STATE OF DELAWARE
DEPARTMENT OF TRANSPORTATION
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P.O. BOX 778
DOVER, DELAWARE 19903

SHANTÉ A. HASTINGS
SECRETARY

# MEMORANDUM

**TO:** Mark Luszcz, Chief Engineer

**VIA:** Cassidy Blowers, Chair, MASH Committee

**FROM:** Andrew Short, Support Engineer

**DATE:** June 12, 2026

**SUBJECT:** **MASH Self-Certification: MASH Compliant 31" Curved Guardrail**

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In 2009, the American Association of State Highway and Transportation Officials (AASHTO) published the *Manual for Assessing Safety Hardware* (MASH) which superseded NCHRP Report 350 *Recommended Procedure for Safety Performance Evaluation of Highway Features* as the guidelines for roadside safety hardware performance evaluation. In 2016, AASHTO published the second edition of the MASH manual as well as agreed to a joint implementation agreement with the Federal Highway Administration (FHWA). The joint implementation agreement outlined the sunset dates for NCHRP Report 350 compliant roadside safety hardware and sunrise dates for MASH 2016 compliant roadside safety hardware for work performed on the National Highway System (NHS). The January 7, 2016 agreement stated that all "cable barriers, cable barrier terminals, and crash cushions" would be MASH 2016 compliant for contracts let after December 31, 2018.

On May 26, 2017, the FHWA issued an open letter to the states which stated that "The FHWA's Federal-aid eligibility letters are provided as a service to the States and are not a requirement for roadside safety hardware to be eligible for federal-aid reimbursement." This letter also went on to state, "Since its official launch questions about the AASHTO MASH criteria have been identified by a range of stakeholders. Until such time these questions are answered and the transportation community has more experience with AASHTO MASH requirements, FHWA will require manufacturers and States to run all AASHTO MASH recommended crash tests in order to qualify for a FHWA Federal-aid eligibility letter." In addition, a letter from the FHWA to its Division Administrators issued on April 9, 2018 stated that "An eligibility letter is not a

requirement for roadside safety hardware to be determined eligible for Federal funding. Roadside safety hardware is eligible for Federal funding if it has been determined to be crashworthy by the user agency (i.e. State DOT)."

A team that consisted of staff from George Mason University and FHWA's Federal Outdoor Impact Laboratory (FOIL) recently performed crash testing on a short radius curved guardrail system intended to be MASH compliant. The development of the short radius curved guardrail system, including the crash testing performed and associated implementation recommendations are documented within the Transportation Research Board (TRB) National Cooperative Highway Research Program's (NCHRP's) Research Report 1013: *Roadside Barrier Designs near Bridge Rails End with Restricted Rights-of-Way.* The purpose of this letter is to document the crashworthiness analysis performed by the Department and to make an associated recommendation for the application's use in the State.

DelDOT, as well as other transportation agencies, have a distinct need for a roadside safety hardware system that can protect lateral roadside safety hazards at intersection locations where space is limited. A common roadside hardware treatment used to protect hazards at these locations is to install a short radius curved guardrail system that allows for a controlled vehicle deceleration and containment within a prescribed area that is free of obstructions. To date, when shielding in these situations is warranted, DelDOT's common practice has been to install the curved guardrail system shown in DelDOT Standard Construction Detail B-18. The application contained within Standard Construction Detail B-18 was initially developed in 1988 under NCHRP Report 230 criteria and is generally considered a TL-2 application. DelDOT's Standard Construction Detail B-18 has not been reevaluated for compliance under MASH or NCHRP Report 350 criteria since its original development.

The George Mason University and FHWA's Federal Outdoor Impact Laboratory (FOIL) researchers considered the short radius curved guardrail application as a re-directive crash cushion under MASH's crashing testing criteria. Table 1 outlines the applicable tests for a re-directive crash cushion and summarizes the crash test results achieved or provides a brief explanation as to why the researchers did not perform the test.

Table 1: 2016 MASH Evaluation

| Test No. | Test Run? | Test Evaluation Summary |
|---|---|---|
| 3-30 | No | Test 3-30 is intended to evaluate occupant risk, vehicle stability, and vehicle trajectory for head-on impacts, primarily for narrow crash cushions and end treatments. There is no defined end of the curved guardrail that could be impacted. Test 3-31, with similar impact angle, speed, and evaluation criteria with the much higher energy pickup truck, was conducted successfully. As predicted by the computer simulation of this test and in the pickup truck tests, a smaller vehicle would deflect the barrier far less. In addition, Test 3-30 was not considered necessary in any previously accepted curved radius designs. Therefore, this test was deemed unnecessary and not performed. |
| 3-31 | Yes | Test considered applicable and conducted on October 25th, 2016. The crash resulted in a passed test. |

| Test No. | Test Run? | Test Evaluation Summary |
|---|---|---|
| 3-32 | Yes | Test considered applicable and conducted initially on March 2nd, 2017, and then retested May 3rd, 2017. Initial crash resulted in a failure while the second crash conducted on a modified design resulted in a passed test. |
| 3-33 | Yes | Test considered applicable and conducted on June 29th, 2017. The crash resulted in a passed test. |
| 3-34 | No | Test 3-34 is intended to evaluate the impact performance of crash cushions and end treatments at the critical impact point (CIP), where the behavior of the device changes from gating or capturing to redirecting. Test 3-35 was essentially a CIP test, making Test 3-34 redundant. |
| 3-35 | Yes | Test considered applicable and conducted on September 14th, 2017. The crash resulted in a passed test. |
| 3-36 | No | Test 3-36 is designed to examine the behavior of end treatments when attached to rigid barriers or other very stiff features; it essentially is a transition test. The proposed design incorporates a Thrie-beam transition design that had been previously tested and accepted as crashworthy; therefore, this test was considered redundant. |
| 3-37 | No | Test 3-37 examines the behavior on a reverse-direction impact used primarily to detect possible snagging concerns. The proposed design consists of standard 10-gauge W-beam, with little likelihood of snagging; therefore, this test was considered redundant. |
| 3-38 | No | Test 3-38 is intended to evaluate the performance of a crash cushion designed as a staged device during impacts by a mid-size vehicle. This test was not considered relevant as the application is not a staged device. |

In addition to the testing described in Table 1, the researchers also performed a modified 3-33 crash test at a speed of 50 mph where a 2H:1V drop-off was installed directly behind the barrier. The barrier performed acceptably and passed the modified 3-33 test. Therefore, it is the researchers' opinion that the application is also acceptable in front of a 2H:1V down slope at 50 mph.

DelDOT concurs with the researchers' opinion that all the necessary and relevant MASH crash tests have been performed to justify the application's use as a TL-3 application when the down slope behind the barrier is 6H:1V or flatter and as a TL-2 application when the down slope behind the barrier is steeper than 6H:1V up to a 2H:1V down slope. Furthermore, it is DelDOT's assessment that the recently crash tested short radius curved guardrail system signifies a significant advancement in roadside safety hardware. Therefore, it is recommended that the short radius detail be adopted and utilized where applicable. To this end, DelDOT has developed a new construction detail based on the crash testing performed as part of NCHRP Report 1013.

The DelDOT detail makes one notable alteration to the crash tested application by replacing the wood post end anchor that was crash tested with DelDOT's newly adopted steel post end anchor. The change was made to reduce future maintenance and to bring greater uniformity to DelDOT's roadside safety hardware. The steel post end anchor is considered a crashworthy application based on the crash testing performed under the Midwest Roadside Safety Facility's (MWRSF's) Research Report TRP-03-370b-20. The end anchor's function within the short radius curved guardrail system is to tension the guardrail system; therefore, changing from the crash

tested wood post end anchor to the steel post end anchor is not considered a significant change which could impact the crashworthiness of the overall short radius curved guardrail application.

The crash tested wood post end anchor did not utilize a ground strut between the two wood posts within the end anchor. By removing the ground strut from the end anchor, the bottom cable of the crash tested short radius guardrail system was able to anchor near the ground surface within the end anchorage. The crash tested steel post end anchor does utilize this ground strut. Removing the ground strut from the steel post end anchor without confirmatory crash testing being performed is considered a significant change which could affect the system's overall crashworthiness. Several alternatives were developed to mitigate the conflict between the system's bottom cable anchorage and the ground strut. After discussion, it was decided to modify the anchor bearing plate by shortening the plate so that it sits atop of the ground strut. DelDOT performed an assessment of the shortened bearing plate and determined that its modification would not jeopardize the overall crashworthiness of the system. The analysis focused on two key aspects which could have affected crashworthiness:

- Cable tautness – The shortened bearing plate does increase the ability for the bearing plate to slide which could lead to the cable becoming less taut. The size of the openings in the upper post of the steel post end anchor and the size of swaged cable assemblage were assessed and it was determined that there is limited ability for the end plate to slide even with its shortened length. In addition, if the bearing end plate were to slide, it was determined that the limited sliding would not jeopardize the overall tautness of the cable. After evaluation, the proposed modification is deemed to not to affect the required cable tautness.
- Bearing plate capacity – The shortened bearing plate could also affect the structural integrity of the swaged cable connection. The entire cable anchorage system was evaluated to assess this potential affect. The crash tested application's lower cable is anchored to the post with the bearing plate and through an anchor plate attached to a Thrie-beam guardrail as part of a stiffness transition to a rigid barrier. The anchor plate utilizes an end plate to connect the cable end fitting to the anchor plate and Thrie-beam guardrail. The end plate has a smaller bearing capacity than the bearing plate and the modified bearing plate based on its smaller thickness and overall size. Therefore, the end plate would fail before the anchor plate both with and without the modification being made to the bearing plate. Additionally, the threads on the bolt would fail before either the end plate or bearing plate were to fail. For these reasons, the shortening of the bearing plate is not deemed to affect the overall crashworthiness of the application.

After careful evaluation, it is DelDOT's assertion that the use of the steel post end anchor in place of the wood post end anchor will not affect the overall crashworthiness of the system. It is recommended that DelDOT continue to monitor on-going research, crash testing, as well as in-service field performance as additional information becomes available.

DelDOT also recognizes that the NCHRP Report 1013 application contains components that are not currently used in typical hardware applications across the State. Additionally, the hardware has several design considerations associated with its use which need to be properly evaluated before prescribing the installation for implementation. Therefore, as part of the adoption

of the new curved guardrail detail, DelDOT will perform an educational effort to ensure that the application is properly prescribed and installed.

This report contains the following Appendices:

A. January 7, 2016 FHWA/ AASHTO MASH Implementation Agreement Memo
B. May 26, 2017 FHWA Open Letter to the States
C. April 9, 2018 FHWA Letter to Division Administrators, Federal Lands Division Engineers and Directors of Field Services
D. DelDOT Standard Construction Detail B-18
E. Pages from NCHRP Report 1013
F. DelDOT Standard Construction Detail B-5
G. DelDOT MASH Compliant Short Radius Curved Guardrail Detail

AS:mn
Attachment (list of appendices)

This MASH Self-Certification is recommended for approval:

**RECOMMENDED**

Andrew Short 06/12/2026

Andrew Short, Support Engineer Date

**REVIEWED**

06/12/2026

Cassidy Blowers, On Behalf of the MASH Committee Date

**APPROVED**

06/16/2026

Mark Luszcz, Chief Engineer Date

# Appendix A: January 7, 2016 FHWA/ AASHTO MASH Implementation Agreement Memo

U.S. Department of Transportation
Federal Highway Administration

# Memorandum

Subject: **INFORMATION:** AASHTO/FHWA Joint Implementation Agreement for Manual for Assessing Safety Hardware (MASH)

Date: JAN - 7 2016

From: Thomas Everett
Director, Office of Program Administration

In Reply Refer To: HSST

Michael S. Griffith
Director, Office of Safety Technologies

To: Division Administrators
Directors of Field Services
Federal Lands Highway Division Directors

**Purpose**

The purpose of this memorandum is to share information regarding the American Association of State Highway and Transportation Officials (AASHTO)/FHWA Joint Implementation Agreement for the AASHTO Manual for Assessing Safety Hardware (MASH). Recently, the agreement was successfully balloted by AASHTO's Standing Committee on Highways and approved by FHWA.

**Information**

On November 12th, 2015, FHWA issued a memorandum (http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/policy_memo/memo111215/) indicating that all modifications to NCHRP 350-tested devices will require testing under MASH in order to receive a Federal-aid eligibility letter from FHWA. In addition, a Federal Register Notice (https://www.federalregister.gov/articles/2015/11/13/2015-28753/manual-for-assessing-safety-hardware-mash-transition) was also issued regarding this action. This action provided a significant step forward to the implementation of MASH.

Through the AASHTO/FHWA partnership, the agreement was executed to define actions needed for full implementation of MASH over the course of several years. Per the agreement, the implementation of the forthcoming edition (anticipated Spring 2016) of the AASHTO Manual for Assessing Safety Hardware (MASH) will be as follows:

- The AASHTO Technical Committee on Roadside Safety will continue to be responsible for developing and maintaining the evaluation criteria as adopted by

AASHTO. FHWA will continue its role in issuing letters of eligibility of roadside safety hardware for federal-aid reimbursement.

- Agencies are urged to establish a process to replace existing highway safety hardware that has not been successfully tested to NCHRP Report 350 or later criteria.
- Agencies are encouraged to upgrade existing highway safety hardware to comply with the 2016 edition of MASH either when it becomes damaged beyond repair, or when an individual agency's policies require an upgrade to the safety hardware.
- For contracts on the National Highway System with a letting date after the dates below, only safety hardware evaluated using the 2016 edition of MASH criteria will be allowed for new permanent installations and full replacements:
    - December 31, 2017: w-beam barriers and cast-in-place concrete barriers
    - June 30, 2018: w-beam terminals
    - December 31, 2018: cable barriers, cable barrier terminals, and crash cushions
    - December 31, 2019: bridge rails, transitions, all other longitudinal barriers (including portable barriers installed permanently), all other terminals, sign supports, and all other breakaway hardware
- Temporary work zone devices, including portable barriers, manufactured after December 31, 2019, must have been successfully tested to the 2016 edition of MASH. Such devices manufactured on or before this date, and successfully tested to NCHRP Report 350 or the 2009 edition of MASH, may continue to be used throughout their normal service lives.
- Regarding the federal-aid eligibility of highway safety hardware, after December 31, 2016:
    - FHWA will no longer issue eligibility letters for highway safety hardware that has not been successfully crash tested to the 2016 edition of MASH.
    - Modifications of eligible highway safety hardware must utilize criteria in the 2016 edition of MASH for re-evaluation and/or retesting.
    - Non-significant modifications of eligible hardware that have a positive or inconsequential effect on safety performance may continue to be evaluated using finite element analysis.

Division Offices should discuss the MASH implementation agreement with state transportation agency partners and monitor the actions taken and progress towards the dates established in the agreement.

If you have any questions or comments, please contact Brian Fouch in the Office of Safety at (202) 366-0744.

# Appendix B: May 26, 2017 FHWA Open Letter to the States

U.S. Department
of Transportation
**Federal Highway
Administration**

1200 New Jersey Ave., SE
Washington, D.C. 20590

May 26, 2017

An open letter to all in the highway safety hardware and roadside design community:

The Federal Highway Administration (FHWA) is improving its process for issuing Federal-aid eligibility letters for roadside safety hardware systems. The FHWA's Federal-aid eligibility letters are provided *as a service* to the States and are not a requirement for roadside safety hardware to be eligible for Federal-aid reimbursement. This change focuses the FHWA on analyzing the materials submitted for review, rather than addressing the types of crash tests that should be submitted, as the latter are determined by the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Roadside Safety Hardware* (MASH).

This letter serves to notify you that FHWA is implementing immediate process changes as described in this letter.

Effective immediately, FHWA is implementing the following changes on how requests for Federal-aid eligibility letters for roadside safety hardware systems are accepted:

1. Moving forward, in order for manufacturers and States to qualify for a FHWA Federal-aid eligibility letter, all roadside hardware devices *must complete the full suite of recommended tests* as described in AASHTO MASH. This applies to:
    a. all devices currently in the FHWA queue that have not received an eligibility letter by the effective date of this letter and,
    b. retroactively to requests received after January 1, 2016.

    Manufacturers and States that received an eligibility letter under AASHTO's MASH standards and did not run the full suite of tests will be required to run the remaining tests in order to retain the Federal-aid eligibility letter. The FHWA has contacted the affected manufacturers. These affected parties have up to one year, from the date of this letter, to run the balance of crash tests and re-submit their request for an eligibility letter. A written request, including crash test results from an accredited laboratory, must be submitted to FHWA within one year.

    The retroactive date of January 1, 2016, corresponds to the official implementation date balloted by AASHTO and the date FHWA began issuing Federal-aid eligibility letters using standards from AASHTO's MASH only, i.e., when FHWA ceased issuing eligibility letters using National Cooperative Highway Research Program (NCHRP) Report 350 guidance.

2. FHWA will no longer provide Federal-aid eligibility letters for modifications made to an AASHTO MASH-crash tested device. Manufacturers who have submitted requests for eligibility letters based on modifications have been notified.

These changes are based on several important factors. The transition from guidance in the NCHRP Report 350 to standards in the AASHTO MASH continues per the FHWA-AASHTO Implementation Agreement balloted by AASHTO. Since its official launch, questions about the AASHTO MASH criteria have been identified by a range of stakeholders. Until such time these questions are answered and the transportation community has more experience with AASHTO MASH requirements, FHWA will require manufacturers and States to run all AASHTO MASH recommended crash tests in order to qualify for a FHWA Federal-aid eligibility letter.

This is a prudent action to support highway safety for the traveling public. This opportunity for improvement and consistency was noted in the Government Accountability Office's (GAO) final report dated June 2016, *"Highway Safety: More Robust DOT Oversight of Guardrails and Other Roadside Hardware Could Further Enhance Safety," GA0-16-575* and *Evaluation of the Roadside Safety Hardware Process* – Prepared for the FHWA's Office of Policy by the John A. Volpe National Transportation Systems Center.

The changes promote efficiency of Federal resources while advancing our Federal role to support public safety and ensuring that decision-making is at the State and local level. The FHWA will address the initial "entry" of a device into the possibility for Federal-aid reimbursement, through examining crash testing, but the final decisions on selection and modifications to devices will be at the State and local level.

States and manufacturers will now have an outstanding opportunity to collaborate and deploy manufacturers' innovative modifications in a timely manner and/or respond to State-specific needs requiring significant and non-significant modifications – without the need of another Federal-aid eligibility letter from FHWA.

The change helps emphasize that understanding the performance of roadside safety hardware begins in a controlled, sterile laboratory environment using crash test scenarios and standards set and maintained via AASHTO's MASH. However, laboratory tests cannot account for all the variables and situations drivers may encounter. Therefore, FHWA continues to encourage States to perform in-service performance evaluations to identify real world performance of hardware so all stakeholders have a more comprehensive understanding of these devices' performance.

Thank you in advance for your cooperation in helping FHWA to implement these improvements to enhance the safety of roadside hardware. We will notify you of any future improvements to the eligibility letter process. For more information, please visit our website at https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/elig_process.cfm.

If you have any questions or comments, please contact Brian Fouch at (202) 366-0744.

Sincerely yours,

Elizabeth Alicandri
Associate Administrator for Safety

# Appendix C: April 9, 2018 FHWA Letter to Division Administrators, Federal Lands Division Engineers and Directors of Field Services

U.S. Department of Transportation
**Federal Highway Administration**

# Memorandum

Subject: **ACTION:** Evaluating a State DOT's Process to Determine Roadside Safety Hardware Crashworthiness on the National Highway System (NHS)

Date: April 9, 2018

From: Michael S. Griffith
Director, Office of Safety Technologies

In Reply Refer To: HSA

To: Division Administrators
Federal Lands Division Engineers
Directors of Field Services

## PURPOSE

The purpose of this memorandum is to provide guidance to the FHWA Division Offices to assist in their evaluation that a State DOT has an acceptable process for determining the crashworthiness of roadside safety hardware used on the National Highway System (NHS).

## BACKGROUND

The FHWA's longstanding policy is that all roadside safety hardware installed on the NHS be crashworthy. To support this policy, the joint implementation agreement for the American Association of State Highway Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH) was adopted by AASHTO and FHWA. This agreement established dates for implementing AASHTO MASH as the criteria for determining crashworthiness of roadside safety hardware.

The FHWA continues to provide a voluntary service of reviewing crash test results and issues eligibility letters for *new* roadside safety hardware only. The FHWA no longer provides Federal-aid eligibility letters for modifications made to an AASHTO MASH-crash tested device. An eligibility letter is not a requirement for roadside safety hardware to be determined eligible for Federal funding. Roadside safety hardware is eligible for Federal funding if it has been determined to be crashworthy by the user agency (i.e., State DOT).

An FHWA eligibility letter should not be the sole basis for a State's determination of crashworthiness. It is each State's responsibility to determine crashworthiness and to approve new or modified roadside safety hardware meeting the State's specific needs. Each State should consider its own operational issues such as installation and

maintenance requirements, climate considerations (e.g., use of wood vs. steel posts), and in-service performance data in determining what roadside safety hardware to use on highway projects. The determination of crashworthiness of roadside safety hardware, acceptance for use on highway projects, and installation and maintenance are responsibilities handled at the State and local level.

**GUIDANCE**

Each FHWA Division Office should work with its respective State DOT to ensure that the State has an acceptable process for determining the crashworthiness of roadside safety hardware. Please note that there is no single recognized procedure or standard for how State DOTs determine crashworthiness, and existing processes may vary from State to State. However, an acceptable process for a State's determination of crashworthiness should be fully documented and may include:

- For new roadside safety hardware:
  - A physical crash test report documenting successful crash testing (relative to the AASHTO MASH test criteria) conducted by an ISO 17025 accredited laboratory.
- For modifications to existing successfully tested roadside safety hardware:
  - Proprietary devices: an engineering analysis conducted by an ISO 17025 accredited crash testing laboratory that determines the modification does not affect the crashworthiness of the roadside safety hardware based on previous crash testing (relative to the AASHTO MASH test criteria). If necessary, crash testing may be warranted based on the results of an engineering analysis.
  - Generic devices: an engineering analysis as described above can be conducted by the State DOT or an ISO 17025 laboratory. If necessary, crash testing may be warranted based on the results of an engineering analysis.

The initial determination of the crashworthiness of roadside safety hardware begins with laboratory testing and engineering analysis as defined by the AASHTO MASH. Once roadside safety hardware is identified as crashworthy and properly installed, States are encouraged to collect and assess in-service performance data on how the device performs in the vast array of real-world collisions. As selectors of hardware, the States are in the best position with complete access to crash data, maintenance information, and other critical elements to perform in-service performance evaluations and to use that data to make improvements to crash testing criteria and to installation and maintenance procedures. States should use all information available to determine the continued crashworthiness of roadside safety hardware.

Chapter 6 in the AASHTO MASH provides guidance on crash testing documentation and Chapter 7 provides guidance on in-service performance evaluations. A list of Q&As and a guidance document are attached for further clarification.

**ACTION**

Each FHWA Division Office should ensure that the State DOT has an acceptable process in place for determining the crashworthiness of all roadside safety hardware installed on the NHS.

Please report to Will Longstreet, Office of Safety, by June 30, 2018, on the existence of an acceptable State DOT process and, if necessary, a timeline for addressing any needed improvements. If you have questions or comments, please contact Will at will.longstreet@dot.gov or 202-366-0087.

Enclosures

CC: Safety field

Division Office Guidelines for Reviewing State Processes for Determining Crashworthiness of Roadside Safety Hardware

This guidance is provided to assist the FHWA Division Offices in reviewing a State DOT process for determining the crashworthiness of roadside safety hardware used on the National Highway System (NHS).

A State DOT's initial determination of crashworthiness of roadside safety hardware should begin with how the device meets current national testing criteria (i.e. AASHTO Manual on Assessing Safety Hardware (MASH)). This initial step often may include full-scale crash testing for new devices and/or an engineering analysis (for modifications of crashworthy devices). Below are some examples of how devices may be determined and documented as crashworthy that State DOTs may implement in their processes.

1. Research (NCHRP or pooled fund studies) conducted through ISO 17025 accredited crash test laboratories (accredited laboratories) showing a device meets AASHTO MASH.
2. Crash test results, videos, and test summary sheets that are completed and reported by accredited laboratories and in accordance with AASHTO MASH.
3. Evaluation of modifications to devices in accordance with AASHTO MASH to determine if additional testing is necessary for a device. At the State's discretion, this may be done through a State DOT's analysis for generic products or requiring manufacturers to have modifications of proprietary products reviewed by an accredited crash testing lab.
4. State requirements for manufacturers to have products tested to AASHTO MASH at accredited laboratories and to provide a manufacturer's certification that the device meets AASHTO MASH criteria supported by concurrence from the accredited crash testing lab.
5. Consultant review of a device's crashworthiness for States that may not have the expertise to review roadside safety hardware.

Once roadside safety hardware is identified as crashworthy and properly installed, States are encouraged to collect and assess in-service performance data on how the device performs in the vast array of real-world collisions. As selectors of hardware, the States are in the best position with complete access to crash data, maintenance information, and other critical elements to perform in-service performance evaluations and to use that data to make improvements to crash testing criteria and to installation and maintenance procedures. States should use all information available to determine the continued crashworthiness of roadside safety hardware.

Full analysis and review of each device submitted for a determination of crashworthiness should also include an operational analysis. This operational analysis may include review and input from other State DOT offices including Design, Construction, and Maintenance.

A State may consider the following when conducting its operational reviews:

- Is the device appropriate for use in your State? For example, is it appropriate for the State's climate; is it compatible with legacy hardware?
- Will the device be difficult for contractors to install correctly?
- Will the device be practical to maintain?
- Will the device require new maintenance protocols and/or inventory stock?
- Does in-service performance data from other users exist that identify potential issues with the device?

**FHWA Division Office Q&As re: a State DOT Determination of Crashworthiness of Roadside Safety Hardware**

1. Does roadside safety hardware installed on the NHS need to be crashworthy?

   It is FHWA's longstanding policy that all roadside safety hardware installed on the NHS be crashworthy. This policy is reinforced through design standards incorporated by reference in 23 CFR part 625, including *A Policy on Geometric Design of Highways and Streets*, 2011 (the AASHTO Greenbook).

2. What should be considered in determining the crashworthiness of roadside safety hardware?

   The initial determination of the crashworthiness of roadside safety hardware begins with laboratory testing and engineering analysis as defined by the AASHTO MASH. This is just the first step—proper installation and maintenance of roadside safety hardware also plays a crucial role in how hardware will perform. For this reason, States are encouraged to collect and assess in-service performance data of roadside safety hardware and take appropriate action as needed. As selectors of hardware, the States are in the best position with complete access to crash data, maintenance information, and other critical elements to perform in-service performance evaluations and to use that data to make improvements to crash testing criteria and to installation and maintenance procedures. States should use all information available to determine the continued crashworthiness of roadside safety hardware.

3. What is the State DOT's role in determining the crashworthiness of roadside safety hardware?

   Each State DOT should have a process in place for determining the crashworthiness of new and modified roadside safety hardware. This process should include documentation supporting the State DOT's determination.

4. Can a State DOT use an FHWA eligibility letter as the sole basis for determining the crashworthiness of a new roadside safety hardware?

   While a State DOT may use an FHWA eligibility letter as *one of the resources* for determining crashworthiness, it should not be the sole basis for a State's determination of crashworthiness. Each State DOT should document its basis for a determination of crashworthiness through review of crash test results and engineering analyses provided by accredited crash test labs and manufacturers. It is the State's responsibility to determine the appropriateness of new and modified roadside safety hardware for approval and use for its needs. Each State should consider its own operational issues such as installation and maintenance requirements, climate considerations (e.g., use of wood vs. steel posts), and in-service performance data in determining what roadside safety hardware to place on their highway projects.

5. What is the role of the FHWA Division Office in the process for ensuring crashworthy roadside safety hardware is incorporated on the NHS?

Each FHWA Division Office should ensure that the State DOT has a process in place for determining the crashworthiness of all roadside safety hardware installed on the NHS.

6. Does FHWA require the State DOT to have an FHWA Federal-aid eligibility letter?

   No. Each FHWA Division Office should rely on the State DOT process to establish the State's determination of crashworthiness of roadside safety hardware installed on the NHS. If a State DOT does not have a process for determining crashworthiness, the Division Office should work with the State DOT in developing one.

7. What is the role of the State DOTs in working with manufacturers regarding modifications?

   An acceptable State process should include a procedure for manufacturers to notify State DOTs of modifications to their devices. State DOT processes should address the review of modifications.

8. Must roadside safety hardware be tested to the full matrix of tests recommended in the AASHTO MASH to be determined crashworthy?

   No. Running the full matrix of tests recommended in the AAHSTO MASH is only required if a State DOT or manufacturer requests an FHWA Federal-aid eligibility letter for a specific roadside safety hardware device. The AASHTO MASH allows for user agencies (i.e., State DOTs) to determine a critical test matrix for generic devices or to consider a critical test matrix developed by a manufacturer. For proprietary devices, State DOTs and manufacturers should consider consultation with an accredited crash testing lab in determining critical test matrices.

9. Can modifications be made to roadside safety hardware that has received an FHWA eligibility letter?

   Yes. Modifications can be made to roadside safety hardware that has previously received an FHWA eligibility letter; however, FHWA no longer considers submissions for Federal-aid eligibility letters for modifications made to an AASHTO MASH-crash tested device. The State DOT should determine the effect of the modification of roadside safety hardware based on the crashworthy criteria established in AASHTO MASH. It is the State DOT's responsibility to determine the appropriateness of modified roadside safety hardware for approval and use for its needs.

10. What is considered a significant modification to roadside safety hardware?

    A modification that adversely affects the crashworthy performance of roadside safety hardware based on the crash testing criteria in AASHTO MASH is deemed to be significant. The determination of significance should be based on engineering analyses. A State DOT

may choose to have an accredited crash testing lab make this determination. If a State DOT determines that there has been a significant modification to a previously tested roadside safety hardware device, then the relevant manufacturer should retest the device in accordance with AASHTO MASH criteria.

11. Can new and existing research be used to determine crashworthiness of roadside safety hardware?

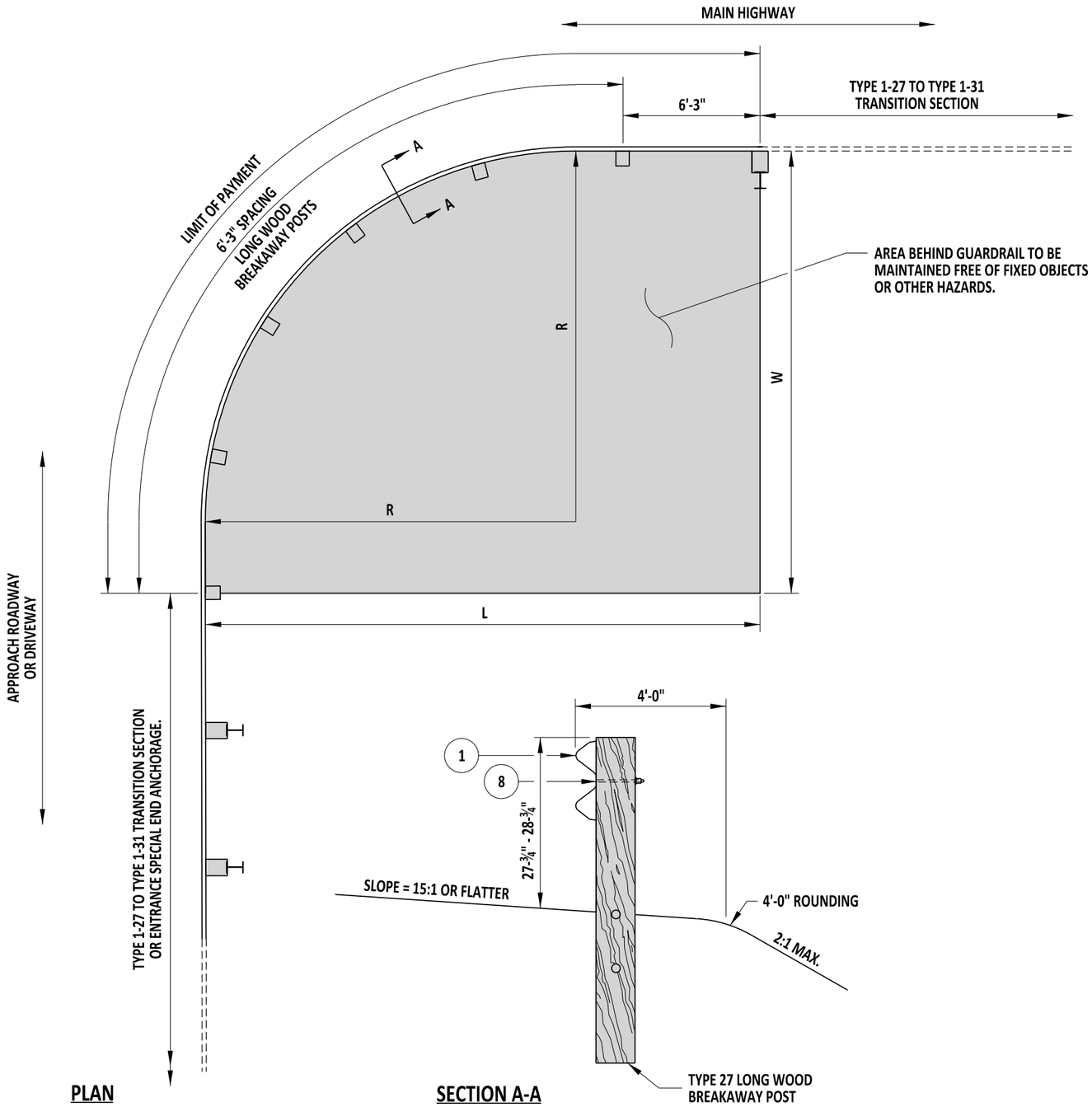
    Yes. A State DOT may consider new and existing research (e.g., NCHRP reports and synthesis; individual crash test reports) conducted by an accredited laboratory or qualified researchers as part of its process to determine the crashworthiness of roadside safety hardware.

12. Does a State have to make new crashworthiness determinations for existing roadside safety hardware currently in place on the NHS?

    No. Existing in-service roadside safety hardware may remain in place until it reaches the end of its service life or it becomes damaged beyond repair. If there is interest in continuing with the same device for future installations, the owner should determine if the device is crashworthy using the latest version of AASHTO MASH criteria.

# Appendix D: DelDOT Standard Construction Detail B-18

SCALE : NTS



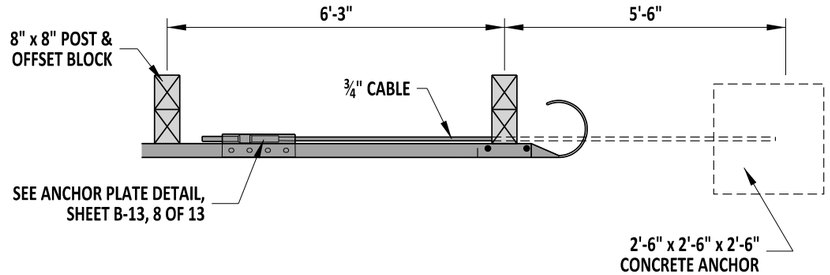

PLAN

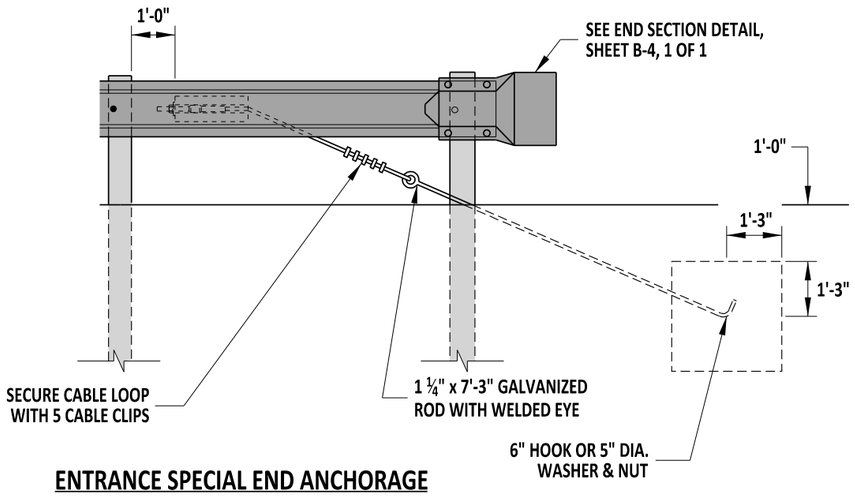



SECTION A-A

| RADIUS | MIN. REQUIRED AREA FREE OF FIXED OBJECTS |
|---|---|
| | L x W |
| 8'-6" | 25'-0" x 15'-0" |
| 17'-0" | 30'-0" x 15'-0" |
| 25'-6" | 40'-0" x 20'-0" |
| 35'-0" | 50'-0" x 20'-0" |

NOTES:
1). NO WASHERS ARE USED ON THE RAIL SIDE OF THE LONG WOOD BREAKAWAY POSTS.
2). THE CURVED GUARDRAIL SECTION SHALL BE SHOP BENT.
3). PLACE GUARDRAIL DELINEATORS AT THE INTERVALS SPECIFIED IN THE DELAWARE MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES.
4). INSTALL CURB IN ACCORDANCE WITH THE CONTRACT AT A MAX CURB HEIGHT OF 2", FLUSH WITH FACE OF GUARDRAIL.
5). ON THE 8'6' RADIUS SYSTEM ONLY, THE RAIL IS NOT TO BE BOLTED TO THE CENTER POST.
6). THIS DETAIL IS BASED ON NCHRP 350 CRASH TESTING. MASH COMPLIANT DETAILS ARE NOT YET AVAILABLE.




ENTRANCE SPECIAL END ANCHORAGE

DelDOT

ENGINEERING SUPPORT — DATE 09/01/2020

RECOMMENDED

CURVED GUARDRAIL SECTION, TYPE 1-27

STANDARD NO. B-18 (2020) | SHT. 1 OF 1

REVIEWED — DEPUTY DIRECTOR - DESIGN — DATE 09/01/2020

APPROVED — CHIEF ENGINEER — DATE 09/01/2020

8/19/2020

Appendix E: Pages from NCHRP Report 1013

CHAPTER 3

# Crash-Test Results

The simulation incrementally reached a point where the project team believed they had achieved a viable design to address the primary project objective. The team then shifted to the next phase of full-scale testing and proving barrier effectiveness. This chapter details the test matrix, system design, and crash-test results.

## 3.1 Crash-Test Matrix

This section briefly explains the reasoning behind selecting the MASH TL-3 tests conducted in conjunction with this project. Because there was no specified crash-test matrix for a curved guardrail (short-radius) design in MASH 2016, the project team and panel relied primarily on historically accepted FHWA tests as appropriate for determining the test matrix. Appendix A in *NCHRP Web-Only Document 334* summarizes these previous tests. Because the design selected was most similar in function to a redirective crash cushion, the MASH 2016 test matrix (see Table 3.1) served as a starting point for selecting the crash tests run under this project. Note that because motorists on the side road approaching the main road will generally face a stop sign, and the barrier will essentially be standard W-beam, no tests were previously considered necessary from this direction.

Based on the design of the Short-Radius Guardrail System (SRGS) developed under this project, and precedent dating to 1989, MASH Tests 3-31, 3-32, 3-33, and 3-35 are considered essential. The following sections summarize these tests.

### 3.1.1 MASH Test 3-31

MASH Test 3-31 was intended to determine whether the system was capable of safely and stably decelerating the 2270P vehicle to a stop when impacted with a high-energy, head-on strike. To accomplish this, the system should redirect the pickup truck when the impact is aligned parallel to the main road and the centerline of the vehicle is aligned with the traffic face of the transition/concrete parapet at the end of the system (see Figure 3.1 for a visual representation of this alignment). This test is designed to evaluate the occupant impact risk and vehicle-trajectory criteria.

### 3.1.2 MASH Test 3-32

MASH Test 3-32 examined the behavior of the system during a 15 degree impact angle relative to the main road on the nose (center post of the radius) of the system. The principal concerns were occupant impact risk and vehicle trajectory. For a curved guardrail installation, it is critical that the vehicle stops safely without penetrating the system. Figure 3.2 shows the alignment of the small car with the system.

**Table 3.1. Tests specified for MASH TL-3 end treatments and redirective crash cushions.**

| | Test Designations | Test Vehicle | Impact Speed (mph) | Impact Angle (deg.) |
|---|---|---|---|---|
| Non-gating | 3-30 | 1100C | 62 | 0 |
| | **3-31** | **2270P** | **62** | **0** |
| | **3-32** | **1100C** | **62** | **15** |
| | **3-33** | **2270P** | **62** | **15** |
| | 3-34 | 1100C | 62 | 15 |
| | **3-35** | **2270P** | **62** | **25** |
| | 3-36 | 2270P | 62 | 25 |
| | 3-37b | 1100C | 62 | 25 |
| | 3-38 | 1500A | 62 | 0 |

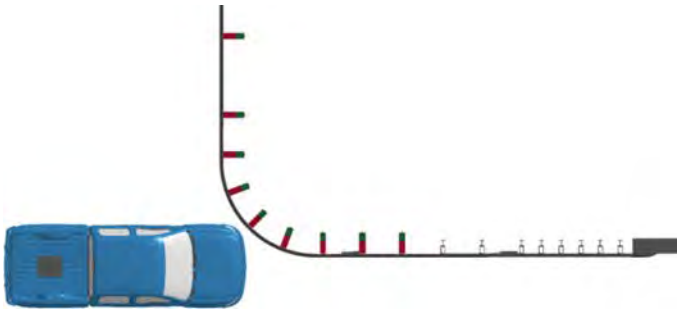


***Figure 3.1. MASH Test 3-31, head-on impact with 2270P.***

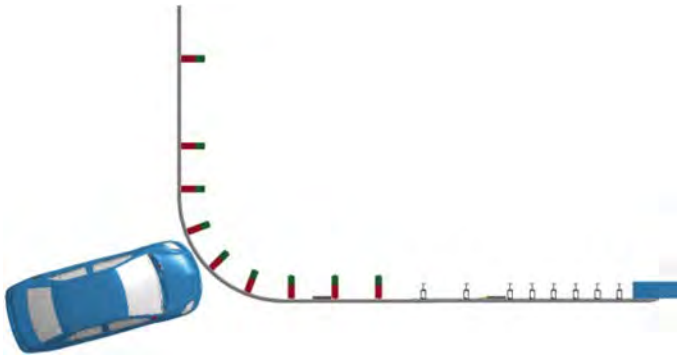


***Figure 3.2. MASH Test 3-32, 1100C vehicle at 15 degrees into curved section.***

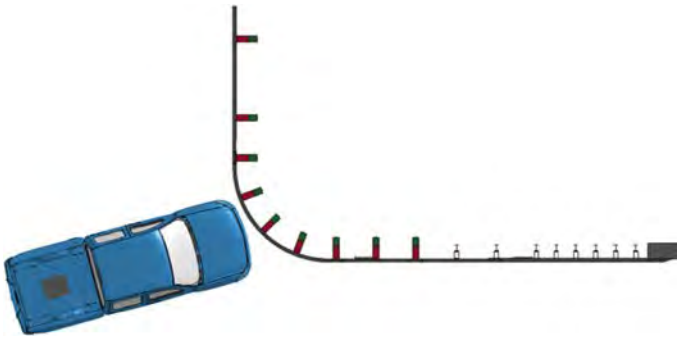


***Figure 3.3. MASH Test 3-33, 2270P vehicle at 15 degrees into curved section.***

### 3.1.3 MASH Test 3-33

MASH Test 3-33 was similar to Test 3-32 but used a pickup truck (larger vehicle). This test examined the behavior of the short-radius system during a 15 degree impact angle relative to the main road on the nose (center post of the radius) of the system. The main concerns with regard to this test were occupant impact risk and vehicle trajectory. Figure 3.3 shows the alignment of the truck with the system.

### 3.1.4 MASH Test 3-35

MASH Test 3-35 examined the capacity of the system to contain or redirect the pickup truck. MASH defines the impact location as the beginning of LON. For non-gating crash cushions, the impact point should be near the end of the system, where behavior changes from capturing to redirecting. Therefore, this test essentially became a CIP test. The truck impacted the system at a 25 degree angle in the first section of guardrail along the main road after the radius where the rail behavior changes from capturing to redirecting. Figure 3.4 shows the alignment of the truck with the system.

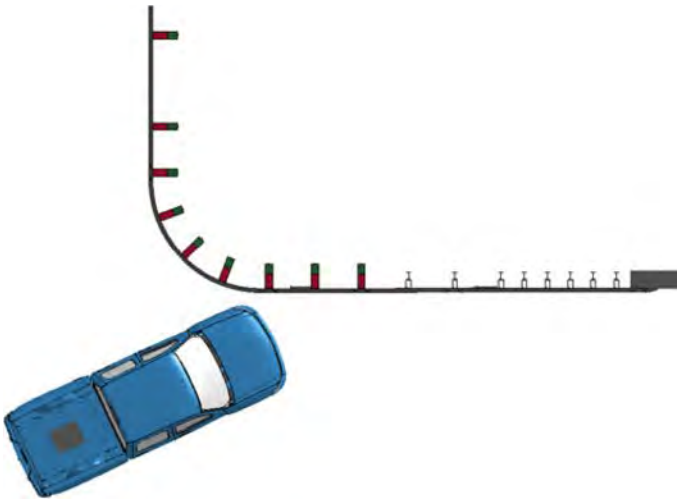


***Figure 3.4. MASH Test 3-35, 25 degree impact at LON/CIP with 2270P vehicle.***

30 Roadside Barrier Designs near Bridge Rail Ends with Restricted Rights-of-Way: A Guide

### 3.1.5 Other MASH Non-gating Crash Cushion Tests

Under the MASH 2016 matrix, the remaining tests (3-30, 3-34, 3-36, 3-37, and 3-38) were not considered necessary for the following reasons:

- Test 3-30 is intended to evaluate occupant risk, vehicle stability, and vehicle trajectory for head-on impacts, primarily for narrow crash cushions/end treatments. As noted under Test 3-31, there was no defined end that could be impacted. Test 3-31, with the much higher-energy pickup truck, was conducted successfully. As predicted by the computer simulation of this test and in pickup truck tests, a smaller vehicle would deflect the barrier far less. In addition, Test 3-30 was not considered necessary in any previously accepted curved-radius designs. Therefore, this test was deemed unnecessary.
- Test 3-34 is intended to evaluate the impact performance of crash cushions and end treatments at the CIP, where the behavior of the device changes from gating or capturing to redirecting. As noted previously for this design, Test 3-35 was essentially a CIP test, making Test 3-34 redundant.
- Test 3-36 is designed to examine the behavior of end treatments when attached to rigid barriers or other very stiff features; it essentially is a transition test. The proposed design incorporates a Thrie-beam transition design that had been previously tested and accepted as crashworthy; therefore, this test was considered redundant.
- Test 3-37 examines the behavior on a reverse-direction impact used primarily to detect possible snagging concerns. The proposed design consists of standard 10-gauge W-beam, with little likelihood of snagging; therefore, this test was considered not relevant.
- Test 3-38 is intended to evaluate the performance of a crash cushion designed as a staged device during impacts by a mid-size vehicle. As this design is not a staged device, this test was not considered relevant.

## 3.2 Evaluation Criteria

Under MASH requirements, each test had to meet three specific criteria: structural adequacy, occupant impact risk, and vehicle trajectory. Table 3.2 provides the specific requirements for these criteria. One or more specific requirements are outlined for each aspect.

## 3.3 Test Facility: Federal Outdoor Impact Laboratory

All SRGS testing was performed at the Federal Outdoor Impact Laboratory (FOIL). The FOIL is an ISO17025-accredited (Cert.# AT-1565) research facility that supports FHWA Safety Research and Technology programs and other federal initiatives. The FOIL is a multifaceted impact-testing facility, primarily designed to test the impacts of vehicles with RSH in accordance with MASH guidelines and standards. Appendix D through Appendix I in *NCHRP Web-Only Document 334* provide a full description of each test report of the FOIL.

### 3.3.1 Vehicle Tow and Guidance System Procedures

A unique FOIL hydraulic propulsion system pulled each test vehicle into the test installation. The vehicles were accelerated on a 220 ft concrete track. The 2270P test vehicles could be brought to speeds over 70 mph. The test vehicles were released into a runout area that is 160 ft by 320 ft. Barriers up to 450 ft in length (usually at 25 degree relative to the track) could be installed in the runout area at the end of the track.

Figure 3.5 shows how the test article was installed to meet the impact angle specifications from MASH for Tests 3-31 (darker hue) and 3-35 (lighter hue). In each case, the barrier was

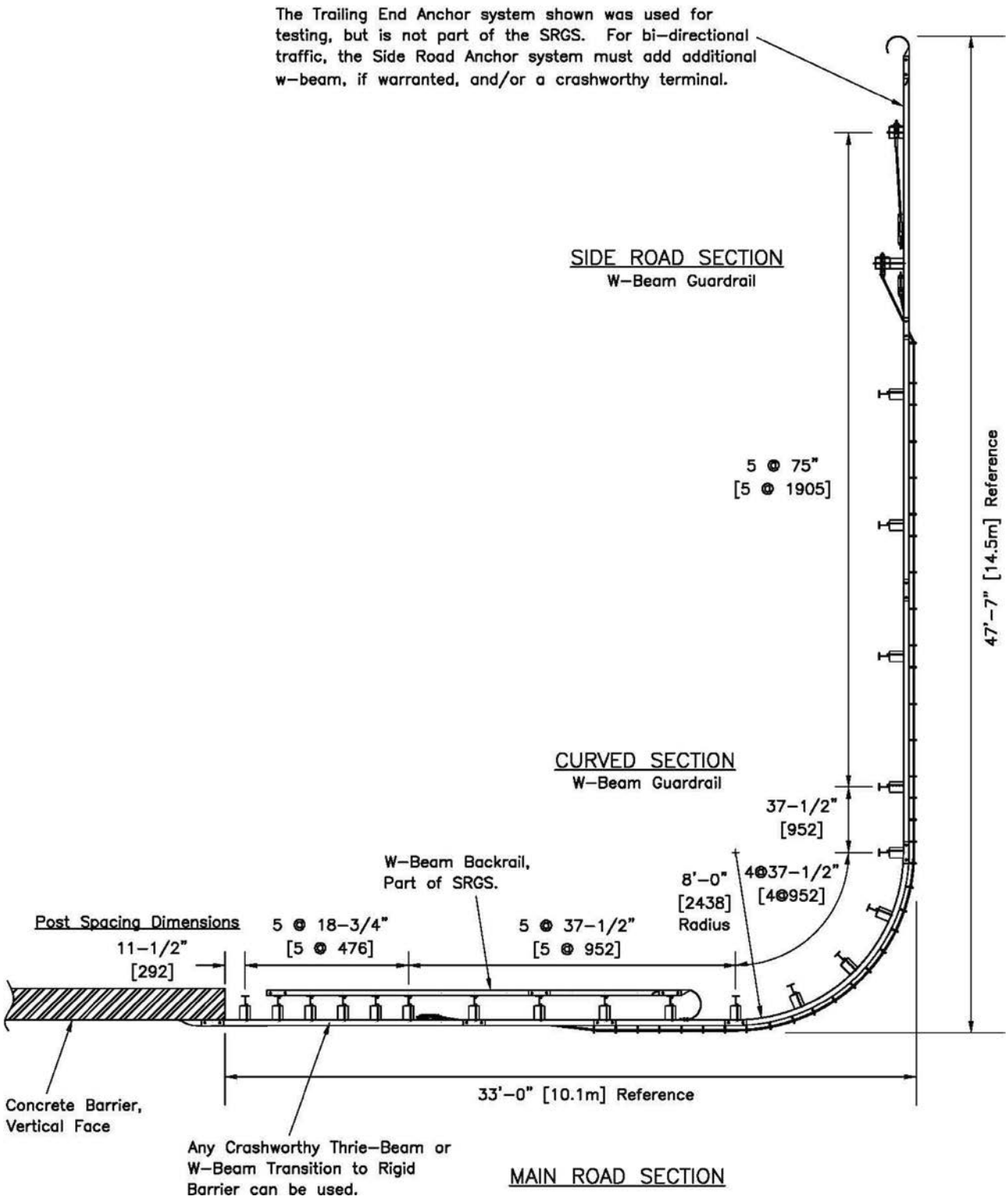


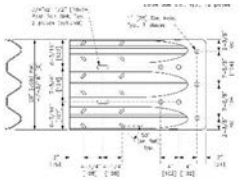
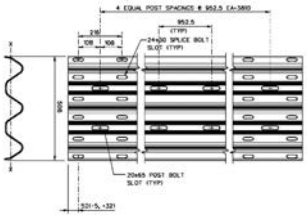
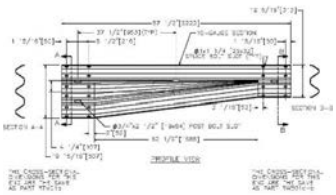
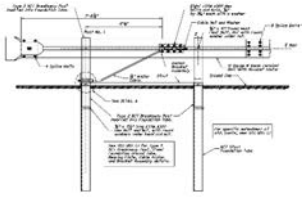

***Figure 3.7. Plan view of SRGS, full installation, as tested.***

Front view of the top and bottom cables on the side road. Lower cable anchored with a bearing plate.

Back view of the top cables on the side road using half of a standard anchor bracket.

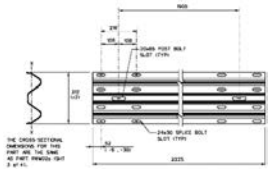
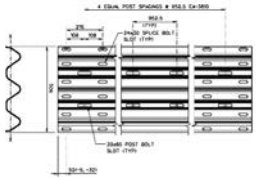
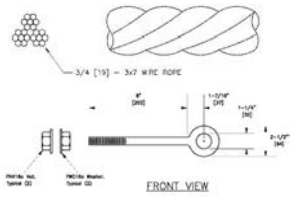
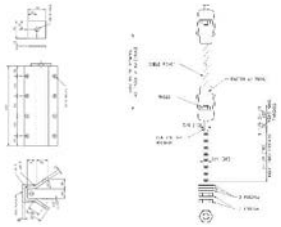
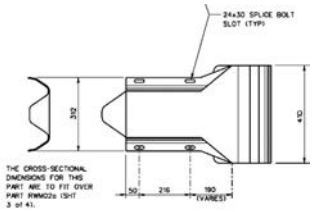
***Figure 3.9. (Continued).***

**Table 3.3. SRGS test installation components.**

| Element Designations and Notes | Task Force 13 Drawing | Photo |
|---|---|---|
| ***Transition Used for Testing*** | | |
| **Part RTE01b**<br>**Thrie-beam Terminal Connector**<br>• 10 gauge.<br>• Thickness: 3.43 mm. |  |  |
| **Part RTM04a-b**<br>**8-Space Thrie-beam Guardrail**<br>• 10 gauge.<br>• Thickness: 3.43 mm.<br>• Total length: 4,130 mm.<br>• Post spacing: 476 mm. |  |  |
| **Part RWT02**<br>**MGS W-beam to Thrie-beam Transition**<br>• 10 gauge.<br>• Thickness: 3.43 mm.<br>• Total length: 2,225 mm.<br>• Post spacing: 952 mm. |  |  |
| ***End Anchor Used for Testing*** | | |
| **End Treatment**<br>**(Ohio Anchor Without the Ground Strut)** |  |  |

*(continued on next page)*

**Table 3.3. (Continued).**

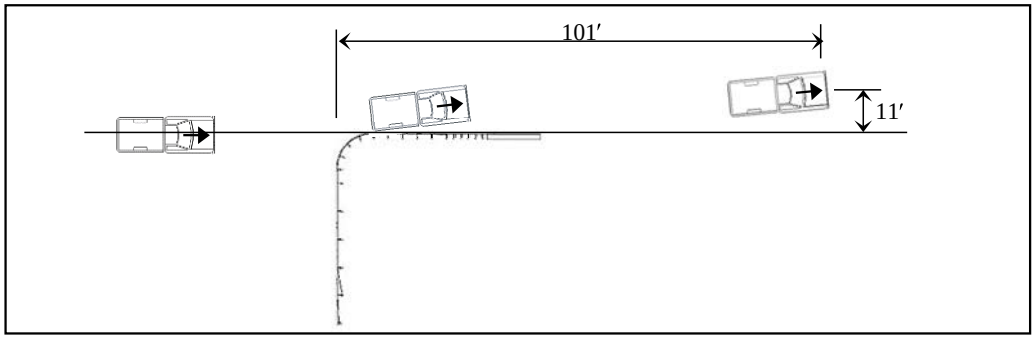
| Element Designations and Notes | Task Force 13 Drawing | Photo |
|---|---|---|
| *SRGS Elements* | | |
| **Part RWM01a-b**<br>**W-beam Spacer Guardrail**<br>• 10 gauge.<br>• Thickness: 3.43 mm.<br>• Total length: 2,225 mm.<br>• Post spacing: 952 mm. |  |  |
| **Part RWM04a-b**<br>**4-Space W-beam Guardrail**<br>• 10 gauge.<br>• Thickness: 3.43 mm.<br>• Total length: 4,130 mm.<br>• Post spacing: 952 mm. |  |  |
| **Cable Tether Linkage**<br>• Cable: 19 mm diameter (RCM01).<br>• Eyebolts: 16 mm diameter. |  |  |
| **Cable-to-Rail Anchor**<br>• Anchor bracket (FPA01 cut in half).<br>• Cable: 19 mm diameter.<br>• Cable end fitting (RCE 03). |  |  |
| **Part RWE03a**<br>**W-beam End Section (Rounded)**<br>• 12 gauge.<br>• Thickness: 2.67 mm. |  |  |

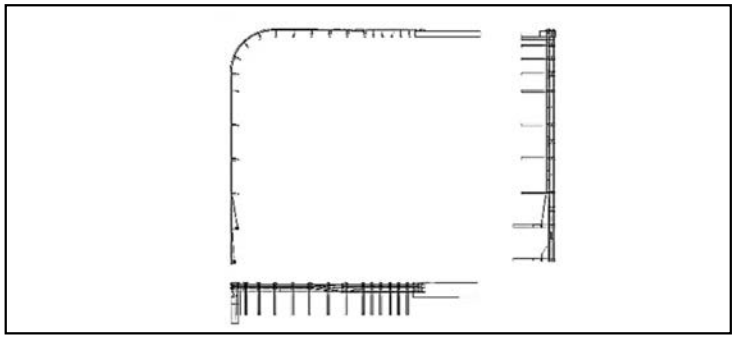
## 3.5.2 Material Specifications

As described previously, this SRGS was fabricated using standard RSH elements. The materials and hardware elements that were delivered met the basic standards in accordance with suppliers or certifications on file at the FOIL office.

## 3.5.3 Soil Conditions

The posts for the SRGS were driven or bored in the designated positions in the FOIL impact area. The soils at the FOIL have been classified as typical Virginia Department of Transportation materials. Soil tests confirmed the compaction and moisture content of the soils were in appropriate ranges consistent with previous testing at the FOIL. These tests, conducted with a nuclear density device, involved repeated measures at multiple positions around the test installation.

**General Information:**
- Test Agency ..... Federal Outdoor Impact Laboratory
- Test Number ..... 19008
- Date ..... 08/08/2019

**Test Article:**
- Type ..... Short-radius guardrail
  - Name or Mfg ..... Generic
- Installation Length ..... 76 ft (23 m)
- Key Elements ..... W-beams, steel posts, cables
  - Size/Dimension ..... 31 in. (787 mm) rail height
  - Material ..... W-beam rail 10-gauge (RWM04a-b)
  - Other ..... 3/4 in. wire rope and 5/8 in. eyebolts

**Test Vehicle:**
- Type/Designation ..... 2270P
- Make and Model ..... 2014 Ram 1500 Quad Cab Pickup
  - VIN No. ..... 1C6RR6GTXES120813
  - Curb ..... 5,056 lb (2,293 kg)
- Test Inertial ..... 4,970 lb (2,254 kg)
- Gross Static ..... 4,970 lb (2,254 kg)

**Soil Conditions:**
- Type of Soil ..... Well-graded gravel with silt & sand
- Soil Strength ..... MASH Standard Soil

**Impact Conditions:**
- Speed ..... 62.7 mph (100.7 km/hr)
- Angle ..... 0 degrees
- Location/Orientation ..... Vehicle centerline aligned with the front face of the transition

**Exit Conditions:**
- Speed ..... 38.2 mph (61.5 km/hr)
- Angle ..... -8 degrees
- Exit Box Criterion ..... Vehicle exited within box

**Post-Impact Trajectory:**
- Stopping Distance ..... NA (brakes applied)
- Vehicle Snagging ..... None
- Vehicle Pocketing ..... No

**Occupant Risk:**
- Longitudinal OIV ..... 29.85 ft/s (9.1 m/s) < 39.4 ft/s (12 m/s)
- Lateral OIV ..... 7.55 ft/s (2.3 m/s) < 39.4 ft/s (12 m/s)
- Longitudinal RA ..... -11.9 G < 20.49 G
- Lateral RA ..... -6.5 G < 20.49 G
- THIV ..... 30.8 ft/s (21.0 mph) = 9.4 m/s (33.7 km/hr)
- PHD ..... 11.6 G

**Test Article Damage:**
Moderate

**Test Article Deflections:**
- Permanent Set ..... 6.03 ft (1.84 m)
- Dynamic ..... 6.03 ft (1.84 m)
- Working Width ..... 6.03 ft (1.84 m)

**Vehicle Damage:**
- VDS ..... 1RFQ3
- CDC ..... 01FZEW2
- Max. Deformation
  - Exterior ..... 19.22 in. (48.8 cm)
  - Windshield ..... 0.11 in. (0.29 cm)
  - Occupant Comp. ..... 1.22 in. (3.10 cm)

**Vehicle Post-Impact Behavior:**
- Vehicle Stability ..... Satisfactory
- Max. Roll Angle ..... -21.2 degrees
- Max. Pitch Angle ..... 6.9 degrees
- Max. Yaw Angle ..... 25.6 degrees

**Overall Performance:** Pass

*Note:* Vehicle Damage Scale (VDS); Collision Deformation Classification (CDC).

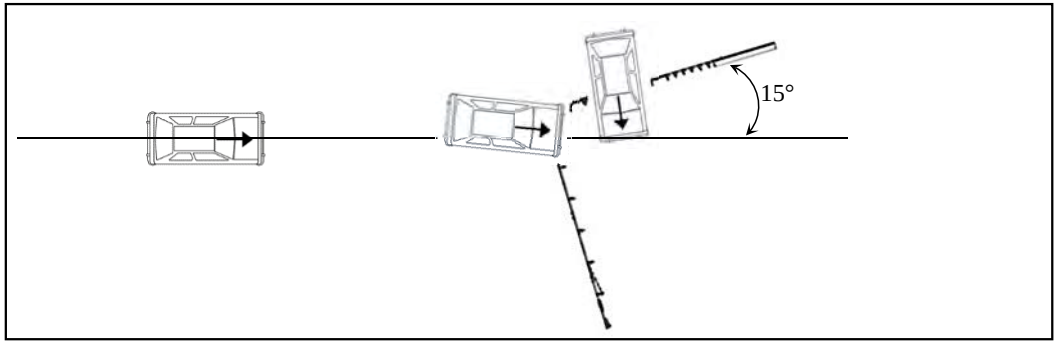
***Figure 3.15. MASH Test 3-31 (FOIL Test 19008) summary sheet for crash-test results.***

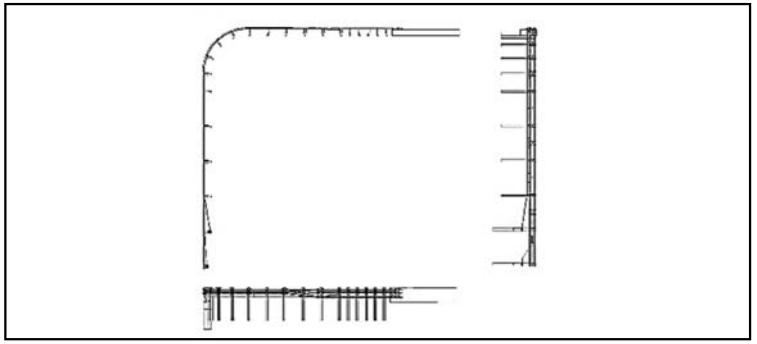

0.000 s


0.110 s


0.340 s


0.800 s



**General Information:**
- Test Agency ..... Federal Outdoor Impact Laboratory
- Test Number ..... 19010
- Date ..... 08/20/2019

**Test Article:**
- Type ..... Short-radius guardrail
  Name or Mfg ..... Generic
- Installation Length ..... 76 ft (23 m)
- Key Elements ..... W-beams, steel posts, cables
  Size/Dimension ..... 31 in (787 mm) rail height
  Material ..... W-beam rail 10-gauge (RWM04a-b)
  Other ..... 3/4 in. wire rope and 5/8 in. eyebolts

**Test Vehicle:**
- Type/Designation ..... 1100C
- Make and Model ..... 2011 Kia Rio (four door)
  VIN No. ..... KNADH4A35B6930306
  Curb ..... 2,491 lb (1,130 kg)
- Test Inertial ..... 2,479 lb (1,124.5 kg)
- Gross Static ..... 2,644 lb (1,199.5 kg)

**Soil Conditions:**
- Type of Soil ..... Well-graded gravel with silt & sand
- Soil Strength ..... MASH Standard Soil

**Impact Conditions:**
- Speed ..... 62.2 mph (100.1 km/hr)
- Angle ..... 15 degrees
- Location/Orientation ... Vehicle centerline aligned with
  ..... curved rail section at center post

**Exit Conditions:**
- Speed ..... Vehicle stopped
- Angle ..... NA
- Exit Box Criterion ..... NA

**Post-Impact Trajectory (from impact point):**
- Stopping Distance ..... x:58/y:36 in. (x:147.3/y:91.4 cm)
- Vehicle Snagging ..... None
- Vehicle Pocketing ..... Yes

**Occupant Risk:**
- Longitudinal OIV ..... 37.40 ft/s (11.4 m/s) < 39.4 ft/s (12 m/s)
- Lateral OIV ..... -1.64 ft/s (-0.5 m/s) < 39.4 ft/s (12 m/s)
- Longitudinal RA ..... -11.3 G < 20.49 G
- Lateral RA ..... 6.0 G < 20.49 G
- THIV ..... 37.73 ft/s (25.72 mph) = 11.5 m/s
  ..... (41.3 km/hr)
- PHD ..... 12.8 G

**Test Article Damage:** Extreme

**Test Article Deflections:**
- Permanent Set ..... NA
- Dynamic ..... NA
- Vehicle Intrusion …… x:5.9/y:10.1 ft (1.82/3.09 m)
  measured from side/main road

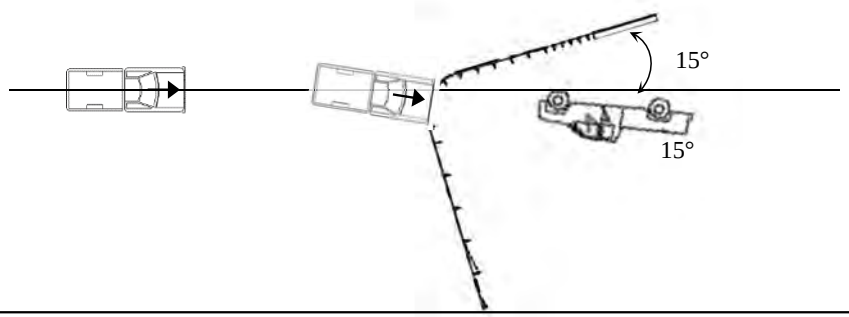
**Vehicle Damage:**
- VDS ..... 12FD3
- CDC ..... 12FDEW2
- Max. Deformation
  Exterior ..... 15.6 in. (39.6 cm)
  Windshield ..... 0.5 in. (1.4 cm)
  Occupant Comp. ..... 0.8 in. (2.1 cm)

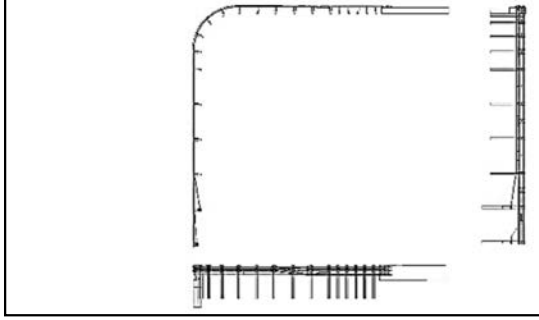
**Vehicle Post-Impact Behavior:**
- Vehicle Stability ..... Satisfactory
- Max. Roll Angle ..... -9.1 degrees
- Max. Pitch Angle ..... -10.1 degrees
- Max. Yaw Angle ..... 92.0 degrees

**Overall Performance:** Pass

*Note:* Vehicle Damage Scale (VDS); Collision Deformation Classification (CDC).

***Figure 3.21. MASH Test 3-32 (FOIL Test 19010) summary sheet for crash-test results.***

**General Information:**
- Test Agency ..... Federal Outdoor Impact Laboratory
- Test Number ..... 19012
- Date ..... 09/05/2019

**Test Article:**
- Type ..... Short-radius guardrail
  Name or Mfg ..... Generic
- Installation Length ..... 76 ft (23 m)
- Key Elements ..... W-beams, steel posts, cables
  Size/Dimension ..... 31 in. (787 mm) rail height
  Material ..... W-beam rail 10-gauge (RWM04a-b)
  Other ..... 3/4 in. wire rope and 5/8 in. eyebolts

**Test Vehicle:**
- Type/Designation ..... 2270P
- Make and Model ..... 2013 Ram 1500 Quad Cab Pickup
  VIN No. ..... 1C6RR6FT8DS617391
  Curb ..... 5,022 lb (2,278 kg)
- Test Inertial ..... 4,978 lb (2,258 kg)
- Gross Static ..... 4,978 lb (2,258 kg)

**Soil Conditions:**
- Type of Soil ..... Well-graded gravel with silt & sand
- Soil Strength ..... MASH Standard Soil

**Impact Conditions:**
- Speed ..... 62.5 mph (100.6 km/hr)
- Angle ..... 15 degrees
- Location/Orientation ... Vehicle centerline aligned with barrier
  ..... curved section at center post

**Exit Conditions:**
- Speed ..... Vehicle rolled
- Angle ..... NA
- Exit Box Criterion ..... NA

**Post-Impact Trajectory:**
- Stopping Distance ..... x:28/y:3.24 ft (x:853.4/y:99.1 cm)
- Vehicle Snagging ..... None
- Vehicle Pocketing ..... Yes

**Occupant Risk:**
- Longitudinal OIV ..... 25.59 ft/s (7.8 m/s) < 39.4 ft/s (12 m/s)
- Lateral OIV ..... 6.89 ft/s (-2.1 m/s) < 39.4 ft/s (12 m/s)
- Longitudinal RA ..... -6.0 G < 20.49 G
- Lateral RA ..... 5.1 G < 20.49 G
- THIV ..... 26.57 ft/s (8.1 m/s) = 18.12 mph (29.2 km/hr)
- PHD ..... 6.1 G

**Test Article Damage:** Extreme

**Test Article Deflections:**
- Permanent Set ..... NA
- Dynamic ..... NA
- Working Width ..... NA

**Vehicle Damage:**
- VDS ..... 12FD3
- CDC ..... 12FDEW2
- Max. Deformation
  Exterior ..... 18.8 in. (47.7 cm)
  Windshield ..... 0.3 in. (0.8 cm)
  Occupant Comp. ..... 0.2 in. (0.4 cm)

**Vehicle Post-Impact Behavior:**
- Vehicle Stability ..... Not satisfactory
- Max. Roll Angle ..... 90 degrees
- Max. Pitch Angle ..... -6.5 degrees
- Max. Yaw Angle ..... 136.4 degrees

**Overall Performance:** Fail

*Note:* Vehicle Damage Scale (VDS); Collision Deformation Classification (CDC).

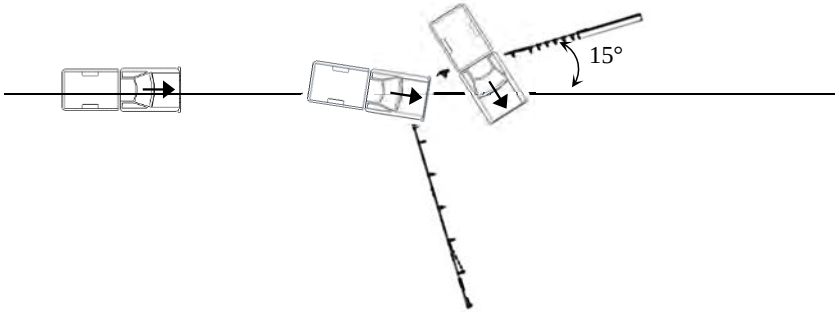
***Figure 3.27. MASH Test 3-33 (FOIL Test 19012) summary sheet for crash-test results.***

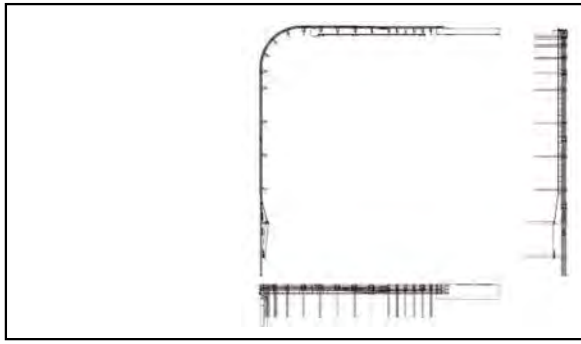
0.000 s

0.460 s

0.910 s

1.600 s



**General Information:**
- Test Agency ..... Federal Outdoor Impact Laboratory
- Test Number ..... 20004
- Date ..... 03/20/2020

**Test Article:**
- Type ..... Short-radius guardrail
  - Name or Mfg ..... Generic
- Installation Length ..... 76 ft (23 m)
- Key Elements ..... W-beams, steel posts, cables
  - Size/Dimension ..... 31 in. (787 mm) rail height
  - Material ..... W-beam rail 10-gauge (RWM04a-b)
  - Other ..... 3/4 in. wire rope and 5/8 in. eyebolts

**Test Vehicle:**
- Type/Designation ..... 2270P
- Make and Model ..... 2014 Ram 1500 Quad Cab Pickup
  - VIN No. ..... 1C6RR6FT8DS617391
  - Curb ..... 4,980 lb (2,259 kg)
- Test Inertial ..... 4,976 lb (2,257 kg)
- Gross Static ..... 4,976 lb (2,257 kg)

**Soil Conditions:**
- Type of Soil ..... Well-graded gravel with silt & sand
- Soil Strength ..... MASH Standard Soil

**Impact Conditions:**
- Speed ..... 62.3 mph (100.3 km/hr)
- Angle ..... 15 degrees
- Location/Orientation ... Vehicle centerline aligned with barrier ..... curved section at center post

**Exit Conditions:**
- Speed ..... Vehicle stopped
- Angle ..... NA
- Exit Box Criterion ..... NA

**Post-Impact Trajectory (from impact point):**
- Stopping Distance ..... x:13.5/y:7.3 ft (x:411.5/y:222.5 cm)
- Vehicle Snagging ..... None
- Vehicle Pocketing ..... Yes/Captured

**Occupant Risk:**
- Longitudinal OIV ..... 24.61 ft/s (7.5 m/s) < 39.4 ft/s (12 m/s)
- Lateral OIV ..... 6.89 ft/s (-2.1 m/s) < 39.4 ft/s (12 m/s)
- Longitudinal RA ..... -8.6 G < 20.49 G
- Lateral RA ..... 6.2 G < 20.49 G
- THIV ..... 28.8 ft/s (8 m/s) = 18.12 mph (29.2 km/hr)
- PHD ..... 10.5 G

**Test Article Damage:** Extreme

**Test Article Deflections:**
- Permanent Set ..... NA
- Dynamic ..... NA
- Vehicle Intrusion ..... x:26.6/y:14.1 ft (8.1/4.3 m) measured from side/main road

**Vehicle Damage:**
- VDS ..... 12FD3
- CDC ..... 12FDEW2
- Max. Deformation
  - Exterior ..... 18.3 in. (46.5 cm)
  - Windshield ..... 0.2 in. (0.5 cm)
  - Occupant Comp. ..... 0.3 in. (0.8 cm)

**Vehicle Post-Impact Behavior:**
- Vehicle Stability ..... Satisfactory
- Max. Roll Angle ..... 6.3 degrees
- Max. Pitch Angle ..... -11.2 degrees
- Max. Yaw Angle ..... 60.8 degrees

**Overall Performance:** Pass

*Note:* Vehicle Damage Scale (VDS); Collision Deformation Classification (CDC).

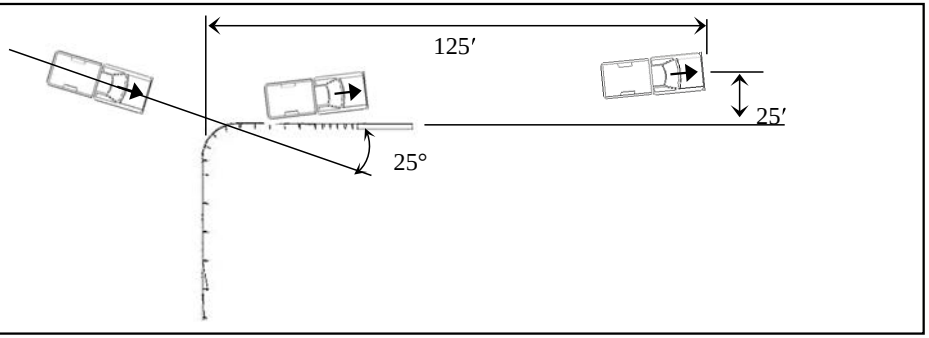
***Figure 3.33. Retest of MASH Test 3-33 (FOIL Test 20004) summary sheet for crash-test results.***

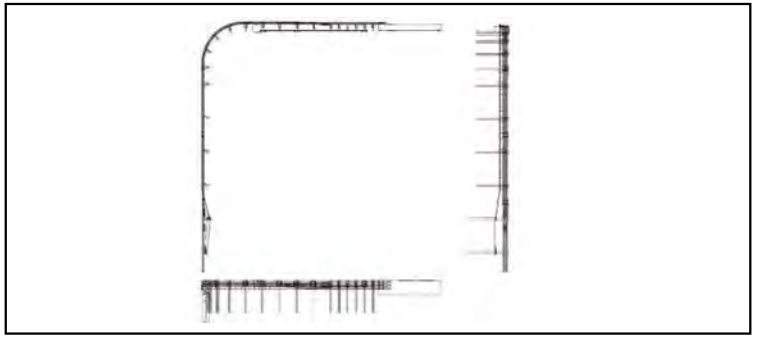

0.000 s


0.140 s


0.210 s


0.290 s



**General Information:**
- Test Agency ..... Federal Outdoor Impact Laboratory
- Test Number ..... 20008
- Date ..... 09/16/2020

**Test Article:**
- Type ..... Short-radius guardrail
  Name or Mfg ..... Generic
- Installation Length ..... 76 ft (23 m)
- Key Elements ..... W-beams, steel posts, cables
  Size/Dimension ..... 31 in. (787 mm) rail height
  Material ..... W-beam rail 10-gauge (RWM04a-b)
  Other ..... 3/4 in. wire rope and 5/8 in. eyebolts

**Test Vehicle:**
- Type/Designation ..... 2270P
- Make and Model ..... 2014 Ram 1500 Quad Cab Pickup
  VIN No. ..... 1C6RR6FT7ES304818
  Curb ..... 4,975 lb (2,256.5 kg)
- Test Inertial ..... 4,945 lb (2,243 kg)
- Gross Static ..... 4,945 lb (2,243 kg)

**Soil Conditions:**
- Type of Soil ..... Well-graded gravel with silt & sand
- Soil Strength ..... MASH Standard Soil

**Impact Conditions:**
- Speed ..... 63.0 mph (101.4 km/hr)
- Angle ..... 25 degrees
- Location/Orientation ... Front-right fender of the vehicle impacted the beginning of the straight section on the main road

**Exit Conditions:**
- Speed ..... 39.1 mph (62.9 km/hr)
- Angle ..... -11 degrees
- Exit Box Criterion ..... Vehicle exited within box

**Post-Impact Trajectory:**
- Stopping Distance ..... 125 ft
- Vehicle Snagging ..... None
- Vehicle Pocketing ..... None

**Occupant Risk:**
- Longitudinal OIV ..... 10.29 ft/s (4.6 m/s) < 39.4 ft/s (12 m/s)
- Lateral OIV ..... -6 ft/s (5.6 m/s) < 39.4 ft/s (12 m/s)
- Longitudinal RA ..... -12.53 G < 20.49 G
- Lateral RA ..... -9.5 G < 20.49 G
- THIV ..... 23.29 ft/s (15.88 mph) = 7.1 m/s ..... (25.6 km/hr)
- PHD ..... 11.7 G

**Test Article Damage:** Moderate

**Test Article Deflections:**
- Permanent Set ..... 10.4 in. (26.3 cm)
- Dynamic ..... 18.7 in. (47.5 cm)
- Working Width ..... 18.7 in. (47.5 cm)

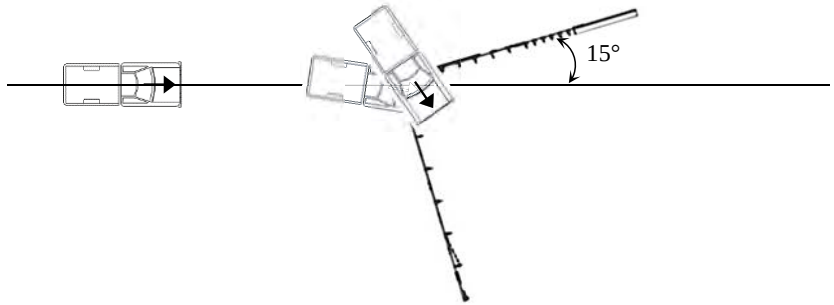
**Vehicle Damage:**
- VDS ..... 1RFQ3
- CDC ..... 01FZEW2
- Max. Deformation
  Exterior ..... 22.4 in. (57.1 cm)
  Windshield ..... 1.6 in. (4.2 cm)
  Occupant Comp. ..... 2.5 in. (6.3 cm)

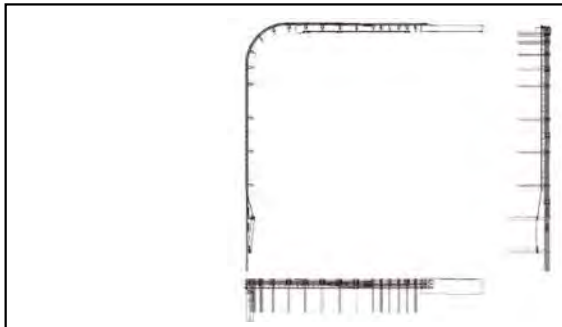
**Vehicle Post-Impact Behavior:**
- Vehicle Stability ..... Satisfactory
- Max. Roll Angle ..... 13.2 degrees
- Max. Pitch Angle ..... 10.9 degrees
- Max. Yaw Angle ..... -37.2 degrees

**Overall Performance:** Pass

*Note:* Vehicle Damage Scale (VDS); Collision Deformation Classification (CDC).

***Figure 3.39. MASH Test 3-35 (FOIL Test 20008) summary sheet for crash-test results.***

**General Information:**
- Test Agency ..... Federal Outdoor Impact Laboratory
- Test Number ..... 20004
- Date ..... 11/04/2020

**Test Article:**
- Type ..... Short-radius guardrail
  Name or Mfg ..... Generic
- Installation Length ..... 77 ft (23.5m), 2:1 slope behind barrier
- Key Elements ..... W-beams, steel posts, cables
  Size/Dimension ..... 31 in. (787 mm) rail height
  Material ..... W-beam rail 10-gauge (RWM04a-b)
  Other ..... 3/4 in. wire rope and 5/8 in. eyebolts

**Test Vehicle:**
- Type/Designation ..... 2270P
- Make and Model ..... 2014 Ram 1500 Quad Cab Pickup
  VIN No. ..... 1C6RR6FT8DS617391
  Curb ..... 5,015.5 lb (2,275 kg)
- Test Inertial ..... 4,954 lb (2,247 kg)
- Gross Static ..... 4,954 lb (2,247 kg)

**Soil Conditions:**
- Type of Soil ..... Well-graded gravel with silt & sand
- Soil Strength ..... MASH Standard Soil

**Impact Conditions:**
- Speed ..... 50.4 mph (81.0 km/hr)
- Angle ..... 15 degrees
- Location/Orientation ... Vehicle centerline aligned with barrier
  ..... curved section at center post

**Exit Conditions:**
- Speed ..... Vehicle stopped
- Angle ..... NA
- Exit Box Criterion ..... NA

**Post-Impact Trajectory (from impact point):**
- Stopping Distance ..... x:10/y:5.1 ft (x:305/y:157 cm)
- Vehicle Snagging ..... None
- Vehicle Pocketing ..... Yes/Captured

**Occupant Risk:**
- Longitudinal OIV ..... 23.95 ft/s (7.3 m/s) < 39.4 ft/s (12 m/s)
- Lateral OIV ..... -4.92 ft/s (-1.5 m/s) < 39.4 ft/s (12 m/s)
- Longitudinal RA ..... -8.7 G < 20.49 G
- Lateral RA ..... 4.5 G < 20.49 G
- THIV ..... 24.93 ft/s (16.96 mph) = 17.6 m/s
  ..... (27.3 km/hr)
- PHD ..... 9.0 G

**Test Article Damage:** Moderate to extreme

**Test Article Deflections:**
- Permanent Set ..... NA
- Dynamic ..... NA
- Vehicle Intrusion ..... x:14.3/y:12.8 ft (4.37/3.9 m)
  measured from side/main road

**Vehicle Damage:**
- VDS ..... 12FD3
- CDC ..... 12FDEW2
- Max. Deformation
  Exterior ..... 3.1 in. (7.8 cm)
  Windshield ..... 0.6 in. (1.6 cm)
  Occupant Comp. ..... 0.6 in. (1.5 cm)

**Vehicle Post-Impact Behavior:**
- Vehicle Stability ..... Satisfactory
- Max. Roll Angle ..... -11.6 degrees
- Max. Pitch Angle ..... -14.6 degrees
- Max. Yaw Angle ..... 60.7 degrees

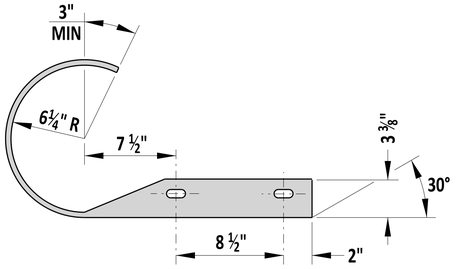
**Overall Performance:** Pass

*Note:* Vehicle Damage Scale (VDS); Collision Deformation Classification (CDC).

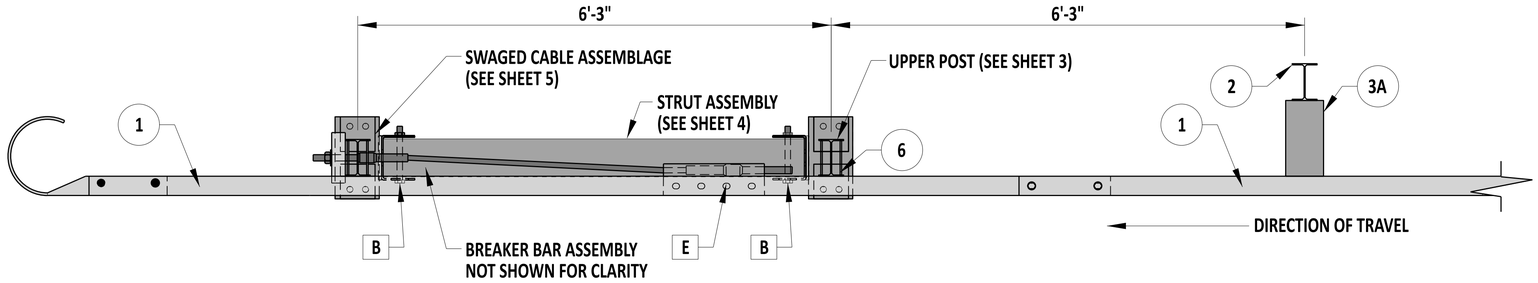
***Figure 3.46. Modified MASH Test 3-33 (FOIL Test 20012) summary sheet for crash-test results.***

Appendix F: DelDOT Standard Construction Detail B-5

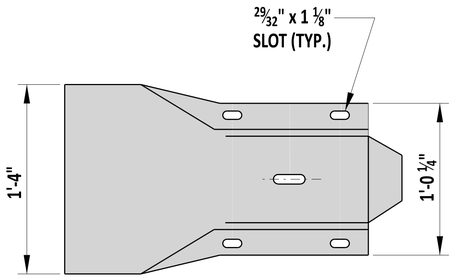
SCALE : NTS



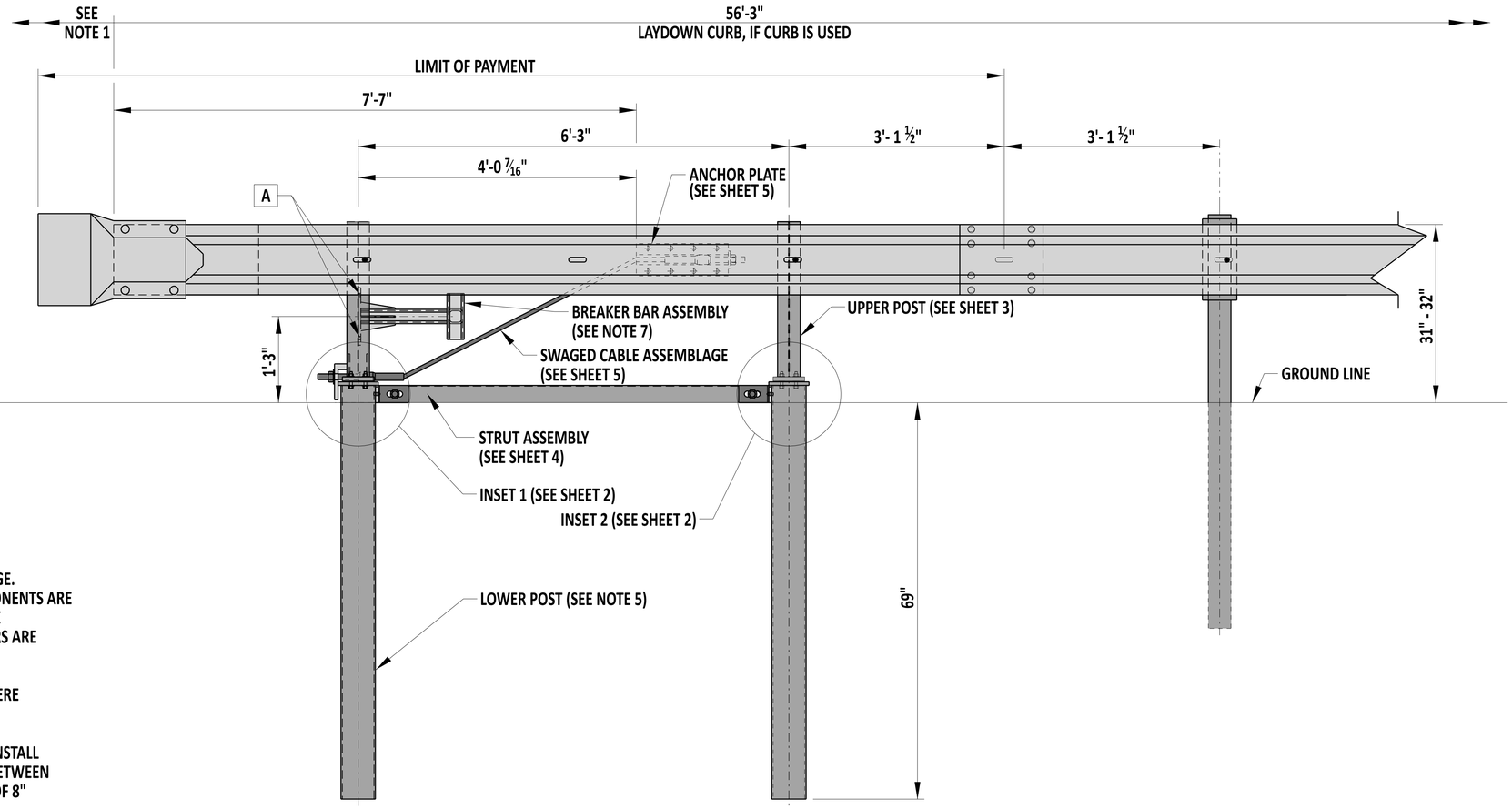

END SECTION PLAN




PLAN VIEW




END SECTION ELEVATION




ELEVATION VIEW

NOTES:

1). IF CURB IS USED, EXTEND LAYDOWN CURB 50'-0" DOWNSTREAM OF THE ANCHORAGE.
2). SEE SHEET 5 FOR COMPONENT LIST AND CONNECTION HARDWARE LIST. ALL COMPONENTS ARE TO BE GALVANIZED IN ACCORDANCE WITH ASTM A123. BOLTS AND NUTS ARE TO BE GALVANIZED IN ACCORDANCE WITH ASTM A153, B695 CLASS 55, OR F2329. WASHERS ARE TO BE GALVANIZED IN ACCORDANCE WITH ASTM A123, ASTM A153, OR F2329.
3). DO NOT PLACE GUARDRAIL REFLECTORS WITHIN THE LIMITS OF THE ANCHORAGE.
4). THIS IS DESIGNED TO ACT AS A DOWNSTREAM END ANCHOR. DO NOT USE THIS WHERE HEAD ON IMPACTS ARE EXPECTED.
5). THIS DETAIL IS BASED ON TESTING PERFORMED REPORT NO. TRP 03-370b-20.
6). SEE DETAIL B-1, SHEET 3 FOR MAINTENANCE PAVEMENT DEPTHS AND MATERIALS. INSTALL MAINTENANCE PAVEMENT WITHIN THE LIMITS OF PAYMENT, TO THE FULL WIDTH BETWEEN THE EDGE OF PAVEMENT, OR BACK OF CURB IF CURB IS INSTALLED, TO A DISTANCE OF 8" BEHIND THE BACK OF POST.
7). TIGHTEN SWAGE CABLE ASSEMBLAGE UNTIL CABLE IS TAUT. DO NOT OVER TIGHTEN OR TWIST THE CABLE. SEE SHEET 5 FOR ADDITIONAL DETAIL ON SWAGE CABLE ASSEMBLAGE.

DelDOT

Andrew Short — ENGINEERING SUPPORT — 10/15/2024 DATE

RECOMMENDED

# STEEL-POST END ANCHORAGE, TYPE 31
# PLAN AND ELEVATION VIEW

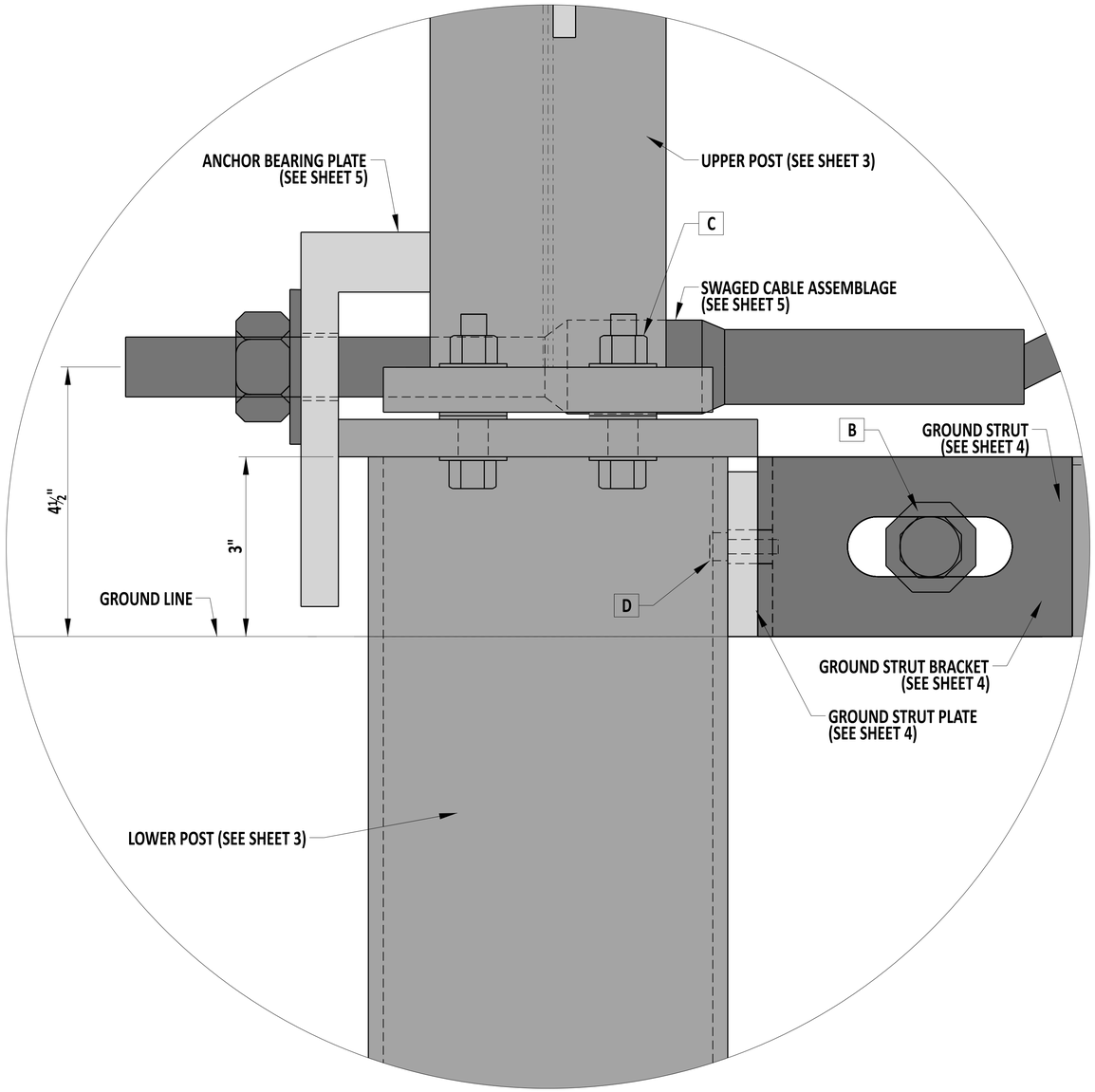
STANDARD NO. B-5 (2025) | SHT. 1 OF 5

REVIEWED — DEPUTY DIRECTOR - DESIGN — 23 October 2024 DATE

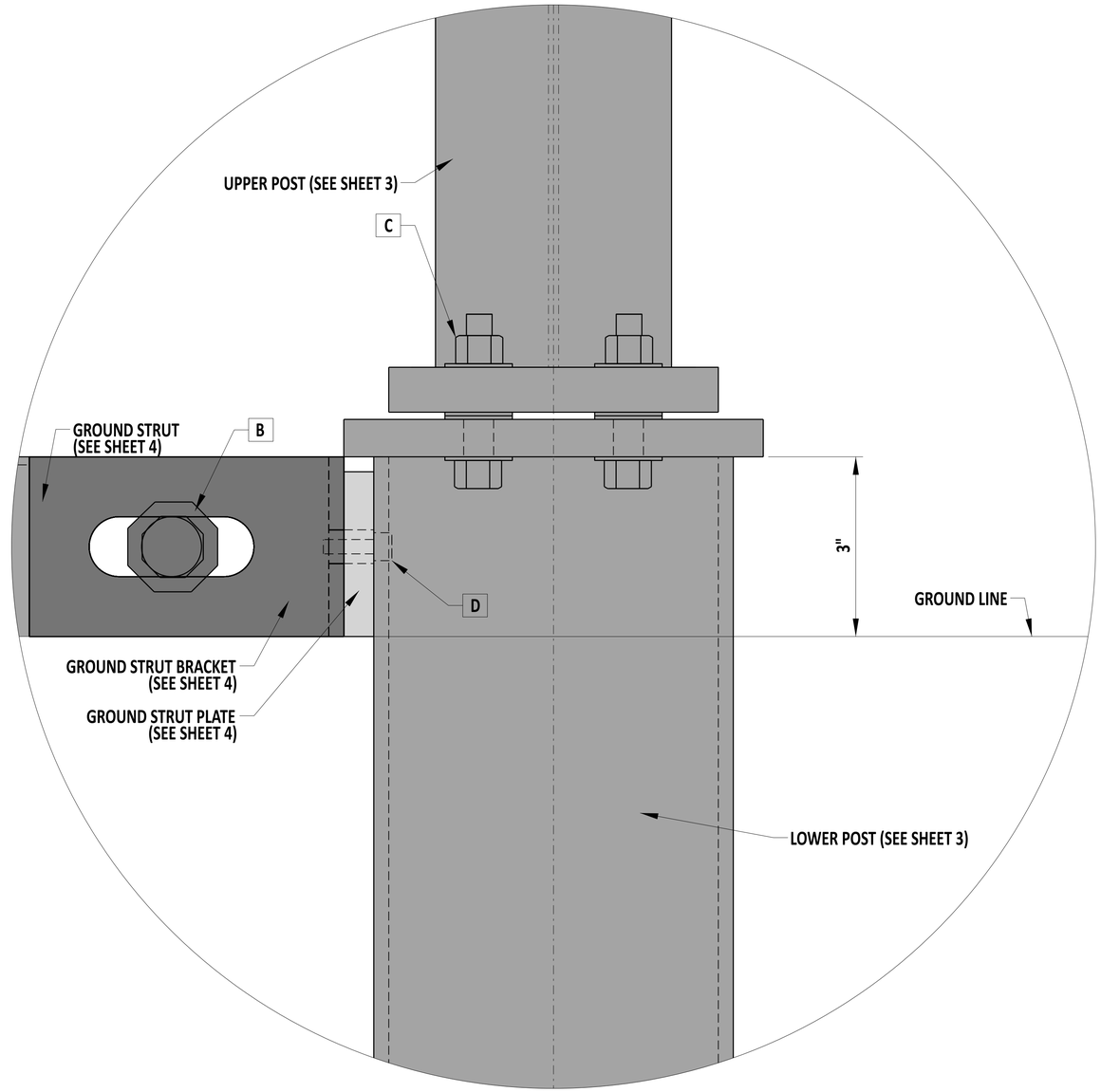
APPROVED — CHIEF ENGINEER — 10/25/2024 DATE

24-SEP-2024

SCALE : NTS




INSET 1




INSET 2

DelDOT

Andrew Shott
ENGINEERING SUPPORT
10/15/2024
DATE
RECOMMENDED

**STEEL-POST END ANCHORAGE, TYPE 31**
**INSETS**

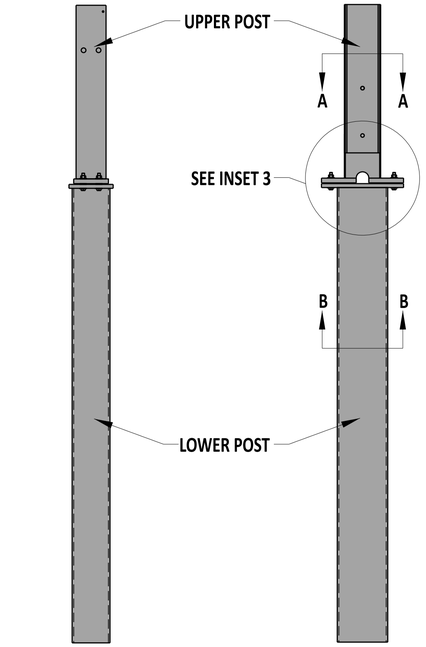
STANDARD NO. B-5 (2025) | SHT. 2 OF 5

REVIEWED
DEPUTY DIRECTOR - DESIGN
23 October 2024
DATE

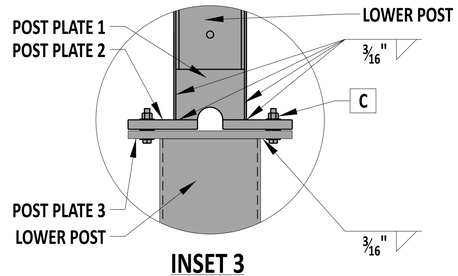
APPROVED
CHIEF ENGINEER
10/25/2024
DATE

24-SEP-2024

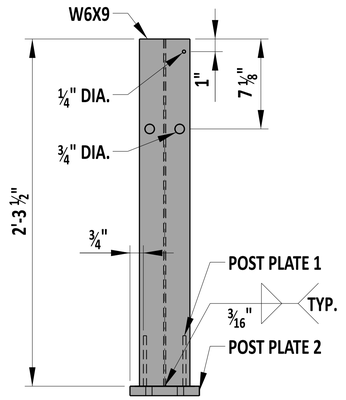
SCALE : NTS



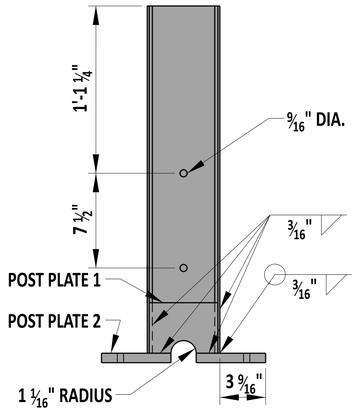

ELEVATION VIEW




INSET 3

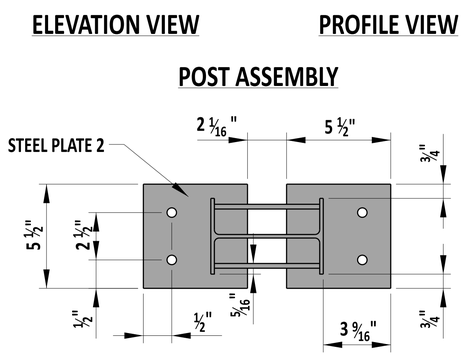



ELEVATION VIEW

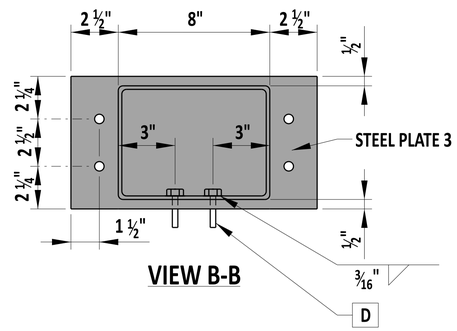



PROFILE VIEW

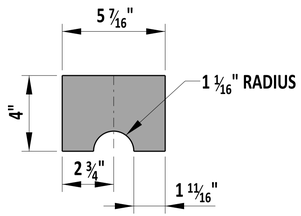
UPPER POST ASSEMBLY




VIEW A-A

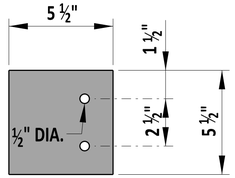



VIEW B-B



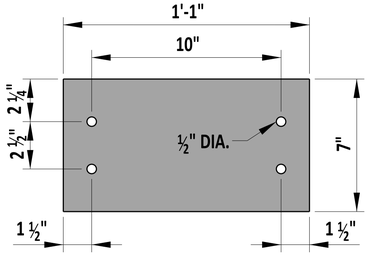

ELEVATION VIEW

POST PLATE 1



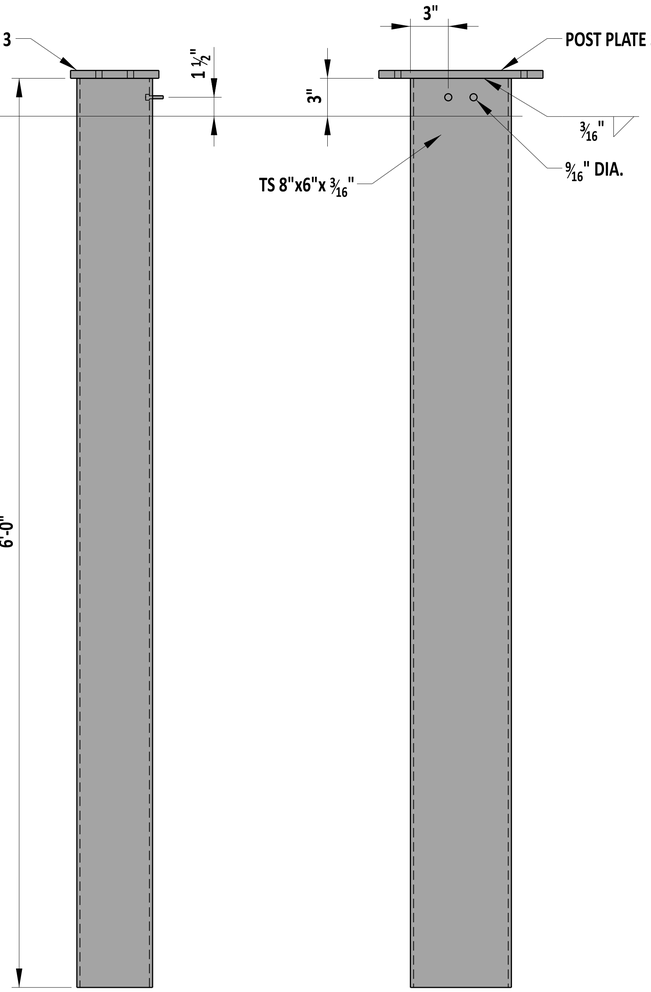

PLAN VIEW

POST PLATE 2




PLAN VIEW

POST PLATE 3




ELEVATION VIEW

PROFILE VIEW

LOWER POST ASSEMBLY

NOTES:

1). SEE SHEET 5 FOR COMPONENT LIST AND CONNECTION HARDWARE LIST. ALL COMPONENTS ARE TO BE GALVANIZED IN ACCORDNACE WITH ASTM A123. BOLTS AND NUTS ARE TO BE GALVANIZED IN ACCORDANCE WITH ASTM A153, B695 CLASS 55, OR F2329. WASHERS ARE TO BE GALVANIZED IN ACCORDANCE WITH ASTM A123, ASTM A153, OR F2329.

DelDOT

Andrew Shoot — ENGINEERING SUPPORT — 10/15/2024 DATE

RECOMMENDED

# STEEL-POST END ANCHORAGE, TYPE 31
# UPPER AND LOWER POST ASSEMBLY

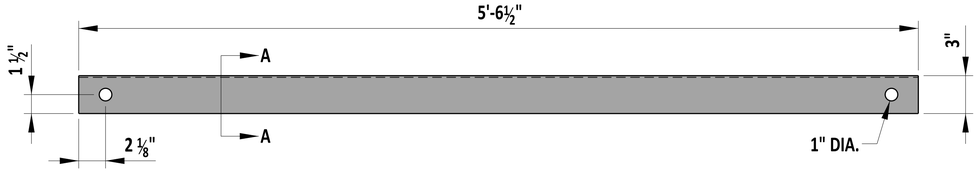
STANDARD NO. B-5 (2025) | SHT. 3 OF 5

REVIEWED — DEPUTY DIRECTOR - DESIGN — 23 October 2024 DATE

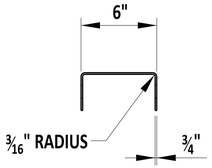
APPROVED — CHIEF ENGINEER — 10/25/2024 DATE

24-SEP-2024

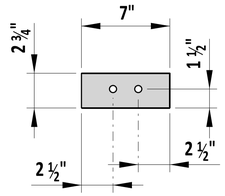
SCALE : NTS




ELEVATION VIEW

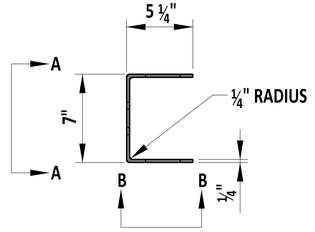



SECTION A-A

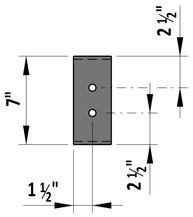



GROUND STRUT PLATE

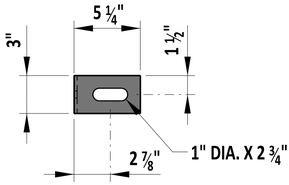
GROUND STRUT




PLAN VIEW

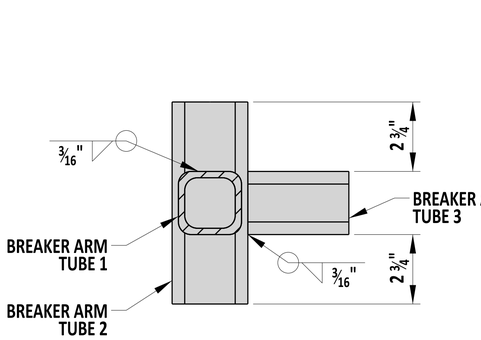



VIEW A-A

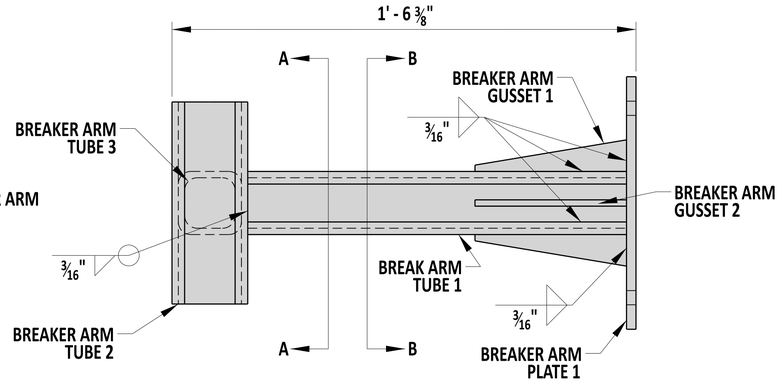



VIEW B-B

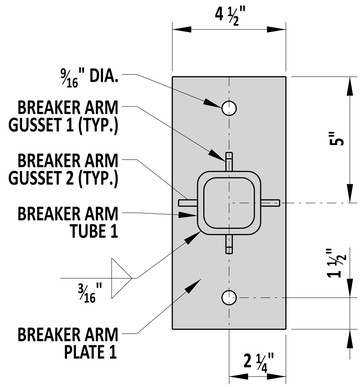
GROUND STRUT BRACKET



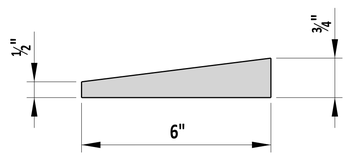

VIEW A-A



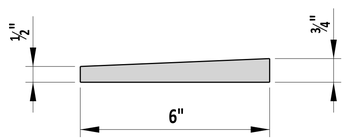

ELEVATION VIEW




VIEW B-B




GUSSET PLATE 1




GUSSET PLATE 2

BREAKER ARM ASSEMBLY

NOTES:

1). SEE SHEET 5 FOR COMPONENT LIST AND CONNECTION HARDWARE LIST. ALL COMPONENTS ARE TO BE GALVANIZED IN ACCORDNACE WITH ASTM A123. BOLTS AND NUTS ARE TO BE GALVANIZED IN ACCORDANCE WITH ASTM A153, B695 CLASS 55, OR F2329. WASHERS ARE TO BE GALVANIZED IN ACCORDANCE WITH ASTM A123, ASTM A153, OR F2329.

DelDOT

ENGINEERING SUPPORT — 10/15/2024 DATE

RECOMMENDED

STEEL-POST END ANCHORAGE, TYPE 31
BREAKER AND GROUND STRUT ASSEMBLIES

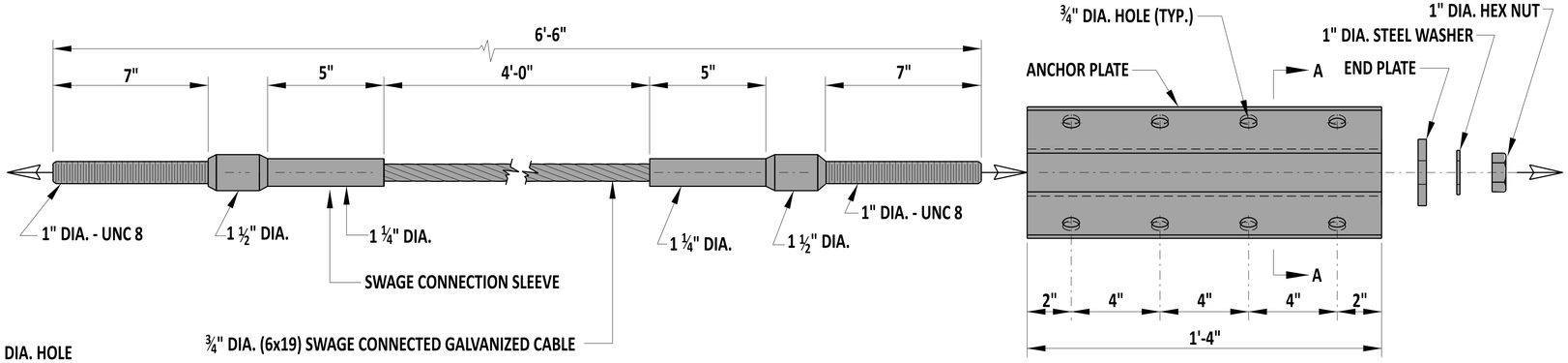
STANDARD NO. B-5 (2025) | SHT. 4 OF 5

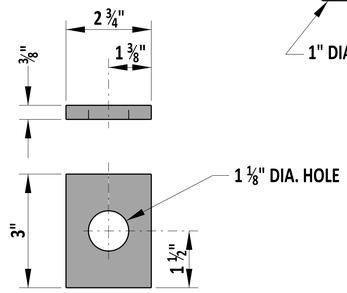
REVIEWED — DEPUTY DIRECTOR - DESIGN — 23 October 2024 DATE

APPROVED — CHIEF ENGINEER — 10/25/2024 DATE

24-SEP-2024

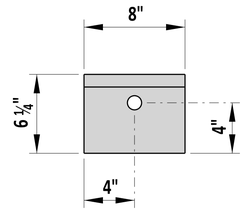
SCALE : NTS



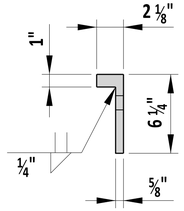




## END PLATE

## SWAGED CABLE ASSEMBLAGE AND RELATED HARDWARE ASSEMBLY

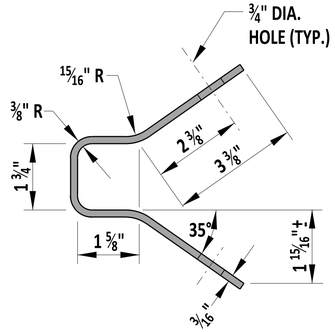



## ELEVATION VIEW

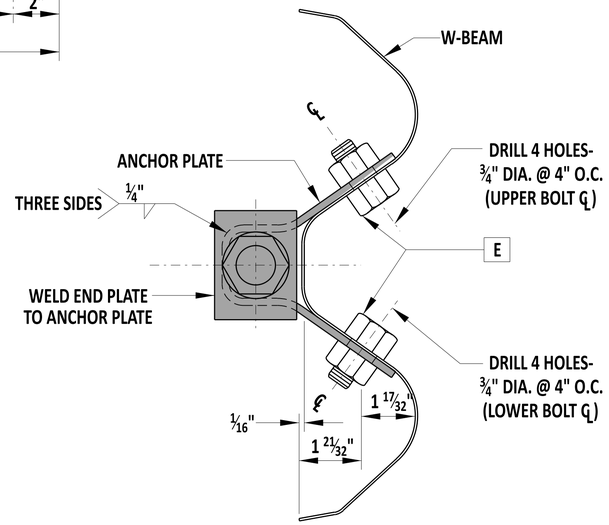



## SECTION VIEW

## ANCHOR BEARING PLATE




## SECTION A-A




## COMPONENT LIST

| COMPONENT | DESCRIPTION | MATERIAL SPECIFICATION |
|---|---|---|
| UPPER POST | W6 X 8.5, 2'-3 ½" LONG | ASTM A992 |
| LOWER POST | TS 8" X 6" X 3⁄16", 6'-0" LONG | ASTM A500, GR. B |
| ANCHOR BEARING PLATE | 8" X 6 ¼" X ⅝" PLATE WELDED TO 8" X 1 ½" X 1" PLATE | ASTM A36 |
| GROUND STRUT | 5'-6 ½" X 11 ¾" X 10-GAUGE BENT CHANNEL STRUT | ASTM A36 |
| GROUND STRUT BRACKET | 1'-5" X 3" X ¼" BENT PLATE | ASTM A36 |
| GROUND STRUT PLATE | 7" X ¾" X ½" PLATE | ASTM A36 |
| POST PLATE 1 | 5 7⁄16" X 4" X ¼" PLATE | ASTM A36 |
| POST PLATE 2 | 5 ½" X 5 ½" X ¾" PLATE | ASTM A36 |
| POST PLATE 3 | 1'-1" X 7" X ⅝" PLATE | ASTM A36 |
| BREAKER ARM TUBE 1 | HSS 2 ½" X 2 ½" X ¼", 1'-3" LONG | ASTM A500, GR. B |
| BREAKER ARM TUBE 2 | HSS 3" X 3" X ¼", 8" LONG | ASTM A500, GR. B |
| BREAKER ARM TUBE 3 | HSS 2 ½" X 2 ½" X ¼", 4" LONG | ASTM A500, GR. B |
| BREAKER ARM GUSSET 1 | 6" X 1 ¼" X ¼" GUSSET | ASTM A36 |
| BREAKER ARM GUSSET 2 | 6" X ¾" X ¼" GUSSET | ASTM A36 |
| BREAKER ARM PLATE | 10" X 4 ½" X ⅜" PLATE | ASTM A36 |

## CONNECTION HARDWARE LIST

| CONNECTION ID. | CONNECTION DESCRIPTION | MATERIAL SPECIFICATION |
|---|---|---|
| A | BOLT AND NUT - ½" - 13 UNC, 1½" LONG HEX BOLT AND NUT<br>WASHER - ½" DIA. WASHER ON BOTH SIDES OF W6 X 8.5 | BOLT - ASTM A307 GR A<br>NUT - ASTM A563A<br>WASHER - ASTM F844 |
| B | BOLT AND NUT - ⅞" - 9 UNC, 8 ½" LONG HEX HEAD BOLT AND NUT<br>WASHER - ⅞" DIA. WASHER | BOLT - ASTM A307 GR. A<br>NUT - ASTM A563A<br>WASHER - ASTM F844 |
| C | BOLT AND NUT - 7⁄16" - 14 UNC, 2 ½" LONG FULLY THREADED HEX TAP BOLT AND NUT (SEE NOTE 1)<br>WASHER - 7⁄16" DIA. WASHER (SEE NOTE 2) | BOLT - ASTM A449<br>NUT - ASTM A563DH<br>WASHER - ASTM F844 |
| D | BOLT AND NUT - ½" - 13 UNC, 2" LONG HEX BOLT AND NUT<br>WASHER - ½" DIA. WASHER | BOLT AND NUT - ASTM A563A<br>WASHER - ASTM F844 |
| E | BOLT AND NUT - ⅝" - 11 UNC, 1 ½" LONG HEX BOLT AND NUT<br>WASHER - ⅝" DIA. WASHER | BOLT - ASTM A307 GR. A<br>NUT - ASTM A563A<br>WASHER - ASTM F844 |

NOTES:

1). TORQUE TO 60-75 FT-LBS.
2). PLACE TWO WASHERS BETWEEN THE TOP UPPER AND LOWER POST. PLACE ONE WASHER BETWEEN THE POST PLATE 2 AND NUT AND BETWEEN POST PLACE AND BOLT HEAD.

DelDOT

Andrew Short — ENGINEERING SUPPORT — 11/21/2025 DATE

RECOMMENDED

**STEEL-POST END ANCHORAGE, TYPE 31**
**SWAGED CABLE ASSEMBLAGE AND COMPONENT LIST**

STANDARD NO. B-5 (2026) | SHT. 5 OF 5

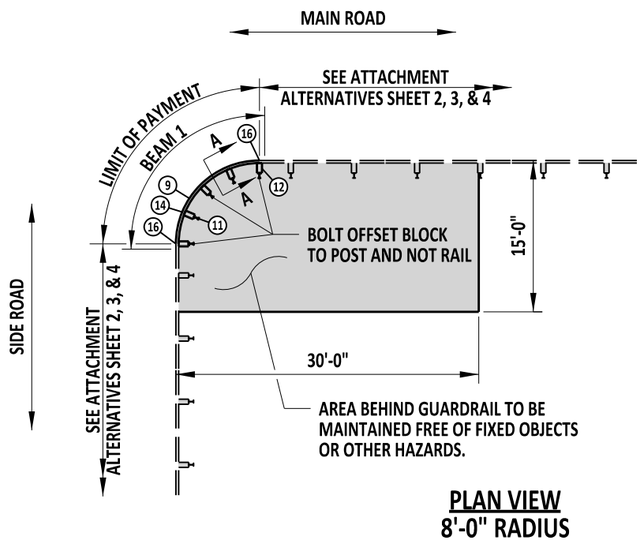
REVIEWED — DEPUTY DIRECTOR - DESIGN — 9 December 2025 DATE

APPROVED — CHIEF ENGINEER — 12/09/2025 DATE

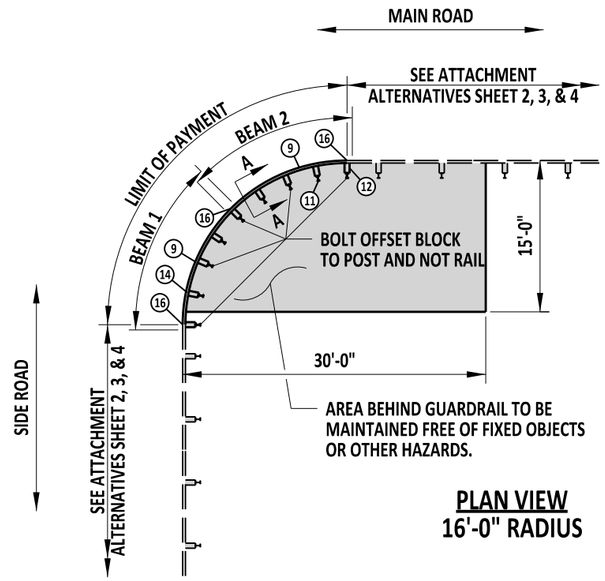
20-NOV-2025

# Appendix G: DelDOT MASH Compliant Short Radius Curved Guardrail Detail

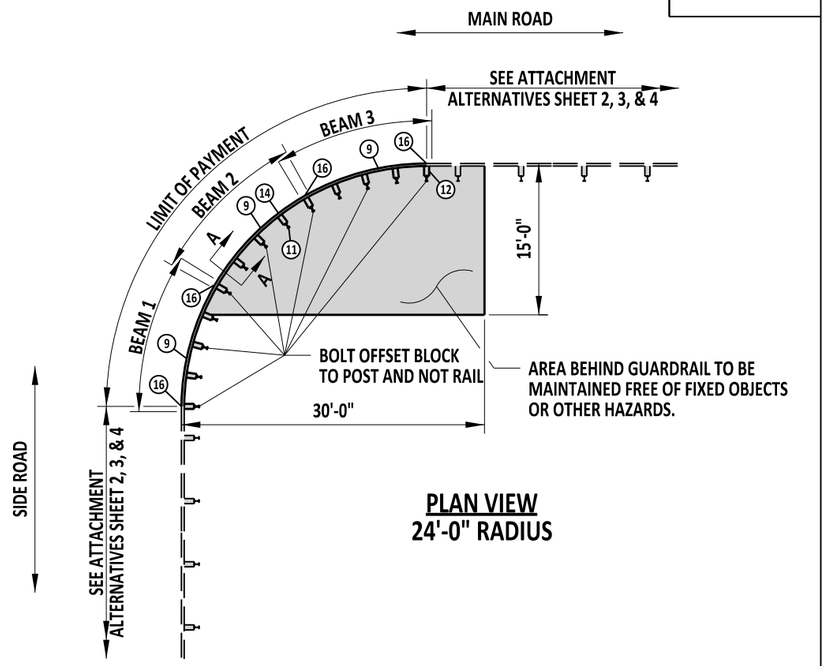
SCALE : NTS




**PLAN VIEW**
**8'-0" RADIUS**

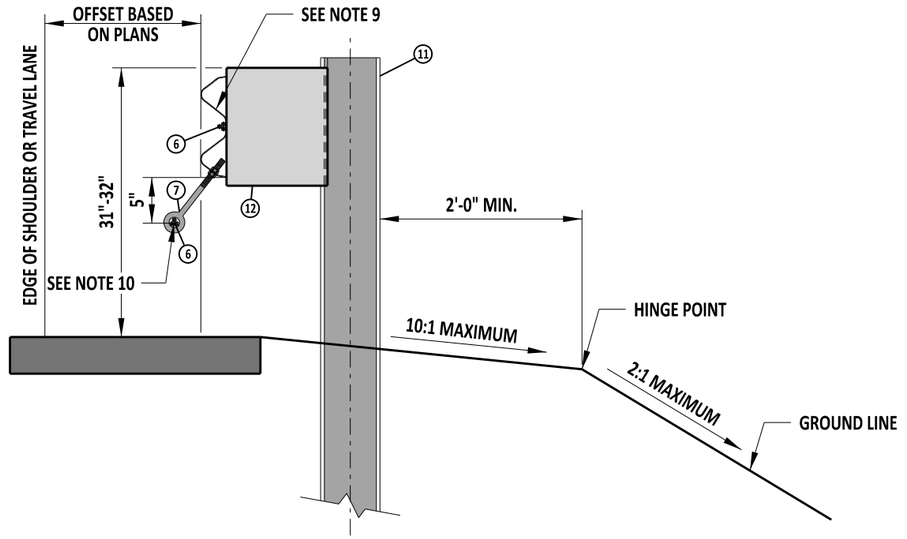



**PLAN VIEW**
**16'-0" RADIUS**




**PLAN VIEW**
**24'-0" RADIUS**

| ITEM NO. | DESCRIPTION |
|---|---|
| 1 | 10 GAUGE THRIE BEAM TERMINAL CONNECTOR (SEE B-13 SHEET 12) |
| 2 | 10 GAUGE W-BEAM SPACER GUARDRAIL W/HOLES, 6'-3" LONG (SEE SHEET 5) |
| 3 | 10 GAUGE SPACER W-BEAM (SEE SHEET 5) |
| 4 | 10 GAUGE ASYMMETRIC W-BEAM TO THRIE BEAM TRANSITION (SEE B-13 SHEET 6) |
| 5 | SWAGED CABLE ASSEMBLAGE AND RELATED HARDWARE (SEE B-5 SHEET 5) |
| 6 | GUARDRAIL CABLE (SEE SHEET 5) |
| 7 | EYEBOLT (SEE SHEET 5) |
| 8 | CABLE-TO-RAIL ATTACHMENT TO GUARDRAIL BEAM |
| 9 | 10 GUAGE 4-SPACE W-BEAM GUARDRAIL W/HOLES (SEE SHEET 6) |
| 10 | 10 GAUGE 4-SPACE W-BEAM GUARDRAIL, STRAIGHT W/HOLES (SEE SHEET 6) |
| 11 | W6 X 9 STEEL POST (SEE B-13 SHEET 2) |
| 12 | 6" x 12" x 14" OFFSET BLOCK (SEE B-13 SHEET 2) |
| 13 | 6" x 8" x 14" OFFSET BLOCK (SEE B-13 SHEET 2) |
| 14 | ⅝" GUARDRAIL BOLT (L=14") AND RECESSED NUT |
| 15 | ⅝" GUARDRAIL BOLT (L=10") AND RECESSED NUT |
| 16 | SPLICE - ⅝" GUARDRAIL BOLTS (L=1¼") WITH RECESSED NUTS (SEE NOTE 5) |
| 17 | ⅞" HIGH STRENGTH STRUCTURAL HEX BOLT (L=VARIES) AND HEX NUT |
| 18 | 10 GAUGE 8-SPACE W-BEAM (SEE SHEET 7) |
| 19 | 10 GUAGE 4-SPACE W-BEAM GUARDRAIL, STRAIGHT W/HOLES AND SLOT (SEE SHEET 7) |
| 20 | 12 GAUGE 4-SPACE W-BEAM ANCHOR GUARDRAIL, W/HOLES FOR END ANCHOR (SEE SHEET 8) |
| 21 | 12 GAUGE 4-SPACE W-BEAM ANCHOR GUARDRAIL, W/HOLES TO GUARDRAIL (SEE SHEET 8) |
| 22 | 10 GAUGE 8-SPACE THRIE BEAM (SEE SHEET 9) |
| 23 | 12 GAUGE W-BEAM END SECTION (SEE SHEET 9) |
| 24 | ⅝" GUARDRAIL BOLTS (L=1¼") WITH RECESSED NUT |
| 25 | MODIFIED BEARING PLATE (SEE SHEET 10) |




**SECTION A-A**

**NOTES:**

1). THE APPLICATION IS CONSIDERED A MASH TL-3 SYSTEM WHEN GRADING BELOW THE HINGE IS 6:1 OR FLATTER. WHEN GRADING BELOW THE HINGE IS STEEPER THAN 6:1 BUT 2:1 OR LESS, THE APPLICATION IS CONSIDERED A MASH TL-2 SYSTEM. SLOPES STEEPER THAN 2:1 SHOULD NOT BE USED.
2). THE LIMIT OF PAYMENT SHOWN ON THIS SHEET IS FOR THE CURVED SECTION. SEE SHEETS 2, 3, AND 4 FOR CURVED SECTION ATTACHMENT ALTERNATIVES.
3). SEE SHEETS 5 THROUGH 11 FOR ADDITIONAL DETAILS ON SYSTEM COMPONENTS.
4). THE CURVED SECTION W-BEAM SHALL BE SHOP BENT.
5). THE AMOUNT OF BOLTS AND NUTS FOR SPLICES VARIES. SEE B-1 SHEET 2 FOR DETAILS ON W-BEAM GUARDRAIL SPLICE.
6). ALL HOLES ARE TO BE PREFABRICATED UNLESS OTHERWISE NOTED. GALVANIZE ALL FIELD DRILLED HOLES.
7). TENSION THE FINISHED CABLE ASSEMBLIES UNTIL SLACK IS REMOVED.
8). INSTALLATION OF CURB IS NOT PERMITTED WITHIN THE CURVED SECTION OF THE APPLICATION.
9). SEE PLAN VIEW FOR W-BEAM DESCRIPTION.
10). 5" SPACING IS A NOMINAL DIMENSION AND IS PROVIDED FOR LAYOUT AND INFORMATIONAL PURPOSES ONLY.
11). THIS DETAIL IS BASED ON TESTING PERFORMED UNDER NCHRP REPORT 1013.

DelDOT

ENGINEERING SUPPORT — DATE
RECOMMENDED

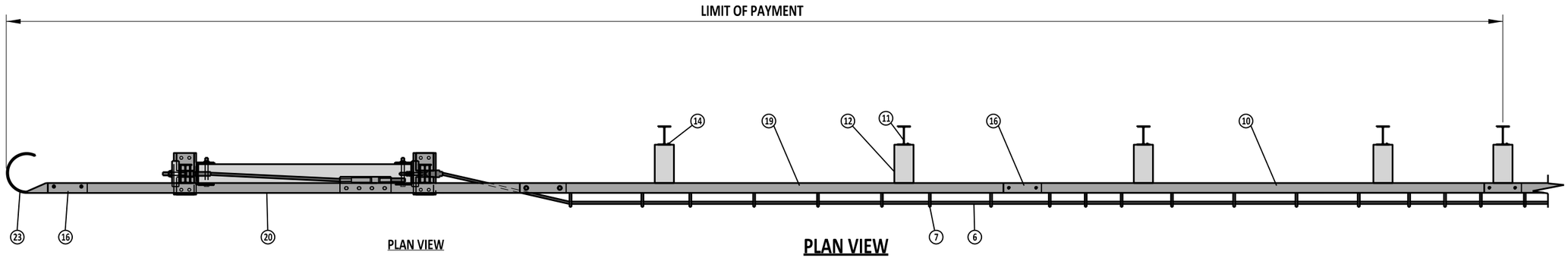
31" CURVED GUARDRAIL

DGM 1-31 | SHT. 1 OF 11

REVIEWED
DEPUTY DIRECTOR - DESIGN — DATE

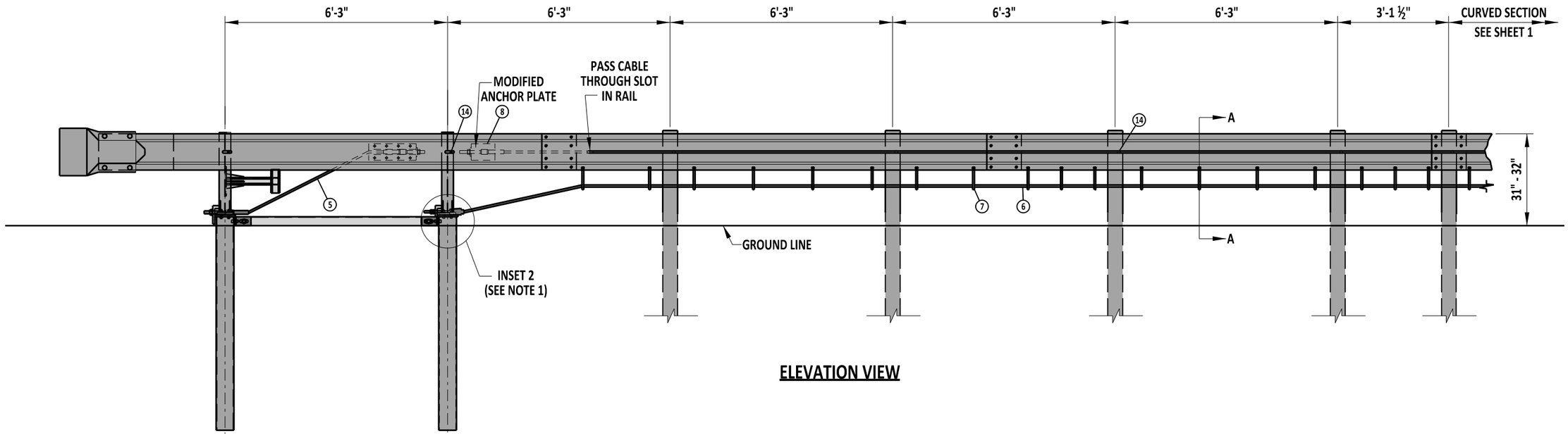
APPROVED
CHIEF ENGINEER — DATE

SCALE : NTS




PLAN VIEW

**PLAN VIEW**




**ELEVATION VIEW**

**NOTES:**

1). CONSTRUCT THE NON-CRASHWORTHY END ANCHOR IN ACCORDANCE WITH B-5 WITH MODIFIED ANCHOR BEARING PLATE. SEE INSET 2 ON SHEET 11 FOR MORE INFORMATION.
2). THE LIMIT OF PAYMENT SHOWN ON THIS SHEET IS FOR A NON-CRASHWORTHY ANCHORAGE. SEE SHEET 1 FOR CURVED SECTION ATTACHMENT.
3). SEE SHEET 1 FOR SECTION A-A.
4). CURB IS PERMITTED WITHIN THIS TANGENT PORTION OF THE APPLICATION. THE CURB USED MUST BE LIMITED TO A LAYDOWN CURB IN ACCORDANCE WITH C-1 SHEET 4.
5). THIS DETAIL IS BASED ON TESTING PERFORMED UNDER NCHRP REPORT 1013.

DelDOT

ENGINEERING SUPPORT — DATE
RECOMMENDED

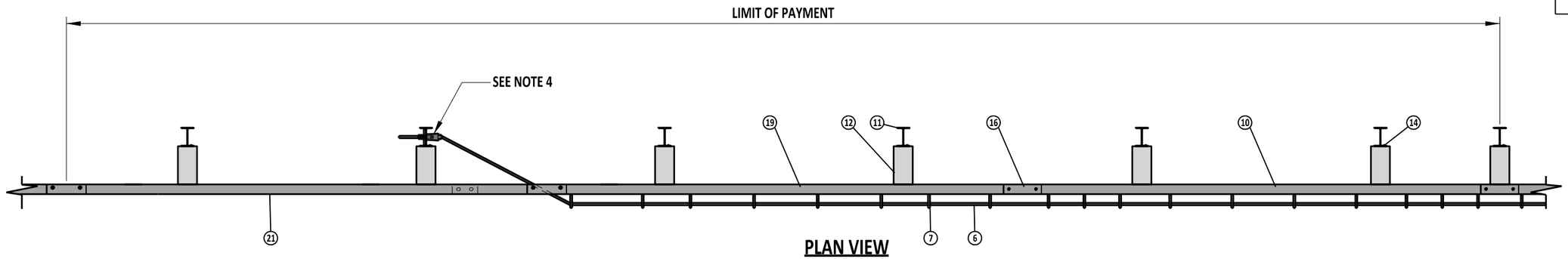
31" CURVED GUARDRAIL, NON-CRASHWORTHY ANCHOR

DGM 1-31 | SHT. 2 OF 11

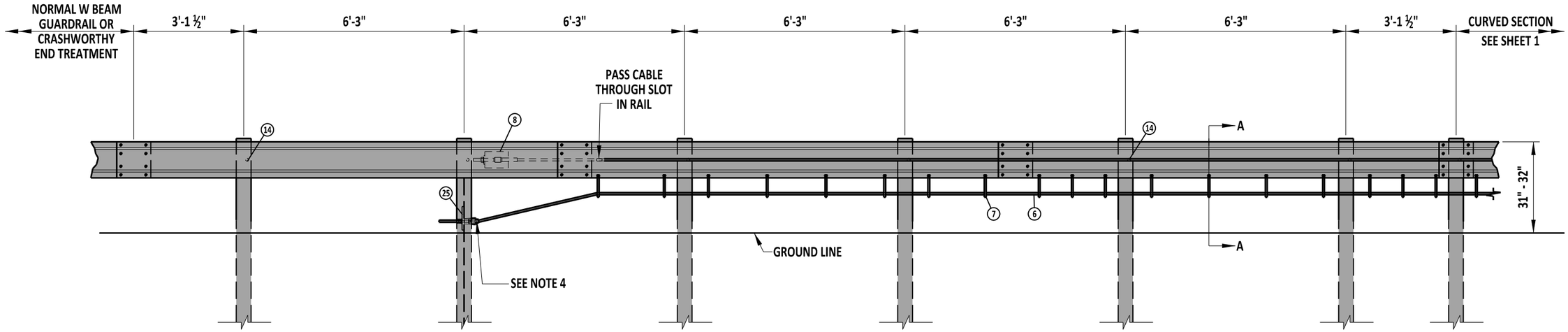
REVIEWED
DEPUTY DIRECTOR - DESIGN — DATE

APPROVED
CHIEF ENGINEER — DATE

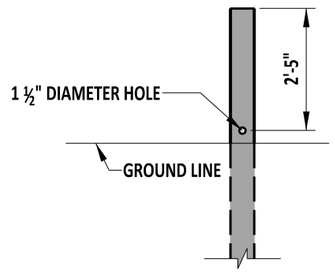
SCALE : NTS




**PLAN VIEW**




**ELEVATION VIEW**




**SIDE VIEW**
POST WITH HOLE

**NOTES:**

1). THE LIMIT OF PAYMENT SHOWN ON THIS SHEET IS FOR A TRANSITION TO A NORMAL W-BEAM GUARDRAIL. SEE SHEET 1 FOR CURVED SECTION ATTACHMENT.
2). SEE SHEET 1 FOR SECTION A-A.
3). CURB IS PERMITTED WITHIN THIS TANGENT PORTION OF THE APPLICATION. THE CURB USED MUST BE LIMITED TO A LAYDOWN CURB IN ACCORDANCE WITH C-1 SHEET 4.
4). INSERT CABLE END FITTING THROUGH FIELD DRILLED HOLE. SEE CONNECTION DETAIL ON SHEET 10.
5). THIS DETAIL IS BASED ON TESTING PERFORMED UNDER NCHRP REPORT 1013.

DelDOT

ENGINEERING SUPPORT — DATE
RECOMMENDED

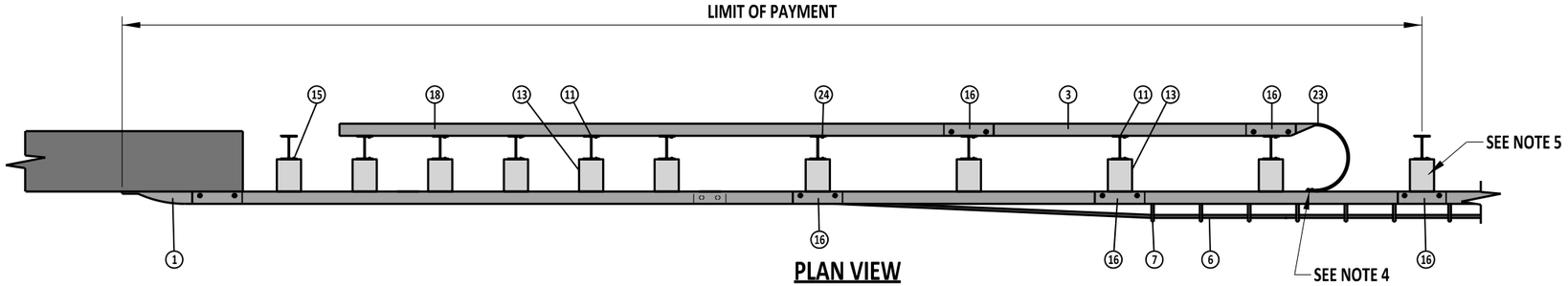
31" CURVED GUARDRAIL, ATTACHMENT TO NORMAL W-BEAM GUARDRAIL

DGM 1-31 | SHT. 3 OF 11

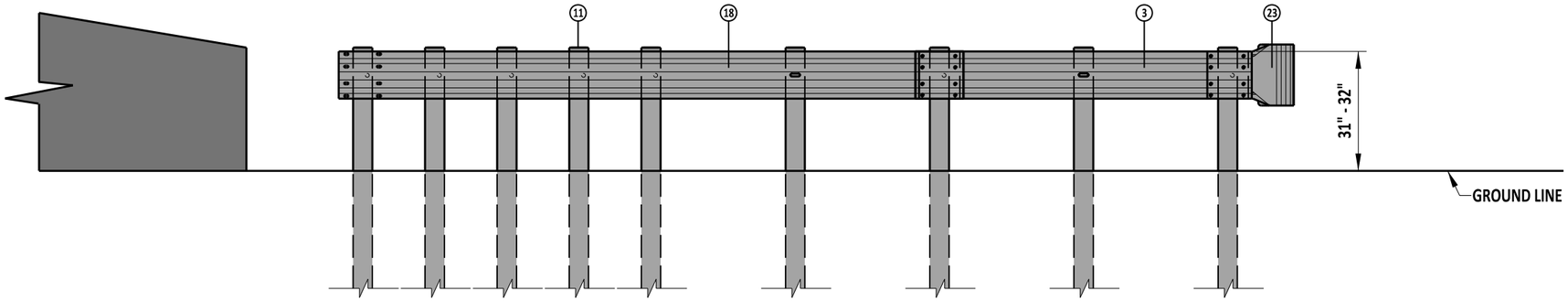
REVIEWED
DEPUTY DIRECTOR - DESIGN — DATE

APPROVED
CHIEF ENGINEER — DATE

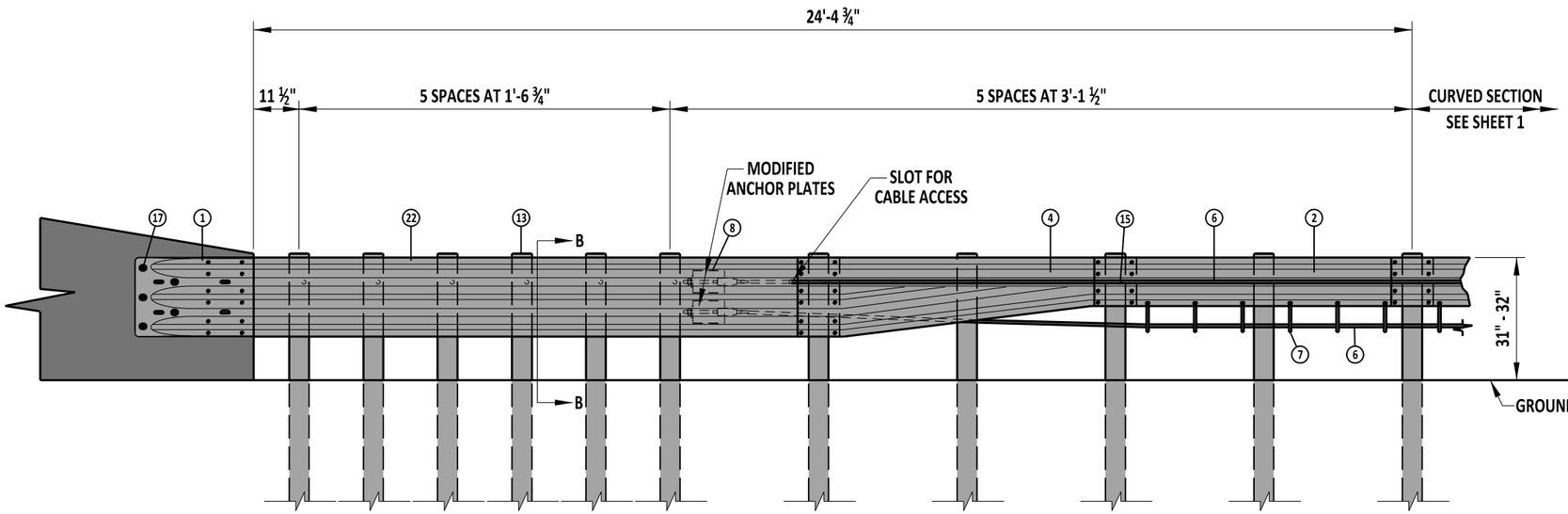
SCALE : NTS



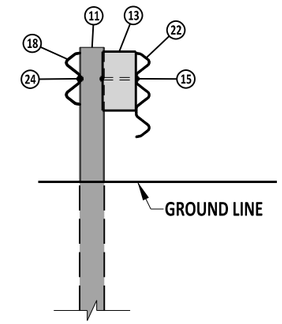

PLAN VIEW




ELEVATION VIEW
NON-TRAFFIC SIDE




ELEVATION VIEW
TRAFFIC SIDE




SECTION B-B

**NOTES:**

1). THE LIMIT OF PAYMENT SHOWN ON THIS SHEET IS FOR A TRANSITION TO A RIGID BARRIER. SEE SHEET 1 FOR CURVED SECTION ATTACHMENT.

2). INSTALLATION OF CURB IS NOT PERMITTED WITHIN THE TANGENT STIFFNESS TRANSITION TO A RIGID BARRIER.

3). THIS DETAIL IS BASED ON TESTING PERFORMED UNDER NCHRP REPORT 1013.

4). FIELD DRILL HOLES AND CONNECT W-BEAM END SECTION TO TRAFFIC SIDE W-BEAM WITH TWO (2) ⅝" DIAMETER GUARDRAIL BOLTS AND RECESSED NUTS. BOLTS ARE TO BE 2" IN LENGTH. PLACE PLAIN ⅝" DIAMETER GUARDRAIL WASHERS ON EITHER SIDE OF THE W-BEAM, UNDER THE BOLT HEAD AND NUT. ORIENT SO THE NUT IS ON THE NON-TRAFFIC SIDE AND THE BOLT HEAD IS ON THE TRAFFIC SIDE.

5). OFFSET BLOCK MAY BE either 12" OR 8" IN DEPTH OUTSIDE OF THE NON-TRAFFIC SIDE RAIL.

DelDOT

ENGINEERING SUPPORT — DATE
RECOMMENDED

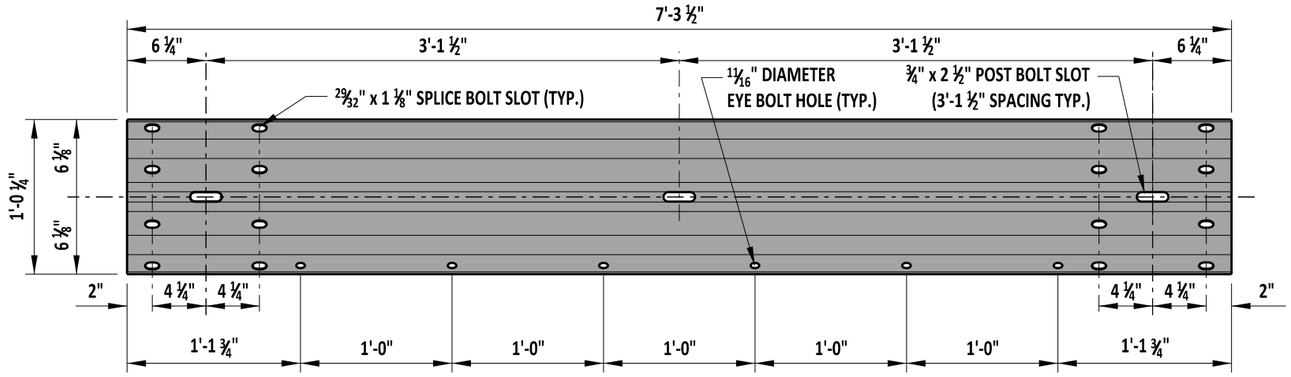
31" CURVED GUARDRAIL, TRANSITION TO RIGID BARRIER

DGM 1-31 | SHT. 4 OF 11

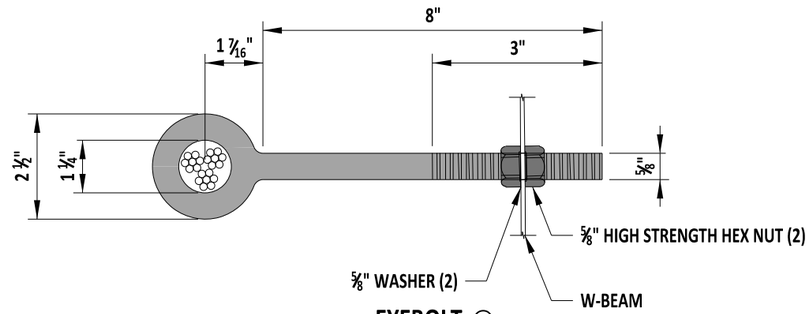
REVIEWED
DEPUTY DIRECTOR - DESIGN — DATE

APPROVED
CHIEF ENGINEER — DATE

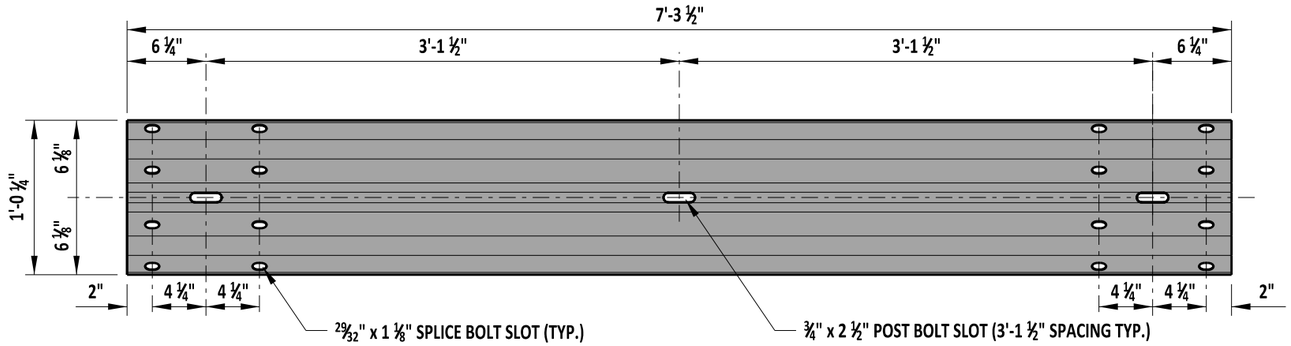
SCALE : NTS



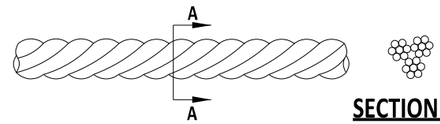

## 10 GAUGE W-BEAM SPACER GUARDRAIL W/HOLES, 6'-3" LONG ②




## EYEBOLT ⑦



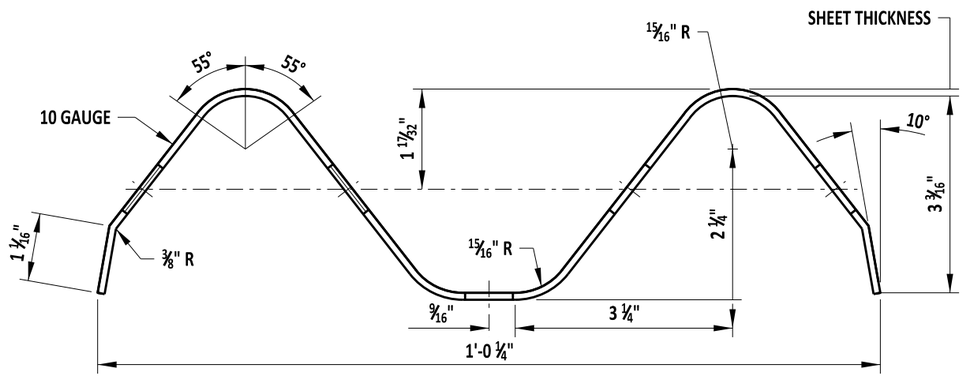

## 10 GAUGE SPACER W-BEAM ③




## SECTION A-A

## GUARDRAIL CABLE ⑥

¾" DIAMETER, 3X7 WIRE ROPE




## 10 GAUGE W-BEAM SECTION

**NOTES:**

1). GUARDRAIL CABLE AND CONNECTING HARDWARE SHALL CONFORM TO THE REQUIREMENTS OF AASHTO M30 TYPE I CLASS A COATING ¾" WIRE ROPE.
THE ROPE, WITH CONNECTING HARDWARE ATTACHED, SHALL BE CAPABLE OF DEVELOPING 24.7 KIPS STRENGTH OF A SINGLE CABLE.

2). THE EYEBOLT SHALL BE MANUFACTURED FROM FORGED STEEL, QUENCHED AND TEMPERED, GALVANIZED, AND ABLE TO WITHSTAND A WORKING LOAD OF 5,200 LBS.

DelDOT

ENGINEERING SUPPORT — DATE
RECOMMENDED

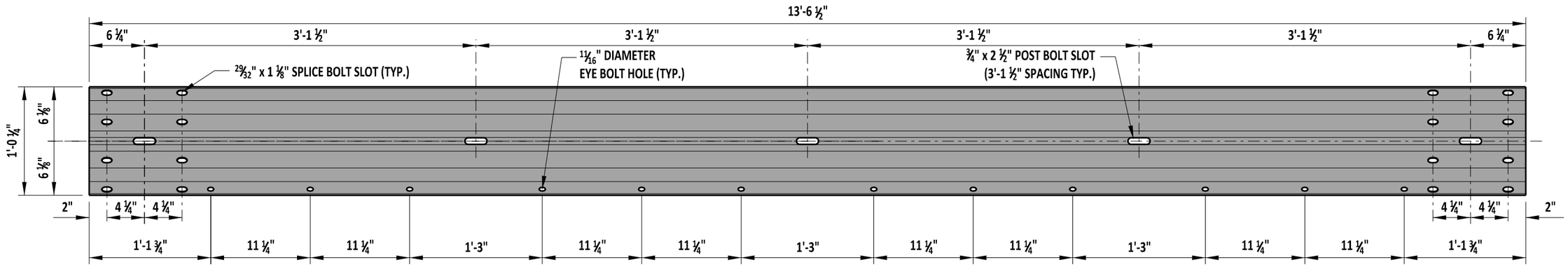
31" CURVED GUARDRAIL, COMPONENTS

DGM 1-31 | SHT. 5 OF 11

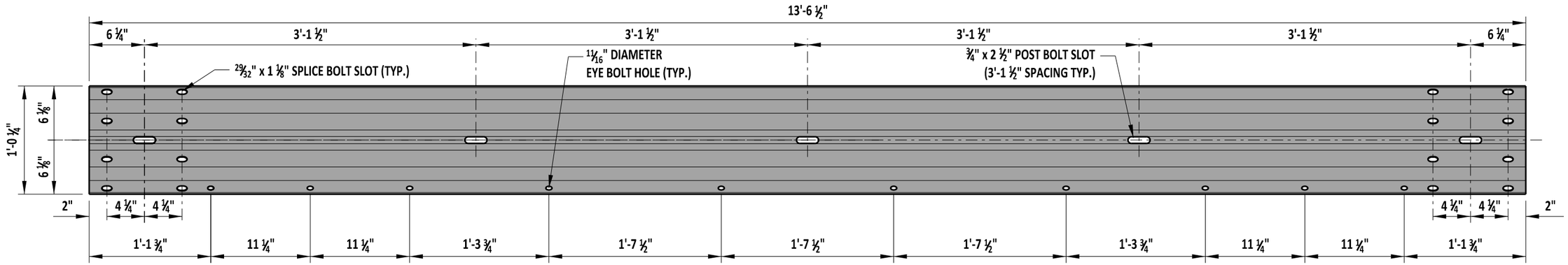
REVIEWED
DEPUTY DIRECTOR - DESIGN — DATE

APPROVED
CHIEF ENGINEER — DATE

SCALE : NTS




## 10 GUAGE 4-SPACE W-BEAM GUARDRAIL W/HOLES ⑨




## 10 GAUGE 4-SPACE W-BEAM GUARDRAIL, STRAIGHT W/HOLES ⑩

DelDOT

ENGINEERING SUPPORT — DATE
RECOMMENDED

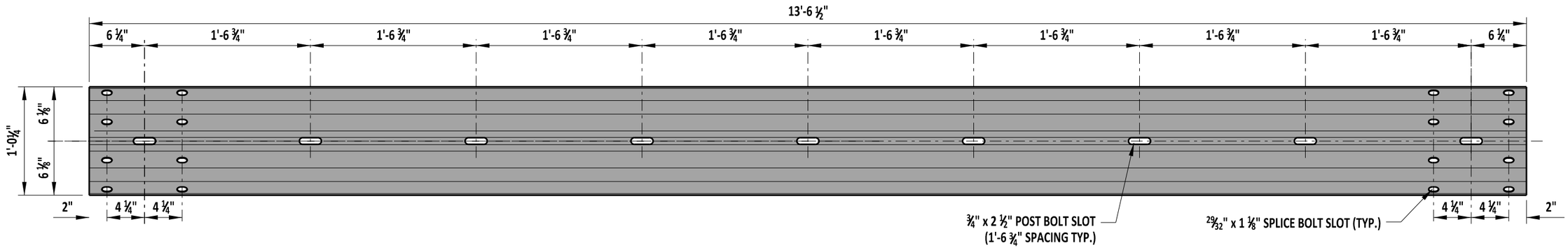
31" CURVED GUARDRAIL, COMPONENTS

DGM 1-31 | SHT. 6 OF 11

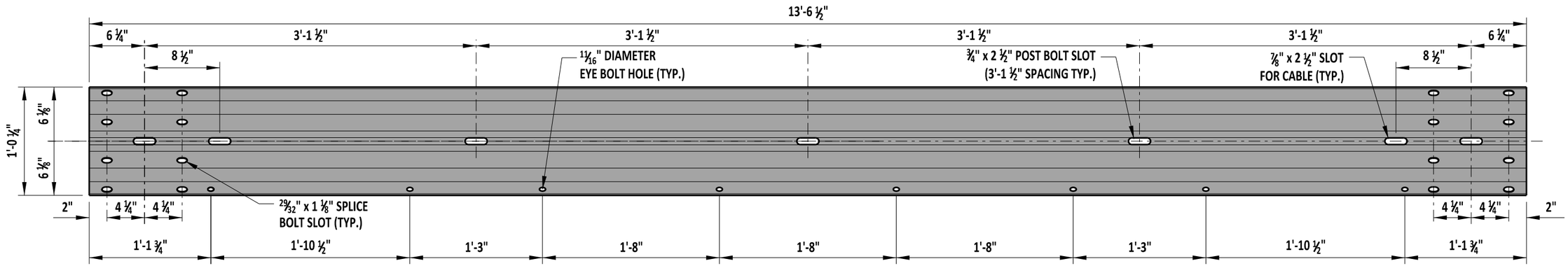
REVIEWED
DEPUTY DIRECTOR - DESIGN — DATE

APPROVED
CHIEF ENGINEER — DATE

SCALE : NTS




## 10 GAUGE 8-SPACE W-BEAM ⑱




## 10 GUAGE 4-SPACE W-BEAM GUARDRAIL, STRAIGHT W/HOLES AND SLOT ⑲

DelDOT

ENGINEERING SUPPORT _____ DATE _____
RECOMMENDED

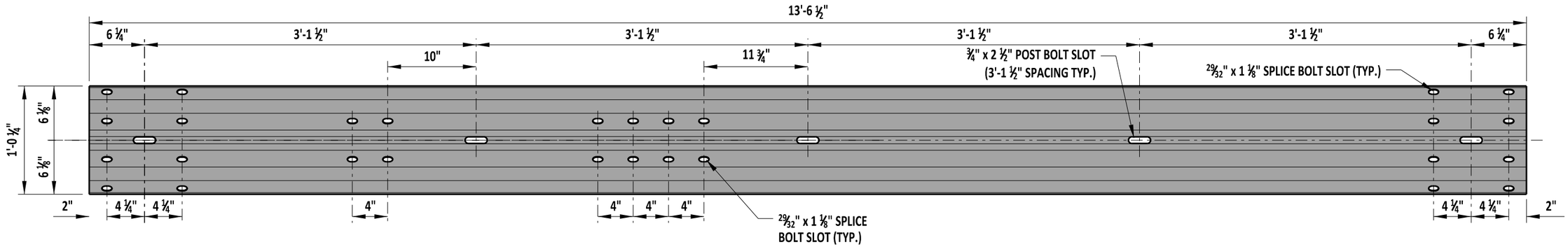
31" CURVED GUARDRAIL, COMPONENTS

DGM 1-31 | SHT. 7 OF 11

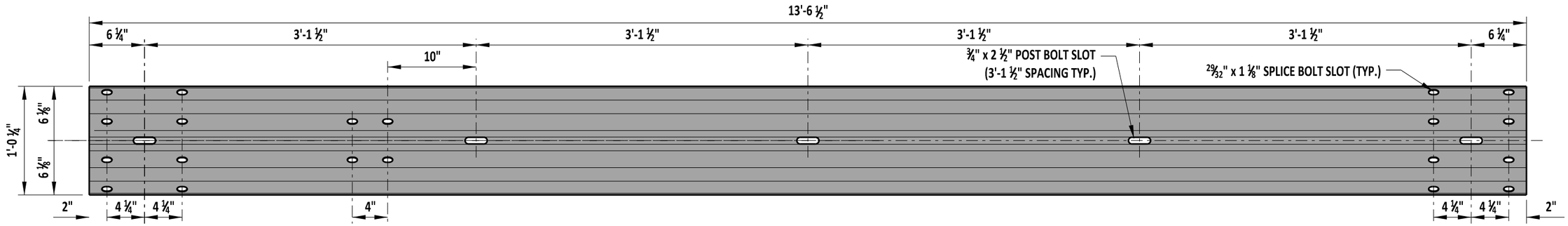
REVIEWED
DEPUTY DIRECTOR - DESIGN _____ DATE _____

APPROVED
CHIEF ENGINEER _____ DATE _____

SCALE : NTS




## 12 GAUGE 4-SPACE W-BEAM ANCHOR GUARDRAIL, W/HOLES FOR END ANCHOR ⑳

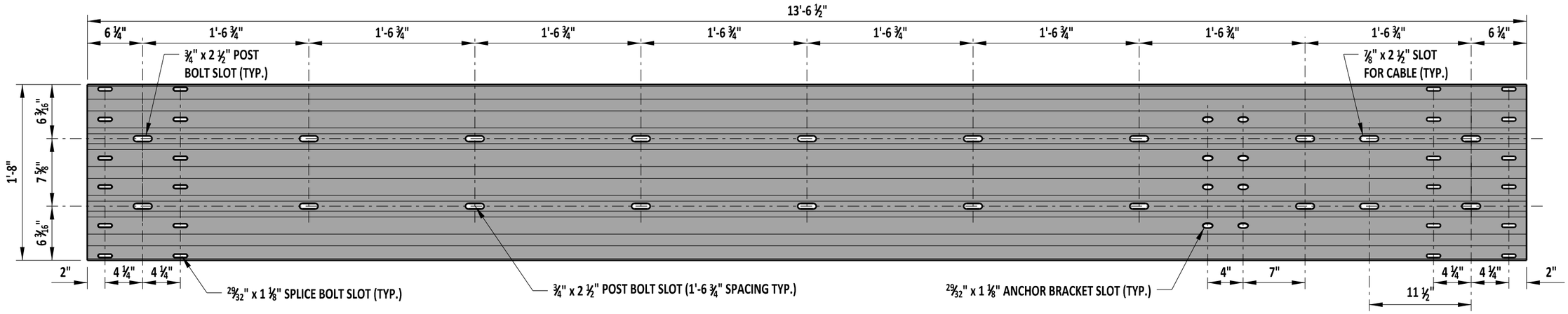



## 12 GAUGE 4-SPACE W-BEAM ANCHOR GUARDRAIL, W/HOLES TO GUARDRAIL ㉑

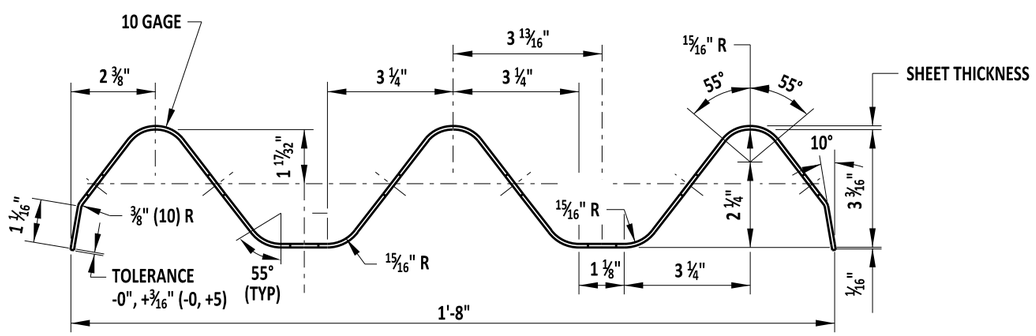
SEE B-13 SHEET 1 FOR 12 GUAGE W-BEAM SECTION VIEW.

| | | | |
|---|---|---|---|
| DelDOT | ENGINEERING SUPPORT — DATE<br>RECOMMENDED | 31" CURVED GUARDRAIL, COMPONENTS | REVIEWED — DEPUTY DIRECTOR - DESIGN — DATE |
| | | DGM 1-31 — SHT. 8 OF 11 | APPROVED — CHIEF ENGINEER — DATE |

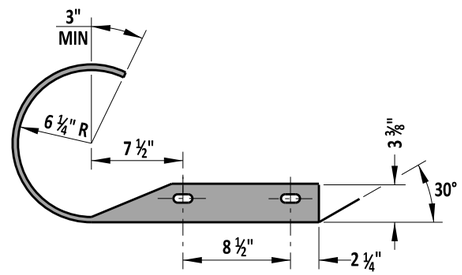
SCALE : NTS



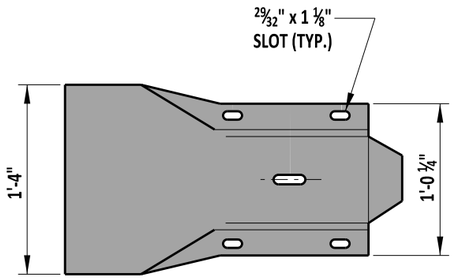

## 10 GAUGE 8-SPACE THRIE BEAM (22)




## 10 GAUGE THRIE BEAM SECTION




## END SECTION PLAN

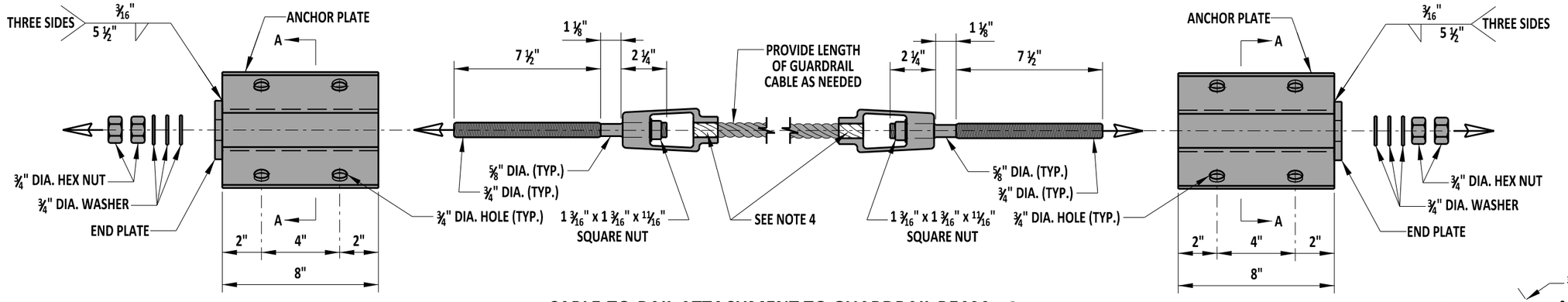



## END SECTION ELEVATION

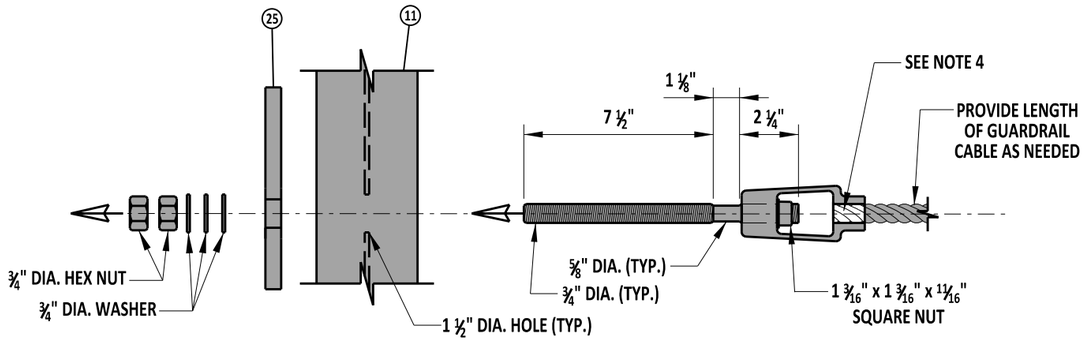
## 12 GAUGE W-BEAM END SECTION (23)

| | | | |
|---|---|---|---|
| DelDOT | ENGINEERING SUPPORT RECOMMENDED DATE | 31" CURVED GUARDRAIL, COMPONENTS | REVIEWED DEPUTY DIRECTOR - DESIGN DATE |
| | | DGM 1-31 SHT. 9 OF 11 | APPROVED CHIEF ENGINEER DATE |

SCALE : NTS

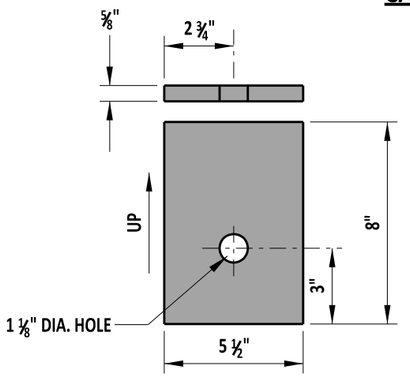



## CABLE-TO-RAIL ATTACHMENT TO GUARDRAIL BEAM ⑧

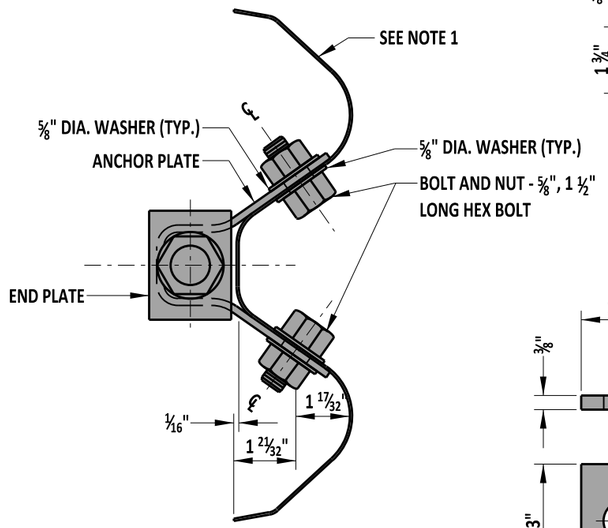



## CABLE-TO-RAIL ATTACHMENT TO NORMAL W-BEAM

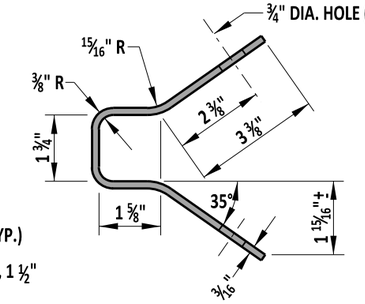
ATTACHMENT TO NORMAL W-BEAM




## MODIFIED BEARING PLATE ㉕

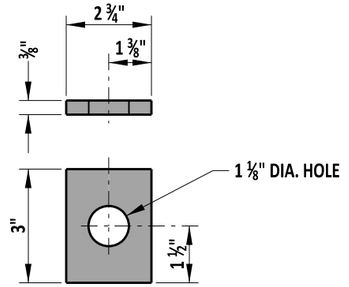



## SECTION A-A




## ANCHOR PLATE

8" x 13" x 3/16"




## END PLATE

**NOTES:**

1). W-BEAM SHOWN IN SECTION A-A. PROVIDE SAME CONNECTION WHEN CONNECTED TO THRIE BEAM.
2). MODIFIED BEARING PLATE SHALL BE AASHTO M270M GRADE 250 STEEL AND ZINC-COATED ACCORDING TO AASHTO M111.
3). ANCHOR PLATES AND END PLATES SHALL BE ASTM A36 STEEL.
4). FASTEN WITH CABLE WEDGE. CRIMP ONE WIRE OF THE GUARDRAIL CABLE OVER THE BASE OF THE WEDGE TO HOLD IT FIRMLY IN PLACE.
5). WIRE ROPE CONNECTING HARDWARE SHALL CONFORM TO AASHTO M269. STEEL COMPONENTS OF THE CONNECTION SHALL CONFORM TO AASHTO M103 GRADE 70-40 CLASS I.

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ENGINEERING SUPPORT — DATE
RECOMMENDED

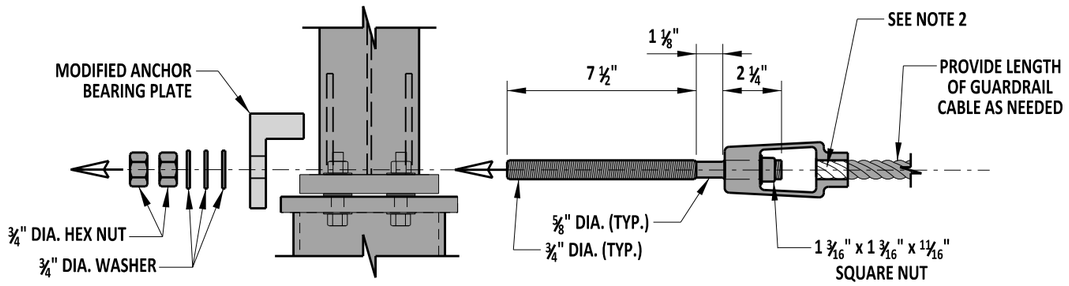
31" CURVED GUARDRAIL, COMPONENTS

DGM 1-31 | SHT. 10 OF 11

REVIEWED
DEPUTY DIRECTOR - DESIGN — DATE

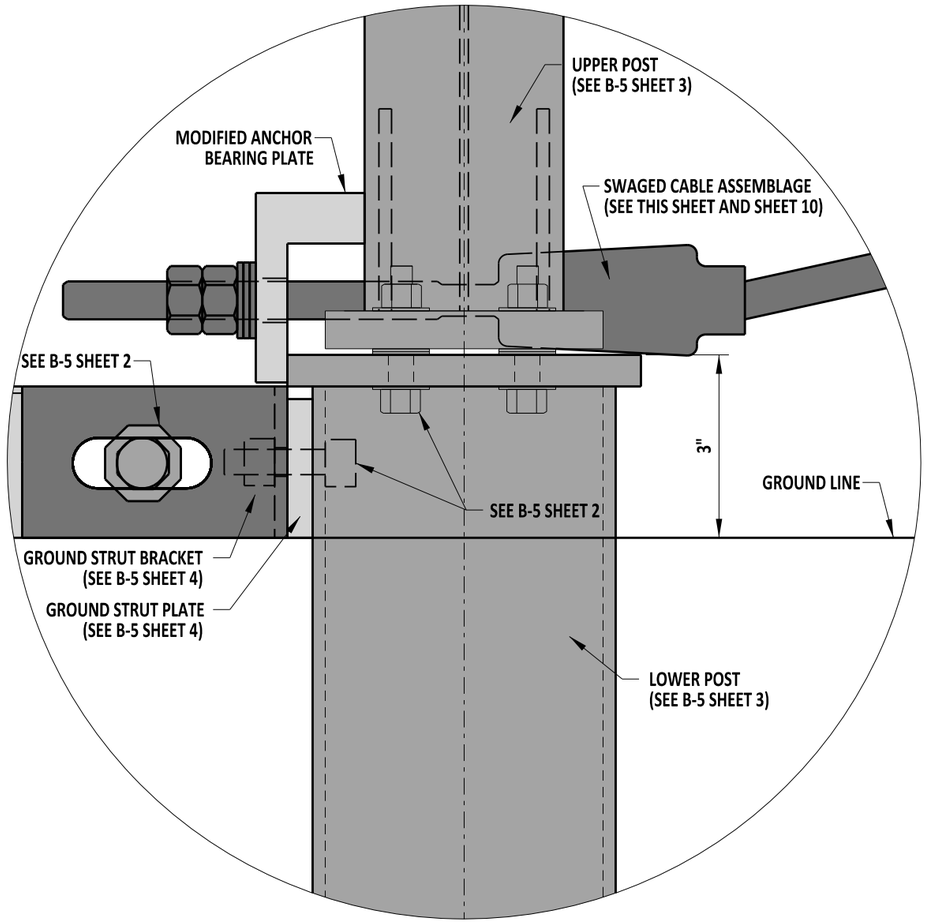
APPROVED
CHIEF ENGINEER — DATE

SCALE : NTS

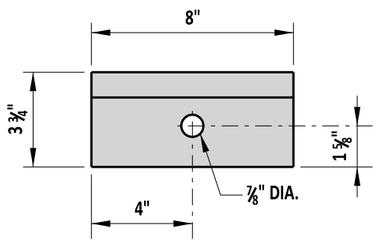



## MODIFIED CABLE-TO-RAIL ANCHOR WITH CABLE END FITTING

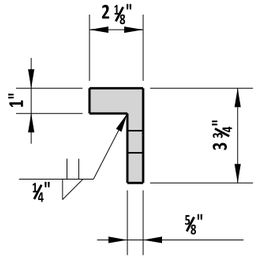
ATTACHMENT TO NON-CRASHWORTHY STEEL END ANCHOR




INSET 2




ELEVATION VIEW




SECTION VIEW

## MODIFIED ANCHOR BEARING PLATE

**NOTES:**

1). MODIFIED ANCHOR BEARING PLATE SHALL BE ASTM A36 STEEL.
2). FASTEN WITH CABLE WEDGE. CRIMP ONE WIRE OF THE GUARDRAIL CABLE OVER THE BASE OF THE WEDGE TO HOLD IT FIRMLY IN PLACE.

DelDOT

ENGINEERING SUPPORT ~~RECOMMENDED~~ DATE

31" CURVED GUARDRAIL, COMPONENTS

DGM 1-31 | SHT. 11 OF 11

~~REVIEWED~~ DEPUTY DIRECTOR - DESIGN DATE

~~APPROVED~~ CHIEF ENGINEER DATE