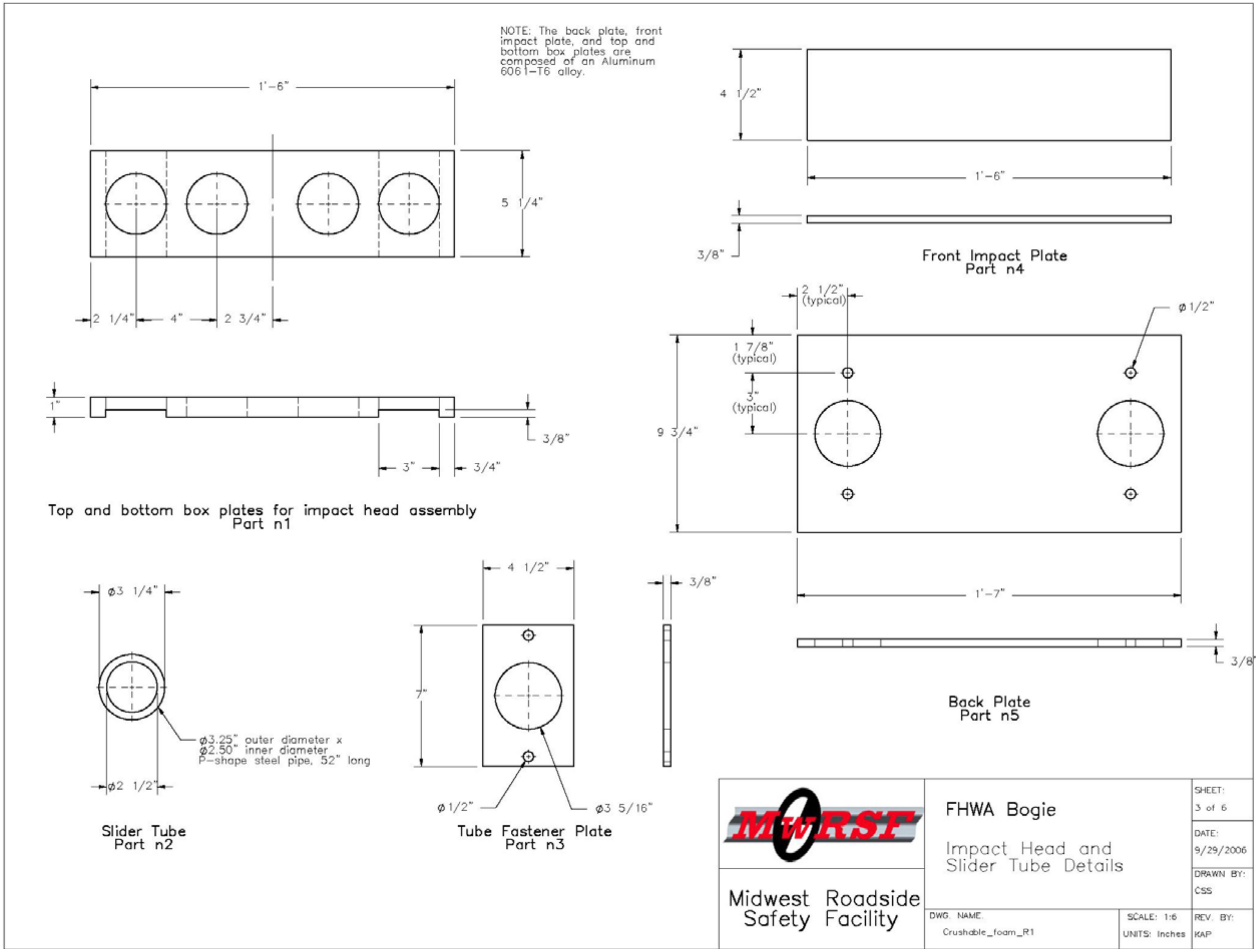
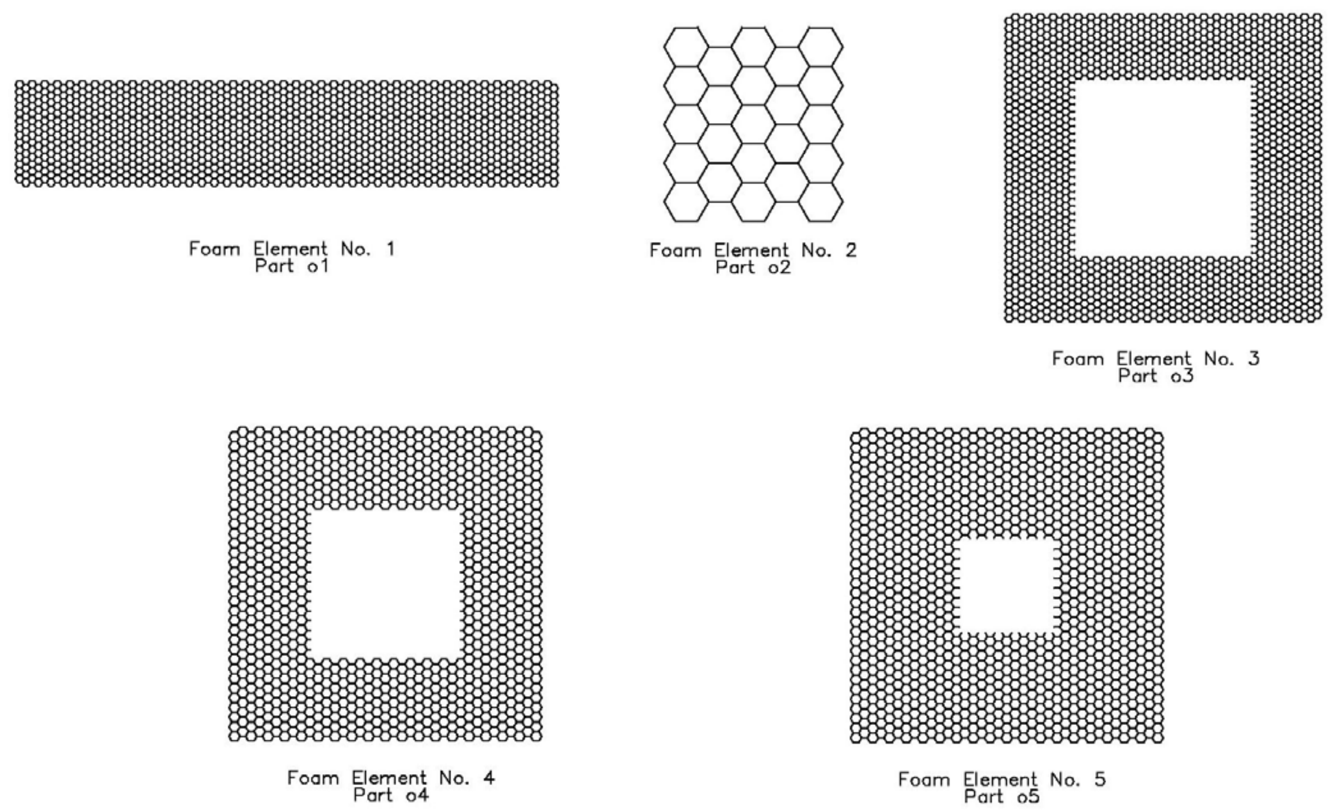


Figure 15. Crushable Nose Details



*See foam punch size note on sheet 5

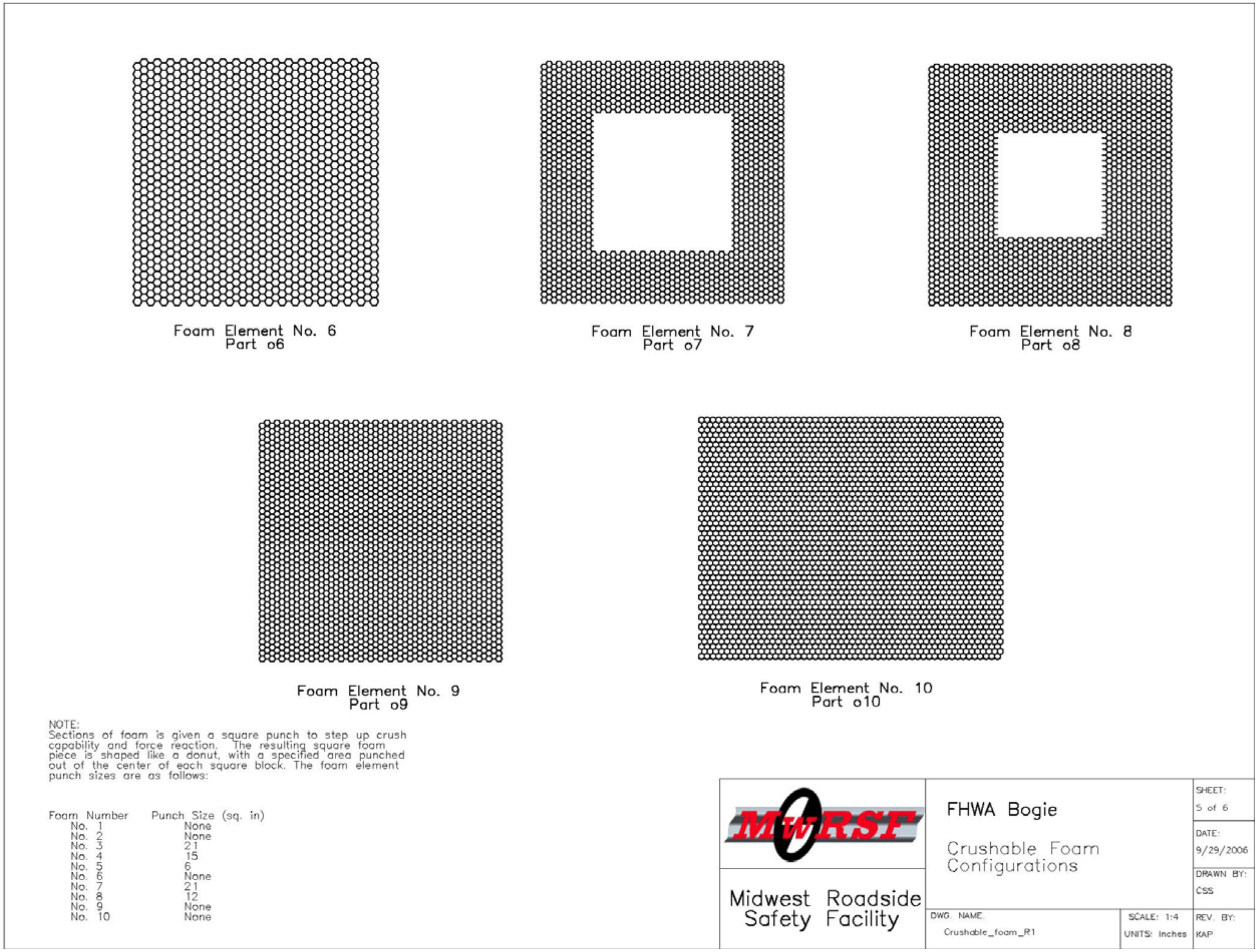
Foam Number	Wall Thickness (in)	Cell Size (in)	Dimensions* (l x h x d, in)	Min Crush Strength (psi)
1	0.001	3/16	2.75x16x3	130
2	–	1	4x5x2	25
3	0.001	3/16	8x8x3	130
4–6	0.002	1/4	8x8x3	230
7–9	0.002	3/16	8x8x3	400
10	0.002	3/16	8x10x3	400

MwRSF
Midwest Roadside
Safety Facility

FHWA Bogie
Crushable Foam
Configurations

SHEET:
4 of 6
DATE:
9/29/2006
DRAWN BY:
CSS
DWG. NAME.
Crushable_foam_R1
SCALE: 1:4
UNITS: Inches
REV. BY:
KAP

Figure 16. Crushable Nose, Aluminum Honeycomb Details



NOTE:
Sections of foam is given a square punch to step up crush capability and force reaction. The resulting square foam piece is shaped like a donut, with a specified area punched out of the center of each square block. The foam element punch sizes are as follows:

Foam Number	Punch Size (sq. in)
No. 1	None
No. 2	None
No. 3	21
No. 4	15
No. 5	6
No. 6	None
No. 7	21
No. 8	12
No. 9	None
No. 10	None

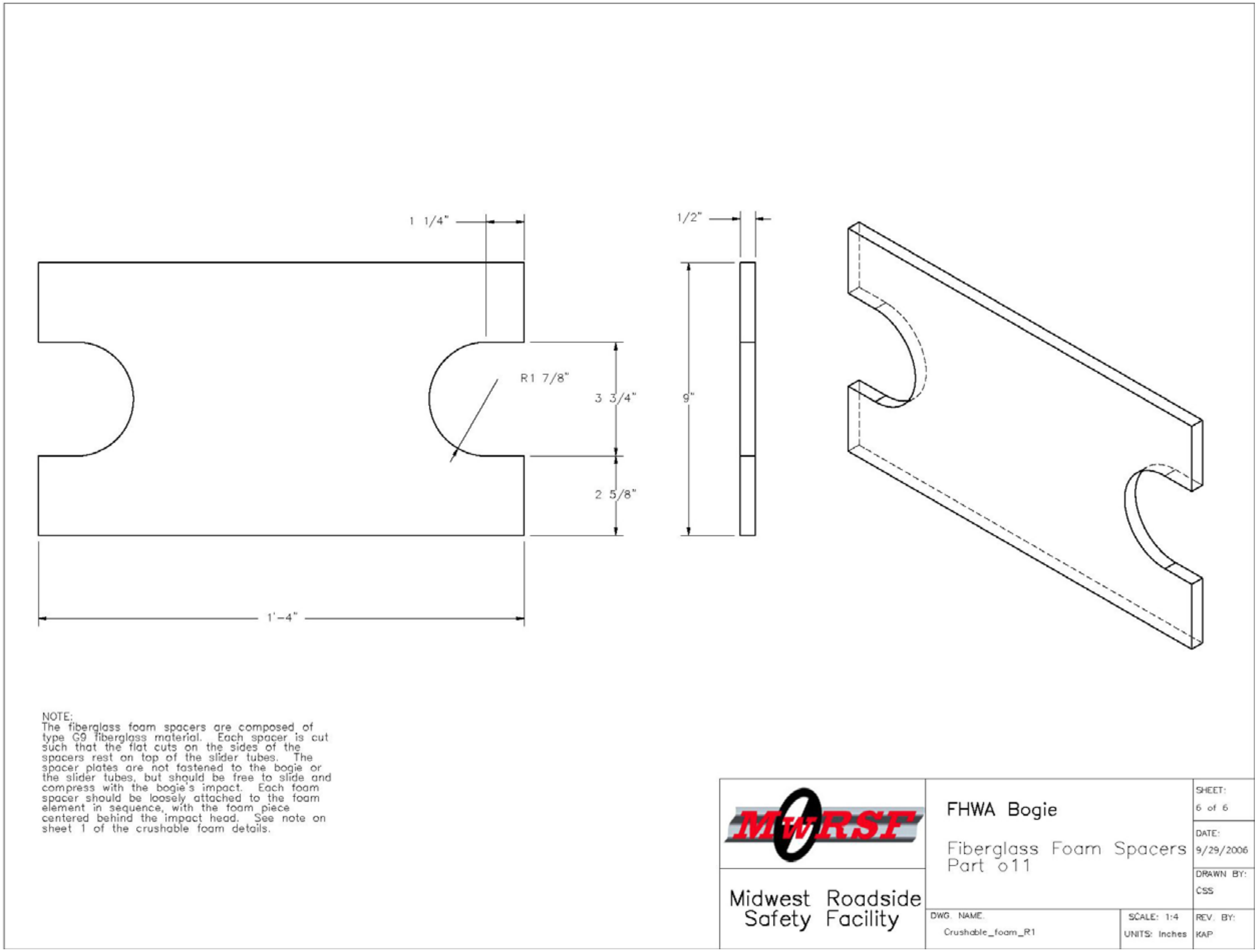
Midwest Roadside Safety Facility

FHWA Bogie

Crushable Foam Configurations

SHEET: 5 of 6
DATE: 9/29/2006
DRAWN BY: CSS
DWG. NAME. Crushable_foam_R1
SCALE: 1:4
UNITS: Inches
REV. BY: KAP

Figure 17. Crushable Nose, Aluminum Honeycomb Details



NOTE:
The fiberglass foam spacers are composed of type G9 fiberglass material. Each spacer is cut such that the flat cuts on the sides of the spacers rest on top of the slider tubes. The spacer plates are not fastened to the bogie or the slider tubes, but should be free to slide and compress with the bogie's impact. Each foam spacer should be loosely attached to the foam element in sequence, with the foam piece centered behind the impact head. See note on sheet 1 of the crushable foam details.

Figure 18. Crushable Nose, Fiberglass Spacers

Figure 19. Pre-Test Pendulum Photographs

3 TEST INSTALLATION DETAILS

The test installation was comprised of an aluminum pole, a pedestrian “hand/man” signal, and a simulated rigid foundation, as shown in Figures 20 through 26. Each component is described separately in the following sections. The assembled test installation is shown in Figure 27. Material certifications are shown in Appendix A

3.1 Pole

A 10-ft (3.1-m) tall, round aluminum pole with a ⅛-in. (3-mm) wall thickness, as shown in Figures 20 and 21, was selected by the NYSDOT to be representative of the poles currently installed for pedestrian “hand/man” signals. The pole had a top outside diameter of 4½ in. (114 mm) and a bottom outside diameter of 6 in. (152 mm). A $^{5}/_{32}$-in. (4-mm) thick, 24-in. (610-mm) tall internal reinforcing sleeve was located at the bottom of the pole and served to strengthen the base of the pole against premature yielding during an impact event. A handhole was placed through both the pole and the internal sleeve and centered at a height of 18 in. (457 mm).

The pole base plate was a 10¼ in. (260 mm) square measuring ⅝-in. (16-mm) thick. The bolt circle was 9½ in. (241 mm) in diameter, and the pole was inserted and welded to a 3½-in. (89-mm) tall cylinder, as measured from the bottom of the base plate.

As specified by the NYSDOT standard sheets, as shown in Figure 22, the bottom of the pedestrian “hand/man” signal was to be installed at a height of 8 ft (2.4 m). To meet this requirement, a 28-in. (711-mm) segment was cut off of the top of the pole. The resulting pole, without the signal attached, was 7 ft – 8 in. (2.3 m) tall and weighed 33 lb (15 kg).

3.2 Pedestrian Signal

The pedestrian “hand/man” signal conformed to Standard Sheet No. 680-10 used by the NYSDOT. The signal was mounted to the pole using a top-mount attachment bracket, as shown in Figures 22 and 25. Both the signal and the attachment bracket were shipped to the MwRSF from the NYSDOT. The signal was attached to the bracket by inserting the top, threaded portion of the bracket into the hole at the bottom of the signal. A nut was then used to securely fasten the signal to the bracket. The bottom of the bracket slid over the top of the pole, and three bolts were tightened against the outside of the pole.

The top of the adjusted pole had a larger diameter than the original 4½-in. (114-mm) outside diameter due to the 28-in. (711-mm) long segment being cut from the top of the tapered pole. As a result, the signal attachment bracket would not slide onto the top of the pole, and the inside of the bracket had to be lathed to increase the inside diameter of the bracket from 4⅝ in. (117 mm) to 4⅞ in. (124 mm), as shown in Figure 26. This reduction in bracket thickness was not believed to have a negative effect on the pendulum test since the bracket still had sufficient strength to secure the signal to the top of the pole and very little load would be transferred through the bracket. This bracket adjustment would not be necessary in real-world applications as long as the pole has the correct height and top diameter. The combined weight of the signal and the reduced thickness bracket was 26 lb (12 kg). After attachment to the pole, the total system weighed 59 lb (27 kg).

3.3 Simulated Rigid Foundation

The base of the pole was bolted to a simulated rigid foundation consisting of a steel W18x119 (W457x177) support beam and two adapter plates, as shown in Figures 23 and 24. The steel support beam had two 1-in. (25-mm) plates reinforcing its web at midspan, and the beam spanned across an 8-ft long by 13-ft wide by 6-ft deep (2.4-m long by 4.0-m wide by 1.8-m deep) concrete pit. The two 36-in. (914-mm) diameter steel adapter plates were bolted to the top flange of the beam at midspan. The adapter plates had additional bolt holes which were used to attach the pole to the simulated rigid foundation.

ASTM F1554 Grade 55 bolts are typically used to anchor pedestrian poles in the state of New York. However, the objective of the study was to analyze the ability of the pole to break away, not the anchor bolts. Thus, the attachment bolts were deemed non-critical components, and FHWA approved the use of any bolt that provided equal or greater strength. As a result, four ¾-in. (19-mm) diameter ASTM A325 hex head bolts, nuts, and washers were used to anchor the pole system to the simulated rigid foundation.

The state of New York typically requires leveling nuts on all pole installations. Therefore, leveling nuts were placed between the adapter plate and the pole base plate. These leveling nuts and the assembled pole installation are shown in Figure 27. As a result, the bottom of the pole's base plate was 1 in. (25 mm) from the ground surface, while the top of the base plate and cylinder was 4½ in. (114 mm) above the ground. In addition, the top of the pedestrian "hand/man" signal was positioned 10 ft – 3 in. (3.1 m) above the ground surface.

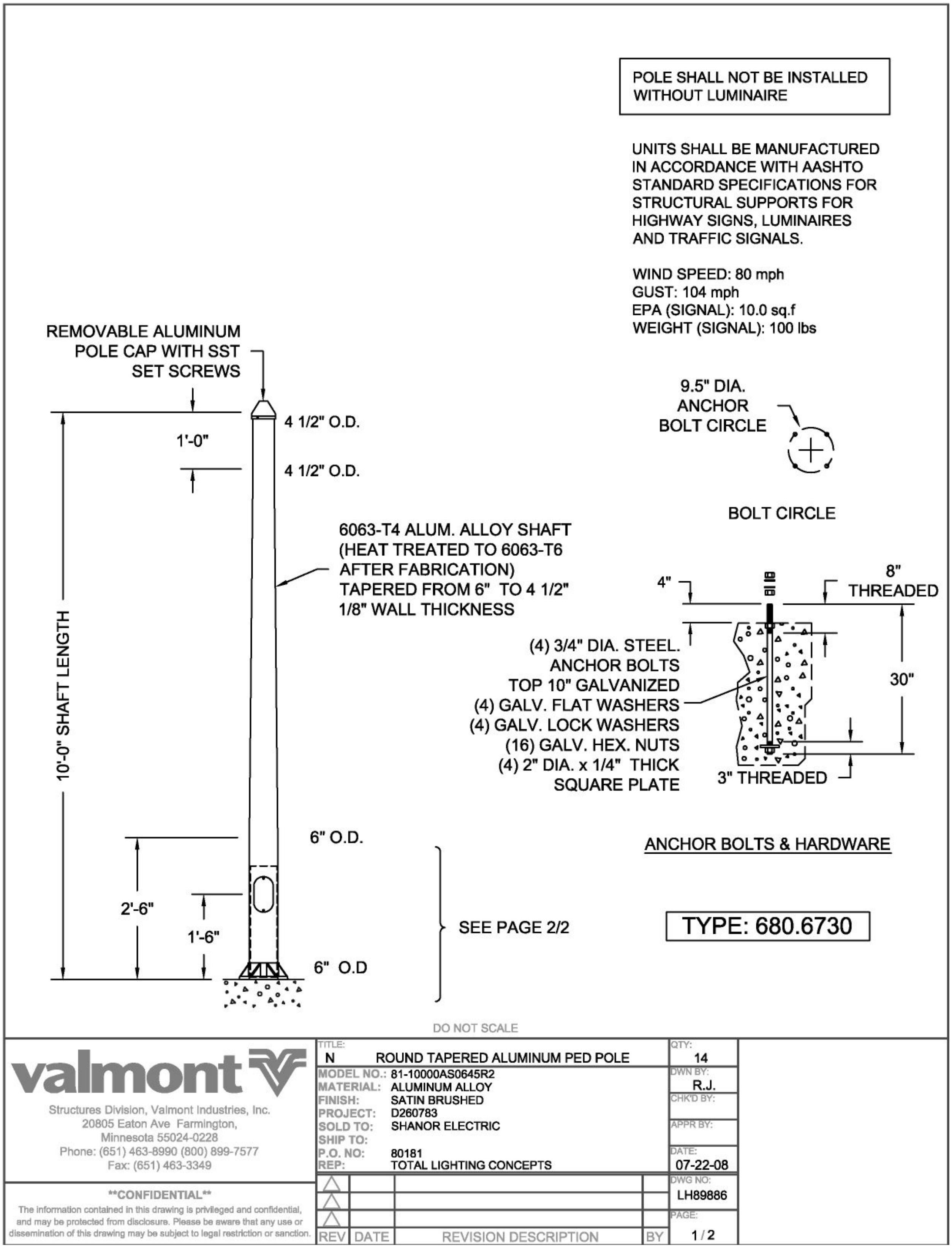


Figure 20. Aluminum Pedestrian Pole Details

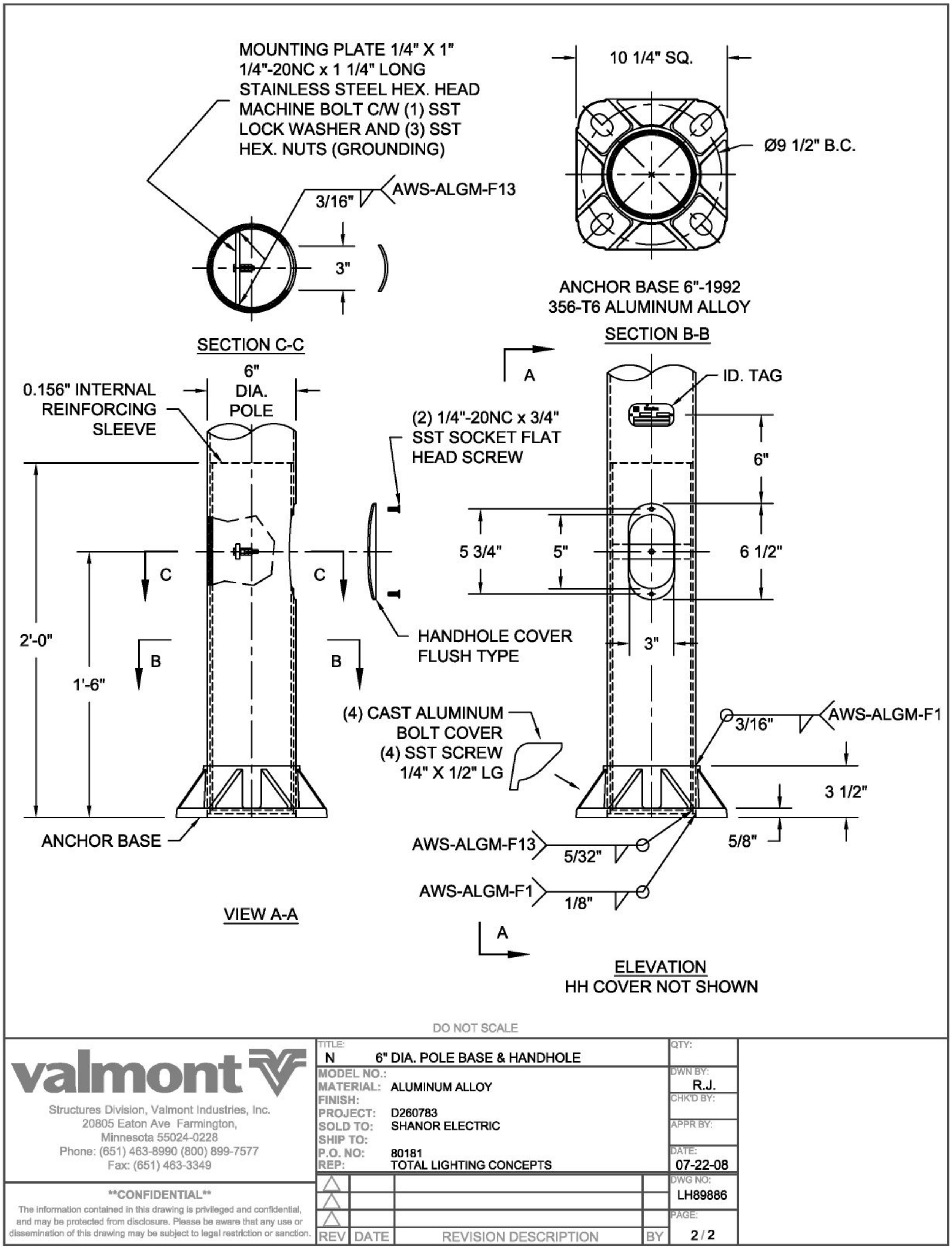
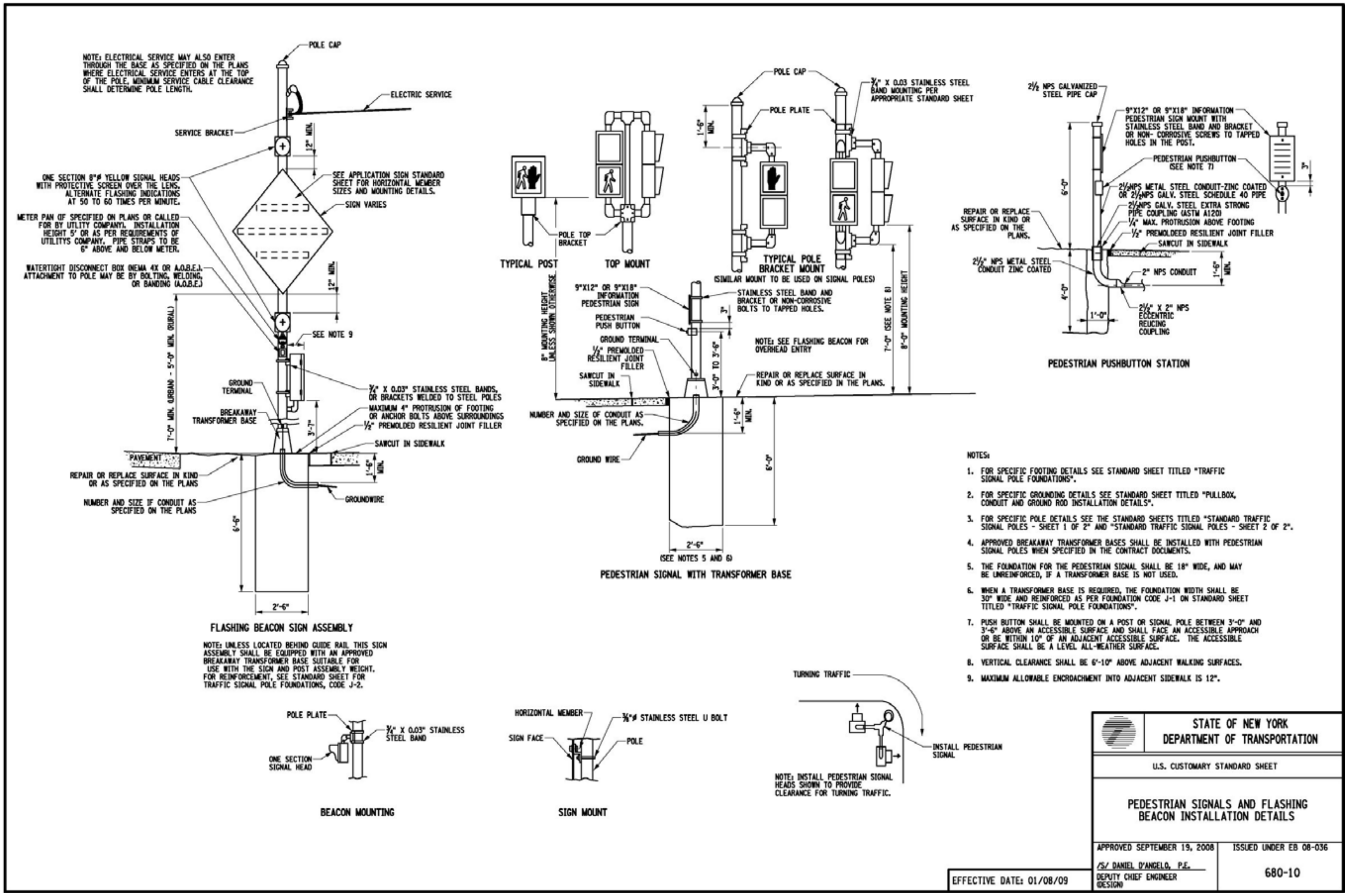


Figure 21. Aluminum Pedestrian Pole Base Details



NOTE: ELECTRICAL SERVICE MAY ALSO ENTER THROUGH THE BASE AS SPECIFIED ON THE PLANS WHERE ELECTRICAL SERVICE ENTERS AT THE TOP OF THE POLE, MINIMUM SERVICE CABLE CLEARANCE SHALL DETERMINE POLE LENGTH.

NOTE: UNLESS LOCATED BEHIND GUIDE RAIL THIS SIGN ASSEMBLY SHALL BE EQUIPPED WITH AN APPROVED BREAKAWAY TRANSFORMER BASE SUITABLE FOR USE WITH THE SIGN AND POST ASSEMBLY WEIGHT. FOR REINFORCEMENT, SEE STANDARD SHEET FOR TRAFFIC SIGNAL POLE FOUNDATIONS, CODE J-2.

NOTE: SEE FLASHING BEACON FOR OVERHEAD ENTRY

NOTE: INSTALL PEDESTRIAN SIGNAL HEADS SHOWN TO PROVIDE CLEARANCE FOR TURNING TRAFFIC.

NOTES:

1. FOR SPECIFIC FOOTING DETAILS SEE STANDARD SHEET TITLED "TRAFFIC SIGNAL POLE FOUNDATIONS".
2. FOR SPECIFIC GROUNDING DETAILS SEE STANDARD SHEET TITLED "PULLBOX, CONDUIT AND GROUND ROD INSTALLATION DETAILS".
3. FOR SPECIFIC POLE DETAILS SEE THE STANDARD SHEETS TITLED "STANDARD TRAFFIC SIGNAL POLES - SHEET 1 OF 2" AND "STANDARD TRAFFIC SIGNAL POLES - SHEET 2 OF 2".
4. APPROVED BREAKAWAY TRANSFORMER BASES SHALL BE INSTALLED WITH PEDESTRIAN SIGNAL POLES WHEN SPECIFIED IN THE CONTRACT DOCUMENTS.
5. THE FOUNDATION FOR THE PEDESTRIAN SIGNAL SHALL BE 18" WIDE, AND MAY BE UNREINFORCED, IF A TRANSFORMER BASE IS NOT USED.
6. WHEN A TRANSFORMER BASE IS REQUIRED, THE FOUNDATION WIDTH SHALL BE 30" WIDE AND REINFORCED AS PER FOUNDATION CODE J-1 ON STANDARD SHEET TITLED "TRAFFIC SIGNAL POLE FOUNDATIONS".
7. PUSH BUTTON SHALL BE MOUNTED ON A POST OR SIGNAL POLE BETWEEN 3'-0" AND 3'-6" ABOVE AN ACCESSIBLE SURFACE AND SHALL FACE AN ACCESSIBLE APPROACH OR BE WITHIN 10" OF AN ADJACENT ACCESSIBLE SURFACE. THE ACCESSIBLE SURFACE SHALL BE A LEVEL ALL-WEATHER SURFACE.
8. VERTICAL CLEARANCE SHALL BE 6'-10" ABOVE ADJACENT WALKING SURFACES.
9. MAXIMUM ALLOWABLE ENCROACHMENT INTO ADJACENT SIDEWALK IS 12".

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION

U.S. CUSTOMARY STANDARD SHEET

PEDESTRIAN SIGNALS AND FLASHING
BEACON INSTALLATION DETAILS

APPROVED SEPTEMBER 19, 2008
/S/ DANIEL D'ANGELO, P.E.
DEPUTY CHIEF ENGINEER
(DESIGN)

ISSUED UNDER EB 08-036

680-10

EFFECTIVE DATE: 01/08/09

Figure 22. Pedestrian Signal Installation Details

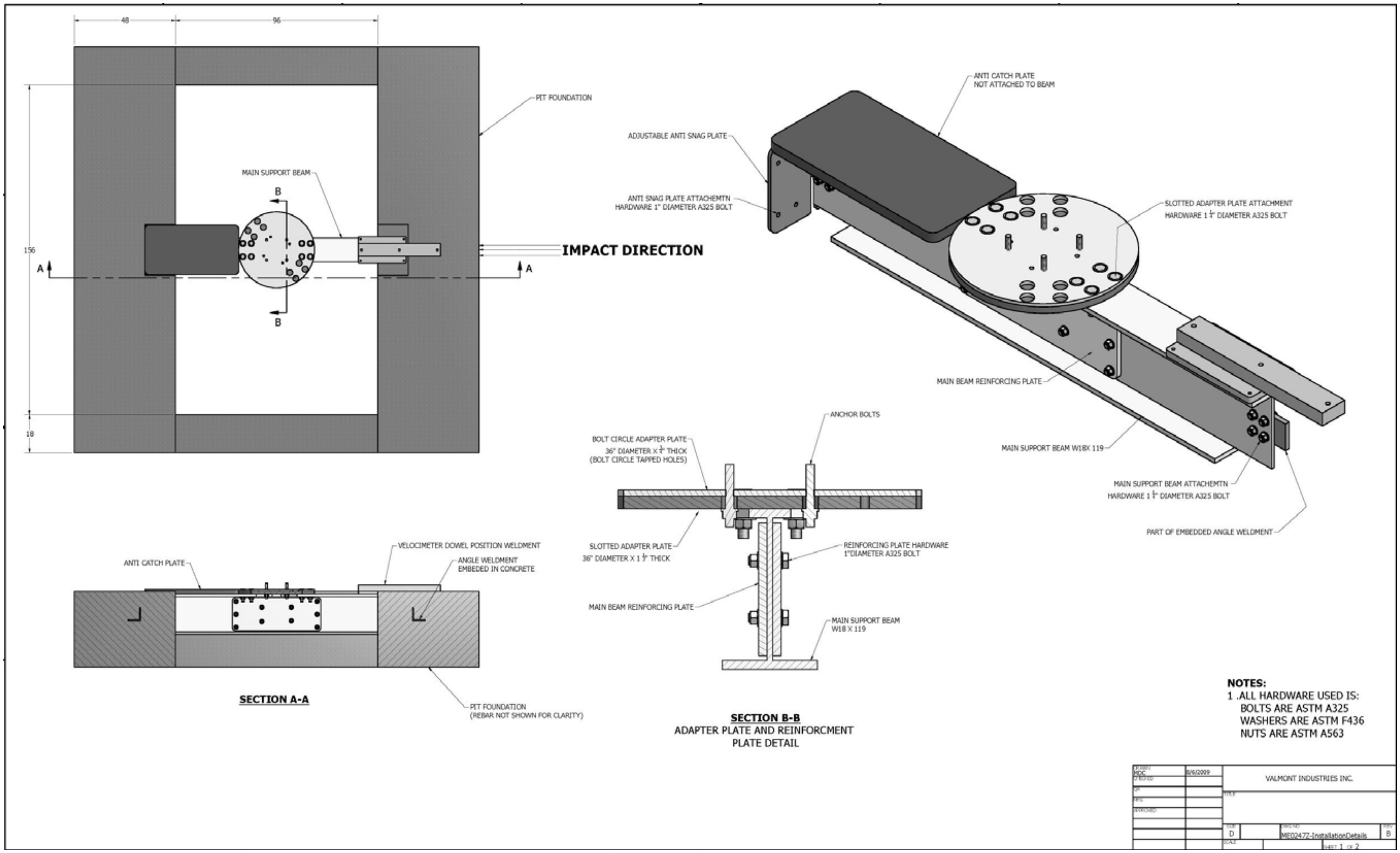


Figure 23. Simulated Rigid Foundation

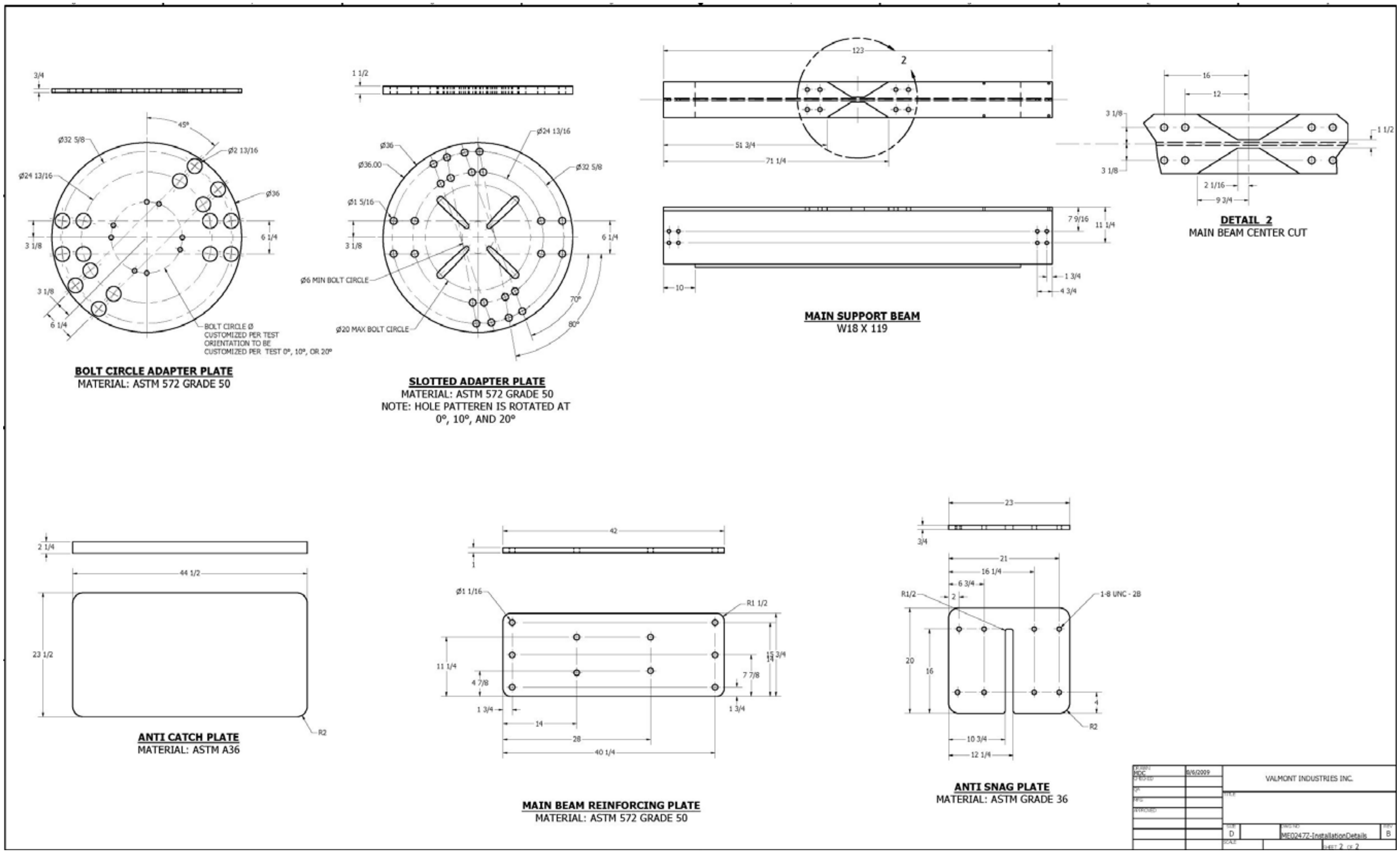


Figure 24. Support Beam and Adapter Plate Details

Figure 25. Pedestrian “Hand/Man” Signal and Attachment Bracket

Figure 26. Left – Reduced Bracket Thickness, Right – Original Bracket Thickness

Figure 27. Assembled Pedestrian Signal Test Installation

4 TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 Test Requirements

Support structures, such as pedestrian signal poles, must satisfy the safety criteria provided in both NCHRP Report No. 350 [1] and *AASHTO's Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals, Fifth Edition* [2] in order to be accepted by FHWA for use on the National Highway System (NHS) on new construction projects or as a replacement for existing designs not meeting current safety standards. According to TL-3 of NCHRP Report No. 350, support structures must be subjected to two full-scale vehicle crash tests. The two crash tests are as follows:

1. Test Designation No. 3-60 consisting of a 1,808-lb (820-kg) passenger car impacting the system at a nominal speed of 21.7 mph (35.0 km/h) and an angle between 0 and 20 degrees.
2. Test Designation No. 3-61 consisting of a 1,808-lb (820-kg) passenger car impacting the system at a nominal speed of 62.1 mph (100.0 km/h) and an angle between 0 and 20 degrees.

The test conditions for TL-3 support structures are summarized in Table 2.

Table 2. NCHRP Report No. 350 TL-3 Crash Test Conditions

Test Article	Test Designation	Test Vehicle	Impact Conditions			Evaluation Criteria [1]
			Speed		Angle (deg.)	
			mph	km/h		
Support Structures	3-60	820C	21.7	35.0	0-20	B,D,F,H,I,K,N
	3-61	820C	62.1	100.0	0-20	B,D,F,H,I,K,N

[1] Evaluation criteria explained in Table 3.

Although the tests described in Table 2 pertain to full-scale crash tests with production vehicles, NCHRP Report No. 350 does allow the use of surrogate vehicles, e.g., bogie vehicles or pendulums. For compliance testing, the surrogate vehicle must be properly designed to replicate the essential properties of the original production model. In 2009, FHWA approved the use of the Valmont-MwRSF/UNL pendulum for the evaluation of breakaway hardware [3]. Therefore, the Valmont-MwRSF/UNL pendulum with crushable nose was used in lieu of a production model vehicle.

In 1975, ENSCO, INC. developed an analytical method for estimating the high-speed (62.1 mph or 100.0 km/h) performance of breakaway device that tested at low-speed (21.7 mph or 35.0 km/h) [7]. Currently, the FHWA recognizes this conservative analytical extrapolation method as an alternative to high-speed, full-scale crash testing [8]. Therefore, only test designation no. 3-60 was performed with the Valmont-MwRSF/UNL pendulum. The results from the high-speed test, corresponding to test designation no. 3-61, were calculated using the analytical extrapolation method.

4.2 Evaluation Criteria

The evaluation criteria were 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 predictability of the breakaway support. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to become involved in secondary collisions with other vehicles or fixed objects, thereby increasing the risk of injury to the occupant of the impacting vehicle and to other vehicles. These evaluation criteria are summarized in Table 3 and defined in greater detail in NCHRP Report No. 350.

In tests of breakaway features, the impulse event on the vehicle may be relatively small and of short duration. In such tests, it is not unusual for the hypothetical occupant to travel less than the necessary distance to contact the interior compartment during the period in which accelerations are recorded or up to the time the vehicle losses contact with the test article. In such cases, the occupant impact velocity should be set equal to the vehicle's change in velocity that occurs during contact with the test article or parts thereof. If parts of the test article remain in contact with the vehicle after impact, the vehicle's change in velocity should be computed at the time in which the vehicle clears the footing or foundation of the test article.

Table 3. Evaluation Criteria for Breakaway Support Structures

<table>
<tr><th colspan="2">NCHRP Report No. 350 Criteria</th></tr>
<tr><td>Structural Adequacy</td><td>B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injury should not be permitted. See discussion in Section 5.3 and Appendix E of NCHRP Report No. 350.</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitch, and yaw are acceptable.</td></tr>
<tr><td>H. Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of NCHRP Report No. 350 for calculation procedure) should satisfy the following:
<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</td><td>9.8 ft/s
(3.0 m/s)</td><td>16.4 ft/s
(5.0 m/s)</td></tr>
</table></td></tr>
<tr><td>I. The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of NCHRP Report No. 350 for calculation procedure) should satisfy the following:
<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 g’s</td><td>20 g’s</td></tr>
</table></td></tr>
<tr><td rowspan="2">Vehicle Trajectory</td><td>K. After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td></tr>
<tr><th colspan="2">AASHTO Fifth Edition Additional Criteria</th></tr>
<tr><td rowspan="2">Structural Adequacy</td><td>Substantial remains of breakaway supports shall not project more than 4 in. (100 mm) above a line between straddling wheels of a vehicle on 60 in. (1500 mm) centers. The line connects any point on the ground surface one side of the support to a point on the ground surface on the other side, and it is aligned radially or perpendicularly to the centerline of the roadway.</td></tr>
<tr><td>The maximum mass of combined luminaire support and fixtures attached to breakaway supports shall be limited to 992 lb (450 kg). Any increases in these limits are to be based on full-scale crash testing and an investigation of the range of vehicle roof crush characteristics that go beyond the recommended testing procedures of NCHRP Report No. 350.</td></tr>
</table>

5 TEST CONDITIONS

5.1 Test Facility

The pendulum testing facility is located at Valmont Industries, Inc. in Valley, Nebraska. The facility consists of the pendulum and a utility building for use in control and setup of the testing.

5.2 Data Acquisition Systems

Two data acquisition systems, consisting of primary and backup accelerometer units, were used to measure the motion of the pendulum. The results from both transducers were analyzed and plotted using custom Microsoft Excel spreadsheets. The acceleration data was processed using both SAE CFC 60 and CFC 180 filtering procedures.

5.2.1 Accelerometers

Two triaxial piezoresistive accelerometer systems, described below, were used to measure the acceleration in the longitudinal, lateral, and vertical directions. The accelerometer systems were mounted on a rigid plate on the top of the pendulum body at the longitudinal center-of-gravity.

Principle EDR:

- Model EDR-4-6DOF-500/1200 – Instrumented Sensor Technology (IST) of Okemos, MI
- Tri-axial accelerometers with ± 500 g's range
- Three axis rate gyro with ± 1,200 deg/sec range
- Up to 15,000 Hz sample rate (10,000 Hz sample rate for standard testing)
- 3 differential channels, 3 single-ended channels
- 24 MB RAM memory on two separate boards
- Variable cutoff frequency lowpass filter (1,667 Hz for standard testing)

Secondary EDR:

- Model EDR-3 –IST of Okemos, MI
- Tri-axial accelerometers with ± 200 g's range
- 3,200 Hz Sample Rate

- 256 kB RAM Memory
- 1,120 Hz lowpass filter

The original FOIL-FHWA pendulum testing into a rigid pole used accelerometers on both the crushable nose and the body of the pendulum. This setup was used to measure the accelerations of the two separate masses in the system. During the pendulum impact into a rigid pole, there was an initial impact that stopped the forward motion of the crushable nose and brought the nose velocity to zero. This impact event was very short and had a relatively low magnitude. The remainder of the impact event consisted of deceleration of the main body of the pendulum which were much higher in magnitude. As such,, the researchers believed that there would be very little error if the crushable nose accelerations were omitted. This assumption seemed to be proven based on review of the test report for the validation of the TTI pendulum system [6]. In this report, TTI showed cross-plots of the pendulum body acceleration and the combined body and crushable nose acceleration. The differences between the acceleration curves were relegated to the initial portion of the impact event and were minor. Recognizing this, the Valmont-MwRSF/UNL pendulum was certified and validated against a rigid pole without an acceleration transducer system conducive to mounting an accelerometer on the crushable nose [3]. Therefore, the current pendulum testing and evaluation program only utilized accelerometers mounted to the pendulum mass.

5.3 High-Speed and Low-Speed Video Photography

For test no. NYPP-1, three high-speed AOS XPRI digital video cameras and two digital video cameras were used. All three high-speed cameras and one digital video camera were set up perpendicular to impact at a distance of 53.5 ft (16.3 m) from the pedestrian pole. The other digital video camera was located 80 ft (24.4 m) directly behind the test article. Camera details, lens information, and camera operating speeds are shown in Table 4.

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

Table 4. Camera Data

	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	5	AOS XPRI Gigabit	1000	Sigma 24-70	24
	6	AOS XPRI Gigabit	500	Sigma 24-135	135
	7	AOS XPRI Gigabit	500	Sigma fixed 50 mm	-
Digital Video	2	JVC – GZ-MC500 (Everio)	29.97		
	3	JVC – GZ-MC500 (Everio)	29.97		

5.4 Speed Trap

For test no NYPP-1, three pressure-activated tape switches mounted on wooden dowels and spaced at 18-in. (457-mm) intervals were used to determine the speed of the pendulum mass before impact. The switches were mounted so that the undercarriage of the pendulum body would incrementally impact all three switches just prior to impact with the pedestrian pole system. Each tape switch fired a strobe light which could be seen in the high-speed camera views. The pendulum speed was then determined from the high-speed video and the times at which each dowel was impacted. A photograph of the speed trap setup is shown in Figure 28.

Figure 28. Speed Tape Setup

5.5 Critical Impact Location

Since the pedestrian signal pole is commonly used at roadway intersections, the pole is subject to impacts from all angles. Therefore, the pole had to be orientated on the support beam such that pendulum impacted the pole at the most critical location. The center of the pendulum's crushable nose was set to impact the pole at a height of 17½ in. (445 mm). Because the pole's handhole was centered at a height of 18 in. (457 mm), it caused a reduction in the pole cross-section and strength at the impact height. The critical pole orientation was determined to consist of the handhole facing the pendulum mass so that the load was applied directly to the weakened cross section. Therefore, the pole was impacted with the handhole facing the pendulum and crushable nose, as shown in Figure 29.

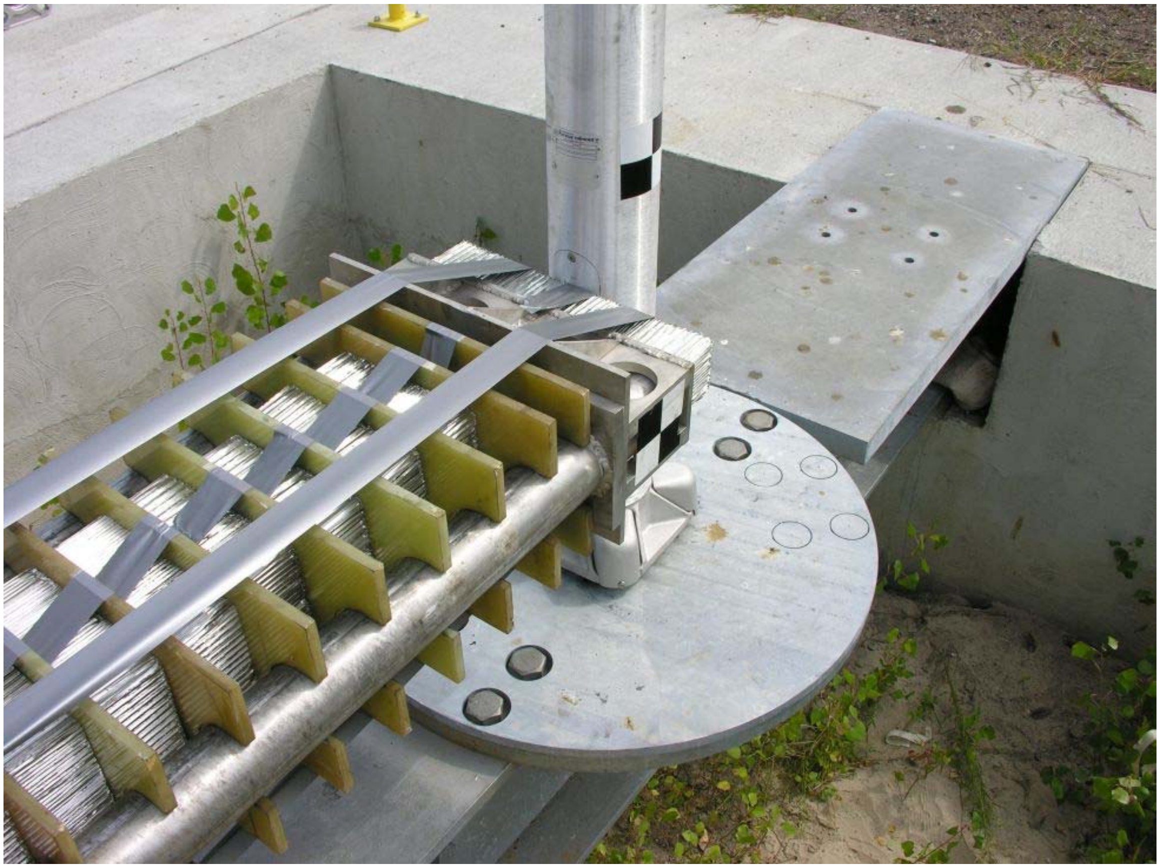


Figure 29. Impact Location

6 PENDULUM TEST NO. NYPP-1

6.1 Weather Conditions

Test No. NYPP-1 was conducted on September 2, 2009 at approximately 3:45 pm. The weather conditions as per the National Oceanic and Atmospheric Administration (station 04924/FET) were reported as shown in Table 5.

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

Temperature	70° F
Humidity	68 %
Wind Speed	11 mph
Wind Direction	150° from True North
Sky Conditions	Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in.
Previous 7-Day Precipitation	1.1 in.

6.2 Test No. NYPP-1

During test no. NYPP-1, the 1,898-lb (861-kg) pendulum with a crushable nose contacted the targeted impact point at a speed of 22.0 mph (35.4 km/h). The resulting impact events have been described in sequential order and are presented in Table 6. A summary of the test and analysis of the processed data is contained in Figure 30. Pre-test and post-test photographs of the test are shown in Figure 31, while sequential photographs are shown in Figures 32 and 33. Acceleration data plots from both the primary and the secondary units are shown in Appendix B.

Table 6. Impact Events for Test No. NYPP-1

TIME (sec)	EVENT
0.000	Impact
0.002	The aluminum honeycomb element on the end of the crushable nose (element no. 1) began to deform.

0.006	Honeycomb element no. 2 began to crush.
0.010	The pole began to rotate backward as honeycomb element no. 1 had completely crushed.
0.014	Honeycomb element no. 2 was completely crushed and element no. 3 began to crush.
0.026	Honeycomb element no. 3 was completely crushed and element no. 4 began to crush. Also, the base of the pole began to slide backward.
0.032	The base of the pole stopped sliding, and the pole was no longer rotating. Also, honeycomb element no. 5 began to crush.
0.038	Honeycomb element no. 6 began to crush.
0.042	The pole began to rotate backward again.
0.046	The welds holding the pole to the base cylinder began to fracture as the pole rotated backward.
0.060	Cracking began in the base cylinder, and the pole continued to rotate.
0.068	A tear appeared on the back side of the pole along the top edge of the internal sleeve. Also, the crack in the base plate and cylinder continued to open, and the bottom of the pole was rotating out.
0.080	The pole rotated and pulled out enough that the front-bottom edge of the pole was visible above the base cylinder.
0.084	The crushable nose was sliding up the bottom portion of the pole as it continued to rotate.
0.092	The bottom of the pole had rotated about 45 degrees from vertical. The tear in the pole along the top of the internal sleeve had extended almost completely around to the front of the pole. The top portion of the pole remained nearly vertical but continued to translate backward.
0.122	The pendulum was no longer in contact with the pole.
0.128	The bottom portion of the pole was no longer in contact with the base structure. The top portion of the pole had rotated back only 15 degrees, but continued to translate backward.
0.180	The bottom segment of the pole contacted the ground and bounced up.
0.466	The top of the pole and the signal box contacted the ground behind the concrete surface. The pole impact with the ground caused the signal to break free from the attachment bracket. Also, the bottom segment of the pole (and internal sleeve) finally broke free from the rest of the pole.

6.3 System Damage

As a result of the pendulum impact, the pedestrian signal pole system was broken into four separate pieces, as shown in Figure 31. The base plate assembly remained attached to the simulated rigid foundation and extendind 4½ in. (114 mm) above the ground surface, as show in Figure 34. Two cracks were found in the base plate assembly. The first crack was located on the cylinder between the gussets surrounding the back-left anchor bolt and extended from the top of the cylinder to the base plate. The second crack began on the top of the cylinder between the gussets surrounding the back-right anchor bolt and continued through the base plate and out the back-right corner. The anchor bolts and nuts remained undamaged.

The aluminum pole was detached from the base plate assembly and fractured into two pieces, as shown in Figures 35 and 36. The bottom piece came to rest 17 ft (5.2 m) behind the pole's original position. The bottom piece of the pole was 24 in. (610 mm) long and contained both the lower portion of the pole and the internal reinforcing sleeve. The bottom end of this segment contained the remains of the welds originally used to connect the pole to the base plate assembly. At the top of this segment, the pole was jagged along the fracture surface. The handhole cover was deformed and pushed inward from the impact, and local buckling of the pole was found on both sides of the handhole.

The top portion of the pole remained largely undamaged and came to rest 34 ft (10.4 m) from the pole's original position. The only damage was the jagged fracture surface located at the bottom end of this segment.

The pedestrian signal was detached from the attachment bracket and came to rest 38 ft (11.6 m) behind the pole's initial position. A piece of the plastic surrounding the attachment bracket at the bottom of the signal had fractured off, as shown in Figure 37. This small piece remained wedged between the bracket and the attachment nut. The attachment bracket itself remained undamaged and fixed to the top end of the pole.

6.4 Occupant Risk

During the analysis of the accelerometer data, it was determined that the hypothetical occupant did not contact the dashboard within the time that the pole was in contact with the vehicle. Therefore, the longitudinal occupant ridedown acceleration (ORA) and occupant impact velocity (OIV) were not applicable. Also, as described in Section 4.2, the pendulum's change in velocity throughout the impact event was recorded and compared against the NCHRP Report No. 350 OIV limit of 16.4 ft/s (5.0 m/s). It should be noted that the calculated change in velocity of 13.91 ft/s (4.24 m/s) was within the provided limits. Table 7 contains a summary of the occupant risk values as calculated from both accelerometers used during test no. NYPP-1. The recorded data from the accelerometers are shown in graphical format in Appendix B.

Table 7. Occupant Risk Summary, Test No. NYPP-1

Evaluation Criteria	Transducer		NCHRP Report No. 350 Limit
	EDR-3	EDR-4	
Longitudinal OIV ft/s (m/s)	NA (no occupant contact)	NA (no occupant contact)	≤ 16.4 (5.0)
Longitudinal ORA g's	NA (no occupant contact)	NA (no occupant contact)	≤ 20
Maximum Vehicle ΔV ft/s (m/s)	14.99 (4.57)	13.91 (4.24)	≤ 16.4 (5.0)
ASI	0.73	0.67	not required

6.5 Discussion

Test no. NYPP-1 showed that the aluminum pedestrian "hand/man" signal pole broke away from the base plate assembly in a controlled and predictable manner. As evidenced by the signal pole falling in front of the surrogate vehicle, neither the signal box nor the fractured pole showed the potential for penetrating or causing large deformations to the occupant compartment. The change in velocity of the pendulum mass from initial impact until the loss of contact with the test article was 13.91 ft/s (4.24 m/s), which falls below the 16.4 ft/s (5.0 m/s) limit established by NCHRP Report No. 350. However, the remaining base plate assembly projected 4½ in (114 mm) above the simulated rigid foundation (or ground surface), thus exceeding the 4 in. (100 mm) maximum stub height requirement provided in *AASHTO Standard Specifications* *for Structural Supports for Highway Signs, Luminaires, and Traffic Signals, Fifth Edition*. Therefore, test no. NYPP-1, performed on a pedestrian signal pole did not pass all of the required safety performance criteria provided in Table 3.


0.000 sec 0.030 sec 0.060 sec 0.090 sec 0.120 sec 0.120 sec

- Test Agency .... MwRSF
- Test Facility .... Valmont-MwRSF/UNL Pendulum
- Test Number NYPP-1
- Date 9/2/2009
- NCHRP Report No. 350 Test Designation No. 3-60
- Test Article .... Pedestrian “Hand/Man” Signal Pole
- Key Component – Tapered Aluminum Pole
  - Height .... 7 ft – 8 in. (2.3 m)
  - Bottom Diameter .... 6 in. (152 mm)
  - Thickness .... ⅛ in. (3 mm)
  - Bolt Circle Diameter .... 9½ in. (241 mm)
- Key Component – Base Plate Assembly
  - Length .... 10¼ in. (260 mm)
  - Width .... 10¼ in. (260 mm)
  - Thickness .... ⅝ in. (16 mm)
  - Bolt Circle Diameter .... 9½ in. (241 mm)
- Key Component – Internal Reinforcing Sleeve
  - Length .... 24 in. (610 mm)
  - Thickness .... $^{5}/_{32}$ in. (4 mm)
  - Position .... Base of Pole
- Key Component – Pedestrian Signal
  - Type .... “Hand/Man” Signal
  - Mount Position .... Top of Pole
  - Height to Bottom of Signal .... 8 ft (2.4 m)
- Total Installation Mass .... 59 lb (27 kg)
  - Pole .... 33 lb (15 kg)
  - Signal & Bracket .... 26 lb (12 kg)
- Total Installation Height .... 10 ft – 3 in. (3.1 m)
- Surrogate Vehicle .... Pendulum
  - Mass .... 1,898 lb (861 kg)
  - Impact Head .... Crushable Nose
- Impact Conditions
  - Speed .... 22.0 mph (35.4 km/h)
  - Angle .... 0 deg.
  - Impact Height .... 17½ in. (445 mm)
- Test Article Damage .... Moderate
  - Pole Broke Away From Base Plate Assembly
- Stub Height .... 4½ in. (114 mm)
- Transducer Data (lost contact with pole before t*)

Evaluation Criteria	Transducer		NCHRP Report No. 350 Limit
	EDR-3	EDR-4	
Longitudinal OIV ft/s (m/s)	NA (no occupant contact)	NA (no occupant contact)	≤ 16.4 ft/s (5.0)
Longitudinal ORA g’s	NA (no occupant contact)	NA (no occupant contact)	≤ 20 g’s
Max. Vehicle ΔV ft/s (m/s)	14.99 (4.57)	13.91 (4.24)	≤ 16.4 ft/s (5.0)
ASI	0.73	0.67	not required

Figure 30. Summary of Test Results and Sequential Photographs, Test No. NYPP-1

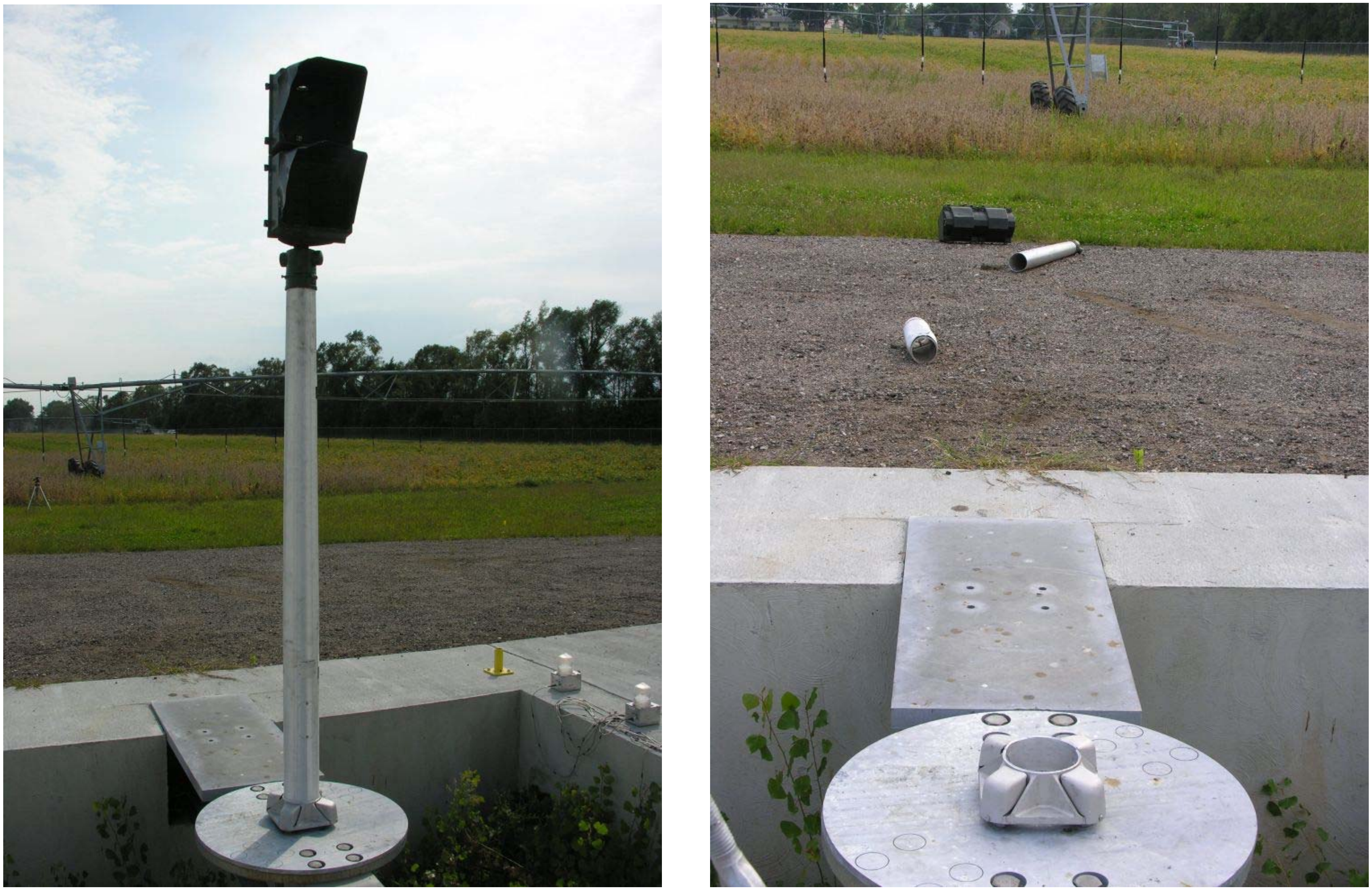
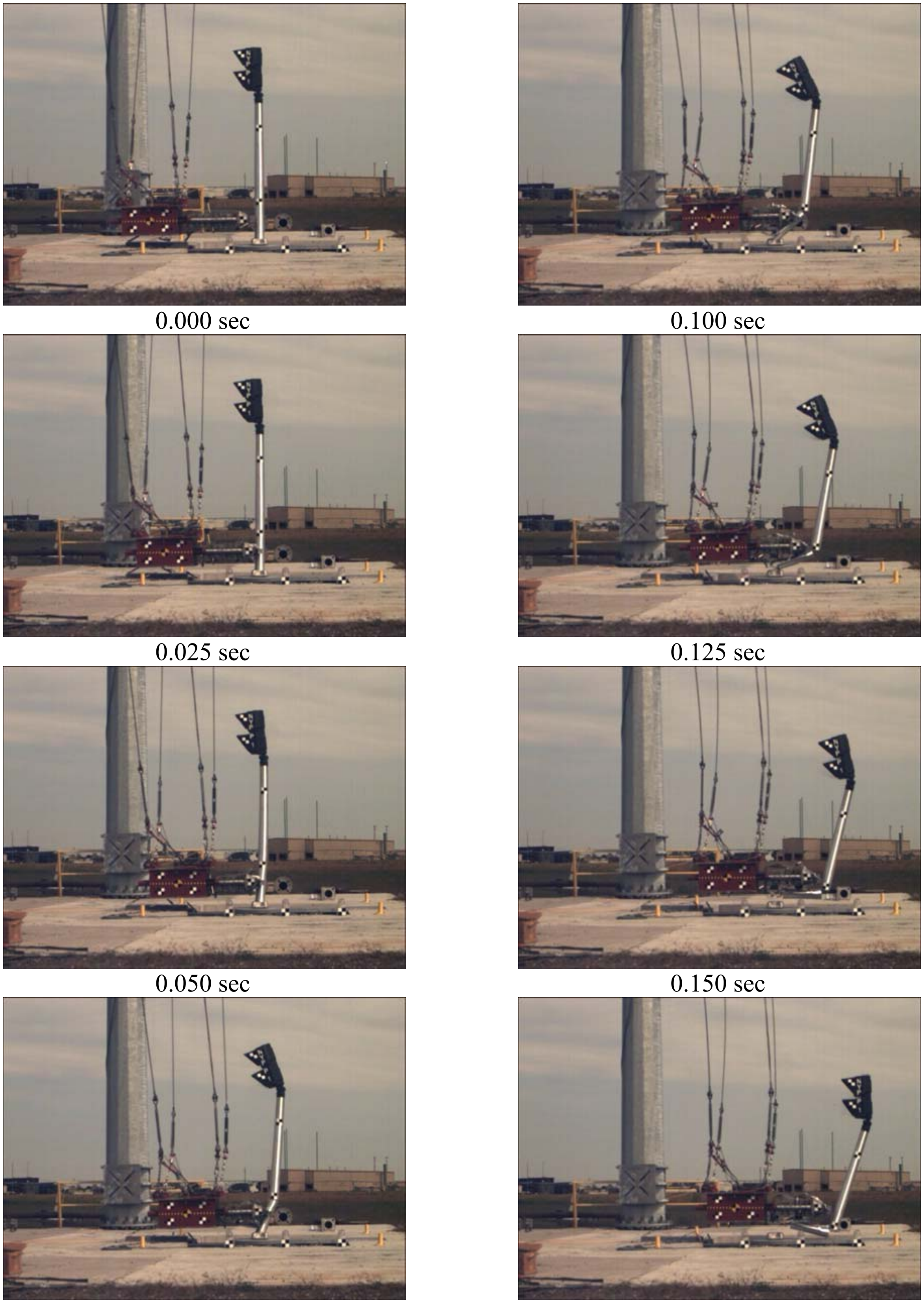


Figure 31. Pre-Test and Post-Test Photographs, Test No. NYPP-1



0.000 sec

0.100 sec

0.025 sec

0.125 sec

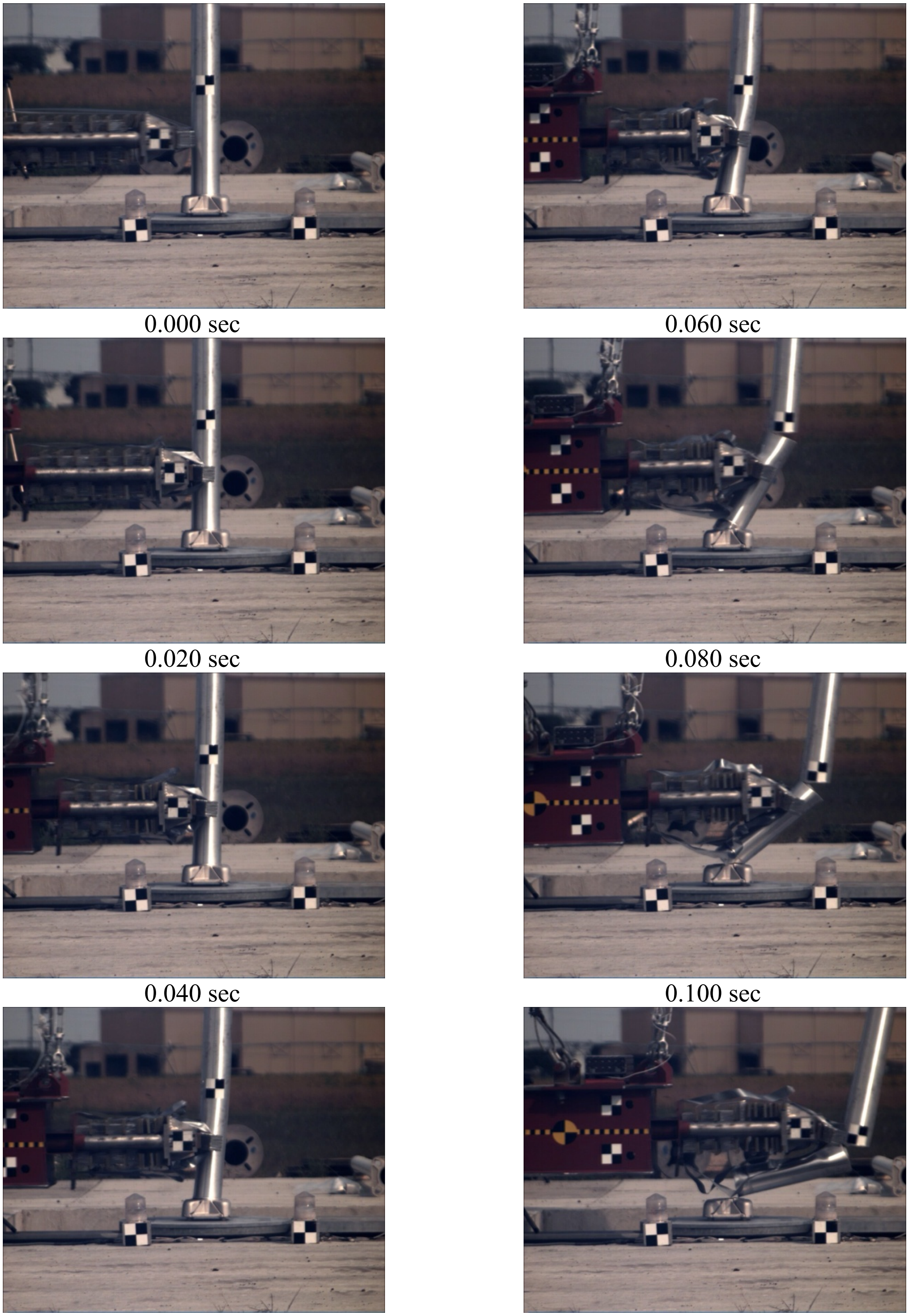
0.050 sec

0.150 sec

0.075 sec

0.175 sec

Figure 32. Sequential Photographs, Test No. NYPP-1



0.000 sec

0.020 sec

0.040 sec

0.050 sec

0.060 sec

0.080 sec

0.100 sec

0.130 sec

Figure 33. Sequential Photographs, Test No. NYPP-1

Figure 34. System Damage - Base Plate Cracks and Fractures, Test No. NYPP-1

Figure 35. System Damage - Bottom Piece of Pole and Internal Sleeve, Test No. NYPP-1

Figure 36. System Damage - Upper Portion of Pole, Test NYPP-1

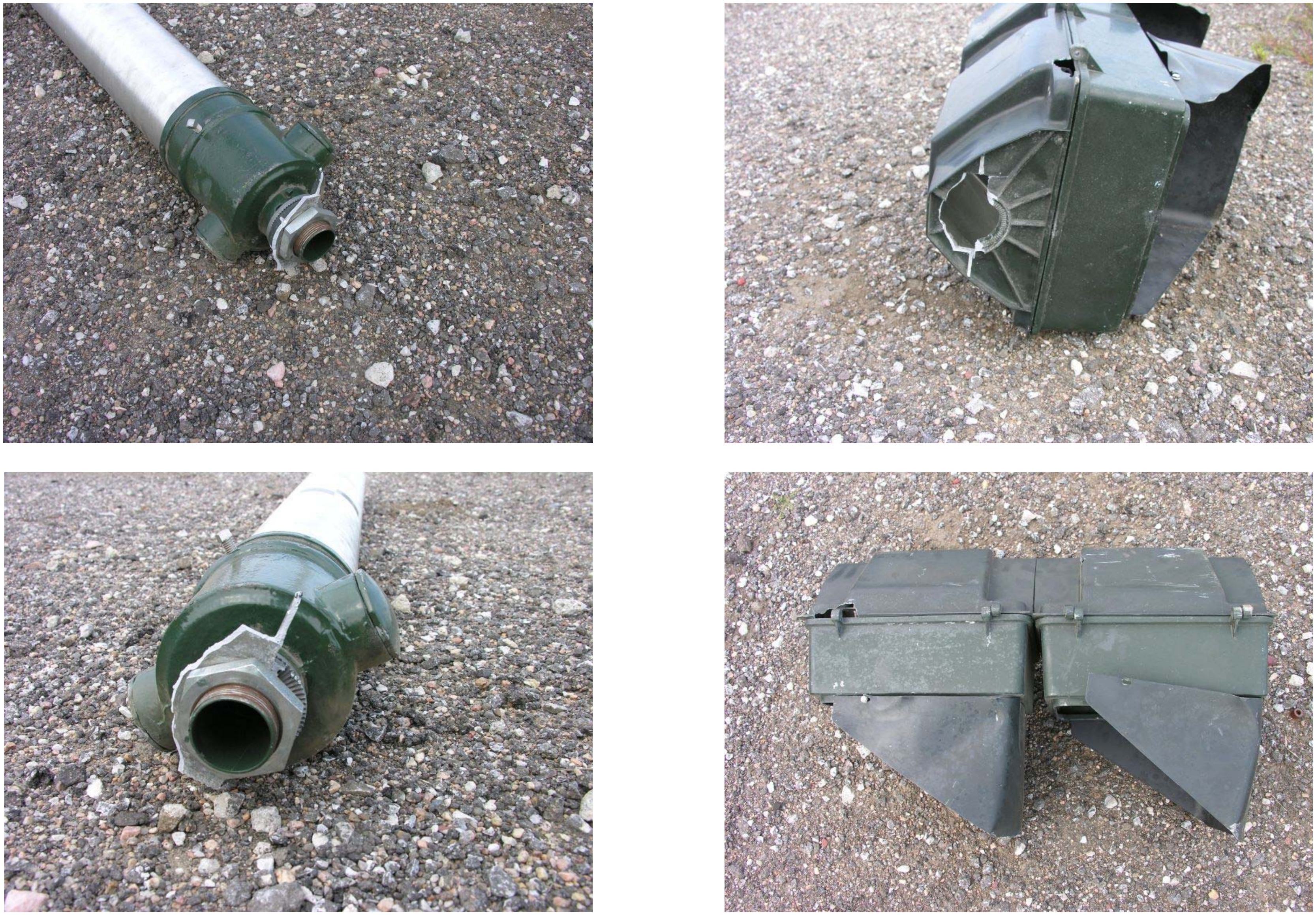


Figure 37. System Damage - Signal and Attachment Bracket, Test No. NYPP-1

7 PREDICTION OF HIGH-SPEED TEST RESULTS

Recall that NCHRP Report No. 350 specifies two tests for evaluating breakaway support structures (test designation nos. 3-60 and 3-61). However, only the low-speed test (test designation no. 3-60) was conducted. The results of the high-speed test (test designation no. 3-61) were estimated using the results from the low-speed test in combination with an analytical extrapolation method recommended by FHWA. Even though test no. NYPP-1 failed to pass the stub height criteria, this would not affect the validity of using the low-speed results to estimate the high-speed results. Therefore, the high-speed test results were still estimated using the equation shown below and following the procedure described in the noted references [7-8].

$$(\Delta MV)_H = \frac{V_L}{V_H}(\Delta MV)_L + b\left(V_H - \frac{V_L^2}{V_H}\right) \tag*{(EQ. 1)}$$

ΔMV = Vehicle momentum change
= Vehicle mass (M) x vehicle velocity change ($V_{(L \text{ or } H)}$-V_x)
$(\Delta MV)_L$ = Measured vehicle momentum change in low-speed test
$(\Delta MV)_H$ = Computed vehicle momentum change for high-speed test
V_L = Measured impact velocity during low-speed test

$$b = 1.1 * M_P\left(\frac{R^2}{R^2 + D_0^2}\right)$$

V_H = Extrapolated vehicle velocity for the highe-speed
M_p = Mass of support
D_o = Distance from support impact point to support center of mass
R = Radius of gyration of support about its center of mass

The following values were used for the variables found in Equation 1:

V_L = 32.3 ft/s (22.0 mph or 35.4 km/h)
V_H = 91.1 ft/s (62.1 mph or 100.0 km/h)
Vehicle Mass = 58.9 slugs (1,898 lb or 861 kg)
$(\Delta MV)_L$ = 58.9 slugs x 13.9 ft/s
819.3 slug-ft/s (3,648 kg-m/s)
M_p = 1.83 slugs (59 lb or 27 kg)
D_o = 40 in. (1.016 m)
R = 37 in. (0.940 m)

With the above values input into Equation 1, the calculated momentum change for the high-speed test was 399.5 slug-ft/s (1,779 kg-m/s). Dividing the momentum change by the mass of the surrogate vehicle, or 58.9 slugs (1,897 lb or 861 kg), the estimated change in vehicle velocity for the high-speed test was 6.8 ft/s (2.1 m/s). Note that this estimated change in velocity satisfies the NCHRP Report No. 350 limit of 16.4 ft/s (5.0 m/s).

Equation 1 can also be used to calculate the support mass limit in which a system passing the low-speed test will pass the high-speed test. In this analytical method described by Owings [7], the targeted vehicle mass, 57.5 slugs (1852 lb or 839 kg), was used in conjunction with the maximum allowable change in velocity established by NCHRP Report No. 350 of 16.4 ft/s (5.0 m/s) to calculate a maximum allowable change in vehicle momentum of 943 slug-ft/s (4,195 kg-m/s). This maximum allowable vehicle change in momentum was used with Equation 1 for both the low-speed and high-speed momentum change. Additionally, the target impact speeds for the two tests were used with Equation 1 in order to solve for the mass of the support (M_p). This process resulted in a support mass limit of 15.1 slugs (486 lb or 220 kg). Thus, any breakaway system with a mass below 15.1 slugs (486 lb or 220 kg) that satisfies the NCHRP Report No. 350 safety performance criteria for the low-speed test would also satisfy the requirements during the high-speed test. The support mass in test no. NYPP-1 was 1.83 slugs (59 lb or 27 kg), well below the calculated support mass limit. Therefore, the test article used in test no. NYPP-1 would not be expected to violate the vehicle change in velocity criteria during the high-speed impact of test designation no. 3-61.

8 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this research project was to evaluate the ability of the NYSDOT aluminum pedestrian “hand/man” signal pole to break away without a frangible transformer base. The evaluation process began with an impact test on the aluminum pedestrian pole in compliance with test designation no. 3-60 of NCHRP Report No. 350. Test no. NYPP-1 was performed with the FHWA-approved, Valmont-MwRSF/UNL pendulum impacting the pole at a speed of 22.0 mph (35.4 km/h). As predicted, the aluminum pole fractured away from the base plate, traveled backward, and fell to the ground without landing on top of the pendulum mass. At no time did the pole or signal show a propensity for striking the pendulum mass. Analysis of the accelerometer data showed that the change in velocity of the surrogate vehicle was 13.91 ft/s (4.24 m/s), satisfying the limit of 16.4 ft/s (5.0 m/s). However, the fractured aluminum base plate assembly projected 4½ in. (114 mm) above the simulated rigid foundation, thus violating the 4-in. (100-mm) stub height limit. Therefore, test no. NYPP-1 did not pass all of the safety performance evaluation criteria required by FHWA in order to garner acceptance. A summary of the safety performance criteria and test results is shown in Table 8.

Even though test no. NYPP-1 was unsuccessful, the low-speed test results were used to predict the results of the high-speed test (test designation no. 3-61). This analytical method, approved by FWHA and documented in the 1997 memorandum, showed that the pedestrian signal pole would also satisfy the vehicular change in velocity limits when impacted at higher speeds. These results, in combination with the belief that the pole would break away in a similar manner under high-speed impacts, lead to the conclusion that only the base plate stub height must be altered in order for the pole system to be found crashworthy.

MwRSF identified three design modifications that would likely result in a crashworthy pedestrian “hand/man” signal pole. The first design modification would include the elimination of the leveling nuts under the base plate. Without the leveling nuts, the base plate assembly would extend only 3½ in. (89 mm) above the surrounding terrain. Thus, after the pole disengaged from the base plate assembly, the remaining portion would not violate the 4-in. (100-mm) maximum stub height limit. Of course, one shortcoming of this concept is that it would be much more difficult to install the poles completely vertical.

The second design modification consists of recessing the base of the pole at least 1 in. (25 mm) into the surrounding concrete foundation in order to meet the stub height requirement. This modification could be achieved by leaving a cavity in the concrete surface where the pole is to be installed. The anchor bolts would extend out from the recessed cavity within the concrete foundation and protrude the standard distance from the concrete surface. The leveling nuts would be installed on the anchor rods below the surrounding ground surface (and above the cavity surface), and the pole would then be attached such that the top of the base plate assembly was within 4 in. (102 mm) of the surrounding surface. A conceptual drawing for this design option is shown in Figure 38. It is important in this design option that the anchor bolts and the pole be attached to a rigid foundation. Therefore, the cavity should be filled with a substance that will harden and provide compression resistance, such as a high-strength, non-shrink grout or concrete. Also, the fill material should be surrounded on all four sides with a rigid material (e.g., concrete) to provide shear resistance and prevent any translational movement of the pole/anchor bolts in relation to the foundation.

The third design modification would include breakaway hardware placed underneath the pole base plate. Breakaway couplings, or similar devices, could be used to connect the base of the pole to the anchor bolts. Of course, the additional hardware must be designed to release before the pole fractures away from its base. Obviously, the down side to this design option is that the additional breakaway hardware (i.e., couplers) would replace the frangible transformer base that was previously eliminated. Thus, the implementation of this concept would result in the reduction or loss of the anticipated cost savings.

Table 8. Summary of Safety Performance Evaluation Results

<table>
<tr><th colspan="2">NCHRP Report No. 350 Criteria</th><th>Test No. NYPP-1</th></tr>
<tr><td>Structural Adequacy</td><td>B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td><td>S</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injury should not be permitted. See discussion in Section 5.3 and Appendix E of NCHRP Report No. 350.</td><td>S</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitch, and yaw are acceptable.</td><td>NA</td></tr>
<tr><td>H. Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of NCHRP Report No. 350 for calculation procedure) or vehicle change in velocity should satisfy the following:
<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</td><td>9.8 ft/s
(3.0 m/s)</td><td>16.4 ft/s
(5.0 m/s)</td></tr>
</table></td><td>S</td></tr>
<tr><td>I. The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of NCHRP Report No. 350 for calculation procedure) should satisfy the following:
<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 g’s</td><td>20 g’s</td></tr>
</table></td><td>NA</td></tr>
<tr><td rowspan="2">Vehicle Trajectory</td><td>K. After collision, it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td><td>NA</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td><td>S</td></tr>
<tr><th colspan="2">AASHTO Fifth Edition Additional Criteria</th><th></th></tr>
<tr><td rowspan="2">Structural Adequacy</td><td>Substantial remains of breakaway supports shall not project more than 4 in. (100 mm) above a line between straddling wheels of a vehicle on 60 in. (1500 mm) centers. The line connects any point on the ground surface one side of the support to a point on the ground surface on the other side, and it is aligned radially or perpendicularly to the centerline of the roadway.</td><td>U</td></tr>
<tr><td>The maximum mass of combined luminaire support and fixtures attached to breakaway supports shall be limited to 992 lb (450 kg). Any increases in these limits are to be based on full-scale crash testing and an investigation of the range of vehicle roof crush characteristics that go beyond the recommended testing procedures of NCHRP Report No. 350.</td><td>S</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

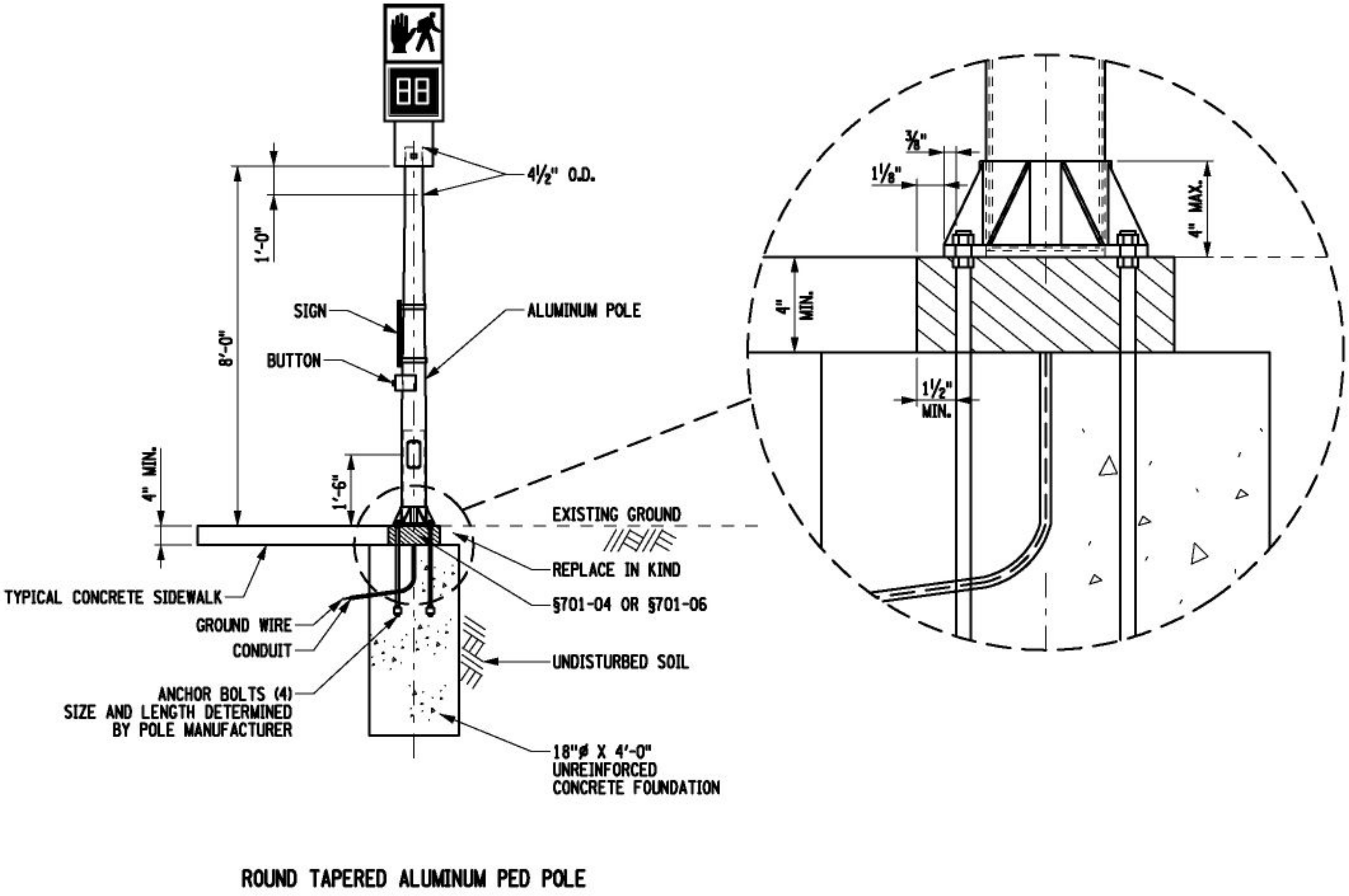


Figure 38. Design Modification No. 2, Setting Base Plate into Surrounding Surface

9 REFERENCES

1. Ross, H.E., Sicking, D.L., Zimmer, R.A., and Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program (NCHRP) Report No. 350, Transportation Research Board, Washington, D.C., 1993.

2. American Association of State Highway Transportation Officials (AASHTO), *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, 5th Edition, Washington D.C., 2009.

3. Bielenberg, R.W, Lechtenberg, K.A., Faller, R.K., and Sicking, D.L., *Validation of the Valmont/MwRSF Pendulum with Crushable Nose*, Research Report No. TRP-03-214-09, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, February 2009.

4. Hott, C., Brown, C., and Totani, N., *Crush Characteristics of the 1,800 lb Pendulum*, Report No. FHWA-RD-90-059, The Scientex Corporation of Washington, D.C. and Federal Highway Administration, Turner-Fairbank Highway Research Center, McLean, VA, July 1990.

5. Hott, C., Brown, C., Totani, N., and Hansen, A., *Crush Characteristics of the Breakaway Bogie*, Report No. FHWA-RD-89-107, Federal Highway Administration, Washington, D.C., March 1989.

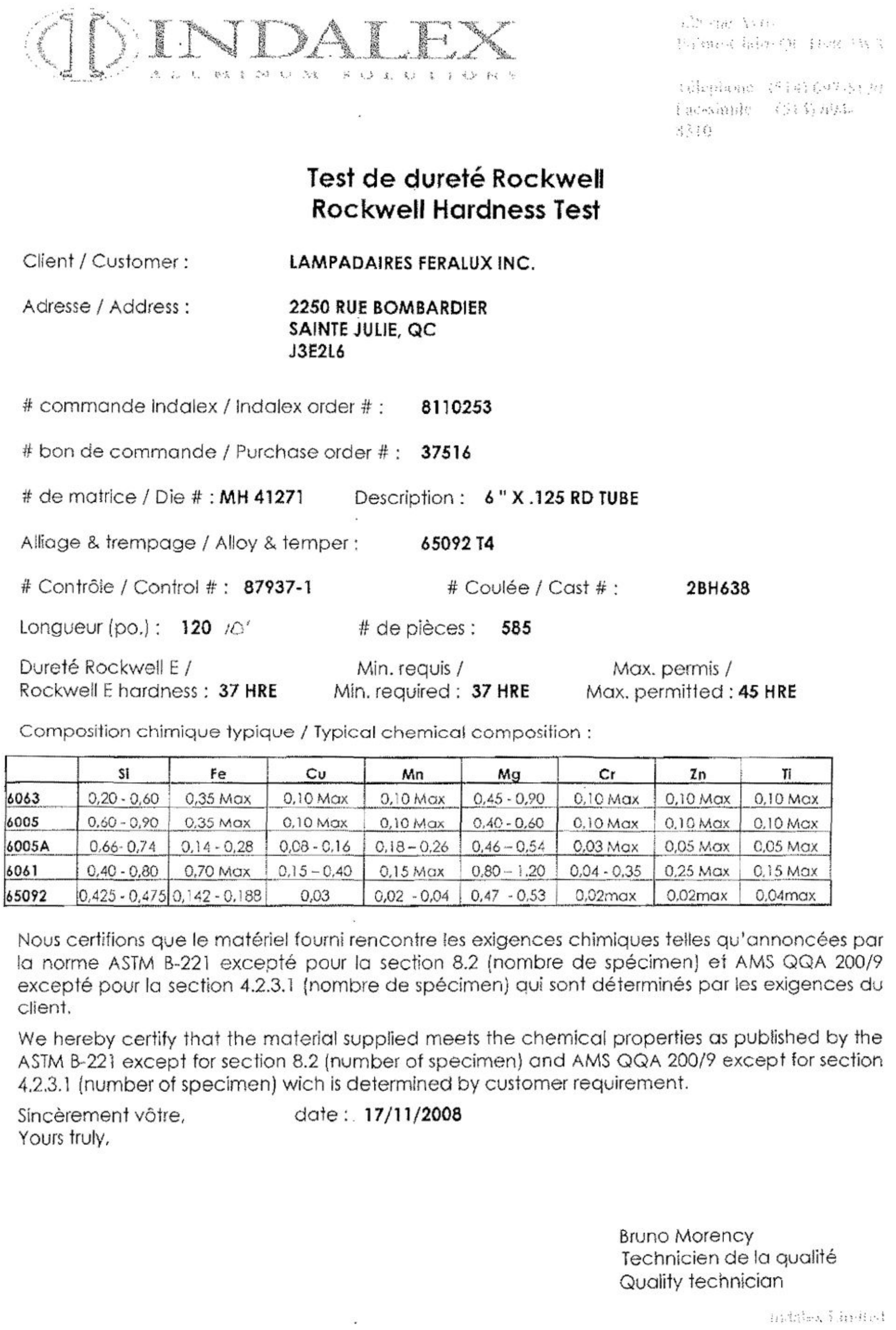
6. Zimmer, R.A. and A.G. Arnold, *Calibration of the TTI 820 KG Pendulum*, Report 270687, Texas Transportation Institute, College Station, TX, June 1997.

7. Owings, R.P, Adair, J.W., and Cantor, C., *Safer Sign and Luminaire Supports – Task L – Final Report*, Report No. FHWA-RD-76-36, ENSCO, INC., Springfield Virginia, October 1975.

8. Steinke, D.P., FHWA Memorandum HNG-14 for Action: Identifying Acceptable Highway Safety Features, To Regional Administrators, Federal Lands Highway Program Administrator, Division Administrators, and Federal Lands Highway Division Engineers, July 25, 1997.

10 APPENDICES

Appendix A. Material Specifications



INDALEX
ALUMINUM SOLUTIONS

Test de dureté Rockwell
Rockwell Hardness Test

Client / Customer : **LAMPADAIRES FERALUX INC.**

Adresse / Address :
2250 RUE BOMBARDIER
SAINTE JULIE, QC
J3E2L6

commande Indalex / Indalex order # : **8110253**

bon de commande / Purchase order # : **37516**

de matrice / Die # : **MH 41271** Description : **6 " X .125 RD TUBE**

Alliage & trempage / Alloy & temper : **65092 T4**

Contrôle / Control # : **87937-1** # Coulée / Cast # : **2BH638**

Longueur (po.) : **120** 10' # de pièces : **585**

Dureté Rockwell E / Rockwell E hardness : **37 HRE** Min. requis / Min. required : **37 HRE** Max. permis / Max. permitted : **45 HRE**

Composition chimique typique / Typical chemical composition :

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
6063	0,20 - 0,60	0,35 Max	0,10 Max	0,10 Max	0,45 - 0,90	0,10 Max	0,10 Max	0,10 Max
6005	0,60 - 0,90	0,35 Max	0,10 Max	0,10 Max	0,40 - 0,60	0,10 Max	0,10 Max	0,10 Max
6005A	0,66- 0,74	0,14 - 0,28	0,08 - 0,16	0,18 – 0,26	0,46 – 0,54	0,03 Max	0,05 Max	0,05 Max
6061	0,40 - 0,80	0,70 Max	0,15 – 0,40	0,15 Max	0,80 – 1,20	0,04 - 0,35	0,25 Max	0,15 Max
65092	0,425 - 0,475	0,142 - 0,188	0,03	0,02 - 0,04	0,47 - 0,53	0,02max	0,02max	0,04max

Nous certifions que le matériel fourni rencontre les exigences chimiques telles qu'annoncées par la norme ASTM B-221 excepté pour la section 8.2 (nombre de spécimen) et AMS QQA 200/9 excepté pour la section 4.2.3.1 (nombre de spécimen) qui sont déterminés par les exigences du client.

We hereby certify that the material supplied meets the chemical properties as published by the ASTM B-221 except for section 8.2 (number of specimen) and AMS QQA 200/9 except for section 4.2.3.1 (number of specimen) wich is determined by customer requirement.

Sincèrement vôtre, date : **17/11/2008**
Yours truly,

Bruno Morency
Technicien de la qualité
Quality technician

Indalex Limited

Figure A-1. Aluminum Pole Material Certification

INDALEX
ALUMINUM SOLUTIONS

325 rue Avro
Pointe-Claire, QC, Canada
H9R 5W3
Téléphone (514) 697-5120
Fac-simile (514) 694-8310

Certificat de conformité
Compliance certificate

Client / Customer : **LAMPADAIRES FERALUX INC.**

Adresse / Address :
2250 RUE BOMBARDIER
SAINTE JULIE, QC
J3E2L6

commande Indalex / Indalex order # : **9051523**

bon de commande / Purchase order # : **39091**

de matrice / Die # : **MH 41271**   Description : **6 " X .125 RD TUBE**

Alliage & trempage / Alloy & temper : **65092 T4**   Customer Part # : **TUBA0600A1406**

Contrôle / Control # : **99253-1**   # Coulée / Cast # : **2BJ673**

Longueur (po.) : **174**   # de pièces : **36**

Composition chimique typique / Typical chemical composition :

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
6063	0,20 - 0,60	0,35 Max	0,10 Max	0,10 Max	0,45 - 0,90	0,10 Max	0,10 Max	0,10 Max
6005	0,60 - 0,90	0,35 Max	0,10 Max	0,10 Max	0,40 - 0,60	0,10 Max	0,10 Max	0,10 Max
6005A	0,66- 0,74	0,14 - 0,28	0,08 - 0,16	0,18 – 0,26	0,46 – 0,54	0,03 Max	0,05 Max	0,05 Max
6061	0,40 - 0,80	0,70 Max	0,15 – 0,40	0,15 Max	0,80 – 1,20	0,04 - 0,35	0,25 Max	0,15 Max
65092	0,425 - 0,475	0,142 - 0,188	0,03	0,02 - 0,04	0,47 - 0,53	0,02max	0,02max	0,04max

Nous certifions que le matériel fourni rencontre les exigences chimiques telles qu'annoncées par la norme ASTM B-221 excepté pour la section 8.2 (nombre de spécimen) et AMS QQA 200/9 excepté pour la section 4.2.3.1 (nombre de spécimen) qui sont déterminés par les exigences du client.

We hereby certify that the material supplied meets the chemical properties as published by the ASTM B-221 except for section 8.2 (number of specimen) and AMS QQA 200/9 except for section 4.2.3.1 (number of specimen) wich is determined by customer requirement.

Sincèrement vôtre,   date : **27/05/2009**
Yours truly,

CONFORME
DATE: 04.06.09
SIGNATURE:

Steve Desbois-Biard
Assistant qualité
Quality assistant

Indalex Limited

Figure A-2. Aluminum Pole Assembly Material Certification

Appendix B. Accelerometer Data Plots

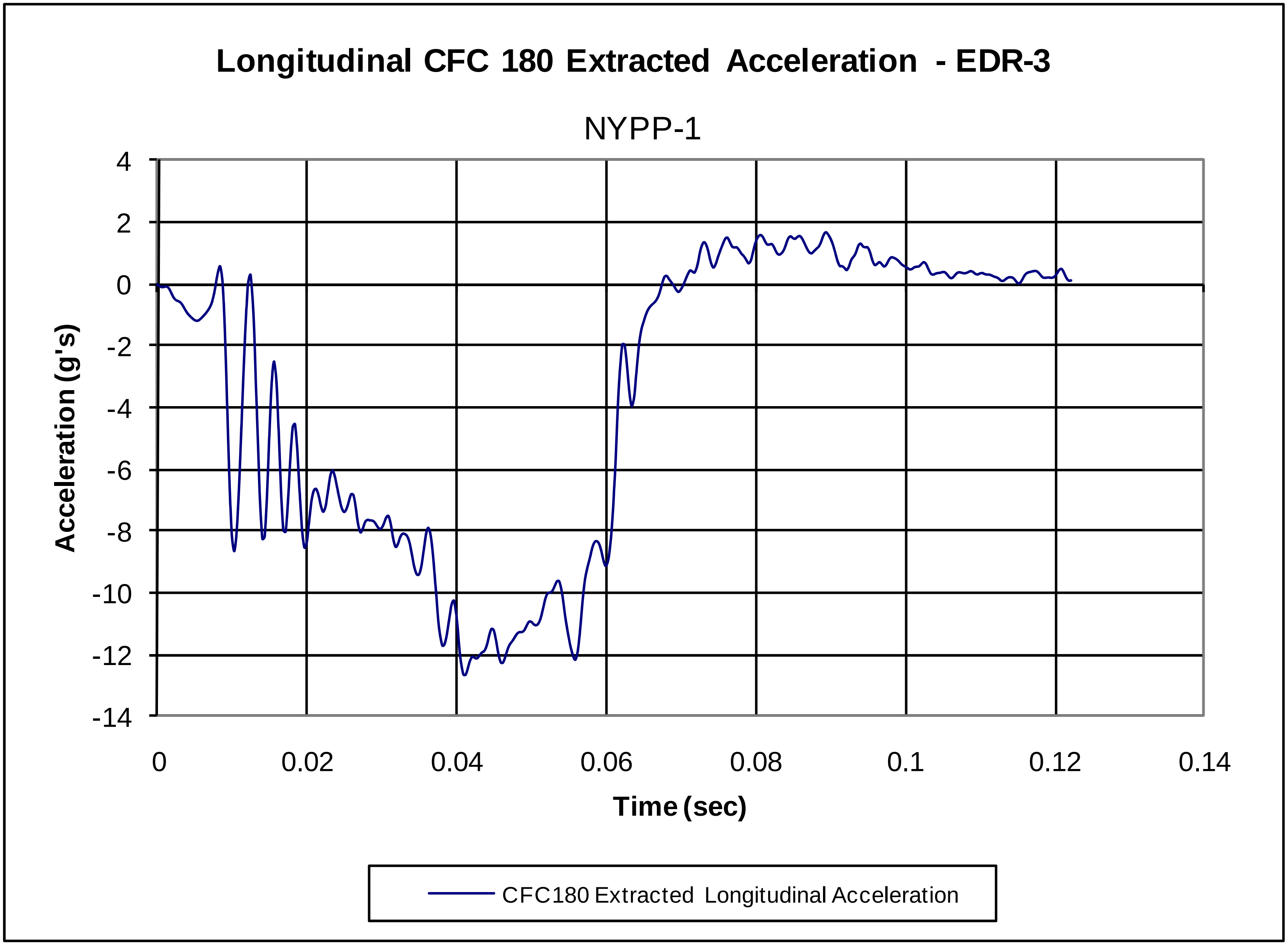


Figure B-1. Longitudinal Deceleration (EDR-3), Test No. NYPP-1

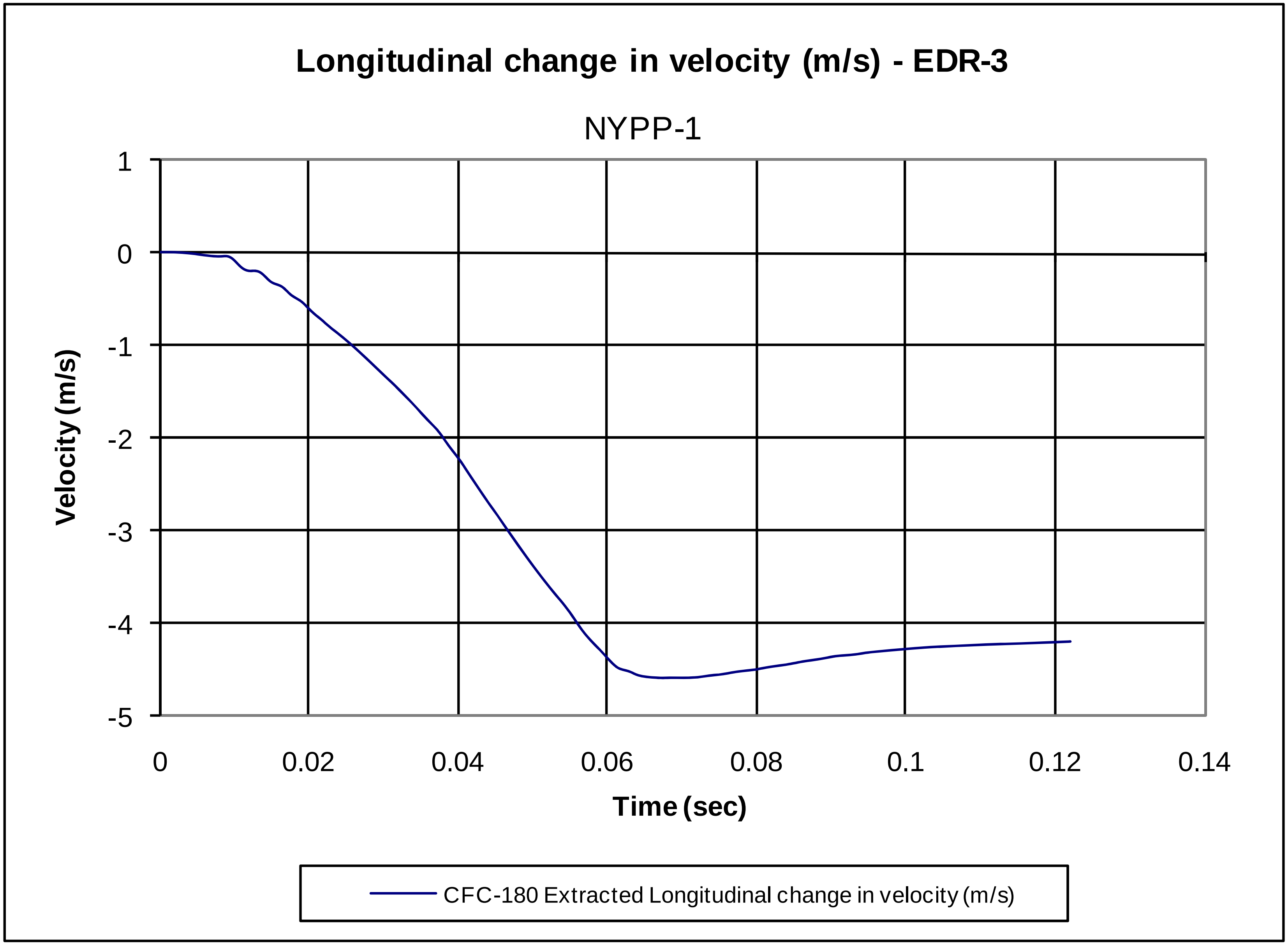


Figure B-2. Longitudinal Change in Velocity (EDR-3), Test No. NYPP-1

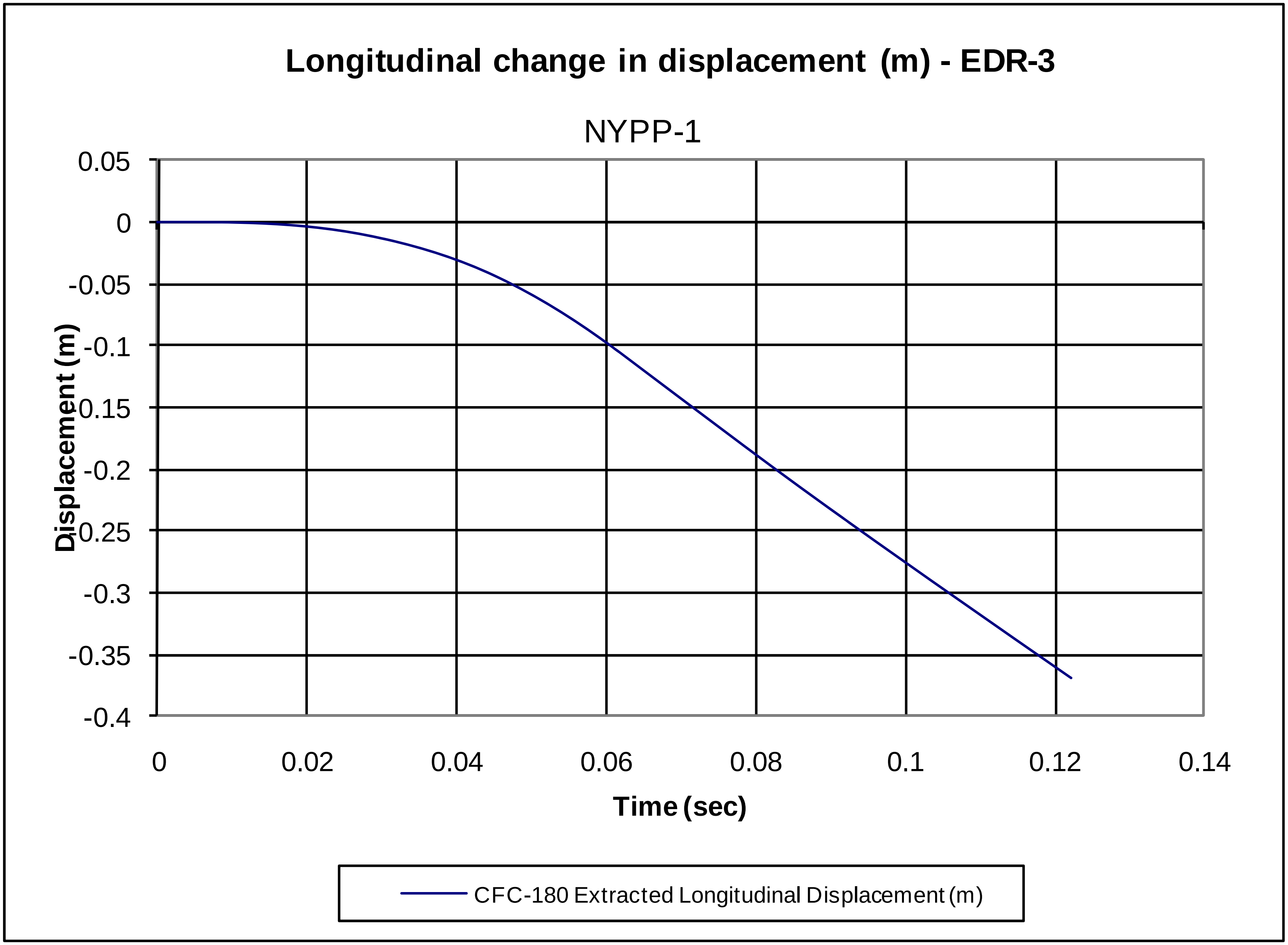


Figure B-3. Longitudinal Occupant Displacement (EDR-3), Test No. NYPP-1

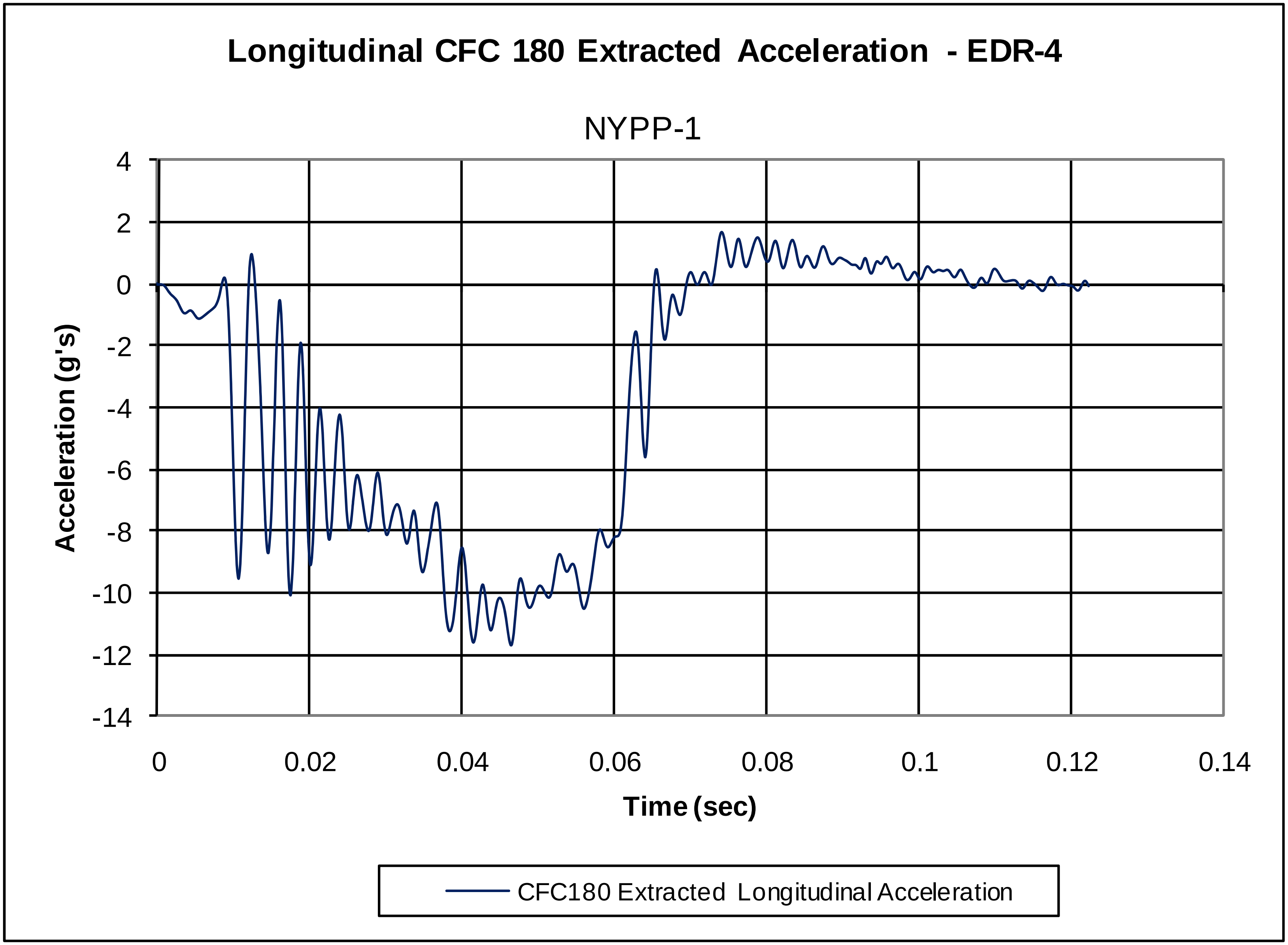


Figure B-4. Longitudinal Deceleration (EDR-4), Test No. NYPP-1

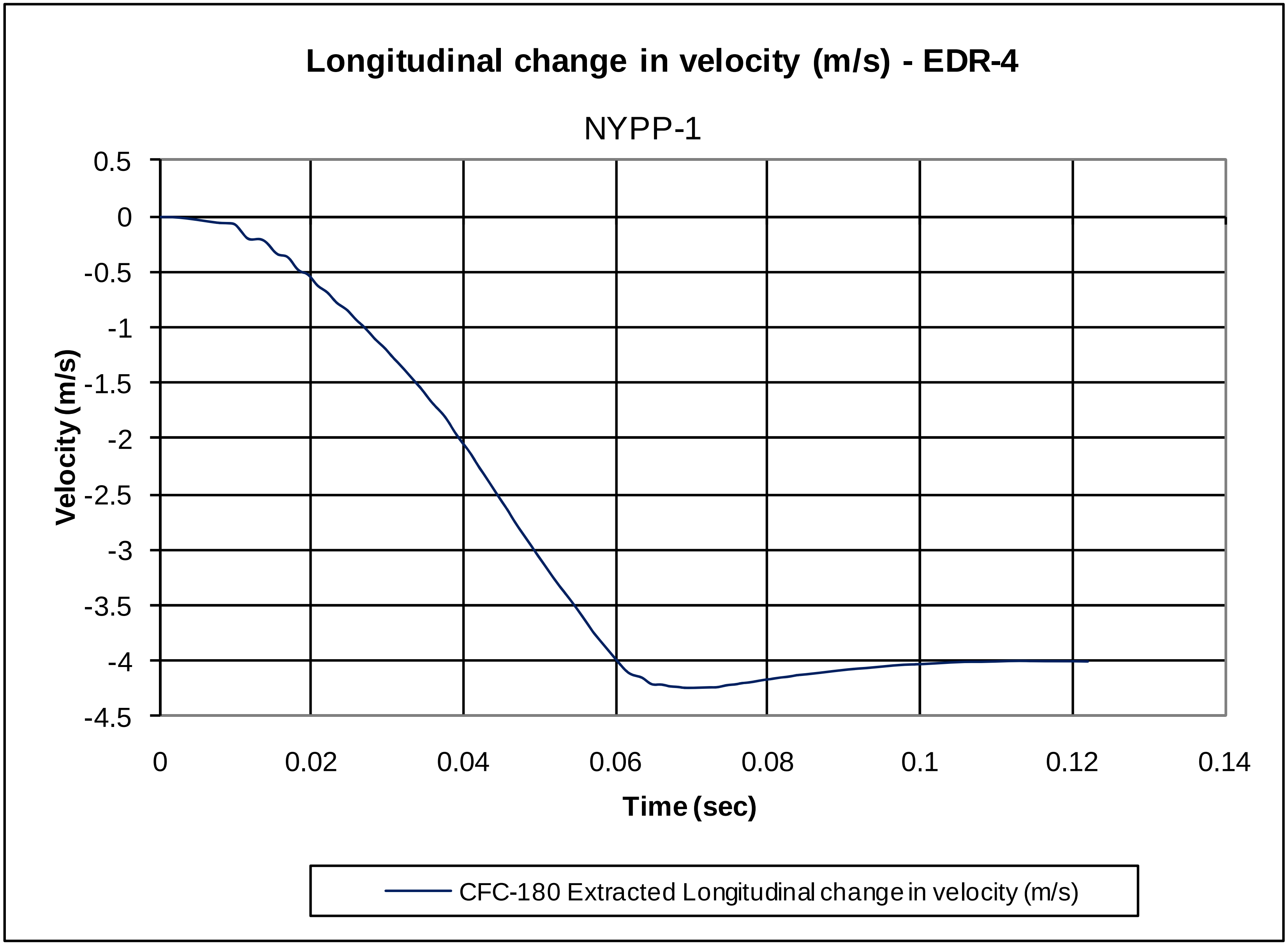


Figure B-5. Longitudinal Change in Velocity (EDR-4), Test No. NYPP-1

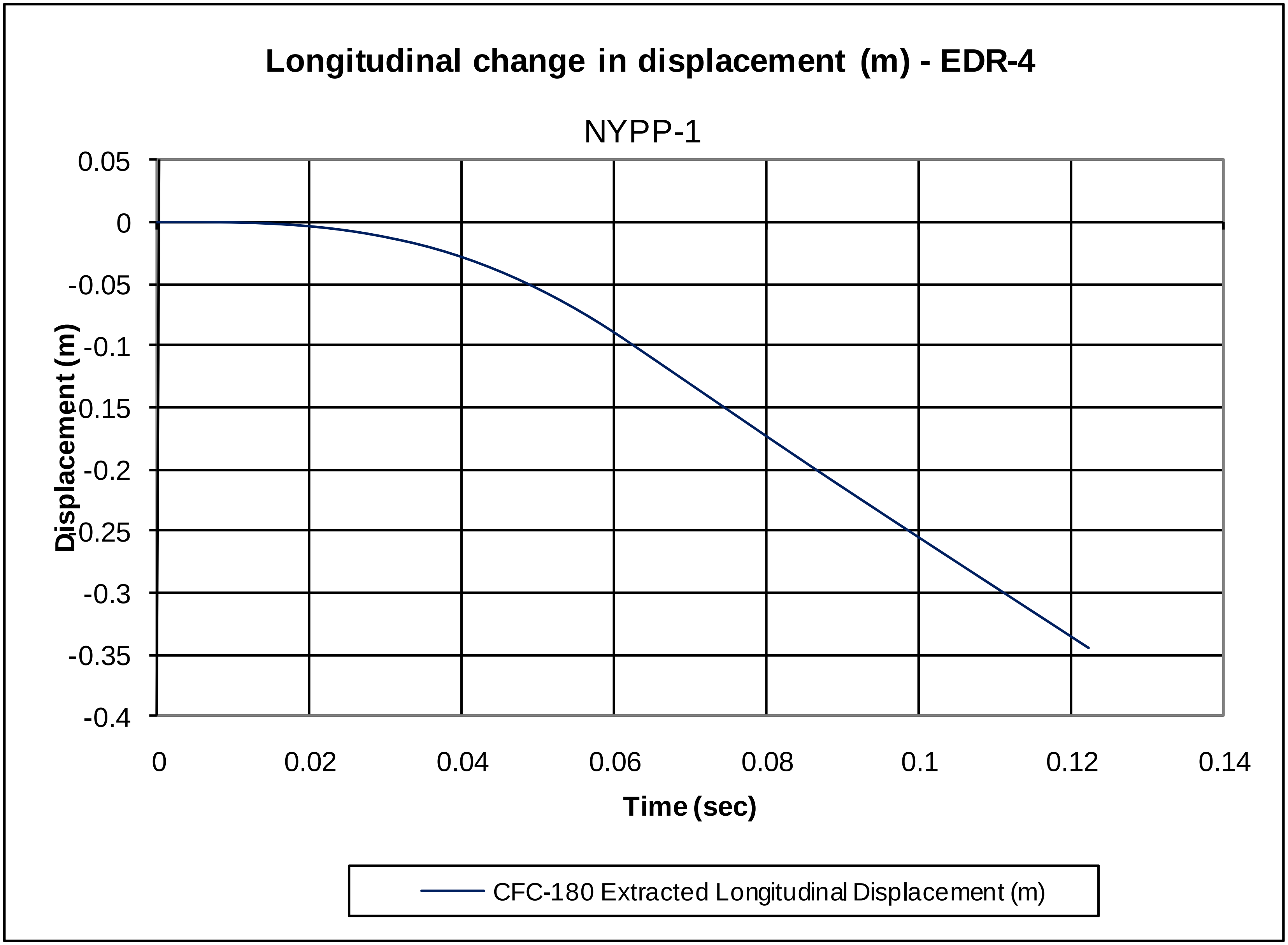


Figure B-6. Longitudinal Occupant Displacement (EDR-4), Test No. NYPP-1

END OF DOCUMENT