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1 Introduction

The NCDOT Ramp Metering System Design Guidelines is focused on consistency in NC's approach to the design phase of implementation. These guidelines assume that the Department is following the Systems Engineering process and sites moving into the design phase have:

- Been evaluated by the Department using current policies and guidelines.
- Found to be beneficial to freeway operations.
- Have adequate roadway and geometric conditions for ramp metering.

Additional information and supporting guidance can be found in the following references.

FHWA Ramp Management and Control Handbook
https://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/index.htm

FHWA Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways
https://mutcd.fhwa.dot.gov/index.htm

NCDOT Standard Specifications for Roads and Structures

https://connect.ncdot.gov/resources/Specifications/Pages/default.aspx

NCDOT Roadway Standard Drawings

https://connect.ncdot.gov/resources/Specifications/Pages/default.aspx

TSMO Unit Design Manual

https://connect.ncdot.gov/resources/safety/Pages/TSMO.aspx

System Engineering Check List
https://connect.ncdot.gov/resources/safety/ITS%20and%20Signals%20Resources/System%20Engineering%20Checklist.pdf

ITS and Signals Project Special Provisions

https://connect.ncdot.gov/resources/safety/Pages/TSMO.aspx

Ramp Metering Feasibility Studies (for Triangle and Metrolina Regions)

https://connect.ncdot.gov/resources/safety/Pages/TSMO.aspx

2 Ramp Meter Location

The ramp metering system is centered around traffic management at the ramp meter signal, but the system effectiveness is supported by multiple individual components working together. **Figure 1** provides a summary of the typical elements of a ramp metering system as the user drives along the entrance ramp. **Figure 2** provides a schematic overview of a typical ramp metering system layout.

The first step in the design process requires that the designer locate the ramp meter signal and stop line. All other design elements are then designed around this location.

The AAHSTO Green Book Table 10-4, which is included on **Figure 3**, provides guidance on locating the ramp meter signal and stop line based on recommended acceleration lane lengths per freeway free flow speeds.

The defined location of the ramp meter signal and stop line then serve as the central point for locating all other components of the ramp metering system.

Figure 1: Typical Ramp Metering Layout Summary

Ramp Entrance	
Advance Warning Beacon	Assembly consisting of signal heads and signage in advance of ramp meter signal
80% Queue Detection	At 80% queue storage capacity, measured from ramp meter signal
Advance Warning Signage	As needed between advance warning signage and ramp meter signal
40% Queue Detection	At 40% queue storage capacity, measured from ramp meter signal
Demand Vehicle Detection	At ramp meter signal stop line
Ramp Meter Signal, Stop Line, Signal Controller Cabinet, Electrical Service	Core of the system
Passage Vehicle Detection	Microwave detection to ensure the vehicle's exit of the system
End of Ramp Merge Area	

Figure 2: Typical Ramp Metering System Layout

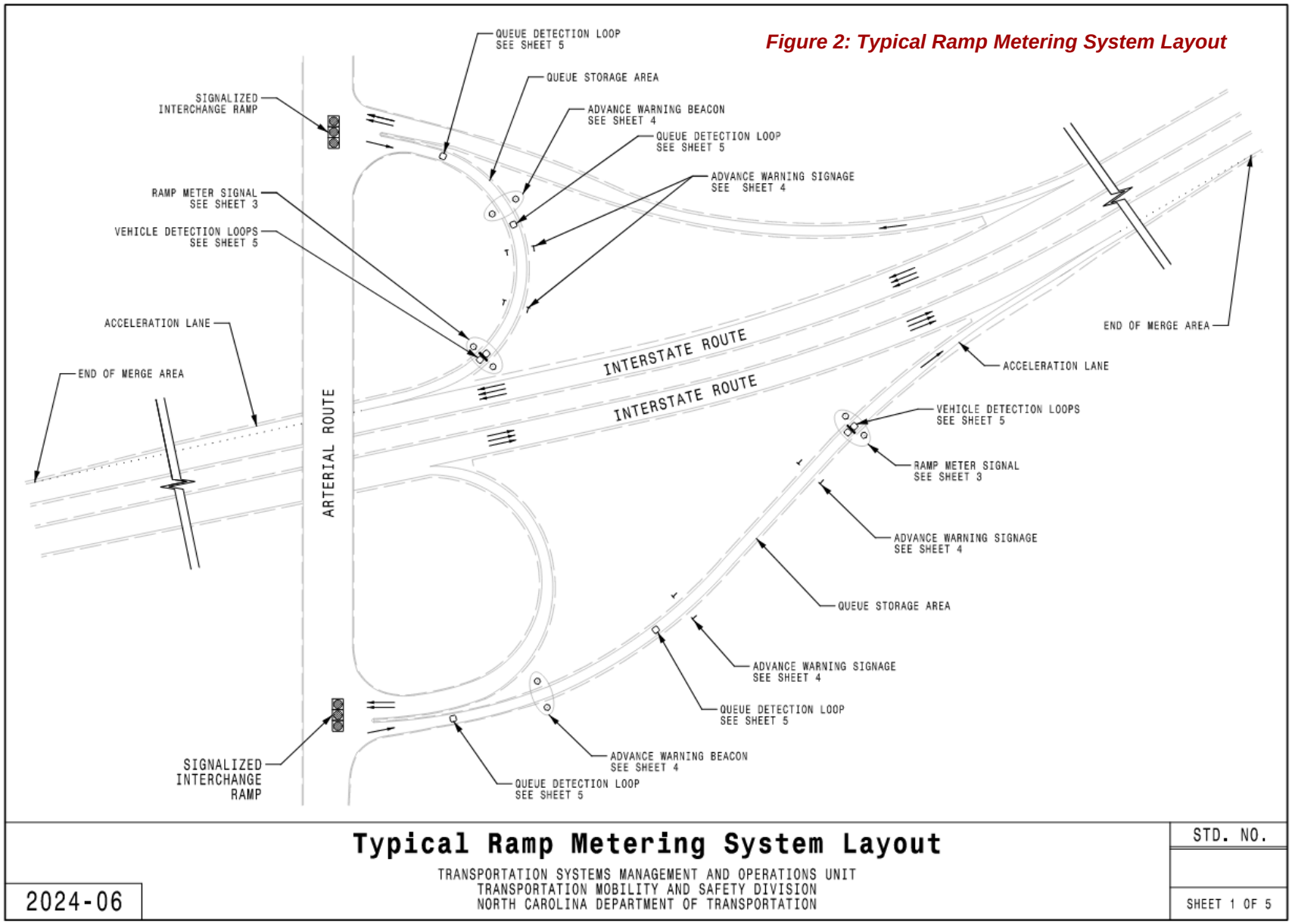
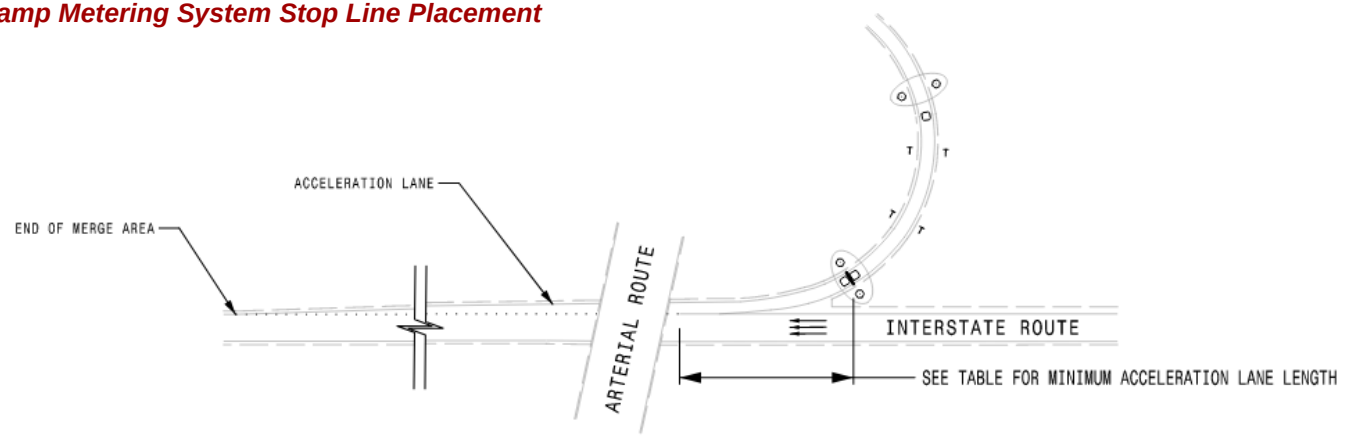
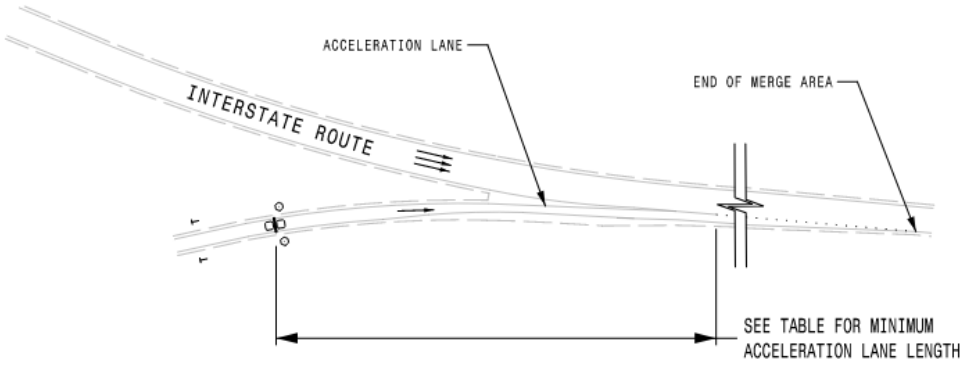


Figure 3: Ramp Metering System Stop Line Placement





Minimum Acceleration Lane Lengths for Entrance Terminals with Flat Grades of Less Than 3 Percent

Design Speed (mph)	Merge Speed (mph)	Acceleration Lane Length (ft)
30	23	180
35	27	280
40	31	360
45	35	560
50	39	720
55	43	960
60	47	1200
65	50	1410
70	53	1620
75	55	1790
80	57	2000

Source: A Policy on Geometric design of Highways and Streets (Table 10-4) (7th Edition)

Ramp Metering System Stop Line Placement

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3 Signal Heads and Support Structures

This section provides guidance on the design of signal heads and signal head support structures.

3.1 Advance Warning Beacon Assembly

An advance warning beacon assembly should be installed for ramp metering systems that operate for only a portion of the day. The assembly includes the following components:

Advance Warning Beacon. The advance warning beacon should consist of two 2-section signal faces with a circular red in the top section and a circular green in the bottom section. The signal faces should flash yellow in an alternating, wig-wag pattern during ramp metering operation. The signal faces should remain dark when the ramp metering system is not in operation. In a typical design scenario, they are powered by the electrical service installed for the corresponding ramp meter signal, and their operation is dictated by the controller installed for the corresponding ramp meter signal. See **Section 6 Controller Cabinets** for more information on controller requirements:

Signage. Advance warning beacons shall be supplemented by “RAMP METERED WHEN FLASHING” signage (W3-8). See **Section 4 Signs** for more information on signage requirements.

Pedestal Mount. The advance warning beacon assembly should be installed on Type III signal pedestals. One assembly should be installed on each side of the ramp. **Figure 6** shows the typical assembly.

Distance. In typical design scenarios, the distance between the advance warning beacon assembly and the ramp meter signal will vary from 500’ to 1,000’. **Figure 4** shows an example installation of an advance warning beacon assembly.

Figure 4: Advance Warning Beacon Assembly Example

3.2 Ramp Meter Signal Assembly

A ramp meter signal assembly, as shown in **Figure 5**, should include the following components.

Ramp Meter Signal. The ramp meter signal consists of two pairs of 12-inch signal heads where each pair of signal heads has one red and one green indication. The red and green indications are active during ramp metering operation. In a typical design scenario, they are powered by the electrical service installed for the corresponding ramp meter signal, and their operation is dictated by the controller installed for the corresponding ramp meter signal. See **Section 6 Controller Cabinets** for more information on controller requirements.

Signage. Ramp meter signals should be supplemented by "STOP HERE ON RED" signage (R10-6) and "ONE VEHICLE PER GREEN" signage (R10-28). See **Section 4 Signs** for more guidance on signage at ramp meter signals.

Pedestal Mount. The ramp meter assembly should be installed on Type III signal pedestals. **Figure 6** shows the typical assembly. In single lane ramp scenarios, sight distance may permit the installation of only one ramp meter signal assembly on the right-hand side of the approach. In single lane ramp scenarios where sight distance is limited, and in all dual lane ramp scenarios, one assembly should be installed on each side of the ramp.

Distance. See **Section 2 Ramp Meter Location** for guidance on the location of ramp meter signal assemblies.

Table 1 shows NCDOT standard drawings and project special provisions sections relevant to signal heads and support structures.

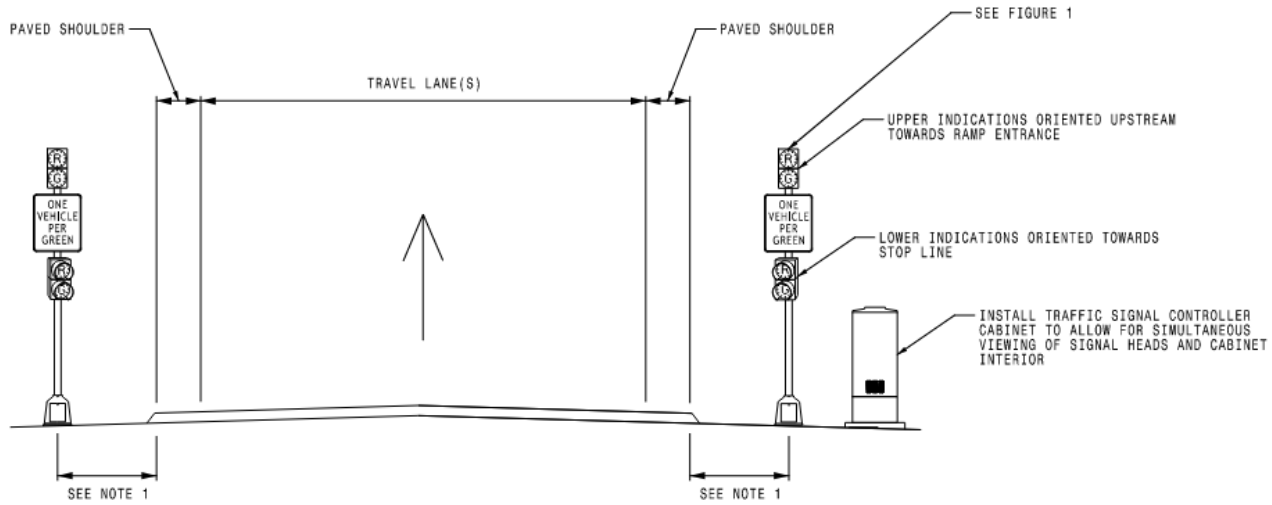
Figure 5: Ramp Meter Signal Assembly Example

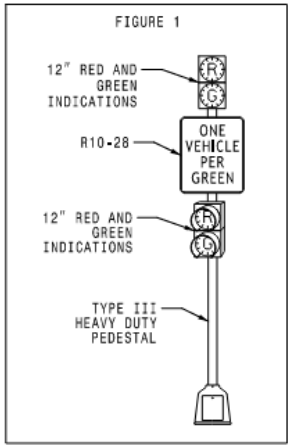
Table 1. Relevant Design Standards – Signal Heads and Support Structures

Standard Specifications (2024)	Standard Drawings (2024)	ITS & Signals Project Special Provisions (Version 24.X)

• Signal Heads (Section 1705)	• Signal Heads
	  ○ Vehicular Signal Heads (No. 1705.01)
	  ○ Mounting (No. 1705.02)
	  ○ Wire Color Conventions (No. 1705.03)
	• Pedestals
	  ○ Normal (Type II) (No. 1743.02)
	  ○ Normal (Type III) (No. 1743.03)
	  ○ Foundation (No. 1743.04)
		• Signal Heads
		• Metal Pole Supports

Figure 6: Ramp Meter Signal Heads and Support Structure Typical Drawing





NOTES:

1) PER NCDOT ROADWAY STANDARD DRAWING FOR PEDESTALS (STD. 1743), BREAKAWAY ANCHOR BOLTS SHOULD NOT BE USED WITH HEAVY DUTY (TYPE III) PEDESTALS. PER THE AASHTO ROADSIDE DESIGN GUIDE (4TH EDITION, 2011), TRAFFIC SIGNAL SUPPORTS AND CONTROLLER CABINETS "SHOULD BE PLACED AS FAR AWAY FROM THE ROADWAY AS PRACTICABLE. SHEILDING THESE SUPPORTS CAN BE CONSIDERED IF THEY ARE WITHIN THE CLEAR ZONE FOR THAT PARTICULAR ROADWAY."
2) AT SINGLE LANE RAMP METER SYSTEMS, A SINGLE SIGNAL PEDESTAL MAY BE USED IF SIGHT DISTANCE ALLOWS. AT TWO-LANE RAMP METER SYSTEMS, TWO SIGNAL PEDESTALS ON EITHER SIDE OF THE RAMP ARE RECOMMENDED.
3) AT TWO-LANE RAMP METER SYSTEMS, A "1 VEHICLE PER GREEN EACH LANE" (SIGN R10-29) MAY BE ADDED TO EACH SIGNAL PEDESTAL BELOW THE LOWEST RED/GREEN INDICATIONS.
4) THE CLEAR ZONE REQUIREMENTS SPECIFIED IN NOTE 1 FOR SIGNAL HEAD PEDESTALS ALSO APPLY TO ADVANCE WARNING BEACON PEDESTALS (SEE SHEET 4).

Ramp Meter Signal Heads and Signal Head Support Structures

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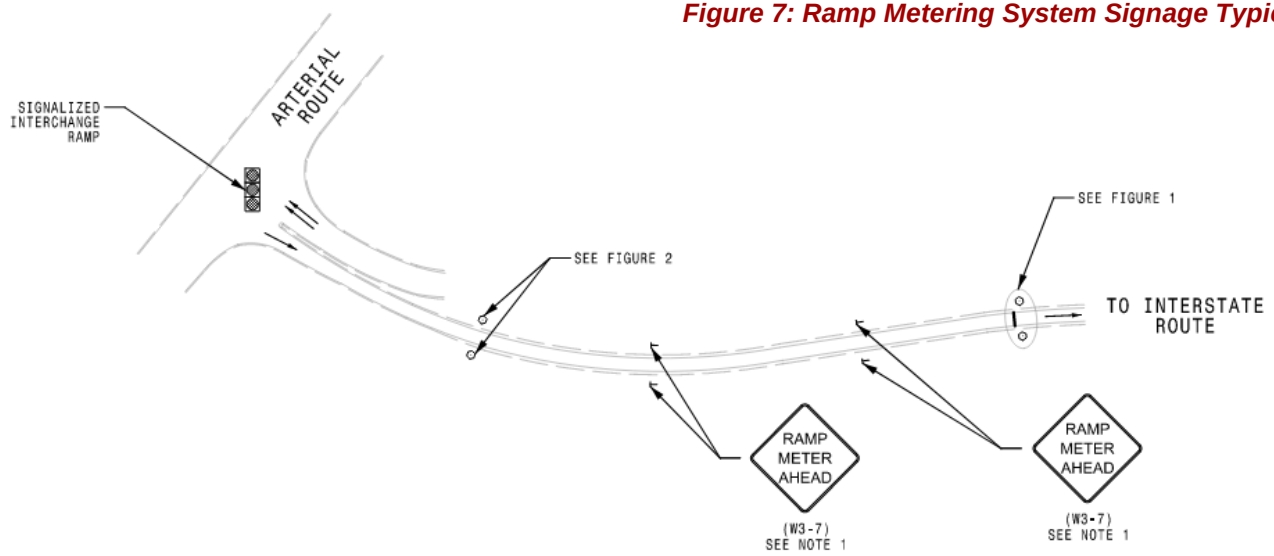
4 Signs

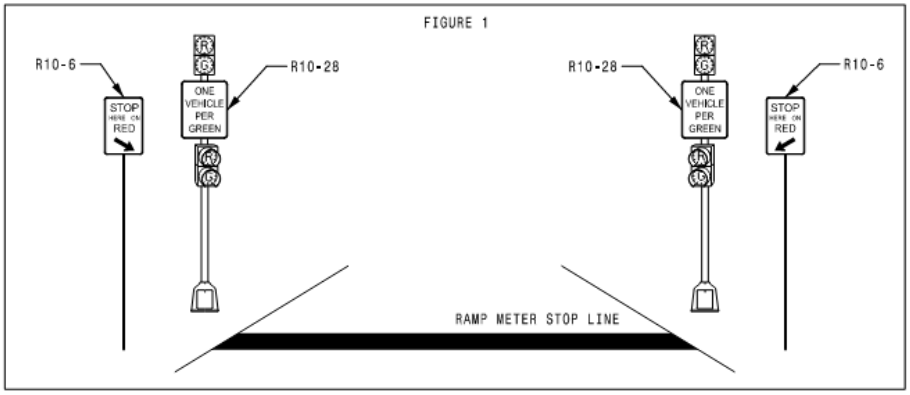
The type and placement of signage on metered ramps ensures that drivers understand the ramp metering system and how to navigate it. **Figure 7** shows the typical placement of signage in the ramp meter system. **Table 2** describes the signage, the purpose or application, and details regarding the installation location.

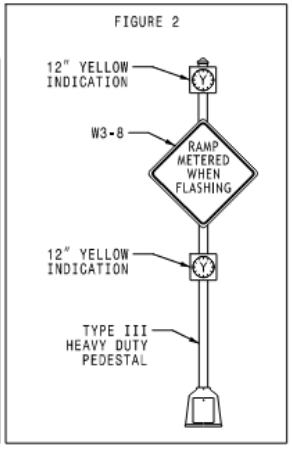
Table 2: Summary of Warning and Regulatory Signage

	Advance Warning Signage		***Ramp Meter Signal Signage***		***Dual Lane Ramp Signage***	
						
	W3-7	**W3-8**	**R10-6**	**R10-28**	**R10-29**	**Custom Sign**
Application	For all ramp meter installations	For ramp meters operating only during certain parts of the day	For all ramp meter installations	For all ramp meter installations	For ramp meter installations on dual lane ramps	For ramp meter installations on dual lane ramps
Installation Location and Details	Ground-mounted in advance of the ramp meter signal near the entrance to the ramp *(Note: if used in conjunction with W3-8 and a warning beacon, W3-7 should be installed beyond the warning beacon and before the ramp meter signal)*	Pedestal-mounted in advance of the ramp meter signal near the entrance to the ramp *(Note: to be supplemented with a warning beacon)*	Ground-mounted in line with the stop line at ramp meter signals *(Note: to be installed on either side of the ramp where the sign installed on the left-hand side includes an arrow pointing down and to the left)*	Pedestal-mounted with ramp meter signal heads *(Note: to be installed between each pair of signal heads on either side of the ramp)*	Pedestal-mounted with ramp meter signal heads	Pedestal-mounted in advance of the ramp meter signal near the entrance to the ramp *(Note: to be supplemented with a warning beacon and RAMP METERED WHEN FLASHING sign (W3-8))*

Figure 7: Ramp Metering System Signage Typical Drawing







NOTES:

1) THE QUANTITY OF W3-7 SIGNAGE AND DISTANCE BETWEEN EACH SIGN WILL VARY BASED ON ROADWAY GEOMETRY. W3-7 SIGNAGE SHOULD BE INSTALLED AS NEEDED TO ENSURE THAT DRIVERS ON THE RAMP HAVE A VIEW OF EITHER AN ADVANCE WARNING BEACON, W3-7 SIGNAGE, OR A RAMP METER SIGNAL HEAD AT ALL TIMES.
2) AT TWO-LANE RAMP METER SYSTEMS, "1 VEHICLE PER GREEN EACH LANE" SIGNAGE (R10-29) IS RECOMMENDED BELOW THE LOWEST RED/GREEN INDICATIONS TO ENSURE PROPER THROUGHPUT.

Ramp Metering System Signage

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5 Vehicle Detection

The efficient operations of ramp metering systems are dependent on accurate and reliable detection. **Figure 9** defines and shows the recommended placement for each of the four vehicle detection types: Passage, Demand, Queue, and Freeway.

Passage and Demand Detection. Passage detection should be located just after the ramp meter stop line. Demand detection should be located just prior to the ramp meter stop line. **Figure 8** shows the installation of passage and demand detection.

Queue Detection. Queue detection should be installed in two locations on the ramp. The first queue detection location should represent 40% of the available ramp storage length from the stop line. The second queue detection location should represent 80% of the available ramp storage length from the stop line.

Figure 8: Passage and Demand Detection with Induction Loops

Freeway Detection. Freeway detection should be located on the mainline upstream of the ramp merge area. The freeway detection should be located where traffic is as free flow as possible and not impacted by weaving sections, merge areas, or lane drop areas.

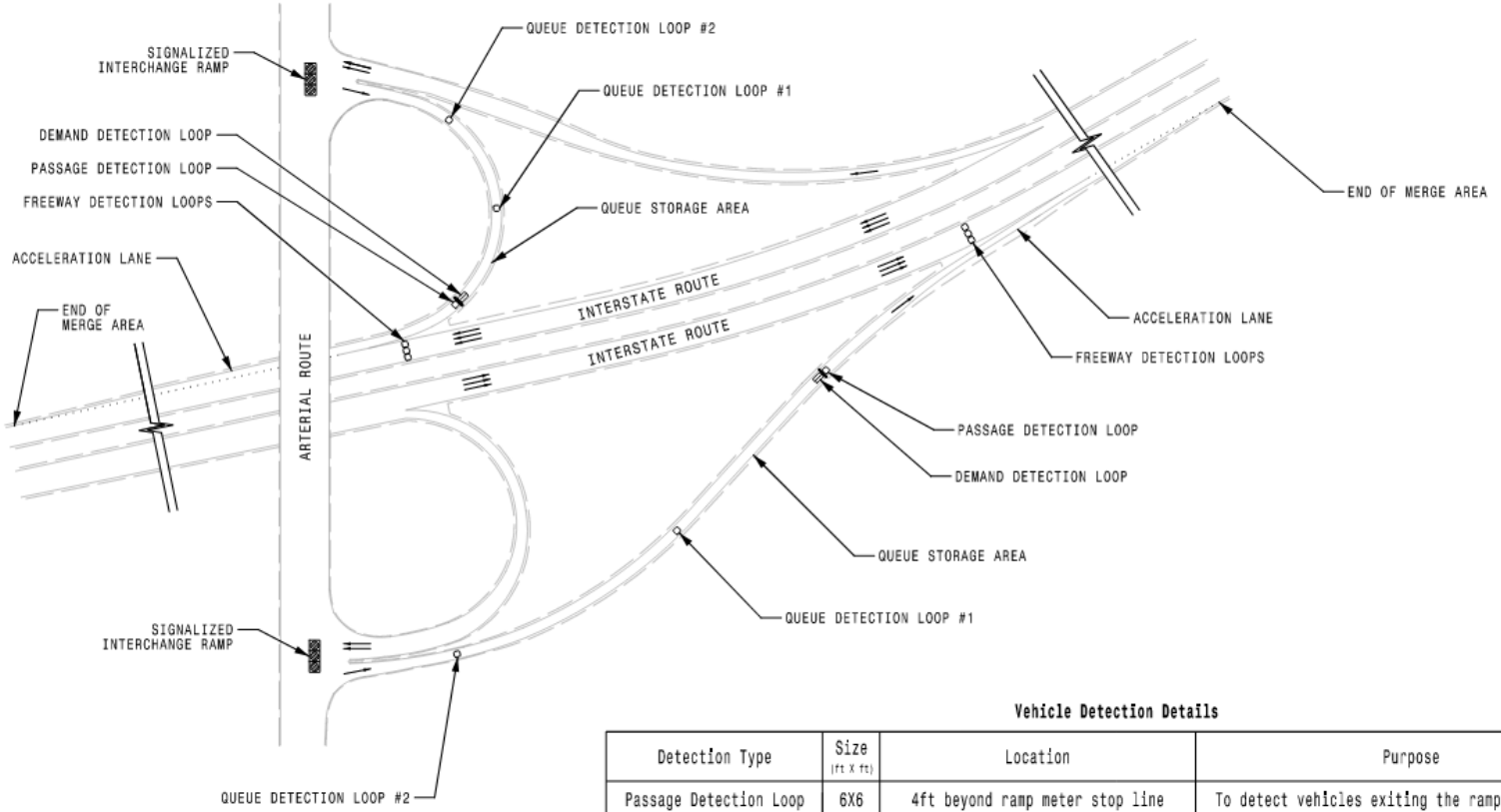
Detection installed on the ramps shall be either inductive loops or non-intrusive detection such as microwave radar. Detection install for the freeway shall be non-intrusive microwave radar. Any detection installed for ramp metering shall be on the Department's ITS Qualified Product List (QPL) to ensure it has been evaluated and meets NCDOT standards. Part of the QPL process also confirms the reliability of the data produced.

Table 3 shows NCDOT standard drawings and project special provisions sections relevant to vehicle detection.

Table 3: Relevant Design Standards – Vehicle Detection

Standard Specifications (2024)	Standard Drawing (2024)	ITS & Signals Project Special Provisions (Version 24.X)
• Inductive Detection Loops (Section 1725) • Lead-In Cable (Section 1726)	• Inductive Detection Loops (No. 1725.01)	• Microwave Vehicle Detector – Single Zone • Microwave Vehicle Detection System – Multiple Detection Zones

Figure 9: Ramp Metering System Vehicle Detection Typical Drawing



Vehicle Detection Details

Detection Type	Size (ft X ft)	Location	Purpose
Passage Detection Loop	6X6	4ft beyond ramp meter stop line	To detect vehicles exiting the ramp meter system
Demand Detection Loop	6X20	4ft behind ramp meter stop line	To detect vehicles waiting for a green indication at the ramp meter stop line
Queue Detection Loop #1	6X6	At 40% total queue storage capacity	To monitor potential for arterial spillback
Queue Detection Loop #2	6X6	At 80% total queue storage capacity	To monitor potential for arterial spillback
Freeway Detection Loops	6X6	Upstream of ramp merge area (one loop per each freeway lane)	To monitor freeway operations immediately upstream from the ramp merge area

Ramp Metering System Vehicle Detection

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6 Controller Cabinets

6.1 Controller Cabinet Placement

The traffic signal controller cabinet houses the signal controller, vehicle detection equipment, communications equipment, and other infrastructure essential to the operation of the ramp metering system.

Preference should be given to base-mounted Caltrans 332 cabinets as opposed to pole-mounted cabinets or Caltrans 336 cabinets. While existing conditions in some design scenarios may not be conducive to the installation of base-mounted 332 cabinets, designers should exhaust all options before turning to pole-mounted and/or 336 cabinets. **Figure 10** and **Figure 11** provide examples of traffic signal controller cabinet placement.

Traffic signal controller cabinets should be oriented so technicians can observe the ramp meter signal heads while working inside the cabinet. Traffic signal controller cabinets should be placed according to NCDOT standard clear zone requirements.

Traffic signal controllers shall be 2070LX models running North Carolina's current statewide ramp metering local software.

Figure 10: Example of Typical Controller Cabinet Placement

Figure 11: Example of Controller Cabinet Placement Requiring Grading and Guardrail

6.2 Electrical Service

Dedicated electrical service should be installed for the ramp metering signal system. This requires coordination with the appropriate power provider. Provisions may be made to access existing power for the ramp meter signal if it is located close to an existing NCDOT electrical service for traffic signals or ITS devices on non-toll facilities. The existing service must meet current National Electric Code (NEC) and NCDOT standards. The existing service shall provide available capacity for the installation of new circuits.

Solar power with battery backup shall not be considered due to reliability concerns.

Table 4 shows NCDOT standard drawings and project special provisions sections relevant to controller cabinets.

Table 4: Relevant Design Standards – Controller Cabinets

Standard Specifications (2024)	Standard Drawings (2024)	ITS & Signals Project Special Provisions (Version 24.X)
• Signal cabinet foundations (Section 1750) • Controllers with cabinets (Section 1751) • Cabinet Base Adapter/Extender (Section 1753 • Signal cabinet foundations (Section 1750)	• Electrical Service Options (No. 1700.01) • Electrical Service Grounding (No. 1700.02) • Controllers and Cabinets – Cabinet Component Layout (No. 1751.01) • Controllers and Cabinets – Power, Ground, and Auxiliary (No, 1751.02)	• Controllers with Cabinets • Electrical Service for ITS Devices

7 CCTV Cameras

CCTV cameras provide TMC operators the ability to effectively monitor ramp metering operations. It is important that the CCTV cameras are designed to provide the desired unobstructed viewing angles, which may require multiple cameras at each location using either separate poles or having multiple cameras mounted on the same pole. In general, designers should try to minimize the number of additional poles, cabinets, and electrical services that are introduced with a ramp metering system.

It is recommended that the CCTV cameras can view:

- Ramp storage
- Arterial operations
- Freeway mainline operations
- Ramp merge area
- Ramp meter signal faces

The designer shall review existing NCDOT CCTV cameras in the area to confirm any potential blind spots. New cameras shall be designed when feasible with fiber-optic communications to support reliable, real-time video access. In some cases wireless or cellular communications may need to be considered.

Table 5 shows NCDOT standard drawings and project special provisions sections relevant to CCTV cameras.

Table 5: Relevant Design Standards – CCTV Cameras

Standard Drawings	ITS & Signals Project Special Provisions (Version 24.X)	ITS Typical Details
• Electrical Service Options (No. 1700.01) • Electrical Service Grounding (No. 1700.02)	• Digital CCTV Camera Assembly • CCTV Equipment Cabinet • CCTV Wood Pole • Air Terminal & Lighting Protection System • CCTV Camera Lowering System • Electrical Service for ITS Devices	• CCTV-Metal Pole Grounding & Aerial Electrical Service Typical Detail • CCTV-Metal Pole Grounding & Underground Electrical Service Typical Detail • CCTV-Metal Signal Pole Installation Typical Detail • CCTV-Wood Pole Grounding & Aerial Electrical Service Typical Detail • CCTV-Wood Pole Grounding & Underground Electrical Service Typical Detail • CCTV-Wood Signal Pole Installation Typical Detail

8 Communications and TMC Integration

All field components of the ramp metering system shall have reliable and fast communications with the controller cabinet. Ramp meter signals shall use standard signal cable to the controller cabinet. Vehicle detection, ramp and mainline locations, shall use electrical cables (loop lead-in, RS-232, or Ethernet) of a length based on manufacturer recommendations. The detection power supply shall be uninterrupted from the device to the controller cabinet. Wireless radio systems should not be used for communication to detection devices.

Ramp metering systems and the CCTV cameras used for monitoring them shall have a remote connection to the Statewide ITS Network. Remote access to the ITS network allows operators to monitor ramp metering operations and implement changes without requiring a field visit.

Each ramp metering controller cabinet should have a fiber-optic connection to an existing NCDOT ITS fiber-optic trunk line. Designers should avoid using cellular connections to the ITS network unless all other options are infeasible. Designers should also avoid integrating a ramp metering system with municipal traffic signal systems or closed loop signal systems. **Table 6** shows NCDOT standard drawings and project special provisions sections relevant to Communications and TMC Integration.

Table 6: Relevant Design Standards – Communications and TMC Integration

Standard Specifications (2024)	Standard Drawings (2024)	ITS & Signals Project Special Provisions (Version 24.X)
• Underground Cable Installation (Section 1715) • Junction Boxes (Section 1716) • Fiber-Optic Cable (Section 1730) • Fiber-Optic Splice Centers (Section 1731)	• Underground Conduit – Trenching (No. 1715.01) • Junction Boxes (No. 1716.01)	• Ethernet Edge Switch