Midwest Pooled Fund Program
Fiscal Years 2021-2024
TPF-5(430) Supplement #21
NDOT Sponsoring Agency Code RPFP-21-POLE-1

BREAKAWAY LUMINAIRE POLE RESEARCH

Submitted by

Jacob G. Conway, M.S.
Former Graduate Research Assistant

Mojdeh Pajouh, Ph.D., P.E
Former Research Assistant Professor

Robert W. Bielenberg, M.S,M.E.
Research Engineer

Ronald K. Faller, Ph.D., P.E.
Research Professor & MwRSF Director

Mohammadreza Rajaee
Former Graduate Research Assistant

MIDWEST ROADSIDE SAFETY FACILITY
Nebraska Transportation Center
University of Nebraska-Lincoln

Main Office
Prem S. Paul Research Center at Whittier School
Room 130, 2200 Vine Street
Lincoln, Nebraska 68583-0853
(402) 472-0965

Outdoor Test Site
4630 N.W. 36th Street
Lincoln, Nebraska 68524

Submitted to

MIDWEST POOLED FUND PROGRAM
Nebraska Department of Transportation
1500 Nebraska Parkway
Lincoln, Nebraska 68502

MwRSF Research Report No. TRP-03-481-25

December 18, 2025

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. TRP-03-481-25	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Breakaway Luminaire Pole Research		**5. Report Date** December 18, 2025
		6. Performing Organization Code
7. Author(s) Conway, J.C., Pajouh, M., Bielenberg, R.W., Faller, R.K., and Rajaee, M.		**8. Performing Organization Report No.** TRP-03-481-25
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) Nebraska Transportation Center University of Nebraska-Lincoln		**10. Work Unit No.**
Main Office: Prem S. Paul Research Center at Whittier School Room 130, 2200 Vine Street Lincoln, Nebraska 68583-0853	Outdoor Test Site: 4630 N.W. 36th Street Lincoln, Nebraska 68524	**11. Contract** TPF-5(430) Supplement #21
12. Sponsoring Agency Name and Address Midwest Pooled Fund Program Nebraska Department of Transportation 1500 Nebraska Parkway Lincoln, Nebraska 68502		**13. Type of Report and Period Covered** Final Report: 2021-2025
		14. Sponsoring Agency Code RPFP-21-POLE-1

15. Supplementary Notes

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

16. Abstract

This document reports efforts to identify critical parameters and configurations for *Manual for Assessing Safety Hardware* (MASH) Test Level 3 (TL-3) compliant breakaway luminaire poles with slip bases. The project aimed to determine pole configurations with the potential to meet MASH TL-3 and recommend critical configurations for full-scale crash testing. First, a comprehensive literature review was conducted which included survey results collected from Midwest Pooled Fund state departments of transportation (DOTs), standard plans from state DOTs, and past luminaire pole testing. Numerical models using LS-DYNA were developed for luminaire poles with a 4-bolt slip base, as utilized by the Utah Department of Transportation, and were validated against the USBLM full-scale crash test series.

The validated model was utilized to simulate various pole configurations with a 4-bolt slip base under MASH test designation nos. 3-60, 3-61, and 3-62 at impact angles of 0 and 25 degrees, with the vehicle impacting at the center and quarter points. Configurations included pole heights ranging from 20 to 50 ft and mast arm lengths ranging from 4 to 20 ft. The simulations were post-processed and analyzed to identify trends regarding MASH safety criteria, including occupant compartment deformation, occupant risk measures, and vehicle instability, to identify the critical parameters and configurations for slip base luminaire poles. The following trends were identified based on the simulation results: (1) no simulations exceeded MASH limits for occupant impact velocity, occupant ridedown accelerations, and roll and pitch values; (2) MASH test designation no. 3-60 impacts appeared to be more critical in terms of roof crush; (3) vehicle center impacts were found to be more critical than quarter-point impacts for roof crush; (4) multiple configurations exceeded the 4-in. roof crush limit roof under MASH test designation no. 3-60 impact conditions, (5) no occupant compartment intrusion occurred in MASH test designation nos. 3-61 and 3-62; and (6) nearly all pole configurations between 450 lb and 600 lb showed potential to meet MASH criteria. Based on these simulations results, critical pole configurations and critical impact conditions were recommended for full-scale crash testing.

17. Key Words Highway Safety, Crash Test, Roadside Appurtenances, MASH 2016, LS-DYNA, Breakaway Poles, Slip Base, Computer Simulation		**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service. 5285 Port Royal Road, Springfield, VA 22161	
19. Security Classification (of this report) Unclassified	**20. Security Classification (of this page)** Unclassified	**21. No. of Pages** 303	**22. Price**

DISCLAIMER STATEMENT

This material is based upon work supported by the Federal Highway Administration, U.S. Department of Transportation and the Midwest Pooled Fund Program under TPF-5(430) Supplement #21. 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 University of Nebraska-Lincoln, state highway departments participating in the Midwest Pooled Fund Program nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names, which may appear in this report, are cited only because they are considered essential to the objectives of the report. The United States (U.S.) government and the State of Nebraska do not endorse products or manufacturers.

ACKNOWLEDGEMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the Midwest Pooled Fund Program funded by the California Department of Transportation, Florida Department of Transportation, Georgia Department of Transportation, Hawaii Department of Transportation, Illinois Department of Transportation, Indiana Department of Transportation, Iowa Department of Transportation, Kansas Department of Transportation, Kentucky Department of Transportation, Minnesota Department of Transportation, Missouri Department of Transportation, Nebraska Department of Transportation, New Jersey Department of Transportation, North Carolina Department of Transportation, Ohio Department of Transportation, South Carolina Department of Transportation, South Dakota Department of Transportation, Utah Department of Transportation, Virginia Department of Transportation, Wisconsin Department of Transportation, and Wyoming Department of Transportation for sponsoring this project; (2) the Holland Computing Center (HCC) at the University of Nebraska-Lincoln for the computational resources, and (3) the Dwight D. Eisenhower Transportation Fellowship Program (DDETFP) for partially funding this research project and supporting the author Jacob Conway. Acknowledgement is also given to the following individuals who contributed to the completion of this research.

Midwest Roadside Safety Facility
J.C. Holloway, M.S.C.E., Research Engineer & Assistant Director –Physical Testing Division
K.A. Lechtenberg, M.S.M.E., Research Engineer
S.K. Rosenbaugh, M.S.C.E., Research Engineer
C.S. Stolle, Ph.D., Research Associate Professor
J.S. Steelman, Ph.D., P.E., Associate Professor
B.J. Perry, M.E.M.E., Research Engineer
A.E. Loken, Ph.D., Research Assistant Professor
T.Y. Yosef, Ph.D., Research Assistant Professor
Q.A. Alomari, Ph.D., Research Assistant Professor
A.T. Russell, B.S.B.A., Testing and Maintenance Technician II
E.W. Krier, B.S., Former Engineering Testing Technician II
D.S. Charroin, Engineering Testing Technician II
R.M. Novak, Engineering Testing Technician II
T.C. Donahoo, Engineering Testing Technician I
J.T. Jones, Engineering Testing Technician II
E.L. Urbank, Research Communication Specialist
Z.Z. Jabr, Engineering Technician
J.J. Oliver, Solidworks Drafting Coordinator
Undergraduate and Graduate Research Assistants

California Department of Transportation
David Whitesel, P.E., Transportation Engineer
Thomas Mar, P.E., Transportation Engineer

Florida Department of Transportation
Derwood Sheppard, P.E., State Roadway Design Engineer
Richard Stepp, P.E., Senior Standard Plans Engineer
Rick Jenkins, P.E., State Standards Plans Engineer

Georgia Department of Transportation
Christopher Rudd, P.E., State Design Policy Engineer
Frank Flanders IV, P.E., Assistant State Design Policy Engineer
Doug Franks, P.E., Bridge Design Group Leader, Sr.

Hawaii Department of Transportation
Brent Ching, Structural Engineer
Keith Kalani, Structural Engineer
Kimberly Okamura, Engineer

Illinois Department of Transportation
Martha Brown, P.E., Safety Policy & Initiatives Engineer
Edgar Galofre, P.E., Safety Design Engineer
Kelli Erickson, Safety Design Evaluation Engineer

Indiana Department of Transportation
Katherine Smutzer, P.E., Standards Engineer
Andrew Blackburn, P.E., Engineer
Elizabeth Mouser, P.E., Standards & Policy Director

Iowa Department of Transportation
Daniel Harness, P.E., Transportation Engineer Specialist
Brian Smith, P.E., Methods Engineer
Mike Thiel, P.E., Transportation Engineer Specialist
Stuart Nielsen, P.E., Methods Engineer

Kansas Department of Transportation
Scott King, P.E., Road Design Bureau Chief
August Zuno, Engineer
Jackie Austin, Engineer
Jeff Sims, P.E., Road Design Leader

Kentucky Transportation Cabinet
Jason J. Siwula, P.E., Assistant State Highway Engineer
Jeff Jasper, Program Leader, University of Kentucky Transportation Center
Matthew Sipes, Transportation Engineer Branch Manager
Tim Layson, Transportation Engineer Director

Minnesota Department of Transportation
Khamsai Yang, P.E., State Design Standards Engineer
Michelle Moser, P.E., Assistant Design Standards Engineer
Braden Cyr, P.E., Bridge Engineer
Brian Tang, P.E., Assistant State Design Standards Engineer
Arielle Ehrlich, P.E., State Bridge Design Engineer

Missouri Department of Transportation
Gidget Koestner, P.E., Policy & Innovations Engineer
Kirby Woods, Jr., Roadside Design Engineer

Nebraska Department of Transportation
Jim Knott, P.E., Construction Engineer
Mick Syslo, P.E., Deputy Director – Operations
Mark Fischer, P.E., PMP, Research Program Manager
Austin White, P.E., Plan Quality & Standards Engineer
Brandie Neemann, P.E., Roadway Design Engineer
Jordan Wipf, P.E., Bridge Load Rating and Barrier Engineer
Todd Hill, P.E., Assistant Roadway Design Engineer

New Jersey Department of Transportation
Hung Tang, P.E., Principal Engineer, Transportation
Joseph Warren, Assistant Engineer, Transportation
Xiaohua "Hannah" Cheng, P.E., Ph.D., Supervising Engineer, Structures
Binyamin Abu Haltam, Engineer
Sowatta Seng Eap, Engineer
Madhavi Andey, Principal Engineer
Vipul J. Shah, Engineer
Manar Alsharaa, Supervising Engineer

North Carolina Department of Transportation
Jordan Woodard, P.E., Design Development & Support Group Lead
Nicole Hackler, P.E., State Plans and Standards Engineer
Shawn Troy, P.E., State Traffic Safety Engineer

Ohio Department of Transportation
Don Fisher, P.E., Roadway Standards Engineer
Andrew Holloway, P.E., Transportation Engineer

South Carolina Department of Transportation
Mark H. Anthony, P.E., Letting Preparation Engineer
Jason Hall, P.E., Engineer

South Dakota Department of Transportation
Sam Weisgram, Engineering Manager
Drew Miller, Standards Engineer

Utah Department of Transportation
Shawn Debenham, Traffic and Safety Specialist
Kelly Ash, Traffic Operations Engineer
Clinton McCleery, Barrier & Attenuation Specialist

Virginia Department of Transportation
Charles Patterson, P.E., Standards/Special Design Section Manager
Andrew Zickler, P.E., Complex Bridge Design and ABC Support Program Manager
Bangfei Han, P.E., Senior Engineer
Junyi Meng, P.E., Senior Structural Engineer

Wisconsin Department of Transportation
Erik Emerson, P.E., Standards Development Engineer
Rodney Taylor, P.E., Roadway Design Standards Unit Supervisor

Wyoming Department of Transportation
William Wilson, P.E., Architectural and Highway Standards Engineer

Federal Highway Administration
David Mraz, Division Bridge Engineer, Nebraska Division Office

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

The American Association of State Highway and Transportation Officials (AASHTO) *Roadside Design Guide* (RDG) addresses the need for appropriate design and placement of crashworthy hardware, including breakaway luminaire supports, in recoverable "clear zones" on the roadside [1]. Over time, numerous variations of breakaway luminaire supports have been developed and the criteria for evaluating their performance have evolved. However, the RDG does not specify the range of available devices or the crashworthiness of different luminaire parameters and configurations, such as height, weight, attachments, etc. AASHTO's *Manual for Assessing Safety Hardware* (MASH) and *LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* set the criteria for determining crashworthiness [2, 3], but no breakaway luminaire supports have been successfully tested to meet MASH evaluation criteria or received a Federal Highway Administration (FHWA) eligibility letter. Thus, there is a critical need to evaluate the crashworthiness of luminaire poles through full-scale crash testing and computer simulations.

Recent full-scale crash tests and simulations conducted under National Cooperative Highway Research Program (NCHRP) Project 22-43 "Proposed AASHTO Guidelines for Implementation of MASH for Sign Supports, Breakaway Poles, and Work Zone Traffic Control Devices," which is an ongoing research project led by the research team at MwRSF, found that existing luminaire poles with transformer bases, specifically TB1-17, the most common base in the U.S. (according to the survey conducted under NCHRP Project 03-119) have little potential to pass MASH due to the excessive occupant impact velocities (OIV) (> 16-ft/s MASH limit) and/or roof crush (> 4-in. MASH limit) [4, 5]. Details can be found in the report [5].

The goal of this research was to identify the critical parameters and configurations for crashworthy breakaway luminaire poles that utilize a breakaway base, specifically a slip base, as well as identifying pole configurations with the potential to meet MASH safety standards. The current Phase (Phase I) of the project involved: (1) a literature review and survey of existing luminaire pole configurations; (2) computer simulations to evaluate the crashworthiness of poles supported by a slip base; and (3) an evaluation of various pole configurations with different heights, weights, and mast arm lengths. Simulation findings helped identify pole configurations that would be likely to meet MASH safety criteria. Finally, recommendations were made for full-scale crash testing in a possible future phase of the project.

The literature review included an examination of past luminaire pole crash testing documentation, state departments of transportation (DOTs) standard plans, and pre-existing survey results collected by MwRSF from state DOTs as a part of the ongoing NCHRP Project No. 03-119, as detailed in the Project No. 03-119 Interim Report [4]. This review included a search to identify a range of parameters representing commonly used breakaway luminaire poles.

Next, a slip base pole model was simulated in LS-DYNA, replicating the test setup used in MwRSF pole test nos. USBLM-1 and USBLM-2 [5, 7]. The system was identical to the system utilized by the Utah Department of Transportation (UDOT). The simulation results were compared to outcomes from test nos. USBLM-1 and USBLM-2. During the validation process, several adjustments were made to the model, including modifications to part geometries, material properties, and vehicle models to more accurately represent the physical crash test. Once validated, the UDOT slip base model was used to identify the critical parameters and configurations for breakaway slip base luminaire poles, with a focus on steel luminaire poles.

1.2 Objective

The objective of this research was to determine the critical parameters and configurations for MASH Test Level 3 (TL-3)-compliant breakaway luminaire supports, including configurations with the potential to meet MASH TL-3 criteria and recommendations for full-scale crash testing. The initial phase included a literature search and survey to identify potential pole configurations, followed by computer modeling to evaluate the impact of variations in pole parameters. This phase concluded with recommendation for critical designs for full-scale crash testing. Follow-up research would be required to conduct full-scale testing and validate the simulation findings.

1.3 Scope

The research objective was achieved through the completion of several tasks. The first task involved: (1) reviewing existing literature on luminaire pole slip base systems and state DOT standard plans that provide design or guidance related to luminaire poles with a slip base; and (2) surveying Midwest Pooled Fund Program member state DOTs to gather information on their use of slip bases and breakaway luminaire pole configurations.

The second task involved: (1) reviewing state pole configurations and selecting a range of pole parameters; (2) developing and validating LS-DYNA models for breakaway luminaire poles; (3) conducting LS-DYNA analysis of various pole parameters and configurations; (4) identifying pole configurations with a potential to meet MASH TL-3 safety criteria; and (5) recommending critical pole configurations for full-scale testing.

The third and final task included preparing a technical report to document the research effort that included the literature review, simulation results, and recommendations for further research.

2 LITERATURE REVIEW

A number of breakaway luminaire systems utilize a slip base, representing approximately 28.8% of all such systems across the U.S., according to survey responses from NCHRP Project No. 03-119 [4]. Nearly all breakaway luminaire poles with slip bases are considered non-proprietary.

2.1 State DOT Survey

A survey was designed and distributed to the Midwest Pooled Fund Program member state DOTs to collect information on their use of breakaway luminaire slip base supports. The survey received 13 complete responses from the following states: California (Caltrans), Georgia, Iowa, Illinois, Florida, Wisconsin, Indiana, South Carolina, South Dakota, North Carolina, Minnesota, Nebraska, and New Jersey. Respondents were asked to answer a series of questions about their state's use of slip bases and provide standard plans or specifications, if applicable. The survey, its results, and attachments are reported in Appendix A. An overview of the survey and its findings are detailed below.

2.1.1 Survey Overview

Question 1: The primary survey participant shall complete the following information: name, position title, organization, department/division, phone number, and email address.

The survey respondents provided information about their organizations, positions, and personal information.

Question 2: Please denote if your state uses luminaires supported by 3-bolt slip bases, 4-bolt slip bases, both 3 and 4-bolt slip bases, or does not use slip base systems for breakaway luminaire poles.

Two respondents, Caltrans and Iowa, reported using a 3-bolt slip base, and one respondent, Georgia, denoted the use of a 4-bolt slip base, while 11 respondents (71.4% of all respondents) denoted no use of a slip base or provided a response that was not relevant. Note that Georgia DOT does not have standard plans showing the use of a slip base with luminaire poles, but they do include slip bases as an approved luminaire pole breakaway device in their standard specifications.

Question 3: Please indicate the number of luminaire pole slip base configurations used by your state. Please provide details for each system your state employs for luminaire poles. If you have more than three systems, please contact the survey distributor to provide additional information.

One respondent, Iowa, denoted the use of only one luminaire pole slip base configuration while another respondent, Caltrans, denoted using three different luminaire pole slip base configurations.

Question 4: System 1: Please enter system name and estimate the frequency of use for currently installed Slip Base Supporting Breakaway Luminaire Supports and upload pertinent design details.

Four respondents provided details on the systems used by their state DOTs. Caltrans reported using the Type 15-SB system, which has five arm lengths available (i.e., 6, 8, 10, 12, and 15 ft), and the capability to mount closed-circuit television (CCTV), vehicle detection systems, and roadside signs. This system is torqued to 150 ft-lb. Iowa denoted the use of the Valmont Millerbernd 3-bolt slip base system. Georgia denoted the use of poles with square bases that are attached at each corner, and in rare cases, a round base with 3 or 4 bolts is used. Additional details can be found in Appendix A.

Question 6: System 2: Please enter system name and estimate the frequency of use for currently installed Slip Base Supporting Breakaway Luminaire Supports and upload pertinent design details.

One respondent provided details on an additional system used by the state DOT. Caltrans reported on the use of the Type 30 system, which has five arm lengths available (i.e., 6, 8, 10, 12, and 15 ft), the capability to mount CCTV, vehicle detection systems, and roadside signs. The slip base bolts for this system are torqued to 150 ft-lb.

Question 8: System 3: Please enter system name and estimate the frequency of use for currently installed Slip Base Supporting Breakaway Luminaire Supports and upload pertinent design details.

One respondent provided details on an additional system used by the state DOT. Caltrans reported the use of the Type 31 system which has one arm length available (i.e., 20 ft), the capability to mount CCTV, vehicle detection systems, and roadside signs. The slip base bolts for this system are torqued to 200 ft-lb.

Question 10: For each system, please estimate the percentage of installed systems. The total MUST add up to 100%.

Caltrans reported that approximately 4% of systems installed are Type 15-SB, 75% are Type 30, and 21% are Type 31. Iowa and Georgia denoted that the 100% of systems installed are the system detailed in Question 4.

Question 11: Has your organization developed current practices and/or standard plans regarding the selection and installation of Breakaway Luminaire Poles Supported by a Slip Base? This would include guidance with respect to the range of luminaire pole configurations that your state uses with slip bases and if and how the slip base system varies based on the luminaire pole configuration used.

Twelve respondents denoted "No," meaning their state had not developed practices or plans related to luminaire pole slip base systems. One respondent, Caltrans, denoted "Yes," meaning the state developed practices or plans relating to luminaire pole slip base systems. Note that one response was discarded as it was not relevant to luminaire poles with a slip base.

As a part of their response, Caltrans attached guidance from state DOT plans and specifications, which are provided in Appendix A. Additionally, North Carolina provided pole details for use with a slip base. The response denoted that: (1) poles are typically made of galvanized steel or aluminum, (2) pole diameter, thickness, and mass vary based on design, (3) pole heights range from 35 to 45 ft, (4) mast arms can be either in a single or dual configuration, and (5) mast arms are generally 15 ft long.

Question 14: Does your organization change the slip base configuration based on the luminaire pole design?

Eleven respondents selected "No," meaning their state did not alter slip base configuration based on luminaire pole design. Two respondents, Caltrans and Georgia, denoted "Yes," meaning their state did alter the slip base configuration based on the luminaire pole design. Note that one response was discarded as it was not relevant to luminaire poles with a slip base.

Caltrans denoted that clamp bolt torques were adjusted based on the pole type designation. Georgia denoted that the design relies on the pole's diameter, height, and base shape.

Question 17: Does your organization have knowledge of safety concerns or performance issues with prior or current Breakaway Luminaire Supports with 3- or 4-bolt Slip Bases identified through in-service performance evaluation, maintenance records, full-scale crash testing, or other means?

Twelve respondents denoted "No," meaning their state did not have concerns about safety or performance of luminaire pole slip base systems. One respondent, Caltrans, denoted "Yes," meaning the state did have concerns about safety or performance of luminaire pole slip base systems. Note that one response was discarded as it was not relevant to luminaire poles with slip bases.

Caltrans denoted older designs had problems with fatigue cracking of anchor bolts, clamp bolts, and post-to-base connections. To address these problems, Caltrans increased bolt circles, bolt diameters, and clamp bolt torque while reducing mast arm length to a maximum of 20 ft. Caltrans also noted that in-service activation problems are difficult to report due to legal and confidentiality issues. Caltrans did mention that similar slip base systems in recent low-speed MASH crash tests were not activated. Additional crash test details are available in Section 2.3.6.

Question 20: Does your state allow additional attachments to slip base mounted luminaire poles? This would include items like cell phone transmitters, wireless internet transmitters, solar power boxes, cameras, or any other additional hardware mounted to the luminaire support outside of the mast arm and light.

Twelve respondents denoted "No," meaning their state did not allow additional attachments on luminaire pole slip base systems. One respondent, Caltrans, denoted "Yes," meaning their state did allow additional attachments on luminaire pole slip base systems. Note that one response was discarded as it was not relevant to luminaire poles with slip bases.

Caltrans specified that the state typically restricts electronics to small and lightweight items mounted near the system's center of mass. Larger items, such as sign panels, are mounted no more than 12 ft from the base, though additional restrictions may be placed in the future based on the low likelihood of passing MASH occupant compartment deformation limits due to the placement of sign panels. Also, Caltrans does not typically allow solar panels or battery packs to be mounted on poles unless their mass is considered insignificant. Additionally, Caltrans raised concern about the challenges posed by small cell site equipment and its impact on weight and performance in windy conditions.

Question 23: What is the typical size and configuration of the wiring for the luminaire pole?

Eight respondents provided comments on wiring. Of these, four states indicated that their DOT does not use slip base systems or that the question was not applicable. North Carolina reported using a 12 AWG Type SOOW cord from the pole to the luminaire.

One respondent noted using No. 10 copper wiring, continuous from the luminaire to the controller. Another respondent mentioned the use of 4c 4AWG direct-buried cable to the pole and 12-2 UF cable within the pole. Another respondent indicated that the state does not use standard wiring, with the size and configuration determined by the lighting system design

Question 24: Is there additional wiring for other attached hardware or devices? If so, please provide details.

Five respondents provided comments on additional wiring. Of these five respondents, three states noted that the question did not apply. Two respondents noted that no other attachments are allowed or that their systems are not designed to incorporate additional hardware or devices.

Question 25: Do your state utilize/require breakaway wiring connections for slip base supported luminaire poles? If so, please provide details on the breakaway wiring connector used.

Eight respondents provided comments on breakaway wiring. Of these eight respondents, two states noted that the question did not apply. Two other respondents had comments that did not apply to the question. One respondent noted that live wire for luminaires should be kinked to ensure the pole is de-energized after a crash, and for additional wiring, an unplugging connection is requested. Another respondent noted that breakaway fuse holders are required for single and dual arm poles. Another respondent noted that breakaway couplings are required for breakaway pole systems. Minnesota noted that there is an approved product list for breakaway fuses, but there is an issue with the breakaway of the neutral wire with the live wires, though the state is working with a manufacturer to break away the two live wires and the neutral wire with one device. Additional plans and specifications provided in response to the question are included in Appendix A.

2.1.2 Survey Summary

A total of 14 respondents participated in the survey. The survey results showed that some Midwest Pooled Fund Program member DOTs utilize luminaire poles with breakaway slip bases; however, standards and designs vary across states. Generally, each state uses a single slip base design for a specific pole model, though arm lengths may differ. Based on the survey results, the only parameter altered in the slip base design is bolt torque, which varies depending on the pole type, as noted by Caltrans. Several states do not have guidelines developed for luminaire pole slip base systems. There are concerns related to clamp bolt fatigue and poor breakaway performance (i.e., failure of the slip base to activate). Attachments to the luminaire pole slip base systems are typically restricted to small, lightweight devices, and states use a variety of wiring configurations.

Given the limited number of survey respondents and the limited details provided on luminaire slip base systems, a more in-depth review of state DOT plans and drawings was required to understand common designs and practices.

2.2 State DOT Luminaire Pole Slip Base Standard Plans

Of the 14 responses received from the slip-base survey sent to Midwest Pooled Fund Program member states, three state DOTs (California, Iowa, and Georgia) reported the use of luminaire poles with slip bases. An additional search was conducted to identify other states with standard plans for luminaire pole slip bases. Three other state DOTs within the Midwest Pooled Fund Program (Utah, Wyoming, and North Carolina) and five non-Midwest Pooled Fund Program member states (Arizona, North Dakota, West Virginia, Washington, and Oregon) had standard details for luminaire pole slip bases. The following sections provide a summary of the standard drawings for luminaire poles with slip bases from these state DOTs.

2.2.1 Caltrans Slip Base Design

In the survey, Caltrans was one of two respondents that stated they utilized different slip bases depending on the size of the pole. Type 15-S, Type 30, and Type 31 luminaire poles account for 4%, 75%, and 21% of poles with slip bases in use, respectively. The Type 30 slip base detail can be used to mount either the Type 15-S, Type 30, or Type 31 luminaire poles. Note that the Type 15-S luminaire pole has a 3-bolt mounting design, though it is a modified version of the 4-bolt Type 15 luminaire pole. Since there are no standard drawings available for the 4-bolt Type 15 slip base and it is not used in the Type 15-S, Type 30, or Type 31 systems (which, according to the survey, constitute 100% of installed systems), only the 3-bolt Type 30 slip base is discussed herein.

The Type 30 slip base is a typical 3-bolt configuration, as shown in Figures 1 and 2 [8]. The slip base uses 1-in. diameter clamp bolts, with heavy hex nuts in a 14-in. diameter bolt circle. The clamp washers are 2.76 in. x 1.97 in. x ½ in. with a center hole diameter of 1.063 in. Each clamp bolt is placed in a 60-degree, ½-in. radius slot in the top plate, with each bolt torqued to 150 ft-lb for Type 15-S and Type 30 pole designs, and to 200 ft-lb for the Type 31 pole design. The top plate is 1¼ in. thick and 13¾ in. x 13¾ in. wide. The keeper plate is 0.0149 in. thick and is 13¾ in. x 13¾ in. wide with a 9-in. center hole diameter. The slip plate has a total thickness of 2½ in., with an upper portion measuring 1½ in. and bottom portion measuring 1 in., and a center hole diameter of 5 in. The slip plate is secured by 1-in. diameter anchor bolts, with heavy hex nuts, arranged in a 15-in. diameter bolt circle. The Type 30 slip base is identical to those used in Caltrans full-scale crash test, including test nos. 616, 617, 618 under NCHRP Report 350 criteria, as well as test nos. 430MASHC17-01, 430MASHC20-01, and 430MASHC22-01, which are discussed in Sections 2.3.5 and 2.3.6 [9].

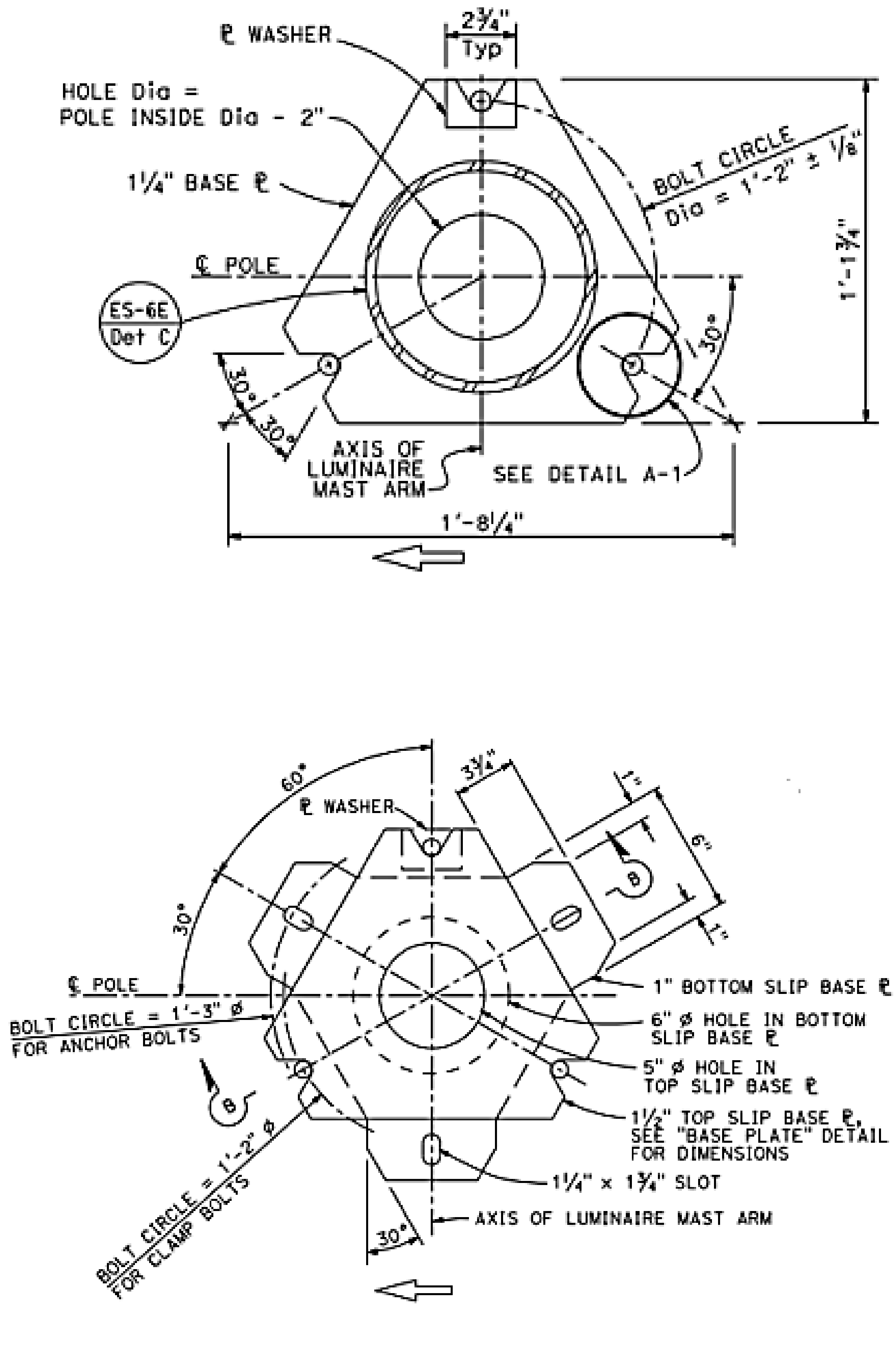


Figure 1. Caltrans Type 30 Slip Base Details [8]

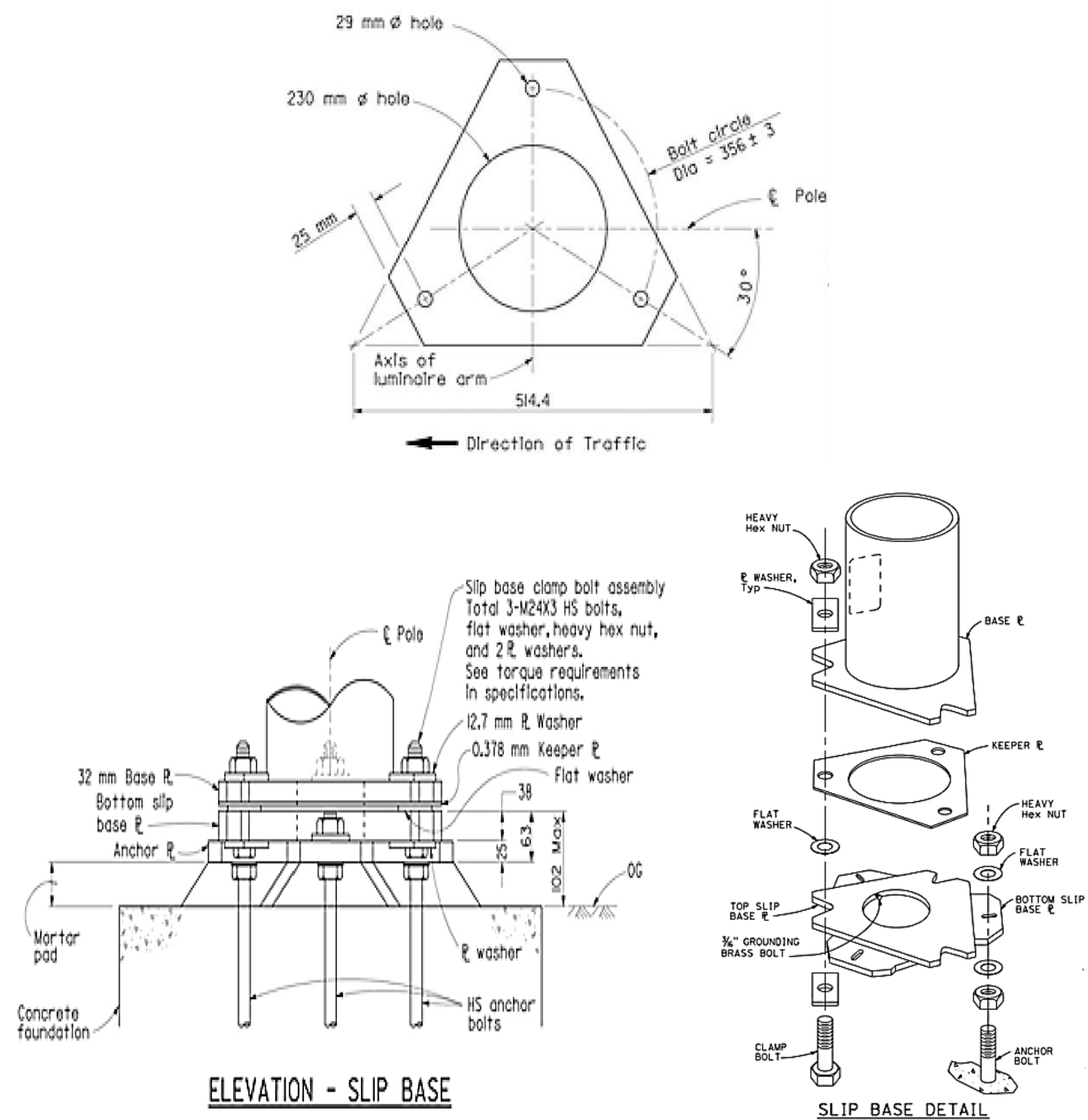
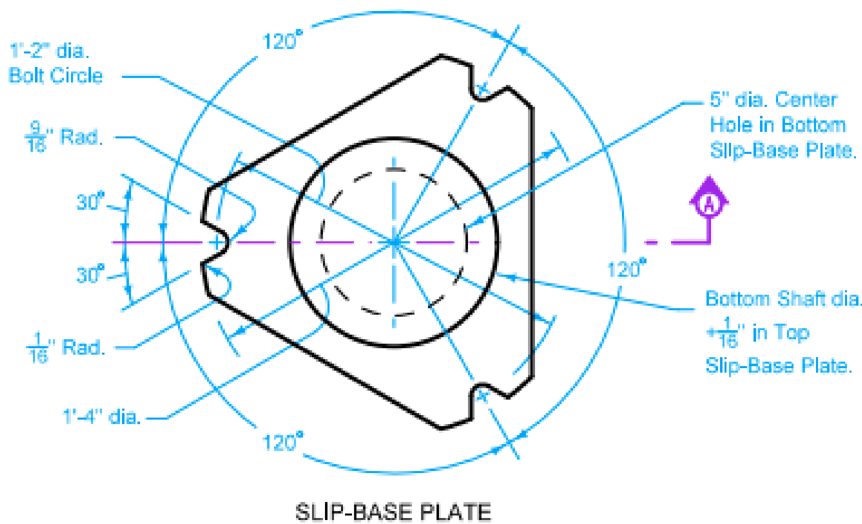


Figure 2. Caltrans Type 30 Slip Base Details, Cont. [8]

2.2.2 Iowa DOT Slip Base Design

In the survey, Iowa DOT reported that the Valmont Millerbernd system made up 100% of installed luminaire pole slip base systems. The Valmont Millerbernd slip base follows a typical 3-bolt configuration, as shown in Figures 3 and 4 [10]. The slip base uses 1-in. diameter, 4½-in. long clamp bolts with heavy hex nuts in a 14-in. diameter bolt circle. The clamp washers measure 3½ in. x 2 in. x 5/16 in. with a center hole diameter of 1⅛ in. Each clamp bolt is placed in a 60-degree, 9/16-in. radius slot in the top plate, with each bolt being torqued to 83⅓ ft-lb. The top slip base plate is 1¼ in. thick and is an inscribed triangle, with the enclosing circle 16 in. in diameter. The keeper plate is 0.0149 in. thick and is an inscribed triangle, with the enclosing circle 16 in. in diameter. The anchor slip plate is 2½ in. thick in total, with an upper portion thickness of 1½ in. and bottom portion thickness of 1 in., and a center hole diameter of 6 in. The anchor slip plate is secured by 1-in. diameter anchor bolts with heavy hex nuts in a 14-in. diameter bolt circle.



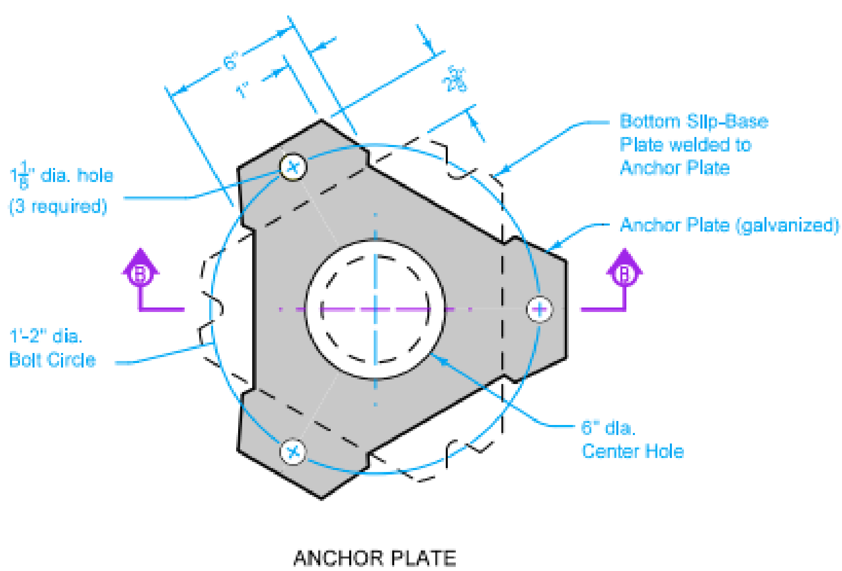
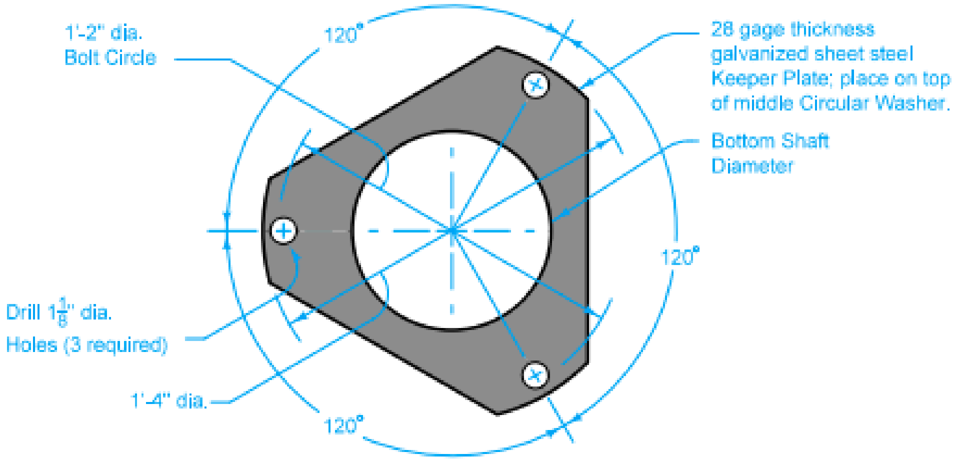


Figure 3. Iowa DOT Valmont Millerbernd Slip Base Details [10]



KEEPER PLATE

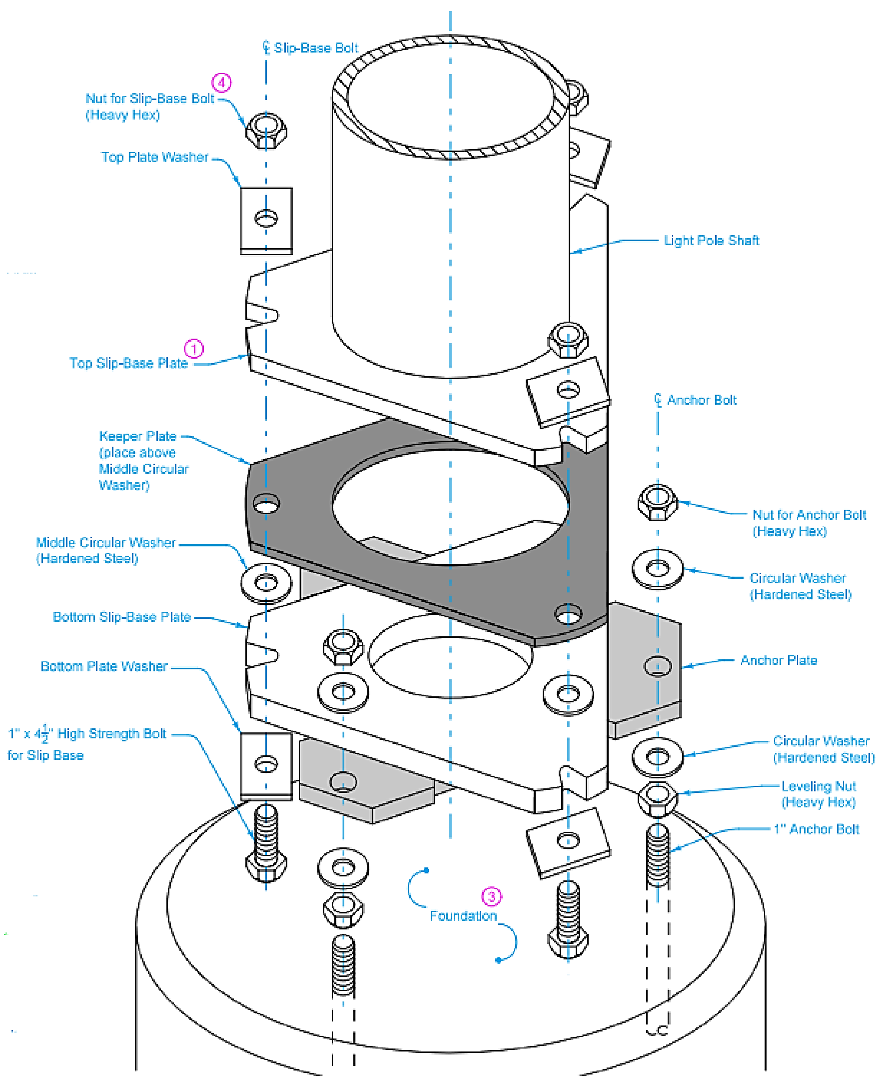


Figure 4. Iowa DOT Valmont Millerbernd Slip Base Details, Cont. [10]

2.2.3 Georgia DOT Slip Base Drawings

In the survey, Georgia DOT stated the use of 4-bolt slip bases, though no additional details were provided. Georgia DOT was one of two respondents that mentioned the use of different slip bases depending on the size of the pole, but no developed practices or standard plans were mentioned. Georgia DOT's standard drawings detailing luminaire pole designs could not be located, thus details could not be verified.

Of note, the Georgia Lighting Standards and Towers specifications states that steel lighting structures can be "attached to an approved breakaway device, such as slip base, aluminum transformer base, breakaway couplings, etc., when so specified." This is the only mention of a luminaire pole slip base in both the standard drawings and lighting specifications.

2.2.4 Utah DOT Slip Base Design

Utah DOT uses luminaire poles with slip bases and has standard plans along with additional lighting guidance [11, 12]. Utah utilizes a typical 4-bolt slip base system, as shown in Figure 5. The slip base shown in the drawings is identical to the those used in Utah DOT-sponsored full-scale crash test nos. USBLM-1 and USBLM-2 [5], which are discussed in Section 2.3.2. The clamp bolts are first torqued to 80 ft-lb, then loosened, and re-torqued to 70 ft-lb.

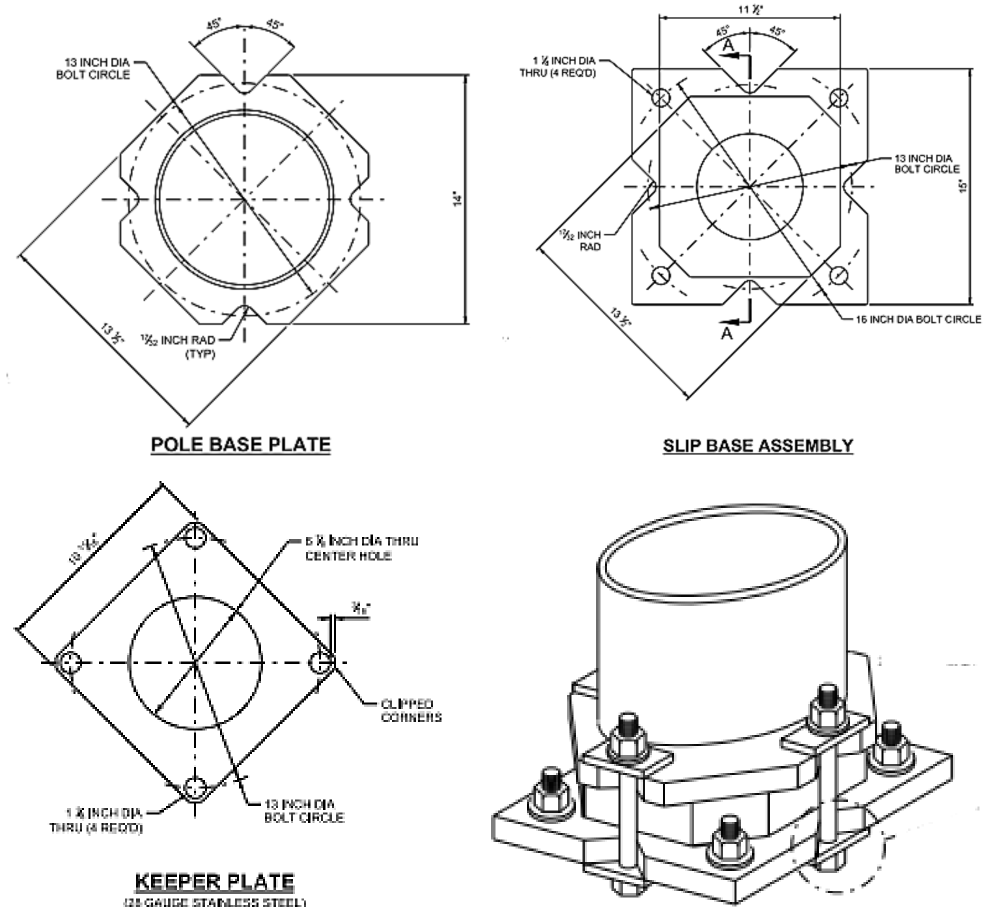


Figure 5. Utah DOT Slip Base Details [11]

2.2.5 Wyoming DOT Slip Base Details

Although Wyoming DOT did not respond to the project survey, this state does use luminaire slip bases and has standard plans. However, slip base drawings used by Wyoming DOT were not found in the most recent plan set. Thus, the slip base drawings included in this report are derived from the crash test report discussed in Section 2.3.4 [13, 14]. Note that the 4-bolt slip base in the drawings is similar to the those used in Wyoming DOT full-scale crash test nos. 472280-1, 472280-2, 472280-3 [14], and WRCG-1 [15].

The slip base is secured by 1-in. diameter bolts with heavy hex nuts in a 13-in. diameter bolt circle. Each bolt is placed in a 90-degree, $\frac{17}{32}$-in. radius slot in the top plate, with each bolt torqued to 80 ft-lb, loosened, then retightened to 70 ft-lb. The top plate is 1 in. thick and 13½ in. x 13½ in. wide. The keeper plate is 0.01563 in. thick and is 10$\frac{11}{16}$ in. x 10$\frac{11}{16}$ in. wide with a 6¾-in. center hole diameter. The slip plate is 2½ in. thick in total, with an upper portion thickness of 1½ in., a bottom portion thickness of 1 in., and a center hole diameter of 6¾ in. The slip base plate is 15 in. x 15 in. and secured by 1-in. diameter bolts with heavy hex nuts in a 13-in. diameter bolt circle. Drawings of the Wyoming DOT slip base are provided in Figures 6 and 7.

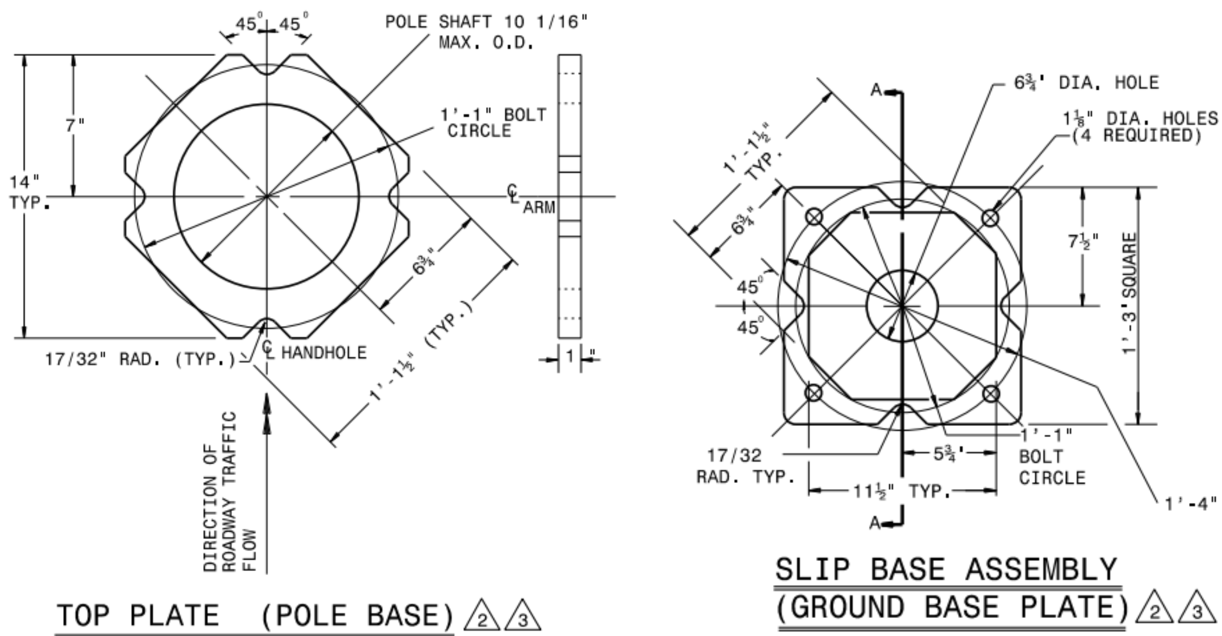


Figure 6. Wyoming DOT Slip Base Details [14]

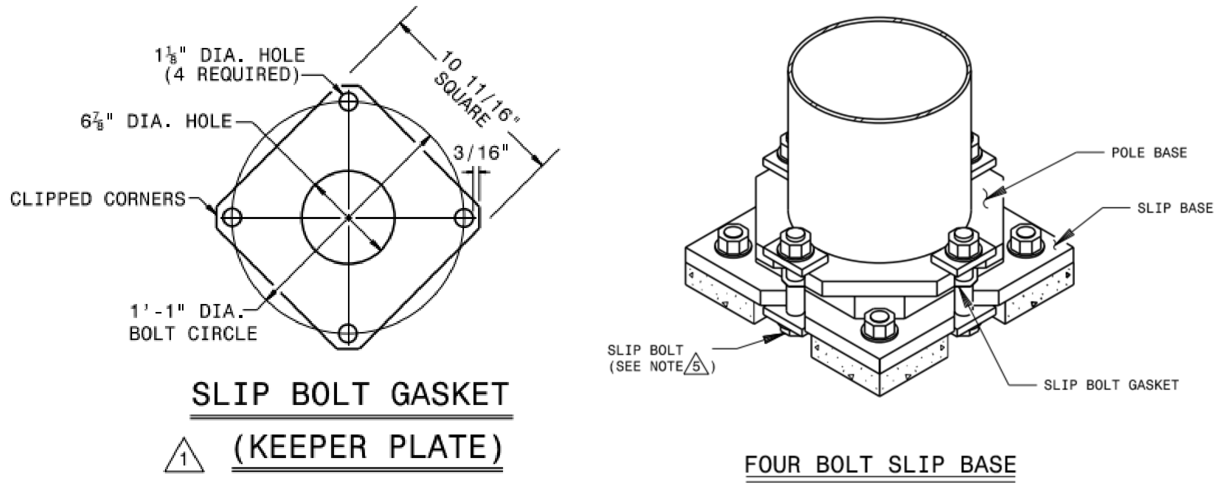


Figure 7. Wyoming DOT Slip Base Details, Cont. [14]

2.2.6 North Carolina DOT Slip Base Design

North Carolina DOT uses a luminaire slip base, as shown in their standard plans [16]. North Carolina DOT utilizes what appears to be a unique 4-bolt slip base system. Minimal details are available, with only a single drawing found. Details are provided in Figure 8.

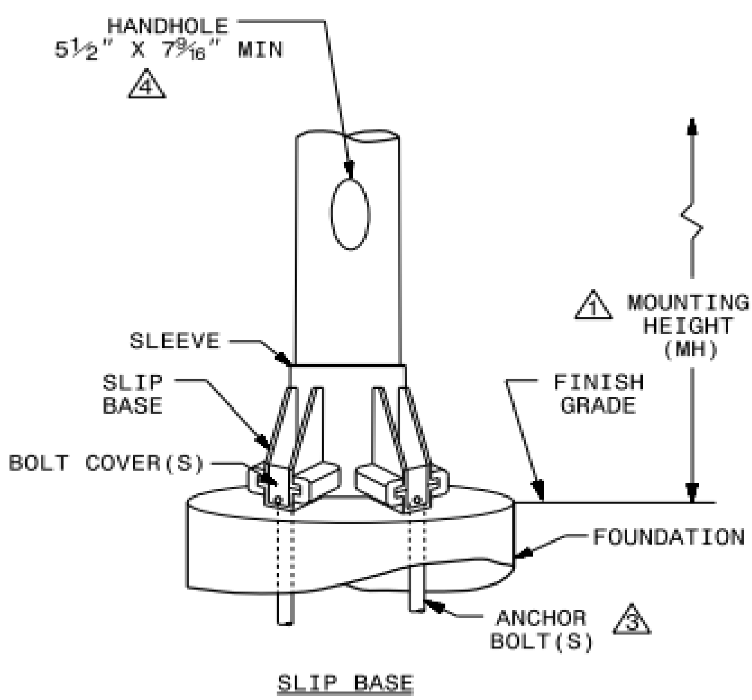


Figure 8. North Carolina DOT Slip Base [16]

2.2.7 North Dakota DOT Slip Base Details

North Dakota DOT is not a part of the Midwest Pooled Fund Program, but their standard plans for luminaire poles with a typical 3-bolt slip base were located and reviewed [17]. The slip base is secured by 1¼-in. diameter bolts with heavy hex nuts. Each bolt is placed in a 60-degree, $^{11}/_{16}$-in. radius slot in the top plate, with each bolt torqued to 83⅓ ft-lb. The top plate is 1¼ in. thick. The keeper plate is 0.0149 in. thick. The slip plate is 2½-in. thick in total, with an upper portion thickness of 1½ in. and bottom portion thickness of 1 in. Additional details, such as bolt circle diameters, were either not provided or are dependent on the shaft diameter of the mounted luminaire pole. Note that North Dakota is the only state in the literature review that adjusts the physical parameters of the slip base (e.g., clamp bolt circle and anchor bolt circle) based on the manufacturer-provided shaft diameter of the pole. Drawings of the North Dakota DOT slip base are provided in Figure 9.

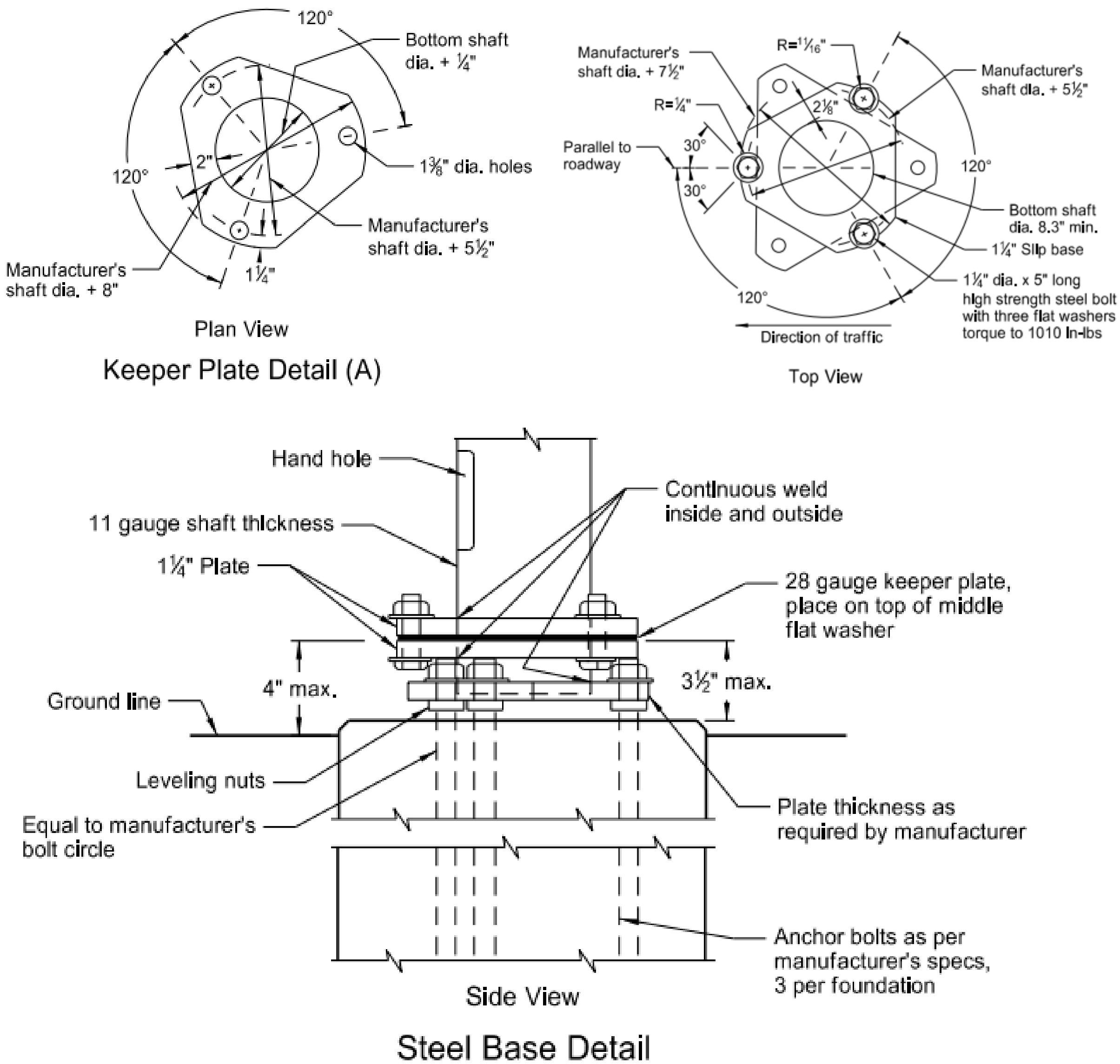


Figure 9. North Dakota DOT Slip Base Details [17]

2.2.8 West Virginia DOT Slip Base Design

West Virginia DOT is not a part of the Midwest Pooled Fund Program, and their current standard plans do not have drawings of slip base. However, the 1994 plan set had luminaire slip base standard plans which were thought to be unique and useful [18]. West Virginia utilized a typical 3-bolt slip base system, with details presented in tabular form, as shown in Figure 10. This system is distinctive because, unlike other DOTs, West Virginia DOT adjusted the dimensions of the slip base based on the mounted luminaire pole in their 1994 plan set. The only other state DOT that modifies the slip base dimensions based on the luminaire pole is North Dakota, as discussed in Section 2.2.7. The various values shown in Figure 10 correspond to the luminaire pole slip base drawings in Figure 11.

	SLIP BASE ASSY.							ANCHOR BOLTS		POLE BASE ℄			CONN. BOLTS	Tw
	LOWER BASE ℄				CTR. ℄		H							
DIA.	B.C.	I.D.	W1	T	W2	T		P	SIZE	B.C.	O.D.	T		
7.0	10"	5"	10⅝"	1"	10¾"	1½"	2½"	2¼"	1"x40"	11½"	13¼"	¾"	⅝"x3¾"	¼"
7.5	10½"		11"		10⅞"									
8.0	11"		11⅜"	1¼"	11⅞"	1¾"	3"	2¾"	1¼"x48"	12¾"	14½"		¾"x4"	
8.5	11½"		11¾"									1"	¾"x4¼"	
9.0	12½"	7"												

	DIA.	B.C.	I.D.	W1	T	W2	T	H	P	SIZE	B.C.	O.D.	T	CONN. BOLTS	Tw
1.	8.5	11½"	5"	11¾"	1½"	11⅞"	2"	3½"	3¼"	1½"x60"	12¾"	14½"	1"	⅞"x5"	⅜"
2.	9.0	12½"	7"										1¼"	1"x5¼"	

(1.) USE THIS DATA FOR 8.5" POLES WITH 45'-0" MTG. HGT.
(2.) USE THIS DATA FOR 9.0" POLES WITH 45'-0" & 50'-0" MTG. HGT.

Figure 10. West Virginia DOT Luminaire Slip Base Design Table (Out-of-date) [18]

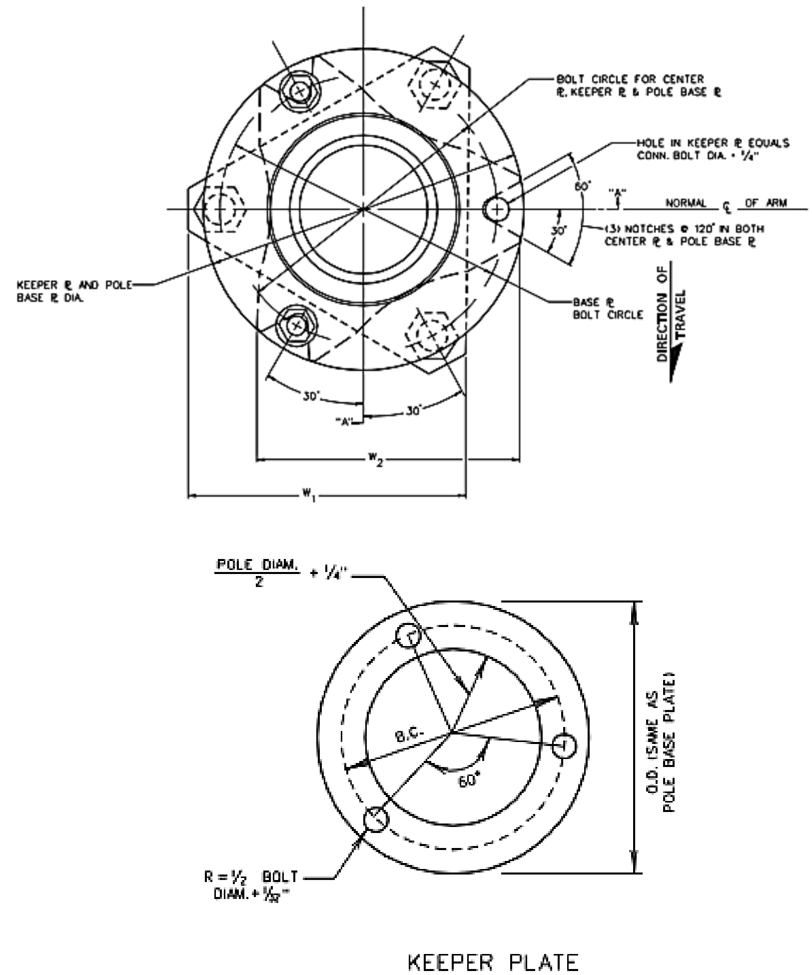


Figure 11. West Virginia DOT Slip Base Design (Out-of-date) [18]

Note that these drawings were included in West Virginia DOT's 1994 standard plan set but are not present in the current 2019 plan set. The West Virginia DOT appears to prefer transformer bases, as these have remained in the current plan set used by the state.

2.2.9 Washington DOT Slip Base Details

Washington DOT is not a part of the Midwest Pooled Fund Program, but their standard plans for luminaire poles with a typical 3-bolt slip base were found in their 2023 standard plans [19]. The slip base is secured by 1⅛-in. diameter bolts with heavy hex nuts. The bolt torque varies depending on the arm configurations, with 90 ft-lb for a single arm and 100 ft-lb for dual arms. The top plate is 1¼ in. thick and the keeper plate is 0.0299 in. thick. The slip plate is 2½ in. thick in total, with an upper portion thickness of 1¼ in. and bottom portion thickness of 1¼ in. The slip bolt circle is 15 in. Drawings of the slip base are provided in Figure 12.

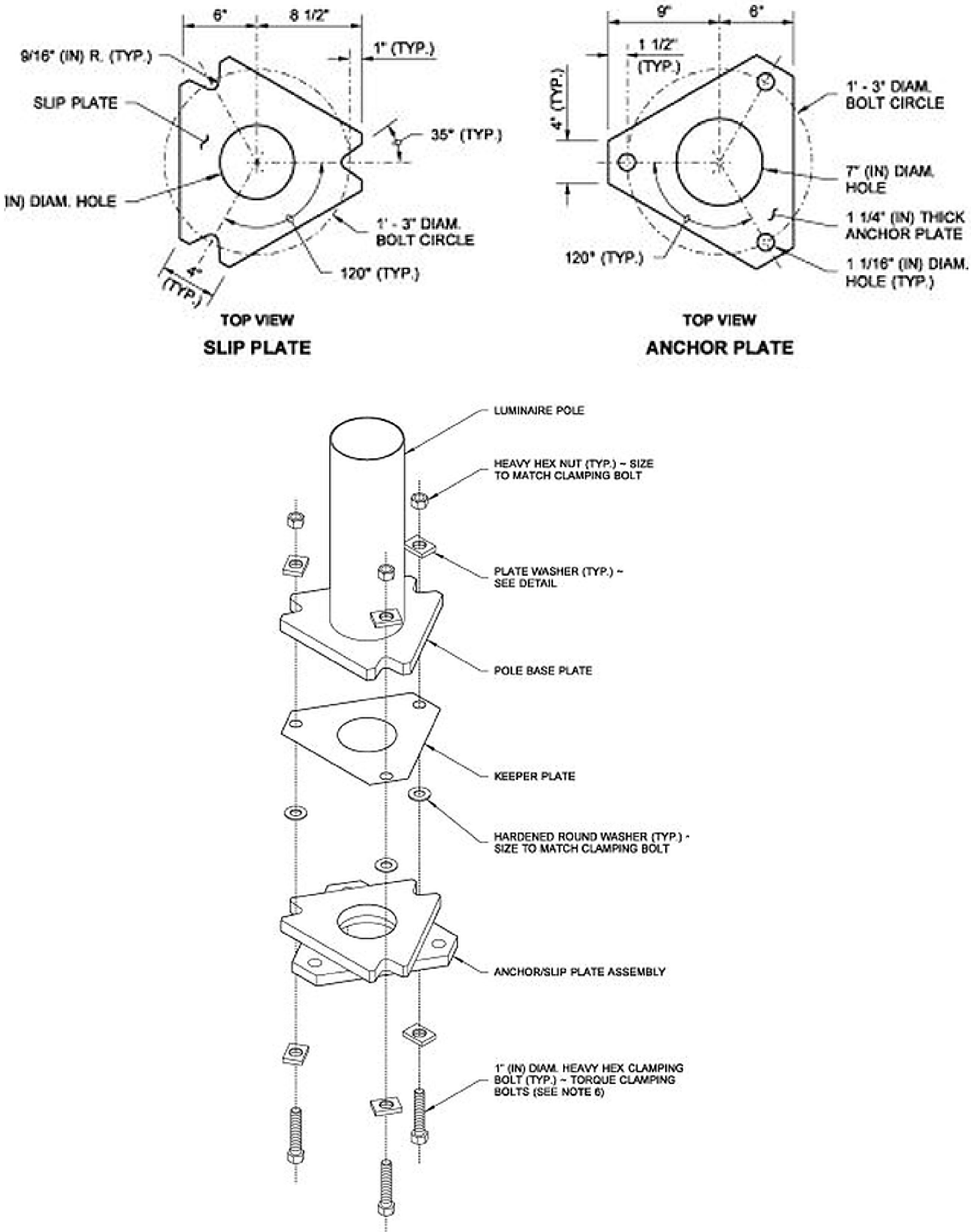


Figure 12. Washington DOT Slip Base Details [19]

2.2.10 Oregon DOT Slip Base Details

Oregon DOT is not a part of the Midwest Pooled Fund Program, but their standard plans for luminaire poles with a typical 3-bolt were found in their standard drawings [20]. The slip base is secured by 1⅛-in. diameter bolts with heavy hex nuts. The bolt torque varies depending on the number of arms, with 90 ft-lb for a single arm and 100 ft-lb for dual arms. The top plate is 1¼ in. thick and the keeper plate is 0.0299 in. thick. The slip plate is 2½ in. thick in total, with an upper portion thickness of 1¼ in. and bottom portion thickness of 1¼ in. The slip bolt circle is 15 in. Drawings of the slip base are provided in Figures 13 and 14.

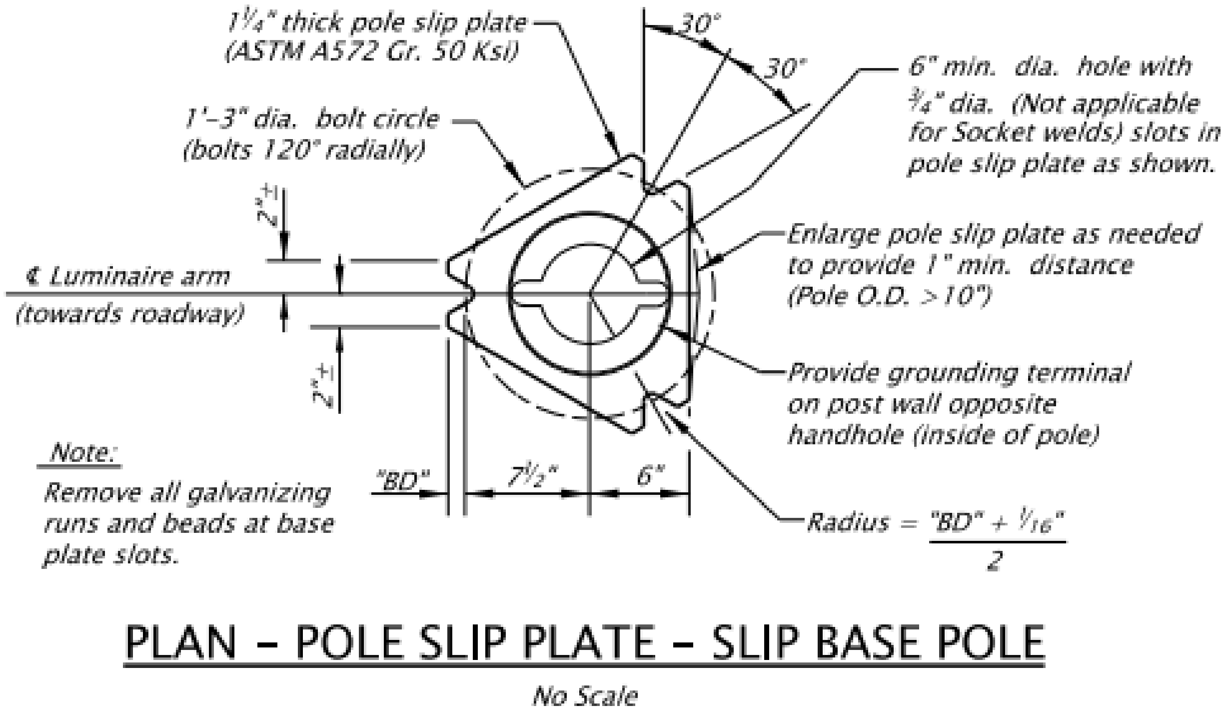


Figure 13. Oregon DOT Slip Base Details [20]

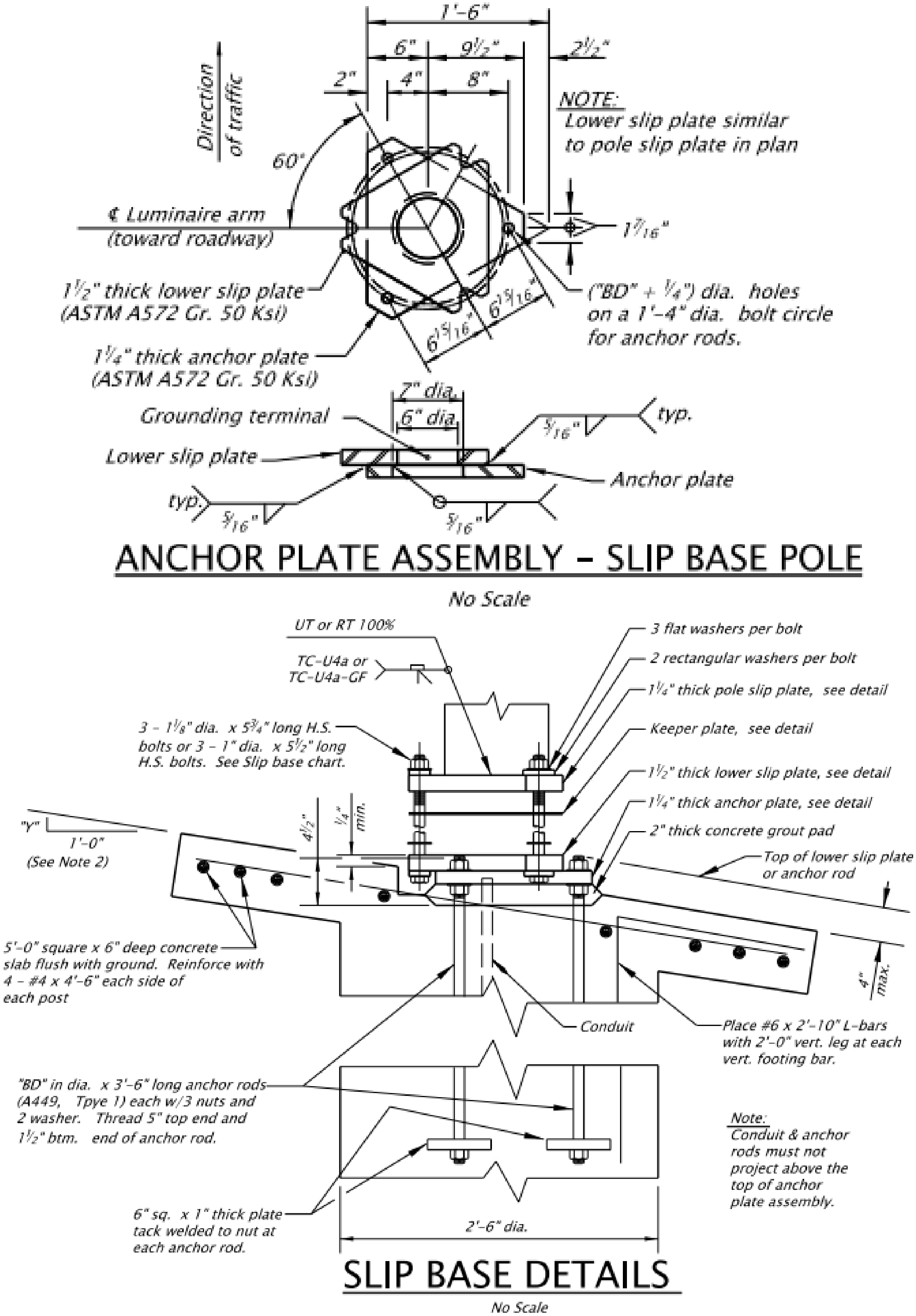


Figure 14. Oregon DOT Slip Base Details, Cont. [20]

2.2.11 Arizona DOT Slip Base Details

Arizona DOT is not a part of the Midwest Pooled Fund Program, and current standard plans for luminaire poles with a slip base were not found. However, an older plan set with luminaire pole slip base drawings was located. These drawings showed a fairly typical 3-bolt slip base that was used in a series of crash tests, which are further discussed in Section 2.3.3.

The Arizona slip base plans were not available through the DOT website, instead located in the report for the crash test discussed in Section 2.3.3 and in the presentation "Arizona DOT Statewide Light Pole Slip-Away Base Replacement Prioritization" by Arizona DOT and Greenlight Traffic Engineering [21]. The presentation's focus was on the replacement of luminaire pole slip base systems due to undesirable performance. Although the presentation does not present an alternative to luminaire pole slip base breakaway devices, it is assumed that luminaire pole transformer base breakaway devices were used to replace slip base systems and are the current standard since the current plan set published by Arizona DOT only has luminaire pole aluminum transformer base breakaway devices. The outdated Arizona slip base drawings are shown in Figure 15.

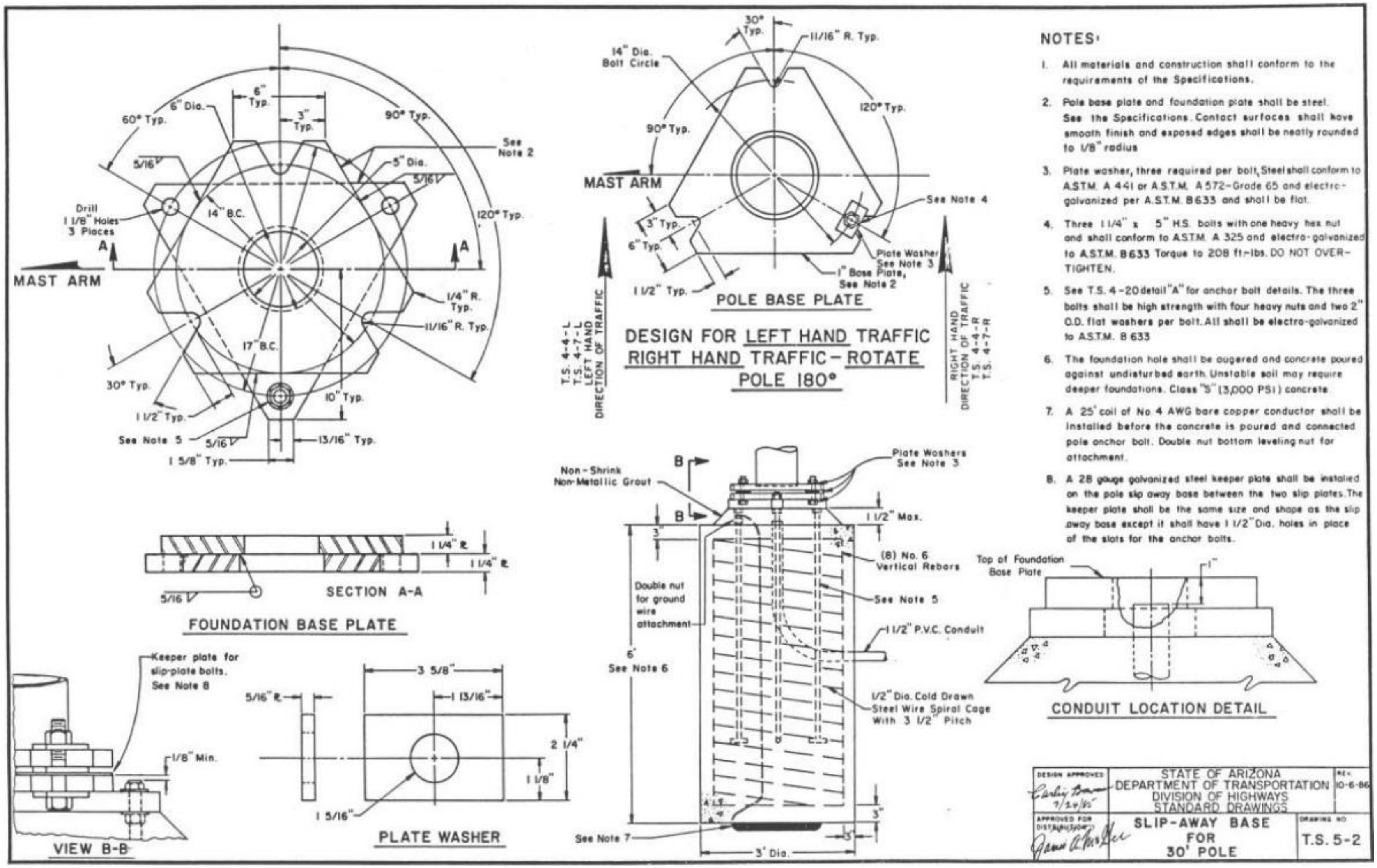


Figure 15. Arizona DOT Slip Base Details (Out-of-date) [21]

2.3 Previous Slip Base Luminaire Full-Scale Crash Tests

Over the past forty years, a total of 20 full-scale crash tests have been conducted on various luminaire poles supported by slip bases. These tests were conducted by MwRSF, Texas Transportation Institute (TTI), or Caltrans, with each test using the most current evaluation criteria available at the time. The evaluation criteria used are outlined in NCHRP Report No. 230 [22], NCHRP Report No. 350 [23], or MASH [2].

2.3.1 Lightweight Luminaire Systems

In 1984, a series of tests were conducted by MwRSF on various lightweight luminaire pole systems [24]. Test nos. 404 and 405 involved a 35-ft tall steel luminaire with one single 20-ft long mast arm mounted on a 3-bolt breakaway slip base. The pole had a wall thickness of 0.179 in. and was tapered to the top, with a bottom diameter of 10⅞ in. and a top diameter of 6 in. The pole was made of galvanized steel and weighed approximately 883 lb. The systems shared many similarities with the Caltrans Type 31 luminaire system. The luminaire pole configuration is shown in Figure 16.

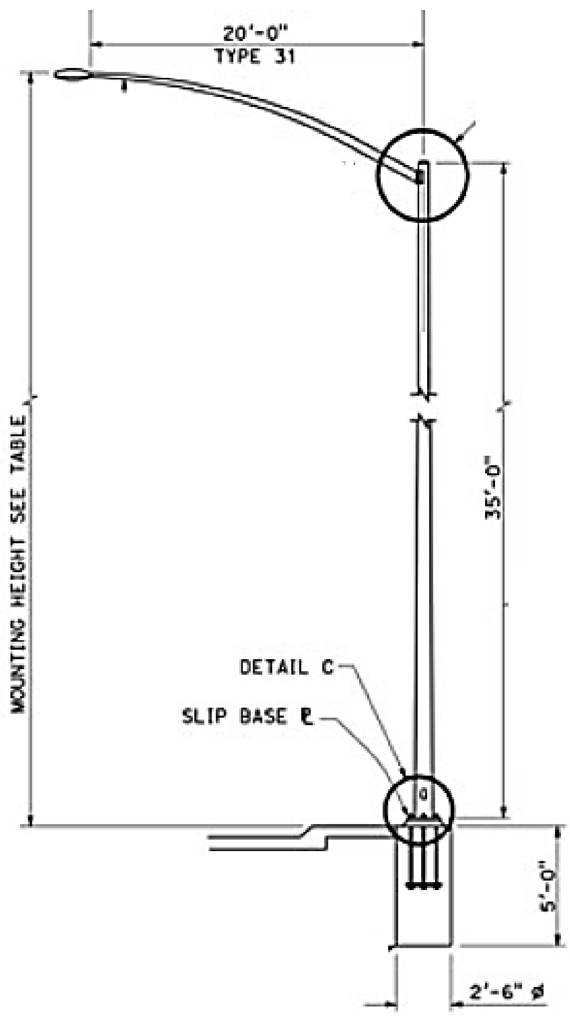


Figure 16. Caltrans Type 31 Luminaire System – Test Nos. 404 and 405 [24]

A modified Caltrans Type 31 luminaire system with a 3-bolt slip base was used in test nos. 406 and 407, conducted under NCHRP Report 230 criteria. This system shares similar features with test nos. 404 and 405, also conducted under NCHRP Report 230 criteria, with the following exceptions: (1) the pole height was 33 feet, (2) the pole base diameter was 10 in., (3) the pole top diameter was 5⅜ in., (4) the pole wall thickness was 0.1193 in., and (5) the pole weighed 627 lb.

In test no. 404, a 2,015-lb Honda Civic impacted the luminaire pole at a speed of 19.9 mph and an angle of 30 degrees according to the recommended procedures outlined in NCHRP Report No. 230. The target impact point was the centerline of the vehicle, aligned with the centerline of the luminaire pole. In this test, the vehicle impacted the pole and the slip base engaged. The pole rolled over the vehicle's hood and roof, causing minimal damage to the vehicle. However, the top of the pole and the mast arm sustained significant damage from the impact with the ground. The recorded occupant impact velocity (OIV) was 8.5 ft/s and the occupant ridedown acceleration (ORA) was 5.4 g's. The test did not meet the structural adequacy criteria. Note that there were no posttest photographs taken at the time of the test. Sequential photographs of the test are shown in Figure 17.

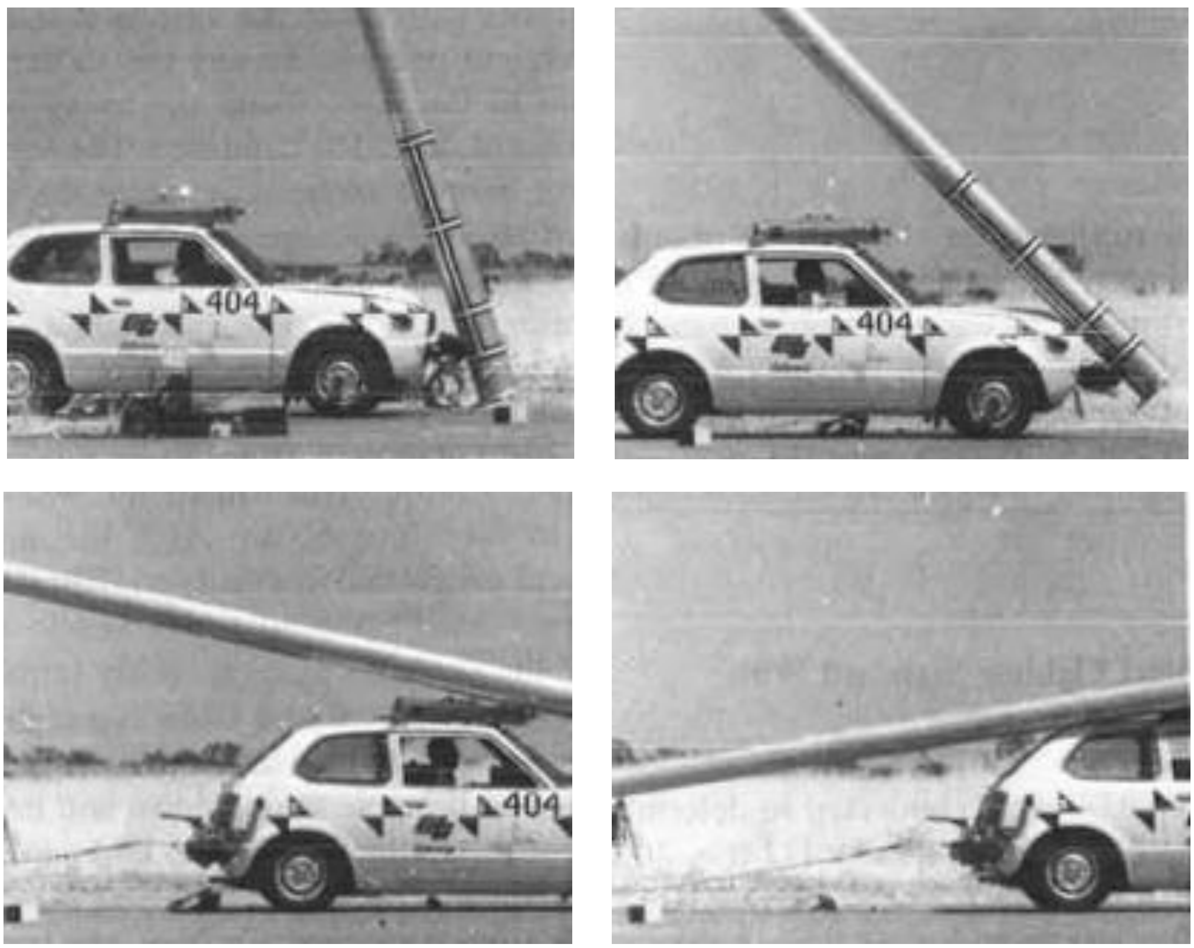


Figure 17. Sequential Photographs, Test No. 404 [24]

In test no. 405, a 2,050-lb Honda Civic impacted the luminaire pole at a speed of 53.9 mph and at an angle of 30 degrees according to the recommended procedures outlined in NCHRP

Report No. 230. The target impact point was approximately 13 in. to the right of the vehicle's centerline. In this test, the vehicle impacted the pole, and the slip base engaged. The pole did not fall onto the vehicle, but there was significant damage to the top of the pole and the mast arm from the impact on the ground. The vehicle's bumper was severely deformed, though the rest of the vehicle sustained minimal damage. The recorded OIV was 12.4 ft/s and the ORA was 7.2 g's. The test did not meet the structural adequacy criteria. There were no posttest photographs taken at the time of the test. Sequential photographs of the test are shown in Figure 18.

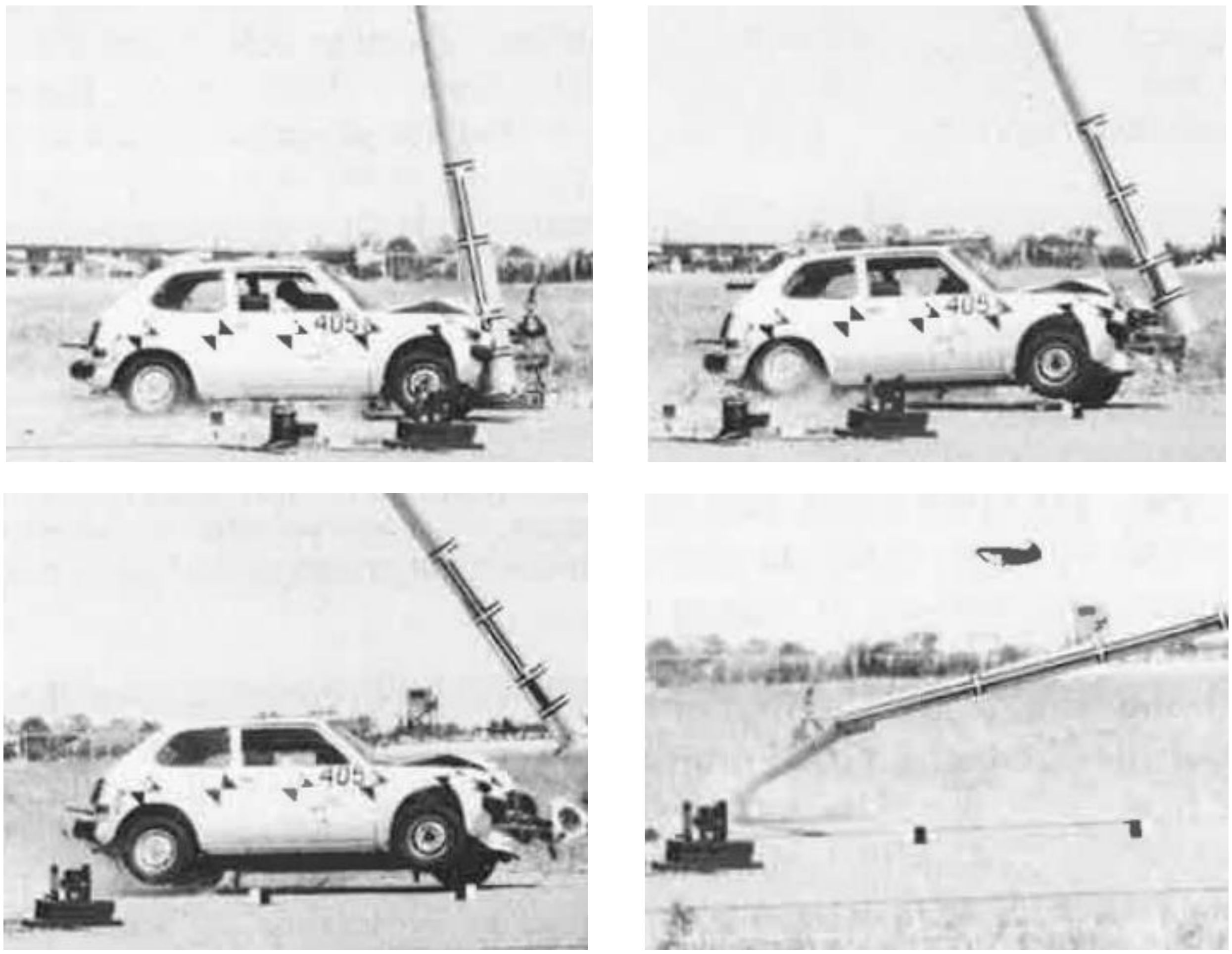


Figure 18. Sequential Photographs, Test No. 405 [24]

In test no. 406, a 2,015-lb Honda Civic impacted the luminaire pole at a speed of 58.8 mph and an angle of 30 degrees according, in accordance with NCHRP Report No. 230. The target impact point was approximately 19 in. to the right of the vehicle's centerline. In this test, the pole did not fall onto the vehicle, though there was significant damage to the top of the pole and mast arm from the impact on the ground. The recorded OIV was 13 ft/s and the ORA was 7.2 g's. The test did not meet the structural adequacy criteria. Sequential photographs of the test are shown in Figure 19.

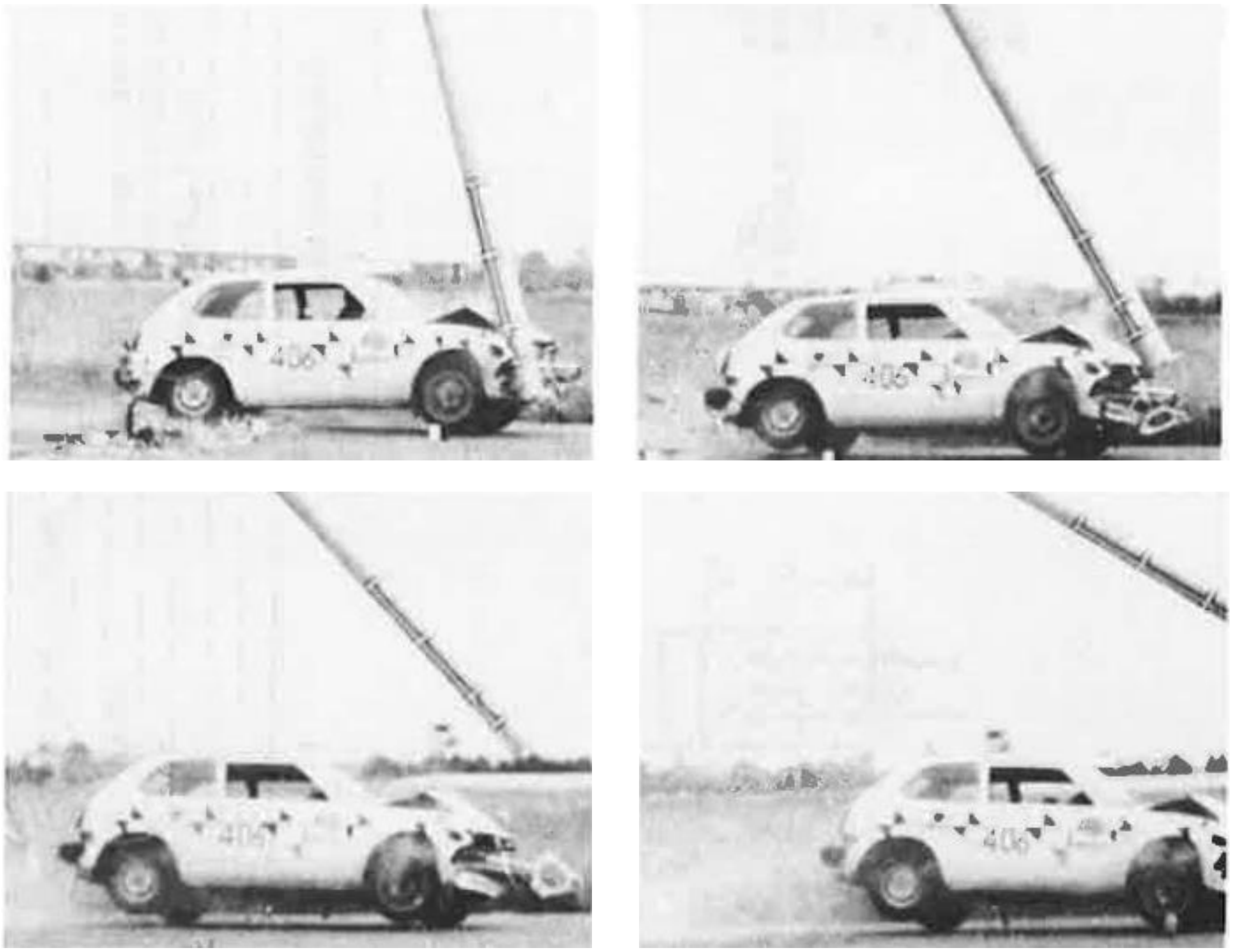


Figure 19. Sequential Photographs, Test No. 406 [24]

In test no. 407, a 2,015-lb Honda Civic impacted the luminaire pole at a speed of 23.7 mph and at an angle of 30 degrees, in accordance with NCHRP Report No. 230. The target impact point was approximately 3 in. to the right the centerline of the vehicle aligned with the centerline of the luminaire pole. In this test, the pole did not fall onto the vehicle, though there was significant damage to the top of the pole and mast arm from the impact with the ground. The recorded OIV was 8.6 ft/s and the ORA was 5.7 g's. The test did not meet the structural adequacy criteria. Sequential photographs of the test are shown in Figure 20.

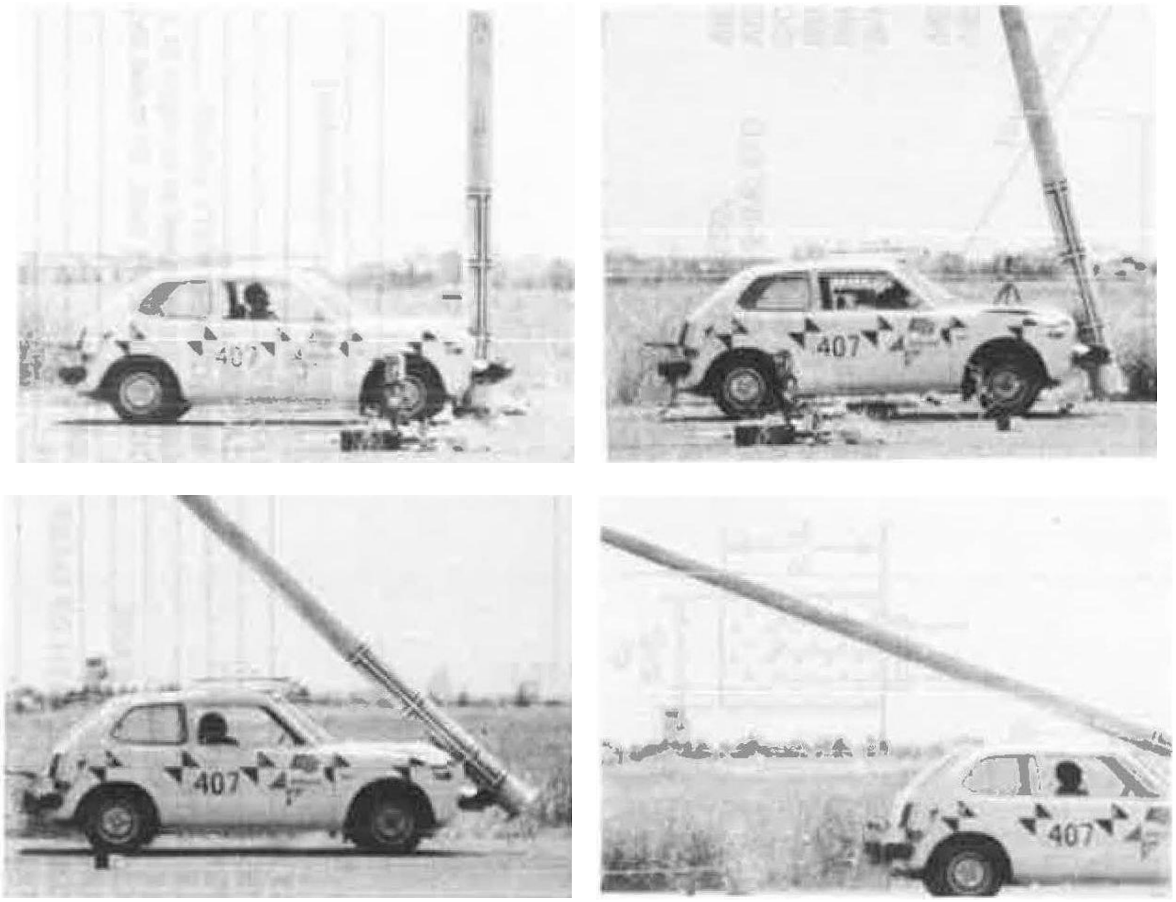


Figure 20. Sequential Photographs, Test No. 407 [24]

2.3.2 Utah Luminaire Pole System Full-Scale Crash Tests

Test nos. USBLM-1 and USBLM-2, conducted on the Utah DOT system, involved a 52-ft steel luminaire pole with dual 15-ft mast arms attached 10 in. below the top of the pole mounted on a 4-bolt slip base [5]. The pole had a bottom diameter of 10 in. and was tapered to a top diameter of 3 in. with a wall thickness of 0.125 in. The pole was made of ASTM A595 Grade A steel and weighed approximately 902 lb. The slip base was secured by 1-in. diameter bolts with heavy hex nuts in a 13-in. diameter bolt circle. Each bolt was placed in a 60-degree, $\frac{17}{32}$-in. radius slot in the top plate, with each bolt torqued to 70 ft-lb. The top plate was 1 in. thick and 13½ in. x 13½ in. wide. The keeper plate was 0.0149 in. thick and was $10\frac{9}{16}$ in. x $10\frac{9}{16}$ in. wide with a 6¾-in. center hole diameter. The slip plate was 2½ in. thick in total, with an upper portion measuring 1½ in. and the lower portion 1 in. thick. The center hole diameter was 6¾ in. The ground slip plate was secured by 1-in. diameter anchor bolts with heavy hex nuts in a 16-in. diameter bolt circle. The anchor bolts were doweled into the existing concrete surface using high strength epoxy and grout. The luminaire pole configuration and slip base are shown in Figures 21 and 22, respectively.

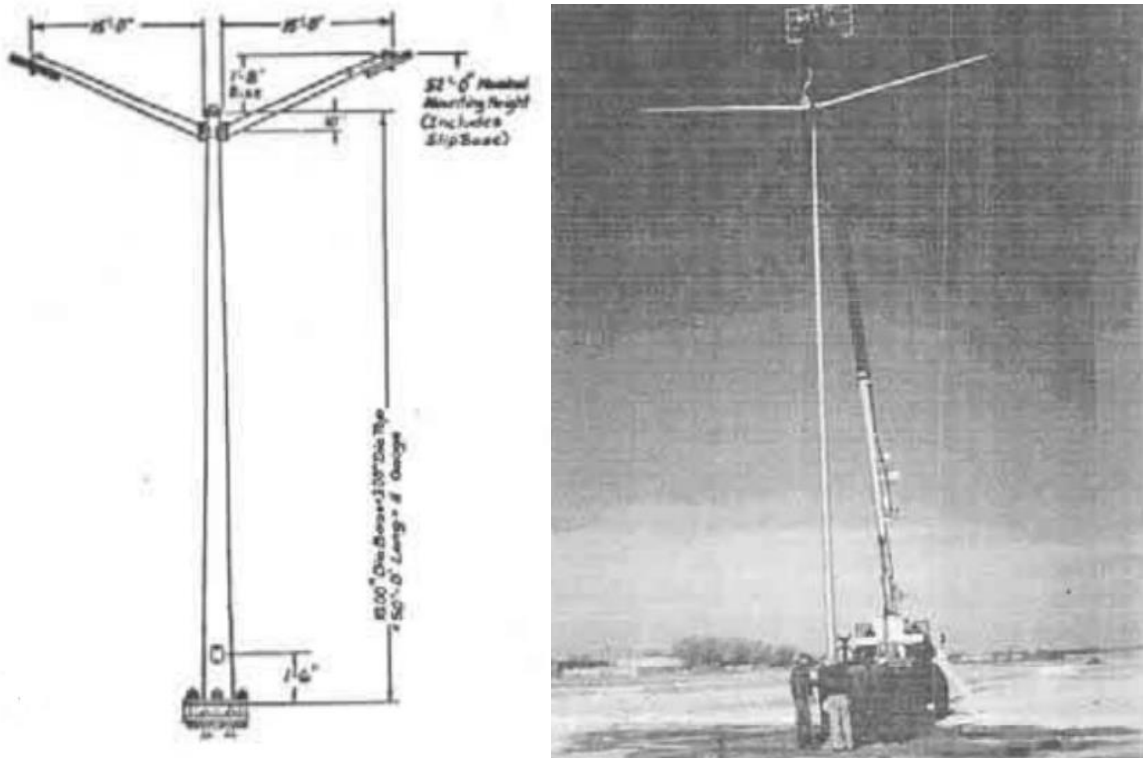


Figure 21. Utah DOT Luminaire Pole System, Test Nos. USBLM-1 and USBLM-2 [5]

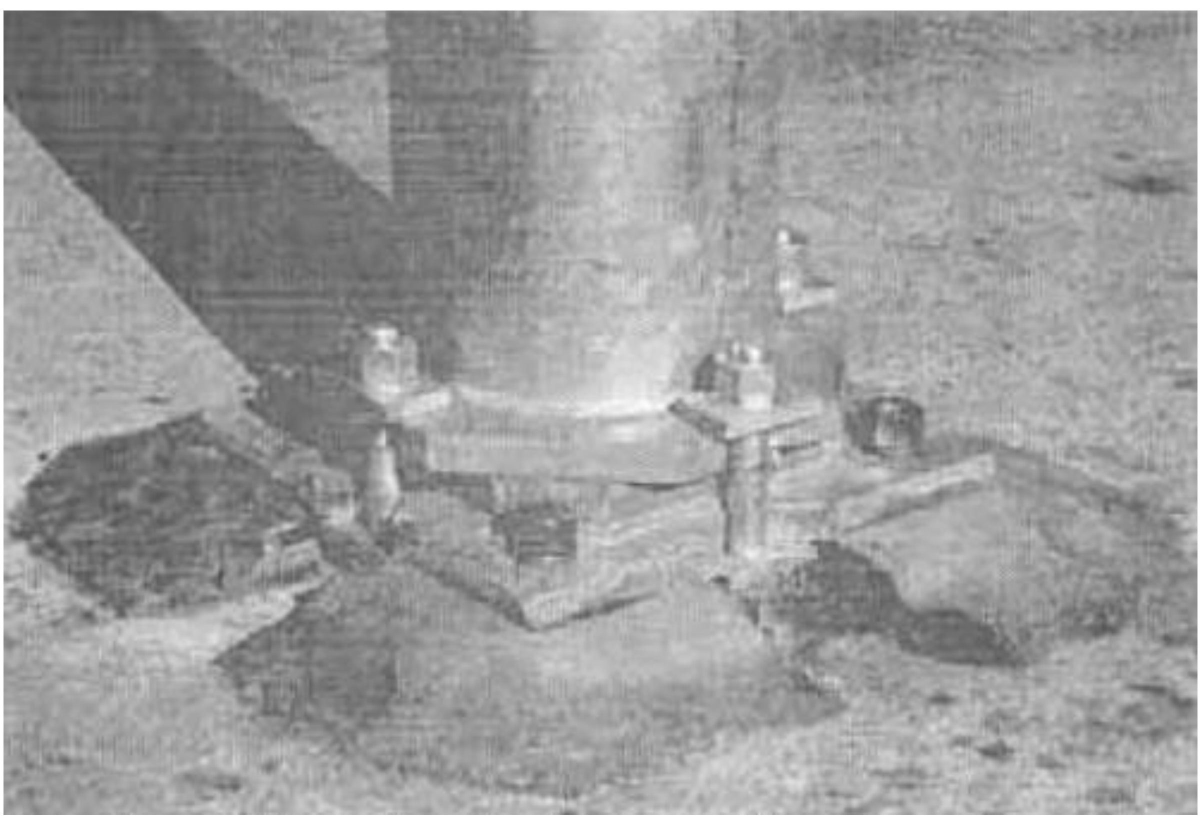


Figure 22. Utah Slip Base, Test Nos. USBLM-1 and USBLM-2 [5]

In test no. USBLM-1, a 1,750-lb Dodge Colt impacted the luminaire pole at a speed of 15 mph and an angle of 0 degrees, in accordance with NCHRP Report No. 230 test designation no. 3-62. The target impact point was the vehicle's centerline aligned with the centerline of the luminaire pole. The slip base engaged up impact and the pole fell onto the roof of the vehicle, though damage was minimal to both vehicle and pole, as shown in Figure 23. The recorded OIV was 7.6 ft/s and the ORA was 3.5 g's. The test met all NCHRP Report No. 230 safety criteria.

Figure 23. Post-Test Photograph, Test Nos. USBLM-1 [5]

Test no. USBLM-2 used the same Dodge Colt as test no. USBLM-1 after the vehicle was repaired. The 1,750-lb vehicle impacted the luminaire pole at a speed of 57.5 mph and an angle of 0 degrees, in accordance with NCHRP Report No. 230 test designation no. 3-63. The target impact point was the centerline of the vehicle aligned with the centerline of the luminaire pole. Upon impact, the vehicle struck the pole and the slip base engaged. The pole did not fall onto the vehicle, but there was significant damage to the top of the pole from the impact with the ground. The vehicle sustained minimal damage, as shown in Figure 24. The recorded OIV was 14.2 ft/s and the ORA was 1 g. The test met all NCHRP Report No. 230 safety criteria for test designation no. 3-63.

Figure 24. Post-Test Photograph, Test No. USBLM-2 [5]

2.3.3 Arizona Luminaire Pole System Full-Scale Crash Tests

In 1994, a series of tests were conducted by TTI on a luminaire system used by the Arizona DOT [25]. Test nos. 472360-1 and 472360-2 involved a 45-ft tall steel luminaire with one single 20-ft long mast arm mounted on a 3-bolt slip base. The pole had a 7-gauge wall thickness and was tapered to the top, with a bottom diameter of 10 in. and a top diameter not being measured. The pole was made of ASTM A595 Grade A steel and weighed approximately 997 lb. The luminaire pole and slip base are shown in Figures 25 and 26. Test no. 472360-3 used the same system hardware as test nos. 472360-1 and 472360-2, except in test no. 472360-3 the pole was 40-ft tall and the pole weighed approximately 850 lb. Note that the slip base utilized in the full-scale crash tests are identical to the slip base design discussed in Section 2.2.11 and is no longer utilized in the Arizona DOT standard plans.

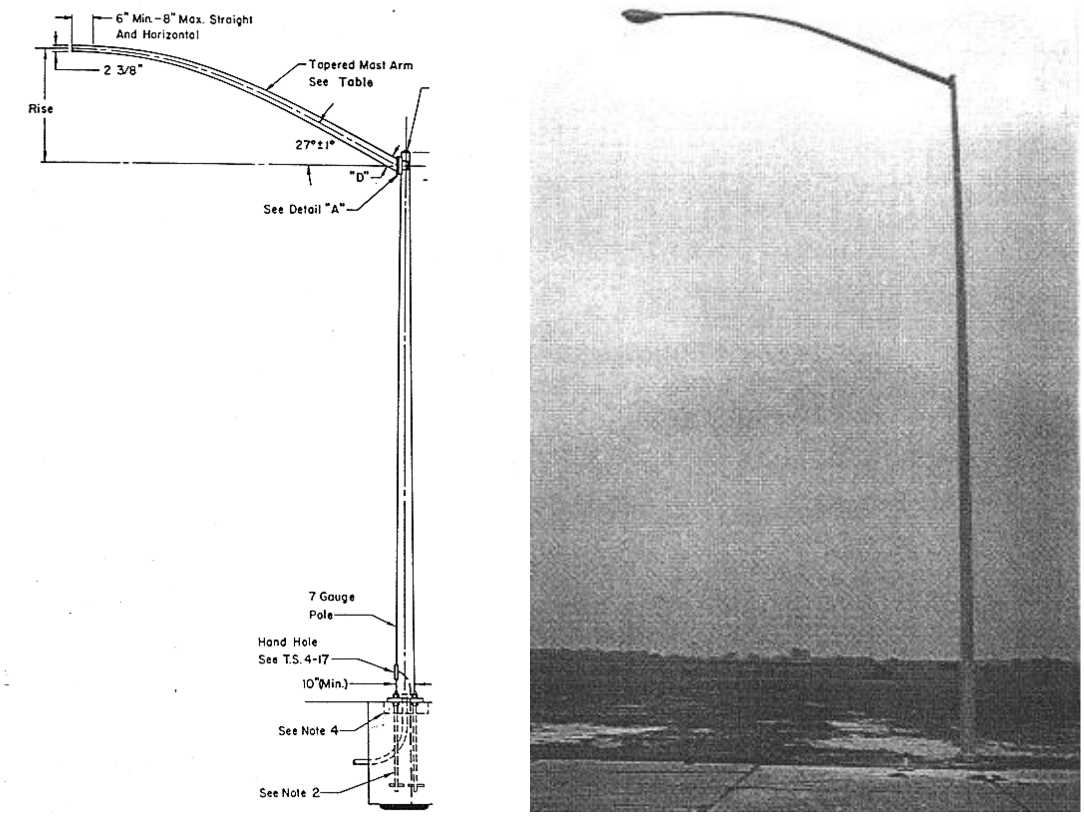


Figure 25. Arizona Luminaire Pole System, Test Nos. 472360-1 and 472360-2 [25]

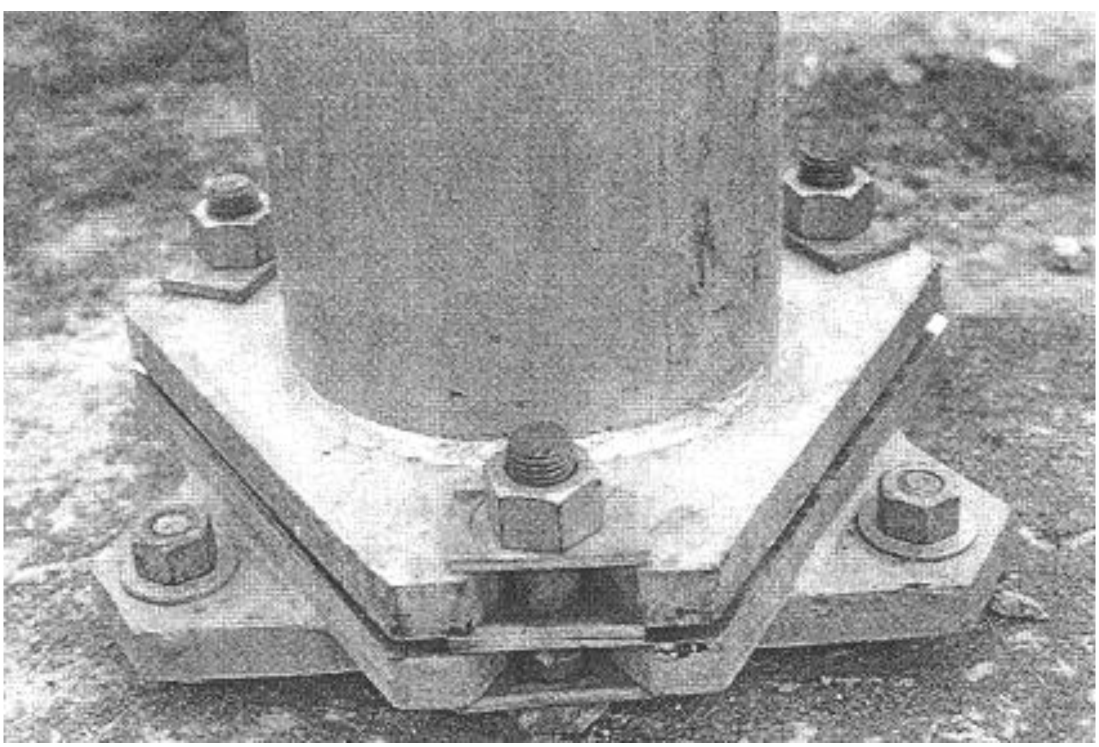


Figure 26. Arizona Slip Base, Test Nos. 472360-1, 472360-2, and 472360-3 [25]

In test no. 472360-1, an 1,808-lb Subaru Justy impacted the luminaire pole at a speed of 63.5 mph and an angle of 0 degrees, in accordance with NCHRP Report No. 350 test designation no. 3-61. The target impact point was the centerline of the vehicle aligned with the centerline of the luminaire pole. In this test, the vehicle impacted the pole and the slip base engaged. The pole did not fall onto the vehicle, as shown in Figure 27, though there was significant damage to the top of the pole and mast arm from the impact with the ground, shown in Figure 28. The vehicle's bumper was severely deformed, though there was little damage to the rest of the vehicle. The recorded OIV was 16.4 ft/s and the ORA was 1.6 g's. Although the OIV was equivalent to the OIV limit in NCHRP Report No. 350, the OIV did not exceed the limit of 16.4 ft/s, thus the test met all evaluation criteria.

Figure 27. Vehicle Damage, Test No. 472360-1 [25]

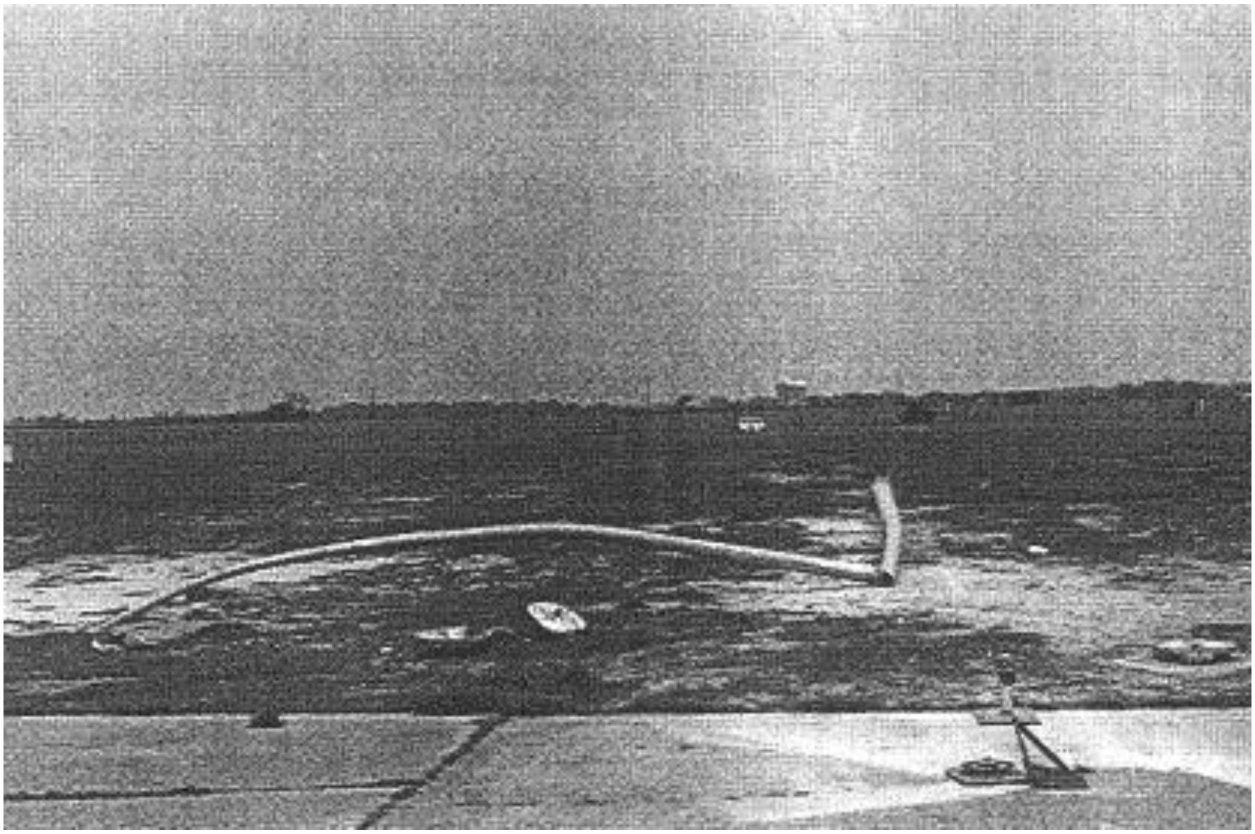


Figure 28. Luminaire Pole Damage, Test No. 472360-1 [25]

In test no. 472360-2, an 1,808-lb Subaru Justy impacted the luminaire pole at a speed of 22.2 mph and an angle of 0 degrees, in accordance with NCHRP Report No. 350 test designation no. 3-60. The target impact point was the centerline of the vehicle aligned with the centerline of the luminaire pole. In this test, upon impact, the slip base engaged. The pole fell onto the roof of the vehicle and caused significant deformation of the roof, with a maximum roof crush of 6.5 in., as shown in Figure 29. The top of the luminaire pole was damaged and the mast arm detached from the pole, as shown in Figure 30. The recorded OIV was 8.6 ft/s and the ORA was 3.2 g's. Although NCHRP Report No. 350 did not define a specific limit for occupant compartment deformation, the testing agency (TTI) determined that there was "severe deformation of or intrusion into the occupant compartment from the roof crush." Based on this engineering judgment, the test failed to meet the occupant risk criteria under NCHRP Report No. 350 and a system redesign was initiated.

Figure 29. Vehicle Damage, Test No. 472360-2 [25]

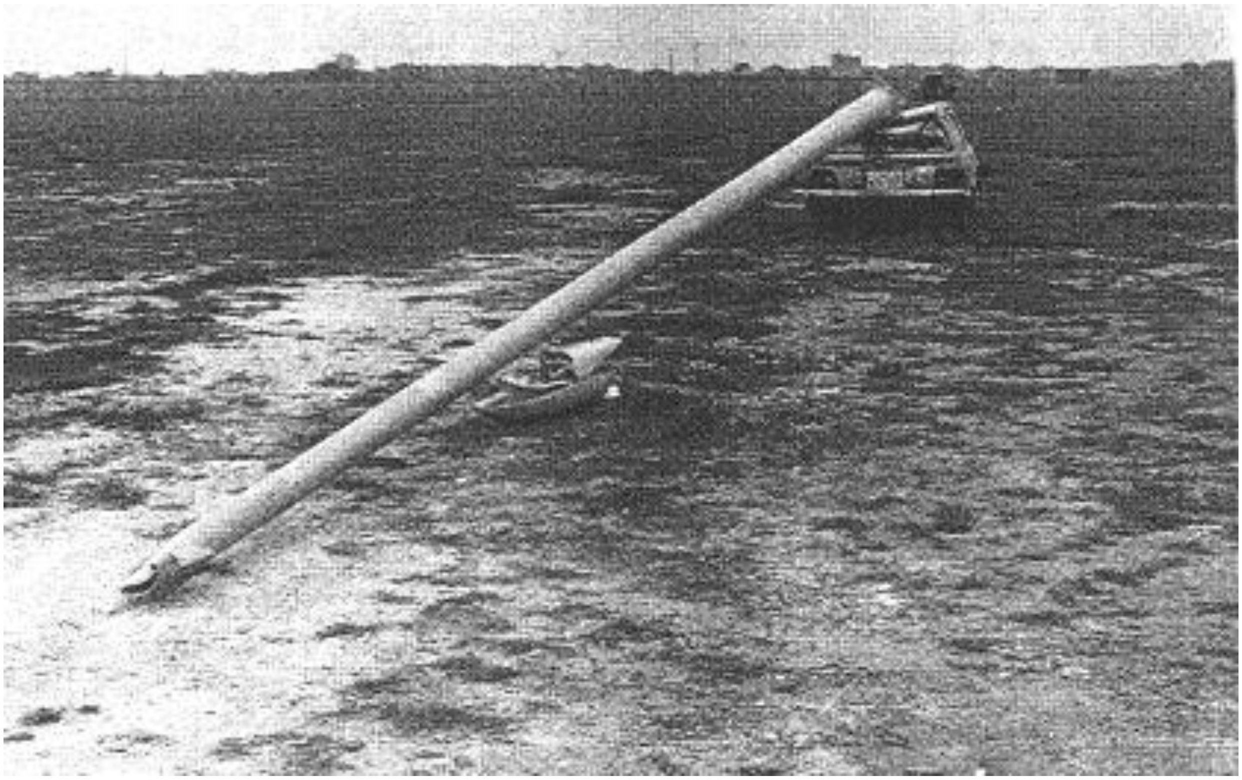


Figure 30. Luminaire Pole Damage, Test No. 472360-2 [25]

In test no. 472360-3, an 1,808-lb Subaru Justy impacted the luminaire pole at a speed of 22.2 mph and an angle of 0 degrees, in accordance with NCHRP Report No. 350 test designation no. 3-60. The target impact point was the centerline of the vehicle aligned with the centerline of the luminaire pole. Upon impact, the slip base was activated and broke away. The pole fell onto the roof of the vehicle, deforming the roof by 4.7 in., as shown in Figure 31. The top of the luminaire pole was damaged and the mast arm detached from the pole, as shown in Figure 32. The recorded OIV was 9.3 ft/s and the ORA was 2.4 g's. The test was deemed marginally acceptable as it met the evaluation criteria of the time. Note that there was no limit to occupant compartment deformation under NCHRP Report No. 350. However, under current MASH crash testing standards, test no. 472360-3 would not pass evaluation due to the occupant compartment deformation exceeding the 4.0-in. limit.

Figure 31. Vehicle Damage, Test No. 472260-3 [25]

Figure 32. Luminaire Pole Damage, Test No. 472360-3 [25]

2.3.4 Wyoming DOT Road Closure Luminaire Pole System Full-Scale Crash Tests

Test no. 472280-1, conducted on the Wyoming system, involved an 18-ft tall steel pole with a single 8-ft mast arm mounted on a 4-bolt breakaway slip base [14]. The pole had a 24-ft long fiberglass and aluminum gate arm mounted 4 ft above the ground when in the down position. The pole had a bottom diameter of 9 in. and was tapered to a top diameter of 6½ in. with a wall thickness of 0.125 in. The pole material was ASTM A595 Grade A steel and weighed approximately 800 lb. The slip base was secured by 1-in. diameter bolts with heavy hex nuts in a 13-in. diameter bolt circle. Each bolt was placed in a 90-degree, $\frac{17}{32}$-in. radius slot in the top plate, with each bolt torqued to 80 ft-lb. The top plate was 1 in. thick and 13½ in. x 13½ in. wide. The keeper plate was 0.01563 in. thick and was 10$\frac{11}{16}$ in. x 10$\frac{11}{16}$ in. wide with a 6¾-in. center hole diameter. The slip plate was 2½ in. thick in total, with an upper portion thickness of 1½ in. and bottom portion thickness of 1 in., and a center hole diameter of 6¾ in. The slip plate is secured by 1-in. diameter bolts, with heavy hex nuts, in a 16-in. diameter bolt circle.

Test nos. 472280-2 and 472280-3 used the same system hardware as test no. 472280-1 with the following exceptions: (1) the poles used in test nos. 472280-2 and 472280-3 were 29 ft tall, (2) the bottom diameter of the poles was 8 in., (3) the top diameter of the poles was 4 in., and (4) the poles each weighed approximately 900 lb. The luminaire pole configuration is shown in Figure 33.

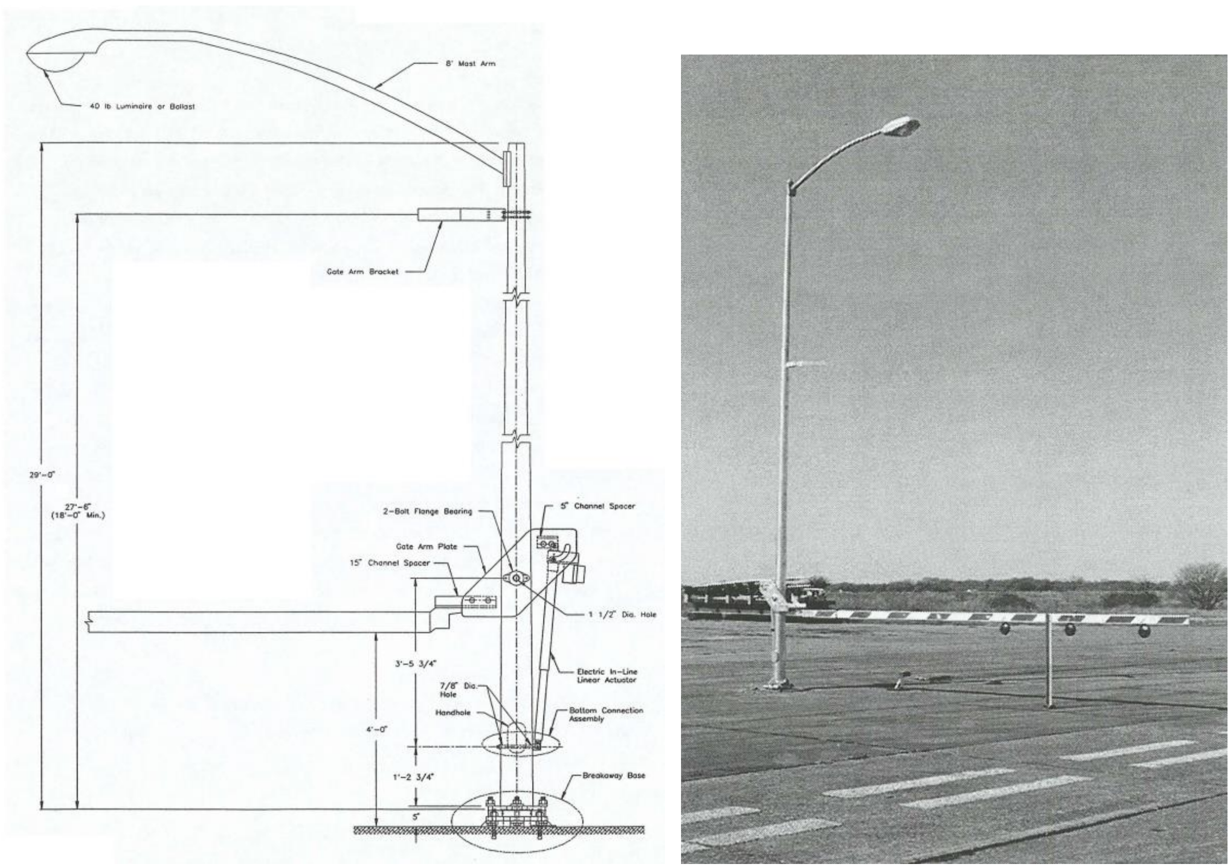


Figure 33. Wyoming Road Closure Luminaire System, Test Nos. 472280-2 and 472280-3 [14]

In test no. 472280-1, an 1,808-lb Chevrolet Sprint impacted the luminaire pole at a speed of 21.6 mph and an angle of 0 degrees, in accordance with NCHRP Report No. 350 test designation no. 3-60 [23]. The target impact point was the left quarter point of the vehicle aligned with the centerline of the luminaire pole. In this test, the vehicle impacted the pole and the slip base engaged. The pole fell onto the vehicle, causing significant deformation of the vehicle's roof. The B- and C-pillars bent inward on both sides, as shown in Figure 34, with a total roof crush of 6.3 in. There was little damage to the pole, as shown in Figure 35. The recorded OIV was 5.5 ft/s and the ORA was 0.8 g's. The test did not meet the evaluation criteria under NCHRP Report No. 350. Thus, the system failed and a redesign took place.

Figure 34. Vehicle Damage, Test No. 472280-1 [14]

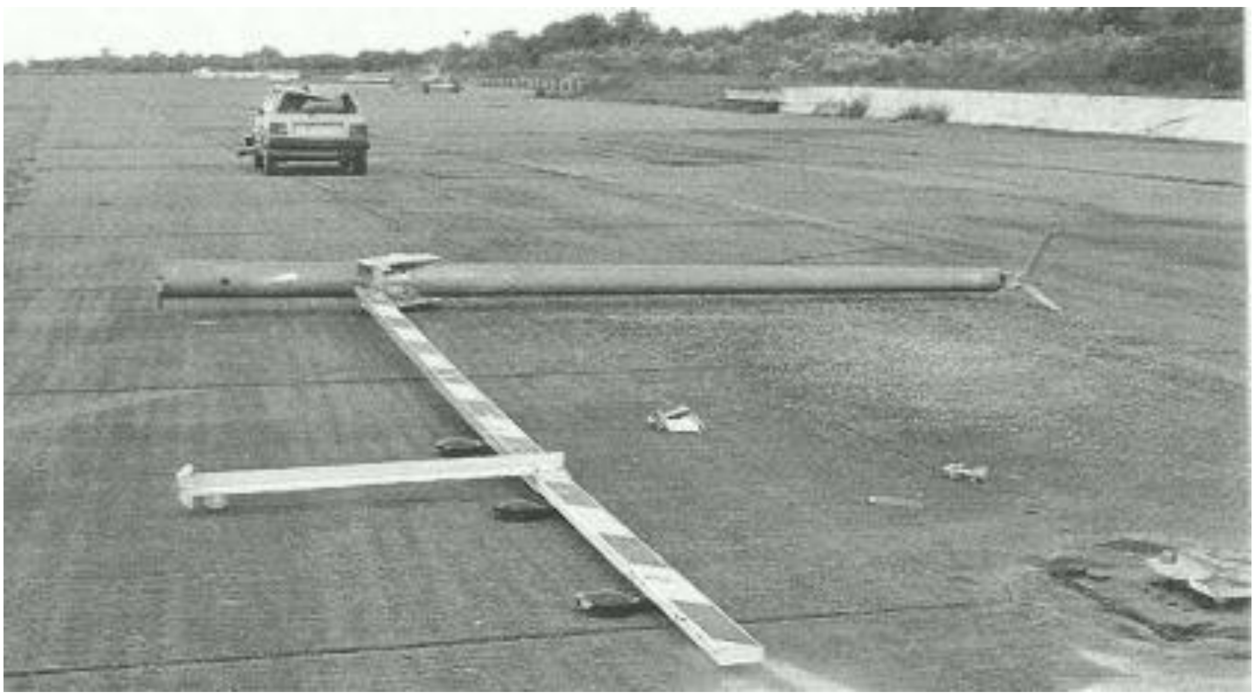


Figure 35. Luminaire Pole Damage, Test No. 472280-1 [14]

In test no. 472280-2, an 1,808-lb Chevrolet Sprint impacted the luminaire pole at a speed of 19.7 mph and an angle of 0 degrees, in accordance with NCHRP Report No. 350 test designation no. 3-60. The target impact point was the left quarter point of the vehicle aligned with the centerline of the luminaire pole. The slip base broke away upon impact. The pole fell onto the vehicle's roof, causing significant deformation of the left rear quarter of the roof and damage to the windshield, as shown in Figure 36. The mast arm detached from the pole and the closure gate was partially damaged, as shown in Figure 37. The recorded OIV was 7.6 ft/s and the ORA was 0.3 g's. However, the test met all evaluation criteria under NCHRP Report No. 350.

Figure 36. Vehicle Damage, Test No. 472280-2 [14]

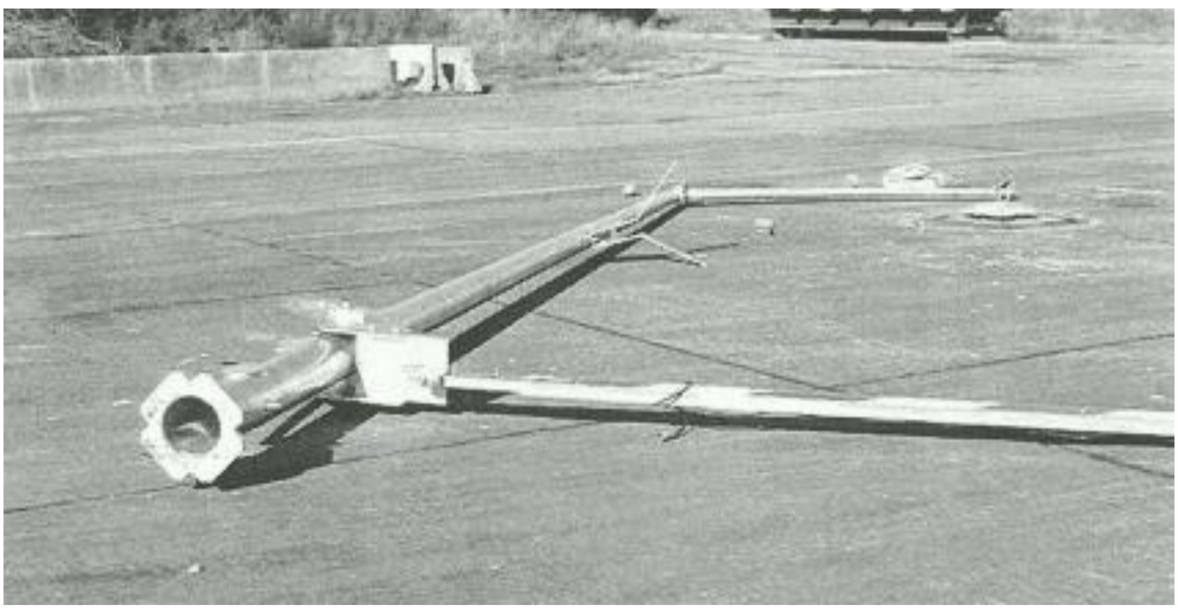


Figure 37. Luminaire Pole Damage, Test No. 472280-2 [14]

In test no. 472280-3, an 1,808-lb Chevrolet Sprint impacted the luminaire pole at a speed of 62.2 mph and an angle of 0 degrees, in accordance with NCHRP Report No. 350 test designation no. 3-61. The target impact point was the right quarter point of the vehicle aligned with the centerline of the luminaire pole. In this test, the vehicle impacted the pole and the slip base engaged. The pole did not land on the vehicle and there was minimal damage to the vehicle, as shown in Figure 38. However, the pole was broken at the location of the pivot rod for the gate arm attachment due to impact with the ground, as shown in Figure 39. The recorded OIV was 10.5 ft/s and the ORA was 0.9 g's. The test met all evaluation criteria under NCHRP Report No. 350.

Figure 38. Vehicle Damage, Test No. 472280-3 [14]

Figure 39. Luminaire Pole System Damage, Test No. 472280-3 [14]

2.3.5 California Luminaire System Full-Scale Crash Tests

Caltrans has conducted crash testing on various luminaire pole systems that are still part of their standard plans [8, 26]. In 2002, test no. 617 involved a 3-bolt slip base, identical to the Caltrans Type 30 slip base discussed in Section 2.2.1. A 40-ft tall steel luminaire pole with a high-pressure sodium filled lamp mounted directly to the top of the pole was used, as shown in Figure 40. The pole had a wall thickness of 0.135 in. and was tapered to the top, with a bottom diameter of 8 in. and a top diameter of 3 in. The pole weight was not recorded.

Figure 40. Caltrans Pole with Top-Mounted Luminaire, Test No. 617 [26]

In test no. 617, a 1,759-lb Geo Metro impacted the luminaire pole at an impact speed of 23.9 mph and at an impact angle of 0 degrees, in accordance with NCHRP Report No. 350 test designation no. 3-60. The target impact point was the centerline of the vehicle aligned with the centerline of the luminaire pole. In this test, the vehicle impacted the pole, and the slip base engaged. The pole fell onto the roof of the vehicle and caused significant deformation of the roof, with a maximum roof crush of 2.5 in., as shown in Figure 41. The top of the luminaire was damaged, and the mounted light was destroyed. The recorded OIV was 8.1 ft/s and the ORA was 1.3 g's. Although there was not a defined limit to occupant compartment deformation in NCHRP

Report No. 350, the testing agency (i.e., Caltrans) determined that "[t]here was unacceptable occupant compartment deformation," thus the test failed the occupant risk criteria under NCHRP Report No. 350 based on engineering judgement rather than a violation of a defined limit, meaning that the test did not meet the evaluation criteria. There were no efforts toward retesting or redesigning the system.

Figure 41. Vehicle Damage, Test No. 617 [26]

Test nos. 618 and 616 were conducted on an 18-ft tall steel luminaire mounted on a 3-bolt slip base, with a warning sign mounted 10 ft – 6 in. from the ground and two flashing beacons, one mounted at 7 ft – 6 in. and the other at 16 ft from the ground. The pole had a wall thickness of 0.1196 in. and was tapered to the top, with a bottom diameter of 8 in. and a top diameter of 5½ in. The pole material was steel, and pole weight was not recorded. The luminaire pole is shown in Figure 42.

Figure 42. Caltrans Warning Beacon Luminaire Pole, Test Nos. 618 and 616 [26]

In test no. 618, an 1,863-lb Geo Metro impacted the luminaire pole at a speed of 23.7 mph and an angle of 0 degrees, in accordance with NCHRP Report No. 350 test designation no. 3-60. The target impact point was the centerline of the vehicle aligned with the centerline of the luminaire pole. In this test, upon impact, the slip base was activated and broke away. The pole fell onto the roof of the vehicle and caused significant deformation of the roof and crushing of the windshield, with a maximum roof crush of 3.5 in., as shown in Figure 43. The top of the luminaire pole and the top beacon were damaged, as shown in Figure 44. The recorded OIV was 7.8 ft/s and the ORA was 1.1 g's. The test was deemed to meet evaluation criteria in NCHRP Report No. 350 since the location of the roof deformation presented minimal danger to occupants, and the occupant compartment deformation was described as moderate. The test would pass current evaluation standards under MASH since the occupant compartment deformation of 3.5 in. is below the 4-in. limit.

Figure 43. Vehicle Damage, Test No. 618 [26]

Figure 44. Luminaire Pole Damage, Test No. 618 [26]

In test no. 616, a 1,764-lb Geo Metro impacted the luminaire pole at a speed of 63.8 mph and an angle of 0 degrees, in accordance with NCHRP Report No. 350 test designation no. 3-61. The target impact point was the centerline of the vehicle aligned with the centerline of the luminaire pole. Upon impact, the slip base was activated and broke away. The pole did not fall on the roof of the vehicle. The vehicle experienced significant bumper deformation but had minimal damage otherwise, as shown in Figure 45. The pole suffered damage to both beacons and the sign, as shown in Figure 46. The recorded OIV was 11.4 ft/s and the ORA was 3.08 g's. The test met all evaluation criteria in NCHRP Report No. 350.

Figure 45. Vehicle Damage, Test No. 616 [26]

Figure 46. Luminaire Pole Damage, Test No. 616 [26]

2.3.6 Recent Caltrans Luminaire and Beacon System Full-Scale Crash Tests

Test nos. 430MASHC17-01, 430MASHC20-01, 430MASHC22-01, and 430MASHC23-01 were conducted between 2018 and 2022 on an 18-ft tall steel luminaire pole mounted on a 3-bolt Type 15-FBS slip base, with a pedestrian crossing sign mounted at 10 ft – 6 in. above the ground and dual flashing beacons mounted at 16 ft above the ground [9]. The pole had a wall thickness of 0.1196 in. and was tapered to the top, with a bottom diameter of 8 in. and a top diameter of 5½ in. The pole weight was not recorded. Due to the recent testing of these systems, no final report is available. However, video, data, and results were provided to MwRSF by Caltrans as part of this project.

In test no. 430MASHC17-01, a 2,443-lb Nissan Versa impacted the luminaire pole at a speed of 26.3 mph and an impact angle of 30.95 degrees, in accordance with MASH test designation no. 3-80. The target impact point was the left quarter point of the vehicle aligned with the centerline of the luminaire pole. In this test, the vehicle impacted the pole and the slip base engaged. The pole did not fall onto the vehicle. The vehicle's bumper was severely deformed, although the rest of the vehicle sustained minimal damage, as shown in Figure 47. There was significant damage to the top of the pole and beacons from the impact with the ground. Note that no post-test photographs of the luminaire were available. The recorded OIV was 8.5 ft/s and the ORA was 0.8 g's. The test met all evaluation criteria, though the impact speed was outside of the 19 mph ±2.5 mph allowance. Additionally, the test designation used for the system was incorrect: the correct test designation, according to MASH, was test designation no. 3-60.

Figure 47. Vehicle Damage, Test No. 430MASHC17-01 [9]

For test no. 430MASHC20-01, an evaluation was not completed, thus there is very limited data. In the test, a Nissan Versa impacted the system at approximately 19 mph. The left quarter point of the vehicle was aligned with the centerline of the luminaire. Upon impact, the slip base did not activate, and the vehicle came to an immediate stop from impact with the pole, as shown in Figure 48. The OIV was 25 ft/s. Due to the immediate deceleration and excessive OIV, the test did not meet MASH safety criteria.

Figure 48. Post-Test Photograph, Test No. 430MASHC20-01 [9]

In test no. 430MASHC22-01, the slip base design was modified by increasing the notch angles of the triangular slip base from 60 degrees to 90 degrees. In this test, a 2,443-lb Nissan Versa impacted the luminaire pole at a speed of 20.3 mph and an angle of 30 degrees, in accordance with MASH test designation no. 3-60. The target impact point was the left quarter point of the vehicle aligned with the centerline of the luminaire pole. In this test, upon impact, the slip base was activated and broke away. The pole fell onto the left side of the vehicle's roof and caused significant roof deformation, with a maximum roof crush of 2.4 in., and the sign panel penetrated the rear windshield, as shown in Figure 49. The top of the pole was damaged and the mounted beacons were destroyed. The recorded OIV was 6.9 ft/s and the ORA was 1.9 g's. The test did not meet MASH safety criteria.

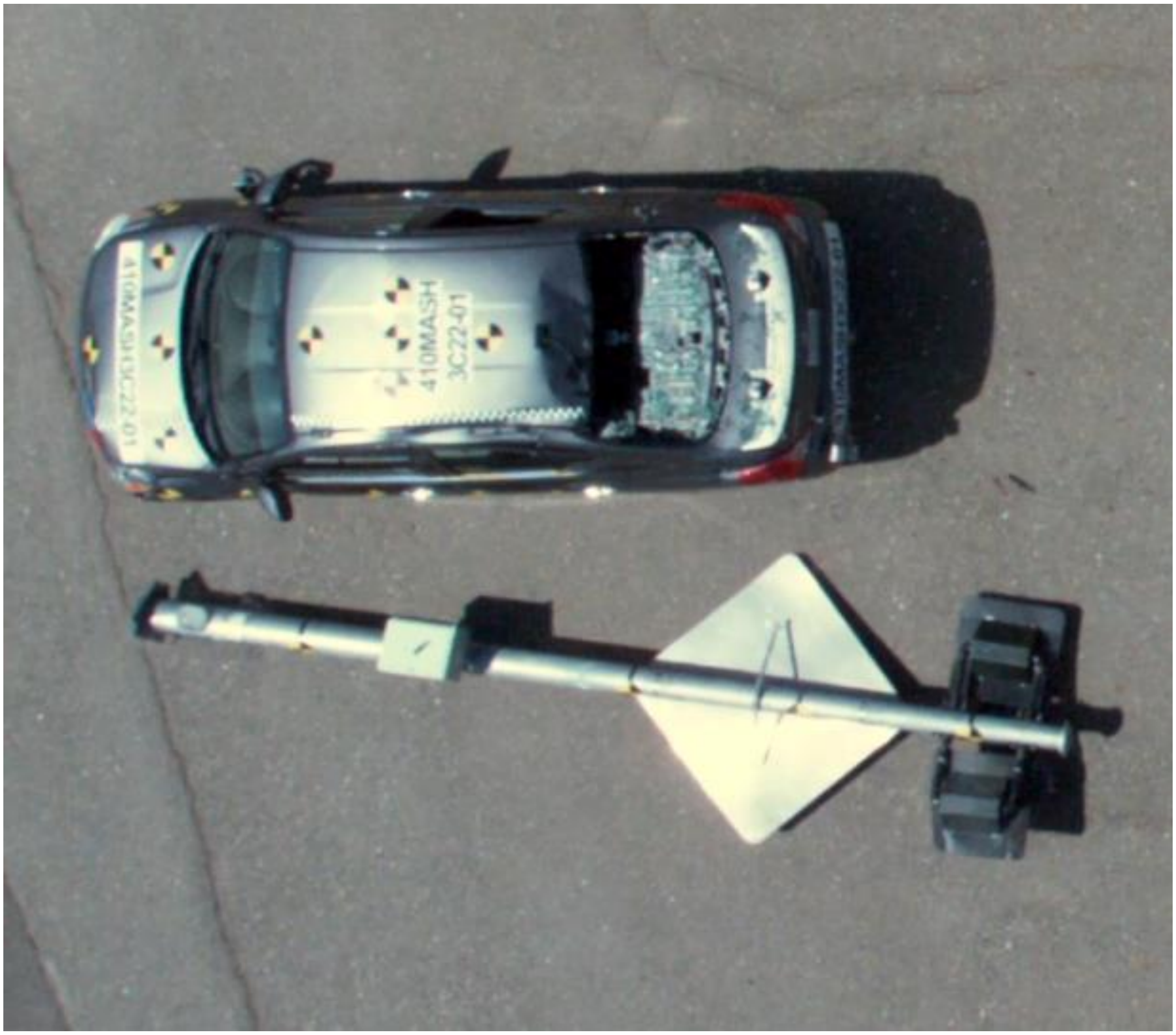


Figure 49. Vehicle Damage, Test No. 430MASHC22-01 [9]

In test no. 430MASHC23-02, the luminaire beacon design was modified by removing one of the two beacons near the top of the pole. The remaining beacon was moved to the top of the pole and the sign was positioned higher up the pole in an attempt to raise the height of the pole's center of gravity (C.G.) and avoid the beacon contacting the vehicle's rear window. In this test, a 2,372-lb Nissan Versa impacted the modified luminaire pole at a speed of 19 mph and an angle of 30 degrees, in accordance with MASH test designation no. 3-60. The target impact point was the centerline of the vehicle aligned with the centerline of the luminaire pole. The slip base was activated and broke away upon impact. The pole fell onto the roof of the vehicle and caused significant deformation of the roof, with a maximum roof crush of 4.9 in., as shown in Figure 50. Due to excessive roof crush, the test did not meet the evaluation criteria under MASH, resulting in system failure. Ongoing efforts are being made to redesign and retest the system.

Figure 50. Vehicle Damage, Test No. 430MASHC23-02 [9]

2.3.7 Recent Wyoming Road Closure Luminaire Pole Full-Scale Crash Tests

A current MwRSF research project is evaluating the crashworthiness of Wyoming's road closure luminaire pole through full-scale crash testing [15]. As the testing is recent, no final report is yet available. However, video, data, and results have been provided in-house at MwRSF for use in this project.

In 2021, test no. WRCG-1 was conducted on a 29-ft tall steel luminaire pole with single 8-ft long mast arm mounted on a 4-bolt breakaway slip base, as shown in Figure 51. The pole had a 30-ft long fiberglass and an aluminum gate arm 4 ft above the ground when in the down position. The pole had a bottom diameter of 8 in. and was tapered to a top diameter of 3.94 in. with a wall thickness of 0.17 in. The pole was made of ASTM A36 Grade A steel and weighed approximately 900 lb.

Figure 51. Wyoming Road Closure Gate Luminaire Pole, Test No. WRCG-1 [15]

In test no. WRCG-1, a 2,434-lb Kia Rio impacted the luminaire pole at a speed of 20.1 mph and an angle of 25 degrees, in accordance with MASH test designation no. 3-60. The target impact point was the left quarter point of the vehicle aligned with the centerline of the luminaire pole. The slip base was activated and broke away upon impact. The pole fell onto the top left quarter of the windshield and caused cracking and puncturing, as shown in Figure 52. The top of the luminaire pole was damaged, as shown in Figure 53. The test did not meet the evaluation criteria under MASH due to intrusion into the occupant compartment from the windshield puncture, resulting in system failure. The project is ongoing, and additional full-scale crash tests may be conducted in the future.

Figure 52. Vehicle Damage, Test No. WRCG-1 [15]

Figure 53. Luminaire Pole Damage, Test No. WRCG-1 [15]

2.4 Other Notable Slip Base Guidance and Testing

A series of pendulum tests were conducted and published in Eligibility Letter No. LS-16, which can be found in Appendix C [27]. These pendulum tests utilized a standard Caltrans Type 31 luminaire pole with 3-bolt slip base, similar to a Caltrans Type 30 slip base. A key difference in this slip base is that the keeper plate is 0.0359-in. thick, compared to the typical 0.0149 in. (28 gauge). The clamp force study, discussed below, uses the 0.0359-in. thick keeper plate, while the thickness of the keeper plate varied between tests in the keeper plate study.

The pendulum testing consisted of two series of tests along with documentation of previous testing. In the first series, called the "clamp force study," identical systems were tested with the only difference between tests being the torque applied to the slip bolts. In the second series of tests, called the "keeper plate study," identical systems were tested except for variations in the keeper plate thickness, which was altered between tests.

The pendulum testing documented in Eligibility Letter LS-16 highlighted significant behavior in slip base luminaire systems. Specifically, even with identical systems, impact speeds, "estimated clamp bolt force," and keeper plate thickness, the calculated OIV varied drastically. Note that this behavior was observed in this testing series for a 3-bolt design with an estimated preload and therefore may not be representative of all luminaire pole slip bases. The eligibility letter does not specify a method for ensuring that the desired clamp force was consistently achieved, so the varying performance may be attributed to discrepancies in the estimated clamp bolt force between tests. In other words, the clamp bolt force may not have been identical in two tests, even though the results table indicated the same estimated clamp bolt force. The drawings of the slip base used in the tests are shown in Figure 54. The results of the clamp force study are shown in Figure 55. Note that the pole thickness in this series was 0.1345 in. (10 gauge), which is thicker than the typical 11 gauge in most modern poles.

In one case, two tests were conducted on an identical system, each with an estimated clamp force of 5,891 lb. In test no. 89F017, the system was impacted at 20.6 mph, resulting in an OIV of 21.4 ft/s. In test no. 89F007, the system was impacted at 20.7 mph, resulting in an OIV of 8.3 ft/s. The difference in OIV values between these identical tests was 13.1 ft/s.

In another case, two tests were conducted on an identical system, each with an estimated clamp force of 7,614 lb. In test no. 89F015, the system was impacted at 20.5 mph, resulting in an OIV of 14.8 ft/s. In test no. 89F008, the system was impacted at 20.5 mph, resulting in an OIV of 6.4 ft/s. The difference in OIV values between these identical tests was 8.4 ft/s.

In yet another case, two tests were conducted on an identical system, each with an estimated clamp force of 9,817 lb. In test no. 89F017, the system was impacted at 20.8 mph, resulting in an OIV of 23.2 ft/s. In test no. 89F011, the system was impacted at 20.5 mph, resulting in an OIV of 7.7 ft/s. The difference in OIV values between these identical tests was 15.5 ft/s.

In the final case, there were two tests on an identical system, each with an estimated clamp force of 11,780 lb. In test no. 89F012 the system was impacted at 20.6 mph with a resulting OIV of 36.9 ft/s, while in test no. 89F010 the system was impacted at 20.7 mph with a resulting OIV of 20.6 ft/s. The difference in OIV values between the identical tests is 16.3 ft/s.

From these pendulum tests, it can be concluded that slip base behavior varies greatly, even when tested under nearly identical conditions. The systems tested in this series are nearly identical to systems used by many state DOTs, or at least are present in their plan sets, which highlights a concern about the performance of the slip-base systems in use today. Again, it is important to note that the keeper plate thickness in some tests, as discussed before, was over double the thickness of what is commonly used today.

In one case, there were three tests on an identical system, each without a keeper plate and with a clamp force of 12,500 lb. In test no. 90P024, the system was impacted at 19.8 mph with a resulting OIV of 8.8 ft/s; in test no. 90P025 the system was also impacted at 19.8 mph with a resulting OIV of 13.2 ft/s; and in test no. 90P026, the system was impacted at 19.9 mph with a resulting OIV of 11.1 ft/s. The range in OIV values between the identical tests is 4.4 ft/s.

In another case, there were two tests on an identical system, each with a 0.0149-in. thick keeper plate, which is typical for modern systems, and a clamp force of 12,500 lb. In test no. 90P027 the system was impacted at 20.0 mph with a resulting OIV of 16.9 ft/s, while in test no. 90P028 the system was impacted at 19.8 mph with a resulting OIV of 35 ft/s. The difference in OIV values between the identical tests was 18.1 ft/s.

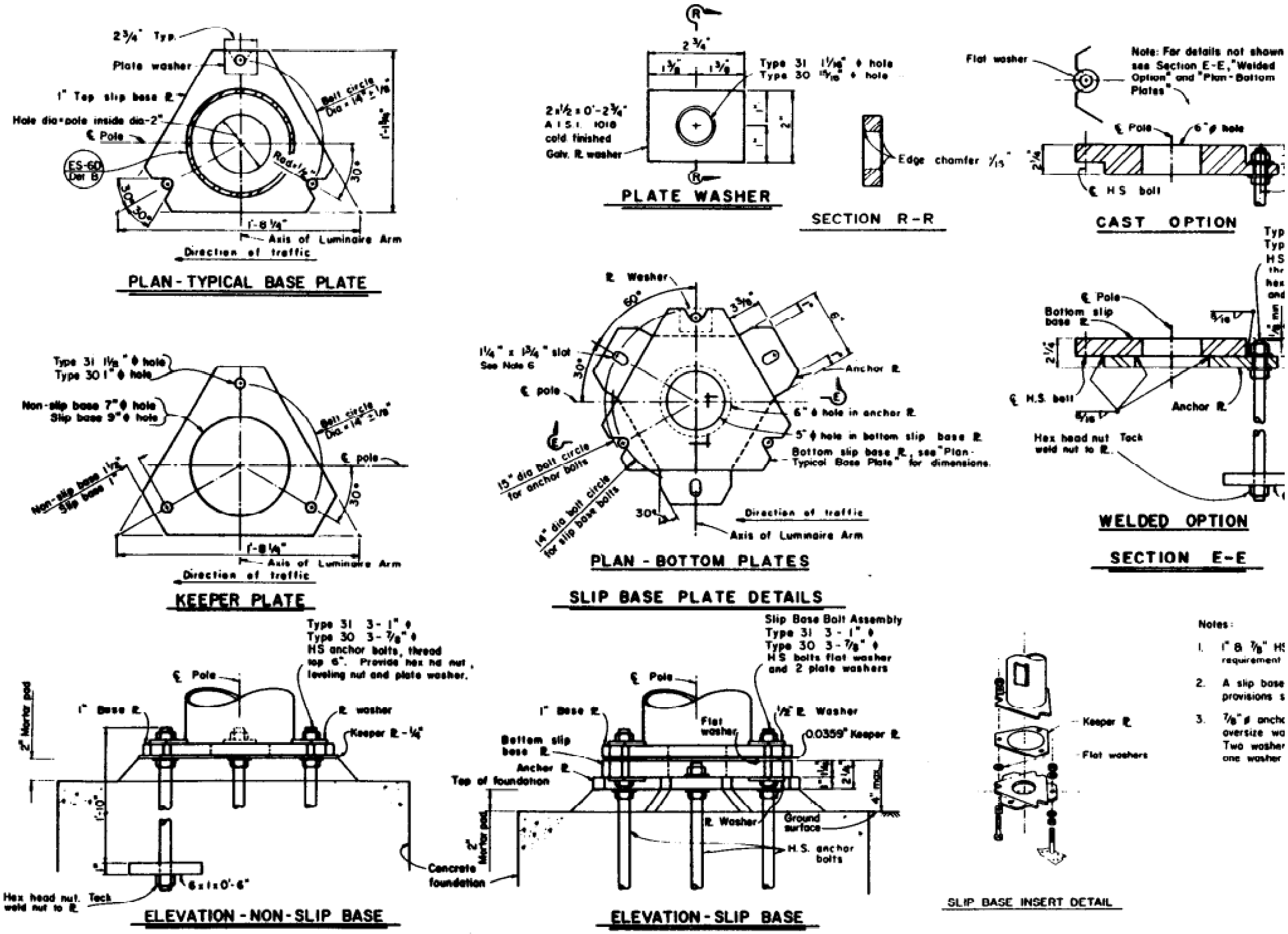


Figure 54. Eligibility Letter LS-16 Pendulum Testing – Slip Base Drawings [27]

Agency Test No. Date	Mastarm(s) Length (ft) Weight (#)	Shaft Length (ft) Weight (#)	Mounting Height (ft) Total Weight (#)	Pole Diam. at base (in) Wall Thick. at base (in)	Slip Base Bolt Circle Diameter (in)	Clamp Bolt Diameter (in)	Est. Clamp Bolt Force 3 @ (lbs) ea	Keeper Plate Thickness (in)	Impact Angle from Roadway (degrees)	Test Veh. Type and Weight (lbs)	Impact speed (m.p.h.)	Occupant Change in Velocity (f.p.s.)
CLAMP FORCE STUDY - FOIL												
89F005 APR 12,'89	None	30.25 275	None 275	7.5 0.1345	14	1	1,965	0.0359	0	FOIL BOGIE 1850	20.6	6.5
89F006 APR 19,'89	*	* *	* *	* *	*	*	3,928	*	0	* *	20.7	5.9
89F007 APR 20,'89	*	* *	* *	* *	*	*	5,891	*	0	* *	20.7	8.3
89F008 APR 24,'89	*	* *	* *	* *	*	*	7,614	*	0	* *	20.5	6.4
89F009 APR 25,'89	*	* *	* *	* *	*	*	9,817	*	0	* *	20.8	23.2
89F010 APR 26,'89	*	* *	* *	* *	*	*	11,780	*	0	* *	20.7	20.6
89F011 APR 26,'89	*	* *	* *	* *	*	*	9,817	*	0	* *	20.5	7.7
89F012 APR 27,'89	*	* *	* *	* *	*	*	11,780	*	0	* *	20.6	36.9 **
89F014 MAY 19,'89	*	* *	* *	* *	*	*	13,743	*	0	* *	20.4	22.7
89F015 MAY 24,'89	*	* *	* *	* *	*	*	7,614	*	0	* *	20.5	14.8
89F016 MAY 25,'89	*	* *	* *	* *	*	*	15,808	*	0	* *	20.4	18.2
89F017 MAY 31,'89	*	* *	* *	* *	*	*	5,891	*	0	* *	20.6	21.4

* A 2-foot high steel tube with 0.25 in. wall thickness was welded to the bottom of a 33 foot tall pole which had a wall thickness of 0.1196 in.

Figure 55. Eligibility Letter LS-16 Pendulum Testing - Clamp Force Study [27]

Agency Test No. Date	Mastarm(s) Length (ft) Weight (#)	Shaft Length (ft) Weight (#)	Mounting Height (ft) Total Weight (#)	Pole Diam. at base (in) Wall Thick. at base (in)	Slip Base Bolt Circle Diameter (in)	Clamp Bolt Diameter (in)	Est. Clamp Bolt Force 3 # (lbs) ea	Keeper Plate Thickness (in)	Impact Angle from Roadway (degrees)	Test Veh. Type and Weight (lbs)	Impact speed (m.p.h.)	Occupant Change in Velocity (f.p.s.)
KEEPER PLATE STUDY - FOIL												
90P023 4/24/90	None None	30.83 486	None 486	10.0 0.1793	14	1	12,500	0.0359	0	FOIL PNDLM 1850	19.9	25.9
90P024 4/25/90	" "	" "	" "	" "	"	"	"	NONE	"	" "	19.8	8.8
90P025 4/25/90	" "	" "	" "	" "	"	"	"	NONE	"	" "	19.8	13.2
90P026 4/26/90	" "	" "	" "	" "	"	"	"	NONE	"	" "	19.9	11.1
90P027 4/26/90	" "	" "	" "	" "	"	"	"	0.0149	"	" "	20	16.9
90P028 5/1/90	" "	" "	" "	" "	"	"	"	0.0149	"	" "	19.8	35 **
90P029 5/2/90	" "	" "	" "	" "	"	"	3,600	0.0149	"	" "	20	5.6
90P032 5/30/90	" "	" "	" "	" "	"	"	3,600	0.0149	"	" "	20	7
90P033 5/31/90	" "	" "	" "	" "	"	"	3,600	0.1049	"	" "	20	6.4
90P034 5/31/90	" "	" "	" "	" "	"	"	9,000	0.0149	"	" "	20	11.8
90P035 6/05/90	" "	" "	" "	" "	"	"	9,000	0.0149	"	" "	20	35.4 **
90P036 6/06/90	" "	" "	" "	" "	"	"	8,000	0.0149	"	" "	20	17.7

** Value includes rebound, thus exceeds impact speed.

Figure 56. Eligibility Letter LS-16 Pendulum Testing – Keeper Plate Study [27]

In another case, there were two tests on an identical system, each with a 0.0149-in. thick keeper plate, which is typical for modern systems, and a clamp force of 3,600 lb. In test no. 90P029 the system was impacted at 20.0 mph with a resulting OIV of 5.6 ft/s, while test no. 90P032 the system was also impacted at 20.0 mph with a resulting OIV of 7.0 ft/s. The difference in OIV values between the identical tests is 1.4 ft/s.

In yet another case, there were two tests on an identical system, each with a 0.0149-in. thick keeper plate, which is typical for modern systems, and a clamp force of 9,000 lb. In test no. 90P034 the system was impacted at 20.0 mph with a resulting OIV of 11.8 ft/s, while in test no. 90P032 the system was also impacted at 20.0 mph with a resulting OIV of 35.4 ft/s. The difference in OIV values between the identical tests is 23.6 ft/s.

Again, the pendulum tests show that slip-base behavior can vary significantly, even under nearly identical testing conditions. It is important to note that significant variations in performance were observed in this test series for a 3-bolt design with an estimated preload. This behavior is likely to occur in all luminaire pole slip bases, including 4-bolt slip bases. Investigation of the variability in slip base performance was not within the scope of the current project, though it was understood and considered in the modeling and validation process, i.e., these findings were taken into consideration when developing a validation model against OIV data from a previous full-scale crash test.

Eligibility Letter LS-16 also included various guidance on geometries and practices when utilizing slip bases. In particular, it provided recommendations on minimum and/or maximum dimensions for slip base parts. The guidance on slip base dimensions was tabularized and is shown in Table 1. Guidance on clamp bolt tension was also provided, as shown in Table 2.

Table 1. Recommended Slip Base and Pole Geometry [27]

Slip Base Part	Minimum	Maximum
Pole Wall Thickness	0.1196 in. (11 gauge)	-
Bolt Circle Diameter	14 in.	-
Base Plate Thickness	1 in.	1¼ in.
Lower Slip Plate Thickness	1¼ in.	1½ in.
Anchor Plate Thickness	-	1¼ in.
Steel Keeper Plate Thickness	-	0.0149 in. (28 gauge)
Height of Top of Lower Slip Plate from Ground Line	-	4 in.
Clamp Bolt Diameter	⅞ in.	1¼ in.
Clamp Bolt Tension per Bolt	-	8,000 lb
Mounting Height	-	56.5 ft
System Weight*	-	1,000 lb

"-" denotes dimensions that were not provided or suggested
*system weight includes the base plate, pole, mast connections, mast arms, and luminaires

Table 2. Recommended Maximum Slip Bolt Torque [27]

Bolt Diameter (in.)	Torque (ft-lb)
7/8	87
1	95
1 1/8	104
1 1/4	111

The bolt torques provided are generally similar to the recommended bolt torques in state DOT plans. The guidance provided in Eligibility Letter LS-16 is as follows: (1) clamp bolts should be galvanized ASTM A325; (2) rectangular clamp bolt washers shall be sufficient length, width, and thickness to prevent significant deflection or bending when clamp bolt is loaded to its tensile capacity; and (3) the hole in the clamp bolt washer should be the bolt diameter plus 1/16 in. with edges chamfered to prevent binding with radius under the bolt head.

Additionally, the letter provides guidance on the orientation of 3-bolt slip base systems. The ideal orientation of a triangular 3-bolt slip base is to have a side of the slip base perpendicular to the direction of adjacent travel. A less preferred, though still acceptable, orientation of the slip base is to position the mast arm directly over a clamp bolt or at the midpoint between two clamp bolts, bisecting the edge of the pole base plate. It was not recommended to orient the slip base so that a clamp bolt is positioned parallel and directly facing the direction of travel. There is no suggestion on the ideal orientation of the slip base should a dual arm luminaire pole system be desired, though it can be reasoned that the second orientation would suffice, with one mast arm positioned directly over a clamp bolt and the other mast arm positioned directly between two clamp bolts, bisecting an edge of the pole base plate. The slip base orientation suggestions are shown in Figure 57.

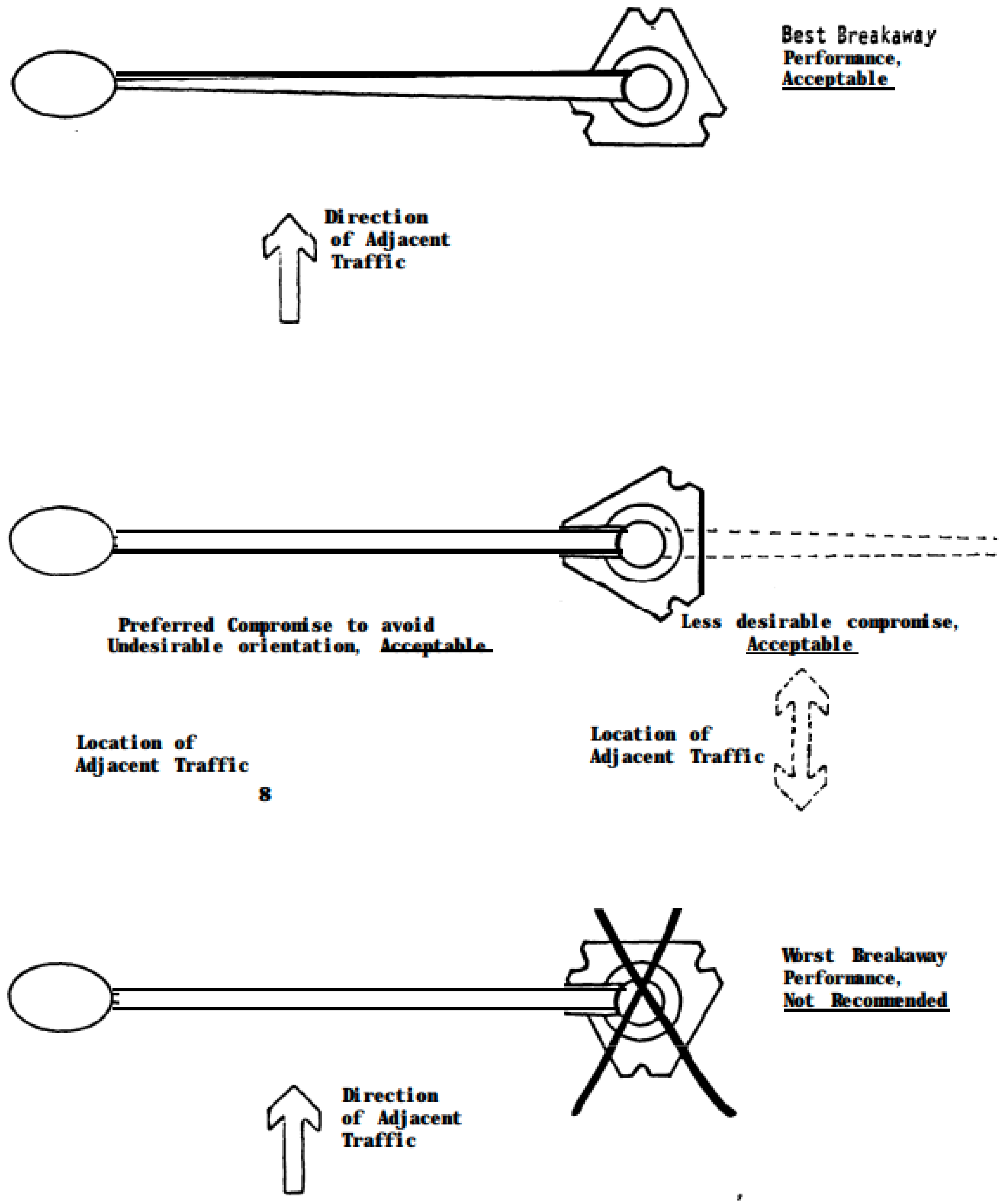


Figure 57. Eligibility Letter LS-16, Acceptable 3-bolt Slip Base Orientation [27]

3 BASELINE SIMULATION MODEL AND VALIDATION

An LS-DYNA finite element model of the Utah DOT (UDOT) 4-bolt breakaway slip base and the luminaire pole was developed and validated against full-scale crash testing previously conducted by MwRSF [5].

The USBLM test series, previously discussed in Section 2.3.2, was chosen for validation of the 4-bolt slip base because: (1) the tests involved a 50-ft pole with dual 15-ft mast arms, representing the heaviest and tallest pole allowed to be mounted on a slip base based on the literature review, which presented a likely worst-case scenario for roof crush and OIV; (2) 4-bolt slip bases are typically selected to support heavier poles, which are most critical for roof crush and OIV; (3) test no. USBLM-1 was conducted with the test vehicle traveling at 15 mph, the lowest speed of all available crash tests, therefore presenting the most critical case for slip base activation; and (4) the tests were conducted at MwRSF [5], where the test videos and data are readily available. The 4-bolt slip base used in the full-scale crash test was identical to the system currently in use in Utah, as described in Section 2.2.4 [11].

The model was developed using LS-DYNA Version 10.1 [7]. The model consisted of several components, including the 4-bolt slip base, pole, mast connections, mast arms, and surrogate luminaire weights.

3.1 LS-DYNA Model Development of Luminaire Pole with Slip Base

3.1.1 4-Bolt Slip Base

The UDOT slip base consisted of a pole base plate, a keeper plate, a ground plate, grout, eight bolts, twelve nuts, and twenty-four washers. Each part was modeled with identical geometry and material properties to the physical crash test. The slip base was assembled using LS-PrePost and is discussed in detail in the following sections.

Pole Base Plate

The pole base plate, constructed from A36 steel, served as the connection between the pole to the slip base system, which was welded to the bottom of the pole. The pole base plate was 1 in. thick, 13½ in. wide, and 13½ in. long, and had a 13-in. bolt circle with four 90-degree, $^{17}/_{32}$-in. radius slots for securing the slip bolts. The diameter of the inner hollow circle of the plate depended on the pole's diameter. The pole plate steel was modeled using the *MAT_PIECEWISE_LINEAR_PLASTICITY material formulation with the stress-strain curve for A36 steel. The geometry of the pole plate was modeled using type 2 fully integrated solid elements. The average size of each element was ½ in. A comparison of the model pole plate to the UDOT drawing is shown in Figure 58.

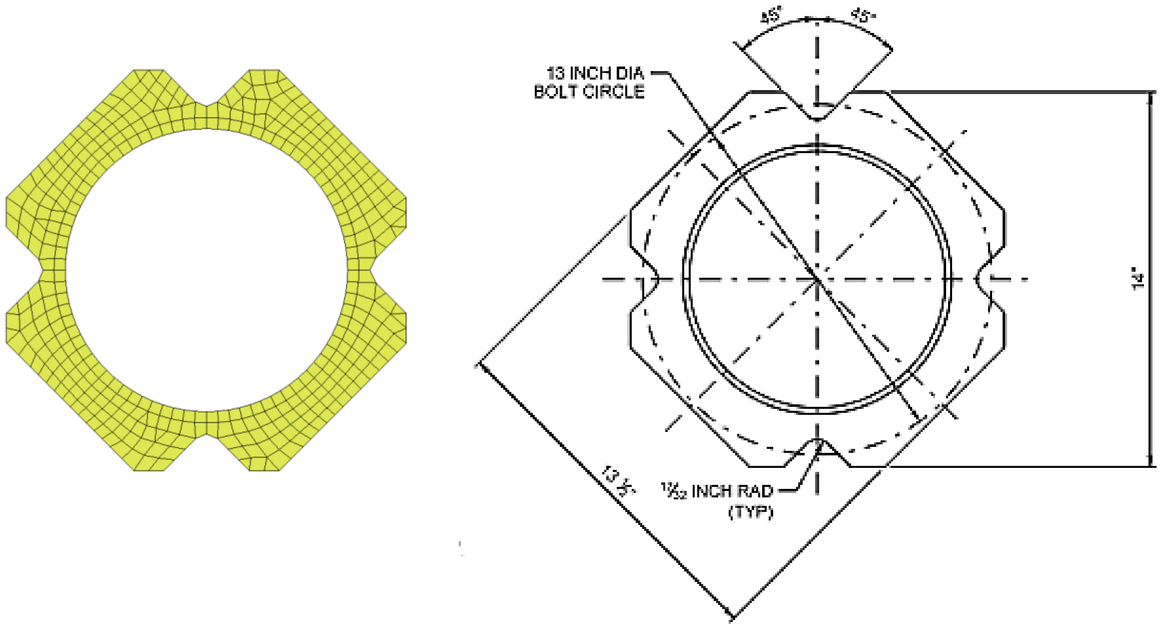


Figure 58. Pole Base Plate: Model (left) vs UDOT Drawing (right) [11]

The pole base plate was modelled using two solid elements for its thickness. As a general rule of thumb, parts modeled as solids should be at least three elements thick to ensure a sufficient number of integration points across the thickness, which helps better capture bending stresses. However, for this case, it was assumed that the pole base plate would not experience significant bending stresses from the slip base preloading or slip base activation. Therefore, modeling the base plate as two elements thick was considered acceptable.

Keeper Plate

The keeper plate, also referred to as a slip bolt gasket in literature, was constructed of ASTM 446 steel and placed between the pole base plate and ground plate. It served to hold the slip bolts in place. The keeper plate was 0.0149 in. thick (28 gauge), 10²¹⁄₃₂ in. wide, and 10²¹⁄₃₂ in. long. The bolt holes were 1⅛ in. diameter, and the central circle cutout was 6⅞ in. diameter. The corners of the keeper plate were clipped to ensure proper fracture.

The keeper plate steel was modeled using the MAT_PLASTIC_KINEMATIC material formulation with yield stress and tangent modulus values derived from ASTM for ASTM 466 steel. The geometry of the keeper plate was fully modeled using type 16 shell elements, with an average element size of ½ in. A comparison of the model keeper plate to the UDOT drawing is shown in Figure 59.

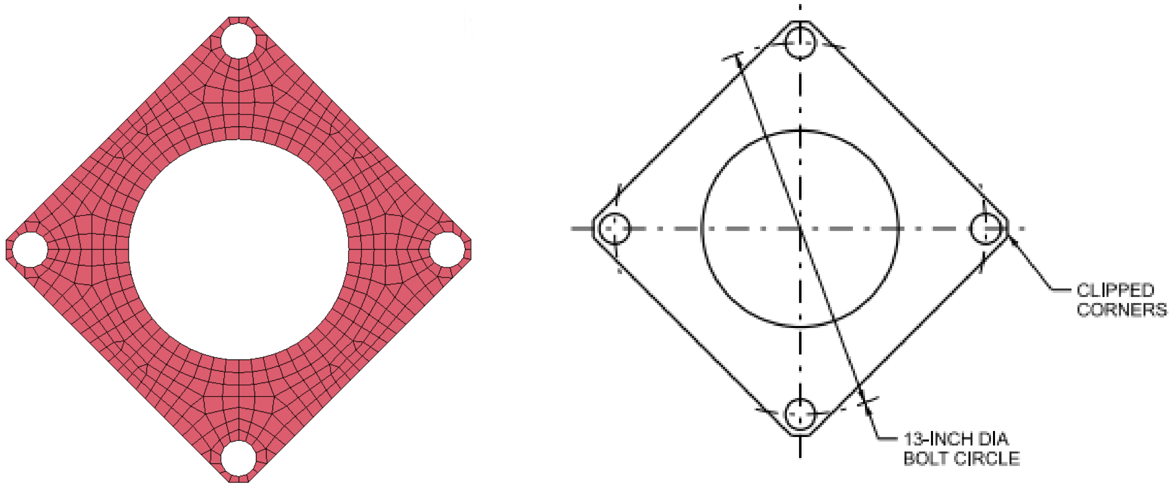


Figure 59. Keeper Plate: Model (left) vs UDOT Drawing (right) [11]

Ground Plate

The ground plate, also referred to as the slip plate in literature, was constructed of A36 steel and was placed below the pole base plate and keeper plate. Alongside the pole base plate, the slip bolts were placed into the ground plate and torqued to secure the slip base. The ground plate was composed of two layers: a 1½-in. thick x 11½-in. wide x 11½-in. long top layer and a 1-in. thick x 15-in. wide x 15-in. long bottom layer. The slip bolts were placed in a 13-in. bolt circle in 90-degree, 17⁄32-in. radius slots. The inner hollow circle was 6.75 in. in diameter and extended throughout the plate thickness. The ground plate was secured by four anchor bolts which extended downward into the grout layer and foundation below. The anchor bolt holes were 1⅛ in. in diameter and were 1¼ in. from each edge of the ground plate.

The ground plate steel was modeled using *MAT_PIECEWISE_LINEAR_PLASTICITY material formulation using the stress strain curve available for A36 steel. The ground plate geometry was modeled completely with type 2 fully integrated solid elements. The average size of each element was ½ in. A comparison of the model ground plate to the UDOT drawing is shown in Figure 60.

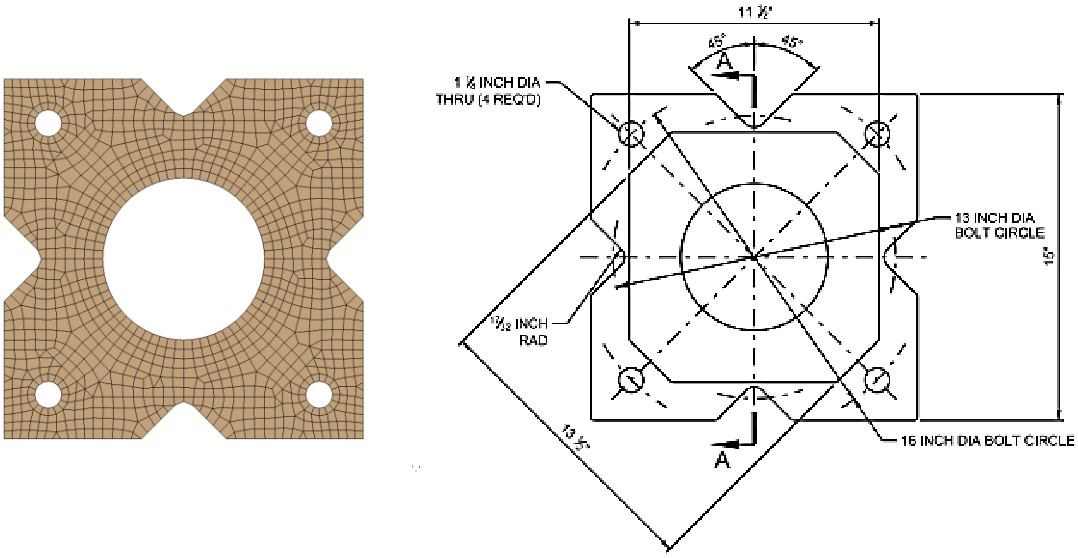


Figure 60. Ground Plate: Model (left) vs UDOT Drawing (right) [11]

Grout

The grout was a 3:1 sand and cement dry packed grout, with no further specifications provided. For the model, the grout was simplified as a 1½-in. thick plate, fully modeled using type 2 fully integrated solid elements with an average element size ½ in. The material was simplified to typical Portland concrete with a *MAT_PLASTIC_KINEMATIC material formulation, with yield stress and tangent modulus values obtained from common material specifications. All the bottom nodes of the grout were fixed, where no translation was permitted in any direction in order to restrain the luminaire system to a ground plane. The grout model geometry is shown in Figure 61.

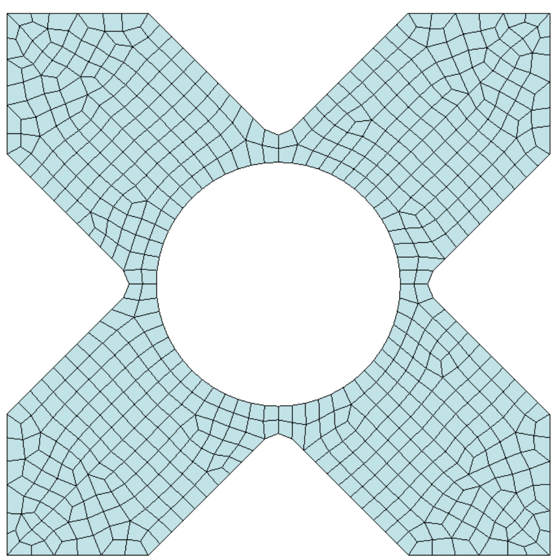


Figure 61. Grout Model Geometry

Slip Bolt Assembly

The slip bolts, also referred to as clamp bolts in the literature, were used to secure the pole base plate and keeper plate together. The slip bolts were inserted through the outer holes of the keeper plate. Each slip bolt had a 1-in. diameter and a length of approximately 6.5 in. The bolts were secured with galvanized heavy nuts, a small washer, and a plate washer on both ends. The plate washers measured 3 in. long x 2 in. wide x and ½ in. thick. The entire slip bolt assembly was made of A325 steel and torqued to 70 ft-lb. Each component – slip bolt, plate washer, small washer, and galvanized nut – was assigned a unique *PART keyword in the model.

The four slip bolts and their assemblies were made of the same steel, modeled using the *MAT_PIECEWISE_LINEAR_PLASTICITY material formulation with stress-strain curves available for A325 steel. The geometry of the slip bolt assembly was fully modeled using type 2 fully integrated solid elements. The average element size was ½ in. To simulate the torque applied to the bolts, a preload was applied to the mid-section of each slip bolt. The details of this preload are discussed later in this section. The slip bolt assembly is shown in Figure 62.

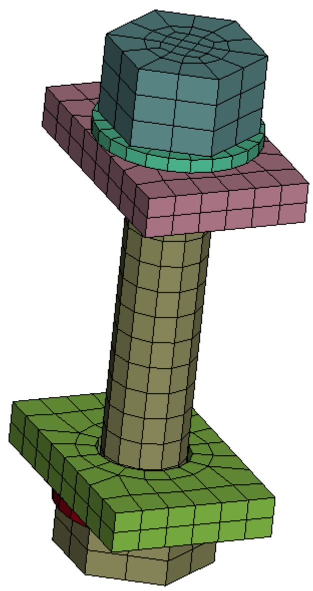


Figure 62. Slip Bolt Assembly Model

Note that the rectangular plate washers were modeled with a thickness of two solid elements. As a general rule of thumb, parts modeled as solids should be at least three elements thick to ensure sufficient integration points across the thickness, which helps capture bending stresses more accurately. However, the rectangular plate washers were expected to have negligible bending stresses from the slip base preloading or activation. Thus, modeling them with a thickness of two elements was deemed acceptable.

Anchor Bolt Assembly

The anchor bolts were used to secure the ground plate to the foundation. Each anchor bolt had a 1-in. diameter and was approximately 15.5 in. long. The bolts were secured with a galvanized heavy-duty nut and a small washer at the top of the ground plate, as well as another washer at the bottom, embedded in the grout. The anchor bolts were extended deeper into the ground, anchoring into the foundation. In the model, the bottom nodes of the anchor bolts were fixed, where no translation was allowed in any direction, to restrain the luminaire system to the ground plane. The entire anchor bolt assembly was made of A325 steel. Each anchor bolt, small washer, and galvanized nut was assigned a unique *PART keyword in the model.

The four anchor bolts and their assemblies were made from the same steel, modeled using the *MAT_PIECEWISE_LINEAR_PLASTICITY material formulation, with stress-strain curves specific to A325 steel. The geometry of the anchor bolt assembly was fully modeled using type 2 fully integrated solid elements, with an average element size of ½ in. The anchor bolt assembly is shown in Figure 63.

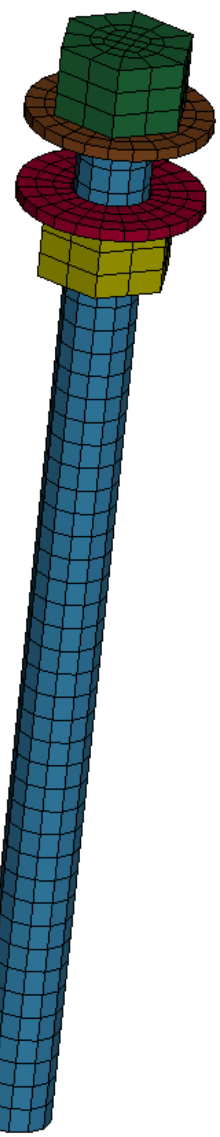


Figure 63. Anchor Bolt Assembly Model

Slip Base Assembly

An assembled and annotated slip base model is shown in Figure 64. A detailed list of slip base parts and their material specifications are provided in Table 3.

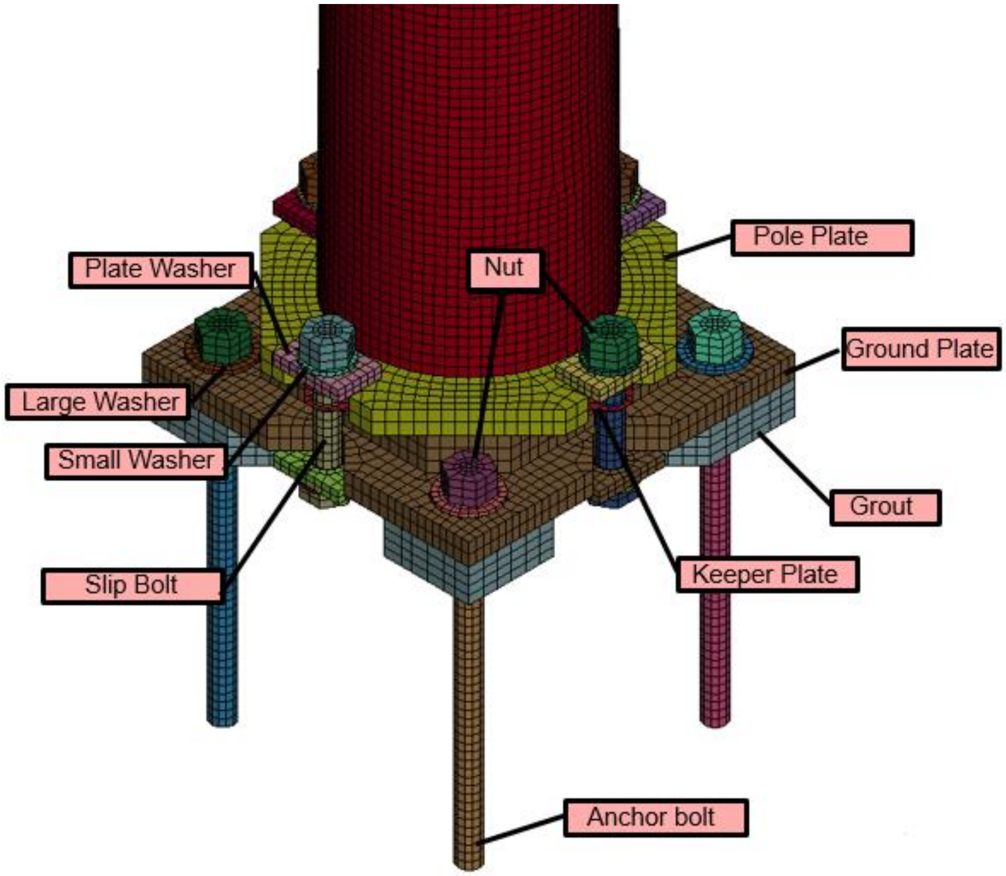


Figure 64. UDOT Slip Base Model Annotation

Table 3. UDOT Slip Base Parts List

Part	Quantity	Material Specification
Ground Plate	1	A36 Steel
Pole Plate	1	A36 Steel
Keeper Plate	1	A446 Steel
Slip Bolt	4	A325 Steel
Slip Nut	4	A325 Steel
Plate Washer	8	A325 Steel
Small Washer	8	A325 Steel
Anchor Bolt	4	A325 Steel
Anchor Nut	8	A325 Steel
Large Washer	8	A325 Steel

Contacts

The *CONTACT_AUTOMATIC_SINGLE_SURFACE keyword was used to define the interaction between the solid slip base parts. This type of contact is generally preferred when working with both solid and shell element types. Note that both the static and dynamic friction factors for the slip base contact were set to 0.2, a commonly used value for *CONTACT keywords involving steel-on-steel interaction.

The *CONTACT_AUTOMATIC_GENERAL keyword was used to define the interaction between the beam elements of the keeper plate and the slip bolts, as discussed further in the following section.

Keeper Plate/Slip Bolt Beam Elements

A previous breakaway slip base modeling effort at MwRSF encountered an issue with keeper plate rupture due to the interaction between the keeper plate, modeled with shell elements, and the slip bolts, modeled with solid elements. The edge of the keeper plate was extremely thin, and the use of different element types made it challenging to accurately model contact. To address this, beam elements were introduced along the edge of the bolt holes in the keeper plate and around the outer perimeter of the slip bolts. These beam elements were assigned an area of 0.1237 mm², corresponding to the squared thickness of the keeper plate. The beam elements were formulated using element formulation 2 (Belytschko-Schwer), and the previously mentioned *CONTACT_AUTOMATIC_GENERAL keyword was used to define their interaction. The beam elements are shown in Figure 65.

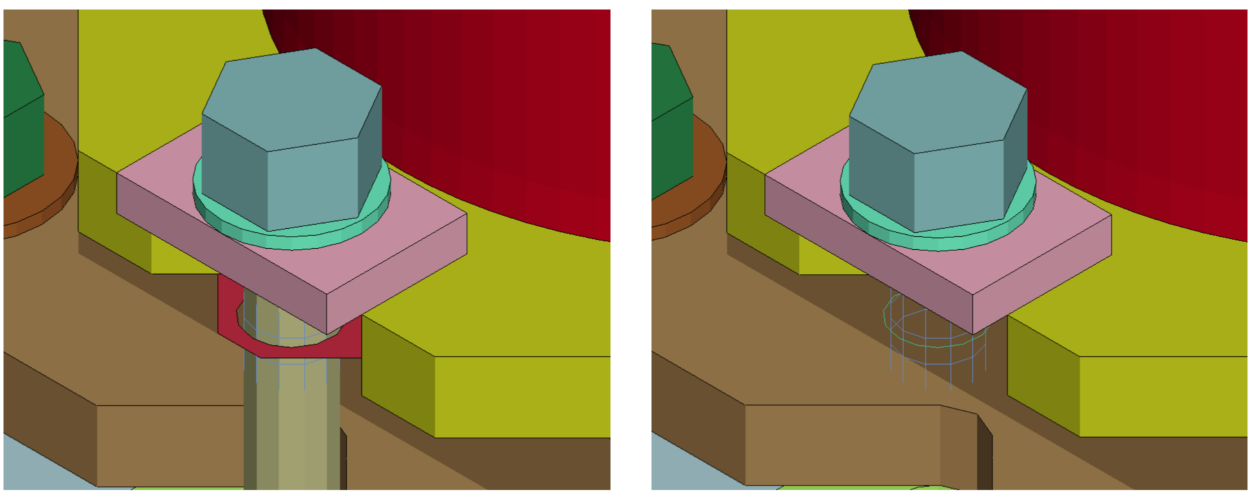


Figure 65. Keeper Plate and Slip Bolt Beam Elements

Preload

The 70-ft-lb bolt preload was applied using the *INITIAL_STRESS_SECTION keyword to a cross-section that intersected the middle of all the slip bolts. By applying stress to the bolts, they were effectively "squeezed" toward the cross-section where the stress was defined, simulating the preload effect. The bolts were gradually stressed to reach the desired preload.

The clamp force per bolt was calculated to relate the applied torque to the required stress per bolt, which was then used in the *INITIAL_STRESS_SECTION keyword.

The bolt torque of 70 ft-lb corresponds to the variable *T* in the equation below. The *K*-value of 0.25 is commonly used for galvanized bolts and represents the energy lost to friction during the tightening process. The value of 1 in. for *D* corresponds to the diameter of the slide bolts. The clamping force per bolt required to achieve the desired torque was calculated using the equation shown in Equation 1 [29].

$$Clamping\ Force\ per\ Bolt = F = \frac{T}{KD} = \frac{70ft * lbs}{0.25(1in. * \frac{1ft}{12\ in.})} = 3360\ lbs = 14.945\ kN;$$

Equation 1. Clamp Force per Bolt [29]

Using the relationship between force and stress, the stress per bolt was calculated. Force *F* represents the clamp force per bolt, which was divided by the cross-sectional area of a single bolt *A*. The stress per bolt was calculated using the equation shown in Equation 2.

$$Stress\ per\ Bolt = \frac{F}{A} = \frac{F}{\frac{\pi}{4}(D)^2} = \frac{3360\ lbs}{\frac{\pi}{4}(1\ in.)^2} = 4278.1\ psi = 0.0294949\ \frac{kN}{mm^2}$$

Equation 2. Stress per Bolt

The stress was applied gradually for 2½ msec to preload the slip base. Additionally, damping was applied to the slip base parts for the first 10 msec of the simulation to stabilize the preloading process. The resulting preload for each of the four slip base bolts and damping, each with a clamping force of 14.945 kN, resulted in a total preload of approximately 60 kN, as shown in Figure 66.

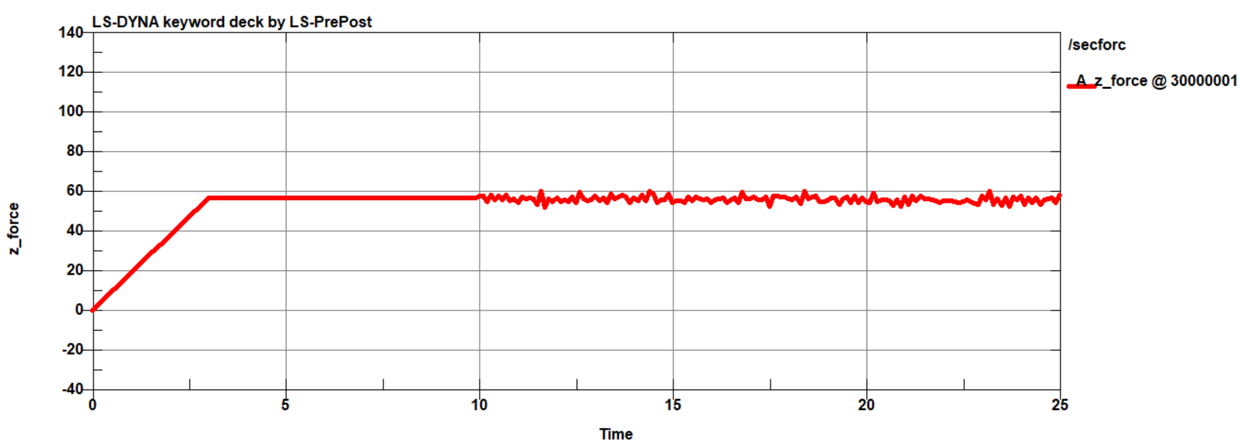


Figure 66. Slip Base Preload

3.1.2 Pole

The pole had a bottom diameter of 10 in. and tapered to a top diameter of 3 in., with a wall thickness of 11 gauge (0.125 in.). The total height of the pole was 50 ft. A mast-arm connection was welded to the pole 6 in. from the top and extending 11 in. downward. The pole was made of ASTM A595 Grade A steel and weighed approximately 902 lb. The pole was modeled using type 16 shell elements, with the material model using the *MAT_PIECEWISE_LINEAR_PLASTICITY formulation. The pole was connected to the pole plate of the slip base via merged nodes. The pole model is shown in Figure 67.

Figure 67. UDOT Pole Model

3.1.3 Pole-Mast Arm Connection

The mast arms were connected to the pole using the mast connection and gussets. The mast connection consisted of two A36 steel trapezoidal plates for each arm, each with three bolt holes. The pole-side mast connection was 1 in. thick and welded to the pole, as mentioned previously, while the arm-side mast connection was ¾ in. thick and welded to the mast arm, with the two connections bolted together. The gussets were welded to both the pole and the back of the pole-side mast connection. The geometries of the pole-side and arm-side mast connections were identical, except for the difference in thickness.

The mast connections were modeled using type 2 fully integrated solid elements. The steel material was represented using the *MAT_PIECEWISE_LINEAR_PLASTICITY formulation. The welds were modeled by merging nodes and applying *CONSTRAINED_NODAL_RIGID_BODY (CNRBs) between the nearest nodes of the pole/arm and the connection. The bolts were not explicitly modeled; instead, the bolted connection was simplified by merging the nodes of the arm-side and pole-side connections. An annotated mast connection is shown in Figure 68.

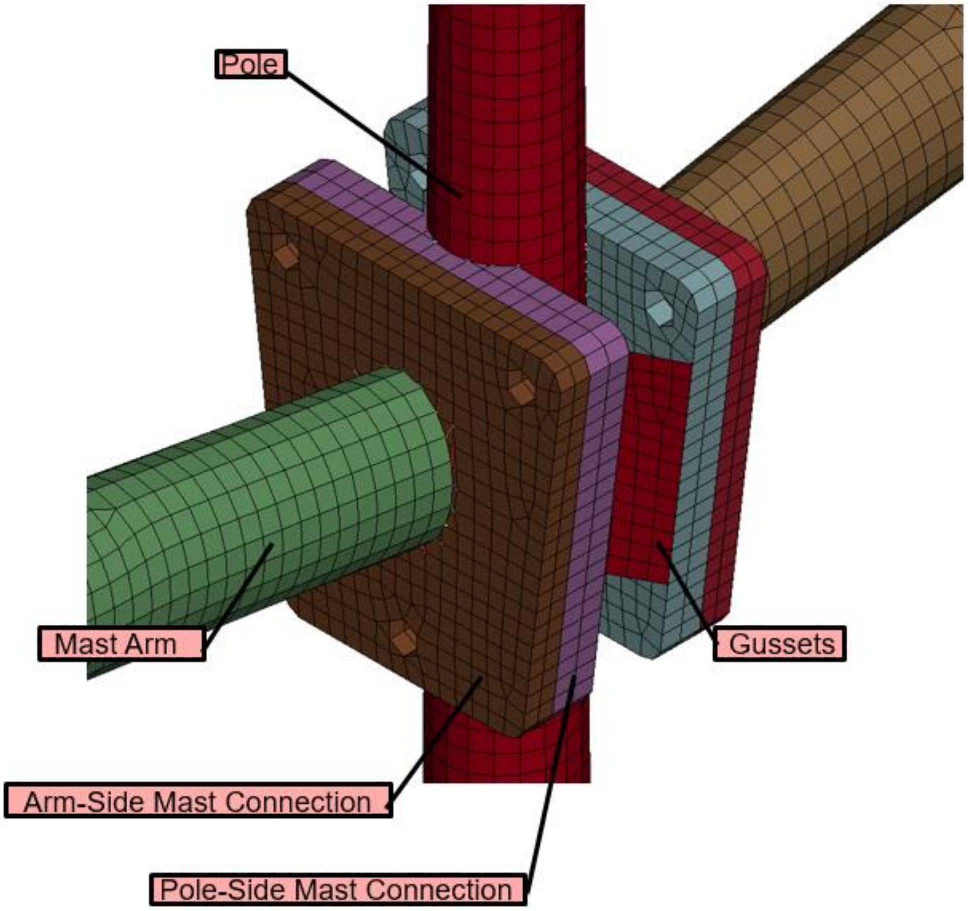


Figure 68. UDOT Pole-Mast Arm Connection Model

3.1.4 Mast Arms

The UDOT pole system in test numbers USBLM-1 and USBLM-2 had dual 15-ft mast arms. The mast arms were made of A595 steel with a thickness of 11 gauge (0.125 in.). The arms extended vertically to a distance of 2.5 ft and had 75-lb weights attached at the ends of each arm.

The mast arms were modeled using type 16 shell elements, with the steel material represented using the *MAT_PIECEWISE_LINEAR_PLASTICITY formulation. The welded connection to the pole-side mast connection was replicated using *CONSTRAINED_NODAL_RIGID_BODY (CNRBs) between the mast arms and the pole-side mast connection, as shown previously in Figure 68.

3.1.5 Surrogate Luminaire Weights

In test nos. USBLM-1 and USBLM-2, three 25-lb weights, for a total of 75 lb, were placed at the end of each mast to simulate a light attachment. The surrogate weight was modeled as a single plate that was attached to the bolt hole at the end of each mast arm using CNRBs, as shown in Figure 69. The MAT keyword assigned to the plate part was altered by adjusting the density of the material card that the plate used in order to achieve a total weight of 75 lb.

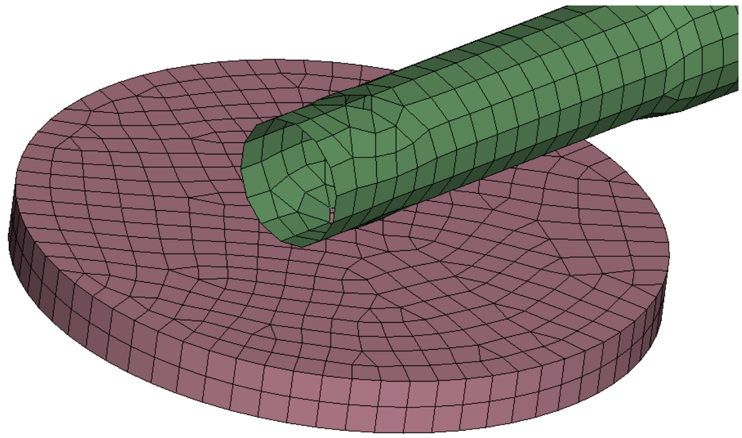


Figure 69. Surrogate Luminaire Model

3.1.6 4-Bolt Slip Base Luminaire Pole Model

The simulated and physical 4-bolt slip base installations are shown in Figures 70 and 71.

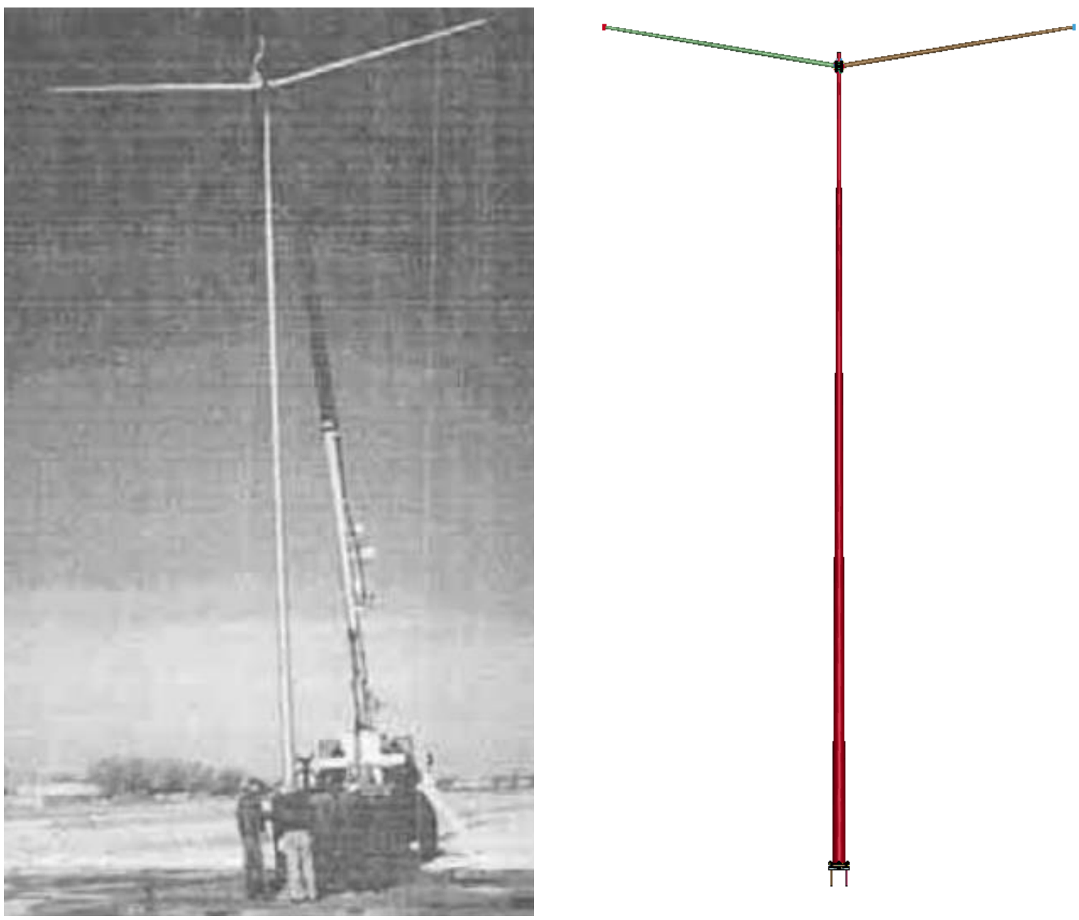


Figure 70. UDOT Luminaire Pole with 4-bolt Slip Base: Physical (left) vs LS-DYNA Model (right) [5]

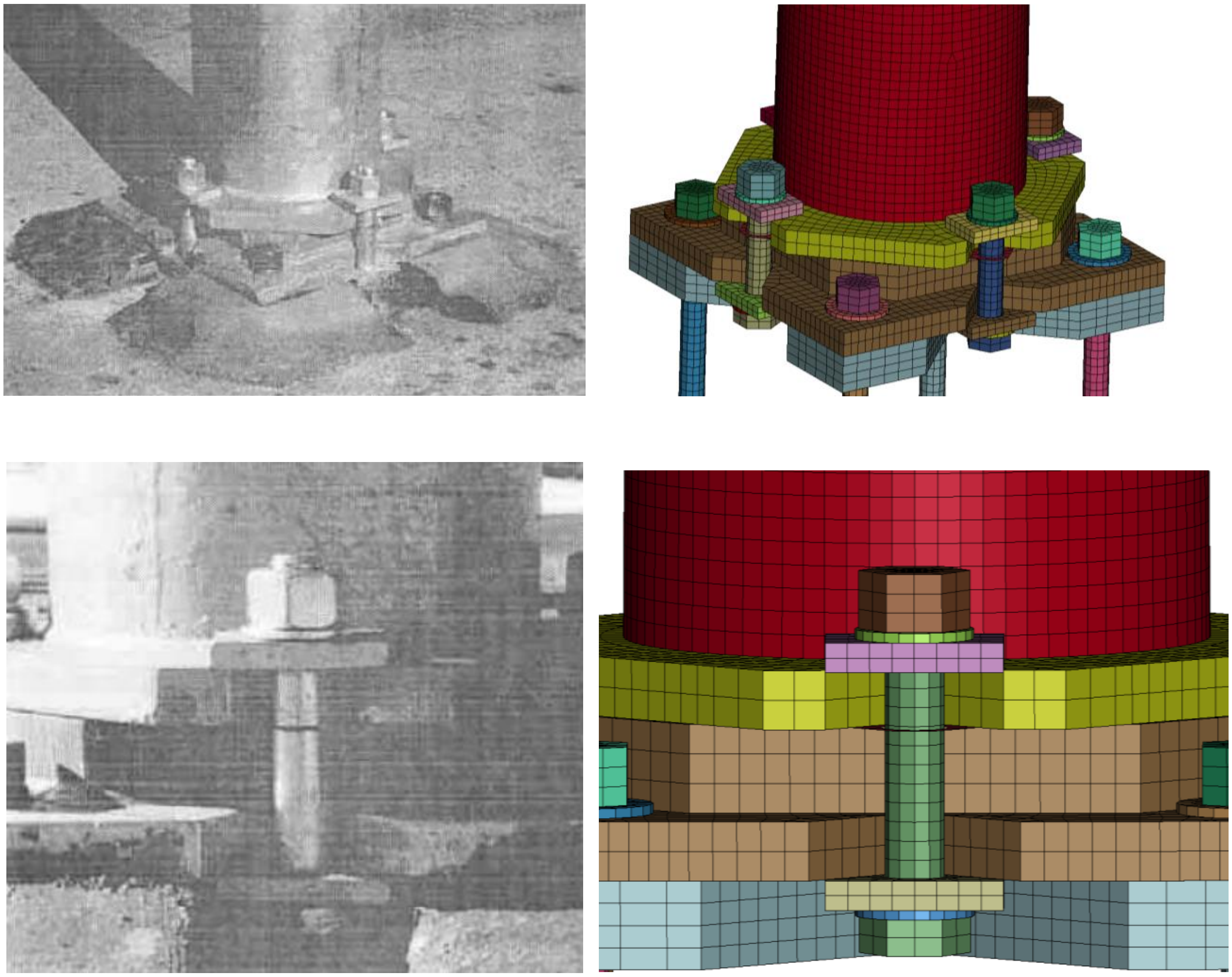


Figure 71. UDOT Slip Base Details: Physical (left) vs LS-DYNA Model (right) [5]

3.2 Vehicle Models

During the validation phase of the modeling effort, a 1,984-lb (900-kg) Geo Metro vehicle model was used. Among the available vehicle models, the Geo Metro model was the most comparable in mass to the 1,750-lb (800-kg) Dodge Colt, which was used to impact the luminaire pole in test nos. USBLM-1 and USBLM-2. The Geo Metro vehicle model was originally developed by the National Crash Analysis Centre (NCAC) [30]. The Geo Metro model is shown in Figure 72.

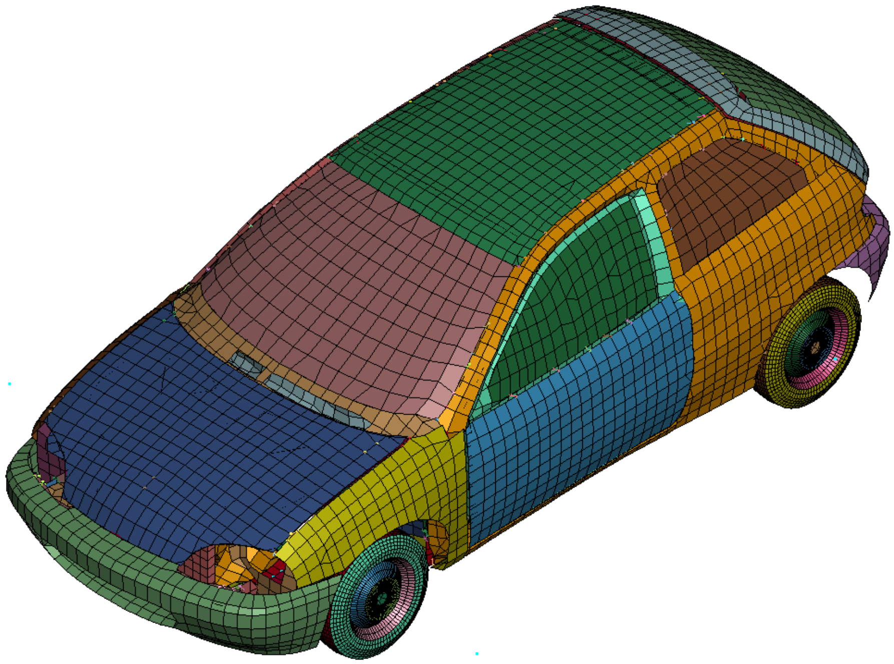


Figure 72. Geo Metro Vehicle Model [30]

A modified 2010 Toyota Yaris vehicle model was used in simulation efforts for MASH test designation nos. 3-60 and 3-61. The Yaris vehicle model was created by NCAC and later modified by MwRSF personnel for use in roadside safety applications [30]. The 2010 Toyota Yaris vehicle model, shown in Figure 73(a), had a test inertial mass of 2,425 lb.

A vehicle model of a 2018 Ram pickup truck was used for the simulation of MASH test designation no. 3-62. The Ram vehicle model was originally developed by the Center for Collision Safety and Analysis Team at George Mason University and was later modified by MwRSF personnel for use in roadside safety applications [31]. The 2018 Ram vehicle model is shown in Figure 73(b).

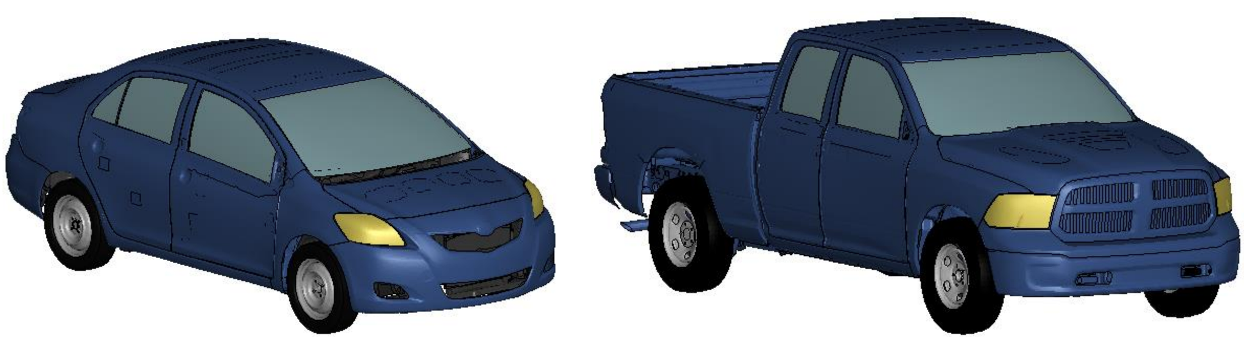


Figure 73. LS-DYNA Vehicle Models: 1100C Vehicle (left) and 2270P Vehicle (right) [30, 31]

3.3 LS-DYNA Model Validation

The simulated luminaire slip base system was validated using the data from full-scale test nos. USBLM-1 and USBLM-2 [5]. To validate the slip base model, several parameters were examined, including pole dynamics, OIV, ORA, change in velocity, and the timing of certain events. The OIV and ORA were calculated for each simulation using the data from the local accelerometer node at the vehicle's C.G. and processed using similar procedures for processing MASH full-scale crash test data.

3.3.1 Simulation of Test No. USBLM-1

As discussed in Section 2.3.2, in test no. USBLM-1, a 1,750-lb Dodge Colt impacted the luminaire pole at an impact speed of 15 mph and at an impact angle of 0 degrees, in accordance with NCHRP Report No. 230 test designation no. 3-62. The target impact point was the centerline of vehicle aligned with the centerline of the luminaire pole. Identical impact conditions were replicated for the model.

Sequential images of the LS-DYNA simulation and the full-scale testing results are shown in Figures 74 through 76, a comparison of change in velocity data is shown in Figure 77, and a summary of the results is shown in Table 4.

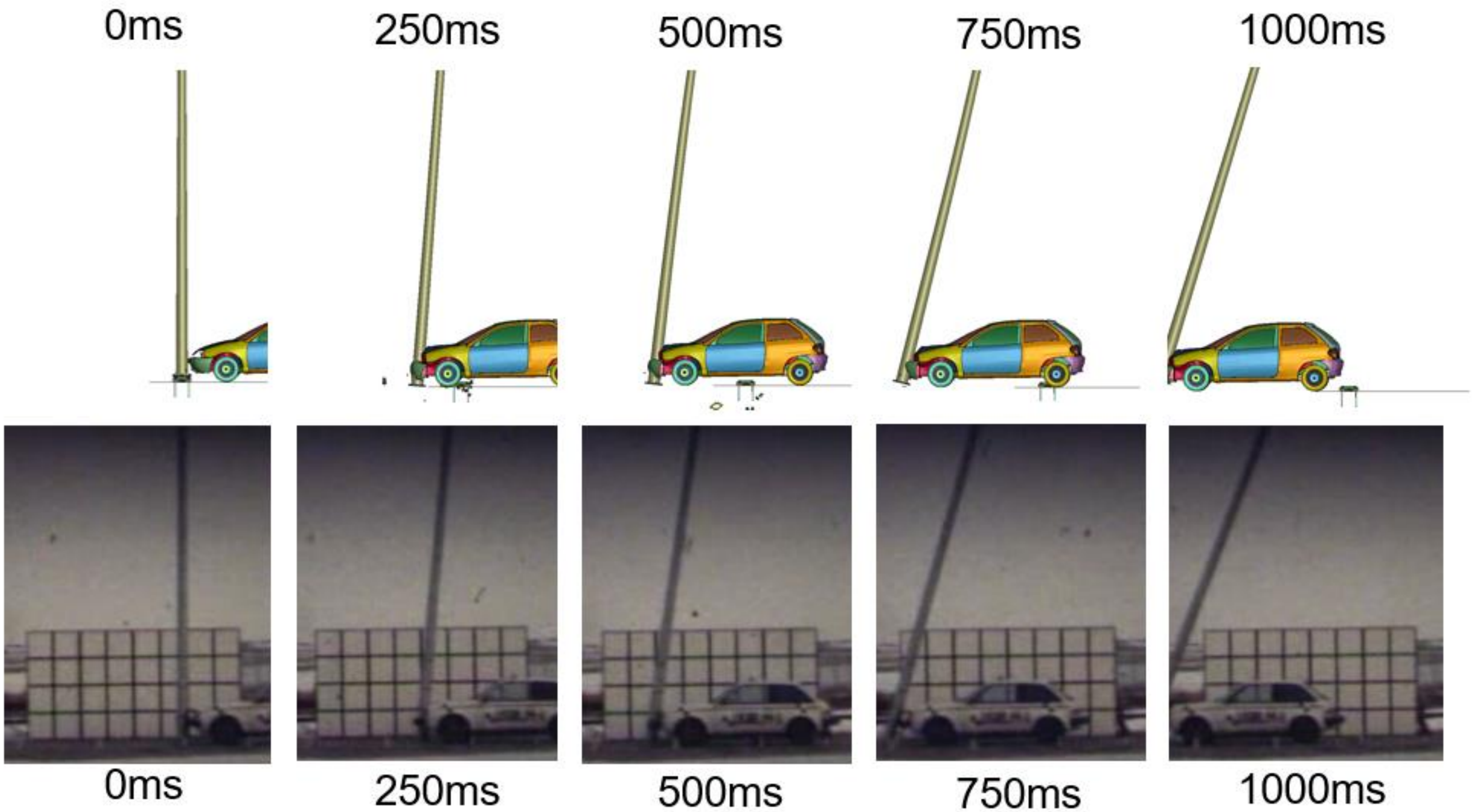


Figure 74. Comparison of Simulation (top) and Test No. USBLM-1 (bottom) Sequential Images [5]

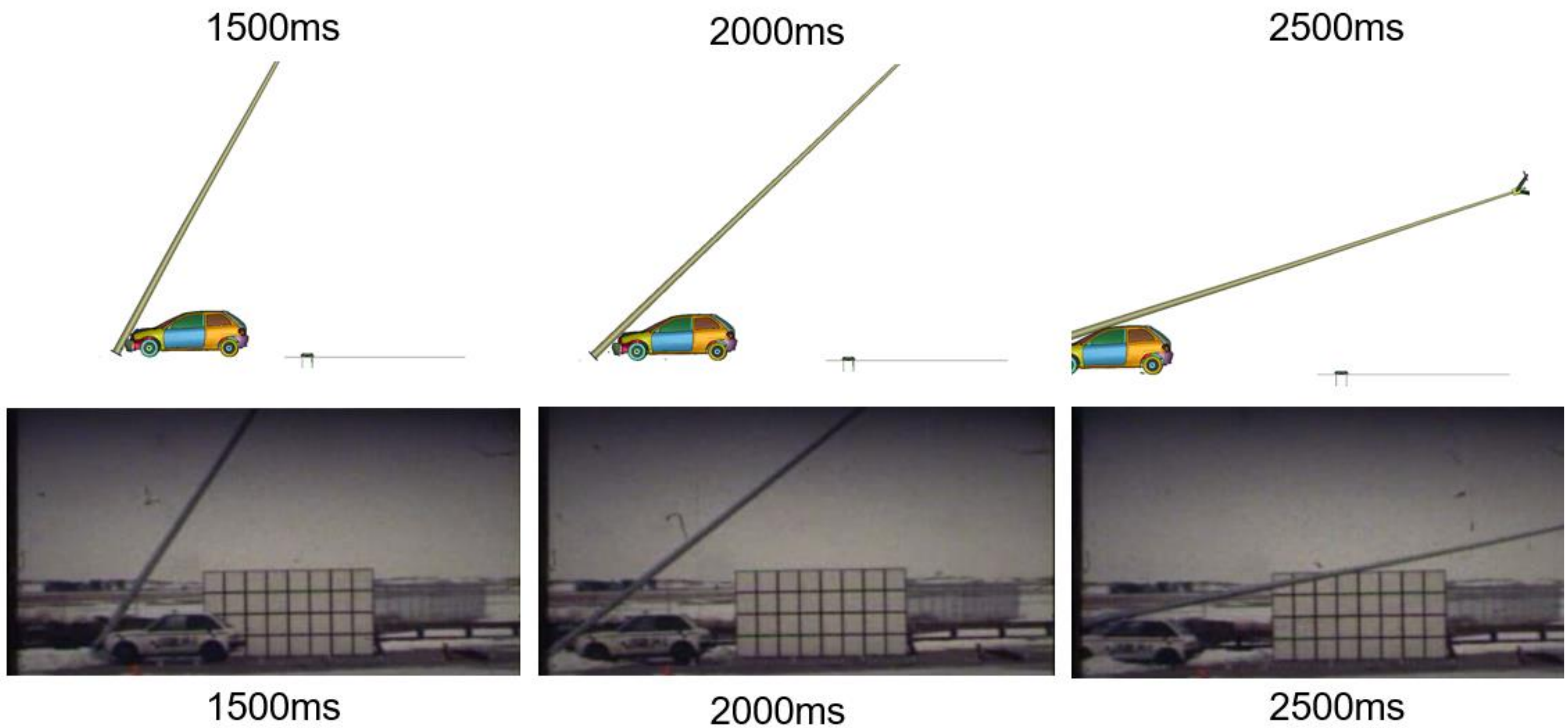


Figure 75. Comparison of Simulation (top) and Test No. USBLM-1 (bottom) Sequential Images, Cont. [5]

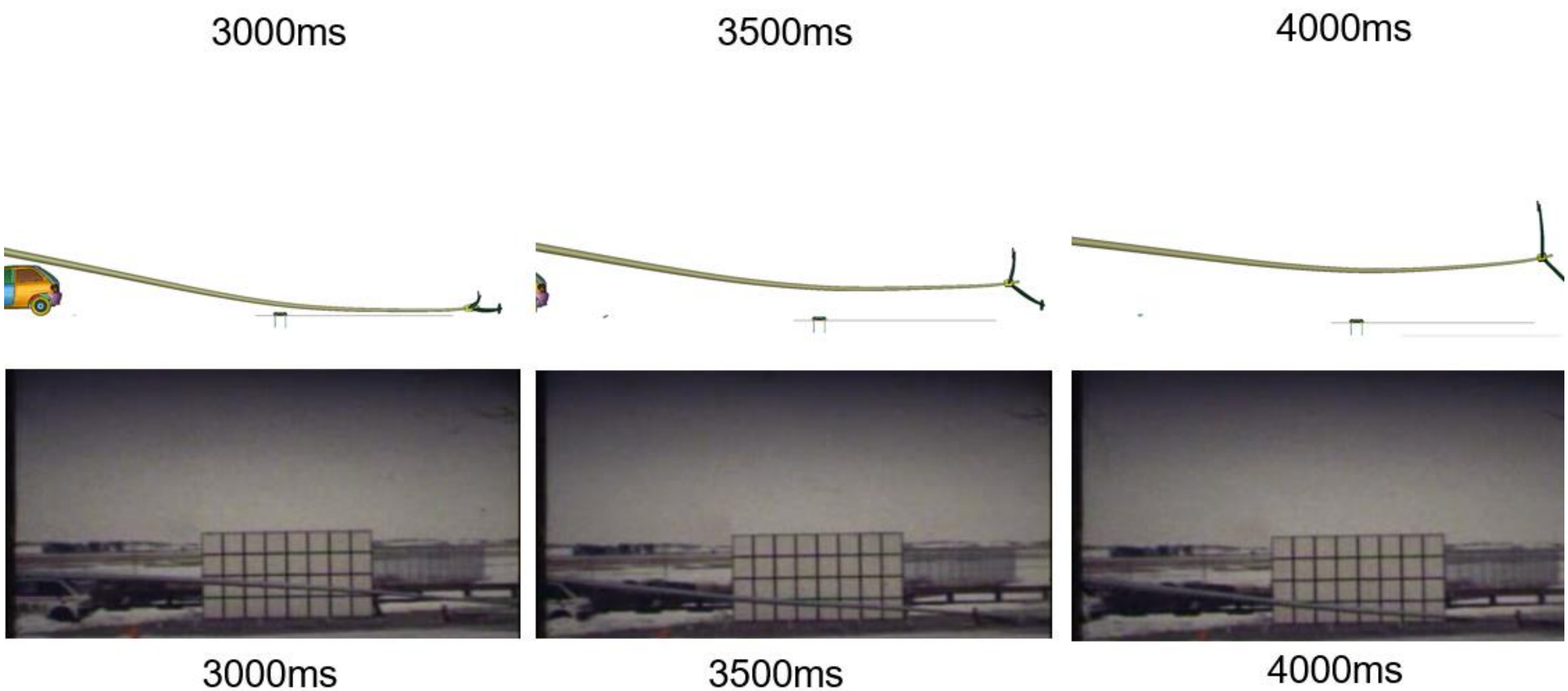


Figure 76. Comparison of Simulation (top) and Test No. USBLM-1 (bottom) Sequential Images, Cont. [5]

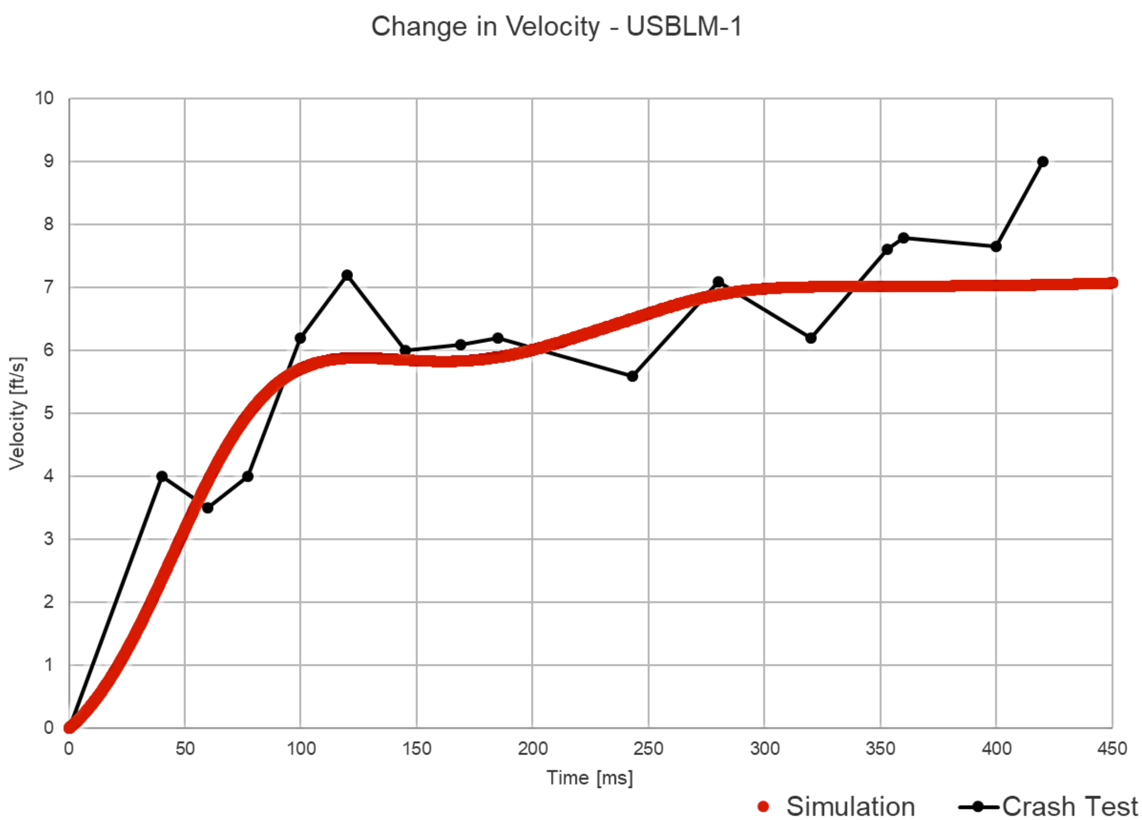


Figure 77. Comparison of Change in Velocity Data in Test No. USBLM-1 and Simulation

Table 4. Comparison of Test No. USBLM-1 and Simulation Results

Evaluation Parameters	**Time of Pole Contact with Roof (sec)**	**Time of Pole Contact with Ground (sec)**	**Roof Crush (in.)**	**Long. OIV (ft/s)**	**Change in Velocity (ft/s)**	**Long. ORA (g's)**
USBLM-1 Crash Test	2.33	2.73	Not Recorded	7.6	6.1	3.5
Validation Model	2.47	2.79	2.06	7.3	5.9	1.6

In both the crash test and the simulation, the vehicle impacted the pole, causing the slip base to break away. The pole fell onto the vehicle's roof, but with minimal deformation. The damage to both the vehicle and the pole was minimal. A comparison of the vehicle damage between the crash test and the simulation is shown in Figure 78.

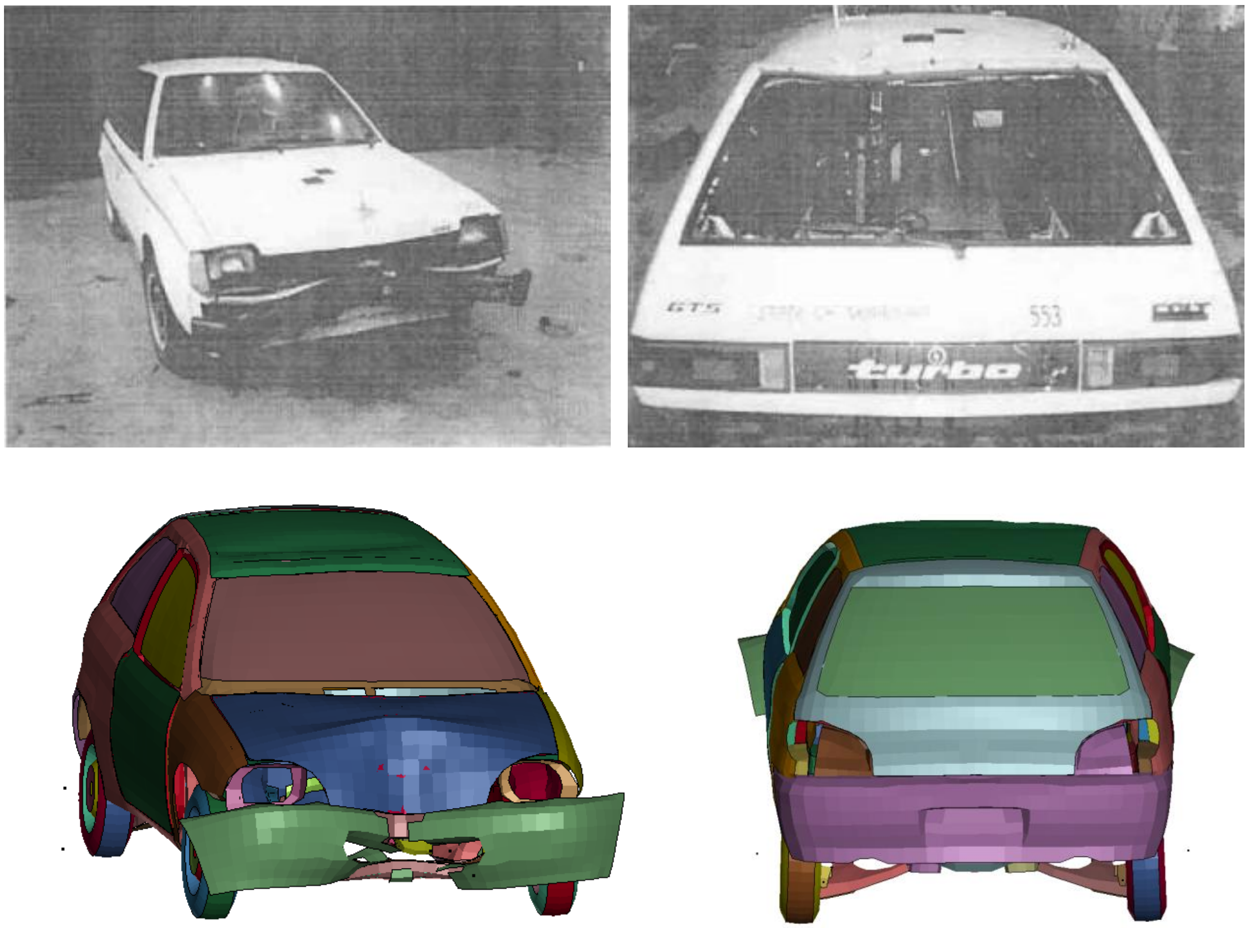


Figure 78. Comparison of Test No. USBLM-1 (top) and Model (bottom) Vehicle Damage [5]

In test no. USBLM-1, the OIV was 7.6 ft/s, the ORA was 3.5 g's, and the change in velocity was 6.1 ft/s. The roof crush was not recorded. In the simulation, the OIV was 7.3 ft/s, the ORA was 1.6 g's, and the change in velocity was 5.9 ft/s. The maximum simulated roof crush was 2.1 in., as shown in Figure 79.

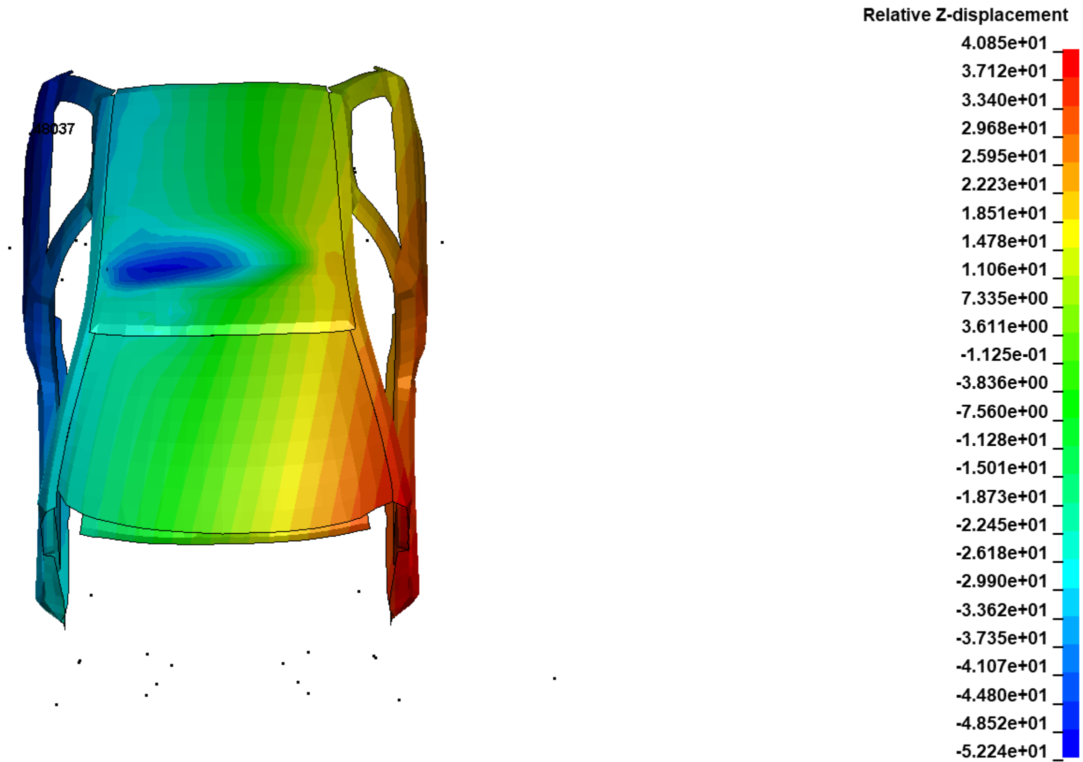


Figure 79. Model Vehicle Roof Crush, Test No. USBLM-1 Simulation

Discussion

Due to the lack of roof deformation measurements from the crash test, comparison of roof deformation was limited to image analysis. In both the crash test and the validation simulation, the damage to the roof was minimal, with a key difference being the deformation at the rear of the roof in the crash test. This difference was attributed to a second impact of the pole onto the rear center of the roof, which occurred after the top of the pole hit the ground. The video from the crash test showed that this second impact resulted in additional deformation at the rear of the roof. It was concluded that this second impact occurred in the crash test due to the vehicle's brakes being applied, slowing the vehicle down. The second impact did not occur in the simulation as no brakes were applied.

The simulation OIV of 7.3 ft/s was 4% lower than the recorded value of 7.6 ft/s from the crash test. Given the small difference in OIV, the simulation was deemed to accurately predict the impact in terms of OIV.

The simulation predicted an ORA value of 1.6 g's, which was 75% lower than the recorded value of 3.5 g's in the crash test. This difference may be due to the methods used to obtain acceleration in both the crash test and the LS-DYNA model. During the time of the USBLM test, video analysis was commonly used to calculate changes in speed, which were derived from changes in displacement. This method can lead to poor data due to the limited number of data points. However, LS-DYNA calculates acceleration through derivatives of displacement over time, similar to the crash test, but captures data 10,000 times per second, which can result in "noisy" data. Therefore, comparing these two methods can lead to inconsistencies. Both the simulated and crash test ORA values were well below the maximum allowable ORA of ±20.49 g's, indicating that the differences in ORA were not a concern.

The simulation predicted a change in velocity value of 5.9 ft/s, which was 3% lower than the recorded value in the crash test of 6.1 ft/s. Given the small difference, the simulation was deemed to accurately model the impact in terms of delta V, as shown in Figure 77.

Accurate prediction of pole dynamics after impact is important for modeling roof crush. The validated model was found to effectively predict the dynamics of the pole upon impact with the vehicle, as shown in the sequential images. The roof crush from the simulation and crash test were also comparable. The small differences observed between the simulation and crash test, in terms of dynamics and event timing, could be attributed to variations in the geometry and mass of the vehicle model compared to the test vehicle. As mentioned previously, the mass of the Geo Metro model was 2,000 lb while the mass of the Dodge Colt from test no. USBLM-1 was 1,750 lb.

3.3.2 Simulation of Test No. USBLM-2

In test no. USBLM-2, the same Dodge Colt from test no. USBLM-1 was repaired and utilized in the crash test. The 1,750-lb vehicle impacted the luminaire pole at an impact speed of 57.5 mph and at an impact angle of 0 degrees, in accordance with NCHRP Report No. 230 test designation no. 3-63. The target impact point was the centerline of vehicle aligned with the centerline of the luminaire pole. Identical impact conditions were replicated in the simulation.

Sequential images of the LS-DYNA simulation and the crash test results are shown in Figures 80 and 81, a comparison of change in velocity data is shown in Figure 82, and a summary of results is shown in Table 5.

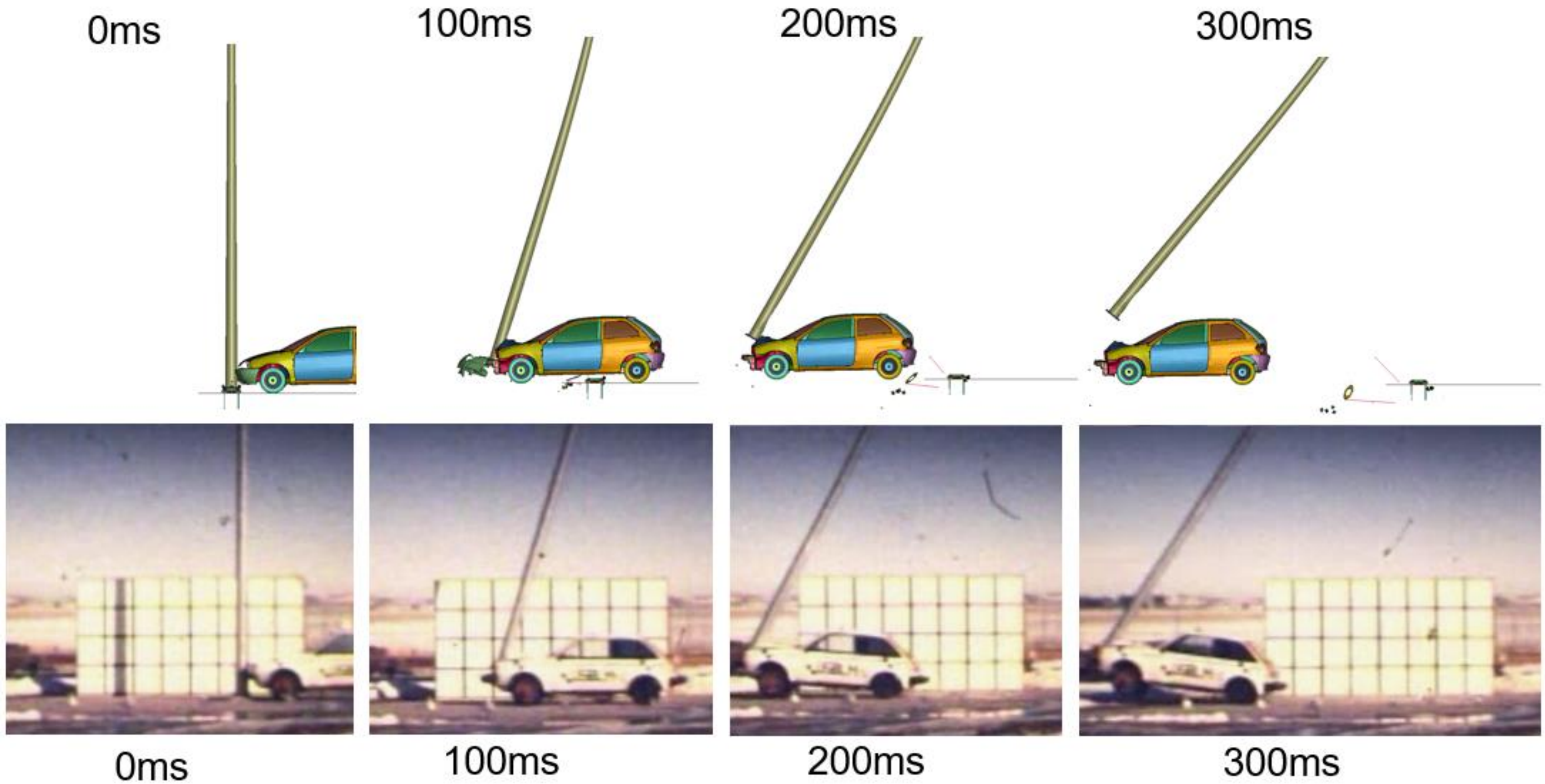


Figure 80. Comparison of Simulation (Top) and Test No. USBLM-2 (Bottom) Sequential Images [5]

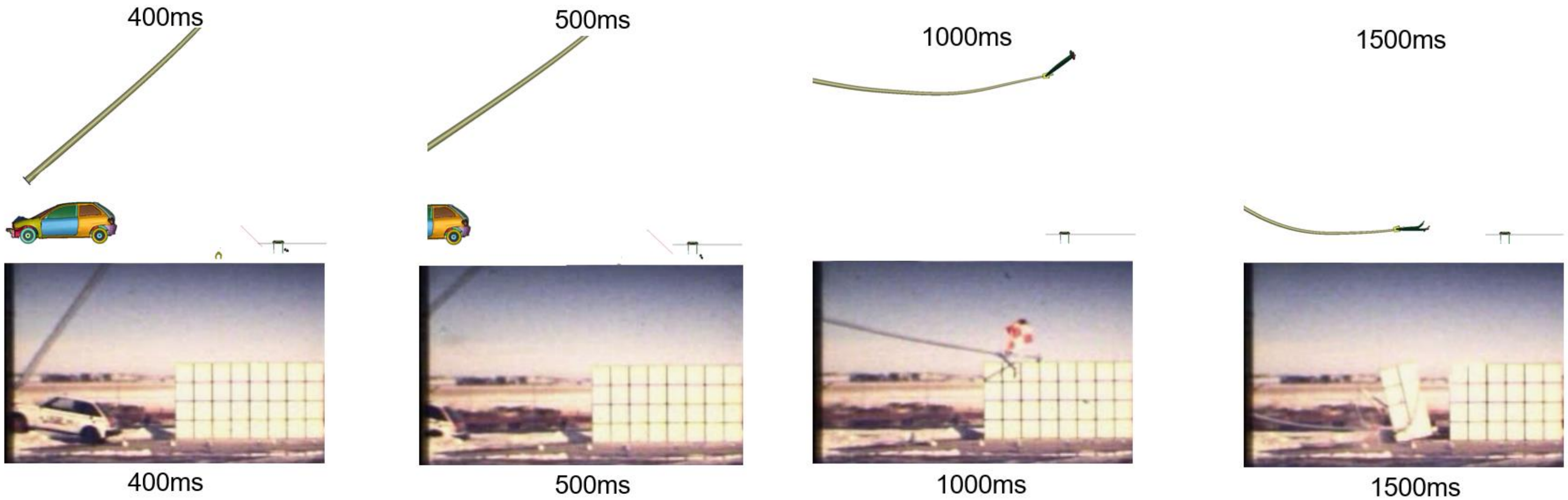


Figure 81. Comparison of Simulation (Top) and Test No. USBLM-2 (Bottom) Sequential Images, Cont. [5]

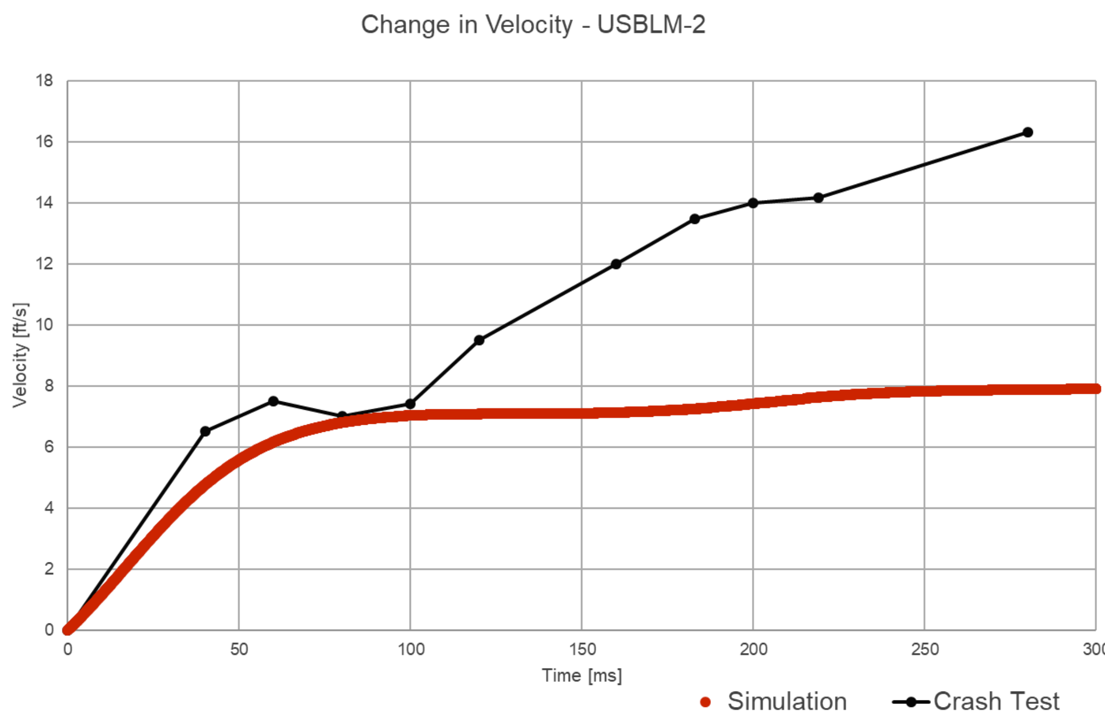


Figure 82. Comparison of Change in Velocity Data in Test No. USBLM-2 and Simulation

Table 5. Comparison of Test No. USBLM-2 and Simulation Results

Evaluation Parameters	Time of Pole Contact with Roof (sec)	Time of Pole Contact with Ground (sec)	Roof Crush (in.)	Long. OIV (ft/s)	Change in Velocity from 0-100 msec (ft/s)	Change in Velocity from 100-175 msec (ft/s)	Long. ORA (g's)
USBLM-2 Crash Test	N/A	1.11	N/A	14.2	7.7	13.5	1.00
Validation Model	N/A	1.31	N/A	10.0	7.1	7.3	1.55

In both the crash test and simulation: (1) the vehicle impacted the pole and the slip base broke away, (2) the pole did not fall onto the vehicle, (3) there was minimal damage to the vehicle, with all damage confined to the front, and (4) the test met all NCHRP 230 evaluation criteria. A comparison of the vehicle damage between the crash test and the model is shown in Figure 83.

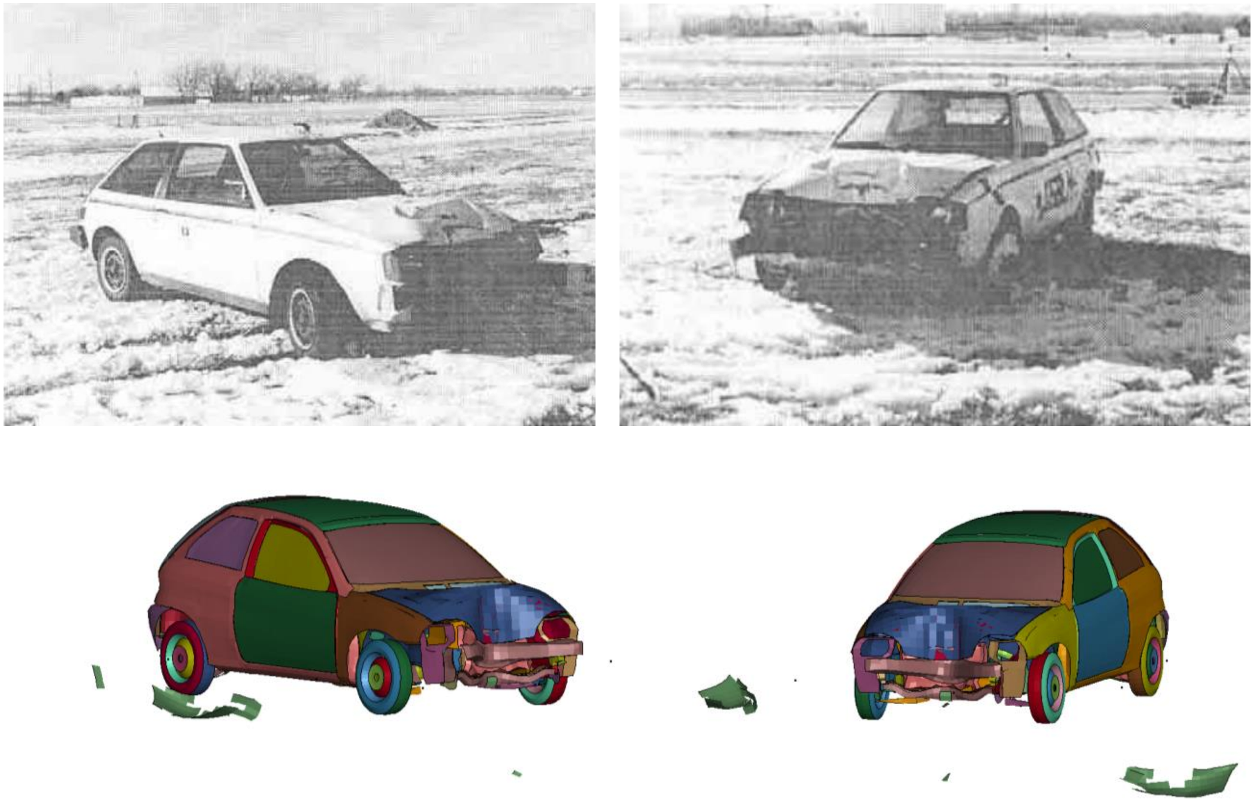


Figure 83. Comparison of Test No. USBLM-2 B (top) and Model (bottom) Vehicle Damage [5]

The simulation could not capture pole buckling at the location of impact; however, this was not a concern as pole damage is not a failure criterion.

<u>Discussion</u>

There was no roof crush in either crash test no. USBLM-2 or the simulation or as the pole did not fall on the vehicle. The simulation predicted an OIV value of 10.0 ft/s, which was 34% lower than the recorded value of 14.2 ft/s in the crash test. This difference could be attributed to the pole base plate catching under the vehicle hood. Additionally, as the literature indicates that OIV can vary by 100% or more under identical test conditions [27], it was deemed reasonable to continue with the simulation.

The simulation predicted an ORA value of 1.7 g's, which was 49% higher than the recorded value of 1 g in the crash test. This difference may be due to variations in how acceleration was measured in the crash test and the model, as discussed in the test no. USBLM-1 section. Since both the simulation and crash test ORA values were well below the maximum allowable ORA of ±20.49 g's, this difference did not raise concerns.

The simulation predicted a peak change in velocity value of 7.1 ft/s between 0 msec and 100 msec, which was 8% lower than the recorded crash test value of 7.7 ft/s. The model also predicted a peak change in velocity of 7.3 ft/s, which was 60% lower than the recorded value of 13.5 ft/s in the crash test. The difference may be due to the pole plate catching on the bumper and hood, as described below, which affected the dynamics of the impact and became significant around 100 msec

In test no. USBLM-2, the pole base plate caught on the front bumper and hood of the vehicle due to the pole moving upward after impact. The pole base plate lifted the front wheels of the vehicle off the ground, starting approximately 180 msec after impact, and was released from the front bumper around 415 msec after impact. The front wheels contacted the ground again approximately 900 msec after impact, meaning the catching event and subsequent lifting of the vehicle lasted roughly 720 msec. In the simulation, the pole plate did not catch on the front of the Geo Metro vehicle model; instead, it moved upward and flipped over the vehicle. The difference in behavior may be due to the Geo Metro vehicle model's front bumper and hood lacking the rigidity and strength of the crash-tested Dodge Colt.

The difference in the impact timing between the top of the pole and the ground between the crash test and simulation could be due to the pole plate catching, which likely impacted the pole's rotational behavior, thus influencing the timing of the pole's impact with the ground.

The difference in the change in velocity of the vehicle between the crash test and the model, shown previously in Figure 82 and Table 5, was likely due to the lack of pole plate catching on the vehicle in the model, as discussed. To properly compare the crash test and the model, two different time periods for change in velocity were analyzed. The time period from 0 msec to 100 msec captures the change in velocity from impact to the moment the pole plate catches on the bumper and hood. The time period from 0 msec to 175 msec captures the change in velocity from impact to the vehicle clearing the base, which aligns with how the change in velocity time period was used in the test no. USBLM-1 comparison. From 0 msec to 100 msec, the change in velocity in the simulation closely matched the crash test. However, from 100 msec to 175 msec, the change in velocity in the simulation did not match well with the crash test.

The validated model was sufficient in estimating the pole dynamics after vehicle impact, as shown in the sequential images and the time of ground contact. The differences observed between the simulation and the crash test, in terms of dynamics and event timing, could be attributed to variations in the geometry and mass of the vehicle model: the mass of the Geo Metro model was 1,900 lb, while the mass of the Dodge Colt from test no. USBLM-2 was 1,750 lb.

An attempt was made to adjust the mass of the Geo Metro vehicle model in the baseline simulation to more closely match the mass of the Dodge Colt used in the crash tests. However, adjusting the density of different vehicle parts to reduce weight is generally avoided, as it can change the positioning of the C.G., affecting the accuracy of the simulation data. Despite this, an effort was made, resulting in a change in velocity of 9.88 ft/s for the test no. USBLM-1 simulation and 11.25 ft/s for the test no. USBLM-2 simulation. Due to this being considered poor modeling practice and the resulting less accurate baseline simulation results, simulations with the altered Geo Metro were not used further. Ultimately, the unaltered simulations were deemed a sufficient match for test nos. USBLM-1 and USBLM-2, and the research effort continued using the developed slip base model.

3.4 Effect of Bolt Torque on Slip Base Performance

The validation of the 4-bolt slip base model was completed using the 70 ft-lb bolt torque used in the full-scale crash test, which was identical to the recommended bolt torque for the slip base in UDOT's standard plans. Since state DOTs use a range of bolt torques for their specific slip base designs, multiple models were created to investigate how varying the bolt torque of the clamp bolts would affect the performance of the slip base system. The range of bolt torque values used in these models was obtained from sources in the literature, as reported in Chapter 2. The range of bolt torque values is provided in Table 6.

Table 6. Bolt Torque Range used for Simulation

Simulation No.	Bolt Torque (ft-lb)	Source
1	60	No reference – Selected for comparison purposes
2	70	UDOT 4-Bolt Slip Base [5, 11]
3	80	WYDOT 4-Bolt Slip Base [13, 14]
4	90	Oregon 3-Bolt Slip Base (for Single Arm) [20]
5	100	Oregon 3-Bolt Slip Base (for Dual Arm) [20]
6	111	LS-16 Upper Bound Recommendation for 3-Bolt Slip Base [27]
7	150	Caltrans Type 15 & 30 Slip Base [8]
8	200	Caltrans Type 31 Slip Base [8]

All simulations were completed using the validated 4-bolt slip base model. A 50-ft tall pole with dual 15-ft mast arms and a weight of 986 lb was mounted on the slip base model. The pole model was chosen to represent the heaviest pole used with a slip base. The Toyota Yaris vehicle model was utilized and run at 19 mph to simulate a MASH test designation no. 3-60 center impact at 0 degrees, since the low-speed test is most critical for slip base activation. These simulations were used to investigate how alterations to bolt torque may affect the behavior of the slip base activation and dynamics of the pole and vehicle.

The modeling process was identical to the setup of the baseline simulation described in Section 3.1, except the bolt torque was changed for each model. The simulations were analyzed to determine the effect of different bolt torques on pole and vehicle dynamics. The simulation results are shown in Table 7.

Table 7. Bolt Torque Alteration Simulation Results

Evaluation Parameters	Time of Pole Contact with Roof or Windshield (sec)	Time of Pole Contact with Ground (sec)	Long. OIV (ft/s)	Long. ORA (g's)	Occupant Compartment Deformation (in.)	Location of Maximum Occupant Compartment Deformation
Sim. No. 1 (60 ft-lb)	1.73	2.08	7.04	0.92	7.13	Rear Center of Roof
Sim. No. 2 (70 ft-lb)	1.71	2.05	7.23	1.24	6.87	Rear Center of Roof
Sim. No. 3 (80 ft-lb)	1.74	2.08	7.24	0.89	6.34	Rear Center of Roof
Sim. No. 4 (90 ft-lb)	1.79	2.16	8.09	0.88	7.49	Rear Center of Roof
Sim. No. 5 (100 ft-lb)	1.79	2.20	8.40	0.80	8.68	Rear Center of Roof
Sim. No. 6 (111 ft-lb)	1.92	2.22	8.42	0.84	7.69	Rear Center of Roof
Sim. No. 7 (150 ft-lb)	1.90	2.28	9.95	1.10	10.69	Rear Center of Roof
Sim. No. 8 (200 ft-lb)	1.89	2.28	10.45	1.46	8.62	Rear Center of Roof

In general, as bolt torque increased, the OIV also increased, and the pole fell more slowly. The highest simulated OIV was 10.45 ft/s, which remained well below the MASH limit of 16 ft/s.

Despite significant increases in bolt torque, the slip base activated in every simulation. The occupant compartment deformation varied between simulations, though the location of the pole's first contact with the vehicle and location of maximum occupant compartment deformation remained nearly identical.

Note that for higher bolt torques, the keeper plate shell elements began to disintegrate before impact, likely due to the significantly higher clamping force between the pole base plate and the ground plate. However, the beam elements along the edge of the keeper plate and edge bolts remained intact at the time of impact. While improvements to the slip base model could address the damage to the keeper plate caused by the clamp force, the beam elements' integrity at the time of impact indicated that the model's performance was not adversely affected. Therefore, the slip base model was not modified for this investigation. The slightly damaged, though still intact keeper plate and beam elements are shown in Figure 84.

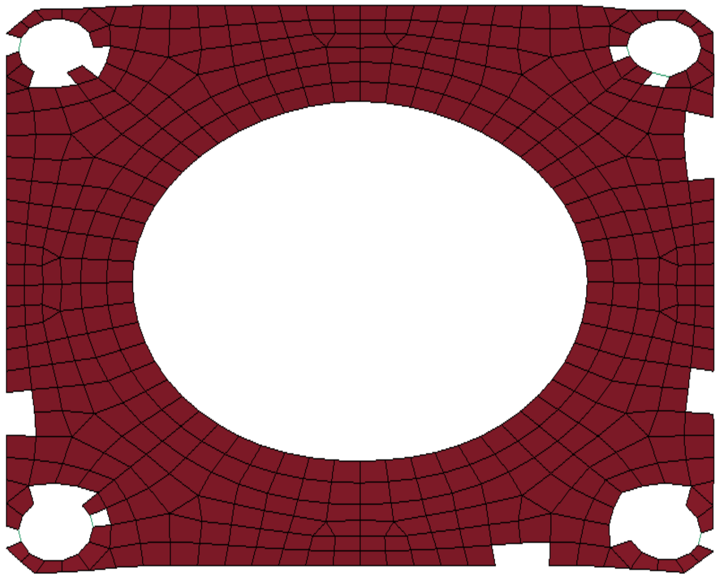


Figure 84. Keeper Plate Condition at Time of Impact for Clamp Bolt Torque = 200 ft-lb

The slip base model was not validated for bolt torques other than 70 ft-lb. Therefore, full-scale crash testing, or at a minimum, pendulum or bogie testing, would be required to analyze the effect of varying bolt torques in more detail.

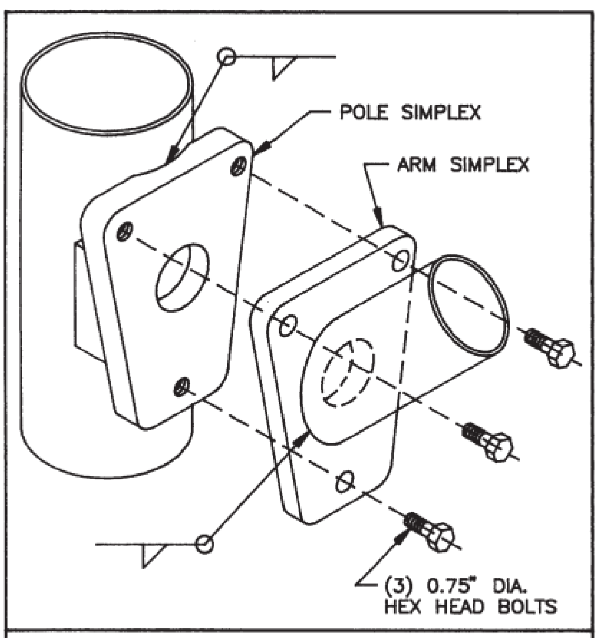
4 CRASHWORTHINESS EVALUATION OF POLE CONFIGURATIONS SUPPORTED ON 4-BOLT SLIP BASE

4.1 Simulation Matrix

4.1.1 Luminaire Pole Configurations

To evaluate the crashworthiness of various steel pole configurations under MASH TL-3 impact conditions, additional simulations were conducted to identify critical pole configurations and impact scenarios. The LS-DYNA simulations were conducted to evaluate steel poles of varying heights, mast arm lengths, and configurations (single and dual mast arms), all mounted on a 4-bolt slip base. These configurations were evaluated against MASH TL-3 safety criteria. The study included pole heights of 20, 30, 35, 40, 45, and 50 ft, each analyzed with single and dual mast arm setups and various mast arm lengths, resulting in 32 luminaire pole configurations. The configurations were chosen to reflect the range of combinations commonly used by state DOTs. Pole and mast arm dimensions (including diameter and wall thickness) and arm configurations were based on specifications from the Valmont Industries Pole Assembly catalog [32].

Details regarding the connections between the mast arms and the poles were obtained from Valmont Industries, Inc.'s online catalog. Steel poles and mast arms had options for bolted connection plates, typically using three to four bolts per mast arm, as shown in Figure 85 (left), or a bracket that supports the mast arm with one to two bolts to hold the arm in place, as shown in Figure 85 (right). During a meeting with representatives from Valmont Industries, Inc., it was determined that the different connection types would perform similarly, ensuring that mast arms remained attached to the pole during an impact event. As a result, the three-bolt connection was selected for all mast arm connections in the simulation matrix. This decision streamlined the matrix by eliminating variations in mast arm connections.



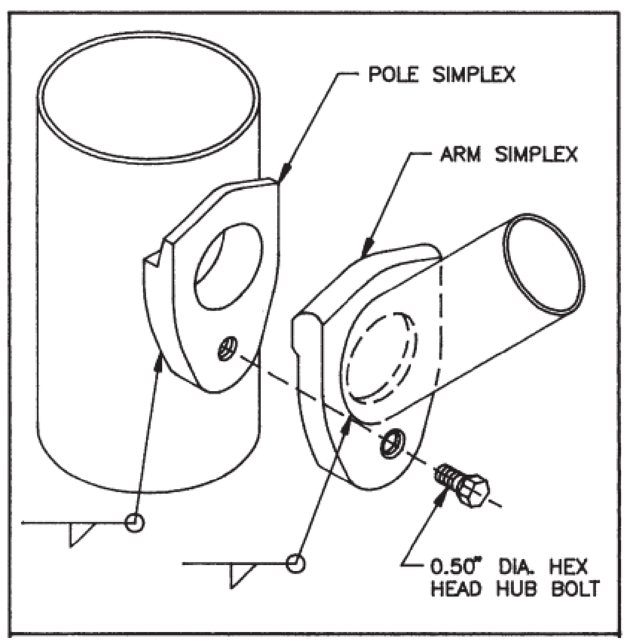


Figure 85. Mast Arm and Luminaire Pole Connection Details for Steel Poles: Bolted Connection Plate (left) and Bracket with Bolts (right)

The final assumption in developing the simulation matrix was that the presence or absence of a truss in the mast arm configuration would not significantly affect testing behavior. Data collected from Valmont Industries, Inc.'s online catalog indicated that mast arm configurations with trusses typically added approximately 20 lb to the system's total weight. For a luminaire support with average height, thickness, and mast arm length, this weight difference amounted to about 5%. This small variation was not expected to significantly alter the overall mass or the C.G. location, which were assumed to be the one of the primary factors influencing the speed at which luminaire poles contact a vehicle's roof.

These pole configurations were modeled using LS-DYNA and mounted on the 4-bolt slip base model from the baseline simulations discussed in Section 3.1.1. The modeling process of the pole configuration was identical to the setup of the baseline simulation model in Section 3.1, which included identical: (1) materials (i.e., ASTM A595 steel for pole and arms, A36 steel for connections), (2) surrogate luminaires (i.e., steel plates), and (3) mast arm connections (i.e., trapezoidal 3-bolt pole and arm plates). The surrogate luminaire weight was reduced from 75 lb, used in the baseline simulation models, to 50 lb for the subsequent simulations. This adjustment was made based on recommendations from state DOT representatives as 50 lb luminaires are more commonly used. As noted earlier, changes to pole height, pole thickness, pole base diameter, pole top diameter, arm length, and arm configuration were made per specifications provided in the Valmont Industries Pole Assembly catalog.

The selected pole configurations and a summary of the primary design parameters are shown in Table 8. The objective of simulating the pole configurations in the matrix was to identify the most critical configurations and determine which were likely to meet MASH criteria. For a configuration to be classified as "likely to pass MASH" it could not violate any of the MASH safety criteria under any of the simulated impact conditions.

Table 8. Steel Pole Configurations

Simulation No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Arm Config.*	Pole wall Thickness (in.)	Pole Base Dia. (in.)	Pole Top Dia. (in.)	Valmont Pole Model Name	Pole Weight (lb)	Arm and Connection (lb)	Mast-end Weights (lb)	Total Weight (lb)
20	20	4	S	0.1196	6.50	3.90	DS36	132	40	50	222
21	20	4	D	0.1196	6.50	3.90	DS36	132	80	100	312
22	20	10	S	0.1196	7.00	4.40	DS36	142	70	50	261
23	20	10	D	0.1196	7.00	4.40	DS36	142	139	100	381
30	30	4	S	0.1196	7.50	3.51	DS32	210	40	50	300
31	30	4	D	0.1196	7.50	3.51	DS32	210	80	100	390
34-1	30	10	S	0.1196	8.00	4.00	DS36	229	70	50	349
34-2	30	10	D	0.1196	8.00	4.00	DS36	229	139	100	468
32	30	20	S	0.1196	8.50	5.28	DS56 (30'-35')	262	121	50	433
33	30	20	D	0.1196	8.50	5.28	DS56 (30'-35')	262	242	100	604
35	35	4	S	0.1196	8.00	3.52	DS50 (32'-45')	257	40	50	347
36	35	4	D	0.1196	8.00	3.52	DS50 (32'-45')	257	80	100	437
39-1	35	10	S	0.1196	8.50	3.80	DS36	274	70	50	393
39-2	35	10	D	0.1196	8.50	3.80	DS36	274	139	100	513
37	35	20	S	0.1196	9.00	5.08	DS56 (30'-35')	314	121	50	485
38	35	20	D	0.1196	9.00	5.08	DS56 (30'-35')	314	242	100	656
40	40	4	S	0.1196	9.00	3.61	DS32	321	40	50	411
41	40	4	D	0.1196	9.00	3.61	DS32	321	80	100	502
44-1	40	10	S	0.1196	9.50	4.11	DS32	347	70	50	466
44-2	40	10	D	0.1196	9.50	4.11	DS32	347	139	100	586
42	40	20	S	0.1196	10.00	5.38	DS56 (40'-45')	385	7	50	556
43	40	20	D	0.1196	10.00	5.38	DS56 (40'-45')	385	242	100	727
45	45	4	S	0.1196	9.50	3.62	DS50 (32'-45')	376	40	50	466
46	45	4	D	0.1196	9.50	3.62	DS50 (32'-45')	376	80	100	557
49-1	45	10	S	0.1196	10.00	4.26	DS56 (40'-45')	409	70	50	528
49-2	45	10	D	0.1196	10.00	4.26	DS56 (40'-45')	409	139	100	648
47	45	20	S	**0.1345**	10.50	5.18	DS56 (40'-45')	505	7	50	676
48	45	20	D	**0.1345**	10.50	5.18	DS56 (40'-45')	505	242	100	847
50	50	8	S	**0.1345**	10.50	4.41	DS66	534	58	50	642
51	50	8	D	**0.1345**	10.50	4.41	DS66	534	116	100	750
52	50	15	S	**0.1345**	10.50	4.41	DS66	534	88	50	672
53	50	15	D	**0.1760**	10.50	4.41	DS66	710	176	100	986

*Note: "S" mast configuration = Single Arm, "D" mast configuration = Dual Arm

4.1.2 Test Requirements and Evaluation Criteria

Various pole configurations were simulated under different MASH impact conditions corresponding to test designation nos. 3-60, 3-61, and 3-62, each with varying impact scenarios. MASH test designation no. 3-60 is a low-speed test with a 1100C test vehicle impacting the pole at a speed of 19 mph. This test is designed to evaluate the kinetic energy required to activate the breakaway mechanism in the support system (i.e., 4-bolt slip base release). MASH test designation nos. 3-61 and 3-62 are intended to evaluate the behavior of the luminaire pole system under high-speed impacts. The primary concerns for these tests are the intrusion of the pole system components into the vehicle windshield, the potential for vehicle instability, and occupant risk measures, including OIV and ORA. The MASH evaluation criteria for support structures (e.g., luminaire poles with slip base systems) is shown in Table 9. The MASH occupant compartment deformation limits are provided in Table 10.

Table 9. MASH 2016 Evaluation Criteria for Support Structures

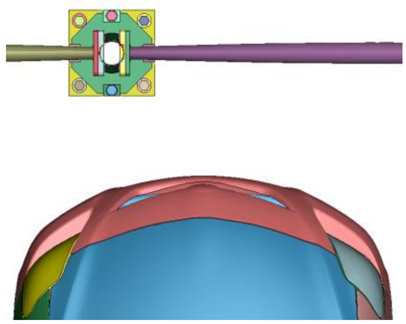
<table>
<tr><td>Structural Adequacy</td><td>B.</td><td colspan="3">Test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td></tr>
<tr><td rowspan="9">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test 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</td><td>10 ft/s
(3.0 m/s)</td><td>16 ft/s
(4.9 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>
<tr><td>Post-Impact Vehicular Response</td><td colspan="4">N. Vehicle trajectory behind the test article is acceptable.</td></tr>
</table>

Table 10. MASH Occupant Compartment Deformation Limits

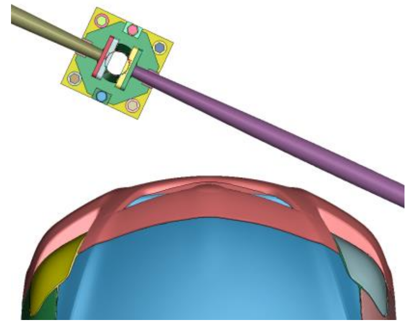
Location	MASH Allowable Intrusion (in.)
Wheel Well & Toe Pan	≤ 9
Floor Pan & Transmission Tunnel	≤ 12
A-Pillar	≤ 5
A-Pillar (Lateral)	≤ 3
B-Pillar	≤ 5
B-Pillar (Lateral)	≤ 3
Side Front Panel (in Front of A-Pillar)	≤ 12
Side Door (Above Seat)	≤ 9
Side Door (Below Seat)	≤ 12
Roof	≤ 4
Windshield	≤ 3
Side Window	No shattering resulting from contact with structural member of test article
Dash	N/A

MASH recommends that a critical impact point be determined that represents the worst-case impact conditions that would be consistent with the manner that the luminaire system will be deployed. Features, such as a luminaire pole used along the outside of divided highways, need only be evaluated for impact angles of 0 to 25 degrees. For the current study, test designation nos. 3-60, 3-61, and 3-62 were evaluated on luminaire pole configurations for impact angles of 0 and 25 degrees.

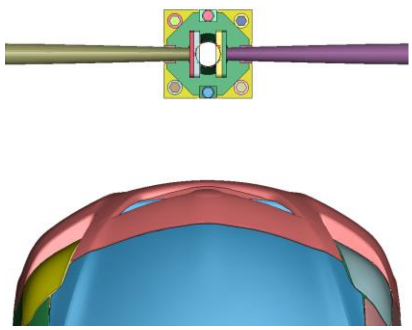
Moreover, MASH recommends that single support structures be tested with the centerline of the support aligned with the left-front or right-front quarter point of the impacting vehicle to promote vehicle instability. However, some past luminaire pole crash testing and simulation efforts (e.g., NCHRP Project 22-43), have revealed impact scenarios where the center impact point would be more critical than the left or right quarter points [5]. The varying vehicle impact conditions at 0-degree and 25-degree angles, including with the vehicle's center point, left-quarter point, and right-quarter point, are shown in Figure 86.



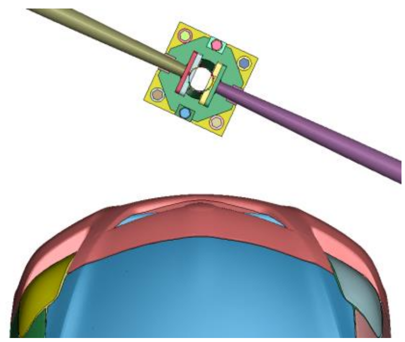
(a) 0 Degrees at Left-Quarter Point



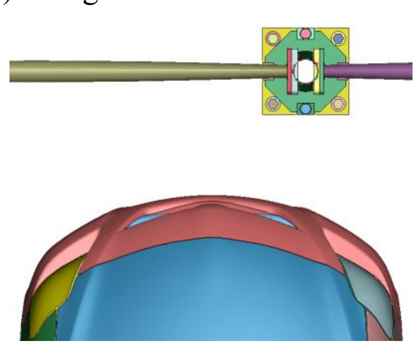
(b) 25 Degrees at Left-Quarter Point



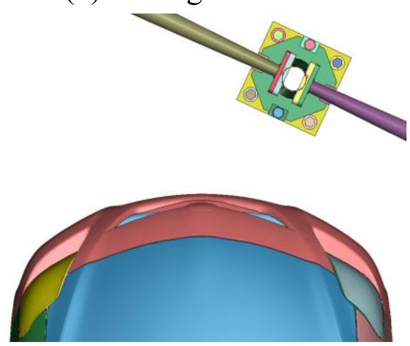
c) 0 Degrees at Center Point



(d) 25 Degrees at Center Point



(e) 0 Degrees at Right-Quarter Point



(f) 25 Degrees at Right-Quarter Point

Figure 86. Mast Arm Orientations – Left-Side Encroachment Off Road

MASH test designation nos. 3-60, 3-61, and 3-62 with a center impact point and 0-degree impact conditions, along with test designation no. 3-60 with a center impact point and 25-degree impact conditions, were applied to every pole configuration. These impact scenarios were considered the most critical due to the increased likelihood of the luminaire pole falling onto the vehicle's roof.

For poles with intermediate mast arm lengths (i.e., 10-ft long mast arms), only MASH test designation no. 3-60 with a center impact at 0-degree and 25-degree impact conditions was simulated. This approach was chosen after an initial review of results for pole configurations with minimum and maximum mast arm lengths. The aim was to focus on MASH test designation no. 3-60 simulations to investigate potential trends.

Additionally, MASH test designation nos. 3-60, 3-61, and 3-62 were simulated with left quarter-point impacts at 0-degree and 25-degree angles, as well as right quarter-point impacts at the same angles, for the heaviest pole configuration in each height category. For example, a 30-ft tall pole with dual 20-ft long mast arms represents the heaviest configuration within the 30-ft height class. Previous research and luminaire pole crash test simulations, such as those from NCHRP Project 22-43, indicated that heavy pole configurations often resulted in significant occupant compartment deformation during low-speed impacts. This deformation was identified as the most likely cause of failure to meet MASH evaluation criteria in earlier modeling efforts [33]. Heavy pole configurations also had high OIV during high-speed impacts, which was identified as a potential failure criterion in previous modeling efforts. To address this, additional simulation rounds were conducted for the heaviest poles under less critical impact conditions to assess the likelihood of excessive occupant compartment deformation or elevated OIV values. To optimize simulation efforts, only the heaviest pole configuration from each height class was subjected to all 18 impact conditions.

Additionally, a selection of single mast arm pole configurations with intermediate weights was simulated under MASH test designation no. 3-60 quarter-point impacts to evaluate the potential for the pole to land on the vehicle roof. Since none of these quarter-point simulations resulted in the pole landing on the vehicle roof and the OIV values were lower than those observed in the center impact point simulations, further quarter-point impact simulations were not pursued for the remaining pole configurations.

The simulated results with varying pole configurations and impact conditions are shown in Table 11. The highlighted cells represent cases that were simulated as a part of this study.

Table 11. Luminaire Pole Simulation Matrix

Simulation No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Arm Config. *	Total Weight (lb)	MASH Test Designation No. 3-60						MASH Test Designation No. 3-61						MASH Test Designation No. 3-62					
					Left 1/4		Center		Right 1/4		Left 1/4		Center		Right 1/4		Left 1/4		Center		Right 1/4	
					0	25	0	25	0	25	0	25	0	25	0	25	0	25	0	25	0	25
20	20	4	S	222							-	-		-	-	-	-	-		-	-	-
21	20	4	D	312	-	-			-	-	-	-		-	-	-	-	-		-	-	-
22	20	10	S	261	-	-			-	-	-	-		-	-	-	-	-		-	-	-
23	20	10	D	381																		
30	30	4	S	300							-	-		-	-	-	-	-		-	-	-
31	30	4	D	390	-	-			-	-	-	-		-	-	-	-	-		-	-	-
34-1	30	10	S	349							-	-	-	-	-	-	-	-	-	-	-	-
34-2	30	10	D	468	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	30	20	S	433	-	-			-	-	-	-		-	-	-	-	-		-	-	-
33	30	20	D	604																		
35	35	4	S	347							-	-		-	-	-	-	-		-	-	-
36	35	4	D	437	-	-			-	-	-	-		-	-	-	-	-		-	-	-
39-1	35	10	S	393							-	-	-	-	-	-	-	-	-	-	-	-
39-2	35	10	D	513	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-
37	35	20	S	485	-	-			-	-	-	-		-	-	-	-	-		-	-	-
38	35	20	D	656																		
40	40	4	S	411							-	-		-	-	-	-	-		-	-	-
41	40	4	D	502	-	-			-	-	-	-		-	-	-	-	-		-	-	-
44-1	40	10	S	466							-	-	-	-	-	-	-	-	-	-	-	-
44-2	40	10	D	586	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-
42	40	20	S	556	-	-			-	-	-	-		-	-	-	-	-		-	-	-
43	40	20	D	727																		
45	45	4	S	466							-	-		-	-	-	-	-		-	-	-
46	45	4	D	557	-	-			-	-	-	-		-	-	-	-	-		-	-	-
49-1	45	10	S	528							-	-	-	-	-	-	-	-	-	-	-	-
49-2	45	10	D	648	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	45	20	S	676	-	-			-	-	-	-		-	-	-	-	-		-	-	-
48	45	20	D	847																		
50	50	8	S	642							-	-		-	-	-	-	-		-	-	-
51	50	8	D	750	-	-			-	-	-	-		-	-	-	-	-		-	-	-
52	50	15	S	672	-	-			-	-	-	-		-	-	-	-	-		-	-	-
53	50	15	D	986																		

* = “s” mast configuration = Single Arm, “D” mast configuration = Dual Arm
Shaded cells indicate simulation was completed and analyzed in this project
“-“ denotes simulations that were not run as a part of the investigation

4.2 Simulation Results

The pole simulations were post-processed, and the results were analyzed to identify possible trends related to the MASH safety criteria, including occupant compartment deformation, occupant risk measures (i.e., lateral, and longitudinal OIV and ORA), and vehicle instability (i.e., roll and pitch angles). The results are discussed by pole height class in Sections 4.2.1 through 4.2.6, and all simulations are discussed Section 4.2.7. Detailed results for each pole configuration are provided in Appendix D.

4.2.1 20-ft Tall Pole Configuration Simulations

A total of four 20-ft tall pole configurations were simulated. These were the shortest poles analyzed and were limited to a maximum mast arm length of 10 ft, in accordance with state DOT standards and the Valmont catalog. The pole base diameters ranged from 6.5 to 7.0 in., with a pole wall thickness of 11 gauge. The total weight of these poles ranged from 222 to 381 lb, making the 20-ft tall pole configurations the lightest among all the selected configurations. The results of the 20-ft tall pole simulations are shown in Tables 12 through 14. An image of the critical state for a critical configuration (i.e., 20-ft tall pole with single 10-ft long mast arm) under MASH test designation no. 3-60 with a center impact point at 25 degrees is shown in Figure 89.

Table 12. Simulation Results for 20-ft Pole Configurations – Maximum Occupant Compartment Deformation (in.)

Simulation No.			**20**	**21**	**22**	**23**
Pole Height (ft)			20	20	20	20
Mast Arm Length (ft)			4	4	10	10
Mast Arm Configuration			S	D	S	D
3-60	Left Quarter	0°	1.10 (C)	-	-	N/A
		25°	1.70 (C)	-	-	0.19 (A)
	Center	0°	0.38	2.79 (RW)	6.07	5.54
		25°	4.14	4.01	8.31	1.59
	Right Quarter	0°	N/A	-	-	N/A
		25°	N/A	-	-	N/A
3-61	Left Quarter	0°	-	-	-	N/A
		25°	-	-	-	N/A
	Center	0°	N/A	N/A	N/A	N/A
		25°	-	-	-	N/A
	Right Quarter	0°	-	-	-	N/A
		25°	-	-	-	N/A
3-62	Left Quarter	0°	-	-	-	N/A
		25°	-	-	-	N/A
	Center	0°	N/A	N/A	N/A	N/A
		25°	-	-	-	N/A
	Right Quarter	0°	-	-	-	N/A
		25°	-	-	-	N/A

"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
"N/A" indicates no occupant compartment deformation was observed.
"(A)", "(B)", and "(C)" indicate deformation was observed at A-pillar, B-pillar, and C-pillar, respectively.
"(FW)"and "(RW)" indicate deformation was observed at front windshield and rear window, respectively.
"-" denotes simulations that were not run as a part of the investigation.
Occupant comp. deformation beyond 4.0 in. MASH limit
Occupant comp. def. between 2.0 in. and 4.0 in.
Note: MASH limit for deformation of windshield is 3.0 in.

Table 13. Simulation Results for 20-ft Pole Configurations – Longitudinal OIV (ft/s)

Simulation No.			20	21	22	23
Pole Height (ft)			20	20	20	20
Mast Arm Length (ft)			4	4	10	10
Mast Arm Configuration			S	D	S	D
3-60	Left Quarter	0°	-2.76	-	-	3.81
		25°	-2.62	-	-	3.1
	Center	0°	3.01	3.01	3.47	3.46
		25°	3.19	3.03	3.38	3.34
	Right Quarter	0°	-2.77	-	-	3.06
		25°	-2.92	-	-	3.04
3-61	Left Quarter	0°	-	-	-	5.88
		25°	-	-	-	5.28
	Center	0°	5.57	5.44	5.55	5.67
		25°	-	-	-	5.88
	Right Quarter	0°	-	-	-	6.16
		25°	-	-	-	5.96
3-62	Left Quarter	0°	-	-	-	4.33
		25°	-	-	-	4.10
	Center	0°	4.41	4.34	4.52	4.53
		25°	-	-	-	4.39
	Right Quarter	0°	-	-	-	4.30
		25°	-	-	-	4.27

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.

Table 14. Potential to Pass MASH Criteria for 20-ft Pole Configurations

Simulation No.			20	21	22	23
Pole Height (ft)			20	20	20	20
Mast Arm Length (ft)			4	4	10	10
Mast Arm Configuration			S	D	S	D
3-60	Left Quarter	0°	Pass	-	-	Pass
		25°	Pass	-	-	Pass
	Center	0°	Pass	Pass	Fail	Fail
		25°	Fail	Fail	Fail	Pass
	Right Quarter	0°	Pass	-	-	Pass
		25°	Pass	-	-	Pass
3-61	Left Quarter	0°	-	-	-	Pass
		25°	-	-	-	Pass
	Center	0°	Pass	Pass	Pass	Pass
		25°	-	-	-	Pass
	Right Quarter	0°	-	-	-	Pass
		25°	-	-	-	Pass
3-62	Left Quarter	0°	-	-	-	Pass
		25°	-	-	-	Pass
	Center	0°	Pass	Pass	Pass	Pass
		25°	-	-	-	Pass
	Right Quarter	0°	-	-	-	Pass
		25°	-	-	-	Pass

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
(red) Low potential to pass MASH due to occupant compartment deformation, roof crush, or OIV.

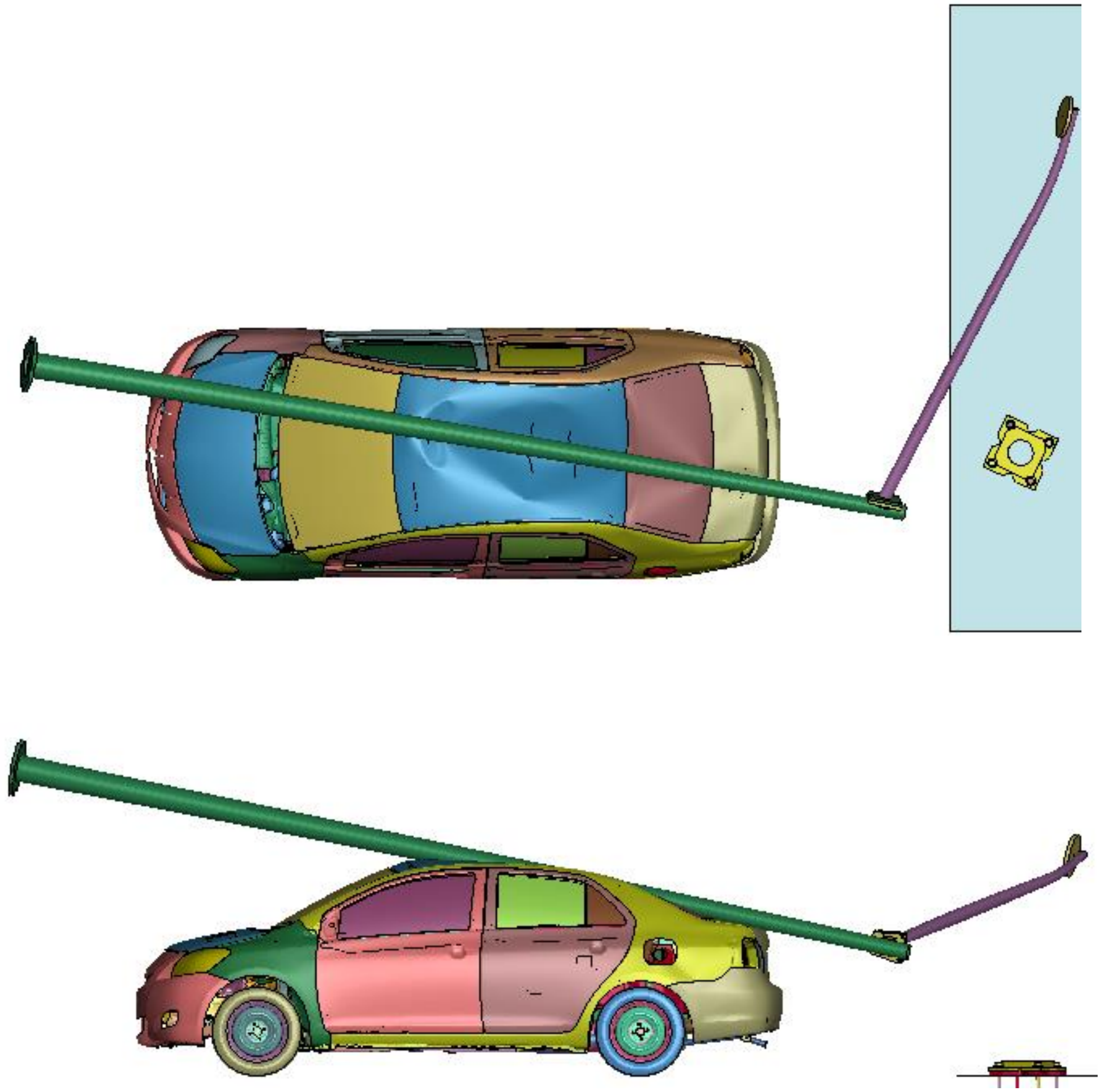


Figure 87. Simulation No. 22: 20-ft Tall Pole with Single 10-ft Long Mast Arm, MASH Test Designation No. 3-60 Center Impact at 25 degrees (Time = 800 msec After Impact)

Discussion – 20-ft Tall Pole Simulation Results

None of the four simulated 20-ft tall pole configurations were likely to meet MASH evaluation criteria. As shown in Table 14, each pole configuration showed at least one impact condition that was likely to result in a failed MASH test. The simulations most prone to failure were MASH test designation no. 3-60 with a center impact at either 0 degrees or 25 degrees, primarily due to excessive occupant compartment deformation. The most critical configuration was the 20-ft tall pole with a single 10-ft long mast arm, as it failed under both 0-degree and 25-degree center impact conditions for MASH test designation no. 3-60. This failure was attributed to the largest occupant compartment deformation observed, measuring 8.31 in.

Occupant Compartment Deformation

All four 20-ft tall pole configuration simulations exceeded the 4-in. occupant compartment deformation limit set by MASH for test designation no. 3-60 with a center impact point. The 20-ft tall poles with 4-ft long mast arms had occupant compartment deformation close to the 4-in. limit, whereas configurations with 10-ft long mast arms had deformation of 5.5 in. or greater. These simulations indicated that longer mast arms were more critical in terms of occupant compartment deformation for the 20-ft tall pole configurations.

For the simulations of 20-ft tall pole configurations at left- and right-quarter point impacts conducted under MASH test designation no. 3-60, only three simulations resulted in contact between the pole and the vehicle after the initial impact. In one instance where contact occurred, the vehicle deformation was caused by the pole grazing the left-side A-pillar or C-pillar. However, this deformation was minimal. Since the remaining simulations showed no contact after the initial impact and the deformation in the one contact case was negligible, left- and right-quarter point impacts were deemed less critical compared to center point impacts

Additionally, in all simulations of 20-ft tall poles under MASH test designation nos. 3-61 and 3-62 at center, left-quarter point, and right-quarter point impact locations, as well as at 0-degree and 25-degree impact angles, the pole did not contact the vehicle after the initial impact. Consequently, there was no occupant compartment deformation in these scenarios.

OIV

For all 20-ft tall poles simulated under MASH test designation nos. 3-60, 3-61, and 3-62, across all vehicle impact locations and impact angles, the OIV values remained well below the MASH limit of 16 ft/s. This indicates a high potential for these configurations to satisfy the MASH OIV criterion. The highest OIV observed was 6.16 ft/s, recorded for the 20-ft tall pole with dual 10-ft long mast arms under MASH test designation no. 3-61 with a left quarter-point impact at 25 degrees.

ORA and Vehicle Stability

The simulated ORA values for all 20-ft tall poles were well below the 20.49-g MASH limit. The highest ORA recorded was 1.02 g for a 20-ft tall pole with dual 10-ft long mast arms under a MASH test designation no. 3-60 center impact at 25 degrees. Additionally, the OIV values remained well below the 16 ft/s limit, and vehicle stability was not critical, as roll and pitch angles stayed well under the 75-degree threshold in all simulations. Detailed simulation results, which include occupant compartment deformation, OIV, ORA, roll, and pitch data for each simulation completed as a part of the simulation matrix, are reported in Appendix D.

Potential to Meet MASH Criteria

Although none of the 20-ft tall pole configurations met MASH criteria based on the simulations conducted, configurations with 4-ft long mast arms showed a high potential for success. All simulation failures were due to excessive roof crush, and closer inspection of occupant compartment deformation for the 20-ft tall pole with 4-ft long mast arms indicated that the failures were marginal. Specifically, poles with single and dual 4-ft long mast arms had roof crush values of 4.14 in. and 4.01 in., respectively, under MASH test designation no. 3-60 with a center impact point and a 25-degree impact angle.

Since these deformation values were only slightly above the 4-in. threshold, there is potential for these configurations to meet MASH criteria if, for example, the simulation vehicle model (2010 Toyota Yaris) over-predicted roof crush deformation. A full-scale crash test could confirm this potential, as the marginal nature of the failures suggests the possibility of a successful MASH test designation no. 3-60 crash test.

4.2.2 30-ft Tall Pole Configuration Simulations

A total of six 30-ft tall steel poles were simulated, categorized as medium-height poles. The mast arm lengths were 4 ft, 10 ft, or 20 ft. The pole base diameters ranged from 7.5 in. to 8.5 in., with a wall thickness of 11 gauge. The total weight of the 30-ft tall poles varied from 300 to 604 lb. The results of the 30-ft tall pole simulations are shown in Tables 15 through 17. An image of the critical state for a critical configuration (i.e., a 30-ft tall pole with single 20-ft long mast arm) under MASH test designation no. 3-60 with a center impact at a 25-degree impact angle is shown in Figure 88.

Table 15. Simulation Results for 30-ft Pole Configurations – Maximum Occupant Compartment Deformation (in.)

Simulation No.			30	31	34-1	34-2	32	33
Pole Height (ft)			30	30	30	30	30	30
Mast Arm Length (ft)			4	4	10	10	20	20
Mast Arm Configuration			S	D	S	D	S	D
3-60	Left Quarter	0°	N/A	-	N/A	-	-	N/A
		25°	N/A	-	N/A	-	-	N/A
	Center	0°	2.14	2.57	6.79	1.98	7.77	3.35
		25°	3.55	3.50 (RW)	8.28	0.50 (FW)	8.40	0.97
	Right Quarter	0°	N/A	-	N/A	-	-	N/A
		25°	N/A	-	N/A	-	-	N/A
3-61	Left Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A
	Center	0°	N/A	N/A	-	-	N/A	N/A
		25°	-	-	-	-	-	N/A
	Right Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A
3-62	Left Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A
	Center	0°	N/A	N/A	-	-	N/A	N/A
		25°	-	-	-	-	-	N/A
	Right Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A

"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
"N/A" indicates no occupant compartment deformation was observed.
"(A)", "(B)", and "(C)" indicate deformation was observed at A-pillar, B-pillar, and C-pillar, respectively.
"(FW)"and "(RW)" indicate deformation was observed at front windshield and rear window, respectively.
"-" denotes simulations that were not run as a part of the investigation.
Occupant comp. deformation beyond 4.0 in. MASH limit
Occupant comp. def. between 2.0 in. and 4.0 in.
Note: MASH limit for deformation of windshield is 3.0 in.

Table 16. Simulation Results for 30-ft Pole Configurations – Longitudinal OIV (ft/s)

Simulation No.			30	31	34-1	34-2	32	33
Pole Height (ft)			30	30	30	30	30	30
Mast Arm Length (ft)			4	4	10	10	20	20
Mast Arm Configuration			S	D	S	D	S	D
3-60	Left Quarter	0°	-3.36	-	-3.32	-	-	3.41
		25°	-2.99	-	-3.34	-	-	4.76
	Center	0°	3.57	3.80	3.51	3.60	3.79	3.86
		25°	3.51	3.48	3.71	3.68	3.74	3.82
	Right Quarter	0°	-3.58	-	-3.37	-	-	3.76
		25°	-3.09	-	-3.25	-	-	3.43
3-61	Left Quarter	0°	-	-	-	-	-	7.33
		25°	-	-	-	-	-	7.84
	Center	0°	6.26	6.37	-	-	6.82	6.97
		25°	-	-	-	-	-	7.22
	Right Quarter	0°	-	-	-	-	-	7.94
		25°	-	-	-	-	-	6.78
3-62	Left Quarter	0°	-	-	-	-	-	4.63
		25°	-	-	-	-	-	4.56
	Center	0°	4.49	4.53	-	-	4.60	4.64
		25°	-	-	-	-	-	4.73
	Right Quarter	0°	-	-	-	-	-	4.70
		25°	-	-	-	-	-	4.72

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.

Table 17. Potential to Pass MASH Criteria for 30-ft Pole Configurations

Simulation No.			30	31	34-1	34-2	32	33
Pole Height (ft)			30	30	30	30	30	30
Mast Arm Length (ft)			4	4	10	10	20	20
Mast Arm Configuration			S	D	S	D	S	D
3-60	Left Quarter	0°	Pass	-	Pass	-	-	Pass
		25°	Pass	-	Pass	-	-	Pass
	Center	0°	Pass	Pass	Fail	Pass	Fail	Pass
		25°	Pass	Fail	Fail	Pass	Fail	Pass
	Right Quarter	0°	Pass	-	Pass	-	-	Pass
		25°	Pass	-	Pass	-	-	Pass
3-61	Left Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass
	Center	0°	Pass	Pass	-	-	Pass	Pass
		25°	-	-	-	-	-	Pass
	Right Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass
3-62	Left Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass
	Center	0°	Pass	Pass	-	-	Pass	Pass
		25°	-	-	-	-	-	Pass
	Right Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
[red] Low potential to pass MASH due to occupant compartment deformation, roof crush, or OIV.

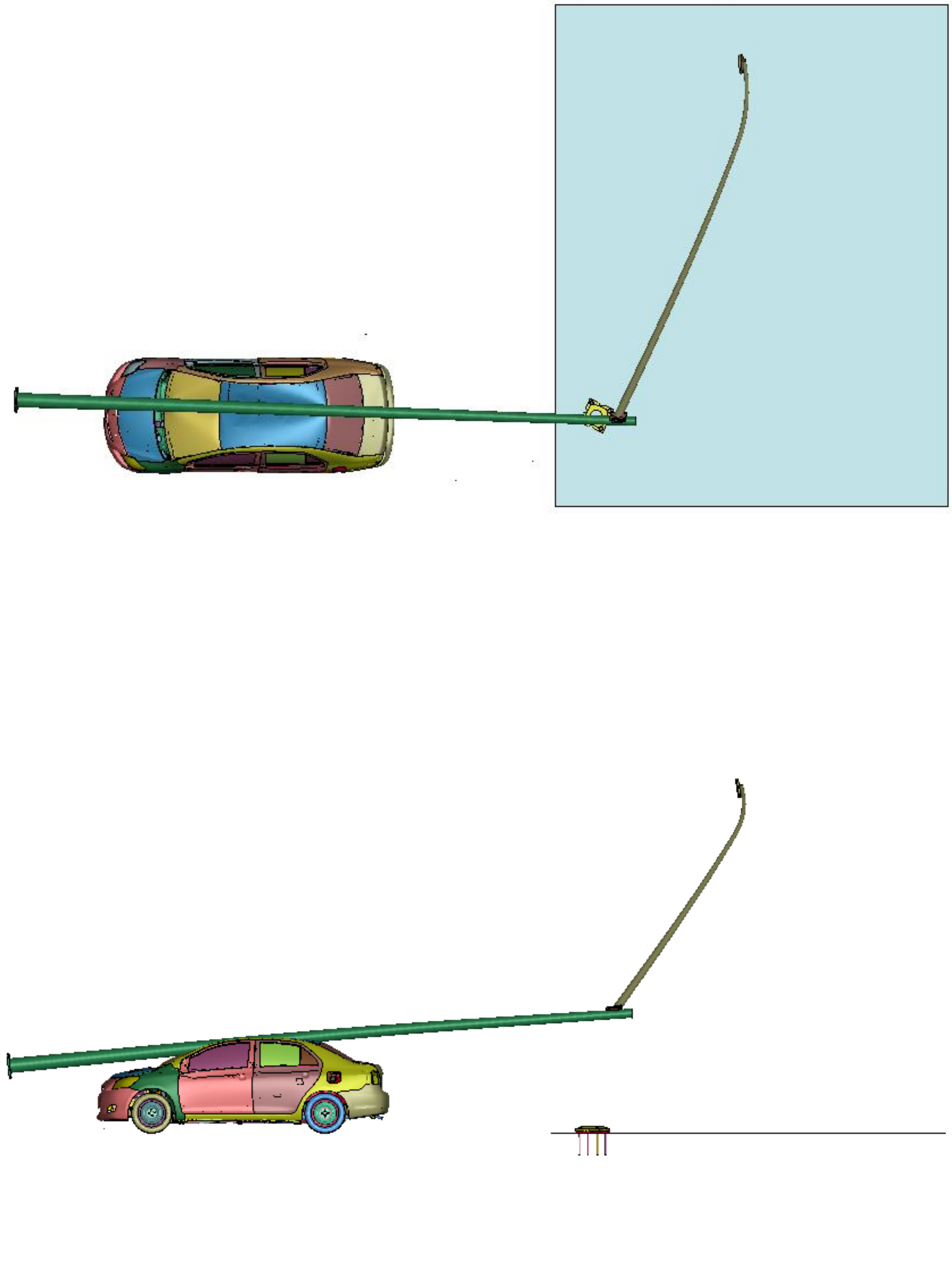


Figure 88. Simulation No. 32: 30-ft Tall Pole with Single 20-ft Long Mast Arm, MASH Test Designation No. 3-60, Center Impact at 25 degrees (Time = 1000 ms After Impact)

Discussion – 30-ft Tall Pole Simulation Results

Of the six 30-ft tall pole configurations that were simulated, three configurations had potential to meet MASH criteria. These configurations were: (1) a 30-ft tall pole with a single 4-ft long mast arm, (2) a 30-ft tall pole with dual 10-ft long mast arms, and (3) a 30-ft tall pole with dual 20-ft long mast arms. As shown in Table 17, three configurations showed at least one impact condition likely to result in failure to meet MASH criteria. The simulations with low potential to satisfy MASH criteria were those under test designation no. 3-60 with a center impact at either 0 degrees or 25 degrees, failing due to excessive occupant compartment deformation (roof crush exceeding the 4.0-in. MASH limit).

The most critical configuration based on simulations was the 30-ft tall pole with a single 20-ft long mast arm, which failed under test designation no. 3-60 with a center impact at both 0-degree and 25-degree angles. This configuration had the largest roof crush of 8.4 in. at a 25-degree impact angle. Another critical configuration was the 30-ft tall pole with a single 10-ft long mast arm, which also failed at both impact angles under test designation no. 3-60 with a center impact, resulting in a significant roof crush of 8.28 in. at the 25-degree impact angle.

Occupant Compartment Deformation

All six 30-ft tall pole configuration simulations resulted in occupant compartment deformation under MASH test designation no. 3-60 center impact conditions, with three configurations exceeding the MASH limit of 4.0 in. The 30-ft tall poles with 4-ft long mast arms had roof crush below the 4.0-in. threshold, whereas those with single 10-ft and 20-ft long mast arms had occupant compartment deformation of 6.5 in. or more. In contrast, the 30-ft tall poles with dual 10-ft and 20-ft long mast arms had roof crush below 4.0 in. These results indicate that for 30-ft tall poles, single long mast arms are more critical in terms of roof crush.

For the simulations of 30-ft tall pole configurations at left and right quarter-point impacts under MASH test designation no. 3-60, none resulted in contact between the pole and the vehicle after the initial impact. As a result, left and right quarter-point impacts appeared less critical compared to center impacts.

Additionally, in all simulations of 30-ft tall poles under MASH test designation nos. 3-61 and 3-62, across center, left-quarter point, and right-quarter point impact locations, as well as 0-degree and 25-degree impact angles, the pole did not contact the vehicle after the initial impact. Consequently, there was no occupant compartment deformation observed in these scenarios.

OIV

For all 30-ft tall poles simulated under MASH test designation nos. 3-60, 3-61, and 3-62, across all impact locations and impact angles, the longitudinal OIV values remained well below the MASH limit of 16 ft/s. The highest OIV observed was 7.94 ft/s for a 30-ft tall pole with dual 20-ft long mast arms under MASH test designation no. 3-61 with a right quarter-point impact at a 25-degree angle.

ORA and Vehicle Stability

The ORA values for all 30-ft tall pole configurations were well below the MASH limit of 20.49 g's. The highest ORA recorded was 1.00 g for the 30-ft tall pole with dual 20-ft long mast arms under MASH test designation no. 3-60 with a center impact at 0 degrees. Furthermore, simulation results indicated that vehicle stability was not a critical issue, as roll and pitch angles remained well within the 75-degree limit in all cases. Detailed simulation results are reported in Appendix D.

Potential to Meet MASH Criteria

Although the 30-ft tall pole with dual 4-ft mast arms did not meet MASH criteria based on the simulations, configurations with 4-ft mast arms showed the most potential. As discussed, all failures were due to occupant compartment deformation. A review of the occupant compartment deformation caused by the 30-ft tall pole with dual 4-ft long mast arms revealed that the failure for this configuration was marginal. Specifically, the configuration had 3.5 in. of deformation to the rear window under MASH test designation no. 3-60 conditions with a center impact at 25 degrees.

Although MASH does not impose a deformation limit for side or rear windows (rear window shattering is allowed as long as no part of the test article penetrates the window), the 3.0-in. windshield deformation limit was conservatively applied, leading to the simulation being classified as a failure. Additionally, the maximum roof crush was 3.90 in., which remained just below the 4.0-in. MASH limit for roof deformation. The deformation, as shown in Figure 89, occurred just above the rear window at the rear center of the roof.

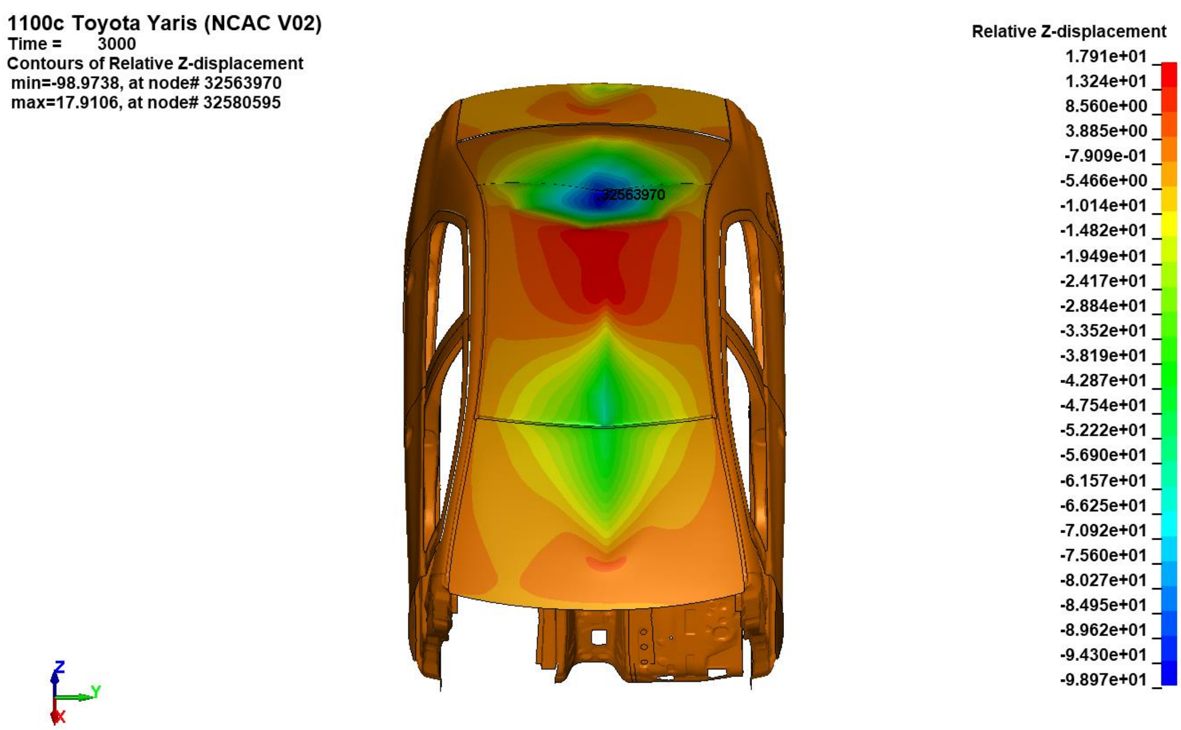


Figure 89. Roof Crush – MASH Test Designation No. 3-60, Center Impact at 25 Degrees for 30-ft Tall Pole with Dual 4-ft Mast Arms

It is likely that in a full-scale crash test, if the 30-ft tall pole with dual 4-ft long mast arms were to contact and deform the roof and rear window in the same manner as in the simulation, the rear window would shatter rather than deform by 3.5 in. As long as the pole does not intrude into the occupant compartment, this outcome could result in a successful crash test.

Additionally, dual arm configurations showed potential to meet MASH criteria. The only dual arm configuration that failed was the 30-ft tall pole with dual 4-ft long mast arms under MASH test designation no. 3-60 conditions with a center impact at 25 degrees. However, as discussed, this failure was marginal, further suggesting the feasibility of this configuration meeting MASH criteria under certain conditions.

4.2.3 35-ft Pole Configuration Simulations

A total of six 35-ft tall pole configurations were simulated. The 35-ft tall poles were categorized as a medium pole height. The mast arm lengths were either 4, 10, or 20 ft. The pole base diameter ranged from 8.0 to 9.0 in. with a thickness of 11 gauge. The total weight of the 35-ft tall poles ranged from 347 lb to 656 lb. The results of the 35-ft tall pole simulations are shown in Tables 18 through 20. An image of the critical state for a critical configuration (i.e., 35-ft tall pole with dual 20-ft long mast arms) under MASH test designation no. 3-60 with a center impact at a 0-degree impact angle is shown in Figure 90.

Table 18. Simulation Results for 35-ft Pole Configurations – Maximum Occupant Compartment Deformation (in.)

Simulation No.			**35**	**36**	**39-1**	**39-2**	**37**	**38**
Pole Height (ft)			35	35	35	35	35	35
Mast Arm Length (ft)			4	4	10	10	20	20
Mast Arm Configuration			S	D	S	D	S	D
3-60	Left Quarter	0°	N/A	-	N/A	-	-	N/A
		25°	N/A	-	N/A	-	-	N/A
	Center	0°	3.64	3.59	4.54	3.64	3.12	5.45
		25°	3.67	1.88	4.36	2.51	4.24	0.39
	Right Quarter	0°	N/A	-	N/A	-	-	N/A
		25°	N/A	-	N/A	-	-	N/A
3-61	Left Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A
	Center	0°	N/A	N/A	-	-	N/A	N/A
		25°	-	-	-	-	-	N/A
	Right Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A
3-62	Left Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A
	Center	0°	N/A	N/A	-	-	N/A	N/A
		25°	-	-	-	-	-	N/A
	Right Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A

"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
"N/A" indicates no occupant compartment deformation was observed.
"(A)", "(B)", and "(C)" indicate deformation was observed at A-pillar, B-pillar, and C-pillar, respectively.
"(FW)"and "(RW)" indicate deformation was observed at front windshield and rear window, respectively.
"-" denotes simulations that were not run as a part of the investigation.
Occupant comp. deformation beyond 4.0 in. MASH limit (red)
Occupant comp. def. between 2.0 in. and 4.0 in. (orange)

Table 19. Simulation Results for 35-ft Pole Configurations – Longitudinal OIV (ft/s)

Simulation No.			35	36	39-1	39-2	37	38
Pole Height (ft)			35	35	35	35	35	35
Mast Arm Length (ft)			4	4	10	10	20	20
Mast Arm Configuration			S	D	S	D	S	D
3-60	Left Quarter	0°	3.40	-	-3.54	-	-	3.79
		25°	4.08	-	-3.82	-	-	4.9
	Center	0°	3.6	3.46	3.72	3.68	3.92	4.80
		25°	3.65	3.76	3.95	3.91	4.73	4.55
	Right Quarter	0°	3.62	-	3.62	-	-	3.94
		25°	3.33	-	3.45	-	-	3.64
3-61	Left Quarter	0°	-	-	-	-	-	8.06
		25°	-	-	-	-	-	7.76
	Center	0°	6.82	7.18	-	-	7.37	7.42
		25°	-	-	-	-	-	8.17
	Right Quarter	0°	-	-	-	-	-	7.79
		25°	-	-	-	-	-	7.79
3-62	Left Quarter	0°	-	-	-	-	-	4.93
		25°	-	-	-	-	-	4.93
	Center	0°	4.63	4.65	-	-	4.75	4.84
		25°	-	-	-	-	-	4.94
	Right Quarter	0°	-	-	-	-	-	5.27
		25°	-	-	-	-	-	4.91

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.

Table 20. Potential to Pass MASH Criteria for 35-ft Pole Configurations

Simulation No.			**35**	**36**	**39-1**	**39-2**	**37**	**38**
Pole Height (ft)			35	35	35	35	35	35
Mast Arm Length (ft)			4	4	10	10	20	20
Mast Arm Configuration			S	D	S	D	S	D
3-60	Left Quarter	0°	Pass	-	Pass	-	-	Pass
		25°	Pass	-	Pass	-	-	Pass
	Center	0°	Pass	Pass	Fail	Pass	Pass	Fail
		25°	Pass	Pass	Fail	Pass	Fail	Pass
	Right Quarter	0°	Pass	-	Pass	-	-	Pass
		25°	Pass	-	Pass	-	-	Pass
3-61	Left Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass
	Center	0°	Pass	Pass	-	-	Pass	Pass
		25°	-	-	-	-	-	Pass
	Right Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass
3-62	Left Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass
	Center	0°	Pass	Pass	-	-	Pass	Pass
		25°	-	-	-	-	-	Pass
	Right Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
(red) Low potential to pass MASH due to occupant compartment deformation, roof crush, or OIV.

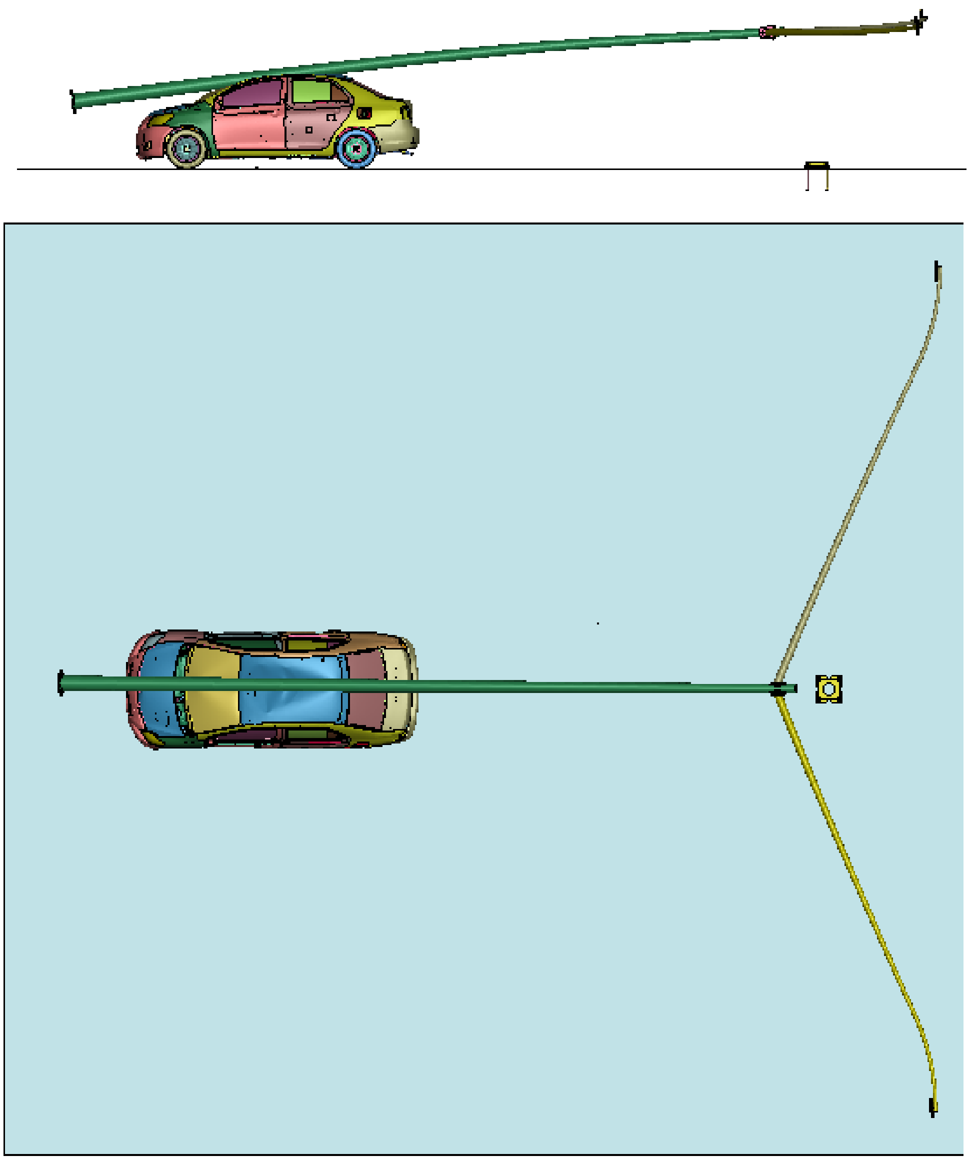


Figure 90. Simulation No. 38: 35-ft Tall Pole with Dual 20-ft Long Mast Arms, MASH Test Designation No. 3-60, Center Impact at 0 degrees (Time = 1,450 msec After Impact)

Discussion – 35-ft Tall Pole Simulation Results

Of the six 35-ft tall pole configurations that were simulated, three configurations had potential to meet MASH criteria. The configurations were: (1) a 35-ft tall pole with single 4-ft long mast arm, (2) a 35-ft tall pole with dual 4-ft long mast arms, and (3) a 35-ft tall pole with dual 10-ft long mast arms. As shown in Table 20, three of the six 35-ft tall pole configurations had at least one impact condition likely to result in a failed MASH test, indicating low potential to pass MASH criteria. The simulations with low potential occurred under MASH test designation no. 3-60 with a center impact at either 0 degrees or 25 degrees, failing due to excessive occupant compartment deformation.

The most critical configuration based on simulations was the 35-ft tall pole with a single 10-ft mast arm, which failed at both impact angles under MASH test designation no. 3-60 with a center impact. Another notable critical configuration was the 35-ft tall pole with dual 20-ft mast arms, which had the largest roof crush, measuring 5.45 in.

Occupant Compartment Deformation

All six 35-ft tall pole simulations had occupant compartment deformation under MASH test designation no. 3-60 center impact conditions, with three configurations exceeding 4.0-in. MASH limit for roof crush. The configurations with 4-ft long mast arms resulted in roof crush below 4 in., while the 35-ft tall pole with a single 10-ft mast arm and both configurations with 20-ft long mast arms had roof crush of 4.0 in. or more. These results suggest that dual long mast arms are more critical in terms of roof crush for 35-ft tall pole configurations.

No simulations of 35-ft tall pole configurations at left or right quarter-point impacts under MASH test designation no. 3-60 resulted in secondary contact between the pole and the vehicle. As there was no contact after the initial impact, left and right quarter-point impacts appear less critical than center impacts.

Additionally, for all simulations of 35-ft tall poles under MASH test designation nos. 3-61 and 3-62, across center, left-quarter point, and right-quarter point impact locations, as well as 0-degree and 25-degree impact angles, the pole did not contact the vehicle after the initial impact, resulting in no roof crush.

OIV

For all 35-ft tall poles under MASH test designation nos. 3-60, 3-61, and 3-62 with all impact locations and angles, simulated OIV values were well-below the MASH limit of 16 ft/s. The largest OIV was 8.17 ft/s for 35-tall pole with dual 20-ft long mast arms at MASH test designation no. 3-61 with a center impact at 25 degrees.

ORA and Vehicle Stability

The ORA values for all 35-ft tall pole configurations were well below the MASH limit of 20.49 g's. The highest ORA recorded was 0.84 g's for the 35-ft tall pole with a single 10-ft long mast arm under MASH test designation no. 3-60 with a center impact at 0 degrees. Additionally, simulation results indicated that vehicle stability was not a concern, as roll and pitch remained below the 75-degree limit in all cases. Detailed simulation results, including occupant compartment deformation, OIV, ORA, roll, and pitch data for each simulation conducted in the simulation matrix, are provided in Appendix D.

Potential to Meet MASH Criteria

Of the 35-ft tall pole height class, poles with 4-ft long mast arms (i.e., 35-ft tall pole with a single 4-ft long mast arm and 35-ft tall pole with dual 4-ft long mast arms) were likely to meet MASH criteria. There were no simulations from these configurations that violated occupant compartment deformation, OIV, or other MASH limits.

4.2.4 40-ft Pole Configuration Simulations

A total of six 40-ft tall pole configurations were simulated, which were also classified as medium height poles. The mast arm lengths were 4 ft, 10 ft, or 20 ft. The pole base diameters ranged from 9.0 in. to 10.0 in., with a wall thickness of 11 gauge. The total weight of the 40-ft tall poles varied from 411 lb to 727 lb. The results of 40-ft pole simulations are shown in Tables 21 through 23. An image of the critical state for a critical configuration (i.e., 40-ft tall pole with single 20-ft long mast arm) under MASH test designation no. 3-60 with a center impact at 25 degrees is shown in Figure 91.

Table 21. Simulation Results for 40-ft Pole Configurations – Maximum Occupant Compartment Deformation (in.)

Simulation No.			40	41	44-1	44-2	42	43
Pole Height (ft)			40	40	40	40	40	40
Mast Arm Length (ft)			4	4	10	10	20	20
Mast Arm Configuration			S	D	S	D	S	D
3-60	Left Quarter	0°	N/A	-	N/A	-	-	N/A
		25°	N/A	-	N/A	-	-	N/A
	Center	0°	1.88	4.08	0.19	1.76	0.22 (C)	3.55
		25°	1.69	0.68 (FW)	3.30	0.84	4.73	3.67
	Right Quarter	0°	N/A	-	N/A	-	-	N/A
		25°	N/A	-	N/A	-	-	N/A
3-61	Left Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A
	Center	0°	N/A	N/A	-	-	N/A	N/A
		25°	-	-	-	-	-	N/A
	Right Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A
3-62	Left Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A
	Center	0°	N/A	N/A	-	-	N/A	N/A
		25°	-	-	-	-	-	N/A
	Right Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A

"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
"N/A" indicates no occupant compartment deformation was observed.
"(A)", "(B)", and "(C)" indicate deformation was observed at A-pillar, B-pillar, and C-pillar, respectively.
"(FW)"and "(RW)" indicate deformation was observed at front windshield and rear window, respectively.
"-" denotes simulations that were not run as a part of the investigation.
[red] Occupant comp. deformation beyond 4.0 in. MASH limit
[orange] Occupant comp. def. between 2.0 in. and 4.0 in.
Note: MASH limit for deformation of windshield is 3.0 in.

Table 22. Simulation Results for 40-ft Pole Configurations – Longitudinal OIV (ft/s)

Simulation No.			40	41	44-1	44-2	42	43
Pole Height (ft)			40	40	40	40	40	40
Mast Arm Length (ft)			4	4	10	10	20	20
Mast Arm Configuration			S	D	S	D	S	D
3-60	Left Quarter	0°	3.83	-	3.91	-	-	4.23
		25°	5.55	-	4.80	-	-	6.94
	Center	0°	3.79	3.92	3.85	4.01	3.97	4.53
		25°	4.07	4.25	4.6	4.60	5.10	5.24
	Right Quarter	0°	4.10	-	4.14	-	-	4.24
		25°	3.72	-	3.78	-	-	3.99
3-61	Left Quarter	0°	-	-	-	-	-	8.55
		25°	-	-	-	-	-	8.25
	Center	0°	7.81	7.70	-	-	8.37	8.74
		25°	-	-	-	-	-	9.44
	Right Quarter	0°	-	-	-	-	-	8.52
		25°	-	-	-	-	-	8.67
3-62	Left Quarter	0°	-	-	-	-	-	5.41
		25°	-	-	-	-	-	5.48
	Center	0°	4.86	4.82	-	-	5.10	5.26
		25°	-	-	-	-	-	5.36
	Right Quarter	0°	-	-	-	-	-	5.25
		25°	-	-	-	-	-	5.12

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.

Table 23. Potential to Pass MASH Criteria for 40-ft Pole Configurations

Simulation No.			**40**	**41**	**44-1**	**44-2**	**42**	**43**
Pole Height (ft)			40	40	40	40	40	40
Mast Arm Length (ft)			4	4	10	10	20	20
Mast Arm Configuration			S	D	S	D	S	D
3-60	Left Quarter	0°	Pass	-	Pass	-	-	Pass
		25°	Pass	-	Pass	-	-	Pass
	Center	0°	Pass	Fail	Pass	Pass	Pass	Pass
		25°	Pass	Pass	Pass	Pass	Fail	Pass
	Right Quarter	0°	Pass	-	Pass	-	-	Pass
		25°	Pass	-	Pass	-	-	Pass
3-61	Left Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass
	Center	0°	Pass	Pass	-	-	Pass	Pass
		25°	-	-	-	-	-	Pass
	Right Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass
3-62	Left Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass
	Center	0°	Pass	Pass	-	-	Pass	Pass
		25°	-	-	-	-	-	Pass
	Right Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
(red) Low potential to pass MASH due to occupant compartment deformation, roof crush, or OIV.

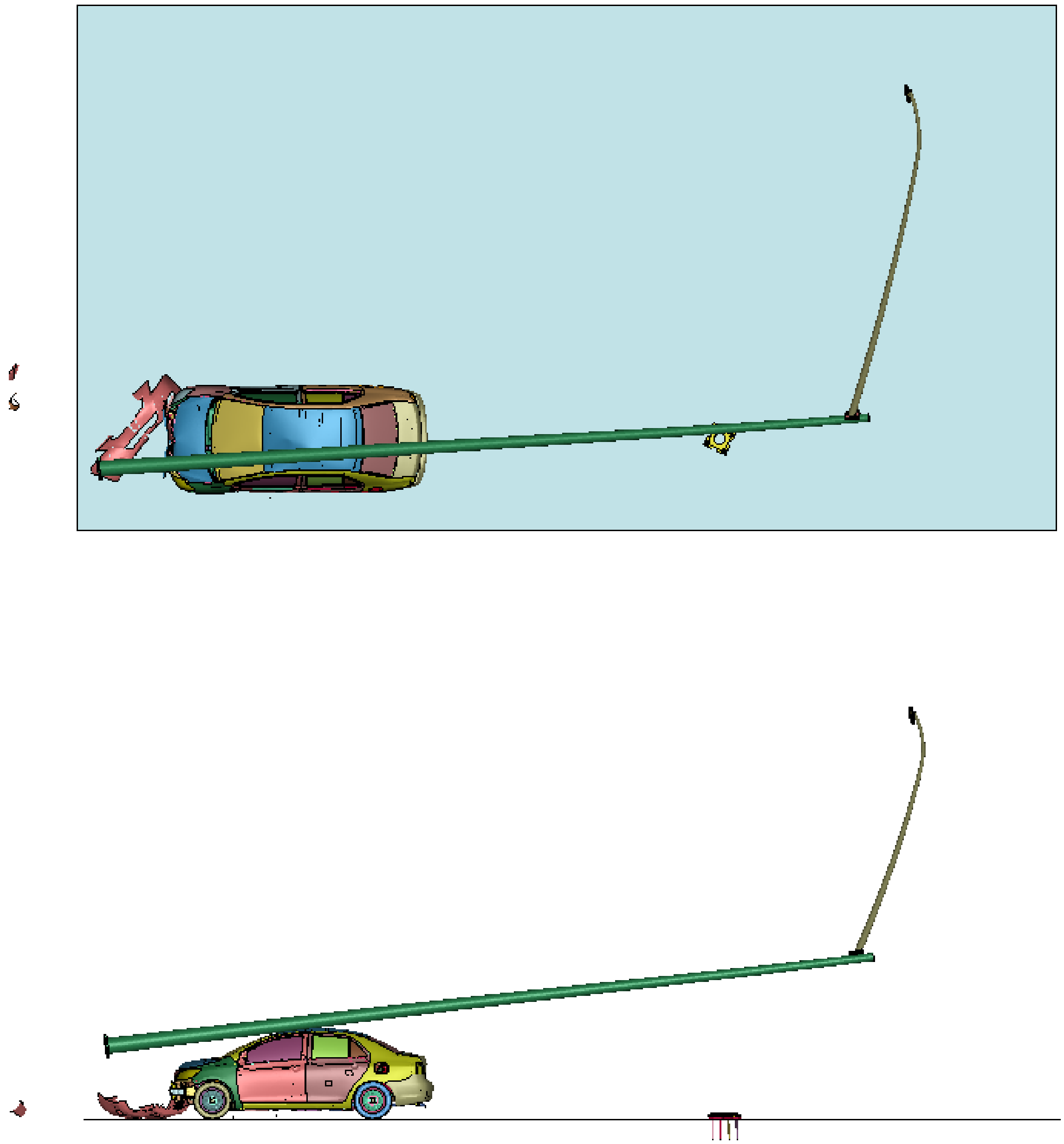


Figure 91. Simulation No. 42: 40-ft Tall Pole with Single 20-ft Long Mast Arm, MASH Test Designation No. 3-60, Center Impact at 25 Degrees (Time = 1300 ms After Impact)

Discussion – 40-ft Tall Pole Simulation Results

Of the six 40-ft tall pole configurations that were simulated, four configurations had the potential to meet MASH criteria. The configurations were: (1) a 40-ft tall pole with a single 4-ft long mast arm, (2) a 40-ft tall pole with dual 10-ft long mast arms, (3) a 40-ft tall pole with a single 10-ft long mast arm, and (4) a 40-ft tall pole with dual 20-ft long mast arms. As shown in Table 17, two of the six 40-ft tall pole configurations showed at least one impact condition likely to result in a failed MASH test, indicating low potential to pass MASH criteria. The simulations with low potential occurred under MASH test designation no. 3-60 with a center impact at either 0 degrees or 25 degrees, failing due to excessive roof crush.

The most critical configuration, based on simulations, was the 40-ft tall pole with a single 20-ft long mast arm, which had the largest roof crush of 4.73 in.

Occupant Compartment Intrusion

All six 40-ft tall pole simulations resulted in occupant compartment deformation under MASH test designation no. 3-60 center impact conditions, with two configurations exceeding the MASH limit of 4.0 in. The configurations with a single 4-ft or 10-ft mast arm and those with dual 10-ft or 20-ft mast arms had roof crush below 4.0 in. In contrast, the configurations with dual 4-ft mast arms and a single 20-ft mast arm had a roof crush of 4.0 in. or more.

No simulations of the 40-ft tall pole configurations at left or right quarter-point impacts under MASH test designation no. 3-60 resulted in secondary contact between the pole and the vehicle. Since there was no contact after the initial impact, left and right quarter-point impacts were considered less critical than center impacts.

Additionally, in all simulations of 40-ft tall poles under MASH test designation nos. 3-61 and 3-62, across center, left-quarter point, and right-quarter point impact locations, as well as 0-degree and 25-degree impact angles, the pole did not contact the vehicle after the initial impact.

OIV

For all 40-ft tall poles under MASH test designation nos. 3-60, 3-61, and 3-62 at all impact locations and angles, simulated OIV values were below the MASH limit of 16 ft/s. The highest OIV was 9.44 ft/s for a 40-ft tall pole with dual 20-ft long mast arms under MASH test designation no. 3-61 with a center impact at 25 degrees.

ORA and Vehicle Stability

The ORA values for all 40-ft tall pole configurations were well below the MASH limit of 20.49 g's. The highest ORA was 1.04 g's for the 40-ft tall pole with dual 20-ft long mast arms under MASH test designation no. 3-60 with a center impact at 0 degrees.

Furthermore, simulation results indicated that vehicle stability was not a concern, as roll and pitch angles consistently remained well below the 75-degree limit in all cases. Detailed simulation results, including ORA, OIV, roll, pitch, and occupant compartment deformation data are provided in Appendix D.

Potential to Meet MASH Criteria

Among all the 40-ft tall poles, the configurations with 10-ft long mast arms (i.e., the 40-ft tall pole with a single 10-ft long mast arm and the 40-ft tall pole with dual 10-ft long mast arms) demonstrated the best potential to meet MASH test criteria. None of the simulations for these configurations violated occupant compartment deformation limits, OIV thresholds, or other MASH criteria.

Although the 40-ft tall pole with dual 4-ft long mast arms did not meet MASH criteria based on the completed simulations, the 4-ft mast arm configurations showed potential. All failures for this configuration were due to occupant compartment deformation. A detailed review indicated that the 40-ft tall pole with dual 4-ft long mast arms had an occupant compartment deformation of 4.08 in. under MASH test designation no. 3-60 with a center impact at 0 degrees, just slightly exceeding the 4.0-in. limit. While this was classified as a failure, the marginal nature of the result suggests potential for improvement. Further refinement of the luminaire pole slip base model, use of a different vehicle model, or completion of a full-scale crash test could potentially result in this configuration passing the MASH criteria, as the failure was minimal.

4.2.5 45-ft Pole Configuration Simulations

A total of six 45-ft tall pole configurations were simulated, classified in the medium pole height category. The mast arm lengths were 4 ft, 10 ft, or 20 ft. The pole base diameters ranged from 9.5 in. to 10.0 in., with a wall thickness of 11 gauge for configurations with 4-ft or 10-ft mast arms and 10 gauge for configurations with 20-ft mast arms. The total weight of the 45-ft tall poles ranged from 466 lb to 847 lb. The results of the 45-ft tall pole simulations are shown in Tables 24 through 26. An image of the critical state for a critical configuration (i.e., 45-ft tall pole configuration with dual 10-ft long mast arms) under MASH test designation no. 3-60 with a center impact at 0 degrees is shown in Figure 92.

Table 24. Simulation Results for 45-ft Pole Configurations – Maximum Occupant Compartment Deformation (in.)

Simulation No.			45	46	49-1	49-2	47	48
Pole Height (ft)			45	45	45	45	45	45
Mast Arm Length (ft)			4	4	10	10	20	20
Mast Arm Configuration			S	D	S	D	S	D
3-60	Left Quarter	0°	N/A	-	N/A	-	-	N/A
		25°	-	-	N/A	-	-	N/A
	Center	0°	0.35 (C)	4.02	0.56 (FW)	6.39	0.45	6.11
		25°	3.00	0.93	1.50	0.60 (C)	1.10	3.41
	Right Quarter	0°	N/A	-	N/A	-	-	N/A
		25°	N/A	-	N/A	-	-	N/A
3-61	Left Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A
	Center	0°	N/A	N/A	-	-	N/A	N/A
		25°	-	-	-	-	-	N/A
	Right Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A
3-62	Left Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A
	Center	0°	N/A	N/A	-	-	N/A	N/A
		25°	-	-	-	-	-	N/A
	Right Quarter	0°	-	-	-	-	-	N/A
		25°	-	-	-	-	-	N/A

"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
"N/A" indicates no occupant compartment deformation was observed.
"(A)", "(B)", and "(C)" indicate deformation was observed at A-pillar, B-pillar, and C-pillar, respectively.
"(FW)"and "(RW)" indicate deformation was observed at front windshield and rear window, respectively.
"-" denotes simulations that were not run as a part of the investigation.
Occupant comp. deformation beyond 4.0 in. MASH limit
Occupant comp. def. between 2.0 in. and 4.0 in.
Note: MASH limit for deformation of windshield is 3.0 in.

Table 25. Simulation Results for 45-ft Pole Configurations – Longitudinal OIV (ft/s)

Simulation No.			**45**	**46**	**49-1**	**49-2**	**47**	**48**
Pole Height (ft)			45	45	45	45	45	45
Mast Arm Length (ft)			4	4	10	10	20	20
Mast Arm Configuration			S	D	S	D	S	D
3-60	Left Quarter	0°	4.10	-	4.30	-	-	4.70
		25°	-	-	6.88	-	-	5.72
	Center	0°	4.04	4.22	4.23	4.63	4.64	4.99
		25°	4.85	4.94	4.85	5.67	4.95	6.25
	Right Quarter	0°	5.35	-	4.39	-	-	4.83
		25°	4.01	-	4.14	-	-	4.26
3-61	Left Quarter	0°	-	-	-	-	-	9.38
		25°	-	-	-	-	-	9.68
	Center	0°	8.02	9.09	-	-	10.00	10.19
		25°	-	-	-	-	-	11.35
	Right Quarter	0°	-	-	-	-	-	9.02
		25°	-	-	-	-	-	8.76
3-62	Left Quarter	0°	-	-	-	-	-	5.84
		25°	-	-	-	-	-	5.93
	Center	0°	5.09	5.06	-	-	5.83	6.00
		25°	-	-	-	-	-	6.05
	Right Quarter	0°	-	-	-	-	-	5.91
		25°	-	-	-	-	-	5.77

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.

Table 26. Potential to Pass MASH Criteria for 45-ft Pole Configurations

Simulation No.			**45**	**46**	**49-1**	**49-2**	**47**	**48**
Pole Height (ft)			45	45	45	45	45	45
Mast Arm Length (ft)			4	4	10	10	20	20
Mast Arm Configuration			S	D	S	D	S	D
3-60	Left Quarter	0°	Pass	-	Pass	-	-	Pass
		25°	-	-	Pass	-	-	Pass
	Center	0°	Pass	Fail	Pass	Fail	Pass	Fail
		25°	Pass	Pass	Pass	Pass	Pass	Pass
	Right Quarter	0°	Pass	-	Pass	-	-	Pass
		25°	Pass	-	Pass	-	-	Pass
3-61	Left Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass
	Center	0°	Pass	Pass	-	-	Pass	Pass
		25°	-	-	-	-	-	Pass
	Right Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass
3-62	Left Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass
	Center	0°	Pass	Pass	-	-	Pass	Pass
		25°	-	-	-	-	-	Pass
	Right Quarter	0°	-	-	-	-	-	Pass
		25°	-	-	-	-	-	Pass

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
[red] Low potential to pass MASH due to occupant compartment deformation, roof crush, or OIV.

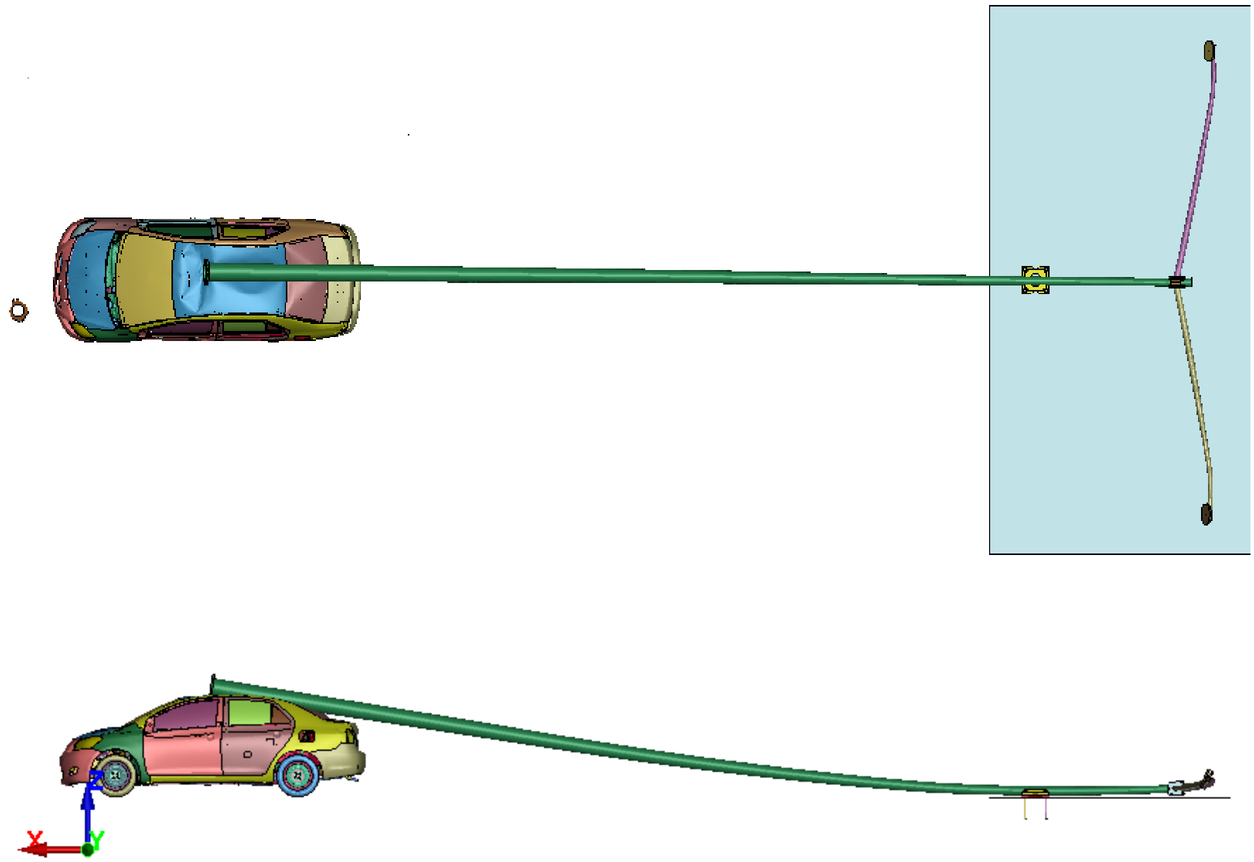


Figure 92. Simulation No. 49-2: 45-ft Tall Pole with Dual 10-ft Long Mast Arms, MASH Test Designation No. 3-60, Center Impact at 0 degrees (Time = 1950 ms After Impact)

Discussion – 45-ft Tall Pole Simulation Results

Of the six 45-ft tall pole configurations that were simulated, three configurations had potential to meet MASH criteria. The configurations were: (1) a 45-ft tall pole with a single 4-ft long mast arm, (2) a 45-ft tall pole with a single 10-ft long mast arm, and (3) a 45-ft tall pole with a single 20-ft long mast arm. As shown in Table 26, three of the six 45-ft tall pole configurations had at least one impact condition likely to result in a failed MASH test. The simulations with low potential to meet MASH criteria occurred under MASH test designation no. 3-60 with a center impact at 0 degrees, and all involved dual mast arm configurations. These failures were attributed to excessive occupant compartment deformation.

The most critical configuration was the 45-ft tall pole with dual 10-ft long mast arms, which had the largest roof crush of 6.39 in. Another notable critical configuration was the 45-ft tall pole with dual 20-ft long mast arms, which also showed a significant roof crush, measuring 6.11 in.

Occupant Compartment Intrusion

All six 45-ft tall pole simulations showed occupant compartment deformation under MASH test designation no. 3-60 for center impact conditions, with three configurations exceeding the MASH limit of 4.0 in. The configurations with single mast arms had deformation below 4.0 in., while the configurations with dual mast arms had deformation of 4.0 in. or more. The roof crush observed for the dual 10-ft and 20-ft mast arm configurations was not caused by the initial pole impact on the roof but resulted from a second impact of the bottom of the pole and the pole base plate onto the rear center of the roof after the top of the pole impacted the ground. For 45-ft tall poles, the simulations indicated that dual arm configurations were more critical regarding roof crush.

No simulations of 45-ft tall pole configurations at left or right quarter-point impacts under MASH test designation no. 3-60 resulted in secondary contact between the pole and the vehicle. Consequently, left and right quarter-point impacts were deemed less critical than center impacts.

The simulation for the 45-ft tall pole with a single 4-ft long mast arm under MASH test designation no. 3-60 with a left-quarter point impact at 25 degrees was not completed due to a 1,000-fold increase in hourglass energy in the model, causing a delayed activation of the slip base. Efforts to resolve this issue are ongoing.

Additionally, in all simulations of 45-ft tall pole configurations under MASH test designation nos. 3-61 and 3-62 at center, left-quarter point, and right-quarter point impact locations, as well as at 0-degree and 25-degree impact angles, the pole did not contact the vehicle after the initial impact. As a result, there was no occupant compartment deformation in these scenarios.

OIV

For all 45-ft tall pole configurations at MASH test designation nos. 3-60, 3-61, and 3-62 at all impact locations and angles, simulated OIV values were well-below the MASH limit of 16 ft/s. The largest OIV was 11.35 ft/s for the 45-ft tall pole with dual 20-ft long mast arms under MASH test designation no. 3-61 with a center impact at 25 degrees.

ORA and Vehicle Stability

The ORA values for all 45-ft tall pole configurations were well below the MASH limit of 20.49 g's. The highest ORA recorded was 1.41 g's for the 45-ft tall pole with dual 20-ft long mast arms under MASH test designation no. 3-61 with a center impact at 0 degrees. Additionally, simulation results indicated that vehicle stability was not a concern, as roll and pitch angles remained well below the 75-degree limit in all cases. Detailed simulation results, including occupant compartment deformation, OIV, ORA, roll, and pitch data for each simulation conducted as part of the simulation matrix, are provided in Appendix D.

Potential to Meet MASH Criteria

Among the 45-ft tall pole configurations, the single-arm configurations (i.e., the 45-ft tall pole with a single 4-ft long mast arm, a single 10-ft long mast arm, and a single 20-ft long mast arm) demonstrated high potential to meet MASH criteria. None of these configurations exceeded the roof crush or OIV limits in the simulations.

While the 45-ft tall pole configuration with dual 4-ft long mast arms did not meet MASH criteria in the completed series of simulations, the 4-ft long mast arm configurations showed potential. An inspection of the 4.02-in. occupant compartment deformation observed for this configuration indicated that the failure was marginal.

4.2.6 50-ft Pole Configuration Simulations

A total of four 50-ft tall pole configurations were simulated. These were the tallest poles analyzed and were constrained to a minimum mast arm length of 8 ft and a maximum mast arm length of 15 ft, based on state DOT standards and the Valmont catalog. The pole base diameter was 10.5 in. and the pole wall thickness was 10 gauge, except for the configurations with dual 15-ft long mast arms, which used 7-gauge walls. The total weight of the 50-ft tall poles ranged from 642 lb to 986 lb, making them the heaviest configurations among all simulated poles. The results of the 50-ft pole simulations are shown in Tables 27 through 29. An image of the critical state for a critical configuration (i.e., 50-ft tall pole with dual 15-ft long mast arms) under MASH test designation no. 3-60 with a center impact at 0 degrees is shown in Figure 93.

Table 27. Simulation Results for 50-ft Pole Configurations – Maximum Occupant Compartment Deformation (in.)

Simulation No.			50	51	52	53
Pole Height (ft)			50	50	50	50
Mast Arm Length (ft)			8	8	15	15
Mast Arm Configuration			S	D	S	D
3-60	Left Quarter	0°	N/A	-	-	N/A
		25°	N/A	-	-	N/A
	Center	0°	5.31	6.20	5.77	6.87
		25°	5.74	N/A	4.04	3.60
	Right Quarter	0°	0.45 (B)	-	-	N/A
		25°	N/A	-	-	N/A
3-61	Left Quarter	0°	-	-	-	N/A
		25°	-	-	-	N/A
	Center	0°	N/A	N/A	N/A	N/A
		25°	-	-	-	N/A
	Right Quarter	0°	-	-	-	N/A
		25°	-	-	-	N/A
3-62	Left Quarter	0°	-	-	-	N/A
		25°	-	-	-	N/A
	Center	0°	N/A	N/A	N/A	N/A
		25°	-	-	-	N/A
	Right Quarter	0°	-	-	-	N/A
		25°	-	-	-	N/A

"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
"N/A" indicates no occupant compartment deformation was observed.
"(A)", "(B)", and "(C)" indicate deformation was observed at A-pillar, B-pillar, and C-pillar, respectively.
"(FW)"and "(RW)" indicate deformation was observed at front windshield and rear window, respectively.
"-" denotes simulations that were not run as a part of the investigation.
[red] Occupant comp. deformation beyond 4.0 in. MASH limit
[orange] Occupant comp. def. between 2.0 in. and 4.0 in.
Note: MASH limit for deformation of windshield is 3.0 in.

Table 28. Simulation Results for 50-ft Pole Configurations – Longitudinal OIV (ft/s)

Simulation No.			**50**	**51**	**52**	**53**
Pole Height (ft)			50	50	50	50
Mast Arm Length (ft)			8	8	15	15
Mast Arm Configuration			S	D	S	D
3-60	Left Quarter	0°	4.44	-	-	6.05
		25°	6.12	-	-	5.2
	Center	0°	4.86	5.05	6.26	7.23
		25°	5.11	5.32	4.83	6.26
	Right Quarter	0°	4.89	-	-	5.76
		25°	4.56	-	-	5.63
3-61	Left Quarter	0°	-	-	-	10.13
		25°	-	-	-	11.81
	Center	0°	9.78	11.52	10.20	12.45
		25°	-	-	-	13.76
	Right Quarter	0°	-	-	-	11.33
		25°	-	-	-	11.44
3-62	Left Quarter	0°	-	-	-	6.97
		25°	-	-	-	7.39
	Center	0°	5.93	5.87	6.02	7.14
		25°	-	-	-	7.14
	Right Quarter	0°	-	-	-	7.15
		25°	-	-	-	7.00

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
(highlighted) OIV beyond 12 ft/s, equal to 75% of MASH limit of 16 ft/s

Table 29. Potential to Pass MASH Criteria for 50-ft Pole Configurations

Simulation No.			**50**	**51**	**52**	**53**
Pole Height (ft)			50	50	50	50
Mast Arm Length (ft)			8	8	15	15
Mast Arm Configuration			S	D	S	D
3-60	Left Quarter	0°	Pass	-	-	Pass
		25°	Pass	-	-	High
	Center	0°	Fail	Fail	Fail	Fail
		25°	Fail	Pass	Fail	Pass
	Right Quarter	0°	Pass	-	-	Pass
		25°	Pass	-	-	Pass
3-61	Left Quarter	0°	-	-	-	Pass
		25°	-	-	-	Pass
	Center	0°	Pass	Pass	Pass	Pass
		25°	-	-	-	Pass
	Right Quarter	0°	-	-	-	Pass
		25°	-	-	-	Pass
3-62	Left Quarter	0°	-	-	-	Pass
		25°	-	-	-	Pass
	Center	0°	Pass	Pass	Pass	Pass
		25°	-	-	-	Pass
	Right Quarter	0°	-	-	-	Pass
		25°	-	-	-	Pass

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
[red] Low potential to pass MASH due to occupant compartment deformation, roof crush, or OIV

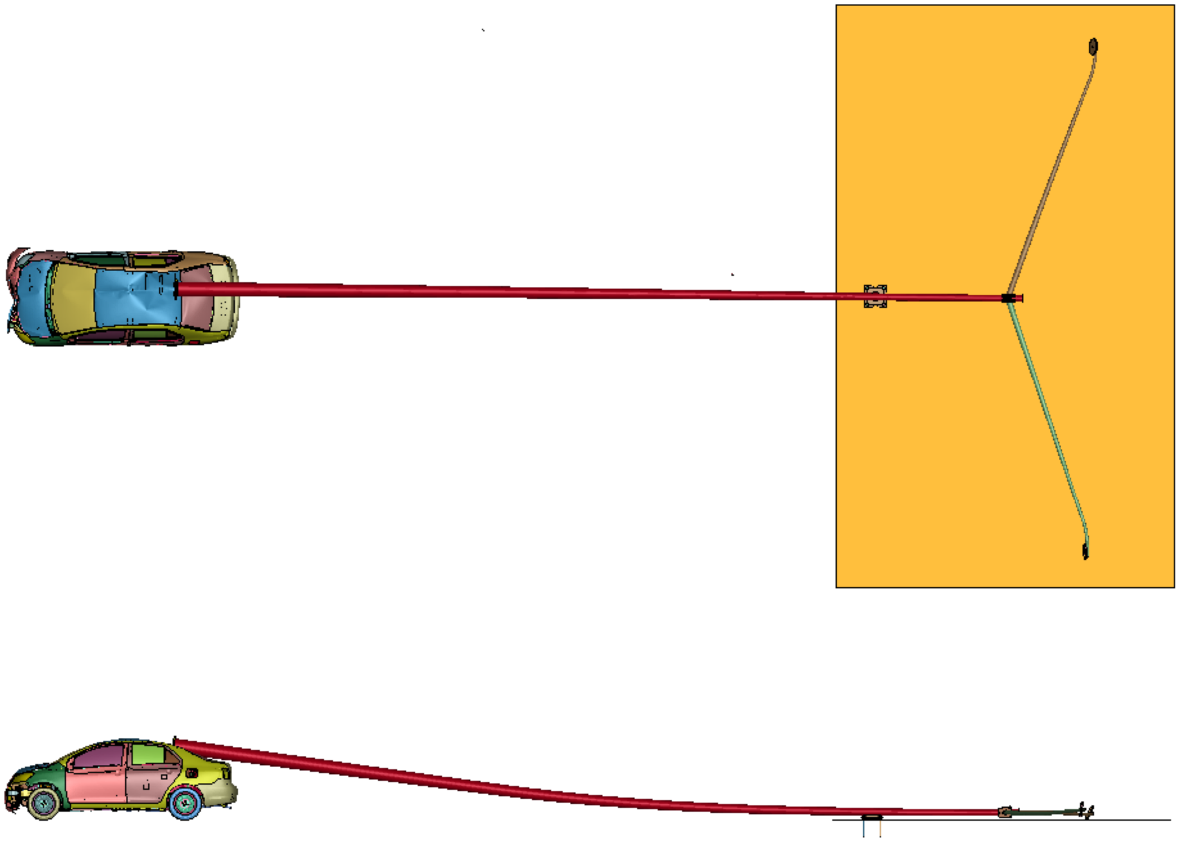


Figure 93. Simulation No. 53: 50-ft Tall Pole with Dual 15-ft Long Mast Arms, MASH Test Designation No. 3-60, Center Impact at 0 degrees (Time = 2650 ms After Impact)

<u>Discussion – 50-ft Tall Pole Simulation Results</u>

Of the four 50-ft tall pole configurations that were simulated, it was unlikely that any configuration would meet MASH criteria. As shown in Table 29, each configuration had at least one impact condition that would likely result in a failed MASH test. The simulations with low potential to meet MASH criteria occurred under MASH test designation no. 3-60 with a center impact at either 0 degrees or 25 degrees, primarily failing due to excessive roof crush. The most critical configuration, based on simulations, was the 50-ft tall pole with dual 15-ft long mast arms, which had the largest roof crush of 6.87 in.

<u>Occupant Compartment Deformation</u>

The roof crush for all four 50-ft tall pole configuration simulations exceeded the 4.0-in. MASH limit under MASH test designation no. 3-60 for center impact conditions. The 50-ft tall poles with single mast arms had a maximum roof crush of 5 in., while the configurations with dual mast arms had roof crush of 6 in. or more. Notably, for the dual 8-ft and 15-ft mast arm configurations, the roof crush was not caused by the initial impact of the pole falling onto the roof but by a second impact involving the bottom of the pole and the pole base plate striking the rear center of the roof after the top of the pole had impacted the ground.

For the simulations of 50-ft tall pole configurations at left and right quarter-point impacts under MASH test designation no. 3-60, there was no contact between the pole and the vehicle after the initial impact. Consequently, left and right quarter-point impacts were deemed less critical than center impacts. Additionally, in all simulations of 50-ft tall poles under MASH test designation nos. 3-61 and 3-62, across center, left-quarter point, and right-quarter point impact locations, as well as at 0-degree and 25-degree impact angles, the pole did not contact the vehicle after the initial impact..

OIV

For all 50-ft tall poles simulated under MASH test designation nos. 3-60, 3-61, and 3-62 across all impact locations and angles, the OIV values were below the MASH limit of 16 ft/s. However, there was concern regarding potential violations of the limit, particularly for the 50-ft tall pole with dual 15-ft long mast arms during center impacts. The simulated OIV values for this configuration under MASH test designation no. 3-61 were 12.45 ft/s and 13.76 ft/s for center impacts at 0 degrees and 25 degrees, respectively.

The concern arises because baseline simulations have been shown to under-predict OIV by approximately 35% for high-speed tests. If this under-prediction is accounted for by adjusting the simulated values upward by 35%, configurations with OIV values above 12 ft/s could potentially exceed the 16 ft/s limit. For example, adjusting the OIV values for the dual 15-ft mast arm configuration would result in estimated values of 16.81 ft/s and 18.57 ft/s for impacts at 0 degrees and 25 degrees, respectively.

It is important to note that this adjustment method is an estimation tool, not a definitive prediction. The potential for exceeding the OIV limit would require validation through full-scale crash testing. The discrepancy observed in OIV under-prediction may be related to differences between simulated and actual test conditions, such as the pole plate catching on the vehicle in test no. USBLM-2, which did not occur in the simulation [5]. The behavior of the pole plate catching on the vehicle is not guaranteed and may not occur in a crash test with a modern vehicle. This variability introduces uncertainty in predicting OIV values accurately. Additionally, the performance of luminaire slip bases can vary even under identical testing conditions due to manufacturing tolerances, material inconsistencies, or other factors influencing the activation of the slip base mechanism, as discussed in Section 2.4 regarding the 3-bolt slip base pendulum testing in Eligibility Letter LS-16 [27].

ORA and Vehicle Stability

The ORA values for all 50-ft tall poles were well below the 20.49-g's MASH limit. The largest ORA was 1.92 g's for the 50-ft tall pole with dual 15-ft long mast arms under MASH test designation no. 3-60 with a center impact at 0 degrees. Additionally, the simulation results suggested that vehicle stability was not critical, as roll and pitch remained well below the 75-degree limit in all simulations. Detailed simulation results are reported in Appendix D.

Potential to Pass MASH

Based on the simulations, none of the 50-ft tall pole configurations demonstrated high potential to meet MASH criteria.

4.2.7 All Pole Simulation Results

A total of thirty-two pole configurations were simulated. The pole heights ranged from 20 to 50 ft and had either a single or dual mast arm configuration. The poles had mast arm lengths ranging from 4 to 20 ft. The pole base diameter ranged from 6.5 in. to 10.5 in. and the pole wall thickness was 11, 10, or 7 gauge. The total weight of the pole configurations ranged from 222 lb to 985 lb. The simulation results are shown in Tables 30 through 34.

Table 30. Simulation Results – MASH Test Designation No. 3-60 – All Poles – Occupant Compartment Deformation (in.)

Sim. No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Config.	Total Weight (lb)	C.G. Height (ft)	MASH 3-60					
						Left 1/4		Center		Right 1/4	
						0	25	0	25	0	25
20	20	4	S	222	12.1	1.10(C)	1.70(C)	0.38	4.14	N/A	N/A
21	20	4	D	312	14.4	-	-	2.79(RW)	4.01	-	-
22	20	10	S	261	14.0	-	-	6.07	8.31	-	-
23	20	10	D	381	16.2	N/A	0.19(A)	5.54	1.59	N/A	N/A
30	30	4	S	300	16.8	N/A	N/A	2.14	3.55	N/A	N/A
31	30	4	D	390	19.7	-	-	2.57	3.50(RW)	-	-
34-1	30	10	S	349	17.9	N/A	N/A	6.79	8.28	N/A	N/A
34-2	30	10	D	468	20.9	-	-	1.98	0.50(FW)	-	-
32	30	20	S	433	20.3	-	-	7.77	8.40	-	-
33	30	20	D	604	23.8	N/A	N/A	3.35	0.97	N/A	N/A
35	35	4	S	347	19.0	N/A	N/A	3.64	3.67	N/A	N/A
36	35	4	D	437	22.2	-	-	3.59	1.88	-	-
39-1	35	10	S	393	20.1	N/A	N/A	4.54	4.36	N/A	N/A
39-2	35	10	D	513	23.5	-	-	3.64	2.51	-	-
37	35	20	S	485	22.5	-	-	3.12	4.24	-	-
38	35	20	D	656	26.4	N/A	N/A	5.45	0.39	N/A	N/A
40	40	4	S	411	21.1	N/A	N/A	1.88	1.69	N/A	N/A
41	40	4	D	502	24.4	-	-	4.08	0.68(FW)	-	-
44-1	40	10	S	466	22.2	N/A	N/A	0.19	3.30	N/A	N/A
44-2	40	10	D	586	25.8	-	-	1.76	0.84	-	-
42	40	20	S	556	24.7	-	-	0.22(C)	4.73	-	-
43	40	20	D	727	29.1	N/A	N/A	3.55	3.67	N/A	N/A
45	45	4	S	466	23.2	N/A	N/A	0.35(C)	3.00	N/A	N/A
46	45	4	D	557	26.6	-	-	4.02	0.93	-	-
49-1	45	10	S	528	24.5	N/A	N/A	0.56(FW)	1.50	N/A	N/A
49-2	45	10	D	648	28.2	-	-	6.39	0.60(C)	-	-
47	45	20	S	676	26.4	-	-	0.45	1.10	-	-
48	45	20	D	847	30.6	N/A	N/A	6.11	3.41	N/A	N/A
50	50	8	S	642	27.5	N/A	N/A	5.31	5.74	0.45(B)	N/A
51	50	8	D	750	28.9	-	-	6.20	N/A	-	-
52	50	15	S	672	27.1	-	-	5.77	4.04	-	-
53	50	15	D	986	29.5	N/A	N/A	6.87	3.60	N/A	N/A

"-" denotes simulations that were not run as a part of the investigation.
"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.
"N/A" indicates no occupant compartment deformation was observed.
"(A)", "(B)", and "(C)" indicate deformation was observed at A-pillar, B-pillar, and C-pillar, respectively.
"(FW)"and "(RW)" indicate deformation was observed at front windshield and rear window, respectively.
Occupant comp. deformation beyond 4.0 in. MASH limit

Table 31. Simulation Results – MASH Test Designation Nos. 3-61 and 3-62 – All Pole Configurations – Occupant Compartment Deformation (in.)

Sim. No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Config.	Total Weight (lb)	C.G. Height (ft)	MASH 3-61						MASH 3-62					
						Left 1/4		Center		Right 1/4		Left 1/4		Center		Right 1/4	
						0	25	0	25	0	25	0	25	0	25	0	25
20	20	4	S	222	12.1	-	-	N/A	-	-	-	-	-	N/A	-	-	-
21	20	4	D	312	14.4	-	-	N/A	-	-	-	-	-	N/A	-	-	-
22	20	10	S	261	14.0	-	-	N/A	-	-	-	-	-	N/A	-	-	-
23	20	10	D	381	16.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30	30	4	S	300	16.8	-	-	N/A	-	-	-	-	-	N/A	-	-	-
31	30	4	D	390	19.7	-	-	N/A	-	-	-	-	-	N/A	-	-	-
34-1	30	10	S	349	17.9	-	-	-	-	-	-	-	-	-	-	-	-
34-2	30	10	D	468	20.9	-	-	-	-	-	-	-	-	-	-	-	-
32	30	20	S	433	20.3	-	-	N/A	-	-	-	-	-	N/A	-	-	-
33	30	20	D	604	23.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
35	35	4	S	347	19.0	-	-	N/A	-	-	-	-	-	N/A	-	-	-
36	35	4	D	437	22.2	-	-	N/A	-	-	-	-	-	N/A	-	-	-
39-1	35	10	S	393	20.1	-	-	-	-	-	-	-	-	-	-	-	-
39-2	35	10	D	513	23.5	-	-	-	-	-	-	-	-	-	-	-	-
37	35	20	S	485	22.5	-	-	N/A	-	-	-	-	-	N/A	-	-	-
38	35	20	D	656	26.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
40	40	4	S	411	21.1	-	-	N/A	-	-	-	-	-	N/A	-	-	-
41	40	4	D	502	24.4	-	-	N/A	-	-	-	-	-	N/A	-	-	-
44-1	40	10	S	466	22.2	-	-	-	-	-	-	-	-	-	-	-	-
44-2	40	10	D	586	25.8	-	-	-	-	-	-	-	-	-	-	-	-
42	40	20	S	556	24.7	-	-	N/A	-	-	-	-	-	N/A	-	-	-
43	40	20	D	727	29.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
45	45	4	S	466	23.2	-	-	N/A	-	-	-	-	-	N/A	-	-	-
46	45	4	D	557	26.6	-	-	N/A	-	-	-	-	-	N/A	-	-	-
49-1	45	10	S	528	24.5	-	-	-	-	-	-	-	-	-	-	-	-
49-2	45	10	D	648	28.2	-	-	-	-	-	-	-	-	-	-	-	-
47	45	20	S	676	26.4	-	-	N/A	-	-	-	-	-	N/A	-	-	-
48	45	20	D	847	30.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
50	50	8	S	642	27.5	-	-	N/A	-	-	-	-	-	N/A	-	-	-
51	50	8	D	750	28.9	-	-	N/A	-	-	-	-	-	N/A	-	-	-
52	50	15	S	672	27.1	-	-	N/A	-	-	-	-	-	N/A	-	-	-
53	50	15	D	986	29.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

"-" denotes simulations that were not run as a part of the investigation.

"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.

"N/A" indicates no occupant compartment deformation was observed

Table 32. Simulation Results – MASH Test Designation No. 3-60 – All Pole Configurations – OIV (ft/s)

Sim. No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Config.	Total Weight (lb)	C.G. Height (ft)	MASH 3-60					
						Left 1/4		Center		Right 1/4	
						0	25	0	25	0	25
20	20	4	S	222	12.1	2.76	2.62	3.01	3.19	2.77	2.92
21	20	4	D	312	14.4	-	-	3.01	3.03	-	-
22	20	10	S	261	14.0	-	-	3.47	3.38	-	-
23	20	10	D	381	16.2	3.81	3.1	3.46	3.34	3.06	3.04
30	30	4	S	300	16.8	3.36	2.99	3.57	3.51	3.58	3.09
31	30	4	D	390	19.7	-	-	3.80	3.48	-	-
34-1	30	10	S	349	17.9	3.32	3.34	3.51	3.71	3.37	3.25
34-2	30	10	D	468	20.9	-	-	3.60	3.68	-	-
32	30	20	S	433	20.3	-	-	3.79	3.74	-	-
33	30	20	D	604	23.8	3.41	4.76	3.86	3.82	3.76	3.43
35	35	4	S	347	19.0	3.40	4.08	3.6	3.65	3.62	3.33
36	35	4	D	437	22.2	-	-	3.46	3.76	-	-
39-1	35	10	S	393	20.1	3.54	3.82	3.72	3.95	3.62	3.45
39-2	35	10	D	513	23.5	-	-	3.68	3.91	-	-
37	35	20	S	485	22.5	-	-	3.92	4.73	-	-
38	35	20	D	656	26.4	3.79	4.9	4.80	4.55	3.94	3.64
40	40	4	S	411	21.1	3.83	5.55	3.79	4.07	4.10	3.72
41	40	4	D	502	24.4	-	-	3.92	4.25	-	-
44-1	40	10	S	466	22.2	3.91	4.80	3.85	4.6	4.14	3.78
44-2	40	10	D	586	25.8	-	-	4.01	4.60	-	-
42	40	20	S	556	24.7	-	-	3.97	5.10	-	-
43	40	20	D	727	29.1	4.23	6.94	4.53	5.24	4.24	3.99
45	45	4	S	466	23.2	4.10	-	4.04	4.85	5.35	4.01
46	45	4	D	557	26.6	-	-	4.22	4.94	-	-
49-1	45	10	S	528	24.5	4.30	6.88	4.23	4.85	4.39	4.14
49-2	45	10	D	648	28.2	-	-	4.63	5.67	-	-
47	45	20	S	676	26.4	-	-	4.64	4.95	-	-
48	45	20	D	847	30.6	4.70	5.72	4.99	6.25	4.83	4.26
50	50	8	S	642	27.5	4.44	6.12	4.86	5.11	4.89	4.56
51	50	8	D	750	28.9	-	-	5.05	5.32	-	-
52	50	15	S	672	27.1	-	-	6.26	4.83	-	-
53	50	15	D	986	29.5	6.05	5.2	7.23	6.26	5.76	5.63

"-" denotes simulations that were not run as a part of the investigation.

Table 33. Simulation Results – MASH Test Designation Nos. 3-61 and 3-62 – All Pole Configurations - OIV (ft/s)

Sim. No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Config.	Total Weight (lb)	C.G. Height (ft)	MASH 3-61						MASH 3-62					
						Left 1/4		Center		Right 1/4		Left 1/4		Center		Right 1/4	
						0	25	0	25	0	25	0	25	0	25	0	25
20	20	4	S	222	12.1	-	-	5.57	-	-	-	-	-	4.41	-	-	-
21	20	4	D	312	14.4	-	-	5.44	-	-	-	-	-	4.34	-	-	-
22	20	10	S	261	14.0	-	-	5.55	-	-	-	-	-	4.52	-	-	-
23	20	10	D	381	16.2	5.88	5.28	5.67	5.88	6.16	5.96	4.33	4.10	4.53	4.39	4.30	4.27
30	30	4	S	300	16.8	-	-	6.26	-	-	-	-	-	4.49	-	-	-
31	30	4	D	390	19.7	-	-	6.37	-	-	-	-	-	4.53	-	-	-
34-1	30	10	S	349	17.9	-	-	-	-	-	-	-	-	-	-	-	-
34-2	30	10	D	468	20.9	-	-	-	-	-	-	-	-	-	-	-	-
32	30	20	S	433	20.3	-	-	6.82	-	-	-	-	-	4.60	-	-	-
33	30	20	D	604	23.8	7.33	7.84	6.97	7.22	7.94	6.78	4.63	4.56	4.64	4.73	4.70	4.72
35	35	4	S	347	19.0	-	-	6.82	-	-	-	-	-	4.63	-	-	-
36	35	4	D	437	22.2	-	-	7.18	-	-	-	-	-	4.65	-	-	-
39-1	35	10	S	393	20.1	-	-	-	-	-	-	-	-	-	-	-	-
39-2	35	10	D	513	23.5	-	-	-	-	-	-	-	-	-	-	-	-
37	35	20	S	485	22.5	-	-	7.37	-	-	-	-	-	4.75	-	-	-
38	35	20	D	656	26.4	8.06	7.76	7.42	8.17	7.79	7.79	4.93	4.93	4.84	4.94	5.27	4.91
40	40	4	S	411	21.1	-	-	7.81	-	-	-	-	-	4.86	-	-	-
41	40	4	D	502	24.4	-	-	7.70	-	-	-	-	-	4.82	-	-	-
44-1	40	10	S	466	22.2	-	-	-	-	-	-	-	-	-	-	-	-
44-2	40	10	D	586	25.8	-	-	-	-	-	-	-	-	-	-	-	-
42	40	20	S	556	24.7	-	-	8.37	-	-	-	-	-	5.10	-	-	-
43	40	20	D	727	29.1	8.55	8.25	8.74	9.44	8.52	8.67	5.41	5.48	5.26	5.36	5.25	5.12
45	45	4	S	466	23.2	-	-	8.02	-	-	-	-	-	5.09	-	-	-
46	45	4	D	557	26.6	-	-	9.09	-	-	-	-	-	5.06	-	-	-
49-1	45	10	S	528	24.5	-	-	-	-	-	-	-	-	-	-	-	-
49-2	45	10	D	648	28.2	-	-	-	-	-	-	-	-	-	-	-	-
47	45	20	S	676	26.4	-	-	10.00	-	-	-	-	-	5.83	-	-	-
48	45	20	D	847	30.6	9.38	9.68	10.19	11.35	9.02	8.76	5.84	5.93	6.00	6.05	5.91	5.77
50	50	8	S	642	27.5	-	-	9.78	-	-	-	-	-	5.93	-	-	-
51	50	8	D	750	28.9	-	-	11.52	-	-	-	-	-	5.87	-	-	-
52	50	15	S	672	27.1	-	-	10.20	-	-	-	-	-	6.02	-	-	-
53	50	15	D	986	29.5	10.13	11.81	12.45	13.76	11.33	11.44	6.97	7.39	7.14	7.14	7.15	7.00

“-“ denotes simulations that were not run as a part of the investigation.

Table 34. Potential to Meet MASH Criteria for All Pole Configurations – MASH Test Designation No. 3-60

Sim. No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Config.	Total Weight (lb)	C.G. Height (ft)	MASH 3-60					
						Left 1/4		Center		Right 1/4	
						0	25	0	25	0	25
20	20	4	S	222	12.1	Pass	Pass	Pass	Fail	Pass	Pass
21	20	4	D	312	14.4	-	-	Pass	Fail	-	-
22	20	10	S	261	14.0	-	-	Fail	Fail	-	-
23	20	10	D	381	16.2	Pass	Pass	Fail	Pass	Pass	Pass
30	30	4	S	300	16.8	Pass	Pass	Pass	Pass	Pass	Pass
31	30	4	D	390	19.7	-	-	Pass	Fail	-	-
34-1	30	10	S	349	17.9	Pass	Pass	Fail	Fail	Pass	Pass
34-2	30	10	D	468	20.9	-	-	Pass	Pass	-	-
32	30	20	S	433	20.3	-	-	Fail	Fail	-	-
33	30	20	D	604	23.8	Pass	Pass	Pass	Pass	Pass	Pass
35	35	4	S	347	19.0	Pass	Pass	Pass	Pass	Pass	Pass
36	35	4	D	437	22.2	-	-	Pass	Pass	-	-
39-1	35	10	S	393	20.1	Pass	Pass	Fail	Fail	Pass	Pass
39-2	35	10	D	513	23.5	-	-	Pass	Pass	-	-
37	35	20	S	485	22.5	-	-	Pass	Fail	-	-
38	35	20	D	656	26.4	Pass	Pass	Fail	Pass	Pass	Pass
40	40	4	S	411	21.1	Pass	Pass	Pass	Pass	Pass	Pass
41	40	4	D	502	24.4	-	-	Fail	Pass	-	-
44-1	40	10	S	466	22.2	Pass	Pass	Pass	Pass	Pass	Pass
44-2	40	10	D	586	25.8	-	-	Pass	Pass	-	-
42	40	20	S	556	24.7	-	-	Pass	Fail	-	-
43	40	20	D	727	29.1	Pass	Pass	Pass	Pass	Pass	Pass
45	45	4	S	466	23.2	Pass	-	Pass	Pass	Pass	Pass
46	45	4	D	557	26.6	-	-	Fail	Pass	-	-
49-1	45	10	S	528	24.5	Pass	Pass	Pass	Pass	Pass	Pass
49-2	45	10	D	648	28.2	-	-	Fail	Pass	-	-
47	45	20	S	676	26.4	-	-	Pass	Pass	-	-
48	45	20	D	847	30.6	Pass	Pass	Fail	Pass	Pass	Pass
50	50	8	S	642	27.5	-	-	Fail	Fail	-	-
51	50	8	D	750	28.9	-	-	Fail	Pass	-	-
52	50	15	S	672	27.1	-	-	Fail	Fail	-	-
53	50	15	D	986	29.5	Pass	Pass	Fail	Pass	Pass	Pass

"-" denotes simulations that were not run as a part of the investigation.

"S" stands for single mast arm configuration and "D" stands for dual mast arm configuration.

(red) Low potential to pass MASH due to occupant compartment deformation, roof crush, or OIV.

Table 35. Potential to Meet MASH Criteria for All Pole Configurations – MASH Test Designation Nos. 3-61 and 3-62

Sim. No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Config.	Total Weight (lb)	C.G. Height (ft)	MASH 3-61						MASH 3-62					
						Left 1/4		Center		Right 1/4		Left 1/4		Center		Right 1/4	
						0	25	0	25	0	25	0	25	0	25	0	25
20	20	4	S	222	12.1	-	-	Pass	-	-	-	-	-	Pass	-	-	-
21	20	4	D	312	14.4	-	-	Pass	-	-	-	-	-	Pass	-	-	-
22	20	10	S	261	14.0	-	-	Pass	-	-	-	-	-	Pass	-	-	-
23	20	10	D	381	16.2	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
30	30	4	S	300	16.8	-	-	Pass	-	-	-	-	-	Pass	-	-	-
31	30	4	D	390	19.7	-	-	Pass	-	-	-	-	-	Pass	-	-	-
34-1	30	10	S	349	17.9	-	-	-	-	-	-	-	-	-	-	-	-
34-2	30	10	D	468	20.9	-	-	-	-	-	-	-	-	-	-	-	-
32	30	20	S	433	20.3	-	-	Pass	-	-	-	-	-	Pass	-	-	-
33	30	20	D	604	23.8	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
35	35	4	S	347	19.0	-	-	Pass	-	-	-	-	-	Pass	-	-	-
36	35	4	D	437	22.2	-	-	Pass	-	-	-	-	-	Pass	-	-	-
39-1	35	10	S	393	20.1	-	-	-	-	-	-	-	-	-	-	-	-
39-2	35	10	D	513	23.5	-	-	-	-	-	-	-	-	-	-	-	-
37	35	20	S	485	22.5	-	-	Pass	-	-	-	-	-	Pass	-	-	-
38	35	20	D	656	26.4	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
40	40	4	S	411	21.1	-	-	Pass	-	-	-	-	-	Pass	-	-	-
41	40	4	D	502	24.4	-	-	Pass	-	-	-	-	-	Pass	-	-	-
44-1	40	10	S	466	22.2	-	-	-	-	-	-	-	-	-	-	-	-
44-2	40	10	D	586	25.8	-	-	-	-	-	-	-	-	-	-	-	-
42	40	20	S	556	24.7	-	-	Pass	-	-	-	-	-	Pass	-	-	-
43	40	20	D	727	29.1	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
45	45	4	S	466	23.2	-	-	Pass	-	-	-	-	-	Pass	-	-	-
46	45	4	D	557	26.6	-	-	Pass	-	-	-	-	-	Pass	-	-	-
49-1	45	10	S	528	24.5	-	-	-	-	-	-	-	-	-	-	-	-
49-2	45	10	D	648	28.2	-	-	-	-	-	-	-	-	-	-	-	-
47	45	20	S	676	26.4	-	-	Pass	-	-	-	-	-	Pass	-	-	-
48	45	20	D	847	30.6	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
50	50	8	S	642	27.5	-	-	Pass	-	-	-	-	-	Pass	-	-	-
51	50	8	D	750	28.9	-	-	Pass	-	-	-	-	-	Pass	-	-	-
52	50	15	S	672	27.1	-	-	Pass	-	-	-	-	-	Pass	-	-	-
53	50	15	D	986	29.5	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

"-" denotes simulations that were not run as a part of the investigation.

Discussion – All Pole Simulation Results

As shown in Table 34, the simulations with low potential to pass MASH occurred under test designation no. 3-60 with a center impact at either 0 degree or 25 degrees. These simulations failed due to excessive roof crush. The most critical configuration was the 30-ft tall pole with a single 20-ft long mast arm since it had the largest occupant compartment deformation at both 0 degrees and 25 degrees of 7.77 in. and 8.40 in. respectively.

Occupant Compartment Deformation

All 32 pole configuration simulations resulted in occupant compartment deformation under MASH test designation no. 3-60 with center impact conditions, with 19 configurations exceeding the MASH limit.

For the limited simulations conducted at left and right quarter-point impacts under MASH test designation no. 3-60, only one simulation (a 20-ft tall pole with dual 10-ft long mast arms at a left quarter-point impact with a 25-degree angle) resulted in contact between the pole and the vehicle. The deformation observed in this case was minimal and caused by the pole grazing the vehicle's left-side A-pillar. Since contact after the initial impact was minimal in this case and absent in other simulations, left and right quarter-point impacts appeared less critical than center impacts. However, additional simulations or tests are necessary to validate this conclusion.

Furthermore, for all simulations under MASH test designation nos. 3-61 and 3-62, across center, left-quarter point, and right-quarter point impact locations, as well as 0-degree and 25-degree impact angles, no pole contacted the vehicle after the initial impact. A comparison of the pole dynamics of different pole configurations is shown in Tables 36 and 37.

In general, as pole height increased, the poles had slower fall dynamics. Additionally, taller poles contacted the vehicle for a longer duration because the top of the pole impacted the ground while the bottom of the pole remained on the vehicle. This extended interaction caused additional damage to the occupant compartment as the pole and pole base plate slid along the roof while the vehicle continued moving.

A comparison of the impacts of various pole configurations with the vehicle roof under a MASH test designation no. 3-60 center impact is shown in Tables 38 and 39. Note that the images display how the pole impacted the roof differently at different pole heights, mast arm lengths, mast arm configurations, and impact angles. Tables 38 and 39 are not comprehensive, i.e., they do not include images for all MASH test designation no. 3-60 center impact simulations. Instead, the images should be used to compare how different configurations and impact angles influence pole dynamics and how these dynamics affect the manner in which the pole impacts the vehicle roof. Descriptions of simulation pole dynamics are provided in Appendix D.

Table 36. Simulation Pole Dynamics Comparison at MASH Test Designation No. 3-60 Center Impact

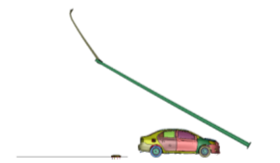
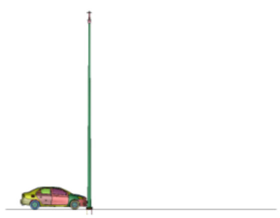
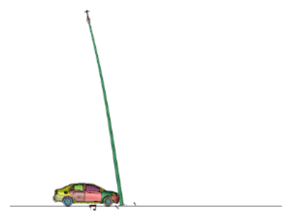
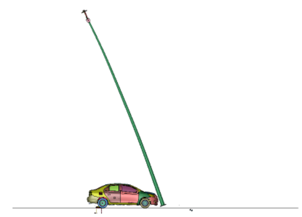
Simulation	Time			
	0 msec	250 msec	500 msec	750 msec
20-ft tall pole single 10-ft long mast arm - MASH 3-60 center impact at 25 degrees				
30-ft tall pole with single 20-ft long mast arm - MASH 3-60 center impact at 25 degrees				
40-ft tall pole with dual 4-ft long mast arms – MASH 3-60 center impact at 0 degrees				
50-ft tall pole with dual 15-ft long mast arms – MASH 3-60 center impact at 0 degrees				

Table 37. Simulation Pole Dynamics Comparison at MASH Test Designation No. 3-60 Center Impact, Cont.

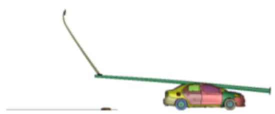
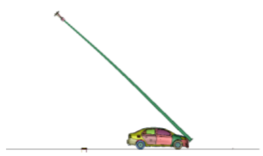
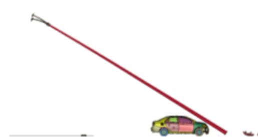
Simulation	Time			
	1000 msec	1500 msec	2000 msec	2500 msec
20-ft tall pole with single 10-ft long mast arm - MASH 3-60 center impact at 25 degrees			Simulation ended at 1500 msec	Simulation ended at 1500 msec
30-ft tall pole with single 20-ft long mast arm - MASH 3-60 center impact at 25 degrees			Simulation ended at 1500 msec	Simulation ended at 1500 msec
40-ft tall pole with dual 4-ft long mast arms – MASH 3-60 center impact at 0 degrees				
50-ft tall pole with dual 15-ft long mast arms – MASH 3-60 center impact at 0 degrees				

Table 38. Simulation Vehicle Roof Impact Comparison at MASH Test Designation No. 3-60 Center Impact

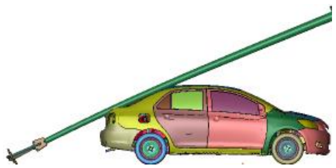
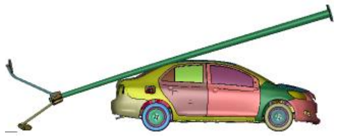
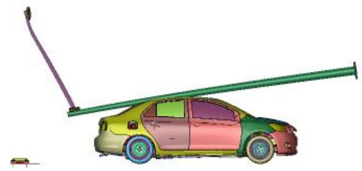
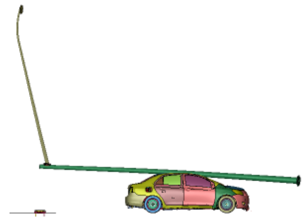
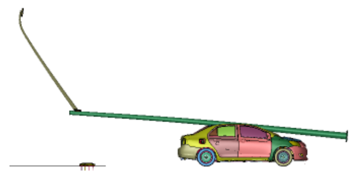
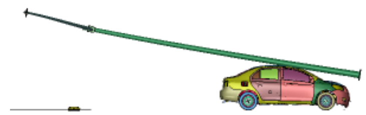
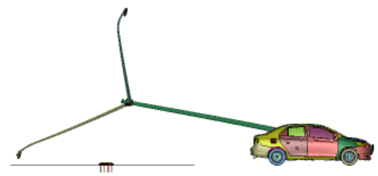
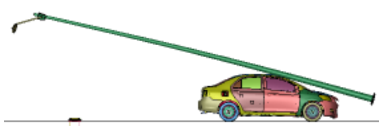
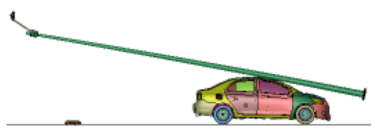
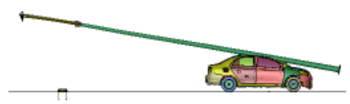
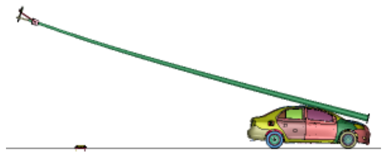
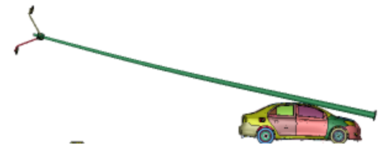
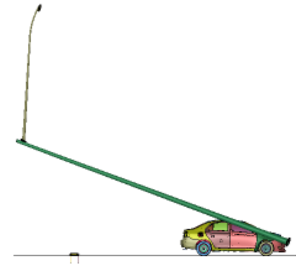
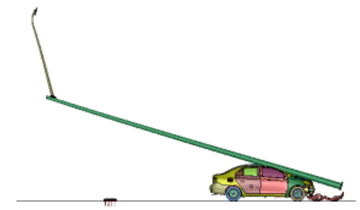
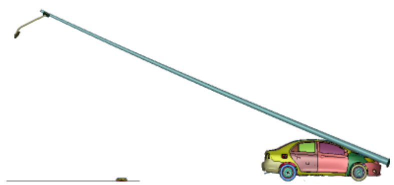
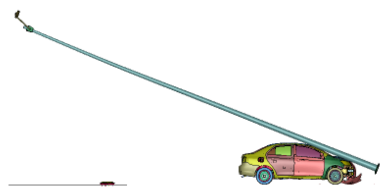
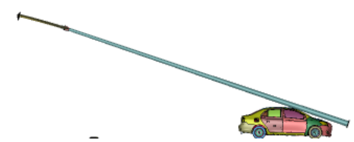
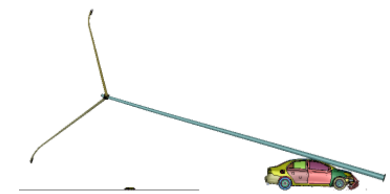
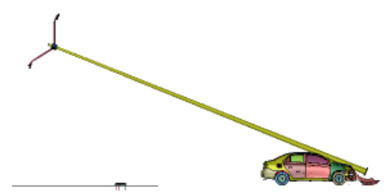
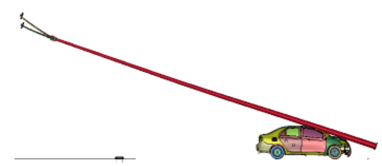
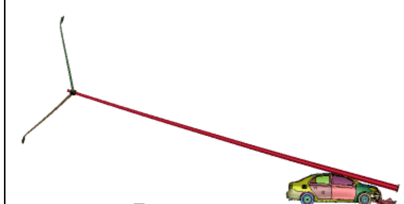
Pole Height	MASH 3-60 Center Point Impact - Vehicle Roof Impact Image			
	Configuration One - 0-deg. Impact	Configuration One - 25-deg. Impact	Configuration Two - 0-deg. Impact	Configuration Two - 25-deg. Impact
20-ft tall	 Dual 4-ft Mast Arms at 0-deg impact (t=950 msec)	 Dual 4-ft Mast Arms at 25-deg impact (t=950 msec)	 Single 10-ft Mast Arm at 0-deg impact (t=800 msec)	 Single 10-ft Mast Arm at 25-deg impact (t=800 msec)
30-ft tall	 Single 20-ft Mast Arm at 0-deg impact (t=1000 msec)	 Single 20-ft Mast Arm at 25-deg impact (t=1000 msec)	 Dual 20-ft Mast Arms at 0-deg impact (t=1300 msec)	 Dual 20-ft Mast Arms at 0-deg impact (t=1300 msec)
35-ft tall	 Single 4-ft Mast Arm at 0-deg impact (t=1100 msec)	 Single 4-ft Mast Arm at 25-deg impact (t=1100 msec)	 Dual 20-ft Mast Arms at 0-deg impact (t=1400 msec)	 Dual 20-ft Mast Arms at 25-deg impact (t=1400 msec)

Table 39. Simulation Vehicle Roof Impact Comparison at MASH Test Designation No. 3-60 Center Impact, Cont.

Pole Height	MASH 3-60 Center Point Impact - Vehicle Roof Impact Image			
	Configuration One - 0-deg. Impact	Configuration One - 25-deg. Impact	Configuration Two - 0-deg. Impact	Configuration Two - 25-deg. Impact
40-ft tall	 Dual 4-ft Mast Arms at 0-deg impact (t=1400 msec)	 Dual 4-ft Mast Arms at 25-deg impact (t=1400 msec)	 Single 20-ft Mast Arm at 0-deg impact (t=1200 msec) ***Pole does not contact roof***	 Single 20-ft Mast Arm at 25-deg impact (t=1200 msec)
45-ft tall	 Single 4-ft Mast Arm at 0-deg impact (t=1300 msec)	 Single 4-ft Mast Arm at 25-deg impact (t=1300 msec)	 Dual 20-ft Mast Arms at 0-deg impact (t=1600 msec)	 Dual 20-ft Mast Arms at 25-deg impact (t=1600 msec)
50-ft tall	 Dual 8-ft Mast Arms at 0-deg impact (t=1550 msec)	 Dual 8-ft Mast Arms at 25-deg impact (t=1550 msec) ***Pole does not contact roof***	 Dual 15-ft Mast Arms at 0-deg impact (t=1700 msec)	 Dual 15-ft Mast Arms at 25-deg impact (t=1700 msec)

For different pole configurations, the impact location of the pole onto the vehicle roof changed. In general, 20-ft and 30-ft tall poles impacted the vehicle roof near the midsection of the pole, i.e., near the pole's C.G., while 45-ft and 50-ft tall poles impacted the vehicle roof near the bottom of the pole. Additionally, as the pole configurations increased in weight, the time of impact occurred later, i.e., heavier pole configurations generally impacted the vehicle at a later time.

Pole configurations with single mast arms rotated counterclockwise, as viewed from the top, about the pole's vertical axis while falling. Pole configurations with single 4-ft long mast arms could rotate nearly 180 degrees while falling before impacting the vehicle's roof, while pole configurations with single 20-ft long mast arms may have rotated about 60 degrees. Pole configurations with dual mast arms did not tend to rotate about the pole's vertical axis.

Additionally, the impact angle affected how the pole fell onto the vehicle. The 25-degree impact angle contributed to the mast arms being oriented differently upon impact compared to a 0-degree impact angle. Also, the slip base disengaged differently in 25-degree impacts compared to 0-degree impacts due to the asymmetric geometry of the slip base in that orientation. The pole disengaged from the base, and the bottom of the pole generally "kicked out" toward the passenger side of the vehicle by about ½ in. to 1 in.

OIV

For all poles between 20 ft and 45 ft under MASH test designation nos. 3-60, 3-61, and 3-62, across all impact locations and angles, the simulated OIV values were well below the MASH limit of 16 ft/s. The highest OIV among these configurations was 11.35 ft/s, recorded for the 45-ft tall pole with dual 20-ft long mast arms under MASH test designation no. 3-61 at a center impact with a 25-degree angle.

For the 50-ft tall pole with dual 15-ft long mast arms at center impacts, there was a concern about potentially exceeding the 16 ft/s limit. The simulated OIV for this configuration under MASH test designation no. 3-61 was 12.45 ft/s at a 0-degree center impact and 13.76 ft/s at a 25-degree center impact. This concern arises because the baseline simulation underpredicted OIV by approximately 35% for high-speed tests, as discussed in Section 4.2.6. The simulated OIV plotted versus the system weight for all simulations is shown in Figure 94.

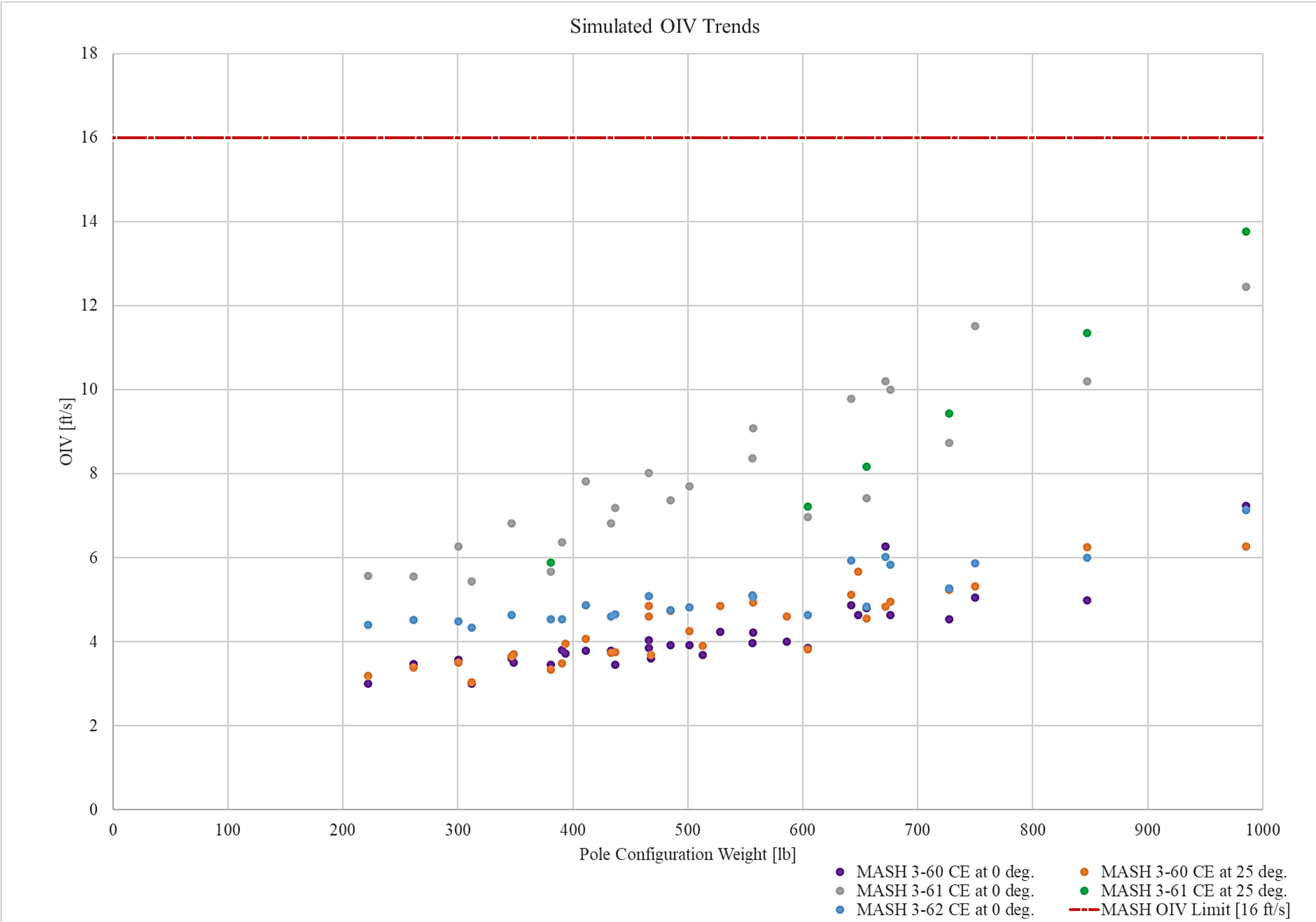


Figure 94. Simulated OIVs vs. System Weights

<u>ORA and Vehicle Stability</u>

The ORA for all pole configurations was well below the 20.49-g MASH limit. The largest ORA was 1.92 g's for a 50-ft tall pole with dual 15-ft long mast arms under MASH test designation no. 3-60 with a center impact at 0 degrees. Additionally, the simulation results suggested that vehicle stability was not critical, as roll and pitch remained well below the 75-degree limit in all simulations. Detailed simulation results are reported in Appendix D.

Pole Configurations with High Potential to Meet MASH Criteria

Although no other family of configurations showed a strong potential to meet MASH criteria, further analysis of the results indicated a "window of opportunity" for pole configurations weighing between approximately 450 lb and 600 lb. Configurations within this weight range either passed or marginally failed to meet MASH criteria in the simulations, suggesting that designs in this weight category may warrant additional investigation or optimization. The simulated roof crush for all pole configurations, sorted from lowest weight to highest weight, is shown in Table 40. The highest deformation in the range from 450 lb to 600 lb was 4.73 in., which could be considered as a marginal potential for failure.

A similar "window of opportunity" was identified for pole configurations with a C.G. from 21 ft to 26 ft. The simulated roof crush for all pole configurations, sorted from lowest C.G. to highest C.G., is shown in Table 41. The highest deformation in the range of C.G. from 21 to 26 ft is 4.73 in., which again could be considered as a marginal potential for failure.

A simulation matrix with the MASH test designation no. 3-60 center impact results that highlights configurations that have a high potential to meet MASH criteria is shown in Table 42. Note that the only configuration that did not have 4-ft long mast arms or was in a window of opportunity was Simulation No. 43, i.e., the 40-ft tall pole with dual 20-ft long mast arm.

Table 40. Simulation Results - MASH Test Designation No. 3-60 - Occupant Compartment Deformation, Sorted by Total Weight

Sim. No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Config.	Total Weight (lb)	C.G Height (ft)	MASH 3-60 Center 0	MASH 3-60 Center 25
20	20	4	S	222	12.1	0.38	4.14
22	20	10	S	261	14.0	6.07	8.31
30	30	4	S	300	16.8	2.14	3.55
21	20	4	D	312	14.4	2.79 (RW)	4.01
35	35	4	S	347	19.0	3.64	3.67
34-1	30	10	S	349	17.9	6.79	8.28
23	20	10	D	381	16.2	5.54	1.59
31	30	4	D	390	19.7	2.57	3.50 (RW)
39-1	35	10	S	393	20.1	4.54	4.36
40	40	4	S	411	21.1	1.88	1.69
32	30	20	S	433	20.3	7.77	8.40
36	35	4	D	437	22.2	3.59	1.88
44-1	40	10	S	466	22.2	0.19	3.30
45	45	4	S	466	23.2	0.35 (C)	3.00
34-2	30	10	D	468	20.9	1.98	0.50 (FW)
37	35	20	S	485	22.5	3.12	4.24
41	40	4	D	502	24.4	4.08	0.68 (FW)
39-2	35	10	D	513	23.5	3.64	2.51
49-1	45	10	S	528	24.5	0.56 (FW)	1.50
42	40	20	S	556	24.7	0.22 (C)	4.73
46	45	4	D	557	26.6	4.02	0.93
44-2	40	10	D	586	25.8	1.76	0.84
33	30	20	D	604	23.8	3.35	0.97
50	50	8	S	642	27.5	5.31	5.74
49-2	45	10	D	648	28.2	6.39	0.60 (C)
38	35	20	D	656	26.4	5.45	0.39
52	50	15	S	672	27.1	5.77	4.04
47	45	20	S	676	26.4	0.45	1.10
43	40	20	D	727	29.1	3.55	3.67
51	50	8	D	750	28.9	6.20	N/A
48	45	20	D	847	30.6	6.11	3.41
53	50	15	D	986	29.5	6.87	3.60

“N/A” indicates no occupant compartment deformation was observed.
“(A)”, “(B)”, and “(C)” indicate deformation was observed at A-pillar, B-pillar, and C-pillar, respectively.
“(FW)”and “(RW)” indicate deformation was observed at front windshield and rear window, respectively.
“-“ denotes simulations that were not run as a part of the investigation.
Occupant comp. deformation beyond 4.0 in. MASH limit

Table 41. Simulation Results- MASH 3-60 - Occupant Compartment Deformation, Sorted by C.G. Height

Sim. No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Config.	Total Weight (lb)	C.G. Height (ft)	MASH 3-60	
						Center	
						0	25
20	20	4	S	222	12.1	0.38	4.14
22	20	10	S	261	14.0	6.07	8.31
21	20	4	D	381	14.3	2.79 (RW)	4.01
23	20	10	D	520	16.2	5.54	1.59
30	30	4	S	260	16.7	2.14	3.55
34-1	30	10	S	349	17.8	6.79	8.28
35	35	4	S	307	18.9	3.64	3.67
31	30	4	D	449	19.6	2.57	3.50 (RW)
39-1	35	10	S	393	20.1	4.54	4.36
32	30	20	S	433	20.2	7.77	8.40
34-2	30	10	D	571	20.9	1.98	0.50 (FW)
40	40	4	S	371	21.0	1.88	1.69
36	35	4	D	426	22.1	3.59	1.88
44-1	40	10	S	397	22.2	0.19	3.30
37	35	20	S	485	22.5	3.12	4.24
45	45	4	S	496	23.1	0.35 (C)	3.00
39-2	35	10	D	495	23.4	3.64	2.51
33	30	20	D	604	23.7	3.35	0.97
41	40	4	D	362	24.3	4.08	0.68 (FW)
49-1	45	10	S	528	24.4	0.56 (FW)	1.50
42	40	20	S	442	24.7	0.22 (C)	4.73
44-2	40	10	D	568	25.8	1.76	0.84
47	45	20	S	625	26.3	0.45	1.10
38	35	20	D	535	26.4	5.45	0.39
46	45	4	D	656	26.6	4.02	0.93
52	50	15	S	672	27.0	5.77	4.04
50	50	8	S	642	27.5	5.31	5.74
49-2	45	10	D	516	28.2	6.39	0.60 (C)
51	50	8	D	648	28.8	6.20	N/A
43	40	20	D	555	29.1	3.55	3.67
53	50	15	D	949	29.4	6.87	3.60
48	45	20	D	847	30.6	6.11	3.41

"N/A" indicates no occupant compartment deformation was observed.
"(A)", "(B)", and "(C)" indicate deformation was observed at A-pillar, B-pillar, and C-pillar, respectively.
"(FW)"and "(RW)" indicate deformation was observed at front windshield and rear window, respectively.
"-" denotes simulations that were not run as a part of the investigation.
Occupant comp. deformation beyond 4.0 in. MASH limit
Note: MASH limit for deformation of windshield is 3.0 in.

Table 42. Simulation Results – MASH 3-60 – All Pole Configurations (Highlighted: Configurations with Potential to Pass MASH) – Occupant Compartment Deformation (in.)

Sim. No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Config.	Total Weight (lb)	C.G. Height (ft)	MASH 3-60					
						Left 1/4		Center		Right 1/4	
						0	25	0	25	0	25
20	20	4	S	222	12.1	1.10(C)	1.70(C)	0.38	4.14	N/A	N/A
21	20	4	D	312	14.4	-	-	2.79(RW)	4.01	-	-
22	20	10	S	261	14.0	-	-	6.07	8.31	-	-
23	20	10	D	381	16.2	N/A	0.19(A)	5.54	1.59	N/A	N/A
30	30	4	S	300	16.8	N/A	N/A	2.14	3.55	N/A	N/A
31	30	4	D	390	19.7	-	-	2.57	3.50(RW)	-	-
34-1	30	10	S	349	17.9	N/A	N/A	6.79	8.28	N/A	N/A
34-2	30	10	D	468	20.9	-	-	1.98	0.50(FW)	-	-
32	30	20	S	433	20.3	-	-	7.77	8.40	-	-
33	30	20	D	604	23.8	N/A	N/A	3.35	0.97	N/A	N/A
35	35	4	S	347	19.0	N/A	N/A	3.64	3.67	N/A	N/A
36	35	4	D	437	22.2	-	-	3.59	1.88	-	-
39-1	35	10	S	393	20.1	N/A	N/A	4.54	4.36	N/A	N/A
39-2	35	10	D	513	23.5	-	-	3.64	2.51	-	-
37	35	20	S	485	22.5	-	-	3.12	4.24	-	-
38	35	20	D	656	26.4	N/A	N/A	5.45	0.39	N/A	N/A
40	40	4	S	411	21.1	N/A	N/A	1.88	1.69	N/A	N/A
41	40	4	D	502	24.4	-	-	4.08	0.68(FW)	-	-
44-1	40	10	S	466	22.2	N/A	N/A	0.19	3.30	N/A	N/A
44-2	40	10	D	586	25.8	-	-	1.76	0.84	-	-
42	40	20	S	556	24.7	-	-	0.22(C)	4.73	-	-
43	40	20	D	727	29.1	N/A	N/A	3.55	3.67	N/A	N/A
45	45	4	S	466	23.2	N/A	N/A	0.35(C)	3.00	N/A	N/A
46	45	4	D	557	26.6	-	-	4.02	0.93	-	-
49-1	45	10	S	528	24.5	N/A	N/A	0.56(FW)	1.50	N/A	N/A
49-2	45	10	D	648	28.2	-	-	6.39	0.60(C)	-	-
47	45	20	S	676	26.4	-	-	0.45	1.10	-	-
48	45	20	D	847	30.6	N/A	N/A	6.11	3.41	N/A	N/A
50	50	8	S	642	27.5	N/A	N/A	5.31	5.74	0.45(B)	N/A
51	50	8	D	750	28.9	-	-	6.20	N/A	-	-
52	50	15	S	672	27.1	-	-	5.77	4.04	-	-
53	50	15	D	986	29.5	N/A	N/A	6.87	3.60	N/A	N/A

"N/A" indicates no occupant compartment deformation was observed.
"(A)", "(B)", and "(C)" indicate deformation was observed at A-pillar, B-pillar, and C-pillar, respectively.
"(FW)"and "(RW)" indicate deformation was observed at front windshield and rear window, respectively.
"-" denotes simulations that were not run as a part of the investigation.
[red] Occupant comp. deformation beyond 4.0 in. MASH limit
[orange] Occupant comp. def. between 2.0 in. and 4.0 in. Note: MASH limit for deformation of windshield is 3.0 in.

4.2.8 Trends

4.2.8.1 Test Designations

MASH Test Designation No. 3-60

After completing the simulations, it was determined that MASH test designation no. 3-60 was the most critical test designation. This outcome aligns with expectations based on the review of previous full-scale crash tests in Section 2.3. In all pole configurations under MASH test designation no. 3-60 with center impact points, the pole impacted the vehicle, resulting in occupant compartment deformation. In general, left-quarter point and right-quarter point impacts were less critical.

For all MASH test designation no. 3-60 simulations, the simulated OIV values were well below the MASH limit of 16 ft/s. The largest simulated OIV was 7.23 ft/s with an ORA of 1.92 g's for the 50-ft tall pole with dual 15-ft long mast arms under MASH test designation no. 3-60 with a center impact at 0 degrees. Additionally, there was little concern about violations of ORA and vehicle stability criteria under MASH test designation no. 3-60 based on the simulation results.

MASH Test Designation No. 3-61

The simulations indicated that MASH test designation no. 3-61 was not critical. For all impacts under this designation, there were no instances of occupant compartment deformation, as the pole did not contact the vehicle after the initial impact.

For all MASH test designation no. 3-61 simulations, the simulated OIV values were below the MASH limit of 16 ft/s. However, for the 50-ft tall pole with dual 15-ft long mast arms configuration during center impacts, there was a concern of potentially exceeding the 16 ft/s limit. The simulated OIV values for this configuration were 12.45 ft/s at 0 degrees and 13.76 ft/s at 25 degrees, the largest OIVs recorded in the simulations. This concern arises because the baseline simulation under-predicted OIV by approximately 35% for high-speed tests, as discussed in Section 4.2.6. There was little concern that MASH test designation no. 3-61 impacts would violate ORA or vehicle stability criteria based on the simulation results.

MASH Test Designation No. 3-62

MASH test designation no. 3-62 was determined to be the least critical test designation. Simulations under this designation showed no instances of occupant compartment deformation, as the pole did not contact the vehicle after the initial impact.

For all MASH test designation no. 3-62 simulations, the simulated OIV values were well below the MASH limit of 16 ft/s. The highest simulated OIV was 7.39 ft/s for the 50-ft tall pole with dual 15-ft long mast arms during a left quarter-point impact at 25 degrees. There was little concern about violating ORA or vehicle stability criteria under MASH test designation no. 3-62 based on the simulation results.

4.2.8.2 Impact Conditions

Vehicle Impact Point

Based on the simulations, the center impact was the most critical vehicle impact point due to the high likelihood of the pole falling onto the vehicle and causing occupant compartment deformation in MASH test designation no. 3-60. In contrast, the left quarter point and right quarter point impacts were generally not critical for occupant compartment deformation. This was because the vehicle's impact caused the pole to move laterally away from the vehicle, preventing it from landing on the vehicle. Note that all impact locations showed similar simulated ORA and vehicle stability values, which were well below the MASH limits in all cases.

Vehicle Impact Angle

Based on the simulations, there was no clear trend between 0-degree and 25-degree impact angles, although the 0-degree impact angle was marginally more critical than the 25-degree impact. For MASH test designation no. 3-60 with a center impact at 0 degrees, all thirty-two pole configurations resulted in occupant compartment deformation, with fourteen configurations exceeding the MASH limit. For a center impact at 25 degrees, thirty-one of the thirty-two pole configurations resulted in occupant compartment deformation, with eleven configurations exceeding the MASH limit.

At MASH test designation nos. 3-61 and 3-62 with a center impact, the 0-degree impacts resulted in slightly lower OIV values compared to 25-degree impacts. However, under MASH test designation no. 3-60, both impact angles produced similar OIV values. Across all impact angles, the simulated ORA and vehicle stability values were comparable and well below the MASH limits.

4.2.8.3 Pole Height

Short Poles

For 20-ft configurations under MASH test designation no. 3-60 with a center impact, single long arms (i.e., 10-ft long mast arms) were the most critical. These configurations resulted in the largest roof crush values. The significant roof crush was likely due to the pole impacting the vehicle's roof near the pole configuration's C.G., resulting in a more direct vertical downward force on the roof.

Additionally, the pole's rotation about its vertical axis during the fall may have contributed to the increased roof deformation for these configurations. As the pole fell, the single mast arm rotated approximately 60 degrees counterclockwise (viewed from above) and maintained a near-vertical orientation (i.e., the mast arm was mostly perpendicular to the ground surface from a side view). This positioning caused the force of the arm and surrogate luminaire to contribute directly to the roof deformation.

Medium Poles

Medium pole configurations (i.e., 30-ft to 40-ft tall poles) generally experienced the fewest failures and the least occupant compartment deformation. The largest simulated roof crush for poles between 35 ft and 40 ft was 5.45 in., while the other four failures had occupant compartment deformation ranging from 4.08 in. to 4.73 in., indicating that most failures for medium pole configurations were marginal.

For 30-ft tall pole configurations, long single arms (i.e., 10-ft and 20-ft mast arms) proved to be the most critical. The 20-ft single arm configurations showed the largest roof crush values, measuring 7.77 in. and 8.40 in. at 0 degrees and 25 degrees, respectively. These large roof crush values were likely to be due to the pole impacting the vehicle roof at the pole configuration's C.G., resulting in a more direct vertical downward force on the roof.

Additionally, the rotation of the pole about its vertical axis during the fall likely contributed to the increased roof deformation for these configurations. The single mast arm rotated approximately 60 degrees counterclockwise (as viewed from above) and remained relatively vertical (i.e., mostly perpendicular to the ground surface in a side view) as the pole fell onto the vehicle. This orientation caused the force of the arm and surrogate luminaire to contribute directly to the roof crush.

Tall Poles

For tall pole configurations (i.e., 45-ft to 50-ft tall poles) under MASH test designation no. 3-60 with a center impact, all dual-arm configurations at a 0-degree impact angle resulted in over 4.0 in. of roof crush. The consistent failures of these tall poles with dual arms at a 0-degree impact angle were likely due to the high weight of these configurations.

Because dual-arm configurations have symmetric loading about the vertical axis, the poles tended to fall straight along the center of the vehicle without significant rotation. This lack of rotation meant that the full weight of the pole impacted directly onto the vehicle, resulting in roof crush, windshield deformation, or both. Given the weight of these tall pole configurations, ranging from 560 lb to 1,000 lb, the resulting deformations were generally large. The largest roof crush observed occurred under MASH test designation no. 3-60 at 0 degrees for tall poles with dual mast arms. This highlights the critical nature of these configurations in terms of occupant compartment deformation under center impact conditions.

4.2.8.4 Mast Arm Configuration

Single Mast Arm

A total of nine out of the sixteen single mast arm configurations demonstrated a low potential to meet MASH criteria. After impact, single mast arm configurations typically fell while rotating counterclockwise about their vertical axes, as viewed from above. The extent of this rotation was influenced by the length of the mast arm, with longer arms contributing more to the moment of inertia about the vertical axis compared to shorter arms.

Single 4-ft mast arm configurations rotated 180 degrees during the fall, while single 20-ft mast arm configurations rotated approximately 60 degrees. This behavior in single mast arm rotation is consistent with observations from previous crash testing, such as the Arizona 3-bolt crash test series explored in Section 2.3.3. Pole configurations that were 20 ft or 30 ft tall with single 10-ft or 20-ft long mast arms were some of the most critical since all had large roof crush deformation and low potential to meet MASH criteria.

Dual Mast Arms

A total of ten out of the sixteen dual mast arm pole configurations demonstrated a low potential to meet MASH criteria. After impact, dual mast arm configurations typically fell without significant rotation about their vertical axes due to their symmetrical design. The 45-ft and 50-ft tall pole configurations with dual mast arms were among the most critical. These configurations consistently showed large roof crush deformations and had a low potential to meet MASH criteria.

5 RECOMMENDATIONS FOR FUTURE FULL-SCALE CRASH TESTING

The developed slip base model was validated using data from past crash tests; however, inconsistent patterns were observed for poles with different configurations under various MASH impact conditions. Therefore, conducting multiple full-scale crash tests under MASH impact conditions is needed to confirm the findings and evaluate the accuracy of the simulations. The results from these full-scale crash tests can be used to validate and/or refine the LS-DYNA simulations, improving their accuracy.

5.1 Preliminary Crash Test Recommendations

Based on the simulation results shown in Tables 30 and 32, the priority for crash testing luminaire poles with 4-bolt slip bases was assigned to systems that indicated the most concerning behavior in terms of occupant compartment deformation and maximum OIV. The systems that are recommended for further evaluation with crash testing are summarized as follows and shown in Table 43. In total, four full-scale crash tests are recommended:

1. Crash Test No. 1: a 50-ft tall pole with dual 15-ft long mast arms and weight of 986 lb to be tested under MASH test designation no. 3-61 with a center impact point and a 25-degree impact angle.

2. Crash Test No. 2: a 50-ft tall pole with dual 15-ft long mast arms and weight of 986 lb to be tested under MASH test designation no. 3-60 with a center impact point and a 0-degree impact angle.

3. Crash Test No. 3: a 30-ft tall pole with a single 20-ft long mast arm and weight of 433 lb to be tested under MASH designation test no. 3-60 with a center impact point and a 25-degree impact angle.

4. Crash Test No. 4: a 20-ft tall pole with a single 10-ft long mast arm and weight of 261 lb to be tested under MASH test designation no. 3-60 with a center impact point and a 25-degree impact angle.

Table 43. Full-Scale Crash Test Recommendations – Steel Luminaire Poles with 4-Bolt Slip Base

Sim. No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Config.	Total Weight (lb)	MASH 3-60						MASH 3-61						MASH 3-62					
					Left 1/4		Center		Right 1/4		Left 1/4		Center		Right 1/4		Left 1/4		Center		Right 1/4	
					0	25	0	25	0	25	0	25	0	25	0	25	0	25	0	25	0	25
20	20	4	S	222							-	-		-	-	-	-	-		-	-	-
21	20	4	D	312	-	-			-	-	-	-		-	-	-	-	-		-	-	-
22	20	10	S	261	-	-		4*	-	-	-	-		-	-	-	-	-		-	-	-
23	20	10	D	381																		
30	30	4	S	300							-	-		-	-	-	-	-		-	-	-
31	30	4	D	390	-	-			-	-	-	-		-	-	-	-	-		-	-	-
34-1	30	10	S	349							-	-	-	-	-	-	-	-	-	-	-	-
34-2	30	10	D	468	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	30	20	S	433	-	-		3*	-	-	-	-		-	-	-	-	-		-	-	-
33	30	20	D	604																		
35	35	4	S	347							-	-		-	-	-	-	-		-	-	-
36	35	4	D	437	-	-			-	-	-	-		-	-	-	-	-		-	-	-
39-1	35	10	S	393							-	-	-	-	-	-	-	-	-	-	-	-
39-2	35	10	D	513	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-
37	35	20	S	485	-	-			-	-	-	-		-	-	-	-	-		-	-	-
38	35	20	D	656																		
40	40	4	S	411							-	-		-	-	-	-	-		-	-	-
41	40	4	D	502	-	-			-	-	-	-		-	-	-	-	-		-	-	-
44-1	40	10	S	466							-	-	-	-	-	-	-	-	-	-	-	-
44-2	40	10	D	586	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-
42	40	20	S	556	-	-			-	-	-	-		-	-	-	-	-		-	-	-
43	40	20	D	727																		
45	45	4	S	466		-					-	-		-	-	-	-	-		-	-	-
46	45	4	D	557	-	-			-	-	-	-		-	-	-	-	-		-	-	-
49-1	45	10	S	528							-	-	-	-	-	-	-	-	-	-	-	-
49-2	45	10	D	648	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	45	20	S	676	-	-			-	-	-	-		-	-	-	-	-		-	-	-
48	45	20	D	847																		
50	50	8	S	642							-	-		-	-	-	-	-		-	-	-
51	50	8	D	750	-	-			-	-	-	-		-	-	-	-	-		-	-	-
52	50	15	S	672	-	-			-	-	-	-		-	-	-	-	-		-	-	-
53	50	15	D	986			2*							1*								

*indicates the test was recommended based on critical behavior, i.e. occupant compartment deformation or OIV

- indicates simulation was not conducted.

Recommended for full-scale crash testing

<u>Crash Test No. 1: 50-ft Tall Pole with Dual 15-ft Mast Arms under MASH Test Designation No. 3-61</u>

As shown in Table 32, none of the simulations had an OIV above the MASH limit of 16 ft/s, though the 50-ft tall pole with dual 15-ft mast arms had the highest simulated OIV in the entire matrix at 13.76 ft/s when impacted under MASH test designation no. 3-61 with a center impact point at a 25-degree impact angle. As discussed in Section 3.3.2, the baseline simulation model underpredicted the OIV by 35% at high speeds, suggesting potential for the OIV in a full-scale crash test to exceed the 16 ft/s MASH limit. Note that the behavior of certain luminaire pole slip base systems can vary widely, as discussed in Eligibility Letter LS-16 and Section 2.4, where pendulum tests documented that changes in velocity could fluctuate by over 100% for the same tested systems.

At least one high-speed crash test is required to determine whether the model can accurately predict OIV for modern luminaire pole slip base systems. Additionally, since the 50-ft tall pole with dual 15-ft mast arms had the highest OIV of all simulations, the entire matrix of pole configurations could meet MASH safety criteria for OIV if this configuration passes the MASH OIV requirement in a full-scale crash test. Note that further analysis of the breakaway forces of the slip base would be necessary to determine whether the 0- or 25-degree orientation is critical for OIV during high-speed impacts.

A similar pole configuration has been tested in the past as part of the USBLM test series, discussed in Section 2.3.2, though there are some key differences, which include: (1) the recommended pole thickness is 7 gauge, compared to 11 gauge in test no. USBLM-2; (2) the test vehicle weight is 2,400 lb, compared to 1,750 lb in test no. USBLM-2; (3) the recommended pole slip base is oriented at 25 degrees, compared to 0 degrees in the USBLM-2 crash test; and (4) the recommended impact velocity is 62 mph, compared to 57.5 mph in test no. USBLM-2. These differences are substantial enough to warrant this crash test. The simulated occupant compartment deformation, which displayed no damage due to the lack of contact between the pole and vehicle after initial impact, is shown in Figure 95.

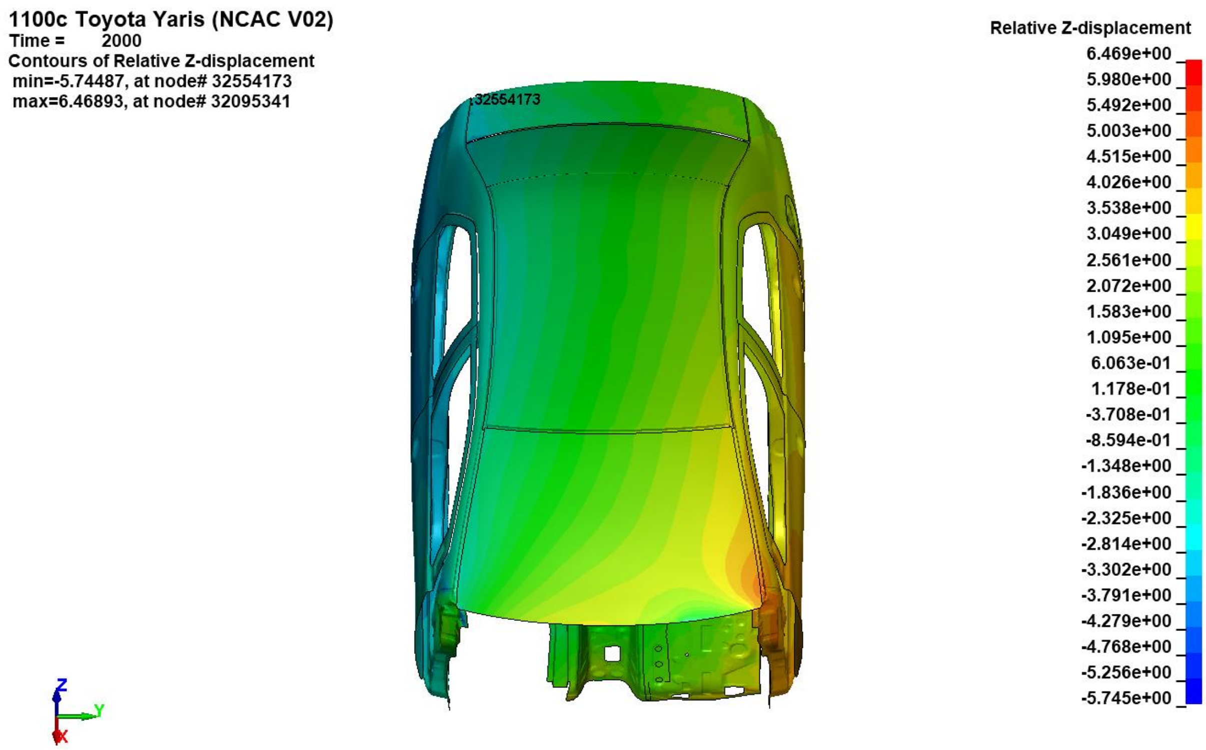


Figure 95. Occupant Compartment Deformation – 50-ft Tall Pole with Dual 15-ft Long Mast Arm under MASH Test Designation No. 3-61, Center Impact Point and 25-degree Impact Angle

Crash Test No. 2: 50-ft Tall Pole with Dual 15-ft Mast Arms under MASH Test Designation No. 3-60

The 50-ft tall pole with dual 15-ft mast arms under MASH test designation no. 3-60 with a center impact point and a 0-degree impact angle had the largest simulated roof crush, measuring 6.87 in. At least one low-speed crash test on a tall, heavy pole configuration is recommended to evaluate vehicle roof crush for such poles.

This crash test may complement the first recommended crash test as both involve the same pole configuration but are conducted at different speeds and angles. Conducting these tests together would provide valuable insights into the vehicle and tall, heavy pole dynamics for identical systems subjected to varying impact conditions.

The simulated roof crush is shown in Figure 96. An image of the critical state (i.e., pole falling onto the vehicle, maximum roof crush) is shown in Figure 97.

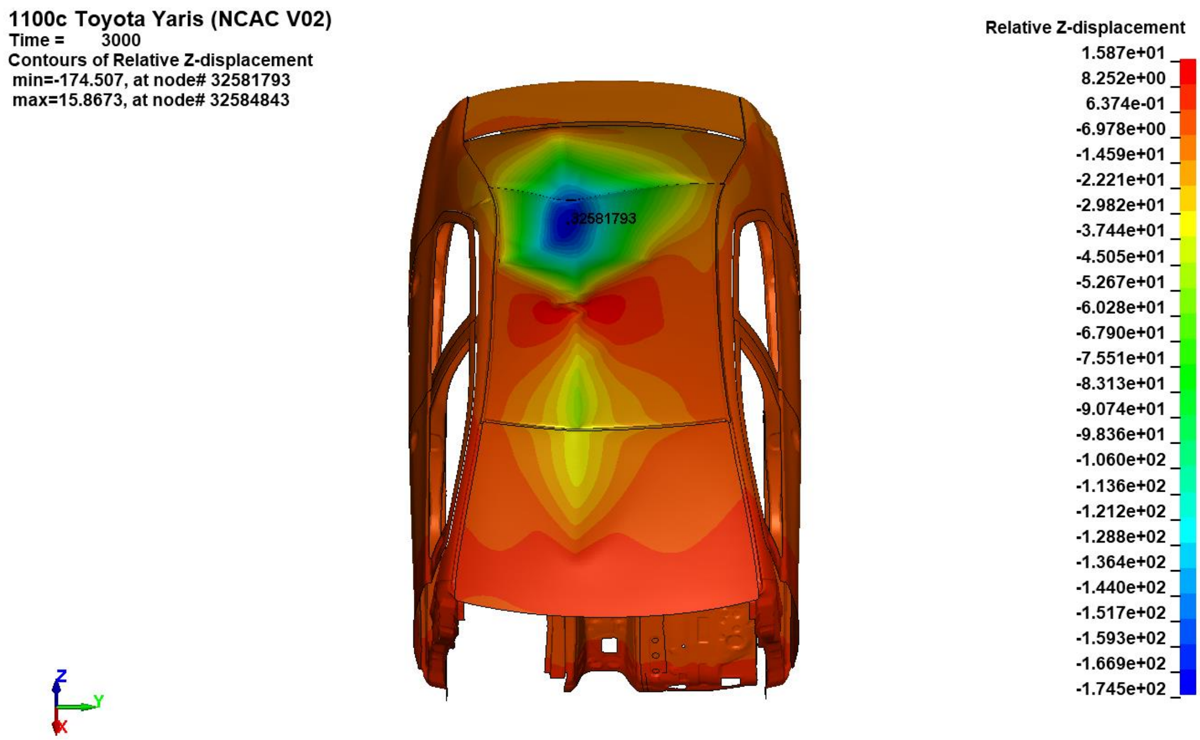
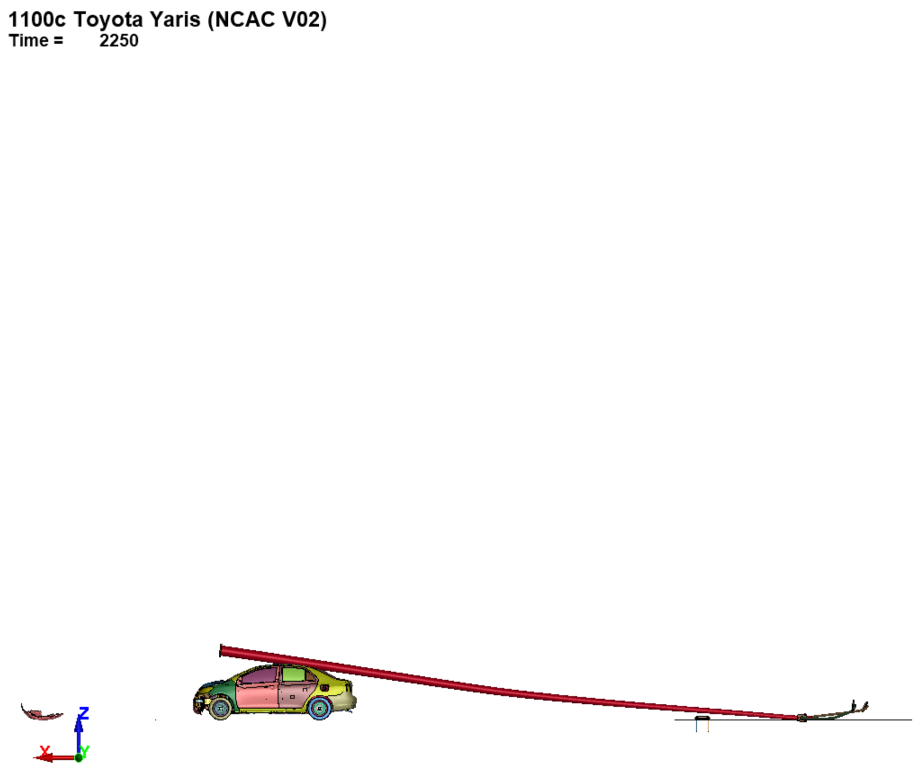


Figure 96. Occupant Compartment Deformation - 50-ft Tall Pole with Dual 15-ft Long Mast Arms Configuration under MASH Test Designation No. 3-60, Center Impact Point and 0-degree Impact Angle



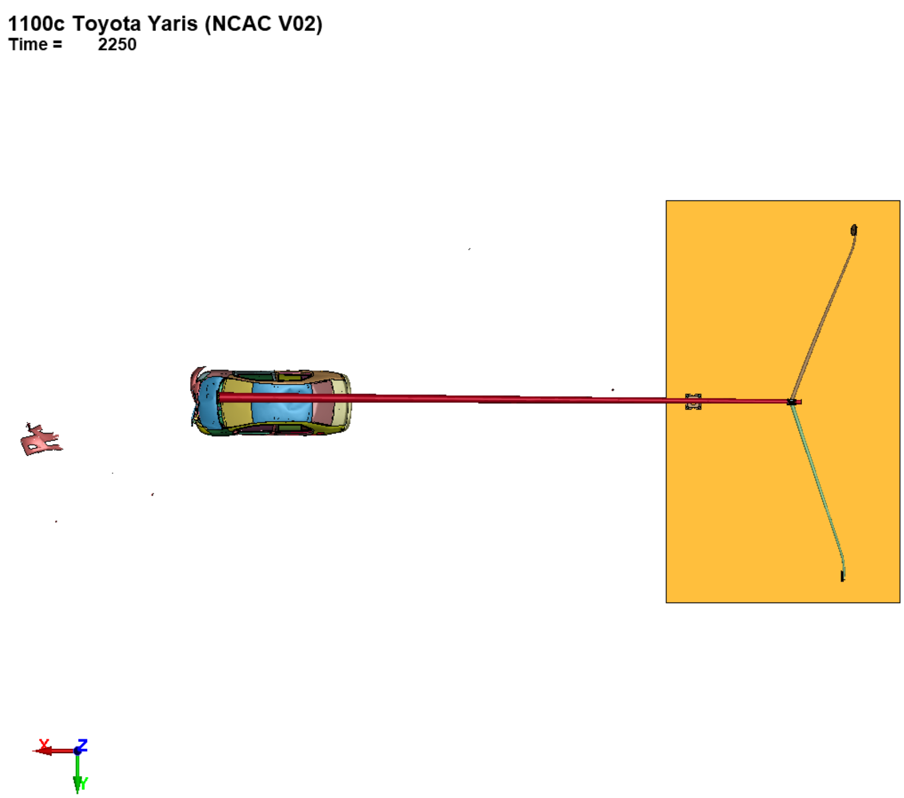


Figure 97. Critical State - 50-ft Tall Pole with Dual 15-ft Long Mast Arms Configuration under MASH Test Designation No. 3-60, Center Impact Point and 0-degree Impact Angle

<u>Crash Test No. 3: 30-ft Tall Pole with Single 20-ft Long Mast Arm under MASH Test Designation No. 3-60</u>

The 30-ft tall pole with a single 20-ft mast arm under MASH test designation no. 3-60 with a center impact at 25 degrees had the highest simulated roof crush of all pole configurations, measuring 8.40 in. This configuration is recommended for testing as the simulation highlighted the critical behavior of how pole rotation can contribute to roof crush. Additionally, the pole contact occurred at the vehicle roof directly under the pole configuration's C.G., resulting in a more vertical downward force compared to other configurations.

Note that a similar pole configuration has not been tested previously. The closest available comparison is the 45-ft tall (later redesigned as 40-ft tall) single 15-ft mast arm configuration tested in the 472360 series, which investigated an Arizona 3-bolt luminaire pole slip base system., as discussed in Section 2.3.3. The simulated roof crush is shown in Figure 98. An image of the critical state (i.e., pole falling onto the vehicle, maximum roof crush) is shown in Figure 99.

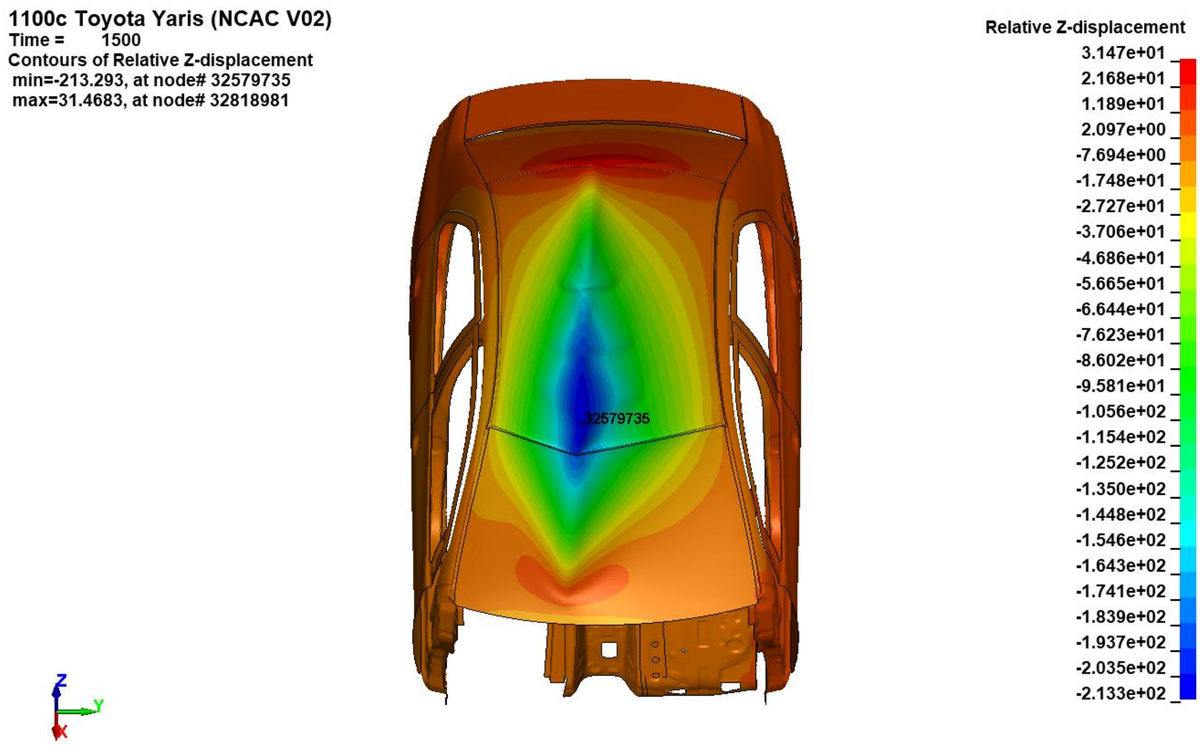
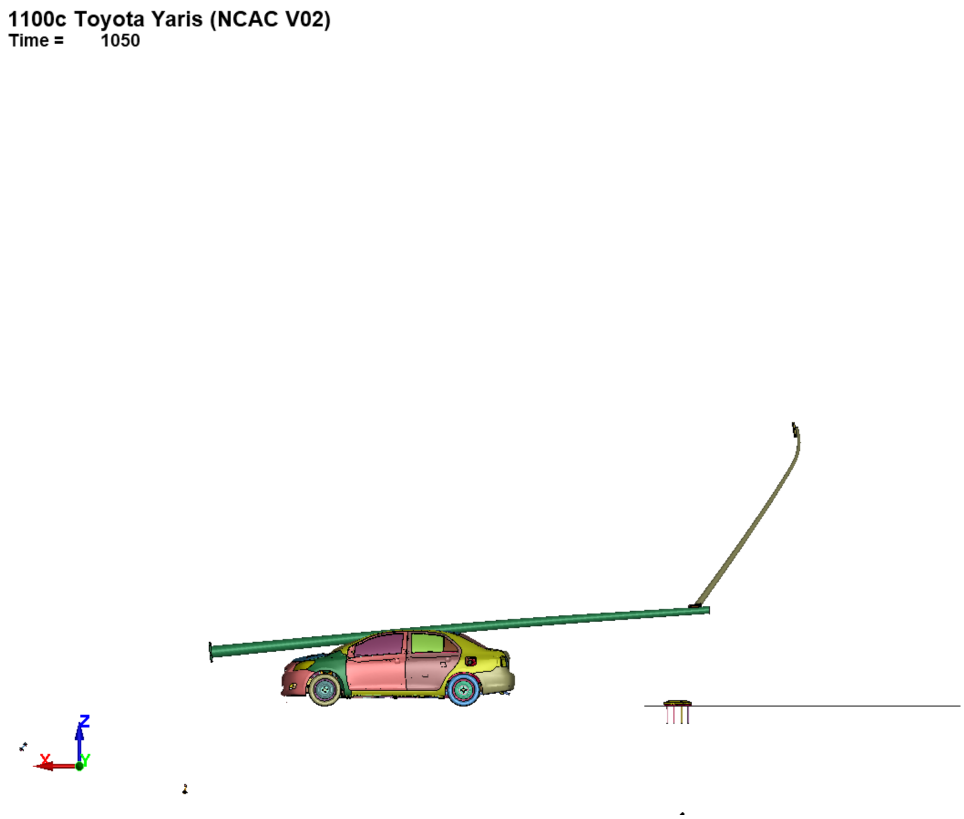


Figure 98. Occupant Compartment Deformation - 30-ft Tall Pole with Single 20-ft Long Mast Arm Configuration under MASH Test Designation No. 3-60, Center Impact Point and 25-degree Impact Angle



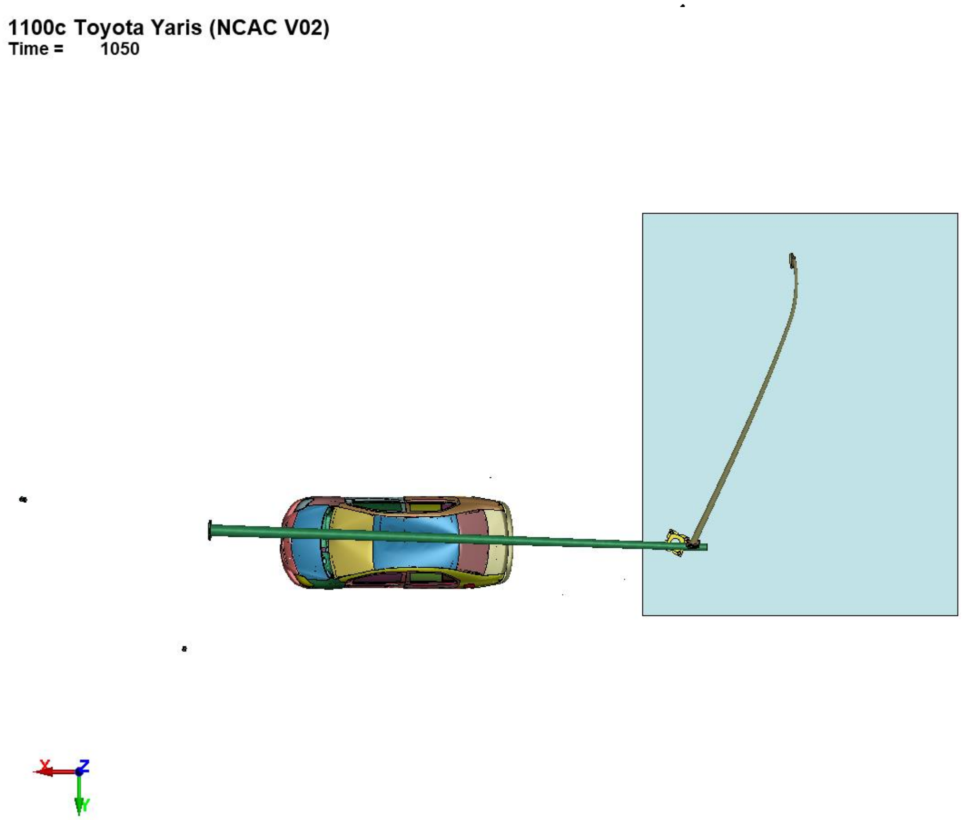


Figure 99. Critical State - 30-ft Tall Pole with Single 20-ft Long Mast Arm Configuration under MASH Test Designation No. 3-60, Center Impact Point and 25-degree Impact Angle

Crash Test No. 4: 20-ft Tall Pole with Single 10-ft Long Mast Arm under MASH Test Designation No. 3-60

The 20-ft tall pole with a single 10-ft mast arm under MASH test designation no. 3-60 with a center impact at 25 degrees had the highest simulated roof crush among the short pole configurations, measuring 8.31 in. Similar to the third recommended crash test, this configuration featured a single arm and the simulations for both configurations demonstrated similar behaviors, including rotation about the pole's vertical axis and impact on the vehicle roof near the configuration's C.G. Note that a similar pole configuration has not been tested previously.

The simulated roof crush is shown in Figure 100. An image of the critical state (i.e., pole falling onto the vehicle, maximum roof crush) is shown in Figure 101.

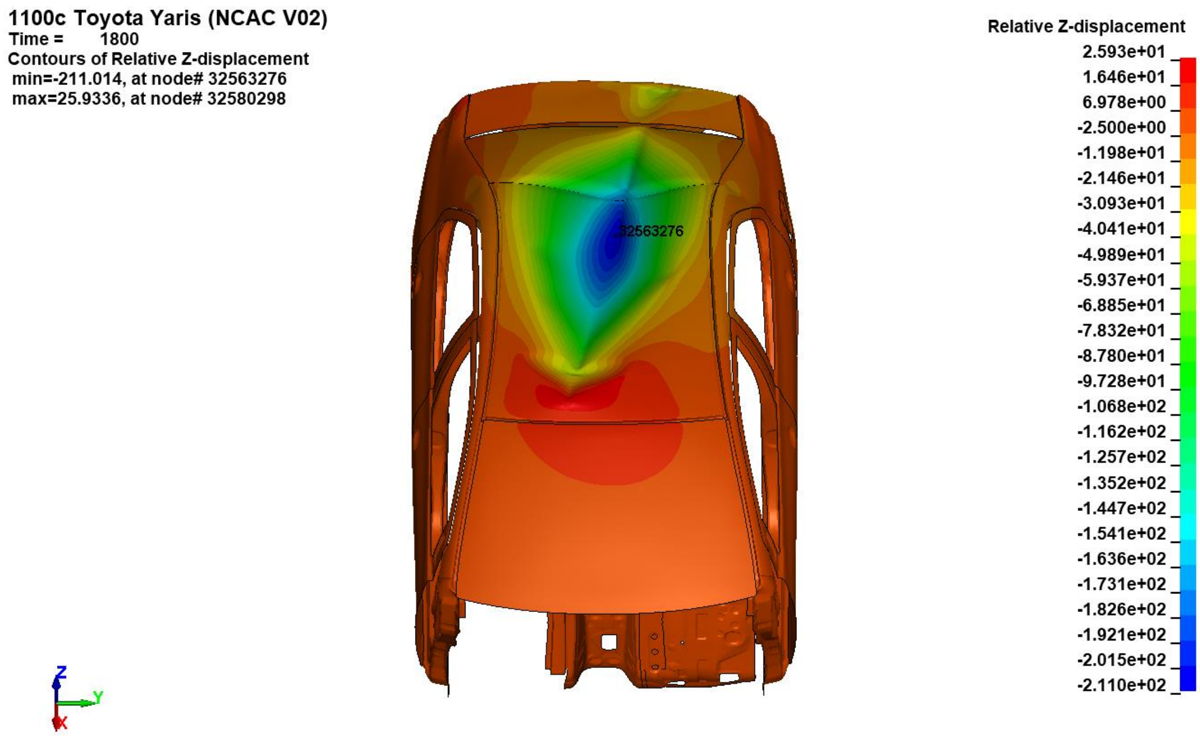
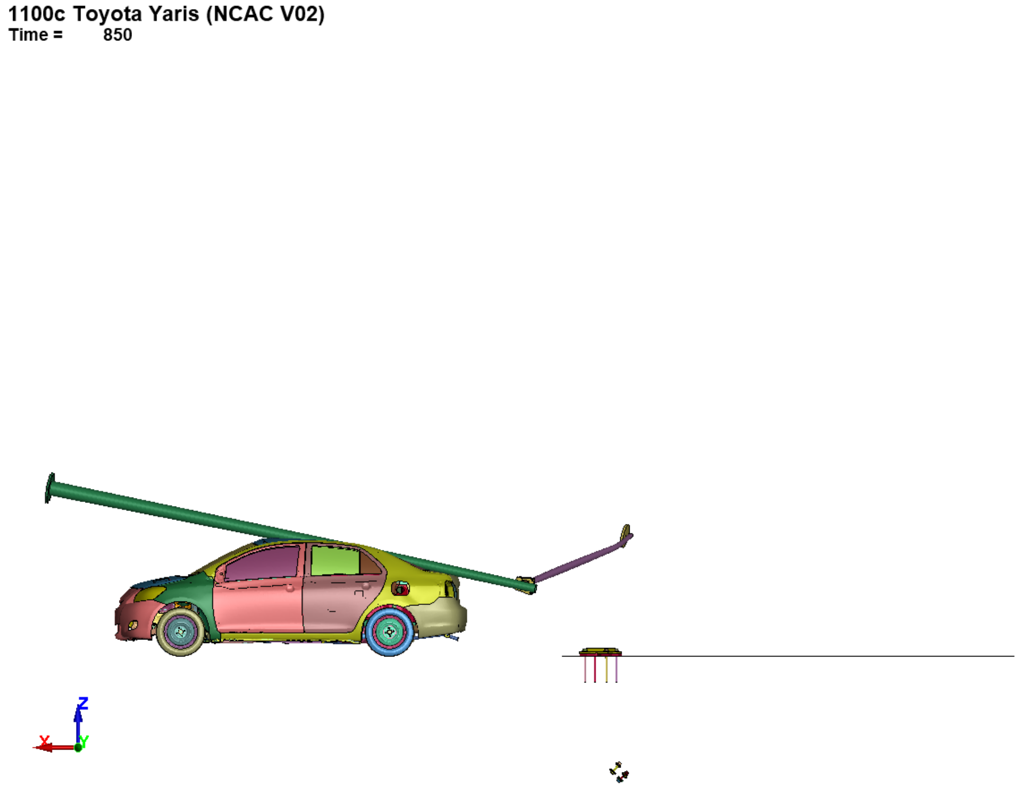


Figure 100. Occupant Compartment Deformation - 20-ft Tall Pole with Single 10-ft Long Mast Arm under MASH Test Designation No. 3-60, Center Impact Point and 25-degree Impact Angle



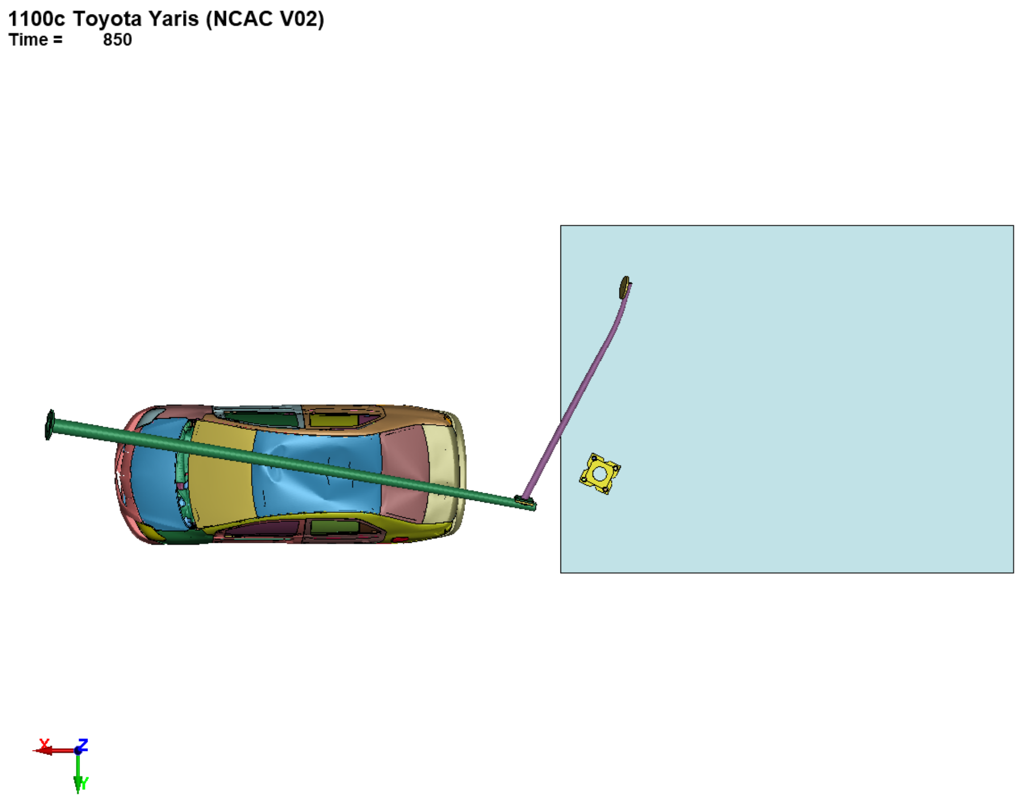


Figure 101. Critical State - 20-ft Tall Pole with Single 10-ft Long Mast Arm under MASH Test Designation No. 3-60, Center Impact Point and 25-degree Impact Angle

To more accurately determine the clamp force in the slip base during these crash tests, the torquing of the bolts should be investigated. Since methods for determining bolt torque are often questionable in accuracy, MwRSF researchers propose directly measuring the bolt tension in the slip bolts. This approach would provide a more accurate determination of the clamping force in the slip base.

5.2 Additional Pole Crash Test Recommendations

Following internal discussions of previous luminaire pole crash tests and the simulation matrix results, MwRSF researchers recommend conducting additional testing, as detailed in the following section.

As the objective of this research project emphasizes identifying critical configurations for full-scale crash testing, MwRSF researchers have proposed alternatives to the previously recommended crash tests. These alternatives include configurations that may have potential to meet MASH criteria. These configurations fall within one of the "windows of opportunity," as discussed in Section 4.2.7. Conducting one or more crash tests on these configurations could provide valuable insights into the model's behavior. The additional recommendations, along with the previously discussed recommended crash tests, are detailed in Table 44.

Table 44. Additional Full-Scale Crash Test Recommendations – Steel Luminaire Poles with 4-Bolt Slip Base

Sim. No.	Pole Height (ft)	Mast Arm Length (ft)	Mast Config.	Total Weight (lb)	MASH 3-60						MASH 3-61						MASH 3-62					
					Left 1/4		Center		Right 1/4		Left 1/4		Center		Right 1/4		Left 1/4		Center		Right 1/4	
					0	25	0	25	0	25	0	25	0	25	0	25	0	25	0	25	0	25
20	20	4	S	222			†	†			-	-		-	-	-	-	-		-	-	-
21	20	4	D	312	-	-	†	†	-	-	-	-		-	-	-	-	-		-	-	-
22	20	10	S	261	-	-		4*	-	-	-	-		-	-	-	-	-		-	-	-
23	20	10	D	381																		
30	30	4	S	300			†	†			-	-		-	-	-	-	-		-	-	-
31	30	4	D	390	-	-	†	†	-	-	-	-		-	-	-	-	-		-	-	-
34-1	30	10	S	349							-	-	-	-	-	-	-	-	-	-	-	-
34-2	30	10	D	468	-	-	†	†	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	30	20	S	433	-	-		3*	-	-	-	-		-	-	-	-	-		-	-	-
33	30	20	D	604			†	†														
35	35	4	S	347			†	†			-	-		-	-	-	-	-		-	-	-
36	35	4	D	437	-	-	†	†	-	-	-	-		-	-	-	-	-		-	-	-
39-1	35	10	S	393							-	-	-	-	-	-	-	-	-	-	-	-
39-2	35	10	D	513	-	-	†	†	-	-	-	-	-	-	-	-	-	-	-	-	-	-
37	35	20	S	485	-	-	†	†	-	-	-	-		-	-	-	-	-		-	-	-
38	35	20	D	656																		
40	40	4	S	411			†	†			-	-		-	-	-	-	-		-	-	-
41	40	4	D	502	-	-	†	†	-	-	-	-		-	-	-	-	-		-	-	-
44-1	40	10	S	466			†	†			-	-	-	-	-	-	-	-	-	-	-	-
44-2	40	10	D	586	-	-	†	†	-	-	-	-	-	-	-	-	-	-	-	-	-	-
42	40	20	S	556	-	-	†	†	-	-	-	-		-	-	-	-	-		-	-	-
43	40	20	D	727			†	†														
45	45	4	S	466		-	†	†			-	-		-	-	-	-	-		-	-	-
46	45	4	D	557	-	-	†	†	-	-	-	-		-	-	-	-	-		-	-	-
49-1	45	10	S	528			†	†			-	-	-	-	-	-	-	-	-	-	-	-
49-2	45	10	D	648	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	45	20	S	676	-	-	†	†	-	-	-	-		-	-	-	-	-		-	-	-
48	45	20	D	847																		
50	50	8	S	642							-	-		-	-	-	-	-		-	-	-
51	50	8	D	750	-	-			-	-	-	-		-	-	-	-	-		-	-	-
52	50	15	S	672	-	-			-	-	-	-		-	-	-	-	-		-	-	-
53	50	15	D	986			2*							1*								

† indicates the test was selected based on potential to meet MASH criteria, i.e., configuration has 4-ft long mast arms or is in a "window of opportunity"
* indicates the test was selected based on critical behavior, i.e. occupant compartment deformation or OIV
- indicates simulation was not conducted.
Recommended for full-scale crash testing (red)
Additional recommendations with high potential to pass MASH (orange)

6 SUMMARY AND CONCLUSIONS

This project began with the distribution of a survey to member state DOTs of the Midwest Pooled Fund Program. The survey results showed that most responding state DOTs typically use a single slip base design. While some states use only one luminaire pole configuration with their slip base, others utilize a variety of pole configurations. According to the survey findings, the only parameter of the slip base that is adjusted to accommodate the different pole configurations is the slip (clamp) bolt torque.

A review of existing state DOT standard plans and drawings was conducted to understand standard practices for luminaire pole slip base systems. A total of 11 states have drawings or guidance related to luminaire pole slip bases. The slip base designs are either 3-bolt or 4-bolt systems. For 3-bolt slip base systems, the bolt torque ranges between 90 ft-lb and 200 ft-lb, while for 4-bolt systems, the bolt torque ranges from 70 ft-lb to 80 ft-lb. Generally, state DOTs do not modify the dimensions of their slip bases when using different poles. Exceptions to this are found in North Dakota's current plan set and West Virginia's 1994 plan set [17, 18]. Luminaire pole configurations mounted on slip bases are typically subject to the following limitations: (1) pole height cannot exceed 50 ft, (2) the number of mast arms is limited to one or two, (3) mast arm lengths cannot exceed 20 ft, and (4) the total weight of the pole system cannot exceed 1,000 lb.

Additionally, a review of previous full-scale crash tests was conducted. A total of 20 full-scale crash tests have been completed by various testing agencies according to the requirements outlined in NCHRP Report No. 230 [22], NCHRP Report No. 350 [23], or MASH [2]. A total of nine crash tests failed the full-scale crash test evaluation. Of these, two failures were due to structural inadequacy as defined in NCHRP Report No. 230, six were caused by excessive occupant compartment deformation or intrusion, and one failure resulted from the non-activation of the slip base. The failures due to excessive occupant compartment deformation or intrusion occurred during low-speed impact tests, typically around 19 mph (e.g., the Arizona 3-bolt luminaire pole system in crash test no. 472360-2). While some high-speed crash tests resulted in the OIV nearing or exceeding the evaluation criteria limits (e.g., the Arizona 3-bolt luminaire pole system in crash test no. 472360-1), none of the crash tests violated the MASH OIV limits.

A review of FHWA Eligibility Letter LS-16 showed that pendulum testing of identical 3-bolt slip base luminaire pole systems, similar to the Caltrans Type 30 system, resulted in widely varying OIV values, with discrepancies exceeding 100% in some cases [27]. Note that the clamp force was estimated in the test series, which may have contributed to the observed variations in performance. It cannot be confirmed whether similar variations in behavior occur with 4-bolt slip base systems without conducting a series of tests comparable to those outlined in FHWA Eligibility Letter LS-16. However, the behavior observed in the 3-bolt systems was considered during the modeling and validation process.

A baseline simulation was developed using the USBLM test series to validate a slip-base system model [5]. The system consisted of a 50-ft tall pole with dual 15-ft mast arms and a total weight of 901 lb mounted on a 4-bolt slip base. The crash test involved an 1,800-lb vehicle impacting at a speed of 15 mph for the low-speed impact and 57.5 mph for the high-speed impact. The low-speed impact simulation closely matched test no. USBLM-1, with similar OIV and pole dynamics observed. In test no. USBLM-2, the simulation was unable to capture the pole base plate catching on the front bumper of the vehicle, likely due to the vehicle model used, which affected the OIV and pole dynamics. However, the model did predict the change in velocity well before the pole plate "catching" event occurred. Overall, the simulation successfully captured the pole dynamics and anticipated vehicle damage in both crash tests.

The validated slip base model was then used to conduct a series of simulations for MASH test designations nos. 3-60, 3-61, and 3-62, under a variety of impact conditions and for a range of luminaire pole configurations. These simulations included: (1) pole heights ranging from 20 to 50 ft, (2) mast arm configurations with either single or dual arms, (3) mast arm lengths ranging from 4 to 20 ft, and (4) total weights ranging from approximately 200 to 1,000 lb. The results of the simulations were post-processed and analyzed.

The results of the MASH test designation no. 3-62 simulations indicated that all pole configurations had a high potential to meet MASH criteria, as there were no instances of occupant compartment deformation or violations of the MASH OIV limit.

The results of the MASH test designation no. 3-61 simulations showed that all pole configurations had a high potential to meet MASH criteria, as there were no instances of occupant compartment deformation or violations of the OIV limit. However, the simulated OIV approached the 16 ft/s MASH limit for poles weighing near 1,000 lb (i.e., taller and heavier poles).

The results of the MASH test designation no. 3-60 simulations indicated that many pole configurations had a low potential to meet MASH criteria, as roof crush exceeded the 4.0-in. MASH limit. For each pole height (i.e., 20, 30, 35, 40, 45, and 50-ft tall poles), at least two pole configurations failed to meet the MASH test designation no. 3-60 criteria when impacted at the center impact point due to excessive roof crush. The simulation results led to the following conclusions:

1) MASH test designation no. 3-62 is likely the least critical test designation, as all pole configurations are expected to meet MASH criteria based on simulation results. OIV was well below the limit, and there were no instances of occupant compartment deformation.

2) MASH test designation no. 3-61 may present an OIV issue for heavier poles (i.e., poles weighing approximately 1,000 lb), though no simulations resulted in OIV exceeding the limit, and there were no instances of occupant compartment deformation.

3) MASH test designation no. 3-60 is the most critical, as occupant compartment deformation beyond the MASH limit occurred in center impact simulations for all pole heights and various pole configurations.

4) Pole configurations with total weights between 450 and 600 lb generally have a reasonable chance of passing MASH TL-3 testing, as all simulations that failed MASH evaluation criteria can be considered marginal failures. The largest recorded occupant compartment deformation for poles in this weight range was 4.73 in., and no simulations exceeded the OIV limit.

Based on the simulation results, four full-scale crash tests are recommended for critical pole configurations. These tests are expected to aid in further validation efforts, improving model accuracy, and evaluating the crashworthiness of slip base poles according to MASH TL-3 safety criteria.

- Crash Test No. 1: MASH test designation no. 3-61 with a center impact point and a 25-degree impact angle on a 50-ft tall pole with dual 15-ft long mast arms and a weight of 986 lb.

- Crash Test No. 2: MASH test designation no. 3-60 with a center impact point and a 0-degree impact angle on a 50-ft tall pole with dual 15-ft long mast arms and a weight of 986 lb.

- Crash Test No. 3: MASH test designation no. 3-60 with a center impact point and a 25-degree impact angle on a 30-ft tall pole with a single 20-ft long mast arm and a weight of 433 lb.

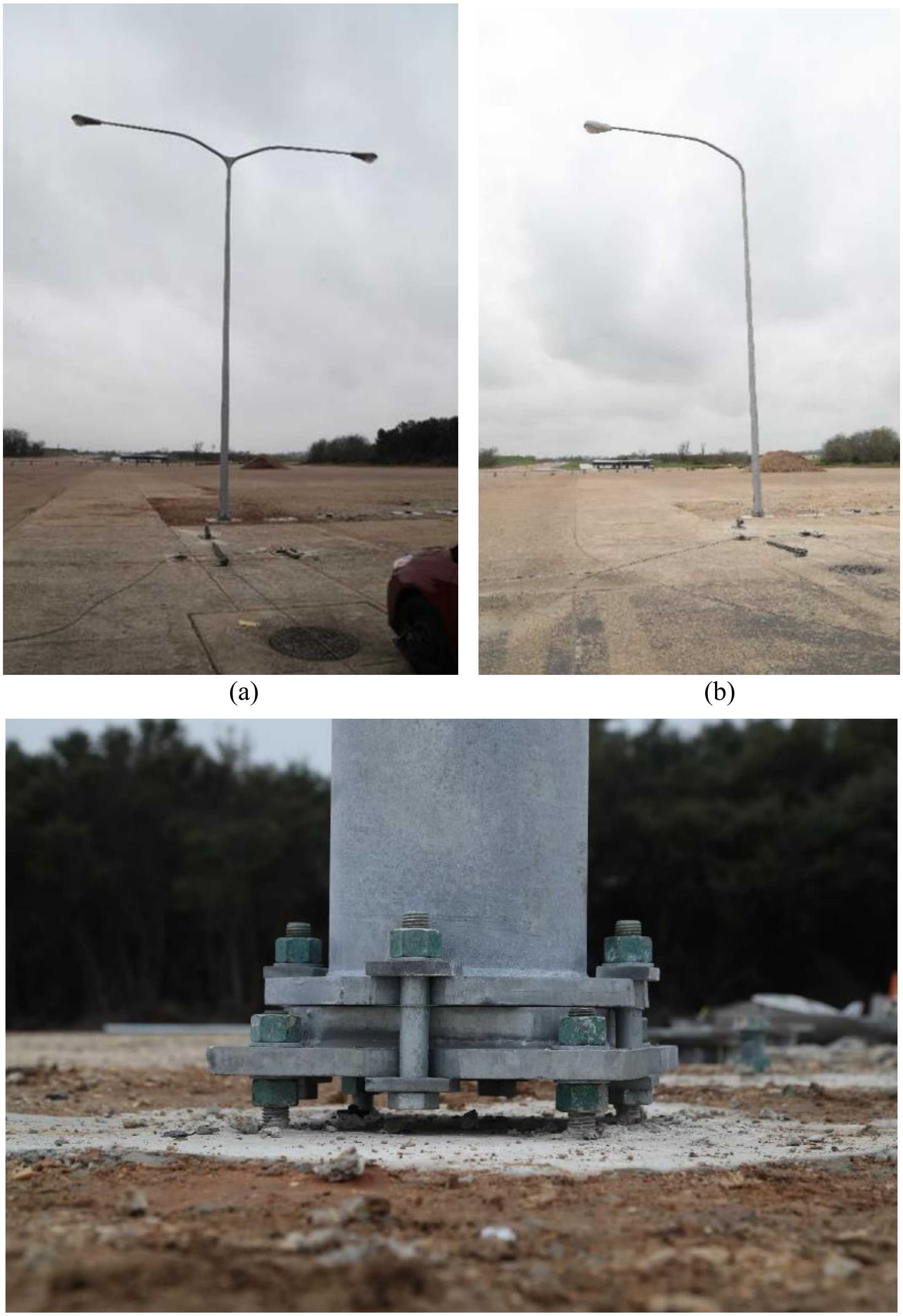
- Crash Test No. 4: MASH test designation no. 3-60 with a center impact point and a 25-degree impact angle on a 20-ft tall pole with a single 10-ft long mast arm and a weight of 261 lb.

December 2024 Update

At the conclusion of this phase, Phase I (December 2024), the details of recent TTI crash tests on a 4-bolt slip base, conducted as part of the Roadside Safety Pooled Fund program, became available [33]. This effort began with a literature review and a state survey to identify commonly used designs for luminaire pole slip bases. Based on the findings from the literature review and state survey, the TTI research team selected a configuration for full-scale crash testing. In this effort, three full-scale crash tests were conducted on steel luminaire poles mounted on 4-bolt slip bases under MASH test designation no. 3-60 (small car at a low speed).

TTI's testing began with the heaviest pole, mast, and luminaire combination available. The results of these tests led to subsequent tests with lighter designs. In test no. 618911-01-1, a 34-ft 9-in. pole with dual 15-ft long mast arms and a weight of 730 lb was tested under MASH test designation no. 3-60, as shown in Figure 102. This test failed MASH criteria due to excessive roof crush (6.3 in. > 4.0-in. limit) and rear window penetration, as shown in Figure 103. In test no. 618911-01-2, a 24-ft 10-in. pole with dual 15-ft mast arms and a weight of 650 lb was tested under MASH test designation no. 3-60. This test also failed MASH criteria due to rear window penetration. Both tests were conducted with a vehicle center impact point and 0-degree impact angle, which was identified as the most critical impact condition for symmetric systems. In the third test, test no. 618911-01-3, a 34-ft 9-in. pole with a single 15-ft mast arm and a weight of 560 lb was tested under MASH test designation no. 3-60 and successfully met MASH safety criteria. This third test was conducted with a vehicle quarter point impact to increase the likelihood of the asymmetric test article rolling across the vehicle's roof.

These results align with the simulation findings from Phase I of the current project, where poles weighing between 450 to 600 lb were found likely to meet MASH criteria. The results of TTI's tests confirmed the need for further research on the crashworthiness of luminaire poles and their support structures. These findings will be considered during Phase II crash testing for the current project.



(a) (b) (c)

Figure 102. (a) Luminaire Pole Prior to Testing, Test No. 618911-01-1, (b) Luminaire Pole Prior to Testing, Test No. 618911-01-3, and (c) 4-Bolt Slip Base Support for Luminaire Poles [33]

(a)

(b)

Figure 103. (a) Rear Impact Side of Test Vehicle after Test No. 618911-01-1, and (b) Rear of Test Vehicle after Test No. 618911-01-2 [33]

Phase II of this research project is recommended to focus on MASH TL-3 full-scale testing to evaluate critical pole configurations and potentially identify slip base pole designs that may meet MASH TL-3 criteria. These tests are also expected to support simulation model validation, improve model accuracy, and assess the crashworthiness of slip base poles. Phase I simulations suggested that pole configurations with total weights between 450 and 600 lb generally have a higher likelihood of passing MASH TL-3. Considering the recent TTI tests (which showed failures with poles heavier than 600 lb), the MwRSF-recommended Crash Test Nos. 1 and 2, which involve 50-ft tall poles weighing 986 lb (as listed above), with a low chance of passing MASH, may not be the best candidates for testing in the initial run. At the beginning of Phase II, the updated recommendations, including the associated risks of failure for each configuration, will be shared with the Midwest Pooled Fund Program member state DOTs. State DOTs may prioritize crash tests on the heaviest/tallest poles with a higher likelihood of passing MASH, such as a 40-ft tall pole with dual 10-ft mast arms weighing 590 lb, under MASH test designation nos. 3-60 and 3-61.

It is recommended that a minimum of two full-scale tests be conducted in Phase II: one MASH test designation no. 3-60 test (small car at a low speed) and one MASH test designation no. 3-61 test (small car at a high speed) on a pole configuration within the relatively likely to pass weight range (450 to 600 lb). To increase the likelihood of the pole falling on the center of the vehicle's roof (which has the least stiffness) and maximize roof crush risk, symmetric poles with dual mast arms are recommended, with a vehicle center impact point and a 0-degree impact angle. The MASH test designation no. 3-60 test will evaluate roof crush concerns, while the MASH test designation no. 3-61 test will address OIV concerns. Based on the results of the first crash test, recommendations for the second test pole configuration will be provided.

7 REFERENCES

1. *Roadside Design Guide (RDG), Fourth Edition,* American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2015.

2. *Manual for Assessing Safety Hardware (MASH), Second Edition*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2016.

3. *LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, American Association of State Highway & Transportation Officials (AASHTO), Washington, D.C., 2016.

4. *NCHRP Project 03-119 Interim Report Phase I, Application of MASH Test Criteria to Breakaway Sign and Luminaire Supports and Crashworthy Work-Zone Traffic Control Devices*, George Mason University and Midwest Roadside Safety Facility, Revised September 2018.

5. Pajouh, M.A., Bielenberg, R.W., Faller, R., Stolle, C., Fang, C., Ruskamp, R., Rajaee, M., Marzougui, D., Tahan, F., and Kan, C.S. *Guidelines for Evaluating Crashworthiness of Sign Supports and Breakaway Luminaire Poles,* NCHRP Report No. 1123. 2024.

6. Pfeifer, B.G., Holloway, J.C., Faller, R.K., and Post, E.R., *Full-Scale 1,800 lb. Vehicle Crash Tests on a 4-bolt Breakaway Slipbase Design,* Report No. TRP-03-25-91, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, August 1991.

7. *LS-DYNA Keyword User's Manual, Volume 1 R10.1,* Livermore Software Technology Company (LSTC), Livermore, California, 2017.

8. *Standard Plans, 2023 Edition,* California Department of Transportation, 2023.

9. 4*30MASHC17, 430MASHC20, 430MASHC22, and 430MASHC23 Full-Scale Crash Test Data* [Unpublished Data Set], Caltrans, Sacramento, California, 2023.

10. *Standard Road Plan, Sheet LI-211,* Iowa Department of Transportation, 2015.

11. *2024 Standard Drawings, Sheet SL 14,* Utah Department of Transportation, 2024.

12. *UDOT Lighting Design Manual,* Utah Department of Transportation, 2023.

13. *Standard Plans,* Wyoming Department of Transportation, 2022.

14. Mak, K.K., Bligh, R.P, and Alberson, D.C., *Testing and Evaluation of Wyoming Road Closure Gate, FHWA-RD-97-,* Texas Transportation Institute and Texas A&M Research Foundation, College Station, Texas, January 1997.

15. *WRCG-1 Full-Scale Crash Test Data* [Unpublished Data Set], Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, 2021.

16. *2024 Roadway Standard Drawings, Sheet 1404.01,* North Carolina Department of Transportation, 2024.

17. *North Dakota Standard Drawings, Sheet D-770-5,* North Dakota Department of Transportation, 2015.

18. *Standard Details Book, Volume II, Sheet TEL-19,* West Virginia Department of Transportation.

19. *Standard Plans, Sheet J-28.43-01,* Washington Department of Transportation, 2023.

20. *Oregon Standard Drawings, Sheet TM630,* Oregon Department of Transportation, 2023.

21. Kelley, S., *Arizona DOT Statewide Light Pole Slip-Away Base Replacement Prioritization,* Arizona Department of Transportation, Greenlight Traffic Engineering, 2017.

22. Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances,* National Cooperative Highway Research Program (NCHRP) Report No. 230*,* Transportation Research Board, Washington, D.C., 1981.

23. 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 350, Transportation Research Board, Washington, D.C., 1993.

24. Stoughton, R.L., Abghari, A., Dusel, J.P., Hedgecock, J.L., and Glauz, D.L., "Vehicle Impact Testing of Lightweight Lighting Standards," *Transportation Research Record,* No. 1233, p. 51-64, 1984.

25. Bligh, R.P., Ross, H.E., and Bullard, D.L., *Test and Evaluation of Arizona Slip-Away Base Luminaire Supports,* TTI Report No. 472360-1F*,* Texas Transportation Institute, Texas A&M University, College Station, Texas, November 1994.

26. *Crash Testing of Various Roadside Hardware, FHWA/CA/MI-2006/22,* California Department of Transportation (CalTrans), 2006.

27. Staron, L.A., *Eligibility Letter LS-16,* Letter to D.H. O'Brien of Valmont Industries, Federal Highway Administration, U.S. Department of Transportation, June 29, 1990.

28. Ray, M.H., Plaxico, C.A., and Anghileri, M., *Procedures for Verification and Validation of Computer Simulations Used for Roadside Safety Applications,* NCHRP Web-Only Report No. 179, NCHRP Project No. 22-24, March 2010.

29. *Bolt Clamping Force Calculations,* EngineerExcel, Retrieved from https://engineerexcel.com/calculate-clamping-force/, February 1, 2024.

30. *Vehicle Modeling,* National Crash Analysis Center, George Washington University, Washington, D.C. Retrieved from: http://www.ncac.gwu.edu/research/reports.html, August 20, 2014.

31. Dhafer, M., *Update on New MASH Pickup Truck Model,* Center for Collision Safety and Analysis, TRB 98th Annual Meeting (2019) Roadside Safety Design Computational Mechanics Subcommittee, AFB20(1), Washington, D.C., January 14, 2019, Obtained on February 12, 2019.

32. Valmont Industries, Inc., Valmont Structures Pole Assemblies Catalog, Available https://www.valmontstructures.com/products-solutions/product-catalog/us/pole-assemblies, Accessed Feb 2, 2024.

33. Kovar, J.C., Mazon, N., Curran, D., and Bastin, B. E., *Evaluation of a Four Bolt Slip Base for Breakaway Luminaire Supports with Various Pole Configurations.* TTI Report No. TRNO. 618911-01-1 - 3*,* Texas Transportation Institute, Texas A&M University, College Station, Texas, December 2024.

8 APPENDICES

Appendix A. State DOT Survey and Results

RPFP-21-POLE-1: Breakaway Luminaire Supports

(untitled)

1. The primary survey participant shall complete the following information:

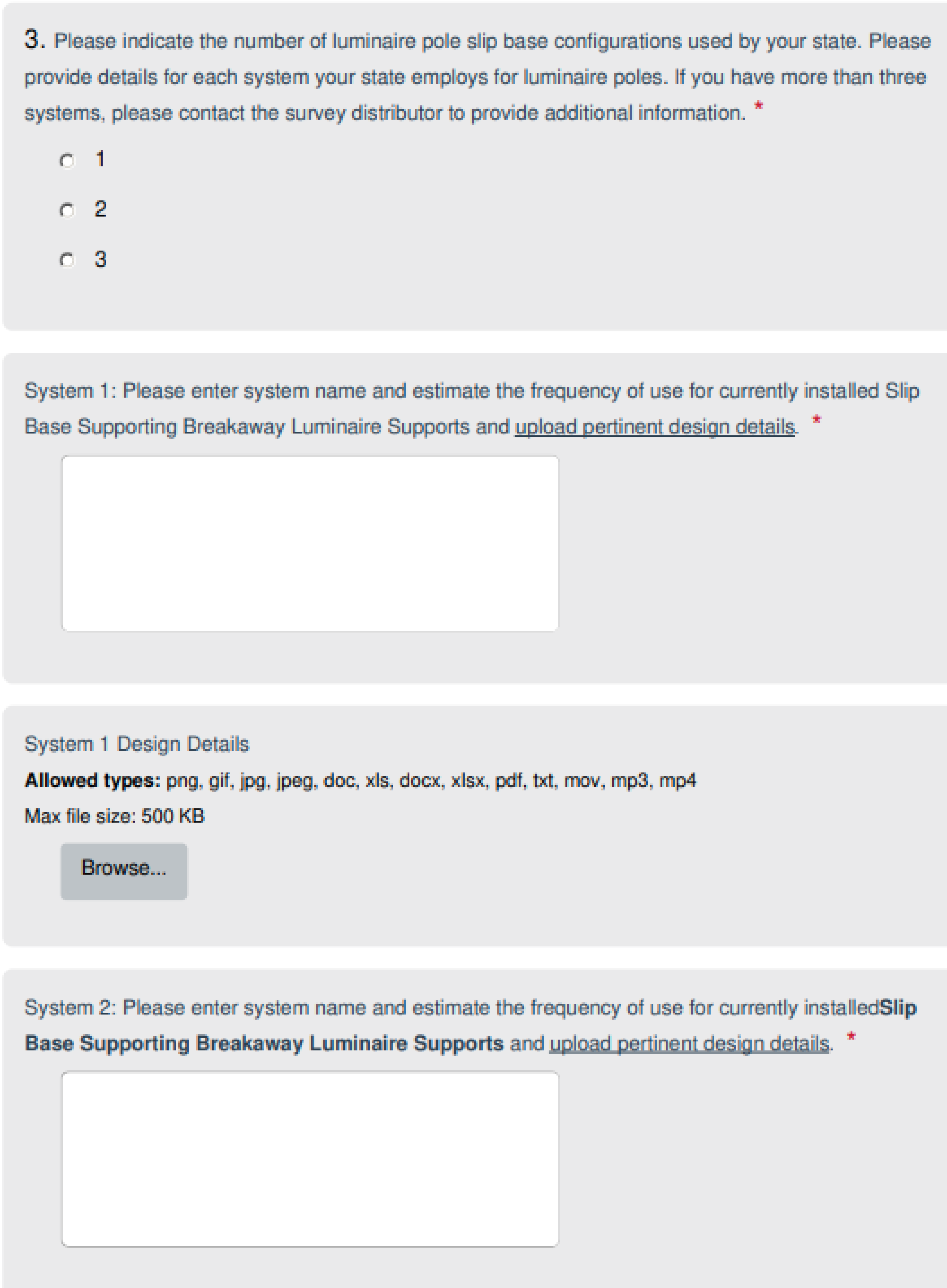
	Response:
Name: *	
Position Title:	
Organization: *	
Department/Division:	
Phone Number: *	
Email Address: *	

(untitled)

2. Please denote if your state uses luminaires supported by 3-bolt slip bases, 4-bolt slip bases, both 3 and 4-bolt slip bases, or does not use slip base systems for breakaway luminaire poles. *

- 3-bolt slip base
- 4-bolt slip base
- Both
- None

Figure A-1. State DOT Survey – Page 1



3. Please indicate the number of luminaire pole slip base configurations used by your state. Please provide details for each system your state employs for luminaire poles. If you have more than three systems, please contact the survey distributor to provide additional information. *

- 1
- 2
- 3

System 1: Please enter system name and estimate the frequency of use for currently installed Slip Base Supporting Breakaway Luminaire Supports and upload pertinent design details. *

System 1 Design Details

Allowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4

Max file size: 500 KB

Browse...

System 2: Please enter system name and estimate the frequency of use for currently installed**Slip Base Supporting Breakaway Luminaire Supports** and upload pertinent design details. *

Figure A-2. State DOT Survey – Page 2

System 2 Design Details

Allowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4

Max file size: 500 KB

Browse...

System 3: Please enter system name and estimate the frequency of use for currently installed **Slip Base Supporting Breakaway Luminaire Supports** and upload pertinent design details. *

System 3 Design Details

Allowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4

Max file size: 500 KB

Browse...

For each system, please estimate the percent of installed systems. The total **MUST** add up to 100%. *

System 1:

System 2:

System 3:

0 out of 100% Total

Figure A-3. State DOT Survey – Page 3

4. Has your organization developed current practices and/or standard plans regarding the selection and installation of Breakaway Luminaire Poles Supported by a Slip Base? This would include guidance with respect to the range of luminaire pole configurations that your state uses with slip bases and if and how the slip base system varies based on the luminaire pole configuration used. *

- Yes
- No

If YES, please provide pole design details (standard plans, special plans, etc.) supported by slip bases, using the electronic document upload link.

Allowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4

Max file size: 500 KB

Browse...

Figure A-4. State DOT Survey – Page 4

Please provide the following pole details if not included in the uploaded details/plans:

Pole material

Pole thickness

Pole height range

Pole diameter range

Pole mass range

Arm configuration (single or dual)

Arm length range

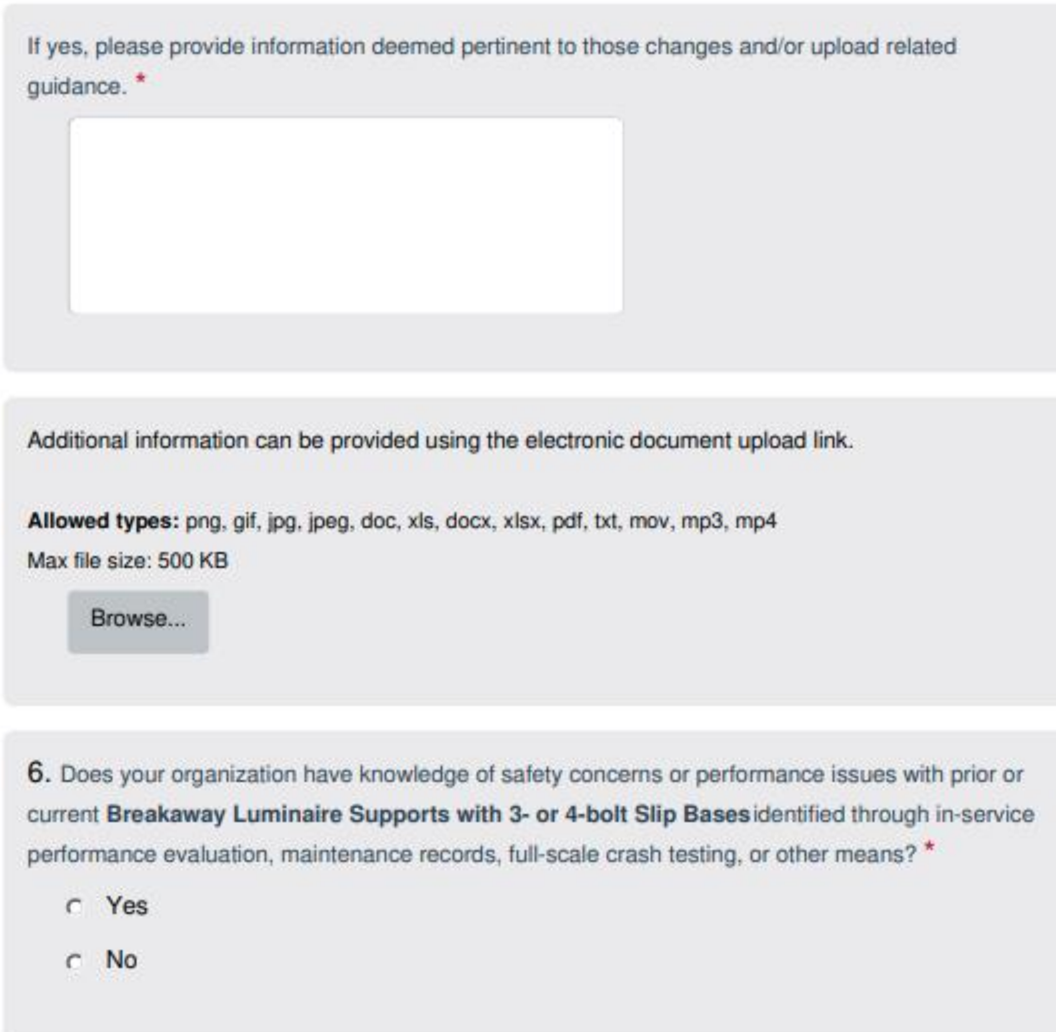
Associated slip base design for different pole configurations

Slip base foundation/base details

5. Does your organization change the slip base configuration based on the luminaire pole design? *

- Yes
- No

Figure A-5. State DOT Survey – Page 5



If yes, please provide information deemed pertinent to those changes and/or upload related guidance. *

Additional information can be provided using the electronic document upload link.

Allowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4
Max file size: 500 KB

Browse...

6. Does your organization have knowledge of safety concerns or performance issues with prior or current **Breakaway Luminaire Supports with 3- or 4-bolt Slip Bases** identified through in-service performance evaluation, maintenance records, full-scale crash testing, or other means? *

- Yes
- No

Figure A-6. State DOT Survey – Page 6

If yes, please provide pertinent information and details as it pertains to non-activation of the breakaway mechanism, device penetration into the roof, windshield, and floor pan, or large deformations to the occupant compartment in frontal and side-impact crashes. *

Additional information can be provided using the electronic document upload link.

Allowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4

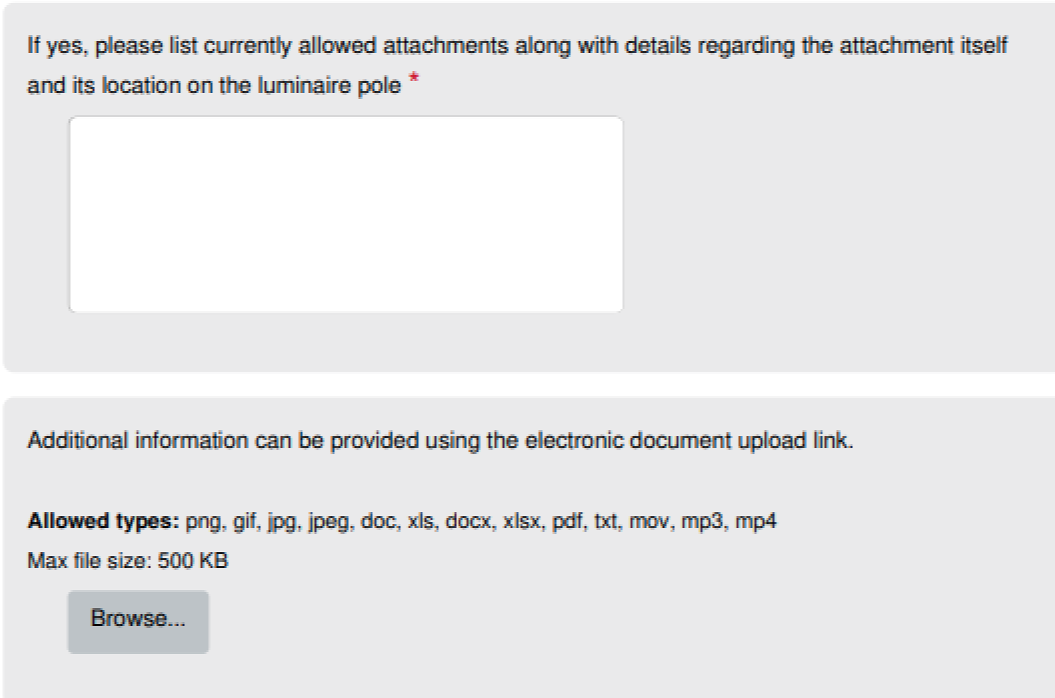
Max file size: 500 KB

Browse...

7. Does your state allow additional attachments to slip base mounted luminaire poles? This would include items like cell phone transmitters, wireless internet transmitters, solar power boxes, cameras, or any other additional hardware mounted to the luminaire support outside of the mast arm and light. *

- Yes
- No

Figure A-7. State DOT Survey – Page 7



If yes, please list currently allowed attachments along with details regarding the attachment itself and its location on the luminaire pole *

Additional information can be provided using the electronic document upload link.

Allowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4

Max file size: 500 KB

Browse...

Figure A-8. State DOT Survey – Page 8

8. Please provide details on wiring standards used for slip base mounted luminaire poles.

What is the typical size and configuration of the wiring for the luminaire pole?

Is there additional wiring for other attached hardware or devices? If so, please provide details.

Does your state utilize/require breakaway wiring connections for slip base supported luminaire poles? If so, please provide details on the breakaway wiring connector used.

Figure A-9. State DOT Survey – Page 9

State	Response::Organization::The primary survey participant shall complete the following information:
Florida	FDOT
Wisconsin	WisDOT
California	Caltrans
Iowa	Iowa DOT
Indiana	INDOT
South Carolina	South Carolina Dept. of Transportation
South Dakota	South Dakota DOT
Illinois	Illinois DOT
North Carolina	NCDOT
Minnesota	MnDOT
Nebraska	NDOT
Nebraska	Nebraska Dept. of Transportation
New Jersey	NJDOT
Georgia	GA Department of Transportation

Figure A-10. State DOT Survey Responses

Report for RPFP-21-POLE-1: Breakaway Luminaire Supports

Response Counts

Completion Rate:	**100%**	
	Complete	14
		Totals: 14

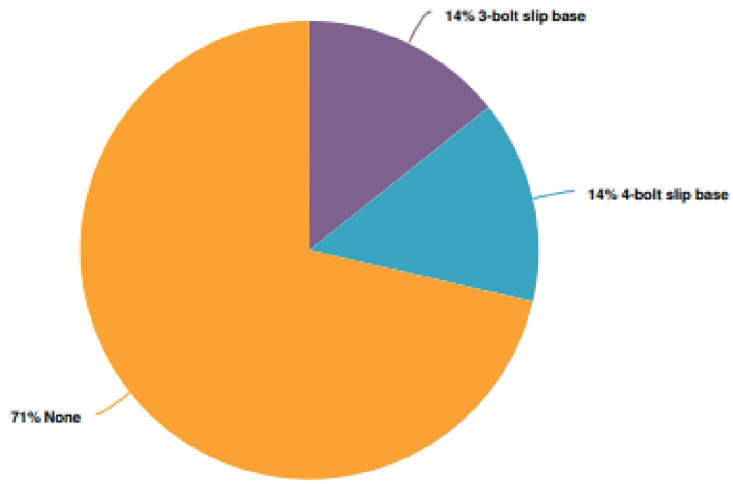
Figure A-11. State DOT Survey Results – Page 1

1. The primary survey participant shall complete the following information:

	Response:	**Responses**
Name: Count Row %	14 100.0%	14
Position Title: Count Row %	11 100.0%	11
Organization: Count Row %	14 100.0%	14
Department/Division: Count Row %	11 100.0%	11
Phone Number: Count Row %	14 100.0%	14
Email Address: Count Row %	14 100.0%	14
Totals		14 100.0%

Figure A-12. State DOT Survey Results – Page 2

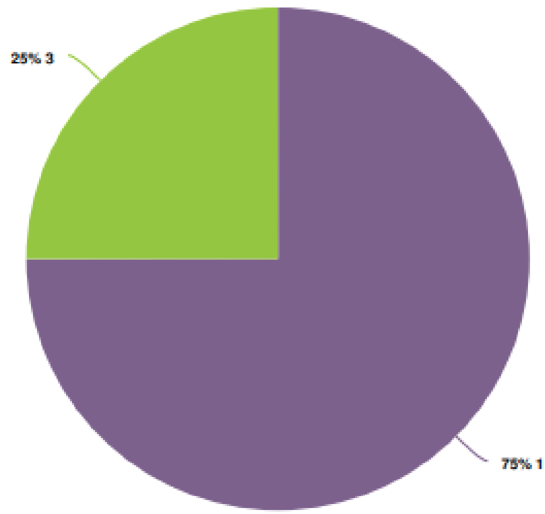
2. Please denote if your state uses luminaires supported by 3-bolt slip bases, 4-bolt slip bases, both 3 and 4-bolt slip bases, or does not use slip base systems for breakaway luminaire poles.



Value	Percent	Responses
3-bolt slip base	14.3%	2
4-bolt slip base	14.3%	2
None	71.4%	10
		Totals: 14

Figure A-13. State DOT Survey Results – Page 3

3. Please indicate the number of luminaire pole slip base configurations used by your state. Please provide details for each system your state employs for luminaire poles. If you have more than three systems, please contact the survey distributor to provide additional information.



Value	Percent	Responses
1	75.0%	3
3	25.0%	1
		Totals: 4

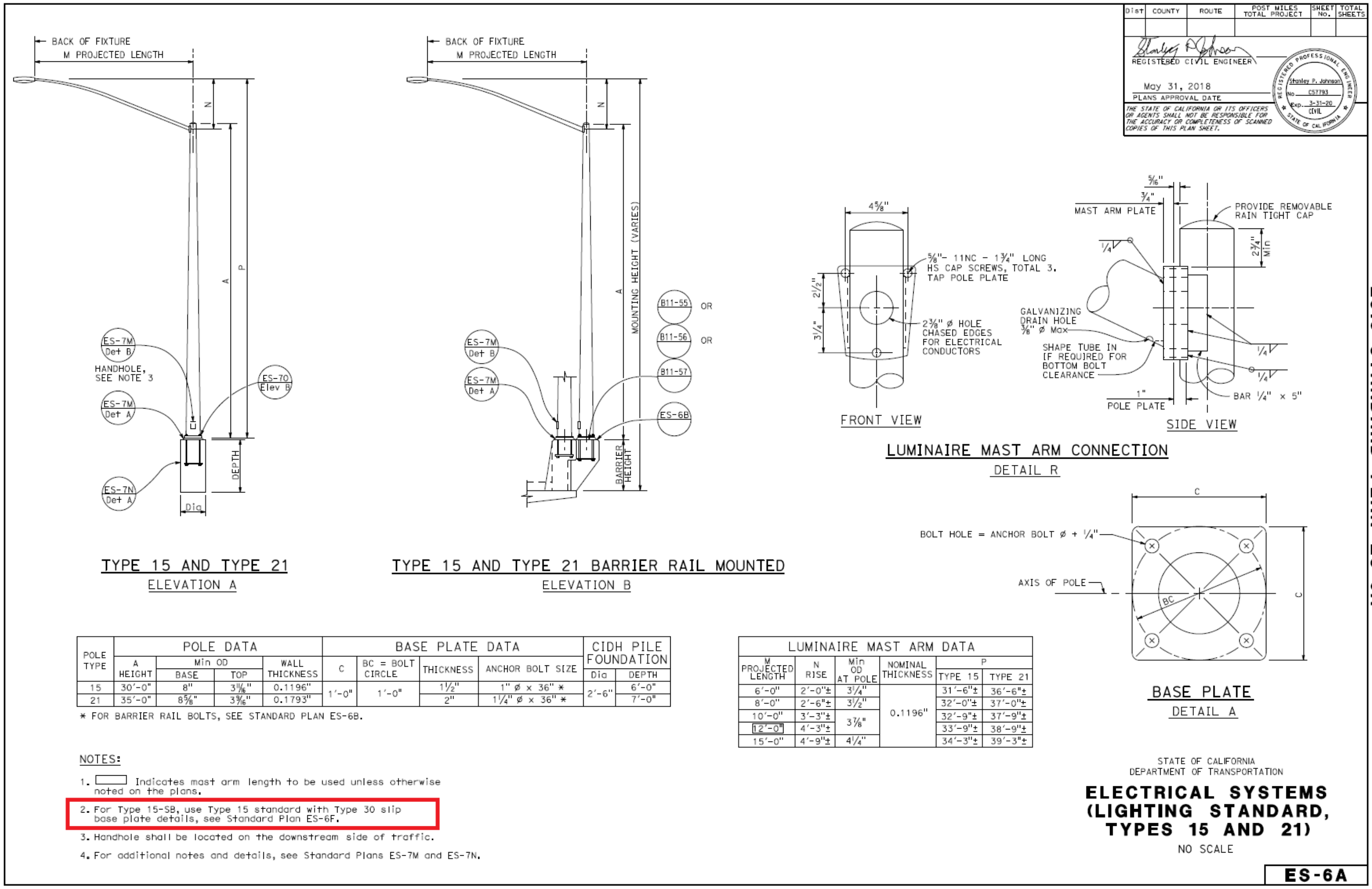
Figure A-14. State DOT Survey Results – Page 4

4. System 1: Please enter system name and estimate the frequency of use for currently installed Slip Base Supporting Breakaway Luminaire Supports and upload pertinent design details.

ResponseID	Response
20	Type 15-SB. Note that there are 5 arm lengths available. Also note CCTV, vehicle detection systems, and roadside signs are sometimes added to the poles. Clamp bolt tightening torque 150 ft-lb.
31	Valmont Millerbernd
39	Illinois uses generic breakaway couplings. The contractor submits a breakaway coupling manufacturer to our inspectors on a job by job basis, and they accept the coupling based on crash test certification.
56	For poles that are on square bases, the bolts are attached at each corner of the base. In the rare case of a round base, we use 3 or 4 bolts depending on the size of the pole.

Figure A-15. State DOT Survey Results – Page 5

508



POLE TYPE	POLE DATA				BASE PLATE DATA				CIDH PILE FOUNDATION	
	A HEIGHT	Min OD BASE	Min OD TOP	WALL THICKNESS	C	BC = BOLT CIRCLE	THICKNESS	ANCHOR BOLT SIZE	Dia	DEPTH
15	30'-0"	8"	3 11/16"	0.1196"	1'-0"	1'-0"	1 1/2"	1" ø x 36" *	2'-6"	6'-0"
21	35'-0"	8 5/8"	3 9/16"	0.1793"			2"	1 1/4" ø x 36" *		7'-0"

* FOR BARRIER RAIL BOLTS, SEE STANDARD PLAN ES-6B.

LUMINAIRE MAST ARM DATA

M PROJECTED LENGTH	N RISE	Min OD AT POLE	NOMINAL THICKNESS	P TYPE 15	P TYPE 21
6'-0"	2'-0"±	3 1/4"	0.1196"	31'-6"±	36'-6"±
8'-0"	2'-6"±	3 1/2"		32'-0"±	37'-0"±
10'-0"	3'-3"±	3 7/8"		32'-9"±	37'-9"±
12'-0"	4'-3"±			33'-9"±	38'-9"±
15'-0"	4'-9"±	4 1/4"		34'-3"±	39'-3"±

NOTES:

1. [ ] Indicates mast arm length to be used unless otherwise noted on the plans.
2. For Type 15-SB, use Type 15 standard with Type 30 slip base plate details, see Standard Plan ES-6F.
3. Handhole shall be located on the downstream side of traffic.
4. For additional notes and details, see Standard Plans ES-7M and ES-7N.

Figure A-16. State DOT Survey Results – Page 6 - Caltrans Attachments

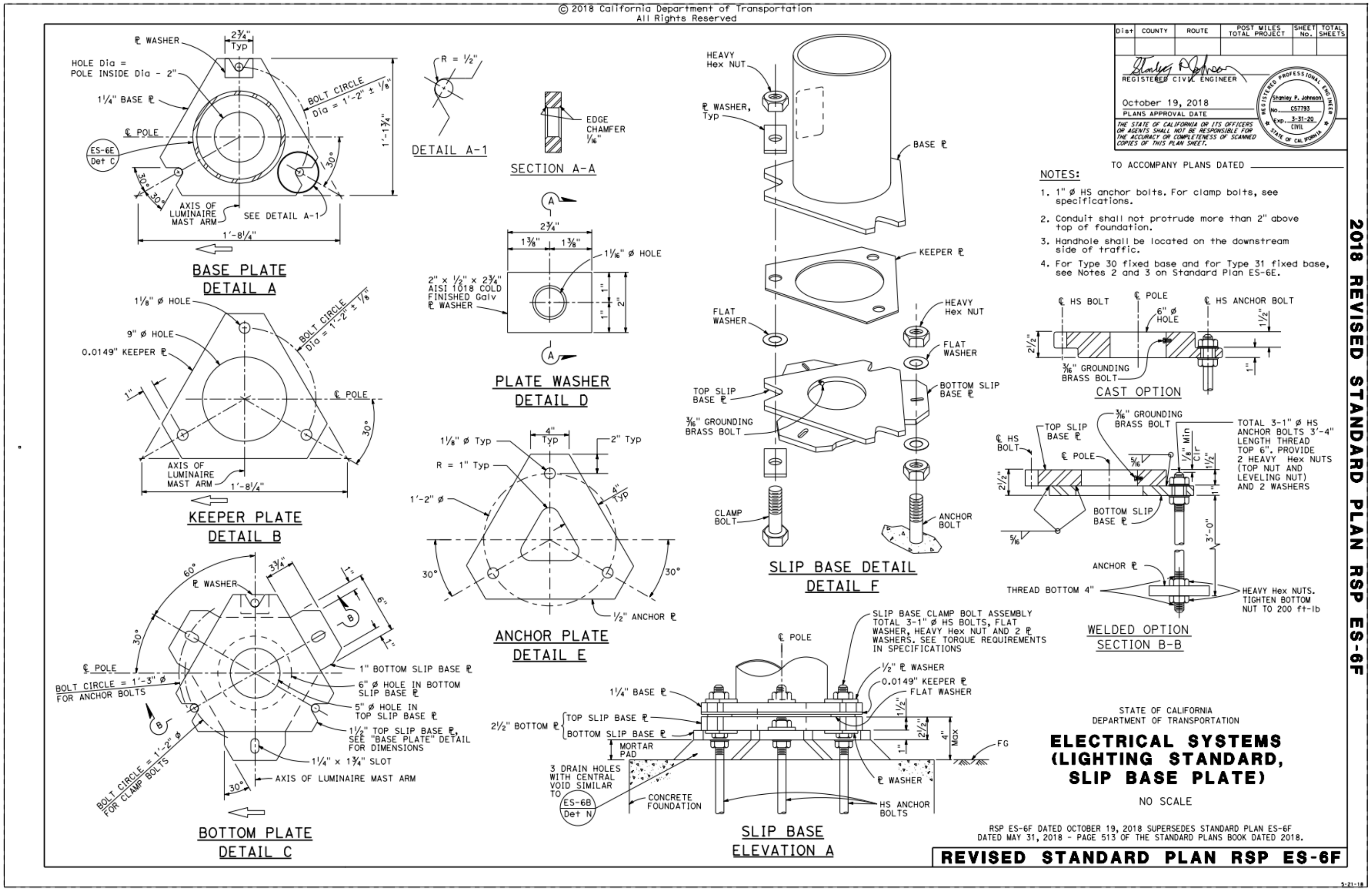


Figure A-17. State DOT Survey Results – Page 6 - Caltrans Attachments, Cont.

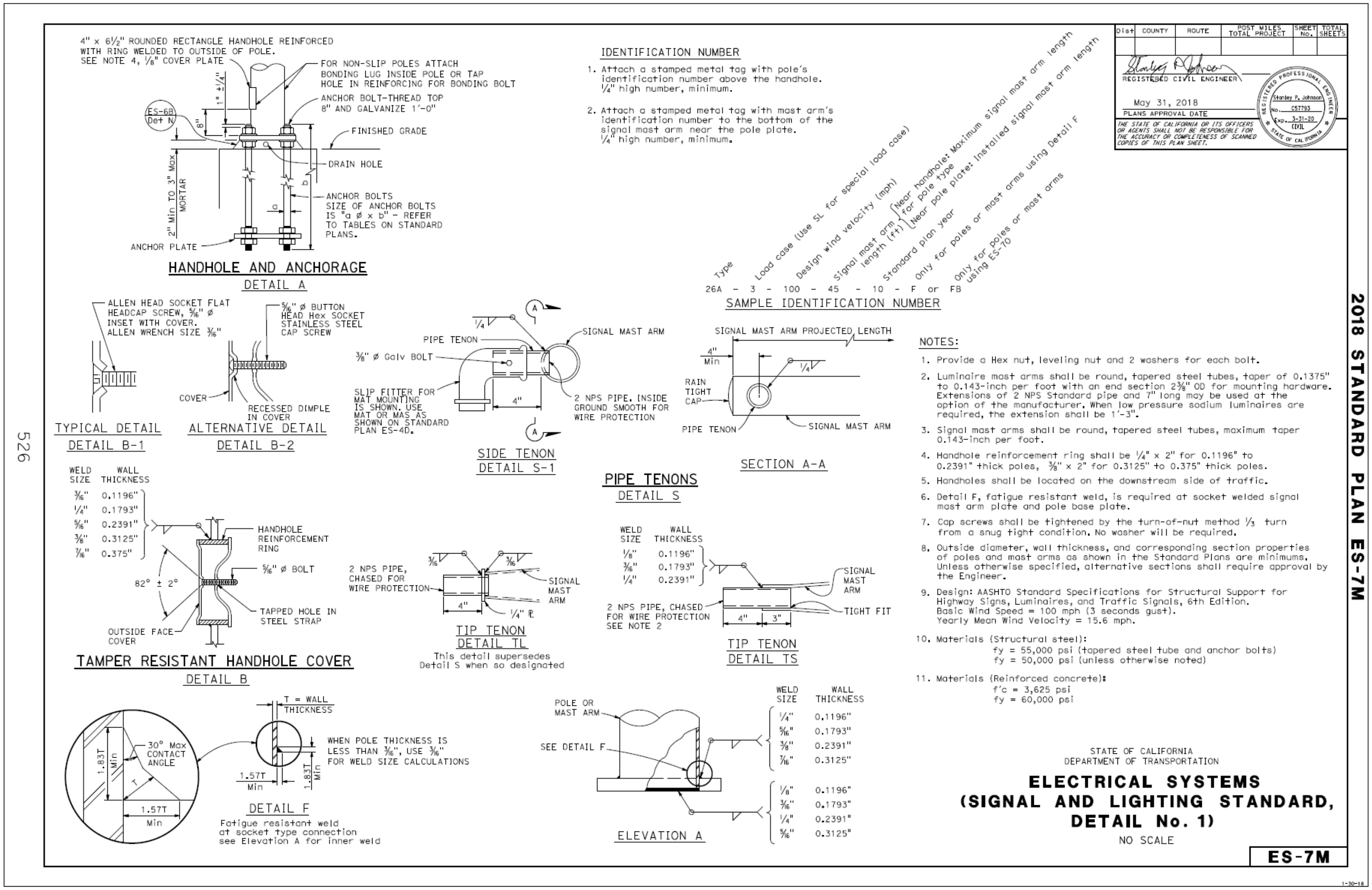
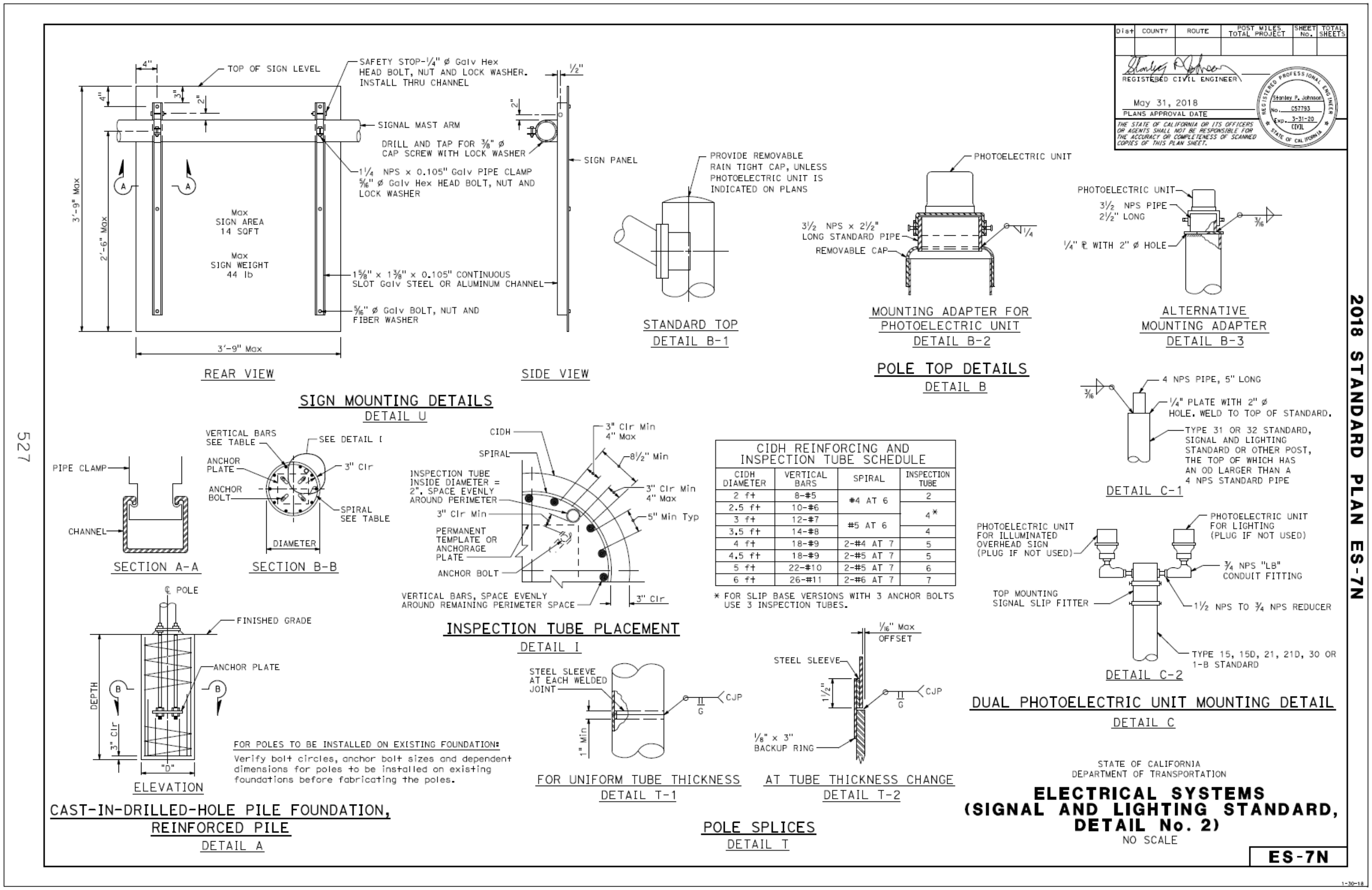


Figure A-18. State DOT Survey Results – Page 6 - Caltrans Attachments, Cont.



CIDH DIAMETER	VERTICAL BARS	SPIRAL	INSPECTION TUBE
2 ft	8-#5	#4 AT 6	2
2.5 ft	10-#6		4*
3 ft	12-#7	#5 AT 6	
3.5 ft	14-#8		4
4 ft	18-#9	2-#4 AT 7	5
4.5 ft	18-#9	2-#5 AT 7	5
5 ft	22-#10	2-#5 AT 7	6
6 ft	26-#11	2-#6 AT 7	7

Figure A-19. State DOT Survey Results – Page 6 - Caltrans Attachments, Cont.

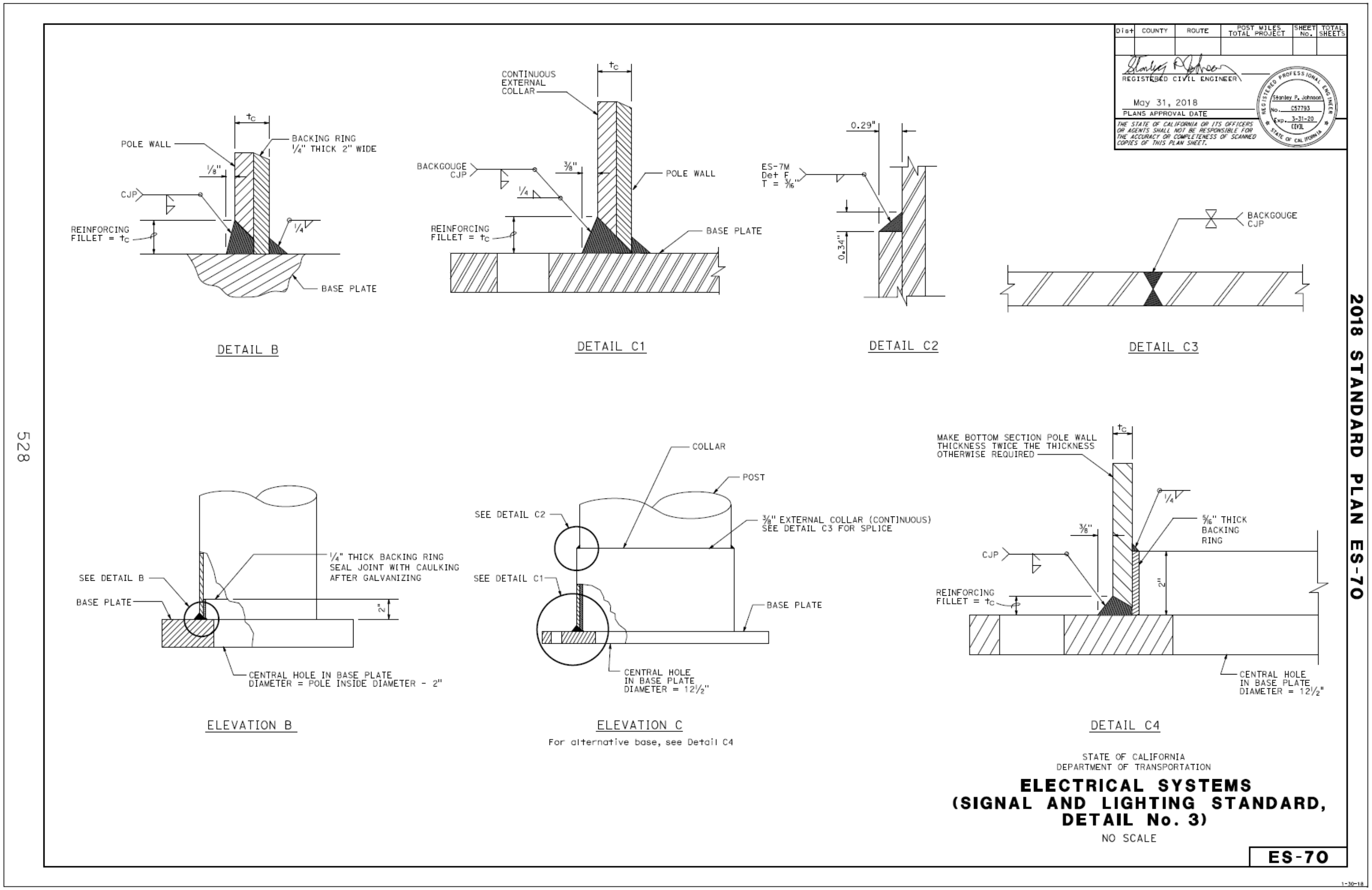


Figure A-20. State DOT Survey Results – Page 6 - Caltrans Attachments, Cont.

Dist	COUNTY	ROUTE	POST MILES TOTAL PROJECT	SHEET No.	TOTAL SHEETS

REGISTERED ELECTRICAL ENGINEER

May 31, 2018
PLANS APPROVAL DATE

REGISTERED PROFESSIONAL ENGINEER Hamid Zolfaghari No. E15636 Exp. 12-31-19 ELECTRICAL STATE OF CALIFORNIA

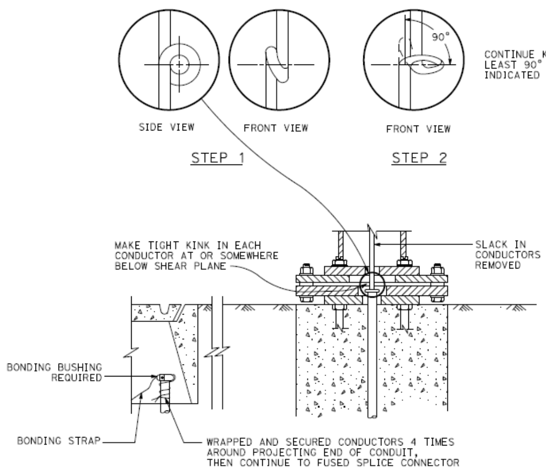
THE STATE OF CALIFORNIA OR ITS OFFICERS OR AGENTS SHALL NOT BE RESPONSIBLE FOR THE ACCURACY OR COMPLETENESS OF SCANNED COPIES OF THIS PLAN SHEET.

CIRCUIT VOLTAGE	FUSE VOLTAGE RATING	FUSE CURRENT RATING						
		HPS LAMP BALLAST		LOW PRESSURE SODIUM BALLAST	INDUCTION SIGN LIGHTING	SINGLE PHASE (TWO WIRE) TRANSFORMERS (PRIMARY SIDE)		
		70 W	100 W	180 W	85 W	1 kVA	2 kVA	3 kVA
120 V	250 V	5 A	5 A	5 A	5 A	10 A	20 A	30 A
240 V	250 V	5 A	5 A	5 A	5 A	6 A	10 A	20 A
480 V	500-600 V	5 A	5 A	3 A	1 A (SEE NOTE 2)	3 A	6 A	10 A

NOTES:

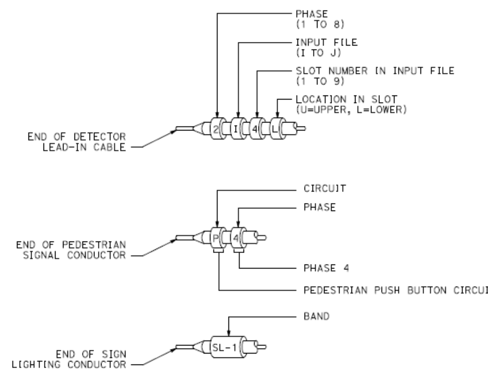
1. Primary lines of multiple ballasts shall be provided with fused connectors. Fuse ratings shall be as noted above.
2. See Standard Plan ES-15D, Type SC3 control.

FUSE RATINGS FOR FUSED CONNECTORS



KINKING DETAIL FOR SLIP BASE STANDARDS

DETAIL A



TYPICAL BANDING DETAILS

DETAIL B

2018 STANDARD PLAN ES-13B

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

ELECTRICAL SYSTEMS (FUSE RATING, KINKING AND BANDING DETAIL)

NO SCALE

ES-13B

545

Figure A-21. State DOT Survey Results – Page 6 - Caltrans Attachments, Cont.

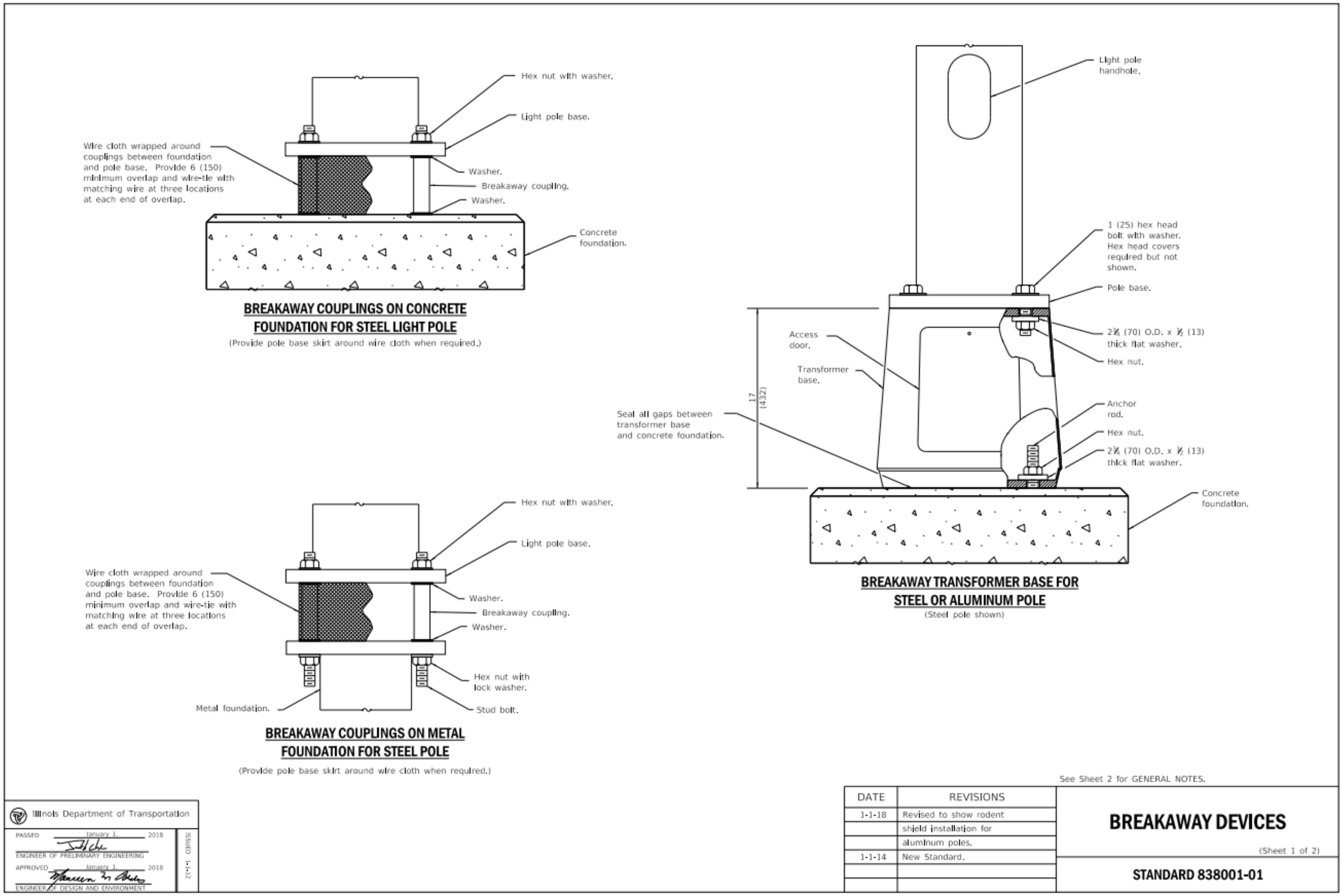


Figure A-22. State DOT Survey Results – Page 6 - Illinois DOT Attachments

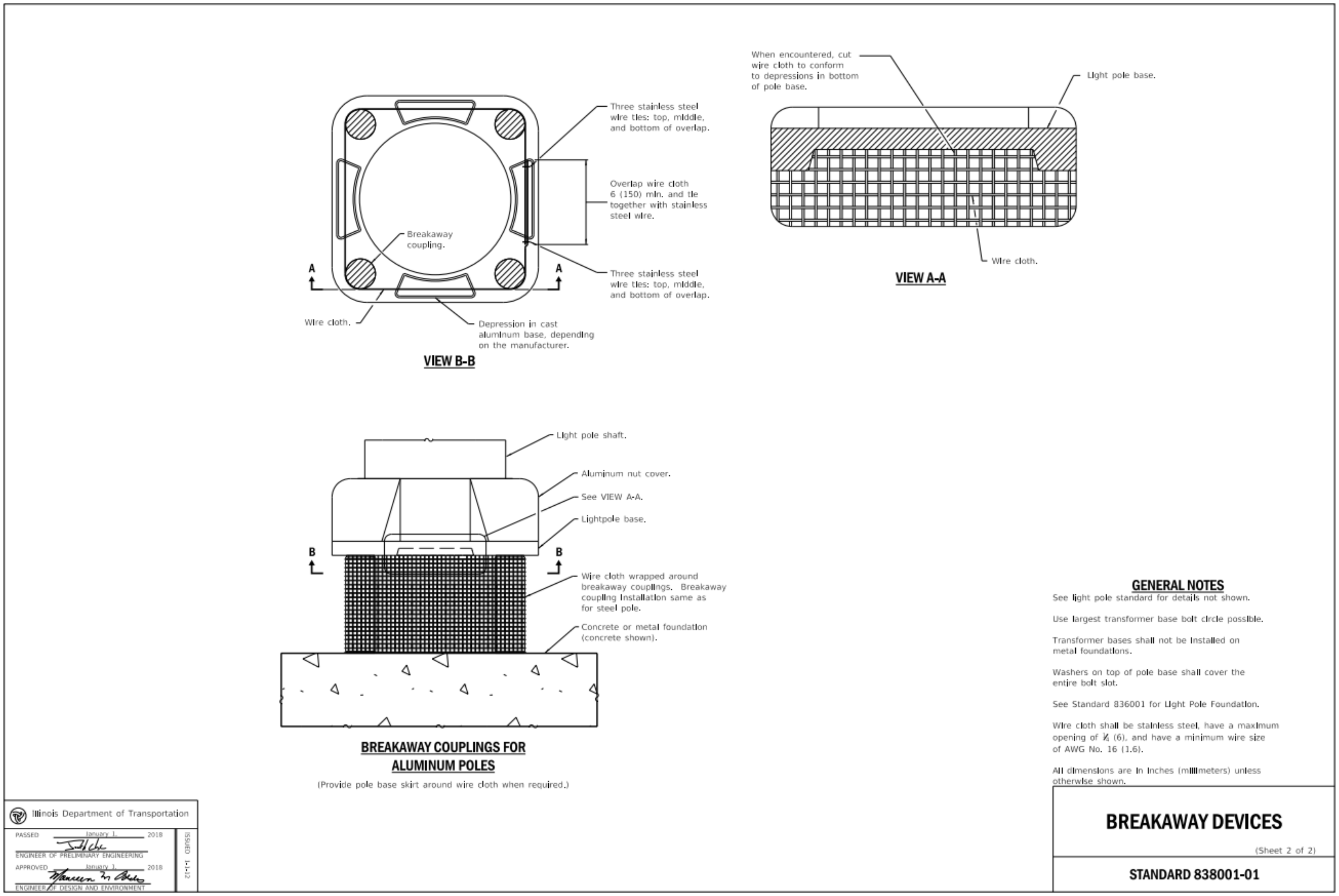


Figure A-23. State DOT Survey Results – Page 6 - Illinois DOT Attachments, Cont.

6. System 2: Please enter system name and estimate the frequency of use for currently installed Slip Base Supporting Breakaway Luminaire Supports and upload pertinent design details.

ResponseID	Response
20	Type 30. Note that there are 5 arm lengths available. Also note CCTV, vehicle detection systems, and roadside signs are sometimes added to the poles. Clamp bolt tightening torque 150 ft-lb.

Figure A-24. State DOT Survey Results – Page 7

7. System 2 Design DetailsAllowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4 Max file size: 500 KB
1 File Uploaded

Attachments on page 8 (excluding sheet ES-6E) are identical to attachments found on page 6

Figure A-25. State DOT Survey Results – Page 8

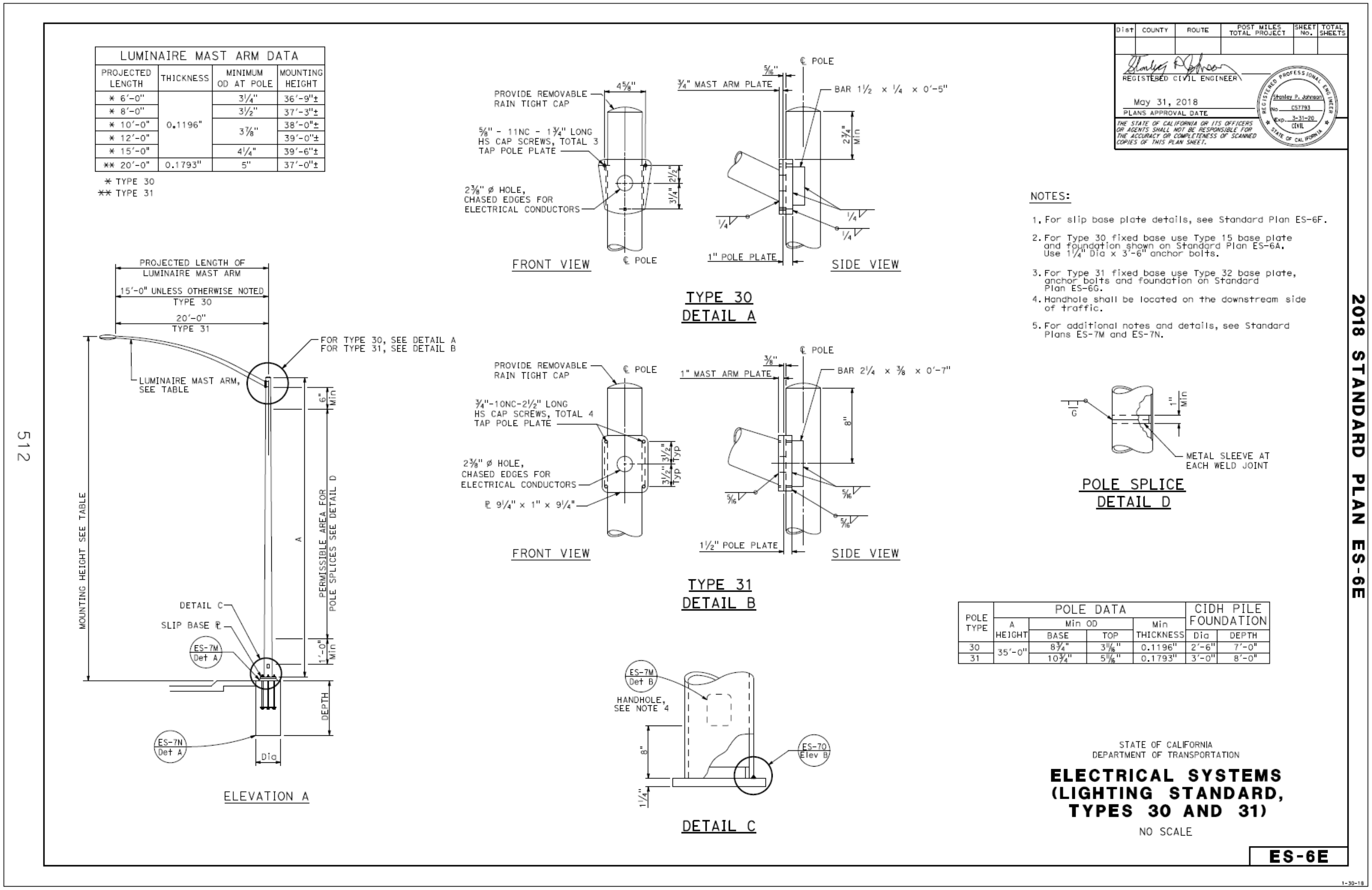


Figure A-26. State DOT Survey Results – Page 8 - Caltrans Attachments

8. System 3: Please enter system name and estimate the frequency of use for currently installed Slip Base Supporting Breakaway Luminaire Supports and upload pertinent design details.

ResponseID	Response
20	Type 31. Note that there is only one arm length available. Also note CCTV, vehicle detection systems, and roadside signs are sometimes added to the poles. Clamp bolt tightening torque 200 ft-lb.

Figure A-27. State DOT Survey Results – Page 9

9. System 3 Design DetailsAllowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4 Max file size: 500 KB
1 File Uploaded

Attachments on page 10 are identical to attachments found on page 8

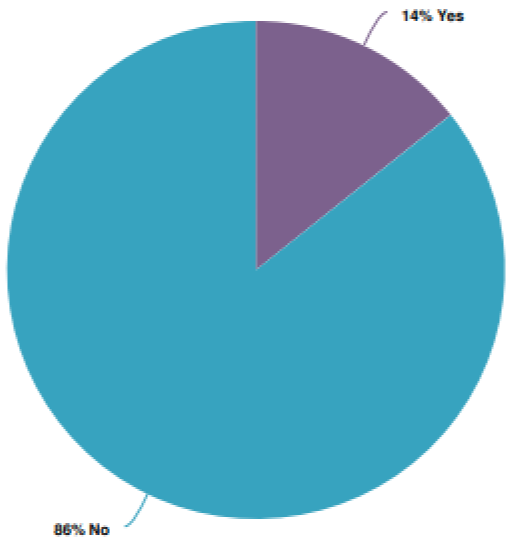
Figure A-28. State DOT Survey Results – Page 10

10. For each system, please estimate the percent of installed systems. The total MUST add up to 100%.

Item	Average	Min	Max	StdDev	Sum	Total Responses
System 1:	76.0	4.0	100.0	41.6	304.0	4
System 2:	37.5	0.0	75.0	37.5	75.0	2
System 3:	10.5	0.0	21.0	10.5	21.0	2

Figure A-29. State DOT Survey Results – Page 11

11. Has your organization developed current practices and/or standard plans regarding the selection and installation of Breakaway Luminaire Poles Supported by a Slip Base? This would include guidance with respect to the range of luminaire pole configurations that your state uses with slip bases and if and how the slip base system varies based on the luminaire pole configuration used.



Value	Percent	Responses
Yes	14.3%	2
No	85.7%	12
		Totals: 14

Figure A-30. State DOT Survey Results – Page 12

12. If YES, please provide pole design details (standard plans, special plans, etc.) supported by slip bases, using the electronic document upload link.Allowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4 Max file size: 500 KB
2 Files Uploaded

Figure A-31. State DOT Survey Results – Page 13

Illinois Department of Transportation

Information below extracted from the Standard Specifications for Road and Bridge Construction

POLES AND TOWERS

SECTION 830. LIGHT POLES

830.01 Description. This work shall consist of furnishing and installing a light pole complete with an arm(s), when specified, and all hardware and accessories required for the intended temporary or permanent use of the pole.

830.02 Materials. Materials shall be according to the following.

Item Article/Section

(a) Light Poles 1069.01-1069.05

(b) Mounting Pad 1069.07

(c) Pole/Unit Identification 1069.06

CONSTRUCTION REQUIREMENTS

830.03 Installation. The light pole shall be set plumb on the foundation without the use of shims, or washers for leveling. On bridge parapet walls, a vibration mounting pad shall be installed between the foundation leveling plate and the light pole.

The handhole shall be located such that workers accessing the handhole shall face oncoming traffic directly or located on the back side of the pole facing the roadway. On bridge parapet walls, the access handhole shall be oriented facing the roadway. On center median barrier walls, all access handholes shall be oriented to the one side with the least traffic flow.

Arms shall be set at right angles to the centerline of the pavement. Poles shall not be left in place without arm(s) and luminaire(s).

The Contractor shall be responsible for furnishing pole mounting equipment that is of adequate strength and compatible for the pole it supports. This shall include, but

Figure A-32. State DOT Survey Results – Page 13 – Illinois DOT Attachments not be limited to, the foundation, breakaway device (when specified), anchor rods, and hardware.

Lighting unit identification numbers shall be installed before the lighting unit is energized.

(a) Foundation Mounted Poles. The Contractor shall avoid contact of dissimilar metals in erecting the pole on its foundation and/or breakaway device. Any concern of trapped moisture or potential corrosion cell shall be resolved to the satisfaction of the Engineer.

(b) Direct Embed Fiberglass Pole. The depth of a direct embed fiberglass pole in the ground shall not be less than ten percent of the pole length plus 2 ft (600 mm) with a minimum of 6 ft (1.8 m). Direct embed poles shall be raked 1 ft (300 mm). Care shall be taken to get the shear plane of the pole at groundline for breakaway poles. Backfill shall be tamped and compacted around the pole in 6 in. (150 mm) lifts.

(c) Wood Pole. Poles shall be stored and handled according to ANSI O5.1. The depth of the pole in the ground shall not be less than ten percent of the pole length plus 2 ft (600 mm) with a minimum of 6 ft (1.8 m). The poles shall be raked 1 ft (300 mm). Backfill shall be tamped and compacted around the pole in 6 in. (150 mm) lifts.

Pole guying shall be provided where indicated on the plans, at every dead end pole, and at any pole having non-offsetting cable support stresses.

830.04 Temporary Installation. Wood poles used for a temporary lighting installation may be previously used poles as approved by the Engineer. The poles shall be in good condition and shall be according to the applicable ANSI requirements for sweep, crook, defects, and mechanical damage. Poles deemed unacceptable by the Engineer shall be removed from the jobsite.

830.05 Basis of Payment. Wood poles will be paid for at the contract unit

Figure A-33. State DOT Survey Results – Page 13 – Illinois DOT Attachments, Cont.

price per each for LIGHT POLE, WOOD, of the length, class and arm (quantity and length) type specified.

All other light poles will be paid for at the contract unit price per each for LIGHT POLE, of the material type, mounting height, and arm (quantity and length) type specified.

When breakaway devices are specified, the devices will be measured and paid for separately according to Articles 838.04 and 838.05.

FOUNDATIONS AND BREAKAWAY DEVICES

SECTION 836. POLE FOUNDATION

836.01 Description. This work shall consist of constructing or furnishing and installing a light pole foundation.

836.02 Materials. Materials shall be according to the following.

Item Article/Section

(a) Portland Cement Concrete 1020

(b) Anchor Rods 1070.02

(c) Light Pole Foundation, Metal 1070.01

(d) Fine Aggregate 1003.04

CONSTRUCTION REQUIREMENTS

836.03 Installation. Foundations installed within the clear zone (unless behind guardrail) shall not protrude more than 4 in. (100 mm) above the finished grade within a 5 ft (1.5 m) chord across the foundation, with anchor rods and breakaway device included. If foundation heights, including anchor rods and fractured breakaway device extend beyond these specified limits, the foundation shall be replaced.

(a) Drilled Shaft Foundations. Drilled shaft foundations shall be constructed according to Section 516 and the following.

Figure A-34. State DOT Survey Results – Page 13 – Illinois DOT Attachments, Cont.

The submittal requirements as stated in Article 516.04 shall not apply and the entire length of the drilled shaft shall be vibrated.

Grounding electrodes shall be according to Section 806.

The raceway and full length anchor rods shall be properly positioned and secured in the augered hole prior to placing the concrete. The bend radius of the anchor rods shall be at least four times the rod diameter.

The wiring window shall be perpendicular to the roadway. After installation of cable, voids within the wiring window shall be filled with fine aggregate.

The top of the foundation shall be constructed level. A liner or form shall be used to produce a uniform smooth side to the top of the foundation. The depth of the form shall be as shown on the plans.

The foundation form shall remain undisturbed for at least 24 hours after the concrete has been poured.

Concrete shall be cured before poles are installed.

When obstructions are encountered, the Contractor shall request to relocate the foundation. Any abandoned holes shall be backfilled to the satisfaction of the Engineer.

When rock is encountered, the foundation depth may be reduced 6 in. (150 mm) for every 12 in. (300 mm) of embedment in rock. The minimum depth of any foundation shall be 4.5 ft (1.4 m).

When the foundation depth is reduced to less than specified, the anchor rods shall be cut, threaded, and a steel plate of the diameter shown on the plans shall be installed on the bottom of the anchor rods 6 in. (150 mm) above the bottom of the excavated hole with 1 in. (25 mm) nuts.

(b) Metal Foundations. The metal foundation shall be installed with its axis plumb. The light pole shall be installed plumb without the use of shims, grout, or other leveling devices.

Any voids within the metal screw-in foundation shall be filled with fine aggregate.

Figure A-35. State DOT Survey Results – Page 13 – Illinois DOT Attachments, Cont.

Wiring windows shall be oriented to be parallel to the roadway unless otherwise directed by the Engineer to achieve alignment with grade or to minimize bends in the feeder wiring into the foundation.

The Contractor shall use a torque indicating device to install metal foundations. A shear pin indicator or other Engineer approved method shall be used to ensure the foundation is installed properly. A metal foundation shall not be installed to a torque which exceeds the manufacturer's maximum torque rating nor shall it be installed to an installation torque value of less than 3,500 ft lb (5,000 N m). Metal foundations that are not installed to full installation depth or do not achieve the minimum installation torque shall be removed and replaced with a concrete foundation at no additional cost to the Department.

Driven grounding electrodes will not be required when metal foundations are specified.

836.04 Method of Measurement. Concrete foundations will be measured for payment in feet (meters) in place. The length measured will be limited to that shown on the plans or authorized by the Engineer. Any offsets in the foundation will be measured along the vertical and horizontal centerlines of the foundation without overlap.

Relocation of a foundation due to an obstruction and any shaft excavation to that point will not be measured for payment.

Excavation in rock will be measured for payment according to Article 502.12.

836.05 Basis of Payment. Concrete foundations will be paid for at the contract unit price per foot (meter) for LIGHT POLE FOUNDATION, of the diameter specified.

Metal foundations will be paid for at the contract unit price per each for LIGHT POLE FOUNDATION, METAL, of the bolt circle, diameter, and length specified.

Figure A-36. State DOT Survey Results – Page 13 – Illinois DOT Attachments, Cont.

Excavation in rock will be paid for according to Article 502.13.

SECTION 838. BREAKAWAY DEVICES

838.01 Description. This work shall consist of furnishing and installing a breakaway device on a pole foundation.

838.02 Materials. Materials shall be according to the following.

Item Article/Section

(a) Breakaway Devices 1070.04

CONSTRUCTION REQUIREMENTS

838.03 Installation. All entryway points created by the use of breakaway devices shall be permanently and completely sealed against rodent entry. This includes the pole base plate and foundation plate openings, elongated holes for anchor rods, the opening below the pole base plate, and the wiring windows in both steel and concrete foundations. Where breakaway couplings are used in conjunction with steel foundations, the Contractor shall match the plate sizes in order to seal out rodents between the foundation and pole base. Breakaway devices are not allowed on bridge parapets, barrier walls, or pedestrian conflict areas, and are not required behind guardrail. The Contractor shall verify that the loading of the pole, arm(s), luminaire(s), and appurtenances does not exceed the capacity of the breakaway device.

(a) Transformer Base. The transformer base shall be installed level and flush with the foundation without the use of leveling washers or shims according to the manufacturer's installation procedures. The anchor bolts shall be inserted full depth into the slotted holes of the transformer base. The transformer base shall be installed with access door aligned with light pole handhole. All nuts, bolts, washers, and lock washers required to complete the installation of the transformer base shall be included.

(b) Breakaway Couplings. The breakaway couplings shall be coordinated to

Figure A-37. State DOT Survey Results – Page 13 – Illinois DOT Attachments, Cont.

match anchor rod size. The breakaway coupling shall be installed on the anchor rod according to the manufacturer's recommendations. When used with a metal foundation, a nut shall be installed under the foundation plate on the stud bolt to prevent it from backing out of the breakaway coupling. The coupling installation shall not be used to level the pole base in lieu of a level foundation.

The screen shall be tied back on itself and secured with stainless steel wire ties. The screen shall fit tightly and shall completely fill all openings including the voids in the bottom of the pole base.

838.04 Method of Measurement. Transformer bases used for breakaway devices will be measured for payment as each, for each transformer base used. Breakaway couplings used for breakaway devices will be measured for payment as each, for each individual coupling used, not as a set of four.

838.05 Basis of Payment. This work will be paid for at the contract unit price per each for BREAKAWAY DEVICE, TRANSFORMER BASE, of the bolt circle indicated; or BREAKAWAY DEVICE, COUPLING WITH ALUMINUM SKIRT OVER STAINLESS STEEL SCREEN, or COUPLING WITH STAINLESS STEEL SCREEN

Figure A-38. State DOT Survey Results – Page 13 – Illinois DOT Attachments, Cont.

13. Please provide the following pole details if not included in the uploaded details/plans:

Pole material

ResponseID	Response
43	galvanized steel or aluminum

Pole thickness

ResponseID	Response
43	varies based on design

Pole height range

ResponseID	Response
43	35' - 45'

Pole diameter range

ResponseID	Response
43	varies based on design

Pole mass range

ResponseID	Response
43	varies based on design

Arm configuration (single or dual)

ResponseID	Response
43	single or dual

Arm length range

Figure A-39. State DOT Survey Results – Page 14

ResponseID	Response
43	15'

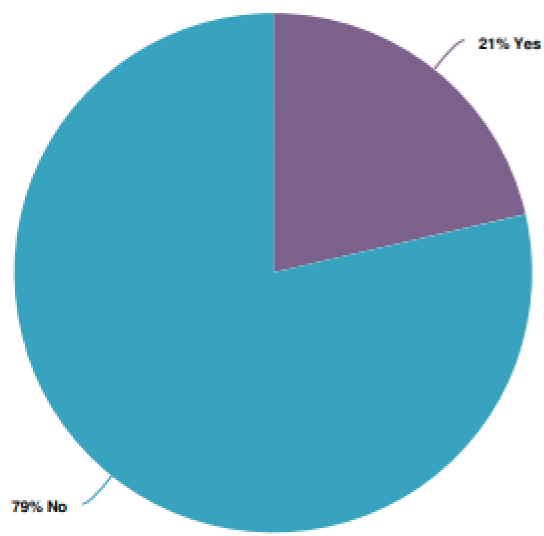
Associated slip base design for different pole configurations

ResponseID	Response

Slip base foundation/base details

Figure A-40. State DOT Survey Results – Page 15

14. Does your organization change the slip base configuration based on the luminaire pole design?



Value	Percent	Responses
Yes	21.4%	3
No	78.6%	11
		Totals: 14

Figure A-41. State DOT Survey Results – Page 16

15. If yes, please provide information deemed pertinent to those changes and/or upload related guidance.

ResponseID	Response
20	Clamp bolt torques change based on pole type designation.
39	The bolt circle depends on the light pole design.
56	It all depends on the diameter of the pole, height of the pole and shape of the pole base (square or round).

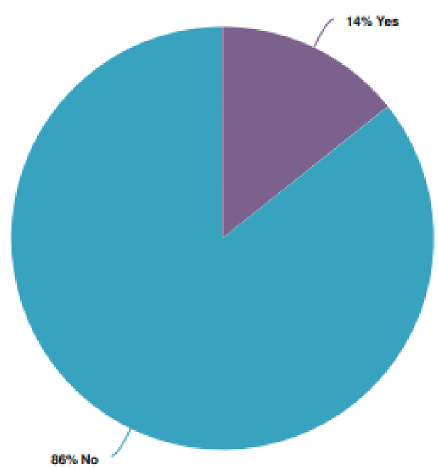
Figure A-42. State DOT Survey Results – Page 17

16. Additional information can be provided using the electronic document upload link.Allowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4 Max file size: 500 KB
0 Files Uploaded

Note that there were no files uploaded by state DOTs

Figure A-43. State DOT Survey Results – Page 18

17. Does your organization have knowledge of safety concerns or performance issues with prior or current Breakaway Luminaire Supports with 3- or 4-bolt Slip Bases identified through in-service performance evaluation, maintenance records, full-scale crash testing, or other means?



Value	Percent	Responses
Yes	14.3%	2
No	85.7%	12
		Totals: 14

Figure A-44. State DOT Survey Results – Page 19

18. If yes, please provide pertinent information and details as it pertains to non-activation of the breakaway mechanism, device penetration into the roof, windshield, and floor pan, or large deformations to the occupant compartment in frontal and side-impact crashes.

ResponseID	Response
20	Our older designs had problems with fatigue cracking of anchor bolts, clamp bolts, and perhaps post to base connections. Increases in bolt circles, bolt diameters, clamp bolt torques and reduction in maximum mast arm length (30' and 25' no longer used) seems to have largely solved the problem. activation problems in service are difficult to report here due to legal / confidentiality issues. A slip base design similar to our luminaires did not activate in a recent MASH low speed car test. It appears it began to slip, but then stopped slipping (perhaps when the tiny gaps in the clamp bolt vs V-slots had been taken up).
39	Illinois DOT has experienced corrosion problems with breakaway couplings in the past. We inspect our couplings, and monitor manufacturer and other state findings to watch for this problem going forward.

Figure A-45. State DOT Survey Results – Page 20

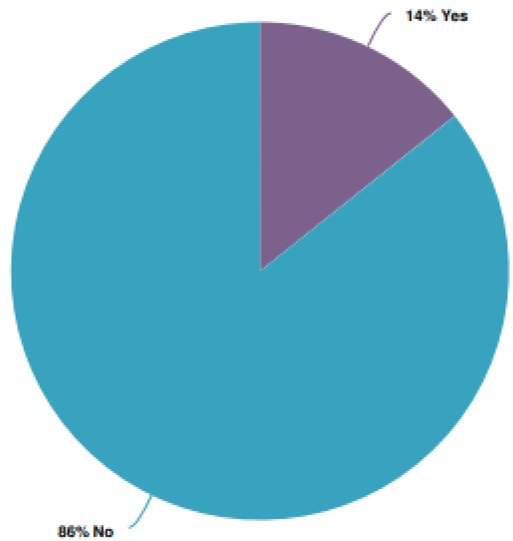
19. Additional information can be provided using the electronic document upload link.Allowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4 Max file size: 500 KB

0 Files Uploaded

Note that there were no files uploaded by state DOTs

Figure A-46. State DOT Survey Results – Page 21

20. Does your state allow additional attachments to slip base mounted luminaire poles? This would include items like cell phone transmitters, wireless internet transmitters, solar power boxes, cameras, or any other additional hardware mounted to the luminaire support outside of the mast arm and light.



Value	Percent	Responses
Yes	14.3%	2
No	85.7%	12
		Totals: 14

Figure A-47. State DOT Survey Results – Page 22

21. If yes, please list currently allowed attachments along with details regarding the attachment itself and its location on the luminaire pole

ResponseID	Response
20	Currently tend to restrict electronics to fairly small and light items and usually require them to be located on pole near center of mass of system or near center of rotation or point of least initial horizontal motion from prior crash test videos. Larger items such as sign panels, if allowed would tend to be lower (not more than 12' from base) but we might place additional restrictions on these lower items based on how difficult it seems to be to get breakaway items to pass MASH testing when it comes to roof/windshield damage. Usually solar panels and battery packs not being allowed new installation on our breakaway poles unless much lighter than usual. Requests for allowing small cell site equipment on breakaway poles could present a challenge due to weight and wind area.
55	ITS devices (RUS etc.), solar panels, junction boxes, etc. for new standard drawings of luminaire poles (AASHTO LRFDLTS). Existing standards with transformer base only supports lighting but can be used for ITS devices if loads not excessive.

Figure A-48. State DOT Survey Results – Page 23

22. Additional information can be provided using the electronic document upload link.Allowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4 Max file size: 500 KB
0 Files Uploaded

Note that there were no files uploaded by state DOTs

Figure A-49. State DOT Survey Results – Page 24

23. What is the typical size and configuration of the wiring for the luminaire pole?

Count	Response
1	Will have to get back to you later on this one
1	SCDOT does not employ slip base luminaire poles. We specify and use frangible couplings for most poles and have allowed fiberglass direct burial (Shakespeare breakaway poles). The sizing of the wiring is determined by the contractor installing the lighting system. We require the use of breakaway electrical disconnects, specifying waterproof in-line fuse types.
1	N/A, we do not use slip bases of any type
1	Typical wiring is No. 10 copper, continuous from luminaire to controller. Wiring is covered by our Standard Specifications, Section 821 (attached below).
1	Per the NCDOT Standard Specifications and Standard Drawings, the wiring in the pole to the luminaire is required to be 12 AWG Type SOOW cord.
1	Underground is typically 4c 4AWG direct buried cable Up pole is 12-2 (with ground) UF cable within the light pole
1	N/A
1	We do not have a typical. The size and configuration depends on the lighting system design.

Figure A-50. State DOT Survey Results – Page 25

24. Is there additional wiring for other attached hardware or devices? If so, please provide details.

Count	Response
1	Will have to get back to you later on this one.
1	Our lighting systems, including the poles, wiring, and cabinets, are not designed to incorporate additional hardware, or devices.
1	N/A, we do not use slip bases of any type
1	No other attached hardware is allowed.
1	N/A

Figure A-51. State DOT Survey Results – Page 26

25. Does your state utilize/require breakaway wiring connections for slip base supported luminaire poles? If so, please provide details on the breakaway wiring connector used.

Count	Response
1	We include a detail for the live wire for the luminaire to be kinked. This is to make sure the pole is de-energized after a crash. For added wiring we often ask for some kind of unplugging connection, but would be helpful to have research and guidance on what should be acceptable
1	We use breakaway transformer base TB 17-1 for our lighting poles.
1	We do not utilize slip base supported luminaire poles. We do require breakaway wiring connections for breakaway poles using other means to separate safely during impact.
1	N/A, we do not use slip bases of any type
1	Yes. Breakaway fuseholders are required for all single arm and dual arm poles.
1	MnDOT has an approved product list of breakaway fuses. An issue has been the ability to breakaway the neutral with the hot wires. We are currently working with a manufacturer that is making a device for us that will be UL (or NRTL) listed and will breakaway the 2 hots and the neutral with one device.
1	N/A
1	Yes, we require breakaway couplings when during a breakaway base.

Figure A-52. State DOT Survey Results – Page 27

26. Additional information can be provided using the electronic document upload link.Allowed types: png, gif, jpg, jpeg, doc, xls, docx, xlsx, pdf, txt, mov, mp3, mp4 Max file size: 500 KB

2 Files Uploaded

Figure A-53. State DOT Survey Results – Page 28

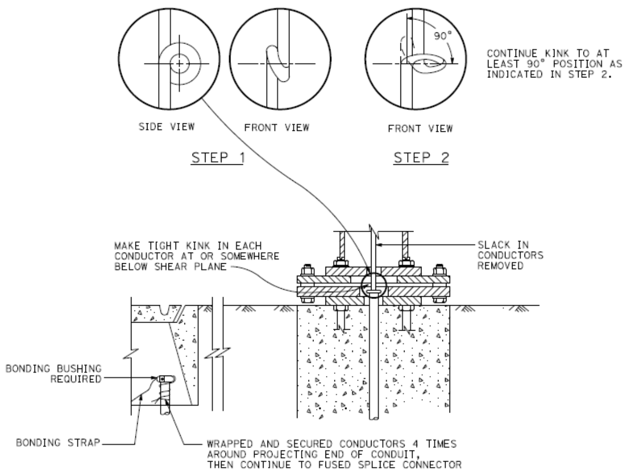
545

CIRCUIT VOLTAGE	FUSE VOLTAGE RATING	FUSE CURRENT RATING						
		HPS LAMP BALLAST		LOW PRESSURE SODIUM BALLAST	INDUCTION SIGN LIGHTING	SINGLE PHASE (TWO WIRE) TRANSFORMERS (PRIMARY SIDE)		
		70 W	100 W	180 W	85 W	1 kVA	2 kVA	3 kVA
120 V	250 V	5 A	5 A	5 A	5 A	10 A	20 A	30 A
240 V	250 V	5 A	5 A	5 A	5 A	6 A	10 A	20 A
480 V	500-600 V	5 A	5 A	3 A	1 A (SEE NOTE 2)	3 A	6 A	10 A

NOTES:

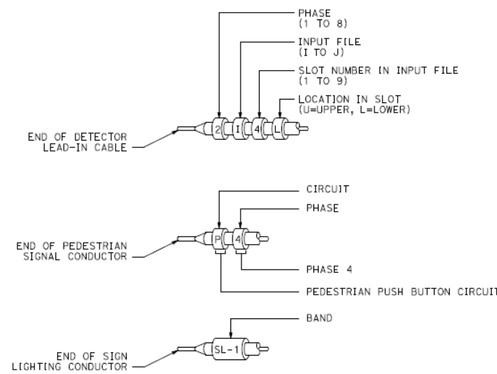
1. Primary lines of multiple ballasts shall be provided with fused connectors. Fuse ratings shall be as noted above.
2. See Standard Plan ES-15D, Type SC3 control.

FUSE RATINGS FOR FUSED CONNECTORS



KINKING DETAIL FOR SLIP BASE STANDARDS

DETAIL A



TYPICAL BANDING DETAILS

DETAIL B

Dist	COUNTY	ROUTE	POST MILES TOTAL PROJECT	SHEET No.	TOTAL SHEETS

REGISTERED ELECTRICAL ENGINEER

May 31, 2018

PLANS APPROVAL DATE

THE STATE OF CALIFORNIA OR ITS OFFICERS OR AGENTS SHALL NOT BE RESPONSIBLE FOR THE ACCURACY OR COMPLETENESS OF SCANNED COPIES OF THIS PLAN SHEET.

REGISTERED PROFESSIONAL ENGINEER Hamid Zolfaghari No. E15636 Exp. 12-31-19 ELECTRICAL STATE OF CALIFORNIA

2018 STANDARD PLAN ES-13B

STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION

ELECTRICAL SYSTEMS (FUSE RATING, KINKING AND BANDING DETAIL)

NO SCALE

ES-13B

1-26-18

Figure A-54. State DOT Survey Results – Page 28 – Caltrans Attachments

Illinois Department of Transportation

Information below extracted from the Standard Specifications for Road and Bridge Construction

SECTION 821. ROADWAY LUMINAIRES

821.01 Description. This work shall consist of furnishing and installing a luminaire.

821.02 Materials. Materials shall be according to the following.

Item Article/Section

(a) Luminaire 1067

(b) Wire in the Pole 1066.09

(c) Fuseholders and Fuses 1065.01

(d) Lamps 1067.06

(e) Fasteners and Hardware 1088.03

(f) Lightning Protection 1065.02

CONSTRUCTION REQUIREMENTS

821.03 General. Each luminaire shall be installed according to the luminaire manufacturer's recommendations.

Luminaires which are pole mounted shall be mounted on site such that poles and arms are not left unloaded. Pole mounted luminaires shall be leveled/adjusted after poles are set and vertically aligned before being energized. When mounted on a tenon, care shall be exercised to ensure maximum insertion of the mounting tenon.

Each luminaire ballast and/or ballast arrangement shall be checked to ensure compatibility with the project power system. When the luminaire has a multi-tap ballast, the tap shall be adjusted as necessary to ensure a voltage match.

When the night-time check of the lighting system by the Engineer indicates that any luminaires are misaligned, the misaligned luminaires shall be corrected at no additional cost. Should the photometric results of the luminaire indicate, in the

Figure A-55. State DOT Survey Results – Page 28 – Illinois DOT Attachments judgment of the Engineer, a tilt adjustment is warranted, the adjustment shall be made at no additional cost.

No luminaire shall be installed before it is approved. Where independent testing is required, full approval will not be given until complete test results, demonstrating compliance with the specifications, have been reviewed and accepted by the Engineer.

Pole wiring shall be provided with the luminaire. Included with the pole wiring shall be a surge protection device and fusing located in the handhole. Wire shall be trained within the pole or sign structure so as to avoid abrasion or damage to the insulation.

Pole wire shall be extended through the pole, pole grommet, luminaire ring, and any associated arm and tenon. The pole wire shall be terminated in a manner that avoids sharp kinks, pinching, pressure on the insulation, or any other arrangement prone to damaging insulation value and producing poor megger test results. Wires shall be trained away from heat sources within the luminaire. Wires shall be terminated so all strands are extended to the full depth of the terminal lug with the insulation removed far enough so it abuts against the shoulder of the lug, but is not compressed as the lug is tightened.

When installing the lamp or performing any other activity that requires opening of the optical assembly, care shall be exercised to avoid touching the reflector or allowing contaminants to enter the assembly. Each lamp and lens shall be free of all dirt, smudges, etc. Should the reflector or refractor require cleaning, a mild soap or non-abrasive detergent, containing no chlorinated or aromatic hydrocarbons, shall be used and then rinsed clean with cold water and wiped dry.

821.04 Conventional Pole Installation. Horizontal mount luminaires shall be installed in a level, horizontal plane, with adjustments as needed to ensure the optics are set perpendicular to the traveled roadway.

When the pole is bridge mounted, a minimum size stainless steel 1/4-20NC set

Figure A-56. State DOT Survey Results – Page 28 – Illinois DOT Attachments, Cont.

screw shall be provided to secure the luminaire to the mast arm tenon. A hole shall be drilled and tapped through the tenon and luminaire mounting bracket and then fitted with the screw.

821.05 Highmast Installation. Luminaires having asymmetrical photometric distributions shall be carefully oriented with respect to the roadway as indicated on the plans and as directed by the Engineer. The Contractor shall confirm all luminaire orientations with the Engineer prior to installation.
For horizontal mounts having rotating optical assemblies, after the orientation of each mast arm tenon is inspected and approved by the Engineer, the position shall be permanently marked in a manner acceptable to the Engineer. The luminaire shall then be leveled to the plane of the luminaire ring.
When the luminaire position and orientation has been confirmed and approved by the Engineer, the luminaire shall be anchored with a minimum size 1/4-20NC stainless steel bolt installed through tapped holes in the tenon and mounting bracket of the luminaire. The bolt shall not penetrate into the tenon more than 1/4 in. (6 mm). Counterweights on un-used tenons shall be mounted in a similar manner.
Pre-installed wire on the tower ring shall have the ends of each wire capped at the tenon with butt type crimp-connectors for un-used tenons. The wires shall then be re-inserted into the tenon end and the tenon end shall be capped.

821.06 Underpass Installation. When attached directly to a structure, the underpass luminaire shall have stainless steel brackets installed between the luminaire and the structure to create a gap of not less than 1 in. (25 mm).
When specified, an aluminum underpass luminaire numbering decal bracket for each underpass luminaire shall be installed as shown on the plan. The bracket shall be large enough to accommodate the identification and shall be mounted on the pier or retaining wall from which the luminaires are electrically fed as directed by the Engineer.

Figure A-57. State DOT Survey Results – Page 28 – Illinois DOT Attachments, Cont.

When suspended, the underpass luminaire shall be installed 1 in. (25 mm) above the lowest underpass beam and shall be mounted parallel to the plane of the roadway, taking into consideration the applicable grade and superelevation of the traveled lanes. Vibration dampening assemblies shall be used and sized to the weight and shape of the underpass luminaire. All mounting hardware, including the vibration dampers, shall be stainless steel.

The underpass luminaire shall include, from the junction box mounted at the abutment to the luminaire(s), all conduit, fittings, attachment hardware, cable, and stainless steel junction boxes required to complete the branch circuit.

821.07 Sign Lighting Installation. Each luminaire shall be mounted on the sign walkway structure with stainless steel hardware and with at least three points of attachment. The mounted luminaire or mounting hardware shall not extend above the bottom of the sign or below the bottom of the walkway support.

The center-to-center spacing of the luminaires will be determined by the Engineer. The end sections shall not exceed one-half the spacing between luminaires.

The mounting shall provide the correct position of the luminaire as recommended by the manufacturer and shall be able to withstand assigned loading according to AASHTO. The sign lighting installation shall include, from the sign truss handhole to the luminaire, all aluminum conduit, fittings, attachment hardware, cable, and a stainless steel disconnect switch with lockable exterior handle mounted within reach from the walkway.

Disabling brightness shall be shielded from traffic approaching either the front or back of the sign.

821.08 Basis of Payment. This work will be paid for at the contract unit price per each for LUMINAIRE, of the lamp type, mount type, and wattage specified; UNDERPASS LUMINAIRE, of the wattage and lamp type specified; or SIGN

Figure A-58. State DOT Survey Results – Page 28 – Illinois DOT Attachments, Cont.

Appendix B. Standard Plans for Luminaire Poles Supported by Slip Bases

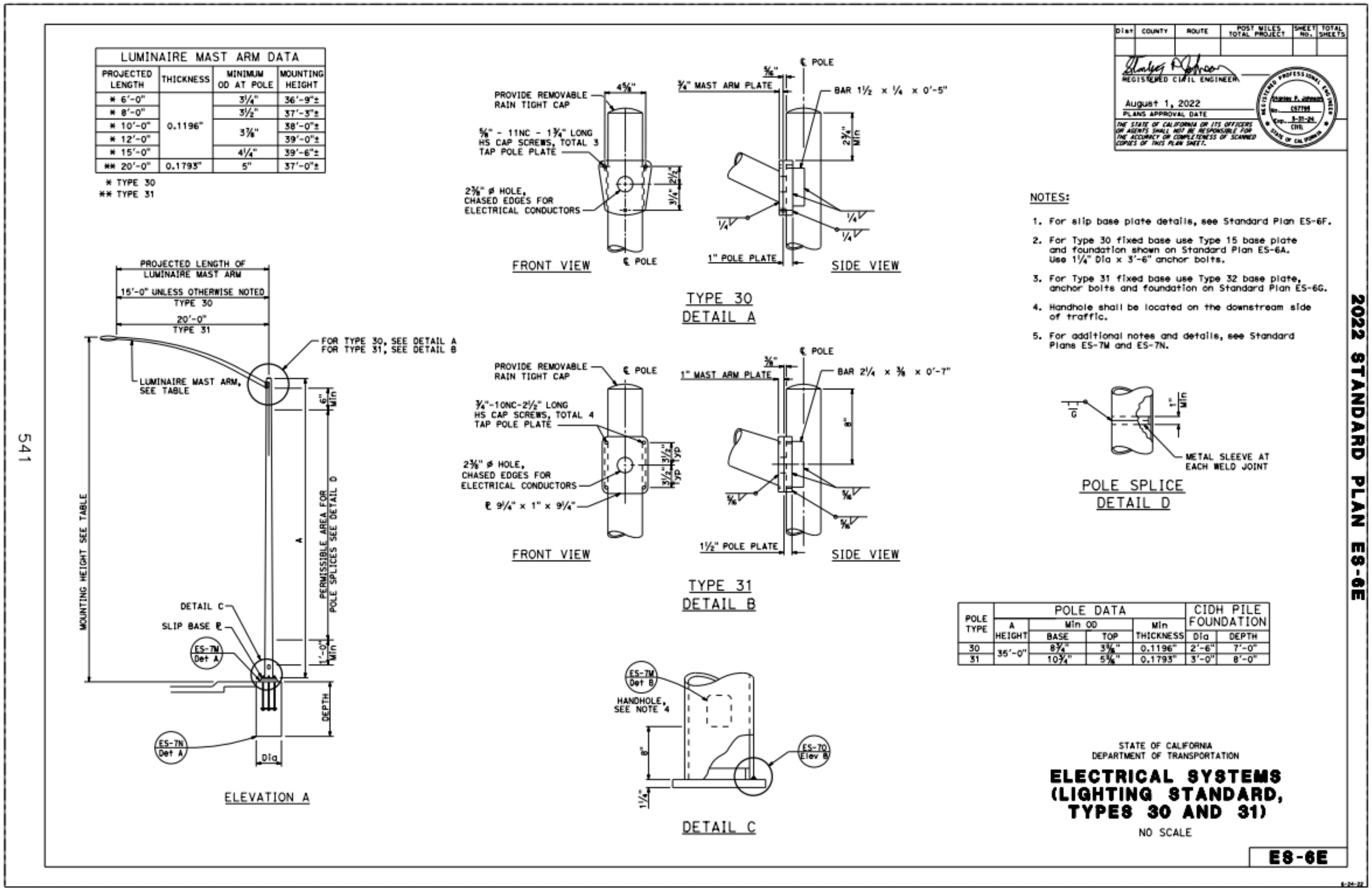


Figure B-1. Caltrans Luminaire Pole and Slip Base Standard Plans [8]

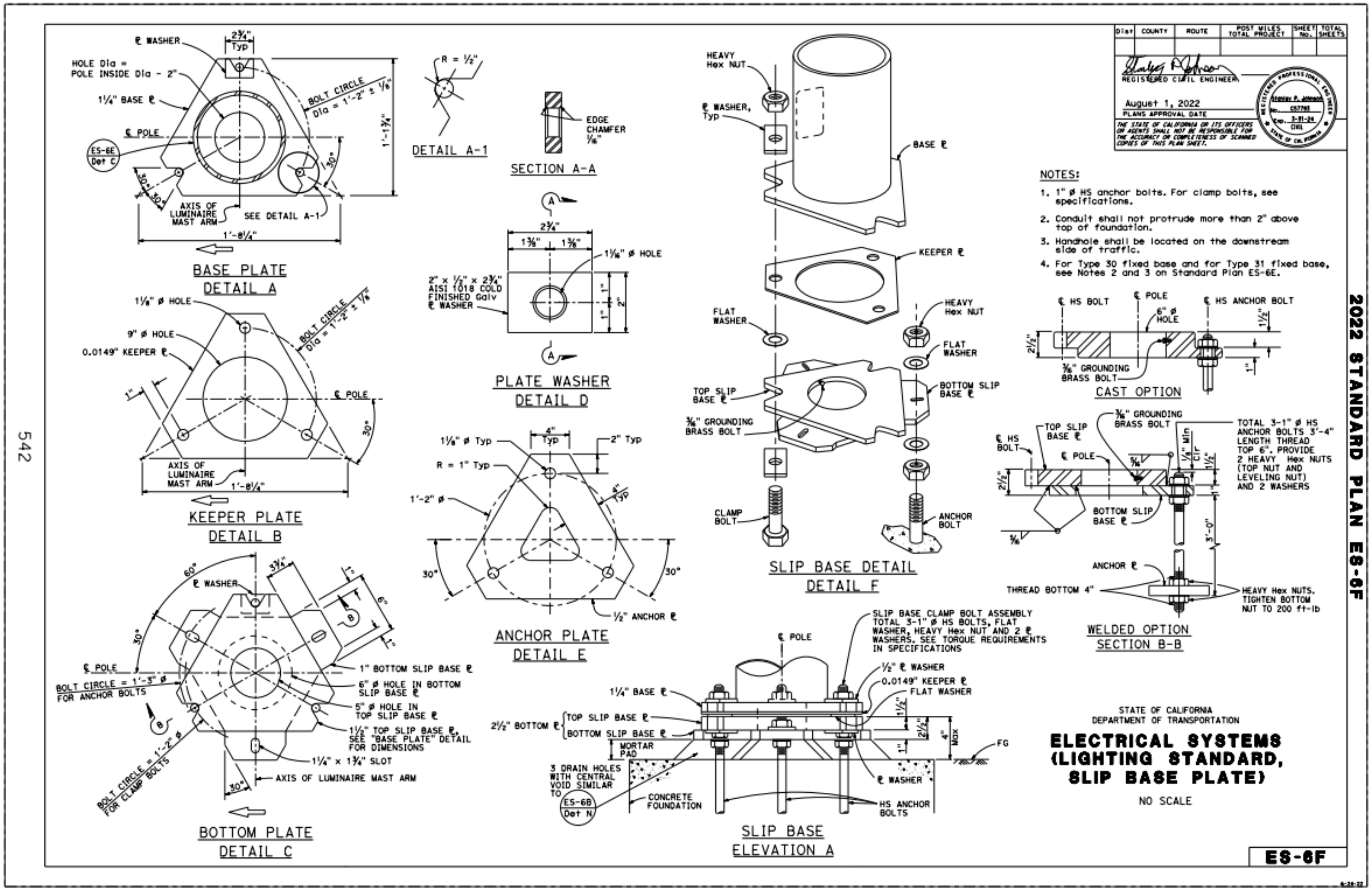


Figure B-2. Caltrans Luminaire Pole and Slip Base Standard Plans, Cont. [8]

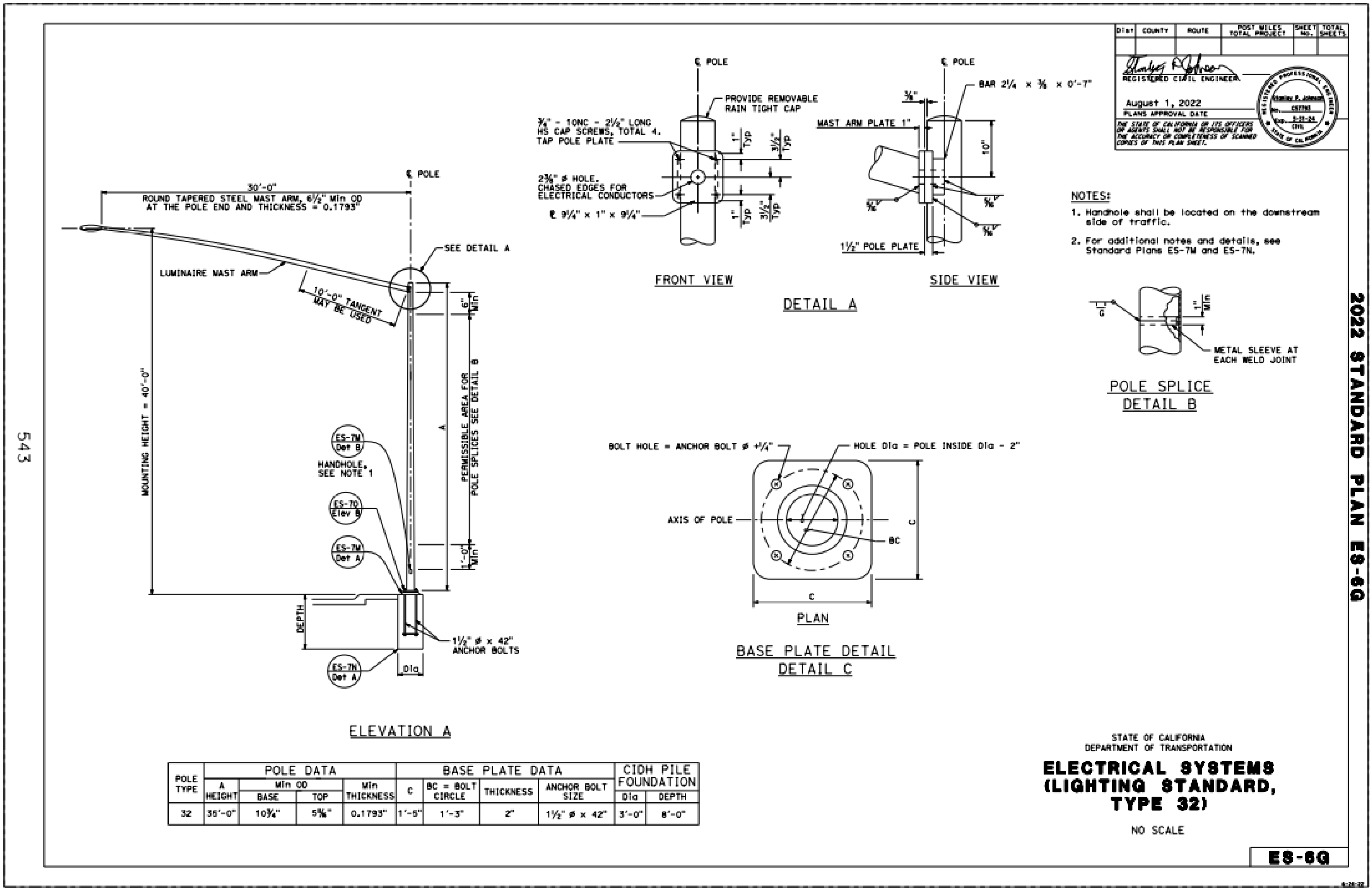


Figure B-3. Caltrans Luminaire Pole and Slip Base Standard Plans, Cont. [8]

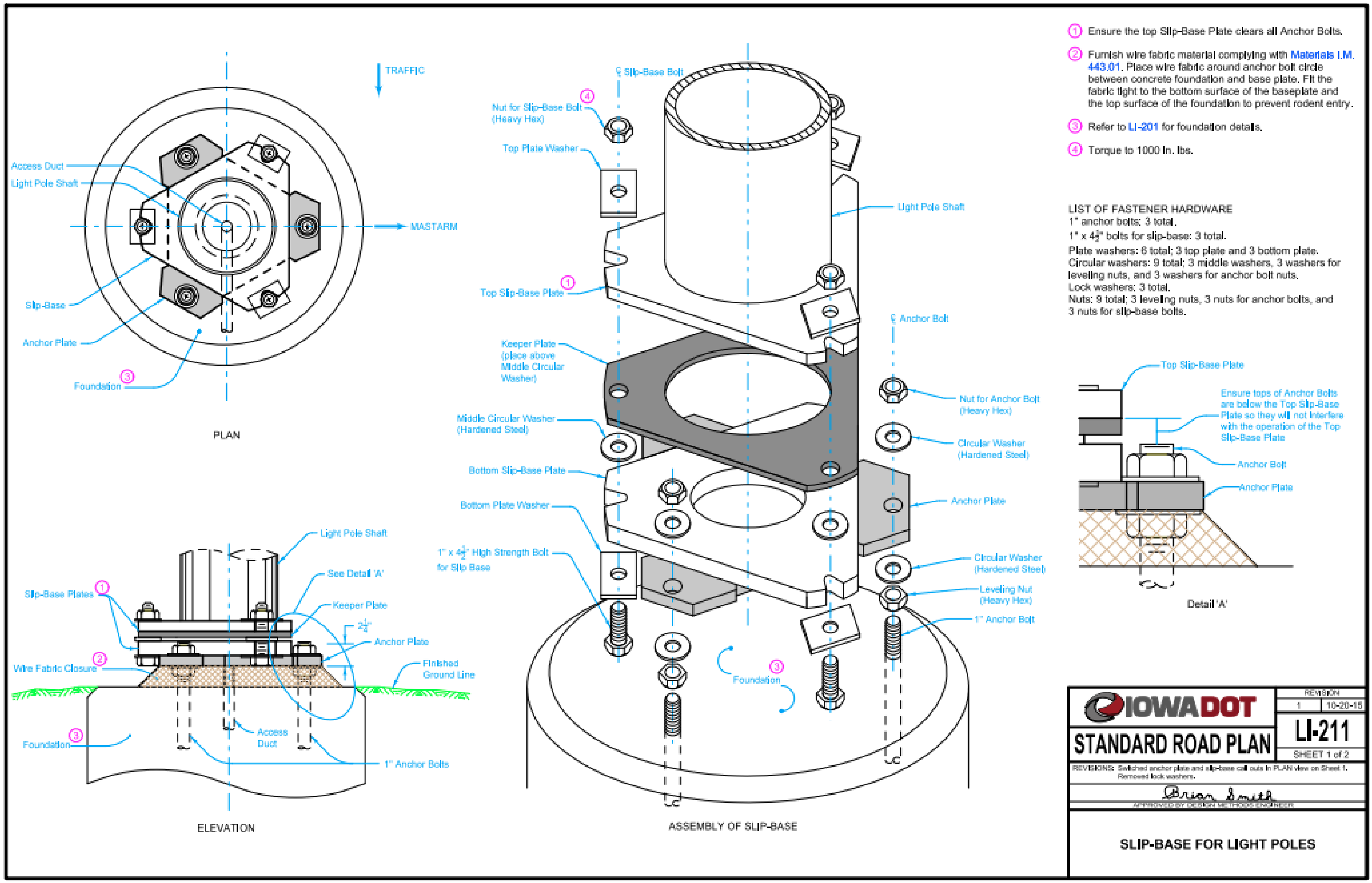


Figure B-4. Iowa DOT Luminaire Pole and Slip Base Standard Plans [10]

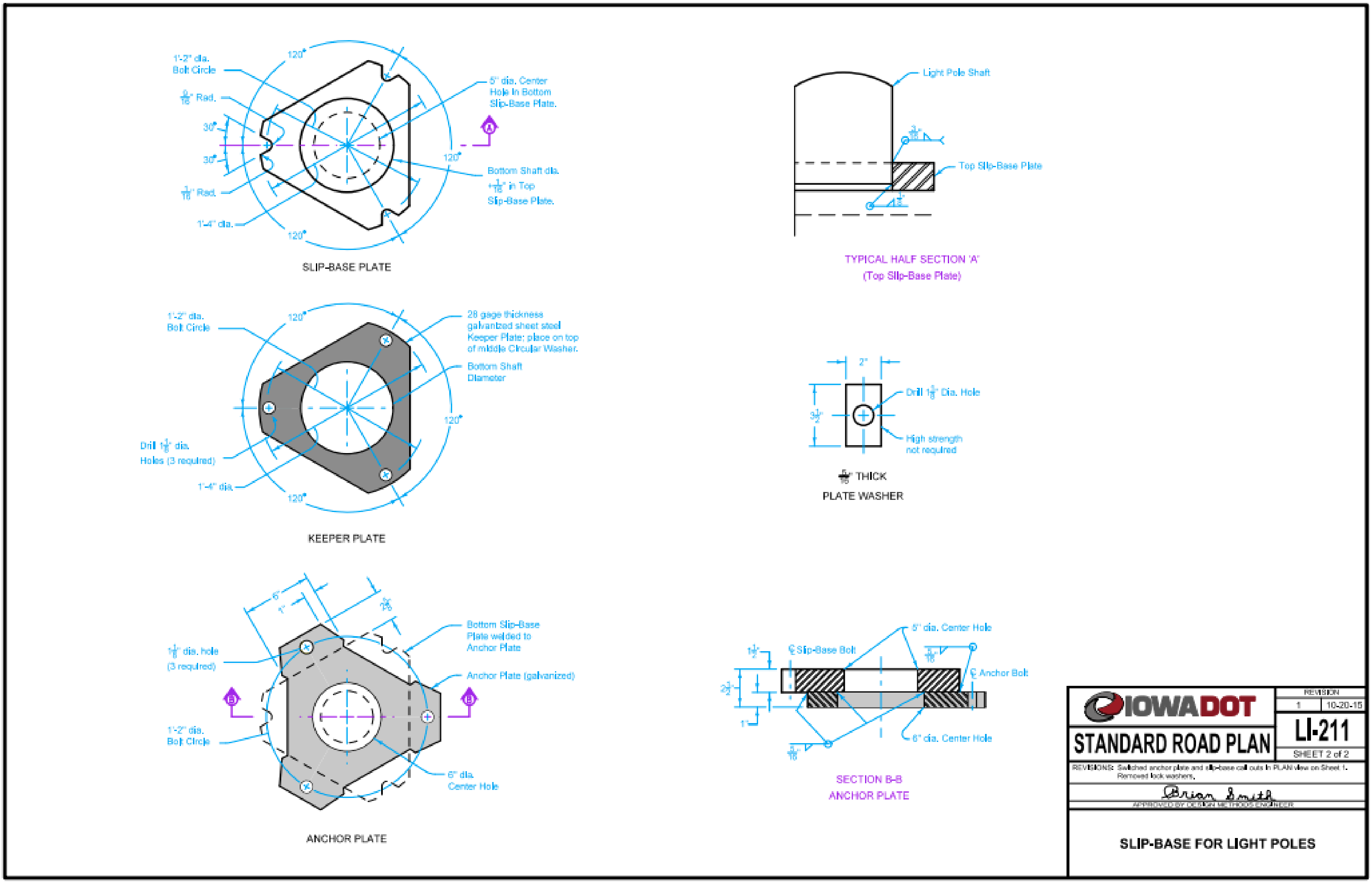


Figure B-5. Iowa DOT Luminaire Pole and Slip Base Standard Plans, Cont. [10]

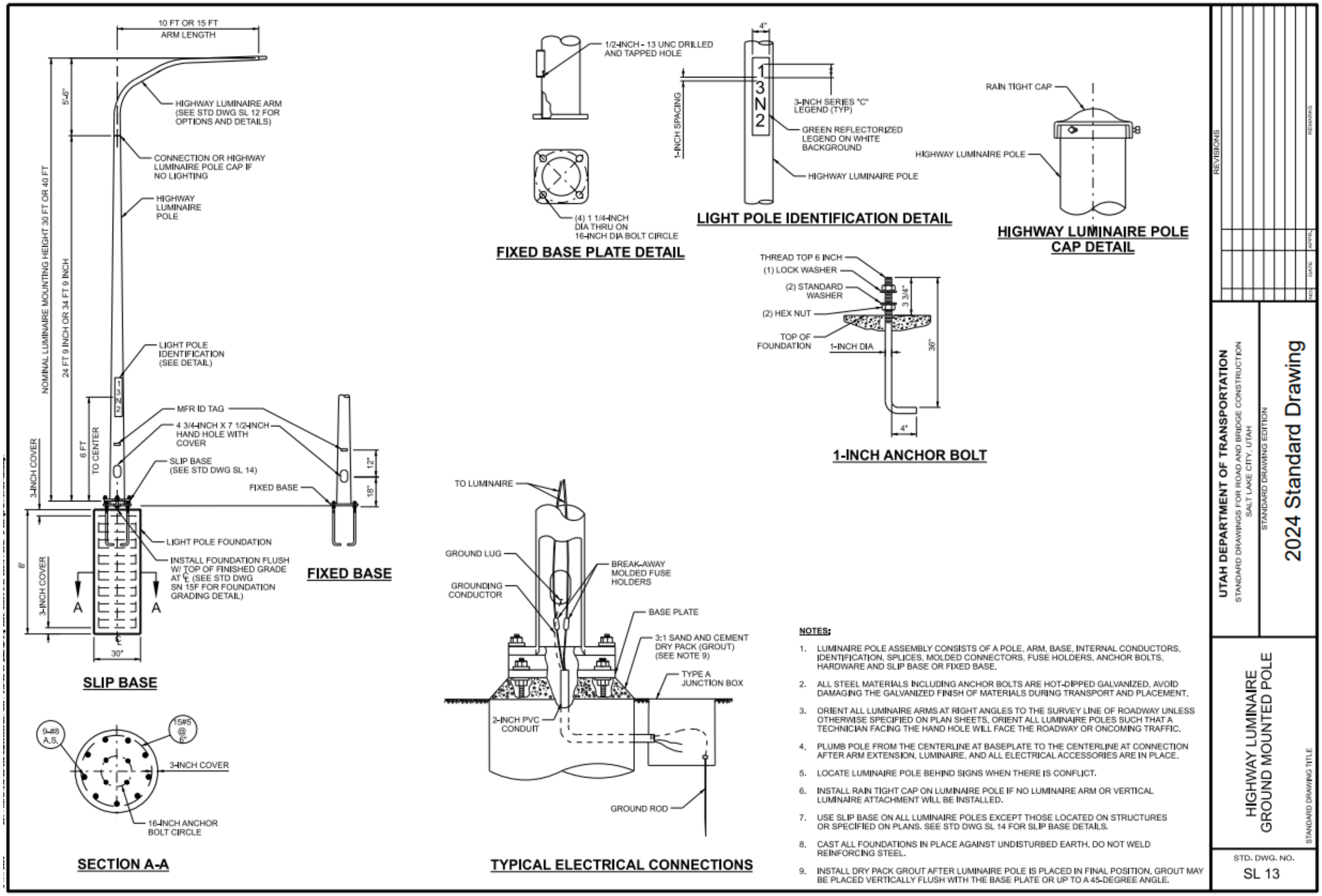


Figure B-6. Utah DOT Luminaire Pole and Slip Base Standard Plans [11]

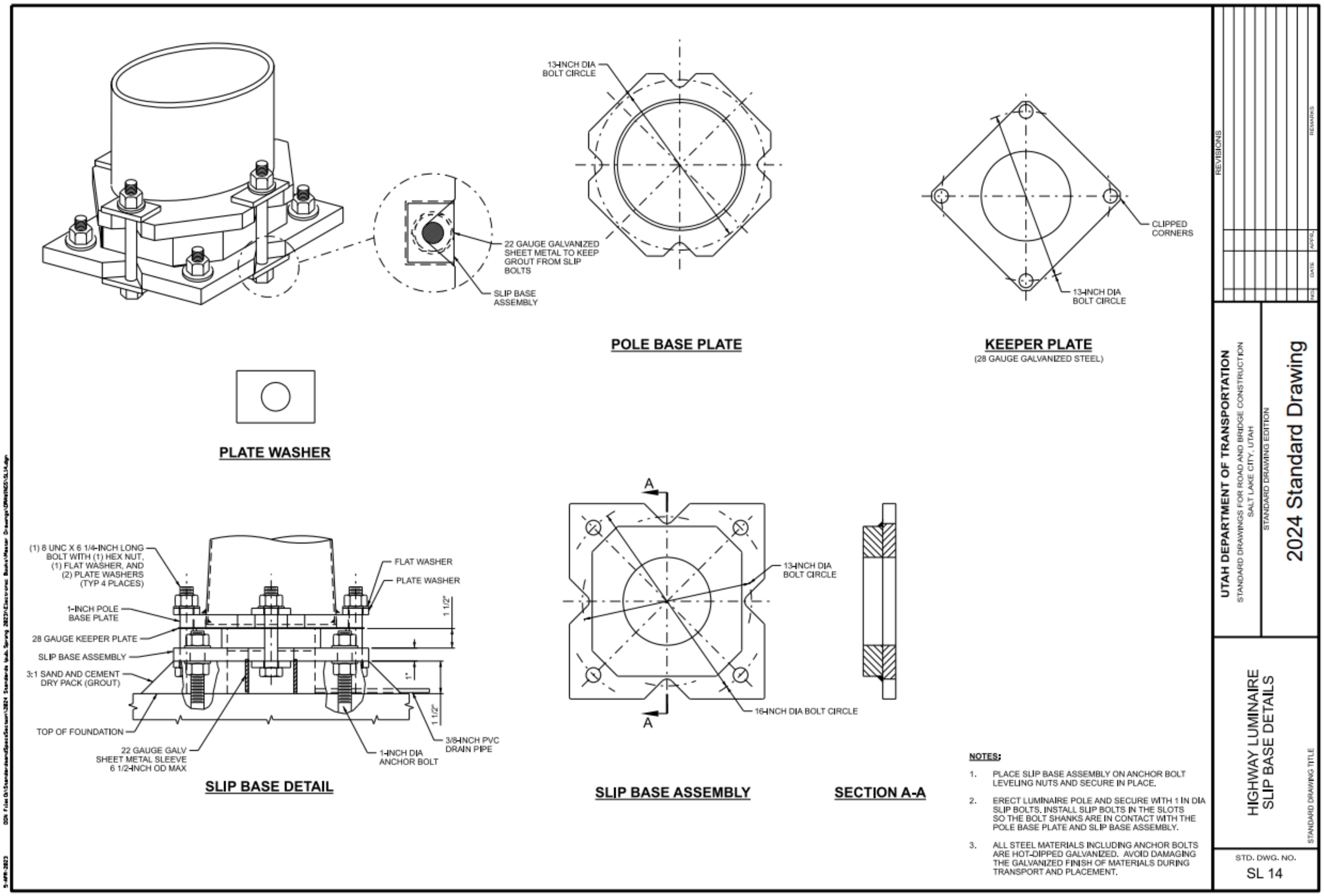


Figure B-7. Utah DOT Luminaire Pole and Slip Base Standard Plans, Cont. [11]

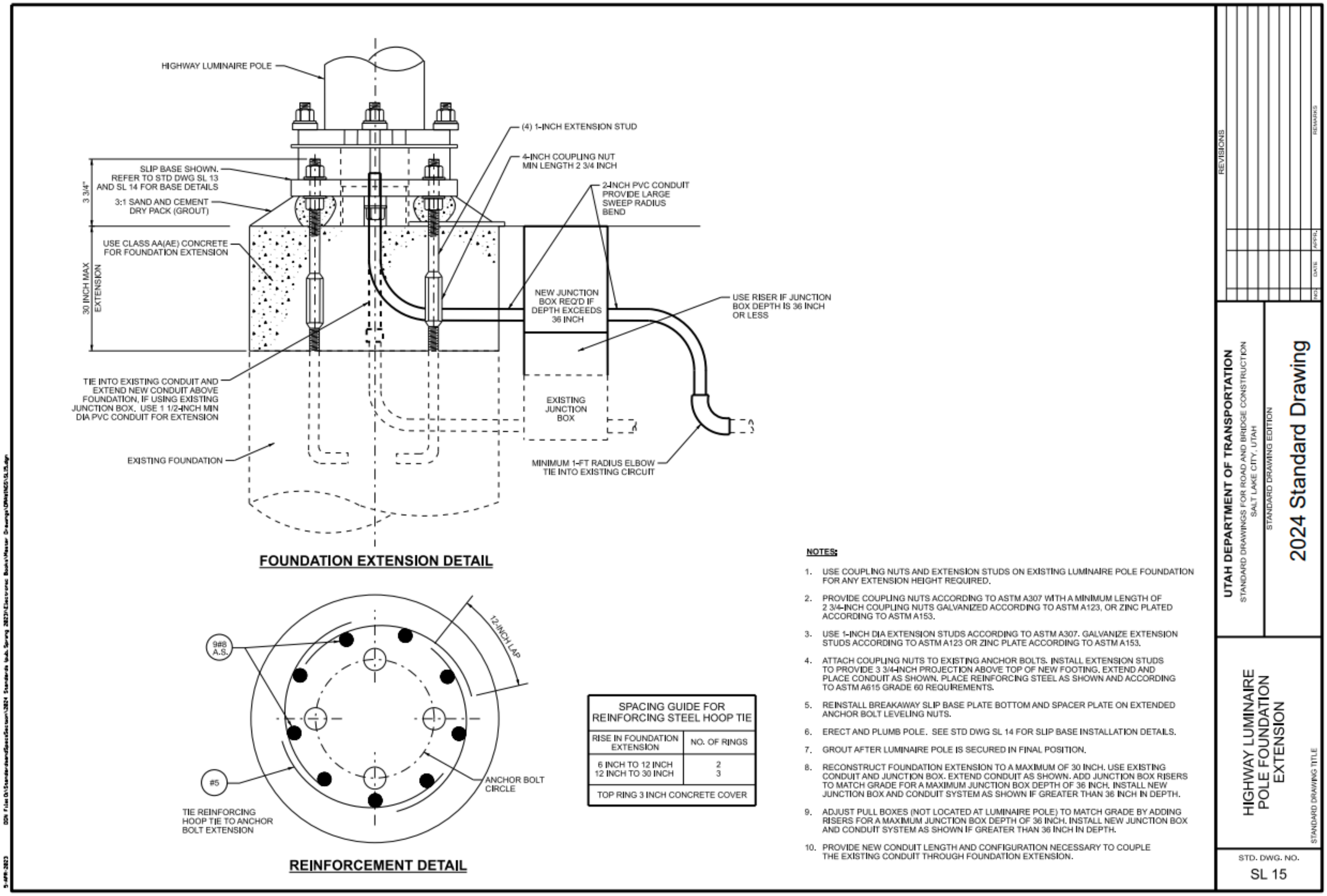


Figure B-8. Utah DOT Luminaire Pole and Slip Base Standard Plans, Cont. [11]

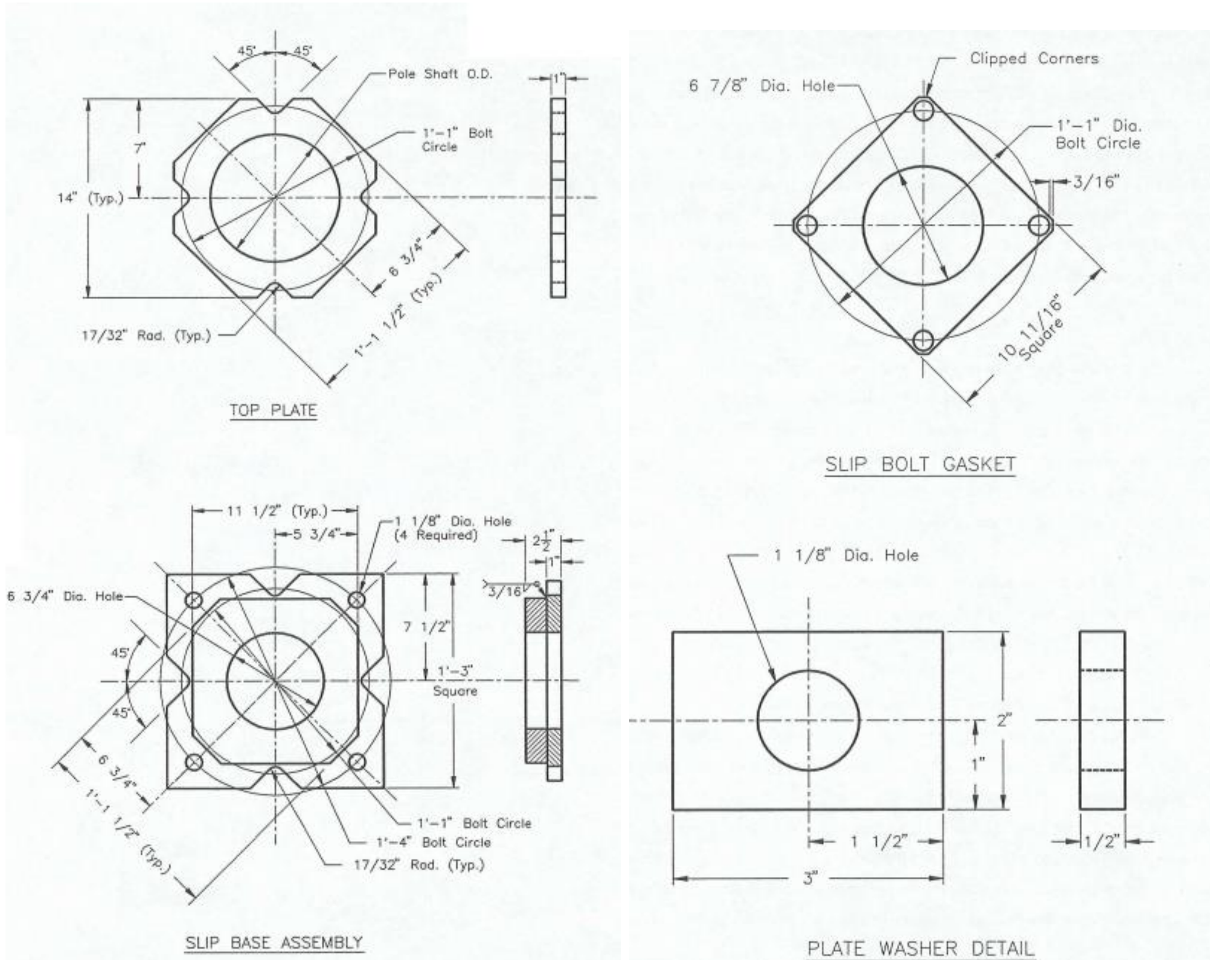


Figure B-9. Wyoming Luminaire Pole and Slip Base Standard Plans [13]

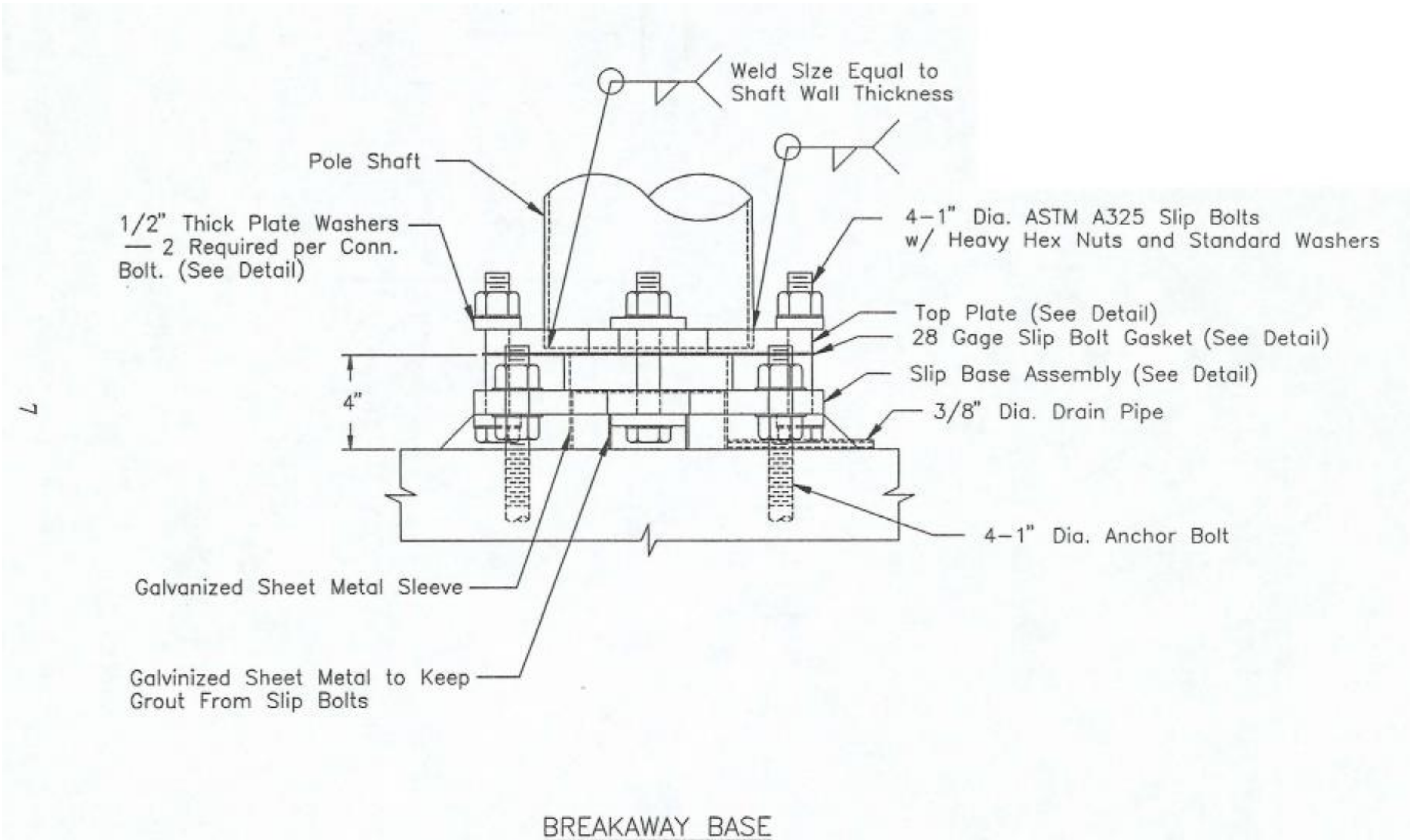


Figure B-10. Wyoming Luminaire Pole and Slip Base Standard Plans, Cont. [13]

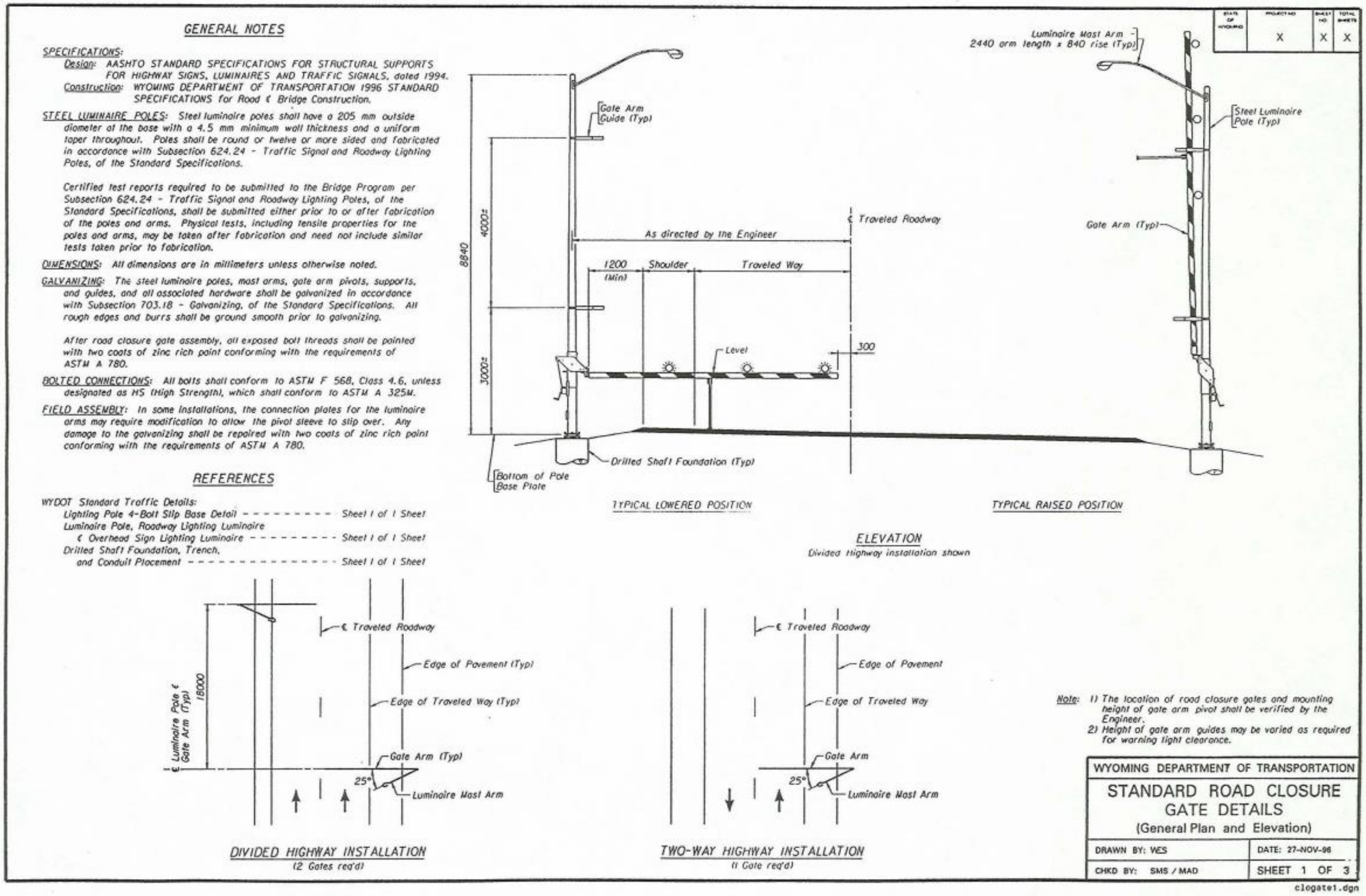


Figure B-11. Wyoming DOT Luminaire Pole and Slip Base Standard Plans, Cont. [13]

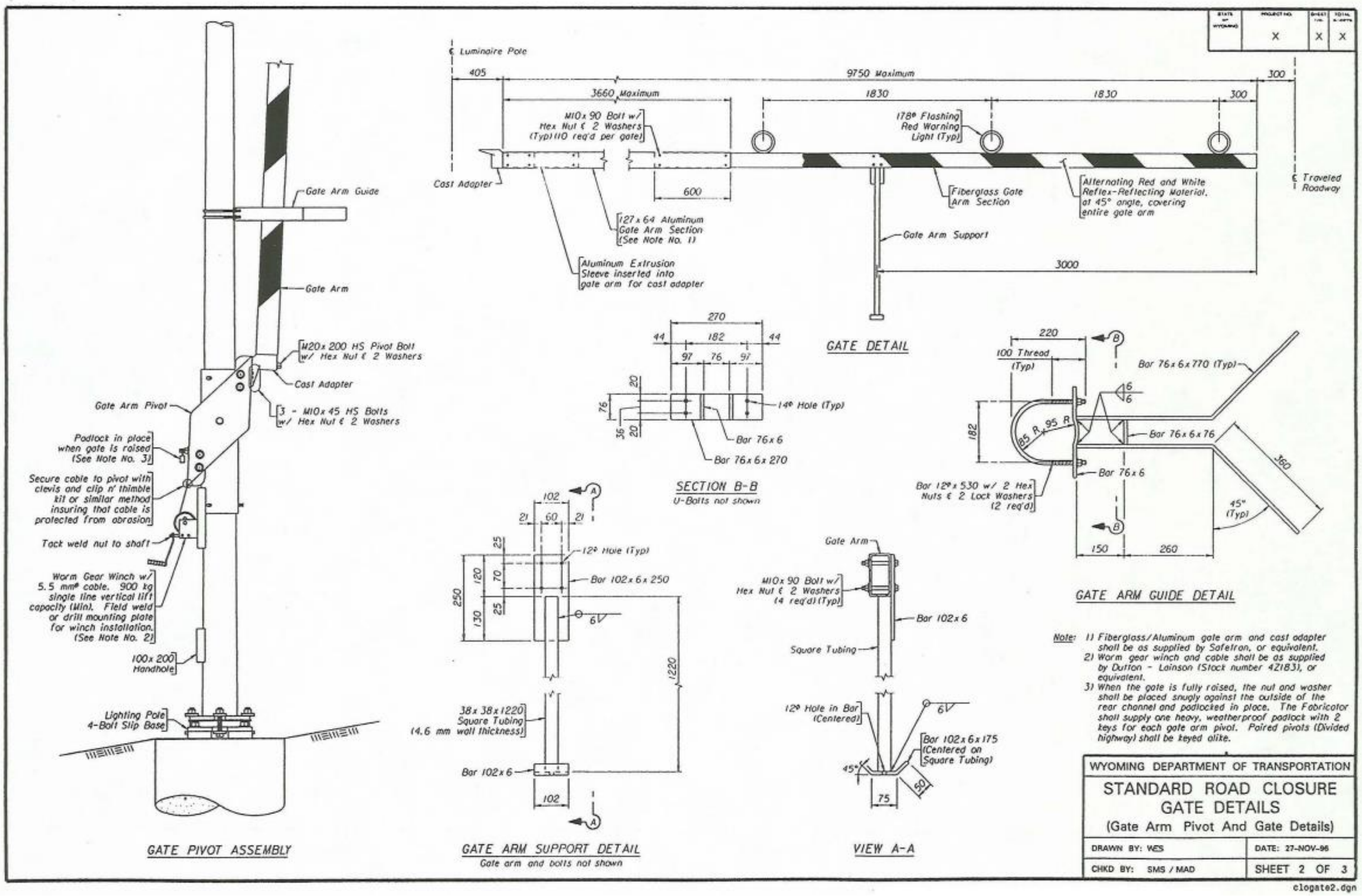


Figure B-12. Wyoming Luminaire Pole and Slip Base Standard Plans, Cont. [13]

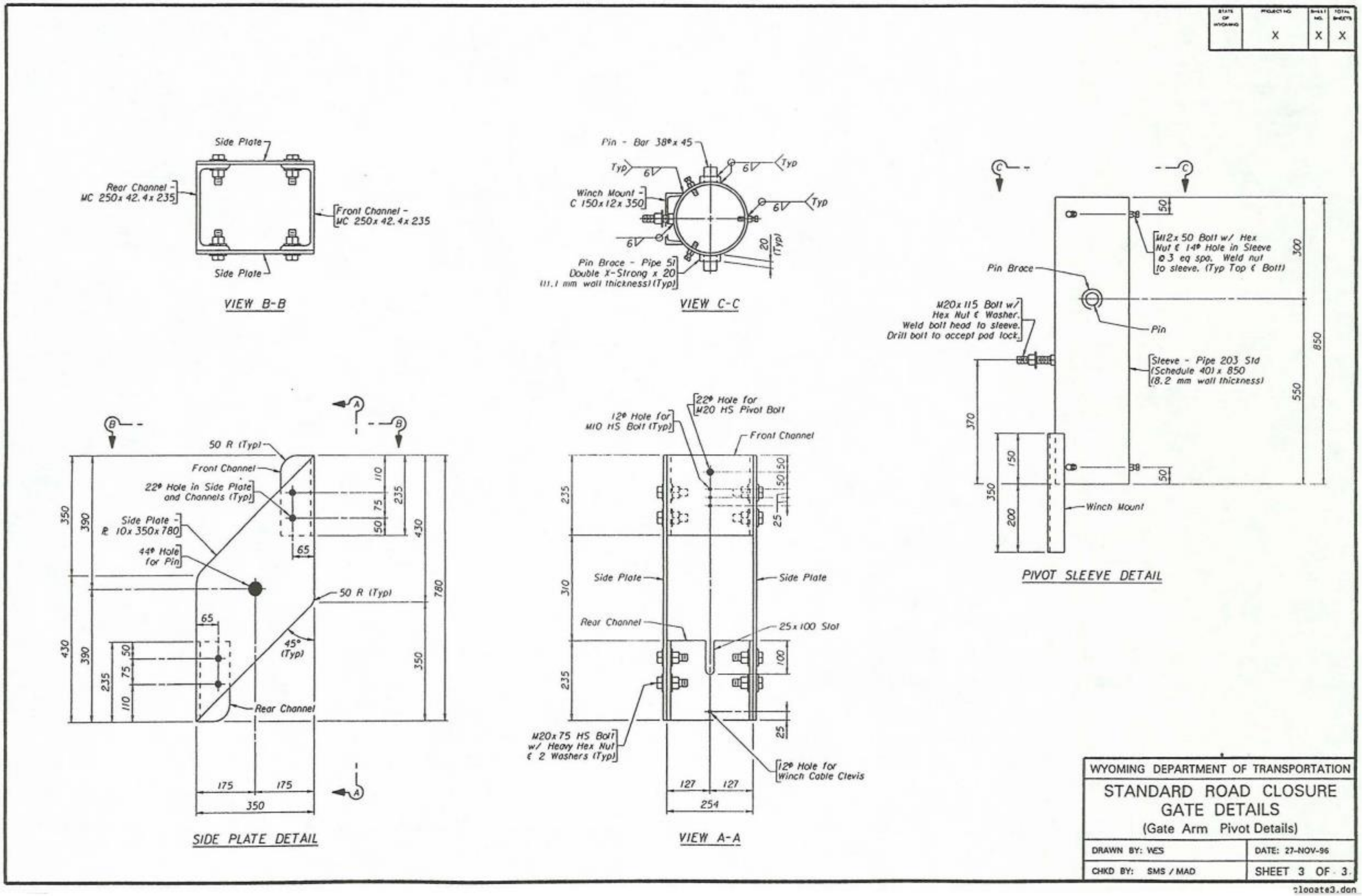


Figure B-13. Wyoming DOT Luminaire Pole and Slip Base Standard Plans, Cont. [13]

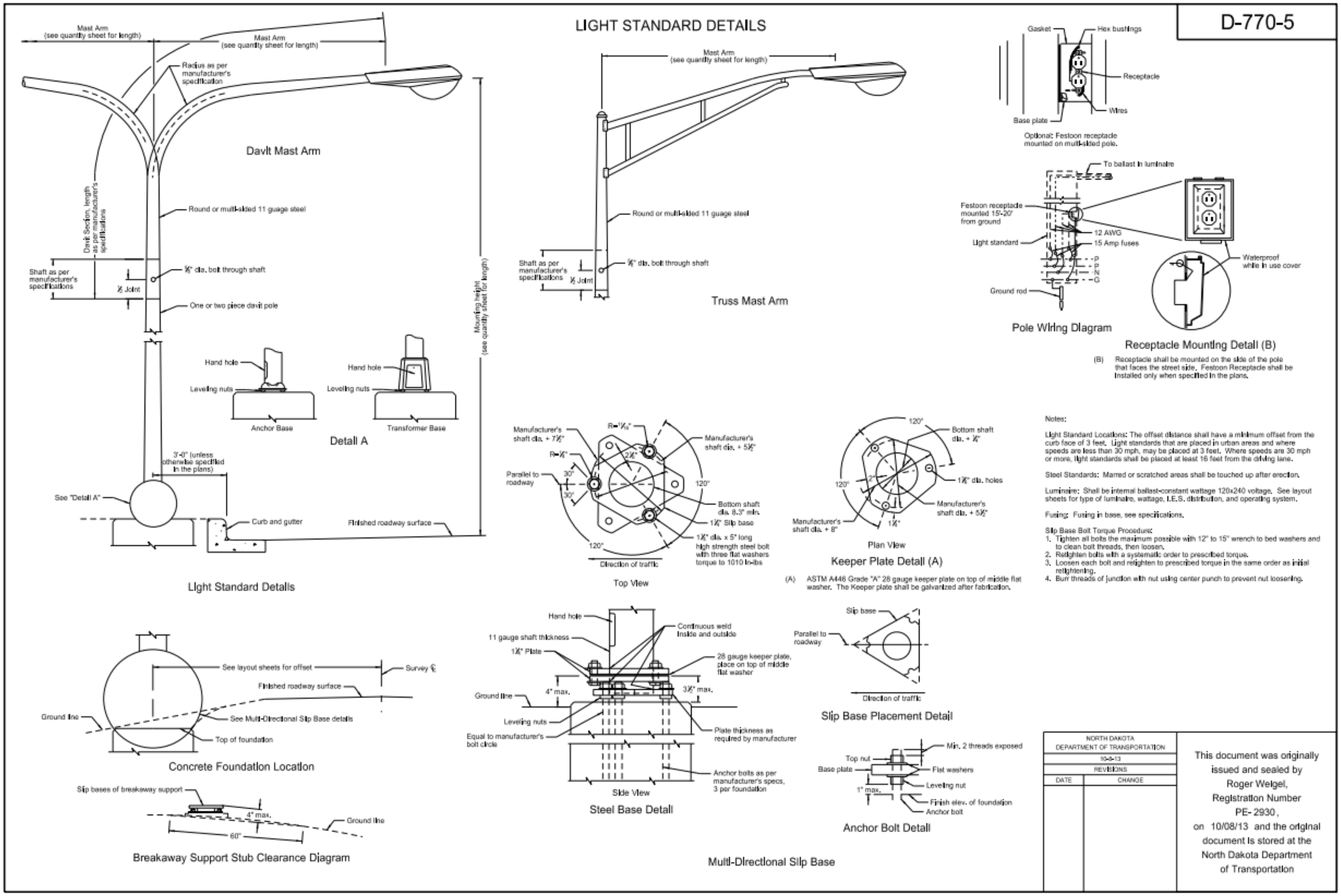


Figure B-14. North Dakota DOT Luminaire Pole and Slip Base Standard Plans [17]

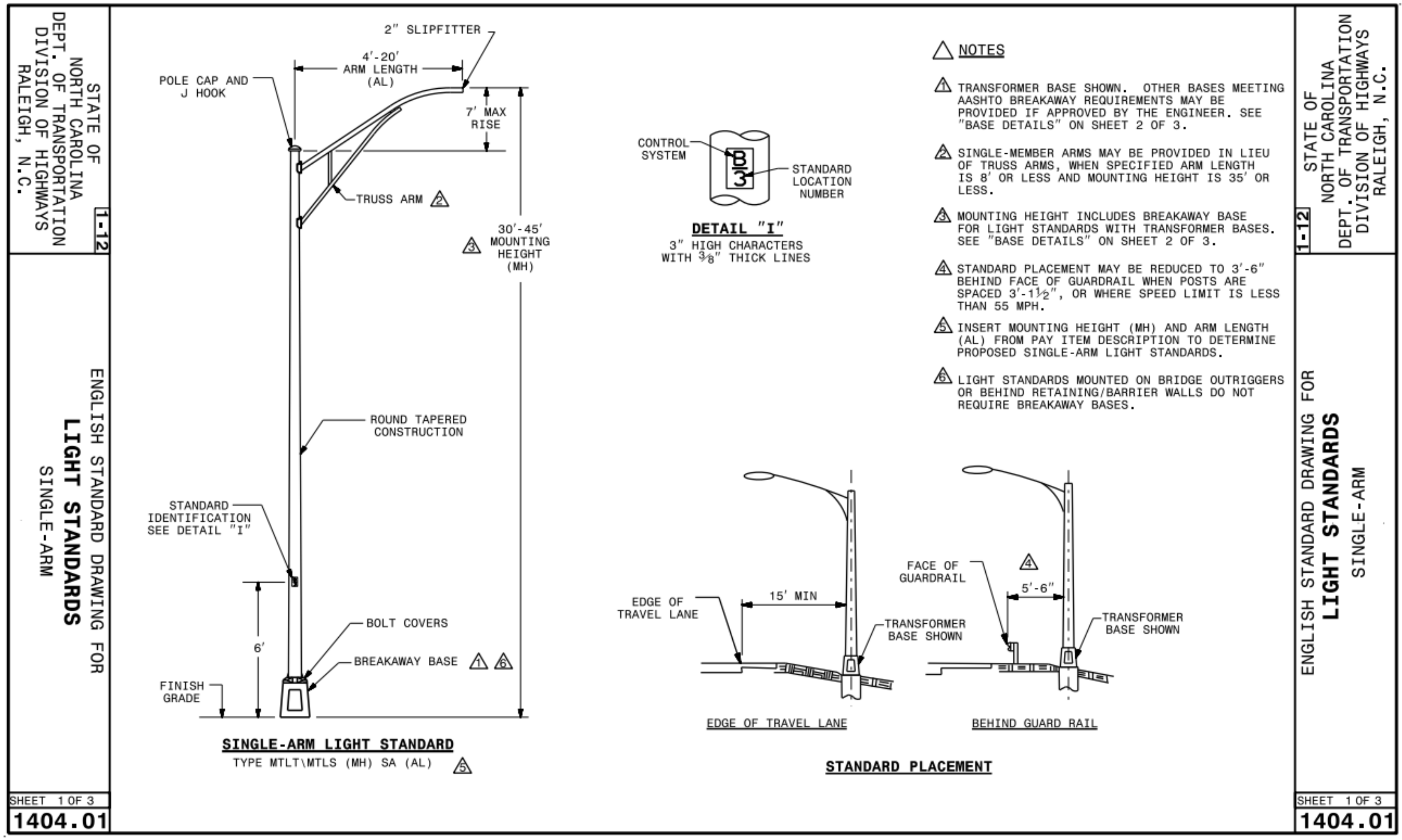


Figure B-15. North Carolina DOT Luminaire Pole and Slip Base Standard Plans [15]

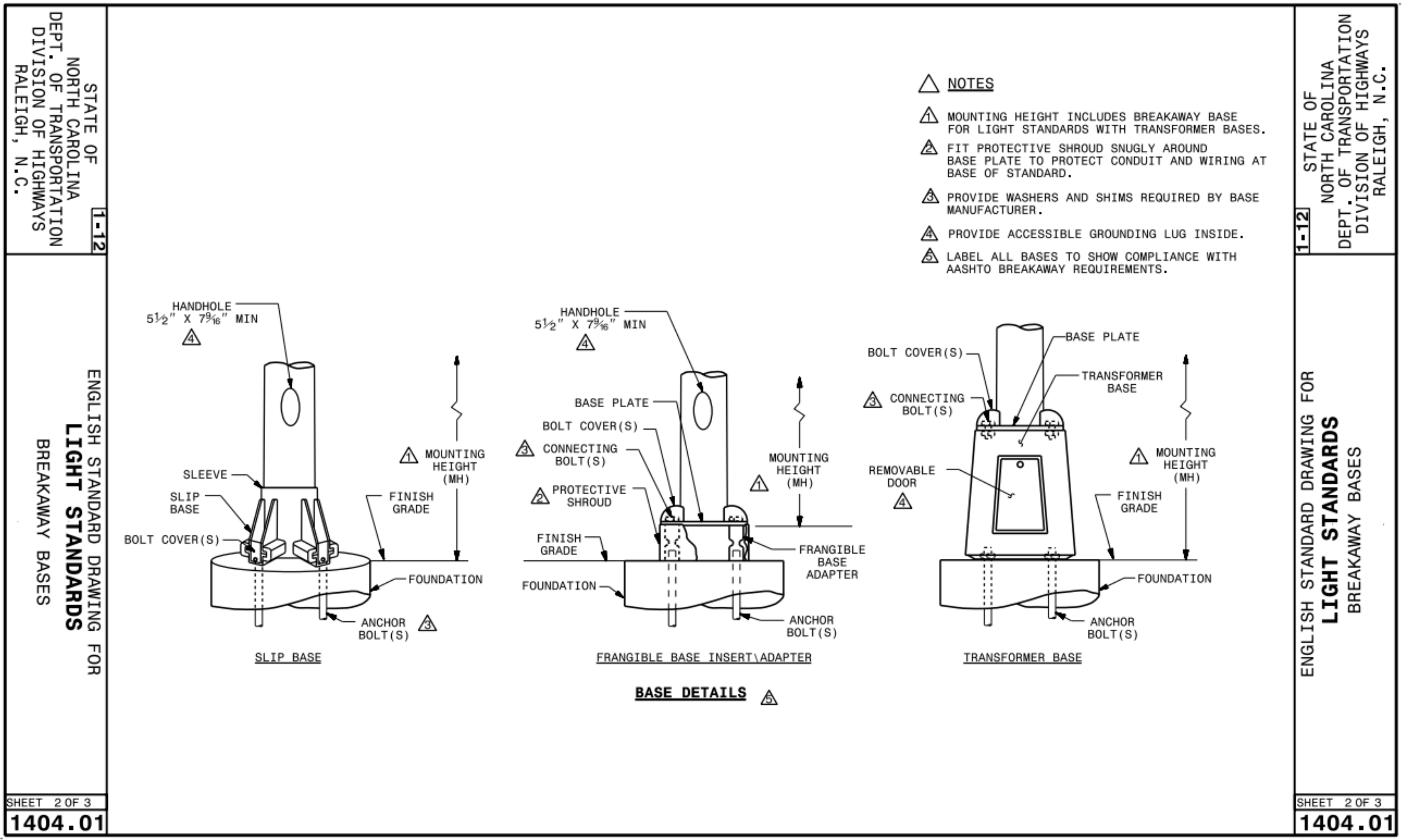


Figure B-16. North Carolina DOT Luminaire Pole and Slip Base Standard Plans, Cont. [15]

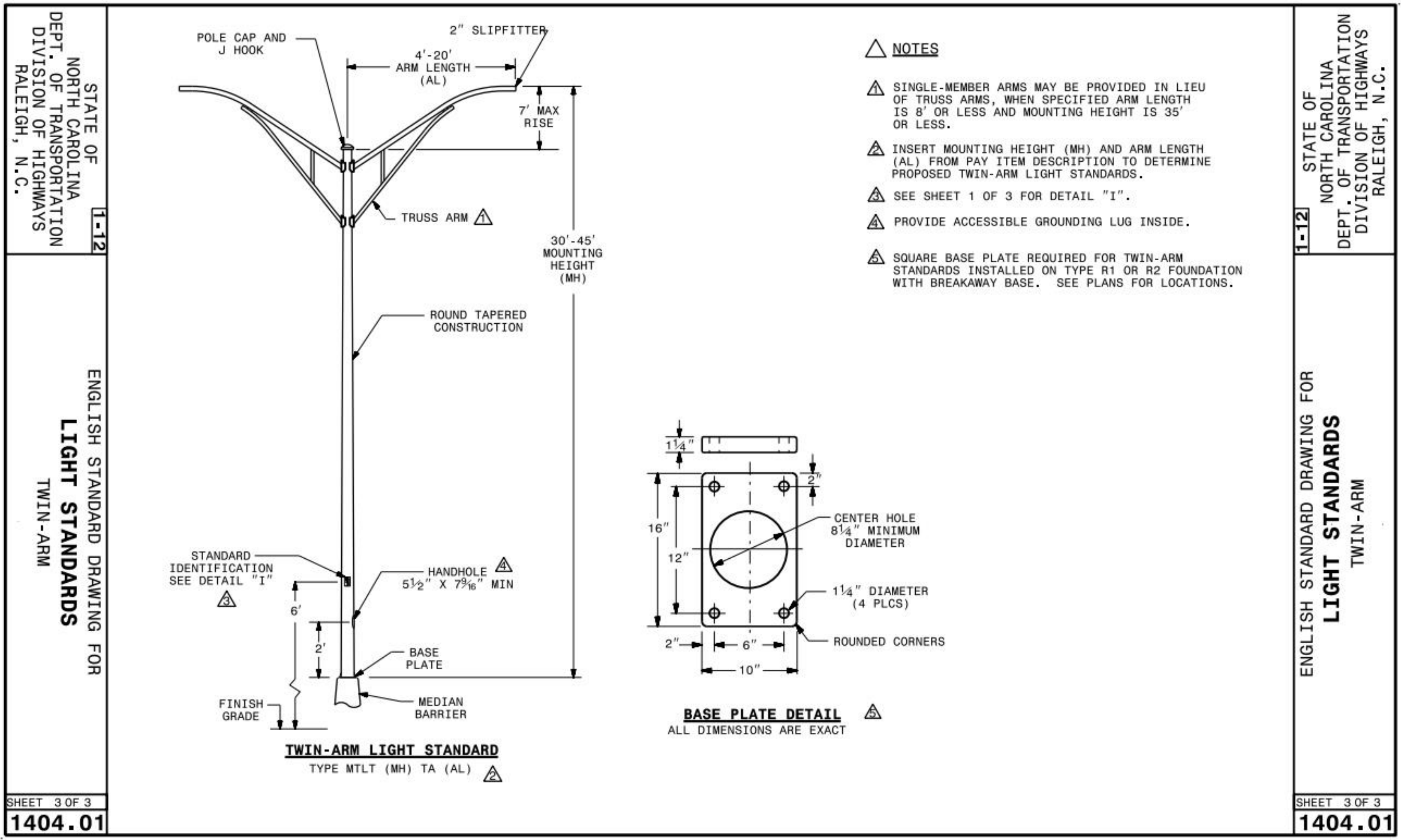


Figure B-17. North Carolina DOT Luminaire Pole and Slip Base Standard Plans, Cont. [15]

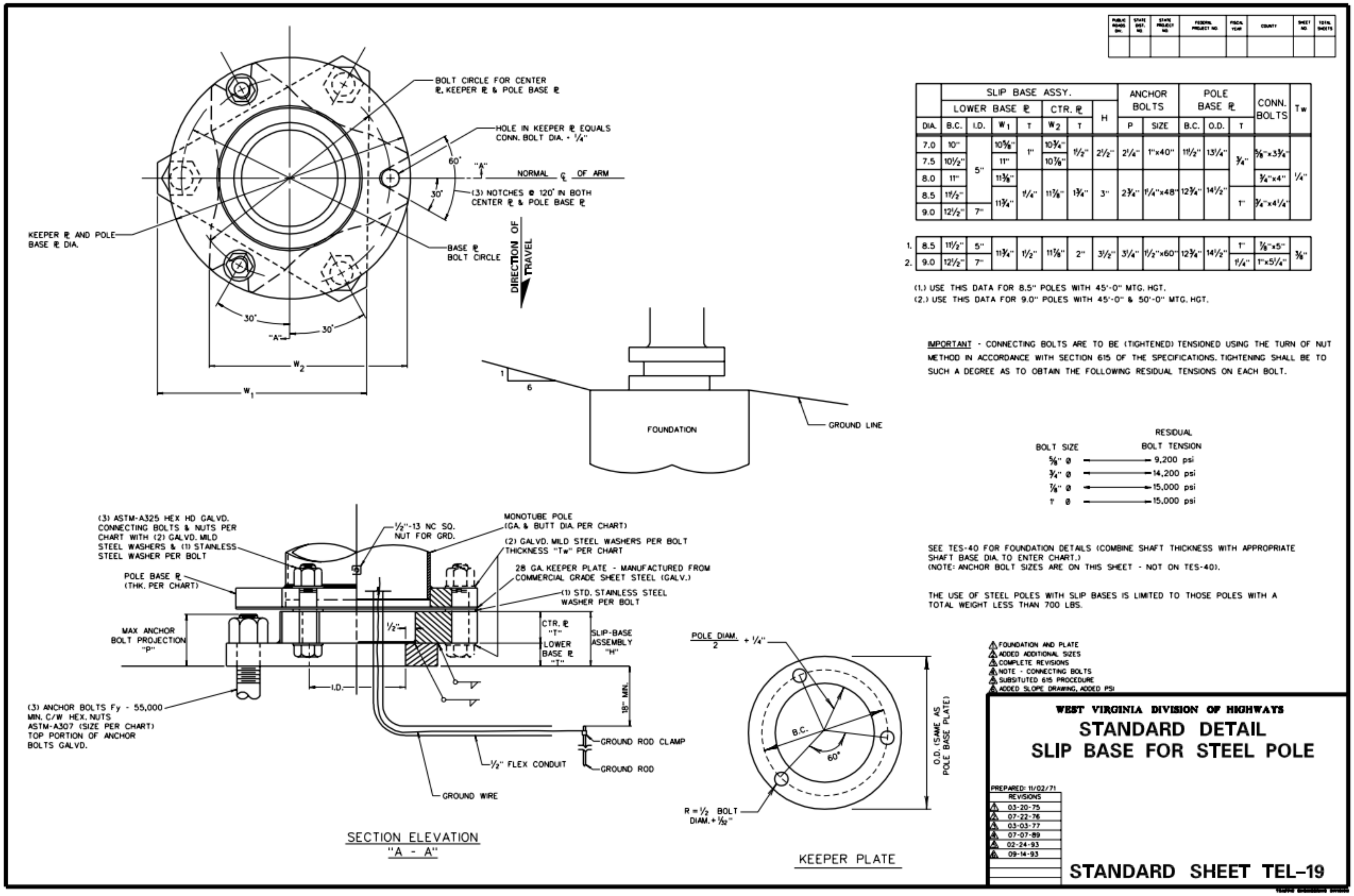


Figure B-18. West Virginia DOT Luminaire Pole and Slip Base 1994 Standard Plans [18]

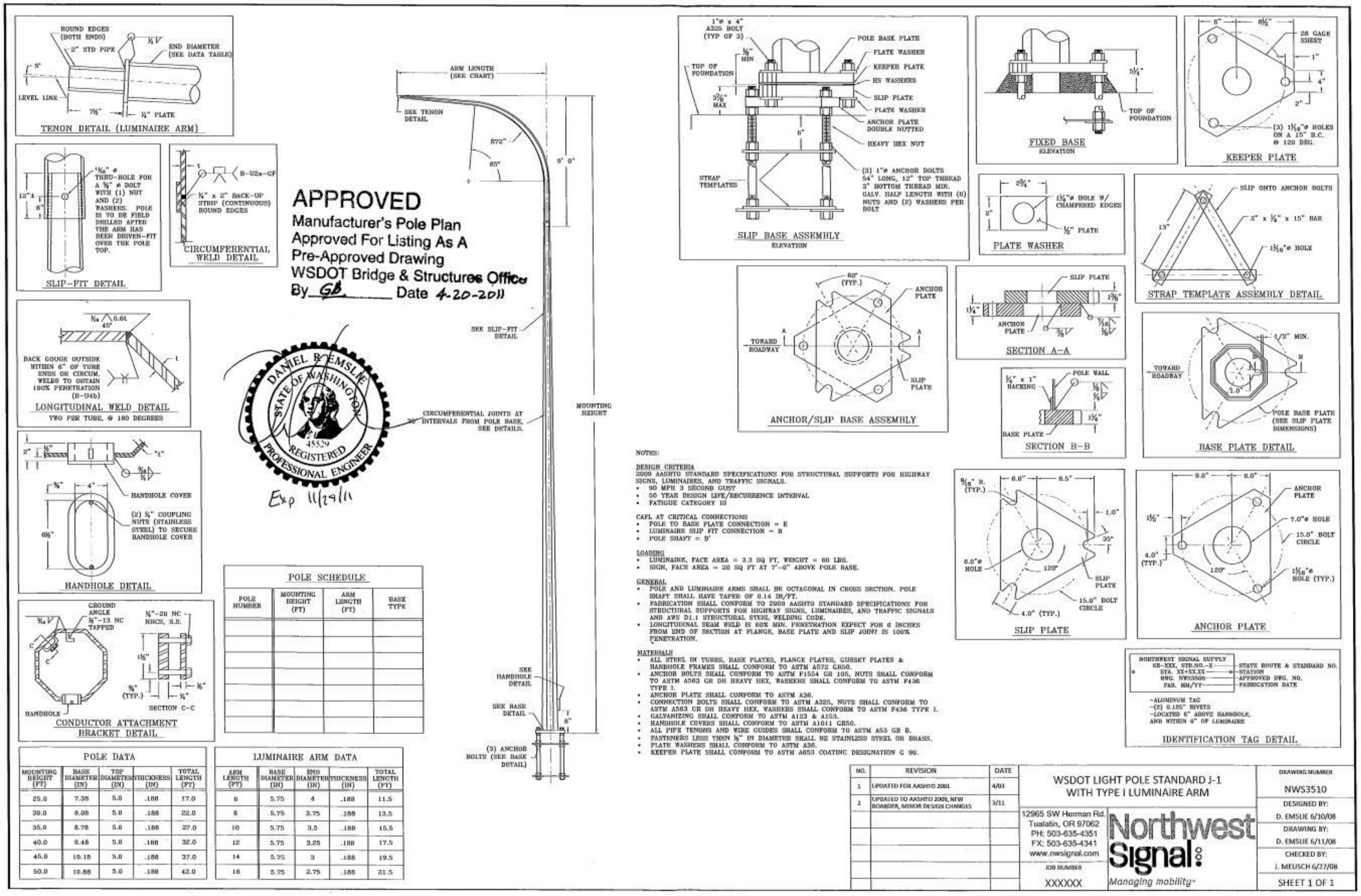


Figure B-19. Washington State DOT Luminaire Pole and Slip Base Standard Plans [19]

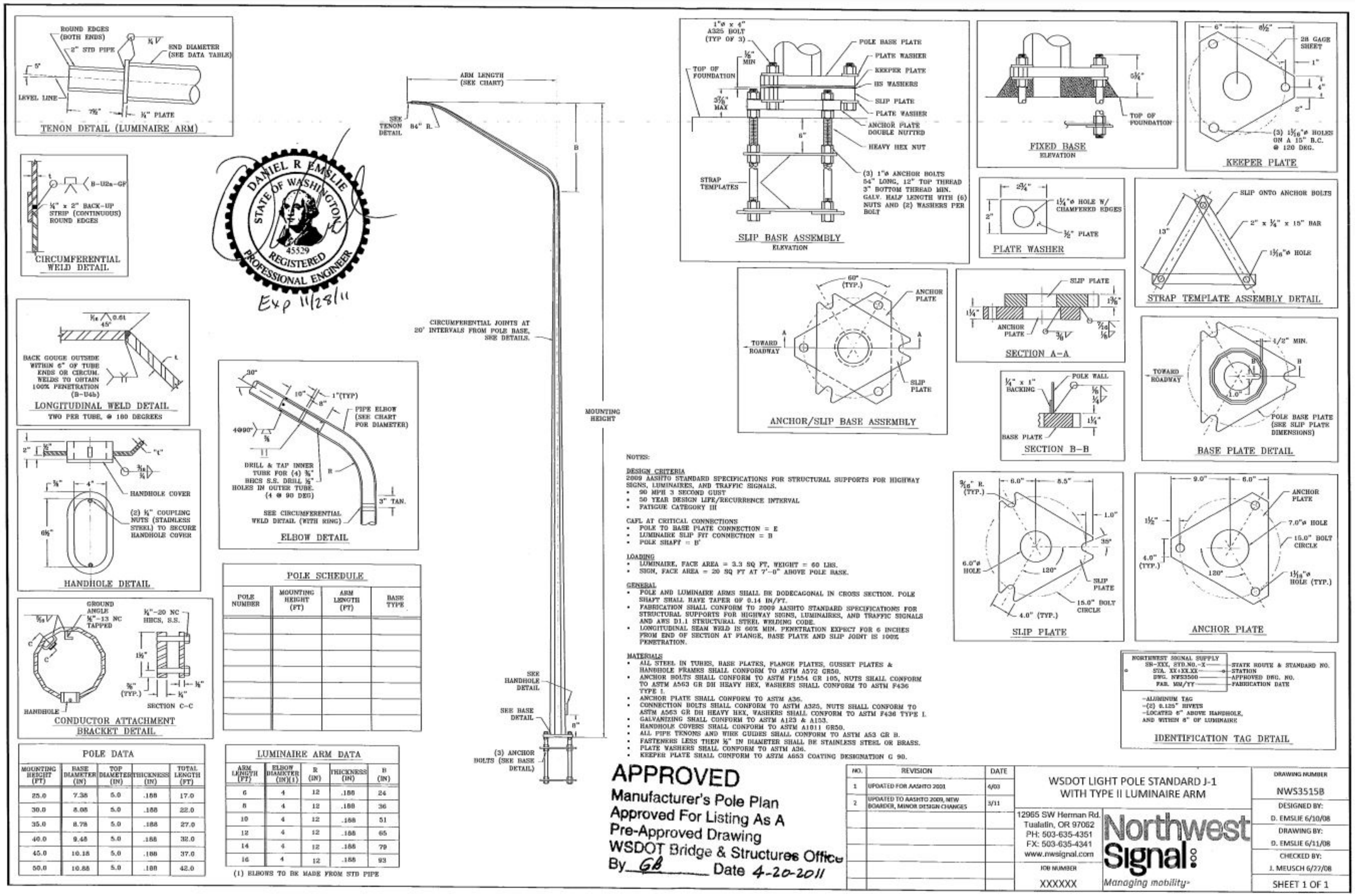
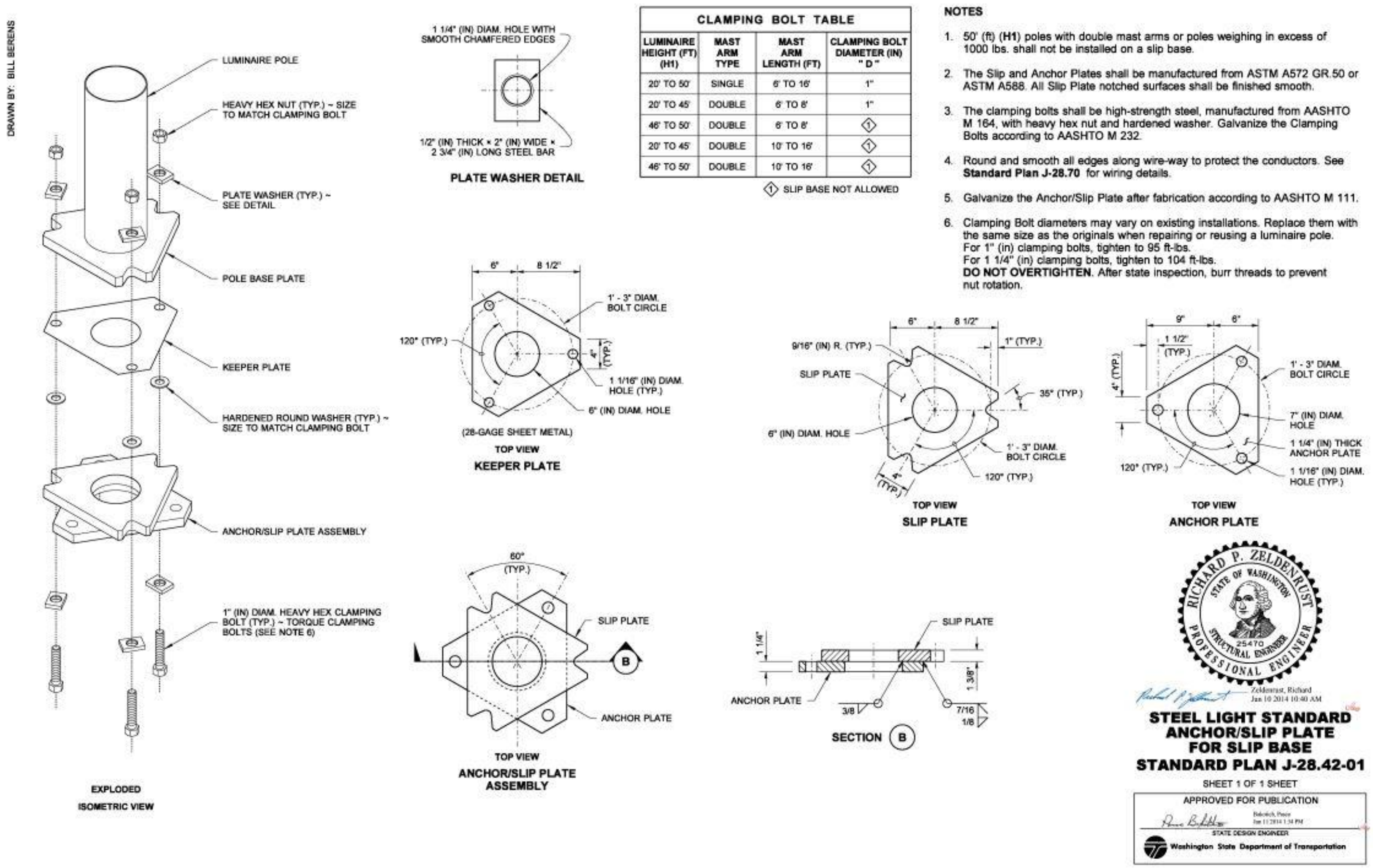


Figure B-20. Washington State DOT Luminaire Pole and Slip Base Standard Plans, Cont. [19]



CLAMPING BOLT TABLE

LUMINAIRE HEIGHT (FT) (H1)	MAST ARM TYPE	MAST ARM LENGTH (FT)	CLAMPING BOLT DIAMETER (IN) " D "
20' TO 50'	SINGLE	6' TO 16'	1"
20' TO 45'	DOUBLE	6' TO 8'	1"
46' TO 50'	DOUBLE	6' TO 8'	◇1
20' TO 45'	DOUBLE	10' TO 16'	◇1
46' TO 50'	DOUBLE	10' TO 16'	◇1

◇1 SLIP BASE NOT ALLOWED

NOTES

1. 50' (ft) (**H1**) poles with double mast arms or poles weighing in excess of 1000 lbs. shall not be installed on a slip base.
2. The Slip and Anchor Plates shall be manufactured from ASTM A572 GR.50 or ASTM A588. All Slip Plate notched surfaces shall be finished smooth.
3. The clamping bolts shall be high-strength steel, manufactured from AASHTO M 164, with heavy hex nut and hardened washer. Galvanize the Clamping Bolts according to AASHTO M 232.
4. Round and smooth all edges along wire-way to protect the conductors. See **Standard Plan J-28.70** for wiring details.
5. Galvanize the Anchor/Slip Plate after fabrication according to AASHTO M 111.
6. Clamping Bolt diameters may vary on existing installations. Replace them with the same size as the originals when repairing or reusing a luminaire pole.
   For 1" (in) clamping bolts, tighten to 95 ft-lbs.
   For 1 1/4" (in) clamping bolts, tighten to 104 ft-lbs.
   DO NOT OVERTIGHTEN. After state inspection, burr threads to prevent nut rotation.

Figure B-21. Washington State DOT Luminaire Pole and Slip Base Standard Plans, Cont. [19]

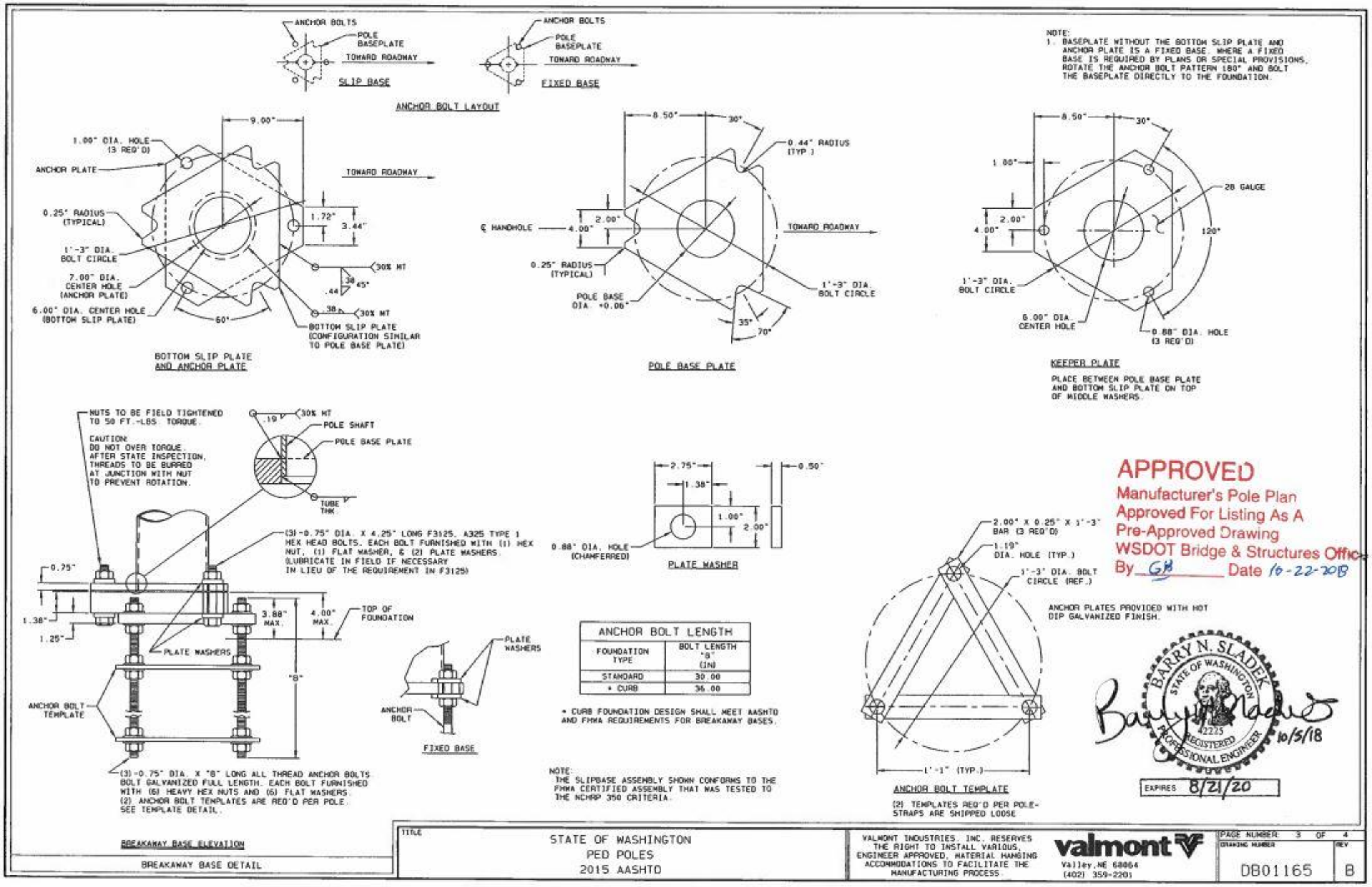


Figure B-22. Washington State DOT Luminaire Pole and Slip Base Standard Plans, Cont. [19]

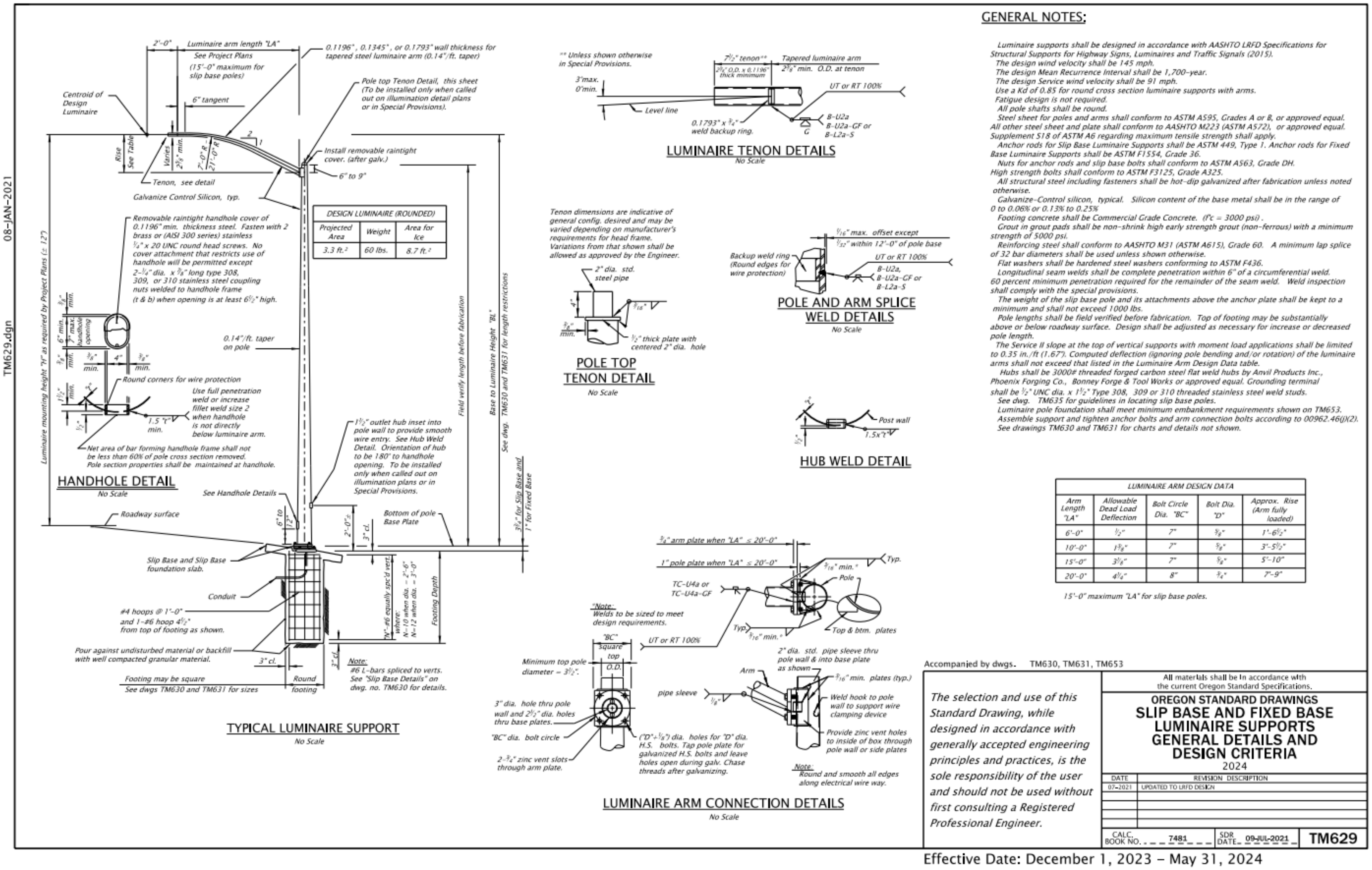


Figure B-23. Oregon DOT Luminaire Pole and Slip Base Standard Plans [20]

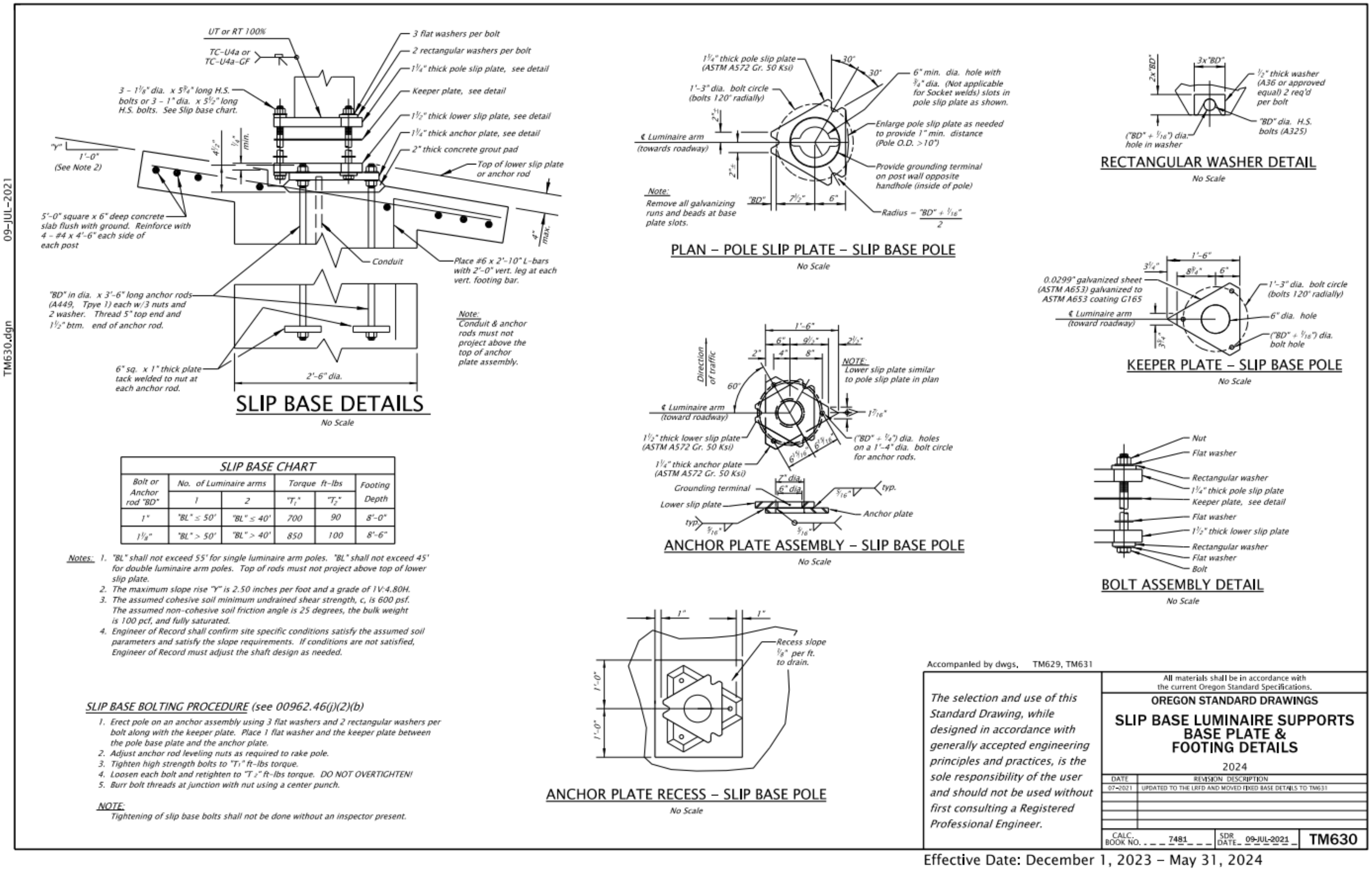


Figure B-24. Oregon DOT Luminaire Pole and Slip Base Standard Plans, Cont. [20]

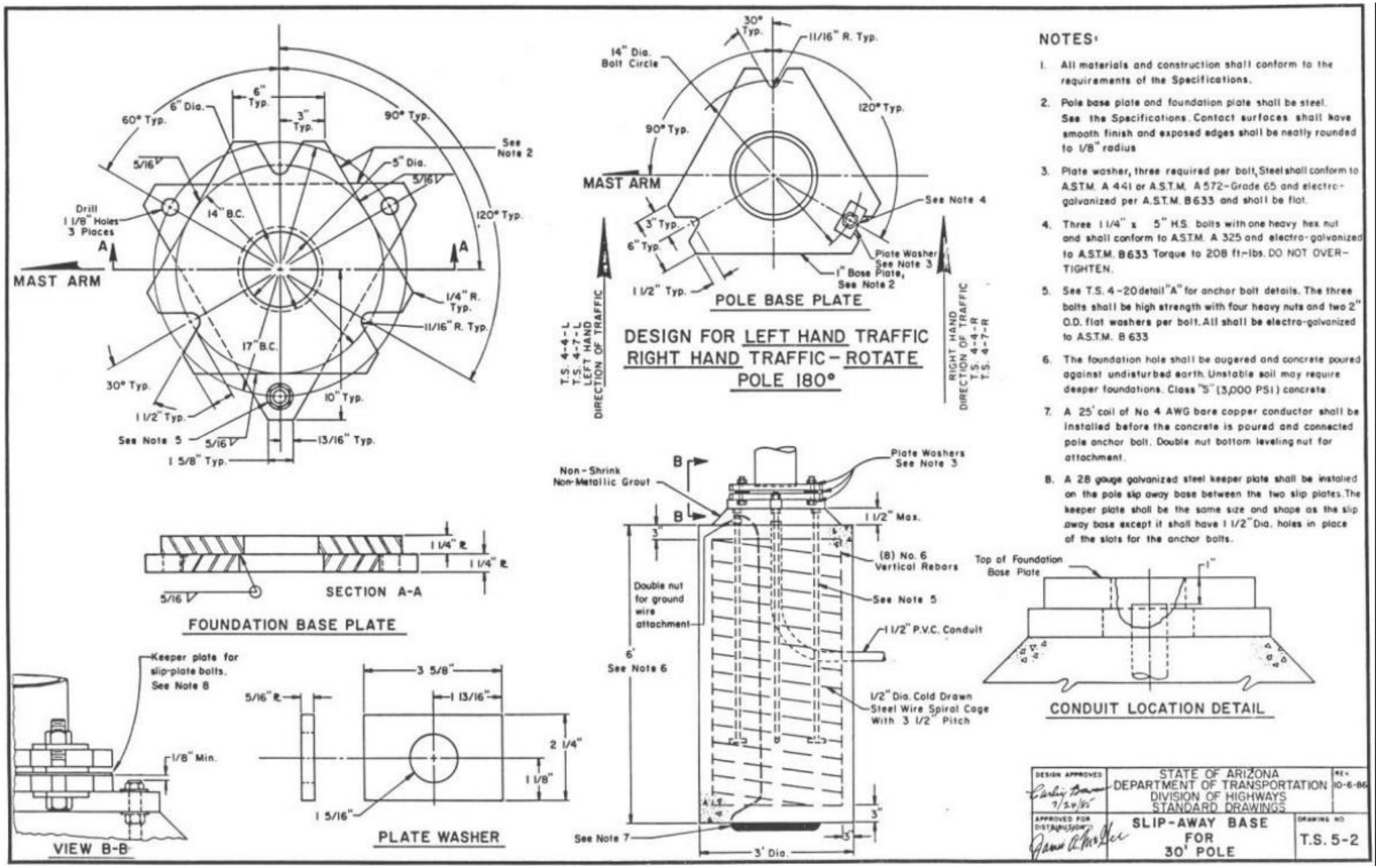
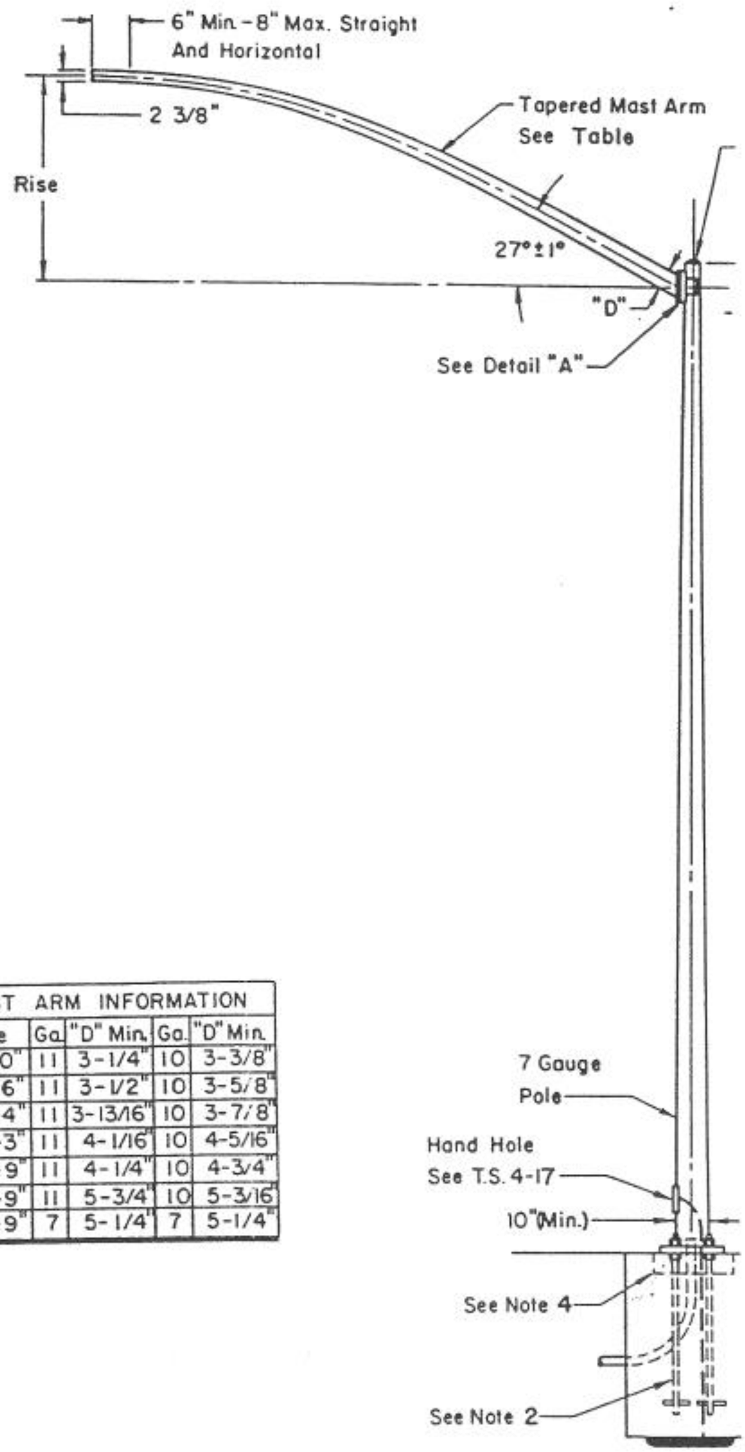


Figure B-25. Arizona DOT Luminaire Pole and Slip Base Standard Plans (Out of Date) [21]



MAST ARM INFORMATION					
Lgth.	Rise	Ga.	"D" Min.	Ga.	"D" Min.
6'	2'-0"	11	3-1/4"	10	3-3/8"
8'	2'-6"	11	3-1/2"	10	3-5/8"
10'	3'-4"	11	3-13/16"	10	3-7/8"
12'	4'-3"	11	4-1/16"	10	4-5/16"
15'	4'-9"	11	4-1/4"	10	4-3/4"
18'	5'-9"	11	5-3/4"	10	5-3/16"
20'	5'-9"	7	5-1/4"	7	5-1/4"

1 ft = 0.305 m
1 in = 25.4 mm

Figure B-26. Arizona DOT Luminaire Pole and Slip Base Standard Plans, Cont. (Out of Date) [21]

Appendix C. Eligibility Letter LS-16

U.S. Department of Transportation
Federal Highway Administration

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

JUN 29 1990

Refer to: HNG-14

Dennis H. O'Brien, P.E.
Manager, Product Planning
Industrial & Construction Products Division
Valmont Industries, Inc.
Valley, Nebraska 68064

Dear Mr. O'Brien:

By your September 16 and 22, 1988, letters to Mr. Thomas O. Willett, Director, of Office of Engineering, you requested Federal Highway Administration (FHWA) acceptance of steel breakaway slip-base luminaire supports for use on Federal-aid highway projects. As you know, considerable effort has gone into evaluating steel slip-base luminaire supports since you made your request. Your cooperation and assistance in that effort is much appreciated. Enclosure I summarizes the tests FHWA has evaluated in reaching a decision on the breakaway acceptability of steel slip-base luminaire supports.

In each of the tests shown in the summary the geometry of the slip-base was nominally the same as California Department of Transportation's (Caltrans) Type 31 base, which is shown on Enclosure II, except that in one series of tests the keeper plate thickness was reduced to 0.0149 inches (28 gage). The pole base plate in the type 31 base Is 1 inch thick, the lower slip plate is 1 1/4 inches thick, and the anchor plate is 1 inch thick. We would also point out that in all tests two of the slip-base clamp bolts lay in a line parallel to the direction of traffic and were on the street side of the pole.

from the summarization of tests it can be seen that there is considerable scatter in the results and that in some tests FHWA's maximum 16-foot-per-second breakaway change in velocity requirement was exceeded and in some instances the test device was actually stopped. Because of the apparently unpredictable nature of the slip-base the testing effort was extended and a theoretical analysis of the slip-base release mechanism was undertaken. As a result of this work we are now confident that safe slip-base luminaire supports can be configured that will be within substantial compliance with FHWA's breakaway requirements. Thus, steel slip-base luminaire supports will be acceptable for use on Federal-aid highways if proposed by a State highway agency provided they fall within the limitations setforth below:

Basic Type: Triangular, three-bolt base similar to Caltrans' Type 30 and 31 bases (see Enclosure II).

Minimum Shaft Wall Thickness: 0.1196 inches for diameters up to 10 inches.

Bolt Circle Diameter: 14 inches (minimum).

Base Plate Thickness: 1 inch (minimum), 1 1/4 inches (maximum).

Figure C-1. Eligibility Letter LS-16 - Page 1

Lower Slip Plate Thickness: 1 1/4 inches (minimum), 1 1/2 inches (maximum).

Anchor Plate Thickness: 1 1/4 inches (maximum).

Steel Keeper Plate Thickness: 0.0149 inches before coating (28 gage) (maximum).

Height Top of Lower Slip Plate from Ground Line: 4 inches (maximum).

Clamp Bolt Type: Galvanized ASTM A325 with dry lubricant (Heads and nuts shall have heavy hex dimensions).

Clamp Bolt Size: 7/8-inch to 1 1/4-inch diameter.

Rectangular Clamp Bolt Washer Size: Length, width, and thickness shall be sufficient to prevent significant deflection (bending) when clamp bolt is loaded to its tensile capacity.

Hole in Clamp Bolt Rectangular Washer: Camp bolt diameter plus 1/16 inch, with edges chamfered to prevent binding with radius under bolt head.

Clamp Bolt Tension: 8,000 pounds per bolt (maximum). In the absence of a more exact method of determining bolt tension the following maximum tightening torques shall be used:

Bolt diameter (inches)	7/8	1	1 1/8	1 1/4
Torque (foot-pounds)	87	95	104	111

Finish: All faying surfaces to be galvanized, free of paint, and smooth and free of ridges, scallops, nicks, and burrs.

Mounting Height: 56 feet, 6 inches measured from bottom of pole base plate to centerline of luminaire mounting tenon (maximum).

Weight: 1,000 pounds (include luminaire, mast arm(s), pole, and base plate) (maximum).

Mast Arm Orientation: Mast arm may be parallel to a flat side of the base provided that side faces approach traffic or may pass over a clamp bolt (see Enclosure III.)

Placement: The terrain about the pole base shall not inhibit translation of the pole and approach topography shall be such that a vehicle leaving the roadway at design speed and an angle of up to 25 degrees will not strike the pole at a height greater than were the pole located at the edge of the pavement. (The approach terrain will not cause an errant vehicle to become airborne.)

Figure C-2. Eligibility Letter LS-16 - Page 2

3

While the restrictions listed here are rather extensive and in some instances differ from some current practices, for example the clamp bolt tension, keeper plate thickness, and mast arm oriention prescribed differ from those in the Caltrans standard, one should not infer FHWA is apprehensive about the use of slip-base luminaire supports. It is just that our extensive study of these structures has given us an insight that leads us to believe they will work best and the public will be best served by adhering to the guidance we have outlined.

Sincerely yours,

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

Enclosures

Geometric and Roadside Design acceptance letter number LS-16.

Figure C-3. Eligibility Letter LS-16 - Page 3

Agency Test No. Date	Mastarm(s) Length (ft) Weight (#)	Shaft Length (ft) Weight (#)	Mounting Height (ft) Total Weight (#)	Pole Diam. at base (in) Wall Thick. at base (in)	Slip Base Bolt Circle Diameter (in)	Clamp Bolt Diameter (in)	Est. Clamp Bolt Force 3 @ (lbs) ea	Keeper Plate Thickness (in)	Impact Angle from Roadway (degrees)	Test Veh. Type and Weight (lbs)	Impact speed (m.p.h.)	Occupant Change in Velocity (f.p.s.)
CALTRANS	CALIFORNIA	TYPE 31 SLIP BASE										
404 JUL 26, 84	20 189	35 627	37 883	10.875 0.1793	14	1	11,400	0.0359	30	'79 HONDA 1865	19.9	8.5
405 MAY 23, 85	20 189	35 627	37 883	10.875 0.1793	14	1	11,200	0.0359	30	'79 HONDA 1885	53.9	12.4
406 MAY 8,'87	20 132	35 *	39.25 627.4	10 0.25 *	14	1	18,600	0.0359	30	'79 HONDA 1850	58.8	13.0
407 JUNE 23,'87	20 132	35 *	39.25 639.4	10 0.25 *	14	1	12,200	0.0359	30	'79 HONDA 1840	23.7	8.6
CAPABILITY TESTS - FOIL	VALMONT SLIP BASE											
87F033 MAR 12,'87	1.33 AND 16 115 AND 112	48.5 630	55.5 964	10 0.1793	14	1	12,500	0.0359	0	FOIL BOGIE 1850	19.8	14.5
87F034 MAR 13,'87	1.33 AND 16 115 AND 112	48.5 630	55.5 964	10 0.1793	14	1	12,500	0.0359	0	FOIL BOGIE 1850	58.7	15.5
THIN WALL TESTS - FOIL												
89F023 SEP 21,'89	1.33 AND 15 120 AND 107	46.5833 415	53.42 744	10 0.1196	14	1	12,500	0.0359	0	FOIL BOGIE 1850	20.7	24.4
89F024 SEP 27,'89	1.33 AND 15 120 AND 107	46.5833 415	53.42 744	10 0.1196	14	1	12,500	0.0359	0	'79 RABBIT 1850	19.8	15.8
89F025 OCT 5,'89	1.33 AND 15 120 AND 107	46.5833 415	53.42 744	10 0.1196	14	1	12,500	0.0359	0	'79 RABBIT 1850	59.2	13.2
89F026 OCT 24,'89	1.33 AND 15 120 AND 107	46.5833 415	53.42 744	10 0.1196	14	1	12,500	0.0359	0	FOIL BOGIE 1850	60.6	13.7

Figure C-4. Eligibility Letter LS-16 - Page 4

Agency Test No. Date	Mastarm(s) Length (ft) Weight (#)	Shaft Length (ft) Weight (#)	Mounting Height (ft) Total Weight (#)	Pole Diam. at base (in) Wall Thick. at base (in)	Slip Base Bolt Circle Diameter (in)	Clamp Bolt Diameter (in)	Est. Clamp Bolt Force 3 @ (lbs) ea	Keeper Plate Thickness (in)	Impact Angle from Roadway (degrees)	Test Veh. Type and Weight (lbs)	Impact speed (m.p.h.)	Occupant Change in Velocity (f.p.s.)
CLAMP FORCE STUDY - FOIL												
89F005 APR 12,'89	None	30.25 275	None 275	7.5 0.1345	14	1	1,965	0.0359	0	FOIL BOGIE 1850	20.6	6.5
89F006 APR 19,'89	"	" "	" "	" "	"	"	3,928	"	0	" "	20.7	5.9
89F007 APR 20,'89	"	" "	" "	" "	"	"	5,891	"	0	" "	20.7	8.3
89F008 APR 24,'89	"	" "	" "	" "	"	"	7,614	"	0	" "	20.5	6.4
89F009 APR 25,'89	"	" "	" "	" "	"	"	9,817	"	0	" "	20.8	23.2
89F010 APR 26,'89	"	" "	" "	" "	"	"	11,780	"	0	" "	20.7	20.6
89F011 APR 26,'89	"	" "	" "	" "	"	"	9,817	"	0	" "	20.5	7.7
89F012 APR 27,'89	"	" "	" "	" "	"	"	11,780	"	0	" "	20.6	36.9 **
89F014 MAY 19,'89	"	" "	" "	" "	"	"	13,743	"	0	" "	20.4	22.7
89F015 MAY 24,'89	"	" "	" "	" "	"	"	7,614	"	0	" "	20.5	14.8
89F016 MAY 25,'89	"	" "	" "	" "	"	"	15,808	"	0	" "	20.4	18.2
89F017 MAY 31,'89	"	" "	" "	" "	"	"	5,891	"	0	" "	20.6	21.4

* A 2-foot high steel tube with 0.25 in. wall thickness was welded to the bottom of a 33 foot tall pole which had a wall thickness of 0.1196 in.

Figure C-5. Eligibility Letter LS-16 - Page 5

Agency Test No. Date	Mastarm(s) Length (ft) Weight (#)	Shaft Length (ft) Weight (#)	Mounting Height (ft) Total Weight (#)	Pole Diam. at base (in) Wall Thick. at base (in)	Slip Base Bolt Circle Diameter (in)	Clamp Bolt Diameter (in)	Est. Clamp Bolt Force 3 @ (lbs) ea	Keeper Plate Thickness (in)	Impact Angle from Roadway (degrees)	Test Veh. Type and Weight (lbs)	Impact speed (m.p.h.)	Occupant Change in Velocity (f.p.s.)
KEEPER PLATE STUDY - FOIL												
90P023 4/24/90	None None	30.83 486	None 486	10.0 0.1793	14	1	12,500	0.0359	0	FOIL PNDLM 1850	19.9	25.9
90P024 4/25/90	" "	" "	" "	" "	"	"	"	NONE	"	" "	19.8	8.8
90P025 4/25/90	" "	" "	" "	" "	"	"	"	NONE	"	" "	19.8	13.2
90P026 4/26/90	" "	" "	" "	" "	"	"	"	NONE	"	" "	19.9	11.1
90P027 4/26/90	" "	" "	" "	" "	"	"	"	0.0149	"	" "	20	16.9
90P028 5/1/90	" "	" "	" "	" "	"	"	"	0.0149	"	" "	19.8	35 **
90P029 5/2/90	" "	" "	" "	" "	"	"	3,600	0.0149	"	" "	20	5.6
90P032 5/30/90	" "	" "	" "	" "	"	"	3,600	0.0149	"	" "	20	7
90P033 5/31/90	" "	" "	" "	" "	"	"	3,600	0.1049	"	" "	20	6.4
90P034 5/31/90	" "	" "	" "	" "	"	"	9,000	0.0149	"	" "	20	11.8
90P035 6/05/90	" "	" "	" "	" "	"	"	9,000	0.0149	"	" "	20	35.4 **
90P036 6/06/90	" "	" "	" "	" "	"	"	8,000	0.0149	"	" "	20	17.7

** Value includes rebound, thus exceeds impact speed.

Figure C-6. Eligibility Letter LS-16 - Page 6

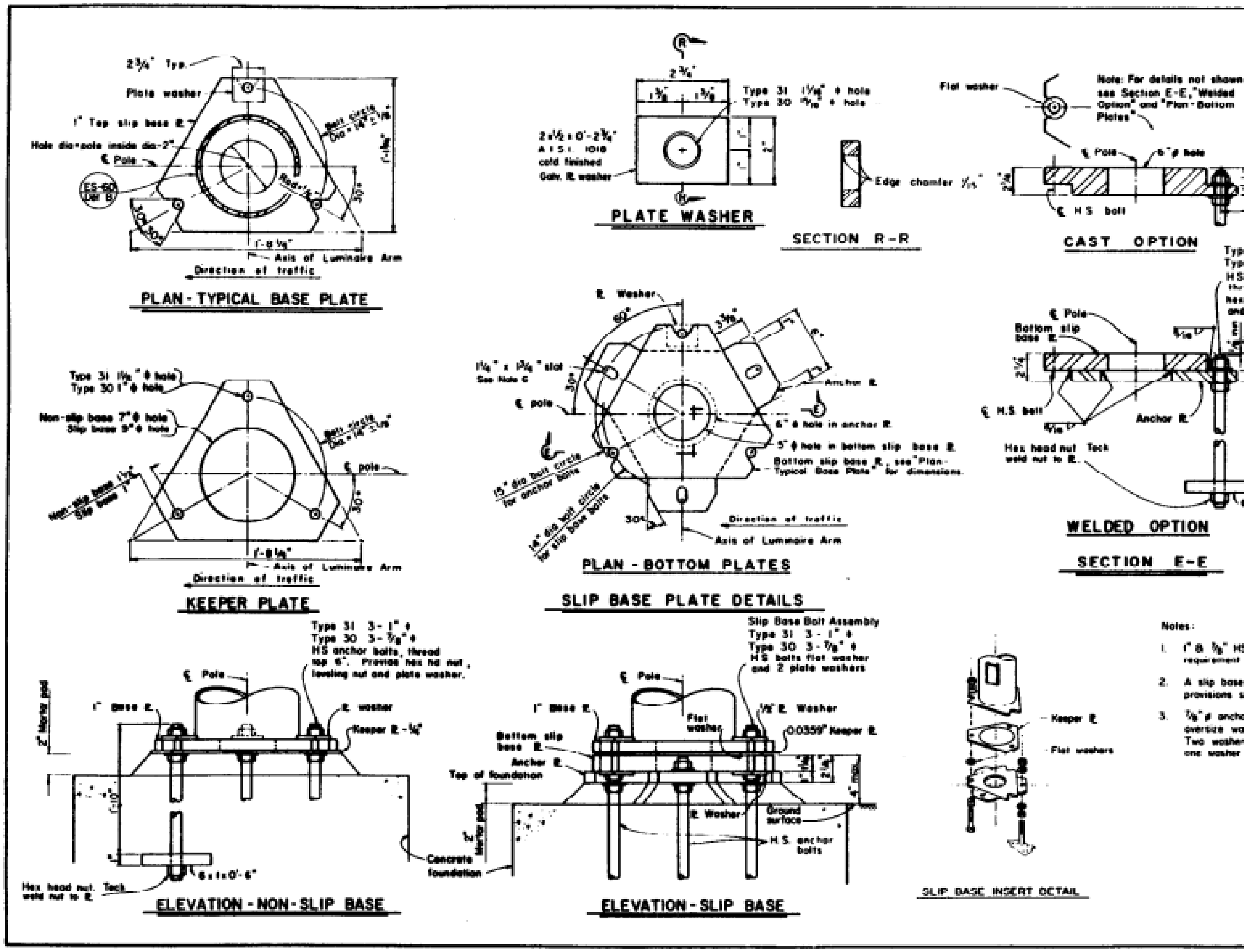


Figure C-7. Eligibility Letter LS-16 - Page 7

Enclosure II I

Luminaire Slip Base Orientation

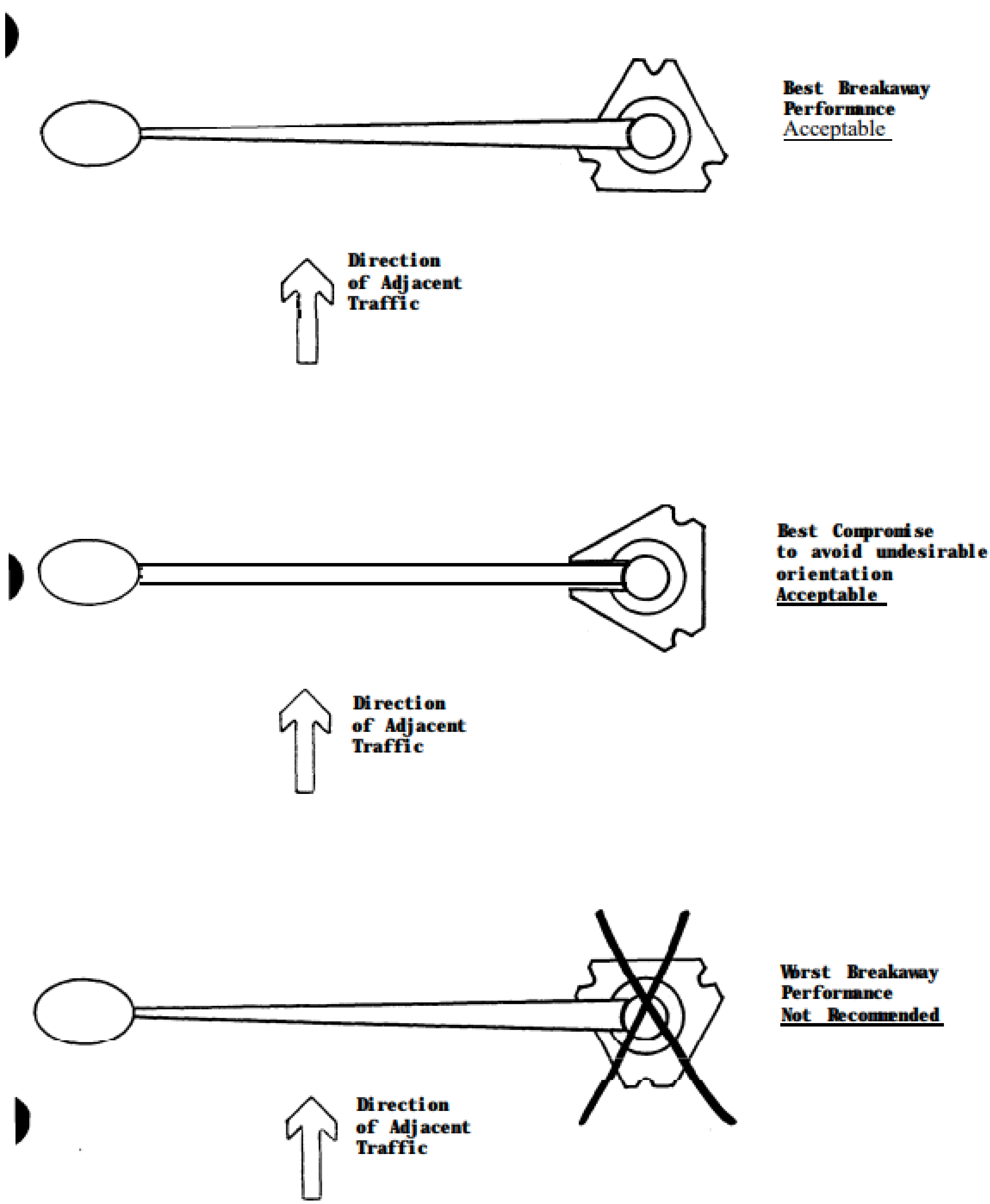


Figure C-8. Eligibility Letter LS-16 - Page 8

LS-16. Addendum

U.S. Department of Transportation
Federal Highway Administration

Memorandum

Washington, D.C. 20590

Subject: Slip-Base Luminaire Supports

Date: JAN 28 1991

From: Chief, Federal-Aid and Design Division

Reply to Attn. of: HNG-14

To: Regional Federal Highway Administrators
Federal Lands Highway Program Administrator

Our July 6, 1990, memorandum "Breakaway Sign and Luminaire Supports," transmitted a sketch titled "Luminaire Slip-Base Orientation." This sketch illustrated three ways that the triangular slip-base could be welded to the pole with respect to orientation of the mast arm These were shown in decreasing order of preference with respect to crashworthiness. We have had questions regarding the middle sketch, which showed an acceptable compromise situation where the far side of the triangular slip-base was parallel to traffic. Although our memorandum did not address the situation where the orientation of the triangular slip-base is such that the near side is parallel to traffic, it is an acceptable, though less desirable, compromise. A revised copy of that sketch is attached to show that traffic may pass to either side of a slip-base where one face is parallel to the edge of the road.

L. A. Staron

Attachment

Figure C-9. Eligibility Letter LS-16 - Page 9

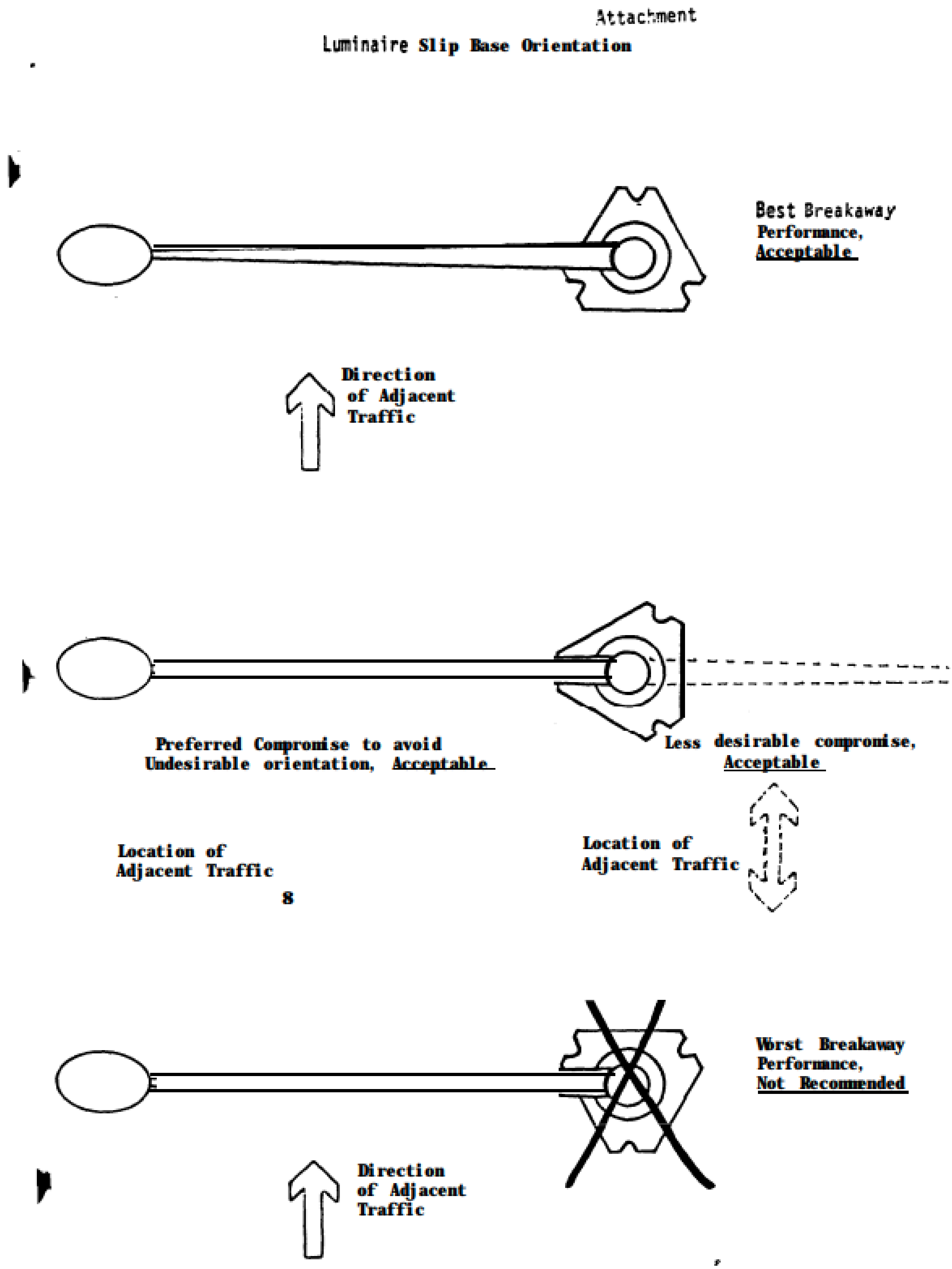


Figure C-10. Eligibility Letter LS-16 - Page 10

U.S. Department
of Transportation
**Federal Highway
Administration**

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

Refer to: HNG-14

SEP 30 1993

Dennis H. O'Brien, P.E.
Manager of Product Planning
Industrial & Construction Products Division
Valmont Industries, Inc.
Valley, Nebraska 68064-0358

Dear Mr. O'Brien:

Thank you for your letter of September 2 requesting clarification of acceptable mounting heights for breakaway luminaire supports. In general, dimensions such as mounting height, pole diameter and mass, bolt size and torque, should not exceed those of the tested hardware. We place these limitations in our hardware acceptance letters to assure that the hardware used in the field is no less forgiving of the errant motorist than the hardware used in the crash tests. In our memorandum of June 15, 1989, to the Federal Highway Regional Administrator in Portland, Oregon, where we discussed luminaire support recommendations, however, we stated:

> "... the advice is not nearly as forceful on the issue of height as it is on the need to limit weight. After considering the likely effect of a 60-foot pole in comparison to a 55-foot pole, we conclude there would be little difference for an impacting vehicle. Therefore, we would recommend allowing 60-foot mounting heights (base of pole to level of luminaire.) However, we also believe this should be considered an absolute maximum in the absence of further study and testing to investigate the effects of pole height and weight."

We still believe this to be sound advice, even under the 1985 American Association of State Highway and Transportation Officials breakaway criteria. Therefore, luminaire supports which are considered breakaway by way of our Geometric and Roadside Design Acceptance letters LS-16 and LS-25 dated June 29, 1990, and October 10, 1991, respectively may use a nominal mounting height of up to 18.3 m (60 feet) as requested in your letter.

You also wished to alert us to the need for increasing the pole wall thickness when the height is raised. This causes us some concern, as the crash tested hardware found acceptable by way of LS-25 weighed 409 kg (902 pounds) This approaches the 454 kg (1000-pound) maximum mass we have set for breakaway luminaire supports to control the risk to vehicle occupants from a pole's

Figure C-11. Eligibility Letter LS-16 - Page 11

2

falling on a vehicle's roof. We will not sanction pole plus mast arm plus luminaire masses in excess of 454 kg (1000 pounds) without automobile crash tests to confirm their acceptability.

Sincerely yours,

L. A. STARON

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

Supplement to Geometric and Roadside Design Acceptance Letters LS-16 and LS-25

Figure C-12. Eligibility Letter LS-16 - Page 12

Appendix D. Detailed Simulation Results

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
20	20'	6.5" Base	Single 4'	4-Bolt Slip Base	11 ga.	222 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	C Pillar: 1.1 in.	Roll:	0.36	Long.:	-2.76	Long.:	-0.39	C Pillar: 1.1 in.	High
												Pitch:	-1.45	Lat.:	0.14	Lat.:	0.82		
									25	Keeper Plate Rupture, Bolt Release	C Pillar: 1.7 in.	Roll:	-0.41	Long.:	-2.62	Long.:	-0.39	C Pillar: 1.1 in.	High
												Pitch:	-1.03	Lat.:	0.14	Lat.:	0.63		
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 0.38 in.	Roll:	-0.79	Long.:	-3.01	Long.:	-0.26	Roof: 0.38 in.	High
												Pitch:	-0.26	Lat.:	0.05	Lat.:	1.01		
									25	Keeper Plate Rupture, Bolt Release	Roof: 4.14 in.	Roll:	1.10	Long.:	-3.18	Long.:	0.50	Roof: 4.14 in.	Low
												Pitch:	-2.09	Lat.:	0.03	Lat.:	0.54		
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.27	Long.:	-2.77	Long.:	0.07	No occupant compartment def.	High
												Pitch:	-0.20	Lat.:	0.09	Lat.:	-0.09		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.39	Long.:	-2.92	Long.:	-0.07	No occupant compartment def.	High
												Pitch:	-0.19	Lat.:	-0.04	Lat.:	0.09		
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-2.50	Long.:	-5.57	Long.:	0.27	No occupant compartment def.	High
												Pitch:	-0.58	Lat.:	0.29	Lat.:	-0.24		
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.55	Long.:	-4.41	Long.:	-0.16	No occupant compartment def.	High
												Pitch:	2.06	Lat.:	0.13	Lat.:	-0.22		

Figure D-1. Detailed Simulation Results, Simulation Number 20

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
21	20'	6.5" Base	Dual 4'	4-Bolt Slip Base	11 ga.	312 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Rear Window: 2.79 in.	Roll:	-0.15	Long.:	-3.01	Long.:	0.79	Rear Window: 2.79 in.	Medium
												Pitch:	-2.15	Lat.:	0.04	Lat.:	0.07		
									25	Keeper Plate Rupture, Bolt Release	Roof: 4.04 in.	Roll:	0.21	Long.:	-3.03	Long.:	0.31	Roof: 4.04 in.	Low
												Pitch:	-1.33	Lat.:	0.03	Lat.:	0.18		
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.30	Long.:	-5.44	Long.:	0.22	No occupant compartment def.	High
												Pitch:	-2.03	Lat.:	0.65	Lat.:	0.29		
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-3.88	Long.:	-4.34	Long.:	-0.18	No occupant compartment def.	High
												Pitch:	1.72	Lat.:	0.06	Lat.:	0.22		

Figure D-2. Detailed Simulation Results, Simulation Number 21

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
22	20'	7" Base	Single 10'	4-Bolt Slip Base	11 ga.	261 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 6.07 in.	Roll:	1.54	Long.:	-3.47	Long.:	-0.43	Roof: 6.07 in.	Low
												Pitch:	-1.59	Lat.:	0.02	Lat.:	-0.60		
									25	Keeper Plate Rupture, Bolt Release	Roof: 8.31 in.	Roll:	0.19	Long.:	-3.39	Long.:	0.47	Roof: 8.31 in.	Low
												Pitch:	-1.62	Lat.:	0.03	Lat.:	0.53		
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	1.11	Long.:	-5.55	Long.:	-0.24	No occupant compartment def.	High
												Pitch:	-3.91	Lat.:	0.59	Lat.:	0.30		
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.54	Long.:	-4.52	Long.:	-0.22	No occupant compartment def.	High
												Pitch:	0.62	Lat.:	0.04	Lat.:	-0.21		

Figure D-3. Detailed Simulation Results, Simulation Number 22

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
23	20'	7" Base	Dual 10'	4-bolt Slip Base	11 ga	381 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.41	Long.:	-3.81	Long.:	0.27	No occupant compartment def.	High
												Pitch:	-0.41	Lat.:	0.10	Lat.:	-0.51		
									25	Keeper Plate Rupture, Bolt Release	A-Pillar: 0.19 in.	Roll:	-0.41	Long.:	-3.10	Long.:	-0.84	A-Pillar: 0.19 in.	High
												Pitch:	-0.37	Lat.:	0.12	Lat.:	0.51		
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 6.07 in.	Roll:	-0.20	Long.:	-3.46	Long.:	0.67	Roof: 6.07 in.	Low
												Pitch:	-2.77	Lat.:	0.02	Lat.:	-0.27		
									25	Keeper Plate Rupture, Bolt Release	Roof: 1.59 in.	Roll:	1.82	Long.:	-3.34	Long.:	-0.87	Roof: 1.59 in.	High
												Pitch:	-0.80	Lat.:	0.02	Lat.:	-1.02		
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.30	Long.:	-3.06	Long.:	-0.20	No occupant compartment def.	High
												Pitch:	-0.50	Lat.:	0.11	Lat.:	0.61		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.41	Long.:	-3.04	Long.:	-0.08	No occupant compartment def.	High
												Pitch:	-0.21	Lat.:	-0.09	Lat.:	0.11		
							MASH 3-61	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.99	Long.:	-5.88	Long.:	-0.17	No occupant compartment def.	High
												Pitch:	-0.58	Lat.:	1.63	Lat.:	0.44		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.57	Long.:	-5.28	Long.:	-0.17	No occupant compartment def.	High
												Pitch:	-0.53	Lat.:	0.04	Lat.:	0.20		
								Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.33	Long.:	-5.67	Long.:	-0.25	No occupant compartment def.	High
												Pitch:	-0.99	Lat.:	0.58	Lat.:	0.30		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	0.64	Long.:	-5.88	Long.:	-0.22	No occupant compartment def.	High
												Pitch:	1.06	Lat.:	1.47	Lat.:	0.36		
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-1.00	Long.:	-6.16	Long.:	0.29	No occupant compartment def.	High
												Pitch:	1.58	Lat.:	-0.72	Lat.:	-0.37		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	1.57	Long.:	-5.96	Long.:	0.37	No occupant compartment def.	High
												Pitch:	1.40	Lat.:	-0.54	Lat.:	-0.41		
							MASH 3-62	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	2.76	Long.:	-4.33	Long.:	-0.17	No occupant compartment def.	High
												Pitch:	2.34	Lat.:	0.94	Lat.:	-0.32		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	-1.61	Long.:	-4.10	Long.:	-0.19	No occupant compartment def.	High
												Pitch:	0.57	Lat.:	0.68	Lat.:	0.23		
								Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-2.77	Long.:	-4.53	Long.:	-0.18	No occupant compartment def.	High
												Pitch:	-2.46	Lat.:	0.03	Lat.:	-0.27		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.47	Long.:	-4.39	Long.:	-0.21	No occupant compartment def.	High
												Pitch:	0.70	Lat.:	0.19	Lat.:	-0.24		
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	1.47	Long.:	-4.30	Long.:	-0.23	No occupant compartment def.	High
												Pitch:	-1.51	Lat.:	-0.69	Lat.:	0.41		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	1.77	Long.:	-4.27	Long.:	-0.18	No occupant compartment def.	High
												Pitch:	-0.78	Lat.:	-0.51	Lat.:	0.41		

Figure D-4. Detailed Simulation Results, Simulation Number 23

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
30	30'	7.5" Base	Single 4'	4-Bolt Slip Base	11 ga.	300 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.37	Long.:	-3.36	Long.:	0.07	No occupant compartment def.	High
												Pitch:	-0.37	Lat.:	0.14	Lat.:	0.10		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.36	Long.:	-2.99	Long.:	-0.09	No occupant compartment def.	High
												Pitch:	-0.37	Lat.:	0.11	Lat.:	-0.09		
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 2.14 in.	Roll:	0.54	Long.:	-3.57	Long.:	-0.55	Roof: 2.14 in.	Medium
												Pitch:	-0.87	Lat.:	0.04	Lat.:	-0.20		
									25	Keeper Plate Rupture, Bolt Release	Roof: 3.55 in. FW: 2.90 in.	Roll:	0.58	Long.:	-3.51	Long.:	-0.93	Roof: 3.55 in. FW: 2.90 in.	Medium
												Pitch:	-0.76	Lat.:	0.00	Lat.:	0.43		
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.35	Long.:	-3.58	Long.:	0.09	No occupant compartment def.	High
												Pitch:	0.19	Lat.:	0.16	Lat.:	0.12		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	0.28	Long.:	-3.09	Long.:	-0.10	No occupant compartment def.	High
												Pitch:	-0.19	Lat.:	0.08	Lat.:	0.12		
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.78	Long.:	-6.26	Long.:	-0.25	No occupant compartment def.	High
												Pitch:	-0.78	Lat.:	0.64	Lat.:	0.33		
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.55	Long.:	-4.49	Long.:	-0.19	No occupant compartment def.	High
												Pitch:	0.59	Lat.:	0.14	Lat.:	0.23		

Figure D-5. Detailed Simulation Results, Simulation Number 30

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
31	30'	7.5" Base	Dual 4'	4-Bolt Slip Base	11 ga.	390 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 2.57 in.	Roll:	-0.20	Long.:	-3.80	Long.:	-0.08	Roof: 2.57 in.	Medium
												Pitch:	-0.78	Lat.:	0.02	Lat.:	-0.08		
									25	Keeper Plate Rupture, Bolt Release	Roof: 3.90 in. FW: 3.50 in.	Roll:	0.15	Long.:	-3.48	Long.:	-0.70	Roof: 3.90 in. FW: 3.50 in.	Low
												Pitch:	-0.60	Lat.:	-0.01	Lat.:	0.20		
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.61	Long.:	-6.37	Long.:	0.22	No occupant compartment def.	High
												Pitch:	-0.86	Lat.:	0.35	Lat.:	0.41		
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.89	Long.:	-4.53	Long.:	-0.17	No occupant compartment def.	High
												Pitch:	4.74	Lat.:	0.11	Lat.:	-0.30		

Figure D-6. Detailed Simulation Results, Simulation Number 31

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
34-1	30'	8" Base	Single 10'	4-Bolt Slip Base	11 ga.	349 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.38 Pitch: -0.37	Long.: -3.32 Lat.: 0.15	Long.: -0.09 Lat.: -0.08	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -0.37 Pitch: -0.35	Long.: -3.34 Lat.: 0.10	Long.: -0.08 Lat.: -0.07	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 6.79 in.	Roll: 1.78 Pitch: -1.36	Long.: -3.51 Lat.: 0.02	Long.: -0.73 Lat.: -0.67	Roof: 6.79 in.	Low
									25	Keeper Plate Rupture, Bolt Release	Roof: 8.28 in.	Roll: 0.44 Pitch: -2.30	Long.: -3.71 Lat.: 0.03	Long.: -0.70 Lat.: -0.30	Roof: 8.28 in.	Low
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.32 Pitch: -0.19	Long.: -3.37 Lat.: 0.11	Long.: 0.08 Lat.: 0.15	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -0.51 Pitch: -0.20	Long.: -3.25 Lat.: -0.02	Long.: 0.10 Lat.: 0.11	No occupant compartment def.	High

Figure D-7. Detailed Simulation Results, Simulation Number 34-1

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
34-2	30'	8" Base	Dual 10'	4-Bolt Slip Base	11 ga.	468 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 1.98 in.	Roll: 0.19 Pitch: -0.62	Long.: -3.60 Lat.: 0.04	Long.: -0.78 Lat.: 0.18	Roof: 1.98 in.	High
									25	Keeper Plate Rupture, Bolt Release	Front Windshield: 0.50	Roll: 0.79 Pitch: 0.59	Long.: -3.68 Lat.: 0.02	Long.: -0.53 Lat.: -0.36	Front Windshield: 0.50	High

Figure D-8. Detailed Simulation Results, Simulation Number 34-2

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
32	30'	8.5" Base	Single 20'	4-Bolt Slip Base	11 ga.	433 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 7.77 in.	Roll: 1.27 Pitch: -1.68	Long.: -3.85 Lat.: 0.01	Long.: -1.00 Lat.: 0.66	Roof: 7.77 in.	Low
									25	Keeper Plate Rupture, Bolt Release	Roof: 8.40 in.	Roll: 0.93 Pitch: -2.31	Long.: -3.74 Lat.: 0.03	Long.: -0.72 Lat.: 0.42	Roof: 8.40 in.	Low
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 1.04 Pitch: 0.93	Long.: -6.82 Lat.: 0.52	Long.: 0.31 Lat.: 0.36	No occupant compartment def.	High
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 1.02 Pitch: 2.13	Long.: -4.60 Lat.: 0.19	Long.: -0.19 Lat.: -0.26	No occupant compartment def.	High

Figure D-9. Detailed Simulation Results, Simulation Number 32

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
33	30'	8.5" Base	Dual 20'	4-bolt Slip Base	11 ga	381 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.38	Long.:	-3.40	Long.:	0.07	No occupant compartment def.	High
												Pitch:	-0.36	Lat.:	0.13	Lat.:	-0.10		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	0.45	Long.:	-4.76	Long.:	-0.13	No occupant compartment def.	High
												Pitch:	-0.36	Lat.:	-0.05	Lat.:	0.20		
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 3.35 in.	Roll:	0.09	Long.:	-3.74	Long.:	-0.35	Roof: 3.35 in.	Medium
												Pitch:	0.67	Lat.:	0.03	Lat.:	-0.18		
									25	Keeper Plate Rupture, Bolt Release	Roof: 0.97 in.	Roll:	-0.24	Long.:	-3.82	Long.:	-0.31	Roof: 0.97 in.	High
												Pitch:	-0.68	Lat.:	0.01	Lat.:	0.40		
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.33	Long.:	-3.76	Long.:	0.12	No occupant compartment def.	High
												Pitch:	-0.18	Lat.:	0.16	Lat.:	0.11		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.49	Long.:	-3.43	Long.:	0.12	No occupant compartment def.	High
												Pitch:	-0.19	Lat.:	-0.13	Lat.:	-0.13		
							MASH 3-61	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	2.75	Long.:	-7.33	Long.:	-0.26	No occupant compartment def.	High
												Pitch:	1.17	Lat.:	1.05	Lat.:	0.66		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	1.68	Long.:	-7.84	Long.:	-0.35	No occupant compartment def.	High
												Pitch:	0.76	Lat.:	0.63	Lat.:	0.64		
								Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	1.58	Long.:	-6.97	Long.:	0.22	No occupant compartment def.	High
												Pitch:	-0.76	Lat.:	0.41	Lat.:	0.34		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	0.39	Long.:	-7.22	Long.:	0.27	No occupant compartment def.	High
												Pitch:	-5.34	Lat.:	0.57	Lat.:	0.37		
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	1.86	Long.:	-7.94	Long.:	-0.38	No occupant compartment def.	High
												Pitch:	-0.35	Lat.:	0.06	Lat.:	-0.50		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	0.65	Long.:	-6.78	Long.:	-0.31	No occupant compartment def.	High
												Pitch:	3.73	Lat.:	-0.16	Lat.:	0.34		
							MASH 3-62	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.69	Long.:	-4.63	Long.:	-0.24	No occupant compartment def.	High
												Pitch:	0.67	Lat.:	1.10	Lat.:	-0.31		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.56	Long.:	-4.56	Long.:	-0.26	No occupant compartment def.	High
												Pitch:	1.15	Lat.:	1.07	Lat.:	-0.28		
								Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.99	Long.:	-4.64	Long.:	-0.21	No occupant compartment def.	High
												Pitch:	-3.71	Lat.:	0.15	Lat.:	-0.26		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	0.67	Long.:	-4.73	Long.:	-0.25	No occupant compartment def.	High
												Pitch:	2.26	Lat.:	0.23	Lat.:	-0.25		
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.99	Long.:	-4.70	Long.:	-0.20	No occupant compartment def.	High
												Pitch:	0.62	Lat.:	-1.01	Lat.:	0.43		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	1.67	Long.:	-4.72	Long.:	-0.23	No occupant compartment def.	High
												Pitch:	1.45	Lat.:	-0.80	Lat.:	0.48		

Figure D-10. Detailed Simulation Results, Simulation Number 33

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
35	35'	8" Base	Single 4'	4-Bolt Slip Base	11 ga.	347 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.35 Pitch: -0.37	Long.: -3.40 Lat.: 0.11	Long.: -0.07 Lat.: 0.09	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.47 Pitch: -0.37	Long.: -4.08 Lat.: 0.08	Long.: -0.14 Lat.: -0.09	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 3.64 in.	Roll: 0.23 Pitch: -0.55	Long.: -3.60 Lat.: 0.04	Long.: -0.06 Lat.: -0.11	Roof: 3.64 in.	Medium
									25	Keeper Plate Rupture, Bolt Release	Roof: 3.67 in.	Roll: 0.25 Pitch: -0.79	Long.: -3.65 Lat.: 0.02	Long.: -0.35 Lat.: 0.21	Roof: 3.67 in.	Medium
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.34 Pitch: -0.19	Long.: -3.62 Lat.: 0.13	Long.: 0.13 Lat.: 0.15	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.30 Pitch: -0.18	Long.: -3.33 Lat.: 0.06	Long.: 0.09 Lat.: 0.14	No occupant compartment def.	High
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.37 Pitch: -3.38	Long.: -6.82 Lat.: 0.92	Long.: 0.32 Lat.: -0.37	No occupant compartment def.	High
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 1.14 Pitch: 0.58	Long.: -4.63 Lat.: 0.24	Long.: -0.18 Lat.: 0.21	No occupant compartment def.	High

Figure D-11. Detailed Simulation Results, Simulation Number 35

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
36	35'	8" Base	Dual 4'	4-Bolt Slip Base	11 ga.	437 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 3.59 in.	Roll: 0.06 Pitch: 0.75	Long.: -3.46 Lat.: 0.02	Long.: -0.07 Lat.: -0.09	Roof: 3.59 in.	Medium
									25	Keeper Plate Rupture, Bolt Release	Roof: 1.88 in.	Roll: 0.65 Pitch: -0.47	Long.: -3.76 Lat.: 0.01	Long.: -0.48 Lat.: -0.35	Roof: 1.88 in.	High
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: -0.40 Pitch: -0.98	Long.: -7.18 Lat.: 0.20	Long.: -0.34 Lat.: 0.38	No occupant compartment def.	High
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.55 Pitch: 0.57	Long.: -4.65 Lat.: 0.09	Long.: -0.18 Lat.: -0.28	No occupant compartment def.	High

Figure D-12. Detailed Simulation Results, Simulation Number 36

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
39-1	35'	8.5" Base	Single 10'	4-Bolt Slip Base	11 ga.	393 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.36	Long.:	-3.54	Long.:	-0.08	No occupant compartment def.	High
												Pitch:	-0.35	Lat.:	0.10	Lat.:	0.09		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	0.43	Long.:	-3.82	Long.:	-0.12	No occupant compartment def.	High
												Pitch:	-0.36	Lat.:	0.08	Lat.:	0.16		
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 4.54 in.	Roll:	-0.48	Long.:	-3.72	Long.:	-0.84	Roof: 4.54 in.	Low
												Pitch:	-0.73	Lat.:	0.02	Lat.:	0.41		
									25	Keeper Plate Rupture, Bolt Release	Roof: 4.36 in.	Roll:	0.12	Long.:	-3.95	Long.:	-0.67	Roof: 4.36 in.	Low
												Pitch:	-0.93	Lat.:	0.01	Lat.:	0.31		
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.33	Long.:	-3.62	Long.:	-0.16	No occupant compartment def.	High
												Pitch:	0.22	Lat.:	0.13	Lat.:	0.12		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.35	Long.:	-3.45	Long.:	0.12	No occupant compartment def.	High
												Pitch:	-0.18	Lat.:	0.04	Lat.:	-0.11		

Figure D-13. Detailed Simulation Results, Simulation Number 39-1

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
39-2	35'	8.5" Base	Dual 10'	4-Bolt Slip Base	11 ga.	513 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 3.64 in.	Roll:	0.09	Long.:	-3.68	Long.:	-0.51	Roof: 3.64 in.	Medium
												Pitch:	0.46	Lat.:	0.01	Lat.:	-0.12		
									25	Keeper Plate Rupture, Bolt Release	Roof: 2.51 in.	Roll:	0.22	Long.:	-3.91	Long.:	-0.35	Roof: 2.51 in.	Medium
												Pitch:	0.52	Lat.:	0.00	Lat.:	0.17		

Figure D-14. Detailed Simulation Results, Simulation Number 39-2

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
37	35'	9" Base	Single 20'	4-Bolt Slip Base	11 ga.	485 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 3.12 in.	Roll:	-1.83	Long.:	-3.92	Long.:	0.06	Roof: 3.12 in.	Medium
												Pitch:	-1.27	Lat.:	-0.01	Lat.:	0.09		
									25	Keeper Plate Rupture, Bolt Release	Roof: 4.24 in.	Roll:	0.53	Long.:	-4.73	Long.:	-0.70	Roof: 4.24 in.	Low
												Pitch:	-1.31	Lat.:	0.04	Lat.:	0.32		
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-1.22	Long.:	-7.37	Long.:	0.23	No occupant compartment def.	High
												Pitch:	1.46	Lat.:	0.61	Lat.:	0.31		
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-1.36	Long.:	-4.75	Long.:	-0.19	No occupant compartment def.	High
												Pitch:	-0.64	Lat.:	0.14	Lat.:	-0.34		

Figure D-15. Detailed Simulation Results, Simulation Number 37

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
38	35'	9" Base	Dual 20'	4-bolt Slip Base	11 ga	656 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.43 Pitch: -0.35	Long.: -3.79 Lat.: 0.09	Long.: -0.14 Lat.: 0.16	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.49 Pitch: -0.36	Long.: -4.90 Lat.: -0.25	Long.: 0.28 Lat.: -0.79	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 5.45 in.	Roll: 0.25 Pitch: -0.28	Long.: -4.80 Lat.: 0.06	Long.: 0.12 Lat.: -0.17	Roof: 5.45 in.	Low
									25	Keeper Plate Rupture, Bolt Release	Roof: 0.39 in.	Roll: 0.39 Pitch: 0.56	Long.: -4.55 Lat.: 0.00	Long.: -0.46 Lat.: -0.36	Roof: 0.39 in.	High
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.33 Pitch: 0.20	Long.: -3.94 Lat.: 0.20	Long.: 0.12 Lat.: -0.13	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.31 Pitch: 0.20	Long.: -3.64 Lat.: 0.11	Long.: 0.10 Lat.: -0.16	No occupant compartment def.	High
							MASH 3-61	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 1.43 Pitch: 1.99	Long.: -8.06 Lat.: 0.81	Long.: -0.43 Lat.: 0.60	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -1.70 Pitch: -0.65	Long.: -7.76 Lat.: 0.32	Long.: 0.23 Lat.: 0.69	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.72 Pitch: -0.83	Long.: -7.42 Lat.: 0.27	Long.: 0.26 Lat.: 0.43	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -1.42 Pitch: -2.33	Long.: -8.17 Lat.: 0.39	Long.: -0.38 Lat.: 0.51	No occupant compartment def.	High
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 1.20 Pitch: -0.53	Long.: -7.79 Lat.: -0.45	Long.: 0.29 Lat.: -0.53	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 4.34 Pitch: 0.45	Long.: -7.79 Lat.: -0.91	Long.: 0.25 Lat.: -0.70	No occupant compartment def.	High
							MASH 3-62	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: -1.49 Pitch: 0.84	Long.: -4.93 Lat.: 1.20	Long.: -0.20 Lat.: -0.33	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.64 Pitch: -1.94	Long.: -4.93 Lat.: 1.16	Long.: -0.20 Lat.: -0.29	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.83 Pitch: 0.91	Long.: -4.84 Lat.: 0.01	Long.: -0.20 Lat.: 0.22	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -0.48 Pitch: 1.54	Long.: -4.94 Lat.: 0.43	Long.: -0.21 Lat.: 0.26	No occupant compartment def.	High
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 1.48 Pitch: -2.19	Long.: -5.27 Lat.: -1.00	Long.: -0.40 Lat.: 0.55	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 1.57 Pitch: 2.05	Long.: -4.91 Lat.: -1.06	Long.: -0.27 Lat.: 0.47	No occupant compartment def.	High

Figure D-16. Detailed Simulation Results, Simulation Number 38

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
40	40'	9" Base	Single 4'	4-Bolt Slip Base	11 ga.	411 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.37 Pitch: -0.35	Long.: -3.83 Lat.: 0.10	Long.: -0.16 Lat.: 0.12	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.60 Pitch: -0.35	Long.: -5.55 Lat.: 0.11	Long.: -0.16 Lat.: -0.23	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 1.88 in.	Roll: -0.20 Pitch: 0.31	Long.: -3.79 Lat.: 0.00	Long.: -0.10 Lat.: -0.09	Roof: 1.88 in.	High
									25	Keeper Plate Rupture, Bolt Release	Roof: 1.69 in.	Roll: -0.40 Pitch: 0.52	Long.: -4.07 Lat.: -0.02	Long.: -0.68 Lat.: 0.42	Roof: 1.69 in.	High
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.34 Pitch: 0.21	Long.: -4.10 Lat.: 0.15	Long.: 0.11 Lat.: -0.13	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -0.39 Pitch: 0.26	Long.: -3.72 Lat.: -0.05	Long.: 0.11 Lat.: -0.13	No occupant compartment def.	High
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.39 Pitch: -0.94	Long.: -7.81 Lat.: 0.81	Long.: 0.37 Lat.: 0.37	No occupant compartment def.	High
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 4.53 Pitch: 4.25	Long.: -4.86 Lat.: 0.32	Long.: -0.19 Lat.: 0.26	No occupant compartment def.	High

Figure D-17. Detailed Simulation Results, Simulation Number 40

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
41	40'	9" Base	Dual 4'	4-Bolt Slip Base	11 ga.	501 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 4.08 in.	Roll: -0.11 Pitch: 0.23	Long.: -3.92 Lat.: 0.01	Long.: -0.32 Lat.: 0.15	Roof: 4.08 in.	Low
									25	Keeper Plate Rupture, Bolt Release	Front Windshield: 0.68	Roll: 0.67 Pitch: 0.45	Long.: -4.25 Lat.: -0.03	Long.: -0.52 Lat.: -0.42	Front Windshield: 0.68	High
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.34 Pitch: -1.17	Long.: -7.70 Lat.: 0.15	Long.: -0.55 Lat.: 0.40	No occupant compartment def.	High
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 1.49 Pitch: -1.00	Long.: -4.82 Lat.: 0.06	Long.: -0.27 Lat.: -0.21	No occupant compartment def.	High

Figure D-18. Detailed Simulation Results, Simulation Number 41

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
44-1	40'	9.5" Base	Single 10'	4-Bolt Slip Base	11 ga.	466 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.38 Pitch: -0.35	Long.: -3.91 Lat.: 0.09	Long.: -0.12 Lat.: -0.10	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.50 Pitch: -0.35	Long.: -4.80 Lat.: 0.01	Long.: -0.13 Lat.: -0.19	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 0.19 in.	Roll: -0.61 Pitch: 0.55	Long.: -3.85 Lat.: 0.02	Long.: -0.54 Lat.: 0.58	Roof: 0.19 in.	High
									25	Keeper Plate Rupture, Bolt Release	Roof: 3.30 in.	Roll: 0.17 Pitch: 0.64	Long.: -4.60 Lat.: 0.04	Long.: -0.51 Lat.: 0.22	Roof: 3.30 in.	Medium
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.33 Pitch: 0.22	Long.: -4.14 Lat.: 0.18	Long.: 0.15 Lat.: -0.14	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.31 Pitch: 0.27	Long.: -3.78 Lat.: 0.13	Long.: 0.14 Lat.: -0.18	No occupant compartment def.	High

Figure D-19. Detailed Simulation Results, Simulation Number 44-1

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
44-2	40'	9.5" Base	Dual 10'	4-Bolt Slip Base	11 ga.	586 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 1.76 in.	Roll: 0.09 Pitch: 0.69	Long.: -4.01 Lat.: 0.02	Long.: -0.36 Lat.: 0.12	Roof: 1.76 in.	High
									25	Keeper Plate Rupture, Bolt Release	Roof: 0.84 in.	Roll: 0.51 Pitch: 0.84	Long.: -4.60 Lat.: 0.06	Long.: -0.37 Lat.: -0.27	Roof: 0.84 in.	High

Figure D-20. Detailed Simulation Results, Simulation Number 44-2

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
42	40'	10" Base	Single 20'	4-Bolt Slip Base	11 ga.	556 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	C-Pillar: 0.22 in.	Roll: 0.52 Pitch: -0.52	Long.: -3.97 Lat.: -0.01	Long.: -0.28 Lat.: 0.21	C-Pillar: 0.22 in.	High
									25	Keeper Plate Rupture, Bolt Release	Roof: 4.73 in.	Roll: -0.82 Pitch: -0.81	Long.: -5.10 Lat.: -0.03	Long.: -0.66 Lat.: 0.45	Roof: 4.73 in.	Low
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.48 Pitch: -1.47	Long.: -8.37 Lat.: 0.68	Long.: 0.47 Lat.: 0.50	No occupant compartment def.	High
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: -0.54 Pitch: -0.70	Long.: -5.10 Lat.: 0.28	Long.: -0.29 Lat.: -0.18	No occupant compartment def.	High

Figure D-21. Detailed Simulation Results, Simulation Number 42

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
43	40'	10" Base	Dual 20'	4-bolt Slip Base	11 ga	727 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.44 Pitch: -0.34	Long.: -4.23 Lat.: 0.12	Long.: -0.19 Lat.: -0.14	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.68 Pitch: -0.35	Long.: -6.94 Lat.: 0.03	Long.: -0.40 Lat.: -1.45	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 3.55 in.	Roll: 0.10 Pitch: 0.24	Long.: -4.53 Lat.: 0.00	Long.: -1.04 Lat.: 0.34	Roof: 3.55 in.	Medium
									25	Keeper Plate Rupture, Bolt Release	Roof: 3.67 in.	Roll: 0.45 Pitch: 0.31	Long.: -5.24 Lat.: -0.07	Long.: -0.75 Lat.: -0.78	Roof: 3.67 in.	Medium
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.35 Pitch: 0.25	Long.: -4.24 Lat.: 0.14	Long.: -0.11 Lat.: -0.15	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.33 Pitch: 0.32	Long.: -3.99 Lat.: 0.14	Long.: -0.10 Lat.: -0.12	No occupant compartment def.	High
							MASH 3-61	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: -2.10 Pitch: 0.61	Long.: -8.55 Lat.: 0.38	Long.: -0.62 Lat.: 0.59	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.72 Pitch: 0.83	Long.: -8.25 Lat.: 0.06	Long.: 0.35 Lat.: 0.62	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.35 Pitch: -1.38	Long.: -8.74 Lat.: 0.16	Long.: -0.40 Lat.: 0.39	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.41 Pitch: 2.65	Long.: -9.44 Lat.: 0.48	Long.: -0.79 Lat.: 0.50	No occupant compartment def.	High
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: -1.26 Pitch: 1.87	Long.: -8.52 Lat.: -0.55	Long.: -0.27 Lat.: -0.76	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -0.94 Pitch: 0.67	Long.: -8.67 Lat.: -0.26	Long.: 0.26 Lat.: -0.62	No occupant compartment def.	High
							MASH 3-62	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: -0.51 Pitch: 0.91	Long.: -5.41 Lat.: 1.23	Long.: -0.21 Lat.: -0.31	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 1.52 Pitch: 1.49	Long.: -5.48 Lat.: 1.32	Long.: -0.28 Lat.: 0.52	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 1.90 Pitch: 3.46	Long.: -5.26 Lat.: 0.07	Long.: -0.26 Lat.: -0.21	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -0.57 Pitch: -0.83	Long.: -5.36 Lat.: 0.19	Long.: -0.26 Lat.: 0.34	No occupant compartment def.	High
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: -1.21 Pitch: 4.78	Long.: -5.25 Lat.: -1.11	Long.: -0.28 Lat.: -0.41	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -0.86 Pitch: 1.25	Long.: -5.12 Lat.: -1.01	Long.: -0.25 Lat.: 0.38	No occupant compartment def.	High

Figure D-22. Detailed Simulation Results, Simulation Number 43

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
45	45'	9.5" Base	Single 4'	4-Bolt Slip Base	11 ga.	466 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.42	Long.:	-4.10	Long.:	-0.20	No occupant compartment def.	High
												Pitch:	-0.34	Lat.:	0.06	Lat.:	-0.13		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	-1.01	Long.:	-19.66	Long.:	0.72	No occupant compartment def.	Low (Bad Model)
												Pitch:	-0.43	Lat.:	-3.54	Lat.:	0.76		
								Center	0	Keeper Plate Rupture, Bolt Release	C-Pillar: 0.35 in.	Roll:	-0.56	Long.:	-4.04	Long.:	-0.42	C-Pillar: 0.35 in.	High
												Pitch:	0.34	Lat.:	0.04	Lat.:	-0.22		
									25	Keeper Plate Rupture, Bolt Release	Roof: 3.00 in.	Roll:	-0.33	Long.:	-4.85	Long.:	-0.70	Roof: 3.00 in.	Medium
												Pitch:	0.67	Lat.:	0.08	Lat.:	0.46		
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.42	Long.:	-5.35	Long.:	-0.12	No occupant compartment def.	High
												Pitch:	0.25	Lat.:	0.12	Lat.:	-0.18		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	0.30	Long.:	-4.01	Long.:	0.10	No occupant compartment def.	High
												Pitch:	0.31	Lat.:	0.10	Lat.:	0.13		
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.47	Long.:	-8.02	Long.:	0.43	No occupant compartment def.	High
												Pitch:	-1.13	Lat.:	0.74	Lat.:	0.35		
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.47	Long.:	-5.09	Long.:	0.22	No occupant compartment def.	High
												Pitch:	-0.82	Lat.:	0.38	Lat.:	-0.33		

Figure D-23. Detailed Simulation Results, Simulation Number 45

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
46	45'	9.5" Base	Dual 4'	4-Bolt Slip Base	11 ga.	557 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 4.02 in.	Roll:	0.12	Long.:	-4.22	Long.:	-0.07	Roof: 4.02 in.	Low
												Pitch:	0.77	Lat.:	0.00	Lat.:	-0.11		
									25	Keeper Plate Rupture, Bolt Release	Roof: 0.93 in.	Roll:	0.16	Long.:	-4.94	Long.:	-0.55	Roof: 0.93 in.	High
												Pitch:	0.35	Lat.:	0.05	Lat.:	0.15		
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.38	Long.:	-9.09	Long.:	-0.69	No occupant compartment def.	High
												Pitch:	-2.28	Lat.:	0.20	Lat.:	0.48		
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.57	Long.:	-5.06	Long.:	-0.22	No occupant compartment def.	High
												Pitch:	3.58	Lat.:	-0.02	Lat.:	-0.26		

Figure D-24. Detailed Simulation Results, Simulation Number 46

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
49-1	45'	10" Base	Single 10'	4-Bolt Slip Base	11 ga.	529 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.39	Long.:	-4.30	Long.:	-0.13	No occupant compartment def.	High
												Pitch:	-0.34	Lat.:	0.04	Lat.:	-0.15		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	0.70	Long.:	-6.88	Long.:	-0.09	No occupant compartment def.	High
												Pitch:	-0.36	Lat.:	0.03	Lat.:	-0.17		
								Center	0	Keeper Plate Rupture, Bolt Release	Front Windshield: 0.56 in.	Roll:	-0.66	Long.:	-4.23	Long.:	-0.71	Front Windshield: 0.56 in.	High
												Pitch:	0.57	Lat.:	-0.01	Lat.:	0.58		
									25	Keeper Plate Rupture, Bolt Release	Roof: 1.50 in.	Roll:	-0.73	Long.:	-4.85	Long.:	-0.62	Roof: 1.50 in.	High
												Pitch:	0.39	Lat.:	0.08	Lat.:	0.69		
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.33	Long.:	-4.39	Long.:	-0.09	No occupant compartment def.	High
												Pitch:	0.30	Lat.:	0.21	Lat.:	0.13		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	0.32	Long.:	-4.14	Long.:	0.10	No occupant compartment def.	High
												Pitch:	0.31	Lat.:	0.03	Lat.:	0.16		

Figure D-25. Detailed Simulation Results, Simulation Number 49-1

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
49-2	45'	10" Base	Dual 10'	4-Bolt Slip Base	11 ga.	648 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 6.39 in.	Roll:	0.10	Long.:	-4.63	Long.:	-0.29	Roof: 6.39 in.	Low
												Pitch:	0.31	Lat.:	0.01	Lat.:	0.13		
									25	Keeper Plate Rupture, Bolt Release	C-Pillar: 0.60 in.	Roll:	0.36	Long.:	-5.67	Long.:	-0.68	C-Pillar: 0.60 in.	High
												Pitch:	0.53	Lat.:	-0.08	Lat.:	-0.47		

Figure D-26. Detailed Simulation Results, Simulation Number 49-2

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
47	45'	10.5" Base	Single 20'	4-Bolt Slip Base	**10 ga.**	676 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 0.45 in.	Roll:	0.70	Long.:	-4.64	Long.:	-0.10	Roof: 0.45 in.	High
												Pitch:	-0.30	Lat.:	0.01	Lat.:	-0.11		
									25	Keeper Plate Rupture, Bolt Release	Roof: 1.10 in.	Roll:	-0.57	Long.:	-4.95	Long.:	-0.81	Roof: 1.10 in.	High
												Pitch:	0.75	Lat.:	0.07	Lat.:	0.52		
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	1.08	Long.:	-10.00	Long.:	-0.57	No occupant compartment def.	High
												Pitch:	-2.70	Lat.:	0.79	Lat.:	0.82		
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-1.78	Long.:	-5.83	Long.:	-0.33	No occupant compartment def.	High
												Pitch:	2.80	Lat.:	0.29	Lat.:	0.33		

Figure D-27. Detailed Simulation Results, Simulation Number 47

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
48	45'	10.5" Base	Dual 20'	4-bolt Slip Base	**10 ga**	847 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.41 Pitch: -0.36	Long.: -4.70 Lat.: 0.04	Long.: -0.12 Lat.: -0.14	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -0.69 Pitch: -0.38	Long.: -5.72 Lat.: 0.09	Long.: -0.37 Lat.: -0.99	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 6.11 in.	Roll: 0.12 Pitch: 0.56	Long.: -4.99 Lat.: 0.02	Long.: -0.42 Lat.: 0.15	Roof: 6.11 in.	Low
									25	Keeper Plate Rupture, Bolt Release	Roof: 3.41 in.	Roll: 0.19 Pitch: -0.15	Long.: -6.25 Lat.: -0.19	Long.: 0.37 Lat.: 0.37	Roof: 3.41 in.	Medium
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.33 Pitch: 0.30	Long.: -4.83 Lat.: 0.33	Long.: -0.08 Lat.: -0.26	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.30 Pitch: 0.24	Long.: -4.26 Lat.: 0.11	Long.: 0.08 Lat.: 0.15	No occupant compartment def.	High
							MASH 3-61	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: -2.33 Pitch: -4.72	Long.: -9.38 Lat.: -0.02	Long.: -0.36 Lat.: 0.56	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 1.45 Pitch: -1.38	Long.: -9.68 Lat.: -0.44	Long.: -0.73 Lat.: 0.84	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.62 Pitch: -2.57	Long.: -10.73 Lat.: -0.13	Long.: -0.73 Lat.: 1.41	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -4.58 Pitch: 7.02	Long.: -11.35 Lat.: 0.30	Long.: -0.67 Lat.: 0.71	No occupant compartment def.	High
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 1.15 Pitch: 1.31	Long.: -9.02 Lat.: 0.13	Long.: -0.34 Lat.: -0.62	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 1.39 Pitch: 2.42	Long.: -8.76 Lat.: 0.12	Long.: 0.42 Lat.: -0.52	No occupant compartment def.	High
							MASH 3-62	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: -0.97 Pitch: 2.69	Long.: -5.84 Lat.: 1.22	Long.: -0.32 Lat.: 0.42	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -0.75 Pitch: 0.63	Long.: -5.93 Lat.: 1.08	Long.: -0.52 Lat.: 0.71	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: -2.81 Pitch: 1.91	Long.: -6.00 Lat.: 0.17	Long.: -0.31 Lat.: -0.30	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -1.37 Pitch: 0.74	Long.: -6.05 Lat.: 0.24	Long.: -0.41 Lat.: 0.33	No occupant compartment def.	High
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: -0.79 Pitch: 0.52	Long.: -5.91 Lat.: -0.99	Long.: -0.29 Lat.: -0.70	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -0.80 Pitch: 0.88	Long.: -5.77 Lat.: -1.11	Long.: -0.33 Lat.: -0.33	No occupant compartment def.	High

Figure D-28. Detailed Simulation Results, Simulation Number 48

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]		OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]		Ridedown Acc. [g] [P: 15g; Max:20.49g]		Simulation Results	Potential to Pass MASH
50	50'	10.5" Base	Single 8'	4-Bolt Slip Base	**10 ga.**	642 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll:	0.35	Long.:	-4.44	Long.:	-0.18	No occupant compartment def.	High
												Pitch:	-0.37	Lat.:	0.09	Lat.:	0.19		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	0.68	Long.:	-6.12	Long.:	0.13	No occupant compartment def.	High
												Pitch:	-0.40	Lat.:	0.09	Lat.:	-0.25		
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 5.31 in.	Roll:	-0.21	Long.:	-4.86	Long.:	-0.56	Roof: 5.31 in.	Low
												Pitch:	0.79	Lat.:	0.01	Lat.:	-0.28		
									25	Keeper Plate Rupture, Bolt Release	Roof: 5.74 in.	Roll:	-0.32	Long.:	-5.17	Long.:	-1.81	Roof: 5.74 in.	Low
												Pitch:	0.17	Lat.:	0.00	Lat.:	-1.13		
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	B Pillar: 0.45 in.	Roll:	0.37	Long.:	-4.89	Long.:	-0.11	B Pillar: 0.45 in.	High
												Pitch:	0.47	Lat.:	0.30	Lat.:	0.20		
									25	Keeper Plate Rupture, Bolt Release	None	Roll:	0.30	Long.:	-4.56	Long.:	0.11	No occupant compartment def.	High
												Pitch:	0.45	Lat.:	0.18	Lat.:	0.19		
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.62	Long.:	-9.78	Long.:	-0.42	No occupant compartment def.	High
												Pitch:	-2.00	Lat.:	0.74	Lat.:	0.55		
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll:	-0.83	Long.:	-5.93	Long.:	-0.26	No occupant compartment def.	High
												Pitch:	0.80	Lat.:	0.47	Lat.:	0.34		

Figure D-29. Detailed Simulation Results, Simulation Number 50

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
51	50'	10.5" Base	Dual 8'	4-Bolt Slip Base	**10 ga.**	749 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 6.20 in.	Roll: 0.09 Pitch: 0.60	Long.: -5.05 Lat.: 0.03	Long.: -0.51 Lat.: -0.12	Roof: 6.20 in.	Low
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.24 Pitch: 0.52	Long.: -5.41 Lat.: 0.00	Long.: -0.48 Lat.: -0.35	No occupant compartment def.	High
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.86 Pitch: -3.60	Long.: -11.52 Lat.: -0.26	Long.: -1.02 Lat.: 0.83	No occupant compartment def.	High
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.52 Pitch: 2.19	Long.: -5.87 Lat.: 0.03	Long.: -0.25 Lat.: -0.32	No occupant compartment def.	High

Figure D-30. Detailed Simulation Results, Simulation Number 51

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
52	50'	10.5" Base	Single 25'	4-Bolt Slip Base	**10 ga.**	676 lb	MASH 3-60	Center	0	Keeper Plate Rupture, Bolt Release	Roof: 5.77 in.	Roll: -0.43 Pitch: 0.75	Long.: -6.26 Lat.: 0.01	Long.: -0.66 Lat.: 0.59	Roof: 5.77 in.	Low
									25	Keeper Plate Rupture, Bolt Release	Roof: 4.04 in.	Roll: -1.91 Pitch: -0.41	Long.: -4.83 Lat.: 0.01	Long.: -0.92 Lat.: 0.72	Roof: 4.04 in.	Low
							MASH 3-61	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.76 Pitch: -0.73	Long.: -10.20 Lat.: 0.57	Long.: 0.26 Lat.: -0.52	No occupant compartment def.	High
							MASH 3-62	Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: -1.01 Pitch: 0.62	Long.: -6.02 Lat.: 0.39	Long.: 0.42 Lat.: -0.40	No occupant compartment def.	High

Figure D-31. Detailed Simulation Results, Simulation Number 52

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Failure Mechanism	Occupant Compartment Deformation	Max. Roll and Pitch Angle (Degree) [Max: 75°]	OIV [ft/s] [P: 10ft/s; Max: 16 ft/s]	Ridedown Acc. [g] [P: 15g; Max:20.49g]	Simulation Results	Potential to Pass MASH
53	50'	10.5" Base	Dual 15'	4-bolt Slip Base	**7 ga**	986 lb	MASH 3-60	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.53 Pitch: -0.43	Long.: -6.05 Lat.: -0.11	Long.: -0.17 Lat.: -0.21	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.52 Pitch: -0.47	Long.: -5.20 Lat.: -0.01	Long.: -0.20 Lat.: 0.24	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	Roof: 6.87 in.	Roll: 0.16 Pitch: -0.15	Long.: -7.23 Lat.: -0.02	Long.: -1.24 Lat.: 0.87	Roof: 6.87 in.	Low
									25	Keeper Plate Rupture, Bolt Release	Roof: 3.60 in.	Roll: 0.16 Pitch: 0.29	Long.: -6.19 Lat.: 0.02	Long.: -1.92 Lat.: -0.69	Roof: 3.60 in.	Medium
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.37 Pitch: 0.34	Long.: -5.76 Lat.: 0.62	Long.: -0.14 Lat.: -0.26	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.35 Pitch: 0.32	Long.: -5.63 Lat.: 0.17	Long.: 0.12 Lat.: -0.20	No occupant compartment def.	High
							MASH 3-61	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 1.23 Pitch: 1.25	Long.: -10.13 Lat.: -0.57	Long.: -0.30 Lat.: 0.59	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 1.30 Pitch: -1.54	Long.: -11.81 Lat.: -0.45	Long.: 0.57 Lat.: 0.83	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 0.45 Pitch: -0.61	Long.: -12.45 Lat.: 0.00	Long.: 0.73 Lat.: 0.67	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: 0.46 Pitch: -1.61	Long.: -13.76 Lat.: -0.30	Long.: 1.54 Lat.: -0.54	No occupant compartment def.	High
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: -3.53 Pitch: -5.85	Long.: 11.33 Lat.: 0.94	Long.: -0.29 Lat.: -0.78	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -2.15 Pitch: 1.53	Long.: -11.44 Lat.: 0.28	Long.: -0.78 Lat.: -1.07	No occupant compartment def.	High
							MASH 3-62	Left 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: 1.77 Pitch: 0.79	Long.: -6.97 Lat.: 1.13	Long.: -0.47 Lat.: 0.74	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -1.09 Pitch: 2.60	Long.: -7.39 Lat.: 0.76	Long.: 0.60 Lat.: 0.96	No occupant compartment def.	High
								Center	0	Keeper Plate Rupture, Bolt Release	None	Roll: 2.46 Pitch: 0.65	Long.: -7.14 Lat.: 0.18	Long.: -0.52 Lat.: -0.41	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -3.07 Pitch: 0.64	Long.: -7.14 Lat.: 0.33	Long.: -0.36 Lat.: -0.42	No occupant compartment def.	High
								Right 1/4	0	Keeper Plate Rupture, Bolt Release	None	Roll: -5.00 Pitch: 0.63	Long.: -7.15 Lat.: -1.00	Long.: -0.34 Lat.: -0.94	No occupant compartment def.	High
									25	Keeper Plate Rupture, Bolt Release	None	Roll: -0.71 Pitch: 0.53	Long.: -7.00 Lat.: -1.35	Long.: -0.63 Lat.: -1.07	No occupant compartment def.	High

Figure D-32. Detailed Simulation Results, Simulation Number 53

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
20	20'	6.5" Base	Single 4'	4-Bolt Slip Base	11 ga.	222 lb	MASH 3-60	Left 1/4	0	Pole falls to the rear side of the vehicle and clips the c-pillar while falling
									25	Pole falls to the rear side of the vehicle and clips the c-pillar while falling
								Center	0	Pole rotates ~135 deg CCW about the z-axis while falling and impacts front passenger side of roof, just above front passenger side door, then falls off roof
									25	Pole rotates ~90 deg CCW about the z-axis while falling and impacts rear passenger side of roof and rear window, then falls off roof
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
							MASH 3-61	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-33. Simulation Pole Dynamics Description, Simulation Number 20

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
21	20'	6.5" Base	Dual 4'	4-Bolt Slip Base	11 ga.	312 lb	MASH 3-60	Center	0	Pole falls without rotating about the z-axis and falls on the rear center of the roof and rear window, then falls off roof
									25	Pole falls without rotating about the z-axis and falls on the rear center of the roof and rear window, then falls off roof
							MASH 3-61	Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-34. Simulation Pole Dynamics Description, Simulation Number 21

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
22	20'	7" Base	Single 10'	4-Bolt Slip Base	11 ga.	261 lb	MASH 3-60	Center	0	Pole rotates ~75 deg CCW about the z-axis while falling and impacts passenger side of roof and rear window, then falls off roof
									25	Pole rotates ~45 deg CCW about the z-axis while falling and impacts rear center of roof and rear window, then falls off roof
							MASH 3-61	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-35. Simulation Pole Dynamics Description, Simulation Number 22

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
23	20'	7" Base	Dual 10'	4-bolt Slip Base	11 ga	381 lb	MASH 3-60	Left 1/4	0	Pole falls to the driver side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the driver side of the vehicle and clips the A-pillar while falling
								Center	0	Pole falls without rotating about the z-axis and falls on the rear center of the roof and rear window, then falls off roof
									25	Pole falls without rotating about the z-axis and falls on the front passenger side of the roof, then impacts rear passenger side of the roof while falling off vehicle
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
							MASH 3-61	Left 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Right 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Left 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Right 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-36. Simulation Pole Dynamics Description, Simulation Number 23

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
30	30'	7.5" Base	Single 4'	4-Bolt Slip Base	11 ga.	300 lb	MASH 3-60	Left 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole rotates ~135 deg CCW about z-axis while falling and impacts front passenger side of roof and front windshield, and then impacts rear passenger side of roof while falling off roof
									25	Pole rotates ~150 deg CCW about z-axis while falling and impacts front center of roof and front windshield, and then impacts rear passenger side of roof while falling off roof
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
							MASH 3-61	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-37. Simulation Pole Dynamics Description, Simulation Number 30

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
31	30'	7.5" Base	Dual 4'	4-Bolt Slip Base	11 ga.	390 lb	MASH 3-60	Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof and front windshield, then impacts rear center of the roof while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls on the front center of the roof and front windshield, then impacts rear center of the roof and rear window while falling off vehicle
							MASH 3-61	Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-38. Simulation Pole Dynamics Description, Simulation Number 31

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
34-1	30'	8" Base	Single 10'	4-Bolt Slip Base	11 ga.	349 lb	MASH 3-60	Left 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole rotates ~75 deg CCW about z-axis while falling and impacts the front passenger side of roof, defroming the length of the roof to the rear passenger side, then falls off roof
									25	Pole rotates ~75 deg CCW about z-axis while falling and impacts the frontcenter of roof, defroming the length of the roof to the rear center of roof, then falls off roof
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment

Figure D-39. Simulation Pole Dynamics Description, Simulation Number 34-1

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
34-2	30'	8" Base	Dual 10'	4-Bolt Slip Base	11 ga.	468 lb	MASH 3-60	Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof and front windshield, then impacts rear center of the roof while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls on the front passenger side of the roof and front windshield, then impacts rear passenger side of the roof while falling off vehicle

Figure D-40. Simulation Pole Dynamics Description, Simulation Number 34-2

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
32	30'	8.5" Base	Single 20'	4-Bolt Slip Base	11 ga.	433 lb	MASH 3-60	Center	0	Pole rotates ~60 deg CCW about z-axis while falling and impacts the front center of roof, defroming the length of the roof to the rear passenger side, then falls off roof
									25	Pole rotates ~60 deg CCW about z-axis while falling and impacts the front center of roof, deforming the length of the roof to the rear center of roof, then falls off vehicle
							MASH 3-61	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-41. Simulation Pole Dynamics Description, Simulation Number 32

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
33	30'	8.5" Base	Dual 20'	4-bolt Slip Base	11 ga	381 lb	MASH 3-60	Left 1/4	0	Pole falls to the driver side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the driver side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof, then impacts rear center of the roof while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls on the rear passenger side of the roof, then falls off vehicle
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
							MASH 3-61	Left 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Right 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Left 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Right 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-42. Simulation Pole Dynamics Description, Simulation Number 33

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
35	35'	8" Base	Single 4'	4-Bolt Slip Base	11 ga.	347 lb	MASH 3-60	Left 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole rotates ~180 deg CCW about z-axis while falling and impacts front center of roof, and then deforms rear passenger side of roof while falling off roof
									25	Pole rotates ~180 deg CCW about z-axis while falling and impacts front center of roof, and then deforms rear passenger side of roof and rear window while falling off roof
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
							MASH 3-61	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-43. Simulation Pole Dynamics Description, Simulation Number 35

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
36	35'	8" Base	Dual 4'	4-Bolt Slip Base	11 ga.	437 lb	MASH 3-60	Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof and front windshield, then impacts rear center of the roof while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls on the front passenger side of the roof, then impacts rear passenger side of the roof while falling off vehicle
							MASH 3-61	Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-44. Simulation Pole Dynamics Description, Simulation Number 36

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
39-1	35'	8.5" Base	Single 10'	4-Bolt Slip Base	11 ga.	393 lb	MASH 3-60	Left 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole rotates ~75 deg CCW about z-axis while falling and impacts the front driver side of roof, then impacts rear center of the roof while falling off vehicle
									25	Pole rotates ~75 deg CCW about z-axis while falling and impacts the front center of roof and front windshield, then impacts rear passenger side of the roof while falling off vehicle
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment

Figure D-45. Simulation Pole Dynamics Description, Simulation Number 39-1

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
39-2	35'	8.5" Base	Dual 10'	4-Bolt Slip Base	11 ga.	513 lb	MASH 3-60	Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof, then impacts rear center of the roof while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls on the front center of the roof, then impacts rear passenger side of the roof while falling off vehicle

Figure D-46. Simulation Pole Dynamics Description, Simulation Number 39-2

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
37	35'	9" Base	Single 20'	4-Bolt Slip Base	11 ga.	485 lb	MASH 3-60	Center	0	Pole rotates ~60 deg CCW about z-axis while falling and impacts the front driver side of roof, defroming the length of the roof to the rear center of roof, then falls off roof
									25	Pole rotates ~45 deg CCW about z-axis while falling and impacts the front center of roof, defroming the length of the roof to the rear center of roof, then impacts rear center of the roof while falling off vehicle
							MASH 3-61	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-47. Simulation Pole Dynamics Description, Simulation Number 37

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
38	35'	9" Base	Dual 20'	4-bolt Slip Base	11 ga	656 lb	MASH 3-60	Left 1/4	0	Pole falls to the driver side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the driver side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof and deforms the length of roof to the rear center of the roof, then falls off vehicle
									25	Pole falls without rotating about the z-axis and falls on the front passenger side of roof, then impacts rear passenger side of the roof while falling off vehicle
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
							MASH 3-61	Left 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Right 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Left 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Right 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-48. Simulation Pole Dynamics Description, Simulation Number 38

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
40	40'	9" Base	Single 4'	4-Bolt Slip Base	11 ga.	411 lb	MASH 3-60	Left 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole rotates ~180 deg CCW about z-axis while falling and impacts front driver side of roof, and then deforms rear driver side of roof while falling off roof
									25	Pole rotates ~150 deg CCW about z-axis while falling and impacts front driver side of roof, and then deforms rear driver side of roof while falling off roof
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
							MASH 3-61	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-49. Simulation Pole Dynamics Description, Simulation Number 40

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
41	40'	9" Base	Dual 4'	4-Bolt Slip Base	11 ga.	501 lb	MASH 3-60	Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof, then impacts rear center of the roof while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls on the front passenger of the roof and front windshield, then impacts passenger side C-pillar while falling off vehicle
							MASH 3-61	Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-50. Simulation Pole Dynamics Description, Simulation Number 41

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
44-1	40'	9.5" Base	Single 10'	4-Bolt Slip Base	11 ga.	466 lb	MASH 3-60	Left 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole rotates ~90 deg CCW about the z-axis while falling and impacts front and rear driver side of roof, just above driver side doors, then falls off roof
									25	Pole rotates ~90 deg CCW about the z-axis while falling and impacts front center of roof, then impacts rear driver side of roof while falling off vehicle
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment

Figure D-51. Simulation Pole Dynamics Description, Simulation Number 44-1

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
44-2	40'	9.5" Base	Dual 10'	4-Bolt Slip Base	11 ga.	586 lb	MASH 3-60	Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof, then impacts rear center of the roof while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls on the front passenger side of the roofand front windshield, then impacts rear passenger side of the roof while falling off vehicle

Figure D-52. Simulation Pole Dynamics Description, Simulation Number 44-2

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
42	40'	10" Base	Single 20'	4-Bolt Slip Base	11 ga.	556 lb	MASH 3-60	Center	0	Pole rotates ~60 deg CCW about the z-axis while falling and impacts just above driver side doors and the C-pillar , then falls off roof
									25	Pole rotates ~60 deg CCW about the z-axis while falling and impacts front driver side of roof, then impacts rear driver side of the roof while falling off vehicle
							MASH 3-61	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-53. Simulation Pole Dynamics Description, Simulation Number 42

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
43	40'	10" Base	Dual 20'	4-bolt Slip Base	11 ga	727 lb	MASH 3-60	Left 1/4	0	Pole falls to the driver side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the driver side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof, then impacts rear center of the roof while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls on the front center of the roof, then impacts rear passenger side of the roof while falling off vehicle
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
							MASH 3-61	Left 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Right 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Left 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Right 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-54. Simulation Pole Dynamics Description, Simulation Number 43

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
45	45'	9.5" Base	Single 4'	4-Bolt Slip Base	11 ga.	466 lb	MASH 3-60	Left 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole rotates ~180 deg CCW about z-axis while falling and impacts driver side A-pillar, and then deforms driver side C-pillar while falling off vehicle
									25	Pole rotates ~180 deg CCW about z-axis while falling and impacts front center of roof, and then impacts rear driver side of roof while falling off vehicle
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
							MASH 3-61	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-55. Simulation Pole Dynamics Description, Simulation Number 45

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
46	45'	9.5" Base	Dual 4'	4-Bolt Slip Base	11 ga.	557 lb	MASH 3-60	Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof, then impacts rear center of the roof while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls on the front passenger side of the roof, then impacts rear passenger side of the roof while falling off vehicle
							MASH 3-61	Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-56. Simulation Pole Dynamics Description, Simulation Number 46

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
49-1	45'	10" Base	Single 10'	4-Bolt Slip Base	11 ga.	529 lb	MASH 3-60	Left 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole rotates ~90 deg CCW about the z-axis while falling and impacts front windshield, then impacts rear driver side of roof, just above driver side rear door, then falls off vehicle
									25	Pole rotates ~90 deg CCW about the z-axis while falling and impacts front driver side of roof and front windshield, then impacts rear driver side of roof and driver side C-pillar while falling off vehicle
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment

Figure D-57. Simulation Pole Dynamics Description, Simulation Number 49-1

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
49-2	45'	10" Base	Dual 10'	4-Bolt Slip Base	11 ga.	648 lb	MASH 3-60	Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof, then impacts rear center of the roof while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls on the front passenger side of the roof and front windshield, then impacts rear passenger side of the roof and passenger side C-pillar while falling off vehicle

Figure D-58. Simulation Pole Dynamics Description, Simulation Number 49-2

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
47	45'	10.5" Base	Single 20'	4-Bolt Slip Base	**10 ga.**	676 lb	MASH 3-60	Center	0	Pole rotates ~60 deg CCW about the z-axis while falling and impacts just above driver side doors, then falls off roof
									25	Pole rotates ~60 deg CCW about the z-axis while falling and impacts front driver side of roof and front windshield, then impacts rear driver side of roof and driver side C-pillar while falling off vehicle
							MASH 3-61	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-59. Simulation Pole Dynamics Description, Simulation Number 47

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
48	45'	10.5" Base	Dual 20'	4-bolt Slip Base	**10 ga**	847 lb	MASH 3-60	Left 1/4	0	Pole falls to the driver side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the driver side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof, then impacts rear center of the roof and rear window while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls on the front center of the roof and front windshield, then impacts rear center and passenger side of the roof while falling off vehicle
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
							MASH 3-61	Left 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Right 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Left 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Right 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-60. Simulation Pole Dynamics Description, Simulation Number 48

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
50	50'	10.5" Base	Single 8'	4-Bolt Slip Base	**10 ga.**	642 lb	MASH 3-60	Left 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole rotates ~150 deg CCW about z-axis while falling and impacts front center of roof, then deforms rear center of roof while falling off vehicle
									25	Pole rotates ~135 deg CCW about z-axis while falling and impacts front center of roof and front windshield, then impacts the rear center and driver side of roof and rear window while falling off
								Right 1/4	0	Pole falls to the passenger side of the vehicle and clips the c-pillar while falling
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
							MASH 3-61	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-61. Simulation Pole Dynamics Description, Simulation Number 50

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
51	50'	10.5" Base	Dual 8'	4-Bolt Slip Base	**10 ga.**	749 lb	MASH 3-60	Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof, then impacts rear center of the roof and rear window while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls to the passenger side of the vehicle without contacting the roof or windows. There is small deformation to the rear passenger side door (~0.5 in.)
							MASH 3-61	Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-62. Simulation Pole Dynamics Description, Simulation Number 51

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
52	50'	10.5" Base	Single 25'	4-Bolt Slip Base	**10 ga.**	676 lb	MASH 3-60	Center	0	Pole rotates ~90 deg CCW about the z-axis while falling and impacts front driver side of roof, then impacts rear center of the roof and rear window while falling off vehicle
									25	Pole rotates ~90 deg CCW about the z-axis while falling and impacts front driver side of roof and front windshield, then impacts rear center of the roof and rear window while falling off vehicle
							MASH 3-61	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Center	0	Pole flips over vehicle, while rotating CCW about the z-axis, without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-63. Simulation Pole Dynamics Description, Simulation Number 52

Pole	Height [ft]	Pole Dimensions	Mast Arm	Breakaway Base Type	Pole Thickness	Weight [lb]	MASH Desig.	Impact Location	Impact Angle (Degree)	Pole Dynamics Description
53	50'	10.5" Base	Dual 15'	4-bolt Slip Base	**7 ga**	986 lb	MASH 3-60	Left 1/4	0	Pole falls to the driver side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the driver side of the vehicle and does not make contact with the occupant compartment
								Center	0	Pole falls without rotating about the z-axis and falls on the front center of the roof, then impacts rear center of the roof and rear window while falling off vehicle
									25	Pole falls without rotating about the z-axis and falls on the front driver side of the roof, then impacts rear driver side of the roof and rear window while falling off vehicle
								Right 1/4	0	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
									25	Pole falls to the passenger side of the vehicle and does not make contact with the occupant compartment
							MASH 3-61	Left 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Right 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
							MASH 3-62	Left 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Center	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
								Right 1/4	0	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first
									25	Pole flips over vehicle without contacting the occupant compartment or the rest of the vehicle, then hit the ground, with the top of the pole hitting first

Figure D-64. Simulation Pole Dynamics Description, Simulation Number 53

END OF DOCUMENT